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Sodar studies of the monsoon trough boundary layer at Jodhpur (India)

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सार – 700 मीटर की ऊंचाई तक तापीय सीमा सतह का अध्ययन करने के लिये मानसून द्रोणी के अंतिम छोर, जोधपुर में एक मोनोस्टेटिक सोडार की स्थापना की गई। यह प्रयास मानसून गतिकी (dynamics) के अध्ययन के लिये समन्वित बहुसंस्थात्मक परियोजना का एक भाग था। तापीय पिच्छक (plume), भूस्थित सतहों, तरंगित (undulated) और अन्तरगित उन्नयित (elevated) बहुसतहों तथा बिन्दु प्रतिध्वनियों की सामान्य रचनाएं देखी गई। किन्तु प्रातः काल के समय भूमि के ऊपर उठती, हुई सतह के रूप में सामान्यतः दिखाई पड़ने वाला प्रतिलोमन (inversion) तथा सतह का अपरदन (erosion) जून से अगस्त 1990 तक के पूरे प्रेषण काल के दौरान अनुपस्थित रहा। प्रस्तुत लेख में वर्षा सम्बन्धी गतिविधियों के लिये प्राप्त आँकड़ों (data) के एक अध्ययन को प्रस्तुत किया गया है। प्रारम्भिक अध्ययनों से यह पता चलता है कि मौसम सम्बन्धी जानकारी प्राप्त करने के परम्परागत तरीकों से प्राप्त सूचना की अपेक्षा सोडार संरचनाओं से अधिक जानकारी मिल सकती है।

ABSTRACT. A monostatic sodar was set up at Jodhpur, the extreme end of the monsoon trough, to study the thermal boundary layer up to a height of 700 m. This effort was a part of the co-ordinated multi-institutional project to study the monsoon dynamics. The usual structures of thermal plumes, ground based stable layers, elevated/multi-layers with or without undulations and dot echoes were seen. However, erosion of the inversion layer normally observed in the morning in the form of a rising layer over land areas was absent all through the period of observation from June to August 1990. In the paper, a study of the observed data in relation to the rainfall activity has been made. A preliminary examination shows that sodar structures may provide additional information, not available normally through the conventional meteorological tools.

Key words — Sodar, Monsoon trough, MONTBLEX, Atmosphere, Boundary, Thermal, Turbulent, Depression, Rainfall.

1. Introduction

Monsoon is a characteristic phenomena of summer rainfall in north India. Cyclonic disturbances (monsoon lows, depressions) are formed at varying intervals along the eastern coast of India over the north Bay of Bengal, the seat of organised deep moist convection. These disturbances which move over the plains of north India from east to west, are closely associated with a quasi-stationary low pressure area, usually called the monsoon trough. Mean trough line runs approximately parallel to the southern edge of the Himalayas and exhibits periodic movement to the north and south of its normal position. When the axis moves north of its normal location close to the foothills of the Himalayas, conditions become favourable for a general cessation or 'break' in the monsoon rains over the plains of India and heavy rains occur over the foothills. However, when the axis of the trough lies over the Gangetic plains, active monsoon conditions prevail over north India generating good rains even up to the western end of the monsoon trough.

It has been observed that normal conditions are modified in different temporal and spatial scales by the formation and movement of synoptic scale disturbances on 3-7 day scale and active-weak monsoon spells on 10-20 day scales (Rakshit & Goel 1990). It is likely that the local boundary layer processes are driven by the large scale monsoon conditions. However, very little information is available on the activity of the boundary layer processes associated with deep moist, unsaturated and near dry processes within the monsoon trough, which is very important for the understanding and investigations of the monsoon dynamics.

Studies of the monsoon boundary layer in India were first undertaken through IIOE-64 during the sixties (1963-66) when inversion layers were observed within the large-scale low level monsoon current over the west and central Arabian Sea. Subsequently in national and international experiments, ISMEX-73 and MONEX-79, studies were conducted in the monsoon boundary layer over the ocean (maritime boundary layer) to understand the large scale air-sea interaction. No data could be collected on the processes within the boundary of the land-locked monsoon trough although lower tropospheric stratification is known to change considerably during different epochs of monsoon.

