Satellite Derived Inferences to Some Characteristics of the South Pacific Atmospheric Circulation Associated with the Niño Event of 1972–73

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ABSTRACT

Analyses of daily and multi-day satellite mosaic sequences are used to obtain evidence regarding the atmospheric circulation pattern over the South Pacific from the winter of 1971 to the summer of 1972–73. Interseason comparisons indicate a strong increase in cyclonic activity in the autumn, winter, and spring of 1972 over the ocean to the west of the coast of Chile accompanied by an apparent eastward trend in the movement of the quasipermanent South Pacific cloud band. Such a pattern is consistent with available conventional observations and it suggests an anomalously high frequency of northerly component in the surface winds over the higher latitude course of the Peru current. The latter would thus be retarded, presenting conditions favorable to a Niño season.

1. Introduction

El Niño is the name given to an anomalous season on the coast of Peru and Ecuador associated with warm sea surface temperatures in a region usually under the influence of the cold Peru current and upwelling. Such warmer ocean temperatures are of considerable economic importance because of the seriously adverse effect on the anchovy fisheries, resulting in a greatly depleted fishmeal supply to the world market. The phenomenon is often accompanied by a southward displacement of the intertropical convergence zone (ITCZ) leading to unseasonable rainfall in otherwise arid regions.

The Niño event of 1972–73 (Miller, 1973; Wooster and Guillen, 1974) has redirected attention to the history of this recurring climatic anomaly, and to the broad-scale ocean-atmosphere interrelations of which it is a manifestation. Quinn (1974) has made an analysis of southern oscillation indices to show the sequences preceding and accompanying the most recent and earlier events. His data suggest that Niño events occur when a relatively rapid relaxation takes place from a situation characterized by

a) large interannual strengthening of the southeast Pacific high (as measured by the pressures at Easter Island) and
b) large interannual deepening of the equatorial low pressure region over Indonesia (as measured by the Darwin pressures)

to a situation characterized by pressure anomalies opposite in sign over the two areas.

Thus, Niño events apparently tend to occur when the South Pacific high has decayed relatively steeply over a period of some eighteen months from abnormal strength to a very weak intensity. It seems that such variations in one of the major high pressure cells of the Southern Hemisphere should be accompanied by other discernable changes in the hemispheric extratropical circulation or, at least, in that over the South Pacific itself. However, an assessment of such changes represents a considerable problem, first in view of the almost total absence of meteorological data for the central and eastern South Pacific, and second because of limited knowledge as to the characteristics of a "normal" pattern.

Data on the general circulation features of the region are based on inferences derived by Taljaard and van Loon principally from the IGY data (Taljaard, 1972) and the estimates from limited satellite data (Streten and Troup, 1973). However, interseasonal comparisons may indicate apparently significant differences, and satellite derived inferences present a possible consistent method of comparison. Such a method must, however, represent only an unsatisfactory substitute for a reliable long term synoptic chart sequence.

An attempt is made here to use the satellite data to obtain inferences to circulation characteristics in the region for the period from mid 1971 to the end of the 1972–73 summer.

2. Analysis of satellite data in climatic investigations

Satellite derived computer generated mosaics covering a large geographical area may be utilized for longer term circulation studies in several ways. In the present

[1] Analysis of much of the data presented here was made while the author was at the Geophysical Institute, University of Alaska, in 1974.

