CYCLES AND QUASI-PERIODICITIES IN THE GLOBAL DISTRIBUTION OF SEA-LEVEL PRESSURE

by

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Ciklusok és kváziperiodicitások a tengerszinti légnyomás földgömbi eloszlásában. A dolgozat azt elemzi, hogy a légnyomáseloszlás meridionális földgömbi profilját hány harmonikus összetevő hullám írja le megbízhatóan, továbbá, hogy kimutathatóak-e ciklusok, illetve kváziperiodicitások a tengerszinti légnyomás időbeli menetében a Földön. A reális periodicitásokat statisztikai szignifikancia-vizsgálat segítségével határoztuk meg. Az évi és félévi ciklusokat vektoriális formában közöltük.

Megállapítottuk, hogy a légnyomáseloszlás meridionális földgömbi profiljának 1. és 2. harmonikusa jól tükrözi a tengerszinti légnyomás egyenetlen eloszlását a két félteke között. A harmadik harmonikus - mely a globális légnyomási mező állandó vonásait mutatja - kisebb súlyú tényező. Az összes további harmonikus jelentéktelen a profil kialakításában. A tengerszinti légnyomás évi és félévi ciklusainak vizsgálata - eltérő adatbázison - lényegében ugyanazokra a következtetésekre vezetett, melyekre *HANN és SÜRING (1939)*, illetve *HSU és WALLACE (1976)* jutottak. A tengerszinti légnyomás idősorok harmonikus analízisével kapott periodikus összetevő hullámok statisztikai szignifikancia-vizsgálata alapján leszögezhetjük, hogy a tengerszinti légnyomás időbeli menetében a Földön csak kétféle ciklus létezik: a jellegzetes *12* havi és a kevésbé markáns *6* havi. Számos szerző által mindezidáig megállapított nagy számú és igen különböző, statisztikailag szignifikánsnak tekintett egyéb periódusok adatainkban nem tapasztalhatóak. A leggyakrabban kutatott periodicitások - a 11 éves napfoltciklus, a troposzférikus kvázikétéves (leginkább 26 hónapos) oszcilláció, s a Déli Oszcilláció - a tengerszinti légnyomás időbeli menetében nem tükröződnek.

The study analyses *how many harmonic component waves describe the meridional global profile* of sea-level pressure distribution reliably; in addition, it analyses whether cycles or quasi-periodicities can be found on the Earth, in the temporal course of sea-level pressure. The real periodicities are determined by a statistical significance test. The yearly and half-yearly cycles are presented in vectorial form.

It has been established that the 1st and 2nd harmonics of the meridional global profile of air pressure distribution well reflect the uneven distribution of sea-level pressure between the two hemispheres. The 3rd harmonic, which shows the steady features of global air pressure field, is a factor of lesser importance. All the further harmonics are unimportant in the formation of this profile. The investigation of the yearly and half-yearly cycles of sea-level pressure has essentially led - on a different data basis - to the same conclusions to which *Hann and Süring (1939)*, as well as *Hsu and Wallace (1976)* had come. On the basis of the statistical significance test of the periodical component waves obtained by a harmonic analysis of the sea-level pressure time series it can be found that on the Earth, in the temporal course of sea-level pressure, there exist only two kinds of cycles: the characteristic *12*-month and the less sharp 6-month one. Consequently, the great number of, and very different, periodicities pointed out in the temporal course of sea-level pressure and considered to be *statistically significant by numerous* authors, are probably not real ones. The most frequently investigated periodicities - the 11-year sunspot cycle, the tropospheric quasi-biennial (mostly 26-month) oscillation, and the Southern Oscillation - are not reflected in the temporal course of sea-level pressure.

1. Object

The following questions arise: how many harmonic component waves do describe the meridional global profile of sea-level pressure distribution reliably, and what are the monthly and yearly courses of the individual component waves like? The first of the questions can be put with other words: how great a proportion of the full variance of the zonal monthly and yearly means of sea-level pressure can be explained by the first few harmonics? If this proportion is considerable, then producing further harmonics is unnecessary.

It will be examined, moreover, how the data base reflects the cycles and quasi-periodicities of sea-level pressure, which – in case of their reality – are of great importance from the point of view of long-range forecasts. The real periodicities will be determined by a statistical significance test. The yearly and half-yearly cycles will be presented in vectorial form.

2. Introduction

Besides the evident daily and yearly cycles, in sea-level pressure time series an astonishingly wide range of other periodicities have also been established. In the North Atlantic area, in surface and sea-level pressure time series periods of *2, 3.5–4.0, 5–6* and *11–12* months *(AMELUNG, 1962; LANDSBERG et al., 1966; BERKES, 1968; LOGINOV and SHUKHOMOZOVA, 1972)*, furthermore periods of *4–5* years *(LANDSBERG et al., 1966; SCHONWIESE, 1969, 1971)*, as well as of *5–6* years *(WAGNER, 1971; MICHELCHEN, 1981)* and of *21* years *(WAGNER, 1971)* have been discovered. In the Southern Hemisphere, in the time series of the air pressure differences between *January* and *July*, cycles of *3, 5, 11* and *18*-years can be found *(KHAMINOV, 1966)*. By the harmonic analysis of the Southern Oscillation Index *TRENBERTH (1976)* obtained a period of *3–6* years. The semi-annual mean zonal index of given temperate-belt latitudes (35-55°), derived from monthly mean *500-hPa* charts, shows *5,5-* and *10*-year periods *(WANG, 1963)*. In the intensity of the meridional circulation over the tropical Pacific Ocean *FU (1979)* found a fluctuation of *32–48*-month periods, *PECZELY (1978)* determined the same period in the time series of pressure anomalies over the subtropical zone of the South Pacific, and over the equatorial zone of the Pacific Ocean. *ANGELL and KORSHOVER (1968)* suppose that between latitudes *30°N* and *30°S* the periodicities of the two hemispheres are fundamentally in phase; in addition, they establish that in winter and spring there is a period of about 16 years at the *500-hPa* geopotential level over the Northern Hemisphere in the changes of meridional current, heat flux, zonal wind and temperature. By the harmonic analysis of the aridity index series over certain areas of India, *BHALME and JADHAV (1983)* discovered statistically significant quasi-periodicities of *3.3-6.6, 10* and *20* years. Of these periods, the first two are close to the modal peaks of the Southern Oscillation, suggesting that the oscillation of the aridity indexes can be brought into connection with the large-scale changes in air pressure over the Indo-Pacific. The other two periods (the *10-* and the *20*-year ones) are close to the 11-year sunspot cycle and the 22-year double sunspot cycle.

