ABSTRACT

This paper is a detailed study of the influence of the 11-year solar cycle on precipitation on a world scale. The present is the third paper on this subject.

The conclusions of the previous papers (Xanthakis, J., 1972 and Xanthakis, J.- Poulakos, C. - Tritakis, B., 1974) are reported in the introduction.

In continuation of the previous two papers the treatment of this subject which has been adopted is as follows. Firstly the whole of the Southern hemisphere of the earth was examined in accordance with the technique described in the introduction.

The results of the study of the Southern hemisphere are proportional to those for the Northern, namely:

1) There are high values of correlation coefficients between the Zonal annual precipitation departure from minimum $(\overline{R - R_0})$ and the area index I_α, within the high latitude zones ($\varphi > 50°$ S).

2) In the equatorial zones the correlation between $R - R_0$ and I_α is also high although there are inversions in the phase of the time-series $\overline{R - R_0}$.

3) In the middle-latitude zones ($40°$ S $\geqslant \varphi \geqslant 20°$ S) the correlation is rather low.

Subsequently in order to establish patterns of long-term variations of the time-series $(\overline{R - R_0})$ the 11-year moving averages $\overline{R - R_0}$-values have been calculated for both the Northern and the Southern hemisphere.

The processing of these values indicated the existence of long-term periodic variations (12 - 90 years) which can be defined by the general relation:

$$L_t = \sum_{i=1}^{i=n} \alpha_i \sin \frac{2\pi}{\Omega_i} (T - T_0)$$

where Ω_i various periodicities expressed in years and α_i, T, T_0, constants.

It is considered that the long-term variations L_t are of terrestrial origin.

Consequently the removal of these variations from the time-series $\overline{(R-R_0)}$ would make the influence of the 11-year cycle on precipitation more evident.

From tables No. 3, 4 we conclude that the correlations between the term $\overline{(R-R_0)} - L_t$ and the indices of solar activity are indeed significantly higher than the correlations between these indices and the term $\overline{(R-R_0)}$.

Afterwards we attempted to represent the zonal annual precipitation departure from the minimum $\overline{(R-R_0)}$ within each terrestrial zone by a relation of the form:

$$\overline{R-R_0} = S_\alpha + L_t + W$$

where, $S_\alpha = \alpha \pm b I_\alpha$ where I_α the area index by which we express the solar activity and a, b constants calculated by the least-square method.

L_t, represents the long-term periodicities on the precipitation we mentioned above.

W, are short-term sporadic variations (4-8 years) which are most probably caused by local climatic conditions. It is worth mentioning that we have studied these short-term sporadic variations W.

The conclusions of this study will be published at a later date, independently.

RÉSUMÉ

Dans ce travail nous avons étudié la corrélation entre l'activité solaire et la variation moyenne annuelle de la précipitation $(\overline{R - R_0})$, dans les différentes zones de la surface terrestre.

Deux publications (Xanthakis, J., 1972, et Xanthakis, J. - Poulakos, C. - Tritakis, B., 1974) ont précédé cette étude, dont les résultats sont exposés dans l'introduction du présent travail.

Des résultats obtenus, pour les zones de l'hémisphère Sud, sont analogues à ceux des zones correspondantes à l'hémisphère Nord, c.à.d.:

1) Nous avons trouvé des corrélations élevées, entre l'activité solaire exprimée par l'indice des aires I_α, ou par le nombre de Wolf WN, et des valeurs moyennes annuelles de la variation de la précipitation $\overline{R - R_0}$, dans les zones de hautes latitudes ($\varphi > 50°$ S).

2) Pour les zones équatoriaux, les corrélations entre $\overline{R - R_0}$ et I_α sont aussi élevées, avec la différence qu'on observe, un inversement des phases, des ceux deux variables, pour certaines dates.

3) Pour les zones moyennes ($40°\text{ S} \geqslant \varphi \geqslant 20°\text{ S}$) la corrélation est plutôt très petite et sans signification statistique.

Par suite pour constater s' il y a des variations périodiques avec des périodes plus longues que 11 ans, nous avons calculé pour toutes les zones de l'hémisphère Nord et Sud. «Les moyennes mobiles, de onze ans de $(\overline{R - R_0})$».

L'analyse de ces valeurs a montré l'existence des variations périodiques, de longue période 12 à 90 ans, qui peuvent être representées par la relation :

$$L_t = \sum_{i=1}^{i=n} \alpha_i \sin \frac{2\pi}{\Omega_i} (T - T_0)$$

où Ω_i représente les différentes périodes qui sont exprimées en années et α_i, T, T_0 représentent des termes constantes.

Sil'on soustrait les termes périodiques L_t, des valeurs $\overline{R - R_0}$, les différences $\overline{R - R_0} - L_t$ sont plus fortement correlées avec l'activité solaire.

En effet comme le montrent les tableaux 3 et 4 les corrélations entre les quantités $(\overline{R - R_0}) - L_t$ et les indices de l'activité solaire sont sensiblement plus élevées, que les corrélations, entre les indices de l'activité solaire et les valeurs $(\overline{R - R_0})$.

Finalement, nous avons cherché de représenter la variation moyenne annuelle de la précipitation $\overline{R - R_0}$ dans chaque zone terrestre par une relation de la forme:

$$(\overline{R - R_0}) = S_\alpha + L_t + W$$

où $S_\alpha = \alpha \pm b\, I_\alpha$, où I_α est l'indice des aires avec lequel nous exprimons l'activité solaire et a, b les constantes qui ont été calculées par la méthode des moindres carrés.

L_t représente les termes périodiques à longue période, qui ont été également donnés ci-dessus.

Et finalement W représente les termes périodiques qui apparaissent dispersés dans la relation précédente et qui sont dûs probablement aux causes climatologiques locales. Des termes W ont en général des faibles amplitudes et leurs périodes varient entre 4 et 8 ans.

L'étude détaillée de ces termes W, faira l'objet d'une étude dont les résultats seront publiés prochainement.

ΠΕΡΙΛΗΨΙΣ

Ἡ πραγματεία αὐτὴ ἀποτελεῖ λεπτομερῆ μελέτη τοῦ φαινομένου τῆς ἐπιδράσεως τοῦ 11-ετοῦς ἡλιακοῦ κύκλου ἐπὶ τῆς βροχοπτώσεως.

Τῆς ἐργασίας αὐτῆς ἔχουν προηγηθῆ δύο ἀνακοινώσεις (Xanthakis, J., 1972 καὶ Xanthakis, J. - Poulakos, C. - Tritakis, B., 1974), τὰ πορίσματα τῶν ὁποίων ἐκτίθενται εἰς τὴν εἰσαγωγὴν τῆς παρούσης.

Ἡ ἐπέκτασις τῶν ἐρευνῶν εἰς τὰς ζώνας τοῦ Νοτίου ἡμισφαιρίου ἔδωσεν ἀποτελέσματα ἀνάλογα μὲ ἐκεῖνα τοῦ Βορείου ἡμισφαιρίου, ἤτοι:

1) Παρατηροῦνται ὑψηλαὶ συσχετίσεις μεταξὺ τῆς ἡλιακῆς δραστηριότητος ἐκφραζομένης διὰ τοῦ δείκτου τῶν ἐμβαδῶν I_α ἢ τῶν ἀριθμῶν Wolf (W.N.) καὶ τῆς μέσης ἐτησίας μεταβολῆς τῆς βροχοπτώσεως ($\overline{R - R_0}$) εἰς τὰς ζώνας ὑψηλοῦ γεωγραφικοῦ πλάτους ($\varphi > 50^\circ$ S).

2) Εἰς τὰς ἰσημερινὰς ζώνας ἡ συσχέτισις μεταξὺ $\overline{R - R_0}$ καὶ I_α εἶναι ἐπίσης ὑψηλὴ μὲ τὴν διαφορὰν ὅτι παρατηροῦνται ἀντιστροφαὶ φάσεως μεταξὺ τῶν δύο τούτων μεταβλητῶν εἰς ὡρισμένας ἐποχάς.

3) Εἰς τὰς μέσας ζώνας ($40^\circ \text{S} \geqslant \varphi \geqslant 20^\circ \text{S}$) ἡ συσχέτισις εἶναι μᾶλλον χαμηλὴ ἄνευ στατιστικῆς σημασίας.

Ἐν συνεχείᾳ, προκειμένου νὰ ἐντοπισθοῦν περιοδικαὶ μεταβολαὶ μὲ περίοδον 11 ἐτῶν, ὑπελογίσθησαν δι᾿ ὅλας τὰς ζώνας Βορείου καὶ Νοτίου ἡμισφαιρίου οἱ ἑνδεκαετεῖς κινητοὶ μέσοι ὅροι τῶν τιμῶν $\overline{R - R_0}$. Ἡ ἀνάλυσις τῶν τιμῶν τῶν ὅρων τούτων ἔδειξε τὴν ὕπαρξιν περιοδικῶν μεταβολῶν μακρᾶς περιόδου (12 - 90 ἐτῶν), αἱ ὁποῖαι δύνανται νὰ παρασταθοῦν διὰ τῆς γενικῆς σχέσεως:

$$L_t = \sum_{i=1}^{i=n} \alpha_i \sin \frac{2\pi}{\Omega_i} (T - T_0)$$

ὅπου Ω_i αἱ διάφοροι περιοδικότητες ἐκπεφρασμέναι εἰς ἔτη καὶ α_i, T, T_0, σταθεροὶ ὅροι.

Οἱ περιοδικοὶ ὅροι μακρᾶς περιόδου L_t ὑποτίθεται ὅτι εἶναι γηΐνης προελεύσεως. Συνεπῶς ἡ ἀφαίρεσις ἐκ τῶν διαφορῶν $(R - R_0)$ τῶν ἐπιδράσεων τῶν ὅρων L_t θὰ καθίστα τὴν 11-ετῆ ἐπίδρασιν τῆς ἡλιακῆς δραστηριότητος πλέον ἐμφανῆ. Πράγματι, ὅπως δεικνύουν οἱ πίνακες 3 καὶ 4, αἱ συσχετίσεις μεταξὺ τῶν ποσοτήτων $(R - R_0) - L_t$ καὶ τῶν δεικτῶν τῆς ἡλιακῆς δραστηριότητος εἶναι αἰσθητῶς ὑψηλότεραι ἀπὸ τὰς συσχετίσεις μεταξὺ τῶν ἐν λόγῳ δεικτῶν καὶ τῶν διαφορῶν $\overline{R - R_0}$.

Κατόπιν τῶν ἀνωτέρω ἐπεζητήσαμεν νὰ παραστήσωμεν τὴν μέσην ἐτησίαν μεταβολὴν τῆς βροχοπτώσεως $(R - R_0)$ εἰς ἑκάστην γηΐνην ζώνην διὰ μιᾶς σχέσεως τῆς μορφῆς:

$$\overline{(R - R_0)} = S_\alpha + L_t + W$$

ὅπου $S_\alpha = \alpha \pm b I_\alpha$, καὶ I_α ὁ δείκτης τῶν ἐμβαδῶν διὰ τοῦ ὁποίου ἐκφράζεται ἡ ἡλιακὴ δραστηριότης καὶ α, b σταθεραὶ ὑπολογιζόμεναι διὰ τῆς μεθόδου τῶν ἐλαχίστων τετραγώνων.

L_t, παριστῶσι τὰς ἀνωτέρω μακρᾶς περιόδου περιοδικὰς μεταβολὰς τῆς βροχοπτώσεως.

Τέλος W, παριστᾷ περιοδικοὺς ὅρους ἐμφανιζομένους σποραδικῶς, οἱ ὁποῖοι ὀφείλονται πιθανῶς εἰς τοπικὰ κλιματολογικὰ αἴτια. Οἱ ὅροι W_i κέκτηνται μικρὸν σχετικῶς εὖρος, αἱ δὲ περίοδοι αὐτῶν κυμαίνονται μεταξὺ 4-8 ἐτῶν.

