

The Central American temporal: A long-lived tropical rain-producing system

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ABSTRACT

The general characteristics of the Central American *temporal* are described, as well as the synoptic conditions which produce it. As an example, the synoptic situation and the rainfall distribution over Costa Rica associated with the *temporal* of May 1982 are discussed.

The *temporal* resulted from the development of a low pressure center over the Gulf of Honduras, which was observed from the surface up to the 250 hPa level. This low pressure center produced a westerly flow (interrupting the predominant northeasterly flow), which interacted with orography producing persistent rain for several days. The maximum daily rainfall values over Costa Rica were about 150 mm, which are quite significant considering that the rainy season on the Pacific side and the Central Valley of Costa Rica begins in May.

The modification of the environment by the occurrence of the *temporal* is also discussed. Vertical cross sections during the *temporal* show that a cooling below approximately 600 hPa and a warming above this level took place. A large increase in humidity was observed and the thickness of the convective and conditional layer above surface decreased during the *temporal*.

1. Introduction

The Central American *temporal* is a tropical disturbance that produces continuous rain during a period greater than twenty four hours (usually from about two to four days), and that affects the land areas and neighboring Pacific Ocean and/or Caribbean Sea. The sky is completely covered by nimbostratus and altostratus clouds but in some cases convective systems are embedded within the disturbance. The *temporal* may sometimes be

accompanied by strong winds and normally not by significant electric activity. A distinction is usually made, when it is possible, between a Pacific *temporal* and a Caribbean *temporal* depending of which side of Central America is affected, the Pacific or Caribbean, respectively. Such a distinction is made because the *temporal* affects in many cases only one of the two sides. Part of the reason for this is that most of Central America is divided into two zones, the Pacific and the Caribbean, by a system of mountains ranges which induces orographic ascent. Consequently, a much larger increase in the amount of rainfall with respect to the average is observed on the windward side of the mountains.

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Pacific *temporales* occur from May to November, but more frequently in June and September–October, which is related to the annual latitudinal migration of the Intertropical Convergence Zone (ITCZ) over the Eastern tropical Pacific and to the occurrence of tropical cyclones and other deep lower and middle troposphere troughs in the easterlies. The Caribbean *temporales* occur more frequently in the Northern Hemisphere winter, when Central America is under the influence of outbreaks of cold air from the interior of North America and upper tropospheric troughs in the midlatitude westerlies, which propagate into the tropics reaching as far south as the southern part of Central America.

Lessmann (1964) has made a distinction between *temporalic weather* and a *temporal* in terms of their duration and intensity. The *temporalic weather* is characterized by continuous rains which last about one day and which are usually less intense than those of the *temporal*. Nevertheless, the synoptic causes for the *temporalic weather* and the *temporal* appear to be the same, differing only in the intensity and degree of organization of the synoptic systems. Among those synoptic causes, the following can be mentioned:

a) Deep lower and middle troposphere troughs in the easterlies, excluding hurricanes

The trough (organized for example up to 500 hPa) produces, because of its circulation, an intense transport of warm and humid air from the Pacific into the Central American continental areas. When the trough system is deep enough it produces the separation of small cyclonic eddies from the ITCZ, which may later move close to the coast or develop into tropical depressions or hurricanes in the Pacific. In the case described by Reyes Rivera (1965), *temporalic weather* on June 9–10, 1965, was produced by a trough system which was initially observed in the surface map from the Central part of Cuba to the Caribbean coast of Nicaragua. The trough was also observed at 850 hPa and 500 hPa and it caused the separation of two small cyclonic eddies from the ITCZ, one of which moved close to the coast of El Salvador and produced *temporalic weather* over this country. The rainfall maximum for one day was about 170 mm. This synoptic situation described by Reyes Rivera (1965), although not mentioned by him, also produced *temporalic weather* over Costa Rica and other parts of Central America.

Reyes Rivera (1965) has pointed out that when the intense extra-tropical cyclones of the Central and Eastern parts of the United States intrude into tropical latitudes, they may also change into a trough system that affects the ITCZ (for example the *temporal* of November 1963 which affected El Salvador).

b) Intrusion of an upper troposphere trough in the middle latitude westerlies into tropical latitudes

Grandoso (1979) studied the *temporal* of December 1970, which produced heavy rains and floods on the Caribbean side of Costa Rica. He found that insignificant synoptic systems were observed in the lower troposphere. In the upper troposphere (above 500 hPa), however, a trough in the middle latitude westerlies deepened and intruded into the tropics reaching the latitude of Costa Rica. This upper trough took an orientation NE–SW in the tropics and resulted in the formation of a shear line or a cut low. The anomalous northeasterly flow in the upper troposphere extended upward the normal northeasterly winds in the lower troposphere, and the upward motion associated with the upper low increased the thickness of the layer with hydrostatic potential instability. The interaction of the northeasterly flow with the mountain ranges produced heavy orographic rains. In addition, upstream blocking in the first few hundred meters occurred, which produced a return current close to the surface. Convergence between this return current of the blocking and the northeasterly synoptic flow resulted in heavy rains in the coastal areas. The rainfall maximum of the *temporal* was about 350 mm in one day, 700 mm in two days, and 800 mm in three days.

c) Outbreaks of cold air from North America

During the Northern Hemisphere winter season, Central America is affected by outbreaks of cold air, commonly known as *nortes*, which originate in the interior of the North American Continent. They travel southward until they reach the southern part of the region.

When the cold dry air crosses the Gulf of Mexico, it is modified by the gain of latent and sensible heat from the surface, and on arrival at Central America interacts with the pronounced orography, producing persistent rains (*temporales*) on the windward side (Caribbean side) of the mountain ranges. These

