Tellus (1978), *30*, 126–135

The southwest monsoon over India and its teleconnections with the middle and upper tropospheric flow patterns over the Southern Hemisphere

By C. RAMASWAMY and R. S. PAREEK, *The Observatory, Lodi Road, New Delhi—110 003, India*

(Manuscript received November 8, 1976; in final form May 3, 1977)

ABSTRACT

The paper contains an analysis of the daily synoptic charts of July 1972 between 50° N and the South Pole and between 50° E and 160° E with reference to the activity of the southwest monsoon (summer monsoon) over India. The month commenced with a spell of normally active monsoon for 8 days and ended with a spell of large-scale break in the monsoon for 9 days with two transitional phases in between. There was nearly simultaneous development in the middle-latitude westerlies in the middle and upper troposphere in both the hemispheres especially during the break period. Blocking ridges over and near the Tasman Sea extended far towards the southsoutheast during the break conditions. The pronounced troughs and ridges observed in the meridional profiles along 35° N and 35° S, especially along the latter during break conditions, have been discussed and certain tentative explanations have been put forward regarding the developments in the Southern Hemisphere.

1. Introduction

In 1965, the first author of this paper (Ramaswamy, 1965) published a diagram showing the mean meridional profiles at the 300 mb level along 40°, 50° and 60° in the Southern Hemisphere (SH) between 50° E and 180° E during spells of large-scale active and weak monsoon over the Indian subcontinent. These profiles were based on a very large amount of data collected by the International Meteorological Centre at Bombay during the International Indian Ocean Expedition (IIOE) between 1963 and 1965 and also specially obtained by the first author from the International Antarctic Analysis Centre at Melbourne (both of these institutions are now defunct). The meridional profiles along 40° S and 50° S may be seen in Fig. 1. The pronounced trough with its axis between 110° E and 120° E and the pronounced ridge with its axis near 70° E along 40° S during the weak monsoon spell in July 1963 may be noted. A brief summary of the subsequent work of the first author on this subject has been published in the *Proceedings of the Symposium on "Tropical*

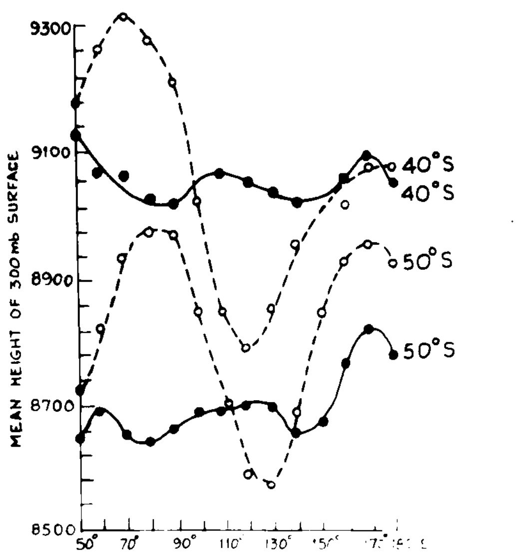

Fig. 1. Mean meridional profile of the 300 mb level along 40° S and 50° S in association with normally active (1–7 August 1963) and weak (17–21 July 1963) monsoon. Full lines active monsoon, dashed lines weak monsoon. (Adopted from the diagram published by the first author 1965.)

Monsoons" (Ramaswamy, 1976) held at Pune, India. The present paper is a more detailed treatment of the basic ideas contained in the summary referred to.

2. Mean troughs over the Indian Ocean and Australian region at the 300 and 500 mb levels in July—the Meteorological Atlas of IIOE

July and August are the months in which the southwest monsoon is considered as well established over the Indian subcontinent.

Fig. 2 shows the mean 300 mb level streamlines in July as published in the IIOE Atlas of Ramage and Raman (1972). The trough and ridge lines in this diagram between 15° S and 50° S have been drawn by the present authors. The errors in our determination of the longitudinal positions of the trough and ridge lines may not exceed plus or minus 3 degrees in the sea areas.

It will be seen that there is a trough near 127° E over and near the Great Australian Bight (Trough marked 3). It is not far from the position of the trough (120° E) referred to by Reiter (1963) and considered by him as a possible monsoonal effect of the Himalayas. This trough is, however, of very small amplitude.

The trough near 147° E is of slightly larger amplitude. It is probably part of a major trough, the southern part of which has its axis near 160° E.