Σημειοῦμεν ἐνταῦθα ὅτι ἡ μελέτη τῶν περιοδικῶν ὅρων W θὰ μᾶς ἀπασχολήσῃ ἰδιαιτέρως, τὰ δὲ πορίσματα τῆς μελέτης ταύτης θὰ δημοσιευθοῦν αὐτοτελῶς, προσεχῶς.

SOLAR ACTIVITY AND A GLOBAL SURVEY OF PRECIPITATION

1. INTRODUCTION

In this paper we intend to study the relation between the annual variations in precipitation in different zones of the Earth's surface and the variations of solar activity for the corresponding period.

For this purpose let R_i represent the annual level of precipitation in a station, and R_0 the lowest precipitation recorded in that station in any year during the period under study. The difference $R_i - R_0$ represents the variation, in any one year, between the minimum precipitation in that station and the actual one for the year observed.

If, instead of considering an individual station one considers the total number of stations (N) in a zone of the Earth's surface, then the average value

$$\overline{R - R_0} = \frac{1}{N} \Sigma (R_i - R_0)$$

will represent the annual departure from minimum over the whole zone. This will be called «Zonal annual precipitation departure from minimum».

Zones were determined by dividing the surface of the Earth into different latitude belts, defined by parallels of geographic latitude 10 degrees latitude apart as follows:

$$\varphi_i \leqslant \varphi \leqslant \varphi_{i+10^\circ}, \qquad i = 0, 10^\circ, 20^\circ, \ldots, 70^\circ.$$

It is obvious that an objective determination of the $\overline{R - R_0}$-values in each latitude zone would require, 1) a large number of stations in that zone and 2) stations uniformly distributed over the whole area of this particular latitude belt. In practice however, these ideal conditions are rarely met, because the number of stations with complete records since 1880 is limited while the uneven distribution by longitude of oceans and continents results in a irregular distribution of stations.

For these reasons, in computing the $\overline{R - R_0}$ - values, we were forced to include data from all available stations in each latitude zone, regardless of the year of the beginning of precipitation records in such stations.

The increase of the number of stations operating between 1880 and 1960 was found to be more or less gradual and is commented upon in § 2 (see also fig. 4).

The solar activity cycle was expressed by either the area index or the sunspot numbers. In this research work we used mostly the area index I_α, simply defined by the relation:

$$I_\alpha = \frac{1}{2}\left[\sqrt{A} + \sqrt{f}\right]$$

where A and f are the total areas of sunspots and faculae respectively, corrected for foreshortening, which are given by the relevant publications of Greenwich observatory. The use of the area index in preference to the sunspot numbers is due firstly to the fact that Ia has physical significance, because depends directly on the areas of the solar activity centres (spots and faculae) and secondly to the high correlation coefficients found between this index of solar activity and various solar and terrestrial phenomena **[1]**. It should also be mentioned that, as a rule, these correlation coefficients obtained with I_α were found to be greater than the corresponding ones obtained using the Wolf numbers (WN).

The results of the above mentioned research work, can be summarized as follows **[2]**, **[3]**.

1) In latitude zone $70^\circ \leqslant \varphi \leqslant 80^\circ$ N, a positive correlation exists between $\overline{R - R_0}$ and I_α ($r = +0.77$) as well as between $\overline{R - R_0}$ and the relative sunspot numbers ($r = +0.65$).

2) In the belt $60^\circ \leqslant \varphi \leqslant 70^\circ$ N, the quality $\overline{R - R_0}$ is negatively correlated with both the area index and sunspot numbers ($r = -0.65$ and $r = -0.63$, respectively).

Figure 1 shows the time series of $\overline{R - R_0}$ in these two latitude belts (the upper curve refers to the 70° - 80° and the lower to the 60° - 70° latitude belt). In that figure I_α - values are also shown (dashed curve) for the same

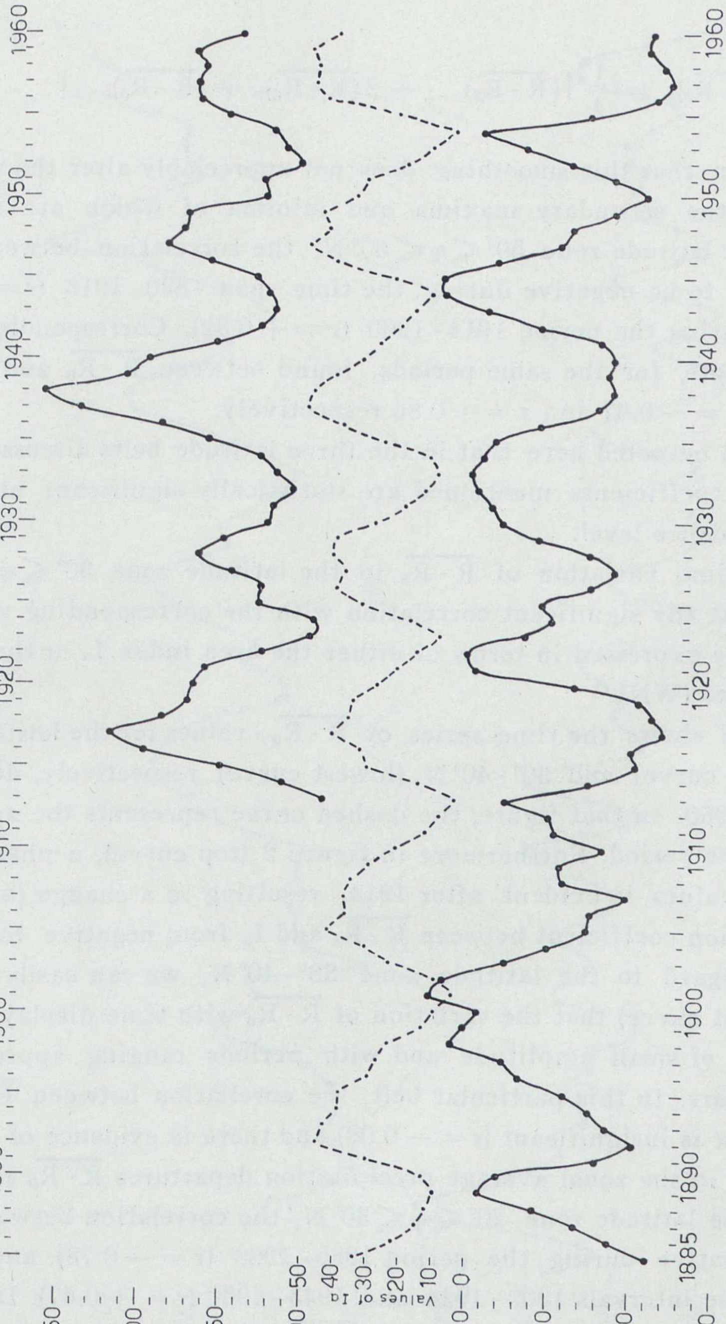

Fig. 1. (Upper). The continuous curve represents the values of $\overline{R \cdot R_0}$ in the 70° - 80° N latitude zone. (Middle). The dashed curve represents the values of the area index I_α. The bottom curve refers to the 60° - 70° latitude belt values of $\overline{R \cdot R_0}$.

period 1880 - 1960. In that figure, the observed $\overline{R - R_0}$ - values were smoothed by the formula

$$(\overline{R - R_0})_n = \frac{1}{4}\left[(\overline{R - R_0})_{n-1} + 2(\overline{R - R_0})_n + (\overline{R - R_0})_{n+1}\right].$$

It is well known that this smoothing does not appreciably alter the observed $\overline{R - R_0}$ - values, the secondary maxima and minima of which are retained.

3) In the latitude zone $50^\circ \leqslant \varphi \leqslant 60^\circ$ N, the correlation between $\overline{R - R_0}$ and I_α is found to be negative during the time span 1890 - 1913 ($r = -0.74$) and positive during the period 1914 - 1960 ($r = +0.82$). Corresponding correlation coefficients, for the same periods, found between $\overline{R - R_0}$ and sunspot numbers are: $r = -0.67$ and $r = +0.86$ respectively.

It should be noted here that in the three latitude belts discussed above all correlation coefficients mentioned are statistically significant at a better than 0.01 confidence level.

4) The time variation of $\overline{R - R_0}$ in the latitude zone $30^\circ \leqslant \varphi \leqslant 40^\circ$ N, does not present any significant correlation with the corresponding variations in solar activity expressed in terms of either the area index I_α or the relative sunspot numbers (WN).

Figure 2 shows the time series of $\overline{R - R_0}$ - values for the latitude zones 50° - 60° N (top curve) and 30° - 40° N (lowest curve) respectively, during the period 1886 - 1960. In that figure, the dashed curve represents the area index during the same period. Furthermore in figure 2 (top curve), a phase chance in the $\overline{R - R_0}$ - values is evident after 1914, resulting in a change in the sign of the correlation coefficient between $\overline{R - R_0}$ and I_α from negative to positive.

With regard to the latitude zone 30° - 40° N, we can easily see from figure 2 (lowest curve) that the variation of $\overline{R - R_0}$ with time displays sinusoidal variations of small amplitude and with periods ranging approximately from 4 to 8 years. In this particular belt, the corellation between $\overline{R - R_0}$ and the areas index is insignificant ($r = -0.03$) and there is evidence of a perceptible lowering in the zonal average precipitation departures $\overline{R - R_0}$ since 1917.

5) In the latitude zone $20^\circ \leqslant \varphi \leqslant 30^\circ$ N, the correlation between $\overline{R - R_0}$ and I_α is negative during the period 1885 - 1908 ($r = -0.78$) and positive during the time intervals 1909 - 1924 and 1943 - 1960 ($r = +0.67$). During the period 1925 - 1942, the time variation of $\overline{R - R_0}$ displays sinusoidal variations with periods varying from about 3 to 6 years.

