

The Zonal Flow of the Free Atmosphere Between 10N and 80S, in the South American Sector

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ABSTRACT

Data from all available sources have been used to construct vertical cross sections of the seasonal mean flow of the atmosphere between 900 and 30 mb, over the western and southern part of South America. Monthly zonal wind profiles are presented for the subpolar region where the stratospheric circumpolar westerlies in late winter are strongest. For these latitudes, an extrapolation of the zonal wind up to the 10-mb level is attempted.

1. Introduction

Before the International Geophysical Year, comparatively little was known about the winds in the middle and upper layers of the atmosphere over South America. For other sectors of the Southern Hemisphere, studies prepared by Flohn (1950), Loewe and Radok (1950), Hutchings (1950), Gibbs (1952), and van Loon (1955) at least gave a preliminary picture of the zonal flow, but not much could be done with regard to the conditions over South America, mainly because there were not enough reliable (all-weather) upper air observations available. This situation was partially remedied in 1957 with the installation of five U. S. radiosonde and rawin stations along the western coast of South America between 2 and 41S. In 1960 Schwertfeger published the first analysis of average zonal winds over South America, prepared from data of these five stations, in addition to four Argentine aerological stations with a rather irregular record, and two British stations which were the only ones in continuous operation several years prior to the IGY. Since then, more information has become available so that it is now possible and necessary to prepare a more detailed, accurate and extended picture.

Both directly measured and computed wind data can be used for such an analysis. The first ones are the only source of information in the equatorial region. In the higher latitudes, the mean values obtained from observed winds become less reliable, and generally too small in the upper layers. This is so because on days with continuously strong winds throughout the troposphere, the wind measurement by radar or radiotheodolite frequently comes to an end before the balloons reach the stratosphere. On many days, the reception of the pressure and temperature data extends to higher

levels than the wind sounding. This statement is true for all aerological stations which up to the present have been operating in the extratropical part of South America, but the performance-characteristics differ from station to station and with the seasons. The effect is most pronounced in the series with the Finnish radiosonde (which were given the least weight in the following elaboration), and is also rather strong with the British and German equipment, but is less so with the U. S. Weather Bureau type.

Consequently, more realistic values of the average zonal wind can be obtained, as has been done in many earlier analyses, by computing the geostrophic wind between stations at different latitudes and approximately equal longitude. Thus, at least, one can diminish the selection-effect which unilaterally favors situations with relatively weak winds. Then, however, there appears another serious obstacle: at the aerological stations of South America and the American sector of Antarctica, the above mentioned *four* different types of radiosondes have been used during the past years, and the temperature—and consequently the height values—for the pressure levels beyond 200 mb can be accepted only on a relative scale which depends upon the evaluation procedure, in particular upon the application or not of corrections for radiation errors and time lag. Between 100 and 25 mb (the highest level considered in this study) the effect of these differences in instruments and procedures on the computed heights and still more, of course, on the computed height differences, increases alarmingly. For these layers, computed mean geostrophic winds give reasonable and mutually consistent results *only* if pairs of stations with the same equipment and regulations are used.

These considerations have been taken into account in the following study. Direct wind observations have

