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THE INDIAN INSTITUTE OF TROPICAL METEOROLOGY

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March 1981

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ABSTRACT

Aerological data collected by conventional and special observational platforms during the field phase of Summer Monex-79 are analysed. The characteristic features of the near equatorial oceanic ITCZ during the pre-onset/onset, as well as the established phase of the monsoon and its superimposed disturbances are documented based on the analysis of data at 700 mb.

The onset phase ITCZ is characterised by a narrow shear zone having maximum cyclonic vorticity, convergence, colder temperature, high moisture content and is also the region of convective weather. The pre-onset ITCZ abruptly intensifies at the time of onset of monsoon and the system moves north/northwestward. The oceanic convergence zone again becomes prominent during the established phase of monsoon when the monsoon cycles from active to break/weak phase. The characteristic features of the ITCZ during the established phase are more or less similar to those of the onset phase.

Introduction

Several questions have been raised in the GARP (WMO, 1976) document on the scientific objective of Monex as to what happens to the spring season near equatorial ITCZ with the advance of the monsoon over India and whether it has any

identity during the established phase of the monsoon. Godbole and Ghosh (1975) have studied some features of the near equatorial ITCZ at the onset phase of the monsoon in the Arabian sea using the Russian research ships data collected during the ISMEX-73. Studies with Satellite photographic data (Srinivasan 1968; Sikka and Dixit 1972; Sikka and Gadgil 1979) etc. show that during the months of July and August while a dominant and persistent convective zone lies in the vicinity of the monsoon trough, another zone of convective activity intermittently appears on the scale of 1-3 day in the near equatorial oceanic region (5-10°N) over north Indian ocean. As the monsoon cycles from 'active to break' phase, the near equatorial convective zone becomes the dominant one and assumes the characters of a shear zone with low-middle level cyclonic disturbances forming within it and moving in a NW direction. This appears to occur more frequently in the longitudinal belt between 70-95°E. Koteswaram (1950) was the first to document the existence and westward movement of the near equatorial cyclonic disturbances at 700 mb during 'break' periods. Mukherjee and Natarajan (1968) have documented several such sequences.

In this paper we propose to document the characteristics of the near-equatorial shear zone and its superimposed disturbances (synoptic scale) at the pre-onset/onset phase of the monsoon as well as during the established phase utilising the field phase data collected by land based

observatories, research ships and research flights.

2. Data used and Methodology adopted

We have combined the daily data of different observational platforms to maximise the data coverage. As most of the research flights were undertaken between 05 and 10Z, the research ships and land stations data used are corresponding to 06 and 12 Z respectively. As we are concerned with the description of the large scale characteristics of the ITCZ we believe that this rather small (3 to 6 hours) non-uniformity in the time of data coverage may not seriously hamper our results. The data have been analysed basically in two ways : (1) analysis of meridional sections/time section of the observed data, (2) analysis of the wind, temperature and moisture fields (Relative humidity) at 850, 700 and 500 mb and the relevant parameters obtained at 2° latitude/longitude grid intervals. The grid point data were derived over the region covering 66°E to 86°E and 0° to 20°N and latitudinal averages of the parameters were obtained to determine the large scale characteristics of the ITCZ.

3. Discussion of Results

3.1 Characteristics of the ITCZ during pre-onset-onset phase of the monsoon (4 - 14 June 1979)

The near-equatorial oceanic ITCZ generally fluctuated between 3-6°N from the third week of May to the begi-

nning of June 1979. This period was also marked by above normal pressures over the northern Indian and adjoining Pakistan which showed that the thermal low in that region had not reached its seasonal intensity (Sikka, 1979). The equatorial convergence zone during this period was discernible in the surface flow between the equatorial westerlies and the flow-emanating from the anticyclonic centre over the Central Arabian sea. Satellite photographs showed an east-west belt of cloudiness between 60-90°E fluctuating along 3-5°N and Cloud clusters were observed to form within it and move from east to west. Synoptic analysis indicated that the equatorial trough associated with the convergence zone was most marked at 700 mb and the cloud cluster scale disturbances were associated with the cyclonic circulations seen within the 700 mb trough.

Fig. 1 shows the meridional section during 4-14 June 1979 at 700 mb from northern India stations Patiala (30.3°N,76.5°E) and New Delhi (28.6°N, 77.1°E) to the location of the southern most Russian research ship (4.7°N, 66.7°E) of the stationary polygon formed over the SE Arabian sea. The figure shows the continental NW flow to the north of 20°N changing into NE/E flow around the subtropical ridge along about 18°N. The air is warmest and driest near the ridge line. The wind shifts over the Russian ships in the equatorial region suggests the passage of the two cyclonic systems between 4-5 June and 8-9 June. After the passage of

the second disturbance, a dramatic change is observed in the strength of the equatorial westerlies on 13 June accompanied with the northward extension of the westerlies upto 8-10°N. The Figure also shows that the air stream between 18-30°N is rather dry but the moisture is high within the equatorial latitudes.

Fig. 2 (a) shows the meridional section (approximately along 65°E) in the vertical on 7 June, before the abrupt strengthening of the equatorial westerlies. Fig. 2 (b) shows the same on 14 June after the equatorial westerlies became nearly 40 kt strong and also extended to 10°N. For both of these Figures data obtained from intensive research airflight missions over the Arabian sea between 65-73°E have been used. On 7 June, the shear-line which is associated with the ITCZ, is located at about 12-14°N at 850 mb and to the south of 4°N at 700 mb. The moist layer depicted by the 80% R.H. is also restricted upto 850 mb. On 14 June the shearline is seen up to 400 mb along about 12°N without any significant slope. The horizontal shear along the axis is also considerably increased as the equatorial westerlies have strengthened. The moist layer within the equatorial westerlies has also built upto 400 mb. The equatorial westerlies to the south of the shear line are colder upto 600 mb and no significant meridional temperature difference exist between 4-20°N between 600 and 400 mb.

This abrupt strengthening of the equatorial wester-

lies and the intensification of the ITCZ observed between 7-14 June was accompanied with the following events :

i) Intensification of the heat low over northern India to its normal intensity between 6-8 June.

ii) Movement of a cyclonic circulation at 700 mb from SW Bay of Bengal to SE Arabian sea between 10-12 June and its intensification and northward movement between 12 to 14 June.

iii) Final disappearance of the spring season central Arabian Sea anticyclonic flow on 7 June.

iv) Establishment of the strong low-level cross-equatorial flow off east African coast and its spread towards the central and east Arabian sea.

