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Diurnal variation of lower tropospheric winds (0-3 km) over Thumba during 18-20 August 1976

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ABSTRACT. The wind data from seventeen balloon ascents conducted at Thumba during 18-20 August 1976 for providing meteorological support to the Indo-Soviet M-100 rocket diurnal launching series, have been subjected to isopleth analysis, land-sea breeze study, wind shear analysis and harmonic analysis. The lower tropospheric winds (0-3 km) are northwesterly with wind speeds increasing upto 1 to 1.5 km and then decreasing to almost half this speed above that altitude. Maximum intensity of the sea breeze (Approx. 10 m/s) is around 1530 IST at altitudes 200 to 600 m. The land breeze effect is maximum around 0300 IST (Approx. 10 m/s) at the altitude around 0.4 km. The wind shear values are of the order of 30×10^{-4} per second and is maximum in the first 100 metres above ground level. The diurnal oscillation of zonal and meridional winds is strongest at 0.5 km with almost equal amplitudes of 2.62 m/s and 2.52 m/s respectively and accounts for 60 per cent of the total variation while for the semidiurnal oscillation, accounting for the remaining 40 per cent the zonal wind oscillation is strongest (amplitude 1.90 m/s) at 1.0 km and the meridional oscillation is strongest (amplitude 1.35 m/s) at 3.0 km.

1. Introduction

The winds in the lower troposphere affect considerably the performance of the launch vehicles and hence play an important role in the design and flight test of aerospace vehicles. The process of applying correction to the launcher settings-elevation and azimuth-depending upon the prevailing wind conditions is called wind weighting and it is necessary both from the safety point as well as from the desired level of performance of the rocket. Also the lower level wind data are essential during the take-off and landing operations of aircrafts. Vertical wind shear in the lowest layers of the atmosphere is a significant sub-parameter of the wind field and finds immense application in the design and operation studies of aerospace vehicles. Vertical wind shears in the lower layers of the atmosphere and ground wind characteristics at Thumba Equatorial Rocket Launching Station have been reported based on the 200 ft meteorological Tower wind measurements (Rao *et al.* 1965, Narayanan and Pillai 1971, Narayanan and Devassy 1972). The present study is aimed at the diurnal wind variability upto 3 km altitude at Thumba during the peak of the south-west monsoon period based on balloon wind measurements for two consecutive days in August 1976.

2. Data and observations

A series of nine M-100B meteorological rocket launchings were conducted from Thumba during 18-20 August 1976 for studying the diurnal variation in the stratospheric and mesospheric winds and temperature. In connection with this Indo-Soviet collaborative experiment, seventeen balloon ascents were taken at intervals of approximately three hours to provide meteorological support to the rocket launching and for supplementing the rocket launching data as per the details given in Table 1. It can be seen from this table that out of the 17 ballon ascents, 7 were high altitude rawin ascents for supplementing the rocket data. However, these rawin balloons were initially tracked by optical theodolite and winds were computed in the same manner as in pilot balloons (PB). PB winds were computed at 100 metres interval upto 3 km altitude with the aid of Minsk-22 computer. Four flights terminated below 3 km and the data from these flights were also utilised by interpolating the missing data using the nearest available wind observations from the meteorological Centre, Trivandrum about 10 km away from Thumba.