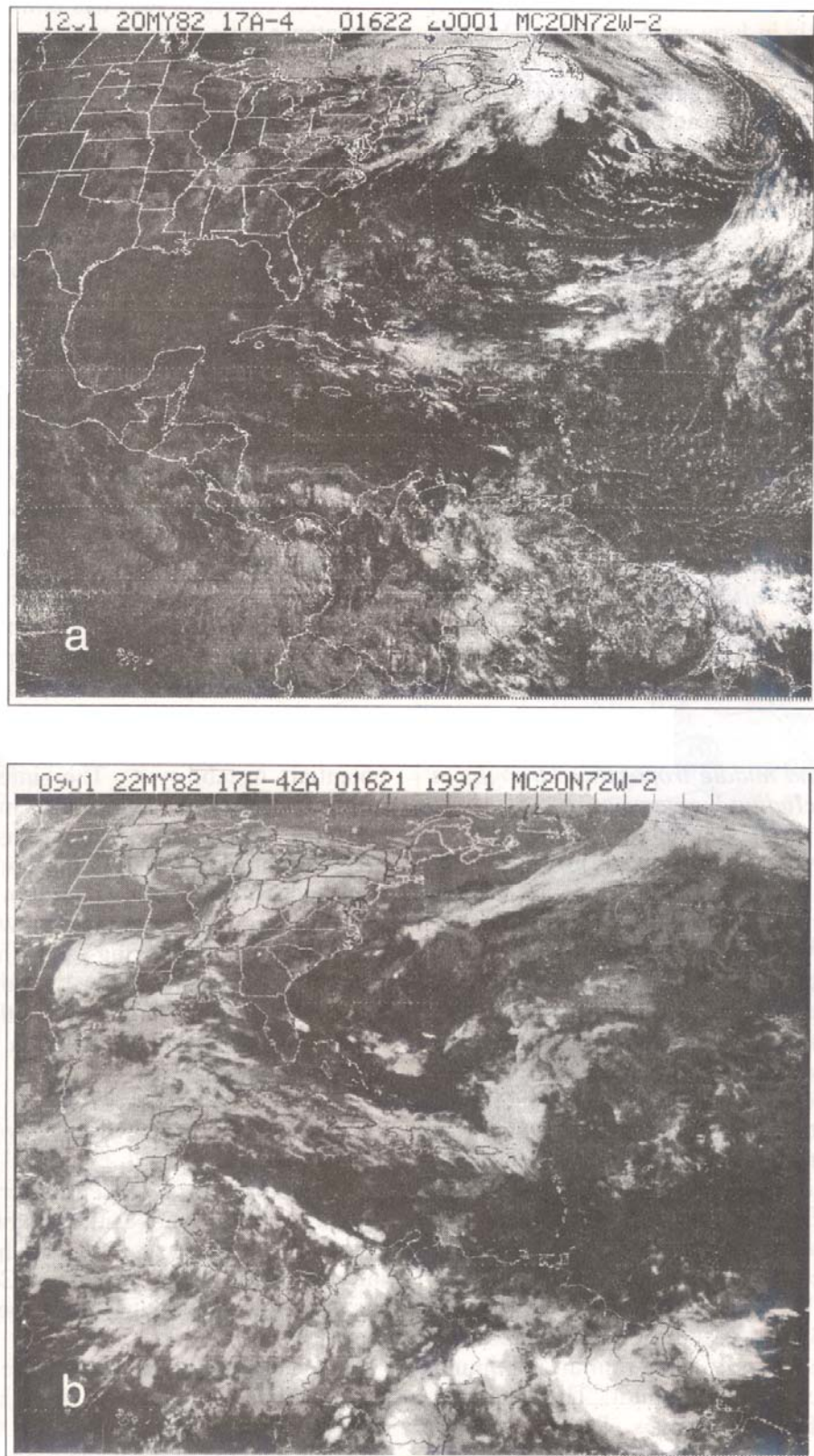


Fig. 2. Satellite pictures of (a) May 20, 1982, at 12:01 GMT, (b) May 22, 1982, at 09:01 GMT,

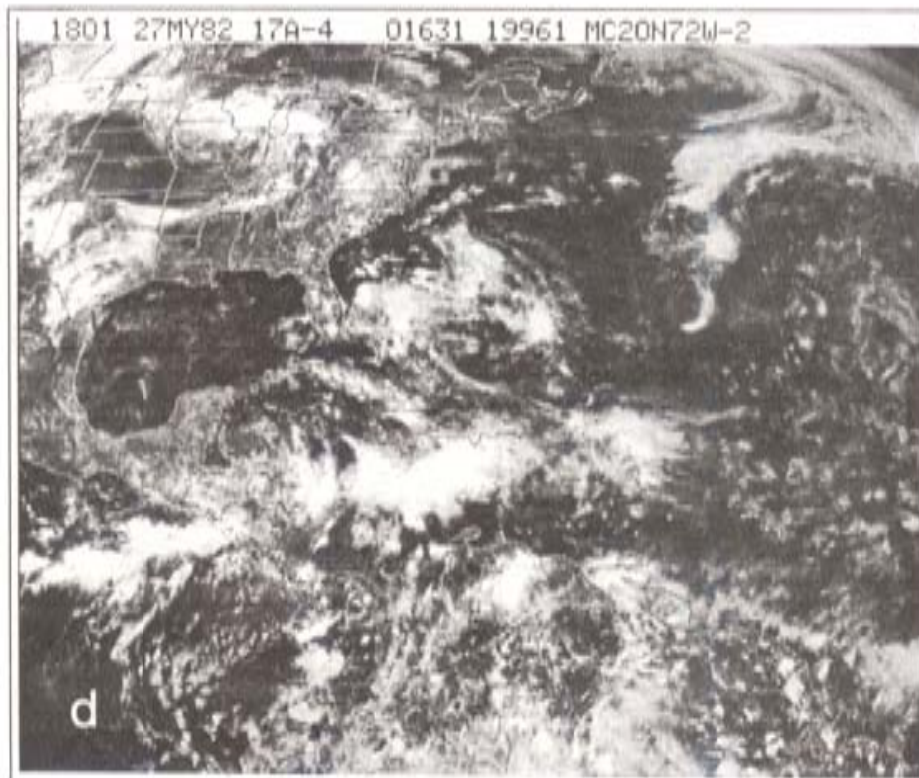
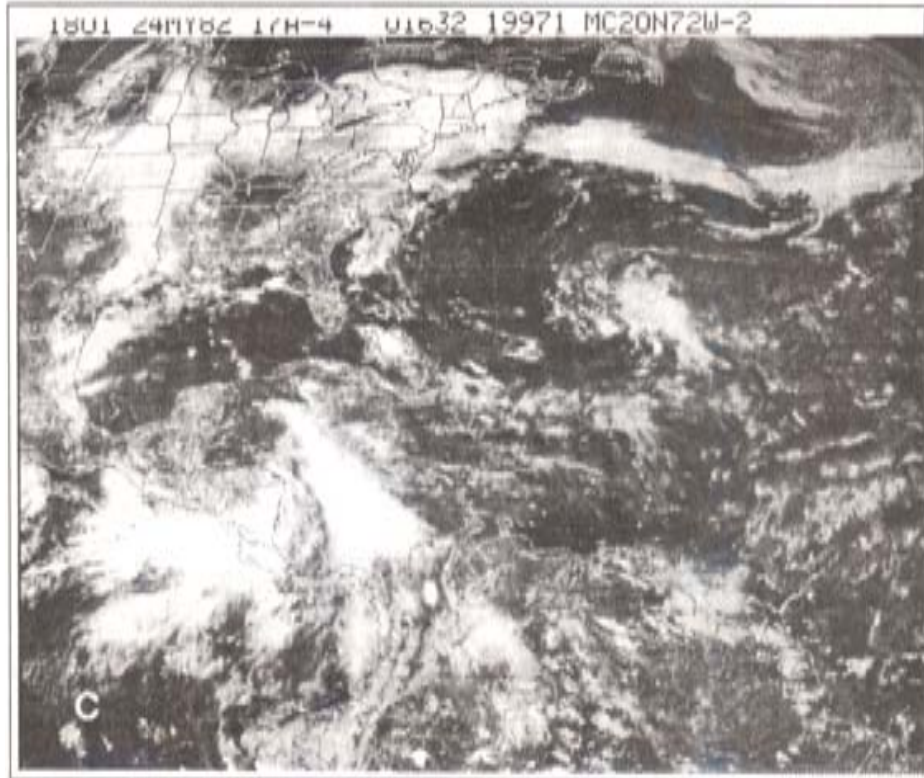


Fig. 2. Satellite pictures of: (c) May 24, 1982, at 18:01 GMT, (d) May 27, 1982, at 18:01 GMT.

