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14. Abstract/Notes

The climatic influence of the hydrologic cycle is reviewed with emphasis on tropical regions. The latitudinal distribution of precipitation shows a maximum in the Intertropical Convergence Zone (ITCZ), relative minima in the regions dominated by the subtropical anticyclones and secondary maxima in mid latitudes. On the other hand, evaporation presents maxima in the regions of the subtropical anticyclones. Global patterns indicate that the tropics rainfall is larger over continents than over oceans. The hydrologic cycle of a large continental area, the Amazonas Basin, is discussed in more detail. The long term average water balance of this basin, together with the hypotesis of climate stability, are used to demonstrate that the annual river discharge is equal to the net advection of water vapour into the basin. The computed net advection was found to explain about 50% of the mean annual rainfall. The remaining 50% is provided by water evaporated locally. In this scenario, the controvertial interaction between the forest and the hydrologic cycle is highlighted. An attempt is made to show how the removal of forest in tropical regions may affect the hydrologic cycle.

15. Remarks *Present at the Climate Conference for Latin America and the Caribbean, Paipa (Boyaca), Colombia - 28 Nov - 3 Dec. 1983, Sponsored by the World Meteorological Organization.*

THE WATER BALANCE AND CLIMATE

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1. INTRODUCTION

The climate of a region on the Earth's surface depends on several factors of large, or macro, and regional scales, called climatic controls, the most important being.

a. Macro-scale climatic controls:

- The solar constant, i.e. the short-wave radiative energy arriving from the sun at the "top" of the atmosphere per unit area, per unit time; the orbital parameters and the gaseous and particulate components of the Earth's atmosphere together determine the latitudinal distribution of the solar energy on the planet's surface. This is, by far, the most important source of energy sustaining life and the variety of physical phenomena occurring in the earth-atmosphere system;
- The distribution of continents and oceans, with their contrasting albedos;
- The general circulation of the atmosphere, which can be regarded as a consequence of the two factor above.

b. Regional scale climatic controls:

- The general circulation of the atmosphere, acting on this scale;
- The local topography;
- The nature of surface cover;
- The hydrologic cycle;
- The influence of oceans currents on coastal regions.

In this paper, the hydrologic cycle as a climatic control will be discussed, with no consideration to the cryosphere. The hydrologic cycle has to be considered as a climate forming factor, first of all because it is not only a product of the climate itself but also of the biogeophysical landscape; second, it exerts an influence on climate which cannot be reduced to just the combined effects of the other climate forming factor, namely the interaction between the atmospheric moisture, precipitation and run off .

After discussing the world water balance and the relationship between the hydrologic cycle and the mean tropospheric flow, the water budget of the Amazonas Basin will be considered.

2. THE HYDROLOGIC CYCLE AND THE TROPOSPHERIC CIRCULATION

The long term average of the surface hydrology requires that precipitation (P) equals to evaporation (E) plus run off (R). For the globe as a whole, precipitation equals to evaporation.

Table 1 adapted from Brutsaert (1982) shows the estimates of world water balance made in the past decade. The available data base required for this purpose is recognized to be far from adequate. Neverthless, there is a fair agreement among the calculate values, being the estimated global precipitation (evaporation) about 1 m y^{-1}.

TABLE 1

RECENT ESTIMATES OF WORLD WATER BALANCE (my^{-1})

REFERENCE	LAND ($1.49 \times 10^8 Km^2$)			OCEANS ($3.61 \times 10^8 km^2$)			GLOBAL
	P	E	E/P	P	E	E/P	P=E
Budyko (1970, 1974)	0.73	0.42	0.58	1.14	1.26	1.11	1.02
Lvovitch (1970)	0.73	0.47	0.64	1.14	1.24	1.09	1.02
Lvovitch (1973)	0.83	0.54	0.65	-	-	-	-
Baumgartner and Reichel (1975)	0.75	0.48	0.64	1.07	1.18	1.10	0.97
Korzun et alii (1978)	0.80	0.485	0.61	1.27	1.40	1.10	1.13
Average	0.77	0.48	0.62	1.16	1.27	1.09	1.04

Over the land, the evaporation is about 62 percent of precipitation. Assuming long term average and climate stability, the average run off is 38%.Over the oceans, however, evaporation is some 10% higher than precipitation; this excess is supplied by the land surface run off.

