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# METEOROLOGY FROM SPACE : INDIAN EXPERIENCE

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Meteorology operations as well as research are immensely benefited by the advent of satellite observations, starting with TIROS polar satellites in the early 1960's. Today, polar NOAA and geosynchronous INSAT (and other) satellites are employed routinely for weather monitoring and forecast. A series of experimental satellites (IRS–P4, IRS–2A etc.) are also planned by India besides improved versions of INSAT (such as INSAT–2E, 3A and 3D etc). The data of these satellites can be analysed/processed to obtain several meteorological and oceanographic parameters such as : Cloud cover and type, Cloud motion vectors, Water vapour tracer vectors, Snow cover, Atmospheric temperature and humidity profiles, Sea surface temperature and Winds and rainfall. These data combined with *in-situ* data, can help in better characterisation and prediction of : tropical cyclones, monsoon in its various phases, western disturbances, sea-state, and climatic trends. The methods employed for the purpose may range from empirical/statistical relations to numerical weather prediction models wherein statellite data may be assimilated.

This review article gives a broad exposition of the types of satellite meteorological data available and likely to be available in India, and indicate their applications in meteorology – with a few case studies where available – (but will not deal at length with the aspect of parameter retrieval from basic satellite data which is becoming a separate discipline by itself). The review is indicative, not exhaustive; it is mainly restricted to Indian experiences.

**Key Words : Space Meteorology, AVHRR ; INSAT ; IRS ; MONSOON**

## Introduction

Meteorology involves the science of the motion of the atmosphere and specific systems within it such as depressions and cyclones. These phenomena know no boundaries—particularly artificial political borders, and also land/sea edges, hence weather monitoring and forecast must be at least 'regional'. Indeed, for medium-range (5 days) and longer forecasts, even 'global' observations are called for. Conventional *in-situ* observations while important, need to be supplemented by the wider coverage afforded by satellite data. This is particularly true over otherwise data-sparse areas like the oceans. Further, certain 'patterns', be they cloud patterns, sea-surface temperature patterns, etc., cannot be sensed by point measurements; satellite imagery and data become indispensable for seeing these. For example, it is now-a-days routine to assign intensity (''Dvorak's T-number'') to a tropical cyclone from its tightness pattern seen in INSAT imagery, which could not be done with conventional observations—even coastal cyclone-radars would capture a cyclone only when it enters the 200km zone of radar observations, whereas satellite image starts seeing the cyclone even when it is much farther from coast, say 1000km away, deep into the ocean. The present review article will give a broad idea of the type of satellite meteorological observations now available and likely to be available in India over the next few years, and indicate some applications of the same (Indian experiences). The uses can be in various modes — combining with conventional data to improve the synoptic analysis, empirical/statistical methods of forecast, and assimilation into numerical weather prediction models. Attempt is made to show examples of these various methods. A previous Review Paper may also be referred to, for further examples [1].

## Satellite, Sensors and Met/Ocean Parameters

In this Section, we briefly list the available and planned satellites providing meteorological/oceanographic observations, and the corresponding sensors and parameters, so that the stage is set for further describing their applications. (A global compilation of satellites/sensors for earth observations can be found in CEOS Yearbooks[2]).

The two distinct types of orbits employed for met/ocean satellites are : polar and geosynchronous. The operational polar satellites are the U.S. NOAA and Russian METEOR satellites series. Data from NOAA are regularly receivable at Delhi and Hyderabad besides experimentally at Ahmedabad and Goa. There are two types

of sensors onboard NOAA satellites *viz.*, 'imaging' and 'sounding' sensors, described below.

