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DR H. P. BERLAGE

SCHOMMELINGEN VAN DE ALGEMENE LUCHTCIRCULATIE MET PERIODEN VAN MEER DAN EEN JAAR, HUN AARD EN BETEKENIS VOOR DE WEERSVERWACHTING OP LANGE TERMIJN

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FLUCTUATIONS OF THE GENERAL ATMOSPHERIC CIRCULATION OF MORE THAN ONE YEAR, THEIR NATURE AND PROGNOSTIC VALUE

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VOORWOORD

Deze publicatie is het resultaat van een onderzoek, dat in 1925 werd aangevat door Dr. H. P. BERLAGE, toenmaals wetenschappelijk medewerker bij het Koninklijk Magnetisch en Meteorologisch Observatorium te Batavia en belast met de ontwikkeling van moessonverwachtingen in het voormalig Nederlands Indië, welk onderwerp voor het eerst werd bestudeerd door Dr. C. BRAAK.

Dit onderzoek werd voortgezet op het Koninklijk Nederlands Meteorologisch Instituut, waar de schrijver in 1951 werd belast met de studie der weersverwachtingen op lange termijn, daarbij de arbeid van Dr. S. W. VISSER voortzettend.

De voorliggende studie behandelt de mogelijkheden voor seizoenverwachtingen op gematigde breedten op de basis van de langperiodieke schommelingen in de algemene circulatie in de atmosfeer en de hydrosfeer, welke met redelijk praktisch resultaat moessonverwachtingen in de tropen mogelijk blijken te maken. Voornamelijk is daarbij evenwel aandacht geschonken aan die schommelingen in de algemene atmosferische en hydrosferische circulatie, welke een physische oorzaak en betekenis hebben, hoe en waar deze ontstaan, hoe hun invloed zich voortplant over de aardbol en waar deze invloed nog kenbaar en wellicht voor praktische toepassing bruikbaar is.

De publicatie wordt in de Engelse taal uitgegeven.

De Hoofddirecteur van het K.N.M.I.
Ir. C. J. WARNERS

PREFACE

This paper is the outcome of an investigation started in 1925 by Dr. H. P. BERLAGE, at that time research associate at the Royal Magnetic and Meteorological Observatory in Batavia and charged with the development of monsoon forecasting in the former Netherlands Indies, first studied by Dr. C. BRAAK. This investigation was continued at the Royal Netherlands Meteorological Institute, when in 1951 the subject of seasonal forecasting was placed before the writer, he having succeeded Dr. S. W. VISSER in the study of this subject.

The paper is concerned with the prospects of seasonal forecasting in moderate latitudes on the basis of those long period fluctuations in the general atmospheric circulation which had allowed monsoon forecasting in the tropical Far East to become reasonably practicable. Stress, however, is mainly laid on a careful discrimination of oscillations in the general atmospheric and hydrospheric circulation which possess physical significance, how and where they originate, how their influence is propagated over the globe and where this influence is still distinguishable and perhaps applicable.

The Director in Chief R.N.M.I.
Ir. C. J. WARNERS

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0. INTRODUCTION

The discussion given in this paper centres around the large scale natural phenomenon, which was called the Southern Oscillation by Sir GILBERT WALKER. It summarizes in an unhistorical way the evolution of ideas about the Southern Oscillation, which appears to be fundamental among the long periodic fluctuations of the general atmospheric and hydrospheric circulation whose physical reality should be recognized.

A great deal of evidence has been accumulated from many sides since, 30 years ago, the author became acquainted with the subject and found data pointing to an explanation of the Southern Oscillation which he brought into theoretical form. He stated that this early hypothesis was fertile and allowed some details of the Southern Oscillation to be related to variations in solar activity. He found it useful to publish an extensive list of references, in which are stored up all the pieces of the great puzzle which confronts us when dealing with periodicities and correlations existing within the frame of the present problem.

The author was, of course, not in the position to give requisite attention to some papers which have appeared only very recently. He makes however an exception with regard to one publication, because it touches the heart of the matter, and he gladly acknowledges in a study on the nature and origin of the Southern Oscillation by I. I. SCHELL [144g], which came into his hands after the present contribution was in print, a new confirmation of his own conception.

The author is greatly indebted to the Directors of the British Meteorological Office, the Commonwealth Meteorological Branch of Australia, the India Meteorological Office, the New Zealand Meteorological Service, the Meteorological Service of Chile and the Météorologie Nationale de France, for observational data from several dispersed places in the world and in many forms. The author is equally grateful to the Director of the Meteorological and Geophysical Service of Indonesia for sending him the average air pressure at Djakarta (Batavia) by air-mail every month during many years.

1. EMPIRICAL PERIODS ABOVE ONE YEAR AND THEIR SIGNIFICANCE

1.1 A survey of empirical periods

It was with his sound sense of humour, but also with a good deal of distrust that Sir NAPIER SHAW, in the second volume of his Manual of Meteorology compiled a list of 131 „empirical periods derived from the examination of long series of observations by arithmetical manipulation or by inspection" [156]. The list contains only periods of one year and longer, the longest period cited being one of 260 years duration.

As a matter of fact, when we take stock of the results of all past investigations of longperiodic oscillations in weather elements, we soon feel completely lost in a profusion of periods more or less seriously advocated by numerous authors. The entanglement is such that there seems to remain almost no number of years which so far has never been mentioned as the average interval in which some weather element repeats a cycle of departures from its normal value. One typical example is the following. SHAW's list contains an uninterrupted sequence of whole-year periods from 11 to 23, and one 25-year period. Now, it is exactly a 24-year period which became stressed by GROISSMAYR in recent years [68j, m], whereas a 10-year period was detected in Berlin temperature and precipitation by O. MEISZNER, although considered unproved [105a, b].

It is an almost hopeless task to test even the majority of the waves assumed on their statistical significance. The promotors of a certain periodicity hardly ever applied one or more of the wellknown severe criteria of verification such as persistence through separate parts of the total series of observations. Moreover, every one who is acquainted with „periodicities" of this kind knows that the cyclic processes in the physical sense which might explain such phenomena are never strictly periodic, but always present that wide margin of variability about a certain average wavelength which lowers their prognostic values to mere uselesness. They should be termed „recurrences", as was suggested by C. E. P. BROOKS [31].

BRÜCKNER's once famous 35-year cycle, for instance, though we shall reconsider it presently, is no longer taken seriously by any author, and we have lived to see WAGNER himself doubting in 1940 [178c] the physical significance of the 16-year cycle, which he supported so strongly in 1924 [178a].

Hence, even if an author is not the victim of some „quasi-periodicity", every value given to the length of the period discovered has to be considered as a mean value dependent on the series of years which have been used in its deduction. The only promising way to deal with this matter is to see what logic there is in the total collection of periods found and to grope with great care for its real basis.

The very vagueness of all cycles longer than KÖPPEN-EASTON's 89-year cycle in the character of European winters [95c; 49a, b], a period which was recently supported again by SCHERHAG [145b] leaves us free to behead SHAW's list at this famous instance. Further we find considered in the list the whole spectrum of periods which Sir W. BEVERIDGE discovered by harmonic analysis of the series of yearly wheat prices in Europe 1545–1864 [17]. Although the importance of the fluctuations of these prices should not be underestimated, since we are to consider them from the climatological point of view, they are of the agricultural phenological kind and will be disregarded here.

Neither shall we retain in the list which we are about to compile, a couple of empirical periods which we are surprised to notice in SHAW's original list, such as TURNER's 80-year cycle in Chinese earthquakes and RUSSELL [140] and LOCKYER's [98a] 19-year „provisional cycle for the southern hemisphere", the old lunar Saros, which was not confirmed by later investigations of climatic changes. We do not hesitate, however, to include the periods found by DOUGLASS [47] and HUNTINGTON [81a] by harmonic analysis of their famous measurements of the widths of the year rings of *sequoia gigantea* in Arizona and California. These fluctuations are also of the phenological type. However, in these cases it is at least a plant's physiological response to living conditions which is measured, mainly controlled by climate, although not directly a meteorological factor. It is the same with the average 3,32-year period found by BERLAGE [15e, f] from year ring measurements of teak wood, *tectona grandis*, in Java, provided it is permissible to assume its reality. In fact we should never forget the remark first shown to be true by BESSON [16] that in every random succession of departures of some element from its normal value the average interval between two successive maxima or minima is statistically three units. On the other hand, it should be noted that these phenological periods are in no case independent of periods found otherwise and already included in the table. There may be slight differences, but there are several reasons for knowing that these are not serious and certainly no real discrepancies.

A large part of the periods in our list is due to Sir DAVID BRUNT's outstanding analysis of the fluctuations of air pressure, temperature and precipitation which have occurred at several places in Europe presenting long series of observations [36a, b]. There is no reason to notice the periods discovered by this author in one or two elements at only one station, since it would be hard to prove the real significance of any of them. Let us retain in our list only those periods which BRUNT found in the departures of the elements at more than one place, provided that the geographic extent of their presence enhances the probability that we must attach some kind of reality to them.

Since the appearance of Sir NAPIER SHAW's instructive compilation more attention has been paid to weather periodicities in the vast region covered by the Pacific and Indian Oceans and in the countries bordering these oceans.

In the first place it is generally agreed that a 3–3,5 year period in Indo-Pacific weather is an outstanding phenomenon. J. H. DE BOER [24b, c] found by harmonic analysis of the air pressure deviations of Djakarta (formerly Batavia) a mean length of 3,36 years. This length differs so little from the mean value of 3,32 years which was, according to BERLAGE, indicated by tree growth in Java that the value of this latter period is evidently confirmed. M. O. JOHNSON [88] who investigated the fluctuations of precipitation in the Pacific area suggests 3,29 years or 3,33 years according to different views. If precipitation records are tabulated by 23-year periods, that is by double the length of the solar period, they usually show seven cycles, whereas, if precipitation records are tabulated by 10-year periods they usually show three cycles.

The total result of DE BOER's analysis was the following series of prominent periods in Djakarta air pressure: 2,34, 3,36, 5,97, 7,32, 8,47, 11,12 (solar period) and 15,97 years, or, rounded off: $2\frac{1}{3}$, $3\frac{1}{3}$, 6, $7\frac{1}{3}$, $8\frac{1}{2}$, 11,12 and 16 years. The present writer repeated this analysis with the aid of the rapid sign-coefficient method devised by DE BOER [24a], and plotted the periodogram shown in fig. 1. It is based on the complete series of 174 seasonal air pressure anomalies at Djakarta Oct–Mar and Apr–Sep 1866–1953.

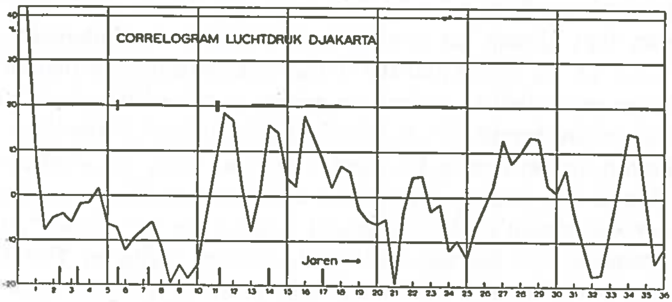

FIG. 1. Periodogram of Djakarta (Batavia) air pressure, derived by autocorrelation. The apparently basic periods are indicated by vertical dashes.

This periodogram proves the following.

1. There is a prominent persistency of deviation from one half year to the next. Even the correlation at intervals of one year is still positive.
2. The correlation at intervals of 2 years is at a negative extreme, and the periodogram seems to give rather strong support to a 4-year period, especially so when it is taken into account that the whole part of the graph between 2 and 8 years appears depressed in consequence of the existence of several prominent longer cycles. The 4-year cycle is supported by 8, 12, 16 and 28-year crests, denied however by 20, 24, 32 and 36-year hollows, and after all insignificant.

3. It is the strong negative correlation between air pressure values at 9 and 21 years intervals which suggests the prominency of a 6-year and an 18-year periodicity. The negative correlation between air pressure values at 36 years interval directly shows, however, that there is no 36-year periodicity. Hence, the 6-year, 12-year and 18-year periodicities are all weak.
4. The 7-year periodicity is weak, but the 14-year periodicity is pronounced and supported by the strong negative correlation at 21-years interval and the strong positive correlation at 28-years interval.
5. The 8-year and 16-year periodicities are not confirmed by 24 and 32-year periodicities and apparently insignificant. The 17-year periodicity, however, is confirmed by a remarkably sharp 34-year periodicity.
6. The sunspot cycle is well pronounced by successive tops at 11, 22 and 34 years. One half sunspot cycle is also a prominent cycle.
7. There are indications of the reality of a $7\frac{1}{3}$-year cycle which is independent of the 14-year cycle. This remark was also made by DE BOER.

Hence the following series of prominent long periods in Indonesian weather, rounded off in thirds of years results: $2\frac{1}{3}$, $3\frac{1}{3}$, $5\frac{2}{3}$, $7\frac{1}{3}$, $11\frac{1}{3}$, 14, 17, $22\frac{2}{3}$, 28, 34.

The triplets 11, 14, 17 and 22, 28, 34 are so very clearly marked in Djakarta's periodogram that almost no doubt remains about the independence of the octaves 11–22, 14–28, 17–34 and the world-wide significance thereof.

It is always profitable to follow up traces as far as they lead. The higher pitched octaves are found at 5,5, 7, 8,5, that is at half of the solar period, at a 7-year period and at one of DE BOER's periods. They are all drowned in the „noise", that is the almost continuous spectrum of shorter cycles. The one or the other prominent cycle emerges at times from the „noise". The almost classical examples are the beautiful 19th century trains of Far Eastern air pressure waves which have led to the conception of a 3-year cycle. Contrary to this, outstanding in the „noise" are almost only a 4,5- and 7,5-year cycle. This leads us finally to the recognition of the importance of the series: 2,33, 4,66 and 7 years.

Let us cite here among recent authors SILVIO POLLI [121] who mentions an example of periodic analysis made with the aid of VERCELLI's method [174]. In the number of sunshine hours at Trieste the following periods in years become manifest: 2,25, 3,5, 5,5, 7,5, 11,25, 22,5. Nevertheless POLLI concludes from more than one hundred analyses that only the following periods in world weather may claim physical reality: the succession 5,6, 11,15 and the succession 4, 8, 16. With regard to the conclusions which will presently be drawn, it should be noted here that POLLI finds evidence for no more than two independent successions, a solar one and a terrestrial one. Although our assumptions differ slightly numerically there is no fundamental difference of interpretation. Finally SCHOSTAKOWITSCH [147a, b] by ample discussion of meteorological, hydrological and biological longperiodic cycles found traces of an approximate 3-year, 6-year and 11-year cycle in a large number of cases and in several kinds of phenomena throughout the world. When counting statistically the frequency of occurrence of different varieties of the shortest one of the three main cycles, we find them distributed as follows:

years	2,30–2,39 /	2,40–2,49 /	2,50–2,59 /	2,60–2,69 /	2,70–2,79 /
	1	3	8	15	14
years	2,80–2,89 /	2,90–2,99 /	3,00–3,09 /	3,10–3,19 /	3,20–3,29 /
	13	4	2	3	1

It is reasonable to conclude that the approximate 3-year cycle which SCHOSTAKOWITSCH pointed out presents an average period of 2,75 years. In his 6 and 11-year cycles we recognize well-known cases, although similar frequency computations would suggest 6,2 and 11,5 years as average lengths rather than the 5,6 and 11,2 years which we expect.

The empirical periods in world weather which would seem to claim recognition are compiled in table 1. Periods longer than 36 years are, however, not considered this time. The authors supporting the prominency of the cycles included are mentioned in alphabetical order.

TABLE 1. *Empirical periods in world weather in years* (1–36)

36	Europe (BAUR, DE BOER, HANN, TRAUTMANN)
35	Europe (BRAMANTI, BRÜCKNER, BRUNT, POLLI)
34	Treegrowth U.S.A., Nile floods, Indonesia (BERLAGE, BROOKS, HUNTINGTON)
28	Indonesia (BERLAGE)
27	Europe (MIELKE)
25	Europe, California (BRUNT, MCEWEN)
24	Europe, Arctic, Japan (GROISSMAYR, MEISZNER, EHIRO and TUDIKAWA)
23	Worldwide = 2 × solar cycle (several)
22	Europe (BRUNT, POLLI)
21	Treegrowth U.S.A. (HUNTINGTON)
18	Europe (BAUR, PORTIG, SANSON)
17	Indonesia (BERLAGE)
16	Europe, Indonesia (DE BOER, POLLI, WAGNER)
15	Europe (BRUNT, VISSER)
14,5	Europe (BRUNT)
14	Europe, Indonesia (BERLAGE, BRAMANTI, BRUNT)
13	Europe, Japan (BRUNT, FUGITA, OZAWA, PORTIG)
11,12	Worldwide = solar cycle (several)
8,5	Indonesia (DE BOER)

TABLE 1. *(continued)*

8	Europe, U.S.A. (BIGELOW, BRAMANTI, MAURER, PETTERSON, POLLI, PORTIG, TETRODE)
7,5	Europe (BRUNT, VISSER)
7,4	Japan (FUGITA, OZAWA)
7,3	Treegrowth U.S.A., Indonesia (DE BOER, DOUGLASS)
7,2	Europe (BAUR, PEPPLER)
7	U.S.A. (CLOUGH)
6,8	S. America (BERLAGE)
6	Worldwide (ANGENHEISTER, BRUNT, DE BOER, GROISSMAYR, NEWCOMB, SCHOSTAKOWITSCH, SPITALER)
5,56	Worldwide = $\frac{1}{2}$ solar cycle (several)
5,3	Europe (BRAMANTI)
5,25	Atlantic Ocean (DE BOER)
5,1	Britain (BAXENDELL, BROOKS)
4,8	Arctic (BROOKS, MEINARDUS, WIESE)
4,66	Indonesia (BERLAGE)
4,08	Europe (BRUNT)
4	Europe (POLLI)
3,75	India–Australia–South America = $\frac{1}{3}$ solar cycle (LOCKYERS)
3,36	Europe, Indonesia (BAUR, BERLAGE, BRAAK, DE BOER)
3,08	Europe (BAXENDELL, BRUNT, DANILOW)
2,75	Worldwide = $\frac{1}{4}$ solar cycle (SCHOSTAKOWITSCH)
2,66	Europe (BRUNT, WALLÉN)
2,58	Europe (BRUNT)
2,42	Europe (BAUR, BAXENDELL, BRUNT, DANILOW)
2,33	Europe, Indonesia, Japan, U.S.A. (BRUNT, CLOUGH, BERLAGE, DE BOER, OGAWAZA, WALLÉN)
2,25	Europe, Atlantic Ocean (BAUR, VISSER, WALLÉN)
2,22	Worldwide = $\frac{1}{5}$ solar cycle (ARCTOWSKY, BAXENDELL, BRUNT)
2,17	Europe (BAUR, BRUNT, PORTIG, WALLÉN)
2,08	Europe (BROOKS, WALLÉN)
2	Europe, Treegrowth U.S.A. (BIRKELAND, DOUGLASS, WALLÉN, WOEIKOF)
1,92	Europe (BRUNT, WALLÉN)
1,72	Europe (BRUNT)
1,58	Europe (BRUNT, DANILOW)
1,22	Europe (BRUNT)
1,11	Europe (BRUNT)
1,08	Europe (WALKER)
1,03	Europe (BRUNT, WALKER)

The chapter on periods in the general circulation was entitled „resilience" by Sir NAPIER SHAW. The present author must confess that he was obliged to consult his English dictionary on the meaning of this word. He was thinking that Sir NAPIER in his humorous way meant to say „resignation" and that „resilience" was a poetical expression for the same idea. However, when he came across the word „resignation", which was in fact the last word preceding „resilience", he knew himself to have been a victim of Freudian „psychopathology of everyday life". Finally he concluded that „resilience" was not the right expression for the terrestrial cause behind these long term oscillations, and that not „resignation" but „resilience" was the better expression for the behaviour of an investigator faced with such a multitude of apparently significant long term periods.

1.2 Modulations, multiplications and partitions of periods

BRUNT [36b] and DE BOER [24b] have investigated the case in which the amplitude of a basic harmonic oscillation with a period T_b varies harmonically according to a period T_o. They have shown that two new periods emerge, T_1 and T_2, so that

$$\frac{1}{T_1} = \frac{1}{T_b} + \frac{1}{T_o}; \quad \frac{1}{T_2} = \frac{1}{T_b} - \frac{1}{T_o} \tag{1}$$

As a matter of fact, when

$$x = A \sin (2\pi \frac{t}{T_b} + \varphi_1) \tag{2}$$

and

$$A = P - Q \sin (2\pi \frac{t}{T_o} + \varphi_2) \tag{3}$$

we obtain

$$\begin{aligned} x = P \sin (2\pi \frac{t}{T_b} + \varphi_1) - \frac{Q}{2} \cos \left\{ 2\pi t (\frac{1}{T_b} + \frac{1}{T_o}) + \varphi_1 + \varphi_2 \right\} + \\ + \frac{Q}{2} \cos \left\{ 2\pi t (\frac{1}{T_b} - \frac{1}{T_o}) + \varphi_1 + \varphi_2 \right\} \end{aligned} \tag{4}$$

Generally, harmonic analysis of the resulting fluctuations will thus reveal to us three periods, the basic one and two modulations. The modulating cycle does not appear explicit.

The amplitudes of the two modulated oscillations are known to be not larger than half the amplitude of the modulating oscillation. We should therefore be very careful with the interpretation of empirical fluctuations according to this principle. Some quantitative relations are a requisite. On the other hand we know how inconspicuous the major part of the empirical fluctuations are, and the present writer received the strong impression that only very few long periodic cycles are basic. Evidence points in the direction of an explanation of all other empirical cycles in the way suggested here.

This evidence is obtained mainly, because the possibilities towards explanations of this kind are much enlarged by the fact that similarly derived periods arise, when the amplitude of the basic oscillation is constant whereas its period is fluctuating harmonically.

With this point in view, suppose

$$x = A \sin \left\{ 2 \pi t \left(\frac{1}{T_b} + \alpha \sin 2 \pi \frac{t}{T_o} \right) + \varphi_1 \right\} \tag{5}$$

This formula leads to

$$\begin{aligned} x = A \Big\{ & \sin \left(2 \pi \frac{t}{T_b} + \varphi_1\right) \cos \left(2 \pi t \alpha \sin 2 \pi \frac{t}{T_o}\right) + \\ & + \cos \left(2 \pi \frac{t}{T_b} + \varphi_1\right) \sin \left(2 \pi t \alpha \sin 2 \pi \frac{t}{T_o}\right) \Big\} \end{aligned} \tag{6}$$

which is an unpractical expression because, even when α is very small, it cannot be developed in pure harmonics. Easier to handle is the expression in which not the period, but the phase varies harmonically, the adaptation to the actual fluctuations being achieved in an almost identical manner. When

$$x = A \sin \left(2 \pi \frac{t}{T_b} + \varphi_1 + \varphi_2 \sin 2 \pi \frac{t}{T_o}\right) \tag{7}$$

we obtain

$$\begin{aligned} x = A \Big\{ & \sin \left(2 \pi \frac{t}{T_b} + \varphi_1\right) \cos \left(\varphi_2 \sin 2 \pi \frac{t}{T_o}\right) + \cos \left(2 \pi \frac{t}{T_b} + \varphi_1\right) \times \\ & \times \sin \left(\varphi_2 \sin 2 \pi \frac{t}{T_o}\right) \Big\} \end{aligned} \tag{8}$$

In this case, when φ_2 is small, we may write

$$x = A \sin \left(2 \pi \frac{t}{T_b} + \varphi_1\right) + A \left\{ \varphi_2 \cos \left(2 \pi \frac{t}{T_b} + \varphi_1\right) \sin 2 \pi \frac{t}{T_o} \right\} \tag{9}$$

or

$$\begin{aligned} x = A \sin \left(2 \pi \frac{t}{T_b} + \varphi_1\right) & + A \frac{\varphi_2}{2} \cos \left\{ 2 \pi t \left(\frac{1}{T_b} + \frac{1}{T_o}\right) + \varphi_1 \right\} \\ & + A \frac{\varphi_2}{2} \cos \left\{ 2 \pi t \left(\frac{1}{T_b} - \frac{1}{T_o}\right) + \varphi_1 \right\} \end{aligned} \tag{10}$$

In this limiting case the same solution is obtained as in the case of amplitude modulation. If φ_2 is large our mathematical expression is not easy to handle. The picture then obtained is, however, that of the basic oscillation and superimposed upon it 2 modulated oscillations which are not strictly harmonic.

Now, since a non-harmonic wave can always be developed in Fourier series we may expect that harmonic analysis of the resulting oscillation would indicate that also the higher harmonics occur, or

$$\frac{1}{T_k} = k\left(\frac{1}{T_b} \pm \frac{1}{T_o}\right); \; k = 2, 3, 4 \ldots. \tag{11}$$

On the other hand, surprisingly good representations of existing fluctuations are obtained by expressions like

$$x = A \left\{ \cos^2\pi \frac{t}{T_o} \sin\left(2\pi \frac{t}{T_m} + \varphi_1\right) + \sin^2\pi \frac{t}{T_o} \sin\left(2\pi \frac{t}{T_n} + \varphi_2\right) \right\} \tag{12}$$

Because $\cos^2\pi \frac{t}{T_o} + \sin^2\pi \frac{t}{T_o} = 1$, it is then as if the energy of one oscillation with a period T_m is transferred periodically to another oscillation with a period T_n. This is a phenomenon well known from coupled pendulums. Here it is replaced by suggesting the existence of a basic fluctuation with a period T_b, so that, say

$$\frac{1}{T_b} = \frac{1}{2}\left(\frac{1}{T_m} + \frac{1}{T_n}\right)$$

Since

$$\cos^2\pi \frac{t}{T_o} = \frac{1}{2}\left(1 + \cos 2\pi \frac{t}{T_o}\right) \tag{13}$$

and

$$\sin^2\pi \frac{t}{T_o} = \frac{1}{2}\left(1 - \cos 2\pi \frac{t}{T_o}\right)$$

(12) can be written as

$$x = \frac{A}{2} \left\{ \sin\left(2\pi \frac{t}{T_m} + \varphi_1\right) + \sin\left(2\pi \frac{t}{T_n} + \varphi_2\right) + \right.$$
$$\left. \cos 2\pi \frac{t}{T_o} \sin\left(2\pi \frac{t}{T_m} + \varphi_1\right) - \cos 2\pi \frac{t}{T_o} \sin\left(2\pi \frac{t}{T_n} + \varphi_2\right) \right\} \tag{14}$$

The new periods which arise and would result from harmonic analysis are

$$\frac{1}{T_1} = \frac{1}{T_o} + \frac{1}{T_m} \tag{15}$$

$$\frac{1}{T_2} = \frac{1}{T_o} - \frac{1}{T_m} \tag{16}$$

$$\frac{1}{T_3} = \frac{1}{T_o} + \frac{1}{T_n} \tag{17}$$

$$\frac{1}{T_4} = \frac{1}{T_o} - \frac{1}{T_n} \tag{18}$$

From every aspect of harmonic analysis we get the impression that large numbers of „quasi periodicities" are added to those which have been found significant in some place and for some length of time, the more so as it has been here assumed so far that if the basic oscillation was not strictly periodic at least the deviations from strict periodicity were. If amplitude and phase of a fundamental fluctuation vary at random, harmonic analysis is always misleading.

The fate of harmonic analysis is that it always produces a couple of answers. The answers require interpretation. If two waves of a relatively variable wave train succeed each other at a very short interval, harmonic analysis counts the two crests for one. In this way significance is erroneously attached to a cycle with a longer than average period of the basic wave train. On the other hand an abnormally large interval between two other crests automatically suggests the existence of a cycle which produces a secondary crest within this interval, and this cycle will present a period which is shorter than the average period of the basic wave train.

The periodogram of an ordinary sequence of fluctuations of the element investigated will therefore mostly show a kind of line spectrum, the lines being sometimes broadened or even almost dissolved in bands. The total series of periods which was found by BRUNT and others and compiled by SHAW presents conspicuously this spectral type and is in fact suggestive of only a very small number of fundamental cycles.

We should add the remark that also multiples of certain basic periods are always naturally found and that in cases of waves which deviate from the strict sinusoidal type the same is true for a number of fractions of the basic period.

The almost classical instance of this occurence is the 11-year solar period whose physical reality cannot be denied. The average duration of the solar cycle is 11,12 years. Its actual length however varies between 9 and 13 years. Natural oscillations of this kind all assume more or less the type of relaxation oscillations, well known from the geyser phenomenon. Their behaviour is within certain limits stochastic. The average length of one oscillation is a statistical quantity. Every wave is an individual. In the case of sunspots the relevant wave shows not the „sinus" but the „sawtooth" character. It is this fact which enhances the amplitude of the halfwave and thus also the amplitude of fluctuations of weather elements with an average period which is half the solar period.

1.3 An attempted understanding of the list of periodicities

Following the preceding paragraph it is logical to expect the average periods in world weather listed in table 2. It is rather a surprise to find them all, without a single exception, remarked by one or more investigators.

TABLE 2. *Fundamental solar periods in world weather*

Theoretical	Observed
3,71	one third solar period
5,56	half solar period
11,12	solar period
22,24	double solar period
33,36	33,5 C. E. P. BROOKS, 33,8 HUNTINGTON
44,48	44,5 EASTON, KÖPPEN, 45 ALLDIS
55,60	54 BEVERIDGE, 57 KEELE
66,72	68 BEVERIDGE, 66,0 C. E. P. BROOKS
77,84	76,8 C. E. P. BROOKS, 77,7 CLAYTON
88,96	89 EASTON, S. W. VISSER
100	100

Apart from periods already mentioned, we easily recognize EASTON's cycle and half EASTON's cycle, the occurence of which was confirmed by other authors, in particular S. W. VISSER [175g]. In fact these periods were mostly explained on the same basis, that is as multiples of the solar period. Further we discover a conspicuous one among HUNTINGTON's tree ring periods. Even the longest two of BEVERIDGE's periods in European wheat prices between 1545 and 1864, which was intentionally not stressed earlier, appear without any constraint. C. E. P. BROOKS noted 33,5-, 66,0- and 76,8-year recurrences [30d] in Nile floods and KEELE a 57-year one [89] in Nile floods and rainfall in Britain, a period, which may well be identified with the shorter one of BEVERIDGE's periods mentioned here. CLAYTON [39c] has remarked that in several cases a sequence of 4 intense solar cycles was followed by a sequence of 3 weak solar cycles, making him adhere to the significance of a 77,7 year recurrence in world weather. We shall, at a later stage, be obliged to correct this rather improbable view. It should, however, not detain us here. Finally it has been more than once remarked by different investigators, and it also appeared to the present writer as seeming slightly more than just chance, that certain particular aspects of world weather return at intervals of approximately one century.

This is the external rhythm brought into the pulsations of the general atmospheric circulation by the variations of solar activity. We must now turn our attention to the proper rhythms due to terrestrial causes.

As regards the search for the interval of years in which a fundamental terrestrial period is located it is somewhat similar to the search for the region from which a given plant originates. The botanist knows that he must look for the area where he meets the greatest number of this plant's varieties. Now, when a count is made in the provisional list of the number of varieties of periods within intervals of one half year these numbers are as follows

1–1,5	1,5–2	2–2,5	2,5–3	3–3,5	3,5–4
4	4	6	3	2	2

This frequency distribution strongly suggests – provided we can indicate *one* basic terrestrial cycle besides the trivial annual one – that its wavelength is between 2 and 2,5 years.

In the following chapters we shall discuss this fundamental fluctuation in the general circulation. It is, since Sir GILBERT WALKER [180], known as the „southern oscillation", while recent investigations have convinced the present writer of the fact that the 2,33-year recurrence discovered in Europe, in the U.S.A., and also in Indonesia is the one which is basically attached to the „southern oscillation". This length of the period is remarkably well in harmony with our arguments.

Accepting here provisionally the truth of this statement it is also reasonable to expect the average periods in world weather compiled in table 3.

TABLE 3. *Fundamental terrestrial periods in world weather*

Theoretical	Observed
2,33	2,33 BRUNT, DE BOER, CLOUGH, WALLÉN
4,66	4,8 BROOKS, 4–5 MEINARDUS, WIESE
7	7 CLOUGH
14	14 BERLAGE, 15 ALLDIS
21	21 HUNTINGTON
28	27 MIELKE, 28 BERLAGE
35	35 BRÜCKNER, BRUNT, 35,5 BEVERIDGE 36 BAUR, BROOKS, CLOUGH
42	—
49	50 WATSON, GREGORY
56	54 BEVERIDGE, 57 KEELE

Again, we have listed beside our theoretical values the periods observed and advocated by one or more authors. As a matter of fact, the empirical values are very near the theoretical ones.

Let us realize once more, although we continue at the present moment to take these periodicities at their face values, that we have no strict periodicities in view, neither those of solar nor those of terrestrial origin. Very probably the solar cycle continuously interferes with the terrestrial one. Hence, an exchange of impulses and effects of resonance is to be expected.

There is first of all the more or less random interference towards the longer periods in roughly the following way

0		0
6		7
11		14
17		
		21
23		
28	=	28
34		
		35
39		
45		42
51		49
56	=	56

On the other hand there is the possible modulating effect towards the shorter periods following processes which were discussed in the preceding paragraph. Periodicities which may arise in this way are summarized in table 4 and compared with the empirical periods from table 1 (between brackets).

TABLE 4. *Empirical periods as possible effects of beating*

						1	
				2,33		2,33	1,78 (1,72)
			4,66 (4,8)	4,66	1,56 (1,58)	4,66	1,27
			4,05 (4,08)	5,56	1,64	5,56	1,21 (1,22)
			3,50 (3,36)	7	1,75 (1,72)	7	1,17
	11,12		2,96 (3,08)	11,12	1,92 (1,92)	11,12	1,10 (1,11)
51,33 (51)	14	6,16 (6)	2,80 (2,75)	14	2,00 (2,00)	14	1,08 (1,08)
22,24 (23)	22,24	7,08 (7)	2,60 (2,66)	22,24	2,11 (2,08)	22,24	1,05
16,68 (17)	33,36	8,34 (8, 8,5)	2,55 (2,58)	33,36	2,18 (2,17)	33,36	1,03 (1,03)
			2,46	44,48	2,22 (2,22)		
			2,42 (2,42)	66,72	2,25 (2,25)		

It is certainly illuminating to find that almost every one of the numerous empirical periods which are shorter than the solar period and listed in table 1 will arise spontaneously, at very nearly the average length previously mentioned, by effects of beating under favourable conditions. As exceptions only the two sets of empirical periods 5,1, 5,25, 5,3 and 7,2, 7,3, 7,5 years are noteworthy. These two sets of periods, clustering round 5,2 and 7,3 years, are so suggestively near to two and three times the value around which the empirical Southern Oscillation periods cluster that we are induced to ask whether they have a character of their own and will return to this point in the following paragraphs.

Moreover, as if to complete this explanation, it is inferred from the small table preceding table 4 that a 51-year periodicity may well occur. This is a cycle which De Boer [24e] showed to be significant, by means of harmonic analysis of the series of tree ring widths measured by Berlage in Java.

Hence, one wonders whether it is really too adventurous to suggest that the 21, 22, 24 and 25-year cycles are distortions of the 23-year cycle, which is double the solar cycle, that the 16 and 18-year cycles are distortions of the 17-year cycle and the 13, 14,5 and 15-year cycles are distortions of the 14-year cycle. After the insight now gained into processes which may have led different authors to attach significance to quasi-periods, the writer is willing to accept the thesis that none of the periods just mentioned points to some fundamental oscillation, neither solar nor terrestrial, other than those which have already received our full attention.

In this way the whole strange spectrum of periods would appear reduced to effects of the play of three basic cycles, the terrestrial $2\frac{1}{3}$-year cycle and the solar cycle, both of variable amplitude and period, and the strictly annual cycle. But why does the $2\frac{1}{3}$-year cycle proper, notwithstanding its fundamentality, appear rather unimportant empirically?

It is in the first place the great variability of the period which may have so greatly weakened the amplitude of the $2\frac{1}{3}$-year swing in the periodogram of fig. 1. This figure even shows a negative ordinate at the abscissa $2\frac{1}{3}$ years. We should, however, not take this apparently reverse indication too seriously. The shorter periodicities are all negatively depleted by the positive amplitudes of the longer prominent periods. Moreover, according as the period is longer its variability is relatively less. It is therefore dangerous to rely too much on the relative significance of the values of amplitudes which are empirically found in the course of periodogram analysis.

This point may have induced De Boer erroneously to define the 3,36- and the 7,32-year periods in Djakarta air pressure and temperature as the physically „real" ones and the 2,34- and 5,97-year periods as the „unreal" or derived ones. It is extremely difficult to prove in such cases which cycles are the cause and which the effect. The present writer has found greater fertility in the assumption that a 2,33-year cycle is fundamentally real and a 3,50-year and a 1,75-year cycle are derived by the occurrence of a 7-year periodicity, 7 being equal to $2 \times 3{,}50 = 3 \times 2{,}33 = 4 \times 1{,}75$.

The 5,97-year periodicity should be considered also as unreal according to DE BOER. It is assumed here to be an effect of the interference between the 14-year cycle and the 11,12-year solar cycle. We agree in considering the Brückner-period as of solar origin. DE BOER assumes it to be independent and its length 36 years. It is assumed here that its length simply is 3 times the fundamental solar period or 33,36 years on an average. From the interplay of the solar- and Brückner-periods DE BOER derives two new periods, a 8,50-year one and a 16,09 year one. It is assumed here that a similar derivation leads to an 8,34 and a 16,68-year period, 33,36 being equal to $2 \times 16{,}68 = 3 \times 11{,}12 = 4 \times 8{,}34$.

The most puzzling instance finally remains the 7-year recurrence already hinted at several times. Is it dependent or independent?

1.4 The 7-year period, dependent or independent

In order not to lose the red thread through the labyrinth of dispersed information, a recapitulation follows of what has been learned so far about those different cycles which used to be designated as „the" 7-year cycle in world weather, as a first approximation to the physical facts.

CLOUGH was the first to draw attention to an approximate 7-year period in North American weather [40a]. An approximate 7-year recurrence is perhaps most spectacularly demonstrated by the periodic arrival about Christmastime, for the duration of the first months of the characteristic year, along the west-coast of Peru, of a warm tropical ocean current from the North, removing for some time the normal and relatively cold Peru- or Humboldt-Current from the South (MURPHY [109], MEARS [102], SCHOTT [148]). Such a situation may lead to disastrous rainfall during these critical months in some coastal provinces which remain almost completely dry during the rest of the time.

