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NOAA/TOVS derived upper tropospheric temperature changes associated with the onset of southwest monsoon over Kerala coast

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सार—ध्रुवीय कक्षां में घूमने वाले नोआ श्रृंखला के मौसम उपग्रहों में टी०ओ०वी०एस० (टाइरॉस ऑपरेशनल वर्टिकल साउंडर) नामक उपकरण भी होता है। केरल तट पर दक्षिण-पश्चिम मानसून के आरम्भ के संदर्भ में, इस उपकरण द्वारा पाकिस्तान के उष्ण कमदाब और तिब्बत के क्षेत्र पर रिकॉर्ड किये गए तापमान के आंकड़ों की जांच की गई है। मानसून आरम्भ से लगभग दो सप्ताह पूर्व ही उच्चतर क्षोभमण्डल में तापमान की उल्लेखनीय वृद्धि दिखाई दी है।

ABSTRACT. The NOAA-series of polar orbiting meteorological satellites carry onboard an instrument TOVS (TIROS Operational Vertical Sounder). The temperature profile data from this instrument over Pakistan heat low region and Tibetan plateau region is examined in relation to the onset of southwest monsoon over Kerala coast. A significant temperature increase in upper troposphere nearly two weeks in advance of onset of monsoon has been observed.

Key words — NOAA-TOVS satellite data, Upper air temperature, Pakistan heat low, Onset of monsoon

1. Introduction

The onset of southwest monsoon is now generally accepted as the commencement of the monsoonal rains over Kerala coast (Ananthakrishnan *et al.* 1967). This date has great significance for the farmers and the planners. Well analysed statistics of these dates have been presented by Ananthakrishnan and Soman (1988). There have been attempts to functionally relate the upper air parameters like temperature, wind and geopotential height in the month of April (Kung and Shariff 1982) to the onset of monsoon. The India Meteorological Department also uses the combination of various surface and upper air parameters for its operational long range forecasting of the onset of monsoon. The main cause of the monsoonal circulation is the differential heating of the land and the ocean. Hence the thermal features, particularly over deserts or Tibetan plateau carry the signatures of monsoon circulation. It is thus worthwhile to examine the relationship between the thermal features over these locations and their role in the monsoon circulation.

The TOVS sensors onboard NOAA series of polar orbiting meteorological satellites have the capability of providing atmospheric temperature profiles. These temperature profiles are now routinely available since 1979. The layer mean temperatures are available in fifteen layers of varying thickness up to 1 hPa. The TOVS data have recently been used for examining various features of monsoon circulation by different authors, *viz.*, Joshi and Desai (1985), Joshi *et al.* (1989) and Narayanan and Rao (1981). A good description of the TOVS data set is given by Khalsa and Steiner (1988). Joshi *et al.* (1990) and Murakami and Ding (1982) have found that the upper tropospheric temperatures over thermally strategic locations like Pakistan heat low and the Tibetan Plateau abruptly increase prior to onset of monsoon. Murakami and Ding's study was only for the FGGE year, whereas Joshi *et al.*'s study covered the FGGE year and 1982. In the present paper we have made detailed examination of the temperature changes over Pakistan heat low in relation to onset of monsoon for the years 1979-1985. Section 2 describes the source of the data as well as the methodology adopted in the analysis. Section 3 describes the results obtained and the conclusions are summarised in section 4.

2. Data and methodology

Beginning with the launch of TIROS-N in October 1978, a number of satellites have been launched, which are capable of providing the temperature profiles. The details of the sensors onboard these satellites is available in the NOAA User's Guide (Kidwell 1986). NOAA—NESDIS is providing

