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Cambios intraestacionales en la circulación regional sobre México

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Resumen. Se describen los cambios intraestacionales de la circulación regional en México mediante el análisis de valores medios para cinco días en los campos de viento, temperatura y alturas geopotenciales, extraídos de los análisis operativos a escala global del *European Centre for Medium-range Weather Forecast* (ECMWF). Para mostrar aspectos del desarrollo de la estación de lluvias, datos de radiación saliente de onda larga (RSOL) son sobrepuestos a los campos de viento en 200hPa. Cambios en la circulación de niveles bajos son consistentes con la evolución de la estación de lluvias sobre México. En la alta troposfera, el alta de México se desarrolla rápidamente sobre el Pacífico oriental cerca de Guatemala durante la fase de inicio de la estación de lluvias en América Central y sur de México. El desplazamiento de este sistema al norte del país es temporal y espacialmente consistente con la distribución de la actividad convectiva sobre México.

Palabras clave: RSOL, actividad convectiva, monzón mexicano.

Intraseasonal changes in the regional circulation over Mexico

Abstract. Intraseasonal changes in the regional circulation over Mexico are described by means of 5-day averaged data extracted from the operational analyses of the European Centre for Medium-range Weather Forecast (ECMWF). OLR fields are superimposed upon 200 hPa winds to illustrate features of the convective activity over the studied region. Changes in the low-level circulation over the Caribbean and the eastern North Pacific, explain variations in the evolution of the rainy season over Mexico. In the upper troposphere, the Mexican High, as delineated from the ECMWF data, develops rapidly in the eastern Pacific close to Guatemala during the onset phase of the rainy season in Central America and southern Mexico. The northward movement of this system is temporally and spatially consistent with the distribution of low OLR over Mexico.

Key words: OLR, convective activity, Mexican monsoon, Mexican high.

INTRODUCTION

The onset of the summer rainfalls in Mexico has been traditionally linked with changes in the trade winds. As the boreal summer approaches, the easterly current builds up into higher levels and moves toward higher latitudes and the entire country comes under the influence of a deep, wide easterly flow which penetrates Mexico with generally light but moist winds (Mosiño and García, 1974).

Recently, more attention has been paid to the circulation over the eastern Pacific and its influence on precipitation over Mexico. For example, Reyes and Cadet (1986, 1988) suggest that the intensification of the South Pacific high propels a low-level moisture flux across the equator toward western Mexico. Douglas *et al.* (1993) propose that both the eastern Pacific and the Gulf of California play an important role as sources of moisture, which is transported by the time-mean low-level circulation into western Mexico. Schmitz and Mullen (1996) have further analyzed the importance of the Gulf of Mexico, the Gulf of California, and the eastern tropical Pacific as moisture sources for the Sonoran Desert region during the period from July to September. They suggest the northern Gulf of California as a major source of low-level moisture, with significant

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contributions from the Gulf of Mexico at the upper-levels.

Since previous authors have focused on the mechanisms responsible for the transport of moisture mainly into northwest Mexico, their analyses do not treat aspects related to the process of seasonal changes and intraseasonal variations in the regional circulations. Consequently, details of the transition process with a temporal resolution of less than one month have not been precisely described. The present study is an extension of Cortez-Vázquez (2000), and its primary purpose is to further analyze variations in the mean circulation patterns over Mexico using 5-day averaged data. Although the entire year is considered, special attention is given to the rainy season. Conditions associated with the onset and demise of the wet season are also examined.

The area of study extends from the East Pacific (140° W) to the Atlantic Ocean (60° W), and from 40° N to 10° S (see Figure 1 for geographical reference). This broad area is included in order to evaluate the influence of such regional circulation systems as the subtropical North Atlantic and North Pacific highs, the mid-latitude westerlies, the trade easterlies, and the equatorial westerlies.

DATA AND PROCEDURES

This study utilizes low and upper-air global analyses data extracted from the European Center for Medium-range Weather Forecast (ECMWF), with a horizontal resolution of 2.5° longitude/latitude, averaged for the period from 1980 to 1992. Data points taken daily at 12 GMT were used to obtain 5-day mean wind, temperature, and geopotential heights for the specified levels of 1 000, 850, 500 and 200 hPa. In order to reduce the impact of synoptic atmospheric systems during specific years due to a relatively short observations period, a 1-2-1 filter was applied to the original pentad data.

