A synoptic climatology of satellite observed cloud vortices over the Southern Hemisphere

By N. A. STRETN and A. J. TROUP

Commonwealth Meteorology Research Centre, Division of Atmospheric Physics, C.S.I.R.O., Melbourne, Victoria, Australia Aspendale, Victoria, Australia

(Manuscript received 13 March 1972; in revised form 23 May 1972. Communicated by Dr. G. B. Tucker)

SUMMARY

A classification scheme for satellite observed cloud vortices is used to assess some general features of the behaviour of Southern Hemisphere depressions. From coincident conventional observations the mean variation of surface pressure and upper level geopotential anomaly near the centre of, and in west-east cross-section through an extratropical vortex is determined in relation to its age. Data are obtained on the geographical variation of occurrence of vortex type, duration, and frequency of change between development stages. The percentage of vortices developing without a pre-existing cloud band is found to be greater at higher latitudes but, in general, over 50 per cent of developments occur in this way.

Persistent maxima of early vortex development are found in the western South Atlantic and in the central South Pacific, both regions extending into lower latitudes than elsewhere in the hemisphere. Two less prominent maxima are located in the central Indian Ocean, and south of Australia. Generalized vortex track and speed data are obtained, and several areas of high frequency of termination of depression track are observed at high latitudes near the Antarctic coast.

In total, the observations tend to point to a circulation pattern having a high frequency of major long wave troughs east of the Andes, and in the central Pacific, with a further frequent trough more variable in space and time being located between the central Indian Ocean and the longitude of the Great Australian Bight.

1. INTRODUCTION

For the greater part of the Southern Hemisphere oceans synoptic analysis at present depends largely on qualitative interpretation of satellite pictures against a fragmentary background of scattered island observations.

Using data from the ESSA satellite series, a study has been recently made of synoptic scale vortex patterns over the Southern Hemisphere. A classification scheme was developed based on the observed evolutionary development of extratropical vortices which may be readily followed on hemispheric mosaics, and which has been described by several authors (e.g. Boucher and Newcomb 1962; Widger 1964; Chang and Sherr 1969). These classified vortices were then related to conventional observations and a series of statistical patterns of anomaly from the long term mean data of Taljaard, Van Loop, Crutcher and Jenne (1969) was obtained as a guide in analysis. The details of this work are described elsewhere (Troup and Streten 1972).

The data obtained are capable of providing synoptic climatological information on the general seasonal pattern of cyclonic evolution and decay over the hemisphere. Although it is probable that not all low pressure systems which would be depicted on a weather chart in the presence of good observations produce identifiable cloud vortex patterns, it is felt that the major large-scale synoptic systems can usually be identified from the satellite picture alone. The analysis follows some earlier attempts with shorter periods of hemispheric TV mosaics and multi-day mosaics to observe prominent features of the hemispheric circulation (Streten 1968, 1970).

In an operational sense, sectors of the hemispheric mosaic are up to 24 hours old even at its time of production in the United States. Consequently synoptic systems viewed in this way may need to be 'projected' subjectively in time and in evolution to be useful for input to an analysis at a particular synoptic hour. Such mosaics must also be used as a
control guide to a numerical prognosis model output which has itself stemmed from an initial analysis with the same asymptotic defects. It is hoped that some of the data described here may enable such projections to be made with more confidence until a regular 4-dimensional numerical data assimilation scheme is developed using indirect vertical sounding data.

2. Data period and treatment

In order to adopt a standard approach the seasonal definitions as used by Taljaard (1967) have been adopted, these being linked to the seasonal pattern of sea temperature régime over the higher southern latitudes.

Summer: December to March inclusive.
Spring and Autumn combined as the 'Intermediate Season':—April, May, October and November.
Winter: June to September inclusive.

![Figure 1. Key map.](image)

The observations cover 12 summer months (or 3 complete seasons) and 7 months of the intermediate season during a period from November 1966 to March 1969. The satellite TV coverage is limited to latitudes lower than about 45°S during the winter due to poor illumination and extensive sea ice at higher latitudes. The hemisphere south of 20°S was observed daily, limited only south of latitudes 65°S to 70°S by the polar ice cap and by the construction of the mosaics.