The Advanced Very High Resolution Radiometer (AVHRR) is an imaging sensor with wide swath (around 3000km), high spatial resolution (about 1km) and 5 spectral channels : visible (0.58-0.78 micron), near-infrared (0.73-1.1 micron), middle-infrared (3.55-3.93 micron), and split thermal channels (10.3-11.3 and 11.5-12.5 microns). The prime application of the visible channel is cloud imaging (in the daytime), whereas the split thermal channels are meant to provide sea-surface temperature maps (during day and night, in cloud free/partially cloudy regions) along with the 3.7 micron—but at night only, as solar reflectance disturbs it in daytime. A reduced resolution version of the AVHRR, called Automated Picture Transmission (mainly for cloud imagery) is also broadcast. Onboard recording at 4km is also done, to collect and archive global data. These can be procured in *post-facto* mode. The TIROS Operational Vertical Sounder (TOVS) is a complex of three sounding sensors, called HIRS (High Resolution Infrared Sounder, 20 spectral channels in the IR with typically 20km spatial resolution), MSU (Microwave Sounding Unit with 4 channels in the microwave range, and typical spatial resolution of 150km) and SSU (Stratospheric Sounding Unit, a pressure-modulated 3-channel $CO_2$ radiometer for stratospheric temperature estimates). The HIRS and MSU (or its advanced version AMSU in next NOAA) together provide tropospheric temperature (15 layers) and humidity (3 layers) profiles. The 6.7-8.3 micron $H_2O$ range in HIRS provides the humidity profile, whereas the Oxygen channel (55-60 GHz) MSU and the $CO_2$ channels in HIRS (4.3 and 15 micron ranges) provide temperature profiles. TOVS can also help in SST retrievals from AVHRR by providing vertical distribution of water vapour[3].

The geosynchronous orbit permits the same region (about one-third of the globe) to be repeatedly imaged due to the apparently 'fixed' position of the satellite over the equator, having orbital period of 24 hours. Over the Indian Ocean, we have the INSAT series (1D, 2A/2B, shortly 2E, and later 3A, 3D) having Very High Resolution Radiometer (VHRR) with 2 channels (visible .55-.75 micron with 2 km resolution and thermal IR 10.5-12.5 micron with 8 km resolution) in the case of 1D, 2A/2B and 3 channels (the above two plus 6.7 micron water vapour channel) in the case of 2E. INSAT 2E also has a 3-channel CCD Camera with 1 km resolution for snow/cloud discrimination, aerosols, vegetation index etc. The INSAT-3D satellite is still in design phase, and may carry even a full-fledged sounder besides advanced VHRR (may be similar to NOAA AVHRR and also with 6.7 micron). Generally, VHRR scans one line at a time and then steps to the next line ; the entire 'disk' image can be generated in about 30 minutes. Thus, in principle one can make 48 observations a day but only 12 are scheduled—8 at 3-hourly intervals, and at two points of time, 2 additional coverage 1/2hr before and after a central image are done to create a 'triplet' to derive cloud motion vectors, a proxy for upper-air winds (generally at around 850 mb and 200 mb). Further, with the fixed vantage point, INSAT type of satellite is ideally placed to track tropical cyclones. Hence, an optional 'sector'-scanning mode is also provided for in VHRR, whereby a 5 degree (N-S) belt can be repeatedly scanned in just a few minutes. One-hourly total image is taken during some severe cyclones, also.

The thermal IR band on INSAT VHRR is related also to the cloud top temperature/height and hence indirectly to outgoing longwave radiation (OLR) and rainfall rates. Quantitative Precipitation Estimates (QPE) on a monthly average scale at 2.5 deg × 2.5 deg grid are routinely produced by IMD based on cloud temperature thresholding from INSAT VHRR[4]. Of course, there is scope for further research[5], especially as the thresholds seem to require modification in mountain regions. Use of visible channel too, may be helpful. For flood warnings in fact, the rapid growth, merger etc. of clouds over catchment areas of rivers are to be monitored with half-hourly imagery of VHRR, but this is not routinely done. Experiment may be worth attempting. The higher resolution visible channel is desirable for this, but at night time IR has to be used. OLR maps are also produced experimentally.