This famous phenomenon induced the writer to give the name Pacific cycle to the 7-year cycle in previous publications [15a, h]. However, the term Pacific cycle in this sense will not be retained in the present paper. The modification is of minor importance. The Pacific-cycle was then considered to be a natural duplication of one more fundamental approximate 3,4-year cycle in Indo-Pacific weather and hence showing a wave length of 6,8 years on an average. We are considering here a 7-year cycle which is a triplication of the fundamental 2,33-year cycle.

The present problem, however, is whether an independent meteorological cycle exists whose period would be definitely longer than 7 years. In fact BAUR [10a, f] hinted at a 7,2-year recurrence in European weather, more specifically in temperature departures at German stations. BRUNT [36a] found evidence for a 7,5-year recurrence in Padua and Edinburgh precipitation throughout one century, VISSER [175b] the same in Netherlands precipitation throughout two centuries. DOUGLASS [47] pointed out a 7,3-year periodicity in U.S.A. tree growth and finally DE BOER [24b, c] found indications of an original 7,32 year cycle in Djakarta air pressure, which means in Indo-Pacific weather. It was confirmed in 1.2. OZAWA and FUGITA [114] pointed out a 7,4-year periodicity in Japan.

The results of the investigations surveyed here would thus suggest largely different lengths of the 7-year wave ranging from 6,8 up to 7,5 years, whereas when speaking of a 7-year periodicity in world weather we think of CLOUGH's period in general and of the El Niño phenomenon along the Peruvian coast in particular.

As a matter of fact it is a great surprise to discover that the El Niño phenomenon has lately repeated itself in a strict 7-year periodicity, at least between 1911 and 1953, although it did not become actually detectable every time. A similar recurrence is remarkable over a vast region of tropical South America. Precipitation figures of Paramaribo (Surinam) present, as is shown by fig. 2, the same strict 7-year periodicity causing extremely dry winter seasons

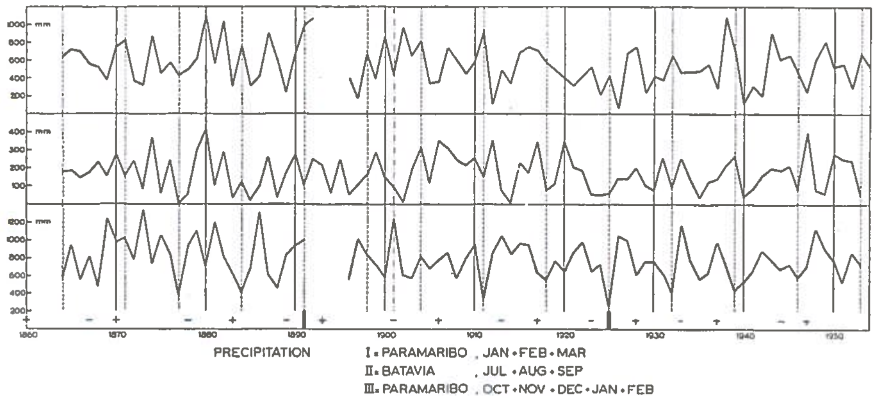

FIG. 2. The approximate 7-year period in seasonal precipitation in the tropical East (Batavia, Java) and West (Paramaribo, Surinam).

Oct-Feb in 1911–12, 1918–19, 1925–26, 1932–33, 1939–40, 1946–47, 1953–54. The year 1925 was outstanding in the present series of Peru floods and Surinam droughts. Nevertheless the most prominent year of occurrence of the El Niño phenomenon before 1925 was 1891. Since a 34-year interval became obvious, definitely related to and confirmed by the extreme droughts occurring in Java in the dry seasons of exactly the same years, the present writer formulated earlier the hypothesis that the real periodicity behind these phenomena was a 6,8-year one. It was therefore expected that a 6-year interval would follow after 1946. However, the 7-year periodicity was not interrupted. 1953 became a Peru rain year and the 1953–54 Paramaribo precipitation values, although in this instance not equally conclusive, leave no doubt about a repetition in the sense indicated. Seven uninterrupted and exactly 7-year waves certainly constitute a high mark among longperiodic fluctuations in recent and carefully observed meteorological quantities.

Dating backwards for Paramaribo precipitation one receives the impression that 1904 instead of 1905 is to be considered as a Peru rain-year, especially so when we are reminded of the long range symmetry point in 1901 in Djakarta air pressure deviations which was discussed by the writer [15c] and may probably be considered as a more than local attribute.

At any rate one 6-year interval must have occurred about the latest turn of the century. Hence two 6-year intervals occurred, (1905–1911) or (1898–1904), and (1871–1877) or (1864–1870), and one 8-year interval (1835–1843) in the course of almost one and a half centuries. The average period of the cycle under consideration here would thus become very near 7 years indeed. However, the large negative ordinate at 21 years in fig. 1 excludes the existence of a true 7-year periodicity. Our conclusion therefore is that the cycle is mostly closed in 7 years, but sometimes in 6 and sometimes in 8 years. This behaviour is very probably a consequence of the fact that the El Niño phenomenon is naturally linked with a certain part, actually the first quarter, of a given year. The intervals between Peru rain years can only encompass whole numbers of years. As a matter of fact, if 18th century witnesses and correspondents are reliable [50, 58] the sequence of Peru rain years before 1814 is 1728, 1735, 1742, 1749, 1756, 1763, 1770, 1777, 1784, 1791, 1798, 1804. This would leave a 10-year interval between 1804 and 1814.

Now, faced with this irregularity, we need not adhere too much to the idea of an exception. The 7-year cycle doubtlessly is not singular. It has different aspects. Berlage and De Boer showed that the 7-year wave in Indo-Pacific air pressure and even tree ring widths, presents a double wave, that is a 3,5 year wave on an average. The diagnosis which will be defended here is, that the 7-year cycle is ideally built up by couples of three 2,33-year waves, but actually in the sense of 3, 2, 2, 3, 2, 2, 3, etc. When a series of waves in air pressure with wavelengths which vary as above are analyzed harmonically, it is known that apart from a 2,33-year component, a 3,50-year and a 1,75-year component appear (fig. 3). As a matter of fact, if waves of lengths varying between 2 and 3 years should succeed each other by mere chance, although then with the provision that two of every three waves possessed a length of 2 years and one a length of 3 years, in the long run it is very doubtful whether the 7-year repetition in wet and dry years in tropical South America would be as pronounced as it actually is. Moreover, it will be pointed out later that the system of succession of 2- and 3- year waves is not pressed upon the general circulation by a 7-year steering wave, but is controlled by sunspot numbers, that is by variations of solar activity.

These are two aspects of the same subject which would readily explain the unusual occurrence of the 10-year interval 1804–1814 in Peru rain years. The yearly sunspot relative numbers remained below 20 from 1807 through 1814 and the 2–3 year wave in Indo-Pacific air pressure presented, as will be shown in 3.4, the unique example of a 5th crest within the current sunspot cycle. Moreover the 7-year rhythm in a sequence of waves of the nature 3, 2, 2, 3, 2, 2, 3, etc. is easily interrupted by one 10-year interval in the following way, which would include a certain kind of symmetry point,

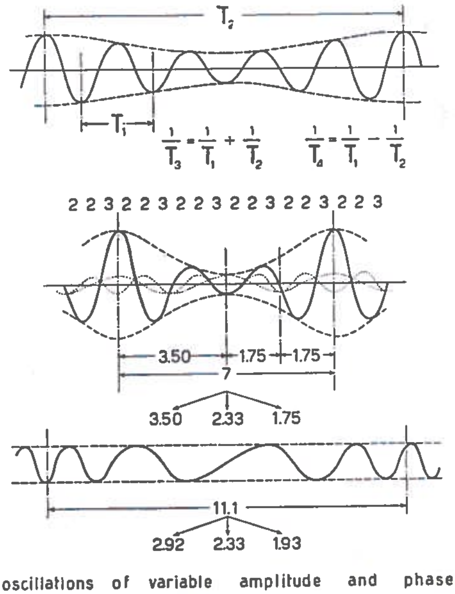

FIG. 3. New harmonical oscillations result from beating processes. Two practical examples are given. The amplitude of a 2,33 year wave varies with periodicities of 7 and 11,1 years.

7	7	10	7	7
3, 2, 2	3, 2, 2	3, 2, 2, 3	2, 2, 3	2, 2, 3 etc.

The counterpart of this effect might be the incidental occurrence of one 4-year interval between successive Peru rain years.

For the limits of the length of the average 7-year cycle the following interpretation suggests itself. There are two tendencies. Three 7-year cycles are synchronized with 2 solar cycles, which would lead to an average length of 22,24:3 = 7,41 years during a certain interval, or five 7-year cycles are synchronized with 3 solar cycles, which would lead to an average length of 33,36:5 = 6,67 years during another interval. The actual result apparently is a more or less random sequence of 7-year waves in the weather elements of several places and the conclusion is that it is surprising to find the 7-year recurrence so strictly definite along South America's westcoast. In the Indo-Pacific region it would seem to be the 14-year recurrence which is the more pronounced. It should be noted, however, that a tendency towards the greater regularity of the longer periods in long series of observations is only natural, since the ratio between the normal limits of variation of a 2,33-year, a 7-year and a 14-year period, or 3:2, 8:6 and 15:13 respectively, is rapidly decreasing.

At length, the smaller or greater independence of a 7-year cycle from the 2,33-year cycle still presents some problems. These problems cannot be solved before more is known about the way in which both cycles are operating under solar direction. This will be treated in paragraph 3.4.

2. THE SOUTHERN OSCILLATION FUNDAMENTAL

2.1 Facts

This paragraph will be devoted to facts about the „Southern Oscillation", and confined to those of the Indo-Pacific region, where this oscillation was discovered by HILDEBRANDSSON as early as 1897 [76], and attains its strongest development.

The Southern Oscillation in the first place is an air pressure „see-saw" between the equatorial low pressure area of the Malay Archipelago and the subtropical high pressure area which is centered near Easter Island (27°10'S, 109°26'W). The influence of this latter High extends over the Island of Juan Fernandez (33°37'S, 78°52'W) and the Chilean coastal station Punta Galera (40°01'S, 73°44'W). From both these stations a long series of air pressure measurements is available. The series of monthly averages of Juan Fernandez air pressure values was, however, several times interrupted in earlier years.

The writer is greatly indebted to the Director of the Meteorological Office of Chile for putting at his disposal the complete list of Juan Fernandez monthly air pressure values. As Juan Fernandez is a relatively old established oceanic station, situated rather near the centre of the permanent subtropical High of the South Pacific, it is one of those „key stations" which can reveal the most reliable picture of the Southern Oscillation.

With the aid of this list the differences between the Juan Fernandez air pressure values and the corresponding values for Punta Galera and Santiago, taken from the World Weather Records, were computed. The conclusion to which this comparison leads was, that very probably the air pressure values of Juan Fernandez require the following corrections in mm: 1915–1916, +1,5; 1917–1920, —0,5; 1920–1921, —1,5; 1923–1925, +1,5; 1925, +1,0. After the application of these corrections the failing monthly values for Juan Fernandez were interpolated from the Punta Galera values by the subtraction of one mm. Santiago air pressure varies strongly with the seasons, therefore a reduction of Juan Fernandez values to Punta Galera values was considered the best way to obtain a reliable and complete list for the former station. After changing to millibars the final list of monthly mean air pressure values in Juan Fernandez is the one compiled in 5.1.

Similar procedures were applied when the author eliminated inhomogeneties in the invaluable airpressure series of Mauritius, 5.2.

In fig. 4 and fig. 5 the Southern Oscillation is already demonstrated in the negative correlation between air pressures at Santiago and Djakarta and between air pressures at Juan Fernandez and Djakarta respectively, separately for winter and summer. The correlation figures obtained are Santiago–Djakarta Oct–Feb: —0,321, Apr–Aug: —0,548; Juan Fernandez–Djakarta Oct–Mar: —0,303, Apr–Sep: —0,471. It is easily understood why these coefficients are

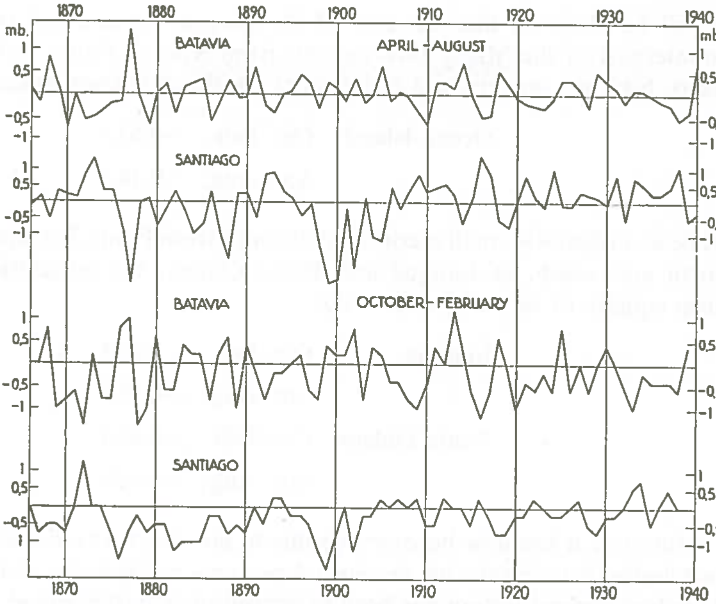

FIG. 4. The Southern Oscillation expressed by the opposition of Batavia and Santiago seasonal air pressure anomalies.

higher in the winter season and lower in the summer season. In fact the sub-tropical High stretches through the Eastern part of the South Pacific Ocean and the South American continent in winter, while it is reduced to a smaller area round Easter Island in summer.

From the following high figures of correlation between Djakarta air pressure and air pressure at two widely dispersed places from which sufficiently long series of observations are available

Apia (Samoa)	Oct–Feb:	—0,567
	Apr–Aug:	—0,405
Punta Tortuga	Oct–Feb:	—0,430
	Apr–Aug:	—0,517

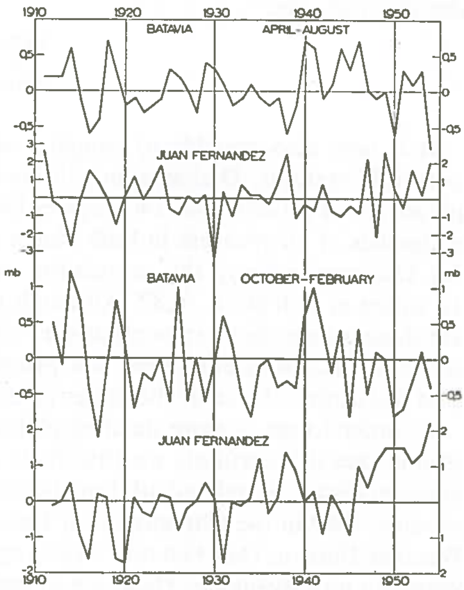

FIG. 5. The Southern Oscillation expressed by the opposition of Batavia and Juan Fernandez seasonal air pressure anomalies.

it will be observed that the axis of the pressure area which operates as the counterpart of the Malay Low extends from Apia to Punta Tortuga and Santiago. Near the western end of this area are the data from Ocean Island

Ocean Island	Oct–Feb:	—0,032
	Apr–Aug:	—0,143

while at a relatively small meridional distance from Punta Tortuga and Santiago north and south, at Iquique and Punta Galera, the correlation coefficients drop equally to very low values, viz.

Iquique	Oct–Feb:	—0,039
	Apr–Aug:	—0,253
Punta Galera	Oct–Feb:	—0,034
	Apr–Aug:	—0,076

Moreover it has now become possible to give the first reliable figures for the correlation between the air pressure departures at Djakarta and Easter Island. A meteorological station has been in operation at Easter Island since Jul 1949. The correlation figures between air pressure at Easter Island and Juan Fernandez are high, viz:

Oct–Mar:	+0,72
Apr–Sep:	+0,59

It is now also possible to compare air pressure between the two opposite „central" stations, Djakarta and Easter Island, for a period of 6 years. Both places are at no less than 140 degrees longitude apart. Yet, when the monthly anomalies of air pressure in both places are added up from Jan–Jun and from Jul–Dec respectively, the correlation coefficient between the two series of 12 values is as high as –0,82. Although to the eye of a statistician these series are dangerously short in comparison with the series of observations of other stations, the coefficient found is a promising confirmation that Easter Island is at the centre of one of the scales of the great pressure balance.

In order to get a more detailed picture of the air pressure relations in the Pacific area it is certainly worthwhile to compare seasonal pressure deviations between Easter Island and all those island stations the data of which are reported since 1949 in the Climatological Data for the World published by the U.S. Weather Bureau. Oct–Feb and Apr–Aug correlation figures covering 4, 5 or 6 years are now available. These are in fact a very short series, but it is the only material at our disposal at present. The series of correlation coefficients with Easter Island is summarized in table 5.

TABLE 5. *Seasonal correlation coefficients between air pressure deviations at Easter Island and other Pacific stations*

			Oct–Feb	Apr–Aug
Guam	13°34′N	144°55′E	—0,04	—0,64
Truk	07°27′N	151°50′E	—0,38	—0,56
Rabaul	04°13′S	152°11′E	+0,33	—0,86
Lae	06°43′S	147°00′E	+0,24	—0,64
P. Moresby	09°26′S	147°13′E	—0,45	—0,84
Ocean I.	00°52′S	169°35′E	—0,23	—0,85
Funafuti	08°31′S	179°12′E	—0,54	—0,98
Rotuma	12°30′S	177°05′E	—0,60	—0,99
Lauthala Bay	18°09′S	178°27′E	—0,36	—0,71
Apia	13°48′S	171°47′W	+0,01	+0,38
Rarotonga	21°12′S	159°46′W	—0,23	+0,95
Willis I.	16°18′S	149°59′E	—0,53	—0,59
Papeete	17°32′S	158°57′E	+0,26	+0,01
Noumea	22°16′S	166°27′E	—0,04	—0,21
Lord Howe I.	31°31′S	159°04′E	+0,27	+0,79
Norfolk I.	29°03′S	167°56′E	+0,47	+0,63
Hobart	42°53′S	147°20′E	+0,50	+0,91
Auckland	36°51′S	174°46′E	+0,97	+0,99
Hokitika	42°43′S	170°57′E	+0,80	+0,97
Invercargill	46°25′S	168°22′E	+0,40	+0,93
Chatham I.	43°58′S	176°33′W	+0,53	+0,92
Campbell I.	52°32′S	168°59′E	—0,06	—0,95
Macquarie I.	54°30′S	158°57′E	—0,82	—0,84
Juan Fernandez	33°37′S	78°52′W	+0,71	+0,56
Biak	01°12′S	136°07′E	—0,77	—0,96

These values sometimes very much above and below expectation are, of course, not to be taken too seriously. Nevertheless they were of invaluable aid in designing details of the patterns of seasonal correlation coefficients fig 14 and fig. 15.

For one to one and a half years air pressure is above normal in the Malay region and below normal in the Easter Island region. For the next one to one and a half years the reverse is true.

However, random causes may be the source of cyclic processes (SLUTSKY [157a]), the classical example being the Brownian motion of a small particle in suspension. Hence our statisticians are hardly ever convinced by graphs and will always require numerical confirmation of the significance of any suggested periodicity. For this reason the writer mentions also the results of a counting of the duration in halves of years, firstly of the phases, that is the intervals between one extreme and the next, and secondly the intervals between successive minima among the 174 half-yearly air pressure deviations at Djakarta 1866–1953. The phase test was executed with the aid of the formula

$$P = \frac{6\,(d^2+3d+1)\,(N-d-2)}{(d+3)\,(2N-7)} \times 100 \text{ percent}$$

which is true for a random series of N values.

It yields table 6 in which the numbers of intervals observed are compared with the numbers of intervals computed for $d = 1, 2, 3, \ldots .7$

TABLE 6. *Djakarta (Batavia) half-yearly air pressure deviations*

percentages of frequency of intervals between successive extremes in halves of years							
d	1	2	3	4	5	6	7
empirical	43	29	20	7	1	0	1
expected	62	28	8	2	0	0	0

Table 7 contains the observed numbers of intervals between minima and the numbers of intervals computed for an infinite random series of deviations by C. E. P. BROOKS and N. CARRUTHERS [31].

TABLE 7. *Djakarta (Batavia) half-yearly air pressure deviations*

percentages of frequency of intervals between minima in halves of years							
	2	3	4	5	6	7	8
empirical	18	21	27	23	9	0	2
expected	40	33	17	7	2	0,6	0,13

No doubt the Djakarta series is particular in a certain sense. An important persistency is at least manifest. Such persistency is a necessary but not a sufficient requirement for proving the existence of a more or less strict periodicity. Nevertheless, if the persistency is at least accepted as a partial proof it suggests the predominancy of 4–5 half-year intervals between successive tops of Djakarta air pressure and this is in accordance with the assumed predominancy of 2,33-year intervals.

The tables 6 and 7, which are of course not independent of each other, are rather strong proof against the danger of becoming the victim of a „quasi" periodicity. This is perhaps even more clearly demonstrated by contrast with table 8, which contains the same kind of percentages among the 76 half-yearly air pressure deviations at Juan Fernandez 1911–1949. As a matter of fact table 8 is curiously different from table 7.

TABLE 8. *Juan Fernandez half-yearly air pressure deviations*

	percentages of frequency of intervals between maxima in halves of years						
	2	3	4	5	6	7	8
empirical	38	33	17	4	4	4	0
expected	40	33	17	7	2	0,6	0,13

In this case the empirical and theoretical percentages are so similar that no periodicity whatever seems indicated. From it appears how easily the Djakarta figures could have been less impressive than they are, or even equally uninformative. It accentuates the singularity of Djakarta, the chief point of which is probably its equatorial situation. As a matter of fact physically real recurrences are easily overshadowed by random fluctuations, as soon as data from stations outside the tropical zone are analyzed. It is permissible to say, therefore, that the correlation figures Djakarta–Juan Fernandez given above, as well as the relatively large amplitude of the longperiodic air pressure waves in Juan Fernandez leave no doubt that it also occupies a vital position in the Southern Oscillation. While the axis of the Equatorial Low-region, the one active region, is defined by Bombay–Djakarta–Darwin, the axis of the Subtropical High-region, the other active region, is defined by Samoa–Easter Island–Juan Fernandez.

It is illuminating to follow the course of the waves at the first set of stations in one figure (figs 24 and 25). Remembering how great the distances between Bombay, Djakarta and Darwin are (Bombay–Djakarta = 4650 km, Djakarta–Darwin = 2730 km) we are surprised by the almost exact similarity of the three curves. On the other hand we observe at several points small lags of phase between the three waves which may indicate that they are not always perfect standing waves, but running for a short time in the one direction or the other.

From this standpoint it is interesting to list the seasonal correlation coefficients between Djakarta and Juan Fernandez air pressure values in halves of years with intervals from $-2\frac{1}{2}$ to $+3$ years.

TABLE 9. *Correlation coefficients Djakarta—Juan Fernandez air pressure*

	Years	Two seasons		Total
	$2\frac{1}{2}$	+0,299	—0,065	+0,039
Djakarta (Batavia)	2	+0,124	—0,006	+0,053
before	$1\frac{1}{2}$	+0,188	—0,318	+0,043
Juan Fernandez	1	—0,227	—0,463	—0,312
	$\frac{1}{2}$	**—0,371**	**—0,467**	**—0,441**
	0	—0,178	—0,447	—0,281
	$\frac{1}{2}$	+0,114	—0,312	—0,190
	1	+0,234	—0,139	+0,040
Djakarta (Batavia)	$1\frac{1}{2}$	+0,157	+0,149	+0,152
after	2	**+0,355**	**+0,326**	**+0,306**
Juan Fernandez	$2\frac{1}{2}$	**+0,426**	+0,030	**+0,316**
	3	+0,314	+0,165	+0,222

The largest negative coefficient is reached between the departures from normal at Djakarta half a year before those at Juan Fernandez. Hence the impression that the one activity, which is creating the opposite air pressure deviation on the other side of the South Pacific Ocean, starts from the Malay Low. It is not directly achieved in the Easter Island High, but one half year later. The other activity, so to speak, emanates from the Easter Island High and is apparently due to create pressure departures of the same sign in the Malay Low two and a quarter years later on an average.

This is not in accordance with expectation, because $2\frac{1}{4}+\frac{1}{2} = 2\frac{3}{4}$ years is not equal to half the fundamental period. On the contrary it is roughly equal to the whole period and this would suggest the actual stimulation of an approximate 5,5-year cycle. Very probably this somewhat puzzling feature is related to a similar feature shown by the Djakarta air pressure periodogram. Intercorrelation of Djakarta air pressure values is not even positive at intervals of 2,33 years, it is, however, positive at intervals of double the length of the fundamental period. The solution of the problem apparently is that the variability of the wavelength of the fundamental oscillation is such that the chance of touching the right phase after an interval of twice the mean wavelength is greater than the chance of touching it after an interval of only one mean wavelength. Furthermore, a 5,5-year period approaches the semisolar period whose reflection may well become visible in the present data. On the other hand we are reminded so strongly of the 5,1–5,3 year periods, which were detected in European weather, that the existence of a relation with these periods is even more probable.

It is important to state here that the amplitude of the Juan Fernandez air pressure fluctuations is approximately twice as large as the amplitude of the Darwin air pressure fluctuations, while the Darwin fluctuations are some fifty percent larger than the Djakarta fluctuations. In the Indo-Pacific area the amplitude of the Southern Oscillation decreases apparently from the tropics to the equator. This is a very significant fact, which should be considered apart from the well-known general tendency towards increasing amplitude of long-periodic oscillations from the equator towards the poles. This somewhat surprising tendency was already pointed out by VON SCHUBERT in his analysis

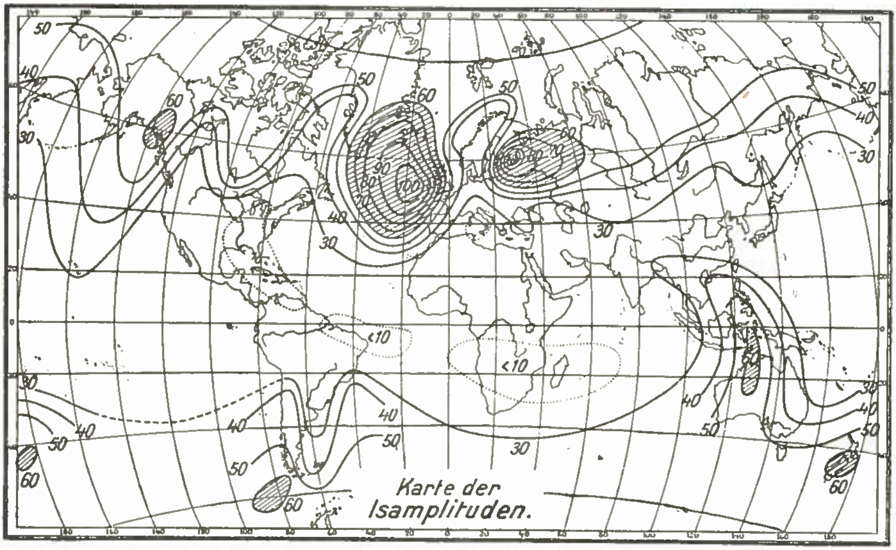

FIG. 6. A world map of isoamplitudes of the sequence of 3-year period waves of air pressure, 1896 1905 (after VON SCHUBERT).

of the famous world wide 3-year wave train 1896–1905 [150]. It should not induce us, however, to suspect the origin of the Southern Oscillation in polar latitudes. There are several reasons for this latitude effect. The part of the surface of the globe north and south of 45° latitude is only 30 percent of the total surface and hence any wavelike motion emanating from the tropical zone may show a tendency towards increasing amplitude in higher latitudes by mere continuity. Secondly, the random part of all air pressure fluctuations is so much enlarged in higher latitudes that, in the statistical average, harmonic analysis will also yield greater amplitudes of the systematic fluctuations. Thirdly, there probably is a specific reason for pulsations in the general circulation of the kind of the Southern Oscillation to be reflected into moderate and polar regions with increased amplitudes. This latter point is one of those which will be treated in paragraph 2.2, which is explanatory.

Before closing these remarks on the longperiodic fluctuations of air pressure, mention must here be made of the significant fact that they are not greatest at sea level and decreasing with height proportional to pressure or, what might have been expected, perhaps even more quickly than pressure. As was pointed out by BAUR in the Alps (10b) and by BRAAK in his careful investigation of the climate on Java mountain tops (26f), and as could be confirmed by an analysis of the uninterrupted series of aerological measurements 1913–1940 at Soesterberg, Netherlands, the amplitude of the longperiodic waves in air pressure remains at 3000–5000 m at least as large as it is at sea level. The writer verified this thesis again recently by comparing the mean yearly deviation of air pressure from normal, averaged over the Alpine stations Säntis, Obir, Zugspitze and Sonnblick on the one side and over Zürich and Vienna on the other side between 1880 and 1950. He found 0,875 mb for the first group and 0,860 mb for the second group of stations. This proves that the higher airlayers are of outstanding importance in the teleconnections studied here.

To summarize what is known of the fluctuations of temperature in the Indo-Pacific region, the region where the Southern Oscillation is the absolute dominant feature.

In previous publications the writer was able to prove that in the South Pacific Ocean and South East Asia area air temperature fluctuates with air pressure in roughly parallel or antiparallel waves (15). In those cases when the temperature fluctuations and the pressure fluctuations show the same sign the temperature waves follow the pressure waves with a difference in phase varying between 0 and 7 months. In the Malay Low air temperature waves lag roughly 7 months behind air pressure waves of the same sign. This is the largest difference of phase observed in the whole area considered. In previous publications this fact was proved by simply drawing air pressure and temperature graphs of running 6 monthly means of deviations from normal on transparent paper and noting in which position relative to each other the curves fit best. It is

TABLE 10. *Correlation coefficients Djakarta*

Air pressure	Temperature											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Jan 1866–1900	+,15	+,28	+,37	+,28	+,30	+,38	+,44	+,42	+,38	+,36	+,35	+,37
Jan 1901–1940	+,28	+,32	+,33	+,32	+,20	+,27	+,12	+,07	+,09	+,16	–,17	+,08
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Jul 1866–1900	+,14	–,02	+,05	+,38	+,46	+,43	+,48	+,55	+,56	+,51	+,42	+,32
Jul 1901–1940	+,10	+,16	+,47	+,50	+,44	+,65	+,47	+,55	+,39	+,53	+,28	+,35

intended to confirm here these earlier conclusions with the aid of correlation computations.

Table 10 presents the coefficients of correlation between the Djakarta air pressure anomalies in Jan and Jul, and the temperature anomalies in Jan and Jul and each of the following 11 months. The significance of the figures presented is stressed by the division of the total series of years available in two independent series, from 1866–1900 and from 1901–1940 respectively.

As a matter of fact in these four cases the highest positive coefficients occur at the following numbers of months after the time of origin

6 and 7

2

7 and 8

5,7 and 9

Apart from the very weak second case, typifying a certain diffusion in twentieth century conditions relative to nineteenth century conditions, the average lag is 7 months and the coefficients are high enough to give due weight to this value. This illuminates one aspect of the problem clearly.

Since the study of HELLAND HANSEN and NANSEN [72] we are familiar with the conception that the longperiodic terrestrial cycles are a product of the slow flow of ocean currents, which, with their enormous latent heat, carry temperature anomalies almost unperturbed from one part of the globe to the other. This aspect of the general circulation was, of course, most carefully investigated in the North Atlantic, where the Gulfstream is the classical example of an ocean current of tropical origin dominating climate up to high latitudes (BAUR [10e], BERGSTEN [14], BRENNEKE [28], BROOKS, C. F. [34a], GALLÉ [61], WIESE [186f]). However, tropical conditions may be expected to permit conclusions to be drawn which are statistically more important.

The present writer's earlier investigations suggested that Juan Fernandez experiences temperature variations which are synchronous with, and of the same sign as, the pressure variations in the Malay Low, that Iquique (Chile) experiences temperature variations lagging – but not more than $2\frac{1}{2}$ months – behind pressure variations of the same sign in the Malay Low, and that Malden Island (3°59′S, 155°0′W), Apia (13°48′S, 171°46′W) and Tulagi (9°5′S, 160°8′E) show temperature variations parallel to the pressure variations in the Malay Low, but lagging approximately 4 months behind the latter variations [15g, h].

Coefficients of correlation between monthly air pressure deviations at Djakarta, Jan and Jul, and temperature deviations at Juan Fernandez, Iquique and Apia in Jan to Jun in the one case and in Jul to Dec in the other case, are compiled in the tables 11, 12 and 13.

TABLE 11. *Juan Fernandez temperature* (1911–1954)

Djakarta pressure	Jan	Feb	Mar	Apr	May	Jun
Jan	+0,168	+0,099	+0,097	+0,051	+0,167	+0,201
	Jul	Aug	Sep	Oct	Nov	Dec
Jul	+0,282	+0,038	+0,230	—0,102	—0,104	+0,140
Mean of both	+**0,225**	+0,078	+0,164	—0,026	+0,032	+0,171

TABLE 12. *Iquique temperature* (1900–1940)

Djakarta pressure	Jan	Feb	Mar	Apr	May	Jun
Jan	+0,119	+0,304	+0,312	+0,234	+0,138	+0,124
	Jul	Aug	Sep	Oct	Nov	Dec
Jul	+0,248	+0,515	+0,349	+0,472	+0,341	+0,491
Mean of both	+0,184	+**0,410**	+**0,331**	+**0,353**	+0,240	+0,308

TABLE 13. *Apia temperature* (1890–1940)

Djakarta pressure	Jan	Feb	Mar	Apr	May	Jun
Jan	+0,365	+0,467	+0,571	+0,373	+0,449	+0,189
	Jul	Aug	Sep	Oct	Nov	Dec
Jul	—0,300	+0,023	+0,062	+0,335	+0,247	+0,258
Mean of both	+0,032	+0,245	+**0,317**	+**0,354**	+**0,348**	+0,224

These figures, although much less spectacular than the Djakarta coefficients, suggest that the lag of the temperature fluctuations behind the Djakarta pressure fluctuations is roughly 0, 2 and 3 months in Juan Fernandez, Iquique and Apia on an average. This trend confirms our hypothesis on the vital influence of the ocean currents, *in casu* the South Equatorial Current.

Even the lag of phase of roughly 6 months between the local temperature fluctuations in Fanning Island (3°55′N, 159°23′W) and the pressure fluctuations in the Malay Low is not exceptional, because Fanning Island is not directly affected by the South Equatorial Current, but actually affected a couple of months later by the Equatorial Counter Current (fig. 7). On the other hand, the independence of proper kinds of waves in Fanning Island temperature curve is also easily understood.

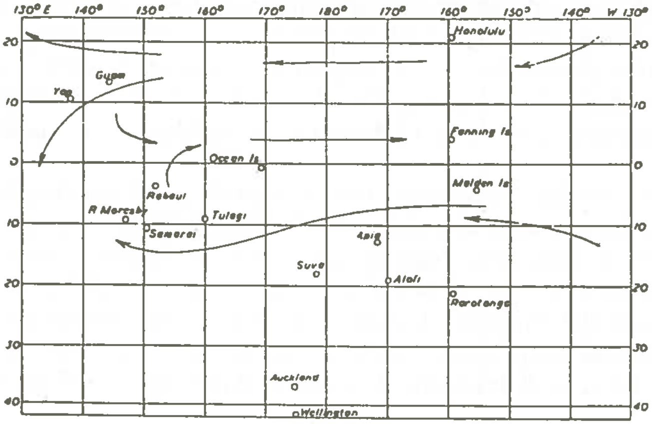

FIG. 7. Hydrospheric circulation in the Pacific Ocean showing how seasurface temperature anomalies are propagated.

Rabaul (4°10′S, 152°10′E) and Ocean Island (0°52′S, 169°35′E) in a direction northwestward from Samoa show temperature variations which are roughly opposite to the Malay pressure variations (table 14).

TABLE 14. *Ocean Island temperature* (1910–1940)

Djakarta pressure	Jan	Feb	Mar	Apr	May	Jun
Jan	—0,342	—0,071	—0,193	—0,320	—0,340	—0,387
	Jul	Aug	Sep	Oct	Nov	Dec
Jul	—0,184	—0,051	+0,017	—0,123	+0,042	—0,198
Mean of both	**—0,263**	—0,061	—0,088	—0,222	—0,149	**—0,293**

The same occurs in Rarotonga (21°21′S, 159°45′W), Alofi (19°2′S, 169°55′W) and Suva (18°8′S, 178°26′E), in a direction southwestward from Samoa (table 15).

TABLE 15. *Suva temperature* (1910–1940)

Djakarta pressure	Jan	Feb	Mar	Apr	May	Jun
Jan	—0,240	—0,316	—0,126	—0,359	—0,283	—0,047
	Jul	Aug	Sep	Oct	Nov	Dec
Jul	—0,347	—0,433	—0,404	—0,286	+0,007	—0,064
Mean of both	—0,294	**—0,375**	—0,265	**—0,323**	—0,138	—0,056

The writer is inclined to explain this fact by the situation of these latter stations out of the flow of the South Equatorial Current. The water masses in that area are more or less stagnant and air temperature apparently more directly dependent on surface wind direction and force, the kind of advective air, or on secondary features such as convective cloudiness and precipitation. A remarkable depression of air temperature in Alofi in 1930, followed by temperature depressions in Suva and Rarotonga with no counterpart in the Malay air pressure curve (see Djakarta) are other proofs of exceptional conditions.

Attention must here be drawn to the fact that the Southern Oscillation is not confined to the southern hemisphere. A belt north of the equator, including such stations as Honolulu, Manila, and above all Bombay, takes part in it. The oceanic stations Yap (9°29′N, 138°8′E) and Guam (13°24′N, 144°38′E) and also Manila in the Philippine Islands show temperature variations which, just like the Djakarta temperature variations, lag behind the pressure variations in the Malay Low, as if transmitted to these islands by the North Equatorial Current.

However, a significant negative correlation between pressure deviations in the Malay Low and those in the subtropic Hawaii High lasts for one season only, Apr–Aug, the northern summer. It is alternated by a no-correlation season Oct–Feb. Sir Gilbert Walker even found a positive correlation as high as +.38 between pressure fluctuations in Darwin and Honolulu during the northern winter quarter Dec–Feb. Hence, the character of the temperature fluctuations in Yap, Guam and Manila cannot be explained along lines similar to those applied in the case of the South Pacific Ocean, that is, by the operation of a more or less independent Northern Oscillation of the general circulation on the basis of a pressure balance between the Malay Low and the Hawaii High. Therefore, the question arises whether sufficient water is perhaps transferred from the South Equatorial Current into the Equatorial Counter Current and from this Current into the North Equatorial Current. This might possibly explain the direct cooperation of Yap, Guam and Manila in the Southern Oscillation scheme.

