SEASONAL VARIATIONS IN THE ZONAL AND MERIDIONAL CIRCULATION OVER INDIA

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1. General Circulation

THE large-scale wind systems of the atmosphere have their origin in the non-uniform distribution of heat and cold sources in the atmosphere. Over the tropics and sub-tropics the earth-atmosphere system receives more radiation than it sends out to space while at higher latitudes the conditions are just the opposite. Again, over the tropics the atmosphere receives heat in the lower levels by contact with the ground as well as by the latent heat released from the condensation of water vapour while there is a continual loss of heat by radiation from the top of the atmosphere. This non-uniform distribution of heat and cold sources in the atmosphere gives rise to horizontal gradients of temperature and pressure that drive the atmospheric heat engine converting potential and thermal energy into kinetic energy of air motion.

1.2. The seasonal oscillation of the sun between the Tropics of Cancer and Capricorn produces a corresponding oscillation in the disposition of the heat and cold sources and consequently of the wind systems of the atmosphere. The problem of the general circulation is concerned with the description and explanation of the large-scale wind systems.

2. Effect of Land-Sea Contrasts

2.1. The non-uniform distribution of land and sea over the globe influences profoundly the pattern of wind circulation. The ratio of land to sea area for the earth as a whole is 29 : 71. For the northern hemisphere this ratio is 39 : 61 while for the southern hemisphere the ratio is 19 : 81. Considering the eastern and western halves of the northern hemisphere, the areas covered by land and water are nearly equal for the eastern half while three-quarters of the western half are covered by sea. The extensive land masses of Eurasia and north Africa in the eastern half of the northern hemisphere constitute a major heat source in the summer months and a cold source in the winter months. These heat and cold sources are primarily responsible for the summer and winter monsoons of South Asia for which there is no parallel elsewhere in the world. The Tibetan plateau which is the highest and most extensive plateau in the world also influences the general circulation over South Asia.

2.2. The influence of land-sea contrasts on the wind circulation is noticed up to high levels in the atmosphere. This is clearly brought out by Figs. 1 (*a*, *b*) and 2 (*a*, *b*) in which isopleths of the zonal winds over the latitude belt 0° to 60° N. are presented for the winter (December-January-February) and the summer (June-July-August) seasons at the standard isobaric levels of 500, 300, 200 and 100 mb. The strongest westerly winds in the winter occur at 200 mb. near latitudes 35° N. and longitude 140° E. (the southern parts of Japan); the strongest easterly winds in the summer months occur at 100 mb. level near latitude 15° N. and longitude 80° E. (the south Indian peninsula).

3. Mean Monthly Zonal and Meridional Circulation over India

3.1. The seasonal variations in the zonal and meridional circulations over India have been studied using all the available rawin data at the 16 stations given in Table I for the period 1957-64.

Table I

	Station	Latitude	Longitude	Period of data
1	Ahmedabad	.. 23° 04′ N	72° 38′ E	1961-1964
2	Allahabad	.. 25° 27	81° 44	1957-1964
3	Amritsar	.. 31° 38	74° 52	1957-1960 (Jul) (Jan)
4	Bombay	.. 19° 04	72° 06	1957-1964
5	Calcutta	.. 22° 39	88° 27	1957-1964
6	Gauhati	.. 26° 05	91° 43	1957-1964
7	Jodhpur	.. 26° 16	73° 03	1957-1964
8	Madras	.. 13° 00	80° 11	1957-1964
9	Minicoy	.. 08° 18	73° 00	1963-1964 (May)
10	Nagpur	.. 21° 03	79° 07	1957-1964
11	New Delhi	.. 28° 35	77° 12	1957-1964
12	Port Blair	.. 11° 40	92° 43	1957-1964
13	Srinagar	.. 34° 05	74° 50	1962-1964 (Aug)
14	Trivandrum	.. 08° 30	76° 59	1957-1964
15	Veraval	.. 20° 55	70° 22	1957-1964 (Jul) (Jan)
16	Visakhapatnam	.. 17° 43	83° 14	1960-1964 (July)

