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Annual and semi-annual temperature oscillations in the northern hemisphere

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ABSTRACT. 1000-850 mb and 1000-300 mb mean monthly thicknesses have been subjected to hormonic analysis at about 200 stations in the northern hemisphere. Salient features of the annual mean, the annual oscillation and the semi-annual oscillation are presented. It is shown that the heat low which appears over southeast Asia during the summer monsoon is partly due to the permanent warm temperatures over this region. In the annual oscillation, largest amplitudes occur at about the same place and at about the same time in the entire troposphere. It is shown that the annual oscillation of tropospheric temperature over southeast Asia is not spectacularly different from that over the rest of the northern hemisphere in the same latitudes. It is, therefore, suggested that the special features of the annual monsoon of southeast Asia are due to special permanent features of temperature (and associated pressure and wind) field over the area rather than due to very special features of the annual temperature oscillation over the area.

1. Introduction

A number of authors have recently analysed the annual wave in the stratosphere and mesosphere (Reed 1962, 1966; Angell and Korshover 1970, Van Loon and Jenne 1970 b). Ebdon (1971) analysed Canton Island data of wind and temperature to determine the relative importance of the quasi-biennial, the annual and the semi-annual oscillations in the equatorial stratosphere and found significant annual oscillation in temperature.

The study of semi-annual oscillation in the stratosphere has also gained importance during recent years. Significant semi-annual wave in the temperature of the tropical stratosphere was discovered by Reed (1964). So far as the troposphere is concerned, Van Loon and Jenne (1969) studied the semi-annual oscillation in respect of zonal wind and temperature in the southern hemisphere. Van Loon *et al.* (1972) has summarised these in good detail for the southern hemisphere. A similar diagnostic study for the troposphere of the whole northern hemisphere was lacking in literature, till Asnani and Mishra (1975) and Asnani and Verma (1975) brought out the analysis of the annual and the semi-annual pressure oscillations for the northern hemisphere, from sea level to 100 mb level.

The thickness of a layer between two constant pressure surfaces is a measure of the mean virtual temperature of the layer. For some purposes it can be considered as a more useful parameter for studying the temperature distribution in the atmosphere than the actual temperature at constant heights or constant pressure levels. The authors have chosen thicknesses of layers 1000 to 850 mb and 1000 to 300 mb, primarily to represent the lowest tropospheric layer and also the entire tropospheric layer respectively.

The purpose of the present study is to bring out the salient features of the tropospheric annual and semi-annual temperature oscillations for the whole northern hemisphere, and to relate these features to the spectacular annual monsoon cycle of southeast Asia.

2. Data Sources

(*i*) 'Climatological Normals (CLINO) for climat and climat ship stations for the period 1931-1960.' WMO/OMM-No. 117 TP. 52, 1971—for m.s.l. pressure and surface temperature.

(*ii*) 'Short period averages for 1951-1960 and provisional average values for climat temperature and climat temp ship stations.' WMO/OMM- No. 170 TP. 82, 1965—for geopotential heights of 850 mb and 300 mb pressure levels.

(*iii*) For 18 additional near-equatorial stations five-year (1967-71) averages were prepared from the monthly values given in *Monthly Climatic data for the World*, Vols. 20-24, published by WMO in co-operation with U.S. Weather Bureau.

