ATMOSPHERIC TIDAL OSCILLATIONS
PART 2. DIURNAL VARIATION OF PRESSURE OVER INDIA*

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ABSTRACT

Hourly surface pressure data (annual and monthly) over a network of Indian stations have been harmonically analysed. The spatial and temporal variation of the amplitude, phase and percentage contribution towards variance of the time series in respect of the first four harmonics of the barometric oscillation are discussed.

INTRODUCTION

The discovery of atmospheric tidal oscillations in the seventeenth century and the historical developments leading to the present thermo-tidal theory of these oscillations were dealt within Part 1 of this paper. Here we propose to give an account of the salient observational features of the barometric oscillation over India. The diurnal variation of many meteorological elements including pressure at Indian stations have been discussed in a series of publications towards the end of the last century by Blanford[1] and Eliot[2]. A global study of the semi-diurnal pressure oscillation utilising the data of over 200 stations was made by Simpson[3] while working in the India Meteorological Department at Simla. Alvi and Jagannathan[4] studied the barometric oscillation at 38 Indian stations. We have recently examined the diurnal variation of pressure at 62 Indian stations using the hourly pressure data for periods ranging from 5 to 12 years at individual stations. Figure 1 gives the location of the stations.

HARMONIC ANALYSIS OF HOURLY PRESSURE

The annual and monthly mean values of the hourly pressure data at the stations were subjected to harmonic analysis to determine the amplitude, phase and the percentage contribution to the variance of the time series in respect of the first four harmonics denoted (following the usual convention) by $S_1(p)$, $S_2(p)$, $S_3(p)$ and $S_4(p)$. As example, the results of the analysis for six selected stations—Trivandrum, Kodaikanal, Madras, Bombay, Nagpur and Jodhpur—are shown in figures 2(a), (b), (c). In general $S_1(p)$ and $S_2(p)$, whose amplitudes are comparable, account for most of the variance of the pressure time series. The residual variance is practically fully accounted for by $S_3(p)$ and $S_4(p)$ whose amplitudes are an order of magnitude less than those of the first two harmonics. For each station, the figure gives the monthly variation of the amplitude, variance and phase. The term phase is here used to denote the time at which the first maximum of the oscillation occurs, expressed in local mean solar time (LMT) reckoned from zero at local midnight. The annual values of the parameters are indicated by thick dots for $S_1(p)$ and $S_3(p)$ and by open circles for $S_2(p)$ and $S_4(p)$.

ANNUAL VARIATIONS OF THE HARMONIC COMPONENTS

24-hourly oscillation, $S_1(p)$: The amplitude and phase of $S_1(p)$ show large spatial variations. The amplitudes range from 0.5 to 1.0 mb at coastal stations and from 1.0 to 1.5 mb at inland stations. Large amplitudes are found over north and central India. A diagram showing isopleths of amplitude over the globe for annual $S_1(p)$ by Haurwitz and Cowley[5] indicates the maximum amplitude over India as 1.04 mb which is an underestimate. The present study reveals that the

* Part 1 of this article was appeared in September 20, 1984 issue of *Curr. Sci.*