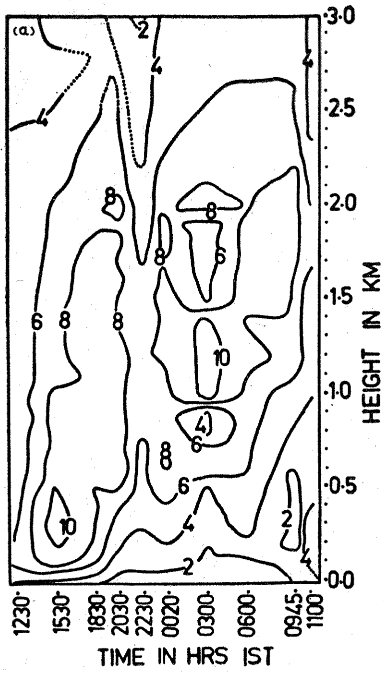

Fig. 1(*a*). Vertical cross section of average zonal wind

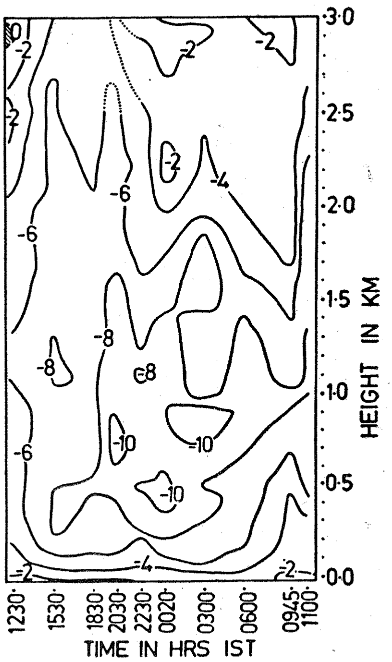

Fig. 1(*b*). Vertical cross section of average meridional wind

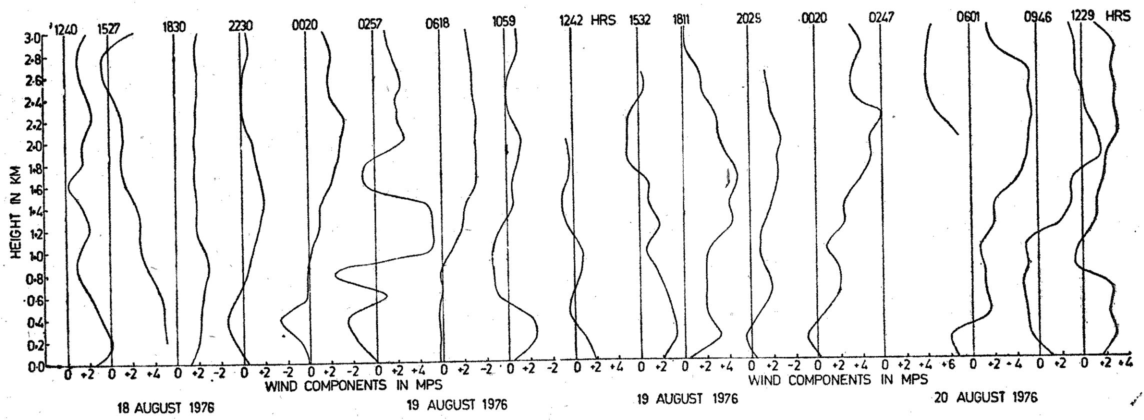

Fig. 2. Profiles of wind component normal to the coast line showing the effect of land-sea breezes

3. Method of analysis

3.1. The balloon wind data were subjected to (*a*) isopleth, (*b*) land-sea breeze, (*c*) vertical wind shear and (*d*) harmonic analysis. Isopleth analysis was carried out for the zonal and meridional winds separately. For isopleth, analysis, average winds were found from the 17 sets of data by reducing it to 10 sets representing wind conditions upto 3 km altitude over a day. For averaging, winds at the same time (subject to a margin of 30 min.) on the three days were taken into consideration. For instance, the average winds from the PB ascents at 1240 IST on 18 August, 1242 IST on 19 August and 1229 IST on 20 August were taken as the winds at 1230 IST. There were ascents at 2230 IST on 18 August, 1059 IST on 19 August and 0946 IST on 20 August and these were retained as such for the respective hours. These 10 sets of data corresponding to 1230, 1530, 1830, 2030, 2230, 0020, 0300, 0600, 0945 and 1100 IST were used for constructing the vertical cross section of winds at 100m interval upto 3 km. Figs. 1(a) and (b) show the vertical cross sections of the zonal and meridional winds.

3.2. It is assumed for the land-sea breeze study that these breezes are better represented by the wind component normal to the coast line (Dayakishan and Pradhan 1977). The coast line at Thumba is along the direction 145-325 deg. (Narayanan 1967). The resultant PB winds were resolved to obtain the components

TABLE 1

Particulars of the meteorological balloon soundings from Thumba 18-20 August 1976