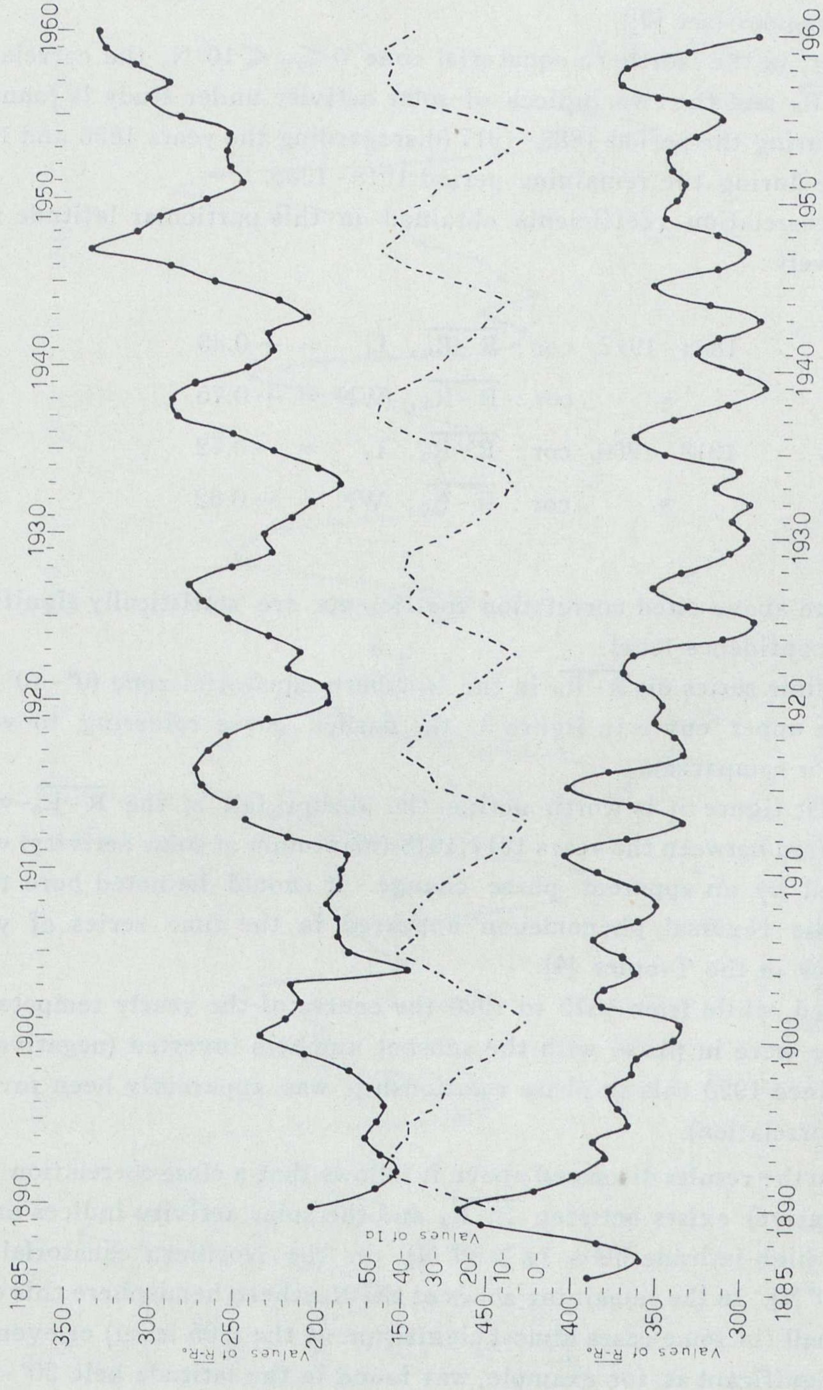

Fig. 2. (Upper). The continuous curve represents the values of $\overline{R} - R_0$ in the 50° - 60° N latitude belt. The dashed curve (middle) represents the values of the area index and the lower continuous curve the values of $\overline{R} - R_0$ in the latitude zone 30° - 40° N.

6) In the latitude belt $10^\circ \leqslant \varphi \leqslant 20^\circ$ N, the time variation of $\overline{R - R_0}$ is somewhat irregular (see [**3**]).

Finally, in the Northern equatorial zone $0 \leqslant \varphi \leqslant 10^\circ$ N, the correlation between $\overline{R - R_0}$ and the two indices of solar activity under study is found to be positive during the period 1888 - 1917 (disregarding the years 1896 and 1901) and negative during the remaining period 1918 - 1960.

The correlation coefficients obtained in this particular latitude zone are respectively:

1888 - 1917, cor : $\overline{R - R_0}$, I_α $= +0.83$

» cor : $\overline{R - R_0}$, WN $= +0.75$

1918 - 1960, cor : $\overline{R - R_0}$, I_α $= -0.72$

» cor : $\overline{R - R_0}$, WN $= -0.62$

All the above cited correlation coefficients are statistically significant at the 0.01 confidence level.

The time series of $\overline{R - R_0}$ in the Northern equatorial zone (0° - 10° N) is show by the upper curve in figure 3, the dashed curve referring to yearly I_α - values for comparison.

In that figure it is worth noting the abrupt fall of the $\overline{R - R_0}$- values which occurred between the years 1917/1918 (maximum of solar activity) which was followed by an apparent phase change. It should be noted here that a similar phase reversal phenomenon appeared in the time series of yearly temperatures in the Tropics [**4**].

Indeed, while from 1875 to 1920 the course of the yearly temperatures in that zone were in phase with the sunspot numbers inverted (negative correlation), since 1920 this in-phase relationship was apparently been reversed (positive correlation).

From the results discussed above it follows that a close correlation (positive or negative) exists between $\overline{R - R_0}$ and the solar activity indices only in either the high-latitude belts ($\varphi \geqslant 50^\circ$ N) or the Northern equatorial zone ($0 \leqslant \varphi \leqslant 10^\circ$ N). In the remaining zones of the Northern hemisphere this correlation is small (in some cases almost significant at the 0.05 level) or even completely insignificant as, for example, was found in the latitude belt 30° - 40° N.

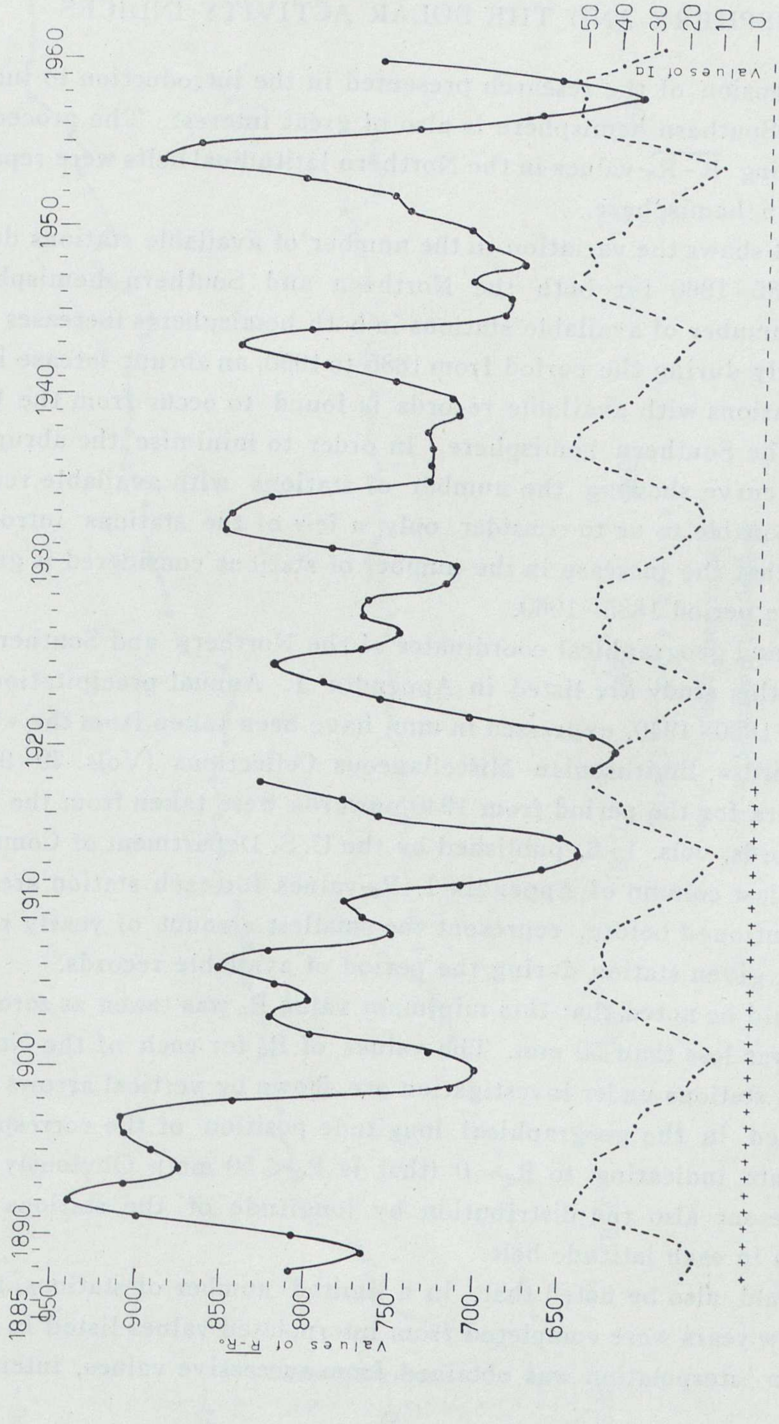

Fig 3. (Upper). The time series of $\overline{R}-R_0$ in the Northern equatorial zone 0° - 10° N. The dashed curve referring to yearly area index values.

2. THE CORRELATION BETWEEN $\overline{R - R_0}$ IN THE SOUTHERN HEMISPHERE AND THE SOLAR ACTIVITY INDICES

The extension of the research presented in the introduction to include the terrestrial Southern hemisphere is also of great interest. The procedures used in evaluating $\overline{R - R_0}$-values in the Northern latitudinal belts were repeated in the Southern hemisphere.

Figure 4 shows the variation in the number of available stations during the period 1885 - 1960 for both the Northern and Southern hemispheres. Although the number of available stations in both hemispheres increases more or less gradually during the period from 1885 to 1950, an abrupt icrease in the number of stations with available records is found to occur from the 1950's especially in the Southern hemisphere. In order to minimise the abruptness change in the curve showing the number of stations with available records, it seemed reasonable to us to consider only a few of the stations introduced after 1950 so that the increase in the number of stations considered is gradual over the entire period 1885 - 1960.

Names and geographical coordinates of the Northern and Southern stations used in this study are listed in Appendix I. Annual precipitation data for the period 1880 - 1940, expressed in mm, have been taken from the «World Weather Records», Smithsonian Miscellaneous Collections (Vols. 79 - 90 and 105). Same data for the period from 1940 onwards were taken from the World Weather Records, vols. 1 - 6, published by the U. S. Department of Commerce.

In the last column of Appendix I, R_0-values for each station are given which, as mentioned before, represent the smallest amount of yearly rainfall observed in a given station during the period of available records.

It should be noted that this minimum value R_0 was taken as zero when, the amount was less than 50 mm. The values of R_0 for each of the Northern and Southern stations under investigation are shown by vertical arrows in Fig. 5 and 6 located in the geographical longitude position of the corresponding stations, points indicating to $R_0 = 0$ (that is $R_0 < 50$ mm). Obviously, these figures represent also the distribution by longitude of the stations under consideration in each latitude belt.

It should also be noted that, in a limited number of stations, missing data for a few years were completed from interpolated values listed in Appendix II. When interpolation was obtained from successive values, interpolated