The results are briefly discussed here for the four stations Trivandrum, Madras, Nagpur and New Delhi which lie approximately along the meridian of 77° E. and cover the latitude belt

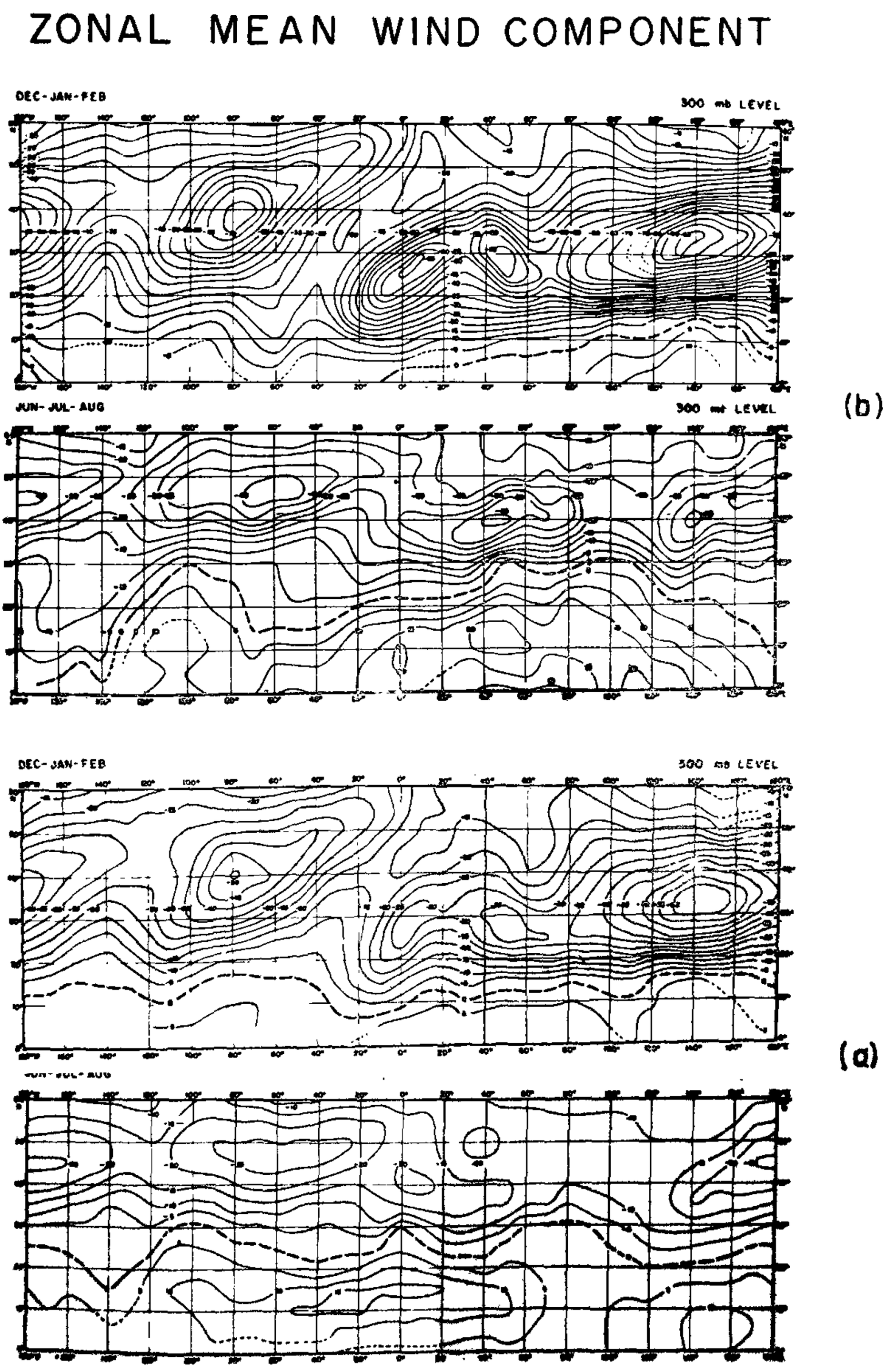

FIG. 1. (—) FROM WEST SPEED IN KNOTS

from 8° 30′ N. to 28° 30′ N. Figures 3, 4, 5 and 6 depict isopleths of monthly mean zonal and meridional winds for these stations for the period 1957-1964. To bring out the salient

