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Surface wind at Leh

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सार–अप्रैल से अक्टूबर तक लेह हवाई अड्डे पर तीव्र गति की सतही पवन चलती है। नवम्बर से मार्च तक सतही पवन कुछ कम गति की होती है। सतही पवन के तीव्र गति से चलने का कारण घाटियों के बीच पवन के गुजरने के लिए स्थान का कम या अधिक होना तथा उष्मीय प्रभाव प्रतीत होता है। कैटाबैटिक और ऐनाबैटिक प्रवाह तथा फॉहन प्रभाव पवन की तीव्र गति से सम्बन्धित प्रतीत नहीं होते। सिन्धु नदी के साथ-साथ लेह क्षेत्र में बहुत से ऐसे स्थान हैं जहां पर पवन तीव्र गति से चलती है। ऐसे स्थान पवन शक्ति उपार्जन के लिए लाभदायक सिद्ध हो सकते हैं।

ABSTRACT. Leh airfield normally experiences gale speed surface winds during the period from April to October. From November to March, the winds are relatively weak. The reason for the gale strength speed appears to be the channelling effect. Katabatic /anabatic flows or Foehn effects do not appear to be the significant contributory factors. There are numerous points along the river *Indus*, where similar gale strength speeds are encountered and hence these appear to be good wind energy prospecting potential sites.

Key words — Katabatic/anabatic flow, Foehn effects, Channelling effect.

1. Introduction

From the Pamirs a number of mountain ranges radiate in an easterly direction. The most southerly of these is the Himalayan range which is the loftiest and longest range in the world. The Himalayas which run first southeastwards from the Pamir knot and later in an easterly direction constitute a massive mountain wall extending over 2500 km with a varying width of 250 to 300 km. At its northern end Zanskar mountains and Ladakh range run parallel to the Great Himalayas. Further to the north, and almost parallel to the Himalayas is the great Karakoram range running southeastwards from the Pamir knot. The northernmost range radiating from the Pamir is Tien Shan range which runs in an easterly direction through northern Sinkiang.

Leh airfield is situated in the Indus valley at a height of 3256 m. It is bounded by high ranges on the north and south but eastern and western ends are more or less open. The area is arid and cold. The hills are devoid of any vegetation. The snow line in summer is at about 5.0 km a.m.s.l. and by winter it lowers down to valley level. Plan view map of the area along with contours is shown in Fig. 1.

Leh airfield experiences strong surface winds during the months of April to September, particularly in the afrernoon and night. The wind from westnorthwest direction often reaches gale force. An attempt is made in this paper to study the diurnal and seasonal variation of the surface wind at Leh airfield.

2. Earlier work

Lakshminarayanan (1979) on the basis of 1973-76 surface wind data from Leh airfield concluded that strong winds are usually from westerly direction. The high frequency of strong winds is from April to October during the afternoon/first half of night with the maxima occurring between 1600 and 2000 IST at the airfield while in the Leh town the winds are relatively weak and he concluded that the strong winds may be due to the narrowing of the valley. Meiklejohn (1955) studied the local surface wind at Milfield, Northumberland in England and concluded that the wind was not purely katabatic and its main cause appeared to be some feature of the local topography. Defant (1951) explains the 'jet effect', as a purely local increase in wind intensity owing to possibly certain orographic configuration. The pressure gradients responsible for the 'jet wind effect' extends over very short horizontal distances and can be detected only by special investigation. Atkinson (1981) stated that the mean velocity is larger in deep valleys than in shallow valleys. Yoshino (1977) refers to a study by Fuh where the relative wind speed in the valley is dependent on the angle β between the wind direction and the valley as well as the ratio of the width L of the valley to the height, H of the mountain on both sides of the valley. The wind velocity in the valley is greater than that in the open country when the angle β is smaller than 15°-35°, but less when β is larger than 15°-35°. In the former situation, the smaller the angle β and the ratio L/H, the stronger the wind speed in the valley becomes, but in the latter situation the larger the angle β and smaller L/H, the weaker the wind becomes. Thomas (1982) reported 'low level mountain parallel jet streams' in the Sierra cooperative pilot project. However, these jets between 600 and 1500 m a.g.l. were not local in nature but extended to more than 100 km in length. Mukherjee and Ghosh (1965) studied the airflow in the Assam valley in different seasons and concluded that except during the monsoon, easterly air at low levels originated from the Himalayas in the form of katabatic flow. During monsoon the air tended to flow towards the Himalayas.