These events brought about the onset of the monsoon over Kerala coast on 11-12 June. A tropical depression formed within the intensive shear zone (13°N, 71°E) on 16 June which moving in a NW direction further intensified into a severe cyclonic storm and struck Arabian coast on 20 June. With the movement of this system, the monsoon progressively advanced northward and covered the entire west coast by 21 June.

The quasi-stationary nature of the near equatorial oceanic ITCZ during the spring season and its abrupt strengthening and northward progression with the onset of monsoon over India may be understood in the following way. The location of the ITCZ during the spring is such that heated conti-

nental region lies to its north but the intensity of the heat source is not yet sufficiently developed to significantly influence the ITCZ. As the heating of the continent and overlying airmass progresses and the seasonal pressure systems of the summer monsoon begin to form and intensify, resulting in peripheral heat low/trough system extending from east Africa, to the Gangetic plains over India through Arabia and Pakistan, a situation is reached when the ITCZ responds to the intense heat source. Under the large scale response of the continental thermal low to the north and the dynamical influence of a transient perturbation within the ITCZ, the near-equatorial convergence zone breaks down with the simultaneous onset of strong monsoonal flow (which in turn may be the result of southern and northern hemispheric interactions) over the Arabian sea. The strengthening of the monsoon flow in the lower-middle troposphere over SE Arabian sea gives rise to further intensification of the transient disturbances of the ITCZ and the entire system progressively moves northward, advancing the monsoon along the west coast of India.

Our analysis of the synoptic charts for the period 4-14 June, 1979 during the pre-onset and onset phase of summer monsoon showed that the equatorial shear zone was intermittently active between 64-88°E and the most active belt at the time of the onset was located between 66-72°E. We consider that by studying the averages of various parameters based on grid point data over the longer belt 64-88°E, we may get some insight into the characteristic behaviour of the

larger scale shear zone as it intensified from the week pre-onset stage to active onset stage. Besides, as the major disturbance which lead to the onset of monsoon formed in the western part of this large scale shear zone, we have also prepared the averages of the relative vorticity and divergence for the belt 66-72°E inorder to study the evolution of the Kinematic properties of the flow field over an area typical of the disturbed region.

In Fig. 3 are shown the meridional profiles of temperatures, relative humidity, zonal wind and relative vorticity at 700 mb averaged over 64-88°E for three typical days viz. 7, 10 and 14 June. The following features are observed :

i) Air temperature increases from equator towards 20°N, the meridional gradient is rather small between equator to 8°N and increases further northward. The equatorial westerlies are colder by 3-4°C. The axis of the shear zone lies in the region of colder temperature but to the north of it marked increase in temperature is observed.

ii) Equatorial westerlies are more moist. As the shear zone intensifies, a nose (maximum) in the relative humidity profile develope at the axis of the shear zone. The gradient in the relative humidity profile to the north of the shear zone also increase with the intensifica-

tion of the shear zone.

iii) Progressive increase in the strength of the equatorial westerlies occurred between 7 to 14 June and the westerlies also extended northward (8°N on 7 June to 11°N on 14 June).

iv) Relative vorticity is generally positive from 4 to 15°N. The profile has a maximum which almost coincides with the axis of the shear zone and the magnitude of the maximum increases from about 1.5 units ($\times 10^{-5}$ sec^{-1}) on 7 June to 5.0 Units on 14 June.

v) Weather observed during the research flight on 14 June across the shear zone showed deep convective clouds with moderate turbulence while crossing the shear zone. The rainfall over Kerala increased as the shear zone approached and lay near this area. Rainfall of 5 to 15 cm in 24 hours were reported over Kerala on 12 and 14 June.

Figs. 4 (a) and 4 (b) show the time variation of relative vorticity and divergence at 700 mb from 2-18°N averaged for the belt 66-72°E. Note that the relative vorticity maximum has shifted from 2°N on 4 June to 12°N on 14 June, the shift being rather rapid between 12 and 14 June. The maximum has also intensified to a value of 7.5×10^{-5} sec^{-1}

on 14 June. Convergence of magnitude $\geqslant 1 \times 10^{-5}$ sec^{-1} is observed in the vicinity (within about 2° latitude) of the location of shear zone.

3.2 Characteristics of the shear zone in the established phase of the monsoon (20-27 July 1979)

In the third week of July 1979, the monsoon showed weakening in its intensity and the rainfall decreased over the central India. Sea level pressure remained also above normal over most of the India during the same period and a region of maximum positive pressure anomaly lay over Central India. A near equatorial trough at 700 mb was noticed in the south Bay of Bengal on 22 July 1979. Several research flight missions were undertaken between 22-27 July during the field phase of Monex to study the characteristics of this trough (shear) zone.

Fig. 5 shows the meridional section at 700 mb along 85-90°E based on the data of the research flights, research ships and the two Indian coastal station along north Bay of Bengal, Digha (21.8^{o}N, 87.8^{o}E) and Bhubaneshwar (20°N, 86°E). The Figure shows that a shear zone existed near 11°N on 22 July between the southeast flow over the central Bay of Bengal and the equatorial westerlies (monsoon westerlies). Synoptic analysis of the charts showed that as the monsoon weakened over Central India, a ridge extended westward from SE Asia to central Bay of Bengal at 700 mb. The SE flow between 15-20°N, which is seen in this section in Fig. 5 during

the period 20-25 July, is associated with this ridge. Two cyclonic circulations at 700 mb moved from the south Bay of Bengal towards the east Arabian sea across the Peninsula along 10-15°N during 22-27 July. Along with these the 700 mb trough also shifted northwards. On 28 July a low pressure area formed in the shear zone in the central Bay of Bengal and moved towards the north Bay on 1st August. These changes are discernible in Figure 5 through the progressive northward shift of the axis of the shear zone from 11°N on 22 July to 19°N on 31 July. This sequence clearly shows that a near equatorial shear zone had developed during a weak phase of the monsoon and that the shear zone progressively moved northward from about 10°N to 20°N (its near normal position at 700 mb during the established phase of the monsoon circulation) over a period of about 10 days. The shear zone had also large scale horizontal dimensions and extended between about 65-90°E.

