551.577.2(54) : 517.512.2

Fourier Analysis of India Rainfall *

KATHARINA LETTAU and FRED WHITE†

Department of Meteorology, University of Wisconsin

(*Received 11 July 1963*)

ABSTRACT. The temporal and areal distribution of monthly precipitation normals over the Indian sub-continent is studied by means of harmonic analysis. Amplitude and phase angle charts of the first three harmonics illustrate the regional boundaries for different rain patterns. The annual distribution over South India is discussed in some detail as an example of the super-imposition of the two dominating annual events which are the SW monsoon and the NE monsoon. The importance of topography on the actual amount of rainfall and its distribution under the influence of both regimes at Coondapoor and Nagercoil is described with the aid of characteristic amplitude ratios.

A secondary maximum during February is well established over the mountains of West Pakistan and Kashmir. The phase angle charts show that it is propagated in two geographic directions, from northwest to southeast along the south side of the Himalayas, and from north to south along the west side of the Baluchistan mountains. The only area where the intensity of winter rains exceeds that of summer precipitation was found to be the intermontane region of Baluchistan.

1. Introduction

India has impressive records of precipitation observations. This can be explained by the fact that the annual and the year-to-year variations of the monsoon rains are utterly important to India's economy. According to Hann (1910), the annual cycle of precipitation has been recorded and described in detail as early as 1882 by Eliot, and by Blanford. Every textbook of climatology devotes much space to the rains of India. Temperature and precipitation trends produce three climatological seasons in India: a cool, a hot and a rainy season. However, the beginning and duration of each season differs greatly throughout the country. There is no time of the year when rain is not falling in some part of the sub-continent. Even more, one can say that each month shows either the main maximum or a secondary maximum of rainfall in at least one province of India. While the SW monsoon usually begins during the last week of May at the southwestern tip, it reaches the northwestern provinces not before the third week of June. And before the NE monsoon season ends in Madras Province, the winter rains begin in the northern provinces.

The purpose of this study is to apply harmonic analysis to the description of the annual march of precipitation in relation to India's geography and topography, in an objective attempt to locate boundaries or mixing zones between the different types of rainfall during the annual cycle. Fig. 1 shows the boundaries of the provinces and the location of those stations mentioned later in this study.

2. Data

With high-speed computers now available, it is possible to apply harmonic analysis to observations at a great number of stations. The program was described and developed by Bryson and Lowry (1955) and since then has been employed in several precipitation studies (Bryson 1957a, 1957b and Sabbagh and Bryson 1962). A detailed description of the method and its advantage in comparison with qualitative analysis of rainfall is given in the study by Horn and Bryson (1960),

---

*This research was in part carried out at the Center for Climatic Research, directed by Prof. Reid A. Bryson, University of Wisconsin, under support by the National Science Foundation, Grant GP-444.

†In attendance at the University of Wisconsin during the Academic year 1961-1962. Permanent address: The National Science Foundation, Washington 25, D.C.

Fig. 1. Boundaries of the provinces and the locations of stations mentioned in this study

entitled "The Harmonic Analysis of the Annual March of Precipitation over the United States."

In 1947, the Indian Meteorological Service published annual and monthly normals of rainfall for some 3000 reporting stations throughout India up to 1940 (India met. Dep. 1947). From this total, 250 stations were selected which are distributed evenly over the sub-continent. The material is not completely homogeneous. The monthly means are based on more than 50 years of observations, some up to 70 years. In order to show that the length of period is not critical to the harmonic analysis, a ten-year period was arbitrarily selected from the 66-year record for Madras and analyzed with the following results—

Length of record	10 years		66 years	
	ampl.	phase	ampl.	phase
1st harmonic	4·5	179°	5·1	177°
2nd ,,	2·6	225°	2·6	227°
3rd ,,	1·3	227°	1·9	289°
4th ,,	·8	329°	1·2	10°
5th ,,	·3	133°	·5	84°
6th ,,	·07	89°	·4	90°

This example shows a remarkable agreement in all six harmonics, in amplitudes as well as in phase angles which may be attributed to the monsoon character of rainfall in Madras. This is particularly interesting because in a monsoon climate, excessive amounts of rain are possible within a short period of time (for instance, 500 mm in 24 hours at Madras) which must affect monthly averages of long standing. In addition, it is known that the monsoon rains, although coming with great persistancy (nearly 100%), vary considerably in the date of occurrence, and at times may not occur at all over some areas. According to Flohn (1943), the extreme deviation of the peak of the monsoon at Madras is ± fifteen days.