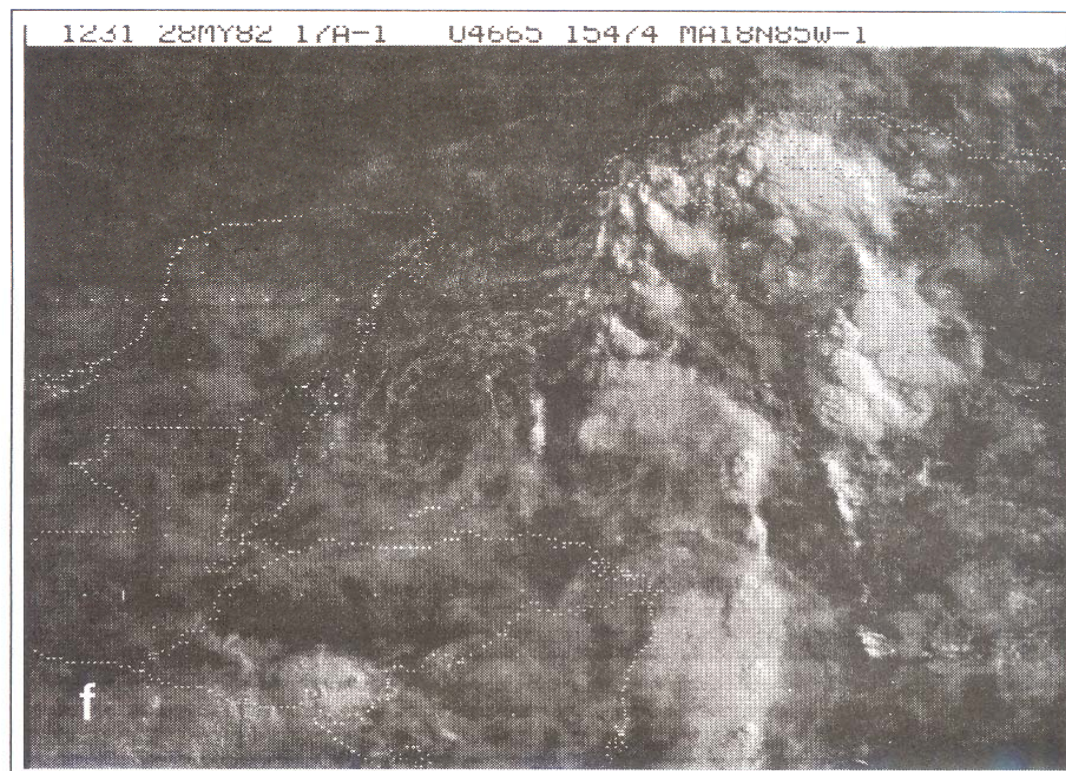
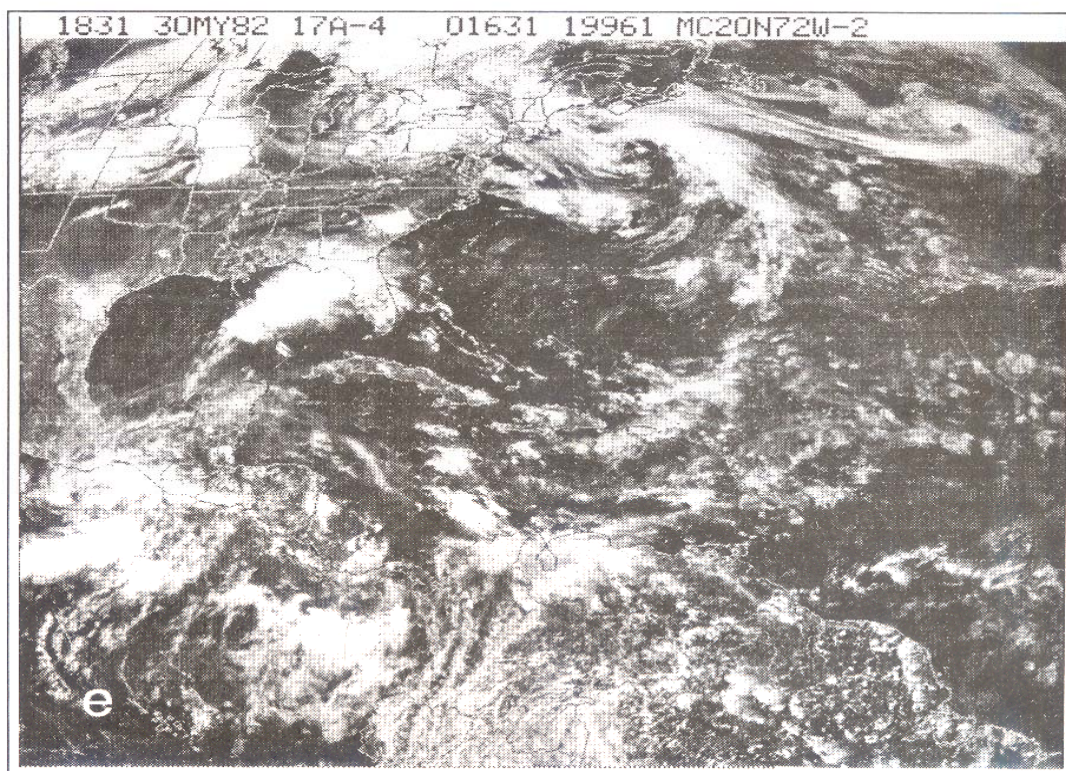


Fig. 2. Satellite pictures of: (e) May 30, 1982, at 18:31 GMT and (f) May 28, 1982, at 12:31 GMT.

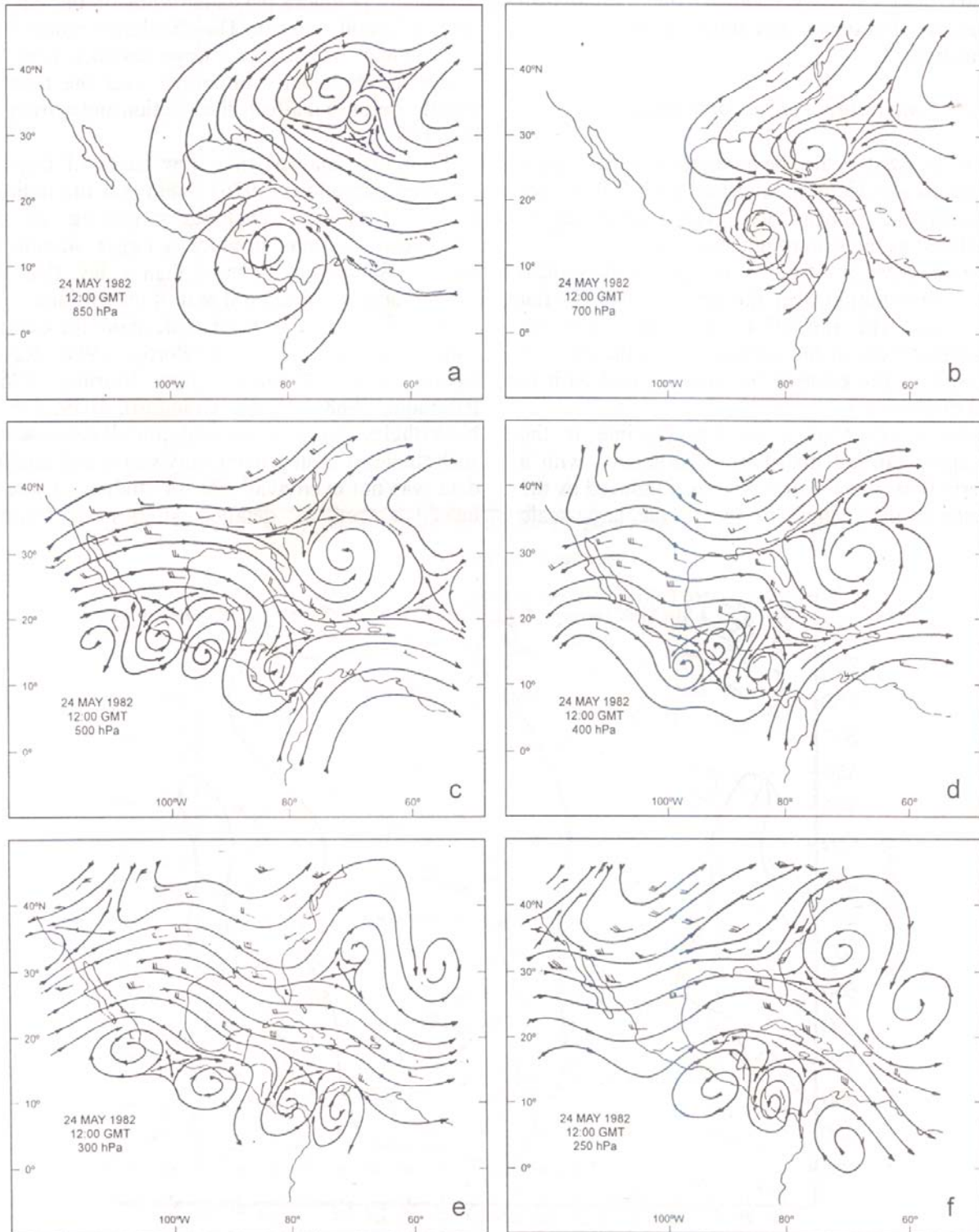


Fig. 3. Upper level charts at 12:00 GMT on May 24, 1982: (a) 850 hPa, (b) 700 hPa, (c) 500 hPa, (d) 400 hPa, (e) 300 hPa, and (f) 250 hPa.

events (e.g., Portig, 1958; Grandoso *et al.*, 1982) occur mainly during the months of December, January, and February. During the March-April period, the frequency and intensity of the *nortes* diminishes.

d) *Direct and indirect effects of tropical cyclones*

A *temporal* may also be produced when a tropical cyclone crosses Central America or when it crosses the western Caribbean Sea. These cases can be considered as intense trough systems.