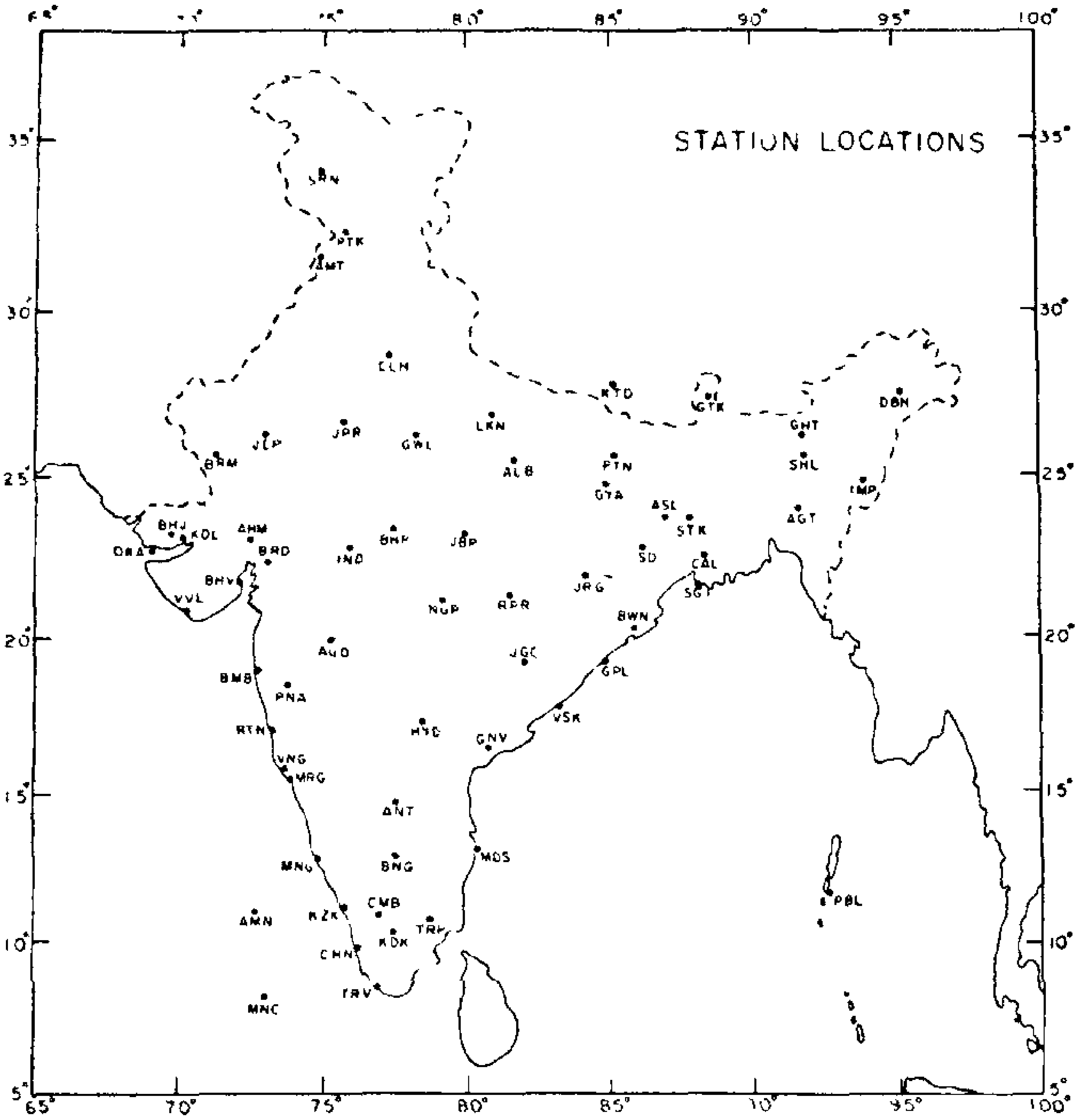

Figure 1. Station Locations

highest global amplitude slightly exceeding 1.5 mb occurs over the interior of India. This is presumably associated with the large land-sea thermal contrasts over this part of the globe which generates the monsoon circulations. The phase of $S_1(p)$ varies from 05 to 09 hr LMT, the later values occurring at the north Indian stations. The contribution of $S_1(p)$ towards variance ranges from 30 to 60% at different stations.

12-hourly oscillation, $S_2(p)$: The behaviour of $S_2(p)$ is more regular and organised than that of the diurnal component. The amplitude of this oscillation ranges generally from 1.0 to 1.5 mb and its phase from 0950 to 1050 hr LMT. Comparison with the global isopleths of amplitude given by Haurwitz and Cowley[5] shows that the highest amplitudes of this oscillation occur over south India. The amplitudes decrease with latitude (ϕ) generally following $\cos^3 \phi$. The variance contributed by the semi-diurnal oscillation ranges from 40 to 80% at individual stations. The ratio of the amplitudes of $S_1(p)$ and $S_2(p)$ shows scatter from 0.5 to 1.3 at individual stations with a mean value of about 0.8.

The 8-hourly oscillation, $S_3(p)$: The amplitude of the third harmonic varies between 0.04 and 0.14 mb, following approximately $\cos^3 \phi \sin \phi$ variation, with largest amplitudes at the north Indian stations. The phase of the oscillation lies between 0150 and 0300 hr. Its contribution to variance is mostly less than 0.5%.

The 6-hourly oscillation, $S_4(p)$: The amplitude of $S_4(p)$ is generally about half that of $S_3(p)$. Its