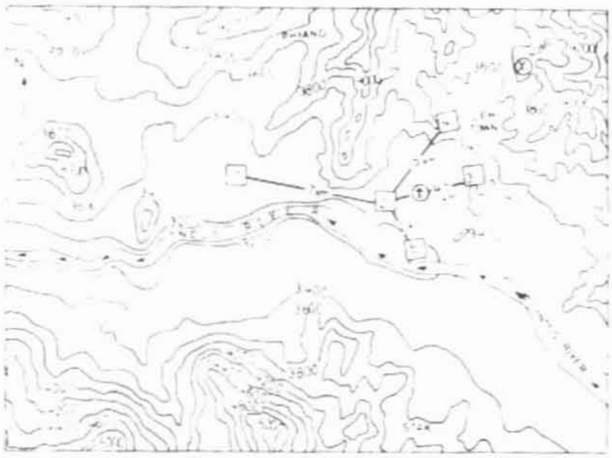

Fig. 1. Plan view map of Leh area with contours and observation points 1-5

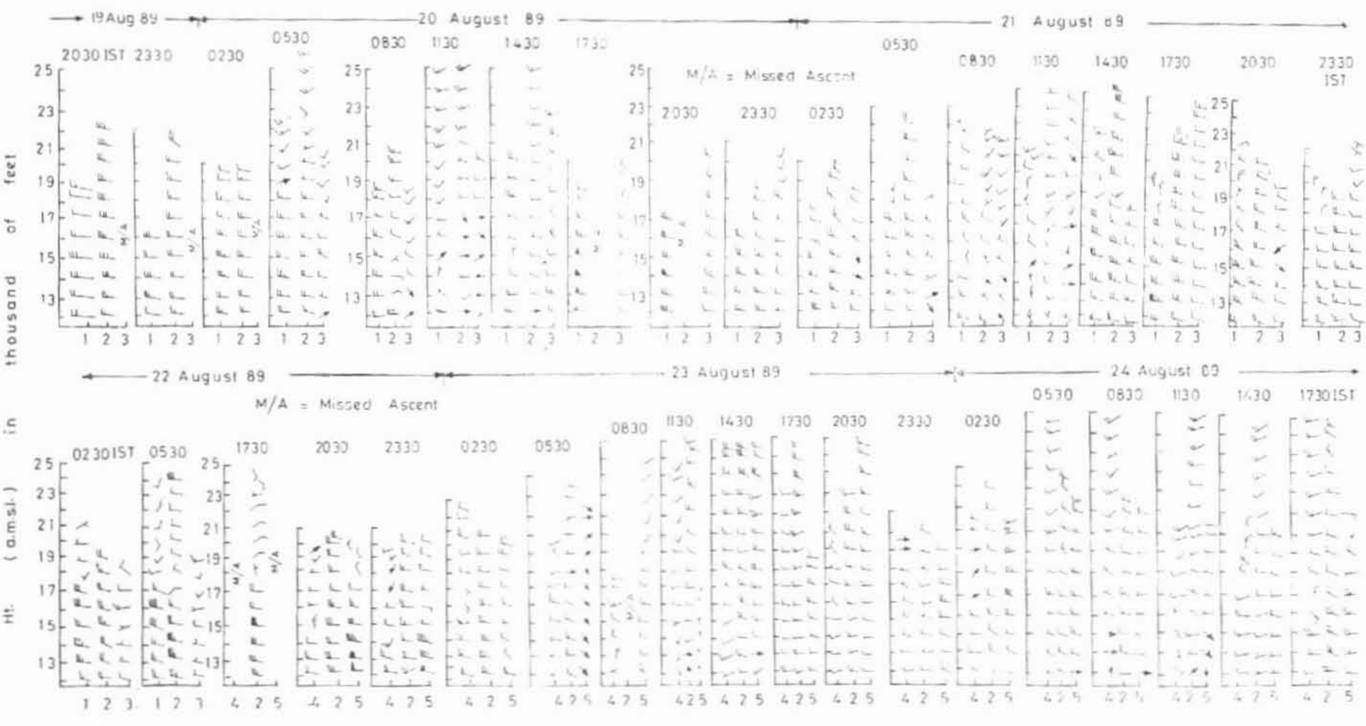

Fig. 2. Time section along and across the Leh valley

3. Data collection, analysis and presentation

Hourly surface wind data at the Leh airfield for the year 1988 has been collected and analysed. For studying the diurnal variation of the surface wind, which is related to planetary boundary layer and immediate higher layer, pilot balloon ascents were taken at three points located along the valley. at all synoptic hours from 2030 IST on 19 Aug' 89 to 0530 IST on 22 Aug' 89. Subsequently, the pilot balloon ascents were taken across the valley from 1730 IST on 22 Aug' 89 to 1730 IST on 24 Aug' 89. The points along the valley have been labelled as 1, 2 and 3 (Fig. 1). The points across the valley have been labelled as 4, 2 and 5. The point 2 is the Leh airfield. The observation points 1 to 5 and the distances between them have been shown in Fig. 1. Pilot balloon (PB) ascents at more than three points simultaneously could not be taken due to logistics and associated difficulties. On 20 Aug' 89, smoke candles were used at different times of the day near a hill and photographs taken to see the existence of upslope/downslope winds and flow patterns.

The two mutually perpendicular components of the surface wind, *viz*., flow parallel to the valley and its normal components were examined for katabatic/anabatic wind effect. Vector wind average and scalar wind average at each hour in a month were calculated to examine the existence of mountain/valley wind system and to have a first guess of the potential of wind power. The average vector wind and scalar wind at every alternate hour is given in Table 1. Highest wind velocity reached during 24-hr period on any day in the year is given in Table 2. The surface wind has also been studied by making wind roses, but for brevity sake, have not been presented. Time section of the PB data along

