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Effect of westward moving cloud organisations in west and near equatorial Pacific Ocean on the monsoon rainfall of India

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सार — विभिन्न सिनाप्टिक प्रणालियां दक्षिण-पश्चिम मानसून ऋतु के दौरान भारत में होने वाली वर्षा को प्रत्यक्ष अथवा अप्रत्यक्ष रूप से प्रभावित करती हैं। इनमें से, उत्सुकता पैदा करने वाली एक प्रणाली वह है जिसमें विषुवतीय पश्चिमी प्रशांत महासागर क्षेत्र पर मेघ स्पंद पश्चिम की ओर गतिमान होते हैं। इनसैट-1 भू-स्थिर उपग्रह से प्राप्त चित्रों में देखे गए मेघ स्पंदों को भारत के चुनिंदा मौसम उप-खंडों की वर्षा से जोड़ने का प्रयास किया गया है जो कि उक्त स्पंदों से प्रभावित प्रतीत होते हैं।

ABSTRACT. There are various synoptic systems which affect the rainfall over India during southwest monsoon season directly or indirectly. Among them, one subject of interest is the westward moving cloud pulses over the equatorial west Pacific region. An attempt has been made to connect the satellite cloud pulses in the equatorial west Pacific, as seen in the INSAT-1 geostationary satellite imageries, with the rainfall of selected meteorological subdivisions of India which are seemingly affected by these pulses.

Key words — Cloud pulses, Cloud organisation, Maximum cloud zone, West Pacific equatorial region, Pulse, Rainfall.

1. Introduction

The equatorial low pressure trough girdles with variable seasonal excursions, into northern and southern hemispheres in the summer season of each. This zone is the principal line along which flow from both the hemisphere converges, especially the NE and SE trade winds. On any day, a narrow cloud band thousands of kilometre long along the trough exists. The cloudiness, however, is highly variable and the continuous line becomes broken or disorganised at any instance and even vanishes at times. In its place, organised cloud masses are seen moving westward. These are called cloud clusters and are associated with equatorial waves.

The spells of increased cloudiness propagating westward in the latitude belts of 15° to 30°N, and to some extent between 0° and 10°S, are referred to as significant in the interference with the northward propagating mode (Prasad *et al.* 1988). Near the equatorial region organised cloud masses are seen moving westward or northward as pulses of monsoon flow. Over large parts of the trade wind areas during summer, weak low pressure troughs with a wavy easterly flow undulating between NE and SE travel westward long distances with an average speed of about 7° longitude per day. The waves are most common in northern hemisphere, where the easterly current of the tropics is broadest and most extensive.

Sikka and Gadgil (1980) pointed out that the organised moist convection associated with the monsoon trough may be attributed to the continental ITCZ over the region. They consider the monsoon Maximum Cloud Zone (MCZ) as a "manifestation of a continental ITCZ and the secondary MCZ of an oceanic one". They observed a temporary disappearance of the monsoon MCZ associated with a following spell of break monsoon conditions during which time the oceanic ITCZ becomes dominant. They also stated that an MCZ which develops near the equator moves to 30°N at the rate of about 1° latitude per day. Prasad *et al.* (1983) as well as De *et al.* (1992) have shown that there exists an inverse relationship between the cloudiness in the SHET zone (equator to 10°S) and the rainfall activity over central India. According to Yasunari (1981), the 'active' and 'break' phases in the atmospheric field over India follow a 15-day cycle apart from the predominant periodicity of 40 days as a quasi-stationary mode obtained through the analysis of cloudiness fluctuations. Krishnamurti and Bhalme (1976) had also expressed similar views.

South of 15°N and east of 85°E, the land portions are comparatively tiny in the vast field of the two great oceans, *viz.*, the Bay of Bengal division of the Indian Ocean and the Pacific Ocean, and thus may not cause much resistance to, or variations in the nature of the intense westward moving systems. It is quite probable, therefore, that any system or organisation of considerably long duration moving westward, would induce a wavelike disturbance over the Burmese-Malaysian regions as well as the Indian subcontinent. This effect might add to the seasonal increase of rainfall.

