Satellite Based Climate Change Study

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ABSTRACT

The emerging scenario of global change indicates changes in the rainfall pattern over Indian region with possibilities of severe weather systems replacing the normal pattern of rainfall. One of the major factors is the variability of monsoon rainfall and its impact on agriculture and water management. The effects of global warming on the Indian subcontinent vary from the submergence of low-lying islands, frequent flooding, coastal degradation and melting of glaciers in the Indian Himalayas. Droughts, flash floods, cyclones, avalanches, landslides brought on by torrential rains, and snowstorms pose the greatest threats. Several global climate models are run using inputs from satellites and ancillary observations and results indicate high intensity rainfall events over Indian region leading to floods.

The INSAT and IRS satellites in early 1980s heralded the era of Space observations. The IRS satellites are providing observations of parameters such as land use/cover, forest, water bodies and crops. INSAT provides quantitative products such as Cloud Motion Vectors (CMVs), Quantitative Precipitation Estimates (QPEs), Outgoing Long-wave Radiation (OLR), Vertical Temperature Profiles (VTPRs), Sea Surface Temperature. Currently INSAT satellites are providing global and regional observations. IRS satellites provide dynamic information on land cover, vegetation, soil conditions, which are directly relevant to the study of climate change.

The parameters provided by satellites on an operational basis include vegetation, soil condition, rainfall, groundwater, land use/cover, ocean temperature and Ocean productivity. The data provided from the weather satellites when combined with the aforementioned information provide a unique database for study of climate change over India. Some of the unique studies include Mapping of Himalayan Glaciers, Biodiversity Mapping, Early Warning of Drought and Severe Weather Events. The paper presents several case studies leading to better understanding of climate change and its causative factors.

Key Words: IRS, INSAT, Climate Change, Satellite application and monitoring.

1. Introduction

The potential climate changes and possible adverse impacts on the economy and society at large are causing concern. Recent times have witnessed increasing impact of industrialization and urban growth on environment. In India, one of the major effects of climate change is the variability of monsoon rainfall and its impact on agriculture and water management. Though it is difficult to clearly identify the natural variability of atmosphere versus anthropogenic impacts, the recent report of the International Panel on Climate Change has quantified the impacts. Observations indicate the possibility of more frequent severe weather events and high intense rainfall events.

Further, there are concerns about the submergence of low-lying islands, coastal areas, frequent flooding, coastal degradation and melting of glaciers in the Indian Himalayas. The various parameters associated with environment and climate change need to be monitored and analysed. Indian agriculture being heavily dependent on the monsoon and the potential impact of climate change on monsoon dynamics through ocean warming needs attention. While studying the climate change scenarios, it is essential to build up necessary strategies at local level to reduce the adverse impacts especially on agriculture and water management. It will be a challenging task to counter the effect of climate change through scientific means.

2. Climate Change – a Complex interaction

Since the industrial revolution, human activity has increased the amount of greenhouse gases in the atmosphere (shown in the graph to the right). The increased amount of gases which absorb heat, has directly lead to more heat being retained in the atmosphere and thus an increase in global average surface temperatures. This change in temperature is known as global warming. The increase in temperature is also leading to other effects on the climate system. Together these affects are known as anthropogenic (human caused) climate change.

The weather and climate of Earth is due to a complex interaction between land-atmosphere-ocean systems. Recent years have seen increased impact of human activities in terms of industry, deforestation, urbanisation etc. that has potential to change climate system. The major factors are given below:

a)   Of utmost concern in the anthropogenic factors is the increase in CO_2 levels due to emissions from fossil fuel combustion, followed by aerosols (particulate matter in the atmosphere) and the CO_2 released by cement manufacture. Other factors, include land use, ozone depletion, and deforestation.

b)   The oceans contain more carbon dioxide (CO_2) than the atmosphere and they can also absorb CO_2 from the atmosphere. When the CO_2 is in the oceans it does not trap heat as it does when it is in the atmosphere. If CO_2 leaves the oceans and moves back into the atmosphere this can contribute towards a warmer climate.

c)   On a global scale, patterns of vegetation and climate are closely correlated. Vegetation absorbs CO_2 and this can buffer some of the effects of global warming.

