Mapana J Sci, 14, 1 (2015), 25-39
ISSN 0975-3303 | doi:10.12723/mjs.32.4

Climate Change Analysis using Satellite Data

Kamsali Nagaraja* and Balakrishnan Manikiam †

Abstract

Recent times have witnessed increasing impact of industrialization and urban growth on environment. In addition, the potential climate changes and possible adverse impacts on the economy and society at large are causing concern. In India, one of the major concerns is the variability of monsoon rainfall and effects on agriculture and water management. The various parameters associated with environment and climate change need to be monitored and analyzed. 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. Indian satellites INSAT and IRS launched 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, crops etc. while 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. The satellite data is operationally used for generating long term database on vegetation, soil condition, rainfall, groundwater etc.. Some of the unique studies are Biosphere Reserve Monitoring, Mapping of

---

* Department of Physics, Bangalore University, Bangalore 560056; kamsalinagaraj@gmail.com
† Sir M Visvesvaraya - ISRO Chair, Department of Physics, Bangalore University, Bangalore 560056; Manikiam@yahoo.co.in

Glacial Lakes & Water Bodies in Himalayas, Biodiversity Mapping, Early Warning of Drought and Severe Weather Events. The paper presents details of the studies and salient results.

Keywords: Climate Change, Land cover, Vegetation, Satellite data

1. Introduction

The beginning of Atmospheric science can be traced back to ancient India, as the Upanishads contain in depth discussion about the processes of cloud formation and rain, and the seasonal cycles caused by the movement of Earth around the Sun. Varāhamihira's classical work *Brihatsamhita*, written about 500 AD provide a clear evidences for the understanding of several atmospheric processes in those times, even though it is complex. Atmospheric physicists attempt to model Earth's atmosphere using fluid flow equations, chemical models, radiation balancing, and energy transfer processes in the atmosphere and underlying oceans. The weather phenomena include thunderstorms, tornadoes, tropical cyclones, jet streams, and global-scale monsoon circulations. Besides the network of weather observatories of Indian Meteorological Department, the satellites launched by ISRO are providing data on atmospheric parameters and weather systems.

Recent times have witnessed increasing concern over the climate changes and possible adverse impacts on the economy and society at large. The identification of effect the natural variability of atmosphere versus anthropogenic impacts is difficult to quantify. The recent report of the International Panel on Climate Change [1] has attempted to quantify the impacts. With regard to India, the major concern is the likely impact on monsoon rainfall and its spatial distribution.

2. Indian Scenario

In India, we experience four major seasons viz. winter, summer, monsoon and post monsoon. The monsoon season extends from June to September. During the post monsoon season, cyclonic storms form over the Bay of Bengal and rarely over Arabian sea and move into the coastal areas.

The climate change impact on monsoon is expected to be in terms of its duration and quantum of rain. The impact of such variation is different in different regions of the country based on the agroclimatic zones. Global model predictions indicate raise in frequency and intensity of weather based disasters such as drought, flash flood, cyclone and landslides. Other dangers include frequent summer dust storms.

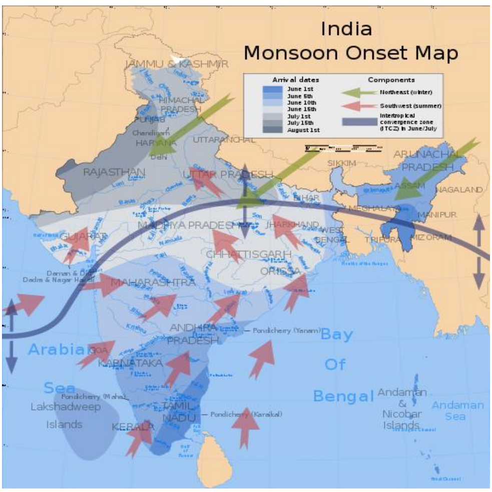


Fig. 1: Progress of Monsoon over India – Normal dates

(Adopted from IMD web site)

Indian agriculture is heavily dependent on the monsoon as a source of water. In some parts of India, the failure of the monsoons result in water shortages, resulting in below-average crop yields. This is particularly true of major drought-prone regions such as southern and eastern Maharashtra, northern Karnataka, Andhra Pradesh, Orissa, Gujarat, and Rajasthan. In the past, droughts have periodically led to major Indian famines. The schematic in Fig. 2 shows the role of atmosphere, land and oceans on climate change. The human activities also contribute to these changes.

