SOUTHERN OCEAN ANALYSIS WITH SPECIAL REFERENCE
TO THE PERIOD DECEMBER 1954 - MARCH 1955

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Abstract: This paper covers mainly the synoptic analysis of the Southern Ocean from South America to New Zealand from December 1954 to March 1955.

The pertinent reason for day to day analysis of the Southern Ocean is the control of the weather of southern Australia by the westerlies. Points that satisfy objectivity are sketched, though subjectivity, mainly in determining development in the present and, occasionally in post-analysis, will always be a limiting factor.

Conclusions from the analysis of the four month period include the fairly uniform longitudinal distribution of cyclones, the determination that lat. 45°S has the highest frequency of cyclogenesis, and an obvious source of polar anti-cyclogenesis south of the Atlantic Ocean.

Various factors suggest a complexity of the circulation regime that a uniform surface should not engender. More efficient determination of chart evolution must await the establishment of complete radio aids over all of the network.

1. INTRODUCTION

To those in any way associated with the demands of synoptic meteorology, an attempt at analysis over the region to the south of Australia, which is bounded by reporting stations on the 70°E and 160°E meridians (nearly 4,000 miles apart along latitude 50°S), would be expected to yield both
little observational detail and practical advantage. It would be readily imagined that objectivity would be submerged in a welter of subjective conclusions.

On the other hand, there is no need to stress what difficulties lie in the face of the forecaster in southern Australia without oceanic data. Shipping reports do not often assist materially as the chart can already be extrapolated to the few degrees south of the continent embracing the trade routes. The westerlies dominate the weather regime of Tasmania in all seasons, and in winter they extend northwards to 30° S. Hence it is necessary to probe the westerlies. How the oceanic and antarctic data can be used to achieve this in some measure is set out below.

Although daily charts (now twice daily) have been drawn for the adjacent Southern Ocean since the inauguration of stations at Heard and Macquarie Islands in 1948, the basis of this report is the period from December 1954 to March 1955. Data from Norwegian and Japanese whalers, South African synoptic data, and once daily charts for South America were used. Fig. 1 shows the positions of the land stations and the average distribution of the whaling ships.

2. BASIS OF SOUTHERN OCEAN ANALYSIS

The biggest contribution to success in this type of analysis rests with the conception of fronts and air masses. It is the air mass boundary that can be detected moving across the region, and which is projected over the ocean south of the continent. Along with other features of the secondary circulation, the fronts are relatively long-lived; thus, for example, it is not extraordinary to observe a front passing Cape Leeuwin two or three days after one has passed Amsterdam Island (or Kerguelen Island). They are usually identifiable as one and the same front. This primary datum gives confidence in continued projection of fronts in latitudes higher than 40° S between longitudes 70° E and 160° E even when they do not penetrate north of 40° S. It is true to say that most of the fronts of the Australian region have begun their life history at least by long. 70° E. There are exceptions: mainly resulting from frontogenesis in the northern fringe of the westerlies, and as a result of outbursts of Polar air which, if they occur between long. 40° E and 120° E, will normally affect at least southern Australia.
The unique position fronts hold in this type of analysis is confirmed by the classical association of fronts and depressions in the form of waves, and the more general recent conclusion of the sufficiency of advection of large amounts of positive vorticity above a surface front for cyclogenesis. This intimate association between fronts and low pressure development permits delineation on any particular chart of areas of possible cyclogenesis. Because of this, meteorologists in southern Australia are alerted toward specific areas of the daily chart rather than being left suspicious of the whole of the adjacent Southern Ocean as the likely breeding ground of a cyclone.

Indirect analysis is basically not so subjective when it is considered that the event sought is one of two, cyclone or anticyclone, trough or ridge. It is of great consequence that no third feature can fill the area between two troughs, i.e., the probability of finding a cyclone or trough between two ridges is never less than one. This fact is applied, also because of other reasons, when for instance no fronts have passed east of Kerguelen Island for, say, two days, and a cyclone is stationary just south of West Australia—a ridge, or independent anticyclone, is drawn at 50°S south of the cyclone. This non-subjective conclusion alerts at least the Tasmanian meteorologist to the possibility of a front entering the State from the south before it feels the effects of the cyclone.