In pursuit of the problem to understand and investigate the monsoon boundary layer dynamics, a large multi-institutional DST sponsored project (Goel & Srivastava 1990) was carried out during the monsoon period of 1990 through a co-ordinated research programme called "Monsoon Trough Boundary Layer Experiment" abbreviated as MONTBLEX. As a part of the programme, four 30 m instrumented towers were set up at four locations, Kharagpur, Varanasi, Delhi and Jodhpur, covering largely the trough layer from the active eastern end to the western dry end.

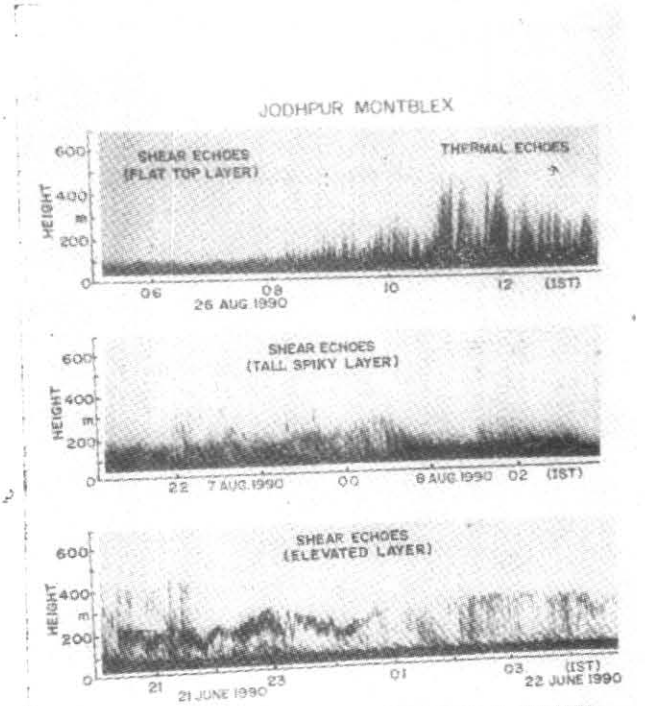


Fig. 1. Typical shear echo and thermal echo structures seen at Jodhpur

Two monostatic sodars, one each at Varanasi and Jodhpur, and a Doppler sodar at Kharagpur were also set up as a part of the programme. A few selected slow rising balloon flights, tethered sonde flights and aircraft flights were also made to supplement data from the upper air of the planetary boundary layer.

National Physical Laboratory (NPL) sodar group had participated in the above effort by setting up a monostatic sodar at Jodhpur, the extreme end of the monsoon trough. In the paper, preliminary results oriented to the studies of the monsoon boundary layer at Jodhpur with the help of sodar are presented.

2. Experimental site and investigational systems

Jodhpur (26°18′N, 73°04′E) is a dry zone in the Thar desert and is near the western limit of the monsoon trough. It is on the Aravali range and has a hill and valley terrain. Rainfall at Jodhpur is normally very low. During summer monsoon months, days are extremely hot and are followed by sudden nocturnal cooling.

Monostatic sodar system was set up in the plain grounds of the Central Arid Zone Research