3. Data

The data basis of the study consists of the monthly mean sea-level pressure values of *247 stations* referring to the *30* years between *1951* and *1980 (Fig. 1)*.

From *17* stations – since they have incomplete data – we have uniformly taken into consideration the monthly mean values of the *23* years between 1958 and 1980 into. Among the stations there are weather ships *(39., 65., 66., 85., 91. and 108.)*, buoys *(166. and 184)*, and there are interpolated data *(84., 150., 198., 203., 208., 215., 236., 237., 245. and 247.)* as well. We have collected the pressure data series on the basis of the data of the volumes *"World Weather Record"*, as well as the mean sea-level pressure charts of monthly publications *"Monthly Climatic Data for the World"* and *"Die Witterung in Übersee"*.

The global distribution of the stations is relatively equal, but it is to be mentioned that, e.g., there are no data from China at all, and the number of stations is small in Siberia, as well as over the Pacific Ocean,

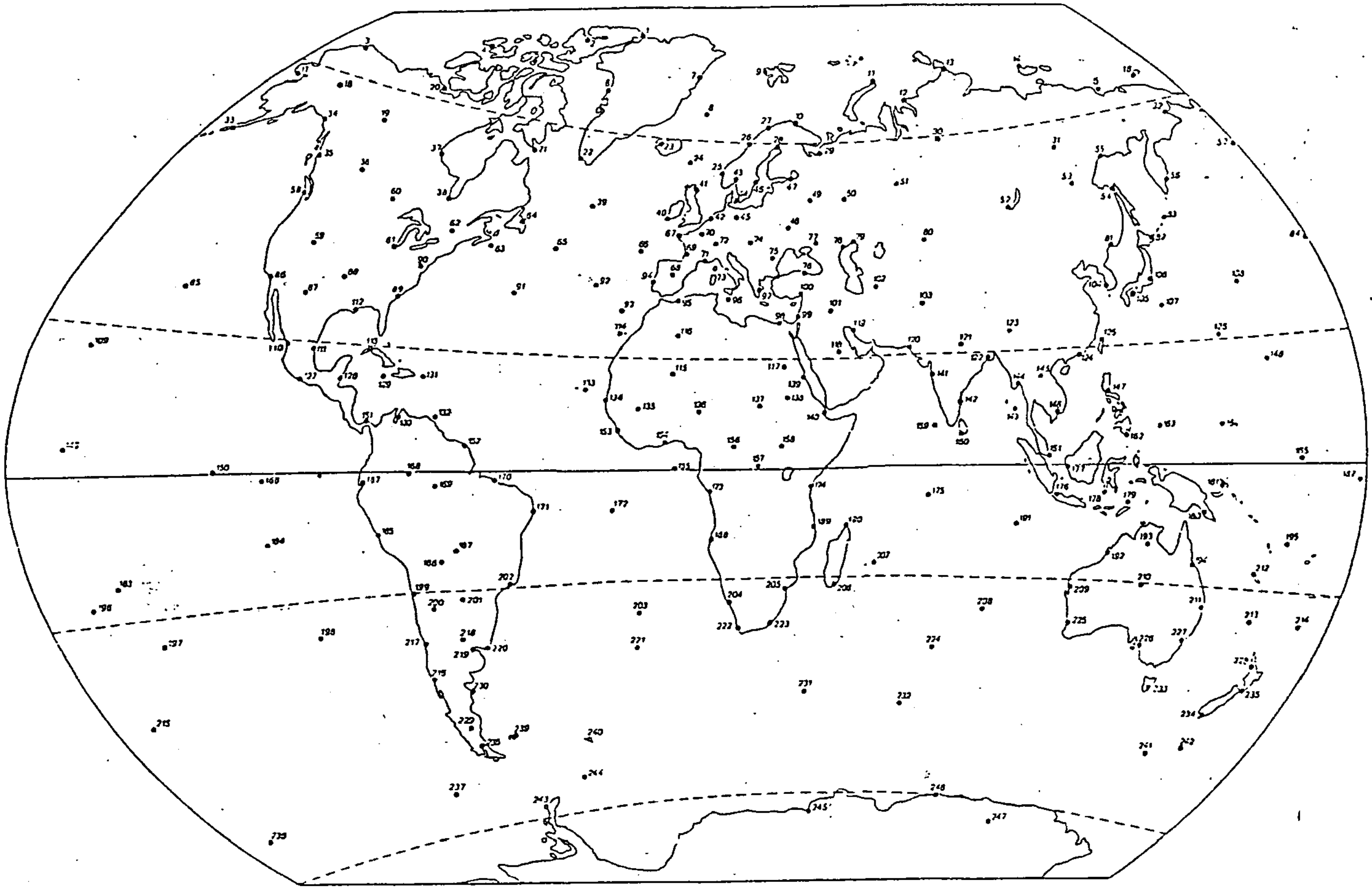

Fig. 1 Stations

furthermore, in the temperate-belt and polar regions of the Southern Hemisphere, too. The zonal distribution of the stations is included in *Table 1*.

Table 1

Zonal numbers of stations

90–80° N	2	0–10° S	17
80–70° N	14	10–20° S	13
70–60° N	17	20–30° S	19
60–50° N	24	30–40° S	14
50–40° N	27	40–50° S	7
40–30° N	24	50–60° S	7
30–20° N	18	60–70° S	5
20–10° N	22		
10– 0° N	17		
Northern Hemisphere	165	Southern Hemisphere	82

Earth 247

The distribution of the stations according to height above sea level is also determined *(Table 2)*.

Table 2

Percentage of stations found lower than a given height above sea level (m)

50 m	<	66.40 %
100	<	79.76
200	<	88.26
300	<	89.88
400	<	93.52
500	<	96.35
1000	<	99.18
1300	<	100.00

Results

The first five harmonic components of the samples, and their sums, consisting of the monthly and yearly means of sea-level pressure, by *10°* latitudes have been determined. Of them, those of the central months of each season, and those of the year are presented *(Figs. 2a, b, c, d, e)*. Investigations with similar purposes have already been performed by KAUFELD *(1972)* as well. The monthly mean sea-level pressure values, by *10°* latitudes, forming the basis of his investigations, had come from the data of the *International Geophysical Year (IGY)* – i.e. from the sea-level pressure values of globally *1,462* grid points measured at *1200 GMT* daily between *July 1, 1957 and December 31, 1958*. In this way KAUFELD (1972) produces and analyses the first 4 harmonics of the meridional profile of global sea-level pressure by *10°* latitudes.

