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A decade of satellite meteorology in India*

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1. Introduction

It is now ten years since the first weather satellite, TIROS I, was launched by the United States of America on April 1, 1960. These ten years have been extremely fruitful ones for the growth of a new science of Satellite Meteorology. There have been 34 meteorological satellites orbited so far, 25 by USA and 9 by the USSR.

When we consider the phenomenal growth in the short period of a decade, two features stand out— the great engineering skill in designing the sensing equipment and the massive scientific returns. The early weather satellites carried with them television cameras and medium resolution infra red (MRIR) radiometers. But within a few years a large number of refinements were introduced. Advanced Vidicon Cameras (AVCS) and high resolution radiometers (HRIR), for example, have substantially added to the range resolution and variety of information which the satellite can now provide. Other sophisticated instruments quickly followed. I shall refer to them subsequently.

The meteorological satellite has not only provided a new observational platform in space but has added a new dimension to the investigations of the earth's atmosphere. It has revealed hitherto unsuspected cloud formations and structures of atmospheric disturbances, provided truly global views of the world's weather and opened up new vistas for measuring a variety of parameters in the earth's atmosphere from space platform. The collection and distribution of satellite meteorological data is now the prime objectives of the World Weather Watch(WWW) Programme.

2. Automatic Picture Transmission (APT) from Meteorological Satellites

Of special interest to us in India was the development of Automatic Picture Transmission (APT) facility in 1962. This has enabled almost all countries of the world to derive immediate benefits from U. S. meteorological satellites. When the International Meteorological Centre (IMC) was set up at Bombay as a part of the International Indian Ocean Expedition (I.I.O.E.) the United States National Science Foundation provided an APT receiving set as their contribution to the I.I.O.E. This has been functioning at Colaba ever since December, 1963. There are at present more than 300 such APT sets operating in different parts of the world.

I have always felt that the principal forecasting centres in India should be equipped with APT receiving equipment so that they can obtain instantaneous cloud pictures both day and night. Since we had only one APT equipment, we made arrangements early in 1968 to transmit pictures of important weather development, by land-line photo facsimile to the meteorological centres at Calcutta, Madras and Delhi. Our technical experts at Poona and Delhi have very recently succeeded in developing this useful piece of equipment in our department with locally available material and two of the sets have started functioning at New Delhi and Madras a fortnight ago. A third set will be installed at Calcutta before the end of this month. Similar sets can be supplied to other meteorological offices in due course as and when necessary. We are also negotiating with the World Meteorological Organisation to obtain under VAP aid an APT set capable of photographic reproduction and more sophisticated monitoring facilities.

3. Geostationary Satellites

While orbiting satellites take instantaneous pictures of the earth's cloud cover over large areas geostationary satellites which orbit at an altitude of about 36,000 km and appear stationary over desired locations provide observation facilities over large segments of the earth on an almost continuous basis. Two geostationary Application Technology Satellites (ATS) relaying cloud pictures are keeping watch over the Pacific and Atlantic Oceans for the last 3 or 4 years. A geostationary

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ATS satellite is likely to be positioned over the Indian area in 1972 by agreement with the NASA of the USA and the Indian Space Research Organisation (ISRO). If minimum meteorological facilities could be provided on this satellite it will indeed be of very great advantage for our studies of the Indian Monsoon and the tropical cyclones and would result in a substantial improvement of short and medium range meteorological forecasts in our country. I, however, understand that there is no provision at present for meteorological observational capability on this satellite.

There are plans by USA, USSR, France and Japan to launch orbiting as well as geostationary satellites during the forthcoming Global Atmospheric Research Project (GARP). The tropical experiment planned in the Atlantic Ocean will have the facility of a geostationary satellite obsering the tropical systems. Geostationary satellites are considered essential for GARP experiments. When the study of the Indian monsoon circulation is undertaken as a part of the First GARP Global Experiment (FGGE) sometime in 1974, a geostationary meteorological satellite will be available over Indian area.