Direct effect of a tropical cyclone is the typical rainfall distribution over the sea or relatively flat land areas. The rainfall is associated with the convergent field in the central part of the cyclone (the wall in the case of hurricanes) and with the spiral rainbands.

Indirect effect of a tropical cyclone is the orographic rainfall distribution associated with a westerly flow over Central America, induced by the presence of the cyclone or due to the large-scale

circulation at the periphery of the cyclone. The interaction of this westerly flow with the pronounced orography produces persistent rains on the Pacific side of Central America. The circulation induced by the tropical cyclone, at a large distance from its center, is particularly important over the Eastern Pacific, because it affects the location and activity of the ITCZ.

From the analysis of a few cases of tropical cyclones, Grandoso (1976) found that the indirect effect of tropical cyclones occurring in the Caribbean Sea may produce a larger amount of rainfall, for periods of more than a day, than the convergence in the central part of the cyclone.

A few studies have been made about the Central American *temporales* (e.g. Portig, 1958; Reyes Rivera, 1965; Pallmann and Murino, 1967; Pallmann, 1968a, 1968b; Grandoso, 1979, 1982). Nevertheless, the synoptic and rainfall data used in such studies was, in general, very scarce and satellite data was not even available for studies. There is indeed a need of detailed studies of Central

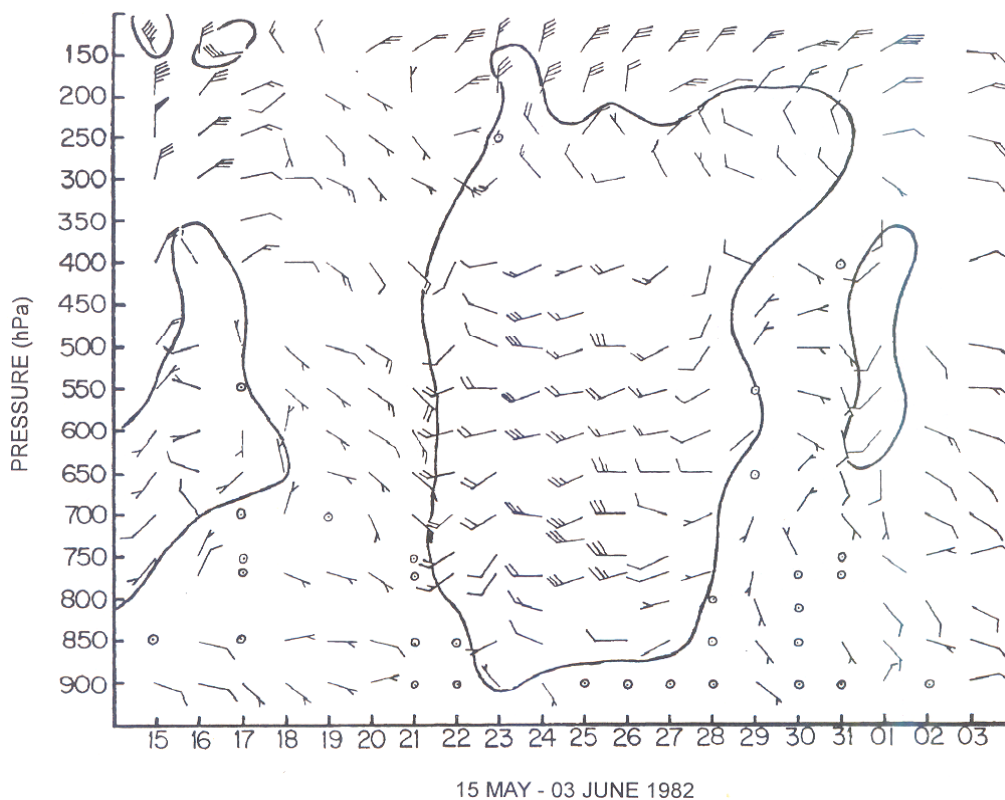


Fig. 4. Vertical cross section of wind at 06:00 LST (12:00 GMT) at Juan Santamaría International Airport (10°N, 84°12'W), Costa Rica, for the period May 15-June 3, 1982.

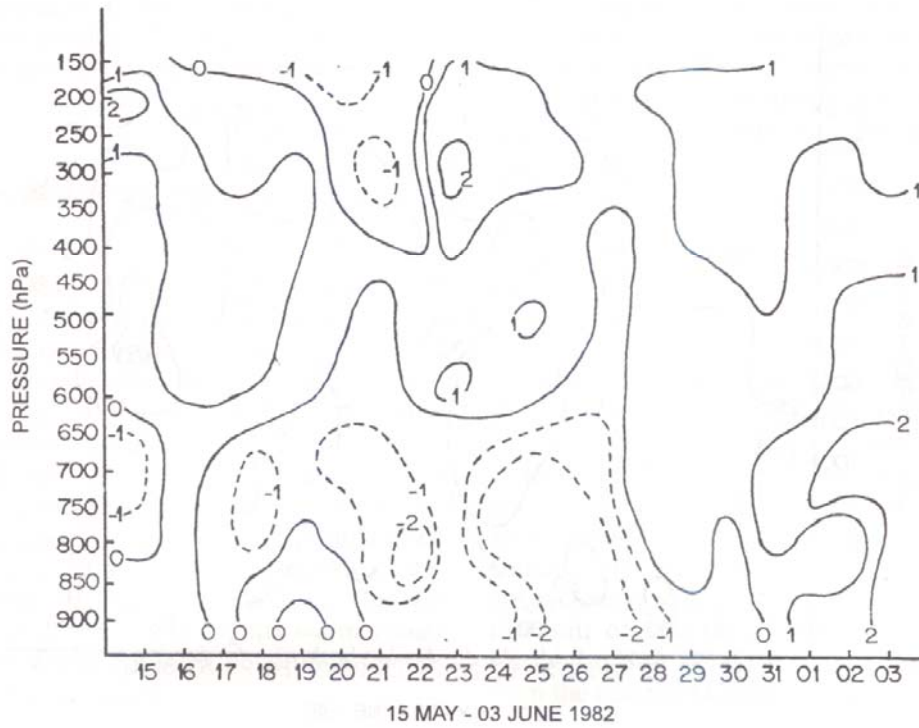


Fig. 5. Vertical cross section of temperature anomaly at 06:00 LST (12:00 GMT) at Juan Santamaría International Airport (10°N, 84°12'W), Costa Rica, for the period May 15-June 3, 1982.

