

Mountain waves over Himalayas

SQN. LDR. AJIT TYAGI and WG. CDR. O. P. MADAN

Directorate of Meteorology, Air HQ, New Delhi

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सार — यह शोधपत्र पश्चिमी और मध्य हिमालय पर पर्वतीय तरंगों के प्रेक्षणात्मक प्रमाण का दस्तावेज है। प्रस्तुत मामलों की प्रेक्षित तरंग की लम्बाई में 13 कि. मी. से 22 कि. मी. तक बदलती पाई गई है। तिब्बत पठार पर, जो कि तरंग घटना का उच्चतम आवृत्ति वाला प्रदेश भी है, पश्चिमी और मध्य हिमालय के प्रतिपवन (ली) में सर्वाधिक स्पष्ट और सुसंगठित पर्वतीय तरंगों प्रेक्षित की गई हैं। पर्वतीय तरंगों के साथ संबंधित माध्य स्थायित्व पाश्चिका (प्रोफाइल) विकसित की गई है और यह ऊंचाई पर कम स्थायित्व वाली और 5-9 कि. मी. की परत में उच्च स्थायित्व दर्शाती है।

ABSTRACT. This paper documents the observational evidence of mountain waves over western and central Himalayas. The observed wave length of the cases presented varies from 13 km to 22 km. The most marked and well organised mountain waves are observed to the lee of western and central Himalayas over Tibet plateau, which is also the region of highest frequency of wave occurrence. Mean stability profile associated with mountain waves has been developed and it shows high stability in the layer 5-9 km with less stability aloft.

1. Introduction

Air flow over mountain ranges under favourable conditions of thermal stability and wind profile leads to the formation of mountain waves. Mountain waves are considered hazardous to aviation because of associated vertical currents, turbulence and icing. In India, Sarker (1965) studied the occurrence of mountain waves on the lee of Western Ghats theoretically and showed that the air stream of winter season has the favourable stable stratification for producing mountain waves on the lee of Western Ghats provided the wind is westerly. De (1970, 1971) investigated the presence of mountain waves over the Assam and Burma hills with the help of satellite pictures. Wave length as observed from the satellite photographs vary from 17 km to 34 km and are in good agreement with the theoretically computed wavelengths. Sinha Ray and De (1982) carried out theoretically studies of mountain waves over western Himalayas.

This paper documents the mountain waves over western and central Himalayas as observed in satellite pictures during monsoon season and discusses the atmospheric and synoptic conditions favourable for their occurrence.

2. Topography

The term western and central Himalayas in this study mainly covers Great Himalayan range over Jammu & Kashmir, Himachal Pradesh and Uttar Pradesh up to 85°E. Karakoram range being higher than Himalayan ranges in Jammu & Kashmir is also included in the study. There are series of mountain ranges aligned northwest to southeast practically one behind the other covering the entire region.

The average elevation of Great Himalayas is between 5 km and 7 km. Important peaks in this region are

Nanga Parbat (8472 m), Dhaulagiri (8172 m), Annapurna (8018 m) and Nanda Devi (7817 m). To the lee of Great Himalayas lies Tibet plateau at an elevation of 4 km to 5 km. The two dimensional profile of western Himalayas as viewed from Punjab is shown in Fig. 1.

3. Data used

The satellite cloud pictures from polar orbiting satellites from January 1981 to July 1984 were analysed for the study. AVHRR pictures of 1983 were also made use of in the study. Available radiosonde data of Srinagar, Patiala, Delhi and Lucknow were used to study the atmospheric conditions. The normal radiosonde and upper wind data was taken from normals of climatic temperature published by India Meteorological Department (India Met. Dep.) and *Meteorological Atlas of the IIOE Expedition*, Volume 2. The cases selected for the study are only those where mountain waves were clearly identifiable and minimum of 5 wave bands were present.

4. Observational aspect

The date, time, latitude and longitude in the place of the occurrence of the mountain waves and their observed wavelength are shown in Table 1.

