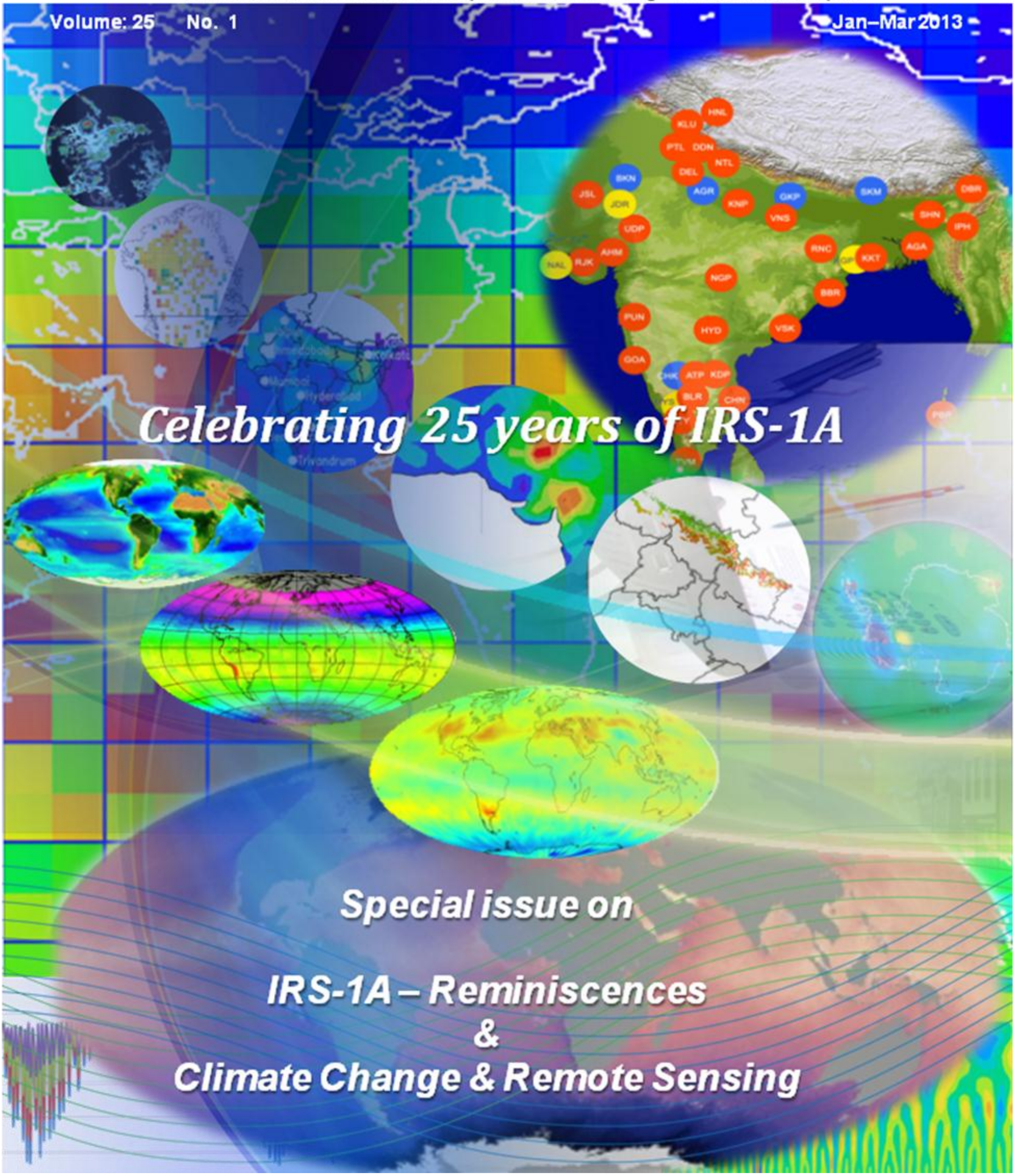
Signatures

ISRS

Newsletter of the Indian Society of Remote Sensing –Ahmedabad Chapter

Volume: 25 No. 1 Jan–Mar 2013



ISRS

Signatures

Newsletter of the Indian Society of Remote Sensing, Ahmedabad Chapter Volume: 25, No.1, January- March 2013

Celebrating 25 years of IRS-1A

Special Issue on

IRS-1A -REMINISCENCES

&

CLIMATE CHANGE &

REMOTE SENSING

Inside This Issue

जय हिन्द

सत्यमेव जयते

भारत सरकार GOVERNMENT OF INDIA
अंतरिक्ष विभाग DEPARTMENT OF SPACE
अंतरिक्ष उपयोग केन्द्र
SPACE APPLICATIONS CENTRE
अहमदाबाद AHMEDABAD - 380 015
(भारत) (INDIA)
दूरभाष PHONE : +91-79-26913344-46, 26928401
फैक्स/FAX : +91-79-26915843
ई-मेल E-mail : director@sac.isro.gov.in

ए.एस.किरण कुमार
निदेशक
A.S. Kiran Kumar
Director

MESSAGE

It is extremely heartening to learn that the Indian Society of Remote Sensing, Ahmedabad Chapter (ISRS-AC) is bringing out a Special Issue of its newsletter `Signatures' on Climate Change and Remote Sensing with a Special Section on `IRS-1A : Reminiscences'. It is indeed appropriate to release such an issue on the occasion of the Silver Jubilee celebration of IRS-1A launch.

With the launch of IRS-1A, India joined the nations harnessing earth's resources using its own remote sensing satellite data. The data from IRS-1A catered to a variety of application areas ranging from agriculture, forestry, geology, hydrology, wetland mapping, to the critical areas of disaster management. Apart from that, it saw the growth of operational ground stations, data processing systems and user services in the international arena. Subsequently, with the launch of meteorological satellites such as INSAT-VHRR, Oceansat-1&2, Megha-Tropiques, etc, there has been a growing expertise in the fields of meteorology, weather monitoring and climate modelling related studies. The significance of climate, its changes and implications on the earth and its environment are the subjects of global concern and policy making. This special issue has addressed some of the critical areas in this domain by collecting informative articles from the experts in this field.

I hope this Special Issue will be of immense interest to the readers. Sincere efforts put in by the team behind the issue in collecting and compiling informative articles from the pioneers in the field of Optical Remote Sensing in India are praiseworthy. Apart from that, interviews with some of the pioneering scientists behind the IRS-1A mission, is an interesting feature of this special issue.

My heartiest congratulations to the Editorial team behind this newsletter.

(A. S. Kiran Kumar)

Ahmedabad
March 08, 2013

ISRS

ISRS-AC OFFICE BEARERS

Shri D.Subrahmanyam, Chairman

Prof. R D Shah, Vice-Chairman

Dr. Parul Patel, Secretary

Shri Anurag Kandya, Jt. Secretary

Shri K.M. Rana, Treasurer

ISRS-AC EC Members

Shri Nilesh M. Desai
Shri Devang Mankad
Dr. Mehul Pandya
Dr. Abha Chhabra
Dr. Arun Bhardwaj

ISRS-AC ADDRESS

Room No. 4372,
Space Applications Centre (SAC),
ISRO, Ahmedabad-380015.
Email: parul@sac.isro.gov.in
Phone: +91 79 2691 4372

ISRS MAIN BODY

C/o Indian Institute of Remote Sensing, 4, Kalidas Road,
Dehradun - 248 001, India.
Email: isrs@iirs.gov.in,
Fax: +91 135 2741 987
Web: www.isrsindia.org

From the Chairman's Desk

Dear Readers,

ISRS-AC, has been taking initiatives, during the past few years, in order to bring out theme based Newsletter-Signatures which has been well appreciated by the ISRS-AC members. The positive feedback coming from the members and some of the valued readers is truly heartening. The Signatures editorial team have been working in harmony with the ISRS-AC team to evolve themes which are not only dealing with current issues in the field of remote sensing in India, but also are extremely informative to all the readers. This special issue has two sections. One is on IRS-1A-Reminiscences, and the other is on the theme- Climate Change and Remote Sensing. Both these topics gain significance from the fact that both are of current interest due to the silver jubilee year of the IRS-1A being celebrated on 17th March, 2013, and the second one due to its importance in the global scientific community as of today.

The Signatures team has taken extra initiatives to bring together the scientific community from all across the ISRO/DOS centers, in order to get interesting and highly valuable articles on Climate Change. The team along with the Guest Editor had to toil hard in order to get such quality papers from the experts in their respective fields, and they have done a superb job in this matter.

I am sure that this special issue will be of great interest to all our readers. The retired employees of SAC, who are well known as the pioneers in the field of Optical Remote Sensing in India, have also taken active interest and have contributed very informative articles for the particular section.

We are grateful to Dr. George Joseph, Dr. Ranganath R Navalgund and Shri A S Kiran Kumar for sparing their valuable time in giving interviews for this issue, which will surely generate interest in the readers who can get more insight into technological challenges faced during the nascent stages of the project.

The ISRS-AC is grateful to Sri A S Kiran Kumar, Director, SAC, for encouraging the experts to contribute their papers for this issue. I am also thankful to Sri D R M Samudraiah, Vice President, ISRS, for his valuable suggestions.

Finally, I am extremely grateful to Dr. R P Singh, the Guest Editor, and Ms Arundhati Misra, the Editor of Signatures, who have been relentlessly working towards making this issue a grand success. I on behalf of the executive committee am extremely pleased to acknowledge the enthusiasm extended by all the members.

My heartiest congratulations to the editorial team.

Best wishes

D.Subrahmanyam

IRS-1A -REMINISCENCES

An Interview with Dr. George Joseph

Honorary Distinguished Professor, ISRO
Director (Retd.), Space Applications Centre, Ahmedabad
georgejoseph1938@gmail.com

ISRS:

Sir, we all know that you are one of the pioneers of Remote Sensing Program, in India. Please share some of your experiences with us about the scenario when the Indian remote sensing program was in its nascent stage?

Dr. George Joseph:

Let me start with a story of initiation of remote sensing activity in India, as told by Prof. Pisharoty. During the UN Conference on Peaceful Uses of Outer Space (COPOUS) held in Vienna, Austria in 1968 couple of papers on use of space was presented and discussed, including applications of remote sensing. In addition to Prof. Vikram Sarabhai the conference was also attended by Prof. P R Pisharoty. At the end of the Conference Prof. Sarabhai, told Pisharoty that, remote sensing technology has great potential for India and that he should work on this and develop some good projects of relevance to the country. That was the germination for the Indian Remote Sensing Program. We respectfully consider Prof. Pisharoty as 'father of remote sensing', who started remote sensing activities in India.

Later it was the vision of Prof. Yash Pal to organize the activities at SAC covering all the facets of remote sensing what he calls 'an end to end' concept. It is worth noting that nowhere in the world can we find all activities under one roof like in ISRO, starting from sensor development, data processing, application and interfacing with end user (what was called user cell). I believe because of this vision SAC could emerge as leader in the area. Prof Yash Pal identified Mr DS Kamat, Dr Baldev Sahai and self to lead data products, applications, and sensor development. When SAC was started in 1973, there was not adequate place in the present SAC campus to accommodate various laboratories and offices.

Therefore floors were hired in the premises of the Sahjanand College, and for carrying out RS activities a few flats in the Leena apartment were hired. Serious work on sensor development started from this place. Kitchen in one of the apartments was used as a dark room to carry out initial development activities of electro-optical sensors. The state of art electro-optical sensor laboratory now in SAC, has its humble beginning in a kitchen which many new entrants in ISRO would find it hard to believe.

One of the activities from the Leena apartment laboratories was to design a multi-spectral camera system to be carried by balloons to about 25km. This was the idea of Prof Yash Pal. At TIFR I was sending my instruments by balloons to high altitude to study cosmic radiation and emission of neutrons from the sun. So I also found it interesting. The BRIDE-Balloon Resource Inventory Development Experiment- was conducted and some interesting data was obtained. But it was not continued since the course of the balloon could not be controlled, which is important for collecting data over specific areas.

ISRS:

Sir, in your view how has been the journey of sensor development in the late 80's & early 90's and the development so far?

Dr. George Joseph:

The ISRO MSS activity was initiated in mid 1974, the first test flight was conducted in

1976, and operationally used from 1977. This was the first digital sensor ISRO developed for earth observation. The Multi Spectral Scanner (MSS) has been used for a number of experiments to understand the spectral characteristics of land cover, application demonstration etc. The Charge Coupled Devices just entered in imaging market. The SAC payload team decided to try out this new technology for remote sensing and initiated a program in 1975 for developing the aerial camera using CCD. SAC procured 256 and 1024 element CCDs from Fairchild and built an aerial CCD camera, Aircraft Linear Imaging Self Scanning (ALISS) system, which was successfully flight tested. SAC was thus one of the firsts to master this new technology. The only other operational initiative was by the SPOT systems. But SPOT was launched only in 1986.

In November 1980, Chairman ISRO set forth the IRS Project Organization with Dr K Kasturirangan as the Project Director. The order identified the primary payloads as that of MSS and Linear Imaging Self Scanner (LISS). The other functionaries included Dr George Joseph, APD(P/L),and Sri D.S Kamat APD(DP). In addition an EOS programme office was formed to strengthen the overall planning for the future, with Mr Y S Rajan as the Director.

ISRS:

All the earlier missions of ISRO have been realised with limited resources, all the learning was on the job. What were the challenges faced during the design and realisation of IRS-1A mission?

Dr. George Joseph:

Sensor team at SAC made a very detailed assessment on the development of MSS and LISS sensors taking into account the technical issues, future growth potential, availability of critical components etc. During this period the area CCDs were used for the astronomical observation because of its large integration capability compared to photographic plates. Linear arrays were at that time used for facsimile. So we realized the potential of CCD and parallel study was conducted for future sensors for satellites. I prepared a technical paper highlighting the advantage of going for a CCD based camera for IRS 1A and sent it to Dr Rangan. Based on my recommendation a committee was set up by Prof UR Rao, then Director ISAC, to review my proposal. Taking various technical aspects and the growth potential the committee unanimously recommended to have an all CCD camera system for IRS-1A. Prof Rao and Dr. Rangan should be complimented for taking this historic decision when CCD did not have any pedigree in space imaging. But for this decision we would not have realized IRS-1C, PAN having the highest spatial resolution civilian camera in 1995. Finally IRS-1A was launched on 17th March, 1988.

ISRS:

IRS-1A was launched from Baikonur Cosmodrome USSR on 17th March 1988. It carried two payloads LISS-I & LISS-II, how did the configuration of the satellite and performance of the payloads compare with the ones in orbit during the same time from NASA or ESA?

Dr. George Joseph:

Prior to IRS-1A satellite, the Bhaskara satellite was launched with a Microwave radiometer and two TV cameras. Bhaskara payload gave a lot of experience. For the IRS – 1A payloads the comparisons were with Landsat MSS & Thematic Mapper (TM). The LISS-I camera had much better specification than the Landsat MSS. The bands chosen were much narrower than MSS and the camera performance in terms of MTF was better than LANDSAT for

LISS-I & LISS-II. This was possible since we have optimized each channel using separate optics. When we were doing the configuration study except for RBV, all other earth observation sensors had a single collecting optics for all spectral channels. For many, the proposed LISS configuration did not appear very compact and 'elegant'. However the results showed that this was the correct choice and later adopted for OCM also. This is to the credit of Mr. Kiran Kumar's ingenuity, who proposed the scheme and convinced me to adopt it. Again- 'not going the traditional way'!

ISRS:

There must have been anxious moments when you were to receive the first day images from IRS-1A? Can you share your experiences?

Dr. George Joseph:

On the first day the experience was unique. I was in Russia after the launch and on the way to India. Dr K. Kasturirangan, Prof U R. Rao, Sri M G. Chandrasekhar, Dr. P S. Goel all were there. Dr AKS Gopalan was sitting at the data reception centre at Hyderabad and everyone was anxious about the payload functioning, as well as the quality of the data. On switching the cameras on it was found that both cameras gave excellent quality pictures. In flight calibration data showed that the stability was very good, and no drift was found.

ISRS:

ISRO's mantra is 'Harnessing Space technology for societal benefits'. What was the most significant contribution of IRS-1A to the nation from societal benefits point of view? What are the ways in which ISRO's future RS programme can benefit the national and International community?

Dr. George Joseph:

The IRS series of satellite have made noteworthy contribution for the societal benefits of this country. The sensors have identified many ground water potential areas in various regions of the country for the drinking water mission. Integrating Remote Sensing input along with ground survey the success rate of identifying ground water has reached to more than 95%. Remote sensing data is mostly used for public good i.e. for the betterment of society and not used extensively for commercial applications as in the case of satellite communication. Remote sensing data has applications in global warming, forestry -like assessing deforestation; Crop production estimation; waste land mapping; delineation of landslide/flood prone areas, to mention a few areas where remote sensing has been successfully used. 16 categories of waste land have been mapped. Some of the waste land can be converted into agricultural land. Our aim was to make cameras best suited for our specific application needs. In that process we conceived and realized some of the unique earth observation cameras. For example WIFS two band camera with 188 m resolution and about 800km swath giving better revisit capability was developed with crop production applications in mind. Subsequently AWIFS was developed with better spatial resolution and more number of bands. Close interaction with application scientists like Dr. R R Navalgund, Dr. V K Dadhwal, Dr. J S

Parihar and many others formed the basis for drawing specifications of this sensor. It is also heartening to note that US agricultural department is extensively using the AWIFS data.

ISRS:

ISRO has had International collaboration in Earth Observation & Planetary Scientific exploration of MOON. In your opinion, what is the long term benefit that our country derives from the Indian planetary and astronomical missions to Sun, Moon and Mars?

Dr. George Joseph:

It is a very good question! Many of the scientific investigations and benefits accrued take longer time for realization. It is said that Lord Kelvin once commented “It is impossible to have a flying machine heavier than air”, but now airplanes are flying commercially and satellites are being launched into space regularly. Thus predicting the future of technology is very difficult. India should be at the forefront of technology in all spheres. Space colonization will be a reality. There will be Terra forming of Mars to make it habitable like that on earth. There will be lot of activities on moon and the countries who participated in these exploratory missions will naturally have the rightful claim to be part of all these activities, which cannot be carried out by a single country. Other powerful countries cannot deny our moral right on Moon/Mars as we are also actively participating/ pursuing these missions. Planetary exploration is of strategic and commercial importance. Studies have shown that Hellium-3 is found on moon in abundance which can be used for generation of power through nuclear fusion. Exotic crystals can be grown in micro gravity. We can have solar panels in space and sun’s energy can be suitably harnessed. These are only a few examples to cite, but there can be many more benefits.

ISRS:

Please share your vision for *Future Trends* in remote sensing activities in optical and microwave domain for the coming years?

Dr. George Joseph:

I would propose observations from geo stationary orbits, with medium resolution systems- say about 50 – 70 meters resolution should be pursued fast. In fact, CCD camera of INSAT-3D can be used very effectively to answer certain basic scientific issues in remote sensing. We should configure it as an intelligent sensor with coarse spatial resolution but higher spectral resolution over ocean and higher spatial resolution at relatively coarse spectral resolution when one studies the land.

Since low earth orbiting remote sensing sensors have a limited swath to cover, so to increase repeated observations, we should have a constellation of six satellites which have about 30 meter resolution which can give two days repetivity. An international body like GOE should take the lead to have such a system as a joint activity of interested countries. Microwave sensors are needed for covering the tropical areas which are under constant cloud cover. Multi frequency and multi polarization microwave sensors will greatly help application scientists in various disciplines. Fundamental studies to model scattering / emission on polarization, dielectric constants etc. have to be taken up for realizing the remote sensing applications in the microwave domain. It is left to our imagination to explore new application areas. We should be able to think as a solution provider, not just data provider, so that the common man gets benefited, thus realizing Dr. Vikram Sarabhai’s vision. Retreivel

ISRS:
We would finally request you to give your advice to our readers in order to enable them to excel in their respective domains.

Dr. George Joseph:
Irrespective of what job you do, you should excel in that. It is possible only if you enjoy what you do. Do everything from your heart with dedication and commitment. If you have to give your best you have to 'worry' about solutions which you are not able to find, which could lead to sleepless nights. Good engineers/scientists can't rest unless they find a solution to the scientific/technical problems they are faced with.

Brief Biodata of Dr. George Joseph

Dr. George Joseph started his research career in 1962 at the Tata Institute of Fundamental Research (TIFR), Bombay, where he was involved in the study of cosmic rays. A novel detector system designed by him was flown on the first Indian Satellite ARYABHATA to detect solar neutrons. He was first amongst the few to set useful upper limits on the solar neutron flux which is fundamental to the understanding of solar surface nuclear reactions.

Since 1973, at Space Applications Centre (SAC), he was instrumental in developing a variety of electro-optical sensors for earth observations which were first of its kind in India. These include ground-truth radiometers, multispectral scanners, multiband TV camera for BHASKARA satellite, CCD cameras for the operational Indian Remote Sensing satellite (IRS), Very High Resolution Radiometer (VHRR) for meteorological observation from INSAT, etc. The IRS PAN Camera with a resolution of 5 meter flown on IRS 1C in 1995 was the best spatial resolution civilian earth observation system at that time. He is rightfully considered the pioneer of satellite based imaging sensors in the country. Another noteworthy contribution of Dr Joseph is the study report on Indian Mission to Moon in the capacity as Chairman, Lunar Mission Study Task Force.

During 1994-1998, he was Director Space Applications Centre, ISRO Ahmedabad. During 2006-2009, he was Director, Centre for Space Science & Technology Education in Asia & the Pacific (CSSTE-AP), (affiliated to UN)

He has authored a book titled `Fundamentals of Remote Sensing', which is the first complete textbook on remote sensing written by an Indian author for beginners. He is Fellow of number of National Academies such as: Indian Academy of Sciences, National Academy of Sciences, India, and Indian National Academy of Engineering.

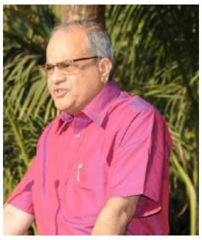
In recognition of his outstanding contributions to electro optical sensor development and for his distinguished achievements in furthering the remote sensing utilization in the country, he has been honored in 1999 by the Government of India's civilian award – Padma Bhushan.

Call for Articles

Readers are requested to contribute short articles for publication in the forthcoming issue of *Signatures*, related to the specific theme ***"Remote Sensing Data Products & Retrieval Algorithms"***.

The deadline for inclusion in the next issue is **May 31, 2013.**

\- Editorial Team



An Interview with Dr. Ranganath R. Navalgund

Vikram Sarabhai Distinguished Professor, ISRO HQ
Director (Retd.), Space Applications Centre, Ahmedabad
navalrr@gmail.com

ISRS:
Sir, thank you for taking the time for giving this interview. IRS-1A was one of the many missions you have contributed to in your career of over three decades. For the benefit of our readers, could you lay out the context of the project initiation for IRS-1A; i.e. what were the key priorities while defining the project? What were the key application areas that were targeted during the planning phase?

Dr. R. R. Navalgund:
Successful launch of Bhaskara 1 & 2 and the availability of 1km data in two bands had given us some familiarity of satellite data analysis. Availability of Landsat MSS data at 72m resolution in four spectral bands provided further opportunity of handling space borne data for resource inventory and mapping in the early eighties. The spectral bands of LANDSAT MSS were not ideally tuned for vegetation applications. During this period, we carried out many ground based experiments and aerial surveys employing narrow band multi spectral scanner to arrive at selection of optimum bands for IRS-1A. While all resource areas such as geology, water resources, forestry, soils, coastal zone were areas of relevance, needs of applications in agriculture were of high priority. Mapping at both 1:250,000 and 1:50,000 were envisaged. Although, it meant trade off with swath. Availability of LANDSAT thematic mapper data at 30 m resolution in six spectral bands and 120m in thermal band gave us opportunity to try many more applications. Based on the maturity of applications and likely data to be available from IRS-1A, four types of applications were defined. These were i) operational, ii) quasi-operational iii) experimental and iv) technique development projects. While NRSA was assigned the responsibility of carrying out the first two, SAC was asked to demonstrate the other two. These included crop production forecasting, watershed development, water quality monitoring, coastal zone management, marine fisheries, crop yield modeling and crop stress detection. Identification of a crop and it`s area estimation in single-crop dominated districts was already demonstrated for wheat and rice with LANDSAT data. How well, we can do this exercise for many more crops and in many more districts with IRS 1A data was a major objective.

ISRS:
Could you also discuss some of the scientific challenges that the IRS-1A applications team faced during the project?

Dr. R. R. Navalgund:
IRS-1A was a successful launch and data from both cameras LISS-1 and LISS-2 started flowing. Management was impatient to see results in term of successful applications. One had to contend with band to band registration and radiometry. While LANDSAT TM had 30 m resolution, 8 bit radiometry and 185 km swath, IRS LISS-2 had 36 m resolution, 7 bit radiometry and 140 km swath. Comparisons were obvious. Application scientists had to devise ingenious methods of analysis and choose suitable test site to demonstrate results. Normalising data across two scenes acquired on two different dates was a challenge. Familiarity with digital techniques

was not much in those early years. SAC did not have necessary digital image processing facilities. Procedures for atmospheric correction were not well developed.

ISRS:
Please throw some light on some of the lessons learned from our experience with IRS-1A and IRS-1B. For example, a short wave Infra-Red band channel was added to our remote sensing satellites from IRS-1C onwards. Why?

Dr. R. R. Navalgund:
Based on both ground based experiments and analysis of LANDSAT TM data, it was clear, inclusion of data from short wave infra red (1.5 -1.75 μm) improves crop discrimination and also helps in quantification of moisture stress in vegetation. IRS-1A did not have this band unlike LANDSAT TM. It was also realized that 22 day repetitivity does not provide enough coverage required during a crop growth cycle. We also need higher radiometry for seeing subtle differences in crop reflectance. Co-existence of a set of cameras on a single platform to acquire data at higher resolutions, at higher repetitivity, at higher radiometry and in more relevant spectral bands was felt a necessity for applications particularly in agriculture.

ISRS:
Moving a little ahead in time, there have been a host of technological enhancements from IRS-1A to the recent Resourcesat-2, such as the addition of the short wave IR channel and AWiFS camera. Could you discuss the ways in which the level and sophistication of applications of these satellites progressed over time?

Dr. R. R. Navalgund:
While we were able to identify and estimate crop area in single-crop dominated districts only with IRS 1 A/B data, national-level crop production forecasts are demonstrated successfully in advance of harvest particularly for wheat using AWiFs data. More quantitative drought assessment has been possible with Resourcesat-1/2 data. Snow cover monitoring and identification of wet snow and fresh snow has been possible in view of the increase in dynamic range of the payloads. More detailed urban level mapping is done using panchromatic data. Characterisations of watersheds at more detailed level is possible because of 5.8m multispectral data. Simultaneous availability of multispectral data at three different resolutions 5.8m, 23.5m and 56m has enabled multi stage sampling and many more applications world over.

ISRS:
Could you specifically comment on the importance of wide field cameras on satellites with high repetivity, to our remote sensing applications?

Dr. R. R. Navalgund:
In order to capture temporal changes in natural eco systems such as crops, forests, mangroves, snow cover, river flows, coastal zone etc. it is necessary to have camera systems with frequent revisits. This can be accomplished by cameras with large swath, tilting capability or multiple satellites with identical camera systems. One may have to compromise on spatial resolution in case of large swath system. It is worth, provided the camera systems have high radiometry and full dynamic range.

ISRS:
What impact will the recently launched RISAT-1 have on our crop forecasting models? What are the benefits of having our own radar imaging satellite?

Dr. R. R. Navalgund:
More than fifty per cent of Indian agriculture production comes from the Kharif season (June-Oct). There is invariably cloud cover

during this period precluding availability of optical RS data. So, any operational space based crop forecasting system worth its name must have access to microwave radar data to estimate crops during cloud cover. C-band SAR flown on RISAT-1 is only a first step in that direction. There are crops other than rice which require radars operating perhaps at longer wavelengths. Estimation of soil moisture at root zone of the crops is another important requirement. Estimating snow depth is another important requirement. Many of the oceanic physical parameters are amenable to only microwave remote sensing. Atmospheric profile parameters for cloud covered regions can come from microwave sounders. So, there are a host of observational requirements demanding microwave measurements.

ISRS:
On a more general note, could you comment on the state of the Indian Earth Observation program in the context of the current global scenario?

Dr. R. R. Navalgund:
Earth observation systems have evolved over the years everywhere. There are a large number of EO systems which cater to measurement of environmental parameters on operational basis. There are high resolution systems catering to applications in mapping and infrastructure development in the commercial sector. There are systems specifically meeting the strategic needs. There are also innovative systems to address specific science questions. Need for calibrated climate quality products is getting emphasis. Indian Earth observation systems are progressing in all these areas. We do have commitment for minimum observations over land, atmosphere and oceans to ensure continuity of operational applications, high resolution and stereo missions and science missions. We need to make greater efforts on the development of microwave instruments and also on calibration & validation activities.

ISRS:
Maybe we can shift to a few questions regarding your immensely successful career. You have made contributions starting from conducting field experiments and going up to the institutionalization of the remote sensing applications programme in India. Could you share some thoughts on this journey?

Dr. R. R. Navalgund:
When I joined the Space Applications Centre in August 1977, I did not know what I would be really doing in my career. Indian Remote Sensing Programme was just getting defined. Choice of sensors and their specifications were yet to be firmed up. Concept of National Natural Resources Management System and the role of remote sensing in that frame work was evolving. Importance of involving all the stake holders from the beginning in this endeavour was recognized. My assignments reflected this direction. I took up the work in earnest not really worrying whether my qualifications and background suited or not. I believed in the goals set.

ISRS:
Could you also share a few thoughts on the evolution of Ocean Color Monitoring in India from project definition to operationalization? You have played a pioneering role in this evolution. What is the future of this field in India?

Dr. R. R. Navalgund:
Personally, I was exposed to this field during my stint at the Optoelectronic Institute, DFVLR, Oberpaffenhofen, Germany in early 1981. I had an occasion to look at ocean colour data collected from an airborne radiometer and do analysis. Later, I also had some exposure to the data from Coastal Zone Colour Scanner, the first space borne ocean colour instrument. I must say, I had basic understanding of the issues and what can be done using such data. Turning point came, when I was asked to organize the IRS-P3 science and utilization project. IRS-P3 carried advanced ocean colour instruments. Work involved development of procedures for atmospheric correction, deriving water leaving radiances, development of algorithms for estimating chlorophyll, suspended sediments, yellow substances, organizing ship cruises for in-situ data collection and validation. Success of marine fisheries work gave further impetus to the development of our own operational ocean colour instrument flown onboard IRS-P4. Since dissemination of fishery prospect chart has become a successful operational programme in the country, commitment to continuity of space borne ocean colour missions is a must. We also need to build advanced ocean colour instrument with narrower and more specific spectral bands which will provide estimation of fluorescence, better estimate of primary productivity and climate quality biophysical products.

ISRS:
Please elaborate on the role of private industries and it evolution in the field of RS applications. How do they meet the challenges of our space missions?

Dr. R. R. Navalgund:
There is definite role for private industries/entrepreneurs in different aspects of remote sensing applications. Generation of multi-date/multi-band registered ortho-rectified products for the entire country is an important requirement and repetitive in nature. Given proper procedures industry can take up this assignment. Preparation of thematic maps and organizing suitable databases is another important task. Development of customized software for different applications is equally challenging.

ISRS:
How would the academic institutions in India play a major role in our future space programmes?

Dr. R. R. Navalgund:
Academic institutes have a crucial role in

i) running suitable courses at graduate and post graduate level,

ii) carrying out research in different resource areas using RS data, simulations and modeling

iii) In defining newer missions.

ISRS:
What do you consider to be the greatest achievements in your career? Do you have any particular scientific forum of tremendous importance, in mind, which you would like to share with the readers?

Dr. R. R. Navalgund:
Well, I did my bit in the growth of remote sensing activities in the country and promoting it among the stake holders. I had the tremendous support of many of my colleagues and youngsters in this journey. I owe it to them.

There are many international forums devoted to the promotion of remote sensing. International Society for Photogrammetry and Remote Sensing is a professional society well run, and organises many workshops, symposia and a quadrennial Congress, publishes a peer reviewed journal and recognizes professionals with merit. I encourage your readers to participate in its activities at different levels either independently or through the Indian Society of Remote Sensing.

ISRS:

Before we conclude this interview, we would like to turn our gaze to the future. What do you feel are the biggest unexplored areas in remote sensing? What are the most important products and services that the Indian Remote Sensing program can deliver to our society in the future?

Dr. R. R. Navalgund:

Entire areas of hyperspectral remote sensing and microwaves are unexplored in India. Use of RS data in process based investigations/modeling needs greater emphasis. We are yet to deliver operational services and products (rigorously validated) in many of the resource areas. Early warning methods for disasters require much greater efforts. Improved weather and ocean state forecasting at suitable scales are very important services requiring attention.

ISRS:

Finally, we would request you to kindly leave a message for the members of ISRS-AC.

Dr. R. R. Navalgund:

Enjoy the work that you do and try excelling in that. Be sensitive to the needs of the society.

Brief Biodata of Dr R R Navalgund

Ranganath R. Navalgund is currently Vikram Sarabhai Distinguished Professor at the Indian Space Research Organisation, Bangalore. He joined the Space Applications Centre in August 1977 immediately after his PhD and served till he formally retired in March 2012. He was the Director of the Space Applications Centre, ISRO, Ahmedabad during the period July 2005 to March 2012 and was at the National Remote Sensing Agency, Hyderabad as its Director during the period May 2001 to November 2005. Born on March 17, 1948 at Dharwar, Karnataka, he obtained his postgraduate degree in Physics from the Indian Institute of Technology, Mumbai in 1970 and Ph.D. in Physics from the Tata Institute of Fundamental Research, Mumbai (Bombay University) in 1977. His main contributions are in the area of earth observation, development of application programmes of societal relevance and in promoting the use of space technology among various stake holders.

An Interview with Shri AS Kiran Kumar

Director, Space Applications Centre, Ahmedabad
kiran@sac.isro.gov.in

ISRS:
Sir, you have been involved deeply in defining & shaping the Indian Remote Sensing program for the last three decades. Please share some of your experiences during the course of defining the Indian Remote Sensing programmes?

DIR SAC:
SEO a Satellite for Earth Observation was configured to avail the opportunity to build a satellite and launch it using a Russian rocket. BHASKARA TV payload carried on the spin stabilized satellite was our first essay in building optical remote sensing instruments. Starting with a one kilometer spatial resolution imaging in 1988 we were able build instruments which could provide images up to one meter resolution in 2001. We have also been able to establish an impressive array of satellite based observation systems encompassing land ocean and atmosphere through instruments working in optical , infra red and microwave regions of electro magnetic spectrum. All along emphasis was on adopting enabling technologies to put in place an observation system to address specific national issues. Towards this using three tier imaging (IRS-1C) and use of wide swath imager (WiFS and AWiFS) and realization of ocean color monitor, Along track stereo imager (CARTO-1), Scatterometer (Oceansat-2) VHRR and CCD payload from GEO platform, Synthetic Aperture Radar for RISAT-1 are all examples. These developments have been possible because of the work carried out by a large team of dedicated people willing to learn and use their skills in realizing hardware against all odds.

ISRS:
Sir, in your view how does the Indian remote sensing program compare to that of others in the world so far?

DIR SAC:
Indian RS Programme has made an excellent progress to meet the challenging requirements of the country for monitoring the natural resources, weather and other applications. We were the first to provide a three tier imaging concept. Indian RS Satellite provided high resolution ocean color data. We are also the first to have a CCD based sensor on a GEO satellite. We provided the first High Resolution (2.5 meters) optical stereo imager (CARTO-1). We have been addressing the prime requirements of the country and trying to build capability which meets the demand. While we have not been competing with the international systems our work has at times provided unique and superior data sets (between 1995 and 1999 we had the highest spatial resolution imaging systems in the civilian domain). SAR on RISAT has capabilities not present among the current microwave imagers (wide swath polarimetric imaging).

ISRS:
What were the challenges faced during the design and realization of LISS-I & LISS-II payloads for the IRS-1A mission?

DIR SAC:
Having made the choice of using solid state sensor technology for providing multi spectral images the challenge was to implement this. We had to choose between single telescope

and multiple refractive optics. SPOT, LANDSAT had single telescope as collecting optics for all spectral bands while MESSR had 1 refractive optics for two spectral bands during that time. One of the key challenges was to realize the refractive assemblies and put them on a common structure and realize the Band to band registration needed for generating false color composites. Then in the data transmission chains S and X bands provided a complete redundancy of technology which helped not only the IRS-1A project but also in other missions. IRS-1A was the first 3 axis stabilized satellite to be flown by India. Satellite attitude related errors had to be corrected on ground.

ISRS:

Mars Orbiter Mission is the next big leap ISRO is taking towards assertion of its dream of being *'second to none in application of advanced technologies to the real problem of man and society'* as put by the great visionary Dr. Vikram Sarabhai. What are the technological feats being achieved by this important mission? In what way will the country benefit from these planetary missions of ISRO?

DIR SAC:

Man and society are always interlinked. Satellite technology has been always used for societal benefits and mankind. Technological developments in this respect will be aiding our future satellite missions. In this context the Chandrayaan mission was conceived, which gave us knowledge in respect of gravitational, deep space communication and control systems point of view which is much different from that of earth based satellite missions. So these challenges give ample scope for furthering our capability to take up tougher technological developments. MARS mission will enable us to address long duration missions by building small compact observing instruments and autonomous satellite capability in addition dealing with communication systems needed for satellites millons of kilometer from earth. Such technological capabilities will enable future

observations in the field of climate monitoring from Lagrange point. In the near future the miniaturization of satellites, autonomous systems etc can also become a reality due to these advanced techniques. This can also enable us to handle extreme environmental conditions which can be extended to earth observation at much lower costs.

ISRS:

What are the future activities planned in Earth Observation, Astronomy, Planetary science and their applications under ISRO's vision till the year 2020?

DIR SAC:

In the 12th Five year plan ASTROSAT, lander, rover, planet orbiter etc. have been planned. Current services should have continuity - this is a mandate. Four different kinds of resolutions namely the spatial, spectral, temporal and radiometric resolutions are needed to be made more finer to address improvements. These are much needed in both microwave as well as in the optical domain. Disaster management, crop monitoring, etc under cloud cover need microwave observations. Significant progress has been made with Resourcesat-2, Cartosat series, INSAT- 3A, Oceansat-II and RISAT-1. So the continuity missions will be there. In the near future INSAT-3D imager and sounder will very significantly enhance our weather monitoring and prediction. GEO based microwave along with optical sensors will evolve.

ISRS:
Climate change has become a geo political issue. In this scenario what is ISRO's role in defining national policy framework?

DIR SAC:
Yes, Climate change has become a global concern, calling for concerted efforts with international cooperation in Earth Observation to monitor Essential Climate Variables. ISRO has initiated efforts in understanding the impact of climate change on various important parameters like: agricultural productivity, sea level rise and its consequences on the monsoon pattern etc. Under the Geosphere, Biosphere programme, study of green house gases, radiative forcing and study on aerosols are undertaken. Today, we have information generation capacity which is put to use for preparing various models and data sets to define and predict the impact of Climate Change which in turn will be instrumental to drawing a national policy.

ISRS:
When and how far do you see the penetration of remote sensing application data as similar to use of mobile phones in day to day life of a common man?

DIR SAC:
Google global map is a classic example of game changer in the RS data utilization and its application power. RS data penetration and diversified applications are far reaching. Today, in our country, communication network has reached to farmers and fishermen and general public at times of cyclone warning. On the other hand we have a classified information and capabilities to generate region-wise required information using Electro-optics and Microwave satellites. Various forums working towards dissemination of this information, needs to work together and act like a link between the information generation agencies like us and the end users like farmers, fishermen etc. According to me, RS data related information being available on mobile network is a matter of very short time from now.

ISRS:
What is your view on India’s stand on participating in International Space Station?

DIR SAC:
Space exploration and various experimentations in space are of common interest to all the space exploring countries. Since it is quite expensive, working together is very meaningful. ISS is providing the platform for various international forums working together for the meaningful purposes and we could make use of the opportunity to gain experience by having our astronauts conduct experiments in the zero G environment.

ISRS:
Do we also have plans for active-passive combinations of microwave sensors on the same platform such as ESA/JAXA/NASA etc? Why didn’t ISRO go for its own LEO based Microwave/mm-wave and IR radiometers from the same platform as in the case of NASA for deriving more accurate climate quality products?

DIR SAC:
CNES, NASA, JAXA and other international agencies are working with each other and giving priorities for climate monitoring activities by building instruments. We have also started working with international space agencies for building active and passive microwave sensors for weather and climate

studies. Meghatropiques and SARAL are examples. We are also working with NASA for generating climate quality wind vectors from Oceansat-2 Scatterometer data by utilizing the Quickscat pointed data for intercalibration.

ISRS:
How do you foresee the advances of onboard computing in our space missions? Will it help in faster dissemination of products to users and thus help mankind especially during disaster situations such as flood, cyclone, etc?

DIR SAC:
Certain level of automation is required for the on board data processing for disaster monitoring, cyclone, flood, volcanic eruption, fire etc. to help quick dissemination of information. Due to advancement in computational power ground processing can become very fast and reduce the turnaround time for many applications. However onboard processing capability increase could be much more useful if the satellites are interlinked through communication network so that the satellites can decide on the observation tasks can be decided based on the instantaneous needs. For example in case of certain critical events observed by one satellite it is able to inform other inorbit satellites to perform specific observations and downlink the required information. Increased computing power and intelligaence could then be effectively utilized.

ISRS:
Please tell us what is your idea about the prospects of nano-technology, micro-electro-mechanical systems (MEMS), and micro-opto-electro-mechanical systems (MOEMS) for our future payloads?

DIR SAC:
A lot of development has taken place in the field of NANO technology such as in MEMS and MOEMS. Adaptation to these miniature devices will revolutionize the satellite instruments in terms of their size, higher capabilities and longer life. We can think of sensor’s web for Electo-optics and microwave satellites. It will help in building the hyper spectral instruments. In the present scenario specific observations are very much limited due to the hardware size. It will be possible to realize compact instruments with enhanced capabilities by implementation of these Micro/nano-devices.

ISRS:
What kind of instruments should we be launching in the next 10-15 years that can provide better accuracy in weather prediction models, especially in tropical regimes? What would you rate as our greatest needs in terms of improving our disaster management and mitigation capability?

DIR SAC:
We need to build hyperspectral IR sounders from LEO and GEO platforms. Find ways of measuring vertical wind profiles. We also need to evolve microwave sounder and radiometric observations from geo platforms to address the cloud cover affected visible and IR measurements. In other words we need to move towards GEO based observations of visble, IR and microwave regions of Electro magnetic spectrum.

ISRS:
Thank you very much for sparing your valuable time for ISRS-AC. Kindly say a few words to our ISRS members who have been working in the field of remote sensing.

DIR SAC:
ISRS is doing excellent work since its inception. It conducts well structured

programs and object oriented events. Its most admiring role is dissemination of RS data to student community: (schools and higher secondary) and popularizing RS in the society. Thus, it is playing a vital role in bringing awareness and building capacity for future. My best wishes are always there for their endeavors.

Brief Biodata of Shri A S Kiran Kumar

Shri Alur Seelin Kiran Kumar is currently Distinguished Scientist/Director, Space Applications Centre (ISRO), Ahmedabad. He obtained his B.Sc. in Physics (Honours) and M.Sc. in Electronics from Bangalore University in 1971 and 1973, respectively, and his M. Tech. Degree in Physical Engineering from Indian Institute of Science in 1975. Shri Kiran Kumar joined Indian Space Research Organisation (ISRO) in 1975. During his career, Shri Kiran Kumar has commendably contributed to the design and development of Electro-Optical Imaging Sensors for Airborne, LEO and GEO platform based payloads right from Bhaskara to the advanced TMC ad HySI payloads for Chandrayaan missions. He has made significant contributions towards evolving observation strategy encompassing, land, ocean and atmospheric studies and planetary missions. Notable among them being, the 3-tier imaging system for IRS-1C to Resourcesat-1, ocean colour monitoring instruments to cater to PFZ forecast, high resolution along track stereo imaging system of Cartosat-1, sub-meter resolution optical imaging capability with TES to Cartosat-2 series, meteorological payloads of 2-channel and 3-channel VHRR, third generation imager and sounder from GEO platform as well as TMC and HySI for Chandrayaan-1/2 missions.

Shri Kiran Kumar has been steering the activities leading to indigenization of CCD technology with SCL, Chandigarh as well as IR sensitive quantum dot area array detectors realization alongwith IIT-Bombay.

Contributions of Shri Kiran Kumar to the earth observation programme, planetary missions as well as to the space programme, in general, have been well-recognized in the form of awards/laurels conferred by prominent national/international institutions. He is a Fellow of National Academy of Engineering and Corresponding Member of International Academy of Astronautics. He has represented ISRO in international forums like, World Meteorological Organisation (WMO) and Committee on Earth Observation Satellites (CEOS) in various capacities.

Shri Kiran Kumar has more than 60 publications to his credit.

Groundwork for IRS 1A Data Utilisation

Baldev Sahai
Deputy Director (Retd.), Space Applications Centre, ISRO, Ahmedabad
Present Address: 56, Nehru Park, Vastrapur, Ahmedabad
E-mail: baldevsahai@yahoo.com

Introduction

Breadth of visions of Professors Satish Dhawan, Yash Pal and P.R. Pisharoty gave fillip to building of an edifice at the Space Applications Centre (SAC) for exploiting Remote Sensing for natural resources management. A step in this direction was the Agricultural Resources Inventory and Survey Experiment (ARISE), conducted in collaboration with Indian Council of Agricultural Research. ARISE was the first semi-operational multispectral aerial survey in the country covering Anantapur district (Andhra Pradesh) and Patiala district (Punjab). A bank of Hasselblad cameras as well as aerial photographic films was imported in a record time to carry out the campaigns. This bank of 4 cameras was fitted in the belly of a vintage aircraft – Dakota - to carry out multispectral aerial photography using panchromatic and colour infrared films. Facilities were set up for film-processing and interpretation. Infrastructure created helped later campaigns covering Panch Mahals District (Gujarat) and Idukki district (Kerala). Four bands were chosen for the above-mentioned campaigns to match the bands of the Landsat imagery so as to facilitate interpretation as also to serve as 'ground truth' for the same.

Prof. Pisharoty was a Principal Investigator for Landsat (then called ERTS) from India. So Landsat imagery of the country (film format) was made available by NASA, leading to establishment of facilities for visual interpretation of this multi-band imagery. Many interpretation aids such as Large Format Optical Enlarger, Diazo Printer and 23-cm format Colour Additive Viewer were developed at SAC for the same.

With the launch of experimental satellites Bhaskara 1 and 2 in 1979 and 1981, respectively, India entered space–based remote sensing. In spite of the poor resolution (1 km) of the 2-band TV imagery, valuable experience was gained in data processing and interpretation for some applications. Encouraged by this experience India launched the Indian Remote Sensing Satellite (IRS) programme.

Joint Experiments Programme (JEP)

A Joint Experiments Programme (JEP) was launched by the Indian Space Research Organisation with various user ministries /agencies, in particular, dealing with agriculture, water resources, irrigation, mining, petroleum, and fisheries. The JEP was initiated with the following objectives, keeping in view the Indian diversity, scenario and varied national needs.

i) to optimize spectral bands, spatial resolution, temporal resolution and other IRS mission parameters,
ii) to develop an operational applications programme, and
iii) to get ready for utilizing IRS data

The JEP covered a wide spectrum of application areas in order to meet the above objectives. These studies were carried out, essentially in the end-to-end mode, by SAC and NRSA in collaboration with user ministries/ agencies.

Prof. Dhawan, then Chairman ISRO, led an awareness campaign amongst all user ministries/ departments/agencies of the Government of India by addressing separate meetings of such ministries/departments/ agencies to elucidate the proposed Indian Remote Sensing Satellite IRS)

Programme. In these expositions, potential of space-based remote sensing technology for national natural resources management was comprehensively brought out.

NNRMS Seminar

A concrete step towards creating awareness about the potentialities of Remote Sensing in the country for development activities was taken by organising National Natural Resources Management System (NNRMS) Seminar at Hyderabad in May 1983. The Seminar, organized by the Department of Space, with the support of the Planning Commission, proved to be a cornerstone in developing an application programme based on the integration of remotely sensed data and conventional techniques /methodologies. The seminar was attended by about 500 scientists and decision makers from all across the country. The results of the studies, carried out under the JEP involving end-to-end approach and other similar studies carried out separately by various organizations, numbering about 50, were presented in the 1983 NNRMS Seminar. Selected papers from the Seminar were published as a special issue: Indian National Natural Resources Management System, of the International Journal of Remote Sensing – Vol. 6, Nos. 3 and 4, March/April 1985. Incidentally 10 out of the 21 papers published in this special issue were based on studies carried out by SAC.

NNRMS Seminar arrived at a 16-point programme of activity for the following years including nation-wide use of Remote Sensing with special emphasis on IRS 1 programme as well as follow-on programmes. Immediate follow up action was the setting up of Planning Committee NNRMS (PC-NNRMS) chaired by Member Planning Commission. Six Standing committees, chaired by secretaries of the concerned ministry/department of the Government of India were

SC-O Ocean Resources
SC-B Bio-resources and the Environment
SC-A Agriculture and Soils
SC-G Geology and Mineral Resources
SC-W Water Resources
SC-T Remote Sensing Technology and Training

These standing committees provide valuable inputs about the specific spatial information requirement for their own natural resources management system project their requirements for future IRS systems and support financially application projects pertaining to their resources/disciplines.

Group Director RSAG is the Member-Secretary of SC-B, the most active of the standing committees in funding various application projects.

In addition, National Task Forces for nine specific application areas were also setup covering

i) Agriculture,
ii) Cartographic Representation of Data,
iii) Forestry,
iv) Geology,
v) National Resources Information System,
vi) Oceanography, Marine Resources and Coastal Studies,
vii) Soils and Land Use,
viii) Urban and Rural Studies, and
ix) Water Resources.

These Task Forces submitted their reports detailing the information needs, existing conventional information systems and the role of remote sensing in each area.
SAC played an important role in these task forces.

IRS Utilisation Programme (IRS-UP)

IRS-UP was a comprehensive programme initiated in 1984 to take advantage of satellite-based remote sensing for resources survey and management in conjunction with conventional data. Main objectives were

i) To use the IRS 1data for applications in selected areas of resource management viz, agriculture, water resources, mining, environment,

ii) To transfer technology of applications to the user agencies and to develop an infrastructure which would support the future remote sensing information system in the country, and

ii) To provide inputs for the IRS 1 follow-on programme.

Main considerations taken into account in chalking out the programme were:

i) Utility vis-à-vis National Natural Resources Management System and the long- term perspective,

ii) IRS-1 system and its capabilities in terms of ground resolution, spectral response etc.

iii) IRS -1 sensors and their capabilities,

iv) Expertise and infrastructure available in the country,

v) Past experience in remote sensing, and, in particular that demonstrated by JEP projects,

vi) Constraints on the availability of trained manpower and funds, and

vii) The schedule of IRS mission.

The main application areas considered where IRS-1 appeared to show potential was:

a) Agriculture and Land Use,

b) Forestry,

c) Geology (Mineral Resources)

d) Water Resources,

e) Environmental Studies,

f) Marine Resources,

g) Cartography

Keeping in view the primary goal of IRS Mission i.e. operationalisation of Remote Sensing applications for natural resources management in the country, the envisaged applications were evaluated based on the status of technology and the experience of Department of Space [Space Applications Centre (SAC), and National Remote Sensing Agency(NRSA)], user agencies and academic institutions.

An application is considered operational when a technique is adopted by a user agency in its day-to-day working. This status is acquired by going through three stages, viz,

i) Technique development phase,

ii) Experimental phase, and

iii) Quasi-operational phase.

Sixteen application projects were taken up under the IRS Utilisation Programme (IRS-UP) and the overall responsibility for execution was entrusted to Space Application Centre. Prof. P.D. Bhavsar was designated as Director IRS –UP. Broadly these projects fell into 4 categories. The National Remote Sensing Agency was entrusted with the task of executing Operational and Quasi-operational projects as the lead agency. The challenging task of carrying out the Experimental and Techniques Development projects was assigned to Space Applications Centre as the lead agency. These experiments were:

A. Operational Application Projects

1. Regional Geological Mapping
2. Ground Water Exploration
3. Flood Mapping

B. Quasi-operational Application Projects

1. Land Use/Land Cover Survey and Monitoring
2. Land Degradation including Desertification
3. Snow Mapping
4. Drought Monitoring
5. Soil Mapping

C. Experimental Application Projects

1. Crop Production Forecasting
2. Forest Mapping and Damage Detection
3. Water Quality Mapping
4. Watershed Characterisation
5. Monitoring of Coastal Environment
6. Marine Fisheries

D. Techniques Development Projects

1. Crop Stress Detection
2. Crop Yield Monitoring

All these projects in the pre-IRS phase were carried out using Landsat and aerial data in conjunction with ground-truth data and conventional data. Data from the French satellite SROT and Terra Experiment carried out during Indo-USSR space flight 1984 were also made use of.

At the Space Applications Centre, we had the involvement of 36 agencies in IRS-UP programme as collaborating agencies.

Training Courses: Although the Indian Institute of Remote Sensing, Dehradun was identified as the main agency within DOS to undertake training of personnel, but to address adequacy of trained man-power, particularly involved in projects at SAC, five 12-week in-house training courses were carried out during 1984-86 period. These had 45 participants from user agencies and 48 in-house participants.

These experimental projects laid the foundation for many projects under the Remote Sensing Application Missions.

During 1986 when onslaught of drought looked imminent, DOS volunteered to carry out hydrogeomorphologial mapping on 1:250,000 scale for four states which were threatened. SAC carried out such mapping for the states of Gujarat and Rajasthan within 4-6 weeks so as to provide extremely valuable maps for ground water targeting.

NNRMS - State Support Services

Under this programme major effort was made by interacting with state-government departments /agencies, universities and other academic institutions to apprise them about IRS Programme. Appraisal seminars were organized during the period 1984-87 for officials of 16 states resulting in either getting them involved immediately in IRS Utilisation projects and/or setting up state remote sensing centres.

Remote Sensing Application Missions (RSAM)

During 1986, it was decided that SAC should undertake remote sensing projects in a "Mission Mode" i.e. at the behest of user departments/ministries/agencies willing to participate in and to fund such projects. It was envisaged that this approach would accelerate operationalisation of applications. Accordingly following Remote sensing missions were taken up at the national level.

These missions broadly fall into the following categories, broadly coinciding with the resources covered by first five PC-NNNRMS Standing Committees:

- Agriculture, Crops, Soils, Land Use and Drought
- Land and Water Resources
- Ocean Resources and Environment
- Forestry and Environment
- Geology and Mineral Resources.

SAC had undertaken to execute the following projects.

1. Nation-wide Hydro-geo-morphological Mapping for the National Drinking Water Mission, now called the
   Rajiv Gandhi National Drinking Water Mission: 1987-1990.
   - Dept. of Rural Development, GOI
2. Crop Acreage and Production Estimation (CAPE)
   - Ministry of Agriculture, GOI
3. Cotton Acreage and Condition Assessment
   - Ministry of Textiles, GOI
4. Urban Land Use and Sprawl
   - Urban Development Authorities of Ahmadabad, Mumbai & Calcutta

5 Agro-climatic Land Use Mapping
   - Planning Commission

6. Brackish water Aquaculture Development
   - Ministry of Agriculture, GOI
7. Inland Fisheries: 1990-91
   - Ministry of Agriculture, GOI

8 Environmental Impact of Mining and Superthermal Power Complexes: 1987-90
   - Ministry of Environment & Forests

9. National Grassland Mapping
   - Ministry of Environment & Forests, GOI
10. Environmental Impact of River Valley Projects
   - Ministry of Environment & Forests, GOI
11. Marine Fisheries
   - Ministry of Agriculture, GOI

12. Watershed Prioritisation
13.
    - Ministry of Agriculture, GOI
14. Coastal Environment: 87-89
    - Ministry of Environment & Forests, GOI
14. Glacier Inventory: 1990-91
    - Dept. of Science & Technology, GOI
15. National Wasteland Mapping: 1986-88
    - Ministry of Agriculture, GOI
16. Coastal Regulation Zone Mapping: 1992-94
    -Ministry of Environment & Forests, GOI
17. National Wetland Mapping: 1992-
    - Ministry of Environment & Forests, GOI
18. Impact and Management of Irrigation in IGNP Through Remote Sensing
    - Indira Gandhi Nahar Pariyojana
19. National River Action Plan: Land Use Mapping for Sewerage Treatment Plants: 1993-
    - Ministry of Environment & Forests

Projects carried out or initiated under the IRS Utilisation Programme and Remote Sensing Application Missions not only provided valuable experience but also an opportunity for the application scientists to switch over gradually from dependence on visual interpretation to digital image processing. Adequate facilities for the digital image processing at national level had become available apart from SAC at the 5 Regional Remote Sensing Service Centres set up under NNRMS at Jodhpur, Dehradun, Bangalore, Nagpur and Kharagpur. Data from Landsat, SPOT and NOAA were freely made use of during this learning phase.

Utilisation of Data Products

All this groundwork for getting ready to make full use of data products started bearing fruit when the first Indian operational satellite IRS 1A, was launched on March 17, 1988. Application scientists were well prepared to extract information about natural resources encompassing agricultural crops, soils, land use, water resources, ocean resources, forests, environment, geological/mineral resources etc. from the satellite imagery. Both the LISS 1 and LSS II multispectral data with spatial resolution of 73 m and 36.5 m, respectively, were put to use. All ongoing projects under IRS Utilisation Programme as well as Remote Sensing Application Missions, which covered a wide spectrum of natural resources, switched over to making use of the IRS 1A data products. Initially, some quick feasibility studies were carried out to assess the potential and adaptability of the data for various applications. Ongoing projects and studies soon adopted the data products without any difficulty.

Conclusions

This note briefly enumerates the efforts at SAC made towards operationalising remote sensing applications for natural resources management in the country. Starting with semi-operational aerial multispectral photographic survey campaigns for inventorying resources to the use of data from operational space-borne Remote Sensing sensors for natural resources management, the application scientists have gained wide and valuable experience in going through evolution of the operationalisation steps. The launch of IRS 1A is a major milestone towards complete operationalisation of all remote sensing applications in natural resources management in conjunction with some conventional data.

This note is restricted mainly to mentioning the efforts of remote sensing application scientists in the erstwhile Remote Sensing Applications Group. In no way implies that others have not made any contribution in this march towards preparedness for IRS 1A data utilization. The author had the privilege of working along these scientists whose number had grown to almost 100. All of them have made very valuable contribution. However, particular mention must be made of Dr. R R. Navalgund, Dr. J.S. Parihar, Dr. Ajai and Dr. V.K. Dadhwal who have gone on to shoulder greater responsibilities.

Realisation of IRS-1A Payloads

Dr. Ramrattan

Asso. Director (Retd.) SAC Ahmedabad

Introduction

On March 17, 1988, India joined the elite group of nations capable of developing and operationalising remote sensing satellites. On this day IRS-1A, precursor of Indian built remote sensing satellites, was successfully launched into a polar sun-synchronous orbit from the Soviet Cosmodrome at Baikonur. The electro-optical payloads carried by IRS 1A were significantly different and much more advanced compared to those previously flown on Bhaskara 1 and 2.