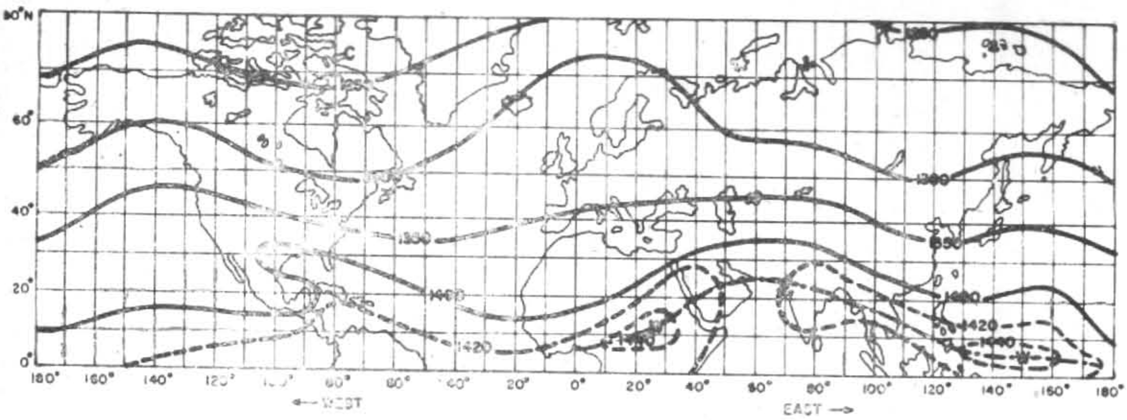

Fig. 1(a). Annual mean thickness (gpm) of 1000-850 mb layer. The dash-dot line is the line of largest thickness.

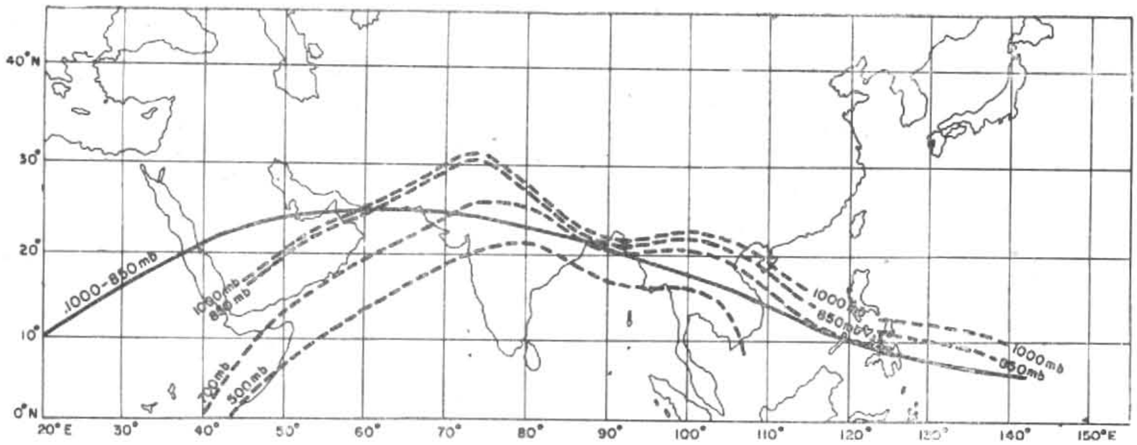

Fig. 1(b). Position of monsoon trough at 1000, 850, 700 and 500 mb levels (dotted lines) during July and that of maximum thickness line for the 1000-850 mb layer (continues line).

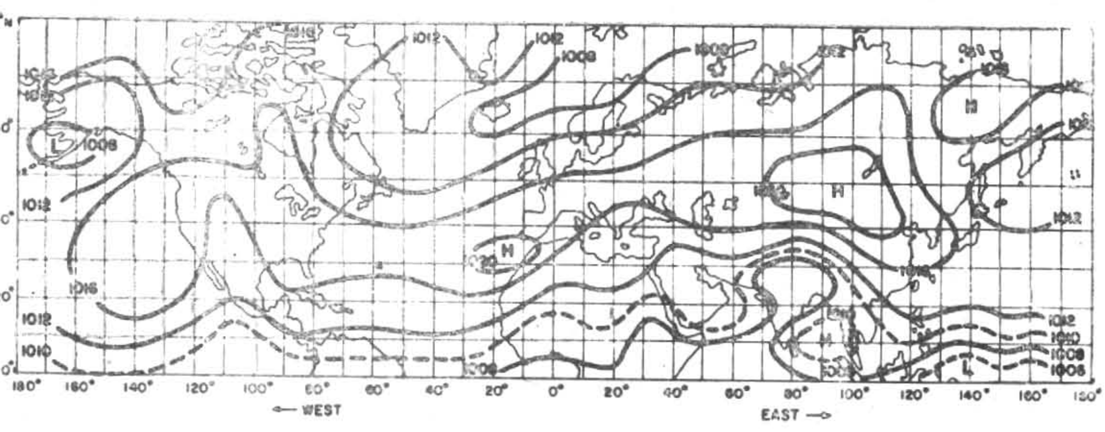

Fig. 1(c). Annual normal sea level pressure (mb) layer.