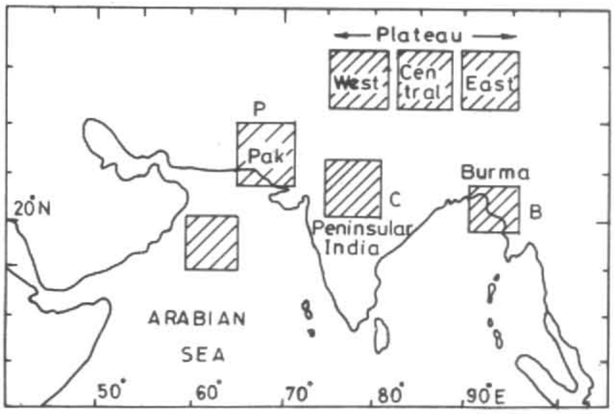

Fig. 1. Locations and their areal extent of the different regions considered

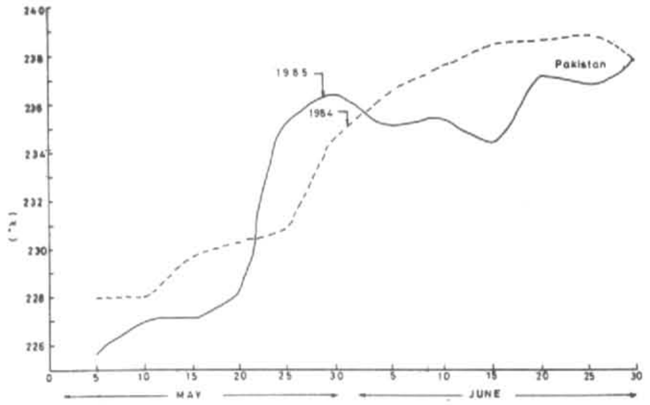

Fig. 2. NOAA-TOVS derived layer mean temperatures at 300-200 hPa layer around Pakistan heat low region during 1984 and 1985. The onset date in corresponding year is shown by an arrow

the finished sounding products on a commercial basis.

The present study uses the mean layer temperatures of several layers, ranging from 950-850 hPa to 200-100 hPa, obtained from NOAA soundings (finished products). These are generally believed to be accurate (Smith *et al.* 1970) to about 1-2 °K. The daily data for the months of May and June in the years 1979-1985 was used. Due to unavailability of further data we could not extend the study upto 1992. The retrieved satellite data is available in 1.5° × 1.5° grid. In our study we examined the daily averages. Thus the spatial scales of data coverage for averaging should also be large. To cover two grid points on both the sides of the centre point, we have taken a 6° × 6° box for averaging. The daily temperatures were averaged in a 6° × 6° box centred around different locations near the Indian subcontinent. These locations are shown in Fig. 1. For example, the Pakistan heat low region is centred around 28°N, 68°E, the Tibetan plateau regions are centred as: eastern (33°N, 93°E), central (33°N, 85°E), western (33°N, 77°E). The dates of onset of monsoon and the total seasonal monsoon rainfall were taken from reports published by India Meteorological Department.

As discussed above the temperature profiles are available only after 1979. Also, we did not have access to the data beyond 1987. The onset period during 1983, 1986 and 1987 had many data gaps. Hence the study period is limited upto the year 1985. The dates of onset of monsoon are listed in Table 1. It is to be observed that except for 1979 the onset occurred within two days of normal date (*i.e.*, first June) of onset of monsoon. For the year 1979 the onset was very much delayed. Thus, it is to be noted that the period of study had a very restricted range of variation.

3. Results and discussion

We analysed layer mean temperatures from 950-850 hPa to the 200-100 hPa layer. In general, in all the years most of the layers showed an increase in temperature—as was expected keeping in line with the zenith angle of the sun. However, the layer 300-200 hPa showed unusual temperature changes prior to the onset of monsoon. As an illustration the temperature changes in this layer over Pakistan heat low region are shown in Fig. 2 for the years 1984 and 1985. The date of onset of monsoon is shown by an arrow in the corresponding figure. We find that a few days prior to onset, the temperature starts increasing abruptly and the trend is continued for next few days. Afterwards it saturates or even decreases after the full establishment of the monsoon circulation. However, the Arabian Sea region, the peninsular region and the Burma region do not show any appreciable increase in the temperature. To get the full view of the changes occurring at different layers, the temperatures during the onset of monsoon in 1982 are shown in Figs. 3 (a-c). We again find that nearly two weeks in advance of the onset of monsoon, the temperature starts increasing

