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Study on special ABL features observed over Tirupati using sodar

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A monostatic acoustic sounder (sodar) has been developed in the Department of Physics, Sri Venkateswara University, Tirupati, for the study of dynamical behaviour of the atmospheric boundary layer (ABL) phenomena over Tirupati. The infrasonic pressure variations have been recorded near sodar site using a microbarograph. Short-period waves/down-flow structures (rare phenomena) caused due to onset of drainage flow are reported. The short-period wave (fluctuations) is usually associated with either convective plume activity or ground-based inversions in the evening transition hours. It is inferred that these short-period waves are caused due to the onset of nocturnal drainage flows under convection/thermal inversion of variable depth.

1 Introduction

In acoustic sounding technique, recognition of a pattern or identification of the signature of the atmospheric phenomena is important[1-3]. Various types of atmospheric structures are observed on sodar echograms, which give complete information about the height, depth and period of existence of convection/inversions in the atmospheric boundary layer[4] (ABL). Apart from the usual ABL structures like thermal plumes and temperature inversions the sodar has revealed certain special features in the form of short-period waves (down-flow) phenomena, a rare feature observed over Tirupati valley. The localized inversions are common in a valley, as cold air mass gets collected near the ground. The salient feature of the temperature inversion is that the inversion inhibits vertical mixing which leads to the development of large atmospheric inhomogeneities including the accumulation of pollutants below and within the inversion[5].

In this paper, we study the generation of short-period waves and identification of meteorological processes that affect the down-flow phenomena. Discussion is made in the light of sodar facsimile recordings and pressure fluctuations obtained with microbarograph system. The rationale for this combination lies in the fact that the microbarograph provides moving snapshot of pressure/wind fluctuations, whereas the sodar, by contrast, yields indirect information with great temporal and spatial resolution. This indirect information includes definition of the location and thickness of turbulent layers and identification of the character of mixing processes, whether they are dominated by small-scale turbulence or large motions such as Kelvin-Helmholtz instability. We have structured our discussion of short-period waves following their diurnal evolution: first, their onset in the presence of opposing as well as aiding winds and, secondly, their evolution, as influenced by topography and ambient meteorology.

2 Site description and data base

Tirupati (lat. 13°40′ N; long. 79°27′ E) is located at the foot hills of the Tirupati range of Cuddapah formations in the Eastern Coastal plains at an elevation of 170 m above m.s.l. It is bounded by ridges to the north and to the south, and is thus in a valley. The sodar monitors the dynamics of the thermal structure of the lowest ABL right from ground up to an altitude of about 1 km. Simultaneous to sodar operation, the infrasonic pressure variations also have been recorded at Tirupati (10 m away from the sodar site) using a microbarograph operating in 0.001-2.0 Hz range.

The description of the sodar and microbarograph systems are given elsewhere[6]. The data taken for the present study refers to the period January 1988 - December 1988. These two complementary techniques, thus, form a comprehensive system to study the nature of down-flow structures most effectively.

3 Observations and interpretation of special ABL features

From the sodar observations it has been found that several types of temperature inversions exist in the lower atmosphere[7]. A ground-based inversion can be identified on the facsimile record as a continuous patch extending from the ground up to certain altitude. The most frequent ones are ground-based inversions, caused by the radiative cooling of the earth's surface at evenings/nights. The thickness of the ground-based inversions usually ranges from several tens of metres to within a few hundred metres from the surface[8].

Neff[9] described the interpretation of characteristic sodar echo patterns observed in drainage flows. Several researchers have dealt with drainage flow (from the sodar echoes) associated with jets[10], elevated inversions[11], and strongly sheared stable layers[12]. The onset of drainage flow occurs under different meteorological phenomena such as convection/thermal inversions, sea breeze effect and thunderstorms[13]. In this paper, the onset of drainage flow under convective/stable conditions has been discussed. Generally, the plumes disappear completely leaving a clear demarcation between the daytime convective conditions and the onset of nighttime structures (stable conditions)[14]. Most of the time it has been observed that the daytime convective structure does not dissipate completely but rather turns out slowly from convective to less convective and to a mixed structure, which takes the shape of a typical nighttime structure.