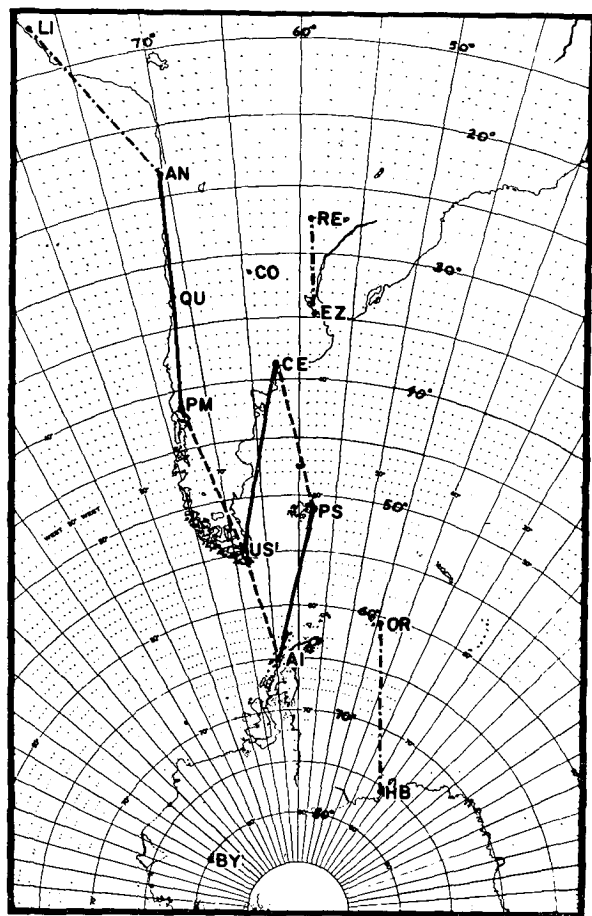


FIG. 1. Location of aerological stations listed in Table 1, used for wind computations. The solid lines are between stations of the same radiosonde type, from the height differences of which the geostrophic wind was computed up to 30 mb. Wind determination across dashed and dashed-dotted lines were used as additional information mainly in the lower part of the atmosphere.

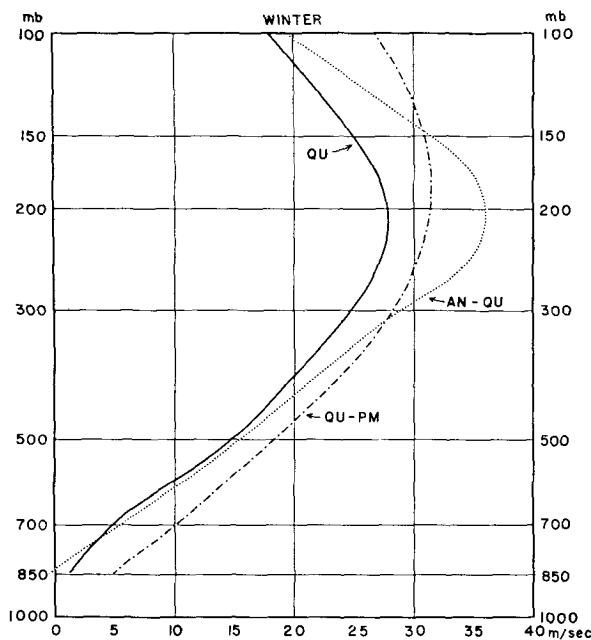


FIG. 2. The zonal component of the wind over central Chile in winter. Solid line: observed wind at Quintero; dotted: computed mean wind between Antofagasta and Quintero; dash-dotted: the same between Quintero and Pto. Montt.

been used only as far as the series seemed to be reasonably free of the systematic low wind speed selection effect, and geostrophic wind computations for the levels above 100 mb only for pairs of stations using sondes of the same type. This critical procedure leads to results of some homogeneity and reliability and justifies, in the opinion of the authors, the present publication.

2. Stations and records

The map of Fig. 1 shows the places for which aerological data were available. The continuous lines join pairs of stations with the same equipment; for these, the zonal component of the mean geostrophic wind has been determined up to the highest level with sufficient numbers of measurements. The dashed lines join stations of different equipment for which the computed winds have been taken into account only in the troposphere. In Table 1, the abbreviations used, coordinates, radio-

sonde types, and lengths of record are listed. Only certain of these stations have records from which the winds in the stratosphere beyond the 100-mb level could be determined (see the cross sections, Figs. 3 to 6), with October 1963 the latest month available on U. S. National Weather Records Center (NWRC) microfilm. The sources of all data are given in the second part of the list of references.

All height values used for the computation of the geostrophic winds have been carefully checked for consistency of values of the mean temperature, thickness and height. The number of corrections to be made was considerable. As a further test into the reliability and mutual compatibility of the results, wind profiles were drawn for each set of data; these graphs also best indicated up to which level the observed winds could be considered representative. Only one example is here included, in Fig. 2.

For two pairs of stations, essential for a complete picture of the zonal flow in the stratosphere between 40 and 65S, CE-US and PS-AI, the number of soundings available was small for 50 mb—and even smaller for 30 mb (see Table 2). For these four stations and two levels, the heights have been computed using the so-called difference-method which tends to diminish the bias toward days with relatively low wind speeds: month by month, the mean thickness of the 50- to 100-mb layer is determined for those days on which the soundings have reached the 50-mb level, and this mean thickness-value is added to the height of the 100-mb

TABLE 1. Stations and records.