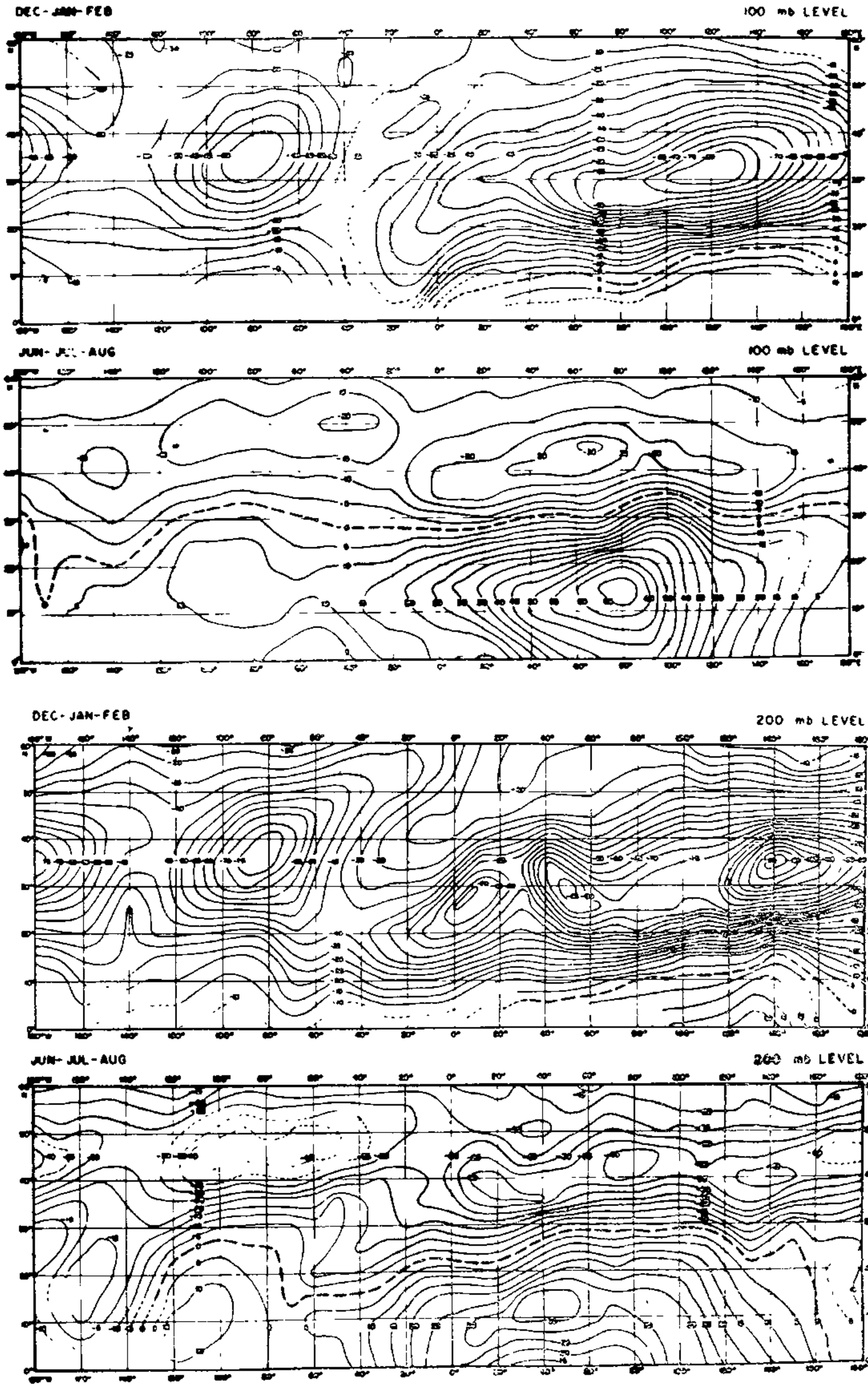

FIG. 2. (–) FROM WEST SPEED IN KNOTS

features, isopleths have been drawn at intervals of 20 knots of wind speed for both the zonal and meridional components.