From the sodar structure it is observed that the short-period wave (down-flow) phenomena are found to start especially during evening transition hours (1600 to 1900 hrs IST) after a hot sunny morning. Usually the down-flow phenomena start from the ridge of the Tirumala hills (1170 m above m.s.l.) and exhibit an exponential decay-like phenomenon with time and finally merge with convection/thermal inversion[15]. This phenomenon persists usually for a period of 1 to 2 h. On a majority of the occasions the ABL structure at the lower end was found to be dissipating plume structures or ground-based inversions. Figure 1(a) shows phenomena associated with ground-based inversions (spiky top). From Fig.1 (b) it is seen that the down-flow phenomena appeared along with thermal plumes. On some days the structures were found to occur more than once in quick succession [Fig. 1(b)]. Figure 1 also shows the onset period of the drainage flow. Several features are evident from Fig. 1 [(a) and (b)]:

(i) Initially, in addition to the development of the ground-based inversion, the cool air slides down from the ridge of the valley due to the onset of drainage flow.

(ii) As the cool air slides down to a particular height where the air below also cools uniformly with height around 1800 hrs IST, the ground-based inversion becomes stronger below 200 m.

(iii) After an elevated inversion appears at 1900 hrs IST [Fig.1(a)], the stability of the air above the ground-based inversion continues

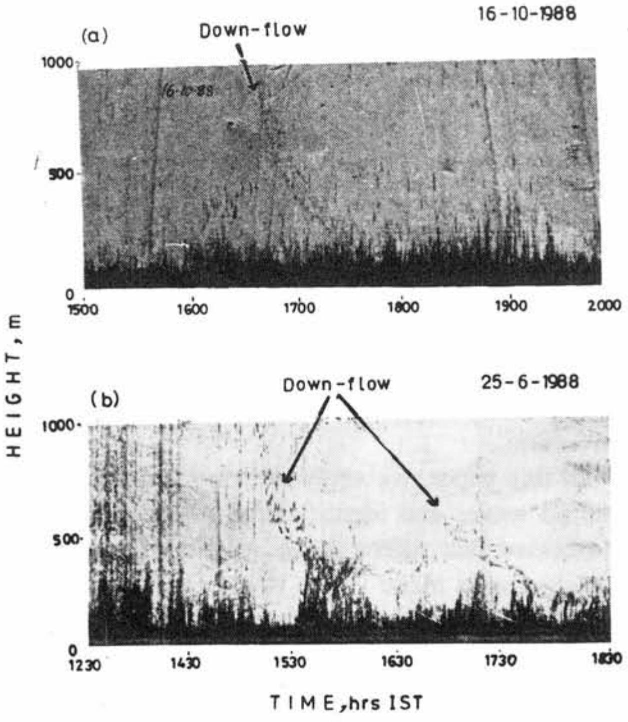

Fig. 1—Typical sodar echograms showing short-period wave fluctuations

to increase. Reasons for the increase in stability above the developed drainage flow may include subsidence and/or horizontal advection.

Monthly occurrence percentage of short-period (down-flow) phenomena observed from different sodar structures is shown in Fig.2. From Fig.2 it is observed that the down-flow occurs more frequently during monsoon followed by post-monsoon season as wind circulation pattern persists in the months of monsoon and post-monsoon seasons, which carries the down-flow to the sodar site.

3.1 Infrasonic pressure variations

Microbarograph can detect and measure small amplitude pressure fluctuations occurring with periods of a few seconds to several tens of minutes and have been used for years to detect the acoustic signals from explosions, severe weather, the aurora, and other neutral sources. The normal microbarograph record shows random variations due to infrasonic pressure fluctuations. The origin of these microbaroms (pressure variations of few microbars) has been explained as originating from interfering ocean waves in the marine storm areas[16]. Microbaroms, originating over the ocean can be received at distant ground-based stations after one or more upper-level reflections. If an adequate and continuous microbaroms source is present, short-interval variations in signal strength can be related to the variations in temperature or wind or both at the reflection level[17].

Short-period waves are characterized by variations in the wind speed, the atmospheric density and the atmospheric pressure. Therefore, besides the direct visual evidence for atmospheric waves that are afforded by the mountain wave clouds, it is possible to determine the existence of the waves by measuring the small changes in the atmospheric pressure produced during the passage of a short-period wave. This is done by using a microbarograph that is capable of measuring pressure changes of the order of a few microbars. Figure 3 illustrates simultaneously the observed surface wind variations and pressure fluctuations. Figure 3 shows a fairly good correlation between wind speeds and pressure fluctuations. Winds with larger speeds obviously resulted in comparatively large fluctuations of pressure. A high correlation between wind speeds and pressure fluctuations is observed up to 600 μ bar and the correlation co-efficient is found to be 0.8085.