| Abbrev. | Station | Lat. | Long. | Rasonde type | Wind record | Height record |
|---------|----------------|-------|-------|--------------|------------------|--|
| BA | Balboa | 09.0N | 79.5W | US | Jan. 51–Dec. 61 | — |
| BO | Bogotá | 04.7N | 74.2 | US | Sept. 60–Dec. 63 | — |
| GU | Guayaquil | 02.2S | 79.8 | US | July 57–July 60 | — |
| LI | Lima | 12.1 | 77.0 | US | Oct. 57–June 61 | Oct. 57–Dec. 63 |
| AN | Antofagasta | 23.5 | 70.4 | US | July 57–Dec. 63 | July 57–Dec. 63 |
| RE | Resistencia | 27.5 | 59.0 | Fi | — | Jan. 58–Dec. 63 ¹ |
| CO | Córdoba | 31.3 | 64.2 | Fi | Jan. 62–Nov. 63 | — |
| QU | Quintero | 32.8 | 71.5 | US | July 57–Dec. 63 | July 57–Dec. 63 |
| EZ | Ezeiza | 34.8 | 58.5 | Fi | — | Jan. 58–Dec. 63 ² |
| CE | Cte. Espora | 38.7 | 62.2 | Ge | July 60–Dec. 63 | May 60–Dec. 63 ⁴ |
| PM | Pto. Montt | 41.5 | 72.9 | US | Aug. 57–Dec. 63 | July 57–Dec. 63 |
| PS | Pto. Stanley | 51.7 | 57.9 | Br | Jan. 55–Dec. 63 | May 54–Dec. 63 ^{3,5} |
| US | Ushuaia | 54.8 | 68.3 | Ge | — | Sept. 57–April 58 and May 60–Dec. 63 ⁴ |
| OR | Orcadas | 60.7 | 44.7 | Ge | — | July 57–Nov. 58 and July 60–Dec. 63 |
| AI | Argentine Isl. | 65.2 | 64.3 | Br | — | Aug. 54–Dec. 63 ^{3,5} |
| HB | Halley Bay | 75.5 | 26.6 | Br | — | Apr. 57–Dec. 63 |
| BY | Byrd | 80.0 | 120.0 | US | Apr. 57–Dec. 63 | Apr. 57–Dec. 63 |

¹ Irregular record with several interruptions.

² With some interruptions.

³ Heights for 200 mb and higher levels only from Jan. 56.

⁴ Heights for 50 and 30 mb only May 60–June 62.

⁵ Heights for 50 and 30 mb only Mar. 59–Feb. 63.

level in order to obtain a height value for the 50-mb level which is considered more representative than a simple average of the 50-mb heights. This procedure can then be applied successively for the upper layers and levels.

3. Cross sections of mean zonal flow

The main result of the study is presented in the form of “meridional” cross sections for the four meteorological seasons (Figs. 3 to 6). As can be seen from the map, Fig. 1, the term meridional is here quite loosely applied, and more correctly it may be said that the cross sections describe the main characteristics of the southern circumpolar flow in a broad sector over, and to the south of, South America. A complete picture of the circumpolar stream-pattern was given by van Loon (1961) in his average 500-mb contour maps for the four midseason months. Certainly there must be noticeable variations with longitude, in particular from the west to the east coast of the tropical and subtropical part of the continents. It is likely, however, that such variations are relatively more pronounced in the weak meridional than in the strong zonal flow (Schwerdtfeger, 1961), and that they decrease with height, since the upper wind field is mainly determined by the thickness- (mean temperature) pattern, and the heat budget of the stratosphere is mainly regulated by radiation processes.

Figs. 3 to 6 are self-explanatory, and it is not intended to give a detailed discussion of specific features. It may suffice to mention that there are significant changes with regard to earlier representations, that the stratospheric

TABLE 2. Number of days with temperature and height data available for the higher levels at Cte. Espora, Ushuaia, Pto. Stanley and Argentine Islands. N* = number of all days of the respective period (see Table 1, footnotes 4 and 5).

| Season | N* | 50 mb | 30 mb | 50 mb | 30 mb |
|--------|-----|--------------|-------|--------------|-------|
| | | Cte. Espora | | Ushuaia | |
| Summer | 180 | 132 | 85 | 141 | 74 |
| Fall | 215 | 143 | 80 | 155 | 85 |
| Winter | 214 | 151 | 91 | 116 | 57 |
| Spring | 182 | 154 | 104 | 133 | 68 |
| | | Pto. Stanley | | Arg. Islands | |
| Summer | 361 | 145 | 76 | 162 | 67 |
| Fall | 368 | 161 | 114 | 156 | 69 |
| Winter | 368 | 174 | 100 | 97 | 37 |
| Spring | 364 | 138 | 59 | 187 | 89 |

easterlies in the summer are well defined, and that the strength of the winter and spring westerlies in the stratosphere considerably surpasses earlier estimates.

