KONINKLIJK NEDERLANDS METEOROLOGISCH INSTITUUT

MEDEDELINGEN EN VERHANDELINGEN

No. 88

Dr. H. P. BERLAGE

THE SOUTHERN OSCILLATION AND WORLD WEATHER

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DE ZUIDELIJKE SCHOMMELING EN HAAR MONDIALE UITBREIDING

1966

Prijs f 15.50

STAATSDRUKKERIJ / 'S-GRAVENHAGE

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PUBLIKATIE: K.N.M.I. 102-88

U.D.C. 551.543.3:
551.513.7:
551.509.33

PREFACE

Professor Dr. H. P. Berlage, former head of research of the Division of Climatology and Agricultural Meteorology of the Royal Netherlands Meteorological Institute, who had collected a wealth of information on the fascinating problem of the Southern Oscillation during his work in the Netherlands East Indies and Indonesia, has composed the present paper in which not only the Southern Oscillation itself but also its relations to certain meteorological and oceanographical quantities in other parts of the world are discussed.

This thorough and complete treatise, in which professor Berlage's great knowledge of the extensive literature on the subject also comes to the forefront, is presented to the scientific community with the hope that it may assist in unravelling one of the most tricky problems in meteorology and oceanography, namely that of the teleconnections in world weather and their relations to the foreshadowing of regional weather phenomena in particular in those parts of the world where the annual production of food is so heavily dependent on rain or shine.

The Director in Chief
Royal Netherlands Meteorological Institute
Prof. Dr. W. Bleeker

CONTENTS

0. INTRODUCTION

0.1 The course of the investigation

The significance of the fluctuation in atmospheric circulation within the Indo Pacific region known as the „Southern Oscillation" (S.O.) was discussed in a previous publication in the same series (BERLAGE 1957). In the present paper the S.O. is reanalyzed in detail (Chapter 1) and its reality confirmed. It is concluded that the S.O. is the most prominent short period climatic variation of near global extension.

The S.O.'s periodicity has a range of 1-5 years. The amplitude of its air pressure variations generally decreases with decreasing period.

The S.O. is generated spontaneously and its period and amplitude are determined by terrestrial causes, viz. the properties of the general atmospheric and hydrospheric circulation. Even large scale sea level changes reflect it (FAIRBRIDGE and KREBS 1962).

The S.O. is better understood if it is assumed that two steering factors exist, viz. the variations of solar activity and the variations of the transparency of the atmosphere due to stratospheric dust veils from heavy volcanic eruptions. These factors influence the basic intertropical airpressure gradients and hence the speed of the general atmospheric and hydrospheric circulation.

The periods of acceleration and deceleration of the general circulation appear longer than the one characteristic of the S.O. These major oscillations are of the relaxation type, deceleration occurring rather abruptly after prolonged acceleration.

In Chapter 2 influences between the interdependent antarctic and intertropical regions are analysed with the aid of a series of seasonal southern hemisphere airpressure anomaly maps 1955-1961, and early antarctic data.

In Chapters 3 and 4 a standard type and a global picture of the S.O. are developed. In particular the connections with a semi-independent „North Atlantic Oscillation" are traced, and the possible relations between the S.O. and the quasi biennial fluctuations of the equatorial stratospheric winds investigated.

Only a brief review is given of the application of S.O. information to seasonal forecasting in areas of the eastern tropics, as this was investigated earlier. However, a forecast of winter droughts in the Guianas, part of the western tropics, is developed step by step with promising results.

0.2 Acknowledgments

The author is extremely grateful for having received the opportunity to do research work with I. I. SCHELL at Tufts University, Boston-Medford, in the course of 1962. It enabled him in particular to obtain the results reviewed in Chapter 2. He needed data which he received directly from the U.S. Weather Bureau, Washington.

The author is moreover greatly indebted to the Meteorological Service of Chile and to the Meteorological and Geophysical Service of Indonesia for sending him pressure data from Easter Island and Djakarta in advance of their publication every month during many years. He expresses also his thankfulness for the receipt of up-to-date

Puerto Chicama seasurface temperature measurements through the intermediary of the Deutscher Wetterdienst, Seewetterwarte, Hamburg, and for the receipt of all kinds of information from the British Meteorological Office, the Météorologie Nationale de France, the Weather Bureau, Union of South Africa, the Japanese Meteorological Agency, the Servicio Meteorologico Nacional, Argentina, the Direccion de Geografia y Meteorologia, Mexico, the Servicio Meteorologico, Angola, and the Tidal Institute, University of Liverpool, Birkenhead.

The author, finally, owes words of special gratitude to his colleague W. BLEEKER, for having read the manuscript of this paper critically and having proposed many valuable ameliorations of presentation.

1. THE SOUTHERN OSCILLATION REANALYZED

1.1 Essential properties

An essential feature of the S.O. is the exchange of air between an equatorial low pressure area, which may be represented by Djakarta (6°11'S, 106°50'E), and a subtropical high pressure area, which may be represented by Easter Island (27°10'S, 109°26'W).

Fig. 1 is a graph of the sixmonthly running (overlapping) means of the airpressure anomalies at Djakarta during a century, 1866-1965. Fig. 2 represents the course of the corresponding anomalies at Santiago (33°27'S, 70°42'W), the South American station nearest to Easter Island which possesses an even longer series of meteorological observations than Djakarta. To facilitate intercomparisons the ordinates of these graphs are in the ratio 4 : 5.

A comparison of airpressure anomalies at Djakarta and Easter Island shows that amplitudes of the S.O. air pressure waves for Easter Island are about double those for Djakarta (Fig. 9). This might partly be due to the difference in area of the two regions. Meridional air currents converge from equator to subtropics. Moreover the variations of cloud cover and precipitation probably reduce the amplitudes of the sea level pressure changes along the wet equatorial belt relative to the dry subtropics (BERLAGE 1957).

The average decrease of the amplitude of Santiago pressure waves between the 1870s and the 1950s is of particular interest. A large pressure amplitude was reestablished in the 1960s.

The airpressure fluctuations show a 2 to 3 year rhythm. This rhythm is more pronounced in the Indonesian equatorial area than in the Southeast Pacific subtropical area, probably because the latter area is already strongly subjected to higher latitude travelling cyclones. These cause a higher 'noise level'.

There is no strict periodicity in the S.O., the length of its pressure waves varying between 1 and 5 years roughly; however, the reality of this quasi-periodical phenomenon is well documented by Table 1. It contains the frequency distribution of intervals in half years between successive minima, as observed and as probable according to the statistics of random variations. This frequency distribution is such that randomness seems to be excluded.

The two scales of the S.O. pressure balance experience, as shown by Fig. 3 and Fig.

TABLE 1. *Percentages of frequency of intervals between minima of Djakarta semi annual airpressure deviations in half years.*

Number of half years	2	3	4	5	6	7	8
Empirical percentages	18	21	27	23	9	0	2
Expected percentages	40	33	17	7	2	0.6	0.13

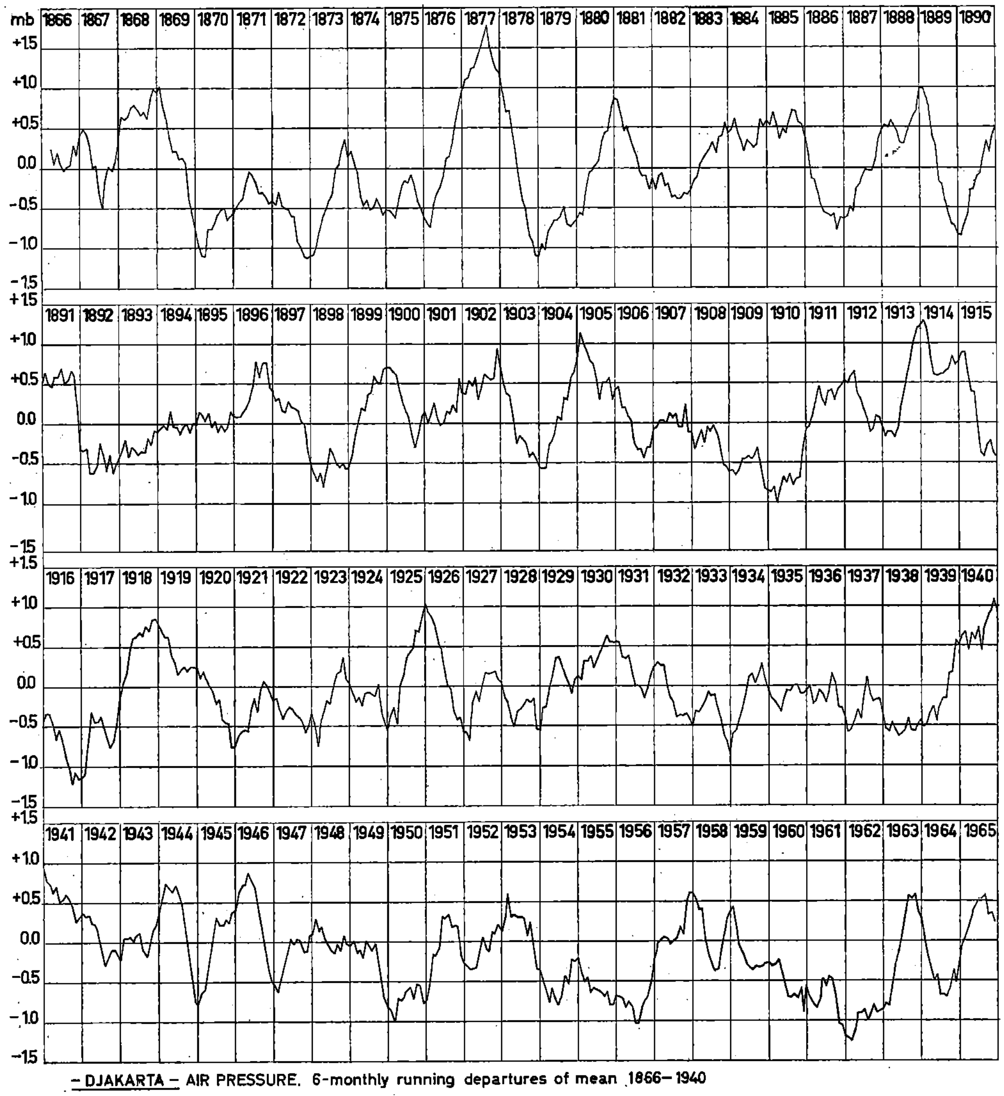


Fig. 1 Running six-monthly averages of Djakarta air pressure anomalies 1866-1965.

4, an annual deformation, which is an important feature of its operation. In both intervals, April-August and October-February, the two scales show strikingly similar contours. Their orientation, however, is predominantly from WNW to ESE during northern summer and predominantly from WSW to ENE, although less marked, during southern summer.

The four charts of seasonal correlation, with reference to WALKER's S.O. Index,

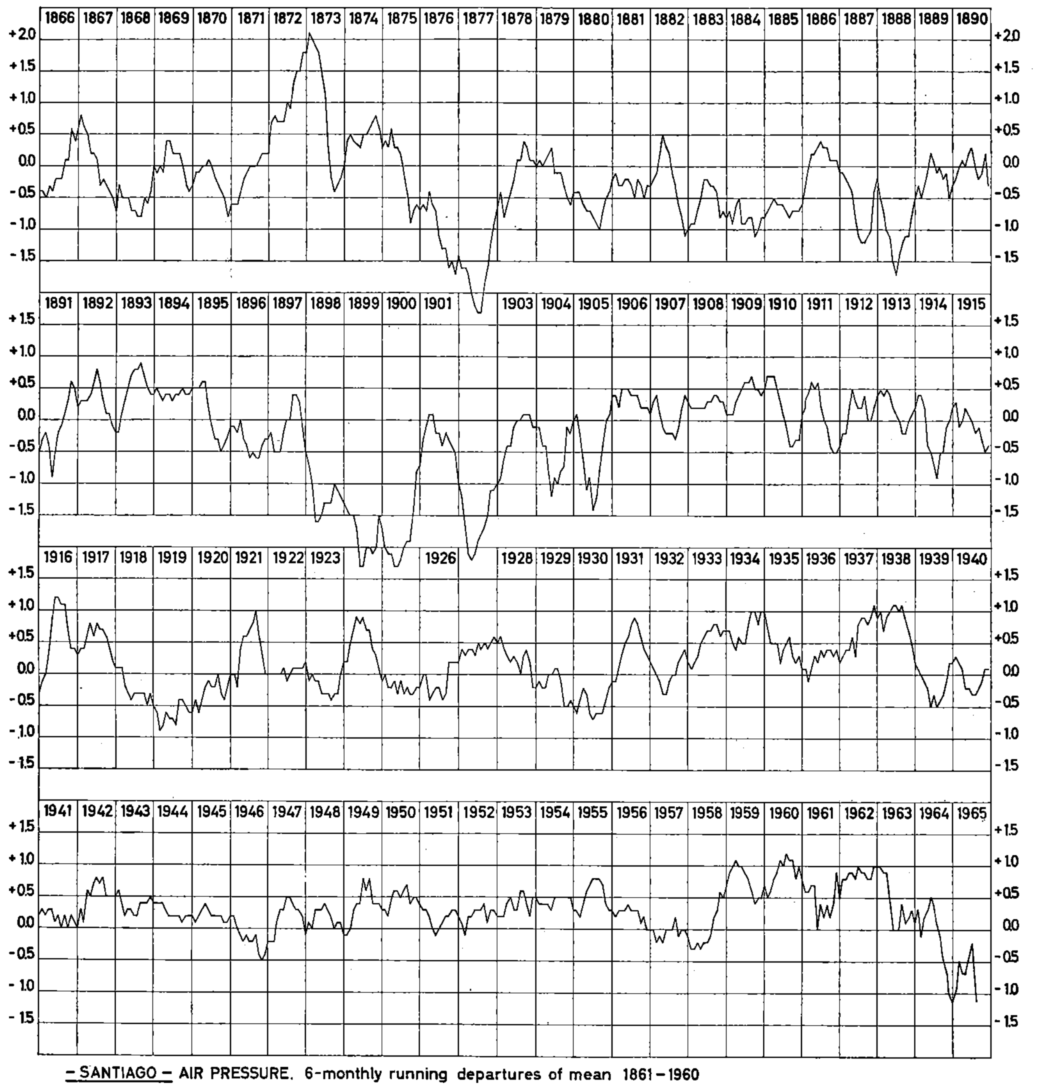


Fig. 2 Running six-monthly averages of Santiago air pressure anomalies 1866-1965.

published by TROUP (1965), reveal, of course, more flexible contours of the two scales, and the present author agrees that in southern winter, June-August, Djakarta fails to occupy the 'focal position' which it holds during the other three seasons.

As the centre of gravity of this important pressure balance is south of the equator, the name Southern Oscillation is to the point and will be used in this paper for identification purposes.

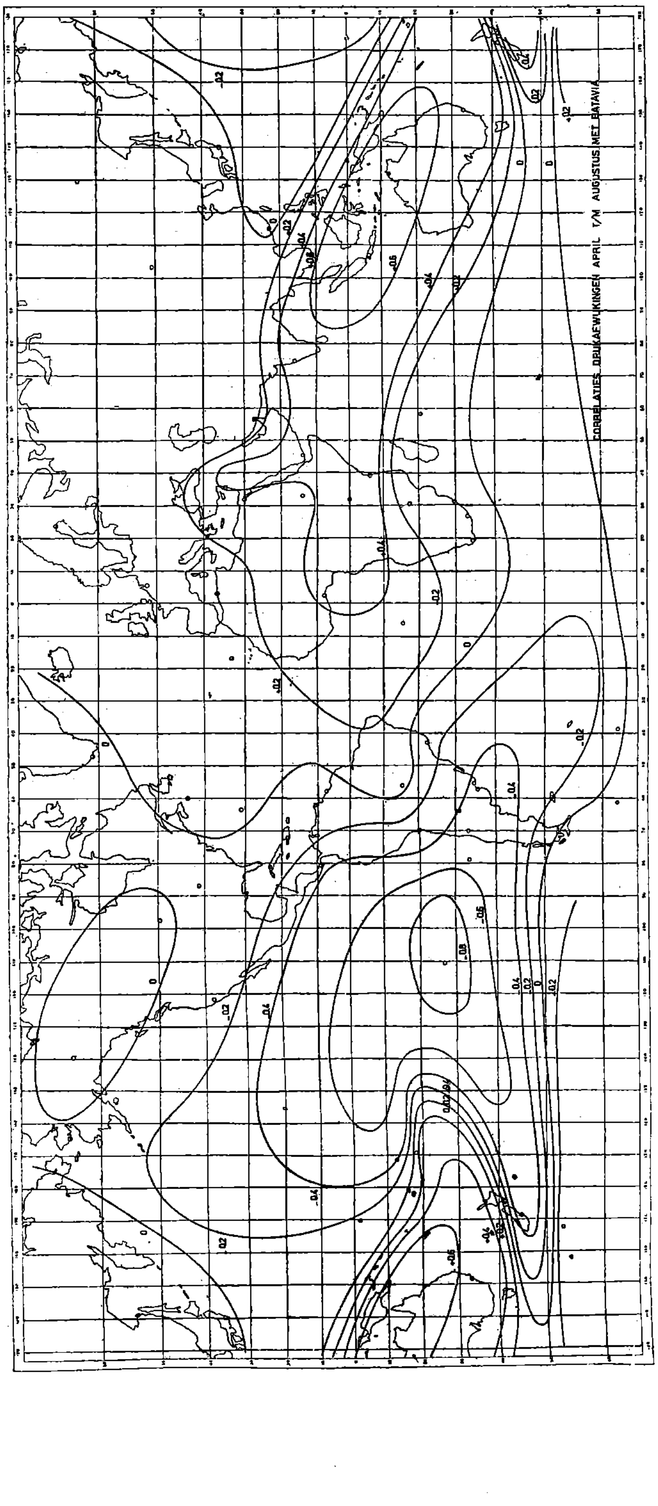


Fig. 3 Simultaneous correlations of air pressure anomalies with Djakarta airpressure anomalies, Apr-Aug.

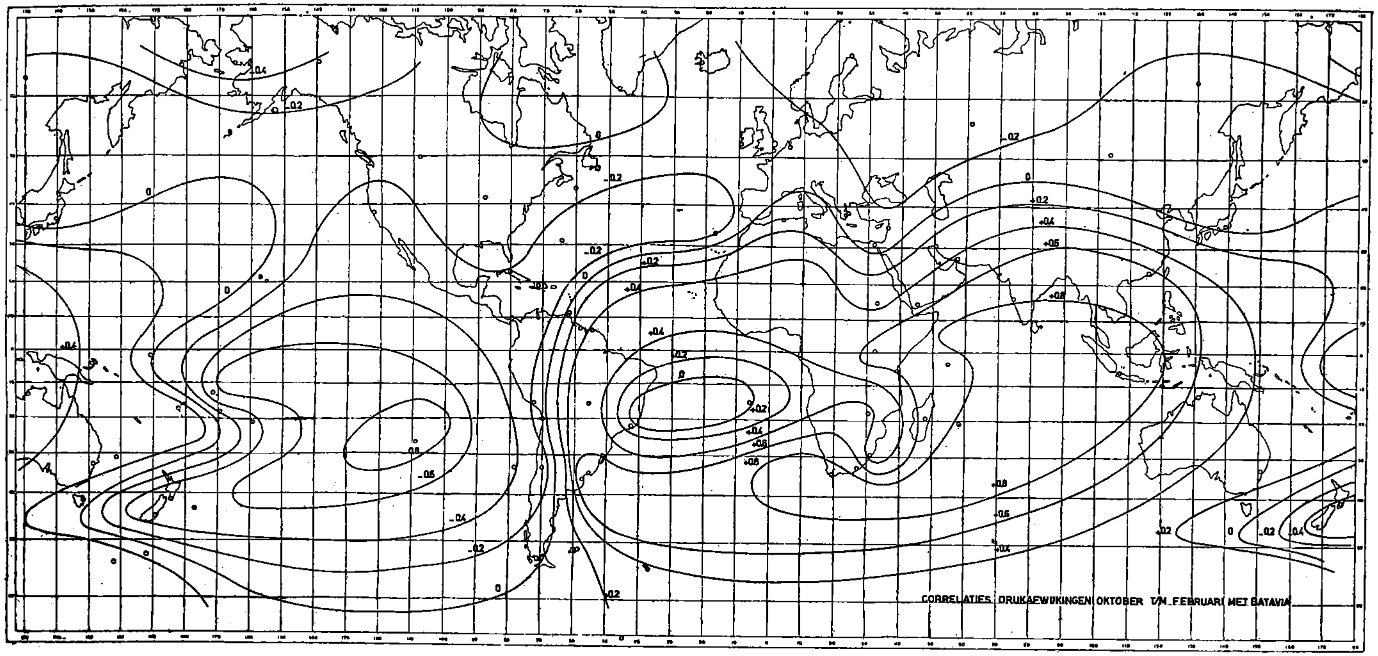


Fig. 4 Simultaneous correlations of air pressure anomalies with Djakarta air pressure anomalies, Oct-Feb.

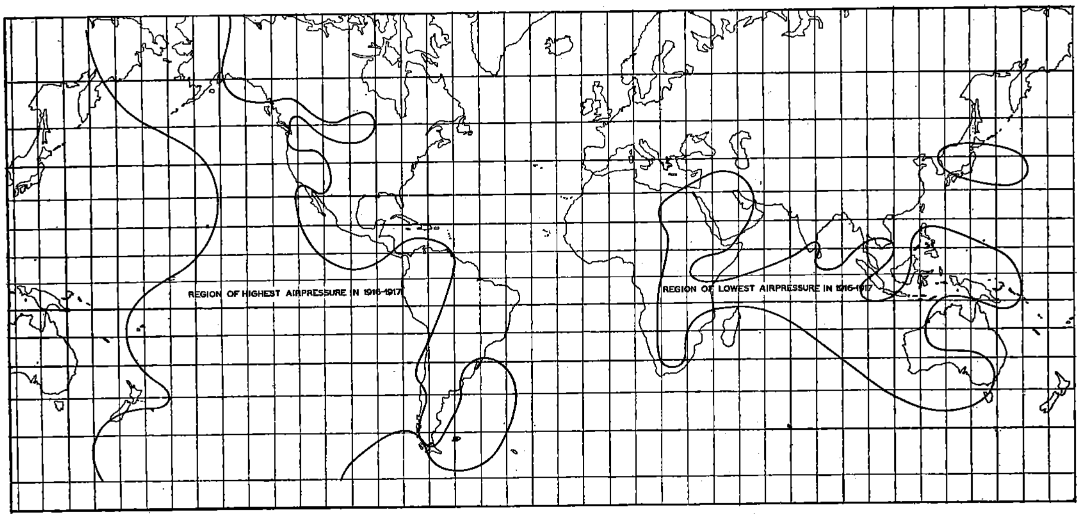


Fig. 5 Global picture of the regions where air pressure was highest and lowest in 1916-1917.

However, the global extension of the S.O. should be stressed. This is illustrated best by Fig. 5, which represents the regions where in 1916-1917 airpressure was higher or lower than in any other year of the total series of years of observation at every station. These regions are the scales of the S.O. balance when it is turned over most strongly in one direction.

World Weather Records 1941-1950, edited 1959, containing for the first time a series of observations made in Southwest Africa since 1901, show that Luanda (8°49′S, 13°13′E) and therewith the greater part of Angola, is attached to the region showing the lowest pressure in 1916-1917. This region is increased by an appreciable low latitude western extension.

Fig. 5 reveals a remarkable symmetry of the pressure pattern relative to the equator. Hence, when the S.O. is considered rightly as a 2-3 year fluctuation of the intensity of the general circulation, its wide extension over Northeast Africa and Southeast Asia on the one side and over the North Pacific Ocean on the other side should be borne in mind.

In times when the S.O. has its strongest grip on World Weather it embraces large parts of the northern hemisphere, thus disclosing interhemispherical features of the general circulation, already pointed out by several authors (Schell 1939, Rodewald 1959, Rao 1960, Namias 1963, Porisenkov 1965, and Schweigger in private communication). Such features stress both the zonal and the meridional character of the S.O. Nevertheless, its origin in the southern hemisphere can hardly be denied. This implies that natural fluctuations of the general atmospheric and hydrospheric circulation over and through the water-hemisphere, having its centre near New Zealand (Fig. 6), act as a dominant feature of world weather.

The S.O. presents a clear zonal fraction, since the exchange of air is mainly between

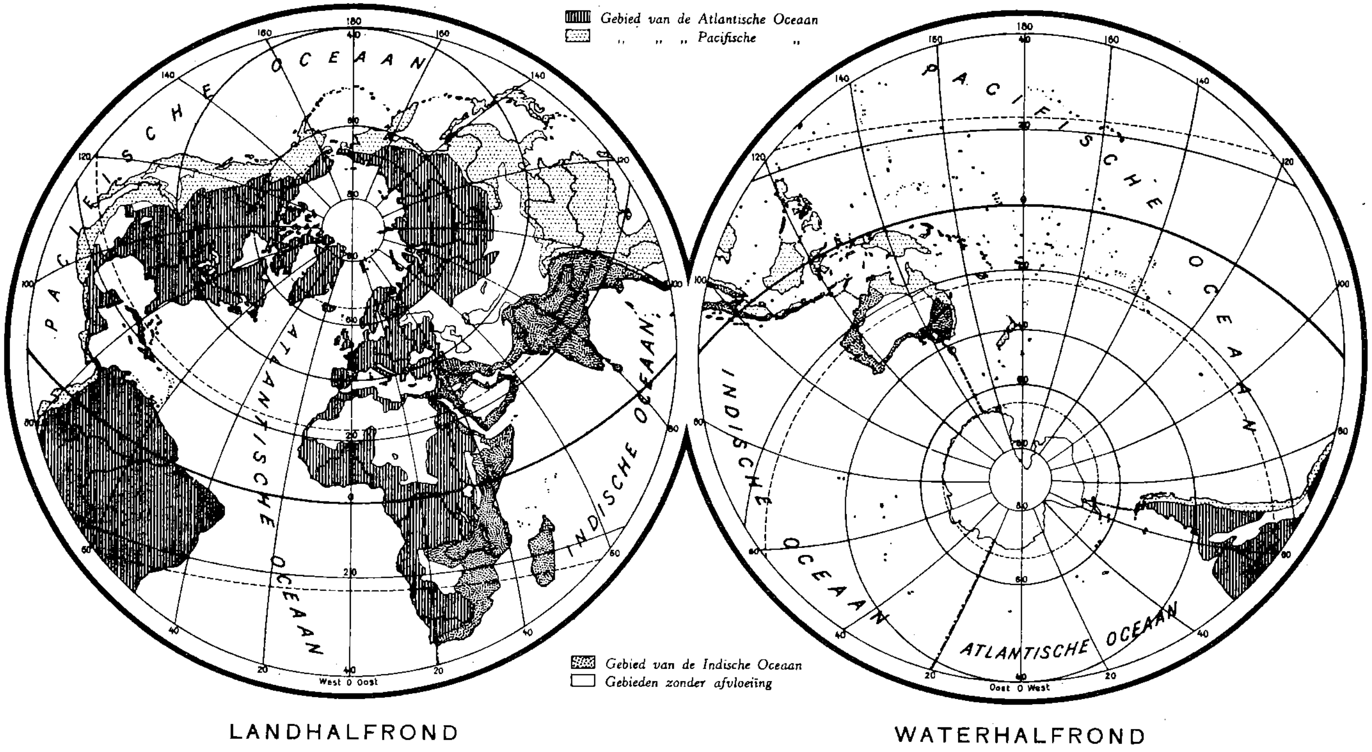


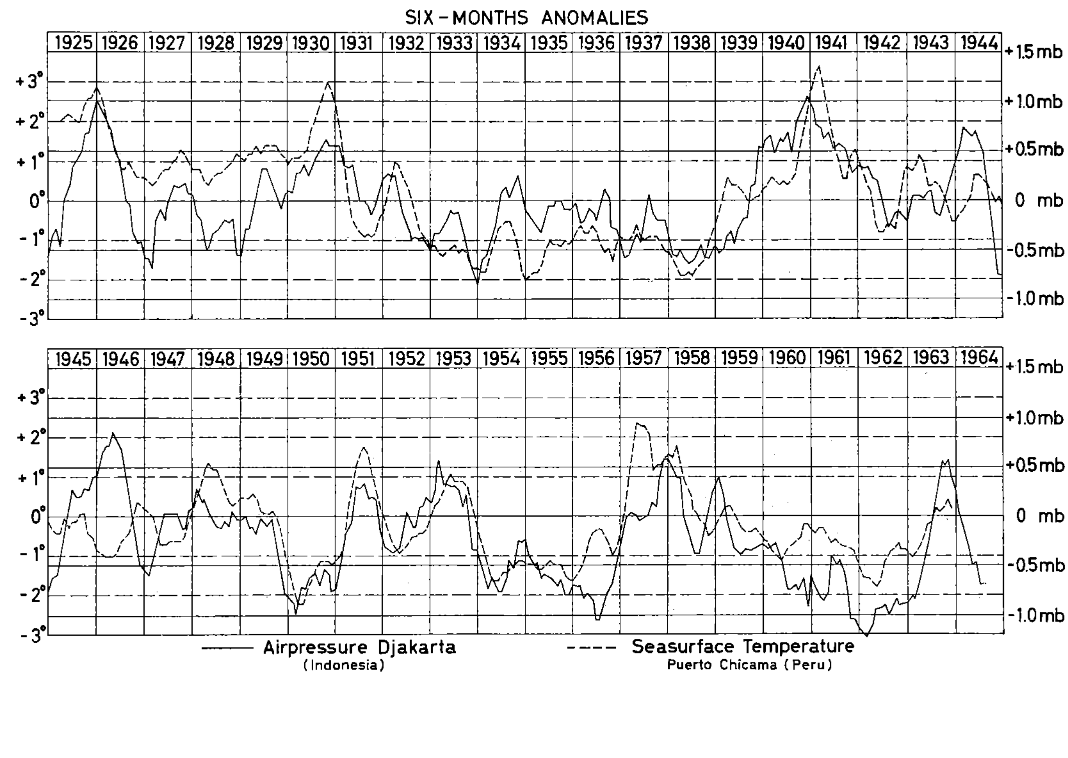
Fig. 6 Land and water hemispheres.

an equatorial low and a subtropic high. However, the two scales of the S.O. balance are so widely separated that the one encompasses the Indian Ocean and the other the Southeast Pacific Ocean.

Fig. 6 also emphasizes the importance of Antarctica in the complete picture. Antarctica, being crossed by every meridian, is also situated on the meridian separating the two scales of the S.O. balance. Consequently, the possibility of direct liaisons Antarctica-Indian Ocean toward one side and Antarctica-Southeast Pacific toward the other will have to be investigated carefully. This investigation will be facilitated by the many facts revealed by the I.G.Y.; facts not available to SCHELL (1956), who was the first to point out these relations.

Fig. 7 demonstrates most clearly the world wide connection discussed here. This figure shows the fluctuations, for 1925-1964, of air pressure at Djakarta and sea surface temperature at Puerto Chicama (7°47′S, 79°28′W) on the west coast of Peru. These are fluctuations of two completely different physical quantities at two almost antipodal stations. The parallelism of the two curves is so marked that antiparallelism (e.g. 1945-1946) clearly suggests exceptional circumstances, requiring close study. The 1945-1946 anomaly, which was also treated by SCHWEIGGER (1959), will be reconsidered in para 2.4.

Fig. 7 Running six-monthly average anomalies of Djakarta air pressure and Puerto Chicama sea-surface temperature 1925-1964.



1.2 Spontaneous generation

The author's hypothesis on the spontaneous generation of the S.O., discussed from an empirical and theoretical point of view in several papers (1927, 1929, 1933, 1957), is the following. Reference is made to the chart of ocean surface currents (Fig. 46).

When pressure is relatively high in the Southeast Pacific subtropical high and relatively low in the Indonesia equatorial low, the general atmospheric and hydrospheric circulation through the South Pacific Ocean is accelerated. The Peru Current becomes stronger and relatively cold water along the Peru coast is fed into the South Equatorial Current. The trade winds and the South Equatorial Current are also strenghthened. Sea surface temperatures and air temperatures in Indonesia will decrease. Consequently pressure in the Indonesia low will increase and pressure in the Southeast Pacific high will decrease. When pressure thus has become relatively high in the Indonesia equatorial low and relatively low in the Southeast Pacific subtropical high, the general atmospheric and hydrospheric circulation through the South Pacific Ocean is decelerated. The Peru Current becomes weaker and relatively warm water along the Peru coast is fed into the South Equatorial Current. The trade winds and the South Equatorial Current are also weakened. Sea surface temperatures and air temperatures in Indonesia will increase. Consequently pressure in the Indonesia low will decrease and pressure in the Southeast Pacific high will increase, thus completing the cycle.

The time lag between the pressure deviations and the associated temperature deviations in Indonesia averages approximately $7\frac{1}{2}$ months. The period of the Southern Oscillation, which was shown to be four times this lag, averages in fact 30 months. The natural damping of the S.O. is apparently slightest when the period is about 32 months (BERLAGE, 1957, p. 56), whereas if the period increases to 36 months the most impressive successions of pressure waves are generated.

The above mentioned interval of $7\frac{1}{2}$ months is too short to be strictly interpretable by the advection of water masses from near South America to the Malay Archipelago. However, since the water is dragged by the wind and the associated evaporation tends to speed up the apparent motion of the anomalies of the sea surface temperature (TROUP, 1965) it is not surprizing that this apparent motion is intermediate between current speed and wind speed.

The low speed of the east-west connections through the equatorial Pacific Ocean was recently confirmed by FLOHN (1965). Rainfall at Guayaquil and Galapagos Islands was found to be highly correlated with rainfall at Canton Island, Pukapuka, Aitutaki, Truk and Fanning Island from 1 to 10 months later. On the other hand, as already pointed out by the author (1957) an adequate explanation of long period sea surface temperature variations in tropical parts of the Pacific Ocean would need to cover variations, in strength and location, of the Equatorial Countercurrent.

As KNAUSS (1961) stated: 'The most unusual observation concerns the variation in transport. In August 1958 the transport was in excess of 60×10^6 m^3/sec. Eleven months later it was nearly zero' (See also 1.8).

Moreover the detailed investigations of the Gulf Stream by ISELIN (1936, 1940, 1952).

FUGLISTER (1951, 1955), FUGLISTER and WORTHINGTON (1951) and others, have demonstrated that small scale conditions and local convection frequently suppress the effects of large scale operations, such as the advection of temperature anomalies with the main current from distant sources. BULLIG (1954) and RIEHL (1956) reaffirmed this doubt about the possibility of the transfer of ocean temperature anomalies through long distances. Recently, WORTHINGTON (1965) stated that many difficulties inherent in our simple concept of the Gulf Stream can be overcome by assuming the existence of two large vortices instead of one in the North Atlantic Ocean circulation. BLANFORD (1965) concluded 'that steady, purely inertial models are inadequate to describe even the lower latitude growth region of the Gulf Stream' and NAMIAS (1965), discussing the association between monthly sea-surface temperature and overlying winds in the North Pacific, stated poor results 'where meanders from the Kuroshio current may play a major role'.

Similar and even farther reaching arguments were brought forward by SCHWEIGGER (1959) and WYRTKI (1963) with regard to the Peru Current. Does the upwelling cold water along successive parts of the coast of Chile and Peru from south to north, associated with the motion of the surface water westward or northwestward as a result of the earth's rotation, perhaps merely suggest to us the existence of a unified northerly current?

It should be remembered that in currents like the Gulf Stream, Kuroshio and Peru Current, moving through different latitudes, the transport of vorticity introduces a multitude of eddies blurring the basic pictures. A zonal current like the South Equatorial Current, considered by the author in particular, is almost free from eddies. In fact, neither the patterns of sea surface isotherms covering the North Atlantic and North Pacific (SVERDRUP 1956), nor the isothermal pattern of the Tropical Pacific, are interpretable without realizing how conservative the temperature of large moving watermasses is.

With regard to the Tropical Pacific, the author has perhaps stressed the advection of temperature anomalies from the east through long distances too much, CROMWELL (1953), MONTGOMERY and STROUP (1954), FOFONOFF and MONTGOMERY (1955), AUSTIN and RINKEL (1957), and AUSTIN (1960) have paid more attention to the fall of sea surface temperatures near the equator by upwelling, due to divergence of the east-west equatorial currents when the trade winds are strong, and the rise of the sea surface temperatures due to convergence of the main currents when the trade winds are weak.

The detailed survey of the thermal structure of the Eastern Pacific Ocean presented by WYRTKI (1964) is particularly relevant to the present discussion. He noted: 'The isolated patches of higher temperature occurring near 20°S from November to February and between 5°S and 10°S from January to March cannot be caused by advection and indicate that local heating is important', but concluded, parallel with our ideas, as follows: 'At the equator, lowest sea surface temperatures of less than 20°C occur southwest of the Galapagos Islands in September. It seems likely that advection of cool water from the Peru Current contributes considerably to the lowering of sea surface temperature in this area, while farther west the low temperatures are due to equatorial upwelling.'

However, as PALMER (1951, 1952) pointed out, the trades in the eastern Pacific behave like a jet between two stagnant air masses, the subtropical highs. Such a jet is dynamically unstable and breaks up into the vortices which characterize the western Pacific. Evidently, with increasing trade winds the region of vortex production is displaced westwards.

'Consequently', TROUP (1965) adds, 'there should be an incraese in the latent heat release west of the nodal zone and a decrease to the east of it. This results in warming at upper levels in the former region and cooling in the latter so that the zonal temperature gradient is increased, with a consequent strengthening of the eastward ageostrophic flow aloft and with increased upper divergence to the west. Thus a rise in pressure in the Pacific highs will tend to result in a fall in pressure over the Indian Ocean and adjacent regions'.

As was already pointed out by RODEWALD (1960), these newly discovered effects only add arguments in favour of the author's main thesis concerning the generation of the S.O. Even when following the east-west course from the Pacific Ocean through Indonesia into the Indian Ocean, we find our arguments confirmed by what happens in the Java Sea. The eastmonsoon, which is the SE trade wind strengthened from May to October, evidently causes upwelling of cold water from the deep Timor Sea and its transport into the shallow Java Sea (BERLAGE 1927), where it acts in accordance with the whole operation.

Moreover, according to the investigations of ARCHIPOVA (1960) and SHELLARD (1962) there is no doubt about the adequacy of sea temperature anomalies to sustain atmospheric circulation anomalies over periods of several months; a valuable conclusion, because, as was shown by BRUNT (1944) and brought forward again recently by SAWYER (1964), without intervention of the ocean the total kinetic energy of the atmosphere is completely lost, through dissipation by external friction along the earth's surface, in about two days.

Quite generally, the S.O. fluctuation can be generated, but not sustained, by a terrestrial internal mechanism proper. It is the sun that spends the energy continuously, while the period and the amplitude of the S.O. are determined by terrestrial causes.

A very stimulating experiment with this kind of generation and persistence of oscillations of a simple thermal system, was described by WELANDER (1957).

1.3 Peru Current and El Niño

The slowing down of the Peru Current might be associated with the appearance along the Peru Coast of 'El Niño', a southward transgression of warm equatorial surface water, an after-Christmas phenomenon highly dependent on the character of the general circulation. El Niño appearances are clearly indicated in Fig. 7 by outstanding positive sea surface temperature anomalies recorded at Puerto Chicama.

Well known El Niño seasons occurred in 1925-1926, 1930, 1932, 1939-1941, 1943, 1951, 1953 and 1957-1958.

The most serious hydrospheric disturbances were associated with the most impressive peaks of high pressure in the Indonesia equatorial low. These occurred during the years of lowest pressure gradient Easter Island-Djakarta and when the southeast tradewinds were abnormally weak.

The term El Niño should not be confined to the 'legitimate' current distinguished by SCHWEIGGER (1945) and defined by POSNER (1957) as no more than 'a leakage of water on a small scale from the Gulf of Guayaquil onto the northernmost Peru littoral'. It should be used in a broader sense. Apparently even the extreme temperature maximum of Peru coastal waters recorded early in 1941, and so strongly suggestive of El Niño, was not brought about by El Niño proper. As reported by LOBELL (1942) no evidence was found of upwelling, but also no evidence of a highly developed El Niño.

The rather unusual El Niño of 1943 is well explained by the abnormal combination of relatively low pressure values at Easter Island and relatively high pressure values at Santiago. Against the rules of the S.O. the 1943 conditions were locally such as to cause only very weak southerly or perhaps even northerly winds along the Chile coast and consequently an exceptional slowing down of the Peru Current.

We refer here to the 'El Niño' study made by J. BJERKNES (1961) who pointed out the possibility that the causes of El Niño are not uniform. They may depend on two kinds of instability. Whereas the catastrophic El Niño of 1891 had been preceded by the weakest tradewinds ever recorded in the East Pacific (up to 1961), the equally catastrophic El Niño of 1925, according to SCHOTT (1931), had not been preceded by weak tradewinds.

There are other striking differences between the conditions in the Indo Pacific region during those two years, although these conditions have led to similar effects. For instance, 1891 started with relatively high pressure values in Djakarta, 1925 with relatively low pressure values. The impulse to a southward transgression of warm surface water along the Peru Coast early in 1925 must have originated from other sources than the impulse to such a transgression early in 1891.

BJERKNES mentions 'prevailing NW winds in Balboa and (by implication) along the northern part of the coast of Colombia, which may have impeded the normal northward current and made more warm water available for a transequatorial circulation'. The present author's suggestion is that prevailing low west-east pressure gradients between Juan Fernandez (33°37′S, 78°52′W) and Santiago (33°27′S, 70°42′W) during 1924 decelerated the Peru Current to such an extent that El Niño got its chance early in 1925.

The hydrospheric anomalies of 1891 and 1925 are similar in character despite their different origins. This indicates a need to refine our rough picture of how airpressure difference between the Easter Island subtropic high and the Djakarta equatorial low influences the intensity of the general atmospheric and hydrospheric circulation. It is necessary to consider the positions of the centres of this high and this low. Moreover, it will be necessary to take into account more carefully the antithesis between continent and ocean, in particular in the subtropical and moderate latitudes where the seasonal fluctuations of the incoming solar radiation are greatest.

Since airpressure at Mazatlan, Mexico (23°12′N, 106°25′W) was extremely high Oct-Dec 1924 and extremely low Oct-Dec 1890, the 1924 East Pacific tradewinds were probably stronger than those of 1890. During Oct-Dec 1890 the subtropical high pressure area in the eastern South Pacific might have extended so far over South America that the Peru Current was not effectively stimulated, perhaps even decelerated, during the southern summer.

As stressed by SCHWEIGGER (1959), it is necessary to distinguish between two kinds of oceanographic anomalies, two ways in which warm surface water accumulates along the Peru coast and extends unusually far south.

These two ways are a stimulation of the Peru surface countercurrent, which is the normal El Niño, a rather narrow coastal stream of equatorial or even transequatorial origin, and the eastward transgression of off-shore warm surface water from south of the Galapagos Islands (0°,90°W). A flow of the latter kind, as was demonstrated by SCHOTT (1931), occurred in 1891.

This might have contributed to the width of the Cromwell Current east of 113°W in that year (J. BJERKNESS 1961). However, it seems that the south equatorial countercurrent (WOOSTER 1960, 1961), the subsurface California countercurrent (J. L. REID JR, 1961) and the Peru-Chile southwardly directed undercurrent, discovered recently (WOOSTER and GILMARTON, 1961) do not play primary roles in atmosphere-hydrosphere interrelations and are therefore not pertinent to an explanation of the Southern Oscillation. These phenomena are unimportant in as much as they are of secondary nature in principle.

1.4 Fundamental pressure differences

With reference to para 1.3 it should be noted from Table 2 that the pressure anomalies were weak positive and strong positive at Santiago, while weak negative and still weaker negative at Djakarta in 1890 and in 1924, such that the difference in the pressure anomalies was positive but small in 1890 and positive but large in 1924. In 1891 and 1925 the pressure anomalies were weak positive and strong positive at Santiago, and strong positive and weak positive at Djakarta, such that differences in the pressure anomalies were negative and low in 1891 and positive and high in 1925.