Date (1976)	Time (IST)	Type of balloon	Maximum altitude (km)	Remarks
18 Aug	1240	SR32	3	PB
,,	1527	SR300	3	Rawin
,,	1830	SR32	1.2	PB(Trivandrum Rawin supplemented)
,,	2230	Kaysam 2338	3	Rawin
19 Aug	0020	SR32	3	PB
,,	0257	SR300	3	Rawin
,,	0618	SR32	1	PB (Trivandrum Rawin supplemented)
,,	1059	Kaysam 2398	3	Rawin
,,	1242	SR32	2	PB
,,	1532	SR300	3	Rawin
,,	1811	SR32	3	PB
,,	2029	SR32	2.5	PB
20 Aug	0020	SR32	3	PB
,,	0247	SR300	2-3 (radar tracking)	Rawin (data missing for the first one km)
,,	0601	SR32	3	PB
,,	0946	SR300	3	Rawin
,,	1229	SR32	3	PB

normal to the coast. The positive components represent sea-breeze and the negative components the land-breeze. Fig. 2 illustrates the vertical profiles of the winds with the land-sea breeze contrast.

3.3. Wind shears were computed separately for the zonal and meridional components at 100 m interval with reference to the top level, *i.e.*, build-up shear.

$$s\,(\triangle z,\, z) = \frac{V\,(z) - V\,(z - \triangle z)}{\triangle z}$$

The vertical cross-section of the wind shear for zonal and meridional winds during 18-20 August 1976 thus obtained are presented in Figs. 3(a) and (b).

3.4. To study the diurnal and semi-diurnal oscillations, harmonic analysis was carried out with 8 sets of wind data spaced at 3 hours interval subject to a margin of 30 minutes with 1230 IST as reference hour. The data for 2130 IST were interpolated from the cross-section analysis. The harmonic analysis method adopted by Harris (1959) was followed for detecting the amplitude and phase of the diurnal and semi-diurnal oscillations of both zonal and meridional winds at surface, 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 km levels. The results of the harmonic analysis are presented in Table 2. Figs. 4(a) and (b) show the amplitude and phase variation of zonal and meridional winds for different altitudes. In this analysis the phase means the time interval in hours between the reference hour and the time of occurrence of maximum deviation. Another factor worthy of mention is that because by convention the mean meridional wind is negative, being northerly throughout, the positive variation when added to the mean wind will only lower its magnitude. Therefore, as for example, the meridional wind of 0.5 km, although the wind appears to be strongest at 2300 IST due to the meridional oscillation, the strongst wind is 12 hours earlier or later.

4. Discussion of the results

4.1. *Zonal winds* (*Fig.* 1*a*)

The zonal winds are westerly in August with maximum speed of 10-12 m/s occurring around 1530 IST in the layer 200-500 m. The same speed occurs again at an altitude of 900-1300 m in the early morning around 0300 IST. Above 1.5 km the wind speed decreases to almost half (5-6 m/s) with altitude.

4.2. *Meridional winds* (Fig. 1*b*)

The meridional winds are northerly throughout. The maximum speed is of the same order as the zonal component (10-12 m/s during night time between 300 to 900m). Winds below 200 m are generally less than 6 m/s from afternoon (around 1500 IST) till morning (around 0600 IST). There is a general tendency of the meridional wind to decrease above 1.5 km.

4.3. *Land and sea breezes*

A study of the sea breeze at Thumba has been reported earlier (Rao *et al.* 1967) based on pre-monsoon and post-monsoon wind data. The present study provided unique opportunity to find out the time of onset, intensity, variation with the time and altitude and the maximum vertical extent of the land and sea breezes. Thumba being located on the coast line, the land and sea contrast influences the winds in the lower layers; but because of its close proximity to the sea the contrast is not much marked at Thumba (Prasad *et al.* 1977). Moreover, the prevailing steady south-west monsoon current in August masks the sea breeze effect considerably. The wind profiles (Fig. 2) demonstrate the land-sea breeze structure. The sea breeze sets in around 1000 IST. It gradually strengthens and extends upwards. By 1830 IST the entire 3 km layer is occupied by winds from the sea with speed approximately 4 m/s. This wind may be a combination of the sea breeze and the prevailing westerly wind as was seen from the data above 3 km. Maximum speed is seen from 200 to 600 m