Broadly, the regions of occurrence can be grouped into following geographical regions :

- | | |
|--|---------------------------|
| (a) Region A : Lee of Pir Punjab, Zansakar and Ladakh ranges over Kashmir, Ladakh and adjoining Tibetan region | 33°-36°N,
72°-84°E |
| (b) Region B : Lee of Karakoram range | 35°-39°N,
East of 76°E |

TABLE 1

Date, time & location of mountain waves & their observed wavelengths

Date	Time (IST)	Wave length (km)	Area of occurrence	Region			
				A	B	C	D
22 Aug '81	1440	15-18.0	33-35°N, 75-81°E	A	—	C	—
25 Sep '81	1145	17.6	31-35°N	—	—	C	—
26 Sep '81	0855	19-21	31-34°N, 78-84°E	A	—	C	—
30 Sep '81	1100	15.5	30-33.5°N, 80-85°E	—	—	C	D
30 Sep '81	1315	18.5	29-33°N, 80-88°E	—	—	C	D
24 Aug '82	1457	13-16.5	33-37°N, 76-80°E	A	B	—	—
25 Aug '82	1445	16.5-19.5	33-35°N, 76-80°E 31-35°N, 78-85°E	A	B	C	—
26 Aug '82	1435	15.8	34-35°N, 77-79°E 32.5-34°N, 78-81°E	A	—	—	—
27 Aug '82	1425	16.5	30-35°N, 80-86°E	—	—	C	D
28 Aug '82	1410	15	33-36°N, 84-87°E 30-32°N, 81-84°E	—	—	C	D
29 Aug '82	1356	16.4	33-35°N, 77-83°E 30-32°N, 81-84°E	—	—	—	D
06 Jul '83	0845	16.32	29-34°N, 80-86°E	—	—	C	D
07 Jul '83	0810	13.0	30°N, 83-85°E	—	—	—	D
11 Jul '83	0800	14.0	30-35°N, 80-84°E	—	—	C	D
11 Jul '83	1357	17.6	31-33°N, 81-84°E	—	—	—	D
18 Sep '83	1504	18.0	33.5-30.5°N, 78-82°E	A	—	—	—
24 Sep '83	0817	20.5	30-34°N, 77-75°E	A	—	C	D
24 Sep '83	1530	20.6	35-37°N, 73-75°E	A	—	C	D
25 Sep '83	0800	16.3	30-35°N, 73-98°E	—	—	C	D
12 Jul '84	1605	21-25	37-35°N, 79-88°E	—	B	—	—
17 Jul '84	0800	22.9	37-38°N, 79-85°E	—	B	—	—
18 Jul '84	1630	22.2	35°N, 81-85°E	A	B	—	—

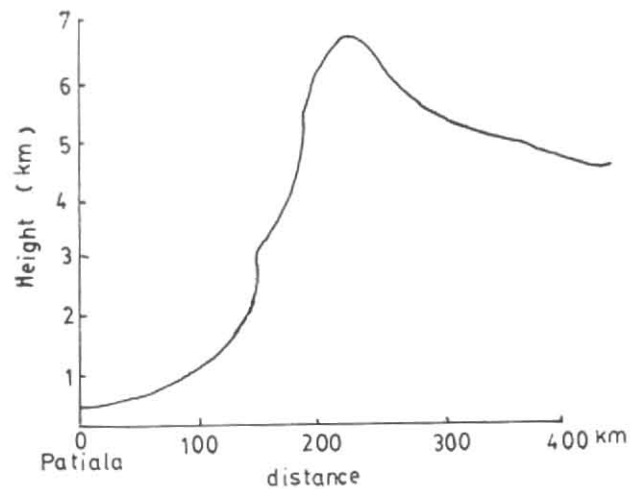


Fig. 1. A two dimensional profile of western Himalayas in southwest-northeast direction from Punjab plains

(c) *Region C* : Lee of western Himalayas Himachal and adjoining west Uttar Pradesh hills over Tibet plateau 30°-34°N, East of 76°E

(d) *Region D* : Lee of central Himalayas (Uttar Pradesh & adjoining Nepal hills) over Tibet plateau 27°-31°N, East of 79°E

All the 22 cases of mountain waves fall in the monsoon season. Not a single case was observed during winter season which is generally considered to have favourable flow pattern to cause mountain waves over western Himalayas. The close scrutiny of AVHRR pictures of 1983, which have resolution of 1.1 km have also confirmed the absence of satellite observed mountain waves over western and central Himalayas during winter season.