In this connection it is extremely thought provoking to see how the well-known dry tongue, emanating from the Easter Island High stretches westward along the equator almost as far out as New Guinea. We can hardly be mistaken in indicating the South Equatorial Current and the dry tongue of air travelling over it as the medium of transport of temperature anomalies, not even only to the islands of the Malay Archipelago south of the equator, but also to those north of it.

Tables 16 and 17, however, militate against overestimating the strength of the relation between air pressure and temperature fluctuations in Darwin and Manila in comparison with the strength of the same relation at Djakarta.

TABLE 16. *Darwin temperature* (1882–1940)

Djakarta air pressure	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Jan	+,34	+,26	+,38	+,21	+,10	–,18	+,34	+,26	+,38	+,21	+,10	–,18
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Jul	–,51	–,62	–,60	–,40	+,18	+,11	+,23	+,23	+,16	+,41	+,23	+,21

TABLE 17. *Manila temperature* (1887–1940)

Djakarta air pressure	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Jan	–,26	+,03	+,25	+,42	+,40	+,38	+,14	–,06	+,28	+,08	+,18	+,12
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Jul	+,32	–,03	+,07	+,17	+,15	+,03	+,02	–,03	–,09	+,09	–,24	–,18

Darwin shows an average phase lag of 8 months between temperature and pressure deviations of the same sign, a lag which is slightly superior to the lag shown by Djakarta. Correlations are, however, much weaker in the case of Darwin. Besides, table 16 shows how intimate the negative correlation is between air pressure and temperature in the southern winter, and how strongly pressure and temperature deviations persist during Java and North Australia's east monsoon time: May–Oct. Evidently Darwin is in a situation too continental to be sufficiently representative of the effect described here.

As regards Manila, a 7-month lag between air temperature and air pressure deviations of the same sign, which earlier publications suggest, is evidently lacking. However, a 4-month lag between temperature fluctuations and the corresponding pressure fluctuations appears clearly, at least in the first half of the year. The figures in the second row are quite insignificant. We get the impression that Manila fits much better into the following sequence: Iquique–Apia–Manila, the phase lag between temperature and pressure variations increasing in this way from 2 to 3 and from 3 to 4 months. In previous publications the writer expressed himself perhaps too positively when concluding that the lag increased gradually from South America to South East Asia and Australia. He is obliged now to make certain reserves and to say that the optimal lag of 7 and even 8 months, so evident in Djakarta and Darwin, occurs in the southern part of the Malay Archipelago as an ultimate effect, which it is difficult to trace back directly to the South Equatorial Current anomalies.

Nevertheless, the following possible ways of relationship should be carefully considered.

Alongside Samarai (10°37′S, 150°40′E) and Port Moresby (9°29′S, 147°9′E) on the southcoast of New Guinea a branch of the South Equatorial Current enters Torres Strait and flows into the Alfura, Banda and Flores Seas. Samarai and Port Moresby, however, both show temperature fluctuations bearing no singular relationship to the pressure fluctuations. Evidently the geographic situation of these places is also such that air temperature there is not uniquely determined by the temperature of the adjacent waters. A branch of the North Equatorial Current enters the same seas through the Molucca Sea, Celebes Sea and Makassar Strait. Thirdly, Djakarta is touched by two strong monsoon currents, one southward through the China Sea and eastward through the Java Sea during the northern winter, and one westward through the Java Sea and northward through the China Sea during the northern summer.

The next point to be elucidated is the important relation between air pressure in the region Kupang–Darwin and sea surface temperature measured in that same region, more specifically on the KPM-steamer route through the Flores Sea between Bima (8°26′S, 118°43′E) and Makassar (5°08′S, 119°28′E). These temperature measurements were made from 1913 to 1938. As was pointed out by the writer as long ago as 1927 (15a, b, d, g) the temperature of the sea surface and the change of air pressure in this area are strongly correlated negatively.

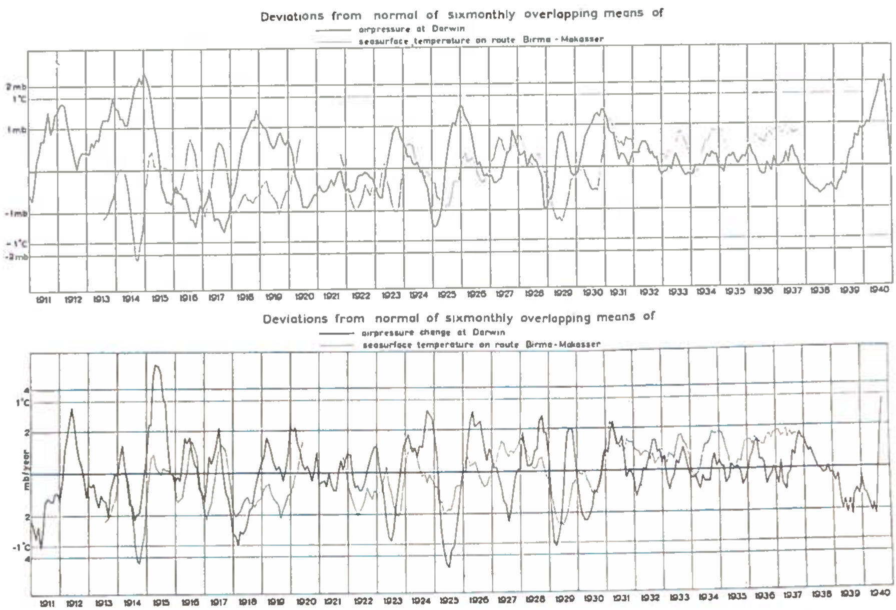

FIG. 8. A comparison of the relations between air pressure at Darwin and sea-surface temperature in the Flores Sea (above) and those between the air pressure change at Darwin and sea-surface temperature in the Flores Sea.

Fig. 8 contains overlapping half-yearly means of both quantities and is very expressive. When correlation coefficients are computed for successive halves of years, table 18 is obtained.

TABLE 18. *Correlation between sea-surface temperature on the route Bima-Makassar and the change of air pressure in Darwin*

Oct–Mar	—0,050	Feb–Jul	—0,720	Jun–Nov	—0,294
Nov–Apr	—0,678	Mar–Aug	—0,683	Jul–Dec	—0,156
Dec–May	—0,583	Apr–Sep	—0,628	Aug–Jan	+0,087
Jan–Jun	—0,774	May–Oct	—0,198	Sep–Feb	+0,363

Correlation is strongest around the first of April that is, particularly during the spring monsoon change. When the difference of half-yearly air pressure anomalies in Darwin (Apr–Sep)-(Oct–Mar) is correlated with sea surface temperature anomalies on the shipping route Bima–Makassar between 6° and 7°30′S (Jan–Jun) a coefficient as high as —0,774 is obtained.

On the other hand sea surface temperature deviations and air pressure deviations in the same part of the year (Jan–Jun) are correlated up to a coefficient as high as +0,667. Moreover, if one correlates these same temperature values with air pressure values 7 months earlier (Jun–Nov) the coefficient is again high, +0,576.

The complementary season presents a quite different picture. When the difference of the half-yearly air pressure anomalies in Darwin (Oct–Mar)–(Apr–Sep) is correlated with sea surface temperature anomalies (Jul–Dec) a coefficient as low as —0,156 is obtained. Synchronous sea surface temperature and air pressure deviation (Jul–Dec) are now negatively correlated up to a coefficient as high as —0,825, whereas, if this same sea surface temperature anomaly is correlated with air pressure 7 months earlier (Dec–May) a coefficient of only —0,073 appears.

As regards the both very high, but opposite correlation coefficients between air pressure and sea surface temperature in the two seasons considered, the point is that in the one season (Dec, Jan, Feb, Mar) water masses are blown from west to east through the Java Sea and Flores Sea, in the other season (Jun, Jul, Aug, Sep) from east to west. Evidently the correlation between air pressure and sea surface temperature is thereby oppositely affected in the two cases. Hence, one understands why the synchronous negative correlation between air pressure and temperature, which is mostly strong between the tropics, appears in this region on an average less significant than the correlation between air pressure and sea surface temperature 7 months later. If an average value for the year the mean of the coefficients found in both seasons may be assumed, (—0,774 —0,156):2 = —0,465 is the normal coefficient of correlation between sea surface temperature and change of air pressure; (+0,667 —0,825): 2 = —0,079 is the coefficient of correlation between sea surface temperature and air pressure at the same time; and (+0,576 —0,073):2 = +0,256 is the coefficient of correlation between air pressure and sea surface temperature 7 months later.

The remaining question is, whether air temperature or sea surface temperature has the controlling influence. Air temperature variations and sea surface temperature variations in the Timor region are very similar. The coefficients of correlation between these variations, when air temperature is measured in Kupang, prove to be +0,743 on an average, from Jan through Jun and +0,729 on an average from Jul through Dec. These coefficients show how persistent the correlation is throughout the year. Let us concede that they mean that a percentage of not much above 50 percent of air temperature departures at Kupang is actually determined by sea surface temperature departures. The influence of even the temperature of the sea surface proper should therefore not be overestimated, irrespective of the problem whether air temperature measured on an island like Timor may well be used instead.

When air temperature at Kupang is correlated with the air pressure changes at Darwin, a coefficient of —0,601 is obtained in the Jan–Jun season and a coefficient of —0,322 in the Jul–Dec season. When sea surface temperature was chosen we found —0,774 and —0,156 respectively. It is, of course, physically significant that the dispersion of the coefficients is larger in the latter case. However, the average value of the correlation coefficient for the year is —0,462 when air temperature is used and this value is not significantly different from —0,465, the annual average coefficient which is found when sea surface temperature is taken. Thus our assumption, that in the island region of the tropical belt of the Pacific Ocean working with air temperature is much the same as working with sea surface temperature, is confirmed by the present figures. However, the prognostic value of sea surface temperature surpasses the prognostic value of air temperature significantly in the first half of the year, whereas in the second half of the year the reverse is true.

Further, the more or less incidental positive correlation between sea surface temperature and the change of air pressure at Darwin, which is observed in the Sep–Feb period, should be pointed out. The author assumes that it is not an essential but only a secondary fact, expressing simply an exceptional persistence or even reinforcement of the air pressure anomaly which has existed in the last quarter of the year into the first quarter of the next year. As is clearly revealed by fig. 9 (p. 56) pressure tops in this region are not quite randomly distributed in time, but most acute in southern summer. Evidently the tendency towards presistence of pressure conditions through the spring monsoon change on Java, well known already to BRAAK [26f], plays its part here. It may explain the remarkable sharpness of so many pressure peaks and the „saw tooth" character of the pressure variations, and very probably implies the way in which the stretching of the natural mean period of the Southern Oscillation from 2,33 years to 2,56 years, which will be studied later, is actually brought about.

As a final remark, the writer ventures the assumption that the reason why sea surface temperature and air temperature in this Kupang area only – that is in a relatively small part of a much larger area where the same relation might have been expected – are so obviously producing air pressure variations, is the dry character of this area during the greater part of the year. In dry conditions no rainfall interferes with the pressure temperature relations. Temperature and air pressure are both correlated with precipitation. What in moderate and high latitudes is usually of negligible importance, but what in the tropics, where millibars count, may be significant, is: that evaporation increases air pressure and precipitation decreases air pressure. Furthermore the air is heated or cooled by the processes of evaporation, condensation, „austausch" and actual precipitation in a very complicated manner. It certainly reduces the intimacy of the relations under investigation.

2.2 Theory

It was shown in 2.1 that over large parts of the Indo-Pacific region the following relation applies

$$\triangle T(t) = a \triangle P(t-t_0) \qquad (1)$$

where

$\triangle T(t)$ = deviation of local air temperature from normal at time t

$\triangle P(t)$ = deviation of Djakarta air pressure from normal at time t

a = a positive constant

t_0 = a lag of time

On the other hand, in the southeastern part of Indonesia, New Guinea and North Australia, more specifically over the seas of this region, the following relation also applies

$$\frac{d}{dt} \triangle P(t) = -b \triangle T(t) \qquad (2)$$

where

b = a positive constant

According to equation (1) air temperature is passive relative to air pressure, equation (2) expresses the active role which air temperature plays in the thermodynamic relations between air temperature and air pressure.

Thus, in the above mentioned relatively small region (1) and (2) are both valid. The combination of both equations leads to

$$\frac{d}{dt} \triangle P(t) = -ab \triangle P(t-t_0) \qquad (3)$$

an equation in one variable only. This equation is easily solved and proves that air pressure in the „temperature-active" region is not „free".

When the right side of (3) is expanded into an infinite Taylor series, (3) is transformed into

$$-\frac{1}{ab}\frac{d}{dt}\triangle P(t) = \triangle P(t) - t_0 \frac{d}{dt}\triangle P(t) + \frac{t_0^2}{2\,!}\frac{d^2}{dt^2}\triangle P(t) - \text{etc.} \tag{4}$$

The general solution of equation (4) is

$$P(t) = \Sigma A\, e^{z\frac{t}{t_0}}$$

if z is the root of the characteristic equation

$$-\frac{z}{abt_0} = 1 - z + \frac{z^2}{2\,!} - \frac{z^3}{3\,!} + \ldots \tag{5}$$

or

$$-\frac{z}{abt_0} = e^{-z} \tag{6}$$

As z may assume both real and imaginary values we substitute

$$z = p \pm qi \tag{7}$$

Equating the real and imaginary parts of (6) we obtain

$$p = -q \cot q \tag{8}$$

and

$$q = abt_0\, e^{q \cot q} \sin q \tag{9}$$

As was shown in earlier publications, the general solution of (3) consists of two parts, an exponential term

$$P_1(t) = A_1 e^{-\frac{t}{t_0}} \tag{10}$$

and a second term

$$P_2(t) = A_2 e^{p\frac{t}{t_0}} \cos\left(q\frac{t}{t_0} + \delta\right) \tag{11}$$

which assumes different forms in three different cases

a) $abt_0 > \frac{\pi}{2}$, $\frac{\pi}{2} < q < \pi$, $\cot q < 0$, $p > 0$

b) $abt_0 < \frac{\pi}{2}$, $0 < q < \frac{\pi}{2}$, $\cot q > 0$, $p < 0$

c) $abt_0 = \frac{\pi}{2}$, $q = \frac{\pi}{2}$, $\cot q = 0$, $p = 0$

namely

a) a harmonic oscillation with increasing amplitude
b) a harmonic oscillation with decreasing amplitude
c) a pure harmonic oscillation

The period of the oscillation is

$$T = \frac{2\pi}{q} t_0 = \frac{2\pi}{ab \sin q} e^{-q \cot q} \tag{12}$$

and the damping ratio

$$\varepsilon = e^{-2\pi \cot q} \tag{13}$$

If

$$abt_0 = e^{-1} \tag{14}$$

the general solution of (3) assumes the form

$$P(t) = A_1 e^{-\frac{t}{t_0}} + A_2 t e^{-\frac{t}{t_0}} \tag{15}$$

representing an aperiodically damped oscillation.
Hence, if

$$abt_0 < e^{-1} \tag{16}$$

no periodic solution exists.
In the aperiodic cases

$$T = \infty \tag{17}$$

Hence, when a and b are given there is a value t_0 at which T reaches a minimum value. This is the case when

$$q = \sin 2q \tag{18}$$

that is for the value q which makes the function

$$e^{q \cot q} \sin q \tag{19}$$

assume a maximum value. The solution of (18) is

$$q = \frac{\pi}{3{,}31} = 0{,}949 \text{ or } q = 54{,}4^\circ \tag{20}$$

The period corresponding with (20) is

$$T = \frac{2}{ab} \frac{e^{-0{,}949 \operatorname{tg} 35{,}6^\circ}}{\cos 35{,}6^\circ} \sim \frac{4}{ab} \tag{21}$$

The damping ratio in this case is, of course, very large namely

$$\varepsilon = e^{-2\pi \times 0{,}716} = e^{-4{,}5} \tag{22}$$

These theoretical conclusions are of great interest because they point to a possible physical explanation of longperiodic cycles through the interaction of air pressure and temperature, a process the probabilities of which have been already discussed by C. Braak [26a, b, c, e, f]. The generation of longperiodic cycles evidently depends on the fact whether values of abt_0 of sufficient magnitude are reached somewhere. Oscillations of this kind which are strongly damped will never appear plainly. Hence, wherever the value abt_0 remains significantly inferior to $\pi/2$ there is no chance for the development of any fluctuation of prevailing period. On the other hand, where abt_0 becomes superior to $\pi/2$, not only a periodic oscillation will originate, but also its amplitude will grow. However, in cases like this, nature will always allow the amplitude to grow to a certain limit only – in a similar way to that in processes of resonance – and then will keep it at that level. As a matter of fact, dissipation of energy intervenes and the constants a, b and t_0 in given places will assume values automatically such that

$$abt_0 \leqq \pi/2$$

while the oscillation which comes out eventually undamped, has a period

$$T = 4t_0$$

Other oscillations are expected to be the more intensely damped the larger the difference between abt_0 and $\pi/2$.

Let us now inquire whether, and in what measure, the Southern Oscillation fits into the theoretical scheme.

Fig. 8 would seem to indicate that in this example

$$a \sim \tfrac{1}{2} \text{ centigrade/mb} \qquad (23)$$

$$b \sim \tfrac{1}{3} \text{ mb/centigrade month} \qquad (24)$$

so that

$$ab \sim \tfrac{1}{6} \text{ per month} \qquad (25)$$

Now, since sea surface temperatures measured during crossings between Makassar (Celebes) and Bima (Sumbawa), Indonesia, are available from 1913–1938 only, fig. 8 also relates to these 26 years only. The relations (23) and (24) need not, however, be considered separately in order to obtain the value of the product ab which is the vital quantity, because it can be empirically deduced directly from (3). Table 19 contains the numbers of cases in which the values

Table 19. *Darwin air pressure, half-yearly sums of monthly deviations from normal* (1882–1950), *numbers of cases in given intervals* (thousandths of inches)

	0–49	50–99	100–149	150–199	200–249
$\triangle_n P$	228	192	141	98	74
$\triangle_n P - \triangle_{n-1} P$	269	187	151	87	66

	250–299	300–349	350–399	400–449	450–499
$\triangle_n P$	46	17	13	7	
$\triangle_n P - \triangle_{n-1} P$	33	10	8	4	1

$\triangle_n P$ and $\triangle_n P - \triangle_{n-1} P$ at Darwin occur between the indicated limits, while n is the indicator of a given 6-months interval, and $\triangle_n P$ is the sum of the 6 monthly deviations in the n-th interval, expressed in thousandths of an inch.

Since the two frequency tables obtained are not significantly different and are both based on 6-months intervals, it is concluded that indeed

$$ab \sim \tfrac{1}{6} \text{ per month}$$

thereby confirming (25).

The value of ab obtained in this way is, however, only a first approximation to the real value. As a matter of fact the two pictures of fig. 8 and the two rows in table 19 are not homogeneous. Every value plotted in the upper picture and enumerated in the upper row is an average departure obtained in one given half-year interval, while every value plotted in the lower picture and enumerated in the lower row represents a difference between average departures obtained in two consecutive half-year intervals. The better smoothing of the pressure change curve makes it more easily comparable with the temperature curve and with the air pressure curve itself, but the value ab resulting from this operation has become depressed in a certain measure relative to the value, which would have been found were it derived from pressure changes restricted to the same 6-months intervals as those on which the pressure values are based.

The question how reasonably to correct the above value of ab is very similar to the question how to estimate the mean amplitude reduction which is achieved when in a series of values of a certain quantity $\ldots y_{n-1}, y_n, y_{n+1} \ldots$, measured at equal intervals of time, the average value

$$\tfrac{1}{3}\,(y_{n-1} + y_n + y_{n+1})$$

which is based on two successive intervals is compared with the average value

$$\tfrac{1}{3}\,(\tfrac{1}{2}\,y_{n-1} + 2\,y_n + \tfrac{1}{2}\,y_{n+1})$$

which is based on one and the same interval.

The ratio of the two average values is

$$\alpha = \frac{y_{n-1} + y_n + y_{n+1}}{\tfrac{1}{2}\,y_{n-1} + 2\,y_n + \tfrac{1}{2}\,y_{n+1}}$$

The writer is indebted to his colleague J. H. de Boer for having calculated the limiting value to which this ratio approaches in a random series and found

$$\lim \alpha = 0{,}816.$$

When this ratio is applied for the correction of (25) we find

$$ab \sim \frac{1}{4{,}9} \qquad (26)$$

TABLE 20. *The quotient Q of air pressure change and air pr*

	7—1 6+11	Q	8—2 7+12	Q	9—3 8+1	Q	10—4 9+2	Q	11—5 10+3	Q	12—6 11+4
1885	−1 −127	0,01	17 −121	−0,14	8 −93	−0,09	27 −94	−0,29	17 −74	−0,23	−34 −49
1886	−89 89	−1,00	−29 55	−0,53	−61 74	−0,83	−25 41	−0,61	1 31	0,03	−78 −31
1887	32 −319	−0,10	46 −397	−0,12	19 −375	−0,05	35 −377	−0,09	25 −354	−0,07	21 −350
1888	39 −97	−0,40	6 −76	−0,08	−44 −111	0,40	11 −93	−0,12	27 −35	−0,78	26 −16
1889	−92 8	−11,50	−49 34	−1,44	−108 98	−1,10	−35 135	−0,26	11 194	0,06	−44 175
1890	48 −313	−0,15	−11 −357	0,03	−16 −411	0,04	−3 −423	0,01	17 −417	−0,04	41 −428
1891	60 −66	−0,91	51 −219	−0,23	7 −231	−0,03	3 −209	−0,01	4 −123	−0,03	29 −76
1892											
1893											
1894											
1895											
1896	15 −82	−0,18	70 −79	−0,89	43 −75	−0,57	70 −81	−0,87	−41 −68	0,60	44 −77
1897	−23 113	−0,20	−14 157	−0,09	−72 185	−0,39	94 147	0,64	39 162	0,24	47 138
1898	5 −106	−0,05	61 −53	−1,15	99 −175	−0,57	3 −223	−0,01	−41 −322	0,13	9 −329
1899	35 −163	−0,22	−19 −154	0,12	57 −148	−0,38	38 −118	−0,32	18 −122	−0,15	8 −93
1900	−71 152	−0,47	−92 160	−0,57	−82 189	−0,44	−41 233	−0,18	−25 283	−0,09	68 289
1901	−4 −78	0,05	2 −10	−0,20	32 26	1,22	−15 80	−0,19	19 88	0,22	12 100
1902	41 96	0,43	−25 108	−0,24	30 92	0,33	19 127	0,15	9 117	0,08	13 146
1903	−101 257	−0,39	−58 270	−0,22	31 298	0,10	−6 338	−0,02	−14 242	−0,05	−64 185
1904	18 −47	−0,38	42 −111	−0,38	16 −77	−0,19	29 −109	−0,27	45 −102	−0,44	−6 −138
1905	−23 98	−0,23	−15 92	−0,16	−98 127	−0,77	−51 155	−0,33	55 245	0,22	32 310
1906	−40 132	−0,30	−27 164	−0,16	−72 152	−0,47	−42 147	−0,29	−51 182	−0,28	−1 210

tions from normal at Darwin, as explained in the text

-7 -5	Q	2—8 1+6	Q	3—9 2+7	Q	4—10 3+8	Q	5—11 4+9	Q	6—12 5+10	Q
19 -4	-4,75	-33 17	-1,94	-10 16	-0,62	-62 33	-1,88	-87 45	-1,94	2 72	0,03
22 8	-0,19	-2 -116	0,02	23 -205	-0,11	4 -234	-0,02	12 -295	-0,04	84 -320	-0,26
15 38	0,10	18 -254	-0,07	58 -222	-0,26	19 -176	-0,11	-12 -157	0,08	-3 -122	0,03
54 28	-2,28	37 -31	-1,19	59 8	7,38	-19 14	-1,36	-31 -30	1,03	-84 -19	4,42
54 44	-0,37	-12 60	-0,20	6 -32	-0,19	-11 -81	0,14	81 -189	-0,43	50 -224	-0,22
2 47	0,04	22 -297	-0,08	86 -249	-0,34	47 -258	-0,18	25 -274	-0,09	12 -277	-0,04
25 51	0,49	-12 -39	0,31	-103 21	-4,90	-10 72	-0,14	-18 79	-0,23	-66 82	-0,81
8 6	-0,50	-38 -44	0,86	15 -29	-0,52	-24 41	-0,58	10 84	0,12	-66 154	-0,43
2 8	0,15	48 82	0,58	99 59	1,68	7 45	0,15	6 -27	-0,22	34 -67	-0,51
6 3	-0,02	30 -289	-0,10	-4 -284	0,01	29 -223	-0,13	68 -124	-0,55	48 -121	-0,40
9 5	-1,16	44 23	1,91	50 58	0,86	6 39	0,15	-16 96	-0,17	-40 134	-0,30
6 3	0,13	54 233	0,23	8 162	0,05	12 70	0,17	6 -12	-0,50	-42 -53	0,79
6 6	-0,15	35 64	0,55	-10 60	-0,17	29 62	0,47	20 94	0,21	17 79	0,20
8 6	0,17	40 183	0,22	-96 224	-0,43	-57 199	-0,29	-60 229	-0,26	-24 248	-0,10
4 5	0,27	-32 101	-0,32	7 0		-36 -58	0,62	6 -27	-0,22	80 -33	-2,42
5 2	-0,26	28 -52	-0,54	90 -34	-2,65	65 8	8,12	-34 24	-1,42	-12 53	-0,23
2 5	-0,04	-5 264	-0,02	35 241	0,15	28 226	0,12	-55 128	-0,43	-50 77	-0,65
4 5	-0,03	-4 105	-0,04	55 65	0,85	38 38	1,00	58 -34	-1,70	-15 -76	0,20

The other way is to take the original values of the 6-monthly running means of air pressure deviations $\triangle$ at Darwin and compute the average value of all Q's when

$$Q_n = \frac{(\triangle_{n-2}+\triangle_{n-1}+\triangle_{n}+\triangle_{n+1}+\triangle_{n+2}+\triangle_{n+3}) - (\triangle_{n-3}+\triangle_{n-2}+\triangle_{n-1}+\triangle_{n}+\triangle_{n+1}+\triangle_{n+2})}{(\triangle_{n-3-t_0}+\triangle_{n-2-t_0}+\triangle_{n-1-t_0}+\triangle_{n-t_0}+\triangle_{n\div 1-t_0}+\triangle_{n\div 2-t_0})} \qquad (27)$$

where n is the indicator of a given month.

The difficulty however is, that if the correct value of abt_0 is in fact reached the oscillation becomes purely harmonic, whereas, if the oscillation is not purely harmonic the correct value of abt_0 is not obtained from the actual figures, but certainly one which is too small. Actually our result is obtained from two sources which are both more or less polluted, whereas the theory could be built up just because signs of both sources are available in one and the same region.

It was therefore found profitable to compute the average value of the ratio Q of Darwin's pressure change deviations and pressure deviations from normal for those periods in which the most famous pressure waves occurred, that is from 1885 to 1891 and from 1896 to 1906, or throughout 18 years, including two series of pressure waves which have a period of 3 years exactly. In this computation no whole number of months for t_0 could be adopted. This number was taken equal to $7\frac{1}{2}$ and this is, as will be shown presently, perhaps even better than having taken it equal to 7 months. Table 20 resulted.

Now, evidently, if the denominator of the quotient is very small the ratio Q becomes too large to be representative and should not be included in the average. 10 was assumed as the critical denominator value and thus the Q-values —11,50, —4,75, +7,38, +8,12 and ∞ were not taken into consideration. The resulting mean is

$$\overline{Q} = -\frac{36,93}{211}$$

or

$$ab \sim \frac{1}{5,7} \qquad (28)$$

The writer's impression is that this value is very near the true value which occurred in the two series of years investigated, because if t_0 should reach the value 9 months, we get

$$\frac{9}{5,7} = \frac{\pi}{2}$$

and

$$T = 4 \times 9 = 36 \text{ months} = 3 \text{ years}$$

This is in perfect agreement with the prominence and apparently undamped nature of 3-year waves during the intervals which were studied here. Exactly those 3-year period wave trains which have been analyzed to this effect have never been surpassed in regularity.

However, as mentioned before, this matter must be handled with great care. If those 3-year waves had been strictly harmonic we should have found also strictly

$$ab = \frac{\pi}{18} \sim \frac{1}{5{,}7}$$

Hence the actually true value of *ab* is greater than 1:5,7. Irregular fluctuations, the „noise" according to an expression adopted from electronics, always reduce the empirical value *ab* relative to the actually true value. It can be found out only by successive approximations. The empirical value *ab* approaches asymptotically the theoretical value of harmonic oscillations $\pi/2T$ the nearer the actual oscillations come to the harmonic type. In view of (26) it is therefore finally assumed that

$$ab = \tfrac{1}{5} \tag{29}$$

with

$$a = \tfrac{1}{2},\ b = \tfrac{2}{5} \tag{30}$$

in the Malay Low.

It is very valuable to see how the different aspects of our problem can now be assembled into one coherent picture. The final results are given in tabel 21.

TABLE 21

		Period	Damping ratio
$t_0 = 7$	$abt_0 = \frac{7}{5}$	$T = 2{,}33$ years	$\varepsilon = 0{,}64$
$t_0 = 7\frac{1}{2}$	$= \frac{3}{2}$	$T = 2{,}5$	$\varepsilon = 0{,}84$
$t_0 = 8$	$= \frac{8}{5}$	$T = 2{,}67$	$\varepsilon = 1{,}10$

Thus, the theory that longperiodic oscillations in the general atmospheric and hydrospheric circulation may occur in consequence of the interaction between air pressure and air temperature (sea surface temperature) is quantitatively confirmed in the case of the Southern Oscillation.

Evidently t_0 must reach a value of 7 months at least in order to stimulate the Southern Oscillation. Moreover, since $t_0 = 7$ for Djakarta and $t_0 = 8$ for Darwin, it is permissible to assume a value $t_0 = 7\frac{1}{2}$ months for the seas in the southeast of Indonesia where temperature appears to be positively active in the process. This fact would explain equally well that the period of the Southern

Oscillation is effectively $4 \times 7\frac{1}{2}$ months $= 2\frac{1}{2}$ year. It is normally stretched slightly above its basic length. A return to this point will be made later on.

There is, however, one thing which should not be overlooked and allows of a refinement of the theory proposed. It has been assumed so far that a and b are both constants. Now, b is indeed probably a more or less invariable factor, designating how the surface temperature of the sea affects the change of pressure of the air above this sea. The value a, on the contrary, is expected to diminish naturally with the increasing length of the stretch which the ocean current has to follow, since in the long run no anomaly is strictly conservative.

Since not the length of the route is given, but the lag of time t_0 which is correlated with it, temperature amplitudes were plotted together with t_0 at certain stations. In table 22 beside t_0 the maximum monthly temperature deviations from normal are given at eight stations along the route which – as we see it now - the sea surface temperature anomalies are due to follow with the great ocean currents. These values were given in order quickly to arrive at some measure of the relative values of a in these places.

TABLE 22

		δT(max)	t_0
Easter Island	1949–1955	2,2°	0
Juan Fernandez	1911–1940	3,9	0
Iquique	1900–1940	4,8	2
Apia	1890–1940	3,5	3
Manila	1887–1940	3,6	4
Djakarta	1866–1954	3,1	7
Darwin	1883–1940	4,3	8

There is sufficient reason to assume that the value δT(max) reported from Easter Island is much too small because the series of observation years is still very short relatively. Moreover Easter Island itself is not touched by the two ocean currents which are the chief actors in the drama, the Peru Current and the South Equatorial Current, but Juan Fernandez is. The δT(max) from Easter Island should therefore not be taken into account. Iquique and Darwin are stations too continental to be representative of the sea surface temperature pursued here. When these places are also left out of consideration the course of δT(max), and with it probably also the course of a, is easily represented by an exponential function.

Let

$$a = a_0 \, e^{-kt_0}$$

where a_0 is a constant. Then with $k = 0{,}03$ we obtain the values compiled in table 23.

TABLE 23

	t_0	δT(max)		a
		obs.	comp.	
Juan Fernandez	0	3,9	3,9	0,7
	1		3,8	
	2		3,7	
Apia	3	3,5	3,6	0,6
Manila	4	3,6	3,5	0,6
	5		3,4	
	6		3,3	
Djakarta	7	3,1	3,2	0,5
	8		3,1	
	9		3,0	

The series of computed and observed values δ T(max) covering each other reasonably well under these conditions, it is possible to derive a, while its value at Djakarta, 0,5, is now given. Evidently the shorter oscillations are more weakly damped and the longer oscillations more strongly damped than would occur according to our first simple theory.

Another way of looking into the problem of variable t_0 is the following. When the general circulation is speeded up t_0 decreases while a increases, when the circulation is slowed down t_0 increases while a decreases. Hence, the product abt_0 is not so much dependent on the phase of the oscillation, while T fluctuates with t_0. All this points to a great flexibility of the prevailing cycle. This is exactly what is observed. In reality the period of the Southern Oscillation varies between 2 and 3 years. It is probably t_0 which is varying between 6 and 9 months without much variation of the damping ratio. On the one hand it is known that the period of the wave cannot decrease below 20 months, while in that case the wave is already very heavily damped. On the other hand we get the strong impression that t_0 never grows significantly above 10 months, a condition which might produce well developed cycles of 40 months or $3\frac{1}{3}$ years, if no reverse action should occur. In fact, one beautiful example of an exceptionally long wave with exceptionally large original amplitude shows signs of rather strong damping, the period decreasing meanwhile. In fig. 9 the Djakarta air pressure curve is shown. The oscillation starting in 1876 is outstanding in its character of a free oscillation whose period decreases from $3\frac{1}{2}$ through 3 to 2 years, while the damping ratio is very nearly $\varepsilon = 0{,}5$. The whole figure reminds one of the trace of an earthquake recorded by a rather feebly damped seismograph.

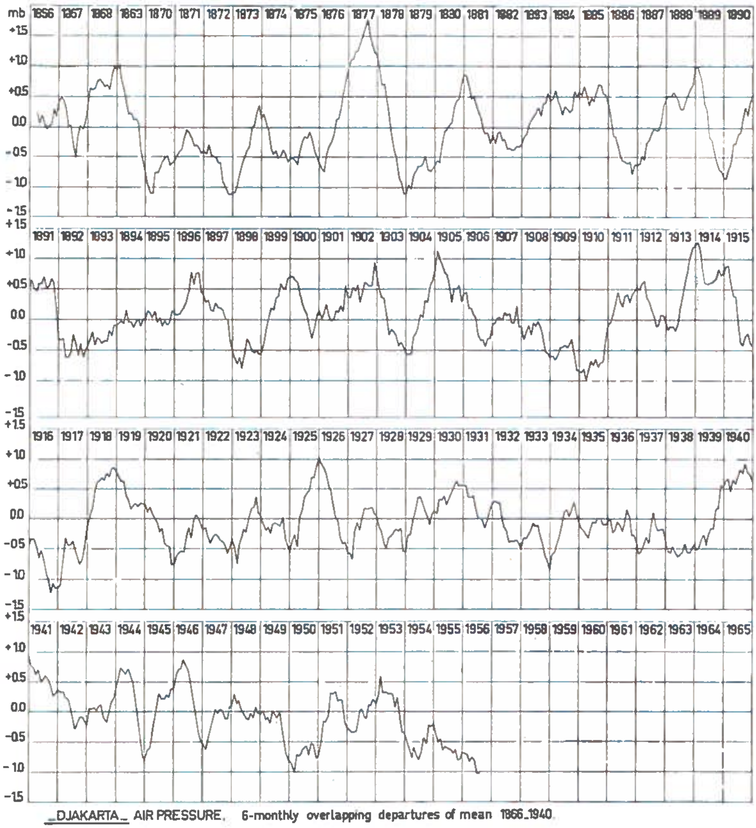

FIG. 9. Djakarta (Batavia) 6-monthly running air pressure anomalies, 1866–1956.

These different arguments suggest the approximate validity of the following table of damping ratios in function of the period of the Southern Oscillation.

Period in months	20	24	28	32	36	40	44	48
ε	0	0,6	0,8	0,9	0,7	0,5	0,2	0

The $\varepsilon = 1$ is never reached, because we cannot imagine the Southern Oscillation ever to be self-sustaining. It is not an oscillation like that of a frictionless pendulum. It is driven by solar radiation, while its energy is continuously dissipated, and gets a fair chance of evolution only in periods of between 2 and 3 years.

Thus, notwithstanding the necessity of pointing out several minor disagreements between data, while trying to conceive an overall picture of the Southern Oscillation, we return to an early theory, which is summarized as follows.

When air pressure is abnormally low in the Malay Low it is abnormally high in the Easter Island High. The general air and water circulation through the South Pacific Ocean is accelerated. The Peru Current and the South Equatorial Current are accelerated and consequently colder than normal. The negative temperature anomaly created in the east of the South Pacific Ocean arrives $7\frac{1}{2}$ months later at the Malay Low. Consequently air pressure in the Malay Low increases, while air pressure in the Easter Island High decreases. When air pressure in the Malay Low is abnormally high, it is abnormally low in the Easter Island High. The air and water circulation through the South Pacific Ocean is slowed down. The Peru Current and the South Equatorial Current are slowed down and consequently warmer than normal. The positive temperature anomaly created in the east of the South Pacific Ocean arrives $7\frac{1}{2}$ months later in the Malay Low. Consequently air pressure in the Malay Low decreases, while air pressure in the Easter Island High increases. Herewith the cycle is closed.

Let us stress immediately that we have now explained only one aspect of the Southern Oscillation, its automatic development into periodicity. We have not explained how an air surplus and an air deficit are regularly exchanged between the Easter Island High and the Malay Low. When assuming the square of the coefficient of correlation which exists on an average between the pressure anomalies in both centres, as a measure of the extent to which this exchange of air is actually complete, we find that 68 percent of a surplus in one centre finds its way to the other centre while 32 percent is dispersed towards other parts of the world (see also 4.2). Now, this exchange is not a question of months but of days. Moreover we know that the upper air takes a very active part in the longperiodic oscillations of pressure which we are considering (2.1). Probably the amplitude of the longperiodic pressure fluctuations at the 500 millibar level throughout the world would prove to be of the same magnitude in millibars as the amplitude of the oscillations at ground level, since experience at mountain stations has proved this to be the case at least in Europe and Indonesia. As regards the Southern Oscillation it is naturally with the trade winds that air moves from the Easter Island High towards the Malay Low and with the anti-trades and the strong westerlies (jet stream) that the air moves from the Malay Low towards the Easter Island High. Zonal index and meridional circulation in the Indo-Pacific region no doubt both fluctuate with the Southern Oscillation. Reference should be made here to RAMAMURTI's attempt [126] to formulate the essence of these variations in the vicinity of South America.