The different character of the regional circumstances in 1924 and 1925 is shown by the fact that at Santiago airpressure stayed high from 1924 through 1925, the difference being only —0.1 mb, whereas at Juan Fernandez the annual mean pressure at sea-level dropped from 1020.1 to 1018.3 mb, the difference being 1.8 mb (Table 7). Since Juan Fernandez pressure level reflects rather strongly Easter Island pressure level (Fig. 8) and since the strength of the Peru Current depends in the first place on the pressure difference between Easter Island and Santiago, it is not surprizing that the flow of the Peru Current was decelerated from 1924 to 1925 to the same extent as apparently it was from 1890 to 1891.

The great difference between the situation in equatorial South America October 1890-February 1891 and October 1924-February 1925 is also shown by the fact that Surinam was devastated by an extremely severe drought in winter 1924-1925, whereas

TABLE 2. *Annual airpressure anomalies Santiago and Djakarta and anomalies*

	Santiago Δs mb	Djakarta ΔD mb	Δs-ΔD mb		Santiago Δs mb	Djakarta ΔD mb	Δs-ΔD mb
1861	+0.50	−0.60	+1.10	1887	−0.62	−0.27	−0.35
62	+0.27	−0.67	+0.94	88	−1.00	+0.60	−1.60
63	−0.19	−0.57	+0.38	89	−0.19	+0.11	−0.30
64	−0.37	+0.70	−1.07	1890	+0.05	−0.09	+0.14
65	−0.04	+0.43	−0.47	91	−0.01	+0.61	−0.62
66	−0.02	+0.20	−0.22	92	+0.27	−0.46	+0.73
67	+0.05	+0.21	−0.16	93	+0.58	−0.24	+0.82
68	−0.51	+0.67	−1.18	94	+0.42	0.00	+0.42
69	+0.06	+0.38	−0.32	95	+0.10	+0.02	+0.08
1870	−0.14	−0.75	+0.61	96	−0.26	+0.50	−0.76
71	−0.03	−0.29	+0.26	97	+0.03	+0.13	−0.10
72	+1.14	−0.67	+1.81	98	−1.19	−0.54	−0.65
73	+0.86	−0.33	+1.19	99	−1.81	+0.33	−2.14
74	+0.59	−0.18	+0.77	1900	−1.90	+0.35	−2.25
75	−0.09	−0.37	+0.28	01	−0.01	+0.29	−0.30
76	−0.90	−0.07	−0.83	02	−1.62	+0.56	−2.18
77	−1.58	+1.41	−2.99	03	−0.04	0.00	−0.04
78	−0.10	−0.03	−0.07	04	−0.47	+0.04	−0.51
79	−0.02	−0.71	+0.69	05	−0.42	+0.75	−1.17
1880	−0.58	+0.11	−0.69	06	+0.39	−0.07	+0.46
81	−0.25	+0.22	−0.47	07	+0.03	+0.03	0.00
82	−0.17	−0.18	+0.01	08	+0.37	−0.14	+0.51
83	−0.66	+0.26	−0.92	09	+0.49	−0.42	+0.91
84	−0.74	+0.40	−1.14	1910	+0.19	−0.79	+0.98
85	−0.66	+0.67	−1.33	11	+0.17	+0.31	−0.18
86	+0.18	−0.34	+0.52	12	+0.18	+0.31	−0.13

in winter 1890-1891 precipitation in Surinam remained high. This is the more remarkable, because the S.O. was clearly reflected in Surinam droughts 1868, 1877, 1884, 1888, 1895, 1896, 1900, 1902, 1911, 1918, 1925, 1928, 1930, 1932, 1935, 1939, 1946, 1957, 1958, 1963. This series will be discussed in para 3.4. Let us note here in particular the appearance of 1946 in the Surinam scheme. It stresses the limited regional extent of the conditions to which some apparent Peru Current and El Niño exceptions are due.

Fig. 9 shows the fluctuations of airpressure at Easter Island and Djakarta since 1942, this being the year when observations started at the first station. The antiparallelism of both curves is striking. Some doubt is permitted about the reliability and homogeneity of the measurements made at both Easter Island and Djakarta towards the end of World War II, but evidently we have to accept the abnormal coincidence of the pressure tops reached at both stations in the course of 1946. Since Santiago pressure anomaly of 1946 was —0.27 mb against +0.40 mb reached at Djakarta (Table 2); both values having the normal opposite signs, it becomes evident that the low sea *of the pressure differences Santiago-Djakarta, 1861-1964*

	Santiago Δs mb	Djakarta ΔD mb	Δs-ΔD mb		Santiago Δs mb	Djakarta ΔD mb	Δs-ΔD mb
1913	+0.25	+0.37	−0.12	1939	−0.31	−0.04	−0.27
14	−0.06	+0.87	−0.93	1940	−0.03	+0.73	−0.76
15	−0.06	+0.21	−0.27	41	+0.17	+0.58	−0.41
16	+0.59	−0.77	+1.36	42	+0.51	−0.03	+0.54
17	+0.69	−0.58	+1.27	43	+0.29	+0.09	+0.20
18	−0.24	+0.62	−0.86	44	+0.19	+0.37	−0.18
19	−0.53	+0.46	−0.99	45	+0.25	+0.06	+0.19
1920	−0.29	−0.14	−0.15	46	−0.27	+0.40	−0.67
21	+0.42	−0.19	+0.61	47	+0.19	−0.14	+0.33
22	−0.03	−0.37	+0.34	48	+0.13	+0.09	+0.04
23	−0.29	−0.07	−0.22	49	+0.37	−0.17	+0.54
24	+0.50	0.00	+0.50	1950	+0.43	−0.68	+1.11
25	+0.43	+0.17	+0.26	51	−0.57	+0.05	−0.62
26	−0.14	+0.26	−0.40	52	−0.07	−0.06	−0.01
27	+0.29	+0.02	+0.27	53	+0.58	+0.31	+0.27
28	+0.27	−0.26	+0.53	54	+0.58	−0.59	+1.17
29	−0.39	+0.06	−0.45	55	+0.50	−0.58	+1.08
1930	−0.50	+0.51	−1.01	56	+0.09	−0.75	+0.84
31	+0.50	+0.14	+0.36	57	−0.42	+0.11	−0.53
32	+0.01	−0.02	+0.03	58	−0.25	+0.18	−0.43
33	+0.45	−0.29	+0.74	59	+0.75	−0.12	+0.87
34	+0.67	−0.11	+0.78	1960	+1.00	−0.43	+1.43
35	+0.41	−0.07	+0.48	61	+0.50	−0.71	+1.21
36	+0.22	−0.07	+0.29	62	+0.86	−0.91	+1.77
37	+0.55	−0.28	+0.83	63	+0.54	+0.03	+0.51
38	+0.90	−0.44	+1.34	64	−0.22	−0.42	+0.20

surface temperatures observed at Puerto Chicama in 1946 were caused by a very strong Peru Current. This current was due to a great pressure difference, Easter-Island-Santiago, again a regional anomaly, causing the most spectacular exception to the Southern Oscillation rules (1.1, 2.4).

Figure 8 gives interesting information about the rather wide diversions of airpressure fluctuations for Juan Fernandez and Easter Island. The roughly parallel course of these fluctuations is an easily explained dominant feature. The greatest difference, a prolonged very large positive anomaly of the pressure difference Easter Island-Juan Fernandez, occurred in 1956. It contributed to the persistence of a relatively quick general circulation through the South Pacific Ocean before this terminated in relaxation (1.7).

The mechanism appears to be as follows. The Easter Island high, built up in the course of several years, breaks down abruptly, the surplus air expanding in a west-northwesterly and east-southeasterly direction through the South Pacific, Samoa included.

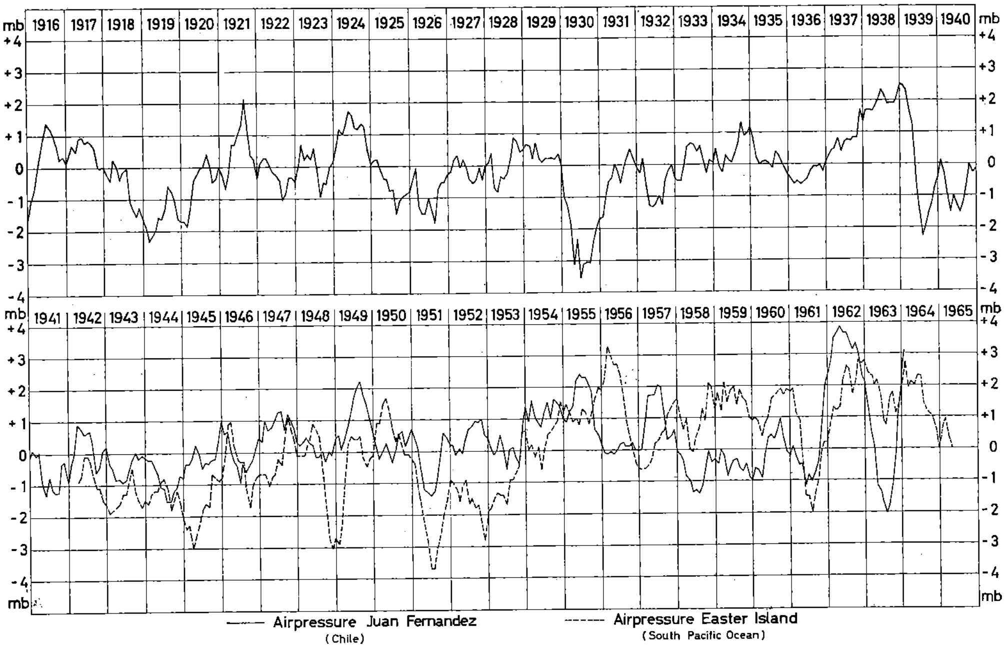


Fig. 8 Running six-monthly average anomalies of Juan Fernandez and Easter Island air pressure.

As TALJAARD, SCHMITT and VAN LOON (1961) pointed out, in every southern winter the centre of the Southeast Pacific high shifts westward from near Easter Island (27°10'S, 109°26'W) towards near Rapa Island (27°0'S, 144°30'W). In addition, the intertropical isobaric maps, published by Deutscher Wetterdienst, Seewetteramt Hamburg, reveal the occassional splitting up of the Southeast Pacific high, the two highs in these cases being separated by a trough extending frequently in a south-southwesterly and north-northeasterly direction.

These two phenomena require further study.

SCHELL (1965) assembled sufficient data to draw mean monthly isobaric maps for the Southeast Pacific between 10° and 50°S. He deduced from these the prevailing atmospheric circulaton, considering in particular the periods (a) March-November 1951, 1953, 1957 and 1952, 1954, 1955, 1956, (b) March-May 1957 and 1956, and (c) March 1957 and 1956. SCHELL indicates that the major controls of seasurface temperratures along the west coast of South America 'and presumably the strength of the Peru Current and Cape Horn Current as well as the upwelling over longer time intervals and the development of El Niño, lie in the strength and convergence of the westerlies between 135-90°W and 35-50°S, and in the strength of the southerlies and southeasterlies along and inland from the coast linked to the westerlies'.

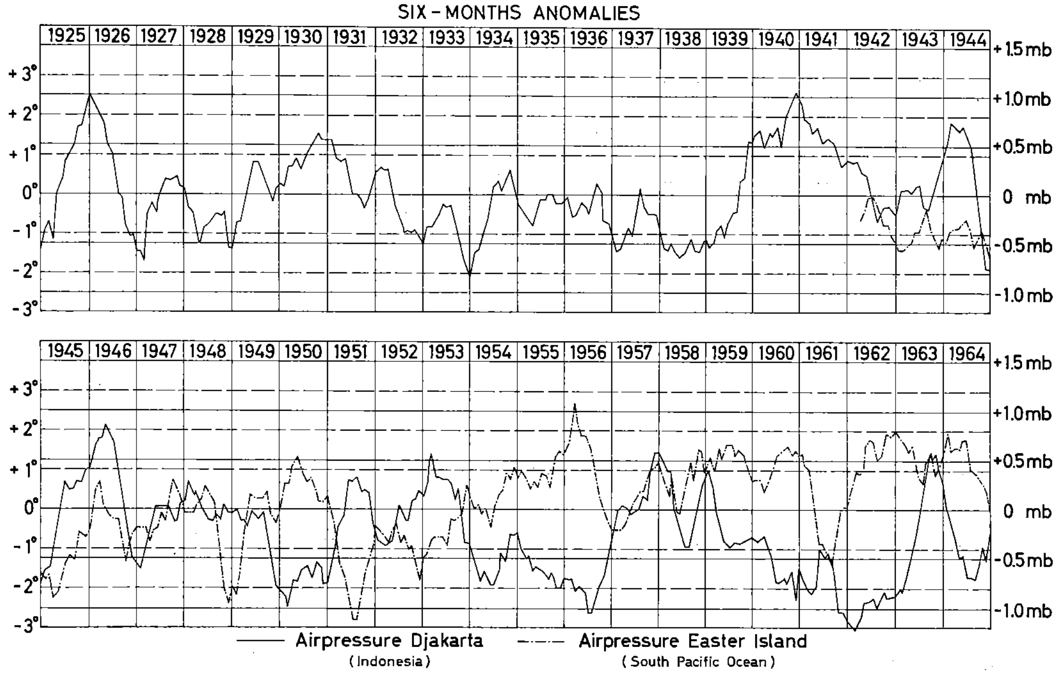


Fig. 9 Running six-monthly average anomalies of Djakarta and Easter Island air pressure.

These arguments run parallel to those of the present author and promise to be of prognostic value.

1.5 Longperiodic fluctuations

Table 2 is particularly instructive as regards the essential operation of the Southern Oscillation, because it goes back as far as 1861. For the years 1861-1865 the mean of the pressure anomalies observed at Bombay, Madras and Calcutta could be used instead of the mean of those from Djakarta. Both pressure anomaly series assembled in Table 2 have been reduced to the total average pressure value 1861-1963.

The normal pressure level at Santiago has been generally rising, the normal pressure level at Djakarta generally falling in the course of the past hundred odd years. This decrease of pressure at Djakarta is associated with a remarkable rise of temperature there since the beginning of observations (De Boer and Euwe, 1949, Schmidt-Ten Hoopen, 1951) and with an increase of evaporation of the Indian Seas (Jagannathan and Ramasastry, 1964). These are important aspects of the variations in global climatic conditions pointed out by many investigators (WMO-Bibliography on Climatic Fluctuations, 1961).

TABLE 3. *The numbers of positive and negative anomalies of the annual average pressure differences Santiago-Djakarta.*

	negative	running 30-year sums	positive	running 30-year sums
1861-1870	6		4	
1871-1880	4	17	6	13
1881-1890	7	17	3	13
1891-1900	6	18	4	12
1901-1910	5	19	5	11
1911-1920	8	17	2	13
1921-1930	4	14	6	16
1931-1940	2	9	8	21
1941-1950	3	9	7	21
1951-1960	4		6	

Table 3 reminds us of the sharp distinction between the pressure patterns on the west coast of South America during the periods 1911-1940 and 1941-1952, pointed out by RUBIN (1955).

The trend shown by Table 3 does not involve persistence. It reveals rather the long period variation, defined as the 'major pressure oscillation' by SCHOVE (1961). This author, by studying world wide pressure changes in overlapping 30-year periods, found the extreme swings of the S.O. centered about 1891 and about 1923.

The fact that the S.O. is essentially a fluctuation of the intensity of the general circulation becomes clearer when it is noted that the Northwest Atlantic took part in the downward pressure trend shown by the Southeast Pacific. This fluctuation has been relatively slow in the 30 years centered about 1891 and relatively rapid in the 30 years centered about 1923, thus causing tropical and subtropical eastcoast stations and North Atlantic westcoast stations to become wetter from the first to the second period, whereas American and African eastcoast stations became drier. The period of the S.O. was roughly 3 years in the former interval and roughly 2 years in the later interval.

Table 3 demonstrates an acceleration of the intertropical circulation in the Indo-Pacific region between the 1890s and the 1940s, a rather long term trend, but nevertheless also easily integrated in the excellent summary of our present knowledge about world wide climatic variations, published by RÜGE (1965). From this we learn: 'The general circulation of the atmosphere is the carrier of climatic changes. The changes (during the present century) were connected with a remarkable strengthening of the general circulation, being effective at first in zonal directions, since 1931 in meridional directions. The corresponding movements of the main centres of action were irregular. The trade-wind circulation showed similar trend. Since the 1940s the general circulation is weakening. In the Atlantic region the observed changes are strongest', and: 'During the 1890s the global climatic trend turned to the warmer side. The climax was reached in the subarctic regions during the late 1930s . . . Since the

1940s, when frequently severe winters occurred in the northern temperate latitudes, there are signs of a gradual cooling spreading from the polar regions.'

It will be shown in para 1.11 that the rhythm behind these variations is probably identical with the approximate 89-year cycle, discovered by Easton (1918) in European winters. All this would explain also why Roden (1965) found no trace of secular changes of pressure along the Pacific coast of North America in a period of this length, the 90 years 1873-1963.

1.6 The Sunspot Cycle in World Weather

Whether the sunspot cycle has a traceable influence on phenomena at the bottom of the atmosphere has remained a doubtful point to many investigators up to the present time. Their doubt, however, apparently shared by Allan in his recent summary of arguments (1964), rests, if the present author sees it rightly, on the difficulty of explaining such an influence and not on the lack of convincing evidence for it.

For instance, Troup (1960, 1962) pointed out that 'over the tropics as a whole, the correlations between sunspot number and tropical temperature which prior to 1920 were on the whole negative, have become zero or even positive subsequent to this date', but C.E.P. Brooks (1951) reported already on connections between sunspots and temperature: 'Temperature over the Earth as a whole is lowest at sunspot maxima and highest at sunspot minima. This relation is most strongly and clearly developed in the tropics and extends towards the poles along the main warm ocean currents. In middle and high latitudes it becomes irregular. The relation is best developed in the cloudy rainy regions of the tropics. In regions or seasons of little cloud, and in parts of middle and high latitudes furthest removed from the influence of warm oceans, there is no correlation or even a small positive one between sunspot numbers and temperature'.

Hence, the remarks made by Troup do not contradict the more fundamental view that the intertropical atmospheric circulation is accelerated in times of increased solar activity- or many sunspots- and decelerated in times of decreased solar activity- or few sunspots. Since primarily an increase of temperature at sea level causes stronger evaporation, stronger ascending motion of air and more precipitation, which causes secondarily a decrease of temperature in the lower air layers, we have to balance the one influence against the other. The relationship between sunspot numbers and air temperatures in the tropics is apparently not linear. Consequently, when the sign of the correlation, between sunspots and temperature in the wet tropical belt, changes from negative to positive in the nineteen twenties this might be explained as follows. During the earlier period low sea-level air temperatures were associated with high sunspot numbers because the cooling influence of precipitation in the lower air layers exceeded the heating influence of radiation, whereas in the later period the reverse was the case.

In low latitudes these relationships are two sided and the subtlety of their character is reflected in the observation that, on the average, 2/3 rd of the energy transfer between

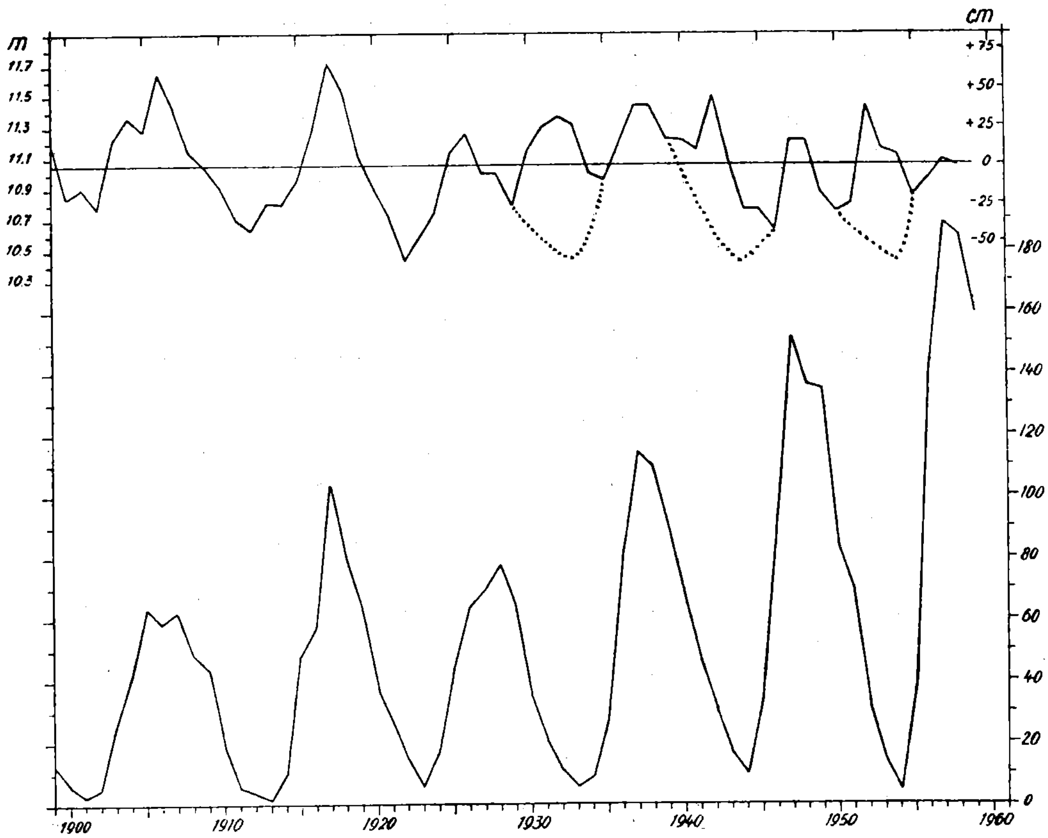


Fig. 10 Variations of the level of Lake Victoria and sunspot numbers 1899-1959.

ocean and atmosphere is in the form of latent heat of evaporation and 1/3 rd as sensible heat (ARCHIPOVA, 1960 and SHELLARD, 1962).

These relationships might even explain the high linear correlation between the level of equatorial Lake Victoria, measured at Entebbe (0°05′N, 32°30′E) and Jinja (0°30′N, 33°30′E), and the number of sunspots in early years as well as the apparent failure of such correlation in later years.

Fig. 10, a well known one, but provided with three dotted artificial lines, strongly suggests that, in recent years, the variation of solar activity in the course of one sunspot cycle was associated with a duplication of the oscillation of Victoria Lake's level. Yet, the primary precipitation cycle might well be due to an acceleration of the Hadley circulation with high sunspot numbers or high solar activity and a deceleration with low sunspot numbers or low solar activity. Generally, strong meridional circulation is associated with a quick rise of equatorial air and high equatorial rainfall. This is in accordance with the pre-1930 kind of operation. However, as shown by the complicated low tropospheric flow pattern, developed by FLOHN (1960), the air that delivers the rains might have suffered minor deflections from its average course and thus could be of either continental or marine origin. Therefore, a very small systematic change of contour pattern and of the location and structure of the I.T.C. with the solar cycle, may associate high rainfall with low sunspot numbers.

Hence, duplication of rainfall peaks in one primary solar cycle on the high plateau of Lake Victoria might find an explanation separate from the global climatic cycle of half the sunspot period, pointed out by BAUR (1956, 1958) and others. The high plateau of Lake Victoria is an equatorial area surrounded by chains of mountains, some of them with snow covered tops, e.g. Kilima Ndjaro (6010 m). Even the remarkable fact that the three solar cycles immediately preceding the sunspot maximum of 1928 showed different effects to the three immediately following 1928, might simply depend on differences in the two climatic periods (KRAMES, 1951 and BUTZER, 1957).

In any case Lake Victoria data seem to support the thesis that the intertropical general circulation is speeded up when solar activity increases and slowed down when solar activity decreases. The same thesis is supported by the fact that the annual anomaly of the pressure difference Santiago-Djakarta (Table 2) is positive in 7 out of 10 sunspot maximum years and negative in 7 out of 10 sunspot minimum years; the non conformative cases being also accumulated in the recent past.

The relationship between the annual sunspot number and the S.O. index, as determined by the anomaly of the pressure difference Santiago-Djakarta, is evidently rather complicated. The author's suggestions with respect to the way in which solar activity affects the S.O. fluctuations, promising, but not quite satisfactory so far (1961), will be mentioned at a later stage; it can hardly be doubted that an intimate relationship exists.

In fact the strongest sunspot maxima in the period 1861-1964 (Table 2) were those of 1871, 1937, 1947 and 1958 with the greatest emphasis on the most recent maximum. Consequently, it seems possible that an undeniable intensification of solar activity in recent decennia might account for the persistent appearance of positive anomalies of the pressure difference Santiago-Djakarta during the years since the nineteen twenties. Large numbers of sunspots also characterize 1870, 1871, 1872, opening the series 1870-1875, and the most impressive sequence of years with positive anomalies of this pressure difference falls between the 1860s and the 1920s.

Hence, greater or smaller pressure differences Santiago-Djakarta, or say Easter Island-Djakarta, are associated with greater or smaller numbers of sunspots. The obvious meaning is that stronger and weaker solar activity cause a strengthening and a weakening of the Hadley cell circulation between the tropics and the equator in the South Pacific. During periods of great pressure differences Easter Island-Djakarta the general circulation between the tropics and the equator is intensified. Consequently, during intervals of great pressure differences the S.O. is accelerated and hence its proper period shortened, whereas during intervals of small pressure differences the S.O. is decelerated and hence its proper period lengthened.

The interval 1876-1891, through 16 years, following Table 2, shows a mean annual anomaly of the pressure difference Santiago-Djakarta of —0.62 mb and is characterized at Djakarta by six successive pressure tops: 1877, 1881, 1883, 1885, 1888, 1891, and hence by a mean proper period of the S.O. amounting to 2.8 years.

The interval 1896-1905, through 10 years, shows a mean annual anomaly of this pressure difference of not less than —1.01 mb and is characterized at Djakarta by four successive pressure tops: 1896, 1899, 1902, 1095, and hence by a mean proper period of the S.O. of 3.0 years.

Next in length comes the interval 1864-1869 through 6 years. It shows a mean annual anomaly of the pressure difference of —0.57 mb and is characterized at Santiago by two pressure valleys: 1864, 1868, and hence by a proper period of the S.O. of 4.0 years. However, it is characterized at Djakarta by a secondary pressure maximum between the peaks of 1864 and 1868, and hence by a proper period of the S.O. of 2.0 years. We shall see later that the same periodicity, 1864, 1866, 1868 characterizes Surinam droughts. It is thus suggested that a secondary equatorial 2 year periodicity might be impressed upon a primary S.O. periodicity of other wavelength. In this case the octave was easily led by the key-note. Whether this 2-year periodicity was induced by the now well known equatorial stratospheric 2-year periodicity is a point which will be touched later (4.2).

On the other hand we note a few long sequences of years with positive anomalies of the airpressure difference Santiago-Djakarta. In Table 2 the period 1870-1875 through 6 years is the first of these. It shows a mean annual anomaly of +0.82 mb. Next comes the period 1906-1910 through 6 years, showing a mean annual anomaly of +0.61 mb. The two 4 year series 1892-1895 and 1947-1950, both showing a mean annual anomaly of the pressure difference of +0.51 mb, are less impressive. More important are the 4-year series 1953-1956 and the 6 year series 1959-1964 showing mean annual anomalies of +0.84 and +0.99 mb respectively.

The series 1870-1875 and 1931-1938 were both followed by an exceptionally high pressure peak at Djakarta, the one of 1877 and the one of 1940. These pressure peaks were followed by peaks 1880-1881 and 1944, that is after 3½ and 4 years respectively.

The period 1906-1910 was followed by a rather normal pressure maximum in 1911. However, in 1914, hardly three years later, there followed an exceptionally high pressure peak. The next peak occurs 4½ years later, in 1918-1919, delayed apparently because a heavy sunspot maximum, occurring in 1917, kept pressure exceptionally low even after the low pressure year 1916. In this way a record pressure valley was formed (BERLAGE, 1957). We refer here to Fig. 5.

Let us note that sunspot minima occurred in 1878 and in 1913, a circumstance which evidently contributed to the height of the Djakarta pressure maxima in 1877 and in 1914. As regards the third case already mentioned, the high pressure year 1944 was distinguished too by a sunspot minimum.

We should also consider that extremely heavy sunspot maxima contributed to the distinction of the series 1870-1875, 1931-1938 and 1947-1950. However, the highest sunspot maximum ever recorded occurred 1957-1958, in the two years following the series 1953-1956, while their association with abnormally high pressure in Djakarta and abnormally low pressure in Santiago provides us with the most remarkable apparent exception to S.O. rules.

The interpretation of this exception is tied up with the interpretation of the S.O. as a relaxation oscillation. The probability of such an interpretation was brought forward by BERLAGE and DE BOER (1959, 1960 en 1962).

1.7 The Southern Oscillation driven by relaxation

As BERLAGE (1927, 1929, 1957) indicated by numerical examples, the Southern Oscillation proper is a damped oscillation, which may be expressed by the equation

$$\ddot{u} + 2\alpha\dot{u} + \omega_0^2 u = 0, \tag{1}$$

in which

u = deviation of barometric pressure from normal
α = damping constant
ω_0 = the resonance frequency of the system multiplied by 2π.

As this oscillation is superimposed on the motion of the basic air pressure level, and this basic level shows a relaxation oscillation during a period $t = t_1$, the relaxation will act as an external force on the damped oscillation of the S.O. proper. This external force will also influence the resonance frequency. Let us express the external force provisionally by

$$A + B(1 + e^{-\beta t}), \tag{2}$$

an expression in which A, B and β have constant values during the relaxation period t_1.

The influence of the external force, as expressed in (2), is such that in the static case, when (1) is reduced to $u = 0$, the mathematical expression for u does not depend on t. Therefore (2) and (1) combined give

$$\ddot{u} + 2\alpha\dot{u} + \omega_0^2\left\{1 + \frac{B}{A}(1 + e^{-\beta t})\right\}u = A + B(1 + e^{-\beta t}). \tag{3}$$

Equation (3) represents the Southern Oscillation under the influence of an external force, which is given by the right hand side of (3), and is valid in the interval $0 \leqslant t \leqslant t_1$. The solution of equation (3), superimposed on the right hand side of (3), plotted as a function of t then expresses the barometric curve of Djakarta in the interval $0 \leqslant t \leqslant t_1$. In the next interval $t_1 \leqslant t \leqslant t_2$ the same expressions are true, but for a different set of values for the constants.

The solution of the differential equation (3) depends on the value of B/A. The solution for $B/A \leqslant 0$ is

$$u = \frac{A}{\omega_0^2} + Ce^{-\alpha t} \sin\left[\left\{\frac{2}{\beta}\sqrt{\omega_0^2\left(1 + \frac{B}{A}\right) - \alpha^2}(-y + \tanh^{-1}y)\right\} + \varphi\right] \tag{4}$$

in which

$$y = \left\{ 1 + \frac{\omega_0^2 \frac{B}{A} e^{-\beta t}}{\omega_0^2 \left(1 + \frac{B}{A}\right) - \alpha^2} \right\}^{\frac{1}{2}} \tag{4a}$$

For $B/A < 0$ the solution is

$$u = \frac{A}{\omega^2} - Ce^{-\beta t} \sin \left[\left\{ \frac{2}{\beta} \sqrt{\omega_0^2 \left(1 + \frac{B}{A} \right) -} \right. \right.$$

$$\left. \left. - \alpha^2 (y + \operatorname{cotanh}^{-1} y) \right\} + \varphi \right] \tag{5}$$

in which

$$y = \left\{ 1 + \frac{\omega_0^2 \frac{B}{A} e^{-\beta t}}{\omega_0^2 \left(1 - \frac{B}{A}\right) - \alpha^2} \right\}^{\frac{1}{2}} \tag{5a}$$

C and φ are integration constants.

Formula (4) represents a damped oscillation, the period of which decreases with increasing rapidity, whereas formula (5) represents a damped oscillation the period of which increases with increasing rapidity, provided $\omega_0^2 \geqslant \alpha^2$.

When we realize that it is the long continued building up of the pressure difference tropic-equator and the sudden break down of it that constitutes the relaxation phenomenon in the general circulation through South Pacific and Indian Ocean, there seems hardly any chance of finding instances of sudden changes from the slow to the quick regime. In fact, both series of famous three-year waves, those with pressure maxima at Djakarta 1885-1888-1891 and 1896-1899-1902-1905 show more an asymptotic than an abrupt ending.

An airpressure drop as from 1868 to 1870 is to be interpreted as an asymptotic fall of the basic level from above to below normal, while the S.O. proper superimposed on this basic level intensifies the fall (DE BOER and BERLAGE 1962). The intervals between the pressure tops since 1864 are 4, 3, 2½ and 1½ years successively, the intervals shortening according to the rules, the last pressure top being a small one in 1875. Fig. 11 and Fig. 12 are reproduced from the above mentioned paper.

The relaxation occurring in 1876 suddenly generates at Djakarta pressures higher than ever recorded since. It introduces the next S.O. pressure waves with maxima 1877, 1880-1881, 1883-1884, at intervals decreasing from 3½ to 3 years. In 1884 a new pressure rise occurred leading to the wave train showing crests in 1885-1888-1891, at regular 3-year intervals.

Very likely the outstanding 3-year wave trains are examples of the second type of basic level oscillations, and are caused by a resonance effect due to the relaxation

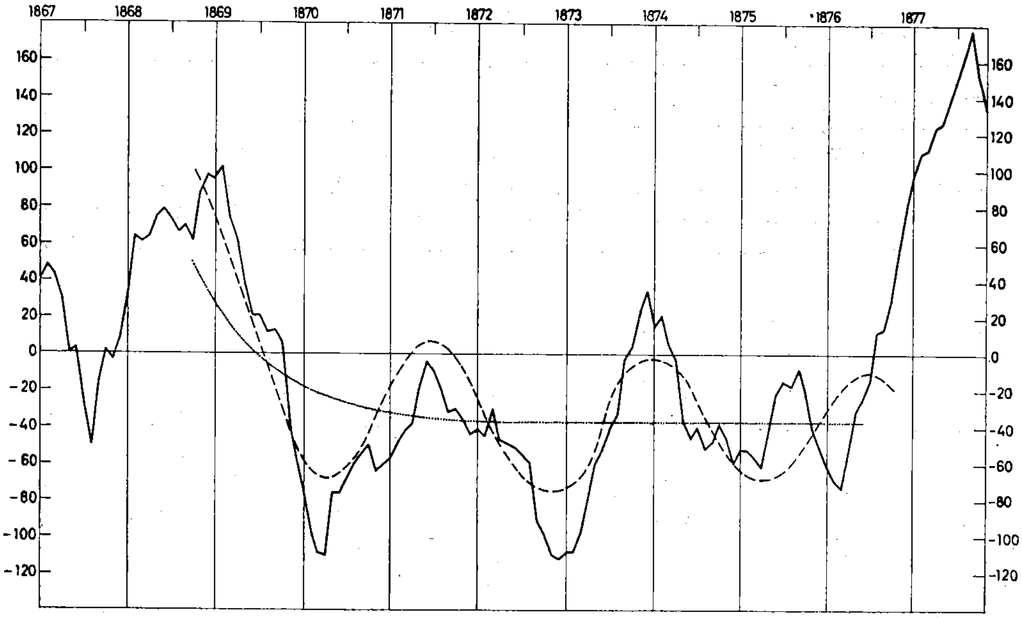
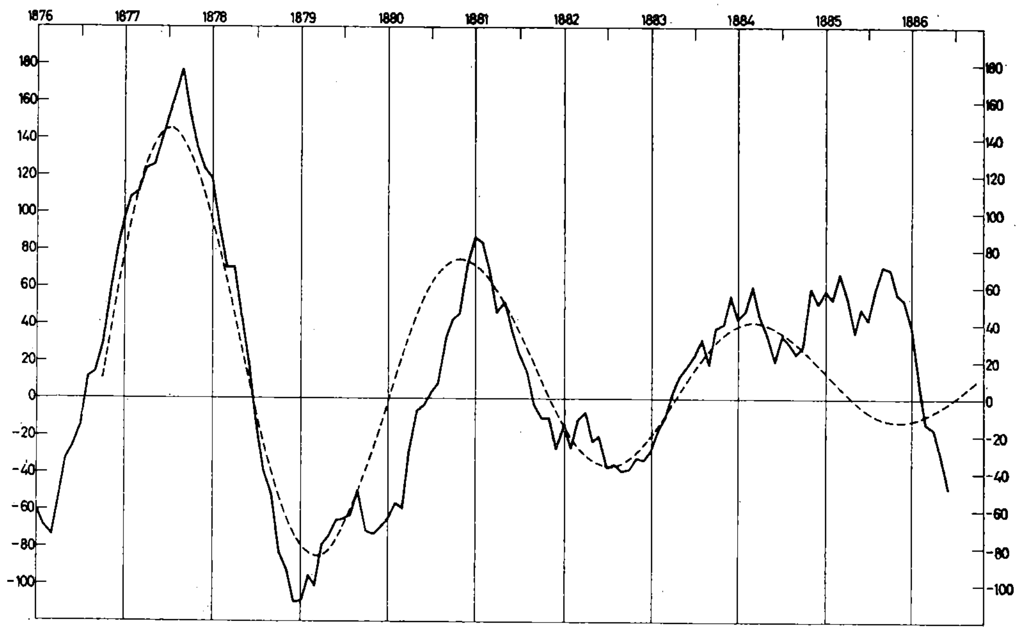


Fig. 11 Djakarta air pressure 1867-1878 ———— actual - - - - - - theoretical . . . . . . basic level.

Fig. 12 Djakarta air pressure 1876-1887 ———— actual - - - - - reconstructed.



period t_1 being synchronized with the period T_0 of the S.O. proper. This would explain the well-known sawtooth character of the 3-year waves, the sawtooth being in most cases projected forwards.

NAGVI (1956) noted a similar background of the fluctuations of July rainfall in Karachi. He writes: 'the amounts go on increasing in subsequent years until a high value is reached. Then there is generally a sudden drop when the next period begins. There is a 53 percent chance that the period will be of four years, a 31 procent chance of its being three years long and a 15 percent chance that it will extend to five years'.

1.8 Periodicity dependent on basic level of pressure differences

Evidently the acceleration of the S.O. which occurs in times of high airpressure difference Santiago-Djakarta and leads to a gradual shortening of the waves and a reduction of their amplitudes, terminates in a typical sudden relaxation rise of the basic level at Djakarta, followed by a wave of abnormally large amplitude and period.

Fig. 13 is a reproduction of Fig. 1, however, it shows also the fluctuation of the basic level of Djakarta pressure as distinguished from the S.O. proper.

The downward trend of the pressure curve between relaxations, denoted by the exponential factor β in para 1.7, is independent of the damping constant, explaining the reduction of the amplitude of the S.O. if no 'external' force would intervene.

Now, going into greater detail and extending the application of the theory developed in para 1.7 to cover the total series of years with available observations, we observe that the factor β evidently depends on the influx of solar radiation and therefore is not constant. Besides depending on the number of sunspots, β apparently depends on the variation of the basic level in the course of one year from the anomaly existing at the beginning of the year.

By trial and error the author found the following adequate expression for the downward trend of the anomaly u_0 of the Djakarta basic pressure level in millibars, between relaxations,

$$\Delta u_0 \text{ (in one year)} = -0.1(u_0 + 0.5) - 0.002(n - 20) \qquad (6)$$

where n represents the annual number of sunspots. With the term $u_0 + 0.5$ mb we accept -0.5 mb as the extreme anomaly of the basic level from which there is upward recovery always when solar activity is low. Only when n is greater than 20 the basic level may drop further.

TABLE 4 *Anomalies of Djakarta basic pressure level in mb, after relaxation.*

1864	+0.6	1891	+0.5	1926	+0.4	1946	+0.2
1876	+0.6	1896	+0.6	1929	+0.4	1951	0
1883	+0.3	1911	+0.5	1939	+0.6	1957	+0.5
1887	+0.3	1923	+0.1	1940	+0.4	1963	+0.4

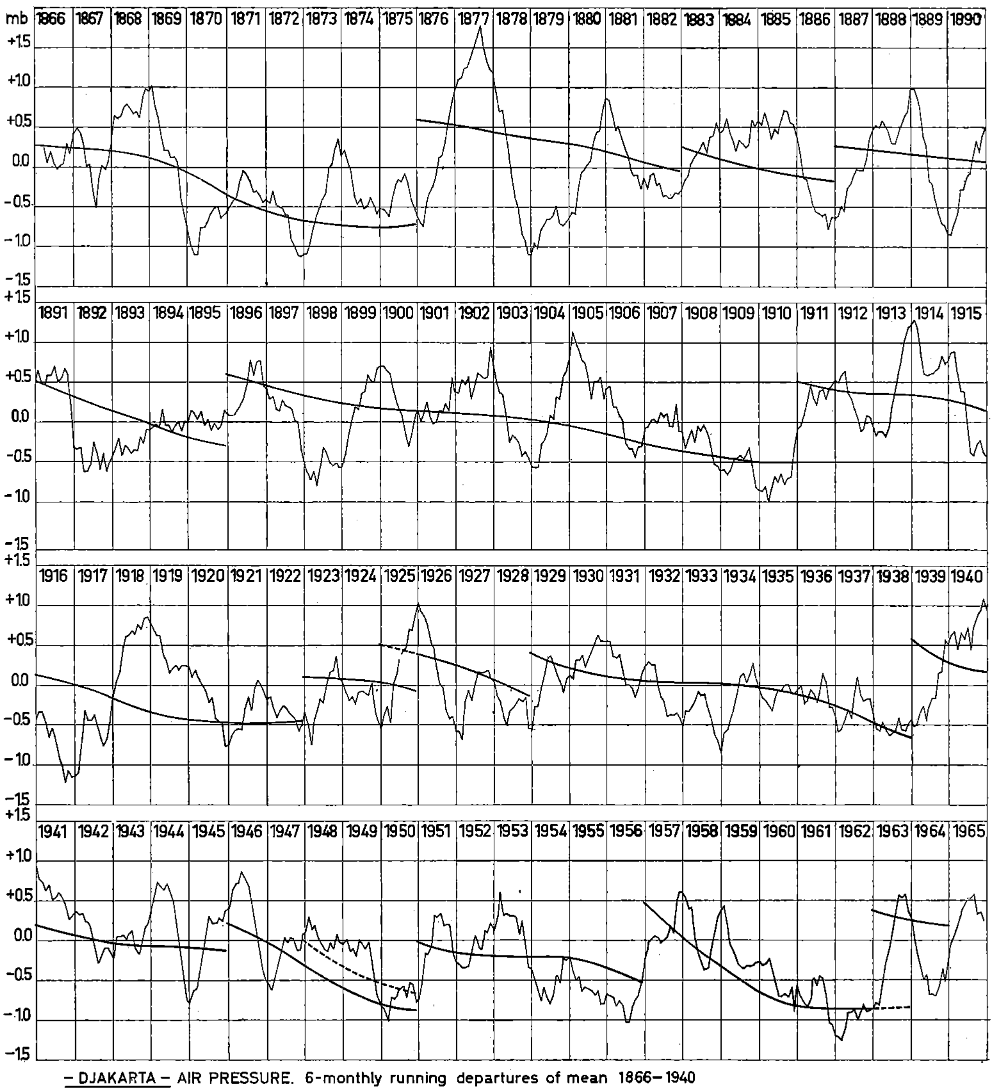


Fig. 13 Running six-monthly anomalies of Djakarta air pressure and the relaxation oscillation of its basic level.

Equation (6) has been applied to determine the fall of the basic level of Djakarta pressure as given in Fig. 13 between the moments of relaxation. Relaxation occurs after one or more years of successive positive anomalies of the pressure difference Santiago-Djakarta.

As anomalies of the basic pressure level after relaxation rises at Djakarta the approximate heights in mb given by Table 5 were assumed.

Sudden rises of the basic pressure level at Djakarta are made in this way. They generally increase with the sum of the positive annual anomalies of the pressure difference Santiago-Djakarta recorded for the immediately preceding years.

TABLE 5 *Sudden rises of Djakarta basic pressure level in mb (right) induced by quantities (left) explained in text.*

1882	+0.01	+0.37	1950	+2.02	+0.89
1890	+0.14	+0.39	1895	+2.05	+0.91
1945	+0.19	+0.36	1910	+2.86	+1.01
1886	+0.52	+0.48	1956	+3.36	+1.05
1925	+0.76	+0.47	1938	+4.85	+1.25
1928	+0.80	+0.53	1962	+4.87	+1.24
1922	+0.95	+0.58	1875	+4.92	+1.31

It should be noted that in Table 4 and Fig. 13 the year 1879 and the pairs of years 1916-1917 and 1942-1943 have not been taken into account, although according to Table 2 attention should have been given to these years.