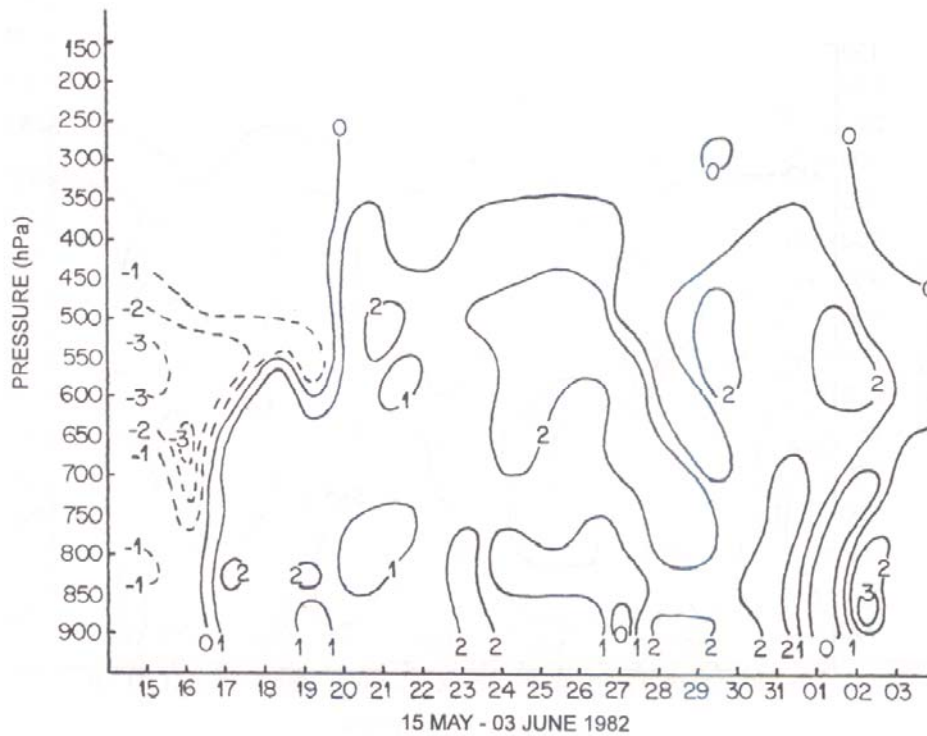


Fig. 6. Vertical cross section of specific humidity anomaly at 06:00 LST (12:00 GMT) at Juan Santamaría International Airport (10°N, 84°12'W), Costa Rica, for the period May 15-June 3, 1982.

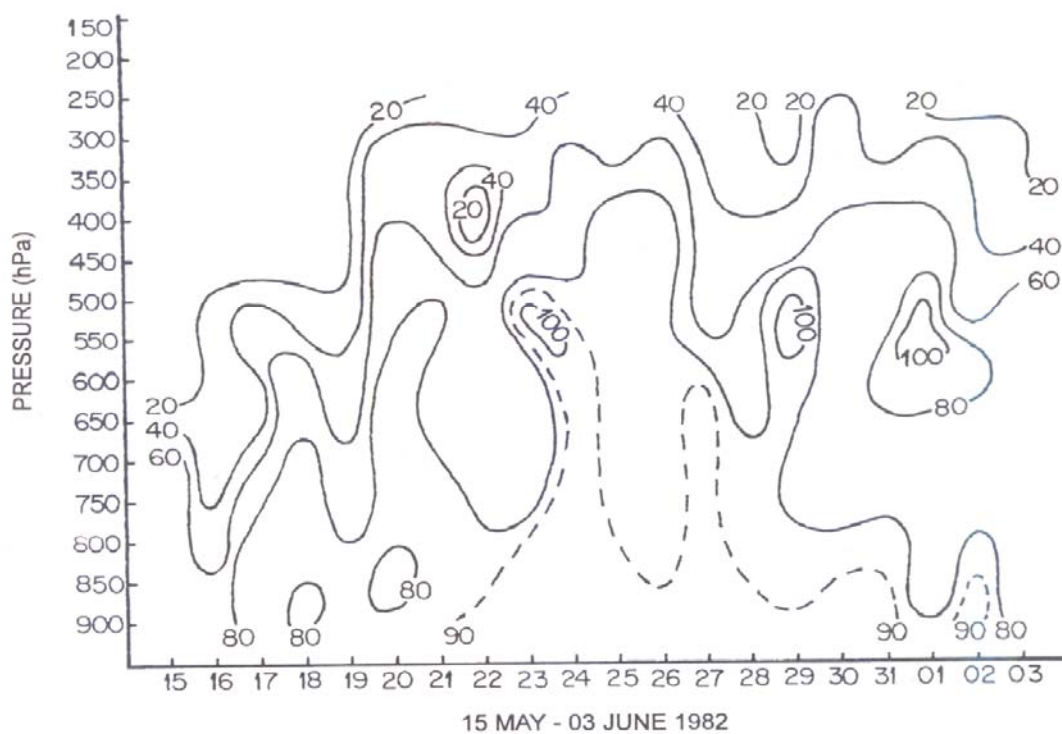


Fig. 7. Vertical cross section of relative humidity at 06:00 LST (12:00 GMT) at Juan Santamaría International Airport (10°N, 84°12'W), Costa Rica, for the period May 15-June 3, 1982.

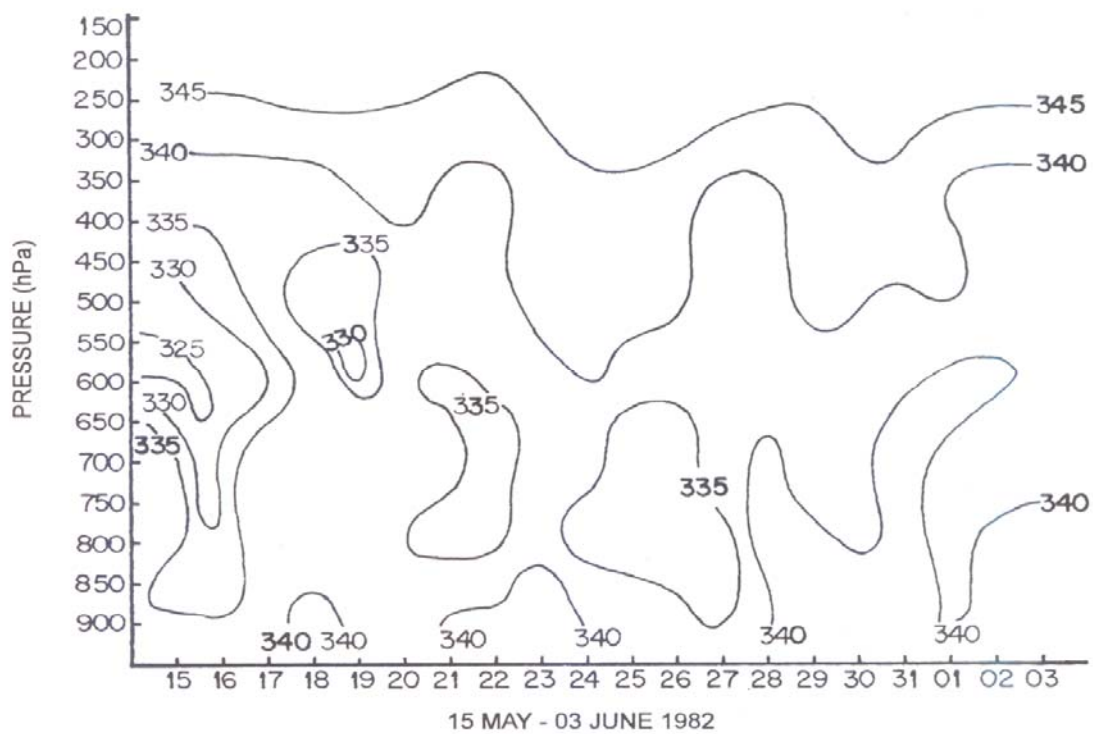


Fig. 8. Vertical cross section of equivalent potential temperature at 06:00 LST (12:00 GMT) at Juan Santamaría International Airport (10°N, 84°12'W), Costa Rica, for the period May 15-June 3, 1982.

American *temporales*. In the following sections the Pacific *temporal* of May 1982 will be analyzed and particular attention will be given to its effects over Costa Rica.

2. Typical meteorological conditions in May over Costa Rica

The rainy season on the Pacific side and the Central Valley of Costa Rica begins in May. In this month, showers occur frequently in the afternoon and *temporales* occur very infrequently.

On a typical day of May the easterly trade winds are observed in the morning; during the afternoon westerly winds are observed. The spatial rainfall distribution is controlled by the orography and the location of the sea breeze front, which results from the convergence produced by the interaction of the trade winds with the westerly sea breeze. This sea breeze is rich in humidity and slightly warmer than the trades, which are optimum conditions for the development of convection.

The typical synoptic situation is that in which a sufficient pressure gradient (for example between the center of the Bermuda anticyclone and Central America) exists to maintain the easterly trades, which are only interrupted by the sea breeze from the Pacific.

3. The synoptic situation

a) Surface charts

Figure 1 shows the surface charts prior (a), during (b, c and d), and after (e) the occurrence of the *temporal*; satellites pictures are shown in Figure 2.