The decision to develop a state of the art remote sensing satellite, named Indian Remote Sensing Satellite, had been taken by ISRO in the late seventies. The remote sensing satellites operational at that time were Landsat belonging to NASA (1972), and SPOT belonging to CNES, France (1983). The experience gained from these missions helped to define the objectives of IRS, especially the spectral bands, ground resolution, revisit time and time of pass. Most application scientists were familiar with Landsat and SPOT data, so the IRS program was of a similar nature.

Payload Details

IRS 1A was the first of the operational remote sensing satellites. It was very different from the previously flown Bhaskara and Aryabhatta spacecraft. It was much heavier, almost one ton compared to about 450 kg for Bhaskara, and three axis body stabilized compared to spin stabilized in earlier spacecraft, so that continuous imagery could be obtained during the orbital pass. The orbital altitude was much higher (917 km compared to 550 km). The payloads consisted of two cameras, one low resolution four band multispectral camera named Linear Imaging Self Scanned sensor (LISS-1)

which utilized the along track motion of the space craft to generate imagery. The second payload was the medium resolution four band multispectral LISS -2. The four bands consist of the blue (Band 1: 0.45 to 0.52 micrometers), green (Band 2: 0.52 to 0.59 micrometers), red (Band 3: 0.62 to 0.68 micrometers) and the near infra red (Band 4: 0.77 to 0.86 micrometers).

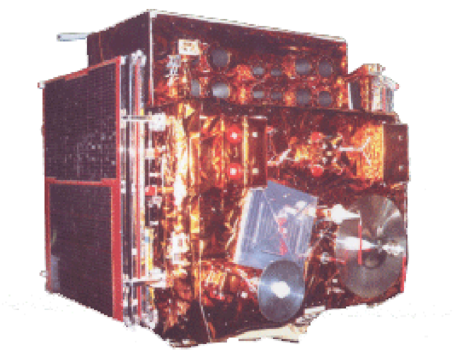


Figure 1: IRS 1A spacecraft

Figure 2: LISS -1 camera

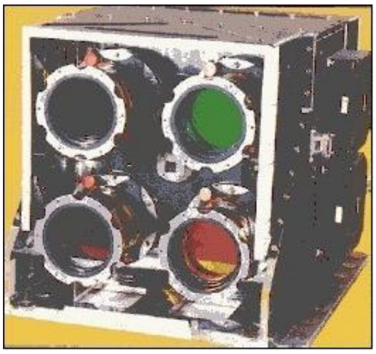


Figure 3: LISS - 2 camera

It was very challenging to develop various subsystems that formed the electro-optic payloads on board IRS 1A, because many concepts were being tried out for first time. In IRS-1A a great deal of system studies helped in selecting the modular configuration for four bands of LISS-1 and 2, and selection of radiometric quantisation level to 7 bits. Spatial resolution improved to 36m from 1km of the previous TV payload. This was ISRO's first CCD based spaceborne mission operating in pushbroom mode. Electronics systems were designed with discrete available non-qualified components after suitable qualification. AIT processes such as band to band registration were also well established.

Each LISS camera consisted of an optics subassembly, imaging detectors, in-flight calibration system, the processing electronics, and data formatting electronics.

Table 1 shows the main features of the LISS – I and II cameras.

Table 1: Specifications of the LISS - I and -II instruments

Parameter	LISS-I	LISS-II A/B
Focal length	162.2 mm	324.4 mm
FOV, IFOV	9.4º, 80 µrad	4.7º+ 4.7º, 40 µrad
Spectral bands (µm)	0.46 - 0.52 (blue) 0.52 - 0.59 (green) 0.62 - 0.68 (red) 0.77 - 0.86 (NIR)	0.46 - 0.52 (blue) 0.52 - 0.59 (green) 0.62 - 0.68 (red) 0.77 - 0.86 (NIR)
Integration time	11.2 ms	5.6 ms
Ground resolution	72.5 m (each band)	36.25 m (each band)
Swath width	148 km	2 x 74 km
Radiometric resolution	7 bit	7 bit
Detector, elements	CCD, 2048	CCD, 2048
Data rate	5.2 Mbit/s	2 x 10.4 Mbit/s
Instrument mass, power	38.5 kg, 34 W	2 x 80.8 kg, 2 x 34 W

Optical systems

In the early eighties, there were no Indian establishments capable of fabrication, assembly and testing of the lens assemblies required for the LISS -I and LISS -II cameras. The specifications of these lens assemblies were generated by ISRO and these lens assemblies were procured from France.

LISS - I camera utilised four similar, but not identical lens assemblies with matched focal length of 162.2 mm. Each band had its own lens assembly which was optimised for maximum image quality in the band. Band definition was obtained using a bandpass filter placed in front of the lens elements. The lens assembly consisted of eight lens elements

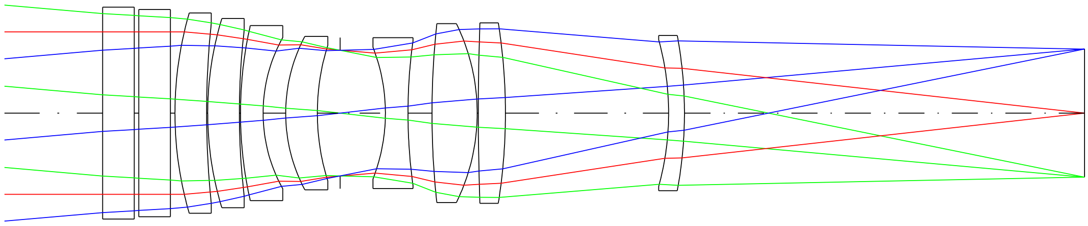


Figure 4: Optical schematic of LISS – I

arranged in a suitable mechanical barrel. The location of the eighth lens element was used to match the image format for the four assemblies. The first element was a neutral density filter for reducing the light input to the lens assembly, and the second was the bandpass filter. The swath covered by the four cameras was matched to the length of the detectors within a quarter of a pixel. Extensive testing by the manufacturer at the initial stage and after each space qualification test including thermovacuum testing, vibration, humidity, and thermal cycling was carried out and the results verified by ISRO. All material used in the lens assembly were space qualified and all processes used in the realisation of these lens assemblies were also space qualified. The lens assemblies were provided with a purging mechanism which would vent when exposed to vacuum so that no residual air was trapped during operation in vacuum. The lens assemblies were focussed for imaging in vacuum and while testing in lab conditions, provision was made to provide the necessary offset in focus.

LISS - II camera consisted of two sets of identical four band multispectral cameras named A and B. The image format for these cameras (52 mm) was double that of the LISS – I camera, but the detectors at that time were only 26 mm in length, so only half the useful format could be imaged by a single camera using the available CCD. Just like in LISS – I, each camera utilised four similar, but not identical lens assemblies with matched focal length of 324.4 mm. Each band had its own lens assembly which was optimised for maximum image quality in the band. Band definition was obtained using a bandpass filter placed in the front of the lens assembly. The lens assembly consisted of eight lens elements arranged in a suitable mechanical barrel. The location of the eighth lens element was used to match the image format for the four assemblies. The first element was a neutral density filter for reducing the light input to the lens assembly, and the second was the bandpass filter. The swath covered by the four cameras (half that of LISS-1) was matched to the length of the detector within a quarter of a pixel. Testing carried out were similar to that on LISS – I.

Figure 4 shows the optical schematic of the lens assembly for LISS – I. The schematic for LISS – II is similar. The optical design used is a variant of the Double Gauss design, which is commonly used in photographic cameras. The design is highly corrected for all aberrations such as spherical aberration, coma, astigmatism, distortion, and chromatic aberration. The image quality is diffraction limited.

In LISS – II, the image format is double what can be imaged by the 2K detector, hence one half of the image is not utilised. The total swath of 148 km is imaged by one LISS – II camera viewing the first 74 km and the same band in the second camera viewing the other 74 km.

Notice the eighth lens element, on the extreme right, is used for focus adjustment and trimming the image format.

Detectors:

Each band of LISS - I used a single 2048-element linear CCD detector array (Fairchild CCD 143A). The pixel was square in shape with 13 x 13 micrometer pixels. The total length of the device was 26 mm. On board calibration systems used two appropriate LEDs per band placed close to the devices.

Prior to IRS 1A, the cameras used TV cameras with vidicon sensors which required high voltages of several kilovolts. IRS 1A was ISRO's first experience with Charge Coupled Devices (CCDs) and the performance of these devices paved the way for usage of these for all future missions. The advantages of CCDs include high dynamic range, low noise and therefore high SNR, low voltages for bias and clocks (a few volts), high readout rates leading to very low integration times, high quantum efficiency and large format. The performance of the CCD pixels were regularly monitored by illuminating them with a set of LEDs placed close to the detector head assembly.

Mechanical structure:

The four cameras of LISS – I were attached to an invar structure so that the registration among the bands is not affected by vibration or thermovacuum changes.The mechanical structure was light weighted by scooping a solid block and providing mounting holes and interfaces for the lens assemblies and detector head assemblies. Several temperature sensors and heaters were attached to the structure to monitor and regulate the temperature of the payload. Lugs were provided at the bottom of the structure to attach the EO module to the spacecraft mounting deck.

Camera electronics:

These packages provide regulated electrical power to the CCD, heaters, temperature sensors and calibration LEDs as well as processing the video from the CCD and formatting it for the BDH. There were a number of such packages required for the payloads.

IRS 1A mission was completed in July 1996 after serving for 8 years and 4 months instead of designed life 3 years. IRS 1A mission was followed by similar payload IRS 1B.The unprecedented success of IRS-1A/1B had put Indian Remote Sensing Program firmly on the world map by the end of the eighties.

Conclusion

The development of the IRS 1A payloads, LISS-I and LISS-II, was challenging for several reasons. These include:

1. Use of multispectral cameras for generating simultaneous images in four bands
2. Very accurate registration of the images to better than a quarter pixel on the ground.
3. Design and development of the mechanical structure which maintained the initial registration and focus for all the four bands
4. Synchronisation of power supplies with clocks and biases
5. Poor yield of CCDs and qualification issues
6. Mismatch between device gate capacitance and drive electronics
7. Large optical crosstalk in Band 4 CCDs
8. ESD issues with CCDs

As these instruments were complex and CCD based solid state technology was involved for the first time, it was a great learning experience to all of us. However, these instruments were realized successfully as a result of relentless efforts made by a dedicated team of engineers at SAC. Under Dr. George Joseph, APD of this project was a great source of support both technically and personally to all of us providing very able leadership. Every facility was eager to extend their fullest cooperation and support which I thankfully acknowledge.

Remembering IRS-1A Payloads Development

D.R.M Samudraiah

SAC Ahmedabad, drms@sac.isro.gov.in

IRS -1A development was a major mile stone in the IRS programme. We were working under the leadership of Dr George Joseph. I was introduced to this project immediately after Bhaskara-2 launch. We were working initially on Multi-spectral scanner as prime payload for IRS-1A and CCD payload as a piggy back payload. Prior to that, Sensor development team at Space Applications Centre had the rich experience of development of TV payload which was very tough because of technological elements involved and that too it was the first space payload made by the team. While TV payload development was in progress, one small set of people worked on the development of Aircraft Multi Spectra Scanner (MSS) with complex technologies like scan mechanism, cooled detectors, synchronous data acquisition, recording system etc. Along with MSS, a small CCD camera was developed by Shri Nagachenchaiah and team. It was flight tested and the imagery generated by this small camera has played major role in finalization of the payload configuration for IRS-1A. I remember very well that the payload team did lot of system trade off studies and convinced everybody to take the decision of flying all solid state sensors in push-broom scanning using state of the art linear CCDs. It may be noted that most of IRS-1A payload documents contain the imagery obtained from this small camera. Initially CCD142 was selected based on the availability in commercial domain but subsequently the manufacturer has come forward to develop custom sensor with better electro-optical performance. LISS-1, LISS-2A and LISS-2B were having a common system design with necessary scaling to meet the different resolution requirement. The designs were modular to minimize interaction from one band to another band from electro-optical performance point of view. The reliability was major consideration and even one subsystem failure could lead to only one band failure but not the total system failure. This approach also minimized the number designs to be handled and gave definite advantage with respect to reliability, development, fabrication, testing and integration. Based on the experiences of Bhaskara and aircraft sensors development, the team always worked with confidence compared to Bhaskara. We were to design the video chain with bandwith of ~10 times read out rate as we have to consider processing pulse amplitude modulated (PAM) signals and the concept of correlated double sampling was tried for the first time. As the bandwidth increases, noise will increase but our goal was to ensure that the total noise was <0.5 LSB of ADC so that we can ensure quantization limited noise performance at the system level. It was a tall order of asking based on the experience of Bhaskara but was achieved successfully. We had learnt the Op-amps small and large signal parameters and their implication on the designs of circuits. One of the major problems faced was the non-availability of space qualified components particularly in analog and mixed signal processing. Attempts were made to realize the same functions with discrete components as well as to develop confidence on the non-standard integrated circuits by subjecting them to rigorous characterization and testing under various environmental conditions including life tests. Considering enormous exercises carried out and their consistent results, it was decided by project QA to clear integrated circuit based approaches as eventually they give better reliability. Even at the time of spacecraft pre-shipment review, the confidence issue on ADC was raised and got cleared. It may be noted that there was no failures reported after launch and the system worked for very long time with consistent performance. This experience was unique and gave confidence in dealing with such situations in subsequent projects as all of the payloads were state of the art type and always non-standard components were required to be used. We did many of the detailed reliability analyses together along with QA personnel during IRS-1A. This gave us clarity on spirit of quality assurance aspects and also firm understanding that quality has to be built in the design, be it circuit/system design, component selection, lay out/ interconnection design, incorporation of provisions for quality fabrication, testing and integration. And it was clearly understood by one and all that quality can not be added by simply incorporating inspection stages alone. This made us to practice of quality designs and carry out all related analysis and testing before the designs are offered to QA team for checks.

The mechanical design of Electro-optical module was carried out using INVAR as material for near zero coefficient of expansion. Hi-rel welding aspects were learnt w.r.t optical quality assemblies. It was a great learning that how the assembly and thermal generated stresses affect the stability of optical alignment. Very innovative way of interconnecting of the barrels of 4 bands was arrived at to minimize these effects. This gave the team a live experience of handling difficult problem. It helped the team to develop necessary analysis approaches and also different design approach for design of future Electro-optical module. It was also great experience to develop test benches for testing CCDs, electronic cards and packages and also integrated payloads. Computerised payload testing was introduced. Dr George, APD, Payload used to give directions only after thorough discussions. At the end of discussions, he used to tell the team leaders to decide. He had identified team leaders for various activities and guided them. The payload reports used to be different compared to others as it was made simple and supported by results and clear analysis. As the payload development is an interdisciplinary activity, all the members used to learn subjects other than their core strengths simply because of proximity and thanks to very good reports. The members used to cross question each other and convince each other and this helped to get very unusual feedback for a designer who was doing this activity for the first time and there was no expert previously in that field. This process of discussion and decision making became the strength for sensors team as this culture is being followed even now meticulously. All the deliberations of committees like Material review board (MRB), test and evaluation (T&E) committee etc., used to be very lively. The deviations and their impacts used to be discussed very detailed way. This system of systematic analysis gave feedback to designers, fabricators and integrators and that was always taken into account in the next project.

We also got experience of facing different types of personalities who were very intelligent and can always bring out new points for consideration than the designers/ fabricators thought. Many of our colleagues worked for development of facilities at Sensors development division and also in Test, evaluation, standards and Calibration (TESC) divisions. After going through qualification models for LISS-1 and LISS-2, we faced an interesting problem during integration of LISS-1 FM. Very occasionally, we used to observe wrong code once in million or so. It was a Herculean task of observing the problem and was a great experience of tracing the reason, simulating the problem and finding out alternate solutions. It was traced to fast rise/ fall transitions of some digital signals picked up by ADC convert command through harness and ground lines. The problem used to occur only when these transitions coincide with internal clock of ADC. It was very interesting to see that signals of LISS-2 were having slow rise times tha those of LISS-1. It was very remarkable achievement that we could solve the problem though we could not physically see the transitions on the Oscilloscope. This led us to completely change the grounding schemes in the next projects.

The experiences of IRS-1A gave very strong foundations for the development of subsequent payloads and it was a unique experience.

Call for Articles

Readers are requested to contribute short articles for publication in the forthcoming issue of *Signatures,* related to the specific theme ***"Remote Sensing Data Products & Retrieval Algorithms"***.

The deadline for inclusion in the next issue is **May 31, 2013.**

- Editorial Team

Mechanical System for Indian Remote Sensing Satellite, IRS-1A

D. Subrahmanyam
SAC Ahmedabad

IRS-1A, the first of the series of indigenous state-of-art remote sensing satellites, was successfully launched into a polar sun-synchronous orbit on March 17, 1988 from the Soviet Cosmodrome at Baikonur by Vostak rocket. IRS-1A carries two cameras, LISS-I with four bands (B1, B2, B3 and B4) in the spectral range of 0.45 - 0.86 microns with resolutions of 72.5 m and a swath of 148.48 Km and LISS-II with four bands in the spectral range of 0.45 - 0.86 microns with resolutions of 36.25m with a swath of 145.48 km.The swath of LISS-II was achieved by combining two cameras i.e LISS-IIA and LISS-IIB.

IRS-1A mission is completed during July 1996 after serving for 8 years and 4 months in the orbit. This being the first remote sensing mission, it was a challenging task to design, develop and deliver a space borne system to all the engineers and scientists involved in the project.

IRS-1A has three camera structures, one for LISS-I and two for LISS-II. It uses the pushbroom technique of imaging using charge coupled devices (CCD) placed at the focal plane of imaging optics.

Design of Mechanical System: Mechanical system design to meet the stringent payload requirements was a very challenging task. Design of mechanical system starts with the optical layout. Optical system consists of collecting optics (i.e the Lens), band pass filter and inflight calibration system (i.e LEDs). The Lens system was designed and delivered by M/S Matra Ltd, France. The Lens housing was made of aluminium alloy Al 6061T6. The flange focal distance (FD) of the typical lens was about 240mm in LISS-II. The d(FD)/dT of the Lens system was of the order of 5µ/0C. It was very important to maintain the separation between Lens and detector to get the best performance for operating condition of 20±50C. A housing was designed to hold the lens system at one end and detector head assembly at another end. A typical housing is shown in Fig-1. Invar was chosen as housing material due to its low CTE. Low CTE helps to maintain separation between lens and detector for operating temperature range of 20±50C. Invar is a hard material to machine. So, residual stresses get introduced during machining. To remove the residual stress, heat treatment was carried out at 300 °C after pre machining but before final machining. Furthermore, Invar is subject to some dimensional instability due to physicochemical effects. It is therefore necessary to perform accelerated aging of the part before use, by baking at 100°C for 24 hours followed by slow cooling to ambient temperature at a rate of 10C per hour.

This aging treatment is for rearranging carbon atoms in to relatively stable configuration for long term dimensional stability.

Detector head was also made out of invar material and two stage heat treatment was carried out i.e stress relieving and aging.

To get preliminary design estimate, the housing was assumed as double cantilever beam fixed at its flange. Maximum stress and deflection was calculated for 15g steady state load. After that it was analyzed by Finite element method.

The main load bearing structure was bracket. The function of the bracket was to hold four housing assembly and to maintain the alignment among them i.e. band to band registration(BBR) among the bands. It also holds the Detector Electronics Package (4 nos) as shown in Fig-2.

The bracket was made out of aluminium plates welded together by TIG welding process. TIG welding was carried out at VSSC. To qualify the TIG welding process for space application, various samples were made for tensile and shear strength. After due qualification, this process was successfully used in IRS-1A for all three cameras. To prevent corrosion, anodizing was carried out for bracket. Also to stabilize the structure, thermal cycling was carried out only for welded structure. To remove the residual stress introduced during welding, vibratory stress relief method "formula 62" was carried out. This produces a more dimensionally stable structure and reduces the random distortion that often occurs in unstable work-pieces.

Electro Optics Module (EOM) consists of main bracket, Lens assembly, Housing, Detector head assembly, DE packages, alignment cube etc.

The main design requirements was that EOM should survive the steady state load of 15g/6g/6g along roll, pitch and yaw direction respectively and dynamic loads like sine and random vibration loads. To design independently from spacecraft and to avoid dynamic coupling with spacecraft, it was decided to keep the EOM frequency over 100 Hz. Structural model was made and vibrated to qualify the structure from vibration point of view with dummy lens and detector head mass.

During the engineering model realization, it was observed that BBR among four bands changes after the integration of DE packages. After due investigation and detailed studies, it was found that all four housing assemblies move independently due to double cantilever mounting. So, coupling plates one at Lens end and other one at detector end were introduced to arrest the independent movement of lens and detector head assembly. Also, the coupling plates increases the stiffness of the total assembly. After introduction of coupling plates, BBR problem was solved to restrict misregistration within permissible limits and all the four lenses were aligned mechanically such that their optical axes were parallel within 1/8th of IFOV.

Detector Electronics package (4 nos) were separate packages and mounted on the sides of bracket (two on each side). The packages were mounted close to detector so that the harness length between detector and DE packages were minimum, otherwise it will introduce more noise into the signal. The packages were fabricated out of aluminium alloy Al6061 T6. Main box with bottom, front and rear sides and two side plates (LH & RH) was made out of single block. The top plate was separate. It was fixed to main box with fasteners.

ETM and FM EOM had undergone successfully thermo vacuum, thermal cycling and vibration tests. It was really exciting and challenging for me to conceptually designing, analyzing with existing tools and realizing a mechanical structure which was flown for first time in Indian remote sensing mission.

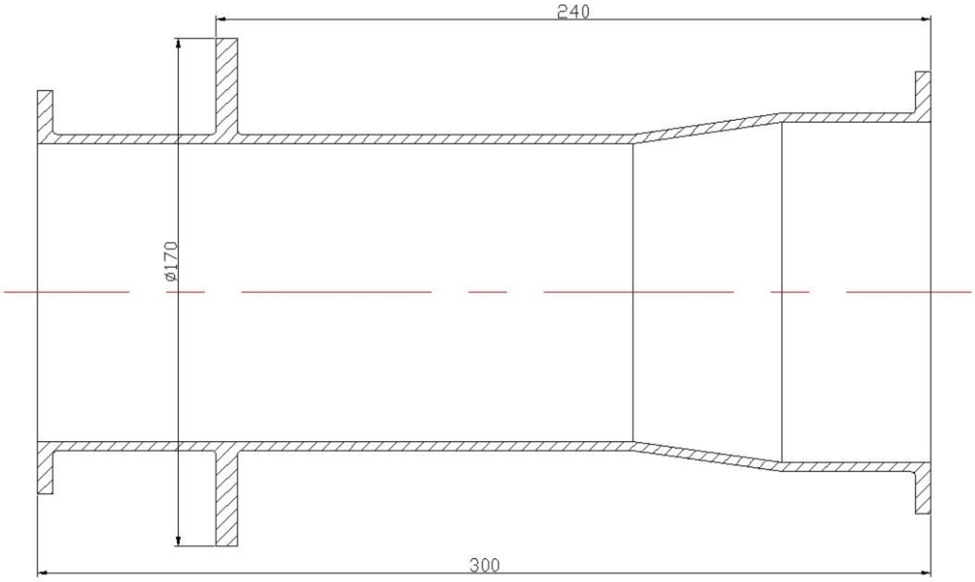


Fig1: TYPICAL HOUSING (INVAR) FOR SINGLE BAND

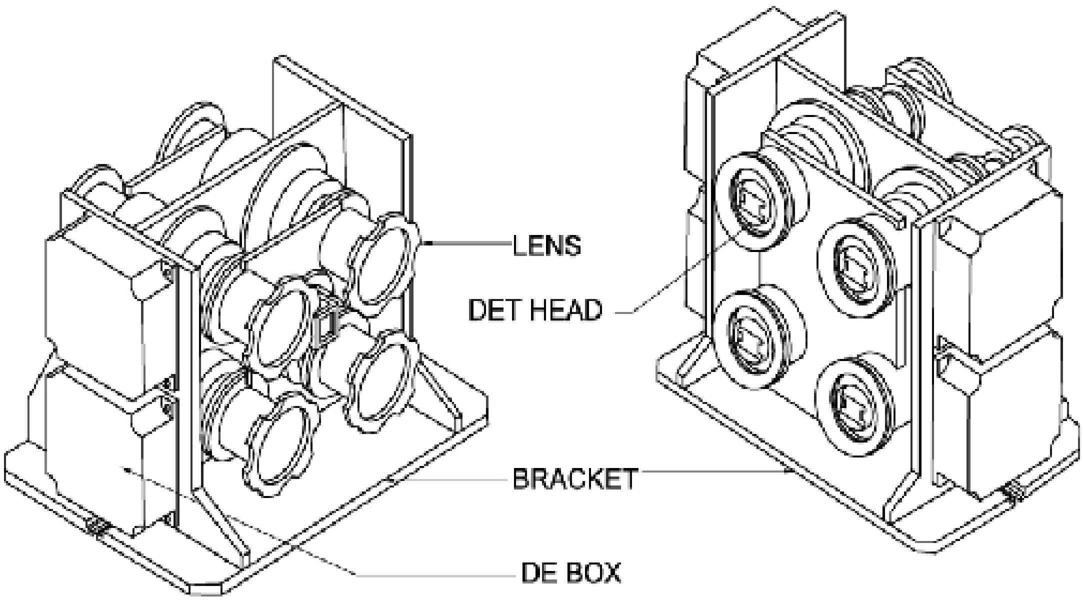


Fig2: LISS-I E.O.MODULE

IRS-1A Data Products System - A Reminiscent

K. L. Majumder

DPD, OD of IRS-1A & Deputy Director (Retd.), Space Applications Centre, ISRO, Ahmedabad

IRS-1A was launched on 17th March 1988 at an altitude of 904km with two payloads LISS-I, LISS-II operated in four Spectral bands in visible & Near infra-red regions with 22 days receptivity from Russian Baikonur Cosmodrome for collecting Remote Sensing Data, operationally, for Mapping and Management of National Natural Resources viz. agriculture, forestry, hydrology, geology, land use and land cover, snow, coastal areas etc.

In order to generate the Data Products from this mission, an Operational Data Products System was established with the involvement of IRS-1A Project Ground Segment elements from SAC, ISAC, ISTRAC, NRSC and IISU. The details of IRS-1A satellite, its various sub-systems, including Orbital &Attitude characteristics, RF communications and Spacecraft Control TT&C are given in [1], [2], [3].

DATA PRODCUTS SYSTEM: This Indigenous Data Products System was developed with the goal of generating different types of Data Products for IRS-IA, operationally. The requirements of different types Data Products were generated after detailed discussions with Applications Scientists of ISRO (DOS) and other users in the country. Product definitions and specifications and throughput requirements were finalized after critical analysis and deliberations with the designers of different Ground Segment sub-system designers. The Operational System for IRS-1A Data Products generation is broadly shown in the Figure-1.

TYPES OF DATA PRODUCTS: The different types of Data Products were defined as per their levels of processing. For example, LEVEL-0 RAW data, LEVEL-1 Radiometric Corrected BROWSE Product, LEVEL-2 Geometrically corrected STANDARD Products, LEVEL-3 Precision Products using GCPs and LEVEL – 4 Special Products .The details of the requirements, definitions and specifications of products are given in Table -1 [4].

IRS-1A DATA PROCESSING SOFTWARE : Data Processing Software was developed at Space Applications Centre, in collaboration with ISAC, NRSC, ISTRAC and IISU and installed at NRSC to generate Digital & Photographic products, operationally.

Prior to the Launch of IRS-1A, exhaustive data Simulation and Modeling was carried out with LANDSAT MSS//TM data for testing all types of algorithms. Contingencies were built in the software system so as to produce good quality FIRST DAY Data Products on time . The developed software was installed on a system configuration, named, Data Products Generation System (DPGS), consisted of VAX-11/750, 780 computer systems, FPS 5205 Array Processor for Number crunching with small main, cache memory & bulky multiples of 300 GB hard Disk drives, HDDTR, MFPH special hardware device and Tape Drives to produce the Digital Data products in a number of Standard Formats or Photo Compatible Tapes in various densities. The Processing system was so configured for Automation under a Scheduler, controlling all the processing functions and peripherals. The entire software for Data Products system was designed and developed following the software Engineering concepts, for computer processing, data communication support, data display, storage and archive media available at that time. End to end testing of the systems were carried out with exhaustive simulations with the data from LANDSAT Satellite and other available sources. Due to these efforts the simulated First Day Product for IRS-1A was generated quite in advance.

Separate Processing Systems were identified for different types of Data Products, Viz. Browse, Standard, Precision & Special Data Products with enhanced geo-location accuracy and Value added products like Various Image Enhancements.

APPROACHES USED IN DATA PRODUCTS : For correcting the Radiometric and Geometric distortions of the IRS-1A data [4] systematic modeling for charactering error sources were carried out. Laboratory test data for sensors on board IRS-1A were used for modelling the basic inputs for radiometric correction algorithms and sensor alignments for geometric corrections. The models for Radiometric Correction were modified after launch with actual scene data and Look up Tables (LUTs), as required. The LUTs were generated using global, regional or local scene data. Geometric processing involves each pixel to be corrected for all the distortions caused during data acquisition . A number of options available for generation of output on user required Ellipsoid, Map Projection with desired resampling techniques.

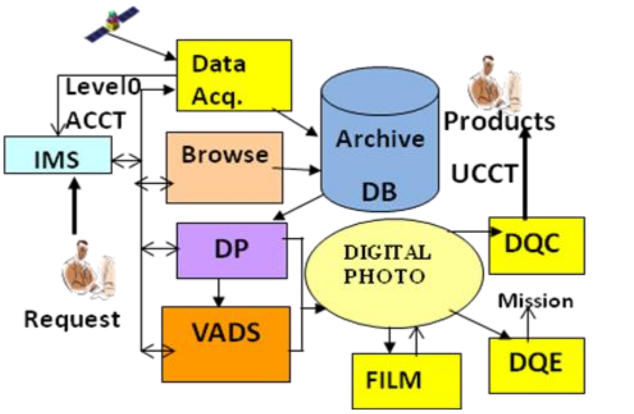


Figure-1: Operations Flow for a Typical Data Processing System

IMPROVING TECHNIQUES: Some activities related to improving the location accuracies were carried out with exhaustive system studies, developing models for orbit, attitude, attitude rates, automatic registration techniques, digital mosaicing, Swath Modeling, Geocoding, Precision Geocoding. Concept proving exercises using IRS-1A data sets for improving Geo-Location accuracy by SWATH (FULL pass) Model were carried out. Also a number of Algorithms were developed and used for improving the visual quality of image data.

CREATION OF GCP LIBRARY: Activities for building a GCP Library in collaboration with Survey of India (SOI) was initiated to process IRS-1A data, which were continued for subsequent missions.

DATA QUALITY EVALUATION: An independent System was designed and developed for the periodic calibration, evaluation of all the products in terms of radiometric and geometric accuracies and quality of photographic products.

GROUND SEGMENT COMMITTEE: For reviewing and monitoring the progress of activities of IRS-1A Data Products, an inter-centre Ground Segment Committee was formed. This committee used to meet periodically at different centers, in rotation, to discuss the activities under design and development. The Scientists/Engineers up to working levels used to participate in the decision making. Also, the committee was involved in sorting out the overlap areas of work for the centers in order to minimize duplications and sharing the software and other resources.

ACCOMPLISHMENTS: Data Products System for IRS-1A, developed in collaboration with the other ISRO (DOS) Centres, mentioned earlier, was installed at Operation Centre at NRSC and made operational before the launch of the satellite ,after an exhaustive Test and Evaluation of the total system. Data Products generated for IRS -1A used to be compared with the LANDSAT and SPOT systems available at that time. Subsequent IRS projects used this system as basic reference and augmented/modified with additional hardware and software, fast communications /network systems to arrive at higher throughput systems. For the first time the Scientists/Engineers working in different Ground Segment elements were working as one integrated unit for making the full system ready for Data Products generation, including the First Day Products, released to press, media & users.

Table -1: Types of Data products

IRS – 1A Data Products			
Sensor	Product Type	Scene Area	Output Format
LISS- 1 (72.5 m) B:0.45-0.52 G:0.52-0.59 R:0.62-0.68 N:0.77-0.86	Full scene, Radiometrically (RAD) corrected	148 km ×148 km	LGSOWG
	Full scene, Standard {RAD + Geometrically (GEO)}, Precision (with GCPs) Corrected	148 km ×148 km	LGSOWG PCT (BW or FCC)
LISS-II A/B (36.25)	Sub scene RAD	72 km × 72 km	LGSOWG
	Sub scene Standard Precision	72 km × 72 km	LGSOWG PCT (BW or FCC)
	Full scene Standard (Mosicked)	145 km x145 km	LGSOWG PCT (BW or FCC)
LISS-1/II	Geocoded	15´ x 15´	PCT LGSOWG

ACKNOWLEDGEMENTS: Author would like to thank Chairman ISRO, Directors of ISRO centres, PD of IRS-1A, Dr George Joseph, APD-Payload ,Mr D S Kamat, APD-Data Products, Dr.AKS Gopalan, APD, Data Products, Mr D V Raju, Dy Director, NRSC, Mr S. Raghunathan, APD, NRSC for their continuous guidance, support & encouragement to develop and establish the Operational System. Also wish to acknowledge the contribution of Mr.S.K.ShivaKumar, MD, IRS-1A,Mr. A.S.Kiran Kumar, Payload, my senior colleagues in IRS-1A Ground Segment team from SAC,NRSC,ISAC,ISTRAC , IISU and users from ISRO(DOS) to make the First Operational Data Products System for Indian Remote Sensing mission a success with the available resources and technology at that time. My special thanks are due to Dr R Ramakrishan for providing some of the inputs for this from the archives.

References:

[1] A.K.S. Gopalan, Proceedings of the Twenty-Third International Symposium of Remote Sensing of the Environment, Vol. I, p. 71, ERIM, Ann Arbor, MI, 1990.

[2] G. Joseph, B. L. Deekshatulu, "Evolution of Remote Sensing in India," Space in Pursuit of New Horizon, National Academy of Sciences publication, (editor: R. K. Verma and others), Allahabad, 1992, pp. 331-354K

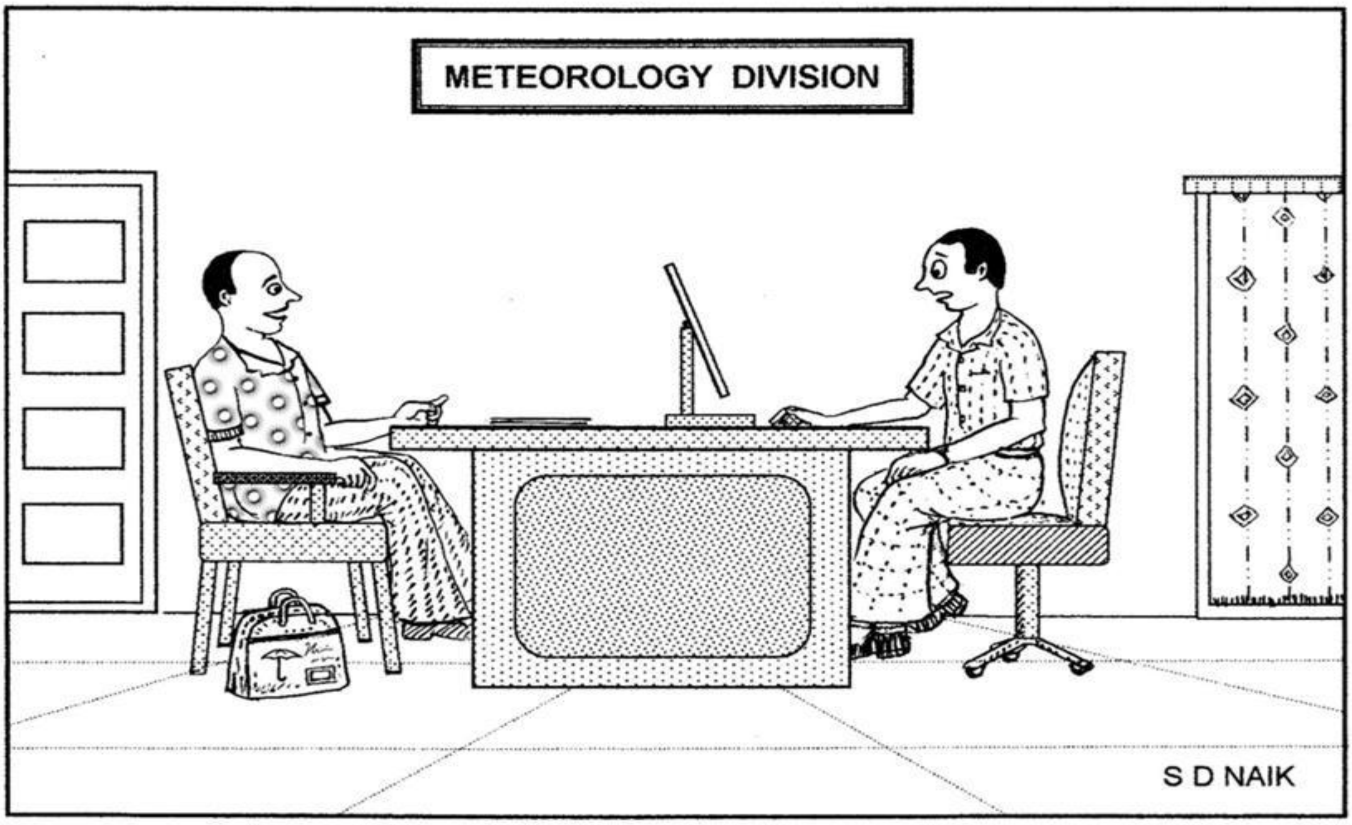
[3] Kasturirangan, G. Joseph, et al., "IRS Mission," Current Science, Vol. 61, No. 3 and 4, Aug. 25, 1991, pp. 136-151

[4] P. S. Goel, "Spacecraft Technology Development in India," Space Forum, Vol. 5, No 1-3, 2000, pp. 5-38"Indian Remote Sensing Satellite and Associated Data Products,"

CLIMATE CHANGE

&

REMOTE SENSING



What your satellite says about this year's monsoon ? ....
Incidentally I am a manufacturer of umbrellas, not an agriculturist

From the Guest Editor's Desk

Special issue on "Climate Change and Remote Sensing" is with you. We are happy to bring this issue looking at very good response of ISRS members on earlier special issues of 'signature ' on different themes such as Astronomy and Planetary sciences, Future trends in remote sensing, RISAT-1 and Megha Tropique etc. This issue is dedicated to the successful mission of 25 years of IRS series of satellites and valuable information on land, ocean and atmosphere collected by these missions. After operationalization of Indian earth observation program in the field of resource management, ocean and atmospheric observation, there is need to develop technologies to understand the complexities of earth as a system. Accurate observation and retrieval of essential climate change (ECV) variables is a challenge. Satellite based observations has been the major source of significant climate change findings related with glacier retreat, sea level rise, increase in green house gases and global warming .

Looking at the emerging technological and scientific development in the field of climate change, this issue of *signatures* brings out informative article on different aspect of remote sensing based climate research such as ECV, role of aerosols, green house gases and impact on cryosphere, hydrosphere, and biosphere. Contributors of the articles are young researchers and experienced experts who are pioneer in their fields in national and international spheres. They represent the core research theme of space based climate change studies being carried out in national centres/laboratory of the country. I thank all the authors for sparing their valuable time from their busy schedules for this special issue of *Signature.* I am sure that readers would find the articles informative and interesting.

I would like to sincerely thank to the editorial committee of *Signature*, to provide me this opportunity of being guest editor of this important issue. I am grateful to Shri Sheshakumar Goroshi, Dr. Mehul R Pandya and Shri C.P. Singh for their support in bringing out this issue.

R. P. Singh

Head, Environment and Hydrology Division

Space Applications Centre (ISRO)

Ahmedabad

Ongoing Climate Change – An Overview

Satyendra Bhandari
Hon. Professor
ICCSIR, Ahmedabad – 380 009
E-mail: satyendra_bhandari@yahoo.com

Outline

'Climate Change', of our own making, is already upon us and would likely be consequential for centuries ahead even if mankind takes reasonable remedial measures now. In the present scenario of build up of greenhouse gases in the atmosphere, its adverse impacts are already being seen to accelerate and, may intensify further in future. Ongoing and future 'climate change' therefore represents the most fundamental challenge facing mankind. It is therefore crucial to document it globally and understand it in as comprehensive a manner as possible, to mitigate and adapt to it in the best possible way.

Remote Sensing from Space provides us with the most suitable and affordable means to observe different aspects of Earth as a planet, including its environment, weather and climate. In addition to the primary attributes of affording long-term uniform global repetitive coverage, observations from space provide 'area averaged' measurements that are inherently suitable for climate monitoring. Today, a wide array of space based measurements of geophysical parameters of importance to 'climate' and 'climate change' issues are being regularly made for monitoring, understanding, modeling and prediction of the likely future climate scenarios.

Remote sensing from space has played, and is playing, an important role in observing and understanding the interactions and inter-relations between different components of the Earth's climate system. This has paved the way for an improved understanding of ongoing 'climate change' and has helped climate modelers arrive at future climate scenarios.

Earth's climate has been known to vary significantly over all time scales -ranging from millions of years to decades - in the past, even in the absence of any human perturbation. Over the last 200 years or so, human technological progress has added a new dimension to the otherwise natural climate variability, mainly through the large increases in greenhouse gases. The climate variability induced by this 'anthropogenic' perturbation is referred to 'Climate Change'. The challenge lies in disentangling the human induced 'climate change' from the natural 'climate variability'. This requires a thorough analysis, understanding and modeling of well calibrated and consistent long term data sets of climatic variables of consequence. Presently, the efforts of global climate science community are devoted to this. In spite of uncertainties, the reasonably close match between the 'temporal' and the 'geographical' fingerprints of observed and model-predicted climatic changes clearly validate the existence, and our understanding, of 'anthropogenic' perturbations to Earth's climate in recent times.

While, no definite agreements and plans to curb the anthropogenic emission of greenhouse gases have been implemented so far, there is always a hope. This is exemplified by the manner in which the global scientific community dissected the cause that eventually led to successfully addressing the seemingly threatening issue of 'ozone hole' over the polar regions. Latest news that the ozone hole over Antarctica has shrunk to its smallest size since its discovery, and may close completely before the end of the decade, gives hope that a science based policy action can possibly turn around the increase in rising greenhouse gas emissions towards limiting the adverse impacts of 'anthropogenic climate change' .

Weather, Climate, Climate Variability and Climate Change:

Long ago, it was lamented that 'Everyone talks about the weather, but no one does anything about it' [generally, but perhaps mistakenly, attributed to Mark Twain - 1882]. Well, the present day situation about Climate and Climate Change is no different. Today, due to increased awareness of the direct impacts of 'Global Warming', everyone seems to know and talk about 'Climate Change'. However, in spite of a reasonably clear understanding of its causes as well as consequences on a planetary scale, no tangible action has yet been initiated. As we go along, we will try to describe and discuss the issues relating to 'Climate Change', but let us first discuss what we mean by 'weather', 'climate' and 'climate change'.

Weather generally refers to the 'state of the atmosphere' at a given place and at a given time. A set of parameters are used to describe this. These are pressure, temperatures, humidity and winds at the Earth's surface and in the overlying atmosphere. In addition, sunshine, fog, cloudiness, snow and rainfall, dust storms etc. that result from a combination of the basic weather parameters also enter into defining the weather. As such, the weather varies quite significantly from place to place and from time to time. Climate, on the other hand, is meant to describe the gross or long term behavior of weather over a given place and its surroundings. This is arrived at by statistically averaging weather information over a long period of say 30 years over the region of interest. While average values provide a good starting point for planning various activities over that region, these hide large variance e.g. seasonal changes associated with it. Climate studies therefore take into account full statistical information including the weather extremes experienced during that period.

1 The oft repeated quote – "The Climate Is What You Expect, The Weather Is What You Get" - attributed to Mark Twain (1887) - nicely embodies the essence of our definitions of weather and climate.

2 If we have weather measurements extending over decades and centuries, it is possible to define long term averages and variabilities associated with them in the form of Climate Normals. Over a period of time, these normals themselves may trend or fluctuate. These fluctuations, if found to be random, indicate climate variability. On the other hand, if there are statistically significant systematic trends in the normals, we refer to these as 'changes' in climate. The present day 'Climate Change' – the topic of present article – refers to such systematic changes induced by human activities on the planet Earth. As such the current climate change is referred to as "Anthropogenic Climate Change". This is over and above the climate variability caused by natural factors. In line with naming of past geologic eras, the present era is christened - "Anthropocene" - by Prof. Paul Crutzen – winner of Nobel Prize for his insights into the process of 'Ozone Hole' formation and mitigation.

Climate of the Earth:

The climate of the planet Earth, and its different regions, is created and controlled by the manner in which the energy from the Sun is received and dispersed. The Earth receives maximum heat from the Sun over the tropics and distributes it polewards either swiftly through atmospheric circulation, or sluggishly through oceanic circulations.

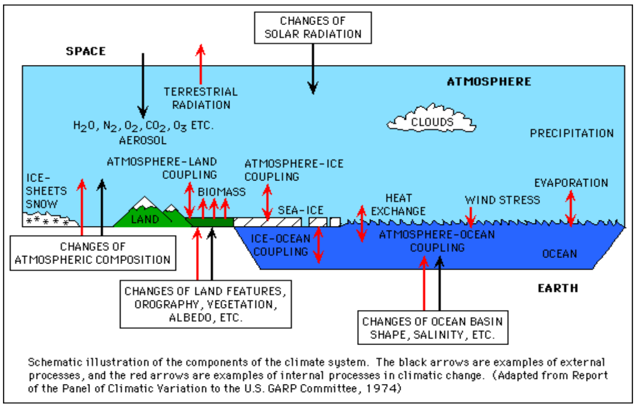
The amount of solar heat reaching a place is constantly modulated on a variety of time scales ranging from millennia to seasons due to periodic changes in Earth's orbital precession, eccentricity, obliquity etc. The Sun itself is a variable star (all starts are) with its own sunspot and magnetic activity cycles.

Apart from the Sun, the Earth itself is a dynamic planet – its continents drift and volcanoes erupt off-and-on. These factors result in modifying the energy balance.

Climate of any given location is further influenced by a variety of local factors like the geographical setting – how near or far is the place from large water bodies like the Lakes, Seas or the Oceans, how high is the place located e.g. in the mountains etc.. In addition, regional and local effects of deforestation, industrialization, urbanization etc. play their role.

Further, the internal and external causes are associated with many positive and negative feedbacks. The climate system is, therefore, an extremely complex one with non-linear interactions between its components.

Fig. 1 shows different components of the Climate System and how they are linked to each other.



Schematic illustration of the components of the climate system. The black arrows are examples of external processes, and the red arrows are examples of internal processes in climatic change. (Adapted from Report of the Panel of Climatic Variation to the U.S. GARP Committee, 1974)

Fig. 1 - Interacting components of the Earth's Climate System

Due to simultaneous existence of a multiplicity of forcings, the climate of a given location undergoes systematic as well as irregular variations over an extremely wide range of time scales, from decades to millennia to millions of years.

Lessons from the past:

The role played by each and every factor described above in changing the climate of the Earth over the past million years have been ascertained or borne out by analysing the paleo-climatic records obtained from a variety of sources that include – tree rings in recent past, ocean bottom sediments and ice cores for the distant past. By studying past changes in the global climate, we have increased our knowledge about changes in current climate and how it may behave in the future.

The most direct indicator of Earth's climate is the surface temperature. Fig. 2 shows the Earth's temperature record for the last 40,000 years derived using proxy indicators.

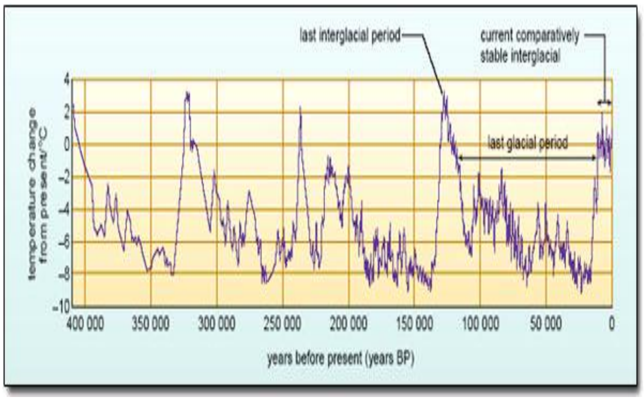


Fig. 2 – Earth's climatic history over the last half a million years or so as exemplified by proxy measurements of surface temperatures from Vostok ice core.

(http://labspace.open.ac.uk/mod/resource/view.php?id=388876)

As we can see, the Earth's Climate has varied significantly and continuously on different time scales. It has gone through periods of extreme warmth and through ice ages called glacials. Earth's surface temperature has fallen and risen by ~5 °C through 10 major cycles. After coming out of the last ice age 20,000 years ago, the last 10,000 years have been relatively stable at the warmer end of this temperature range. Usually these changes have taken place gradually, but once in a while some rapid changes have occurred within a span of few decades.

<u>'Anthropocene' – the present era</u>:

As against the past million years' decoded history of Earth's climate, the scenario during the past 200 years shows something very distinct. The Global Average surface temperatures show a consistently increasing trend, and values have reached above what was seen earlier for a long long time. This is what is termed as 'Global Warming'.

Why is this happening? None of the changes in external forcings are able to provide a satisfactory explanation. Finally, it dawned that the changing composition of Earth's atmosphere has a role to play. Somehow, the Earth is not able to radiate sufficient heat to space and in the process is getting warmer. The radiative equilibrium of the Earth is undergoing a significant change.

In fact, way back in 1827, Joseph Fourier concluded that the earth is unable to lose its absorbed solar heat back to space freely because, clouds and gases in the atmosphere absorbed the Earth's radiant heat and reradiated it back to the surface. He likened this to a glass bell jar trapping heat, and this process eventually came to be known as "The Greenhouse Effect". The radiative equilibrium arrived using these arguments explained the observed average temperature of the Earth as +15 °C rather than close to -18 °C that it would have in the absence of greenhouse effect. Later, John Tyndall demonstrated that the bulk of the atmosphere made up of oxygen and nitrogen had no effect on the radiant heat from the earth, but that water vapor, carbon dioxide and ozone did. He correctly identified water vapor as the most important heat trapping gas. Based on similar arguments, Arrhenius in 1884 predicted that warming would be greater in winter, and at higher latitudes, and estimated that if carbon dioxide were to double, global average temperatures would increase by 5-6 °C. The magnitude of the warming was overestimated by Arrhenius and the corrected value of 2-4.5 °C was arrived at by Knut Ångström in 1900.

Therefore, the possibility that the recent increase in surface temperature could be the result of increase in heat trapping gases like the CO2 was becoming apparent – the Earth might be experiencing an "enhanced' level of Greenhouse Warming.

During the first half of 20th Century, it was becoming clear that the industrial revolution and the burning of fossil fuels, for energy and for transportation, as well as due to deforestation, were indeed releasing CO2 in the atmosphere at an increasing rate.

The first experimental evidence of the increasing burden of CO2 in the atmosphere came from measurements started by Charles Keeling at Mouna Loa, Hawaii and at Antarctica more than 50 years ago (Fig. 3).

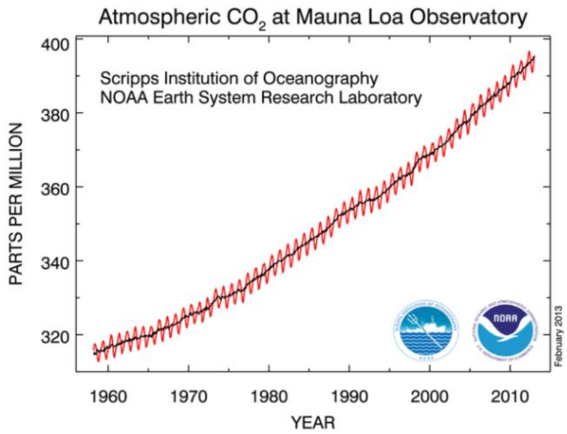


Fig. 3 shows the continuous increase of CO2 in the atmosphere over the last 50+ years.

These measurements clearly brought out the following:

The measured level of CO2 in the atmosphere, right at the beginning, was much higher than the pre-industrial value of 280 ppmv and that its concentration was increasing systematically year by year. Presently, the CO2 concentration is close to 400 ppmv. This is an increase of more than 100 ppmv since the start of the Industrial Revolution. As can be seen in Fig. 4, this level of CO2 concentration never existed in the Earth's atmosphere during the last 800,000 years.

Simultaneously, other trace gases have been rising, as well (Fig. 5). Carbon Monoxide (CO), Methane (CH_4) from rice paddy production and fermentation, are increasing, as are man-made chlorofluorocarbons (CFCs) that have been used for many years as refrigerants and to produce foam.

CFC productions later stopped due to implementation of Montreal Protocol, resulting in recovery of 'Ozone Hole' over Antarctica . Methane is found to be much more potent greenhouse gas than CO2.

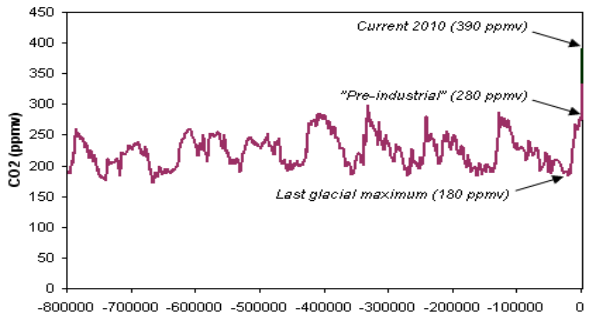


Fig. 4 -- CO2 concentration over the past 800,000 years from Antarctic ice cores at Dome C, Vostok, Taylor Dome, and Law Dome

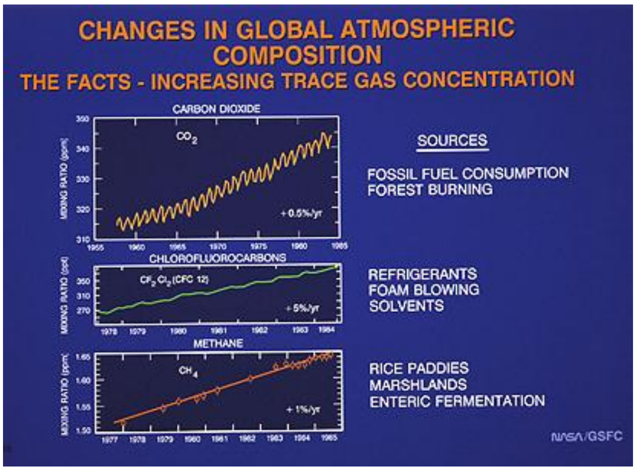


Fig. 5 – Rising levels of Greenhouse Gases in the Earth's Atmosphere during the last 50 years

Based on the above understanding of the underlying physics of absorption and reemission of thermal IR radiation by CO2 and other GHG molecules in Earth's atmosphere and the observed rise in atmospheric CO2 concentration since the industrial revolution, it became clear that human activities are indeed responsible for the recent Global Warming.

Due to accumulated effect of warming caused by increasing GHGs, over the last 50 years, Earth has increasingly warmed. In fact, the warmest 10 years in the Earth's known past have all occurred during the last 20 years (Fig. 6). . The year 2012 once again has continued the trend.

Global Warming and Climate Change-Consequences:

Now, as the anthropogenic perturbation or radiative forcing is building up constantly, and the Earth is warming, what do we expect in terms of changes in Earth's Climate?

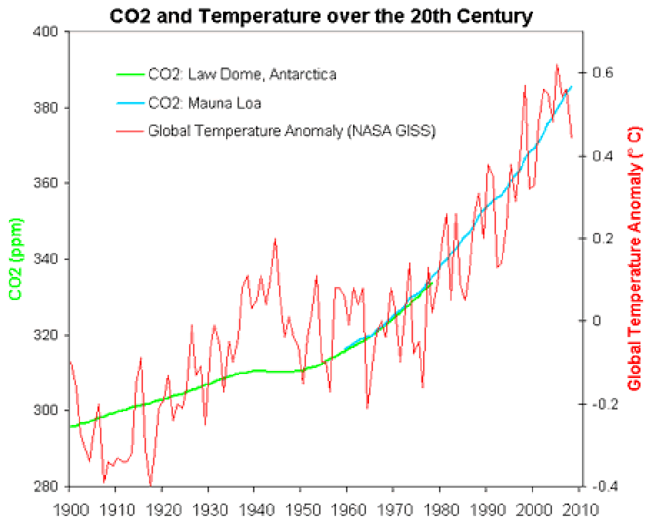


Fig. 6 – Increasing CO2 and other GHGs have led to increasing Global average temperature. Notice the higher rate of rise during last few decades.

There are a few major consequences of 'Global Warming" in terms of changes in Earth's weather and climate.

First of all, as the Earth's surface heats up there would be more evaporation from the oceans and land. This would increase the amount of WV in the atmosphere, which may further amplify the warming, since WV itself is a strong GHG. This would increase possibility of stronger rainfall.

Secondly, the icy regions of the Earth's Cryosphere – the mountain glaciers, the polar ice caps, ice shelves and the polar sea ice- would be expected to begin melting. This would again serve as an amplification factor for Polar Warming though positive ice-albedo feedback – decreasing ice would expose less reflective surfaces of oceans and land that would absorb more sunlight leading to further warming.

The third major influence is the global rise in sea level – both due to thermal expansion of ocean waters and due to melting of ice caps.

There are a multitude of other effects, like cooling of the stratosphere, changes in the atmospheric and oceanic circulations, precipitation patterns, ocean acidification etc.

The above effects of Global Warming would come into play differently over different regions and over different time scales and would result in a complex climate change scenario.

Observing the Earth from Space– Monitoring Climate Change:

Fortunately, in parallel with increasing human perturbation to the Earth's Climate, over the last 50 years, human technological advance has provided us with unique capability and means to observe the entire planet, from pole to pole, in unprecedented detail from space. Space based remote sensing has helped not only in understanding various aspects of Earth's climate but also in providing direct evidence about most of the expected consequences of Global Warming and Climate Change.

The best place to look for effects and consequences of anthropogenically induced Global Warming is of course the pristine Polar Regions which are covered with ice. Due to positive ice-albedo-feedback, the polar regions are expected to be warming about 3-4 times the global average. Polar regions, therefore, serve as highly sensitive early indicators of the Climate Changes resulting from Global Warming.

In fact, both on the Antarctic and Greenland ice sheets, as well as mountain caps and glaciers have been observed to show a negative mass balance attributable to Global Warming. Much more dramatic has been the decline in sea ice cover and the thinning of sea ice over the Arctic to the extent that the Arctic region might soon be free of ice cover, first time in known history. Fig. 7 above shows the dramatic spiraling down of Arctic sea ice volume by Pan-Arctic Ice-Ocean Modeling and Assimilation System (PIOMAS), based on combination of in-situ and space based remote sensing data, most recently from CRYOSAT-2.

Global sea level rise is another most obvious expression of climate change in the oceans. Recent measurements of sea level based on satellite data clearly support the sea level rise resulting from combined effects of thermal expansion and ice melt (Fig. 8). Precise sea level measurements over last 2 decades are derived from continuing series satellite radar altimetry missions.

