The Midsummer Drought over Mexico and Central America

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ABSTRACT

The annual cycle of precipitation over the southern part of Mexico and Central America exhibits a bimodal distribution with maxima during June and September–October and a relative minimum during July and August, known as the midsummer drought (MSD). The MSD is not associated with the meridional migration of the intertropical convergence zone (ITCZ) and its double crossing over Central America but rather with fluctuations in the intensity and location of the eastern Pacific ITCZ. During the transition from intense to weak (weak to intense) convective activity, the trade winds over the Caribbean strengthen (weaken). Such acceleration in the trade winds is part of the dynamic response of the low-level atmosphere to the magnitude of the convective forcing in the ITCZ. The intensification of the trade winds during July and August and the orographic forcing of the mountains over most of Central America result in maximum precipitation along the Caribbean coast and minimum precipitation along the Pacific coast of Central America.

Changes in the divergent (convergent) low-level winds over the ''warm pool'' off the west coast of southern Mexico and Central America determine the evolution of the MSD. Maximum deep convective activity over the northern equatorial eastern Pacific, during the onset of the summer rainy season, is reached when sea surface temperatures exceed 29°C (around May). After this, the SSTs over the eastern Pacific warm pool decrease around 1°C due to diminished downwelling solar radiation and stronger easterly winds (during July and August). Such SST changes near 28°C result in an substantial decrease in deep convective activity, associated with the nonlinear interaction between SST and deep tropical convection. Decreased deep tropical convection allows increased downwelling solar radiation and a slight increase in SSTs, which reach a second maximum (~28.5°C) by the end of August and early September. This increase in SST results once again in stronger low-level convergence, enhanced deep convection, and, consequently, in a second maximum in precipitation.

The MSD signal can also be detected in other variables such as minimum and maximum surface temperature and even in tropical cyclone activity over the eastern Pacific.

1. Introduction

The annual cycle in the climate of the Northern Hemisphere tropical Americas is characterized by minor fluctuations in surface temperature, but a well-defined rainy period exists during the months of May through October (Hastenrath 1967). In this region, many economic activities, especially those related to agriculture and hydropower generation, are linked to the seasonal cycle of precipitation. The success or failure of a crop depends on the characteristics of the rainy season (onset, length, temporal distribution, etc.) in rainfed areas. In order to define normal or anomalous rainy seasons, that is, the interannual variability in precipitation, it is necessary to precisely describe the regional annual cycle and examine the mechanisms that control it.

The summer rainy season over the central–southern part of Mexico, most of Central America, and parts of the Caribbean is characterized by a bimodal distribution in precipitation, with maxima in June and September–October and a relative minimum during July–August (Mosiño and García 1966; Coen 1973). According to Hastenrath (1967), copious precipitation over Central America and the Caribbean occurs during May and June, with an abrupt change around late June, and with July and August being drier and less cloudy. This relative

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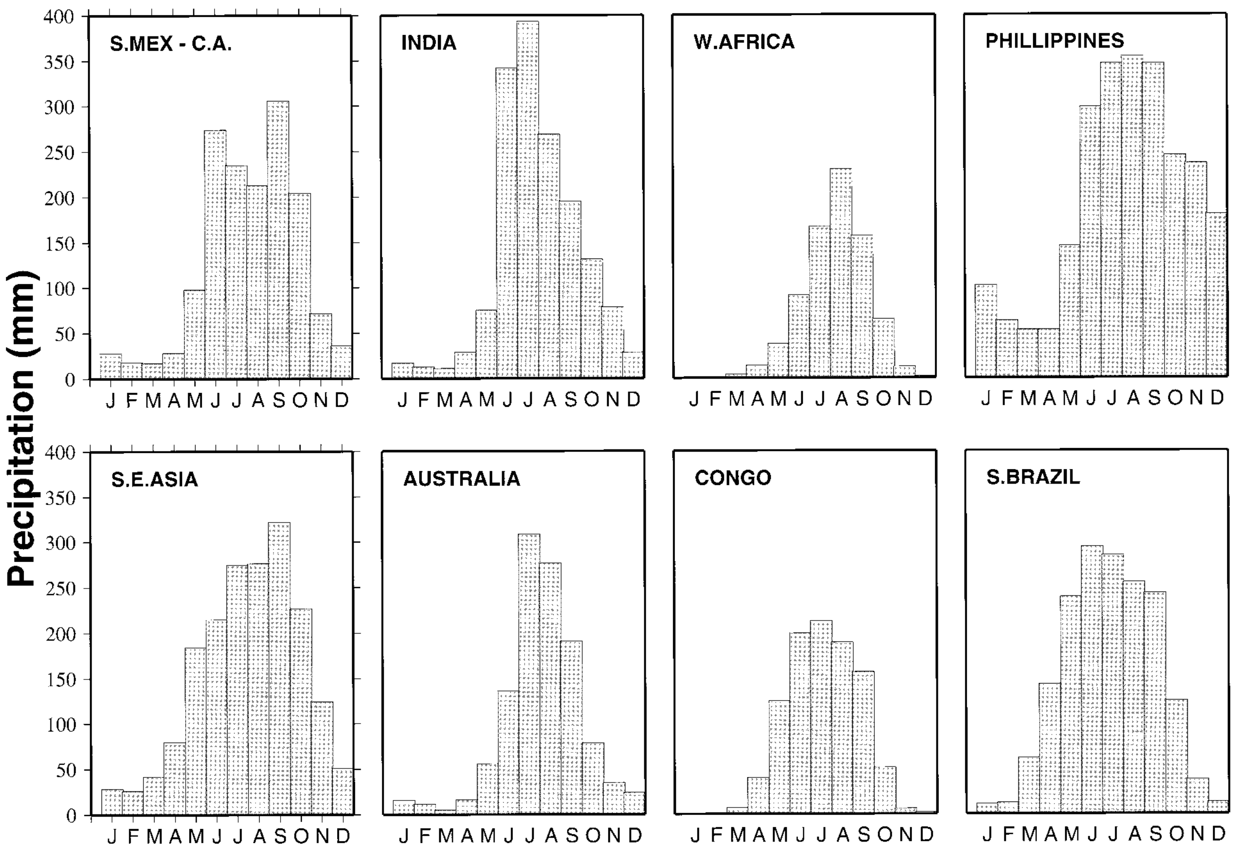

FIG. 1. Precipitation climatology at various regions: south Mexico and Central America (10°–20°N, 260°–280°E), India (10°–20°N, 70°–90°E), West Africa (10°–20°N, 350°–10°E), the Philippines (10°–20°N, 110°–130°E), southeast Asia (10°–20°N, 90°–110°E), Australia (10°–20°S, 120°–140°E), Congo (10°–20°S, 20°–40°E), and south Brazil (10°–20°S, 300°–320°E). Data from Legates and Willmott (1990).

minimum in convective activity and precipitation is known as the midsummer drought (MSD), ''canicula'' or ''veranillo,'' depending on the region where it is experienced. This temporal behavior in precipitation has been known for a long time but has never been explained.

