Top. Meteor. Oceanogr. , 5(2): 91-102, 1998

A Climatic Feature of the Tropical Americas: The Trade Wind Easterly Jet

Jorge A. Amador[1]

Center for Geophysical Research and School of Physics (LIAP/DFAOP)
Universidad de Costa Rica
San José, Costa Rica

(Received 20 may 1998, accepted 16 june 1998)

ABSTRACT

Using data from the NCEP/NCAR Reanalysis global monthly means for the period 1982-94, a previously not reported feature of the climate circulation of the tropical Americas is documented: The Trade Wind Easterly Jet. This jet develops in low levels (especially in 925, 850 and 700 mb) in the central part of the Caribbean Sea and from May to July, the wind increases to a maximum and then, the mean current decreases from the later to September. Values in excess of 14 ms^{-1} are observed in the 925 mb zonal mean field during July. Basic dynamical estimates of horizontal wind shear show that this flow is barotropically unstable during the peak of the summer months at low levels, so, disturbances may grow from the mean kinetic energy of the flow. Cross circulations associated to the jet exit region are consistent with the low level vertical velocity (*dp/dt*) and a maximum of precipitation found in the eastern Caribbean near the Central American coast during the summer months.

1. Introduction

Mean circulation patterns in the tropics have provided extensive research material to studying the dynamical basis of atmospheric phenomena. The origin and structure of many weather systems in low latitudes and their associated convective activity and rainfall distribution have been related to these circulations. A type of Hadley cell of the two hemispheres dominates the global scale atmospheric circulations over the tropics. The position and strength of these cells vary substantially with time of year and define fundamental characteristics of tropical climate, such as, the low latitude trough zone and the related confluence and convergence belts. In a smaller scale, regional circulations show a wide range of flow patterns that have been associated with characteristics of local ocean-land and orographic

---

[1] Corresponding author address : Dr. Jorge A. Amador, Centro de Investigaciones Geofisicas y Escuela de Fisica (Laboratorio de Investigaciones Atmosfericas y Planetarias, Departamento de Fisica Atmosferica, Oceanica y Planetaria, LIAP/DFAOP), Tel. (506) 207 5320, Fax. (506) 234 2703, E-mail : jamador@cariari.ucr.ac.cr

distributions. As an example of this interaction in regional scales, differential heating between the ocean and land masses increases, as the summer season approaches, defining in some cases adequate dynamical conditions for the existence of monsoon circulations and relatively intense mid or low level flows (jet streams). Some of these strong flows have been related to the origin of wave-like disturbances, as it is the case of the low level jet over western Africa and the so called African waves. (Burpee 1972, Reed et al. 1977). Other regional flows, such as the Atlantic trades, undergo substantial seasonal and interannual variations that have not been fully studied, although, it has long been recognized that these winds are the basic flow where a lot of tropical disturbances develop and are maintained. The purpose of this note is to document, in the context of the tropical Americas regional climate, by use of the NCEP/NCAR Reanalysis data (Kalnay et al. 1996), the temporal, horizontal and vertical structure of an intense jet-like low level flow (the Trade Wind Easterly Jet, TWEJ) located over the West Caribbean near the Central America coasts during the northern hemisphere summer. The basic dynamical characteristics of the TWEJ and its relationship with precipitation distribution over the region, especially during the summer months, are examined. Some ideas about the role of this jet in the growth of nearby tropical disturbances are discussed.

2. A short review of prominent tropical jets

In a recent review of flow patterns over the global tropics, Hastenrath (1991) makes reference to prominent jet-like concentrations of wind of low latitudes. Among those, the Subtropical Westerly Jet (SWJ) dominates the upper-tropospheric circulations of the northern hemisphere lower latitudes during winter. This jet, of circumglobal extent, shows speed maxima over the Americas, the Middle East and East Asia. According to Palmen and Newton (1969), its existence is primarily owned to the convergence of the poleward transport of westerly absolute angular momentum in the upper poleward direct branch of the Hadley cell, however, its precise formation mechanism is not currently known, nor understood.

The Tropical Easterly Jet (TEJ) is another prominent feature of the upper tropospheric circulations of low latitudes and extends approximately form Southeast Asia across the Indian Ocean and Africa to the Atlantic, lasting from late June to early September (Hastenrath 1991). In his review, Hastenrath says that "the TEJ owns its origin to the circumstance that the maximum heating and tropospheric thickness pattern in summer is located in the subtropics rather than near the Equator". The position of the TEJ during August 1995 and the mean July precipitation over a tropical belt from approximately 20°W to 150°E was discussed by Koteswaram (1958) with good agreement between the abundant summer rainfall over the southern portion of West Africa and the vertical motion field resulting from the cross circulations associated to the TEJ, near its exit region. The East African low level jet ("Somali Jet") is a relevant lower tropospheric circulation feature located over the Western Indian Ocean during the boreal summer southwest monsoon. The jet core speeds are in the order of 12 - 15 ms^{-1} and it has strong horizontal and vertical shears. (Hastenrath 1991).

