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A study of the seasonal oscillations in the upper air temperatures over India

A. K. BANERJEE and K. K. SHARMA

Regional Meteorological Centre, Nagpur

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ABSTRACT. The results of the harmonic analysis of the mean monthly upper air temperature of 13 radiosonde stations in India have been presented in this paper. Diagrams showing the spatial distributions of the amplitudes and phase angles of the first two harmonics over the different parts of the country are presented and discussed. Broadly, two maxima of temperature amplitudes are found, *viz.*, one from ground upto about 850 mb and the other higher up in the troposphere between 600 and 150-mb levels. The existence of these two distinct regimes seem to indicate two different types of physical processes operating to cause the seasonal temperature changes.

1. Introduction

It is well known that the temperatures in free air undergo various types of periodic variations. The variations of short periods, like the diurnal variations, have been studied by Riehl (1947), Kay (1951), Teweles and Finger (1960) and others. Salient features of the diurnal variations of upper air temperatures over India have been brought out by Pant (1960) and Rangarajan and Sikka (1963).

From an examination of the distribution of normal upper air temperatures over India in each of the months of the year, it is observed that they also undergo considerable variations particularly from one season to another. There is also a suggestion of long period waves embedded in these variations. The purpose of this paper is to isolate these long period oscillations by subjecting the relevant data to usual harmonic analysis and to study their characteristic properties over the Indian region.

2. Data studies

Monthly normal temperature of 13 radiosonde stations of India, as shown in Fig. 1, at various standard isobaric levels, for different months of the year, are utilised for the study. The data are taken from the India Meteorological Department publication entitled "Normals (1955) of temperatures, contour heights and dew point temperatures at standard isobaric levels of evening ascents of Indian Radiosonde Stations." The isobaric levels chosen for the study, in addition to the surface level, are —850, 700, 600, 500, 400, 300, 200, 150 and 100 mb. The number of observations on which the monthly normal temperatures for the above levels have been worked out for any particular station, are on the average : 240, 220, 220, 215, 200, 175, 115, 65 and 20 respectively per month. The normals for the 150 and 100-mb levels may not be as representative as for the lower levels due to comparatively less number of observations.

3. Method of analysis

The monthly normal temperatures values of the above stations at the various isobaric levels are subjected to harmonic analysis and the amplitude maxima together with the corresponding phases of the first five harmonics are worked out. It is observed that beyond the third harmonic, the amplitude maxima of the rest of the oscillations contributed very little to the total variations except at 100 and 150-mb levels and as such only the first three harmonic waves have been considered for the present study.

The first harmonic maxima and the corresponding phases in respect of the above stations for any particular isobaric level are plotted on a small map of India at the appropriate positions. Thereafter, iso-amplitude lines (at an interval of 1°C) and iso-phase lines (at an interval of 10°) are drawn very carefully on this map. These operations are carried out for other levels also. Now in order to make a representative three dimensional picture of the analysis, diagrams (Figs. 2 and 3) showing the variations in amplitude maxima and phases of the first harmonic oscillation with height (millibaric) along different latitudes through four longitudinal sections at 75°, 80°, 85° and 90° E are prepared. Most of the values of the amplitudes and phases of these diagrams have been picked up from the maps, referred to above, showing the iso-amplitude and iso-phase lines. Similar cross-sectional diagrams are prepared for the second and third harmonic oscillations as well.

4. Results and Discussions

(*A*) *First Harmonic Oscillation*

Four sectional diagrams showing the variations of the amplitude A_1 and phase ϕ_1 at 75°, 80°, 85° and 90°E longitude have been prepared. But since the basic features in all these diagrams are more or less identical; only two diagrams, one at

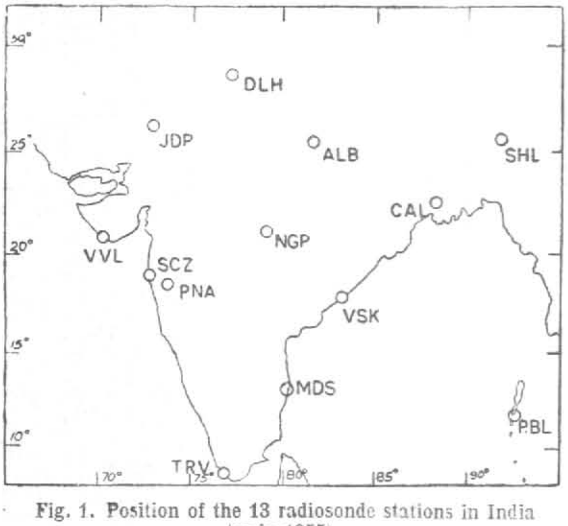

Fig. 1. Position of the 13 radiosonde stations in India (as in 1955)

