direkt von den Turbulenzbedingungen abhängt. σ_ϑ erfaßt aber außerdem noch Winddrehungen, die eine Turbulenzzunahme vortäuschen. Die beste indirekte Methode zur Bestimmung der Ausbreitungskategorien ist diejenige nach dem Temperaturgradienten und der Windgeschwindigkeit. Da in 97% aller Fälle eine Abweichung von höchstens einer Kategorie auftritt, hat sie noch eine ausreichende Zuverlässigkeit um Einzelsituationen zu beurteilen. Die Parameter Strahlungsbilanz/Windgeschwindigkeit sowie der Exponent des Windprofils eignen sich dagegen kaum noch zur Beurteilung von Einzelsituationen. In 12% der Fälle bestimmt man damit die Ausbreitungsbedingungen um 2 und mehr Kategorienstufen falsch. Sie eignen sich deshalb nur für statistische Untersuchungen.

Die Parameter σ_φ und σ_ϑ sowie das Windprofil hängen entscheidend von der Rauhigkeit des Untergrundes ab, während dies bei dem Temperaturgradienten- und Strahlungsbilanzschema kaum der Fall ist. Überträgt man die obigen Schemata auf Standorte mit anderer Rauhigkeit, so sind die Kategorien nicht mehr einheitlich definiert. Bestimmt man die Kategorien rauhigkeitsunabhängig, wie das heute noch weitgehend üblich ist, so bleiben nur beim Temperaturgradienten und der Strahlungsbilanz die Einteilungsschemata unverändert. Der Rauhigkeitseinfluß muß in diesem Fall durch eine Änderung der σ_y- und σ_z-Werte berücksichtigt werden.

Es sollten jedoch in Zukunft Ausbreitungskategorien so definiert werden, daß man unabhängig vom Standort immer dieselben Kurvenscharen für σ_z und σ_y verwenden kann. Als Parameter für diese Scharen kämen σ_φ, σ_ϑ oder, mit den genannten Einschränkungen, p in Frage. Der Einfluß der Rauhigkeit würde sich bei Verwendung dieser Parameter bereits in deren Häufigkeitsverteilung widerspiegeln.

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An Aerological Climatology of South America

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Zusammenfassung. Für den südamerikanischen Kontinent werden zu den extremen Jahreszeiten (Südsommer, Südwinter) aus den Radiosondenbeobachtungen die troposphärischen Wind-, und (näherungsweise über die relativen Topographien und die vertikale Windscherung) die Temperaturstrukturen, sowie aus den Bodenbeobachtungen die Niederschlagsfelder dargestellt. Mit Hilfe der Vertikalverteilung der Zonalwinde entlang eines Meridians ergibt sich eine Einteilung der Zirkulation in einen ozeanischen und einen kontinentalen Typ, die im wesentlichen durch den Wärmehaushalt des Untergrundes bestimmt sind. Diese Klassifizierung erlaubt eine einfache und zunächst qualitative Vergleichsmöglichkeit zwischen der atmosphärischen Zirkulation über dem afrikanischen und südamerikanischen Kontinent auf klimatologischer Skala.

Abstract. The mean circulation over South America is derived for the two extreme seasons (southern summer and winter). The patterns of the tropospheric wind and vertically-integrated temperature are shown using rawinsonde observations. The areal precipitation structure is also presented. A north—south cross section of the zonal winds indicates that two circulation types over South America exist: a continental and an oceanic type both of which are related to the surface heat budget. A comparison with the circulation over Africa shows significant differences.

Introduction

The general circulation of the atmosphere is closely related to its surface boundary conditions. This for example becomes evident by comparing the large scale circulation of the troposphere induced by a mountain barrier with the circulation over a homogeneous ocean. Even different continental vegetation regimes (desert, savanna, rain forest) lead to distinct circulation variations. Especially in the tropics, the influence of the earth's surface structure on the weather and climate predominates.

The tropical zones in Africa and South America provide an unique opportunity for empirical investigations of the large scale influence due to different surface conditions. This permits one further to compare the circulations above both continents. The position of Africa and South America in relation to the equator is similar, although the largest portion of Africa lies in the northern hemisphere. The topographic and the vegetational characteristics are very different since no comparable mountain range such as the Andes extends the north—south length of Africa. Additionally, the equatorial part of South America is almost totally occupied by the tropical rain forest, whereas the African rain forest is essentially smaller with large deserts on its poleward boundaries. The meridional cross section of the zonal wind distribution shows these differences as reflected by the large scale circulation pattern. However, any inferences how the circulation pattern is related to the surface conditions, or vice-versa, will not be discussed here.

