OBSERVATIONS OF CLEAR AIR TURBULENCE IN THE ATMOSPHERE

by

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ABSTRACT

The paper describes the chief features of the fan used in the Indian F-type radio-meteorograph and how it enables one to know from the radiosonde data whether the balloon is descending due to accumulation of snow or strong vertical currents. Instances when the balloon went up and down due to accumulation and melting of snow have been described. The decrease in the rate of ascent and even the descent of the balloon due to strong downward currents in a thunderstorm on the 26th April, 1950, have been estimated. The paper also shows how the F-type radiosonde data can be used to identify regions of clear air turbulence. The paper describes some observations of variation of turbulence associated with tropospheric inversions, in the upper troposphere and in the stratosphere.

Introduction

The problem of turbulence in free air has grown in recent years to be of great importance in aircraft operations and to aircraft engineers. Turbulence in clear air unrelated with thunderstorm conditions first came to be noticed with the introduction of routine high level flying, as bumpy regions about 50 miles wide, 2000 to 3000 ft. deep and extending for hundreds of miles. They are known to occur both above and below the tropopause and in low and high pressure regions, as often with large as with small horizontal wind, and seem to have no preference for any particular temperature gradient. An extract(1) from a description of turbulence encountered on the 21st September, 1950 near Ottawa will be of interest. "S/L O. C. Brown, flying Mustang aircraft 1951 was climbing to height in connection with certain tests. At 1600 hours EDST in clear air, he experienced turbulence. The turbulence commenced at 23,000 feet and was still present at 26,000 feet, the maximum height of this particular ascent. The maximum turbulence was experienced at 24,000 feet at which height an acceleration of 3g. (accelerometer type Kollsman) was recorded at an indicated air speed of 170 kt."

Though a satisfactory explanation for free air turbulence has yet to be found, it is generally assumed that turbulence is a result of the instability of laminar flow and a number of attempts has been made to determine the criteria for this transition. It has become the concern of the meteorologist to understand its causes and to forecast its occurrence.

Many countries are now co-operating on a gust research programme, for the development of turbulence indicators suitable for installation in aircraft with which quantitative measurements can be made, particularly in high altitudes. Meteorological services in various countries are also trying to develop turbulence measuring devices to be incorporated in routine radiosonde or radio/radar wind equipment. The effects of turbulence on a free hydrogen filled balloon will be to affect its rate of ascent, but since the gusts will be of short durations, they cannot be easily detected from the rate of ascent of the balloon, computed from the observations of pressure signals received from the radiosonde. The necessary accuracy is also not possible in pilot balloon observations for the detection of turbulent layers.

In the U.S.A., a parachuted telemetering instrument, called the gust-sonde has been developed for measuring free air turbulence[2]. This instrument consists of a small, very high frequency radio-transmitter with transducers for measuring pressure and vertical acceleration. A cantilever-vane accelerometer measures the acceleration within $\pm\frac{1}{2}$ gravity by causing an amplitude-modulated radio frequency to vary with the acceleration. The signal is transmitted at 148·95 mc to a ground recorder. The instrument is carried *aloft* to above 60,000 ft. and a record of the vertical accelerations experienced by the specially designed stable parachute carrying the gust-sonde, is begun after the balloon bursts and its fragments are discarded by a release mechanism. The data are recorded only in descent since the balloon is found to be too unstable to premit its response to be correlated with vertical velocity changes. The rate of fall of the gustsonde varies from about 40 ft. per sec. at 36,000 ft. to 22 ft. per sec. at 30,000 ft. to 13 ft. per sec. at sea level.

But this instrument appears to be too complicated for operational use. The present paper describes some of the special features of the F-type radiosonde of the India Meteorological Department[3] and its adoption as a simple device for the measurement of turbulence in the atmosphere. The results of observations utilising the above technique over India are compared with those obtained in U.S.A. with the gust-sonde[2].