Bimodal seasonal cycles in precipitation have also been detected at other latitudes, as in the upper midwest of the United States, where the annual march of precipitation is characterized by maxima during June and September and a relative minimum during July and August. Several mechanisms have been put forward by Keables (1989) to explain this bimodal structure of precipitation, including changes in midtropospheric circulations such as well as tropical cyclone activity over the Gulf of Mexico. Some regions near equatorial latitudes, such as the southern Sahel and some parts of the Amazon Basin, also exhibit bimodal distributions in precipitation (Hartmann 1993). In both of these regions, the meridional migration of the ITCZ, with the heaviest precipitation following the solar declination angle into the Summer Hemisphere, leads to a double maximum in precipitation. In the Tropics, but away from the equator (10°–20° of latitude), it is only in southern Mexico, Central America, and parts of the Caribbean where a bimodal structure in precipitation is observed (Fig. 1). Most other regions at these latitudes exhibit a single maximum in summer precipitation. As shown by Mosiño and García (1966), the signal of the MSD can be detected as far north as 20°N where the ITCZ does not cross twice (Waliser and Gautier 1993), ruling out this hypothesis.

Studies on the dynamics of the MSD are relatively scarce. Mosiño and García (1966) quantified the geographic and temporal distribution of the MSD and proposed that changes in the atmospheric circulation and ocean conditions control this phenomenon. They suggest that during July and August, a surface high pressure system over the southeastern United States, combined with a cyclonic circulation at midatmospheric levels over the Gulf of Mexico, produces northerly dry winds that lead to the occurrence of the MSD over south-central Mexico. However, no such circulation has been observed as a climatologically stationary feature. The only cyclonic circulations observed over the Gulf of Mexico correspond to tropical cyclones, which are only transient circulations. Other theories to explain the dynamics of the MSD, such as changes in the circulation regimes, or hurricane activity in the eastern Pacific or the Gulf of Mexico, are yet to be explored.

Grandoso et al. (1982) found that, as the easterly winds intensify during July and August, precipitation increases on the Caribbean side of Central America and decreases over the Pacific coast. Such a feature reflects the regional characteristics of precipitation and its variability in relationship to the MSD.

In recent years, the interest in predicting convective activity anomalies has increased. The study of forms of interannual climate variability, such as the El Niño–Southern Oscillation (ENSO), requires an adequate description of the annual cycle in precipitation. Therefore, in the present study we will concentrate on examining the characteristics of the MSD as a unique feature of the annual cycle of summer precipitation over Mexico and Central America. We propose a mechanism to explain the dynamics of this phenomenon that involves atmosphere–ocean–land processes.

In section 2, the data used for the analysis will be described. In section 3, the MSD in various meteorological parameters is documented. Here, we also analyze and discuss the dynamical mechanisms that control the MSD. Summary and conclusions are given in section 4.

2. Data

Given the nature of the present study, mainly corresponding to a description of precipitation in a region where mesoscale orographic features are important, a high spatial resolution precipitation dataset is necessary. This dataset should also have temporal resolution higher than monthly means, so that the beginning and end of the MSD may be established. A 1° latitude–longitude daily precipitation dataset has been developed based on station data and satellite estimates. The precipitation station data comprise data (i) from the archives of the National Center for Atmospheric Research (NCAR) for the southern United States, northern South America, and the Caribbean Islands; (ii) compiled by the Mexican Weather Service, and (iii) for Central America from the National Weather Services. The daily precipitation data correspond to the period 1979–93. The record length for station data varies. Data spanning for a period of at least 10 yr have been considered, resulting in more than 300 stations used in the analysis.

Microwave sounding unit (MSU) daily precipitation estimates over the oceans, obtained by Spencer (1993), have also been used. These are gridded data with a 2.5° latitude–longitude spatial resolution for the period 1979–96.

Precipitation station data and satellite estimates for the ocean were blended to create a $1° \times 1°$ gridded dataset through cubic spline spatial interpolation, using a minimum curvature gridding method (Smith and Wessel 1990). This algorithm includes a tension factor to eliminate extraneous inflection points. Daily precipitation fields were obtained for the domain 0°–35°N, 140°–60°W, for the period 1 January 1979–31 December 1993. Monthly climatological means from these data were computed and compared with those from Legates and Willmott (1990). The two analyses differ by less than 20% over most of the domain except over some oceanic regions, where MSU estimates were used. The low spatial resolution of precipitation estimates over the ocean make the data smoother over these regions than over the continent.

Global tropospheric daily analyses of wind, temperature, radiation, and other meteorological variables were obtained from the National Centers for Environmental Prediction–NCAR reanalysis data (Kalnay and Jenne 1991). These data are given on a 2.5° latitude–longitude grid at 12 vertical levels for the same period for which precipitation data were prepared. Weekly sea surface temperature (SST) analyses with a 2.5° latitude–longitude spatial resolution (Reynolds and Smith 1994) for the period 1982–94 were employed.

Finally, tropical cyclone data (location, intensity, etc.) for the eastern Pacific, the Caribbean, and the Gulf of Mexico for the period 1953–95 were obtained from the data archives of the Mexican Ministry of Water and Agriculture and the University of Hawaii.

After trying various temporal averages in precipitation, it was determined that biweekly averages are the most appropriate to study the MSD. Resolution higher than a week makes the identification of the MSD difficult, while monthly means do not allow a proper determination of the onset and end of this phenomenon. Throughout this work, biweekly data means will be used.

3. The MSD over Mexico and Central America

a. Changes in precipitation

As previously described, precipitation over Mexico and Central America exhibits maxima during June and September–October and a relative minimum during July and August. Minimum and maximum temperatures also show a bimodal distribution during summer, related to the MSD. Time series of climatological rainfall and surface temperature for Oaxaca, Mexico (17°N, 97°W), are presented in Fig. 2. Changes in cloudiness and solar radiation modulate surface temperature. By April and May the maximum temperature is above 30°C, leading to the onset of the rainy season. As cloudiness increases, solar radiation at the surface diminishes, and the maximum temperature drops below 28°C. The increase in moisture during May and June maintains relatively high minimum temperatures (~16°C). As precipitation decreases during July and August, maximum temperature raises to almost 28°C. This relative minimum in cloudiness and precipitation during August coincides with a relative maximum in maximum temperature and a relative minimum in minimum temperature. As convective activity and precipitation increase during September, so

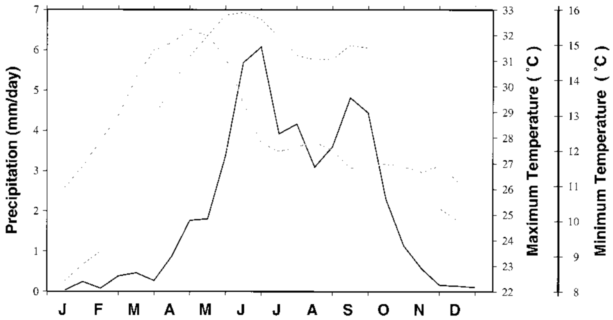

FIG. 2. Precipitation (black solid line), maximum temperature (gray solid line), and minimum temperature (dotted line) biweekly climatologies for Oaxaca, Mexico (17°N, 97°W).

does the minimum temperature, while maximum temperature drops below 27°C.

