Stationary Waves in the Southern Hemisphere Mid-Latitude Zone Revealed from Average Brightness Charts

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Abstract

An analysis was made of zonal stationary waves in the Southern Hemisphere mid-latitude zone (20°S–60°S) by the use of 3-monthly (90 day) average brightness charts for the two extreme seasons (summer and winter) and one intermediate season of 1969, produced from daily satellite cloud pictures.

Harmonic analyses of average brightness along the four latitude circles reveal the predominance of stationary waves of wavenumber 1, 2, 3, and 4. At the main westerly zone (40°S–50°S), the maximum brightness, which corresponds to the trough of pressure wave, of wavenumber 1 stays in the eastern Atlantic through Indian Ocean, and at the subtropical latitudes (20°S–40°S), it stays in the central Pacific. Wavenumber 2 may be the fundamental mode through the mid-latitude zone with its maxima in the western Indian Ocean and the central Pacific. Wavenumber 3 is superior in the main westerly zone, and its maxima are located in the eastern parts of the three ocean. At the subtropical latitudes, wavenumber 4 is prominent, whose maxima are located in the extremely eastern parts of the three oceans and the central Pacific. These stationary waves (wavenumber 1 to 4) generally show NW–SE tilt. The features of wavenumber 1 and 3 are in good agreement with those depicted from 500 mb monthly mean charts by van Loon and Jenne (1972), but the predominance of wavenumber 2 and 4 is also confirmed by the present analysis.

1. Introduction

Studies of daily harmonic waves in the Southern Hemisphere have been made by several authors (Anderssen, 1965; Eliasen and Machenhauer, 1969 and others) based upon the conventional radiosonde data during I.G.Y., although these data were still unsatisfactory for complete analyses because of sparse and maldistributed observation stations. In contrast, a study on stationary waves based upon monthly mean charts has been made only by van Loon and Jenne (1972) up to the present. Their results for the mid troposphere are summarized as follows:

1. A wave of wavenumber 1 is predominant at the sub-polar latitudes (40°S–70°S) with its ridge in the central Pacific, and at the sub-tropical latitudes (around 30°S) with its ridge in the eastern Atlantic. This wave south of 40°S reflects the shape of Antarctica whose area is much smaller on the Pacific than on the Indian Ocean side.
2. In the mid-latitude zone (40°S–60°S), a wave of wavenumber 3 has the second largest amplitude, with its ridge near Africa, Australia, and South America, respectively. So, there may be a connection between this wave at middle latitudes and the influence of these three continents on the genesis and movement of pressure systems in the westerly zone.

In recent years, meteorological satellites have provided massive informations about the general circulation over the Southern Hemisphere, especially over the broad southern oceans, where both surface and upper air data have been lacking. For example, synoptic and climatological studies were made by the use of daily and 5-day mean cloud pictures by the Australian group (Martin, 1968; Streten, 1968a; Streten and Troup, 1973 and others). Their results revealed some characteristics of structure and distribution of mid-latitude cyclones and frontal zones.

In this paper, average brightness charts are analyzed to find stationary waves and their characteristics by examining zonal distribution of digitized average brightness along four mid-latitude circles, and a comparison with the results by van Loon and Jenne (1972) is made.

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2. Average brightness distribution and cyclone activity over the Southern Hemisphere

Average brightness charts are produced at NOAA by integrating brightness signals of daily satellite cloud pictures over various numbers of days, and normalizing to a grey scale of 16 grades. The charts for 5 days, 30 days, and 90 days are available. Though average brightness is composed of mixed distribution of the reflection from cloud cover, snow cover, sea ice, and the ground, it is considered as an indication of cloud