The West African Mid-Tropospheric Jet (WAMTJ) is an easterly wind maximum found in the middle troposphere over West Africa most of the year. The jet attains values in excess of 10 ms^{-1}, with a more defined structure during the spring to the late summer months. Since some of the WAMTJ characteristics are relevant to this paper, further attention is given to this feature. The easterly jet region in lower levels has been, as mentioned before, associated with westward travelling disturbances. The probable role of this shared region in the origin of these disturbances has been discussed by Burpee (1972). Instability analysis performed for an easterly jet that resembles the observed flow over Central and Western Africa has shown that the most unstable disturbance has a growth rate of 0,27 $(day)^{-1}$, a wavelength close to 4000 km and a phase speed of about 9 ms^{-1} in good agreement with observations (Simmons 1977). Because of the well known strong surface heating over the Sahara (the temperature increases northward in the lower tropcsphere in this region) and the approximate thermal wind balance that exists at these latitudes (Amador 1981), the

WAMTJ has been regarded as a product of the strong temperature contrast in the sub-Saharan region (Reed 1979). According to Reed et al. (1977), baroclinic and barotropic conversions were found to contribute about equally when Phase III of GATE data from both land and ocean areas were used in the diagnostic of wave energetics. When ocean and land areas were used separately, these authors found that, the barotropic energy conversion was stronger over the ocean than over land, being the baroclinic conversion relatively weak over the first area. By use of modeling results, both Rennick (1976) and Simmons (1977) indicated a primary role for the barotropic conversion process. Amador (1981) using dynamically initialized data fields from Phase III of GATE (Met 011 Analysis Group 1976), studied among other things, the wind and thermal structure over an extended A scale array. Over West Africa, near 15°N in the layer 900-800 mb, observed temperature gradients are in good qualitative and even quantitative agreement with observed vertical shears (5-6 10-3 s^{-1}). The thermal wind equation holds in this region and is consistent with the observed large values of zonal velocity associated with the WAMTJ. Moreover, the larger meridian differences found between 10° and 20°N in West Africa (as compared to those of East Africa) are also in good agreement with the fact that the easterly flow near the jet core strengthens downstream over these regions.

Over the Caribbean, reference of a wind maxima during summer has been made in analysis of synoptic data (e.g. Sadler and Oda 1980), however, a jet like structure over the Caribbean has not been documented, even in a recent review about the importance of low levels jets in climate (Stensrud 1996).

From the review presented above, it is seen, that these prominent jets are of fundamental importance when explaining the existence of tropical disturbances and precipitation distributions in some tropical regions.

3. Data

Primary source for this study is the NCEP/NCAR Reanalysis monthly means 1982-94 (Kalnay et al. 1996). This global atmospheric analysis is based on the NCEP operational model, with a T62 resolution with 28 vertical levels. The NCEP model uses a wide range of input data. Global rawindsondes provided by NCAR, or archived by other countries dating back to 1948, SST's from different sources, aircraft winds, synoptic data collected by first order stations around the globe, and satellite sounder data (TOVS), were the basic resources for the reanalysis runs (Basist and Chelliah 1997).

4. The Trade Wind Easterly Jet

4.1. Mean characteristics and summertime monthly variation.

The trade winds are the low level tropospheric equatorward branch of the tropical Hadley cell. The trades occupy nearly half of the surface of the earth and they account for a large amount of the moisture convergence flux at low latitudes and the related convective activity near the ITCZ.

The Trade Wind Easterly Jet (TWEJ) is a low level wind maximum near 900 mb that dominates the boreal summer in the Caribbean Sea and that is part of the intense and continuous trade wind regime across the Atlantic. Figures 1 to 4 show the development and decay of the jet from May to September at four different levels, 1000, 925, 850, and 700 mb, respectively. The jet axis is near 15°N and extends east - west with the absolute maximum lying usually between 70°W and 80°W. Figure 1 (a through e) shows trade wind maxima, one in the Western Caribbean and the other in the Atlantic near 45°W and 12°N. As it can be seen, wind increases in the Western Caribbean to a maximum in excess of 10 ms^{-1} from May to June at the 1000 mb level. NCEP/NCAR reanalysis data do not show a similar increase in the Atlantic maximum to the northeast of the Brazilian coast. Lack of data in the western Atlantic is a strong limitation to better defining wind flow over this region. Trades during July (Figure 1c) show a greater maximum (11m s^{-1} approximately) to that of June in the Western Caribbean that decreases in intensity in August and September. (Figure 1d and Figure 1e, respectively). Figure 2 presents the mean zonal wind component from May to September