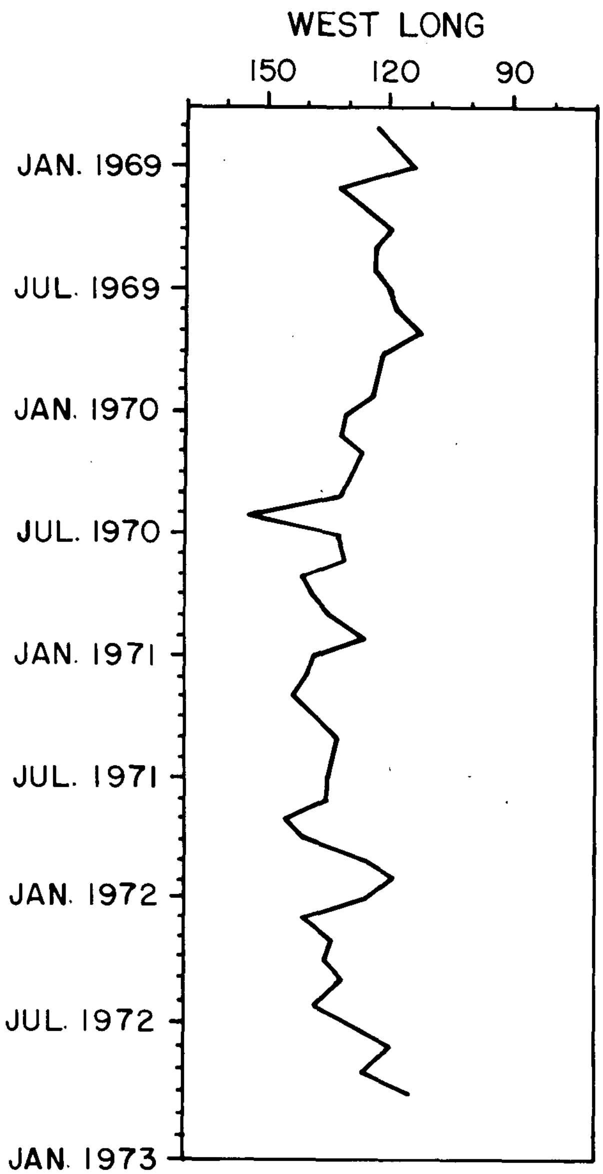


FIG. 1. Time section of the monthly median longitude of 5-day averaged cloud bands for the South Pacific sector averaged between 30°S and 40°S.

case the following are the most obvious:

a) The use of some indicator of the long wave pattern over the region, e.g., identification of progressive changes in the location of the well defined South Pacific quasi-meridional cloud band may provide a guide to seasonal changes in the predominating long wave pattern. An account of this feature and an analysis of previous data have been given elsewhere (Streten, 1970, 1973a).

b) A census of synoptic scale cloud vortices as an indicator of regional cyclonic activity and its variation from season to season. Further, by identification of vortex type according to a classification previously developed (Troup and Streten, 1972; Streten and Kellas, 1973) the possibility exists of using the gross totals of the number of vortices of different type to give an indication of the location of the principal negative anomalies of surface pressure or upper level geopotential averaged over a particular season.

c) The construction of track sequences of depressions in conjunction with the cloud vortex classification system. The principal difficulties in this approach lie in the wide variation between individual tracks and in the assessment of anomalies in the absence of a long sequence of track data [see, e.g., Streten and Troup (1973) and the discussion on this paper (Streten, 1973b)].

In the present case an analysis has been made using methods (a) and (b) above. The data employed were the Southern Hemisphere daily mosaics and the multiday brightness imagery for periods of 5 and 30 days. These products of the National Environmental Satellite Service have been described by Leese *et al.* (1970).

3. South Pacific cloud band sequences

An analysis of the variations in location of this prominent non-zonal cloud feature observed in time-averaged Southern Hemisphere mosaics (Streten, 1973a) was continued from December 1971 up to the last available observation in October 1972. These longer term data based on the 5-day averaged brightness charts are shown in Fig. 1.

The plotted location is the monthly median longitude of the 5-day averaged bands for the South Pacific averaged between 30°S and 40°S. The 30-day averaged data were also used and gave generally similar results to that of Fig. 1. However, sequences of 5-day data are generally more satisfactory and are less susceptible to differences in the necessarily subjective interpretation.

The locations of the band shown in Fig. 1 indicate a general trend to the east beginning around March 1972, although an earlier marked eastward displacement was evident between October and December of 1971. Between June 1972 and the last available position in October of that year the feature had moved some 15° of longitude to the east.