Where areal frequencies are displayed in map form the method used by Taljaard (1967) is employed to reduce data to a standard area and seasonal length. This involves counting the frequency of particular systems per 'unit block' of 5° latitude by 10° longitude and multiplying the figure obtained by a factor $4 \cos 45/({n \cos \phi})$ where $n$ is the number of months of data and $\phi$ the mid latitude of the 5° latitude band of each block. This gives the number of systems per 'unit block' centred on 45°S and per season of 4 months, the unit area being 438,000 km².
Because of better conditions of observation in summer the absolute number of vortices at high latitudes ought not to be compared between the two seasons. However, the data should be geographically comparable within the same season at similar latitudes in terms of absolute numbers.

3. General characteristics of the vortex evolution and sequence

The primary cloud vortex classification employed is described and illustrated in more detail elsewhere (Troup and Streten 1972). However, the terminology is shown briefly in Table 1, and Fig. 2 shows schematic diagrams of the different common extratropical types W to D.

![Schematic diagram of primary classification of extratropical vortex evolutionary patterns](image)

**Figure 2.** Schematic diagram of primary classification of extratropical vortex evolutionary patterns (see Table 1). The distance taken as vortex 'radius' in each case is shown by r.

**TABLE 1. PRIMARY CLOUD VORTEX CLASSIFICATION**

<table>
<thead>
<tr>
<th>W</th>
<th>wave development – localized thickening of a cloud band</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>early vortex development – 'comma cloud' merged with a major cloud band or in isolation</td>
</tr>
<tr>
<td>B</td>
<td>late vortex development – a hook shaped cloud with a marked development of a slot of clear air</td>
</tr>
<tr>
<td>C</td>
<td>full maturity – cloud vortex with spiralling of clear air around a well defined centre</td>
</tr>
<tr>
<td>D</td>
<td>decay – either $D_2$ having considerable cloud near the centre or $D_y$ with fragmentary cloud near the centre</td>
</tr>
<tr>
<td>F/G</td>
<td>frontless vortices – corresponding respectively to $D_2$ and $D_y$ types but not associated with a cloud band</td>
</tr>
<tr>
<td>E/K</td>
<td>tropical cyclones in latitudes south of 20°S. Type E, with no frontal band and Type K having an associated band. These types are easily identified by the characteristic spiral structure at maturity and by their historical development in the Tropics and motion into higher latitudes.</td>
</tr>
</tbody>
</table>

During the period of observation some 582 sequences of evolution of individual cloud vortices were followed, the minimum criterion for inclusion being that the system should be observed on 3 successive mosaics, i.e. that it should have a duration of at least 2 days. As the mosaics are available only on a daily basis, it is assumed that an observed change of type between consecutive mosaics occurs at the mid point in time between the pictures. In the sequences the individual types and characteristics were noted. However, in cases where, close to a termination point of a sequence, a cloud mass clearly associated with a decaying system but not clearly of a specific classification was observed, it was included in the sequence and indicated as X.

Table 2 displays the frequency distributions of vortex duration in particular stages of development as determined from the mosaic sequences. The duration of vortex types in the formative stages is notably shorter and the Table provides some guide to the estimation of the development stage likely within a specified time. Table 3 shows the percentage frequency with which one type of vortex is followed by another on the succeeding mosaic – i.e. approximately 24 hours later.
The general pattern of vortex development in terms of surface pressure and 500 mb and 300 mb geopotential anomaly is shown in Fig. 3. Here, using the data for the vortex models the mean of all anomaly values within 6 degrees of latitude radius from the vortex centres has been plotted in relation to the mean duration of each type determined from the large number of sequences observed. The commonly observed extratropical development sequence – A → B → C → D → E → F is assumed without the complication of the other less frequent types. Corresponding values of mean anomaly are shown for the W, E/K and F/G types in the inset table of Fig. 3. A rather regular pattern is observed in the mean through the stages in the upper air anomalies. However, the still large surface pressure anomaly for the D type suggests that this stage is not so far advanced in decay, at least at the surface, as might be suggested visually.

