Review Article

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Climate Change Analysis using Satellite Data and Adaptation Strategies

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Abstract

Climate Change is a serious global environmental concern. The global increases in carbon dioxide concentration are due primarily to fossil fuel use and land use change, while those of methane and nitrous oxide are primarily due to agriculture. Global Warming is a specific example of the broader term 'Climate Change' and refers to the observed increase in the average temperature of the atmosphere and oceans in recent decades. Its effect particularly on developing countries is adverse as their capacity and resources to deal with the challenge is limited. Scientific studies have shown that the global atmospheric concentrations of carbon dioxide, methane and nitrous oxide which are the most important Green House Gases, have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values.

Climate change is impacting the natural ecosystems and is expected to have substantial adverse effects in India, mainly on agriculture, water storage in the Himalayan glaciers which are the source of major rivers and ground water recharge, sea-level rise, and threats to a long coastline and habitations. Climate change will also cause increased frequency of extreme events such as floods, and droughts. These in turn will impact India's food security problems and water security.

India over the past three decades have mastered the use of space technology. The operational satellites INSAT and IRS have heralded an era of Space observations with high resolution observations of land, ocean and atmosphere. The IRS satellites are providing observations of parameters such as land use/cover, forest, water bodies, crops etc. The satellite data is operationally used for environmental studies and long term database on vegetation, soil condition, rainfall, ground water etc. is being generated. Some of the unique studies are Biosphere Reserve Monitoring, Mapping of 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, Climate Parameters, Remote Sensing, Satellite Observations

Introduction

Global climate is projected to continue to change over this century and beyond. The magnitude of climate change beyond the next few decades depends primarily on the amount of heat-trapping gases emitted globally, and how sensitive the Earth's climate is to those emissions. Climate change is impacting the natural ecosystems and is expected to have substantial adverse effects mainly on agriculture, water storage and glaciers and snow cover leading to sea-level rise threatening coastal and island habitations. Climate change is also expected to lead to increased frequency of extreme events such as floods, and droughts.

Over the past four decades, the satellite based remote sensing technology has developed rapidly leading to a information revolution in terms of digital data, images and quantitative change detection. The high resolution, multi spectral data provided by satellites has made it possible to characterise dynamic resources like water, vegetation and landuse with very high precision. The meteorological satellites is providing an instant view of global circulation and weather parameters such as temperature, humidity, winds, cloud cover and rainfall. A time series analysis of the satellite derived parameters helps in estimation of global change indicators at global, regional and locale scales.

Recent times have witnessed large concern regarding the global climate change and its impacts on society. The process is complex and needs to be understood well so that appropriate combative measures can be taken up. The satellites, with their capabilityto provide global uniform dataon a repetitive basis are proving to be an invaluable tool in the study of weather and climate changes in a quantitative manner. The weather data available with many countries for past several decades is being re-analyzed and a long term series data with satellite observations is being created. Several unique observations from satellites such as sea surface temperature, cloud water content, energy budget ofearth-atmosphere system will contribute to our study of weather processes and likely changes. The satellites play a key role in providing valuable observations for assessing the impact of climate change. India has a series of remote sensing satellites namely INSAT and IRS satellites operating

in geostationary and polar orbits. These satellites carry CCD based imaging sensors and provide imageries of the Earth in different spectral bands. The advantage of satellites is its capability to provide data over large areas thus providing a synoptic view ofthe region. The climate change studies require observations at high frequency and over large areas which is provided by satellites. The INSAT satellite is capable of monitoring various weather parameters such as temperature, humidity, winds, rainfall etc. and using computer models it is possible to assess the weather over large areas. With long term series of data over an area, the climate change is analyzed and potential changes in temperature and rainfall are assessed. The IRS series of satellites provide observations over the Earth features such as water resources, agriculture, forests, and soil conditions that are directly affected by climate change. Over the past4decades, India has developed databases on all important natural resources in the country and these databases will be very useful to assess the potential impacts ofclimate change.