4. Seasonal vortex frequencies

Using the daily hemispheric mosaics for the period from 1 June 1971 to 31 March 1973 the locations of the individual vortices were noted and mapped for the sector of the hemisphere from 120°E eastward to 60°W (Fig. 2). The vortices were individually classified according to evolutionary stage; however, detailed tracks were not prepared. Comparisons between such vortex frequencies are made difficult by the absence of usable imagery south of approximately 40°S in midwinter, and variations in coverage between this time and midsum-

TABLE 1. Number of days of seasonal data coverage by satellite imagery equatorward of 40°S, and "average cyclonic frequency" (see text) for the 20°S to 40°S zone.

Season	No. of days of data	Average cyclonic frequency
Winter 1971	117	9.3
Spring 1971	58	3.9
Summer 1971–72	119	7.0
Autunn 1972	55	3.7
Winter 1972	117	9.8
Spring 1972	58	6.0
Summer 1972–73	117	5.1

mer when the entire oceanic region of the hemisphere is readily visible. The pattern of usable satellite data is thus fairly well paralleled by the definition of the seasons as originally proposed by Taljaard (1967) and subsequently used by other authors for the middle and high latitudes of the Southern Hemisphere, viz.,

Summer: December to March inclusive
Winter: June to September inclusive
Autumn: April and May
Spring: October and November

This seasonal definition is used in the present investigation.

A census was compiled giving the number of different extratropical vortex stages (A B C D_1 D_2) (Troup and Streten, 1972; Streten and Kellas, 1973) in each 10° latitude by 10° longitude square for each month and season. Initially, however, the frequencies were compared without regard to vortex type. Figure 3 shows the variation at 10° longitude intervals in the number of vortices between 20°S and 40°S for each season. The frequencies are expressed as a percentage of "the average cyclonic frequency." This is defined as the average frequency per 10° of longitude over the entire quadrant for the particular season (Table 1). The table also indicates the number of days in each season when reasonably reliable and complete satellite coverage was available for the whole sector of interest southward to 40°S.

Figure 3 displays clearly the regions of greatest relative cyclonic activity during the particular seasons. In particular, the marked rise in the relative frequencies in the region between 70°W and 100°W just westward of the coast of South America, firstly in the autumn and then more particularly in the winter and spring of 1972, is notable by comparison with the latter seasons of 1971.

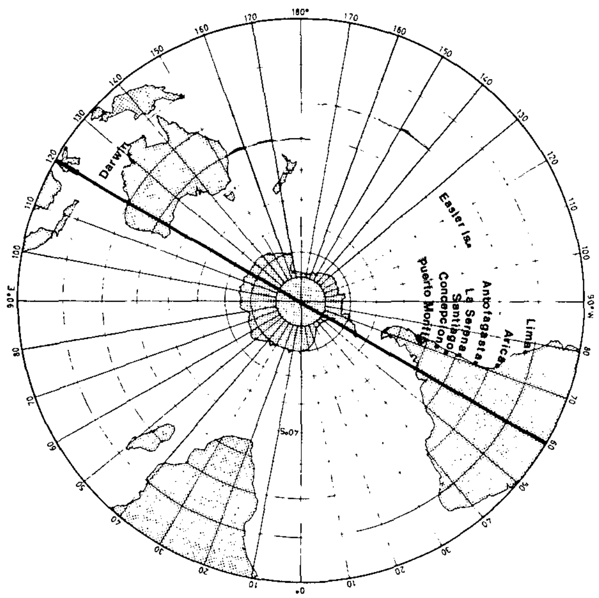
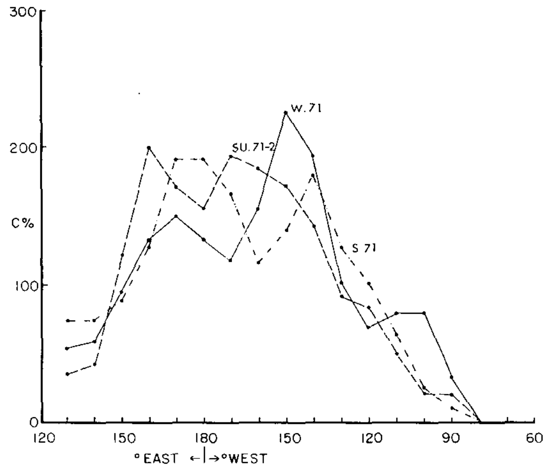
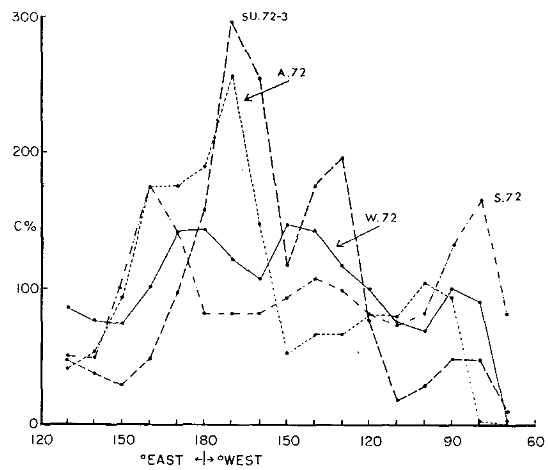


