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Major climatological discontinuities in the monthly monsoon activity in the neighbourhood of the Western Ghats

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ABSTRACT. The major climatological discontinuities in the monsoon activity from July to August and from August to September in the neighbourhood of the Western Ghats have been studied in detail on the basis of a close network of raingauge stations and the role of the Western Ghats has been examined. The criterion used for defining the major climatological discontinuity is based on the quartiles of the monthly rainfall distribution. The Western Ghats appear to play a differential role. Since meteorological conditions are most favourable during July and become progressively less favourable with the advance of the summer monsoon season, the Western Ghats enhance rainfall substantially under favourable conditions, and decrease the rainfall substantially under relatively unfavourable conditions, and thus contribute to the major climatological discontinuities.

1. Introduction

In an earlier study (Mooley 1974) based on limited data, it has been shown that major climatological discontinuities in the monthly summer monsoon activity do occur over the Indian west coast, the Arakan coast of Burma and the Viet Nam coast. The monthly monsoon activity as measured by rainfall undergoes variations due to perturbations on the monsoon trough and changes in sea surface features. In this paper, the major discontinuities in the monsoon activity from July and to August and August to September in the neighbourhood of the Western Ghats have been studied in detail on the basis of a close network of stations and the role of the Western Ghats has been examined.

2. Network of stations and data used

The names of the stations for which rainfall data have been utilised are given in Table 1, along with their latitudes and longitudes. The abbreviations of station names have also been given in Table 1. The stations have been put under four categories, (*i*) west of the Western Ghats, (*ii*) on and near the crest of the Western Ghats, (*iii*) further east of the Western Ghats, and (*iv*) within the gaps on the Western Ghats. In category (*i*), all stations are on the west coast with the exceptions of Amini Divi and Minicoy which are about 300 km west of west coast. The stations in category (*ii*) are located 75 to 125 km east of the coastal stations at the same latitude, and stations in category (*iii*) are located 100 to 150 km east of the stations in category (*ii*) at the same latitudes. These stations are also shown in Fig.1 which gives the orography of the area under consideration; the abbreviations of the station names are the same as given in Table 1. For all these stations, monthly rainfall data for the period 1901-50 have been used; these data on punched cards were obtained from the office of the Deputy Director General of observatories (Climatology and Geophysics), Pune.

3. Criterion used for major discontinuity

As in the previous study (Mooley 1974), the criterion used is based on the quartiles of the monthly rainfall distribution. The criterion may be stated as follows :

$$LQ_1 > UQ_2 ; \text{ or } LQ_2 > UQ_1$$

where LQ and UQ denote the lower and upper quartiles of the monthly rainfall distribution and suffixes 1 and 2 denote the first and the next month respectively.

When this criterion is satisfied, the two monthly rainfall distributions for the station are markedly different. For example, consider Karwar. The upper quartile for Karwar for August rainfall is 266 mm, whereas, lower quartile for July rainfall is 316 mm. Thus, a major discontinuity exists at Karwar. In fact the discontinuity is very sharp; on 96 per cent of the occasions, August rainfall is less than 316 mm but only on 25 per cent of the occasions, July rainfall is less than 316 mm.

The criterion based on quintiles would be more stringent, whereas that based on terciles would be less stringent than the criterion used.

The lower and the upper quartiles of the monthly rainfall distribution were obtained for each of the