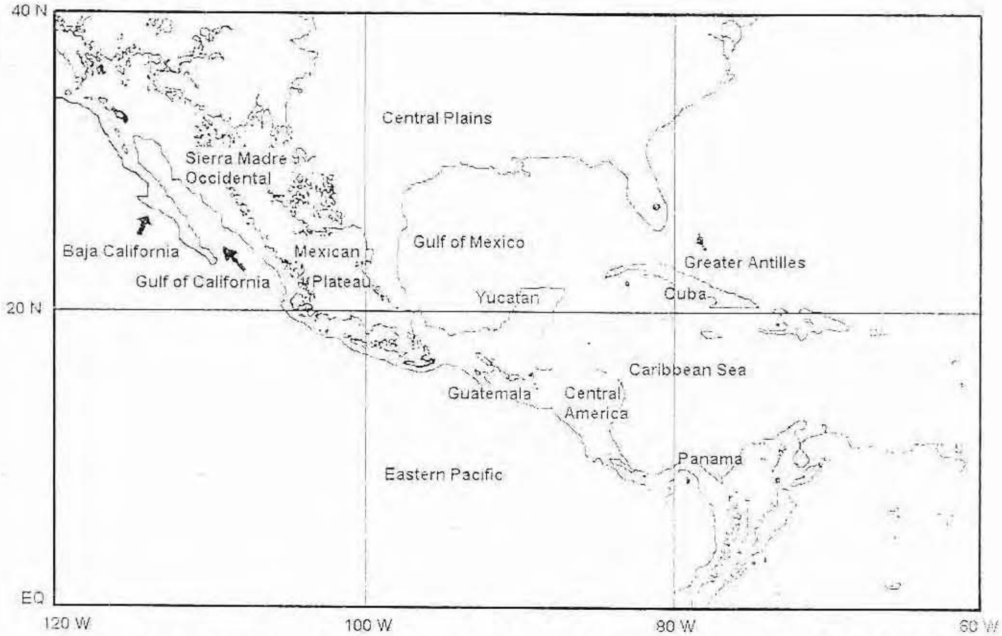


Figure 1. Geography of the area of study showing locations mentioned in the text. The contour line represents elevations of 1 500 m.

To show variations in the patterns of convection associated with changes in the atmospheric circulation systems, this study also utilized a twice-daily Outgoing Long-wave Radiation (OLR) data set from NOAA satellite observations for the 1975-87 period, except 1978. The spatial resolution and procedures applied to the OLR data were the same as those for the ECMWF data, except that the twice-daily values are averaged to attain a daily mean. It is well accepted that low OLR values roughly correspond to heavy rainfall regions in the tropics (Rasmusson *et al.*, 1988; Wang, 1994). In this study, $240Wm^{-2}$ is used as the threshold to delimit active and weak convection areas. On the basis of these data, special attention was paid to spatial and temporal variations in the mid-latitude westerlies, the trade wind easterlies, and the equatorial westerlies.

RESULTS

Low level wind fields (1 000 and 850 hPa)

The large-scale low-level flow over the study region is strongly influenced by the Pacific and Atlantic subtropical highs all year round. During winter (Figure 2), an anticyclonic circulation centered at 30° N, 130° W indicates the position of the North Pacific high, yielding northwesterlies west of Baja California peninsula. On the other side of the continent, an anticyclonic flow over the Greater Antilles and the Gulf of Mexico suggests that the Atlantic high is positioned farther east of the domain. At the same time, strong easterlies are dominant over the Caribbean, across Central America and the eastern tropical Pacific.

The circulation pattern described above tends to change as the boreal summer approaches. During April, that has been identified as the transitional period between the two hemispheric summer monsoons (Murakami and Nakazawa, 1985; Matsumoto, 1990), the North Pacific high shifts northwestward, while the influence of the North Atlantic high extends over southeast USA. After Pentad 22 (mid-April) the intertropical convergence zone (ITCZ) is well established over the eastern North Pacific, as indicated by a band of low OLR along 5° N (Cortez-Vázquez, 1999). During this transition period, the region of maximum convection (OLR less than 200 Wm^{-2}) is located over the equator in the continental region. A noticeable change at 1 000 hPa level is a northward incursion of the southern branch of the trades off the Pacific coast of Colombia (not shown).

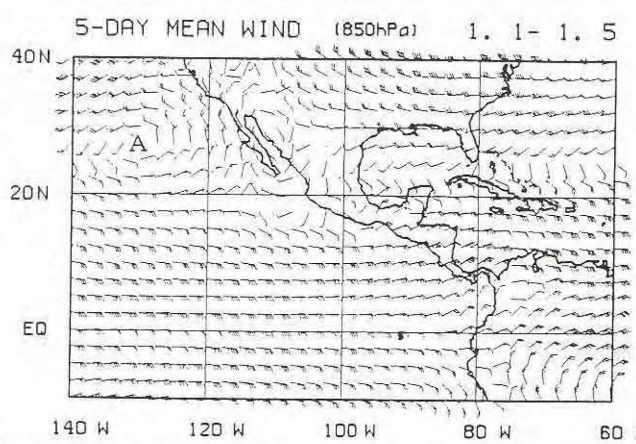


Figure 2. Wind field at 850 hPa for pentad 1 (1-5 January). Half bar represents 1 ms^{-1}, while full bar is 2 m s^{-1}. Cyclone (anticyclone) circulations are identified by C (A).

The low-level summer circulation is characterized by easterlies over the Caribbean, changing to southeasterlies over the Gulf of Mexico, and southerlies in Texas. A noticeable feature over the eastern North Pacific can clearly be seen from Central America to 120° W, where the wind flow at 1 000 hPa alternates from easterly in winter (from November to April) to westerly in summer (from May to October), a common feature in monsoonic regions. Particular variations are: during Pentad 28 (mid May, Figure 3a), identified as the onset period of rainfalls over Central America and southern Mexico (Cortez-Vázquez, 2000), southerlies from the Gulf of Mexico into the Central Plains intensify, while easterlies across Central America into the eastern Pacific weaken. At 1 000 hPa level, a confluence line near 10° N suggests the position of the ITCZ (Figure 4a). We note that minimum OLR values over the eastern Pacific are located equatorward from this confluence line.

