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Diurnal variation of upper air temperatures

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ABSTRACT. The radiosonde observations for the four synoptic hours 00, 03,12 and 15 GMT for New Delhi, Nagpur and Madras have been utilised to study the diurnal variation of upper air temperatures. Nocturnal cooling of the order of 1° to 2° K is indicated. Between the levels 850—300 mb the apparent diurnal range is found to vary from 0·3° to 4·5°K. The variation of the diurnal range with latitude, altitude and season is also examined.

1. Introduction

Information regarding diurnal variation of temperature in the upper air will be quite useful to the forecasters as well as to the climatologists. Attempts have been made in the past to study the upper air diurnal temperature variations both from consideration of radiation balance as well as from direct observations of temperature. The studies of Elsasser (1940), Penner (1948) and London (1951) come under the first category. Using the average soundings of temperature and humidity along with Elsasser's radiation chart, Penner estimated that the mean long-wave radiative cooling in the troposphere varies from 0·4° to 0·8°C per day in winter and from 0·8° to 1·2°C per day in summer at Arctic Bay. Elsasser estimated that the above radiative cooling is about 1°C per day on clear nights in polar air masses and 2° to 3°C in equatorial air masses. London (1951) estimated that the average diurnal radiational temperature change in the troposphere in our latitudes is of the order of 1°C, taking into consideration both the infra-red cooling and the heating due to absorption of insolation.

There are other investigations in which actual observations of upper air temperatures taken at different times of the day have been utilised to study the diurnal variation. From a comparison of mean monthly temperatures for day and night at several American radiosonde stations, Wulf *et al.* (1946) concluded that a diurnal temperature difference large enough to be observed does exist. Further, Scherhag (1948) found from the German aircraft ascents upto the 500-mb level that the annual mean of day to night temperature change is less than 1°C throughout the middle troposphere. Riehl (1947) also found diurnal variations of temperature even in the high troposphere over the East Caribbean during October and November 1944. Another investigation which corroborates the existence of diurnal variation of temperatures in the upper air is that of Belmont (1954) who from an analysis of the upper air soundings made at two stations in Greenland, found that the diurnal range varied from 0·5° to 5·1°C for levels from 950 to 350 mb and from 0·6° to 9·7°C for levels between 350 and 100 mb. The average value was found to be around 2°C in the troposphere.

The diurnal variation of upper air temperatures over India has not so far been studied mainly because observations taken at sufficiently close intervals of time on each day are not readily available for Indian radiosonde stations. However, an attempt has been made here to utilise the available data to make some tangible and useful inferences regarding the diurnal variation of the upper air temperatures, which may be of help in planning special observational programme for studying this in greater detail.

2. Data utilised and the method of analysis

In this study, the diurnal variations at three stations, New Delhi, Nagpur and Madras have been investigated and attention has been confined to 850-, 700-, 500- and 300-mb levels. April, July, October and December are taken to be representative of the four seasons. Prior to 1 April 1957, radiosonde observations were being taken in India at the two synoptic hours of 03 and 15 GMT, whereas from that date the observational timings have been changed to 00 and 12 GMT. Data for about two years are already available for the latter synoptic hours and for many of the radiosonde stations. Hence the monthly means of temperature for the synoptic hours 00 and 12 GMT and for the stations mentioned above have been worked out based on the data for the years 1957 and 1958. The corresponding means for the hours 03 and 15 GMT have been obtained making use of only the data for a two-year period, immediately preceding 1957 (1955 and 1956) so that the two sets of means obtained might be comparable. The mean temperatures for the four months and for the three stations are shown in Tables 1 to 3, along with the apparent diurnal range and nocturnal cooling. Since only four observations, not properly distributed with respect to the times of occurrence of maximum and minimum, are available, it is not possible to draw the diurnal variation curves with sufficient degree of confidence. Hence these curves are not presented here.

