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PRECIPITATION DISTRIBUTION OVER CENTRAL AND WESTERN TROPICAL SOUTH AMERICA

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ABSTRACT

In this study we presented a new analysis of the precipitation distribution over the central and western portions of Tropical South America. To derive this distribution rainfall data for 226 stations were used. We attempted to relate spatial and temporal variability of precipitation to dynamical aspects of the atmospheric circulation over South America. For that purpose we made use of the average circulation and divergent component of the wind field at 200 hPa. Aspects of the large spatial and temporal (seasonal and intraseasonal) variability are discussed. During austral summer maximum precipitation is apparently related to the SACZ. Throughout the year the Andes Cordillera seems to play a fundamental role. It induces regions of very high and very low precipitation on its slopes and likely creates the conditions for the maximum precipitation over western Amazonia.

RESUMO

Apresenta-se uma nova análise da distribuição de precipitação sobre as porções oeste e central da América do Sul Tropical a partir dos dados de um total de 226 estações pluviométricas. Procurou-se relacionar a variabilidade espacial e temporal observadas à aspectos dinâmicos da circulação atmosférica, principalmente a componente divergente do vento em 200 mb. Discute-se diversos aspectos da grande variabilidade tanto espacial como temporal (sazonal e intrasazonal). Verificou-se que, durante o verão austral, os máximos de precipitação estão aparentemente ligados à influência da ZCAS (Zona de Convergência do Atlântico Sul). Durante todo o ano, a Cordilheira dos Andes desempenha um papel fundamental: ao mesmo tempo que induz à formação de regiões com valores muito baixos e muito altos de precipitação nas sua encostas, também cria, provavelmente, as condições para a ocorrência do máximo

1. INTRODUCTION

It is well known that rainfall is the most important meteorological variable in the Tropics. The understanding of rainfall variability is desirable not only because of its impact on society but also because atmospheric circulations in the Tropics and Extra-Tropics are intimately linked to tropical rainfall distribution since condensational heating is a major heat source for such circulations.

In particular, the tropical region of South America acts as a powerful heat source for the atmosphere. Precipitation rates in that region during the rainy season typically average about 10 mm/day which corresponds to an equivalent heating of approximately 2.5 K/day of the tropospheric column through the release of latent heat in cumulus clouds.

However, the distribution of precipitation over tropical South America and primarily the causes of such distribution are not completely known. This is partly due to the lack of a complete and detailed set of surface and upper air observations. Lately the inclusion of satellite observations have considerably augmented our understanding and revealed features of the tropical circulation not previously captured by the inadequate upper air and surface network (Arkin et al., 1986; Chu and Hastenrath, 1982).

Rainfall distribution over the central and western portions of tropical South America has not been studied in detail. Most studies focused on rainfall variability in northeastern Brazil (Nordeste) and others were more descriptive in nature. A few studies in the past established the first steps toward a regional climatology: Ratisbona (1976), Rocha et al. (1984) and Salati (1984) for Brazil, Johnson (1976) for Peru and Ecuador, and Hoffmann (1975) for the whole of South America, but the latter made use of only a handful of stations covering Amazonia.

The objective of this study is to present an updated distribution of precipitation over central and western tropical South America. To derive this distribution we made use of an enlarged data set, primarily over Amazonia. We will also attempt to link the observed distribution of precipitation to the dynamics of tropical circulations and also to topographic features attempting to expand on the work of Nobre (1983a, 1983b) and Molion (1987).

Monthly mean rainfall data for 226 stations were used to derive maps of monthly, seasonal and annual rainfall distributions. Station locations are shown in Figure 1. The data sources are basically the national meteorological services of the countries in South America and are part of the rainfall data base at the Instituto de Pesquisas Espaciais. Most of the data from Brazil have been provided by the Departamento Nacional de guas e Energia Elétrica (DNAEE), and this data set has been verified and corrected by Nobre at al. (1987). Data for some stations were obtained from the Monthly Climate Data for the World publication. A large number of meteorological stations in Amazonia have been established quite recently, therefore we have chosen to emphasize the detailed spatial variability rather than to derive a new 30-year climatology. About 50% of the rainfall time series have 20 years or more of data, 34% between 10 and 20 years and only 16% between 7 and 10 years. The stations containing less than 10 years of data are distributed randomly in Amazonia, Colombia, Peru and Ecuador. Therefore, they are not located in one particular area.