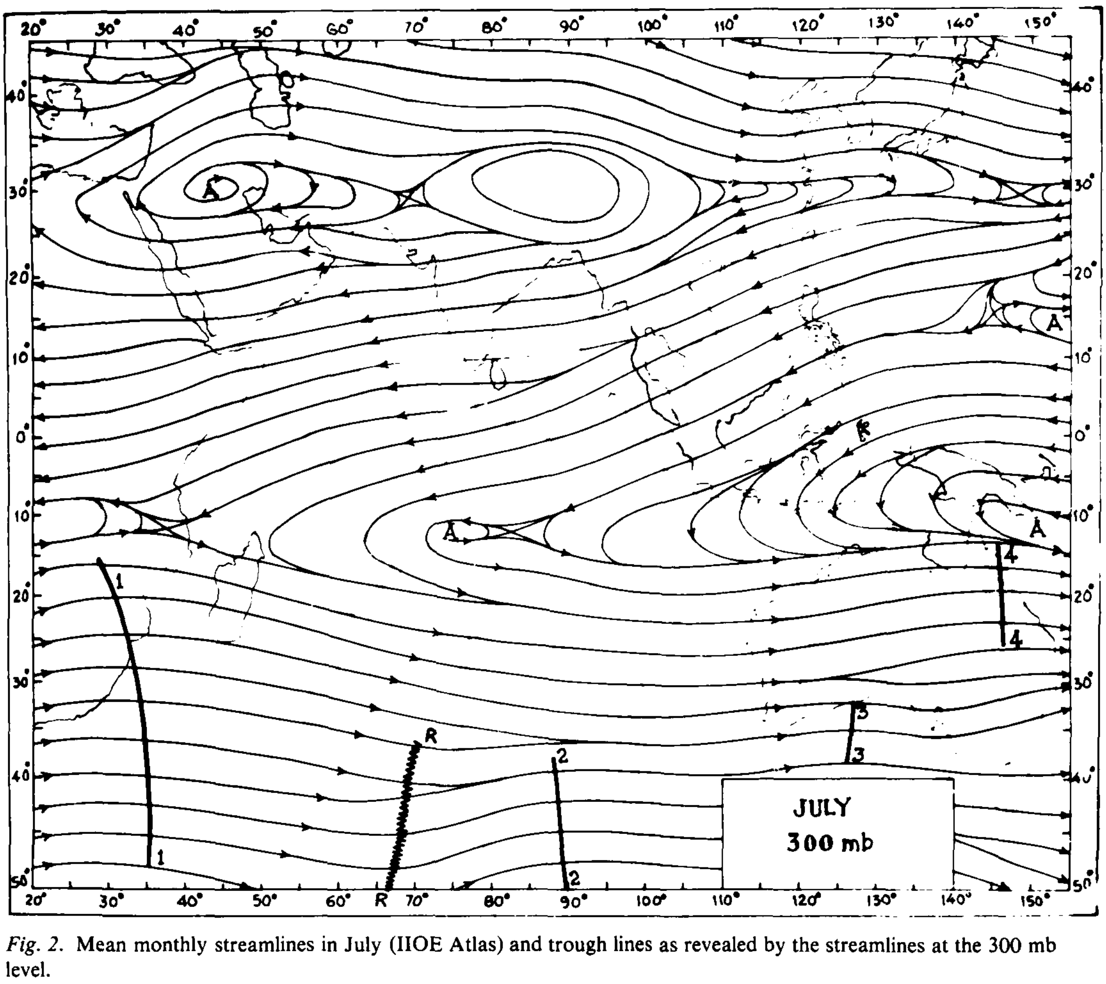

Fig. 2. Mean monthly streamlines in July (IIOE Atlas) and trough lines as revealed by the streamlines at the 300 mb level.

This is supported by the mean 500 mb contours of July as drawn by Taljaard et al. (1969) on the basis of IGY data. We shall refer to this trough as Trough No. 4 or the East Australian Trough.

In addition to the mean troughs 1, 2, 3 and 4, there is also a mean ridge of small amplitude at the 300 mb level with its axis marked RR between 60° E and 75° E and south of 35° S. It appears as a distinct entity in the IIOE Atlas. It is far from the subtropical ridge running from west to east between 10° S and 20° S at the 300 mb level. We shall refer to this feeble mean ridge south of 35° S as the Ramage–Raman ridge in our discussions.

Some of the features discussed above are also seen at the 500 mb level in the IIOE Atlas, but not all. To avoid needless confusion, we shall confine our attention to the troughs and ridges at the 300 mb level only, so far as the IIOE Atlas is concerned.