Each of the above factors contributes to the changes in the climate of Earth and the way they interact with each other makes it more complicated. When the quantity of CO_2 in the atmosphere increases, the temperature of the Earth rises. This in turn would contribute to a warming of the oceans. Warm oceans are less able to absorb CO_2 than cold

ones, so as the temperature rises, the oceans release more CO_2 into the atmosphere, which in turn causes the temperature to rise again through a feedback mechanism as in Fig 1.
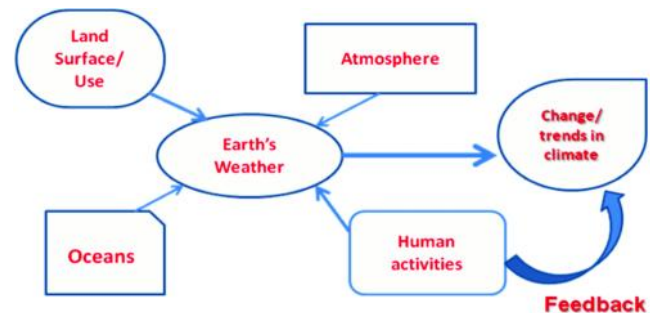

Fig.1:   Complex interaction on Land-Atmosphere-Ocean System.

3. Applications of Satellite Data

Over the past three decades, satellite remote sensing has grown in terms of technology and application potential. Multi-frequency, high resolution sensors have been developed and made operational. India is operating both INSAT and IRS series of satellites (Joshi et al, 2003) for land, ocean and atmospheric applications. The advanced sensors in operation include Atmospheric Sounder in INSAT 3D, OCM in Oceansat 2, Wind Scatterometer in Oceansat 2, WiFS in Resourcesat. These sensors are capable of capturing the dynamic aspects of land processes, ocean dynamics and atmospheric conditions (Manikiam, 2014). Following sections highlight applications of satellite data for climate change studies.

3.1   Land applications

Due to rapid urbanization, the land use is getting changed at a rapid pace and this need to be monitored. The Indian Remote Sensing (IRS) satellites have high resolution sensors operating in visible and near IR region. These are useful in mapping land cover over large areas and quantify the changes. Fig 2 depicts the land cover changes over a period 2001 to 2006 in Karnataka State.

Another application related to land is the vegetation dynamics especially deforestation and associated albedo changes. The vegetation layer provide important information required by high resolution weather models.

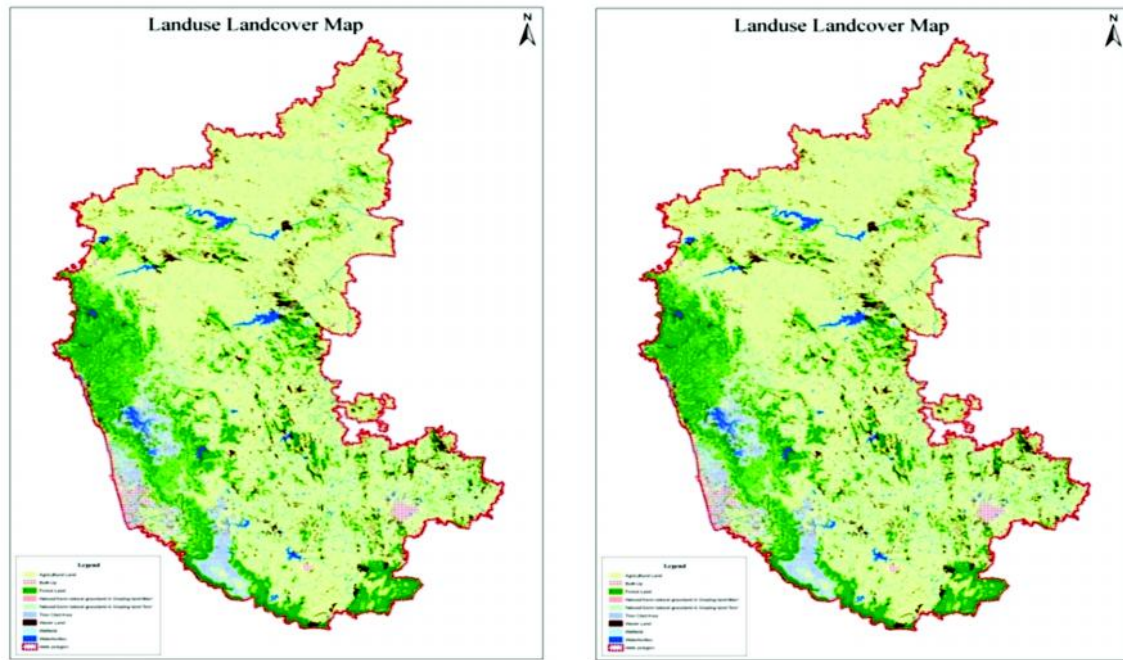The sensitivity of vegetation in visible and