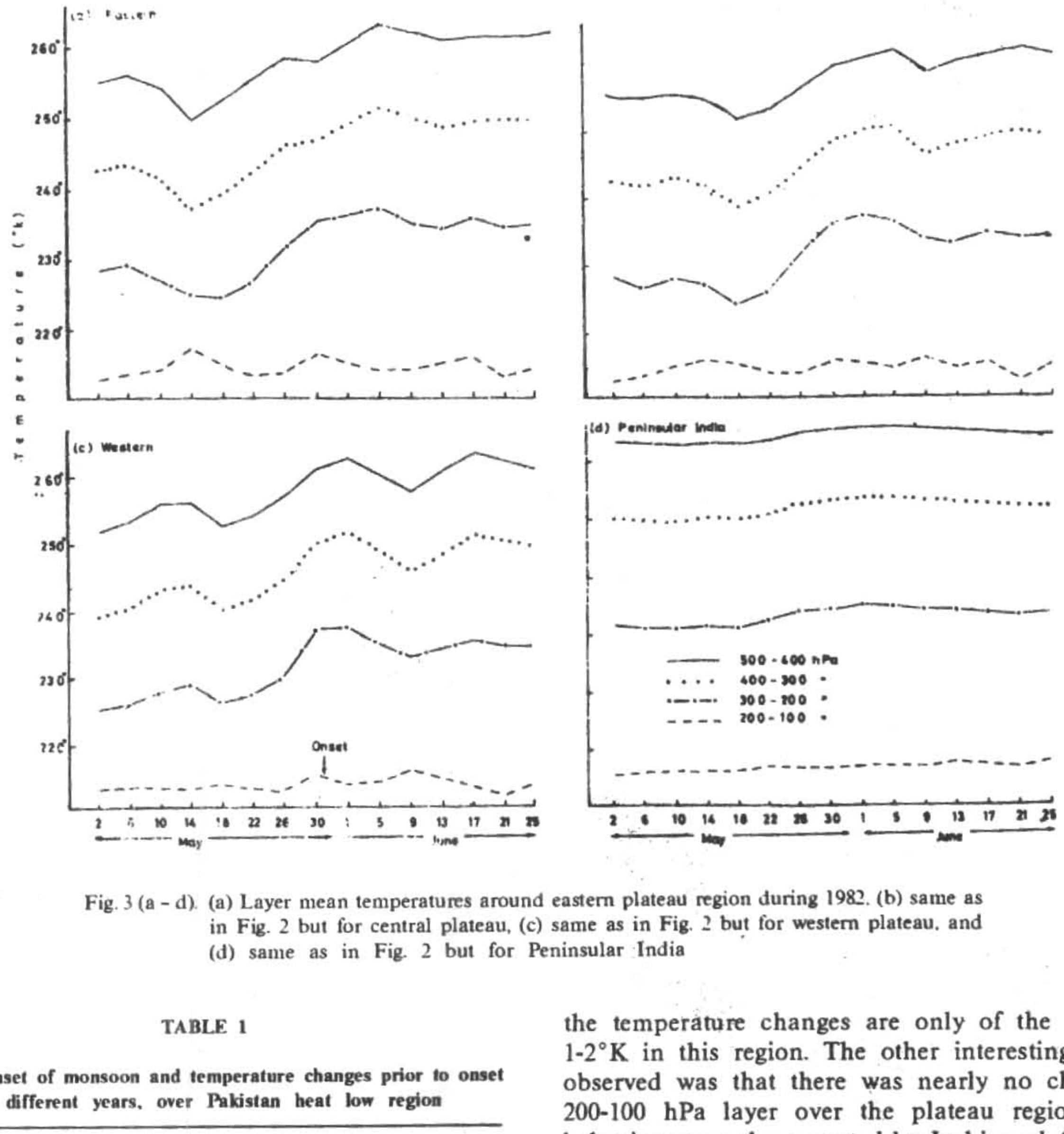

Fig. 3 (a - d). (a) Layer mean temperatures around eastern plateau region during 1982. (b) same as in Fig. 2 but for central plateau, (c) same as in Fig. 2 but for western plateau, and (d) same as in Fig. 2 but for Peninsular India