3.2 Study of down-flow structures using sodar and microbarograph

In ABL, oscillatory motions are often observed in association with stable stratified layers[18]. Keliher[19] utilized microbarograph to detect many atmospheric phenomena, which can shed light on the wave motion mechanism in the lower atmosphere. Hauf *et al.*[20] utilized a ground-based

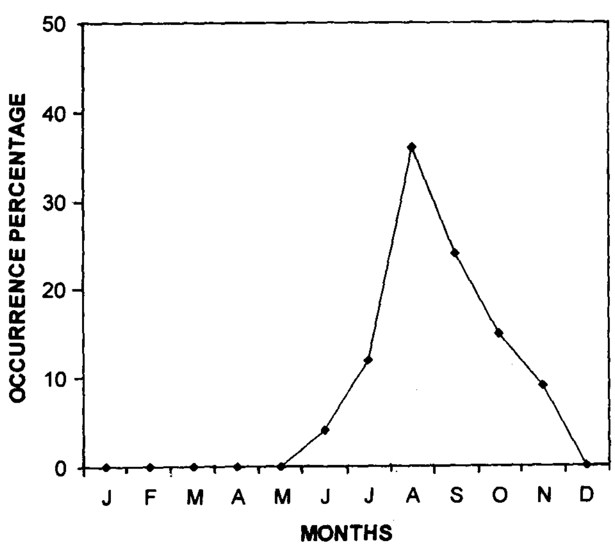

Fig. 2— Monthly occurrence of short-period (down-flow) phenomena

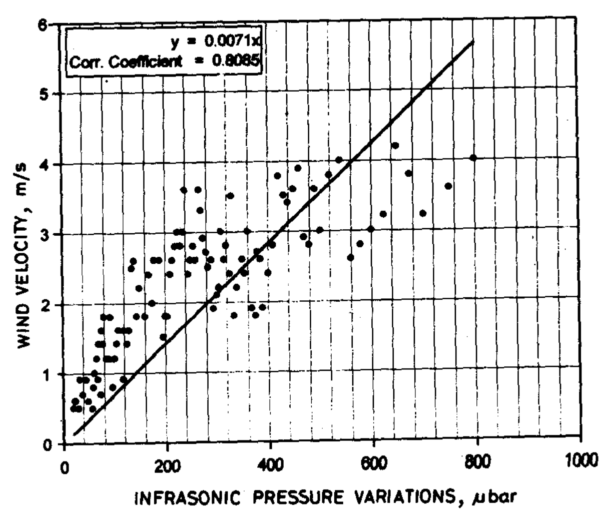

Fig. 3— Plot of pressure fluctuations versus surface wind velocity

network for atmospheric pressure fluctuations. They reported gravity waves, frontal passages, positive and negative solitary waves, and suggested that turbulent winds can be identified from the pressure signals.

An acoustic echo-sounder and microbarograph are deployed to study the short-period wave structures in ABL. Diurnal variation of the occurrence percentage of different structures and infrasonic pressure variations observed between 1400 and 2000 hrs IST are shown in Fig. 4. From Fig. 4 it is seen that the thermal plumes and ground-based inversions (both flat top and spiky) are mostly responsible for the pressure variations between 1630 and 1830 hrs IST. The short-period fluctuations may arise under convectively unstable atmospheric conditions.

Figures 5 and 6 illustrate the simultaneous microbarograph and sodar observations taken on 24 Aug. 1988 and 3 Nov. 1988. Sodar and microbarograph are able to detect the phenomena present when the boundary layer itself is convectively unstable. This can be seen in Fig. 5 during the evening of 24 Aug. 1988. Here, the sodar structures reveal that at low levels there is a great deal of convective plume activity. This plume activity manifests itself on the microbarograph records as pressure fluctuations (~ 250 μ bar) of rather low amplitudes with high wind speeds. Figure 6 shows the structures and the corresponding recording of infrasonic pressure variation observed on 3 Nov. 1988. The thermal plumes have subsided and the structure has started at about 1530 hrs IST. During this period the corresponding microbarograph recording has shown low pressure fluctuations of the order of 300 μ bar.