Some special features of the F-type radiosonde

The F-type radiosonde (Fig. 1) of the India Meteorological Department works on the Bureau's principle and employs a simple paper fan to operate the switching mechanism during the ascent of the balloon, to telemeter the various meteorological elements to the ground. Similar fan driven switching mechanisms are employed in the Vaisala, U.S.S.R. and British radiosondes, but these fans operate on the principle of cup or vane anemometers and rotate both while the balloon ascends and descends and with horizontal winds. The fan of the F-type radiosonde on the other hand, rotates only when it is moved in the forward direction along the axis of rotation, i.e. , only when the balloon goes up or there is a vertical down draught on the fan when it comes down. Horizontal winds have little effect on the rotation of the fan (this was confirmed by tests in the wind tunnel) and since during flight the balloon moves horizontally with the wind the effect of horizontal winds is even less in actual flight. It thus becomes possible to ascertain directly from the record of the F-type radiosonde, whether the balloon is ascending or descending, and if descending whether it is forced down for example by a down draught or by accumulation of snow on the balloon. And from measurements of the rate of rotation of the fan it is also possible to detect regions of vertical currents or turbulence in the atmosphere.

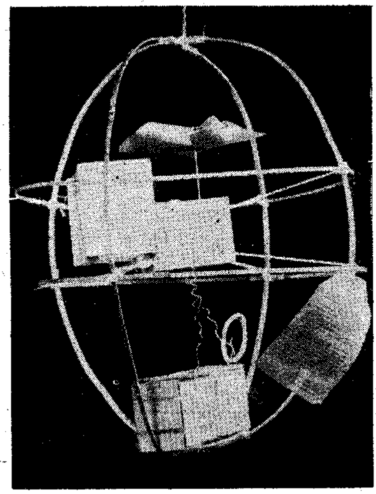


FIG 1.

If, during a radiosonde flight, the balloon develops a leak, the rate of ascent of the balloon will first decrease and later the balloon will descend. This will be reflected in the rate of rotation of the fan which will decrease first and later stop when the balloon begins to descend. If enough snow accumulates on the balloon, the balloon will also descend and the fan will stop rotating except that when the balloon has descended below the freezing level the accumulated snow will melt and the balloon will rise again and the fan will start working. Suryanarayana and Kachare[4] had occasion to observe this phenomenon on two days (6th October 1950 and 7th October 1950) at Poona, when F-type radiosonde ascents were made during rain. Fig. 2 shows the pressure and temperature distribution when the balloon descended due to accumulation of snow and later ascended when it melted. From an analysis of simple observations made at Poona and elsewhere, Kachare *et al*[5] have estimated the amount of water or snow deposited on the balloon, the levels at which snow deposits and melts etc.

If on the other hand, the balloon carrying an F-type radiosonde descends due to a strong downward current of air, the fan will rotate continuously and the rate of descent of the balloon due to this downward current can be estimated from the rate of increase of pressure and temperature. Venkiteshwaran and Tilakan[6] have analysed the movements of a radiosonde balloon in a thunder cloud at Poona on 26th April, 1950. During this ascent, the balloon was at first forced down due to strong downward currents and later due to the accumulation of snow. Fig. 3 gives the variation of pressure and temperature with time experienced by this radiosonde.

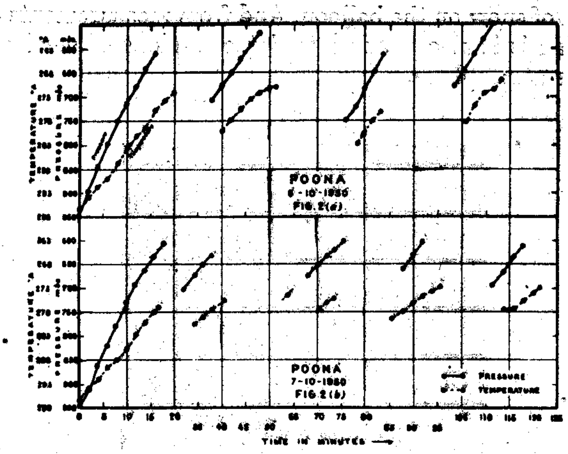


Fig 2.

