

Profiles of mean static energy over India

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सारांश — इस लेख में भारतीय आकाश में माध्य स्थैतिक ऊर्जा का जलवायु संबंधी वितरण तथा इसकी मासिक व ऋत्वििक विविधताएं दी गई हैं। भारतीय आकाश में यह ऊर्जा जुलाई मास में अधिकतम तथा जनवरी मास में न्यूनतम होती है। ऊर्जा की रेखांशिक प्रवणता शीत ऋतु में दक्षिण से उत्तर की ओर होती है तथा वर्षा ऋतु में, जब अधिकतम ऊर्जा उत्तर भारतीय आकाश में मानसून द्रोणी क्षेत्र में घनीभूत होती है, उत्तर से दक्षिण की ओर होती है।

माध्य स्थैतिक ऊर्जा प्रोफाइल यह बताता है कि सारे देश का वायुमण्डल जुलाई मास में उष्ण कटिबंधीय विशेषताएं प्रदर्शित करता है जबकि जनवरी में यह विशेषताएं 18° उत्तर अक्षांश के दक्षिण में ही पाई जाती हैं। प्रोफाइलों से यह भी पता चलता है कि संवहन अस्थिरता पूरे वर्ष दक्षिण देशांतरों का एक सामान्य गुण है। तथापि उत्तर भारत में जनवरी के महीने में ऐसी कोई अस्थिरता नहीं देखी जाती किन्तु जुलाई के महीने में एक गहरी/मोटी (सतह से 6 कि. मी. तक) परत के रूप में मौजूद रहती है।

ABSTRACT. This paper presents the climatological distribution of mean static energy $c_p T + gz + Lq$ over India and its monthly and seasonal variations. The total energy content over India is minimum in the month of January and maximum in July. The meridional gradient of energy is from south to north during winter months and shows a reversal in monsoon months when maximum energy is concentrated in the monsoon trough zone over north India.

Mean static energy profiles show that atmosphere over the whole country exhibits tropical characteristics during July but only south of 18° N latitude in January. The profiles also indicate that convective instability is a normal feature of southern latitudes throughout the year. Over north India, however, no such instability is seen in the month of January but it is present in a deeper layer (from surface upto 6.0 km) in July.

1. Introduction

Study of total energy budget of the atmosphere in a region is useful in understanding the nature of exchange processes taking place during conversion from one form of energy to the other. It gives an idea of the location of sources and sinks of energy and throws light on the causes of prevailing circulation. In fact Palmen *et al.* (1969) state that the preference for different kinds of circulation for high and low latitudes may be considered in the context of the mean distribution of static energy.

Anjaneyulu (1969) studied the total energy budget of the monsoon trough zone over India in July and came to the conclusion that the column of atmosphere in this area is gaining about 8000 cal cm⁻² day⁻¹ in the mean in lower troposphere (below 500 mb) and losing about the same amount aloft by advective processes, and moisture-flux in the total heat budget of the atmosphere in this region is one order of magnitude lower than that of sensible heat ($c_p T$) and potential energy (gz). Bunker (1965) using the International Indian Ocean Expedition (IIOE) research aircraft data calculated the energy budget of the western and eastern sectors (west and east of 60° E) of the Arabian Sea during southwest monsoon and observed that there is a net accumulation of heat in the entire Arabian Sea during monsoon but the

western portion of the Arabian Sea accumulates twice as much heat as the eastern portion. Recently Chowdhury *et al.* (1980) studied the changes in the energy content of the atmosphere over the Arabian Sea during the onset of monsoon in 1979 using MONEX data.

