# METEOROLOGICAL SATELLITES

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Abstract : The paper presents a general overview of satellite systems and characteristics of different satellite orbits viz. polar, and geostationary orbits. Various classifications of satellite sensors e.g. imaging/non-imaging, optical/microwave, and passive/active were discussed with appropriate examples. The basic concept of satellite remote sensing based on the laws of radiation, and terrestrial absorption spectrum are presented in the first part of the article. Observations from two operational satellite sensors viz. NOAA-AVHRR, and INSAT-VHRR are discussed in more detail and with ample examples.

## INTRODUCTION

Meteorology is a discipline concerned with observational earth sciences and theoretical physics. From a theoretical point of view, it has to deal with a turbulent fluid whose behaviour is governed by a complex set of nonlinear, partial differential equations, which model the atmosphere as thermo-hydrodynamical system obeying the laws of an ideal gas. As a branch of observational earth sciences, it has the task of providing an accurate knowledge of the state of the atmosphere, which can only be obtained through regular, simultaneous observations covering the whole globe from the earth surface to the upper atmosphere.

Progress on the observational side other than the surface was recently limited to a network of balloon sounding stations covering practically the whole globe, albeit sparsely. The data obtained through this network permitted the discovery of previously unknown characteristics of the atmospheric motions and provided for the first time a solid basis for work for the theoreticians. Since the introduction of mathematical models and high-speed computers,

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there has been a growing demand for adequately sampled (in space and time) and reliable observational data, since the forecast models are strongly dependent on assumed initial state of the atmosphere, as there are large areas without any conventional soundings of the atmosphere.

Before the advent of weather satellites the weathermen had been severely handicapped by having only a very limited knowledge of the state of the atmosphere at any given time. Even with the expansion of observational networks since the last world war, by various national meteorological services, the vast sparsely populated land areas of the globe and the large oceanic areas are virtually blank as far as conventional meteorological observations are concerned. Meteorological satellites have to a large extent has enabled to overcome this deficiency.

Satellite imagery is an invaluable source of information for operational forecasters. It is being used as (a) an analysis tool, especially to data sparse regions like the tropics; (b) direct aid to short period forecasts (6-12 hours ahead of cloud, rainfall, floods etc.; (c) input to numerical weather prediction models (NWP) for defining initial condition; (d) monitoring the model forecast. It also serves as a valuable indicator of dynamical and physical process at work providing the trained eye, some useful clues on atmosphere structure and its evolution. The sea-surface temperature, the sea surface/upper air winds from scatterometer/cloud motion vectors provide valuable input to numerical models. The rainfall from geostationary satellites, rain rate from microwave sensors, the OLR (Outgoing Longwave Radiation) from polar orbiting satellites are a few parameters which are frequently utilized in the initialization of the data for numerical weather prediction of monsoon.

## METEOROLOGICAL SATELLITES REQUIREMENTS

a) To serve as an observing platform with appropriate sensors on board and transmitting the information (imaging & sounding ) to the stations located on the earth's surface

b) To serve as a collector of meteorological data from unmanned land/ocean based instruments - Data collection platforms

c) To serve as a communication satellite for rapid exchange of meteorological data among centres and for rapid dissemination of weather forecasts, warnings etc. to user agencies.

## TYPES OF METEOROLOGICAL SATELLITES

Meteorological satellites are of two types viz. Polar orbiting and Geostationary (Fig. 1). Polar orbiting satellites pass approximately over the poles at a height of about 850 kms. The whole surface of the earth is observable by these satellites which follow orbits nearly fixed in space while the earth is rotating beneath them. The areas scanned on each pass (swath) are nearly adjacent at the equator with overlapping areas further poleward. The swaths are usually about 2600 km wide. These satellites complete 14 orbits per day and thus can provide global coverage twice in 24 hours. Some of the polar orbiting satellites are NOAA, IRS, ERS-1 &ERS-2, TRMM(low inclination), DMSP, Oceansat-1 etc.

Geostationary satellites orbit around the earth over the equator at a height of about 36000 kms. They complete one orbit in 24 hours synchronised with earth's rotation about its own axis. Thus they remain over the same location on the equator. The main advantage of geostationary satellites lies in the high time-scale resolution of their data. A fresh image of the full earth's disc is available every 30 minutes. However they have limited spatial resolution as compared to the polar orbiting satellites in view of their distance from the earth. Useful information is restricted to the belt between 70 deg. N and south latitudes. Some of the examples of geostationary satellites are GMS( $140^0$ E ), GOES-W, GOES-E, INSAT-1 and INSAT-2 Series., GEOS, METEOSAT -5 (Positioned at $64\ ^0$E ), METEOSAT-6 etc.