75° E and other at 85° E longitude have been presented in Figs. 2 and 3. The following features in the variations are conspicuous —

(*i*) At all the longitudinal cross-sections, the amplitudes have two maxima, one near the surface and the other at higher levels between 400 and 300 mb. The fluctuations attain a minimum value once near about 600-mb level and again at higher layers in the vicinity of 150-mb level. There is also some suggestion of a third maxima aloft 100-mb level.

(*ii*) The amplitudes at all levels from the ground upto the 200-mb level decrease progressively from north to south and this is true for all longitudinal cross-sections. Above 200-mb level, the variations in amplitudes do not conform to any systematic pattern.

(*iii*) The slopes of the iso-amplitude lines in the vicinity of the first maximum near the ground are very prominent from the ground upto 700-mb level in the sections at 75°E and at 80°E (not shown) and comparatively less prominent along 85°E and at 90°E (not shown) section. But, near the second maximum (between 400 and 300-mb levels) the iso-amplitude lines are well organised and their characteristics are almost identical at all the longitudinal cross-sections.

The first harmonic oscillations, as mentioned earlier, have two amplitude maxima, one near the ground and other at higher level. It may be mentioned here that the existence of a maximum at higher levels (at about 6 km) in addition to the one at the ground in respect of the temperature variations in England has also been stated by Brunt (1934). The variations are greatest in the layer between ground and 850-mb level but slowly decrease upwards upto about 700-mb level. Beyond this level, the rate of decrease in amplitude is greatly arrested resulting in a minimum near about 600 mb. The nature of the variations of these oscillations in the layer above the ground level and existence of an amplitude maximum within this layer suggest that these fluctuations occur due to the effects of insolation. It also appears that the effects of ground heating on upper air temperatures is generally confined to below 700-mb level. It can be seen from the phase diagrams [Figs. 2 (b) and 3 (b)] particularly for sections at 75°E longitude, that the oscillations embedded within the layer from ground upto 700-mb level between 10° and 20° N latitudes generally attain their amplitude maxima during the period from middle of March to about end of May. Within the same layer, the maximum amplitudes are attained, in more northern latitudes, progressively between June and July more or less in phase with the annual northward movement of the sun. Thus, it appears that ground heating may be the primary cause for the existence of high amplitude oscillations, confined between surface and 700-mb level. Of course, such an organised sequence is not observed in the phase diagrams for 85°E longitude and 90°E longitude (not shown) since a major portion of this section is covered by sea where the effects due to insolation are comparatively less marked. The slopes of the iso-amplitude lines over the sea area, in these two cross-sections, are also less marked for the same reason.

The second maximum in the oscillation at higher levels, occurs at all longitudinal sections during the summer months, particularly during middle of July to middle of August when the monsoon is in full swing throughout the country. A similar maximum is also found at stations in the middle latitudes of Asia not affected directly by the monsoon. It is, therefore, felt that absorption of heat occurring in the thick layer between 600 to 150-mb levels during summer is perhaps responsible for enhancing the amplitudes of the oscillations within this layer. As mentioned earlier, it is worthwhile to note that this amplitude maximum occurs nearly at the same level (350 mb approx.) in all longitudinal sections and that the iso-amplitude lines around this level are well organised and possess nearly identical characteristic in all the sections. Thus, the second maximum has more or less uniform characteristics at all cross-sections unlike the lower one. It may be pointed out that the heating of the upper troposphere is well marked during the monsoon months and extends from 600-mb to 150-mb level. The depth of the upper atmospheric layers affected by this heating during the monsoon period is clearly indicated in the phase diagrams by the sharp gradient of the iso-phase lines in the vicinity

Phase angles conversion to dates

0°	15 Jan
30°	15 Feb
60°	15 Mar
90°	15 Apr
120°	15 May
150°	15 Jun
180°	15 Jul
210°	15 Aug
240°	15 Sep
270°	15 Oct
300°	15 Nov
330°	15 Dec