A previous investigation on the seasonal variation of the zonal circulation over Africa [7] shows that the response of such parameters as the easterly or westerly wind maxima or rainfall follow the incoming solar radiation with a small time lag. The lack of observations has not allowed such an investigation over the South American continent, although there are several studies on dynamic influences of the Andes as a mountain barrier or on the thermal influence of the Altiplano as a heating surface [1, 4, 6].

During the last decade, however, the aerological network has been tremendously improved. With these data an aerological climatology of South America has been established [5]. These results are presented and compared with the earlier investigation on the zonal circulation over Africa.

The data

30 rawinsonde stations from the area 20°N—20°S, 30°W—90°W, ten of which are not situated at the coastal areas of the continent, have been chosen for a seasonal study of the aerological climatology of the South American continent (Fig. 1). The data set is given for the period from December 1966—August 1970 by rawinsondes for 12 GMT (except Lima and Resistancia at 00 GMT). As some data series are incomplete each station is combined with an individual weight to distin-

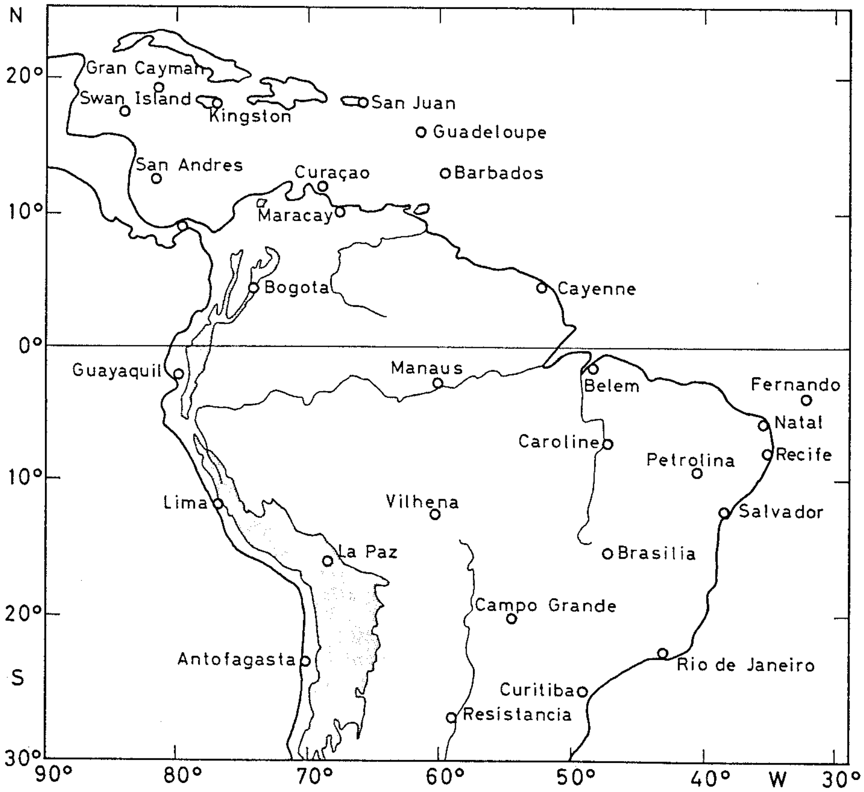

Fig. 1. Rawinsonde network over South America used for this study.

guish between complete and incomplete data series. Supplementary observations from Balboa, Fernando de Noronha, Guayaquil, and La Paz are taken from other periods with the data from La Paz given in heights (km) rather than pressure. Further information has been derived from approximately 150 rainfall stations operative during the same observation period.

These data are classified for either the southern summer (December—February) or the southern winter (June–August). This gives a maximum of about 360 observations for each station which were seasonally averaged from 1966—1970. The following parameters are determined from the aerological and rainfall data:

The resultant winds are used to construct streamline fields at the pressure surfaces 700-, 500-, 300-, 200-, 150-, 100-mb.

The vertical wind shear permits a comparison of the thickness of the layers 300/700 mb, 150/300 mb, and 100/200 mb and indicates the thermal structure.

The rainfall leads to the precipitation isopleths and a further comparison with the above-mentioned thermal structures.

The zonal wind components are used to obtain a meridional cross section.