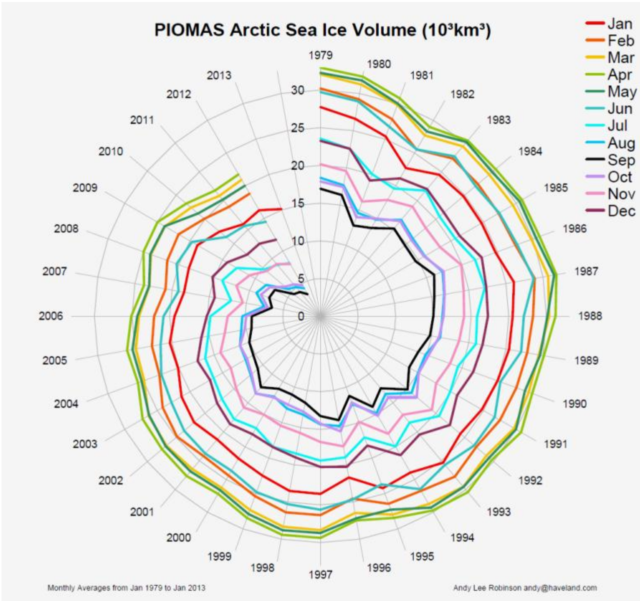


Fig. 7 – Latest, hot-from-the-oven, status of continually thinning Arctic sea ice. Soon the Arctic would spiral down to ice-free ocean with major climatic, economical and geo-political consequences. (http://haveland.com/share/arctic-death-spiral-1979-201301.png)

Currently, the global sea level is rising at a rate of approx. 3-4 mm/ year. This has important consequences for the coastal zones and island communities worldwide.

Apart from global scale consequences of Global Warming induced Climate Change, space based remote sensing has been able to observe and document a variety of dynamic record breaking changes the planet is undergoing at regional and local level – e.g. extreme heat waves, extreme high intensity rainfall, frequent collapses of large portions of Antarctic ice shelves etc.

We live in an interconnected world. No region of the globe can escape the consequences of ongoing climate change. The climatic changes induced by Global Warming produce important geographical pattern due to a variety of oceanic and atmospheric tele-connections and feedbacks. Different geographic regions may therefore experience different magnitudes of the effects.

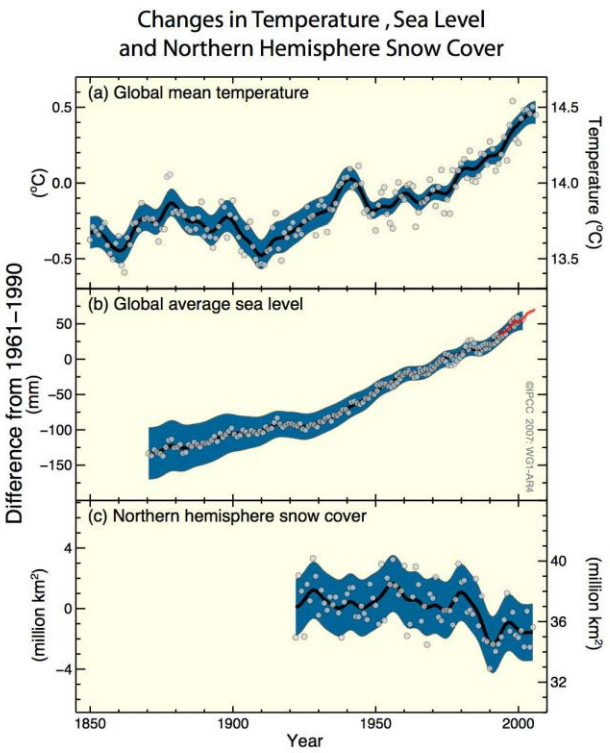


Fig. 8 – Temperature and sea level rise due to Global Warming since industrialization over the last 150 years. The lower panel shows the reduction in Northern Hemisphere Snow cover.

Monitoring Climate and Climate Change, therefore, has to be a global coordinated effort. International agencies like the UN and WMO and different countries have put in place a comprehensive set of satellites in different orbits for precise monitoring of the Earth's climate – covering parameters related to land, oceans, atmosphere, cryosphere and the biosphere. These include, global repetitive mapping of temperature, WV, winds, Clouds and precipitation, GHGs, ice and snow, gaseous minor constituents like ozone, CH4, CO and particulate matter, sea level, gravity variations etc. It also includes land related parameters like vegetation and forest cover, soil moisture, albedo etc. The global network of satellites also help in constant surveillance and monitoring of severe weather systems e.g. Tropical Cyclones and disasters like floods and droughts.

India has a long standing program of meteorological weather imaging, land resources and Oceanographic remote sensing satellites namely, INSAT, IRS and OCEANSAT series of satellites. Two unique Indo-French collaborative missions currently operating in space, namely MEHA-TROPIQUES and SARAL, have enhanced India's capability manifold to monitor global and tropical regions for providing valuable information about Earth's climate.

Modeling the Climate Change:

Present day sophisticated Climate models indicate that over the next 100 years or so, the Earth's surface temperature would rise by another 3-5 °C and sea level by about 30 -50 cms with tremendous consequences. These models use mathematical representations of the climate system, simulating the physical and dynamical processes that determine global/regional climate. They range from simple, one-dimensional models to more complex 3-D coupled global climate models. Climate models used to develop future climate change are run using different forcings scenarios of changing greenhouse gas concentrations and the complex forcings created by the presence of light scattering and absorbing aerosols in the atmosphere. Of course, they include all known external forcings too.

Fig. 9 below summarizes present-day understanding of the role of climate forcing created by different components. Carbon dioxide is causing the bulk of the forcing, and since it resides for a long time in the atmosphere, constant addition of CO2 means commitments to climate change for future generations. Major uncertainty in our modeling the future climate is related to the non-uniform and variable forcing caused by aerosols – it can be both +ve and –ve -- depending on their nature. This part of the uncertainty is of great consequence for the fast industrializing Asian region, as the monsoon system is extremely sensitive to radiative effects of aerosols.

While the Climate Models have their uncertainties in reproducing detailed features of Earth's changing climate, observed large scale *space-time pattern* of temperature increase, ice melt etc. - does support the projected scenario based on known physical processes.

Fig. 10 shows the temporal march of the rise in Global Average temperatures. Clearly, the physically based models incorporating both GHG as well as aerosols radiative effects are needed to reproduce the recent observations more closely.

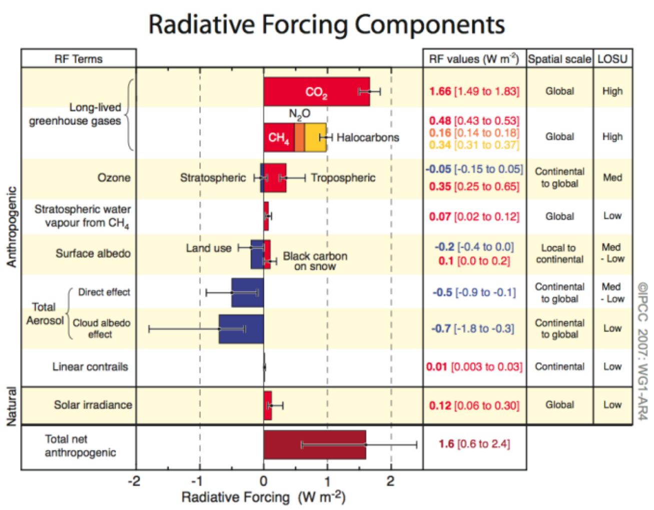


Fig. 9 – Level of understanding of radiative forcing by different components of the Earth's climate system.

Going further, the large scale spatial/geographical distribution of observed temperature rise due to global warming is also correctly reproduced in the models – with Arctic and northern high latitude regions warming much more than the Southern hemisphere, and continents warming more than the oceans.

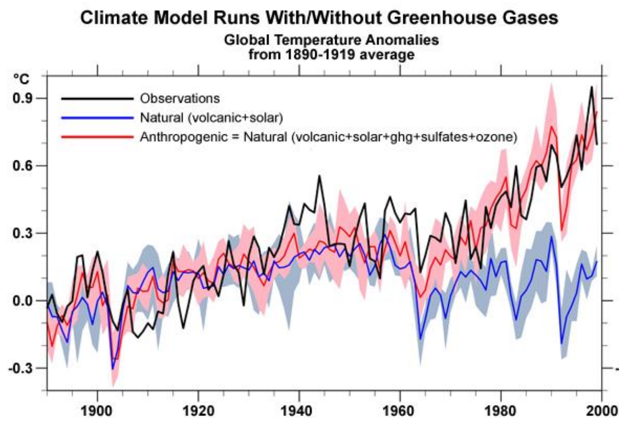


Fig. 10 – Comparison of observed and modeled Global Average Temperature anomalies over the last 100 years.

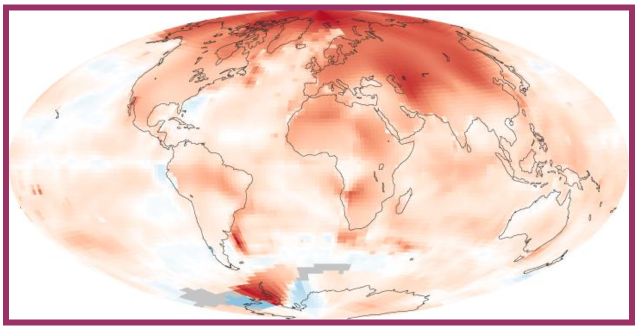


Fig. 11 -- 2000-2009 Global Average Surface Temperature Anomaly

(http://earthobservatory.nasa.gov/IOTD/view.php?id=47628)

Future Climate – The next 100 years

Warming of the planet and consequential climate change is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global mean sea level etc. Climate models have already predicted many of the phenomena for which we now have observational evidence.

Continued GHG emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would very likely be larger than those observed during the 20th century.

Fig. 12 describes the likely increase in global average surface temperatures under different GHG emission scenarios. By end of the present century, the temperatures may rise by 2-3 °C or more. This may have disastrous consequences for the planet Earth without any past analogue.

As against the temporal profile of change over the next 100 years, climate model projections on the spatial pattern of expected change is shown in Fig. 13. Once again, the rise in temperature is seen to be higher over land masses compared to the oceans, and also higher over the northern high latitudes including the Arctic.

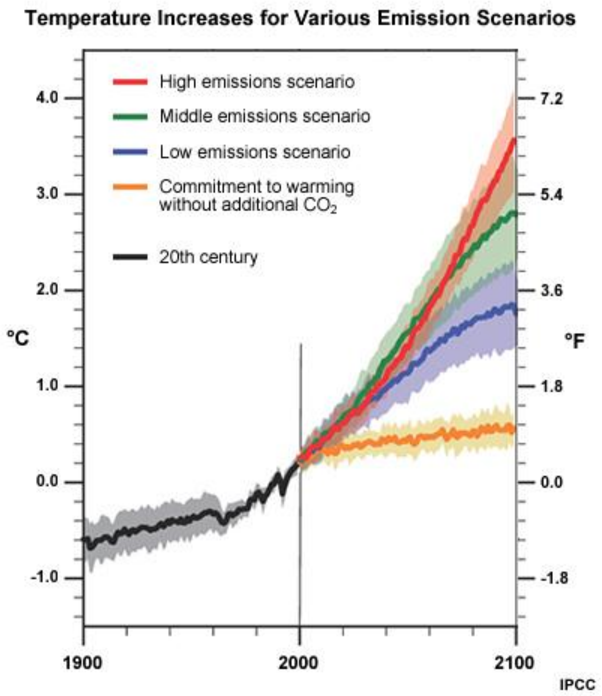


Fig. 12 – Climate models projections of rise in Global Average Temperature for the next 100 years, based on range of GHG emission and aerosol burden scenarios.

Fortunately, for India, the expected rise in surface temperatures is not so alarming, as compared to high latitudes. However, the increasing population and fast developing industrialization scenario is putting ever growing stress on resources, and increased urbanization will lead to high amount of GHGs as well as aerosols. This would impact the weather and climate patterns significantly, particularly the SW Monsoon which is crucial for the region in terms of sustaining the lives of billions of people. Studies are on to delineate such regional and local impacts of Climate Change.

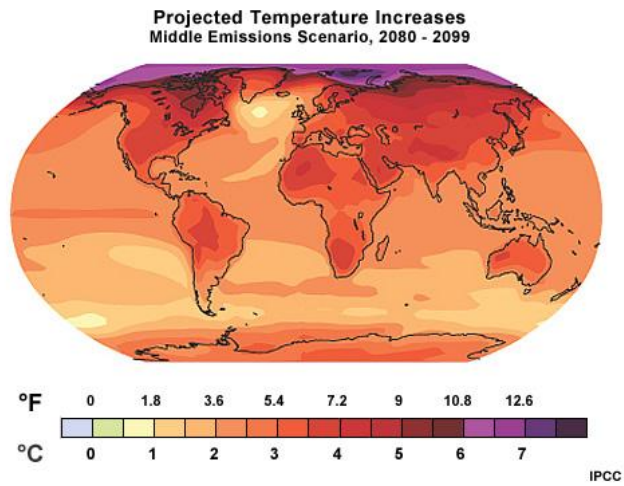


Fig. 13 – Geographical pattern of Model Projected Temperature rise for the last decades of the present Century.

Prolog:

"Climate Change" undoubtedly remains the defining issue of our times.

Looking back at the climatic history of the Earth, one realizes that it was the existence of the "Greenhouse Effect" – the natural one – that made it possible for life on Earth to begin and evolve. On the other hand, it is the very same "Greenhouse Effect" - this time of course the 'enhanced' one due to anthropogenic inputs of additional GHGs to the Earth's atmosphere that is leading us to 'Climate Change", perhaps an unpalatable one for human survival. The issue is being addressed seriously by the scientific community. A timely and well thought out corrective mitigation action is needed on the planetary scale to limit the consequences within reasonable contours. Meanwhile, ingenuous adaptation is most crucial for human survival. This is nicely portrayed by the cartoon below.

(Adopted after adaptation (!) from: http://www.infosysblogs.com/finacle/2012/10/re-engineering_but_isnt_that_s.html)

Let me end by quoting a short excerpt from 'KERAMOS' - a Long Poem by Henry Wadsworth Longfellow (1878) about 'CHANGE'.

Turn, turn, my wheel! All things must change
To something new, to something strange;

Nothing that is can pause or stay;
The moon will wax, the moon will wane,
The mist and cloud will turn to rain,
The rain to mist and cloud again,
Tomorrow be today.
…………

Further Reading:

The interested reader may browse the net for hundreds of books and websites carrying unlimited number of articles on climate and climate change.

Acknowledgements:

First of all, I am grateful to ISRS-Ahmedabad Chapter and Editorial Board of SIGNATURES for providing me this opportunity to describe the ongoing Climate Change in my own way. It has always been and will remain my pleasure to contribute to SIGNATURES.

I also thank and acknowledge a variety of resources on the WWW from where I have derived quite a bit of my knowledge about the subject and for reproducing some of the freely available diagrams. As such I dedicate this article to WWW.

http://kidlat.pagasa.dost.gov.ph/cab/climate_change/Impacts.html

"Nothing endures but change. Change is the only constant".

.........Heraclitus - Greek philosopher (540 BC - 480 BC)

Essential Climate Variables

Mehul R. Pandya

Space Applications Centre, ISRO, Ahmedabad

E-mail: mrpandya@sac.isro.gov.in

Introduction

This article presents a brief write-up on the essential climate variables (ECVs). It covers mainly two aspects, what are ECVs and why ECVs are vital for observing the Earth system.

Changing climate on the Earth

During the last 200 years, industrial activities and six-fold increase in the human population across the globe have put a tremendous pressure on the Earth's climate. The Earth's climate varies naturally, mainly as a result of interactions between the ocean and the atmosphere, changes in the Earth's orbit, fluctuations in energy received from the Sun and volcanic eruptions. However, the best scientific evidence available suggests that the Earth System has recently shifted outside the range of natural variability exhibited in available paleoclimate records covering at least the last half million years. The nature of changes now occurring simultaneously in the global environment, their magnitudes and rates, are unprecedented in human history, and probably in the planet's history.

After the first World Climate Conference in 1979 expressed its concern about the possibility of human-induced climate change, there was almost a decade of accumulating evidence until the Intergovernmental Panel on Climate Change (IPCC) was established in 1988. The Assessment Reports in 1990, 1995, 2001 and 2007 concluded, "There is new and stronger evidence that most of the observed warming observed over the last 50 years is attributable to human activities" and "climate change is no longer a matter for debate. It is 'unequivocal', and 'very likely' that human activities are responsible". Throughout the reports IPCC has stressed the importance of systematic observations and emphasized several variables of Earth system that are observed by satellite.

Why to study the Earth System?

An improved understanding of the Earth System and its components such as, atmosphere, oceans, land, geology, natural resources, ecosystems, and natural and human-induced hazards – is necessary if we are to better predict, adapt and mitigate the expected global changes and their impacts on human society.

Earth observation data and derived information are essential inputs in the development of this understanding. Earth observations provide the necessary evidence for conversant decision-making – supporting the science which underpins strategies for global environmental decision-making – and for monitoring our progress on all geographical scales as we explore new development paths aimed at sustainable management of the planet. The significance of Earth observations in our future decision-making processes is apparent in both the short term and long term.

— The short term: information extracted from short time series (days or hours) of high quality observations is typically used to improve weather prediction by numerical forecast models, or to support operational applications (e.g. air quality, oceanography, land management, meteorology, disaster management). They also support land use and fresh water management and provide information for process studies to better understand physical processes in the Earth/atmosphere system.

— The long term: information extracted from long time series (several decades) of high quality observations is used in support of vital climate studies to observe and characterize the current climate, to detect climate change and to determine the rate of change. Furthermore, this information is analyzed to assist in attributing the causes of change; identify any anthropogenic contribution to climate change; validate and calibrate climate models and assist in prediction of the future climate.

The Global Climate Observing System (GCOS)

Many regions in the world are evidently influenced by changes in climate, and those changes need to be managed now (GCOS, 2012). It took years of work by the IPCC, assessing the climate science literature, and by the World Climate Research Programme (WCRP), advancing the state of climate science, to raise the awareness that observations of climate need to be available on a global scale to underpin decisions. The year 2012 marked the 20th anniversary of the system dedicated to providing the observational data and information that is the foundation for the decisions on climate: the Global Climate Observing System (GCOS). GCOS is a joint undertaking of the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational Scientific and Cultural Organization (UNESCO), the United Nations Environment Programme (UNEP) and the International Council for Science (ICSU). GCOS's goal is to provide comprehensive information on the total climate system, involving a multidisciplinary range of physical, chemical and biological properties, and atmospheric, oceanic, hydrological, cryospheric and terrestrial processes.

The Essential Climate Variables (ECVs)

As we discussed in above sections, the 2007 IPCC assessment unequivocally stated that humans have significantly changed the composition of the atmosphere and, as a result, our climate is changing. To be able to attribute the causes of climate change, analyze the potential impacts, evaluate the adaptation options and enable characterization of extreme events such as floods, droughts and heat waves, globally consistent sets of observational data are needed.

A standardized measuring system has been established by the GCOS. Accurate, reliable and spatially/temporally continuous sets of observations enable to form a coherent picture of how Earth's climate operates and make better forecasts and projections. Since technological and economic limitations make it impossible to measure absolutely everything, the global geo-science community prioritizes certain observational indicators called Essential Climate Variables (ECVs). Similar to how vital signs help medical practitioners monitor a patient's status more efficiently and less invasively, ECVs help scientists more effectively keep track of how the Earth is changing and piece together the dynamics of its environmental systems.

A set of approximately 50 ECVs have been identified by GCOS (GCOS, 2011), which are technically and economically feasible to measure and are useful for monitoring physical, chemical and biological components of the Earth. A list of ECVs with their domain is provided in the table 1 (GCOS website- http://www.wmo.int/pages/prog/gcos). It is to be noted that the ordering within the table is simply for convenience and is not an indicator of relative priority. These variables are the planet's "vital signs," and are categorized as atmospheric, oceanic and terrestrial ECVs. These variables are measured on land, sea and ice.

Majorly they include, surface air temperatures, upper air temperatures, precipitation, water vapour, atmospheric composition (ozone levels, carbon dioxide and aerosol properties), ocean surface temperatures, albedo, biomass, snow cover, ice cap cover, river discharge, soil moisture, etc. While some variables like Earth's radiation budget and sea surface salinity are most useful for longer-term climate predictions, other variables like air pressure and upper air wind speed and direction are useful for short-term weather predictions. Some ECVs are useful for air quality monitoring and forecasts, water resource management and even for assessing the likelihood of disease outbreaks. Most ECVs can be measured from space, but technological limitations require that some, like river discharge, be monitored at the surface.

Table-1: List of the Essential Climate Variables (ECVs)

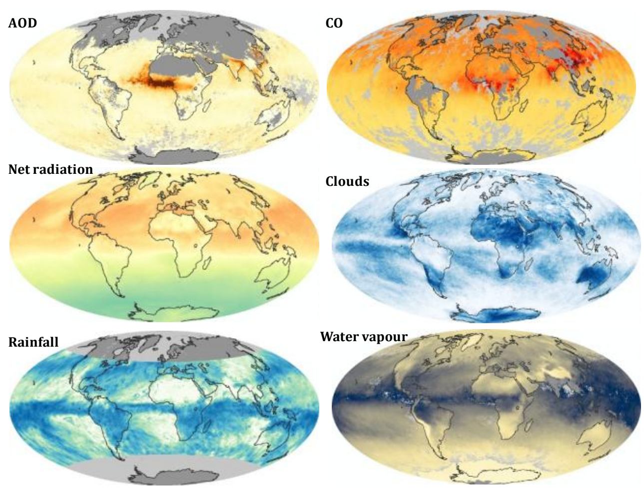
Domain	Essential Climate Variables	
Atmospheric (over land, sea and ice)	Surface[1]	Air temperature, precipitation, air pressure, surface radiation budget, wind speed and direction, water vapour
	Upper air[2]	Earth radiation budget (including solar irradiance), upper air temperature (including MSU radiances), wind speed and direction, water vapour, cloud properties.
	Composition	Carbon dioxide, methane, ozone, other long-lived green house gases[3], aerosol properties, supported by their precursors[4].
Oceanic	Surface[5]	Sea surface temperature, sea surface salinity, sea level, sea state, sea ice, currents, ocean colour (for biological activity), carbon dioxide partial pressure
	Sub-surface	Temperature, salinity, currents, nutrients, carbon, ocean tracers, phytoplankton
Terrestrial		Albedo, land cover (including vegetation type), fraction of absorbed photosynthetically active radiation (fAPAR), leaf area index (LAI), biomass, fire disturbance, soil moisture, river discharge, water use, ground water, lake levels, snow cover, glaciers and ice caps, permafrost and seasonally-frozen ground.

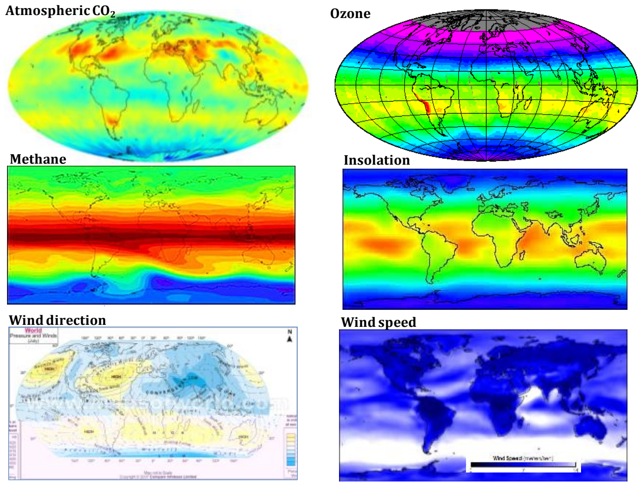
(1) Including measurements at standardized, but globally varying heights in close proximity to the surface. (2) Up to the stratopause. (3) Including nitrous oxide (N2O), chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF6), and perfluorocarbons (PFCs). (4) In particular nitrogen dioxide (NO2), sulphur dioxide (SO2), formaldehyde (HCHO) and carbon monoxide (CO). (5) Including measurements within the surface mixed layer, usually within the upper 15m.

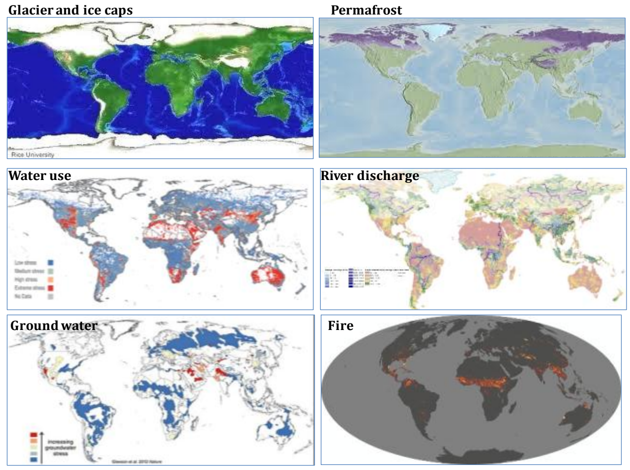
To generate ECVs, it requires observations from land-based in-situ, airborne and satellite remote sensing platforms. Since no single technology or source can provide all the necessary data, instruments are deployed at ground stations, as well as on ships, buoys, floats, ocean profilers, balloons, samplers, aircraft and satellites. This information is then transformed into products through analysis and integration in both time and space. Moreover, information on where and how the observations are taken (meta-data) is absolutely essential. While its implementation is fully dependent on national efforts, success will be achieved only through internationally-coordinated action.

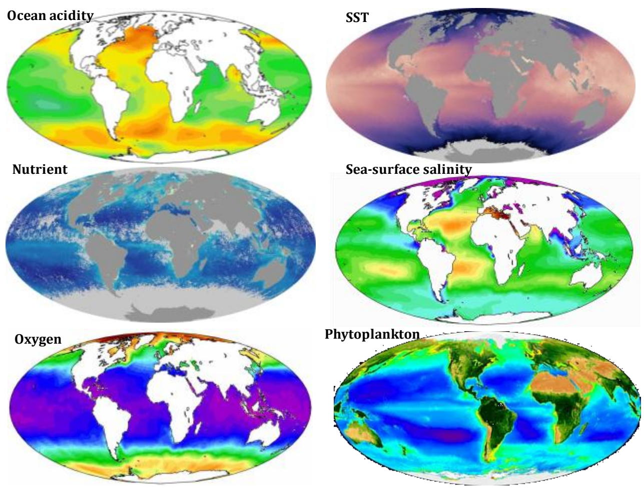
Typical examples of 32 different ECVs on global scale are shown at the end of article, which would present an essence of ECVs and its variability to the readers. It is to be noted that, these ECVs have been compiled from various sources available on the internet.

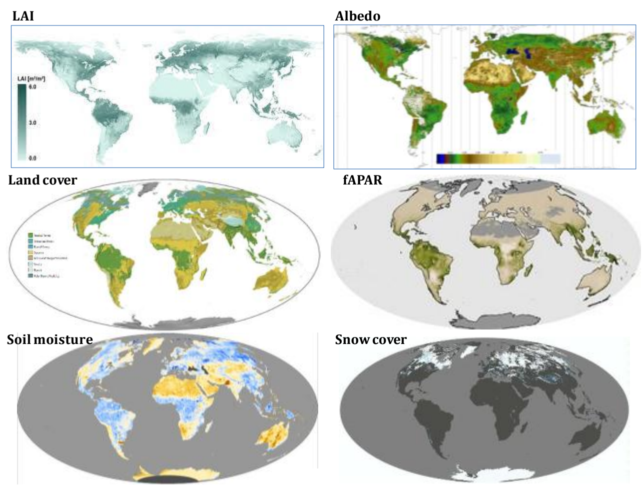
Following section provides example of 32 ECVs on global scales (ordered in atmospheric, oceanic and terrestrial ECVs)











References:

- GCOS (2011): Systematic observation requirements for satellite-based data products for climate Report: GCOS-154. WMO. Switzerland.
- GCOS (2012): Global climate observing system. 1992-2012, 20 years in service for climate observations. WMO. Switzerland.

Electro-Optic Sensors for Monitoring Atmospheric Gases

Kurian Mathew

Space Applications Centre, ISRO, Ahmedabad

Introduction

Remote sensing of atmospheric gases involves measurement of electro-magnetic radiation emitted or absorbed by different gas molecules. Absorption and emission of radiation are associated with transition of gas molecules between different electronic, vibrational and rotational energy states. Energy separation between electronic levels in molecules is comparatively high and corresponding transitions result in the absorption or emission of visible radiation. Molecular transitions between vibrational and rotational levels respectively cause absorption or emission of IR and MW radiation. Relative strength of absorption and emission processes is determined by temperature. Higher the temperature, more molecules are at higher energy states leading to higher probability of emission. Because of this reason, under normal atmospheric conditions, emission of visible radiation will be negligibly small whereas there will be both emission and absorption in the IR and MW region. Present discussion is confined to optical sensors which measure radiance in the visible to thermal IR region (0.4μm-15μm).

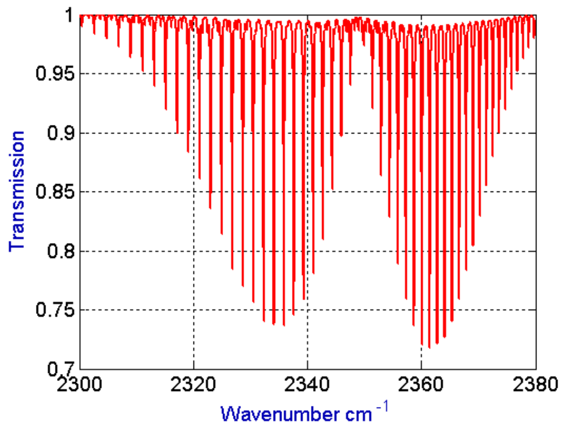


Figure-1 Absorption spectrum CO_2

Absorption or emission spectrum of gas in general consists of narrow spectral lines. The intensity and spectral distribution of absorption lines are characteristics of the molecular species. So it is possible to identify and measure the concentration of a gas simply by measuring its spectrum. But in practice line intensities of many gases overlap and it is extremely difficult to retrieve the concentration of any particular gas.

Figure-1 shows the absorption spectrum CO_2 molecule in a narrow spectral interval. As can be seen it consists of well defined absorption lines at regular spectral intervals. Figure-2 gives line intensities of major gases which contribute to atmospheric radiance. As can be seen, spectral signatures of many gases like CO_2, CO, H_2O, CH_4 overlap. Other factors which further complicate the situation are (1) spectral reflectance of the ground scene and (2) atmospheric scattering due to aerosols and gas molecules. So, in general it is very difficult to retrieve the gas concentrations from the atmospheric spectra.

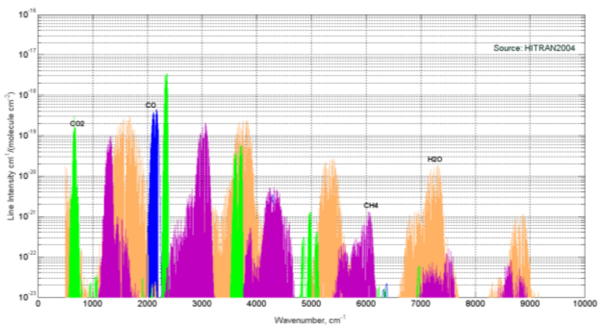


Figure-2 Line intensities of major absorbing molecules in the Earth's atmosphere.

An ideal atmospheric sensor accurately measures the spectral variations of radiance. So, the most important requirement on the sensor is spectral resolution and spectral range. Required spectral resolution varies with the gas specious and spectral range of observation. It also, rather indirectly depends on the radiometric accuracy of measurement. Spectral resolution required for monitoring CO_2 and other trace gases is of the order of 0.001nm in the visible to SWIR region. If the sensor is to map small variations in gas concentration, radiometric performance of the system in terms of SNR and dynamic range should be very high.

Sensors having high spectral resolution and spectral range are called hyper spectral instruments. Depending on the method adopted for spectral separation and spectral definition, hyper spectral instruments can be classified into many categories. In the following sections we discuss three types of sensors which are used for atmospheric remote sensing. They are:

(1) Dispersive Spectrometers
(2) Michelson Fourier Transform Spectrometers
(3) Fabry-Perot etalon sensors

Dispersive Imaging Spectrometers

Dispersive imaging spectrometers make use of either a prism or grating for resolving the spectrum. The resolving power of prism spectrometer is proportional to the width of the prism base and dispersive power of prism material. Since materials with higher dispersion tend to have higher absorption, throughput of prism spectrometers is generally low.

Spectral resolution of grating spectrometer depends on number of rulings in the grating as well as the diffraction order. Optical throughput can be enhanced for the desired spectral range and diffraction order using blazed gratings. Offner and Dyson Imaging Spectrometers which make use of convex and concave gratings respectively are very compact and suitable for satellite remote sensing missions. Offner design is particularly attractive since it is an all reflective design having large field of view. It also requires small grating apertures and operates at low f-numbers. But Offner design is very complex and fabrication of convex grating requires the use of electron beam etching.

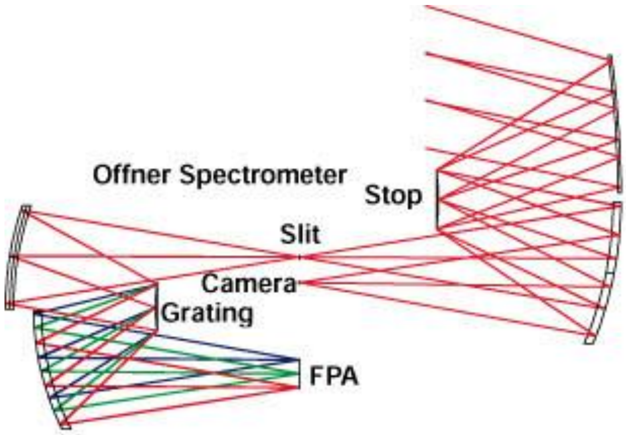


Figure-3 Optical configuration of an Offner grating spectrometer

It possible to obtain high spectral resolution as well as radiometric performance with grating spectrometers. But spectral range of measurement is limited to λ-2λ (where λ is the lower limit of wavelength) due to overlapping of diffraction orders. CO_2 measuring instrument for Orbiting Carbon Observatory (OCO) mission make use of three grating spectrometers to measure radiance in two carbon dioxide absorption bands centered at 1.61μm and 2.06μm and the oxygen a-band centered at 0.76μm

Fourier Transform Imaging Spectrometer

In all Fourier transform spectrometers the input radiance is divided into two equal parts and then made them interfere after one part of the beam transverse through an additional optical path. Since path difference between beams depends on wavelength, interferogram generated is a Fourier transform of spectral intensity. So, inverse Fourier transform of the interferogram gives the spectrum of the scene.

Figure-4 illustrates the principle of Fourier transform spectrometer based on Michelson interferometer. Here, a beam splitter divides the input beam into two parts. The resultant beams which travel in orthogonal paths are retro-reflected by two mirrors and recombine at the focal plane after being reflected or transmitted through the beam splitter. Path difference between two beams is varied by moving one of the mirrors. Detector signal is recorded as a function of mirror position or time. Spectral resolution of Michelson FT spectrometer depends only on the maximum displacement of the moving mirror. So it is generally used when very high spectral resolution is required. Another great advantage of FT spectrometers is the wide spectral range; a single spectrometer unit can cover visible to LWIR spectral region.

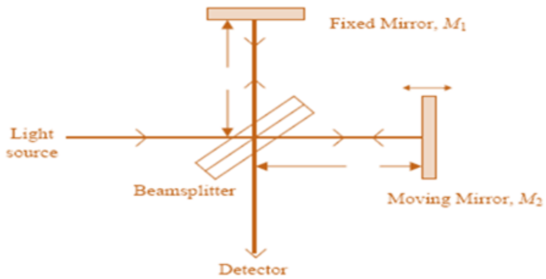


Figure-4 Functional diagram of Michelson interferometer based FT spectrometer.

Since interferogram is generated in temporal domain this type of instruments are more suited for geo-stationary platforms. But FT spectrometers can also be used for LEO missions if coarse sampling of the ground scene is adequate. Greenhouse gas sensor on-board GOSAT is a FT spectrometer with a spectral resolution of 0.1cm^{-1}. Spatial coverage is obtained by scanning the scene in the cross-track direction.

The most important concern about Michelson FT spectrometer is the precision movement of the mirror. Requirements on mechanical stability and precision are very stringent. Figure-6 shows the double pendulum design of Michelson FT spectrometer in which linear motion of the mirror is replaced with the rotational motion which is far easier to control.

Fabry-Perot Etalon Sensors

Fabry-Perot Etalon is a passive optical filter. It consists of a solid block of glass with two internal surfaces extremely parallel and reflecting. When a

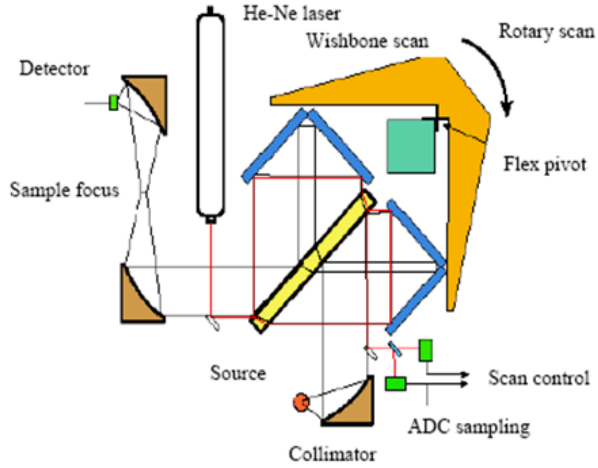


Figure-5 Double-Pendulum design of FT spectrometer

light beam enters etalon, it undergoes multiple reflections. (see figure-7). Due to interference of electro-magnetic waves, the transmitted intensity is modulated as a function of frequency. Figure-7 gives the transmittance of an FPE filter designed to measure CO_2 in the atmosphere. As can be seen, FPE filter transmit light at extremely narrow, well defined spectral bands which are evenly spaced in the frequency domain. So, if the spectra of atmospheric gas consist of evenly spaced line intensities, it is possible to measure radiance only at these spectral lines using an etalon filter.

Measured radiance will be very sensitive to variations in gas concentration since absorption coefficient at the line positions is very high compared to its mean value over a broad spectral band.

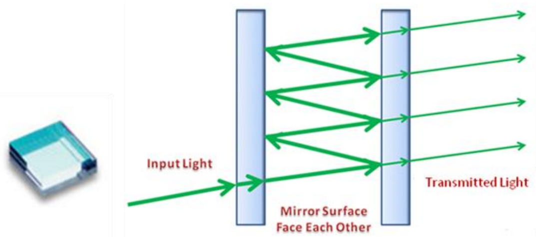


Figure-6 Principle of Fabry-Perot etalon filter

Fabry-Perot etalons are designed for the specific gases to be monitored. Piezo-electric tunable etalons are commonly used in astronomical observations from ground based telescopes. In tunable etalons, spacer thickness between the reflecting surfaces is varied so that transmission bands are scanned across a small spectral region.

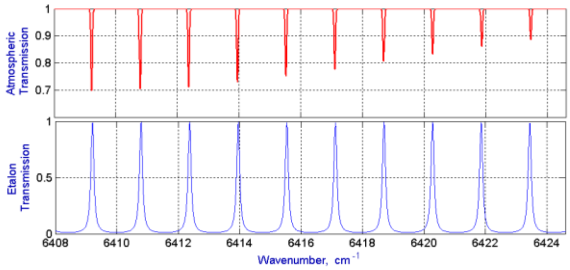


Figure-7 Transmittance of a FPE filter designed to measure CO_2 in the atmosphere.

References

- Fourier transform spectrometer for Greenhouse Gases Observing Satellite (GOSAT), Takashi Hamazaki etal, Proc. of SPIE Vol. 5659.
- Fabrication and Assembly Integration of the Orbiting Carbon Observatory Instrument, Robert E. Haring etal. Proc. of SPIE Vol. 7082, 708213-10.

Call for Articles

Readers are requested to contribute short articles for publication in the forthcoming issue of *Signatures*, related to the specific theme ***"Remote Sensing Data Products & Retrieval Algorithms"***.

The deadline for inclusion in the next issue is **May 31, 2013.**

- Editorial Team

Microwave Sensors for Weather and Climate Missions

Prantik Chakraborty and Tapan Misra

Microwave Remote Sensors Area, Space Applications Centre, Ahmdedabad.

Email: prantik@sac.isro.gov.in, misratapan@sac.isro.gov.in

For after the rain when with never a stain
   The pavilion of Heaven is bare,
And the winds and sunbeams with their convex gleams
   Build up the blue dome of air,
I silently laugh at my own cenotaph,
   And out of the caverns of rain,
Like a child from the womb, like a ghost from the tomb,
   I arise and unbuild it again.

P. B. Shelley, The Cloud

Metaphorically, these memorable lines signify the water cycle which, among other factors, regulates the global climate and its change. The metaphor also underscores the uncertainty in weather phenomena and hence the need for observation at frequent intervals on a global scale. But, in a more implicit way, it underscores the role of microwave sensors in weather and climate monitoring *i.e.* their ability to see through clouds.

I. Microwave Met-Sensors: Global Scenario

Microwave observation of meteorological processes directly from space-borne platforms or estimating them from indirect measurements (e.g. empirically derived models) have started as early as 1973 with the Skylab experiments. Skylab had among its instruments a radiometer and a scatterometer (referred as S-193 or RADSCAT) operating at the same frequency (13.9GHz) and sharing a common antenna which generated spot-beams on the earth's surface at a range of incidence angles for the purpose of studying surface winds and precipitation over the oceans. Since then, several missions for weather and climate studies have flown over the years. The sensors can be primarily classified into the following categories:

1. Microwave Radiometers: They measure emissions from the earth's surface (their utility is primarily over oceans) at a set of frequencies which respond to weather phenomena such as moisture, precipitation, clouds and wind. Owing to lower signal strength of the Earth's Planck radiation curve in the microwave region, the accuracy and radiometric resolution are poorer compared to measurements at infrared (IR) and visible (VIS) wavelengths. The constraints of accommodating a large scanning aperture in the spacecraft also result in poorer spatial resolution even from low-earth orbits. The advantage is the large swath available which enables global coverage on a fine temporal scale. The primary advantage of microwave, however, is that these frequencies are largely unaffected by clouds and are generally easier to correct for atmospheric effects. The observables are:

i) Sea Surface Temperature (SST) — an important geophysical parameter used in estimation of heat-flux at air-sea interface. On a global scale, this is important for climate modeling, study of earth's heat balance and understanding atmospheric and oceanic circulation patterns and anomalies (e.g. El Nino) while, on a local scale, it can be operationally used to assess eddies, fronts and upwellings for marine navigation and to track biological productivity. C-band (6-7 GHz) is sensitive to SST.

ii) Near-surface Wind Speed over ocean.

Traditionally sea-surface emission at X-band (10.6GHz) has been quite successfully used for retrieving wind speed at 10m height on 25km spatial scale in the range of 0—30ms^{-1}. Although dual polarized (horizontal and vertical) measurements have exhibited directional dependence, unambiguous wind direction retrieval has not been possible because of upwind-downwind symmetry. Combining the two polarizations with their cross-correlation terms constitutes the 4 Stokes' parameters which provide complete electromagnetic characterization of the ocean surface and, in principle, are sufficient to uniquely determine wind direction. The Windsat instrument launched on board the Coriolis satellite in 2003 is the world's first radiometer with polarimetric capability. In addition to H- and V-polarizations, it measures linearly polarized emissions at ±45^0 as well as left and right circular polarizations at 10.7, 18.7 and 37 GHz. The geophysical model function relating wind vector to the Windsat brightness temperatures has recently been developed and useful wind products (at par with Quikscat-derived winds except at high rain and low winds less than 6ms^{-1}) are being generated.

iii) Column-integrated water vapor — an important element of the hydrological cycle and plays a key role in the heat transport to the atmosphere from the surface. It is a greenhouse gas in the troposphere that drives weather changes on short time scales and climate change (such as global warming) on longer time scales. The water vapor absorption line near 22 GHz provides accurate means to measure the total water vapor column in the atmosphere.

iv) Cloud liquid water content, Total precipitable water and ice on cloud top — all of these are elements of the water cycle and regulate the atmospheric convective systems and the earth's water and energy budget. At 18 and 37 GHz, the clouds are semi-transparent allowing for measurement of absorption due to precipitable water and ice (at 157GHz) in the viewing path.

v) Precipitation, rain rate — an extremely important parameter that influences climate change, terrestrial habitation, vegetation, agriculture, fresh water availability and almost every aspect of the hydrosphere and the biosphere. Changes in spatial distribution of rainfall have led to the collapse of civilizations. It is difficult to accurately retrieve rainfall using remote sensing because of its extreme variability in space and time. There are dedicated rainfall measuring missions employing a combination of active and passive sensors like the Tropical Rainfall Measuring Mission (TRMM). Launched in 1997 in a low-inclination low-altitude orbit, it is continuing more than a decade long documentation of the diurnal cycle of rainfall over the tropics (the world's maximally rain-affected areas). The TRMM Microwave Radiometer (TMI) has 5 frequencies (10.7, 19.3, 21.3, 36.5 and 85.8 GHz) all dual-polarized (except 21.3, only V). It is soon going to be joined by its global counterpart, the Microwave Radiometer (GMI) onboard the core observatory of the Global Precipitation Measurement Mission.

Besides these sensors, the Advanced Microwave Scanning Radiometer (AMSR-E) onboard NASA and NASDA's Aqua mission (launched in 2002) and its next generation high resolution successor AMSR-2 onboard the Japanese GCOM-W1 mission (launched in 2011) are 6-frequency (6—89GHz) dual-polarized radiometers dedicated for observing the water cycle and monitoring the global climate change.

vi) Sea Ice — it is important to global climate as it acts to regulate heat, moisture and salinity of the polar ocean. The recent increase in summer Arctic sea ice acts as a positive feedback for global warming by changing the albedo. Sea-ice concentration and its classification are estimated using polarization and gradient ratios at 19 and 37 GHz.

vii) Soil Moisture and Ocean Salinity — these elements substantially modify the dielectric constant and hence the emissivity of the respective surfaces and therefore regulate surface emission and heat transfer. Longer wavelengths (L band at 1.4 GHz) are required for surface depth of a few cm and have given birth to a new dimension in microwave radiometry — the concept of aperture synthesis. The SMOS mission (2009) of ESA is the worlds' only synthetic aperture radiometer.

2. Atmospheric Sounders: Frequencies that are absorbed by the gases in the atmosphere are used for sounding its optical depth. Oxygen and water vapor are the principle contributors to atmospheric radiative transfer in the micro-and millimeter wave regime. The line-absorption spectrum of oxygen (pressure-broadened in the troposphere and temperature-broadened in the stratosphere) at 50-60GHz has been exploited by a series of atmospheric sounders over the years for vertical profiling of temperature and pressure. These include the Special Sensor Microwave Imager/Sounder (SSMIS) series of US Defence program, the Advanced Microwave Sounding Unit (AMSU) onboard the Aqua as well as several Eumetsat MetOp missions and the next-generation Advance Technology Microwave Sounder (ATMS). These sensors profile atmospheric humidity in tandem using the water vapor absorption line at 183 GHz. The brightness measurements by these sensors at the top of the atmosphere are routinely assimilated in Numerical Weather Prediction (NWP) models and used for operational weather forecasting.

3. Wind-Scatterometers: Wind vector measurements over observation-sparse oceans using space-borne radars started with the Skylab experiment in 1973 and Seasat in 1978. Wind observation is essential for understanding air-sea interaction and energy transport, the atmospheric and oceanic circulation models as well as tropical and extratropical cyclogenesis. The economic impact is also huge in terms of early cyclone-warning systems, marine navigation, off-shore energy, commercial fisheries and a host of other societal features. Wind scatterometers are real-aperture radars that measure wind-induced ocean-surface roughness in the Bragg-scattering regime at multiple azimuth angles and empirically derived models relate those back-scatter measurements to wind speed and direction. There have been two classes of scatterometers: one that used the C-band (predominantly the ESA intruments) viz. the ERS-1 and ERS-2 scatterometers and the Advanced SCATterometer (ASCAT) and the other class that was preoccupied with Ku-band (NASA and erstwhile NASDA) viz. the Seasat scatterometer, NSCAT and the Quikscat. Quikscat is a rotating pencil-beam scatterometer with a wide swath. The rest are all fan-bean systems having different number of beams (e.g. 3 in ERS, 4 in Seasat and 6 in NSCAT and ASCAT). All have large unavoidable nadir gaps but good radiometric accuracy than the pencil beam configuration. Also large antennas have to be accommodated in the spacecraft or deployed in orbit in case of fan-beam systems while pencil-beam requires a single antenna to be rotated.

4. Altimeters: These nadir-viewing radars image the surface topography of the ocean that leads to understanding of ocean circulation and its effect upon climate. After a brief glimpse of Earth's oceans from the pioneering, but short-lived Seasat, the TOPEX/Poseidon satellite (a NASA-CNES collaboration launched in 1992) was a dedicated oceanographic mission delivering decadal observation of the sea-level, global tides, seasonal changes of ocean currents and inter-annual phenomena like El Nino, La Nina etc. The TOPEX used two altimeters at C-band (5.3 GHz) and Ku-band (13.65 GHz) while Poseidon was an experimental CNES Ku-band altimeter, both sharing the same antenna. Continuing their legacy with a period of simultaneous operation is the Jason-1 mission (launched in 2001).

5. Precipitation Radars: The TRMM precipitation radar is the first space-borne instrument to provide three-dimensional maps of rain and storm structure. It is a Ku-band instrument employing an active phased-array antenna for vertical profiling of rain and atmospheric structures with fine spatial (4.5km) and vertical 0.25-1.4 km) resolutions. The measurements yield valuable information on the intensity and distribution of rain, the type of rain (convective/stratiform), the height of storm and the altitude at which snow melts into rain. Estimates of latent heat released into the atmosphere in the condensation process are also used to improve models of atmospheric circulation. GPM's dual frequency DPR is going to add Ka-band for more accurate rain retrieval. DPR will offer insights into microphysical processes of precipitation.

6. Cloud Profiling Radar: Cloudsat is an experimental mission launched by NASA and CSA in 2006 for 3-D profiling of clouds at very high spatial (2km) and vertical (500m) resolutions using V-band (94 GHz).

7. Doppler Weather Radars: Terrestrial network of these ground-based pulsed Doppler radars are interestingly the backbone of rain and storm observation over land. Examples include NEXRAD (S-band) in USA, COBRA (C-band) in Japan and CPOL (C-band) in Australia.

II. ISRO's Missions

ISRO has a heritage of missions for climatology and oceanography since the inception of its earth observation program.

1. Bhaskara-I: A radiometer called SAMIR having two channels at 19.35 GHz and 22.235 GHz was flown aboard the Bhaskara-I satellite in 1979. It was the earliest met-sat which operated for two years and provided useful data for studies of the ocean state, atmospheric water vapour and cloud liquid water content.

2. Bhaskara-II: An advanced version of SAMIR having 3 channels (19.24, 22.235 and 31.4 GHz) was flown aboard Bhaskara-II in 1981. The legacy of SAMIR continued up to 1983.

3. Oceansat-I: After a lull, the next microwave radiometer was put in orbit onboard Oceansat-I in 1999. The Multi-frequency Scanning Microwave Radiometer (MSMR) was designed to measure several parameters such as the sea-surface temperature, wind speed, water vapour, precipitation and cloud liquid water content using 4 channels (6.6, 10.65, 18 and 21 GHz; all dual polarized). Unfortunately Oceansat-I discontinued operations shortly owing to a failure in the spacecraft's solar array drive assembly.

4. Oceansat-II: The Ku-band scanning pencil beam wind-scatterometer flown onboard Oceansat-II in Sep, 2009 continues to be a reasonably successful mission. Incidentally, it is the only operational Ku-band (13.515GHz) scatterometer in space after Quikscat stopped scanning in Nov, 2009. The instrument has been rigorously calibrated in-orbit using i) deep-space measurements (for instrument noise-calibration) ii) signatures of stable natural target (e.g. the Amazon rain forest) and also iii) cross-calibrated with collocated Quikscat data (repointed to Oceansat-II scatterometer alias Oscat incidence angles), Quikscat-derived winds, buoy data and models like ECMWF and GDAS. Oscat is currently meeting the requirement of operational wind vector retrieval and wind forecast across the globe. Analyses of three years of Oscat data reveal that they have the promise of qualifying for climate data records.

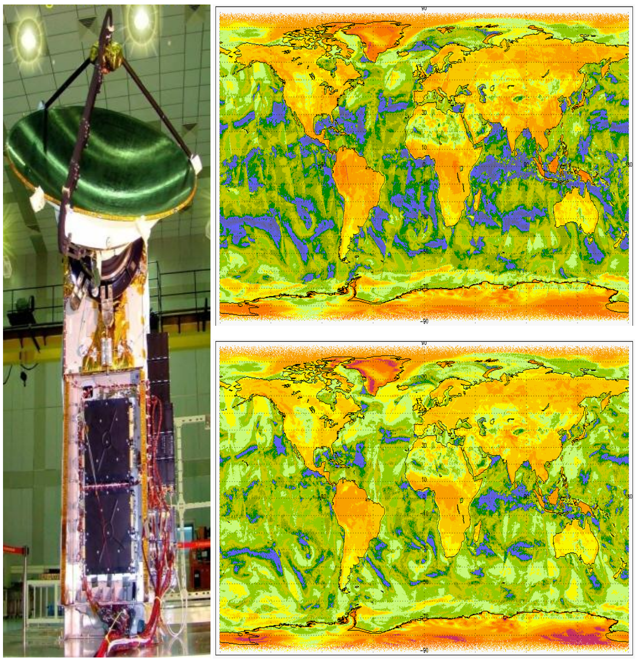


Fig 1: Left: A view of OSCAT in MRSA clean room; Right: Global Backscatter Images from OSCAT; top: HH pol., bottom: VV pol.

5. Megha_Tropiques: The **MADRAS** radiometer onboard the Megha_Tropiques mission (Indo-French collaboration) launched in Oct 2011 is a TMI-like radiometer dedicated for precipitation observation over the tropics. It has 9 channels at 5 frequencies (18.7, 23.8, 37.5, 89 and 157 GHz). The instrument faced a few issues that led to mixing of channel signatures. Algorithms were developed to realign the data through ground-processing. The MADRAS radiometer, by virtue of oversampling, offers excellent opportunity to super-resolve the brightness temperature of its low-frequency channels. An example is cited in Fig 2.

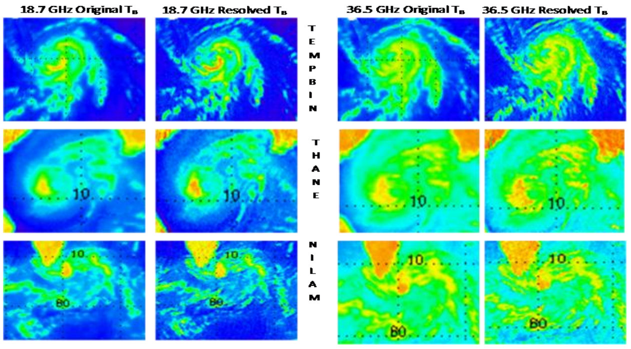


Fig 2: Original and Resolved T_B Images of Tropical Cyclones, Tempbin, Thane and Nilam; Left: 18.7 GHz; Right: 36.5 GHz.

6. SARAL: Another ISRO-CNES collaboration, the soon-to-be-launched SARAL satellite has a Ka-band (35.75 GHz) altimeter (AtiKa) along with a two-channel (23.8 and 37 GHz) radiometer. The AltiKa mission is aimed at ocean meso-scale variability studies with improved vertical and spatial resolution, improvement in coastal altimetry and ice-sheet monitoring as well as improved sea-surface height measurements.

III. Future Prospects

Several new sensors have been conceived for future climate missions. Some of them are in the advanced stage of development. A brief outline is presented here.

1. Temperature Sounding Unit (TSU) & Humidity Sounding Unit (HSU):

Atmospheric sounders for 3-D profiling of temperature and humidity are the new candidates for ISRO's climate missions in near future. A Temperature Sounding Unit (TSU) has been planned in the initial phase (it is ISRO's first leap towards millimeter-wave technology) and its hardware development has reached an advanced stage. A Humidity Sounding Unit (HSU) at 183 GHz will be developed in the next phase.

A novel set of channels (distinct from those of AMSU-A, ATMS and SSMIS) was selected for the TSU. These channels are primarily optimal off-resonance frequencies in the 50-60 GHz oxygen line-absorption spectrum which impose less stringency on bandwidth and sensitivity and yet have adequate overlap of their weighting functions (refer Fig 3) which can be harnessed to achieve the desired vertical resolution. The consortium consists of 11 single-passband line-wing channels (see Figure 1b) with near-uniform bandwidth (300 MHz) and brightness temperature sensitivity (< 0.5K) and can sound up to 30 km with vertical resolution ranging from less than a km to 6 km. There are 2 double-passband channels near line-centres which can sound up to 40 km with poorer resolution. In addition, there are a couple of radiometric channels at 23.8GHz and 31.5 GHz for estimation of surface-contamination as well as for sensing of water vapor and rain.

It has been proposed to fly the TSU as a co-passenger of Oscat follow-on in Oceansat-III mission. The TSU has been configured as a pair of Total Power Radiometers (each sensing a single polarization H/V) that will operate in tandem. Highlights of the instrument are: i) indigenously developed Gregorian reflector antenna having a scanning main reflector and stationary sub-reflector and feed. There are two Gregorian antennas (one for 23/31 GHz and the other for V-band) with their rotating reflectors sharing a common scan mechanism. ii) indigenously developed and characterized black-body targets for K-/Ka- and V-bands iii) indigenously developed MMIC-based low noise-figure mm-wave receivers and iv) high-precision (16-bit) data acquisition system.

2. Oceansat-II Scatterometer Follow-On:

A repeat of Oscat has been planned for the Oceansat-III mission in order to maintain the continuity of wind-products.

3. Geo-based Radiometer and Sounder: The geosynchronous platform provides opportunity for near-continuous (15 min interval in case of limited north-south and east/west scan) observation of cloud, precipitation as well as atmospheric temperature and humidity profiles over the Indian subcontinent (with complete Indian Ocean coverage) while GPM can achieve 3 hours at the best. The challenge of the geo-platform altitude is realizing feasible aperture dimension for achieving reasonable ground-resolution. Exploring sub-millimeter wavelengths and using deployable antennas are some of the options.

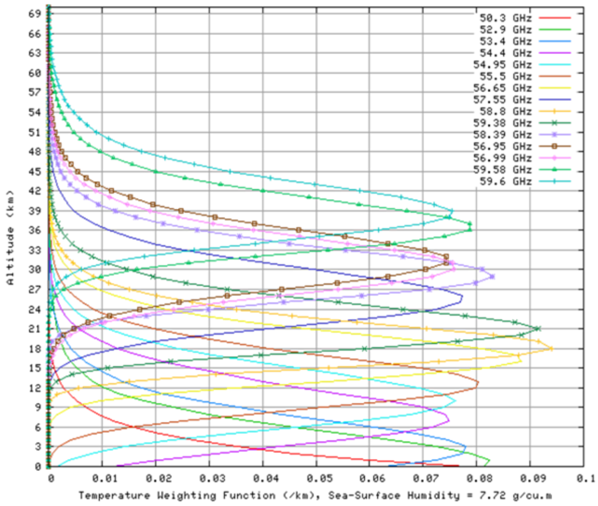


Fig 3: Weighting function of TSU Channels

4. Leo-based Radiometer with Polarimetric Capability:

This will indeed be an extremely useful compliment to the scatterometer (based upon the orbits chosen) for cross-calibration, wider coverage and faster relook. The challenges (from Windsat experience) are maintaining polarization purity and developing highly sensitive receivers because the cross-correlation terms are two orders of magnitude lower than the individual polarizations.