In the first days the above-mentioned pressure gradient between the center of the Bermuda anticyclone and Central America can be observed (Figure 1a); the high pressure of the Bermuda anticyclone extends to the coast of the United States, the Gulf of Mexico and the northern part of the Caribbean Sea. There is a wave in the easterlies from the coasts of Colombia and Venezuela to the

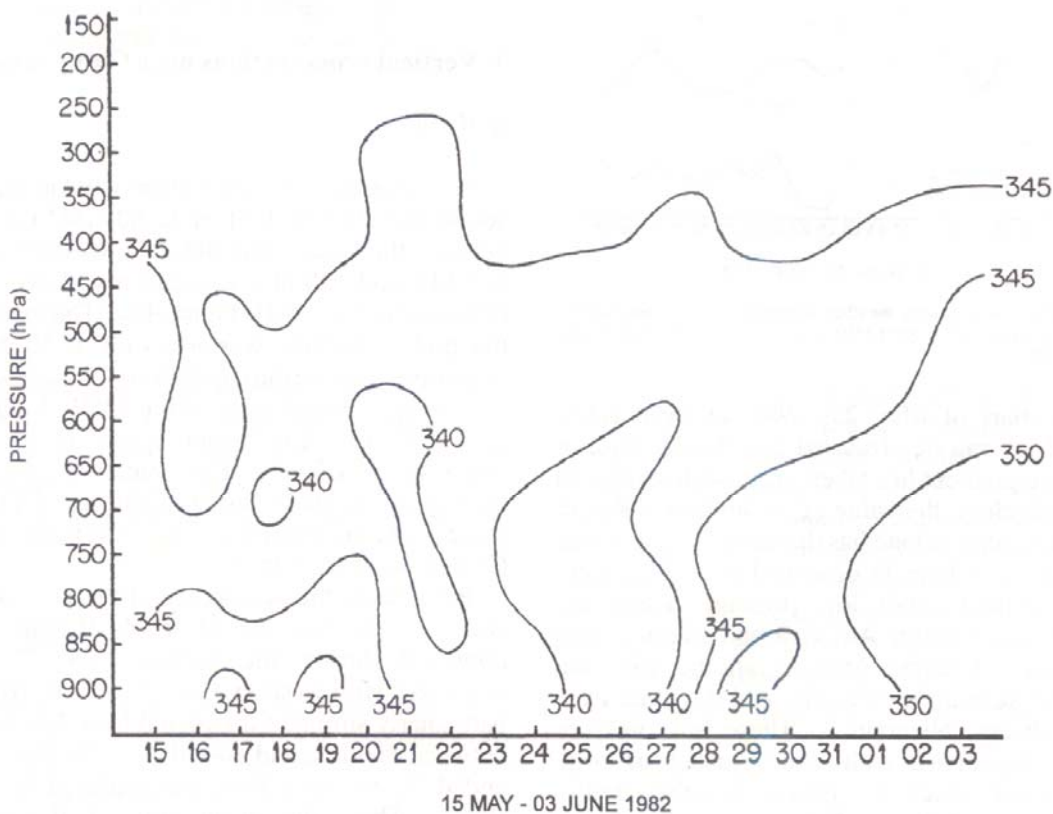


Fig. 9. Vertical cross section of saturated equivalent potential temperature at 06:00 LST (12:00 GMT) at Juan Santamaria International Airport (10°N, 84°12'W), Costa Rica, for the period May 15-June 3, 1982.

Dominican Republic. It could be inferred that the Pacific anticyclone has its northern border near the Galápagos Islands. In the middle of the high pressures of the Pacific and the Atlantic, the intertropical trough is located. Two low pressure nuclei are observed, one over Nicaragua and the other over Yucatán, Mexico.

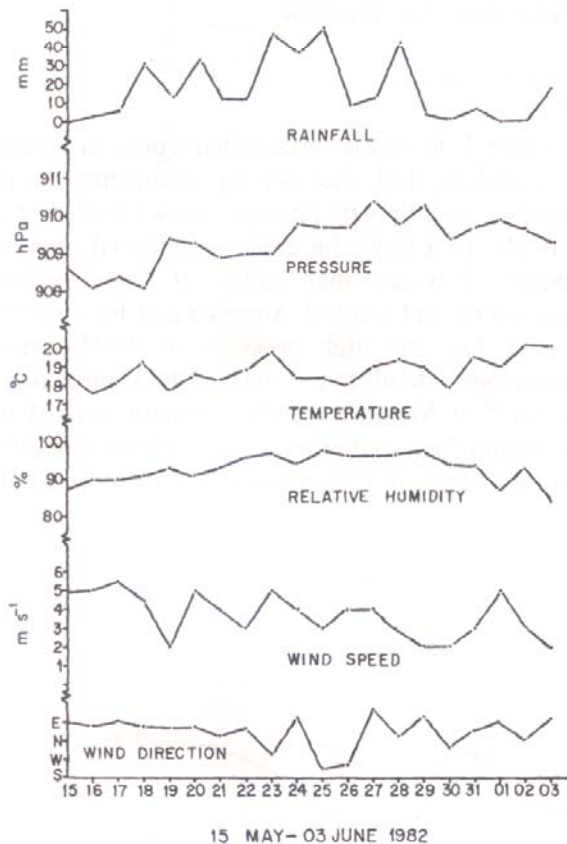


Fig. 10. Surface changes in weather elements at Juan Santamaría International Airport (10°N , $84^{\circ}12'\text{W}$), Costa Rica, for the period May 15-June 3, 1982.

In the chart of May 23, 1982, at 1800 GMT (Figure 1b) it can be observed that the decrease in the pressure gradient has taken place with respect to the previous chart; the value of the highest isobar in the Bermuda anticyclone has decreased in 2 hPa. The tropical storm Aletta is observed near Acapulco, Mexico. Three small low pressure nuclei are observed over Central America and Mexico; one centered over Yucatán, Mexico, another over the Gulf of Fonseca on the Pacific, and the other over Puerto Cabezas, Nicaragua. These low pressure nuclei are associated with cloud clusters of large vertical extent, which are observed in the satellite picture of May 22 (Figure 2b).

In the chart of May 27, 1982, at 0000 GMT

(Figure 1d) a nucleus of 1002 hPa is observed over the Gulf of Honduras. In the corresponding satellite picture (Figure 2d) spiral cloudiness resulting from the cyclonic circulation may be seen.

The surface charts of May 20 and May 23, 1982 (Figures 1a and 1b) show the previous conditions to the formation of a cyclonic system in the Gulf of Honduras, which is observed in the pressure field of latter charts (Figures 1d and 1e); the chart of May 30, 1982, at 1200 GMT (Figure 1c) shows that the cyclonic system has weakened.

b) Upper level charts

Figure 3 shows the conditions for May 24, 1982, at 12:00 GMT at different levels. The cyclonic system associated with the low pressures at the surface develops from lower to upper levels (Figure 3); throughout the period of analysis there is a coupling of the system at all levels. From May 23 to May 28, inclusive, the cyclone is observed at all levels up to 250 hPa (for example see Figure 3 for May 24). At 250 hPa however, the system is not observed as a closed circulation but a trough is present.

4. Vertical cross sections over Costa Rica

a. Wind

Climatologically, the resultant wind in May (from soundings at 06:00 LST or 12:00 GMT) is easterly between the surface and 400 hPa, westerly between 400 hPa and 100 hPa, and easterly above 100 hPa (Grandoso *et al.*, 1981, Figure 12). The extension of the middle latitude westerlies up to 10°N in the higher troposphere during the May-November period is a climatic characteristic at the 84°W , longitude of Costa Rica. The mean speed of the lower troposphere easterly flow and of the higher troposphere westerly flow is about 5 m s^{-1} ; the wind shear between 200 hPa and 800 hPa is about 5 m s^{-1} (Grandoso *et al.*, 1981).