It is obvious that the dating of the beginning or the peak of the monsoon can hardly be done in an objective manner, since it is based on inspection of the records for individual years. A cause for uncertainty is the year-to-year and place-to-place variation of precipitation intensity. The harmonic analysis of the annual cycle, however, is an objective tool. Mean amplitudes and phase constants are based on the precipitation character of the whole year for an individual station. It will be shown that the first three harmonics permit a nearly complete characterization of the time and space development of the Indian Monsoon.

3. Definitions

The results of the Fourier analysis for the first three harmonics are illustrated in Figs. 2,4 and 6 showing isolines of amplitude in inches, and in Figs. 3, 5 and 7 showing isochrones of phase angles in degrees. The marginal insets give the conversion of degrees to dates of maximum. Although all six harmonics have been computed, only the first three are plotted. The amplitude value A_1 of the first harmonic is significant for the tendency of the observed curve towards an annual maximum, A_2 towards a semi-annual and A_3 towards a tertiary. The ratio A_2/A_1, therefore, is a measure of the relative importance of a semi-annual oscillation in comparison to an annual. Since the summer monsoon rains contribute so heavily to the yearly amount, it is to be expected that A_1 will exceed A_2 and A_3 in most parts of India.

Another characteristic of practical significance is the ratio A_1/A_0, the amplitude value of the first harmonic to the mean monthly amount of rainfall. If this ratio approaches unity, then the minimum does correspond to a relatively dry period, whereas if this ratio is small, rainfall is distributed more evenly over the whole year.

A third characteristic is the variance. It is a measure of the month-to-month fluctuation of precipitation. It can be shown that in the terms of amplitudes (A_i) the total variance equals