For the tropical stratosphere, the dashed isolines suggest that for this part of the atmosphere where the now well known, but less well understood, 26-month rhythm of the wind regime appears in a pronounced form, any values for an “average zonal flow” must be considered as somewhat ambiguous or vague, even if at least for one station, Balboa, an 11-yr record of observed winds is available.

For the tropical troposphere north of the equator, the isolines have been drawn consistent with those given by Crutcher (1961) in his meridional cross sections for 70 and 80W.

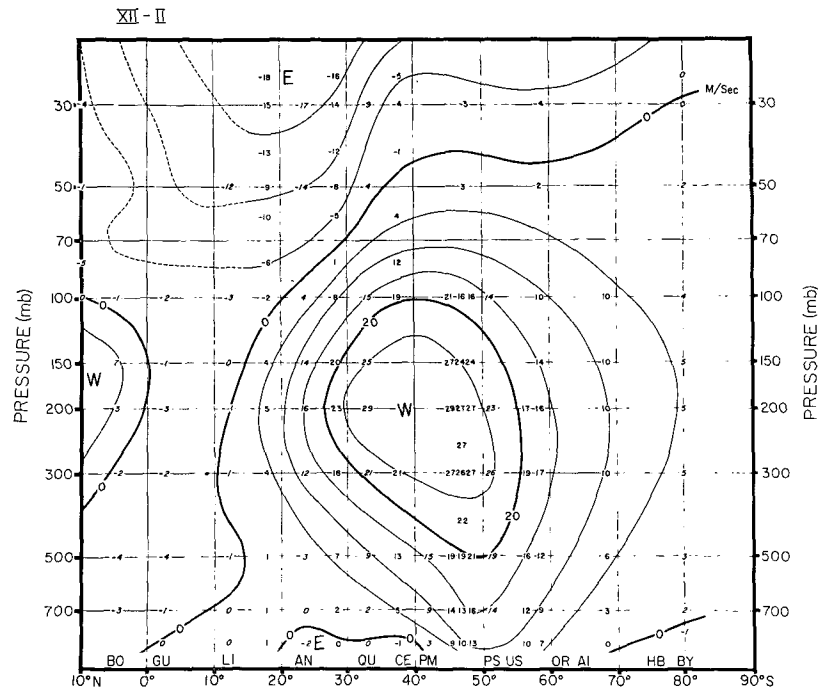


FIG. 3. Cross section of the zonal wind over the western part and to the south of South America, averaged for the three southern summer months, December to February. The slanted numbers represent mean values obtained from observed winds; the others give geostrophically computed winds.

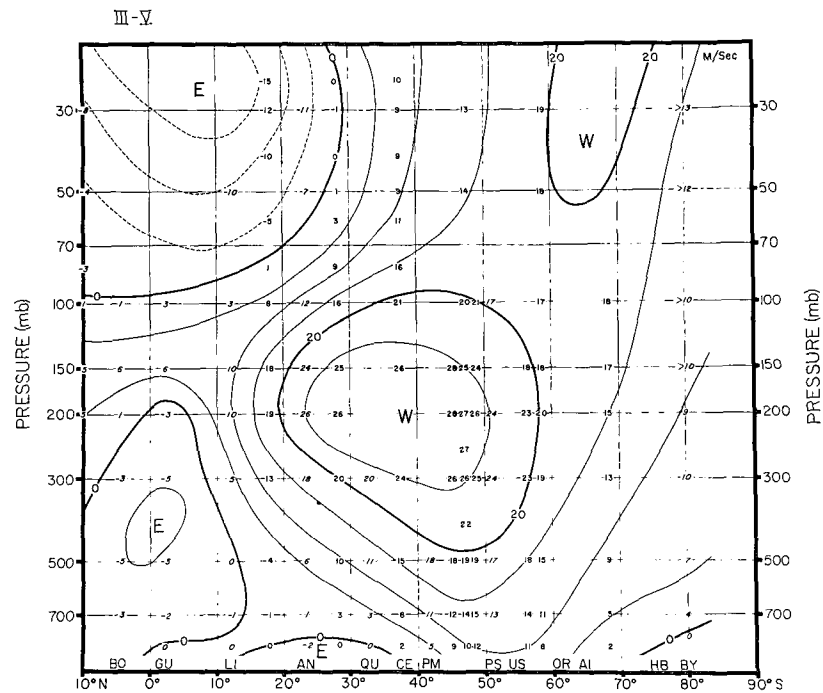


FIG. 4. Same as Fig. 3, for the three southern fall months, March to May.