A broad representation of the vortex development at particular stages of extratropical evolution is shown in Fig. 4 based on some 4,600 surface and 1,600 upper soundings. The diagram shows the mean west to east cross-sections through the vortex centre of anomalies of surface pressure and 500 and 300 mb geopotential. The longitudinal and vertical slopes of the anomaly patterns, which vary from marked asymmetry in the formative stages to a more symmetrical structure with maturity, are in general agreement with theoretical considerations and with the qualitatively observed behaviour of depressions in regions of good observational coverage. It should be noted that the anomaly patterns at a particular atmospheric level are not symmetric with regard to the vortex centre. The detailed patterns from which approximate thickness patterns may be constructed are given elsewhere (Troup and Streten 1972).
Figure 3. Mean departure from long-term monthly mean of MSL pressure $\Delta p$ (mb), and 500 mb and 300 mb geopotentials $\Delta \Phi$ (m) within 6 degrees of latitude radius of vortex centres, shown as a function of time for a regular extratropical sequence (see text). Small numbers on plotted points indicate the number of observations on which each anomaly is based. Inset table shows equivalent values for less frequent vortex types and number of observations.

Frequency distributions of the radii (see Fig. 2) of the particular vortex types indicate a fairly narrow range within each classification. However, the anomaly patterns are not found to vary markedly with size as such, but with development stage in which size is implicitly included. There appears to be no discernable variation in the mean size of particular types with latitude or with season.

4. General geographical variation of vortex frequency

(a) General latitudinal distribution

The zonal variation of the frequency of vortices of extratropical origin is given in Fig. 5 for the two seasons. The histograms include all the systems observed and not only those included in the sequence patterns described earlier, i.e. a total of more than 3,200 extratropical vortices. The same data have been used for the maps of areal distribution to be described later. The generally poleward progression of the zone of highest frequency with advancing development stage is evident. Median latitude of highest frequency for the chief extratropical types is shown in Table 4.

The variation with longitude and consequent features of interest in the hemispheric circu-
lation are conveniently described separately in terms of three extratropical evolutionary stages.

(i) Developing – including 'early development' (types A and W) and 'late development' (Type B)
(ii) Mature – Type C
(iii) Decaying – Type D

The less frequent types E/K and F/G are considered separately.

Figure 4. Mean east-west cross-section of MSL pressure anomaly Δp (mb) and 500 mb and 300 mb geopotential ΔΦ(m) for different development stages W to D.
Figure 5. Percentage frequency of vortices of different classification falling within specified 5° latitude bands for summer and the intermediate season. Numbers on histograms indicate number of observations of each type.

(b) Development stage

Extratropical cyclogenesis is observed on satellite photographs either as a bulging on a cloud band with or without a change in the orientation of the band (Type W), or alternatively as a comma type formation (inverted in the Southern Hemisphere) which may appear in isolation, merged with, or in proximity to a cloud band (Type A). In recent years the evolution of such patterns has been studied by many authors (e.g. Chang and Sherr 1969)
TABLE 4. Median latitude of highest frequency of vortices in different development stages (based on median values over individual ten degree longitude sectors around the hemisphere)

<table>
<thead>
<tr>
<th>Type</th>
<th>Median latitudes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Summer</td>
</tr>
<tr>
<td>A + W</td>
<td>44</td>
</tr>
<tr>
<td>B</td>
<td>48</td>
</tr>
<tr>
<td>C</td>
<td>33</td>
</tr>
<tr>
<td>D</td>
<td>37</td>
</tr>
</tbody>
</table>

and described in practical forecasting manuals (e.g. Anderson, Ashman, Bittner, Farr, Ferguson, Oliver and Smith 1969). As the average time spent in the early stages is smaller than in the latter (Table 2 and Fig. 3) and in order to obtain a larger sample the areal frequency of a single development stage is considered (Fig. 6 for summer). Fig. 6 also shows the mean summer position of the polar front in the Southern Hemisphere according to Taljaard (1968) who based this position on data of observed frontal frequency and of frequency of analysed thickness gradient maxima. The similarity of the maxima of developing depressions with the polar front location, and in particular the pattern of lower

Figure 6. Frequency of developing vortices (Types W, A and B) in summer per 'unit block' and per 'season' (see text). Full line is the position of the Polar Front in summer (after Taljaard 1968).
latitude development in the South Atlantic and South Pacific is further reflected in the multi-day mosaics produced by Kornfield and Hasler (1969) and Taylor and Winston (1968).

The axes of the zones of highest frequency of the early development stage are shown in Fig. 7. A median latitude of highest frequency was obtained for each ten degree longitude zone and the major axes of these points drawn together with such minor axes of higher frequency as appear at different latitudes. Here, the intermediate months' axis is very similar to the three fold frontal pattern of Hattie (1968) and in general, the axis of the zone of early development falls equatorward of that of the later development in both seasons, (Table 6). In summer, the observed zone of highest frequency of early development over much of the hemisphere is particularly regular and, when carefully assessed on the basis of individual latitudes, exhibits a distinct maximum at 45°S.