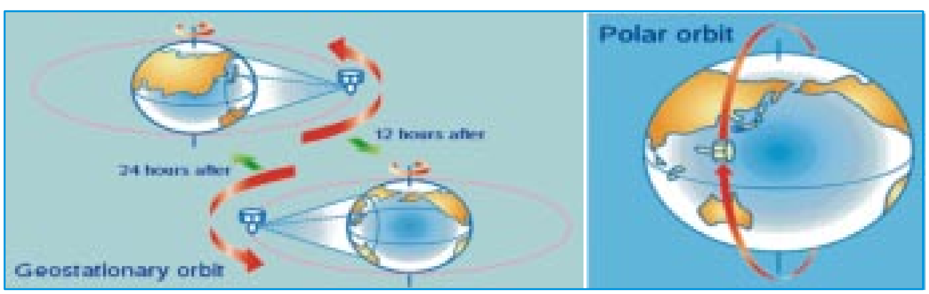


Figure 1 : Geostationary and Polar orbits

### Satellite Sensor System

Most remote sensing instruments (sensors) are designed to measure photons. The fundamental principle underlying sensor operation centers on what happens in a critical component - the detector. This is the concept of the *photoelectric effect* (for which Albert Einstein, who first explained it in detail, won his Nobel Prize). This, simply stated, says that there will be an emission of negative particles (electrons) when a negatively charged plate of some appropriate light-sensitive material is subjected to a beam of photons. The electrons can then be made to flow from the plate, collected, and counted as a signal. A key point: The magnitude of the electric current produced (number of photoelectrons per unit time) is directly proportional to the light intensity. Thus, changes in the electric current can be used to measure changes in the photons (numbers; intensity) that strike the plate (detector) during a given time interval. The kinetic energy of the released photoelectrons varies with frequency (or wavelength) of the impinging radiation. But, different materials undergo photoelectric effect release of electrons over different wavelength intervals; each has a threshold wavelength at which the phenomenon begins and a longer wavelength at which it ceases. Meteorological satellite sensors can be broadly classified as two types : passive and active (Fig. 2). Passive sensors do not use their own source of electromagnetic illumination, and depend upon the radiation emitted or reflected from the object of interest. On the other hand, active instruments use their own source of electromagnetic radiation which they use to illuminate the target, and in most cases use the properties of reflected radiation ( e.g. intensity, polarization, and time delay etc.) to deduce the information about the target. These sensors can be further sub-divided into the following categories and subcategories :

Equally important is the functional classification of these sensors. Meteorological satellite sensors may be deployed to obtain one and/or more of the following characteristics of different objects of the land-ocean-atmosphere system :

(a) Spatial Information : The examples are the extent and temperature of sea surface, clouds, vegetation, soil moisture, etc. The main objective here is to obtain the required information over a 2-dimensional plane. The best suited sensors for this class are imaging radiometers operating in visible, infrared or microwave frequencies. Active sensors like Synthetic Aperture Radar (SAR) are also put to effective use for the imaging applications.

(b) Spectral Information : For certain applications, the spectral details of an electromagnetic signal are of crucial importance. A particular object of interest, for example an atmospheric layer, or, the ocean surface, interacts differently with different wavelengths of electromagnetic(EM) spectra. In most cases, this may be due to the chemical composition of the object.