$$\mathrm{Var} = \sum_{i=1}^{5} A_i{}^2/2 + A_6{}^2$$

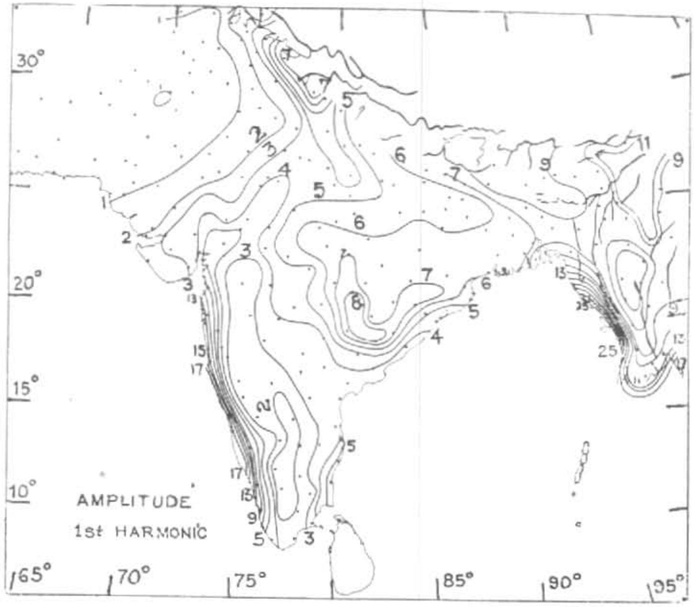

Fig. 2. 1st Harmonic Amplitude

First Harmonic Maxima

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

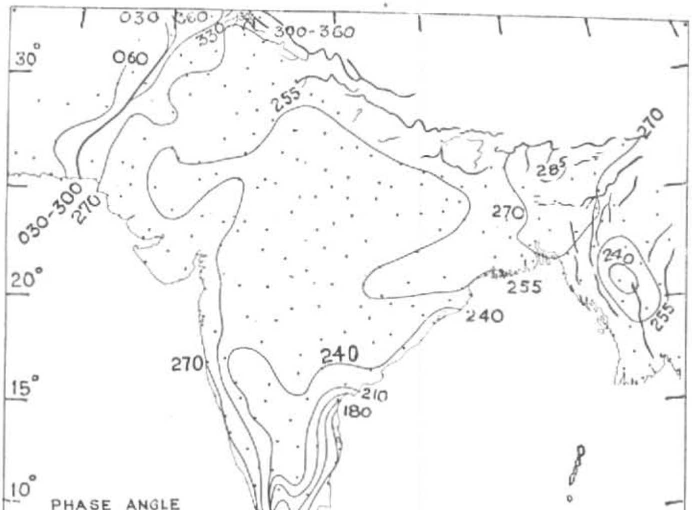

Fig. 3. 1st Harmonic Phase Angle

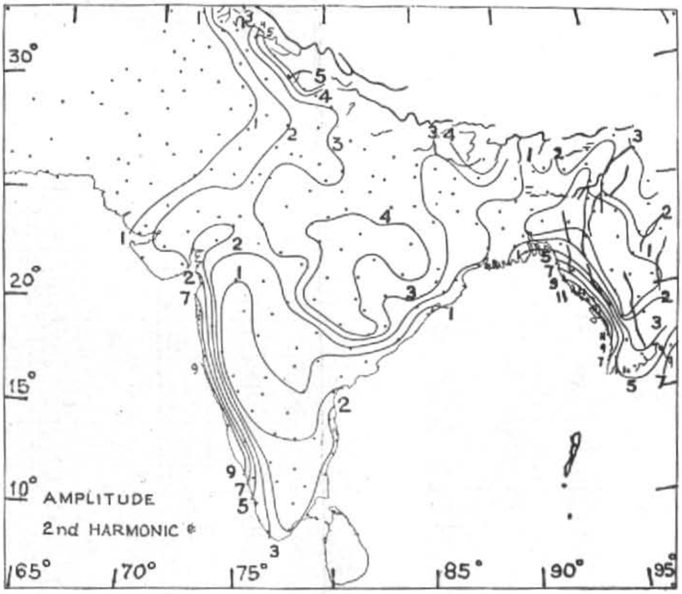

Fig. 4. 2nd Harmonic Amplitude

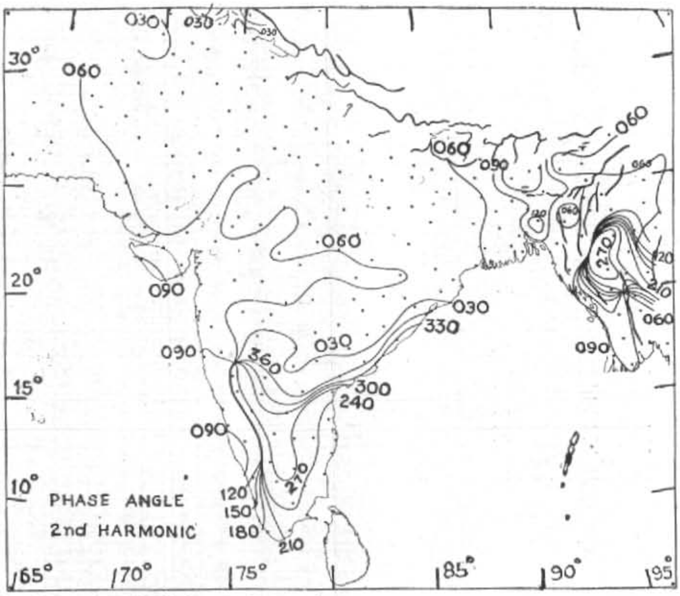

Fig. 5. 2nd Harmonic Phase Angle

Second Harmonic Maxima

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

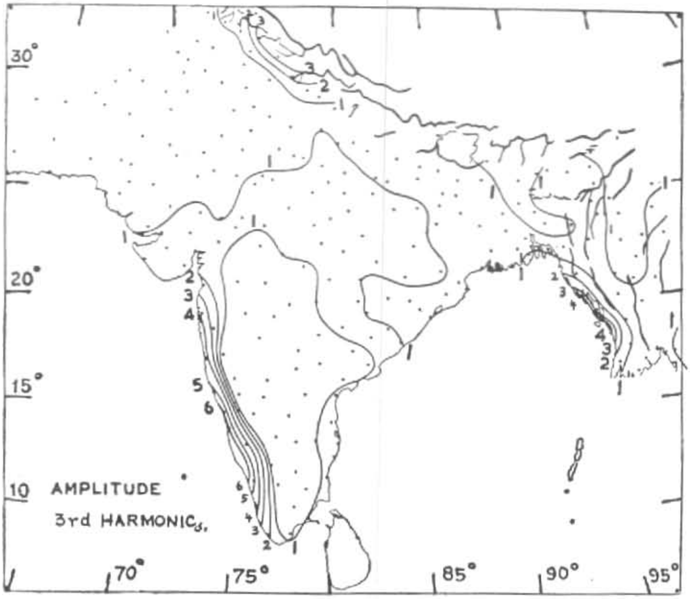

Fig. 6. 3rd Harmonic Amplitude

Third Harmonic Maxima

0°	Feb 15	Jun 15	Oct 15
30	Feb 5	Jun 5	Oct 5
60	Jan 25	May 25	Sep 25
90	Jan 15	May 15	Sep 15
120	Jan 5	May 5	Sep 5
150	Dec 25	Apr 25	Aug 25
180	Dec 15	Apr 15	Aug 15
210	Dec 5	Apr 5	Aug 5
240	Nov 25	Mar 25	Jul 25
270	Nov 15	Mar 15	Jul 15
300	Nov 5	Mar 5	Jul 5
330	Oct 25	Feb 25	Jun 25

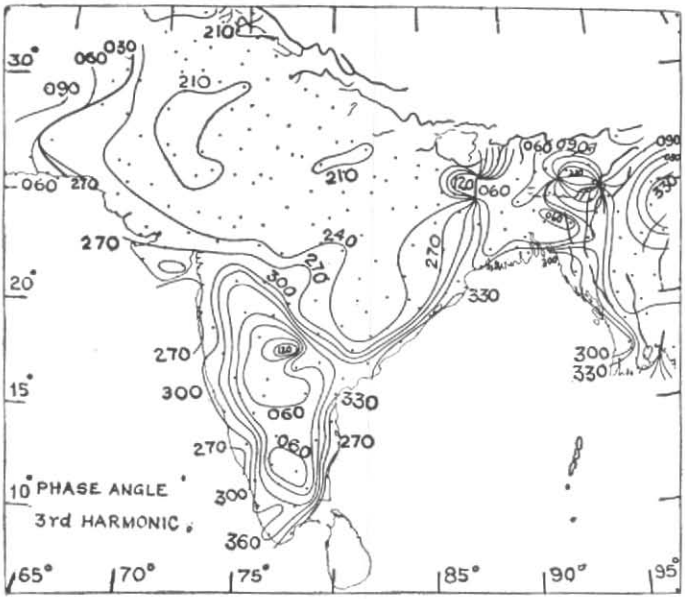

Fig. 7. 3rd Harmonic Phase Angle

Thus, 50 A_i^2/Var constitutes the proportion, in per cent, which the i-th harmonic contributes to the total variance.

This ratio has been computed for representative stations in each province and the results show that the first three harmonics are responsible for over 90 per cent of the total variance. The higher harmonics account for local irregularities which are of minor importance to the overall rainfall pattern of India.

4. The monsoon regime

Fig. 3 is the phase angle chart of the first harmonic. An isoline with the date of 15 July follows the coastline of southwest India, from Cape Comorin in the south to the Bombay area approximately. In the same region isochrones of 1 August and 15 August are running parallel farther inland, indicating the progression of the monsoon perpendicular to the coastline. The 1 August isochrone, however, extends much farther north and encircles nearly completely Central India, whereas the 15 August isoline turns sharply east already at 17° latitude, near Bombay. At the east coast, south of 17° latitude, September to November isolines are found. This suggests that the 15 August isochrone can be considered a boundary line between Central India where the date of maximum varies hardly at all and South India with rapid changes in date-lines. In addition, a well-defined nodal line separates the western part from the eastern part of South India. It marks the boundary zone between one area receiving predominantly summer rains and the other where the maximum occurs in late autumn.

A second isochrone with a date of 15 July can be seen on Fig. 3 in the border area of Bengal, Assam and Burma, a third one in the Arabian Sea where it follows roughly the Indus River Valley. The coast of Burma shows also a July-August maximum of rainfall.