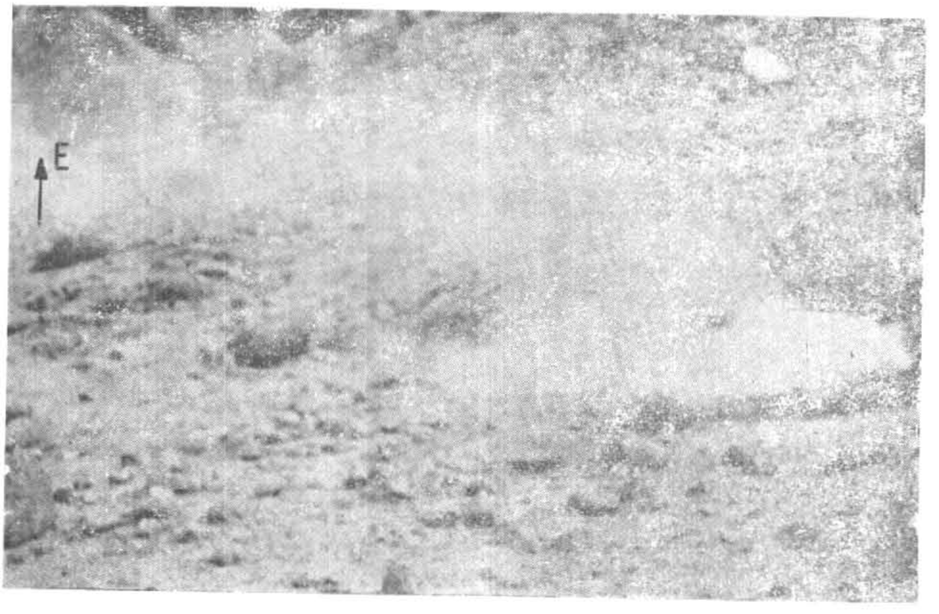

Fig. 3(a). Photograph of smoke candles at 1300 IST on 20 August 1989

Fig. 3(b). Photograph of smoke candles at 1830 IST on 20 August 1989

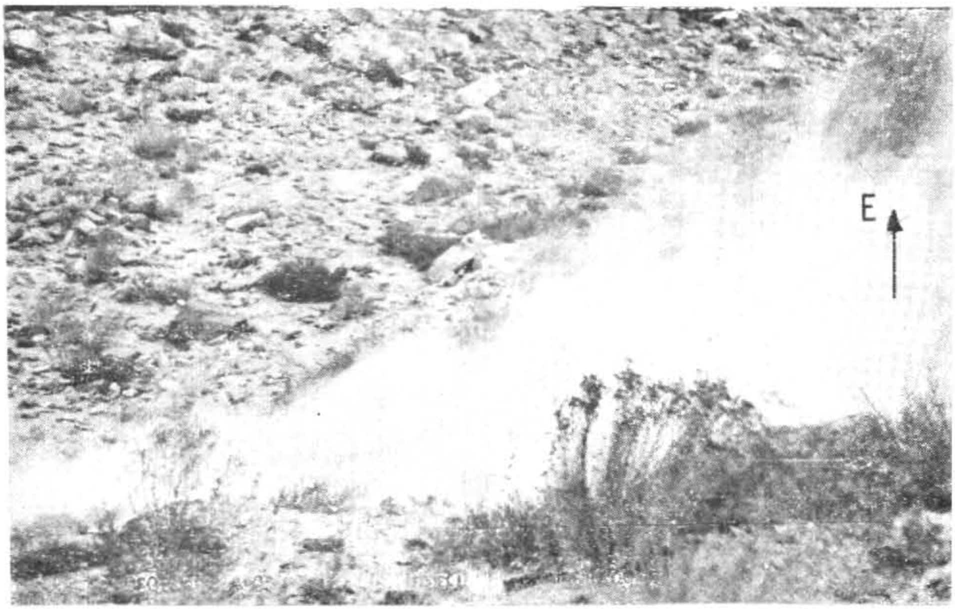

Fig. 3(c). Photographs of smoke candles at 0530 IST on 21 August 1989

TABLE 1

The average vector and scalar wind at Leh airfield for the year 1988

	Hours (IST)											
	02	04	06	08	10	12	14	16	18	20	22	24
					January 1988							
DR	270	260	—	—	220	222	262	275	269	269	270	280
VS	1.5	0.6	0	0	0.2	0.4	0.9	2.4	2.9	3.4	3.3	3.1
SS	1.5	0.6	0	0	0.2	0.5	1.1	2.4	2.9	3.4	3.3	3.2
					February							
DR	285	277	270	270	276	280	277	278	274	276	278	281
VS	4.2	2.6	0.8	1.4	1.1	1.8	2.5	6.5	8.3	9.3	8.3	5.7
SS	4.2	2.6	0.8	1.4	1.1	1.8	2.5	6.5	8.3	9.3	8.3	5.7
					March							
DR	272	270	273	275	273	282	266	273	266	268	274	274
VS	2.9	3.1	2.6	1.7	1.3	1.4	4.5	7.2	7.4	7.1	6.1	5.0
SS	2.9	3.2	2.6	1.7	1.3	1.8	5.8	7.5	8.5	7.9	6.1	4.9
					April							
DR	271	272	270	277	287	236	273	281	272	274	272	271
VS	4.3	1.9	0.6	0.5	0.3	0.9	6.0	12.3	10.2	8.9	8.7	6.9
SS	4.3	1.9	0.6	0.6	0.3	1.1	6.1	12.3	10.4	9.1	8.7	6.8
					May							
DR	271	272	269	278	271	266	277	272	275	273	271	273
VS	8.6	4.7	3.9	3.3	3.7	3.3	10.7	20.6	19.8	14.8	13.9	11.2