A discussion regarding the suitability of the data used for the present study is not only useful but even necessary. One limitation of the data used here is that the data for all the four synoptic hours do not belong to the same period. Since in the present study only mean temperatures for different hours based on large number of observations have been made use of, the above limitation may not be serious. As far as possible, the means for the two different sets of observations [(00 and 12 GMT) and (03 and 15 GMT)] have been separately considered for inferring the diurnal variation and only those conclusions which are justified from theoretical considerations and other observational evidence are presented. In the absence of sufficiently large number of observations for the four synoptic hours made during the same period, it is felt worthwhile to examine the monthly means of temperatures for these hours obtained as described above. It can be expected that they will show up at least some of the more important features of the diurnal variation of upper air temperature.

The monthly means of temperatures, instead of the individual values, have been utilised for the purpose of studying the diurnal variation. There is an advantage in considering the monthly means instead of the individual values, for this would eliminate the day-to-day variations which have to be considered separately.

Another important aspect to be considered in this connection is the effect of insolation errors on the upper air temperature observations utilised here and their effect on the conclusions to be drawn. According to the available information (Mani *et al.* 1959, Väisällä 1957) the radiation errors of the Indian radiosonde are not considerable at the lower levels (below 400 mb) where the density of air and ventilation are sufficient to carry away the excess heat gathered by the temperature element. For the higher levels radiation corrections are being applied at all the Indian radiosonde stations since July 1957. Thus, among the means of temperatures for the stations presented here those for 300-mb level and for the synoptic hours 03 GMT alone will be affected by insolation errors. Thus the ultimate effect of the radiation error will be to decrease slightly the estimates of diurnal range of temperature for 300-mb level presented here. The insolation error will approximately be of the order of 0·5° to 0·8°C at this level for the 03 GMT observation at the stations considered.

TABLE 1

Mean temperature along with apparent diurnal range of temperature and nocturnal cooling at New Delhi

Pressure level (mb)	Mean temperature (°K)								Nocturnal cooling (T_{12}—T_{00}) (°K)	Apparent diurnal range of temperature (°K)
	00 GMT		03 GMT		12 GMT		15 GMT			
	n	*T*	*n*	*T*	*n*	*T*	*n*	*T*		
					APRIL					
850	57	295·4	57	294·3	58	297·4	60	296·3	+2·0	3·1
700	57	282·4	57	281·2	59	283·5	60	281·3	+1·1	2·3
500	57	263·0	56	261·9	56	264·2	57	261·2	+1·2	3·0
300	57	236·7	53	238·6	54	237·9	52	241·2	+1·2	4·5
					JULY					
850	62	295·7	61	295·0	62	297·2	62	297·0	+1·5	2·2
700	62	286·3	61	285·1	62	287·1	61	286·1	+0·8	2·0
500	59	272·3	60	271·2	62	273·2	61	271·6	+0·9	2·0
300	55	250·3	54	249·1	56	250·3	57	249·6	0	1·2
					OCTOBER					
850	61	292·1	59	290·5	62	293·8	61	290·9	+1·7	3·3
700	60	280·7	58	280·8	62	282·5	61	280·8	+1·8	1·8
500	61	265·5	56	266·9	60	266·8	62	266·3	+1·3	1·4
300	61	241·1	51	244·5	58	242·4	59	243·3	+1·3	3·4
					DECEMBER					
850	61	284·0	59	283·9	60	286·1	60	284·7	+2·1	2·2
700	61	277·1	59	274·6	60	278·3	60	275·5	+1·2	3·7
500	61	260·7	57	259·1	60	261·6	59	259·8	+0·9	2·5
300	58	234·6	52	238·7	55	235·8	48	235·7	+1·2	4·1

3. Discussion of results

The difference between the 12 GMT and 00 GMT means of temperatures, both of which have been corrected for insolation errors, will give us an idea of the nocturnal cooling and will also help us establish the reality of the diurnal variation. From Tables 1 to 3, it is seen that this nocturnal cooling is generally between 1° and 2°K, except at 850 mb over Nagpur in April and at 500 mb over Madras in December, where it is about 3°K. These values are in agreement with the estimates given by Elsasser (1940), Penner (1948) and London (1951), from considerations of radiation balance. Thus there does seem to exist a diurnal variation of an observable magnitude. There are a few cases in which even slight nocturnal warming is indicated. But this feature remains to be confirmed by further observations.