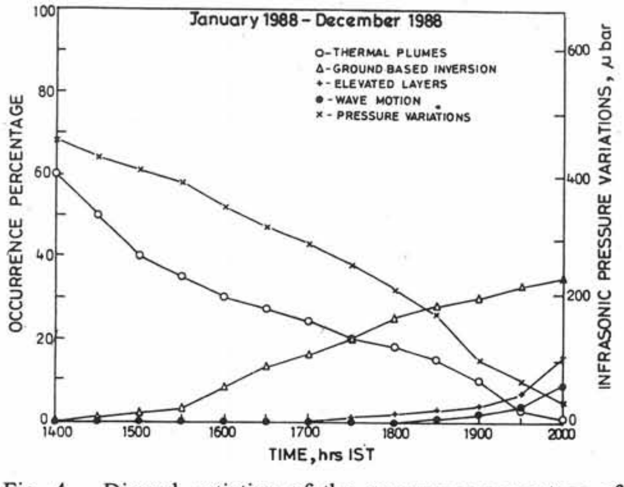

Fig. 4— Diurnal variation of the occurrence percentage of different structures and infrasonic pressure variations

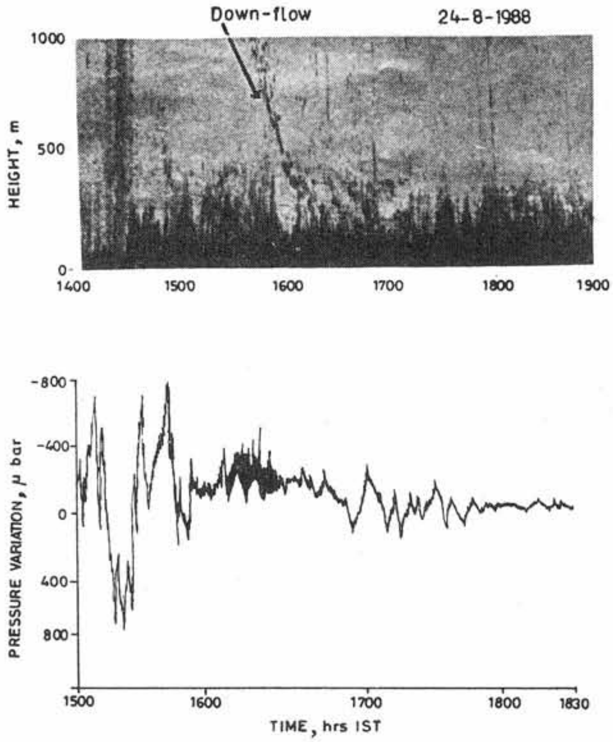

Fig. 5— Simultaneous observations of short-period wave fluctuations and microbarograph variations on 24 Aug. 1988