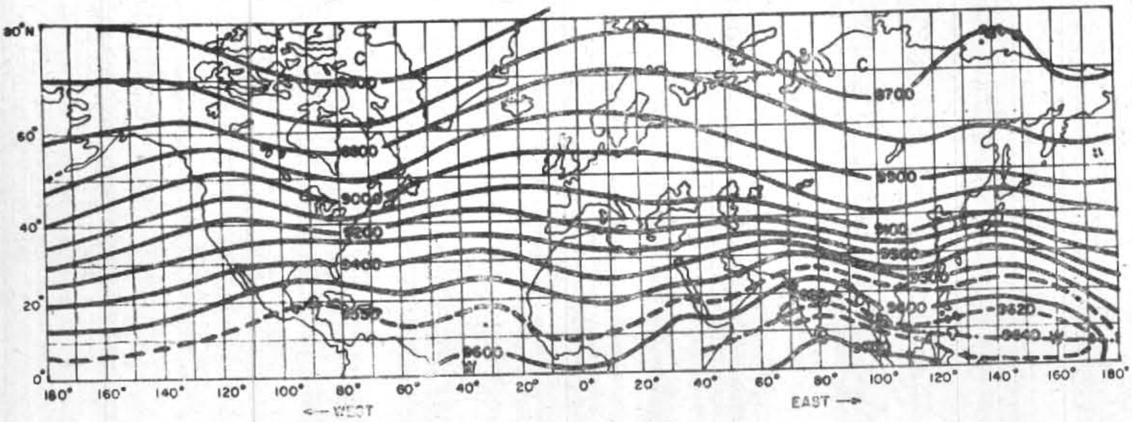

Fig. 2. Annual mean thickness (gpm) 1000-300 mb layer. The dash-dot line is the line of largest thickness.

(*iv*) "Normals of climat temp based on morning and afternoon/evening radiosonde data for the period 1951–1970", India. met. Dep., 1972 for 13 Indian stations.

The data coverage over the sea areas is sparse, but this could not be avoided. Fairly dense data network over land areas and use of island data wherever available justifies the analysis.

3. Analysis Procedure

At each station, the monthly mean values of sea level pressure were converted into the monthly mean values of 1000 mb height, using the relationship

$$Z_{1000\ mb} = \frac{RT}{g} \log \frac{p_{\text{sea level}}}{1000 \text{ mb}}$$

where, T is mean virtual temperature of air between sea level and 1000 mb. Other notations have usual meaning. As an approximation, T was taken to be the station level temperature. Analysis showed that the error introduced by this approximation would not affect our results to any significant extent. Monthly mean values of 1000-850 mb thickness and 1000-300 mb thickness were then obtained at each station. These monthly mean thicknesses were subjected to harmonic analysis to get annual mean as also the amplitude and phase of 12-monthly and 6-monthly oscillation at individual stations. The analyses of the annual mean, the 12-monthly oscillation and the 6-monthly oscillation are presented. Since the data consist of normals commencing from January and ending in December, the zero of the phase angle was counted from mid January.

4. Results and Discussion

4. 1. *Annual mean state*

(a) *1000-850 mb thickness* — Annual mean thickness (gpm) of the layer between 1000 and 850 mb is shown in Fig. 1(a). Broadly speaking, the pattern is characterised by lower thickness values near the pole (1~1250 gpm) increasing towards south (>1400 gpm near the equator). However, one interesting feature deserves special mention. *In the eastern hemispere, the maximum values of thickness, i.e., warmest temperatures occur not at the equator but somewhat to the north of the equator.*

Curiously enough, the warmest region in this annual mean chart has almost the same alignment as the summer monsoon trough in the lower troposphere. For comparison, we show in Fig. 1(b), the position of the summer monsoon trough at 1000, 850, 700 and 500 mb levels during the month of July and also the position of the maximum thickness line for the layer 1000-850 mb (annual mean). It is clear that the heat "low" which appears over the Indo-Gangetic plain in the lower troposphere during the summer monsoon season is partly due to the permanent warm temperatures over this region in the lower troposphere.