Indian Space Programme

India initiated a programme in Space research by taking up launchingofsounding rockets for studyofthe upper and middle atmosphere under aUnited Nations programme. Indian Space Research Organization (ISRO) was set up in early 1970s. The launching of the RH 100 and RH 200 rockets were carried out from Thumba near Tiruvanantha puram in Kerala, which is very close to the Equatorand is ideal for study of atmosphere. These rockets provided data on atmospheric temperature and winds up to heights of 80kms. The rocket observations led to many interesting findings including easterly jet streams, monsoon onset conditions etc. The programme was further extended to include development of launch vehicles, satellites and full fledged space programme. The programme has led to development of Polar and Geostationary Launch Vehicles, a host of communication, weather, remote sensing and research satellites.

Operational Indian satellite Programme

The Indian Space Programme was taken up to develop space capabilities for launching of various satellites and operate them in polar and geostationary orbits. Over the past four decades, the ISRO has designed and launched several satellites to meetcountry's priorities such as weather monitoring, communication, natural resource mapping and ultimately provide valuable inputs to planning ofcountry's resources. This led to aseries ofsatellite systems - IRS (Indian remote Sensing Satellites) and INSAT (IndianNational Satellites). The IRS is apolar orbiting system moving across the poles. Aseries of IRS at an altitude of 800kms has revisit capability of 4-5 days which is required to study the crop growth, forest changes, water management etc. The first IRS satellite was launched in 1982 and since then a series of satellites has been designed and launched (Fig.1). Some of the important remote sensing satellites are given in Table 1.

Table 1: Recent Indian satellites

IRNSS-1A	2013	PSLV-C22	1st in Indian Regional Navigation Satellite System (IRNSS)
IRNSS-1B	2014	PSLV-C24	2nd in Indian Regional Navigation Satellite System
IRNSS-1C	2014	PSLV-C26	3rd in Indian Regional Navigation Satellite System
IRNSS-1D	2015	PSLV-C27	4th Indian Regional Navigation Satellite System
Astrosat	2015	PSLV-C30	ASTROSAT is India's first dedicated space Observatory.
IRNSS-1E	2016	PSLV-C31	5th in IRNSS
IRNSS-1F	2016	PSLV-C32	6th in IRNSS
IRNSS-1G	2016	PSLV-C33	7th and final in IRNSS
Cartosat-2c	June 2016	PSLV-C34	Earth observation/remote sensing satellite (already one launched in 2005)
SCATSAT-1	Sep 2016	PSLV-C35	Miniature satellite to provide weather forecasting, cyclone prediction, and tracking services to India
RESOURCESAT-2A	15Feb 2017	PSLV-C36	a Remote Sensing satellite intended for resource monitoring
CARTOSAT-2D	15Feb 2017	PSLV-C37	Highest number of satellites launched by a single launch vehicle (104 satellites)

Remote sensing usually refers to the technology of acquiring information about the earth's surface (land and ocean) and atmosphere, using sensors onboard airborne (aircraft, balloons) orspace-borne (satellites, space shuttles) platforms. The electromagnetic radiation is normally used as an information carrier in remote sensing. Remote sensing employs passive and/or active sensors. Passive sensors are those which sense natural radiations, either reflected or emitted from the earth. On the other hand, the sensors which produce their own electromagnetic radiation are called active sensors (e.g. LIDAR, RADAR). Remote sensing can also be broadly classified as optical and microwave. In optical remote sensing, sensors detect solar radiation in the visible, near infrared wavelength regions, reflected/ scattered or emitted from the earth, forming images resembling photographs taken by a camera/sensor located high up in space.

Figure 1: Indian Space program

Satellite applications to Weather & Climate Studies

In India, we experience in general four major seasons of winter, summer, monsoon and post monsoon. The severe winter conditions are experienced by northern India while summer heat occurs across the country. The monsoon dynamics is very systematic and year and year shows avalanches, landslides brought on by torrential rains, and consistency with respect to its onset, movement of rainfall snow storms pose the greatest threats. The monsoon is a global flow of moist air mass across the equator to the Indian sub continent bringing copious rainfall.