2. RESULTS AND DISCUSSION

2.1 Rainfall Distributions for Dec-Jan-Feb

Figure 2 shows the total precipitation for the period Dec-Jan-Feb (southern hemisphere summer). The main features are:

a. Centers of high precipitation (900 mm) with a NW-SE orientation are situated in western Amazonia and central Brazil. This orientation coincides with the mean position of the South Atlantic Convergence Zone (SACZ), which is probably associated with low level moisture convergence induced by equatorward-moving frontal systems and also affected by the Andes Cordillera. Frontal influences in tropical South America, notably during austral summer, are quite evident in organizing convection as shown in a number of studies (Kousky and Molion, 1981; Kousky and Virji, 1982; Oliveira and Nobre, 1986). The area of maximum precipitation is centered at about 9 S, 58 W. This latitudinal positioning (9 S) is likely due to solar heating of the surface which is maximum south of the equator at this time of the year. On the other hand, the longitudinal position of this region of maximum precipitation is likely related to the preferred position of convective bands associated with frontal systems. Various theoretical studies show that the upper level anti-cyclonic circulation centered over the Bolivian Plateau (Bolivia High) during austral summer (Figure 3a) is a direct result of latent heat released in this region of high rainfall (Silva Dias et al., 1982; De Maria, 1985; Klemann, 1988; Figueroa and Silva Dias, 1990). As a result of the latent heat release in this zone it would be expected divergent motion at the upper levels and convergent motions at the lower level. This interpretation is supported by the divergent component of the 200 mb winds (Figure 4a), which shows outflow from the region of maximum precipitation. Consistently, for the low levels, Nishisawa and Tanaka (1983) found a region of convergence broadly coinciding with the precipitation maximum over central South America in their analysis of conventional upper air data.

b. The effect of topography in mechanically lifting the low level wind flowing over the barriers seems to be evident as well: Precipitation maxima on the eastern slopes of the Andes Cordillera in Peru and Ecuador and on the western slopes in Colombia, are caused by such effects. On the eastern side the high precipitation totals (2000 mm) in Peru are due to the effects of the mountain barrier on the moisture-laden, mostly westward, low-level flow over Amazonia; likewise, the high precipitation in western Colombia is caused by the topographic effect of the Andes on the eastward winds bringing moisture inland from the Pacific Ocean. The precipitation fields on the Andes slopes present small scale features due to the complexities of the terrain. There may be 5 or 10-fold increases in rainfall for stations only 100 km apart. The precipitation fields shown in this study have been smoothed out as to retain only the large-scale features.

c. Large intraseasonal spatial variability is observed during the austral summer months (not shown). For instance, during December the maximum precipitation centers follow the orientation of the SACZ and are well defined; on the other hand, they are found displaced to the east in February (center at about 53 W, 8 S) and with a quasi-latitudinal distribution. January distribution is similar to the 3-month mean (Figure 2) and the maximum precipitation is centered at approximately 60 W, 10 S, which suggests that the Bolivian High must be quite strong at this time.

2.2 Rainfall Distributions for Mar-Apr-May

The total precipitation for the Mar-Apr-May period is shown in Figure 5. It is readily seen that highest precipitation (900 mm) regions are found along the Equator, with two conspicuous maxima: one along the Atlantic coast and eastern portion of Amazonia and the other over western Amazonia. The maximum along the Atlantic coast is probably associated with instability (squall) lines which form along the coast almost every afternoon and are forced by the sea-breeze circulations (Kousky and Molion, 1981; Cohen et al., 1989). It is known that the zone of the maximum frequency of instability lines is found to accompany the ITCZ migration in the tropical Atlantic Ocean (Cohen et al., 1989). During the March-May period the oceanic ITCZ is found between about 2 S and 4 N along the Atlantic coast where the precipitation maximum is found.

The broad precipitation maximum over western Amazonia is probably due, to a certain extent, to the overall distribution of topography over that area. Most of the maximum lies on the Amazon plains or on the upwind side of the mountains (Andes to the west and the Guyana Shield to the northeast). In that fashion, the relative precipitation minimum separating the two maxima between the Equator and 4 N can, to a first approximation, be ascribed to its location on the downwind side of the Guyana Shield.