Figure 1, extracted from Seller (1965) shows the average annual latitudinal distribution of evaporation (E), precipitation (P) and land surface run off (R). As can be seen, generally speaking the humid tropics are the region contained roughly between 12^{o}N to 10^{o}S where precipitation exceeds evaporation, with the excess of water - the total run off - being transported to higher latitudes. The subtropical regions (20^{o} - 40^{o}) are characterized by an excess of evaporation over precipitation, which is transported equatorward and poleward. As a consequence, the mid latitudes (40^{o} - 60^{o}) present secondary maxima of precipitation.

Figure 2 present the average global patterns of rainfall in mm day^{-1}. Confining the attention to the Central and South American sectors and adjacent oceans, it can seen that the maximum precipitation rates (6 mm day^{-1}) occur over the Amazonas Basin and the southern part of Central America and in a narrow belt over the oceans, the Intertropical Convergence Zone; the subtropical oceans, both the Pacific and the Atlantic are by and large,regions of precipitation minima (1 mm day^{-1}). Other prominent features are the maximum (5 mm day^{-1}) over southern Chile and the sharp gradient northward across Mexican territory.

These patterns are closely tied up with the large scale mean tropospheric flow as it can be seen in Figure 3, supplied by Kousky (1983).

These are charts of mean stream lines for two seasons, summer (Jan) and winter (Jul) and two levels 850 mb and 250 mb. Over the oceans at low levels (Figures 3a and 3c) the subtropical anticyclones (A) are characteristics of both seasons. In this area, occur subsident motion with consequent inhibition of cloud formation and precipitation (see Figure 2). The solar radiation incident over these relatively cloud free areas promotes high rates of evaporation, as illustrated in its latitudinal mean distribution (figure 1). At high levels, in the summer (Figure 3b), an anticyclone (A) centered over Bolivia is well developed. The divergent motion at higher levels is associated with convergence at low level, upward motion and, consequently, high precipitation rates over this large area. In the winter (Jul), this anticyclone (A) is restricted to the northwestern part of South America and parts of Central America so the seasonal maximum of precipitation is displaced as indicated by the double-headed arrow in Figure 2. Most of the Amazonas Basin has its dry season in this period.

In summary, the global patterns of precipitation and evaporation result primarely from the action of general circulation of the atmosphere, as far as the dynamic mechanism are concerned. An attempt is made below to show that a large continental area, such as the Amazonas, can give significant contribution to the local precipitation totals acting as a source of water vapor.

3. THE WATER BALANCE OF THE AMAZONAS REGION

For the purpose of the present discussion the hydrologic cycle is broken into two parts: the surface and the aerological or atmospheric branches.

3.1 The Surface Water Balance

Under natural conditions, disregarding irrigation and dew formation, the principle of continuity for the water substance requires that, for a column of soil extending from the surface to a depth where the vertical moisture exchange is practically absent,

$$P = R + E \pm \Delta m/\Delta t \qquad (1)$$

where

P = precipitation
E = evaporation
R = total runoff
$\Delta m/\Delta t$ = exchangeable soil moisture

On an annual basis, considering long term means, the exchangeable soil moisture tends towards zero and Equation (1) becomes

$$\overline{P} = \overline{E} + \overline{R} \qquad (2)$$

where the overbar indicates annual means.

Dividing both sides by $\overline{P}$ Equation (2) may be written as

$$\overline{R}/\overline{P} + \overline{E}/\overline{P} = 1 \qquad (3)$$

The first term represents the "run off ratio" whereas the second is said to be the "evaporative ratio".

3.2 The Atmospheric Water Balance

For the atmospheric column, extending from the surface to the "top" of the atmosphere, the balance equation, for mass continuity is written as

$$E + A = P \pm \Delta W/\Delta t \qquad (4)$$

where A = net import rate of water vapor into the air column (advection)

$\Delta W/\Delta t$ = storage of water vapor in the column

Again when one takes long term means, the storage of moisture in the column approaches zero and Equation (3) is rewritten as

$$\overline{E} + \overline{A} = \overline{P} \quad (5)$$

As before the overbar indicates annual means. Similarly, dividing both sides by $\overline{P}$ one has

$$\overline{E}/\overline{P} + \overline{A}/\overline{P} = 1 \quad (6)$$

where $\overline{A}/\overline{P}$ is the "advective ratio". Equation (6) partitions the contributions of the locally evaporated water and the advected water vapor to the regional mean precipitation.