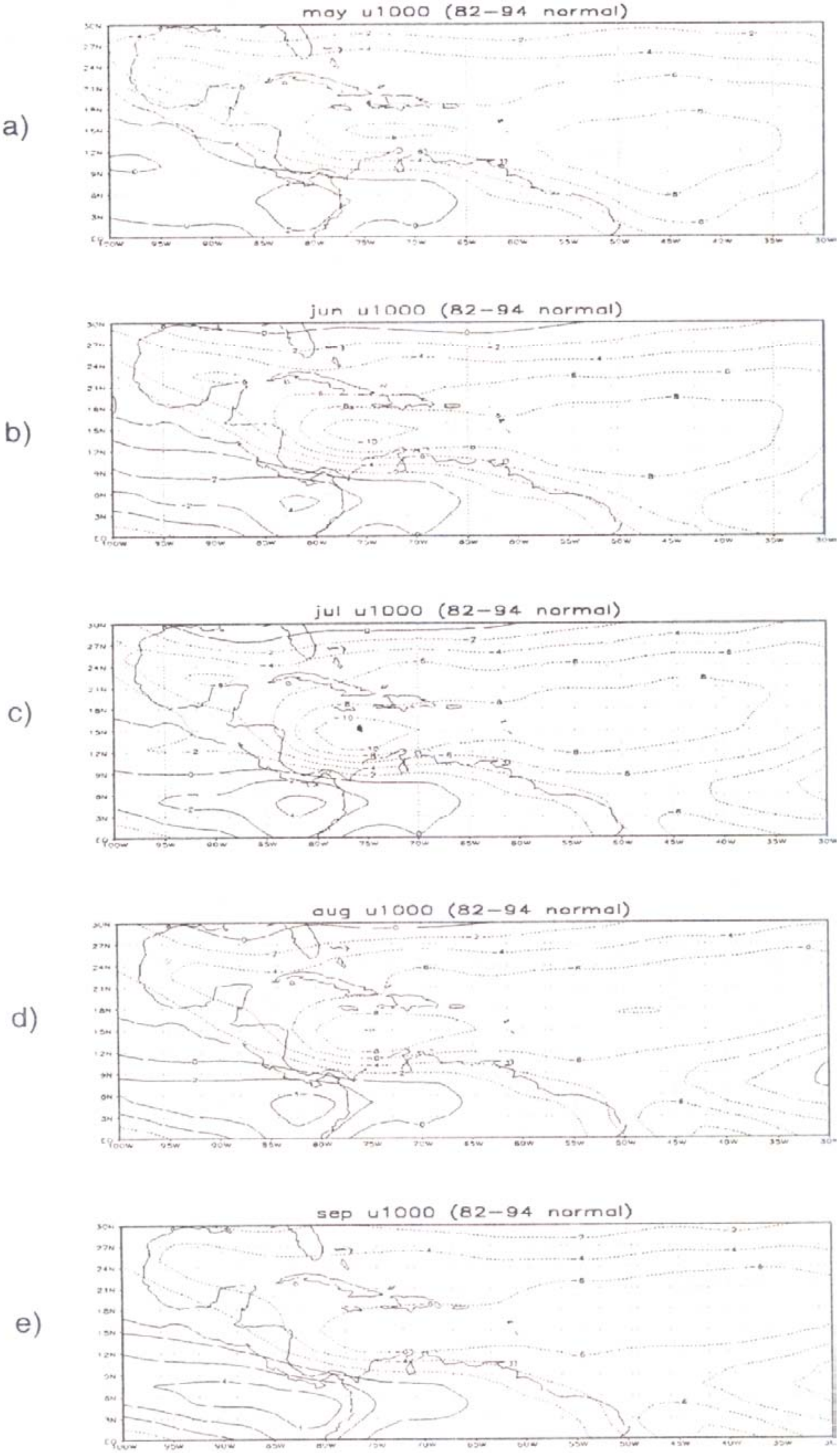

Fig. 1. Mean zonal flow in ms^{-1} at 1000 mb from May to September (a to e, respectively), for the period 1982-1994.

for the period 1982-1994 at 925 mb. As in the lower level (1000 mb) there is a very well defined increase in the trades between May and July (Figure 2a to 2c, respectively). In July, wind speeds are in the order of 14 ms^{-1} with a decrease in August to 10 ms^{-1} and in September to 8 ms^{-1} (Figure 2d and 2e). At the 850 mb level, (Figure 3), the flow exhibits a similar behavior to that of lower levels; an increase in the easterlies from May to June and July (6, 10, and 12 ms^{-1}, respectively in Figure 3a to c) and a decrease from the later to August and September (Figure 3d and e, respectively). At 700 mb (Figure 4a to e) the flow also shows an increase from May to June and July and a decrease during August to September. The internal consistency of the jet in low levels is remarkable and it is not considered to be associated with the model schemes, nor with the way the data were treated. At 600 mb (not shown) the wind presents some jet-like structure, however, above this level, the flow smoothes out rapidly. Idealized vertical profiles of zonal wind for July conditions at 15°N, for different longitudes (70, 75, and 80° W) are presented in Figure 5a. Figure 5b. shows the meridian profile of the zonal flow along 75° W for 925 and 850 mb, also for July conditions. It is very important to note that the period for which the flow is a maximum (July -August) corresponds to the presence in the region of the so called, Mid-Summer Drought (MSD). Magaña et al. (1998) have proposed a mechanism to explain the MSD over Mexico and Central America and its relationship with the strengthening of the easterlies. This 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 (Grandoso et al. 1982, Magaña et al. 1998).

4.2. Barotropic instability

In order to elucidate, some of the dynamical characteristics of the jet, the absolute vorticity (AV) of the flow was computed for both, 925 mb and 850 mb along 75°W from approximately 5° to 25°N using the NCEP/NCAR mean values for the period 1982 - 94. The computed values of AV are examined to determine if the meridian gradient of AV (i.e. $d/dy\ [\,f + U/a(\tan(\phi) - d/dy(U)\,]$, other symbols have their usual meaning) reverses in sign in any region. This, as is well known, constitutes a necessary condition for barotropic instability. AV in the Western Caribbean shows (Figure 5c) a monotic increase from the south to near 10°N at both levels, 925 and 850 mb. From there, to a region just to the north of 15°N, the flow meets the condition that the gradient of AV changes sign. Since the condition for barotropic instability is met in this region, disturbances may grow into systems that extract kinetic energy from the mean flow and that may eventually develop from energy associated to convective activity, as it is the case, for systems in other tropical regions. (Burpee 1972, Reed 1979)

4.3. Cross circulations

From basic dynamical considerations for northern hemisphere conditions, easterly flow increasing towards the west to a maximum near longitude l_o, has the largest positive value of AV to the left of the jet maximum and the smallest or even negative values of AV to the right of the axis. From the approximate well known form of the absolute vorticity equation, $d/dt\,(AV) = -AV\,(DIV)$; where DIV is the divergence of the zonal wind; to the left of the jet axis, convergence (divergence) occurs in the rear (front) of l_o. To the right of the axis, relative vorticity (RV) has opposite sign to f, the Coriolis parameter, making AV less positive or even negative, so divergence (convergence) is expected in the right rear (front) of l_o. From the above considerations of divergence field distributions, northerly (southerly) cross circulations develop perpendicular to the jet axis to the rear (front) of l_o.