The narrow bands of precipitation maxima along the Andes in Peru, Ecuador and Colombia owe their existence to the same reasons (mechanical lifting of the air) described in section 2.1 above for Dec-Jan-Feb.

It is seen that the precipitation pattern as a whole is displaced to the north in Mar-Apr-May and oriented east-west in comparison to the Dec-Jan-Feb. South of this area rainfall decreases rapidly. This type of distribution can be thought of as linked to a more zonally symmetric circulation of the Hadley-type, with subsidence over these areas. It is also known that the descending branch of the Hadley circulation coincides with the subtropical jet core. The upper winds (Figure 3b) show a northward displacement of the southern hemisphere subtropical jet stream consistent with the region of lower precipitation (large-scale subsistence). The divergent component of the upper air circulation (Figure 4b) is also consistent with the broad maximum over western Amazonia.

2.3 Rainfall Distributions for Jun-Jul-Aug

The total rainfall distribution for the northern hemisphere summer is shown in Figure 6. Now the maximum precipitation zone is displaced further north (centered at about 66 W, 3 N) and a sharp decrease is seen south of the Equator. That is the time of the year when the upper level subtropical jet stream is strongest and is displaced equatorward over South America (Figure 3c), again in agreement with the descending branch of a Hadley-type circulation over that area. The episodes of extremely low values of relative humidity in central South America during winter (values as low as 15%) can only be explained by the subsidence of moisture-depleted, upper tropospheric air.

During this season the band of precipitation maxima lies where the tropical South American continent becomes narrower. Therefore, one could expect the latitudinal displacement of this region to follow more closely the displacements of the ITCZ over both oceans (Atlantic and Pacific). Highest precipitation rates in Venezuela, for instance, occur during this season, which is attributed by Goldbrunner (1963) to the ITCZ. The upper level divergent wind does not seem to be directly related to the broad maximum over northwestern South America since the center of the divergent motion is located further north over Central America (we are not showing rainfall over Central America and adjacent oceans which is very high during northern hemisphere summer).

Intraseasonal variability is also high for this season. July precipitation is maximum over northwestern Amazonia and a marked decrease is observed in August. On the other hand, precipitation over Colombia, primarily its Pacific coast, increases in August. This is caused in part by the high SST's along the coast at this time of the year. In fact, not only the SST is maximum at this time of the year but the low level winds show a definite monsoonal character, that is, the wind flows inland.

2.4 Rainfall Distributions for Sep-Oct-Nov

Figure 7 shows total precipitation for the period Sep-Oct-Nov. Important features are:

a) A marked increase over western Colombia (Pacific coast); as mentioned in section 2.3 above. This increase in precipitation is associated to the high SST along the coast and to the onshore winds.

b) Decrease in intensity of the Jun-Jul-Aug maximum precipitation centers and southward migration of the maximum precipitation over western Amazonia.

c) Minimum precipitation over eastern Amazonia, mostly along the Atlantic coast.

d) Establishment of the NW-SE oriented band of enhanced precipitation from western Amazonia through central Brazil.

The upper level subtropical jet stream of the southern hemisphere also shows a southward displacement (Figure 3d) and the center of upper level divergent motion returns to a location over Amazonia (Figure 4d).

Analysis of monthly precipitation fields (not shown) shows that the SACZ appears in October. which coincides with the maximum precipitation over western Colombia. During November all precipitation centers continue their southward progression. The SACZ is completely defined by December which completes the annual cycle of precipitation.

We have only described the average annual cycle of precipitation. This annual cycle can be substantially different during strong ENSO episodes (Nobre and Oliveira, 1986; Kayano et al., 1987 and many others).

2.5 The annual total precipitation

The annual total precipitation is presented in Figure 8 and histograms of monthly total precipitation for selected stations in the area of study are shown in Figure 9. The main features of the annual precipitation distribution are:

a) A broad area of maximum precipitation is seen over western Amazonia around the Equator. With the help of the histograms (Figure 9) it is readily seen that there is no dry season in that area. Although this maximum may be influenced by synoptic-scale phenomena such as westward moving instability lines and frontal influences, its relatively small seasonal variation appears to suggest that the large scale concave shape of the Andes may create the conditions for enhanced low level convergence (Nobre, 1983b) over equatorial western Amazonia.