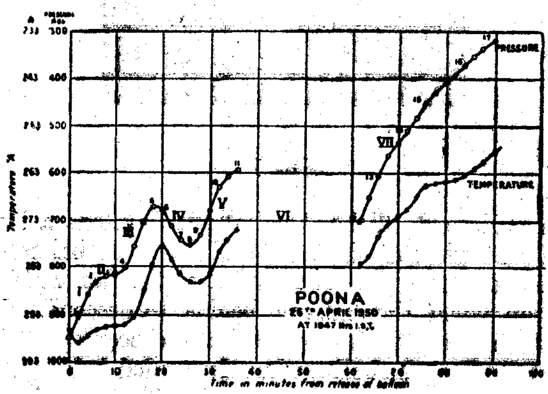


Fig 3.

The F-type radiosonde as a turbulence indicator

The paper fan in the F-type meteorograph is geared to a 10 tooth contact wheel which makes and breaks the H.T. of the radio singnaller about a thousand times during one cycle lasting about one minute. These signals or impulses are automatically recorded during the flight on a paper tape moving at a constant speed. The length of the paper tape for one complete cycle of about 1000 impulses is taken as a measure of the rate of rotation of the fan and will be constant if the rate of rotation is uniform. In actual practice it is, however, found that the length of the record for a cycle is not constant but varies. The length of the record will be less when the fan rotates faster since the cycle of signals is completed in a shorter time and *vice-versa*.

To test whether the changes in the rate of rotation of the fan are truly significant and represent actual conditions existing in the atmosphere, two radiosondes were released with the same balloon and the records compared. The test was repeated with two instruments attached to two different balloons but released simultaneously from the same place. The results of these flights are illustrated in Figs. 4(*a*) and (*b*). The great similarity in the records of the two sondes indicate that the variations in the rate of rotation of the fan are associated with conditions in the atmosphere.

It has also been generally observed that the rate of rotation of the fan decreases when the balloon enters thick layers of inversions or appreciably lower lapse rates. As the behaviour of hydrogen filled balloon can be considered to be similar to that of an ascending volume of a hot or lighter gas, it should naturally be expected to rise at a lower rate through regions of low lapse rates or inversions. The decrease in the rate of rotation of the fan when the balloon passes through such regions indicates the sensitivity of the fan to changes in the vertical motion of the balloon. Such variations are not normally observed by any other technique.

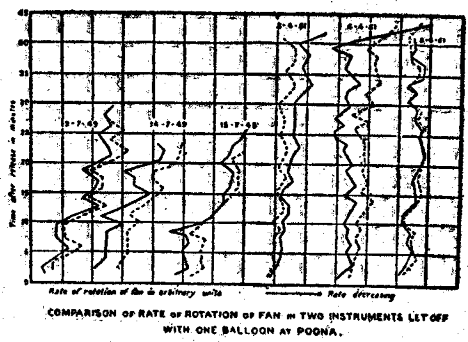


Fig 4(a)

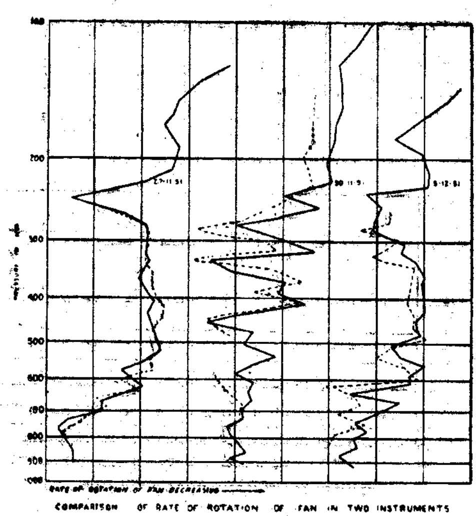
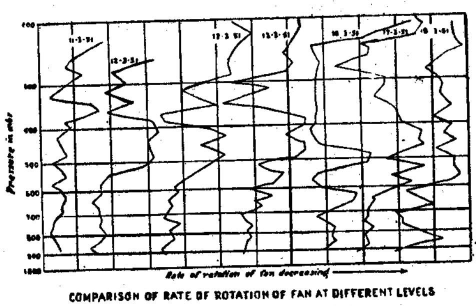