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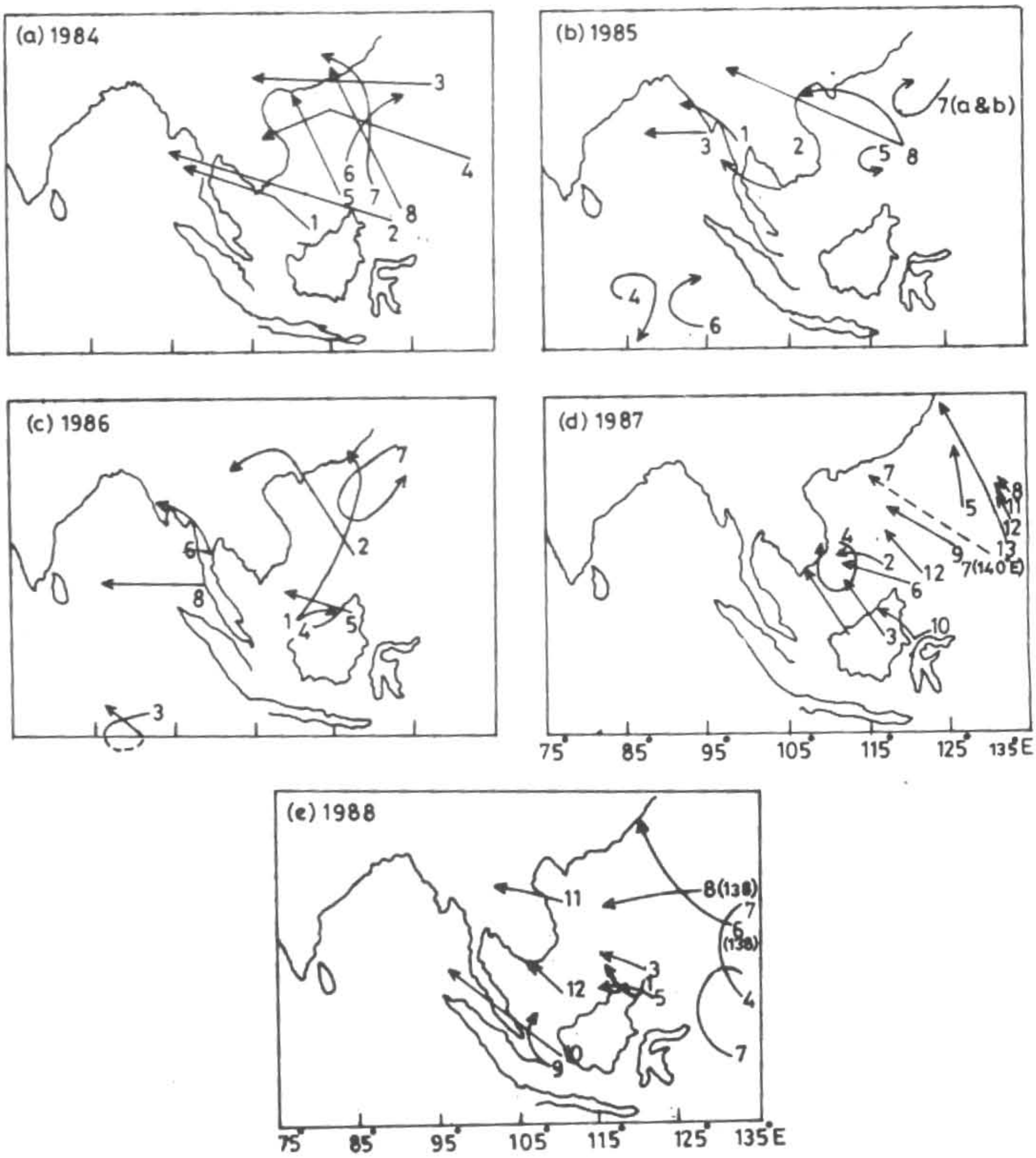


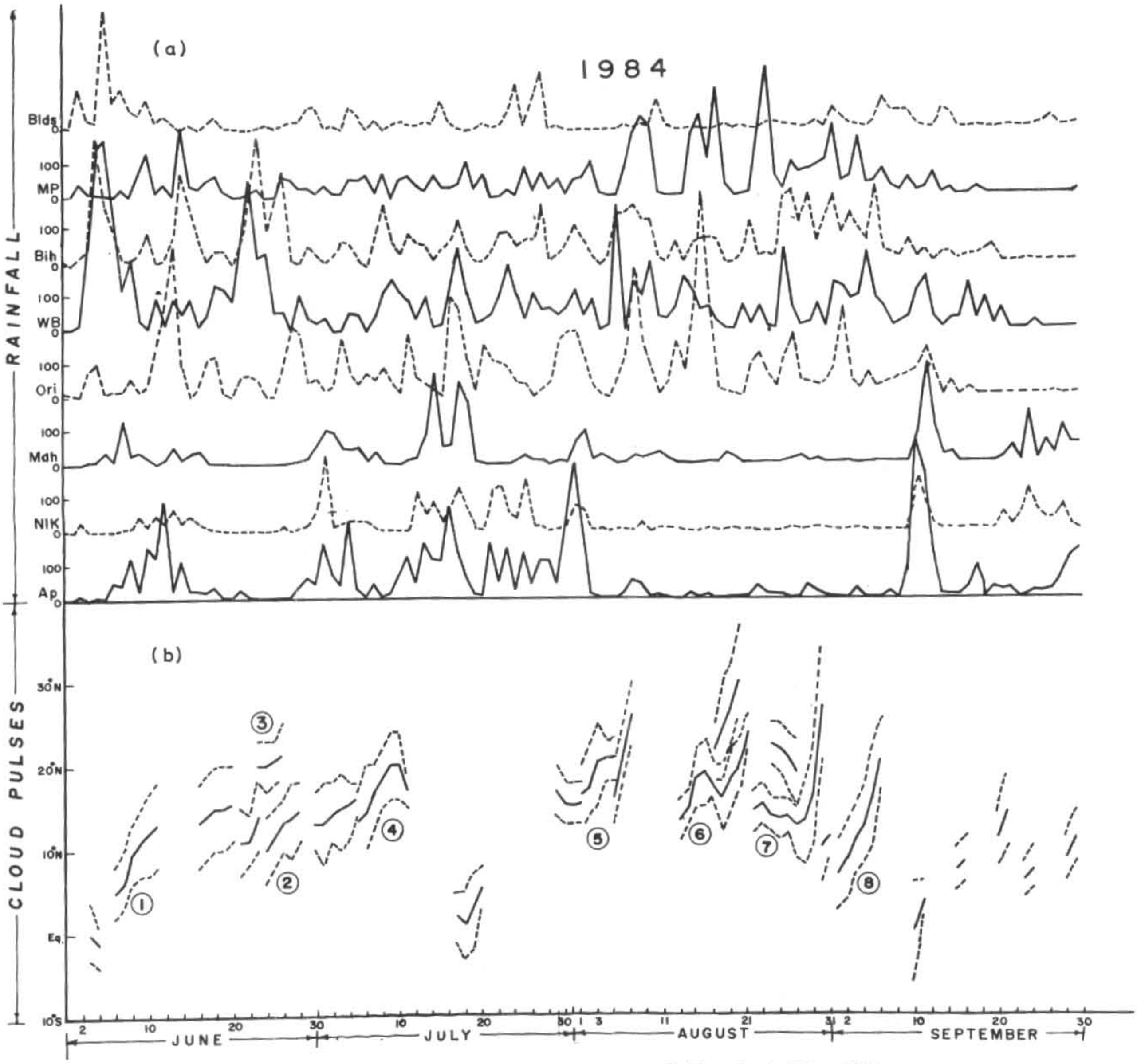
Figs. 1 (a-e). Tracks of cloud organisations: (a) 1984, (b) 1985, (c) 1986, (d) 1987, and (e) 1988