This fact is essentially derived from the dispersive nature of the atmosphere. The simple manifestation of dispersion—a downstream pressure rise (or fall) usually follows an upstream pressure fall (or rise)—is as important a factor in the analysis as the front-cyclone association. The extension of this concept to chain development downstream is more difficult to determine and apply—however, it is not uncommon for a stationary upper trough west of Amsterdam Island to be associated with cold weather at Marion Island and be soon followed by an upper trough and cold weather in southeast Australia (Clarke 1954). Although short waves will complicate the pattern, it is not very often that three upper troughs will be located at 40°S between long. 70°E and 180°E.

Two other factors which support the practicability of the project are the geographical extent of the area to be analysed and the geometry of pressure systems. The
zonal distance between long. 70°E and 180°E is just over one wave-length for stationary waves in middle latitudes; thus ideally there are at most two major upper troughs whose surface features must be resolved. The balance between synoptic complexity and the extent of the area to be analysed with sparse data may well be reached here. That the atmosphere arranges itself in surface features of relatively large and definite extent is an advantage in ocean analysis, in that comparatively few systems must be accounted for. There are upper and lower limits to the size of systems; anticyclones over an extensive surface with north-south temperature gradient tend to be elliptic, and cyclones do not show any affinity for each other when they are large (Priestley 1948). Their comparatively extensive dimensions simplify the analysis; for example, pressure falls due to a cyclone forming or passing near Macquarie Island can also occur in Tasmania. It means that already the broadscale features of the chart can be extrapolated to 50°S from Australia.

The foregoing indicates the likelihood of analysing the completed event; but developments, which have small beginnings are always difficult to locate. In this respect the analysis is not straightforward; it is in fact a forecast, an anticipation of the most likely behaviour of a moving system as it traverses the region of no data. That is the problem which confronts the meteorologist in day to day routine. It must be appreciated that the analysis is never merely historical projection, although this yields the first approximation to the analysis. There is always development. In this respect it is important not only to recognise development, say, on one particular front, in low or ridge, but to discern the broadscale changes, i.e., to appreciate the trend of events, the probable evolution of the chart over as large an area as possible between Kerguelen Island and Macquarie Island. Subjectivity enters here.

3. GENERAL IMPRESSIONS OF ANALYSIS

The outstanding feature, represented daily, is the undulating westerly flow between 40°S and 60°S. Major troughs intersect lat. 40°S about every 70° longitude, and continue usually to polar regions. The high latitude cyclones themselves have the appearance of wheeling eastwards around Antarctica. Some of them possess a completely circular rotation, but in almost all cases the
northerly and southerly windstreams are limited at about 990 millibars when a shallow col appears between each cyclone. The relative lowness of pressure between the cyclones is verified on all charts. Even when an anticyclone is centred at 45°S, westerlies will not be found south of 65°S (unless there has been a recent outbreak, when this might be the case); instead the polar trough will persist with a pressure of about 985 millibars and higher pressure over the continent. Petterssen (1950) has shown that the polar space reveals an export of cyclonic vorticity from the Plateau to its periphery but this is not continuous. Only occasionally is there a cyclone with central pressure below 950 millibars; mostly there are no identifiable circular cyclones south of 60°S but rather a progression of barometric minima in an elongated curving, but broken, trough in the northern zone of which open and frontal cyclones develop. Particularly noticeable is the almost total absence at most longitudes of easterlies between latitudes 45° to 55°S indicating on the whole that the westerly belt is rarely split at high latitudes. That is, separate polar highs are almost non-existent, and the polar air masses traverse the Southern Ocean in areas of relatively high pressure which soon become attached to the temperate high pressure belts as southward extending ridges.

The zone from 50°S to Antarctica is not wholly a region of eastward progression of mature cyclones which travel great distances before filling in some preferred area. It is a region of both growth and decay - of growth in that as many new cyclones form around 50°S as in the low latitude westerlies and temperate region troughs; of decay, in that the general eastward movement is merely the integration of small contributions of individual cyclones, e.g., it is rare for a cyclone to be identifiable as passing from the longitude of Kerguelen Island to that of Macquarie Island.