The long range research aircraft 'Electra' available with the Summer Monex Operational Centre flew an important mission through the shear zone on 24 July. Fig. 6 shows the meridional section (9-21°N and 86°-89°E) in the vertical (1000 to 500 mb) based on the dropsonde data collected during this flight. The Figure shows a weak shear zone at 850 mb along 16°N and an intense shear zone in the equatorial region (near 9-11°N) between 700 and 500 mb with a slight southward tilt with height. The temperature gradient is small across the shear zone at 700, 600 and 500 mb. At 700 mb the air between 9 to 16°N has a temperature within a degree of 10°C and

the air between 17 to 21°N has the temperature within a degree of 12°C. At 600 and 500 mb the temperature differences between different locations are perhaps within the uncertainty of the measurements. At 1000 and 850 mb very moist air (R.H. ~ 80%) prevails between 10-20°N, the extent of this very moist zone is restricted between 9-16°N at 700, 600 and 500 mb. Thus a deep moist layer exists in the vicinity (within 2 to 4° latitude) of the shear zone and the air between 17-20°N in the middle troposphere is relatively less moist (R.H. ~ 60 per cent). The second maximum in the relative humidity at 600 and 500 mb near 21°N which was observed towards the end of the flight is perhaps due to the day time cumulous activity over the marshy continental region adjoining the Bay of Bengal.

Fig. 7 shows the meridional profile of the characteristic features of the shear zone at 700 mb based on the averaged grid points data along 66-86°E. These profiles are shown for three typical days viz. 21 July when the shear zone was in its early formative stage, 24 July when the shear zone was well developed and 26 July 1979 when the shear zone had moved further northward and was becoming rather broad and diffused. The following aspects are observed in the longitudinally averaged profiles of different parameters :

i) Temperature increases from south to north. However, the axis of the shear zone lies in the region of weak temperature gradient.

ii) Maximum moisture zone lies about 2° latitude

to the south of the shear zone. R.H. increased in the section from 21 July to 24 July as the shear zone intensified. On 26 July, R.H. has a maximum along 14°N in comparison to the maximum between 4-8°N seen on the other two days.

iii) A region of weak cyclonic vorticity maximum of 0.5 units is observed between 6-12°N on 21 July which intensified to 2.5 units and became sharp along 11°N on 24 July. On 26 July the region of cyclonic vorticity of about 1.0 units is observed between 9 to 20°N indicating the broad and diffuse nature of the longitudinally averaged vorticity profile.

Conclusion :

Field phase data collected with the help of conventional and special observational platforms during the summer Monex have been analysed to document the characteristic features of the near equatorial ITCZ during preonset/onset phase as well as established phase of the monsoon. The following features are observed :

(a) The preonset phase ITCZ is a region of confluence between the near equatorial westerlies and the tropical flow approaching from north. On the average it is a region of weak cyclonic

relative vorticity ($\sim 1 \times 10^{-5}$ sec^{-1}). However, the embedded parturbations have stronger cyclonic relative vorticity ($\sim 3 \times 10^{-5}$ sec^{-1}) and are associated with convergence ($\sim 1.5 \times 10^{-5}$ sec^{-1}) at 700 mb. The shear zone lies in a region of rather weak temperature gradients in the colder monsoon air. Temperature increases north of the shear zone in the continental tropical air of the northern hemispheric origin. Moisture is also found to be maximum near the shear zone.

(b) The pre-onset phase ITCZ intensifies abruptly at the time of onset of the monsoon and begins to move northward. This event results perhaps from causes which are linked with the (i) response of the ITCZ to the intensification of the heat source to the north (ii) rushing of the strong cross-equatorial flow and its spreading towards the central and eastern Arabian sea, and (iii) amplification of transient disturbance within the ITCZ. These events occurred almost simultaneously during the onset phase of monsoon in 1979 suggesting that they are probably closely related. The intensified ITCZ has generally similar structure as the pre-onset phase ITCZ. However,

it is distinguishable, in the higher magnitudes of cyclonic relative vorticity ($\sim 7 \times 10^{-5}$ sec^{-1}) and associated convergence ($\sim 3 \times 10^{-5}$ sec^{-1}) as well as in the development of a deep moist column (surface - 500 mb) near the axis. Organised convection near the shear zone also intensifies as the monsoon surge (strengthening of the equatorial westerlies) appears. This intensified phase lasts for several days during which the main features remain well organised and held together as the intensified disturbance moves northward and ushers in the monsoon rains along the west coast of India.

(c) During the establishment phase of the monsoon, the near-equatorial oceanic ITCZ again makes itself felt when the monsoon cycles from the active to break/weak phase. During this phase the ITCZ at 700 mb is formed by the confluence between the equatorial westerlies and the tropical maritime easterlies/southeasterlies emanating from the westward progression of the sub-tropical ridge from southeast Asia. The main confluence at 700 mb is therefore in the zonal component during this phase. Its characteristic

features are more or less similar to those of the onset phase. The perturbations in it move in a NW/N direction and establish the whole system once again from the near equatorial region to about 20°N. However, the relative vorticity in its intense stage (24 July 1979, Fig. 6) was somewhat smaller than the intense stage of the onset phase ITCZ (14 June 1979, Fig. 3).

Further observational research with the data collected during Monex is obviously needed to investigate the temporal and spatial fluctuations in the position and intensity of the ITCZ and the associated organised convection as the monsoon evolves from the onset to the established phase and cycle from active to break/weak phase.

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Legends of the Diagrams

Fig. 1 : Meridional section at 700 mb along 66-75°E during 4 - 14 June.

Fig. 2 : Vertical structure across the ITCZ (based on data collected during research flights on 7 and 14 June 1979).

Fig. 3 : Meridional profile of characteristic parameters at 700 mb during the onset phase.

Fig. 4 (a) : Meridional section of relative vorticity at at 700 mb during 4 - 14 June 1979.

Fig. 4 (b) : Meridional section of Divergence at 700 mb during 4 - 14 June 1979.

Fig. 5 : Meridional section at 700 mb along 85°-90°E during 20 - 31 July 1979.

Fig. 6 : Meridional section in the vertical based on data collected during a research flight on 24 July 1979.

Fig. 7 : Meridional profile of characteristic parameters at 700 mb during established phase of monsoon.