3.3 The Regional Water Balance

Comparing Equations (2) and (4) one concludes that, for a stable climate, the total surface run off must balance the net import of water vapor for the atmospheric-soil column, that is:

$$\overline{R} = \overline{A} \quad (7)$$

or from (3) and (6):

$$\overline{R}/\overline{P} = \overline{A}/\overline{P}$$

Assuming an annual mean rainfall equal to 2400 mm and an area equal to 6.3×10^6 km^2 for the Amazonas Region, Molion (1976) used a method described by Palmen (1967) for estimating the divergence of water vapor flux with aerological data extract from Newell (1972) and found the advective ratio to be 0.53. In view of Equation (6), this would mean that the local evaporation contributes 47% to the precipitation over the region, in average. He also used two climatological methods, Penman (1948) and Albrecht (1962), applied to 40 climatological stations in the region and found similar results.

From Equation (3) it is also possible to estimate the evaporative ratio, provided the mean annual river discharge is known and the hypothesis of no leakage through the basin floor is accepted. Taking the river discharge equal to 200.000 m^3 s^{-1} yields a run off ratio equal to 0.44 and therefore, an evaporative ratio equal to 0.56, or 56% contribution to precipitation. This result is of the same order as those listed in Table 1 for continental areas.

Bearing in mind the data base limitations, one may conclude that in the Amazonas Region, in average, the local evaporation contributes about 50% to precipitation, the remaining being provided by advected water vapor mainly from Atlantic Ocean. Studies realized in mid latitudes (see e. g. Rasmusson, 1968; Benton and Estoque, 1954) state that the locally evaporated water contributes about 10% to precipitation. In other words, precipitation is essencially formed by water vapor transported via general circulation into the region. This may be true for mid latitudes. However, in the case of Amazonas, Salati et alii (1983) using an independent methodology, the isotopic hydrology have confirmed the results found by Molion (1976).

4. CONCLUDING REMARKS

It has been pointed out that in the Amazonas Basin the local evaporation contributes about 50% to precipitation as opposed to the mid-latitudes where such a contribution is about 10%.

One of the main concerns relative to climate changes, is the ability that man has acquired of transforming the scenario of large land masses. This is particularly true with respect to deforestation i. e. the removal of natural forests. It appears that a large scale deforestation of Amazonas Region would interfere in the regional climate and possibly in the global climate.

Although there are no proved evidences, scholars agree that deforestation reduces evaporation locally. Numerical experiments (e. g. Henderson-Sellers, 1981) also confirm such a tendency. Since in the Amazonas the local source of water vapor for precipitation is, in average, of the same magnitude of the advected vapor, a reduction of evaporation would change the hydrologic cycle, probably reducing precipitation. The forest, composed of several strata and a litter layer, intercepts presumably 15 - 20% of the annual rainfall. The intercepted rainfall cycles directly back to the atmosphere without taking part in the surface cycle. When forest cover is removed, this amount will be available at ground level mainly to increase the overland flow, changing, drastically the monthly runoff pattern, with larger flood peaks in the rainy season and lower river levels in the dry season.

In the global scale it seems that the Amazonas Region is one of the most important regions of the world providing heat to the General Circulation (Kasahara and Mizzi,1983). However, the magnitude of this latent heat contribution and how a reduction of precipitation, or equivalent latent heat release, would affect the total amount of heat being transported poleward, and consequently the global climate, are not fully known yet.

There is an urgent need to quantify the interaction between the forest and the atmosphere, and to model the possible changes in the hydrologic cycle and the global climate, resulting from a large scale deforestation.