Fig. 2: Land use/Cover changes in Karnataka. Left panel for 2001 and right one during 2006.

infrared is used to derive Normalised Difference Vegetation Index (NDVI) as NIR - G /NIR + G where NIR and G are radiances in near infrared and green bands. This index is very sensitive to rainfall and reflects the anomaly in rainfall and vegetation response. A long term database of about 20-years is available in the country.

Coastal zone is very sensitive to sea level changes and frequency of cyclones and over a period experiences changes in coast line and landforms. Coastal zone thus is a good indicator of climate change IRS satellite data have been used
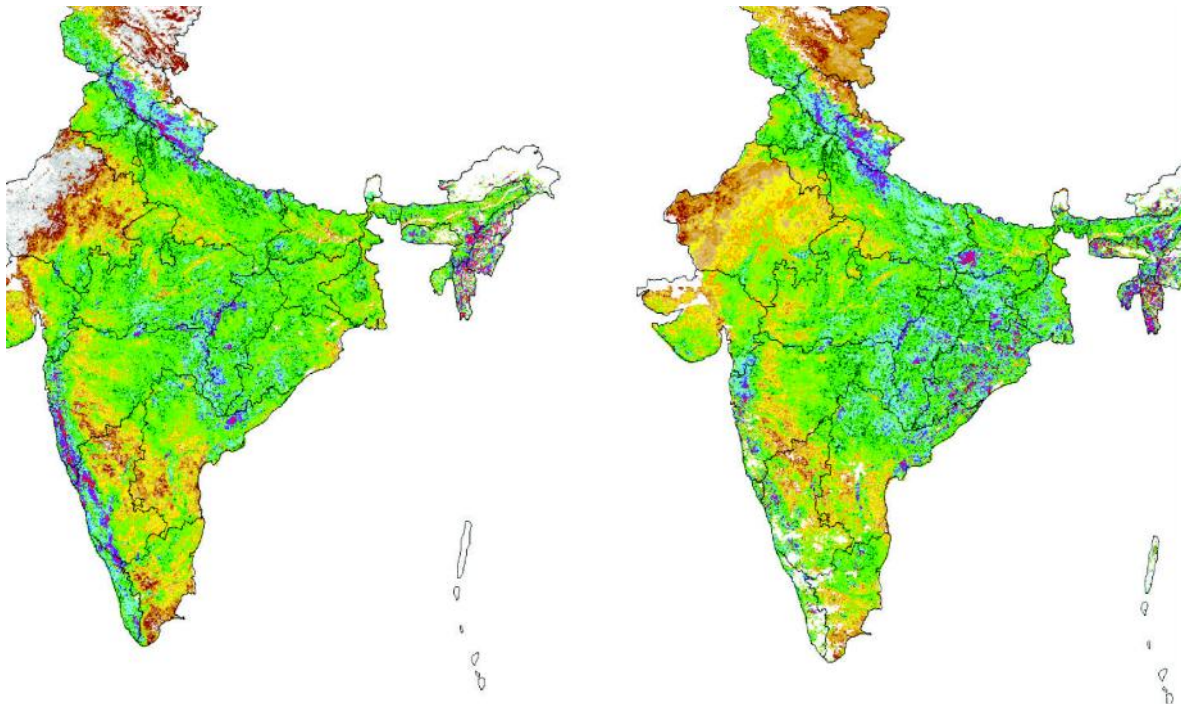

Fig. 3: Vegetation dynamics through the NDVI, left panel for 2002 and right one during 2001.

Table 1
Major land cover changes in Karnataka

No.	Description	Area in Sqkm
1.	Agricultural Land	133191
2.	Built-Up	5449
3.	Forest Cover	29248
4.	Natural/Semi natural grassland &Grazing land	636
5.	Tree Clad Area	7413
6.	Waste Land	8529
7.	Water bodies	7232
8.	Wetland	86

(Prabhaharan et al, 2010) to map the coastline of Vedaranyam in Tamil Nadu and using multidate data, changes in major landforms have been determined.