The climatological mean June–September precipitation shows a broad band of maximum precipitation (in excess 1000 of mm) corresponding to the ITCZ over the eastern Pacific warm pool (Fig. 3). The precipitation pattern associated with the Mexican monsoon over northwestern Mexico may be observed, too. Other precipitation maxima appear over Central America related to small-scale orographic features.

The temporal distribution of biweekly precipitation rates over Mexico, Central America, and the Caribbean for contiguous 5° × 5° areas is presented in Fig. 4. The signal of the MSD extends from northeastern Mexico to Central America. Although there is some indication of a double maximum in precipitation over the Caribbean, the MSD is more clearly defined over southwestern Mexico, Central America, and the eastern Pacific warm pool, where the ITCZ is active during summer. While maxima in precipitation over the Caribbean occur mainly during April and October, the maxima over the MSD region occur during June and September. The signal of the MSD is also clear over the ocean. On the other hand, over northwestern Mexico, there is no indication of an MSD, showing that this phenomenon is dynamically independent of the Mexican monsoon.

It should be emphasized that the MSD does not correspond to an actual drought period but rather to a decrease in the amount of rain. The MSD is part of the annual cycle of precipitation. Even after averaging more than 30 yr of station data, its signal is still present. The meridional extent of the MSD, plus its simultaneous occurrence in separate locations, such as southern Mexico and Nicaragua (Fig. 5), rule out the possibility that the MSD is due to the double crossing of the ITCZ. The coherence of the MSD at these two locations, approximately 5° apart in latitude, may be observed by comparing their histograms and determining the occurrence of maxima and minima in precipitation in individual years. The onset of the rainy season generally takes place during May and reaches a maximum by late June,

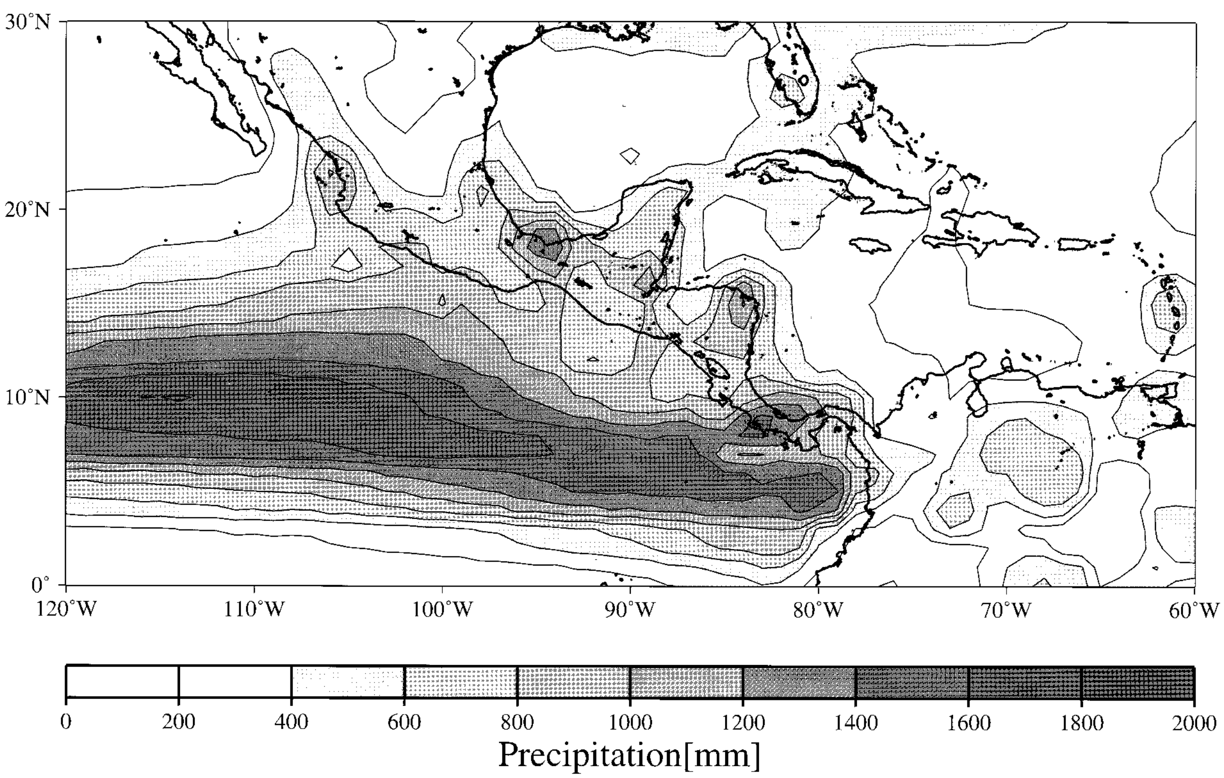

FIG. 3. Climatological precipitation (mm) (1979–95) for Jun–Sep.

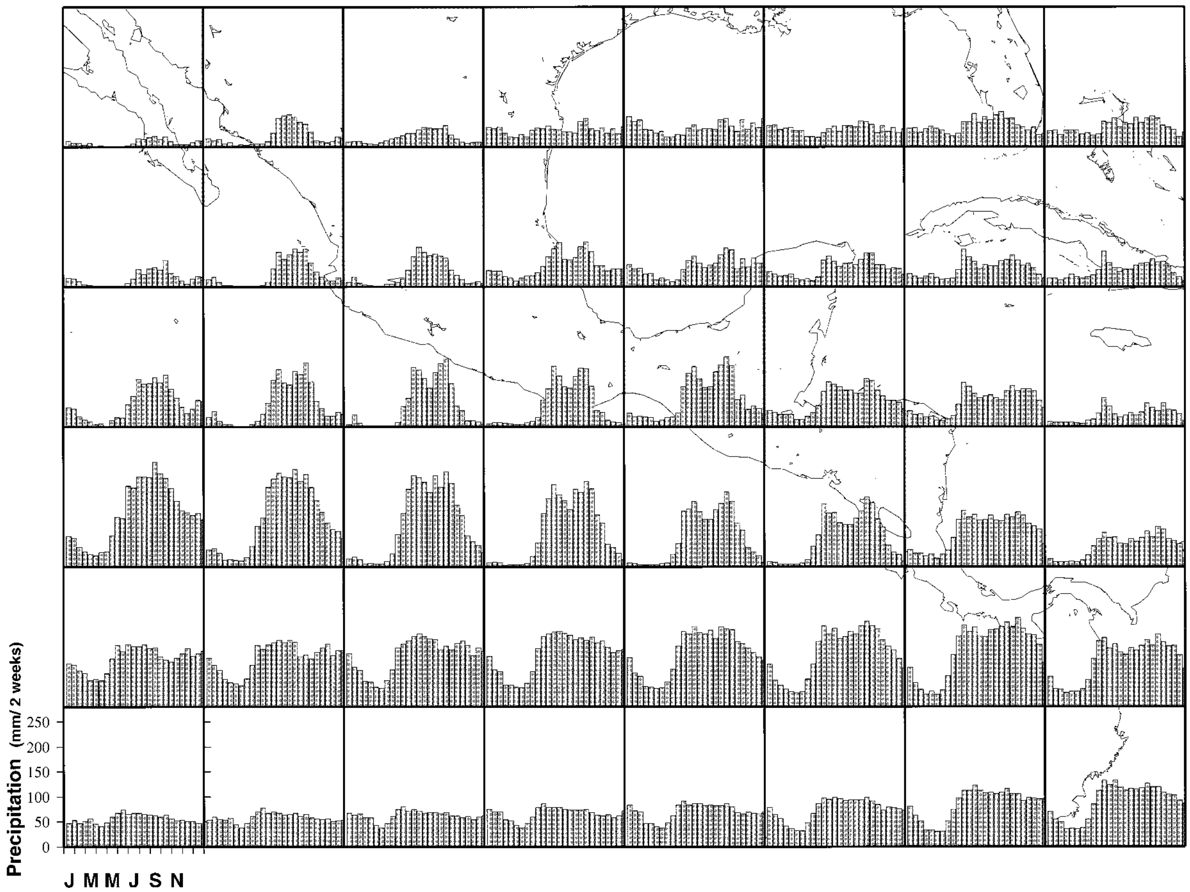

FIG. 4. Climatological distribution of biweekly precipitation rates [mm (2 weeks)$^{-1}$] for contiguous 5° × 5° areas.