Of much longer persistence is the frontal trough which, as a cyclone slows and fills, may move ahead and away from it without any tendency to frontolysis. On these occasions a new cyclone forms (circa 50°S) as an open depression at what is now the furthest southern extension of the front. Moving away from its parent into higher latitudes the new cyclone gradually assumes a circular character. The eastward propagation of a disturbance in which frontogenesis and cyclogenesis are maintained is often preceded by anticyclogenesis to the immediate west of
the front. This general characteristic appears well
developed eastward of Kerguelen Island. When it occurs
the new cyclone has initially an eastward course, but with-
out this pronounced anticyclogenesis, (when new cyclones
tend to form further north), it soon moves southeast to
65°S. It is the low pressure counterpart of the frequently
observed sequence in the Indian Ocean, where a new anti-
cyclone emerges to the east out of a larger system as a
gradual process.

The uniformity and development of the anti-
cyclonic belt at 30° to 45°S is as remarkable as the
persistence of the low pressure trough around Antarctica.
The polar front is mostly contained in the westerlies, and
only at fairly long spatial intervals does it penetrate
north of 40°S. The anticyclonic axis is almost always
east-west, the ridges which may develop in high latitudes
generally do not disturb the orientation but are soon
absorbed in the sub-tropical belt. High latitude anti-
cylogenesis is typical of two regions, viz., the far south
of South Africa where there is a tendency for the develop-
ment and rapid migration of polar anticyclones, and south
of the Tasman Sea where often persistent warm anticyclones
split the upper westerly belt.

Ridges extending north from Antarctica are weak;
often it is impossible to say whether when anticyclogenesis
is occurring at 60° - 65°S, the pressure rise began in
Antarctica or the developing ridge is an extension south-
wards of a sub-tropical anticyclone.

4. CYCLONES AND CYCLONIC ACTIVITY,
DECEMBER 1954 - MARCH 1955

The numerical frequency with which identifiable
cyclones occupied 5° squares is shown in Fig. 2. The
principal concentration of cyclone centres appears between
60° and 65°S where the highest frequency is between 70°E
and 110°E. There was thus in this region an overall higher
proportion of decelerating and decaying cyclones (omitting
cylogenesis) than, say, north of the Weddell Sea where
cyclone frequency is much less.

In the middle latitude westerlies (45° to 55°S)
the South Atlantic contained most cyclones with maxima
southeast of South America and in the neighbourhood of
Marion Island. Eastward of Marion Island cyclone density
FIG 2. FREQUENCY (NO OF DAYS) OF CYCLONIC CENTRES OCCURRING AT 0600 G.M.T. IN 5° SQUARES - DECEMBER 1954 TO MARCH 1955.
FIG 3. FREQUENCY OF CYCLONES AND CYCLOGENESIS. DECEMBER 1954 TO MARCH 1955.
is patchy. North of 40°S the main concentration is in the central Indian Ocean, where sub-tropical depressions often formed in the cold west of the main Indian Ocean anticyclone, revealing that the influence of the heated continents is directly controlling the location of these is ineffective.

There was no suggestion of preferred paths of cyclones emerging from low and middle latitudes. The only clear preference was for cyclones to cluster around Antarctica where the tendency was for eastward movement. The westerlies were strongest between 50° and 60°S south of the Indian Ocean and Australia; winds were more variable over the South Atlantic with westerlies more prevalent here at 40°S than elsewhere. The month of least cyclone frequency was February when also the contribution of tropical dips south of the continents and in the west Indian Ocean was highest.

The frequency in 5° squares of cyclones deeper than 970 millibars is shown in Fig. 3, illustrating clearly the remarkable cyclonic activity in the region of Marion Island. It was only here and through 40° eastward that deep cyclones occurred north of 55°S, apart from two instances in the South Atlantic. This extreme cyclonic activity is characteristic of all seasons. Excluding the unknown South Pacific Ocean the lowest pressure on the 50th parallel and the greatest interdiurnal variation of pressure apparently occur between Marion and Kerguelen Islands. Seventy per cent of the deep cyclones occurred between 60° and 65°S, followed by a rapid decrease over the next 5° southwards. In December the mean latitude of these deep cyclones was north of 60°S, while in February there were only isolated occurrences north of 60°S, the mean latitude being close to 65°S.

An attempt was made to plot the frequency of cyclogenesis as observed at 0600 GMT. Although the results must be incomplete they reveal (Fig. 3 inset) a probability of cyclogenesis spread over all latitudes, the highest frequency occurring between 40° and 50°S, with a mean latitude of 45°S. Unlike Petterssen's (1950) charts for the northern hemisphere there is no secondary subtropical peak. However if the hemisphere is divided into longitudinally bounded regions, a secondary maximum is revealed in the southwest Indian Ocean rather than over the continents. If there were preferred areas, they were south of 40°S in the southwest Atlantic Ocean, south of
South Africa and south of Australia, with a secondary area in the south central Indian Ocean. North of 40°S the southwest Indian Ocean is cyclogenetic in midsummer — usually developments in the easterlies.