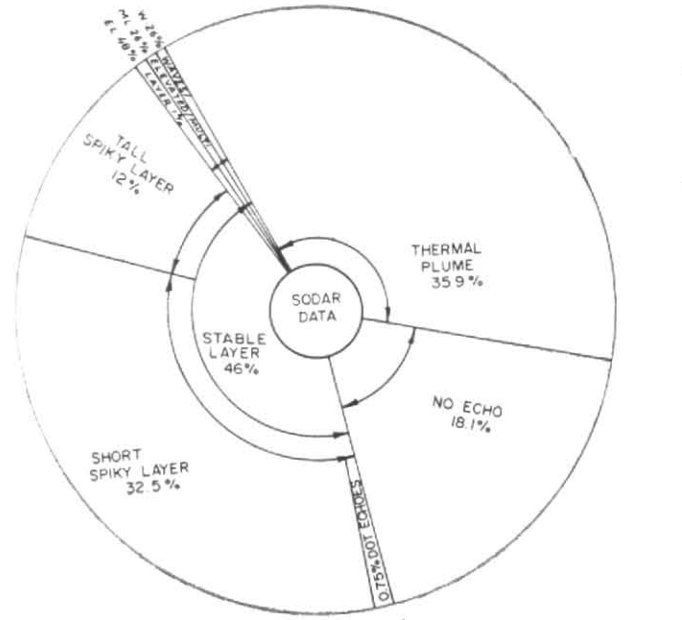


Fig. 2. Occurrence percentage of the various types of sodar echograms at Jodhpur

Institute located on the outskirts of the Jodhpur city. The 30 m instrumented tower was also located adjacent to the sodar antenna in the same ground. Sodar instrumentation and recorder were housed in the single-storeyed observatory building 100 m away from the sodar antenna. This building was also being used to house tower data acquisition and processing system.

The sodar was indigenously designed, developed and operated by the scientists of the National Physical Laboratory, New Delhi. In the system (Singal & Gera 1982), sound pulses of 80 millisecond duration after proper amplification were being sent vertically up in the atmosphere every four seconds and were being received by the same antenna after suffering reflections from the thermal inhomogeneities of the atmosphere. The received signal after proper amplification, filtering and detection was being displayed on a facsimile recorder. The operating frequency for the audio system was 2200 Hz and the system could probe a maximum height of 700 m.

3. Results and discussion

Data were collected round the clock for 1827 IST during the months of June to August 1990. These included the intensive observation period identified by Montblex Operational Control Centre (MOCC) on the basis of the review of the synoptic weather conditions.

Typical shear echo and thermal echo structures as shown in Fig. 1 were seen. Shear echoes were constituted of ground based layer structures (both flat top and tall spiky top), and multi/elevated layer structures, both with and without undulations superposed over them. Thermal echoes were constituted of vertically growing thermal plumes with broad to thin base. Shear echoes were seen for 46.0% of the time, thermal echoes were seen for 35.9% of the time while for the rest

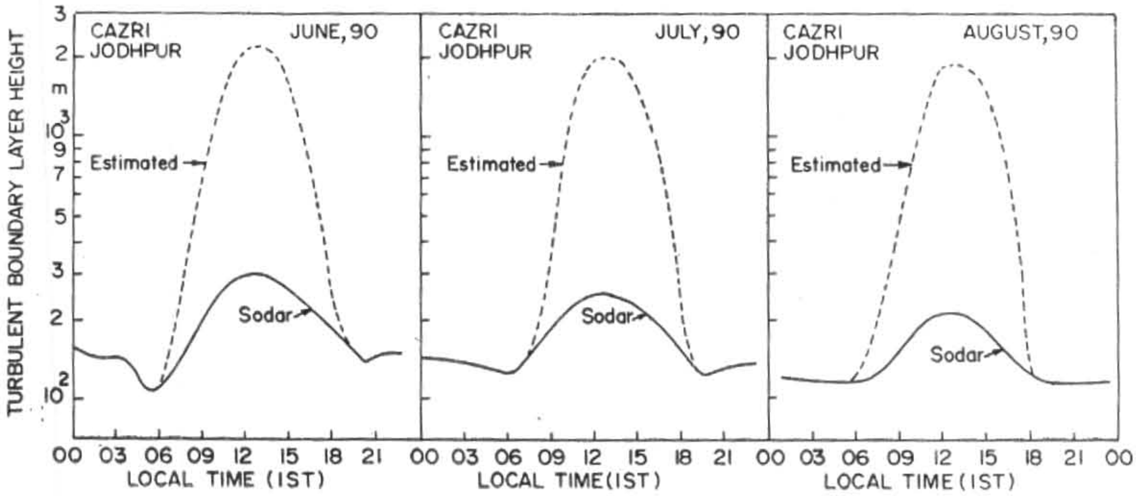


Fig. 3. Sodar observed and Holzworth model estimated height of the turbulent boundary layer at Jodhpur