SS	9.4	5.3	3.9	3.9	4.0	5.1	12.2	22.6	21.5	16.5	15.5	11.9
					June							
DR	272	296	292	286	304	272	302	285	272	266	262	261
VS	8.2	2.8	1.7	2.1	1.5	1.3	5.7	16.2	21.4	20.8	16.6	12.8
SS	8.6	4.9	3.3	4.1	4.3	7.5	13.2	17.9	22.4	21.6	17.8	14.1
					July							
DR	275	177	182	267	266	244	268	272	270	270	275	275
VS	8.1	5.9	2.7	1.5	1.7	1.2	6.4	10.1	15.9	16.4	12.9	10.2
SS	8.4	6.3	6.7	8.1	8.5	7.9	10.0	13.9	18.5	17.2	13.5	10.9
					August							
DR	265	169	169	261	264	239	147	261	268	270	270	267
VS	15.1	9.15	7.0	4.6	3.6	1.1	2.8	11.5	17.6	18.9	16.9	14.2
SS	15.7	9.1	7.0	5.2	4.0	2.6	4.1	12.5	18.5	19.5	16.9	14.9
					September							
DR	266	269	270	276	275	275	260	273	271	271	272	273
VS	6.6	3.4	2.6	1.4	2.7	0.4	3.8	10.1	11.1	10.2	8.7	7.2
SS	6.8	3.4	2.6	2.0	3.5	1.6	4.6	11.4	12.9	12.0	9.1	7.5
					October							
DR	270	270	270	—	270	270	261	265	270	262	264	268
VS	3.8	2.0	1.0	0	0.5	0.2	1.7	7.2	8.2	6.6	6.7	4.8
SS	3.8	2.0	1.0	0	0.5	0.2	1.9	7.8	8.7	6.9	6.9	4.9
					November							
DR	270	250	—	250	—	090	235	262	251	259	263	270
VS	0.2	0.3	0	0.2	0	0.1	0.3	2.0	1.9	2.6	1.5	0.6
SS	0.2	0.3	0	0.2	0	0.1	0.3	2.1	2.0	2.7	1.9	0.6
					December							
DR	290	290	—	—	290	296	279	278	270	270	270	285
VS	1.1	0.2	0	0	0.3	0.8	1.3	2.0	1.5	0.7	0.5	1.1
SS	1.1	0.2	0	0	0.3	0.9	1.6	2.1	1.5	0.7	0.5	1.1