The climatological event behind this pattern of isolines is, of course, the monsoon cycle. Its maximum phase occurs simultaneously along the southwestern coasts of South Asia (Burma, India, Ceylon). The wide spacing of isolines over the Central provinces of India (present Madhya Pradesh, Uttar Pradesh, Rajasthan and Maharashtra) means that the "peaking" of the monsoon occurs at almost the same time from Bombay province (present Maharashtra) to the Himalaya mountains and eastward to the Ganges Delta. Towards fall, with the beginning of the cooler season, the monsoon recedes from the North and Central provinces (present Punjab, Rajasthan, Uttar Pradesh and Madhya Pradesh). Then the east coast receives the heavy rains from the moisture-laden air over the Bay of Bengal, with NE winds. The date of maximum changes from the first half of August at the Orissa coast to September-October in the Madras province. In the southern-most part of the peninsula the maximum is found as late as 15 November.

Although the entire continent of India is under the influence of the monsoon regime at some time during the year, its cycle can be observed best in South India because of little interference from other disturbances. Thus, a detailed discussion of the plotted results, obtained by harmonic analysis, concerning the monsoon regime will be restricted to South India, with special attention given to topographical factors.

The importance of topography on climatological elements is well known. Elevation, slope, exposure to the prevailing winds variegate the amount of rainfall at stations located in the same geographical area under the same precipitation pattern.

The area which shall be considered, has roughly the shape of a triangle, with Cape Comorin at the southern point and the 15 August isochrone as the opposite side. Parallel to the coast, approximately 50 miles inland, the nearly unbroken mountain range of the Western Ghats lies directly in the path of the Southwest Monsoon, thus forcing the warm moist air to rise 5000 to 8000 feet. The Eastern Ghats, a mountain area along the Madras coast, do not form a real barrier to the Northeast Monsoon. They are farther away from the shore and broken up by valleys. Rivers coming from the highland of Mysore flow generally from east to west. Thus, each of the three geographical areas, the West coast, the East coast and the highland between the Ghats must possess a distinctly different rainfall distribution over the year.

On the amplitude chart (Fig. 2), the steep gradient along the West coast reveals that the heavy rains are confined to the immediate coastal area. A slight bulge is noticeable in Figs. 2 and 3, indicating a deeper penetration inland. This happens where the mountains are lower and nearest to the shore, at the Palghat gap. The A_1 values decrease sharply perpendicular to the coastline and more slowly along the shore northward and southward. They are very small in the interior and approach zero along the nodal line (*see* Fig. 3) which delineates the border zone between a summer and a fall maximum. Farther east, the A_1 values increase again but the gradient is much weaker than at the West coast.

It is interesting to demonstrate the usefulness of the harmonic components in a discussion of rainfall distribution over the year at two selected stations, both under the influence of the monsoon but at different geographical locations.

One station shall be Coondapoor. It is situated at the West coast at about 13° latitude in a narrow coastal plain out of which mountains rise to heights of 5000 to 8000 feet. The other shall be Nagercoil (elevation approximately 2000 feet), at the southern end of the Cardamom Hills near the tip of the peninsula. The distance between the stations is approximately 350 miles. Characteristic ratios can be listed as follows—

A_0	A_1/A_0	A_2/A_1	$50A_1^2/\text{Var}$	$50A_2^2/\text{Var}$
		COONDAPOOR		
11·9	1·55	0·55	68%	20%
		NAGERCOIL		
3·0	0·46	1·60	21%	53%

A_0=Arithmetic mean of 12 monthly means of rainfall in inches

At Coondapoor A_2/A_1 is small, which means that the tendency towards one annual maximum is dominant. The variance of the first harmonic accounts for 68% of the total variance, or in other words, the annual oscillation contributes most to the month-to-month fluctuations. The actual precipitation curve at Coondapoor shows one strong annual maximum, and a pronounced dry season from December through April. The resultant of the two harmonics would bring the precipitation exactly to zero at the time of the winter minimum provided the phase angles coincide. This is confirmed by the examination of the phase angles.