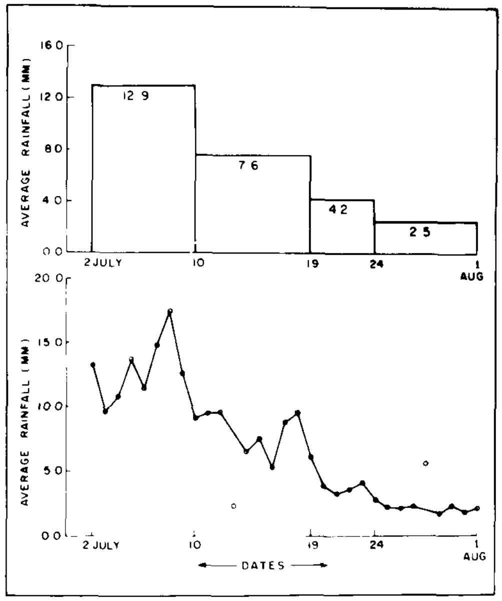

Fig. 3. Regimes of southwest monsoon rainfall over India, July, 1972, corresponding to 00 GMT synoptic charts 1–8, 9–17, 18–22 and 23–31.

3. The case selected for study and the tools used in the analysis

During the last 9 days of July 1972, India suffered from a large-scale and severe break in the monsoon. An analysis of the rainfall over India during July 1972 (Fig. 3) based on checked-daily data of about 180 plain-stations well distributed over the country shows that the monsoon rainfall during that month could be divided into four distinct regimes: 2–9, 10–18, 19–23 and 24 July to 1 August 1972. These correspond to the synoptic charts for 00 GMT for the periods 1–8, 9–17, 18–22 and 23–31 July 1972 respectively. The rainfall shown against each day in the lower part of Fig. 3 represents the 24-h rainfall ending at 0300 GMT on that day. The first of the four rainfall regimes corresponds to normally active monsoon conditions while the last of the four regimes corresponds to severe break conditions in the monsoon. The second and the third regimes may be considered as transitional phases between the first and the last regimes.

For the Northern Hemisphere (NH), we depended mainly on the maps prepared at the NH Analysis Centre at New Delhi. For the Southern Hemisphere (SH) we prepared our own 700, 500 and 300 mb maps from the data received at the Indian Ocean and Southern Hemisphere Analysis Centre (INOSHAC) at Pune, India. However, in the case of all the island stations equatorward of 50° S (including Kerguelen at 49°20′ S, 70°13′ E and Hobart at 42°50′ S, 147°30′ E) we obtained the data specially by post from the countries concerned, so that we could be quite sure that the data were accurate and free from mutilations which might occur during RTT Transmissions. For sea level, we utilized the charts published by the Weather Bureau of Australia. The charts for 700, 500 and 300 mb levels published by the New Zealand Meteorological Service which extended up to the South Pole were also utilized in our study. It may be added that great care was taken to ensure continuity in analysis in space as well as time, right from sea level to the 300 mb level, especially over the SH on all the 31 days of July 1972.

4. Flow patterns in the Northern and Southern Hemispheres at 500 mb level during break conditions in the monsoon

The 500 mb flow patterns at 00 GMT on 26 July 1972 in NH and SH between 50° E and 160° E are shown in Fig. 4. We have not plotted the contour height values in the NH portion of the diagram to