DR : Wind direction, VS : Vector wind speed (kt), SS : Scalar wind speed (kt)

TABLE 2

Highest wind velocity (kt) and the corresponding time during 1988

Date	Daily maximum speed							
	Jan		Feb		Mar		Apr	
	Speed	Time	Speed	Time	Speed	Time	Speed	Time
1	27008	2300	27012	2100	29020	1900	27010	1700
2	27010	1500	27010	2100	29010	2000	27015	1900
3	14005	1400	27010	2300	27010	1800	27020	1800
4	27010	1800	27005	1900	25015	2200	27025	1700
5	27008	2000	0	////	27010	2200	27020	1900
6	27015	2400	27020	1700	27015	1900	27010	2200
7	27008	2000	30015	1700	29035	1700	29018	1700
8	27010	1800	29035	1600	25012	1700	27025	1600
9	27005	1500	29025	2000	29010	1500	29025	1600
10	0	////	27010	2000	29018	1600	29014	1700
11	27005	2200	27020	1900	14012	1800	27010	1500
12	27010	1400	27020	1800	27012	1000	29018	1500
13	27010	1800	27020	1900	27012	1900	27035	1900
14	27008	2300	27020	1900	29012	1600	14005	1700
15	0	////	27025	2000	27010	1000	29035	1600
16	0	////	27015	1700	0	////	27050	2300
17	0	////	27015	1700	27008	1000	27020	2200
18	0	////	27010	1900	27010	2400	27020	1500
19	0	////	27015	1800	30010	1800	27035	1500
20	27010	1500	27010	2000	23015	1700	27010	1200
21	0	////	27020	2000	27010	2000	27020	2100
22	27015	1700	27012	1600	27015	2100	27025	1600
23	27012	2000	29010	2300	27020	1400	27020	1800
24	27010	2000	27020	1600	27010	2400	27025	1800
25	27008	2400	29010	2000	27020	1800	27020	2100
26	27010	1900	27010	1600	27015	1300	11010	1800
27	27008	2000	0	////	27040	1500	27010	1700
28	27015	1800	27025	1600	27010	2000	27015	2200
29	0	////	////	////	26025	1600	27012	1900
30	27010	2200	////	////	29025	1500	27025	2300
31	0	////	////	////	27060	1500	////	////