The calculation evidently shows a remarkable variability of the individual monthly means from which the seasonal averages are derived. As an example for the variability all available monthly wind averages at the 300 mb level for the southern winter are given in Fig. 2.

Fields of streamlines

a) Southern summer

Fig. 3 describes the mean wind field over the South American continent. A strong anticyclone in the upper troposphere is the most recognizable feature. It starts building up at the 500 mb level over the Peruvian-Bolivian Highland and over the south western Amazonas. At 300 mb and higher levels it appears as a closed system which is coupled with a trough towards the east. Both the upper anticyclone and the trough form a system which determines the mean synoptic situation up to the tropopause. In the northern hemisphere this trough-ridge-system is limited by the southern portions of the subtropical jet stream.

The lower troposphere (represented by the 700 mb level) on the northern hemisphere is influenced by the trade wind regime, whereas in the southern hemisphere the subtropical high pressure cell in the southern Atlantic is replaced by a weak heat low over the Chaco Boreal.

b) Southern winter

The features of the wind field in this season (Fig. 4) are as follows: The center of the southern hemisphere high pressure cell has moved towards the north (up to 10 °S)

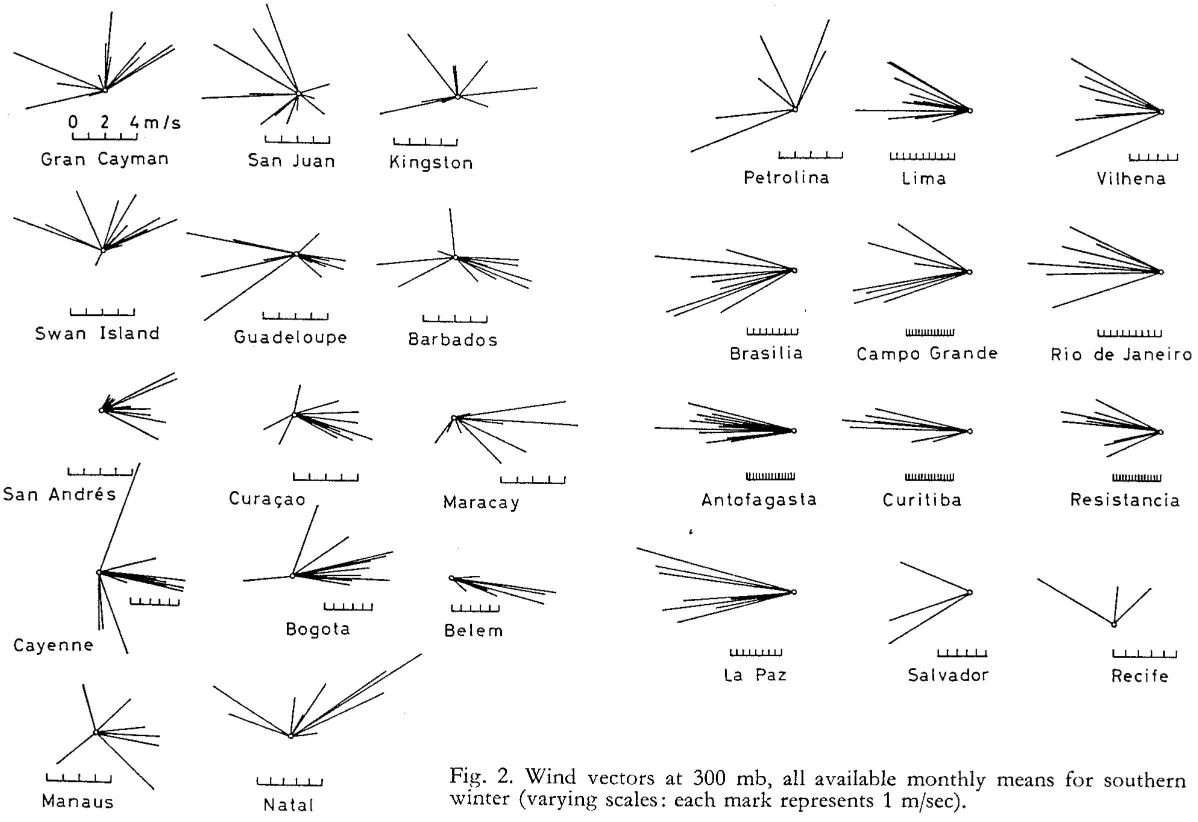

Fig. 2. Wind vectors at 300 mb, all available monthly means for southern winter (varying scales: each mark represents 1 m/sec).