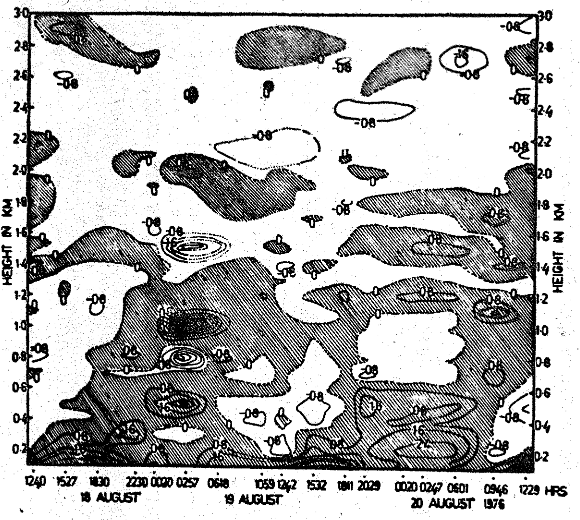

Fig. 3(*a*). Cross section of zonal wind shear

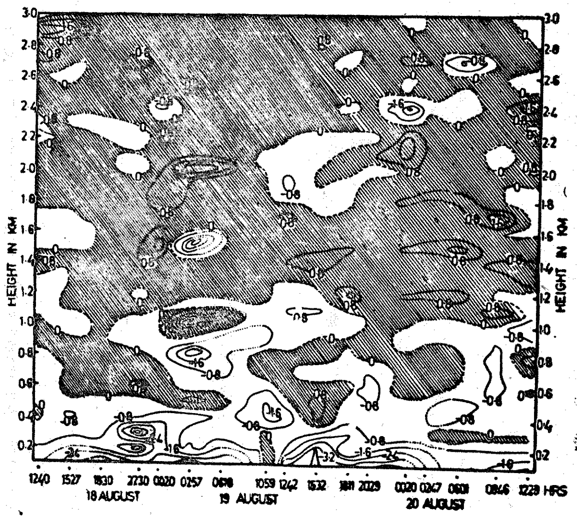

Fig. 3(*b*). Cross section of meridional wind shear

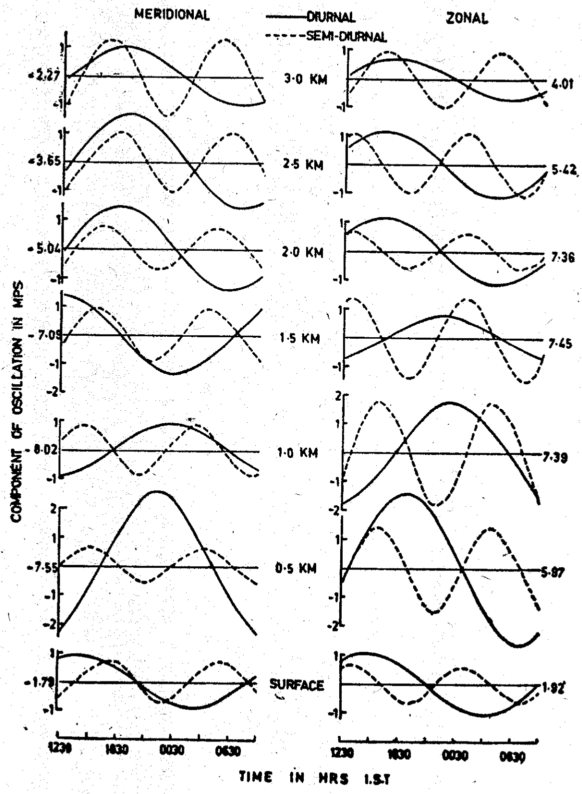

Fig. 4(*a*). Diurnal and semi-diurnal oscillations of meridional and zonal wind components at various levels from surface to 3.0 km with average wind 'Ao'

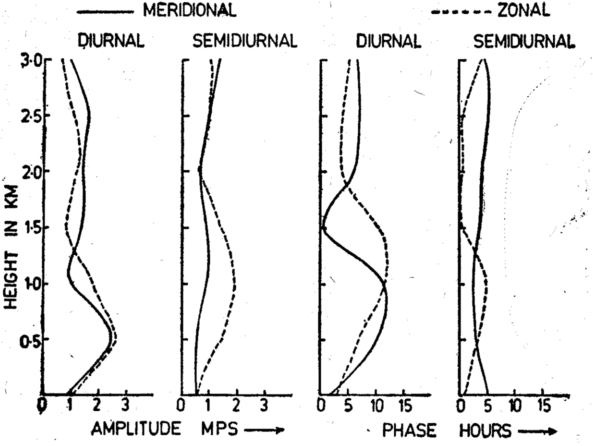

Fig. 4(*b*). Variation of amplitude and phase of diurnal and semi-diurnal oscillations with altitude