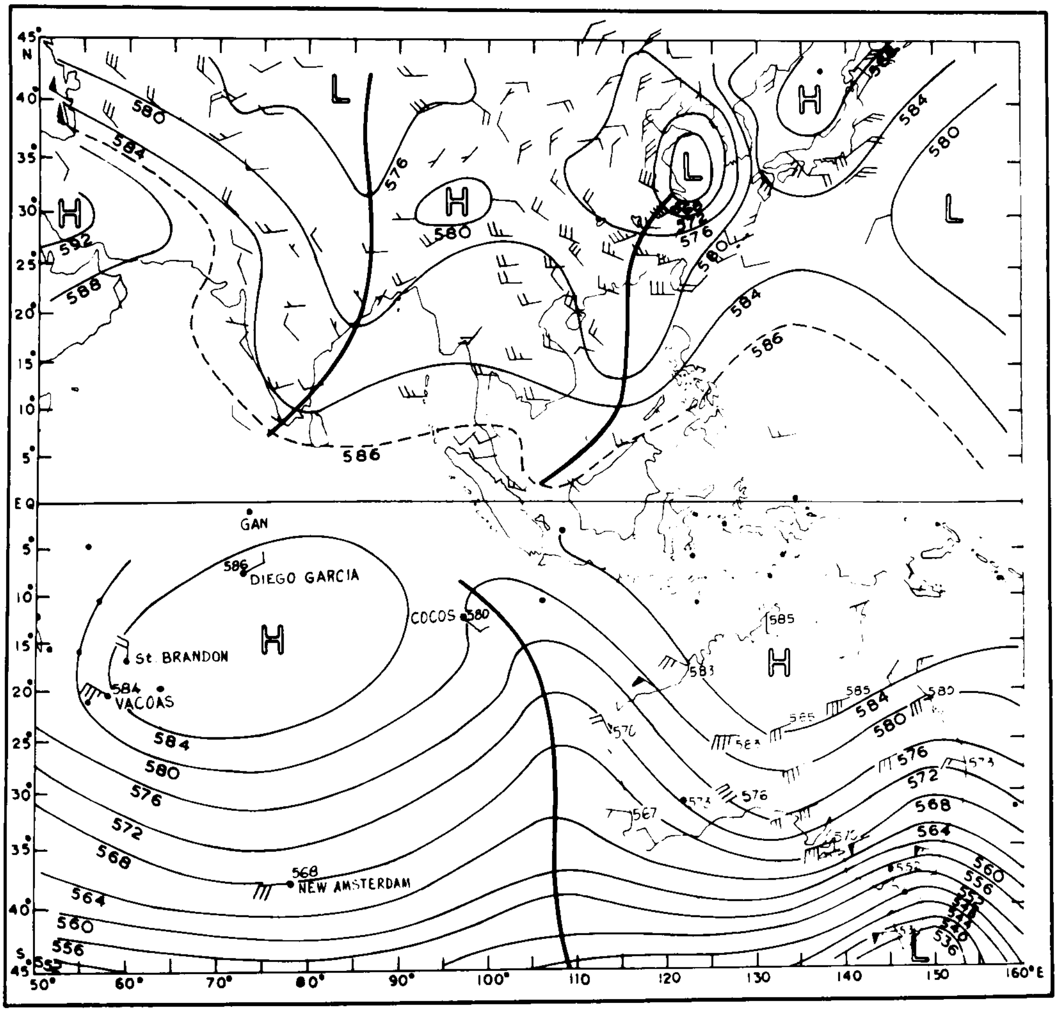

Fig. 4. 500 mb chart on 26 July 1972 00 GMT (the peak phase of break in the monsoon).

avoid undue congestion on the map. We would like to reiterate here what one of us has already explained in detail elsewhere (Ramaswamy, 1968), that the 500 mb level is the most "sensitive" level for the study of the intrusion of the middle latitude westerlies *into India* in association with breaks in the monsoon.

The diagram shows the synoptic conditions at nearly the peak phase of the break in the monsoon. Weather over the whole of India during the 24 h ending at 03 GMT of 27 July 1972 was almost dry except east of 85° E, to the north of 25° N, i.e. along and near the foot of the eastern Himalayas where, as is to be expected (Ramaswamy, 1968, 1972, 1976), there was fairly widespread rain with locally heavy falls over the extreme northeast.

Fig. 4 shows the following:

(a) A large-amplitude trough in the middle latitude westerlies has made a deep intrusion into extreme South India and even into Sri Lanka. It has developed large amplitude on account of the weak basic current over the Tibetan Plateau (Ramaswamy, 1962). The invasion of the westerlies into the Indian subcontinent in association with this trough was so pronounced between 23 and 31 July 1972 that the usual high which lies at the 500 mb level on the equatorward side of the trough and the easterlies which prevail over the extreme south of the peninsula to the south of the high were absent. In passing, it may be mentioned that this is not the only instance in which a deep trough in the westerlies intruded so far equatorward in association with a large-scale break in the monsoon (see U.S. 500 mb NH printed charts 12–18 July 1951).

(b) The planetary trough on the leeward side of the Himalayas has also considerably increased in its amplitude equatorward. The major part of its axis lies near 115° E. A typhoon from the China Sea had merged into the planetary trough on this day, 26 July. This led to a temporary intensification and eastward shift (see Fig. 5) of the planetary trough. After the 26th, it shifted westwards and occupied its westernmost position on the 30th.

(c) A pronounced high cell lies to the northeast of the planetary trough with its core near 43° N 137° E.

(d) The circulation in SH poleward of 10° S has become markedly meridional. There is a large amplitude trough with its axis running nearly north to south between 105° E and 110° E, i.e. *not far from the longitudinal position of the planetary trough in NH on this day.*

The 300 mb pattern in SH on this day is quite similar to and consistent with the 500 mb pattern in SH in Fig. 4. The westerlies were, however, as to be expected, much stronger than at the 500 mb level (diagram not reproduced here).

5. Retrograde motion of the pronounced high cell and increase in the amplitude of the planetary trough at the 300 mb level during break conditions in the southwest monsoon

Fig. 5 shows the approximate positions of the centre of the high cell to the northeast of the planetary trough on the leeward side of the Himalayas at 00 GMT daily between 23 and 31 July 1972 at the 300 mb level and the corresponding positions of the apex of the planetary trough. It will be seen that as the pronounced high moved