The positive anomalies of the pressure difference Santiago-Djakarta show no specific relaxation rises of the basic level during these years, but are caused by the very large amplitude of the S.O. wave. This amplitude was generated by relaxation and induced regular pressure tops in Santiago and pressure valleys in Djakarta. These are simply examples of the S.O. proper in its most outspoken conditions of operation.

Moreover, it seems likely, as already noted by DE BOER and BERLAGE (1962), see Fig. 12, that pressure at Djakarta remainded about 0.5 mb below expectations towards the end of 1879 and during the whole year 1880. It is as if relaxation failed to occur.

As regards famous 1916-1917, Fig. 5 shows clearly that the general circulation throughout the globe must have been extremely quick in the course of these two years. The symmetry of the picture about the equator is such that we would expect the cold Labrador Current, southward through Davis Strait and along the eastcoast of Canada, to be associated with highest pressure, as is the Falkland Current northward along the eastcoast of Argentine. The same would be true for the East Greenland Current on the Iceland side. As a matter of fact, in 1917 Stykkisholm (65°5′N, 23°46′W) showed the highest pressure since 1845. At Ivigtut (61°12′N, 48°10′W) on the Greenland side, highest pressure was recorded in 1892, but the second highest was recorded in 1917.

The particular character of the years 1916-1917 derives from the occurrence of relaxation, which became truly effective in 1913, and led to the outstanding pressure wave 1914, 1915, 1916, 1917, 1918, 1919, which had an amplitude of about 1.0 mb at Djakarta. In RUBIN's description (1955) July 1917 in particular is very impressive.

An equal amplitude is only reached by the very large pressure wave 1876, 1877,

PACIFIC OCEAN, HEIGHT OF SEA-LEVEL, RUNNING SIX-MONTHLY MEANS

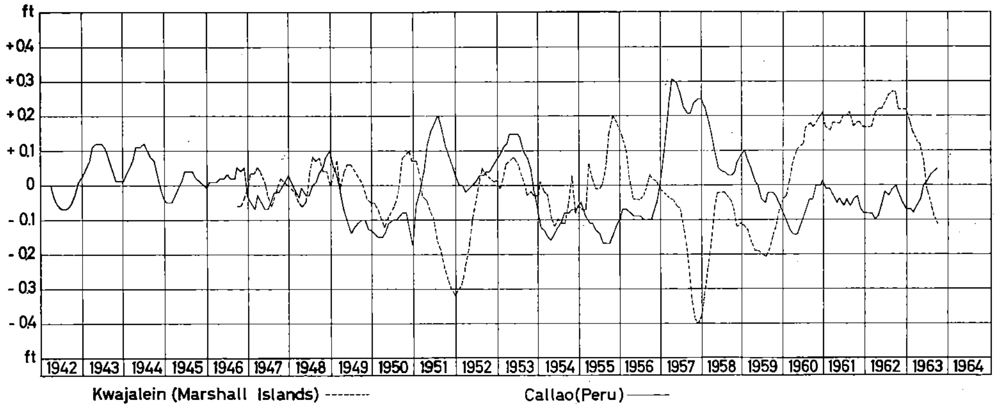


Fig. 14 Pacific Ocean mean height of sea-level, Kwajalein, Callao.

1878, 1879, 1880, 1881, associated with the first exception. An amplitude of roughly 0.7 mb was reached by the pressure wave 1939, 1940, 1941, 1942, 1943, 1944, associated with the third exception.

It should be observed here that relaxation of the basic level in 1945 is a rather unusual early feature; however, it might explain why a high pressure year, 1946, followed within two years of the previous one, 1944.

The exceptional character of 1946 was already mentioned (1.1). Pressure at Juan Fernandez and Easter Island rose to a high level, as it did at Djakarta, while the large positive pressure difference Juan Fernandez-Santiago maintained strong southerly winds along Chile's coast, a strong Peru Current, and low sea surface temperatures at Puerto Chicama. This was unexpected from both the Djakarta and the Santiago points of view.

This exception can be explained at a later stage. It is probably due to certain relations between the atmospheric circulations of the South Pacific and Antarctica (2.4).

The great efficiency of relaxation 1956 is demonstrated by the fact, already mentioned in para 1.6, that 1957 and 1958 became highpressure years in the Djakarta region, although these years were characterized by the highest sunspot maximum ever recorded. The amplitude of this pressure wave did not exceed 0.6 mb.

There is every reason to combine this obvious relaxation in the circulation through the Pacific Ocean and the Indian Ocean in the course of 1956, and the break-down of the zonal circulation during the period January 8-13, 1956 described by F. DEFANT and HESSAM TABA (1958). It was this break-down which finally led to the excessively cold February 1956 in West Europe (ref. 4.5).

Our impression of the almost global scale of these fluctuations is greatly enhanced by Fig. 14, which represents the course of sea level heights at two distant nearly

TABLE 6. *Monthly Mean sea-surface temperatures in the Peru Current, Longitude 70°-80° W, according to observations made by Netherlands ships.*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
						Latitude 5°-10° *S*						
1958						20.4	**21.3**		**18.2**	18.2	18.4	20.2
1959	**21.7**	**24.8**	**24.6**	22.4	23.6	22.0	18.5		17.2	17.1	18.8	19 0
1960	19.2	21.1	22.3	19.2	18.5	19.0	17.7	17.8	17.4	15.9	18.9	20.0
1961	20.6	23.1	21.6	19.0	19.8	19.9	18.1	17.6	16.6	16.7	19.2	18.0
1962	20.8	22.5	20.3	19.4	19.5	20.1	17.4	16.7			18.0	
1963	16.6	21.3	22.7	21.9	20.5							
1964	21.0	22.9	21.9				17.5	16.4		17.6	18.2	18.7
1965	19.4			**24.5**	**24.0**	**23.5**	19.8	**21.4**	17.6	**27.0**	**22.6**	**21.8**
						Latitude 10°-15° *S*						
1958	**23.9**	23.2*	21.1*	**24.0**	**21.9**	20.4	18.3	17.7	**17.2**	**18.1**	**19.5**	**21.2**
1959	22.2	**24.0**	24.0	22.8	21.1	18.8	17.1	17.5	16.9	17.5	18.9	20.1
1960	21.5	21.6	21.4	19.9	21.4	18.6	16.2	17.0	16.5	17.4	18.5	20.7
1961	22.6	23.0	22.1	19.2	19.4	18.1	17.3	17.9	15.9	16.1	19.0	18.3
1962	20.7	21.6	21.4	21.2	20.3	18.2	17.1	16.7	16.4	16.9	18.5	19.6
1963	19.1	23.0	21.9	20.3	20.6		17.6	17.5	17.1	17.4	18.4	
1964	21.7	22.8	21.7	18.6	18.0	19.0	17.8	16.1	15.4	17.4	19.3	20.4
1965	22.6	21.1	**24.5**	23.5	21.5	**20.6**	**18.4**	**19.1**	17.0	17.1	18.0	19.4
						Latitude 15°-20° *S*						
1958	22.1	22.2*	21.1*	23.1	**21.4**	19.1	**18.2**	17.0	16.7	**17.8**	18.8	**23.3**
1959	21.1	22.3	22.3	21.6	20.0	18.9	17.2	16.8	16.4	17.2	18.4	19.6
1960	21.8	21.9	21.9	19.2	21.0	17.8	16.8	16.4	15.6	16.8	17.8	20.1
1961	**22.9**	23.3	**23.7**	19.6	19.5	17.1	16.4	16.0	15.8	16.6	18.0	19.8
1962	21.9	22.8	22.6	21.8	19.8	18.4	16.6	16.6	16.4	16.4	18.6	19.5
1963	19.9	**24.0**	23.0	**23.3**	19.8			16.7	16.2	16.7	18.0	19.9
1964	21.4	22.4	22.2		19.5	18.1	16.5	15.8	15.6		**19.5**	20.2
1965	22.6	21.9	23.0	21.7	20.5	**19.6**	17.9	**17.5**	**17.3**	17.3	17.8	19.9
						Latitude 20°-25° *S*						
1958	20.2	**23.0***	21.3*	21.0	**20.2**	**18.8**	**17.4**	17.1	**16.2**	**16.7**	17.8	18.5
1959	20.1	21.5	21.8	20.2	18.8	17.5	16.6	15.8	15.8	16.4	18.0	19.4
1960	20.4	22.1	**24.2**	20.0	20.0	17.4	16.4	15.3	15.0	16.2	17.6	**20.7**
1961	20.8	22.0	22.5	**22.0**	18.6	17.0	16.4	15.9	15.4	16.3	17.4	18.1
1962	21.5	21.2	21.4	19.6	18.7	17.3	15.9	15.9	15.8	16.3	**18.2**	15.9
1963	19.7	22.4	23.3	20.7	18.8			16.7	**16.2**	**16.7**	17.7	19.2
1964	20.7	20.9	20.7		17.9	17.5	16.0	16.1	15.0		18.1	20.2
1965	**22.1**	22.9	22.1	21.3	19.3	18.4	**17.4**	**17.3**	16.0	16.1	17.4	19.6

* Deutsche Seewarte.

equatorial stations, namely Kwajalein (Marshall Islands 08°44'N, 167°44'E), 1942-1963, and Callao (Peru, 12°03'S, 77°09'E), 1946-1963[1]).

We recognize immediately the S.O. antithesis between western and eastern Pacific stations, including the 1950 and 1956 relaxations of the trade wind system. These relaxations caused a rather sudden zonal levelling off of the equatorial Pacific Ocean, associated with a strong superficial Equatorial Countercurrent and the accumulation of relatively warm water along the Peru coast, as in 1951 and 1957 (Fig. 7). Normally equatorial water piles up towards the Austral-Asiatic side of the Pacific Ocean and there is a relatively stronger subsurface Cromwell countercurrent.

The rather exceptional parallelism of both curves in 1953 might be related to the remarkably high southward accumulation of air in 1953 (2.2, 2.3).

TABLE 7. *Annual airpressure anomalies Juan Fernandez, Santiago, Djakarta, 1911-1964, in mb.*

	Juan Fernandez Δ_F	Santiago Δ_S	Djakarta Δ_D	Δ_F-Δ_S	Δ_F-Δ_D
1911	+1.3	0.0	+0.3	+1.3	+1.0
1912	0.0	0.0	+0.3	0.0	−0.3
1913	−0.5	+0.1	+0.4	−0.6	−0.9
1914	−1.7	−0.3	+0.9	−1.4	−2.6
1915	−0.6	−0.3	+0.2	−0.3	−0.8
1916	+0.2	+0.4	−0.8	−0.2	+1.0
1917	+0.4	+0.5	−0.6	−0.1	+1.0
1918	−0.6	−0.4	+0.6	−0.2	−1.2
1919	−1.5	−0.7	+0.5	−0.8	−2.0
1920	−0.6	−0.5	−0.1	−0.1	−0.5
1921	+0.5	+0.2	−0.2	+0.3	+0.7
1922	+0.6	−0.2	−0.4	+0.8	+1.0
1923	+0.7	−0.5	−0.1	+1.2	+0.8
1924	+1.1	+0.3	0.0	+0.8	+1.1
1925	−0.7	+0.2	+0.2	−0.9	−0.9
1926	−1.1	−0.3	+0.3	−0.8	−1.4
1927	−0.1	+0.1	0.0	−0.2	−0.1
1928	0.0	+0.1	−0.3	−0.1	+0.3
1929	+0.2	−0.6	+0.1	+0.8	+0.1
1930	−2.6	−0.7	+0.5	−1.9	−3.1
1931	−0.2	+0.3	+0.1	−0.5	−0.3
1932	−0.5	−0.2	0.0	−0.3	−0.5
1933	0.0	+0.3	−0.3	−0.3	+0.3
1934	+0.5	+0.5	−0.1	0.0	+0.6
1935	+0.1	+0.2	−0.1	−0.1	+0.2
1936	−0.3	0.0	−0.1	−0.3	−0.2
1937	+0.6	+0.4	−0.3	+0.2	+0.9
1938	+1.8	+0.7	−0.4	+1.1	+2.2
1939	0.0	−0.5	0.0	+0.5	0.0
1940	−0.8	−0.2	+0.7	−0.6	−1.5
1941	−0.6	0.0	+0.6	−0.6	−1.2
1942	+0.1	+0.3	0.0	−0.2	+0.1
1943	−0.5	+0.1	+0.1	−0.6	−0.6
1944	−1.0	0.0	+0.4	−1.0	−1.4
1945	−0.3	+0.1	+0.1	−0.4	−0.4
1946	−0.2	−0.5	+0.4	+0.3	−0.6
1947	+0.9	0.0	−0.1	+0.9	+1.0
1948	0.0	−0.1	+0.1	+0.1	−0.1
1949	+1.0	+0.2	−0.2	+0.8	+1.2
1950	+0.3	+0.2	−0.7	+0.1	+1.0
1951	−0.4	−0.8	+0.1	+0.4	−0.5
1952	+0.4	−0.3	−0.1	+0.7	+0.5
1953	−0.1	+0.4	+0.3	−0.5	−0.4
1954	+1.3	+0.4	−0.6	+0.9	+1.9
1955	+1.5	+0.3	−0.6	+1.2	+2.1
1956	0.0	−0.1	−0.8	+0.1	+0.8
1957	+1.0	−0.6	+0.1	+1.6	+0.9
1958	−0.5	−0.5	+0.2	0.0	−0.7
1959	−0.5	+0.6	−0.1	−1.1	−0.4
1960	0.0	+0.8	−0.4	−0.8	+0.4
1961	−0.5	+0.3	−0.7	−0.8	+0.2
1962	+3.6	+0.7	−0.9	+2.9	+4.5
1963	−0.5	+0.3	0.0	−0.8	−0.5
1964	+0.5	−0.4	−0.4	+0.9	+0.9

Figures 13 and 14 indicate a relaxation rise at Djakarta of the basic pressure level of 1.24 mb occurring at the close of 1962. The sum of the preceding positive annual anomalies of the pressure difference Santiago-Djakarta had then reached the value + 4.87 (Table 5). On the other hand, 1963 was not a year of exceptionally low pressure at Santiago. Although having decreased strongly, pressure at Santiago remainded above normal, while the anomaly of the pressure difference Santiago-Djakarta remained also positive in 1963 and again in 1964.

The relaxation which apparently became effective not earlier than 1964 has really led to abnormally low pressure at Santiago and high pressure at Djakarta in 1965. This situation has also led to abnormally low pressure at Easter Island and Juan Fernandez and to a deceleration of the Peru Current.

As a matter of fact southern summer 1964-1965 opened a period of abnormally high sea surface temperatures in the Peru Current (Table 6). Apparently El Niño proper 1965 did not become serious in the well known sense, however, as well, both El Niño 1877 and El Niño 1940 have not been serious. El Niño 1941, associated with very high sea surface temperatures in Puerto Chicama, became serious (MEARS, 1943).

Table 7 shows the annual airpressure anomalies 1911-1964 at Djakarta, Juan Fernandez and Santiago reduced to the normal pressure levels for this period at all three stations and moreover the anomalies of the differences Juan Fernandez-Djakarta and Juan Fernandez-Santiago.

Table 7 shows reverse signs for the pressure anomalies at Juan Fernandez and Djakarta in 41 of the 54 cases, that is in 4 out of 5 cases. This ratio is significantly greater than the 2 out of 3 cases in which reverse signs of the pressure anomalies exist between Santiago and Djakarta, as was mentioned earlier. This was to be expected. Between Santiago and Juan Fernandez we find not more than 33 cases of the same sign of the pressure anomalies and as many as 21 cases of the reverse sign. Hence the antithesis between continent and ocean must be strong in this area, the more so since the antithesis applies in particular to summertime conditions. A rather long periodic swing of the sign of the anomaly of the pressure difference Juan Fernandez-Santiago stresses the significance of this influence.

It is easy, of course, to adjust Table 4, by corrections in hundredths of millibars in such a way that Table 5 would show a strict parallelism for the two factors concerned. We should, however, not overestimate the value of such adjustment. As a matter of fact the fluctuations of the basic level shown by Fig. 13 are derived from the pressure gradients Santiago-Djakarta, the advantage being the long period covered by the observations and their unique reliability. However, because Santiago is a continental station showing effects of antithesis with the subtropical oceanic stations, which are essentially better counterparts of Djakarta, it is necessary to try to base considerations, as far as possible, on the pressure differences Juan Fernandez-Djakarta following Table 7.

[1]) Association d'Océanographie Physique, U.G.G.I., Publication Scientifique, No. 20 (1959) et No. 24 (1963).

The author distrusts the positive value of the anomaly of the pressure difference Juan Fernandez-Djakarta noted in 1911. He suggests that there have been errors of observation in Juan Fernandez in the beginning of the series at this station. Moreover, there were gaps in the data from Juan Fernandez and the complete pressure series has been built up with the aid of interpolations. Consequently it should be borne in mind that Table 7 contains some doubtful values. Nevertheless the parallelism with the series of annual anomalies of the pressure difference Santiago-Djakarta is generally good. On the other hand some outstanding differences certainly exist.

These differences strongly suggest that relaxation occurred at the end of 1924 rather than at the end of 1925. A second adjustment is the assumption of relaxation at the close of 1947. Evidence for this relaxation is found in particular in the data for Easter Island.

In addition, it could be assumed that relaxation occurs at the end of 1929 instead of at the end of 1928. Figure 13 supports such a changeover, but the occurrence of the intense winter drought in Surinam 1928-1929 provides contrary evidence. The pressure fluctuations at Juan Fernandez 1956-1957 are strongly at variance with those at both Santiago and Easter Island. Hence it is not warranted to shift the relaxation forward a year, from the end of 1956 to the end of 1957, as suggested by Table 7.

As illustrated by Figure 13 only a few points relating to the fluctuations of the almost classical Djakarta airpressure curve remain unexplained. One such point concerns the rather unexpected upward motion of pressure, or even renewal of the weakness of the general circulation 1883-1884, while sunspots were numerous, although the sunspot maximum was a weak one. The unexpected increase in pressure is probably due to the Krakatoa eruption of August 8, 1883. This eruption veiled the tropical stratosphere around the world, causing weaker meridional gradients in the troposphere and a natural slowing down of the Hadley circulation and consequently of the S.O. (Fig. 12).

The impression that the general circulation in the Indo Pacific area is affected by a relaxation oscillation as well as by the S.O. proper therefore prevails. These oscillations are not primary and secondary phenomena. The relaxation oscillation of the basic pressure level must influence the S.O. and the S.O. may cause relaxation to occur at a certain moment.

Solar activity and volcanic eruptions are external causes that steer, more or less, the course of events. How strictly will be reviewed at a later stage. Whereas high solar activity, at least solar activity associated with many sunspots, tends to increase meridional airpressure gradients and hence to accelerate the general atmospheric circulation, volcanic dust veils tend to decrease meridional airpressure gradients and hence to decelerate the general atmospheric circulation.

1.9 Characterisation by semi annual indices

It is stimulating to trace the operation of the Southern Oscillation as far backward in time as is possible with reasonable accuracy. This can be achieved only in the Indian Ocean area, and there with promising reliability from 1841 onward, the year when

3 meteorological stations in that area were established, Madras, Capetown and Hobart. We may add Djakarta, as deduced from observations made at Singapore (1°18′N, 103°53′E) 1841-1845, Buitenzorg (6°35′S, 106°47′E) 1842-1843 and 1846-1854[1]), Batavia-Weltevreden (6°11′S, 106°50′E) 1846-1847[2]) and Padang (0°56′S, 100°22′E) 1850-1852[3]). Next come Bombay 1847, Mauritius 1853, Calcutta 1855, Adelaide 1857, Batavia 1866, Darwin 1882, Durban 1884, and Perth 1885.

Following SCHOVE it seemed advisable to determine 'indices' for the halfyears April-September and October-March separately, indices denoting the deviations of the S.O. from its normal 'level' in the Indian Ocean area (SCHOVE and BERLAGE, 1965). The indices used here are sums of halfyearly average pressure deviations from normal for a number of stations. Different combinations of stations were used for the two seasons because of the difference in form of the Southeast Asia-Indian Ocean-Australia scale of the S.O. balance.

These deviations were calculated relative to 30 year normals, 1841-1870, 1871-1900, 1901-1930, 1931-1960, the only exception being Durban. In the Durban series of observations there is a break in 1911. The change of site there evidently caused a discontinuity in the pressure values, although they all were reduced to sea-level. The Durban anomalies assumed here were those taken relative to averages through 1884-1910, 1912-1930, 1931-1960.

In order to complete the pressure deviations of as many stations as possible back to 1841 in a reasonably reliable way, the Bombay anomalies were simply equalized to the Madras anomalies 1841-1846, whereas the Djakarta anomalies 1856-1865 were equalized to the mean anomalies of Bombay and Madras in the same years.

Table 8 reveals marked deviations in the percentages for Calcutta, Durban, and Capetown in April-September and for Mauritius, Durban and Hobart in October-March. Evidently these values should be deleted from the Table, much in accordance with Figures 3 and 4. It was finally decided that valid S.O. Indian Ocean indices, homogeneous and of equal weight could be computed for the two half-yearly intervals by averaging the pressure anomalies in the following manner.

April-September

1841-1854 Bombay, Madras, Djakarta, Hobart.
1855-1884 Bombay, Madras, Djakarta, Mauritius, Adelaide.
1885-1960 Bombay, Madras, Djakarta, Darwin, Mauritius, Perth.

October-March

1841-1854 Bombay, Madras, Djakarta, 2 times Capetown.
1855-1884 Bombay, Madras, Djakarta, Calcutta, Adelaide, Capetown.
1885-1960 Bombay, Madras, Djakarta, Calcutta, Darwin, Perth, Capetown.

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1) P. L. ONNEN, Meteorologische Waarnemingen te Buitenzorg op het eiland Java.
2) Natuurkundig Tijdschrift v. Ned. Indië Vol. 1, p. 73 and p. 279, 1851.
3) Meteorologische Waarnemingen in Nederland en zijne bezittingen, Kon. Ned. Meteor. Inst., Jaarboek 9, 273-322, 1857.

TABLE 8. *Percentages of the same and of opposite sign of the pressure anomalies at Djakarta and ten other stations.*

	April-September		October-March			April-September		October-March	
Calcutta	60	40	82	18	Durban	55	45	62	38
Bombay	75	25	85	15	Capetown	56	44	71	29
Madras	76	24	85	15	Perth	68	32	83	17
Darwin	83	17	83	17	Adelaide	68	32	78	22
Mauritius	64	36	58	42	Hobart	66	54	54	46

The results are summarized in Table 9 and Table 10.

From the tables of annual means and deviations of the annual mean from their average values we can obtain an impression of what would be a more logical kind of Southern Oscillation index. The average pressure at Juan Fernandez 1911-1961 is 1019.0 mb, the one at Djakarta 1866-1940 is 1009.8 mb. The difference between the two values is 9.2 mb. The highest annual mean at Juan Fernandez was reached in 1962, its deviation from normal being +3.6 mb. The lowest annual mean at Djakarta was equally reached in 1962, its deviation from normal being —1.0 mb. That makes a difference of + 4.6 mb.

The lowest annual mean at Juan Fernandez was reached in 1930, its deviation from normal being —2.6 mb. The highest annual mean at Djakarta was reached in 1877, its deviation from normal being +1.4 mb. That makes a difference of —4.0 mb. Hence we may expect indices to run from

$$9.2 + 4.6 = 13.8 \quad \text{to} \quad 9.2 - 4.0 = 5.2$$

These two values are in the proportion 4.6 to 1.7, values very near the maximum and minimum length of the S.O. period in years. If 16.5 is added to the provisional indices compiled in Tables 9 and 10 the highest index, the one for April-September 1877, amounts to 25.9, and the lowest index, the one for October-March 1889-1890, to 8.4. Dividing by 6 we obtain 4.3 and 1.4.

The table of indices shows a maximum in 1914 and again in 1918-1919. This makes one wavelength of 4.5 years, whereas in the thirties we have maxima in 1930, 1931-1932, 1933, 1934, 1935-1936, 1937 thus yielding 5 S.O. cycles in 7 years, or an average wavelength of 1.4 years.

In this way we can give the S.O. index a time dimension independent of the area, whether Pacific or Indian Ocean. The average period of the S.O. would then be 16.5 : 6 = 2.75 years, or 33 months, while in fact, following the lag correlations between pressure and temperature in Djakarta, we might have expected S.O. periods of 18 months as well as of 48 months, that is from very short ones hardly emerging from the 'noise' (DE BOER 1957) to very long ones of outstanding amplitude, after relaxation.

TABLE 9. *Southern Oscillation Indices April-September*

	1	2	3	4	5	6	7	8	9	10	
	Bombay	Madras	Djakarta	Calcutta	Darwin	Mauritius	Capetown	Perth	Adelaide	Hobart	Index
Average	**6.3**	**5.7**	**9.9**				**19.2**	**2.7**	**18.8**	**13.6**	
1841	(+0.1)	+0.1	(+0.4)				+0.6		(+1.0)	+1.9	+2.5
42	(−0.7)	−0.7	−0.7				−0.3		(−2.0)	−4.0	−6.1
43	(+0.1)	+0.1	0				+0.5		(−0.4)	−0.7	−0.5
44	(−0.4)	−0.4	−0.3				+0.5		(−0.6)	−1.1	−2.2
45	(+0.2)	+0.2	+0.1				+1.0		0	0	+0.5
46	(+0.5)	+0.5	+0.4				−0.3		(+1.0)	+1.9	+3.3
47	−0.5	−0.3	+0.1				−0.2		(−1.5)	−2.9	−3.6
48	0	−0.3	−1.3				−1.0		(−0.3)	−0.6	−2.2
49	−0.6	−1.0	−0.8				+0.1		(−0.1)	−0.2	−2.6
1850	+0.3	0	+0.5				−1.2		(+1.9)	+3.8	+4.6
51	−0.5	−0.3	−0.3				−0.3		(−1.8)	−3.6	−4.7
52	−0.1	+0.3	+0.2				−0.1		(+0.5)	+0.9	+1.3
53	+0.6	+0.2	+0.6			−0.5	+0.9		(−1.6)	−3.1	−1.7
54	−0.3	−0.2	−0.4			−0.4	+0.9		(+0.7)	+1.4	+0.5
55	+0.7	+0.6	+0.6	−0.1		+0.4	+0.8		(+0.3)	+0.6	+2.5
56	−0.3	0	(−1.1)	−0.2		−0.8	+0.6		(−3.1)	−6.2	−7.8
57	−0.1	+0.3	(+0.4)	−0.7		0	+0.3		+1.1	+1.8	+2.0
58	0	+0.3	(−0.2)	−0.4		−0.4	0		−0.8	+0.4	−1.1
59	+0.3	+0.8	(+0.8)	+0.8		+0.9	−0.4		+1.4	+0.5	+4.2
1860	0	−0.4	(+0.1)	−0.2		0	−0.6		+0.7	+3.8	+0.4
61	−0.4	−0.5	(−0.8)	−0.5		+0.2	−0.6		−1.4	+1.0	−3.1
62	−0.5	−0.1	(−0.6)	−0.1		−0.6	−2.1		−1.2	−0.2	−2.4
63	−0.8	−0.6	(−0.6)	−1.2		−0.1	+0.4		−0.5	+0.4	−2.5
64	+1.0	+1.2	(+0.7)	+0.4		+1.1	0		−0.2	+1.5	+2.7
65	−0.1	+0.6	(+0.5)	+0.6		+0.9	+0.2		+0.9	0	+1.9
66	+0.6	−0.1	+0.3	0		+0.4	+0.5		+0.7	+0.7	+1.9
67	0	−0.2	−0.1	+0.4		−0.1	+0.2		−1.0	+0.4	−1.3
68	+1.3	+0.5	+0.9	+1.0		+0.1	+0.2		+1.2	+1.0	+4.0
69	+0.1	−0.7	+0.4	+0.3		+1.0	+0.4		+2.6	+1.0	+3.4
1870	0	−0.8	−0.5	+0.1		+0.3	+0.1		−2.0	−0.5	−3.0

TABLE 9. *Southern Oscillation Indices April-September.*

	1 Bombay	2 Madras	3 Djakarta	4 Calcutta	5 Darwin	6 Mauritius	7 Capetown	8 Perth	9 Adelaide	10 Hobart	Index
Average	**6.6**	**5.6**	**9.9**	**2.8**	**11.4**	**18.3**	**19.3**	**18.6**	**19.6**	**13.8**	
1871	0	+0.1	−0.1	−0.1		+0.5	−0.4		−1.7	−1.7	−1.2
72	−0.6	−0.2	−0.6	+0.4		−1.2	−0.7		−1.2	−1.4	−3.8
73	−0.2	+0.1	−0.4	−0.4		+0.1	−1.0		−0.6	−1.0	−1.0
74	−0.5	−0.1	−0.4	+0.4		−0.2	+1.1		−1.9	−0.8	−3.1
75	−0.3	−0.1	−0.1	−0.2		0	+0.3		−1.3	−2.4	−1.8
76	−0.1	−0.4	−0.1	−0.2		+1.6	+0.7		+1.5	−1.2	+2.5
77	+1.4	+1.9	+1.5	+1.5		+1.3	−0.4		+3.3	+1.8	+9.4
78	−0.6	+0.9	−0.1	+1.5		−1.1	−0.1		−1.3	−4.0	−2.2
79	−0.4	−0.3	−0.6	−0.1		+0.3	−0.2		0	+1.1	−1.0
1880	+0.3	−0.3	0	0		+0.2	+0.9		−0.1	−1.3	+0.1
81	+0.4	+0.1	+0.2	−0.2		0	+1.4		+8.9	+1.8	+1.6
82	−0.3	−0.3	−0.4	−0.2	−0.7	+0.1	+0.7		−1.2	−3.9	−2.1
83	−0.2	−0.3	+0.2	−0.8	−0.8	−0.3	−0.4		−0.3	−0.6	−0.9
84	+0.2	+0.6	+0.3	−0.1	0	−0.7	+0.8		+0.6	+0.5	+1.0
85	+0.3	+1.0	+0.4	+0.4	+0.8	−0.2	−0.7	−0.2	+1.7	+1.5	+2.1
86	−0.2	0	−0.6	+0.3	−1.2	−0.2	−0.8	+0.7	0	+1.5	−1.5
87	+0.4	0	−0.1	−0.4	−0.4	+0.3	+0.3	+0.2	−0.1	+0.6	+0.4
88	+0.5	+0.5	+0.3	−0.5	+0.3	+0.2	−0.9	+0.7	+1.6	+1.2	+2.5
89	−0.4	−0.2	−0.2	+0.4	−0.6	+0.1	+0.2	−1.7	−0.4	+1.0	−3.0
1890	−0.2	−0.1	−0.1	+0.1	−1.1	−0.5	−0.2	−1.4	−1.3	+0.4	−3.4
91	+0.6	+0.7	+0.7	−0.1	+1.0	+0.7	−0.2	+1.7	+2.4	+4.1	+5.4
92	−1.1	−0.7	−0.2	−0.1	−0.4	−0.2	−0.4	+0.1	−0.4	−0.2	−2,5
93	−0.2	+0.1	−0.4	+0.1	−0.6	+0.2	−0.5	−1.8	−2.6	−0.9	−2.7
94	−0.6	−0.6	0	−0.5	−0.1	−0.7	+0.1	+0.6	−0.2	−1.0	−1.4
95	+0.2	+0.1	0	+0.5	0	−0.3	−0.3	+0.3	−0.8	−1.0	+0.3
96	0	+0.3	+0.5	−0.7	+1.0	+0.2	−0.1	+0.7	0	0	+2.7
97	−0.5	+0.1	+0.2	+0.7	+0.3	+0.1	+0.8	+0.5	+0.5	+0.5	+0.7
98	−0.5	−0.2	−0.3	−0.3	−0.2	−1.1	−0.1	−0.3	+0.4	+1.2	−2.6
99	+0.8	+0.3	+0.4	+0.2	+1.0	+0.5	−0.2	+0.3	+1.5	+4.4	+3.3
1900	+0.3	+0.4	+0.2	+0.7	+0.4	+0.1	−0.7	−1.1	−1.4	−0.9	+0.3

TABLE 9. *Southern Oscillation Indices April-September.*

	1	2	3	4	5	6	7	8	9	10	
	Bombay	Madras	Djakarta	Calcutta	Darwin	Mauritius	Capetown	Perth	Adelaide	Hobart	Index
Average	**6.3**	**5.4**	**9.9**	**2.7**	**11.7**	**18.0**	**19.2**	**18.3**	**19.3**	**13.9**	
1901	+0.5	+0.3	0	0	+0.5	+0.3	+0.3	+0.8	+0.9	0	+2.4
02	+0.1	+0.2	+0.5	+0.5	+1.3	−0.8	−1.3	+1.8	+2.6	+4.0	+3.1
03	−0.3	0	−0.3	+0.9	−0.2	−0.3	+0.2	−0.2	−0.9	−0.3	−1.3
04	+0.3	+0.2	+0.1	−0.7	+0.1	+1.0	+0.2	+0.3	+1.2	+0.7	+2.0
05	+0.9	+0.6	+0.6	+0.6	+0.7	+0.1	−0.5	+0.2	+0.2	−1.1	+3.1
06	0	0	−0.3	−0.1	−0.2	−0.5	+0.5	−0.6	−0.8	−2.8	−1.4
07	+0.3	+0.3	+0.1	−0.2	+0.1	−0.2	+0.5	−0.6	−0.9	−2.0	0
08	+0.1	−0.1	−0.1	0	0	+0.3	+1.0	+1.4	+1.4	+1.3	+1.6
09	−0.1	0	−0.4	+0.6	−0.4	−0.3	−0.3	−0.7	−1.3	−0.9	−1.9
1910	−0.4	−0.5	−0.8	+0.3	−0.8	0	−0.7	−1.9	−0.7	−0.6	−4.4
11	+0.7	+0.1	+0.2	−0.5	+0.7	+0.5	+1.4	+1.1	−0.1	+0.7	+3.3
12	0	+0.2	+0.2	+0.7	+0.6	−0.2	+0.3	+0.1	+0.1	+1.0	+0.9
13	0	−0.1	+0.2	−0.1	+1.0	+0.7	−0.9	+1.0	+2.0	+2.0	+2.8
14	−0.1	+0.5	+0.6	+0.8	+1.4	+0.4	−0.2	+3.0	+3.7	+2.5	+5.8
15	+0.1	0	−0.1	+0.5	+0.1	−0.8	−0.5	−1.6	−3.0	−3.5	−1.8
16	−1.1	−0.4	−0.6	0	−0.8	−1.2	−1.0	−0.3	−1.5	−0.4	−4.4
17	−0.5	−0.3	−0.4	+0.3	−1.1	−1.1	−0.4	−2.2	−3.5	−4.7	−4.9
18	+0.6	+0.4	+0.7	−0.2	+0.8	+0.8	+0.1	−0.4	+1.0	+1.5	+2.9
19	0	+0.3	+0.2	+0.4	+0.5	+0.4	+0.5	+1.4	+2.1	+1.6	+2.8
1920	+0.1	+0.2	−0.2	−0.4	−0.9	+0.6	−0.9	−1.5	−1.7	−1.1	−1.7
21	−0.5	−0.5	−0.1	−0.7	−0.3	−0.3	−0.1	−0.3	0	−0.3	−2.0
22	−0.4	−0.4	−0.5	−0.7	−0.1	+1.1	−0.1	+0.5	−0.7	+1.5	+0.2
23	−0.5	−0.6	−0.2	−1.1	+0.3	+0.1	−0.6	−1.4	−3.2	−3.3	−2.3
24	−0.8	−0.4	−0.1	−0.2	+0.1	−0.3	+0.4	+0.6	+1.5	+0.5	−0.9
25	0	+0.6	+0.1	+0.1	+0.1	+0.4	−0.4	+1.7	+1.3	+2.8	+2.9
26	−0.1	+0.3	+0.2	+0.3	+0.3	−0.6	+1.0	−1.1	−1.2	−0.5	−1.0
27	−0.1	−0.1	−0.1	0	0	+0.8	+0.4	−0.4	+0.3	+0.4	+0.1
28	0	−0.5	−0.3	−0.1	+0.3	+0.5	+1.0	−1.0	−0.9	−1.8	−1.0
29	−0.1	−0.2	+0.4	−0.1	+0.8	+0.1	+0.1	+0.7	+0.8	−0.1	+1.7
1930	+0.4	+0.3	+0.3	+0.3	+1.0	+0.1	+1.0	0	+1.5	+2.3	+2.1

TABLE 9. *Southern Oscillation Indices April-September.*

	1 Bombay	2 Madras	3 Djakarta	4 Calcutta	5 Darwin	6 Muaritius	7 Capetown	8 Perth	9 Adelaide	10 Hobart	Index
	6.0	**5.3**	**9.8**	**2.5**	**11.9**	**18.6**	**19.5**	**18.2**	**19.7**	**14.3**	
1931	0	−0.3	+0.1	0	0	−0.2	+0.6	0	−1.1	−2.2	−0.4
32	0	0	−0.1	−0.1	+0.3	−0.3	−0.3	−0.2	−0.7	+1.8	−0.3
33	+0.1	+0.6	0	+1.1	+0.1	−0.4	−0.5	+0.4	+0.3	+1.4	+0.8
34	+0.3	0	+0.2	0	−0.1	+0.7	−0.4	+0.6	+0.4	+3.1	+1.7
35	+0.4	−0.6	0	−0.1	+0.1	−0.9	+0.2	+0.5	−1.3	−0.3	−0.5
36	+0.1	−0.4	−0.1	+0.1	−0.4	+0.1	+0.5	+0.9	+0.3	−0.3	+0.2
37	+0.1	−0.4	0	−0.1	+0.2	−0.7	−0.1	+0.8	+0.4	+2.0	0
38	−0.6	−0.8	−0.5	−0.1	−0.9	−0.5	−0.5	−0.1	+0.4	+1.4	−3.4
39	+0.5	−0.3	−0.2	−0.7	0	−0.2	0	−0.7	−1.7	−2.3	−0.9
1940	+0.8	+0.6	+0.8	+0.9	+1.5	+0.3	+0.2	+2.0	+3.1	+2.8	+6.0
41	+0.7	+0.4	+0.7	0	+1.3	+0.3	−0.6	+0.3	+1.4	+1.6	+3.7
42	−0.2	0	0	+0.2	−0,4	+0.6	+0.9	−2.1	−2.5	−2.9	−2.1
43	+0.3	+0.4	+0.2	0	−0.4	+0.9	+0.2	−0.4	−1.6	−2.0	+1.0
44	+0.4	+0.5	+0.7	+0.7	+0.7	−0.3	+0.3	+0.9	+2.1	+1.8	+2.9
45	+0.2	−0.1	+0.4	+0.4	+0.1	−1.2	−0.1	−1.5	+0.2	+1.1	−2.1
46	−0.3	+0.4	+0.8	0	+0.8	+0.2	+0.3	−0.7	−0.6	−3.0	+1.2
47	−0.6	−0.2	+0.1	−0.2	+0.1	+0.3	+0.7	−0.7	−0.2	−1.6	−1.0
48	−0.7	−0.5	0	−0.6	−0.2	−0.2	+0.2	+0.6	+0.4	−1.2	−1.0
49	−0.6	−0.1	+0.1	+0.2	+0.4	−0.5	+0.1	+0.6	+2.5	+3.0	−0.1
1950	−0.5	−0.6	−0.5	−0.8	−1.1	−0.5	−0.5	−0.6	+0.7	+2.9	−3.8
51	+0.6	+0.6	+0 4	−0 2	+0 2	+0.5	−0.1	+0.8	−3.1	−1.4	+3.1
52	+0.4	+0.3	+0.2	+0.1	+0.1	+1.1	−0.4	+0.1	−1.8	−2.0	+2.1
53	+0.4	+0.3	+0.4	+0.2	+0.6	+0.1	−0.5	+0.3	−1.0	−2.1	+2.1
54	−1.1	−0.9	−0.7	−0.7	−0.6	−0.5	−0.3	+0.7	+1.0	+1.6	−3.1
55	−0.5	−0.5	−0.6	+0.4	−1.0	−0.5	−0.7	−1.7	+0.4	−0.1	−4.8
56	−0.8	−0.6	−0.9	−0.8	−1.1	+0.7	−0.2	−1.1	−2.9	−4.3	−3.8
57	+0.7	+0.8	+0.1	+0.7	+0.7	+0.8	−0.7	−0.3	+1.4	+0.6	+2.8
58	−0.1	+0.2	−0.2	0	−0.5	0	+0.8	−0.9	+0.2	−1.2	−1.5
59	−0.8	−0.1	−0.2	−0.8	0	0	−0.5	+0.9	+4.3	+4.5	−0.2
1960	−0.3	−0.2	−0.6	−0.4	−0.4	0	+0.4	0	−0.6	−4.2	−1.5

TABLE 10. *Southern Oscillation Indices October-March.*

	1 Bombay	2 Madras	3 Djakarta	4 Calcutta	5 Darwin	6 Mauritius	7 Capetown	8 Perth	9 Adelaide	10 Hobart	Index
Average	**12.7**	**12.0**	**9.8**	**13.9**		**13.8**	**14.7**		**14.2**	**11.0**	
1841/41											
41/42	(−0.6)	−0.6	−0.3				+0.2		(+0.8)	+1.7	−1.1
42/43	(+0.2)	+0.2	0				+0.3		(−0.2)	−0.3	+1.0
43/44	(+0.3)	+0.3	0				−0.5		(+0.1)	−0.6	−0.4
44/45	(+0.2	+0.2	+0.2				+0.3		(+0.7)	+1.4	+1.2
45/46	(+0.9)	+0.9	+0.6				+0.7		(−0.9)	−1.8	+3.8
46/47	(−0.4)	−0.4	−0.4				+0.3		(+0.5)	+1.1	−0.6
47/48	−0.4	−0.3	−0.7				−0.4		(+0.4)	+0.8	−2.2
48/49	+0.1	−0.7	−0.8				0		(−1.9)	−3.8	−1.4
1849/50	−0.2	−0.6	−0.7				−0.6		(−0.3)	−0.6	−2.7
50/51	−0.2	−0.1	−0.4				+0.1		(−0.2)	−0.2	−0.5
51/52	−0.5	−0.6	+0.3				−0.4		(−0.4)	−0.7	−1.6
52/53	0	−0.1	+0.6				+0.6		(−0.6	−1.1	+1.7
53/54	+0.3	+0.3	+0.6			−0.4	+0.2		(+0.4)	+0.8	+1.6
54/55	0	+0.3	+0.5			−0.5	+0.4		(+0.2)	+0.4	+1 6
55/56	+0.5	+0.9	(+0.7)	+0.4		+0.5	+0.8		(+0.7)	+1.4	+4.0
56/57	−0.4	−0.3	(−0.2)	−0.8		−0.5	+0.2		(−1.2)	−2.3	−2.7
57/58	+0.6	+0.6	(+0.7)	+0.2		−0.1	+1.0		+0.6	+1.8	+3.7
58/59	+0.4	+0.6	(+0.4)	+0.5		+1.3	+0.2		+0.5	+2.2	+2.6
1859/60	−0.3	−0.3	(−0.3)	−0.9		0	−0.3		−0.1	+1.7	−1.9
60/61	−0.3	−0.3	(−0.2)	−0.9		+0.1	−0.1		−0.5	+2.2	−2.3
61/62	−0.3	−0.4	(−0.3)	−0.6		−0.3	−0.3		−0.9	−0.7	−2.8
62/63	−1.0	−0.9	(−0.9)	−1.1		−1.6	−0.8		0	+1.4	−4.7
63/64	+0.3	+0.1	(+0.1)	−0.4		−0.1	−0.2		−1.1	+0.1	−1.2
64/65	+0.6	+1.4	(+0.7)	+1.3		+0.1	0		+1.2	+1.3	+5.2
65/66	+0.2	+0.1	(0)	+0.2		−0.2	−0.3		−1.1	+0.5	−1.3
66/67	+0.6	+0.5	+0.4	+0.8		+1.2	+0.1		+0.4	+0.1	+2.8
67/68	+0.9	+0.6	+0.3	+1.1		−0.8	+0.4		−0.1	−3.4	+3.2
68/69	+0.8	+0.3	+1.0	+0.6		+0.6	+0.6		+0.9	−0.9	+4.2
1869/70	−0.7	−1.0	−0.8	−0.7		+0.2	−1.1		−1.4	−0.8	−5.7