5. Dual-Frequency High-Resolution Scatterometer: C-band provides improved wind-retrieval in the presence of moderate to high rain and its HH-polarization measurements exhibit no sign of saturation at high wind-speeds (cyclonic conditions). Ku-band, on the other hand, provides finer spatial resolution and better retrieval at low wind speeds. Combining these two frequencies on the same platform has all the potential of all-weather and all-wind retrieval. The challenge, however, is handling the power and rotating a large aperture (almost twice of Oscat). A simultaneous requirement is high-resolution observation which again necessitates more power and/or larger aperture and also exploring the possibility of onboard SAR processing.

6. Polarimetric Scatterometer: Imparting polarimetric capability (measuring correlation of co- and cross-pol backscatter cross-section) to the existing Oscat configuration will entail minimum hardware modification but has tremendous potential of unambiguous wind retrieval (eliminating need of external *a priori* information for ambiguity removal) and improving the nadir performance. This is an area of advanced research.

7. Ku- and Ka-Band Precipitation Radar: Dual-frequency nadir-viewing radars for high-resolution 3-d profiling of rain and storm and for studying precipitation microphysics will be a next generation state-of-the-art instrument. Realizing Ku- and Ka-band TR modules and the active phased-array antenna will a technological leap for us.

8. Doppler Weather Radar: Ground-based C- and S-band polarimetric pulsed Doppler radars for observing rain, hail, storm and atmospheric structures in motion over a range of 300km at 300m resolution are currently being designed. It is planned to demonstrate an array of such radars to support operational meteorology.

9. Synthetic Aperture Radiometer: Preliminary system study of an L-band synthetic aperture radiometer has been carried out. Digital correlators are being firmed up. This payload, apart from its LEO-based applications for soil-moisture and ocean-salinity measurements, can be configured for the GEO-orbit to achieve fine spatial resolution at the other radiometric frequencies.

Acknowledgement: We grateful to Smt Arundhati Misra for encouraging us and Shri Deepak Putrevu and Shri Ananya Ray for their support.

Radar and Radiometer Methods in Continental and Antarctic Ice Studies as Indicators of Climate Change

G. Raju

Formerly, ISRO, Project Director, Megha Tropiques

Global atmospheric and oceanic activities such as sea-level rise, ozone depletion, greenhouse effect, global warming, El Nino, La Nina, tsunamis, flash floods, cyclones, cloud burst, and so on are some of the major climate-related phenomena still difficult to comprehend, measure and predict quantitatively. All these fall under the current topics of climate change, weather-forecasting and disaster monitoring. We are yet to develop effective models to predict any of these satisfactorily.

One of the major contributors for climate change is the variation in the quantity of ice/snow at global scale. The dynamics of the ice parameters such as thickness, extent, melting, etc., have a long-term impact on climate change. Particularly, knowledge on the rate of accumulation or depletion of ice sheets of Antarctica and Greenland as well ice/snow in the continental mountains and glaciers is an important question still necessitating continued measurements and monitoring of the ice on a global scale. A number of countries have established bases globally, to conduct experiments round the year for various scientific investigations including studies related to snow/ice extent and melting, thus addressing the major task of determination of global water and mass balance. It is still a challenging task and deals with measurement and monitoring the thickness of large ice masses of glacier ice both in the main continents as well as the Polar Regions.

In the above context, radar and radiometer methods operating at microwave and RF frequencies have predominantly contributed in the detection of ice extent, ice depth, rate and phase of ice melting and the resulting water run-off that could cause large scale inundation and floods. Spaceborne microwave radiometers and radars from early missions such as Nimbus and Seasat satellites have established such capabilities in seventies.

This paper briefly highlights the sensor capabilities with a few examples from previous spaceborne missions supplemented by the author's own contribution in development and application of a modern unfocussed synthetic-aperture radar (SAR) operated in Antarctica to demonstrate the capabilities of radar for measuring thick sheets of Antarctic ice.

The radar was developed at the University of Kansas, USA, under a project funded by the US National Science Foundation, when the author was associated in conducting polar research and instrumentation while doing his doctoral work in the eighties. The radar proved to be a very effective tool for these measurements and was successfully operated from an aircraft as well as a mobile hut. It detected ice thickness of more than 1.5 km in the fast-moving dynamic Downstream-B glacier in the West Antarctic Mountains. Periodic measurements of the ice-covered regions such as the Arctic and Antarctic ice sheets will provide very valuable information for generating models related to global water and mass balance. Similar radar instruments along with more modern instruments such as a spaceborne synthetic-aperture radar and radiometer when used over the vast mountainous terrains. Such instruments and their operations over the Himalayas will not only contribute in global climate change studies but also in important applications related to floods, inundation survey, development of hydrological models, and disaster monitoring applications, especially in India.

2. ICE PARAMETERS RELEVANT TO CLIMATE CHANGE STUDIES

Apart from numerous oceanographic, atmospheric and meteorological parameters that affect climate change, the following ice-/snow- related parameters derivable from microwave sensors are addressed below. They are:

2.1. Spatial extent of ice/ice cover

2.2. Depth of ice cover

2.3. Structure of ice sheets

2.4. Melting phase of ice/snow

2.5. Ice/iceberg motion (velocity) in oceans/Antarctica

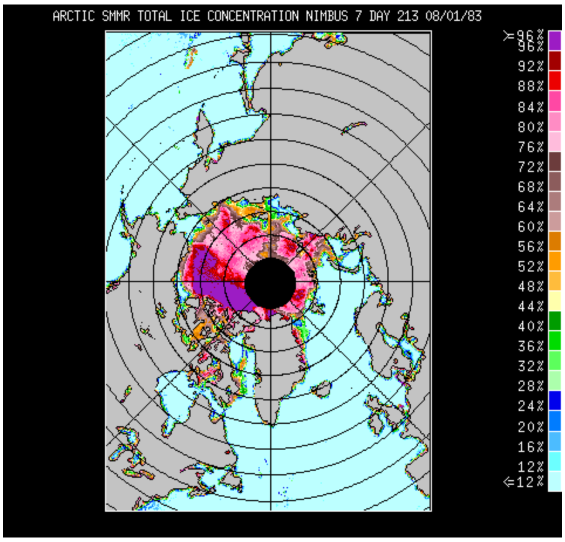
2.6. Sea-ice

The above parameters have been measured and monitored in many of the previous missions and planned for future missions as well. The capability of microwave sensors in quantitatively measuring the parameters along with representative results is briefly highlighted in the next sections.

3. EARLIER MISSIONS:

3.1 Microwave Radiometers

Some of the most effective spaceborne microwave missions that have provided very useful and comprehensive results in context with the ice monitoring studies are the US missions, viz., Nimbus-5,-6, & -7 [1] and SEASAT-A spacecraft which carried both active instruments such a synthetic-aperture radar (SAR), scatterometer and altimeter as well as the passive instrument, viz., the ESMR - electronically scanning microwave radiometer, and the SMMR-scanning multi-channel microwave radiometer. More Radiometer missions were also followed by the US Defence Meteorological Satellite Programmes (DMSP) carrying Special Sensor Microwave Imager (SSM/I), which are operated as a continued programme. There have also been more recent missions such as the advanced microwave scanning radiometer (AMSR) on ADEOS missions. A few significant results are shown in the following sections.



The imaging radiometers were able to detect seasonal changes of ice cover in the Antarctic and the Arctic regions. Both ESMR and SMMR contributed a significant part of more than 30+year sea ice coverage data set that has been used to investigate climate trends [11].

3.2 Scatterometers

Data provided by scatterometers has been used for many years for weather and wave forecasting. More recently it has been used to study unusual weather phenomena such as El Niño, the long-term effects of deforestation and changes in sea-ice masses around the poles, all of which play a central role in regulating global climate. Studies have also been done on the use of scatterometers to understand the connection between changes in polar sea ice and climate changes at the equator. Scatterometers are proving to be an extremely useful tool in this research.

Recording the date of melt onset and the duration of the melt season are other important parameters for studying the long-term trends of sea ice. Earlier melt onset dates and lengthened duration of the melt season have resulted in significant reductions of sea ice extent in the Arctic ocean over the past twenty-five years, with record low sea ice extent occurring in the summer of 2002 (Serreze et al., 2003) and predictions from climate models that the Arctic will be essentially ice-free in summer by the year 2100 (Johannessen et al., 2002).

While originally designed for wind measurement over the ocean, scatterometers have proven to be very effective in monitoring land cover and ice conditions as well. Scatterometer data is being operationally used for iceberg tracking and sea ice extent mapping. The frequent, global measurements make the instrument particularly well suited for global monitoring and the long-time series of scatterometer measurements provide a valuable baseline for studies of climate change.

3.3 Synthetic-aperture radars (SAR)

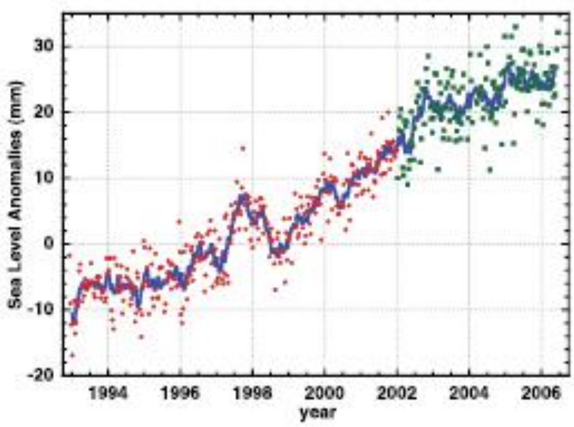
The synthetic-aperture radars have shown significant capability particularly to measure ice motion/velocity. Ice velocity is a fundamental parameter in studying the dynamics of ice sheets. Until recently, no complete mapping of Antarctic ice motion had been available. The ice motion measured by six sensors on board the Japanese ALOS PALSAR, the European Envisat ASAR ERS-1 and ERS-2 and the Canadian RADARSAT-1 and RADARSAT-2 are now available [10].

3.4 Altimeters

Ocean circulation and mesoscale ocean dynamics have been derived from satellite altimetry for a long time. Since 1992, satellite altimetry has provided an unprecedented monitoring of sea level and ocean circulation variations. Continuous measurements from satellites like TOPEX/Poseidon and Jason-1 have helped to understand and foresee the effects of the changes in ocean circulation on climate and on extreme climate events such as El Nino and La Nina.

Altimeter measurements have improved our understanding of both the dynamics and thermodynamics of western boundary currents by providing a synoptic view of the current systems and their interannual variations, and allowed scientists to quantify eddy-induced salt and heat transport, and seasonal and interannual variations in eddy kinetic energy.

Since 1992 global mean sea level can be computed at 10-day intervals by averaging the altimetric measurements from the TOPEX/Poseidon (T/P) and Jason satellites over the area of coverage (66°S to 66°N) (Nerem and Mitchum, 2001).



Variations in global mean sea level (difference to the mean 1993 to mid-2001) [7]

4. COHERENT ANTARCTIC RADAR DEPTH SOUNDER (CARDS)

4.1 Historical background

Electromagnetic waves propagate in ice/snow with negligible attenuation in the ice medium. Application of this property was recognised through an interesting incident as reported in the literature [8]. In late 50's, an aircraft flying over Greenland crashed on the thick icy terrains which covered the land since its altimeter readings indicated a larger flying altitude than its actual clear altitude from the surface. Fortunately there were no casualties since the crash was over a softer terrain with ice. This was attributed to the fact that the radar reflections originated from deeper land surfaces than the top ice layers through which the electromagnetic waves had penetrated, thus indicating the possibility of measuring ice thickness by radar techniques.

4.2. Physical principles: Ice and snow have a dielectric constant of 3.1 to 3.2 at microwave frequencies. Hence they permit propagation of electromagnetic energy through ice and snow with negligible attenuation, α, given by:

$\alpha = 1.449 \times 10^{-6}$ SQRT $[\varepsilon'(\omega) \tan(\delta)]$,

where ω is the angular frequency, tan (δ) is the loss tangent. At 150 MHz, the attenuation is 0.01 dB per m., in ice. The microwave energy easily traverses through the medium and is reflected and scattered by the bottom rock surface. Thus the time delay represents the round-trip time of propagation giving a measure of the range/ depth of ice.

4.3 Radar instrument: The Coherent Antarctica Radar Depth Sounder (CARDS) [9] at 150 MHz was developed using the modern technique of pulse-compression providing the dual advantage of low power with high spatial resolution. It is operated from a specially configured aircraft with skis for Antarctic operations. The radar was also operated from a mobile hut pulled by a "Tucker" vehicle. The radar was equipped with subsystems which could be field-replaceable, if required, due to the harsh Antarctic environment.

Figure: 150 MHz Coherent Antarctic Radar Depth Sounder being hauled on ice in Antarctica. Note: the same radar was also flown on-board a Twin-Otter aircraft [9]

The radar instrument provided very useful results on the ice depth and correlated well with previous measurements obtained by other researchers. This method will be very effective and useful for routine monitoring of ice thickness if configured on flights of opportunity.

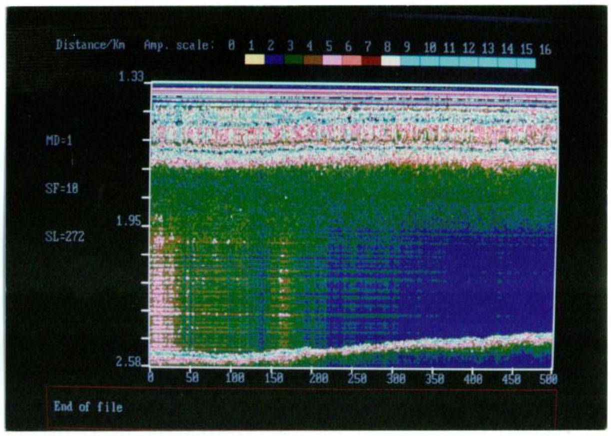


Figure: Vertical profile indicating ice depth and bottom bed rock structure at Antarctica, along a specific flight path in Downstream-B Glacier

5 CONCLUSION AND FUTURE PROSPECTS:

Microwave remote sensing instruments such as radars and radiometers are well proven for detection of ice cover, ice extent and ice depths to a reasonably good accuracy for effective global applications of ice monitoring and ice depth measurements to provide valuable input parameters for climate models to detect and quantify climate change. Persistent efforts are necessary in spaceborne and airborne measurements using microwave radars and radiometers for global and regional applications. Such missions are particularly important in the Indian context of ice and snow studies in the Himalayan region, for applications in disaster monitoring, weather-forecasting and climate change studies.

REFERENCES:

1. Donald J. Cavalieri, Clarie L. Parkinson, Per Gloersen, and H. Jay Zwally, [1995], "*Arctic and Antarctic Sea Ice Concentrations from Multichannel Passive-Microwave Satellite Data Sets: October 1978 - September 1995*" - User's Guide, NASA Technical Memorandum 104647.
2. John Paden, David Braaten, Prasad Gogineni [2011], "*A Next-Generation Ice Radar*", IEEE Spectrum, September 2011.

3. Raj Kumar, "*OCEANSAT-2 Scatterometer – Status and Va;ue-added Products"*, IOVWST Meet, Utrecht, 12-14 June 2012.
4. D. G. Long and Jensen, M. A., "The Scatterometer Climate Record Pathfinder: Tools for Climate Change Studies", American Geophysical Union, Fall Meeting 2001.
5. Yongsheng Xu, Jianke Li and Shenfu Dong, *"Ocean circulation from altimetry: progresses and challenges"*
6. Sea Level Change during the Last Decade from Satellite Altimetry.
7. *IPCC Fourth Assessment Report: Climate Change 2007.*
8. Waite, A. H., [1959], "*Ice depth soundings with ultra-high frequency radio waves in the Arctic and the Antarctic", and some observed over altimeter errors,* US Army Res. And Dev. Lab, Tech. Rep. 2092.
9. G. Raju [1989], "*Coherent Antarctic Radar Depth Sounder (CARDS): Design, development and Results*", Ph. D. Dissertation, University of Kansas, USA.
10. Jeremie Mouginot, Bernd Scheuchl and Eric Rignot, "*Mapping of ice motion in Antarctica using synthetic-aperture radar data"*, Remote Sens. 2012, 4, 2753-2767.
11. Per Gloerson, Imaging Microwave Radiometers in Space.

Aerosols and Climate Change

S. Ramachandran

Physical Research Laboratory, Ahmedabad

E-mail : ram@prl.res.in

1. Introduction

Atmospheric *aerosols* (a mixture of solid or liquid particles suspended in air) are concentrated in the source regions and exhibit strong spatio-temporal heterogeneity, unlike the principal greenhouse gases which are globally well mixed.

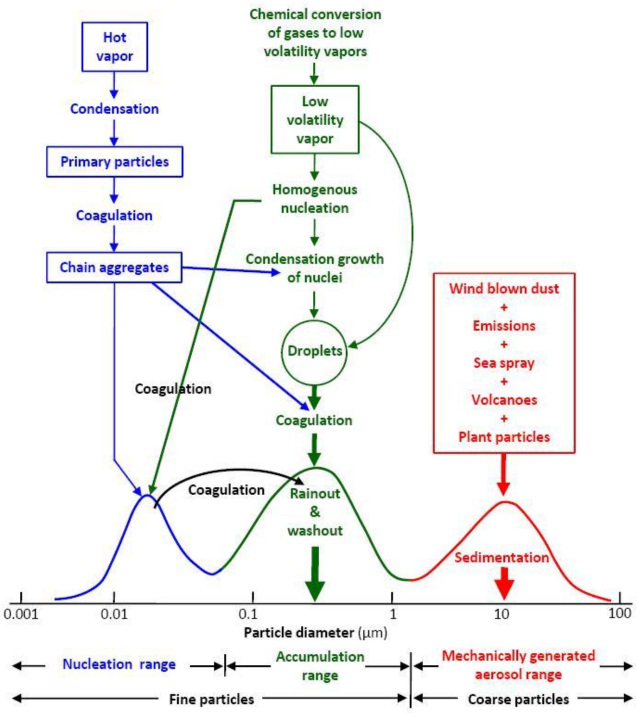


Figure 1. Schematic of aerosol size distribution as function of particle diameter, showing three modes of aerosol distribution, production and removal mechanisms (adopted from Whitby, 1978).

The characteristic primary or direct sources of aerosols include the world oceans (sea salt particles), arid and semi-arid regions (wind blown mineral dust), terrestrial biota (biological material of plant origin) and smoke from forest fires (Figure 1). In addition, land-use changes, anthropogenic emissions (soot, smoke, road dust), volcanic eruptions, extraterrestrial and interplanetary dust produce aerosols. The secondary or indirect source, which is the major source of particles < 1 µm, is the conversion of the available natural and anthropogenic trace gases into solid or liquid particles. This process known as the *gas-to-particle conversion mechanism* depends on number of precursors which include sulfur and nitrogen bearing gases among others. The major aerosol species present in the atmosphere include sea salt, mineral dust, sulfate, black carbon, organic carbon, and nitrate.

While due to above processes aerosols are incessantly created and transformed, aerosols existing in the atmosphere are regularly removed by a variety of dry and wet removal processes. Dry deposition includes settling of particles by gravitation, impaction and diffusion, and wet removal occurs by rainwash. The removal efficiencies are a function of the particle size. Aerosols in the size range of 0.01 to 10 µm can reside up to a week in the lower troposphere, while in the upper troposphere they reside up to a few months. In the stratosphere the residence time of aerosols can extend to a few years. The aerosol concentrations vary as a function of altitude and seasons. For example, over the Indian subcontinent, the aerosol number density in the lower troposphere is about a few thousands of particles during pre-monsoon, while after monsoon their number is reduced due to removal by rainwash. In the stratosphere, in volcanically quiescent i.e. background conditions the aerosol concentration is quite less, while after major volcanic eruptions the aerosol concentration can go up by more than one order of magnitude. Most of the aerosols are concentrated between 0 and 35 km in the atmosphere, with the bulk of them in the troposphere which varies with seasons and locations and produce regional effects, the stratospheric aerosols are long-lived and can produce global effects.

2. Global climate: Global climate is influenced by natural (variation in the solar irradiance and volcanic eruptions) and anthropogenic processes (changes in the atmospheric composition of gases including greenhouse gases and ozone, and aerosols, and alteration of surface reflectance characteristics by land use) (IPCC, 2007). The influence of different agents on the Earth's climate is evaluated by radiative forcing which is expressed in Watts per square meter (Wm^{-2}). Radiative forcing is defined as the influence a species has in altering the balance of the incoming and the outgoing energy of the Earth-atmosphere system. Thus, radiative forcing is a measure by which one can assess and compare the natural and anthropogenic drivers of climate change (IPCC, 2007).The radiative forcing due to all greenhouse gases (carbon dioxide, methane, nitrous oxide and halocarbons) is positive (warming) as each gas absorbs the infrared radiation in the atmosphere. Increase in carbon dioxide concentrations among the greenhouse gases has caused the largest atmospheric warming. Tropospheric ozone increase has resulted in warming while decrease in stratospheric ozone has produced cooling (IPCC, 2007).

3. Direct and indirect radiative effects of aerosols: Atmospheric aerosols are gaining considerable importance in the present-day scenario due to increases in anthropogenic activities as well as due their direct/indirect effects on climate. The direct radiative effects of aerosols involve scattering and absorption of solar radiation, and the relative importance of these processes depends on the chemical composition, refractive index and size distribution of aerosols. Scattering (sulfate, sea salt) and absorbing (black carbon, mineral dust) aerosol species cool the surface of the Earth and give rise to *global dimming*, while their radiative effects vary with altitude in the atmosphere. The radiative forcing at the top of the atmosphere is similar to that of the surface forcing for scattering type particles; while the surface forcing is about 2 to 3 times larger than the top of the atmosphere forcing for absorbing aerosols. Therefore, absorbing aerosols produce a large atmospheric warming. The greenhouse gases are globally well mixed and their radiative effects are homogeneous (warming). In contrast, aerosols exhibit regional signatures and can either warm or cool the atmosphere depending on their type. Although aerosols are present in abundance near source regions, they can impact global climate as they and their radiative influence can get transported to other regions via atmospheric circulation. In addition, the aerosol forcing is greatest in daytime and summer, whereas greenhouse gas forcing acts over full diurnal and seasonal cycles. Thus, it is abundantly clear that aerosols perturb the Earth's radiation budget differently than greenhouse gases.

Cloud droplets are produced in the lower atmosphere by condensation of water on existing aerosol particles. Sulfate and organic carbon, being water soluble, act as good cloud condensation nuclei (CCN). Thus, the concentration, size and composition of the aerosols that can act as CCN not only determine the properties of clouds, but also their evolution and development of precipitation. Aerosols may also play a role in the formation of ice nuclei in clouds. The indirect radiative effects of aerosols are more uncertain than the direct radiative effects of aerosols (IPCC, 2007). The indirect effects of aerosols on clouds and precipitation occur through the following three major pathways: (a) aerosols can increase the life time of clouds and reflectivity (albedo), thereby decreasing the precipitation and radiation reaching the surface of the Earth, (b) aerosols can absorb the solar radiation, re-emit as thermal radiation and by heating the air mass may cause evaporation of cloud droplets, and (c) an increase in the ice nuclei can increase the precipitation efficiency of clouds (IPCC, 2007). Recent studies have indicated that large concentrations of anthropogenic aerosols can either lead to a decrease and/or increase of rainfall as a result of their radiative and CCN properties.

4. Aerosols and Climate: The most important aerosol parameters required to estimate the aerosol radiative effects are aerosol optical depth (AOD), single scattering albedo (SSA) and asymmetry parameter. Aerosol optical depth is directly proportional to aerosol loading, and the size distribution of aerosol mass burden in atmospheric column; typically, in an aerosol size distribution sub-micrometer aerosols are orders of magnitude higher than super-micron particles. The size distribution is crucial to determine SSA (ratio of scattering to extinction (scattering+absorption)), as the value of SSA (whether high or low) is determined by the ratio of the number of absorbing to scattering particles in a size distribution. The angular distribution of light scattered by aerosols is represented by asymmetry parameter. Asymmetry parameter is higher for an aerosol size distribution consisting of larger particles; for example, asymmetry parameter is higher for maritime (coarse mode) aerosols when compared to continental/urban (fine mode) aerosols. Asymmetry parameter depends both on the size distribution and chemical composition of aerosols. Single scattering albedo and asymmetry parameter also vary as a function of relative humidity.

AOD is the most crucial parameter to study aerosol-climate interaction among the three, because aerosol radiative forcing changes due to increase in AODs overwhelm the forcing changes due to increases in SSA and asymmetry parameter (Ramachandran, 2005). The aerosol radiative forcing at the surface is linearly related to AODs. For the same AOD value when SSA is lower, the surface forcing is higher and the atmospheric forcing also becomes larger. In addition, the top of the atmosphere radiative forcing can become positive when aerosols of lower SSA exist over regions of higher surface albedo (continent, snow) (IPCC, 2007).

Natural aerosols (mineral dust and sea salt) dominate the aerosol mass concentration, while anthropogenic aerosols (water soluble and black carbon) dominate the aerosol optical depth. Black carbon aerosols contribute ~50% and 65% to the surface and atmospheric radiative forcing respectively, corroborating that black carbon aerosol is a strong contributor to global warming on regional scales (Ramachandran et al., 2012). The large positive atmospheric warming and negative surface forcing due to aerosols can impact the atmospheric stability and cloud formation in the tropics, and can lead to a weaker hydrological cycle (IPCC, 2007).

5. Aerosols - Remote sensing perspective: Large information on optical, physical and chemical characteristics of aerosols, and their evolution can be obtained from ground based and in situ measurements, however, they are usually restricted in time and space. Therefore, for an extensive period of observation and for global coverage, satellites are best suited. The SAM II (Stratospheric Aerosol Measurement II) experiment onboard NASA's NIMBUS 7 satellite launched in October 1978, the SAGE (Stratospheric Aerosol and Gas Experiment) onboard NASA AEM-2 satellite launched in February 1979, SAGE II launched in October 1984, and later SAGE III launched in December 2001 have provided an exhaustive and an important data set in the last four decades for the study of nonvolcanic, background and volcanically perturbed conditions, and the decay of stratospheric aerosols, connected throughout in time and space, on a global scale. The Improved Stratospheric and Mesospheric Sounder (ISAMS) onboard the Upper Atmospheric Research Satellite (UARS), was launched in September 1991 to study stratospheric aerosols. Columnar AOD retrievals began in the '90s with the Advanced Very High Resolution Radiometer (AVHRR) measured radiances. However, aerosol optical depth retrievals were restricted to one wavelength (630 nm) and oceans. The Total Ozone Mapping Satellite (TOMS) provided AOD in the UV spectral region.

Satellite observations of aerosols are playing an increasingly important role in climate studies. A variety of instruments and algorithms are available for aerosol remote sensing now. The newer instruments, more specifically designed for aerosol retrievals over both ocean and land, such as Polarization and Directionality of Earth's Reflectance (POLDER), Multi-angle Imaging Spectroradiometer (MISR), Ozone Monitoring Instrument (OMI) and

Moderate Resolution Imaging Spectroradiometer (MODIS), provide better measurements of aerosol optical depth at several wavelengths and size distribution information. MODIS sensors on board the Terra and Aqua satellites were launched in December 1999 and May 2002 respectively. The satellites operate at an altitude of 705 km with Terra spacecraft crossing the equator at about 1030 LST (ascending northward) while Aqua spacecraft crosses the equator at around 1330 LST (descending southward) (Remer et al., 2008).

AOD retrieved from MODIS exhibits significant seasonal and spatial variations (Figure 2). Biomass burning aerosol is significant over the Gulf of Guinea region during winter, which shifts to southern Africa during monsoon (IPCC, 2007). Transport of mineral dust from Africa to south America occurs during winter while mineral dust gets transported over west Indies and central America during monsoon (Figure 2).

The aerosol sources over India vary from natural (mineral dust and sea salt) to anthropogenic (industrial, vehicular and urban emissions). AODs are higher in monsoon when compared to post-monsoon over India (Figure 3). Aerosol characteristics can get modulated by winds, rainfall, relative humidity and long-range transport. For example, during winter over India the winds are calm, north/northeasterly and bring in fine mode particles from the northern hemisphere, while during pre-monsoon and monsoon the winds are stronger, come from the west and transport mineral dust and sea salt respectively.

6. Future Outlook: Aerosols are produced from natural processes and anthropogenic activities. Dust, sea salt and sulfate produced over the oceans dominate the natural global aerosol abundance, however, a fraction of dust in the atmosphere could be due to anthropogenic activities.

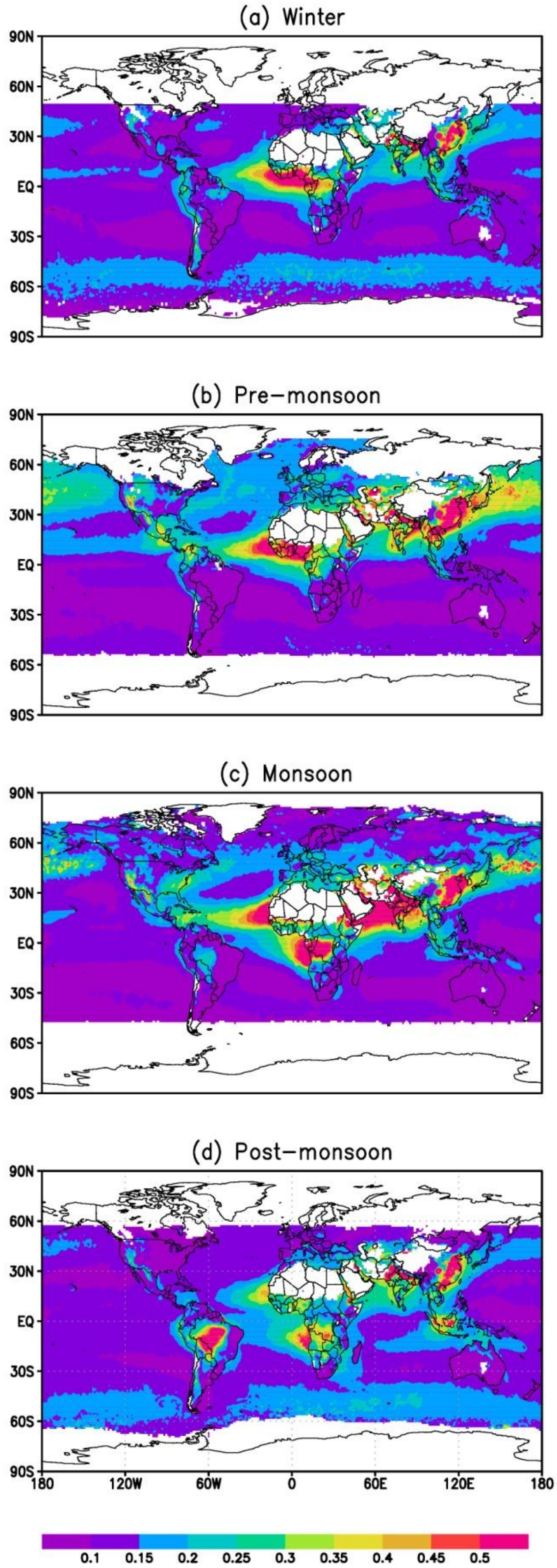


Figure 2. Global seasonal mean climatology (2001-2010) of MODIS Terra aerosol optical depth.

Similarly, smoke produced by natural burning (forest fires) is treated as natural component of biomass burning; while the burning of fuel wood, dung cake and crop waste burning are anthropogenic processes. Therefore, it is difficult to obtain an accurate estimate of natural/anthropogenic fraction of aerosols.

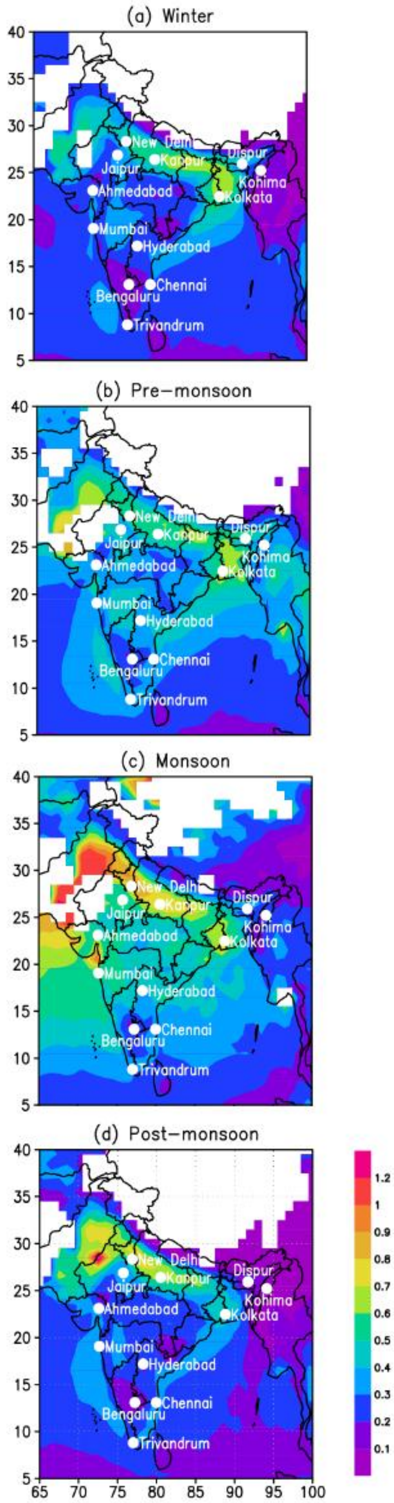


Figure 3. Mean climatology (2001-2010) of MODIS Terra aerosol optical depth over India in different seasons.

The uncertainty in direct and indirect radiative effects of aerosols arises due to the uncertainty or non-availability of spatial and temporal variation of aerosol size distribution, chemical composition, asymmetry parameter, state of aerosol mixing (whether the different aerosols are mixed externally, as core-shell or internally) and vertical profile. Thus, the challenges include delineating the anthropogenic fraction of aerosols from the natural counterpart, quantifying the spatio-temporal variations in aerosol radiative effects (direct and indirect), and aerosol-cloud interaction more accurately.

The Indian subcontinent apart from being a source region for aerosols, is bordered by densely populated and industrialized areas on the east and western sides from where different aerosol species are produced and transported, and is one of the regional aerosol hot spots. The Indian landmass comprises coastal regions, inland plains, semi arid regions, mountains and plateau regions, and experiences tropical and subtropical climatic conditions resulting in extreme temperatures, rainfall and relative humidity which modulate the aerosol characteristics.

The need of the hour, is to establish a network of aerosol observatories in India and the surrounding oceans, similar to the ISRO-Geosphere-Biosphere-Programme Aerosol Radiative Forcing over India (ARFI) (Moorthy et al., 2009), where in measurements of chemical composition, size, shape, mixing state of aerosols, and cloud parameters should be performed. In addition, satellite remote sensing of aerosol distribution, their chemical composition, microphysical properties of clouds, solar irradiance and terrestrial longwave radiation need to be performed using high-precision, multi-angle, and polarized measurements.

The results from these proposed studies will provide hitherto unavailable spatial and temporal distribution of aerosol morphology (size and shape), chemical composition (refractive index), optical depths, single scattering albedo, natural and anthropogenic fraction, and cloud parameters, all of which will result in an improved and a more reliable quantification of direct and indirect radiative effects of aerosols.

Conclusion: This article gives details about the sources and sinks of aerosols, how they influence the radiation budget, climate and contribute to climate change. The spatial and temporal heterogeneity in aerosol characteristics is outlined. The importance of satellite observations of aerosols is stressed. The challenges involved in more accurate quantification of the radiative effects of aerosols are highlighted. Suggestions for future studies which will enable to reduce the uncertainty in direct and indirect radiative effects of aerosols, and hence climate change have also been enlisted.

Acknowledgements: MODIS AOD data are downloaded from the GES-DISC, NASA. The author thanks Dr. Sumita Kedia, CDAC, Pune for her help in drawing the figures.

References:

- Intergovernmental Panel on Climate Change (IPCC), 2007: Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Solomon. S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor, H.L. Miller (eds.), Cambridge University Press, Cambridge, UK and New York, NY, USA, 2007, pp. 1-18, 2007.
- Moorthy, K.K., Babu, S.S., Satheesh, S.K., Lal, S., Sarin, M.M., Ramachandran, S. and Dutt, C.B.S., Climate implications of atmospheric aerosols and trace gases: Indian scenario, in Climate Sense, World Meteorological Organization (WMO), 157-160, 2009.
- Ramachandran, S., Premonsoon shortwave aerosol radiative forcings over the Arabian Sea and tropical Indian Ocean: Yearly and monthly mean variabilities, Journal of Geophysical Research, 110, D07207, doi:10.1029/2004JD005563, 2005.
- Ramachandran, S., Srivastava, R., Kedia, S., and Rajesh, T.A., Contribution of natural and anthropogenic aerosols to optical properties and radiative effects over an urban location, Environmental Research Letters, 7, 034028, 2012.
- Remer L. A., Kleidman, R. G., Levy, R. C., Kaufman, Y. J., Tanre D., Mattoo, S., Martins, J. V., Ichoku, C., Koren, I., Yu, H. and Holben, B. N., Global aerosol climatology from MODIS satellite sensors, Journal of Geophysical Research, 113, D14S07 doi:10.1029/2007JD009661, 2008.
- Whitby, K.T., The physical characteristics of sulphur aerosols, Atmospheric Environment, 12, 135-139, 1978.

Aerosol Radiative Forcing and Climate Change: Synergy of Ground Based and Space Borne Observations

S. Suresh Babu and K. Krishna Moorthy

Space Physics Laboratory, Vikram Sarabhai Space Centre, Trivandrum

Email: krishnamoorthy_k@vssc.gov.in and s_sureshbabu@vssc.gov.in

Introduction

During the past few decades, international concern has grown about human-caused (anthropogenic) climate change. Since the industrial revolution (1850), surface of the Earth has warmed by about 0.6 K reaching the highest level in the last millennium, which is attributed to a shift of less than 1% in the energy balance of the Earth-atmosphere system. Global estimates have shown that 10 of the 12 years of the current century have been consistently warmer than the long term average. The chief agents responsible for this are the anthropogenic greenhouse gases and aerosols (the ubiquitous suspensions of solid or liquid particles in air). The greenhouse gases reduce the emission of thermal radiation to space, thereby warming the surface, where as aerosols mainly reflect and absorb solar radiation (direct effect) and modify cloud properties (indirect effect), thereby perturbing the balance. While scattering aerosols and whiter clouds tend to cool the Earth and offset the greenhouse warming, aerosols such as black carbon absorb the incoming solar radiation and warm the atmosphere and cool the surface thereby adding to the greenhouse effect and reducing the atmosphere's vertical temperature gradient and thereby causing decline in evaporation and cloud formation. It has also been suggested that aerosols tend to reduce cloud droplet sizes, and hence precipitation. Thus the rain and snow may be shifted from highly polluted populated areas to the more pristine oceanic regions. Thus, the investigation of the spatio-temporal variation and long term trend in aerosol assumes great importance. This is especially so for aerosols, due to their large spatio-temporal heterogeneity and short life times. In this context, ISRO has taken a lead role in the study of aerosols and their radiative impacts over Indian region, both using space borne and ground-based network observations.

Aerosol Radiative Forcing over India: Systematic investigations of the physico-chemical properties of aerosols, their temporal and spatial heterogeneities, spectral characteristics, size distribution and modulation of their properties by regional mesoscale and synoptic meteorological processes have been initiated by ISRO in the early 1980s under the multi-agency funded, Indian Middle Atmosphere Programme (I-MAP). This modest beginning, networking a few selected locations, was fortified with a regional climate forcing focus, since the 1990s, under the Indian Space Research Organization's Geosphere Biosphere Program (ISRO-GBP). Under this several special aerosol observatories have been setup at distinct and remote locations over the land and the adjoining oceans, as well as thematic campaigns were carried out both over land and oceans to characterize some of the important properties of aerosols. Efforts were focused on measurements of newer parameters of aerosols, such as BC, and collect data from special environments or for special themes. Airborne measurements of vertical profiles were attempted and regional campaigns were conducted to examine specific questions pertinent to this region. Based on the outcome and recognizing the importance of aerosol radiative forcing on regional climate, the Aerosol Radiative Forcing over India (ARFI) project was formulated, under ISRO-GBP, with a long-term and regional perspective. Under this project, a regional network (ARFINET) of ~ 40 aerosol observatories spread over India [Figure-1; in which each circle represents one ARFINET observatory, superposed on the digital elevation map of India], has been established, which covers urban, remote, island, coastal, inland, semi-arid, arid, and remote mountain regions over the mainland and the adjoining oceanic regions. Systematic measurements of several climate sensitive parameters of aerosols are being measured from these stations regularly following a common protocol. ARFI aims at generating regional aerosol database, periodic radiative forcing maps and ultimately the regional climate impact of aerosols and its effect on global climate. In addition ARFINET data is widely used for the validation of satellite derived AOD data product over Indian region [Das et al., 2001; Vinoj et al., 2004].

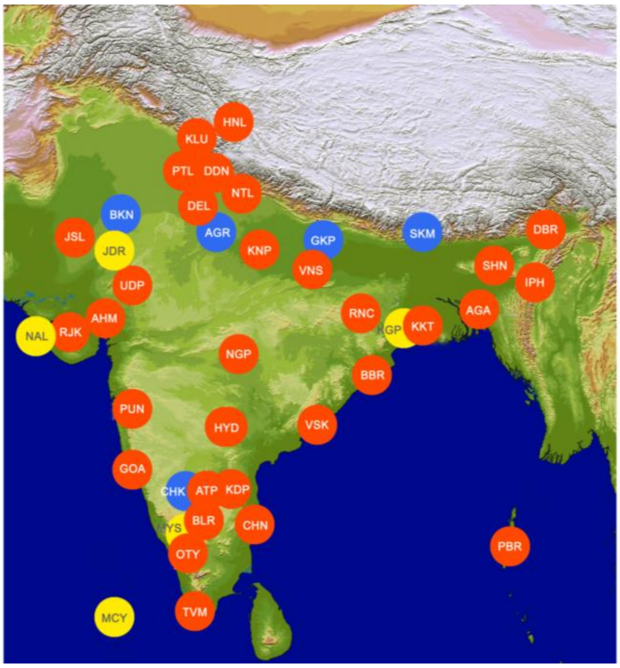


Figure-1:Spatial distribution of ARFINET observatories over Indian region

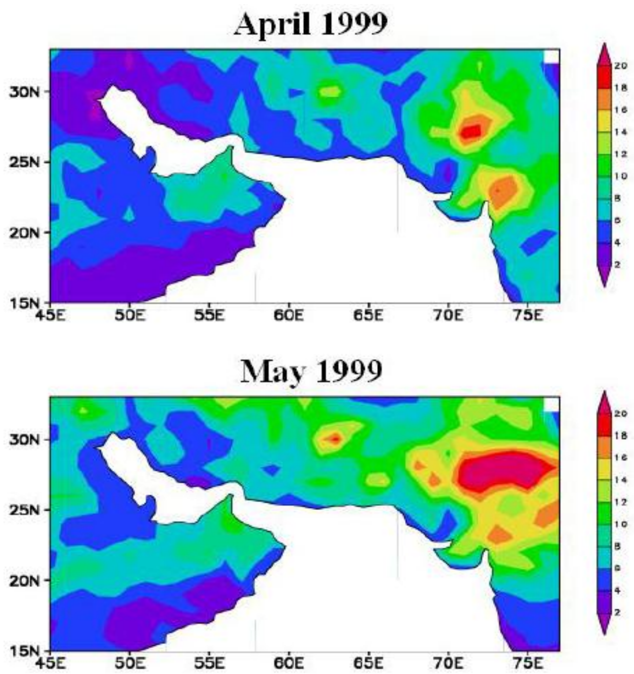
Aerosol observation from Space: In view of the large spatio-temporal variability of aerosols, satellite remote sensing delivers the most convenient way to characterize the aerosols on a global scale. With the advent of sophisticated satellite aerosol retrievals and satellite measurement of angular dependence of radiance and polarization at multiple wavelengths from UV through the infrared at good spectral resolution, retrieval of spectral values of AOD with some information about particle size has now become possible both over the land and ocean; though there still exist several concerns on the accuracies of the retrieved parameters over the landmass due to the large spatio-temporal variation of its spectral reflectance (Albedo). By improving the accuracy of aerosol products from satellites together with improvements in characterizing the earth's surface and clouds, the uncertainties associated with the global estimation of aerosol radiative forcing can be reduced. Using the retrieved aerosol microphysical properties such as size, absorption, and no-spherical fraction, the anthropogenic component of direct radiative forcing also can be estimated.

However the accuracy in the estimation of the indirect effect of aerosols from satellite is still much poorer due to the poor accuracy in the measurement of aerosol size distribution, characterization of aerosol type, account of impacts of water uptake on aerosol optical depth and determination of fraction of aerosols that is at the level of clouds. In addition, satellite remote sensing is not sensitive to particles much smaller than 0.1 μm in diameter, which normally acts as cloud condensation nuclei. The measurements of SSA and other microphysical properties of aerosols using existing space borne sensors are also difficult and do not exist, because the viewing geometry of the satellite restricts to the scattering of the tropospheric aerosols rather than extinction. Few attempts were made in this direction using multiple satellites and ground based measurements, but still uncertainties are beyond the acceptation level [*Satheesh et al.,* 2009].

The spatial and temporal distributions of aerosol optical depth has been examined making use of satellite instruments such as AVHRR [*Husar et al.,* 1997], METEOSAT [*Jankowiak and Tanré,* 1992], ATSR [*Veefkind et al.,* 1999], OCTS [*Nakajima et al.,* 1999], MODIS [*Remer et al.,* 2002], MISR [*Diner et al.,* 2002], POLDER [*Boucher and Tanré,* 2000]. Over the Indian region, AODs were retrieved over marine regions at 765 and 865 nm respectively using the data obtained from IRS P4-Ocean Color Monitor (OCM) [*Das et al.,* 2002; *Mishra et al.,* 2008; *Chauhan et al.*, 2009, *Menon et al.*, 2011].

The Clouds and the Earth's Radiant Energy System (CERES) which measures broadband solar and terrestrial radiances combined with satellite retrievals of aerosol optical depth can be used to determine aerosol direct radiative forcing. The measurements of aerosols absorption from space is highly challenging [*Kaufman et al.,* 2002] and TOMS and OMI instruments have the capability to detect partially absorbing aerosols over land and ocean but the retrievals are only semi-quantitative [*Hsu et al.,* 1999]. The active remote sensing sensors onboard CALIPSO has the capability to provide vertical distribution of aerosols up to the ground through the clouds of medium opacity [*Winker et al.,* 2007], whereas the earlier attempts using the limb scanning techniques onboard the SAGE were limited only to the upper troposphere and stratosphere [*Kent et al.,* 1995]. However, the optical properties retrieved from the CALIPSO are only qualitative [*Winker et al.,* 2007] and requires further validation and refinements. Most of these satellite sensors measure the AOD at more than one wavelength and this information is highly useful in constraining the models and establishing the relationship between physical and optical properties. Multi angle measurements in the MISR are the latest technological achievements to study the microphysical (eg: shape) properties of aerosols [*Kahn et al.,* 2005]. However, these measurements were less reliable over the highly reflecting land surfaces. To overcome this difficulty, measurements of the polarization of backscattered light are made onboard POLDAR to retrieve the AOD over land [*Herman et al.,* 1997]. Combining the merits of the above techniques, *Space Physics Laboratory, VSSC* has proposed a new satellite payload, AEROSAT (AEROsol SATellite), for multi-spectral, multi-angle and multi-polarization measurements from space [*Satheesh and Moorthy,* 2007] as a better tool for estimating the AOD over land.

Generally satellite sensors employ visible wavelength for the retrieval of aerosols. However, remote sensing of dust over land is very difficult with visible wavelengths because the land surfaces are highly variable in nature and are characterized by a wide range of reflectance. In addition, remote sensing in the visible wavelengths cannot discriminate dust properties from that of other aerosols. In this context, thermal infrared remote sensing is the best option for retrieval of aerosols [Legrand et al., 2001], which has the advantage that it can distinguish dust from other aerosol species. Thus the depression in the thermal IR radiance at the top of the atmosphere, detected by the satellite, resulting from the presence of dust layer known as Infrared Difference Dust Index (IDDI) is extensively used by the investigators in aerosol study.



Using synergy of ARFINET data and satellite infrared measurements, it is found that the absorption efficiency of dust is higher over Asia than over Africa [Moorthy et al., 2007]. The regional distribution of dust absorption efficiency over the desert region of India and Arabia is shown in Fig.2. Further, the dust absorption efficiency is found to be higher during winter when the dust is aged and mixed with soot, while the more nascent summer dust, has lower absorption efficiency.

Satellite Validation: Validations of satellite measurements are highly demanding because of the uncertainties in the retrieval algorithms [*Kaufman et al.,* 2002]. Inter-comparison and validation of satellite measurements with accurate in-situ measurements were carried out extensively during the last decade and uncertainty in AOD measurements at 550 nm using MODIS were reduced significantly over the ocean [*Remer et al.,* 2009]. Generally, satellite measurements of AOD over the ocean during the clear sky are reliable, while its spectral dependences are deviating from the in-situ observations, which demands further scientific attention. It is claimed that the satellite sensors such as the MODIS and MISR can retrieve AOD (τ) under cloud free conditions with an accuracy of ±0.05 ± 0.20τ over land and better than ±0.04 ± 0.1τ over ocean at mid-visible wavelength (Remer et al., 2005).

Over Indian region, ARFINET is playing a major role in the validation of satellite data products over distinct environments, besides providing accurate ground truths and primary data. Based on the extensive measurements of AOD from the ISRO- Laboratory for Aerosol Radiation and Chemistry (I-LARC) at Port Blair in Andaman islands and extensive cruise measurements over BoB, Vinoj et al., [2004] reported very good agreement between the MODIS derived AOD and ground based measurement with a mean difference of ~ 0.01 and root mean square difference of ~ 0.03. This agreement provided the first-time validation of MODIS data with ground based measurements over Oceanic regions adjoining India. Inter comparison of IRS P4 – OCM derived AOD over south eastern Arabian Sea with the ground based MWR derived AOD from the ARFINET station at Trivandrum (TVM) showed a good correlation of ~0.9 (Das et al., 2002). Chauhan et al (2009) reported a good correlation (R^2 ~0.89) and RMSE (16 %) between the IRS P4-OCM derived AOD and cruise based AOD measurements over Northern Arabian Sea.

Summary: Aerosols affect the regional climate directly by scattering and absorption of solar radiation and indirectly through the formation, sustenance and dissipation of clouds. Understanding the optical and microphysical properties of aerosols and its spatio-temporal variability over a region assumes utmost importance. Extensive measurements of these parameters over Indian region are being carried out under ARFI Project of ISRO-GBP by establishing a network of aerosol observatories (ARFINET) and by carrying out integrated field experiments. In addition, satellite data sets are also used extensively. The synergistic use of data from the ground based ARFINET with satellite data not only provided the excellent spatial coverage but also useful to derive new products such as dust absorption efficiency, three dimensional heating rate due to aerosols, as well as in the study of aerosol cloud interaction. In addition ARFINET data can be extensively used in the development of aerosol models for AOD retrieval from satellite over Indian region as well as for the validation of satellite AOD products over Indian region.

References:

- Boucher, O., and D. Tanré (2000), Estimation of the aerosol perturbation to the Earth's radiative budget over oceans using POLDER satellite aerosol retrievals, Geophys. Res. Lett., 27, 1103-1106.
- Chauhan, P., N. Sanwlani and R. R. Navalgund, Aerosol optical depth variability in the northern Arabian Sea during winter monsoon: a Study using in-situ and satellite measurements, Indian Journal of Marine Sciences, Vol 38(4), 390-396, 2009.
- Das, I., M. Mohan, K. K. Moorthy, Detection of marine aerosols with IRS P4-Ocean Colour Monitor , Proc. Indian Acad. Sci. (Earth Planet. Sci.), 111, No. 4, pp. 425-435, 2002.
- Diner, D., J. Beckert, G. Bothwell, and J. Rodriguez (2002), Performance of the MISR instrument during its first 20 months in Earth orbit, IEEE Trans. Geosci. Remote Sens., 40, 1449-1466.
- Herman, J., P. Bhartia, O. Torres, C. Hsu, C. Seftor, and E. Celarier (1997), Global distribution of UV-absorbing aerosols from Nimbus-7/TOMS data, J. Geophys. Res., 102, 16911-16922.
- Hsu, N.C., Herman, J.R., Torres, O., Holben, B.N., Tanre, D., Eck, T.F., Smirnov, A., Chatenet, B.,

Lavenu, F., 1999. Comparisons of the TOMS aerosol index with sunphotometer aerosol optical thickness: results and applications. J. Geophys. Res. 104, 6269–6279.

- Husar, R. B., J. Prospero, and L. L. Stowe, Characterization of tropospheric aerosols over the oceans with the NOAA-AVHRR aerosol optical thickness operational product, *J. Geophys. Res.*, *102*, 16,889–16,909, 1997.
- Jankowiak, I., and D. Tanre´ (1992), Satellite climatology of Saharan dust outbreaks: Method and preliminary results, J. Clim., 5, 646–656.
- Kahn, R. A., B. J. Gaitley, J. V. Martonchik, D. J. Diner, K. A. Crean, and B. Holben (2005), Multiangle imaging spectroradiometer (MISR) global aerosol optical depth validation based on 2 years of coincident aerosol robotic network (AERONET) observations, J. Geophys. Res., 110, D10S04, doi:10.1029/2004JD004706.
- Kaufman, Y. J., D. Tanré, and O. Boucher (2002), A satellite view of aerosols in the climate system, Nature, 419, doi:10.1038/nature01091.
- Kent, G. S., P. H. Wang, M. P. McCormick, and K. M. Skeens, 1995: Multiyear Stratospheric Aerosol and Gas Experiment- II measurements of upper-tropospheric aerosol characteristics. *J. Geophys. Res.,* 100, 13 875–13 899.
- Legrand, M., et al. (2001), Satellite detection of dust using the IR imagery of Meteosat 1. Infrared difference dust index, J. Geophys. Res., 106(D16), 18,251–18,274.
- Menon, H. B., Sangekar, N., Lotliker, A., Krishna Moorthy, K., and Vethamony, P., Aerosol optical thickness and spatial variability along coastal and offshore waters of the eastern Arabian Sea, ICES Journal of Marine Science, 68: 745–750, 2011.
- Mishra, A. K., Dadhwal, V. K., Dutt, C. B. S., Analysis of marine aerosol optical depth retrieved from IRS-P4 OCM sensor and comparison with the aerosol derived from SeaWiFS and MODIS sensor, *J. Earth Syst. Sci*, 117, pp. 361–373, 2008.
- Moorthy, K. K., S. S. Babu, S. K. Satheesh, J. Srinivasan, and C. B. S. Dutt (2007), Dust absorption over the ‘‘Great Indian Desert’’ inferred using ground-based and satellite remote sensing, J. Geophys. Res., 112, D09206, doi:10.1029/2006JD007690.
- Nakajima, T., A. Higurashi, K. Aoki, T. Endoh, H. Fukushima, M. Toratani, Y. Mitomi, B. G. Mitchell, and R. Frouin, Early phase analysis of OCTS radiance data for aerosol remote sensing, *IEEE Trans. Geosci. Remote Sens*., *37*(3), 1575–1585, 1999.
- Remer, L. A., et al. (2002), Validation of MODIS aerosol retrieval over ocean, Geophys. Res. Lett., 29(12), 8008, doi:10.1029/2001GL013204.
- Remer, L. A., M. Chin, P. DeCola, G. Feingold, R. Halthore, R. A. Kahn, P. K. Quinn, D. Rind, S. E. Schwartz, D. Streets, and H. Yu (2009), Executive Summary, in Atmospheric Aerosol Properties and Climate Impacts, A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. [Mian Chin, Ralph A. Kahn, and Stephen E. Schwartz (eds.)]. National Aeronautics and Space Administration, Washington, D.C., USA.
- Satheesh, S. K., and Moorthey K. K, Multi-angle polarization imager: A satellite sensor for studies of continental aerosols, Curr. Sci., 92, No. 2, (2007).
- Satheesh, S. K., O. Torres, L. A. Remer, S. S. Babu, V. Vinoj, T. F. Eck, R. G. Kleidman, and B. N. Holben (2009), Improved assessment of aerosol absorption using OMI-MODIS joint retrieval, J. Geophys. Res., 114, D05209, doi:10.1029/2008JD011024
- Satheesh, S. K., O. Torres, L. A. Remer, S. S. Babu, V. Vinoj, T. F. Eck, R. G. Kleidman, and B. N. Holben (2009), Improved assessment of aerosol

absorption using OMI-MODIS joint retrieval, J. Geophys. Res., 114, D05209, doi:10.1029/2008JD011024

- Veefkind, J. P., G. de Leeuw, P. A. Durkee, P. B. Russell, P. V. Hobbs, and J. M. Livingston (1999), Aerosol optical depth retrieval using ATSR-2 and AVHRR data during TARFOX, J. Geophys Res., 104, 2253–2260.

- Vinoj, V., S. S. Babu, S. K. Satheesh, K. K. Moorthy, and Y. J. Kaufman (2004), Radiative forcing by aerosols over the Bay of Bengal region derived from shipborne, island-based, and satellite (Moderate-Resolution Imaging Spectroradiometer) observations, J. Geophys. Res., 109, D05203, doi:10.1029/2003JD004329.

- Winker, D., W. H. Hunt, and M. J. McGill (2007), Initial performance assessment of CALIOP, Geophys. Res. Lett., 34, L19803, doi:10.1029/2007GL030135

Remote Sensing of Atmosphere and Oceans for Climate Change Studies

C.M. Kishtawal
Space Applications Centre, ISRO, Ahmedabad
E-mail: chandra_k@sac.isro.gov.in

The International Geophysical Year (IGY) in 1957/1958 saw the emergence of a new subject of research: ' Planet Earth '. For the first time, scientists sought to understand and analyze the Earth as a whole. It was also the first time that the oceans became the subject of international cooperation. By a coincidence, this was also the beginning of the space age: the first satellite was launched in 1957. From then on, they would be used to observe the whole of the Earth from space. It was a genuine revolution for the study of the earth-oceans-atmosphere system. Satellites, which are able to encompass the entire ocean-atmosphere system and can take continuous measurements over long periods of time, have made it possible to discover and analyze the complexity and variability of its structures on all spatial and temporal scales. Satellites make excellent tools for addressing the issue of climate change because they provide representative observations at large spatial extents, using either same or similar instruments during long period of time.

The oceans and the atmosphere are complexly linked to one another and are responsible for Earth's weather and climate. The oceans help to regulate temperature in the lower part of the atmosphere. The atmosphere is in large part responsible for the circulation of ocean water through waves and currents. Satellites have provided long-term global observations of ocean-atmosphere system that helped monitor and assess the nature and magnitude of climate change.