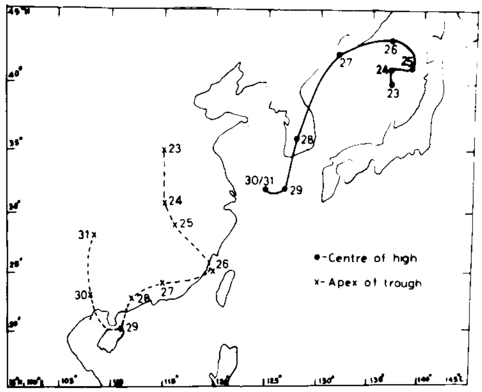

Fig. 5. Positions at 300 mb of pronounced high cell and apex of planetary trough east of the Himalayas during the period 23–31 July 1972. (Period of severe break in the monsoon).

southwards, the planetary trough also increased in its amplitude southward. It also shifted westwards like the high cell although not to the same extent. This is because of the Tibetan high to its west. As stated in an earlier section, the *easterly* component of the planetary trough between the 25th and 26th was a temporary one caused by the north-westward movement of a typhoon from the east China coast and its merging with the planetary trough. By 29 July, the trough had extended to its southernmost position. Between 29 and 31 July, there was only a slight westward movement of the pronounced high cell. During this period, the planetary trough also moved slightly westwards. Later, it began to move northwards, i.e. to its normal position.

6. Meridional patterns of great amplitude and depth in the Southern Hemisphere during break conditions in the monsoon

Fig. 6 shows the ridges between 130° E and 170° W at the 300 mb level in SH during the period 23–31 July 1972. These have been drawn by us on the basis of the printed charts of the New Zealand Meteorological Service. Those marked with a prime, e.g. 23′, 24′, 25′ and so on, appeared for the first time in the area of the map on 23 July and moved (fairly fast) eastward. Those without any

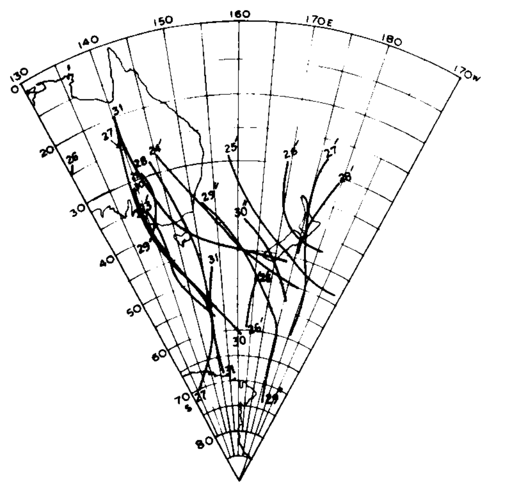

Fig. 6. Ridge–lines at 300 mb level in SH between 23–31 July 1972 (break-monsoon).

suffix, e.g. 26, 27 and so on, represent a second series of ridges which entered the area of the map on 26 July. It will be noted that the ridges without any suffix were quasi-stationary between 27 and 31 July. The ridge lines with two primes, e.g. 29″, 30″, appear to be those which got "fractured" from the main ridges (without any suffix) or developed *in situ* and thereafter slowly moved eastwards. It will be noted that *the ridge on 27 July (without any suffix) extended as far south as Antarctica.* The ridges at the 500 mb level during the same period (23–31 July) showed similar characteristics. Most of them extended to 60° S and the ridge on 28 July touched the Antarctica (not reproduced here).

The daily sea level weather maps. at 0900 EST (23 GMT), for Australia and the neighbouring seas between 23 and 31 July 1972 (not reproduced here), showed that the sea level patterns become more and more meridional and shifted southeastward. On 31 July 1972, the core of a high lay to the southeast of Tasmania with the corresponding isobars running south to north. The 00 GMT 700 mb charts published by the New Zealand Meteorological Service support the sea level charts published by Australia and give an insight into the depth of the meridionally oriented high extending upwards from the sea level during break conditions in the monsoon over India.

7. Flow patterns over the Northern and Southern Hemispheres during normally active monsoon conditions

As stated earlier, the period 1–8 July 1972 represents a period of normally active monsoon conditions over India. A brief description of the synoptic features at the 500 and 300 mb levels over and to the north of India between 1 and 8 July 1972 is given below:

(a) The 500 mb level patterns over India were associated with two low pressure areas which moved westnorthwestwards at sea level from the head of the Bay of Bengal into the central parts of the country and finally merged with the seasonal monsoon trough.

(b) The westerlies to the north of India at the 300 mb level were zonal between 35° N and 45° N and even further to the north. However, the Pamir trough (Flohn, 1965), which lay with its axis on most days between 70° E and 75° E, fluctuating in its position and amplitude during the second half of the period, was somewhat influencing the orientation of the 300 mb contours to the east of the trough.

(c) The planetary trough on the leeward side of the Himalayas was, on most days, situated to the north of 35° N and to the east of 130° E at the 300 mb level.