Back to theory we are immediately aware that the stability of the „pendulum" and its „proper period" are determined by the fact that the oscillation is an act played between a relatively cold high pressure area and a relatively warm low pressure area. Let us, for instance, imagine what would happen in an extremely well comparable case, the famous air pressure balance between the subtropical

Azores High and the subpolar Islandic Low in the North Atlantic Ocean. When air pressure is abnormally low in the Icelandic Low it is abnormally high in the Azores High. The air and water circulation through the North Atlantic Ocean is accelerated. Consequently the Gulf Stream is accelerated and warmer than normal. The positive temperature anomaly arrives after some time at the Icelandic Low. Consequently air pressure in the Icelandic Low decreases further. This would lead to no cyclic process but to instability. Our theory is applicable to the present case provided a is a negative value.

On the one hand this remark accentuates the reason why the Southern Oscillation is such a unique phenomenon. In no other ocean besides the Indo-Pacific Ocean a situation exists which would allow an oscillation of this kind to be generated. It is the extreme equatorial width of the Indo-Pacific basin which provides a sufficient length of phase lag t_0 in a circulation between a subtropic High and an equatorial Low. Every oscillation of this nature elsewhere is largely damped or if it should occur between a subtropic High and a subpolar Low it shows the features of instability and no periodic character.

On the other hand we meet here an independent reason for the puzzling fact, already mentioned by VON SCHUBERT [150], the fact that the amplitude of the Southern Oscillation in air pressure does not decrease, but – on the contrary – increases more or less generally with geographic latitude. Apart from the fact that for continuity reasons the amplitude of any air pressure wave starting from the equator towards the poles will show a tendency to grow with latitude, instability will act in the same sense.

Stable oscillations are again to be expected where our picture of the process is applicable to an antithetic subpolar Low and arctic High. Such oscillations may again have a steering effect in the whole play. They close – so to speak – the scene from the other end. Their operation, however, is conditioned by the existence of open ocean between the two centres. Hence, in the southern polar region free oscillations are hardly imaginable, because the subpolar low pressure belt there is in direct touch with the antarctic continent or ice barrier. Through the north polar basin, on the contrary, a large scale and very effective water circulation exists. The Gulf Stream proceeds along the Norwegian coast into the Barentz Sea and its water masses return south of Spitzbergen through the Greenland Sea and finally as the East Greenland Current from the north into the Icelandic Low again.

In the North Pacific where Asia and North America are almost touching each other no comparable conditions exist and it is therefore that we look a priori to the North Atlantic for possible extensions of the scene and the localization of some oscillation similar to the Southern Oscillation. Before following up this track in an endeavour to grasp the whole picture, it is, however, necessary to pursue first the influence of the Southern Oscillation from its birthplace through the rest of the world.

2.3 Correlation charts

The correlation charts presented here are not based on coefficients obtained in one and the same series of years of observation. All selection was simply disregarded and coefficients computed from longer and shorter series of available data have been used without distinction.

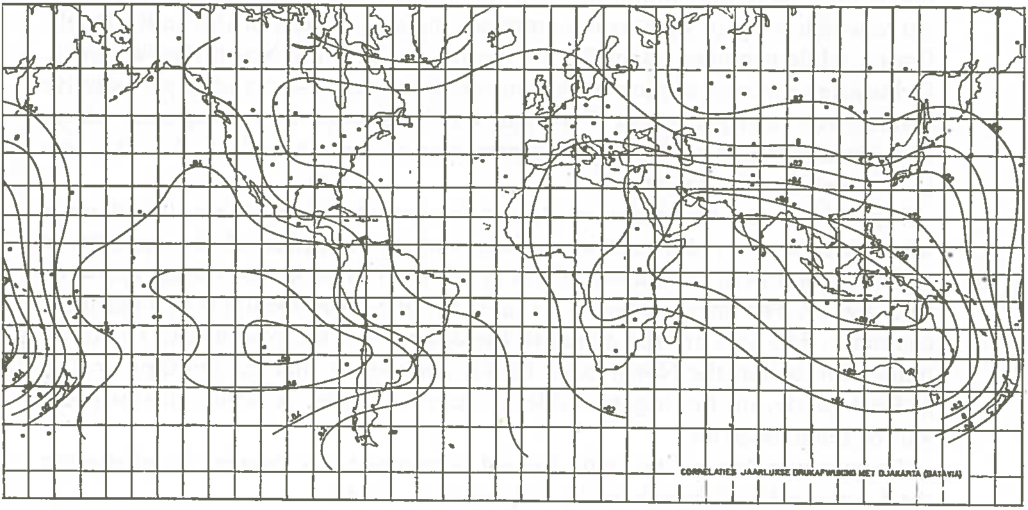

FIG. 10. Correlations of annual air pressure anomalies with Djakarta (Batavia) annual air pressure anomalies.

Fig. 10 shows how the annual air pressure anomaly of a great number of stations throughout the world is correlated with the annual air pressure anomaly at Djakarta (Batavia), the station which is at the heart of the Malay Low. A correlation of +0,8 and higher is found in an area which extends over South India, Indonesia and North Australia. This key area is an elongated area with its axis directed from Darwin through Djakarta to Bombay. The +0,6 curve encompasses Australia and New Guinea, India and the northeastern half of the Indian Ocean. The +0,4 curve envelopes Southeast Asia and the Philippine Islands, the greater part of the Indian Ocean, and transgresses far into Africa. Fig. 10 demonstrates very clearly how far and with what intensity the Southern Oscillation extends into the Northern Hemisphere. That the Malay Low is in the monsoon area par excellence is not without significance in this regard. In the Bombay–Djakarta–Darwin area air masses of the Northern and Southern Hemisphere communicate.

When surveying this map, which is most impressive in so far as the world proves to be simply divided into two singly connected plus and minus areas, it must be remembered that correlation coefficients smaller than $|0{,}4|$ are already practically insignificant. Yet it is, of course, significant that the plus area points strongly northwestward. It includes a large part of Europe and Canada with the North Atlantic Ocean.

Continuing our survey with the negative correlations, it will be noticed that the eastern part of the Pacific Ocean is totally on the negative side. The zero line is for a large part found between the meridians 140° and 150°E. The —0,4 curve which is again significant comprises the greater part of the South Pacific Ocean, while it bulges rather far northward out into the North Pacific Ocean. Delineating the area where correlation coefficients are —0,6 and larger negative would have been guesswork if we had not been aided by the separate winter and summer pictures which will be presented in figs. 14 and 15. A —0,8 area is centered around Easter Island.

Fig. 10 is very expressive in its delineation of the antithetic world parts which are not very different in surface, and its indication of the measure in which the Southern Oscillation affects the globe. Two more impressions proceed from fig. 10. The one impression is that the whole phenomenon is of a maritime character. The seas are the actors in the drama, not the continents. The other impression is that the North polar Cap is completely, and the Southpolar Cap at least partly, on the negative side of the correlation. A return to this point will be made later on.

To continue this analysis with the aid of two pictures showing in what sense the Southern Oscillation is really unique of its kind.

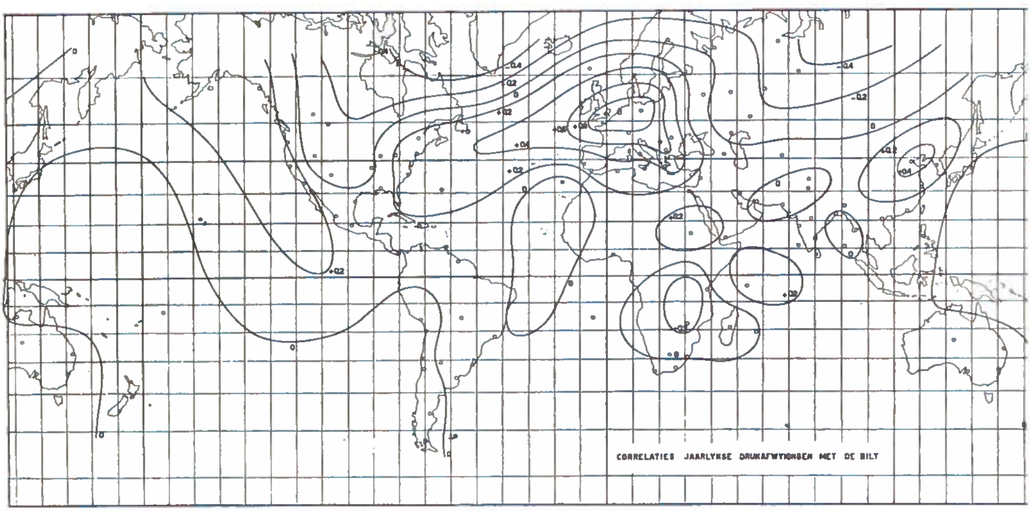

FIG. 11. Correlations of annual air pressure anomalies with De Bilt annual air pressure anomalies.

Fig. 11 is a similar picture drawn up relative to De Bilt, a European station. It demonstrates the well-known balance of air pressure between the subtropical high pressure region of the North Atlantic near the Azores and the subpolar low pressure region near Iceland. A large plus area extends along the Gulf Stream, expressing the well-known influence of the Gulf Stream on Western European weather. Another arm reaches into Egypt pointing to the Abyssinian Highlands and the sources of the Nile. It expresses a certain relation between the Nile floods and European weather which has received the early attention of several investigators. The North Atlantic Oscillation, which dominates fig. 11 does not, however, extend into the Southern Hemisphere. It is of a more local character than the Southern Oscillation. Moreover, no area presents correlation figures on the negative side larger than —0,4.

Fig. 12 shows a similar correlation map centered at Chicago, a North American station. It is particularly interesting owing to a large plus area extending through the tropical Atlantic towards North Africa. This feature is probably to be regarded as the counterpart of the influence of the Gulf Stream on European weather. It expresses the influence of the North Equatorial Current on North American weather. Again, no extension points to the other hemisphere, and no area presents coefficients lower negative than —0,4.

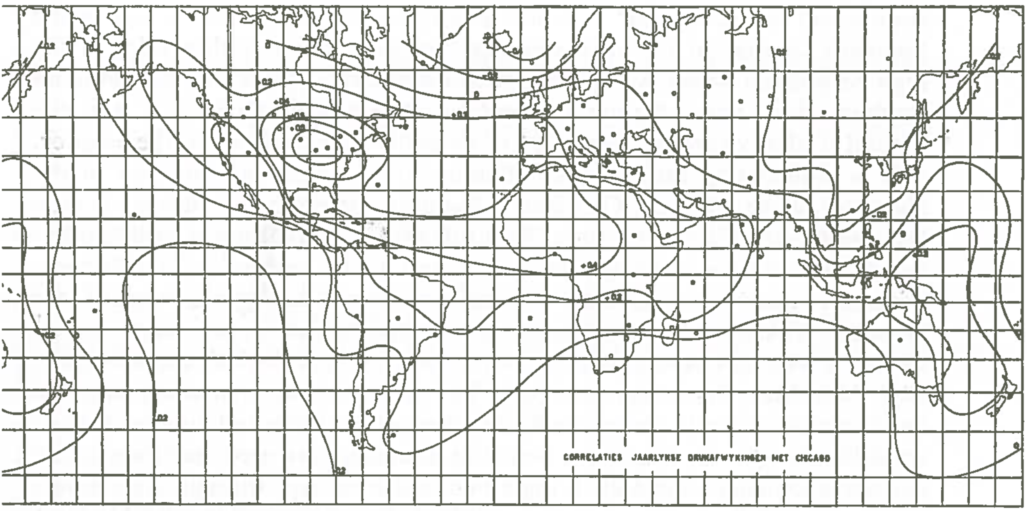

FIG. 12. Correlations of annual air pressure anomalies with Chicago annual air pressure anomalies.

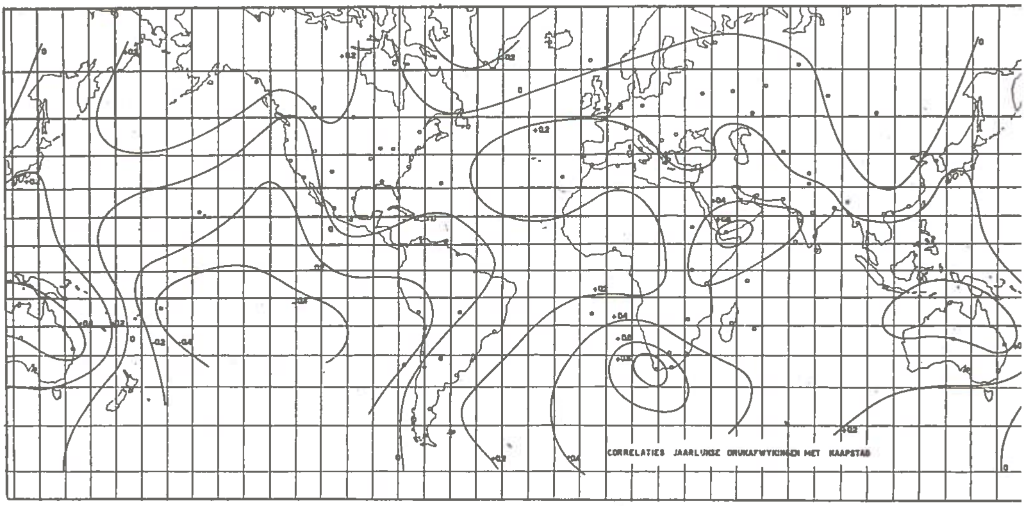

FIG. 13. Correlations of annual air pressure anomalies with Capetown annual air pressure anomalies.

Fig. 13 shows a similar correlation map centered at Capetown, a South African station. Evidently this map does not add much to fig. 11. It simply shows the Southern Oscillation in operation. No more would be likely to be added to what is already known about the Southern Oscillation if a map of coefficients of correlation with the air pressure anomalies of a South American station had been presented. It would be too near the South Pacific pole of the Southern Oscillation to reveal any new aspect. An interesting thing is the high correlation which Aden presents to Capetown. This is very probably no random effect, but a feature inherent to the Southern Oscillation, viz. the natural tendency towards symmetry of its pattern with respect to the equator.

It is illuminating now to turn attention to the seasonal variation in the character of the Southern Oscillation. Monthly correlation coefficients appear less spectacular than yearly ones. That this should be the case is easily understood. The year is actually too long a unit to be handled with efficiency, because in yearly averages any seasonal variation is completely masked. Sir GILBERT WALKER in his studies of World Weather as a rule made use of qaurterly averages concerning the conventional climatological quarters Dec–Feb, Mar–May, Jun–Aug, Sep–Nov. The present writer remarked that the most expressive results are probably obtained when spring and autumn are not considered separately, but when 5-months anomalies are used, particularly the average anomalies from Oct through Feb and from Apr through Aug, hence with pre- and full-season anomalies combined. The equinoxial months Mar and Sep are better excluded.

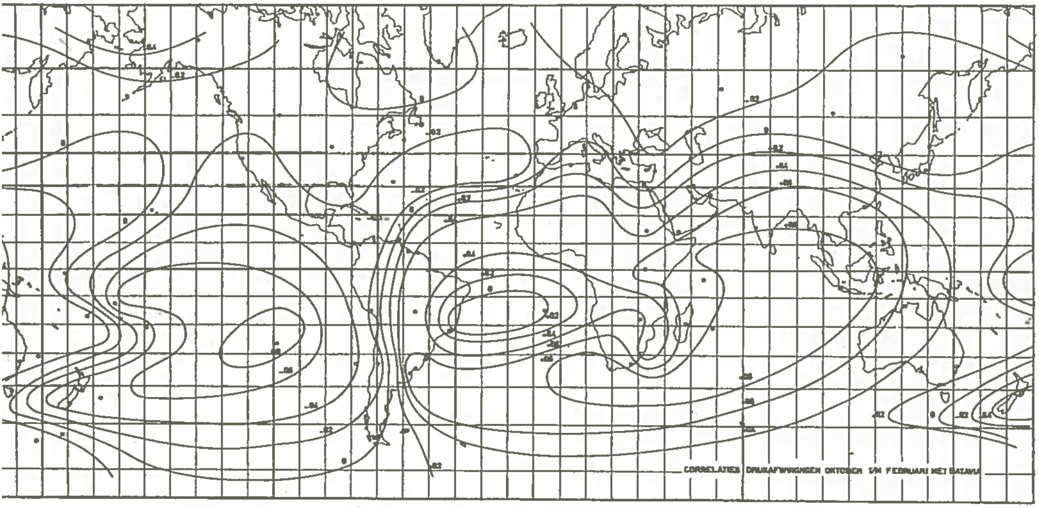

FIG. 14. Correlations of Oct–Feb air pressure anomalies with Djakarta (Batavia) Oct–Feb air pressure anomalies.

Fig. 14 shows the map of coefficients of correlation between the air pressure anomalies at Djakarta and those at other stations throughout the world for the season Oct–Feb. It is quite a surprise to find that a region of coefficients greater than +0,8 extends through the Indian Ocean and envelopes Capetown. The axis of the plus area is directed from Indonesia towards South America. Even Buenos Aires is correlated with Djakarta by a coefficient as high as +0,7. The region of +0,4 and higher envelopes even the greater part of South America, while unmistakably an isolated area without correlation of any significance remains in the subtropical part of the South Atlantic. This basin plays an indefinite role.

The writer must concede that the picture of the Southwest Pacific is based largely and insecurely on only 5 years of air pressure observations made on several islands since the second world war and published in the U.S. Weather Bureau's Climatological Data for the World. However, the South Pacific picture reveals unmistakably a certain similarity with the Indian Ocean picture, which may convince us of its reality. Another remarkable feature is the steep gradients between the plus and minus region. It is strongly suggestive of a standing wave pattern with a nodal zone, a remark made as early as 1926 by A. DEFANT [44b]. It warns us also in particular against WALKER's tacid assumption, that the sum of the air pressure deviations from normal at Santiago, Cordoba and Buenos Aires represents South American air pressure variations in the most efficient manner.

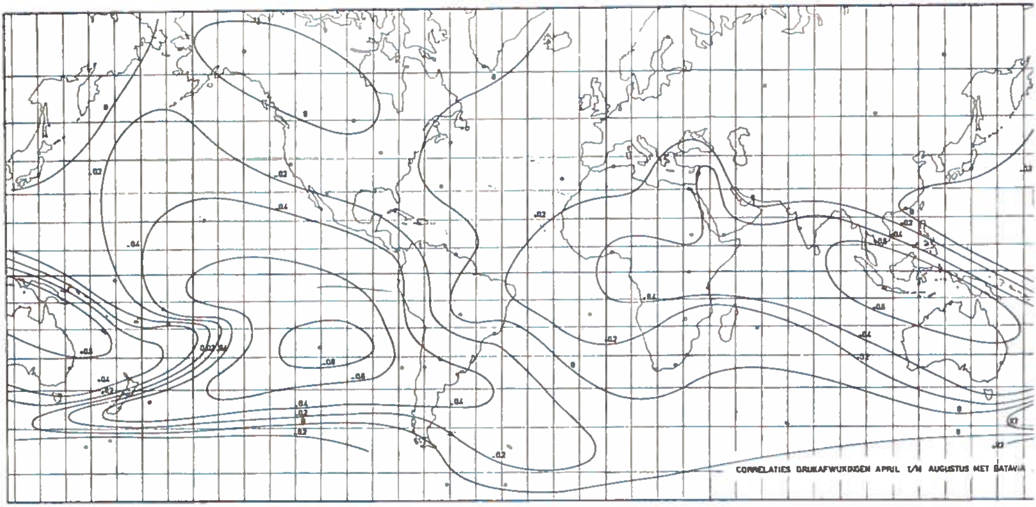

FIG. 15. Correlations of Apr–Aug air pressure anomalies with Djakarta (Batavia) Apr–Aug air pressure anomalies.

Fig. 15 shows the behaviour of air pressure deviations in the southern winter season Apr–Aug. The directions of the „stretching" of the positive and negative regions which are predominantly from W.S.W. to E.N.E. during northern winter are more nearly from W.N.W. to E.S.E. during southern winter. This time the positive region envelopes the subtropical part of the South Atlantic while the negative region transgresses through the southern part of South America into the southern part of the South Atlantic. On the whole the correlation coefficients are less spectacular in the second case. Yet gradients in the South Pacific are again steep.

The remarkable similarity between the two patterns, the one in the Indian and South Atlantic Ocean and the other in the South Pacific Ocean points to a close relation with the also similar general circulations in both ocean regions. Further we get the strong impression that during southern winter the antarctic icecap pushes back the regions of high correlation towards the equator, while during southern summer these regions expand into the belt of westerlies.

2.4 Extreme years

With a view to clarify the repercussion which the Southern Oscillation has throughout the world, use was made further of those exceptional years in which occurred what may be called the „pathological cases". It is not only in psychology that much about normal behaviour can be learned from abnormal behaviour.

That is the reason why on world charts at every available station (from the W.W.R.) the year in which air pressure was highest and the year in which air pressure was lowest on record has been noted. This was done no matter whether the series of observation years at a given station were long or short, because otherwise some phenomenal years which certainly should not be lacking in this survey are only recorded by the older stations. This procedure was repeated on other charts with the second highest pressure year and second lowest pressure year, and with the third highest pressure year and the third lowest pressure year.

In this way quickly it became clear that those years which are memorable in the Southern Oscillation, such as 1877 and 1914 for their extreme high pressure in Djakarta and 1916–1917 for their extreme low pressure in Djakarta (see fig. 9), were abnormal in the one way or the other throughout large parts of the globe.

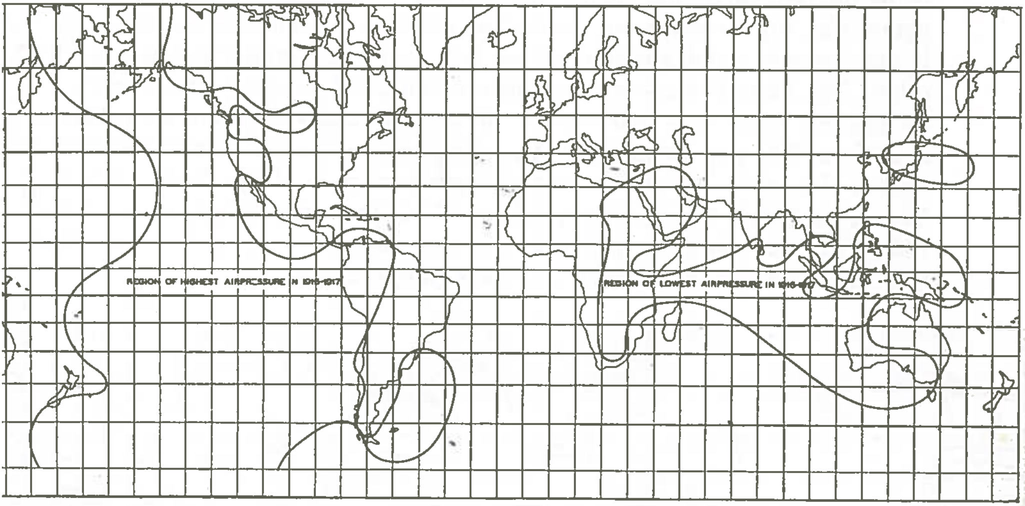

FIG. 16. Global picture of the regions where air pressure was highest and lowest in 1916–1917.

Fig. 16 shows, for instance, that the years 1916 and 1917 were years with exceptionally high air pressure from Alaska in the far north, through northwest Canada and the western U.S.A., through the Pacific Ocean to Samoa and Colon, to Christchurch in New Zealand and Punta Galera in Chile, the east coast of Argentina and the Falkland Islands in the far south. Lowest air pressure on record in 1916 or 1917 is to be found through east Africa from Beirut to Kimberley and through the Indian Ocean as far as Adelaide in South Australia, in Indonesia, the Philippines and northward up to Tokyo. Evidently this is the Southern Oscillation functioning under extremely strained conditions.

An interesting feature of this picture is its rather prominent symmetry relative to the equator, indicating at least that the general circulation in the North Pacific is involved in much the same sense as the general circulation in the South Pacific. Very clearly the Southern Oscillation has totalitarian Indo-Pacific characteristics. The Atlantic plays, as we already know, a secondary part only.

In consequence of the dominantly standing type of the long-periodic pressure wave which we are investigating, what the writer expected to be possible was not difficult to achieve. One easily succeeds in grouping the partial and often small areas in which a certain year showed extreme pressure features, dispersed over the globe, into two primary areas, which are roughly the same on all six charts of abnormal cases, pairwise reproduced in figs. 17, 18 and 19. These two regions are also roughly coincidental with the two regions already delineated by the zero curve, the ,,nodal line" on our world map of yearly correlation figures (fig. 10). However, we are now in a position to follow this ,,nodal line" in much greater detail and to conclude how it moves from one situation to the other. The basic theme – so to speak – is indicated by some mean curve. It divides the world into two regions showing normally opposite air pressure deviations. The one includes mainly the eastern and greater part of the Pacific Ocean, the other includes mainly the southern part of the South Atlantic Ocean, the Indian Ocean and the southwest Pacific Ocean with southeast Asia, Indonesia and Australia. The borderline between the two regions can be rather well traced through the Pacific. It crosses New Zealand.

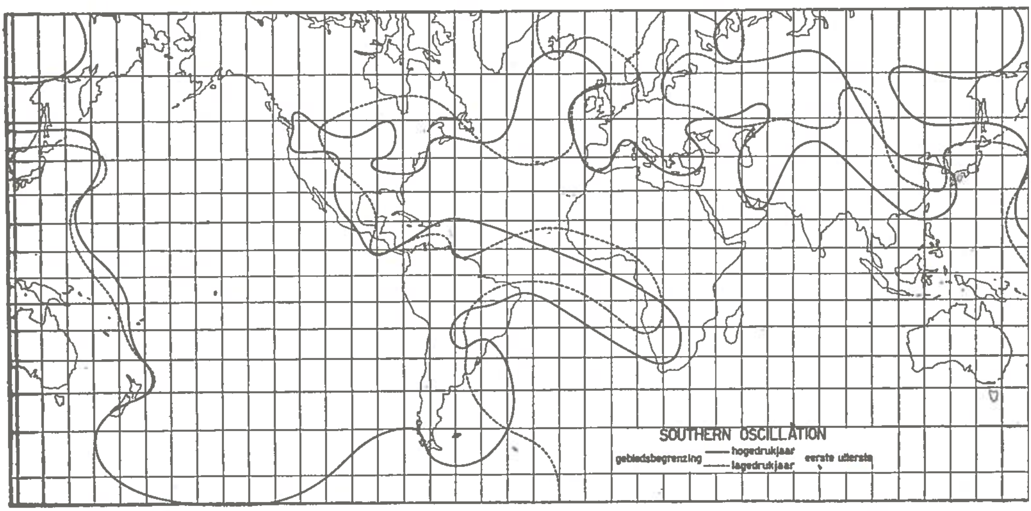

FIG. 17. Southern Oscillation. Demarkation of regions where annual airpressure attained its absolute maximum (———) and its absolute minimum (---------).

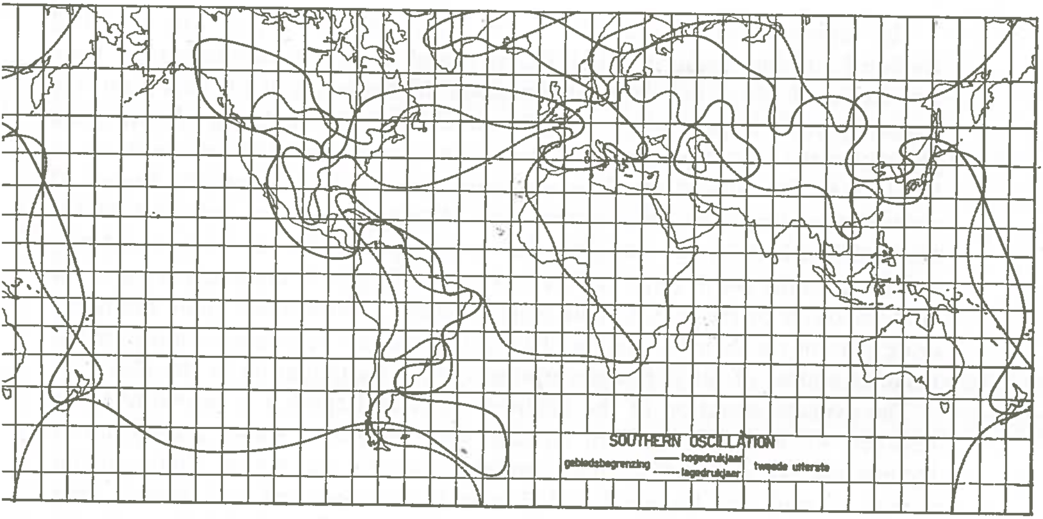

FIG. 18. Southern Oscillation. Demarkation of regions where annual air pressure attained its second highest maximum (———) and its second lowest minimum (---------).

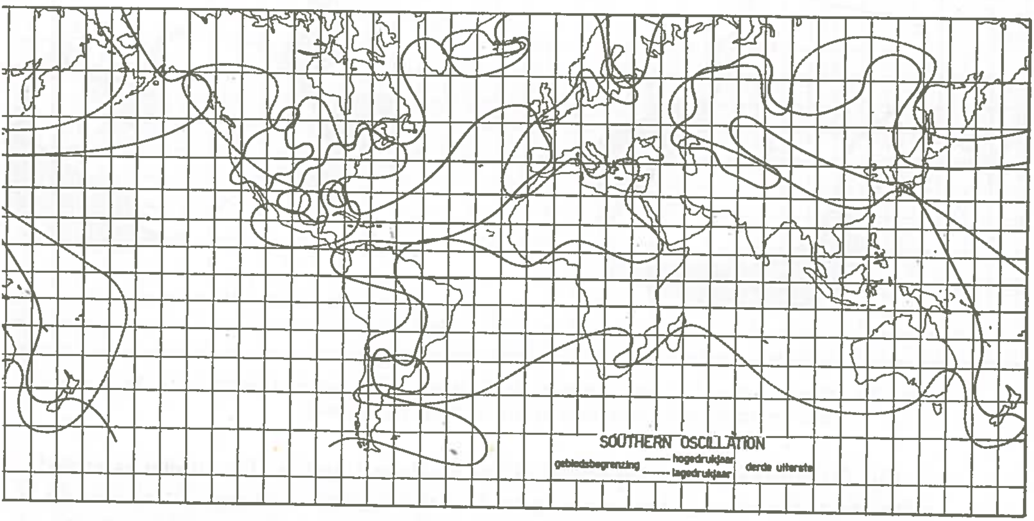

FIG. 19. Southern Oscillation. Demarkation of regions where annual air pressure attained its third highest maximum (———) and its third lowest minimum (---------).

The region in which Djakarta is the representative station will be called Region I and the region in which Easter Island plays this role Region II. Then it is Region I which normally encompasses the countries of the near East, the eastern part of South Africa, Central Africa and North Africa, and in most years also the subtropical part of the North Atlantic and the eastern states of the U.S.A. We noticed this frequent direction of influence earlier. Region II normally encompasses the western half of South America and part of the tropical South Atlantic, including the western part of South Africa, and may extend from the south into the North Atlantic. Region II encompasses also the western states of the U.S.A. and North Canada, and in most years the temperate part of the North Atlantic. The rest of the world follows a more or less random course of air pressure variations while participating in the play.

The average situation of the northern limit of Region I is probably found between 40° and 50° northern latitude while Region I shows a tendency to include the Antarctic. Region II probably includes the Arctic. Summarizing, it may be said that Region I and Region II are separated by a border zone, a „no man's land" through which both regions invade each other's territories in apparently irregular succession.

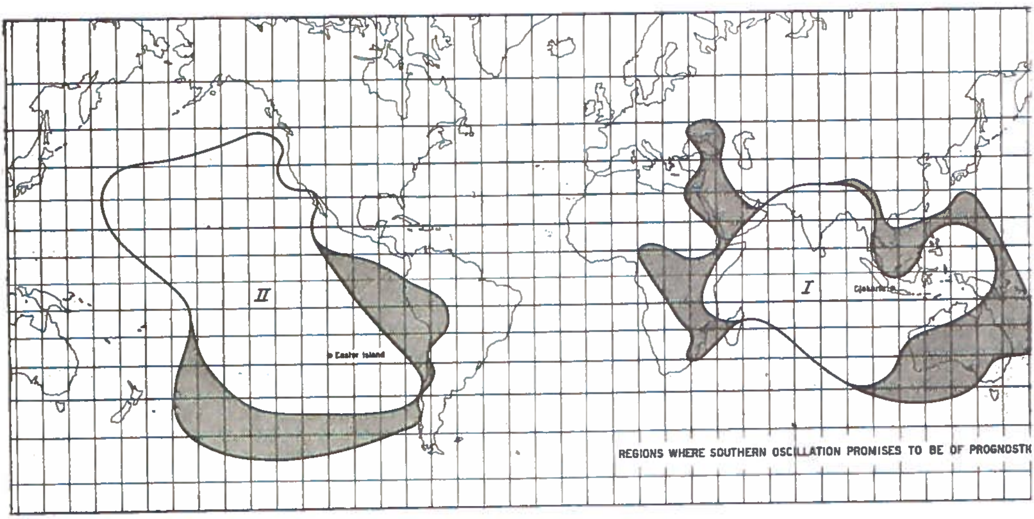

FIG. 20. Regions I and II are common in all three cases exposed in fig.'s 17, 18, 19 and their extensions are common in two of these three cases.

Fig. 20 illustrates the two nuclei of the Regions I and II. The nuclei extended with shaded portions, are common to 4 of the 6 pictures of figs 17, 18 and 19, the restricted nuclei are common to all 6 pictures. It is improbable that further investigations would change these nuclei materially and we are induced to point out the almost exact agreement between the nuclei of Region I and Region II, distinguished in the way indicated here, and the areas where correlation of yearly air pressure anomalies with Djakarta air pressure anomalies are | 0,4 | or greater. It is a confirmation of the remark previously made and quite recently once more stated by A. M. GRANT [66] that within the panel of the present problem and its data correlation coefficients below | 0,4 | are not worth much. As a matter of fact it is generally agreed upon that a correlation factor of 0,4 indicates that certain anomalies are controlled for a part equal to the square of this factor, or for 16 percent only, by certain other anomalies.

The charting discussed here leads further to the following interesting conclusion. The basic swayings between Region I and Region II generate high pressure and low pressure by turn in the years comprised in the 32 partial series summed up in table 24.

TABLE 24. *16 irregular Southern Oscillation waves in 80 years*

II	I	II	I	II	I	II	I
1860	**1864**	1869	1876	1878	1880	1882	**1883**
1861	1865	1870	**1877**	1879	**1881**		1884
1862	**1866**	1871					**1885**
1863	1867	1872					
	1868	1873					
		1874					
		1875					
II	**I**	**II**	**I**	**II**	**I**	**II**	**I**
1886	1887	1889	**1891**	1892	**1896**	1898	**1899**
	1888	1890		1893	1897		1900
				1894			
				1895			
II	**I**	**II**	**I**	**II**	**I**	**II**	**I**
1901	**1902**	1906	1907	1909	**1911**	1915?	**1918**
	1903		1908	1910	1912	1916	**1919**
	1904				**1913**	1917	
	1905				**1914**		
					1915?		

TABLE 24. *(continued)*

II	I	II	I	II	I	II	I
1920	**1925**	1926	1927	1933	1934	1937	1939
1921			1928		**1935**	1938	**1940**
1922			**1929**		1936		
1923			**1930**				
1924			1931				
			1932				

We learn from table 24 that what occurs in the first place is an apparently aperiodic or at least irregular worldwide pressure oscillation between both regions. It *may* be related in some way or another to variations in solar activity, but no such relation was discovered so far. Now, the 16 periods of successive complete waves are of the following duration in years

9 9 4 4 3 3 6 3 5 3 6 5 6 7 4 4

Reviewing this series, we are easily induced to divide both unreasonably long 9-year waves up in two 4-year and two 5-year waves. After this partition the frequency distribution of numbers of waves over given wavelengths is as follows:

Wavelength in years	2	3	4	5	6	7	8
Number of waves	0	4	6	4	3	1	0

The average length of the period is 4,45 years and the frequency distribution is so unstrained that the impression grows that here is a cycle longer than the basic Southern Oscillation cycle and having perhaps some physical background. One is induced to ask whether the coincidence of the average length of this cycle and the top at exactly 4,5 years in the periodogram of fig. 1 is merely incidental. The question whether it is the „arctic cycle" will be touched later.

At the back – so to speak – of this more or less random fluctuation the Southern Oscillation proper is developed. Its prominent high pressure years in Region I are printed heavy in table 24. A dubious role is played by the year 1915, which will, however, not detain us here.

2.5 Precipitation, passive and active

GROISSMAYR [68n] investigated the world pattern of precipitation compensation, that is the pattern of the areas which are balanced out as regards annual rainfall, and found in the series 1885–1930 the highest negative correlations between rainfall in Argentina (mean of Corrientes, Goya and Buenos Aires) and rainfall in Trinidad, Northwest India (mean of Allahabad, Jaipur, Hyderabad and Karachi), Queensland (mean of Welltown, Miles and Mitchell) and Amboina in the Southern Moluccas. The coefficients of correlation found in these four cases are —0,40, —0,52, —0,45 and —0,61 respectively.

Besides the antithesis between precipitation in Argentina and Trinidad we easily recognize in the antithesis between Argentina rainfall on the one hand, and Indian, Indonesian, and Australian rainfall on the other, the effect of the Southern Oscillation. GROISSMAYR remarks especially the coincidence of the most extreme drought in Australia and the most abundant rainfall in Argentina in 1914.

It is worthwhile to notice here in the first place the intimate relations which exist between air pressure and rainfall in the Far East. Meteorologists in India, Indonesia, Australia, and New Zealand, have accumulated a wealth of information on these relations. Monsoon forecasting in India and Indonesia is in the main forecasting rainfall on the basis of the Southern Oscillation.

In Java, for instance, it is precipitation in the dry season, that is during southern winter, which correlates highly with air pressure. We give the two coefficients of correlation between air pressure and rainfall in Djakarta, Jul–Aug and Sep–Oct.

	Jul–Aug	Sep–Oct
Djakarta	—0,57	—0,72

However, it is during southern winter also that India receives its large monsoon rains and Sir GILBERT WALKER and his followers worked out successful prognostic rainfall formulae for India on the basis of his famous compilation of „Correlations in seasonal variations of weather". By far the greatest number of significant relationships with other centres is found in N.W.-India, Djakarta, Darwin, Samoa and S. America. Again clearly the Southern Oscillation is used (World Weather III, see also 4.3).