After Pentad 34 (June 15-19), when the North Pacific high is located in its seasonal northernmost position, and few days prior to the onset of the Mexican monsoon (MM), northwesterlies at 850 hPa weaken and turn westward near Southern Baja California, leading a southerly flow into central-western Mexico within 100° to 105° W, that seems to be a precursor to the onset of the wet season in northwest Mexico (Figure 3b). Another interesting change after this time is a southeasterly flow parallel to the southwest coast of Mexico. This wind emanates from the eastern tropical Pacific and appears to flow farther north than 20° N (Figure 3c), and turn west over the southern Gulf of California. Inside the gulf, westerly to southwesterly winds appear to flow most of the time, an observation that contradict an analysis that utilized radiosonde data (Douglas *et al.*, 1993). Despite this discrepancy, the ECMWF analyses denote an improvement over other global objective analyses in that region as discussed in Schmitz and Mullen (1996). Figure 4 corresponds to 1 000 hPa level circulation during (a) the onset phase of the rainy season in Central America and southern Mexico (mid-May), and (b) during mid-July, when the MM has extended over northwestern Mexico, as indicated by low OLR values along the Sierra Madre Occidental (Figure 5c). Comparison of Figure 4b with Figure 3c (Pentad 40, mid-July) reveals that over the Gulf of Mexico and the Caribbean the circulation patterns at both levels are basically similar, while over the eastern Pacific some differences arise. Over the latter region the northwesterly and southwesterly winds converge around 15° N at 1 000 hPa, customarily identifying the position of the ITCZ, while at 850 hPa southerly winds are visible near 25° N, west of Baja California (Figure 3c).

Southeasterlies along the west coast retreat after mid-August (Figure 3d). A cyclonic flow related to the thermal heat-low (Rowson and Colucci, 1992; Douglas and Li, 1996) moves southward into northwestern Mexico (Figure 3e), and northwesterlies strengthen over Baja California as the North Pacific high returns to its wintertime position (Figure 3f).

Upper-level (200 hPa)

During winter the upper level circulation (200 hPa) is dominated by westerly winds over the entire region (Figure 5). During the summertime the flow is dominated by the Mexican high that appears centered over northwest Mexico at the end of July, when a low OLR axis along the Sierra Madre Occidental has developed (Figure 6c). The movement of the high from the eastern Pacific close to Guatemala where it starts to develop in mid-May (Pentad 28, Figure 6a), northward into northwestern Mexico is accompanied by a reversal in the flow from westerly to easterly in the equatorward side of the high. A qualitative reinforcement of this system during the onset Pentad of the MM

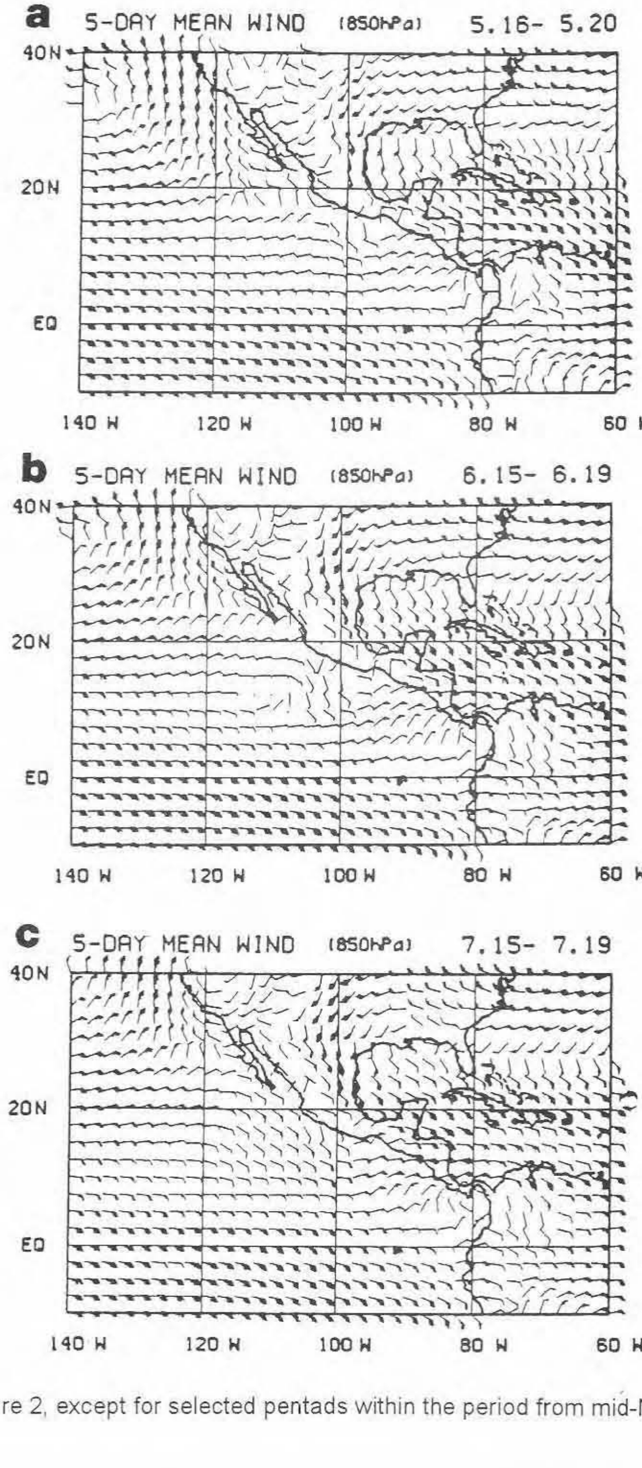
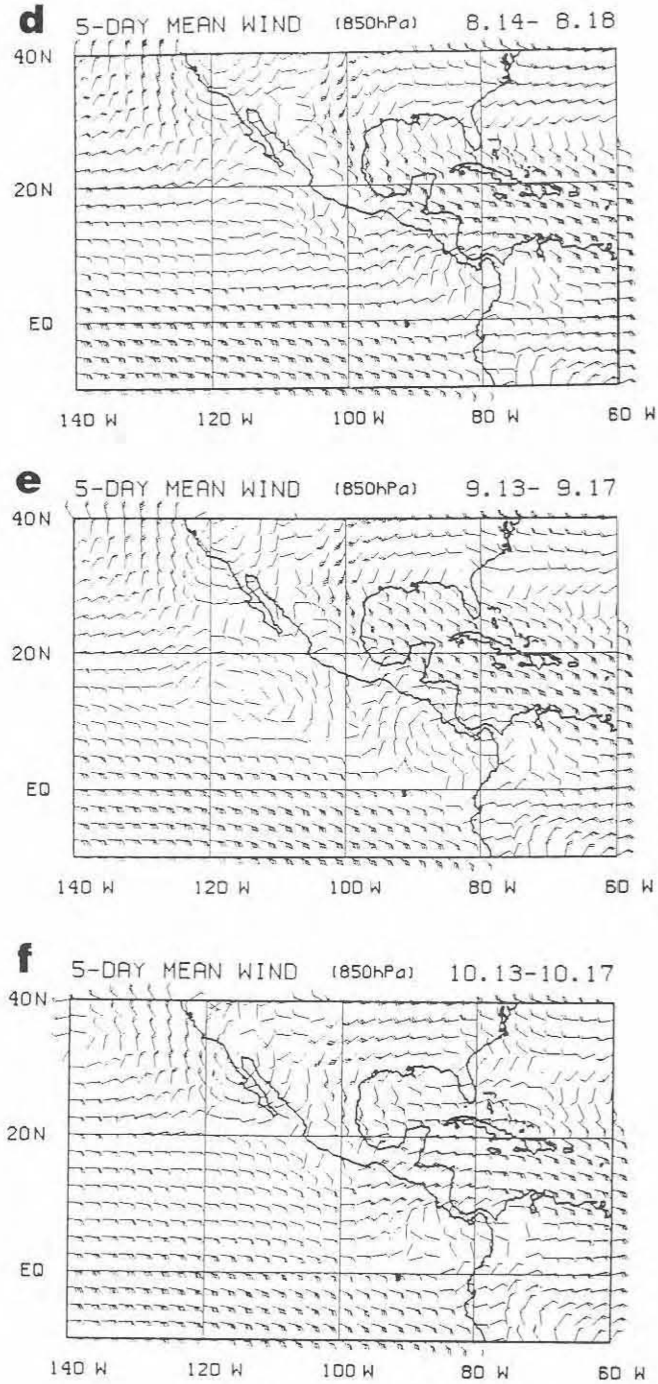