FIG. 2. The Southern Hemisphere showing the boundaries of the quadrant from 120°E to 60°W for which the cloud vortex census was compiled and geographical locations mentioned in the text.



a

FIG. 3a. Cyclonic frequency C between 20°S and 40°S for specified seasons of 1971–72 expressed as a percentage of the average frequency per 10° longitude between 120°E and 60°W. W, winter; S, spring; Su, summer; A, autumn.



b

FIG. 3b. As for Fig. 3a but for seasons of 1972–73.

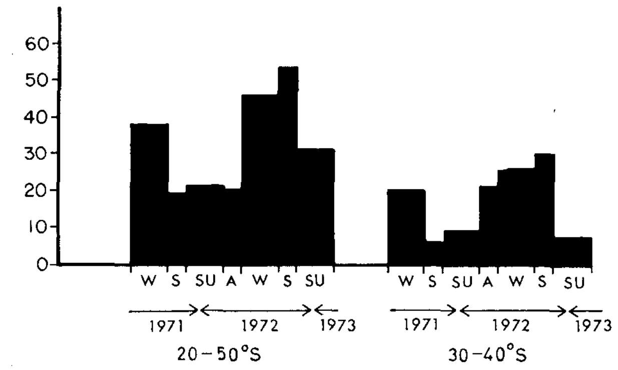


FIG. 4. Histograms showing the total number of cloud vortices for indicated latitude bands and seasons over the southeast South Pacific. Season abbreviations as for Fig. 3.

Actual numbers of depressions (derived from the daily satellite census) located westward of South America in the sector from 120°W to 70°W for two latitude ranges are shown in Fig. 4. A considerable increase occurred in the winter and spring of 1972 over the whole range from 20°S to 50°S and a marked progressive increase occurred from the spring of 1971 to the spring of 1972 between latitudes 30°S and 40°S. Over the whole quadrant from 120°E to 60°W the number of observed vortices on daily mosaics between 20°S and 40°S increased from 228 in the winter and spring of 1971 to 275 in the corresponding season of 1972.

In Fig. 5a the data of Fig. 3 are grouped by pairs of seasons and show clearly the increase in cyclonic activity between 20°S and 40°S west of South America in the winter and spring of 1972 relative to the 1971 winter/spring and the 1971/72 summer-autumn period. As shown in Fig. 3b, however, the increasing frequency to the east was first marked in the autumn of 1972. For the higher latitudes (40°S to 60°S) (Fig. 5b) the difference between the seasons is less marked. However, the winter/spring of 1972 displays a much higher level of cyclonic activity south of Australia from 40°S to 50°S than in the corresponding seasons of the previous year.

5. The pattern of surface pressure anomaly

A possible improvement in the index of cyclonic activity lies in consideration of the intensity of the depressions concerned as well as their number. In the classification of vortices described elsewhere (Troup and Streten, 1972; Streten and Kellas, 1973) a mean figure was derived for the mean sea level negative pressure anomaly $\bar{\Delta}p$ (averaged over a radius of 6° of latitude from the centers) associated with each of the types. These values are given in Table 2.

Ideally, statistically derived variations due to size and latitude could be applied to these values. However, these have not been considered in the present case as the corrections are, for the most part, small.