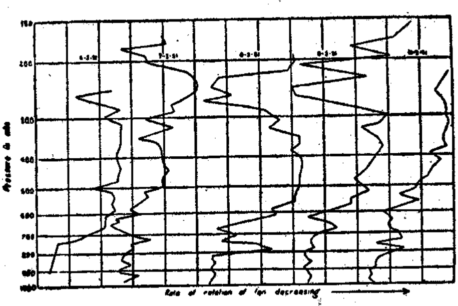
Fig 4(b)

Variation of turbulence with height and its persistence

Fig. 5(*a*) and 5(*b*) give a series of curves showing the variation of the rate of rotation of the fan at different levels at Poona (Lat. 18°32′N and Long. 73°51′E) from 11th March 1951 to 18th March, 1951 and over Trivandrum (Lat. 8°29′N, Long. 76°57′ E) from 6th to 10th March 1951. It will be observed from these that in some regions there were frequent and large increases in the rate of rotation of the fan. Its occurrence in a particular region, its persistence on a few days and absence later are significant. It seems from these diagrams that turbulence was a feature in March in this region of the atmosphere between about 400 and 250 mb. (*i.e.* between about 10–12 km.) at Trivandrum. There seems to be another region of turbulence over Trivandrum between 700—600 mb. (3–4·5 km.). Anderson(2) has also noticed with the gustsondes, a region of turbulence with its maximum at about 11 km. The type of persistence observed in the gustsonde ascents and their distribution with height over U.S.A. are similar to those observed with the F-type radiosonde over India. Fig. 5(*c*) shows the curves for both Poona (Lat. 18°32′ N, Long. 73°51′ E) and Nagpur (Lat. 21°09′ N; and Long. 79°07′ E) for the period 11-3-51 to 17-3-51. These ascents show a good degree of agreement in the turbulence distribution. Anderson(2) in working out the correlation between turbulence from the gustsonde and rawinsonde, is of the view that fairly persistent turbulence having horizontal dimensions averaging at least 10 to 20 miles can exist." The Poona-Nagpur data seem to reveal even a wider distribution.

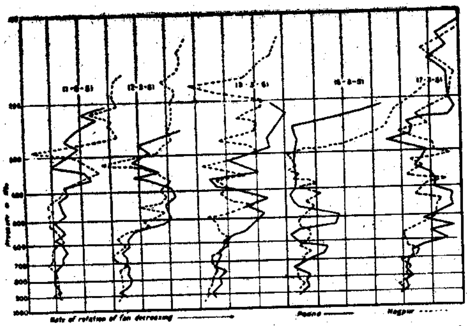


COMPARISON OF RATE OF ROTATION OF FAN AT DIFFERENT LEVELS ON A FEW CONSECUTIVE DAYS AT POONA



COMPARISON OF RATE OF ROTATION OF FAN AT DIFFERENT LEVELS ON A FEW CONSECUTIVE DAYS AT TRIVANDRUM.

Fig 5(a) and (b)



COMPARISON OF RATE OF ROTATION OF FAN IN RADIO SONDES RELEASED AT ABOUT 1500 HRS GMT AT POONA AND NAGPUR

Fig 5(c)

Turbulence at the base and top of tropospheric inversions

An examination of the performance of the fan in some sharp temperature changes in the atmosphere also showed certain interesting features[8]. Fig. (6) shows a few T-ϕ grams for Poona, with the corresponding values of the rate of rotation of the fan. It will be observed that sharp variations of temperature are associated with characteristic changes in the rate of rotation of the fan. In Fig. 6(*a*), there is a sharp rise in the rate of rotation , immediately above the inversion while in Fig. 6(*b*) and 6(*c*), the sharp increase is indicated in the layers immediately below the inversion, in Fig. 6(*b*), this feature is observed in the whole layer of temperature discontinuity. It is interesting to note that similar features have been noticed with gustsondes in U.S.A. in connection with the tropospheric inversions. Anderson(2) has found that regions above and below inversions are associated with above-normal-turbulence.