The other geosynchronous meteorological satellites are GOES of USA (pair of satellites), METEOSAT of ESA and GMS of Japan. India may possibly receive some data of GOES in near-real-time, in exchange for INSAT data. Besides receipt of raw data (which entails considerable processing/analysis), India does receive 'finished' products of meteorological parameters like upper-air temperatures, winds etc. on the Global Telecommunication System (GTS) — these data include both, conventional and satellite-derived parameters.

In delayed mode (for *post facto* research), data from experimental satellites of various countries are available in India. Later on, India's own experimental met/ocean satellites will be launched, and data would be available *post facto* in general (near-real-time on request). Some of the foreign experimental satellites are : (NB-ADEOS not listed as it has failed).

— ERS, European Remote Sensing Satellite with oceanic sensors : Along-track-scanning radiometer (ATSR) giving improved sea-surface temperature (*via* dual-angle approach) and cloud height/thickness, altimeter giving sea-surface wave heights and sea topography (from which variability of circulation can be inferred *via* geostrophy) [TOPEX is a special mission with 2-frequency altimeter] and scatterometer giving sea-surface-wind-vector. A nadir-look-

ing microwave radiometer corrects altimeter for water vapour affect.

— TRMM, Tropical Rain Monitoring Mission with passive and active (mainly microwave) sensors for mapping rain rate and both its horizontal and vertical distribution (this gives frequent tropical coverage due to inclined orbit).

— DMSP, Defence Meteorological Satellite Program which carries microwave radiometers called Special Sensor Microwave Imager and Temperature Sounder (SSM/I, SSM/T) giving SST, SSW, Atm. Water Vapour, Liq. Wtr, Temp. Profile. etc.

Indian experimental meteorological/oceanographical satellites launched/expected to be launched in polar/inclined orbits in the next 5 years are as follows :

— *IRS P3* : Already launched in March 1996, it carries MOS (Multispectral Optoelectronic Scanner), a German-made payload giving atmospheric aerosols in different layers and oceanic chlorophyll, and WiFS (Wide Field Sensor) an Indian payload giving vegetation index. Compared to the 2-day repeat cycle of P4 (next in list), the P3 has a longer repeat cycle of 22 days which makes it operationally non-suitable, but the methodology of estimating aerosols and chlorophyll can be learnt from its data. This satellite may be useful during the experiment devoted to aerosols called 'INDOEX', Jan.-Apr. 1999.

— *IRS P4 (or OCEANSAT-1)* : This polar satellite will carry Ocean Colour Monitor (OCM) for chlorophyll estimation and Multi-channel Scanning Microwave Radiometer (MSMR) for providing global data of sea-surface-temperature (even in cloudy regions), sea-surface-wind speed, atmospheric water-vapour and liquid-water, plus a few experimental products like rainfall rate, soil moisture etc. However, the global data would be recorded onboard and dumped over Indian station once every 12 hours hence, real-timeness is not assured — however, for local data of Indian Ocean, provision for this exists which may be activated if user demand is received.

— *IRS 2A (or OCEANSAT-2/CLIMATSAT)* : to be launched around 2002 AD in polar OR inclined orbit (may be at 40 deg), this may carry an altimeter, a scatterometer, along-track scanning radiometer and one or two 'climate' sensors, yet under consideration (e.g. radiation budget sensor is one possibility). Thus, it will be largely similar to ERS (with again, 12-hourly global coverage) — but if required, real-time data reception/dissemination may be provided.

## Meteorological Applications — Examples

The parameters indicated in the previous section, available from various satellites, may be put to use in meteorology either through empirical/statistical methods or in numerical weather prediction models. A few examples of each type are given below.