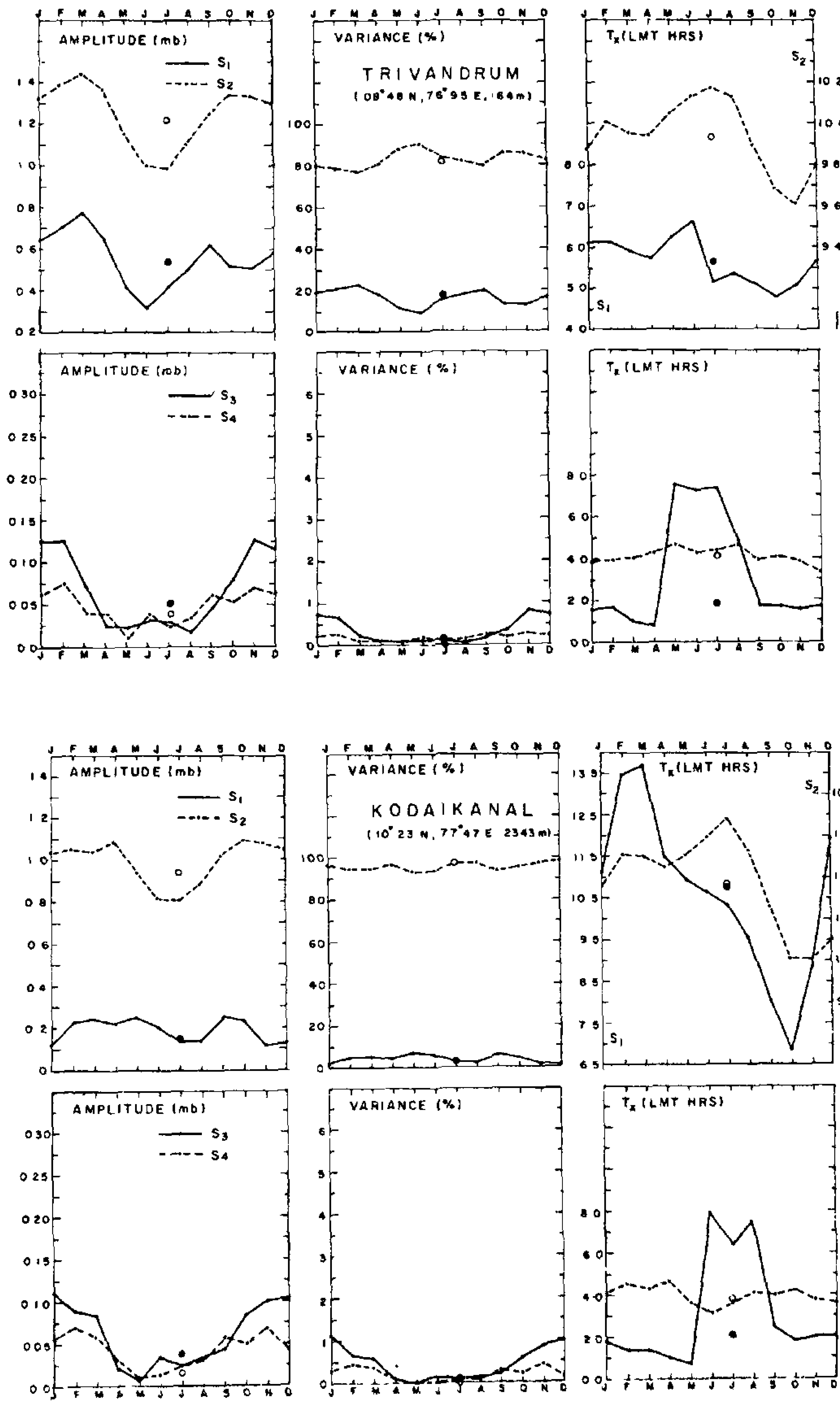

Figure 2(a). Monthly progression of the amplitudes, phases and variance contribution of the harmonic components: Trivandrum and Kodaikanal.

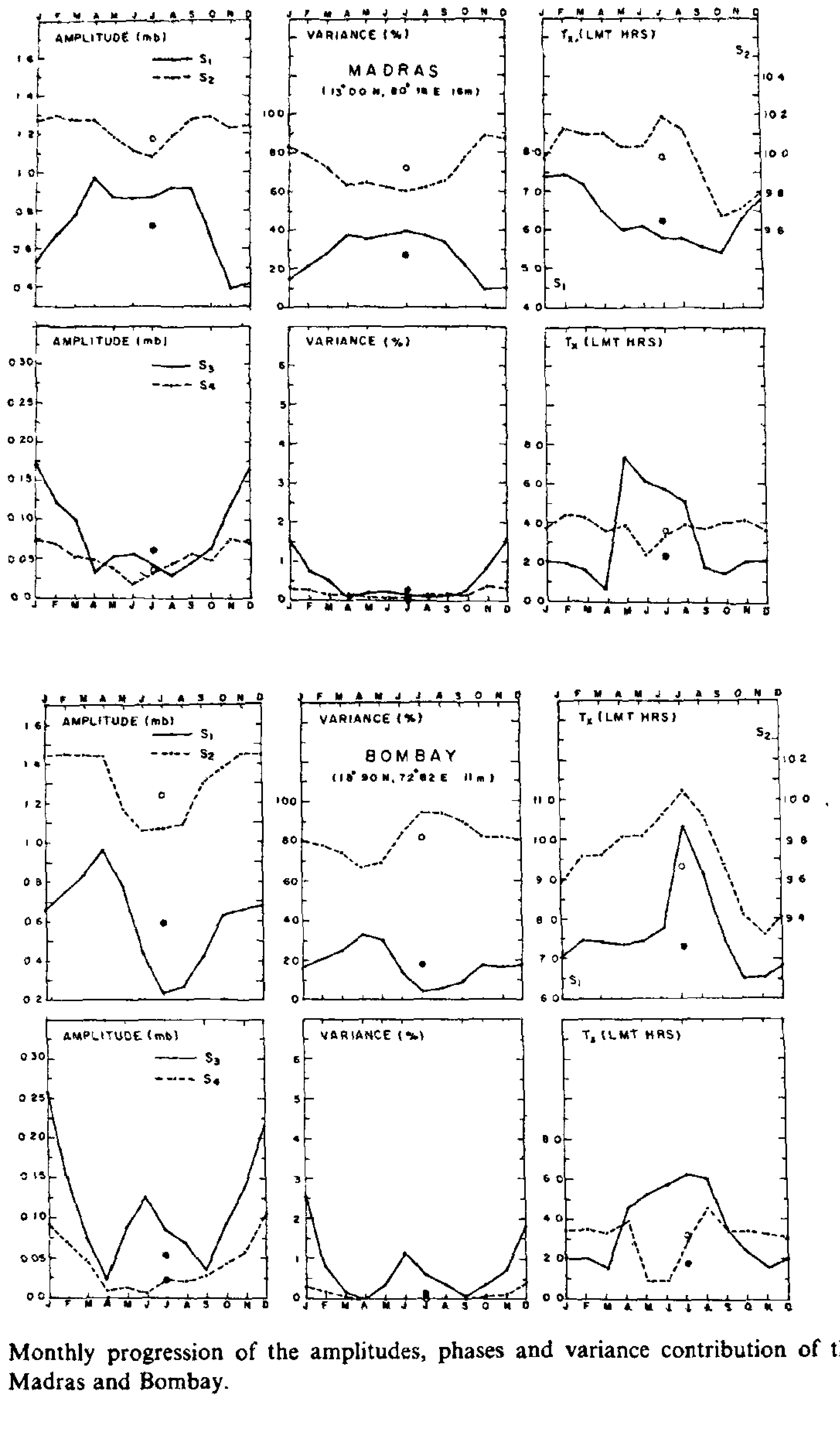

Figure 2(b). Monthly progression of the amplitudes, phases and variance contribution of the harmonic components: Madras and Bombay.