TABLE 1

Raingauge stations

Stations west of the Western Ghats			Stations just east of the Western Ghats			Stations further east of the Western Ghats			Stations within gaps in Western Ghats		
Station	Lat. (°N)	Long. (°E)	Station	Lat. (°N)	Long. (°E)	Station	Lat. (°N)	Long. (°E)	Station	Lat. (°N)	Long. (°E)
Ahmedabad (Obsy) (AHM)	23° 04′	72° 38°	Nasik (NSK)	20° 00′	73° 47′	Ahmednagar (AHG)	19° 05′	74° 55′	Palghat (PLG)	10° 47′	76° 39′
Broach (BRC)	21° 42′	72° 58′	Junnar (Pune Dist.) (JNR)	19° 13′	73° 53′	Dahiwadi (DHD) (Satara Dist.)	17° 42′	74° 33′	Pollachi (Coimbatore Dist.) (PLH)	10° 39′	77° 01′
						Sholapur (Obsy) (SLP)	17° 40′	75° 54′			
Surat (SRT) (Obsy)	21° 12′	72° 50′	Khed (KHD) (Pune Dist.)	18° 51′	73° 54′	Bijapur (Obsy) (BJP)	16° 49′	75° 43′	Shenkottai (SHN) (Tirunelveli Dist.)	8° 58′	77° 15′
Umbargaon (Surat Dist.) (UBG)	20° 12′	72° 46′	Pune (PNA) (Obsy)	18° 32′	73° 51′	Bagalkot (Bijapur Dist.) (BGT)	16° 12′	75° 42′	Tenkasi (Tirunelveli Dist.) (TKS)	8° 57′	77° 19′
Bombay (BMB) (Colaba Obsy)	18° 54′	72° 49′	Wai (WAI) (Satara Dist.)	17° 56′	73° 54′	Hospet (HPT) (Bellary Dist.)	15° 38′	76° 54′			
Roha (RHA) (Kolaba Dist.)	18° 26′	73° 07′	Satara (STR)	17° 41′	73° 59′	Chitaldrug (Obsy) (CHT)	14° 14′	76° 26′			
Dapoli (DPL) (Ratnagiri Dist.)	17° 46′	73° 12′	Patan (Satara Dist). (PTN)	17° 22′	73° 54′	Tumkur (TMK)	13° 21′	77° 06′			
Ratnagiri (Obsy) (RTN)	16° 59′	73° 20′	Kolhapur (KLP)	16° 42′	74° 14′	Mandya (MDA)	12° 32′	76° 53′			
Rajapur (Ratnagiri Dist.) (RJP)	16° 39′	73° 31′	Gadhinglaj (GDH) (Kolhapur Dist.)	16° 13′	74° 21′						
Devgad (Ratnagiri Dist.) (DVG)	16° 22′	73° 22′									
Vengurla (Ratnagiri Dist.) (VNG)	15° 52′	73° 38′	Belgaum (Obsy) (BLG)	15° 51′	74° 32′						
Karwar (KWR)	14° 47′	74° 08′	Dharwar (DWR)	15° 27′	75° 00′						
Kumta (KMT) (North Kanara Dist.)	14° 25′	74° 25′	Hangal (Dharwar Dist.) (HNG)	14° 46′	75° 08′						
Bhatkal (North Kanara Dist.) (BTK)	13° 59	74° 33′	Shimoga (SMG)	13° 56′	75° 38′						

TABLE 1 *(contd)*

Stations west of the Western Ghats			Stations just east of the Western Ghats			Stations further east of the Western Ghats			Stations within gaps in Western Ghats		
Station	Lat. (°N)	Long. (°E)	Station	Lat. (°N)	Long. (°E)	Station	Lat. (°N)	Long. (°E)	Station	Lat. (°N)	Long. (°E)
Coondapur (South Kanara Dist.) (COP)	13° 38′	74° 41′	Belur (Hassan Dist.) (BLR)	13° 10′	75° 51′						
Udipi (UDP) (South Kanara Dist.)	13° 21′	74° 45′	Poonampet (PNP) (Coorg)	12° 09′	75° 56′						
Mangalore (Obsy) (MNG)	12° 52′	74° 51′	Coimbatore (Obsy) (CMB)	11° 00′	76° 58′						
Kasargode (Cannanore Dist.) (KGD)	12° 31′	74° 59′									
Cannanore (CNR)	11° 52′	75° 22′									
Kozhikode (Obsy) (KZK)	11° 35′	75° 47′									
Amini Divi (AMN)	11° 07′	72° 44′									
Ponnani (Palgahat Dist.) (PNI)	10° 47′	75° 55′									
Cranganore (Trichur Dist.) (CRN)	10° 13′	76° 12′									
Ft. Cochin (Obsy) (CHN)	9° 58′	76° 14′									
Quilon (QLN)	8° 53′	76° 36′									
Trivandrum (Obsy) (TRV)	8° 20′	76° 57′									
Minicoy (Obsy) (MNC)	8° 18	73° 00′									
Nagercoil (Kanyakumari Dist.) (NGC)	8° 10′	77° 27′									

stations. In addition, the percentage of cases when August rainfall is less than the lower quartiles of July rainfall distributions, and also the percentage of cases when September rainfall is less *than* the lower quartile of August rainfall distribution, were obtained. By definition, major discontinuities exist when these percentages exceed 75.