According our computations it is sufficient to produce the first five harmonics of each sample, (the 5^{th} one will not be graphically published now) for these five components explain *87-90* per cent of the total variance

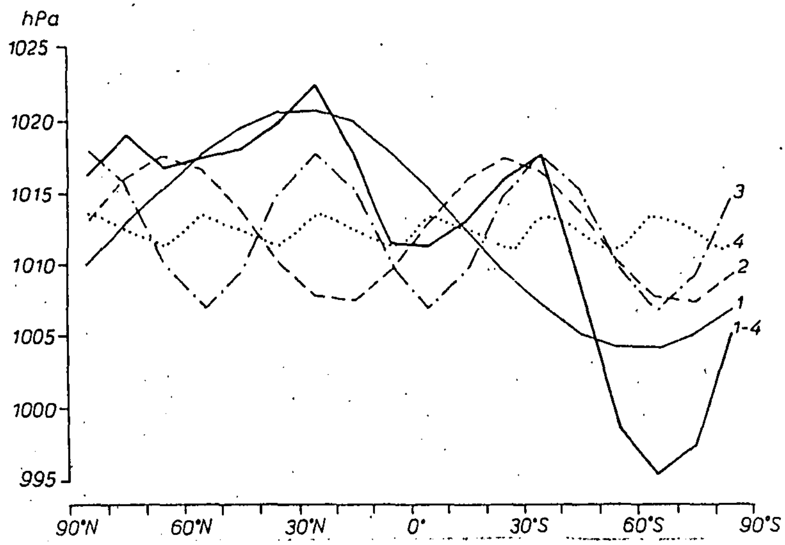

Fig. 2a The first four harmonics (1, 2, 3, 4) and their sum (1-4) of mean sea-level pressure, counted from the averages of mean monthly values at each 10th degree of latitude, January

of the original samples *(Table 3)*. The statistical significance of the amplitudes for the harmonics of the individual samples is indicated by the ratio A/E, where A is the amplitude and E is the mean value of the amplitudes. (A_{18}/E measures the statistical reality of the amplitudes of the first harmonic components for each *18*-element sample; A_9/E shows the statistical reality of the amplitudes of the second harmonic components for the same samples mentioned above, etc..) The 4^{th} and 5^{th} harmonics, e.g. contribute to the total variance of the individual samples *(Table 3)* in approximately the same and already an extraordinarily slight degree; consequently, they have little role in the modification of the meridional profiles of the monthly and yearly global mean sea-level pressure – as it is reflected by the graphic picture of the 4^{th} harmonic as well *(Figs. 2a, b, c, d, e)*.

Table 3

Cumulative variance and statistical significance of harmonic components

	explained variance	A_{18}/E	A_9/E	A_6/E	A_5/E	A_3/E
January	0.904	***2.389***	1.448	1.533	0.338	0.301
April	0.878	1.819	***2.086***	1.477	0.292	0.359
July	0.878	1.880	***2.302***	1.051	0.106	0.330
October	0.874	***2.161***	1.854	1.308	0.172	0.410
Year	0.886	***2.068***	***1.971***	1.348	0.261	0.319

The italicized values are significant at the 95 per cent level

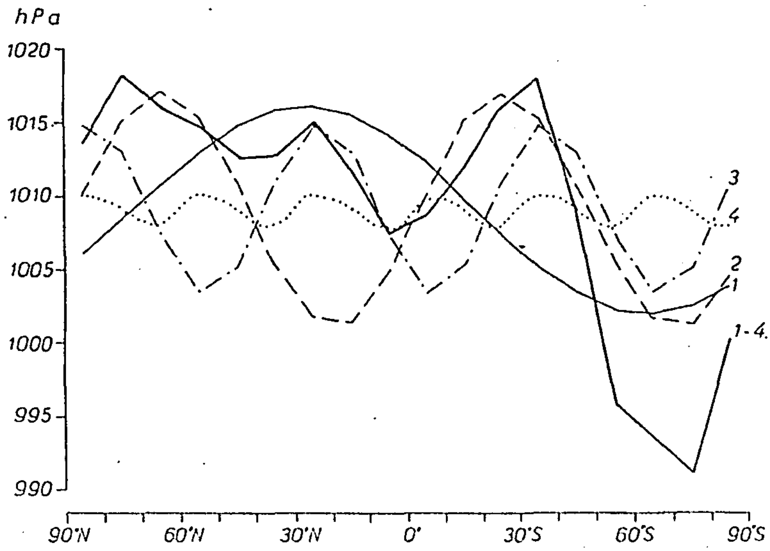

Fig. 2b The first four harmonics (1, 2, 3, 4) and their sum (1-4) of mean sea-level pressure, counted from averages of mean monthly values at each 10th degree of latitude, April

The sum of the first four harmonics clearly shows the most marked characteristic of the global distribution of sea-level pressure, i.e. the extraordinarily powerful decrease of air pressure in the southern hemispheric westerlies, in the subantarctic pressure trough. The subtropical high-pressure belt in the Southern Hemisphere is similarly characteristic, especially in the summer and autumn of the Northern Hemisphere. Its northern hemispheric counterpart is more characteristic only in winter, but in summer it disappears, and is, also in yearly average, less developed than the southern hemispheric one. The equatorial depression is the weakest in the summer of the Northern Hemisphere; in the other seasons of the year, as well as in the yearly average it definitely deepens. In spring and summer, in the polar region of the Northern Hemisphere, high pressure is more characteristic than in the subtropical belt. Air pressures are about equivalent over the two regions even in the yearly average, and the subtropical area has a higher pressures only in autumn and winter. In the temperate belt of the Northern Hemisphere, sea-level pressure has a local minimum, which exists during the whole year, but is the most characteristic in spring. The reason for this is that under the influence of increasing radiation the contrast of temperature between oceanic and continental surfaces, as well as between the regions of the lower and the higher latitudes increases greatly. That increases the pressure-gradient, so the intensity of the westerlies grows in this area; which brings about a more powerful decrease of pressure in the temperate belt.

The first harmonic shows the fact that air pressure is higher in the Northern Hemisphere than in the Southern Hemisphere. In summer the maximum is between the latitudes *10°N* and *20°N*, in the other seasons and in the yearly average it is between the latitudes *20°N* and *30°N*. On the other hand, according to *KAUFELD*'s calculations *(1972)* the maximum in the annual mean can be found near the latitude *11°N*, i.e. in the vicinity of the thermal equator. In the *KAUFELD*'s study *(1972)* the first harmonic indicates the fact that in lower latitudes air pressure is higher than over higher latitudes.

