(NASA-CR-173408) THE AMAZON AND CLIMATE N84-22115
(Instituto de Pesquisas Espaciais, Sao Jose)
10 p HC A02/MF A01 CSCL 04B
G3/47 Unclas 12952

SECRETARIA DE PLANEJAMENTO DA PRESIDÊNCIA DA REPUBLICA

CONSELHO NACIONAL DE DESENVOLVIMENTO CIENTÍFICO E TECNOLÓGICO

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ORIGINAL PAGE IS
OF POOR QUALITY

1. Publication Nº
INPE-2999-PRE/451

2. Version

3. Date
Feb., 1984

5. Distribution
☐ Internal ☒ External
☐ Restricted

4. Origin *DME/DPM*
Program *METBA*

6. Key words - selected by the author(s)
AMAZON; CLIMATE; PRECIPITATION; CLOUDINESS
TROPICAL METEOROLOGY
HADLEY-WALKER CIRCULATIONS

7. U.D.C.: *551.58 (811.3)*

8. Title *INPE-2999-PRE/451*

THE AMAZON AND CLIMATE

10. Nº of pages: *9*

11. Last page: *8*

12. Revised by
Luiz Carlos B. Molion

9. Authorship *Carlos Afonso Nobre*

Responsible author

13. Authorized by
Nelson de Jesus Parada
Director General

14. Abstract/Notes

In this paper we review the climatologies of cloudiness and precipitation for the Amazon, explaining the physical causes of some of the observed features and pointing out those which are not well known. The atmospheric circulation over the Amazon is discussed within the framework of the large-scale tropical circulations (Hadley-Walker circulations) forced by deep diabatic heating sources. The question of weather deforestation leads to a reduction in evapotranspiration into the atmosphere, also a reduction in precipitation and its implications for the global climate is discussed. There are some indications that for large-scale clearing of tropical rainforests there would indeed be a reduction in rainfall and that would have global effects in terms of climate and weather both in the tropical and extratropical regions.

15. Remarks *Presented at WMO Climate Conference for Latin America and the Caribbean, held in Paipa, Colombia - Nov 28 through Dec 3, 1983.*

THE AMAZON AND CLIMATE

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1. Introduction

The state of knowledge of the maintenance of the tridimensional time-mean planetary-scale atmospheric flow in the tropics is not nearly as complete as it is for its midlatitude counterpart. Just a few decades ago, motions in the tropics were thought to be forced essentially by midlatitude disturbances propagating equatorward. Currently it is widely recognized that the large-scale tropical circulations are forced mostly by heating of condensation in cumulus clouds within the tropics.

Historically, after the realization that the energy sources for the large-scale motions in the tropics was due to the latent heating of condensation, the next step towards the understandind of the role of the tropics for the general circulation of the atmosphere was to regard tropical circulations as being nearly axisymmetric (Hadley cell type), i.e., symmetric in the east-west direction, and forced by the release of heat of condensation in a narrow strip close to the equator in the region of convergence of the trade winds of both hemispheres, the Intertropical Convergence Zone (ITCZ). Figure 1 for the satellite-derived mean global cloudiness strikingly reveals narrow cloud bands running parallel, and close, to the equator almost ininterruptedly over the tropical oceans. The narrow ITCZ cloudiness bands break down, however, over the tropical continents of South America, Africa and the Indonesian "maritime" continent where cloudiness extends much further poleward.

Land surfaces, unlike oceans, do not store much of the absorbed solar radiation due to their considerably smaller heat capacity. Over tropical continents, a large fraction of the absorbed solar radiation at the surface is used for evapotranspiration and the rapid diurnal warming of the land surface by solar radiation makes the atmospheric column gravitationally unstable so that the water vapor in the planetary boundary layer, when available, is carried upward which upon condensation in cumulus clouds heats up the large-scale environment. This heating of the large-scale environment by an ensemble of deep cumulus clouds creates favorable conditions for water vapor convergence at the lower levels in the boundary layer overa broad area. In turn, boundary layer water vapor convergence reinforces deep convection by making water vapor available for individual cumulus clouds thus establishing a kind of cooperative mechanism between the large and small scales.