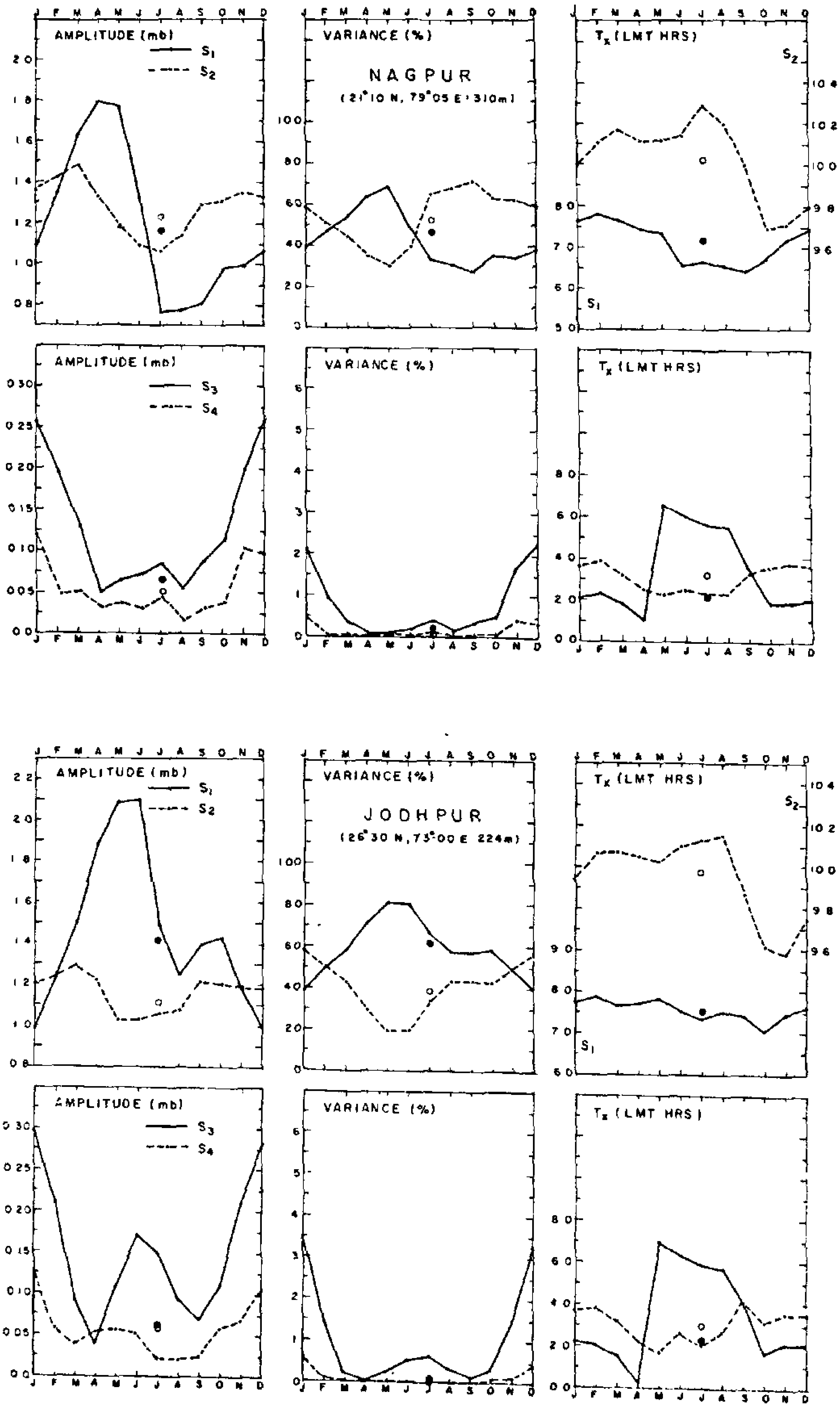

Figure 2(c). Monthly progression of the amplitudes, phases and variance contribution of the harmonic components: Nagpur and Jodhpur.

phase is found to be between 0250 and 0450 hr at individual stations. Its contribution to variance is of the order of 0.2% or less.

Figures 3 and 4 give a pictorial representation of $S_1(p)/S_2(p)$ and $S_3(p)/S_4(p)$ at selected stations. The harmonic components are depicted as vectors originating from the stations, the length of the vector being proportional to the amplitude. The direction of the vector gives the phase of the oscillation as per the harmonic dials shown on the diagrams.

SEASONAL VARIATIONS OF THE HARMONIC COMPONENTS

The 24-hourly oscillation, $S_1(p)$: The diurnal oscillation attains maximum amplitudes in the hot weather months March to May, the amplitudes ranging from 1.0 to 2.0 mb, with high values at the north and central Indian stations. The minimum amplitudes from 0.2 to 1.0 mb occur mostly in the southwest monsoon months of July—August. Very low amplitudes are noticed at the west coast stations in July. The ratio of the minimum to the maximum amplitude of $S_1(p)$ at individual stations varies from 0.2 to 0.7 with a mean value of about 0.45. The phase of the oscillation is earliest in the monsoon months (mean value for July 6.84 hr LMT) and latest in the winter months (mean value for February 7.89 hr LMT). The variance accounted for by $S_1(p)$ ranges from a maximum of 40% to 70% in the hot weather months and a minimum of 5% to 30% in the monsoon/winter months.