after which a decrease in precipitation occurs. Precipitation increases once again by late August reaching a maximum in late September and decreasing by late October or the beginning of November. In some years, such as 1980 or 1985, the MSD is hard to define, while in years like 1988 or 1991 it is clearly identifiable. The magnitude of the MSD is also highly variable, even though there is not a standard measure for it.

The regions where the most drastic changes in precipitation occur, in relation to the onset and end of the rainy season and the MSD, may be determined by constructing composites of changes in precipitation during transition periods. So the beginning of the rainy season, the onset of the MSD, and the end of the MSD may be used as key events in the summer rains cycle. As an index of reference, the area-average precipitation over Mexico and Nicaragua was used. The dates for the beginning and end of the MSD were subjectively selected from Fig. 5. The composites correspond to changes between two consecutive biweekly periods.

Composites for precipitation show that the region where the largest changes take place, in relation to the MSD, are located along the western coast of Mexico and Central America, where the eastern Pacific warm pool and the ITCZ form during summer (Fig. 6). This composite shows that it is changes in the activity of the eastern Pacific ITCZ, over the region of sea surface temperature between 28° and 29°C, where the signal of the MSD is stronger (Fig. 7).

b. The trade winds

During summer, easterly low-level winds extend from the Caribbean Sea to the eastern Pacific (Fig. 7). Grandoso et al. (1982) proposed that changes in the intensity of the trade winds over the Caribbean are associated with the MSD. Based on the previous composite index for biweekly precipitation changes, composites for the changes in lower-tropospheric (925 hPa) winds during transitions have been constructed (Fig. 8). The composite fields for the acceleration of the flow between two biweek periods during the onset and the end of the MSD show that the most drastic changes in the trade wind field occur over southern Mexico and Central America. During the onset, the trade winds intensify along with the formation of an anticyclonic circulation over the western coast of Mexico. During the end of the MSD the trade winds weaken, in relation to the

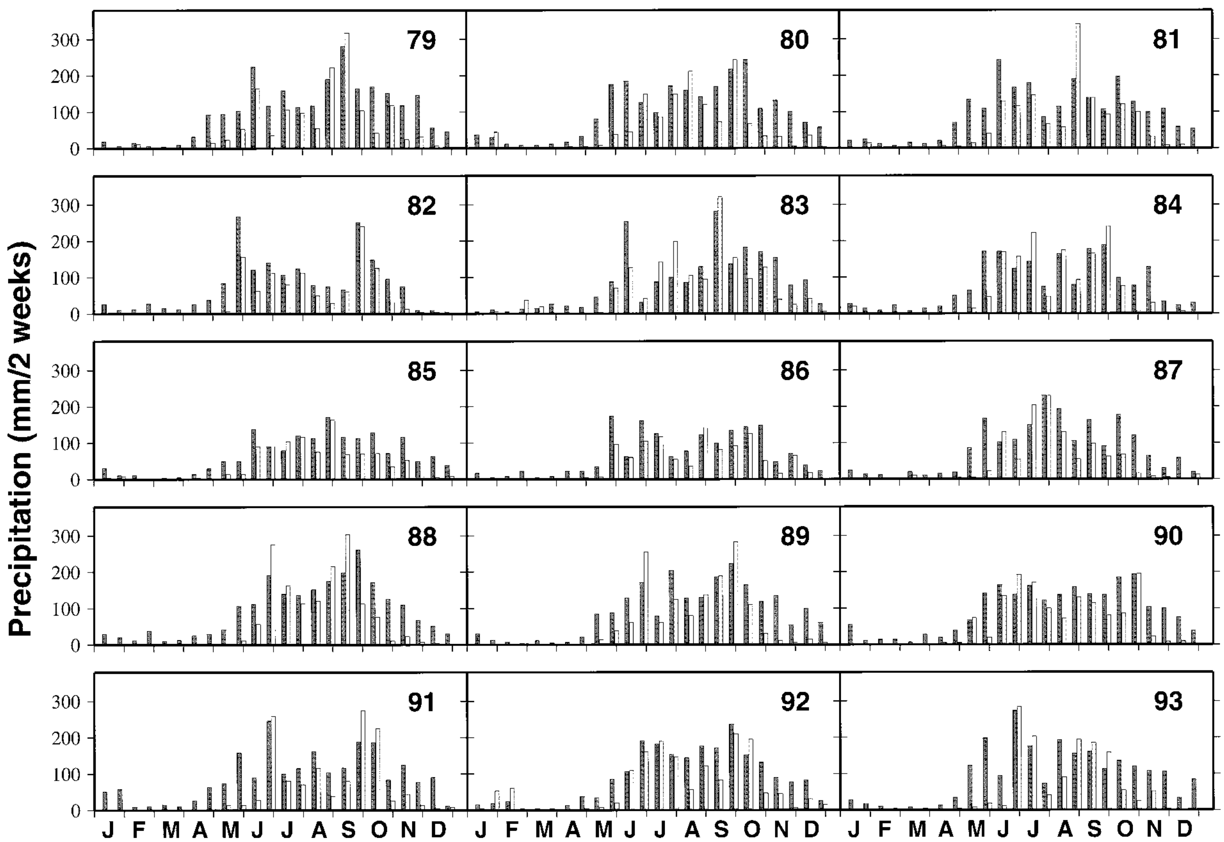

FIG. 5. Biweekly distribution of precipitation rates [mm (2 weeks)$^{-1}$] for 5° × 5° subdomains centered on 17.5°N, 97.5°W (light bars) and 12.5°N, 87.5°W (dark bars).

appearance of cyclonic circulations straddling the southern-central part of Mexico. Fluctuations in the trade wind intensity extend from the surface up to around 700 hPa (not shown). The anticyclonic and cyclonic anomalies that are established during July, August and September resemble the lower-tropospheric circulation anomalies associated with a tropical convective forcing around the eastern Pacific. According to Gill (1980), when a thermal (convective) forcing is set slightly north of the equator, the response in the lower levels corresponds to a cyclone, northwest of the forcing. Considering that Gill's model is linear, a decrease in the intensity of the forcing would result in a less intense cyclonic circulation. The transition into the MSD, in terms of tropical convection and precipitation, reflects as a weaker cyclonic circulation. So the transition pattern corresponds to an anticyclonic acceleration northwest of the center of maximum convective activity. A similar reasoning may be applied to understand the appearance of an anticyclonic acceleration during the transition from the MSD into a period of intense convective activity in the eastern Pacific ITCZ.