Observations show that the distribuition of precipitation in the tropics presents local maxima over continents, and these are relatively confined in relation to the large expanses of the tropical and subtropical oceans where (except for the narrow oceanic ITCZ) rainfall has very low values. Nobre (1983) has shown that localized and intense heat sources in the tropical atmosphere, resulting from continental precipitation, give rise to strong upward motion with associated convergence at the lower levels and divergence at the upper levels and cause large-scale subsidence around the source region. The cloudless and low precipitation areas of the subtropical oceans and deserts are thus likely related to this large-scale subsidence.

These circulations are directly forced by the strong heating gradient with deep heating of the atmosphere in the regions with active convection and cooling due to radiative losses to space in cloudless areas. It is called Hadley cell when the circulation is mostly confined in the meridional plane (north-south direction), and Walker cell when it occurs predominantly in the zonal plane (east-west direction). In reality, observations show a "spill over" of mass in all direction at the upper tropospheric levels over the regions of intense and localized heating. Perhaps a more appropriate name would be Hadley-Walker circulations.

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The Amazon is similar to the other convectively active continental regions of the globe in many respects. It presents local maximum of precipitation, is covered by and large by the same type of vegetation - the tropical rainforest - and is an important heat source for the general circulation of the atmosphere. It differs from the other regions in that it has a narrow and high mountain range, the Andes, extending predominantly in the north-south direction. Such formidable barrier to the prevailing easterly winds profoundly affects the circulation in the lower part of the atmosphere and probably the middle-and upper troposphere as well. The Amazon is also unique in that it exhibits the world's largest drainage basin and the largest forest.

In this paper we review the climatologies of cloudiness and precipitation for the Amazon, explaining the physical causes of some of the observed features and pointing out those which are not well known. Also the question of whether deforestation leads to a reduction in evapotranspiration into the atmosphere, also a reduction in precipitation and its implications for the global climate are discussed in this paper. There are some indications that for large-scale clearing of tropical rainforests there would indeed be a reduction in rainfall and that would have global effects in terms of climate and weather both in the tropical and extratropical regions.

2. Cloudiness and Precipitation

Cloudiness is not a quantitave measure of precipitation; its study, however, provides important information about geographical and seasonal distribution of regions of strong convection and thus precipitation, primarily over the oceans , due to the sparcity of reliable precipitation measurements for those regions.

From Figure 1 for the southern summer season (DJF), we note the following features for South America and adjacent oceans:

a) a very bright area accurring over the central portion of the Amazon,

b) the mean latitude of the ITCZ cloudiness band of Atlantic and Pacific Oceans is 5° - 6°N,

c) over South America and southern Atlantic, cloudiness takes a NW-SW orientation which is similar to the orientation ot the southern Pacific convergence zone (SPCZ) cloudiness band.

For the southern winter season (JJA):

a) a very bright area over eastern equatorial Pacific and northwestern South America,

b) the mean position of the ITCZ cloudiness band over the Atlantic and Pacific Oceans is 7° - 8°N,

c) the width of the ITCZ is larger over the eastern part of the oceans basins (Pacific and Atlantic) than over the western part.

We point out that the oceanic ITCZ cloudiness band lags behind the continental band of cloudiness in its latitudinal migration following the sun's motion. The oceanic ITCZ's southernmost (northernmost) position happens during the MAM (SON) season, whereas the continental cloudiness responds more quickly to the solar forcing, i.e., its southernmost (northernmost) displacement occurs in the DJF (JJA) season. This oceanic lag is due to the much larger thermal inertia of oceans in comparisson to the atmosphere and the tendency for the ITCZ cloudiness bands to lie over warm waters, i. e., the peak of sea surface temperatures occur a few months after the peak of solar heating. This fact is important once one realizes that when the oceanic ITCZ over the Atlantic reaches its southernmost position in March, its western end lies over northeasthern Brazil and causes heavy precipitation over land areas. This ITCZ-induced precipitation is probably the most important mechanism for that semi-arid region.

Figure 2 shows the mean annual precipitation for South America. It shows a region of maximum precipitation to the east of the basin, along the Atlantic coast, with rainfall in excess of 3000 mm a year and a second, fairly broad, maximum to the westnorthwest of the basin with maximum precipitation of over 3500 mm a year. In between these two maxima there is a relative minimum in the lower Amazon basin with annual values in the range of 1600 mm. This area of lower precipitation is flanked to the south by a region of relatively high values of precipitation (maximum greater than 2500 mm a year). That secondary maximum joins with the western maximum in an almost continous high precipitation band from the headwaters of the Negro River to the Brazilian highlands, forming a semi-circle which approximately follows the shape of the Andean Mountain Range.