The 12-hourly oscillation, $S_2(p)$: The semi-diurnal oscillation shows maximum amplitude of 1.0 to 1.7 mb in February—March and minimum

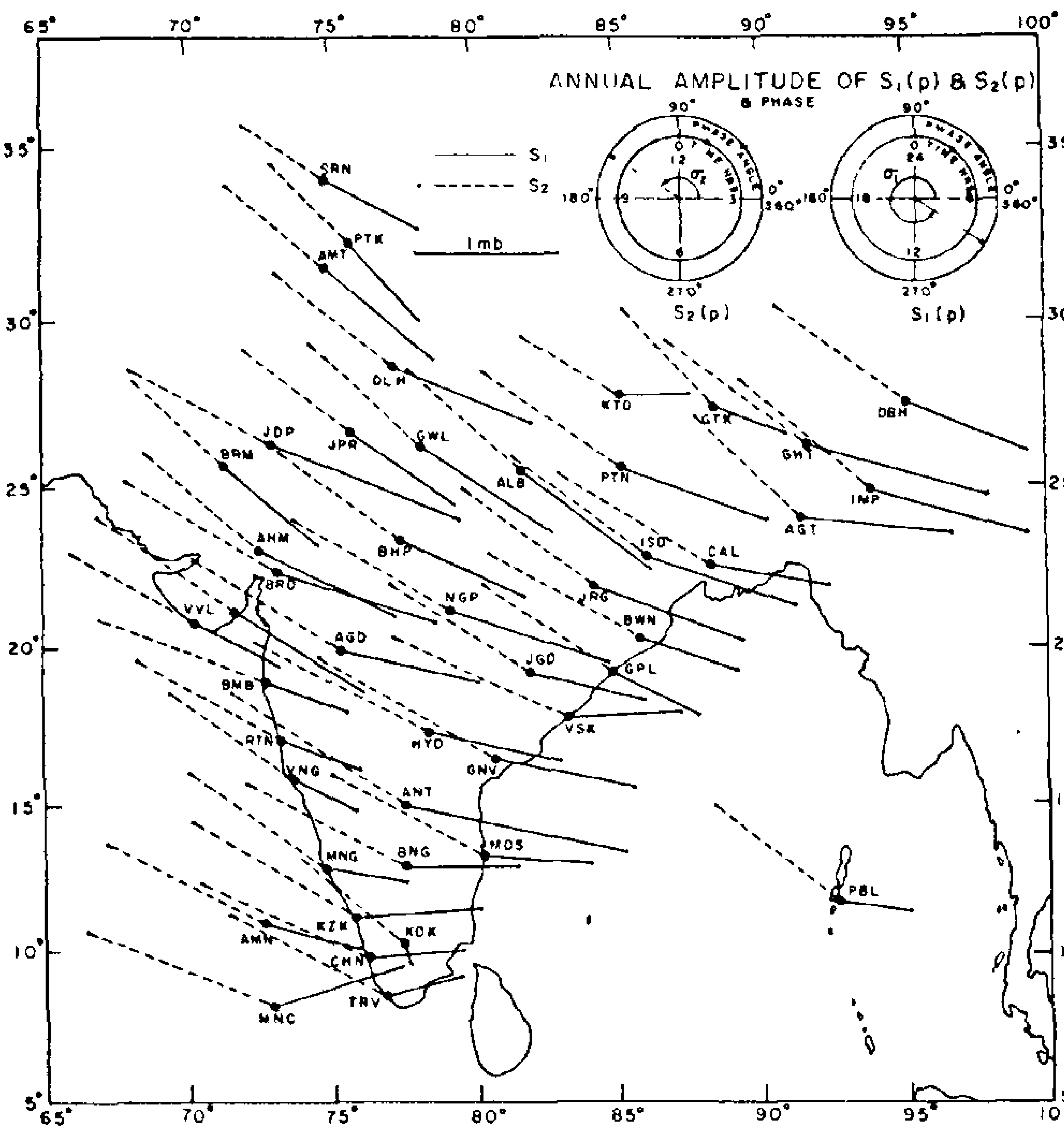

Figure 3. Vectorial representation of $S_1(p)$ and $S_2(p)$ at selected stations.