![Figure 7](image)

**Figure 7.** Axes of the zone of highest frequency of early development (A and W) for summer (dotted) and Intermediate season (full line). Where a secondary maximum occurs it is shown as a finer line.

A further method of obtaining an indication of relative frequency of cyclogenesis is to observe the sequences of vortex patterns lasting at least 2 days enabling some 548 mid latitude depression tracks to be constructed. The initial points of these tracks were recorded as 'points of cyclogenesis'. The areally mapped patterns of such points and of the axes of maximum frequency (not reproduced) are rather similar to those obtained by the analysis based on the appearance of cloud patterns alone (Figs. 6 and 7). Fig. 8 gives an indication of cyclogenesis as a function of longitude. Prominent is the very high frequency east of South America in both seasons. The South Pacific displays three maxima between 180° and
110°W in both seasons but more prominently in the intermediate months. Over the Indian Ocean a maximum occurs in both seasons near 85°E with a further prominent maximum near 120°E in the intermediate season. Careful analysis of tracks in this region close to the ‘day break’ in the hemispheric mosaics appears to indicate that the maxima here are real. In summer, a second small maximum is located at the longitude of eastern Australia.

From these observations and from examination of multi-day mosaics the impression is gained that the South Atlantic and South Pacific zones of maximum cyclogenesis are semi-permanent features in time, although varying in exact position from month to month. The former appears to be the more stable, its location probably being fixed by the combination of the upper trough east of the Andes and the confluence of the Falkland and Brazil current off the central east coast of South America. The Pacific zone extends over a greater longitudinal range and varies to some degree in location. Over the Indian Ocean the cyclogenesis pattern appears to be more variable with the maxima sometimes further to the north-west towards Madagascar, and at other times, particularly in summer, more zonal, near 45°S. In the mean, however, a maximum occurs eastward from Kerguelen Island to the south-west of Western Australia exhibiting a peak near 85°E.

Such a cyclogenesis pattern tends to suggest a broad scale circulation favouring a semi-permanent upper trough east of the Andes, a relatively frequent major trough in the central Pacific, and a somewhat more variable trough-ridge pattern over the central Indian Ocean and Australasia.

A more detailed examination was made of the cloud systems originating each of the extratropical vortex sequences. Of the total of 548 some 380 were first observed in the formative stage – 40 per cent as type A, 51 per cent as type B, and 9 per cent as type W. These data lead to some general conclusions regarding the process of cyclogenesis over the hemisphere.

(i) The frequency of non-frontal development increases towards higher latitudes. (Table 5).

(ii) The frequency of frontal and non-frontal developments over all latitudes is approximately the same in both seasons. (Table 5).
(iii) Over 60 per cent of wave developments are associated with an observed change of frontal orientation.

(iv) Where development is first observed as a distinct type A or type B formation, some 55 to 60 per cent of cases occur in the absence of a major cloud band.

If an observed organized cloud band can be taken as a necessary and sufficient indication of the existence of a substantial zone of baroclinicity, it appears that more than half the developments take place in the absence of such a zone i.e. such developments are of the second type described by Petterssen and Smeybe (1971) and apparently occur with greater frequency over the Southern Hemisphere oceans than observed in the Northern Hemisphere studies quoted by these authors.

TABLE 5. Percentage of vortices observed in formative stages (W, A or B) which did not form on a major cloud band (front). Bracketed figures give the number of observations for each case.

<table>
<thead>
<tr>
<th>Season</th>
<th>20–30°S</th>
<th>30–40°S</th>
<th>40–50°S</th>
<th>50–60°S</th>
<th>All latitudes</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>23(17)</td>
<td>26(43)</td>
<td>46(134)</td>
<td>71(63)</td>
<td>48(257)</td>
</tr>
<tr>
<td>I</td>
<td>6(3)</td>
<td>50(40)</td>
<td>57(60)</td>
<td>34(59)</td>
<td>31(23)</td>
</tr>
<tr>
<td>B</td>
<td>16(23)</td>
<td>37(83)</td>
<td>50(194)</td>
<td>68(78)</td>
<td>49(380)</td>
</tr>
</tbody>
</table>


On the average approximately 50 per cent of A type (comma clouds), develop to systems lasting at least 2 days. Between 20°S and 40°S in summer only 27 per cent of observed A type comma clouds develop as opposed to 48 per cent in the intermediate months. Between 40°S and 60°S the corresponding figures are 51 and 42 per cent.