Are the mechanisms responsible for the observed distribution of precipitation in the Amazon known? There are no widely accepted answers to this questions and that is probably because our present understanding of the large-scale atmospheric processes governing the motions in that region, and of the interaction of the forested surface with the atmosphere is incomplete.

The extremely high and localized values of precipitation in narrow strips along the Andean eastern slopes are due to the well-known fact of upglide condensation, i.e., wet areas on the upwind side of a mountain and a "rain shadow" on the downwind side so those localized maxima are due to the easterly winds being lifted when they flow over the Andes. The reasons for the other precipitation maxima are less well-known.

The shape of the maximum precipitation line, which approximately forms a semi-circle along the basin's southern and western border and roughly parallel to the Andes seems to suggest that low-level convergence of the large-scale flow caused by mechanical deflection of the air flow by the Andes may account for the observed maxima.

Kousky and Molion (1981) have suggested an alternative explanation for these maxima. They might owe their existence to westward-moving lines of instability which have their origin in the sea-breeze along the Atlantic coast--which incidentally, causes the traditional late afternoon showers in the city of Belem. As these lines of instability propagate westward, they cross the regions of low precipitation in the lower Amazon during night-time and for that reason they would generate less convection and thus less precipitation in the lower Amazon. By the time the lines of instability reach western Amazon during the following day they would intensify due to the strong surface heating by the sun, thus causing more rainfall and so contributing to the precipitation maximum in that region. Firm observational evidence for this hypothesis is still lacking both in terms of frequency, i. e., a large number of these lines would have to occur in a year to account for the observed distribution of rainfall, and also in terms of rain-generating potential of these events.

Kousky (1980) has suggested that the coastal rainfall maximum is probably caused by nocturnal convergence between the trade-winds and the nocturnal land-breeze. The different surface friction of land and the ocean surface could also contribute to creating convergence along the coast, therefore causing that maximum. The observational basis at the moment does not allow one to draw conclusions on which physical mechanism is more important in determining that rainfall maximum.

So far we have discussed the geographical distribution of the mean annual precipitation. Now we turn our discussion to temporal changes in the rainfall patterns or the seasonal distribution of rainfall over South America. Figures 3a and b show the global distribution of precipitation for DJF and JJA seasons, respectively. It is clear from these figures, and it was already evident in Figure 1 for the seasonal cloudiness, that the distribution of rainfall experiences profound changes with the seasons. For the DJF season most of the precipitation is concentrated in the southern hemisphere; over the Amazon is intense (greater than 10 mm/day) and quite localized both longitudinally and latitudinally, and centered at about 10°S. For the JJA season the maximum over South America is centered at 10°N with a NW-SE orientation following the orientation of land in Central America; there is high precipitation over northwestern Amazon. The MAM season resembles more closely the DJF season in that most of the rainfall is to be found in the southern hemisphere; whereas the SON season is closer to the JJA season with most of the precipitation concentrated in the northern hemisphere.

To a first approximation the seasonal displacement of the centers of maximum precipitation is due to solar forcing, i.e., it follows the solar motion from one hemisphere to the other. The general SE-NW movement of the center of rainfall maximum may be understood in terms of the tendency for the maximum to lie over land due to the mechanisms mentioned in the Introduction. The region of maximum precipitation over western Amazon experiences no well-defined dry season, presents heavy rains all year long which explains why the maximum is found there. The central and southern portions of the Amazon experience a well-defined dry period during the southern winter. On the eastern part along the Atlantic coast there is no marked dry season and not surprisingly that region presents a rainfall maximum. This suggests that the rain-producing mechanisms for that region are less dependent directly on the solar forcing as are, for instance, those for central and southern Amazon.

3. The Tropical Rainforest and Climate

Another important question that arises in connection with tropical precipitation is the relationship between tropical precipitation and the underlying surface, whether ocean, forested land, land covered with crops or pasture, or bare land. Are forested surfaces active in providing the conditions for the observed copious rainfall over tropical continents or are they just passively responding to high precipitation and consequently high soil moisture content that would be high even in the absence of the rainforest?