### *a) Tropical Cyclone Prediction/Warnings*

A prime example of useful and convincing application of satellite data in meteorology no doubt, lies in tropical cyclone monitoring, prediction and warnings[6]. Classification of the intensity of cyclone into what are called Dvorak's T-numbers is facilitated by examination of satellite imagery, wherein the tightness, spiral bands and other visual features are employed. To this may be added the cloud top height from cloud top temperature estimated from TIR radiance. In fact, this is not a uniform feature of the entire cyclone ; quantitative dissection into regions of different height help to know the percentage-area exceeding a certain threshold height (temperature). This not only helps to compare cyclones of different intensities (or stages of the same cyclone), but also gives rainfall estimate on the presumption that taller (cooler) clouds are more rainbearing. The key kinematic feature of cyclone is its warm-core at about 300 mb ; this can be delineated using NOAA MSU data, and the intensity quantified[7].

Next to intensity estimation of a tropical cyclone, it is important to predict its path—particularly the landfall point. A sequence of imagery of the cyclone can help to some extent, by the use of *(a)* climatology *(b)* persistence and *(c)* model of future trajectory. The first two are operational (persistence combined with climate is a commonly used method with fair success). Model of trajectory is not truly available and it will have corresponding data needs also. Two of the research attempts — not full fledged models but quasi-models/quasi-empirical approaches are briefly as follows. The path prediction is especially critical in case of recurving cyclone — where 'persistence' will fail. It has been observed that, at the mature (strong) phase of the cyclone, the cloud-top structure (upon computer processing) has an elliptical shape. The major-axis of this ellipse shows a turning behaviour, by the same angle, by which the trajectory later turns, facilitating prediction[8]. Another approach, tried in Australian and Indian regions, is based on 'chaos' theory wherein, the centre-positions of previous six 6-hourly states of the cyclone are combined to predict the 7th position. The coefficients of the predictor are determined from historical data, statistically[9]. This method requires the centre position accurately, which has

been shown to be obtainable from ERS scatterometer winds[10].

### *b) Monitoring Monsoon Variability*

Intraseasonal variability of monsoon has been studied through analysis of TIROS/NOAA imagery from monitoring the Maximum Cloud Zone[11]. The 30-35 day mode is detected in humidity field from NOAA[12]. Interannual variability of monsoon rainfall has been analysed from INSAT data[13].

### *c) Monsoon Onset Prediction*

For agriculture, water resource, power and other applications, the date of onset of the southwest monsoon is critical, and the early warning of it would be very useful. The NCMRWF (National Centre for Medium Range Weather Forecast) uses numerical weather forecast model to predict the onset (and subsequent monsoon behaviour), 5 days in advance. Empirical methods based on satellite observations in the Indian Ocean are being developed. UR Rao *et al.* have found a clear reversal of the overall wind direction, using sea-surface-wind vectors from ERS scatterometer data, in the western Arabian Sea, four weeks prior to the onset of monsoon over Kerala[14]. Wind speed also increases near the west coast of India, but this occurs later, almost close to the onset date ; thus the direction is a definitive advance indicator of the arrival of monsoon. Upper-air temperature and humidity changes (from NOAA sounder) are also found useful[15]. Significant warming of troposphere is seen to be pre-requisite for the onset of monsoon.

### *d) Prediction of Monsoon Performance*

Monsoon rainfall predictions on various time/space scales are important for different purposes. The India Meteorological Department (IMD) gives overall Indian southwest monsoon rainfall forecast in the last week of May, for the average rain of June to September over the whole of India, using a 16-parameter multiple regression — a statistical approach. Some of these 16 parameters are amenable to satellite observation, for example El-Nino (particularly due to clouding in Central/East Pacific, the forthcoming MSMR sensor on IRS-P4 satellite would be useful in this regard, to obtain sea-surface-temperatures there), 500 mb ridge in April (this could be delineated from NOAA soundings[16]), Eurasian snow cover (the forthcoming INSAT 2E with CCD camera having 1.6 micron channel might be useful).