These changes in the intensity of the trade winds are reflected in the local characteristics of precipitation, especially over Central America, where the orographic barrier imprints a distinctive signal on the summer rains. Over the Caribbean side, strong trade winds combined with the orographic barrier lead to enhanced ascending motion and intense convective activity and precipitation. On the other hand, strong subsidence on the Pacific side results in a decrease in both convective activity and precipitation. Histograms of the climatological monthly precipitation in stations along the Caribbean and the Pacific coast of Central America show that during July and August, when the MSD takes place on the Pacific side, precipitation is at a maximum along the Caribbean coast of Central America (Fig. 9).

The relationship between the intensity of the trade winds and the ITCZ activity may be more clearly identified when composites of the divergent component of the 925-hPa wind are constructed (Fig. 10). During the establishment of the MSD, the low-level winds show a divergent anomaly over the MSD region, while a convergent anomaly appears ~5° to the south. The result is a weakening in low-level convergence, a decrease in deep convection, and less precipitation. During the transition from the end of the MSD into an active tropical convection period, convergence over the Pacific coast enhances, leading to an intensification of the ITCZ and more precipitation.

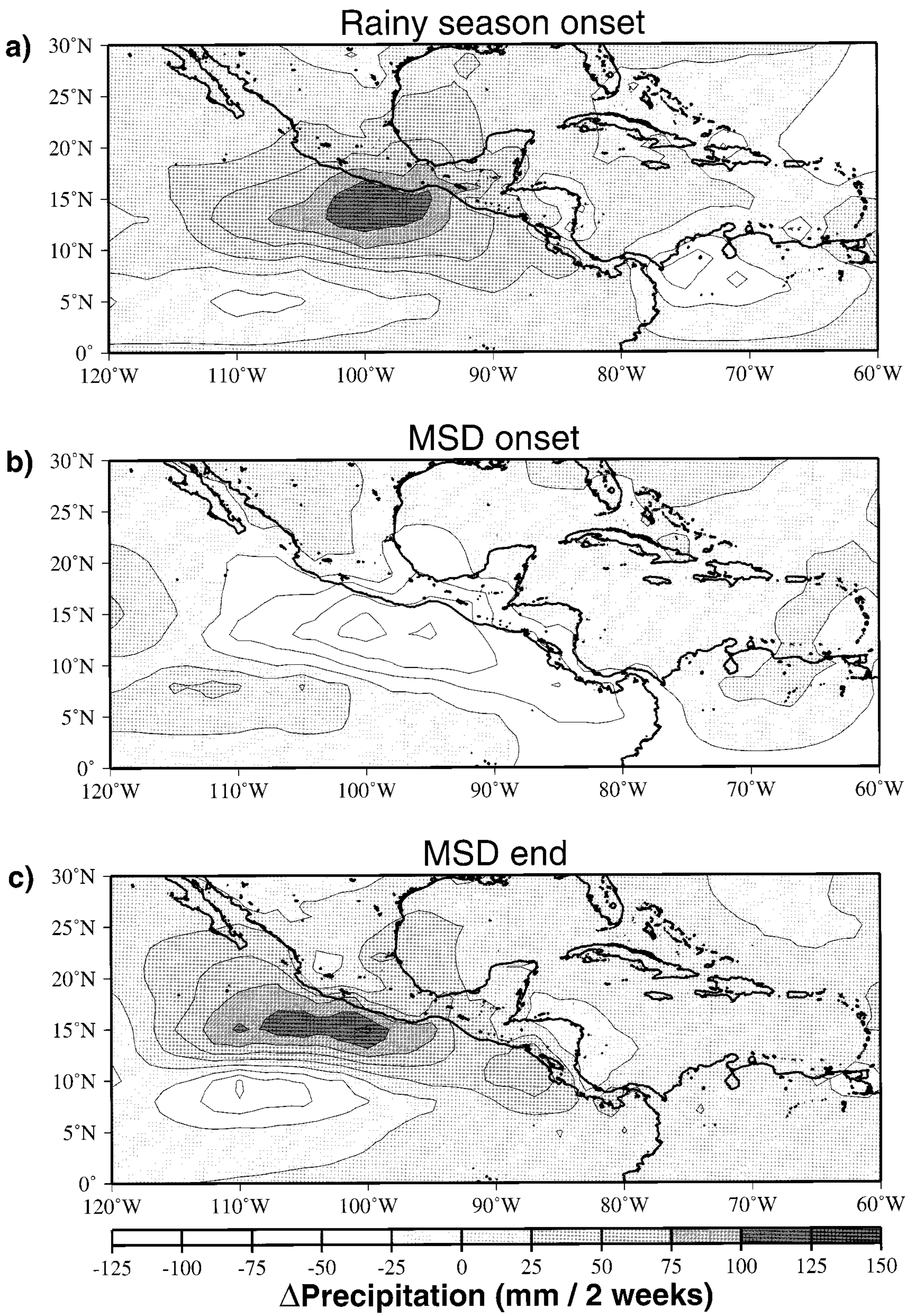

FIG. 6. Composite patterns for precipitation changes between two biweekly periods during (a) the onset of the rainy season, (b) the onset of the MSD, and (c) the end of the MSD.

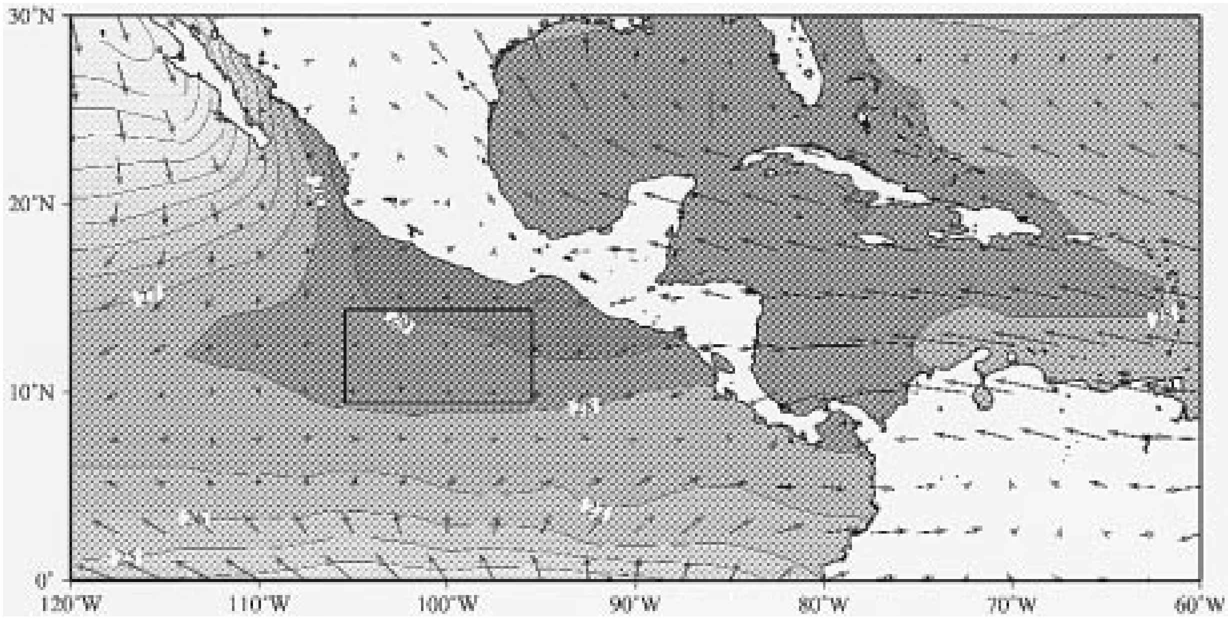

FIG. 7. The 925-hPa wind and SST (°C) climatologies for Jun–Sep.