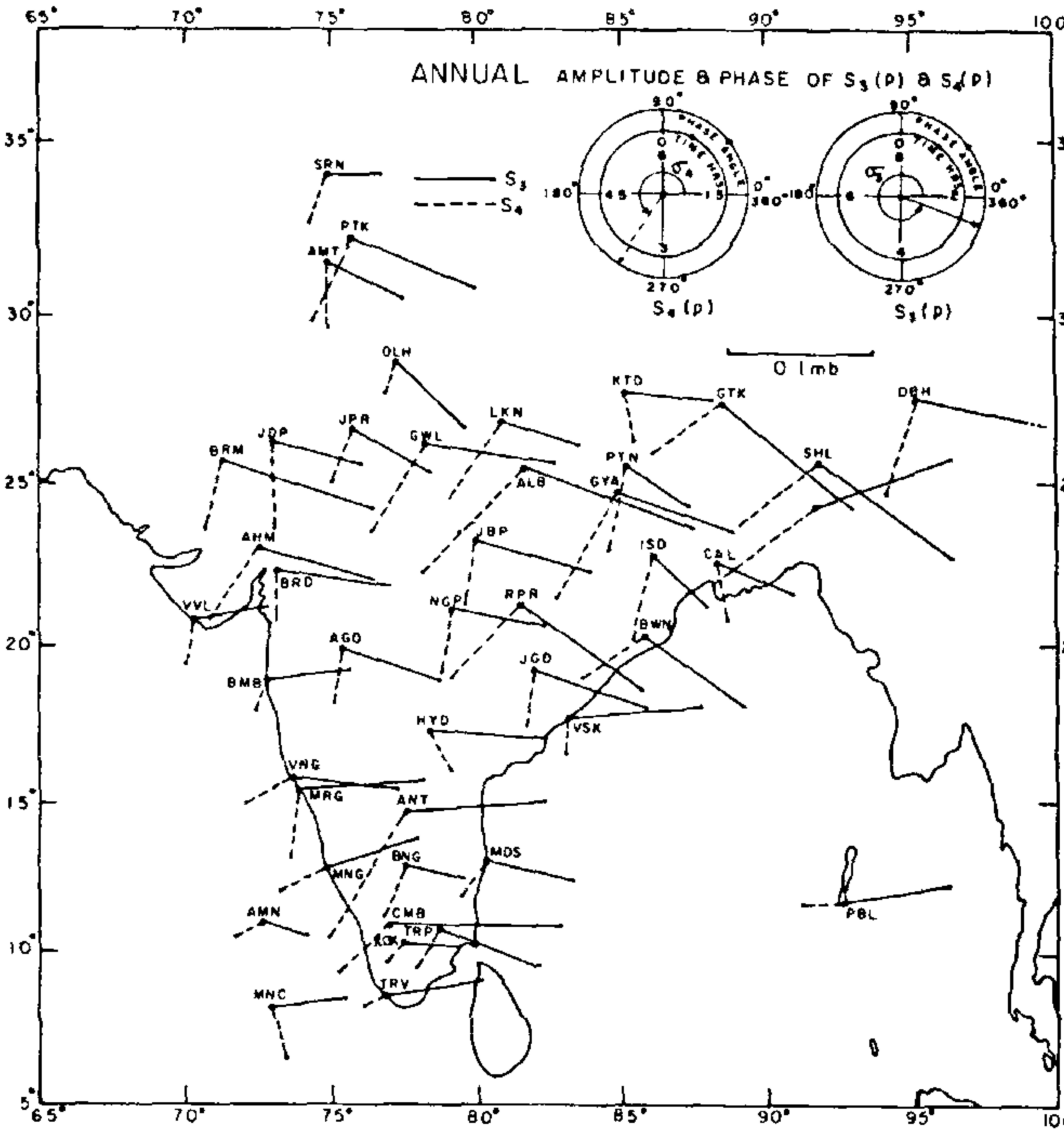

Figure 4. Vectorial representation of $S_3(p)$ and $S_4(p)$ at selected stations.

amplitude of 0.6 to 1.2 mb in June—July. The amplitudes decrease with increasing latitude generally following $\cos^3 \phi$. The ratio of the minimum to the maximum amplitude at individual stations varies from 0.6 to 0.9 with a mean value of about 0.73. Thus the seasonal variation of the amplitude of $S_2(p)$ is less than that of $S_1(p)$. The phase of $S_2(p)$ is earliest in November (mean value for all stations 9.78 hr LMT) and latest in July (mean value 10.43 hr LMT). It may be noted that the seasonal variations of the phases of $S_2(p)$ and $S_1(p)$ show roughly opposite behaviour. The percentage variance accounted for by $S_2(p)$ has a seasonal variation opposite to that of $S_1(p)$; the minimum values are found in the months April—May—June and the maximum values generally in July—August. It may be noted that since $S_1(p)$ and $S_2(p)$ together make up practically the entire variance of the time series, the variance curves corresponding to these oscillations in figure 2 appear nearly as mirror images of each other about the horizontal line corresponding to 50% variance.

The monthly progression of the ratio of the amplitudes $S_1(p)/S_2(p)$ for 16 stations is shown in figure 5. The low values of the ratio at stations along the west coast during the southwest monsoon months may be noted. At most of the interior stations the ratio exceeds unity in the hot weather months. The thick dots in this diagram indicate the value of the ratio in respect of the annual data.

The 8-hourly oscillation, $S_3(p)$: The third harmonic shows interesting seasonal variations in amplitude and phase. The amplitude has two maxima, a primary maximum in December—January and a secondary maximum in June—