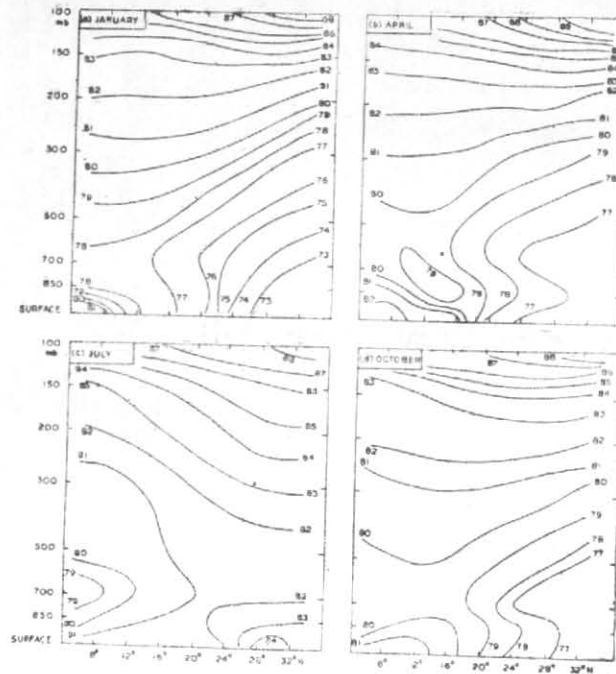
In the present paper an attempt has been made to present the climatological picture of the distribution of mean static energy over India and neighbourhood and its monthly and seasonal variation.

2. Data used

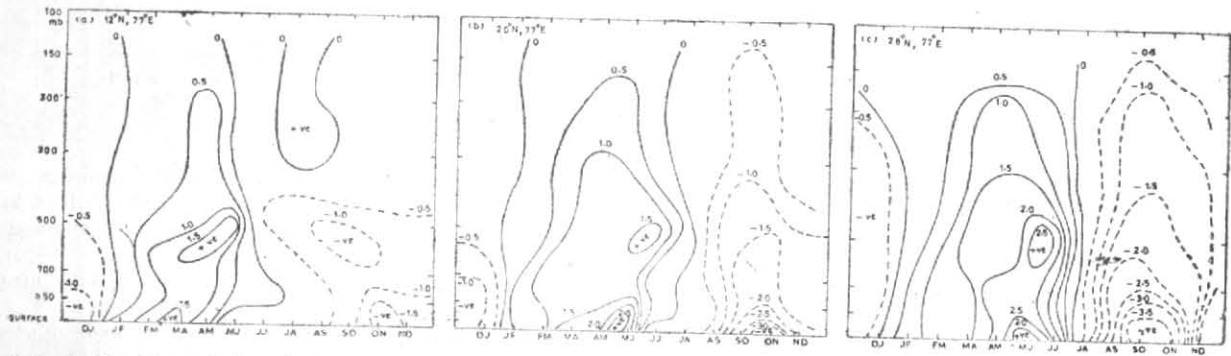
The total static energy is expressed as

$$Q = c_p T + gz + Lq$$

where Q is total static energy in cal/gm, g acceleration due to gravity (cm/sec²), z height above m.s.l. (cm), c_p the specific heat of air at constant pressure (cal/gm/degree C), T the absolute temperature, L the latent heat of condensation (cal/gm), q the specific humidity (gm/gm) and J the Joules constant (erg/cal). In this study Q has been calculated for surface and other standard isobaric levels upto 100 mb using the mean surface data of 30 stations and upper air data of seventeen radiosonde/rain stations in India, and of Rangoon in Burma. Monthly mean charts of Q were prepared for surface



Figs. 1(a-d). Vertical distribution of mean static energy ($c_p T + gz + Lq$) cal/gm from 8° N to 32° N Lat. along 77° E Long. in the month of (a) January, (b) April, (c) July & (d) October



Figs. 2 (a-c). Monthly variation of static energy at (a) Lat 12° N, Long. 77° E; (b) Lat. 20° N, Long. 77° E; (c) Lat. 28° N, Long. 77° E

and other standard isobaric levels upto 100 mb and its horizontal and vertical distributions were studied along 77° E for the four representative months of January, April, July and October.

3. Vertical and horizontal distribution of Q

In Figs. 1(a-d) are presented vertical cross-sections of Q along 77° E from 8° to 32° N for January, April, July and October respectively. It can be observed that :

(i) In January the maximum of Q lies over extreme south from surface to at least 150 mb with decreasing values to the north. The south-north gradient is maximum at the surface with decreasing trend upwards. It

almost vanishes at about 150 mb above which the gradient is reversed. Another noticeable feature is that a layer of minimum energy exists at about 700 mb to the south of about 20° N. North of it no such layer exists and the energy shows a gradual increase with height.