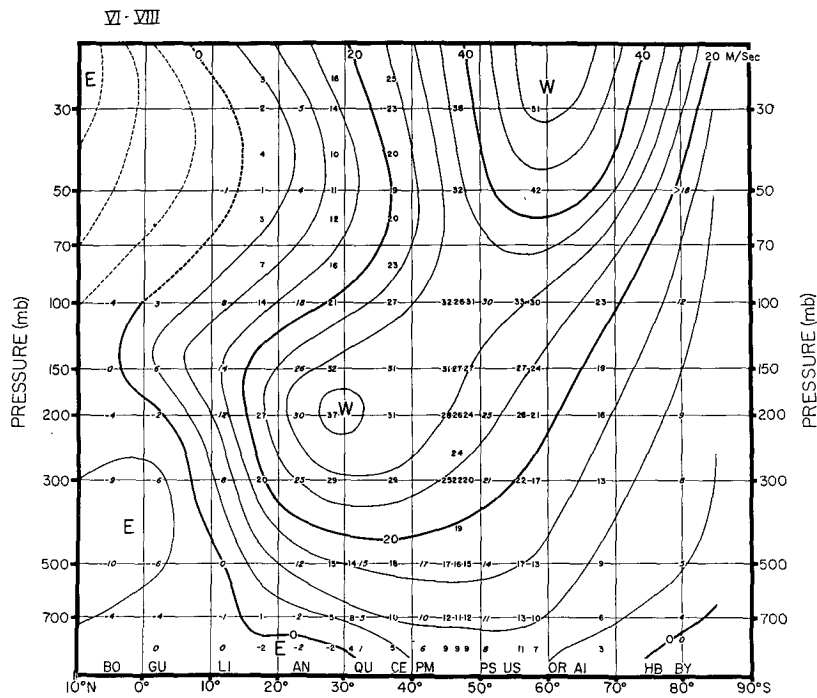


FIG. 5. Same as Fig. 3, for the southern winter months, June to August.

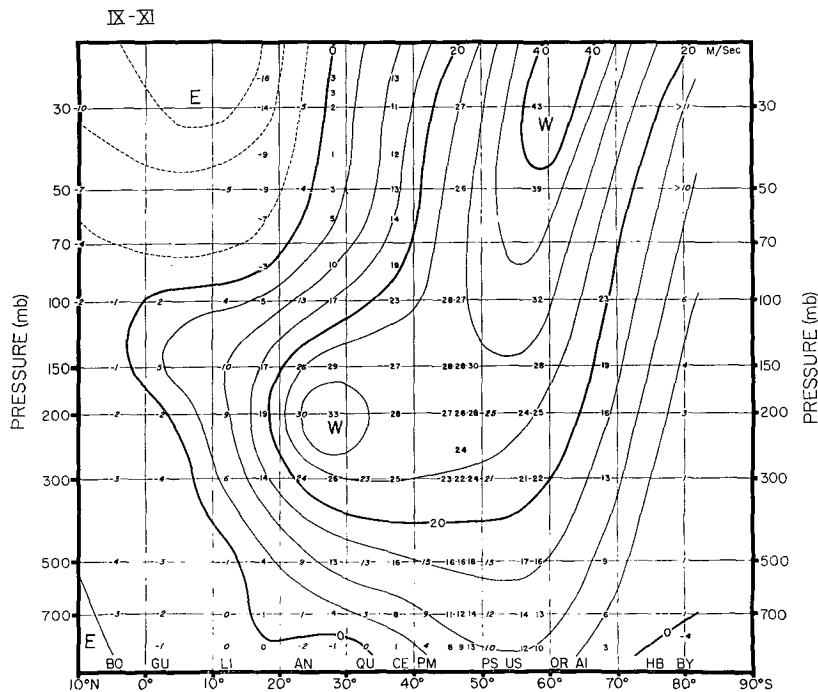


FIG. 6. Same as Fig. 3, southern spring months, September to November.