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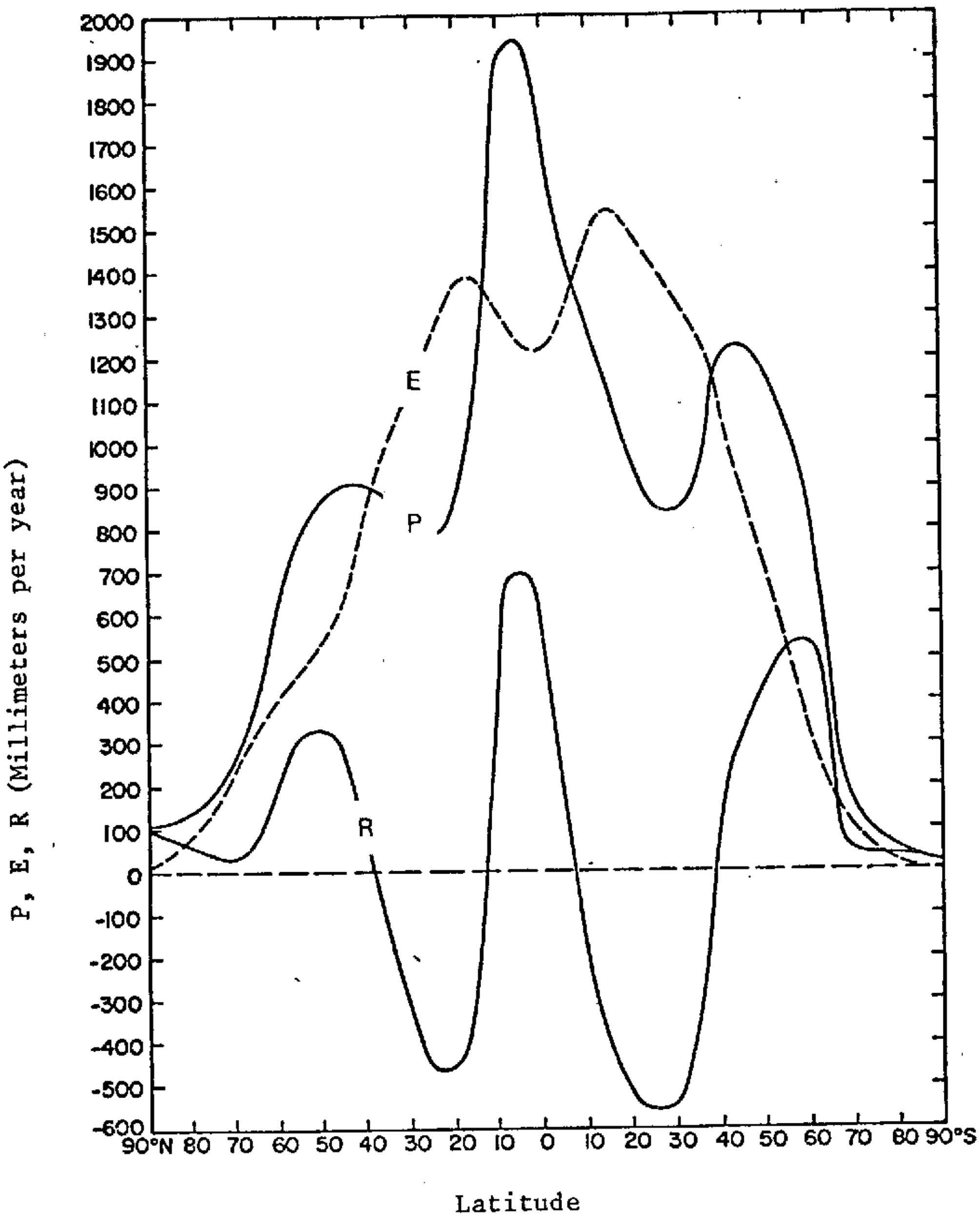

Fig. 1 - The average annual latitudinal distribution of precipitation (P), evaporation (E) and total run off (R).

Source: Sellers, 1965.