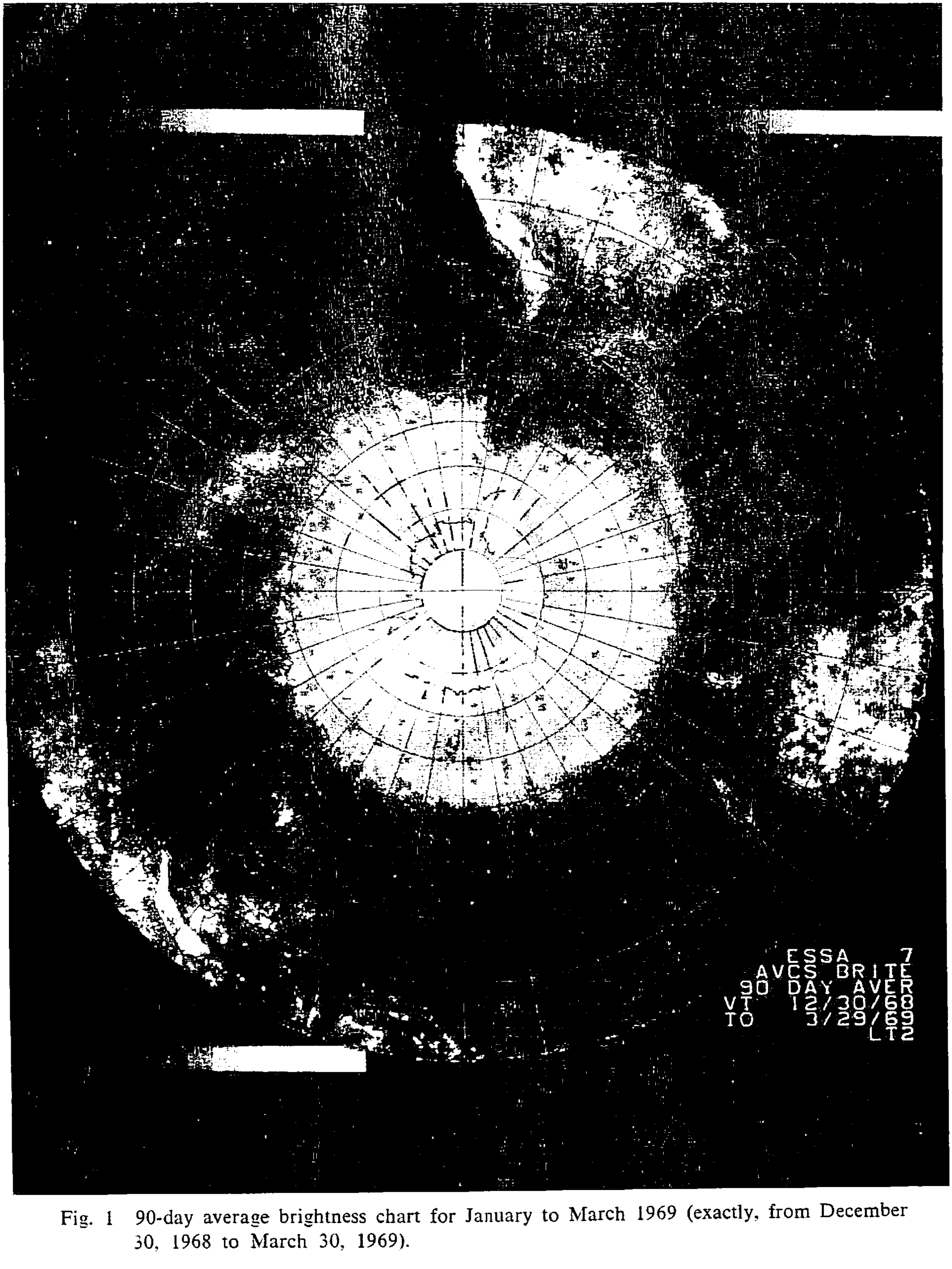


Fig. 1 90-day average brightness chart for January to March 1969 (exactly, from December 30, 1968 to March 30, 1969).

cover, if the area is limited over the oceans and seas except sea ice region of polar latitudes, and over the non snow-covered ground. The average brightness chart for January to March of 1969 (90 days) is shown in Fig. 1. To compare with digitized average brightness, mean cloud amount along 45°S and 55°S during January of 1969 is calculated by eye from ESSA-7 daily mosaic pictures in 2° latitude and 2° longitude squares over the western half of the Southern Hemisphere. The cloud amount in each 2°×2° square is taken to be as 1 (or 0) if the cloud cover is larger (or smaller) than the half. The relationship between the digitized average brightness and the mean cloud amount is shown in Fig. 2. Roughly speaking, the average brightness values are proportional to the mean cloud amount, but they are scattered with some width around the mean cloud amount. It is pointed out that brightness of clouds observed from each satellite picture is an index of thickness of cloud or cloud top height (Conover, 1965; Tsuchiya, 1972), namely degree of development of each cloud. Therefore, average brightness value is considered as a value multiplied "degree of development of each cloud" by "frequency of cloud cover". In other words, average brightness indicates frequency of cloud cover accounting degree of development of daily clouds, while mean cloud amount indicates frequency of cloud cover only, which is the reason why the average brightness values are scattered around the mean cloud amount as is seen in Fig. 2. In order to clarify the areas of frequent cyclone development, average brightness charts seem to be more suitable than those of mean cloud amount for the reason mentioned above. Fig. 3 shows the locations of cyclogenesis and cyclone tracks during January and March of 1969 plotted and traced from daily mosaic pictures. The term "cyclogenesis" in this paper is definited as the first stage of evolutionary patterns of extratropical cyclones classified by Streten and Troup (1973) shown in Fig. 4, and is limited in the case that any moving cloud system could not be found in the previous day but found in the next day. Namely, cyclogeneses in this paper correspond mostly with the

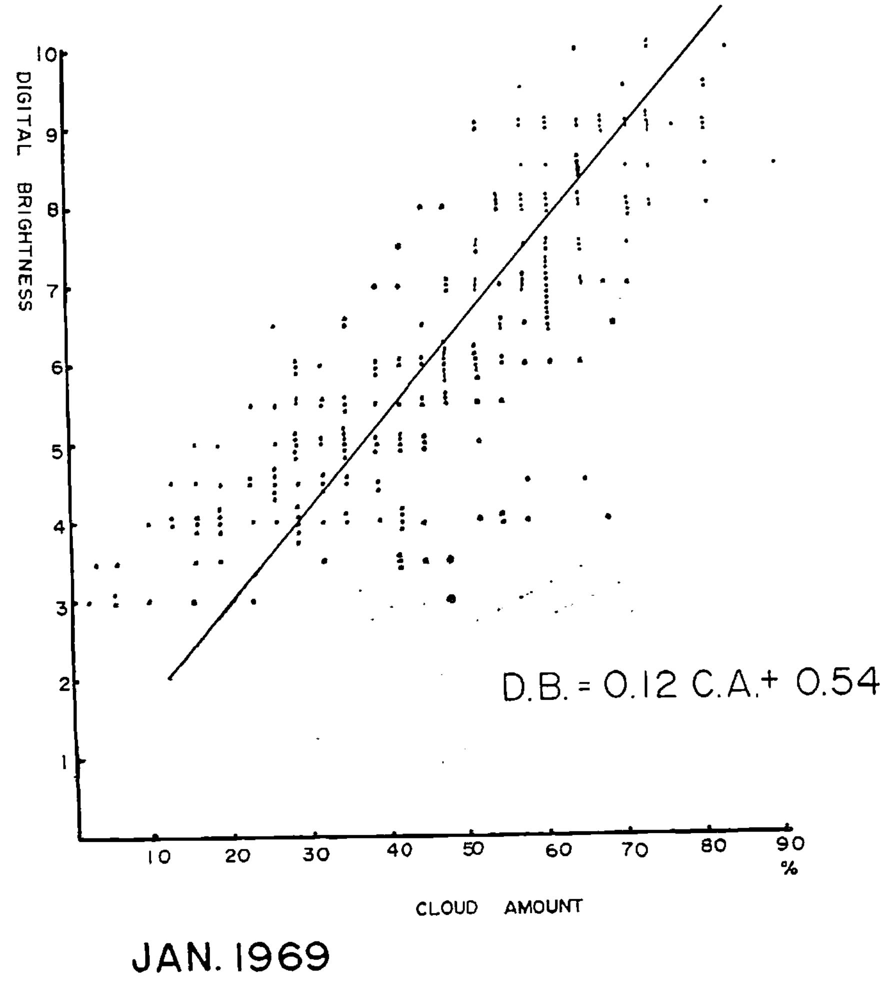


Fig. 2 Relationship between the mean cloud amount and the digitized average brightness for January, 1969.