Cooling between 00 and 03 GMT at levels up to 500 mb is generally indicated at New Delhi and Nagpur*. It is more frequent at New Delhi than at Nagpur and is very infrequent at Madras. Cooling in the early hours of the day in the lower layers may be due to

*My attention was drawn by the Editor to an unpublished paper by N.C. Dhar and H. Mitra. The special radiosonde observations at New Delhi reported by them show a similar cooling.

TABLE 2

Mean temperature along with apparent diurnal range of temperature and nocturnal cooling at Nagpur

Pressure level (mb)	Mean temperature (°K) 00 GMT n	T	03 GMT n	T	12 GMT n	T	15 GMT n	T	Nocturnal cooling ($T_{12}-T_{00}$) (°K)	Apparent diurnal range of temperature (°K)
					APRIL					
850	56	297·1	54	297·7	57	300·3	53	300·2	+3·2	3·2
700	55	283·8	51	285·2	55	285·3	52	284·8	+1·5	1·5
500	51	265·4	44	266·9	48	266·9	47	267·2	+1·5	1·8
300	49	240·5	44	243·7	46	241·5	43	241·0	+1·0	3·2
					JULY					
850	62	293·2	58	292·6	60	294·1	56	293·9	+0·9	1·5
700	61	284·9	58	284·6	59	285·0	58	284·4	+0·1	0·6
500	58	271·3	53	270·1	56	271·1	53	270·5	—0·2	1·2
300	54	247·9	37	249·5	42	248·5	30	248·2	+0·6	1·6
					OCTOBER					
850	61	292·2	58	290·8	60	293·2	55	291·9	+1·0	2·4
700	59	281·4	58	282·3	59	281·8	55	282·3	+0·4	0·9
500	54	267·4	50	268·5	52	267·9	49	268·3	+0·5	0·9
300	46	240·6	43	244·9	43	241·6	27	244·5	+1·0	4·3
					DECEMBER					
850	62	287·7	51	287·0	62	289·1	54	288·2	+1·4	2·1
700	59	281·5	50	279·7	58	281·6	48	279·4	+0·1	2·2
500	60	265·2	47	265·4	60	265·3	49	263·9	+0·1	1·5
300	59	239·1	45	240·2	58	238·5	47	239·2	—0·6	1·7

turbulence and the consequent adiabatic ascent of air from the lower levels. But the cooling at the much higher levels, if real, cannot similarly be explained. Around 1525 m Riehl (1947) noticed a similar cooling in the morning hours.

It can be inferred from the mean temperatures for the four hours of observation that at Nagpur and New Delhi the minimum temperature at levels upto 500 mb generally occurs around 03 GMT and it occurs about 00 GMT at 300-mb level, whereas at Madras the temperature at all levels is lowest around 00 GMT. Among the means of temperatures for the four hours of observation, that for 12 GMT is generally the highest at all stations and levels considered here and there is a general rise in temperature prior to 12 GMT and a fall after 12 GMT indicating that maximum temperature is likely to occur between 03 and 12 GMT, perhaps closer to 12 GMT. In the lower layers (in the first 1 km also), where turbulent exchange is an important process of transfer of heat upwards from the surface of the earth,

TABLE 3

Mean temperature along with apparent diurnal range of temperature and nocturnal cooling at Madras