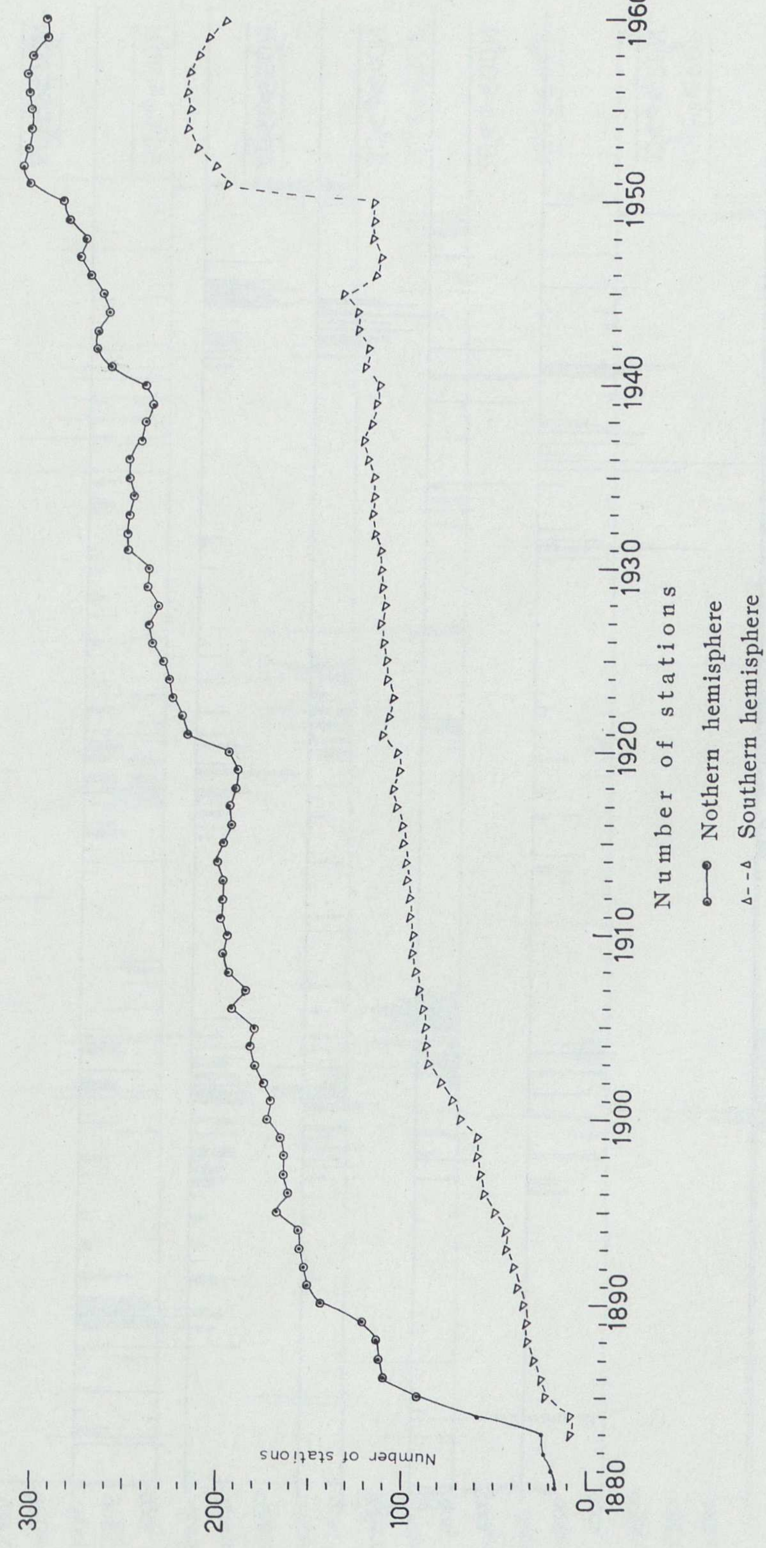

Fig. 4. Number of stations for the Northern and Southern hemisphere.

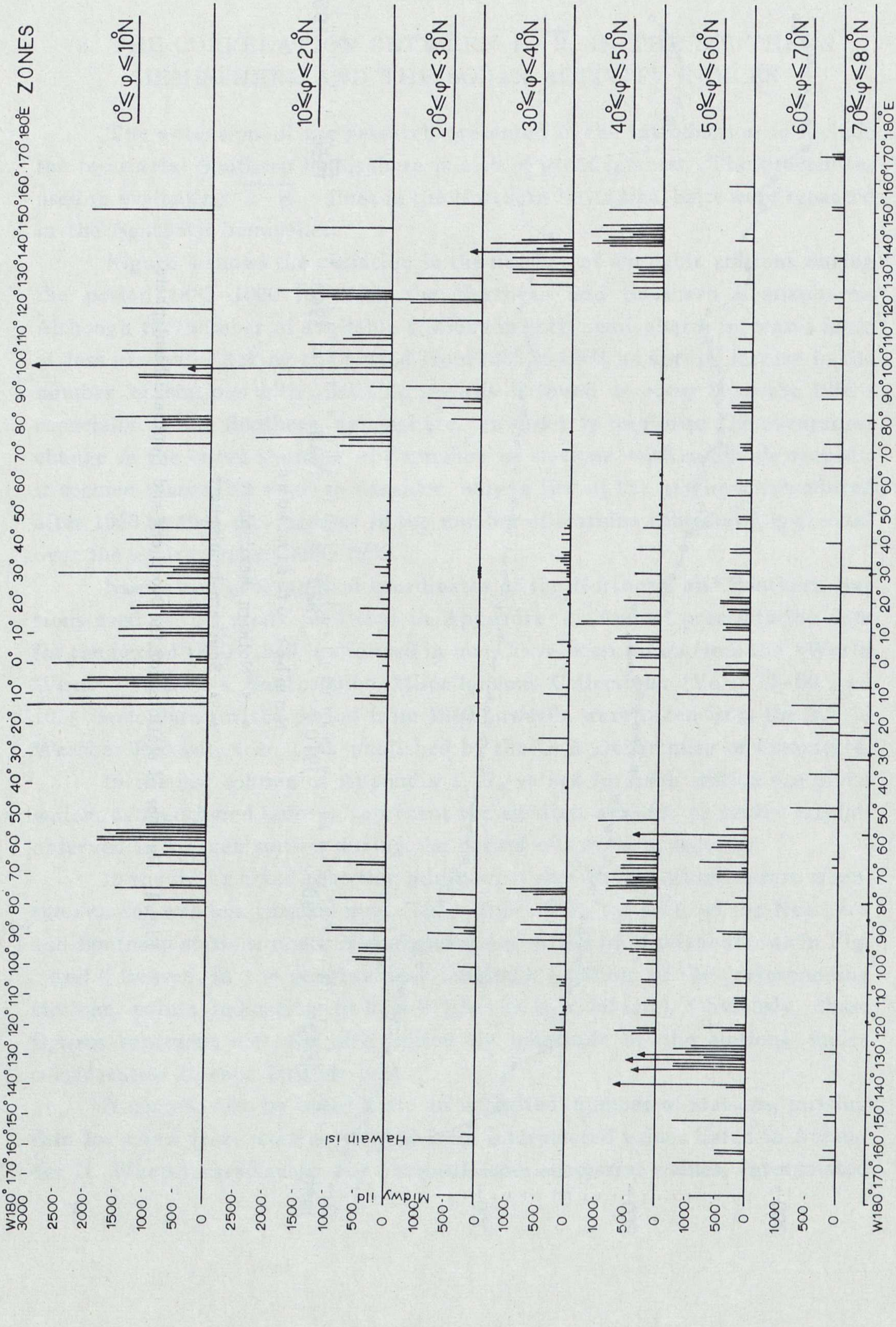

Fig. 5. The vertical arrows represent the values of R_0 for each station of the Northern hemisphere.

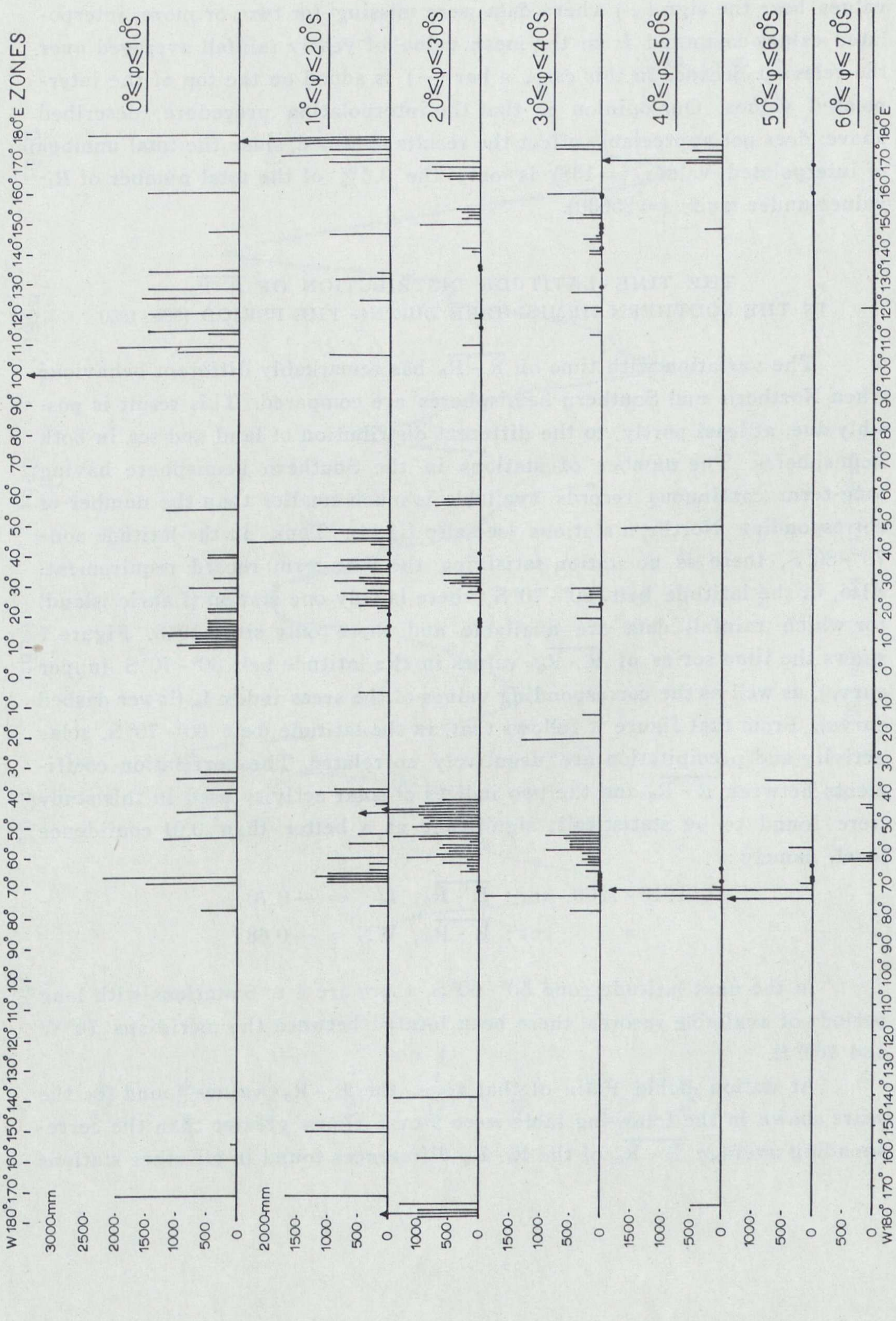

Fig. 6. The vertical arrows represent the values of R_0 for each station of the Southern hemisphere.

values bear the sign (+) where data were missing for two, or more, interpolated values computed from the mean value of yearly rainfall averaged over the relevant decade. In this case, a bar (—) is added on the top of the interpolated values. Our opinion is that the interpolation procedure, described above, does not appreciably affect the results obtained, since the total number of interpolated values (= 138) is only the 0.6% of the total number of R_i-values under study (= 25630).

THE TIME-LATITUDE DISTRIBUTION OF $\overline{R - R_0}$ IN THE SOUTHERN HEMISPHERE DURING THE PERIOD 1885-1960

The variation with time of $\overline{R - R_0}$ has remarkably different behaviour when Northern and Southern hemispheres are compared. This result is possibly due, at least partly, to the different distribution of land and sea in both hemispheres. The number of stations in the Southern hemisphere having long-term continuous records available is much smaller than the number of corresponding Northern stations (see also fig. 4). Thus, in the latitude zone 70° - 80° S, there is no station satisfying the long-term record requirement. Also, in the latitude belt 60° - 70° S, there is only one station (Laurie island) for which rainfall data are available and those only since 1913. Figure 7 shows the time series of $\overline{R - R_0}$-values in the latitude belt 60° - 70° S (upper curve), as well as the corresponding values of the areas index I_α (lower dashed curve). From that figure it follows that, in the latitude belt 60° - 70° S, solar activity and precipitation are negatively correlated. The correlation coefficients between $\overline{R - R_0}$ and the two indices of solar activity used in this study were found to be statistically significant at a better than 0.01 confidence level, namely:

$$1913-1960, \quad \text{cor}: \overline{R - R_0}, \; I_\alpha \; = -0.70$$

$$» \quad \text{cor}: \overline{R - R_0}, \; WN = -0.68$$

In the next latitude zone 50° - 60° S, there are 4 to 8 stations with long periods of available records, these been located between the meridians 74° W and 169° E.