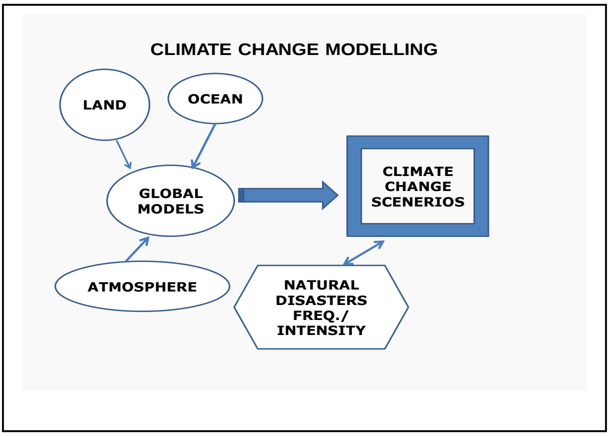


Fig. 2: Role of land-ocean-atmosphere interactions

3. Satellite Applications to Climate change Studies

The launch of the first meteorological satellite TIROS-1 in April 1960 heralded the era of Space observations and gave the first glimpses of the dynamic cloud systems surrounding the Earth. Since then the technology has developed by leaps and bounds in observation capabilities in terms of spatial, spectral and temporal resolutions. A global system of Space observations with both geostationary and polar orbiting satellites has evolved [2-4].

Currently several operational meteorological satellites are providing global and regional observations. Six different types of satellite systems currently in use are - 1) Visible/Infrared/Water Vapour Imagers, 2) Infrared Sounders, 3) Microwave Imagers, 4) Microwave Sounders, 5) Scatterometers and 6) Radar Altimeters. Though the water vapour imaging capability is available only on the geostationary satellite, the visible and infrared imagers are available on geostationary as well as polar orbiting satellites. The last four are currently available only on polar orbiting systems [3].

We first describe in detail below the INSAT system which is the primary satellite for weather surveillance in this part of the globe. It is a multipurpose geostationary satellite that caters to the requirements of Meteorology and Communication. It carries a met payload called Very High Resolution Radiometer (VHRR) that enables us to have visible, infrared and now even water vapour images [4].

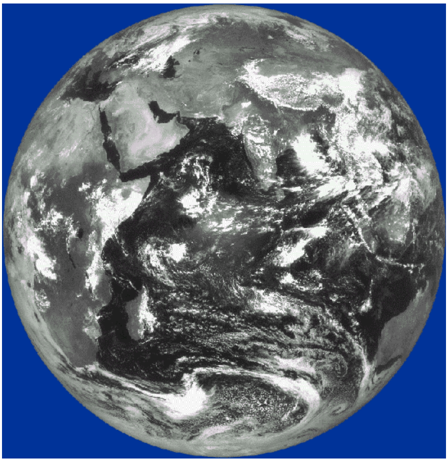


Fig. 3: Monitoring weather with INSAT

The following numerical products are obtained from INSAT on a daily basis:

1. Cloud Motion Vectors (CMVs)
2. Quantitative Precipitation Estimates (QPEs)
3. Outgoing Long-wave Radiation (OLR)
4. Vertical Temperature Profiles (VTPRs)
5. Sea Surface Temperatures (SSTs)

The Indian Remote Sensing (IRS) satellites have sensors viz. Linear Self Imaging Scanning (LISS) with spatial resolutions ranging from 36 meters to 2 meters, Wide Field Sensor (WiFS) with wide coverage, Panchromatic Camera (PAN) with high resolution, Ocean Colour Monitor (OCM). These sensors help in mapping a number of features of earth’s surface [5] such as terrain, land use/cover, vegetation, water bodies, coastline etc. The IRS satellite data thus has wide applications in monitoring the land, ocean, soil, water etc. And provide quantitative inputs to environmental assessment.

4. Observational Requirements for climate change

The climate change studies require accurate observations on a long term basis on parameters related to Atmosphere, Oceans, Land surface and weather related extreme events.