TABLE 10. *Southern Oscillation Indices October-March.*

	1 Bombay	2 Madras	3 Djakarta	4 Calcutta	5 Darwin	6 Mauritius	7 Capetown	8 Perth	9 Adelaide	10 Hobart	Index
Average	**12.8**	**11.8**	**9.8**	**13.6**	**7.2**	**13.6**	**14.6**	**14.6**	**15.0**	**10.9**	
1870/71	−0.5	−0.3	−0.5	−0.4		0	−0.5		−0.8	+1.4	−3.0
71/72	−0.4	0	−0.4	0		+0.4	0		−0.9	+1.2	−1.7
72/73	−0.7	−0.9	−1.0	−0.6		−1.4	−1.0		−0.4	+2.1	−4.6
73/74	+0.4	+0.2	+0.2	+0.5		0	−0.1		+0.4	+1.3	+1.6
74/75	−0.2	−0.4	−0.5	−0.3		+0.6	−0.5		−0.3	−1.0	−2.2
75/76	+0.1	0	−0.6	−0.4		−1.3	+0.1		−1.4	−2.3	−2.2
76/77	+0.8	+1.1	+1.0	+1.6		+0.3	+1.7		+0.1	−0.8	+6.3
77/78	+0.6	+1.6	+1.2	+1.4		+0.8	+0.2		+2.3	+0.2	+7.3
78/79	−1.1	−1.0	−1.0	−1.1		−0.1	+0.1		−0.4	−4.1	−4.5
1879/80	−0.5	−0.5	−0.6	−0.8		+0.6	−0.3		−1.5	−2.3	−4.2
80/81	+0.9	+1.1	+0.9	+1.3		+1.3	+0.4		+1.0	+1.2	+5.6
81/82	−0.1	−0.1	−0.1	−0.5		−0.4	+0.3		−0.2	0	−0.7
82/83	−0.4	−0.7	−0.2	−0.4	−0.8	+0.2	−0.1		+0.1	−0.7	−1.7
83/84	+0.6	+0.8	+0.5	+0.4	−0.4	−0.1	+0.3		0	−0.6	+2.6
84/85	+0.6	+1.0	+0.6	+1.2	+0.1	−0.2	+0.3		−0.1	−1.6	+3.6
85/86	+0.3	+0.3	+0.5	+0.5	+0.7	+0.1	+0.2	+0.5	+2.2	+3.0	+2.9
86/87	−0.4	−1.0	−0.6	−0.6	−1.5	+0.9	+0.6	+1.4	−0.7	−0.1	−2.1
87/88	+0.6	+0.2	+0.5	+0.6	+0.3	+0.6	+0.8	+0.9	+0.9	+1.1	+3.9
88/89	+0.9	+0.9	+1.1	+1.2	+1.6	+0.9	+0.7	+1.2	+1.5	+2.0	+7.6
1889/90	−0.8	−1.5	−0.8	−1.4	−1.9	+0.6	−0.5	−1.2	−0.9	+2.1	−8.1
90/91	+0.3	+0.2	+0.6	+0.8	−0.2	+0.2	0	−0.6	−0.3	−2.6	+1.3
91/92	−0.5	−0.5	−0.3	−0.3	+0.4	−0.4	0	0	+0.2	+0.8	−1.2
92/93	−0.4	−0.6	−0.4	+0.2	−0.7	−0.3	−0.5	−0.6	−0.6	+1.3	−3.0
93/94	−0.2	−0.1	−0.2	+0.2	−1.0	−0.4	−0.4	−0.4	−0.7	+1.8	−2.1
94/95	−0.2	+0.1	0	+0.2	0	−0.9	−0.6	+0.2	+1.0	+2 5	−0.3
95/96	+0.1	+0.3	+0.2	−0.2	+0.1	−0.2	−0.2	−0.4	+0.2	−1.0	−0.1
96/97	−0.1	+0.1	+0.5	+0.1	+1.4	+0.1	+0.3	+0.4	+1.3	+1.3	+2.7
97/98	−0.4	−0.5	−0.5	−0.6	−1.0	−0.5	0	−0.9	−1.1	−1.7	−3.9
98/99	−0.7	−0.5	−0.5	−0.5	−0.2	−0.9	−0.2	−0.9	−1.9	−3.1	−3.5
1899/00	+0.4	+1.2	+0.8	+0.5	+2.1	+0.6	+0.3	+0.7	+0.4	−0.3	+6.0

TABLE 10. *Southern Oscillation Indices October-March.*

	1 Bombay	2 Madras	3 Djakarta	4 Calcutta	5 Darwin	6 Mauritius	7 Capetown	8 Perth	9 Adelaide	10 Hobart	Index
Average	**12.5**	**11.6**	**9.8**	**13.8**	**7.5**	**13.5**	**14.9**	**14.5**	**14.8**	**11.0**	
1900/01	+0.6	+0.6	+0.1	+1.0	+0.5	+1.2	−0.5	+0.1	+0.4	−0.8	+2.4
01/02	+0.2	+0.8	+0.4	0	+0.7	+0.7	−0.1	+0.3	+0.2	−0.5	+2.3
02/03	+0.9	+0.8	+0.7	+1.0	+1.4	−1.5	+1.1	+1.6	0	−0.8	+7.5
03/04	−0.4	−0.4	−0.6	−0.5	−0.6	+0.2	−0.3	−1.0	−0.6	+1.8	−3.8
04/05	+1.0	+0.9	+0.8	+1.0	+1.4	−0.1	+0.8	+1.5	+0.6	−1.3	+7.4
05/06	+0.5	+0.4	+0.4	+0.3	+1.0	−0.2	+0.4	+0.6	+0.3	+0.6	+3.6
06/07	+0.3	0	−0.1	+0.3	−0.5	+1.3	−0.3	−0.7	0	−0.4	−1.0
07/08	−0.2	−0.1	−0.1	−0.1	0	−1.5	+0.6	+0.9	−0.7	−0.9	+1.0
08/09	−0.2	−0.2	−0.6	−0.5	−0.2	−1.1	+0.1	−0.1	+0.2	+0.9	−1.7
1909/10	−0.7	−0.8	−0.9	−1.2	−0.8	+0.1	−0.4	+0.2	+0.3	+0.2	−4.6
10/11	+0.1	+0.1	−0.1	−0.4	−0.6	−0.4	+0.1	+0.5	−0.6	+0.1	−0.3
11/12	+0.3	+0.5	+0.5	+0.2	+1.4	−0.2	0	+0.3	+0.2	−0.3	+3.2
12/13	+0.2	+0.2	−0.1	+0.2	+0.4	+0.1	−0.2	+0.2	−0.1	−1.3	+0.9
13/14	+0.9	+1.2	+1.2	+1.1	+1.5	+0.4	+0.6	+0.6	+0.2	−0.6	+7.1
14/15	+0.6	+0.7	+0.7	+1.0	+2.3	+1.2	+0.1	+0.2	+1.9	+2.8	+5.6
15/16	−0.5	−0.6	−0.4	−1.4	−0.6	−0.4	0	−0.9	−0.4	−1.6	−4.4
16/17	−1.0	−0.8	−1.2	−0.8	−0.9	−0.4	−1.0	−1.8	−1.9	−0.6	−7.5
17/18	−0.8	−0.9	−0.1	−1.1	−0.6	+0.4	−0.2	−0.8	−0.4	+2.1	−4.5
18/19	+0.4	+0.5	+0.8	+0.8	+1.2	+0.1	+0.4	+0.4	+0.7	−0.1	+4.5
1919/20	−1.1	−0.5	+0.2	−0.4	+0.7	−0.3	+0.4	+0.7	+1.6	+2.5	0
20/21	−0.9	−0.7	−0.8	−1.1	−0.6	+0.2	−0.6	−0.5	+1.2	+2.6	−5.2
21/22	0	+0.4	−0.2	+0.1	−0.5	−1.4	−0.1	−1.1	−0.8	+0.1	−1.4
22/23	0	+0.1	−0.4	+0.2	−0.4	+0.6	+0.2	−0.5	−1.0	−2.8	−0.8
23/24	−0.3	+0.2	0	+0.1	+0.6	−0.1	−0.3	+1.0	−0.2	−1.6	+1.3
24/25	−0.4	−0.7	−0.6	−0.9	−1.3	+0.5	−0.4	−1.3	−1.5	−1.0	−5.6
25/26	+0.5	+1.0	+1.0	+1.3	+1.5	+0.7	+0.8	+1.3	+1.1	+0.2	+7.4
26/27	−0.9	−0.7	−0.6	−0.9	−0.2	−1.5	−0.5	−0.8	−0.6	−1.8	−4.6
27/28	+0.1	+0.5	0	+0.3	+0.5	+0.6	+0.1	+0.4	+0.6	+3.1	+1.9
28/29	−0.4	−0.7	−0.6	−0.1	−1.0	+0.9	+0.3	−0.1	−1.3	−1.9	−2.6
1929/30	−0.2	−0.4	+0.1	−0.2	−0.2	−0.6	+0.2	0	+0.7	+0.9	−0.7

TABLE 10. *Southern Oscillation Indices October-March.*

	1 Bombay	2 Madras	3 Djakarta	4 Calcutta	5 Darwin	6 Mauritius	7 Capetown	8 Perth	9 Adelaide	10 Hobart	Index
Average	**12.1**	**11.4**	**9.7**	**13.5**	**7.7**	**13.9**	**14.8**	**14.3**	**15.1**	**11.3**	
1930/31	+0.6	+0.4	+0.7	+1.0	+1.1	+0.1	+0.1	+1.4	+1.0	+0.3	+5.3
31/32	+0.3	+0.4	+0.4	+0.5	+0.1	−0.6	+0.3	+1.0	+0.5	−0.3	+3.0
32/33	−0.3	−0.3	−0.4	−0.2	−0.4	0	−0.2	−0.5	−0.7	−1.9	−2.3
33/34	−0.6	−1.0	−0.7	−0.8	−0.4	−0.1	−0.7	−0.6	+0.3	+3.1	−4.8
34/35	+0.7	+0.2	+0.1	+0.2	−0.2	−0.6	−0.1	+0.2	−0.4	+0.1	+1.1
35/36	+0.3	−0.2	+0.1	−0.1	+0.2	−0.3	+0.5	+0.6	0	+2.1	+1.4
36/37	+0.1	−0.2	−0.3	+0.1	−0.2	−1.2	−0.3	−0.1	−0.2	0	−0.9
37/38	−0.4	−0.9	−0.2	−0.6	−0.4	−0.9	−0.4	+0.2	−0.5	+1.0	−2.7
38/39	0	0	−0.3	−0.3	−0.8	+0.5	−0.2	−0.8	−0.6	+0.7	−2.4
1939/40	+0.8	+0.4	+0.7	+0.7	+0.7	+0.3	0	+0.7	+0.5	−2.2	+4.0
40/41	+0.6	+0.7	+1.1	+0.9	+2.1	−0.4	+0.7	+1.8	+1.6	+0.9	+7.9
41/42	−0.2	−0.1	+0.5	+0.2	+1.1	+0.4	+0.8	+0.8	+1.0	+0.2	+3.1
42/43	−0.5	−0.4	−0.1	−0.5	−0.7	0	+0.2	−1.4	−0.5	+0.3	−3.4
43/44	+0.5	+0.2	+0.5	+0.8	0	+0.9	0	+0.4	+0.4	+1.1	+2.4
44/45	−0.9	−1.2	−0.7	−1.1	−0.3	−0.9	−0.2	−0.6	−0.7	−3.0	−5.0
45/46	+0.1	+0.2	+0.5	0	+0.2	−0.3	+0.5	+0.9	−0.2	−1.4	+2.4
46/47	−1.3	−0.8	−0.4	−0.4	+0.4	−1.0	−0.1	−0.4	−0.6	+0.3	−3.0
47/48	+0.1	+0.4	+0.2	+0.3	0	+0.8	−0.1	+0.3	+0.2	+0.3	+1.2
48/49	+0.1	+0.4	+0.1	+0.1	−0.2	−0.4	+0.1	+0.2	−0.6	−2.0	+0.8
1949/50	−0.2	−0.1	−0.7	−0.7	−1.3	−0.2	−0.6	−0.8	−1.5	−1.1	−4.4
50/51	−0.4	−0.3	−0.6	−0.6	−1.4	−0.2	+0.6	−0.6	−2.2	+1.4	−3.3
51/52	−0.5	−0.2	−0.2	−0.6	+0.9	+1.1	−0.1	+0.5	−0.5	−1.2	−0.2
52/53	+0.3	+0.3	+0.3	−0.1	+0.3	+1.8	−0.2	+0.4	−0.7	+0.7	+1.3
53/54	+0.1	+0.2	−0.2	−0.1	+0.2	0	+0.4	+0.6	+0.1	−0.6	+1.2
54/55	−0.1	0	−0.3	−0.1	−0.3	−0.4	−0.5	−0.6	+0.6	+2.0	−1.9
55/56	−0.9	−0.5	−0.6	−0.9	−1.0	−0.1	−0.5	−1.5	−0.5	−0.9	−5.9
56/57	+0.2	+0.4	−0.1	+0.6	−0.5	+0.1	−0.4	−0.8	+0.3	−3.0	−0.6
57/58	+0.7	+1.1	+0.7	+0.5	+1.1	+0.2	+0.7	+1.1	+1.9	−2.1	+5.9
58/59	+0.2	+0.3	+0.5	−0.1	+0.2	+0.4	0	−0.5	+0.6	+2.0	+0.6
1959/60	−0.3	+0.2	−0.3	−0.2	−0.4	−0.4	+0.1	−0.8	+0.3	+2.1	−1.7

These data are very consistent and support previous conclusions. In addition the tables of indices are useful in many ways. They show, for instance, that we should not overestimate the low value of the Indian Ocean pressure level in the years 1931-1937.

When these low values are investigated it is seen that Bombay and Perth both showed relatively high pressure throughout these years, these two stations being east-coast stations. This was noted earlier (BERLAGE and DE BOER, 1960) from the narrow and rather small equatorial part of Indonesia and the Indian Ocean area where airpressure deviations show correlations with those at Djakarta up to factors of +0.9 and higher.

El Niño was noted in 1932, although it did not show serious consequences, while there was also a sunspot minimum relieving airpressure in the Indian Ocean region. In addition, the pressure anomaly Juan Fernandez-Santiago was negative 1930-1936.

The most obvious relaxation times suggested by Tables 9 and 10 are 1844, 1850, 1864, 1876, 1896, 1911, 1918, 1939, 1951, 1957, 1964.

A series of at least 3 years with indices below normal preceded these times, with only slight corrections 1842, 1873, 1895, 1948, 1961. We are induced to add as years of relaxation 1925 from the Indian Ocean point of view and 1930 from the Pacific Ocean point of view. There is a certain parallelism in what happened 1911-1912-1913 and 1951-1952-1953, since 1911 and 1951 are definitely stressed from the Indian Ocean side, 1913 and 1953 from the Pacific Ocean side.

By using Table 11, SCHOVE (1965) added another twenty-eight years, 1813-1840, of sufficiently reliable data. Therefore, 150 years of S.O. in the Indian Ocean sector are adequately known at present. From the Pacific Ocean sector the almost only information is El Niño, known to have occurred 1814 and 1828 with serious consequences. A last aid toward the past are pressure observations made at Madras 1796-1806 (SCHOVE and BERLAGE, 1965).

1.10 Heavy volcanic eruptions and their consequences

If we are obliged (1.8) to conclude that the Krakatoa eruption (6°S, 105°E), August 27, 1883 gave a particular impulse to the Southern Oscillation, we must certainly take into consideration the similar influence of the Tambora eruption (8°S, 118°E), April 5, 1815 ,which is known to have been even heavier.

The interesting thing is that two sequences of years around 1815 and 1883 present a challenging analogy. A sunspot maximum occurred 1883-1884 in the one case, and 1816 in the other case, both nearly coinciding with the two most spectacular volcanic eruptions of the nineteenth century in the same equatorial region, although the one occurred east and the other west of Java. The two sunspot maxima were both relatively weak. The annual numbers of sunspots were 63.7 in 1883, 63.5 in 1884 and only 45.8 in 1816. It therefore seems justifiable to bring the two series in Table 12 into parallelism.

The mean relative year-ring width of central Java teak wood is introduced here as an S.O. Indian Ocean index; the advantage of this index being that values are available from 1519. The running 11-year average is taken as 100 (BERLAGE, 1931; DE BOER, 1951, 1952).

TABLE 11. *Southern Oscillation Indices 1813-1840.*

	Apr-Sep	Oct-Mar		Apr-Sep	Oct-Mar		Apr-Sep	Oct-Mar
1813	+ 2	+ 2	1823	− 6	− 4	1833	+ 3	− 1
1814	+ 5	− 7	1824	− 1	−14	1834	0	+ 2
1815	− 9	− 5	1825	+ 4	− 9	1835	+12	+11
1816	− 3	+ 6	1826	0	0	1836	+ 8	+ 4
1817	− 7	0	1827	0	− 2	1837	+ 8	− 8
1818	− 4	−12	1828	− 4	− 7	1838	0	− 6
1819	− 1	− 8	1829	− 3	+ 2	1839	− 4	+ 1
1820	+ 2	+ 1	1830	+ 5	+10	1840	−14	(− 3)
1821	+ 2	+ 2	1831	− 8	− 9			
1822	0	0	1832	− 6	+ 2			

There are however disadvantages involved. The tree-ring widths are chiefly dependent on the duration of the west monsoon, the wet season that normally begins in October and ends in April. The width corresponding to a particular year is developed during the season that begins in that year and ends in the next. It should therefore correlate with the S.O. index given to the half-year period October-March. However, the intensity and end of the previous dry season and the intensity and start of the next dry season are important factors.

Therefore it is better to assign the tree-ring widths to the whole year and ignore such cases as 1819-1820 opposite to 1887-1888 where the values show an inverse relationship. Minor phase shifts in the succession of S.O. pressure waves might also contribute to such cases. Deviations of this nature will appear again in para 3.4.

TABLE 12. *A challenging case of analogy through 12 years.*

Sunspot	Eruption	Year	Java treering width	Sunspot	Eruption	Year	Java treering width
min		1810	92			1878	90
		1811	110	min		1879	116
		1812	116			1880	128
		1813	123			1881	100
		1814	85			1882	81
	Tambora	1815	91	max	Krakatoa	1883	84
max		1816	78	max		1884	122
		1817	59			1885	75
		1818	70			1886	84
		1819	84			1887	137
		1820	133			1888	87
		1821	110	min		1889	115

Despite these difficulties, the 12 year series in Table 12 remains as a prominent example of analogy. It is even possible that the large difference in the values of the tree-ring widths for 1816 and 1884 derived from the different characteristics of the two volcanoes. The different position and time of occurrence of each volcanoe must have influenced the character of the dust veils produced, including the initial direction of propagation. The two comparable Java high pressure years have evidently become 1817 and 1885.

Both major volcanic eruptions were followed by an S.O. relaxation and high air-pressure over Indonesia two years later. The same is true for the near equatorial heavy eruptions of the Isle of Knights (5°S, 148°E) March 13, 1888, and of Mont Pelée (14°N, 61°W) May 8, 1902 and Santa Maria (14°N, 91°W) October 24, 1902, as Djakarta airpressure rose very quickly in 1890 and 1904, although the characteristic Djakarta high pressure years, associated with very dry eastmonsoons on Java have become 1891 and 1905.

Perhaps these facts may even assist us in explaining the difference in behaviour of the two catastropic El Niño years, 1891 and 1925, a subject touched already in para 1.3. The 1925 tree-rings in Java were extremely narrow, 45, whereas 1891 tree-rings were of average width, 100. On the other hand 1924 tree-rings were wide, 104, whereas 1890 tree-rings rather narrow, 85. It is a great pity that we have no tree-ring data from Java since 1929.

Two other heavy volcanic eruptions, this time in high northern latitudes, are those of Katmai, Alaska (58°N, 155°W) in June 8, 1912 and of Bezumianny, Kamtchatka (56°N, 161°E) in October 22, 1955. The meteorological consequences of the latter eruption have been investigated by GORSHKOV (1958). It caused a pressure rise of 23.5 mb at a point 45 km from the volcano and a pressure rise of one mb at a point in northern Siberia 1100 km away, while the pressure wave was traced on sensitive barographs for 1½ circulations of the globe. According to BULL (1958) dust from this eruption was noted in the stratosphere over Western Britain on 3 and 4 April 1956.

The global pressure anomaly pattern following the Katmai eruption, October 1913-February 1914, has been published and discussed earlier (BERLAGE 1957). It shows rather strong zonal characteristics and is a prominent case of slowing down of the general circulation and disappearance of the Southern Oscillation 'see-saw'. It is reproduced here (Fig. 16) together with the two global pressure anomaly patterns following the Krakatoa eruption, October 1884-February 1885 (Fig. 15), and the Bezumianny eruption, October 1957-February 1958 (Fig. 17).

The zonality of all three patterns is very impressive. The similarity of the October 1957-February 1958 and the October 1913-February 1914 patterns is remarkable, but the October 1884-February 1885 pattern shows the reverse signs, apparently in concordance with the typical difference in latitude where the eruptions occurred. The first two were subpolar, the latter was equatorial. Yet a closer analysis of the latter pattern shows us that in this case too the S.O. general circulation is slowed down, the consequences being the same in all cases. This conclusion was already inferred from the general course of pressures in the Pacific-Indian Ocean region, and is not surprising.

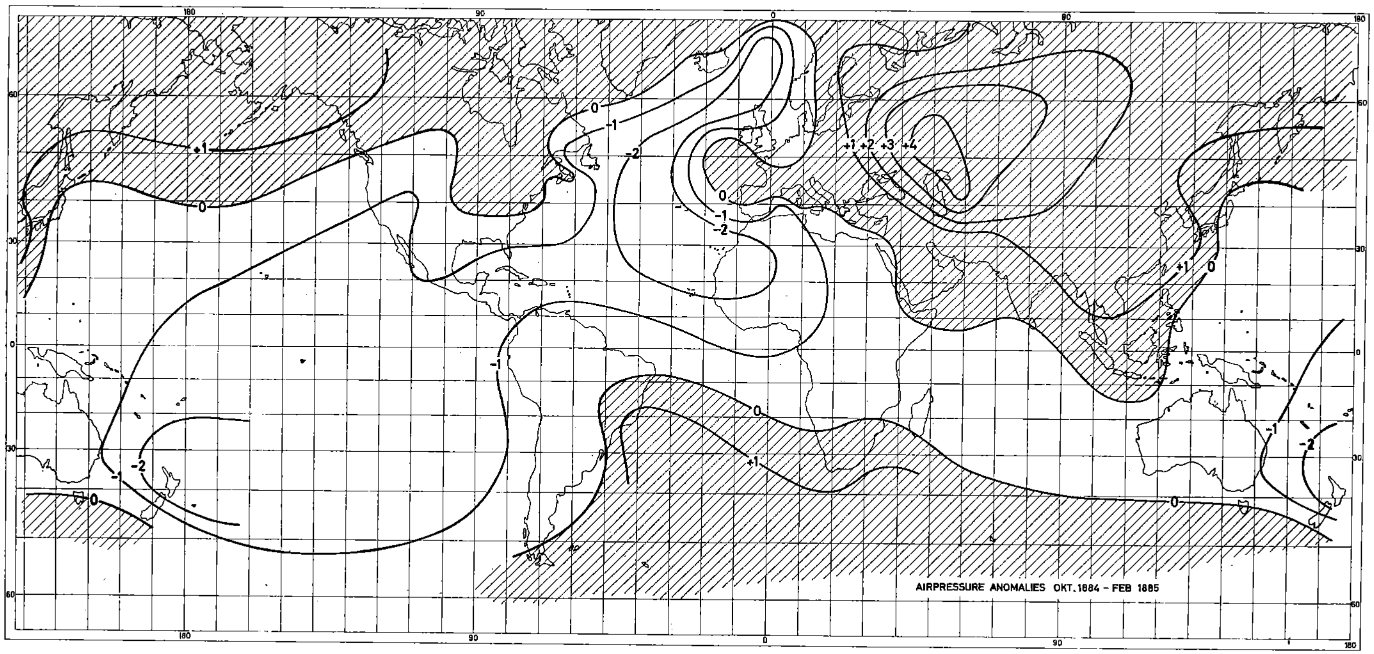


Fig. 15 Global pattern of air pressure anomalies after eruption of Krakatoa, Java, August 27, 1883.

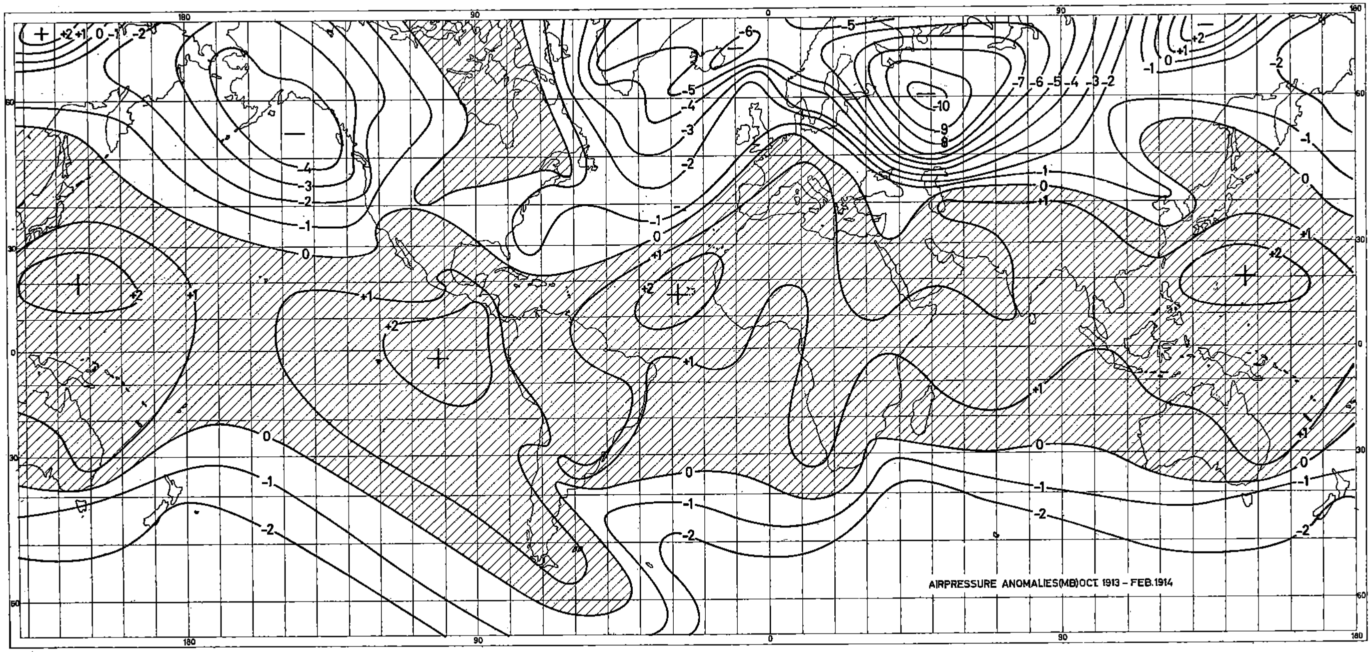


Fig. 16 Global pattern of air pressure anomalies after eruption of Katmai, Alaska, June 6, 1912

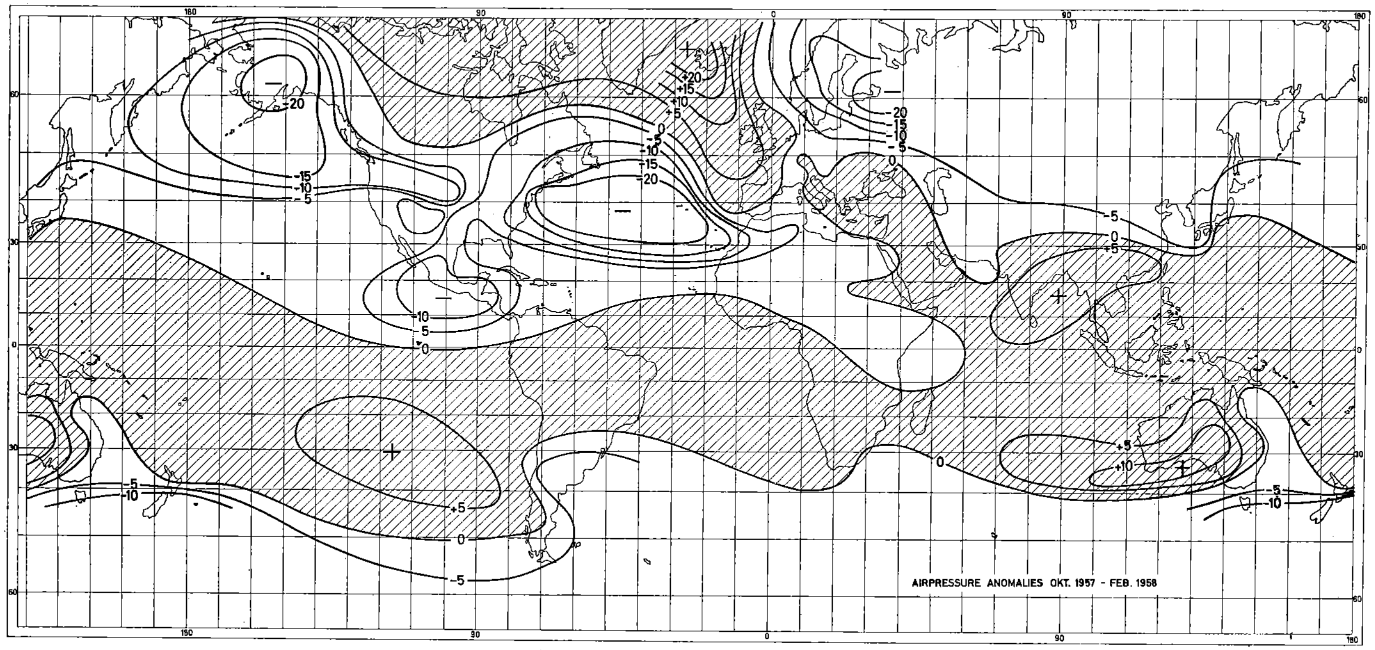


Fig. 17 Global pattern of air pressure anomalies after eruption of Bezumianny, Kamtchatka, October 22, 1955.

The anomalous quick pressure rise 1913 in the Indonesia equatorial low, if actually due to the Katmai eruption about one year earlier, as was already suggested by BRAAK (1919), would prove that a heavy volcanic dust veil produced in polar latitudes may finally cover the whole globe within the course of one year, or else reduce the general atmospheric circulation all over the world by encroachment of its parts.

As a matter of fact, in 1958 and 1959, the existence of such a quick distribution of polar stratospheric air over the world was proved by tracing the radioactive debris delivered at high altitudes by Russian nuclear bomb tests executed in Novaja Zemlya. The speed of this distribution is so great probably because, as BREWER (1961) showed with the aid of atmospheric ozone measurements, the transport from stratosphere into troposhere occurs so easily near the subtropical jet. Here the tropopause changes level abruptly from moderate, in moderate latitudes, to high, between the tropics, thus leaving a zonal window open.

Since the publication of W.M.O. Technical Note No. 43, on meteorological factors influencing the transport and removal of radioactive debris, edited by BLEEKER (1961), a valuable review of all possible means of this transfer through the tropopause and within the stratosphere has been given by NEWELL (1963). According to STOREBO (1960) full replacement of stratospheric air occurs within two years. The likely conclusion is that, apart from the obliteration of any trace of the newly introduced S.O. phase, all trace of the volcanic disturbance vanishes within one S.O. cycle.

By far the heaviest volcanic eruption in the Indonesian area in recent years was the one of Gunung Batur, Bali (8°S, 115°E), February 9, 1963. It was immediately followed by a remarkable pressure wave at Djakarta (Fig. 1) presenting a high crest in the second half of 1963.

Since, according to the arguments of para 1.8 a relaxation wave of this magnitude was due to occur after four successive years of positive anomalies of the pressure difference Santiago-Djakarta we should be careful with our interpretations. However, the speed with which pressure at Djakarta has been rising again in 1965 strongly suggests that the singular Djakarta pressure peak 1963-1964 is of volcanic origin, and comparable with the singular pressure peak 1913-1914 which followed the Katmai eruption. Hence the pressure wave 1963-1964 may well be denoted as 'quasi' relaxation wave, whereas the 1965-1966 pressure wave, introduced early in 1965, is probably caused by major relaxation. This most recent pressure wave is rather late, since 1964 was the sunspot minimum year contributing to it, in the same sense as 1913 apparently did to the 1913-1914 wave. Yet, it may also be considered as coming at the right time, because 1965 is actually the first year in which the annual anomaly of the pressure difference Santiago-Djakarta changed to a negative value after the passage of five successive years in which these anomalies were positive and the S.O. was speeded up.

By comparing figures 15, 16 and 17 it can be seen that the Krakatoa eruption, by causing a pressure rise in Southeast Asia and a pressure fall in the Southeast Pacific, induced a new S.O. wave directly. This induction was achieved without any apparent interference with the general global circulation that is due to the difference in solar radiation received in equatorial and polar latitudes, unlike the Katmai and Bezumianny cases where such interference obviously occurred.

Hence we should take care not to assume too uncritically that eruptions in the tropical east, such as those of Krakatoa and Tambora have the same grip on the S.O. as those in the tropical west. As a matter of fact, when we investigate what happened after the heaviest eruptions in that part of the world, those of Coseguina (12°N, 87°W) January 20, 1835 and Mont Pelée (14°N, 91°W) May 8, 1902, and Santa Maria (14°N, 91°W), October 24, 1902, we do not find the immediate pressure rises at Djakarta which characterized 1884 and 1913, but, on the contrary, pressure falls in 1836 and 1903.

However, the Coseguina and Mont Pelée and Santa Maria eruptions occurred in typical Djakarta high pressure years, 1835 and 1902 followed at regular S.O. three-year intervals by two other high pressure years, 1838 and 1905. Consequently we are only able to make the following remarks.

As already mentioned, the unusually early pressure rise at Djakarta and pressure fall at Santiago 1904 is the kind of relaxation considered, probably induced by the Mont Pelée and Santa Maria dust veils. On the other hand, the impulse given to the 1835-1838-1841 very regular pressure wave train must have been particularly strong, because 1838 is a year distinguished by a sunspot number as high as 103.2. The conclusion is that the amplitude of the pressure oscillation, since it diminishes by the natural damping, must have been particularly large at the start in 1835, and hence relaxation 1834 particularly effective. Now, the dust veil produced by the Coseguina eruption may indeed have contributed to the height of the pressure arrived at in the Indian Ocean region; because this eruption occurred in January, that is very early in the year. As a matter of fact the April-September S.O. index amounted to +5.8 in 1835, a value comparable to those of the three historic Djakarta high pressure years 1877 (+9.4), 1914 (+5.8) and 1940 (+6.0). This indicates that 1835 is an equally exceptional high pressure year.

Finally, the author wishes to draw attention to the following fact. S.O. changes following the Krakatoa and Katmai eruptions strongly suggest an incidental volcanic grip on the S.O. This grip explains why a Djakarta high pressure year occurred in 1838, three years after the high pressure year 1835, contrary to sunspot rules. It seems, therefore, that sunspot rules simpler than those published previously (Berlage 1947, 1957, 1961) are due. There is no need to make 'ad hoc' adjustments to two of the rules, with regard to 1838 and 1884. Moreover, one rather painful exception, the fact that not 1863 but 1864 became the high pressure year in the Indian Ocean region, might find its redress if we are allowed to correct the curious 1863 secondary depression in the annyal Wolf-Wolfer sunspot numbers,

1861	77.2	1862	59.1	1863	44.0	1864	47.0	1865	30.5

by raising 44 to, say, 55.

There are thus a number of reasons for considering that the variations of insolation, due to variations of solar activity and of volcanic dust in the higher layers of the atmosphere, are the main external conditions by which the Southern Oscillation receives new impulses, or is accelerated or decelerated in its current movement.

In particular we have noted with A. DEFANT (1924) that heavy volcanic eruptions cause a deceleration of the general atmospheric circulation. A reacceleration would occur, according to DEFANT, one or two years later, a complete regeneration would be established in three or four years.

This conclusion converges with the many arguments brought forward by WEXLER (1951, 1956, 1960) in favour of the hypothesis that variations of the turbidity of the terrestrial atmosphere would explain our major climatic variations, even those of longer duration.

The subject was taken up recently by BLOCH and HESTER (1963) with regard to Israel. Deceleration of the general atmospheric circulation means in general more rain in dry regions and less rain in wet regions. In regard to fluctuations in the level of the Dead Sea during 1800-1960 (C. KLEIN, 1961) it seems obvious that the two major rises in level, 1819-1837 and 1883-1896, are related to the two major volcanic eruptions, Tambora and Krakatoa. The persistence of the climatic after-effects at these outbreaks, the strongest eruptions ever recorded, is not yet understood.

1.11 Analogy in series of years

Table 13 contains the results of the application of analogues through one century 1777-1876, whereas Table 14 is a condensation of the natural repetition of events in the course of three successive EASTON cycles, 1699-1784-1876-1964 between sunspot minima, each pair separated by eight 11-year primary cycles of solar activity. The lengths of these three EASTON cycles are 84, 92 and 88 years. Their average length is 88.2 years.

The physical reality of the roughly 89-years cycle, discovered by EASTON (1918, 1928), at least in European winters, was recently strongly supported by VISSER (1950, 1959), DE BOER (1951, 1952), WALDMEIER (1957) and WILLETT (1965). It has certainly a natural preference because its duration is 4 times the basic 22-years period of solar activity pointed out by HALE, whereas the cycles of 77 years and 100 years, which have also sometimes been advocated, are less acceptable because they encompass 7 and 9 times, that is an uneven number of times, the primary 11-year sunspot cycle.

Table 13 was prepared on the basis that sunspot maxima and minima, tree-ring widths, and El Niño appearances for corresponding sequences of years should coincide as nearly as possible. Java eastmonsoon rainfall was used as a prominent indicator of parallelism, as far back as rainfall records exist.

Table 14 shows sunspot maxima, Java narrow tree-rings (finishing 1929), Java dry eastmonsoons (starting 1829), Indian Ocean high circulation index (starting 1841) and Peru excessive rains (starting 1720). The years are grouped in rough analogy and are printed bold when their character is excessive.

TABLE 13. *Southern Oscillation original and analogue years 1777-1888.*

Original				Analogue			
Sun spot	year	Java tree ring		Sun spot	year	Java tree ring	
	1777	104		max	1837	87	
max	1778	90			1838	90	
	1779	116			1839	94	
	1780	128			1840	133	
	1781	100			1841	105	
	1782	81			1942	81	
	1783	82		min	1843	125	
min	1784	102			1844	107	
	1785	111			1845	93	
	1786	91			**1846**	77	
	1787	101		max	1937		
max	1788	140			1938		
	1789	81			1939		
	1790	72			1940		Peru
	1791	96	Peru		**1941**		Peru
	1792	104			1895	100	
	1793	96			1896	72	
	1794	110			1897	89	
	1795	143			1898	97	
	1796	82			1899	87	
	1797	105			1900	145	
min	1798	81		min	1901	74	
	1799	67			1902	73	
	1800	80			1903	87	
	1801	130			**1904**	142	
	1802	129		max	1884	122	Peru
max	1803	83			1885	75	
	1804	99	Peru		1886	84	
	1805	106			1887	137	
	1806	92			1888	87	
	1807	95			1889	115	
	1808	89			**1890**	85	
	1809	124			1920	115	
min	1810	92			1921	92	
	1811	110			1922	141	
	1812	116		min	1923	123	
	1813	127			1924	104	
	1814	85	Peru		1925	45	Peru
	1815	91			**1926**	76	
max	1816	78		max	1928	152	
	1817	59			1929	60	
	1818	70			1930		
	1819	84			1931		

original				analogue			
Sun spot	year	Java tree ring		Sun spot	year	Java tree ring	
	1820	133			**1932**		
	1821	110			1908	102	
	1822	87			1909	109	
min	1823	120			1910	142	
	1824	94			1911	88	
	1825	79			1912	87	
	1826	135		min	1913	66	
	1827	61			1914	69	
	1828	129	Peru		1915	94	
max	1829	109			1916	133	
	1830	111		max	**1917**	107	
	1831	109			1864	91	
	1832	90			1865	105	
min	1833	115			1866	82	
	1834	83		min	1867	92	
	1835	97			1868	81	
	1836	114			**1869**	131	
max	1837	87		max	1917	107	
	1838	90			1918	78	
	1939	94			1919	81	
	1840	133			1920	115	
	1841	105			1921	92	
	1842	81			1922	141	
min	1843	125		min	1923	123	
	1844	107			1924	104	
	1845	93			**1925**	45	Peru
	1846	77			1914	69	
	1847	99			1915	94	
max	1848	66			1916	133	
	1849	94		max	1917	107	
	1850	118			1918	78	
	1851	120			1919	81	
	1852	122			1920	115	
	1853	81			**1921**	92	
	1854	104			1924	104	
	1855	49			1925	45	Peru
min	1856	89			**1926**	76	
	1857	109		min	1933		
	1858	127			1934		
	1859	111			1935		
max	1860	80			1936		
	1861	128			1937		
	1862	86		max	1938		

original				analogue			
Sun spot	year	Java tree ring		Sun spot	year	Java tree ring	
	1863	127			1939		
	1864	91	Peru		1940	Peru	
	1865	105			1941	Peru	
	1866	82			1942		
min	1867	92			**1943**		
	1868	81			1891	100	Peru
	1869	131			1892	111	
	1870	116		max	1893	106	
max	1871	106			1894	116	
	1872	85			1895	100	
	1873	84			1896	72	
	1874	105			1897	89	
	1875	105			1898	97	
	1876	86			**1899**	87	
	1877	78	Peru		1940		Peru
	1878	90	Peru		1941		Peru
min	1879	116			1942		
	1880	128			1943		
	1881	100		min	1944		
	1882	81			1945		
max	1883	84			1946		
	1884	122			1947		
	1885	75		max	1948		
	1886	84			1949		
	1887	137			1950		
	1888	87			1951		

There is a definite phase shift from Java narrow tree-rings to excessive Peru rains in the following cases: 1719-1720, 1725-1726, 1727-1728, 1762-1763, 1790-1791, 1803-1804, 1827-1828, 1890-1891, 1940-1941, 1957-1958. The last two cases involve the assumption that the Djakarta high pressure years 1940 and 1957 brought with them narrow tree-rings on Java. Coincidence of Java narrow tree-rings and Peru excessive rains, occurred 1770, 1814, 1864, 1877, 1925. However, when analyzing the two most recent cases we note that the excessive pressure wave 1876, 1877, 1878, presented no exception, since it was associated with Peru rains not only in 1877 but also in 1878. Similarly in the course of the pressure wave 1924, 1925, 1926 Peru rains were not only abundant in 1925, but also in 1926, and it was in 1926 that sea surface temperatures on the west coast of Canada showed their top values. The global course of events must have been quite different in the two cases cited here. Santiago

TABLE 14. *Analogies through three Easton cycles 1699-1964.*

Easton Cycle I

sunspot min	sunspot max	JAVA tree rings narrow	JAVA east monsoon dry	JAVA high pressure	India dry	West Australia dry	Peru rains
		1700					
		1704					
		1707					
		1711		(1711)			
		1719					**1720**
		1723		(1723)			
		1725					1726
		1727					**1728**
		1729					
		1734					
		1737		(1737)			
		1744					
		1746					
		1748					
	1750	1750					
1755		**1754**		(1754)			
		1757					
	1761	1762		(1762)			1763
		1764					
1766		1767					
	1769	1770		(1769)	69/70		1770
				(1772)			
1775		1775					
	1778	1778					
		1782		(1782)	82/83		
1784							

(no barometric evidence)

shows high pressure through 1924-1925, while probably low pressure occurred at Easter Island through 1925-1926, complementary to high pressure at Djakarta. Hence winds above the Peru Current must have been weak or even directed southward throughout the year 1925, explaining that year's critical El Niño.