At station Bahia Felix of that zone, the $R_i - R_0$ - values found for the years shown in the following table were 2 to 7 times greater than the corresponding average $\overline{R - R_0}$ of the $R_i - R_0$ differences found in all other stations

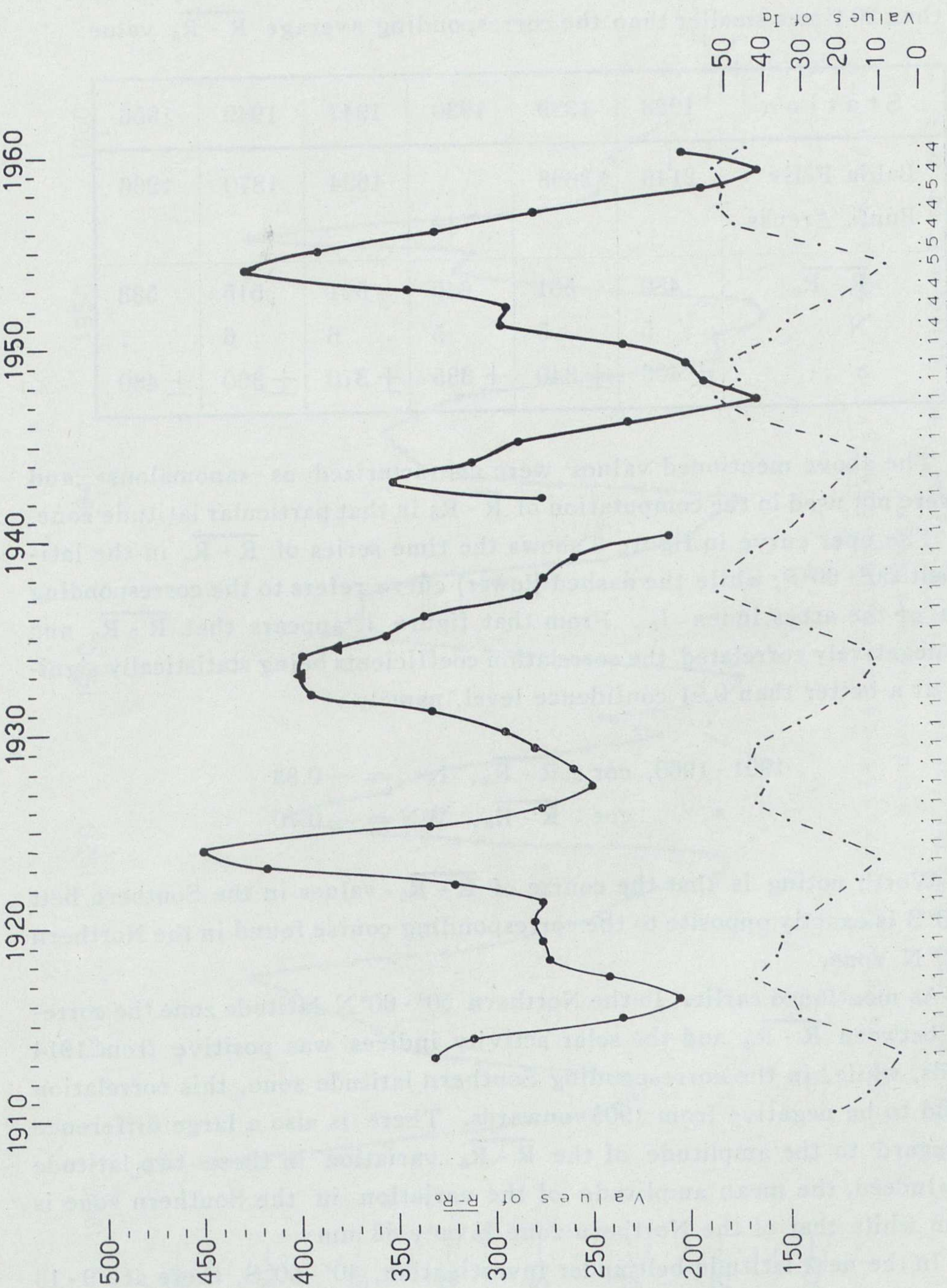

Fig. 7. The continuous curve represents the time series of $\overline{R-R_0}$ values in the latitude belt 60° - 70° S. The dashed curve represents the corresponding values of the area index.

in that latitude belt. Also, in Punta Arenas the $R_i - R_0$ for the year 1930 is more than 20 times smaller than the corresponding average $\overline{R - R_0}$ value.

Station	1928	1929	1930	1947	1949	1956
Bahia Felix	2146	3698		1624	1870	1266
Punta Arenas			19			
$\overline{R - R_0}$	480	501	645	521	515	583
N	5	5	5	6	6	7
σ	± 403	± 340	± 335	± 370	± 360	± 480

The above mentioned values were characterized as «anomalous» and they were not used in the computation of $\overline{R - R_0}$ in that particular latitude zone.

The uper curve in figure 8 shows the time series of $\overline{R - R_0}$ in the latitude belt $50^0 - 60^0$ S, while the dashed (lower) curve refers to the corresponding values of the areas index I_α. From that figure it appears that $\overline{R - R_0}$ and I_α are negatively correlated, the correlation coefficients being statistically significant at a better than 0.01 confidence level, namely :

$$1901 - 1960, \quad \text{cor}: \overline{R - R_0}, \; I_\alpha = -0.83$$
$$» \quad \text{cor}: \overline{R - R_0}, \; WN = -0.70$$

Worth noting is that the course of $\overline{R - R_0}$ - values in the Southern belt $50^\circ - 60^\circ$ S is exactly opposite to the corresponding course found in the Northern $50^\circ - 60^\circ$ N zone.

As mentioned earlier, in the Northern $50^\circ - 60^\circ$ N latitude zone the correlation between $\overline{R - R_0}$ and the solar activity indices was positive from 1914 onwards, while, in the corresponding Southern latitude zone, this correlation is found to be negative from 1906 onwards. There is also a large difference with regard to the amplitude of the $\overline{R - R_0}$ variation in these two latitude zones. Indeed, the mean amplitude of the variation in the Southern zone is 195 mm while that of the Northern zone is only 83 mm.

In the next latitude belt under investigation, $40^\circ - 50^\circ$ S, there are 9 - 13 stations located between the meridians 176° W and 175° E. From figure 9 it

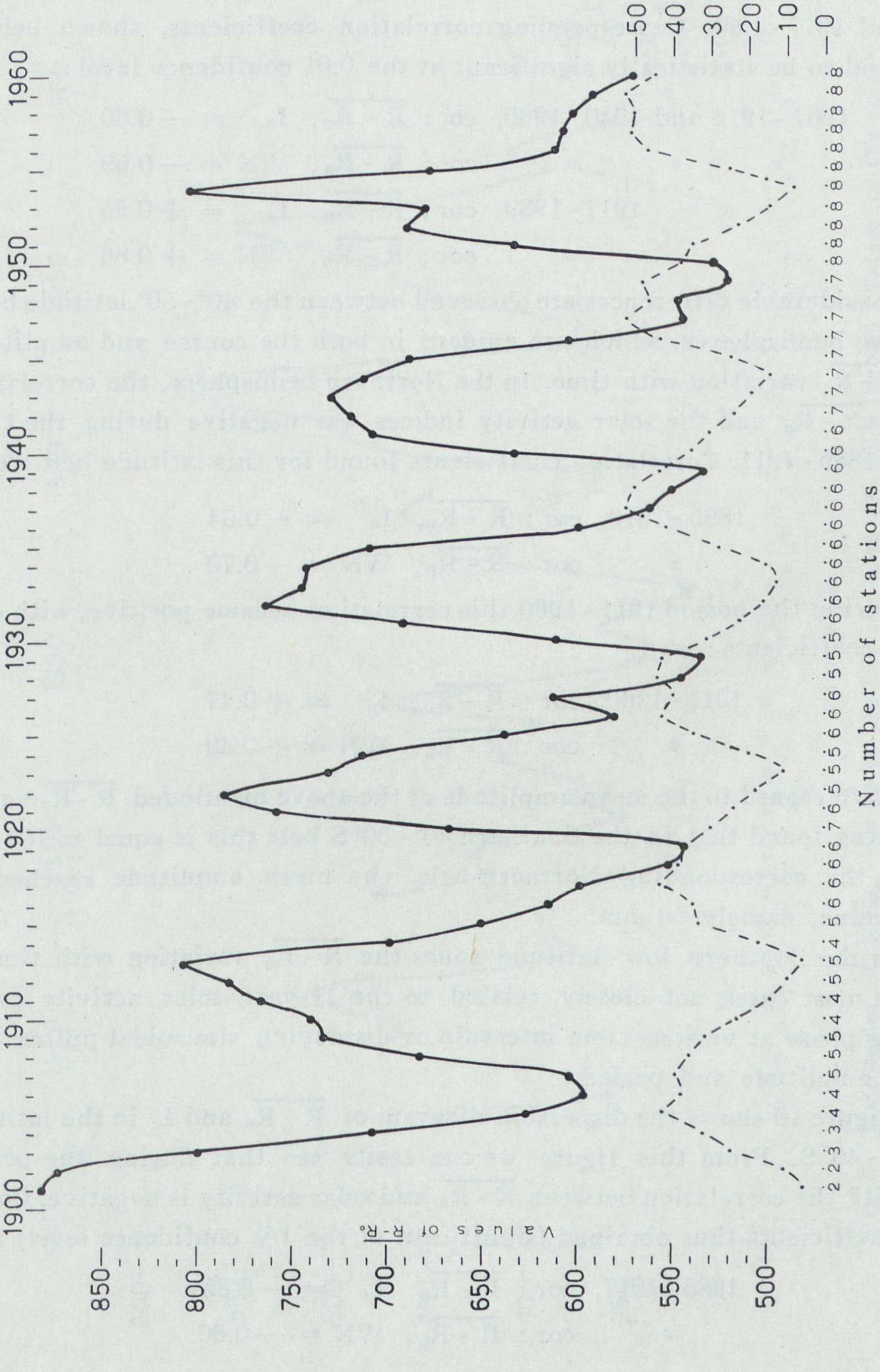

Fig. 8. The upper curve shows the time series of $\overline{R - R_0}$ values in the latitude belt 50° - 60° S. The dashed curve refers to the corresponding values of the area index.

appears that $\overline{R - R_0}$ is negatively correlated with the areas index during the time intervals 1907 - 1916 and 1940 - 1960, but positively correlated during the period 1917 - 1939. Corresponding correlation coefficients, shown below, were found to be statistically significant at the 0.01 confidence level:

1907 - 1916 and 1940 - 1960, cor : $\overline{R - R_0}$, I_α = —0.60
» » » cor : $\overline{R - R_0}$, WN = —0.59
1917 - 1939, cor : $\overline{R - R_0}$, I_α = +0.85
» cor : $\overline{R - R_0}$, WN = +0.86

Considerable differences are observed between the 40° - 50° latitude belts in the two hemispheres, which are evident in both the course and amplitude of the $\overline{R - R_0}$ variation with time. In the Northern hemisphere, the correlation between $\overline{R - R_0}$ and the solar activity indices was negative during the time interval 1885 - 1911. Correlation coefficients found for this latitude belt were:

1885 - 1910, cor : $\overline{R - R_0}$, I_α = —0.64
» cor : $\overline{R - R_0}$, WN = —0.70

During the period 1911 - 1960 this correlation became positive, with correlation coefficients:

1911 - 1960, cor : $\overline{R - R_0}$, I_α = +0.47
» cor : $\overline{R - R_0}$, WN = +0.49

With regard to the mean amplitude of the above mentioned $\overline{R - R_0}$ variation, it was found that in the Southern 40° - 50° S belt this is equal to 104 mm while in the corresponding Northern belt, the mean amplitude reached its lowest value, namely 50 mm.