Major theme	Sub themes	Accuracy required	Satellite observations
Land cover / use	a) Terrain – contours b) Vegetation cover c) Built up areas d)Water bodies–Rivers, Lakes, e) Coastal zones f) Barren lands g) Mountainous terrain h) Snow cover	± 5 ms ± 5 % ± 5 ms ± 5% ± 5 ms ± 5 ms ± 5 ms ± 2 %	IRS – LISS-2/3 IRS – LISS2/3, WiFS IRS – PAN, LISS3 IRS – LISS 2/3, OCM IRS- LISS 2/3 IRS- LISS 2/3 IRS – stereo view, LISS 2/3 IRS – LISS 3, WiFS, PAN
Atmosphere	a) Greenhouse gases b) Pollution c) Aerosols d) Ozone concentrations e) WV in Stratosphere f) temp/humidity profiles	± 1 ppm ± 2 ppm ± 2 % ± 1 ppm ± 2 % ± 5 %	MODIS, UARS MODIS MODIS NIMBUS, MODIS INSAT 3D, NOAA-TOVS NOAA-TOVS, INSAT 3D-Sounder
Oceans	a) Sea Surface Temp. b) Ocean Salinity c) Ocean surface winds d) Ocean Waves e) Productivity f) Rainfall over oceans g) Mixed Layer Depth	± 0.2 0 C ± 5 % ± 1 m/s ± 5 cms ± 2 % ± 0.5 mm ± 5 ms	Ocean Sat – 1 MSMR, NOAA-AVHRR Ocean Sat – 1 MSMR, SMMR Ocean Sat – 2 Scatterometer Ocean Sat – 2 Scatterometer Ocean Sat – 2 OCM DMSP-SMMR, TRMM SMMR
Extreme weather events	a) Cyclones, Drought, Flood, Storms b) Frequency- occurrence c) Intensity	.... ± 0.5 T	INSAT VHRR INSAT VHRR INSAT VHRR, DMSP-SMMR

Foot note; Abbreviations used in Table-1

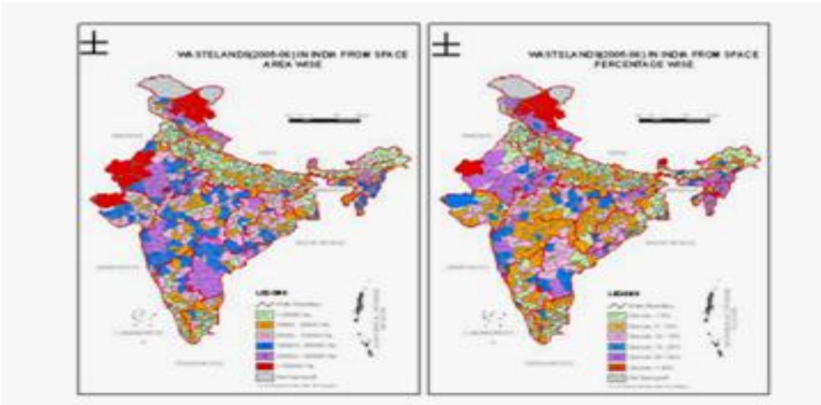
LISS–linear Imaging Self Scanning, VHRR–Very High Resolution Radiometer, WiFS– Wide Field sensor, AVHRR – Advanced Very High Resolution Radiometer, PAN – Panchromatic, MSMR - Multifrequency Microwave Scanning Radiometer, TOVS – TIROS Vertical Sounder, SMMR – Satellite Multi freq. Microwave Radiometer, OCM–Ocean Colour Monitor

The approach is to acquire satellite observations and validating with ground/sea truth data and build a long term series on above parameters. Currently such database is available on land use/ cover, water resources, sea surface temperature, cyclones, droughts, rainfall.

5. Case studies using satellite data

Some of the case studies and applications that are directly relevant to climate change are as follows:

a. **Wasteland Mapping**: Wastelands are land areas which are not productive for several years due to highly variable rainfall. This could be due to natural constraints like flooding, soil erosion, aridness etc. The remote sensing data was used to identify wastelands in 13 categories and generate a statistics for the whole country [2]. At the behest of Department of Land Resources (DoLR), inventorying of wastelands using satellite data on 1:50,000 scale was carried out during 1986 to 2000 and a National Wastelands Atlas was brought out. The extent of wastelands at that time was 63.85 M ha. Further development actions were initiated to bring such land under agriculture, plantation, social forestry etc.



b) **Coastal Zone Mapping**: Study of dynamics of coastal landforms

Coastal zones are highly sensitive to climate change and are good indicators of sea level data and field observations. The Uttara Kannada coast in the State of Karnataka lying on the west coast of India, characterized by diverse terrains with widely differing structures, is an important region for many developmental activities. In order to understand its coastal landforms, and their seasonal and long term dynamics, multidate satellite data of SPOT and IRS have been studied along with the Survey of India toposheet from 1976-77 as the baseline [6]. In the present study approximately 100 km of the coast of the Uttara Kannada district has been covered Coastal landforms were mapped and the dynamics were assessed using satellite, collateral data and field observations. The SOI maps and satellite derived maps for multi dates were co-registered with one pixel accuracy to assess the changes in the coastal landforms. The study revealed that the coast is studded with several estuaries and creeks that support extensive mudflats, which are being used for salt production and aquaculture activities. The coast is also marked by spectacular cliffs/headlands, bays, beaches, sand dunes, spits, offshore islands, bars/shoals and river.