Wind speed is in kt

TABLE 2 (*Contd.*)

Highest wind velocity (kt) and the corresponding time during 1988

Date	Daily maximum speed							
	May		Jun		Jul		Aug	
	Speed	Time	Speed	Time	Speed	Time	Speed	Time
1	27030	1600	27035	2000	27035	1800	27030	1600
2	27025	1900	32030	1400	27028	1900	27015	0200
3	27040	1800	27030	2000	27030	2300	27015	2000
4	27045	1500	27035	1600	27040	1800	27015	2300
5	27030	1700	27030	1900	27035	2000	27020	2000
6	27035	1800	27035	1500	27025	0300	27020	2000
7	27020	1800	27030	1500	29038	1600	27020	1900
8	27025	1900	30030	2000	32010	0700	27035	1900
9	27030	1900	27025	1400	27020	1900	27030	1400
10	27040	1700	27030	1800	27020	2000	27025	1900
11	27025	1800	29025	1900	27025	1900	27025	1700
12	27025	1600	27025	1800	27020	0300	27025	1900
13	27016	1600	27025	2200	14008	1200	25025	2100
14	27050	1700	27030	1800	12020	1600	27040	1900
15	27035	1800	27030	1400	30005	1600	27020	2000
16	30030	1900	27030	1800	29025	1500	27030	2200
17	29025	2300	27030	1300	27010	2000	27015	1800
18	27028	2300	32025	1400	30025	1900	27015	1800
19	29025	1400	36010	1000	27020	1900	27030	1900
20	27020	2100	27010	1500	27020	1800	27025	2000
21	27030	1900	27015	2100	30030	2200	27025	1600
22	27040	1600	27025	1700	27020	1000	27035	1700
23	27035	1500	27035	1800	27015	0500	27025	1500
24	29030	2000	27025	1700	27035	1800	27035	2200
25	27040	1600	27025	2000	27025	2100	27035	1600
26	27030	1700	27035	2100	27020	2000	27020	2400
27	27035	2300	27048	1900	27025	2300	27025	1900
28	27055	1500	27038	1900	27030	1900	27030	1800
29	27025	1600	27040	1700	27030	1800	27025	2100
30	27020	0300	32038	1800	27025	2000	27030	1700
31	27050	1400	////	////	27025	2100	27015	2200

Wind speed is in kt.

TABLE 2 (Contd.)

Highest wind velocity (kt) and the corresponding time during 1988

Date	Daily maximum speed							
	Sep		Oct		Nov		Dec	
	Speed	Time	Speed	Time	Speed	Time	Speed	Time
1	27020	2200	27010	1700	27010	1900	0	////
2	27020	2000	18015	1800	27013	2400	0	////
3	27026	1800	27020	1600	27010	1700	0	////
4	27020	2200	27040	2200	25008	1300	0	////
5	27025	2100	27020	1800	0	////	0	////
6	27030	1700	27010	2100	0	////	23005	1500
7	27030	1700	27024	1600	0	////	0	////
8	27015	1700	27020	1600	23010	1800	27003	1400
9	27035	1600	27015	1800	27008	1800	0	////
10	27013	1700	27020	2000	0	////	0	////
11	27025	1900	27015	1900	0	////	0	////
12	0	////	27020	1500	0	////	0	////
13	25005	1800	27020	2200	0	////	0	////
14	0	////	27010	1800	0	////	27010	2200
15	27035	2000	18010	1600	0	////	27007	1400
16	27025	1700	0	////	27025	1700	0	////
17	27010	1800	27010	0200	0	////	0	////
18	27025	1800	27030	1700	27010	1900	27010	1900
19	27020	2000	27020	2100	0	////	27035	0200
20	27025	2100	27025	1500	0	////	0	////
21	27020	2000	27005	1500	0	////	0	////
22	27020	2100	25008	2200	0	////	0	////
23	27010	1500	27008	2000	27010	1600	29035	1600
24	27010	1400	23015	1800	27025	2200	05005	1400
25	27020	0800	23015	1700	23008	1800	05003	1200
26	27005	1700	27013	1700	25007	2000	0	////
27	27020	1800	0	////	27025	1900	0	////
28	21012	1700	0	////	0	////	0	////
29	25025	1500	23008	2200	0	////	0	////
30	27020	2100	27010	2400	0	////	27010	1600
31	////	////	32025	1800	////	////	0	////

Wind speed is in kt.