Air pressure changed from very low to very high in the Indian Ocean region between 1863 and 1864. If pressure had changed in the Southeast Pacific region inversely at the same time El Niño would probably not have come through earlier than 1865. However, airpressure was already low in 1863 and this may have led to El Niño's occurrence at the start of 1864.

Easton Cycle II

sunspot		JAVA			India	West Australia	Peru
min	max	tree rings narrow	east monsoon dry	high pressure	dry	dry	rains
		1786					
	1788						
		1790		(1790)	90/91		1791
		1793					
		1796					
1798		**1799**		(1799)			
					02/03		
	1804	1803		(03/04)	04/05		1804
		1806					
		1808		(1808)			
1810		1810		(1810)			
		1814		(1814)			1814
	1816	**1817**					
		1818					
1823		1822		(1821)			
		1825			24/25		
		1827					1828
	1829	1829					
1833		1832	1833		32/33		
		1834	**1835**	(35/36)	34/35		
	1837	1837	1838	(1837)		1838	
			1841				
		1842	1842				
1843			1845				
		1846	1846	1846			
	1848	1848					
			1850				
		1853	1853				
		1855	**1855**	1855			
1856				1858			
	1860	1860					
		1862			61/62		
		1864	1864	1864		1864	1864
		1866		1866	66/67	1866	
1867		1868		1868	68/69	1869	
	1870					70/71	1871
		1873	1873			1874	
			1875				

(no barometric evidence)

Easton Cycle III

sunspot		JAVA			India	West Australia	Peru
min	max	tree rings narrow	east monsoon dry	high pressure	dry	dry	rains
1878		**1877**	**1877**	**1877**		77/78	77/78
		1880	1881	1880		1881	
	1883	1882	1883	1883			
				1884			1884
		1885	1885	1885			
		1888	1888	1888		1888	
1889		1890	**1891**	**1891**		1891	**1891**
	1893	1893					
		1896	1896	1896			
		1899		1899			1899
1901		**1902**	1902	1902			
		1905		1905			
	1906	1907					
				1911		1911	
1913		**1913**	**1913**	**1913**			
		1914	**1914**	**1914**		1914	
	1917						1917
		1918	1918	1918			1918
		1921					
1923							
		1925	**1925**	**1925**			**1925**
	1928						
		1929	**1929**	1929			
				1930			
1933							1932
			1935				
	1937						1939
			1940	**1940**		1940	1940
				1941			1941
1944			1944	1944			1943
			1946	1946			
	1947						
			1951	1951			1951
			1953	1953			1953
1954							
	1957		1957	1957			1958
			1961				

topyears are printed bold

What exactly happened around 1770 and 1814 is difficult to reconstruct, however, a very serious drought devastated India in wintertime 1769-1770, as did droughts 1782-1783 and 1790-1791. Since Java tree-rings were very narrow 1782 and 1790, we get the impression that a narrow Java tree ring 1769 should have been the more systematic feature, particularly because 1770 was a sunspot maximum year.

The sequence of events in 1814 might have been similar to that of 1925, but it might also have been similar to the sequence in 1926. As a matter of fact 1816 and 1928 were both sunspot maximum years of minor importance, 1817 and 1818 both characterized by very narrow Java tree rings, 59 and 70, while 1929 (tree-ring 69) and 1930 (tree-ring not known) are similarly successive high pressure years in Java characterized by very dry east monsoons.

Despite these few obvious irregularities the general trend of events on the global scale is obvious and detectable, even throughout the eighteenth century, which provides only limited information.

1737 must have been an extreme year towards the high pressure side in Java. In this year Java tree-rings were narrowest, reaching down to 41. It surpassed 1925, characterized by a tree-ring width as low as 45 and associated with an October 1925-March 1926 index as high as +7.4 (Table 10).

There are higher indices: the October 1940-March 1941 index, amounting to +7.9, the corresponding tree-ring width being unknown, the October 1888-March 1889 index, amounting to +7.6 (tree-ring width 87) and the October 1902-March 1903 index, amounting to +7.5 (tree-ring width 73). The case of the October 1904-March 1905 index, amounting to +7.4 although the associated tree-ring width is 142, is evidently to be explained by the fact that, whereas 1925, 1888, 1902 were characterized by very dry eastmonsoons in Java, it was not 1904, but 1905 that presented the same type. Next come the October 1877-March 1878 index, amounting to +7.3 (tree-ring width 78) and the October 1913-March 1914 index, amounting to +7.1 (tree-ring width 66).

As no strong correlation between the October-March Southern Oscillation index and the width of the Java tree-ring developing in that same season, can be expected, it is not surprising to state similar weakness of correlations even in the topcases discussed here. Yet, when inquiring into these cases from the standpoint of analogy, it is interesting to note how far the normalisation of the S.O. waves goes into minor details.

1.12 The role of South America

The South American continent is one of the most important operators in the S.O. In this paper its influence will be more fully discussed than in previous papers by the author. It was shown earlier (Berlage, 1957) that not only El Niño and the capricious precipitation associated with hydrographic disturbances along the west coast of Peru, but also precipitation in Surinam, in particular rainfall during the months between August and March, depends rather strongly on the Southern Oscillation.

Since we have learned to consider the S.O. as a prominent part of the natural meridional oscillation between pressure along the equator and along the tropics, we might have expected Surinam, in general the Guianas, as a tropical country, to be among the regions where the S.O. is dominating the short period climatic variations. However, the S.O. grip on Surinam winter rains is suprisingly strong, as Surinam is a country bordering the Atlantic Ocean and consequently situated rather far outside the two typical scales of the S.O. balance (Fig. 5).

Yet, obvious climatic relations between South America and the S.O. exist. This fact was already pointed out by Mossman (1919, 1920) and Walker (1928) for the Brazilian northeast province Ceara, frequently visited by devastating droughts and famines, as well as by Bliss (1927, 1930, 1936) for the height of the Parana river and for the West Indies.

East-west lag correlations through the tropical Atlantic, more promising than those discovered by Walker and Bliss, were found by Bullig (1949), Flohn (1960) and Eickermann and Flohn (1962). These showed that when forecasting Guiana and N.E. Brazil precipitation we have to take into account previous conditions in South Africa, and the advection of ocean temperatures with the North and South Equatorial Currents, under the influence of the trade winds over the tropical Atlantic Ocean.

That this relation is connected with the S.O. was shown, with the aid of global air-pressure correlation patterns relative to Djakarta on the one side and to Easter Island on the other side 1949-1957, by Berlage and De Boer (1959). As was pointed out by Flohn and Hinkelmann (1952) the extreme variations of precipitation in the equatorial zone of South America and the Pacific are to be derived from an aperiodic shifting of the Intertropical Convergence Zone and the trades. El Niño appears in accordance with the shifting of a splitting I.T.C. to about 10°S.

Table 15. *Mean precipitaion anomalies Georgetown-Paramaribo September (given year)-February (next year) in mm.*

1894	+210	1904	— 71	1914	+ 97	1924	— 42	1934	— 9	1944	+ 4	1954	+173
95	—290	05	— 84	15	— 91	25	—566	35	—229	45	—148	55	+308
96	—287	06	+135	16	+196	26	+289	36	+ 43	46	—255	56	+195
97	+307	07	—152	17	+ 62	27	+396	37	+ 60	47	+ 78	57	—293
98	+217	08	— 1	18	—309	28	—252	38	— 46	48	+181	58	—467
99	—143	09	+ 57	19	+ 64	29	—145	39	—483	49	+701	59	+ 5
1900	—341	10	+ 99	20	—172	30	—239	40	—202	50	+115	60	—191
01	+444	11	—553	21	+339	31	—154	41	— 96	51	—150	61	—177
02	—220	12	+113	22	+360	32	—251	42	+482	52	+258	62	+ 54
03	—189	13	+115	23	— 39	33	+665	43	+ 47	53	— 57	63	—520

Let us recognize the far reaching analogy of conditions in the atmospheric and hydrospheric circulation through the equatorial East Pacific and Atlantic Oceans.

The Guianas experience a dry time in late summer, August-September-October and a secondary one in early spring, February-March. Circumstances become economically dangerous when the first drought persists to the latter one and a real winter drought develops.

Table 15 contains the seasonal precipitation September-February inclusive, as recorded at Paramaribo (Surinam) since 1849, although with gaps, and at Georgetown (British Guiana) since 1894. The total averages, 772 mm in Paramaribo and 741 mm in Georgetown, are of equal weight.

Assuming a rain shortage of —200 mm as the critical limit, we note that serious Surinam droughts occurred in northern wintertime of the following years:

1864-65	1877-78	1896-97	1911-12	1925-26	1932-33	1940-41	1957-58
1866-67	1884-85	1900-01	1918-19	1928-29	1935-36	1946-47	1958-59
1868-69	1888-89	1902-03	1920-21	1930-31	1939-40	1951-52	1963-64

The characters of two winters, are unknown, those of 1892-93 and 1893-94, but obvious relation with the S.O. makes serious droughts during these years highly improbable. In fact, we recognize in the above series the closing or transition seasons from prominent Djakarta high pressure years to the following years, with a few exceptions to which we will return in para 3.5.

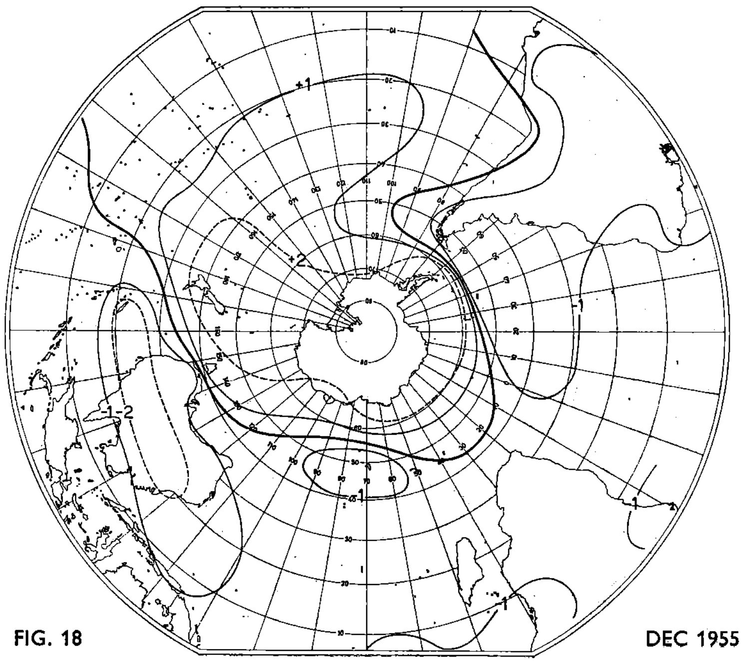


FIG. 18 DEC 1955 - FEB 1956

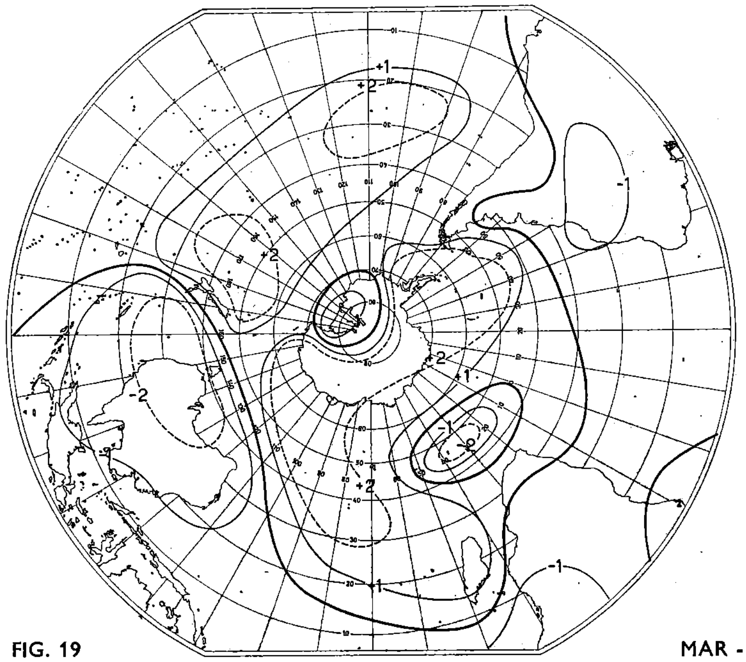


FIG. 19 MAR - MAY 1956

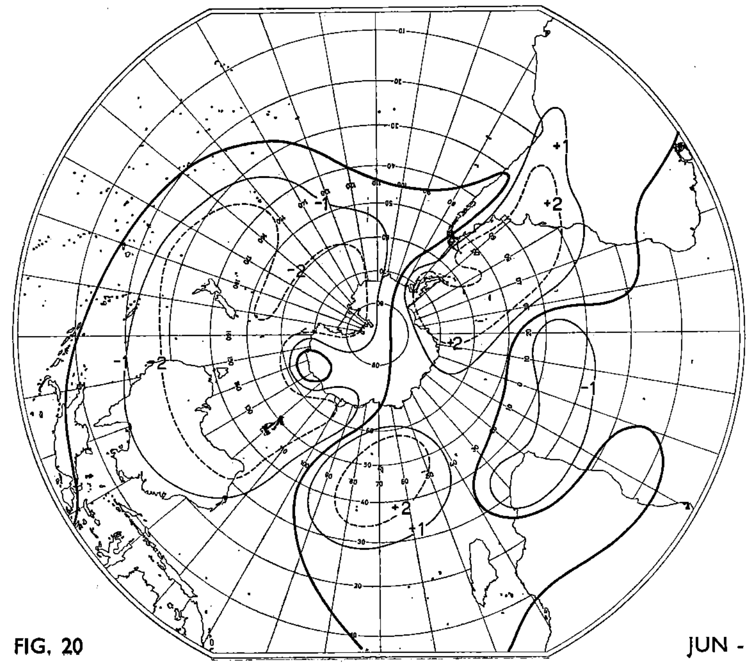


FIG. 20 JUN - AUG 1956

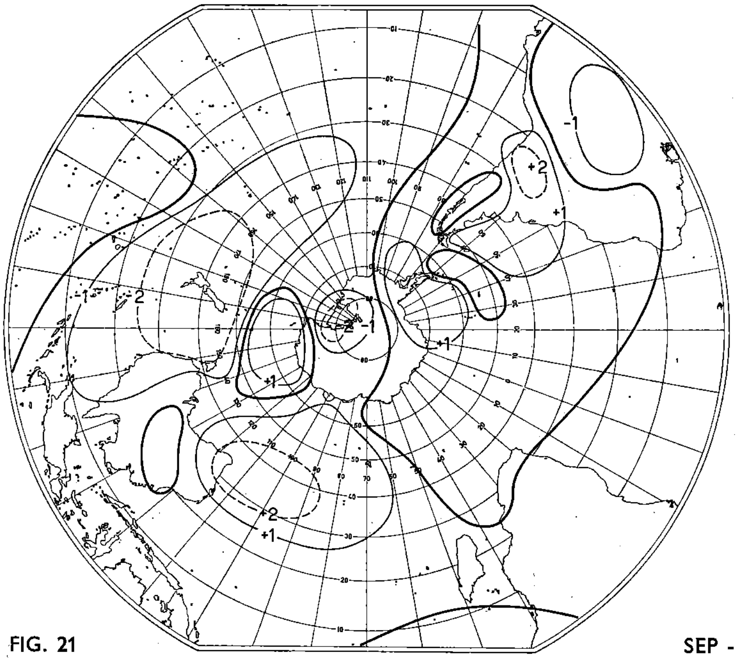


FIG. 21 SEP - NOV 1956

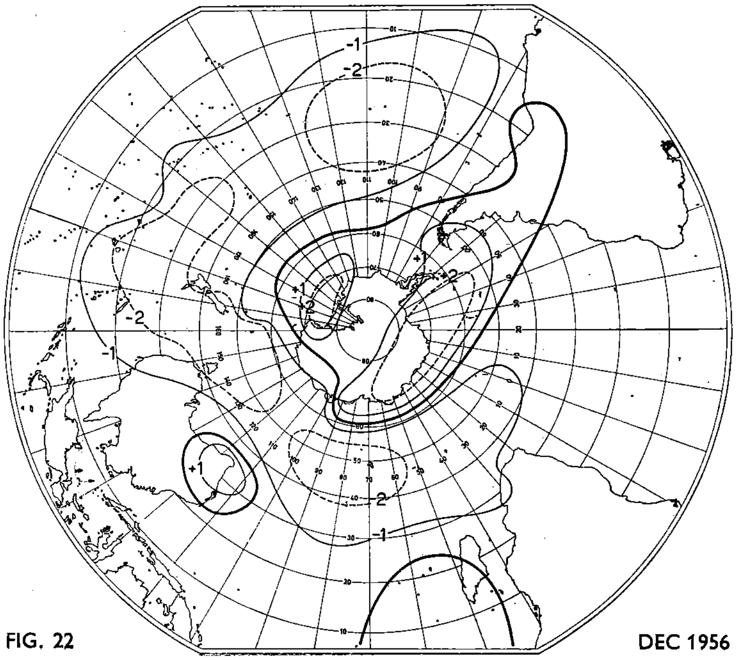


FIG. 22 DEC 1956 - FEB 1957

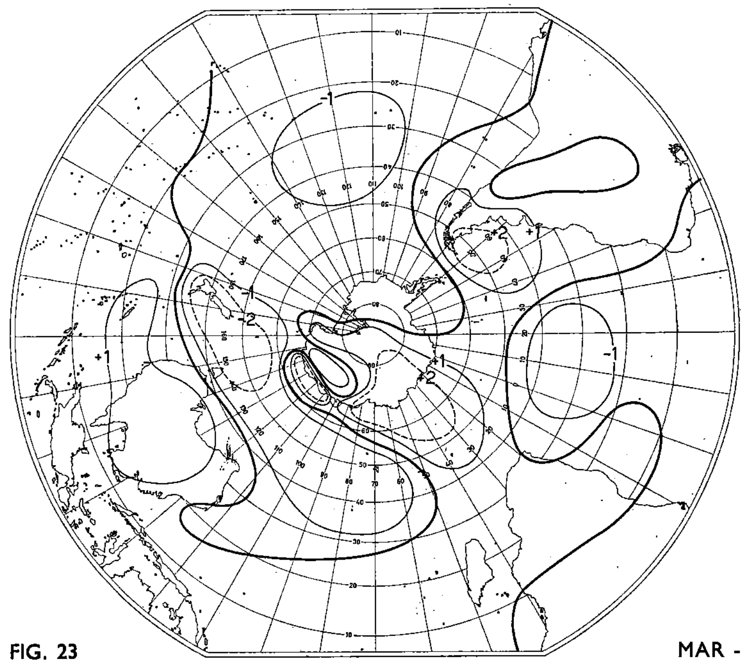


FIG. 23 MAR - MAY 1957

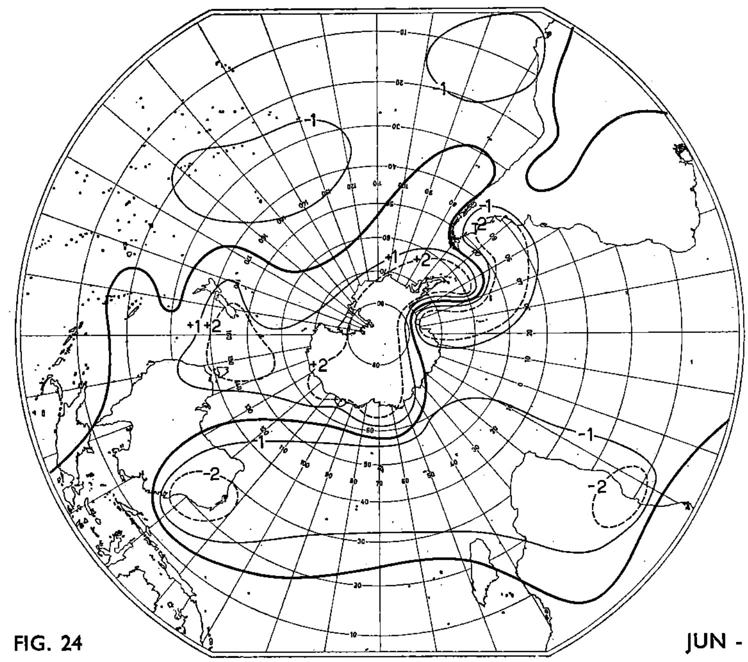


FIG. 24 JUN - AUG 1957

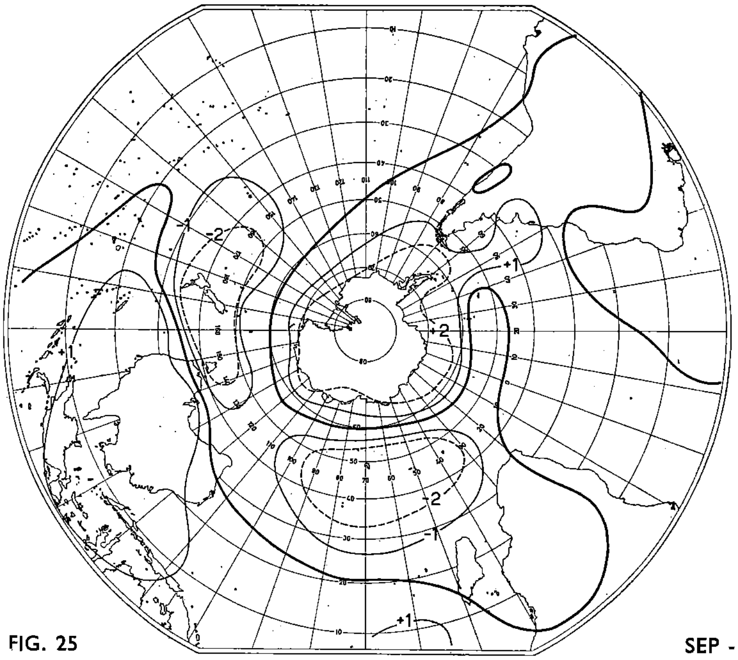


FIG. 25 SEP - NOV 1957

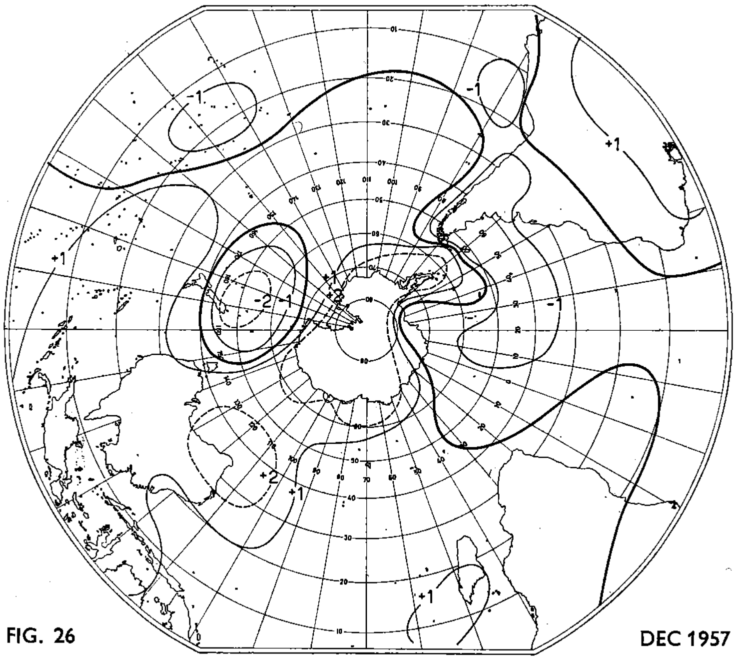


FIG. 26 DEC 1957 - FEB 1958

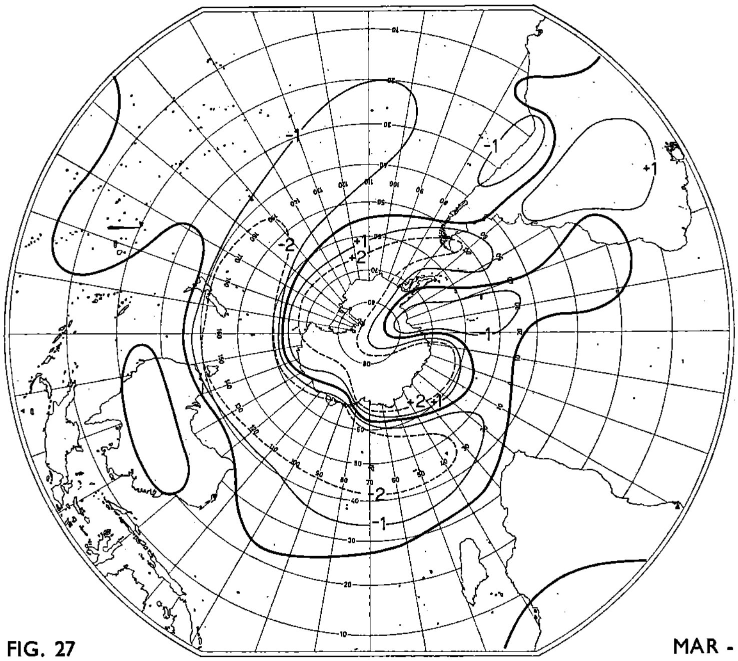


FIG. 27 MAR - MAY 1958

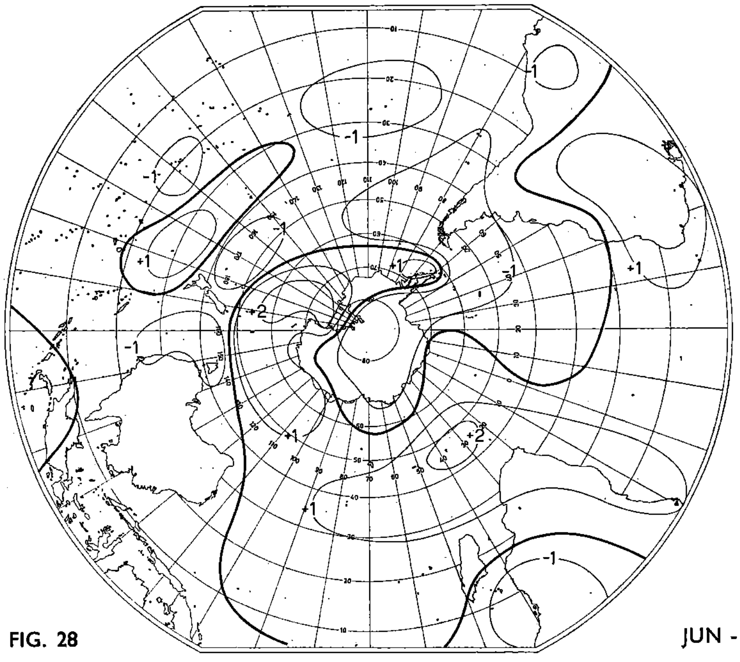


FIG. 28 JUN - AUG 195

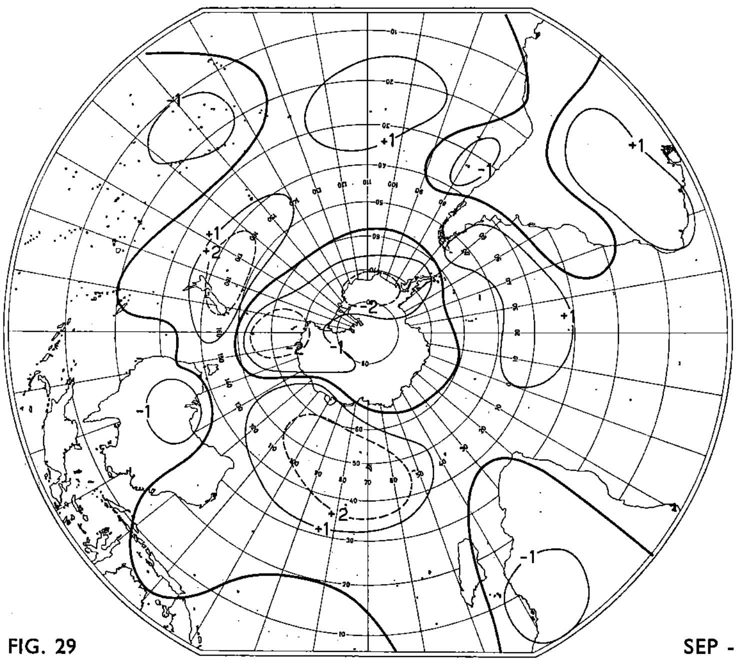


FIG. 29 SEP - NOV 1958

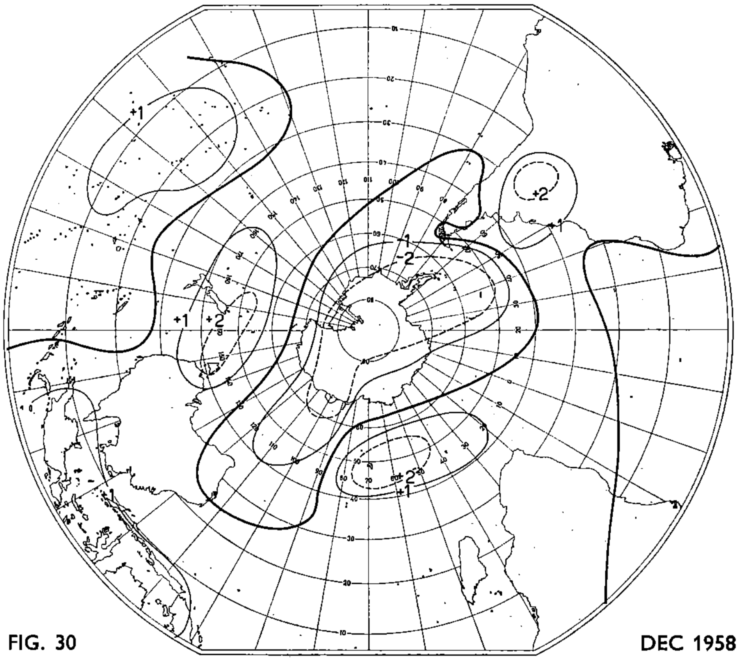


FIG. 30 DEC 1958 - FEB 1959

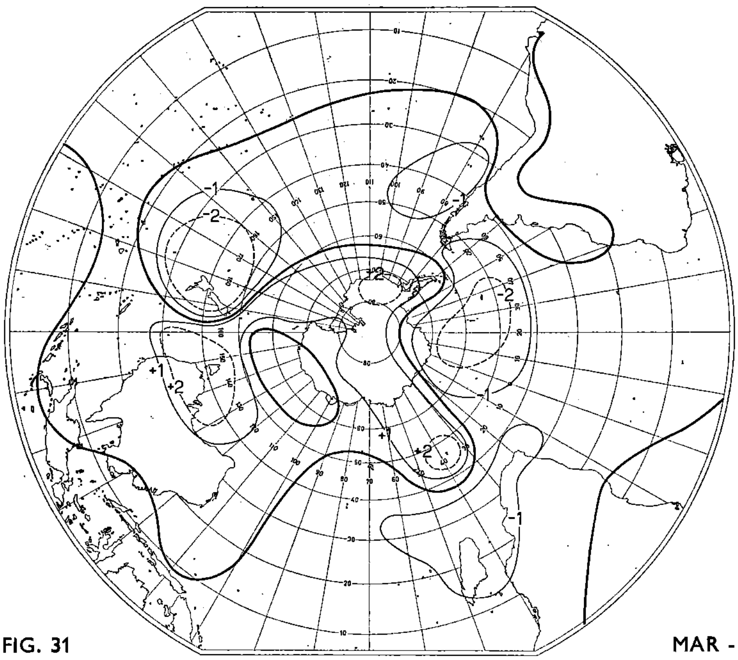


FIG. 31 MAR - MAY 1959

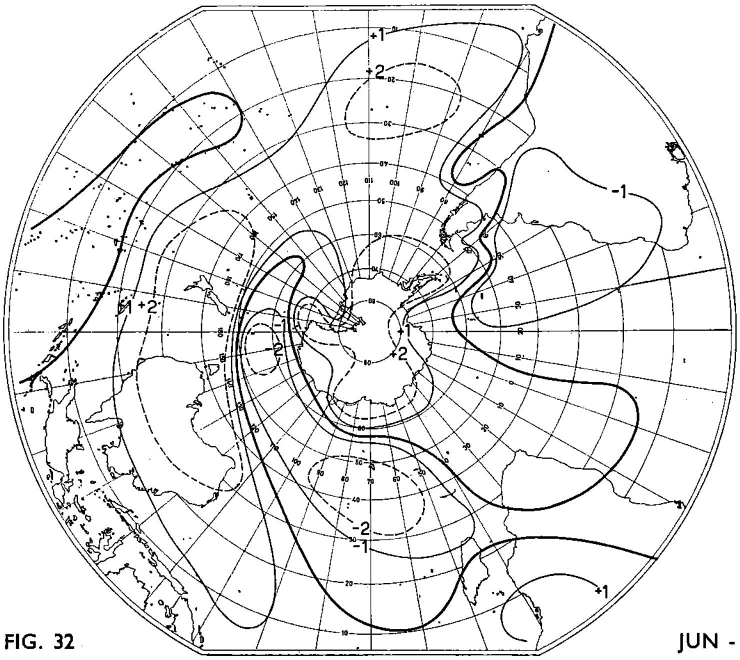


FIG. 32 JUN - AUG 1959

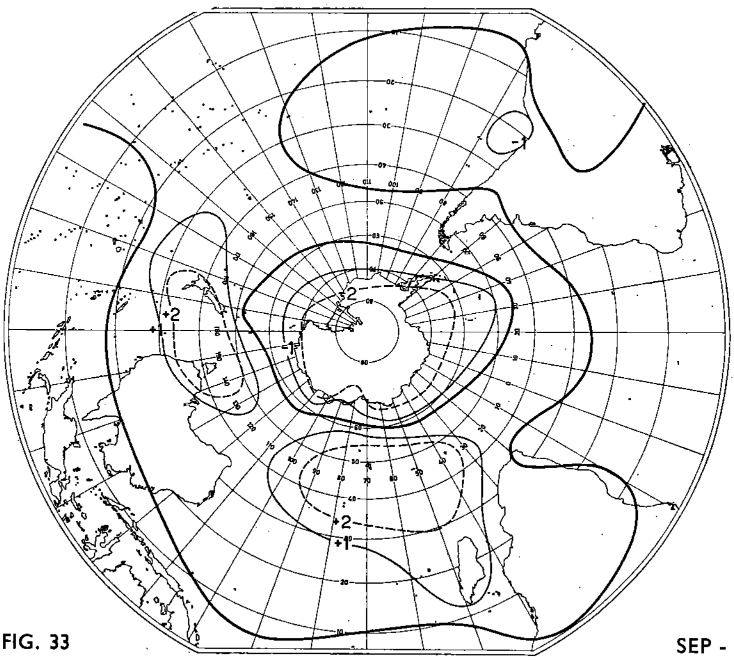


FIG. 33 SEP - NOV 1959

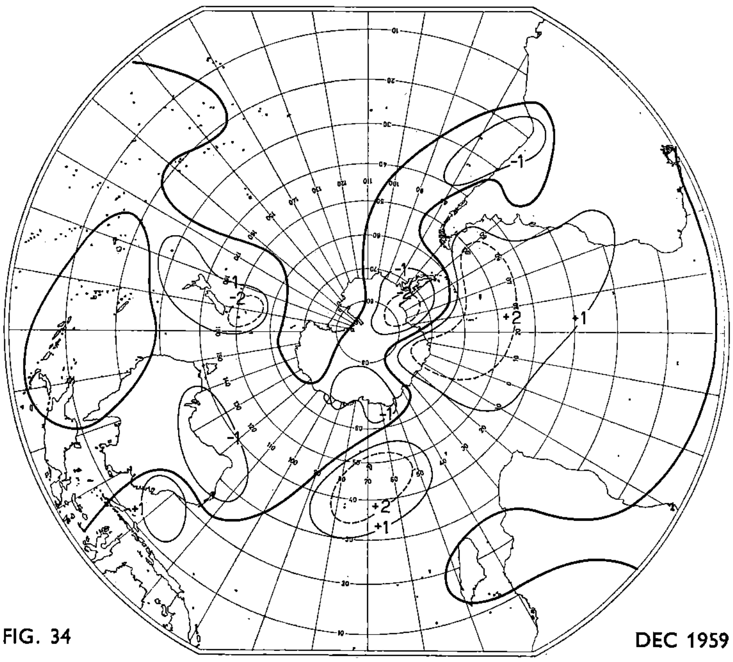


FIG. 34 DEC 1959 - FEB 1960

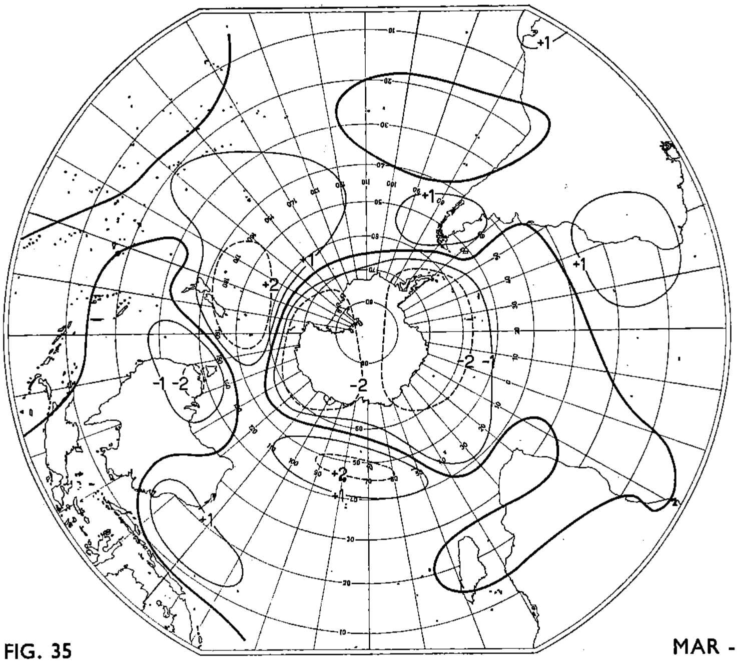


FIG. 35 MAR - MAY 1960

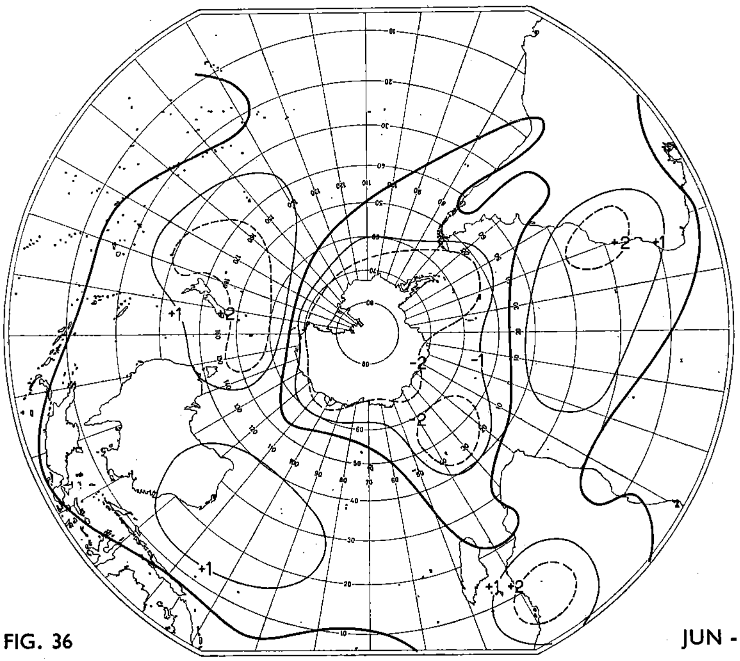


FIG. 36 JUN - AUG 1960

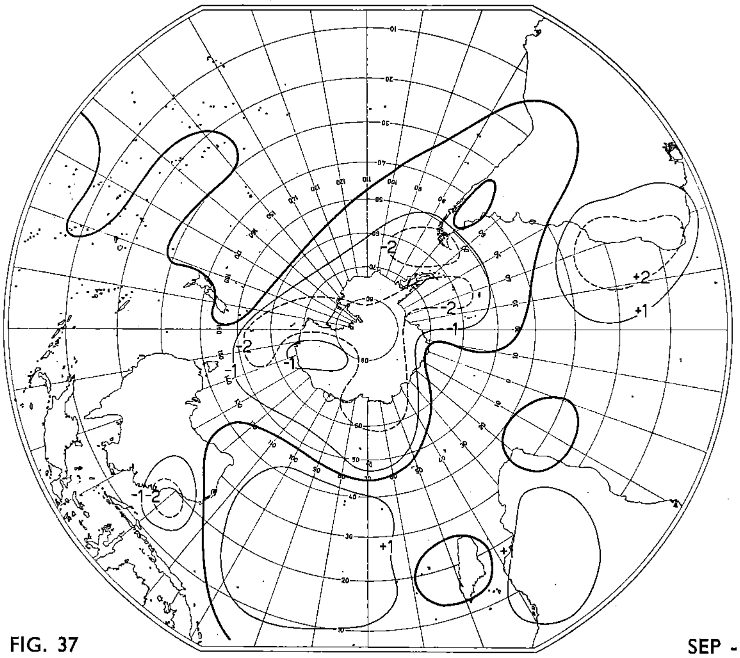


FIG. 37 SEP - NOV 1960

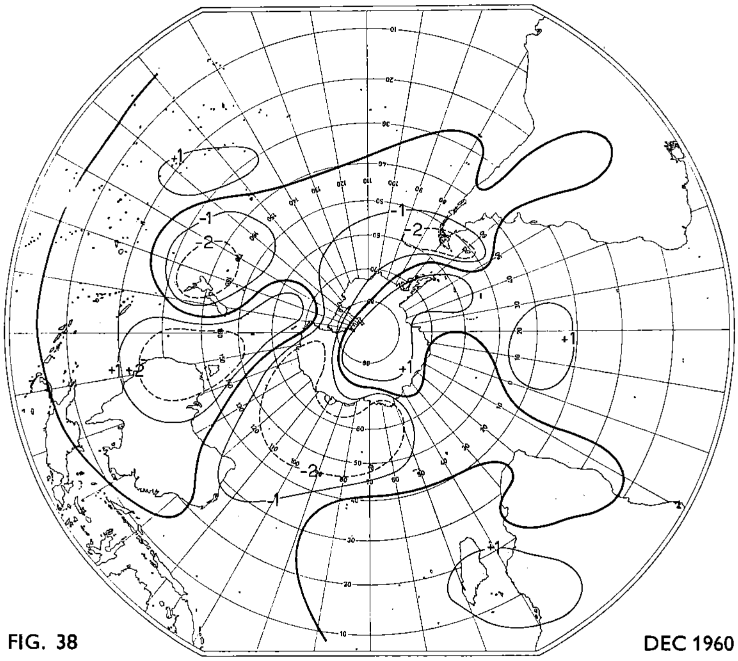


FIG. 38 DEC 1960 - FEB 1961

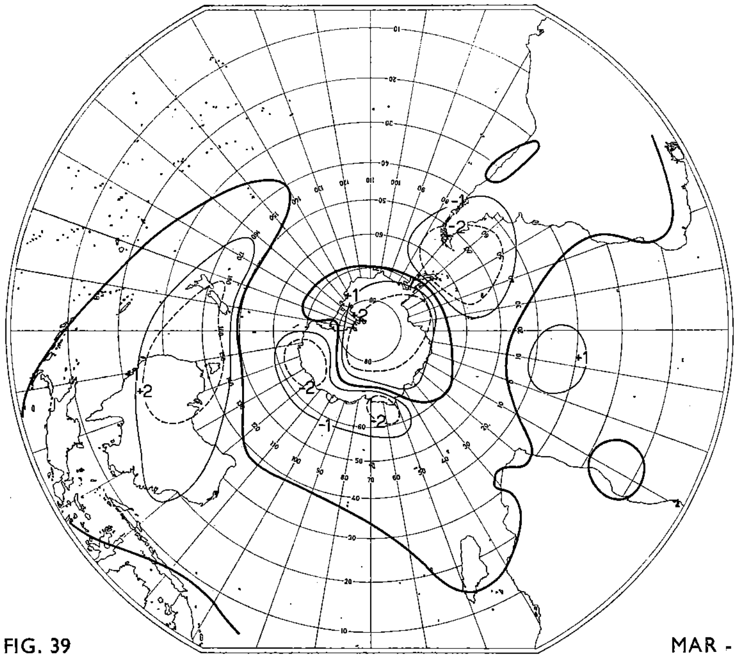


FIG. 39 MAR - MAY 1961

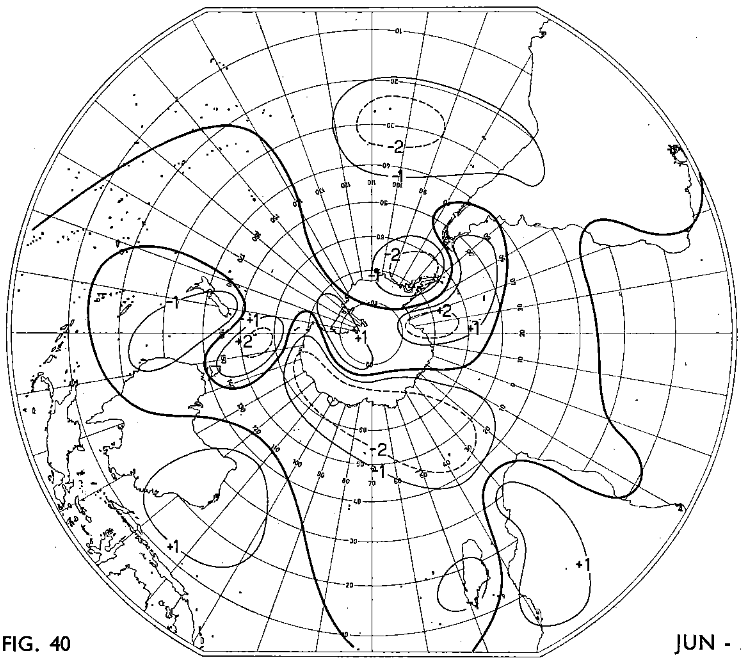


FIG. 40 JUN - AUG 1961

2. INTERFERENCE BETWEEN CONDITIONS IN THE ANTARCTIC AND THE MODE OF OPERATION OF THE SOUTHERN OSCILLATION

2.1 Southern hemisphere pressure and circulation patterns

The present discussion starts with an examination of 23 southern hemisphere maps of mean threemonthly sea-level pressure anomalies (Fig's 18-40). Because of uncertainties isoplethes were drawn only for +2, +1, 0, —1, —2 mb. The first of these maps is for the quarter December 1955-February 1956, the last for the quarter June-August 1961. They cover the I.G.Y., its introduction and part of its continuation. Antarctic data are numerous from January 1957.