On a relatively smaller scale, Extended Range Monsoon Prediction is being attempted at Space Applications Centre. Here, average rain of each S.W. monsoon month in each of 5 quasi-homogeneous zones of India is to be predicted at the end of the preceding month. For this purpose a global dynamical numerical model of the atmospheric circulation is employed. There is considerable scope to use satellite-based data in this effort. Specifically, boundary conditions like snow-cover, vegetation, soil moisture, sea-surface-temperature play an important role at this scale (particularly in the tropical weather), and most of these could be obtained from satellite sources. Another important factor is 'forcing' terms, for example the latent heat released in convective systems. Using satellite-based rainfall as a proxy for this, the model was 'nudged' with good success in further prediction[17]. Similarly, ocean-atmosphere heat exchanges have been estimated from satellite data[18]. On yet smaller scale, the 5-day, 2 deg × 2 deg forecasts are produced by NCMRWF. As inputs to the model, 'assimilated' satellite data have been found useful, specifically : INSAT CMV's (proxy for 850 mb winds)[19], ERS sea-surface-winds[20], and humidity profiles estimated from INSAT, NOAA and DMSP[21]. Similarly, NOAA soundings have helped in Limited Area Model[22].

Besides use in models as boundary and initial conditions and as forcing functions, satellite data may also help in sharpening 'process' representations/parameterisations in the models. For example, the success in rainfall nudging experiment in ERMP has implied that deep convective scheme should be incorporated in the model. A regionwise characterisation of the cloud, rain, latent heat and radiation (with horizontal/vertical distributions) would be very useful in building up a realistic convective parameterisation scheme. Rainfall estimation from Space is a current topic of research[23]. Satellites such as TRMM (rain details), IRS P4 (Liquid water from MSMR), OCEANSAT-2 (ATSR type stereo sensor for cloud thickness/height) etc. would help besides INSAT. Deep clouds have been studied from INSAT[24]. The relation of sea-surface-temperature with organised convection (such as ITCZ) is another aspect, that has been studied using satellite data[25]. The morphology and dynamics of monsoon depressions has been studied through DMSP SSM/I data[26]. Radiation Budget over the Asian Monsoon region (from ERBE, Earth Radiation Budget Experiment, a special radiation-measurement satellite) was studied in Global Circulation Model[27]. Also, TIROS-N (predecessor of NOAA) satellite was used in estimating radiative heating rate profile[28]. INSAT VHRR was used to obtain OLR and vertical velocity[29]. These and other such studies help to improve physical schemes of numerical weather/climate models. An earlier review article by Desai[30] may also be seen for some details of meteorological applications of satellite data. Finally, in short-range (upto 3 days) forecast, INSAT imagery as discussed on TV are known to large population and bear no emphasis.

### *e) Climate Scale Predictions/Analysis*

Climate being a slower, averaged process, the nature of data needed is less dynamic but more in the form of

boundary conditions and broad forcing functions. Even here, satellites can help provide : sea-surface-temperature, snow-cover, soil-moisture, albedo, radiation budget, solar radiation, atmospheric constituents (particularly greenhouse gases, aerosols and ozone-chemistry players) and ocean circulation which is an integral component of climate dynamics. A review of satellite observations for the study of global change has been given by Desai and Joseph[31].

## Concluding Remarks

It is seen from the examples cited above and from normal operational/research experience that satellite data are indispensable and have vast potential, in meteorology. The fairly long archive of several meteorological parameters from satellite data (*e.g.*, radiation budget parameters from TIROS/NOAA since 1962) including in particular, Indian Satellite data (INSAT CMV's since 1984 for example) may be useful to take up research problems. In the coming years, with the forthcoming launches of enhanced INSAT and experimental lower orbital Indian Satellites like IRS-P4, further reserach/operational uses may be planned.