The second harmonic mostly shows the disproportions between the Northern and the Southern Hemisphere. Its maximums are not symmetrical to

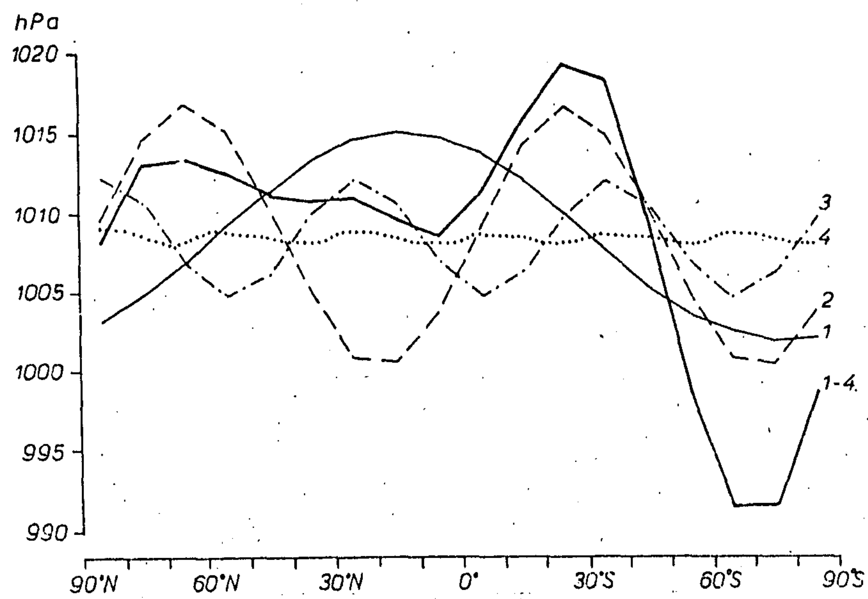

Fig. 2c The first four harmonics (1, 2, 3, 4) and their sum (1-4) of mean sea-level pressure, counted from averages of mean monthly values at each 10th degree of latitude, July

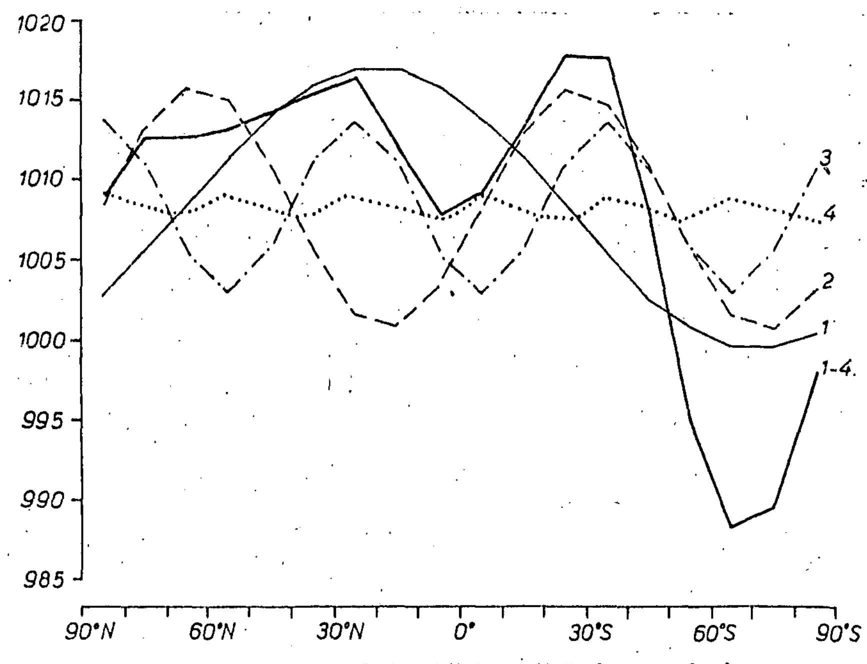

Fig. 2d The first four harmonics (1, 2, 3, 4) and their sum (1-4) of mean sea-level pressure, counted from averages of mean monthly values at each 10th degree of latitude, October

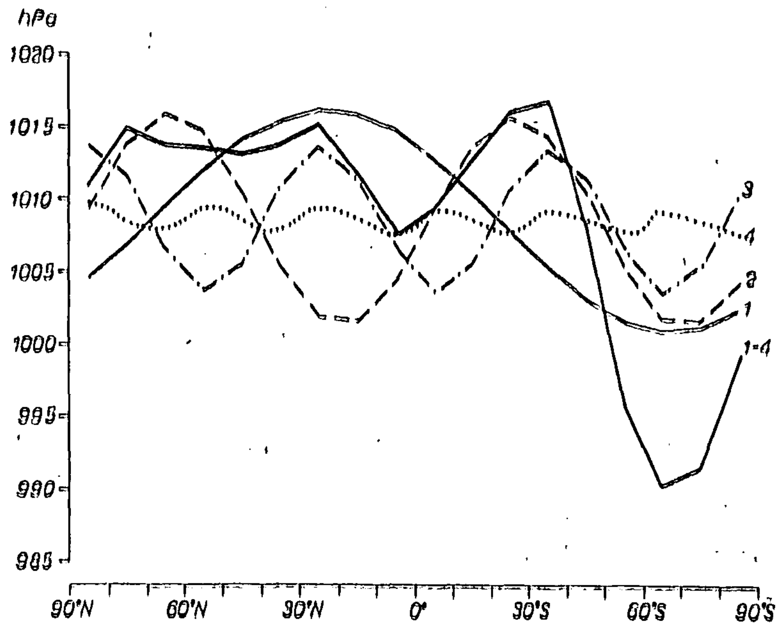

Fig. 2a The first four harmonics (1, 2, 3, 4) and their sum (1–4) of mean sea-level pressure, counted from averages of mean monthly values at each 10th degree of latitude, year

the equator, but seasonally and in the yearly average alike they shift northwards approximately by 20 degrees. In the yearly average, *KAUFELD (1972)* came to the same conclusion. In spring and summer the amplitude of the second harmonic is bigger than that of the first harmonic; in autumn and winter it is smaller; and it is smaller in the yearly average, too, where *KAUFELD (1972)* got a contrary result. The amplitude and the phase of the third harmonic are the most stable both seasonally and in the yearly average. It is almost symmetric to the equator, and shows the permanent global air pressure distribution: an equatorial low-pressure trough, subtropical high-pressure zones in the area of the latitudes *30°*, subpolar low-pressure belts in the neighbourhood of the latitudes *60°*, and polar high-pressure areas. As regards the yearly average, *KAUFELD (1972)* came to the same conclusion.