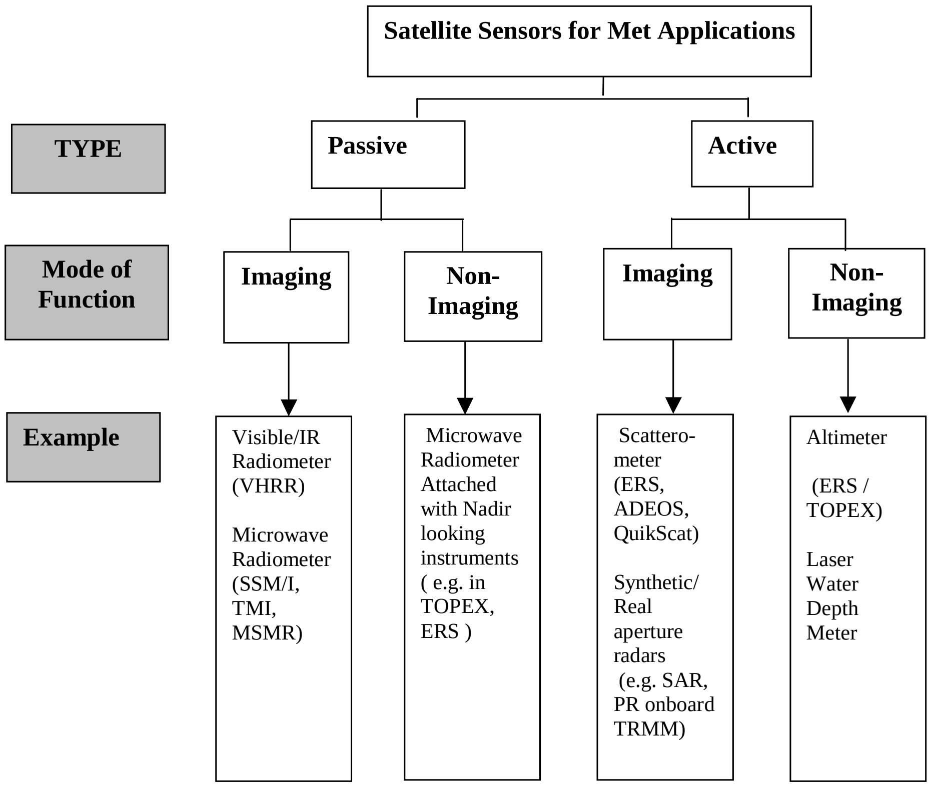


Figure 2 : Satellite sensors for Meteorological applications

Absorption, emission, or reflection of an EM radiation from an object is a function of the wavelength of EM radiation, and the temperature of the object. Thus, the spectral information can provide details of chemical composition, and/or the temperature of the object. Meteorological satellite sensors use this information for sounding applications, where the vertical structure of temperature, humidity, and in some cases, the atmospheric gases is retrieved. An example of this sensor is High Resolution IR Sounder (HIRS), and Advance Microwave Sounding Unit (AMSU) onboard NOAA series of satellites. Future satellites will carry more advanced sensors like imaging spectrometers. Geostationary Imaging Fourier Transform Spectrometer (GIFTS) is a fine example of this new-generation sensor. GIFTS, when operational, is expected to provide the vertical profiles of temperature, humidity, and winds at several atmospheric layers in vertical.

(c) Intensity Information : The intensity of EM radiation can provide several clues about the object of interest. In most cases, the satellite sensors measure the intensity of the radiation reflected from the object to know the dielectric properties and the roughness of the object. By the use of suitable algorithms these parameters can be translated to the properties of geophysical parameters like soil moisture, ocean surface roughness, ocean surface wind speed, and wind direction, etc. The sensors that use this information are radar, scatterometer, and polarimeters.

## PRINCIPLES OF SATELLITE REMOTE SENSING

All objects emit electromagnetic radiation. The hotter the source, the greater is the intensity of emission. Substances which absorb all the radiation falling on them at every wavelength are called "black bodies". The coefficient of absorption is then unity. As per Kirchhoff's law, good absorbers are good emitters as well. Hence a black body also has an emissivity unity. At any wavelength it emits the maximum amount of radiation that is appropriate to its temperature.

Most substances, however, are not perfect black bodies. Their emissivity is less than unity. Figure 3 shows wavelengths of different types of radiation and the channels used for satellite imagery. It includes the spectra of solar radiation (at temperatures of about 6000 deg. K and also of terrestrial radiation of the earth and atmosphere at temperatures between 200 and 300 deg. K). Solar radiation is in shorter wavelengths and the terrestrial radiation is in longer wavelengths. Solar radiation of significant intensity occurs at wavelengths between 0.2 and 4.0 μm, the peak intensity at about 0.5 μm in the visible part of the spectrum. Terrestrial radiation is emitted at wavelengths between 3 and 100 μm which falls entirely within the infrared region. The maximum intensity is around 11 μm.

Unlike solids and liquids, gases are not black bodies. They only absorb or emit strongly at certain wavelengths. Water vapour ($H_2O$), carbon dioxide ($CO_2$) and ozone ($O_3$) are such gases within the visible and infrared wave bands that are important in meteorology. Each of these gases is active in certain narrow absorption bands. There are other regions where the absorption by all the gases is so weak that the atmosphere is almost transparent. These regions are known as "windows" and are used for production of cloud imagery. Satellite imagery is obtained from radiometers that measure scattered electromagnetic radiation emitted from the sun, earth and the atmosphere.