(b) *1000-300 mb thickness* — Fig. 2 depicts this pattern. As in case of 1000-850 mb thickness, lower thickness values (8600 gpm) occur near the pole, increasing towards the south (9600 gpm near the equator). Again, the noteworthy feature is observed, *i.e.*, in the eastern hemisphere, the maximum values of thickness (or the warmest temperatures) occur not at the equator but somewhat north of the equator.

4.2. *Annual oscillation*

(a) *1000-850 mb thickness* — Fig. 3(a) shows the amplitude of 12-monthly oscillation in the thickness of 1000-850 mb layer. These amplitudes are lowest (<10 gpm) near the equator and increase northwards upto about 60°N. There are two distinct maxima around 60°N latitude circle; one near 120°E (NE Aisa, 100 gpm) and the other near 120°W (NW Canada, 80 gpm). Fig. 3 (b) shows

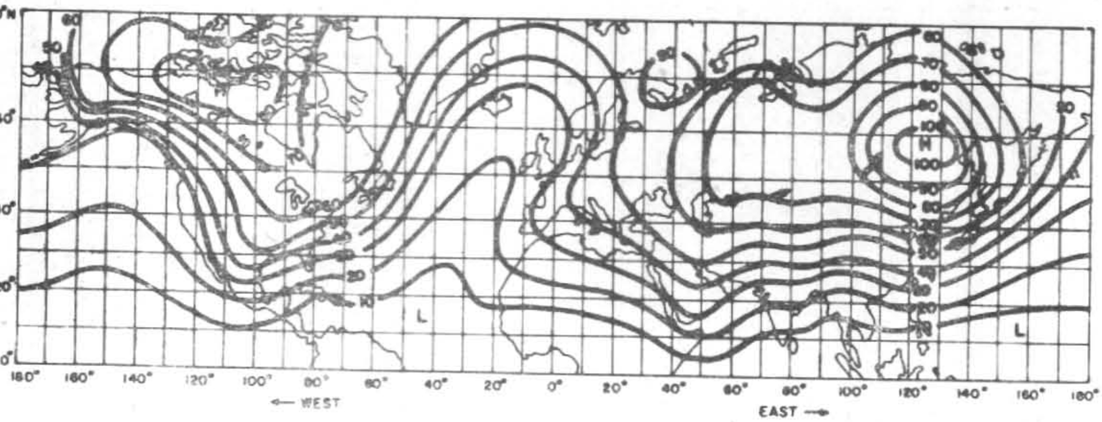

Fig. 3(a). Amplitude (gpm) of 1000-850 mb thickness in annual oscillation.

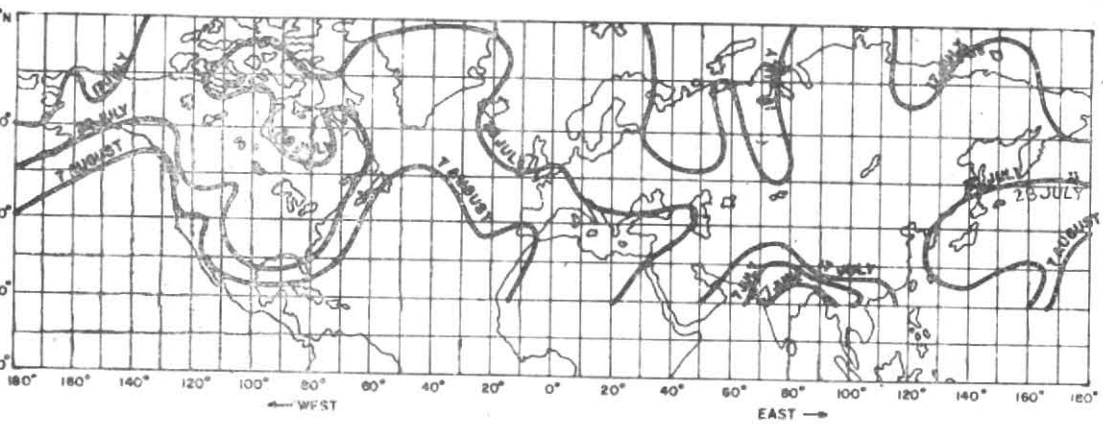

Fig. 3(b). Time of occurrence of maximum thickness (1000-850 mb) in annual oscillation,