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## References

1 P C Pandey and R R Kelkar In : *Advances in Space Research in India*, (Ed. R K Verma) INSA (1994) 191
2 Committee on Earth Observation Satellites '*Coordination for the Next Decade*', CEOS, ESA (1995) p 133
3 A K Mathur and V K Agarwal In *Oceanography of the Indian Ocean* (Ed. B N Desai) Oxford & IBH New Delhi (1991) 673
4 R R Kelkar *Indian J Radio & Space Phys* **23** (1994) 325
5 S M Bhandari and A K Varma *Int J Rem Sens* **16** (1995) 2023
6 G S Mandal *Tropical Cyclone Program* WMO (1991) p 422
7 B M Rao, M S Narayana, C M Kishtawal, P K Pal, V S Prasad, A N Nath, K H Rao and M V Rao *Proc 15th Asian Conf Rem Sens* ISRO/NOC (1995) C-2-1
8 P K Pal, B M Rao, C M Kishtawal, M S Narayanan and Rajkumar *Proc Indian Acad Sci - Earth & Planet Sci* **98** (1989) 353
9 P K Pal *Mon Weather Rev* **119**(1991) 3095
10 B M Rao, C M Kishtawal, P K Pal and M S Narayanan *Int J Rem Sens* **16** (1995) 351
11 D R Sikka and S Gadgil *Mon Wea Rev* **108** (1980) 1840
12 C M Kishtawal, P K Pal and M S Narayanan *Proc Indian Acad Sci (Earth & Planet Sci)* **100** (1991) 341
13 R R Kelkar and A V R K Rao *Mausam* **41** (1990) 183
14 U R Rao, P S Desai, P C Joshi, P C Pandey, B S Gohil and B Simon *Proc Indian Acad Sci EPS* (to appear).
15 P C Joshi, B Simon and P S Desai *Int J Climatol* **10** (1990) 49
16 P C Joshi, B Simon and S K Patra *Indian J Radio Space Phys* **18** (1989) 117
17 M S Narayanan *(Private Commun—Preprint)*
18 N Nair, P C Pandey, B Simon and N Gautam *Int J Climatol* **15** (1995) 303
19 P C Joshi, C M Kishtawal, M S Narayanan, P K Pal, O P Sharma and H C Upadhyay *Adv Space Res* **7** (1987) 353
20 P C Joshi, B Simom, M S Narayanan, S R H Rizvi and R K Bansal In : *Advances in Tropical Meteorology (Ed.* R K Datta) Concept Publ Co New Delhi (1996) 85
21 A K Bohra, D Rajan and A K Mitra *Proc TROPMET-97* IMS (to appear) paper 3.6 in *Abstracts*
22 P N Khanna, R C Bhatia and Y V Rama Rao *Proc TROPMET-97* IMS (to appear) paper 5.2 in *Abstracts*
23 S M Bhandari In : *Advances in Tropical Meteorology (Ed.* R N Keshavamurthy and P C Joshi) Tata McGraw Hill Pub Co New Delhi (1993) 238
24 A Gambheer and G S Bhat *Proc TROPMET-97 IMS (to appear)* paper 1.6 in Abstracts
25 S Gadgil, P V Joseph and N V Joshi *Nature* **312** (1984) 141
26 P N Mahajan, M C Tod and E C Barrett *Univ Bristol Tech Note BCD & GR IND* 2900375 (1995)
27 M Rajeevan, D S Pai and R Krishnan *Proc TROPMET-97* IMS *(to appear)* paper 1.1 in Abstracts
28 P N Mahajan, G R Chinthalu and S Rajamani *Proc TROPMET-97* IMS *(to appear)* Paper 4.7 in Abstracts
29 P L Kulkarni, D R Talwalkar, S Nair and S Rajamani In : *Advances in Tropical Meteorology (Eds.* R N Keshavamurthy and P C Joshi) Tata McGraw Hill Pub Co New Delhi (1993) 379
30 P S Desai *Indian J Radio & Space Phys* **24** (1995) 255
31 P S Desai and G Joseph *Indian J Radio & Space Phys* **23** (1994) 101