3.1. *Zonal Circulation*

3.1.1. The major feature of the zonal circulation is the regularity of the variations associated

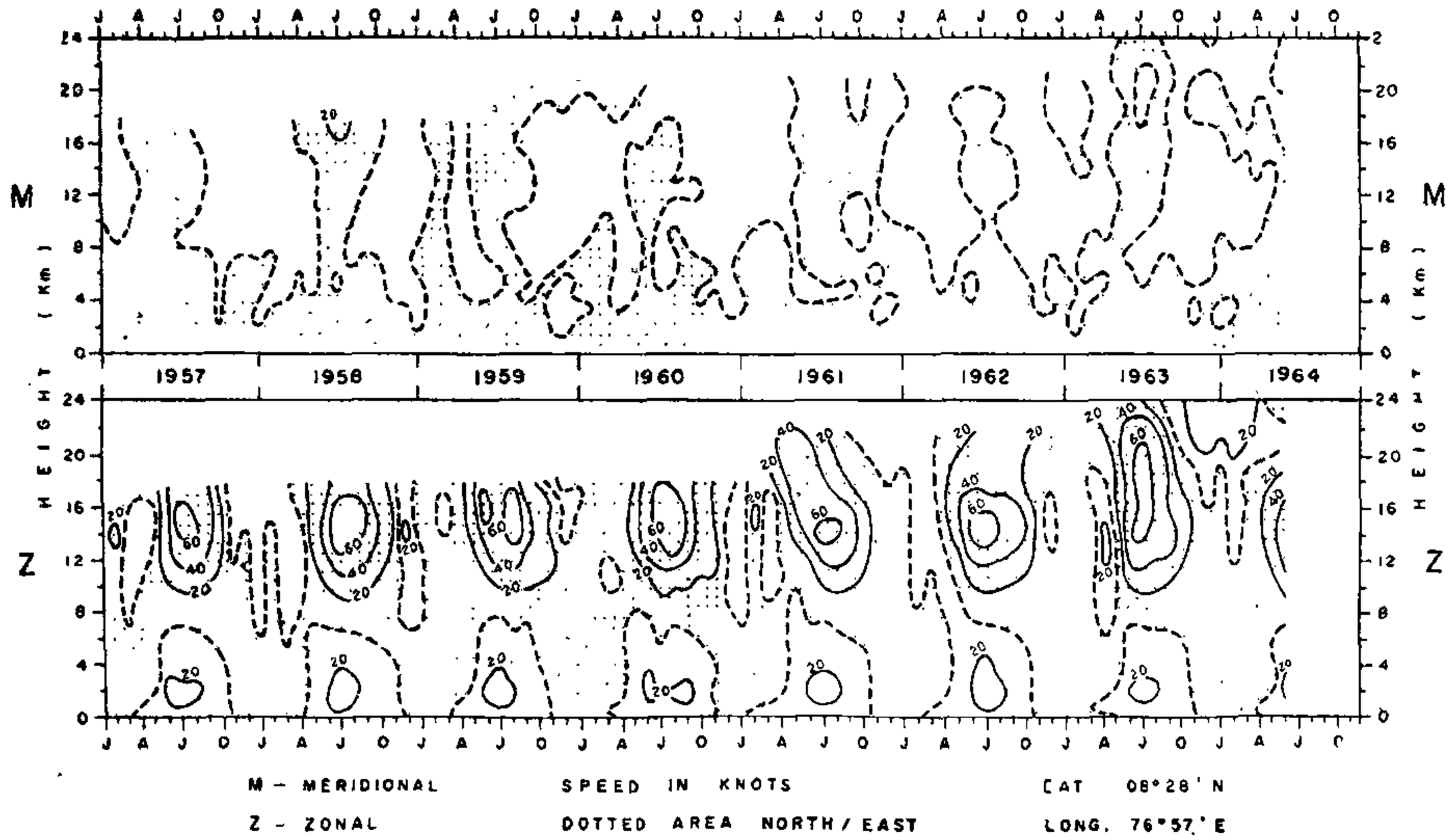

FIG. 3.