Fig. 7 shows the 300 mb flow patterns over the SH on 4 July 1972, the mid-point of the normally active monsoon period. It will be seen that the westerlies over most of Australia and the neighbouring area of the Indian Ocean are broadly zonal. There is a trough over the Great Australian Bight and its position is roughly the same as that of Trough No. 3 in Fig. 2. Trough No. 4 is in its normal position near 160° E. The Ramage–Raman ridge is also seen as a feeble ridge south of 40° S.

The kinetic energy in the flow patterns was much greater in SH than in NH at the 500 as well as the 300 mb levels (NH patterns not reproduced here). It is also of interest to note here that during the period of normally active monsoon conditions over India, there was an extensive anticyclone over Australia at sea level and a series of deep cyclonic systems moved from west to east to the south of Australia. This was in striking contrast to what we have described in an earlier section which corresponded to the break conditions in the Indian monsoon.

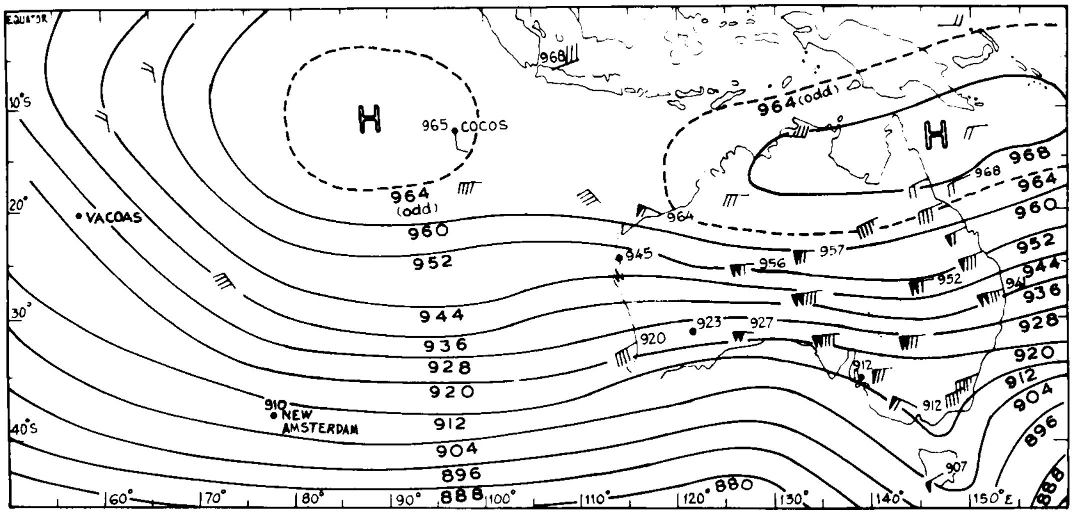

Fig. 7. 300 mb level on 4 July 1972 (mid-point of period of normally active Indian southwest monsoon).

8. Mean meridional profiles along 35° N and 35° S at the 300 mb level during the four monsoon regimes in July 1972

Fig. 8 shows the mean meridional profiles referred to above. The noteworthy features in this diagram are discussed below:

35° S. (a) By far the most important feature is the pronounced wave pattern of troughs and ridges in the 35° S profile during the period 23–31 July over the entire longitude range 50° E to 160° E. Trough No. 4 of the IIOE Atlas and the feeble mean trough over the Great Bight (Fig. 2) have apparently shifted westwards and probably coalesced into a single trough of large amplitude with its axis near 115° E. In place of Trough No. 4, we have a pronounced mean ridge over southeast Australia with its axis near 145° E. It corresponds to the daily quasi-stationary ridges between 140° E and 150° E seen in Fig. 6. It is interesting to note that the mean large-amplitude trough near 115° E is also seen in the meridional profile along 40° S in the weak monsoon situation in July 1963 in Fig. 1.

(b) To the west of the pronounced trough near 115° E lies a pronounced ridge with its axis near 70° E. This pronounced ridge is probably the same as the very feeble mean Ramage–Raman ridge in the IIOE Atlas at the 300 mb level in Fig. 2. Again, it is interesting to observe that there is a pronounced

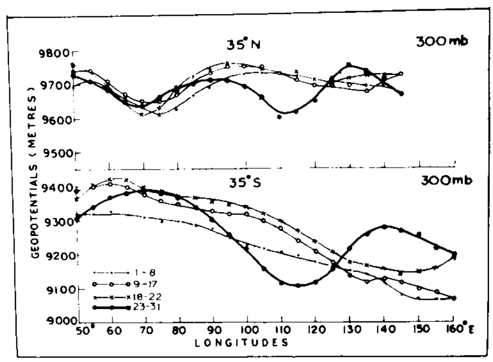

Fig. 8. Mean meridional profiles along 35° N and 35° S (300 mb) during the four Indian southwest monsoon rainfall regimes in July 1972.

ridge near 70° E in the 40° S meridional profile in the weak monsoon situation in July 1963 in Fig. 1.