In another study, the SOI maps and satellite derived maps for multi dates were co-registered with one pixel accuracy to assess the changes in the coastal landforms in Paradeep area in Orissa coast. .

The study revealed that the coast is studded with several estuaries and creeks that support extensive mudflats, which are being used for salt production and aquaculture activities. The coast is also marked by spectacular cliffs/headlands, bays, beaches, sand dunes, spits, offshore islands, bars/shoals and river.ise. Satellite data has been interpreted using digital techniques to prepare coastal land use, mangrove maps at dominant community level, coral reefs maps at eco geo-morphological level, coastal landform maps on 1:25,000 scale. Ecological status of coastal areas has been brought out by comparing maps prepared for the period 1989-91 and 2004-06. Models have been developed to study coastal land use changes and their impact.

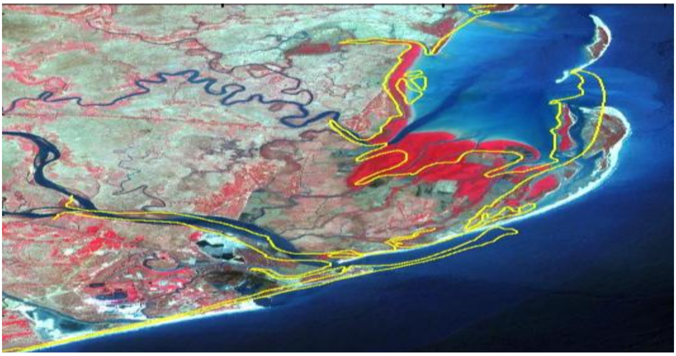


Fig. 5 : Coastal Zone map of Paradeep area in Orissa, indicating changes from the survey (yellow line) made in 1920s.

c. Cyclone monitoring and warning: Tropical cyclones occur in the Bay of Bengal and Arabian sea in the months of March-June and September – December every year. The cyclones form as small vortices and grow into a large system as they move towards the coast. The INSAT satellite provides valuable data for monitoring and forecasting of cyclones [7-8]. The INSAT/VHRR images are operationally used to identify the cyclonic system over the oceans, where no observational data is available. The hourly INSAT imageries is the only tool to track the cyclone movement and assessment of their intensity assessment. The satellite based rainfall estimation over the cyclones is made from the TRMM satellite data. Several cyclones that occurred in the Bay of Bengal were studied using satellite data (Figure 4). The study of pre and post satellite period showed [7] a statistical increase in number of cyclones per year. This is due to the fact that prior to the satellites, several cyclones have gone unreported.

The intensity of cyclones derived from satellite data can be used to determine the maximum winds in the cyclone field. The wind maxima is related to the cyclone central pressure by the formula [9]

$Vmax = K \sqrt{P - Pc}$

where Pc is the central pressure, and Vmax is the maximum wind. The constant K has been calibrated for the Indian Ocean region using a number of cyclones studied using satellite data.

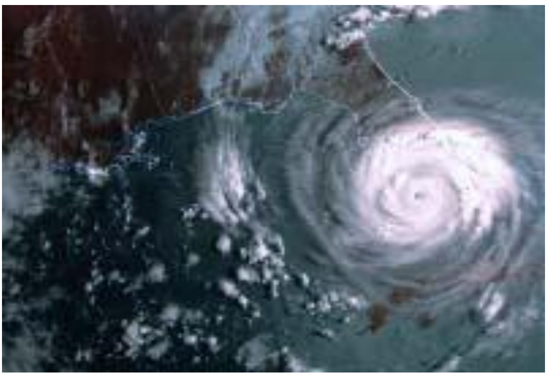


Fig. 6: Tropical cyclone in Bay of Bengal as seen by INSAT

d. Sea Surface Temperature (SST): The SST is a key indicator of the oceans and plays a key role in ocean – atmosphere interactions, cyclone development and movement, monsoon flow etc. Observation of the SST is a complex issue due to large expanse of oceans and the slow variation over seasons. The satellites play a key role in measurement of SST using the thermal channels in the 10.5-12.5 µm regions. The satellite data from NOAA and INSAT geostationary satellite is used to prepare weekly Sea Surface Temperature maps. The accuracy achieved is in the region of $\pm 0.7\,^{0}C$.