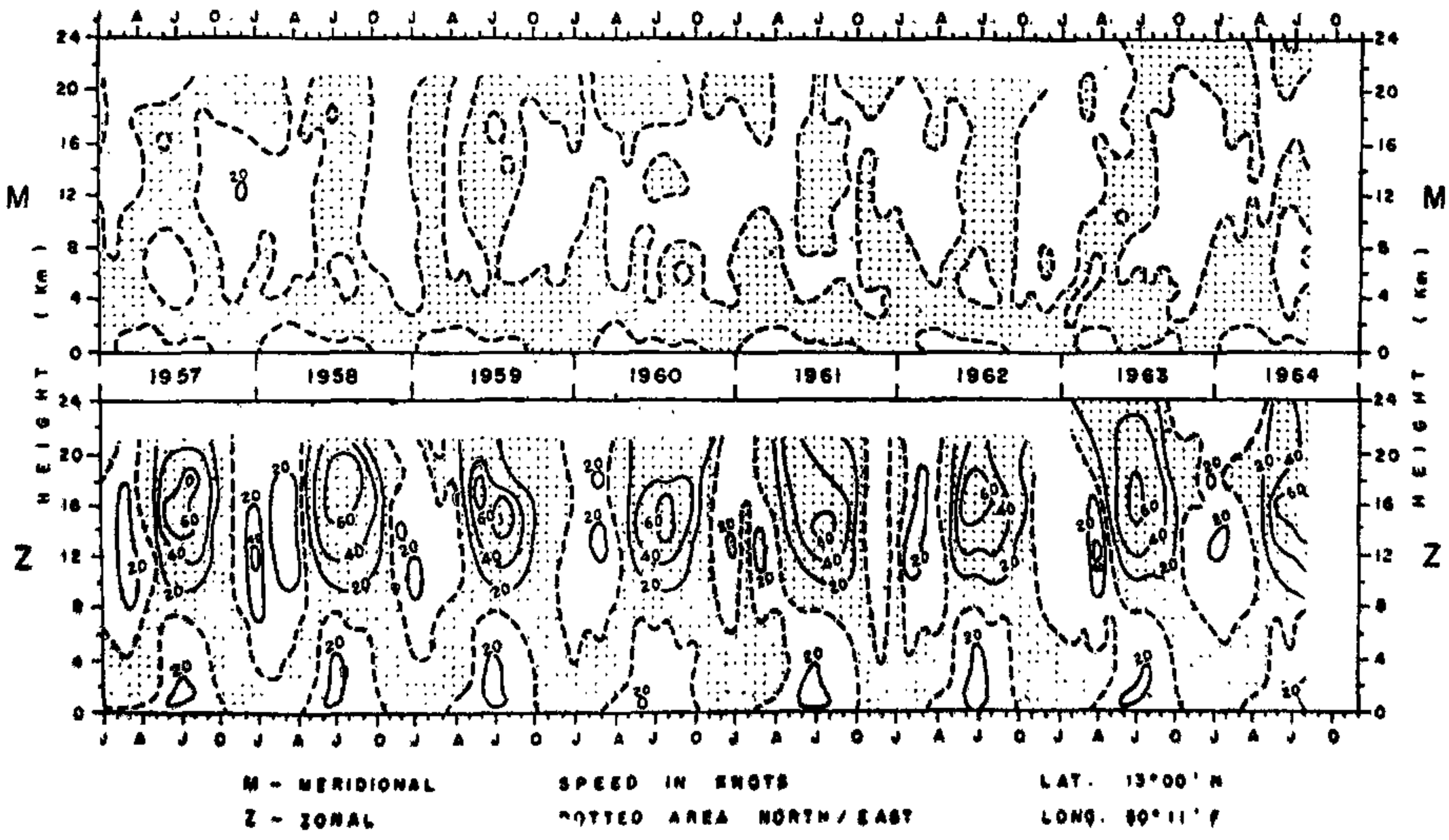

FIG. 4

with the two well-defined seasons—Summer and Winter—into which the year as a whole can be divided. Over Trivandrum, the southernmost station, the zonal flow in the lower troposphere up to 6/7 km. consists of westerlies from May to October and easterlies from November to