In the Southern low - latitude zones the $\overline{R - R_0}$ variation with time is found in most cases not closely related to the 11-year solar activity cycle, changing phase at various time intervals or displaying sinusoidal pulses with varying amplitude and period.

Figure 10 shows the dispersion diagram of $\overline{R - R_0}$ and I_α in the latitude belt 30° - 40° S. From this figure we can easily see that during the period 1885 - 1917 the correlation between $\overline{R - R_0}$ and solar activity is negative. Correlation coefficients thus obtained (significant at the 1% confidence level) are:

1885 - 1917, cor : $\overline{R - R_0}$, I_α = —0.65
» cor : $\overline{R - R_0}$, WN = —0.66

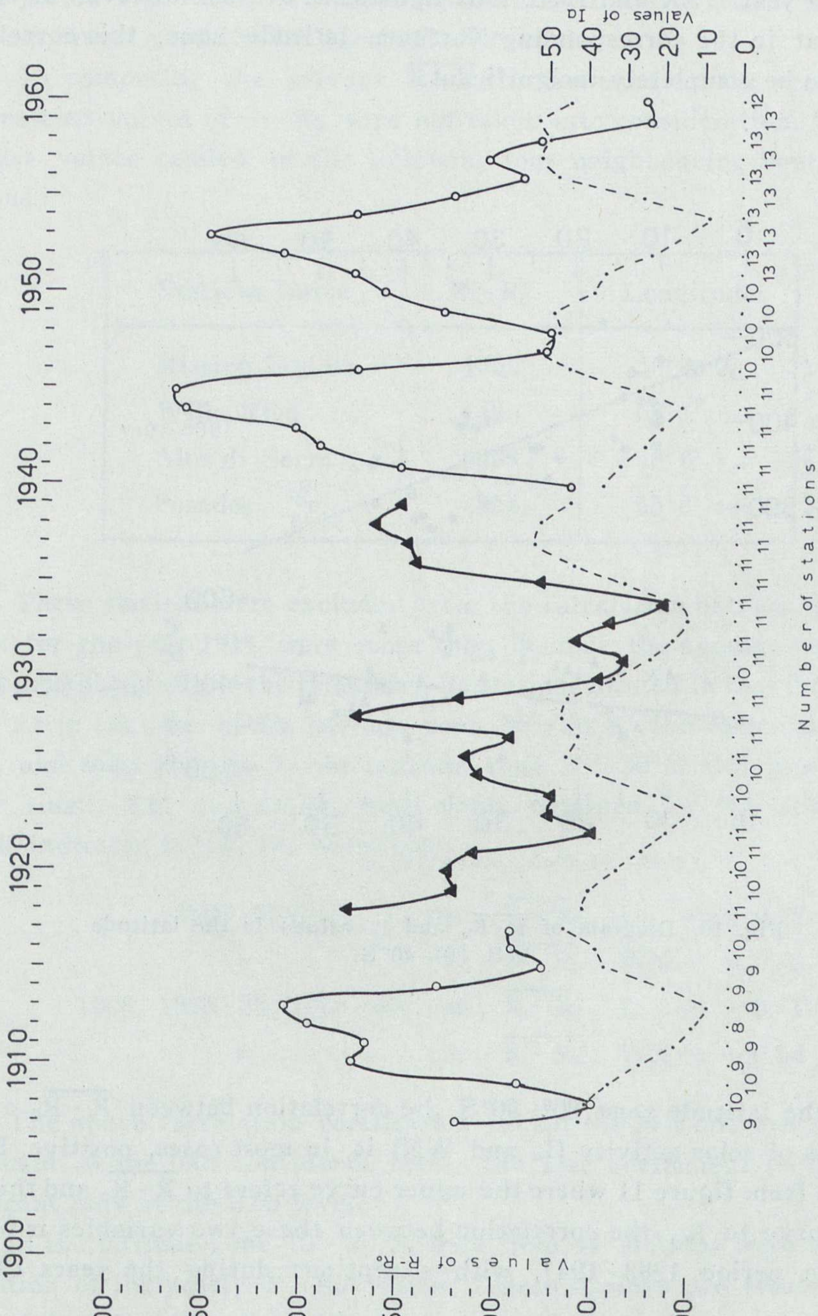

Fig. 9. Time series of $\overline{R - R_0}$ - values in the latitude zone 40° - 50° S (upper). Values of the area index I_α (lower dashed curve).

During the period 1918-1960 this correlation became positive and, omitting the years 1937 and 1938, it is significant at the 0.01 level. It should be noted that in the corresponding Northern latitude zone, this correlation was found to be completely insignificant.

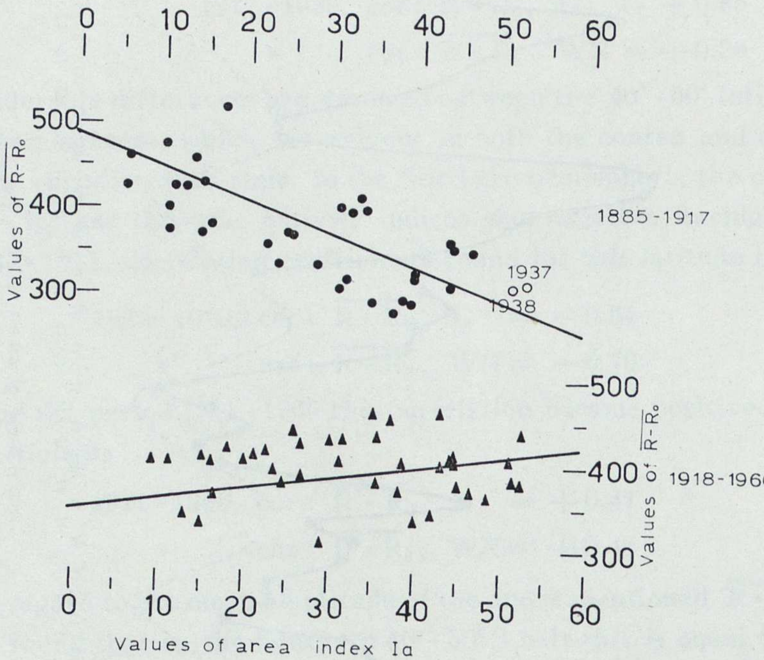

Fig. 10. Diagram of $\overline{R-R_0}$ and I_α values in the latitude belt 30°-40° S.

In the latitude zone 20^0-30^0 S, the correlation between $\overline{R-R_0}$ and the two indices of solar activity (I_α and WN) is, in most cases, positive. Indeed, as appears from figure 11 where the upper curve refers to $\overline{R-R_0}$ and the lower (dashed) curve to I_α, the correlation between these two variables is positive during the period 1883-1947, with exceptions during the years 1906 and 1935-38.

In the two-year period 1947/48, that is during the maximum of the

18th solar cycle, an abrupt fall in the $\overline{R - R_0}$ - values occurred and the correlation between $\overline{R - R_0}$ and I_α became negative, and remained such, for the whole period 1948 - 1960. A similar abrupt fall in $\overline{R - R_0}$, was also observed in solar maximum year 1905 of the 14th solar cycle.

In computing the average $\overline{R - R_0}$ in that zone for the year 1911, four «anomalous» values of $R_i - R_0$ were not taken into consideration. These «anomalous» values related to the following four neighbouring South American stations :

Stations Name	$R_i - R_0$	Longitude
Mission Inglese	1252	58° 4′ W
Willa Rica . . .	1425	58° 1′ »
Alto di Serra .	2238	46° 6′ »
Posades	1254	55° 8′ »

These stations were excluded from the calculation because their $R_i - R_0$-values for the year 1911 were more than 3 times the average value $\overline{R - R_0}$ (=494 mm) obtained for the remaining 28 stations located in that latitude zone.

As in the case of the latitude zone 30° - 40° S, the correlation between $\overline{R - R_0}$ and solar activity in the latitude zone 20° - 30° S although positive is rather small. The correlation coefficients obtained for the different subperiods indicated below, are as follows:

1883 - 1947,	cor : $\overline{R - R_0}$, I_α	$= +0.62$
»	cor : $\overline{R - R_0}$, WN	$= +0.49$
1906, 1935 - 38, 1948 - 60,	cor : $\overline{R - R_0}$, I_α	$= -0.71$
»	cor : $\overline{R - R_0}$, WN	$= -0.54$

The above correlation coefficients except the last one are statistically significant at the 0.01 confidence level, the last coefficient (—0.54) being significant only at the 0.05 level.

In the latitude zone 10° - 20° S, data from 44 stations were used in the calculation of the yearly $\overline{R - R_0}$ - values. These stations are located between the meridians 174° W and 178° E.

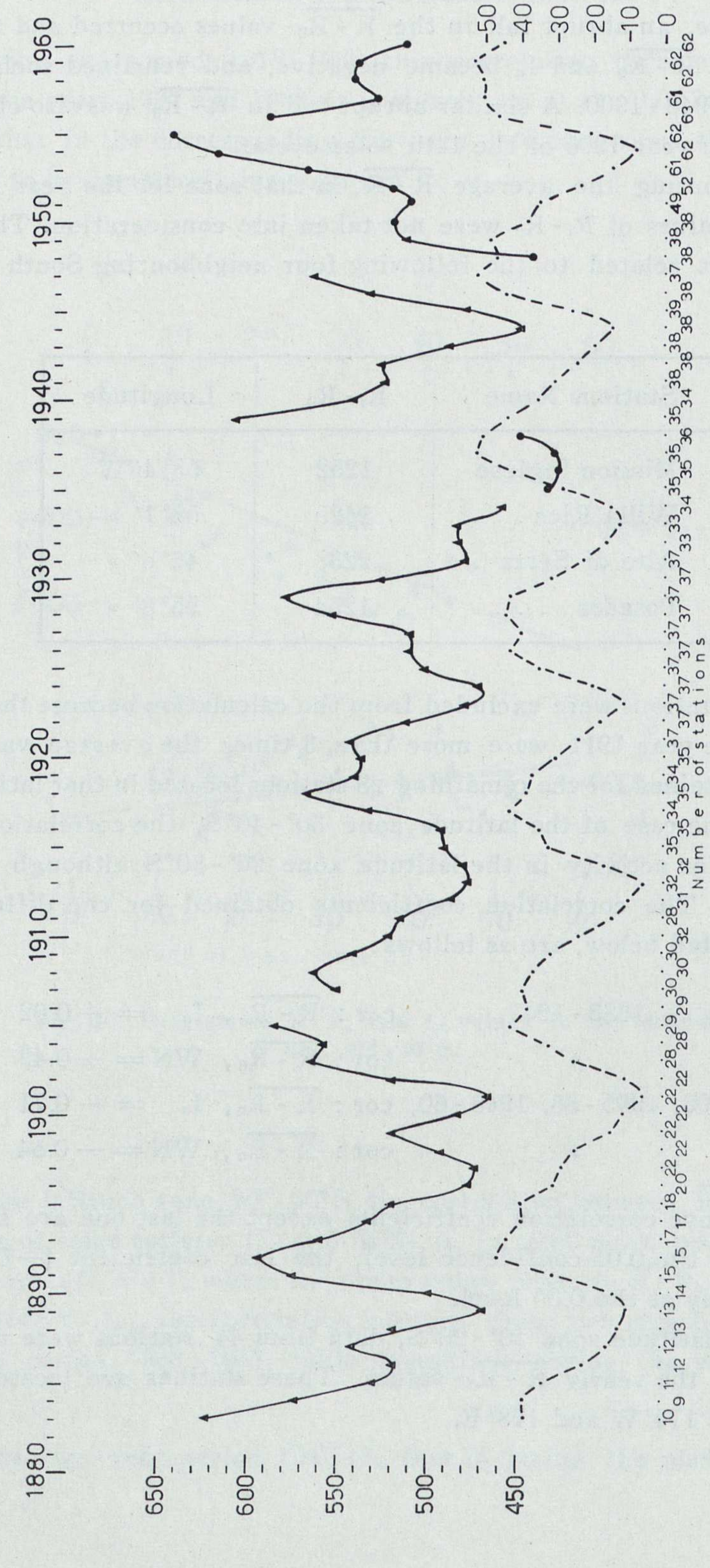

Fig. 11. The time series of $\overline{R - R_0}$ values in the latitude zone 20° - 30° S (upper). The values of area index Iα (bottom).