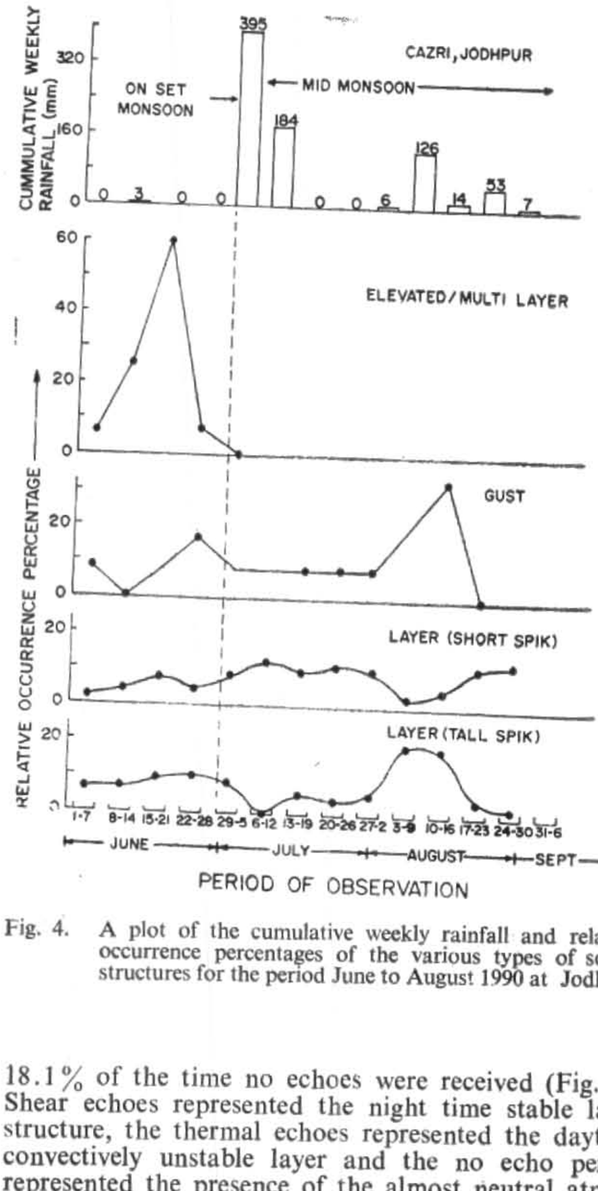


Fig. 4. A plot of the cumulative weekly rainfall and relative occurrence percentages of the various types of sodar structures for the period June to August 1990 at Jodhdur

18.1% of the time no echoes were received (Fig. 2). Shear echoes represented the night time stable layer structure, the thermal echoes represented the daytime convectively unstable layer and the no echo period represented the presence of the almost neutral atmosphere during the evening transition period. Shear echoes were further found to be constituted of flat or short spiky top ground based stable layer structures for 33.0% of the time, tall spiky top ground based layer structures for 12.0% of the time and elevated/multilayer structures (both oscillating and non-oscillating) for 1.0% of the time.

The ground based thermal plume structure started developing with the day break, with shorter plumes growing into taller plumes as the solar heating increased. A maximum in the height of the thermal echoes was achieved during 1200 to 1400 IST. Erosion of the morning inversion layer usually observed in the form of a rising layer above the growing thermal plumes, a usual phenomena at Delhi or at many other places, was not seen for the Jodhpur atmospheric boundary layer for any one of the days of observations. Another noteworthy observation was that elevated/multilayer structures were seen only under disturbed weather conditions.