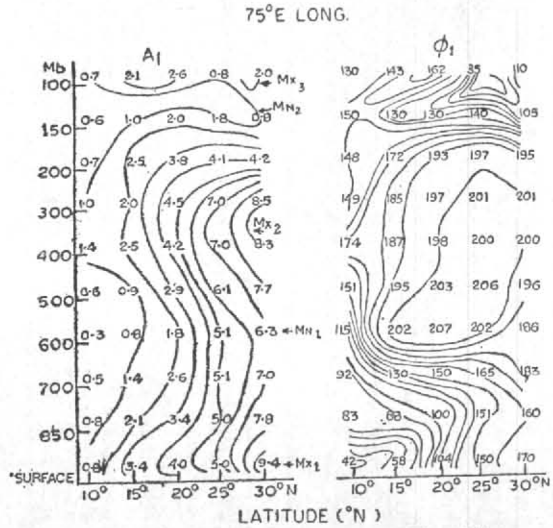

Fig. 2(a) Fig. 2(b)

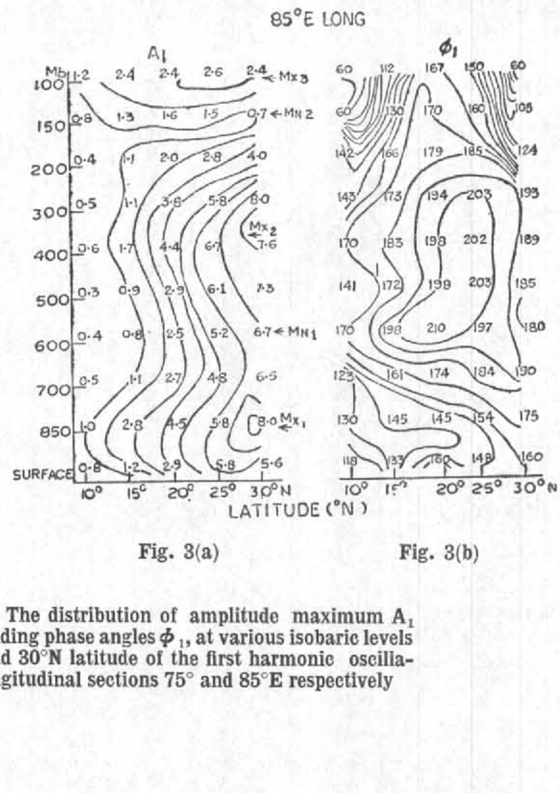

Fig. 3(a) Fig. 3(b)

Figs. 2 and 3. The distribution of amplitude maximum A_1 and the corresponding phase angles ϕ_1, at various isobaric levels between 10°N and 30°N latitude of the first harmonic oscillations for the longitudinal sections 75° and 85°E respectively

1. Amplitudes are expressed in °C and phases in degrees

2. The continuous lines on the amplitude diagrams (A_1) are the iso-amplitude lines drawn at an interval of 1°C and similar lines on the phase diagrams are iso-phase lines drawn at an interval of 10 deg.

3. The dates of maximum amplitudes corresponding to different phase angles are indicated along side the diagram.

4. MX_1, MX_2 and MX_3 stand for the first (near the ground), the second (near 350 mb) and the third (near 100 mb) maximum, in amplitude maximum A_1 distribution respectively.

5. MN_1 and MN_2 stand for the first and the second minimum in amplitude maximum distribution respectively.

6. Approximate positions of these maxima and minima are shown in the marginal space of the amplitude diagrams.

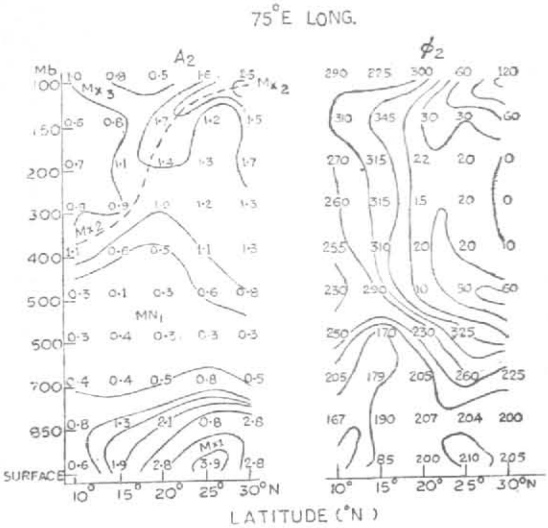

Fig. 4(a) **Fig. 4(b)**

Phase angles conversion to dates

0°	15 Jan/Jul
30°	1 Feb/Aug
60°	15 Feb/Aug
90°	1 Mar/Sep
120°	15 Mar/Sep
150°	1 Apr/Oct
180°	15 Apr/Oct
210°	1 May/Nov
240°	15 May/Nov
270°	1 Jun/Dec
300°	15 Jun/Dec
330°	1 Jul/Jan