TABLE 2. Average MSL pressure anomaly $\bar{\Delta}p$ associated with vortices in particular development stages (average over 6° radius from vortex center).

Classification	Development stage	$\bar{\Delta}p$ (mb)
W	Wave	−1.4
A	Comma cloud	−5.2
B	Hook stage	−7.7
C	Mature spiral	−8.8
D_1	Decay (symmetric)	−6.6
D_2	"Decay" (asymmetric)	−10.4
E/K	Tropical cyclone	−8.8

Using the mapped frequencies of different vortex types, the value $\Sigma\,\bar{\Delta}p$ was derived for each 10° latitude by 10° longitude square (i.e., the total negative anomaly

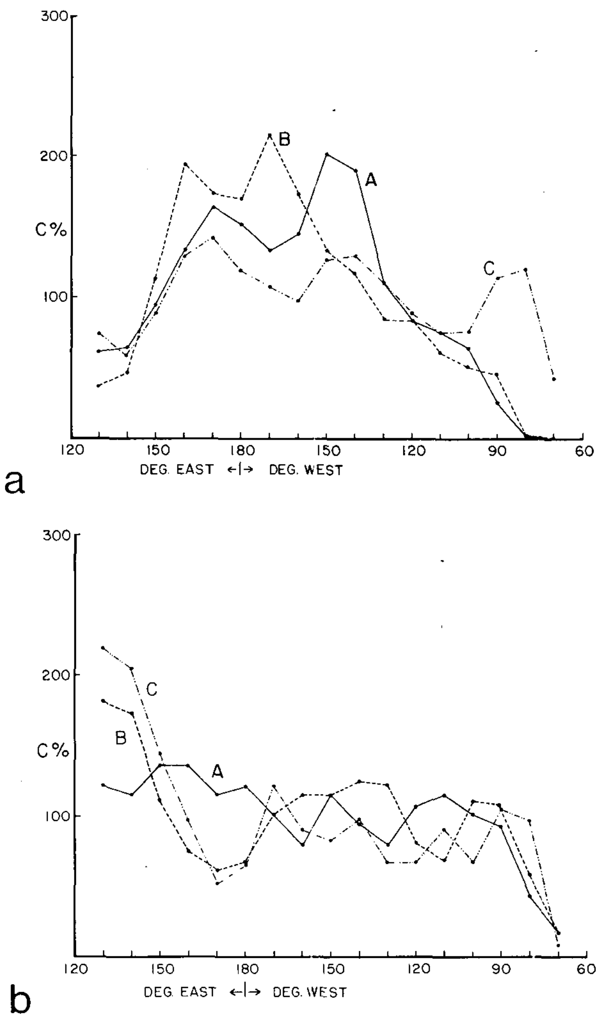


FIG. 5. Cyclonic frequency C expressed as a percentage of the average frequency per 10° longitude between 120°E and 60°W. (a) Between latitudes 20°S and 40°S for A, winter and spring of 1971; B summer of 1971–72 and autumn of 1972; C, winter and spring of 1972. (b) Between latitudes 40°S and 50°S for the same seasons A and C and between latitudes 40°S and 60°S for season B.