(ii) In April the south to north gradient of energy still persists as in January though the value of gradient has decreased, particularly in lower levels. Actually there is a slight decrease in Q in southern latitudes and considerable increase in northern latitudes leading to a weaker gradient in this month than in January. The level of minimum energy continues to be around 700 mb south of about 16° N but to the north, it shows a rise upto about 850 mb and then gradual fall upto 32° N. These changes (increase and decrease) are quite sharp north of 16° N. In the upper troposphere conditions

remain more or less the same as in January. It can be inferred from this that with the approach of summer, the build-up of energy in northern latitudes starts, particularly in lower levels, leading to a rise in the level of minimum energy. Above this level, however, the winter conditions still prevail.

(iii) The change in July is striking. The gradient of energy has reversed completely. It is now from north to south at all levels right upto 100 mb and quite steep. The maximum of energy in lower levels lies in the latitude belt 27° to 32° N and minimum in the extreme south. In fact, the values have risen steeply in north India and remained more or less the same in the extreme south resulting in the reversal of energy gradient. The layer of minimum energy now extends from about 500 mb in the north to about 700 mb in the south and is very well marked. The maximum of energy in lower levels is again at the surface above which it uniformly decreases to the level of minimum energy.

Another feature of interest noticeable in July is that the vertical gradient of energy which was quite strong in northern latitudes both in January and April is considerably weak in July. In fact, the weakening of vertical gradient is markedly noticeable in the northern latitudes than in the south where it is only marginal.

(iv) In October, the picture is almost the same as in April. The layer of minimum energy remains at about 700 mb. The meridional gradient is reversed (from that of July) in the lower troposphere and is from south to north again.

(v) It can also be seen that the mean energy content over the country is minimum in January and maximum in July. Values in April and October are in between the two.

4. Seasonal variation of Q

Distribution of Q at surface, 500, 300 and 100 mb levels in January, April, July and October and the changes in the distribution of Q between October-January, January-April, April-July and July-October were studied. It was noticed that in January there is general decrease of energy over the country at all levels with respect to October except at 100 mb which shows a rise to the north of about 17° N. From January to April, there is a rise at all levels throughout the region, more sharp in the north and less in the south, more in lower levels and less in higher levels. The energy continues to rise in this period over northwest India upto 300 mb. At 100 mb the maximum rise is observed to occur over the central parts of the country.

From April to July there is a sharp rise in Q over north and central India from surface to 500 mb and there is slight fall over extreme south of the country and central and south Bay. The condition is more or less the same at 300 mb but there is complete change at 100 mb. Here the energy rises over south and central India and falls in north India. From July to October there is a fall in the energy content in north India and rise over south India and adjoining seas upto 500 mb level. The rise is confined to only extreme south of the country at 300 mb. At 100 mb, however, there is fall all over the country.

From the foregoing it can be said that large changes in the mean total energy content occur over the surface and in lower levels of the atmosphere and less in higher levels. At 100 mb, the changes are mostly in the opposite direction and generally represent the conditions in the lower stratosphere.

5. Monthly variation of Q

(i) Monthly variations of mean static energy from surface to 150 mb level were studied at three locations, viz., 12° , 20° and 28° N along 77° E (Figs. 2 a, b, c). It is found that at 12° N monthly variation of mean energy is positive from January through June and becomes negative thereafter, except for a small positive variation in upper troposphere from July to September.

(ii) At 20° and 28° N the energy increases from January to July and decreases thereafter.

(iii) Maximum monthly variation, either positive or negative, occurs in the lower troposphere. Whereas at 12° N the positive variation is maximum from March to April, at 20° N and 28° N it is from May to June. Maximum negative variation of Q , however, occurs from October to November at all the three locations. The variations are comparatively larger at 28° N than at 20° or 12° N.

(iv) A secondary maximum of positive variation is observed at about 500 mb level at all the three locations. It occurs from April to June at 12° N and from June to July at 20° and 28° N.

6. Contributions of different terms to total energy content

By and large the sensible heat energy ($c_p T$) has the largest contribution to the total energy content (Q) of the atmosphere. Its contribution is maximum near the ground (more than 90 percent) and decreases slowly with height upto about 500 mb level where its contribution is about 80 percent. It decreases rather rapidly thereafter and remains only 50 per cent at 100 mb level. While the sum of sensible heat ($c_p T$) and potential energy (gz) increases with height through most of the troposphere, the latent heat energy (Lq) decreases sharply with height. Contribution of Lq is found to be maximum near the ground (10 to 15 per cent) and is rather small at 500 mb level (1 to 3 per cent). Above this level its contribution becomes insignificant.