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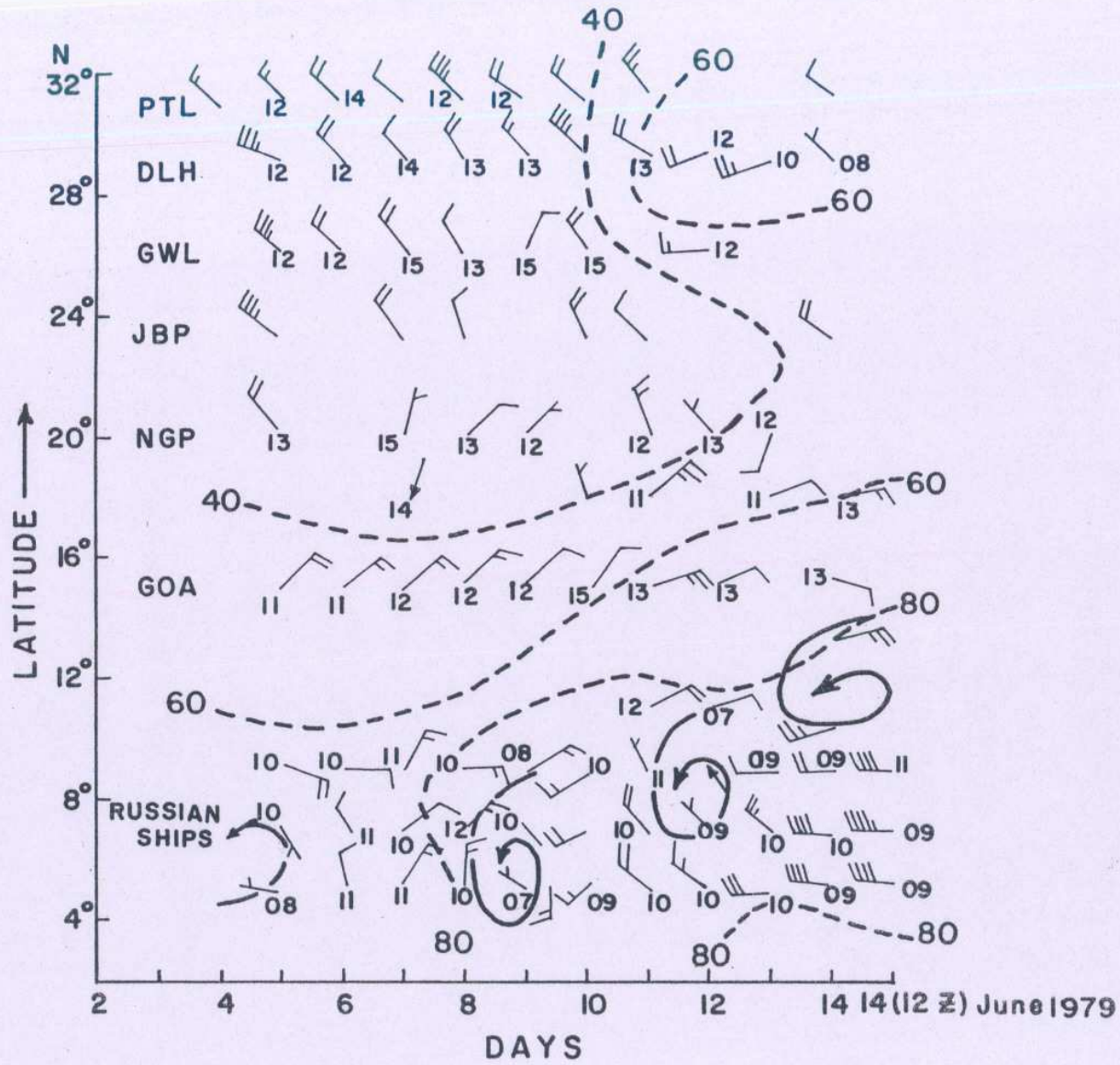

---- ISOPLETHS OF REL. HUMIDITY

Fig. 1.

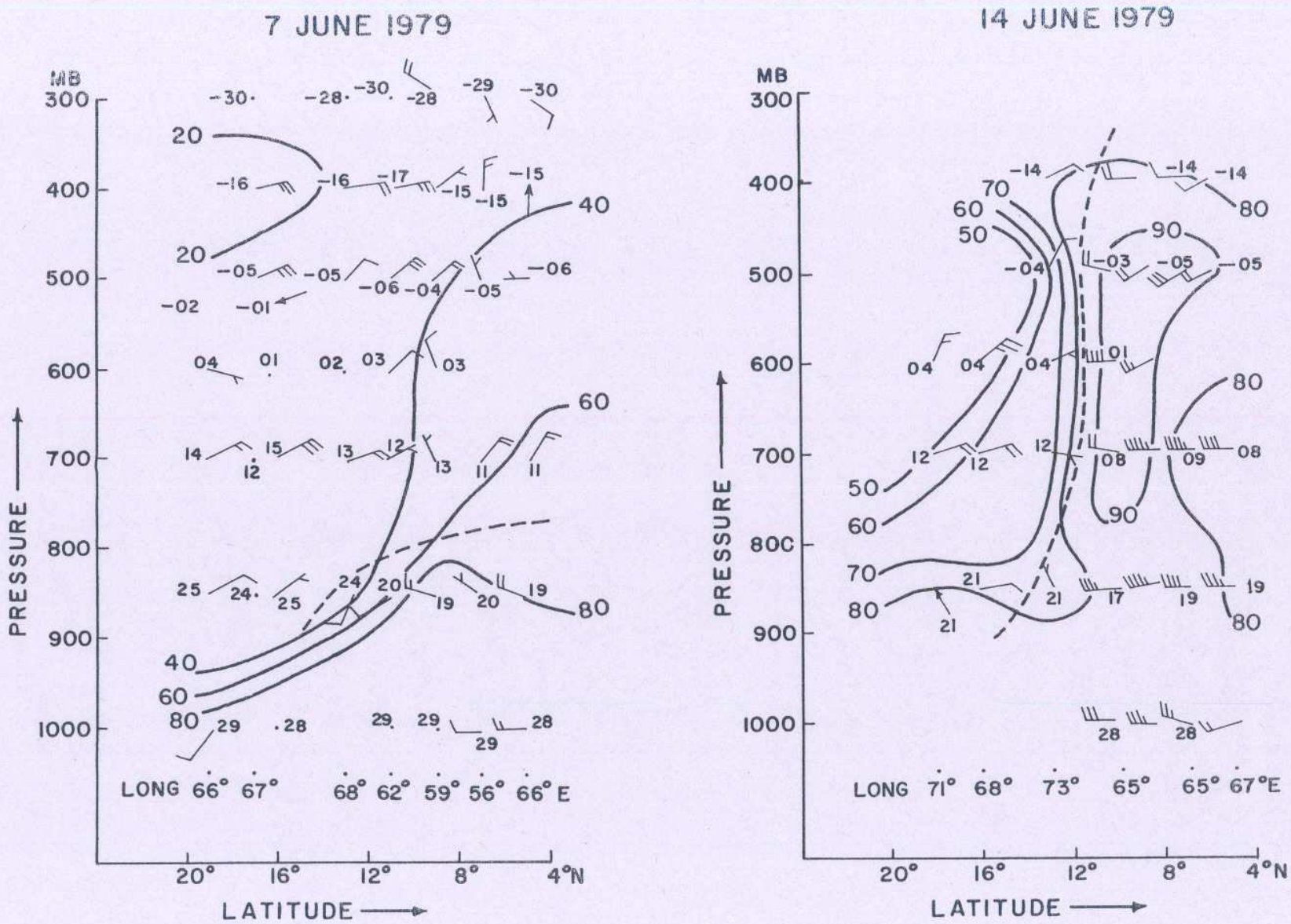

Fig. 2.