Some pictures of this series may require final adjustments. Hence, the present discussion of the meteorological interaction between Antarctic and lower southern latitudes, which is moreover confined to sealevel conditions, must be considered preliminary. Nevertheless, the author's impression, stimulated by SCHELL, is that very useful information can be obtained from the data given by the Antarctic stations which have been in operation through a large number of years, McMurdo Sound (77°50'S, 166°36'E) and Little America (78°14'S, 161°55'W) on the one hand, and Deception Island (62°59'S, 60°43'W), off Palmer Peninsula, and other nearby stations on the other. Deception Island is in excellent opposition to Punta Arenas (53°10'S, 70°54'W) relative to Drake Passage, and possesses a continuous air pressure record from February 1944 up to the present time.

Table 16 indicates the characteristic features of the South Pacific general circulation in the course of four S.O. waves, one 3-year wave followed by three waves of decreasing length, 1½, 1½ and 1¼ year respectively. These four waves total one interval between sudden weakenings of the S.O. circulation, moments of major relaxation. However, as was noted in para 1.10, the dust veils caused by the eruptions of Bezumianny (Kamtchatka), October 1955, and of Gunung Batur (Bali), February 1963, almost surely have contributed to the opening of this interval and the opening of a new interval. Hence, the author felt obliged to qualify the relaxations occurring Dec 1955-Feb 1956 and Jun-Aug 1963 as quasi relaxations. Let us add Mar-May 1959, Sep-Nov 1960 and Mar-May 1962 as seasons in which minor relaxations occurred. These minor relaxations are to be considered as features of the normal S.O. cycle, its pressure waves being, as we know, not strictly sinusoidal, but of a saw-tooth type (1.7). The minor relaxations are inessential. Very probably the two major relaxations in the past ten years occurred in the southern winter quarters Jun-Aug 1956 and Jun-Aug 1964, their interval amounting to 8 years (See Fig. 13).

Early in 1956, after two years of abnormally high pressure in Easter Island and low pressure in Djakarta, leading to a top value of the anomaly of the pressure difference between these two places of +3.0 Mar-May 1956 (Fig. 19) and having been naturally associated with a very quick S.O. circulation, a long pressure wave is introduced by relaxation. The sense of this relaxation is well expressed by the rather sudden decrease of the pressure difference between Punta Arenas and Deception Island from relatively

TABLE 16. *Characteristic features of South Pacific circulation.*

Relaxation	Season	Eruption Java Monsoon El Niño	S.O. Circulation 0°-40° and Peru Current	West Circulation 40°S-60°S Pacific Ocean	Airpressure Antarctica	Pressure gradient anomaly mb		Sea Suface temperature anomaly Puerto Chicama
						Easter Is.-Djakarta	Punta Arenas Deception Is.	
	Mar 55-May 55		quick	zonal		+0.9	+1.1	—1.3
	Jun 55-Aug 55		quick	zonal		+0.9	+1.7	—1.1
	Sep 55-Nov 55	Bezumianny	quick	zonal		+1.0	+3.0	—1.2
quasi	Dec 55-Feb 56		decelerating	meridional	high	+1.1	—5.7	—2.0
	Mar 56-May 56		decelerating	meridional	high	+3.3	—5.8	—0.5
major	Jun 56-Aug 56		decelerating	meridional	normal	+0.6	+1.3	—0.3
	Sep 56-Nov 56		decelerating	weak	normal	—0.2	+1.8	—0.7
	Dec 56-Feb 57		decelerating	weak	normal	—2.7	+0.4	—0.4
	Mar 57-May 57		slow	meridional	divided	—1.6	+4.4	+2.4
	Jun 57-Aug 57	Java dry	very slow	meridional	high	—1.1	—1.9	+2.3
	Sep 57-Nov 57		very slow	meridional	very high	—1.2	—2.2	+0.2
	Dec 57-Feb 58	El Niño	very slow	meridional	very high	—0.2	—3.2	+2.8
	Mar 58-May 58		accelerating	zonal	high	—2.3	+1.8	+0.7
	Jun 58-Aug 58		accelerating	meridional	low	—0.5	—0.4	+0.3
	Sep 58-Nov 58		quick	zonal	normal	+1.5	+3.9	—0.4
	Dec 58-Feb 59		decelerating	zonal	low	—0.9	+5.3	—0.4
minor	Mar 59-May 59		decelerating	meridional	normal	—0.1	+0.2	+0.7
	Jun 59-Aug 59		accelerating	meridional	high	+1.5	—2.4	—0.5
	Sep 59-Nov 59		accelerating	zonal	low	—0.2	+3.3	—0.3
	Dec 59-Feb 60		accelerating	meridional	normal	—0.1	+2.3	—0.5
	Mar 60-May 60		accelerating	zonal	low	—0.4	+5.0	—1.2
	Jun 60-Aug 60		quick	zonal	low	+0.4	+2.0	—0.7
minor	Sep 60-Nov 60		decelerating	meridional	divided	+1.5	—1.5	—0.4
	Dec 60-Feb 61		decelerating	meridional	divided	+1.2	—2.9	—0.1
	Mar 61-May 61		accelerating	zonal	divided	—0.1	+1.4	—0.5
	Jun 61-Aug 61	Java dry	decelerating	meridional	divided	—4.8	+2.8	—0.9
	Sep 61-Nov 61		accelerating	zonal	low?	—0.1	+3.6	—0.8
	Dec 61-Feb 62		accelerating	zonal	low?	—0.7	+6.1	—1.0
minor	Mar 62-May 62		accelerating	meridional	high?	+2.5	+2.9	—2.0
	Jun 62-Aug 62		accelerating	zonal		+0.8	+3.7	—0.9
	Sep 62-Nov 62		quick	meridional		+1.3	+0.8	—0.5
	Dec 62-Feb 63	Batur Bali	quick	zonal		+3.2	+5.6	—1.2
	Mar 63-May 63		quick	zonal		+0.4	+2.0	—0.5
quasi	Jun 63-Aug 63		decelerating			+0.3	—3.7	+0.1
	Sep 63-Nov 63		decelerating			—1.4	—5.2	+0.2
	Dec 63-Feb 64		accelerating			+0.3	+0.1	+0.2
	Mar 64-May 64		accelerating			+0.8	—0.4	—1.7
major	Jun 64-Aug 64		decelerating			+1.6	—2.8	—1.7
	Sep 64-Nov 64		decelerating			—0.8	+3.2	—1.0
	Dec 64-Feb 65		decelerating			—0.2	—4.4*	—1.2
	Mar 65-May 65		slow			—1.1	+1.8*	+2.3

* According to pressure gradient Rio Callegos-Deception Is.

high positive anomalies, +1.1, +1.7, +3.0 mb in Mar-May 1955, Jun-Aug 1955, and Sep-Nov 1955 respectively, to exceptionally low negative anomalies, —5.7, —5.8, +1.3 mb in Dec 1955-Feb 1956 (Fig. 18), Mar-May 1956 (Fig. 19) and Jun-Aug 1956 (Fig. 20) respectively. The strong zonal west circulation through Drake Passage was blocked thoroughly through summer and autumn 1955-1956.

During the following four quarters, Sep-Nov 1956 to Jun-Aug 1957 (Fig. 21, 22, 23, 24), the S.O. circulation and the Peru Current were steadily weakening. From Sep-Nov 1956 (Fig. 21) to Mar-May 1958 (Fig. 27) the pressure difference between the Easter Island subtropical high and the Indonesia equatorial low remained low, so that during this interval the S.O. circulation and the Peru Current continued weak. The high positive pressure difference Punta Arenas-Deception Island during Mar-May 1957 (Fig. 23), although stimulating westerlies and a strong flow of water through Drake Passage, did not contribute to a reacceleration of the S.O.circulation and the Peru Current, apparently because the west circulation showed strong meridional components. Increased flow of South Sea water eastward through Drake Passage in this case was associated with decreased flow northward along the west coast of South America.

Sea surface temperature at Puerto Chicama increased from a very low value in summer, Dec 1955-Feb 1956, to an exceptionally high value in winter, Jun-Aug 1957. The Peru Current must have been very weak. This weakness must have been favourable to the advection of equatorial warm water along the Peru coast southward. The sea surface temperature top in the early part of 1958 characterized that year as an El Niño year, similar to 1932, 1939, 1941 and 1943 (Fig. 7). Blocking of the west circulation in this case is indicated by the very low negative anomaly of the pressure difference Punta Arenas-Deception Island in summer, Dec. 1957-Feb 1958 (Fig. 26).

The important gradual change occurring between the quarters Dec 1955-Feb 1956 and Dec 1957-Feb-1958 in the central equatorial Pacific section, along the 150°W meridian, most probably led, as was shown by AUSTIN (1960), to an important easterly transport of warm surface water from the West. A rather definite relaxation of the general circulation in this region occurred about September 1957, and this may have implied the equatorial counter current's contribution to the abnormal southward flow of warm water along the Peru coast early in 1958.

In autumn, Mar-May 1958 (Fig. 27), the S.O.circulation is already growing stronger again. This acceleration is connected with a strong zonal west circulation, the reappearance of a positive anomaly of the pressure gradient Punta Arenas-Deception Island and elimination of the blockings. The return of the blockings and frequent meridional air flow between 40° and 60°S in winter, Jun-Aug 1958 (Fig. 28), does not obstruct the acceleration of the S.O. circulation and the Peru Current, evidently because pressure has meanwhile risen strongly in the Easter Island subtropical high. In fact, the S.O. circulation is accelerated and remains strong through spring, Sep-Nov 1958 (Fig. 29). In the meantime sea surface temperature at Puerto Chicama has been sinking below normal.

In the following summer, Dec 1958-Feb 1959 (Fig. 30) the S.O. circulation is normalized, the west-circulation is mostly zonal, in particular through Drake Passage, as evidenced by abnormally high pressure differences Punta Arenas-Deception Island. These conditions have not been associated with an acceleration of the S.O. circulation. The S.O. circulation is slowing down, sea surface temperature at Puerto Chicama is rising even slightly above normal, as if El Niño would come through this time.

The two S.O. waves which are going to follow are rather similar. Pressure anomalies in the S.O. region proper, with the exception of winter Jun-Aug 1961, remain favourable to a rapid S.O. circulation and a strong Peru Current, yielding low sea surface temperatures in Puerto Chicama. When looking backward through the pressure fluctuations we even discover three successive analogue waves of $1\frac{1}{2}$ years duration. The repetition of circumstances is remarkably well demonstrated by (a) the variation of the anomalies of the pressure gradient Punta Arenas-Deception Island, (b) the succession of zonal and meridional types of west circulation in latitudes 40°-60°S. We observe how three times in succession a very high pressure difference Punta Arenas-Deception Island, persisting through two seasons (Sep 1958-Feb 1959 (Fig. 29, 30), Mar 1960-Aug 1960 (Fig. 35, 36), Sep 1961-Feb 1962) and associated with a strong zonal west circulation, is followed by a very low pressure difference (Jun-Aug 1959 (Fig. 32) Sep-Nov 1960 (Fig. 37), Mar-May 1962, as well as by very high positive anomalies of the pressure difference Easter Island-Djakarta. This common rhythmic movement of two pressure differences, completely distinct regionally, the one in tropical and the other in polar latitudes, is a rather strong indication of the significance of interactions between areas in these two very different latitudes.

There is conspicuous similarity of conditions during Dec 1955-Feb 1956 and Jun-Aug 1964, extremely high pressure difference Easter Island-Djakarta and extremely low pressure difference Punta Arenas-Deception Island, associated with very low sea surface temperature Puerto Chicama. The transitions from previous toward following conditions are less analogous. The trends are different, but involve relaxations.

Since a small pressure difference Punta Arenas-Deception Island, or even for some time a negative difference, indicates blocking of the west circulation, we may conclude that these sudden variations from a predominantly zonal to a meridional type of circulation, and the gradual intensification of the west circulation between the times of relaxation, are phenomena connected with the evolution and dissipation of mid latitude planetary waves in the southern hemisphere general circulation. They are enhanced by the existence of the Andes and the Palmer Peninsula chain of mountains, barring the general eastward flow of air and leaving only Drake Passage free to west winds.

It seems possible to illustrate the basic type of Southern Oscillation even somewhat more distinctly. This is done in Table 17 containing two series of values, viz:

(1) The sum of the two seasonal anomalies of the pressure differences Easter Island-Djakarta and Punta Arenas-Deception Island.

(2) The difference of the two seasonal anomalies of the pressure differences Easter Island-Djakarta and Punta Arenas-Deception Island.

TABLE 17. *Sums and differences of the seasonal anomalies of the pressure differences Easter Island-Djakarta and Punta Arenas-Deception Island.*

Mar 55-May 55	+2.0	−0.2	Mar 60-May 60	+4.6	−5.4
Jun 55-Aug 55	+2.6	−0.8	Jun 60-Aug 60	+3.3	−2.5
Sep 55-Nov 55	+4.0	−2.0	Sep 60-Nov 60	−0.3	+3.3
Dec 55-Feb 56	−4.7	+6.8	Dec 60-Feb 61	−2.7	+4.1
Mar 56-May 56	−2.5	+9.1	Mar 61-May 61	+1.3	−1.5
Jun 56-Aug 56	+1.9	−0.7	Jun 61-Aug 61	−2.0	−7.6
Sep 56-Nov 56	+1.6	−2.0	Sep 61-Nov 61	+3.5	−3.7
Dec 56-Feb 57	−2.3	−3.1	Dec 61-Feb 62	+5.4	−6.8
Mar 57-May 57	+2.8	−6.0	Mar 62-May 62	+5.4	−0.4
Jun 57-Aug 57	−3.0	+0.8	Jun 62-Aug 62	+4.5	−2.9
Sep 57-Nov 57	−3.4	+1.0	Sep 62-Nov 62	+2.1	+0.5
Dec 57-Feb 58	−3.4	+3.0	Dec 62-Feb 63	+7.8	−2.4
Mar 58-May 58	−0.5	−4.1	Mar 63-May 63	+2.4	−1.6
Jun 58-Aug 58	−0.9	−0.1	Jun 63-Aug 63	−3.4	+4.0
Sep 58-Nov 58	+5.4	−2.4	Sep 63-Nov 63	−6.6	+3.8
Dec 58-Feb 59	+4.4	−6.2	Dec 63-Feb 64	+0.4	+0.2
Mar 59-May 59	+0.1	−0.3	Mar 64-May	+0.4	+1.2
Jun 59-Aug 59	−0.9	+3.9	Jun 64-Aug 64	−1.2	+4.4
Sep 59-Nov 59	+3.1	−3.5	Sep 64-Nov 64	+2.4	−4.0
Dec 59-Feb 60	+2.2	−2.4	Dec 64-Feb 65		

As a result of smoothing minor variations, the second series shows most clearly the longer cycle. The first series, on the contrary, shows most clearly the subdivision into shorter cycles. The high values of the second series point to the sudden variations from strong to weak general circulation, or relaxations. Major relaxations occur apparently during the intervals Mar-Aug 1956 and Jun-Nov 1964. This suggested that a great S.O. swing similar to the one which occurred 1957-1958 was due to occur again 1965-1966. In fact, as is clearly shown by both Fig. 1 (Djakarta) and Fig. 2 (Santiago), the 1964-1966 S.O. pressure wave grew large, but, with refeience to EASTON's period (1.5), not as large as the threatening 1876-1878 pressure wave.

2.2 Meridional and zonal interrelationships

Our present picture shows that the Southern Oscillation is to a certain extent tied in with the west circulation through subantarctic latitudes. It is probably also affected by conditions in Antarctica.

The antarctic pressure patterns often show central symmetry with regard to the South Pole. The antarctic continent acts as a natural unit. HOFMEYR (1957) pointed out that 'correlations between pressures at widely distant stations on Antarctica can be as high as 0.8. However all relationship across the circumpolar trough is poor'.

Nevertheless, as Table 18 shows, the *variations* of the anomalies of the pressure difference Easter Island-Djakarta and Punta Arenas-Deception Island from one season to the next show reverse signs in 44 cases and the same sign in 21 cases out of a total of

TABLE 18. *Seasonal anomalies of airpressure differences in mb.*

	Punta Arenas-Deception Is.	Easter Island Djakarta		Punta Arenas-Deception Is.	Easter Island Djakarta		Punta Arenas-Deception Is.	Easter Island Djakarta
Mar 44-May 44	+0.5	−0.7	Dec 47-Feb 48	+2.9	−1.7	Sep 51-Nov 51	−5.3	−1.9
Jun 44-Aug 44	−2.0	−1.8	Mar 48-May 48	+0.4	+0.6	Dec 51-Feb 52	+1.6	−0.3
Sep 44-Nov 44	−9.0	−1.6	Jun 48-Aug 48	−1.8	+2.1	Mar 52-May 52	+0.9	−1.0
Dec 44-Feb 45	−3.0	+0.3	Sep 48-Nov 48	−1.3	−2.4	Jun 52-Aug 52	+0.6	−1.0
Mar 45-May 45	−4.6	−3.5	Dec 48-Feb 49	−1.8	−3.2	Sep 52-Nov 52	+1.9	−2.4
Jun 45-Aug 45	−6.5	−0.8	Mar 49-May 49	−4.9	−0.4	Dec 52-Feb 53	+5.8	−1.9
Sep 45-Nov 45	+0.4	−2.5	Jun 49-Aug 49	−0.1	+1.8	Mar 53-May 53	−3.0	−0.7
Dec 45-Feb 46	−4.1	+0.4	Sep 49-Nov 49	+5.8	−0.2	Jun 53-Aug 53	+1.4	−2.0
Mar 46-May 46	+1.2	+0.3	Dec 49-Feb 50	−5.4	+2.0	Sep 53-Nov 53	−2.2	+1.0
Jun 46-Aug 46	+2.9	−1.5	Mar 50-May 50	−5.0	+2.6	Dec 53-Feb 54	+3.1	+1.3
Sep 46-Nov 46	−3.6	−0.5	Jun 50-Aug 50	−2.4	+1.9	Mar 54-May 54	+5.1	+0.7
Dec 46-Feb 47	−4.4	+0.3	Sep 50-Nov 50	+0.1	+1.5	Jun 54-Aug 54	−0.7	+0.1
Mar 47-May 46	+0.3	−0.4	Dec 50-Feb 51	+1.9	+0.6	Sep 54-Nov 54	+0.2	+2.7
Jun 47-Aug 47	+1.5	−0.3	Mar 51-May 51	−2.9	−2.1	Dec 54-Feb 55	+1.8	+1.8
Sep 47-Nov 47	+1.4	—	Jun 51-Aug 51	+2.4	−3.6	Mar 55-May 55	+1.1	+2.5

69 cases. In 4 cases one of the variations is zero. Hence the variations with time of pressure differences characteristic of the Southern Oscillation are frequently linked with variations characteristic of connections South America-Palmer Peninsula. This relationship points to a mode of operation of the S.O. such that antarctic latitudes are frequently involved.

Moreover, as SIMPSON (1919) pointed out already, pressures in McMurdo Sound and at stations in the subtropical high pressure belt through the South Pacific and Indian Ocean are inversely related. His investigation was based on observations made during only 4 years, viz. 1902, 1903, and 1911, 1912.

It is, therefore, extremely interesting that SIMPSON's conclusion, which probably holds for the entire Ross Sea, could be verified through 1929-1930 (Little America II, Byrd Antarctic Expedition), 1934-1935 (Little America II, Byrd Antarctic Expedition), 1940-1941 (Little America III, U.S. Expedition) and 1957-1961 (Little America IV and V, IGY and successive years). The coefficients of correlation between McMurdo Sound - Little America and Djakarta seasonal pressure anomalies through 11 years, are given in Table 19.

These values are relatively high positive, with the one exception of southern winter. If the annual anomalies are considered, the correlation coefficient rises to R = +.78, a value which is highly significant. Now, the maps of the seasonal pressure anomalies only rarely show a direct connection between the Indonesia and the Ross Sea areas. Hence we must conclude that this outstanding positive relationship between the pressure anomalies in both areas is to be explained by similarity of zonal pressure

TABLE 19. *Coefficients of correlation between contemporary seasonal air pressure at McMurdo Sound-Little America and Djakarta through 11 years.*

Dec-Feb	R = +.54	Jun-Aug	R = −.24
Mar-May	R = +.47	Sep-Nov	R = +.54

TABLE 20. *Characteristics of South Pacific general circulation.*

Southern Latitude	0-20° equatorial	20°-40° subtropic	40°-50° middel	50°-60° subantarctic	60°-70°	70°-80° antarctic	80°-90° antarctic
Characteristic Winds	zonal trades (monsoons)	meridional weak	zonal westerlies weak	westerlies strong	stormy	meridional strong	weak
Representative Stations	Djakarta	Easter Is.	Chatham Is.	Punta Arenas	Deception Is.	McMurdo Sound	Amundsen Scott
General Circulation			*Contemporary Pressure Anomalies* September-May				
weak	+	−	−	+	−	+	+
strong	−	+	+	−	+	+	+
			June-August				
weak	+	−	−	+	−	−	+
strong	−	+	+	−	+	+	−

index. Consequently it is very useful to state how far the S.O., essentially an air pressure see-saw between the Easter Island subtropical high and the Djakarta equatorial low is covered by zonal relationships. Our final conclusion in this respect is contained in Table 20.

In his 1957 publication the author, with reference to a paper by VON SCHUBERT (1927), stated p. 85 a 'principal antithesis between the tropical belt and the polar caps'. He must correct himself here and wishes to support, at least for the southern hemisphere 'a principal antithesis between the equatorial belt (0-20°) and the subantarctic belt (60°-70°) and between the subtropical belt (20°-40°) and the antarctic cap (70°-90°)'.

We mention the inverse correlation of the zonal winds at the 50.000 ft level at Canton Island (2°46′S, 171°43′W) and Singapore (1°18′N, 103°53′E) pointed out by Reed and Rogers (1962), because it suggests S.O. fluctuations reach such a height. At the 60.000 and 70.000 ft level these zonal winds are sharing the now well known biennial fluctuations from easterly to westerly directions in the equatorial stratosphere, contemporary all around the globe. It can, however, hardly be of any significance in pressure relationships, as 10.000 ft is the 700 mb and 50.000 ft is the 80 mb level in the atmosphere. The coefficients of correlation between the annual pressure anomalies at Djakarta and Chatham Island through no less than 32 years, 1930-1961, are negative and as high as R = —.64. Hence, Chatham Island (44°20′S, 176°00′W) is definitely included in the Easter Island region of the S.O. pressure variations, whereas the nodal line of this oscillation crosses New Zealand. The coefficients of correlation between the annual pressure anomalies at Djakarta and those at Campbell Island (52°33′S, 169°07′E), Macquarie Island (54°30′S, 150°57′E) and Camp Dumont d'Urville (Terre Adélie 66°40′S, 140°01′E), three stations all south of New Zealand, are low. However, as expected, pressure anomalies at Campbell Island and Macquarie Island mostly bear the same sign as those at Chatham Island, whereas pressure anomalies at Camp Dumont d'Urville, on the antarctic coast, mostly bear the same sign as those of McMurdo Sound and Little America.

During the polar night the Ross Sea apparently is part of the subantarctic zone. In southern winter, the antarctic polar area is contracted while storm tracks frequently enter Antarctica (Rubin and Van Loon, 1954, Vowinckel, 1956) This might explain the negative correlation between Ross Sea and Djakarta pressure anomalies in southern winter.

To ascertain how conditions in the Antarctic are related to the general circulation in the low and middle latitudes, planimeter measurements were made of Antarctic areas featured in the seasonal southern hemisphere sea level pressure maps (published in Notos). These areas were within the high latitude low pressure belt, enclosed by the 1005 mb sea level isobar. The period covered was Mar-May 1951 to Mar-May 1959. The results of these measurements for each of the sectors 70°W-20°E, 20°E-110°E, 110°E-160°W, 160°W-70°W and in the area as a whole are given in Table 21.

The total area where pressure is lower than 1005 mb, without corrections for those few cases where the Antarctic low pressure area is distinguished by an anticyclonic centre where pressure exceeds 1005 mb, is on the average smallest in southern autumn, March-May. From December 1952 through November 1953 this area remained strongly reduced, reaching its smallest extension in the winter of Jun-Aug 1953. This emphasis on the year 1953 is related to the fact pointed out by Kraus (1960) that the annual air mass oscillation between the northern and the southern hemisphere yielded greatest mass accumulation between 12°30′S and 37°30′S as well as between 37°30′S and 62°30′S throughout the year 1953, the highest value being reached in winter. The radical southern hemisphere-wide change in the zonal circulation during 1952 was pointed out by Berson and Radok (1959).

2.3 Interactions with Antarctica

When considering the individual areas listed in Table 21, the most outstanding contraction of the Antarctic low pressure area occurred within the sector 160°W-70 W, the Southeast Pacific area, Mar-Aug 1953. This situation may be compared with the situation prevailing during Jun-Nov 1957, when the area considered reached its greatest extension. In this latter case a high pressure ridge between the Easter Island subtropical high and Antarctica barred the westerlies in middle and subantarctic latitudes, weakening the S.O. circulation and the Peru Current. Consequently sea surface temperatures at Puerto Chicama increased strongly.

In southern autumn and winter 1951 very high sea surface temperatures at Puerto Chicama were also regularly associated with very large negative anomalies of the principal pressure gradient Easter Island-Djakarta, which amounted to —2.1 and —3.6 mb in Mar-May and Jun-Aug, respectively. However, Antarctic low pressure areas were not equally contracted, as in 1953 during these seasons. The situations prevailing during Mar-May 1951 and Jun-Aug 1951 were probably similar to those prevailing during Dec 1956-Feb 1957 and Mar-May 1957, the anomalies of the principal pressure gradient Easter Island-Djakarta amounting then to —2.7 and —1.6 mb, respectively. The anomalies of the pressure gradient Punta Arenas-Deception Island amount to —2.9 and +2.4 mb in the first instance and to —0.2 and +2.4 mb in the second instance. Thus, none of the two cases is characterised by pressure ridge building between Antarctica and the Southeast Pacific subtropic high. Hence in autumn and winter 1951 as well as in summer and autumn 1957 the very low pressure difference Easter Island-Djakarta is solely responsible for a weak S.O. circulation and a very weak Peru Current.

2.4 The 1945-1946 anomaly

It is not surprising that different conditions exist in higher latitudes, together with outstanding similarities in conditions in lower latitudes for 1951 and 1953. As shown by Fig. 7 the fluctuations of sea surface temperature at Puerto Chicama are mainly determined by the Southern Oscillation pressure fluctuations and hence the strength of the Peru Current. The coefficient of correlation between the annual pressure anomalies at Djakarta and the annual sea surface temperature anomalies at Puerto Chicama through 30 years, 1925-1954, is as high as $R = +.61$.

It is this prominent and persistent relationship between sea surface temperature and pressure on opposite sides of the Pacific Ocean which the author considers to be one of the strongest arguments in favor of his thesis regarding the origin of the S.O. proper. From the important exceptions to this rule we may learn a great deal about both the normal and the abnormal behaviour of the S.O.

Let us consider in detail the anomaly of 1945-1946, which certainly is the most spectacular one. Through the greater part of 1945 and 1946 Easter Island pressure moved up and down with Djakarta pressure, while sea surface temperature at Puerto

TABLE 21. *Antarctic areas within the high latitude low pressure belt enclosed by 1055 mb isobar, measured in arbitrary units.*

	70°W-20°E	20°E-110°E	110°E-160°W	160°W-70°W	70°W-20°E	20°E-110°E	110°E-160°W	160°W-70°W	70°W-20°E	20°E-110°E	110°E-160°W	160°W-70°W	70°W-20°E	20°E-110°E	110°E-160°W	160°W-70°W
		Dec-Feb				Mar-May				Jun-Aug				Sep-Nov		
1950-51					82	91	86	86	98	95	88	105	99	117	107	91
1951-52	112	105	91	92	73	117	113	60	91	86	77	85	86	96	90	82
1952-53	97	92	82	57	103	94	80	53	84	98	79	35	85	100	99	60
1953-54	101	93	89	65	99	99	95	59	92	108	93	104	87	107	87	67
1954-55	98	101	89	90	95	96	79	82	88	98	73	93	84	99	98	80
1955-56	106	95	73	87	81	90	66	75	68	93	107	94	91	104	87	85
1956-57	111	112	97	78	95	102	88	68	102	132	102	78	105	139	125	95
1957-58	126	124	111	91												
1958-59					114	108	102	79								

Totals	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov
1950-51		345	386	414
1951-52	400	363	339	354
1952-53	328	330	296	344
1953-54	348	352	397	348
1954-55	378	352	352	361
1955-56	361	312	362	367
1956-57	398	353	414	464
1957-58	352			
1958-59		403		
Average	366	351	364	379

Chicama fell very low and subsequently returned to normal. As Santiago pressure remained very low in 1946, maintaining the regular antiparallelism with Djakarta, the irregular parallelism was shown in particular by Easter Island, representative of the Southeast Pacific subtropical high.

The reason for the anomalous rise of pressure at Easter Island in 1946 was, apparently, the persistence of very high air pressure in the Deception Island region during 1944-1945. As Table 22 shows, the average monthly pressure differences Punta Arenas-Deception Island remained very low from July 1944 through August 1945. They even reached the negative average value of —1.7 mb in August 1945, a condition leading to easterly winds through Drake Passage. Such monthly average negative pressure differences occurred in only six other cases, namely in January 1947, November 1951, December 1955, August 1957, August 1963 and July 1964.

This unusually effective barring of Drake Passage to westwinds (SCHWERDTFEGER, 1962) was associated with the building of a high pressure ridge between Antarctica and the Southeast Pacific subtropical high and by reinforcement of the latter. High pressure prevailed there through 1946, while low pressure prevailed in Santiago. The steep pressure gradient Easter Island-Santiago probably caused a strong Peru Current and low sea surface temperatures at Puerto Chicama through 1946.

The contrasts between conditions in 1945-1946 and those in 1956-1957 are as follows. Pressure at Easter Island rose in 1945-1946 and fell in 1956-1957 and it seems likely that during the first period the building of the high pressure ridge between Antarctica and the Southeast Pacific high started from Antarctica, whereas in the second year it started from the Southeast Pacific high. Hence in 1945-1946 the pressure difference Easter Island-Santiago was raised, in 1956-1957 it was lowered. Consequently in the first case the southerly winds along the Chile coast were strengthened, while in the second case they were weakened, and hence in the first case the Peru Current was accelerated and in the second case decelerated.

TABLE 22. *Difference of mean monthly sea level pressure between Punta Arenas and Deception Island (1944-1964).*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1944	—	9.3	12.8	15.6	8.8	13.9	6.3	6.2	7.6	1.7	3.9	1.8
1945	11.6	9.8	9.8	11.8	0.2	9.5	5.1	−1.7	11.8	19.4	12.4	7.9
1946	9.1	2.9	12.1	16.3	11.9	15.1	8.3	17.7	13.3	12.8	5.5	11.2
1947	−2.1	7.7	10.4	18.2	8.0	4.2	12.4	10.3	17.0	11.2	18.4	10.8
1948	—	16.3	13.9	11.6	11.5	8.9	9.0	9.2	8.5	18.3	15.6	4.7
1949	12.9	9.0	2.8	12.5	5.6	3.0	10.4	18.6	18.5	21.1	19.5	1.9
1950	5.5	8.6	3.8	9.6	7.2	1.6	9.3	14.4	15.5	12.1	15.1	9.1
1951	14.0	14.8	4.3	19.9	5.8	14.4	14.7	10.5	17.2	10.0	−0.8	9.8
1952	12.5	14.5	11.5	11.2	15.7	8.8	11.0	14.5	17.4	14.4	16.2	20.3
1953	11.3	17.8	11.9	14.0	0.8	17.8	12.6	6.2	1.6	18.6	15.6	11.7
1954	13.9	15.8	13.4	18.5	19.0	16.8	6.2	7.4	15.6	16.5	10.7	0.9
1955	9.5	16.4	13.9	11.5	13.6	11.9	17.6	8.1	15.4	19.3	16.5	−1.3
1956	5.6	10.7	9.3	5.8	3.2	11.8	5.2	19.2	9.7	19.9	18.2	12.2
1957	7.4	13.8	16.9	19.4	12.7	14.8	14.9	−3.1	13.7	13.5	7.5	2.4
1958	12.0	8.2	14.0	13.6	13.4	12.1	1.6	17.4	23.2	19.5	11.3	18.9
1959	17.2	11.8	10.9	10.8	14.6	5.6	14.2	6.5	13.0	16.3	22.8	11.3
1960	13.3	14.5	20.4	17.4	12.9	7.5	13.2	20.4	13.3	12.1	11.5	10.5
1961	4.7	8.3	14.9	6.7	18.4	15.3	13.5	11.9	11.3	23.2	18.7	17.8
1962	11.2	21.4	11.6	16.2	16.7	13.6	18.0	11.9	14.1	15.4	15.2	12.1
1963	17.6	19.3	19.9	8.6	13.1	19.0	12.8	−0.4	1.4	12.2	13.2	12.6
1964	7.7	12.2	10.7	12.0	11.9	13.2	−2.3	13.0	13.0	10.7	18.2	7.9

We may thus conclude that the 1945-1946 anomaly was due to Antarctica interfering with the circulation in the eastern South Pacific north of 40°S. As illustrated by Fig. 41 frequent polar outbreaks through 1945 may have contributed to the intensification of the Southeast Pacific high which persisted through 1946. The rarity of this occurrence is probably connected with the realisation of a certain limiting configuration of the pressure pattern towards the close of 1944. In fact, as shown by Table 18, through southern spring, Sep-Nov 1944, the pressure difference Punta Arenas-Deception Island remained no less than 9.0 mb below the normal. This situation strongly favours an invasion of antarctic air into the Southeast Pacific and Southwest Atlantic along Palmer Peninsula, whereas under normal conditions cold polar outbreaks tend to occur more frequently down from the massive Enderby and Victoria Quadrants of Antarctica, as was shown by RUBIN and VAN LOON (1954), VOWINCKEL (1956), GLASSEY (1961) and ALT and others (1959).

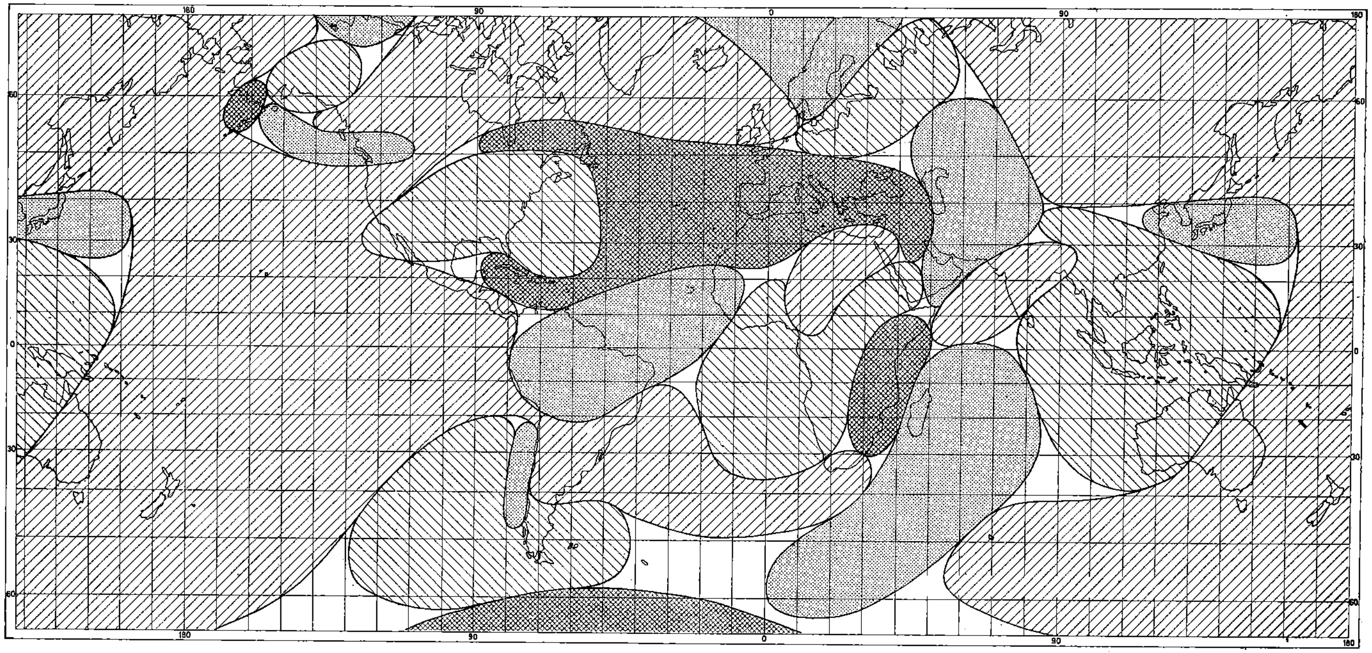


Fig. 41 Global areas where air pressure through 1945-1946-1947 was

lowest in 1946 | highest in 1946 | highest in 1945 | highest in 1947

TABLE 23. *Statistically significant lag correlations between seasonal air pressure anomalies.*

Jun-Jul-Aug		*Sep-Oct-Nov*
Honolulu	+0,36	San Francisco
	−0,42	Lahore+Karachi
	−0,68	Darwin
	−0,38	Brisbane+Adelaide+Alice Springs
Jun-Jul-Aug		*Dec-Jan-Feb*
Buenos Aires+Santiago	+0,56	Samoa
	−0,46	Lahore+Karachi
	−0,56	Darwin
	−0,56	Brisbane+Adelaide+Alice-Springs
	−0,48	Mauritius
	−0,56	Zanzibar
	−0,48	Capetown
Charleston	+0,44	Buenos Aires+Santiago
Sep-Oct-Nov		*Dec-Jan-Feb*
Lahore+Karachi	−0,42	Charleston
Darwin	−0,50	
Brisbane+Adelaide+Alice Springs	−0,38	
Buenos Aires+Santiago	−0,44	Irkutsk+Eniseisk
Brisbane+Adelaide+Alice Springs	+0,36	
Lahore+Karachi	−0,62	Samoa
	+0,36	Mauritius
	+0,64	Zanzibar
	+0,48	Capetown
Sep-Oct-Nov		*Mar-Apr-May*
Lahore+Karachi	−0,56	Samoa
	−0,38	Buenos Aires+Santiago
	−0,48	San Francisco
	+0,34	Irkutsk+Eniseisk
Darwin	+0,38	
Brisbane+Adelaide+Alice Springs	+0,50	
Dec-Jan-Feb		*Mar-Apr-May*
Capetown	−0,56	Samoa
Cairo	−0,54	
Zanzibar	−0,42	Buenos Aires+Santiago
Capetown	−0,50	
Dec-Jan-Feb		*Jun-Jul-Aug*
Irkutsk+Eniseisk	−0,46	San Francisco
Zanzibar	−0,40	Darwin
	−0,56	Honolulu
Mar-Apr-May		*Jun-Jul-Aug*
Ponta Delgada	−0,54	Irkutsk+Eniseisk
Stykkisholm	+0,50	
Mar-Apr-May		*Sep-Oct-Nov*
San Francisco	−0,44	Irkutsk+Eniseisk
Honolulu	+0,60	Samoa
	+0,40	San Francisco
	−0,44	Darwin

3. THE STANDARD TYPE OF SOUTHERN OSCILLATION

3.1 The tree-year scheme and its modifications

Table 23 contains a summary of WALKER's statistically significant lag correlations between quarterly airpressure anomalies. It is cited here from Table 33 of the author's main paper (1957).

A careful discussion of these indications resulted in the author's acceptance of a normal 3-year scheme of the Southern Oscillation as represented in Table 24. Besides

TABLE 24. *Southern Oscillation Three Year Scheme.*

Djakarta Years	I Highpressure				II Downward Transition				III Upward Transition			
	D-F	M-M	J-A	S-N	D-F	M-M	J-A	S-N	D-F	M-M	J-A	S-N
airpressure anomaly												
Irkutsk				+	+	+	+		−	−	−	−
Stykkisholm						+				−		
Ponta Delgada					−	−				+		
Charleston					−	−			+			
San Francisco		−	−	−						+	+	+
Honolulu	−	−	−					+	+	+	+	
Djakarta		+	+	+	+		−	−	−			
Brisbane				+	+							
Zanzibar					+				−			
Capetown					+				−			
Samoa				−	−	−			+	+		
Santiago	−	−	−	−		−		+	+	+	+	
Antarctica			+	+	+		−	−	−			
other phenomena												
Tradewinds	−	−	−					+	+	+		
Relaxation									+	+		
El Niño	+	+										
Ceara rainfall	−	−										
Abyssinia rainfall	−	−										
Level Nile			−									
Java rainfall			−	−								
Angola rainfall	−										−	
Surinam rainfall				−	−							
Australia rainfall				−	−							
Peru Current						+						
Cape Verde temp.						−	−	−		+	+	+
S.Africa rainfall					−							

conditions at the stations mentioned in Table 23, Cairo being deleted because too vaguely incorporated, it includes conditions in the Antarctic along the lines developed in Chapter 2.

The scheme as such gives airpressure anomalies, but the following phenomena are added: the strength of the trade winds in the Pacific Ocean, the appearance of high sea surface temperatures along the Peru Coast, likely associated with El Niño Dec-May, Java eastmonsoon droughts Jun-Nov, Australia summer droughts Sep-Feb, Surinam winterdroughts Sep-Feb, Angola droughts Sep-Feb, Ceará droughts Dec-May, Abyssinia dry Dec-May, low Nile Jun-Aug, South Africa dry summer Dec-Feb, South Africa cold winter Jun-Aug, Canada cold winter Dec-Feb, Cape Verde Islands (St Vincent) temperatures Mar-Nov.