The answer is likely to be that the overall rainfall distribution for the equatorial continents would be high even in the absence of the rainforest since some of the global-scale mechanisms contributing to high equatorial precipitation such as the solar heating of the land-surface and water vapor convergence due to convergence of the trade winds of both hemispheres would still be present no matter what the underlying surface is. The rainforest, however, is very likely to be an important climatic factor in determining the total amount of rain and its seasonal distribution because this vegetation type is capable of maintaining high evapotranspiration rates into the atmosphere, probably higher than any other vegetation type, and also for its high soil moisture holding capacity so evapotranspiration is not limited by water stress. Continued levels of high soil moisture are kept by a complex system including the top layers of the soil and the forest's dense root system which allows minimal water losses from the system. Therefore precipitation in the tropics would be high even if the land-surface were not covered by the rainforest but not nearly as high as what is observed which is probably due to the efficient recycling of moisture by the forest through the mechanism of evapotranspiration.

There have been a number of attempts to assess the effects of changing soil moisture and albedo (earth's reflectivity to solar radiation) on a global scale making use of numerical models of the general circulation of the atmosphere (GCM's) as a mean to investigating changes in the vegetation cover. The results of such numerical calculations have been inconclusive to date (Mintz,1982). Our presently inadequate knowledge of the physical processes involved in ground hydrology and in the planetary lower (boundary) layer of the atmosphere, notably how to correctly represent evapotranspiration and how to include the effects of cumulus clouds in the GCM's, have severely limited the usefulness of these numerical models to study regional and global effects of large-scale tropical deforestation.

The sensitivity of weather and climate resulting from changes in evapotranspiration and albedo is difficult to assess from observation. Mintz et al (1983) remarked that several calculations have shown that a decrease in the latent heat transfer, i. e., a decrease in evapotranspiration from the land into the atmosphere is nearly balanced by an increase in the sensible heat transfer. Sensible heat, however, warms the air only in a relatively shallow layer in the planetary boundaty layer and it is also localized in time and space. The latent heat heats up the free atmosphere to the tropopause when the condensational heat is released in tall cumulus clouds. This has important dynamical implications for the general circulation of the atmosphere because motions of a planetary-scale can be generated by this deep heat source. The Hadley-Walker circulations, for instance, are directly forced by these deep heat sources. The sensible heating by contrast can generate only shallow, localized circulations. Also due to the transpot of water vapor the latent heating can be realized at some distant place and at a later time. Therefore the difference in the vertical distribution of sensible and latent heating makes the thermally-forced planetary scale atmospheric circulation in the tropics sensitive to evapotranspitation, thus to the type of vegetation cover.

Large scale changes in tropical precipitation in the Amazon would translate into changes in the strength and location of the Hadley-Walker circulations. These are of planetary scale and linked to the general circulation of the extra-tropics, thereby providing the mechanism by which changes in the vegetation cover in the tropics over a broad area might ultimately influence the climate and weather on a global scale.

Recently Webster and Holton(1982) have shown that propagation of energy from one hemisphere to the other is possible when there is a 'duct' of equatorial westerly winds at the upper troposphere. The upper tropospheric equatorial westerly winds are, however, a branch of the Walker cell being forced directly by tropical heat sources. A change in intensity and position of these heat sources that might be caused by large scale deforestation would have the effect of changing the strength and position of the upper level westerly winds. thus affecting the interhemispheric transfer of energy.

Nobre(1983) has suggested that the subtropical jet stream of the winter hemisphere, which is a important feature of the general circulation of the atmosphere, is forced partly by the tropical heat sources over tropical continents and the jet stream connects the upper tropospheric atmospheric circulation of the tropics with the extra-tropics. Through this connection a change in the forcing mechanism in the tropics would affect a remote location in the extra-tropics.

4. Conclusions

It probably can be said that the climate of the Amazon is in dynamical equilibrium with the underlying tropical rainforest, and that the observed high levels of precipitation are at least partly due to the existence of the forest which efficiently recycles water vapor back to the atmosphere. Large scale removal of the tropical rainforest actually might lead to a reduction in the amount of rainfall as a result of a decrease of land evapotranspiration to the atmosphere. Environmental degradation following deforestation would lead to soil erosion and compaction would greatly increase run-off and peak streamflows of Amazonian rivers. Also a decrease in total precipitation would be manifested as an increase in the duration of the dry season and consequently a reduction of streamflow for that period.

In addition to these basin-scale effects there might be global effects on weather and climate due to changes in the thermally-forced planetary scale tropical circulations which are forced by tropical latent heating, and also changes in the subtropical jet stream which links tropical and extra-tropical atmospheric circulations in a truly global scale. It also should be mentioned that clearing and burning of tropical rainforests is likely to increase the concentration of CO_2 in the atmosphere, therefore enhancing the "greenhouse" effect of the earth's atmosphere which might cause global climatic changes.