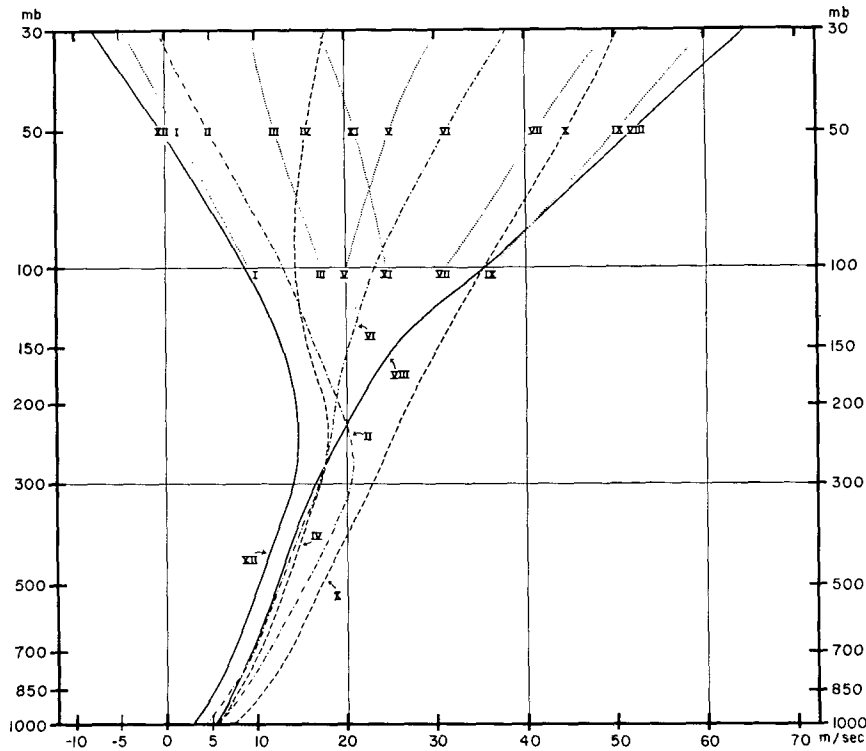


FIG. 7. Monthly vertical profiles of the mean zonal wind at about 58.5S, 60W, as computed from the height differences Pto. Stanley-Argentine Isl. For the layer from 1000 to 100 mb, every second month is omitted. (Months are designated by roman numerals: I for Jan.; XII for Dec.)

4. An overall check of the winds at the 30-mb level

It must be realized that nearly all aerological information becomes less reliable with increasing height: possible small systematic errors of the temperature soundings immediately affect the computed mean heights, and for a high level the resulting error can become considerable.¹ The wind measurements do not always reach the layers beyond 10 km (200 mb and less), and even when they do the height angles often become so small that a tiny inexactness of the readings and/or disregarded refraction effects can produce a large error for the wind.

Under such circumstances it is desirable to make a reexamination of the zonal wind data as given in the cross sections. This has been done for the 30-mb level, summer and winter season, by recomputing the height differences which correspond to wind speeds read from the cross sections, in steps of 5 deg latitude, from 23.5S (Antofagasta) to 80S. The average 30-mb height of Byrd station has been taken as representative for 80S. The result is the following:

| | Summer | Winter |
|--|--------|------------|
| Average 30-mb height, Antofagasta | 23,920 | 23,960 gpm |
| Average 30-mb height, Byrd station | 24,090 | 21,480 gpm |
| Difference | -170 | +2,480 gpm |
| Difference computed from zonal wind cross sections | -290 | +2,590 gpm |

The comparison indicates a satisfactory agreement for the winter cross section, indirectly confirming the very strong westerlies which characterize the southern circumpolar vortex in the stratosphere.

For the summer season it seems doubtful whether the rather rough procedure of the comparison is compatible with the relatively small height differences. If one accepts, for the sake of the argument, the above given summer values for the height of the 30-mb level, one comes to the conclusion that the cross-section winds (at this level easterlies throughout) are an overestimate. This can easily be so: as there generally are westerly winds in the troposphere and lower stratosphere, the radiosonde balloons reach the largest distance from the receiver station in the layer where the flow changes from west to east. Therefore, the chances to receive signals from the east-wind layer must on the average be better on days when this change happens at a relatively low height and when the easterlies in the upper layer are relatively strong, and vice versa. The result

¹ Note: A systematic error of 1C through the layer from 1000 to 30 mb corresponds to an error in height of about 100 gpm.

would be a bias toward an easterly wind component in the stratosphere.