The 3-year scheme opens with I, a Djakarta high pressure year, as classified already by C. BRAAK (1919). This is followed by II, a Djakarta downward transition year or low pressure year, and III, a Djakarta low pressure year or upward transition year. On this basis the conditions at other stations were founded, according to known correlations. This grouping shows very clearly that the S.O. is fundamentally a global pressure oscillation of meridional character. The tropical and polar anomalies are in phase, the subtropical anomalies have the opposite sign, both roughly steered east-westward and west-eastward by what is essentially the S.O. operation. It directs the speed of the general atmospheric and hydrospheric circulation.

In the southern hemisphere the antarctic continent is essentially involved, in the northern hemisphere Stykkisholm and Irkutsk are the most northerly stations showing S.O. influences. The Arctic is apparently not associated in any significant way.

We have known this distinction from the beginning. The morphology of continents and seas is such that the Arctic is barred from the rest of the globe roughly along the 70° parallel. The S.O. originates as a water hemisphere phenomenon. It is not without significance that New Zealand designates the centre of the water hemisphere. It is located on the borderline between the two scales of the S.O. balance, on the one side the equatorial Indian Ocean low pressure area defined by Djakarta, and on the other side the subtropic Southeast Pacific high pressure area defined by Easter Island.

The station at Easter Island and even the one at Juan Fernandez did not exist at the time of the famous S.O. 3-year wave trains of the nineteenth and early twentieth century. Santiago, operating since 1861, was therefore taken as representative of the Southeast Pacific high, although this is not strictly justifiable (1.8). However, it makes more sense to work with Santiago situated on the west coast of South America, west of the Andes chain, than to work with the average pressure anomalies Buenos Aires + Corboda + Santiago. When WALKER worked with these pressure anomalies attention had hardly been fixed on Juan Fernandez, where observations started in 1911, and of course not yet on Easter Island where observations started in 1942.

The 3-year scheme represents the S.O. in its purest form, yet a sequence of 3-year waves is rarely maintained. Shorter waves frequently intervene and lead, apparently, as suggested earlier (Table 1.7), to relaxation and a wave-length up to 4 or even 5 years.

Table 25 contains the past one hundred years scheme of years, divided in the classes

I, II, III. This scheme evolved from a detailed analysis of all possible contributing factors. Among these are sunspot numbers, heavy volcanic eruptions, the appearance of El Niño and next Sep-Feb rainfall in Surinam.

The long S.O. waves encompass the following intervals.

	number of years		*number of years*
1871-1876	5	1925-1929	4
1891-1896	5	1940-1944	4
1914-1918	4	1946-1951	5
1919-1923	4	1958-1963	5

EASTON's period is well pronounced between 1873 and 1961, both years with average sunspot numbers below 81, whereas the preceding years, 1872 and 1960 present numbers above 100. There is no other case of such a quick fall of numbers after the passage of a maximum in the whole known series since 1749. The years 1874 and 1962 similarly lead to relaxation. There are, however, indications that the rise of pressure at Djakarta in 1963 was due to the heavy Bali eruption, as this must have caused an equatorial volcanic dust layer in the stratosphere for some time (1.10), whereas 1875 shows no events of this kind. The possibility of similar behaviour of 1964-1965-1966 and 1876-1877-1878 is nevertheless great and of the greatest interest, because of the incomparable conditions which have distinguished the earlier couple of years. The years 1964 and 1876 were both distinguished by a fall of the average sunspot number below 13.

In fact, the analogy of the courses of air pressure failed. Apparently two successive relaxation rises of pressure at Djakarta (Fig. 13) in 1963 and 1965 occurred in stead of one really excessive rise, as occurred 1876-1877. However, three phenomena confirmed the excessivity of 1965. The one is the height of sea surface temperature along the Peru coast (Table 6), associated with unusually heavy winter rains along this coast. India was ravaged by an extreme and persistent drought 1964-1965, unequalled since 1868, whereas Surinam experienced a winter drought 1965-1966, almost as serious as the winter drought occurring 1963-1964.

There are quite a number of cases in which the S.O. is, in a sense abortively, reduced to a two-year swing. The pattern than becomes I, II, I, II, as for instance in 1923; 1924, 1925, 1926; 1930, 1931, 1932, 1933; 1944, 1945, 1946, 1947 or 1951, 1952, 1953, 1954. Two year intervals between Surinam droughts are also rather frequent, as for instance those between droughts occurring at the end of 1864, 1866, 1868; 1900, 1902; 1918, 1920; 1928, 1930, 1932; 1963, 1965. This fact reminds us of the possibility that there is a connection between the S.O. and the approximate two year east-west oscillation in the tropical stratospheric winds, a point to which we will return (3.5, 4.2). Of course, inclinations to either modify the scheme or keep it intact will depend on the weight given to the individual factors. For instance, when we give Indian conditions greater weight than Australian conditions within the Indian Ocean area, we tend to bring 1919 over from column I to column II. If we give opposite weights, and moreover take account of the very low pressure recorded in 1919 at Santiago, within the

TABLE 25. *Southern Oscillation through one hundred years.*

I. Djakarta Highpressure Year

Heavy Volcanic Eruptions	El Niño	Number of Sunspots	39 years	Chile Pressure Tendency South	North	Surinam Rainfall Anomaly Sep-Feb mm
	×		1864			−203
			1866			−315
			1868			−268
	×	+	1871			+337
		−	1876			+ 86
	×	−	1877			−422
			1880			−103
Krakatoa			1883			−184
			1884			−404
			1885			− 49
			1887			−212
Knights/Bandaisan			1888			−369
	×		1891			+204
			1896			−287
		−	1899			−143
		−	1900			−341
Pelée/Santa Maria		−	1902			−220
			1905			− 84
Ksudatsj			1907			−152
		−	1911	−	+	−553
		−	1913			+115
Minami			1914	−	+	+ 97
	×		1918			−309
			1919	−	+	+ 64
			1923	−	+	− 39
	×		1925	−	−	−566
			1929			−145
			1930	−	+	−239
Quitsapu	×	−	1932			−251
			1935			−229
	×	+	1939	−	+	−483
	×		1940	−	−	−202
		−	1944	−	+	+ 4
		+	1946	−	+	−255
	×		1951			−150
	×		1953			− 57
	×	+	1957	−	+	−289
	×	+	1958	−	+	−476
Bali			1963			−448

\+ number of sunspots over 81
− number of sunspots below 13

II. Djakarta Downward Transition Year

Heavy Volcanic Eruptions	El Niño	Number of Sunspots	31 years	Chile Pressure Tendency South	North	Surinam Rainfall Anomaly Sep-Feb mm
			1865			+179
		−	1867			+ 97
			1869			+430
		+	1872			+117
	×	−	1878			+145
			1881			+387
Tarawera			1886*			+501
			1889			+ 89
			1892			
			1897			+307
		−	1901			+444
			1903			−189
			1906			+135
			1908			− 1
			1909			+ 57
Katmai	×	−	1912	+	−	+113
			1915			− 91
			1920			−172
			1924*	+	+	− 42
	×		1926	−	+	+289
			1931			−154
		−	1933			+665
			1936			− 43
	×		1941			− 96
			1945*			−148
		+	1947			+ 78
			1952			+258
		−	1954	+	+	+173
Bezumianny			1955	+	+	+308
		+	1959			+ 9
		−	1964*			+ 32

\+ number of sunspots over 81
− number of sunspots below 13
* relaxation

Southeast Pacific area, and remember the almost inevitable coupling of 1918 and 1919, when trying to understand the rules of relation between the S.O. and sunspot numbers (Berlage 1947, 1957, 1961), we get the impression that the scheme is right.

Another example is 1934. Emphasising India, we would say 1934 is an Indian

III. Djakarta Transition Year

Heavy Volcanic Eruptions	El Niño	Number of Sunspots	31 years	Chile Pressure Tendency South	North	Surinam Rainfall Anomaly Sep-Feb mm
		+	1870			+184
			1873			+555
			1874			− 33
Askja			1875*			+386
		−	1879			+437
			1882*			0
			1890*			+196
		+	1893			
			1894			+210
			1895*			−290
			1898			+217
			1904			− 71
			1910*			+ 99
			1916			+196
	×	+	1917	+	+	+ 62
			1921	+	+	+339
			1922*	+	+	+360
			1927	+	−	+396
			1928*	+	+	−252
		−	1934			− 9
		+	1937			+ 60
		+	1938*	+	−	− 46
			1942	+	+	+482
	×		1943	+	+	+ 47
		+	1948			+181
		+	1949			+701
		+	1950*			+115
		+	1956*			+123
		+	1960			−151
			1961			− 32
			1962*			− 25

+ number of sunspots over 81
− number of sunspots below 13
* relaxation

Ocean high pressure year and has to move from column III to column I. This correction is the more probable, as 1934 is still a year with an average sunspot number below 13, and hence tending to high pressure in the area considered. However, Santiago pressure was extremely high in 1934, and 1935 brought Java a strong and dry east monsoon, because the pressure difference Darwin-Djakarta was abnormally great during the eastmonsoon season. For the same reason the Java eastmonsoon 1961 became strong and seriously dry. Finally, 1935 was also followed by a serious winter drought in Surinam.

The only other year of thorough low pressure type at Djakarta, although that year's average sunspot number remained below 13, is 1879. However, the pressure pit in 1879 is preceded by the spectacular pressure top of 1877, the natural result of a Southern Oscillation relaxation wave of amplitude greater than any recorded since.

The case of 1879 finds its counterpart in 1957-1958 when at Djakarta a pressure top occurred even though these two years were characterized by sunspot numbers above 81. It is similarly the natural result of Southern Oscillation relaxation wave of great amplitude.

The scheme confronts us with a few obvious parallelisms. Among the prominent analogies we note here,

1914	1915	1916	1917	1918
1940	1941	1942	1943	1944

This one is interesting in particular, because both 1917 and 1943 have been distinguished by hydrographic disturbances along the Peru coast, viz. heavy coastal rains, although perhaps not associated with prominent El Niño appearances. The Djakarta pressure curve, in any case, does not indicate the probability of these appearances, but sea surface temperatures at Puerto Chicama show the characteristic El Niño top early in 1943 (Fig. 7).

As a matter of fact we mentioned the smaller-scale anomalous low pressure gradient Easter Island-Santiago in 1943 as the probable reason for an extremely slow Peru Current. This gradient for 1917 is not known, however, the author has no argument for leaving the 1943 Peru anomaly out of consideration. BJERKNES (1961) amongst others does not even mention the case, as if it could be disregarded.

The volcanic eruptions noted in Table 25 all delivered more than one cubic km of ash into the atmosphere (F. BAUR, 1948, Bezumianny-Kamtchatka and Batur-Bali added). It is remarkable that seven eruptions are associated with a Djakarta high pressure year, no more than three with a downward transition year, and only one with an upward transition year, 1875. This latter year provides the rather curious example of a relaxation year immediately followed by the unique S.O. wave 1876-1877-1878.

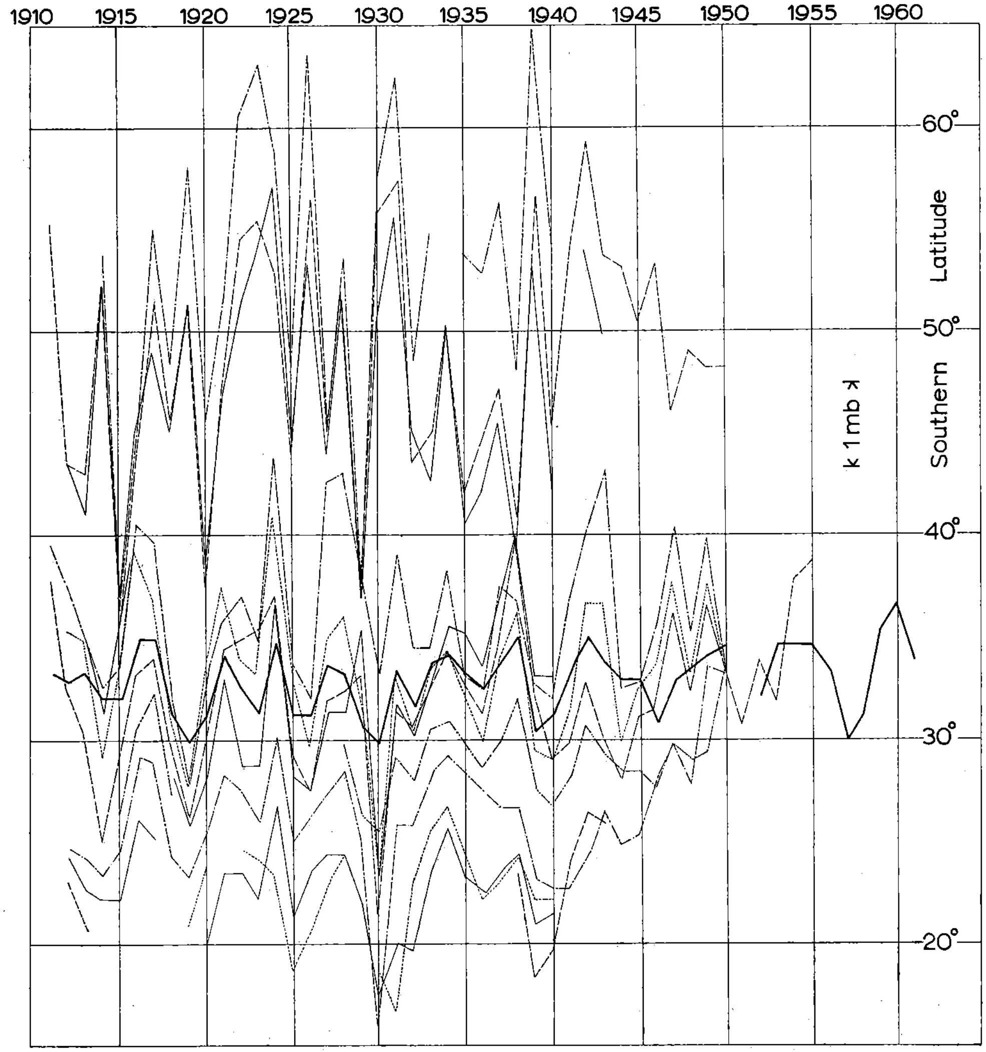
The fact that this grouping is obviously not due to random causes is convincing evidence that volcanic dust veils interfere with the S.O. and thus with the general global circulation. The reader is referred to para 1.10.

3.2 South America a meridional barrier

In Table 25 important indications from the South American side of the S.O. are also given. The variations of pressure at the following Chilean stations are known since 1911.

North of 50°S				*South of 50°S*	
Iquique	23°12′S	San Fernando	34°35′S	Punta Dungeness	52°24′S
Caldera	27°03′S	Punta Tumba	36°37′S	Is. Evangelistas	52°24′S
Punta Tortuga	29°55′S	Temuco	38°45′S	Punta Arenas	53°10′S
Los Andes	32°50′S	Punta Galera	40°01′S	San Isidro	53°47′S
Valparaiso	33°01′S	Frutillo	41°08′S		
Santiago	33°27′S	Isla Guafo	43°34′S		

Fig. 42 Annual air pressure anomalies at 12 Chilean stations in different latitudes.



Variations mean annual airpressure at 12 stations in Chile

There is every reason to separate as in Table 20 the subtropic type of general circulation in the latitudes between 20° and 40° South from the subpolar type between 50° and 60° South (RUBIN 1955).

As demonstrated by Fig. 42 and numerical data, in a large number of years the pressure anomalies in the north and south part of Chile have opposite signs. This is in accordance with the normal picture of meridional variation between subtropic and subpolar latitudes, for instance in 1911-1912, 1914, 1926-1927, 1938-1939, 1946, 1957-1958, 1960, years in which large amplitudes dominate the relationships.

There are, however, other cases which stress parallellism very probably derived from the influence of the South-American continent and the Andes chain of mountains, which constitute a unique north-south barrier against the east-west movement of air and water in the southern hemisphere, for instance in 1917, 1921-1922, 1924-1925, 1940, 1942-1943, 1954-1955.

The circulations north and south of 50°S are both typical, but at certain times more or less independent from each other and at other times closely linked together. The first case is probably realized when the west circulation around 50°S is of the zonal type, the second when this west circulation is more frequently meridional. This would mean that independence is associated with a strong general circulation and dependence with a weak general circulation.

In Table 25 prominent years are distinguished by the following combination of plus and minus signs of the mean annual pressure anomalies.

	a	*b*	*c*	*d*
north	—	—	+	+
south	—	+	—	+

As a matter of fact we meet all cases a and b in column I. The only exception is 1926. The cases *c* and *d* are all found in columns II and III. This partition is a matter of course, since the minus sign between 20° and 40°S along the South-American west coast typifies the S.O. opposition to the high pressure occurring at the same time in the Indonesian equatorial low. The cases of low pressure in both the northern and southern part of the southeast Pacific are limited to 1925 and 1940, the two years which are distinguished by extremes, but in other respects are not similar.

We should in fact avoid overstressing analogies. There is much similarity in the two sequences.

1925	1926	1927	1928	1929
1940	1941	1942	1943	1944

however, the opening and the closing years of these series,

1924 and 1930 1939 and 1945

are dissimilar to such an extent that there is no hope of learning much from similar successions.

We admit the inclination to move 1926, the sole exception, from column II to column I and to intercompare the pairs 1925-1926 and 1939-1940. However, when noting how high rainfall in Surinam was in the winter 1926-1927 and how extremely low in the winter 1928-1929 we are inclined to move 1928 from column III to column I.

Such consideration clarifies the situation. The S.O. operation is not strictly in phase in the two 'scales' of the balance. The one scale often moves in advance of schedule while the other lags a little behind. A scale adopts an early or late character according to the prevailing circumstances. It has already been recognised that some of these circumstances are external and consequently unforeseeable in most cases, e.g. volcanic eruptions and sunspots.

Fig. 42 shows us that even the atmospheric and hydrospheric operations around Easter Island and around Juan Fernandez are often not in unison. In particular a year like 1956 is difficult to place. The author's suggestion is that we should keep it in column III simply because this column contains the years of least certain behaviour. Column III is the column of the relaxation type of years such as 1875, 1895, 1910, 1922, 1928, 1938, 1950, 1956, 1962, distinguished in Table 25 by an asterisk.

Evidently in years of type *b* the general circulation between subtropical and subpolar latitudes is decelerated, in years of type *c* it is accelerated. This is in good agreement with our conclusion that the general circulation between subtropical and equatorial latitudes is decelerated in years of type *a* and *b* and accelerated in years of type *c* and *d*.

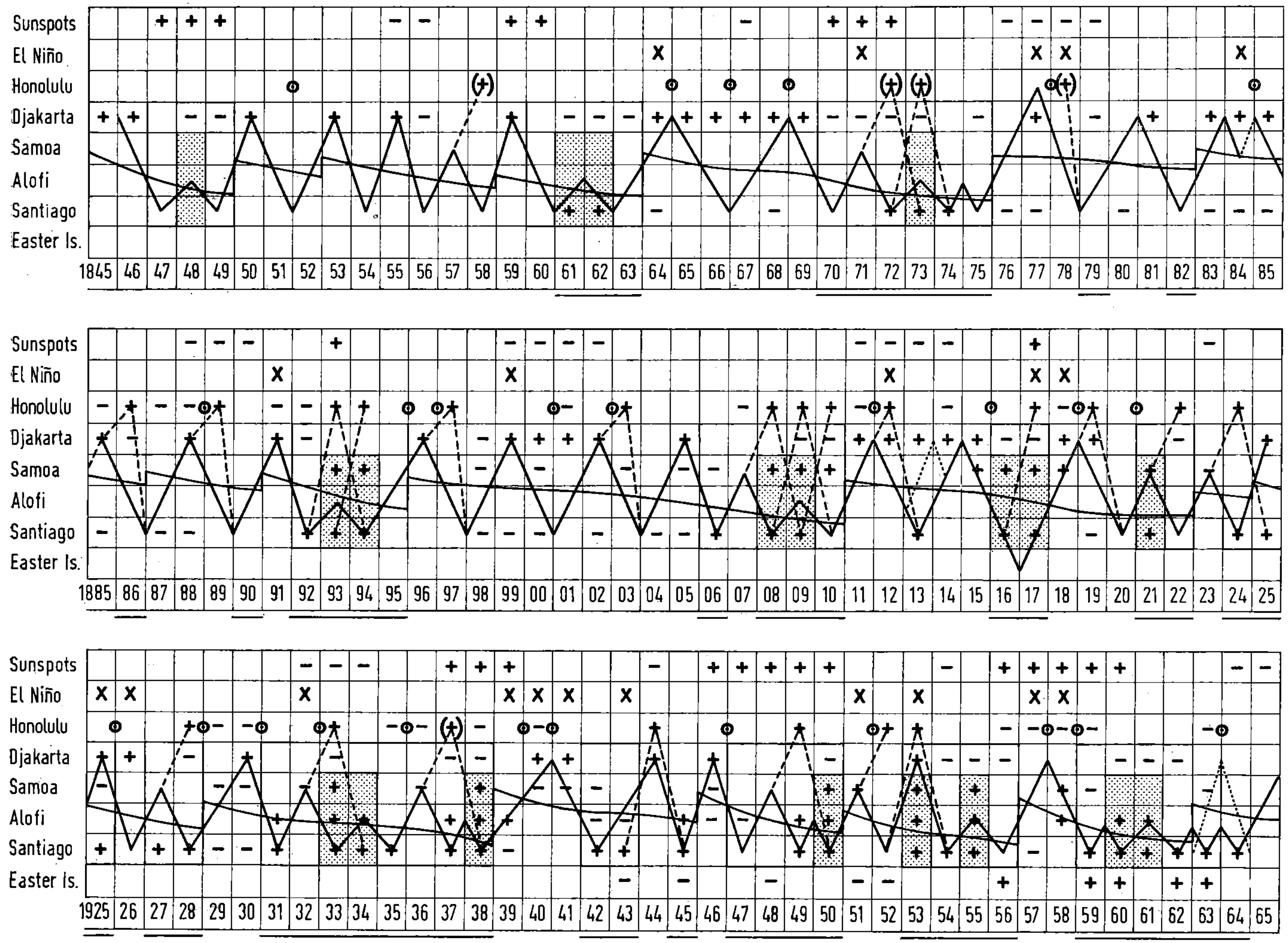
3.3 Reconstructing Southern Oscillation pressure fluctuations

Fig. 43 is a graph in which the pressure fluctuations in Djakarta (compare Fig. 1) are reconstructed with the aid of some simple principles. Extreme annual positive (+) and negative (—) pressure anomalies are every year attached to Easter Island, Santiago, Alofi, Samoa, Djakarta and Honolulu, that is along a course from the South Pacific subtropic high to the North Pacific subtropic high through the equatorial low in Indonesia. Lines connecting plus signs, or suggesting their connection, produce an excellent schematic representation of the Djakarta airpressure curve. Double lines are placed under the years of positive annual anomalies of the pressure difference Santiago-Djakarta. The sums of the anomalies considered through this underlined series of years are represented by the numbers attached to the lines. The occurrence of El Niño and of a Surinam winter drought has been indicated as well as when sunspot numbers surpassed 81 or when sunspot numbers remained below 13.

In the course of the 118 years 1845-1962, 19 relaxation oscillations occurred. The mean duration of a relaxation oscillation therefore is 6.2 years. Between 1911, when Juan Fernandez started observations, and 1962, 9 relaxation oscillations occurred. Hence their mean duration in the course of these 51 years is 5.7 years. This might explain the puzzling series of correlation coefficients Djakarta-Juan Fernandez airpressure presented in the author's earlier paper (Berlage, 1957, Table 9), revealing that a 5.5 year S.O. rhythm has preference over one of half that value, that is the normal S.O. rhythm. This does not mean that the average S.O. rhythm is not 29 months

Fig. 43 Reconstruction of Djakarta air pressure fluctuations 1845-1965.

⊙ Surinam winter drought



but unly that outstanding correlations exist in the longer time interval suggesting a 66 months rhythm.

Pressure fluctuations at Juan Fernandez (BERLAGE 1957, Table 8) are much more than those at Djakarta influenced by the 'noise' in the higher latitudes, whereas pressure correlations between the two places, which are not far from antipodal, are noteworthy only in the rhythm of relaxations of the general circulation.

The points requiring our attention are the following.

1. Relaxation induces a pressure wave whose length increases with the sum of the positive annual anomalies of the pressure gradient Santiago-Djakarta through a recent sequence of years.

2. This large pressure wave is followed by a series of waves of decreasing period and amplitude. The general circulation is accelerated. Persistence of conditions is greatest where the S.O. is pure 3-yearly, as in case of the Djakarta pressure maximum in 1885, 1888, 1891 and in 1896, 1899, 1902, 1905.

3. Finally, the average annual anomaly of the pressure difference Santiago-Djakarta remains positive throughout more than 2 successive years.

4. Then high pressure extends from Santiago towards Alofi or even Samoa. This extension introduces relaxation.

5. The first noteworthy reduction of amplitude occurs in a year preceding a year in which extremely high pressure is going to occur in Honolulu. The pressure fluctuations in the North Pacific high and South Pacific high are coming in phase, the encroachment between the Hadley circulation North and South of the equator being apparently direct. Characteristically, this is not the case in times of regular 3-year S.O. waves. In the next year high pressure is going to occur in Santiago, provided relaxation has not yet started.

6. The second noteworthy reduction of amplitude is associated with a reduction of the scale of the general circulation involved in the S.O. Then, apparently, the S.O. no longer governs the game and the Indian and Pacific Oceans no longer cooperate.

7. This rule fails in 1884, proving that the Krakatoa eruption disturbed the course of the S.O. As a volcanic dust veil reduces global pressure differences it induces relaxation and generates a long S.O. wave.

8. El Niño appears at about the time of smallest airpressure difference Easter Island-Djakarta. In 1924-1925 very low pressure must have occurred in the Easter Island area, as in 1925 pressure at Santiago was above normal. Similar arguments apply to 1943.

9. Generally, Surinam winter droughts occur towards the end of a year of extreme low pressure at Santiago. There are three noteworthy exceptions, 1925, 1928 and 1963. The features of 1925 mentioned earlier are evidently related to its exception here.

3.4 Forecasting Southeast Asia monsoon rainfall

Sir GILBERT WALKER and many followers attempted to formulate reliable forecasts of precipitation associated with the critical monsoon, for areas of India, Pakistan and Indonesia.

No comments will be made here on these attemps. A great number of lag-correlations of prognostic value have contributed towards an understanding of the Southern Oscillation, on the other hand almost all lag correlations that are clearly significant derive from the S.O.

The most recent forecast attempt was made by RAO and GHOSE (1964), and concerned the June-September rainfall in the catchment area of Damodar Valley. These authors finally chose the anomalies of the following indicators:

Darwin pressure	Mar-May	—
South American pressure	Feb-May	+
Capetown pressure	Mar-May	+
Pressure difference Port Blair-New Delhi	Mar-May	—
Leh temperature	Dec	+
Capetown precipitation	Dec-Feb, Mar-May	—
Colombo temperature	Dec-Feb, Mar-May	—
Colombo precipitation	Dec-Feb	—
Rangoon precipitation	Dec-Feb	—
Laurie Island precipitation	Dec-Feb	—
Tokyo temperature	Mar-May	—

When looking through this table we recognize immediately the Southern Oscillation as the physical process on which the forecast is founded. The pressure pattern is set by Darwin and Capetown on the one side and by South America on the other side. The pressure difference Port Blair-New Delhi is a measure for the intensity of the monsoon. Colombo temperature - compare Djakarta (1.2) - designates the variation of pressure with time. Capetown-Colombo-Rangoon-precipitation will confirm the correctness of our impression about the phase of the S.O. Tokyo and Leh temperatures represent continental conditions of the preceding winter in the North.

Laurie Island (South Orkneys) precipitation represents maritime conditions of the preceding summer in the far South. These may interfere with an otherwise normal course of S.O. events.

3.5 Forecasting Surinam winter droughts

3.5.1. The disastrous drought experienced in Surinam during winter 1963-1964, only five years after an almost equally serious drought, in winter 1958-1959, again focussed attention on the urgent problem of forecasting these almost rainless seasons (1.12).

Table 25 included Surinam rainfall anomalies Sep-Feb, based on observations made at Paramaribo (Surinam) since 1864 and Georgetown (British Guiana) since 1894. We note shortages greater than, as an example, —400 mm in the years 1877-1878, 1884-1885, 1911-1912, 1925-1926, 1939-1940, 1958-1959, 1963-1964. This immediately suggests that the relation of Surinam precipitation to the Southern Oscillation must be intimate. However, difficulties in recognizing the exact relationship are also quickly discovered. Why, for instance, is 1891-1892 absent, whereas 1925-1926 is present? This is an outstanding problem, already mentioned (1.3, 1.4).

At any rate, there is a clear tendency of the extremely dry seasons in Surinam to lag behind high pressure seasons in Djakarta and low pressure seasons in Santiago, and this makes endeavours in forecasting hopeful. This general tendency, and further trial and error, led the author towards a test of the following formula, entirely based on the primary S.O. fluctuations.

Rainfall mean anomaly Paramaribo (Surinam) and Georgetown (British Guiana) Sep-Feb, is proportional to minus the change of pressure anomaly Djakarta (Jan-Aug, from previous to current year), plus the change of pressure anomaly Santiago (Jan-Aug. from previous to current year), plus pressure anomaly Djakarta (Sep-Dec, previous year) minus pressure anomaly Santiago (Sep-Dec, previous year).

The first year of the series involved in this relation is 1864, the last is 1963. Paramaribo precipitation data fail in 1893, 1894 and 1895. Missing values, such as Paramaribo July-December 1898 were interpolated from Georgetown. For years in which only one station was functioning, as from 1864-1892, that station was given full weight.

The correlation coefficient through the complete 98 years is +0.44, an unimpressive figure, and although we know that seasonal lag-correlations, in particular those between pressure and precipitation, hardly ever surpass such values, we may conclude that the above formula should not be used in its general sense. In order to achieve reasonable results let us confine ourselves to what we actually need, a warning at the close of August when the Surinam dry season starts, for extreme droughts, say shortages greater than —200 mm, during the coming months September-February.

In Table 26 column I, drought years are listed, and in column II the years when a warning would have been given on the basis of the right side of the formula having surpassed the value —200 hundredths of a millibar.

When inspecting Table 26, our experience with the S.O. makes us only wonder why we meet 1866, 1895 and 1928 in column I and 1874 in column II. Actually, in 12 cases out of 30 the forecast would have been right, in 6 cases the forecast would have been wrong, in 12 cases a drought would have come unannounced.

The unannounced precipitation shortages have become

	mm		mm		mm
1866	—315	1900	—341	1932	—251
1884	—404	1925	—566	1935	—229
1895	—290	1928	—252	1940	—202
1896	—287	1930	—239	1958	—467

TABLE 26. *Years of extreme drought in Surinam, September-February, I experienced, II forecast.*

I	II	I	II	I	II
1864	1864	1895		1930	
1866		1896		1932	
1868	1868		1899	1935	
	1874	1900		1939	1939
1877	1877	1902	1902	1940	
	1880	1911	1911	1946	1946
1884		1918	1918		1951
1887	1878	1925		1957	1957
1888	1888	1928		1958	
	1891		1929	1963	1963

The most impressive failures among these cases are 1884, 1925 and 1958.

The precipitation anomalies observed in the years when the predicted drought did not occur, were as follows

	mm		mm		mm
1874	— 33	1891	+204	1929	—145
1880	—103	1899	—143	1951	—150

In five of these six cases the anomaly was at least negative, and we may even add that perhaps an accumulation of minor factors, diffuse and unpredictable, kept the precipitation shortages in 1880, 1899, 1929 and 1951 within normal limits. The most impressive discrepancy is noted in 1891. This dispels any hope, derived from the other series, that spectacular El Niños, such as those of 1925 and 1958, might be used as additional indicators.

3.5.2 A consideration of several possible relationships has convinced the author that the abnormally high precipitation in Surinam winter 1891-1892 is a consequence of the extremely low pressure which has reigned from summer 1890 to summer 1891 in the southeast part of the North Pacific Ocean, as demonstrated by Mazatlan, Mexico (Lat 23°12′N, Long 106°25′W, H = 4 m). The monthly anomalies of pressure at Mazatlan through 1890 and 1891 run as follows:

	J	F	M	A	M	J	J	A	S	O	N	D	
1890	+0.4	0	+0.4	+1.6	0	+0.7	—1.9	—1.6	—1.7	—2.9	—2.9	—2.0	mb
1891	—1.7	—3.6	—3.2	—2.4	—1.5	—3.7	—3.2	—1.7	—2.3	—2.0	—2.1	—1.5	mb

This depression is unequalled in the whole series of pressure observations at Mazatlan, dating back to 1880. It is this depression which caused the weakness of the trade winds in the East Pacific pointed out by SCHOTT (1931) in relation to the appearance of the catastrophic El Niño early in 1891. Hence, it follows that the dissimilarity of the Surinam rains during Sep-Feb of 1891-1892 and 1925-1926 is due to the remarkable difference of the 1891 and 1925 circulation patterns, even though both lead to similar hydrographic disturbances along the Peru coast.

If the anomaly of airpressure at Mazatlan during past Jan-Aug is introduced as an indicator and subtracted from the right side of our formula, the greatest difficulty is eliminated. We thus come to Table 27.

TABLE 27. *Years of extreme drought in Surinam, September-February, I experienced, II forecast.*

I	II	I	II	I	II
1864	1864	1896		1930	
1866		1900		1932	
1868	1868	1902	1902	1935	1935
	1874		1905	1939	1939
1877	1877		1907	1940	
	1880	1911	1911		1944
1884			1914	1946	1946
1887	1887	1918	1918		1951
1888	1888		1922	1957	1957
	1894	1925	1925	1958	
1895		1928		1963	1963

The situation now is that in 14 cases out of 34 the forecast would have been right, in 10 cases the forecast would have been wrong and in 10 cases the drought would have been unpredicted.

The unpredicted precipitation shortages have become

	mm		mm		mm
1866	—315	1900	—341	1940	—202
1884	—404	1928	—252	1958	—476
1895	—290	1930	—239		
1896	—287	1932	—251		

The most impressive failures now remain 1884 and 1958.

The precipitation anomalies observed in the years of wrong prediction of drought were as follows

	mm		mm		mm
1874	— 33	1907	—152	1951	—150
1880	—103	1914	+ 97	1961	— 32.
1894	+210	1922	+360		
1905	— 84	1944	+ 4		

This latter list makes a disappointing impression. While discarding the 1891 failure, we have introduced two new evident failures, 1894 and 1922. We should, however, not forget that 1891 and 1925 were famous Djakarta high pressure years, whereas 1894 and 1922 were characteristic Djakarta low pressure years. The latter are years of dubious type to which we have to return in any case, in particular because 1894 comes 3 years after 1891 and 1922 precedes 1925 by 3 years.

3.5.3 A third approximation is made when the appearance of El Niño is taken into account by an addition of —1.5 mb to the right side of our formula. We are thus led to Tabel 28.

TABLE 28. *Years of extreme drought in Surinam, September-February, I experienced, II forecast.*

I	II	I	II	I	II
1864	1864		1899	1932	1932
1866		1900		1935	1935
1868	1868	1902	1902	1939	1939
	1871		1905	1940	1940
	1874		1907		1943
1877	1877	1911	1911		1944
	1880		1914	1946	1946
	1883	1918	1918		1951
1884	1884		1922		1953
1887	1887	1925	1925	1957	1957
1888	1888		1926	1958	1958
	1894	1928			1961
1895			1929	1963	1963
1896		1930			

The situation now is that in 18 cases out of 41 the forecast would have been right in 17 cases the forecast would have been wrong and in only 6 cases a drought would have been unpredicted.

The unpredicted precipitation shortages have become

	mm		mm		mm
1866	—315	1896	—287	1928	—252
1895	—290	1900	—341	1930	—239

The most impressive failure in the latter list is 1900. However, it should be noted that 1900 and 1930 are preceded by typical Djakarta high pressure years, 1899 and 1929, which are years for which a drought forecast would have been given. The years 1895 and 1928 of this list are coupled in the same way.

The years 1895 and 1928 are distinguished as years of relaxation and hence are in a dubious position, their tendency evidently being towards the Djakarta high pressure side, 1928 even coming 3 years after 1925.

Since Georgetown precipitation and Mazatlan pressure are unknown for 1866 that year's forecast might not be a failure at all. If only average pressure at Mazatlan during Jan-Sep 1866 was as high as in years such as 1907 or 1908, our forecast would have been correct.

The precipitation anomalies observed in the years of wrong prediction of drought were as follows

	mm		mm		mm
1871	+337	1905	— 84	1944	+ 4
1874	— 33	1907	—152	1951	—150
1880	—103	1914	+ 97	1953	— 57
1883	—184	1922	+360	1961	— 32
1894	+210	1926	+289		
1899	—143	1943	+ 47		

The list, this time, is disappointingly long. On the other hand, a consistent pattern is evident, A 3-year rhythm is remarkably well developed in the successions 1868-1871-1874-1877-1880-1883 and 1896-1899-1902-1905, years which are marked in the forecast sense, proving that we have remained on an S.O. basis.

The most obvious discrepancies are noted in 1871, 1894, 1922 and 1926. The remarks we can make with regard to these four cases are the following.

(1) The year 1871 is only a quasi-highpressure year at Djakarta. Pressure remained below normal there throughout the year, almost certainly kept down by high solar activity. The author even doubts the reliability of the rather popular history about El Niño having been active in 1871. Was it not only suggested by the quasi-regularity of the nearly 7-year cycle in 1864-1871-1877-1878-1884-1891? Rainfall may in fact have been abnormal in some Peruvian districts as, for instance, in 1961. Very probably we would have concluded that no Surinam drought was to be expected in 1871. We can discard it.

(2) When following Bombay and Calcutta more strictly than Djakarta, we should have distinguished 1895 as the high pressure year and 1896 as the associated high pressure year, just as we have dinstinguished the couples 1883-1884, 1887-1888, 1899-1900, 1929-1930 and 1939-1940, mentioned earlier. This change would line up 1894 with 1922 among the years of relaxation of deviant behaviour, the deviance being due, in these years, to abundant precipitation in Surinam.

(3) The year 1926, although coupled with famous 1925, is not to be considered as a regular El Niño year. Nor, apparently, is 1878, the year after the spectacular Djakarta high pressure year 1877. Pressure at Djakarta is so rapidly sinking in the course of 1926 that this year is undoubtedly the downward transition year following the extreme high pressure year 1925, and not leading to a Surinam drought. If El Niño 1926 had

not been taken seriously as an indicator, the Surinam drought 1926 would not have been forecast. These considerations are emphasised when it is noted that 1928 follows three years after 1925 and, significantly, leads to the Surinam drought, which as we know, would have remained unforecast.

Our conclusion is that the basic picture we are developing is justified. However, the rather narrow phase shifts in the S.O. waves are extremely difficult to foresee. Let us, for instance, recapitulate what was mentioned about the Djakarta high pressure and historic El Niño year 1891 and the following wave top reached in the course of 1894-1895-1896, as compared with the Djakarta high pressure and historic El Niño year 1925 and the following wave top reached in the course of 1928-1929-1930. These two series are two S.O. world weather cycles, both extended in relaxation and redress, which might have covered each other in almost perfect analogy, if minor external influences and phase shifts would not have led to outstanding differences in their regional consequences.

3.5.4 A fourth approximation is finally proposed. This time the appearance of El Niño is not taken into account. However, let us recognize the particular tendency of Bombay pressure variations from one year to the next to stress the years 1866 and 1895 as years of Surinam drought, and subtract this Bombay variation from the right side of our formula, giving it the same weight as the Djakarta variation. In agreement with directives given by SCHOVE and BERLAGE (1965), the argument is very simple. The centre of gravity of the Southern Oscillation low pressure area is moved westward from Djakarta towards the Indian Ocean. We are thus led to Table 29, a table similar to, but not quite comparable with the previous tables, because this time —180 mm was taken as the limiting value of a Surinam drought.

TABLE 29. *Years of extreme drought in Surinam September-February, I experienced, II forecast.*

I	II	I	II	I	II
1864	1864	1900		1932	
1866		1902	1902	1935	1935
1868	1868	1903		1939	1939
1877	1877		1904	1940	
	1880		1905		1943
1883	1883		1907		1944
		1911	1911		
1884			1917	1946	1946
1887	1887	1918	1918		1951
1888	1888		1922	1957	1957
1895		1925	1925	1958	
1896		1928			1961
	1899	1930		1963	1963

The situation now is that in 15 out of 37 cases the forecast would have been right, in 11 cases the forecast would have been wrong, while in 11 cases the drought would have been unpredicted.

The unpredicted precipitation shortages have become

	mm		mm		mm
1866	—315	1900	—341	1932	—251
1884	—404	1903	—189	1940	—202
1895	—290	1928	—252	1958	—467
1896	—287	1930	—239		

The precipitation anomalies observed in the years of wrong prediction of drought were as follows

	mm		mm		mm
1880	—103	1907	—152	1944	+ 4
1899	—143	1917	+ 62	1951	—150
1904	— 71	1922	+360	1961	— 32
1905	— 84	1943	+ 47		

The value of the present approximation is that it bestows on us an enhanced ability to detect the significance of the minor phase shifts between reality and forecast in the two-year couples.

1883-1884	1902-1903	1943-1944
1887-1888	1904-1905	1957-1958
1895-1896	1917-1918	
1899-1900	1939-1940	

What definitely remains unexplained is the high rainfall anomaly in Surinam Sep 1922-Feb 1923. It was +451 mm in Georgetown and +269 mm in Paramaribo and hence covered a large area. Yet all indicators, including the remarkable dryness of the eastmonsoon 1923 on Java, converge towards a forecast of extreme drought in Surinam.

An exception is 1928 when an extreme drought came, the precipitation anomaly reaching the value —340 mm in Georgetown and —164 mm in Paramaribo, and this without the slightest warning. On the other hand there is much in common between 1921-1922-1923 and 1927-1928-1929, the years 1922 and 1928 both having been distinguished as relaxation years. Relaxation means that some threshold value in the general circulation is reached and a new pattern is introduced. It means instability, regionally anything is possible over an extended period. It certainly is not without significance that 1922 comes four years after 1918 and 1928 three years after 1925.

A forecast of a Surinam drought in 1904, 1905, 1922, 1944, 1961 would indeed have been meaningless. The author has not the same feeling with regard to 1917 and 1943 because, as should be repeated, these years were in fact characterized by the appearance of El Niño. Hence, a drought forecast in 1880, 1899, 1907, 1917, 1943 and 1951 may be considered as having been appropriate.

Consequently, the author believes in the possiblity to give a correct forecast in 20 out of 36 cases or, roughly, in more than half of the cases. Random coincidence, where 25 extreme droughts have occurred in 100 years and 25 forecasts have been made, would take place in one fourth of the cases. Hence there is reality and a strong positive advantage in the system leading to the forecasts just discussed.

3.5.5. In order to put long range forecasting of rainfall in the Guianas on a more firm footing it is good to introduce here the significant, even remarkably high, correlation between precipitation at Luanda (Angola, West Africa, 8°49′S, 13°13′E) and precipitation on the island Fernando de Noronha (3°50′S, 32°25′W) near Brazil east point, and the northeast Brazil State of Ceará. This correlation is directed east-westward in accordance with the general tendency in the equatorial zone, incorporated in the general circulation, as noted by BERLAGE (1957, Fig. 28). It offers a time lag of 3-4 months over a distance of 5000 km, as noted by EICKERMANN and FLOHN (1962).

Luanda rainfall January-August in mm was as shown by Table 30.

TABLE 30 *Rainfall January-August at Luanda, Angola, in mm.*

1901	263	1917	531	1933	584	1949	311
1902	79	1918	156	1934	304	1950	532
1903	317	1919	9	1935	593	1951	152
1904	189	1920	206	1936	160	1952	403
1905	156	1921	264	1937	293	1953	142
1906	254	1922	275	1938	244	1954	242
1907	275	1923	481	1939	340	1955	438
1908	224	1924	501	1940	261	1956	354
1909	398	1925	183	1941	144	1957	530
1910	378	1926	395	1942	148	1958	40
1911	65	1927	329	1943	68	1959	600
1912	416	1928	215	1944	513	1960	479
1913	307	1929	319	1945	153	1961	378
1914	47	1930	202	1946	111	1962	537
1915	218	1931	178	1947	360	1963	543
1916	607	1932	43	1948	37	1964	70

Selecting from Table 30 the years in which rainfall at Luanda Jan-Aug remained below 200 mm, we obtain 20 of them, viz.