The following satellite observations of ocean-atmosphere system have been the focus of climate-change research during the recent past.

1. Sea Surface Temperature (SST)

Oceanic processes are at the heart of the climate change problem. Covering 71% of the earth's surface, the oceans directly absorb the majority of solar heat, retaining it for much longer periods of time than either the land or the atmosphere. So in effect, the seas work like vast reservoirs of heat. Energy stored in top two meters of ocean is equivalent to the energy contained in the entire atmosphere. So, any changes in ocean energy and the fraction of the energy that gets transferred to the atmosphere may have serious consequences on our climate. Global climate science community has always placed emphasis on accurate measurement of Sea Surface Temperature (SST) from space platforms. Since the 1980's most of the information about global SST has come from satellite observations.

Instruments like the Moderate Resolution Imaging Spectroradiometer (MODIS) onboard NASA’s Terra and Aqua satellites can gather more SST data in 3 months than all other combined SST measurements taken before the advent of satellites. The ocean and most other objects emit radiation in the infrared and the microwave wavelengths. The amplitude of these wavelengths vary with the temperature of the ocean and therefore can be used to measure it. Satellite sensors can measure these bands from space. Infrared radiation of the ocean comes from the top 10 microns of the surface. Microwave radiation results from the topmost 1-millimeter layer. India’s geostationary satellite INSAT-3D, equipped with a split-channel infrared imager, and scheduled to be launched in near future will provide accurate and continuous measurements of SST over the Indian Ocean region. Two global satellite SST datasets currently exist that are long enough for climate change detection.

The Advanced Very High Resolution Radiometers (AVHRRs) have been operating on board National Oceanic and Atmospheric Administration (NOAA) polar-orbiting satellites since 1981, providing a continuous source of SSTs.

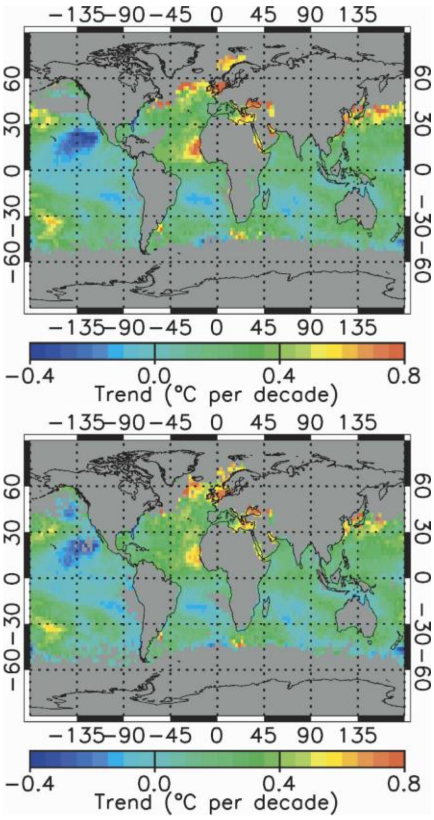


Fig 1. Trends of satellite derived SST past during past 34 years.

The Along-Track Scanning Radiometer (ATSR) series has spanned three instruments: ATSR-1 and -2 on *European Remote Sensing Satellite-1* (*ERS-1)* and *-2*, and Advanced ATSR on *Envisat*, with the data record beginning in 1991. SST observed by microwave instrument TRMM Microwave Imager (TMI), and Advance Microwave Scanning Radiometer (AMSR) is considered to be more accurate than AVHRR based measurements, but these observations are available only since 1998. Despite their short span, satellite observations could reveal the trends of global oceanic warming across the globe. Analysis of satellite observations suggest that the highest increases in SST were situated in the northwest Atlantic, the northwest and southwest Pacific, and in areas to the south of Africa and to the west of Australia. Negative trends were also found in the mid- and northeast Pacific and at the lowest latitudes.

2. Tropical Cyclones

How the changes in SST impact the weather over the globe? It is difficult to measure small changes in day-to-day weather. Severe weather events like tropical cyclones have recently gained attention of climate change scientists. Contrary to normal weather, the occurrence of the cyclones is monitored very carefully by meteorological centers across the globe, and a good enough record of frequency, duration and intensity of tropical cyclones exists for over 100 year period. If there is a noticeable change in tropical cyclone occurrences, or intensity, it can be considered an important indicator of changing atmospheric state. Theoretical analysis suggests that with every 1^{o} C rise in SST, the cyclone intensity increases by 4-5%, but some researchers are skeptical about whether such small trends can be detectable at all. The long term impact of enhanced SST on the number and severity of tropical cyclones has been a highly debated topic of research. Some studies reported a significant increase in TCs' power dissipation index during the past 50 years over the Atlantic and West Pacific basins, while another study noted substantial century-scale increases in Atlantic tropical cyclone frequency and attributed some of this increase to anthropogenic forcing. On the other hand, many researchers doubt the validity of such changes in cyclone behavior, and question the quality of the past cyclone observations itself.

Before the satellite era, many cyclones went un-noticed, or, were under/over estimated for intensity. It is only after the year 1986 that globally uniform observations of cyclones were available from satellite platforms. This dataset of cyclones during "satellite-era" is valuable for the climate-change perspective. Recently, the analysis of this "satellite-era" dataset has revealed that the tropical cyclones are reaching to peak intensity about 10 hours earlier now compared to 25 years earlier. Over the Atlantic basin, where largest warming trends were detected in satellite-based SST observations, cyclones intensity to peak level, almost 24 hours earlier. This is a significant climate-change signal that has been detected exclusively based on satellite data.

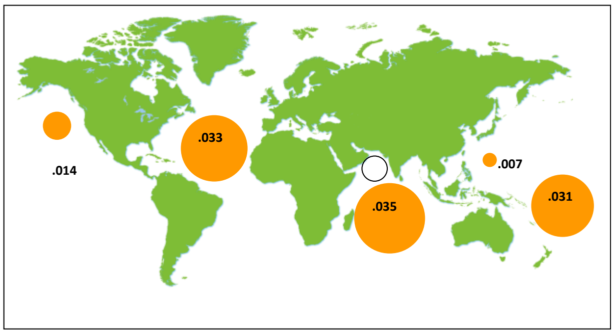


Fig. 2: Trends of tropical cyclone intensification (kt/hour/year) based on satellite data for past 25 years. There were not many cases over the Indian Ocean to make a meaningful statistical analysis.

3. Water Vapour and Clouds

Water vapour is the largest single Greenhouse gas. It also forms an important link between the land and the ocean, it is a carrying mechanism transporting energy around the globe and is therefore a major driver of weather patterns. Violent tropical cyclones are powered by evaporation from tropical oceans. However water vapour concentration varies strongly in space and time across the planet. Only space-based monitoring can measure water vapour concentrations on a global basis, either measuring vertical columns of water vapour or assessing atmospheric humidity through a cross section of the atmosphere. Geostationary satellites like KALPANA, INSAT-3D, GOES, Meteosat, GMS etc consist of imaging instruments to measure water vapor at high temporal sampling. Polar orbiting satellites like MODIS, NOAA, Metop etc. provide high-resolution measurements of global water vapor albeit with smaller temporal sampling. Microwave radiometers like TMI, SSM/I, MSMR and AMSR provide highly accurate observations of vertically integrated water vapor amounts over the ocean surfaces. These observations help to address the following key climate science questions (a) Is there any noticeable change in global atmospheric water vapor as a consequence of global warming? (b) What is the nature of radiative feedback of these changes. For example, an increase in water vapor concentration would result in additional greenhouse warming. But, if the increased water vapor is converted to low and mid level clouds, the greenhouse warming is more than offset by radiative cooling by low and mid level clouds. On the contrary, if the excess water vapor is pumped to upper tropospheric levels, it would result in additional warming, because upper level clouds trap more radiation than they emit. So, small changes in vertical distribution of water vapor can set the radiative feedbacks in significantly different directions. Present generation hyperspectral satellite sounders like AIRS, and IASI provide observations of minute variations of the changes in water vapor at different vertical levels. These measurements are crucial to reduce the uncertainty associated with water vapour-radiation feedback process.

4. Outgoing Longwave Radiation (OLR)

Outgoing longwave radiation (OLR, the emitted radiation in 2-100 µm spectral band) at the top of the atmosphere (TOA) is a barometer of interactions of the surface and atmosphere due to the changes in temperature, cloud, and humidity in response to the incoming solar radiation, and the anthropogenic forcings caused by the increase in greenhouse gases. It provides a useful metric to evaluate the reliability and consistency of climate feedback processes depicted in climate models. "Climatic Sensitivity" is the term used to assess the magnitude of global response (e.g. warming) to external radiative forcings (e.g. emissions by greenhouse gases, changes in solar radiation etc). Present day climate models show large inter-model differences in the climatic sensitivity, and this leads to a large uncertainty about the nature of global change predicted by these models. The most important factor behind these discrepancies is the way these models treat cloud formation and cloud radiative process in their computations. Current generation climate models also exhibit significant biases in tropospheric temperature and humidity compared to satellite observations. Since the clear-sky OLR is highly sensitive to temperature and atmospheric water vapor (and also anthropogenic greenhouse gases and aerosols), it is useful to evaluate the sensitivity of clear-sky OLR to changes in temperature and water vapor arising from different sources of observable climate variability. Observations of OLR by satellites not only help in identification of shortcomings in model physics, but also serve as an independent data for assessing the climate change.

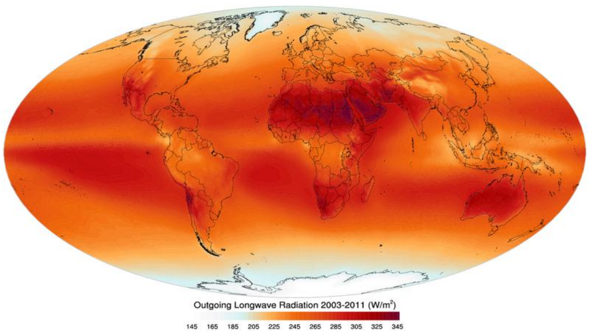


Fig. 3 Mean OLR from 2003-2010 period

Ideally, the broadband sensors like CERES (onboard satellites TRMM, Aqua, Terra and NPP) are deployed for measuring the OLR for climate studies. Alternately, other satellite observations like radiances from thermal infrared and water vapor channels are used to derive OLR with adequate accuracy (< 1% of mean OLR). This approach is used to retrieve OLR using observations from KALPANA, and INSAT-3D, and other geostationary and polar orbiting satellites. Long term variations of OLR not only provide information on the radiative balance of our planet, but also give important clues about the way the circulation of the atmosphere is getting modified. For example, clouds are identified by low OLR values of OLR in satellite observations. These clouds are formed when low level winds converge and pump the moisture at upper levels where it gets condensed to form clouds. The clouds formation processes are also affected by atmospheric stability defined by the thermal structure of the atmosphere. Fig. 4 shows that during past 33 years, the OLR has been reducing over most of the tropical region, particularly the west Pacific ocean, and the Indian monsoon region, indicating intensification of cloud formation over these regions. These trends hint at the intensification of atmospheric overturning circulation (known as Hadley circulation) or the reduction of atmospheric stability or both. Such trends in cloud formation process may have significant implications of global and regional water balance.

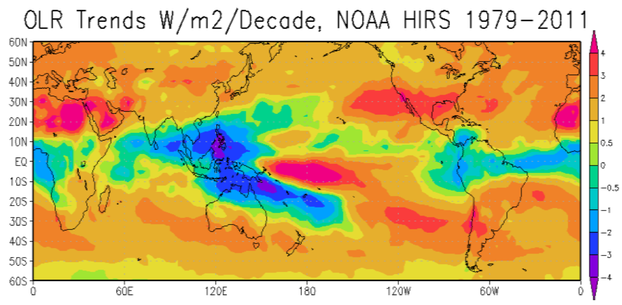


Fig. 4 Linear trends in satellite derived OLR from past 33 years.

5. Winds

Winds over the ocean modulate air-sea changes in heat, moisture, gases and particulates, regulating the crucial bond between atmosphere and ocean that establishes and maintains global and regional climate. Measurements of surface wind velocity can be used in regional and global numerical weather models to improve our ability to predict weather. As the only remote-sensing system to provide accurate, frequent, high-resolution measurements of ocean surface wind velocities, under all weather conditions, scatterometers play an increasingly important role in oceanographic, meteorological and climatic studies. QuikScat, NSCAT, SeaWinds and OSCAT are fine examples of scatterometers that provided wealth of information about the ocean surface winds. On the other hand, passive microwave radiometers viz. SSM/I, TMI, MSMR and MADRAS provide very accurate measurements of ocean surface wind speeds (not direction). Valuable information of atmospheric winds are also obtained routinely by tracking the motion of cloud and water vapor tracers in geostationary satellite images. These winds contribute to a significant portion of information that satellites provide to numerical models.

The magnitude of the volume of satellite observations is likely to increase by approximately 1000 times during the next decade. This is a challenge for atmospheric scientists to analyze such large amount of information and extract meaningful climatic signals from them. Another challenge will be to use this information for day-to-day monitoring and prediction of weather events. Interestingly, 95% of input for today's weather prediction models comes from satellite observations, still this information is just 5% of what satellites observe. There is a huge gap between what satellites observe and how much of that we are able to use. Discovering innovative ways and techniques for more effective use of satellite observations is definitely a challenge for scientists of present generation.

Call for Articles

Readers are requested to contribute short articles for publication in the forthcoming issue of *Signatures,* related to the specific theme ***"Remote Sensing Data Products & Retrieval Algorithms"***.

The deadline for inclusion in the next issue is **May 31, 2013.**

\- Editorial Team

Satellite based Measurement of Atmospheric Carbon Dioxide

R.P.Singh[1]*, Prabunath Prasad[2], Shantanu Rastogi[2] and S. Panigrahy[1]

[1]Space Applications Centre (ISRO), Ahmedabad

[2]DDU Gorakhpur University, Gorakhpur

Email: *rpsingh@sac.isro.gov.in

Introduction

Inter annual increase in concentration of carbon dioxide (CO_2) in atmosphere is an important indicator of human induced climate change. This paper reports the physical basis, present status and future trend of measurements of trace gases using high spectral resolution spectrometers on space platform. The present knowledge about spatial and temporal patterns of sources and sinks of CO_2 are due to inverse modeling of the in-situ measurements of a highly accurate but rather sparse global network of surface stations (NOAA-CMDL). The coherent indigenous network for long-term surface observations of trace gases is under initial stage in India. One such long term data set of atmospheric CO_2 is available from published (ISLSCP II Global view data) flask measured values (Fig. 1) over Caperama station (15.08 N, 73.83 E), Goa, India (http://islscp2.sesda.com). Retrieval of the amount and distribution of trace gases from space-based remote sensing instruments has the potential to overcome the limitations of the surface network.

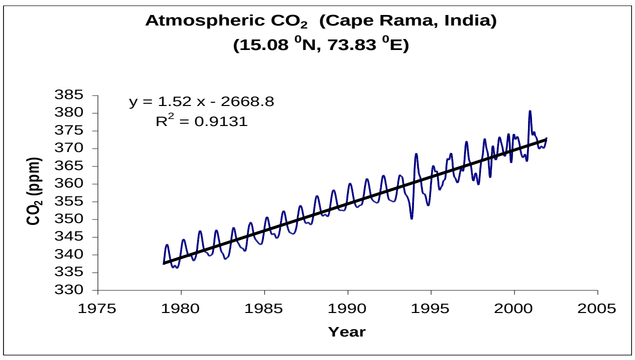


Figure 1. Atmospheric CO2 variability and its seasonal cycle observed/modeled over Cape Rama, India.

The observations of atmospheric CO_2 from instruments on board satellites having sufficient spatial and temporal resolution are only independent approach for reliable global prediction of the future trends in carbon balance.

Physical Basis of CO_2 Detection

Instrumentation aboard satellite platform has been successfully used to measure the atmospheric GHG concentration. There are two distinct approaches, generally used in assessing the amount of GHG in atmosphere. The first approach uses the back scattered and reflected sun light from atmosphere in very high spectral resolution (< 1 nm) channels in the NIR absorption region of the gaseous molecules (SCIAMACHY, GOSAT, OCO etc.). The second approach is based upon the very high spectral resolution passive radiometric principle. The space-borne radiometer detects emission signal of atmosphere in the gaseous absorption Thermal Infra Red (TIR) region (EOS-AIRS). Lasers can also be used to detect trace gases by illuminating the scene and receiving the absorbed signal in the gaseous absorption band. The Differential Optical Absorption Spectroscopy (DOAS) approach is used to estimate the concentration. The classical DOAS approach uses the Lambert - Beer law to obtain a linear system of equation where the column density to be retrieved is directly proportional to the measured differential optical density (τ).

The Intensity of light received in a given frequency $I(\nu)$ is given by:

$$I(\nu) = I_0(\nu)\exp(-\int \sigma(\nu, p, T)c(s)ds)$$

$$\tau = \ln(\frac{I_0(\nu)}{I(\nu)}) \approx \sigma(\nu, \overline{p}, \overline{T}) \int c(s)ds$$

$$= \sigma(\nu, \bar{p}, \bar{T}) S$$

where $I_0(\nu)$ is incident intensity of light, $\sigma(\nu, p, T)$ is absorption cross section which is a function of frequency (ν), pressure (p) and temperature (T). S denotes the slant column density which is defined as the path integral of the concentration of the respective absorber (c (s)) along the actual light path (ds). Figure 2 shows, how the atmospheric transmittance decreases with increase in CO_2 concentration near 1600 nm SWIR absorption band. These spectra were simulated using PCLnWin3.1 line by line code using HITRAN database in tropical atmospheric condition.

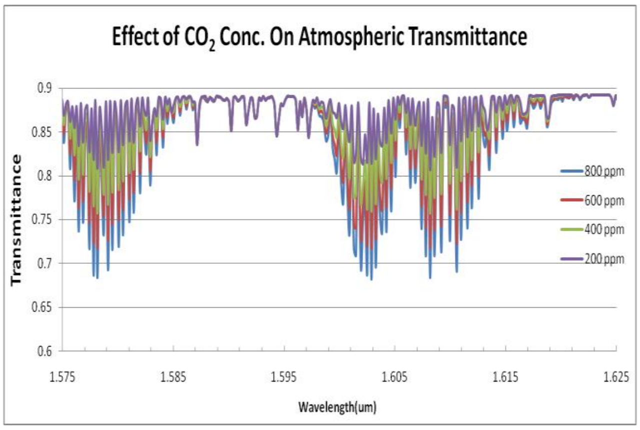


Figure 2. The Simulated spectra of atmospheric transmittance at varying concentration of CO_2 concentration.

Present Satellite Systems

Measurement of CO_2 from space is comparatively a new research area (in comparison to other trace gases such as ozone) and only a few relevant studies exist. Chedin et al. (2003) have reported initial findings of global mid-tropospheric CO_2 concentration in the tropical region (20^0N-20^0S) derived from NOAA-10/TOVS observations. Presently retrieval of CO_2 has been carried out using ENVISAT-SCIAMACHY, EOS-AIRS and GOSAT-TANSO FTS data. Table 1 provides the details of sensor specifications for important missions related with CO_2 estimation.

ENVISAT-SCIAMACHY: SCIAMACHY is an imaging spectrometer whose primary mission objective is to perform global measurements of trace gases in the troposphere and in the stratosphere. The solar radiation transmitted, backscattered and reflected from the atmosphere is recorded at relatively high resolution (0.2 nm to 0.5 nm) over the range 0.24 µm to 1.7 µm, and in selected regions between 2.0 µm and 2.4 µm. The high resolution and the wide wavelength range make it possible to detect many different trace gases despite low concentrations.

GOSAT-TANSO-FTS: The Greenhouse gases Observing SATellite is the only present satellite mission fully dedicated to measuring CO_2 and CH_4, for the benefit of climate science. GOSAT is a sun-synchronous satellite with two instruments: The Thermal and Near infrared Sensor for carbon Observation-Fourier Transform Spectrometer (TANSO-FTS) and TANSO-Cloud and Aerosol Imager (TANSO-CAI). TANSO-FTS observes visible and Short Wave Infra Red (SWIR) radiation of the sun reflected by Earth's atmosphere and surface as well as the Thermal Infra Red (TIR) radiation from the ground and atmosphere. TANSO-FTS is an instrument based on the principle of a Michelson interferometer.

EOS-AQUA AIRS: The Atmospheric Infrared Sounder (AIRS) instrument measures 2378 high spectral resolution infrared radiances between 650 and 2665 cm-1 with resolving power of 1200 and nadir spatial resolution of 13 km. AIRS is launched in EOS-Aqua spacecraft and takes continuous global measurements twice each day in a sun synchronous orbit (1:30 am, 1:30 pm) from 705 km altitude. AIRS primarily aimed to improve operational weather forecasting. Spectral channel 791.7 cm-1 which has high sensitivity to CO_2 and low sensitivity to temperature is useful in estimation of CO_2 concentration.

Indian Experience

Regional distribution as well as seasonal/inter-annual variability of atmospheric carbon dioxide over India is reported using measurements from ENVISAT-SCIAMACHY, AIRS and GOSAT data. It was observed from SCIAMACHY measurements that vegetated region such as forests of Himalaya and Western Ghats were associated with relatively low CO_2 concentration (~350 ppm) as compared to arid region of Rajasthan (~ 375 ppm). Spatial and seasonal variability of the CO_2 derived using SCIAMACHY data (fig. 2) for three years (2003-2005) and AIRS data (2003-2010) showed increasing trend (Fig. 3) with seasonal cycle also known as the Keeling curve. Spatial variability of average atmospheric CO_2 concentration estimated using GOSAT data is shown in Fig. 4. Western parts of India (Rajasthan) show relatively higher concentration in comparison to other regions (J& K). It can be seen that parts of Arabian Sea shows relatively high concentration as compared to Tibetan Plateau

Table 1. Important missions related with carbon dioxide measurements

Sensors	Agency	Spectral Range	Spectral resolution	Spatial resolution	Target gases	Remarks
ENVISAT-SCIAMACHY	ESA	214-334 nm 300-412 nm 383-412 nm 593-812 nm 773-1063 nm 971-1773 nm 1934-2044 nm 2259-2386 nm	0.24 nm 0.26 nm 0.44 nm 0.48 nm 0.54 nm 1.48 nm 0.22 nm 0.26 nm	30 km	O3, $H_2$0 CH_4, NO, NO_2, NO_3, ClO, SO_2, BRO, HCHO, CO, CO_2, O_2	Launched in March 2002. Grating based spectrometer
GOSAT-FTS	JAXA	Vis.12900-13200 cm-1 SWIR. 5800-6400 cm-1 SWIR-2 4800-5200 cm-1 TIR 700 – 1800 cm-1	0.2 cm-1 0.2 cm-1 0.2 cm-1 0.2 cm-1	10 km	CO_2 and CH_4	Launched in Jan. 2009. Fourier Transform Spectrometer
EOS-AQUA-AIRS	NASA	650- 2665 cm-1 (2378 channels)	Resolving power=1200	13 km	CO_2	Instrument operational in Sept 2002 and mainly aimed for atmospheric sounding of temp. and Humidity.
OCO-2	NASA	760 nm 1610 nm 2060 nm	Resolving power=21000	10 km/1 km	CO_2	Proposed Mission for dedicated CO2 retrieval. High Resolution Grating based spectrometer

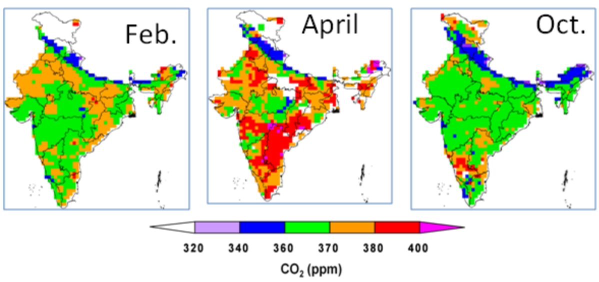


Figure 2. Average monthly CO_2 concentration (in ppm) in Feb., April and Oct. during 2003-05 over India using SCIAMACHY data.

Future Trends

Presently available CO_2 measurement operational missions such as SCIAMACHY and GOSAT have proven their potential in addressing the concept and application. SCIAMACHY relies on detection in SWIR spectrum whereas GOSAT uses both SWIR and Thermal region to measure the CO_2 concentration. These missions are going through validation and need further improvements to address the complete issues of climate change. All the major space agencies (NASA, JAXA, ESA, CNES and ISRO) have plans to develop and launch CO_2 mission in future.

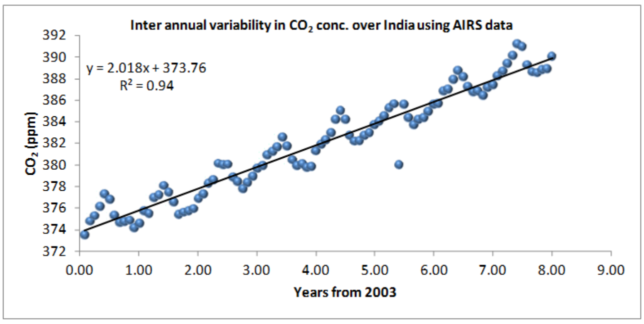


Figure 3. Measurements of average atmospheric CO_2 concentration over India using AIRS data

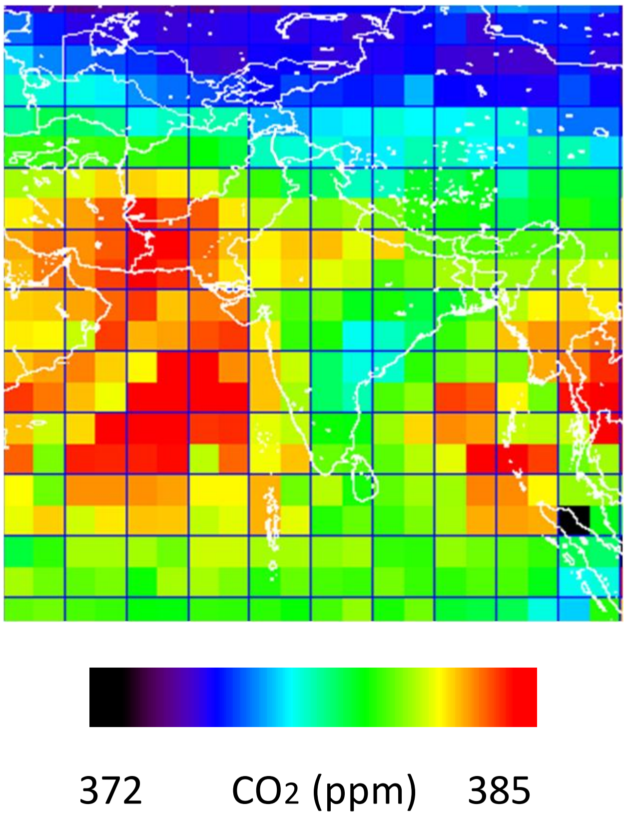


Figure 4. Spatial variability of average atmospheric CO_2 concentration during 2010 over India estimated using GOSAT data.

The important future mission based on detection of reflected sun light in SWIR spectrum include Orbiting Carbon Observatory (OCO) of NASA , MicroCarb of CNES, GOSAT-2/3 of JAXA, ENVSAT-1 mission of India. Passive systems which rely on reflected sunlight are limited by variable sensitivity at different solar illumination angles and sun glints. Thermal infrared emission sounders are capable of making global day-night observations independent of solar illumination; however, their measurements are most sensitive to CO_2 in the mid- to upper-troposphere. An active remote sensing mission (LIDAR) allows measurements to be taken day and night, over ocean and land surfaces. Active CO_2 remote sensing enables enhanced sensitivity to CO_2 in the lower troposphere, where its atmospheric concentration shows the most response to surface fluxes. Looking at limitation of passive sensing, LIDAR based system has been proposed as second generation of dedicated CO_2 mission. Two important future LIDAR missions are ASCENDS from NASA and A-SCOPE from ESA. Brief description of important future missions is as follows.

Orbiting Carbon Observatory (OCO): OCO mission of NASA would measure CO_2 (1.6um , 2.0um) and O_2 (0.76 um) spectral radiances via passive near infrared grating spectroscopy, to provide column-averaged CO_2 dry air mole fraction, XCO_2, with the precision (0.3 %). Its temporal and spatial resolution (10 km/1 km) and coverage are designed to characterize the variability of CO_2 sources and sinks on regional spatial scales. OCO carries a single instrument designed to make co-boresighted spectroscopic measurements of reflected sunlight in near-infrared CO_2 and molecular oxygen (O_2) bands. OCO will fly in formation with the A-train to enable correlation of Earth observations with instruments onboard other A-train satellites, particularly AIRS.

MicroCarb: It is a proposed CNES mission related with CO_2 detection. It is based on the concept of Static fourier transform interferometry. The Static Fourier Transform Interferometer concept consists in a multitude of Michelson interferometers in parallel, each presenting a fixed and specific path difference. Advantage of static interferometry is that, it does not have moving mirrors and can achieve very high spectral resolution. MicroCarb mission also aims to use 0.76 um, 1.6um and 2.0um spectral channels for CO_2 detection as legacy followed by GOSAT, SCIAMACHY.

A-SCOPE (Advanced Space Carbon and Climate Observation of Planet Earth): ASCOPE is a proposed LIDAR mission of ESA's Living Planet Programme. It aims at observing atmospheric carbon dioxide (CO_2) for a better understanding of the carbon cycle. A-SCOPE mission is advanced concept to observe the Earth from space based on a Differential Absorption LIDAR. LIDAR will operate in 1572 nm and 2051 nm wavelength with 50 and 55 mJ Laser Pulse Energy respectively. A-SCOPE will follow a near-polar sun-synchronized orbit with 6 hours local time descending node, at a relatively low reference altitude in the range of 325 to 400 km. The low altitude has been chosen to improve the LIDAR radiometric budget. Dawn-dusk orbit would provide a stable thermal environment and low Earth reflected Sun background light.

ASCENDS Mission: The NASA Active Sensing of CO_2 Emissions over Nights, Days, and Seasons (ASCENDS) mission is considered as technological next step of NASA Orbiting Carbon Observatory (OCO). ASCENDS mission enhances CO_2 remote sensing capability to include uninterrupted/all-season coverage of high-latitude regions and night time observations with sensitivity in the lower atmosphere. ASCENDS consists of a nadir-viewing Laser Absorption Spectrometer (LAS) system (1.57 um / 2.06 um) and a passive sounder suite. The LAS system is comprised of a CO_2 and O_2 LAS integrated with a pseudo noise encoded altimeter sharing a common telescope. This system would provide simultaneous measurements of column CO_2 and O_2. A passive sounder suite would provide temperature profiles, CO column and profile measurement, and visible imagery to enable cloud detection.

High Spatial and Temporal Resolution Precipitation measurements from Kalpana for Hydrological, Meteorological and Climatological Applications

Atul Kumar Varma
Space Applications Centre, ISRO, Ahmedabad
E mail: avarma@sac.isro.gov.in

1. Introduction

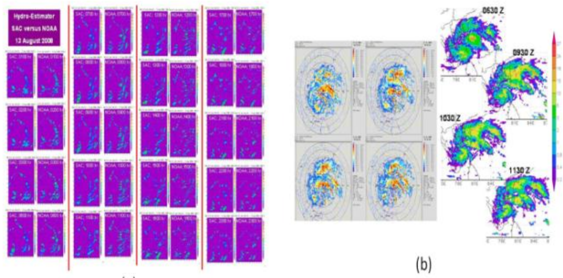
Precipitation is one of the best indicators of the climate change. Any change in the climate may induce direct changes in the precipitation intensity, amount and shifting of the precipitation patterns in both spatial and temporal domains. In order to have a meaningful study of the climatic behaviors, continuous monitoring of the precipitation at the global scale is desired. The most convenient means to measure the precipitation over the large area is possible only by using the satellite-based observations that offer frequent and uniform coverage. However, the satellite measurements suffer from large errors resulting from their well known scientific limitations. While Visible/IR methods suffer from their inability to sense hydrometeors directly (Barrett and martin, 1981, Bhandari and Varma, 1995), microwave measurements suffer due to so called beam filling problem, and uncertainty in the drop-size distribution, drop temperature, fall velocity and shape and orientation of the hydrometeors, etc. (Varma et al, 2003, 2004 and Varma and Liu, 2006, 2010, Varma and Pal, 2012). The clouds are opaque at IR wavelengths and thus allow measurement of only cloud top brightness temperature (CTT) which is not very strongly related to the rain falling below the clouds. Such indirect and weak relationship between CTT and surface rain always leads to the poorer estimations of rainfall. Thus any rain algorithm based on cloud top brightness temperature alone suffers from large errors, especially those resulting due to rain from the warm clouds which contribute up to 20% rainy area over oceans and 7.5% over land (Liu and Zipser, 2009). Despite of the known deficiencies in the measurements, the errors associated with them are difficult to be precisely quantified because the precipitation is a scale-dependent, highly variable and discontinuous process that poses unresolved challenges to its accurate validation (Piyush et al., 2012).

In order to overcome the problem of indirect measurement of precipitation using thermal IR measurements, various researchers have suggested blending of IR measurements with ancillary knowledge/observations. The Scofield (1987) provided a scheme for instantaneous precipitation estimation and outlooks for next 30 minutes called IFFA (Interactive Flash Flood Analyzer). Their scheme was successful but required experience and skill of a trained meteorologist who calculated the precipitation estimates. In order to automate IFFA, Vicente et al. (1998) proposed a new scheme called Auto-Estimator (A-E). The A-E method often produced false rain from cirrus clouds. In order to further improve the A-E method, Scofield and Koligowaski (2003) proposed further modifications to A-E called Hydro-Estimator (H-E). The work presented herein is based on H-E that blends the IR CTT with other environmental parameters from Numerical Weather Prediction (NWP) and atmospheric thermodynamic models and surface elevation model to estimate instantaneous precipitation rate at every pixel location. The basic difference in H-E at NOAA and SAC is that at NOAA it is coded in MaCIDAS (Man-Computer Interactive Data Assessment System) whereas in SAC required MaCIDAS features are coded in Fortran for its easy portability. Apart from that different models/schemes and NWP datasets are used for producing the warm cloud-top correction, topography, dry-tropospheric corrections, etc. At Space Application Centre, the Hydro-Estimator is one of the three precipitation estimation schemes that are developed for the operational use. The basic difference between H-E and other schemes is that unlike the H-E the other schemes uses cloud top temperature alone to estimate rain at a coarser resolution.

2. Data and Estimation Method

The H-E uses thermal infrared (IR) band observations from Very High Resolution Radiometer (VHRR) onboard Kalpana satellite. The study utilizes 6 hourly, $1^{o}x1^{o}$ grided NCEP NWP model derived fields of total precipitable water (TPW), 850 mb wind (u and v components) and vertical profiles of relative humidity (RH) and environmental temperature. The study also utilizes 2'x2' surface elevation model that is obtained from National Geophysical Data Centre (NGDC), NOAA (USA), and which is popularly known as ETOPO2.

In IR based precipitation estimation methods, the cirrus clouds that produce low CCT are inadvertently considered as raining. In H-E method the cirrus rain was avoided by considering the pixel under consideration with respect to its neighborhood pixels. The pixels that are sufficiently cooler than the mean surrounding temperature are marked as raining. In H-E method, convective and non-convective cores are identified and different R-Tb relationships are provided for them. This allows higher precipitation rates for the convective cores. The R-Tb relationship is dynamic in nature with different coefficients at each pixel depending upon available Precipitable Water (PW) at that pixel. The precipitation at a pixel is allowed to be combination of both convective and non-convective core. The precipitation thus estimated is further modified to account for the wetness/dryness of the atmosphere and also for the precipitation that comes from the warm clouds at such locations where level of neutral buoyancy (LNB) in the environment as given by the atmospheric thermodynamic model lies in lower levels. Further corrections are carried out for orographic rain using a technique developed by Joyce et al. (2001) which primarily utilizes gradient of surface slopes along the 850 mb wind direction



(a) (b)

Fig.1: (a) Qualitative comparison of pixel-scale, hourly rain measurements from Kalpana by SAC and from Meteosat by NOAA. (b) Qualitative comparison of pixel-scale, hourly rain measurements from Kalpana by SAC and surface radar observations. The Radar images are taken from Indian Meteorology Department report on cyclonic disturbances over North Indian Ocean during 2008 (Anonymous, 2009).

The Fig.1 (a) and (b) show the qualitative comparison of hourly pixel-scale precipitation using Kalpana VHRR data by us and NOAA, and with surface radar during a cyclonic storm, Nisha. The two measurements seem to be in good agreement. The minor discrepancies in Fig. 1 (a) are expected because of different NWP model fields used at SAC and NOAA. Figure 2 shows intense precipitation over Rajasthan on 21 August 2012 at 2130 Z which resulted in flash flood and associated loss of lives and property.

As the Hydro-Estimator precipitation is produced at high spatial resolution (at every pixel) and at every 30 minutes, it can be used for providing warning for the occurrence of the intense rain that may potentially lead to flash flood. Thus a report on the occurrence of intense precipitation events is intended to be provided through a website. A sample report of intense rain occurring during last one hour on 3 Sep 2012 at 1500 Z is provided in Fig.

Table 1: Area of the High Rain (Rain >10 mm, and within it the Highest Rain Amount with location

Area(km*2)	Highest Rain	Lat/Long
23168	118.59	22.41/71.86
15808	114.80	19.97/82.91
14528	100.66	21.80/76.95
20480	77.92	25.73/71.56
320	60.34	21.47/73.14
5440	53.11	23.14/92.49
704	26.33	13.34/80.30
448	25.40	28.16/96.29

This is an automated computer generated report with precipitation map of high intensity rain (> 5 mm h^{-1}) along with a table showing area, associated highest rain amount and location of the each rain event in the map, and another table showing list of districts that experienced high rain (>10 mm h^{-1}) with district averaged rain amount and the corresponding meteorological subdivision. Though information on intense rain occurred during last one hour is to be provided near real time, it may still be useful for providing warning and relief to the people in distress. However, in future, we look forward to provide 3-hourly outlook of the rain that may help people to take necessary measures to deal with the disaster.

3. Climatic Applications of H-E precipitation

The precipitation variability over a long period is the manifestation of the climate change. The changes in the precipitation amount, intensity, type (convective/stratiform), and its spatial and temporal variability are all resulting from the climate change. The high resolution H-E precipitation will not only able to provide changes in the process that occur in the longer scales but also the processes that occur in the smaller scales and often go unnoticed by satellite observation that are in the coarser scales. For example, changes in the diurnal variability of the cloudiness cannot be studied with microwave measurements which have coarser time resolution but can easily be discerned by the high resolution precipitation provided by H-E.

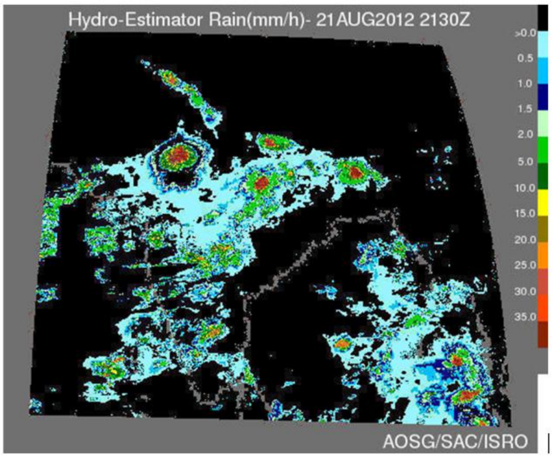


Fig.2: Intense precipitation in Rajasthan on 21 August 2012 at 2130 Z which led to flash flood.

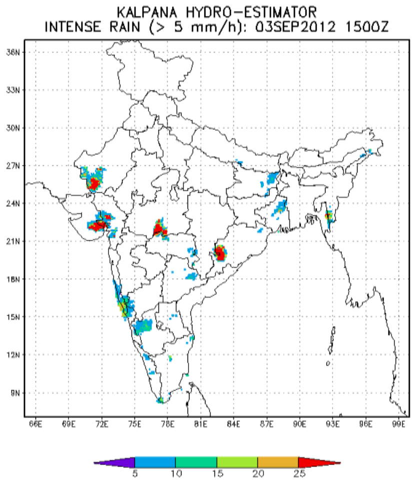


Fig. 3: Report on intense rain even

The Intra-seasonal variability of the monsoon precipitation is studied using H-E. Figure 4 shows the time series analysis of H-E daily averaged rain rate for monsoon season of year 2009 over the most active area, i.e., north part of the Bay of Bengal above latitude of 15°N. The upper panel of the figure shows the variation of daily precipitation whereas the lower panel presents the plot of the corresponding real component of complex Morlet wavelet coefficients in time frequency domain. The abscissa in these figures is time (days) whereas the ordinate is frequency in octave, with each marking on the axis represents period with increasing power of 2. The Figure 4 shows various modes of 30-40, 10-20, and 5-7 days. The modes exhibited by the wavelet analysis are in agreement with known intra-seasonal variability of the monsoon (e.g., Samir et al., 2003). The 30-40 days oscillations are possibly resulting from the passing Maiden-Julian (M-J) oscillations which result from non-linear coupling of large scale flow with convection. The higher frequency modes are possibly due to passing transient systems. Thus the wavelet analysis clearly shows the intra-seasonal behavior of monsoon.

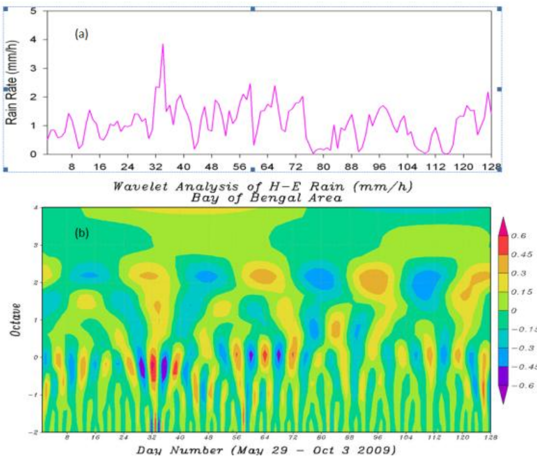


Fig. 4: Over the North Bay of Bengal north to 15o N , (a) Time series of H-E daily averaged rain rate for monsoon season of year 2009, (b) corresponding real component of complex Morlet wavelet coefficients in time frequency domain.

4. Conclusion:

The satellite IR based precipitation measurements are always indirect in nature and hence they suffer with large errors. These errors further deteriorate the measurements when they convolve with the errors resulting from the rain variability at small spatial and temporal scales. In order to strengthen relationship between brightness temperature and rain rate ancillary precipitation sensitive parameters from other sources need to be amalgamated in the retrieval scheme. The Hydro-Estimator (H-E) technique presented herein tries to carry out such integration of observations from various sources to produce measurement of precipitation in the best possible spatial and temporal resolution. In this paper, description of a pixel-scale half-hourly precipitation measurement technique called Hydro-Estimator (H-E) that blends the IR observations from a geostationary satellite with various parameters from NWP, thermodynamic and the earth elevation models to derive very high spatial and temporal resolution precipitation measurements over Indian region. The plants are afoot to quick dissemination of information related to intense precipitation events for flash-flood relief and rescue operations. Apart from various routine operational applications, the measurements provided by H-E can help understanding inter and intra-seasonal behavior of monsoon which may help addressing issues related to climate change. The wavelet analysis presented herein demonstrates use of H-E precipitation for such studies. Several years of the rainfall measurements can provide the behavior of the various rain associated processes and their inter-linking.

The study presented herein is carried out using Kalpana observations which will be extended to measurements from INSAT-3D in future. The H-E presented herein is developed under IMD-PS as an R & D project which is successfully completed.

Table 2: DISTRICTS EXPERINCED HIGH RAIN (>5mm) DURING PAST 1 HOUR: 03 SEP 2012 1500 Z

District Name	Met Subdivision	Rain (mm)
KISHANGANJ	BIHAR	5.53
BARMER	WEST-RAJASTHAN	13.28
ARARIA	BIHAR	6.99
PURNIA	BIHAR	7.19
SURENDRANAGAR	SAURASHTRA-&-KUTCH-DADAR-NAGAR-HAVELI-&-DAMAN	16.80
AHMEDABAD	GUJARAT-REGION	35.24
LUNGLEI	NAGALAND-MANIPUR-MIZORAM-TRIPURA	14.95
GANDHINAGAR	GUJARAT-REGION	6.89
KHEDA	GUJARAT-REGION	7.46
RAJKOT	SAURASHTRA-&-KUTCH-DADAR-NAGAR-HAVELI-&-DAMAN	9.34
LAWNGTLAI	NAGALAND-MANIPUR-MIZORAM-TRIPURA	7.06
HARDA	WEST-MADHYA-PRADESH	38.02
EAST-NIMAR	WEST-MADHYA-PRADESH	9.88
BETUL	WEST-MADHYA-PRADESH	12.88
BHAVNAGAR	SAURASHTRA-&-KUTCH-DADAR-NAGAR-HAVELI-&-DAMAN	19.18
BHARUCH	GUJARAT-REGION	5.42
NUAPADA	ORISSA	33.42
BALANGIR	ORISSA	9.09
KALAHANDI	ORISSA	31.35
RATNAGIRI	KONKAN-&-GOA	5.94
KOLHAPUR	MADHYA-MAHARASH	8.09
SINDHUDURG	KONKAN-&-GOA	14.16
NORTH-GOA	KONKAN-&-GOA	17.05
SOUTH-GOA	KONKAN-&-GOA	16.22
CHITRADURGA	SOUTH-INTERIOR-KARNATAKA	5.08
DAVANGERE	SOUTH-INTERIOR-KARNATAKA	9.29
SHIMOGA	SOUTH-INTERIOR-KARNATAKA	7.33
WAYANAD	KERALA	5.17
KANNIYAKUMARI	TAMILNADU-&-PONDICHERRY	10.74

5. Acknowledgement:

The Author is thankful to Dr. Robert Kulligowaski, NOAA/STAR for providing necessary literature to develop H-E at SAC. Also thanks to NOAA for GFS NWP model parameters and ETOPO

6. References

- Barrett, E. C. and Martin, D. W., 1981, The use of satellite data in rainfall monitoring, Academic Press, London.
- Bhandari, S.M and A. K. Varma, 1995, On Estimation of Large Scale Monthly Rainfall Estimation Over the Indian Region Using Minimal INSAT-VHRR Data, *International Journal of Remote Sensing*, **16**, 2023-2030.
- Joyce, R., J. Janowiak, and G. Huffman, 2001, Latitudinally and seasonally dependent zenith-angle corrections for geostationary satellite IR brightness temperatures, *Journal of Applied Metorology*, **40**, 689-703.
- Liu, C, and E. J.. Zipser, 2009, ''Warm Rain'' in the Tropics, Seasonal and Regional Distributions Based on 9 yr of TRMM Data, *Journal of Climate*, **22**, 767-779.
- Piyush, D N, A K Varma, P K Pal and G Liu, 2012, An Analysis of Rainfall Measurements over Different Spatio-Temporal Scales and Potential Implications for Uncertainty in Satellite Data Validation, *Journal of Meteorological Society of Japan*, **90 (4),** DOI: 10.2151/JMSJ.2012-408.
- Pokhrel, S., A. K. Varma, R. M. Gairola, , Vijay K. Agarwal, 2003, Distribution and intraseasonal variability of rain over Indian Oceanic region from Indian Remote Sensing Satellite IRS-P4 Multifrequency Scanning Microwave Radiometer, *Journal of Geophysical Research*, **108 (C10**), 3314, doi:10.1029/2003JC001886.
- Scofield, R. A., 1987, The NESDIS Operational Convective Precipitation Estimation Technique, *Monthly Weather Review*, **115**, 1773-1792.
- Scofield, R. A., and R. J. Kuligowaski, 2003, Status and outlook of operational satellite precipitation algorithms for extreme-precipitation events, *Weather and Forecasting*, **18**, 1037-1051.
- Varma, A. K. and G. Liu, 2010, On Classifying Rain Types Using Satellite Microwave Observations, *Journal of Geophysical Research*, **115**, D07204, doi:10.1029/2009JD012058.
- Varma, A. K., and G. Liu, 2006, Small-Scale Horizontal Rainrate Variability by Satellite, *Monthly Weather Review*, **134** (10), 2722-2733.
- Varma, A. K., G. Liu, and Y. J., Noh, 2004, Sub-Pixel Scale Variability of Rainfall and Its Application to Mitigate the Beam-Filling Problem, *Journal of Geophysical Research*, **109**, D18210, doi:10.1029/2004JD004968.
- Varma, A K and P K Pal, 2012, Use of TRMM Precipitation Radar to address the problem of rain detection in Passive Microwave Measurements, *Indian Journal of Radio and Space Physics*, **41** 411-420.
- Varma, A.K., Samir Pokhrel, Rakesh Mohan Gairola, and Vijay K. Agarwal, An Empirical Algorithm for Cloud Liquid Water From MSMR and Its Utilization in Rain Identification, *IEEE Transactions on Geosciences and Remote Sensing*, **41 (8)**, 1853-1858, 2003.
- Vicente, G. A., R. A. Scofield, and W. P. Menzel, 1998, The operational GOES infrared rainfall estimation technique. *Bulletin of the American Meteorological Society*, **79**, 1883–1898.

Climate Change in Terrestrial Cryosphere

N. K. Vyas
Scientist (Retired), Space Applications Centre, ISRO, Ahmedabad
Curr. Addr. : 4/14 Aalay Apt., Near Vastrapur Bus-Stand, Ahmedabad
E-Mail : dr.nkvyas@gmail.com

1. Introduction

The word "**cryosphere"** comes from the Greek word "cryos" meaning "cold", "frost" or "ice". It refers to the region of the earth's surface containing ice or super cooled water at temperatures below or equal to the freezing point of water. The components of earth's cryosphere include sea ice, lake ice, river ice, snow cover, glaciers, ice caps and ice sheets and seasonally frozen ground or perennially frozen ground (permafrost).

Cryosphere plays a very important role in shaping the climate. The properties of ice are such that they strongly influence the climate system which, in turn, influences the Cryosphere. These processes are called feedback mechanisms. They control the evolution of the fluxes of surface energy and moisture that, in turn, affect cloud formation, precipitation, and atmospheric and oceanic circulation. Any perturbation in climate will change the cryosphere and any perturbations in cryosphere will change the climate.

In this article, we will, at first discuss some of the important processes governing the interaction of the cryosphere with the climate and then discuss the observed changes in the terrestrial cryosphere over the period of available satellite observations.

2. Interaction of Cryo-Sphere with The Climate:

The important properties of ice that are responsible for influencing the climate are its high reflectivity (albedo) and its low thermal conductivity. The high albedo causes the large part of the solar radiation flux to get reflected back to the atmosphere and the low thermal conductivity does not allow the heat flux from the ocean waters to pierce through and reach the atmosphere in significant proportions. We will discuss below, in short, how these properties influence the energy and the moisture fluxes between the earth's surface, the ocean and the atmosphere.

2.1 The Ice Albedo feedback:

The principle of the Ice-Albedo Feedback is simple (see fig. 1). As the temperatures rise due to some reason (like transition from winter to spring or increase in green house gas concentration), snow and ice start melting and either open sea water or the land mass starts getting exposed. Both of them have a much lower albedo, compared to that of snow / ice. So, more sunlight starts getting absorbed by the earth's surface, and the temperature rises further. The process goes on enhancing the surface temperature at each stage. This is called positive ice albedo feedback.

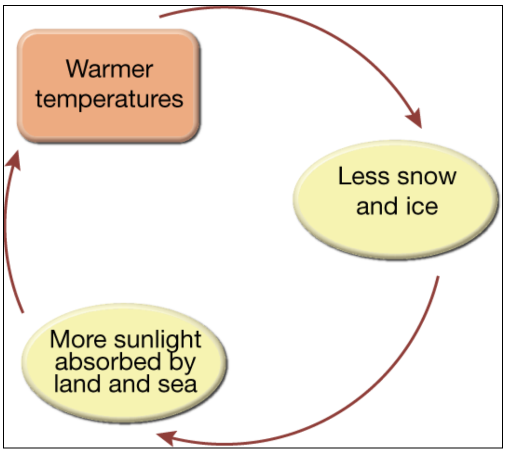


Fig. 1 : Positive Ice Albedo Feedback Mechanism [from EETB Website]

The reverse process can also be initiated by the same positive feedback mechanism. If the temperatures go down, more ice is formed, more sunlight gets reflected, less is absorbed and the earth becomes further cooler.

Changes in Albedo constitute the main reason why IPCC (Intergovernmental Panel on Climate Change) expects that the polar temperatures in the northern hemisphere may rise up to twice as much as those in the rest of the world.

2.2 Carbon Cycle Feedbacks:

Warming is also likely to cause release of carbon (in the form of methane, trapped in the permafrost) in the Arctic region (Kvenvolden, 1988). Methane released from melting permafrost such as the frozen peat bogs in Siberia, and from methane clathrate on the sea floor, would go to the atmosphere, and enhance the green house effect, thereby further warming the climate, resulting in further release of methane from the permafrost and from the sea floor.

2.2.1 Methane release from melting permafrost peat bogs:

An area of about more than a million km^2 in the western Siberia is considered to contain permafrost peat bog, formed about 11,000 years ago. (i.e. towards the end of the last ice age). western Siberia is the world's largest peat bog (~ 10^6 km^2 in area, containing ~ several 10^{10} tonnes of methane). Any melting initiated in this region may release large quantities of methane in near future and act as an additional source of greenhouse warming. As much as 70,000 million tonnes of methane might be released over the next few decades, creating an additional source of greenhouse gas emissions (Pearce, 2011)

2.2.2 Methane release from Arctic Seafloor hydrates:

Methane clathrate (also called methane hydrate) is a special form of water ice which is found, in large amounts, under sediments on the sea and ocean floors in the Arctic. It contains large amounts of methane within its crystal structure. A rise in temperature could result by the release of this trapped methane. It can cause the global temperatures to rise additionally by ~ 5° C. Levels of methane up to 100 times above normal have been detected in the Siberian Arctic, by an American Geophysical Union research expedition. They are considered to be due to the release of methane by methane clathrates through the holes in the frozen seabed permafrost, between the Laptev Sea and East Siberian Sea (Shakhova, 2007).

2.3 Thermal Insulation Properties of Snow and Ice:

Snow cover insulates the ground surface, and sea ice insulates the underlying ocean, affecting both the heat and the moisture fluxes going to the atmosphere. The flux of moisture from a water surface is practically cut off by even a thin layer of ice. However, the heat flux requires the ice layer thickness to rise to values more than ~ 30-40 cm, to become relatively less important. But, a thin layer of snow on top of the ice layer can drastically reduce the heat flux, thereby reducing significantly any further growth of the existing ice layer. Snow and ice, due to their low heat conductivity, insulate land and ocean surfaces from large energy losses in winter. They also act to slow down warming in the spring and summer because of the large amount of energy required to melt ice. The cooling associated with a heavy snow cover and resulting moist soils in the spring season over the Eurasian region is found to influence the summer monsoon circulation over India (Vernekar et al., 1995).

I. Satellite Observations of Cryosphere :

The cryospheric regions are generally remote and have very hostile climate. So, collecting data regularly on a large scale is very difficult. Satellites provide a very convenient means for routinely monitoring the state of the cryosphere and give us an idea how it is evolving with time. In the beginning, Television and Infrared Observation Satellite – 2 (TIROS-2) showed vast potential of satellites to monitor spring ice break-up in the Arctic. From 1972 onwards, Landsat series of satellites provided high resolution visible and IR images of the polar regions, but with limited use due to winter darkness and high summer-time cloud cover over the these regions. However, around the same time, Nimbus-5 Electrically Scanning Microwave Radiometer (ESMR) provided good quality passive microwave observations not affected by darkness, and later in 1978, Scanning Multichannel

Microwave radiometer (SMMR) was launched that provided much improved microwave data.

In 1979 and 1981, Indian Space research Organization (ISRO) launched SAMIR-1 and 2 that provided useful microwave data over oceans. In 1987, Special Sensor Microwave Imager (SSM/I) was launched under US Defence Meteorological Satellite Program (DMSP) that provided passive microwave images over the polar regions on an operational basis. In 2002, Advanced Microwave Scanning Radiometer went onboard ADEOS-II, but provided data only for 9 months. However, AMSR-E onboard Aqua started providing high quality microwave measurements from 2002 onwards. It provided higher spatial resolution and wider spectral range that enabled estimation of ice temperatures with better temporal coverage. Passive microwave remote sensing data has also been used for estimating thin ice thickness in coastal polynyas. (Singh et al , 2011).

ISRO launched Oceansat-1 in 1999 carrying Multichannel Scanning Microwave Radiometer (MSMR) onboard. The data from MSMR found several applications and was extensively used for the study of Antarctic Sea Ice extent and concentration and also for identifying large scale land ice features on the Antarctic continental landmass. (Vyas and Dash, 2000, Dash et al. 2001, Bhandari et al., 2002, Vyas et al., 2001, 2003, 2004).

Coming to Active Microwave Sensors, ERS-1 and- 2 carried AMI (Active Microwave Instrument) on board in 1991 and 1995 respectively. In 1996, NASA launched the NASA Scatterometer (NSCAT), a Ku-band fan-beam system. But, it failed in 1997. Quikscat was launched in 1999 to replace NSCAT. The active microwave instruments have been found to be very useful for the study of melt onset, for tracking sea ice motion and for classifying different ice types.

ISRO launched Oceansat-2 with pencil beam Ku-band scatterometer onboard, in 2009. It is providing overall sea ice detection accuracies of about 95 % (Oza et al., 2011a, 2011b).

ISRO has also launched RISAT-1 (RADAR Imaging Satellite-1) on April 26, 2012 and also going to launch soon a Ka-band Altimeter Altika onboard SARAL under a joint ISRO-CNES Mission. Presently, more recent data is available from missions, such as CryoSat-2, IceSat, GRACE, GOCE, SMOS, ENVISAT, RADARSAT-1 and -2. These data are useful for the study of the mass balance estimates, ice sheet dynamics, ice berg discharge, snow, snow albedo and snow water equivalent, permafrost, glaciers and what is all the more important, to study the role of Cryosphere in climate.

II. Climate Change In Cryosphere:

4.1 Climate Change in the Antarctic :

Antarctica appears to be warming around the edges but cooling in the interior. The central and southern parts of the west coast of the Antarctic Peninsula have warmed by nearly 3°C. There is no evidence for a decline in overall Antarctic sea ice extent. The strongest cooling is found to be at the South Pole, and the region of strongest warming is observed along the Antarctic Peninsula. Researchers have found that Antarctic snow is melting farther inland from the coast, at higher altitudes and on the ice-shelves.

Rate at which the Antarctic Ice-Mass is changing has been estimated using the GRACE data from 2002-2009 (Chen et al., 2009) and is shown in fig. 2 in the units of sea level equivalent (SLE) water height change per year (Dark Blue: - 8 cm/year to Dark Red +8 cm/year). It can be seen clearly that the west Antarctic ice sheet is losing mass at the maximum rate.

4.2 Disintegration of Northern Larsen Ice Shelf in Antarctica:

It is found that the northern part of the Larsen Ice Shelf in the Antarctic Peninsula is decaying very rapidly. In about last two decades, large parts of Larsen C Ice Shelf have already depleted and also parts of Larsen A and B ice shelves are going the same way. Fig. 3 depicts the present condition of the ice shelves as discussed by Rott, 2010.