Very sensitive indicators of precipitation are the tropical islands in the Pacific (K. KNOCH [93]). They can be divided into different groups according to their situation in the following characteristic regions: Horse Latitudes, Northeast and Southeast Trades, the Equatorial Zone and those of the Asiatic Monsoon and the Australian Monsoon. Fig. 21 is reproduced from an extensive investigation made by TÜLLMANN [171]. These regions do not cover regions of similar quantity of yearly precipitation, this quantity being largely dependent on air mass modifications.

Apart from this stands the relationship between seasonal rainfall in these islands and Djakarta seasonal air pressure deviations, representing the Southern Oscillation. Table 25 contains a small list of some notable correlation coefficients.

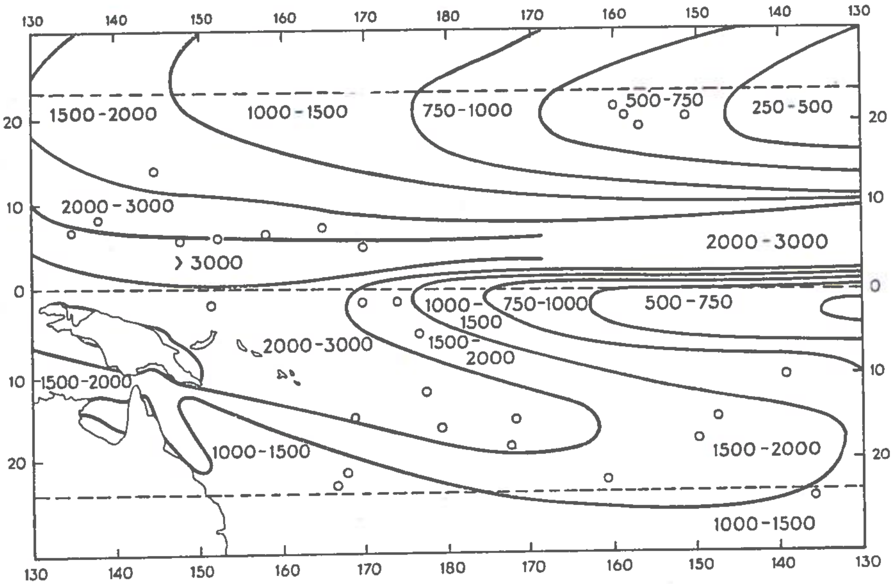

FIG. 21. Distribution of mean yearly rainfall in the Western Pacific.

TABLE 25. *Correlations with contemporaneous Djakarta air pressure*

	rainfall Jun–Oct	rainfall Dec–Apr
Avarua (21°12′S, 159°47′W)	—0,21	—0,44
Tulagi (9°6′S, 160°10′E)	—0,18	—0,72
Apia (13°48′S, 71°47′W)	—0,24	—0,41
Suva (18°8′S, 178°26′E)	—0,19	—0,19
Yap (9°29′N, 138°8′E)	+0,15	—0,44

There is another group of stations, Malden Island, Nauru (Gilbert Islands) and Raniola (Bismarck Archipelago) showing positive correlations with Djakarta air pressure. We refrain from calculating separate coefficients for these stations as their series of observations first compiled by W. W. REED [129] rarely survived the first world war and are moreover far from complete. Fig. 22 reproduces a graph from previous publications, which leaves not the slightest doubt about the intimacy of the relations between pressure and precipitation at eight Pacific island stations. In this graph the sign of the rainfall deviations at the stations of the larger group have been reversed.

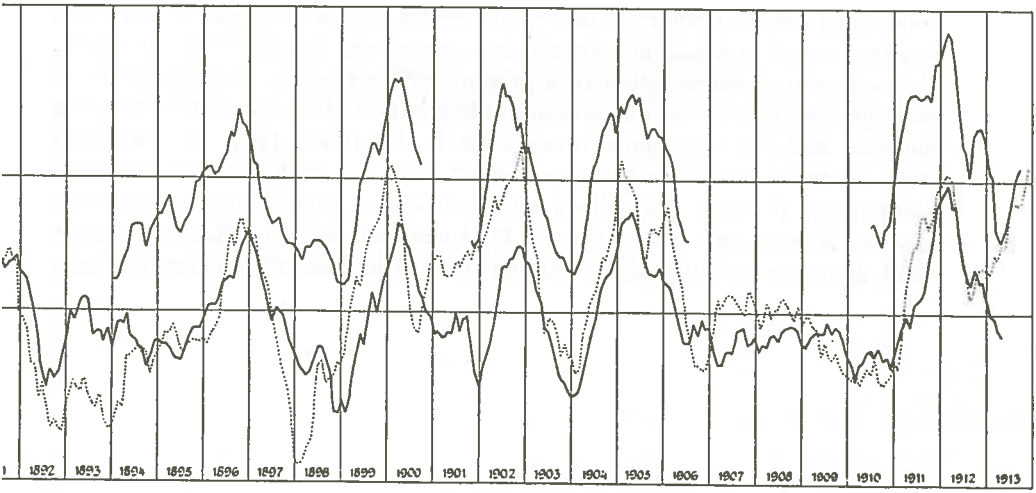

FIG. 22. a. Smoothed departures of rainfall at Nauru (Gilbert Island);
b. Smoothed departures of rainfall at 8 Polynesian stations (3 reversed) (———) and Darwin air pressure (----).

The division of the two groups of stations seems to be rather systematic. The stations of the smaller group, where rainfall is positively correlated with Djakarta air pressure, are situated near the equator, those of the larger group where rainfall is negatively correlated with Djakarta air pressure, are found to be the stations farther away from the equator.

The total picture is rather simple and coherent. The stations near the equator are found along the axis of the „dry tongue" which extends from east to west through the Pacific roughly between 10°S and 3°N. The other stations are typical of generally more abundant rainfall in the tradewind or monsoon regions north and south. Hence it is only logical that the former stations are dryer and the latter stations wetter than normal when the pressure gradients in the Southern Oscillation are steep and the general circulation through the Pacific is accelerated.

It is important to note that correlation of Apia rainfall and Apia air pressure yields the coefficients —0,01 (Jun–Oct) and +0,12 (Dec–Apr). One might have expected two rather high plus values. The conclusion, however, is that seasonal rainfall in Apia is much more highly correlated with Djakarta seasonal air pressure than with Apia's proper seasonal air pressure. Apia air pressure therefore is certainly much less representative of the Southern Oscillation than Djakarta air pressure. This is no new point of view. Apia is too near the boundary between the two antithetic parts of the world in the Southern Oscillation to claim this representativity.

One final remark is appropriate here. In the tropical belt, increased convective cloudiness and precipitation lowers air temperature in the lower air layers. This secondary compensation of a primary positive excess of temperature in the tropics relative to the temperature in higher latitudes may explain why in a cloudless and dry subtropical area as the Easter Island High the amplitude of the Southern Oscillation is highest, why it is smaller in Darwin (N. Australia) and Kupang (Timor), places in a monsoon region experiencing at least one very dry season, and still smaller in Djakarta (Batavia) and Bombay, places which are more typically equatorial and cloudier and wet throughout the year.

3. THE OPERATION OF THE LONGPERIODIC OSCILLATIONS

3.1 Normalization of the Southern Oscillation

It is not only with a sense of honesty in regard to past failures in the meteorological service of himself and his predecessors that the writer reproduces in fig. 23 a graph from a previous publication [15h], illustrating the outstanding

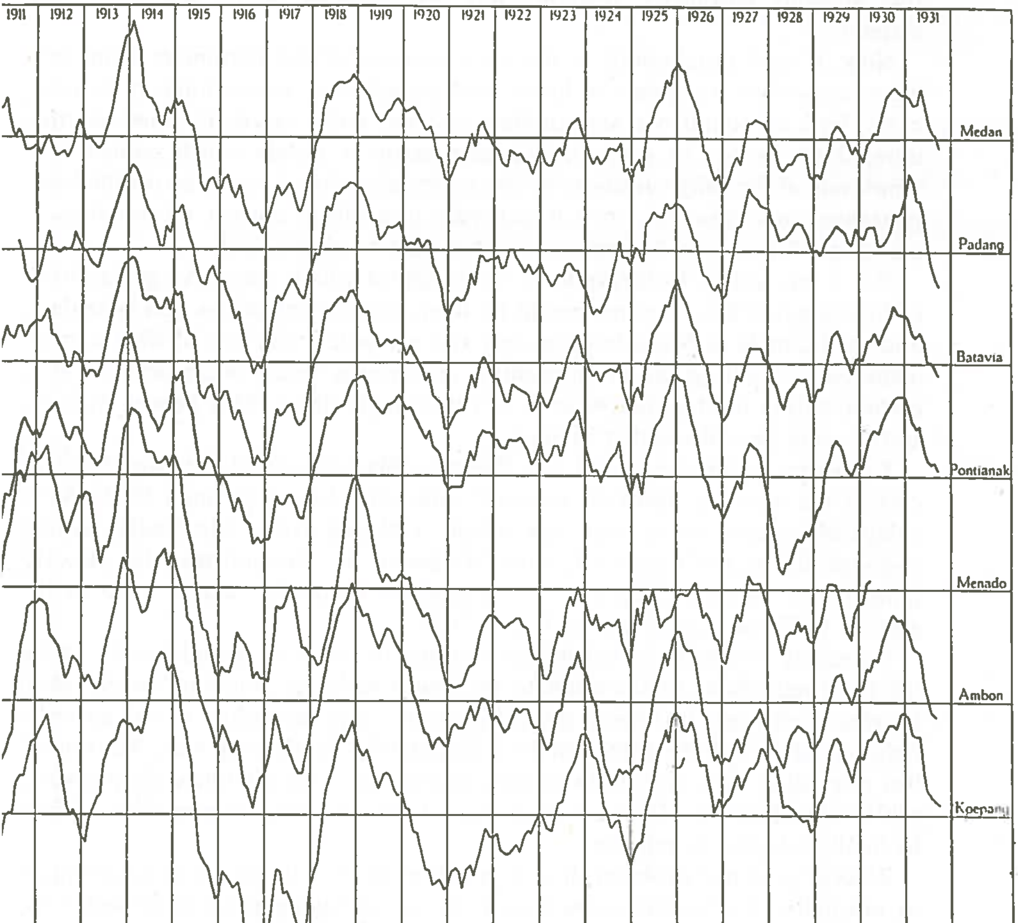

FIG. 23. Parallelism of air pressure fluctuations in Indonesia.
Smoothed departures at stations which are at distances apart of the order of 1000 km.

parallelism of pressure fluctuations at seven stations widely dispersed in Indonesia, but all within the confines of the Malay „key area" of the Southern Oscillation. Considering this picture we should recall the fact that the average distance between two stations is of the order of 1000 km. Nevertheless inter-correlations between these stations would discover values of coefficients at least very near +0,9. The clearer does it become that air pressure measurements at Menado (N. Celebes) have been defective from 1920 to 1930. The error in the Menado barometer readings was not detected before ten years had elapsed.

Now, if such unreliability is due to a removal of the barometer from one place to another at a higher or lower level, an adequate correction can, in most cases, be later found out and applied, and the series saved. If, however, the unreliability is due to some instrumental error or inertia which reduces the amplitude of the daily variation, or else to erroneous readings by an insufficiently trained new observer, then it is hardly possible to correct the misshapen curve and the attempt to improve it later must be abandoned.

Not a few series of observations, the length of which successive generations of investigators have become proud of, have needed corrections at a later date and the example of Menado given here is a valuable indication of what can be achieved in restating lost mean monthly or seasonal values of air pressure at a certain station by the interpolation of values taken from other nearby stations in the same „world weather" region.

The writer is convinced that e.g. Djakarta (Batavia) could very well help to correct the monthly mean air pressure values in Darwin through 1895–1896, values which have never been successfully deduced from admittedly wrong readings during this couple of years. Moreover, fig. 24 confirms what BRAAK pointed out already [26f], viz. that a positive correction would have to be applied to Darwin air pressures before 1898.

Especially removals of barometer stations to other sites and levels, while the right reductions of the older to the newer series are missing – which was no rare occurrence in several distant stations – can, according to the writer's opinion, often still be corrected in a completely satisfactory way. He found it a rewarding task to publish in the present paper the complete air pressure tables for Mauritius, Ocean Island, Juan Fernandez and Paramaribo, which he finally adopted as reliable.

Returning to our problem there is much to be said in favour of an attempt to normalize the Southern Oscillation by an averaging process, in order to eliminate typically zonal or local irregularities. Now as we are well informed over many years about the course of air pressure in the central area of Region I by its key stations Bombay–Djakarta–Darwin, it is extremely interesting to compare in fig. 24 and fig. 25 the courses of air pressure in Darwin and Djakarta, and in Bombay and Djakarta respectively.

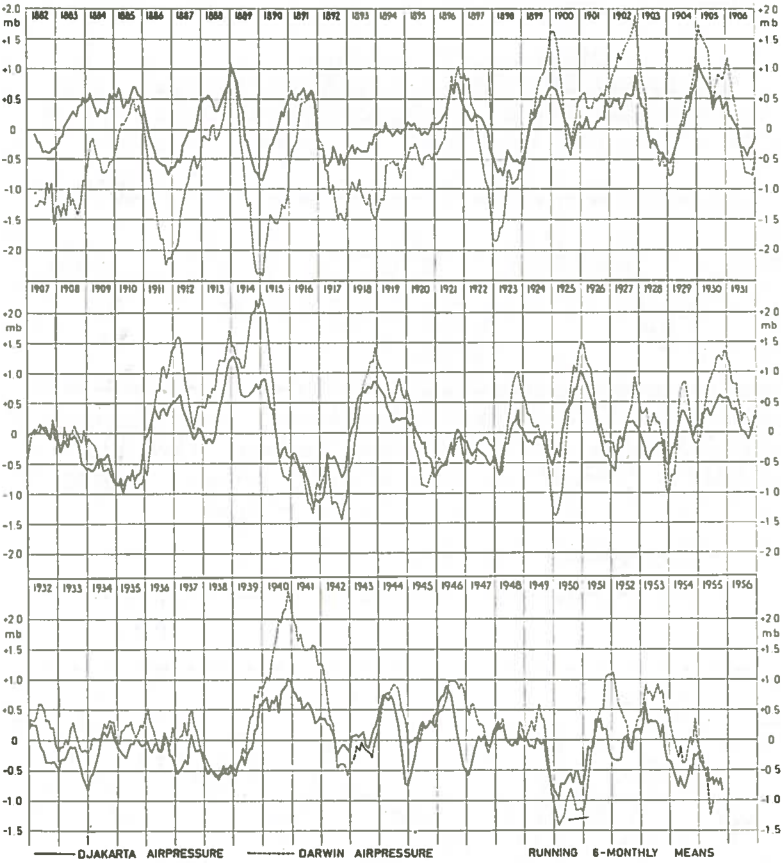

FIG. 24. Parallel run of Djakarta and Darwin air pressure.

There are some characteristic differences between both pairs of pressure curves besides those of amplitude, and these differences naturally must not be neglected, because they may give valuable information about what is happening exactly ,,round about'' the Southern Oscillation. In the last paragraph of this chapter attention will be concentrated on these discordancies. Let us consider here fig. 26, which contains a curve of running half-yearly means of air pressure deviations computed from $\frac{1}{3}$ (Bombay + Djakarta + Darwin), through 74 years, from 1882 to 1955.

The writer's impression is that the average curve looks – so to speak – less agitated than each of the three component curves, without any evident loss of amplitude, and this is to be regarded as indicating that something noteworthy has been gained by the execution of this sommation. On the other hand,

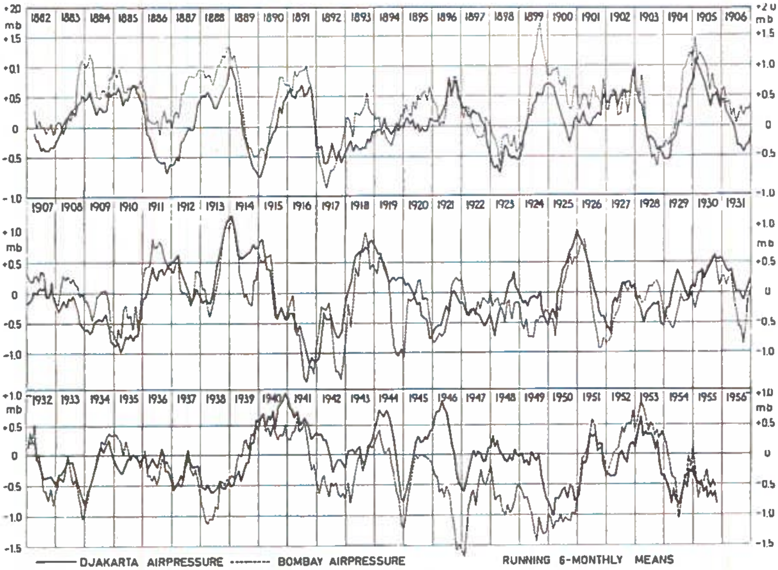

FIG. 25. Parallel run of Djakarta and Bombay air pressure.

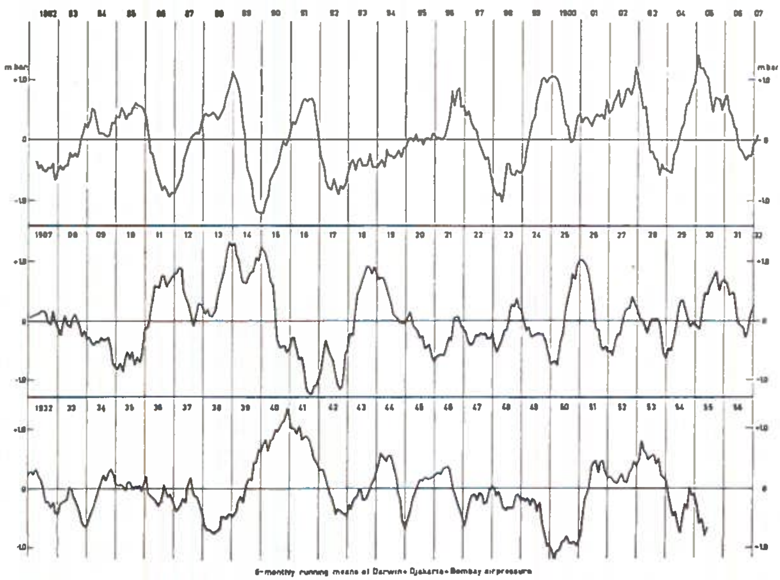

FIG. 26. The Southern Oscillation represented by 6-monthly running means of air pressure anomalies, $\frac{1}{3}$ (Darwin + Djakarta + Bombay).

it is hardly imaginable that the resulting air pressure curve could in any way be further simplified. A study of the normal behaviour of the Southern Oscillation may well start from this final curve.

Curiously enough the definite impression remains that the Southern Oscillation was less regularly and less intensively developed after 1925 than before, although especially the outstanding 1940–1941 wave crest promises to contribute to clearing up the mystery. The late twenties and early thirties present, as the writer detected from different points of view, the worst example of a Southern Oscillation wave train. They tend, by their irregular behaviour, to discredit the safety of the structure which we are attempting to erect. Yet the writer, although he fears to express himself unscientifically, endeavours to say, that the late twenties and early thirties should not be regarded with too much distrust. This point will be referred to in the later paragraphs of this chapter.

It would have been of extremely great value had we at our disposal an equally reliable curve through a similarly large number of years of observation, summarizing the air pressure fluctuations in the central area of Region II. Samoa air pressure fluctuations fail in as much as Samoa is too near to the boundary between Region I and Region II. Since this is the case, Juan Fernandez is the only remaining key station, presenting at least a series of observations dating, with some interruptions, back to 1911. We are aided in our intentions by the circumstance that the gaps in Juan Fernandez records could be reasonably well filled by the support of the records from Punta Galera, a coastal place which does not yet show, as Santiago does, the typical large annual variation of continental stations. Fig. 27 shows what results from the addition

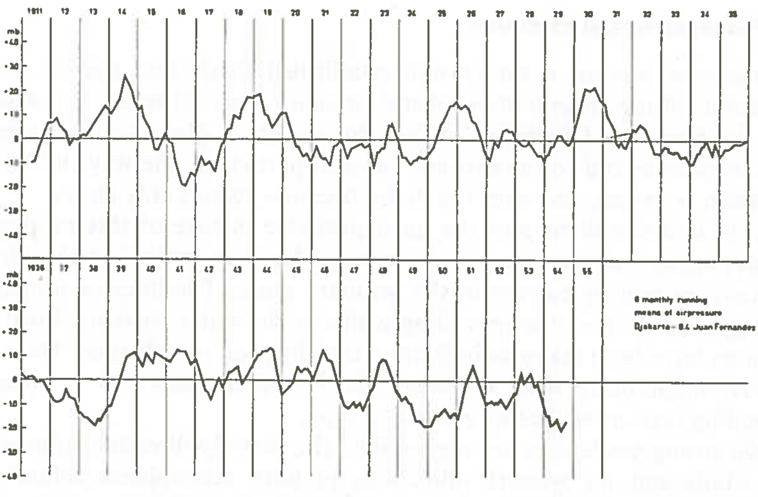

FIG. 27. The Southern Oscillation represented by 6-monthly running means of air pressure anomalies, (Djakarta —0,4 Juan Fernandez).

Djakarta (Batavia) —0,4 Juan Fernandez 1911–1954. The factor 0,4 was chosen for Juan Fernandez because, as is known, the amplitude of the pressure fluctuations in Juan Fernandez and the amplitude of the Djakarta fluctuations are roughly in this ratio. In the writer's opinion, however, Juan Fernandez is not representative enough of Region II to allow of seeing in fig. 27 an amelioration or better standardization of the basic Southern Oscillation pressure curve. Most probably Juan Fernandez is situated so far south that the disturbances of moderate latitudes leave already too many random imprints on its pressure fluctuations. The same remark was made earlier, when it was pointed out that Juan Fernandez air pressure fluctuations show a definitely more stochastic variability than Djakarta air pressure fluctuations. The basic Southern Oscillation pressure curve is therefore probably better represented by fig. 26. Nevertheless there are some very interesting points in fig. 27. For instance, strong stress is laid upon the 1930 extreme. As a matter of fact the years 1930 and 1931 are well known for abnormalities in the South Pacific general circulation, especially the hydrospheric circulation. A record longperiodic cold wave was observed in many islands, and abnormal speeds of currents associated with it have been pointed out by Barlow [9]. Here we certainly touch on one of those pathological cases which the writer has suggested several times for a more detailed study because they are so instructive, also with regard to normal behaviour. It should be remarked that the 1930-top in the resulting air pressure curve of fig. 27 does not clash with the Djakarta records proper. On the contrary, it is only accentuated thereby, and this is a promising conclusion.

3.2 Propagation and extension

It has now become a rather well established thesis that the longperiodic fluctuations of the general atmospheric circulation are all based on, or derived from, the Southern Oscillation. When due weight is given to the correlation charts in general and to the extreme cases in particular, the way the Southern Oscillation is propagated over the globe becomes remarkably clear.

Fig. 28 is designed to give the most probable picture of this propagation. The propagation arrows are not to be considered as indicating the direction of a wave motion or current in the ordinary sense. The lines of propagation are imagined to follow the prevailing winds or the water currents. Protrusions of an area have been taken as indicating the direction of influence. The arrows, however, might have been reversed. The influences may – so to speak – be of a pulling type as well as of a pushing type.

Three strong tendencies are perceptible, the easterly direction following the trade winds and the westerly directions in both hemispheres following the prevailing winds in moderate and even rather high latitudes. The oceanic circulations are taken into account, whereas the whole course of development

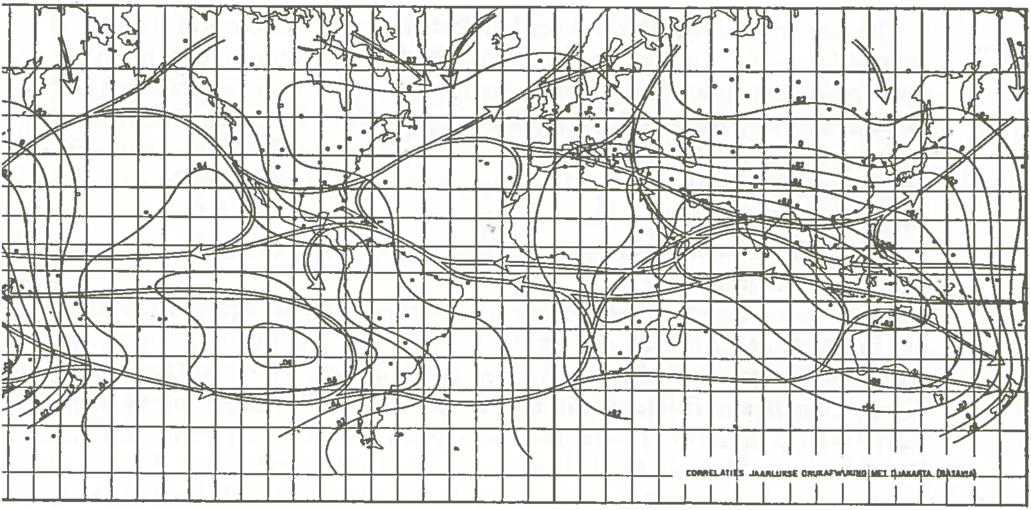

FIG. 28. Probable directions of propagation of the Southern Oscillation with the general atmospheric and hydrospheric circulation, represented on the map of annual air pressure correlations with Djakarta (Batavia).

is restricted as far as is reasonable to the seas. The continents are evaded with the exception of their narrow parts and of the polar caps.

The arctic is to be included in Region II. The question, how the Southern Oscillation is normally extended into the antarctic cannot yet be answered with certainty because of the lack of data. Undoubtedly the continuous series of observations which have been made at some points of the antarctic continent in recent years and the endeavour to be expected in the coming International Geophysical Year will contribute much to the answer. However, at the present moment it is still a theme for discussion whether the antarctic is in Region I or in Region II. That the antarctic continent which is surrounded by an ocean through which the westerlies blow round the globe, would be partly in Region I and partly in Region II is highly improbable. The inclusion of the antarctic as a whole in one of the two regions is equally well possible. As the worldwide longperiodic oscillations are always more or less zonally bounded, the tropical belt and both polar caps standing in opposition, and since we have observed the apparent symmetry with regard to the equator of fig. 16, the writer would consider the inclusion of the antarctic with the arctic in Region II as the most probable state. When looking at the antithetic geomorphology of the arctic and antarctic it might perhaps also occur to install the antarctic in Region I, yet the writer is inclined to doubt this suggestion, because the arctic and antarctic are both icecovered. We must wait untill a final conclusion is definitely reached.

The northern one of the two central east-west round-the-world tracks from Indonesia, passes through India, the tropical Indian Ocean, Central Africa, the tropical Atlantic Ocean, the West Indies and the tropical North Pacific Ocean. A branch deviating from this track goes from the Indian Ocean northwestward through the Red Sea, northward through the Black Sea, northeastward through Russia, eastward through North Siberia and finally southeastward through East Siberia. The southern central east-west track from Indonesia keeps south of the equator, picking up the other track along the north coast of South America.

From the northern east-west track the Kuro Shiwo trace derives. It branches out in Alaska. One branch closing the North Pacific circulation along the west coasts of Canada and the U.S.A. The other branch goes eastward through North Canada and debouches in the North Atlantic. From the southeastward track through the North Pacific a branch crosses eastward the Central American States and the Mexican Gulf. It picks up the Gulf Stream track through the North Atlantic. From this track an eastward Mediterranean track branches out. This is combined with the northeastward track through Russia. However, a west wind drift particularly in the upper air can easily be pursued through the near East and South Asia. It associates eventually with the Kuro Shiwo track. The apparently rather contradictory course of influences through the North Indian Ocean is actually solved in the monsoons. In the southern summer in the southern hemisphere the stress is on the westerlies while in the southern winter the stress is on the tradewinds.

A second branch from the Gulf Stream track passes through the Baltic. It is directed eastward along the polar icecap and finally southward through Behring Strait. A third branch from the Gulf Stream track curves back westward, south of Spitsbergen, rounding Iceland and going southwestward with the East Greenland Current.

In the southern hemisphere – as we mentioned already – it is the anti-trade starting from Indonesia which is important. It is associated with the strong westerlies circling the globe. These westerlies cross the south part of South America. The track of influence, vital in the Southern Oscillation, branches out in the South Pacific from the westerlies. It goes northward along the west coast of South America with the Peru Current and is directed back to its origin with the tradewinds through the South Pacific.

In the South Atlantic Ocean the Benguela Current plays a role similar to the Peru Current, but it is probably not very effective. In the South Indian Ocean, along the west coast of Australia a northward ocean current closes the circulation.

In this answer to the question how world weather influences „flow" we have given the winds their easiest ways and will not bother about minor details in the picture of the general circulation. It is certainly open to improvement. What becomes very clear meanwhile is the large scale eddies which obstruct, more or less, the general air circulation above the oceans. These eddies are the roller bearings in the circulation, and, while the water masses are drawn along with the prevailing air streams it is the immense storing up capacity of heat and cold of these water masses which explains the delayed action of temperature in certain favourable areas and the development of the longperiodic oscillations, which are investigated in this paper.

The circulating water masses through the oceans are oscillators and these oscillators are linked by air streams having crossed a continent at a narrow part from one ocean to the other.

The circulations in the North Pacific, the South Pacific and the Indian Ocean are directly coupled by the tradewind systems in one Indo-Pacific circulation. The North Atlantic circulation is linked with the Indo-Pacific circulation by the equatorial easterlies through Central Africa. The South Atlantic circulation is to a certain extend defective, because what should be its driving force, the southeast tradewind deviates for the greater part into the North Atlantic. The South Atlantic, although, as J. J. CRAIG pointed out [41], it has a direct link by monsoonal westerlies with the Abyssinian highlands and the sources of the Nile, fills a secondary role in the whole play. This explains why no investigator has ever found reasons to distinguish more than three oceanic oscillations (WALKER [180], STEIN [160]).

It is not surprising, therefore, to meet in the North Atlantic the only longperiodic oscillation which is worth mentioning apart from the Indo-Pacific oscillation. As a matter of fact the only instance of a significant negative correlation of air pressures between great centres of action extending over both seasons, besides the one between, say Djakarta and Easter Island, is the one between the Azores and Iceland. Even the North Pacific oscillation, outstanding in winter, drops seriously in summer, as is shown in table 26 which is extracted from Sir GILBERT WALKER's tables.

TABLE 26. *Seasonal correlations of air pressure in North Atlantic and North Pacific oscillations*

	Dec–Feb	Mar–May	Jun–Aug	Sep–Nov
		Stykkisholm (Iceland)		
Punta Delgada (Azores)	—0,54	—0,60	—0,48	—0,40
		Juneau + Atlin + Sitka (Alaska)		
Honolulu (Hawaii)	—0,70	—0,52	—0,28	—0,22

The North Atlantic Oscillation (A. DEFANT [44a]) is evidently not „fed back" in any effective way on the Southern Oscillation through South America. This supports the independence of the Southern Oscillation and its relatively undisturbed evolution. The North Pacific Oscillation, if considered apart, is in fact influenced by the North Atlantic Oscillation and probably vice versa through zonal communications. The South Pacific circulation is therefore relatively the most free oscillator. The other circulations are oscillators which are more or less forcibly driven by the Southern Oscillation. Theory confirms this conclusion at which we have arrived through the inspection of charts only. However, where there is action there is always reaction and it is interesting to discover in more detail how the coupling between the Indo-Pacific or Southern Oscillation and the North Atlantic Oscillation operates.

The weather in the Eastern States of North America is affected by the fluctuations of the Atlantic tradewind system, and, as a matter of fact, correlation figures pointed from Chicago southeastward towards North Africa (fig. 12). West European weather is affected by the Gulf Stream and, as a matter of fact, correlation figures pointed from De Bilt southwestward along the Gulf Stream (fig. 11). The well-known affection of European weather by the Nile floods is demonstrated by one track of influence emanating from the Southern Oscillation, and Beirut's significant correlation with Djakarta in northern summer time. Here we meet an example in which the protrusion of a region of equal correlation evidently goes against the prevailing wind direction, in this case the famous and steady summertime etesian winds. In northern wintertime it apparently is the western influence from the North Atlantic which transgresses through the Mediterranean south of the Alps into the Near East and south of the Himalaya and the Tibetan Highlands into the Far East. A „good Nile" in summer, according to Bliss [22] is associated with low air pressure in Region I in which Djakarta is a central station, and the winter North Atlantic circulation varies inversely with the Nile. Such is probably the most effective feeding back of the North Atlantic Oscillation on the Southern Oscillation.

Since wintertime circulations are mostly stronger than summertime circulations, it would be reasonable to find influences of the Southern Oscillation affecting the North Atlantic Oscillation mostly during the northern summer and influences of the North Atlantic Oscillation affecting the Southern Oscillation mostly during the northern winter. In fact, Dec–Feb conditions in the northern hemisphere are mostly affected by Jun–Aug conditions in Region I, including Egypt and the Nile. E.g. Bliss states:

„Out of 310 correlation coefficients with Greenwich temperature of Dec to Feb as representing winter in Northwest Europe the largest appear to indicate the following relationships,

(1) with pressure of the previous summer at Cairo,

(2) with temperature of the previous Jun to Aug at Madras, Samoa, Batavia and Perth,

(3) with the previous Nile flood, the relationship here being inverse.

The results indicate that conditions in the Southern Hemisphere play a part comparable with that of the North Atlantic Oscillation in controlling subsequent winter weather in the British Isles."

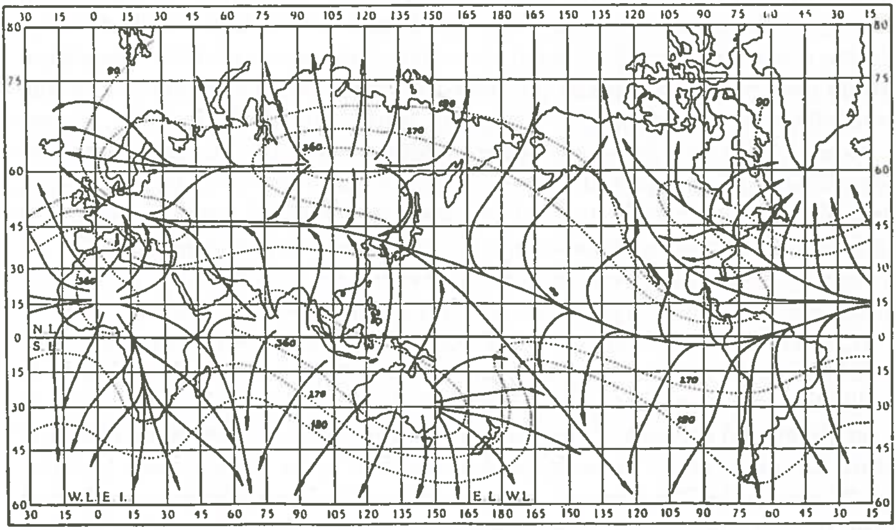

FIG. 29. Isophasic lines of the sequence of 3-year period waves of air pressure, 1896–1905 (———) and lines of propagation (---------) (after VON SCHUBERT).

In conclusion, it is interesting to compare our present picture with the picture of isophasic lines of the 3-year fluctuation of air pressure and lines of propagation (fig. 29) designed by O. VON SCHUBERT [150]. His figure was based on data obtained by an analysis of the Southern Oscillation in the years 1896–1905, in the period when the Southern Oscillation assumed an explicit 3-year wave type and was strongly persistent. The writer's impression is that VON SCHUBERT discovered much more of a running character of the basic pressure wave than is really in it. Looking at VON SCHUBERT's chart very carefully, it will be seen that its sense is principally a standing meridional oscillation with „Quellen" and „Senken" in more or less zonal arrangement and a principal antithesis between the tropical belt and the polar caps, while the outstanding „Quelle" is the Malay Low and the outstanding „Senke" is the Easter Island High.

On attempting to state, what our picture and VON SCHUBERT's picture express in fact, they appear to agree much better than the first impression would suggest.

3.3 Periods, East and West

There is now adequate evidence for the hypothesis that the Southern Oscillation behaves like an almost free pendulum with a proper period of 2,33 years. It will be seen later how this period is lengthened apparently by solar control to a 2,56-year period in the region of the Southern Oscillation itself, the Indo-Pacific region. This period is what the writer, contrary to previous suggestions, would now be inclined to call the Indo-Pacific Period. A shortening by similar controlling factors apparently causes the North Atlantic Period of 2,22 years.

Now, there must always be some physical reason for the appearance of a prevailing particular period in a given area, since it may well be asked why it prevails over other derivatives of the same fundamental periods. When solar radiation fluctuations do cause a 2,56-year wave, derived from the 2,33-year basic wave to prevail in the Indo Pacific Ocean, we wish to know what factors direct this prevalence and prevalences in other parts of the world.

It is very difficult to prove, but if one of the present writer's earlier papers [15h] points to the truth, $5\frac{1}{2}$ months after a certain pressure deviation in the Icelandic Low a temperature deviation of the same sign arrives there with the East Greenland Current. This means a phase lag between pressure and temperature variations of the same sign and of the right order of magnitude to explain a 2,22-year cycle. The more so, because this oscillation might get some impetus from or also stimulate an average 4,45-year cycle which we found in the more or less aperiodic background of the Southern Oscillation. If this 4,45-year period is identical with the „arctic period" of 4–5 years, there may be one good reason more for the prevalence of a 2,22-year period in the North Atlantic. Finally, and this strengthens the case, theory led us to expect to find an oscillation of the nature of the southern one, if ever it occurred, between a relatively warm subpolar low pressure area and a relatively cold arctic high pressure area, in casu the Icelandic Low and the Arctic High. Very probably there *is* no North Atlantic Oscillation, there is only an Arctic Oscillation playing some sort of independent part beside the Southern Oscillation.

We are reminded here of the hypothesis which F. BAUR developed in his Einführung in die Grosswetterkunde p. 70 (sec. Ed. 1948).

„A positive anomaly of air pressure difference Leningrad-Stykkisholm in winter which is connected with a strengthening of the Gulf Stream drift, is followed generally by less ice in the Barents Sea in the next Apr–Jun. A smaller ice area in Apr–Jun produces, however, higher water temperatures in the Barents Sea. Consequently the transportation of surface water and ice from the polar basin towards the north- and east coast of Iceland is stimulated and this affects air pressure conditions in the northern Ice Sea. Therefore a negative anomaly of air pressure difference Leningrad-Stykkisholm follows after a certain lapse of time. This is connected with a weakening of the Gulf Stream drift and an accumulation of ice in the Barents Sea. This is followed by high pressure in the Barents Sea and later by a positive anomaly of the pressure gradient Leningrad-Stykkisholm. Herewith the original situation is restated. The whole cyclic process (the period of the proper oscillation) lasts about 4 years."