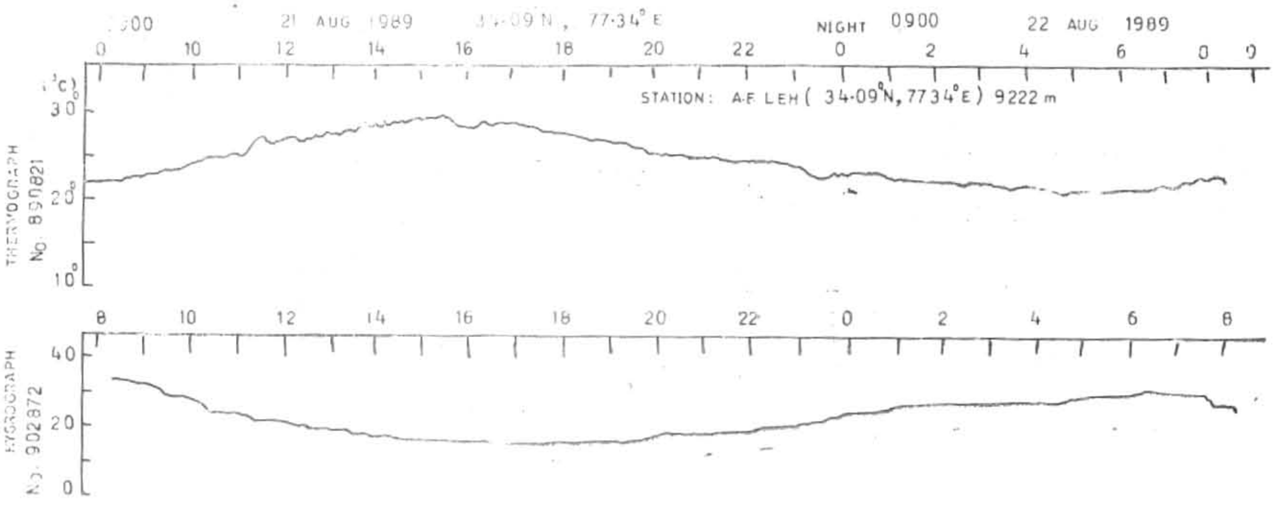

Fig. 4. Thermograph and hygrograph of Leh airfiled on 21 & 22 August 1989

the valley over the points 1, 2 and 3 and across the valley over the points 4, 2 and 5 is given in Fig. 2. Photographs of the smoke candles at different times of the day is given in Fig. 3. Thermograph and hygrograph of 21 Aug' 89 are shown in Fig. 4.

4. Discussion

From Table 1, it is noticed that surface wind direction is predominantly from westnorthwest direction, which is broadly parallel to the direction of the valley. The cross component or reversal of the wind during the course of the day is negligibly small, which suggests that katabatic or anabatic effects of the hills are not clearly manifested. The surface wind picks up speed sometime during the afternoon and continues to be strong throughout the evening and night and slows down sometime after sunrise. Scalar speeds from April to September, exceeding 10 kt prevail for 8 to 10 hours nearly on all days, indicating "wind energy—prospecting potential". Table 2 indicates that from April to October wind speed very often exceeds 25 kt on many days and on a number of occasions has even exceeded 50 kt from westnorthwest direction. The time of occurrence of maximum speed is generally towards evening or early part of the night .

Time section in Fig. 2 indicates that low level jet builds up at point 1 which is an upwind point with respect to Leh airfield, sometimes after 1400 IST and the strong wind continues throughout the night till day break. After sunrise, the wind speed decreases and remains low, about 10 kt till 1430 IST. The pattern is repeated at point 2 and point 3 also, but the speed decreases considerably down wind from point 2 to point 3. In general, the observed wind speeds at point 3 are always much lower than that at point 1 and 2. The direction of the wind is usually from westnorthwest. Fig. 2 which also shows the time section of PB data across the valley, through points 4, 2 and 5 indicates jet speed wind at point 5 only on 22 Aug '89, the winds were comparatively lighter at all the points, though point 2 recorded the strongest.