Previous to the occurrence of the *temporal* there was easterly flow at all levels (Figure 4). The *temporal* during the period May 22-28 was associated with westerly flow (Figure 4), which was particularly strong in the period May 24-26, mainly between 800 hPa and 400 hPa. After the *temporal* ended the westerly flow was replaced by easterly flow. Thus, the occurrence of the *temporal* interrupted the predominant flow regime.

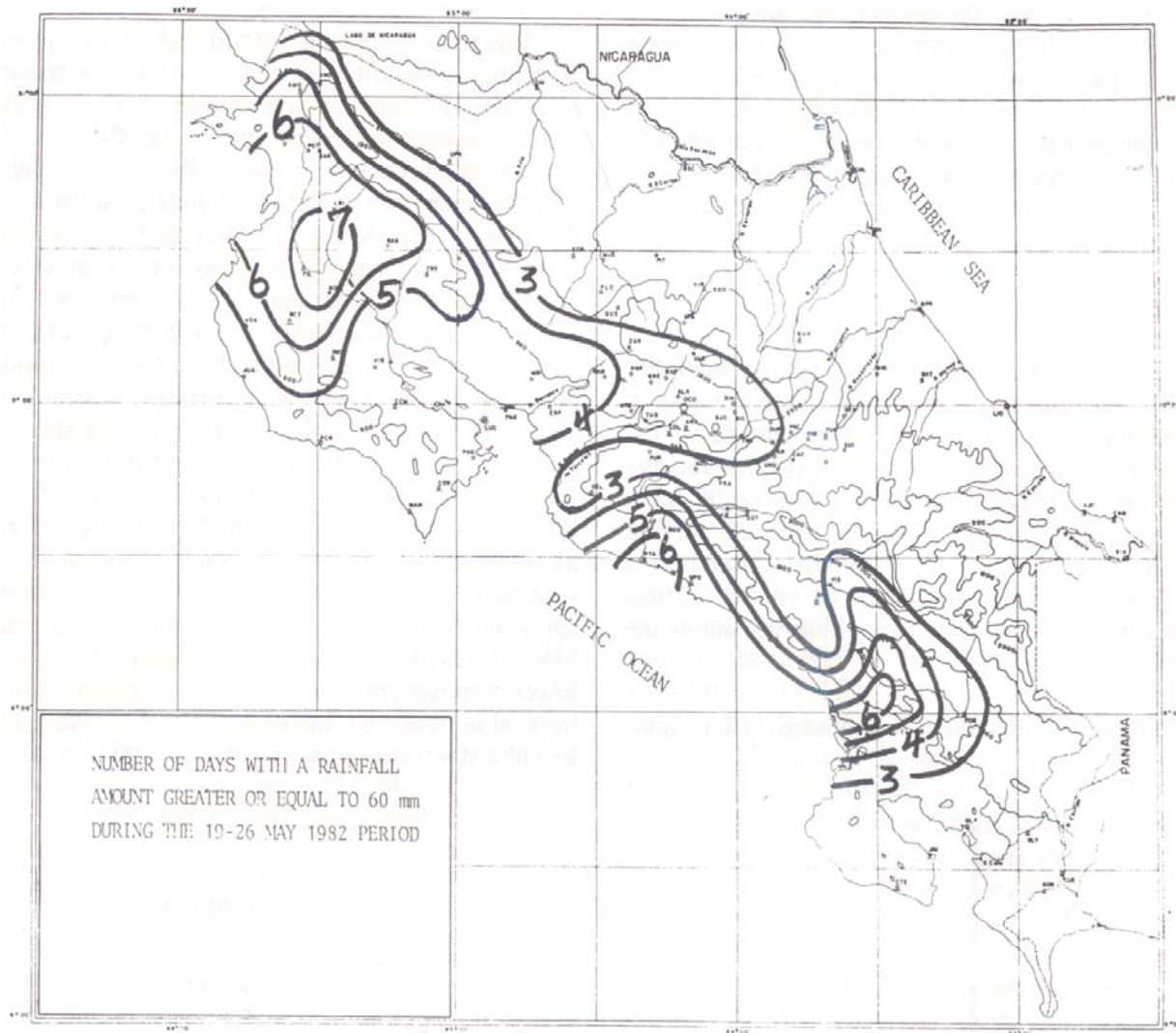


Fig. 11. Areal distribution, on the Pacific side of Costa Rica, of the number of days with a rainfall amount equal or greater than 60 mm during the period May 19-26, 1982.

It is observed that the westerly flow associated with the *temporal* has a mean speed much larger than the predominant trades of the previous days. There are two maxima in the westerly flow; one between 600 hPa and 450 hPa on May 24 and the other between 700 hPa and 800 hPa on May 25 (Figure 4).

b. Temperature

Climatologically, temperature anomalies in May (from soundings at 06:00 LST) are very small below 100 hPa (less than 0.7 °C in absolute value), with positive values below 700 hPa and negative values above 500 hPa (Grandoso *et al.*, 1981, Figure 2)

The vertical structure of temperature anomaly

during the *temporal* is shown in Figure 5. Cooling of a layer below 600 hPa is observed during the *temporal* as a consequence of downdrafts and the evaporation of precipitation. Since the rainfall is mostly orographic and continuous (see Figure 10), the downdrafts are mainly on the mesoscale rather than on the convective-scale. Associated with the downdrafts are two competing effects: evaporative cooling and adiabatic compressional warming. Observations show that the former effect dominates over the latter. Cooling of a layer near the ground has also been observed associated with the occurrence of convective systems over the sea and land areas (*e.g.*, Fernández, 1980, 1982a, 1982b); however, the depth of the layer in which the cooling takes place is much smaller in the cases of

convective systems than in this *temporal* case.

Above 600 hPa the temperature anomalies are positive, implying a warming. This may suggest descent forced by processes other than evaporation. However, it may also be a consequence of continued subsidence in the presence of decreased evaporation. This latter mechanism would also explain the positive temperature anomalies at lower levels at the end of the *temporal*.

c. Humidity

The vertical distribution of specific humidity anomaly (Figure 6) shows that a large increase in humidity took place with the occurrence of the *temporal*. Climatologically, the average relative humidity in May (from soundings at 06:00 LST) decreases from about 80% at the surface to 50% at about 500 hPa and to 30% at 300 hPa (Grandoso *et al.*, 1981, Figure 4). This contrasts with the vertical distribution of relative humidity observed during the *temporal* (Figure 7).

d. Equivalent potential temperature (θ_E) and

saturation equivalent potential temperature (θ_{ES})

Palmén and Newton (1969) used the term "potential instability" to refer to the combined condition of "convective instability" ($\partial\theta_E/\partial z < 0$) and "conditional instability" ($\gamma > \gamma_S$, or $\partial\theta_{ES}/\partial z < 0$) when a deep layer is considered. In general, either of these latter types of instability may exist without the other. The terms potential and convective instability are sometimes used synonymously. Potential instability is related to processes which produce vertical motions that affect layers of the atmosphere. In our case, we are interested in ascent produced by the orography and how it affects the hydrostatic stability of the ascending air masses.