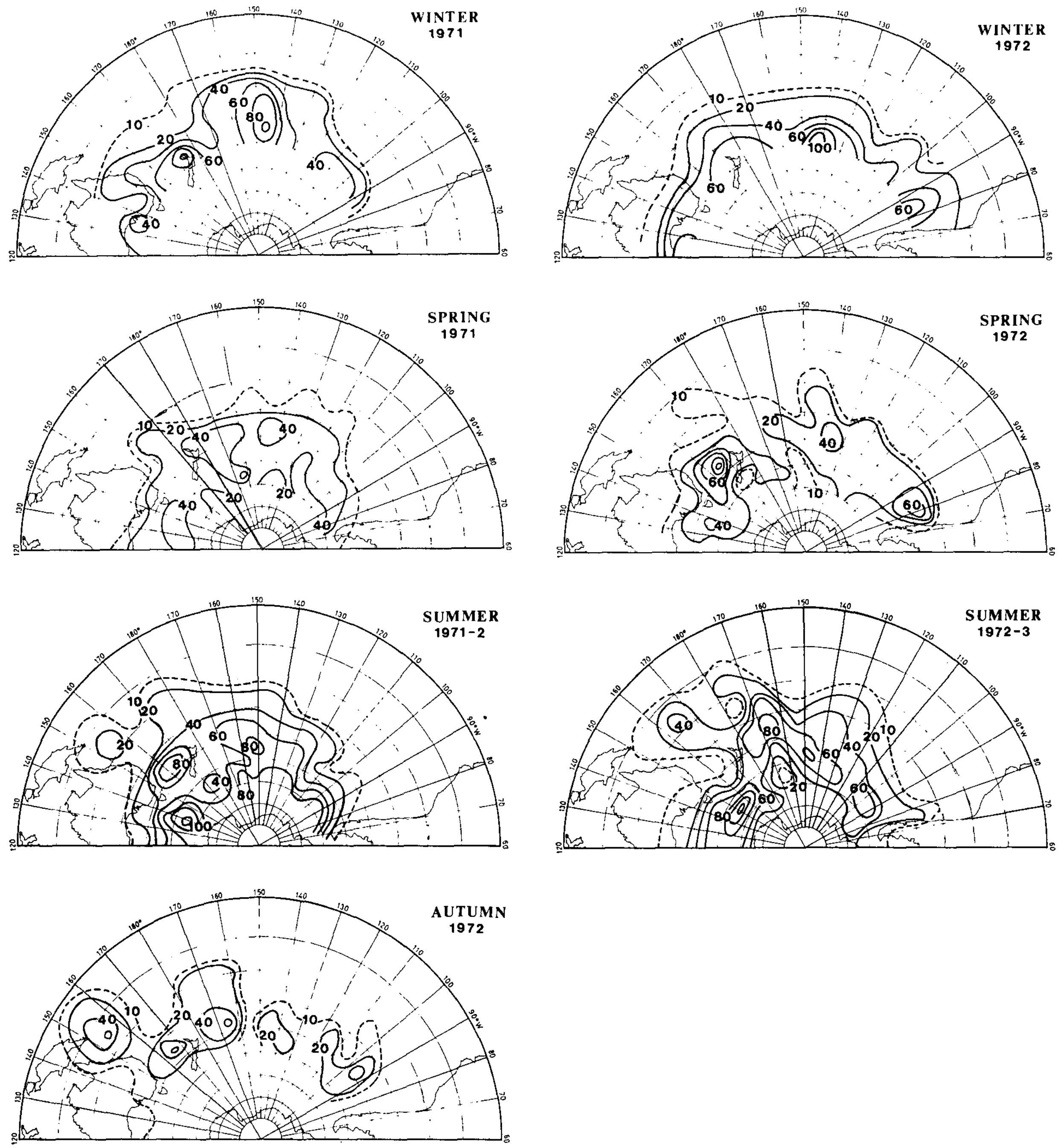


FIG. 6. Cumulative mean negative anomalies $\Sigma\ \bar{\Delta}p$ (mb) for specified seasons associated with depressions at different development stages over the South Pacific.

associated with the observed vortices) for each season. Maps of the seasonal distribution of $\Sigma\ \bar{\Delta}p$ are given in Fig. 6. This procedure represents an attempt to give some numerical assessment to the relative cumulative negative anomaly resulting from the pattern of the frequency of depressions at different development stages. It must, of necessity, be only an approximation to reality.

The charts show the development of a negative anomaly pattern westward of South America commencing in the autumn and becoming more pronounced during the winter and spring of 1972. This contrasts with the situation of the corresponding seasons of the previous year and of the intervening summer and autumn. Figure 6 thus largely reflects the patterns of Fig. 3.