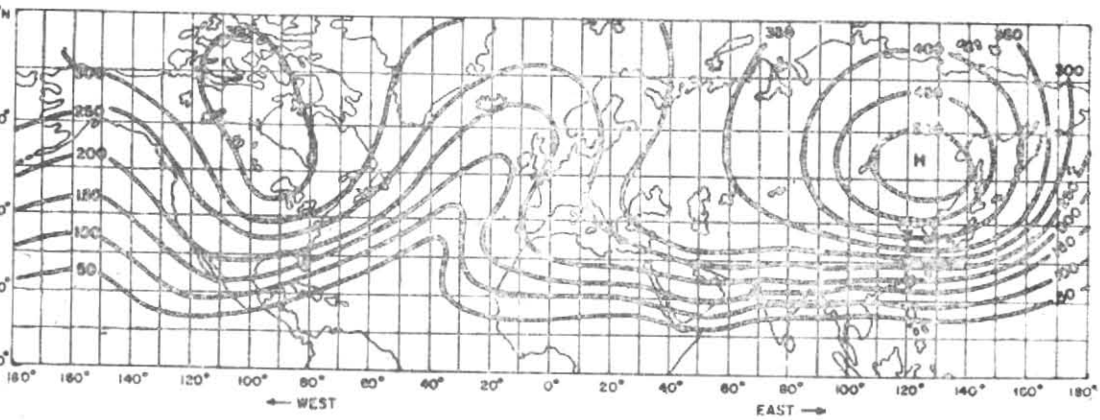

Fig. 4(a). Amplitude (gpm) of 1000-300 mb thickness in annual oscillation.

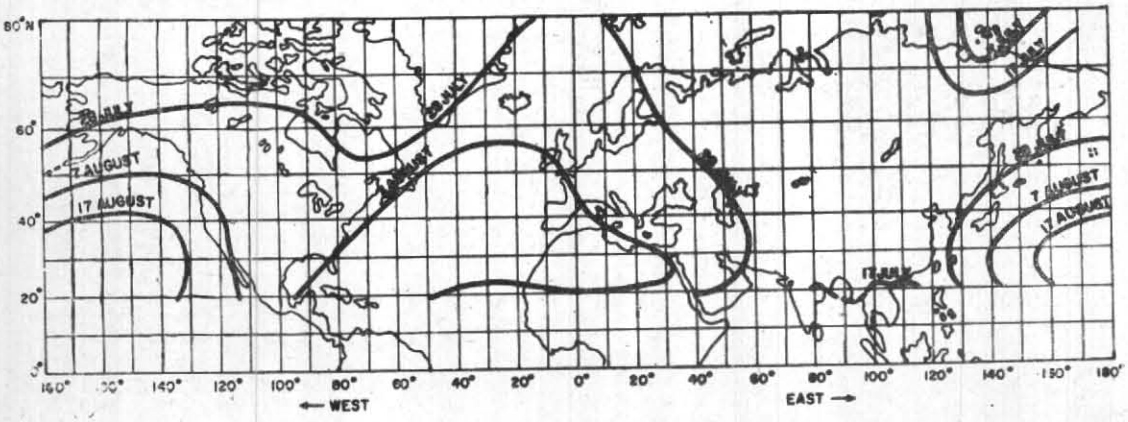

Fig. 4(b). Time of occurrence of maximum thickness(1000-300 mb) in annual oscillation.

the time of occurrence of maximum thickness. It is seen that the largest values of the oscillation over NE Asia as well as over NW Canada occur during later part of July.