Pressure level (mb)	Mean temperature (°K)								Nocturnal cooling (T_{12}—T_{00}) (°K)	Apparent diurnal range of temperature (°K)
	00 GMT		03 GMT		12 GMT		15 GMT			
	n	*T*	*n*	*T*	*n*	*T*	*n*	*T*		
					APRIL					
850	58	294·2	27	295·8	60	295·5	59	295·9	+1·3	1·7
700	57	284·6	27	285·3	60	285·5	58	284·4	+0·9	1·1
500	50	267·9	27	269·0	57	269·0	56	267·9	+1·1	1·1
300	40	242·7	21	245·6	45	244·4	44	244·8	+1·7	2·9
					JULY					
850	61	292·8	59	292·5	61	294·3	62	293·4	+1·5	1·8
700	61	283·0	56	283·0	61	282·7	62	282·8	—0·3	0·3
500	59	267·6	52	269·0	60	268·5	59	268·7	+0·9	1·4
300	56	242·9	49	244·9	56	241·4	47	244·7	—1·5	3·5
					OCTOBER					
850	62	291·5	60	292·0	62	292·7	62	292·0	+1·2	1·2
700	62	282·5	57	283·4	61	283·7	60	282·8	+1·2	1·2
500	59	267·6	54	269·3	60	268·5	55	268·3	+0·9	1·0
300	49	242·3	49	246·0	54	242·5	49	243·8	+0·2	3·7
					DECEMBER					
850	62	288·8	62	288·2	62	289·2	61	288·1	+0·4	1·1
700	62	282·5	62	283·3	62	283·3	61	283·1	+0·6	0·8
500	59	265·7	59	268·7	60	268·3	58	267·8	+2·6	3·0
300	50	240·7	48	243·6	45	242·9	50	242·4	+2·2	3·0

there will be a lag in the time of occurrence of maximum along with a reduction in the amplitude of the diurnal variation as we go higher up (Brunt 1944). Riehl (1947) did not notice any lag of considerable magnitude at the higher levels.

The apparent diurnal range (the difference between the maximum and minimum among the means for the four synoptic hours) for the levels considered here (850—300 mb) varies from 0·3° to 4·5°K (Tables 1 to 3). It may be pointed out here that the actual diurnal range, especially for the levels below 300 mb, can be expected to be higher than the apparent range, since none of the observations utilised in this study is close to the hour of maximum temperature, though one of them may be close to the hour of minimum temperature. The diurnal range is found to vary with latitude, altitude and season. There is a general tendency for the diurnal range to decrease from north to south. Further, the range was found to vary with height. But it does not seem to either steadily increase or decrease with height at all stations and levels. Thus, this study does not corroborate the conclusion of Riehl that beyond 1525 m, the range steadily increases upto 13 km.

Just as at the surface, in the upper air also the diurnal range should depend on the particular air mass over the place, which itself varies with the season. Hence it is reasonable to expect that this diurnal range will vary with season. The average diurnal range for the four levels considered here, is lowest in July at Nagpur and New Delhi and it is almost the same during all the four months at Madras. During the monsoon season almost the entire country is under the spell of the monsoon air with the associated cloud system. The clouds act as radiation shield and effectively decrease the diurnal range of temperature at the lower layers. This will not be the case for layers beyond the clouds. Unlike in the monsoon season different air masses prevail over different parts of the country in the other seasons. Hence the maximum range will occur in different months at each one of the stations, though the minimum at all stations may occur during the monsoon.

The present study has shown the existence of diurnal variation of an observable magnitude in the upper air temperatures. The diurnal range of temperature was found to vary with latitude, altitude and season. On the basis of the results discussed above and on the basis of some of the earlier studies on the subject, it is felt that four more radiosonde observations (over and above the existing observations at 00 and 12 GMT) taken at 04, 08, 16 and 20 GMT at least for one month in each season at a few stations will be of considerable help in obtaining a more detailed picture of the diurnal variation of upper air temperatures, which is not only of theoretical interest but is also useful for forecasting upper air temperatures for aviation.

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