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14. Abstract/Notes *This study aims at obtaining a better understanding of the relationship between Northeast Brazil interannual precipitation variability (droughts and flooding events) and the global changes in atmospheric circulation. Particularly, the work of Namias (1972) is further explored by analysing ten years of monthly mean upper air data (1968-1977) for the region 48N-48S, 20W-90W. At 700mb, results show an increase of eddy momentum flux ($\overline{u'v'}$) in the tropical North Atlantic for a wet year (1974) and a decrease for a dry year (1972). The eddy potential energy flux ($\overline{v'\phi'}$) shows a reversal of slope in the tropical region (about 20S to 10N) for these two years. Most of the contribution comes from the longitude band of 20W-50W, which includes Northeast Brazil. The 200mb flow is westerly in most of the cases in the North Atlantic sector up to 5N or even to the equator. This condition favors the coupling between the Northeast Brazil region and the extra-tropics, by allowing the propagation of mid-latitude perturbations into the tropics (Webster and Holton, 1982; Simmons, 1982). On the other hand at 700mb the flow is easterly in most of the tropical North Atlantic, thus raising the importance of baroclinicity in this problem. A simple, non-linear, two layer model similar to that of Mak (1969) is used with realistic forcing in the northern boundary (35N) to intercompare the model results for two extreme cases of drought (year 1972) and flood (year 1974) and to verify conditions for equatorward propagation when baroclinicity is present.*

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A STUDY OF THE INFLUENCE OF EXTRA-TROPICAL LATITUDE SYSTEMS ON THE CLIMATIC VARIABILITY IN NORTHEAST BRAZIL

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ABSTRACT

This study aims at obtaining a better understanding of the relationship between Northeast Brazil interannual precipitation variability (droughts and flooding events) and the global changes in atmospheric circulation. Particularly, the work of Namias (1972) is further explored by analysing ten years of monthly mean upper air data (1968-1977) for the region 48N-48S, 20W-90W. At 700mb, results show an increase of eddy momentum flux ($\overline{u'v'}$) in the tropical North Atlantic for a wet year (1974) and a decrease for a dry year (1972). The eddy potential energy flux ($\overline{v'\phi'}$) shows a reversal of slope in the tropical region (about 20S to 10N) for these two years. Most of the contribution comes from the longitude band of 20W-50W, which includes Northeast Brazil. The 200mb flow is westerly in most of the cases in the North Atlantic sector up to 5N or even to the equator. This condition favors the coupling between the Northeast Brazil region and the extra-tropics, by allowing the propagation of mid-latitude perturbations into the tropics (Webster and Holton, 1982; Simmons, 1982). On the other hand at 700mb the flow is easterly in most of the tropical North Atlantic, thus raising the importance of baroclinicity in this problem.

A simple, non-linear, two-layer model similar to that of Mak (1969) is used with realistic forcing in the northern boundary (35N) to intercompare the model results for two extreme cases of drought (year 1972) and flood (year 1974) and to verify conditions for equatorward propagation when baroclinicity is present.

1. Introduction

The interannual variability of precipitation over Northeast Brazil (hereafter called Nordeste) is quite high. The occurrence of recurrent drought conditions severely affects a population of over 30 million people. This variability seems to be linked to the large-scale atmospheric circulation anomalies over the globe as has been pointed out by Namias (1972), who associated years with high cyclonic activity at 700mb in the Newfoundland - Greenland region with rainy years in Nordeste and the reverse for drought years. Intense blocking conditions over North America are usually associated with devastating droughts over Nordeste.

Recently, Moura and Shukla (1981), extending the work of Hastenrath and Heller (1977), suggested that a possible mechanism associated with the occurrence of severe droughts is the establishment of an anomalous thermally induced direct cell with ascending motion in the North Atlantic (in the ITCZ region, near 10N) and descending motion to the south of the equator over Nordeste and adjacent oceanic region. This anomalous cell arises because of the existence of a dipole type of sea surface temperature anomalies in the Atlantic for years of severe droughts.

Mak (1969) suggested that large-scale turbulent motions in the tropics could have their origin from lateral forcing by baroclinic processes in mid-latitudes. His two-layer model includes a parabolic basic zonal flow and symmetric stochastic forcing at 30N and 30S. The results show that the pressure work done at the boundaries increases the tropical eddy kinetic energy which is converted into zonal kinetic and eddy available potential energy. Opposing this suggestion, Dickinson (1971) showed that equatorward flux of Rossby wave energy cannot propagate beyond the line where the wave phase speed matches the speed of the zonal flow. The effectiveness of such a barrier has been shown to be smaller if non-linear baroclinic processes are included in a model (Murakami, 1974). Further, Webster and Holton (1982) have shown that in a non-linear barotropic model planetary scale waves cannot propagate equatorward beyond the critical latitude. Nevertheless, if the basic state is not taken zonally symmetric but contains a duct with westerly winds, waves with zonal scale smaller than the duct can influence not only the tropical region but even the other hemisphere. Simmons (1982) has also noted that equatorward propagation increases as the westerlies approach the equator.

On the other hand, an observational study by Paegle and Paegle (1983) using FGGE data shows a possible contradiction between the above theoretical results and the observations since most of the apparent linkage between tropics and mid-latitude seems to occur through regions of easterly winds.

An interesting study by Wilson and Mak (1984) uses a quasi-linear barotropic numerical model with a basic flow consisting of a steady planetary wave superimposed on a zonal shear flow, prescribed according to observed 200mb seasonal or annual mean flow. Their results show the influence of the tropical mean basic flow upon impinging waves from middle latitudes, in agreement with Webster and Holton (1982) and in part with Paegle and Paegle (1983). Nevertheless their model cannot fully explicit the importance of vertical and horizontal interactions because it lacks baroclinicity and full non-linearities.

The understanding of the mechanisms by which mid-latitude circulation anomalies can be coupled with the tropical atmosphere and tropical disturbances is fundamental in atmospheric predictability in general in all time and space scales. For the case of the interannual variability of precipitation over Nordeste this is particularly important as shown by the observational studies of Namias (1963, 1972), Hastenrath and Heller (1977) and Kousky (1979).

In this study, ten years (1968 - 1977) of monthly mean wind data at 700 and 200mb for the region from 48N to 48S and 20^{O}W to 90^{O}W are analysed to verify the relative importance of eddy momentum and potential energy transports, particularly for years drier and wetter than normal in Nordeste. In addition, a two-layer non-linear model similar to that of Mak (1969) is used with observed data at the northern boundary to intercompare the model results to boundary forcings for two selected cases (drought year and year wetter than normal) over Nordeste.

2. Wind and Precipitation Data

The data used in the diagnostic study are the monthly grid point tropical (48N-48S) wind data from 1968 to 1977 available at NCC, Asheville, USA (Gray and Vernadore, 1978). The monthly precipitation data at Quixeramobim ($5^{o}18'S$, $39^{o}18'W$), Petrolina ($9^{o}23'S$, $40^{o}30'W$) and Natal ($5^{o}55'S$, $35^{o}15'W$) stations are available at the Instituto Nacional de Me teorologia (INEMET, Brazil) for 1968 to 1977, while the climatological monthly precipitation values are given by Serra (1969).