(c) Mature stage

Maps of the areal frequency of mature depressions (Type C) (not reproduced) indicate:

(i) The pattern is more regular in summer with a maximum close to 55°S south of Australasia. North of 40°S the only substantial frequencies are in the central South Pacific and off the central east coast of South America.

(ii) In the intermediate season, higher frequencies are located northward to 30°S in many places. One higher frequency zone extends from south-east Australia and from the north of New Zealand towards Cape Horn, a second across the South Atlantic, and a third in detached regions south and south-west of Australia. The median latitude (Table 4) of the C type in both seasons is 5° to 10° of latitude south of that of the late and early development types respectively.

(d) Decaying stage

The decaying stage (type D) is, in general, observed only between 50°S and the coast of Antarctica, (median latitude of 56° to 57°S). Maps of areal frequency indicate higher frequencies than for the other types because of the considerably longer duration of the D stage.

A further measure of the location of dying systems may be obtained by analysis of the 'terminal points' of the track sequences. These are generally of the D type, but may also be of the F/G type and sometimes of the X classification (see Section 3). Mapped frequencies are very similar to those of the D type cloud patterns alone, and a frequency distribution as a function of longitude is given in Fig. 9.

Although the latter analysis shows considerable seasonal variation with longitude there are several prominent regions of cyclonic decay which appear to be major features of the circulation pattern and are located in the sectors corresponding to the following areas on or close to the Antarctic Coast.
(i) The Bellinghausen Sea.
(ii) The coast of East Antarctica between 110°E and 150°E with a maximum east of Terre Adelie (140°E).
(iii) West of the Enderby Land peninsula.
Further smaller areas of high frequency are located: 
(iv) East of Prydz Bay and Amery Ice Shelf.
(v) North of the central and eastern Ross Sea.
(vi) North of the western extremity of Dronning Maud Land eastward of the Weddell sea embayment.

(e) The less frequent vortex types

(i) The F/G (frontless type): Analysis of observations indicated that these types were associated with the most intense upper air cold core anomaly (Trup and Streten 1972). The highest frequency is observed to occur at latitudes south of 50°S with maxima north-north-west of Enderby Land and in regions south-east of Australia. This pattern suggests that such systems may be more frequent in regions of high frequency of deep cold outbreaks of air eastward of preferred positions of long wave ridges. The pattern of cyclogenesis and cyclolysis described above suggests that these areas may well be located in the vicinity of 30°E to 60°E, and in the longitude of eastern Australia and the western Ross Sea. Prominent upper ridge maxima were found in both areas for a limited winter period viz: (Streten 1969).

(ii) Tropical cyclones in higher latitudes: The warm cored (E/K) vortices penetrate higher latitudes with frequency as shown in Fig. 10. During this period the systems were more frequent in the Indian Ocean than in the south-west Pacific. Satellite observations confirm the well known absence of such systems in the South Atlantic and the south-east Pacific.
Figure 10. Frequency of warm cored tropical cyclone (Types E/K) per 'unit block'. The numbers refer to the total frequency of such systems observed over the 19 months. The inset histogram shows percentage frequency in 5° latitude ranges and total number observed.

Figure 11. Vortex track diagram—Heavy lines, 'major' tracks; finer lines, 'minor' tracks (see text) November (open dotted); January (full dotted); March (full line).
5. Track and Movement Speeds of Vortices

Although the variability in the tracks of vortices is considerable there is sufficient regularity in movement to reflect some major features of the circulation. Fig. 11 shows diagrams of the track axes for three individual months, the tracks of three seasons being included. A 'major track' was plotted as the axis of the zone 5° of latitude in width between each pair of meridians 10° of longitude apart which contained the greatest concentration of tracks. Where the total number of tracks in each 10° longitude zone is comparatively small or where abrupt latitudinal changes in the position of the major zone occur, the track axis is shown as a finer line in Fig. 11. Minor tracks are also shown as finer

![Diagram showing percentage distribution of vortex speeds](image)

**Figure 12.** Percentage distribution of vortex speeds (°/day) for specified latitude zones in summer and the intermediate season. The numbers on each histogram indicate mean speed in each zone and the bracketed figure the number of observations of daily movement in each case.
lines leading into a major track where substantial numbers of vortices followed these paths.