Entire coastal zone of the country has been mapped and bench mark prepared. Using satellite data, it is now possible to identify "hotspots" where large change in coastal line is taking place. A number of studies have been taken up for inventory, monitoring and retreat of Himalayan glaciers using satellite data. Glacial inventory has been carried out for the glacial regions of Indus, Ganga and Brahmaputra Basins covered approximately in 1:50,000 scale. Specific measurements of mapped glacier features are used as inputs for generating the glacier inventory data. Glacier mass balance

studies have been taken up for 10 selected medium sized sub-basins spread over in Indian Himalayan region (Indus, Ganga and Brahmaputra Rivers). The IRS LISS III scenes are used to ascertain the boundary of glaciers using higher resolution data. Glacier boundaries are overlaid on all AWiFS scenes sequentially.

Glacier Retreat mapping was done for the 14 selected basins spread over in Indian Himalayan Region. This involves, creation of database of spatial extent of all glaciers and overlaying of the boundaries; checking of the boundaries in the accumulation zone based on shadow of the ridges & on the drainages; identification of glacier retreat and estimation of glacier area evacuated and verification in the field the location of snout using GPS observations. Monitoring of snow cover of the Indian Himalayan region covering Indus, Ganga and Brahmaputra river basins have been carried out using multidate AWiFS data from Resourcesat-1 and snow cover atlases have been prepared.

Careful monitoring is essential to assess any reduction in snow cover and retreat of snow lines due to climate change.

3.2. Ocean applications

The oceans and atmosphere store and exchange energy in the form of heat, moisture, and momentum. The oceans are obviously the Earth's largest reservoir of moisture. They also absorb heat more effectively than land and ice surfaces, and
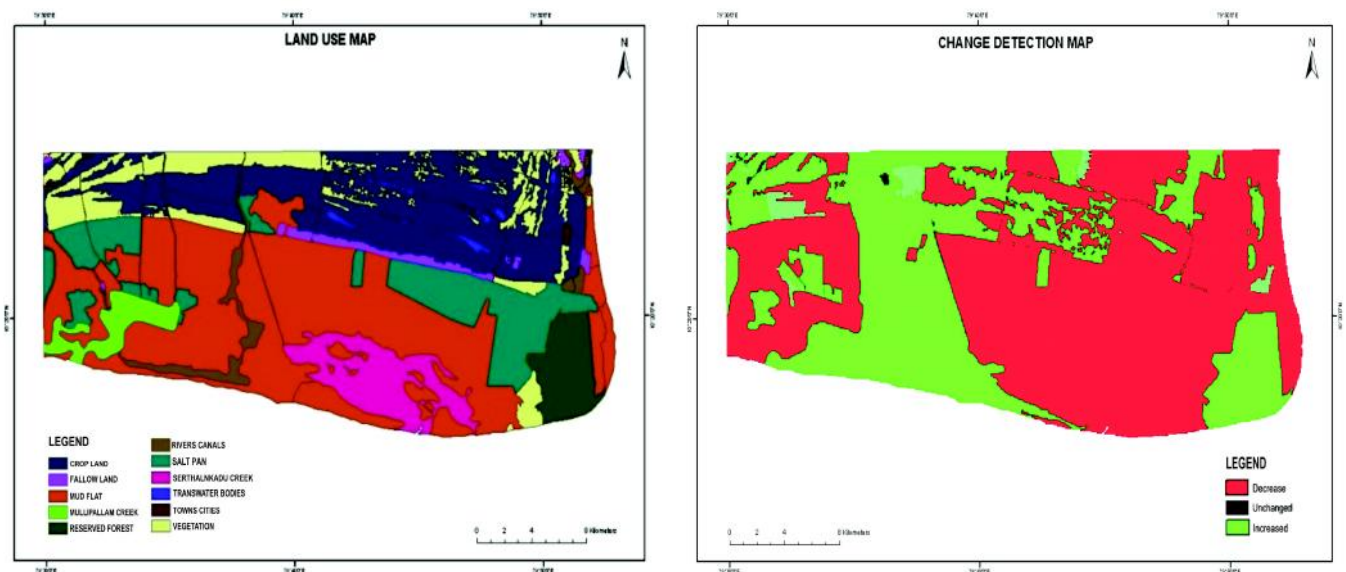