Acknowledgements

Part of this work was done while the author was at the Goddard Space Flight Center, MD, U.S.A. and was sponsored by USRA under contract NAS5-27297 with NASA.

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DECEMBER JANUARY FEBRUARY

MARCH APRIL MAY

JUNE JULY AUGUST

SEPTEMBER OCTOBER NOVEMBER

Figure 1 Satellite-derived tropical cloudiness for each season

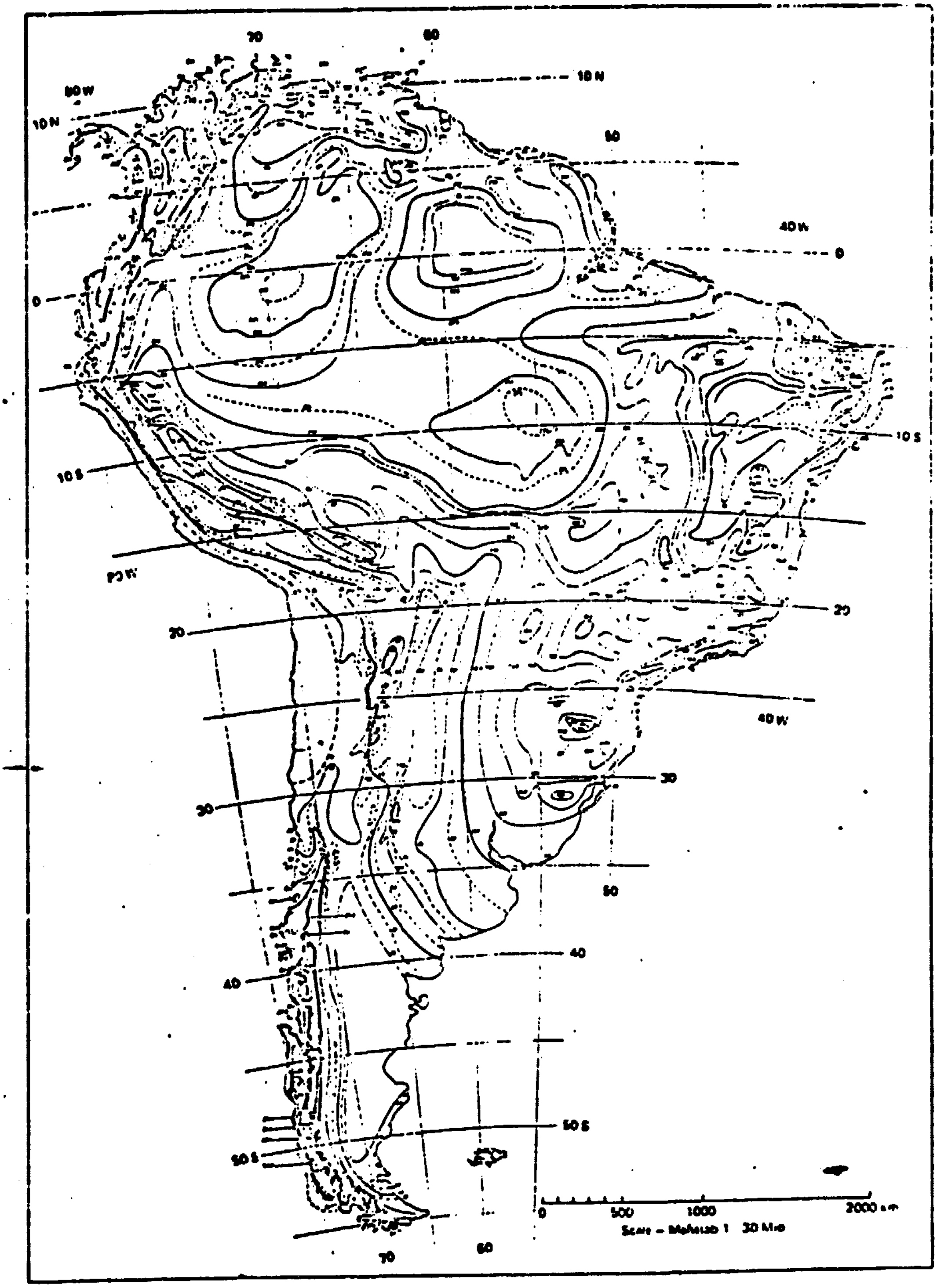

Figure 2 Mean annual precipitation for South America in centimeters of water (after A. Baumgartner and E. Reichel, 1975)