As it is seen in Figure 6, vertical velocity (dp/dt) at 850 mb near the jet exit during July is consistent with the cross circulation patterns discussed above. The vertical velocity field, induced by the presence of the jet in the Central Caribbean, is believed to be responsible for the convective activity and associated precipitation maximum that is observed near 12°N in July, just off the Central America coast. This maximum has long been known to exist and it is located between Costa Rica and Nicaragua in a region that is considered to be far from orographic

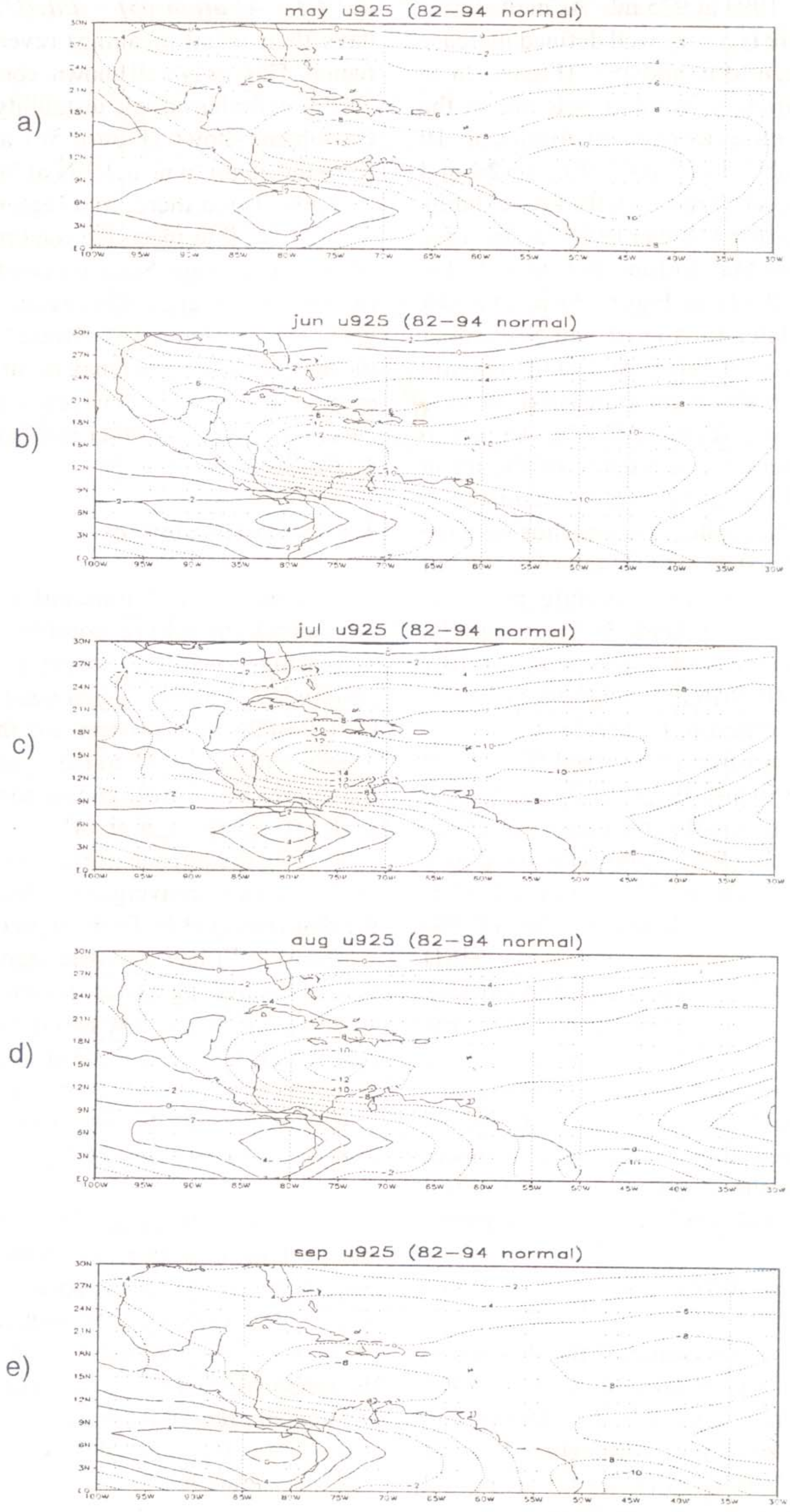

Fig. 2. As in Fig. 1, except for 925 mb.