4. Results and discussions

4.1. *Major discontinuity from July to August*

Table 2 gives the percentage of cases when August rainfall is less than the lower quartile of July rainfall. It can be seen from this table that the major climatological discontinuity in the activity of the monsoon from July to August

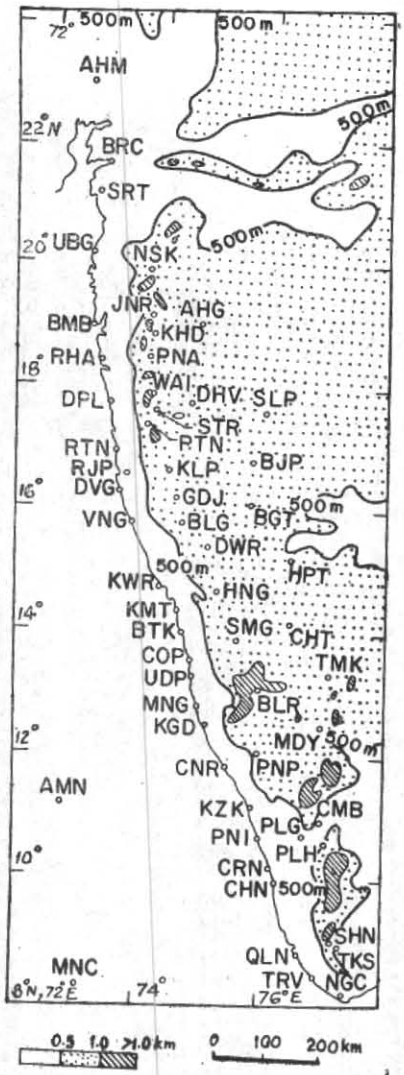

Fig. 1. Network of raingauge stations and orography of western India

exists on the west coast between 9° 15′N and 18°N which is very close to the estimate of 9°N to 17°N obtained from the earlier study. Four maxima are observed in the percentages listed in Table 2. These are located near Dapoli (17°46′N), Karwar (14°47′N), Coondapur (13°38′N) and Kozhikode (11°15′N). The highest maximum among these is the one located near Karwar (about 15°N). It may be mentioned that the rainfall data of Vengurla, Karwar, Bhatkal, Coondapur, Cannanore and Kozhikode exhibit major climatological discontinuities even if the more stringent criterion based on the quintiles of the monthly rainfall distribution is applied. This means that for these stations the first quintile of the rainfall distribution for July is greater than the fourth quintile of the rainfall distribution for August. An examination of the sea surface temperatures over the Arabian Sea during the International Indian Ocean Expedition period 1963-64 shows that the maximum eastward advance from July to August of the cold water from the western parts of the Arabian Sea, as judged by the sea surface 27° C isotherm, occurred along about 15°N. Saha (1970) who studied the sea surface temperature changes along 10°N and 15°N latitudes has shown that along 15°N, the 27°C sea surface isotherm advances from 63°E to 69°E from July to August.

It is worth noting that major discontinuity does not exist at Amini Divi located at latitude 11°07′N, about 300 km west of the Western Ghats, whereas on the west coast, major discontinuity exists further south upto about 9°N.

The data of the stations within the two gaps in the Western Ghats exhibit a major discontinuity since the influence of orography on airflow is experienced within these gaps as on the west coast in approximately the same latitude belts.

On or near the crest of the Western Ghats, the discontinuity is found to exist in two latitudinal belts, 16°30′N-18°N and 12°N-14°30′N. The stations on the west coast and the corresponding stations on or near the crest of the Western Ghats are approximately separated by a distance which varies from 75 to 125 km. Stations near the crest of the Western Ghats and south of 11°N show a different rainfall regime, *viz.*, July rainfall being less than August rainfall; hence in this category of stations, data of stations south of Coimbatore have not been given. As we move further east of the Western Ghats, the discontinuity disappears. Even over the portion on or near the crest of the Westen Ghats, the discontinuity is restricted to two narrow latitudinal belts, which situation is in marked contrast to the much wider belt of about 9°N-18°N of the discontinuity on the west coast. When we move further west to Amini Divi, we find that the discontinuity disappears. It is thus clearly seen that the major climatological discontinuity in the monsoon activity from July to August disappears beyond some specific distance to the east and west of Western Ghats.