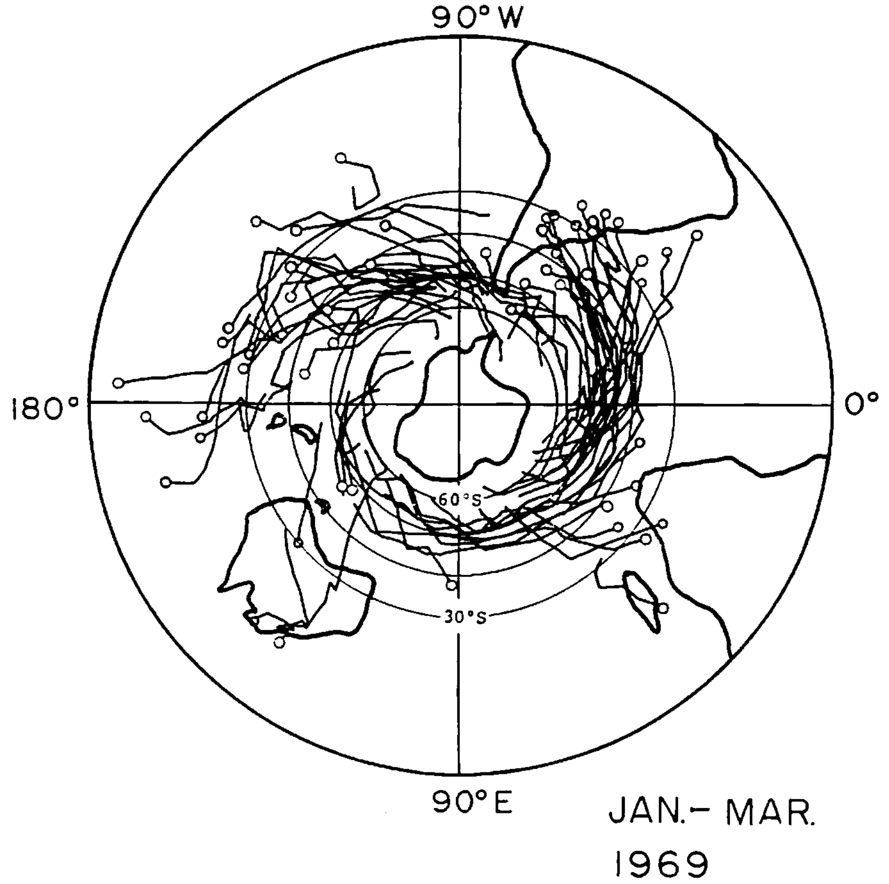


Fig. 3 Points of cyclogenesis (white dots), and cyclone tracks (solid lines) for the period January 1 to March 31.

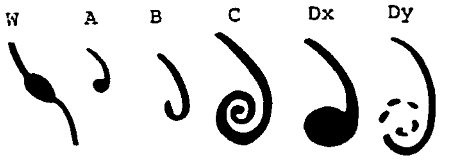


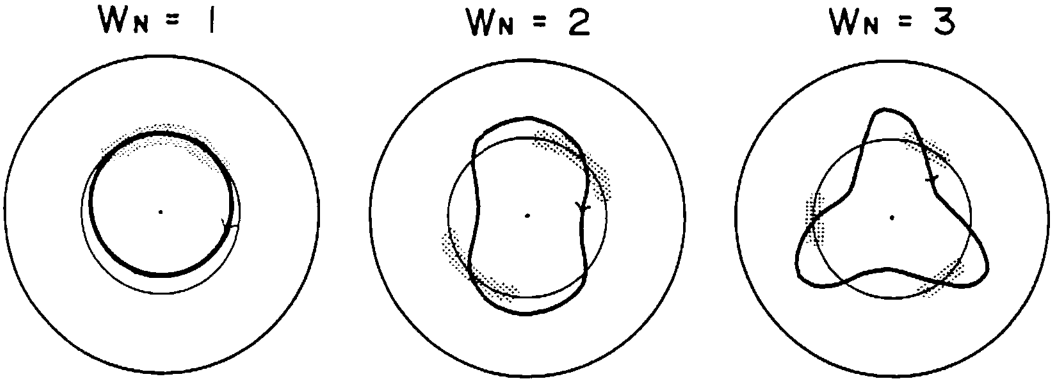
Fig. 4 Schematic diagram of primary classification of extratropical vortex evolutionary patterns (after Streten and Troup, 1973).

type W in the classification of Fig. 4. In Fig. 3, cyclones which decay (type Dy in Fig. 4) but later develop again (type A or B in Fig. 4) are traced as one cyclone as far as any continuous cloud vortex can be recognized. It is noteworthy that the points of cyclogenesis are grouped four areas around the south-east coast of South America, the central Pacific, the south-east coast of Africa, and around Australia and that most of them are concentrated into the former two areas. It is also seen that meridionally most of them are not located in the main westerly zone (40°S–60°S) but in the lower mid-latitude zone (20°S–40°S). The cyclone tracks going through the evolutionary pattern of Fig. 4 from the points of cyclogenesis are indicated with solid lines.

Zonally distributed high brightness area over the higher latitude zone poleward of 40°S in Fig. 1 indicates the concentration of cyclone tracks along the main westerly zone as is seen Fig. 3, though the high brightness over the area higher than 60°S can at least partly be a reflection of Antarctic ice sheet and sea ice around Antarctica. Also, the cloud bands which Streten (1968b) pointed out are recognized over the Pacific Ocean and the Atlantic Ocean in Fig. 1, and they correspond with the areas of concentrated cyclone tracks from the two major areas of cyclogenesis mentioned above. In contrast, over the Indian Ocean near Africa and around Australia, the band structure is not seen in this period.

3. Distribution of digitized average brightness along latitude circles

It is shown in the previous section that the average brightness distribution in the mid-latitude zone is an index of the frequency of cyclones including the degree of development. Consequ-



(a) (b) (c)

Fig. 5 Schematic patterns of relationship between stationary pressure waves (Wn = 1 to 3) and zonal distributions of average brightness. Supposed high brightness areas are shaded.

ently, on the average brightness charts of sufficiently long period (say 1–3 months), it is supposed that high (or low) brightness areas indicate the patterns of the stationary pressure waves of long or ultra-long scale in the middle or upper troposphere, as is shown schematically in Fig. 5. For example, if a wave of wavenumber 1 is predominant especially around the latitudes of circum-polar frontal zone (40°S–60°S), maximum and minimum brightness area will be found each other at the opposite side of the hemisphere, according to the eccentric distribution of cyclone tracks around the pole (see Fig. 5(a)). Two maximum (minimum) brightness areas in each opposite side of the hemisphere will show the mode of wavenumber 2, corresponding with the major two areas of frequent cyclone development (see Fig. 5(b)). When waves of wavenumber 3 or more number are dominant in the pressure field, maximum (or minimum) brightness areas should appear in the eastern (or western) part of each troughs of these waves (see Fig. 5(c)).