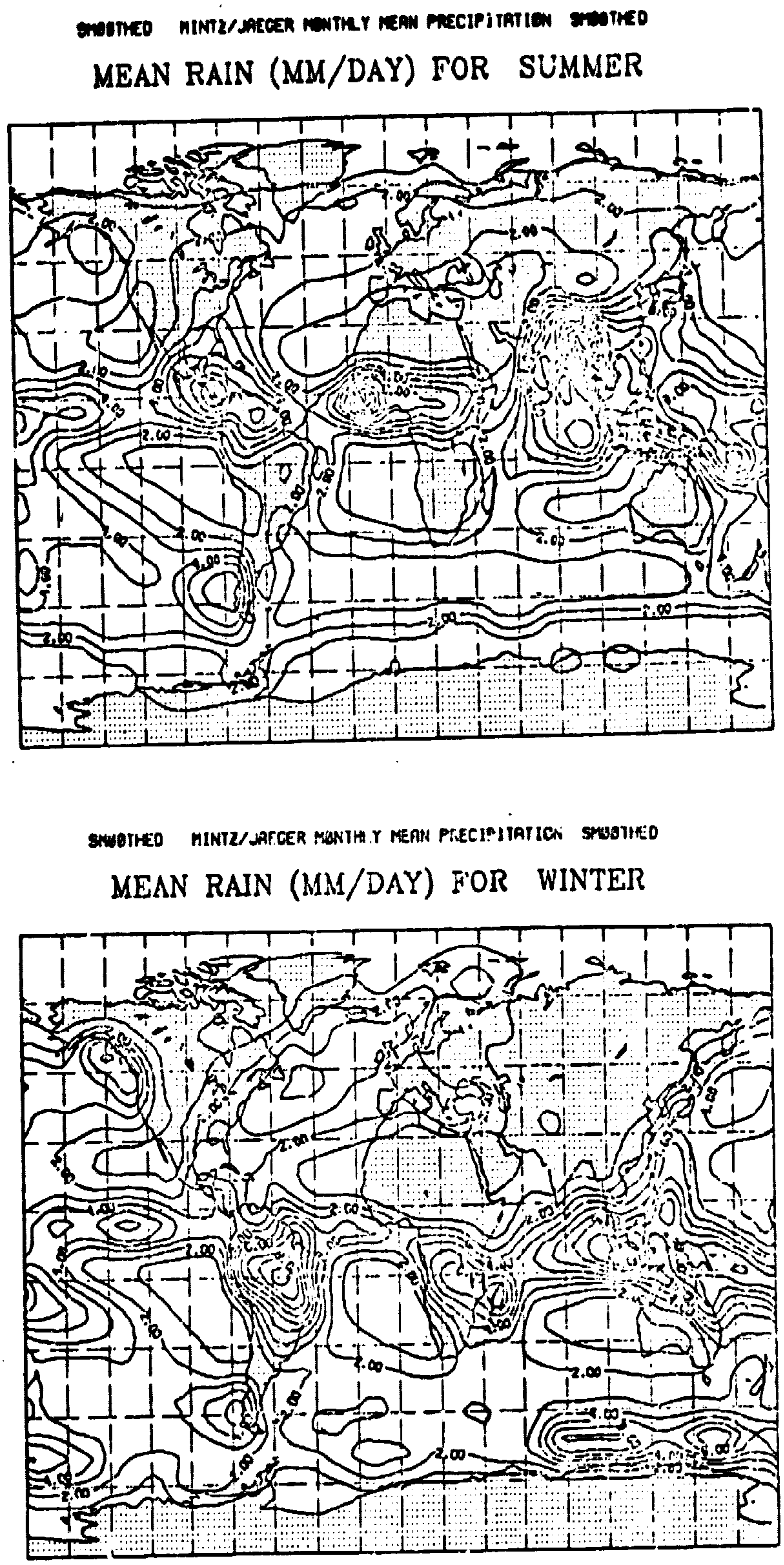

Figure 3 - Seasonal precipitation for the globe in mm/day.
a) December-January-February season;
b) June-July-August season.