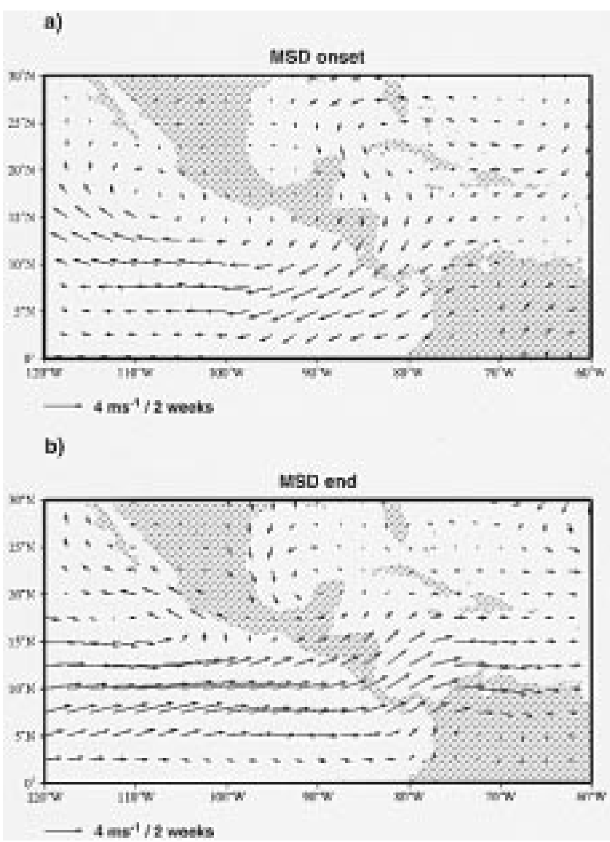

FIG. 8. Composite patterns for 925-hPa wind changes between two biweekly periods during (a) the onset of MSD, and (b) the end of the MSD.

Lindzen and Nigam (1987) suggested that the convergent airflow over tropical oceans is largely determined by the distribution of SST over those regions. They concluded that the SSTs, along with their gradients, constitute an important forcing of the low-level tropical flow and wind convergence. It appears that such an effect may be important over the eastern Pacific warm pool, affecting the intensity of the convergent flow.

c. Sea surface temperature

Over the eastern Pacific warm pool, off the coast of Mexico and Central America, the SSTs may experience large changes in response to intense low-level winds. For instance, the occurrence of ''Tehuantepecers'' during winter (Lavín et al. 1996) may lead to changes in SSTs over the Gulf of Tehuantepec as large as 8°C.

During summer, the trade winds, evaporation, and precipitation over the warm pool region modulate the SST. Weekly SST values over the eastern Pacific warm pool exhibit fluctuations that appear to be related to the MSD (Fig. 11). During April and May, the SSTs increase, reaching a maximum ($>$29°C) by mid- or late June, leading to the onset of the rainy season. As convective activity in the ITCZ increases and the trade winds intensify, the SSTs begin to lower. A decrease of the order of 1°C may occur during July or August. During late August and early September, the SSTs slightly increase ($\sim$0.5°C), decreasing once again by October. Sometimes, a third relative maximum in SSTs is reached by November, which does not always lead to deep convective activity.

According to Zhang (1993), small SST anomalies in regions of warm water (SST $>$ 27°C) may lead to large

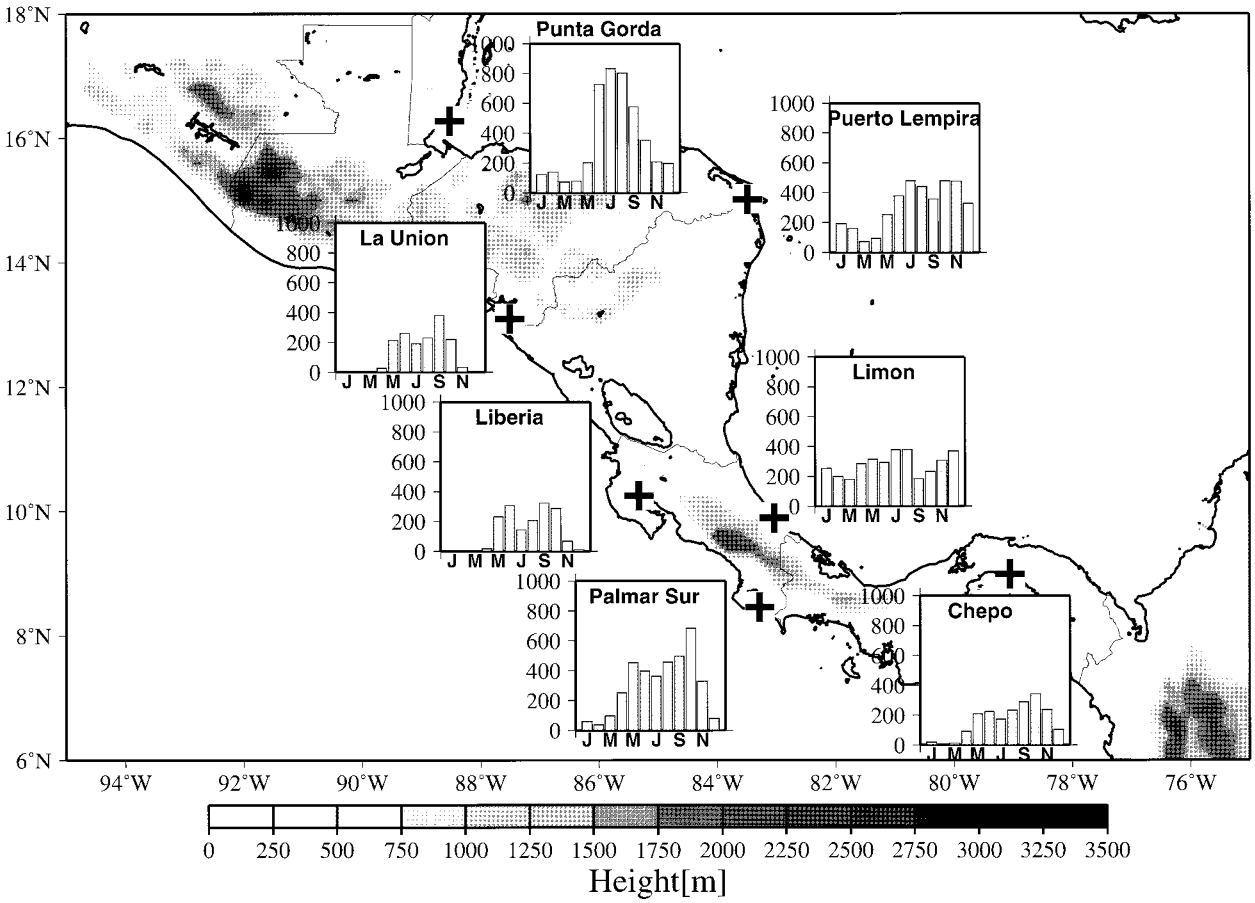

FIG. 9. Central American topography and monthly precipitation (mm) climatologies for stations along the Caribbean and the Pacific coast.