- - - - - SHEAR LINE

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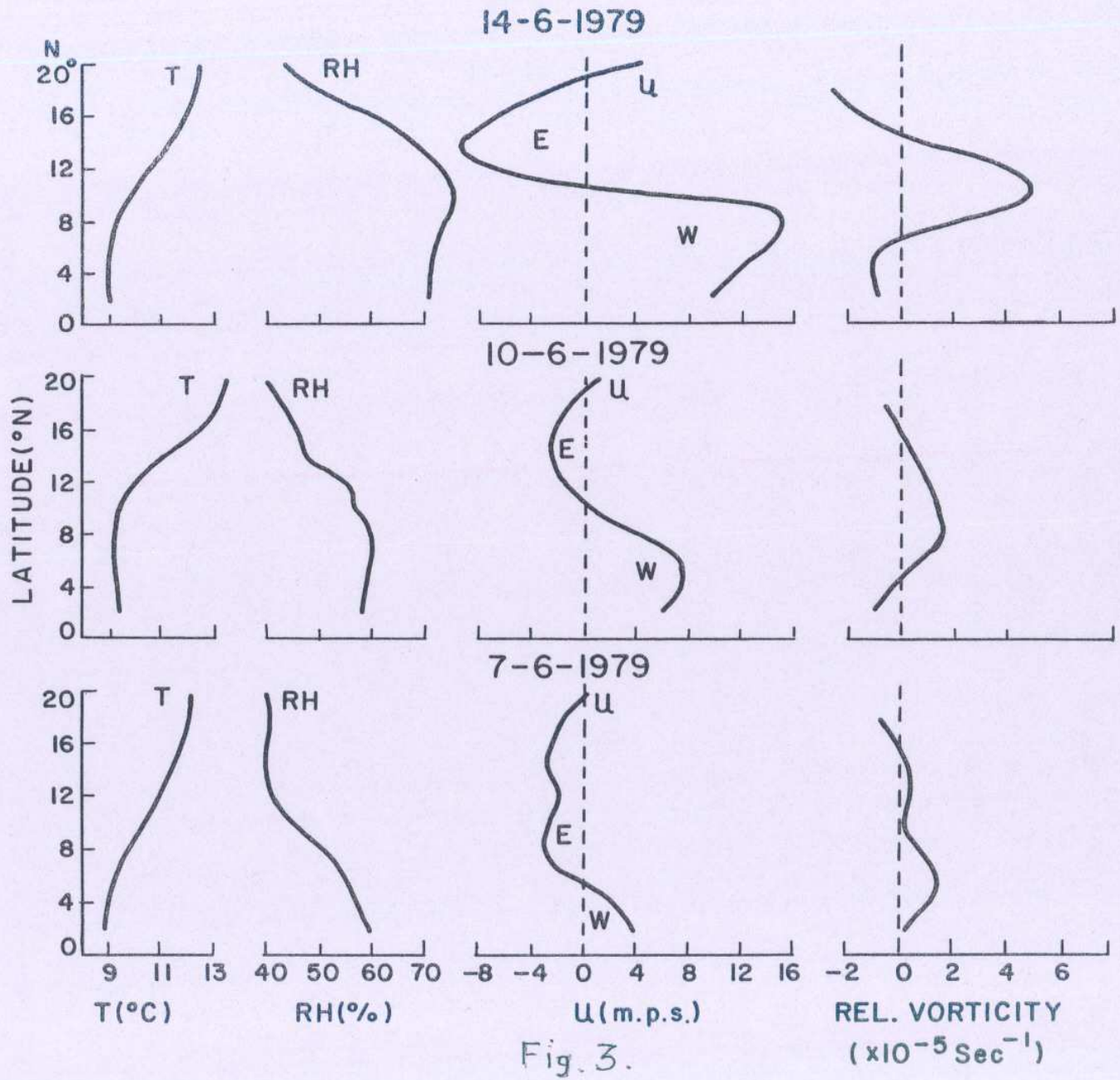

14-6-1979
10-6-1979
7-6-1979
LATITUDE(°N)
N
20°
16
12
8
4
0
T
RH
u
E
W
9 11 13
T(°C)
40 50 60 70
RH(%)
-8 -4 0 4 8 12 16
u(m.p.s.)
-2 0 2 4 6
REL. VORTICITY
(x10⁻⁵ Sec⁻¹)

Fig. 3.