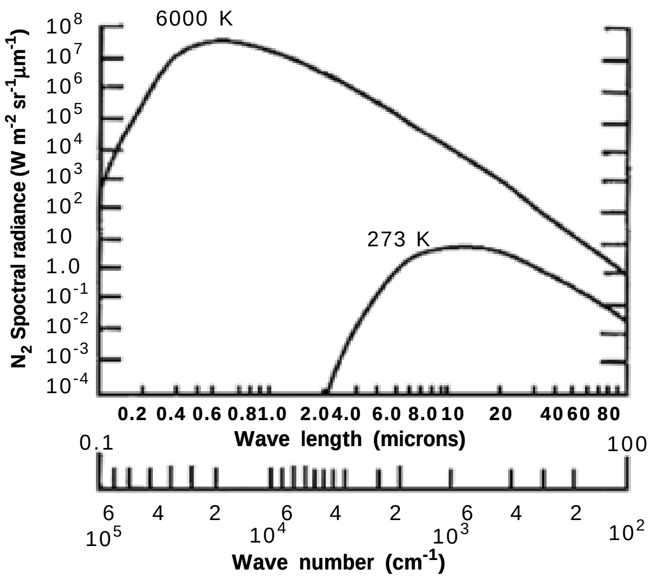


Figure 3 : Blackbody radiation emitted at temperatures corresponding to the Sun and the Earth

The satellite imageries in common operational use are :

a) Visible (VIS) - imagery derived from reflected sunlight at visible and near-infrared wavelength (0.4 - 1.1 µm).

b) Infrared (IR) imagery (Fig. 3) derived from emissions by the earth and its atmosphere at thermal infrared wavelengths (10-12 µm)

c) Water Vapour (WV) imagery derived from water vapour emissions (6-7µm) and

d) 3.7µm (often referred to as channel 3) imagery in the overlap region of solar and terrestrial radiation and hence sometimes called near IR.

e) Images from microwave radiometer such as Special Sensor Microwave/ Imager (SSM/I), and TRMM Microwave Imagers (TMI) can provide a lot of useful information. Microwave radiation is not affected by the presence of clouds and that is an important factor in the science of weather. Microwave observations are widely used for inferring sea surface temperature, sea surface wind speed and atmospheric water vapor content (over ocean surfaces), cloud liquid water content, rainfall, and the fraction of ice/snow particles within the raining systems.

## DATA FROM WEATHER SATELLITES

The initial phases of the satellite era (almost for two decades) saw the use of visual imageries provided by the polar orbiting satellites. Towards the end of the seventies the sounders in polar orbiting satellites, the shifting of the US GOES satellite to the Indian latitudes during MONEX experiment and the launch of Japanese GMS satellites provided new avenues. The beginning of eighties saw the INSAT series of the meteorological satellites. The new generation of INSAT satellites to be launched in couple of years from now would have much more atmospheric information over this part of the Asian continent. Besides some experimental satellites such as the Defense meteorological satellite, ERS-1 and satellite like TRMM, are providing valuable information in describing the monsoon features, water vapour , SST, wind and rainfall (Kidder and Vonder Haar, 1995).

Tropical rainfall affects the lives and economies of a majority of the earth's population. Tropical rain systems like hurricane, typhoons and monsoons are crucial to sustaining the live hoods of those living in the tropics. Excess floods can cause drought and crop failure. The TRMM satellite's low inclination (35 degrees), non-sun synchronous, and highly processing orbits allow it to fly over each position on earths surface at different local time. The TRMM has Precipitation radar , TRMM microwave imager(TMI) and visible /infrared scanner.

Now we have launched our own Oceansat-1 onboard IRS-P4 on 26$^{th}$ May, 2003 which contained 8 channel onboard sensor called Ocean colour monitor ( Chlorophyll content ) over ocean and another microwave sensor called Muti-channel microwave radiometer (MSMR) with channel frequencies (6.6 GHz, 10.8Ghz, 18 GHz and 21 GHz) in both horizontal and vertical polarization, and is used to measure geophysical parameter related to ocean such as sea surface temperature (SST), wind speed, total integrated water vapour, and cloud liquid water vapour content (Krishna Rao, 2000).

