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MOUNTAIN WAVES OVER WESTERN HIMALAYAS

The Western Himalayas and the lower ranges extend in a NW-SE direction from longitude 73 to 85 deg. E in the Himachal Pradesh and adjoining areas. A vertical profile of the mountain from Patiala in a SW-NE direction is shown in Fig. 1. In the winter season the air stream over NW India is predominantly stable and is suitable for the formation of wave perturbation provided the direction of the air flow has an appreciable component normal to the orography. In this case an air stream moving either northwestward, northward or northeastward (southeasterly, southerly or southwesterly winds) is the favoured direction for the formation of lee waves.

2. The radiosonde data for Patiala (30 deg. 20′ N; 76 deg. 28′ E) for the months December to March were examined for the years 1978—80. On the days when the wind direction in the lower and the middle troposphere (upto 6 km) or higher were either southerly, southeasterly or southwesterly the data was taken up for further examination. The stability parameter $f(z)$ and the Scorer parameter for various days were computed from this data.

3. From the wind direction and speed the component of wind along 225 deg. was determined as this is the direction normal to extension of the orography. From the vertical distribution of $U(z)$ and $T(z)$ following parameters were computed :

$$f(z) = \frac{g(\gamma^* - \gamma)}{U^2 T} - \frac{1}{U}\frac{d^2U}{dz^2} + \left\{\frac{\gamma^* - \gamma}{T} - \frac{g}{XRT}\right\}$$

$$\times \quad \frac{1}{U}\frac{dU}{dz} - \frac{2}{XRT}\left(\frac{dU}{dz}\right)^2 - \left(\frac{g - R\gamma}{2RT}\right)^2$$

$$l^2 = \frac{g\beta}{U^2} - \frac{1}{U}\frac{d^2U}{dz^2}$$

where U is the wind speed and T the temperature along the X direction which is perpendicular to the mountain barrier. γ is the actual lapse rate and γ^* is the dry adiabatic lapse rate, R=Universal gas constant

$$X = \frac{c_p}{c_v} = 1.4, \quad \beta = \frac{\gamma^* - \gamma}{T}$$

Cases favourable for the occurrence of the lee waves were selected by examining the Scorer's criteria for existence of lee waves :

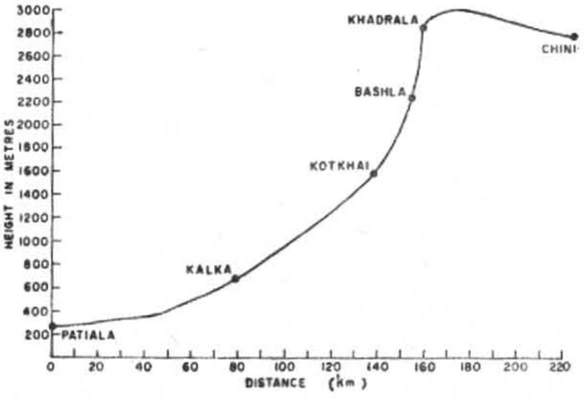

Fig. 1. A two-dimensional profile of Western Himalayas in SW-NE direction

TABLE 1

Date	Time (GMT)	Wave-length (km)	Average l_1^2	Average l_2^2	$l_1^2 - l_2^2$
7 Feb '78	00	9.0	2.72	0.210	2.510
9 Mar '78	12	8.5	3.57	0.760	2.810
10 Mar '78	12	12.0	2.06	0.490	1.570
15 Feb '79	00	11.8	1.39	0.607	0.783
16 Feb '79	00	6.8	5.965	0.021	5.934
5 Mar '79	12	15.7	0.922	0.330	0.592
8 Mar '79	12	9.0	3.181	1.214	1.967
27 Jan '80	12	10.9	6.593	0.177	6.326
29 Mar '80	Mean*	17.6	0.923	0.321	0.601

*Mean of 00 and 12 GMT, $\pi^2/4h^2 = 0.1543$

$$l_1^2 - l_2^2 > \pi^2 / 4h^2$$

where h is the depth of the lower layer and l_1^2 and l_2^2 are the values of l^2 in lower and upper layer respectively. In the present study the lower layer was taken from surface upto 4 km and the upper layer from 4 km to about 8 km. The values of l_1^2 and l_2^2 for such cases are tabulated in Table 1. In all these cases according to Scorer's criteria existence of lee waves can be predicted for next few hours if we assume that the air stream remains steady for such small period. From the vertical profile of wind and temperature for all these cases $f(z)$ values were numerically computed at the interval of 0.25 km. A typical case for occurrence of lee waves, its wind, temperature, $f(z)$ profile and the synoptic charts are given in Figs. 2 & 3.