4.3 Climate Change in the Arctic :

Large parts of the Arctic including the North Pole are in the oceanic region. Satellite data indicate a reduction in annual mean arctic sea ice extent of ~2.7 % per decade since 1978. The decline for summer extent is larger, ~ 7.4 % per decade. On the contrary, Antarctic observations show higher interannual variability but no consistency in the trend. Submarine-derived data for the central Arctic indicate average sea ice thickness in the central Arctic decreased by ~ 1 m between 1987 and 1997. (Lemke et al., 2007). Arctic Sea Ice Volume from 1980-2012 (data up to 31-1-2013) is estimated to be decreasing by ~ 3100 km^3 / decade (See fig. 4) as reported in a recent study at Polar Science Center (PIOMAS, 2013).

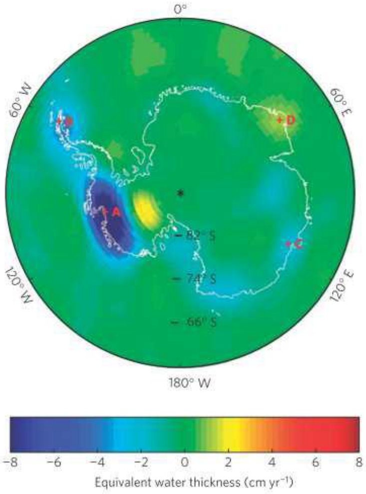


Fig. 2 : Rate of change of Ice Mass from GRACE Data from 2002-2009. (Chen et al, 2009).

4.4 Ice Elevation Changes in Greenland :

Ice in the Central Greenland is thickening but coastal regions are thinning due to ice melt in the range ~ -40 to + 40 cm / year . (See fig. 5). Flow speeds of some Greenland and Antarctic outlet glaciers have increased. The estimated contribution to sea level rise from the Greenland ice sheet is ~ - 0.07 to + 0.17 mm sea level equivalent (SLE) per year for the period 1993-2003. The estimated contribution of the Antarctic Ice Sheet to sea level rise is ~ –0.14 to + 0.55 mm SLE per year) for the same period. (Lemke et al , 2007).

4.5 Glaciers and Permafrost :

Glaciers and ice caps are estimated to be melting at a rate of ~ 0.77 mm SLE per year during the period 1991-2004, which is considered to be a result of post-1970 warming. Largest contribution to sea level rise appears to be coming from the glaciers in Alaska, the Arctic and the Himalayas.

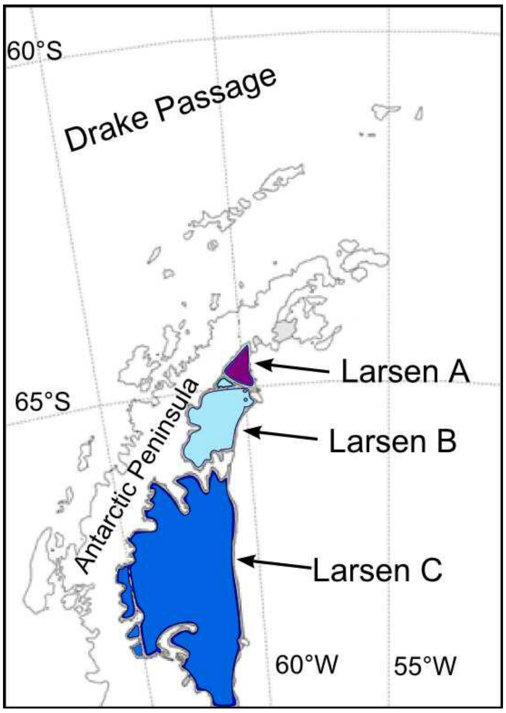


Fig. 3: Present condition of the rapidly declining Northern Larsen Ice Shelf (from Rott, 2010).

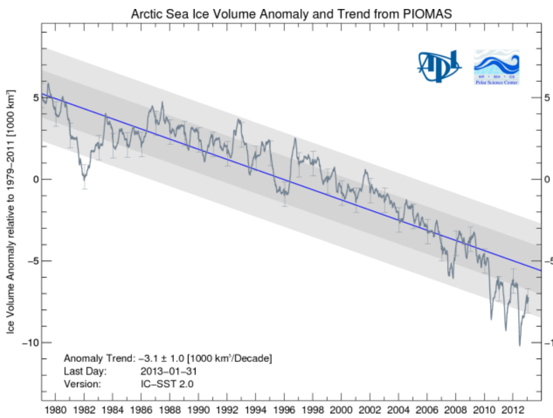


Fig. 4 : Arctic Sea Ice Volume Trend from 1980-2012 (Source : PIOMAS, 2013)

Surface temperatures of the permafrost layer in the Arctic have increased by up to 3°C since the 1980s.. The permafrost is estimated to be melting by up to 0.04 m / year in Alaska since 1992 and 0.02 m / year on the Tibetan Plateau since the 1960s. (. (Lemke et al, 2007).

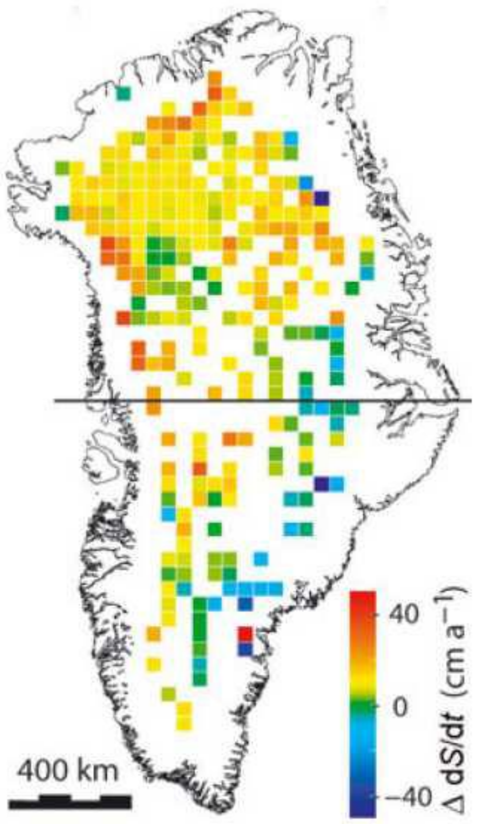


Fig.5: Spatial distribution of the rate of ice elevation changes in Greenland (from: Rott, 2010)

5 CONCLUSIONS :

Cryosphere is the region of the earth's surface containing ice or super cooled water at temperatures below or equal to the freezing point of water. It plays a very important role in shaping the earth's climate. It interacts with the earth's radiation balance through strong positive feedback processes like the ice albedo feedback and the carbon cycle feedback. Also, the thermal insulation properties of sea ice effectively cut off the moisture flux and reduce the heat flux from the ocean to the atmosphere. Surface observations of cryosphere are limited due to the hostile terrain and weather conditions. However, with the advent of the satellites, regular monitoring of the Cryosphere has now become possible. ISRO and India have played an important role in the observations of the cryosphere and in the research on its interaction with climate.

While there is no clear-cut trend observed for the time series of sea or land ice melts in Antarctica, there are strong evidences for the rapid depletion of the Larsen Ice Shelf and for the surface warming of Antarctic Peninsula. Also, the west Antarctic ice sheet is losing mass at a higher rate than the east Antarctic ice sheet. Arctic sea ice has clearly shown a decaying trend which is much stronger in summer than in winter. The Greenland ice sheet is thickening in the interior, but thinning in the coastal regions. There are large uncertainties about its overall scenario, but there is a higher probability for it to have a net positive melting rate. The glaciers appear to be melting and receding, and the Alaskan and the Himalayan Glaciers appear to be contributing maximum to the sea level rise. Permafrost in the Arctic as well as in Tibet appears to be slowly melting. This may be the initial stage of global warming (if any) and if the positive feedback cycles strengthen, their effect on the climate could be significant.

6 REFERENCES :

- Bhandari, S.M., M.K. Dash, N.K. Vyas, N. Khare and P.C. Pandey (2002) : "Microwave Remote Sensing of Sea Ice in the Antarctic Region from Oceansat-1 MSMR", Advances in Marine and Polar Science, D. Sahoo and P.C. Pandey (eds.), A.P.H. Publishing Corporation, New Delhi, pp 423-443.

- Chen, L. Wilson, C.R., Blankenship, D. and B. D. Tapley. (2009) : "Accelerated Antarctic ice loss from satellite gravity measurements." *Nature Geoscience 2*, pp. 859 – 862. doi:10.1038/ngeo694

- Dash M.K., S.M. Bhandari, N.K. Vyas, N. Khare and P.C. Pandey (2001) : "Oceansat MSMR imaging of the Antarctic and the Southern Polar Ocean", International J. Remote Sens., Vol. 22, pp. 3253-3259.
- EETB (Earth Exploration Tool Book), Part 5 – Analyze Relationships between data-sets, Step-6 Reflect on the relationships "Feedback loop

snow-ice" (Website : http://serc.carleton.edu/eet/albedo/part_5.html

- Kvenvolden, K. A. (1988) : "Methane Hydrates and Global Climate". *Global Biogeochemical Cycles, Vol.* **2** (3): p. 221.

- Lemke, P., J. Ren, R.B. Alley, I. Allison, J. Carrasco, G. Flato, Y. Fujii, G. Kaser, P. Mote, R.H. Thomas and T. Zhan (2007): Observations: Changes in Snow, Ice and Frozen Ground. (Contribution of WG I to the 4th, IPCC Assessment Report) In: *Climate Change 2007:* Cambridge University Press, UK.

- Oza, S R, Singh R K K, Vyas N K and Sarkar, Abhijit (2011a) : "Study of inter-annual variations in surface melting over Amery Ice Shelf, East Antarctica, using space-borne scatterometer data", *J. Earth System Sci.,* Vol..120, pp.329-336.
- Oza, S.R., R.K.K. Sigh, N.K. Vyas, B.S. Gohil and A. Sarkar (2011b): "Spatio-temporal coherence based technique for near real time sea ice identification from scatterometer data", J. Indian Soc. Remote Sens., Vol. 39, pp 147-152.

- Pearce, F. (2005-08-11). "Climate warning as Siberia melts". New Scientist. http://www.newscientist.com/article/mg18725124.500
- PIOMAS (2013): Pan-Arctic Ice Ocean Modeling and Assimilation System (PIOMAS), at the Polar Science Center (Source : Arctic Sea Ice Volume Anomaly, version2) http://psc.apl.washington.edu/wordpress/research/projects/arctic-sea-ice-volume-anomaly/

- Rott Helmut (2010) : Satellite Observations for Cryospheric Research, Alpbach_2010 Summer School Presentation http://www.summerschoolalpbach.at/docs/2010/lectures/Cryosphere_Alpbach-2010_Rott.pdf

- Shakhova N., I. Semiletov, A. Salyuk, D. Kosmach, and N. Bel'cheva (2007). "Methane release on the Arctic East Siberian shelf". *Geophysical Research Abstracts* **9**: 01071.

- Singh, R.K., Oza, S.R., Vyas, N.K., Sarkar, A. (2011): "Estimation of Thin Ice Thickness From the Advanced Microwave Scanning Radiometer-EOS for Coastal Polynyas in the Chukchi and Beaufort Seas", IEEE Trans. on Geoscience and Remote Sensing, Vol. 49, pp 2993-2998.

- Vernekar, A. D., J. Zhou, and J. Shukla, 1995: The effect of Eurasian snow cover on the Indian monsoon. J. Climate, 8, 248-266.

- Vyas, N.K. and M. K. Dash (2000) : "Oceansat-MSMR observes interesting features on the frozen continent and the surrounding sea", J. Indian Soc. Remote Sens., Vol. 28, p. 67.
- Vyas, N.K. and M. K. Dash, S.M. Bhandari N. Khare, A. Mitra and P.C. Pandey (2001) : "Large Scale Antarctic features captured by Multi-frequency scanning microwave radiometer onboard Oceansat-1", Current Science, Vol. 80, pp. 1319-1322.

- Vyas, N.K., M. K. Dash, S.M. Bhandari N. Khare, A. Mitra and P.C. Pandey (2003): "On the secular in sea ice extent over the Antarctic region based on Oceansat-1 MSMR Observations", International J. Remote Sens., Vol. 24, pp. 2277-2287.

- Vyas, N.K., S.M. Bhandari, M. K. Dash, P.C. Pandey N. Khare, A. Khanolkar and N. Sharma (2004): "An Atlas of Antarctic Sea Ice from Oceansat-1 MSMR)", Joint SAC(ISRO)-NCAOR Scientific Report, SAC-NCAOR-01-2004, Published by National Centre for Antarctic and Ocean Research, Goa-India.

Coral Bleaching: An SOS from the Sea

Nandini Ray Chaudhury

Space Applications Centre, ISRO, Ahmedabad

E-mail: nandinirc@sac.isro.gov.in

1. Introduction

SOS of our warming planet keeps on coming from a place we never thought of: a world under the seas! Planet earth may lose one of her unique and beautiful natural heritage called coral reefs. Corals are tiny marine organisms that sculpt an underwater rock-garden called reef (Fig.1) which fosters approximately one-third of known marine life. In shallow, warm, transparent, sunlit waters of tropical oceans, fringing the continental coasts, islands and even some of the sub-marine volcanoes, tiny coral polyps build a marvel of undersea, wave-resistant, calcium-carbonate, three-dimensional landscape. World's largest reef structure: Australia's Great Barrier Reef - a world heritage site was thus built by millions of living organisms since nine thousand years! Extending over a length of 2,300 km in the east coast of Australia, this natural, ocean wonder now draws the attention of serious science regarding its future in the next fifty years! This bleak story is by far the same for other reefs in the world.

As marine organisms corals are found across the global oceans including the cold and deep water corals. However, reef-building corals commonly colonize the tropical oceans within the latitudinal limits of 30° north and south where sea-water temperature ranges between 18° and 30° C, salinity varies between 32 and 40 ppt and sea floor substrate is rich in calcium carbonate, hard and silt-free.

Rainforests of the seas, coral reefs represent a biodiversity paradox in nutrient-poor or oligotrophic waters of the tropical oceans. The spectacular beauty of reefscape comes from the co-habitation of aesthetically celebrated coral communities and millions of reef associates including benthic flora and fauna.

High productivity and biodiversity of this marine ecosystem in otherwise oceans' desert is still a mystery! Scientists attribute this to the successful partnership or symbiosis between coral polyps (animal) and their endo-symbiont (residing within coral's cell), dinoflagellate algae (plant) named zooxanthellae. Autotrophic zooxanthellae photosynthesize and supply photosynthetic products (sugar, amino acids, etc.) to their invertebrate host (coral tissues). Coral hosts, in addition to shelter, give zooxanthellae crucial plant nutrients (ammonia and phosphate) from their waste metabolism (Lesser 2004). For their life and wide variety of colours, corals depend on zooxanthellae.

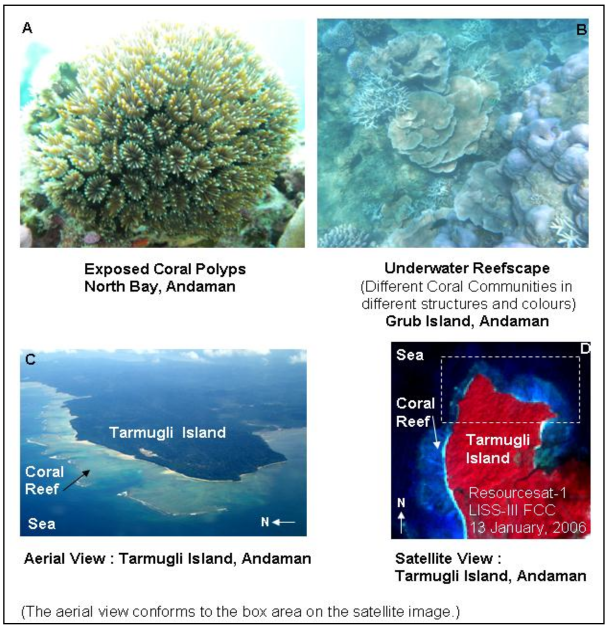


Fig. 1: Corals and Coral Reefs (A: Live corals; B: Underwater photograph of coral reef C: Aerial view of coral reef and D: Satellite image of coral reef)

2. Climate Change Stresses on Coral Reefs

In the last three decades, time and again, coral reefs across the world have signaled their superlative sensitivity towards increasingly warmer and acidic oceans. Effects of a warming planet have become apparent in different ecological responses that coral reefs give right from coral (animal) to reef (landform) scale.

In events of abnormal but persistent rise in the Sea Surface Temperature (SST) and higher ultra-violet radiation, corals expel their zooxanthellae, lose their hues and colours and finally worn down to white calcium carbonate skeletons. This common stress-response phenomenon is known as **coral bleaching** (Fig. 2) which is now frequently happening worldwide. Thermal stress in events of high SSTs is known to be the most common cause of coral bleaching. However, coral bleaching and successive coral mortality can also result due to negative thermal anomaly, heavy downpour, abnormal fluctuations of salinity, excessive sedimentation, exposure to air at low tides and low sea level conditions, coral diseases, marine pollution, etc. (Brown 1997). Photo bleaching (in case of intense solar radiation, especially at Ultra-Violet wavelengths and high Photosynthetically Active Radiation or PAR) is known to aggravate the effect of thermal bleaching. The severity of coral bleaching may range from negligible, partial coral bleaching in patches with probable recovery chances to catastrophic mass mortality or Mass Coral Bleaching (MCB) where minimum 80% of the live coral cover of a reef system gets destroyed. Recovery of corals at individual organism scale (allowing fresh symbiosis) and at large reef scale is indeed a slow process. Reef recovery (live coral cover and species diversity) and restoration (reconstruction of lost reef frameworks) processes need long time: in decades and centuries (Baker et al. 2008). With frequency of bleaching events on the rise it is becoming difficult to monitor recovery process in reefs exposed to multiple sequential bleaching events.

The more the oceans absorb greenhouse gases from the earth's atmosphere the seawater becomes more acidic. Ocean acidity affects the skeletal health of all calcifying corals and other organisms like snails who find it tough to build their limestone shells! As a result reef structures become fragile, vulnerable to strong wave actions and storm impacts. Sea level rise is considered another potential impact of climate change where existing Holocene reefs may get drowned affecting the human civilizations of some of the important island nations. Coupled with these natural threats are anthropogenic impacts like eutrophication, pollution, overfishing, coastal developments and commercial exploitation of this critical eco-resource. Resilience of this geologically persistent ecosystem has been put to hard and continuous tests across the globe, in this millennium.

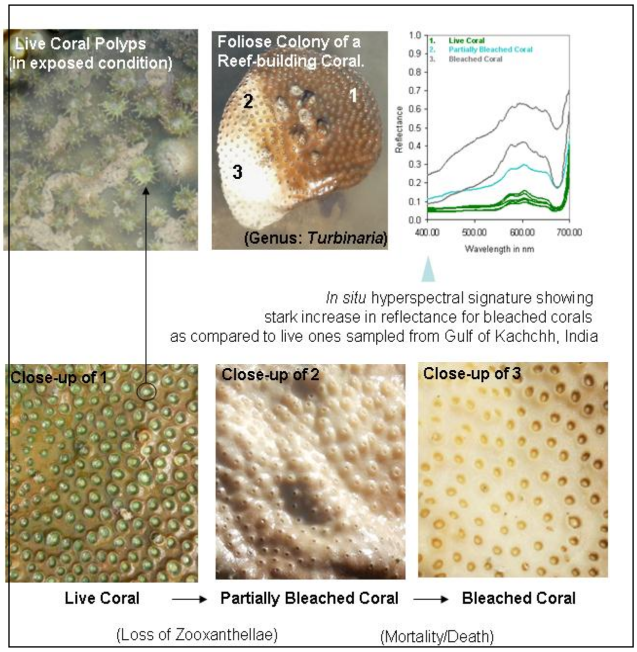


Fig. 2: Coral Bleaching Process

3. MCB Events

The occurrence of MCB events correlates well with observed increases in global sea temperatures and particularly thermal anomalies (Fig.3; Baker et al. 2008). The connection of coral bleaching with climate change gets established with the fact of its episodic, regional to global nature MCB events consequent upon SST anomalies. It is observed that increasing frequency, regional severity and geographic extent of MCBs are an apparent result of a steadily rising baseline of SSTs combined with region specific El Niño (warm ocean current in East Pacific) and La Niña (counterpart of El Niño) events (Reaser et al. 2000). MCB correlated with El Niño warming event was first described by P.W. Glynn in 1984 (Brown 1997).

Globally, MCB episodes show a concurrency with intensified El Niño Southern Oscillation (ENSO) events and resultant SST anomalies whose recurrence interval is generally 2 to 7 years (Nicholls et al. 2007). ENSO event has even been identified as a driver for 2500 year collapse of eastern Pacific coral reefs (Toth et al. 2012).

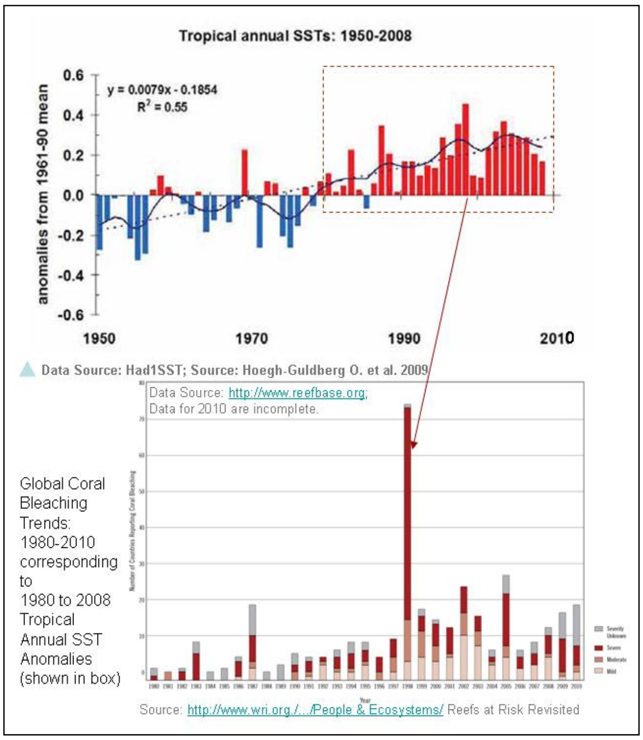


Fig. 3: Tropical Annual SST Anomaly (1950-2008) and MCB Trends (1980–2010)

Since, 1979 to 1999 six major episodes of MCB (Hoegh-Guldberg 1999) are reported in the world with massive coral mortalities. Out of these six, MCBs of 1982-83, 1986-87, 1993-94 and 1997-98 are known to be severe and widespread ones in the world. The last one coincided with pronounced El Niño Southern Oscillation (ENSO) event in one of the hottest years on record (Parry et al. 2007). In the last decade (2001-2010) the world has experienced coral bleaching in regional to global scale in the years: 2002, 2004-05 and 2010; the last one again being the worldwide worst. The Caribbean coral reef bleaching of 2005 was also a severe one. Within a span of 25 years (1980-2005) 30% of the warm-water coral reefs have been lost to thermal bleaching whose frequency and intensity are on the rise (Raven et al. 2005). Warming of the tropical and sub-tropical waters of the global ocean over the second half of the twentieth century has already pushed the reef building corals to their thermal tolerance limits (Hoegh-Guldberg 2007).

4. Satellite Surveillance on Coral Bleaching

July 2005 ushered in new hopes for coral reef conservation when USA's National Oceanic and Atmospheric Administration (NOAA)'s Coral Reef Watch (CRW) team operationalised an e-mail based Satellite Bleaching Alert (SBA) system for subscribed reef sites of the world (http://www.coralreefwatch-satops.noaa.gov).This attempt demonstrated the potential of synergistic use of space data in near-real time ecosystem management. NOAA's CRW 'HotSpot' suite of products (whose experimental development began as early as 1997 by U.S. National Environmental Satellite Data and Information Service or NESDIS) popularised the application of NOAA's Polar-orbiting Operational Environmental Satellite (POES) Advanced Very High Resolution Radiometer (AVHRR) long-term SST data products to monitor coral reefs turning into 'Bleaching HotSpots'. AVHRR kind of sensor has utilized the thermal infrared region to the best capacity to sense and monitor the SST over a long period of time. Coral reefs turn into 'bleaching HotSpots' once SST of that particular location exceeds the normal summer maxima (summer monthly climatology) temperature by 1° to 2°C and persists for 3 to 4 consecutive weeks. If the thermal anomaly persists less than 3-4 weeks consecutive period, it is a "warm spot" likely to turn into a HotSpot but definitely not a "bleaching HotSpot" (Bahuguna et al. 2008). In the present paradigm of climate change science, synergistic use of sequential AVHRR data with corresponding high resolution reef images has realized operational forecasts of Mass Coral Bleaching (MCB) and monitoring of Phase Shift events across the global oceans. High temporal resolution and Global Area Coverage (GAC) mode of data acquisition over the global oceans have helped in monitoring ocean circulation processes impacting coral reefs.

Space Applications Centre (SAC) of Indian Space Research Organisation has kept an eye from space on these critical marine habitats of our country right from 1980s. Reef and reef habitat mapping have been carried out in routine priority for environmental conservation plans at different scales and levels using different remotely sensed data and processing methods (Ajai et al. 2012; Navalgund et al. 2010; Nayak and Bahuguna 1997). SAC has developed an Operational Ecosystem Reference Point (OERP) based conceptual model on reef health. This two stage model computes a 7-parameter based Ecological Index and a 4- parameter based Damage index in the first stage. Additively these two indices give a Reef Health Index in stage two. This model can generate a 3-parameter based Warning Index specifying different warning level conditions for reef managers and planners. This three stage Coral Reef health Model has been customized as an application package on IGIS software platform. This multi-parameter, reef health model concept is first of its kind in the world as it considers the impact of oceanographic parameters concurrent to the ecosystem health unlike bleaching forecast models focusing only on SST parameter (Ajai et al. 2012).

5. Coral Bleaching: Indian Experience

As a maritime nation, Indian coast is blessed with strategically located coral reef systems: both in its continental shelf and oceanic settings in Arabian Sea and Bay of Bengal. Amidst the threats of coastal development, fringing reefs thrive in Gulf of Kachchh and Gulf Mannar while far from the Indian peninsula, Indian island groups of Andaman and Nicobar and atolls of Lakshadweep foster great reef biodiversity. Indian coral reefs share sixty genera of reef-building corals out of one hundred and eleven genera reported in the world (Venkataraman, 2003) and thus share 54% of global coral diversity at genera level. Indian coral reefs have experienced twenty-nine widespread bleaching events since 1989 with intense bleaching in 1998 and 2002 (Vivekanandan et al. 2009). Reefbase data of worldwide bleaching records classify Andaman, Gulf of Mannar and Lakshadweep reef regions as sites of high bleaching events while already degraded reefs of Gulf of Kachchh are depicted as reefs recording medium to low bleaching (Baker et al. 2008). The unprecedented MCB event of 1997-98 had greatly destroyed the live coral cover of shallow water coral reefs of India (Wilkinson 2000; Venkataraman, 2011). Field surveys conducted during or after the bleaching events reported a 20% to 30% reduction of live coral cover in Gulf of Kachchh and Gulf of Mannar, 20% to 30% in Lakshadweep and less than 10% in Andaman and Nicobar Islands (Venkataraman 2011). In the last decade Indian reef regions experienced local to regional scale, severe bleaching episodes during 2002 (Gulf of Mannar: Kumaraguru et al. 2003; Andaman: Krishnan et al. 2011), 2004-05 (Gulf of Kachchh: Bahuguna 2008) and in 2010 (Andaman: Krishnan et al. 2010; Lakshadweep: Ajith Kumar and Balasubramanian 2012).

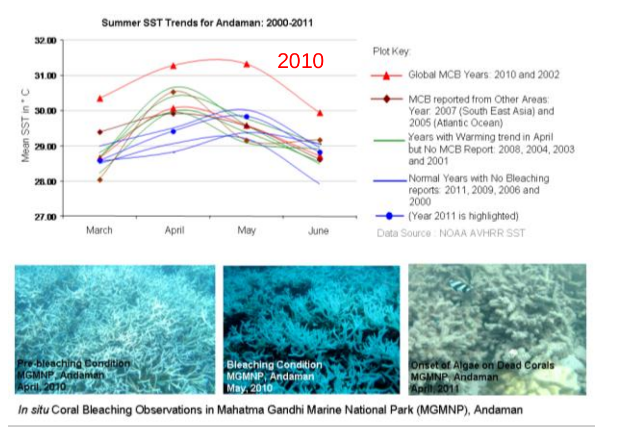


Fig. 4: Thermal bleaching of Andaman corals in 2010

Andaman reefs recorded severe bleaching ranging from 30% to 70% (Krishnan et al. 2011) at various sites and surpassed earlier records in terms of geographical extent and severity during the latest 2010 MCB event. Long term NOAA AVHRR SST data reveals that summer month of April is the hottest month of the year over Andaman reef region. The April heating trend is conformed by the summer SST patterns of 2001, 2002, 2003, 2004, 2005, 2007 and 2008 out of which 2002 was a global MCB year. MCB were reported from the Atlantic Ocean in 2005 and from South East Asia in 2007 (Fig. 4). Rest of the years had no reports of MCB. Interestingly the normal years with no bleaching records (2000, 2006, 2009 and 2011) show a different trend identifying May as the hottest month of the summer. In case of 2010, the summer SST was 1.2 to 1.9°C higher from the previous ten year's monthly means. The 1 to 2°C rise in the SST and its persistence over April-May period resulted in the inevitable MCB for Andaman reefs in 2010. It was observed that not only corals but many other reef associate fauna like sea anemones and giant clams (who also have zooxanthellae association) bleached during this MCB event. Visual signals of large-scale MCB became apparent from May, 2010 and August 2010 reef surveys confirmed growth of filamentous algae on dead corals (Fig. 4 images and Fig.5 graph).

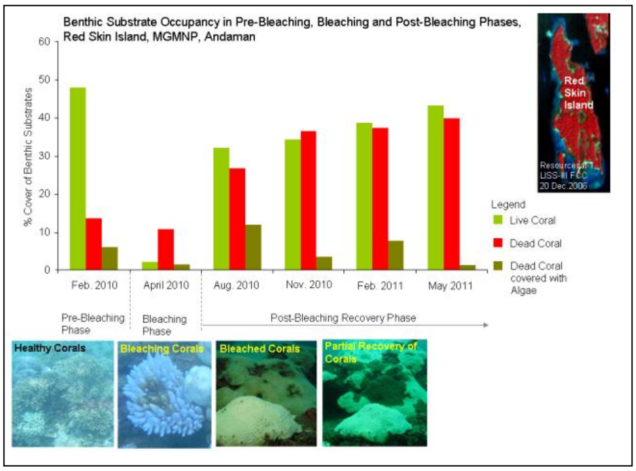


Fig. 5: Monitoring post-bleaching reef recovery in Red Skin Island, MGMNP, Andaman

Partial recovery was noticed since the post-monsoon surveys of November, 2010 (Fig. 5). Interestingly reef associates like sea anemones and giant clams recovered fast compared to corals. Within a year's time the reefs of Mahatma Gandhi Marine National Park (MGMNP) in Andaman has shown enough resilience to match its original live coral cover but the recovery process is still continuing.

6. Trajectories for Future

Undoubtedly this precious marine ecosystem of the tropical seas stands as a fragile empire today! Genus or species specific bleaching response of corals and their successive recovery are areas of research which need serious dedicated attention. It has been observed that delicate branching corals like Acropora are more vulnerable to bleaching as compared to massive corals like Porites. This calls for developing a systematic database on region and species specific historic coral bleaching records and a robust monitoring network dedicated to the bleaching events. Region and species specific thermal bleaching thresholds are slowly becoming necessary for effective conservation of this endangered ecosystem through the worldwide network of national Marine Protected Area or MPAs. Aided with constant satellite surveillance, mankind should join hands to save coral reefs from becoming silent sentinels in ocean, frequently signaling distress alerts with earth's changing climate.

Acknowledgements

Author is thankful to Director, Space Applications Centre and Deputy Director, EPSA/SAC for their constant encouragement, support and overall guidance to monitor coral reefs under various programmes related to Earth Observation Applications Mission. Author thanks Dr. Sushma Panigrahy, former Group Director, ABHG/EPSA/SAC for her support and interest in the study. Field support and contribution of the dedicated research team from Division of Fisheries Science, Central Agricultural Research Institute (CARI), Port Blair, Andaman is acknowledged with thanks.

References

- Ajai et al. 2012. *Coastal Zones of India*. Space Applications Centre, (ISRO). Ahmedabad.
- Ajith Kumar, T. T. and Balasubramanian T. 2012. Bleaching of corals in Agatti-Lakshadweep, India: A window view. Proc. 12th Intl. Coral Reef Symp. Cairns, Australia, 9-13 July 2012.
- (http://www.icrs.2012.com/proceedings/manuscript/icrs2012_9A/1.pdf)
- Bahuguna, A. 2008. Impact of climate change on coral reefs. *ISG Newsletter*, ***14***(1-4), 44-48.

- Bahuguna et al. 2008 *Assessment of coral reef health using satellite data.* Space Applications Centre, (ISRO), Ahmedabad.

- Baker, A. C., Glynn, P. W. and Riegl, B. 2008. Climate Change and coral reef bleaching: An ecological assessment of long-term impacts, recovery trends and future outlook. Estaur. Coast. Shelf Sci. **18**, 1-37.

- Brown B. E. 1997. Coral bleaching: causes and consequences. *Coral Reefs*. **16**. S129 – S138.

- Hoegh-Guldberg, O. 1999. Climate change, coral bleaching and the future of the world's coral reefs. GREENPEACE Report.

- Hoegh-Guldberg, O. et al. 2007. Coral reefs under rapid climate change and ocean acidification. *Science*, **318**, 1737-1742.

- Hoegh-Guldberg, O., Hoegh-Guldberg, H., Veron, J.E.N., Green, A., Gomez, E. D., Lough, J., King, M., Ambariyanto, Hansen, L., Cinner, J., Dews, G., Russ, G., Schuttenberg, H. Z., Peñaflor, E.L., Eakin, C. M., Christensen, T. R. L., Abbey, M., Areki, F., Kosaka, R. A., Tewfik, A., Oliver, J. 2009. The coral triangle and climate change: Ecosystems, people and societies at risk. WWF Australia, Brisbane. (Referred in figure 3).

- http://www.wri.org › ... › People & Ecosystems › Reefs at Risk Revisited (Referred in figure 3) .http://www.coralreefwatch-satops.noaa.gov.

- Krishnan, P., Dam Roy, S. George, G., Srivastava, R.C., Anand, A. Murugesan, A. Kaliyamoorthy, M. Vikas, N. and Soundararajan, R. 2011. Elevated sea surface temperature during May 2010 induces mass bleaching of corals in the Andaman. *Current Science*. **100** (1), 111-117.

- Kumaraguru A. K., Jayakumar, K. & Ramakritinan, C. M. (2003). Coral bleaching 2002 in the Palk Bay, southeast coast of India. *Current Science*, **85**(12), 1787-1793.

- Lesser, M. P. 2004. Experimental biology of coral reef ecosystems. *Journal of Experimental Marine Biology and Ecology*. **300**. 217-252.

- Navalgund et al. 2010 *Coral Reef Atlas of the World Vol.1 Central Indian Ocean*, Space Applications Centre, (ISRO), Ahmedabad.

- Nayak S. R. & Bahuguna, A. 1997. *Coral Reef Atlas of India*: Space Applications Centre (ISRO), Ahmedabad.

- Nicholls, R. J., Wong, P. P., Burkett, V. R., Codignotto, J. E., Hay, R. F., McLean, S., Ragoonaden S., & Woodroffe, C. D. 2007. Coastal systems and low-lying areas. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, & C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 315-356.

- Parry, M.L., Canziani, O. F., Palutikof, J. P., Linden van der P. J., & Hanson, C. E., Eds. 2007. Cross-chapter case study. In: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, UK, 843-868.

- Raven, J. 2005. Ocean acidification due to increasing atmospheric carbon dioxide. *The Royal Society Report produced by Working Group chaired by Raven J*, Clyvedon Press Ltd.Cardiff, UK.

- Reaser, J. K., Pomerance, R. Thomas, P.O. 2000.Coral bleaching and global climate change: Scientific findings and policy recommendations. *Conservation Biology.* **14**(5), 1500-1511.

- Toth, L.T., Aronson, R.B., Vollmer, S.V., Hobbs, J.W., Urrego, D.H., Cheng, H., Enochs, I. C., Combosch, D.J., Woesik, R. and Macintyre, I. G. 2012. ENSO drove 2500-year collapse of eastern Pacific coral reefs. *Science,* **337**, 81-84.

- Venkataraman, K., Satyanarayana, Ch., Alfred, J.R.B. and Wolstenholme, J. 2003. *Handbook on Hard Corals of India*, Zoological Survey of India, Kolkata.

- Venkataraman K. 2011. Coral reefs of India. In David Hopley (ed.) *Encyclopedia of Modern Coral Reefs*. Springer. 267-275.

- Vivekanandan, E., Ali M. H., Jasper, B. and Rajagopalan, M. 2009. Vulnerability of corals to warming of the Indian seas: a projection for the 21st century. *Current Science*. **97**(11). 1654 -1658.

- Wilkinson, C. (ed.) 2000. *Status of Coral Reefs of the World: 2000*. Australian Institute of Marine Science. Townsville. Australia.

Climate Change and Water Security: An Indian Perspective

R K Mall

Institute of Environment & Sustainable Development

Banaras Hindu University, Varanasi

E-mail: mall_raj@rediffmail.com, rkmall@bhu.ac.in

Introduction

The United Nations Environment Programme (UNEP) defines water security as: "*water security represents a unifying element supplying humanity with drinking water, hygiene and sanitation, food and fish, industrial resources, energy, transportation and natural amenities, all dependent upon maintaining ecosystem health and productivity*." World water planner now understands that climate change will affect the water security of developing countries and policymakers need better information about the regional impact of climate change on water supplies, and on ways of adapting to it.

Water resources occupy a special place among other natural resources. Water is the most widely distributed substance on our planet: albeit in the different amounts, it is available everywhere and plays a vital role in both the environment and human life. Understanding the problem of fresh water scarcity begins by considering the distribution of water on the planet. Approximately 97.5% of water is saline and only 2.5% is fresh on the earth. Of that 2% almost 68.6% is ice caps, permanent snow and glaciers 30% is in the groundwater. Less than 0.3% of all freshwater is in rivers, lakes, and the atmosphere, and an even smaller amount of the Earth's freshwater (0.003%) are contained within biological bodies and manufactured products (Gleick, 1993). Fresh water is crucial to community-not just for drinking, but also for agriculture, Industry and many other activities. It is expected to become increasingly scarce in the future, and this is partly due to climate change. Protecting the world's freshwater resources requires diagnosing threats over a broad range of scales, from global to local (Vorosmarty et al., 2010).

Water scarcity and conflicts are the symptoms of an increasing gap between water demand and supply. In India, increasing water shortage and declining water quality from pollution during the past few decades has drawn attention to the inherent fragility and scarcity of water and led to concern about water availability to meet the requirements of the 21st Century. Because of increasing population and changing patterns of water use in India, additional demand is likely to be accompanied by a sharp decline in per capita water availability. Lack of fresh water to drink, agriculture and for use in industry and for multitude of other purposes where water is essential, is a limiting factor –hindering development in many parts of the globe. China, India, Peru, or Bolivia struggle with establishing basic water services like clean drinking water and sanitation, and emerge here as regions of greatest adjusted human water security threat. Lack of water infrastructure yields direct economic impacts (WHO/UNICEF, 2010). Given escalating trends in species extinction, human population, climate change, water use and development pressures, freshwater systems will remain under threat well into the future. For Organization for Economic Co-operation and Development (OECD) and BRIC (Brazil, Russia, India and China) countries alone, 800 billion US dollars per year will be required in 2015 to cover investments in water infrastructure, a target likely to go unmet (Ashley and Cashman, 2006; Vorosmarty et al., 2010).

India accounts for about 17.5 % of the world's population and roughly 4% of the total available fresh water resources. Ground water resources provide for more than 60% of the irrigated land which has already depleted to large extent in many pockets of the country. (Mall et al., 2010; INCCA, 2010; Kumar, 2013). The average annual rainfall including snowfall in India is 4000 Billion Cubic Metres (b.cu.m.) and natural runoff as per the estimate of Central Water Commission (CWC) is 1869 b.cu.m as documented by *National Water Mission-2010*. However, due to the uneven nature of distribution of surface water resources and topographic constraints only 690 b.cu.m can be utilized of the available water resources. The Central Ground Water Board (CGWB) has assessed the quantum of replenishable ground water as 433 b.cu.m. The net utilizable water resources can be summed up as 1122 b.cu.m. The current utilization from surface and groundwater resources is about 63 and 37 percent respectively.

It is projected by Ministry of Water Resources, India that total water requirement for different sectors for the year 2010 and 2025 will be 813 and 1093 b.cu.m respectively (Planning Commission of India, 2007). The projected demand represents that it will be possible to meet the future demands of water by 2025 only by exploiting almost all the utilizable available water resources.

With the growing recognition of the possibility of global climate change, an increasing emphasis on the assessment of future availability of water resources on various spatial and temporal scales is needed. A warmer climate will accelerates the hydrologic cycle, altering rainfall, magnitude and timing of runoff and warm air holds more moisture and increase evaporation of surface moisture (Figure 1). With more moisture in the atmosphere, rainfall and snowfall events tend to be more intense, increasing the potential for floods. However, where there is little or no moisture in the soil to evaporate the incident solar radiation goes into raising the temperature, which could contribute to longer and more severe droughts (Mall et al., 2006). This type of change in climate will affect the soil moisture, groundwater recharge and the frequency of flood or drought episodes and finally level of ground water in different areas at different type of rates and scenarios A number of studies have been reported in the literature to assess the impact of climate change scenarios on hydrology of various basins and regions (Milly et al., 2002; Mall et al., 2006; Gosain et al., 2006; MoEF, 2010; Viviroli et al., 2011; Moors et al., 2011; Roy et al., 2013).

Water resources will come under increasing pressure in Indian subcontinent due to the changing climate. The climate affects the demand for water as well as the supply and quality. Particularly, in arid and semi-arid regions of India any shortfall in water supply multiplied with climate change will enhance competition for water use for a wide range of economic, social and environmental applications. In the future scenarios, larger population will lead to heightened demand for irrigation and perhaps industrialization at the expense of drinking water. Disputes over water resources may well be a significant social consequence in an environment degraded by pollution and stressed by climate change. **UN Commission for Sustainable Development,** Second Session, New York, 1994 noted as "*As the crisis approaches and as water resources become scarcer, the risk of conflict over them will became greater. After 2025 AD climate change could also make conditions worse if rainfall amounts decreases in the major food producing regions and evaporation rates increase. Urgent and decisive action must begin now if impending water crisis of a national proportions later in the 21st Century-are to be avoided during the next 30 years.*" On the **United Nations News Centre** website on March 4th, 2008, the following message also drew world-wide attention: UN warns of climate change effects on water shortages ***"****The UN Food and Agricultural Organization has warned in a new report that climate change is likely to reduce agricultural output and make water shortages in the Middle East worse, threatening the poor of the region. The report warns of an increased risk of conflict over scarce resources, and predicts that an extra 155–600 million people could experience additional water stress if* *temperatures increase by a few degrees"* (www.un.org/News).

Assessing the potential socioeconomic impacts of climate change involves comparing two future scenarios, one with and one without climate change. Uncertainties involved in such an assessment include: (1) the timing, magnitude and nature of climate change; (2) the ability of ecosystems to adopt either naturally or through managed intervention to the change; (3) future increase in population and economic activities and their impacts on natural resources systems; and (4) how society adapts through the normal responses of individuals and businessman and through policy changes that after the opportunities and incentives to respond. The uncertainties, the long time periods involved and the potential for catastrophic and irreversible impacts on natural resources systems raise questions as to how to evaluate climate impacts and investments and other policies that would affect or be affected by changes in the climate. In view of the above, an attempt has been made in this study to give a brief resume of water resources and climate change and way for a sustainable water management in India.

India's Rainfall, Population, Food and Freshwater Needs

Long period average annual rainfall over the contiguous Indian area is about 117 cm; however, this rainfall is highly variable both in time and in space. Almost 75% (88 cm + 10 SD) of the long average annual rainfall comes down in the four months of June to September(SW monsoon).The heaviest rains of the order of 200-400 cm or even more occur over northeast India and along the Western Ghats situated along the west coast of the of the peninsular India. Largely, the annual average rainfall over the northern Indo-Gangetic plains running parallel to the foothills of the Himalayas varies from about 150 cm in the east to 50 cm in the west. Over the central parts of the India and northern half of the peninsular India, it varies from 150 cm in the eastern half to about 50 cm on the lee side of the Western ghats. In the Southern half of the Indian peninsula, average annual rainfall varies from 100 cm to 75 cm as we go from east to west. On the other hand, some regions in the extreme western part of the country, such as western Rajasthan, receive average annual rainfall, which is of the order of about 15 cm or even less. There are considerable intra-seasonal and inter-seasonal variations as well (Source: IMD).

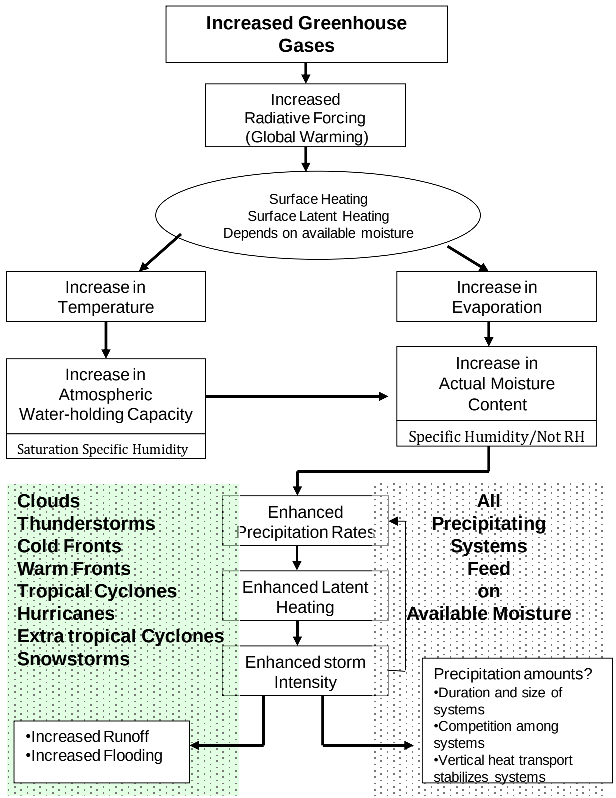


Figure 1: Conceptual model of the effect of greenhouse gases and global warming on the hydrologic cycle and phenomena associated with many climate extremes. (Source: Trenberth, 1999; Mall et al., 2006)

Droughts, floods and desertification are directly connected with monsoon/rainfall patterns, ocean circulation and soil moisture and water availability. As discussed above the problem of Indian rainfall are diverse, in terms of both geographical distribution and seasonality, and spread over a period of years. There are large variations in the total rainfall received in each geographical division, causing both droughts and floods. The fury of these natural disasters has arguably been more intense and more frequent by the abuse of nature and degradation of environment. The adverse impacts of these two natural disasters cannot be assessed merely in economic terms based on destruction of crops, property and infrastructure because the toll of human misery in the form of death, disease, injury, loss of employment, psychological trauma, and above all the set-back to development are too difficult to evaluate (Revi, 2008; Mall et al., 2011).

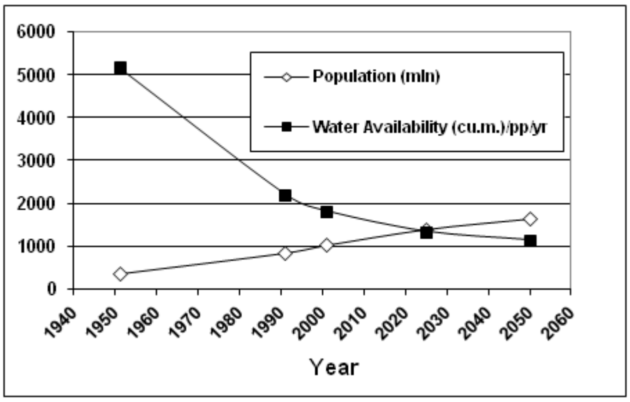


Figure 2. Observed and projected decline in per capita average annual freshwater availability and growth of population from 1951 to 2050 (source: mall et al., 2006)

A major part of India's population of 1,210 millions with decadal growth of 17.64% from 2001-2011 is rural and agriculturally oriented for whom the rivers and groundwater are the source of their prosperity. The United Nation has estimated that the world population grew at an annual rate of 1.09% during 2000-2010. China registered a much lower annual rate of growth (0.47%) along with USA as 0.75% during 2000-2010, as compared to India (1.41% during 2001-2011). However, country's population is expected to reach a level of around 1,390 million by 2025 and 1,700 million by 2050 (Census of India, 2011).

In India, average food consumption at present is 550 gm per capita per day whereas the corresponding figures in China and USA are 980 gm and 2850 gm respectively. Present annual requirement based on present consumption level (550 gm) for the country is about 230 Mt., which is almost equal to the current production. While the area under foodgrain, for instance, fell from 126.67 mha to 122 during the period from 1980-81 to 2008-09, the production registered as increase from 129.59 Mt. to 234 Mt. during that period. The food grain production looked quite impressive in 2008-09, which is more than 4 times the production of 50.82 Mt in 1950-51 (Source: Directorate of Economics and Statistics, Ministry of Agriculture, New Delhi, India). It is feared that the fast increasing demand in next two or three decades could be quite grim particularly in view of serious problem of soil degradation. The total gross irrigated area has nearly trebled from 22.6 mha in 1950-51 to 75.94 in 2008-09. The per capita average annual freshwater availability has reduced from 5177 cubic meters from 1951 to about 1820 cubic meters in 2001 and is estimated to further come down to 1341 cubic meters (projected) in 2025 and 1140 cubic meters (projected) in 2050 (MoWR, 2003; NWM, 2010). This clearly indicates the 'two sided' effect on water resources - the rise in population will increase the demand of water leading to faster withdrawal of water and this in turn would reduce the recharging time of the water tables (figure 2). As a result, availability of water is bound to reach critical levels sooner or later.

Present Water Resources Scenarios

Surface Water Resources

India has a large and intricate network of river systems of which the most prominent are the Himalayan river systems draining the major plains of the country. Apart from this, the numerous water bodies present in the subcontinent make it one of the wettest places in the world after South America. The annual precipitation including snowfall, which is the main source of the water in the country, is estimated to be of the order of 4000 billion cubic metres (BCM). The Resource potential of the country, which occurs as natural run off in the rivers is about 1869 cu.km. as per the basin wise latest estimates of Central Water Commission, considering both surface and ground water as one system. Ganga-Brahmaputra-Meghna system is the major contributor to total water resources potential of the country. Its share is about 60 percent in total water resources potential of the various rivers. Based on 2001 census, the per capita freshwater availability of water works out to 1820 cu.m. Due to various constraints of topography, uneven distribution of resource over space and time, it has been estimated that only about 1123 BCM. of total potential of 1869 BCM. can be put to beneficial use, 690 BCM. being due to surface water resources. Again about 40 percent of uitlisable surface water resources are presently in Ganga-Brhamputra-Meghna system. In majority of river basins, present utilisation is significantly high and is in the range of 50 percent to 95 percent of utilisable surface resources. But in the rivers such as Narmada and Mahanadi percentage utilisation is quite low. The corresponding values for these basins are 23 percent aud 34 percent respectively.

Ground Water Resources

Groundwater is a replenishable, finite resource. Rainfall is the principle sources of its recharge, though in some areas canal seepage and return flow from irrigation also contribute significantly to the groundwater recharge. Groundwater resources comprises of two parts namely dynamic, in the zone of water table fluctuation and static resource, blow this zone, which usually remains perennially saturated. As per the National Water Policy, 2002, the dynamic groundwater resource is essentially the exploitable quantity of groundwater, which is recharged annually, and is also termed as replenish able groundwater resource. The annual replenishable groundwater resource of the country is 433 billion Cubic metres (bcm) and the net groundwater availability is 399 bcm after allocating 34 bcm for natural discharges during non-monsoon season. The annual groundwater draft for the year 2004 was 231 bcm, out of which 213 bcm is utilized for irrigation and 18 bcm is used for domestic and industrial purposes. Overall stage groundwater development is 58% (Rana Chatterjee, 2009). However, 1615 assessment units fall under semi-critical (550), critical (226) and over Exploited (839) category, indicating that the groundwater resources in these areas are already being developed, more than that is being recharged. Further areas of the 30 assessment units are completely covered by saline groundwater. The rainfall contributes 67% of the country's annual replenishable groundwater resource (Rana Chattejee, 2009), indicating the dependence on rainfall for recharge of groundwater resources. The south west monsoon contributes 73% of the country's annual replenishable groundwater recharge, taking place during Kharif period of cultivation. The stage of groundwater development is high in the states of Delhi, Haryana, Punjab and Rajasthan and Union Territories of Daman & Diu, and Pondicherry, where the overall stage of groundwater development is more than 100%.

Water Development Use Scenarios
Water Demand

Water demand is growing fast due to a rapid population growth and economic activity, but water supply is not growing at the same rate because of serious financial and physical limits for supply augmentation. At present, available statistics on water demand shows that the agriculture sector is the largest consumer of water in India. About 83% of the available water is used for agriculture alone. The quantity of water required for agriculture has increased progressively through the years as more and more area was brought under irrigation. Irrigated area in India rose from 22.60 Million ha (1950-51) to 75.14 Million ha (2008-09). The contribution of surface and groundwater resources for irrigation has played a significant role in India attaining self-sufficiency in food production during the past 3 decades and is likely to become more critical in future in the context of national food security. According to available estimates, the demand on water in this sector is projected to decrease to about 68% by the year 2050 though agriculture will still remain the largest consumer. In order to meet this demand, augmentation of existing water resources by development of additional sources of water or conservation of the existing resources through impounding more water in the existing water bodies and its conjunctive use will be needed. In 1999, The National Commission for Integrated Water Resources Development (GOI, 1999) estimated the water requirements for the years 2010, 2025 and 2050 at the national level (Table 1).

Use Category	Year 2010			Year 2025			Year 2050		
	Low	**High**	**%**	**Low**	**High**	**%**	**Low**	**High**	**%**
Irrigation	543	557	78	561	611	72	628	817	68
Domestic	42	43	6	55	62	7	90	111	9
Industry	37	37	5	67	67	8	81	81	7
Power	18	19	3	31	33	4	63	70	6
Inland Navigation	7	7	1	10	10	1	15	15	1
Environmeal Ecology	5	5	0	10	10	1	20	20	2
Evaporatio Loss	42	42	1	50	50	6	76	76	7
Total	**694**	**710**	**100**	**784**	**843**	**100**	**973**	**1180**	**100**

Table 1. Projected water demand for India: 2010, 2025 and 2050 in BCM (Source: Report of the National Commission for Integrated Water Resources Development Plan, Ministry of Water Resources, Government of India, Volume 1, Sept., 1999, 542 p.p).

The Scarcity of Water

The scarcity of water is understood in a very simple terminology of supply demand imbalances. Initially, the good olden days, generations have grown up with an idea of water as a free gift of nature, meaning thereby, it is available in abundance against the then demand situation. Whereas, now it is a scarce resources (supply and the quality) against the enhanced demand. The challenge would be much more in coming years when the demand curve would shift upwards with relatively inelastic supply (demand growth rate would be higher than the supply growth rate) due to increased demand of agricultural , infrastructure development, uneconomic use, high population pressures etc. And, here is the challenge of management of increased demand and low supply (Saleth, 2011). Garg and Hassan (2007) pointed out that water scarcity is alarming and calls for urgent action before it becomes unmanageable. Das, S., (2008), has suggested climatic changes to global warming will make water an increasingly scarce commodity in the coming years.

Long Term Water Supply

Recent research studies predict that, if the demand–supply gap continues to increase, nine basins that have over four-fifths of the total water use in India will face physical water scarcity by 2050 (Amarasinghe et al., 2007a,b; 2009). For a heavily populated, monsoon-dependent and rural-based country, such as India, water scarcity of this magnitude will not only lead to serious water conflicts among sectors and regions, but also have a devastating effect on the food and livelihood fronts.

In order to fulfill water demands in the future, we will need to rationalize on the various means of capturing and storing water. Harvesting of rain water should contribute to meeting the future water requirements sustainability in India. The rivers and rivulets of the Indian sub continent are mainly monsoon fed with 80 to 90 percent runoff generated during the monsoon. The principle source for ground water recharge is also monsoon precipitation. The country receives more than 75% monsoon rainfall from June to September except in the eastern coast. Annually the rainy days vary from 12 to 100, and actual rainfall time varies from a few hours to over 300 hours. Incidences of upto 60 percent annual rainfall within a few days duration are not uncommon, which cause excessive runoff, taking a heavy toll of life, agriculture and property. The interannual variability of the monsoons is expected to increase in the future due to possible climate change making the monsoons less reliable as an assured source of water. Therefore, efforts are needed for more efficient groundwater recharge and harvesting of rainwater through identification, adoption and adaptation of technological options. Harnessing of excess monsoon runoff to create additional ground water storage will not only increase the availability of water to meet the growing demand but also help in controlling damages from floods.

The sub surface reservoirs are very attractive and technically feasible alternatives for storing surplus monsoon runoff, which can store substantial quantity of water. The sub surface reservoirs, located in suitable hydro geological situations, will be environment friendly and economically viable proposition. The sub surface storages have advantages of being free from the adverse effects like inundation of large surface area, loss of cultivable land, displacement of local population, substantial evaporation losses and sensitivity to earthquakes. The underground storage of water would also have beneficial influence on the existing ground water regime. The deeper water levels in many parts of the country either of natural occurrence or due to excessive ground water development, may be substantially raised, resulting in reduction on lifting costs and energy saving. The quality of natural ground water would substantially improve in brackish and saline areas. The conduit function of aquifers can further help in natural sub surface transfer of water to various need centres, thereby reducing the cost intensive surface water conveyance system. The effluence resulting from such sub surface storage of various surface intersection points in the form of spring line, or stream emergence, would enhance the river flows and improve the degraded eco-system of river tracts, particularly in the outfall areas. The structures required for recharging ground water reservoirs are of small dimensions and cost effective such as check dams, percolation tanks, surface spreading basins, pits, sub-surface dykes, etc. and these can be constructed with local knowledge.

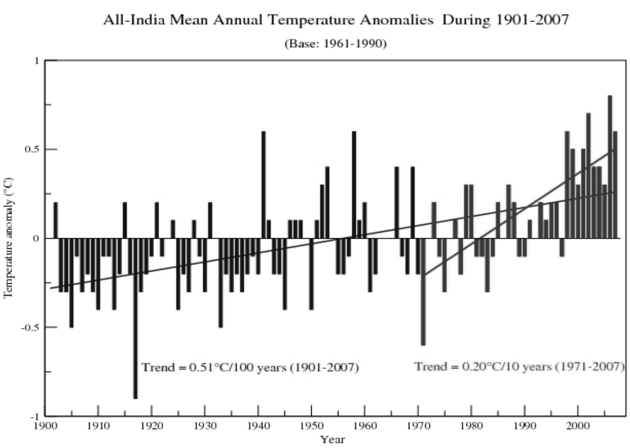


Figure 3 All India Mean annual temperature anomalies during 1901-2007 (Source: IITM, Pune).