For the rainy season from January to May, Table I shows the normalized precipitation for the three stations taken to represent the precipitation regime in northern Northeast Brazil. The values shown in Table I are the sum of the precipitation deviations from thirty year normals for each station, divided by the sum of these normals. In this study we have selected the years 1972 and 1974 to represent conditions drier and wetter than normal, respectively. Table II shows monthly deviations of 700mb geopotential in the Newfoundland area (about 50N, 55W) and in the location of the North Atlantic Subtropical High for these two selected years. These values are obtained from the charts published in the Monthly Weather Review, taken at the locations of deviation maxima.

Transient eddy momentum and meridional potential energy fluxes have been calculated for the ten year period in order to understand their interannual variability and possible association with extreme precipitation (droughts and floods) events over Northeast Brazil. The region under study comprises 48N-48S and 20W-90W. The northern boundary includes part of the Newfoundland area where Namias (1972) found important link between anomalous circulations and precipitation variability in Northeast Brazil.

The southern region is under the influence of cold fronts or their remains which might also affect rainfall in the region (Kousky, 1979).

The ten year mean of the monthly wind field is computed and the deviations for each year are plotted to show circulation anomalies for years wetter or drier than normal. This is done for 700, 500, and 200mb and for the months from January to May (the rainy season in Nordeste).

The geopotential fields are computed from the wind data using the linear balance equation, while the vertical (omega) velocities are calculated with the simplified omega equation (Haltiner, 1971). The solutions of both equations are obtained via the sequential relaxation method of Liebmann (Haltiner, 1971).

3. Discussion of Results

The wind field analysis has been performed for the months of January to May from 1968 up to 1977 for the 200mb, 500mb and 700mb levels. From this analysis only the years 1972 (dry) and 1974 (wet) will be discussed. The month of March is chosen because it corresponds to the rainy season peak in northern Nordeste.

Fig. 1 shows the transient eddy momentum flux $(\overline{u'v'})$ for 1972 and 1974 as compared to the mean (1968-77) at 700mb. Even though the word transient is not appropriate for monthly mean, here it is used to represent temporal variation and not standing variation. Fig. 1b indicates that most of the contribution to the 20W-90W mean (Fig. 1a) comes from the longitude band 20W-50W. It can be seen that the wet case has a large momentum flux when compared to the mean, while the dry case has smaller values in most latitudes. Most of the contribution in the tropics comes from the Northern Hemisphere (NH). For the Southern Hemisphere (SH) caution is needed in drawing conclusions because of data sparse area in most of South Atlantic.

Fig. 2 shows large negative values of transient eddy potential energy $(\overline{v'\phi'})$ for the wet case when compared to the mean or the dry case from about 10S to 20N. Basically there is a slope reversal of $(\overline{v'\phi'})$ for the two cases from 20S to 10N, thus exibiting a possible increase of kinetic energy for the wet case (1974) and decrease in the dry case (1972) in this area. The SH values again need to be taken with caution.

By taking Dickinson's (1971) formulation $(\overline{v'\phi'}) = -(U-c)(\overline{u'v'})$, we note in the curve $(\overline{v'\phi'})$ that the so called "critical latitude" could be located at about 20N for the months of January to May 1974 (Fig. 2). This is in agreement with results obtained by Paegle and Baker (1982) for the FGGE data set. Since the winds are westerlies at 200mb up to 5N (Fig. 3a) and since there are disturbances in the tropical Atlantic near Nordeste (Fig. 3b), we might argue if such a theoretical barrier is indeed effective.

At 200mb we have observed an anomalous cyclonic circulation in the tropical North Atlantic near Nordeste for the dry case (figure not shown) as contrasted to an anomalous anticyclone in the wet case (Fig. 3b). This certainly indicates changes in the ITCZ position and/or eddy activity during drought years contrasted to wet years as suggested by Moura and Shukla (1981).

It can be noted (Fig. 4) that at 700mb an anomalous north-easterly flux towards Nordeste exists for the wet year as compared to the dry year (Fig. 5) for all the months analysed (January to May). This is in agreement with previous result of Namias (1972). It can also been noted from the analysis of 700mb that a northward displacement of the South Atlantic Subtropical High occurs for the dry case as compared to the wet case (Figs. 4 and 5) as pointed out by Hastenrath and Heller (1977).

The deviations of vertical motion (not shown) did not show significant differences between the dry and wet cases and this could be due to the approximate method used (quasi-geostrophic omega equation) for calculation and poor data coverage in the Southern Hemisphere.

4. Numerical Experiment

A simple numerical experiment is performed to verify the importance for the tropics of lateral forcing by the pressure work done at the boundaries due to mid-latitude disturbances. Specifically we would like to verify Namias (1972) findings with respect to the linkage between cyclonic activity in the Newfoundland area and monthly precipitation variability in Nordeste. The results must be viewed only as a preliminary intercomparison between dry and wet cases.

We have used a two-layer, non-linear primitive equation model, in equatorial beta plane, p-coordinate, without topography, similar to that of Mak (1969), but laterally forced by realistic disturbances in the wind and pressure at the northern boundary (see Buchmann, 1981). The region under integration is 35N to 35S and 90W to 20W (east-west cyclic).

The model equations in flux form (Haltiner, 1971, pag. 55) are:

$$\frac{\partial u}{\partial t} + \nabla.(\vec{V}u) + \frac{\partial \omega u}{\partial p} - \beta y v = -\frac{\partial \phi}{\partial x} \quad (1)$$

$$\frac{\partial v}{\partial t} + \nabla.(\vec{V}v) + \frac{\partial \omega v}{\partial p} + \beta y u = -\frac{\partial \phi}{\partial y} \quad (2)$$

$$\frac{\partial \theta}{\partial t} + \nabla.(\vec{V}\theta) + \frac{\partial \omega \theta}{\partial p} = 0 \quad (3)$$

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial \omega}{\partial p} = 0 \quad (4)$$

$$\frac{\partial \phi}{\partial p} = -\alpha \quad (5)$$

Where $\vec{V} = (u,v)$ is the wind vector, while u and v are the components of the wind field in the x and y directions, ω is the vertical p-velocity, ϕ is the geopotential, θ is the potential temperature, and α is the specific volume for the air.

The finite difference equations are numerically solved using Schuman's space differencing and Euler-Backward time differencing schemes (Haltiner, 1971).

The integration is started with a parabolic symmetric mean zonal flow ($U = a + by^2$) geostrophically balanced at 750mb and 250mb levels. At 750mb the easterly (up to 20N) basic flow has a maximum of 2.15 ms^{-1} , while at 250mb the maximum is 8.49 ms^{-1} with westerlies up to 10N.

To this basic flow perturbations in the wind, geopotential and temperature fields are imposed at the northern boundary (35N). The deviation values of u and v are subject to a Fourier analysis at 750mb and 250mb as shown in Table III. The wave number 1 (between 20W and 90W) is taken for the fixed forcing during the integration of both dry and wet cases, since it gives the largest contribution to ($\overline{u'v'}$) and ($\overline{v'\phi'}$) at 35N (a detailed description of the model is given in Buchmann 1981).

During the integration, we note a pattern of alternating rising and sinking motion propagating day after day from the northern boundary towards the equator. After 3 days of integration this pattern of rising and sinking motion at 500mb is established for both cases. Figs. 6a and 6b show this vertical velocity field at the fourth day of integration for the dry and wet cases, respectively.