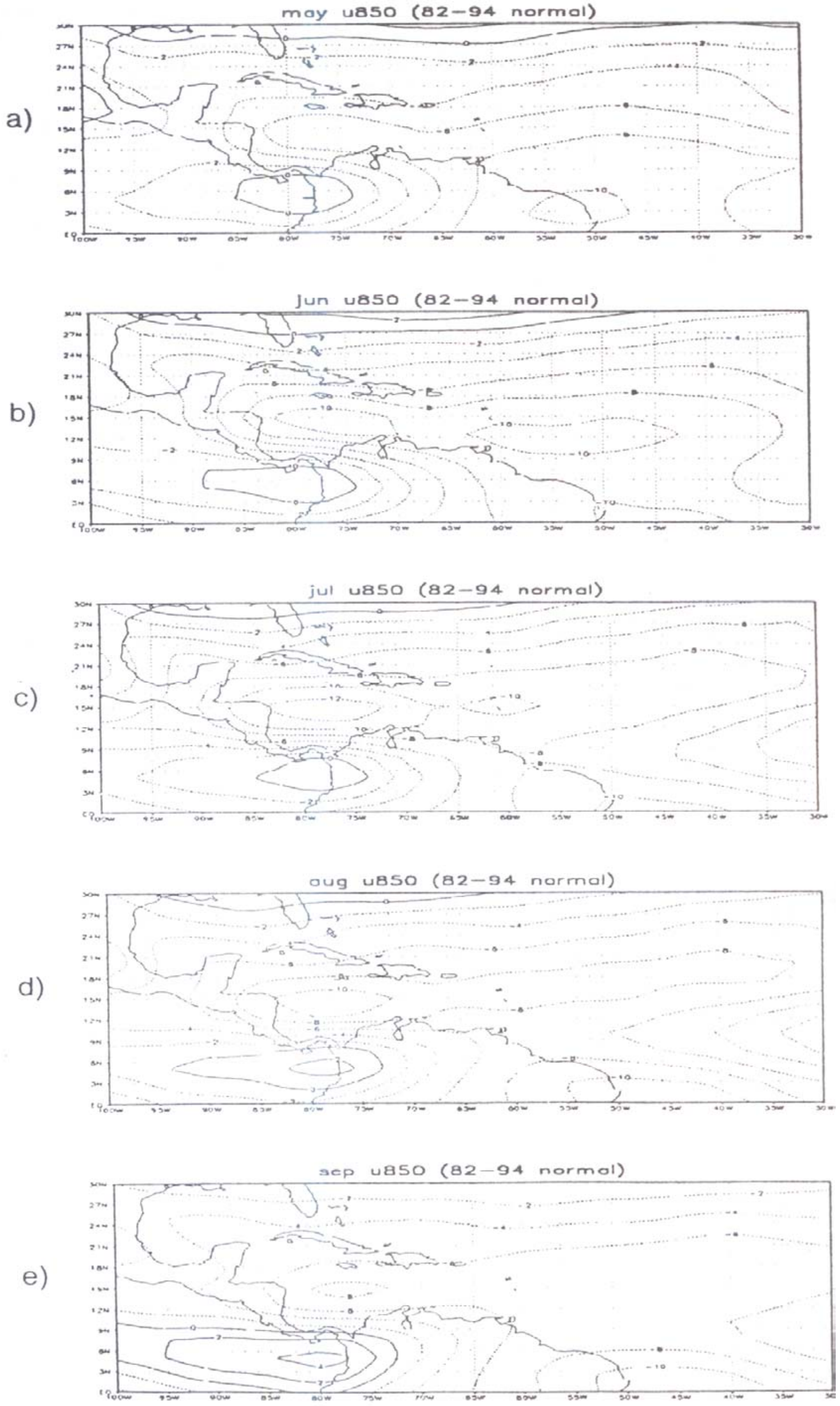

Fig. 3. As in Fig. 1, except for 850 mb.