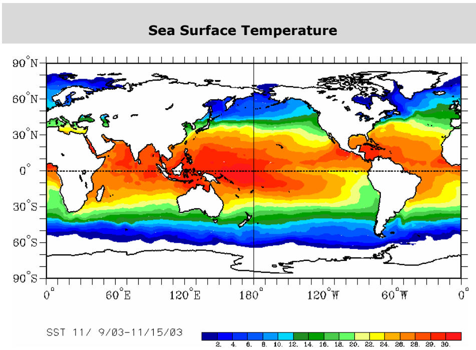


Fig. 7: Global sea Surface Temperature map derived from satellite data

The variability in the SST is a unique indicator of climate change and the long term series of data is one of the key inputs to climate change analysis

e) Ocean productivity: Ocean productivity depends on key parameters such as ocean colour, chlorophyll concentration, mixed layer depth and sea surface temperature. The data from Ocean Colour Monitor of OCEANSAT 2 and Sea Surface Temperature from NOAA and INSAT are used to estimate ocean productivity. Figure 6 gives the productive regions in the ocean (Arabian Sea) and its temporal variation in a week's time

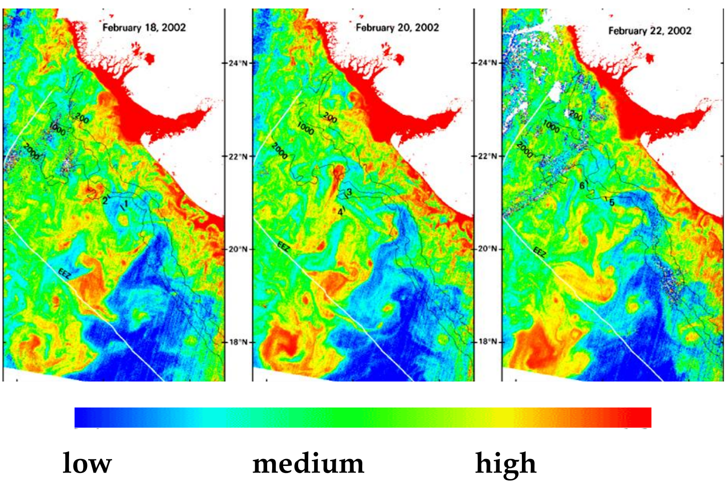


Fig. 8 : Ocean productivity maps for Gulf of Kuchtch region, Gujarat

The climate change scenarios indicate large intake of CO_2 by oceans leading to increased productivity. IRS satellite observations have led a database of ocean productivity over Indian oceans for past two decades.

f) Agricultural Drought monitoring; The rainfall variability leads to decreased rainfall in certain regions of the country leading to aridity. Parts of Karnataka, Andhra Pradesh and Maharashtra have recurrent droughts. Study of the rainfall anomaly and extent and frequency of drought can help in locating highly vulnerable areas to climate change. The vegetation responds to rainfall and solar radiation and this is reflected in the satellite measurements as vegetation index (NDVI) . The physical basis of this relation is vegetation, mainly grown due to soil moisture availability as the result of the seasonal rainfall, which intercepts photo-synthetically active radiation (PAR) and hence directly influences the aggregate of NDVI. Although there have been several studies reporting the relation between AVHRR NDVI and rainfall in semi-arid regions the sensitivity of this relation in varying dry [10] land conditions has rarely been analyzed quantitatively. The present study aims to interpret seasonal AVHRR NDVI variations with the seasonal aggregate of rainfall and fraction of soil moisture used by vegetation in the six drought prone districts of Karnataka State, India representing very severe, severe and moderate drought conditions. Area averaged seasonal transpiration which has been theoretically linked to integrated NDVI (INDVI), has been realized up to a certain extent in the study areas. The variability in rainfall and its reflection in the vegetation cover is revealed in this study in dry land ecosystems.