(b) *1000-300 mb thickness* — Fig 4(a) shows the amplitude of 12-monthly oscillation in the thickness of 1000-300 mb layer. Here also, as in Fig. 3(a), the amplitude of the oscillation is smallest (<50 gpm) near the equator and increases northwards upto about 60°N. Around this latitude circle, there are two maxima, one over NE Asia (500 gpm) and the other over NW Canada (350 gpm). The peak values of this oscillation also occur during later part of July. The phase analysis is shown in Fig. 4(b).

Figs. 3 and 4 brings out the following features :

(*i*) Along a latitude circle, amplitude of the annual oscillation is smaller over the oceanic regions (Atlantic and Pacific) and larger over the continents (Eurasia and North America). Between the land masses, the oscillation is larger over Eurasian land mass. As a consequence, in the mid-summer, the troposphere is warmer over land masses than over oceanic regions. In mid-winter, the reverse takes place. It is somewhat surprising that this land-sea contrast is not seen so much in the *annual mean* thickness charts of the lower troposphere (Fig. 1a) and of the entire troposphere (Fig. 2.) but is very well marked in the 12-*monthly oscillation* of the lower troposphere as well as the entire troposphere. Obviously the lower, midde and upper troposphere, all get more heated during the summer and more cooled during the winter over the continental land mass than over the oceanic region.

(*ii*) It is generally believed that sensible heat transfer at the earth-air interface is largely responsible for temperature oscillations in the lower troposphere and that the release of latent heat during condensation of water vapour is responsible for heating in the middle and upper troposphere. Figs. 3(b) and 4(b) indicate the time when the maximum in the annual oscillation is reached in respect of 1000-850 mb and 1000-300 mb thicknesses respectively. It is seen from these figures that in the *lower troposphere* as well as in the *entire troposphere*, maximum thickness occurs *practically over the same region and almost at the same time*. We propose to undertake a more detailed study of the thickness oscillation for smaller layers, like 850-700 mb, 700-500 mb, 500-300 mb etc to see the spatial and temporal progression of thickness maxima for various layers. Their space and time relationships will indicate how strong is the vertical coupling between the various layers. If Figs. 3 and 4 are any indication, it would appear that there is perhaps *one and the same physical mechanism* responsible for the *annual* temperature oscillations at various levels. If the physical processes like diffusion of sensible heat from below and release of latent heat in the middle troposphere be really different and unconnected, then there is no reason to anticipate such similarity as we find in Figs. 3 and 4, unless the apparently different processes are in fact mutually linked very intimately. If so, we may attempt *a unified parameterisation of diabatic heating through sensible heat transfer and latent heat release, so far as annual cycle on the global scale is concerned*. The other possibility is that out of the two physical processes, sensible heat transfer and latent heat release, only one process is dominant for this annual oscillation.

(*iii*) *What causes the spectacular annual monsoon cycle of southeast Asia as distinct from the rest of the world?* This question is discussed below with reference to the computational results presented above.

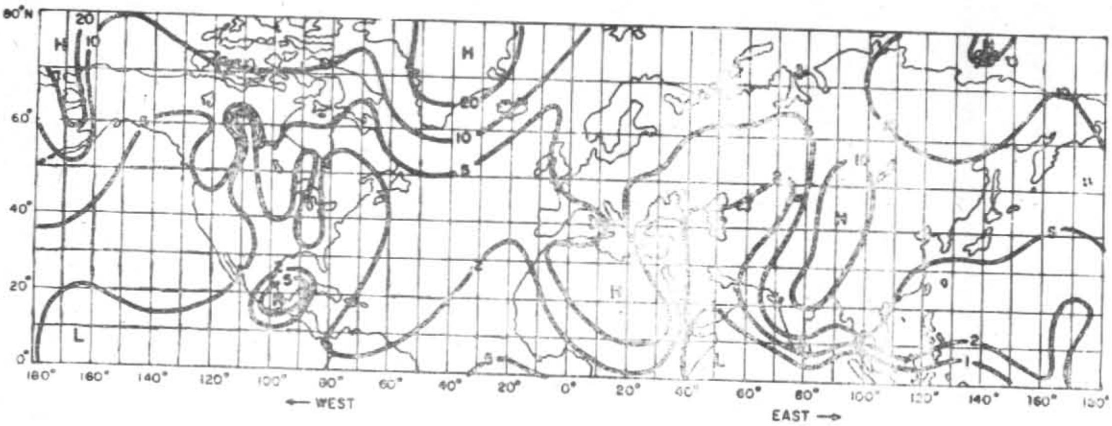

Fig. 5. Amplitude (gmp) of 1000-850 mb thickness in semi-annual oscillation.