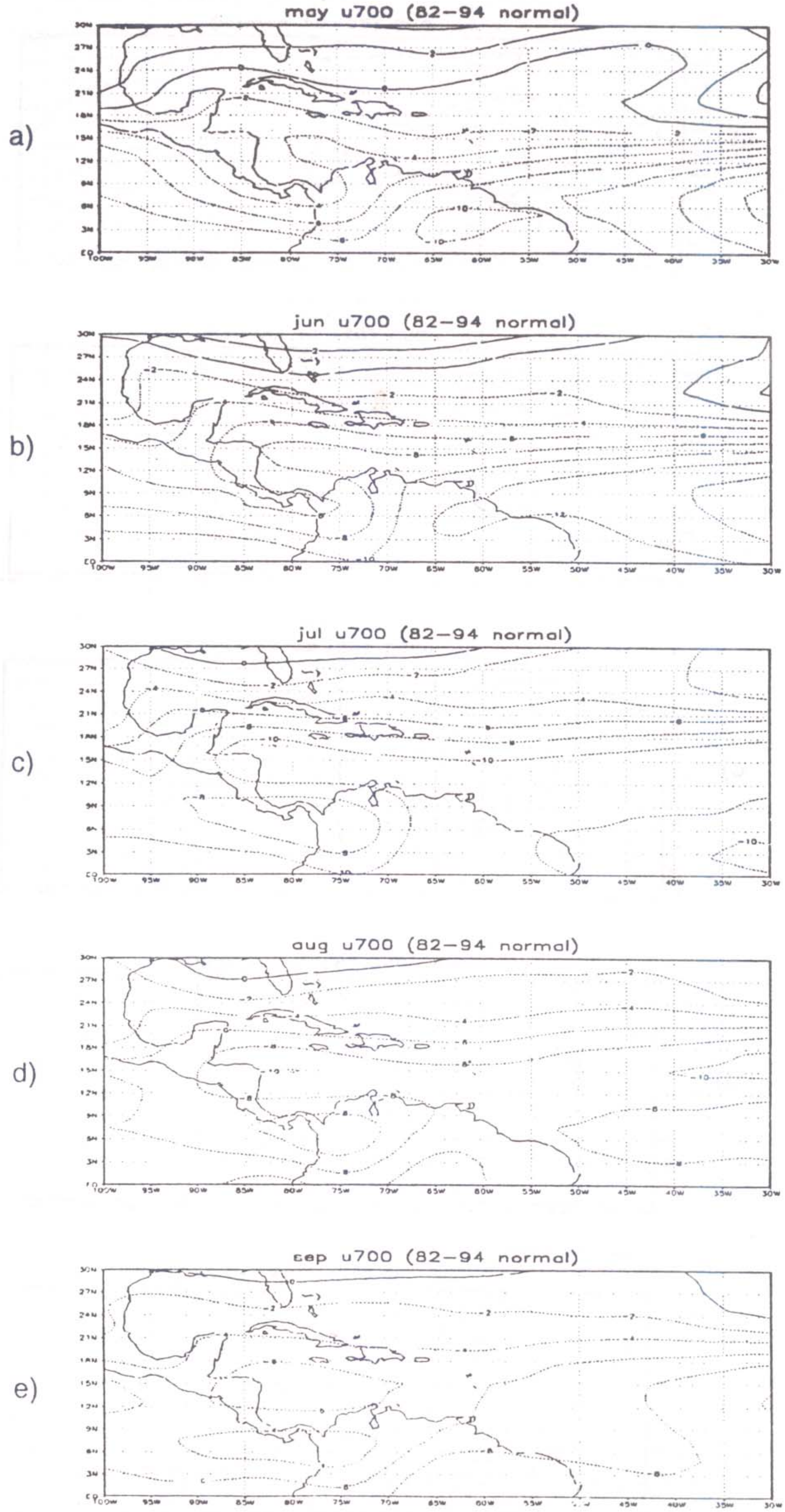

Fig. 4. As in Fig, 1, except for 700 mb.

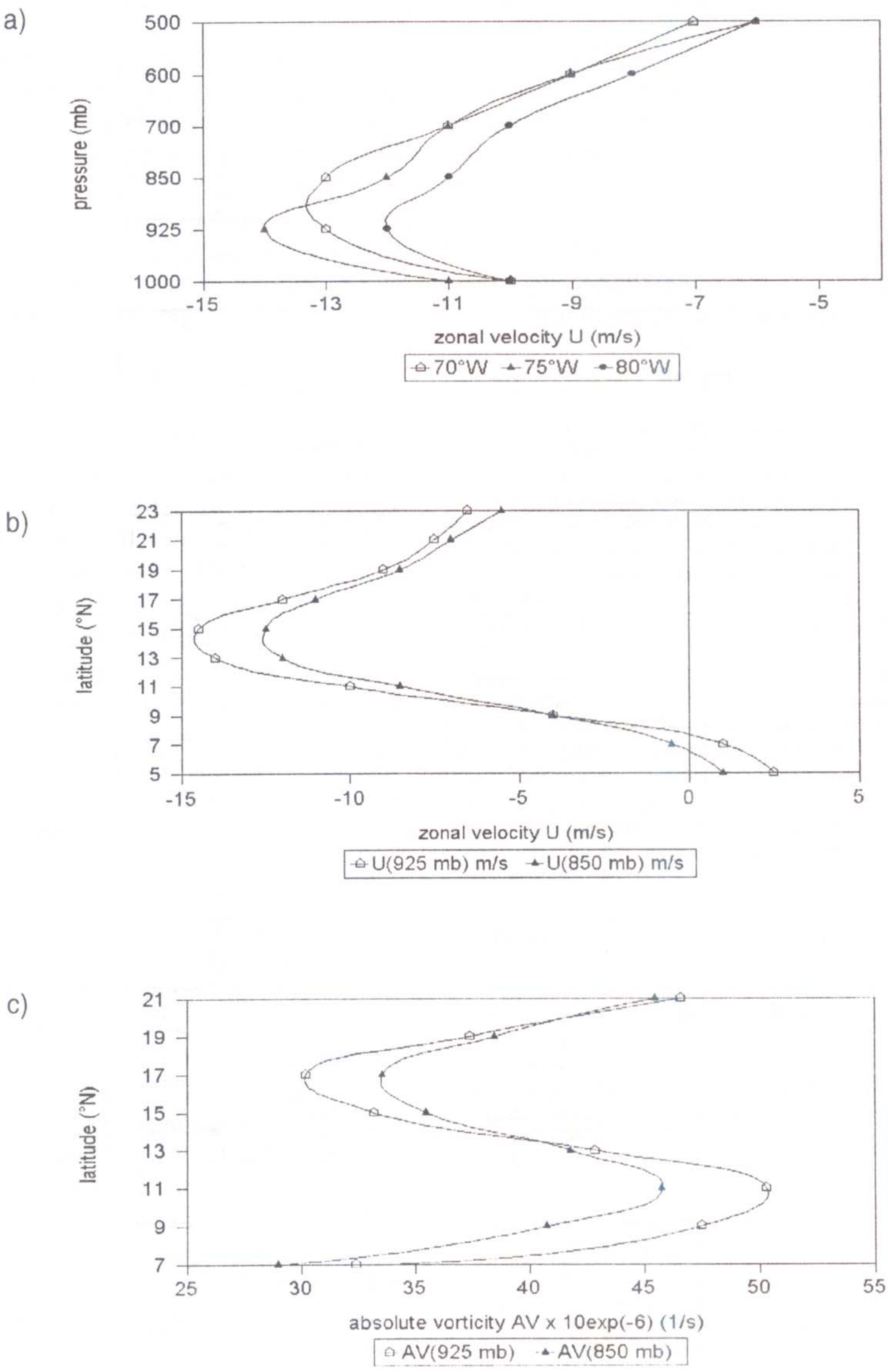

Fig. 5. a) Vertical profile of the zonal flow at 15° N for different longitudes along the jet axis, b) meridional profile of the zonal flow at 925 and 850 mb along 75° W and, c) meridional distribution of absolute vorticity at 925 and 850 mb along 75° W; during July mean conditions for the period 1982-1994.