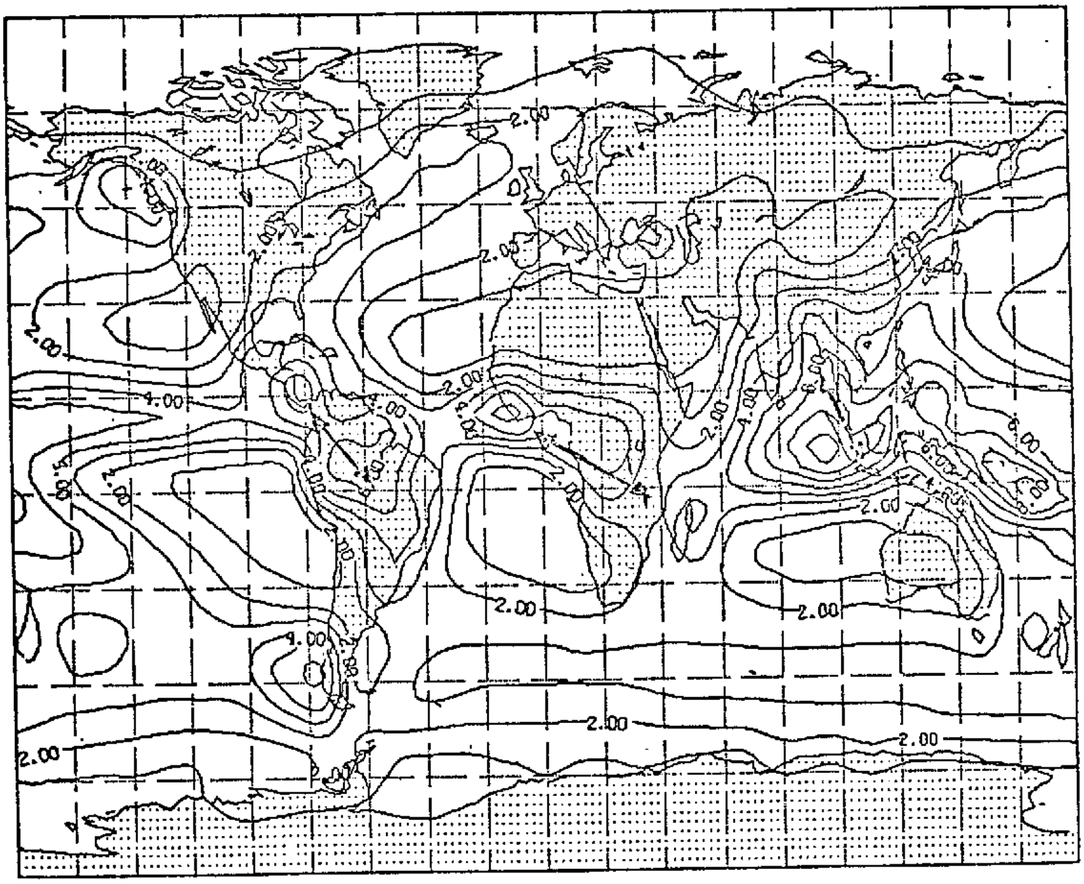

Fig. 2 - Global annual precipitation in mm/day (map prepared at GLAS based on data from Jaeger, 1976). Arrows indicate direction of displacement of centers of maximum precipitation between summer and winter (courtesy of C. A. Nobre, 1983).