According to Mooley and Shukla (1989), the number of low pressure systems moving westward is not significantly related to the monsoon rainfall over India. However, the relation of the number of days of such systems is directly and highly significant with the rainfall of India. Also Saha *et al.* (1981) have found that about 87% of all the Bay systems had their origin in the disturbances moving from the east.

Thus, an effort is made in this paper to relate the pulses visualised in the cloud clusters in the equatorial west Pacific Ocean, in the belt of 20°N to 10°S and the longitudes from 95° to 140°E, except for two stray pulses as indicated in Figs. 1(b & c), with those of the monsoonal rainfall activity over the Indian regions. In the absence of conventional, routine and sufficient observations over the oceans, the satellite imageries, mainly clusters type, have been used as pointers of processes in these regions influencing the monsoon rainfall of India.

2. Data and method

After the launch of the geostationary satellites, INSAT series, comprehensive cloud imageries of the visible full disc have been made available from 1984. The 0600 UTC satellite imageries of 1984 to 1988 from INSAT-1 were scrutinized for cloud clusters of sufficiently long duration (at least 3 to 5 days' life) for any development that could be envisaged as a pulse manifesting in the visual form of clouds. For this purpose the pulses may not be categorised into different



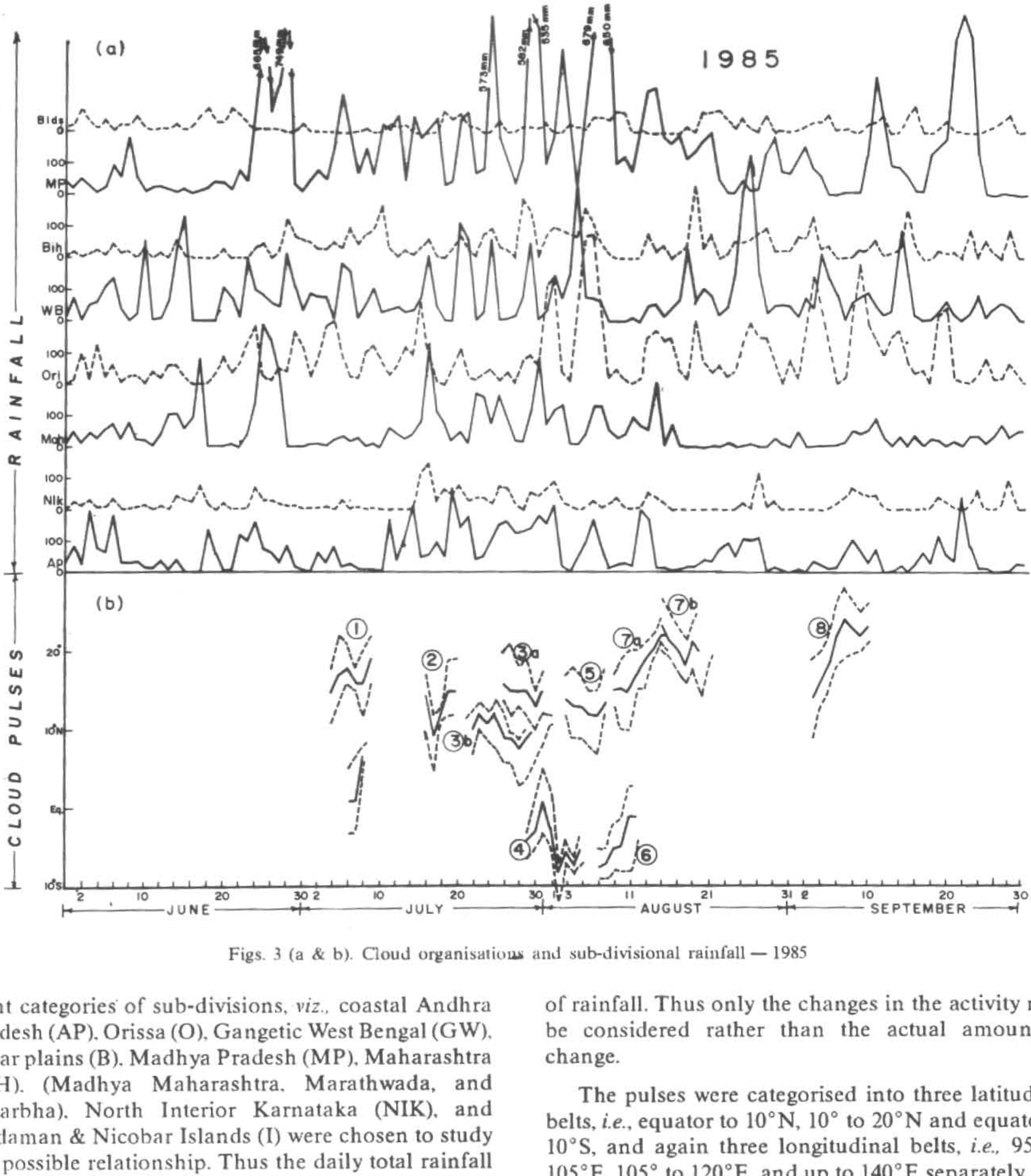
Figs. 2 (a & b). Cloud organisations and sub-divisional rainfall — 1984