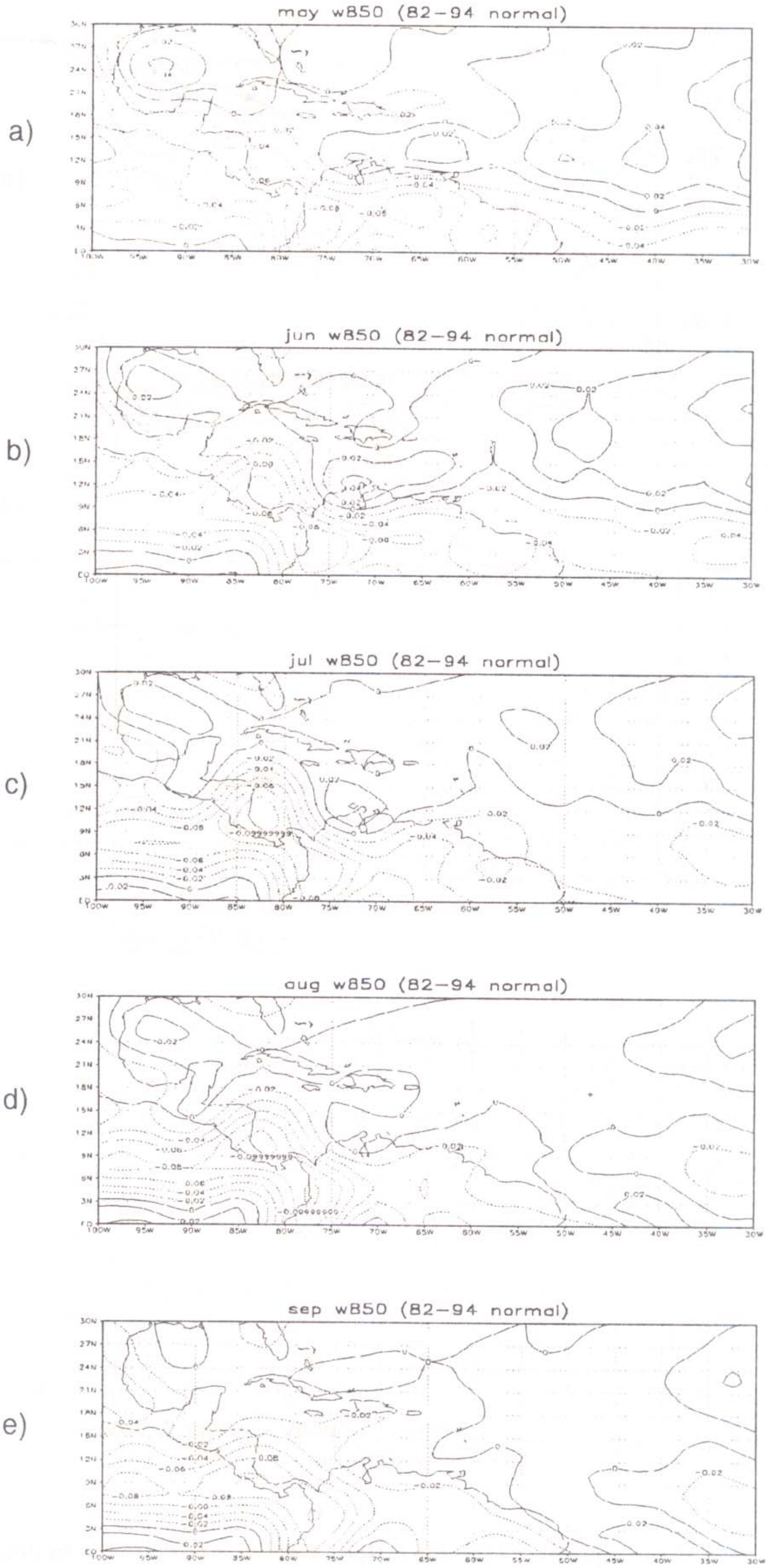

Fig. 6. Vertical velocity (*dp/dt*) in Pa s^{-1} at 850 mb, from May to September (a to e, respectively) for the period 1982-1994.

interaction. According to a climatological and hydrological Atlas prepared by IPGH (1975), the maximum annual precipitation in that area is in the order of 6000 mm. It is interesting to note that the summer months (June-July-August), contribute with about one third of the total annual precipitation in this region (IPGH 1975, FAO 1985). This evidence supports the idea of the importance of the cross circulations and associated vertical velocity field near the jet exit in the precipitation maximum during the summer months in this region.