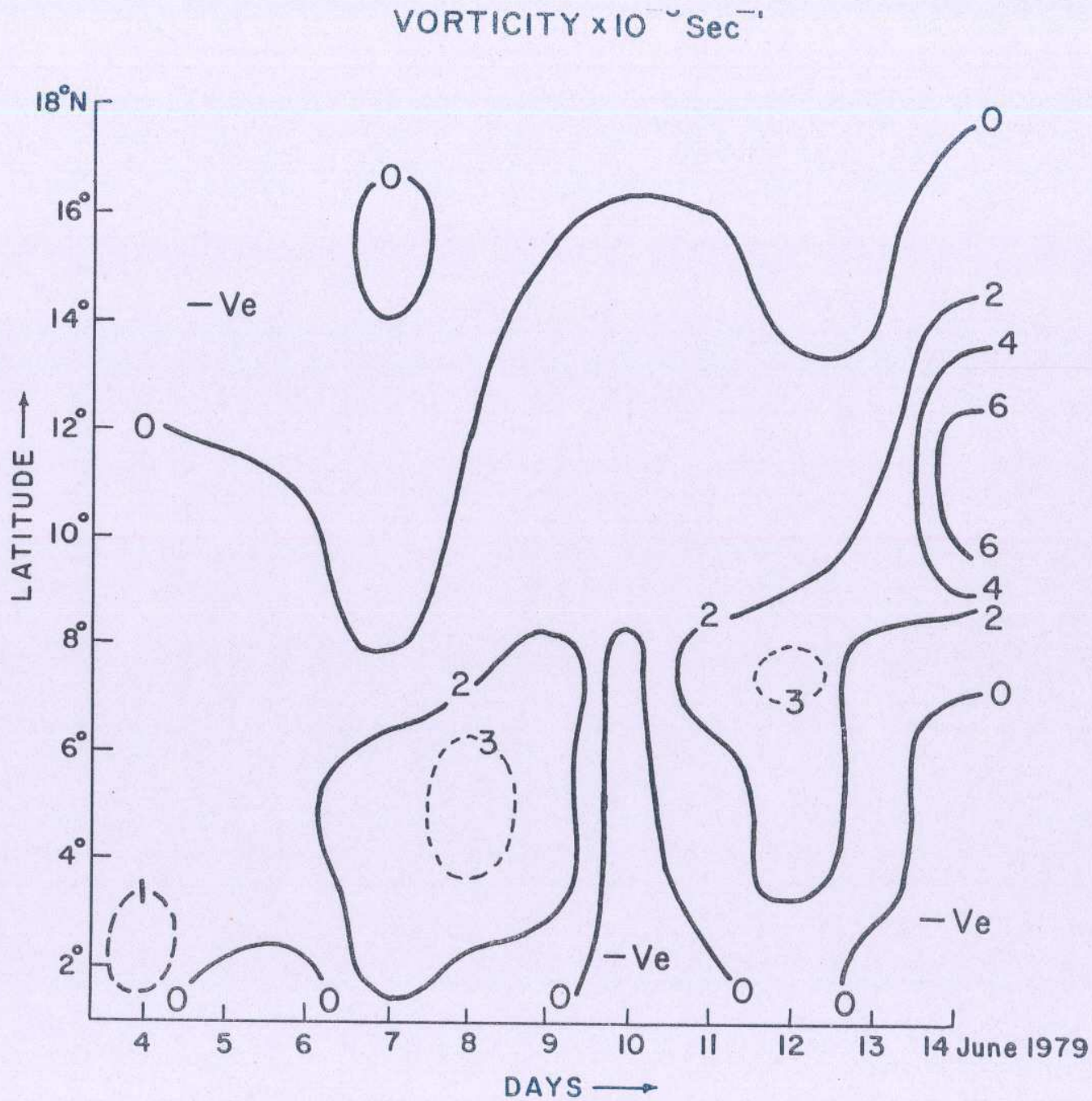
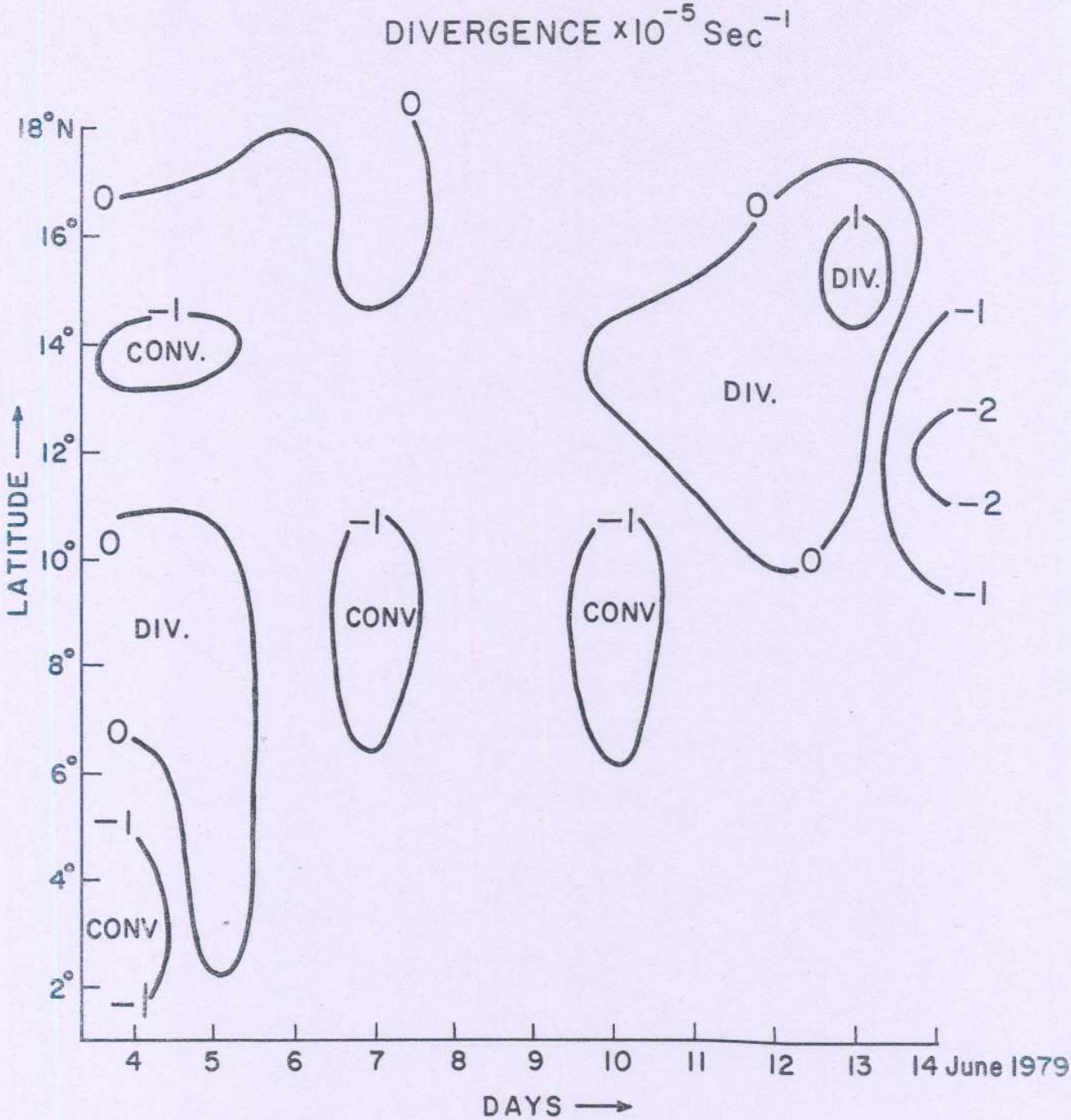