TABLE 1

Date of onset of monsoon and temperature changes prior to onset for different years, over Pakistan heat low region

Year	Onset date of monsoon	Temperature changes		
		°C	In days	°C/day
1979	11 Jun	8	11	0.7
1980	1 Jun	6.5	19	0.3
1981	30 May	3	17	0.2
1982	31 May	8	15	0.5
1984	31 May	7.5	20	0.4
1985	29 May	10	14	0.7

rapidly. For comparison, the temperature around Peninsular India are shown in Fig. 3 (d). We see that the temperature changes are only of the order of 1-2°K in this region. The other interesting feature observed was that there was nearly no change at 200-100 hPa layer over the plateau region. Such behaviour was also reported by Joshi *et al.* (1990) by analysing the FGGE data.

In the above we have presented few examples for the years 1982, 1984 and 1985. In all other years also similar changes took place prior to onset of monsoon. However, the exact quantum of change for every year was varying.

The temperature changes over Pakistan heat low region and the onset dates for all the years are given in Table 1. For the year 1983 there were many data gaps around the onset period of monsoon, hence results are not included for this year. We observe that the temperature changes per day range from 0.2°C/day to 0.7°C/day. Also, it appears that mostly

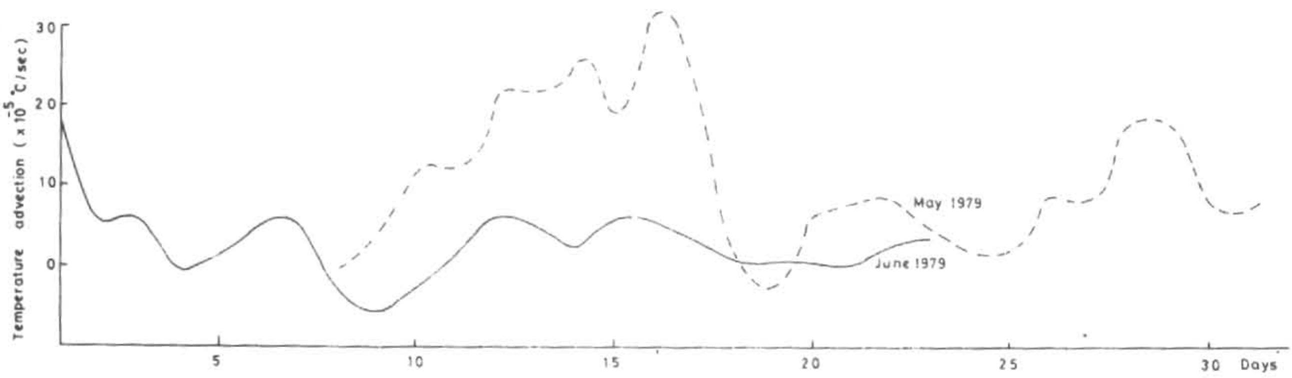

Fig. 4. Temperature advection in western plateau region during May and June 1979

the drought years are associated with steep tropospheric temperature changes prior to onset of monsoon. However, the data sample is small and a conclusive statement could not be made. Some weather transients may also change the temperatures temporarily. Such changes have to be distinguished from the regular systematic change. Thus the simultaneous analysis of the synoptic charts is also desirable. The accuracy of TOVS temperature retrievals is 1-2°K. However, averaging for a larger time period like 10-15 days may smoothen the error. Thus, the per day increase of a fraction of a degree Celsius may still be worthwhile increase or a factor showing significant temperature increase, though it falls within the accuracy of the temperature retrievals. Recently Simon and Joshi (1992) have also analysed the upper atmospheric moisture data available from TOVS in relation to the southwest monsoon circulation. They observed that middle layer moisture changes over western Indian Ocean showed a remarkable change prior to onset of monsoon. Here also the places like the eastern Arabian Sea or the Bay of Bengal region did not show any significant change in the middle layer moisture. Thus the temperature and the moisture data available from the TOVS data may be combined to monitor the onset of monsoon a couple of weeks in advance. It is needless to add that a single parameter may not be sufficient to predict the onset of monsoon.

Krishnamurti and Ramanathan (1982) examined some observational aspects of the evolution of energy exchanges and differential heating during FGGE. One of the features found by them was the movement of the differential heating during the onset period to a favourable position for the generation of eddy available potential energy and its release to eddy kinetic energy. With this formulation (mainly the rotational and divergent wind component interaction), they were able to simulate the sudden rise in kinetic energy with the onset of monsoon. However, no feature showing abrupt increase of upper tropospheric temperature was seen in their calculations, suggesting a reason other than differential heating.