Other dangers include belt across the country and withdrawal. The monsoon season frequent summer dust storms, which usually track from north extends from June to September. During the post monsoon to south; they cause extensive property damage in North season, cyclonic storms form over the Bay of Bengal and India and deposit large amounts of dust from arid regions. Rarely over Arabian Sea and move into the coastal areas.

Accurate andreliable weather and climate prediction holds the key for socio-economic development and is essential for food security of the human society. The day-to-day changes in weather are another factor that has direct impact of human society. The agricultural operations of ground preparation, tilling, sowing, weeding, fertilizer/ pesticide applications, irrigation, harvesting etc. are decided based on weather situation and trends. Availability of weather information to the rural community through forecasts in short and medium range can significantly reduce the risk involved in agriculture operations and lead to improved productivity. The crop selectionto alarge extend is based on arrival ofmonsoon and its expected performance. Further, the post-harvest operations such as drying, transportation etc. also critically depend on fair weather.

Recenttimes have witnessed increasing concern overthe climate changes and possible adverse impacts on the economy and societyat large. Though it is difficultto clearly identify the natural variability of atmosphere versus anthropogenic impacts, the recent report ofthe International Panel on Climate Change has attempted to quantify the impacts. Accurate weatherforecast will need observations from global to regional to local scales.

One of the concerns is with respect to the variability of monsoon rainfall. Every monsoon is distinct and shows changes from the expected normal. Climate-related natural disasters cause massive losses of Indian life and property. Droughts, flash floods, cyclones, Hail is also common in parts of India, causing severe damage to standing crops such as rice and wheat.Itis interestingto note thatwhile the overall rainfall remains within± 10% of Long Term Average of 900 mm, there is large variability in rainfall at district and local scales. The impactofsuch variability is different in differentregions ofthe country andthe countryis divided into various agro climatic zones (Fig. 2) based on the rainfall, temperature and agricultural practices.

Development of Indian Satellite Applications

The launch of the first meteorological satellite TIROS-I in primarysatellite for weather surveillance inthis partofthe April 1960 herald an eraofSpaceobservations and gave globe. It is amultipurpose geostationarysatellitethatcaters the first glimpses ofthe dynamic cloud systems surrounding to the requirements of Meteorology and Communication. It the Earth, Since then the technology has developed by leaps carries a met payload called Very High Resolution Radiometer and bounds in observation capabilities interms ofspatial, (VHRR) thatenables us to have visible, infrared and now spectral andtemporal resolutions.

A global system of Space even water vapour images. Observations with both geostationary and polar orbiting Monitoring weather with INSAT satellites has evolved. The advantages of Space observations The Indian Meteorological Department is the primary agency emanate from several factors such as: to monitor weather and give predictions. The Indian Space programme since inception gave great thrust to meteorology provide continuous monitoringwhile polarorbiting and weather forecasting.

INSAT series of geostationary satellites (Fig. 2) give typical twice daily coverage; such data satellites was conceived to meet the operational needs of is relevant for study of weather system dynamics. Meteorology and weather services.