b) On the northeastern portion of this maximum one can observe a sharp decrease of annual rainfall in the Brazil- Venezuela-Guyana border region. Over this region there is a marked dry season that can be seen by comparing the annual march of precipitation of stations 55 and 58 (Figure 9). It is likely that the relative minimum is associated to the effect of the Guyana Shield.

c) There is an elongated relative minimum from the coast in Suriname to the south as far as 4 S and then to the southeast, where annual precipitation is less than 2 m. It is probable that the westward decrease of precipitation inland from the coast is simply due to the decreasing frequency of rain-producing instability lines. That is, most of the squall lines stay close to the coast (Cohen et al., 1989). To the southwest of this precipitation minimum, the increase in precipitation can be attributed to the interaction of frontal systems with tropical convection which, for reasons not well understood, has a NW-SE orientation as shown in Oliveira (1986).

d) The presence of the Andes Cordillera is quite important for directly causing the orographic rains in the eastern slopes of Peru, Ecuador (stations 47,33 and 13 in Figure 9) and in the western slopes of Colombia (station 178 in Figure 9). The histograms of the stations located south of the Equator show a general westward precipitation increase caused mostly by a shorter dry season. (compare stations 118, 109, 96, 73 and 26). Again this shows the importance of the Andes Cordillera in possibly creating a region of low level moisture convergence near its vicinity. The north-south barrier is also important in channeling cold air during the penetration of frontal systems in the Tropics. Explosive convection episodes in Bolivia and Peruvian Amazonia are apparently linked to these cold air outbursts.

e) It is interesting to notice that the position of the precipitation maximum, located near 9 S, 58 W during austral summer, follows an elliptic trajectory in its annual march. During Mar-Apr-Jun it is found over western Amazonia, in Jun-Jul-Aug, over the northern part and in Sep-Oct-Nov further west. This observation agrees with that of Kagano (1979) which showed that the brightness maximum of satellite images associated with the Bolivian High also presented an elliptic trajectory during the year.

3. CONCLUSIONS

In this study we presented a new analysis of the precipitation distribution over the central and western portions of Tropical South America. To derive this distribution rainfall data for 226 stations were used. We attempted to relate spatial and temporal variability of precipitation to dynamical aspects of the atmospheric circulation over South America. For that purpose we made use of the seasonal average circulation and divergent component of the wind field at 200 mb.

Substantial differences have been found between seasons and from month to month. During southern hemisphere summer, a band of maximum precipitation is observed with a NW-SE orientation which coincides with the average position of the SACZ. It is interesting to note that the maximum precipitation center is located at about 9 S, 58 W on the gentle slopes of the Brazilian Highlands (border between the Amazon Plains and the Brazilian Highlands). The Andes Cordillera strongly affects the precipitation distribution; such that the highest values of rainfall were found on the Andean slopes, to the east of the mountains in Peru and Ecuador and to the west of them in Colombia. During this season, maximum precipitation occurs over central and western Peru. However, almost no rain falls over the Peruvian coast throughout the year.

During Mar-Apr-May season the maximum precipitation areas are oriented more zonally (east-west) and drife to the north as compared to the austral summer season. Maximum precipitation during this time of the year occurs over western Ecuador, which seems to be related to the southernmost migration of the Pacific ITCZ (that is the time at which the Pacific SST maximum reaches its southernmost latitude). On the other hand, rainfall on the eastern side of the Andes in Ecuador occurs throughout the year and this is related to mechanical lifting of the low level wind by the mountains.

The precipitation maximum centers show their maximum northward displacement during northern hemisphere summer. In this season the precipitation in Venezuela is very high.

During Sep-Oct-Nov precipitation maximum centers lose intensity compared to the previous season and move to the west and southwest. Maximum precipitation over Colombia occurs at this time of the year and rainfall also starts to increase in Peru at this time after the dry season. It is during October that convection organized by frontal systems in the SACZ region reappears, but yet at moderate intensity. It will become fully established only in December.

The annual precipitation distribution shows a broad maximum around the Equator over western Amazonia. This region shows a maximum mainly because it presents no dry season. The lack of a dry season is probably related to the presence of the Andes to the west of the maximum which could provide sustained convergence of the low level flow throughout the year. We also observed that the centers of maximum precipitation describe an approximate elliptic trajectory during the year over the central and western portions of Tropical South America.

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