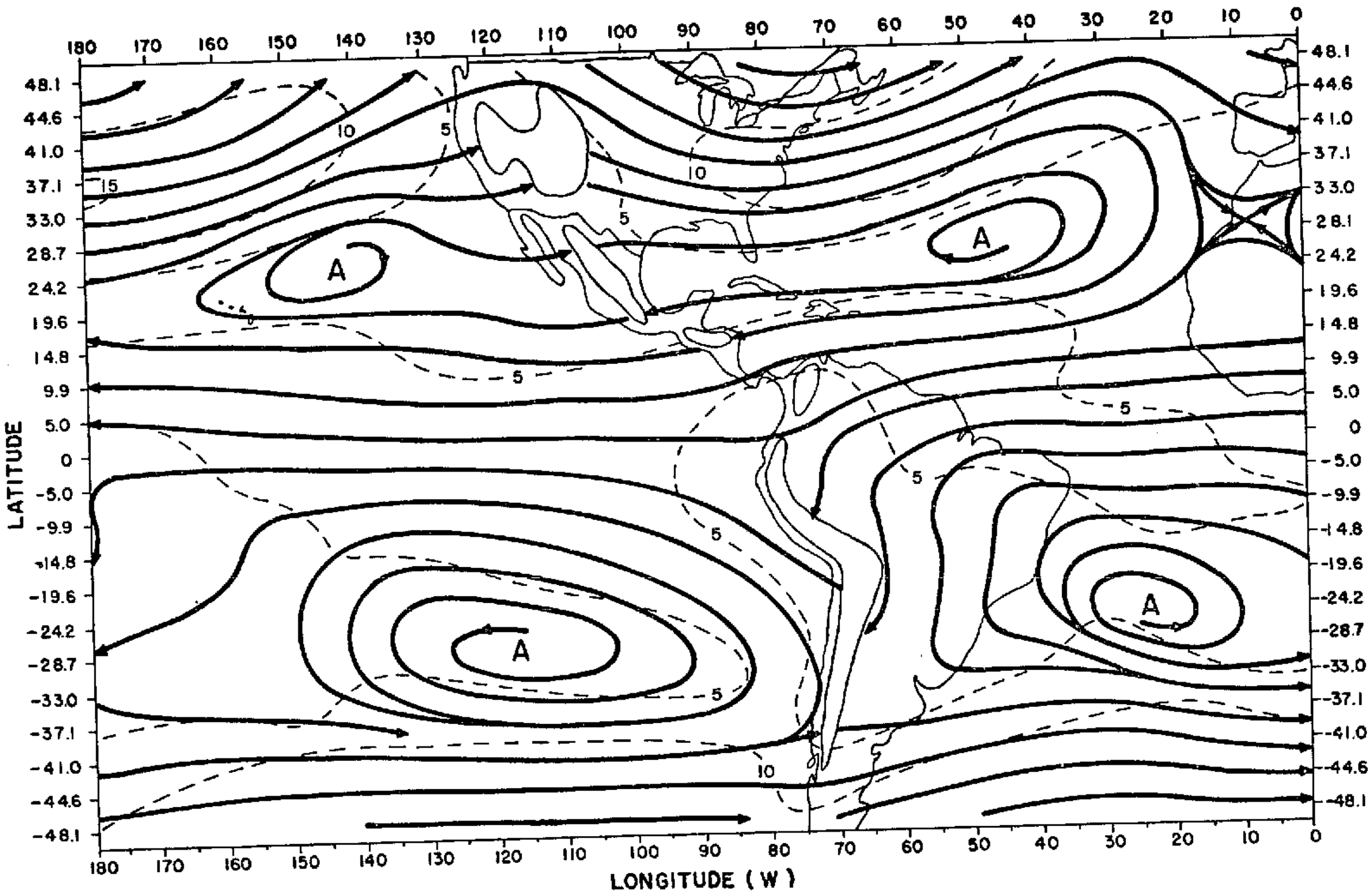

Fig. 3a - Streamlines representing the mean tropospheric flow for January at 850 mb (Kousky, 1983).