VORTICITY x 10 Sec
18°N
16°
14°
12°
10°
8°
6°
4°
2°
LATITUDE
DAYS
4
5
6
7
8
9
10
11
12
13
14 June 1979
-Ve
-Ve
-Ve
0
2
4
6
-3
-1

Fig. 4 (a)


DIVERGENCE ×10⁻⁵ Sec⁻¹
18°N
16°
14°
12°
10°
8°
6°
4°
2°
LATITUDE
0
-1
CONV.
DIV.
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-2
4
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7
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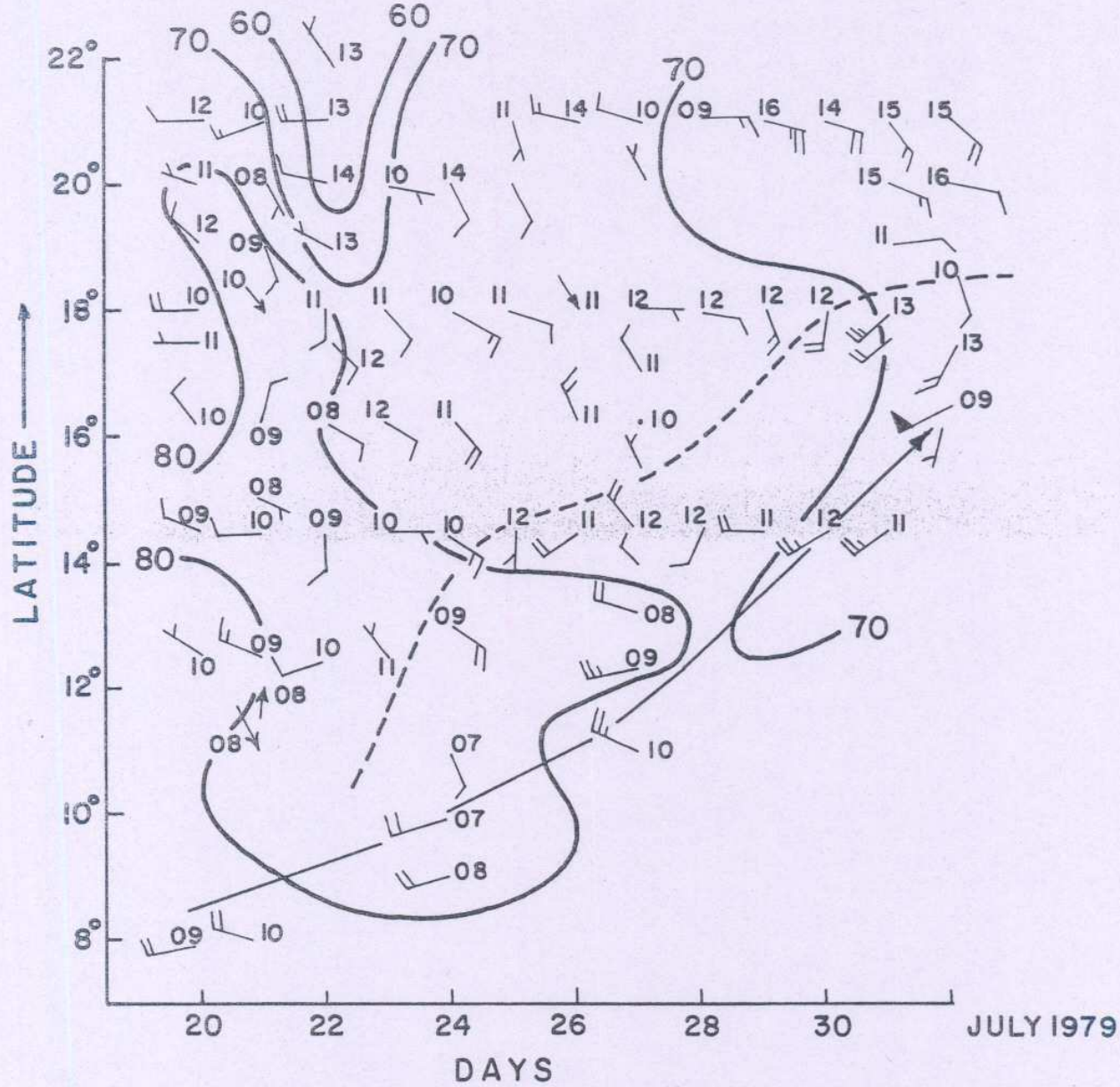
12
13
14 June 1979
DAYS

Fig. 4(b)



MAXIMUM WIND IN WESTERLIES

ISOPLETHS OF REL. HUMIDITY

AXIS OF THE TROUGH

Fig. 5.