Figure 3. As in Figure 2, except for selected pentads within the period from mid-May to mid-October.



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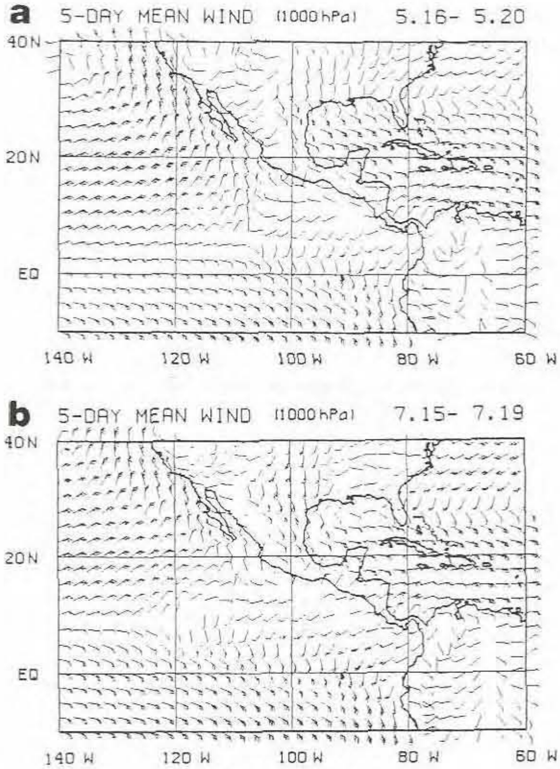


Figure 4. Wind at 1 000 hPa level during (a) Pentad 28 (mid-May), and (b) Pentad 40 (mid-July). Wind velocity as in Figure 2.