Much of the future demand will need to be met from the groundwater resources, which may have immense potential. The water potential of the Ganga valley can irrigate an additional 200 Mha of land which can sustain rice productivity of about 4 tonnes per hectare and can produce another 80 million tonnes of rice that can sustain another 350-400 million people[60]. The excess water requirement in the future can, however, only is made through properly planned and precise management. Studies carried out for the Ganga basin need to be conducted for all major river basins in the country in order to discover additional potential sources of water such as deep artesian aquifers.

Observed Changes in Climate During 20th Century

In India, several studies shows that there is increasing trend in surface temperature i.e. 0.5 to 0.6^{o} C during 1901-2005 and 0.05^{o} C/decade year during the period 1901-2003 (figure 3), the recent period 1971-2003 has seen a relatively accelerated warming of 0.22^{o}C/decade, (Singh and Sontakke, 2002; Kothawale and Rupakumar, 2005; Mall et al. 2006; Das & Hunt 2007), no significant trend in rainfall and/or decreasing/increasing trends in rainfall and sharp decrease in rainy days (Singh and Sontakke, 2002; Goswami et al., 2006; Rajeevan et al., 2006; Ramesh and Goswami, 2007). Singh and Sontakke (2002) found that the summer monsoon rainfall over western Indo Gangetic Plain Region (IGPR) shows increasing trend (170 mm/100 yrs, significant at 1% level) from 1900, while over central IGPR it shows decreasing trend (5 mm/100 yrs, not significant) from 1939, and over eastern IGPR decreasing trend (50 mm/100 yrs, not significant) during 1900-1984, and insignificant increasing trend (480 mm/100 yrs, not significant) during 1984-1999. Broadly it is inferred that there has been a westward shift in rainfall activities over the IGPR. Recently Goswami et al (2006) found that the frequency of occurrence as well as intensity of heavy and very-heavy rainfall events have highly significant increasing trends; low and moderate events have significant decreasing trend over Central India. As is evident, floods and drought occurring in India are closely associated with the nature and extent of the summer monsoon. The interannual fluctuations in the summer monsoon rainfall over India are sufficiently large to cause devastating floods or serious droughts (figure 4).

Projected Climate during Coming Decades

IPCC (2007) projected an increase in global mean surface temperature of 1.4-.5.8°C, global mean precipitation at regional scales both increases and decreases are projected of typically 5- 20% and global mean sea level rise by 0.09 to 0.88m over the period 1999 to 2100, but with significant regional variations.

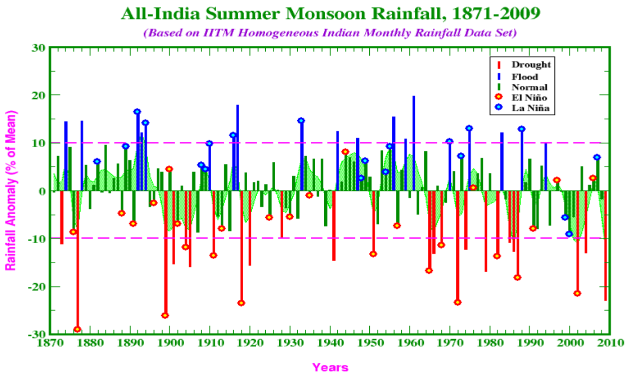


Figure 4: All India Summer Monsoon Rainfall, 1871-2009 (Source: IITM-Pune, India)

Climate models suggest that extreme precipitation events will become more common in an anthropogenically-warmed climate (IPCC, 2007; Rupa Kumar et al., 2006; Allen and Sodan, 2008). Recently, according to report published by Ministry of Environment and Forest, India (MoEF, 2010); the projection of precipitation indicates 3% to 7% overall increase in all India summer monsoon rainfall in 2030s with respect to the 1970s; the annual mean surface air temperature rise by 2030s range from 1.7-2.0°C and the variability of seasonal mean temperature may be more in winter months. This report also indicates that the frequency of rainy days is set to decrease in most part of the country and intensity of rain is going to increase, accept in the Himalayas, northwestern region and southern plateau. The daily extremes in surface temperature may intensify in the 2030s. The spatial pattern of the change in the lowest daily minimum and highest maximum temperature suggests a warming of 1 to 4°C towards 2030s. The fourth assessment report of IPCC and first assessment report of Indian Network of Climate Change Assessment (INCCA, 2010) has confirmed that in future, Climate change is expected to increase the frequency and intensity of current climate related hazards, greater monsoon variability and also the emergence of new hazards turning into disaster i.e. sea level rise and new vulnerabilities with differential spatial and socio-economic impacts on communities. Kumar et al (2011) observed that due to reduction in number of rainy days and an increase in the intensity of rainfall shown over many parts of India during 21st century would have direct implication for water security.

Hydrologic Implication Of Climate Change

Different General Climate Models (GCMs) linking atmospheric chemistry to complex atmospheric and oceanic processes are used to project climate variables such as temperatures and precipitation. Climate model projection vary widely depending upon assumptions as to future scenarios and the sensitivity of the climate to change in atmospheric chemistry and how the models incorporate factors such as cloud cover, ocean currents and land surface characteristics. While the wide range of projection from the different models, methodologies and assumptions make it difficult to draw conclusions at river basin and watershed levels, some pattern as to the likely impacts of a global warming on water resources do emerge. Some of the projected principal hydrologic impact noted in the IPCC (2007) and INCCA (2010) assessment are:

1. An increase in global mean temperature of 1.5 - 4.5° C would increase global mean precipitation about 3-15%.
2. Higher Evapotranspiration rates may lead to decrease runoff even in areas with increased precipitation.
3. More intense precipitation days are likely in some regions, which could contribute to an increase in food frequencies.

4. The frequency and severity of droughts could increase in some areas as a results of a decrease in rainfall more frequent dry spells and greater ET.
5. Higher temperatures would shift the relative amounts of snow and rain and the timing of runoff in mountainous areas. This shift could increase the likelihood of flooding early in the year and reduce the availability of water during period of high demands.

A case study of Orissa and West Bengal estimates that in the absence of protection, one-meter sea levels rise would inundate 1700 km2 of predominantly prime agricultural land (IPCC, 1992). The regional effects of climate change on various components of the hydrological cycle, namely surface run-off, soil moisture, and evapotranspiration (ET) for three-drainage basis of central India is analyzed and results indicated that the basin located in a comparatively drier region is more sensitive to climatic changes. The high probability of a significant effect of climate change on reservoir storage, especially for drier scenarios, necessitates the need of a further, more critical analysis of these effects.

The hydrologic sensitivity of the Kosi Basin to projected land-use, and potential climate change scenarios has been analyzed. It was found that runoff increase was higher than precipitation increase in all the potential climate change scenarios applying cotemporary temperature. The scenario of contemporary precipitation and a rise in temperature of 4o C caused a decrease in runoff by 2-8% depending upon the areas considered and model used (Sharma et al., 2000a, b).

Gosain et al. (2006) projected that the quantity of surface runoff due to climate change would vary across the river basins as well as sub basins in India. However, there is general reduction in the quantity of the available runoff. An increase in precipitation in the Mahanadi, Brahimini, Ganga, Godavari and Cauvery is projected under climate change scenario; however, the corresponding total runoff for all these basins does not increase. This may be due to increase in ET because of increased temperature or variation in the distribution of the rainfall. In the remaining basin, a decrease in precipitation noticed. Sabarmati and Luni basin shows drastic decrease in precipitation and consequent decrease of total runoff to the tune of 2/3rd of the prevailing runoff. This may lead to severe drought conditions in future. The analysis has revealed that climate change scenario may deteriorate the condition in terms of severity of droughts and intensity of floods in various parts of the country. There have been few more studies on climate change impacts on Indian water resources (Roy et al., 2003; Tangri, 2003).

Panda et al. (2007) studied the influence of repeated droughts and increased anthropogenic pressure on the groundwater levels of the state Orissa during the period 1994–2003. Preliminary study showed that the groundwater levels of the network observation wells are very sensitive to the monsoon rainfall, and any irregularity in rainfall directly influences the groundwater levels. Due to drought in 2002, the groundwater level dropped significantly in the consolidated formation that covers 80% of the geographical area of the state Orissa. The fitted curves of both the annual and monsoon rainfall indicated a downward trend although four wet years were experienced during the study period. The effect of droughts and high temperature on groundwater levels should be counterbalanced by the effect of flood, and over years it should remain stable. Mondal et al. (2011) used MODFLOW groundwater model and found that the total groundwater abstraction was about 80.43% of the groundwater recharge, but 10.25 was used up by evapotranspiration. The model was more sensitive to recharge from rainfall, hydraulic conductivity and specific yield. Shah (2009) concluded that by far the most critical response to hydro-climatic change in India's water sector demands exploring synergies from a variety of players for a nationwide groundwater recharge program. India's water policy has so far tended to focus on what governments and government agencies can do. Now, it needs to target networks of players, each with distinct capabilities and limitations. If groundwater recharge is to be a major response to hydro-climatic change, the country needs to evolve and work with an integrated groundwater recharge strategy with roles and space for various players to contribute.

Reddy et al (2008) reported that during 1990 to 2004 Kosi River shows a significant shift of 3.5 km in northwestern part, followed by central and north eastern parts of river with 2.5 km shift. Course change by the rivers is an environmental problem of serious concern in the Indo Gangetic Plain Region (IGPR). At different times in the past different rivers changed their course a number of times. During the period 1731-1963 the course of the Kosi river (the sorrow of Bihar) has shifted westward by about 125 km, the courses of Ganga, Ghaghara and son at their confluence have shifted by 35 to 50 km since epic period ~ 1000 BC and that of Indus and its tributaries by 10-30 km in the 1200 years in the same. Between 2500 BC and 500 the course of the Yamuna river shifted westward to join Indus and then east to join Ganga thrice (Mall et al., 2006).

Singh et al. (2009) highlighted the assessment of the water resources in changing climate for relevant national and regional long-term development strategies. Goyal (2004) studied the sensitivity of ET to global warming for arid regions of Rajasthan and projected an increase of 14.8% of total ET demand with increase in temperature, however ET is less sensitive to increase in solar radiation, followed by wind speed in comparison to temperature. Increase in water vapor has a negative impact on ET (-4.3%). He concluded that a marginal increase in ET demand due to global warming would have a larger impact on resource poor, fragile arid zone ecosystem of Rajasthan. Lal et al (2011) observed that the growing demand for food is being managed by over-pumping groundwater, a measure that virtually assures a drop in food production when the aquifer is depleted.

Roy et al (2013) studied the impacts of climate change (for A2, A1B and B2 scenarios) on water resources of the river basins of India, which have immense importance in domestic, industrial agricultural and hydropower scenario. They found that in A2 scenario (a disintegrated and regionalized world) destruction of vegetation and change in vegetation would be rampant and increase the deterioration of soil structure and water holding capacity of the basin; In B2 scenario (a world with strict implementation of emission law, but with no cooperation or between the countries) predict little less increase of runoff than the A2 scenario; and in A1B scenario (integrated world with moderate restrictions on emission and medium growth in industry) runoff will represent catchment response due to normal climate.

Climate Change Policy in India

The Government in India is actively involved with climate change activities since long. India is a Party to the United Nations Framework Convention on Climate Change (UNFCC). The Eight session of the Conference of Parties (COP-8) to the UN convention on Climate Change in 2002, New Delhi ended here with a Delhi Declaration has successfully resolved the technical parameters necessary for the implementation of the Kyoto Protocol (1997). The Delhi declaration gave primacy for the implementation of the Clean Development Mechanism (CDM) in the climate change process. The National Clean Development Mechanism Authority is operational since December 2003 to support implementation of CDM projects. The Bali conference on climate change (December 2009) showed all the countries the way forward to the next phase of the campaign to control the planet's changing climate, the specific objective being to put a multilateral arrangement in place that will succeed the 1997, Kyoto Protocol of the UN convention on Climate Change, which will terminate in 2012.

To address the future challenges, in June 2007, the Government announced the constitution of a high-level advisory group on climate change and prepared a **'National Action Plan on Climate Change'** and that was released by the Hon'ble Prime minister of India on June 30, 2008 (http:/pmindia.nic.in/Climate%20Change_16.03.09.pdf); which is in line with the international commitments and contains eight missions on climate mitigation and adaptation (NAPCC, 2008). Now relevant ministries are preparing and submitting their respective plans to the Prime Ministers Climate Change Council. One of the missions "**National Water Mission**" will be mounted to ensure integrated water resources management helping to conserve water, minimize wastage and ensure more equitable distribution both across and within states. The mission will take into account the provisions of National Water Policy and develop a framework to optimize water uses and by increasing water use efficiency by 20% through regulatory mechanism and differential entitlements and pricing. It will seek to ensure that considerable share of water needs or urban areas are met through recycling of waste water, and ensuring that the water requirements of coastal cities with inadequate alternative sources of water are met through adoption of new and appropriate technologies such as low temperature desalination technologies that allow for the use of ocean water (Singh et al., 2009).

Based on the this current study it may be mentioned that for long term adaptation from Climate Variability and Climate Change several policy instruments are available at different levels and these instruments are functioning in real sense even at the remote village levels but needs improved governance, productivity and accountability of the government machinery. Conversely, over the last two decades there has been a sharp decline in the quality of services provided by the government to its citizens, especially poor.

National Water Policy-2002 and National Water Mission-2010

National Water Policy (2002) states the vital importance of water for human and animal life, for maintaining ecological balance and for economic and developmental activities of all kinds, and considering its increasing scarcity, the planning and management of this resource and its optimal, economical and equitable use has become a matter of the utmost urgency. Concerns of the community need to be taken into account for water resources development and management. The success of the National Water Policy will depend entirely on evolving and maintaining a national consensus and commitment to its underlying principles and objectives.

National water Policy 2002 setup due to following objectives:

- Growth process and the expansion of economic activities inevitably lead to increasing demands for water for diverse purposes: domestic, industrial, agricultural, hydro-power, thermal-power, navigation, recreation, etc. So far, the major consumptive use of water has been for irrigation. While the gross irrigation potential is estimated to have increased from 19.5 million hectare at the time of independence toabout 95 million hectare by the end of the Year 1999-2000, further development of a substantial order is necessary if the food and fiber needs of our growing population are to be met with. The country's population which is over 1027 million (2001 AD) at present is expected to reach a level of around 1390million by 2025 AD.
- Production of food grains has increased from around 50 million tonnes in the fifties to about 208million tonnes in the Year 1999-2000. This will have to be raised to around 350 million tonnes by the year2025 AD. The drinking water needs of people and livestock have also to be met. Domestic and industrial water needs have largely been concentrated in or near major cities. However, the demand in rural areas is expected to increase sharply as the development programmes improve economic conditions of the rural masses. Demand for water for hydro and thermal power generation and for other industrial uses is also increasing substantially. As a result, water, which is already a scarce

resource, will become even scarcer infuture. This underscores the need for the utmost efficiency in water utilisation and a public awareness of the importance of its conservation.

- Another important aspect is water quality. Improvements in existing strategies, nnovation of new techniques resting on a strong science and technology base are needed to eliminate the pollution of surface and ground water resources, to improve water quality. Science and technology and training have to play important roles in water resources development and management in general.
- National Water Policy was adopted in September, 1987. Since then, a number of issues and challenges have emerged in the development and management of the water resources. Therefore, the National Water Policy (1987) has been reviewed and updated.

The *National Water Mission-2010* suggested some modification in the *National Water Policy*, which was documented in 1987, and was revised in 2002. The mission suggested that for climate change and water management:

1) *It promotes integrated water resource management in order to conserve water and reduce wastage*
2) *It strives to increase water use efficiency by 20%*
3) *It puts emphasis on recycling of waste water to meet a considerable share of the water requirements of the urban areas*
4) *It promotes adoption of modern technologies like desalination techniques to make ocean water usable*
5) *It revisits the National Water Policy (NWP) for better management of the river basins under the climate change scenario of variability in rainfall and river flows*
6) *It seeks to optimize the competence of existing irrigation systems and rehabilitation of the old ones*
7) *It puts emphasis on water neutral and water positive technologies*
8) *The mission seeks to advance*
   a) *Storage (both above and below ground),*
   b) *Rainwater harvesting,*
   c) *Recharging of ground water resources,*
   d) *Sprinklers, drip and ridge and furrow irrigations.*

3 Future Research Needs

It is clear from the above discussion that due to ever-increasing population and demands from various sectors including industry and agriculture the consumption of water is going to jump up in the coming decades and country will require substantial additional water supply to cater increasing demand in the coming decades. Now climate change also poses a threat to the water security of India. Climate change is just one of a number of factors influencing the hydrological system and water resources. Population growth, changes in land use, restructuring of the industrial sector, and demands for ecosystem protection and restoration are all occurring simultaneously. There are many opportunities to reduce the risks of climate variability and change for India's water resources. Past efforts have focused on minimizing the risks of natural variability. Many of the approaches for effectively dealing with climate change are different than the approaches already available to manage risks associated with existing variability. Tools for reducing these risks have traditionally included supply-side options such as new dams, reservoirs, and more recently improving efficiency. This is largely independent of the issue of climate change, which will have important implications for the ultimate severity of future water stresses. Records of past climate and hydrological conditions are no longer considered to be reliable guides to the future. The design and management of both structural and non-structural water-resource systems should allow for the possible effects of climate change, but little professional guidance is available in this area. Thus we may conclude that effective management of surface and groundwater water resources urgently requires more detailed regional / local studies and more reliable climate projections. While artificial groundwater recharges, rainwater harvesting and interbasin water transfers are a solution for meeting the water demand in the near-term, they are also solutions for increasing the potential utilizable water supply in many water scarce river basins.

The commonalities of monsoonal climate, the occurrences of extreme weather events, temporal and spatial variation in rainfall, shared river systems, the predominance of agriculture, the increase in human population and the increasing stress on scarce natural resource necessitate continued collaboration among different stakeholders / states / discipline in relation to water security and climate change. Therefore, further integrated research by civil engineers, hydrologists, water planner's/managers and academicians is needed to fill this gap, as is broader training of scientists in the universities. In addition, the knowledge exchange between them must be improved and oriented towards long-term continuous interaction. Government of India has formulated NAPCC with different missions to counter the impacts of climate change in India. These measures cannot be termed adequate until and unless they are implemented with a determined capacity and in proper direction.

Acknowledgements

I would like to express my gratitude to fellow colleagues Dr. Arijit Dey, Dr Y B Kaushik and Dr K.J. Anandha Kumar Central Ground Water Board, Ministry of Water Resources, Govt. of India for providing valuable information and advise in the preparation of this paper. I shall not forget to mention many thanks to Dr R D Singh, Director, National Institute of Hydrology, Roorkee and Prof A S Raghubanshi, Director, Institute of Environment and Sustainable Development, BHU for their suggestions and help during the study.

References:

- Amarasinghe U, T Shah, Malik R P S (Eds.) 2009: India's water future: Scenarios and issues, Colombo, Sri Lanka: International Water Management Institute, 417 p.
- Amarasinghe U, T Shah, Turral, H, Anand B, 2007a: India's water future to 2025-2050: Business as usual scenarios and deviations, Colombo, Sri Lanka: International Water Management Institute Research Report No. 123.
- Amarasinghe U, T Shah,and Singh O P: 2007b: Changing consumption patterns: Implications on food and water demand in India. Colombo, Sri Lanka: International Water Management Institute Research Report No. 119.
- Ashley, R. & Cashman, A. The impacts of change on the long-termfuture demand for water sector infrastructure. In: Infrastructure to 2030: Telecom, Land Transport, Water and Electricity Ch. 5 (Organization for Economic Co-operation and Development, 2006).
- Chatterjee R and R R Purohit, 2009, Estimation of replenishable groundwater resources of India and their status of utilization, Current Science, Vol 96(12), 1581-1591.
- Das, S., 2008 Five decades of Ground water Development in India, Changing Geohydrlogical Scenario, Hard rock Terrain of Peninsular India, Geological Society of India, Golden Jubilee Volume (xiii – xxix).
- Dash S. K. and Hunt C. R. 2007: Variability of climate change in India, Current Science, vol. 93, no. 6, pp 782-788.
- Garg, N. K. and Hassan, Q. 2007: Alarming scarcity of water in India. Current science, 93 (7) pp 932-941
- Gleick, P.H., ed. (1993). Water in Crisis: A Guide to the World's Freshwater Resources. Pages 504, Oxford University Press. p. 13, Table 2.1 "Water reserves on the earth".
- Gosain, A. K. , Rao, Sandhya and Basuray, Debajit: 2006, Climate change impact assessment on hydrology of Indian river basins, Current Science, 90 (3), 346-353.
- Goswami, B. N., V. Venugopal, D. Sengupta, M. S. Madhusoodanan, and P. K. Xavier, 2006: Increasing trend of extreme rain events over

India in a warming environment, Science. 314, 1442– 1445, doi:10.1126/science. 1132027.

- Goyal, R. K., Agricultual Water Management, 2004, 69, 1-11.
- Goyal, R. K., *Agricultual Water Management*, 2004, **69**, 1-11.
- INCCA, 2010: Indian Network of Climate Change Assessment, Climate Change and India: A 4X4 Assessment - A sectoral and regional analysis for 2030s, Ministry of Environment and Forest, New Delhi, India
- IPCC, 2007. "IPCC Fourth Assessment Report, Synthesis Report: Full Text." In: Encyclopedia of Earth, Stephen C. Nodvin (Topic Editor), Eds. Cutler J. Cleveland (Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment).
- Kothawale, D. R. and K. Rupa Kumar, 2005: On the recent changes in surface temperature trends over India. Geoph. Res. Letters, Vol. 32, L18714
- Kumar M and P P Kumar, 2013: Climate Change, Water Resources and Food Production: Some Highlights from India's Standpoint, Int. Res. Jr of Environment Sc., Vol. 2(1), 79-87 , January (2013) (ISSN 2319–1414)
- Kumar K. Krishna, K. Kamala, Rajagopalan, M Hoerling, Jon K. Eischeid , S. K. Patwardhan ,G. Srinivasan • B. N. Goswami, Ramakrishna Nemani , 2011: The once and future pulse of Indian monsoonal climate, Clim Dyn (2011) 36:2159–2170
- Lal, M 2011: Implications of climate change in sustained agricultural productivity in South Asia, Reg. Environ. Change, 11 (Suppl.1), S79-S94
- Mall R K, R. Bhatla and S. N. Pandey, 2007: "Water resources in India and impact of climate change", Jalvigyan Sameeksha (Min of Water Resources), Vol 22, 157-176.
- Mall R. K. and K J Anandha Kumar, 2010, 'Impact of Climate Change on Estimation of Groundwater Resources of India', In the Proc. of Workshop on Ground Water Resources Estimation, Central Ground Water Board & IIT-Delhi, New Delhi, February 23-24, 2010, pp 166-174.
- Mall R. K., A. Gupta, and K J Anandha Kumar, 2010, "Climate Change and Water Resources: Future Research Agenda", In the Lead Papers. 2010. National Symposium on Climate Change and Rainfed Agriculture, Indian Society of Dryland Agriculture, Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad, India. February 18-20, 2010. Pages 192,pp 63-84.
- Mall RK, Gupta A, Singh R and L S Rathore 2006: Water resources and climate change: An Indian perspective. CURRENT SCIENCE, Vol 90 (12), 1610-1626.
- Mall, R.K., Singh, Ranjeet, Srinivasan, G., Rathore, L. S. and Gupta, Akhilesh, 2006. 'Impact of climate change on Indian agriculture: a review" Int. Jr. of Climatic Change-Springer publ., 78, 445-478.
- Mall R K, R Kumar and R Bhatla, : 2011: Climate Change and Disasters in India, Journal of South Asia Disaster Studies, Journal of SAARC Disaster Management Centre, New Delhi, vol. 4 no. 1, pp 33-70.
- Milly, P. C. D., Wetherald, R. T., Dunne, K. A. and Delworth, T. L., Nature, 2002, 415, 514–517.
- MoEF, 2010: Climate change and India: A 4x4 Assessment – A Sectoral and regional Analysis for 2030s, November 2010, Ministry of Envirnment and Forest, Govt. of India, New Delhi, pp 160
- Mondal N C, V. P. Singh and S. Sankaran, 2011: Groundwater Flow Model for a Tannery Belt in southern India, Journal of Water Resource and Protection, 2011, 3, 85-97.
- Moors E J., A Groot, H Biemans, Catharie, Christian S, Markus Stoffel, C Huggel, A Wiltshir, C Mathison, J Ridley, D Jacob, P Kumar, S Bhadwal, A Gosain, D N Collins, 2011: Adaptation to changing water resources in the Ganges basin, northern India, Environmental Science and Policy,14 (2011) 758 – 769
- MoWR (Ministry of Water Resources), 2003: *Freshwater Year 2003*. Government of India, New Delhi, India, 53pp.
- MoWR (Ministry of Water Resources), 2003: *Vision for Integrated Water Resources*

Development and Management. Government of India, New Delhi, India, 20pp.

- NAPCC, 2008: National Action Plan on Climate Change (http:/pmindia.nic.in/Climate%20Change_16.03.09.pdf)
- Panda, D K, Mishra A., Jena S K., James B.K, Kumar A.,2007: The influence of drought and anthropogenic effects on groundwater levels in Orissa, India Journal of Hydrology, 343, 140– 153
- Planning Commission, 2007, Report of the Expert Group on Ground Water Management and Ownership. September 2007, New Delhi, pp 61.
- Rajeevan, et al., 2006: High resolution daily gridded rainfall data for Indian region: Analysis of break and active monsoon spells, Current Sci., 91, 296– 306.
- Ramesh, K. V. and Goswami, P., 2007: Reduction in temporal and spatial extent of the Indian summer monsoon. Geophy. Res. Letter, Vol. 34, L23704, doi:10.1029/2007 GL031613.
- Reddy S C., Rangaswamy M. and Jha C S 2008: Monitoring of spatio-Temporal Changes in part of Kosi River basin, Bihar, India using remote sensing and GIS, Research Journal of Environmental Sciences, 2(1): 58-62.
- Revi, A, 2008: Climate change risk: an adaptation and mitigation agenda for Indian cities, Environment and Urbanization, Vol. 20 (1), pp 207-229.Roy P K, Asis Mazumdar, 2013: Water Resources in India under Changed Climate Scenario, *International Journal of Engineering Research and Applications (IJERA)* Vol. 3, Issue 1, January -February 2013, pp.954-961, ISSN: 2248-9622 www.ijera.com
- Roy, P. K., Roy, D., Mazumdar, A., and Bose, B., Vulnerability assessment of the lower Ganga-Brahmaputra-Meghna basins, In the Proceedings of the NATCOM- V&A Workshop on Water Resources, Coastal Zones and Human Health, IIT Delhi, New Delhi, 27-28 June, 2003.
- Rupakumar, K., Sahai, A. K., Kumar, Krishna, K., Patwardhan, S. K., Mishra P. K., Revadkar, J.V., Kamala, K., and Pant, G.B.: 2006, High-resolution climate change scenarios for India for the 21st century, Current Science, vol. 90(3), 334-345.
- Saleth R M, 2011: Water scarcity and climate change in India: the need for water demand and supply management, Hydrological Sciences Jr., 56(4), 671-686.
- Shah T., 2009: Climate Change and Groundwater: India's opportunities for mitigation and adaptation, Environ. Res. Lett. 4, 1-13.
- Sharma, K. P., Moore III, B., Vorosmarty, C. J. 2000 (a): Anthropogenic, climatic, and hydrologic trends in the Kosi Basin, Himalaya. Climatic Change, 47 (1-2), 141-165.
- Singh R D, M Arora and Rakesh Kumar, 2009: Climate change impact on Water Resources in India, *Mausam*, (Diamond Jubilee volume, 2009), 91-100
- Singh, N. and Sontakke, N.A. 2002: On climatic fluctuations and environmental changes of the Indo-Gangetic plains, India. Climatic Change, 52, 287-313.
- Tangri, C.D.: 2003: Impact of climate change on Himalayan glaciers. In the Proceedings of the NATCOM- V&A Workshop on Water Resources, Coastal Zones and Human Health, IIT Delhi, New Delhi, 27-28 June, 2003.
- Trenberth, K. E., Nat. Implications Environ. Change, 1999, 5, 2– 15.
- Viviroli D., D. R. Archer, W. Buytaert, H. J. Fowler, G. B. Greenwood, A. F. Hamlet, Y. Huang, G. Koboltschnig, M. I. Litaor, J. I. L´opez-Moreno, S. Lorentz, B. Sch¨adler, H. Schreier, K. Schwaiger. Vuille, and R. Woods 2011: Climate change and mountain water resources: overview and recommendations for research, management and policy, Hydrol. Earth Syst. Sci., 15, 471–504, 2011
- Vorosmarty, C. J, P. B. McIntyre, M. O. Gessner, D. Dudgeon, A. Prusevich, P. Green, S. Glidden, S. E. Bunn, C. A. Sullivan, C. R Liermann & P. M. Davies, 2010: Global threats to human water security and river biodiversity, Nature, Vol. 467, pp 555-561 (2010)
- WHO/UNICEF. Progress on Sanitation and Drinking-Water: 2010 Update. Joint Monitoring Programme for Water Supply and Sanitation (World Health Organisation/UNICEF, 2010).

Satellite Remote Sensing for Climate Change in Terrestrial Biosphere

C. P. Singh, R. P. Singh, S. K. Goroshi, J. S. Parihar, N. Dharaiya*

Space Applications Centre, ISRO, Ahmedabad

*** Department of Life Sciences, HNG University, Patan**

E-mail: cpsingh@sac.isro.gov.in

Introduction

Many categories of scientists study the terrestrial biosphere with various perspectives, using many kinds of tools. Some go into the field to study animals and plants in their native environments. Some study cellular processes in the laboratory with sophisticated equipments. Some do experiments to see how changes in the environment result in changes in the organism. Space scientists use remote sensing to observe a section of the earth each orbit, and then combine the data from many orbits to recreate a region or the whole earth at once. Sensors in space observe the earth in many different wavelengths of light. Combinations of these images are used to determine what is growing in each patch of the earth, and even if it is healthy or not. As sensors get better and more sensitive, the size of the smallest patch that can be observed from space gets smaller and smaller - to within a few meters now. Remote sensing data can be used in estimating biomass, soil moisture, changes in elevation, or even animal population densities. At a smaller scale, other scientists may investigate the processes involved in cycling water and the elements of life through the biosphere: carbon, nitrogen, sulfur, phosphorous, and other elements. These studies can also provide "ground-truth" - observations on the ground which are used to validate the remotely sensed data.

Climate change research poses significant challenges to the scientific community. Physical and biological scientists or natural scientists have grappled with the challenges of data requirements for decades and have identified the utility of satellite remote sensors as major sources of consistent, continuous data for atmospheric, ocean, and land studies at a variety of spatial and temporal scales. An extensive body of literature within numerous natural science disciplines documents the development of, or potential for, satellite sensor data analysis techniques to identify environmental attributes and monitor physical and biological processes relevant to global change research. Satellite sensor data have proven useful to the scientific communities interested in investigating climate change impact, indicators and agents in terrestrial biosphere. The terrestrial biosphere sciences community has made extensive use of satellite image data for mapping land cover, estimating geophysical and biophysical characteristics of terrain features, and monitoring changes in land cover. The role of satellite image data for contributing to studies of bioclimatology is also coming in big way.

More recently, the scientific community has witnessed a growing emphasis placed on investigating the human dimensions of global change. Human dimensions studies of global change must be "grounded" in general within the context of specific nature-society issues and in particular space-time relationships in affecting human behavior in "Land Use and Land Cover in Global Environmental Change." Defining and locating various types of society-land cover interactions for study may pose new challenges for social scientists and challenges are there for space scientists to find out inter comparable data and model to measure these changes in spatial and temporal dimensions. Satellite remote sensing can serve as major sources of data on the effects of human behavior within the biosphere, enabling the establishment of the spatial scale and extent of the direct interaction of humans with the global land cover.

With a view to understand the underlying science aspects, ISRO on its part, through its focused ISRO Geosphere Biosphere Programme (ISRO GBP), has been pursuing on a climate research programme for the past two decades with specific focus on studying atmospheric aerosols, trace gases, GHGs, paleoclimate, land cover change, atmospheric boundary layer dynamics, energy and mass exchange in the vegetative systems, National Carbon Project (NCP) and Regional Climate Modeling (RCM). ISRO has also carried out extensive campaigns with integrated satellite, aircraft, balloon and ground-based measurements jointly with many sister institutions in the country to study quantitatively the above aspects. Many studies have been carried out towards mapping and monitoring of climate change indicators, which include glacier retreat, changes in polar ice cover, terrestrial hydrology, alpine treeline change, coral bleaching, impact on mangroves, impact on horticulture / agriculture etc. These studies have identified the already caused impacts of temperature rise and increased CO_2 levels in atmosphere.

Past 25 years have seen advances in mapping technique to prepare maps with much more information. With growing number of Indian Remote Sensing satellites and their resolutions refinements we are witnessing a greater capability of environmental change analysis. As for as the resolutions are concerned, of specific advantage is the spectral, temporal, and spatial resolution. Spectral resolution refers to the width or range of each spectral band in which observation is recorded. Since, each target affects different wavelengths of incident energy differently; they are absorbed, reflected or transmitted in different proportions. Currently, there are many land resource remote sensing satellites that have sensors operating in the green, red, near infrared and short wave infrared regions of the electromagnetic spectrum giving a definite spectral signature of various targets due to difference in radiation absorption and reflectance of targets. These sensors are of common use for land cover studies, including forest. Multi-sensor remote sensing data has been used for identifying the changes in various terrestrial ecosystems and mapping the country's biodiversity at landscape levels.

Satellite remote sensing is of particular assistance for spatial database creation and is of particular significance in the context of Himalayan studies considering the terrain condition, large extent and difficulty in accessibility for intensive *in-situ* observations. Of the medium-resolution data sets being used for alpine treeline change studies, Landsat satellite platforms gives us the advantage of availability of past orthorectified data. In remote sensing studies of terrestrial vegetation, spectral vegetation indices are normally used. Among all vegetation indices, NDVI (Normalised Difference Vegetation Index) is widely used in detecting vegetation change, vegetation greenness, and vegetation status, as it has good correlation with canopy cover and leaf area index (Myneni *et al*. 1997, Kawabata *et al*. 2001, Steven *et al*. 2003).

The Indian EOS has emerged as a strong constellation of geosationary and polar orbiting satellites to provide the data for mapping and monitoring of ecosystems, detecting the changes in various temporal and spatial scales and retrieval of various geophysical parameters and monitoring our ecosystems. The current remote sensing satellites are theme-specific satellites, with a constellation of ten satellites in operation (Technology Experiment Satellite - TES, Resourcesat-2, and Cartosat-1, 2, 2a & 2b, IMS-1, RISAT-1 & 2, Oceansat-2). The spatial resolution ranges from 55m (AWiFS) to 5.8 m (LISS-4) in multispectral domain with a few days to a few weeks revisiting capability, thereby offering a better scope for such studies. Cartosat-1 provides high-resolution (2.5 m spatial resolution) panchromatic data in the stereo mode, making it possible to generate Digital Terrain Model (DTM) for such applications. The Cartosat-2 is designed to provide much higher resolution stereo data (0.8 m spatial resolution) for cartographic mapping. It is also planned to use the complementary and supplementary data from the other national (Geo-HR-Imager & INSAT systems) international missions to augment the data sources for natural resource monitoring and climate change research in India.

As more and more observational data becoming available from suites of space based sensors and various sets of experimental data becoming available through many designed samplings throughout the country for different ecosystem, it is possible to construct models to help us understand the terrestrial biosphere, how it evolved and functioning, and even providing tools that allow for predicting the future response of the biosphere to global change and human activities. This article is bringing some of the studies being done using space based data and techniques in this direction towards understanding various ecosystems in terrestrial biosphere and its drivers.

Climate Change and Carbon Management: Across the Indian sub-continent, human-driven land use and climate changes are changing the structure, functioning and spatial extent of ecosystems. These changes in natural ecosystems also provide a potential opportunity to increase carbon sink capacity and thereby may contribute in mitigating climate change impacts. A substantial area of degraded land in India (known through Wasteland atlases) can be brought under ecological restoration through a vegetation management plan. Using space based inputs Green India Mission can be made a reality and potential carbon sinks / sources can be quantified (fig.1). ISRO's flux towers and India's Council of Scientific and Industrial Research's Long-term Ecological Record sites which are providing the first-of-its-kind-of- data in the country to characterise ecosystem structure and function and, in turn, quantify carbon exchange are important initiatives. However, more such initiatives are required to cater to unrepresented ecosystems.

India has strong network of scientific institutions located in various bio-geographical provinces, and a dedicated space programme used for direct societal benefits. In contrast, the western space missions are largely science-driven and, in turn, data from these missions are used to investigate land-ocean-atmospheric processes, helping to answer scientific questions that have regional-to-global implications, but overlooking several regional peculiarities in other parts of the world those may contribute significantly in global processes (for e.g., the Himalaya, massive bio-climatic gradient, which has been considered as white spot in IPCC reports due to data deficiency).

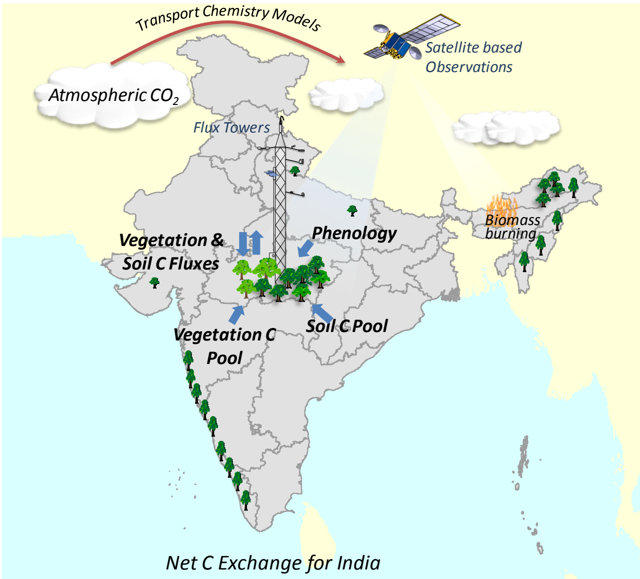


Fig.1 Schematic view of elements of Carbon budgeting.

The ISRO- Geosphere Biosphere Programme (ISRO-GBP) aims to quantify and understand the carbon fluxes from natural and managed ecosystems using satellite sensor data and ground-based observation. However, with rich biodiversity and complex vegetation-soil-atmosphere interactions across the subcontinent, the programme needs a set of priorities to provide a clear-cut mechanism for increasing scientific understanding of earth system processes based on more science-oriented use of space data. Existing vegetation models are not capable to provide accurate simulations of vegetation dynamics (for C sequestration) in India because of poor representation of India's tropical and subtropical vegetation types. There is a strong need for a Dynamic Vegetation Model driven by satellite sensor and ground observations, specific to India, coupled with land surface-atmospheric-ocean model which can allow actual and potential carbon sequestration to be mapped under current and future land use and climate change scenarios. A top-down approach (inversions of atmospheric data) and bottom-up approach (ground and satellite based terrestrial ecosystem models) are needed while making Carbon flux estimates.

Forests Productivity: The productivity of the planet's terrestrial biosphere, on the whole, has been increasing with time, revealing a great greening of the Earth that extends throughout the entire globe. Satellite-based analyses of net terrestrial primary productivity (NPP) reveal an increase of around 6-13% since the 1980s. There is no empirical evidence to support the model-based claim that future carbon uptake by plants will diminish on a global scale due to rising temperatures.

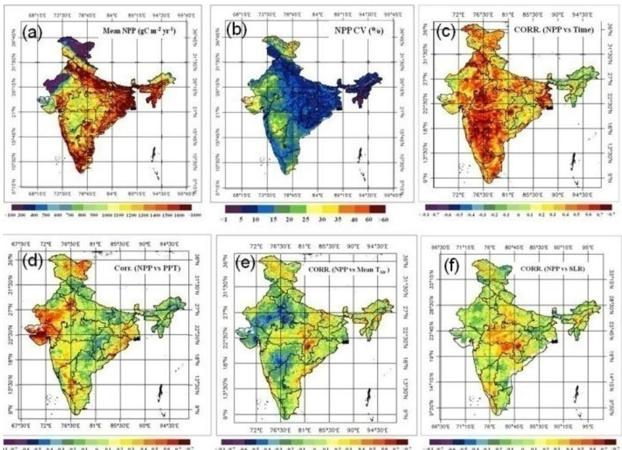


Fig.2 NPP of India: (a). mean NPP, (b). NPP CV(%), (c).Corr. (NPP Vs Time), (d). Corr. (NPP Vs Precipitation), (e). Corr. (NPP Vs Mean T_{air}), (f). Corr. (NPP Vs Radiation)

An analysis over India was carried out using 20 year historical records of global annual NPP generated using GloPEM approach. The highest NPP was observed of the order of 3,000 $gCm^{-2}yr^{-1}$ in agro-ecosystems of West Bengal and the lowest up to 500 gCm^{-2} yr^{-1} in arid region of Rajasthan (Fig.2 *(a)*). Very large NPP with small (<15) variance (CV;%) was observed in NE forest regions compared to small NPP with large CV (>25) in parts of Rajasthan and Gujarat (Fig.2 *(b)*). That shows NE forests are more stable compared to the arid and semi-arid regions (more rain dependent ecosystem). Grid level temporal correlation of NPP shows that, there is no significant increase in vegetal activities in terms of NPP in stable ecosystems like NE forest regions as well as semi-arid regions of western India (Fig.2*(c)*). Whereas, major agro-ecosystem areas of MP, Maharastra and Karnataka showed increasing vegetal trend in terms of NPP (r >0.6). It was interesting to note that, rain showed significant positive corr. (r >0.6) with NPP in areas like Rajasthan and Gujarat, which are mostly rain dependent states (Fig.2 *(d)*). Correlation of NPP with mean air T (Fig.2 *(e)*) showed that, parts of MP, Chhattisgarh, Karnataka & AP is having significant positive corr. (r >0.6). Whereas low correlation was observed in parts of Rajasthan, Gujarat, MH & Karnataka. Correlation of NPP with solar radiation (Fig.2 *(f)*) showed significant positive corr. (r>0.6) in central India. These observations shows the capability of long term remote sensing data towards understanding the role of climatic variables on forest ecosystem productivity.

Foliar Phenology: Leaf phenology provides quantitatively detailed information on seasonality and cycle of leaf functioning and is vital for understanding the interactions between the biosphere and the climate (Arora & Boer, 2005). Understanding and predicting changes in phenology is necessary to infer the response of plants towards the variation of climate. Meteorological and other parameters such as, temperature, rainfall, day-length, relative humidity, and soil moisture are regulating the phenology of leaf or plant. Forest leaf phenological parameters were retrieved from SPOT-NDVI time series data from 1999 - 2007 using Savitzky-Golay curve filtering method. Spatial phenological calendar maps (fig.3) were created to understand the dynamics at spatial level for start of the season, maximum greenness, end of the season (senescence) and length of the season. Evergreen and deciduous forest species were observed with distinguish phenological pattern. Climatic variables are found playing a crucial role in forest phenology especially minimum temperature and rainfall. Across India, long-term satellite sensor-derived records of vegetation phenology are indicating an increase in the length of the growing season. This contemporary technology can be useful to conduct a spatial and temporal phenological study over a large area. However, an Phenological Network in India facilitating the long-term collection of existing and new phenological observations through remote sensing, ground and pheno-cam based is required for proper up-scaling to national level.

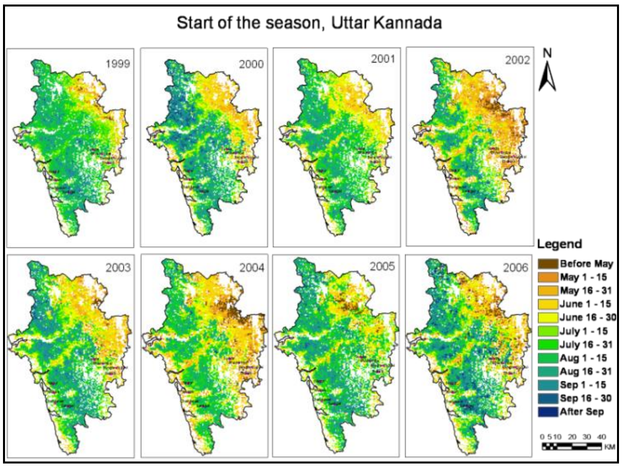


Fig.3 Phenological map of Uttar Kannada, Karnataka.

Alpine treeline dynamics: The projections by Indian Institute of Tropical Meteorology (IITM) using PRECIS (Providing Regional Climates for Impacts Studies) suggests an annual mean surface temperature rise by the end of the century, ranging from 3 to 5°C under A2 scenario and 2.5 to 4°C under B2 scenario, with warming more pronounced in the northern parts of India. It has also been observed that, the concentration of atmospheric CO_2 has increased from a pre-industrial value of about 280 ppm to 379 ppm in 2005. About 45% of this CO_2 has remained in the atmosphere, while about 30% has been taken up by the oceans and the remainder has been taken up by the terrestrial biosphere. Scientific literature suggests that, the Himalayas seem to be warming several times more than the global average rate (Shrestha et al., 1999), that temperature increases are greater during the winter and autumn than during the summer; and that increases are larger at higher altitudes (Liu and Chen, 2000). Climate warming more importantly, may impose competition on alpine plants, species from lower elevations, could force to migrate upwards (fig.4) until they reach the highest elevations (summit trap phenomenon) leading to loss of biodiversity in the alpine ecosystem. Responses of treeline forests to global warming include: (a) expansion of boundaries towards more northerly latitudes and higher altitudes and (b) enhanced productivity, stem density and canopy coverage (Kullman 1990). Dynamics of treeline ecotone can therefore be utilised as an indicator of climate change.

Fig.4 Artistic view of alpine vegetation ingression to higher altitudes.

Recent researches on alpine vegetation implies that its response to climate warming would be fast and flexible (Cannone *et al.*, 2007), contradicting the earlier notion that alpine plants have inherent inertia to an increase of 1–2^{o}C mean temperature. Assuming an average lapse rate of 0.6°C per 100m elevation, a mid-range warming of 3°C could cause current distribution limits shift by 500m. Grabherr *et al.* 1994 concluded from their field work that, an upward altitudinal shift in the alpine vegetation belt could theoretically be occurring at a rate of 8-10m per decade. Treeline rise of up to 150-165m observed in Scandinavia during the 20th century reflect the 1°C summer warming during that period. In a recent study conducted for Indian Himalaya using satellite remote sensing techniques (Panigrahy *et al.,* 2010; Singh *et al.,* 2012), the treeline upward shift of 388±80m in Uttarakhand has been reported during year 1970s–2006. This change is alarming, since from what is known today, treelines have fluctuated much less in the past 10,000 years (< 200 m).

A simulation study was carried out by us to understand future dynamics of alpine treeline shift. The modeling was carried out using environmental niche model on IPCC scenario based bioclimatic indices for a dominant alpine treeline species (*Betula utilis*). The agreement of all scenarios in Himachal Pradesh, Uttarakhand, Sikkim and Arunachal Pradesh shows that the treeline may remain between 2360m to 4905m. However, in J&K it may remain between 2538m to 4987m. Remote sensing based highest current treeline mapped in Uttarakhand is at 4,573m. *i.e.* in 74 years it may move upward @ 4.5m/yr to 4,905m (fig.5). Overall trend shows that the rate of shift of fundamental environmental niche of *Betula utilis* in India could be @ 13m/yr.

In montane ecosystems it has been projected that a 1°C increase in mean annual temperature will result in a shift in isotherm of about 160m in elevation at a lapse rate of 6°C/1000 m. In India, mean annual temperature showed a warming trend of 0.51°C per 100 years during 1901–2007. During 1971–2007, accelerated warming of 0.2°C per decade was reported (Kothawale *et al.*, 2010). However, McDowell, 2002 has mentioned a 1°C elevation in average temperature during 1970–2002 in the Himalayas. Considering a 1°C temperature elevation, a maximum shift of 160m may be expected. But the reported magnitude is more than double, indicating higher temperature elevation in the Himalayas, as also mentioned in the ICIMOD document (Eriksson *et al.,* 2009). In any case, it indicates a disastrous situation ahead. This draws attention to the significance of the Himalayas in relation to global climate change, and likely impact of warming on the Himalayas and ecosystems should be studied in more detail and quantified. However, lack of long term, historical baseline data of most of the alpine regions, is one of the biggest limitations of such studies. This calls for the formation of long term ecological recording sites on the line of GLORIA (Global Observation Research Initiative in Alpine Environments).

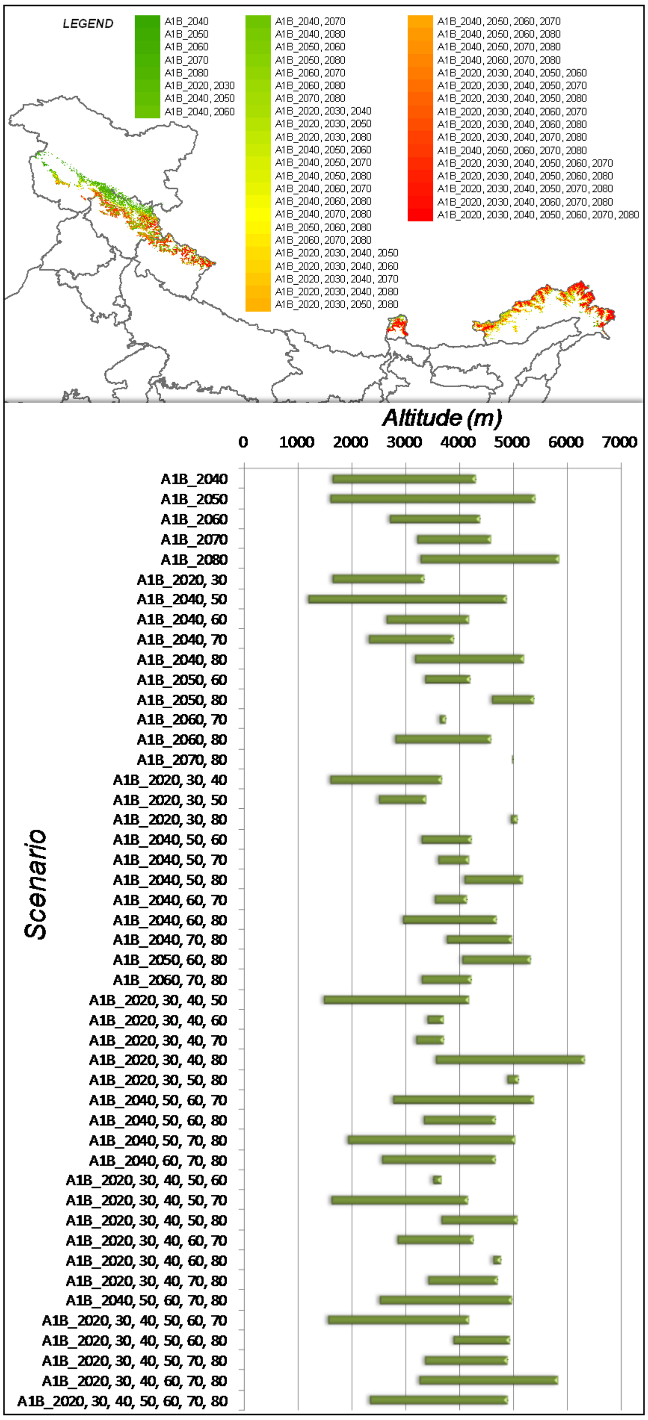


Fig.5 Future Alpine Treeline Scenario in India

Impacts on horticulture in mountains: Apple is the predominant horticulture crop of Himachal Pradesh and Jammu and Kashmir states in India. Efforts are being made to further strengthen this by bringing more areas under the apple crop and improving the condition of the existing orchards. However, the impeding future change in the climatic parameters projected under the global climate change scenario will have significant impact on the apple orchard viability. This is mainly due to its sensitivity to availability of chilling units. In Indian context, the chilling requirement is related to the elevation range of the orchards.

Signs of change are already visible. In the Kullu valley of Himachal Pradesh, apple production has declined after the peak production season of 1988–1989. This is a serious problem because the rise in apple cultivation from about 600 ha in 1960–1961 to about 1,100,000 ha in 1995–1996 was considered one of the success stories of the region's mountain development. Apple cultivators (35,000 families) of the valley perceive that over the years the amount of snowfall has decreased, and that it occurs later than before (Singh *et al*, 2010). The farmers are looking at climate change primarily in relation to the decrease in their apple production. Because of the change in snowfall the chilling hours for apple trees are reduced, affecting the time of its bud-break. Early snow (December to early January) is preferred for its favourable effect on bud-break as well as on soil moisture. It provides a chilling period of about 10 weeks below 5°C, which is required to meet the internal conditions necessary for bud-break in apples in springtime. Late snow (in late January and February), which is less durable, more watery and transitory, restricts bees' activities, including pollination of apple flowers.

An analysis carried out by us using IRS-P6 LISS-III and AWiFS sensor data showed that the orchards in Jammu and Kashmir were distributed in the elevation range of 1,600 m - 2,100 m. Equal proportion of orchards were observed in the elevation range of 1,600m -1,800 m as well as 1,800 - 2,000 m. In case of Himachal Pradesh (Shimal, Kullu, Mandi), the orchards are distributed from 1,600 m - 3,000 m. Further, to predict the suitable elevation of apple growth under the climate change scenario, GARP (Genetic Algorithm for Rule-set Production) model was used to simulate ecological niche for current apple distribution. The simulation showed significant upward shift of the existing belt to higher elevation (fig.6) and change in available area for cultivation (fig. 7).

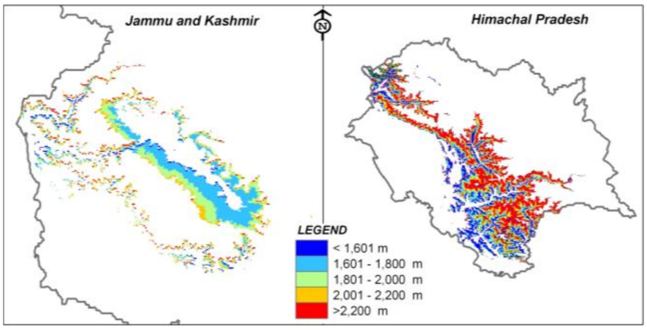


Fig.6 Future scenario of Apple niche using GARP model on bioclimatic indices derived using HadCM3 A1B projections for year 2050.

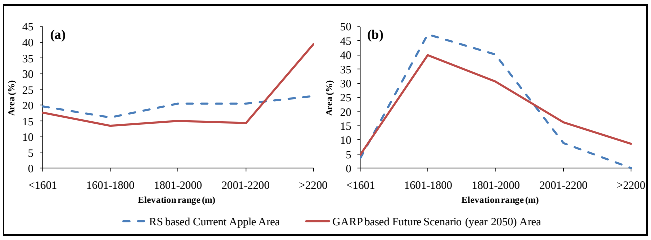


Fig.7 Change in apple area in comparison to future scenario (HadCM3 A1B: 2050) and w.r.t. elevation in (a). Himachal Pradesh and (b). Jammu and Kashmir.

Conclusion: More recently, the science policy in India has witnessed a paradigm shift by launching several national missions to mitigate climate change impacts, and during centenary celebration of the Indian Science Congress this year, the Prime Minister, Dr Manmohan Singh, pledged to double the investment in science in the next five years, with the aim to be top five in the world in terms of research output by 2020. This ambitious science policy initiative led by the top political leadership is expected to provide a stimulus to scientific research. One of the priority areas for both policy-makers and scientists, based upon Indian strength in the space science, should be to utilise the data from satellite sensors to understand processes of the terrestrial biosphere. In this direction there is a need to develop a network for long-term data collection on various ecological and environmental aspects. Benchmark sites at ecological sensitive regions are much needed to regularly monitor the indicators and impacts of climate change. Such studies would require integrated effort with extensive measurement campaigns involving collaboration with the concerned national and international scientific organizations. Being an interdisciplinary study, the support from different scientific groups working on various aspects of vegetation, snow, alpine ecosystems, wetlands and climate change issues would be necessary. The use of geospatial technique and simulation model enhances the scope of preparing a blue print and road map to plan mitigation measures to combat climate change impact on the terrestrial biosphere.

Acknowledgements: Authors are thankful to Director, Space Applications Centre (SAC) for his encouragements. The contributions made by team members in SAC and collaborators are also gratefully acknowledged.

References:

- Arora, V.K. and Boer, G.J., 2005. A parameterization of leaf phenology for the terrestrial ecosystem component of climate models. Global Change Biology, 11. pp.39–59.
- Cannone, N., Sgrobati, S. and Guglielmin, M., 2007. Unexpected impacts of climate change on alpine vegetation. Frontiers in Ecology and the Environment, 5(7). pp.360–364.
- Eriksson, M., Xu, J., Shrestha, A. B., Vaidya, R. A., Nepal, S. and Sandstrom, K., 2009. Report, ICIMOD Kathmandu, Nepal, p. 23.
- Grabherr G., Gotfried M. and Pauli H., 1994. Climate effects on mountain plants, Nature, 369, p.448.
- Liu, X. and Chen, B., 2000. Climate warming in the Tibetan Plateau during recent decades. International J. Clim., 20(14). pp.1729–1742.
- Kothawale D.R., Revadekar J.V. and Rupa Kumar K., 2010. Recent trends in pre-monsoon daily temperature extremes over India, Journal of Earth Syst. Sci., 119, pp.51–65.
- Kullman L., 1990. Dynamics of altitudinal tree-limits in Sweden: a review. Norsk Georgraphy Tidsskr, 44, pp.103–116.
- Panigrahy S., Anitha D., Kimothi M.M. and Singh S.P., 2010. Treeline change detection using topographic map and satellite imagery, Tropical Ecology, 51(1): pp.87-91.
- Shrestha, A.B., Wake, C.P., Mayewski, P.A. and Dibb, J.E., 1999. Maximum temperature trends in the Himalaya and its vicinity: An analysis based on temperature records from Nepal from period 1971–94. J. of Climate, 12(9). pp.2775–2787.
- Singh C.P., Panigrahy S., Thapliyal A., Kimothi M.M., Soni P. and Parihar J.S., 2012. Monitoring the alpine treeline shift in parts of the Indian Himalayas using remote sensing, Current Science, 102 (4), pp.559–562.
- Singh S.P., Singh V., and Skutsch M., 2010. Rapid warming in the Himalayas: Ecosystem responses and development options, Climate and Development, 2, 221–232.