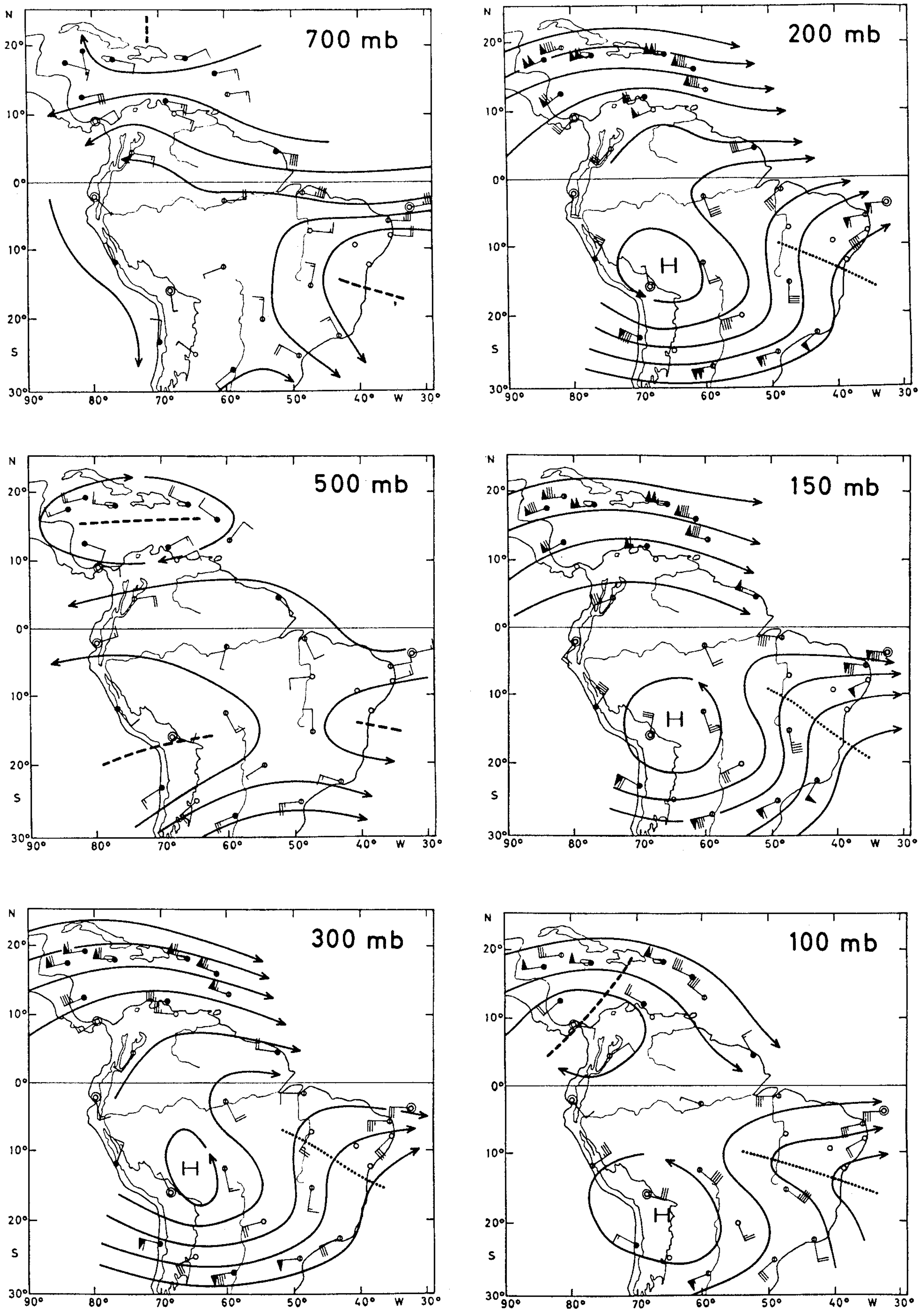

Fig. 3. Streamline pattern over South America during southern summer. ---- Ridge .... Trough
At the station circle the representativeness of this station is indicated by the following symbols: full circle = more than 67% of all possible observations are available, divided circle = 66—33% are available, open circle = less than 32% are available, encircled circle = different observation period. The wind flags have the following meaning: a half bar = 1 m/s, a full bar = 2 m/s, a triangle = 5 m/s.