systems. As seen from satellite, these are only cloud groupings, indicative of any pulse of a system or wave in the atmospheric processes, resulting in rainfall anywhere or devoid of it. Thus the systems might be cyclones, depressions, or only lows. Only the blobs and rainfall over Indian regions, immediately following the active cloud groups after a reasonable lapse of time, have been considered here. The pulses are indicated at their place or origin with extent, alongwith the mean latitudinal positions of their movement and direction, by approximated sketches in Figs. 1 (a-e).

The weekly weather reports of June to September from 1984 to 1988 were compared with relevant tabulations of deficient, normal and excess rainfall regionwise for the week earlier, current and subsequent to the pulses.

Clearcut distinctions could not be visualised owing to the super-impositions of the effect of: (a) other pulses that might have influenced the activity, and (b) the active systems in the regions. Hence this method was considered to be unsuitable in the present study.

The daily rainfall of individual stations, when compared against the pulses, indicated disjointed correspondence. Neither selecting stations randomly that may give loose evidence of the partial influence of any pulse was satisfactory nor scrutinizing the activities of all the available stations was feasible. Compounding the daily rainfall of individual stations in a subdivision was, however, reasonable and considered adequate for comparison. Based on the topography and the direction of the movements of the cloud pulses,



Figs. 3 (a & b). Cloud organisations and sub-divisional rainfall — 1985

eight categories of sub-divisions, *viz.*, coastal Andhra Pradesh (AP), Orissa (O), Gangetic West Bengal (GW), Bihar plains (B), Madhya Pradesh (MP), Maharashtra (MH), (Madhya Maharashtra, Marathwada, and Vidarbha), North Interior Karnataka (NIK), and Andaman & Nicobar Islands (I) were chosen to study the possible relationship. Thus the daily total rainfall (mm) in a sub-division obtained from all the available hydrological stations in that division was computed, and plotted on day-to-day basis for the 4 months' duration (Figs. 2-6). This clearly brings out a near one-to-one correspondence of rainfall activity with the pulse activity.

The respective additive or negative response of the possible 8 sub-divisions were then analysed with respect to the dates and duration of the increase or decrease in rainfall activity, rather than the amount of rainfall. Thus only the changes in the activity need be considered rather than the actual amount of change.

The pulses were categorised into three latitudinal belts, *i.e.*, equator to 10°N, 10° to 20°N and equator to 10°S, and again three longitudinal belts, *i.e.*, 95° to 105°E, 105° to 120°E, and up to 140°E separately. The number of sub-divisions that showed increase or decrease of rainfall activity were tabulated as frequencies.

Individually, the lag time of each response also was analysed with respect to the start of the responses in relation to the origin of the pulse, and the frequencies of these days were computed sub-divisionwise for these 6 categories of pulses with respect to position or sector. The average lag time and the total percentage effect of these pulses on each sub-division are given in

TABLE 1

Latitude/Longitude of occurrence	Total No.		Sub-divisionwise breakup			(No. & %)					Average lagtime	
			AP	NIK	MH	O	GW	B	MP	I	Increase (days)	Decrease (days)
South of 0°	6		6	6	6	5	6	5	3	6		
		%	100	100	100	83	100	83	50	100	3-4	2-3
0°-10°N	18		16	11	15	16	16	12	16	9		
		%	89	61	83	89	89	67	89	50	3*	2-3*
10°N-20°N	26		24	18	21	22	24	24	25	20		
		%	92	69	81	85	92	92	96	77	4-5	2-3
Above 20°N	1		1	1	1	1	—	1	1	—		
Total pulses	51											
Pulses affected	—		47	36	43	44	46	42	45	35		
		%	92	71	84	86	90	82	88	69	3-5	2-3
West of 105°E	8		6	5	6	6	7	6	4	5		
		%	75	63	75	75	87	75	50	63	3-4	3-4
105-120°E	24		20	18	19	19	20	16	19	15		
		%	83	75	79	79	83	67	79	63	3	2-3
East of 120°E	18		13	9	14	16	17	14	14	11		
		%	72	50	78	89	94	78	78	61	3-4	3-4
Total pulses	50											
Pulses affected	—		39	32	39	41	44	36	37	31		
		%	78	64	78	82	88	72	74	62	3-4	2-4
Average effect		%	85	68	81	84	89	77	81	66		
Rank			II	V	III	II	I	IV	III	VI		

In the above break-up—
—Nos. 2 & 3 of 1984 = taken together as one pulse;
since both were in the same region and duration.
—No. 7 of 1986 was taken separately as (>20°N)—
—in the case of latitudewise break-up.
It has been ignored—in the case of longitudewise break-up.
1984-4 (a & b), and 1985-7 (a & b) have been taken separately as 4 pulses.