Turbulence in the upper troposphere over Poona

An examination of the fluctuations in the rate of rotation of the fan was made in the upper troposphere over Poona above the 10 km. level(9). In 1954, about 32 F-type radiosonde flights reached the tropopause and above. The maximum height reached by the balloon was 21 km. Seven out of these flights showed only small or no turbulence above 10 km. When turbulence was observed it was between 12—15 km. or between 15—17 km. and they were below the level of lowest temperature in the tropopause (Fig. 7(*a*) and 7(*b*)). When turbulence is observed in both the regions, they were generally separated by a distance of 2-3 km. The general depth of the regions of turbulence is only about 1 km. or less, though occasionally it has been 2 km. Their intensity is such as to cause the rate of rotation of the fan in the 12—17 km. region, to increase to values normal in the 6—7·5 km. layer. An examination of the gustsonde data by Anderson (2) at the base and top of the tropopause has not shown any strong correlation of the turbulence, though he believes that such a correlation exists. The turbulence maximum at about 11 km. is explained by him to be associated with the base of the jet stream at the primary tropopause over U.S.A.

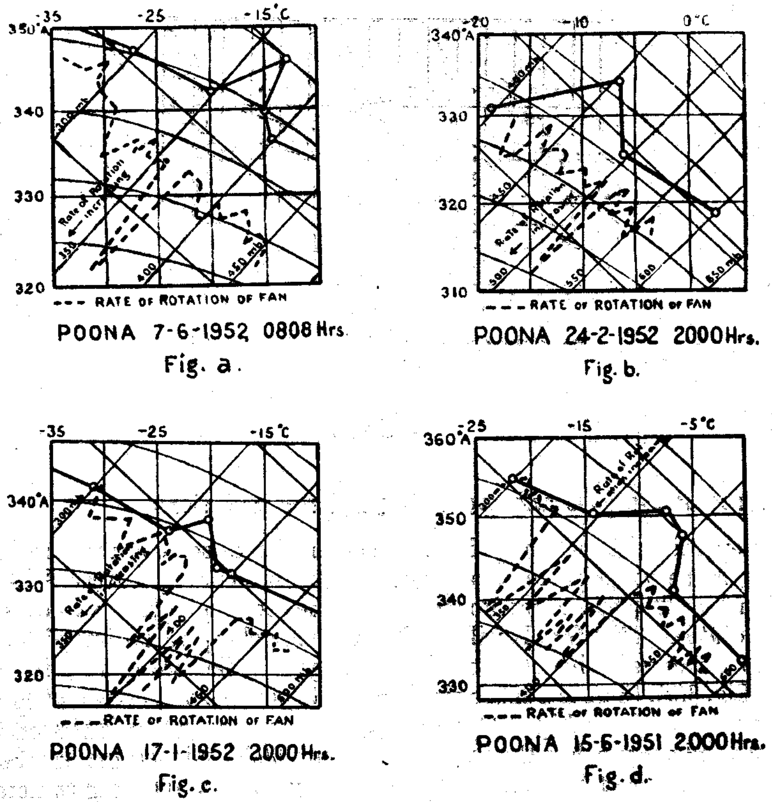


Fig 6

Turbulence in the Stratosphere

Turbulence has not been observed with the F-type radiosonde flights in the stratosphere, mainly because the balloons used were not able to penetrate to high levels. However, observations made by Arnold in U.S.A.[10] and analysis of Dines meteorograph ascents in India[11], [12] seem to show that turbulence may be met with even in the stratosphere in the region of about 23 kms.