Hence, our final impression is that with the 2,33-year basic terrestrial Southern Oscillation and its derivatives, the 2,56-year Indo Pacific- and the 2,22-year North Atlantic Oscillation the scene is almost completely reviewed. The next paragraph will be devoted to following up more closely the relation between the variations in solar activity and the variations of the Southern Oscillation.

It is here the place to recapitulate from table 4 that, when the amplitude or the phase of a 2,33 year wave varies periodically, the period being 3 times the solar period, the resulting fluctuation will show a period almost exactly equal to the Indo-Pacific period. The same is true, of course, when the interfering period is BRÜCKNER's 35-year period. Through this interpretation another connection with the 7-year period may be traced.

So we have been feeling the Earth's pulse and have discovered its fundamental rhythm. The Earth's lifegiving bloodstream is solar radiation. The pulse's variability may be predictable as far as health and illness are, but every other variability will probably always remain as unpredictable as human emotions.

3.4 The Southern Oscillation and fluctuations of solar activity

When trying to obtain the essence of the extensive and rapidly increasing literature on the relations between solar activity and world weather we may feel safe with a 1951 report by C. E. P. BROOKS [30f] giving an excellent summary of some significant results achieved in this field. He presents his conclusions on these relations in the following prudent way.

a. Sunspots and pressure

1. The zonal component of the atmospheric circulation increases in strength (with sunspot numbers).
2. Pressure in regions where the pressure is normally high tends to increase, while in regions where it is abnormally low it tends to decrease. The areas with positive correlation include the quasi-permanent anticyclonic belts, probably the polar regions, the continents in winter and the oceans in summer.
3. In the tropics pressure tends to decrease in the region of Southern Asia, the East Indies and Australia, and to increase in America and the Eastern Pacific. It is probable that there is a natural oscillation between these two areas, and that the fall of pressure in the Asia–Australian region is the primary response to increased solar activity.

b. Sunspots and temperature

1. Temperature over the Earth as a whole is lowest at sunspot maxima and highest at sunspot minima.
2. 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.
3. The relation is best developed in the cloudy rainy regions of the tropics. In regions or seasons of little cloudiness and parts of middle and high latitudes furthest removed from the influence of warm oceans, there is no correlation nor even a small positive one between sunspot numbers and temperature.

c. Sunspots and precipitation

The distribution of precipitation at individual stations is too irregular for relation with sunspot numbers to be clearly determinable, but researches such as those of Sir GILBERT WALKER tend to show that the correlation is positive in the Indo-Australian region where correlation between sunspots and pressure is negative. Further, regions of positive correlation of sunspots and rainfall are almost exclusively regions of negative correlation of sunspots and temperature. On the whole positive correlations with rainfall predominate, and this bears out the contention of W. B. SCHOSTAKOWITSCH [1]) that the rainfall of the Earth as a whole has a positive correlation with sunspots. The rainfall effect is best shown in data which integrate the meteorological conditions over a large area such as the height of the Nile flood, levels of large lakes, or the average width of annual growth-rings in a large number of trees in dry situations.

Approaching the subject via the relationship between WALKER's three oscillations and solar activity, we note his sentence ,,The oscillations are not regarded as controlled by sunspot numbers, but as systematic swayings of interconnected world conditions which are slightly intensified or checked by solar conditions." (W W III)

The present writer concludes from this sentence that his own opinion is largely concurrent with WALKER's opinion. WALKER, however, after having stated that the Southern Oscillation is positively correlated with solar activity, makes certain reserves which find expression in the following:

,,The relationship of an increase in sunspots with a decrease in the general circulation in the North Atlantic and North Pacific Oceans is noteworthy, and warns us against over-confident inferences regarding solar activity." (W W V)

Against this H. C. WILLETT remarks [188b] rightly that WALKER ,,was disillusioned as to any reliable relationship between sunspots and atmospheric

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1) And A. THRAEN [167] (added by the writer).

circulation, because both his North Atlantic and North Pacific oscillations tend to correlate slightly negatively with sunspots, whereas each of these circulations measures essentially the intensity, respectively, of the Icelandic and Aleutian cyclonic centers in their normal positions. What WALKER apparently overlooks is that by his very definition of these oscillations, either an equatorward shift of the cyclonic activity, or a splitting of the centers, i.e., a tendency toward a normal winter low-index pattern, must decrease the oscillation and almost certainly more than offsets any increased cyclonic activity. Thus if there is any tendency for increased sunspots and lower-index patterns to appear together, the correlation between sunspots and these two oscillations should be negative, whereas increased cyclonic activity with sunspots should favor positive correlation."

„WALKER hoped to find negative correlation between pressure and sunspots in the tropics. He finds it only in the Indian Ocean, where it is quite significant at some points. On the Pacific (western hemisphere) the correlation tends to be positive. This means, as WALKER recognizes, that his Southern Oscillation is sufficiently related to sunspots to obscure any purely zonal fluctuation of the general circulation pattern. He found a correlation of only +0,26 between his Southern Oscillation and sunspots, but here again seasonal phase lag, or long-period cyclical effects probably weaken the correlation."

The general impression received from most previous efforts is that expectations went far too much towards a direct relationship between an index characterizing the intensity of the general circulation and the number of sunspots. If such a relation exists it will prove to be without any doubt quite insignificant when compared with the partial relation between sunspot numbers and air pressure, within the confines of the Southern Oscillation. WALKER's abovementioned coefficient of correlation +0,26 is even valid only in the season Jun–Aug. The average coefficient through all seasons is not greater than +0,18. This small coefficient applies to the general trend of the Southern Oscillation which – in Region I – we know to be the adoption of a mean level of air pressure above normal about sunspot minimum and a mean level below normal about sunspot maximum.

The main point in the relationship between the Southern Oscillation and the fluctuations of solar activity is not a correlation between the numbers of sunspots and the intensity of the general circulation in the Indo-Pacific region, although a weak parallelism of this kind exists. It is the controlling influence which sunspots appear to have on the period and phase of this oscillation. The problem in which way this steering influence operates should be tackled by investigating how air pressure at a number of stations changes from one sunspot maximum to the next or from one sunspot minimum to the next, and whether a definite course of air pressure within each solar cycle emerges.

The problem was recognized in this sense by C. BRAAK [26f], E. KIDSON [90b] and E. T. QUAYLE [124a, c]. The latter, with remarkable insight, was inclined „to conclude that the increasing solar activity is such as to cause a sort of forced oscillation, after which terrestrial influences become manifest in a three-year period". H. W. CLOUGH even narrowed rightly down the puzzling relation by stating that „an 11-year variation occurs in the length of the 28-month period in terrestrial temperatures with long and short intervals about four years after the WOLFER epochs of minima and maxima respectively" [40b, c]. BAUR's promising results are discussed in a paper published by R. SCHERHAG [145c], a paper which at this point deserves serious attention.

SCHERHAG pointed out „by the aid of recent material that there are relations between the eleven years' period of sunspots and the fluctuations of the general circulation; that, however, the phases of these relations are not constant. With regard to atmospheric pressure, such leaps in the phases occurred about 1897, 1853 and 1820, thus confirming the leaps in phases found by comparing the severity of the winters with sunspot numbers by means of the Berlin temperature records. When considering long-year records the phases suggest a double oscillation of the meteorological elements during one eleven years' sunspot period, but by using periods characterized by equal phases a clear relation is pointed out between the sunspot period and the general pressure distribution on the earth."

TABLE 27. *Average air pressure deviations in one 11-year sunspot period (mb)*

	Southern high pressure belt (Capetown+Adelaide) after BAUR	Tropics and subtropics (Lisbon, Djakarta, Capetown, Adelaide)		
	1865–1940	1853–1940	1853–1896	1897–1940
2 years after max.	+**0,20**	—0,15	—0,18	+0,03
3 years before min.	—0,21	—0,10	—0,14	+0,04
2 years before min.	+**0,28**	—0,03	—0,08	+**0,05**
1 year before min.	+0,17	+**0,08**	+0,07	+0,01
minimum year	—0,23	+0,05	+0,13	—0,08
1 year after min.	+0,16	+0,09	+0,08	+0,01
2 year after min.	+**0,26**	+**0,20**	+**0,22**	—0,02
2 years before max.	+0,06	+0,11	+0,12	—0,01
1 year before max.	—0,22	—0,11	—0,05	—0,06
maximum year	—0,41	—0,15	—0,12	—0,03
1 year after max.	—0,06	—0,15	—0,18	+0,03

In table 27 SCHERHAG summarizes BAUR's results in the first column and his own results in the second, third and fourth column. We take special notice of these results here for different reasons. Firstly SCHERHAG was far too much under the suggestion that the mean of air pressure deviations taken from Lisbon, Djakarta, Capetown and Adelaide has greater weight than the air pressure deviation of Djakarta proper. We have so far found evidence that representative general circulation fluctuations are obtained from the average of air pressure deviations of at most Bombay, Djakarta, Darwin. We might have added Capetown, but certainly must distrust Adelaide and Lisbon, although both stations are in Region I.

The writer's impression is that especially Lisbon should not have been included and largely disturbs the fundamental course of the fluctuation. This fluctuation is indicated far more precisely by Djakarta, or even by Capetown and Adelaide, as is clearly shown by the summary of BAUR's analyses covering 75 years. One solar period involves at least 3 clear maxima and 3 clear minima of the Southern Oscillation, while the lowest depression is centered on the year of maximum sunspot number. The amplitude of the oscillation deduced by BAUR is also plainly larger than the amplitudes of the oscillations deduced by SCHERHAG. The writer is not opposed to SCHERHAG's conclusion that the average pressure deviation of Lisbon, Djakarta, Capetown and Adelaide presents an eleven year solar period, the phase of which may have shifted notably about 1896. Moreover he agrees with SCHERHAG's remark that „in the interval 1897–1940 the phase was reversed, the fluctuations being, however, so much smaller that this result cannot be considered as proving much". What he wishes to deny is that the first of the last 3 columns suggests the existence, as is stated by SCHERHAG, of a *double* oscillation in eleven years, established in consequence of the superposition of 2 eleven year waves which are out of phase. The positive top values in the first column are, for instance, successively 3 and 8 years apart. They result simply from the fundamental approximate 3-year wave which is camouflaged in both the second and third column more than in the first by the very unsatisfactory inclusion of Lisbon in the value of the quantity considered.

An eleven-year wave in air pressure is since long known to be present, in as much as air pressure in Region I is raised about a sunspot minimum and depressed about a sunspot maximum. Superimposed on this oscillation is the Southern Oscillation proper. We only need to cast a glance at fig. 26 in order to be convinced of this simple relation. The reason for the easy eclipsing of the 2-3 year wave in the average pulse of air pressure in the eleven years enumerated in the second column of table 25 is, that the smoothing used comes to a deadlock. While fig. 26 shows how many times the amplitude of the Southern Oscillation wave, even at the equatorial stations, surpasses 0,5 mb whereas it surpasses perhaps as many times the 1 mb at the subtropic stations, it is disappointing to find +0,20 and —0,15 mb as extremes in the average fluctuation given by SCHERHAG from 1853–1940.

The probable solution of this puzzling solar-terrestrial relationship, as the writer sees it, was published by him in 1947 [15i] and elaborated in a couple of papers presented by him at international geophysical meetings [15j, k, l] The fundamentality of the Southern Oscillation and its most adequate expression in Djakarta air pressure fluctuations induced him to try to find out by the method of trial and error how the air pressure deviations at Djakarta are controlled by the number of sunspots present.

The material to which this method could be applied was not restricted to air pressure deviations. Air pressure deviations at Djakarta are strongly correlated with dry and wet east monsoons in Java. Years of high pressure throughout, and years in the course of which pressure rises from below normal to above normal, develop almost exclusively east monsoons drier than normal. In years of low pressure throughout and in years of pressure fall the reverse is mostly the case. In some years the relation is less close. In 1880, for instance, air pressure was rapidly rising. The east monsoon of this year should have been dry in Java. However, a serious drought occurred in 1881 when air pressure was already rapidly declining. On the other hand the year 1935, for instance, with an extremely dry east monsoon, does not rank among the outstanding high pressure years in the Djakarta records. Yet it is safe to say that the series of east monsoons drier than normal is nearly equivalent to the series of high pressure years.

The great advantage of passing from the series of high pressure years to the series of very dry east monsoons in Java, is of course that the character of the monsoon is known historically over a longer period than barometric pressure in Region I. The air pressure curve of Darwin ranks back to 1883, that of Djakarta to 1866, that of Bombay to 1847, that of Madras to 1841, but the seasalt production on the isle of Madura near Java, which is a very sensitive indicator of drought and precipitation, as well as some administration reports from Java estates, compiled by W. VAN BEMMELEN [13], allow us to draw up the following complete series of east monsoons drier than normal, from 1830 onward.

1833, 1835, 1838, 1841, 1844, 1845, 1850, 1853, 1855, 1857, 1864, 1873, 1875, 1877, 1881, 1883, 1884, 1885, 1888, 1891, 1896, 1902, 1905, 1913, 1914, 1918, 1919, 1923, 1925, 1926, 1929, 1932, 1935, 1940, 1941, 1944, 1945, 1946, 1953.

This then is a series of years representative of the precipitation deviations. Air pressure deviations must have preference as far as they are known, and there is every reason to change 1881 into 1880, to delete 1844 and 1926, and to add 1843, 1866, 1868, 1899, 1911, 1930 and 1951, since these latter years were plain high pressure years. Air pressure is the primary variable, precipitation a secondary one, and it is easy to imagine circumstances which made droughts fail in high pressure years.

After these changes and additions the series which, for identification purposes, will henceforth be called *the* series of high pressure years in Region I may be considered as really complete through 125 years. Having arrived at this series is a very useful achievement. The series is listed below.

1833, 1835, 1838, 1841, 1843, 1845, 1850, 1853, 1855, 1857, 1864, 1866, 1868, 1873, 1875, 1877, 1880, 1883, 1884, 1885, 1888, 1891, 1896, 1899, 1902, 1905, 1911, 1913, 1914, 1918, 1919, 1923, 1925, 1929, 1930, 1932, 1935, 1940, 1941, 1944, 1945, 1946, 1951, 1953.

The mean interval between two high pressure years is 2,79 years. It seems more than a random coincidence that this is very near the period of 2,75 years, found by SCHOSTAKOWITSCH throughout the world (table 1). The frequency of different intervals is given in table 28.

TABLE 28. *Intervals in years between high pressure years in Region I*

Years	1	2	3	4	5	6	7
Number	8	13	13	3	5	1	1

It is difficult to distinguish between the cases of intervals of 1 year and the cases where the wave crest reaching over more than 1 year is simply one and the same, and a zero interval should have been assumed. If this aspect is taken seriously, and the waves coupling 1883–1884–1885, 1913–1914, 1918–1919, 1929–1930, 1940–1941, 1944–1945–1946 are assumed to be single ones, the total number of waves found in the course of the 121 years which are covered by the above series, is reduced to 36. The average wavelength in this case proves to be 3,33 years. When the two cases in which 3 consecutive years were highpressure years, are assumed to represent not one but two waves, which is equally probable, the total number of waves is 38 and the average wavelength 3,16 years. As is clearly to be seen, we here return along the first way to the apparent mean period which was found equal to 3,36 years as the result of harmonic analysis by different investigators in Europe and Indonesia and equal to 3,32 years by BERLAGE from measurements of tree rings in Indonesia, while a return along the second way leads more nearly to the 3,08 year period found by BRUNT in Europe.

Now, the series of high pressure years finally adopted is remarkably well defined by the 5 rules presently to be formulated. They are the rules published earlier [15i], but slightly revised in accordance with experience gained during the current unusually quick increase of sunspot numbers puzzling to every worker in solar research. The main point in these rules is that they are entirely based on the mean yearly sunspot numbers taken from the famous Zurich list, which opens in 1749 and which is the only reliable source of figures on solar activity for a sufficient length of time. It will further be remarked that the selection of high pressure years follows every solar cycle from one sunspot minimum to the next. This procedure is in accord with the astronomers' view that every solar cycle from sunspot minimum through maximum to minimum has its unique character, much like – for instance – geyser eruptions.

Rule 1. The first high pressure year after a sunspot minimum year occurs whenever the sunspot number surpasses 20. It follows 3 years after the previous high pressure year, if the sunspot number 20 has not yet been reached.

Rule 2. The second high pressure year follows 3, 4, 5 or 6 years later. It follows 3 years later if the sunspot number has not, or not yet, reached 81, or when the sunspot number in the previous high pressure year was already greater than 50. It follows 4, 5 or 6 years later, when the sunspot maximum has passed and the sunspot number has decreased below 81.

Rule 3. The third high pressure year follows 2 or 3 years later, 2 years later when the sunspot number has decreased below 54, 3 years later when the sunspot number has not yet decreased below 54.

Rule 4. The fourth high pressure year follows 2 or 3 years later, 2 years later when the sunspot number has decreased below 13, 3 years later when the sunspot number has not yet decreased below 13.

Rule 5. The fifth high pressure year occurs 3 years later if the interval with the next high pressure year defined by Rule 1 is greater than 3 years.

The fundamental pressure swing is apparently not interrupted, but only depressed in years of many sunspots. Hence secondary pressure maxima may appear during these intervals according to

Rule 6. A secondary air pressure maximum is developed between the high pressure years defined by Rule 2 and Rule 3, if the interval between these two years is 5 or 6 years.

Fig. 30 illustrates the contents of these 6 rules in the form of a virtual reconstruction of Djakarta air pressure curve from sunspot numbers in the two different cases which are distinguished. The two sequences of intervals have, however, been chosen quite arbitrarily and should not be regarded as representative in details, that is, occurring frequently in these particular forms.

Now let us, with the aid of the first 5 rules mentioned, review the series of high pressure years which have or should have occurred since the end of the 18th century in Region I. If the year 1799 is the first instance, we obtain

Rule 1: **1799**, 1813, 1824, **1835, 1845, 1857, 1868, 1880**, **1891**, **1902, 1914, 1925, 1935**, 1945, 1955 (compare Rule 4).

Rule 2: 1802, 1816, **1827, 1838, 1850,** 1861, **1873, 1883,** 1894, **1905, 1918+ 1919**, 1928, **1940, 1951.** The years 1918 and 1919 are both taken as the case is dubious.

Rule 3: 1804, **1818, 1830, 1841, 1853,** 1863, **1875, 1885, 1896,** 1908, 1921, **1930**, 1942, **1953.**

Rule 4: 1807, 1821, **1833, 1843, 1855, 1866, 1877, 1888, 1899, 1911, 1923,** 1932, **1944**, 1955.

Rule 5: 1810. There is only one example, which is introduced between 1807 and 1813 in consequence of the successive occurrence of two exceptionally long intervals between the sunspot minima of 1798, 1810 and 1823.

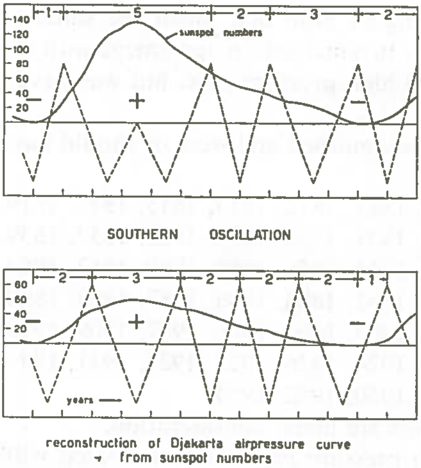


FIG. 30. Two ways in which annual sunspot numbers apparently steer the Southern Oscillation.

The years which are known to have been high pressure years are printed heavy As far back as 1830 these are the years listed previously. We are however in a position to check the character of years before 1830 in Java reasonably well by means of the measurement of the width of the year rings of teak wood, almost the only tropical timber species standing leafless in the dry season (15e). The years 1799, 1818 and 1827 are thereby known to have produced extremely small annual rings, that is, a width of less than 70 percent of the average. For this reason the underlining of these 3 years was thought to be permissable.

The significance is that the dry seasons of these years were extremely dry in Java and the following wet season, the season in which the wood grew, late and consequently very short. The proof should, however, be handled with great care and not be reversed. The extremely dry eastmonsoon of 1891, for instance, was not followed by small tree rings. On the other hand the extremely small tree rings which were observed in 1848 seem to solve a difficulty which existed because 1848 was always considered throughout wet in Java as the seasalt production of that year was very small and because the year was a sunspot maximum year. Actually Madras air pressure remained below normal in 1848, Bombay air pressure, however, was well above normal in the second part of the year. The solution of the discrepancy is probably the following. 1848 was a year of dubious character associated with one of the secondary pressure maxima defined by Rule 6. According to this rule we obtain low tops of air pressure in 1847–1848, 1859, 1870–1871, 1937–1938, 1948–1949. As regards this latter instance, it is interesting to note that much the same as happened in 1848 happened again in 1948. It remained, in agreement with the occurrence of many sunspots, a secondary high pressure year, but was nevertheless very dry in Java.

The years which have so far not been distinguished and were or should have been low pressure years in Region I are
1800, 1801, 1803, 1805, 1806, 1808, 1809, 1811, 1812, 1814, 1815, 1817, 1819, 1820, 1822, 1823, 1825, 1826, 1828, 1829, 1831, 1832, 1834, 1836, 1837, 1839, 1840, 1842, 1844, 1846, 1849, 1851, 1852, 1854, 1856, 1858, 1860, 1862, **1864**, 1865, 1867, 1869, 1872, 1874, 1876, 1878, 1881, **1884**, 1886, 1887, 1889, 1890, 1892, 1893, 1895, 1897, 1898, 1900, 1901, 1903, 1904, 1906, 1907, 1909, 1910, 1912, **1913**, 1915, 1916, 1917, 1920, 1922, 1924, 1926, 1927, **1929**, 1931, 1933, 1934, 1936, 1939, **1941**, 1943, **1946**, 1947, 1950, 1952, 1954.

Their total number is 88 of the 155 which are under consideration.

Those years which were definitely high pressure years and associated with very dry eastmonsoons in Java, thereby violating the rules given so far, have been printed heavy.

It is at this point particularly that the feeling will arise that the 7-year period cannot be left out of the picture. 1864, 1884, 1946 are recognized as Peru rain years, and since in most instances these years are among the high pressure years in the Southern Oscillation the question now obtrudes itself as to what exactly are the relations between the 7-year cycle and the 2–3 year cycle on the one hand, and the solar cycle on the other.

The writer's impression is that the way in which solar activity controls the 7-year cycle is to be formulated according to the following rule.

Rule 7. A year in which the sunspot number drops below 13 (compare Rule 4) may become a high pressure year after which a sequence of high pressure years at 7-year intervals is to follow. If one of these high pressure years is preceded or followed by a year in which the sunspot number drops below 13 this latter year takes over the leading role from the former and becomes the first of a new sequence.

If 1807, a year in which the number of sunspots dropped below 13, is adopted as the starting-point, we obtain the following series of El Niño years:
1807, **1814**, 1821, **1828**, 1835, 1842+1843, 1850, 1857, **1864**, **1871**, **1877+1878**, **1884**, **1891**, **1898**, 1905, 1911+1912, 1918, **1925**, **1932**, **1939**, **1946**, **1953+1954**.

The years in which the El Niño phenomenon was in fact well developed are printed heavy. That these years are all covered by Rule 7, notwithstanding the irregularities which have puzzled every student of the subject (see 1.4) is a confirmation not only of this rule, but also of the status of 1807 in the present relation.

Eguigúren, who studied the rainfall of Piura [50], gives also the following list of years in which moderate rain fell in Piura between 1800 and 1894: 1803, 1817, 1819, 1821, 1824, 1832, 1837, 1844, 1846, 1850, 1852, 1854, 1857, 1862, 1868, 1880, 1887, 1888.

To continue this list up to 1930 Schott [148] adds 1918, 1921, 1926. Among these years are 1821, 1850, 1857 and 1918, four years which confirm the above series of El Niño years. The other years may well be simply regarded as intermediate Southern Oscillation years, which have had much less serious repercussions in the weather along the Peru coast.

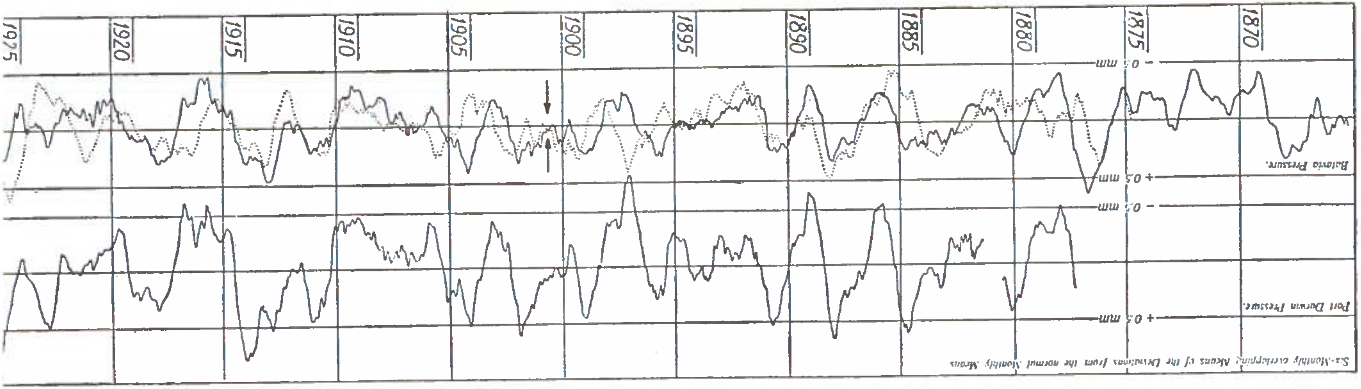
The 18th century famous 7 year recurrence of the El Niño years probably started in 1721 and follows below:
1720+1721, **1728**, 1735, 1742, 1749, 1756, **1763**, **1770**, 1777, 1784, **1791**, 1797+1798, **1804**.

The reason why 1721 is supposed to be the year in which this apparently extraordinarily regular sequence of El Niño years was inaugurated – it cannot be strictly verified – is the following. Since 1750 was a sunspot maximum year, previous maximum years cannot have differed significantly from 1717, 1728, 1739. The year 1721 therefore stands a good chance of having experienced the required drop of its mean sunspot number below 13. On the other hand, if the oldest Peru records are reliable 1720 was an El Niño year and if so, 1721 must have taken over the „lead" from 1720.

The year 1797 evidently took over the „lead" from 1798. The only, and most serious, irregularity in the whole sequence should however be pointed out at once. The year 1811 was to follow in the latter series. However, it appears from the former series that 1807 took over the leading role from 1804. We need, however, not be troubled too much by this abnormality. It apparently occurred at about the same time when, according to Rule 5, one exceptional high pressure year in the shorter cycle was introduced, namely 1810. Two things went „wrong" together when the solar cycle was abnormally stretched. Besides this it is certainly not by chance, but in the line of our argumentation that exactly 3 years elapsed between 1804 and 1807.

Needless to stress that the number of hypotheses „ad hoc" made to elucidate this very complicated matter could thus be reduced to a quite acceptable minimum. This in favourable contrast with the analysis given by Scherhag who assumes no less than 3 leaps of phases. These would have occurred about 1820, 1853 and 1897.

The writer is inclined to raise the question, whether it is by mere chance or whether it is by some natural regulation that Scherhag's „leap-years" occur roughly halfway between the years of adjustment between the 7-year cycle and the solar cycle adopted here, e.g. 1804–1807, 1842–1843, 1877–1878, 1911–1912. On the other hand he wishes to avail himself of this opportunity to cast doubt upon most of those „leaps" or „Klimaverwerfungen" which have



G. 31. Darwin air pressure curve and Djakarta (Batavia) air pressure curve with its principal point of symmetry at 1901.6.

cropped up in meteorological literature (Schmauss [146], Groissmayr [68o]), but rarely allow any kind of reality to be attached to them, if not in the sense of long term symmetry points, such as the one which occurred in 1901 and which is so remarkable in the Djakarta air pressure curve [15c]. It is reproduced in fig. 31, and may confirm with similar arguments (Visser [175b]), that indeed a certain milestone was passed at the last turn of the century.

Let us now add the rule, already stated in earlier publications, which seems to regulate the relation between the 7-year and the 2–3 year cycle.

Rule 8. A high pressure year of the 7-year cycle which is preceded and followed by a high pressure of the 2–3 year cycle remains a high pressure year. If a high pressure year of the longer cycle is preceded or followed by a high pressure year of the shorter cycle they are combined into one and it is the later year which becomes the high pressure year.

This rule poses 1884 as a high pressure year between the high pressure years 1883 and 1885 and poses 1814, 1828, 1864 and 1946 as high pressure years instead of 1813, 1827, 1863 and 1945.

Summarizing results we now indicate as high pressure years according to

Rule 8 **1884**

Rule 1 **1799, 1814, 1824, 1835, 1845, 1857, 1868, 1880, 1891, 1902, 1914, 1925, 1935, 1946,** 1955

Rule 2 1802, 1816, 1828, **1838, 1850,** 1861, **1873, 1883,** 1894, **1905, 1918+1919,** 1928, **1940, 1951**

Rule 3 1804, **1818, 1830, 1841, 1853, 1864, 1875, 1885, 1896,** 1908, 1921, **1930,** 1942, **1953**

Rule 4 **1807, 1821, 1833, 1843, 1855, 1866, 1877, 1888, 1899, 1911, 1923,** 1932, **1944,** 1955

Rule 5 **1810**

Rule 6 Low tops in 1847–1848, 1859, 1870–1871, 1937–1938, 1948–1949.

The known high pressure years previously given have been printed heavy, and now also 1807, 1810, 1814, 1821 and 1824, since there seems to be no reason to doubt that they conformed to the rules.

At this point, it is useful to look at a graph (fig. 32) in which are plotted together the successive half-yearly anomalies of air pressure (Apr–Sep, Oct–Mar) at Djakarta and the theoretical reconstruction of Djakarta air pressure curve following the rules given. The agreement between both curves is appealing to the eye. The coefficient of correlation between the 180 half-yearly air pressure values and the corresponding values read from the theoretical trace is, in fact, not greater than 0,46.

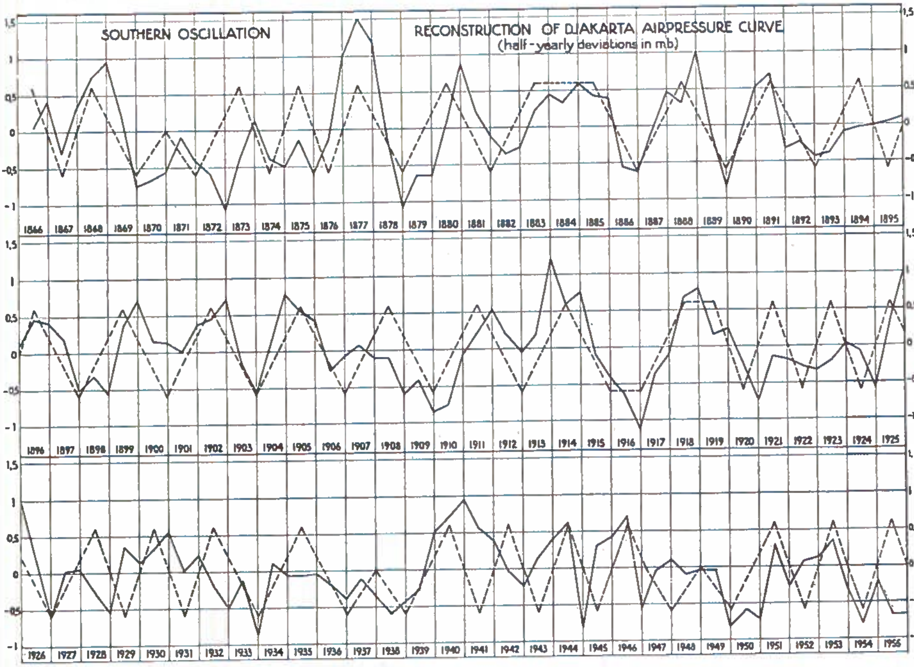


FIG. 32. An attempt to reconstruct Djakarta (Batavia) air pressure curve from annual sunspot numbers.

In order to obtain reliable information about the statistical significance of this result, we do well to compare our theoretical curve, which is built on 5 rules, with a curve representing a mathematical expression containing $m = 4$ independent parameters. Let x_i be the n computed values and y_i be the n empirical values which we suppose to be related, then, according to BROOKS and CARRUTHERS [31] the „goodness of fit" between the mathematical expression and the observational series is adequately represented by a multiple correlation coefficient R, whose definition is

$$R^2 = 1 - \sum_1^n (x_i - y_i)^2 \Big/ \sum_1^n (x_i - \bar{x}_i)^2$$

Now, if s_x^2 = variance of the n values x_i

s_y^2 = variance of the n values y_i

$k = s_y : s_x$

and if x_i and y_i are both reduced to zero, then

$$R^2 = (2r - k)\ k$$

while

$$r = \sum_1^n x_i y_i \Big/ \sqrt{\sum_1^n x_i^2 \, . \, \sum_1^n y_i^2}$$

is the usual coefficient of correlation between the variables x_i and y_i.

TABLE 29

n	$m = 4$ $R \geqslant$	$k = 1$	$r \geqslant$ 0,9	0,8
100	0,300	0,55	0,50	0,46
150	0,247	0,53	0,48	0,44
200	0,215	0,52	0,47	0,43
300	0,176	0,52	0,47	0,42
400	0,153	0,51	0,46	0,41
500	0,137	0,51	0,46	0,41

Table 29 contains, for $m = 4$, the value of R which is significant above the 5 per cent level and the corresponding value of the correlation coefficient r in function of k.

Since the choice of the „amplitude" of this theoretical curve is free we *may* choose a value $k = 1$. In this case r is to be greater than 0,5. It proves directly that statistically significant results in the way pursued here are difficult to achieve. The requirements are, however, slightly less severe, because the variance of the actually observed air pressure values will normally be slightly greater than the variance of computed values, when the point of best agreement is reached. Since $r = 0{,}46$, the value which was empirically found with $n = 180$, appears in the columns $k = 0{,}9$ and 0,8, it may therefore be concluded that the theoretical approximation of Djakarta air pressure fluctuations in the proposed manner just reaches the threshold of statistical significance.

Although this certainly is no spectacular start, there is no reason to consider our first results as illusory. Every possible improvement of the interpretation of the Southern Oscillation on the basis once adopted, though perhaps not to be comprised in one formula, would mean at least raising this interpretation above the lowest level of significance. Recognizing this, let us consider, how the most important remaining inconsistencies might be understood.

Returning to the summary of results given on p. 99, we notice the apparent failure of the years 1802, 1804, 1816, 1828, 1861, 1894, 1908, 1921, 1928, 1932, 1942, 1955 to develop into normal high pressure years in Region I. Now, it strikes us immediately that the years 1802–1804, 1816, 1828, 1861, 1894, 1908, 1928, 1955 all fall into one group of years, whose upward pressure trend may well have been hampered by relatively intense or specific solar activity at or about the nearest sunspot maximum. There is even every reason to include 1921 in this group, because solar activity must have been quite abnormal in 1921.

It figures among the four years which are historically known for the appearance of polar lights in the far eastern tropics. These four years are 1859, 1872, 1909, 1921 [194].

The probable correctness of this simple interpretation of a large number of apparent inconsistencies is strongly supported by the abnormal depression 1872–1873, which, although almost as impressive as the depression 1916–1917, escaped our attention only because the year 1873 brought Java actually a dry east monsoon and was therefore counted as a high pressure year conforming to rule 2. It is certainly one of the dubious cases, the difference between 1872 and 1916 being, of course simply that in the first instance the sunspot maximum had just passed, whereas in the second instance the sunspot maximum was just to come.

The years which remain „unaccounted for" in this way are now only two, 1932 and 1942. They definitely should have developed into high pressure years, but for some reason or other have *not*. On the other hand four famous high pressure years which were also very dry in Java, namely 1827, 1913, 1929 and 1941 are not indicated by the rules given. A return to this point will be made in 3.5.

If our interpretation is right the effective mean period of the Southern Oscillation in the Indo-Pacific region is 2,56 years. In fact we count 81 primary and secondary air pressure maxima in the full 207 years (1749–1955) of the Zurich data. In the later part of this total series of years, the period of Djakarta regular observations, the count is 35 waves in 90 years. This means an average actual period of the Southern Oscillation of 2,57 years, proving its secular constancy. Our final conception thereby is that the fundamental Southern Oscillation wavelength of 28 months is distorted to an average wavelength of 31 months in the Indo-Pacific region. A very interesting conclusion giving us al the more confidence in this conception is, as follows from 2.2, that the actual waves are of the length which agrees with least damping. The damping ratio reaches a value of 0,9 in this case.

Looking at the matter from the „ideal" side it is as if a series of waves

2 2 3   2 2 3   2 2 3   2 2 3   etc.

which shows a 7-year rhythm, is roughly managed by successive sunspot minima in the one or the other of the following two ways

2 2 3 2 2 | 3 2 2 3 | 2 2 3 2 2 | 3 2 2 3 | 2 2 3 2 2 ......
2 2 3 2 2 | 3 2 2 3 2 | 2 3 2 2 3 | 2 2 3 2 2 | 3 2 2 3 2 ......

If the first case were the rule, two solar cycles would encompass three 7-year cycles, in the second case three solar cycles encompass five 7-year cycles. Both cases occur, whereas 4 or 5 air pressure waves of the shorter cycle are caught within one solar cycle. One would almost hesitate to separate the 7-year cycle from the Southern Oscillation, and feel inclined to ask, if the Southern Oscillation will not reveal itself by and by the finest example of a terrestrial cycle controlled by the solar cycle.

If we try to put this relation in a summarized form, we find the following. When the number of sunspots increases (decreases)

then primarily

(1) the mean air pressure level in the Malay Low decreases (increases)

(2) the mean air pressure level in the Easter Island High decreases (increases) much more

and consequently

(3) the pressure gradient between both regions decreases (increases)

(4) the length of the pressure waves increases (decreases)

(5) the amplitude of the pressure wave decreases (increases).

This would mean that in the Malay Low and the Easter Island High, perhaps even through the whole tropical and subtropical zone of the Pacific Ocean air pressure is low during great solar activity and high during weak solar activity. This agrees with the well-known general tendency towards low pressure in low latitudes and high pressure in high latitudes during great solar activity and vice versa [30f].

That air pressure in the Easter Island High in this case is much more affected than air pressure in the Malay Low does not constitute a real contradiction, since the Southern Oscillation shows the same inherent feature; e.g. Juan Fernandez air pressure fluctuations show an amplitude which is double the amplitude of the Darwin or Kupang air pressure fluctuations. These again are superior to the Djakarta and Bombay fluctuations.