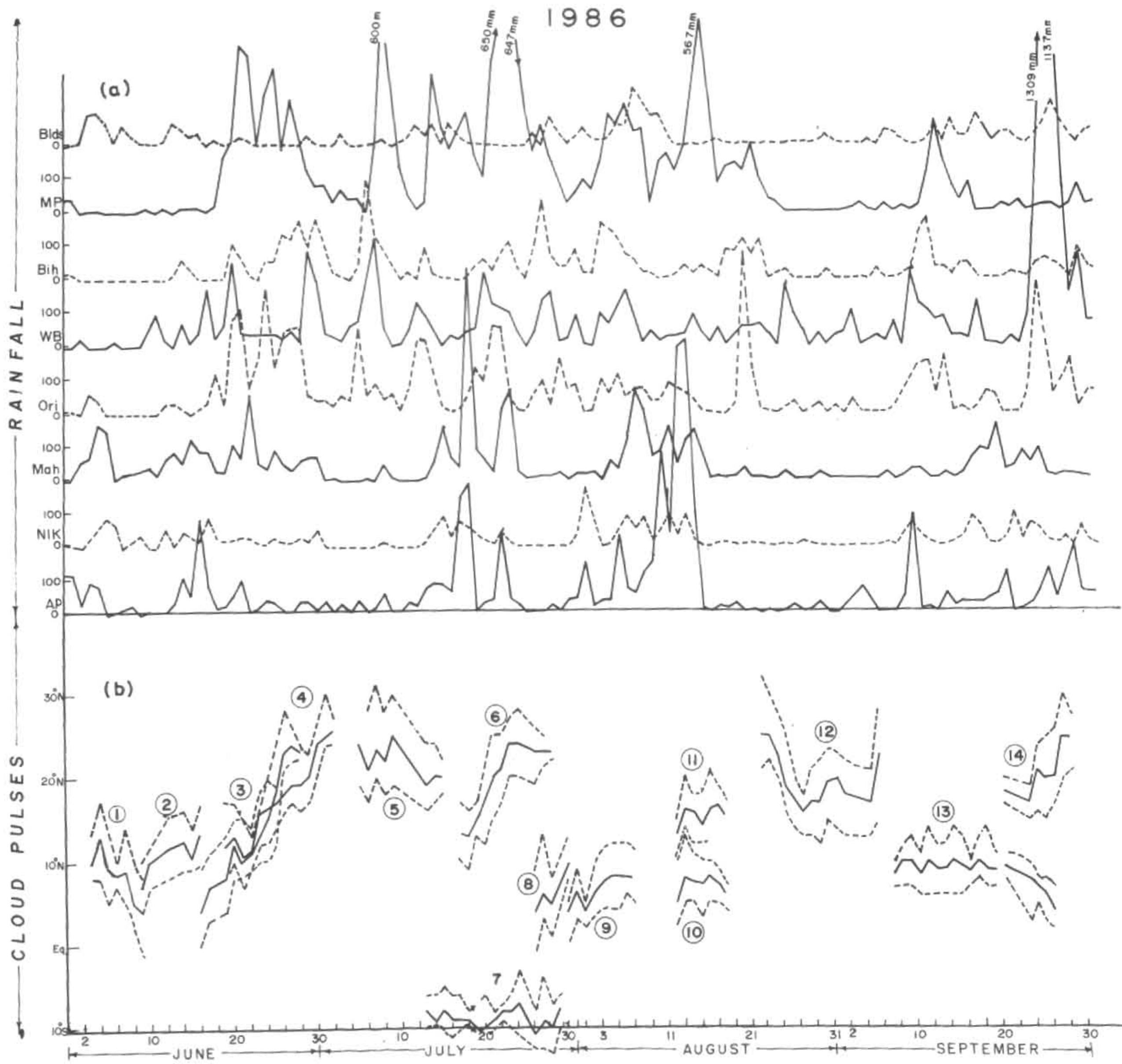
In lag* = for Isles upto 5 days for increase. & 0 to 2 for decrease.

Table 1. Actual pulses in a year and corresponding rainfall realised in the different sub-divisions under study are shown in figures (a & b) respectively in each year of Figs 2 to 6. The x-axis correspond to the dates from 1 June to 30 September. The latitudinal movement of the pulses with their extents in latitude form the ordinate in figure (b); amount of rainfall in cm form the ordinate of figure (a). The ordinate of figure (b) has been split to accommodate the rainfall data of all the sub-divisions in one graph for comparison.

3. Results and discussion

3.1. *Fig. 1 (a)* — Of the pulses during 1984, those during the second fortnight of July, and in September are of Pacific origin. The other four were of south China sea. First two dissipated off the Burma coast, the rest over China coast, only one curved towards north Pacific again.

The first four waves moved west, and the remaining ones northnorthwest or north. The westward moving pulses induced an increase of rainfall in Andhra Pradesh, North Interior Karnataka, Maharashtra, Orissa, Gangetic West Bengal, and Bihar, while the first two waves near the equator induced rainfall in the Andaman & Nicobar Islands, the other two northerly placed ones >12°N, did not show any effect on the Andaman & Nicobar Islands. There was no significant change over Madhya Pradesh that might connect to any of these four waves.