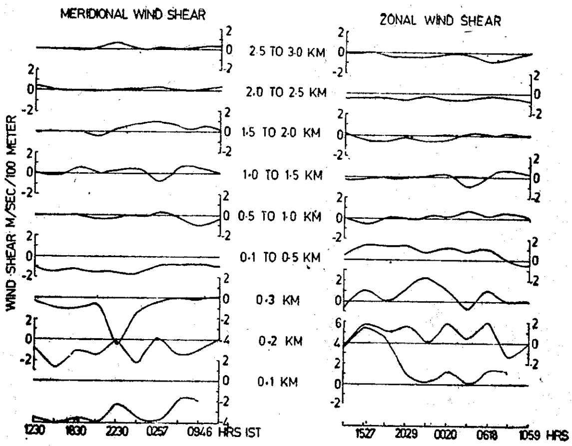

Fig. 5. Daily variation of vertical wind shear averaged over 0.5 km thickness along with the variation at 0.1, 0.2 and 0.3 km

TABLE 2

Harmonic analysis results

Level (km)	Meridional							Zonal						
	A_{oM}	$A1_M$	$S1_M$	$P1_M$	$A2_M$	$S2_M$	$P2_M$	A_{oz}	$A1_z$	$S1_z$	$P1_z$	$A2_z$	$S2_z$	$P2_z$
0.0	—1.79	0.89	58	2.19	0.65	42	5.07	1.92	1.07	64	2.94	0.61	36	1.17
0.5	—7.55	2.52	80	10.29	0.63	20	3.09	5.97	2.62	65	6.72	1.44	35	3.69
1.0	—8.02	0.91	51	11.49	0.87	49	2.40	7.39	1.78	48	11.46	1.90	52	3.93
1.5	—7.09	1.33	59	0.09	0.92	41	3.63	7.45	0.76	36	10.50	1.35	64	0.72
2.0	—5.04	1.39	67	5.88	0.67	33	4.05	7.36	1.16	67	3.96	0.58	33	0.60
2.5	—3.65	1.70	62	6.78	1.04	38	5.43	5.42	1.14	52	4.14	1.04	48	0.57
3.0	—2.27	1.00	43	6.45	1.35	57	4.65	4.01	0.69	42	5.22	0.96	58	4.11

M-Meridional, *Z*-Zonal

Ao-Mean wind (m/s) *A1*—Diurnal amplitude (m/s)

S1-Strength of diurnal component in percentage

S2-Strength of semi-diurnal component in percentage

A2—Semi-diurnal amplitude (m/s)

P1-Phase in hours (diurnal oscillation)

P2-Phase of semi-diurnal component in hours

around 1530 IST. This is in good agreement with those observed at other tropical stations like Jakartha (Riehl 1954). By 2000 IST the land breeze starts replacing sea breeze. The land breeze intensifies and extends upto 1 km. At 0630 IST the winds upto 1 km is from the land and is weak (0.5 m/s). The width profile obtained for 0257 IST on 18 August appears to be rather abnormal wherein alternate layers of varying depths had winds from land and sea with surface winds from sea. This anomalous behaviour could not be confirmed since the observation at corresponding hour on the next day did not yield data for the region of interest, *i.e.*, below 2.5 km.

4.4. *Vertical wind shear*

The average vertical wind shear below 500 m is of the order of 100 × 10^{-4} per sec and above 500 m it is of the order of 30 × 10^{-4} per sec. The lowest 300 m experiences strong shear which is due to the boundary layer frictional effect.

Fig. 5 presents the variation of average wind shear over 500 m layer thickness upto 3 km including at 0.1, 0.2 and 0.3 km levels and the standard levels 0.5, 1.0. ....3 km. In the figure the unit used for wind shear is mps/100 m. This figure clearly illustrates that wind shear is strongest in the first 100 m. The zonal wind shear increases from 1000 IST to 1530 IST in the lower layers which is apparently due to the sea breeze effect. The maximum wind shear **is** 730 ×10^{-4} per sec in the zonal wind at 0257 IST.