From the points of view mentioned above, the distributions of the digitized average brightness along four latitude circles are investigated. Data used are 90 day average brightness charts of January–March (summer), July–September (winter), and October–December (intermediate season) of 1969. One more chart of April–June (intermediate season) of this year was not available. The latitudes chosen for analysis are 55°S, 45°S, 35°S and 25°S. The distributions of digitized average brightness are shown in Fig. 6.

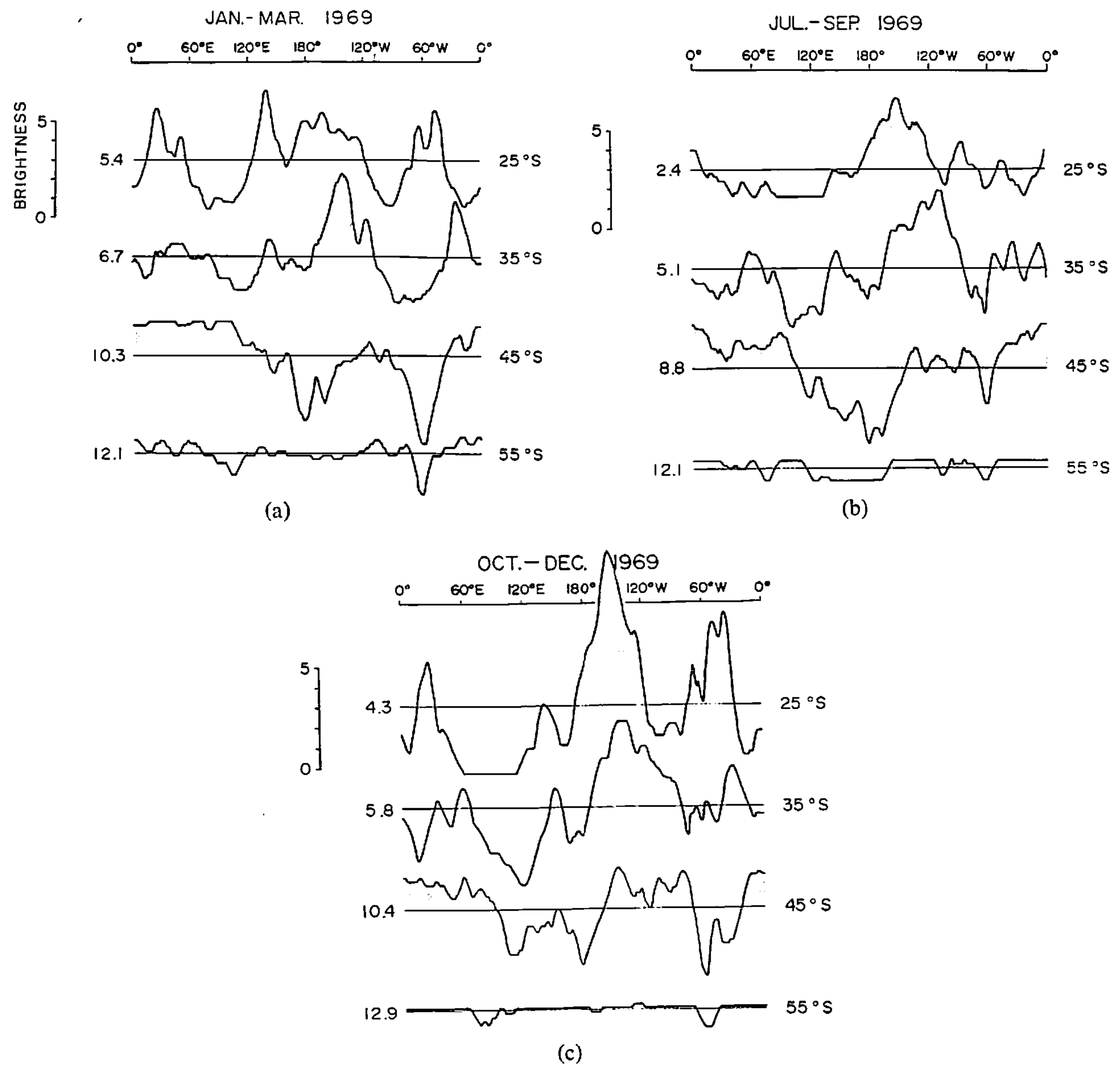
Some characteristic features along each latitude circle in Fig. 6 are summarized as follows:

55°S

Brightness values are generally greater than those of three other latitudes, but their spacial variations are much smaller than the others. This indicates that cyclone tracks are almost zonally oriented and almost uniformly distributed over this latitude zone in spite of high frequency of cyclones. This tendency is stronger in winter, when most of the cyclone tracks shift northward associated with northward shift of the jet stream axis.

45°S

In all cases, a broad low brightness area with a width of 100°–120° longitude is prominent in the western Pacific, and just at the opposite side of the hemisphere, a broad high brightness area exists in the eastern Atlantic through the western Indian Ocean. This feature reminds us of the mode of wavenumber 1. This brightness pattern does not change greatly through all seasons. Over the area near 60°W (from the east coast of South America through the western Pacific), another narrow but very low brightness area can be seen as if it were a "deep valley" of brightness. This low brightness area shows the existence of the strong stationary ridge produced by the orography of the South American continent and the Andes. Boffi (1949) pointed out that this ridge is associated with the strong negative vorticity area over its downstream side where cyclolysis or cyclone decay frequently occurs. Moreover, from daily satellite pictures, we can often observe that clouds of cyclone vortices from the Pacific suddenly vanish over the lee-side of the Andes because of the strong downward motion (for example, see Fig. 7). These two effects seem to produce the "deep valley" of brightness. This low brightness area becomes narrower in winter when the tracks of cyclones shift northward than



(a) (b) (c)

Fig. 6 90-day average brightness variations ((a) Jan.-Mar., (b) Jul.-Sep., (c) Oct.-Dec., 1969) along the four latitudes. The zonal mean value along each latitude is shown in the left side, and the areas of positive deviation from the zonal mean are shaded. Brightness variations are zonally smoothed out by operating 10-longitudinal degree moving average.

in summer when they shift southward around the southern tip of South America. Between the two low brightness areas mentioned above, another broad area of high brightness exists over the central to the eastern Pacific. Compared with the zonal frequency distribution of cyclogenesis analysed by Streten and Troup (1973) (see Fig. 8), the two high brightness areas are found to be located at the east side of the two maximum cyclogeneses areas; namely, the two areas of frequent cyclone development. It is also found that these two high brightness areas are located at the roots of the two cloud bands from lower latitudes shown in Fig. 1. These features suggest the dominancy of the mode of wavenumber 2 at the mid latitude zone.