Fig. 4 : Coastal landform mapping & Change detection for Vedaranyam Coast, Tamil Nadu.

store heat more efficiently than land. Oceanic heat is released more slowly than on land, keeping coastal areas more temperate. Changes in the energy balance between the oceans and atmosphere play an important role in the planet's climate change. The oceans have tremendous thermal and dynamical inertia, which can slow and dampen the rate of climate change. The upper ten feet (~3 m) of the ocean holds as much heat as the entire atmosphere. The moderating effect of ocean temperature reduces the daily and annual range of coastal temperatures, and results in a lag of the global summer and winter seasonal temperatures extremes by several weeks behind the annual track of the sun.

Ocean temperatures play a very crucial role in the Indian Monsoon and in the ocean productivity in terms of fishery potential and chlorophyll production. The satellite data from NOAA and INSAT geostationary satellites are used to prepare weekly Sea Surface Temperature (SST) maps. The accuracy achieved is in the region of ± 0.5 ^{0}C. These

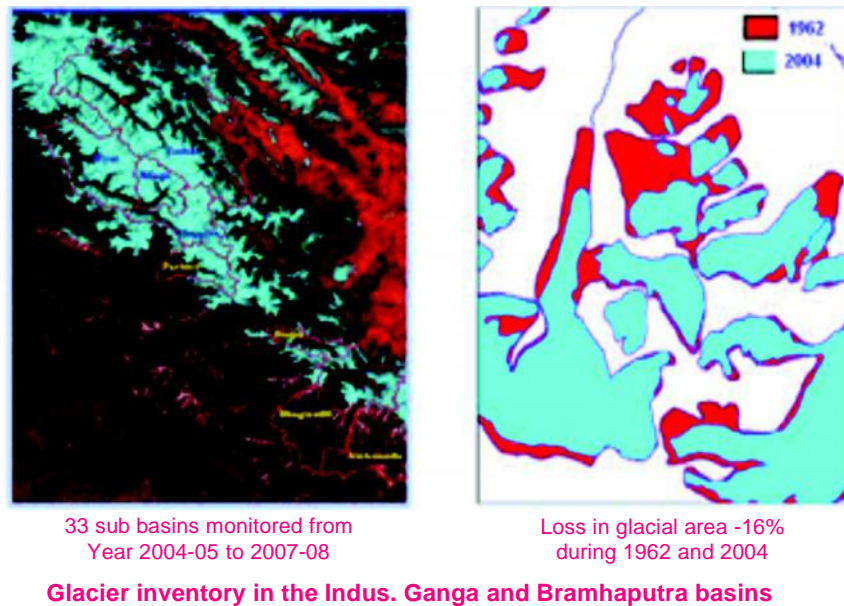33 sub basins monitored from
Year 2004-05 to 2007-08

Loss in glacial area -16%
during 1962 and 2004

Glacier inventory in the Indus. Ganga and Bramhaputra basins

Fig.5:   Satellite based snow and glacier inventory of western Himalayas.
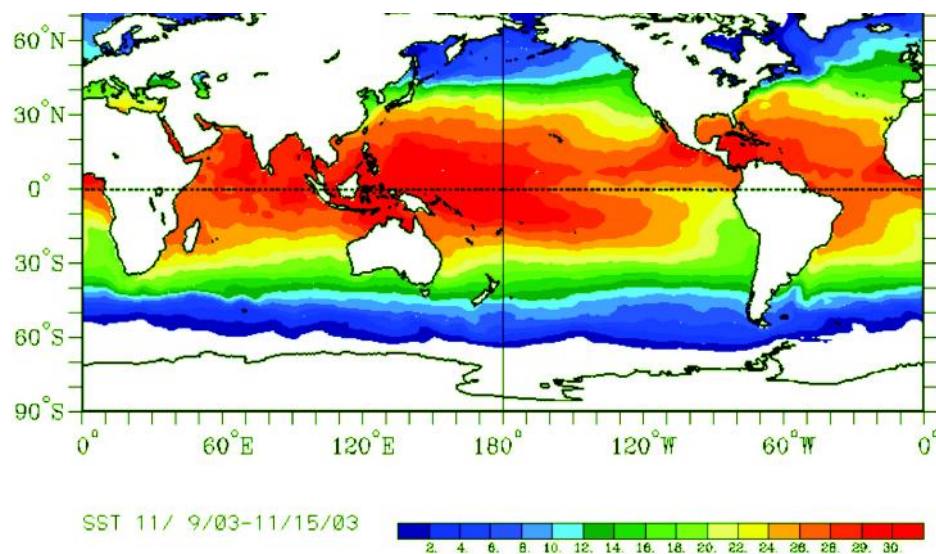