Inasmuch as the axis of the sub-tropical anticyclones was north of 40°S in the South Atlantic Ocean, and never far south of it elsewhere, it is deduced that the majority of cyclones developed in the northern fringe of the westerlies and not between the anticyclones themselves (Palmer 1942).

To illustrate the synoptic complexity of this more or less geographically uniform region a chart for January 1955 showing tracks of cyclones north of 60°S is shown in Fig. 4. It is obvious that there were no preferred paths for the month, and that there was a fairly uniform distribution of cyclones in the westerly belt. The most pronounced northern extension occurs in the southwest Indian Ocean.

5. ANTICYCLONES
DECEMBER 1954 — MARCH 1955

Charts of anticyclonic frequency were not attempted, since their occurrence was almost wholly confined to latitudes north of 40°S. Centres that appeared over the Southern Ocean were small and confined to the region south of South Africa. Cases of anticyclogenesis may be defined as those occurring zonally in the anticyclonic belt with the phenomenon moving eastward, and those occurring in high latitudes with a pronounced meridional displacement. The former was a feature of the eastern half of the region, while the type more characteristic of air mass exchange appeared only in the South Atlantic Ocean. Here pressure rises, rarely to higher than 1010 millibars, were observed at 50°S, and were followed (or accompanied) by cyclogenesis to the east. They all had a rather short zonal travel before merging with a sub-tropical system.

The comparative absence of separate anticyclones in the westerly belt does not mean that the circulation there is so simple that it can be readily generalized. Ridges extending southward from the sub-tropical anticyclones, sometimes with strong links with the polar anticyclone, take their place. Although less
obvious, they must be surmounted by a sufficiently well
developed amplitude of the upper westerly waves to give at
least this part of the hemisphere its marked non-zonal
characteristics so well disclosed by the latitudinal
surface temperature and pressure rise eastwards from
Kerguelen to Macquarie Island (Gibbs et al. 1948).

6. FRONTAL CHARACTERISTICS

To serve as an introduction to this section and
to reveal the general type of analysis on which the report
is based, a series of surface charts is shown, beginning
with a type of frontogenesis occurring south-west of
Marion Island, which area must be regarded as one of the
sources of the polar front of Australia. In this particular
case, however, the front does not reach Australia.

Figs. 5 - 10 inclusive are the surface maps for
6 - 11 January 1955; and the following is a brief
discussion of the main features. Pressure began to rise
south-west of Marion Island on the 5th, and although no
temperature fall was apparent at the ships at 55°S, fronto-
genesis was suspected together with cyclogenesis on the
6th (Fig. 5). Simultaneously with pressure rises in the
ridge, the cyclone deepens tremendously in its passage
eastwards to Kerguelen Island (Fig. 7). The frontal
complex in the area east of Marion Island is capable of
several interpretations based on the data to hand. The
solution (Fig. 8) is akin to the general approach of
Gibbs (1949) whose analysis often included frontogenesis
in the sub-tropical extension of a trough containing a
polar front. (This phenomenon occurs over Australia when
the polar front is orientated WNW-ENE just north of 40°S
as a cyclone moves through the Bight, frontogenesis occurring
in the trough over central Australia. The Coastal Front
is the name for this type of frontogenesis in summer time.)
A marked warm front is disclosed at Kerguelen Island
whereas none is shown by observations from Marion Island.
Westerly thermal gradients must be more open across
long. 40°E than at 10°E on the 8th and the delta so formed
bears a new surface low west of Marion Island. This low
passes north of Marion Island around the now almost
stationary cyclone near Kerguelen Island on the 9th and
10th. At the same time, the characteristic dispersion of
energy spreads eastward, and the 1000 millibar isobar east
of Kerguelen Island attains higher latitudes on the 8th,
9th and 10th, to be followed by cyclogenesis south-west of
Tasmania on the 10th. The polar high remains near Marion
Island on the 10th and 11th, and mainly westerlies are established south-west of Australia. Except south-east of South Africa, the polar air nowhere reaches north of 30°S.