35°S

In contrast to the distribution of 45°S, a prominent high brightness is found in the central Pacific, and its location does not change greatly through these seasons. This high brightness area appears as a zonal cross-section of the quasi-stationary cloud band in the central Pacific. Three other high brightness areas exist in the

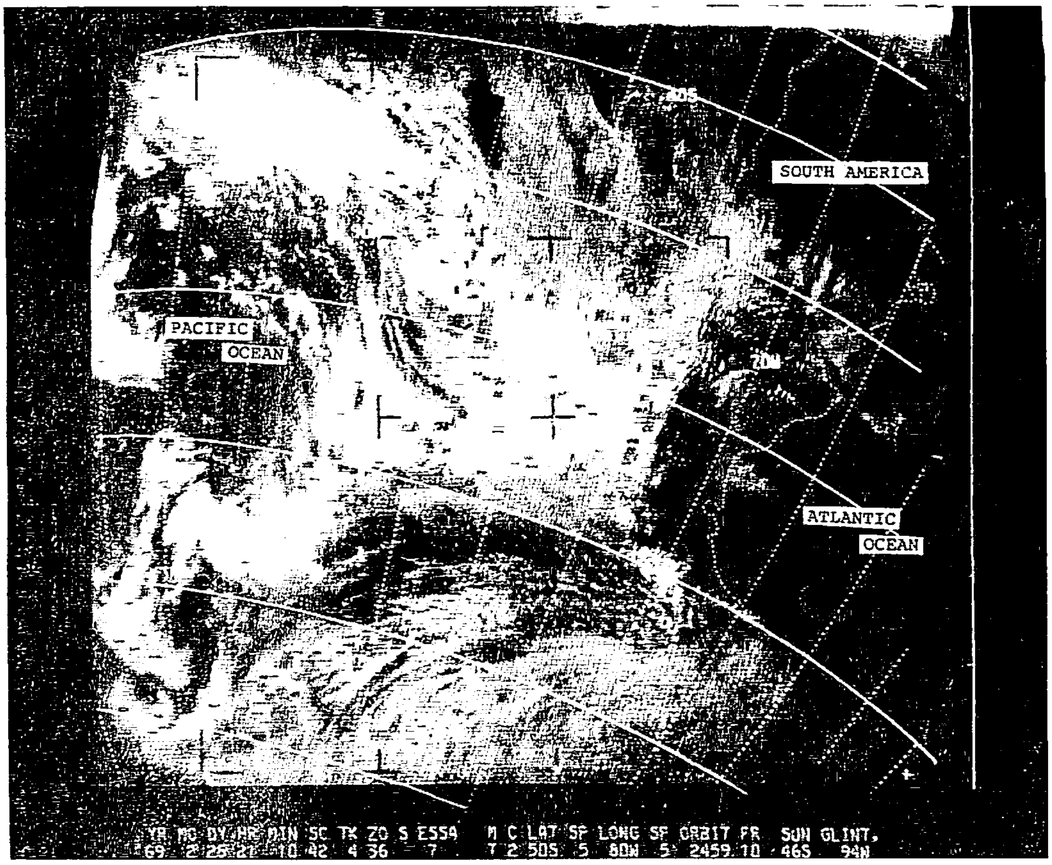


Fig. 7 An example of sudden disappearance of cloud area at the lee side of the Andes from ESSA-7 cloud picture for February, 1969.

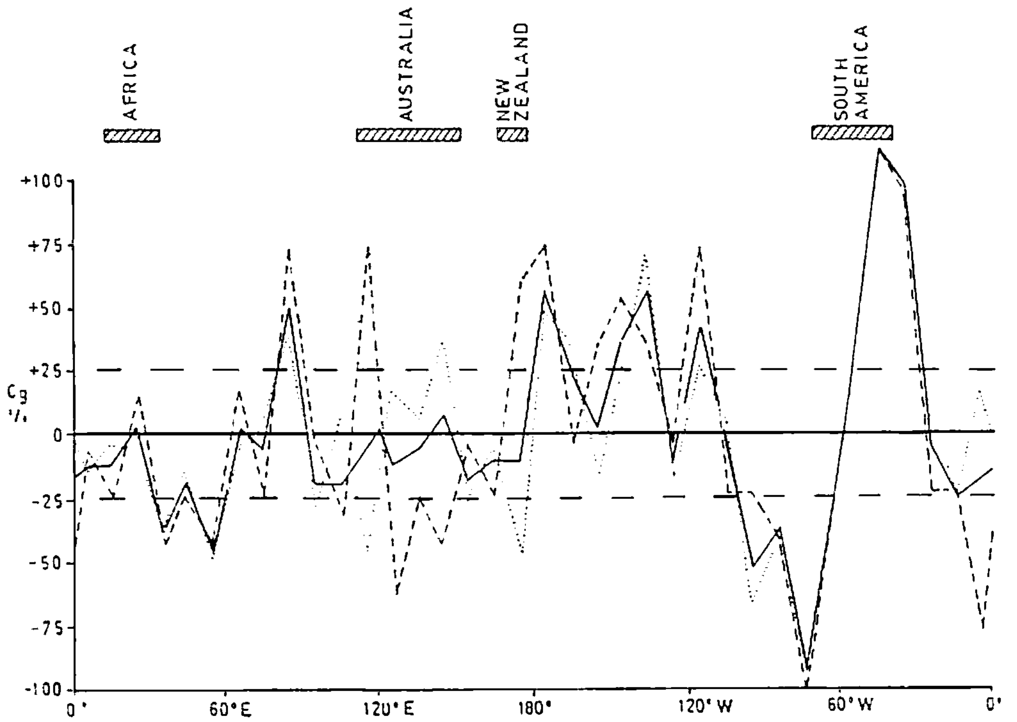


Fig. 8 Distribution of 'Points of cyclogenesis' south of 20°S per 10° of longitude zone expressed as a percentage departure from the zonal average. Summer (dotted), Intermediate season (dashed). Total of 19 months (full line). Longitude boundaries of the continents at latitude 20°S and of New Zealand are shown for reference (after Streten and Troup, 1973).

western Atlantic, the western Indian Ocean and the western Pacific; accordingly near the east coast of the three continents. Another different point with the distribution of 45°S is the existence of the high brightness area near the east coast of Australia. Among these three high brightness areas, the area in the western Atlantic is generally more prominent than the two other areas, which shows the relatively frequent cyclone development in the western Atlantic. It is also noteworthy that the four high brightness areas mentioned above shift their locations westward compared to those of corresponding high brightness areas at 45°S.