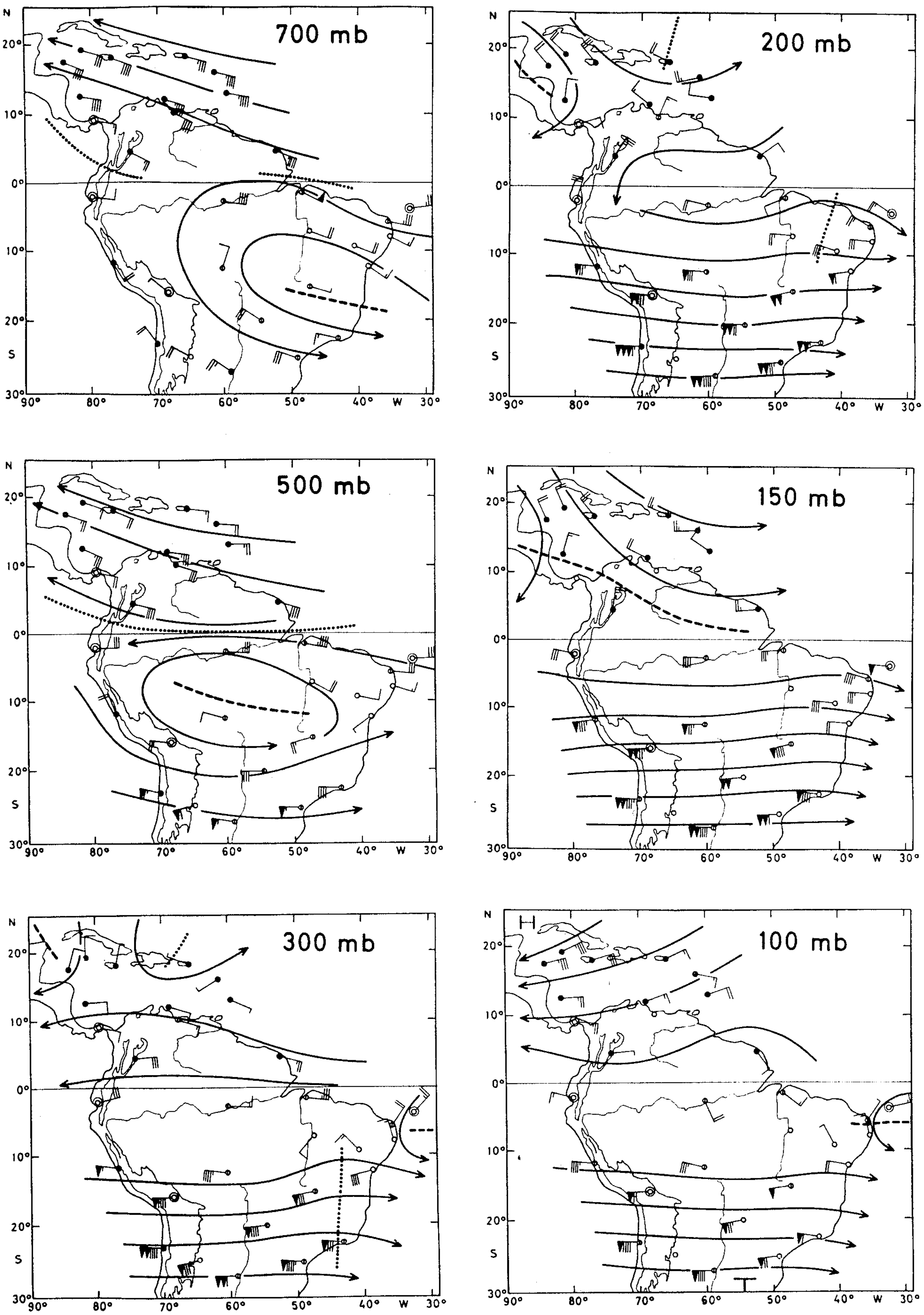

Fig. 4. Streamline pattern over South America during southern winter (symbols same as Fig. 3).