NOAA satellites have the following meteorological payloads

i) Advanced Very High Resolution Radiometer (AVHRR)

ii) TIROS Operational Vertical Sounder (TOVS)

iii) Earth Radiation Budget (ERB)

AVHRR is a five channel scanning radiometer in visible, near infra-red and infra-red wavelengths for analysis of hydrological, oceanographic and meteorological parameters such as vegetation index (i.e. greenness), clouds, snow and ice cover and sea surface temperatures. Data are obtained by all the five channels with a resolution of 1 km. The digital AVHRR data is transmitted from the satellite in real-time (High Resolution Picture Transmission or HRPT) as well as selectively recorded on board the satellite for subsequent playback when the satellite is in communication range of the ground control station. This high resolution data is called Local Area Coverage (LAC). AVHRR data is also sampled on real-time to produce lower resolution Global Area Coverage (GAC) data. The effective resolution of the GAC data is about 4 kms. The spectral characteristics and imaging applications of AVHRR are given in Table 1.

Table 1: Spectral characteristics and applications of AVHRR.

| Channel | Spectral Interval (μm) | Resolution (km) | Application |
|---|---|---|---|
| 1 | 0.58-0.88 | 1.1 | Cloud Mapping |
| 2 | 0.73-1.0 | 1.1 | Surface water boundaries |
| 3 | 3.55-3.93 | 1.1 | Thermal mapping, cloud distribution, fire detection |
| 4 | 10.3-11.3 | 1.1 | Cloud Distribution, SST, WV correction |
| 5 | 11.5-12.5 | 1.1 | ——————do—————— |

TIROS operational vertical sounder (TOVS) incorporates a high resolution infrared radiation sounder (HIRS), a microwave sounding unit (MSU) and a stratospheric sounding unit (SSU). HIRS samples the atmospheric radiation in 20 IR channels and is primarily used to obtain the vertical temperature and moisture distribution in the troposphere. The HIRS uses two carbon dioxide bands for temperature sounding. Seven channels are located in the 15 μm band and six channels are located in the 4.3 μm band. The 4.3 μm channels are added to improve sensitivity (change in radiance for a given change in atmospheric temperature) at relatively warmer temperatures. Moisture is sensed with three channels in the 6.3 μm band of water vapour. The 9.7 μm channel is designed to sense ozone. Three channels are in the atmospheric windows. The 11.1 μm and 3.76 μm channel is used to detect clouds. SSU samples the radiation from the stratosphere in 3 IR channels. MSU samples the radiation from the atmosphere in 4 channels of microwave region and is particularly useful for obtaining the vertical distribution of temperature in the atmosphere below clouds which are opaque in the infra-red radiation.

Because atmospheric motion is driven by differential absorption of solar radiation and infrared loss to space the study of Earth's radiation budget is extremely important. The latest is the Earth radiation budget experiment (ERBE), which flies on NOAA-9 and NOAA-10 as well as ERBS satellite. The ERBE is designed to make highly accurate (~ 1% ) measurements of incident solar radiation, earth reflected solar radiation, and earth emitted solar radiation at scales ranging from global to 250 km.

## INSAT METEOROLOGICAL COMPONENT

The Indian National Satellite (INSAT) is a multipurpose geostationary satellite, which carries both meteorological, and communications payloads. The INSAT-1D is located at 83.5 $^0$E and INSAT-2B is located at 93.5 $^0$E. The VHRR (very high resolution radiometer) onboard the satellite has a visible (0.55-0.75 μm) and infra-red (10.5-12.5 μm) bands with resolution of 2.75 km and 11 km for INSAT-1 series, and 2 and 8 km respectively for the INSAT–2 series. The VHRR scans are taken every 3 hours on routine basis and half hourly to even less than that, for monitoring cyclones etc. One VHRR scan takes about 30 minutes to be completed and is made up of 4096 X 4096 picture elements (pixels) in case of visible channel and 1024 x 1024 pixels in case of IR channel. The meteorological component provides:

a) Round the clock, regular half-hourly synoptic images of weather systems including severe weather, cyclones, sea surface and cloud top temperatures, water bodies, snow etc. over the entire territory of India as well as adjoining land and sea areas.

b) Collection and transmission of meteorological, hydrological and oceanographic data from unattended data collection platforms.

c) Timely warning of impending disasters from cyclones and storms etc.

d) Dissemination of meteorological information including processed images of weather systems to the forecasting offices.

## INSAT-2E

The VHRR on board INSAT-2E spacecraft provides imaging capability in water vapour channel (5.7-7.1 μm) in addition to the visible and thermal IR bands with a ground resolution at the sub-satellite point of 2 km x 2 km in the visible and 8 km x 8 km in the WV (Water Vapour ) & TIR (Thermal Infrared) bands. This geostationary satellite is located over 83.5 $^0$ E.