In an attempt to understand the abrupt changes in temperature around 300 hPa we computed the temperature advection at 300 hPa level using FGGE data for the locations around Tibetan plateau and the Pakistan heat low region. The maximum advection was observed around the western Tibetan region. The advection in the month of May and June in FGGE year around western Tibetan plateau at 300 hPa level is shown in Fig. 4. We find that during the first half of May the advection is very high reaching some days to as high as 30.0×10^{-5} °C/sec. The exact reason for this high value is also not known. During this period, in the lower latitudes there was a tropical cyclone and also the westerlies above the Tibetan plateau at 300 hPa region were very strong. It is to be added here that the average resultant temperature in the region would depend on the following four factors :

(*i*) The advection of temperature, (*ii*) adiabatic temperature change due to area mean vertical motion, (*iii*) the adiabatic temperature change due to vertical motion of spatial eddy, and (*iv*) the diabatic heating.

It is seen that in the period of abrupt temperature changes there is no significant change in the temperature advection. Murakami and Ding (1982) also examined the wind and temperature structures over Eurasia during onset phase of monsoon in 1979. They found that prior to onset of monsoon a rapid intensification of 300 hPa anticyclone took place and around this period intense rains over the east China Sea—Japan region were established. This study also showed through their rigorous computations that the adiabatic heating may produce heating upto 1.5°C/day. The onset is preceded by the full establishment of anticyclone around 300 hPa level. With the anticyclone there is consequent subsidence and hence an increase in the temperatures. Our analysis of the FGGE data showed that nearly two weeks prior to the increase in temperatures the downward motion increases from 0.2 hPa per day to 0.7 hPa per day during the FGGE year. However, after this the downward motion again decreases and remains at a small value. A behaviour similar to this was also reflected in the atlases produced by Mohanty *et al.* (1984). On the basis of the average omega field for the period 1979-1984, they found that in the heat low region the downward motion doubles in the second half of May in comparison to the first half. This again decreases in the first half of June to a value nearly equal to that in the first half of May. All these studies suggest that prior to onset of monsoon there is considerable amount of subsidence taking over the heat low region and may be contributing towards the observed temperature changes prior to onset of monsoon. Presently we have access to the wind data around the region of interest only for the year 1979 hence the numbers for other years could not be compared.

4. Conclusions

The examination of the limited data set shows that the onset of monsoon is preceded by a significant upper tropospheric temperature change nearly two weeks in advance over Pakistan heat low and the Tibetan plateau regions. The temperature changes in individual years vary. Also one has to be careful in estimating the temperature change from minimum to maximum as some weather transients may temporarily disturb the temperature pattern. Analysis of the FGGE data showed a downward motion (nearly 0.2 hPa per day to 0.7 hPa per day) in the second half of May. This downward motion may contribute towards observed temperature changes prior to onset of monsoon. More rigorous theoretical studies are required to understand this phenomenon.