Downstream increase of wavelength was observed in four cases (22 Aug 1981, 26 Sep 1981, 24 Aug 1982, 27 Aug 1982). The increase of wavelength was found to be between 2 and 4 km. In two cases latitudinal variation of wavelength over Regions C and D was 14.0 km whereas to the north over Region A was 20.5 km.

5. Atmospheric conditions

5.1. Static stability

The vertical profiles of static stability for all the cases were analysed. The prominent common feature of these profiles is the increase of static stability from the lower to middle troposphere, peaking between 500 mb and 400 mb and decreasing aloft up to 200 mb followed by increase once again. The average height of the layer of marked stability of 6 to 9 km coincides with the average height of Himalayan peaks and decrease of stability aloft meets the conditions for the development of mountain waves. Satellite pictures of mountain waves over different regions are shown in Figs. 2-5. Corresponding stability profiles derived from temp. data of Srinagar, Patiala, Delhi and Lucknow pertaining to respective cases are presented in Figs. 6(a-d). A mean static stability profile derived from these all 22 cases is given in Fig. 7. It is

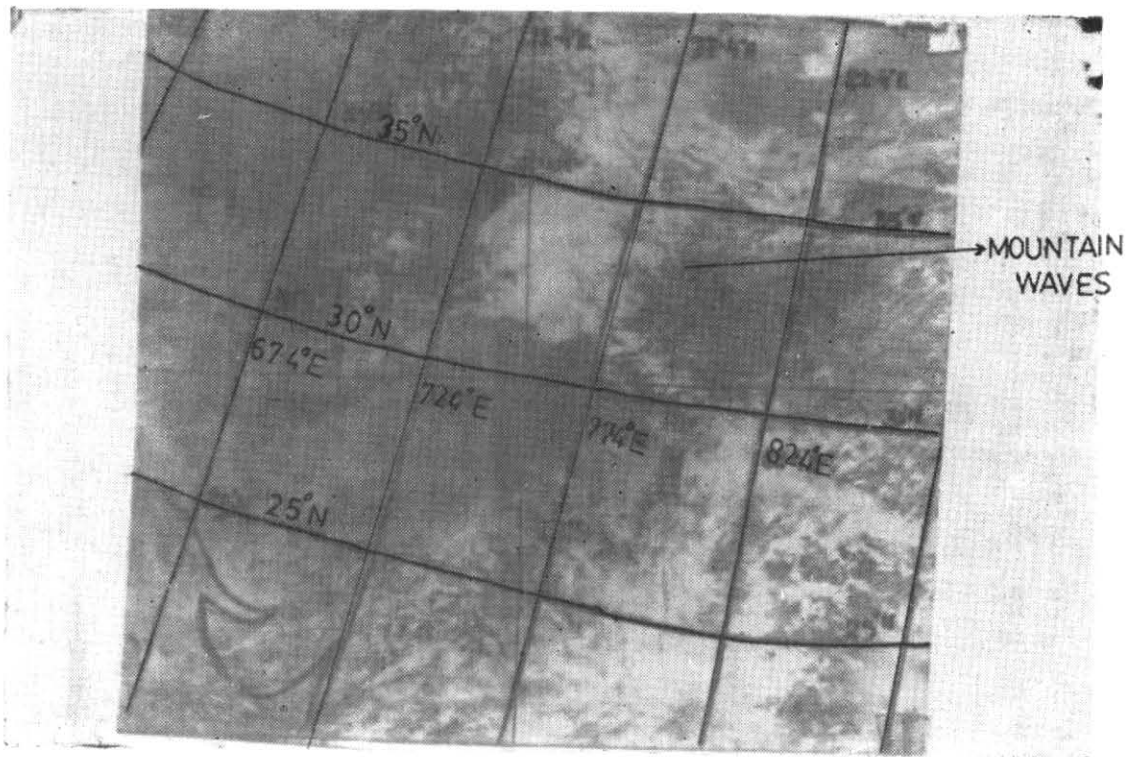


Fig. 2. Mountain waves over Region A

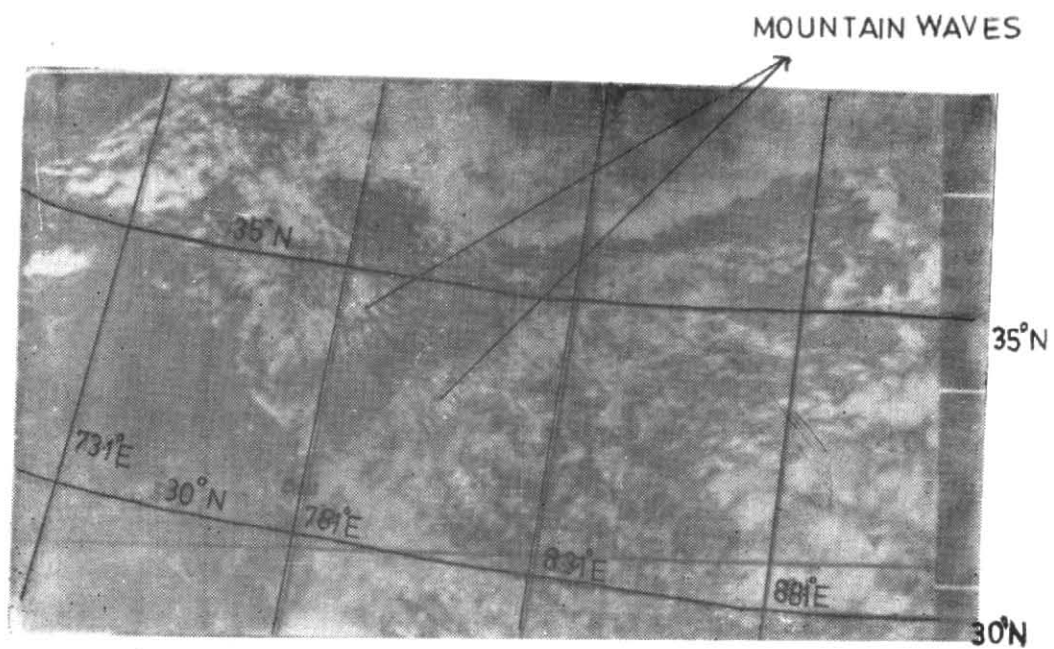


Fig. 3. Mountain waves over Region B

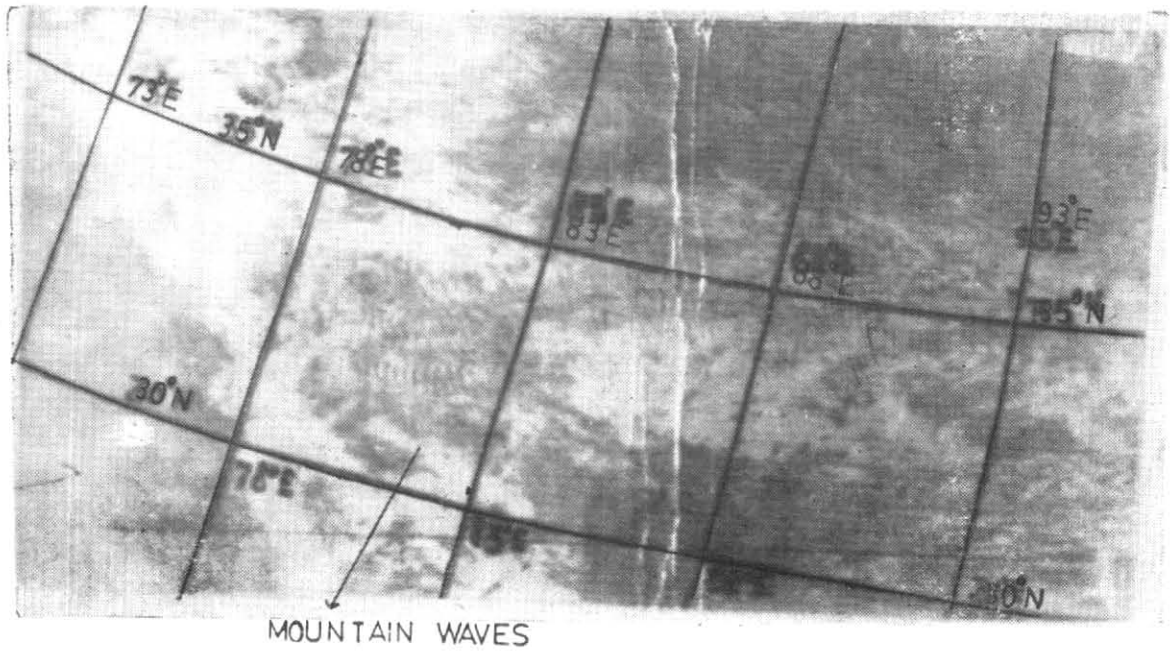


Fig. 4. Mountain waves over Region C

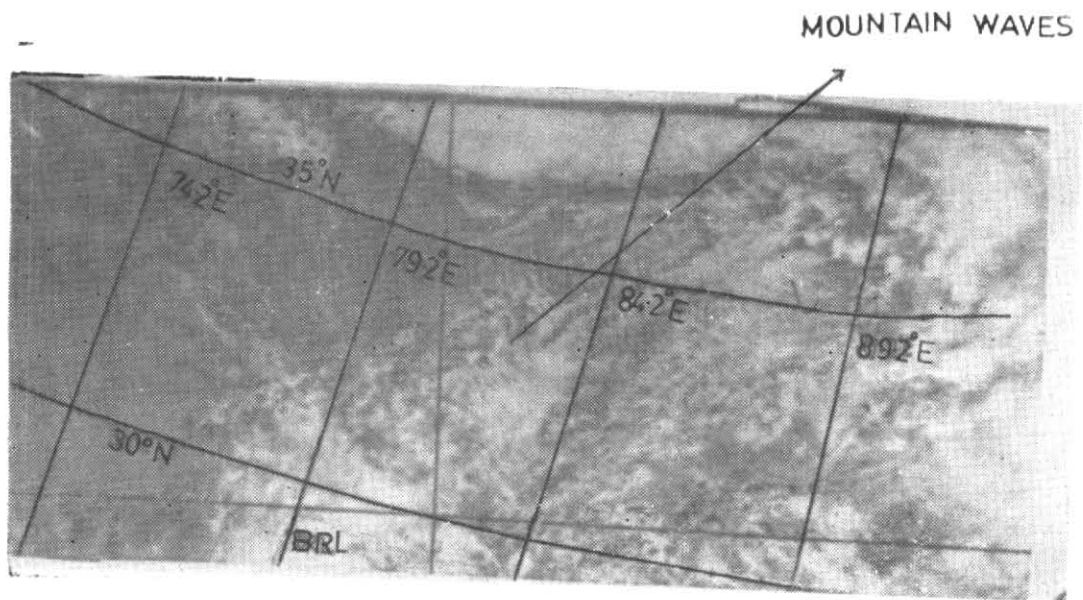