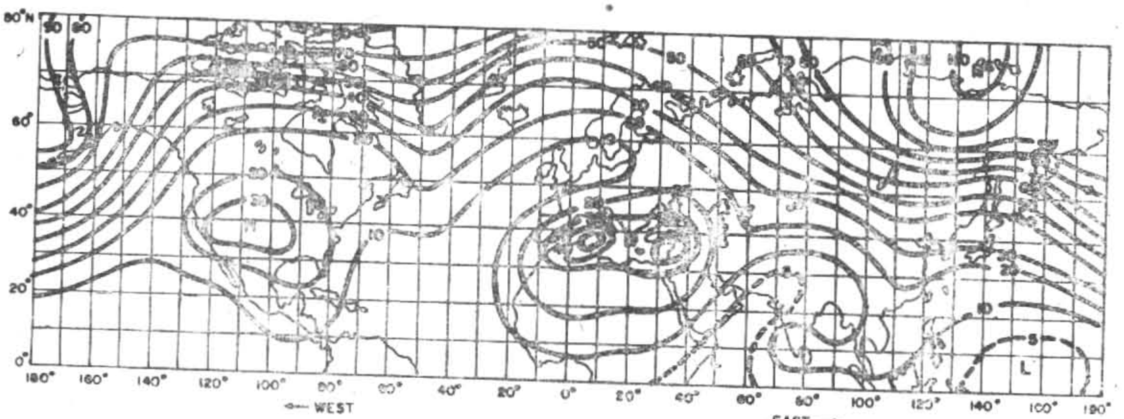

Fig. 6(a). Amplitude (gpm) of 1000-300 mb thickness in semi-annual oscillation.

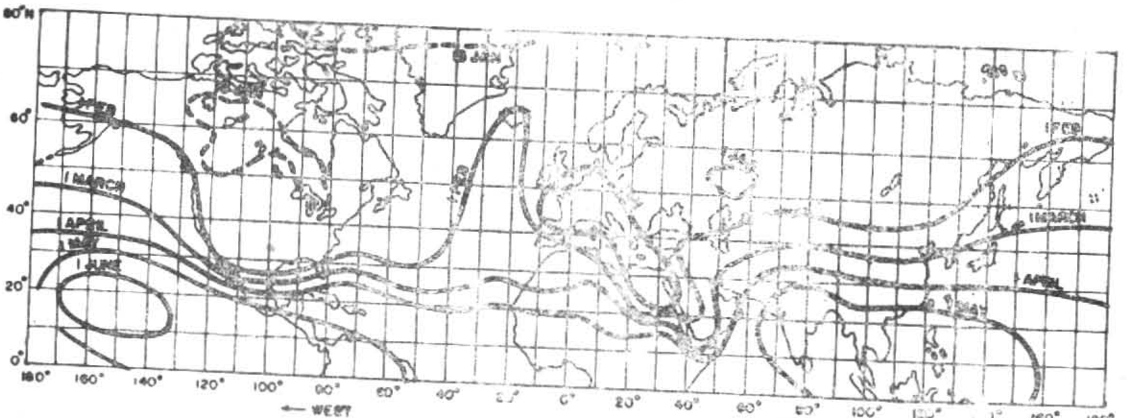

Fig. 6(b). Time of occurrence of maximum thickness (1000-300 mb) in semi-annual oscillation.