After the fifth day this almost stationary pattern continues to grow because the model has no dissipative mechanism to match the energy input through the boundary and numerical instability takes over.

The patterns for both the cases are similar. Nevertheless, phase and amplitude differences might be interpreted and some comparative preliminary conclusions be drawn, having in mind the crudeness of the numerical model.

From the simple numerical experiment we might draw the following preliminary results:

a) The model responds to boundary forcing which can propagate energy towards the equator. The critical latitute does not seem to be a perfect barrier for the cases studied (small values of basic zonal flow and westerlies changing to easterlies at high levels close to the equator). It could be argued that baroclinic processes which have not been included in the theoretical barotropic models (Webster and Holton, 1982) are important to overcome the "barrier".

b) The rising and sinking motion pattern at 500mb established by the model seems to indicate that typical forcings for the wet and dry cases can induce anomalous large scale vertical motions in the tropics worsening conditions for rising motions during drought years. The alternating north-south pattern of rising and sinking anomalous vertical motion could have observational support in Namias (1963).

5. Summary and Conclusions

The diagnostic study supports early investigations which can be summarized as follows:

a) At 200mb the flow is westerly in most of tropical North Atlantic for the cases studied. For a dry year (1972) in Northeast Brazil the subtropical South Atlantic High is closer to the equator and to Nordeste than for a wet year (1974). During the wet year, the High is found southeastwards of its normal position. This agrees with Hastenrath and Heller (1977).

b) At 700mb we found in the North Atlantic an anomalous northeasterly flow towards Nordeste for a wet year, which is not found for a dry year, in agreement with Namias (1972). This seems to suggest the coupling of mid-latitude disturbances with the tropical atmosphere in the Atlantic, which might affect the rainy season over Nordeste.

c) For a dry year there is a decrease in the transient eddy momentum flux ($\overline{u'v'}$), contrasting with a wet year when an increase is noted between the equator and about 30N. The transient eddy potential energy is also higher from 10S to 20N for a wet year. The slope of ($\overline{v'\phi'}$) is reversed between 20S to 20N for the two cases studied, which might indicate an increase in eddy activity for the wet case.

d) Anomalous cyclonic (anticyclonic) circulation at 200mb in tropical North Atlantic near Nordeste appears in dry (wet) years, reflecting different activity in the ITCZ for those years, giving some support to what is found in Moura and Shukla (1981).

In concluding, the present study gives support to the idea that drought occurrences over Northeast Brazil are a regional manifestation of large scale atmospheric variations in the tropics as well as middle and higher latitude synoptic systems. The north and south Atlantic atmospheric circulations with the adjacent Nordeste imbedded respond to global atmospheric changes. The tropical response to extra-tropical latitude system forcings seems to be stronger in the tropical North Atlantic for wetter than drier years in Nordeste.

It is suggested that future studies focus more attention to forcings in the Southern Hemisphere as better and more data becomes available. Also, it is important to study the importance of large scale tropical heat sources, such as the Amazon convective heating upon the variability of the vertical motion over Northeast Brazil.

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TABLE I: Normalized monthly mean precipitation of Quixeramobim ($5^{O}18$'S, $39^{O}18$'W), Petrolina ($9^{O}23$'S, $40^{O}30$'W) and Natal ($5^{O}55$'S, $35^{O}15$'W) stations in Northeast Brazil. M stands for missing.

Data Source: Instituto Nacional de Meteorologia (INEMET, Brazil).

Year / Month	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
Jan	1.6	1.3	1.0	0.9	0.3	0.7	4.6	0.9	0.1	1.7
Feb	0.3	0.7	0.5	M	0.3	2.4	1.9	0.6	2.2	0.4
Mar	0.9	0.9	1.2	0.7	0.5	1.8	1.8	1.2	0.7	M
Apr	0.9	0.6	0.9	0.8	0.8	1.4	2.5	1.7	0.5	M
May	0.9	1.8	1.3	1.1	0.6	1.1	1.4	0.4	0.8	M

TABLE II: 700mb geopotential deviations in gpm near Newfoundland (50N, 55W) and in the region of the Subtropical North Atlantic High. M is missing.

Source: Charts published by Monthly Weather Review.

Month	Newfoundland		North Atlantic High	
	1972	1974	1972	1974
Jan	-60	-90	81	80
Feb	-60	M	56	M
Mar	+40	-60	89	50
Abr	-60	-30	72	60
May	-45	-80	70	10

TABLE III: Amplitudes of u' and v' at 750mb and 250mb obtained by a Fourier analysis at 35N for the year 1972 (dry) and 1974 (wet). The wave number K refers to the longitude band 20W-90W. Units are $m.s^{-1}$

Level	Variable	Year	Wavenumber				
			1	2	3	4	5
250mb	u'	1972	0.69	0.36	0.44	0.18	0.02
		1974	0.95	0.69	0.57	0.31	0.07
	v'	1972	1.20	0.70	0.58	0.13	0.13
		1974	0.93	0.30	0.27	0.43	0.29
750mb	u'	1972	0.56	0.48	0.17	0.10	0.07
		1974	0.52	0.52	0.48	0.24	0.07
	v'	1972	0.78	0.43	0.17	0.04	0.04
		1974	0.36	0.52	0.30	0.26	0.13

Figure Legends

Fig. 1 - Transient eddy momentum flux at 700mb for March. a) Mean value calculated in the longitude band 20W-90W; b) 20W-50W. The full line indicates the mean from 1968 to 1977; dashed line is for the wet year of 1974 and dashed-dotted line is for the dry year 1972.

Fig. 2 - Transient eddy potential energy flux at 700mb for March averaged in the longitude band 20W-90W. Convention as in Fig. 1.

Fig. 3 - 200mb wind field for March 1974. a) Observed field, with maximum of 83.5 ms^{-1}; b) Deviation from the 1968-77 mean, with maximum of 26.6 ms^{-1}.

Fig. 4 - 700mb wind field for March 1974. a) Observed field, with maximum of 21.5 ms^{-1}; b) Deviation from the 1968-77 mean, with maximum of 15.9 ms^{-1}.

Fig. 5 - 700mb wind field for March 1972. a) Observed field, with maximum of 21.5 ms^{-1}; b) Deviation from the 1968-77 mean, with maximum of 9.5 ms^{-1}.

Fig. 6 - Vertical (omega) velocity (10^{-4} $mb.s^{-1}$) at 500mb simulated by the model after 4 days of integration. a) The dry case; b) The wet case. Note the westward displacement of the rising and sinking motions in case a) compared to case b) with stronger descending motion in the Northeast region in the dry case when compared to the wet case.