(c) The mean profile for the period 18–22 July 1972 shows a reasonably consistent transition from the profile for the period 1–8 July (normally active monsoon over India) to the profile for the break monsoon period (23–31 July).

35° N. (a) During the period 23–31 July there is a mean ridge with its axis near 130° E. This position is consistent with that of the pronounced high pressure cell in Fig. 5. It is not very far in its longitudinal position from the ridge seen in SH between 23 and 31 July.

(b) The planetary trough in NH is seen in this profile with its axis at approximately the same longitude as the pronounced trough near 115° E in the profile for 35° S. *The nearly simultaneous development of the same type of wave pattern in the NH and SH between 100 ° E and 160° E during the period of severe break conditions in the monsoon (23–31 July) is particularly interesting.*

(c) The mean ridge to the west of the planetary trough in NH lies with its axis near 90° E (this is the well-known Tibetan High) and has shifted to the west by about 15 degrees longitude, consequent on the retrograde motion of the pronounced high cell.

(d) The Pamir Trough has also slightly shifted westward compared to its position during the normal monsoon regime between 1 and 8 July. Incidentally, it may be added that the meridional profiles along 35° N and 35° S at the 500 mb level show more or less the same characteristics as described above.

9. Earlier work of Taljaard, Van Loon and others on meridional flow patterns, blocking action, etc. in the Southern Hemisphere

Taljaard (1972) has published maps showing zonally averaged monthly v components of the 500 mb geostrophic winds at 35° S, 45° S and 60° S for the Indian Ocean and Pacific sectors based on IGY data. At 35° S, the winter maxima (Indian monsoon months) in these sectors stand out clearly in comparison with the summer minima. They are also in agreement with the monthly mean meridional indices for sea level for 30° S, 45° S and 60° S determined by Taljaard from the data for the period 1952–1958.

Van Loon (1956) has shown that blocking is fairly frequent in late winter and early spring in the middle latitude zone streching eastward from Tasmania to about 160° W. According to him, blocking is most frequent in July, August and September in the southwest Atlantic and Pacific Oceans.

Van Loon (1972) has also worked out the mean meridional winds along 50° S in July. The most interesting feature we have observed in his map is the strong northerly component of the winds between 110° E and 160° E in the Australian region and the southerly component between 50° E and 90° E in July. His diagram clearly shows that *such a strong northerly component is seen nowhere else in the Southern Hemisphere in July.*

Apart from the above, the investigations of Van Loon et al. published in Meteorological Monograph, 1972, have brought out that the greatest latitude anomaly exists in winter and spring in the Australasian and Western Pacific regions which are thus least representative of the average conditions around the hemisphere. We thus note that the findings of the Southern Hemisphere meteorologists about circulation patterns in SH *are quite consistent with our own findings about the anomalies between 50° E and 160° E in the SH in association with the southwest monsoon over India.*

10. Possible explanations for the observed facts

We offer the following three alternative explanations for the facts revealed by Fig. 8.

(i) *Resonance effect*

During large-scale breaks in the southwest monsoon, there is pronounced low index circulation in the middle latitudes to the north of India. In association with this low index circulation, there is also, in the present case, a pronounced high cell in middle latitudes. Similar effects in SH have also been pointed out by us during break conditions in the monsoon. It would thus appear from general considerations that the pronounced high cell was the most important development in NH and that it led to low index circulation in NH and consequent break conditions in the monsoon. On the basis of this hypothesis and also in view of the fact that the phenomenon of blocking is known to be less persistent and less pronounced in SH than in NH, we can postulate that the pronounced wave motion observed by us in SH between 50° E and 160° E may be a resonance effect indirectly caused by the development of the pronounced high cell in NH and its retrograde motion and consequent low index circulation in the westerlies to the north of India. *The nearly simultaneous development of circulation patterns in the westerlies in both the hemispheres would lend support to this hypothesis.* We can also state that the smooth wave motion observed by us in SH over the entire longitude range 50° E to 160° E is due to the fact that there are no barriers, e.g. like mountains, to distort the flow patterns. (50° E to 115° E along 35° S is a sea area and the average height above MSL of Australia is only 350 metres.) We do not, however, know the normal frequencies of oscillation of the atmosphere between 50° E and 160° E either in SH or NH to enable us to make more quantitative statements. Hence, we have to leave our postulate at this stage for further examination by theoreticians.