It is to be mentioned that the monsoon circulation is very complex phenomenon and is a sum total of various forcings—local, regional and global. Particularly the prediction of its various features has to include all such factors. This study points out that the temperature profiles obtained by processing the TOVS data may be one such factor useful in understanding the dynamics of the onset of monsoon.

The regions around the Pakistan heat low and the Tibetan plateau do not have many radiosonde observations. However, there may be some nearby station having long history of radiosonde observations. It would be desirable to examine the temperature changes around these stations in relation to the onset of monsoon. This would corroborate the findings observed through the analysis of the satellite data.

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References

Ananthakrishnan, R., Acharya, U.R. and Ramakrishnan, A.R., 1967, "On the criteria of declaring the onset of the southwest monsoon", Forecasting Manual, No. IV, 18.1, 1967, India Meteorological Department.

Ananthakrishnan, R. and Soman, M.K., 1988, "The onset of southwest monsoon over Kerala : 1901-1980", *J. Clim.*, **8**, 283-296.

Joshi, P.C. and Desai, P.S., 1985, "The satellite determined thermal structure of heat low during Indian southwest monsoon season", *Adv. in Space Res.*, **5**, 57-60.

Joshi, P.C., Simon, B. and Patra, S.K., 1989, "Use of NOAA temperature sounding data in long range forecasting of southwest monsoon rainfall", *Indian J. Radio Space Phys.*, **18**, 117-119.

Joshi, P.C., Desai, P.S. and Simon, B., 1986, Satellite derived tropospheric thermal changes over Tibetan Plateau during onset of monsoon, Proc. National Space Sciences Symposium, Gauhati, p. 76.

Joshi, P.C., Simon, B. and Desai, P.S., 1990, "Atmospheric thermal changes over the Indian region prior to the monsoon onset as observed by satellite data", *Int. J. Clim.*, **10**, 49-56.

Khalsa, S.J.S. and Steiner, E.J., 1988, "A TOVS data set for study of the tropical atmosphere", *J. Appl. Met.*, **27**, 851-862.

Kidwell, K.B., 1986, NOAA polar orbiter data user guide, U.S. Dept. of Commerce, National Climate Data Center, Washington, D.C., 2033.

Krishnamurti, T.N. and Ramanathan, Y., 1982, "Sensitivity of the monsoon onset to differential heating", *J. Atmos. Sci.*, **39**, 1290-1306.

Kung, E.C. and Shariff, T.A., 1982, "Long range forecasting of the Indian summer monsoon onset and rainfall with antecedent upper air and sea surface parameters", *J. Met. Soc. Japan*, **60**, 672-682.

Mohanty, U.C., Hollingsworth, A. and Dash, S.K., 1984, Asian summer monsoon circulation statistics: 1979-1984, European Centre for Medium Range Weather Forecasting, Report.

Murakami, T. and Ding, Y.H., 1982, "Wind and temperature changes over Eurasia during the early summer of 1979", *J. Met. Soc. Japan*, **60**, 183-196.

Narayanan, M.S. and Rao, B.M., 1981, "Detection of monsoon inversion by TIROS-N satellite", *Nature*, **294**, 546-548.

Rao, Y.P., 1976, *Southwest Monsoon*, Met. Monogr. India Meteorological Department.

Simon, B. and Joshi, P.C., 1992, Association of moisture fields over Indian Ocean with the southwest monsoon onset over Kerala coast using NOAA/TOVS satellite data, Proc. Nat. Symp. on Advances in Tropical Meteorology, Ahmedabad, 73-78.

Smith, W.L., Woolf, H.M., Hayden, C.M., Wark, D.Q. and McMillin, L.M., 1970, "The TIROS-N operational vertical sounder", *Bull. Amer. Met. Soc.*, **60**, 1177-1187.