The existence of the four high brightness areas reminds us of the mode of wavenumber 4.

25°S

The zonal brightness distribution shows roughly the similar tendency to that of 35°S. However, predominancy of the high brightness area in the central Pacific is more emphasized than that of 35°S. Especially in winter (July–September), no other high brightness areas can be found except that in the central Pacific. The locations of the high brightness areas shift more westward than those of 35°S, indicating NW-SE tilt of the high brightness areas.

4. Harmonic analysis of digitized average brightness along the latitude circles

In order to clarify the nature of zonal stationary waves, harmonic analyses are applied to digitized average brightness along the latitude circles. The amplitudes of brightness values of wavenumbers 1 to 6 are shown in Fig. 9, and the positions of maximum brightness values of wavenumbers 1 to 4 are illustrated in Fig. 10. The result of the harmonic analysis along each latitude is summarized as follows:

55°S

The amplitudes of all wavenumbers are small, and no remarkable features of wavenumber space are found. In this latitude zone, high brightness exists zonally with very small deviation, indicating too much concentration of zonally-oriented moving cyclones. And also, the general increase of brightness towards higher latitudes saturates from around this latitude zone as is shown in Fig. 1, partly because of the extended sea ice over higher latitude zone (60°S–70°S). In such a case it is suggested that zonal brightness distribution does not so clearly indicate the stationary long wave pattern even for the mode of wavenumber 1.

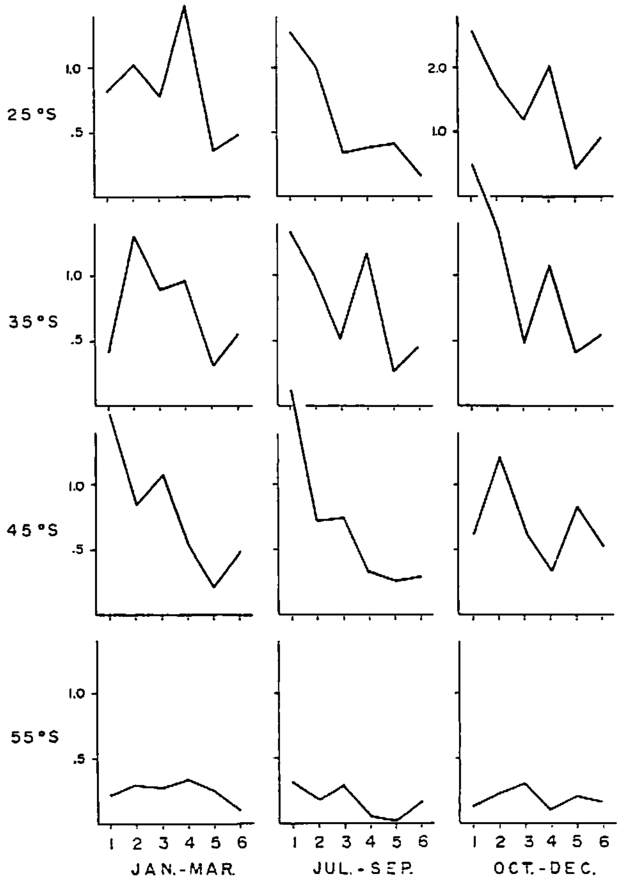


Fig. 9 Amplitudes of wavenumber 1 to 6 for brightness variations along 25°S, 35°S, 45°S and 55°S. Values on the ordinate represent the amplitude in the unit of digital value of average brightness. Note the scale of the ordinate of 25°S for Oct.-Dec. is uniquely different.

45°S

A stationary wave of wavenumber 1 is predominant in summer (Jan.-Mar.) and winter (Jul.-Sep.). The area of maximum value stays at 20°W to 60°W (from the eastern Atlantic to the western Indian Ocean), and the area of minimum value stays at 160°E to 120°W (the western Pacific). The amplitude of a wave of wavenumber 2 is much smaller than that of wavenumber 1. The areas of maximum value stay at 30°E to 80°E (the western Indian Ocean) and 100°W to 150°W (the eastern Pacific). In the case of the intermediate season (Oct.-Dec.), as the low brightness area near South America is much larger than other cases, the amplitude of the wave of wavenumber 2 is larger than that of wavenumber 1. A wave of wavenumber 3 also exists with almost the same amplitude as that of wavenumber 2 in