Stations shown in the table below were excluded from the calculations of $\overline{R - R_0}$ for the years 1909 and 1956, because their $R_i - R_0$ - values (shown in the table below) differ from the mean $\overline{R - R_0}$ for these years by 2 to 4 time the standard deviation.

Stations	1909	1956	Longitude
Nova Lisboa, Angola		1338	15°,7 E
Luso, Angola		1343	19°,9 »
Tamatava.		1978	44°,0 »
Antonanarivo, Madagaskar.	— 208		47°,5 »
Kupang, Indonesia		1476	123°,6 »
Darwin, Australia		1406	130°,8 »
Alofi, Niue Island		1519	169°,9 »
Nabouwala		1562	172°,7 »
$\overline{R - R_0}$	678	720	
n	11	42	
σ	±280	±320	

Figure 12 (diagram of $\overline{R - R_0}$ and I_α) shows that the variation of $\overline{R - R_0}$ in this latitude belt, often undergoes phase reversals, in some cases within very short time intervals. From this figure it is also evident that $\overline{R - R_0}$ and the areas index are positively correlated during the years 1918 - 1937, 1905/1906 and 1954/1955. During the years 1938 - 1960 and 1923/24, the correlation between them is negative.

Correlation coefficients obtained, statistically significant at 0.01 confidence level, are listed below:

1918 - 1937, 1905/06, 1954/55, cor: $\overline{R - R_0}$, I_α $= +0.75$

» cor: $\overline{R - R_0}$, WN $= +0.66$

1894 - 1917, 1923/24, 1938 - 1960, cor: $\overline{R - R_0}$, I_α $= -0.80$

» cor: $\overline{R - R_0}$, WN $= -0.73$

As in the preceding latitude zone, the appearance of phase reversals is also evident in this zone, during both the solar maxima 1905/06, 1937/38 and the solar minima 1923/24, 1954/55.

Finally, in the Southern equatorial zone 0 - 10° S, the analysis was based on data from 39 stations located between the meridians 172° W and 179° E.

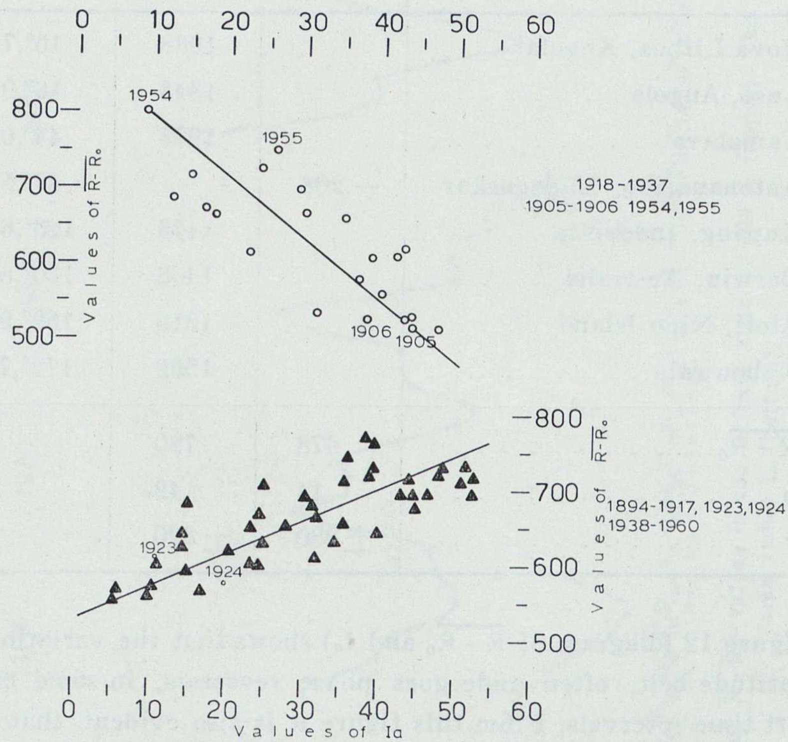

Fig. 12. Diagram of $\overline{R - R_0}$ and I_α - values in the latitude zone 10° - 20° S.

As appears from figure 13 (diagram of $\overline{R - R_0}$ and I_α), which shows the time series of both the $\overline{R - R_0}$ and I_α, the correlation between these two variables is negative during the periods 1904 - 1937 and 1941 - 1960. This correlation became positive during the years 1885 - 1903, 1914, 1916/17 and 1938 - 1940. The corresponding correlation coefficients, listed below, were found to be statistically significant at the 0.01 confidence level:

1885 - 1903, 1914, 1916/17, 1938 - 40, cor : $\overline{R - R_0}$, I_α $= +0.73$

» cor : $\overline{R - R_0}$, WN $= +0.74$

1904 - 1937, 1941 - 1960, cor : $\overline{R - R_0}$, I_α $= -0.70$

» cor : $\overline{R - R_0}$, WN $= -0.58$

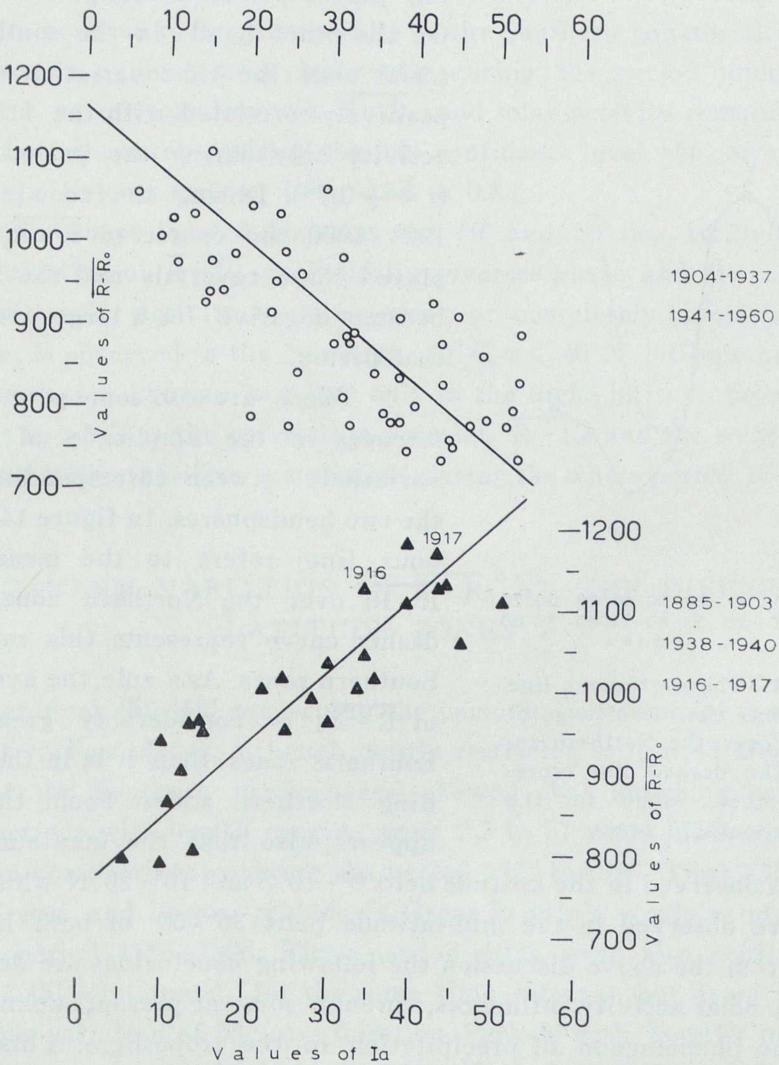

Fig. 13. Diagram of $\overline{R - R_0}$ and I_α - values in the Southern equatorial zone 0° - 10° S.

Again, considerable differences were found between courses of $\overline{R - R_0}$ between the two Northern and the Southern equatorial zones. In the Northern equatorial zone (0° - 10° N) the course of $\overline{R - R_0}$ paralleled the 11-year solar activity cycle ($r = +0.83$) during the period 1888 - 1917. Then, during the solar maximum year 1917/18, it changed phase and a negative correlation occurred between $\overline{R - R_0}$ and solar activity, which continued for the remaining period under investigation 1918 - 1960. On the other hand, in the southern equatorial zone the time variation of $\overline{R - R_0}$ is positively correlated with the 11-year solar activity only during the period 1885 - 1903 ($r = +0.73$). During the remaining period 1904 - 1960 the course of $\overline{R - R_0}$ often displayed phase reversals and the correlation became negative for a large percentage of that period.

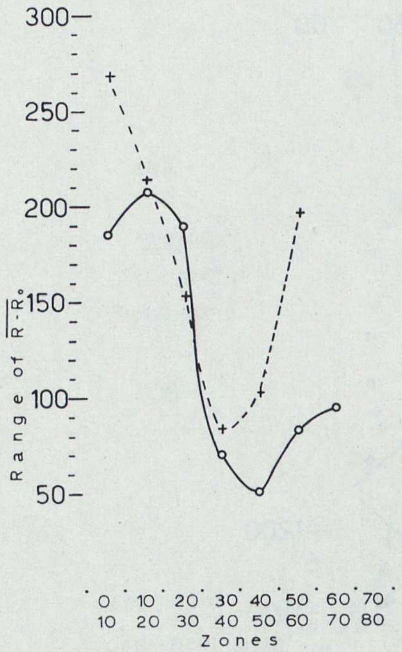

Fig. 14. The continuous line represents the mean range of $\overline{R - R_0}$ over the Northern zones. The dashed line represents this range for the Southern zones.

There are also some perceptible differences in the amplitude of the $\overline{R - R_0}$ variations between corresponding zones of the two hemispheres. In figure 14 the continuous line refers to the mean range of $\overline{R - R_0}$ over the Northern zones, and the dashed curve represents this range for the Southern zones. As a rule, the average range of $\overline{R - R_0}$ is considerably greater in the Southern zones than it is in the corresponding Northern zones. From that figure it appears also that the maximum range of change is observed in the latitude belts 0° - 10° S and 10° - 20° N while minimum values are observed in the mid-latitude belts 30° - 50° of both hemispheres.

From the above discussion the following conclusions are deduced:

1) Solar activity influences, through some at present unknown mechanism, the phenomenon of precipitation in the troposhere. This result was observed when considering the $\overline{R - R_0}$ zonar values, instead of yearly precipitation totals in small areas or isolated stations.

2) This solar influence is revealed unquestionably in the high - latitude zones of both hemispheres ($\varphi > 50°$). In these latitude zones the correlation (positive or negative) between $\overline{R - R_0}$ and the solar activity indices (I_α or WN)

ranges from 0.65 to 0.85 which is a statistically significant correlation at the 0.01 confidence level.