Soundings at 06:00 LST show that θ_E decreases from surface to about 600 hPa (from 355.5 K to 332 K) and increases above 600 hPa, to 342.1 K at 300 hPa (Grandoso *et al.*, 1981, Figure 8). Thus, there is convective instability between the surface and approximately 600 hPa and a stable layer above 600 hPa. The existence of convective instability in the lower troposphere is a climatic characteristic in tropical regions. θ_{ES} increases from the surface to 850 hPa, decreases from 850 hPa to 600 hPa, and

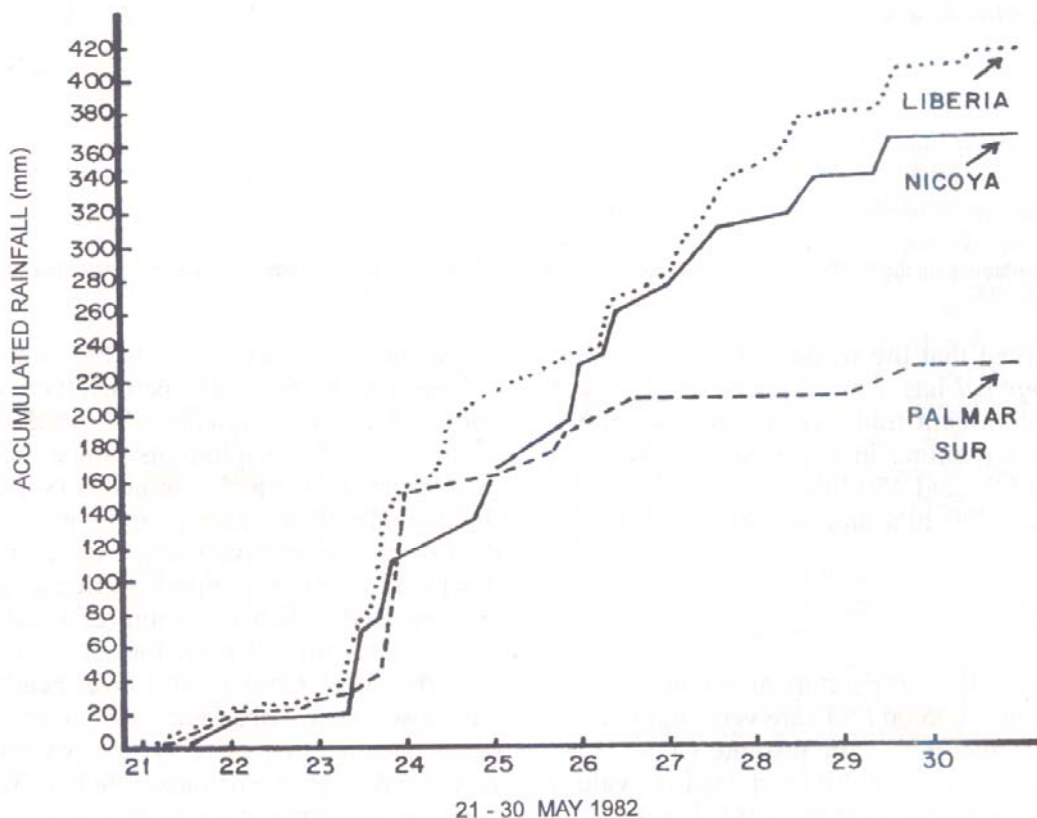


Fig. 12. Two-hour accumulated rainfall at three stations (Liberia, Nicoya and Palmar Sur), during the period May 21-30, 1982.

increases above 600 hPa (Grandoso *et al.*, 1981, Figure 6). The stable layer between surface and 850 hPa is due to the time of the sounding (06:00 LST), when the nocturnal cooling of the surface is large. In general, the θ_{ES} values show that in May there are two well defined layers: one conditionally unstable (θ_{ES} decreases with height) from surface to about 600 hPa and other stable (θ_{ES} increases with height) above 600 hPa.

Cross section of θ_E and θ_{ES} during the occurrence of the *temporal* are shown in Figures 8 and 9, respectively. It is observed that the depth of the convective and conditional unstable layer decreases during the *temporal*. This is due to the cooling produced by the evaporation of precipitation (Figure 5).

As we will discuss later on, the accumulated rainfall amounts at different stations (Figure 12) show a continuous type of precipitation with long periods of moderate rainfall. Most of the synoptic surface observations indicate nimbostratus clouds; thunder was infrequent and occurred mainly at the beginning of the *temporal*. This implies that the orographic ascent does not produce convective motions although the lower troposphere is potentially unstable. Kreitzberg and Perkey (1976, 1977) developed a numerical model to study the release of potential instability by large-scale lifting and the subsequent interaction of cumulus convection and the hydrostatic mesoscale flow. They treat the convection with a simple sequential plume cumulus model and the mesoscale with the hydrostatic primitive equations. Their results indicate that convection dominates the first part of the process. However, the hydrostatic mesoscale updraft, which develops in response to diabatic heating from earlier convection, becomes progressively dominant in the process and produces stratiform precipitation that exceeds the earlier convective precipitation.

5. Surface changes in weather elements

Figure 10 shows the surface changes in weather elements observed at the Juan Santamaría International Airport during the occurrence of the *temporal*. The weather elements plotted are rainfall, pressure, temperature, relative humidity, and wind speed and direction. The rainfall was relatively large during the period May 22-24; there was a change in wind direction but not significant changes

in wind speed, the relative humidity and pressure increased but the temperature did not change significantly. These changes observed during the *temporal* contrast with those observed during the passage of squall lines (*e.g.*, Fernández, 1982a, Figure 5), because in the latter case abrupt changes in most of the weather elements are observed.

6. Rainfall distributions

Since May is the first month of the rainy season in most of the Pacific side of Costa Rica, the rainfall amount during this month is relatively low. It varies from 100 mm in the driest parts of Guanacaste to values between 400 mm and 600 mm in very limited areas of the Central and South Pacific side regions; most of the region has a monthly rainfall amount between 200 mm and 300 mm (250 mm in average). The number of days with rain on the Pacific side varies from 10 in the driest parts to 25 in the areas with maximum rainfall; the average number of days with rain being 17.5. Dividing 250 mm by 17.5 gives a rainfall amount of 15 mm per a rainy day.

Figure 11 shows the areal distribution of the number of days with a rainfall amount equal or greater than 60 mm for the period May 19-26. This value of 60 mm per day occurs very infrequently in May; it is four times the average value of 15 mm mentioned above. It can be seen that the regions with greater rainfall amount are the Central Western part of Guanacaste, the Central Pacific and the South Pacific. The rainfall maximum in Guanacaste was somewhat unexpected, because it corresponds to a relatively flat area with a low rainfall amount. Upstream blocking in the first hundred meters, caused by the Guanacaste mountain range, could be a possible explanation. In some places, small orographic features could also have enhanced rainfall.

The type of rainfall during the *temporal* can be seen from Figure 12, which shows the two-hour accumulated rainfall at three stations during the period May 21-30. It is observed a continuous type of precipitation with long periods of moderated rainfall; the larger rainfall amounts occurred on May 23.

7. Concluding remarks

It has been shown that the Central American

temporal may be produced by different synoptic conditions, particularly for those which are able to sustain for a relatively long period (for example two to four days) an airflow perpendicular to the mountains ranges. This produces lifting and, consequently, continuous rain. The areal rainfall distributions are closely related to orography.

Vertical cross sections during the *temporal* show that a cooling below approximately 600 hPa and a warming above this level took place. A large increase in humidity was observed and the thickness of the convective and conditional layer above the surface decreased during the *temporal*.

The large rainfall amounts produced by the *temporal* produce flooding of rivers, landslides, erosion of roads, and crop damage. Loss of human lives sometimes occurs. Thus, there is indeed a need of more observational studies and of numerical simulations, in order to get a better understanding of the phenomenon. All findings should be taken into account for forecasting purposes and disaster reduction.

RESUMEN

Se describen las características generales del *temporal* de América Central, así como las condiciones sinópticas que los producen. Como ejemplo, se discuten la situación sinóptica y la distribución de lluvia sobre Costa Rica asociadas con el *temporal* de Mayo de 1982.

El *temporal* resultó del desarrollo de un centro de baja presión sobre el Golfo de Honduras, el cual se observó desde la superficie hasta el nivel de 250 hPa. Este centro de baja presión produjo un flujo del oeste (interrumpiendo el flujo predominante del noreste), el cual interactuó con la orografía produciendo lluvia persistente por varios días. Los valores máximos de lluvia diaria sobre Costa Rica fueron cerca de 150 mm.

Se discute también la modificación del entorno por la ocurrencia del *temporal*. Cortes transversales verticales durante el *temporal* muestran que un enfriamiento debajo de aproximadamente 600 hPa y un calentamiento sobre este nivel tuvieron lugar. Se observó un incremento grande de humedad y el grosor de la capa convectiva y condicionalmente inestable sobre la superficie decreció durante el *temporal*.

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