4. A decade of Satellite Data over the Indian Area

During the last ten years, a vast store of pictorial and radiation data gathered by meteorological satellites is available in the Environmental Data Archives of the USA. These include considerable amount of information collected over the Indian Ocean area. The TIROS Operation Satellites (TOS) have provided nearly complete global coverage daily since February 1966.

Radiation data have also been collected and several meaningful parameters like solar albedo, cloud top temperatures, ocean water temperatures and the earth's radiation balance for different geographical areas can be obtained from this wealth of data.

Summaries of satellite video data on a real time basis have now been prepared by U.S. Scientists in both digital and photographic form. Weekly, fortnightly and monthly averages, using the data in photographic format, can now be obtained on film for various studies.

It is a matter of concern to me that we have not yet made full use of this large volume of data over our country. We have not even collected all available data of interest to our country in our archives. A few scientists from India have obtained pieces of data of individual interest from the National Environmental Satellite Centres at Suitland (Mad.). I wish, however, to build up a suitable library of satellite meteorological data in the Department in the near future. It is my intention to see that these satellite data archives are suitably equipped with modern aids for visual examination, display and reproduction so that research workers can make full use of them.

5. Radiation data from Satellites and Vertical Profiles Temperature

Perhaps the greatest bonus which meteorologists have received from satellites is the vast amount of radiation data. Remote sensing in the different parts of the electromagnetic spectrum is now a highly specialised field and is developing at a very rapid rate.

As you are aware, meteorologists had hitherto very little factual information on the total outgoing long wave radiative flux. With the advent of the meteorological satellite, we can now study the association of radiative flux with tropospheric flow patterns, the zonal kinetic energy of the atmosphere and its available potential energy. There are several spectral bands for which sensitive sensors have been developed. There is, for example, the 6 micron band where water vapour is a strong absorber; there is the atmospheric "window" in the 8-12 micron band; there is the 15 micron absorption band of carbon dioxide and finally, the long wave absorption bands of water vapour in the 20-23 micron band. Experiments are in progress to use the microwave band also.

Many of you are aware that by integrating the radiative flux in the 15 micron band of absorption, it is now possible to construct the vertical temperature profiles of the atmosphere over different parts of the globe. The Nimbus III satellite, launched in April 1969, which carried a Satellite Infra Red Spectrometer (SIRS) provided us with the first such vertical temperature profiles which are remarkably close to profiles obtained by conventional radiosondes. With the aid of an Infra Red Interferometer Spectrometer (IRIS) this satellite also provided profiles of water vapour and ozone in the atmosphere.

This is the greatest break-through in meteorological instrumentation since the invention of the radiosonde. It is hardly necessary to emphasize that temperature and water vapour profiles, when available on a real time basis, will lead to very rapid strides in our understanding of the atmosphere. Similar studies with respect to ozone distribution is likely to reveal in the interrelation between weather and ozone. Accurate charts of topography have been prepared for 500 mb, 300 mb and other pressure surfaces using only SIRS data collected from Nimbus III. It is planned that advanced ITOS satellites of the USA will be provided with this vertical probing facility within the next year or two. Other countries like USSR and France are also planning to provide similar capabilities for their meteorological satellites.

Setting up of observatories in remote or inaccessible parts of the earth's surface is a difficult and costly process. There are, consequently, large parts of the earth from which meteorologists have little or no data. Meteorological satellites promise to remove this lacuna in the next two or three years with their newly acquired capacities to collect intelligence from automatic weather stations over deserts and uninhabited areas, meteorological buoys over the ocean and balloons floating in the upper atmosphere.

When vertical profiles of temperature, water vapour and wind are available all over the globe on a real-time basis, it will enable our meteorologists to compute and work out the energetics of the global circulation with a degree of precision hitherto unknown and improve their forecasting capability to a considerable extent. I especially look forward to the day when we shall be able to understand the role of tropics in the circulation of the atmosphere. A question which is engaging the attention of many meteorologists is : Do the low latitudes receive the drive for tropical circulations from the middles latitudes? Are they generated *in situ* by convective processes ? We will have to depend on the information provided by weather satellites to answer basic questions of this nature and hope to have the answers before the present decade ends.