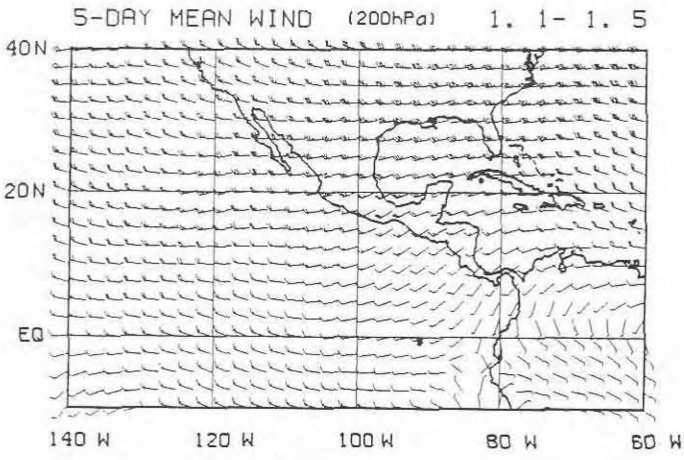


Figure 5. Wind at 200 hPa during Pentad 1 (1-5 January). Half bar denotes wind velocity of 5 m s^{-1}, full bar is 10 m s^{-1}.

is noted, indicating strong convection at the low-levels. As a response to the northward flow near the surface (equatorial westerlies, Figure 4), 200 hPa wind crosses the equator into the Southern Hemisphere.

Another change associated with the northward shift of this anticyclonic vorticity is the establishment of an upper-level trough during late-June and early July across the Greater Antilles into the Yucatán Peninsula (not shown). By the middle of July (Pentad 40, Figure 6c), the trough extends across the Gulf of Mexico and penetrates into the northeastern part of the country, favoring subsidence over this region, which is consistent with the OLR fields, that shows an asymmetric pattern between northeastern and northwestern Mexico during this time (Figure 6c). As the anticyclone moves backward after mid-August the trough returns to its position over the Greater Antilles, and suddenly disappears at the end of September.

After mid-August (Figure 6d) the Mexican high returns southward, mid- and upper-tropospheric winds over northern Mexico change to westerlies, and the axis of low OLR along the Sierra Madre Occidental retreats. During September 23-27, which represents the demise period of the Mexican monsoon (Cortez-Vázquez, 1999), the anticyclone appears positioned over central-western Mexico near 20° N, weakening in mid-October (Figure 6f) and finally disappearing at the end of this month, few days after the conclusion of the rainy season in Central America.

The mid-summer change

Figures 7 and 8 represent differences in the wind, and geopotential heights at 850hPa, as well as differences in the OLR fields between Pentad 31 and 28, and Pentad 34 and 31, prior to and during the onset phase of the rainy season in northwestern Mexico, respectively. Figure 7a reflects features such as increments in the equatorial westerlies over the eastern Pacific south of Mexico, turning southerlies over the Caribbean into the Greater Antilles. A cyclonic center in northern Yucatan indicates enhanced convection, while an anticyclone center over southeast USA and northeast Mexico suggests increased subsidence. This pattern is quite consistent with heights (Figure 7b) and OLR differences (Figure 7c) during the same period.

The above pattern suddenly changes during mid-June. Figure 8a shows that an anticyclone circulation near Cuba replaces the cyclonic center over the Gulf of Mexico, while easterlies from the southern flank of the North Atlantic high strongly intensify over the Caribbean, across Central America, and turn southeasterly along the west coast of Mexico (also noted in the mean flow, Figure 3b). Increments in the OLR fields (Figure 8c) are broadly consistent with changes in the circulation; during this period (mid-June) convection related to the MM tend to increase over central-western Mexico, small regions of negative OLR increments are also visible near of the Florida panhandle, and around 10° N and 110° W in the eastern Pacific (Figure 8a). The opposite tendency (less convection) is visible over the Greater Antilles, the Caribbean and along the west coast of Central America. Convection also tends to decrease over the southwestern USA, the Central Plains, and northeastern Mexico. This change in the low level circulation has been associated with the onset phase of the midsummer drought (Cortez-Vázquez, 2000) .

Although variations in the intensity of trade winds over the Caribbean and Central America during June and July has been described in previous research (Magaña *et al.*, 1999), what is new in the present study is the fact that the change in convection during the onset phase of the MM described