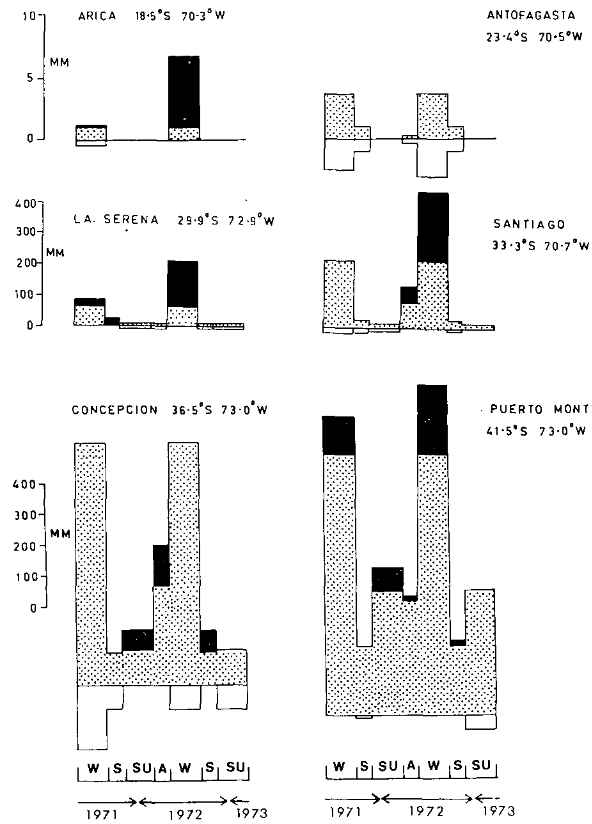


FIG. 7. Seasonal rainfall patterns for specified seasons at Chilean stations: stippled area, 30-year (1931–60) normal; black area, above normal; clear area, below normal. Seasonal abbreviation as for Fig. 3. Note the change of rainfall scale between lower latitude stations (Arica and Antofagasta) and those further south.

6. Discussion of the data

The data analyses described above tend to suggest that from June 1971 to the summer of 1971–72 the pattern of cyclonic activity between 20°S and 40°S in the South Pacific was very similar to that found in the investigations of Taljaard (1967) and Streten and Troup (1973). The principal activity occurred from the Tasman Sea eastward to around 140°W, but with rapid decay of cyclonic activity eastward of this longitude to the coast of South America. By the autumn of 1972 increased cyclonic activity was occurring in the vicinity of 90°W to 100°W.

However, in the winter and more particularly the spring of 1972, the cyclonic frequency increased around the Pacific quadrant, the number of vortices being some 20% higher than in the same seasons of 1971 for the region between 20°S and 40°S. This was particularly marked in the South Pacific east of 120°W.

This satellite derived information is consistent with the observed trend of surface pressure at Easter Island given by Quinn (1974) indicating a decay in the strength of the Southeast Pacific high throughout this period. It is further consistent with the low values shown in the time series of mean monthly surface pressures for Lima where the greatest negative anomaly in the 24 years (1949–72) occurred in August 1972 (Wooster and Guillen, 1974).

The cyclonic frequency indices indicate that the change was more pronounced at latitudes between 20°S and 40°S rather than farther south. Such weakening of the anticyclone and increased cyclonic activity to the east is also possibly related to the markedly increased rainfall over a narrow latitudinal span of the Chile coast during the winter of 1972. North of latitude 30°S and south of latitude 35°S the percentage departure from normal rainfall is not marked. However, between these latitudes considerably above normal winter falls occurred in Chile as exemplified by data from La Serena and Santiago (Fig. 7). It is at these latitudes on the fringe of the westerlies that changes on the broad-scale circulation pattern might be expected to result in abnormal precipitation. It is possible that the weakening of the high may also have been accompanied by its retreat slightly equatorward exposing locations usually under its influence to an increased westerly control.

As shown in Fig. 1 the time sequence of the cloud band locations indicates that the principal eastward movement of the feature began by March 1972 (or possibly earlier). It is interesting to note that a rather similar displacement was observed during 1969 when a minor Niño event also occurred; during the intervening years of the record the cloud band lay generally well to the west.