6. Upper level winds from Satellite Data

A recent development, which is of interest to tropical meteorologists, is concerned with the estimate of upper winds from the cloud blow-offs. Cirrus formations extending over long distances and the cirrus blow-offs from the tops of cumulonimbus clouds are being used to estimate upper tropospheric winds. The geostationary satellite provides frequent pictures of clouds over a particular area. By measuring the motion of individual clouds between two picture times (say 20 minutes), it is possible to estimate winds over the vast oceanic areas unrepresented by conventional observations. In order to deal with the vast amount of data available it will be necessary to computerise the analysis. This has been done and experiments made so far have yielded very encouraging results.

There is however a shortcoming to this technique. We cannot determine exactly the altitude for which the wind-estimates are valid. It is my expectation that this deficiency will be removed when cloud motions are analysed in relation to cloud top temperatures and vertical temparature profiles. The meteorological satellite can also be used to track balloons floating at a constant level in the atmosphere and thus enable the meteorologist to determine the winds at the concerned level with a good degree of accuracy. USA and France have successfully experimented with supper pressure balloons floating for months at different levels in the Southern Hemisphere in their GHOST (Global Horizontal Sensing Technique-USA) and EOLE (France) programmes. Very recently a new technique has been developed for releasing dropsondes from a height of 30 km from a mother-balloon and monitoring their intelligence from orbiting and/or geostationary satellites. This technique is favoured by scientists as most suitable for GARP experiments.

7. Utilisation of Satellite Data for Meteorological Analysis and Forecasting

The India Meteorological Department's use of weather satellite observations commenced since the launching of TIROS-I on 1 April 1960. The Department arranged for special observations to be taken during the picture-taking orbits of this satellite over India. Selected pictures from the TIROS-I satellite were received through the courtesy of the United States Weather Bureau and were studied in conjunction with synoptic maps. The pictures were then used mainly for "post-mortem" analysis and investigational purposes. Soon thereafter, the U. S. Weather Bureau commenced the issue of Nephanalyses bulletins which the meteorological offices in India received regularly through the Northern Hemisphere Exchange Channels. Special bulletins on cyclonic storms in the Arabian Sea and the Bay of Bengal were cabled to India from Washingtion D. C. as and when occasions arose. This arrangement is continuing. When the International Meteorological Centre (IMC) was set up at Bombay in connection with the International Indian Ocean Expedition, the U. S. National Science Foundation provided an APT receiving set to India. This unit, functioning at Colaba, Bombay since December 1963 has had an unbroken record of receptions since then. The assistance and co-operation of the United States Weather Bureau (ESSA) and the National Science Foundation have thus been valuable in the development of satellite meteorology in India right from its inception.

Map analysis at the Northern Hemisphere Analysis Centre (NHAC), New Delhi, the Indian Ocean and Southern Hemispherical Analysis Center (INOSHAC), Poona and the Extended Analysis and Prognostic Centres at the International airports at Bombay and Calcutta is greatly facilitated by satellite data received by the APT unit at Bombay especially over the parts of the oceanic area where ships observations are scanty or absent.

Interpretation of satellite pictures in relation to synoptic situations receive special attention at routine map discussions at these Centres. The Bombay APT unit also interprets the satellite pictures with reference to the corresponding synoptic maps prepared at the Regional Meteorological Centre, Bombay and issues special satellite bulletins. There is at least one bulletin daily, sent out on the teleprinter channels to more than 50 forecasting offices in India including those maintained by the Indian Air Force and the Indian Navy. On occassions of disturbed weather in the Arabian Sea and the Bay of Bengal satellite bulletins are sent to Meteorological office, Colombo, Ceylon over AFTN channels.

Since March 1967, Nephanalyses from the COSMOS satellites launched by USSR are received regularly by NHAC, New Delhi on Radio Tele-type link between Moscow and New Delhi. These are distributed to other centres of the Department as well as to international users. Reception of satellite pictures transmitted by facsimile from Moscow is also arranged regularly. Along with pictures from the U.S. satellite the USSR satellite pictures provide a very useful coverage of the cloud distribution over Asia.