SST 11/ 9/03-11/15/03

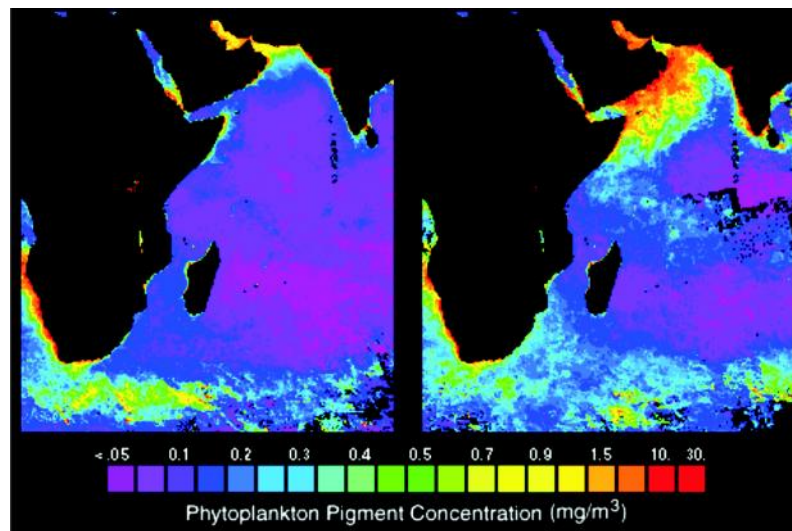Fig. 6 **:** Global Sea Surface Temperature using NOAA data.

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Fig. 7: Spatial and seasonal (monsoon) variability of the chlorophyll-a concentration in NW Atlantic and Indian Oceans.

maps form the basic data for analysis of El Nino/La Nina conditions in Pacific Ocean and Cyclogenesis conditions in the Indian oceans.

Long and short seasonal variations of SST are being monitored on a regular basis. Further, meteorological data along with satellites are valuable for monitoring and forecasting of cyclones. INSAT/VHRR images are being used to identify cloud systems over the oceans (Manikiam et al, 1983), where no observational data are available, as well as for cyclone tracking, intensity assessment and prediction of storm surges, etc. Current research around the globe is concentrating on use of meso-scale models with satellite data inputs to improve the cyclone intensity and track prediction.

The ocean stores and transports not only heat but also carbon dioxide (CO_2), a potential major source of global warming. About half of the total CO_2 added to the atmosphere during the past century by human activity – mostly from the use of fossil fuels and deforestation– has been absorbed by the ocean. Most of the CO_2 emitted into the atmosphere will eventually be absorbed by the ocean. However, this process will take several decades to centuries. Phytoplankton also stores carbon dioxide from the upper layers of the ocean. Many species sequestered CO_2 in their carbonate shells, which eventually sink to the ocean floor for burial, or long-term removal from the carbon cycle.

Ocean Colour Monitor onboard Oceansat 2 has 8 narrow channels in the green and blue region of visible spectrum. This makes it very sensitive to ocean colour due to phytoplankton and sedimentation. Similarly MODIS satellite has multi channels sensitive to ocean productivity.