At the time of the increased cyclonic activity west of South America the multi-day brightness data indicate a tendency for the median position of the mid South Pacific cloud band to be located further eastward by about 15° of longitude. If the latter observation can be taken as an indication of a similar tendency in the long wave pattern as suggested elsewhere (Streten, 1973a), then this would be consistent with the observed higher frequency of mature and decaying cyclones at lower latitudes in the eastern South Pacific during the autumn, winter, and spring of 1972. In other words, cyclones forming at lower latitudes along the band and pursuing their usual track to the southeast would tend to arive at the later stages of their development in the eastern South Pacific at lower latitudes than would normally be the case when the band was further west. The observed prolonged higher cyclonic frequency at longitudes well to the west of the Chilean coast would tend to introduce a higher frequency of northerly component in the low-level winds over the ocean in the region of the more southern part of the Peru current. Such winds would tend to retard this cold current's flow towards the north at higher latitudes. Further north the decay of the southeast Pacific high would result in weakening of southerly winds along the coast, further retard the current's advance, and inhibit upwelling. Such weakening of the Peru current should thus provide a situation favorable for a Niño event.

Only limited upper wind observations are available on the Chile coast to test this hypothesis. Further, the degree to which these observations are representative of conditions over the waters to the west is open to question. However, an analysis has been made of the resultant seasonal components of the 850 mb level winds at three stations. These were then compared with the corresponding 9-year means derived from the microfilms which provide supplementary information to that published by Taljaard *et al.* (1969). The resulting differences between the actual observations and the means (Fig. 8) indicate a northerly anomaly at Puerto Montt in spring 1971 and summer 1971–72, and a more pronounced anomaly in the same sense further north at Quintero from the autumn of 1972 through the summer of 1972–73. Antofagasta also shows a northerly anomaly from the winter of 1972 through the summer of 1972–73. Thus a northerly anomaly of low-level wind (although of small magnitude) appears progressively further north throughout the period from the summer of 1971–72 to that of 1972–73. In general these data, insofar as they are representative, tend to confirm the inferences drawn from the satellite imagery alone. It is also interesting to note that for much of the period of the previous Niño event of 1965 and that of the minor event of 1969 a pattern of northerly anomaly is also found at the two more southerly locations; at Antofagasta, however, the winds were then very close to normal or had weak southerly anomalies.

7. Conclusion

The absence of long term data on the atmospheric circulation patterns over the Southeast Pacific prevents the definition of abnormalities in precise terms. However, the evidence presented here suggests that, associated with the Niño event of 1972–73, a substantial change occurred in the pattern and intensity of cyclonic activity in middle latitudes of the region. This was accompanied by an apparent eastward advance of the mid-ocean long wave trough commencing in the autumn of 1972, or earlier, together with a weakening of the Southeast Pacific high. Further, the rainfall pattern of the 1972 winter in Chile suggests that this weakening may have been accompanied by a slight northward displacement of the axis of the anticyclone. Low-level winds on the Chile coast also tend to display a northerly anomaly during the period. Such variations in the circulation pattern appear to be favorable to the weakening of the Peru current and the onset of El Niño. They would thus consitute a contributory if not causative effect on the phenomenon. The investigation indicates the complexity of the mechanisms involved, and further points to variations in large-scale circulation features perhaps over much of the hemisphere and at middle as well as lower latitudes associated with this particular climatic anomaly.

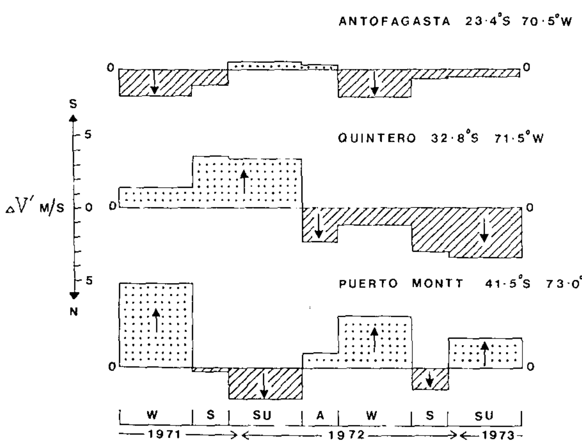


FIG. 8. Seasonal variation of $\Delta v'$(m/s) where $\Delta v' = \Sigma\Delta v - \Sigma\Delta v_n$; Δv is the meridional component of the resultant monthly 850 mb wind and Δv_n is the corresponding 9-year monthly mean.

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