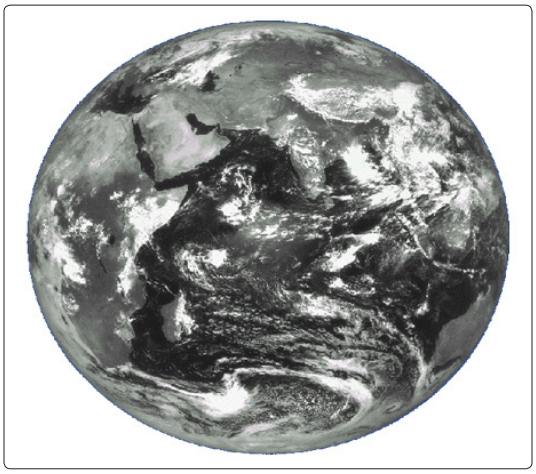

Figure 2: INSAT Satellite Imagery

The INSAT 1 series launched through the 80's carried a Very High resolution than the point in-situ observations and readily usable Radiometer (VHRR) payload which operated in two spectral for weather prediction models. Bands-visible [0.55-0.75 micro meter] and thermal infrared [10.5 -12.5 micrometer]. The INSAT satellites give every hour weather imageries of the country showing the cloud systems, their movement and potential severe weatherevents. One of the earliest studies using satellite data showed wind stress, sea level, cloud liquid water content, the 30-40 dayoscillatorynature ofmonsoon flow. Radiation balance, aerosol are some of the unique The critical role played by the sea surface parameters provided only by satellites. Temperature in the Indian and Pacific Ocean regions was clearly brought out by several studies. Currently several operational meteorological satellites are agro met advisories are generated for helping the providing global and regional observations. Early warning of drought is useful for on-farm operations and to arrive at an optimal local water utilization pattern. Rainfall anomalies as observed from geo-stationary/ meteorological satellites are being used for earlywarning of drought, which is yet to be fully operationalized. Satellite derived vegetation index (VI) which is sensitive to moisture stress is now being used continuously to monitor drought conditions (Fig. 3 and 4) on areal time

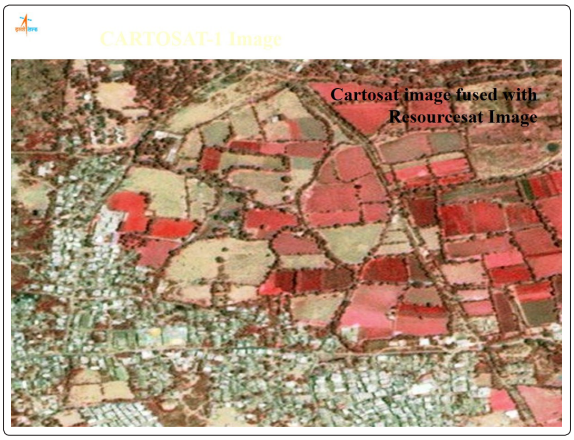

Figure 3: IRS Satellite Imagery of Agricultural Farms

Basic often helping the decision makers initiate strategies for recovery by changing cropping patterns and practices.

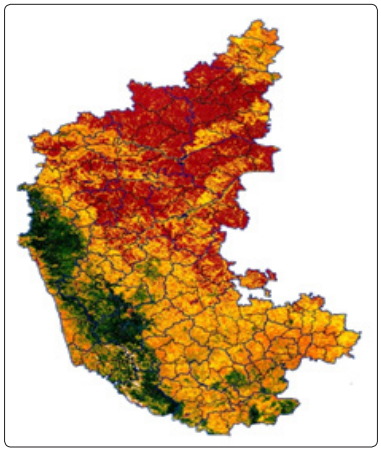

Figure 4: Drought Monitoring using Vegetation Index data from satellite

The quantitative is used to products available from INSAT data compute the following parameters, which are unique and not directly observable:

1. Cloud Motion Vectors (CMVs)
2. QuantitativePrecipitationEstimates (QPEs)
3. OutgoingLong-wave Radiation (OLR)
4. Vertical Temperature Profiles (VTPRs)
5. Sea Surface Temperatures (SSTs)