The role of the *4th* (and of each further) harmonic (and that of the 4th component according to *KAUFELD's* calculations *(1972)* as well) in the forming of the meridional profiles of the monthly and yearly sea-level pressure is –in accordance with the earlier results – not significant *(Figs. 2a, b, c, d, e; Table 3)*.

Summarizing the facts mentioned above, the first and second harmonic components well reflect the uneven distribution of sea-level pressure between the two hemispheres. The third harmonic component, which shows the permanent features of global pressure field, is a factor carrying less weight.

Von HANN and SURING (1939) summarized the main results of the earlier works dealing with the annual course of surface pressure, as follows. Over the equatorial areas, the annual change is very slight. In the higher latitudes, the annual change can be put into three main types: 1. *continental type*, which is characterized by a pressure maximum in winter and a pressure minimum in summer; 2. with the *oceanic type*, the maximum is in summer, the

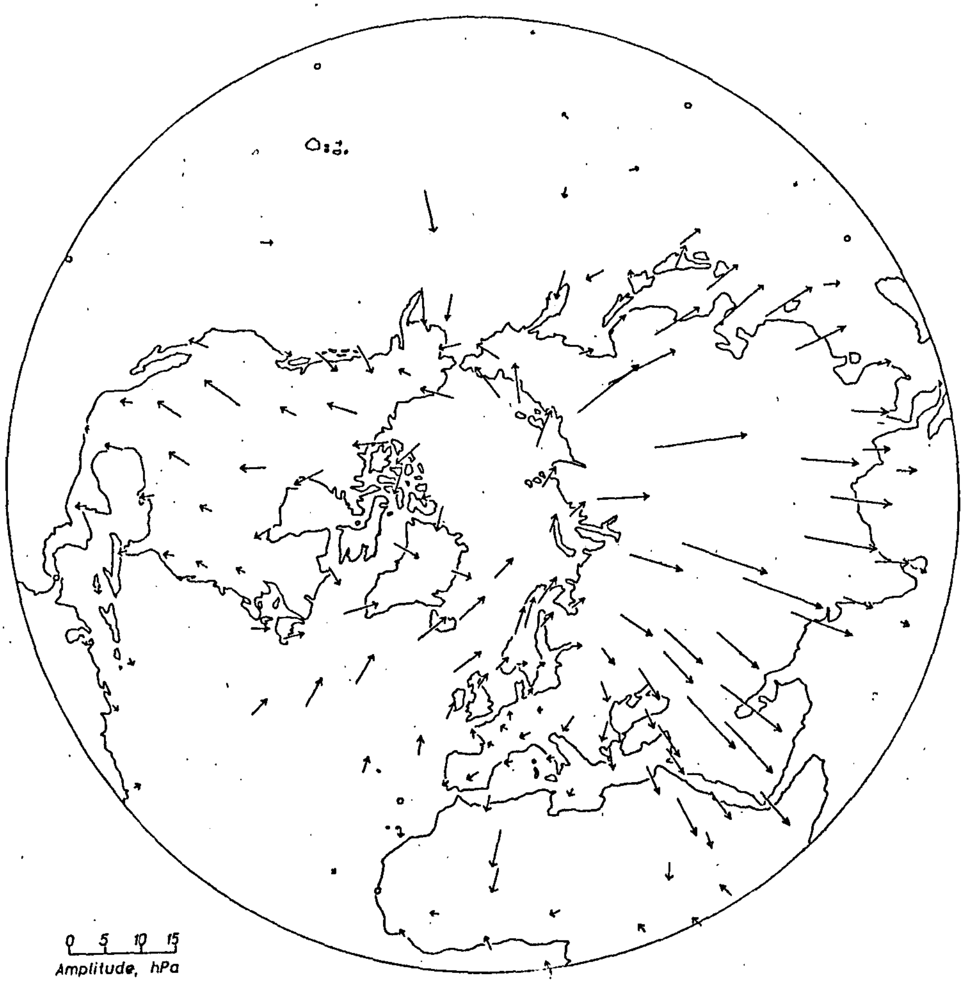

Fig. 3a Amplitude and phase of the annual cycle of sea-level pressure, Northern Hemisphere

minimum is late in the autumn; 3. and with the *arctic* and *subarctic types*, the maximum occurs in April or May, the minimum in January or February, with a secondary maximum in November. The *HAHN* and *SÜRING*'s classification system, which was mainly based on the data of northern hemispheric stations, has essentially been verified by the latest descriptions, too.

Comparing the middle-latitude regions of the oceans, as well as the polar areas of the Southern Hemisphere with the zone between the latitude 50°S and the Antarctic coastal district, the semi-annual cycle shows an opposite phase in the annual course of air pressure. This phenomenon, which is well reflected in our data as well (*Figs. 2a, b*), has already been described by several authors (e.g. *VOWINCKEL, 1955a, 1955b; SCHWERDTFEGER and PROHASKA, 1956; HSU and WALLACE, 1976*). In monthly mean sea level-pressure time series interpolated to grid points, *HSU and WALLACE (1976)* have analysed the global distribution of the annual and semi-annual cycles, and published them in a vectorial form.