changes in deep tropical convective activity. The nonlinear nature between SSTs and deep convection, related to the Clausius–Clapyron equation, suggests that substantial changes in tropical convection occur when SSTs increase over warm pools (Webster 1994). Deep convection tends to be more intense and frequent for high SSTs. In the eastern Pacific warm pool, periods with SSTs higher than 29°C generally correspond to heavy precipitation and deep convective activity. Periods of SSTs around 28°C or less are associated with the MSD occurrence, suggesting that large-scale dynamics (moisture convergence) in addition to high SSTs are important in the maintenance of deep convection in the ITCZ over the eastern Pacific.

In the eastern tropical Pacific, changes in solar radiation result in changes in SSTs after a week or less (Fig. 12). Periods of low SSTs correspond to decreased deep convection and to more solar radiation reaching the surface. A more active ITCZ, in terms of spatial coverage or cloud thickness, leads to diminished solar radiation, cooler SST, and less tropical convection in the ITCZ. Over land, solar radiation is also augmented during the MSD, leading to higher maximum temperatures (Fig. 2). It appears, however, that dynamical effects also play a role in modulating the SST changes. In particular, the increase in low-level easterlies associated with the MSD may lead to enhanced mixing of the upper ocean and a decrease in SST.

In summary, the modulation in convective activity appears to be closely related to low-level wind convergence, which is in turn related to the SST gradients in the eastern Pacific warm pool. The SSTs over this region are strongly influenced by the amount of solar radiation that reaches the surface and low-level winds. On the other hand, radiation depends on the spatial density and depth of tropical convective activity.

d. Tropical cyclone activity

Low-level convergence over the eastern Pacific warm pool acts as a modulator of processes that involve deep convective activity such as hurricanes. The eastern Pacific is a region of strong hurricane genesis during summer. Changes in low-level convergence during the MSD appear to affect the number of hurricanes that form in that region during July and August. Figure 13 corresponds to the number of hurricanes that formed over the MSD region during the period 1954–93. This his-

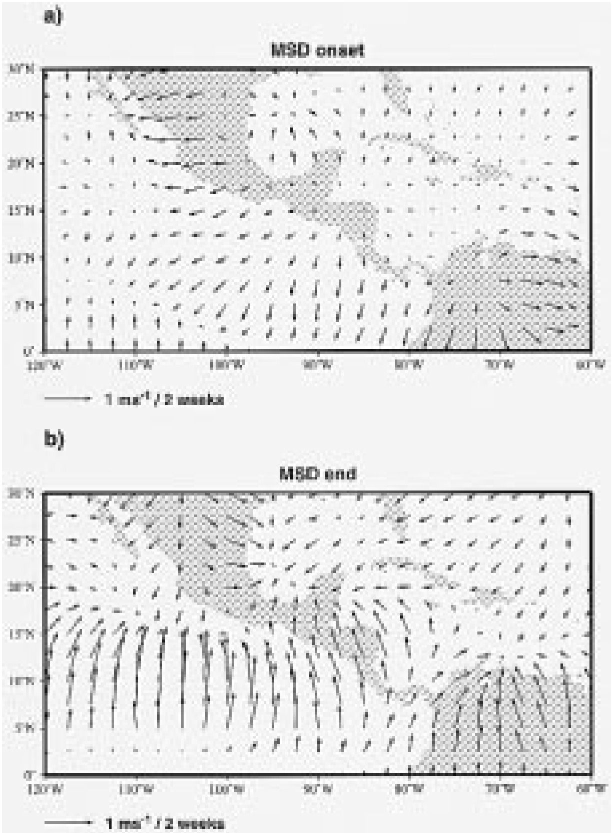

FIG. 10. As in Fig. 8 but for 925-hPa divergent wind changes.

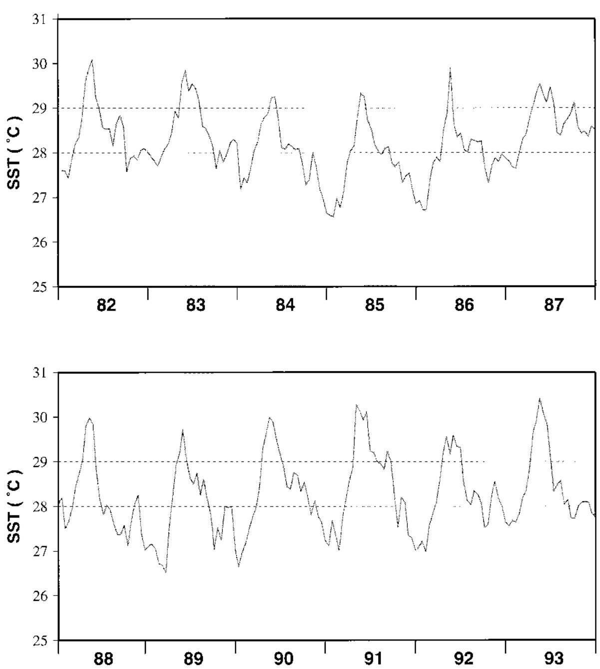

FIG. 11. Weekly SST averaged for the domain (10°–15°N, 105°–95°W) for the 1982–93 period. The gray bars denote the Jun–Sep period.