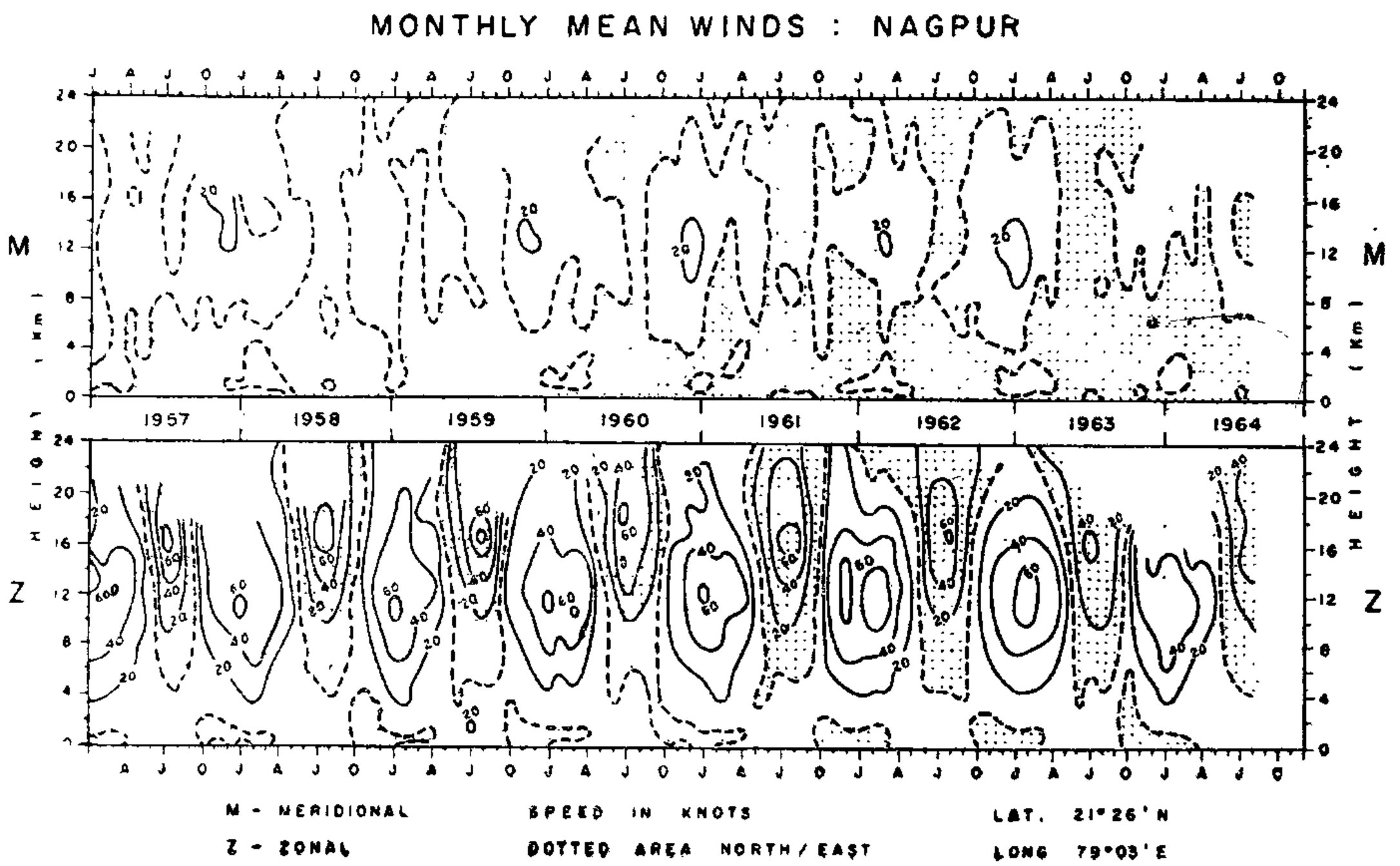

FIG. 5.