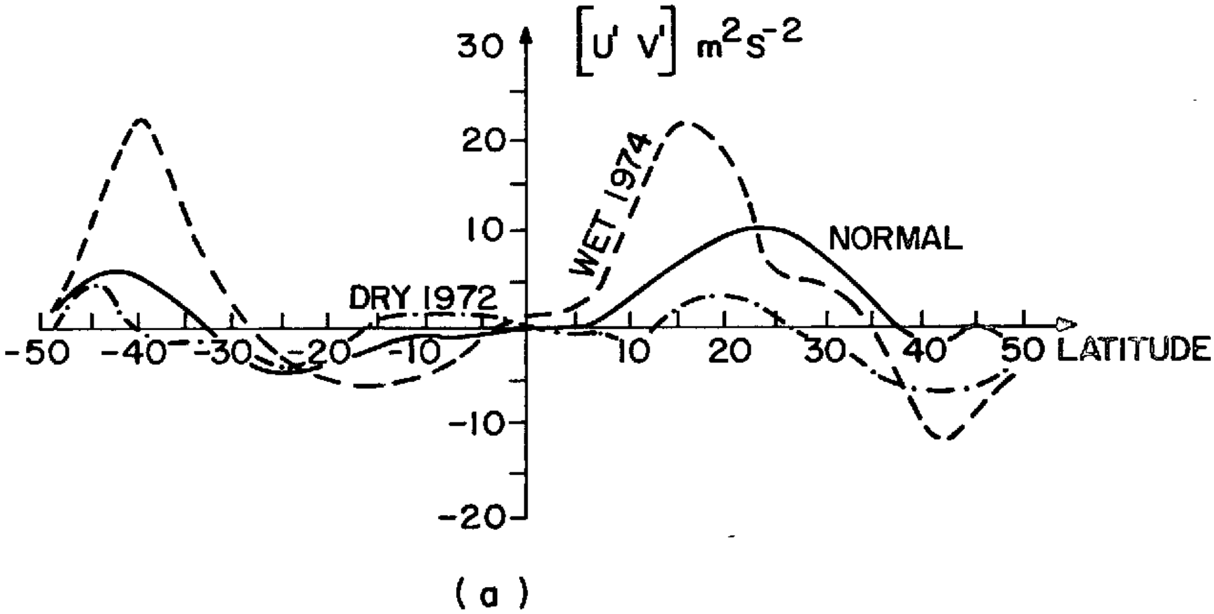
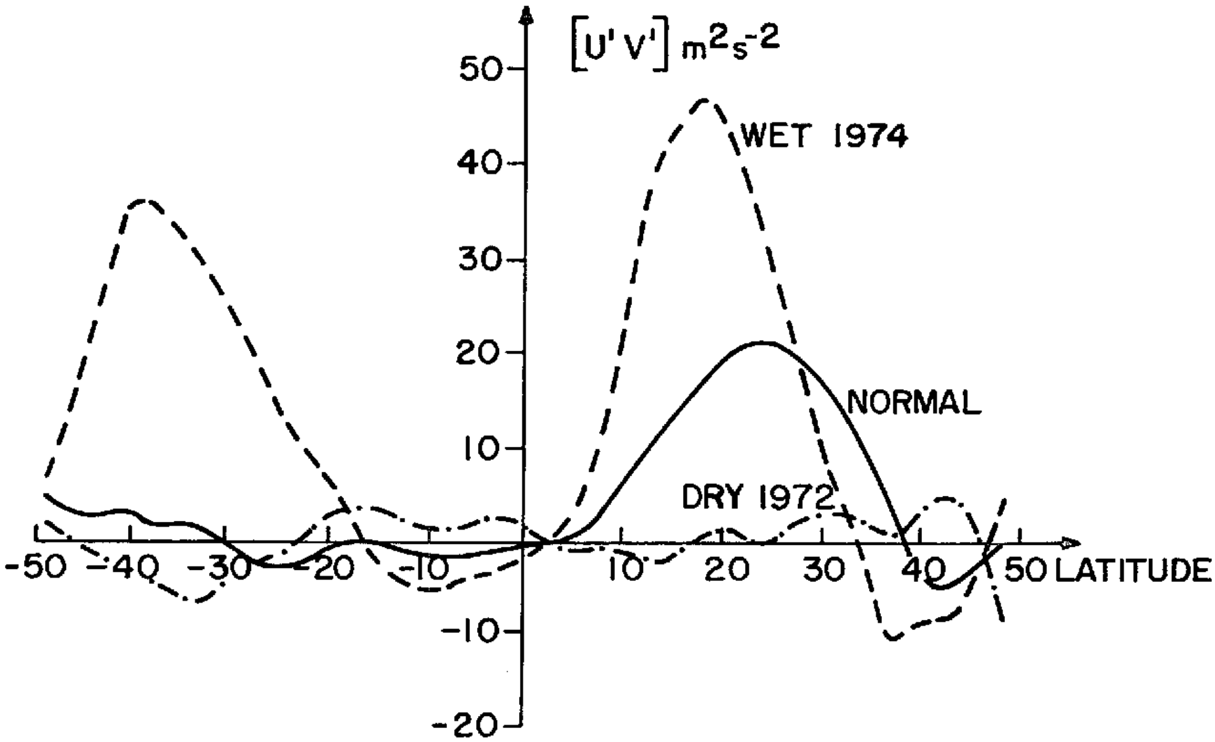

[U' V'] m2S-2
30
20
10
-10
-20
WET 1974
NORMAL
DRY 1972
-50 -40 -30 -20 -10 10 20 30 40 50 LATITUDE
(a)