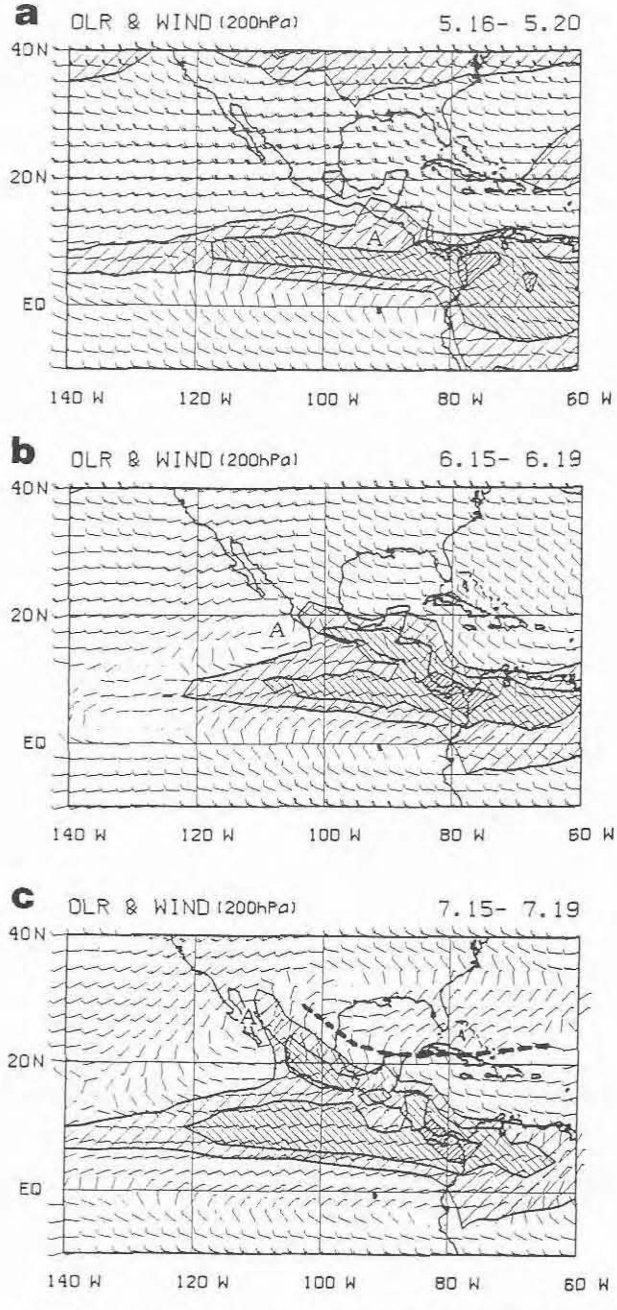
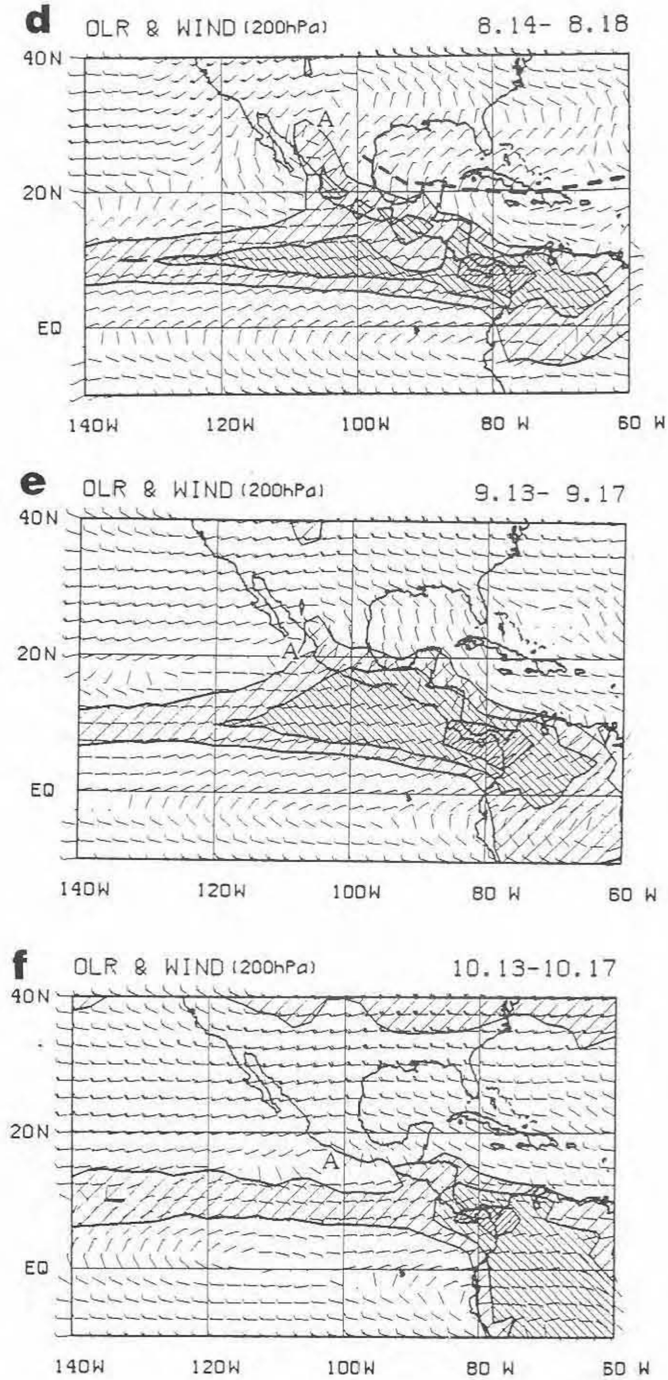


Figure 6. OLR and 200 hPa circulation for selected pentads from mid-May to mid October. Areas with OLR less than 240 W m^{-2} are shaded. OLR contour intervals for 20 W m^{-2}. Contours more than 260 W m^{-2} omitted. Wind velocity as in Figure 5. Dashed line in 6c and d shows the position for the upper-level trough described in the text.