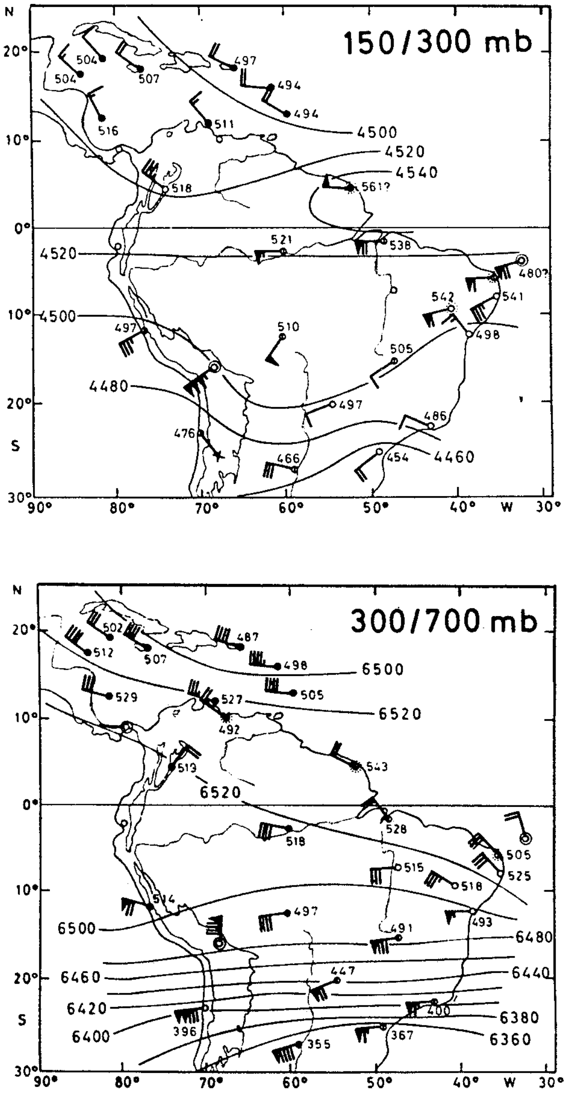

Fig. 5a. Thickness 300/700 mb and 150/300 mb above South America for southern winter (symbols same as Fig. 3).

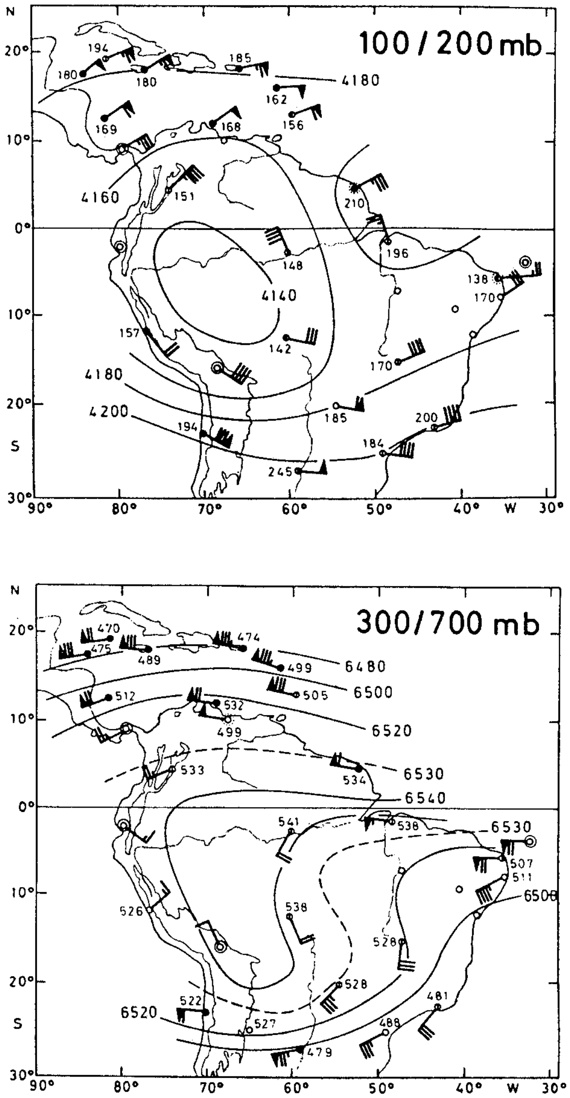

Fig. 5b. Thickness 300/700 mb and 100/200 mb above South America for southern summer (symbols same as Fig. 3).