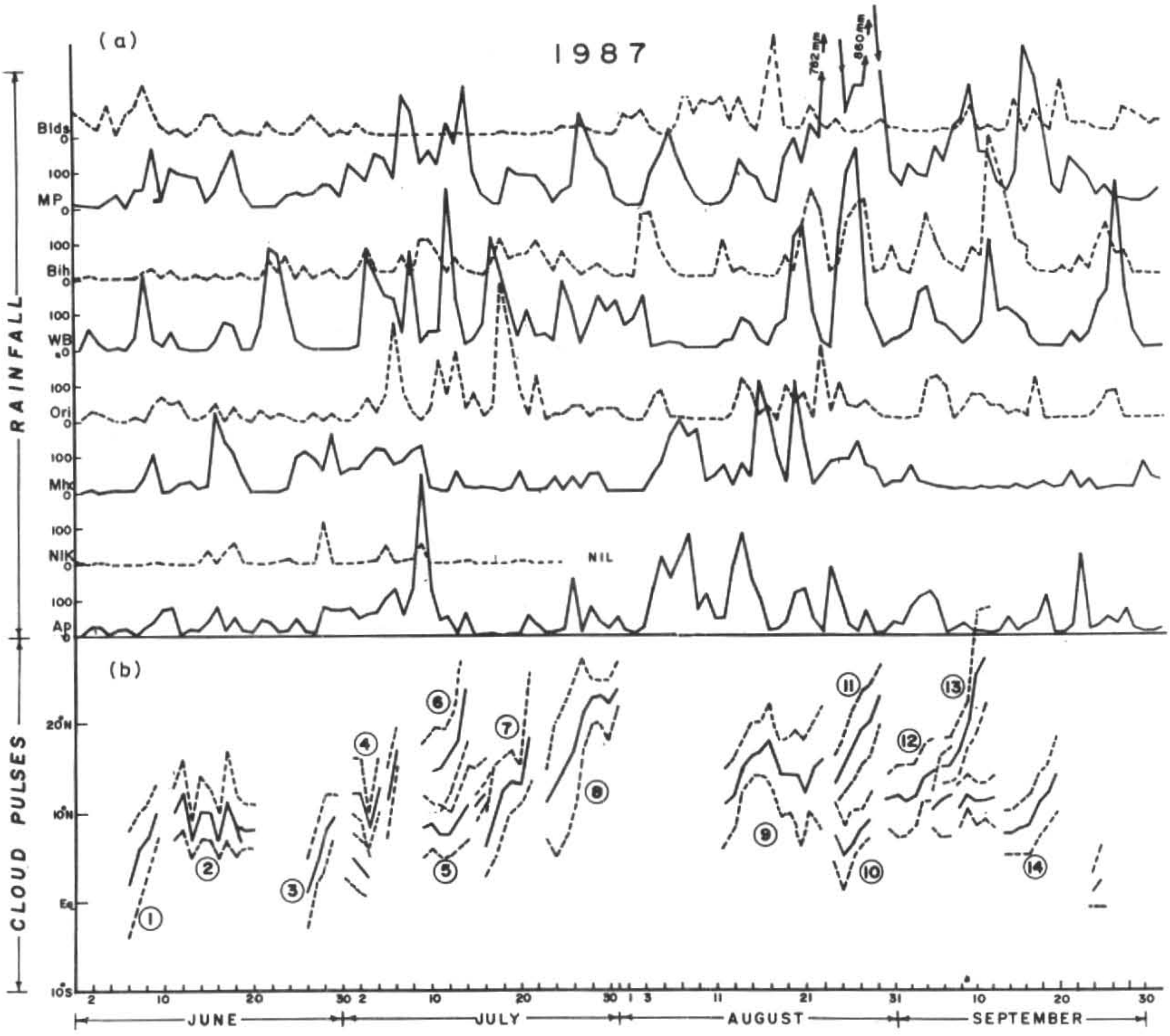


Figs. 4 (a & b). Cloud organisations and sub-divisional rainfall — 1986

The other four waves of the latter part of 1984, produced an oscillatory kind of increase of rainfall over Orissa, Gangetic West Bengal, Bihar, and Madhya Pradesh. The last one from near the equator caused oscillations in the rainfall of Andaman & Nicobar Islands, but in the negative side. These pulses of 1984 and rainfall over 8 sub-divisions are shown in Figs. 2 (a & b).

3.2. *Fig. 1 (b)* — During 1985, the first three pulses originating over the land—Burma and Kampuchea—moved west/northwestward and dissipated over sea. The first one originating at 15°N and moving northwest to west Burma coast, rather decreased the rainfall in 7 sub-divisions with Bihar oscillating. The other two westward moving waves corresponded with increase of rainfall in 7 sub-divisions. Andaman & Nicobar Islands was affected with a positive trend by the second one moving from Kampuchea in an arc towards Arakan coast; but the third one off Burma coast moving west did not register any effect over Andaman & Nicobar Islands [Figs. 3 (a & b)].