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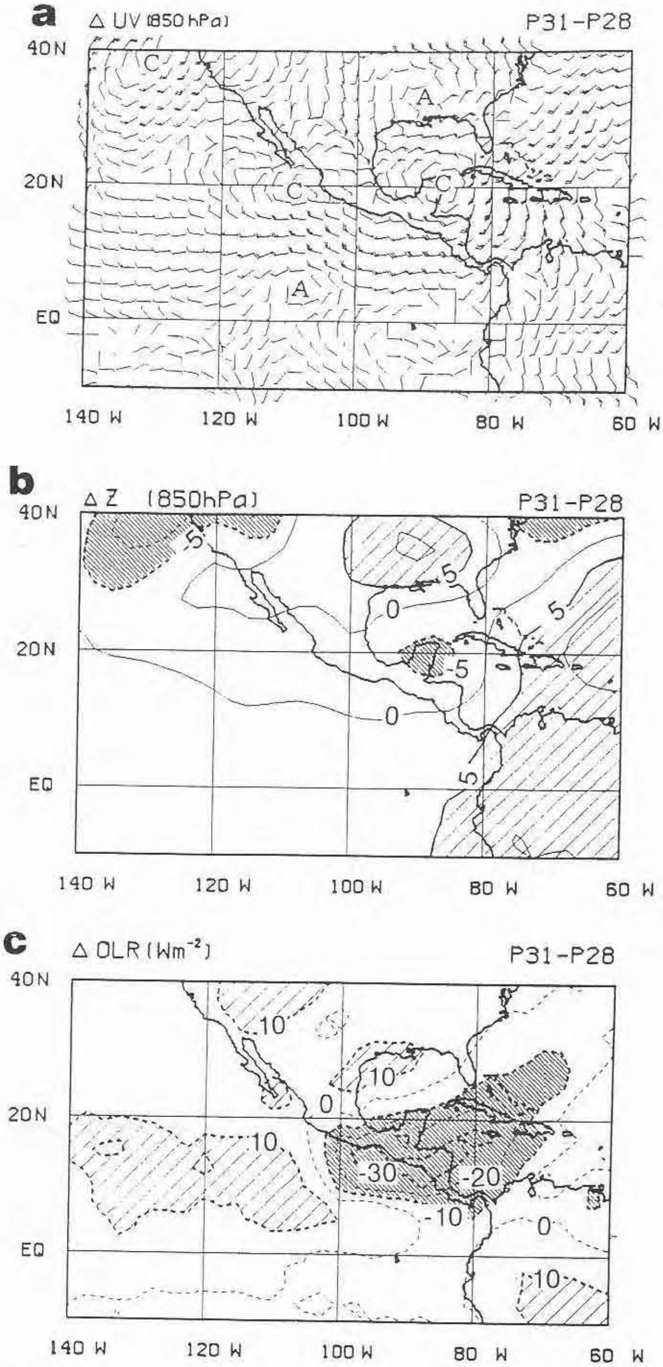

Figure 7. (a) Wind, and (b) geopotential heights (m) difference at 850 hPa between Pentad 31 and Pentad 28. Also shown is (d) OLR difference for the same period. In (a) full bar denotes 1 m^{-2}, half bar 0.5 m^{-2}. Heights and OLR intervals area indicated for each panel.

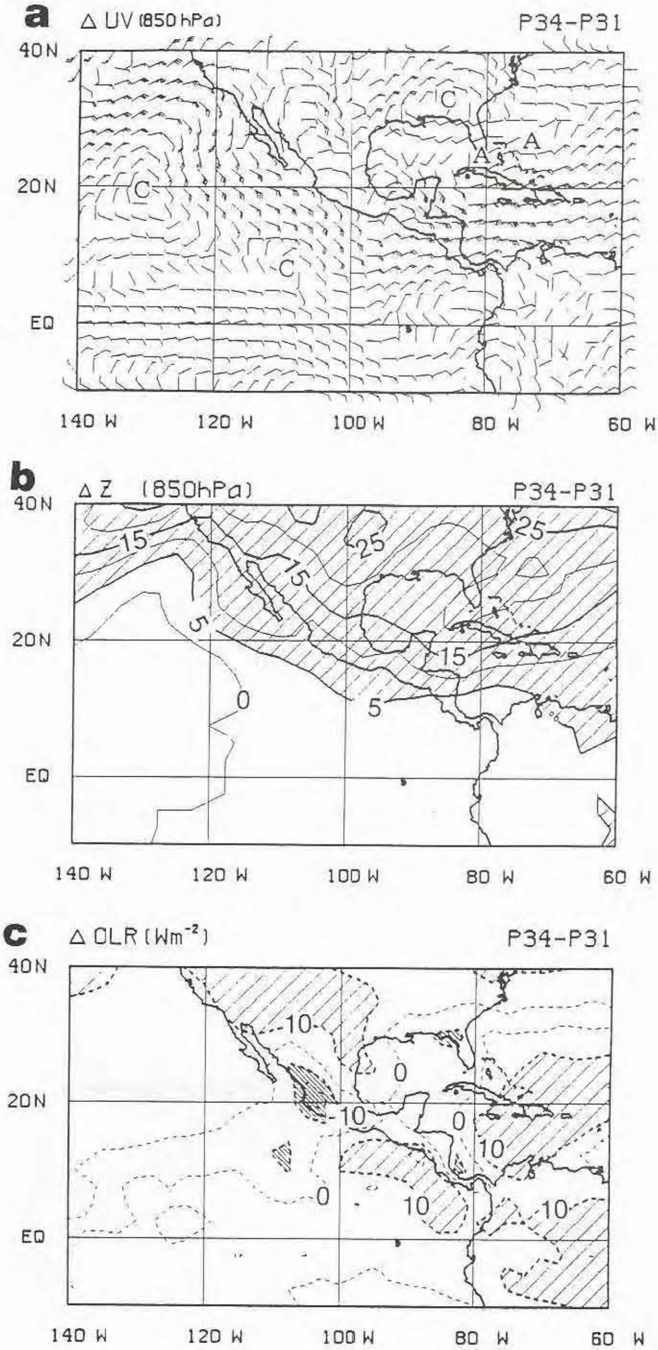

Figure 8. As in Figure 7, except for Pentad 34 and 31.

above is also evident in 200 hPa temperature fields, with cooling in southern Mexico, the Greater Antilles, and Central America, while strong heating (deep convection) is noted over northwest Mexico (Figure 9).