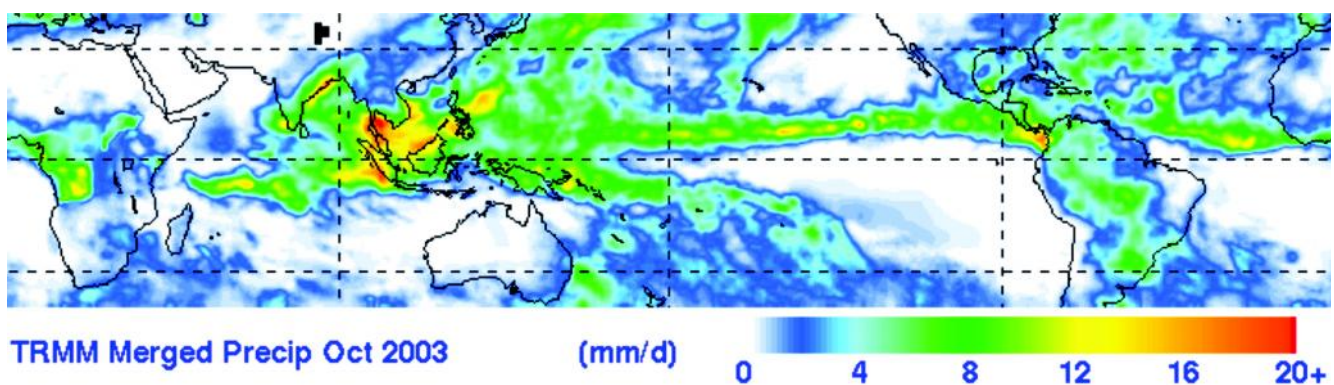The Tropical Rainfall Monitoring Mission

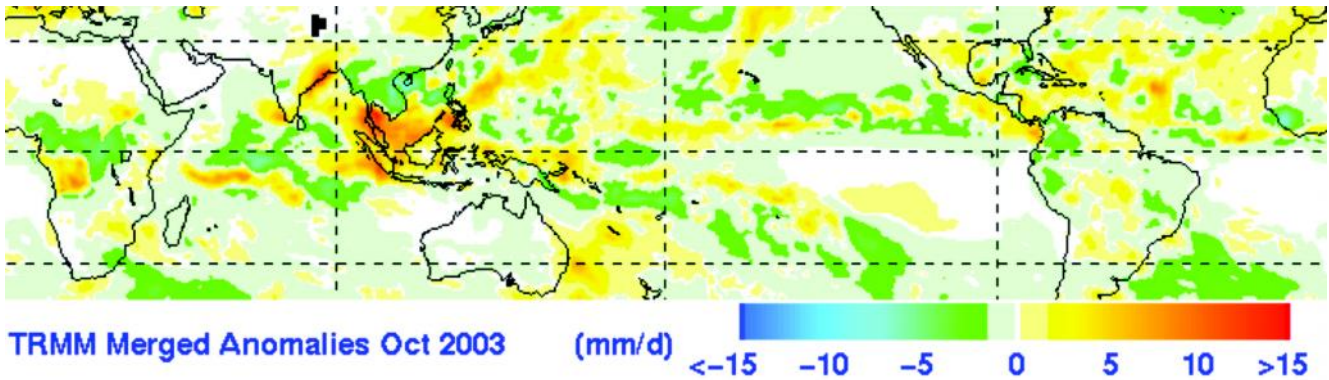Fig. 8: TRMM based rainfall over global oceans.

Fig. 9: Rainfall anomalies over oceans.

(TRMM) has onboard radar to monitor rainfall globally. This satellite gave insights into the rainfall processes and for the first time it gave observations over the oceans.

3.3   Atmosphere related applications

INSAT satellite in 1982 heralded the era of space observations and gave the first glimpses of the dynamic cloud systems over India. Since the launch of INSAT 1A in 1982, a series of satellites are in operation and IMD has developed a long term series of cloud cover, OLR, rainfall etc. The INSAT products will form an important data set in climate change analysis at local and regional level. Currently INSAT satellite is providing global and regional observations. It carries Very High resolution Radiometer (VHRR) payload which operated in two spectral bands – visible [0.55-0.75 ìm] and thermal infrared [10.5-12.5 ìm]. The INSAT satellite gives every hour weather imageries of the country showing the cloud systems, their movement and potential severe weather events. The quantitative products available from INSAT data give the numerical products such as Cloud Motion Vectors (CMVs), Quantitative Precipitation Estimates (QPEs), Outgoing Long-wave Radiation (OLR), Vertical Temperature Profiles (VTPRs) and SST.