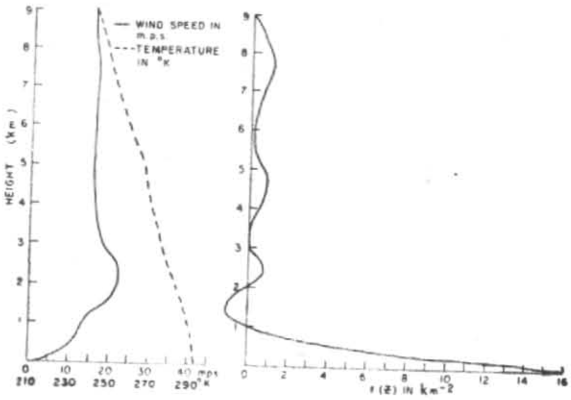

Fig. 2. Vertical profile of wind, temperature and $f(z)$ on 15 February 1979 (1200 GMT)

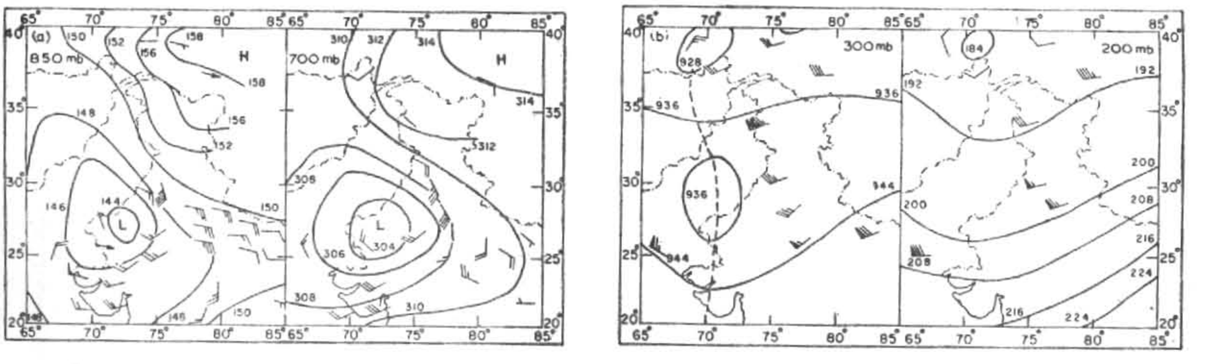

Fig. 3. Upper air charts of 15 February 1979 (1200 GMT)

The wavelengths for all these occasions were obtained by a numerical procedure similar to that of Sarker (1967) and De (1971). The wavelengths were found to vary between 7 and 18 km. Unfortunately, we do not have a long series of radiosonde observations over Patiala which is the nearest station on the upwind side, to obtain more favourable cases of lee wave existence.

On examining the daily weather chart for all the days when mountain waves were theoretically found, it was observed that in all cases there was either a low pressure area and associated cyclonic circulation in the lower troposphere (surface to 700 mb) west of Patiala and a deep trough in mid-upper troposphere (500-200 mb) is clearly detected. These synoptic situations sustain an air flow with a major wind component perpendicular to the barrier from surface to more than 10 km.

The frequency of location of westerly troughs between 25 & 45 deg. N during winter is found to be maximum between the longitudes 65 & 75 deg. E. "This maximum is due to slowing down of the trough in this area or/as well as formation of new trough" (Alexander and Srinivasan 1974). As our area is situated between 73 and 80 deg. E, it is, therefore, a favourable location for the occurrence of mountain waves during the winter season. We do not have any direct observation of lee waves from this area but aircraft flying over this terrain somtimes experience turbulence even when there is no *Cb* clouds.

4.1. The air-stream in the winter months have the required static stability and vertical wind shear to give rise to mountain wave in northwest India.

4.2. The observed wave lengths of the mountain waves were found to vary between 7 and 18 km approximately.

5. The authors are thankful to Deputy Director Generals of Meteorology (Climatology & Geophysics) and (Weather Forecasting) for providing the facilities to carry out the studies and use of NDC Computer for numerical computations.

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