5. Final Remarks

Using data from the NCEP/NCAR Reanalysis global monthly means for the period 1982-94, a previously not reported feature of the climate circulation of the tropical Americas is documented: The Trade Wind Easterly Jet. This jet develops in low levels between 925 and 700 mb in the central part of the Caribbean Sea from May to July, and then, the mean current decreases from the later to September. Values in excess of 14 ms^{-1} are observed in the 925 mb zonal mean field. Basic dynamical estimates of horizontal wind shear show that this flow is barotropically unstable during the peak of the summer months at low levels, so, disturbances may grow from the mean kinetic energy of the flow. Also, cross circulations associated to the jet exit region are consistent with the low level vertical velocity and a maximum of precipitation found in the eastern Caribbean near the Central American coast during July. Undoubtedly, this jet-like structure of the trade wind flow during the summer months, provides new and challenging material for future tropical research. The role of this feature in the regional distribution of precipitation and the downstream growth of disturbances is still to be understood. Upper air observations over the region are relatively scarce and need to be strengthen to get a more detailed structure of the jet. Also, the possible relationship of the TWEJ and the cyclonic gyro in the western Caribbean Sea, as a form of atmospheric forcing, should be pursued. Finally, the jet interannual variability and its relationship with the MSD and ENOS, constitute just two of the important tropical phenomena affecting the region that could be analyzed, through jet energy conversions and modeling studies.

Acknowledgements

This work was partially supported by grants from the vice-presidency for Research, University of Costa Rica (VI-805-94-204 and VI-805-98-506) and the Inter-American Institute for Global Change Research (IAI) projects IAI-ISP 3-030 and CRN-TC3. Thanks are given to Dr. J. Gutiérrez for some suggestions for improving the manuscript. Special thanks to students and staff of the Center for Geophysical Research for their technical support.

RESUMEN

Utilizando datos medios mensuales globales de los Reanálisis de NCEP/NCAR para el período 1982-1994 se documenta una característica de la circulación de las Américas tropicales no reportada hasta el momento en la literatura: la corriente en chorro de bajo nivel en los alisios del este. Esta intensa corriente se desarrolla en niveles bajos (especialmente en 925, 800, 700 mb) en la parte central del Mar Caribe y de mayo a julio, el viento aumenta hasta un máximo y luego la corriente media decrece desde este mes hasta septiembre. Se observan valores en exceso de 14 ms^{-1} en el nivel de 925 mb durante julio. Estimaciones dinámicas básicas de la cortante horizontal del viento muestran que este flujo es barotrópicamente inestable durante los meses de verano en niveles bajos, de manera que perturbaciones tropicales en la región podrían crecer a expensas de la energía cinética media del flujo zonal. Las circulaciones cruzadas asociadas al flujo en la región de salida de la corriente en chorro son consistentes con la velocidad vertical (dp/dt) y con el máximo de precipitación que se encuentra en el este del Caribe cerca de las costas de Centro América durante los meses de verano.

References

Amador, J.A. 1981. Meanfields and synoptic scale system during Phase III of GATE. Ph. D. Thesis. Department of Meteorology, Reading University. 239 pp.

Basist, A. N. and M. Chelliah. 1997: Comparison of tropospheric temperatures derived from the NCEP/NCAR reanalysis, NCEP operational analysis, and the Microwave Sounding Unit. Bull. Amer. Meteor. Soc. 78, 1431 - 1447.

Burpee, R.W. 1972. The origin and structure of easterly waves in the lower troposphere of North Africa. Quart. J. Roy. Meteor. Soc. 29, 77 - 90.

FAO. 1985. Agroclimatological data for Latin American and the Caribbean. Plan Production and Protection Series N° 24. Food and Agricultural Organization, United Nations, Rome, Italy.

Grandoso, H., A. Vargas and V. Castro. 1982. Características de la atmósfera libre sobre Costa Rica y sus relaciones con la precipitación. Informe semestral enero a junio 1981. Instituto Meteorológico Nacional. San José, Costa Rica, 44 pp. (in Spanish)

Hastenrath, S. 1991. Climate dynamics of the tropics, Kluwer Academic Publishers, Dordrecht, Boston, London, 488 pp.

IPGH. 1975. tlas Climatológico e Hidrológico del Istmo Centroamericano. Instituto Panamericano de Geografía e Historia / Comité Regional de Recursos Hidráulicos. Centro América.

Kalnay, E., et al. 1996. The NCEP/NCAR 40 year reanalysis proyect. Bull. Amer. Meteor. Soc. 77, 437 - 471.

Koteswaram, P. 1958. The easterly jet stream in the tropics. Tellus. 20, 43 - 57.

Magaña, V., J. A. Amador, and S. Medina. 1998: The Mid-Summer Drought over México and Central América. Accepted for publication in J. Climate (JCL-2442).

Met 0 11 Analysis Group. 1976. A scheme for the objective analysis of GATE data. Met 0 11 Tech. Note Nº 74. UK. Meteorological Office, Bracknell, England.

Palmen, E. and C.W. Newton. 1969. Atmospheric circulation systems. Academic Press, New York, London, 603 pp.

Reed, R.J., D.C. Norquist. and E.E. Recker. 1977. The structure and properties of African wave disturbances as observed during Phase III of GATE. Mon. Wea. Rev. 105, 317 - 333.

Reed, R.J. 1979. The structure and behavior of easterly waves over West Africa and the Atlantic. Meteorology over the tropical oceans. Shaw, D.B. (ed), Royal Meteorological Society. Bracknell, England, 278 pp.

Rennick, M. A. 1976. The generation of African waves. J. Atmos. Sci. 33, 1955-1969.

Sadler, J.C. and L.K. Oda. 1980. Gate analysis: I. The synoptic (A) scale circulations during Phase I, 26 June - 16 July 1974; II. Means for Phases I, II and III. University of Hawaii, Dept. of Meteorology, Honolulu, Hawaii.

Simmons. A.J. 1977. A note on the instability of the African Easterly jet. J. Atmos. Sci. 34, 1670-1674.

Stensrud, D.J. 1996. Importance of low level jets to climate: A review, J. Climate. 9, 1698 - 1711.