5. Changes from month to month at a selected latitude

The fact that the cross sections represent mean seasonal conditions and thus most of the data are averages for 15 or more months, makes the results relatively safe against the effects of one or two months with rather exceptional conditions (as, for instance, July 1958), but tends, of course, to smooth out some variations which must be quite important for the proper understanding of the behavior of the circumpolar vortex, especially in the stratosphere.

Therefore, one graph (Fig. 7) is added in order to show the yearly march of the zonal flow in a more detailed form, for those latitudes in which the changes within one season, that is, in the southern spring from September to November, are very strong. In this period, the decrease of the westerly winds at the 30-mb level averages 1 m sec⁻¹ per day.

In an earlier study (Schwerdtfeger, 1962) it was shown and explained that the yearly march of the meridional temperature gradient, and of the zonal wind, in the subpolar latitudes is characterized by the predominance of a half-yearly variation (equinoctial maxima) in the troposphere and a yearly variation (late winter maximum) in the lower stratosphere. With the data represented in Fig. 7, the analysis of the yearly march can now be extended to the 30-mb level, and it is tempting to try an extrapolation towards higher levels where no observations are now available.

Such an estimate has been made up to the 10-mb level, corresponding to about 31-km altitude in summer, 29-km in winter. The annual mean of the zonal wind, and the amplitude and phase values of the first and second harmonic component of the average yearly variation were extrapolated as is illustrated by the dashed lines from 30 to 10 mb in Fig. 8. This leads to the following monthly averages of the zonal wind, between the Falkland Islands and Palmer Peninsula, at 10 mb: \bar{u} in m sec⁻¹

| | | | | | | | | | | | |
|-----|-----|-----|-----|-----|-----|-----|-----|------|-----|-----|-----|
| Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec |
| -26 | -9 | 15 | 31 | 42 | 56 | 74 | 87 | 79 | 49 | 8 | -22 |

As there are good reasons to assume that the southern circumpolar vortex at this high elevation is nearly circular, the above values may be useful to characterize the vortex, even if they cannot be considered much more than an "educated guess."

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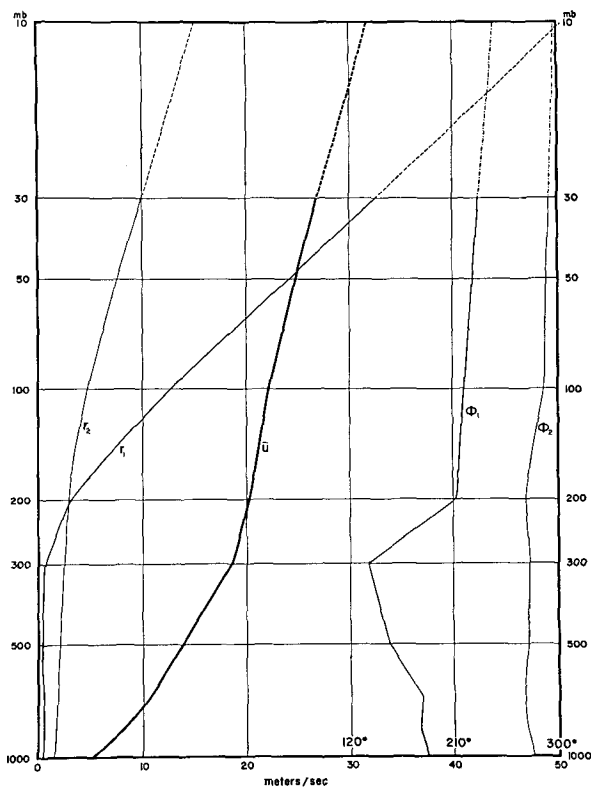


FIG. 8. Parameters of the annual march of the zonal wind between Pto. Stanley and Argentine Islands represented in Fig. 7. \bar{u} = annual mean of the zonal wind; r_1 and r_2 : amplitudes of the first and second harmonic component of the annual variation; φ_1 and φ_2 : corresponding phase values, with $x=0$ for January 1 (see Hisdal, 1960). For all standard levels from 1000 to 30 mb, the values are computed from the series of monthly means. The 10-mb values are extrapolated as indicated by the dashed lines.

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