The data from GPS satellites are used to derive atmospheric conditions, based on the principle that the time delay in arrival of signals from GPS satellite is directly linked to the moisture content and temperature profile of the atmosphere. A new stability index (Deveerappa Jagadeesha, 2014) based on atmospheric refractivity at ~500hPa level and surface measurements of temperature, pressure and humidity is formulated. The new index named here as Refractivity based Lifted Index (RLI) is designed to give similar results as traditionally used lifted index derived from radiosonde profiles of temperature, pressure and humidity. The
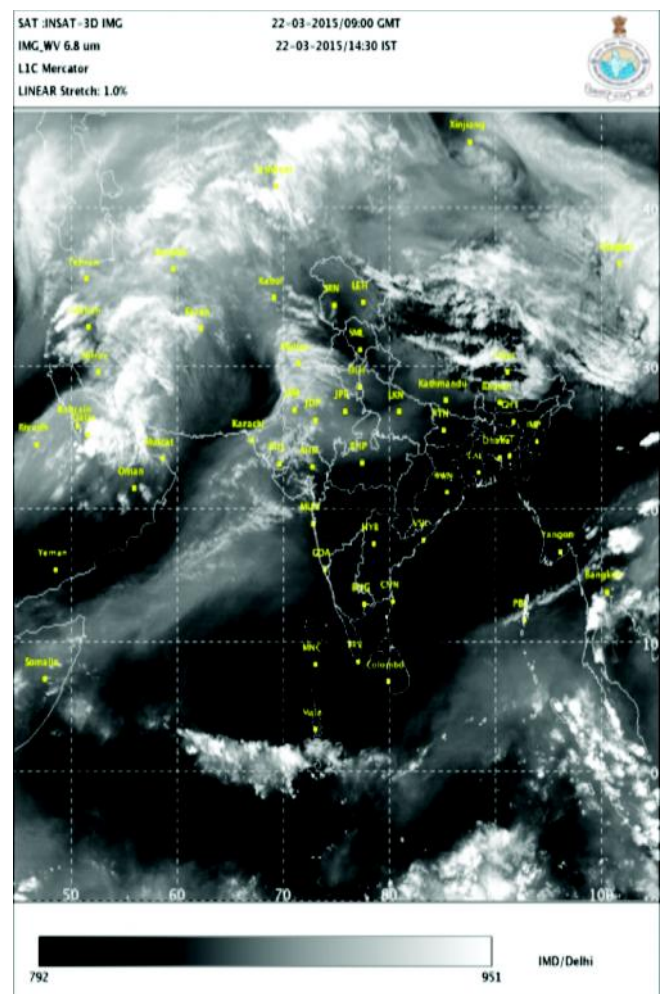

Fig. 10: INSAT Water Vapour Image.

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formulation of the stability index and its comparison with the traditional temperature profile based lifted index (LI) is discussed. The index is tested on COSMIC radio occultation derived refractivity profiles over Indian region. The forecast potential of the new index for rainfall on 2°×2° latitude–longitude spatial scale with lead time of 3–24 hours indicate that the refractivity based lifted index works better than the traditional temperature based lifted index for the Indian monsoon region. Decreasing values of RLI tend to give increasing rainfall probabilities.

4. Summary

The satellites have a great role to play in the study of climate change. Climate change modelling requires accurate and long term observations of land surface, oceans and atmosphere. The satellites with advanced sensors are capable of measuring several critical parameters. Table-1 summarises the capabilities of satellites.

The immediate task is to build a long term series of well calibrated data using satellite and ground/ ocean observations to look for signal of climate change.

Acknowledgements

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Table 2

Parameters available from satellites with their accuracy and duration

Sl. No.	Theme	Parameters	Accuracy	Time series available
1	Land	Land use/cover	~ 5 meters	15 years
		Soil Types	Major types	15 years
		Soil Moisture	~ 10%	5 years
		Vegetation cover	~ 5 %	25 years
		Forest cover	~ 5 %	30 years
		Water resources	~ 5%	30 years
		Drought	± 100 ha	40 years
		Floods	± 100 ha	40 years
2.	Oceans	Sea Surface temperature	± 0.7 ^{0}C	50 years
		Sea level winds	± 10%	5 years
		Sea Level	± few mm	15 years
		Sea Ice	± 10%	15 years
3	Atmosphere/ weather	Weather observations	Daily (3hrly)	> 50 years
		Temp/Humidity profiles	Daily (12 hrly)	> 15 years
		Rainfall	± 5% ~ ppm	> 15 years
		Cyclones		> 50 years
		Aerosol/GHG		>10 years

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