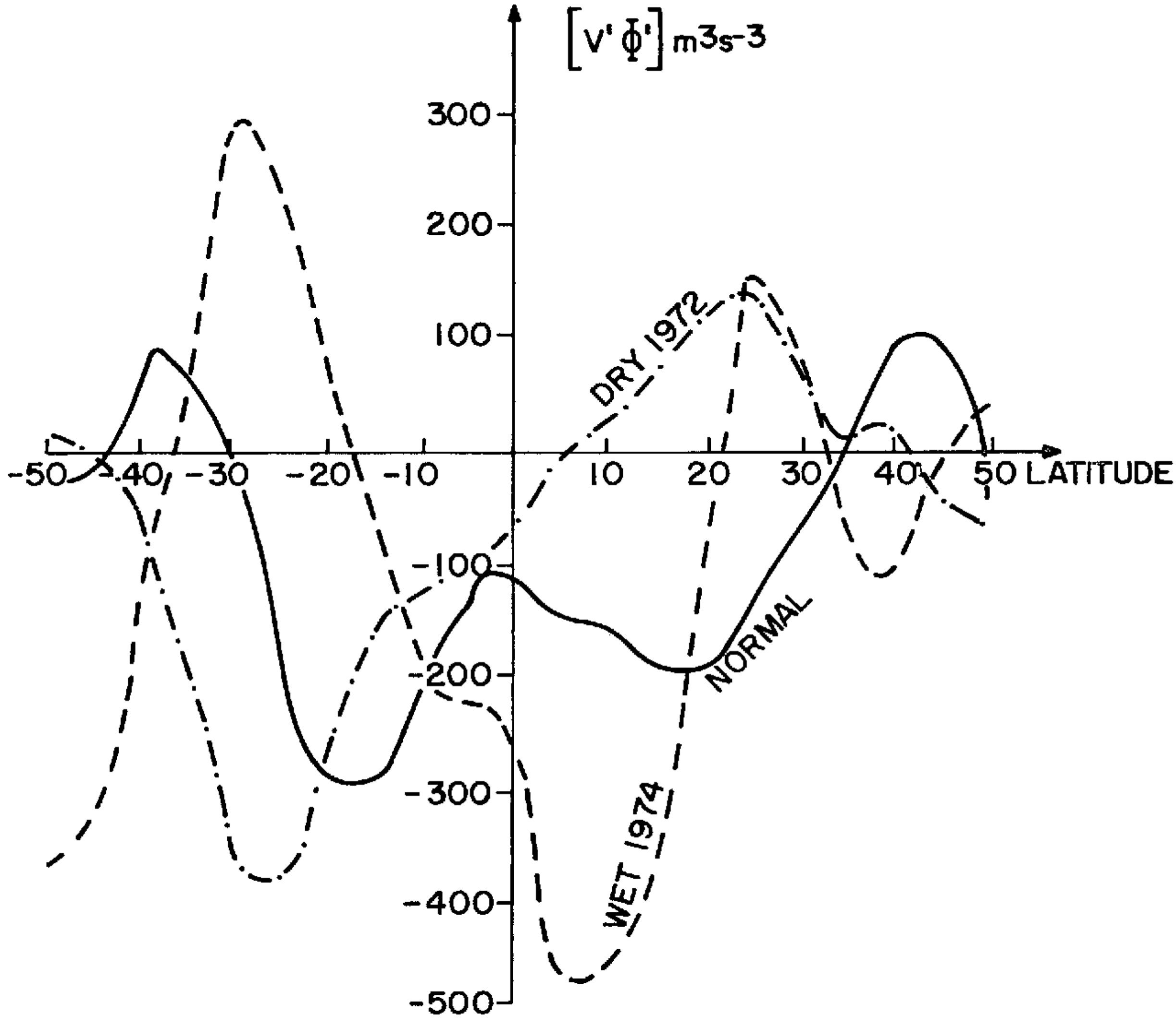
Fig. 1a



[U' V'] m2s-2
50
40
30
20
10
-10
-20
WET 1974
NORMAL
DRY 1972
-50
-40
-30
-20
-10
10
20
30
40
50
LATITUDE

(b)

Fig. 1b



[V' Φ'] m3s-3
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-100
-200
-300
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DRY 1972
NORMAL
WET 1974