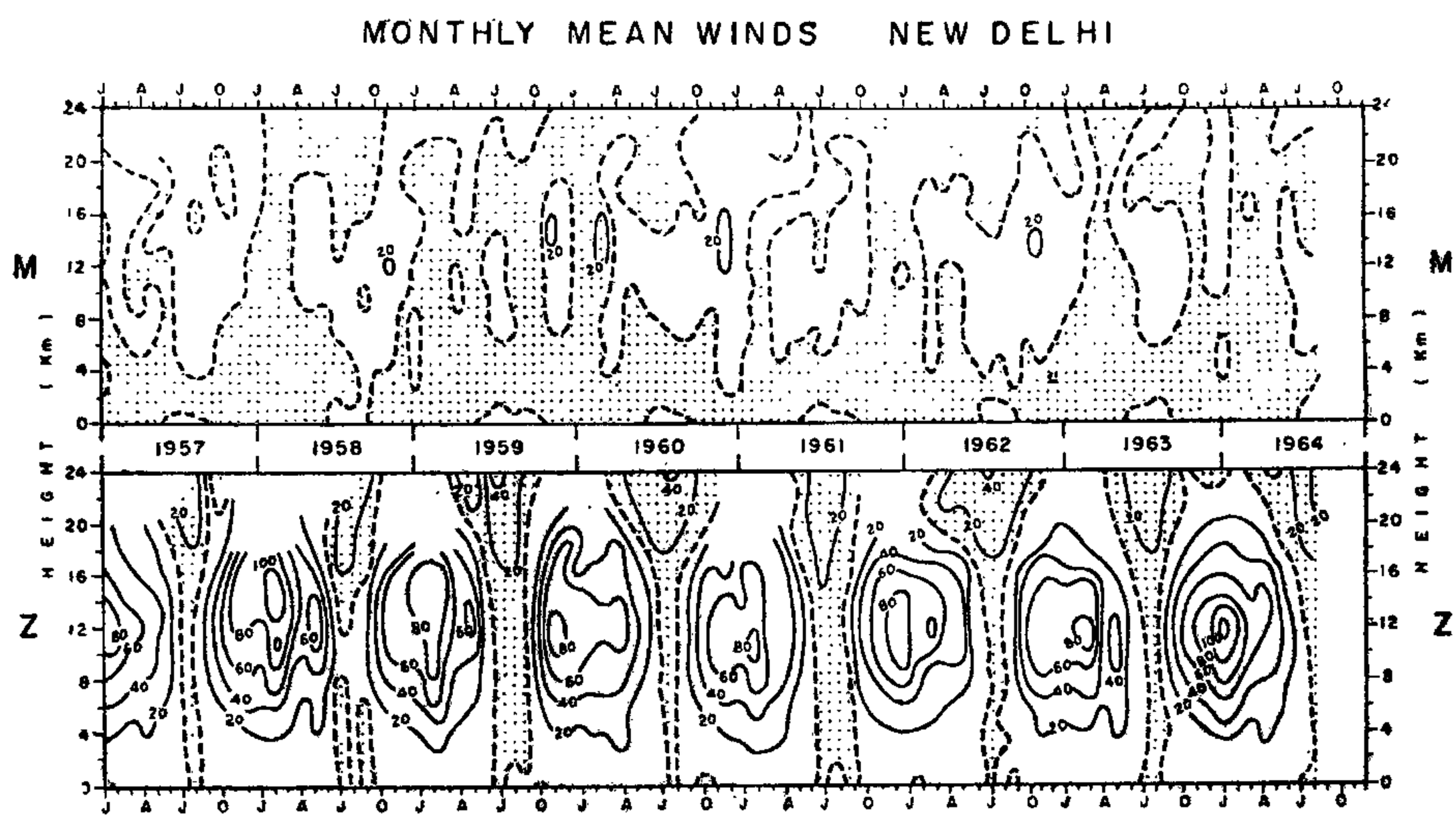

FIG. 6.

April. During the south-west monsoon months of June, July and August westerlies in the lower troposphere exceed 20 knots between 1 and 4 km. In the upper troposphere the flow is mainly easterly. However, spells of westerlies occur in the months December to April. The westerly flow shows appreciable fluctuations from year to year. The easterlies are organised and regular, and attain maximum speed exceeding 60 knots between 14 and 16 km. in the monsoon months of June, July and August. The lower stratospheric westerlies noticed during the period January to April in 1962 are replaced by easterlies in the following year, but are noticed again in 1964 in conformity with the recently discovered biennial oscillation of zonal winds at equatorial latitudes.

3.1.2. The zonal flow over Madras is generally similar to that over Trivandrum with some differences. The westerly regime in the upper troposphere is more pronounced and the zonal westerlies are stronger, the mean speeds exceeding 40 knots in some years. The easterlies attain their maximum speed at 16 km. level in the south-west monsoon months.

3.1.3. At Nagpur the westerly and easterly regimes are nearly equally prominent. Upto 3/4 km. weak easterlies occur in the months October to March/April and westerlies in the remaining months. At higher levels in the troposphere westerlies prevail during October to April/May and easterlies during the remaining months. The maximum speeds of the monthly mean upper tropospheric easterlies and westerlies reach 60 knots. The westerlies attain maximum strength at 11 km. in January/February and the easterlies at 17/18 km. in July/August.