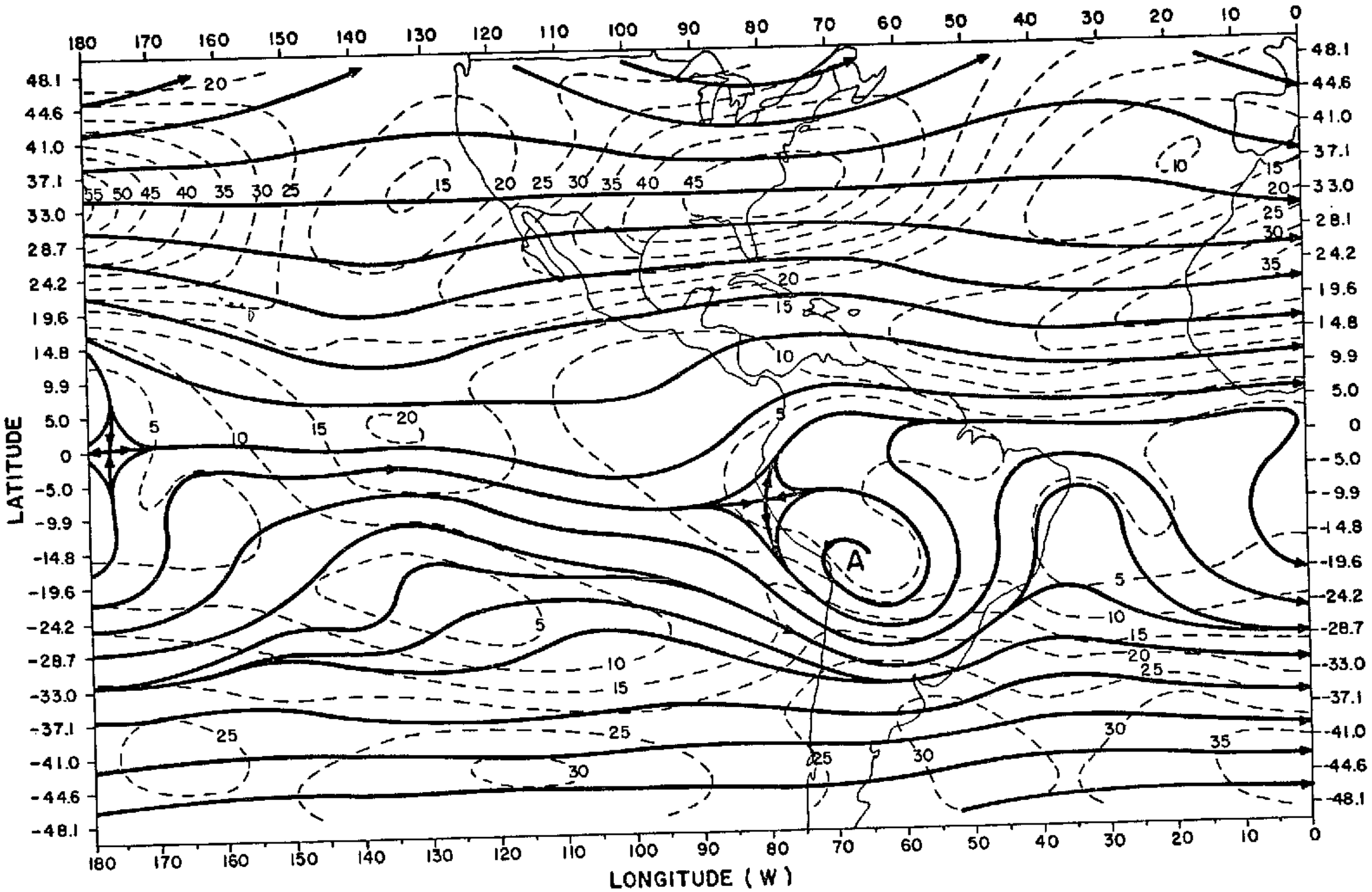

Fig. 3b - Streamlines representing the mean tropospheric flow for January 250 mb (Kousky, 1983).

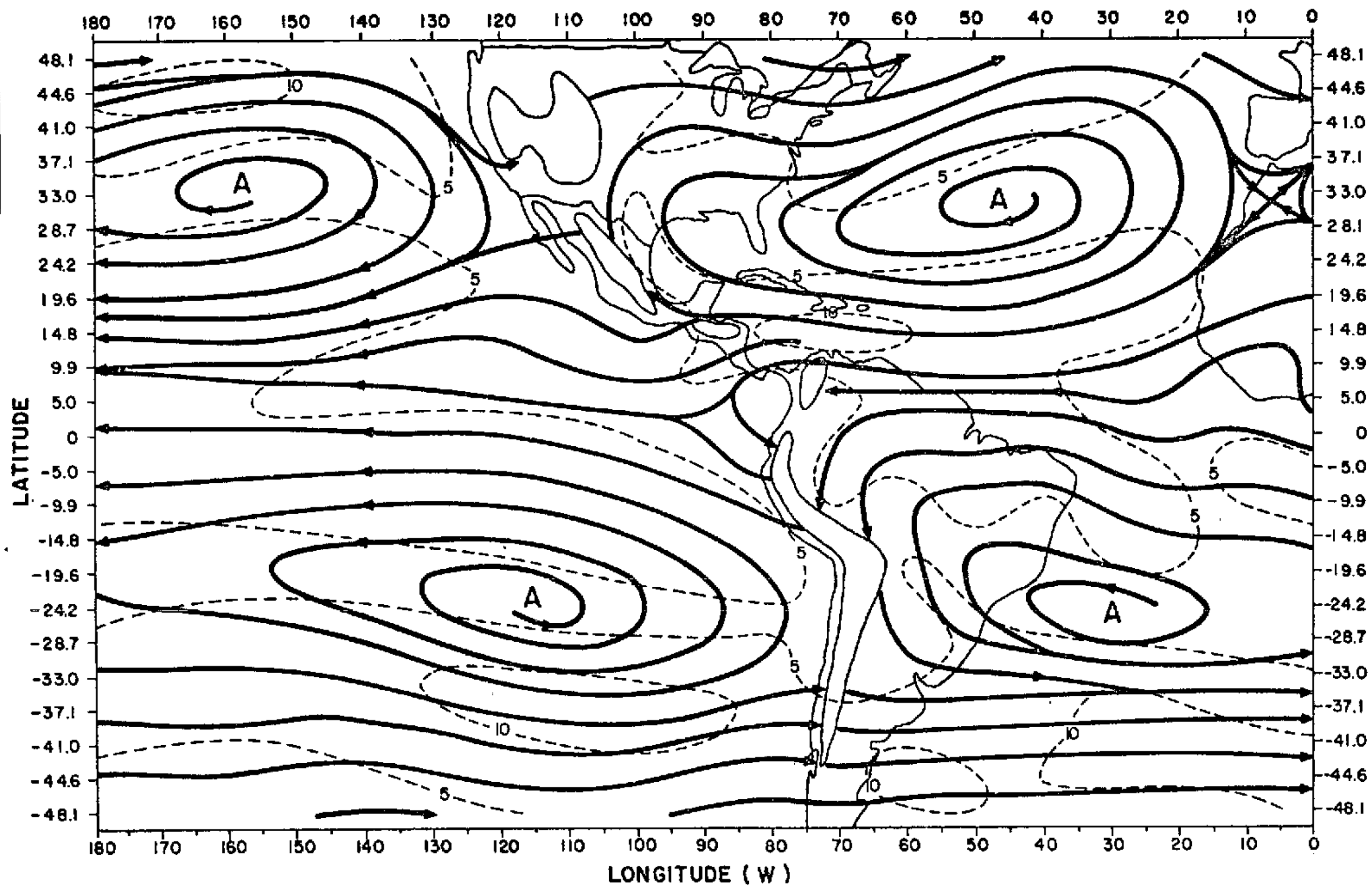

Fig. 3c - Streamlines representing the mean tropospheric flow for July at 850 mb (Kousky, 1983).