7·1. *Satellite data for aviation forecasts*

It is realized that satellite pictures provide very useful information for aviation, especially for long distance flights. The extraordinary meeting of CAeM which met jointly with ICAO Sixth ANC (Montreal, April—May 1969) recommended the display of satellite cloud pictures for purposes of meteorological briefing of air crew. This is being done at a number of international airports. Apart from typical synoptic disturbances like tropical cyclones, extra tropical depressions and fronts, extensive cloud bands in association with the monsoons and tropical disturbances in the low latitudes are also seen in satellite pictures. Spectacular views of cirrus trails extending over thousands of kilometers in association with sub-tropical westerly jet streams in winter are quite common and afford means for determining the positions of the jet stream core. Similar pictures of shearing of cloud tops in the tropical summer easterly jet stream are quite useful in indicating the position of this jet for SST operations in future.

The issue of SIGMET Information bulletin and flight forecasts for long oceanic routes like Bombay-Nairobi, Bombay-Mauritius, Madras-Singapore etc., represent operational tasks in aeronautical meteorology for which satellite information finds direct utilisation.

7.2. *Satellite data for marine forecasts*

One of the problems in the analysis of oceanic charts is the paucity of data over large areas. Since 1967, following the closure of the Suez Canal, the patterns of shipping lanes have got altered substantially; while there has been an increase of ships observations over routes emanating into the Indian Ocean from the Cape of Good Hope, Arabian Sea data, vital for studying especially the southwest monsoon, has decreased substantially in volume and frequency. In regions having ships observation, the data coverage is restricted to the surface charts only. Even in these areas, there is an element of chance on the availability of ships observations, there being no certainty as to whether data would be forthcoming over any particular area of special interest. Surface analysis for the equatorial belt and upper-air analysis of the greater part of the Indian Ocean are therefore greatly handicapped on account of paucity of data. Satellite observations over all such areas are found most valuable for filling up the synoptic charts with some meaningful, if not quite perfect supplementary information in order to carry out rational analysis on the basis of continuity in time and space.

7·3. *Satellte data for tropical cyclone warnings*

One of the principal uses of satellite data in India as elsewhere in the world is for issuing storm-warnings to ships plying in the Indian Seas and warnings to Indian ports. The responsibility for the issue of the warnings rests with the storm-warning centres at Bombay (for the Arabian Sea), Calcutta and Madras (for the Bay of Bengal). The storm-warning centre at Bombay is in a position to make immediate use of the latest satellite pictures as the APT unit is located in Bombay itself. In order to enable the storm-warning centres at Calcutta and Madras to get the benefit of the satellite pictures in addition to the satellite bulletins which they receive as a routine by teleprinter, the records of selected satellite passes are transmitted to them from Bombay by wire-photo or days of disturbed weather in the Bay of Bengal. These centres will have this facility from the storm season of 1970 onwards.

Forecasting centres in India have been using the criteria, developed by the National Environmental Satellite Centre (USA) for the classification of and estimation of maximum winds in tropical cyclones. These criteria pertain to the Atlantic and Western Pacific areas where research flight data of maximum wind speeds in hurricanes and typhoons are available. No such data have been collected for storms in the Indian Sea areas. Experience so far shows that the U.S. criteria offer useful guidance for the Indian cyclones as well. It is not always possible to estimate the position of centres of the disturbances accurately when they are not fully developed and when their eyes are covered with clouds. Differences sometimes exist between the positions of the centres of the disturbances as seen on the synoptic charts and corresponding satellite centres. It is expected that when aircraft reconnaissance facility becomes available for the study of Indian cyclones, it should be possible to determine necessary criteria for estimating the intensities of the disturbances and the maximum winds associated with them more accurately from satellite pictures. It should, however, be mentioned that even at the present stage, the meteorological satellite has become an invaluable aid in detecting and tracking tropical cyclones over the Bay of Bengal and Arabian Sea. In quite a number of cases it has provided the first indication of the existence of the storm and/or its development into hurricane intensity. A Cyclone Warning and Resarch Centre will shortly be set up at Madras with a network of eight S-Band radars along the east and west coasts of the country. The Centre will utilise the information from the meteorological satellites extensively for cyclone warning and research.