According to the previous study (Mooley 1974), the major climatological discontinuity on the west coast from July to August, appears to be caused jointly by (*a*) the decrease in the vigour of the monsoon, (*b*) increase in the number of days of 'break' in the monsoon and (*c*) decrease in the sea surface temperature and in the net sea-air heat flux over the central and south Arabian Sea, from July to August. Now, if these were the only factors jointly leading to the major discontinuity, there

TABLE 2

Percentage of cases when August rainfall is less than the lower quartile of July rainfall

Stations west of Western Ghats	Percentage	Stations just east of Western Ghats	Percentage	Stations further east of the Western Ghats	Percentage	Stations within the gaps in Western Ghats	Percentage
Ahmedabad (Obsy)	50						
Broach	56						
Surat (Obsy)	70						
Umbargaon	72	Nasik	58				
		Junnar	68	Ahmednagar	30		
Bombay (Colaba Obsy)	62	Khed	74				
Roha	70	Pune (Obsy)	60				
Dapoli	80	Wai	74				
		Satara	80	Dahiwadi	46		
				Sholapur	38		
Ratnagiri (Obsy)	76	Patan	86				
Rajapur	78	Kolhapur	78	Bijapur	35		
Devgad	76	Gadhinglaj	68	Bagalkot	38		
Vengurla	86	Belgaum (Obsy)	72				
		Dharwar	58	Hospet	28		
Karwar	96	Hangal	74				
Kumta	80						
Bhatkal	82	Shimoga	80	Chitaldrug	36		
Coondapur	90						
Udipi	80	Belur	78	Tumkur	25		
Mangalore (Obsy)	78						
Kasargode	80						
Cannanore	86	Ponnampet	87	Mandya	14		
Kozhikode (Obsy)	90						
Amini Divi (Obsy)	46	Coimbatore (Obsy)	46				
Ponnani	78					Palghat	84
						Pollachi	72
Cranganore	76						
Fort Cochin (Obsy)	80					Tenkasi	76
Quilon	72					Shenkottai	84
Trivandrum (Obsy)	64						
Minicoy (Obsy)	32						
Nagercoil	50						

NOTE — Stations with nearly the same latitude have been put in the same line to facilitate comparison

appears to be no reason for (*i*) Amini Divi data not exhibiting a major discontinuity, (*ii*) the belts of major discontinuity on the crest of the Western Ghats covering a substantially smaller latitudinal range than that covered by the belt of major discontinuity on the west coast and (*iii*) the data of stations further east of the Western Ghats not exhibiting any major discontinuity. These facts together with the fact that the discontinuities in the field of the Asian summer monsoon as brought out in the earlier study (Mooley 1974) are in the proximity and on the windward side of the mountain ranges and the fact that Bombay and Trivandrum both located near the extremities of the Western Ghats, do not exhibit any discontinuity suggest that the mountain range is playing some role in contributing to the discontinuity on the west coast of India. The Western Ghats with an average altitude of about 900 metres substantially influence the airflow. On the windward side, the airflow is affected over a much wider belt than on the leeward side. It is known that the monsoon trough is most intense in July, *i.e.*, roughly after about a month's time from the epoch of maximum solar radiation. When the decline in solar radiation starts towards the end of June, its effect in decreasing the intensity of the monsoon trough and the monsoon cir-

TABLE 3

Percentage of cases when September rainfall is less than lower quartile of August rainfall distribution