1902	**1918**	1936	1948
1904	1919	1941	1951
1905	**1925**	1942	1953
1911	1931	1943	**1958**
1914	**1932**	**1946**	1964

In the following 9 years Luanda rainfall was lower than 100 mm,

1902	1919	1948
1911	**1932**	**1958**
1914	1943	1964

The years bold printed are those in which extreme drought, a shortage of rainfall greater than —200 mm, in Surinam Sep-Feb followed.

We immediately recognize that the S.O. is basically involved. It is as if the gap in the equatorial zone, where the S.O. dominates the scene, is closed between Africa and South America. It is less certain that our knowledge of this teleconnection is of use in forecasting Surinam Sep-Feb rainfall. The author feels that the clear inclusion of 1932 and 1958 in the above series is an improvement.

On the other hand the Angola 1964 drought came apparently one year late, when we try to link it with the Surinam 1963 drought. Undoubtedly the two droughts have to be considered as associated, because they were separated by an interval as long as 5-6 years from the serious 1958 droughts in both regions. The situation 1963-1964 indicates that the time arrow may sometimes point from west to east, between the Guianas and Angola. There is a noteworthy parallelism between 1963-1964 and 1918-1919. However, we have denoted earlier that the definite reason for the singular S.O. course 1963-1964 was the Gunung Batur (Bali) eruption and the veil that it must have spread through the equatorial stratosphere. As a matter of fact a quick rise of pressure at Djakarta 1963 and the Surinam drought following, suggested a relaxation wave, but this relaxation is apparently camouflaged, positive pressure gradient anomalies Santiago-Djakarta persisting through 1963 and 1964.

3.5.6. Every student of monsoon forecasting in tropical countries, knows that the forecasting of quantities of surplus rainfall is always more difficult than the forecasting of quantities of rainfall deficiency. This is a logical consequence of the fact that large quantities of precipitation are associated with unstable conditions, droughts are however mostly associated with quasi-persistent, rare conditions, towards which different causes must contribute.

The Surinam droughts discussed here are almost all assembled in Group I of Table 25 which contains 40 Djakarta high pressure years. The Surinam abundant

TABLE 31. *Years of extreme precipitation in Surinam September-February, I experienced, II forcecast.*

I	II	I	II	I	II
1869	1869	1894		1922	
	1870	1897		1926	
1871		1901	1901	1927	
1873			1903		1931
1875			1906	1933	
	1878	1913		1937	
1879	1879	1915	1915		1942
1881		1916	1916		1947
1886	1886		1920	1948	
	1889		1921		1959
1892	1892				

rains are almost equally dispersed among Group II and Group III, both containing 31 years, the Djakarta downward transition years and the Djakarta upward transition years.

When applying to the extremely wet periods in Surinam Sep-Feb the same deviations as applied to the extremely dry periods, only with the signs reversed, we are led to Table 31.

The situation now is that in only 7 out of 31 cases the forecast would have been right, in 13 cases the forecast would have been wrong, while in 11 cases the extremely heavy rainfall would have been unpredicted.

The unpredicted precipitation surplusses become

	mm		mm		mm
1871	+246	1897	+241	1933	+396
1873	+563	1913	+386	1937	+206
1875	+393	1922	+225	1948	+359
1881	+443	1926	+279		
1894	+264	1927	+226		

The precipitation anomalies observed in the years of wrong prediction of high rainfall were as follows.

	mm		mm		mm
1870	+174	1906	+ 10	1942	+110
1878	+157	1920	—127	1947	— 56
1889	+ 70	1921	+ 97	1959	+133
1903	—197	1931	—144		

If we consider forecasts given in 1870, 1878 and 1959 as rightly given, then in 10 out of 31 cases or roughly one in three cases they would seem correct. Whereas in 20 out of one hundred years extreme precipitation occurred, and 18 forecasts would have been given, chance coincidence would have led to one good forecast in five years. Hence there is a definite gain, although small, in the use of the extreme precipitation forecasts. Moreover a disastrous succession, the very heavy rains in Sep 1964-Feb 1965 following one of the most extreme droughts ever having occurred, in Sep 1963-Feb 1964, could have been announced sufficiently in advance.

4. A GLOBAL PICTURE OF THE SOUTHERN OSCILLATION

4.1 Introduction

The present analysis of the S.O. has provided us with a large amount of material that will help us to gain insight into meteorological and oceanographical processes of a worldwide nature. The accuracy of long-range forecasting based on the knowledge we have gained will be shown by experience. We can only say that the puzzling duration of certain circulation patterns with their anomaly centres and mean troughs (NAMIAS 1958, 1959) is probably connected with the S.O. in its planetary extension. This association is confirmed by the air pressure and temperature variations in the western United States, California, Oregon and Washington, stated by G. I. RODEN (1965, 1966). The most pronounced warm periods in these states occurred in 1868-1869, 1885, 1925-1926, 1939-1942, 1957-1958, which are without exception Djakarta high pressure periods. The most pronounced cold periods in these states occurred in 1864-1865, 1870-1871, 1893-1895, 1916-1917, 1955-1956, which with the exception of 1864-1865 are typical Djakarta low pressure periods.

It should be noted, as in para 1.1, that the average amplitude of the pressure fluctuations at Easter Island is roughly double the amplitude at Djakarta, indicating that there must be some way for air to be forcefully converged toward the subtropic area of the South Pacific. Most probably, for just the same reason that there is a dynamic high pressure zone along the tropics, there is a stress on the long period fluctuations of pressure, such as the S.O., in that same latitude.

Further, the slowness of the ocean currents and the global dimensions of the Pacific and Indian Oceans allow us to interpret the S.O. as a basically terrestrial cycle. This interpretation is strongly supported by the investigations of NAMIAS (1959, 1963 and 1965), into large-scale air-sea interactions. Therefore, we need not consider variations of solar activity to be the cause of variations of the general atmospheric circulation with periods of only a few years, as suggested by PED and SIDOCHENKO (1959). Converging evidence convinced the author that the S.O. is merely guided by extraterrestrial agencies affecting the higher air layers.

4.2 Relations with the fluctuations in equatorial stratospheric winds

Shortly after the discovery of the quasi-biennial change of wind direction from West to East and from East to West in the equatorial stratosphere by MCCREARY (1959, 1960, 1961), EBDON (1960, 1961) was the first to discuss the interesting question, does this remarkable periodicity of about 26 months show any connection with the Southern Oscillation?

There are strong reasons to doubt the existence of such a connection. For instance, simply because of the discrepancy between the relation of stratospheric wind directions and Southern Oscillation pressure fluctuations at Djakarta (Batavia, 6°11′S, 106°50′E) existing in the early years 1910-1915, when W. VAN BEMMELEN (1916) made his famous recording balloon ascents, up to heights frequently over 18 km, and the relation existing in recent years.

That the equatorial stratospheric biennial swing is continuous and the famous 'Krakatoa Easterlies' are not persistent, is also supported by a series of measurements made by A. BERSON (1910) in tropical East Africa in the course of 1908 ('Berson Westerlies').

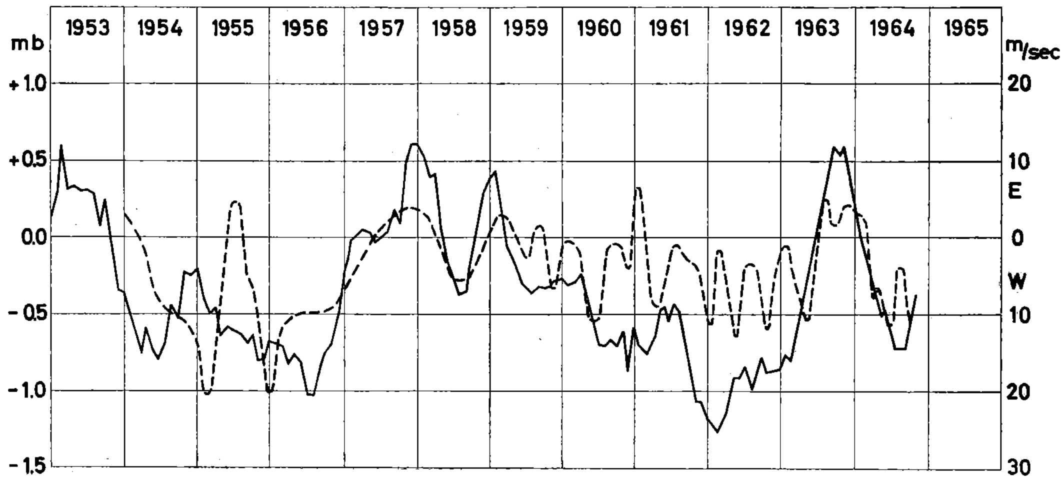
As far as we can see 'no evidence has been obtained that the fluctuation extends down into the troposphere. It appears that the fluctuation occurs almost simultaneously at the same level all round the tropics, but there is a phase lag from higher to lower levels, amounting to five or six months between the 25 mb and 60 mb levels' (VERYARD and EBDON, 1961).

ANGELL and KORSHOVER (1962) concluded that 'the oscillation decreases in amplitude downward and becomes almost undetectable at 100 mb', whereas REED and ROGERS (1962) write: 'Below 25 km the amplitude diminishes, the decrease becoming especially rapid as the tropopause level is approached. Comparison of the 50.000 ft and 70.000 ft winds reveals little or no correspondence between the tropospheric and stratospheric oscillation'.

On the other hand the variations in 200 mb flow in the tropics, studied by TROUP (1961), are evidently associated with the Southern Oscillation. In fact REED and ROGERS (1962) stated that at the 100 mb level there is inverse correlation of the zonal winds at Canton Island (2°46'S, 171°43'W) and Singapore (1°18'N, 103°53'E). This is a clear confirmation of S.O. effects pushing up to that height.

Fig. 44 shows in two curves the Djakarta sea-level pressure fluctuations and the zonal winds at the 150 mb level at Canton Island, according to East and West direction and speed in metres per second. The intimate connection between the two curves

Fig. 44 Djakarta air pressure at sea-level and Canton Island zonal winds at 150 mb level.



is undeniable, the impression being that they are roughly parallel, but in slightly different phase. The wind variations are belated, relative to the pressure variations.

Obviously the tropical atmosphere is operating on two floors. The lower floor is sea-level, the higher floor is the 50 mb level, settled upon the 100 to 50 mb layer of strong tropical tropopause inversion, the temperatures in that layer rising from roughly —80 °C at its bottom to roughly —50 °C at its ceiling.

The multiplicity of tropopause surfaces, the leaves in the equatorial atmosphere pointed out by PALMÉN (1931) and FLOHN (1959), and the multiple regional subsidences associated therewith, only stress the necessity of considering the independence of the large-scale actions on the two main platforms. CHARNEY and DRAZIN (1961) investigated this problem theoretically and showed that most of the time 'there appears to be little mechanical coupling on a planetary scale between the upper and lower atmospheres'. On the other hand, 'when energy is propagated to great heights, non linear vertical eddy transports of heat and momentum associated with the vertically propagating waves should modify the basic zonal flow'. As ATTMANNSPACHER (1963) pointed out no more than a kind of steering by 'drag coupling' remains.

Hence, the biennial variation of stratospheric winds in the tropics requires an explanation separate from the explanation of the S.O. proper. If the explanation of this high altitude variation by some kind of solar cycle, as suggested by SHAPIRO and WARD (1962), and STALEY (1963), should fail, the present author would still not be willing to assume with NEWELL (1964) 'that since much of the circulation of the lower stratosphere is driven by the tropospheric circulation, then perhaps the best place to seek a source for the periodicity is within the tropospheric heat engine'. The present author would point out the similarity of the two explanations. The lag of six to seven months in the changes of wind direction from the 25 mb to the 100 mb level might perhaps play the same role as the lag of seven to eight months in the temperature anomaly between the Southeast Pacific high and the Indonesian low. The two sources of energy might be in the one case the corpuscular 'solar wind', in the other case the solar radiation. The periods of the two oscillations would be four times the lags just mentioned, that is 26 months in the first case and 30 months in the second case. They are not cause and effect, but independent.

All this is documentation of the relative thinness of the tropospheric cover of our globe. BERLAGE (1931), by a very simple theoretical foundation of the mean latitudes of the dynamic subtropical highpressure and subpolar lowpressure belts, ARAKAWA (1952), ISHIMARU (1952), TUCKER (1957) and others were able to show that the zonal and meridional planetary circulation is largely determined by the boundary conditions set by the earth's surface. Yet we must recognize that stratospheric pressure variations reach down to sea-level and in para 1.6 we mentioned one of these cases of probable stratospheric influence on the Southern Oscillation.

At Santiago deep pressure valleys occurred in 1864 and 1868 only, whereas at Djakarta high pressure tops occurred in 1864, 1866, 1868. In these same three years Surinam became dry in winter, thus confirming the significance of this succession at exactly two year intervals. Let us realize, however, that Indonesia and the Guianas are both strictly equatorial regions, whereas Santiago is a station representative of a subtropical high pressure area. It is therefore appropriate to enquire whether or not we can solve the problem by simply assuming stratospheric imprints along the equator and tropospheric imprints along the tropics.

Moreover, the changes of the equatorial stratospheric winds are in the same phase all round the world. This is a vexing problem in itself, but in particular because it is not easily associated with the S.O. However, we know that the pressure fluctuations observed at high altitude observatories in Indonesia (Pangerango, 3024 m) and in South America (La Paz, 3632 m and Quito, 2819 m) go almost parallel whereas the sea-level fluctuations show opposite signs. It should also be noted that in Indonesia pressure variations at 3000 m are as large as those at sea level.

Table 32 contains the synchronous correlation coefficients between the monthly pressure anomalies at Djakarta on the one hand and La Paz and Quito on the other.

TABLE 32. *Synchronous correlation coefficients between monthly pressure anomalies at Djakarta (Indonesia) and at La Paz (Bolivia, 16°30′S, 68°10′W) and Quito (Ecuador 0°13′S, 78°30′W) in South America.*

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					La Paz (1921-1940)						
+0.29	+0.49	+0.51	+0.19	+0.22	+0.03	−0.04	−0.44	−0.15	−0.03	+0.45	+0.63
					Quito (1901-1950)						
+0.33	−0.04	+0.04	+0.12	+0.19	+0.23	−0.09	+0.27	−0.19	+0.33	+0.25	+0.39
					average						
+0.31	+0.23	+0.47	+0.16	+0.21	−0.10	−0.06	−0.04	−0.17	+0.15	+0.35	+0.52

The parallelism fails in southern hemisphere winter. Apparently, in winter the density of the 3000 m air column above the relatively cold Peru and Chile coastal waters and in the Andes Mountains is much higher than that of the corresponding air column over Indonesia. The result is that at 3000 m a pressure gradient west-east, replaces the normal low level pressure gradient east-west.

The necessary insight into the east-west temperature relations is given by Table 33 which we owe to TROUP (1965, Table 7).

TABLE 33. *Temperature differences Darwin minus Lima at standard pressure (mb) levels in °C.*

	850	700	500	300	200	150	100
January	2.9	−0.8	0.2	0.9	0.3	−1.6	−2.4
April	0.7	−1.0	1.1	1.0	0.3	−1.5	−3.8
July	−2.8	−1.2	1.1	1.4	0.4	−0.4	−5.2
October	2.2	−2.6	0.9	0.9	0.5	−0.6	−3.2

TROUP's commentary runs as follows. 'In fact a complicated system of ageostrophic motions is set up, which will depend on the sign of the vertical motion in different parts of the system and of the temperature differences at different levels.'

At Lima, situated west of the Andes' mountain chain on the Peru coast, air descends from the 300 mb to the 700 mb level. Again, the southern winter is different from the other seasons. In the southern winter evidently air moves down to sea-level, the Peru Current acting as a cold sink (4.3). On the other hand, the intertropical atmospheric motions above the 300 mb level have undoubtedly to be considered separately from those in the lower levels.

Let us refer here to Table 19, which shows the same negative relationship in southern winter, Jun-Aug, between pressures at McMurdo-Sound (Little America) in Antarctica, and Djakarta, whereas these stations are positively related in other seasons.

4.3 Relations with variations in the equatorial Upper High at 300-100 mb

In para 4.2 it was noted that the Southern Oscillation is reflected in the 200 mb flow in the tropics (TROUP, 1961). We are, moreover, in possession of the valuable charts of isobaric contours and upper winds over the world drawn by HEASTIE, STEPHENSON and TUCKER (1960) on the basis of observations 1949-1953. FROST and STEPHENSON (1965) published maps of streamlines and isotachs at 700, 500, 300 and 200 mb levels over the Indian and Pacific Oceans and adjacent land areas in particular, aided by a large number of radiowind stations. As these authors suggest, 'the simplest explanation of the observed belt of low level westerlies, and reversed easterlies aloft is that they form part of a simple circulation cell, which has an ascending branch over the heated land mass of Indonesia and a descending branch over the equatorial Indian Ocean at about longitude 60°E.'

'The broadening of the equatorial westerlies could result from additional heating of the land masses of Southeast Asia and India in May and June.'

This statement is complementary to our knowledge of the remarkable, relatively cold area in the Indian Ocean east of Somaliland. We owe a detailed description of this particular area to VERPLOEGH (1954, 1960). However, it is not intended to stress here the coastal, rather small-scale effect, described by LAHEY (1958) in connection with the north coast of South America, and recognised also by FLOHN a.e. (1960) along the Somali coast. This is due to the splitting of the wind along the coast in two parallel streams. In the one the wind is derived upland because of continental friction, whereas over sea the wind remains parallel to the coast. As was pointed out by BERGERON (1950) the forced divergence of the two streams and associated subsidence makes the coast dry.

The interesting large-scale feature of the Indian Ocean pressure pattern, even the annual average one, reproduced in Fig. 45, is the equatorial western high pressure region relative to the eastern, Indonesian, low pressure region.

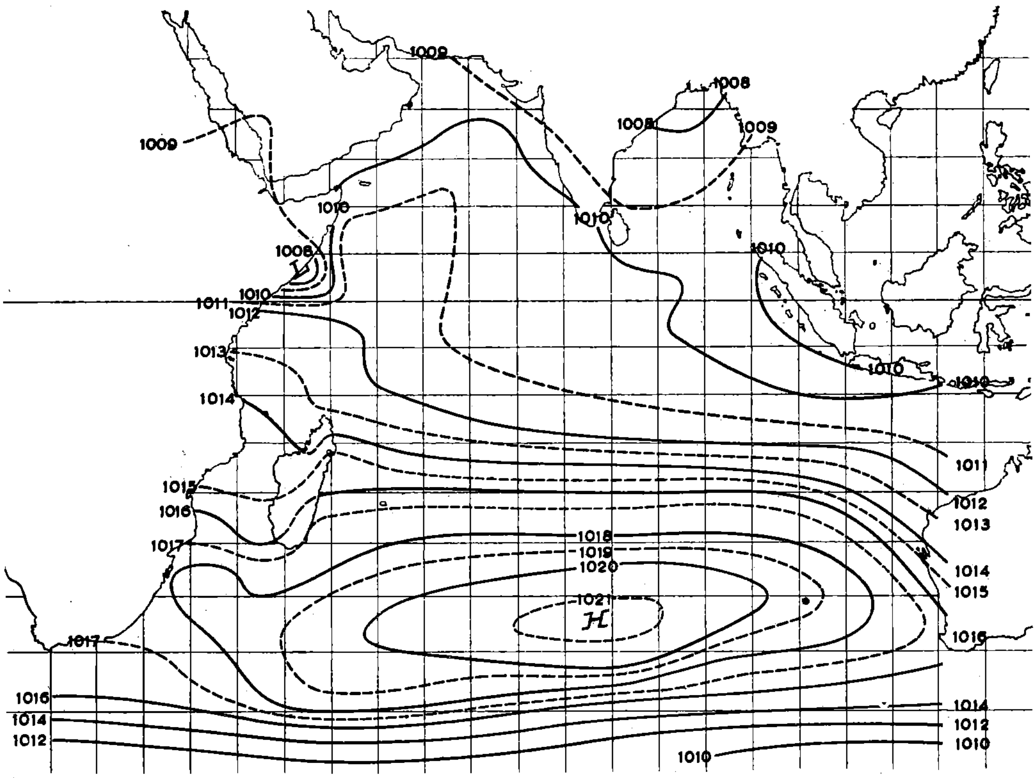


Fig. 45 Indian Ocean annual mean air pressure.

The coolness of this area, most pronounced during the summer monsoon, July-October, must be due to upwelling water in a region where surface currents diverge. It is unique in its equatorial east-coast position. The other well known low latitude cold water masses are along the west coasts of Peru, California, Morocco and South-west Africa, where surface currents move equatorward and tend to switch away from the continent.

The air motion, upward in Indonesia, westward through the upper atmosphere, downward south of Sokotra (longitude 54°E), back eastward as an equatorial counter current in a rather narrow strip, is a primary aspect of the Indian Ocean general circulation. It was investigated by L. WEICKMANN JR (1964), who pointed out that the discontinuities in the zonal pressure field and pattern of airstreams between Africa and Indonesia apparently avoid the equator and are rather motionless and distinct. On the other hand it is only part of the worldwide intertropical circulation.

Surveying it completely, we note that descending branches of this circulation include, besides the one east of Somaliland, a second one west of Angola and a third one over Ecuador.

When noting this we recognize the picture developed by SCHOVE (1963). This author pointed out that the main equatorial Upper High at the 200 mb level covers roughly the Indian-Indonesian scale of the S.O. balance. This scale, at sea-level, has its deepest depression-lower than 1000 mb-over North India in July, and its deepest depression-lower than 1005 mb-over North Australia in January. The equatorial Upper High encompasses in this way the two extreme monsoon patterns, differing so excessively that, for instance, the Intertropical Convergence Zone moves from Lhasa in July to Darwin in January.

Evidently the equatorial Upper High plays an active part in Southern Oscillation dynamics. Its contours follow similar seasonal deformations as the patterns of positive correlation with Djakarta pressure anomalies, illustrated by Fig. 3 and Fig. 4. Moreover it shows a western extension over the Atlantic towards South America. It thus demonstrates its homogeneity. The equatorial Upper High is one with the equatorial Lower Low, thermally generated in one and the same Hadley circulation.

North and South of the Upper High westerlies blow from a point of divergence over South America toward a point of convergence over Indonesia. The two airstreams are similar to the hydrospheric North and South Equatorial Currents, but have opposite directions. These 'Antitrades' apparently cross an upper tropospheric bridge between two heads, the one in Brazil, the other in Borneo.

It should be noted that, in the more restricted sense of the two scales of the S.O. balance, as shown by Fig. 5, the East-to-West pull is not acting continuously, but only at certain times. By the East-to-West pull we mean the pull from the Indian-Ocean scale to the East-Pacific scale, through the upper troposphere over the Atlantic Ocean, where sea-level pressures fail to demonstrate S.O. effects. Do the times of action of this pull coincide with (indicate) relaxation? This is suggested by SCHOVE (1963) when he writes that 1940, one of the most outstanding years after a sudden slowing down of the general circulation 'shows a partial crescent of low pressure extending from South America to Europe and a crescent of high pressure extending from N.W. India to S.E. Australia'. Moreover 'a mean anomaly map for all those years since 1841 in which there were famines in N.E. Brazil showed precisely those features...'

In cases like these, after a cold water intrusion or via a strong South Equatorial Current through the Pacific Ocean (1.2) air pressure has risen in the Far East, the point of convergence of the upper westerlies having moved from Borneo to New Guinea, whereas the upper air pressure has fallen in the area of divergence of the upper westerlies. A Djakarta high pressure year has been inaugurated.

The sequence of events following this operation is elucidated by SCHOVE (1963) in his 'piston' and 'valves' model. It should not be taken too literally, but be considered from the standpoint of the similarity of the cell and parcel formulation of the convection problem (KRAUS and PRIESTLEY 1961).

SCHOVE'S 'piston' and 'valves' model represents the way in which positive pressure anomalies in the eastern crescent in September to November tend to spread westwards in steps in subsequent seasons until they extend to Brazil within twelve months. This model can, howevei, be modified to cover longer periods, as suggested below.

While upper westerlies are flowing in subtropical latitudes, compressing the Upper

High between their flanks, the upper easterlies, in a rather narrow equatorial stream, the 'tropical easterly jet' (KOTESWARAM, 1958), drive the 'piston' westward from January (I.T.C. most southerly) to October. The low easterlies, the Pacific trades, are weak and cause the advection of warm surface water towards Indonesia. The upper easterlies are also weak in the beginning, and might even sometimes give way to upper westerlies in the northern mid-winter (TUCKER, 1965). Towards the end of these three quarters, which are part of a Djakarta highpressure year, the nearest 'valve' opens east of East Africa (Somali), discharging the compressed air in the first cold sink, under circumstances apparently dominated by October conditions.

During the next three quarters, from October to July (I.T.C. most northerly) the upper easterlies drive the 'piston' further westward. The low easterlies, the Pacific trades, are of normal strength and cause the advection of surface water of normal temperature toward Indonesia. Early in this period, in the beginning of a Djakarta 'downward transition' year a 'valve' opens west of South Africa (Angola), discharging the compressed air into the second cold sink, under circumstances apparently dominated by January (I.T.C. most southerly) conditions.

During the next three quarters, from July (I.T.C. most northerly) to April the upper easterlies drive the piston further westward. The low easterlies, the Pacific trades, are strong and cause the advection of cold surface water towards Indonesia. The upper easterlies are also strong in the beginning, in northern mid-summer, reaching far west. Towards the end of this period, a 'valve' opens above mid-winter Brazil, discharging the compressed air into the third cold sink, under circumstances apparently dominated by April conditions.

This time, a definitely strong relaxation in the intertropical general circulation occurs, probably because the North-South American mountain barrier is involved.

During the next three quarters, from April to January (I.T.C. most southerly) the upper easterlies drive the 'piston' further westward. The low easterlies, the Pacific trades, are of normal strength and cause the advection of surface water of normal temperature towards Indonesia. Early in this period, which is part of a Djakarta 'upward transition' year, a 'valve' opens west of Ecuador, discharing the compressed air into the fourth cold sink, under circumstances apparently dominated by July (I.T.C. most northerly) conditions.

Any such discharging of compressed air is to be regarded as a minor relaxation phenomenon. Speaking of the 'burst' of the southwest monsoon through India, most frequently in July[1]), closely related to the onset of the strong mid-summer upper easterlies (SUTCLIFFE and BANNON, 1956), we are almost reminded of relaxation terms.

Thus, after three years of normal S.O. we are back at the starting point, and this may mean the introduction of a new S.O. wave.

As regards the dominant quarter in the successive periods, viz. October, January, April, July, we have followed SCHOVE's picture. However, the October and January are actually successive quarters, from January to April there is more than one year, the April and July are again actually successive quarters. This is a satisfying aspect,

1) It was the sailor's saying: July stand by, August it must, September remember, October all over.

since in the course of the four periods of three quarters, the first two are dominated by the Indian Ocean and Africa, the second two by the Atlantic Ocean and South America. The relaxation brings the Pacific Ocean into the play.

We can also see it as follows. The first two periods are dominated by northern winter conditions (Fig. 3), the second two periods by southern winter conditions (Fig. 4).

The energetic background of southern winter conditions was investigated by FLOHN (1964). After having noted that the 'tropical easterly jet' extends in the layer 200-100 mb from the Philippines to the western Atlantic, this author points out that during July-August in the 'entrance region', above southeast Asia, the high tropospheric component of the cross-circulation is directed south into a region of subsidence, whereas in the 'exit region', above Africa, the high tropospheric component of the cross-circulation is directed north into a region of subsidence. He adds: 'The reversal in the direction of the cross-circulation, corresponding to the transition from acceleration to deceleration of the 'tropical easterly jet' is mainly produced by large scale convection and vertical momentum exchange along the westfacing meridional coasts of both peninsulae, and hence: 'From the thermodynamic and dynamic point of view, we observe in the "entrance region" a direct solenoidal cell with a work producing Hadley circulation, in the "exit region" an indirect antisolenoidal cell with a work consuming anti Hadley circulation'.

We have analysed here an ideal course of one S.O. through 3 years, the period of relaxation and the period of oscillation being of equal length. One detail is of great interest. The way in which the four steps are made is apparently dominated by successive seasonal conditions. However, the simple representation easily fails and in practice one season is easily skipped. This suggests optimal S.O. operation in cases of periods of about 33 months, or even sometimes 30 months. Repetitions of S.O. waves are most likely to occur, when each wave takes 36 months, exactly 3 years, because then the new start is made each time in the same season. This clarifies the fact, referred to in para 1.2, that the average length of well developed S.O. waves, those which are least damped is about 32 months, whereas the most spectacular wave trains occur in the case of 3-year waves.

4.4 The North Atlantic Oscillation

Arguments from papers by VON SCHUBERT (1927), BERLAGE (1957) and BERLAGE and DE BOER (1960) locate an area showing significant positive pressure correlations with the Djakarta region of the Southern Oscillation, at least during intervals of several consecutive years in the Northwest Atlantic Ocean.

This area is not simply identical with the area of the well established airpressure see-saw Iceland-Azores, which was WALKER's North Atlantic Oscillation. It is, rather, identical with the area Greenland-Iceland. Moreover (BERLAGE 1957), the negative coefficients of simultaneous correlation between Stykkisholm and Ponta Delgada, although large, do not increase with the time intervals, when these increase from one month to twelve months. Similar correlation coefficients between airpressure at Djakarta and Easter Island show this increase in a striking manner. Hence, as a rule, individual airpressure anomalies in the North Atlantic in moderate latitudes do not persist for more than one month.

The author can only confirm here what he has assumed since his earliest publications on Java monsoon forecasting (BERLAGE 1943): there is no selfinduced North Atlantic Oscillation covering the Azores-Iceland area, there is, besides the Southern Oscillation, only an Arctic Oscillation playing an independent role. The reason is that spontaneous generation of an oscillation of the S.O. type can only occur between a semi-permanent, relatively cold, high pressure region and a relatively warm, low pressure region over oceans. The most obvious examples are the Easter Island high and the Djakarta low on the one side and the Arctic high and the Icelandic low on the other side. As the Arctic Ice Sea, however, is part of the North Atlantic the term North Atlantic Oscillation is appropriate, and will be used in further discussion.

As a matter of fact, the Gulf Stream continuously transports temperature anomalies from a relatively warm, high pressure area towards a relatively cold, low pressure area, from the southwest to the northeast, and thus reinforces the existing airpressure gradient anomaly Azores-Iceland. The pressure see-saw Azores-Iceland may take over any period from the S.O. when this dominates the intertropical waters. A proper North Atlantic Oscillation period, however, can only be determined by the opposition Arctic high-Icelandic low.

The basic cause in this case is that $5\frac{1}{2}$ months after a certain pressure deviation in the Icelandic low a temperature deviation of the same sign arrives there with the East Greenland Current. The proper N.A.O. period associated with this lag is four times its amount, or 22 months. The S.O. may drive the N.A.O., but it is reflected from high northern latitudes. On the other hand the polar North Atlantic Oscillation may press its proper period on the Southern Oscillation through the intermediary of the see-saw subpolar low-subtropic high.

The Southern Oscillation and the North Atlantic Oscillation can remain independent only to a certain extent. During several years they may both exist without serious 'feed back'. The famous S.O. three-year wave train with Djakarta pressure tops 1896, 1899, 1902, 1905, investigated by VON SCHUBERT (1927), apparently came to its magnificent development because the N.A.O. fluctuations took up the same rhythm.

We can add one remark. As regards the above series of four S.O. waves, VON SCHUBERT's figures (BERLAGE 1957, Fig. 6 and Fig. 29) show top amplitudes west of Ireland, designating the Azores-Iceland region as the main participant in the S.O. However, two other maxima of the amplitude of these three-year pressure waves, the one in Alaska and the other east of Leningrad, and the Rossby meandering of the isoamplitudes, indicate that a high frequency of blocking situations in the general atmospheric circulation in moderate latitudes, stressed these patterns.

Similar indications about a certain connection between the S.O. and the number of blockings in the northern hemisphere were noticed by the author (BERLAGE 1962) from a study of the striking persistence of the 500 mb blocking pattern and drought in northwest Europe through 1959, unequalled in the total 12-year period 1949-1960.

Two recent 8-year periods, 1 Jan 1931-1 Jan 1939 and 1 Jul 1949-1 Jul 1957, were investigated by BERLAGE and DE BOER (1960) on the basis of 351 meteorological stations and 259 grid points in the first instance, and 292 meteorological stations and 256 grid points throughout the world in the second instance.

The following conclusions could be drawn:

(a) 1 Jan 1931-1 Jan 1939. The average length of the period of the N.A.O. amounts to 20.8 months, while its pressure amplitude exceeds the noise amplitude by more than 20 per cent. The average length of the period of the S.O. also amounts to 20.8 months, whereas the noise amplitude is 1.09 times the amplitude of the S.O. Hence the N.A.O. is well developed whereas the S.O. is not. In this case the N.A.O. is generating a forced oscillation in the region of the S.O.

(b) 1 Jul 1949-1 Jul 1957. The average length of the period of the S.O. amounts to 29.8 months, while the pressure amplitude of the S.O. exceeds the noise amplitude by 33 per cent in its own region. The average length of the period of the N.A.O. amounts to 20.8 months while its amplitude is only half the noise amplitude in its own region. The amplitude of the S.O. even exceeds the amplitude of the N.A.O. by 24 per cent in the North Atlantic Ocean. Hence during this interval the S.O. is well developed, whereas the N.A.O. is not.

The correlation patterns show the dominance of a northern summer circulation type during 1931-1939 and of a northern winter circulation type during 1949-1957 in both hemispheres (Fig. 3 and Fig. 4).

The two proper periods, essentially average periods, 20.8 months and 29.8 months, are approached theoretically in a promising way by the 22 months and 30 months, mentioned earlier. They tend to increase to 2 years and 3 years exactly, in outstanding cases. The 2-year swing is a frequent habit of the North Atlantic circulation, the 3-year swing one of the Indo Pacific Ocean circulation.

Hence, the Southern Oscillation (average proper period 30 months) in the course of its natural accelerations after incidental relaxation may, by resonance, get involved in the North Atlantic Oscillation (average proper period 21 months). This is what happened in the 1930's.

The actual operations of the two oscillations at the same time, the normal kind of operation of systems of coupled oscillators, lead to series of oscillations distinguished by quasi repetitions, such as those of 3 times 20.8 and 2 times 29.8, or 62.4 months and 60.0 months, the average amounting to 61.5 months, and 4 times 20.8 and 3 times 29.8, or 83.2 months and 89.4 months, the average amounting to 86.3 months. Hence, these quasi repetitions occur in periods of 5 years 1.5 months and 7 years 2.3 months. In fact, wave trains of these lengths often occur, separated by relaxations. Hence, we are back at the origin of the clustering of empirical periods, summed up by BERLAGE (1957), round 5.2 and 7.3 years, and the average of 6.2 years, noted in para 3.2 of the present paper.

4.5 Relaxations and northwest European cold winters

The occurrence of northwest European cold winters rests on blockings in the

TABLE 34. *Connections between NW European cold winters (right) and S.O. relaxations (left) 1844-1963.*

1844-1845	———	1844-1845	1910-1911		
1849-1850			1917-1918	←——	1916-1917
		1854-1855	1922-1923	——→	1923-1924
1858-1859	←——	1857-1858	1924-1925	←——	
1863-1864	——→	1864-1865	1928-1929	———	1928-1929
		1870-1871	1938-1939	——→	1939-1940
1875-1876					1940-1941
(1879-1880)	——→	1880-1881			1941-1942
1882-1883			1943-1944		
1886-1887	←——	1885-1886	1945-1946	——→	1946-1947
	——→	1887-1888	1950-1951		
1890-1891	———	1890-1891			1953-1954
1895-1896	←——	1894-1895	1956-1957	←——	1955-1956
		1900-1901	1962-1963	———	1962-1963

northern hemispheric circulation. In particular at the 500 mb level a high pressure cell must be established above the North Atlantic Ocean. As quoted from FLOHN by BUTZER (1958) and surveyed by DINIES (1965), these blockings are initiated by northern hemisphere low index circulation anomalies, or relaxations, which may be connected with the S.O. In what sense northwest European cold winters are associated with S.O. relaxations is shown by Table 34.

The list of relaxations contains 21 years, the list of cold winters also 21 years, out of a total of 120 years. Corresponding years have been connected by a dash when they are equal, and by an arrow forward or backward if the correspondence is from one year to the next.

There are 4 cases of coincidence, 6 cases when the cold winter year precedes the S.O. relaxation year, and 6 cases when the S.O. relaxation year precedes the cold winter year. This means that in 16 cases out of 28 cases a situation developed which could have developed by chance in no more than 21 out of $120 : 3 = 40$ cases. A comparison of the two ratios, 0.57and 0.52, confirms that there are interhemispherical weather developments even towards high northern latitudes, and associated with the S.O., in a number of cases, which is above random, although not far above.

The S.O. having taken the initiative, the impulse is apparently given from south to north in those cases where the S.O. relaxation precedes the northwest European cold winter. There are an equal number of impulses apparently given from north to south, when the S.O. relaxation follows the northwest European cold winter. It will be interesting to know whether in these latter cases the initiative was taken by the North Atlantic Oscillation.

Since relaxations in the general atmospheric circulation are influenced by variations in solar activity, there is nothing surprizing in the relations discovered by BAUR (1963), DINIES (1963) and others, between solar activity and northwest European winters, which have not been touched here, and which require defence against the doubts raised on statistical grounds by GLEISSBERG (1962) and others.

A striking subject is the unforeseen, exceptionally cold, West-European winter 1962-1963. It was evidently associated with the global relaxation occurring after the extreme Djakarta low pressure and Santiago high pressure year 1962, the fifth year in a rare succession of six years distinguished by positive anomalies of the pressure difference Santiago-Djakarta. Actually (BERLINER WETTERKARTEN 1963, Beilage Nr. 29) the relaxation in the northern hemispheric circulation and the establishment of strongly meridional circulation must have occurred already in autumn 1962 and have been rather restricted to the northern hemisphere. The corresponding relaxation in the southern hemispheric circulation occurred apparently one half year later, or in autumn 1963 of the southern hemisphere.

Such transfer of abnormal conditions from one hemipshere to the other with the sun's declination is, of course, not improbable. Yet, as was shown in para 1.10, the 1963 relaxation has almost undeniably been stimulated by the spread of a dust veil originating from the heavy eruption of Gunung Batur, Bali, February 9.

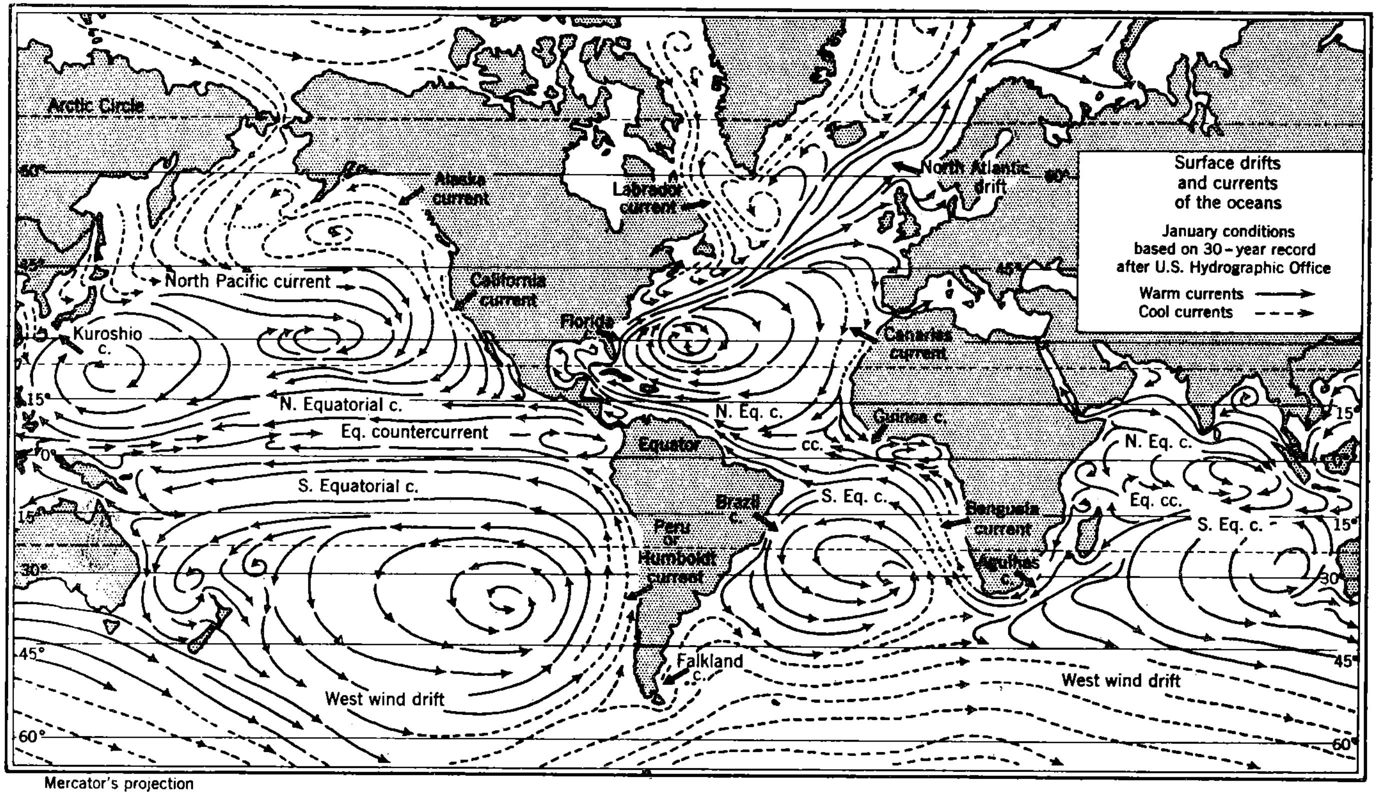


Fig. 46 World chart of ocean surface currents.

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5. SUMMARY

The Southern Oscillation is a fluctuation of the intensity of the intertropical general atmospheric and hydrospheric circulation. This fluctuation, dominated by an exchange of air between the Southeast Pacific subtropical high and the Indonesia equatorial low, is generated spontaneously. Its period varies between roughly 1 and 5 years and amounts to 30 months on the average. A standard type S.O., of wavelength 3 years, was developed. It shows almost global extension.

The fundamental pressure differences and consequently the intensity of the S.O. are subject to relaxation oscillations of a much longer and unsystematic period. The S.O. proper is naturally accelerated, amplitude and period decreasing fairly continuously. The relaxation occurs rather abruptly and is associated with an increase of amplitude and period of the S.O. The conclusion is that variations of solar activity, and of the turbidity of the atmosphere caused by heavy volcanic eruptions, are guiding factors.

The South American meridional mountain barrier is one of the major fronts directing S.O. operations.

Arctic and antarctic conditions both influence the Southern Oscillation. The relations to arctic conditions are dominated by a North Atlantic Oscillation, probably the only self-sustaining oscillation besides the Southern Oscillation. Its proper period is 21 months on the average. The relations to antarctic conditions are apparently restricted to the incidental cases of blocking of the strong southern west circulation by pressure ridges, built between Antarctica and the Southeast Pacific high. Outstanding examples are those of 1945-1946 and 1956-1957, the ridgebuilding starting, in the first case, from Antarctica, in the second case from the Southeast Pacific high.

No plain relations could be traced between the S.O. and the quasi biennial fluctuation of the equatorial stratospheric winds. Probably the S.O. is a tropospheric phenomenon, the other one a stratospheric phenomenon, the two being located on two of the main floors in our atmosphere, the earth's surface and the tropical tropopause inversion. Yet the author believes that both phenomena are generated in a similar way.

The author cherishes the hope that the present report may contribute to the improvement of theories of large scale atmospheric and hydrospheric motions, with adequate long range forecasting in view. One practical example, the forecasting of Surinam winter droughts, was approached by steps and found decidedly promising.

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