Future Satellite programmes

Several satellite missions have been plannedto supportthe operational dataneeds and ongoing research efforts. The future Meteorological satellite missions will carry improved VHRR and vertical sounders for temperature/humidity profiles. The Megha -Tropiques Mission scheduled for 2004 launchwill be a joint project by ISRO and CNES, France with the objective ofstudyingthe water cycle and energy exchanges in the tropics. With an equatorial inclined orbit, the satellite will have high repetitively over tropical regions. The forth coming advanced satellites for weather and climate studies are: INSAT-3D, an exclusive meteorological satellite, is configured with advanced meteorological payloads -a 6 Channel Imager, 19 Channel Sounder along with Data Relay Transponder and Satellite Aided Search & Rescue payloads. The spacecraftplatform is adopted from the standard1-2K bus with a power handling capability of around 1100W with a lift off mass of2090 kg. The Satellite for ARGOS and ALTlKA (SARAL) is a joint ISRO -CNES mission, and was launched during 2012. The Ka band altimeter, ALTlKA, provided by CNES consists of a Ka-band radar altimeter, operating at 35.75 GHz. A dual frequencytotal powertype microwave radiometer (23.8 and 37 GHz) is embedded in the altimeter to correct tropospheric effects on the altimeter measurement. Doppler Orbitography and Radio-positioning Integrated by Satellite (DORIS) on board enables precise determination of the orbit. ALaserRetro-reflectorArray (LRA) helps to calibrate the precise orbit determination system andthe altimeter system several times throughoutthe mission. The future appears bright for our space-based observing system. Advanced, multispectral (visible, IR, and passive microwave) imagers, sounders (infrared and microwave) and scatter meters are planned for launch in the near future. Hyperspectral measurements from newly developed interferometers are expectedto be flown experimentallyby 2006. The information content will vastly exceed that of the current measuring devices. Instead ofafew dozen viewing channels, these instruments will have more than a thousand channels over a wide spectral range.

Effects of Global Warming & Climate Change

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 on-going climate change, the climate of India has become increasingly volatile overthe 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 is 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 necessaryto 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. The effects of emission of gases to atmosphere, deforestation, high density built up areas are considered to be the initiators of climate change. The important indicators are sea level change, change in rainfall, recurrent floods/ extreme events, warming of atmosphere, melting of snow cover in Himalayas, Antarctic & Arctic regions. With the advent of satellite observation with global coverage, each ofthe above factors has been extensively studied. While there are indications of an ongoing climate change, there are still questions to be answered such as whether the signals are above the natural variability of earth system.

The critical parameters related to climate change were listed as under three main themes of land, ocean and atmosphere. The land related parameters are land use changes, biodiversity, coast line change, deforestation. Ocean contributes in terms of sea surface temperature, productivity, sea level change. The atmosphere expresses climate change in terms of circulation patterns, jet streams, near surface temperature, weather systems and intensity. There are classes of satellites such as IRS, SPOT, IKONOS, RISAT, RESORCESAT, and CARTOSAT that give land surface parameters with high resolution.

Oceansat2, ERS 2 are giving ocean parameters with sensors such as OCM, Scatterometer, and Altimeter. The missions such as TRMM, Megha Tropiques, SSM/I, DMSP, INSAT, METSAT are giving wealth of information on weather systems, cloud cover, rainfall, atmospheric conditions etc.

Conclusion

This is a highly debated topic globally with several teams working on various aspects of climate change.

The effects of emission of gases to atmosphere, deforestation, high density built up areas are considered to be the initiators of climate change. The important indicators are sea level change, change in rainfall, recurrent floods/extreme events, warming of atmosphere, melting of snow cover in Himalayas, Antarctic & Arctic regions. With the advent of satellite observation with global coverage, each ofthe above factors has been extensively studied. While there are indications of an ongoing climate change, there are still questions to be answered such as whether the signals are above the natural variability of earth system. The scenario indicates major effect on coastal population due to raise in sea level, increased frequency of storms and rainfall. The urban population has to face extreme weather events such as cloud bursts and high intensity rainfall. One of the serious impacts is on the agricultural systems which depend on weather and any change in rainfall will adversely affect agriculture. The melting office /snow will have long term effect of reduction in river flow and ecosystems. What is needed is a synergy ofall these data and analyzes the land-ocean-atmosphere interactions and derives information on changes happening. Alongterm database is essential for climate change studies and satellites with about a decade or more of observations are a good starting point [1-6].

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