4.5. *Diurnal oscillation* (*Fig.* 4*a* & *b*)

The phase difference between the zonal and meridional winds is 11.3 hr at surface, 15.6 hr at 0.5 km, 12 hr at 1 km, 1.6 hr at 1.5 km, 13.9 hr at 2 km, 14.6 hr at 2.5 km and 13.3 hr at 3 km. This means that, at surface the meridional wind oscillation becomes maximum 11.3 hr after the zonal wind oscillation becomes maximum. This is true for other levels as well. This suggests that the turning of wind (by less than 90 deg.) is effected in 11.3 hours at surface, 15.6 hours at 0.5 km and so on. In their regime this change of direction is attributable to the land and sea breezes.

The diurnal oscillation is strongest at 0.5 km both for zonal and meridional winds with amplitude 2.7 m/s suggesting that the land and sea breeze effect is more prominent at this level. Comparing the diurnal amplitude of the meridional and zonal winds, the meridional amplitude is weaker than the zonal amplitude upto 1 km and above 1 km, the latter is weaker. This factor is also supporting the weakening of the sea breeze above 1 km.

4.6. *Semi-diurnal oscillation*

The phase difference between the zonal and meridional oscillation is 10.9 hr at surface, 5.4 hr at 0.5 km and 4.5 hr at 1.0 km, 8.9 hr at 1.5 km, 9.5 hr at 2.0 km and 10.9 hr at 2.5 km and 6.5 hr at 3 km. As in the case of diurnal oscillation, this means that the semi-diurnal zonal oscillation becomes maximum earlier than the meridional oscillation by 10.9 hr at surface, 5.4 hr at 0.5 km and so on. The maximum amplitude of the semi-diurnal oscillation is 1.9 m/s and is seen at 1 km in the zonal wind. The semi-diurnal amplitude of the zonal wind as well as the difference in amplitude of the zonal and meridional winds is least at surface and it increases with altitude and reaches a maximum at 1 km and then decreases to minimum at 2 km. As for the meridional wind, the amplitude is less than 1 m/s upto 2 km. Above 2 km, the semi-diurnal amplitude of both zonal and meridional winds is approximately of equal magnitude ($\sim$1 m/s). But the phase difference is minimum at 1.0 km (4.5 hr) and the phase difference is maximum at surface and also at 2.5 km level. This semi-diurnal oscillation in wind may be associated with the semi-diurnal pressure oscillation.

Assuming the daily variation as consisting of diurnal and semi-diurnal oscillations, the diurnal oscillation accounts for about 60 per cent and the remaining 40 per cent for the semi-diurnal oscillation. The effect of other harmonics other than fundamental (diurnal) and second harmonic (semi-diurnal) has not been studied. The amplitudes of the diurnal oscillation in the lower troposphere during the peak of S-W monsoon period vary within 3 m/s. This is rather small (but well above the error bar in the wind observation ± 1 m/s (Middleton and Spilhaus 1953) compared to the mean meridional and zonal wind which is of the equal magnitude 10 m/s. Seasonal variation in the diurnal wind oscillation is possible and hence similar experiments are to be conducted in other seasons as well.

5. Conclusions

The main conclusions of the present balloon wind measurements during 18-20 August 1976 are summarised below :

(*i*) Despite cloudiness, rainfall and resulting reduction in land sea contrast of temperature during the SW monsoon over the west coast of India, Thumba lower tropospheric winds show land-sea breeze effect on the prevailing north westerly winds during August.

(*ii*) The wind speeds below 2 km are strong with speeds of the order of 10 m/s while above 2 km, it tends to decrease to nearly half.

(*iii*) The average vertical wind shear values are in the range100×10^{-4} to 30×10^{-4} per sec significant in the lowest 300 m and strongest in the first 100 m layer.

(*iv*) The maximum amplitude of the diurnal oscillation of zonal and meridional winds is 3 m/s and of the semi-diurnal oscillation is 2 m/s thus accounting for 60 per cent and 40 per cent respectively of the daily variation.

It is suggested to conduct similar experiments in other seasons-winter, spring and autumn equinox periods-in clear weather periods to evaluate the seasonal variation in the diurnal oscillation and vertical wind shears.

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