The important specifications are given in Table-2.

Table 2. INSAT 2E - VHRR Specifications

| Detectors | Spectral Band (μm) | Resolution (km) |
|---|---|---|
| Visible (4) | 0.55-0.75 | 2 x 2 |
| Infra Red (1) | 10.5-12.5 | 8 x 8 |
| Water Vapour (1) | 5.7-7.1 | 8 x 8 |

## CCD Payload

The CCD camera Payload on board INSAT-2E spacecraft provides imageries in visible band (0.62 μm - 0.68 μm) & Near IR (NIR, 0.77 μm-0.86 μm) and a short-wave infrared band (SWIR, 1.55-1.69 μm). Table -3 gives the specifications of CCD.

Table 3. CCD Payload Specifications

| Spatial Res. | Frame Size | Spectral Bands | Detector Array | Digitization |
|---|---|---|---|---|
| 1 km x 1 km | 10x10 deg<br>0.77-0.86 μm<br>1.55-1.7 μm | 0.63-0.68 μm | Linear Si CCD<br>(1 & 2)<br>InGaAs | 10 bits |

## SOME IMPORTANT MICROWAVE PAYLOADS AND THEIR APPLICATIONS

As mentioned earlier, microwave sensors have played a very important role in providing valuable information for meteorological applications. These include both active and passive type of sensors. Wind scatterometer, altimeter, and precipitation radar are the examples of active microwave sensors. Scatterometer with operating frequencies in C-Band ( ~ 5 GHz), or K-Band (~ 13 GHz) is an indispensable tool for monitoring the ocean surface wind speed and wind direction with high resolution ( ~ 25 km ) and global coverage. Ocean surface winds have a number of applications. These winds are important factors in the computation of air-sea energy and mass exchange, and they also provide input to the global ocean and wave forecast models. The use of scatterometer winds in assessing the situations leading to the formation of tropical cyclones have been demonstrated. Precipitation radar (PR) onboard Tropical Satellite Measuring Mission (TRMM) satellite is the first precipitation radar in space. This instrument operating at 13.6 GHz is capable of taking observations of vertical profiles of rainfall over the global tropics.

Among passive microwave meteorological systems, Special Sensor Microwave/Imager (SSM/I) onboard US Defense Meteorological Satellite Program (DMSP) satellite is arguably the most successful sensor. Different versions of this sensor have been providing valuable meteorological observations across the globe for nearly 16 years. The operating frequencies of this radiometer are 19.36, 22.23, 37.0, and 85.5 GHz. All the channels except 22.23 GHz operate in dual polarization (V and H), while 22.23 GHz is a single polarization (V) channel. SSM/I provides the global observations of vertically integrated water vapour (PW), sea surface wind speed ( SW), cloud liquid water (CLW), and rainfall rates (RR), though due to the limitation of microwave observations, most of these observations are available only over the ocean surfaces. SSM/I provides these observations with a wide swath ( ~ 1400 km) and high resolution ( ~ 25 km). TRMM satellite launched in October 1997 carried a payload similar to SSM/I, and it is known as TRMM Microwave Imager (TMI). TMI is similar to SSM/I in characteristics however there are some significant differences. TMI is equipped with one additional channel that operates at around 10 GHz (V & H polarization). This sensor makes TMI capable of sensing global sea surface temperature (SST). A combination of observations from TMI and other visible/IR sensor onboard TRMM is being utilized operationally for measurement of daily SST with a significantly improved accuracy of ~ 0.5 K. This channel is also useful in providing improved estimates of rainfall rates. Moreover, TRMM satellite operates from a smaller altitude ( ~ 350 km) compared to SSM/I ( ~ 800 km), which ensures that the TMI observations are available at finer resolution. 85 GHz channel of TMI is highly useful in detecting the regions of active and deep convection ( both over the land and the ocean surfaces ) that are generally associated with the development of thunderstorm and are accompanied by heavy precipitation.

Advance Microwave Sounding Unit ( AMSU) onboard the latest series of NOAA satellites, is a sounding instrument that provides the temperature and humidity sounding in presence of clouds, using the absorption bands of oxygen ( ~ 50 GHz), and water vapour ( ~ 183 GHz) respectively.

## CONCLUSIONS

Various kinds of meteorological satellites such as imaging/non-imaging, optical/microwave and passive/active are available for retrieval of meteorological parameters, weather forecasting etc. INSAT-VHRR and NOAA-AVHRR satellites data are very popular in India for studing meteorological conditions.

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