3.1.4. The zonal flow in the troposphere over Delhi is westerly in all the months of the year except July and August when weak easterlies prevail. The zonal westerlies attain their maximum speed of 80/100 knots in the winter months of January/February at the level of 11/12 km. There are variations from year to year not only in the value of the maximum but also in the month in which the highest mean speed is reached. The speed and duration of the easterlies increase from 16 to 24 km. in the stratosphere.

3.2. *Meridional Circulation*

3.2.1. The meridional flow in the lower troposphere up to 3 km. is predominantly northerly at Trivandrum. At Madras this lower layer of northerlies extends up to 4 km. However, below 2 km. southerlies occur from February to October. At Nagpur the lower tropospheric layer of northerly winds extends up to 5/6 km. with pockets of southerlies up to about 3 km. in the months of January to April. At Delhi the meridional circulation continues to be predominantly northerly up to about 6 km. except for a shallow layer of southerlies confined to the first 1 to 2 km. during the south-west monsoon months June to September.

3.2.2. Above 4 km., the meridional flow over Trivandrum consists of alternating northerly and southerly regimes, the northerlies being prominent in the summer months and the southerlies in the winter months. Nearly similar features are noticed at Madras and Nagpur. Over Delhi on the other hand the meridional flow in the upper troposphere is predominantly southerly in the summer monsoon months and northerly in the winter months. At all the stations the meridional circulation is not only much weaker than the zonal circulation, but shows larger fluctuations from year to year.

A detailed report of our studies will be published elsewhere.