As was first suggested by Sir Gilbert Walker [180 j], supported by H. H. Clayton [39b] and others and finally worked out by B. Haurwitz [71a, b], the consequence of fluctuations in solar activity is probably as follows. Increased eruptive action on the sun increases primarily air temperature in the tropical and subtropical belt relative to air temperature in the moderate and high latitudes. Upper air then moves convectively from lower to higher latitudes. In the equatorial belt, however, increased convective cloudiness and precipitation lowers air temperature in the lower air layers. This would explain the well-known paradoxical drop in temperature at tropical stations during periods of great solar activity, pointed out by W. Köppen [95a] as early as 1873.

If the writer may repeat here a suggestion, this secondary compensation of primary deviations of temperature in the tropics might explain also, why in a cloudless and dry subtropical area such as the Easter Island High the amplitude of the Southern Oscillation is highest, why it is smaller in Darwin and Kupang, places in a monsoon region experiencing still one very dry season and still smaller in Djakarta (Batavia) and Bombay, which are more typically tropical and cloudier and wet throughout the year.

3.5 Other influences, irregularities

In 3.4 the conclusion was reached that 1932 and 1942 are years which failed to develop into high pressure years in Region I, while 1827, 1913, 1929 and 1941 have become high pressure years against the rules.

Now, let us note well that it was Rule 8 which changed the high pressure year 1827, already indicated by Rule 2, into 1828, the latter year being the El Niño year. Besides this the extremely small width of the tree rings due to tree growth in the wet season 1827–1828 in Java was adopted as an indicator of the 1827 drought. It looks very much as if an uncommonly early drought in 1828 made the wet season so very short in this case. There is no reason for the assumption of a serious exception. Moreover there are similar instances in the 20th century. In two other cases, 1913 and 1929, high pressure and extremely dry years precede by some unknown cause, the apparently „regular" high pressure and extremely dry years 1914 and 1930. In fact the only years after 1848 showing tree rings smaller than 70 percent of the average width are 1913, 1914, 1925 and 1929. If 1827 had been simply a year like 1913 or 1929 the mystery would be cleared up.

As regards 1913 there is also the rather strong possibility that the curious air pressure top in that year is to be explained by the dust in the upper air which is known to have depleted solar radiation over the world by 10 per cent approximately for a long time after the Katmai eruption in 1912 (see 3.6). More likely therefore is a comparison between 1827 and 1929 although this comparison does not yield any solution of the problem why these years behaved exceptionally.

Dividing up the entire available series of 90 years into 10-year parts, then for the coefficients of correlation in each of these parts the following are obtained.

1866–1875	+0,25	1916–1925	+0,51
1876–1885	+0,58	1926–1935	+0,11
1886–1895	+0,57	1936–1945	+0,25
1896–1905	+0,51	1946–1955	+0,35
1906–1915	+0,42		

Working backward with the same air pressure values for Bombay, where observations were started in 1847, we may add

1847–1856	+0,63
1857–1866	+0,38

This table shows that the relation whose reality is supported here is persistent in a promising way. Ony one decade, 1926–1935, drops far below expectations. In two other decades, 1866–1875 and 1936–1945 correlations are also disappointing. A closer inspection of both curves of fig. 32 reveals that in the latter two decades there is one year in particular which behaves decidedly abnormally, namely 1872 in the first case and 1941 in the second case. We found arguments for the solar conditioned depression of 1872. The most fatal dissimilarity therefore exists in relatively recent years. Apart from 1928 which, as already noted, may have been sticking to low pressure instead of ascending to high pressure in the same way as 1861, 1872, 1894 and 1908 apparently did, it is in 1929, 1930, 1931, 1932 and again in 1941 that we are mostly dissatisfied.

There is, however, some information available which may indicate certain actual reasons for this failure. In 1930 and 1931 the hydrospheric circulation through large portions of the South Pacific Ocean was truly abnormal and 1941 appears to have been one of those exceptional years in which the El Niño phenomenon occurred along the Peru coast, although in discordance with the 7-year scheme (Mears [102]). A second abnormal El Niño year was, if the old records are sufficiently reliable, 1747 (Frylink [58]).

Of course all problems of world weather present the difficulty that a great number of unpredictable influences disturb the normal sequence of events. There is on the longer periodic side the irregular fluctuation of air pressure between Region I and Region II pointed out in 2.4. On the shorter periodic side there is what is understood by the random „noise". Accumulations of small perturbations may eventually lead to attaining certain threshold values and those unstable situations from which large deviations in the general circulation from which large deviations in the general circulation from normal conditions may derive. The El Niño phenomenon itself is probably one of these occasional happenings. The abnormal behaviour of the general circulation in the South Pacific Ocean to a much greater extent in 1930 and 1931 will perhaps in time come to be explained in the same sense.

Finally, as has been shown, the Indo-Pacific general circulation is no closed mechanical system. It has its branches spreading out towards different sides. It is linked with other circulations, the major one being the North Atlantic circulation. Von Schubert's [150] world picture of isoamplitudes of the famous train of 3-year waves of air pressure 1896–1905, reproduced on p. 35, is illuminating in this respect. It shows two extremely active northern areas, the one in the North Atlantic (amplitude in centre = 1,01 mm) and the other in Russia (amplitude in centre = 1,09 mm). How shall we distinguish in many cases between cause and effect? Is not the remarkably low pressure at Djakarta in 1921, when a high pressure year was due according to the rules, perhaps caused simply by the very high air pressure in Europe which persisted through 1921 after having already reigned over Europe in 1920? Analogy points to a possible explanation of the abnormal 1941 high pressure in Region I by the persistence of abnormally low pressure from 1940 through 1941 in Europe. Effects of this kind may well be due to the „feeding back" of the North Atlantic Oscillation on the Southern Oscillation, including a distortion of our oversimplified scheme.

Finally the writer approached this matter also from the complementary point of view, which is testing other possibilities. Table 30 contains the departures of the yearly mean air pressure values from normal recorded at the four famous alpine mountain stations, Säntis, Obir, Zugspitze and Sonnblick, mentioned earlier. It contains also the average of the available local values; between 1880 and 1950.

TABLE 30. *Annual air pressure deviations from normal at alpine stations in mm*

	Säntis	Obir	Zugspitze	Sonnblick	Mean
1880		+0,13			+0,13
81		—0,53			—0,53
82		+0,50			+0,50
83	—0,12	—0,42			—0,27
84	+0,39	+1,06			+0,72
85	—0,57	—0,26			—0,42
86	—0,94	—0,43			—0,69
87	—0,30	—0,16		—0,31	—0,29
88	+0,06	—0,20		—0,84	—0,33
89	—0,33	—1,48		—0,97	—0,93
1890	+0,04	—0,17		—0,42	—0,18
91	+0,53	+0,49		+0,14	+0,39
92	—0,18	—0,29		—0,49	—0,32
93	+0,86	+0,40		—0,02	+0,41
94	+0,78	+0,81		+0,01	+0,53
95	—0,83	—1,04		—1,62	—1,16
96	+0,44	+0,38		—0,43	+0,13
97	+1,10	+0,90		+0,40	+0,80
98	+1,36	+1,35		+0,72	+1,14
99	+1,41	+1,07		+0,83	+0,77
1900	+0,09	+0,54		—0,52	—0,09
01	—0,36	—0,34	—0,98	—1,23	—0,73
02	+0,12	—0,21	—0,27	—0,56	—0,23
03	+0,67	+0,74	+0,20	+0,04	+0,41
04	+0,90	+1,07	+0,33	+0,28	+0,64
05	+0,43	+0,88	—0,20	—0,22	+0,22
06	+0,34	+0,62	—0,35	—0,20	+0,10
07	+0,63	+0,82	—0,17	+0,17	+0,36
08	+1,14	+1,28	+0,43	+0,74	+0,90
09	—0,65	—1,27	—1,30	—0,90	—1,03

TABLE 30. *(continued)*

	Säntis	Obir	Zugspitze	Sonnblick	Mean
1910	—0,80	—1,22	—1,23	—0,78	—1,01
11	+1,61	+0,58	+0,43	+0,44	+0,77
12	+0,23	—0,57	—0,12	0	—0,12
13	+1,18	+0,37	+0,79	+0,99	+0,83
14	+0,37	—0,18	+0,21	+0,38	+0,20
15	—1,18	—1,19	—1,47	—1,25	—1,25
16	—0,60	—1,02	—0,77	—0,41	—0,70
17	—0,03	—0,57	—0,43	—0,28	—0,33
18	+1,15	+0,73	+0,68	+1,14	+0,93
19	—0,88	—1,37	—1,61	—1,07	—1,23
1920	+1,82	+1,54	+1,49	+2,11	+1,74
21	+2,14	+1,65	+1,89	+2,10	+1,94
22	—0,67	—0,78	—0,91	—0,61	—0,74
23	—0,43	—0,65	—0,55	—0,17	—0,45
24	+0,03	—0,03	0	+0,41	+0,10
25	—0,34	—0,36	—0,47	—0,04	—0,30
26	+0,27	+0,02	+0,03	+0,49	+0,18
27	—0,12	—0,16	—0,27	+0,33	—0,06
28	+0,26	+0,09	+0,16	+0,43	+0,34
29	+0,51	+0,32	+0,41	+0,65	+0,47
1930	—0,41	—0,54	—0,39	+0,03	—0,33
31	—0,54	—0,45	—0,80	—0,67	—0,61
32	+0,90	+1,42	+0,83	+1,03	+1,05
33	—0,17	—0,52	—0,51	—0,47	—0,42
34	+0,87	+1,44	+0,73	+0,84	+0,97
35	—0,77	+0,02	—1,07	—0,83	—0,66
36	—0,60	—0,01	—0,75	—0,42	—0,45
37	—0,92	—0,63	—1,08	—0,51	—0,78
38	+1,17		+0,76	+0,17	+0,70
39	—0,64		—0,85	—1,33	—0,94
1940	—0,78		—1,19	—1,81	—1,26
41	—1,27		—1,30	—1,82	—1,46
42	+0,18		+0,02	—0,39	—0,06
43	+1,98		+1,75	+1,13	+1,62
44	—0,07		—0,26	—1,07	—0,47
45	+1,48		(+0,84)	+0,46	+0,93
46	+0,36		+0,70	+0,25	+0,44
47	+0,45		+0,60	+0,37	+0,47
48	+1,88		+1,18	+1,79	+1,62
49	+2,20		+2,17	+1,84	+2,07
1950				+0,30	+0,30

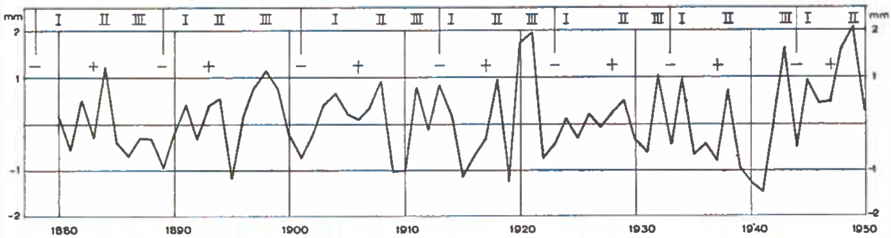


FIG. 33. Air pressure fluctuations in Europe are less evidently dependent on solar activity than air pressure fluctuations in Indonesia.

These overall air pressure deviations may be considered as values well representative for Central Europe, while certainly related to Indonesia anomalies (VISSER [175c]). They have been plotted in fig. 33, including also indications by minus and plus signs of sunspot minimum and sunspot maximum years.

We note 23 relative air pressure tops in 70 years which signifies an average intervall of 3 years between two successive tops in perfect agreement with stochastic distributions. Nevertheless we get the impression that some rule exists by which 3 high pressure years are outstanding in every solar cycle. These high pressure years are marked I, II, III in succession.

The writer attempted – just as an example – to formulate in 3 rules, how the occurrence of these 3 high pressure years is controled by sunspot numbers in a manner analogous to the one by which the 4–5 Djakarta high pressure years are apparently distinguished in every solar cycle. Although there was no a priori reason to doubt this possibility, the writer in fact definitely failed to succeed.

This negative result may well be considered as an additional proof of our hypothesis that the Southern Oscillation is the basic terrestrial oscillation on which solar radiation has its firm grip. In the case treated here, a North Atlantic „recurrence", our impression made us probably an easy victim of a quasi periodicity. We may add that 18 oscillations in 66 years (1878–1944) would mean an average period of 3,67 years. This period, simply $\frac{1}{3}$ solar period, was detected in world weather as a 3,75-year period and brought into relation with an apparently similar period in solar prominences, by W. J. S. LOCKYER [98a]. A 3,67-year period – probably because of its flexibility – was never found prominent by harmonic analysis and, consequently, fails in table 1, but with double this value, or 7,34 years, we are within the wide margin of the European „7-year" periods, namely between those of BAUR (7,2 years) and of BRUNT and VISSER (7,5 years), which may be indicative of its apparent origin.

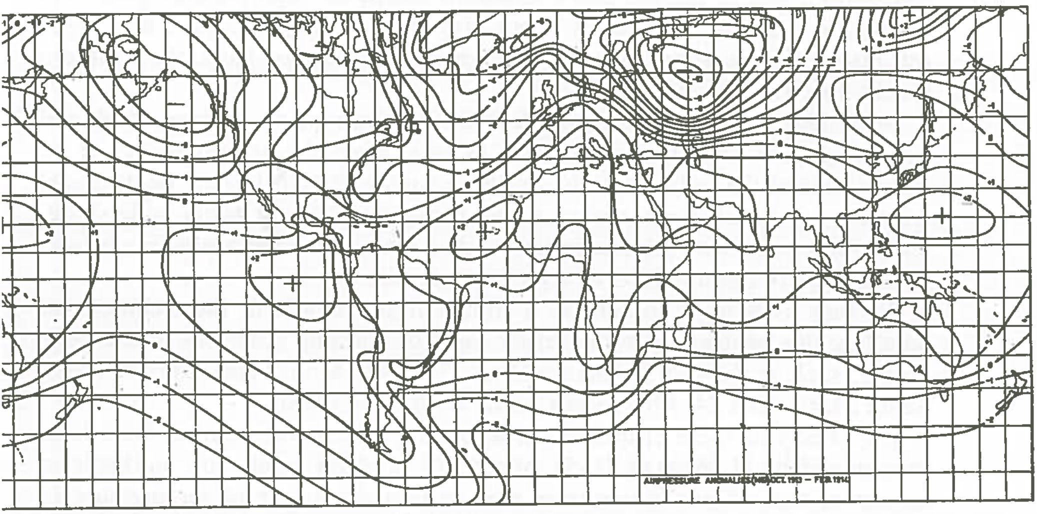
3.6 The abnormal case of 1913 and the effects of volcanic dust veils

Perhaps the most prominent case on record of a year which in its general character evidently deviates from the normal course of the Southern Oscillation is 1913. It was already noted in 3.5. The years 1913–1914 are memorable because, as fig. 9 proves, one high singular air pressure wave, apparently abruptly starting and not leaving proper after-effects, is super-imposed on the longest known regular train of 3-year waves, the one presenting tops in 1896, 1899, 1902, 1905, 1908, 1911, 1914.

One further point which immediately strikes us, when we compare the air pressure curves of Bombay, Djakarta and Darwin (fig's 24 and 25) is that the amplitude of the abnormal 1913 high pressure wave was definitely *not* proportional with the normal amplitudes of the Southern Oscillation waves, but roughly the same in these places. This characteristic, particularly well borne out by fig. 23, distinguishes the 1913 singularity clearly from other ones.

Of course, the writer is aware of the weak points which are in singling out a particular case and designating it as a „pathological" one. However, there are positive signs of the origin of the unusual behaviour of 1913. Different investigators, amongst which the writer, have become convinced, that BRAAK [26f] was right, when suspecting the powerful Katmai eruption of Jun 6, 1912 to be the cause of the 1913–1914 singularity. After the Katmai eruption a veil of volcanic dust was spread through the upper troposphere and stratosphere of such importance that solar radiation – according to ABBOT's compilation – was notably depressed all over the world for at least two years after.

The greatest development of the typical features of the 1913–1914 general circulation is apparently attained in the northern winter season, Oct. 1913–Feb 1914, when Region I shows maximum air pressure anomalies. A world synoptic air pressure deviation chart for that season is shown in fig. 34.



34. Global picture of air pressure anomalies Oct 1913–Feb 1914, an example of an irregular occurrence.

The abnormal sense of this pressure pattern, when compared with the fundamental Southern Oscillation patterns, is the almost flawless zonal arrangement of it. During the whole season illustrated here, air pressure was above normal in the equatorial and subtropical belt and below normal north and south of roughly 40 degrees latitude. There is only one exception. Air pressure anomalies are also positive in the famous extremely cold areas of North Canada and Northeastern Siberia. It is not quite certain, but rather probable that these two areas cohere and that a positive pressure anomaly actually extended above the arctic cap.

We even detect an undeniable symmetry by which a positive pressure anomaly points through South America towards the antarctic continent. We hesitate still before the final conclusion, which would be a very interesting one, that both polar icecaps have shared, although perhaps weakly, in the positive pressure anomalies. However, remembering how small the polar caps in fact are on the globe, and what particular influence their ice coverages may have had, the impression remains that the general zonal arrangement of the pressure pattern and the abnormally high pressure throughout the tropical belt, is most easily explained by a general depletion of the incoming solar radiation.

The fact that 1913 was a sunspot-minimum year may have accentuated the effect which we are investigating. However, low solar activity would probably have had its influence at least through 1912 and 1914 as well and could hardly explain the 1913 pathology which is so evidently restricted in time. It is as if the 1913 air pressure maximum in Region I leaves no traces in the Southern Oscillation, and so there is every reason to accept the high pressure year 1913 in Region I as an „irregularity", but also as a warning example, how weak our attempts in seasonal forecasting, even on the soundest basis, the Southern Oscillation, will always remain.

Nevertheless this investigation of 1913–1914 puts us on a trace which will not be pursued here, because it leads us away from the present points. If we have obtained the right view, the northern winter 1913–1914 may be disjoined from the normal course of events, as this background is now better understood, and be inspected with greater precision than would have been possible before, on the climatological effects of a global dust veil.

We may even hope to achieve a similar improvement in the technique of handling this problem in some earlier cases of volcanic eruptions of the same vigour, such as those of Krakatoa (Aug 27, 1883), Mont Pelée (May 8, 1902), Santa Maria (Oct 24, 1902) and Colima (Feb–Mar 1903).

The effects of these eruptions on insolation and world weather have been reexamined by H. Wexler [185a, b] recently, and his results are markedly in favour of the writer's assumption that certain deviations of air pressure in Region I from its normal Southern Oscillation course, in 1884–1885 and

1903–1904, could be explained in a way similar to the one followed in the case of 1913–1914.

This sorting out of the Southern Oscillation may contribute its part to a new attack on an old problem, (ABBOT and FOWLE [2], ARCTOWSKY [7a], HUMPHREYS [78], KIMBALL [91], KÖPPEN [95b]) the occurrence of climatic variations due to changes in the amount of solar radiation in general and to changes in the dust content of the upper air in particular.

4. THE PROGNOSTIC VALUE OF THE LONGPERIODIC OSCILLATIONS

4.1 The extrapolation of sunspot numbers

Application of our knowledge of the Southern Oscillation to seasonal forecasting requires adequate extrapolation of next year's sunspot number. The writer's experience with this extrapolation is that the actual course of the solar activity leaves us rarely in the lurch. Whether next year's figure will be above or below the limit used in one of the rules is hardly ever dubious. Doubtful cases will be met only in the years of quick rises of sunspot numbers after a sunspot minimum year. For instance 1955 will remain for ever in the memory of astronomers and geophysicists for its exceptionally rapid development of sunspots.

Every solar cycle from one minimum of activity to the next is a phenomenon with a proper character and the formulae developed by WALDMEIER [179], STUART and EGGLESTON [163] and others, destined to extrapolate sunspot numbers are always based on the assumption of a certain average natural growth and fall of sunspot numbers when the actual solar cycle has revealed its specific character. These formulae are more or less impotent in front of every new solar cycle. The only remaining way of taxation of the character of the coming cycle, whether short and strong or long and weak, is following the recurrences in high and low sunspot maxima supposed to exist by different authors.

We are reminded here of the curious fundamental difference in the estimates of the character and the time of the next sunspot maximum made by C. N. ANDERSON [5], L. H. BEAN [12] and H. C. WILLETT [188c] and the decision which at present seems to be already definitely in favour of the first two of these three authors. In 1.3 we mentioned CLAYTON's adherence (39d) to the alternate occurrence of 4 intense and 3 weak sunspot cycles within a major cycle, including 7 sunspot cycles, of an average length of 78 years. This major cycle was confirmed by D. J. SCHOVE [149b]. It does not seem to work, however, in the current instance. Probably the best hypothesis was made by S. W. VISSER [175h]. He found an average increase and decrease of the yearly number of sunspots round about the sunspot maxima in every cycle of EASTON, covering 8 solar cycles. When the sunspot maximum year is assumed to be the middle one of the three years with the highest numbers, and the number associated with this maximum year the mean of the three highest values, table 31 is obtained.

TABLE 31

	1		2		3		4		5		6		7		8
1750	83	1761	71	1770	97	1779	122	1788	128	1803	44	1816	42	1829	66
1837	125	1848	111	1860	89	1871	115	1883	63	1894	76	1906	59	1917	84
1928	70	1938	104	1948	141										
Mean	93		95		109		118		96		60		50		75

This table, which includes all the figures of the Zürich list opening in 1749, also leaves almost no doubt about the character of the next sunspot maximum. It will be a very high one. WALDMEIER even expects the next sunspot maximum to become the highest ever recorded.

Future study should give an answer to the question whether the reliability of forecasts of numbers of sunspots could be raised by a reduction of the interval, through which these numbers are averaged, from one year to, for instance, one half year, and giving seasonal forecasts of sunspot numbers. From the standpoint of the practical application of such an improvement in seasonal weather forecasting, it would seem, of course, most important that the apparently irregular behaviour of some years around sunspot maxima e.g. 1861, 1894, 1908, 1928, 1955 could be interpreted as regular, and new impulses to solar activity after sunspot minima could be recognized earlier.

4.2 The range in forecasting promising optimal results

It is of primary importance to know which unit of time is the most appropriate. For identification purposes let us denominate forecasts extending through any period between 1 month and 1 year as seasonal forecasts. Since seasonal forecasts are primarily based on pressure patterns provided by the Southern Oscillation the best information on the present question is obtained by correlating air pressure at the two main centres in different ways. Analyzing the series of air pressure values at Djakarta and Easter Island Oct 1949 through Sep 1955 in intervals of 1, 3, 6 and 12 months we note as correlation coefficients:

—0,46	±0,09
—0,72	±0,10
—0,82	±0,09
—0,87	±0,10

The mean error of these coefficients is roughly the same in all cases.

The writer is greatly indebted to his colleague H. J. DE BOER for pointing out to him the following interesting conclusions from these figures. Let the Southern Oscillation be equivalent to a harmonic air pressure wave with a period of 30 months and amplitudes a and b at Djakarta and Easter Island respectively. Let $\bar{\delta_i^2}$ and $\bar{\varepsilon_i^2}$ be the mean squares of the random monthly deviations of the air pressure from the basic Southern Oscillation at these same places. Then the two correlation coefficients —0,46 and —0,72 in the cases of monthly and three-monthly intervals give two equations which permit the conclusion that the two quotients

$$\frac{\sqrt{\overline{\delta_i^2}}}{a} \quad \text{and} \quad \frac{\sqrt{\overline{\varepsilon_i^2}}}{b}$$

are not materially different and both equal to 0,76 approximately. Now, when these values are introduced the theoretical correlation coefficients in the cases where 6-monthly and 12-monthly averages are used, amount to —0,81 and —0,85. The excellent agreement between the computed and the empirical correlation coefficients proves two things:

(1) The Southern Oscillation *is* essentially a harmonic air pressure wave of 30 months period,

(2) The mean amplitude of the monthly „noise" amounts to 76 per cent of the amplitude of the basic wave.

Hence, roughly 65 per cent of the total energy of the air pressure fluctuations in the tropical part of the Indo-Pacific Ocean go into the Southern Oscillation proper. This conclusion stresses the importance of the Southern Oscillation in world weather, though, on the other hand, it imposes certain statistical limits on its prognostic value.

The quality of our forecasts is controlled by two factors. The one is the correlation coefficient which increases from —0,46 in the case of monthly forecasts to —0,87 in the case of yearly forecasts. After going through a maximum it will approach eventually again the zero. The other factor is the mean value of the air pressure anomaly which we are going to forecast with the aid of the correlations. This factor has an opposite effect. Because the basic air pressure wave is also ironed out when the range through which data are averaged is increased, the information which the forecasts give decreases with increasing range. In fact, if the range chosen equals the length of the period of the basic oscillation the amplitude of this oscillation is reduced to zero. Hence the two factors cooperate in such a manner that at a certain range the maximum information is given. The determination of this time interval of optimal results is an interesting problem which finds a rational solution in the following way.

If k is the ratio between the reduced amplitude of the smoothed out wave and the amplitude of the actual wave then the most rational thing is to relate k^2 and r. These quantities both represent quotients of squares of amplitudes and may be assumed to have equal weight. The product rk^2 therefore is the quantity which may be expected to measure the quality of the seasonal forecast. It has its top value between 4 and 5 months (fig. 35). This result confirms the writer's empirical finding that the best correlation results are obtained when 5-monthly air pressure departures from normal are used, and this more specifically in the seasonal combinations Apr–Aug and Oct–Feb (2.3).

We have treated so far the question of highest scores from the standpoint of the „prognostic" use of contemporaneous correlations. It presented itself in this most pronounced case of teleconnections as lucid and numerically sound. There is, however, no reason to doubt that when forecasting at intervals from 1 month to 1 year is indeed applying the Southern Oscillation – as we suspect it to be – the same conclusion applies to forecasts which are entitled

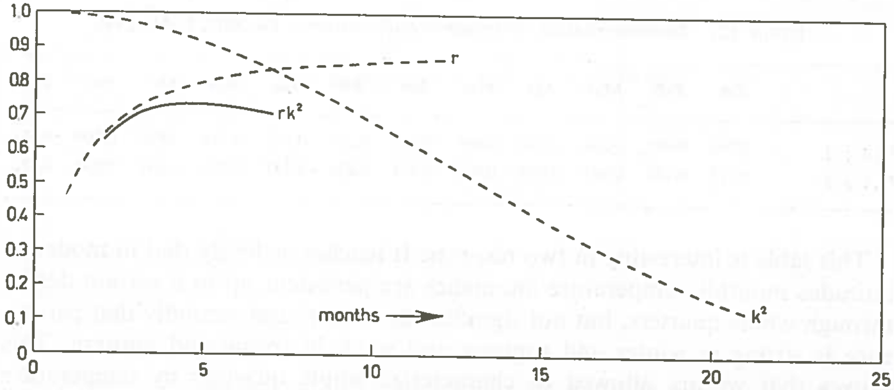


FIG. 35. The interval of greatest reliability in forecasting with the aid of the Southern Oscillation is indicated by the position of the maximum value of rk^2.

to this name, forecasts based on lag correlations. When we confine ourselves to the regions where the Southern Oscillation is dominant we may be sure that successes in weather forecasting are not simply declining with growing range. In these regions a second maximum of scores is to be expected at ranges from 4 to 5 months. Specific seasonal forecasts are advantageous there.

Now, every long range forecaster would wish to make monthly forecasts, such as are now issued in the United States and Western Germany on a routine basis under the direction of J. NAMIAS [110] and A. HOFMANN [77b] respectively, and the question arises whether monthly forecasts make sense between the short range and the seasonal ones.

This discussion teaches at least two things. Firstly, when | 0,4 | is considered as the lowest value of a correlation coefficient which permits positive results, we may conclude that even monthly forecasts would gain from an application of the Southern Oscillation teleconnections in the restricted area where the Southern Oscillation dominates the scene. Secondly, wherever we are, it is advisable to investigate what might be gained by approaching the required monthly forecasts from the side of the longer time intervals as well as from the side of the shorter time intervals, that is to derive the anomalous character of a month from the anomalous character of the season and not only to build up the anomalous character of a month from partial short periodic anomalies.

What is to be learnt in this respect for moderate latitudes from the North Atlantic Oscillation, if it is analyzed in the same way as the Southern Oscillation?

Let us first quote from an extremely useful statistical analysis of the famous Dutch temperature series starting in 1735, made by VAN DER BIJL [37c], table 31 giving the coefficients of correlation between the mean temperatures of every month i and the mean temperatures of the next month $i+1$ and of the second next month $i+2$, De Bilt, 1741–1940.

TABLE 32. *Intercorrelation of monthly temperatures, De Bilt,* 1741–1940

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
$r_{i, i+1}$	0,296	0,407	0,267	0,010	0,099	0,216	0,316	0,382	0,219	0,086	0,206	0,317
$r_{i, i+2}$	0,122	0,143	0,067	0,010	0,032	0,131	0,033	0,247	0,099	0,091	0,039	0,172

This table is interesting in two respects. It teaches us firstly that in moderate latitudes monthly temperature anomalies are persistent up to a certain degree through whole quarters, but not significantly longer, and secondly that persistence is strong in winter and summer and weak in spring and autumn. This proves that we are allowed to characterize whole quarters by temperature indices. It is however advisable to restrict this seasonal typology to winter and summer. We may apparently try seasonal forecasting for winter and summer in moderate latitudes, but can not expect to achieve any noteworthy results in forecasting spring and autumn seasonal conditions. Let us add that the question whether one month or three months forecasts would be the more reliable only applies to summer and winter conditions, but requires in these two cases serious consideration.

As regards the North Atlantic Oscillation more specifically, a computation of the contemporaneous correlation coefficients between Stykkisholm and Ponta Delgada air pressure for the same sequence of intervals as used in the case of Djakarta and Easter Island reveals the following picture:

months	1896–1915	1921–1940	40 years total
1	—0,46	—0,55	—0,51
3	—0,41	—0,48	—0,53
6	—0,36	—0,46	—0,53
12	—0,51	—0,52	—0,52

We see at once that in the present case the correlation coefficient does *not* increase with the length of the interval taken. It is remarkably constant through all intervals in the total series of 40 years which shows that the variations of the correlation coefficient noted in the partial series are statistically insignificant. Hence in the North Atlantic we are outside the area where we may expect optimal forecasting results for intervals greater than one month. The same conclusion may well be true for other large parts of the world. Meanwhile, where we have to shorten our tolerable forecasting interval below one month we are evidently leaving the „safe ground" of the Southern Oscillation, that is our „carrier wave". Let us therefore review finally those practical attempts in seasonal forecasting which would seem to have received a little new support from our analysis of this particular oscillation.

4.3 Significant lag correlations

It is here the place to acknowledge how much we owe to the eminent work on world weather done by Sir GILBERT WALKER, who prudently cast the term „foreshadowing", and his research associates, particularly E. W. BLISS, after BLANFORD's and ELIOT's introduction of „seasonal forecasting" in India, the stimulating investigation of Sir NORMAN LOCKYER and W. J. S. LOOKYER from between 1902 and 1906 [98a], on the air pressure „see-saw" India–Australia–South America, and the famous 1913 compilation of southern hemisphere correlations made by MOSSMAN [108a], at that time in the Argentine Meteorological Office. Table 32 contains a summary of WALKER's statistically significant lag correlations between quarterly air pressure anomalies.

TABLE 33. *Statistically significant lag correlations between quarterly 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

TABLE 33. *(continued)*

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

This work inaugurated in the twenties a real outbreak of investigations of teleconnections. Our attention is thereby drawn to a great number of meteorological relationships throughout long distances in space and time, discovered by BAUR [10c, d, e, f], EXNER [54a, b, c], GROISSMAYR [68], POLLAK [120], and many others.

SAVUR [143], BANERJI [8] and MONTGOMERY [107] were later obliged to correct downward some of WALKER's coefficients, whereas CAPPEL [38] reviewed some of POLLAK's figures, these authors rightly casting strong doubt on correlations which did not prove persistent. Sir NAPIER SHAW in the second volume of his Manual of Meteorology (1928) mentioned the situation in world weather correlations as „bewildering", a very intricate problem being, as YULE [192] was the first to point out; that the presence of periodicity greatly increases the likelihood of obtaining high correlations by chance. We have encountered the severity of this objection in 3.4 when considering the statistical significance of our formal interpretation of the Southern Oscillation by the aid of sunspot numbers.

W. VAN DER BIJL [37a, b] threw perhaps the sharpest spotlights on several pitfalls which beset the path of those in search of statistically significant correlations, while recently A. M. GRANT [66] again criticized very thoroughly the application of correlation and regression to forecasting, when our knowledge of the underlying physical processes is failing. The same undertone sounds in valuable reviews of studies given by PAGE [115] and WEIGHTMAN [184].

Now, the writer is presenting this paper just as such an endeavour to overcome a too critical attitude with regard to longperiodic world weather oscillations and seasonal forecasting by framing, from all those apparently disparate correlations discovered so far, the largest possible number into one probably „significant" physical scheme, although it must be conceded, that this scheme is , as yet, only roughly and superficially constructed. It includes, however, not only those numerous contemporary correlations which are due to the functioning of longperiodic oscillations in the general circulation as more or less standing waves, but also those much less numerous correlations due to actual motions of the hydrosphere and atmosphere, products of what SCHELL rightly conceived as „dynamic persistence" (144e, f), and which may be of prognostic value.

The writer's main thesis at this point is that what we are attempting to do in seasonal forecasting anywhere is merely to apply our knowledge of the Southern Oscillation and its extensions over the globe by the paths of propagation discussed in 3.2. Materials point in the first place to the greatest chance of success with seasonal forecasting in Region I and Region II in the restricted sense of fig. 20. The greatest reliability of operation of the Southern Oscillation exists in these two areas. The one area envelopes the Indian Ocean north of a line connecting South Australia with Madagascar, and a continental part including the northern half of Madagascar, Tanganyika, Kenya, Somaliland, Hadramaut, Pakistan, India, Burma, Indonesia, the southern half of the Philippines, New Guinea and Northwest Australia. The other area envelopes a large part of the eastern Pacific Ocean, with the Hawaiian Islands, a number of Polynesian islands, Easter Island and Juan Fernandez, and a negligibly small continental area along the west coast of Mexico, the Californian Peninsula.

An important although somewhat disappointing aspect of the practical application of seasonal forecasting in the survey given here is the very large extent of the seas relative to the small extent of the countries which could reap noteworthy advantage from seasonal forecasting. It is hardly necessary to remark, how clearly our survey reveals the logic of the fact that seasonal forecasting was born in India (BLANFORD [21], WALKER [180a, b, c], IYER and others [83, 84, 85], KRISNA RAO [96], ROY and others [136, 137], UNAKAR [172]), and is well under way in Indonesia (BRAAK [26d, f], BERLAGE [15a, h], DE BOER and EUWE [24d, 25, 52a, b], although critical voices were not lacking there either (REESINCK [130]).

We have also seen that there is probably good hope of success in seasonal forecasting on the basis of the Southern Oscillation in the hatched parts of the world in fig. 20. They include the Belgian Congo, Rhodesia, Portuguese East Africa, Egypt, Arabia, Iraq, Jordan, Israel, Lebanon, Syria, Eastern Turkey and a small part of Southern Russia, Siam, Vietnam, Cambodja, Malacca, Northwest Borneo, the northern half of the Philippines, the islands east of New Guinea, the greater part of Australia, and on the American side Peru, Bolivia and part of Chile.

It is the writer's conviction that the outlook for sufficiently reliable seasonal forecasts in the countries enumerated so far, is decidedly promising. As a matter of fact strong efforts have been long since made in Australia (LOCKYER [98b], HUNT [79], KIDSON [90a], KEELE [89], QUAYLE [124b], RIMMER and HOSSACK [132], TRELOAR [169]), sharp critics in that country being RADOK [125] and GRANT [66]. For the same good reasons investigations into seasonal forecasting possibilities were undertaken in Burma (MAUNG [100]), Siam (IYER [83a, b]) and Madagaskar (FROLOW [57a, c]). Meteorologists in other parts of the „extended area" should try to find out what can be achieved in this direction.

The advantage of the present discussion is that we have now got the right feeling for those parts of the world, outside Region I and Region II proper, where seasonal forecasting is not quite hopeless or where it is.

Near the seasonal zero line of correlation between Region I and Region II seasonal forecasting will probably be a very intricate problem in principle and hardly to be solved. This remark applies, for instance, particularly to New Zealand. The present writer cannot share SEELYE's optimism [152] as regards seasonal forecasting in that country. As a typical example, New Zealand's wettest years were 1853, 1861, 1893, 1938 while its driest years were 1855, 1859, 1881, 1885, 1914, 1930. This list agrees with the Java east monsoon list, which was quoted several times, with two exceptions: the east monsoon of 1853 was dry and that of 1859 was wet in Java. Extreme years in New Zealand precipitation are apparently apt to agree with Java east monsoons in 8 out of 10 cases. But what about the cases in which deviations are smaller? Will New Zealand meteorologists ever succeed in forecasting whether a season will be dominated by Region I or by Region II? Much the same, the writer fears, is true for Japan. As a matter of fact the keen attempts in seasonal forecasting made in that country by OKADA [113], TAKAHASHI [165] and others have remained so far decidedly unsuccesful.

The seasonal correlation charts indicate that in most countries where seasonal forecasting runs any notable chance of success, it is forecasting winter conditions which has the best chance of sufficient reliability. We get the strong impression, recently stressed by Rubin [138c], that especially winter conditions in one hemisphere control to a large extent next winter's conditions in the opposite hemisphere. The heaviest burden in that game of ball between both hemispheres reposes evidently on the monsoon region in the triangle Africa–Asia–Australia.

One promising line leads via Egypt through the Mediterranean to Europe. It was already followed by Groissmayr [68g] and Rosenan [135]. This is the line along which Nile floods seem to control to a certain extent European weather (Bliss [22a], Brooks and Quennell [33a]).

Other promising lines lead to the tropical part of South America from the East through the Atlantic Ocean with the trade winds. So the height of the Parana River is positively correlated with air pressure in Region I and negatively correlated with air pressure in Region II up to significant values, while these relations show useful lags (Bliss [22c]). Forecasting Ceara (Brazil) droughts along these lines may in time become sufficiently reliable (Walker [180h], Sampajo Ferraz [141]).

The lines through the Atlantic Ocean converge. The West Indies are certainly in a favourable situation from the standpoint of seasonal forecasting. We found Surinam rainfall intimately linked with the Southern Oscillation. Bliss made successful attempts in forecasting seasonal rainfall in the West Indies (22d), extending these forecasts later to Barbados (22e).