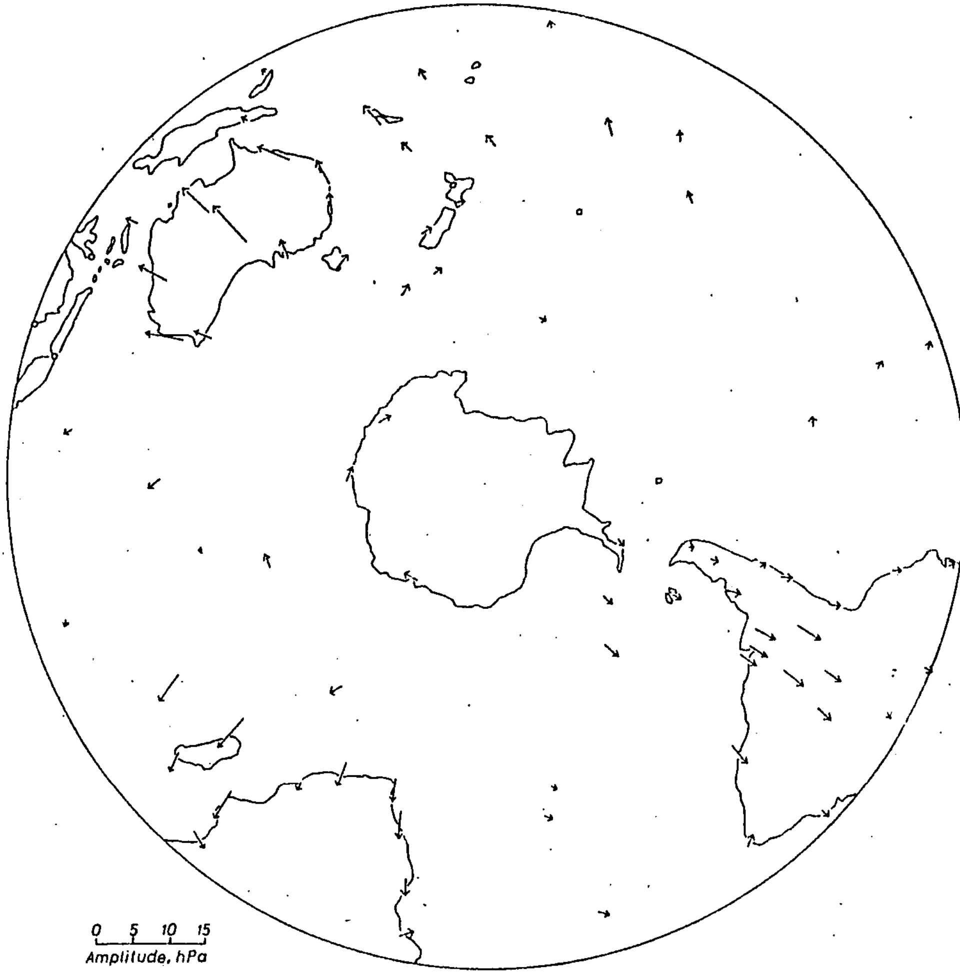

Fig. 3b Amplitude and phase of the annual cycle of sea-level pressure, Southern Hemisphere

After removing the linear trends, sea-level pressure time series of each station have been subjected to a harmonic analysis. The method has already been described by a number of authors. Among them *HAMED et al. (1986)* offer a very clear and concise survey of the harmonic analysis. For deciding the reality of an amplitude belonging to a definite length of period, the same authors *(HAMED et al., 1987)* give such limits - by the aid of the Monte Carlo method - that the probability of amplitudes greater than these limits is already very little: *10, 5,* or *1 %.* In our procedure of decision the significance of the amplitudes haves been found on the basis of these limits.

The amplitudes and phases have been plotted in a vectorial form *(Figs. 3-4)*, where the length of the arrows indicates the amplitude of the yearly cycle, and the direction shows the phase. When plotting, the midpoint of the amplitude length belonging to the given station (or rather to its pressure time series) gets onto the geographical coordinates of the

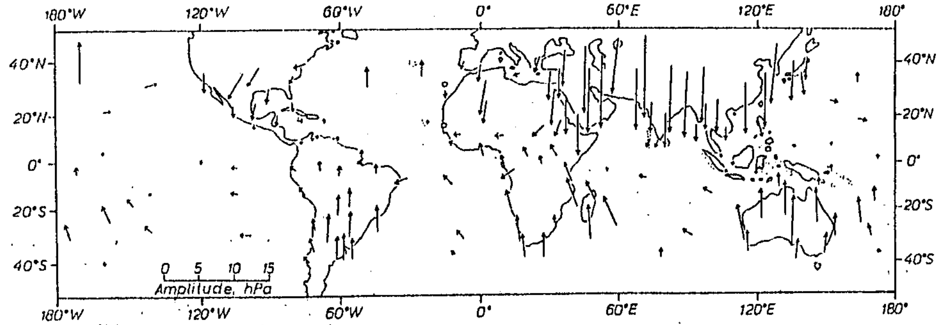

Fig. 3c Amplitude and phase of the annual cycle of sea-level pressure, 40° N - 40° S

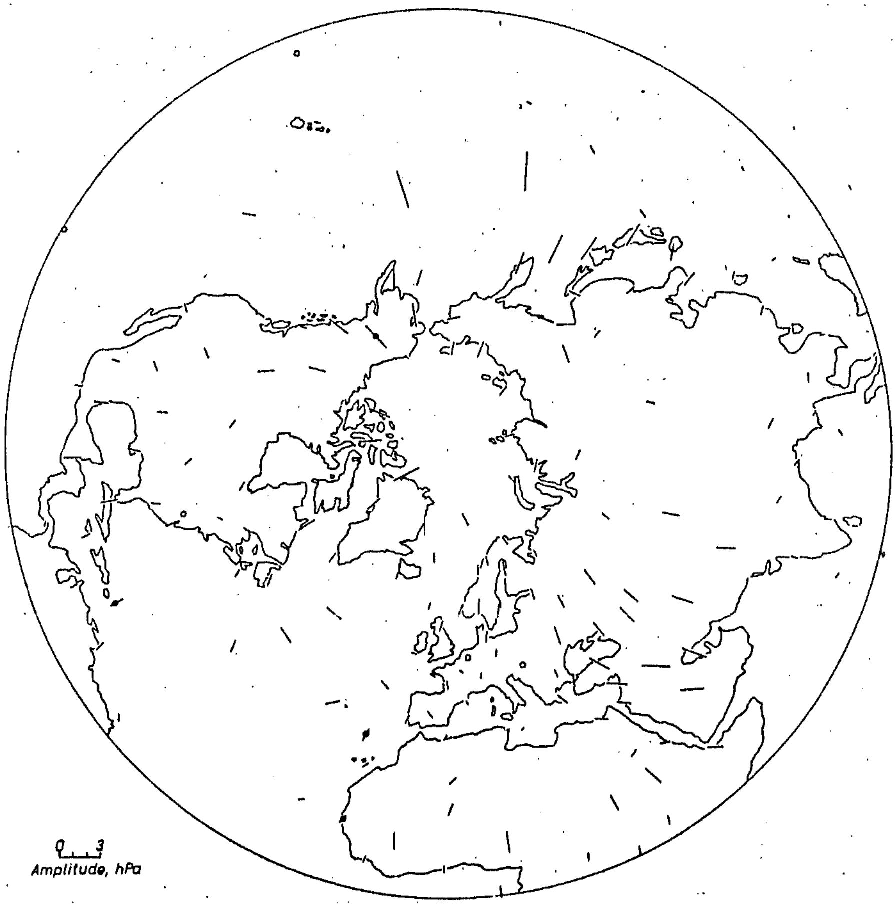

Fig. 4a Amplitude and phase of the semi-annual cycle of sea-level pressure, Northern Hemisphere