It is well understood that acoustic scattering is due to turbulence in the lower atmosphere (Brown & Hall 1978) and thus sodar gives a measure of the height of the turbulent boundary layer close to the surface of the earth. Further, while the height of the nocturnal stable boundary layer is directly measured from the height of sodar shear echoes, the height of the daytime boundary layer can be estimated from an application of the Holzworth model using the empirical relationship (Singal *et al.* 1984) :

$$Y = 4.24\ X + 95$$

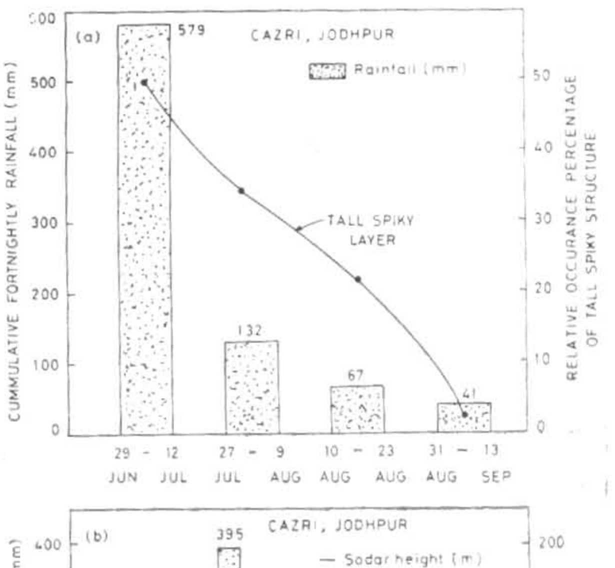
where, Y is the depth of the turbulent boundary layer as per Holzworth model and X is the height of the sodar obserted thermal plumes, both measured in metres.

Applying the above concepts, mean monthly diurnal variations of the turbulent boundary layer have been worked out and plotted as shown in Fig. 3. It can be seen from these plots for the three months of June, July and August 1990, that the maximum height of the nocturnal turbulent stable boundary layer is of the order of 150 m while that of the daytime, the maximum turbulent height is of the order of 2 km.

TABLE 1

Sodar structures during the intensive synoptic observation period

Intensive observation period	Days of deep depression	Time of observation of specific structures (IST)	Specific sodar observation (*) in addition to ground based layer			Remarks
			Elevated/multi layer/waves	Gust	Dot echoes	
14-15 Jun 1990	14 Jun	—	—	—	—	Depression remained far away from Jodhpur
	15 Jun	—	—	—	—	
15-17 Aug 1990	15 Aug	—	—	—	—	Depression progressed towards Jodhpur but started dissipation from Nagpur onwards
	16 Aug	—	—	—	—	
	17 Aug	1900	—	—	*	
	18 Aug	2000	—	—	*	
	19 Aug	—	—	—	—	
20-24 Aug 1990	20 Aug	1900	*	—	—	Depression progressed towards Jodhpur and reached relatively closer
	21 Aug	—	—	—	—	
	22 Aug	1900	—	*	—	
	23 Aug	1900	—	—	*	
	24 Aug	—	—	—	—	



Figs. 5(a&b). A plot of the cumulative: (a) fortnightly rainfall and relative occurrence of the tall spiky structures, and (b) weekly rainfall in relation to the depth of the turbulent stable boundary layer during the period June to August 1990 at Jodhpur

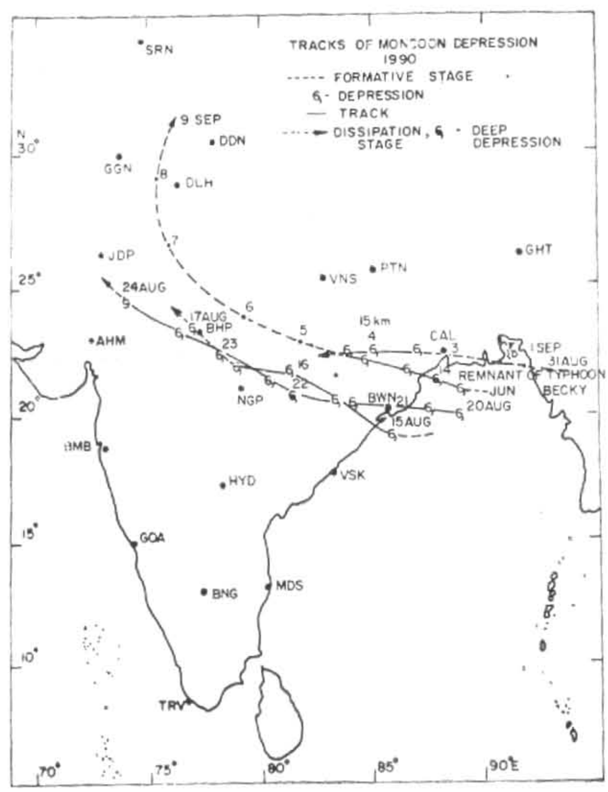


Fig 6. Track of monsoon depression 1990 predicted on the basis of intensive synoptic observations of the upper air