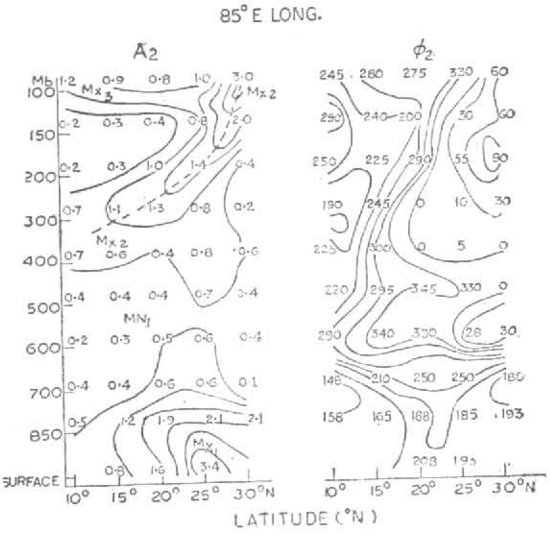

Fig. 5(a) **Fig 5(b)**

Figs. 4 and 5. The distribution of amplitude maximum A_2 and corresponding phases at different isobaric levels, between 10°N and 30°N latitude of the second harmonic oscillations for longitudinal sections at 75° and 85° E respectively

1. The iso-amplitude lines are drawn at an interval of 0·5°C and iso-phase lines at an interval of 30°

2. The thick dotted line in the amplitude diagrams represent the tilted axis of the core of the second maximum MX_2

(Also see the legend given under Figs. 2 and 3) of the 600 and 200-mb levels. In fact, the sharp gradient in the iso-phase lines existing within the layer 700-600 mb, conspicuous in the phase diagrams for 75° E and 80° E longitudinal sections (the latter not presented), separates the troposphere, as it were in two distinct strata, one below 700-mb and other between 600 to 150-mb level. In the lower stratum, the effects due to insolation are predominant, whereas in the upper stratum the effects of heating due to some other physical processes occurring primarily during the summer season are prominent. The effects due to the latter processes, perhaps, do not extend beyond the 150-mb level as is evidenced by the existence of another sharp gradient in the phase diagrams in the vicinity of this level and also because the oscillations apparently attain another minimum near about this level almost in all the four longitudinal sections.

Since the number of observations on which the normals have been worked out for levels above 200-mb is comparatively less, the existence of an amplitude maximum aloft 150-mb level, mentioned earlier, is rather tentative subject to confirmation by future studies undertaken with more number of observations. In view of this, the nature of this amplitude maximum and the reasons for its occurrence etc have not been discussed.

(B) Second Harmonic Oscillation

The salient features of this oscillation as revealed from the four sectional diagrams at 75°, 80°, 85° and 90°E longitude are stated below. Only two diagrams, one at 75° E and the other at 85°E are, however, reproduced in Figs. 4 and 5.

(*i*) The amplitudes are smaller than that of the first harmonic, level for level in each cross-section and at all latitudes except near 200-mb level and above between 25°N and 30°N latitudes where they are of magnitude comparable with the first.

(*ii*) Like the first harmonic oscillation, two amplitude maxima are observed at all sections in this harmonic also, one at the ground level and the other in higher layers generally extending aloft from 400-mb level. The maximum at the higher level is of comparatively small magnitude (1° to 3°C) but is quite distinct. Of the two associated minima, the one at the lower layers is quite prominent in all the sections and it covers a considerable depth of the atmosphere, generally between 700 and 400-mb levels. The minimum at the higher layers is not distinct and it appears over southern latitudes only.

(*iii*) In the vicinity of the first maximum near the surface, the slopes of the iso-amplitudes lines from ground upto 700-mb level are fairly well marked in sections at 75°E and also at 80°E longitude (not shown) and comparatively less marked in the other sections. But, unlike in the case of the first harmonic oscillations, the iso-amplitude lines near the second maximum at higher levels are not well organised. The axis of the core of the second maximum and so also the associated iso-amplitudes lines around it, have a vertical tilt upwards towards northern latitudes (*see* Figs. 4a and 5a).