8. Investigation and Research

A research unit for systematic study in satellite meteorology has not yet been established in the Department, although it was included in our plans some years ago. I hope to set-up this essential unit during the present plan period. It will then be possible to organise large-scale research on the vast data already available for our area. These studies will definitely throw more light on important problems like the development and pulsations of the Indian monsoon circulation, formation, growth and dissipation of monsoon depressions, tropical cyclones etc.

A number of individual workers have, during the past ten years made valuable studies with the limited facilities available. I had studied in 1961 the first satellite pictures of a tropical cyclone in the Arabian Sea in 1960 and found that during its early stages of development, the cloud distribution over the storm was markedly assymetric, with most of the cloud mass situated in the rear sectors. Later studies in the USA corroborated that assymetry of cloud distribution is typical in the developing stages of tropical cyclones all over the world. This is an interesting feature which has to be theoretically investigated in order to determine its role in cyclogenesis. Further case studies of the tropical cyclones and depressions in the Bay of Bengal and Arabian Sea were made by Nedungadi (1962), Mazumdar (1963), Kulshrestha and Gupta (1964 and 1966) Sivaramakrishnan (1965), Rama Rao *et al.* (1967) and Mukherjee and Misra (1968). Srinivasan (1968) made an extensive analysis of the satellite cloud patterns over the Indian Ocean during the southwest monsoon season.

A number of US and Indian scientists working in USA have made significant contributions in satellite studies of the Indian monsoons and the disturbances associated with it. Sadler (1962) determined the track of the Arabian Sea cyclone of May 1960 mentioned earlier with the aid of satellite pictures and found that it did not dissipate over the Arabian Sea as mentioned in India Met. Dep. bulletins but actually crossed the Arabian coast. Krishna Rao (1966) traced the progress of the southwest monsoon over the Indian Ocean area, during the season of 1962. Miller and Keshavamurthi (1968) used satellite pictures as well as radiation data during the monsoon of 1963 and studied the structure of the mid-tropospheric low. Sadler (1965) calculated average monthly cloudiness from the nephanalyses prepared from TIROS V —VIII observations over the Indian Ocean during 1963-64. Later, he extended his work and prepared average monthly cloudiness charts covering the whole tropical zone between 30 degrees of latitude in each hemisphere. A group led by Prof. Suomi of Wisconsin Univ., USA has prepared mean cloudiness maps for the Indian Ocean area with the aid of digitised daily maps which show clearly the progress of the cloud pattern in the Indian monsoon. The NESC, USA have also prepared a number of mean cloudiness maps for the Indian Ocean area during 1967 and for different averaging periods with the help of digitised satellite data.

These are very useful compilations, but today I wish to look ahead for the next five or six years. It is pertinent to enquire in what direction shall we now extend our scientific effort ?

It will be generally agreed that useful though it may be, it is not enough to merely compile a catalogue of satellite pictures and associate them with synoptic situations. Real progress will be achieved only when we are able to advance physical reasons to explain the processes which give us our weather. In this context, I am not asking for more and more of abstract theory. I have always felt that theory without the support of physical reasoning often leads to confusion. What I would like to see, therefore is the development of more numerical mode based on sound physical concepts. For it must be realised that numerical modelling experiments provide us with a powerful tool for isolating certain effects, such as friction and diabatic heating, in order to study their effect on the general circulation. Many of you would have seen two recent and important papers by Professor Lighthill in the *Quarterly Journal of the Royal Meteorological Society* (1969) and the *Philosophical Transactions of the Royal Society* (1969) on the response of the Indian Ocean to monsoon winds. The work of Rosenthal (1967) and Matsuno (1967) on the propagation of waves near the equator is also of great interest for numerical modelling in tropical areas. There is now rapidly growing interest in tropical circulations amongst meteorologists all over the world and the availability of necessary data over the tropics with the aid of meteorological satellites will greatly help in solving these important problems.