Further, there is definitely a diurnal variation of wind even at upper levels. It is seen that for all available winds at 1130 IST, up to 5000 ft a.g.l.,the winds are light. The condition at 0830 IST is similar. Thus the diurnal variation of wind is such that between 8 and 12-hr, the wind is light up to considerable height. Only at that time local influence may be exhibited. on 23 and 24 August, the winds at location 4 were more southerlies and those at location 5 were northerlies. These are indicative of anabatic winds in those locations. But the wind speeds indicate that the influence of this local wind system is very small and may for all practical purposes be neglected. Smoke candle pictures taken in the evening of 20 Aug '89 and morning of 21 Aug'89 lend support to the view about katabatic/anabatic flow. However, the afternoon picture suggests that accumulation and horizontal dispersion just above the ground level indicates possible inversion or subsidence.

Appreciable wind shear along and across the valley at any point are discernible easily. The observation of significant shear along the valley and in the transverse direction establishes the channelling effect of flow at Leh. This also suggests that the site location for possible wind power generation may be to the west of the airfield.

Helicopter pilots, who have considerable experience of flying in the area, have reported numerous points along the river course where the winds are extremely strong. The strong winds have been encountered both in winter and summer, though the strength in winter is relatively less. It is further reported that wherever the hills are devoid of vegetation, the flow is extremely turbulent. The afternoon smoke candle picture indicates possible subsidence due to dynamical reasons. The planetary boundary layer thickness increases and upper level westerlies penetrate close to ground. The jet effect is better manifested where the valley narrows down such as point No. 1. Further, the effect of heating in summer may enhance the orographic effect. The jet effect does not appear to be due to Foehn type flow, because no significant changes in temperatures or humidity are noticed at the time of onset of the strong wind as indicated in Fig. 4. The position of the station is such that one should always expect strong westerly winds. Though strong westerly winds are experienced in winter also, but the frequency and high strength of the wind dominates from April to October. It is possible that katabatic wind may flow from November to March when the snowline shifts to ground level of Leh airfield. Over snow, katabatic wind blows throughout the day as suggested by Godske *et al.* (1957). Along the valley this may blow along the course of the river *Indus*. It follows, the prevailing westerlies and katabatic winds may cancel each other. However, during April to October, katabatic/anabatic or Foehn wind do not appear to be significant factors in causing the wind to attain jet speed strength. The important factors appear to be the thermal effect and channelling. As proposed by Defant (1951), it is felt that thermal effect generates local pressure gradient along the direction of flow, which causes the wind to speed up. In winter time, *i.e.*, Nov/Mar, the thermal effect becomes less effective due to low angle of the sun, increased cloudiness and decreased duration of sunlight. Further, since the valley is fairly deep and as suggested by Atkinson (1981) and Yoshino (1977), the mean wind speed increases.

5. Conclusion

Leh airfield experiences gale speed surface winds from April to October while November to March the surface winds are generally light.

The surface winds exhibit characteristic variation during the course of a day, and these variations are not similar to diurnal variations normally associated with katabatic/anabatic flows. Strongest surface wind is encountered during late afternoon/evening. The surface wind continues to be strong during night. The surface wind speed is at its lowest value between 0800 and 1200 IST. The direction of the wind is usually from westnorthwest, which is parallel to the orientation of the valley.

Jet strength winds in the first few hundred metres develop upstream from Leh airfield and downstream the speed is lower. The development of jet and strong surface wind at Leh airfield appears to be due to channelling and thermal effects. Based on debrief reports of helicopter pilots, it appears that there are numerous locations along the river course, where jet strength winds are encountered. Further, even in winter strong winds are encountered at the same locations, though the strength is relatively less.

Katabatic/anabatic winds may exist at Leh airfield and its neighbourhood, but their contribution in the variation of the surface wind is not the dominant factor. Further the strong surface wind from April-October is not Foehn type either, because no significant change of temperature or humidity is noticed at Leh airfield at the time of onset of the strong wind. From the available observations, it appears that channelling and thermal effects are responsible for the strong surface wind at Leh from April to October.

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