The first maximum near the ground of the oscillation can be ascribed to the effects due to insolation as in the case of the first harmonic. The insolation effects are limited to 700-mb level from ground. It can be seen from the phase diagrams (Figs. 4b and 5b) that the amplitude maxima from ground to about 700-mb level occur in all sections once towards end of April and once again towards end of October when the first and the second summer are in full swing in India.

The domain of the second maximum, as seen from the configuration of 1°C iso-amplitude lines, extends as far south as 10°N in the longitudinal section at 75°E (Fig. 4a) and 80°E (not presented) and penetrates downwards even upto a level of 400-mb. But at the section at 85°E (Fig. 5a) its domain is reduced both in depth and width and more so at 90°E (figure not presented) where it is restricted between 20° and 30°N and between 300 and 100-mb levels in depth. It is seen from the phase diagrams that south of 20°N, the amplitudes of the oscillation within this domain attain their peak values once during the end of May and first week of June and once again after six months towards end of November and first week of December. To the north of 20°N, the axis of the core of the amplitude maxima steepens sharply from north of 25°N between 200 and 100-mb levels. But the significant fact is that the oscillations attain their peak once in January/February and once again during August/September.

The repetition of this maximum again in January/February perhaps takes place on account of of the following factors —

(*i*) Frequent passage of upper air troughs associated with the western disturbances moving across north India.

(*ii*) Influences due to the extra-tropical tropopause which appears slightly below 200-mb level during November to April, and perhaps,

(*iii*) Influences due to tropical type of tropopause which appears in the vicinity of 100-mb level throughout the year.

As regards the first factor, Ganesan (1955) has shown that large fluctuations of temperature in the upper and mid troposphere are associated with the migration of upper level troughs. Venkateswaran and Desai (1953) has ascribed these temperature changes due what they have termed as "damped temperature waves" and found that the amplitudes of these waves increase rapidly in the region of 200-mb level. It may be mentioned here that these migratory upper air troughs associated with the western disturbances travel in more southerly latitudes during February and consequently their effects are likely to be felt as far south as 20°N.

As regards the second factor*, it can be stated that north of 25°N the extra-tropical type of tropopause occurs more frequently during January and February. Thus it appears that the repetition of the amplitude maximum of the second harmonic oscillation north of 20°N in January/February might be due to the combined effect of the factors (*i*) and (*ii*) mentioned above.

It is necessary to point out that in the vicinity of 15°—20°N latitude range, in most of these phase diagrams, a sharp gradient in the iso-phase lines exists in the upper layers above 700-mb level; which perhaps indicate that to the north and south this latitude range, atmospheric processes which contribute towards upper air variations in temperature and build up the second harmonic oscillations are of different nature.

(*C*) *Third Harmonic Oscillation*

These oscillations are extremely small in magnitude except near the ground layers and in the layer between 150 and 100-mb level, where the amplitudes are of the order of 1°C. In the intervening layer of the troposphere, the amplitude of the oscillation are less than 0·5°C.

The effects due to insolation are felt upto 700 mb from the ground level in this oscillation also.

*Based on the tropopause data contained in departmental publications (India met. Dep.) dealing with the Indian radiosonde stations

The amplitude maximum in the layer takes place thrice, towards end of January, May and September and this is generally true for all the cross-sections. The existence of a maximum in the layer between 100 to 150 mb is perhaps due to the influences of the tropical type of tropopause, which exists in the vicinity of 100-mb level throughout the year.

The phase diagrams for this harmonic are in general chaotic in nature. The amplitude and phase diagrams for the third harmonic are not reproduced.

5. Conclusions

From the above statistical analysis, the following conclusions can be tentatively drawn—

(1) The two very effective factors which cause temperature fluctuations in the troposphere are (a) insolation and (b) absorption of heat by the upper troposphere during the summer season.

(2) The effects of the insolation are generally limited upto 700 mb from the ground level whereas the effects of the other factor predominate in the upper tropospheric levels, between 600 and 150-mb. These effects are manifested in all the harmonics.

(3) The other factors which contribute towards the genesis of these fluctuations, particularly in the second harmonic, are—

(*a*) Migratory troughs in the upper air,

(*b*) Influences of both the tropical type and extra-tropical type of tropopause.

(4) The extra-tropical type of tropopause influences the oscillations aloft 150-mb level of all three harmonics almost equally.

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