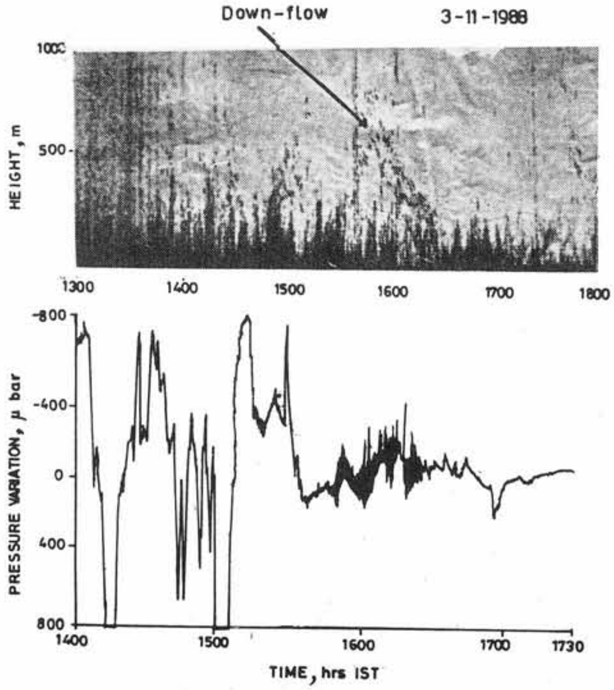

Fig. 6— Same as Fig.5, but for 3 Nov. 1988

The spectrum of periods measured by microbarograph ranges from 10^{-1} to 10^5 s. The high frequency, generally non-periodic noise, is due to turbulence, whereas the low frequency portion of the pressure spectrum is characterized by the semi-diurnal and diurnal tides. Convection and the influence of nearby weather system produce rather more irregular fluctuations with periodicities of 10 min to 1 h. The spectrum of waves observed on microbarograph records on 24 Aug. 1988 and 3 Nov. 1988 (1545 - 1645 hrs IST) was sorted into its frequency components and the results are displayed in Fig.7. In the analysis, waves with periods longer than 1 h are filtered out for the spectral plot. From Fig.7 waves with different periodicities can be observed. It gives some evidence for the onset of drainage flow activity.

Neff and King[21] described a method for the interpretation of acoustic echoes from turbulence in stably stratified flows using both monostatic and bistatic sodars and provided examples of characteristic echo patterns in complex terrain. We used similar method for identifying the meteorological phenomena which cause for the onset of the drainage flow (short-period waves). In Figs 5 and 6 we summarize the drainage flow characteristics from pressure/wind fluctuations and from the sodar echograms. These cases correspond to the weakest opposing flow and reveal a number of essential features of the onset and development of drainage flows. These features, as keyed to the figures, are:

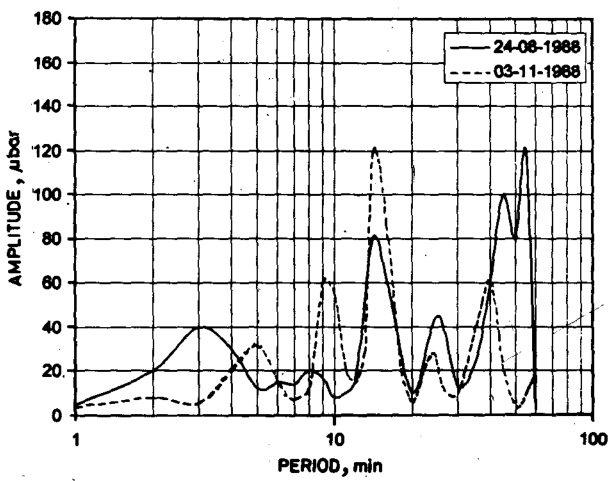

Fig. 7—Frequency spectrum estimation from the microbarograph data on 24 Aug. 1988 and 3 Nov. 1988

(i) On microbarograph records, a distinct characteristic feature is observed on both occasions at the time of drainage flow onset. Usually, microbarograph records show both positive and negative pressure fluctuations (with different amplitudes) associated with some atmospheric/weather phenomena. Whereas, at the time of onset of drainage flow the pressure fluctuations are observed on one (negative) side which gives some indications for the absence of opposing winds.

(ii) With the onset of surface cooling, at around 1600 hrs IST, a slightly stable boundary layer gets formed at the edge of the ridge in the down-slope flow.

(iii) At the same time the Archimedean forces increase sufficiently so that down-slope drainage slides down slowly through the valley.

(iv) During the initial development of the drainage, the depth of the ground-based inversion is very less than that of the drainage flow, presumably, because of the strong shearing and, hence, turbulent mixing between the drainage and the opposing winds.

From the above analysis, it is now presumed that the short-period (down-flow) phenomena are caused due to the onset of drainage flow from the ridge of the valley. However, the onset of drainage can occur at any height due to different atmospheric processes. We emphasize that the onset of drainage flow, at the ridge of the valley, is the main source of generation for short-period waves that are caused by the ascending and descending air currents.

4 Conclusions

The analysis in this paper has traced the onset of nocturnal drainage flows under convection/thermal inversion of variable depth. In elevated terrain and draining valley, the onset of drainage follows a systematic course: a stable boundary layer would first form in the down-slope flow followed by the initiation of drainage when Archimedean forces increased sufficiently. The analysis of the drainage emphasized the use of sodar echograms together with microbarograph. As already illustrated, the microbarograph is also capable of detecting many atmospheric phenomena, which can throw light on the short-period waves in the lower atmosphere. Nevertheless, it is encouraging to see that the sodar facsimile records and the microbarograph data appear to give a reasonably consistent picture of the boundary layer dynamics.

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