From the point of view of the analysis of the four months the following are some aspects of the frontology of the region:

(a) Origins of fronts which affect Australia are

(i) those already in existence in the South Atlantic Ocean;

(ii) frontogenesis occurring as a result of anticyclogenesis near Antarctica;

(iii) frontogenesis in the westerlies.

(b) Often it is not the original front that is being translated eastwards, but the propagation of the frontogenetic mechanism which goes hand in hand with renewed cyclogenesis, i.e., it is probably more correct to say that no front passing from the South Atlantic Ocean reaches Australia but rather the mechanism of frontogenesis associated with it is likely to. In the movement eastward such an original front is certain to move into a region occupied by a decaying front, or again be re-invigorated by the arrival of another front, similar to the complexity which accompanies the identification of individual cyclones moving around Antarctica. This, of course, refers to frontal translation from the South Atlantic.

Of the processes listed under (a) new fronts arising from (ii) and (iii) do not appear to be of frequent occurrence, though from (b) it is the continued cyclogenesis-frontogenesis complex which maintains a particular front from day to day over long periods. From the preference for polar anticyclogenesis in the Southern Ocean around long. 10°E, a definite region of frontogenesis is suggested here. Although continuity in frontal analysis in middle latitudes is achieved in the kinematic displacement of fronts as substantial boundaries for rather long periods, no more detailed statements can be made in respect of preferred areas of frontogenesis.
The discussion has been centred around the overall surface picture during a particular four months. Mention has been made of the lack of zonal concentricity of mean temperature and pressure at least between long. 20°E and 180°E over the whole of the Southern Ocean. Mean monthly charts reveal constantly higher temperature and pressure in the east of this region, suggesting that the mean flow is non-zonal. The preference for polar anticyclogenesis south of Africa (well illustrated in the summer 1954-55) and the tendency for large warm anticyclones to cover the region of Macquarie Island, are particular aspects of this phenomenon. The latter synoptic type, with its well established double-belt of westerlies, is common enough to favour the conclusions of Sutcliffe (1950) — "It appears that the classical model is not always the preferred mode of the general circulation", and of Kidson (see Lamb, 1948) "over the southern hemisphere as a whole ... symmetry (of the general atmospheric circulation), though much greater than in the northern, is far from perfect". It may be only possible to reconcile this non-zonality of properties with the concept that the hemispheric circulation is not even theoretically a closed system. The zonality of the southern circulation has impressed upon it an oscillation possibly derived from the mass exchange across the equator in the monsoons.

The type of cyclone occurring probably after strong high-level surges in the south-westerlies and, not thermally steered, characteristic of winter and spring (Langford 1950), the observations that some outbreaks appear to be bounded or become nearly cut off on the surface at 45°S as they do aloft, the tendency for fronts to be propagated eastward by the genesis of open depressions in high latitudes, north of the parent cyclone, are some characteristics of day to day analysis.

The problems of analysis without the assistance of whaling reports have been barely touched and include the particular problem of the warm front which, if it occurs, does not exhibit the precise requirements of definition as does the cold front. The difficulty is less resolvable because there is little tendency for cyclone families. Often the westerlies south of Australia do not yield satisfactory conclusions and remain unfathomable, so that 50°S — 45°S is the highest latitude in which a fairly confident analysis can be drawn. Usually charts can only be finally
drawn some 24 hours after the map-time, indicating that confidence is not often high enough to warrant forecasts of events which may be directed to Australia from the south and south-west. Fortunately, this condition is rare in that most weather reaches Australia from the west. This difficulty in conclusively defining the chart, even in the vicinity of the islands, often until many hours after the map-time is also a handicap in forecasting beyond two days.

Improvements and refinements in the use of the data for forecasting are bound up with more intensive integration of the upper and the surface charts. Provided radiosonde ascents are made at Kerguelen Island (or Heard Island), fairly comprehensive upper and thickness charts can be drawn (largely indirectly) from Marion Island to Macquarie Island to about 55°S. Although it is not expected that this procedure will overcome all difficulties, it is the recognized technique and will throw more light on the probability of development than can be expected from the surface chart alone. This is a basic requirement - because southern Australia is wide open to the westerlies, and the pattern of these is more complex than the conception of a regular procession of inverted V-depressions and anti-cyclonic ridges implies. The tendency of the pressure field to avoid long unbroken zones of high and low pressure even in the absence of large land masses is disconcertingly revealed in synoptic analysis of the Southern Ocean.

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