Fig. 2

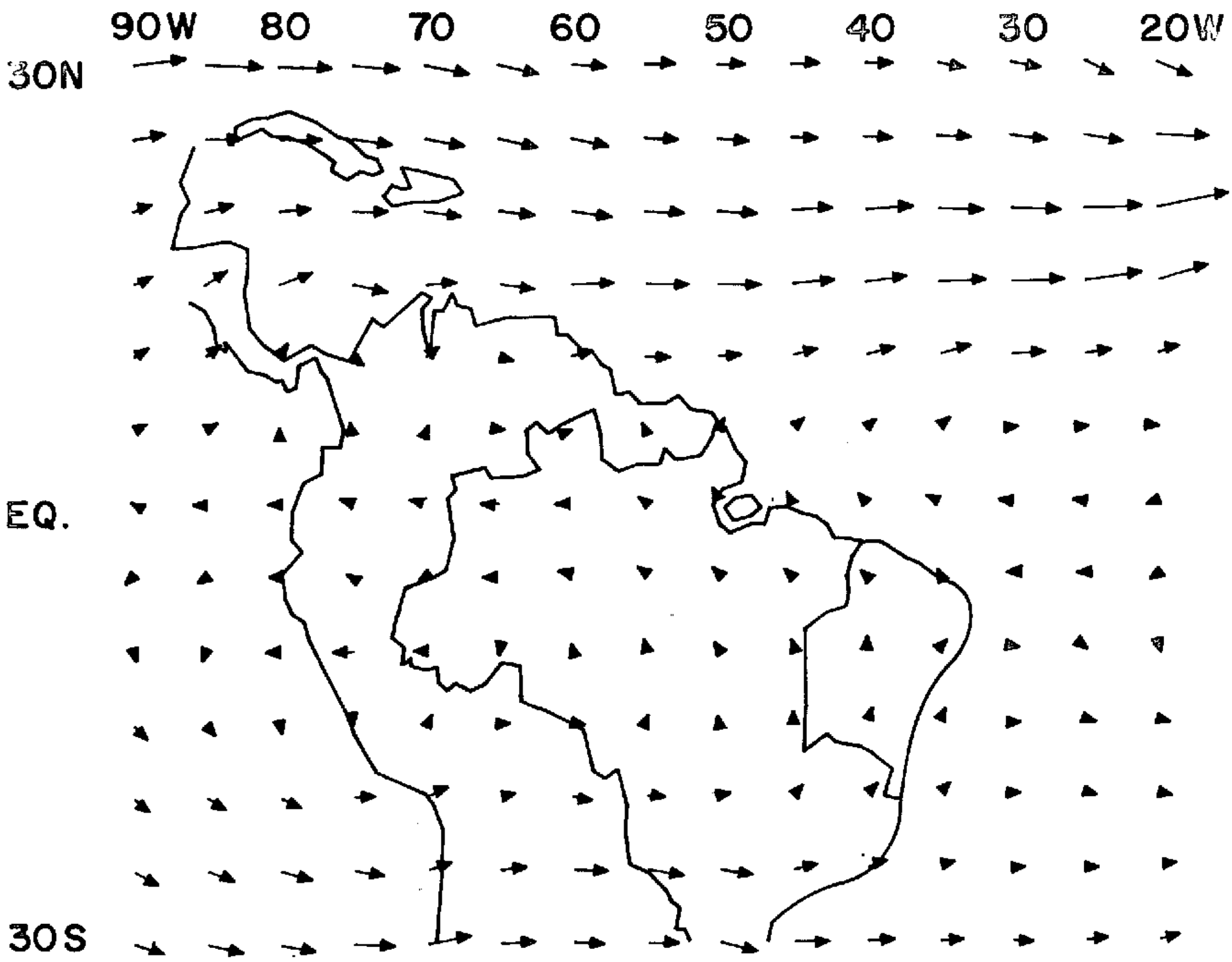

Fig. 3a

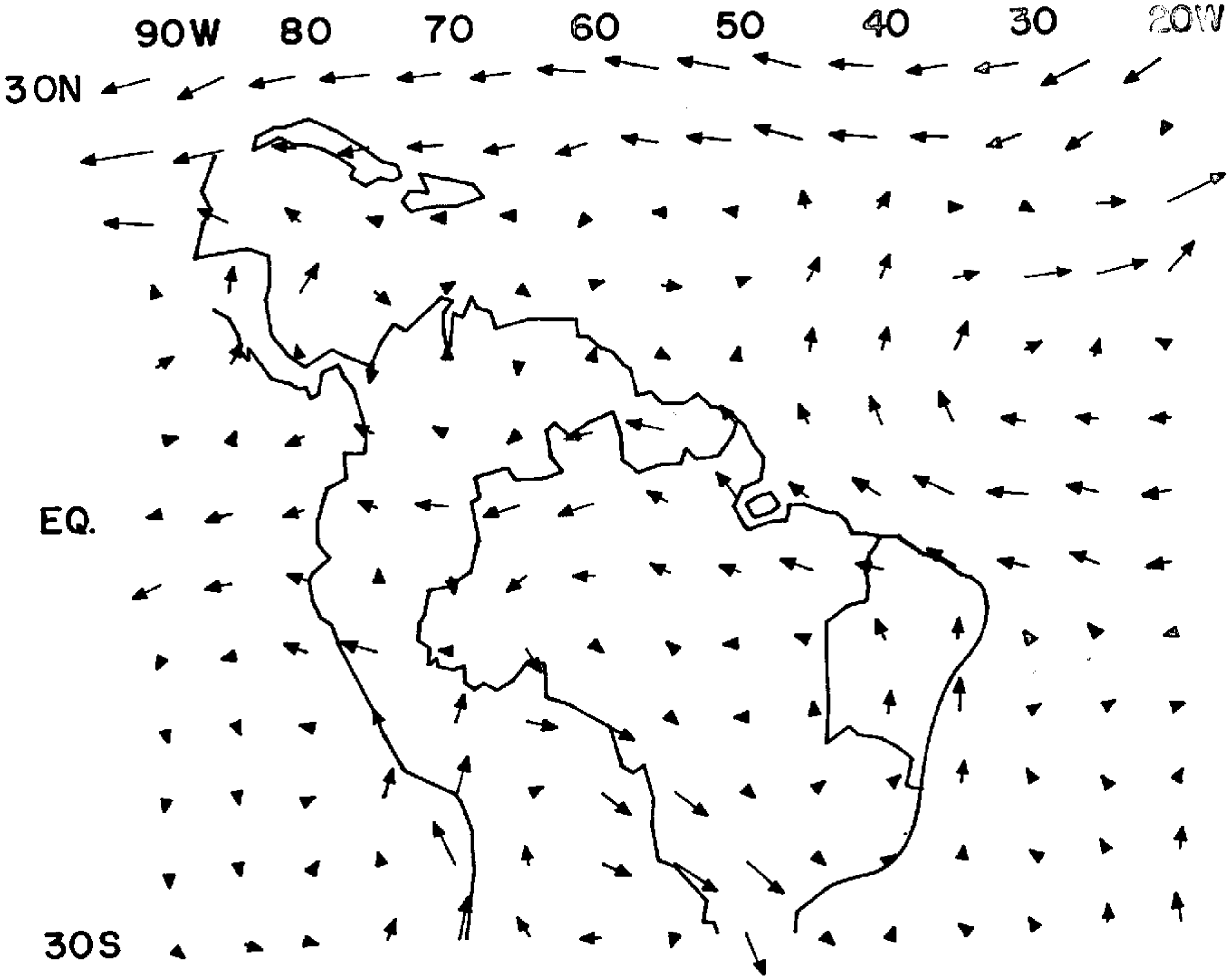

Fig. 3b

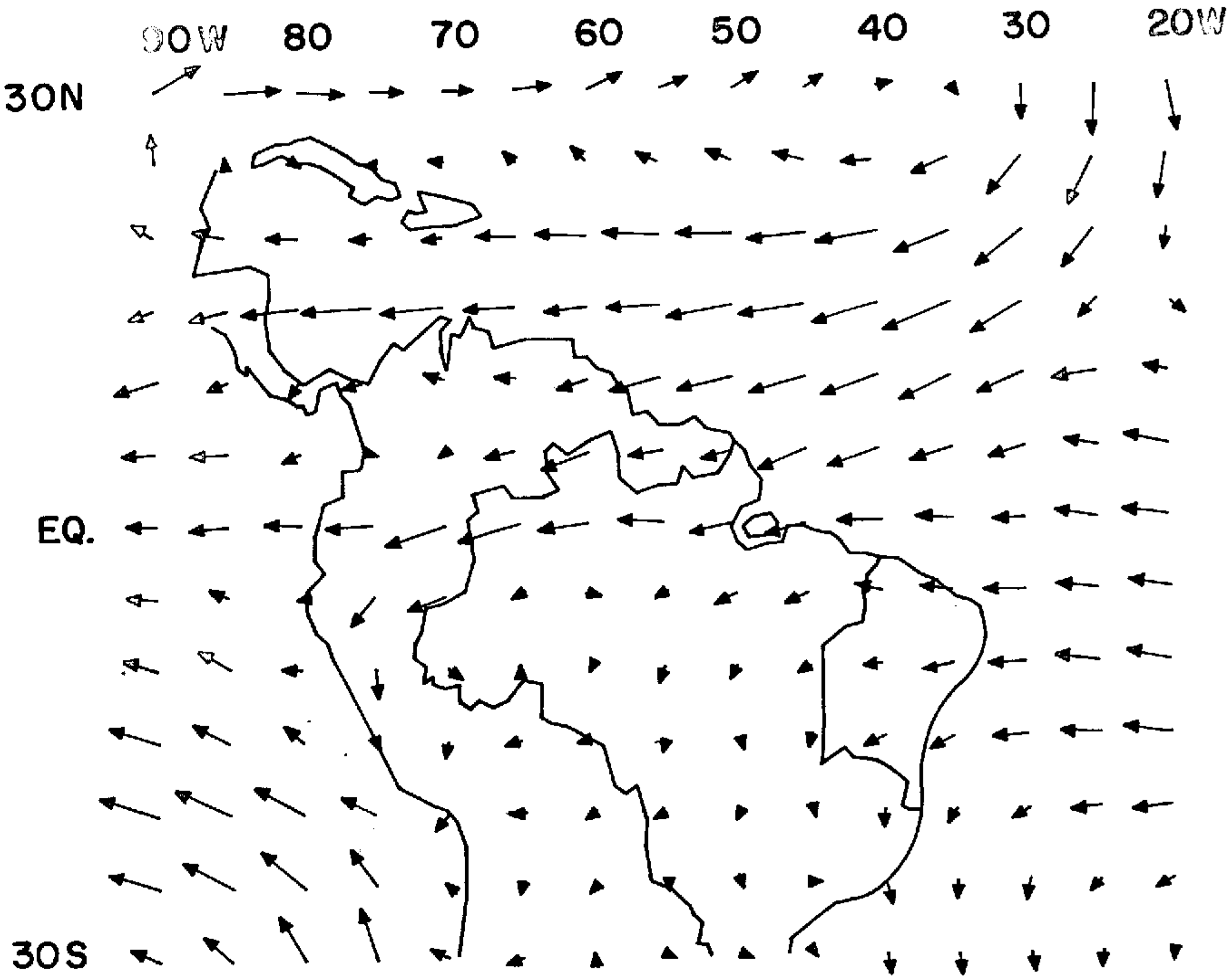

Fig. 4a