Pulses 4 and 6 formed south of equator and moved in a clockwise arc. During the first week of August the fourth pulse moved further south, introducing a dent in the rainfall activities. Though the movement of pulse 6 was opposite in direction but similar, the effect was identical except over Andaman & Nicobar Islands, where due to the proximity and direction of the wave, rainfall increased. Though the origin of the



Figs. 5 (a & b). Cloud organisations and sub-divisional rainfall — 1987

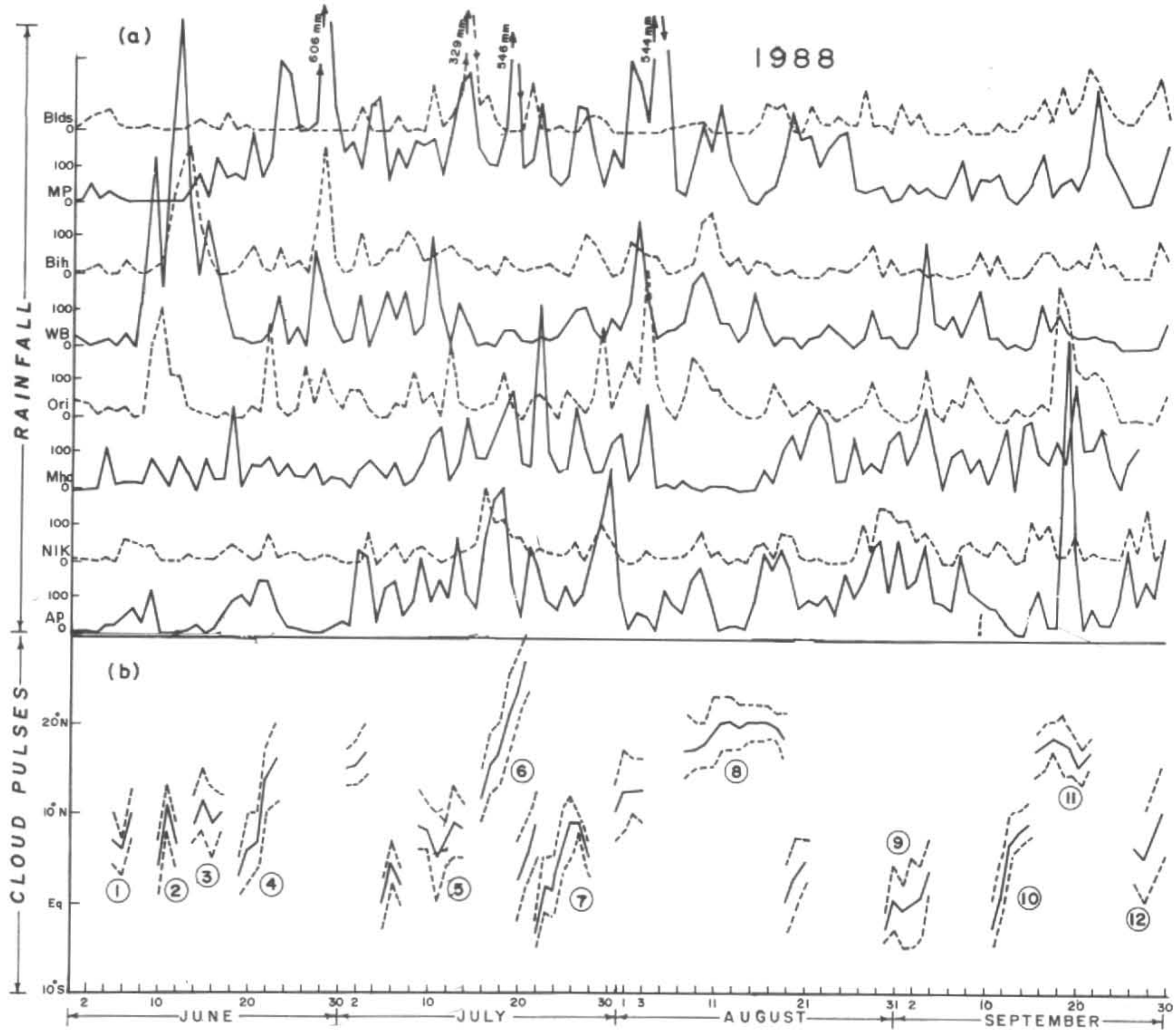
remaining three waves was south China sea, each differed in movement. The small cyclonically moved pulse between 5 and 12 August indicated a swift increase of rainfall in 6 sub-divisions and decrease of rainfall in Andaman & Nicobar Islands.

The seventh was a combination of two successive pulses between 9 and 21 August for a long duration. The former proceeded from 119°E to 105°E, traversing along 19°N for most part; the other descended from 23°N/124°E to 19°N and recurved and ended at 21°N. These successive movements corresponded with the interference pattern and increase of rainfall of four northern sub-divisions. The coastal and southern sub-divisions also registered an increase of rainfall with the former part, whereas Andaman & Nicobar Islands showed a decrease [Figs. 3 (a & b)] during August.

The last pulse was a straight dash from Philippines to Burma in northwest and corresponded with the increase of rainfall in all sub-divisions.

3.3. *Fig. 1 (c)* — Of the eight pulses in 1986, five originated in south China sea except for one, south of equator between 85° & 92°E. A pulse (No. 6) corresponded with an increase of rainfall in Madhya Pradesh only. The interference of the wave of pulse No. 5, which was concurrent in south China sea, may be a plausible explanation for the lack of effect on rainfall by these two pulses, *i.e.,* 5 and 6 and in this period.

The only pulse south of equator (No. 3) first moved southwestward, then looping around moved finally northwestward produced oscillatory effect in



Figs. 6 (a & b). Cloud organisations and sub-divisional rainfall — 1988

Andaman & Nicobar Islands and increase of rainfall in Maharashtra, Orissa, Gangetic West Bengal and Bihar, with decrease of rainfall in Andaman & Nicobar Islands.