7. Discussion

Riehl and Malkus (1958) described the variation of static energy with pressure and latitude relative to the equatorial trough zone. The normal Q profile in the tropics shows a relatively high value at the surface which decreases with height up to mid-troposphere where it shows a minimum. Above this level it increases again, slowly upto tropopause and rather rapidly thereafter. In the extra-tropical regions, on the other hand, the mean static energy continuously increases from surface upwards. In the tropics the occurrence of a level of minimum energy in the middle-troposphere is significant for vertical transfer of energy by convective processes and leads to the postulation of the theory of 'Hot

Towers' as the main mechanism for energy transfer from lower to upper troposphere. But in the extra-tropical regions the vertical profile of total energy does not permit convective transfer as in the tropics. Hence the main mechanism in these regions is postulated to be of 'slantwise' convection both for vertical as well as meridional energy transfer. It may, however, be noted that the actual distribution of energy in a synoptic situation may differ greatly from the mean picture both in tropics as well as in the extratropical latitudes as have been shown by Palmén (1964), Malkus and Riehl (1964) and Lockwood (1968).

From the distribution of static energy in the vertical plane as discussed earlier it can be inferred that the atmosphere over India is under tropical airmass only south of 18° N in January. North of it the energy profile shows extratropical characteristics. In July it is completely tropical in character. But in April and October the picture is rather complicated. Although, in these months too the atmosphere, in general, shows tropical characteristics, but to the north of about 18° N the maximum Q does not lie at the surface but near 850 mb and shows a sharp decrease above, attaining a minimum value at about 600 mb. Of course, it can be seen that from January to April there is increase in Q at all levels, particularly in the lower troposphere with a maximum around 850 mb, *i.e.*, slightly above the ground. Similarly, in October, decrease of Q as compared to July is at all levels upto the mid-troposphere but it is small at 850 mb, showing again that a maximum is attained at about 850 mb between surface and mid-tropospheric minimum. This is apparently because of the shallow ground inversion in the morning hours in April and October in northern India. The inversion lowers the average temperature value in the surface layers but does not extend upto 850 mb. It may be noted that these are the dry months of the year when contribution of moisture to total energy content is very small.

It may be of interest to mention here that the vertical distribution of total static energy follows a pattern similar to that of the equivalent potential temperature and therefore, its variation with height indicates the convective instability in the atmosphere. It can be noticed from Figs. 1(a-d) that in the region to the south of about Lat. 18° N convective instability is a normal feature of the lower troposphere and extends upto about 4 to 5 km. While no such instability exists over north India in the month of January, but in April and October convective instability is present in the layer extending from 1.5 km upto about 5.0 km where the total energy decreases with height. In the month of July, however, convective instability exists in the lower troposphere all over the country and extends through a deeper layer (upto 6.0 km) in the north than in the south where it extends only upto about 3.0 to 4.0 km. Rao (1958)

also drew similar conclusions regarding the existence of thermodynamic instability during monsoon months from the vertical variation of wet-bulb potential temperatures over India.

8. Conclusions

(i) The mean energy content of the atmosphere over India is minimum in January and maximum in July throughout the troposphere. The maximum in January is located over extreme south of the country and lowest over northwest India. Opposite is the case in July when the highest concentration of energy is over north India (in the monsoon trough zone). Thus there is complete reversal of gradient between January and July.

(ii) The increase of static energy from January to April is the highest over north India which shifts to northwest India between April and July.

(iii) In January the atmosphere over India shows tropical characteristics south of 18° N and extratropical to the north of it. In July it is tropical throughout the country. In the pre-and post-monsoon months of April and October, though it shows tropical characteristics, in general, the picture in lower levels is a little distorted. The static energy shows a rise from surface to 850 mb and decreases above attaining minimum value from 700 to 500 mb.

(iv) From the vertical variation of total static energy it is inferred that convective instability is a normal feature of the southern latitudes throughout the year. No such instability exists in the troposphere over north India in January. During the monsoon months, the atmosphere is convectively unstable in a deeper layer (upto 6.0 km) over north India than over south India.

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