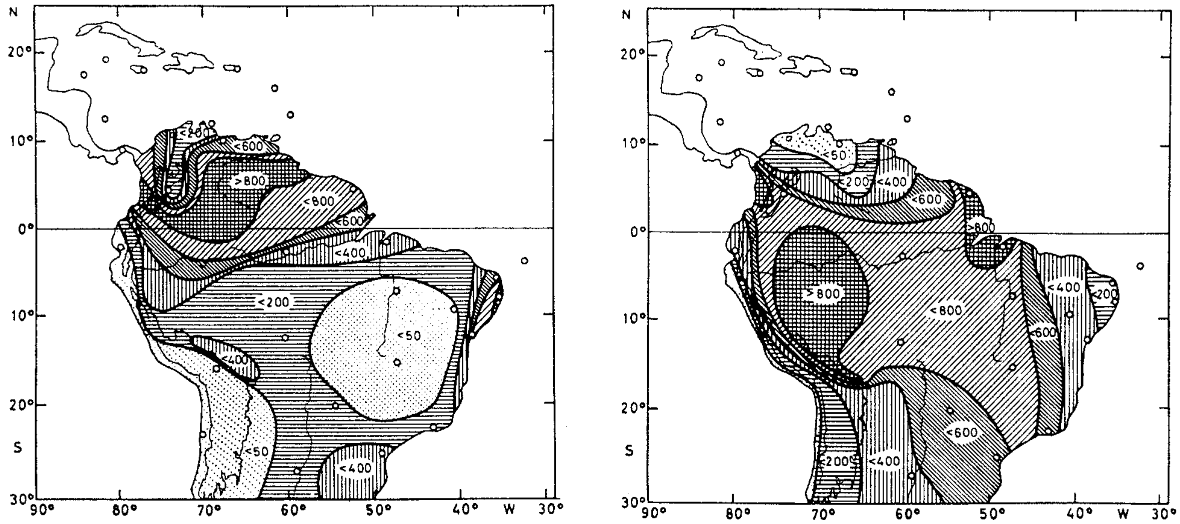

Fig. 6. Rainfall patterns above South America for a) southern winter, b) southern summer.

and has become stronger than during the summer. Thus the trade winds in the Caribbean are strengthened. At 500 mb this cell extends across the entire continent from the equator to 20 °S. In the northern hemisphere there are strongly developed tropical easterlies in the lower and middle troposphere, which are replaced by westerlies above 300 mb, i.e. by the north Atlantic trough. The mid-latitude westerlies of the southern hemisphere occur with jet stream-like velocities.

Thermal structures

The thermal structures over South America are shown by the field of the vertical wind shear, the thickness between the pressure surfaces, and the rainfall. During the southern winter there exists a poleward temperature gradient, with the position of the temperature maximum (derived from the thickness of the layer between the 300 mb and 700 mb pressure surface) situated between 5 ° and 10 °N (Fig. 5a). This pattern agrees well with the observed rainfall structure (Fig. 6a).

However, during the southern summer there is a longitudinally-extended heat center in the middle troposphere over the western Amazonas basin and the Altiplano (Fig. 5b), which is at the same position as the rainfall maximum during summer (Fig. 6b). At the 200 to 100 mb levels a cold dome appears just above the rainfall maximum. This cold area can be explained by either the radiational effects of the cirrus shields of the large rainproducing cumulonimbi or the "over-shoot"[1] of the cumulonimbi.

It can be concluded that the heat center during southern summer is maintained by the elevated heating surface of the Altiplano and by the precipitation processes. A similar situation is described by Flohn [3] for the Tibetan Highlands.

Meridional cross section

A climatic classification [2] allows the definition of two types of the tropical circulation: oceanic and continental. The continental type (over the sections of Africa, Asia and the Indian Ocean) is defined by a deep and relatively strong belt of tropospheric easterlies in the equatorial region, which are not interrupted by westerlies in the higher troposphere. The oceanic type over the Pacific and Atlantic Ocean is characterized by equatorial easterlies which are topped by westerlies within the upper troposphere such that the west wind systems of both hemispheres are connected. The middle tropospheric easterlies of the oceanic type are essentially weaker than the easterlies of the continental type.

A meridional cross section of the mean zonal component along 60 °W over the South American continent (taken from the streamline analysis) shows the continental type during the southern summer and the oceanic type during the southern winter (Fig. 7). This is in contrast to the findings over the African continent (cross section along 20 °E [7]), where the continental type occurs during both the main seasons.