The phase angle $\alpha_1=265^\circ$, when converted to dates, indicates that the maximum occurs on 20 July. The phase angle α_2 of the second harmonic equals 97°, or as shown in Fig. 5, maxima are to be expected on 20 January and 20 July. Thus, one maximum of the semi-annual wave is, indeed, in phase with α_1. This has the effect to raise the summer maximum and bring the winter minimum to zero. In addition, it means that the precipitation curve has a point of symmetry on 20 July. Although the variance of the first and second harmonics contribute already 88% to the total variance, the effect of the third harmonic is not negligible. The phase angle α_3 shows also a maximum in July, though two weeks earlier, followed by two more maxima, each four months apart. The amplitude value A_3 is still relatively large, more than $A_1/3$ which would indicate some irregularities of the actual precipitation curve in November. Thus, the curve would not be completely symmetrical.

At Nagercoil, the situation is obviously quite different. A semi-annual wave definitely prevails. The second harmonic contributes more than two times as much as the first to the total variance. A_1/A_0 is rather small, compared to A_2/A_0 and even A_3/A_0. This signifies that rain may be expected during most of the year. There is no pronounced dry period. Nagercoil is situated within the boundary zone marked by the nodal line on Fig. 3. The date of maximum of the annual wave was found to be 15 August, and the maxima of the semi-annual oscillation occur on 29 April and 29 October. The fact that the maximum of the weak annual wave coincides approximately with one minimum of the pronounced semi-annual wave indicates that the actual precipitation curve at Nagercoil has a secondary summer minimum of rainfall. Although Coondapoor and Nagercoil are under the influence of both the Southwest monsoon and the Northeast monsoon, the amount of rainfall each station receives and the distribution over the year differ widely due to topographic and orographic characteristics.

Geographically, the Burma coast is similar to that of southwest India, and so are the rainfall characteristics. For example, at Sandoway, a station on the Burma coast, we find that $A_2/A_1 = 0\cdot54$ and $A_1/A_0 = 1\cdot56$. At Coondapoor, which can be considered typical for the west coast of South India, the corresponding ratios are $0\cdot55$ and $1\cdot55$. Fig. 2 shows that the A_1-values are even higher in Burma than in India and so are the A_0-values. Here, too, the gradient decreases markedly towards the mountainous interior and more slowly northward. While the constants of the first harmonics show only a gradual transition from the rain pattern of Burma to that of the lowlands of the Ganges, the charts of the second harmonics reveal the existence of a distinctly different pattern in West Bengal and East Pakistan.

The amphidromic line of isochrones, as seen on Fig. 5, indicates that this 'west coast type' of rain pattern does not reach across the mountains of Arakan into the lowlands of Burma. There, the amplitude values A_2 are rather small, only one third to one fourth of A_1. This can mean that the annual wave representing the monsoon influence is dominant, but other effects contribute also to the variation of rainfall over the year. For example, it is known that showers and thunderstorms occur frequently during the hot season from March until May. And in some years the winter rains of the Northwest India reach as far southeast as Calcutta.

Marked features of the phase angle chart of the third harmonic are two pairs of amphidromic points (*see* Fig. 7). Although the A_3-values are very small (all are under one inch), the areas defined by the above nodal points are interesting due to their geographic locations. The easterly discontinuity zone extends over a terrain where the mountains of Assam are separated from the ranges of the Himalayas by the Brahmaputra valley. The westerly discontinuity is located at a geographically similar site. It extends across the Ganges river valley between the Himalayas and the easternmost hills of Bihar. It may be of interest to mention that Julius Hann (1910), in his description of the climate of India, distinguishes between the plains of the Ganges valley above and below Benares, in respect to certain rain phenomena. He found that the valley above Benares has a secondary January-February maximum which is not apparent in the delta area. There the winter rains continue into spring without interruption.

The easterly discontinuity zone appears to coincide with an area of higher annual variability of precipitation imbedded in a region of lower variability, as described by Chatterjee (1951). He attributes the fluctuation to changes in the intensity of the landwinds through the Brahmaputra or Surma Valley, and the fallwinds from the eastern Himalayas, caused by a possible decrease in the strength of the northeastern anticyclone in winter.