In an attempt to examine a correlation between the sodar structures and the monsoon characteristics, we have plotted the cumulative weekly rainfall and the relative occurrence precentages of the various types of sodar structures for the period June to August 1990 (Fig. 4). It may be seen that there is hardly any correlation with the sodar structures except that tall spiky structures show a tendency of increase in height before the onset of the week of heavy rainfall and a decline later on. It may be noted that tall spiky structure has been earlier shown (Singal *et al.* 1986) to be associated with strong surface winds and a monsoon depression is normally accompanied with such strong winds.

To examine further the correlation between the major rainfall spells and the occurrence of tall spiky structure and the depth of the turbulant boundary layer, we have plotted in Figs. 5 (a & b) the cumulative weekly/fortnightly rainfall spells in relation to the relative occurrence percentage of the tall spiky structure and the depth of the turbulent stable boundary layer (average). The plots clearly show the correlation of the amount of rainfall during a weekly/fortnightly spell with the extent of the occurrence of the tall spiky structure and the depth of the turbulent stable boundary layer.

Attempt has been further made to see if the tracks of monsoon depressions (Fig. 6) predicted on the basis of the intensive synoptic observations of the upper air are responsible for the development of certain specific sodar structures during the period of their presence at Jodhpur. The depressions originate from the Bay of Bengal and advance towards Jodhpur. From the listing of the various specific sodar structures (Table 1), other than the normal ground based shear echo structures, during the intensive synoptic observation period (days of monsoon depressions), it may be seen that dot echo structures occur on days when the monsoon depressions touch Jodhpur. Singal *et al.* (1985) have shown that dot echoes during monsoon period are associated with humidity and temperature. Also, depressions are considered to be linked with excess of moisture accompanied with strong winds. It would thus appear that dot echoes on sodar echograms may be used as an additional observation for an approaching depression. However, this would need to be validated with more observations.

4. Concluding remarks

The above studies indicate that sodar has been able to provide additional valuable information about the depth and nature of the thermal structure of the atmospheric boundary layer. These data cannot be obtained inexpensively in real time by using the conventional meteorological techniques. Further, it has been shown that some of the features of the sodar echograms can be used as indicators of monsoon characteristics.

The absence of the morning rising layer above the growing thermal echo structures shows that the noctunal radiational inversion layer is weak and at the same time is very shallow and gets eroded with the initial solar heating of the ground without showing any noticeable features on the sodar echograms. An analysis of the subsequent year 30 m tower data by Singh *et al.* (1992) does corroborate to this sodar observation. They have observed ground based inversion layer up to 10 m height only during monsoon period. Further, they have observed inversion layers to exist up to 30 m during winter period. The existence and behaviour of the inversion layers during winter period have yet to be studied by sodar.

Tower and other meteorological data collected for Jodhpur during the MONTBLEX campaign has not yet become available to the authors. A study of the various types of observed sodar structures *vis-a-vis* the meteorological data is proposed to be made very soon. Looking at the abundance of information available from sodar structures and the difference in terrain of Jodhpur compared to Delhi, it is also proposed to collect sodar data for one complete year.

It is also being felt that highly resolved boundary layer data within the lowest 100 m of the atmosphere may be useful to resolve the present sodar observations as also to understand better the atmospheric boundary layer at a place like Jodhpur. It is suggested that in the future experiments to be conducted at Jodhpur to understand the atmospheric boundary layer, Minisodar and Radio Acoustic Sounding (RAS) techniques may be used in addition to the conventional meteorological tools. These additional remote sensing devices will be able to give vertical thermal structure and profiles of temperature and wind velocity in the lowest 200 m of the atmosphere to understand better the atmospheric boundary layer at Jodhpur.

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