The data indicate:

(a) The comparative regularity of the January track though displaying three major points of entrance from lower latitudes.

(b) The greater northward spread of the tracks in the western South Atlantic and the central Pacific, and to a lesser extent in the central and eastern Indian Ocean in all three months.

(c) The marked three major track pattern in March with variations on this basic pattern in November. In the latter month the pattern differs from that of March with a double track pattern evident in the Australasian region, one originating east of Kerguelen Island and the other near Tasmania.

The rate of movement of the vortices as assessed from day to day may be obtained by knowing the time of each photograph on which the mosaic is based. The data for the 582 tracks were assessed for five separate latitude zones (Fig. 12). The chief difference between the seasons is the increase in speed between latitude 30°S and latitude 40°S from summer to the intermediate season reflecting the expansion of the zone of strong westerlies in summer to the colder months. Fig. 13 indicates the latitudinal profile of the observed speed of vortices and, for comparison, the profile of the mean westerly (U component) of the 500 mb wind based on the long term data of Jenne, Van Loon, Taljaard and Crutcher (1968). The mean data for the intermediate season has been weighted according to the relative numbers of each month used. It will be seen that, over the range from 35°S to 55°S the mean speed of the vortices is approximately half the mean zonal westerly component.

![Diagram](image-url)

Figure 13. Latitudinal variation of mean speed (V) of all vortices compared with the latitudinal profiles of mean westerly wind component at 500 mb (U_{500}) from the long term data of Jenne et al. (1968). Subscripts S and I refer to summer and intermediate seasonal data.

Calculated rates of motion for different vortex types indicate little variation from type to type. Type A (early development comma clouds) have a markedly maximum speed (10 to 11 degrees of latitude per day) between latitude 40°S and 50°S. In both seasons and particularly in the intermediate months the A type is the most rapidly moving. This is probably because its highest frequency is close to the location of the mean position of the polar front and such systems are thus frequently close to the jet core, particularly if, as is supposed, the comma cloud represents a development located at, or extending to the middle troposphere.
6. Conclusion

Over the data void Southern Hemisphere oceans satellite mosaic sequences enable some generalized synoptic climatological information to be obtained, and inferences to be made about large scale hemispheric circulation features.

In general the data indicate:

(i) The development of depressions over the oceans may be tracked by their corresponding cloud pattern 'signatures', and mean numerical values of anomaly in conventional data reflect the three-dimensional evolution of the vortices.

(ii) More than half the vortices developed in the absence of previously observed cloud bands.

(iii) A high frequency of vortex development is observed along well defined axes which delineate the principal frontal zones of the hemisphere.

(iv) A high frequency of decaying depressions is observed in particular longitudes close to Antarctica.

(v) The pattern of cyclonic formation and decay and the tracks of the systems tend to point to a high frequency of a basic 3 long wave pattern around the hemisphere. Such a pattern displays cyclogenesis east of South America associated with cyclostasis near Enderby Land, and further east; cyclogenesis from Kerguelen to southern Australia and cyclostasis near Adelie Land and the Ross Sea; and cyclogenesis in the central Pacific with cyclostasis in the Bellinghausen Sea.

Acknowledgments

The authors are grateful to Dr. G. B. Tucker and Messrs P. Noar and B. Hunt for their constructive comments and to Mr. R. Weinert who drafted the diagrams.

References


Boucher, R. S. and Newcombe, R. J.

Chang, D. T. and Sherr, P. E.

Hattie, J. B.

Jenne, R. L., Van Loon, H., Taljaard, J. J. and Cutchler, H. L.

Kornfield, J. and Hasler, A. F.

Petterssen, S. and Smebye, S. J.

Stretten, N. A.

Taljaard, J. J.


1968 'Zonal means of climatological analyses of the Southern Hemisphere,' Ibid., 17, pp. 35-52.


1970 'A note on the climatology of the satellite observed zone of high cloudiness in the central South Pacific,' Aust. Met. Mag., 18, pp. 31-38.


1968 'Climatic frontal zones of the Southern Hemisphere,' NOTOS, 17, pp. 23-34.