Conclusions

The F-type radiosonde has certain peculiar characteristics, not found in other instruments, which make it the simplest instrument yet devised for the measurement of turbulence in free air. The general observations of turbulence with this instrument in India agree very well with those made with the gust-sonde in the U.S.A. indicating that the variations in the rate of rotation of the fan observed during radiosonde ascents, can reliably be attributed to vertical accelerations and therefore to the vertical gust velocities in the rough air affecting both the balloon and the instrument. Since the rate of rotation of the fan can be measured easily and since this is dependent only on the relative wind speed in the vertical, we have a simple technique for the detection, at least

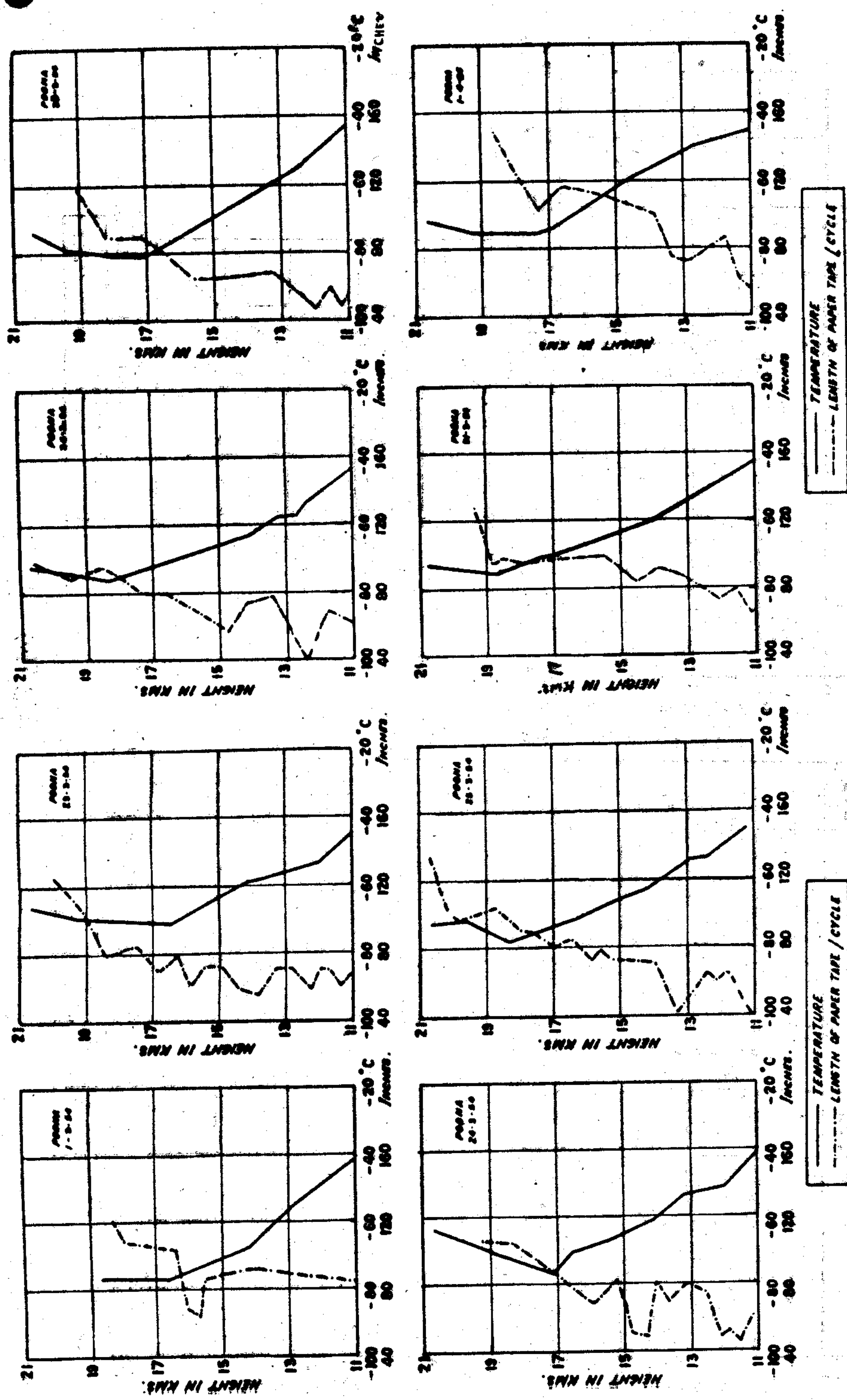

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Fig 7(a)