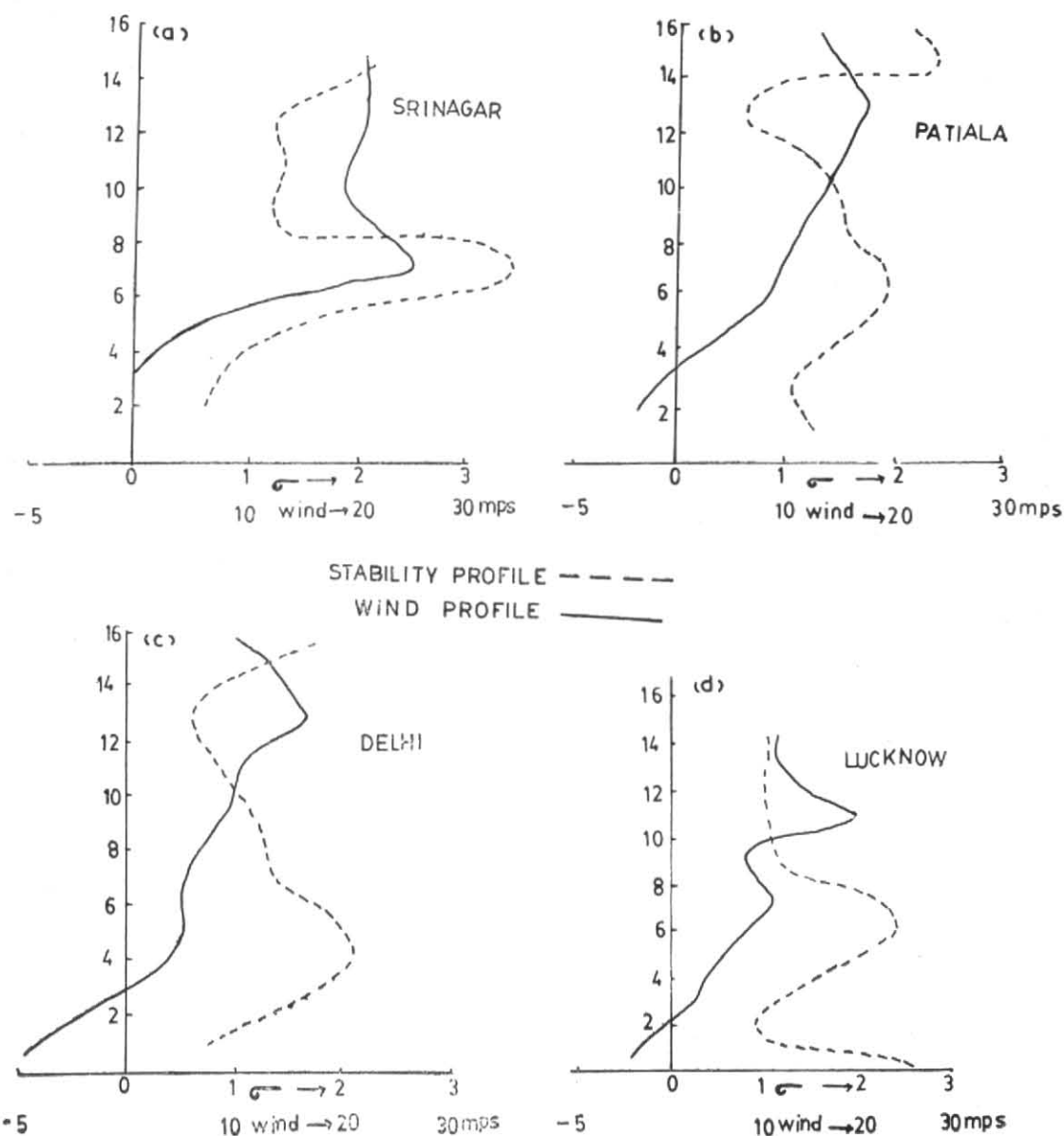


Fig. 5. Mountain waves over Region D



Figs. 6 (a-d). Wind and stability profile associated with mountain waves over (a) Region A based on Srinagar sounding of 18 Sep 1983 at 1200 GMT, (b) Region B based on Patiala sounding of 25 Aug 1982 at 1200 GMT, (c) Region C based on Delhi sounding of 30 Sep 1981, 00 GMT and (d) Region D based on Lucknow sounding of 27 Aug 1982, 1200 GMT

interesting to state that this profile is in conformity with the finding of Sierra wave project.