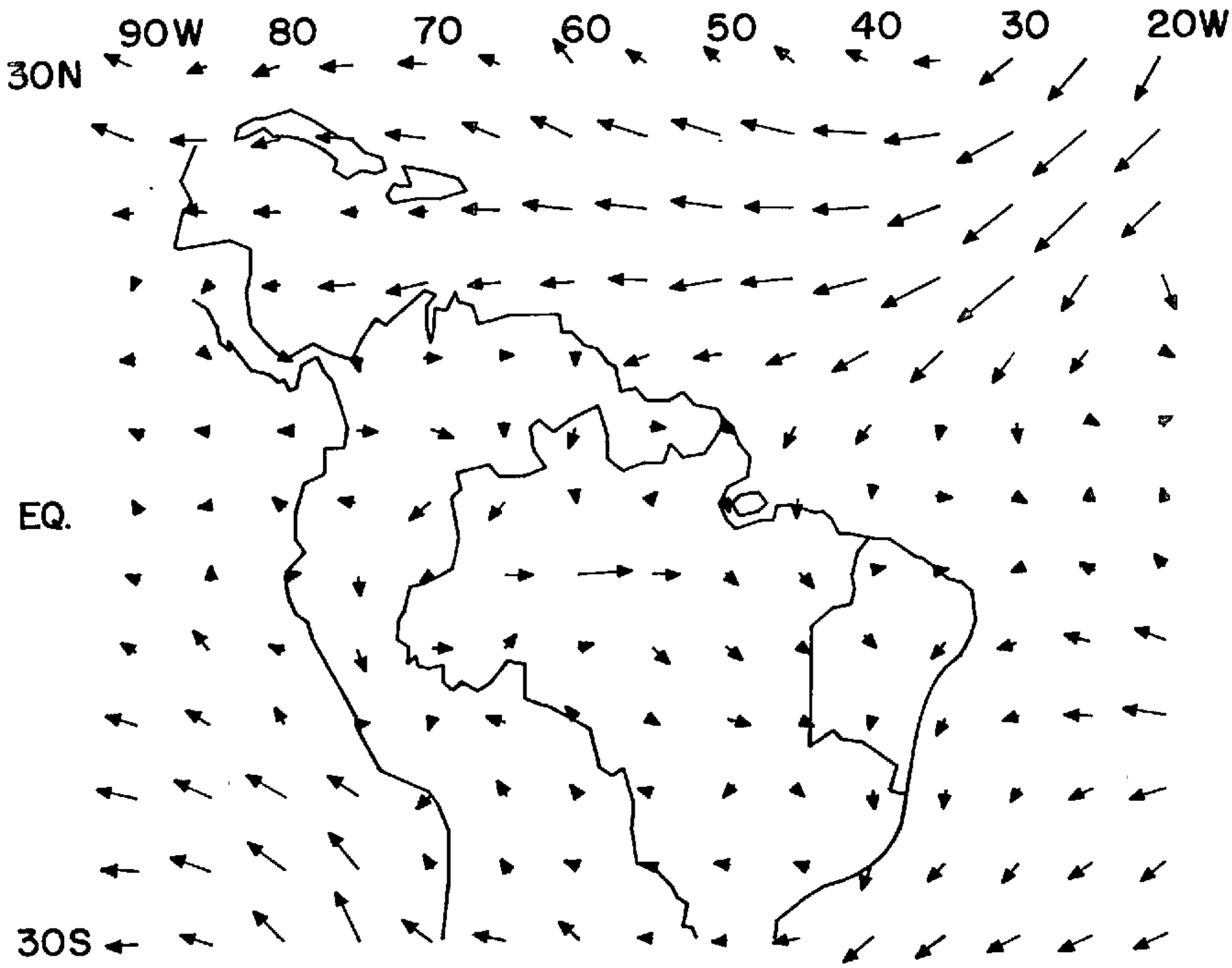

Fig. 4b

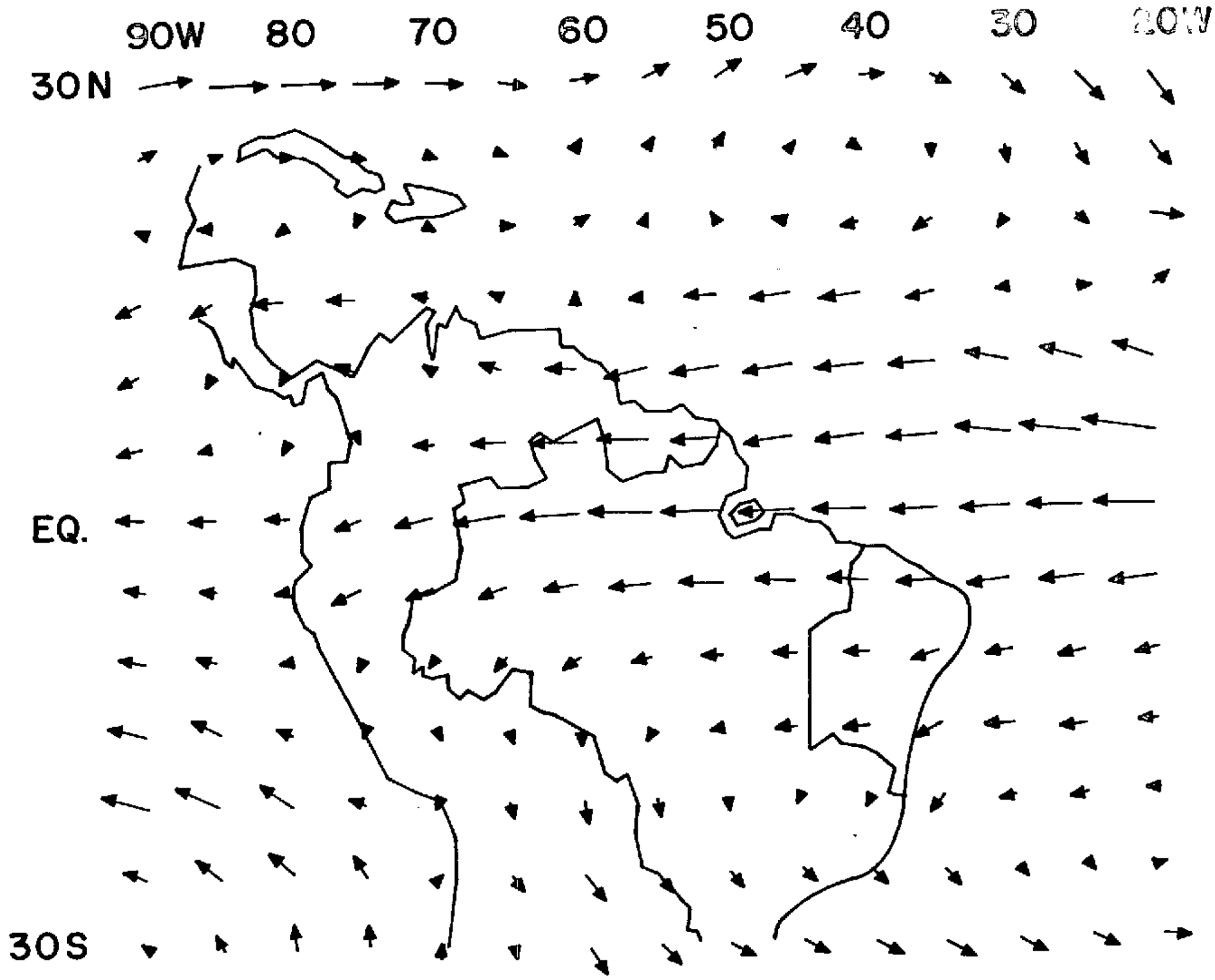

Fig. 5a

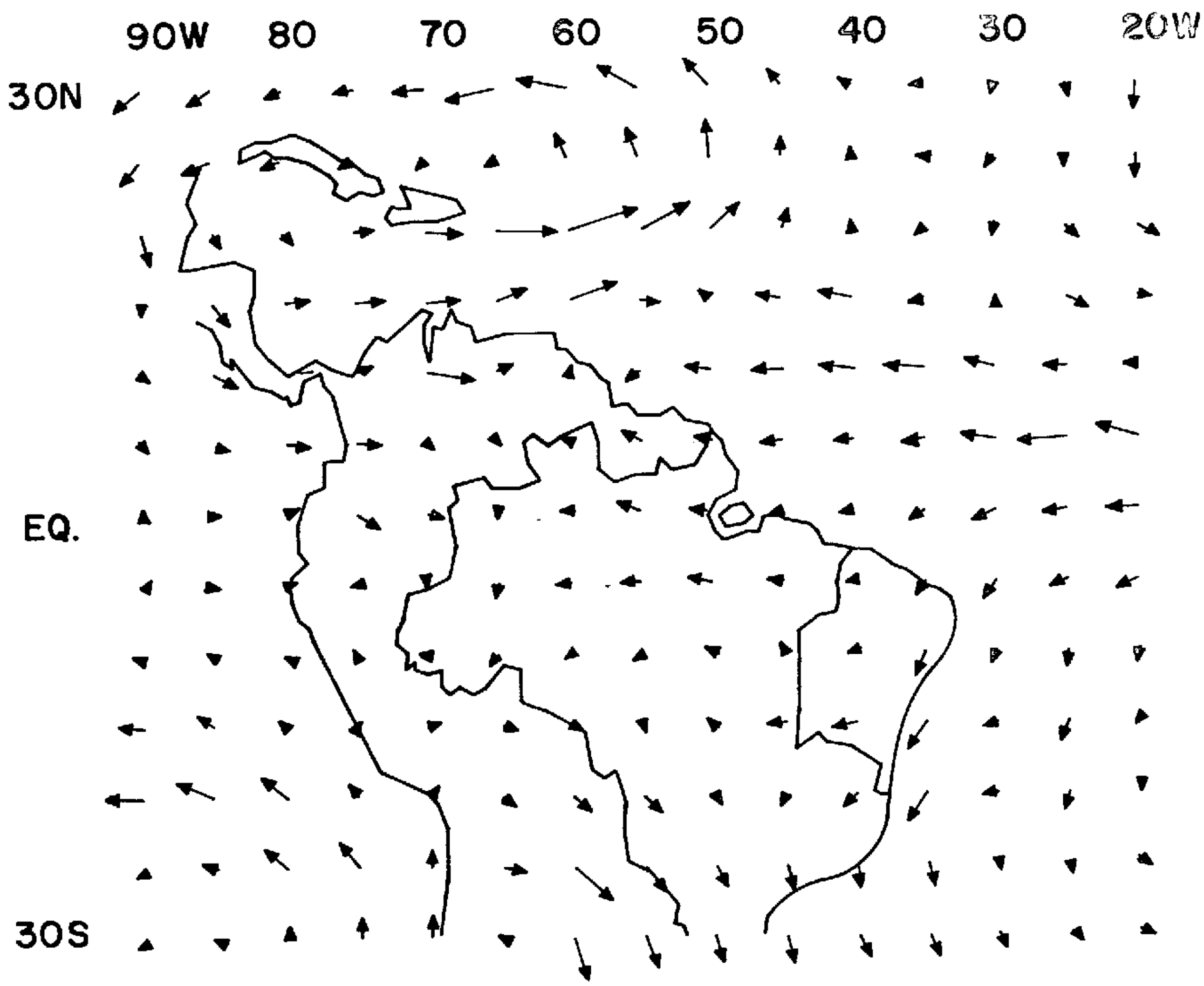

Fig. 5b