Thickness oscillation is another representation of temperature oscillation. Temperature oscillation arises from horizontal temperature advection, diabatic heating and vertical motion. Of these, diabatic heating appears to be playing a dominant role. Whatever be the relative role of these mechanisms of heating, Fig. 3(a) clearly shows that in the lower troposphere (1000-850 mb layer), air over southeast Asia gets heated during summer about as much as the air elsewhere at the same latitude, say over North America. In Fig. 3(a), isopleths of amplitude 10 to 60 gpm are about similarly placed over southeast Asia as over North America between latitudes 10°N and 40°N. Hence, the lower tropospheric summer "heat low" of south Asia which induces the air to "flow into" the land area of south Asia during summer and causes the summer monsoon as distinct from the summer monsoon elsewhere could not be due to any excessive summer heating over southeast Asia. The fact is that the *annual mean patterns* of lower tropospheric temperature (Fig. 1a) and pressure (Fig. 1c, taken from Asnani and Mishra 1973) over southeast Asia are somewhat different from those over the rest of the world. For example, there is *permanent* warm lower troposphere over southeast Asia as shown in Fig. 1(a) and discussed in section 4.1(a) above. There is also a *permanent* low pressure trough over north India as seen in Fig. 1(c). The ultimate causes of these special permanent features of the lower tropospheric temperature and pressure patterns over southeast Asia obviously are the special orography and land sea contrasts in the region It is not the purpose of this paper to go into a discussion of these ultimate causes of permanent features. What is aimed to be brought out here is that the *annual oscillation of lower tropospheric temperature over southeast Asia is not spectacularly different from that over the rest of the world in the same latitudes.*

(*iv*) The *maximum* amplitude of oscillation (Fig. 4a) is larger (500 gpm) over north Asia than over North America (360 gpm). Apparently, the maximum amplitude of oscillation depends upon the horizontal size of the land mass. Eurasian land mass is larger than North American land mass. The dependency of the amplitude of oscillation on the horizontal extent of the source of heating and cooling was first pointed out by Jeffreys (1926) and has been recently emphasised by Jacques and Wiin Nielsen (1971) and Asnani and Mishra (1975)

4·3. *Semi annual oscillation*

Figs. 5 and 6(a) show the amplitude of semi-annual oscillation in the thicknesses of 1000-850 mb layer and 1000-300 mb layer respectively. In the case of 1000-850 mb thickness the amplitudes are smallest (<2 gpm) near the equator and largest (>10 gpm) in the polar latitudes. Phases are not presented as they were found to be highly variable, presumably due to very small amplitudes.

In the case of 1000-300 mb thickness, the lowest amplitudes are near the equator (less than 10 gpm) and largest amplitudes are in the polar latitudes (greater than 60 gpm and even greater that 100 gpm in some regions). Within this general distribution, two secondary maxima are observed in the sub-tropical latitudes, one over U.S.A. and the other over the Mediterranean. The semi-annual oscillations in tropical and higher latitudes are in opposite phase. In higher latitudes maxima occur during January and July, while in tropics maxima occur during April and October.

5. Conclusions

(*i*) In the annual mean, the warmest temperatures in the eastern hemisphere are found to occur not at the equator but somewhat to the north along latitude 10°N. It is shown that the heat low which appears over southeast Asia during the summer monsoon is partly due to the *parmanent* warm temperatures over this region.

(*ii*) Latitude for latitude, the *annual mean* temperatures do not exhibit much contrast between land and sea, but the land-sea contrast is seen very prominently in the *annual oscillation of* temperature.

(*iii*) In the annual temperature oscillation, largest amplitudes occur at about the same place and at about the same time in the lower troposphere and also in the entire troposphere. This suggests that perhaps one and the same physical mechanism is responsible for the diabatic heating in the lower as well as in the middle and upper troposphere, so far as the annual heating cycle, on the global scale, is concerned. On this scale, unified parameterisation of diabatic heating through sensible heat transfer at the bottom of the atmosphere and through latent-heat release in lower and middle troposphere would appear plausible.

(*iv*) It is shown that the annual oscillation of tropospheric temperature over southeast Asia is not spectacularly different from that over the rest of the northern hemisphere in the same latitudes. Question then arises as to what causes the spectacular annual monsoon cycle over southeast Asia. It is suggested that the special features of the annual monsoon of southeast Asia are due to special *parmenent* features of pressure, temperature and wind field over the area rather than due to very special features of the annual temperature *oscillation* over the area.

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