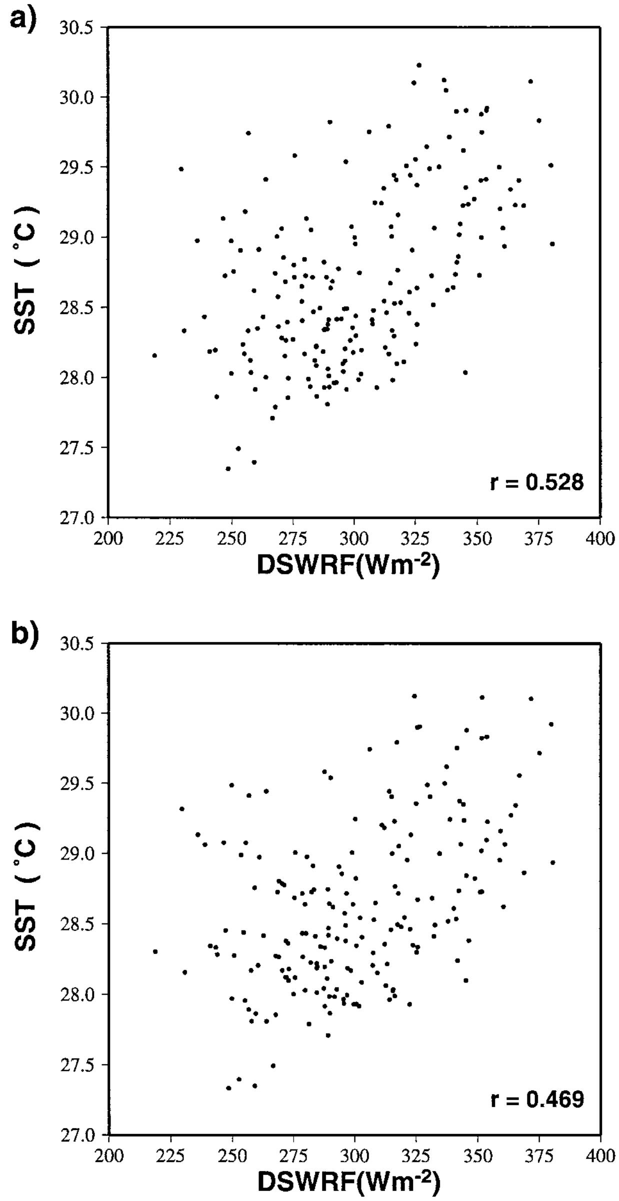

FIG. 12. Dispersion diagram between SST (°C) and downwelling solar radiation (W m^{-2}) over the eastern Pacific warm pool: (a) 0-lag, and (b) solar radiation leading by one week.

togram shows a relative minimum in the number of hurricanes during late July and early August, which appears to be related to the minimum in deep convective activity during the MSD. There seems to be no indication of a similar minimum in hurricane activity over the Gulf of Mexico and the Caribbean Sea (not shown).

4. Discussion and conclusions

The MSD is part of the seasonal cycle and the evolution of the summer rainy season over south-central Mexico, Central America, and parts of the Caribbean.

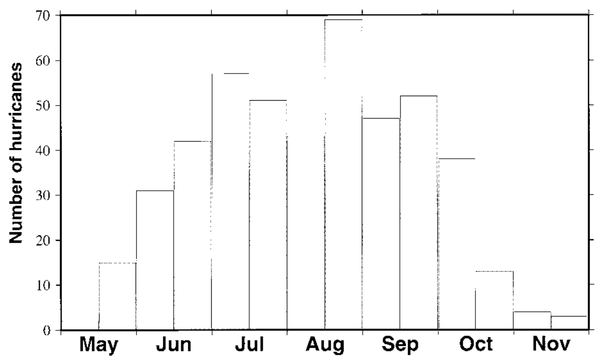

FIG. 13. Biweekly hurricane distribution from 1954 to 1993 over the eastern Pacific warm pool.

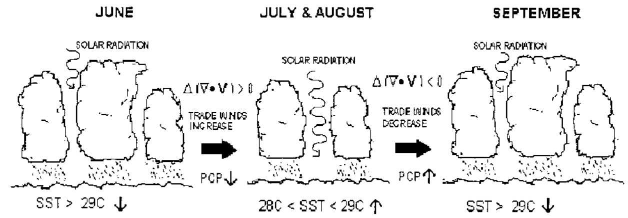

FIG. 14. Schematic diagram of the dynamics of the MSD.

Some theories suggest that the MSD is related to the meridional migration of the ITCZ and its double crossing over Central America and the Caribbean. However, this mechanism cannot explain the occurrence of the MSD at latitudes higher than 10°N nor the simultaneous onset and end of it over a broad latitude band. On the other hand, the hypothesis that lower tropospheric cyclonic circulations over the Gulf of Mexico advect dry air into southern Mexico does not seem to hold either, since atmospheric circulations of this kind, such as tropical cyclones, are only transient.

In the Tropics, surface heating results in a transfer of heat to the air, mean upward motion, and convergence of moist, low-level air in the ITCZ. The seasonal migration of the ITCZ to the north manifests itself as a broad area of tropical convection over the eastern Pacific warm pool. As the rainy season begins during May and early June, intense deep convection develops along with a subtropical lower-tropospheric cyclonic circulation anomaly over the subtropics. This circulation corresponds to the stationary pattern associated with intense convective heating off the equator (Gill 1980). As convective activity diminishes during July and August, this cyclonic circulation weakens, corresponding to an anticyclonic acceleration of the low-level flow and, therefore, to an intensification of the trade winds over Central America (Figs. 8 and 14a), when the MSD occurs. This change in the low-level winds leads to the formation of divergent anomalies that inhibit deep convective activity over the eastern Pacific warm pool. The strengthening of the easterlies forms a low-level jet that extends up to 700 hPa that forces ascending motion and intense precipitation over the Caribbean side of Central America (Fig. 9) and subsidence and clear skies on the Pacific side.

During the active convection phase of the summer rainy season, shortwave radiation reaching the surface diminishes due to the blocking effect of deep clouds. Less solar heating and enhanced evaporation, by stronger easterlies over the warm pool, lead to a decrease in SSTs of the order of a degree by July and August, with SST $\sim$ 28°C (Fig. 14b). Large changes in deep convective activity may relate to fluctuations in SST near 28°C. When the MSD establishes, an anomalous divergent circulation sets over the warm pool. During late July and August there are fewer deep clouds and more incoming solar radiation reaching the eastern Pacific warm pool region, resulting in SST $>$ 28°C. By this time, weakened trade winds and a convergent low-level anomaly lead to enhanced deep convection and a second maximum in precipitation over southern Mexico and the Pacific coast of Central America (Fig. 14c).

It is the fluctuations in the low-level convergent flow, along with the seasonal fluctuations in the SST, modulated by the trade winds and radiation, that act together to produce a bimodal distribution of precipitation during the summer season. In principle, this mechanism might be applicable to other warm pool tropical regions; however, no such bimodal structure has been observed elsewhere. It is yet to be explored why precipitation in the eastern Pacific warm pool exhibits such characteristic structure during summer. Therefore, it is still necessary to determine the timescales involved in the cooling and warming of the SST, its mixed layer, and the corresponding fluctuations in convective activity. Changes in SSTs on various timescales depend, among other things, on the intensity of the surface winds, the dynamics of the ocean mixed layer, precipitation, and the intensity of radiation (Webster 1994). In each case boundary layer processes should be analyzed to understand the connection between all of these elements.

The physical processes proposed to explain the MSD apply to intraseasonal fluctuations in precipitation over southern Mexico and Central America. It is not clear if this mechanism is also responsible for the MSD signal detected over the Caribbean maritime continent. Changes in surface temperature during the MSD, over some continental areas, are determined by the interaction between radiation and clouds. These interactions are clearly reflected in minimum and maximum temperatures over the continent.

It is not yet clear what the relationship between phenomena such as El Niño and the MSD is. The southward displacement that the ITCZ experiences in the eastern Pacific during El Niño years (Walisser and Gautier 1993) and the decrease of low-level moisture convergence over the warm pool (Magaña and Quintanar 1997) influence the intensity of convective activity, leading to an actual drought during summer. However, our precipitation data show that the MSD appears either during El Niño or La Niña years.

Given the socioeconomical importance of the MSD, further analyses are required in order to develop a prediction scheme to determine its onset, intensity, and length.

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