In West India, another isochrone with the date of 15 July is apparent on Fig. 3, curving through the Indus river valley. From there towards Central India, isolines are widely spaced, whereas westwards they converge into a nodal line which extends parallel to the valley through the Baluchistan mountains. This amphidromy delineates a boundary zone separating the semi-arid plains of West Pakistan, the Punjab and Rajasthan from the intermontane region. The mean annual rainfall A_0 is only 0·3 inch in the Sind desert, 0·5 to 1 inch in the Baluchistan mountains and about 2 inches in Rajasthan. A survey of the three amplitude charts reveals that A_1, A_2 and A_3 are all of the same dimension, all under 1 inch. Although a small variation in any A-value can result in marked change of the characteristic ratio A_1/A_0 and A_2/A_1, there is an area where $A_2/A_1 \geqslant 1$ consistently. It coincides rather well with the western slopes of the Baluchistan mountains. Along the line of discontinuity, apparent on Fig. 3, the ratio A_2/A_1 increases from the Arabian Sea northward. This indicates the growing influence of the regime of the winter rains of the northwest which will be discussed in the following section.

The climatological cause of the sparseness of rainfall in West India is the development of a pressure low over this region during the hot season. Thus, the prevailing winds are dry, coming from the west or northwest and not from the Arabian Sea directly.

5. The regime of the winter rains of the northwest

Small depressions, originating over Iran and Afghanistan, and wandering slowly eastward, are the source of the winter rains of Northwest India. Rainfall usually begins during the second half of December. The occurrence of rain during the winter months makes it feasible to grow wheat and other non-tropical crops in this region. Besides that, they are a main source of snowfall for the Himalayas.

A sequence of isochrones of the first harmonic (*see* Fig. 3) suggests a migrating wave travelling from Afghanistan through north of West Pakistan to Kashmir from March to June. These isochrones, which are separate in the north, merge farther south into the nodal line over the Baluchistan mountains. West of this discontinuity, the above mentioned zone where $A_2 \geqslant A_1$, is found. A second such zone extends along the south side of the Himalayas.

The remarkable feature of Fig. 5, the phase angle chart of the second harmonic, is the scarcity of isolines over North India. The two coherent maximum dates of 15 February and 15 August dominate the map without indicating a defined propagation. The short nodal line apparent over Kashmir indicates a change of rain pattern behind the outer ranges of the Himalayas. Amplitude values are very small in the entire northwest. The exception is a limited area over Kashmir where the A-values increase markedly. This can partly be an orographic effect, but it must also be related to a winter maximum since it is also present on the maps of the second harmonic; see Figs. 4 and 5. To determine the propagation of a semi-annual wave characteristic amplitude ratios shall be employed again. The stations (*see* Table 1), situated along the south side of the Himalayas, were selected to demonstrate the profile of changing rain patterns over North India from NW to SE.

Nowshera (near Peshawar), which can be considered representative for the mountain region of West Pakistan, shows a prominent semi-annual wave which contributes 69% to the total month-to-month fluctuations. Maxima occur on 15 February and 15 August. At Udhampur, which lies about 200 miles farther east, the second harmonic still dominates over the first, $A_2/A_1 = 1 \cdot 23$. It is interesting to note that here $A_2/A_0 > 1$, implying that the amount of rainfall is less than zero at the time of the minima. The phase angle α_2 at Udhampur equals 51°, or, maxima occur on 5 February and 5 August. An examination of the phase angle of the fourth harmonic reveals that the dates of the four maxima agree well with the dates of the four extremes of the second harmonic, thus upsetting the apparent negative effect. At Mussoorie, the annual amount of rainfall has increased considerably due to more intensive summer rains. Here A_1/A_0 and A_2/A_0 are larger than one. Investigating the coincidence of phases for the first four harmonics, it was found that all four waves have one maximum on 1 August, ±2 days.