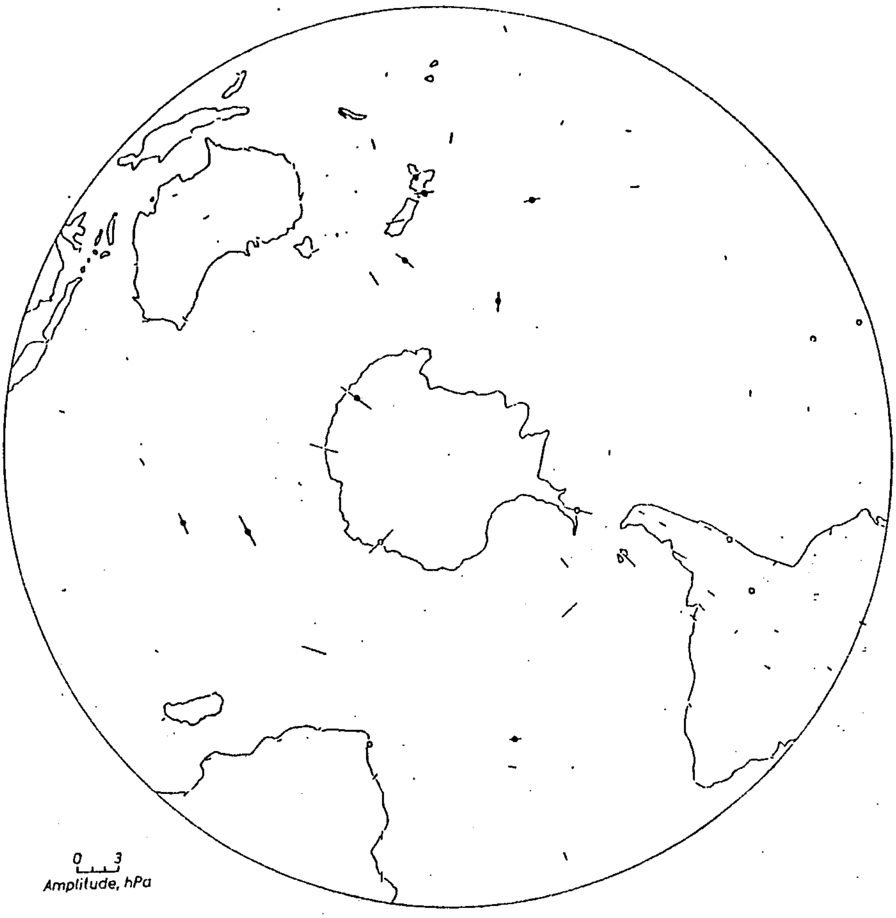

Fig. 4b Amplitude and phase of the semi-annual cycle of sea-level pressure, Southern Hemisphere

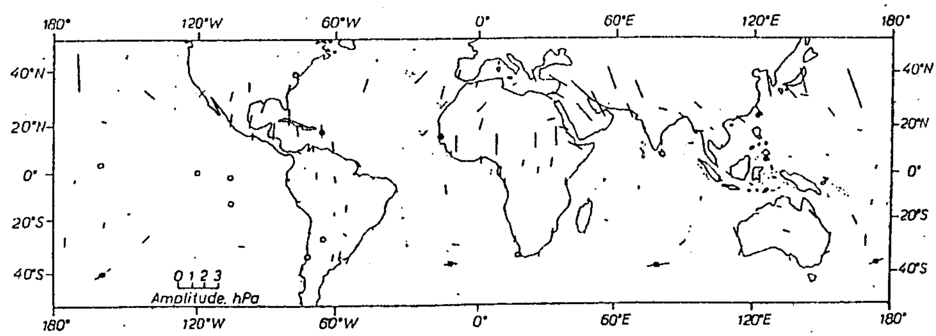

Fig. 4c Amplitude and phase of the semi-annual cycle of sea-level pressure, 40° N - 40° S

station. The interpretation of the phase is as follows. If an arrow points from the north towards the south, it indicates maximum in the annual cycle on 1 January; if it points from the east towards the west, it indicates maximum on 1 April, etc.. Thus the arrows revolve clockwise, about *1°* daily. It must be remarked that with this phase interpretation an arrow which points from the north towards the south indicates in the Northern Hemisphere a winter maximum, at the same time it shows in the Southern Hemisphere a summer maximum, etc.. The interpretation of the phase is the same for the semi-annual cycle, with the limitation that in the extreme points of the vectors there are no arrows. If, in this way, a vector shows in north-south direction, this indicates a semi-annual cycle the maximums of which are on 1 January and on 1 July; if it shows in east-west direction, then maximums occur on 1 April and on 1 October, etc.. This interpretation has been applied after *HSU and WALLACE (1976)*.

The amplitudes and phases of the annual cycle can be seen in *Fig. 3*, while those of the semi-annual cycle are shown in *Fig. 4*. (Supplements. *Figs. 3a, b*: the amplitudes smaller than *0.5 hPa* are denoted by empty circles. *Fig. 3c*: the amplitudes smaller than *0.2 hPa* are denoted by empty circles. *Figs. 4a, b, c*: the amplitudes smaller than *0.1 hPa* are denoted by empty circles. The stations at which the second harmonic of the annual cycle is greater than the first harmonic, are shown by thick circles.)

On the basis of these *Figs. 3-4* the establishments are as follows:

- The *continental type* described by *HANN and SÜRING (1939)* is characteristic over all the continents, in subtropical and temperate latitudes of both hemispheres.

- *HANN and SÜRING*'s *oceanic type* can be shown only for the oceans of subtropical and temperate latitudes of the Northern Hemisphere. A tendency from the maximum of late autumn to that of the winter can be observed over the subtropical oceans of the Southern Hemisphere, where the amplitudes of the annual cycle are considerably smaller than over the neighbouring continents.

- Over the *polar areas of the Northern Hemisphere* it is the tendency of a maximum late in summer that can be seen in the annual cycle, in contradiction to the *HANN and SÜRING*'s conclusion, as well as to the conclusiom of *HSU and WALLACE (1976)*, who have established here a tendency to a spring maximum.