5.2. Wind profile

Although normal flow pattern of July and August does not provide favourable conditions for the wave development, it is observed that on a number of occasions when westerly trough moves across 30° - 35° N, belt of westerlies extends southwards. Vertical profiles of wind component perpendicular to the mountain, for all cases of mountain wave occurrences were analysed. Mean wind profile is given in Fig. 7. Southwest wind component is taken as positive. It is noticed that light

variable or northeasterly wind of 3 to 5 mps is observed up to 3.0 km. Southwesterly component of 5 to 8 mps at 5 km, which increases to 10 mps at 9 km and is of the order of 15-20 mps in the layer between 10 and 12 km.

Analysis of synoptic situations associated with the cases of mountain wave occurrence bring out that the approach development of westerly trough in the middle and upper troposphere and southward shift of Tibetan anticyclone gives rise to southwesterly flow over western and central Himalayas in the middle and upper troposphere and provides favourable wind condition for the development of mountain waves. Favourable location of westerly

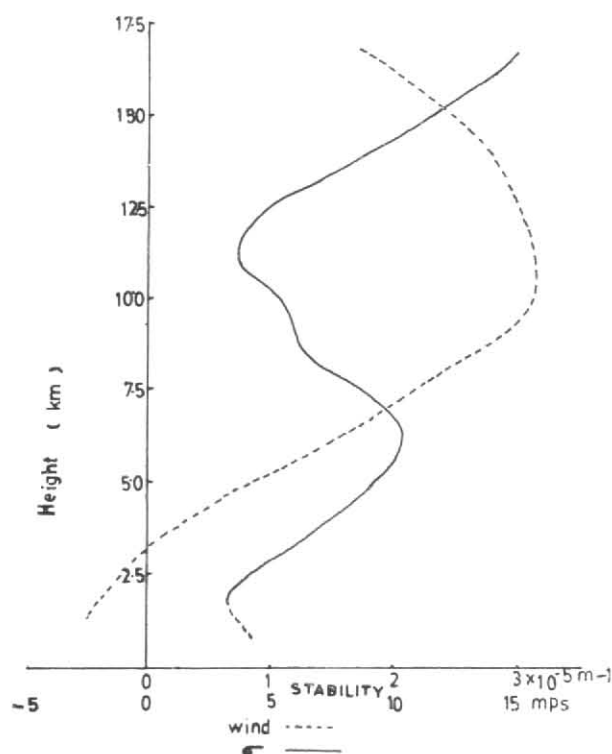


Fig. 7. Mean stability and wind profiles associated with mountain wave occurrence over Himalayas

trough for mountain wave in Regions A and B is between 65°E and 75°E , for Region C between 70° and 77°E and the trough should extend southwards up to 30°N . Region D responds to trough lying between 72° and 79°E and extending up to 27°N .

6. Relationship between the location of jet stream and the region of mountain wave occurrence

It is observed that mountain waves occur over western and central Himalayas during monsoon season when the jet stream is located to the north of Himalayas along 38° - 40°N . Mountain waves occur over Assam and Burma hills between November and April when the subtropical jet lies between 26°N and 33°N . The findings of Seirra wave project about the location of jet stream is in conformity with the present observations. During winter season, since the subtropical jet stream is along 27°N over Indian region, the entire western and central Himalayas lying to the north of it, is not favourably placed for the mountain wave development.

7. Conclusion

This study presents satellite observed evidence of mountain waves over western and central Himalayas and brings out the following observational features of mountain wave occurrence over these regions :

- Mountain waves occur over western and central Himalayas during monsoon season.
- Maximum frequency of occurrence is to the lee of western and central Himalayas over Tibet plateau.
- Most marked and organised waves are observed over Tibetan plateau between 30° & 34°N and extend to a great distance. They occur usually in association with the approach of a westerly trough to the south of the jet stream.
- The wavelength vary between 13 km & 22 km. On 75% occasions wavelength is between 15 and 18 km.
- Latitudinal as well as downstream variation in the wavelength of waves is seen on a number of occasions.
- Maximum frequency of occurrence is between 1100 & 1630 hr. During the period of study not a single wave was observed in night IR-mageries.

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