We are approaching the stage when data will no longer be a problem in the tropics. Although the existing giant computers are still not adequate for global-scale calculations. We hope to reach a stage when adequate computer facilities will be available in the world to undertake the analysis. I am trying to provide computer facilities for operational Numerical Weather Prediction in the department. Limited by funds, larger computers outside the department will also be available for research purposes. There is no reason, therefore, why meteorologists from India should not take a prominent part in the new development of tropical meteorology in the world and eventually solve the problem of the origin, structure and development of the Indian SW Monsoon, on which the economy of our country as well as most countries in South Asia depends to a very large extent.

Selected Bibliography of papers on Satellite Meteorology of the Indian Ocean Area

Koteswaram, P. 1961 Cloud Patterns in a Tropical Cyclone in the Arabian Sea viewed by TIROS. 1 Meteorological Satellite. Sci. Rep. 2, prepared for Geo. Phys. Res. Dir. AFCL. Hawaii Inst. Geophys. Rep., 18, pp. 34.

Kulshreshta, S. M. and Gupta, M. G. 1964 Satellite Study of an Inland Monsoon Depressions, *Indian J. Met. Geophys.*, **15**, pp. 175-182.

1966 Satellite study of the Rameswaram cyclonic storm of 20-23 December 1964, *J. appl. Met.*, **5**, pp. 373-376.

Krishna Rao, P. 1966 A study of the Onset of the Monsoon over India during1962 using TIROS IV Radiation Data, *Indian J. Met. Geophys.*, **17**, pp. 347-356.

Mazumdar, S. 1963 Study of a Cyclonic Spell in the Indian Seas. Tech. Notes, 69, Proc. WMO/FAO Seminar on Meteorology and Desert Locust, Tehran, 25 Nov-11 Dec 1963, pp. 141-161.

Miller, F. R. and Keshavamurthy, R. N. 1967 Structure of an Arabian Sea Summer Monsoon System. IIOE *Met. Monogr.* 1, Hawaii.

Mukherjee, A. K. and Misra, P. K. 1968 Satellite study of a Bay Cyclone. *Indian J. Met. Geophys.*, **19**, pp. 295-304.

Nedungadi, T. M. K. 1962 Satellite Tracking of cyclonic storm, *Indian J. Met. Geophys.*, **13**, pp. 552-554.

Raghavan, K. 1969 Satellite study of Sea-Air Interactions During the Indian Monsoon, *Mon. Weath. Rev.*, **12**, pp. 905-908.

Rama Rao, M. Ramanathan A. S. and Srinivasan, V. 1967 Satellite study of the Cyclonic Storm activity in the Indian Seas between 24 September and 5 October 1969, *Indian J. Met. Geophys.*, **18**, pp. 485-490.

Sadler, J. C. 1962 The First Hurricane Track determined by Meteorological Satellite, *Indian J. Met. Geophys.*, **13**, pp. 29-44.

1965 Satellite Meteorology in the International Indian Ocean Expedition, Proc. Symp. Meteorological Results of IIOE Bombay, pp. 269-284.

1968 Average Cloudiness in the Tropics from Observations. IIOE., *Met., Monogr.* 2, Hawaii.

Sivaramakrishnan, M. V. 1965 Structure of Tropical Cyclones as revealed by TIROS cloud pictures taken over the Indian Region, Proc. Symp. Met. Results of IIOE, Bombay, pp. 285- 294.

Sivaramakrishnan. M. V. and Mary Selvam 1968 On the use of spiral overlay technique for estimating the central positions of Tropical Cyclones from satellite photographs taken over the Indian Region, Proc. 12th. Conf. Radar Met., October 1966, National Severe Storms Laboratory, Oklahoma, USA.

Srinivasan, V. 1968 Some aspects of broad scale cloud distribution over Indian ocean during Southwest Monsoon. *Indian J. Met. Geophys.*, **19**, pp. 39-54.

Srinivasan, V. and Neralla, V. R. 1965 Convective Activity in the Equatorial Trough Zone over Indian Ocean during the Southern Hemisphere Summer Season revealed by TIROS, Proc. Symp. Met. Results of IIOE, Bombay, pp. 305-313.