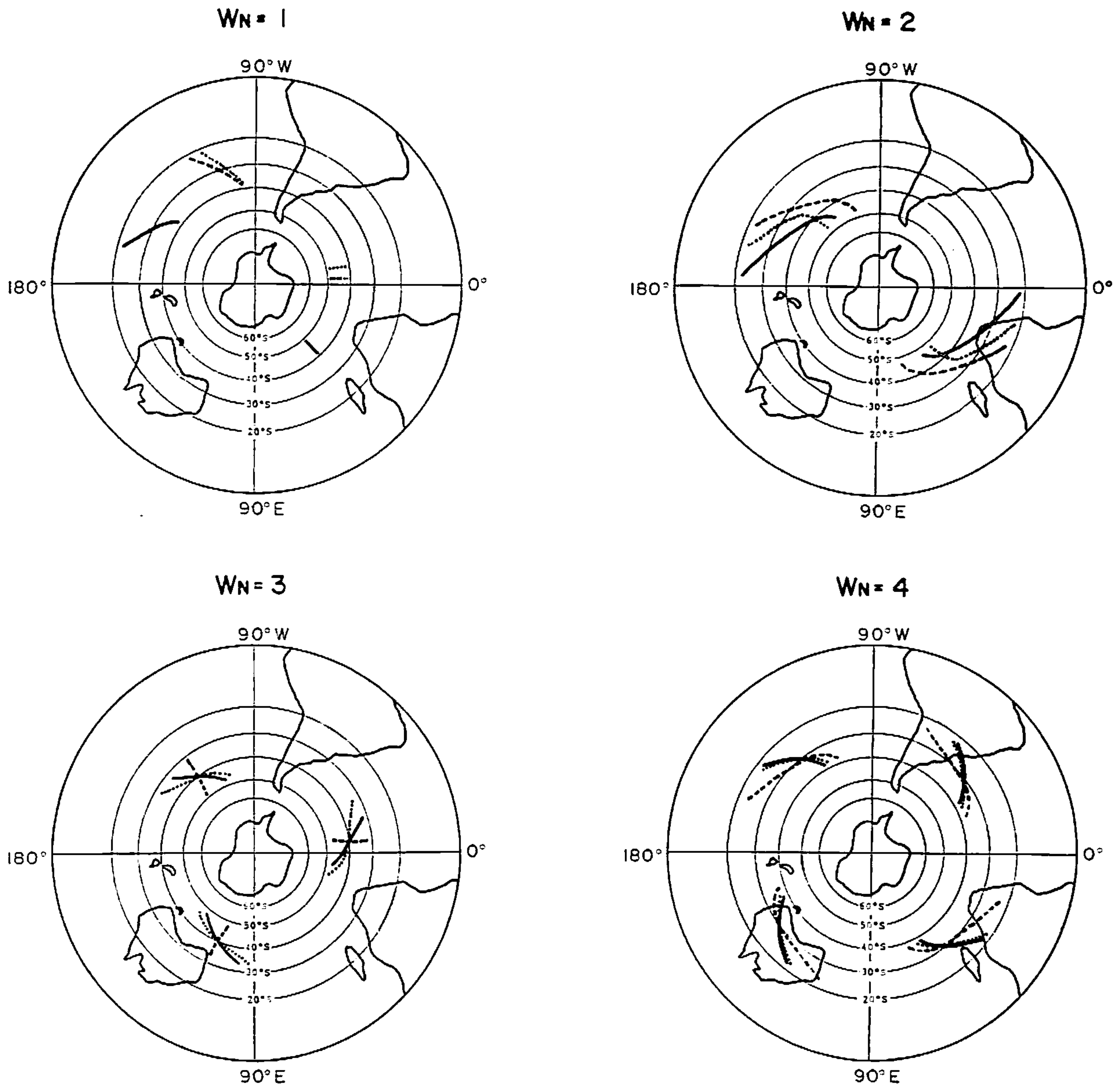


Fig. 10 Positions of maximum brightness areas for wavenumber 1 to 4. Solid lines indicate those for January-March, and dashed lines for July-September, dotted lines for October-December 1969, respectively.

the cases of summer and winter. The positions of maximum values stay at 0°, 120°W, and 120°E; namely at the eastern parts of the three oceans, in correspond to the stationary troughs of the pressure field over the individual oceans. In summer and winter the amplitudes of waves of wavenumbers 4 to 6 are much smaller than those of wavenumbers 1 to 3. In the intermediate season a wave of wavenumber 5 can also be seen as a second largest peak.

35°S

The spectral feature of this latitude zone is somewhat different from that of 45°S. The amplitudes of wavenumber 1 are greatest in two cases, but the positions of maximum are in the central Pacific, while those of 45°S stay in the eastern Atlantic to the western Indian Ocean. It is a remarkable fact that the waves of wavenumbers 2 and 4 are also the dominant modes through the seasons. The areas of maximum value for wavenumber 2 stay at around 30°E (the western Indian Ocean near Africa), and around 150°W (the central Pacific). Those for wavenumber 4 are located at around 60°E (the western Indian Ocean), 150°E (the east coast of Australia), 120°W (the central Pacific), and 30°W (the western Atlantic). These four maximum areas correspond well with the four main routes of cyclone invasion from the lower subtropical zone to the westerly zone. The amplitudes of waves of wavenumber 3 are relatively small compared to the other major modes (wavenumber 1, 2 and 4).

25°S

The spectral features are fundamentally similar to those of 35°S, but the areas of maximum values for wavenumbers 1 to 4 appear systematically with westward shift to those of the higher latitude zones, which show the NW-SE tilt of each stationary wave of average brightness.

To compare the spectral features between different latitude zones, the amplitudes of each wavenumber are normalized by multiplying $1/\sigma$ (σ; standard deviation of brightness variation along each latitude). The normalized amplitudes for the three latitude zones (45°S, 35°S, 25°S) are illustrated in Fig. 11. As is apparently shown in Fig. 11, waves of wavenumbers 1, 2, 3 and 4 are dominant through these latitudes.

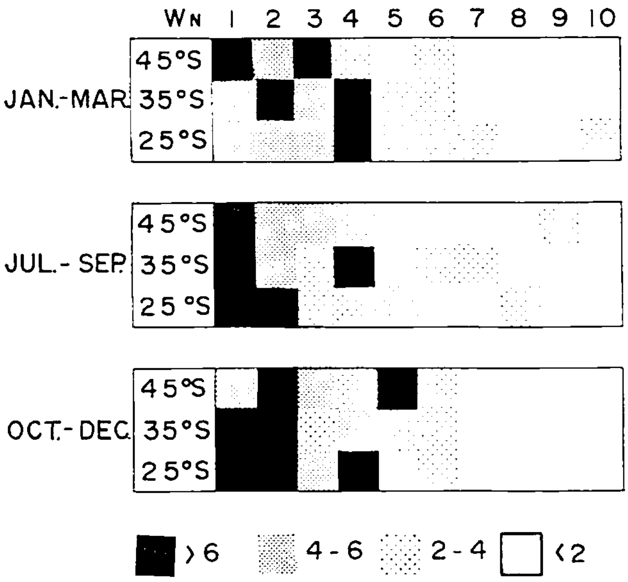


Fig. 11 Normalized amplitudes (see text) for wavenumber 1 to 10 of the three seasons.