The continentality of the southern summer circulation over South America is marked by rather weak tropospheric easterlies in the tropical areas in contrast to Africa. This suggests that the regular type of the South American circulation is oceanic as it is predominant during southern winter. The reason appears to be the similar heat budget of the ocean and the rain forest during both seasons because the fluxes of latent and

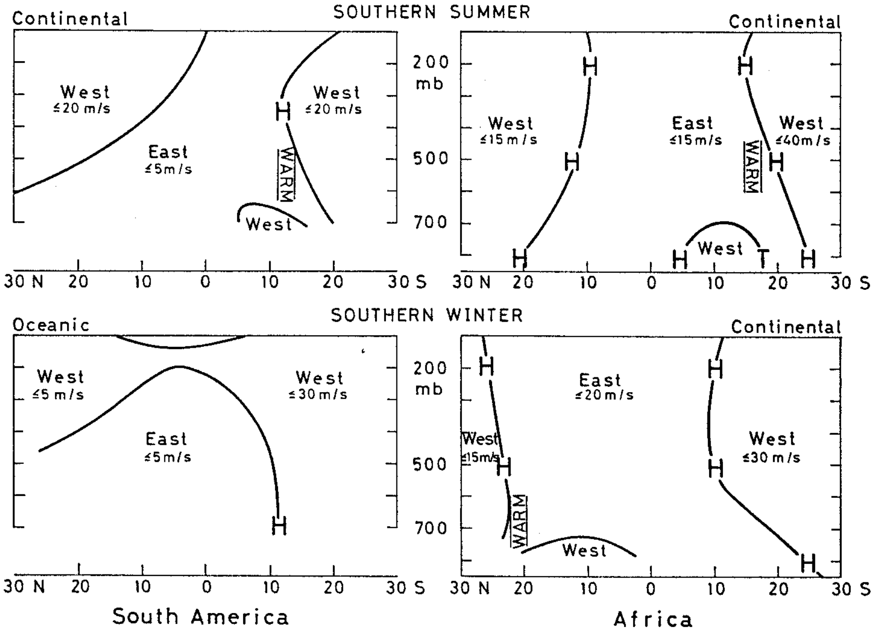

Fig. 7. North-south cross sections of the zonal winds above South America and Africa during southern summer and southern winter.

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[1] The rising air in the updraft penetrates through its equilibrium level and gets cooler than the environment.

sensible heat (Bowen ratio 0.1—0.3) are equivalent. The heating conditions of the Altiplano, causing an upper tropospheric anticyclone, modifies the oceanic-type-circulation by deep easterly winds. Thus the summer circulation appears to be the continental and not the oceanic type.

Additionally a low level west wind belt can be defined by the seasonal averages. Above its poleward limits there are warm cores in the middle troposphere. The causes of these west wind belts are given by the shallow continental heat lows (turning off the trades towards their centers) or by the tropical synoptic scale disturbances, at the equatorward sides of which the cyclonic wind rotation produces westerlies. The latter offers also an explanation for the mid-tropospheric warm cores correlated with the low level west wind band. This west wind belt is missing in the northern summer over the northern part of South America. This may be due to the fact that there is no heat low during the season or that the data are too poor to prove the west wind belt.

Conclusion

During the last decade the number of the rawinsonde stations over South America has rapidly increased. With these new stations the attempt was made to study the circulation over this subcontinent.

The striking features in our results are the warm anticyclone above the Altiplano during southern summer and the adjacent maximum of precipitation to the NE of it. The entire zonal circulation over South America depends upon this anticyclone. Thus the heating effect of the elevated surface of the Altiplano is clearly shown. During winter no such pattern is found.

A change of the circulation types from summer to winter is indicated by the north-south cross section. Following the description of Flohn [2] there exist the continental type during southern winter and the oceanic type during southern summer. It appears that the oceanic type is typical above South America. During the summer this circulation is disturbed by the high tropospheric anticyclone above the Altiplano which leads to the continental type circulation. But more data are needed to prove this hypothesis.

There are two facts which can explain the oceanic type over South America: The large extent of the tropical rain forest (about 5 °S—5 °N) and the shape and position of the subcontinent (the coast to the Caribbean Sea is already found at 10 °N). Consequently, a reduction of the rain forest will have a large effect on the climatology of South America. It would lead to a total change in the heat budget of the surface. As a result the oceanic circulation type would be replaced by the continental one with a strengthening of the west winds in the north during winter and a decrease of the precipitation at the eastern slopes of the Andes.

According to our present knowledge one can state that an extended destruction of the natural vegetation may cause far reaching consequences for the climatology of South America.

Acknowledgement

The authors are indebted to Prof. Dr. H. Flohn for his continuous interest in this work.

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