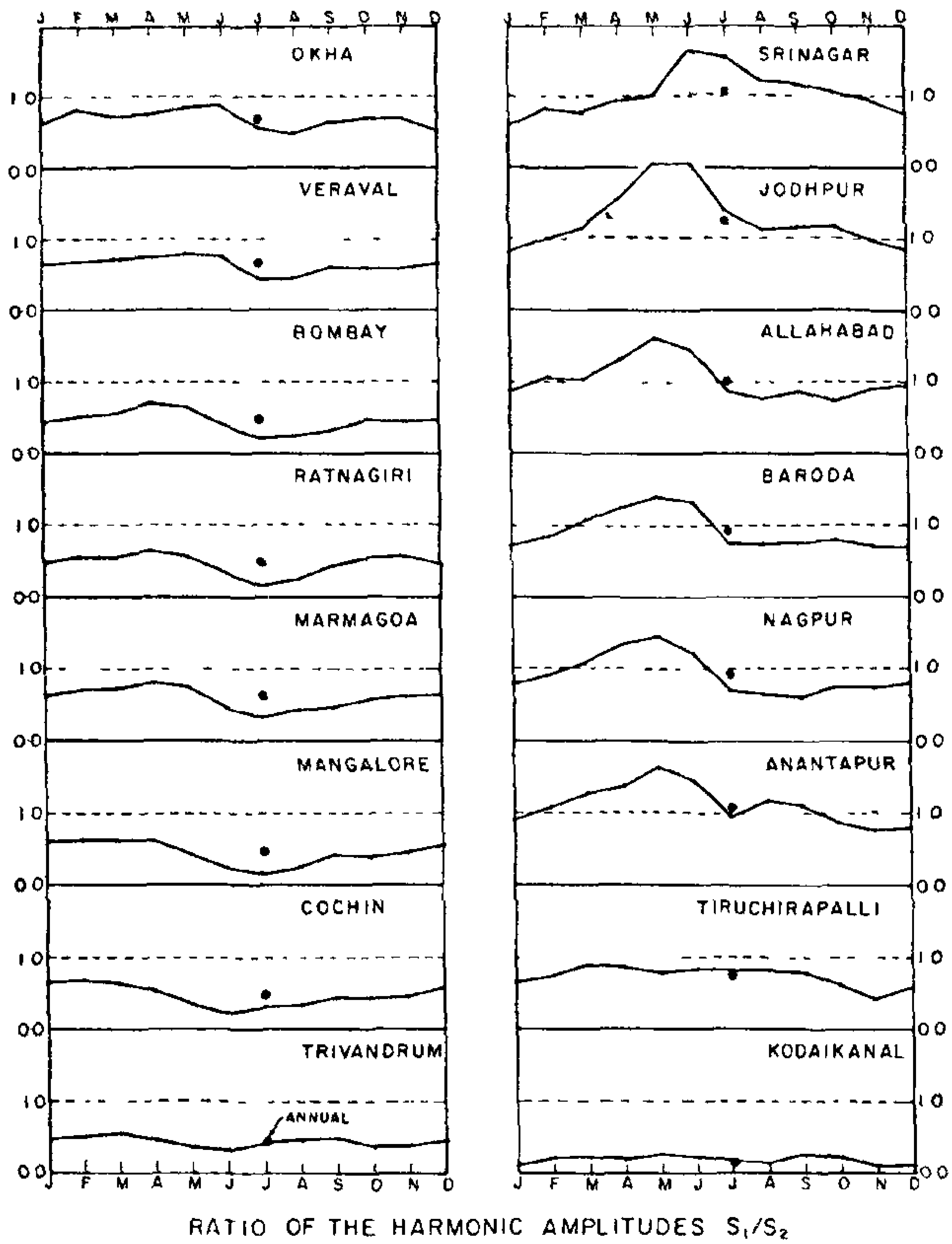

Figure 5. Monthly variation of the ratio of the amplitudes of the diurnal and semi-diurnal components of the barometric oscillation at selected coastal and interior stations.

July. Pronounced minima are found in April—May and in August—September. There is a reversal of phase of the oscillation from about 0205 hr during the epoch of the primary maximum in winter to 0605 hr during the secondary maximum in summer. During the winter months $S_3(p)$ accounts for about 0.5 to 1.5% of the variance at the southern stations and 2 to 6% of the variance at the north Indian stations.

The 6-hourly oscillation, $S_4(p)$: The amplitude of this oscillation is about half that of $S_3(p)$. Similar to the third harmonic, the fourth harmonic is also most pronounced in the winter months with amplitudes increasing from south to north. However, it does not show a secondary maximum nor does it show a reversal of phase from winter to summer. These features can be appreciated from figure 2. The phase of the oscillation varies between 2.7 hr and 3.7 hr LMT. It accounts for about 0.2% of the variance at the southern stations and 0.5 to 1% of the variance at the northern stations during the winter months.