(ii) *"Inter-locking" between the troughs at 115° E in the Northern and Southern Hemispheres*

We have pointed out that, in the break monsoon spell between 23 and 31 July 1972, there were troughs in the meridional profiles in both the hemispheres between 110° E and 120° E. We can therefore postulate that the development in both the hemispheres took place initially independently but that when the troughs in the two hemispheres reached the same longitude, they got interlocked and thereafter there was meridional exchange of energy between the system in the two hemispheres, across the equator and that these systems developed nearly simultaneously. To verify this hypothesis, we will have to study monsoon regimes of shorter durations. This is not so simple as it may appear at first sight because, quite apart from other difficulties, it will introduce errors in the mean values due to random fluctuations during short periods. In any case, this has to be taken up as a separate problem for study.

(iii) *Dynamical interaction between the upper troposphere easterly jet (TEJ) over south India and the westerly circulations in NH and SH on either side of TEJ*

Taljaard (1972) has attempted a partial explanation of the anomalous winter circulation over Australia and the western Pacific Ocean, on the basis of the existence of the Tropical Easterly Jet in NH during the months June to September, not far from the equator. We have, however, no clear idea as to how the TEJ over the extreme south of India lying between the westerly circulations in the two hemispheres dynamically interact with these circulations. Considering this difficulty, we would prefer to lay more emphasis on our simpler postulate of resonance effect and leave the problem for further study especially by theoreticians.

11. Conclusions

This investigation, along with the earlier one conducted by the first author more than a decade ago, clearly establishes that there are teleconnections between the activity of the southwest (summer) monsoon over India and the middle and upper tropospheric flow patterns in the Southern Hemisphere between 50° E and 160° E. These teleconnections have potential value in medium and long-range forecasting of the southwest monsoon. This aspect therefore deserves further study.

The present investigation has also shown that:

(a) there is nearly simultaneous development in the westerly circulation in both the hemispheres between 50° E and 160° E during normally active and break conditions in the monsoon, especially during the latter when there is pronounced low index circulation in both the hemispheres

(b) the planetary trough on the leeward side of the Himalayas increases considerably in its amplitude at the 500 mb and 300 mb levels during the low index phase with corresponding adjustments in the wind and pressure fields to the west of the trough. The increase in the amplitude of the planetary trough is associated in the present case with the development of a pronounced high cell in middle latitudes to the northeast of the trough

(c) the kinetic energy in the flow patterns is far greater in SH than in NH during the active as well as break-monsoon phases

(d) blocking ridges over the Tasman Sea in SH extended far towards the southsoutheast during the break conditions in the monsoon and even touched Antarctica

(e) the troughs and ridges in the meridional profile along 35° S had greater amplitude than in the meridional profile along 35° N

(f) three alternative explanations have been offered for the pronounced wave motion in SH. On the whole, it appears probable that the wave motion observed in SH is the effect of resonance

(g) any model of the southwest monsoon which may be evolved on the basis of Monex-1979 (as a subprogramme of GARP) will have to take into account the inter-hemispheric reactions in the middle and upper troposphere discussed in this paper.

12. Acknowledgements

The first author expresses his gratitude to the Directors of the Meteorological Services of Mauritius and Australia for supplying the data of island stations in their respective jurisdictions, by post; to the U.S. Navy Commander, Department of the Navy Headquarters, Naval Weather Service, Command, Washington D.C., for supply of the data of the island of Diego-Garcia, by post, for July, 1972; and to the Directors of the Meteorological Service of New Zealand for supplying published daily charts of his service for the 700, 500 and 300 mb levels for July, 1972.

The second author is grateful to the Director General of Observatories, New Delhi, for granting him permission to collaborate with the first author in the publication of this paper. Both authors express their sincere gratitude to the Director General of Observatories, New Delhi, for providing them with facilities for conducting this investigation.

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ЮГО-ЗАПАДНЫЙ МУССОН НАД ИНДИЕЙ И ЕГО ТЕЛЕСВЯЗИ С ХАРАКТЕРОМ ТЕЧЕНИЙ В СРЕДНЕЙ И ВЕРХНЕЙ ТРОПОСФЕРЕ НАД ЮЖНЫМ ПОЛУШАРИЕМ

В статье дается анализ ежедневных синоптических карт для июля 1972 г. в области между 50°с.ш. и южным полюсом и между 50°в.д. и 160°в.д. в связи с активностью юго-западного муссона над Индией. Этот месяц начался периодом в 8 дней муссона нормальной активности и закончился периодом крупномасштабного перерыва в муссоне длительностью 9 дней с двумя переходными фазами в промежутке. Наблюдалось почти одновременное развитие средне-широтных западных ветров в средней и верхней тропосфере обоих полушарий, особенно, в течение периода перерыва. В это время блокирующие гребни над Тасмановым морем и вблизи него простирались далеко на юго-юго-восток. Обсуждаются хорошо выраженные гребни и ложбины, наблюдаемые в период перерыва в меридиональных профилях вдоль 35°с.ш. и 35°ю.ш., особенно. вдоль последней и выдвигаются некоторые предварительные объяснения, касающиеся развития процессов в южном полушарии.