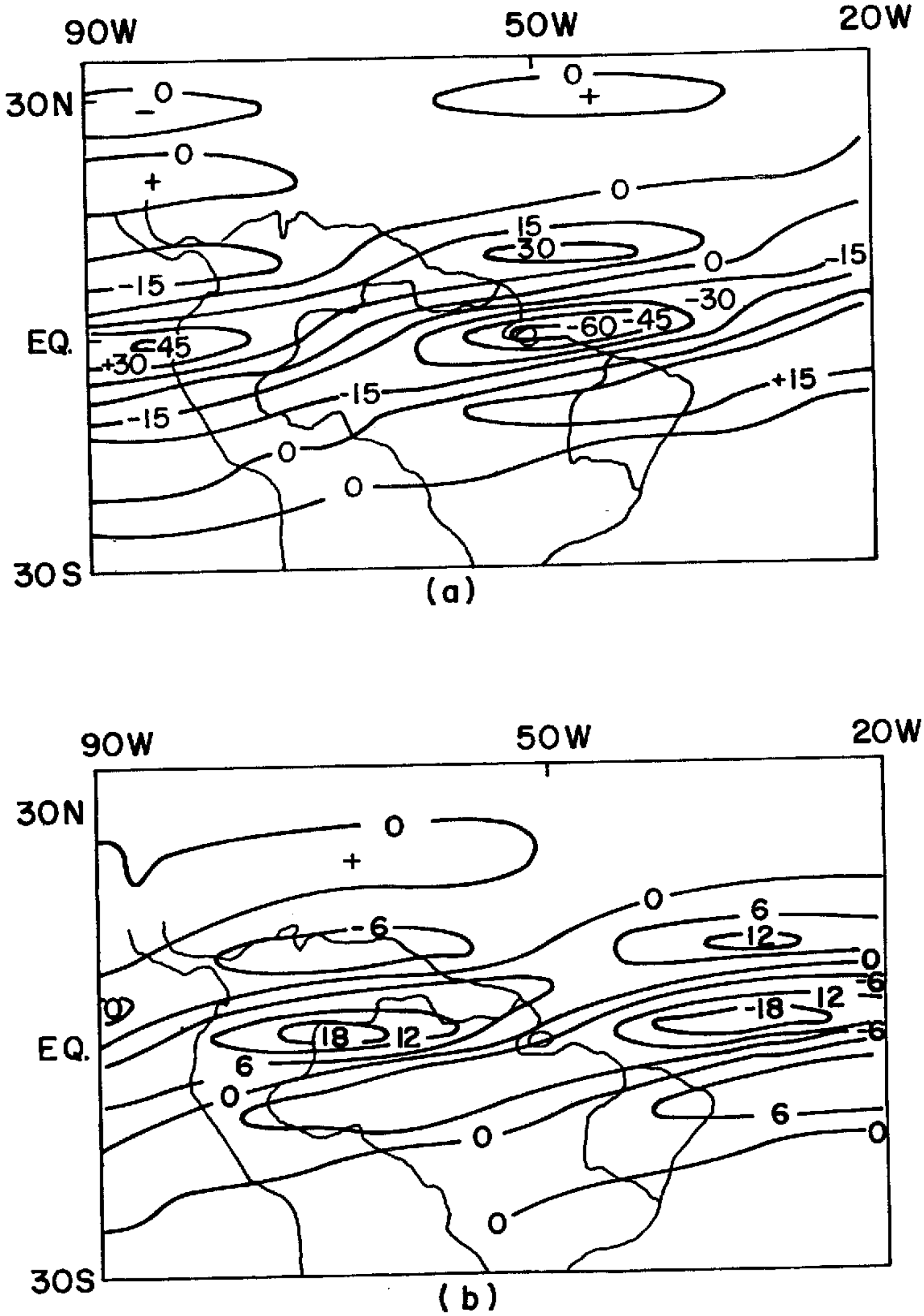
90W
50W
20W
30N
EQ.
30S
0
+
-15
15
30
-30
-60
-45
+30
+15
(a)
90W
50W
20W
30N
EQ.
30S
0
+
-6
6
12
-18
18
(b)

Fig. 6