The change in the low-level circulation apparently is a response to the reinforcement of the North Atlantic high, and to an increment in geopotential heights over the North American sector (Figure 8c) during this time. The heights increment is also noted over southwestern USA and northwestern Mexico, where the largest temperature increment occurs during late June and early July (Rowson and Colucci, 1992). While change in convection is consistent with change in the circulation as explained above, the reasons for general changes in geopotential heights are not clear. One may speculate that they are related to enhanced atmospheric heating over the Mexican Plateau, and increased latent heat associated with deep convection over western Mexico during the onset of the MM; however, the processes leading such a situation remains to be explained.

FINAL REMARKS

Spatial and temporal variations in the regional circulation over Mexico were examined by means of 5-day mean wind, temperature and geopotential heights, extracted from 9-year data period from the ECMWF operational analyses. A 12-year record of OLR obtained from polar orbiting satellites has been also used to describe seasonal changes in the convective activity in the studied region. The low and high-tropospheric circulation analysis presented here, provide information with better temporal resolution compared with analysis of monthly or seasonal mean values.

In the previous literature, monsoon circulation systems over the North American sector have been identified in southwestern United States (Hales, 1974; Tang and Reiter, 1984), along the Mexican coast of the gulf of Mexico and that corresponding to the United States (Tang and Reiter, 1984), and over northwestern Mexico (Douglas *et al.*, 1993). Sometimes these systems are together referred as the North American monsoon system (Higgins *et al.*, 1997, Barlow *et al.*, 1998). All these works have evidenced the regional complexity of the precipitation regimes over the domain. Surprisingly, despite the numerous literature references to these systems, the convective regime over the eastern North Pacific, including Central America and southern Mexico, is not commonly considered as such

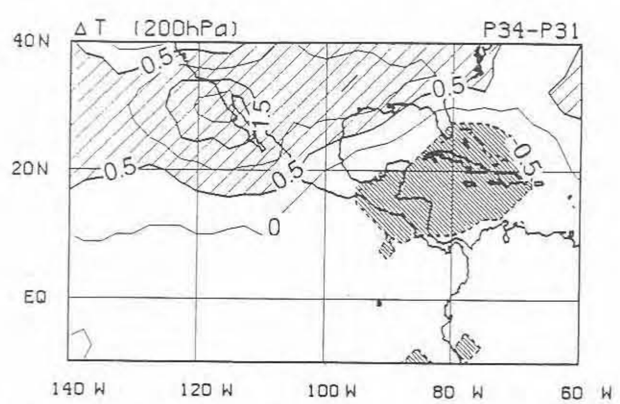

Figure 9. 200 hPa temperature (° C) difference between Pentad 34 and 31. Intervals indicated in the panel.

a system.

During the summer months, we found substantial differences in the mean 1 000 and 850 hPa wind fields over the eastern North Pacific, where the zonal wind near the surface level alternates from easterly to westerly between winter and summer. Accordingly this area can be considered to be a summer monsoon domain, following the criteria used by Murakami *et al.* (1992). However, further analysis on this system is needed.

Wind changes at the 850 hPa level seem to be more closely related with the wet season in northwestern Mexico. In the middle of June the influence of the North Atlantic high extends over the Gulf of Mexico, and as result easterlies from the southern flank of the high increase along the west coast of Mexico. This change in the circulation is quite consistent with variations in the convective patterns.

The out-of-phase relationship between precipitation over northwestern Mexico and the Great Plains discussed in Higgins *et al.* (1997), and Barlow *et al.* (1998) is also displayed by the 5-day OLR increments. However, the onset of the Mexican monsoon is also strongly accompanied by a decrease in convection over the Greater Antilles, the Caribbean, and along the west coast of Central America as discussed in Cortez (2000), and further documented in the present study. Variations in the low-level circulation induced by changes in the position and intensity of the subtropical anticyclones are consistent with changes in convection from the southeastern to the northwestern part of the country.

At high levels, the most striking feature that characterizes the rainy season over the studied region is the rapid development of the Mexican high during mid-May. The northward movement of this system is temporally and spatially consistent with the evolution of the wet season over Mexico. The last days of July and early August represent the period of the northernmost position of the high, while at this time the OLR fields shows an asymmetric distribution in northern Mexico, with low values along the Sierra Madre Occidental, while dry conditions prevail in the northeastern part of the country. Such a pattern suggests that the onset of the Mexican monsoon inhibits convection over eastern Mexico by forcing subsidence.

Conditions during the demise phase of the rainy season in northwest Mexico, although less impressive qualitatively, resemble the reverse of the onset process. At the beginning of August westerlies in the eastern Pacific increase, and few days after this change (mid-August) the MM starts to retreat, and convection moves eastward into eastern Mexico, and southward into the eastern tropical Pacific (Cortez, 2000).

A common practice among meteorologists in Mexico is to identify the position of the ITCZ over the eastern North Pacific in the confluence line where southwesterlies and easterlies meet near the surface level. However, we found the lowest values of OLR (maximum convection) southward of the confluence line. In this regard, as Murakami and Matsumoto (1994) point out, after the satellite era it is more objective to define the ITCZ as an equatorial belt of minimum OLR, where low-level convergence is expected to be stronger.

We believe that results of this study will be useful in the preparation of an integral description of the annual rainfall distribution over Mexico and the surrounding maritime environs. It is hoped that the 5-day mean OLR and wind field analysis here presented will serve as a reference in the daily activities of local weather forecasters.

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