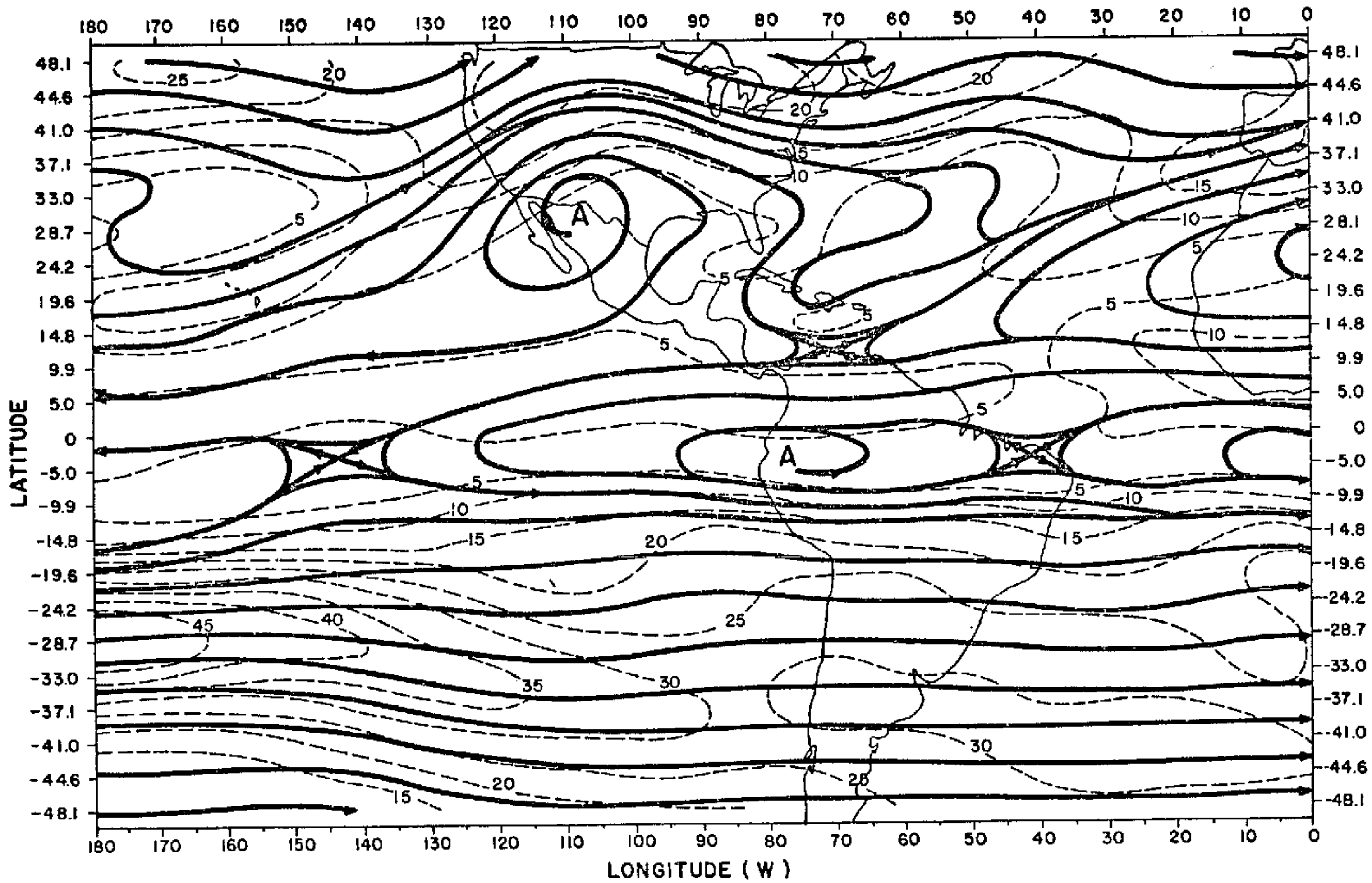

Fig. 3d - Streamlines representing the mean tropospheric flow for July at 250 mb (Kousky, 1983).