A wave of wavenumber 1 is the most predominant through the three latitudes, but as is shown in Fig. 10, the phases of maximum values at 45°S stay in the eastern Atlantic through the western Indian Ocean, while those of 35°S and 25°S stay in the central Pacific. As the circumpolar cyclones are concentrated in the main westerly zone (40°S–60°S) namely a little higher latitudes than 45°S, the mode of wavenumber 1 may correspond with the same mode of the pressure field. This result for 45°S is in good agreement with that obtained by van Loon and Jenne (1972) which is previously mentioned in chapter 1. The result obtained from GHOST balloon at 200 mb level (Solot and Angell, 1973) also suggests the predominance of this wave mode. A wave of wavenumber 1 at 35°S and 25°S resulted from the broad high brightness of the clear cloud band in the central Pacific. Though it is not sure whether corresponding pressure wave pattern dominantly exists at this latitude zone (20°S–40°S) or no, highly frequent tracks of developed cyclones in the central Pacific is supposed the existence of the baroclinic zone associated with the quasi-stationary trough in the eastern Pacific.

Wavenumber 2 seems to be a fundamental mode over the mid latitude zone as is shown in Fig. 11. Although the results obtained from 500 mb charts (van Loon and Jenne, 1972) do not clearly reveal this feature except over Antarctica, the two extended troughs over the eastern Atlantic through the western Indian Ocean and over the central Pacific are supposed to be realistic, considering the existence of the two quasi-stationary cloud bands over the Atlantic and the central Pacific. Moreover, the existence of the two outstanding regions (the extreme south-west part of the Atlantic and the Pacific near New Zealand) where cyclones tend to move eastward with northward component (Taljaard, 1972) may indicate the existence of the two apparent stationary ridges near South America and Australasia. The result from GHOST balloon (Solot and Angell, 1973) also suggests the same feature of this wavenumber. Many factors should be taken into account to explain the predominance of the mode of wavenumber 2, but the symmetrical geographical locations of South America and Australia with respect to the Pole may be one of the most important ones.

It is also confirmed that a wave of wavenumber 3 is superior mainly at 40°S–50°S, and it is supposed to be derived from the distribution of the three continents as is pointed out by van Loon and Jenne (1972).

The last remarkable feature is that a wave of wavenumber 4 is prominent especially at the lower mid-latitude zone (20°S–40°S). As is previously mentioned, there are two major areas of cyclogenesis and cyclone development, but also the two minor areas can be found at the lower mid-latitude zone (20°S–40°S) near Africa and Australia (see Fig. 3). The four areas including these two minor areas of cyclone development seem to account for the mode of wavenumber 4. This wave mode may correspond with the four large subtropical high pressure cells along this latitude zone (20°S–40°S). for example as is analyzed by Taljaard *et al.* (1969).

It is also noteworthy that the phases of maximum (or minimum) brightness values for these significant modes (wavenumbers 1 to 4) show the NW-SE tilt as is seen in Fig. 10. This feature may be mostly due to the NW-SE tilt of high brightness areas on and ahead of corresponding pressure waves to each wavenumber. but partly due to the NW-SE tilt of the stationary pressure waves themselves.

5. Concluding remarks

Throughout the analysis of 90 day digitized average brightness charts for the three seasons of 1969. following conclusions are obtained:

Around the main westerly zone (40°S–50°S). a wave of wavenumber 1 is the most predominant particularly in the two extreme seasons of the year and its maximum stays in the eastern Atlantic through the western Indian Ocean. At the lower mid-latitude zone also. a wave of wavenumber 1 is the most predominant particularly during the colder part of the year with its maximum in the central Pacific.

A wave of wavenumber 2 is also a fundamental wave through the mid latitude zone (20°S–50°S) with its maxima in the western Indian Ocean and the central Pacific. This feature is not so distinguished by the analysis of 500 mb level (van Loon and Jenne. 1972). but the existence of the quasi-stationary cloud bands in the central Pacific and the Atlantic, and the cyclone tracks with northward movement in the western Pacific and the western Atlantic may support the dominancy of this wave mode.

A wave of wavenumber 3 is superior in the main westerly zone (40°S–50°S). and its maximum areas are located in the eastern parts of the three oceans. This wave is supposed to be derived from the geographical distribution of the three continents as is pointed out by van Loon and Jenne (1972).

At the lower mid-latitude zone (20°S–40°S), a wave of wavenumber 4 is prominent. whose maximum areas are located in the extremely eastern parts of the three oceans and the central part of the Pacific. being affected by the four areas of frequent cyclone development. In other words. its minimum areas correspond with the four subtropical high pressure cells. whose center positions stay at 30°S.

These stationary waves (wavenumbers 1 to 4) generally show the NW-SE tilt, which may at least partly be due to the tilt of the corresponding pressure waves themselves.

The features on wavenumber 1 and 3 are in good agreement with those from 500 mb monthly mean charts by van Loon and Jenne (1972), but also the predominance of wavenumber 2 and 4 is suggested from the present analysis.

In the near future, the data of vertical soundings by SIRS and VTPR now being accumulated will reveal stationary wave patterns of each level more clearly. Moreover. the results of FGGE project cooperated with WWW project are expected to offer the more exact features of the quasi-stationary waves in the Southern Hemisphere. The availability of average brightness charts should be preferably promoted by referring these data. For instance. which level of geopotential heights is related to the wave patterns in the average brightness charts may be one of the problems to be solved.

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気象衛星写真からの平均輝度分布を用いた南半球中緯度帯の定常波の解析

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毎日の ESSA 気象衛星写真より合成された90日平均の半球輝度分布図を用いて，南半球中緯度帯 (20°S—60°S) の定常波の検出を試みた。

中緯度帯の4つの緯度円 (25°S, 35°S, 45°S, 55°S) にそった輝度分布を調和解析した結果，波数1, 2, 3, 4の定常波の卓越が見られた。波数1の輝度極大域（気圧場の谷に対応）は，偏西風帯では大西洋東部からインド洋西部にかけて，亜熱帯高圧帯では太平洋中部に存在する。波数2は，中緯度帯を通して極大域は，インド洋西部と太平洋中部にあり，南半球での基本モードのひとつと考えられる。波数3の輝度極大域は，三つの大洋の東部に位置し，卓越性は主に偏西風帯に限られる。波数4は，やや低緯度側 (20°S—40°S) で卓越し，亜熱帯高気圧の4つの大きなセルの分布に対応している。波数1と波数3の様相は，月平均 500 mb 高度分布図により解析した van Loon and Jenne (1972) の結果とよい一致を示しているが，今回の解析では，波数2と波数4の定常波が卓越していることも確認された。

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