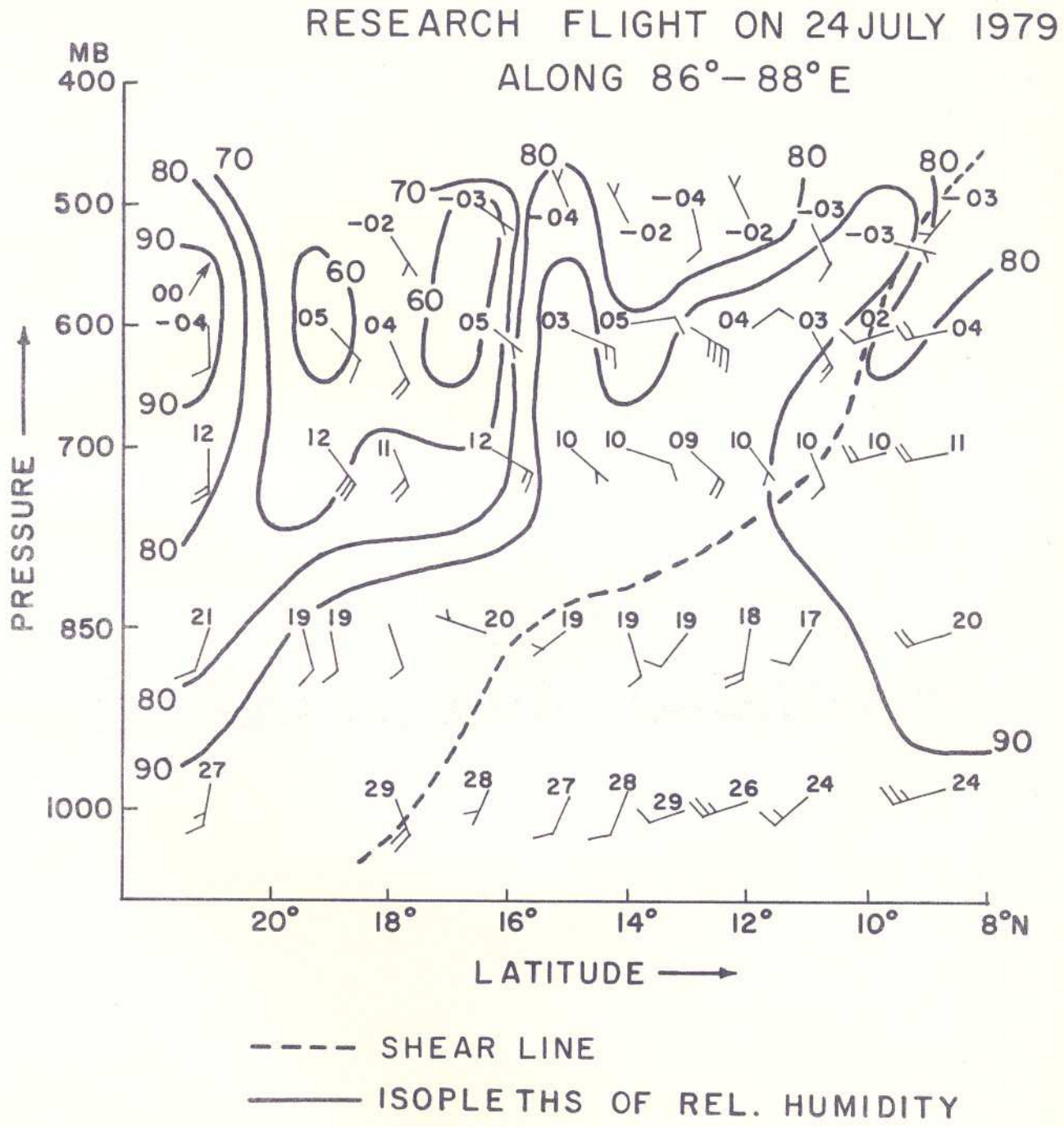

RESEARCH FLIGHT ON 24 JULY 1979
ALONG 86°–88°E
MB
400
500
600
700
850
1000
PRESSURE
20°
18°
16°
14°
12°
10°
8°N
LATITUDE
SHEAR LINE
ISOPLETHS OF REL. HUMIDITY

Fig 6.

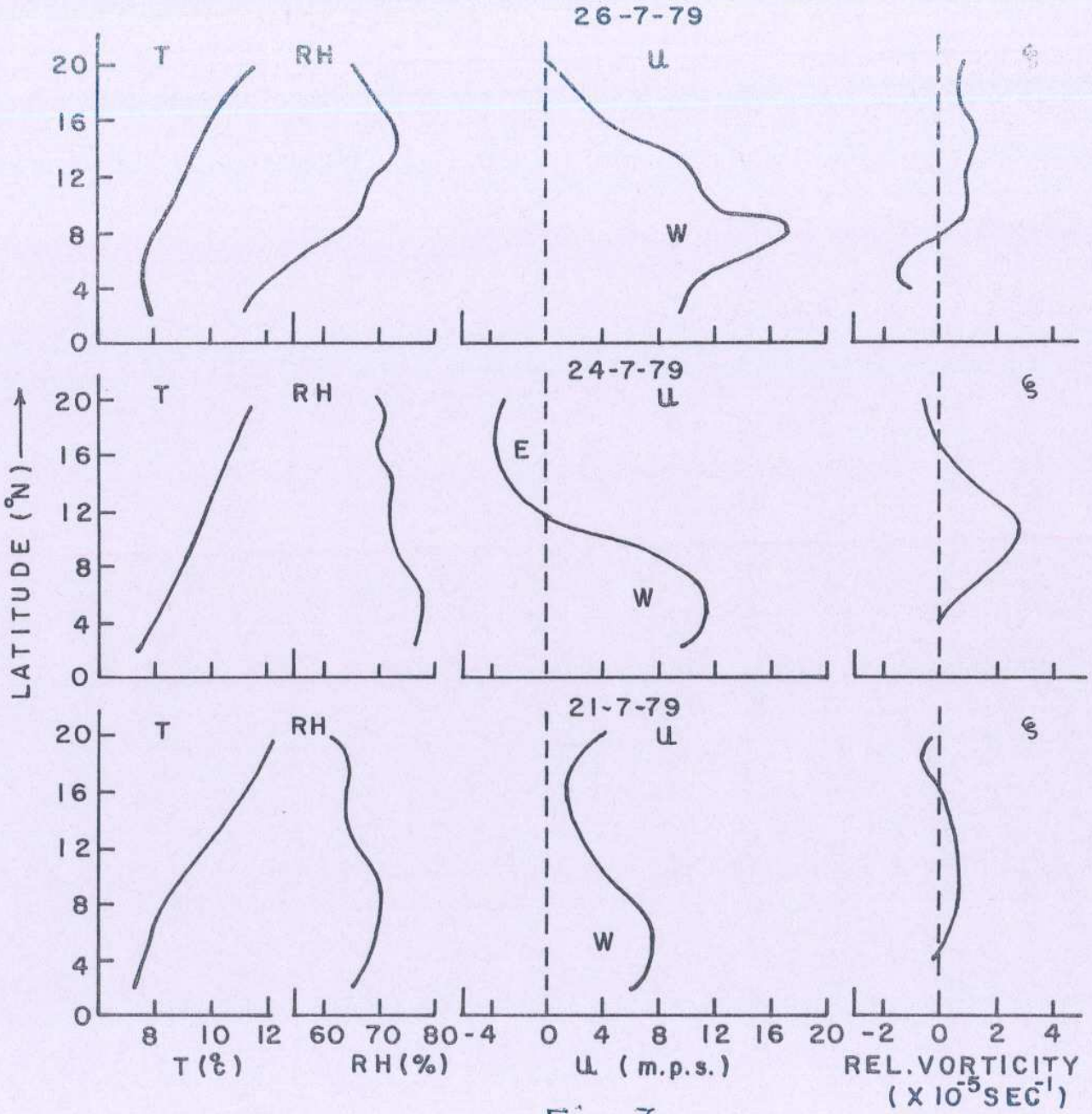


Fig. 7

MERIDIONAL PROFILES OF CHARACTERISTIC PARAMETERS