Of the south China sea waves, pulse 1 of 1986 moved from 4°N to China coast in northnortheast direction decreasing rainfall in six sub-divisions. Second pulse was during the same time as the third one south of equator. Its formation position at 13°N and northwesterly movement into interior China, produced a harmonious effect of oscillating increase in rainfall of six sub-divisions.

Pulses 4 and 5 at 5°N in south China sea were opposite to each other in movement. The former dissipated over Brunei coast and had no effect in rainfall over India. Only Madhya Pradesh showed an increase during this period; pulse 5 from Brunei coast moving northwestward, was in association with pulse 6 from north Malaysian peninsula, also moving northwestward. These corresponded with an increase in Madhya Pradesh only. Pulse 7 was operative in a far northern latitude off China coast in an anticlockwise arc, moving into Pacific Ocean and dissipating over sea. The graph of Fig. 4 reveals no effect in rainfall as can be expected.

3.4. *Fig. 1 (d)* — All the pulses of 1987 were operative either in south China sea or Pacific Ocean. Of the three pulses 1, 3 and 10 — originating near equator and moving northwestward, the first two produced increase of rainfall in four sub-divisions at least. The third one (No. 10) operated alongwith No. 11 in Pacific Ocean, together effecting increase of rainfall in six sub-divisions, Gangetic West Bengal and Madhya Pradesh in excess, while Andaman & Nicobar Islands registered a decrease.

Four other pulses moved west or northwestward in south China sea around 10°N. Of these, two (Nos. 2 and 4) produced oscillatory increase of rainfall in four sub-divisions. During the period of No. 6, one pulse in Pacific moved from 15°N to 24°N in a northerly direction. Andhra Pradesh, North Interior Karnataka, Maharashtra, and Gangetic West Bengal recorded a decrease, and Orissa and Madhya Pradesh an increase. The last one was also the last of 1987 and corresponded with a decrease of rainfall in four sub-divisions—Gangetic West Bengal, Bihar, Madhya Pradesh and Andaman & Nicobar Islands with an increase of rainfall in two, Orissa and Andhra Pradesh. Of the remaining pulses in Pacific Ocean, one (No. 9) was in association with typhoon BETTY (Annual Tropical Cyclone Report 1987). This corresponded with oscillation in seven sub-divisions on the positive side, with Gangetic West Bengal and Madhya Pradesh recording phenomenal increase of rainfall. The other pulses also indicated an increase of rainfall in four sub-divisions in the minimum. In this year majority of the pulses formed north of 10°N and also moved towards north of China and hence can be correlated to the overall decrease of rainfall over all the sub-divisions under study.

3.5. *Fig. 1 (e)* — Out of the twelve pulses in 1988, 7 originated in south China sea and five in Pacific Ocean.

Pulses 10, 11 and 12 were similar in movement towards northwest. But 11 started at 16°N with corresponding oscillations in seven sub-divisions out of which five were on the positive side. Twelfth which originated at 6°N also indicated oscillations in five sub-divisions out of which four were positive. Also, three others showed increase in rainfall. The tenth pulse which started at 3°S and moved northwestward, however, indicated oscillation in five sub-divisions and reduction in two others. Another pulse (No. 9) which also was in the same area of 10, moved north indicating, however, a positively bent oscillation in six sub-divisions, with oscillations inclined tow -ds negative effect in 2 others.

Pulses 1, 3 and 5 operated only inside the area 115° to 120°E, between 5° and 10°N, all moving west. And all of them showed positive effect in five to six sub-divisions as indicated in the graphs of Figs. 6 (a & b). Pulses 6 and 8 were northerly placed ones continuing from far in Pacific Ocean, moving either west or northwest. These showed negative correlation. Pulses 4 and 7 were from south Pacific Ocean moving north, in a clockwise bend. They corresponded with positive effect in all sub-divisions.

From the above discussions, a comparable correspondence of the rainfall activities in any region with the pulses preceding that duration, in any sector is noticeable. However, the effect of the synoptic systems over the regions during the period of the pulses may have an overshadowing effect on these distant responses.

The rate of movement of 1°/day latitudewise as suggested by Sikka and Gadgil (1980), or with an average speed of 7°/day longitudinally as suggested by Parker (1988) could not, however, be noticed. Thus the movement of the pulses may be in consonance with the intensity of the waves they belong to, which is beyond the scope of this study. Only the first immediate effect has been considered here.

4. Conclusions

The conclusions drawn from the study are as follows :

(i) Irrespective of the distance and positions, any and every pulse indicated some effect in the rainfall activity, in relation to the direction of its movement.

(ii) Waves associated with these pulses west of 120°E and below 10°N, moving in a west or northwest direction have a positive impact on the rainfall pattern over the sub-divisions. Those beyond 120°E do not indicate any effect.

(iii) The islands are relatively less affected by pulses from far east moving northwest. However, the southerly pulses do have an impact on the rainfall activity there.

(iv) In association with the southerly movement of a pulse in equatorial region and south of it and with the pulses moving northward of 10°N, there seem to be considerable reduction of rainfall all over.

(v) Irrespective of the positions, generally the time elapsed between pulse and rainfall activity is around 3 to 4 days for all divisions. However, when the effect is negative, there seems to be an immediate response.

(vi) In individual cases the lag is very prominent. Over the islands the time-delay varies from 0 to 5 days for positive responses.

(vii) The extreme rainfall may either be due to direct additive effect of the pulse or due to existing large scale systems, such as vortex, cyclones, etc.

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