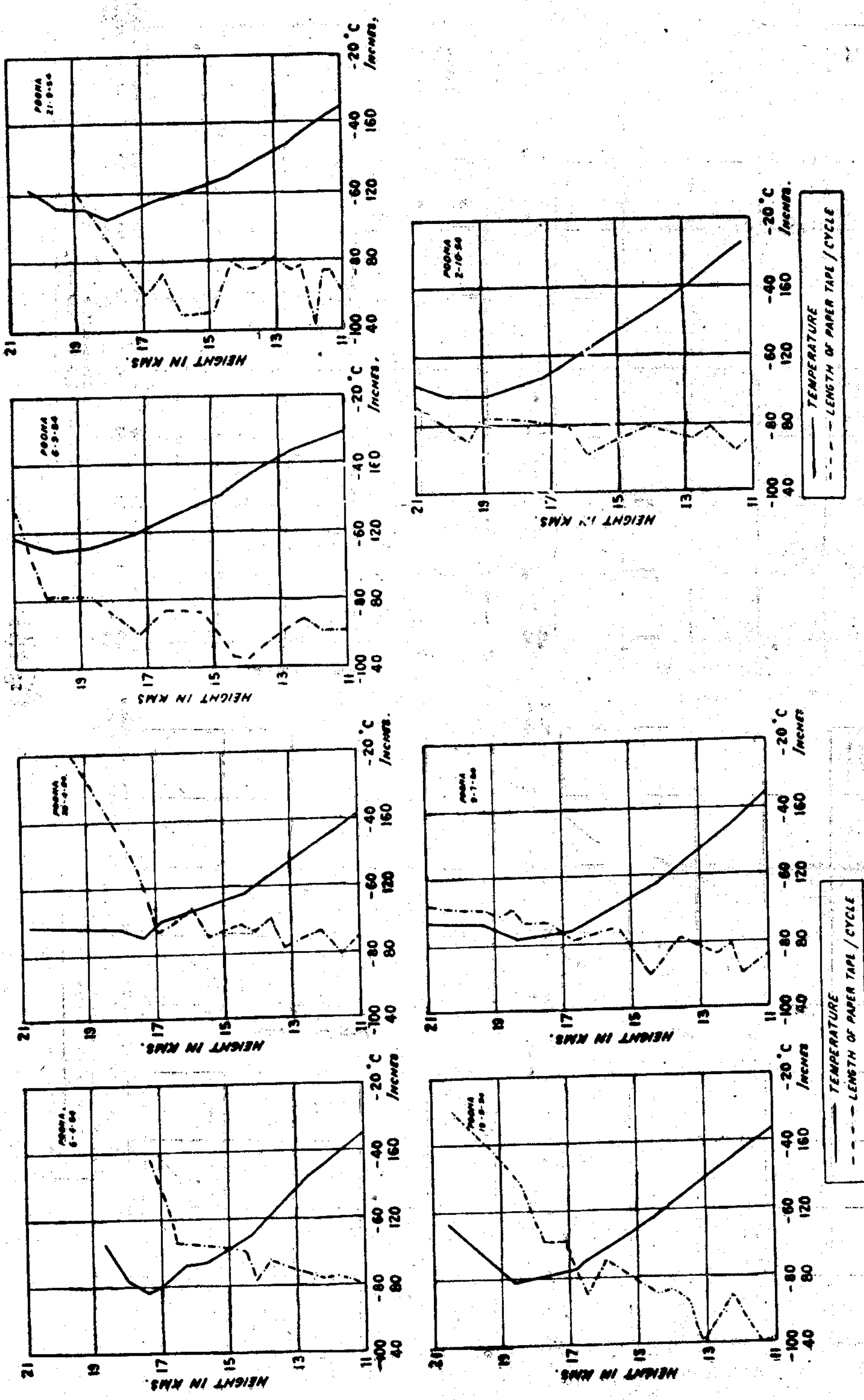
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Fig 7(b)

qualitatively, of the vertical acceleration due to turbulence. A statistical analysis of the observations for different levels in different seasons at the various stations, may be expected to throw more light on the regions of turbulence in the upper air over India.

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