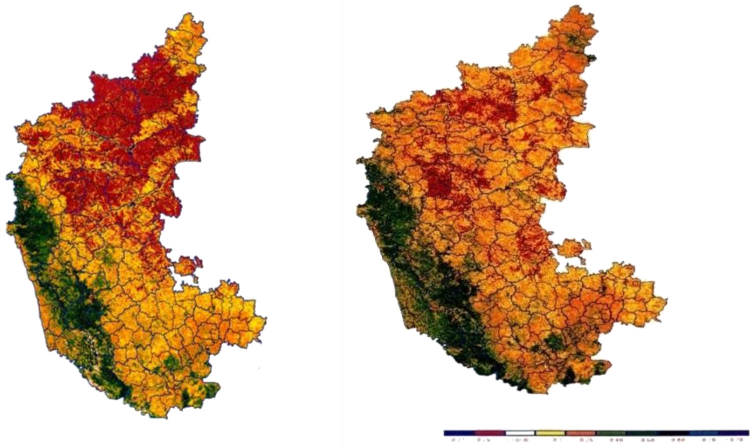


Fig. 9: Agricultural drought (red regions) in Karnataka for years 2000 and 2001 derived from satellite data

3. Effect of Global warming

The effects of global warming on the Indian subcontinent vary from the submergence of low-lying islands and coastal lands to the melting of glaciers in the Indian Himalayas, threatening the volumetric flow rate of many of the most important rivers of India and South Asia. In India, such effects are projected to impact millions of lives. As a result of ongoing climate change, the climate of India has become increasingly volatile over the past several decades; this trend is expected to continue.

Several global climate models run by leading meteorological agencies have indicated possible increase in rainfall over Indian region. This could mean large intensity rain events leading to floods etc. The intensity of cyclones are also expected to increase.

While studying such scenarios, it is essential to build up necessary strategies at local level to reduce the adverse impacts especially on agriculture and water management. It may be necessary to adopt improved agriculture practices with resistant seeds, efficient water management etc. It will be a challenging task to counter the effect of climate change through scientific means.

4. Conclusions

With several satellite missions in the past two decades, India has emerged as a strong operational user of satellite data for applications of direct relevance to the society. The data is being used for natural resources surveys, environment assessment, disaster mitigation and weather forecasting. Recent launches of INSAT -3D with vertical sounders and Megha Tropiques with advanced payloads for study of tropics has led to formulation of national projects on Monsoon, Disaster management and Climate Change. The future planning needs to take cognizance of climate change scenarios. A suitable mix of satellite and ground observations with high resolution weather modelling holds the keyfor future of weather forecasting and climate change assessments.

Acknowledgment

Authors are thankful to the Indian Space Research Organization (ISRO), Government of India for the financial assistance to carry out this work.

References

[1] International Panel on Climate change, IPCC report, 2014.

[2] B. Manikiam, Evolution of Indian satellite meteorological programme, Mausam, vol. 54(1), pp. 1-12, 2003.

[3] V. Jayaraman and M. G. Chandrasekhar, 1992, Second generation Indian Remote Sensing Satellites - IRS-IC &ID, Proceedings of 43rd Congress of the IAF, Aug. 28-Sep. 5, 1992, Washington, D.C.

[4] B. Manikiam, Meteorological satellites: Present capabilities & Future directions, Vayu Mandal, vol. 7(1), pp. 18-23, 1988.

[5] V. K. Kaila, A. S. Kiran Kumar, R. Shivakumar and B. Manikiam, METSAT–a unique mission for weather and climate, Current Science, vol. 83(9), pp. 1081-1088, 2002.

[6] H. HonneGowda, K. Ganesha Raj, A. S. Padmavathy& B. Manikiam, Multidate Satellite data for study of dynamics of coastal landforms of Uttara Kannada, South India, International Journal of Remote Sensing, vol. 16(14), pp. 2539-2553, 1995.

[7] K. Veeraraghavan and B. Manikiam: A statistical study of Bay of Bengal disturbances (1961-¬80) using satellite imagery, Mausam, vol. 34, pp. 219-222, 1993.

[8] B. Manikiam and R. Sridharan, A study of rainfall distribution associated with cyclones, Vayu Mandal, vol. 3(1), pp. 62-66, 1984.

[9] V. F. Dvorak, Tropical cyclone intensity analysis using satellite data. NOAA Tech. Rep. NESDIS.11: 44 pp.177-180, 1993.

[10] S. K. Srivastava, V. Jayaraman, P. P. Nageswara Rao, B. Manikiam, and M. G. Chandrasekhar, Inter linkages of NOAA/ AVHRR derived integrated NDVI to seasonal precipitation and transpiration in dryland tropics, International Journal of Remote Sensing, vol. 18(14), pp. 2931-2952, 1997.