The line of influence rounds the North Atlantic and debouches in Northwest Europe. Even Northwest European winter temperatures are known to be correlated significantly with the previous season's conditions in Egypt, India, Indonesia, Australia, Samoa and South America (Walker [180j, k], Bliss [22b], Groissmayr [68c], Georgii [63]). Along specific parts of these general lines, which point back to the Southern Oscillation, several other investigators attempted to forecast Northwest European winter temperatures from Gulf Stream temperatures (Baur [10e], Bergsten [14], Brooks C.F. [34b], Brooks C. E. P. [30c], Sandström [142]) or even previous trade wind conditions (Brenneke [28], Gallé [61]). Oceanographical and meteorological conditions in the North Atlantic, in particular the intervention of the Labrador Current mentioned by Campbell Hepworth [75] and the meandering and riverlike branching of the Gulf Stream studied by Wüst [191], Fuglister [59], Iselin [82] and others are however evidently much too complex to produce indubitable long range effects in Northwest European countries.

An interesting parallel through the North Pacific is the forecasting of Southwest Canada and Northwest United States winter temperatures by means of correlations between these temperatures and the Southern Oscillation, discovered by Groissmayr [68a, b, e, f], Patterson [116], Walker and Bliss [180j, k] and Willett and Bodurtha [189]. Blair [20] attempted to extend forecasts of winter temperatures to the interior of North America and the Missouri and Mississippi valleys, while J. H. WEBER [183] even defends the proposition: Alaska pressures may indicate New York temperatures. Even WEIGHTMAN in his notoriously critical „preliminary studies" [184] became convinced of the great importance for the United States of just this relationship between the Southern Oscillation and following winter temperatures.

The relationship between the Southern Oscillation and North American precipitation was used by others in the general sense (CLAYTON [39a]) or more specifically to forecast Pacific Coast rainfall (BLOCHMAN [23], MC EWEN [53], FRENCH [56], GORTON [65], HENRY [74a], SCHELL [144c, d]).

Barometric pressure in Northwestern America was related to the temperature of the Pacific currents by STUPART [164], in the same manner as pressure distribution in Europe was often brought into relation with Gulf Stream temperatures.

In moderate latitudes, however, the „noise" crops up too seriously. It is therefore reasonable to assume that the best remaining possibilities for seasonal forecasting are in the southeastern parts of the great continents of the northern hemisphere, the southeastern United States and Southeast China. There is a real base for the intimate correlation which was always found between weather elements in Charleston and the key stations in world weather, though GROISSMAYR has probably exaggerated when nominating Galvaston (Texas) among his poles of annual precipitation correlation [68n]. Rainfall in the southeastern United States is rather intimately related with the Southern Oscillation, as WALKER suggested [180] and WEIGHTMAN confirmed [184]. Chinese meteorologists, in particular TU CHANG-WANG [170], found similar relationships, although only weakly significant, between some provinces in their country and other distant areas.

Through arctic response some weak and probably inefficient correlations may exist between stations in the grip of the Southern Oscillation and the extreme cold areas in winter centered in North Siberia and North Canada. With reference to the fact that the „Arctic Oscillation" probably is the only longperiodic oscillation which is more or less independent from the „Southern Oscillation" it is a rational undertaking to try out, as was done by C. E. P. BROOKS [30b], BROOKS and QUENNELL [33b], MEINARDUS [104b, c] and WIESE [186] in how far the arctic is useful as a key region in seasonal forecasting. The recent extensive studies of the temperature fluctuations in northwest European countries and the severity of their winters made by GOEDECKE [64], KERÄNEN [92], GÖSTA LILJEQUIST [97], LYSGAARD [99], SIMOJOKI [157] and WALLÉN [181] are excellent tools for tackling this problem.

In all other parts of the globe's surface influences are certainly too random and too conflicting to allow seasonal forecasting with any practical degree of reliability.

4.4 Conclusion and prospects

During the past half-century immense trouble has been taken by a great number of scientists in almost all countries of the world to frame regression equations out of some apparently significant correlation coefficients and to issue sufficiently reliable seasonal forecasts. Outside Southeast Asia, however, only poor or entirely negative results have been obtained and many of us are ready to assume the improbability of any improvement in seasonal forecasting if not to consider it as a mere illusion.

Severe statistical tests have revealed many extremely weak points in correlation methods and have reduced the number of apparently „real" meteorological teleconnections to a very low minimum. We have learned that no instances are known where the inclusion of more than two or perhaps three variables in a regression equation would notably increase its reliability. From the definite optimism of the twenties students of the subject have been sliding down towards the pessimistic attitude of the fifties. We have arrived now again at the very bottom of the problem of seasonal forecasting, asking whether there is any hope for some recovery from this almost deadly fall.

There is no point in suspecting the possibilities of seasonal forecasting and supporting the possibilities of monthly forecasts on statistical grounds. Practical considerations may well even lead to certain optimal results when forecasts are made for whole climatological quarters. Three months intervals are at least a substantial fraction of the meteorological periods longer than the annual one.

Our present analysis lends support to the view that anything useful which was achieved in seasonal forecasting was arrived at by the application of the Southern Oscillation, and furthermore that the Southern Oscillation is no pseudo-periodic fluctuation, but a physical process of worldwide extent, by which the general circulation in both hydrosphere and atmosphere is accelerated and decelerated rhythmically with a period varying between 2 and 3 years.

Hydrosphere and atmosphere are perpetually cooking on the solar fire a long periodic meal. Tracing the origin of the special dishes which we get served in our place of residence means following the „assembly line" and testing the significance of the correlations along this line. The „assembly line" as far as we can see now always leads us back to the Southern Oscillation proper, which is an air pressure see-saw between the equatorial Malay Low and the subtropical Easter Island High. Hence every attempt to improve our knowledge of the functioning of the Southern Oscillation under solar steering may improve the reliability of seasonal forecasting everywhere. We have found arguments for the possibility of understanding more of some characteristic details of the Southern Oscillation which have always looked like abnormalities.

The main point in seasonal forecasting in a given area is to investigate what fraction of its air pressure anomalies derives from the basic Southern Oscillation in the direct way. The search for the amplitude of the basic Southern Oscillation in a given place is a matter of trial and error. VON SCHUBERT's investigation of the geographical distribution of the amplitude of the famous 3-year pressure waves between 1896 and 1905 probably gives the best provisional answer to this question.

If this proper Southern Oscillation part is subtracted from the actual air pressure the fluctuations of the remaining air pressure fraction should be reanalyzed. The indirect ways along which the Southern Oscillation may control the weather in a given region are very complicated. We have found however useful indications about these ways, which may include a feeding back of the „North Atlantic Oscillation" on the Southern Oscillation. The North Atlantic Oscillation, or perhaps more precisely the Arctic Oscillation, is probably a more or less independent ally of the Southern Oscillation. Its proper action should be also investigated. We noticed also unpredictable irregular longperiodic fluctuations of air pressure.

Forecasts of seasonal air pressure anomalies certainly have better chances of success throughout the world than forecasts of other meteorological elements. Air pressure is the primary factor, the quantity indubitably measuring the mass of air above a place. Relations between surface temperature patterns and pressure patterns are, however, not uniquely determined and may involve nonlinear relationships. Precipitation is the other interesting secondary variable.

In temperate latitudes temperature forecasts will generally succeed better than precipitation forecasts. Serious possibilities are apparently restricted to forecasts of winter conditions. In the tropics seasonal precipitation forecasts will as a rule be more easily made than temperature forecasts, because temperature variations in the tropics are only small and, moreover, relatively dependent on precipitation.

If the writer may venture to give advice to seasonal forecasters it is to start with the application of a regression equation containing as variables from the Southern Oscillation one equatorial air pressure value, e.g. Djakarta air pressure and one subtropic (sea-surface) temperature value, e.g. Juan Fernandez air temperature, and from the North Atlantic-Arctic Oscillation one polar air pressure value, e.g. Stykkisholm air pressure and one arctic (sea-surface) temperature, e.g. Bodö air temperature. If a well balanced combination of these factors involving adequate lags does not lead to any statistically significant and persistent results it is to be feared that seasonal forecasting is an insoluable problem in the region concerned.

On the other hand, if this first attempt is promising, further ameliorations may still be expected by exhausting our knowledge of the solar cycle, of the physical processes behind the longperiodic oscillations, which are the subject of the present paper, and of the seasonal dependence of temperature and precipitation patterns from the pressure pattern.

5. CORRECTED TABLES OF AIR PRESSURE AT FOUR STATIONS

5.1 Isla de Juan Fernandez

Lat. 33°37′S, Long. 78°52′W

Air Pressure at sea-level in mb. (1000+), *means of 24 hours*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1911	17,5	19,4	22,6	19,1	18,6	23,1	21,5	23,0	20,4	20,2	19,8	18,0	20,3
12	18,9	19,5	17,1	16,4	16,8	17,2	20,8	19,4	20,2	21,2	21,3	18,6	19,0
13	18,7	16,7	17,9	16,3	16,7	17,5	16,3	19,7	22,1	21,5	19,9	18,9	18,5
14	19,0	19,3	19,1	19,8	15,8	12,2	12,3	19,1	17,2	16,4	19,1	18,4	17,3
15	18,6	18,4	18,3	17,1	12,6	20,0	18,9	21,9	20,6	17,3	19,4	18,3	18,4
16	17,2	16,2	16,6	17,7	18,6	21,0	21,2	20,0	22,7	19,7	20,2	19,3	19,2
17	18,7	18,6	18,9	18,3	19,5	17,0	21,5	20,8	20,2	21,7	22,1	15,5	19,4
18	18,9	18,6	18,0	16,6	18,7	18,7	17,9	18,1	21,7	20,3	15,5	17,9	18,4
19	16,3	18,0	16,8	15,9	10,1	18,1	17,6	22,3	19,1	20,7	17,2	17,5	17,5
1920	15,8	17,2	16,0	17,9	13,2	20,4	21,1	20,2	19,7	21,2	18,7	18,9	18,4
21	17,7	18,9	19,3	16,6	13,3	21,2	23,5	20,8	23,5	21,2	21,3	17,0	19,5
22	17,6	18,0	17,7	20,8	19,4	17,6	14,9	18,9	19,7	21,1	20,3	19,5	19,6
23	17,5	17,0	16,4	21,0	21,6	16,0	18,6	18,0	21,1	19,8	19,4	19,5	19,7
24	18,0	19,3	19,4	19,8	19,8	17,9	19,9	23,9	21,2	20,3	22,4	19,7	20,1
25	19,1	17,7	16,0	17,9	19,9	16,7	17,9	19,4	16,3	21,1	18,4	19,5	18,3
26	18,0	17,9	14,4	20,0	18,0	11,5	17,6	19,8	19,8	20,2	19,1	18,4	17,9
27	18,6	18,0	18,7	18,9	17,3	18,4	16,6	21,5	19,8	19,5	19,5	19,8	18,9
28	18,6	17,6	19,5	17,2	14,0	17,1	18,1	22,3	21,7	20,8	21,0	20,6	19,0
29	17,3	18,4	19,3	19,1	17,9	17,5	20,3	17,6	21,0	22,7	20,8	18,4	19,2
1930	19,8	16,6	16,6	13,7	16,2	13,5	13,1	15,7	19,5	18,9	19,7	14,1	16,4
31	16,6	16,4	18,6	16,6	20,8	15,9	17,6	20,6	23,0	21,3	20,0	18,3	18,8
32	18,7	17,2	18,9	17,2	19,7	12,8	15,3	18,4	22,7	21,3	20,6	19,7	18,5
33	17,0	17,3	18,1	17,7	17,7	19,9	21,2	19,7	20,4	19,4	21,6	18,1	19,0
34	18,4	20,0	17,6	19,1	16,0	15,7	21,6	21,3	19,5	23,7	20,8	20,4	19,5
35	18,9	19,7	18,4	18,4	14,3	18,4	19,8	21,7	20,4	20,4	20,3	18,6	19,1
36	18,3	18,4	16,8	16,7	16.4	18,4	18,0	20,7	19,8	21,0	20,3	19,1	18,7
37	18,1	17,6	18,7	19,5	18,6	18,4	20,4	17,1	23,0	22,9	21,1	20,0	19,6
38	20,0	20,3	18,4	22,0	18,4	19,1	21,0	23,4	22,9	23,7	19,7	20,2	20,8
39	18,4	18,4	19,3	20,6	15,9	16,0	17,6	15,8	19,3	17,9	20,7	18,9	18,2
1940	19,7	17,9	19,5	19,0	16,3	15,1	16,2	23,4	20,3	20,3	21,2	18,9	19,0
41	18,9	19,1	17,7	18,0	16,6	17,9	13,9	17,9	23,7	18,6	19,1	18,9	18,4
42	18,9	16,4	17,3	18,9	18,6	23,3	18,4	17,3	20,2	22,0	18,7	19,1	19,1
43	19,3	18,4	18,4	15,8	14,9	16,2	19,7	19,7	21,3	20,7	19,7	18,4	18,5
44	17,9	17,5	18,4	17,3	17,0	16,2	17,2	17,7	20,6	17,6	20,0	18,9	18,0
45	17,6	16,8	17,9	17,3	17,1	19,3	20,3	18,0	17,7	21,3	19,8	20,8	18,7
46	20,2	18,9	19,3	15,8	17,6	16,3	18,4	20,2	18,7	22,3	18,9	18,4	18,8
47	19,7	19,9	20,4	19,6	20,7	16,7	20,6	23,1	24,4	22,6	20,2	20,6	20,7
48	19,0	19,9	19,0	19,3	14,7	10,5	15,0	21,6	18,6	22,2	21,8	20,8	18,5
49	19,8	19,0	19,9	19,8	16,2	20,7	22,1	24,0	24,9	24,5	20,6	18,6	20,8
1950	20,4	19,3	20,2	18,7	15,1	19,3	22,1	19,5	20,8	23,9	21,1	20,6	20,1
51	18,8	19,3	19,9	19,0	17,0	15,1	15,6	20,9	21,6	22,7	22,2	20,1	19,4
52	19,9	18,0	18,0	19,7	17,3	20,5	19,3	22,6	22,4	23,0	21,2	21,1	20,2
53	19,7	17,7	19,4	18,1	16,8	21,4	22,6	17,3	17,8	24,8	20,1	20,4	19,7
54	21,0	21,3	20,2	19,2	21,4	16,2	20,3	22,2	25,7	23,7	21,4	20,5	21,1

5.2 Mauritius (Royal Alfred Observatory)

Lat. 20°06′S, Long. 57°30′E

Air Pressure at station-level in mb. (1000+), *means of 24 hours*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1853	04,7	02,7	04,6	06,3	08,8	10,4	13,0	11,7	11,5	11,9	06,7	06,3	08,4
54	06,4	01,1	05,4	06,6	08,3	11,5	11,5	13,0	11,4	10,0	10,0	06,2	08,2
55	02,5	04,5	03,6	06,0	09,0	11,4	14,5	13,6	12,9	11,6	11,6	06,6	08,8
56	06,8	01,2	04,9	05,9	06,9	11,3	11,0	12,9	11,8	11,0	11,0	04,9	08,0
57	02,7	02,2	05,0	06,2	09,5	09,7	13,2	13,4	13,1	09,4	09,4	05,9	08,2
58	03,4	05,2	05,9	07,6	08,5	10,2	11,3	11,8	13,1	11,1	11,1	06,9	08,7
59	06,4	06,3	05,9	07,9	09,3	12,7	13,7	13,6	12,9	12,2	12,2	06,2	09,6
1860	01,4	05,9	01,9	07,5	08,3	12,2	13,3	12,3	11,4	10,1	10,1	06,4	08,0
61	03,5	05,4	04,9	07,8	08,3	10,9	12,8	12,9	13,2	10,6	10,6	06,4	07,7
62	03,2	02,9	04,7	06,9	08,7	09,7	11,7	12,5	11,7	11,3	06,3	03,9	07,8
63	03,9	00,6	04,5	05,2	10,1	12,4	12,0	12,8	11,6	10,5	08,5	07,0	08,2
64	05,0	04,5	04,0	06,1	09,5	13,2	14,0	13,6	15,3	11,4	08,8	07,2	09,4
65	06,8	01,0	05,2	06,3	09,3	13,0	14,6	14,1	13,2	11,2	09,5	04,4	09,1
66	05,0	04,0	05,5	05,4	08,7	12,0	13,2	13,8	14,1	11,7	10,1	09,0	09,3
67	05,1	04,5	06,9	06,2	08,4	11,7	12,8	12,8	12,6	09,8	09,8	05,9	08,9
68	02,2	04,7	02,5	06,5	08,4	11,0	12,0	14,4	13,2	09,9	10,0	08,6	08,6
69	06,1	03,3	05,6	08,5	09,3	13,2	13,4	13,6	13,0	12,3	08,5	06,5	09,4
1870	05,1	03,6	05,3	05,9	10,3	12,3	12,0	13,4	13,0	10,6	09,5	05,7	08,9
71	04,0	06,1	02,8	05,8	10,4	12,9	13,5	14,3	12,8	10,7	09,4	06,9	09,4
72	04,8	02,1	07,4	05,7	08,9	08,9	11,5	12,6	12,1	10,1	06,9	04,9	08,0
73	02,1	02,6	04,0	06,4	06,5	13,0	13,2	14,8	13,1	10,7	08,0	06,3	08,4
74	04,2	04,6	04,8	07,3	08,5	11,0	13,0	12,9	12,5	10,4	10,2	05,1	08,2
75	03,2	06,7	06,6	07,2	08,3	12,3	13,6	12,8	12,4	10,0	08,0	04,9	08,9
76	01,2	00,6	06,1	07,3	11,4	13,4	15,0	14,3	13,9	11,0	08,1	08,1	09,2
77	05,2	02,2	06,1	06,1	10,9	14,2	15,5	15,4	12,5	11,6	07,8	07,3	09,6
78	05,5	05,1	06,2	05,4	08,3	11,4	11,1	11,9	12,0	09,3	09,2	04,9	08,3
79	05,4	03,5	05,8	09,5	08,6	12,0	11,8	13,4	13,2	11,4	09,2	04,6	09,0
1880	06,7	06,5	06,1	08,1	09,5	11,8	15,5	14,1	13,7	12,6	10,7	08,9	10,4
81	05,2	07,8	06,0	06,8	09,8	12,8	13,6	14,5	13,9	12,1	08,1	06,2	09,7
82	05,7	02,6	04,2	06,5	08,9	12,2	14,5	12,8	12,4	11,2	08,8	07,6	09,0
83	03,8	03,3	05,2	06,8	09,3	10,6	13,6	11,6	13,1	11,4	07,1	06,1	08,6
84	03,6	05,4	04,8	05,5	08,2	11,0	12,5	12,7	12,7	09,5	08,2	07,5	08,2
85	04,6	02,1	05,6	05,7	08,0	13,0	12,9	12,8	12,8	11,2	09,4	04,9	08,7
86	05,3	04,1	04,4	04,1	10,3	12,4	12,1	13,2	13,2	12,2	10,5	07,3	09,0
87	03,3	05,8	04,8	08,1	09,3	12,1	12,4	13,3	13,3	10,9	09,6	07,3	09,2
88	04,9	04,8	04,9	09,0	08,9	11,6	13,4	12,6	12,6	10,1	08,4	07,1	09,1
89	06,6	05,8	06,0	08,4	07,9	11,9	14,3	12,4	12,4	11,3	08,7	07,0	09,4
1890	05,6	04,7	04,9	06,3	09,2	09,9	13,1	12,6	12,6	11,1	09,3	06,2	08,8
91	05,3	03,3	03,9	07,9	09,8	11,7	13,8	13,9	13,9	10,2	09,2	07,5	09,1
92	04,7	01,4	03,2	05,4	09,1	10,8	12,6	13,7	13,7	10,6	08,3	07,4	08,1
93	01,3	05,3	03,8	07,0	09,8	11,7	13,3	12,9	12,9	10,6	09,9	07,0	09,0
94	02,0	01,8	04,8	06,4	08,6	11,6	12,0	12,0	12,0	09,5	09,4	04,0	07,9
95	02,0	03,8	04,6	05,4	09,7	11,5	12,8	12,7	12,7	09,8	09,1	05,9	08,3
96	04,7	01,8	06,1	06,6	09,3	11,6	14,0	13,1	13,1	11,0	08,9	07,6	09,1
97	03,8	03,2	04,7	08,2	09,7	10,9	12,5	13,0	13,0	11,1	07,6	04,5	08,6
98	06,7	02,0	04,0	05,7	08,2	11,4	12,2	11,4	11,4	10,2	07,2	05,4	08,1
99	03,5	02,8	04,5	06,7	09,0	11,7	15,5	13,5	13,5	10,9	08,4	07,6	09,1
1900	06,2	04,8	04,6	06,3	08,7	11,1	14,1	13,8	13,1	12,4	08,9	08,8	09,4

5.2 *(continued)* **Mauritius (Royal Alfred Observatory)**

Lat. 20°06′S, Long. 57°30′E

Air Pressure at station-level in mb. (1000+), *means of 24 hours*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1901	05,4	05,7	04,0	05,8	08,9	11,5	13,1	13,4	13,9	11,5	09,6	07,2	09,1
02	05,3	02,6	06,4	06,6	08,7	10,0	11,4	11,3	12,2	09,9	07,7	03,3	08,0
03	01,9	03,3	02,9	06,0	09,1	10,2	12,5	12,6	12,6	10,7	09,1	06,8	08,2
04	06,4	03,1	03,2	06,6	09,2	13,7	13,0	14,2	14,0	09,8	10,8	07,0	09,2
05	03,1	04,3	03,2	07,9	09,9	11,3	12,2	13,0	10,9	10,3	08,4	05,2	08,3
06	05,0	04,1	04,0	04,9	09,7	10,4	12,8	11,7	12,4	11,2	10,0	07,6	08,7
07	06,7	05,4	05,1	05,8	08,1	12,8	12,1	13,2	11,9	10,0	07,9	05,2	08,4
08	02,9	01,2	01,9	06,0	09,6	12,4	13,5	11,9	13,0	09,3	07,7	05,2	07,9
09	04,1	03,0	02,2	06,4	08,8	10,4	12,6	12,3	12,3	11,6	08,7	07,4	08,3
1910													08,2
11													08,2
12													08,3
13													08,5
14													08,8
15	07,3	04,2	05,7	05,3	09,1	10,2	12,3	12,1	11,3	10,3	08,7	06,6	08,6
16	04,1	02,9	05,3	06,3	05,9	10,9	13,0	13,1	13,0	11,5	09,3	06,7	08,5
17	05,6	04,5	03,2	07,6	08,8	09,4	12,0	13,3	12,2	11,3	10,7	06,6	08,8
18	05,2	06,5	05,0	05,8	09,5	13,3	15,1	15,0	15,5	11,9	09,6	08,1	10,0
19	06,0	04,0	04,0	08,5	09,9	12,7	14,9	13,8	12,3	11,9	08,5	06,4	09,4
1920	04,1	03,6	06,7	06,8	10,4	12,4	15,6	15,0	13,0	11,7	08,9	07,8	09,7
21	05,6	03,9	06,2	08,2	07,9	11,3	12,7	14,1	13,8	10,0	08,0	05,7	08,9
22	04,1	00,6	06,1	07,3	11,5	12,6	16,0	14,4	14,2	11,4	09,1	08,3	09,4
23	07,3	03,9	06,4	06,1	07,7	13,1	14,1	15,8	13,2	11,5	10,0	05,4	09,5
24	05,6	02,8	07,2	05,4	09,7	13,5	13,2	12,9	13,4	10,6	09,4	07,7	09,3
25	05,2	05,5	07,4	09,2	09,7	10,8	14,0	14,8	13,8	11,5	09,1	07,6	09,8
26	05,1	06,9	06,7	05,7	09,8	12,5	12,7	13,4	11,8	10,2	10,3	06,3	09,3
27	03,0	02,1	02,0	07,6	11,3	13,3	15,1	14,1	13,3	12,8	09,9	07,8	09,4
28	06,8	04,1	05,2	07,4	09,6	12,3	13,9	15,2	14,0	11,4	12,2	07,7	10,0
29	06,1	04,6	06,7	06,5	09,1	13,3	14,0	13,8	13,8	10,9	09,0	04,6	09,4
1930	04,0	04,3	06,5	06,4	11,2	10,7	13,5	15,2	13,4	11,6	10,8	08,7	09,7
31	05,9	05,6	03,6	09,2	11,2	12,5	12,5	14,4	12,4	12,8	08,3	07,7	09,7
32	05,7	02,9	04,6	06,7	10,9	12,6	12,8	13,8	14,4	11,2	10,3	08,9	09,3
33	06,0	03,5	05,5	06,7	08,9	12,3	15,0	13,7	14,5	11,8	10,6	07,1	09,6
34	04,1	05,1	06,2	09,1	11,1	12,9	13,8	16,0	14,4	12,4	08,9	06,8	10,2
35	05,0	03,1	05,8	06,6	10,1	11,8	13,7	12,4	13,2	11,5	09,7	07,2	09,2
36	04,9	04,8	05,3	07,8	09,7	14,2	15,3	13,8	13,1	11,2	09,4	06,3	09,6
37	03,4	03,4	04,3	06,5	10,6	11,9	11,9	14,6	13,6	11,7	08,8	07,3	09,0
38	05,7	03,0	03,2	07,7	09,2	13,1	13,7	12,7	14,0	13,4	11,3	07,9	09,6
39	06,0	06,0	03,6	07,7	10,9	12,6	12,7	14,6	13,8	12,1	09,4	07,6	09,8
1940	05,1	06,7	06,5	10,0	09,2	12,2	14,7	15,0	14,2	12,2	09,3	07,4	10,2
41													
42													
43	03,4	05,2	05,2	10,0	09,5	14,4	15,4	14,3	15,1	13,5	10,8	08,3	10,4
44	08,0	03,8	06,2	07,6	10,2	12,1	15,6	14,1	11,8	10,9	08,6	06,5	09,6
45	03,1	02,2	08,4	06,9	09,2	10,3	12,6	13,2	13,8	12,0	10,2	07,7	09,1
46	05,7	04,1	03,6	06,9	10,9	12,6	13,8	14,8	15,4	11,1	08,2	07,4	09,5
47	02,6	02,6	07,5	09,2	10,2	12,9	12,9	15,6	14,0	14,1	11,0	07,6	10,0
48	05,3	05,9	06,3	07,6	10,2	13,3	14,3	13,8	13,1	12,1	09,8	06,3	09,9
49	04,8	04,1	05,7	08,4	09,8	12,0	13,9	12,9	13,5	12,3	08,8	07,2	09,5
1950	03,2	05,4	07,2	07,9	08,6	11,9	14,4	12,6	15,0	10,8	08,3	07,8	09,4

5.3 Ocean Island

Lat. 0°52′S, Long. 169°35′E

Air Pressure at sea-level in mb. (1000+),
0900+2100 zone time (1905–Jun 1920)
0800—2000 zone time (Aug 1920–1954)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1906	8,2	8,9	9,9	9,0	8,7	9,1	8,2	8,6	7,9	8,8	10,5	9,1	8,9
7	8,9	8,7	9,2	10,1	9,4	9,3	8,8	10,0	10,6	10,8	9,9	8,7	9,5
8	8,2	8,8	9,2	9,6	9,4	9,9	10,7	10,6	10,6	10,5	10,6	10,5	9,9
9	10,5	10,8	11,0	11,2	11,4	11,4	12,7	13,4	12,9	12,5	12,3	10,6	11,7
1910	9,5	10,8	11,5	11,2	12,7	12,5	13,1	13,1	13,1	12,8	11,4	8,6	11,7
11	8,7	9,7	9,7	10,3	11,5	12,0	7,9	9,7	9,9	9,9	9,1	7,3	9,6
12	7,1	9,2	9,1	10,4	10,6	10,7	10,0	10,4	10,7	9,5	9,5	7,6	9,6
13	7,3	9,1	8,3	8,9	9,4	10,7	9,8	9,6	10,6	10,6	8,4	9,1	9,3
14	9,5	8,3	9,2	10,4	9,1	9,6	9,7	10,4	10,2	11,0	9,6	8,1	9,6
15	9,3	10,8	10,8	9,8	9,8	9,5	9,6	10,9	10,0	9,5	9,3	8,0	9,8
16	7,0	7,5	8,2	9,1	9,7	9,1	10,0	11,6	10,3	9,9	8,9	6,8	9,0
17	8,7	10,1	8,0	9,4	11,0	10,3	9,9	10,6	11,0	9,3	8,5	7,7	9,5
18	9,2	8,7	9,3	9,0	8,9	9,2	9,6	10,5	11,7	10,0	8,5	7,5	9,3
19	8,1	9,7	9,4	9,8	9,5	9,5	9,4	10,7	9,6	9,4	8,5	7,9	9,3
1920	7,6	7,5	8,9	9,3	10,0	8,9	9,0	9,8	9,9	9,6	8,5	7,1	8,8
21													
22	7,2	8,3	9,3	9,3	10,5	9,7	9,8	10,3	10,3	10,6	9,1	8,8	9,4
23	7,0	8,1	7,7	8,9	9,7	10,3	9,8	10,8	9,7	10,8	8,1	7,9	9,1
24							10,5	10,9	11,1	10,5	9,9	9,6	
25	8,5	8,9	9,3	9,9	9,7	9,7	11,0	9,1	11,1	10,1	10,4	8,9	9,7
26	8,9	9,7	10,7	10,7	10,5	10,8	10,1	10,5	9,9	10,1	9,3	9,3	10,0
27	8,5	11,1	9,7	10,1	10,4	10,7	10,1	10,5	10,7	10,5	8,5	8,2	9,9
28	8,7	8,7	9,5	9,3	10,2	10,1	9,1	10,7	10,3	9,2	9,9	8,0	9,5
29	7,1	8,3	9,6	10,2	10,7	10,7	9,9	9,9	10,3	10,0	8,1	7,8	9,4
1930	8,3	10,3	9,8	9,5	10,7	9,5	9,7	10,5	10,3	10,9	9,9	8,8	9,8
31	9,0	9,4	10,9	10,6	10,9	10,7	10,5	9,8	10,0	9,4	8,7	7,5	9,8
32	7,5	8,9	9,5	9,4	9,9	10,7	9,1	10,3	10,1	10,1	9,4	8,3	9,4
33	8,0	8,3	8,7	9,3	9,9	10,1	9,9	11,5	11,1	10,1	9,5	6,5	9,4
34	5,9	7,1	6,3	6,7	10,4	9,7	9,7	9,9	10,1	10,9	8,9	8,7	8,7
35	7,8	9,3	8,7	8,9	10,1	9,7	8,7	11,1	9,7	9,3	9,2	7,9	9,2
36	7,0	9,1	9,1	9,1	8,9	9,9	9,9	9,3	11,3	10,3	8,9	8,1	9,2
37	6,9	8,9	7,8	9,3	10,7	10,3	9,3	9,6	10,8	10,7	9,1	8,1	9,3
38	8,3	8,4	9,1	9,9	9,7	10,2	9,9	9,9	10,3	11,3	8,9	7,9	9,5
39	8,4	9,5	9,3	9,7	10,1	10,1	10,5	8,4	11,3	10,1	8,5	9,2	9,6
1940	8,7	8,4	9,1	9,4	9,0	9,7	10,4	9,7	10,7	10,9	9,5	9,1	9,6
41	9,5	10,2	10,3	10,3	9,5	10,9	10,8	10,0	10,2	9,6	9,4		
42													
43													
44													
45													
46													
47				9,9	10,5	10,1	9,7	9,3	11,1	9,9	9,5	7,4	
48	8,3	8,9	9,2	10,2	10,0	9,5	10,3	9,4	10,3	10,6	8,9	8,1	9,5
49	8,6	8,8	9,1	10,4	10,7	10,7	10,9	11,3	11,1	10,8	10,1	7,9	10,0
1950	8,9	8,5	10,1	9,5	10,0	9,5	9,9	10,5	10,9	10,8	9,3	8,1	9,7
51	9,7	9,1	9,2	10,4	10,9	10,3	10,7	10,8	10,7	10,6	9,7	9,3	10,1
52	8,1	8,5	9,7	10,7	10,0	10,3	10,4	10,1	10,9	10,2	9,5	9,5	9,8
53	9,9	10,2	9,5	10,9	11,1	10,3	10,9	10,5	11,2	10,8	10,1	9,5	10,4
54	8,4	10,1	9,9	9,9	10,3	10,7	10,3	10,9					

5.4 Paramaribo (Surinam)

1905–1952 Long. 55°19′W, Lat. 05°49′N
1953–1955 Zanderij Aerodrome

Air Pressure at sea-level in mb. (1000+), *means of* 24 *hours*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1905	12,2	12,5	12,0	11,8	11,6	12,1	12,8	12,2	11,2	10,5	10,1	11,8	11,7
06	11,6	12,1	12,1	11,4	11,3	12,0	12,2	11,8	11,2	10,6	09,3	10,0	11,3
07	10,6	11,0	10,9	11,0	11,7	11,7	12,6	12,9	12,1	11,7	11,2	10,9	11,6
08	12,4	12,2	11,7	11,2	11,8	12,8	12,9	12,2	11,3	10,8	10,8	10,9	11,7
09	11,3	11,8	11,2	11,7	11,6	12,0	12,2	12,4	11,6	10,9	10,1	10,5	11,4
1910	11,3	12,0	11,2	11,8	12,4	12,2	12,1	11,8	10,8	10,4	10,1	10,8	11,4
11	11,3	11,0	11,6	11,3	11,4	12,2	12,9	12,0	11,6	11,2	11,2	11,2	11,6
12	12,4	12,4	12,5	12,1	12,0	12,4	12,2	12,0	11,8	11,4	11,0	10,9	12,0
13	11,6	12,2	12,2	11,8	12,0	11,8	12,5	12,0	12,1	12,1	11,4	12,0	12,0
14	12,0	12,1	11,8	11,6	12,8	12,4	13,6	12,6	12,0	11,2	11,0	11,4	12,1
15	11,2	10,9											
16													
17													
18										10,2	10,1	11,4	
19	11,6	12,9	12,2	11,4	11,8	13,2	13,3	13,3	11,4	11,4	10,0	11,4	12,0
1920	12,2	11,7	12,9	13,6	12,4	12,9	14,0	12,5	11,8	11,3	11,3	11,0	12,2
21	12,5	13,0	11,8	12,0	12,2	12,6	14,2	12,6	12,1	10,9	11,0	11,0	12,2
22	11,6	12,4	12,9	13,3	12,1	12,9	14,2	12,4	11,8	11,0	10,0	11,7	12,2
23	11,6	13,0	12,5	12,4	12,4	13,0	13,3	12,9	11,7	10,6	10,8	11,4	12,1
24	12,8	13,2	12,1	11,7	12,4	12,6	12,8	12,8	12,2	11,0	10,8	11,4	12,1
25	13,0	12,5	11,3	11,7	12,6	12,9	13,2	12,6	11,0	11,6	11,3	12,1	12,2
26	13,2	12,9	13,6	14,0	12,5	12,6	12,6	13,0	11,3	10,2	10,2	10,5	12,2
27	11,4	12,4	12,6	11,2	12,4	12,5	14,0	12,2	10,9	10,6	09,7	10,0	11,7
28	11,4	12,4	12,8	11,8	12,6	12,1	13,6	13,4	12,1	11,3	10,4	11,0	12,1
29	12,4	12,4	12,5	12,4	12,5	13,3	13,7	12,6	11,8	11,2	10,1	11,4	12,2
1930	12,5	12,8	12,9	12,5	13,4	12,8	13,0	13,0	12,5	11,0	11,3	10,9	12,4
31	12,1	11,0	12,6	11,8	12,0	13,4	12,5	13,7	12,0	11,6	10,0	10,5	12,0
32	11,6	12,6	11,6	11,0	12,4	12,6	13,4	12,2	12,0	10,9	10,2	10,5	11,7
33	11,0	12,5	12,4	11,8	12,5	12,8	12,8	12,8	11,8	10,8	10,0	10,6	11,8
34	11,8	13,6	12,5	13,2	12,8	12,8	13,2	13,0	12,0	11,7	10,4	11,7	12,4
35	11,8	12,8	12,6	12,2	12,5	12,8	12,8	12,2	12,0	10,8	10,4	10,6	12,0
36	12,4	13,0	11,8	11,7	11,0	12,8	13,7	12,4	12,1	11,4	10,4	10,9	12,0
37	11,2	12,8	11,7	12,5	12,1	13,2	13,3	12,2	11,8	11,0	10,1	10,1	11,8
38	11,2	12,1	11,7	11,6	11,7	13,3	13,3	11,3	12,2	10,9	09,7	10,0	11,6
39	12,5	13,0	12,5	11,7	12,5	12,9	12,4	12,4	12,2	10,6	10,5	12,5	12,1
1940	13,3	13,0	12,1	12,5	12,2	13,3	14,2	13,2	12,1	11,7	09,4	11,7	12,4
41	12,6	12,8	12,6	11,8	12,2	14,2	14,0	12,5	11,4	11,7	10,4	11,8	12,4
42	13,4	11,2	12,4	12,4	12,1	13,3	13,8	12,8	12,1	10,8	09,3	11,2	12,1
43	11,7	12,2	11,8	12,9	12,6	13,3	14,5	12,8	12,2	11,0	10,5	11,0	12,2
44	12,9	13,2	12,9	12,8	12,0	12,5	13,6	12,2	12,1	10,5	08,6	10,0	12,0
45	12,2	11,8	12,4	12,0	12,5	12,8	13,0	12,4	12,6	11,4	10,2	11,7	12,1
46	12,5	12,5	12,6	12,1	12,5	14,4	13,8	13,4	12,4	11,4	10,2	10,6	12,4
47	11,8	12,6	14,1	13,3	12,6	13,0	13,3	13,3	12,4	10,9	10,4	10,5	12,4
48	11,4	12,4	12,0	11,4	11,8	13,2	12,5	12,2	11,4	11,2	10,4	10,9	11,7
49	11,4	11,7	11,4	13,0	12,2	12,5	13,2	12,2	12,2	11,2	09,8	09,0	11,7
1950	10,8	11,5	12,6	11,6	11,4	12,2	12,9	11,9	12,4	10,7	09,1	10,2	11,5
51	11,5	11,1	11,0	12,6	12,6	13,1	13,7	12,5	12,2	11,4	11,0	12,3	12,1
52	12,7	11,2	12,6	12,6	13,1	13,5	13,6	13,2	12,6	11,8	10,1	11,0	12,4
53	13,0	12,4	12,1	12,7	12,5	14,0	14,2	13,8	11,9	11,4	11,4	10,9	12,5
54	12,3	12,1	12,8	12,5	12,4	13,1	13,3	13,3	12,8	11,8	10,7	10,8	11,6
55	12,4	11,9	11,4	11,9	12,8	13,0	13,2	12,9	11,9	10,4	09,8		

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