- Over the *Southern Hemisphere's oceans of temperate latitudes* as well as over the *Antarctic coastal region* a characteristic semi-annual oscillation can be observed. Between the latitudes *40°* and *50°S*, at the time of the equinoxes a tendency referring to a maximum can be found, while south of the latitude *60°S* maximums occur in the periods near the solstices. This semi-annual oscillation of different phases, taking place between the temperate and higher latitudes of the Southern Hemisphere had already been pointed out by a number of researchers previously, as we have already referred to this in what has gone before. (Although the network of stations is extraordinarily sparse in this area, yet it is sufficient for us to point out this phenomenon over most of the Southern Hemisphere's area mentioned above.)

Our results - apart from the third establishment - show good agreement with the *HANN and SÜRING*'s results *(1939)*, as well as with the *HSU and WALLACE*'s conclusions *(1976)*.

The statistical significances of both the annual and the semi-annual cycles of sea-level pressure, as well as those of all the other periodic component waves have been investigated station by station. The investigation referred to *n/2-1* component waves at each stations - from the *2nd* to the *(n/2)nd* periodic component - where *n* is the number of the elements in the sample. (The number of the monthly mean sea-level pressure values in the period taken into consideration.)

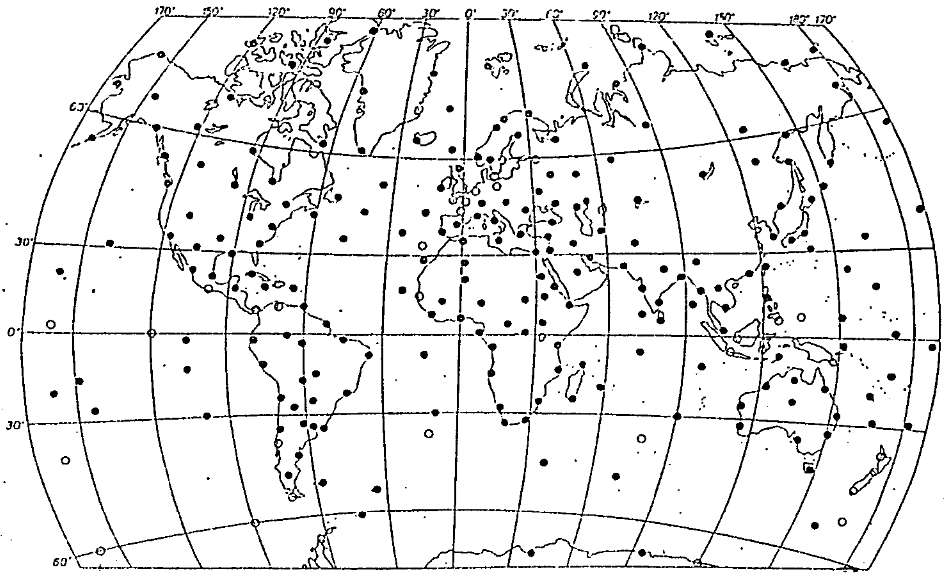

Fig. 5a The 12 monthly cycle of sea-level pressure, by stations;
● = significant, ○ = not significant

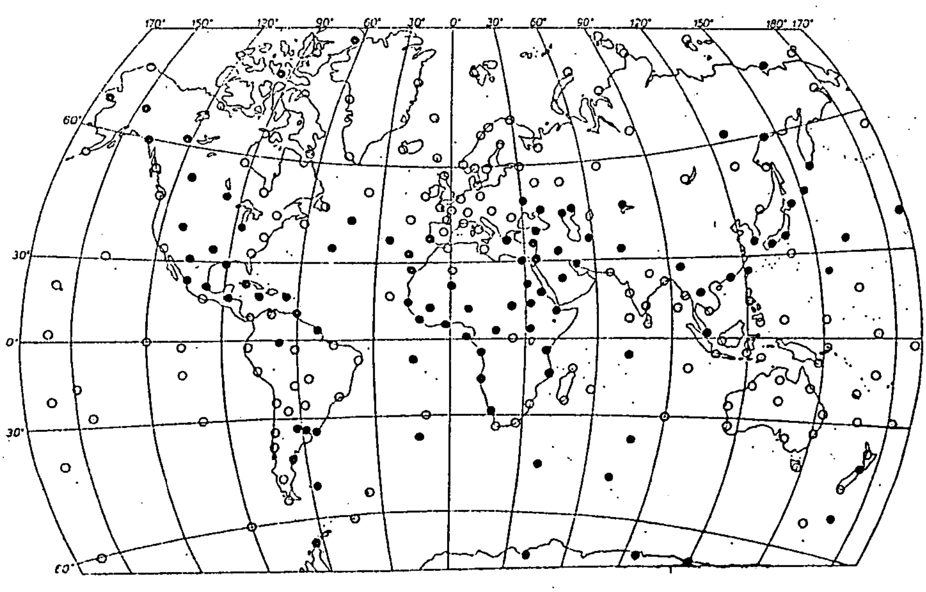

Fig. 5b The 6 monthly cycle of sea-level pressure, by stations;
● = significant, ○ = not significant

The annual cycle was not characteristic only with *13.4* % of the stations. The areas of these are in the southern basin of the Pacific Ocean, in the regions of Indonesia and Central America, as well as in Western Europe and the Baltic countries (*Fig. 5a*). The semi-annual cycle is not to be found in *30.1* % of the stations. It is not shown at all in the whole basin of the Pacific Ocean, in Europe, the polar regions of the Northern Hemisphere, Australia, the Indian subcontinent, and in a considerable part of South America (*Fig. 5b*). Significant periodicities of *11* and *13* months have been found in *19.4* % of all stations. These are parts of the annual cycle, and so they cannot be considered to be completely independent of that. The *14*-month period was statistically significant in 2 cases, the *4*-month one in *6*, the *2*-month one in *4* cases; other periods were statistically real on *1* occasion each, altogether in 7 cases, that is the periods mentioned above were only significant altogether in *6.9* % of the stations examined. On the basis of these results it can generally be established that in the temporal course of global sea-level pressure there exist only two kinds of cycles: the characteristic *12-month*, and the less marked *6-month* one. There is no other periodicity. Consequently, the great number of, and rather different, periods pointed out in the temporal course of sea-level pressure, and considered to be statistically significant by numerous authors, are probably not real ones. The most frequently searched periods - the *11*-year sunspot cycle, the tropospheric quasi-biennial (mostly *26*-month) oscillation, and the Southern Oscillation - are not reflected in the temporal course of sea-level pressure.

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