Stations west of Western Ghats	Percentage	Stations just east of Western Ghats	Percentage	Stations further east of the Western Ghats	Percentage	Stations in the gaps in Western Ghats	Percentage
Bombay	40	Junnar	32				
		Khed	20				
Roha	74	Pune	25	Ahmednagar	4		
		Wai	18				
Dapoli	80	Satara	48	Dahiwadi	4		
				Sholapur	10		
Ratnagiri (Obsy)	52	Patan	82				
Rajapur	72	Kolhapur	58	Bijapur	7		
Devgad	44	Gandhinglaj	58	Bagalkot	10		
Vengurla	70	Belgaum (Obsy)	72				
		Dharwar	36	Hospet	10		
Karwar	68	Hangal	68				
Kumta	78						
Bhatkal	82	Shimoga	36	Chitaldrug	12		
Coondapur	84						
Udipi	82	Belur	32	Tumkur	12		
Mangalore (Obsy)	90						
Kasargode	90						
Cannanore	80	Ponnampet	75	Mandya	4		
Kozhikode (Obsy)	72						
Amini Divi	42						
Ponnani	66					Palghat	80
Cranganore	56					Pollachi	64
Fort Cochin (Obsy)	58						
Quilon	36					Shenkottai	42
						Tenkasi	38
Minicoy	42						

NOTE — Stations with nearly the same latitude have been put in the same line to facilitate comparison

culation is observed in August and from August onwards there is progressive decrease in the intensity of the monsoon trough. Orography leads to convergence and vertical uplift in the approaching air stream well in advance of the barrier. If the thermal structure of the air stream is such that convective instability is present, then the initial trigger (uplift) provided by the mountain, leads to further vertical motion on realisation of the instability and copious rainfalls on the coastal belt. If the airmass is not convectively unstable, the initial lift provided by the mountain would not lead to further uplift of air and the resulting rainfall would be much less. Possibly the airmass is convectively unstable on many more occasions in July than in August. It would thus appear that the progressive decrease in the intensity of the monsoon trough after July (the month of peak intensity), more favourable thermodynamical structure of the air stream in July than in August, and the initial trigger (uplift) provided by the mountin for the release of the instability lead to much more rainfall in July than in August, thus contributing to the discontinuity in monsoon activity on the west coast from July to August. The eastward advance of the cold water in the central and the adjoining south Arabian Sea from July to August might contribute to the unfavourable thermodynamical structure of the air stream in August. The Western Ghats thus play a differential role and are an additional factor leading to the major climatological discontinuity upto some distance on either side.

4.2. *Major discontinuity from August to September*

The percentage of cases when September rainfall is less than the lower quartile of August rainfall distribution is given in Table 3. The major climatological discontinuity on the west coast from August to September is seen to exist in the

belt 11° 30′ N-14° 30′N which is very close to that estimated in the previous study (Mooley 1974). In addition, an isolated major discontinuity is also observed around Dapoli (Lat. 17°46′N). The major discontinuity is most severe near Mangalore and Kasargode, *i.e.*, in the narrow belt 12° 30′N-13°N. The data of both of these stations and of Bhatkal and Udipi show that even with the more stringent criterion of major discontinuity based on the quintiles, the major discontinuities exist at these stations.

On or near the crest of the Western Ghats, no discontinuity is observed except at two isolated locations, *viz.*, Patan (Lat. 17° 22′N) and Ponnampet (Lat. 12° 09′N); this situation is in marked contrast to that on the west coast where the belt of major discontinuity lies between 11°30′N and 14°30′N. Further east of the Western Ghats there is a reversal in the situation, September rainfall being more than August rainfall; however, the increase in rainfall from August to September does not constitute a major climatological discontinuity.

In respect of the four stations within the gaps, only Palghat (Lat. 10°47′N) exhibits a major discontinuity.

The meteorological conditions become still less favourable by September and the major discontinuity from August to September in the belt 11°30′N-14°30′N on the west coast to the west of the Western Ghats appears to be due to the differential role played by the Western Ghats as in the case of the discontinuity on the west coast from July to August.

5. Conclusions

(*i*) From July to August, major climatological discontinuity in the monsoon activity exists, between 9°15′N and 18° N on the west coast, in the belts 16°30′N-18°N and 12°N-14°30′N on and near the crest of the Western Ghats. Further east of the Ghats and beyond some distance west of the west coast, major discontinuity is not observed. The major discontinuity on the west coast is most marked in the neighbourhood of latitude 15°N.

(*ii*) From August to September, major discontinuity exists between 11°30′N and 14°30′N on the west coast and at a few isolated locations on and near the crest of the Ghats. Major discontinuity is not observed further east of the Ghats.

(*iii*) With meteorological conditions being most favourable in July for rainfall and becoming progressively more unfavourable thereafter the Western Ghats appear to play a differential role and contribute to the observed major discontinuities in the monsoon activity.

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