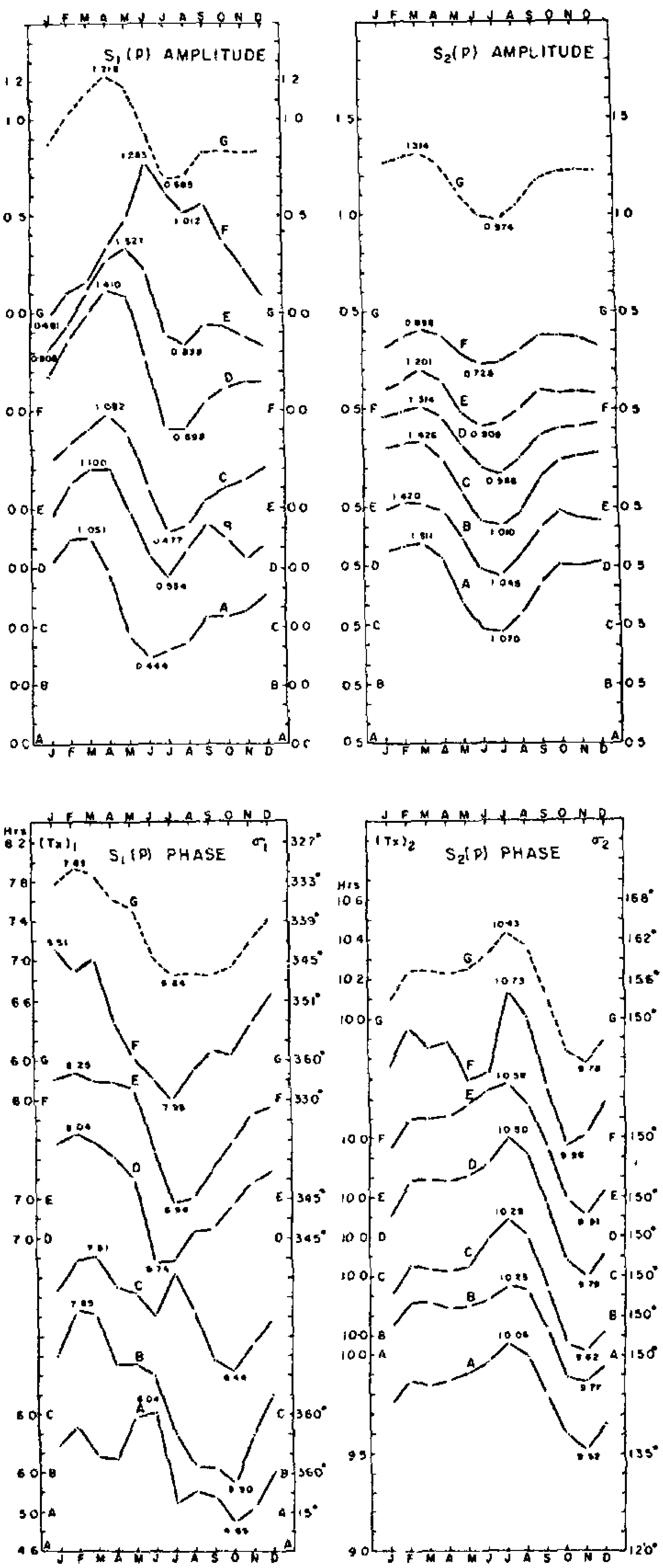

Figure 6. Monthly variation of the amplitudes and phases of $S_1(p)$ and $S_2(p)$ in five-degree zonal belts.

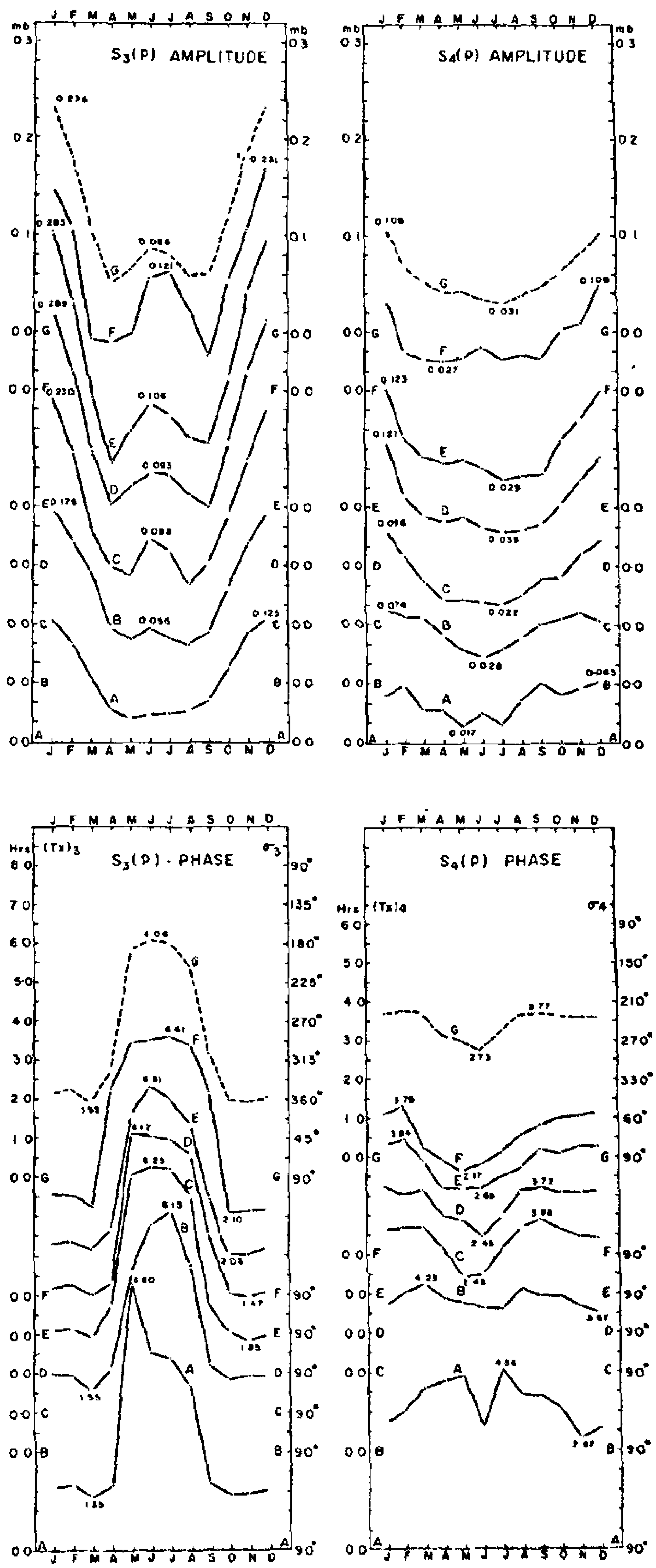

Figure 7. Monthly variation of the amplitudes and phases of $S_3(p)$ and $S_4(p)$ in five-degree zonal belts.

ZONALLY AVERAGED PRESENTATION OF THE HARMONIC COMPONENTS

A graphical presentation of the monthly progression of the amplitudes and phases of the four harmonic components of the atmospheric tidal pressure oscillation over India averaged for stations in five degree zonal belts (05°–10°), . . . (30°–35°) N is given in figures 6(a), (b) and 7(a), (b). The curves A, B, . . . F in these diagrams refer to the six zonal belts. The broken curve G represents the average for all the 62 stations. The maximum/minimum values of the amplitudes and phases are indicated on the respective curves which summarise the major features discussed in the preceding sections.

ACKNOWLEDGEMENTS

One of us (RA) is grateful to the Indian Space Research Organisation (ISRO) for a research grant.

20 June 1984

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NEWS

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