Global and Indian Initiatives towards Climate Change Research

Abha Chhabra
Space Applications Centre, ISRO, Ahmedabad
E-mail: abha@sac.isro.gov.in

1.0 Introduction

With advancement in the scientific knowledge and data records, it has been well established that '*Climate*' has *changed* on all time scales throughout Earth's history. Climate scientists reconstruct the Earth's climate history by studying proxy records including ice cores, corals, and tree rings. These records show natural variability in the Earth's climate with distinct colder glacial periods and warmer interglacial periods. Then, an inquisitive mind may question, "*Is the Current Climate Change unusual compared to the earlier changes in Earth's History and do we really need to worry*?". The answer is "*yes*", with some aspects of the current climate change being not unusual, but '*others are*'. The main reason for the current concern about climatic changes is the rise in atmospheric concentration of green house gases (particularly, carbon dioxide, CO_2), which is very unusual over the geological time scales. The current concentration of CO_2 in the atmosphere has exceeded by far the natural range over the last 650,000 years, and has done so, at an exceptionally fast rate. Changes in atmospheric concentrations of greenhouse gases (GHGs) and aerosols, land cover and solar radiation alter the energy balance of the 'Climate System'; which may lead to a warming or cooling of the climate system. Since the start of the Industrial era (about 1750), the overall effect of human activities on climate has been a warming influence. The human impact on climate during this '*Anthropocene era*' greatly exceeds that due to known changes in natural processes, such as solar changes and volcanic eruptions. Scientific evidence for warming of the climate system is 'unequivocal', now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level (IPCC, 2007). Recent studies have indicated that the current trend of increasing atmospheric CO_2 concentrations would lead to both short and long-term adverse climate changes that would be essentially '*irreversible*' (Solomon et al., 2009).

1.1 Climate Change Research: An overview

From a scientific perspective, Climate Change is defined as '*a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use*. However, United Nations Framework Convention on Climate Change (UNFCCC) in its Article 1 has defined climate change as '*a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods*'. The UNFCCC thus makes a distinction between '*climate change*' attributable to human activities altering the atmospheric composition, and '*climate variability*' attributable to natural causes. Any human-induced changes in climate will be embedded in a background of natural climatic variations that occur on a whole range of time- and space-scales. Therefore, to distinguish anthropogenic climate changes from natural variations, it is necessary to identify the anthropogenic 'signal' against the background 'noise' of natural climate variability.

Climate Change Research includes detailed understanding of the climate system, changes in the climate system and its impacts through a timeline extending from paleo through present to future. Figure 1 illustrates the key science questions addressed in climate change research.

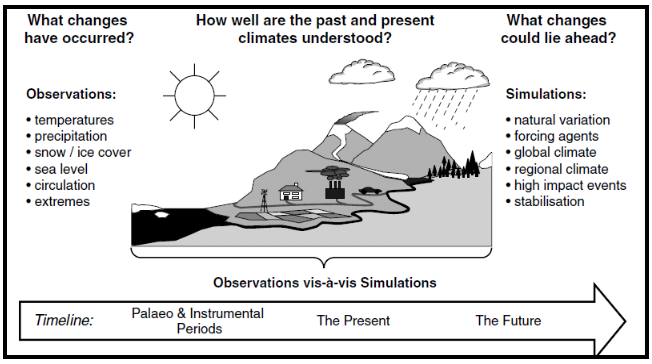


Figure 1: Illustration to understand key questions to climate change research and its relation to humankind (*Source: IPCC TAR, 2001*)

Climate change research encompasses changes in different components of the Earth's climate system including atmosphere, biosphere, hydrosphere, cryosphere, their anthropogenic drivers, processes, indicators, impacts of and responses to climate change, and their interlinkages (Figure 2).

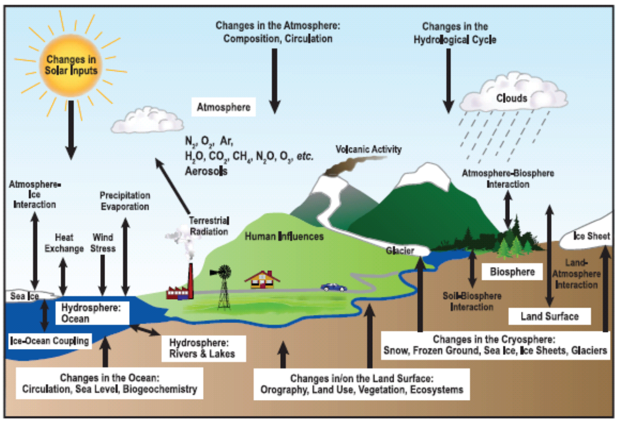


Figure 2: Schematic view of the components of the climate system, their processes and interactions *(Source: IPCC, 2007)*

2.0 Initiatives towards Climate Change Research

United Nations Secretary-General Ban Ki-moon has remarked, '*Climate Change is the major, overriding environmental issue of our time, and the single greatest challenge facing environmental regulators. It is a growing crisis with economic, health and safety, food production, security, and other dimensions*'. There have been serious concerns and initiatives towards climate change research and implementation of science into policy. Various global and country-level science programmes are addressing coordinated and integrated research on different climate change issues. This article highlights only few major global and Indian initiatives towards climate change research.

2.1 Global Initiatives

United Nations Framework Convention on Climate Change

The United Nations Framework Convention on Climate Change (UNFCCC) is an international environmental treaty negotiated at the United Nations Conference on Environment and Development (UNCED), '*Earth Summit*', held in Rio de Janeiro in June 1992. This treaty entered into force on 21 March, 1994 with an objective to "*stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system*". Under the aegis of UNFCCC, Kyoto Protocol was adopted in Kyoto, Japan, on 11 December, 1997 to operationalize UNFCCC. Kyoto protocol legally binds developed countries to '*emission reduction targets*' based on the principles of the UNFCCC. Due to a complex ratification process, Kyoto protocol entered into force on 16 February, 2005. The Protocol's first commitment period started in 2008 and ended in 2012. The second commitment period began on 1 January, 2013 and will end in 2020. There are now 195 Parties to the Convention and 191 Parties to the Kyoto Protocol.

United Nations Environment Programme

The United Nations Environment Programme (UNEP) is an international institution that coordinates United Nations environmental activities, assisting developing countries in implementing environmentally sound policies and practices. It was founded as a result of the United Nations Conference on the Human Environment in June 1972, with its headquarters in Nairobi, Kenya. UNEP works closely with governments at all levels to bolster capacities to increase their resilience to climate change, move towards low-carbon societies, reduce emissions from deforestation and forest degradation (REDD), improve availability and understanding of relevant climate science, and raise awareness of the climate change challenge. To respond to the big challenge of deforestation and forest degradation which account for ~20 per cent of global greenhouse gas emissions, UNEP, in partnership with the United Nations Food and Agriculture Organization (FAO) and the United Nations Development Programme (UNDP), has created the UN-REDD Programme. The core of UNEP's REDD+ activities within UN-REDD are to help countries to reduce emissions from deforestation and forest degradation in order to generate funds that could be used by communities to improve sustainable management of forests, strengthen the role of conservation, shift the forest sector to alternative development pathways, and support biological diversity and livelihoods. In addition, UNEP supports countries to participate more fully in the UNFCCC process, including by supporting meetings of negotiators. UNEP also helps countries meet their obligations on National Communications, Technology Needs Assessments, National Adaptation Plans of Action, and is already providing support to countries on future areas of work, including Nationally Appropriate Mitigation Actions.

The Intergovernmental Panel on Climate Change

The Intergovernmental Panel on Climate Change (IPCC) is the leading international body for the assessment of Climate Change. IPCC was established in 1988 by UNEP and the World Meteorological Organisation (WMO) to provide the world with a clear scientific view on the current state of knowledge in climate change and its potential environmental and socio-economic impacts. In the same year, the UN General Assembly endorsed the action by WMO and UNEP in jointly establishing the IPCC. The IPCC is a scientific body under the auspices of the United Nations. IPCC secretariat is hosted at WMO headquarters in Geneva. It reviews and assesses the most recent scientific, technical and socio-economic information produced worldwide relevant to the understanding of climate change. The IPCC work is shared among three Working Groups, a Task Force and a Task Group. The IPCC Working Group I: '*The Physical Science Basis*'- assesses the physical scientific aspects of the climate system and climate change. IPCC Working Group II: '*Impacts, Adaptation and Vulnerability*'- assesses the vulnerability of socio-economic and natural systems to climate change, negative and positive consequences of climate change, and options for adapting to it. It also takes into consideration the inter-relationship between vulnerability, adaptation and sustainable development. IPCC Working Group-III: '*Mitigation of Climate Change*' assesses options for mitigating climate change through limiting or preventing greenhouse gas emissions and enhancing activities that remove them from the atmosphere. The Task Force on National Greenhouse Gas Inventories (TFI) was established by the IPCC to oversee the IPCC National Greenhouse Gas Inventories Programme (IPCC-NGGIP). The NGGIP also established and maintains an Emission Factor Database. The Task Group on Data and Scenario Support for Impacts and Climate Analysis (TGICA) was established to facilitate co-operation between the climate modeling and climate impacts assessment communities. IPCC Data Distribution Centre (DDC) provides timely information and data to the international climate research community, in particular consistent data sets and guidance material. The IPCC Fourth Assessment report was brought out in 2007. IPCC received The Nobel Peace Prize 2007 jointly with Albert Arnold (Al) Gore Jr., former Vice-president USA "for their efforts to build up and disseminate greater knowledge about man-made climate change and to lay the foundations for the measures that are needed to counteract such change". Currently, Fifth Assessment Reports of all three Working Groups of IPCC are underway and would be released during 2013-14.

Programme of Research on Climate Change Vulnerability, Impacts and Adaptation

The Programme of Research on Climate Change Vulnerability, Impacts and Adaptation (PROVIA) is an exciting new global initiative which aims to provide direction and coherence at the international level for research on Vulnerability, Impacts and Adaptation (VIA). It is a joint collaboration between UNEP, WMO and UN Educational, Scientific and Cultural Organization (UNESCO). Launched with the support of leading scientists and decision-makers, PROVIA responds to the urgent call for a more cohesive and coordinated approach to harmonize, mobilize, and communicate the growing knowledge-base on VIA.

Long-Term Measurements of Key Atmospheric Species Relevant To Climate Change

NOAA/ESRL's Global Monitoring Division (GMD) conducts sustained observations and research related to source and sink strengths, trends and global distributions of atmospheric constituents that are capable of forcing change in the climate of Earth through modification of the atmospheric radiative environment, those that may cause depletion of the global ozone layer, and those that affect baseline air quality. GMD accomplishes this mission primarily through long-term measurements of key atmospheric species at sites spanning the globe, including four fully-equipped Baseline Observatories. These key species include carbon dioxide, carbon monoxide, methane, nitrous oxide, surface and stratospheric ozone, halogenated compounds including CFC replacements, hydrocarbons, sulfur gases, aerosols, and solar and infrared radiation. Figure 3a depicts an example of CO_2 observations measured at Mauna Loa in Hawaii, a premier atmospheric research facility that has been continuously monitoring and collecting data related to atmospheric change since the 1950's. Long term variations of the two major GHGs (CO_2 and CH_4) through on-site measurements at the four NOAA/ESRL/GMD baseline observatories is shown in Figure 3b.

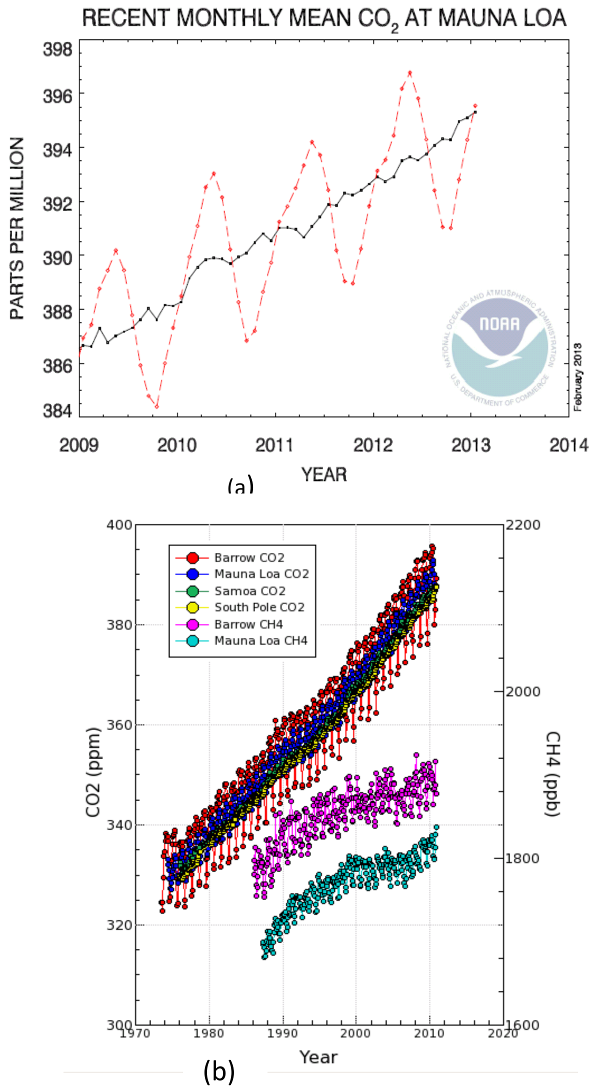


Figure 3: Graphs showing recent monthly mean CO_2 measured at Mauna Loa Observatory, Hawaii (3a), Long-term measurements of CO_2 and CH_4 at four NOAA baseline observatories (3b)
(Source: http://www.esrl.noaa.gov/gmd/ccgg/)

Space Borne Satellite Remote sensing Instruments

Remote sensors are one of the major sources of consistent, continuous data for studying different components of 'Earth Climate system' at a variety of spatial and temporal scales. The Ozone Hole over the Antarctica, discovered by British scientists, was confirmed by the Nimbus-7 Total Ozone Mapping Spectrometer (TOMS) launched in 1978. The Ozone Mapper Profiler Suite (OMPS), is one of five new instruments flown aboard NASA's Suomi National Polar-orbiting Partnership satellite (Suomi NPP) launched on October 28, 2011. OMPS monitors the Earth's ozone layer using advanced suite of three hyperspectral instruments that measure sunlight in the ultraviolet and visible backscattered from the Earth's atmosphere. European Space Agency (ESA) SCIAMACHY-SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY, passive remote sensing spectrometer instrument was launched on board ENVISAT which was operational from March 2002 to April 2012. SCIAMACHY provided global measurements of various trace gases in the troposphere and stratosphere, retrieved from the solar irradiance and Earth radiance spectra. The Greenhouse Gases Observing Satellite "IBUKI" (GOSAT), developed as a joint effort of the Ministry of the Environment (MOE), the National Institute for Environmental Studies (NIES), and the Japan Aerospace Exploration Agency (JAXA) is the world's first spacecraft to measure the concentrations of two major GHGs (carbon dioxide and methane) from space. GOSAT, launched successfully on 23 January, 2009, uses the differential absorption technique, allowing the sampling of the low atmospheric layers, which are directly connected to the surface fluxes. NASA's current operating one of the major satellite mission called "Afternoon Constellation" or "A-Train" is a coordinated group of satellites in a polar orbit, crossing the equator northbound at about 1:30 p.m. local time, within seconds to minutes of each other (Figure 4). This allows near-simultaneous observations of a wide variety of parameters to aid the scientific community in advancing our knowledge of Earth-system science, climate change research and applying this knowledge for the benefit of society. Six satellites currently fly in the A-Train: The Global Change Observation Mission-Water (GCOM-W1), Aqua, Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO), CloudSat, PARASOL, and Aura. On November 16, 2011, PARASOL was lowered to 9.5 km under the A-Train and continues its nominal mission observing clouds and aerosols. PARASOL is a French Space Agency CNES instrument launched into the A-Train orbit in December 2004. CALIPSO is a joint NASA and CNES mission. Orbiting Carbon Observatory 2 (OCO-2) is scheduled to join the 'A-Train' configuration in 2014. It is being designed to provide space-based global measurements of atmospheric CO_2 with the precision and resolution needed to identify and characterize the processes that regulate this important GHG. OCO-2 data would be very useful to climate science focus areas of Carbon Cycle, Ecosystems, and Biogeochemistry of Earth's surface.

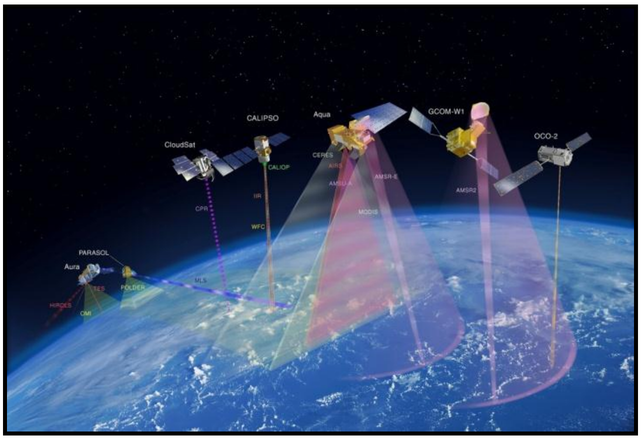


Figure 4: 'A-Train' constellation of satellites *(Source: http://www.nasa.gov/mission_pages/a-train/)*

Two future missions have been proposed for the monitoring of CO_2 from space- '*Advanced Space Carbon and Climate Observation of Planet Earth*' (A-SCOPE) Lidar by the European Space Agency in the Earth Explorer context, while '*Active Sensing of CO_2 Emissions over Nights, Days, and Seasons*' (ASCENDS) by NASA.

Future Earth

Future Earth-Research for Global sustainability is a new 10-year international research initiative, being developed by International Council for Science (ICSU) and other leading international organizations including UN bodies and major science funders. Future Earth will develop the knowledge for responding effectively to the risks and opportunities of global environmental change and for supporting transformation towards global sustainability. This new initiative to be formally launched in 2014 will build on the success of existing global environmental change programmes and projects viz. International

Geosphere Biosphere Programme (IGBP), International Human Dimensions Programme on Global Environmental Change (IHDP), World Climate Research Programme (WCRP) and International Programme of Biodiversity Science (DIVERSITAS), to develop a stronger and broader community.

2.2 Indian Initiatives

Realizing that climate change is a challenge while sustaining the rapid growth of the country, India initiated its dedicated research efforts towards climate change in 1990s. The preparation of India report of the Asian Development Bank's study on Climate Change (ADB, 1994) was the pioneering effort towards compilation of literature and certain studies on impacts of climate change on important sectors of agriculture, water and forests besides sea level rise. ABD-Asia Least Cost Greenhouse Gas Abatement Strategy (ALGAS) was yet another important country level assessment on Greenhouse Gases at the 1990 level (ALGAS, 1998). These studies in effect provided the impetus to the research work relating to climate change issues for the country.

Indian government became a signatory to the UNFCCC on 10 June, 1992 and ratified it on 1 November, 1993. The Climate Change Division of Ministry of Environment and Forests (MoEF), Govt. of India is the nodal agency for climate change cooperation and global negotiations. It is also the executing and implementing agency for the preparation of the national communication. Towards fulfillment of its obligations of furnishing information relating to implementation of the Convention in accordance with Article 4.1 and 12(1) of the UNFCCC, India had communicated its first *National Communication* to the UNFCCC in 2004 with GHG emission data for the year base year 1994 (NATCOM, 2004). For the first time, a well coordinated and dedicated effort was made to produce assessing GHGs of anthropogenic origin from sectors such as Energy, Agriculture, Industry, Land Use, Land Use Change and Forestry and Waste and to assess the climate change Impacts and vulnerability of key sectors of economy. *Indian Network of Climate Change Assessment* (INCCA) launched on 14th October 2009, is a network comprising 127 research institutions across the country, tasked with undertaking research on the science of climate change and its impacts on different sectors of the economy across the various regions of India. INCCA provided updated information on India's Greenhouse Gas Emissions for the year 2007 (MoEF, 2010). The Government of India submitted its *Second National Communication* to the UNFCCC Secretariat in May, 2012 (MoEF, 2012). On 30 June, 2008, Prime Minister Manmohan Singh released India's first '*National Action Plan on Climate Change*' (NAPCC) outlining existing and future policies and programs addressing climate mitigation and adaptation. NAPCC consists of several targets on climate change issues and addresses the urgent and critical concerns of the country through a directional shift in the development pathway. The eight missions identified under NAPCC include- National Solar Mission, National Mission for Enhanced Energy Efficiency, National Mission on Sustainable Habitats, National Water Mission, National Mission for Sustaining the Himalayan Ecosystem, National Mission for Sustainable Agriculture and National Mission on Strategic Knowledge on Climate change. MoEF is the nodal unit for coordinating NAPCC. At the state government level, one of the trendsetter initiatives is the establishment of a separate '*Department for Climate Change*' by the Gujarat Government. It is the only 'First in Asia' and 4th state/province in the world to have a Department for Climate Change. Set up in February 2009, the Department is headed by the Chief Minister to handle issues of Climate Change.

Various premier research/academic institutions across the country have research programmes/centres dedicated to address to various aspects of climate change research. For example, Centre for Climate Change Research at the Indian Institute of Tropical Meteorology, Pune; Divecha Centre for Climate Change at the Indian Institute of Science, Bangalore to name a few. The recent 'National Initiative on Indian Resilient Agriculture' at the National Agricultural Research Institute, New Delhi aims at to make Indian agriculture resilient to climate change through development and application of adaptation and mitigation technologies. The Centre for Advanced Training in Earth System Science and Climate (CATESSC) at IITM, Pune under Earth System Sciences Organization of the Ministry of Earth Sciences, Govt. of India aims for capacity building to develop world class research expertise for understanding and exploring unresolved scientific issues in climate science, particularly imparting training on climate modeling.

Indian Space Research Organisation (ISRO) initiated its ISRO-Geosphere Biosphere Programme (ISRO-GBP in 1990 as an outcome of Indian Middle Atmosphere Programme (IMAP) with a concern all over due to increased GHGs and Ozone hole depletions over Antarctica. ISRO-GBP primarily addresses the issues concerned to parameters and processes responsible or potential for inflicting the climate change. In past more than two decades, ISRO-GBP has organized itself for understanding the climate change related studies with specific focus on studying atmospheric aerosols, trace gases, GHGs, paleoclimate, land cover change, atmospheric boundary layer dynamics, energy and mass exchange in the vegetative systems, with the core strengths of ISRO and collaborating with the various other peer institutes in the country. The 'National Carbon Project' taken up under ISRO-GBP since 2007, aims at full accounting of biogeochemical carbon cycle for India and to establish an observational network and create remote sensing-based spatial databases for modeling & periodic assessment of carbon balance of the country. ISRO's Programme on Climate change Research In Terrestrial environment (PRACRITI), is a remote sensing application programme that had been launched to develop mechanism to quantify the state of changing climate and model its impact on terrestrial ecosystem using space based observations. Studies have been carried out at ISRO towards mapping/detecting the indicators of climate change, monitoring the agents of climate change and understanding the impact of climate change, in national perspectives. The PRACRITI programme includes studies related with modelling the impact of climate change on Agriculture, Himalayan Cryopshere and Hydrology as well as Sensor system studies for monitoring green-house gases. ISRO has also carried out extensive campaigns with integrated satellite, aircraft, balloon and ground based measurements, jointly with many other research institutions in the country.

The India's Earth Observation (EO) programme addresses various aspects of land, ocean and atmospheric applications and capable of providing data of Essential climatic variables that can be measured from space viz. atmosphere (upper air temperature, water vapour, precipitation, clouds, aerosols, GHGs etc.), ocean (sea ice, sea level, SST, salinity, ocean colour etc.) and land (snow, glacier, albedo, biomass, LAI/fAPAR, soil moisture etc.) (Navalgund and Singh, 2011). The Indian Earth Observation System has emerged as a strong constellation of geostationary (INSAT series; INSAT 1, 2 and 3, and METSAT (Kalpana-1) in operation for meteorological applications) and polar orbiting remote sensing satellites (IRS Series-IRS 1 C, IRS-1D, IRS-P3, OCEANSAT-1/2, Technology Experiment Satellite-TES, RESOURCESAT-1/2, and CARTOSAT-1 & 2/2A/2B, RISAT1/2. The recent Megha-Tropiques, an Indo-French Joint Satellite Mission launched in October, 2011 is successfully providing data for studying the water cycle and energy exchanges in the tropics, relevant to climate change research. Future Indian EO missions- SARAL Satellite with ARgos and Altika-Joint ISRO-CNES Mission, INSAT-3D, GEO Imaging Satellite, GISAT would further strengthen the climate change research in the country as well as globally.

3.0 Conclusion

Climate Change has been recognized as a major threat to present day society because of its adverse impacts on ecosystem, agricultural productivity, water resources, socio-economy and sustainability in a global as well as regional basis. Meeting the climate challenges requires individuals and institutions to be able to assess and understand climate change, design and implement adequate policies and, most important of all, to take action on low-carbon and climate resilient growth. Capacity building is a country-driven process, enabling individuals, organizations, and societies at all levels, to unleash, strengthen, build, adapt and maintain their capacities to undertake climate action. A large number of initiatives both at national as well as international levels are being realized. However, climate change studies would need integrated effort with extensive measurement campaigns involving collaboration among national as well as international scientific organizations. Space based observations that serve as an important source of climate variables due to multi scale simultaneous observation (local, regional, and global scales), capability with temporal revisit in tune with requirements of land, ocean and atmospheric processes are a great boon to climate change research. In the present context, the need of the hour is that climate change research must be translated into policy actions. Science and policy must converge to implement meaningful climate change solutions for securing sustainable natural resources and a safe future for coming generations.

Acknowledgement: I wish to sincerely acknowledge and thank Shri D. Subrahmanyam, Chairman ISRS-AC, Shri D.R.M Samudraiah, Vice-President ISRS, Dr (Mrs) Parul Patel, Secretary, Mrs. Arundhati Misra, Editor, '*Signatures*' and Dr. R.P. Singh, Guest Editor '*Signatures*' for providing me this opportunity to contribute to this special issue on '*Climate Change and Remote Sensing*'. It's indeed a privilege that ISRS-AC is bringing out this issue to celebrate the silver jubilee year of the successful launch of IRS-1A, India's first operational remote sensing satellite.

References

Websites

http:// www.ipcc.unibe.ch/, *http:// www.unep.org/*
http://envfor.nic.in/, *http://unfccc.int*
http://www.esrl.noaa.gov/gmd/ccgg/
http://www.isro.gov.in,
http://www.nasa.gov/mission_pages/a-train/

- IPCC 2001, Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Houghton, J.T.,Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 23-24.
- IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 104-105.
- MoEF, 2010. Indian Network for Climate Change Assessment. India: Greenhouse Gas Emissions 2007, Ministry of Environment and Forests, Govt. of India, 64 p.
- MoEF, 2012. India's Second National Communication to the United Nations Framework Convention on Climate Change. Ministry of Environment and Forests, Govt. of India, 310p.
- NATCOM, 2004. India's Initial National Communication to the United Nations Framework Convention on Climate Change, Ministry of Environment and Forests, Govt. of India, 268 p.
- Navalgund RR and Singh RP, 2011. Climate change studies using space based Observation. *Journal of the Indian Society of Remote Sensing*, DOI 10.1007/s12524-011-0092-4.
- Solomon S, Plattner, GK, Knutti R, Friedlingstein P, 2009. Irreversible climate change due to carbon dioxide emissions. *Proc. National Academy of Sciences*, 10(6), 1704–1709.

Energy Security Challenges and Role of Indian Geostationary Satellites

Bimal K. Bhattacharya, Swapnil Vyas and Rahul Nigam

Space Applications Centre, ISRO, Ahmedabad

Email : bkbhattacharya@sac.isro.gov.in

Introduction

In the recent past, scientists and researchers in the satellite remote sensing community were indeed engaged in proving the evidence of climate change impact over Indian landmass or detecting changes in the causal agents of climate change. In most of the cases, either geophysical products from foreign satellites at polar orbiting platform were analyzed or data from Indian polar orbiting satellites were interpreted to support such location-specific detection. The potential of high-temporal data or geophysical products from Indian geostationary satellites with country-scale or continental-scale coverage has been less emphasized or harnessed for climate change and its mitigation studies. It is the appropriate time to look into how satellite data or geophysical products can help generate action plans for climate change mitigation to address energy, water, food and nutritional security challenges of our country under the threats imposed through natural (e.g. emissions) and anthropogenic (e.g. population pressure, over-exploitation of natural resources) *forcing*.

Jawaharlal Nehru National Solar Mission (JNNSM):

This is a major initiative of the Government of India and state governments to promote ecologically sustainable growth while addressing India's energy security challenges. It will also constitute a major contribution by India to the global effort to meet the challenges of climate change. On launching of India's National Action Plan on Climate Change on June 30, 2008, the Prime Minister of India emphasized a graduated shift from economic activity based on fossil fuels to one based on non-fossil fuels and from reliance on non-renewable and depleting sources of energy to renewable sources of energy, specifically to develop solar energy as a source of abundant energy to power our economy and to transform the lives of our people. The objective of the Solar Mission is to create conditions through rapid scale-up of capacity and technological innovation to drive down costs towards grid parity. The Mission anticipates achieving grid parity by 2022 and parity with coal-based thermal power by 2030. It recognizes that there are a number of off-grid solar applications particularly for meeting rural energy needs, which are already cost-effective and provides for their rapid expansion. India is endowed with vast solar energy potential. About 5,000 trillion kWhr per year energy is incident over India's land area with most parts receiving 4-7 $kWhrm^{-2}$ per day. Hence both technology routes for conversion of solar radiation into heat and electricity, namely, solar thermal and solar photovoltaic (PV), can effectively be harnessed providing huge scalability for solar energy in India. It also provides the ability to generate power on a distributed basis and enables rapid capacity addition with short lead times. It is environmental friendly as it has zero emissions while generating electricity or heat. In addition, without effective storage, solar power is characterized by a high degree of variability in space and time. In India, this would be particularly true in the monsoon season. Therefore, demarcation of potential solar energy zones based on regional variability at monthly and annual scale is very important for investment in this sector. Solar imperative is both urgent and feasible to enable the country to meet long-term energy needs.

Surface insolation and Geostationary satellites: Amount of incident solar radiation flux reaching at earth surface is known as surface insolation. It is largely influenced by geographical locations, seasons and atmospheric constituents such as clouds, fog, aerosols etc. It constitutes of direct or beam and diffuse insolation. The amount of monthly and annual availability of assured surface insolation provides an idea to identify locations for setting up solar photovoltaic (PV) or thermal power plants (Janjai et al. 2005) for harnessing available renewable energy resources. Assessing its potential is essential to meet the energy demand defined in JNNSM under national climate change action plan. Further, the performance of efficiency of solar PV for electric power generation is needed for sustainable power supply (Perez et al., 2001). Conventionally, the solar energy maps are prepared from high density network of pyranometers. In India, a very sparse network of pyranometer stations is presently operating through government agencies. Interpolation from sparse network can produce large errors (60-70%) due to substantial variations of intermittent diurnal cloud cover, cloud types and atmospheric turbidity. Moreover, high maintenance costs and lack of availability of real-time data are major impediments. Generally, surface weather observatories for measuring routine weather elements are more than radiation measuring stations. Therefore, during seventies and eighties surface insolation estimation models were largely dependent either on temperature amplitude, sunshine hours and combination of temperature, humidity, rainfall, but these require site and season-specific calibration of coefficients and thus difficult to extrapolate over a larger region such as country or continental scales. Moreover, such models do not explicitly consider the role of atmospheric constituents such as air molecule, aerosol, water vapour, ozone. The use of remote sensing observations from geostationary meteorological satellite provide high temporal sampling frequency (multiple passes every day) which is ideal to capture spatio-temporal variability of clouds, fog, turbidity and therefore surface insolation. A set of attempts have been made in USA, Europe, Japan between 1979 to 2005 to use high-temporal observations per day from geostationary meteorological satellites to estimate surface insolation either using statistical models or radiative transfer schemes.

Insolation product from Indian geostationary satellite

Recently, a spectrally integrated clear-sky and three-layer cloudy-sky models were used at Space Applications Centre to determine atmospheric transmittances and instantaneous surface insolation and its daily integral (Bhattacharya et al, 2012). Half-an-hourly observations at 8 km spatial resolution in optical and thermal infrared bands from Indian geostationary satellite (Kalpana-1) sensor (VHRR) were ingested to provide inputs to these models in addition to global eight-day aerosol optical depth and columnar ozone. The whole algorithm has been packaged and named as KIRAN (Kalpana-1 Incident solar RAdiatioN) which means "ray of light". The instantaneous and daily insolation are regular products from Kalpana-1 VHRR and are being archived at MOSDAC (www.mosdac.gov.in) site. The examples of monthly variability of surface insolation are shown in Figure 1. The validation with *in situ* point measurements produced ±15% error of monthly insolation estimates.

Assured solar energy from relative insolation: The ratio of solar radiation flux at top of atmosphere and surface insolation, known as relative insolation, was further examined to determine pixel-by-pixel thresholds. These thresholds were processed to compute pixel-wise monthly and annual frequency of clear days. The spatial distribution of annual sum of assured available solar energy in India was estimated from both annual surface insolation and frequency of clear days. Three years' (2009 to 2011) analysis using Kalpana-1 data showed that higher solar energy potential (3000 to 4000 MJm^{-2} or 0.834 to 1.112 $GWhrm^{-2}$) exists over parts of western, central India including Chhattisgarh with some promising pockets in Gujarat, Rajasthan, Madhya Pradesh, Maharashtra, Karnataka (Figure 2).

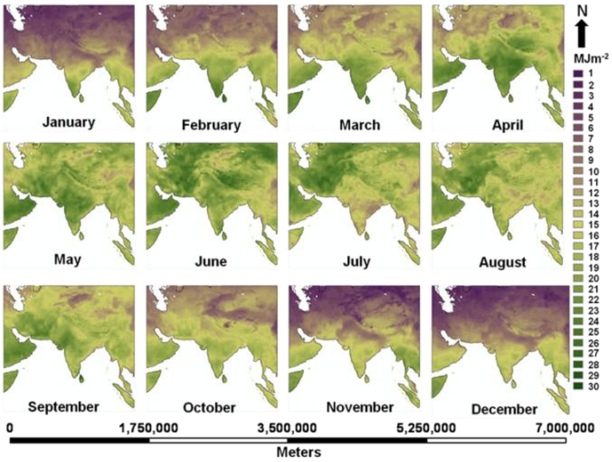


Figure 1. Monthly variability of surface insolation from Kalpana-1 VHRR

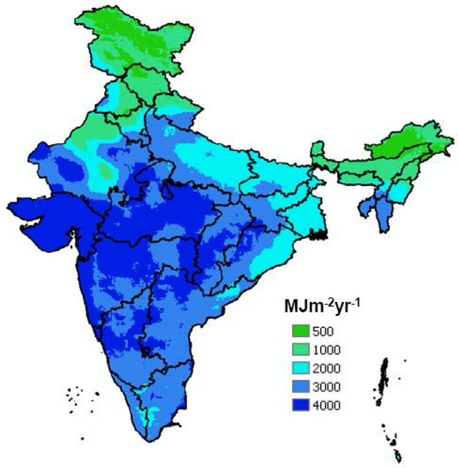


Figure 2. Potential solar energy zones of India determined from Kalpana-1 insolation product

Lesser potential exists over Indo-Gangetic plain where it varied from 1000 to 3000 MJm^{-2} (0.278 to 0.834 $GWhrm^{-2}$). In Western Himalaya, the mountainous terrain received 500 to 1000 MJm^{-2} (0.139 to 0.278 $GWhrm^{-2}$) and valley received relatively larger solar energy of 1000 to 3000 MJm^{-2} (0.278 to 1.112 $GWhrm^{-2}$). In North-eastern hill region, the Mizoram and part of Tripura states received higher clear solar exposure to the tune of 3000 MJm^{-2} (1.112 $GWhrm^{-2}$).

Conclusions: This information is of high demand from Ministry of Renewable energy resources and other state agencies. In future, the enhanced spatial resolution and observational capabilities of INSAT 3D and GISAT would help in further detailed mapping of solar energy. Our recent study on the long term analysis (50 years) of measured solar radiation (Singh et al., 2012) from limited ground stations over major climates of India showed solar dimming rate of the order of 1.5% to 3.4% per decade (10 years) from 1951 to 2003 with a substantial decline in bright sunshine hours (1.12 hrs). This has also attracted the attention of international climate community. The future thrusts should be to process long-term data from Kalpana-1 observations and carry out time series analysis to quantify current decadal rate of solar dimming or dimming of atmospheric clearness on regional scale.

Acknowledgements: Authors are grateful to Shri A. S. Kiran Kumar, Director, SAC and Dr. J. S. Parihar, Dy. Director, SAC for their encouragement and keen interest in this study. The authors would also like to thank MOSDAC, SAC, for providing daily insolation product.

References

- Bhattacharya, B. K., Padmanabhan, N., Ramakrishnan, R., Panigrahy, S. and Parihar, J.S. (2012). Algorithm Theretical Basis Document (ATBD) for surface insolation using Kalpana-1 VHRR observations. SAC/EPSA/ISRO-GBP/SR/ATBD/02/2012.
- Janjai, S., Lakasanaboonsong, J., Nunez, M. and Thongsathitya, A. (2005). Development of a method for generating operational solar radiation maps from satellite data for a tropical environment. *Solar energy*, 78, 739 – 751.
- Perez, R., Kmeicik, M., Herig, C. and Renne, D. (2001). Remote monitoring of PV performances using Geostationary Satellites, *Solar Energy*, 71, 255 – 261.

Singh, J., Bhattacharya, B.K., Kumar, M. (2012). Solar radiation and evaporation trend over India. *Journal of Earth Science and Engineering*, 2, 160-165.

Is Geo-Engineering the Next Step??

Abha Chhabra
Space Applications Centre, ISRO, Ahmedabad
E-mail: abha@sac.isro.gov.in

Amidst the various climate change mitigation measures, Global climate research community is also focusing on '*Carbon Cycle Geoengineering*', as a useful complement to ambitious climate mitigation. The concept of '*Geoengineering*' can be traced back to the 1960s with a US report calling for research on "possibilities to deliberately bringing about countervailing climatic changes" to that of CO_2. The term '*Geoengineering*' itself was originally used in the 1970s by Marchetti to describe the context of the idea of injecting CO_2 into the ocean to reduce the atmospheric burden of this GHG. Since that time, the term has evolved considerably, to encompass a broad variety of concepts for intentionally modifying the Earth's climate at the large scale. '***Geoengineering***' *refers to a broad set of methods and technologies that aim to deliberately alter the climate system in order to alleviate the impacts of climate change (IPCC, 2012)*. Most of the Geoengineering methods seek to either *(a) reduce the amount of absorbed solar energy in the climate system (**Solar Radiation Management, SRM**) or (b) increase net carbon sinks from the atmosphere at a scale sufficiently large to alter climate (**Carbon Dioxide Removal. CDR**)* (Figure 1)*.* SRM methods reduce the net incoming short-wave (ultra-violet and visible) solar radiation received, by deflecting sunlight, or by increasing the reflectivity (albedo) of the atmosphere, clouds or the Earth's surface. Specific examples include the artificial injection of stratospheric aerosols, low-level cloud brightening through the injection of sea-salt particles in the marine boundary layer, or brightening of the Earth's surface. CDR methods refer to a set of techniques that aim to remove CO_2 directly from the atmosphere by either (a) increasing natural sinks for carbon or (b) using chemical engineering to remove the CO_2, with the intent of reducing the atmospheric CO_2 concentration. CDR methods involve the ocean, land, and technical systems.

Ocean-based CDR methods to remove CO_2 from the atmosphere fall into two broad sets, i.e., those that employ changes in the ocean's chemistry to enhance the absorption of CO_2 from the atmosphere and those that employ changes in the ocean's biological pump. The latter might be accomplished either by fertilizing the ocean with micronutrients, such as iron, or by fertilizing it with macronutrients, such as nitrate and/or phosphate. The physical CDR method of direct CO_2 injection in the ocean include direct injection of CO_2 with subsequent dissolution or direct injection with the addition of alkalinity to neutralize the CO_2. Land-based CDR methods are categorized as

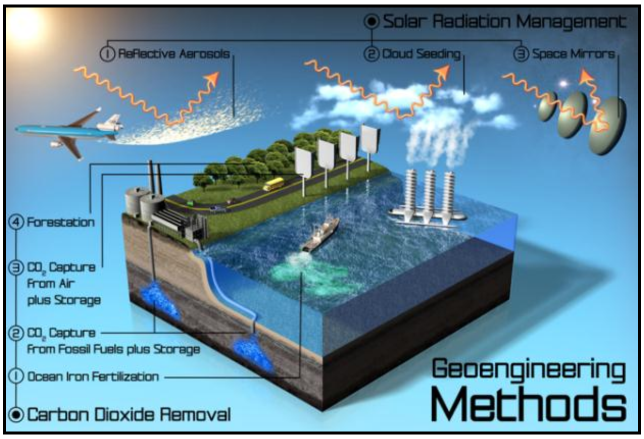


Figure 1: Illustration to show proposed Geo-engineering methods *(Source: www.climatecentral.org)*

– i) those that enhance natural sinks and ii) those that reduce natural sources, particularly by reducing terrestrial respiration. Sink-enhancing methods include afforestation/reforestation, bioenergy with 'Carbon Capture and Storage' (CCS), fertilization of land plants, and enhanced weathering on land. Source reduction CDR methods include the production and deployment of '*biochar*', the application of no till and conservation agriculture, and biomass burial. The scale and intent of Geoengineering methods are of central importance (Figure 2, The Royal Society, 2009). Two key characteristics of Geoengineering methods of particular concern are that they use or affect the climate system (e.g., atmosphere, land or ocean) globally or regionally and/or could have substantive unintended effects that cross national boundaries. Geoengineering is different from weather modification and ecological engineering, but the boundary can be fuzzy (IPCC, 2012).

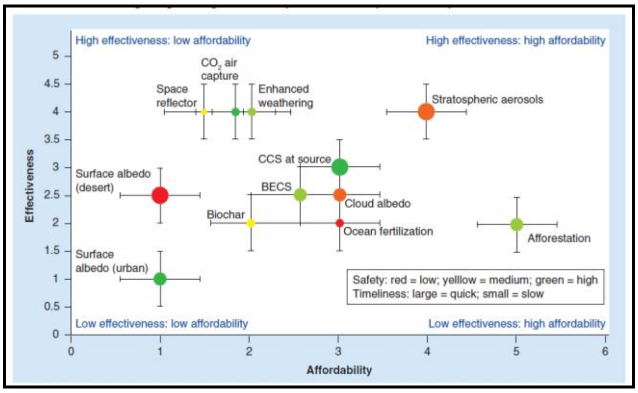


Figure 2: Summary of the effectiveness, affordability, timeliness and safety of Geo-engineering proposals

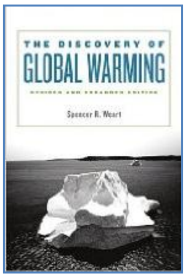
References:

- IPCC, 2012. Meeting Report of the Intergovernmental Panel on Climate Change Expert Meeting on Geoengineering [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, C. Field, V. Barros, T.F. Stocker, Q. Dahe, J. Minx, K. Mach, G.-K. Plattner, S. Schlömer, G. Hansen, M. Mastrandrea (eds.)]. IPCC Working Group III Technical Support Unit, Potsdam Institute for Climate Impact Research, Potsdam, Germany, pp. 99.

- The Royal Society, 2009. Geoengineering the climate: Science, governance and uncertainty. Royal Society, London, UK. 82 pp., (ISBN: 9780854037735.

Significant Events and Findings Related with Climate Change

(Adapted from "the discovery of global warming" by spencer Weart, http://www.aip.org/history/climate. February 2013)



1800-1870• First Industrial Revolution. Level of carbon dioxide gas (CO2) in the atmosphere, as later measured in ancient ice, is about 290 ppm (parts per million)..

1824 • Fourier calculates that the Earth would be far colder if it lacked an atmosphere.

1859 • Tyndall discovers that some gases block infrared radiation. He suggests that changes in the concentration of the gases could bring climate change.

1896 • Arrhenius publishes first calculation of global warming from human emissions of CO2.

1930s • Global warming trend since late 19th century reported.

1938 • Callendar argues that CO2 greenhouse global warming is underway.

1956 • Ewing and Donn offer a feedback model for quick ice age onset. Plass calculated that adding CO2 to the atmosphere will have a significant effect on the radiation balance.

1958 • Telescope studies show a greenhouse effect raises temperature of the atmosphere of Venus far above the boiling point of water.

1960 • Keeling accurately measures CO2 in the Earth's atmosphere and detects an annual rise. The level is 315 ppm.

1967 •Manabe and Wetherald make a convincing calculation that doubling CO2 would raise world temperatures a couple of degrees.

1969 • Astronauts walk on the Moon and people perceive the Earth as a fragile whole. Nimbus III satellite begins to provide comprehensive global atmospheric temperature measurements.

1975 • Warnings about environmental effects of airplanes leads to investigations of trace gases in the stratosphere and discovery of danger to ozone layer.

1976 • Studies find that CFCs (1975) and also methane and ozone (1976) can make a serious contribution to the greenhouse effect. Deforestation and other ecosystem changes are recognized as major factors in the future of the climate.

1977 • Scientific opinion tends to converge on global warming as the biggest climate risk in next century.

1985 • Ramanathan and collaborators announce that global warming may come twice as fast as expected, from rise of methane and other trace greenhouse gases.

1987 • Montreal Protocol of the Vienna Convention requires international restrictions on emission of ozone-destroying gases.

1988• Intergovernmental Panel on Climate Change (IPCC) is established.

1991 • Mt. Pinatubo explodes; Hansen predicts cooling pattern, verifying (by 1995) computer models of aerosol effects.

1993 • Greenland ice cores suggest that great climate changes (at least on a regional scale) can occur in the space of a single decade.

1997 • International conference produces Kyoto Protocol, setting targets for industrialized nations to reduce greenhouse gas emissions if enough nations sign onto a treaty (rejected by US Senate in advance).

1998 • "Super El Niño" causes weather disasters and warmest year on record (approximately matched by 2005, 2007 and 2010). Borehole data confirm extraordinary warming trend.

1999 • Ramanathan detects massive "brown cloud" of aerosols from South Asia.

2002 • Studies find surprisingly strong "global dimming," due to pollution, has retarded arrival of greenhouse warming, but dimming is now decreasing.

2003 • Numerous observations raise concern that collapse of ice sheets (West Antarctica, Greenland) can raise sea levels faster than most had believed.

2005 • Kyoto treaty goes into effect, signed by major industrial nations except U.S. Work to retard emissions accelerates in Japan, Western Europe, U.S. regional governments and corporations.

2007 • Greenland and Antarctic ice sheets and Arctic Ocean sea-ice cover found to be shrinking faster than expected. IPCC jointly with Al Gore (Former vice president USA) received Noble peace prize for their contributions to climate change research.

2012 • Level of CO2 in the atmosphere reaches 394 ppm. Mean global temperature is14.6 degree C, the warmest in hundreds, and probably thousands of years.

Call for Articles

Readers are requested to contribute short articles for publication in the forthcoming issue of *Signatures*, related to the specific theme ***"Remote Sensing Data Products & Retrieval Algorithms"***.

The deadline for inclusion in the next issue is **May 31, 2013.**

- Editorial Team

Glossary: Climate Change

Contributed by Mehul R. Pandya

Space Applications Centre, ISRO, Ahmedabad

Email: mrpandya@sac.isro.gov.in

Climate change has emerged as one of the defining political and socioeconomic issues for the Earth in the twenty-first century. Climate change is a complex issue that covers the full spectrum of scientific, economic, social and political disciplines, and few people have the opportunity to attain a comprehensive and in-depth understanding of all facets of climate change. Following section provides readers to be familiar with the definitions of some (18) of the terms frequently used in the subject.

Adaptation: Adaptation refers to all responses, adjustments, or action by human and natural system to accommodate and/or reduce their vulnerability to the impact of climate change.

Aerosol: Aerosols are solid or liquid particles between 0.01 and 10 μm in size that are air borne in the atmosphere for at least several hours.

Albedo: Albedo is a measure of the reflectivity of a surface. it is a scale from zero to one, where zero represents the perfect absorption of light and one represents the perfect reflectance.

Biosequestration: Biosequestration refers to the process of removing carbon dioxide from the atmosphere and storing it in land or ocean reservoirs through biological processes managed, promoted, or facilitated by humans.

Carbon Cycle: The Carbon cycle refers to the processes by which carbon moves between the atmosphere, the terrestrial (land) system, and the oceans. Carbon is constantly moving the three active reservoirs, and these exchanges are called carbon fluxes. **Carbon Sinks**: A carbon sink is a carbon reservoir that absorbs more carbon dioxide (CO_2) than it emits.

Carbon Tax: A carbon tax is specific tax levied on each unit of carbon dioxide (CO_2) or carbon dioxide equivalent (CO_2e) of the other greenhouse gases, emitted to the atmosphere. it is normally levied at a rate per tonne - for example, $ 10/tonne CO_2.

Climate change feedback: Climate change feedback refers to global warming induced change to the Earth's natural climate regular mechanism that either amplify (positive feedback effects) or subdue (negative feedback effects) the rate of warming.

Climate sensitivity: Climate sensitivity is a term used to describe the relationship between the rise in atmospheric greenhouse gas concentrations and changes in global mean surfaces temperature.

Global dimming: Global dimming is a term describing the reduction in incoming sunlight (or insolation) reaching the Earth's surface in the last 50 years.

Global warming: Global warming is a term used to describe a persistent increase in the Earth's mean surface temperature relative to long-term average conditions (those that prevail over centuries).

Global warming potentials : A global warming potential (GWP) is an index that compares the climate impact of an emission of a greenhouse gas relative to emitting the same amount of carbon dioxide (CO_2).

Greenhouse gases: The greenhouse effect is a natural process that maintains the mean surface temperature of the globe approximately 33^{o}C warmer than it would otherwise be, at 18^{o}C. Without the greenhouse effect, the Earth’s surface temperature would be -15°C and inhospitable to life.

Greenhouse gases: Greenhouse gases are those gases in the atmosphere that absorb Earth's outgoing long-wave radiation and re-emit it back to Earth. The result is the greenhouse effect that warms the Earth's surface and lower atmosphere.

Mitigation: Mitigation refers to human actions that prevent greenhouse gases from entering the atmosphere or to actions that remove greenhouse gases from the atmosphere. The primary objective of mitigation activities is to limit the increase in atmospheric greenhouse gas concentrations and, thereby, to reduce the extent of human - induced climate change the world will experience over the coming century and beyond.

Radiative forcing: The Earth's climate is fundamentally driven by the balance between incoming solar radiation and outgoing infrared radiation. Radiative forcing is derived from anthropogenic greenhouse gas emissions and other factors that force the radiation balance away from its natural state. It is expressed in global annual average Watts per square meter (Wm^{-2}). In effect it is a measure of "how far out of balance" the atmosphere currently is.

Renewable energy: Renewable energy sources are those energy sources that can be constantly replenished. They include sources derived directly or indirectly from the Sun (wind, solar, hydro power, wave power and biomass), moon (tidal) or Earth (geothermal).

UNFCCC: United Nations Framework Convention on Climate Change. Its affiliated Kyoto Protocol is the most important international cooperation on climate change and provides the basis for international action to curb global warming. The Convention was agreed in May 1992 and entered into force on March 21, 1994.

ISRS-AC ACTIVITIES

Environmental Educational Excursion 2012-2013
Marble Mines, Kumbhalgarh Fort, Haldighati, Shree Nath Ji- Nathdwara and Chittaurgarh

The Indian Society of Geomatics - Ahmedabad Chapter (ISG-AC), Indian Society of Remote Sensing - Ahmedabad Chapter (ISRS-AC), Indian National Cartographic Association-Gujarat Branch (INCA-GB) and Indian Meteorological Society - Ahmedabad Chaapter (IMSA) jointly conducted an environmental educational excursion to Marble Mines, Kumbhalgarh Fort, Haldighati, Shree Nath Ji - Nathdwara and Chittaurgarh during 15 - 16 December, 2012. The participants visited some of Geologically Important places along with some of historical places in and around Nathdwara and Chittaurgarh. There were 86 participants including members and their families. The enthusiasm of the participants after announcement of the event and during the tour was worth mentioning.

The tour started on 14th night 2130 hrs from SAC main gate and reached Nathdwara at 0500 hrs. On 15th December, a visit was arranged to R. K. Marble Mines where the participants were enlightened about various processes of marble extraction through a company presentations. This is one of the biggest marble producers in Asia. Kumbhalgarh was the next place of visit. Located 84 kms north of Udaipur in the wilderness, Kumbhalgarh is the second most important citadel after Chittaurgarh in the Mewar region, being the birthplace of Mewar's legendary king, Maharana Pratap. There is a magnificent array of temples built by the Mauryas of which the most picturesque place is the Badal Mahal or the palace of the clouds. The fort also offers a superb bird's eye view of the surroundings. The fort's massive wall stretches some 36 kms with a width enough to take

eight horses abreast. It was really amazing to learn the history and realise the efforts made by the people in the past to build such Forts in the inaccessible places and manage the water resources in those sites.

On the way back they also visited Haldighati, situated towards the south west of Nathdwara. Next day most of the participants visited Sreenathji Temple in the early morning followed by Chittaurgarh. The major attractions in Chittaurgarh were Chittaurgarh Palace, Padmini Palace, Meerabai Temple and Vijaysthambh. The fort stands on a 240-hectares site, on 180m high hill that rises rapidly from the plains. Meerabai Temple, where Meerabai worshipped Lord Krishna is built in north Indian style on a raised plinth with a conical roof and beautiful inner sanctum. An open colonnade around the sanctum has four small pavilions in each corner.

All the participants enjoyed the entire tour and hospitality provided by the organisers. The journey was back at SAC Campus on 17th Early morning.

Kumbhalgarh Fort

Meerabai temple

Expert lecture on 'Remote Sensing in Planetary Sciences: Highlights from NASA's Dawn mission to asteroid Vesta'

Indian Society of Remote Sensing – Ahmedabad Chapter in collaboration with Department of Civil Engineering of Institute of Technology, Nirma University arranged an expert lecture on 'Remote Sensing in Planetary Sciences: Highlights from NASA's Dawn mission to asteroid Vesta' by Prof. Vishnu Reddy, Department of Space Studies, University of North Dakota, Grand Forks, USA & Max-Planck Institute for Solar System Research, Germany and Dr. Lucille Le Corre, Planetary Science Institute, Tucson, Arizona. The lecture was organized at the seminar hall at Nirma University, Ahmedabad on 10th January, 2013. It was attended by around 80 undergraduate students of Civil Engineering, Electronics and Communication. Few scientists of ISRO, senior ISRS members along with the Deputy Director of ISRO Dr. Samudraiah also attended the lecture.

Prof. Vishnu Reddy threw light on the asteroids and meteorites, remote sensing in planetary sciences, ground bases remote sensing techniques while Dr. Le Corre talked about the NASA's Dawn Mission to asteroid Vesta and the basic results of the Dawn mission with a special emphasis on the global surface properties. The lecture was followed by an interactive session between the speakers and the students. The lecture was well received by the audience.

Conferring of ISRS Fellowhip to Shri A.S. Kiran Kumar

Shri A.S. Kiran Kumar, Director, Space Applications Centre was inducted as a Fellow of the Indian Society of Remote Sensing on 27th February 2013 as part of a joint programme that also included the IMS-AC 8th Satish Dhawan lecture. The lecture on ' Space observations for the Meteorology and climate change studies: State-of-Art and challenges' was delivered by Dr. Barbara J. Ryan, Secretariat Director, GEO Secretariat.

AWARDS

Shri A.S. Kiran Kumar, Director, Space Applications Centre, was conferred Fellowship of the Indian Society of Remote Sensing on February 27, 2013

Dr Parul Patel, Scientist, Space Applications Centre, was felicitated in *Science Category* by Shree Swaminarayan Gurukul Vishwavidya Pratishthanam on December 27, 2012.

Superannuation (December 2012)

Sri B.N. Mankad, SEDA

FEEDBACK

Megha-Tropiques Special Issue	**Name:** ***N.S. Pillai*** Feedback: Thank you for sending the special issue of Signature on MT. It is very well produced. Congratulations. Keep the good work going.
	Name: ***G. Raju*** Feedback: Hearty congratulations on the excellent and comprehensive way you have brought out the Special Issue of "Signatures". Keep up the good work. Tom Wilheit's interview is very much appropriate for the theme; I recall my reference to his document on ESMR during Bhaskara-SAMIR which supported my strong argument that 18 GHz will NOT measure SST but ocean wave heights/wind speed,contrary to many experts' views those days that it WILL measure SST only!
Educational Tour to Rajasthan	**Name:** ***Satyendra Bhandari*** Feedback: As a life member of the 3 out of 4 Societies, I joined the Educational Excursion arranged by the professional societies connected with SAC-ISRO. My wife also accompanied me on this excursion. The entire Excursion was highly enjoyable and the entire program scheduled was nicely arranged. We had opportunity to learn about the glorious History and unique resource (marble) of the Mewar region - a part of the geologically ancient Aravalli range of mountains. I wish to place on record my thanks and appreciation about the efforts put in by many colleagues and Executive Members of the four societies who participated. Effective guidance, management and the team work was very evident. We had a nice and enjoyable trip, thanks to the efforts put in by many individuals. Kindly convey my thanks and appreciation to all involved in planning and execution.

From The Editor's Desk

"Innovation distinguishes between a leader and a follower."

---------Steve Jobs

This particular issue has a special significance because its release will be coinciding with the Silver Jubilee celebration of the IRS-1A. On this occasion, we have decided to add some special flavour to the normal course of Newsletter, having a theme of 'Climate Change And Remote Sensing', by including a special section on the 'Reminiscences of IRS-1A'. The Signatures team took a special initiative to get articles on IRS-1A from the pioneers in this field, and who have contributed in a major way to making the IRS programme a huge success. We are thankful to all the authors, most of whom are former scientists from ISRO, for sparing their time and writing informative papers for this issue.

We have taken special interviews of the pioneering scientists for the IRS-1A project, namely Dr George Joseph, Honorary Distinguished Professor and former Director, SAC, Dr RR Navalgund, Vikram Sarabhai Distinguished Professor and former Director, SAC, and Sri A S Kiran Kumar, Director SAC, all of whom had contributed greatly to the IRS-1A. We are grateful to all of them, for sparing their valuable times and responding to our queries. I am sure this will enable our readers to connect to the vision and contributions of such great scientists and leaders.

My heartiest congratulations to the editorial team for their relentless efforts. I am also thankful to the Guest Editor, Dr R P Singh for his great efforts in making the section on 'Climate Change and Remote Sensing'. We are extremely thankful to Sri D Subrahmanyam, Chairman ISRS-AC, Sri D R M Samudraiah, Vice-President, ISRS, and Dr Parul Patel, Secretary, ISRS-AC for their constant help and guidance in bringing out this issue.

We are also including the feedbacks from our readers about the past issue, and for some of the events organised by ISRS-AC.

It will be our utmost pleasure, to get more feedback from our readers, which will help us in improving the quality of 'Signatures' .

Best wishes.

Arundhati Misra (Ray)

Editor, ISRS_AC

ISRS

Signatures

Newsletter of the Indian Society of Remote Sensing
Ahmedabad Chapter
Volume: 25, No.1, January-March 2013

ISRS-Ahmedabad Chapter

Room No-4372,
Space Applications Centre (SAC),
Indian Space Research Organisation (ISRO),
Ahmedabad-380015, Gujarat,
Phone: +91 79 2691 4372

Editorial Team

Arundhati MisraRay, SAC- Editor
S R Joshi, SAC
Ulkesh B. Desai, SAC
Ritesh Kumar Sharma, SAC,
Moumita Dutta, SAC
Kaushik Gopalan, SAC

The cover page was designed by **Dr. C P Singh**

Engineering model of the Indian Remote Sensing Satellite undergoing dynamic balance tests (1986-87)