TABLE 1

Distance (miles)	Station	A_0	A_1/A_0	A_2/A_1	50 A_1^2/Var	50 A_2^2/Var
0	Nowshera (W. Pakistan)	1·21	0·25	3·00	7%	69%
200	Udhampur (Kashmir)	4·81	0·83	1·23	30%	51%
450	Mussoorie (Uttar Pradesh)	8·14	1·34	0·83	54%	37%
640	Lakhimpur (Uttar Pradesh)	3·67	1·42	0·65	69%	28%
950	Bettiah (Bihar)	4·35	1·45	0·51	78%	20%
1170	Darjeeling (West Bengal)	10·00	1·39	0·41	83%	16%

The addition of four sinus waves having one maximum date in common produces one pronounced maximum at that date and a secondary minor one, the size of which depends on the relative importance of A_3 and A_4 since A_2 is almost equal to A_1 and in opposite phase at the time of the minimum.

At Lakhimpur, which lies 200 miles farther east and 50 miles away from the mountains, the total annual rainfall is less than half of that at Mussoorie. Although the harmonic components show all the characteristics of a monsoon-dominated rain distribution, a close inspection of the higher harmonics reveals a small but noticeable winter maximum.

At Bettiah, the phase angles show little change from Lakhimpur. An increase of A_1 and a slight decrease of A_2 indicate that the summer maximum becomes even more prevailing. Finally, at Darjeeling, 1200 miles from the Northwest Frontier, there is no indication any more of a winter maximum.

Thus, it can be concluded that a secondary maximum of rainfall during February is dominant only in the mountains of West Pakistan and Kashmir. It is still pronounced in Uttar Pradesh, but its contribution to the total annual rainfall is minor. Those conclusions, it may be remembered, are drawn from the analysis of monthly averages over many years. In any single year, winter precipitation may penetrate much farther eastward depending on the intensity and trajectories of the winter disturbances.

A different rain pattern exists in Baluchistan. Along the western slopes of the mountains the relative importance of the semi-annual wave prevails somewhat over the annual. But all amplitude values are small, denoting the insignificant seasonal variation of precipitation. East of the discontinuity in the intermontane region, where $A_2/A_1>1$, the annual wave is dominant again. The maximum occurs on 15 February, as indicated by the 60° isochrone on Fig. 3. The second harmonic has also one February maximum, whereas the isochrones of the third are merged into a nodal line indicating a rapid change of date over the mountains. Thus, indications are that the intermontane region of Baluchistan has a dominant winter maximum of rainfall and a minimum during late summer. The inspection of actual precipitation curves confirms this result. Such a distribution is distinctly different from that prevailing over India, where the rain intensity is greater during summer than winter, even in the Northwest Frontier area which shows a double wave during the year.

6. Acknowledgements

The authors wish to express their appreciation to Professor Reid A. Bryson for instigating this study and his valuable suggestions thereafter; to Messrs. Chuck Hutchins and R. Sabatini who helped to prepare the electronic IBM 1620 computer program; and to Professor Lyle Horn and Mr. Don Johnson for their advice on practical applications of harmonic analysis.

REFERENCES

Bryson, Reid A. 1957(a) Fourier Analysis of the Annual March of Precipitation in Australia. *Tech. Rep.*, 5, Inst. Atmos. Phys., Univ. Arizona.

1957(b) Fourier Analysis of the Annual March of Precipitation in Australia, *Tech. Rep. 5 on the Meteorology and Climatology of Arid Regions*, Inst. Atmos. Phys., Univ. Arizona.

Bryson, Reid A. and Lowry, William P. 1955 Synoptic Climatology of the Arizona Summer Precipitation Singularity, *Bull. Amer. met. Soc.*, **36**, pp. 329-339.

Chatterjee, S. B. 1951 Precipitation Characteristics, *Geogr. Rev. India*, **13**.

Flohn, Hermann 1943 Witterungssingularitaten im Monsunklima Indiens, *Ann. Hydrogr. Berl.*, pp. 289-294.

Hann, Julius 1910 *Handbuch der Klimatologie*, **2**, Stuttgart.

Horn, Lyle H. and Bryson, Reid A. 1960 Harmonic Analysis of the Annual March of Precipitation over the United States, *Ann. Ass. Amer. Geogr.*, L., 2, pp. 157-171.

India met. Dep. 1947 Monthly and Annual Normals of Rainfall and Rainy Days, *Mem. India met. Dep.*, **27**, Pt. V.

Sabbagh, Michael E. and Bryson, Reid A. 1962 An Objective Precipitation Climatology of Canada, *Tech. Rep.*, 8, Dep. met., Univ. Wisconsin.