3) In the two Northern and Southern equatorial zones (0° - 10°) the time variation of $\overline{R - R_0}$ changes phase, in the Northern zone ($0 \leqslant \varphi \leqslant 10°$ N) during the years 1917/18 and correspondingly the correlation with solar activity changes from positive to negative, while in the Southern equatorial zone this phase reversal is evident more frequently during the period under study. However, the correlation between $\overline{R - R_0}$ and solar activity remains significant (in spite of phase reversals) at the 0.01 confidence level, the corresponding correlation coefficients ranging from 0.58 to 0.83.

4) In the zones located between the 10° and 50° deg. latitude circles, the time-variation of $\overline{R - R_0}$ periodically reverses phase and the correlation of $\overline{R - R_0}$ with solar activity is rather weak or completely insignificant, as, for example, is observed in the Northern $30° \leqslant \varphi \leqslant 40°$ N latitude belt.

In conclusion, we can say that only in the high-latitude belts of both hemispheres ($\varphi > 50°$) is the correlation between $\overline{R - R_0}$ and the solar activity indices strong (either positive or negative) during the whole period 1885 - 1960.

3. LONG-TERM VARIATION IN $\overline{R - R_0}$ AT THE DIFFERENT LATITUDE ZONES

Earlier work [5] - [16] concerning the periodic behaviour of yearly rainfall totals at various places, although mostly restricted to limited areas of the Northern or the Southern hemispheres, showed that annual precipitation exhibited periods with length ranging from 2.2 to 57 years. This early work was based on observations covering the period 1726 to 1926. Thus KEELE [5], reported 57 year and 19-year periods in Great Britain's yearly rainfall totals during the period 1726 - 1890. These periodicities were also confirmed by BAXENDELL [5] who found, for the same time interval but from independent data, one variation of 53 years duration. Periods with lengths of 36 yrs, 35 yrs and 33 yrs were also found by BROOKS [7] in Chile (1520 - 1907), BRUNT [8] in Padua (1725 - 1900) and by MOORE [9] in Ohio (1839 - 1909).

Periodic changes of less than 30-year duration were discovered by different investigators and in different parts of the world, the principal of which are listed in Table 1.

TABLE 1.

Author	Periodicities indicated	Place	Observations covering
[**10**] D. BRUNT	30	Milano	1764 - 1900
»	25	Padua	1725 - 1900
»	25	Stockholm	1756 - 1905
»	22	Edinburgh	1785 - 1896
»	20	Padua	1725 - 1900
[**11**] F. SCHUSTER	18.6	Karlsruhe	1867 - 1906
[**12**] F. BAUR	18	Germany	1884 - 1919
D. BRUNT	17	Edinburgh	1785 - 1896
»	13	Padua	1725 - 1900
»	13	Milano	1764 - 1900
»	13	Edinburgh	1785 - 1891
»	12	London	1782 - 1922
[**13**] HUNTINGTON	11.4	California	1863 - 1915
[**14**] C. BROOKS	11	Bathurst	1884 - 1915
[**15**] C. HELLMAN	5.6	NW. Europe	1851 - 1905

Finally, recent research has shown cyclic changes, apart from the 11-year cycle, with durations 44 yrs [**16**], and 80 - 90 yrs [**17**] as well as several others shorter than the 11-year period.

It is clear that the appearance of periods in yearly rainfall totals, with shorter or longer than the 11-year duration, will complicate or, at least in part obscure a possible influence of the 11-year variation of solar activity on the phenomenon of precipitation in the different terrestrial latitude zones. If one releases the $\overline{R - R_0}$ - values from their short and, especially, from their long-term periodic variations, most of which seem to be of terrestrial origin, then, one can observe the 11-year periodic component which may be assumed to be related to the 11-year solar activity cycle.

In order to determine the long-term tendency in the variation of

$\overline{R - R_0}$, we computed, for each latitude zone, the 11-year moving averages with the help of the relation:

$$(\overline{R - R_0})_n = \frac{1}{11} [(\overline{R - R_0})_{n-5} + \ldots (\overline{R - R_0})_n + \ldots (\overline{R - R_0})_{n+5}]$$

The results of the use of moving averages can be summarized as follows:

a) Northern Hemisphere.

In figure 15 the small circles correspond to the $\overline{R - R_0}$ moving averages in the Northern latitude belts 0° - 10° N and 10° - 20° N (upper and lower curves, respectively). From that figure we cann see a periodicity in the latitude belt 0° - 10° N, with period of about 40 years and amplitude amouting to 120 mm. However, after the year 1943, this periodicity seems to change phase by 180°, although both the amplitude and period probably remain constant. Because of lack of data after 1960 one cannot be confident as to whether phase reversal is real or not. Moreover, during the period 1918 - 1938, a 12-year variation is probably superimposed. The above mentioned long periodic behaviour can be approximately expressed by the equation:

$$L_t = 60 \sin \frac{2\pi}{40} (T - 1883) - 60 \sin \frac{2\pi}{12} (T - 1918)_{1918 - 1936} \qquad (1)$$

Equation (1) is shown graphically in figure 15a as a continuous line, which probably changes phase by 180° after 1943.

In the latitude zone 10° - 20° N (fig. 15b), the 11-year moving averages of $\overline{R - R_0}$ values, display periodic variations with period of about 40 years and amplitude 160 mm, superimposed on which are short-period variations (dashed lines). This long-term tendency can be approximately be expressed by the relation:

$$L_t = 80 \sin \frac{2\pi}{40} (T - 1878) \qquad (2)$$

In figure 16 small circles represent 11-year moving average $\overline{R - R_0}$'s, for the following 3 latitude zones:

20° - 30° (top curve)
30° - 40° (middle curve)
40° - 50° (bottom curve)

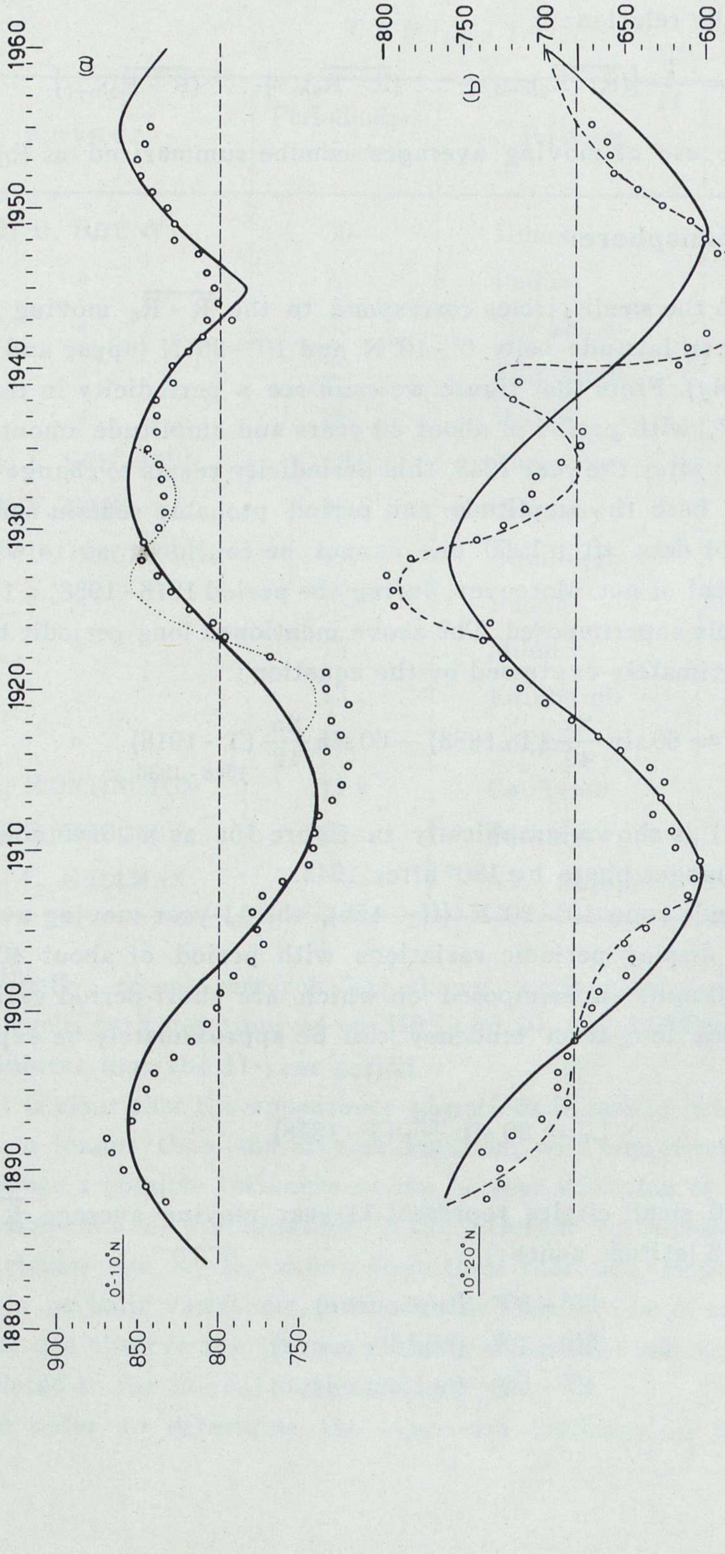

Fig. 15. (a) The small circles represent the 11-year moving average $\overline{R \cdot R_0}$ - values in the Northern latitude zone 0° - 10° N, and the continuous curve the long-term variation L_t expressed by the equation (1). (b) The small circles represent the 11-year moving average of $\overline{R \cdot R_0}$ - values in the latitude belt 10° - 20° N, and the continuous curve the long-term variation L_t expressed by the relation (2). Dashed curves in (a) and (b) represent probable periodic variations.

It would appear that the long-term variation which is evident in the latitude zone 20^0 - 30^0, resulted mainly from two variations: one with period of 36 years and amplitude 160 mm (during 1886 - 1915) and another, which appeared since 1918, with period of 88-years and amplitude 100 mm.

During the time interval 1916 - 1938 a third oscillation is probably superimposed with a 22-year periodicity and amplitude about 100 mm. This long-term tendency can be approximately expressed analytically by the relation:

$$L_t = \underset{1886\,-\,1915}{80 \cos \frac{2\pi}{36} (T - 1886)} - \underset{1916\,-\,1938}{50 \sin \frac{2\pi}{22} (T - 1916)} - 50 \sin \frac{2\pi}{88} (T - 1918) \quad (3)$$

In the latitude zone 30^0 - 40^0 (middle curve in fig. 16) the 11-year moving averages $\overline{R - R_0}$, display a long-term variation probably a periodicity with period of 80-years and amplitude of 70 mm. During the time interval 1884 - 1906, another 22-year variation with amplitude of 40 mm is probably superimposed on the first. This long-term variation can be expressed analytically by:

$$L_t = 35 \sin \frac{2\pi}{80} (T - 1878) + \underset{1884\,-\,1906}{20 \sin \frac{2\pi}{22} (T - 1884)} \quad (4)$$

In the latitude belt 40^0 - 50^0, the $\overline{R - R_0}$ 11-year moving averages, are not likely to undergo any important long-term variation. A probable 36-year variation evident in this belt has, however, very small amplitude. On the other hand, from 1923 until the end of the period, a clearer variation appears with period of 18 years and amplitude of 60 mm, superimposed on that of 36-year already mentioned. In this belt, the long-term variation L_t of the 11-year moving average can be expressed by:

$$L_t = -10 \sin \frac{2\pi}{36} (T - 1878) - 30 \sin \frac{2\pi}{18} (T - 1923) \quad (5)$$

In all three latitude belts discussed above it is worth noting the small amplitude of the variation, especially that found for the 40^0 - 50^0 zone.

In figure 17, small circles represent 11-year moving averages $\overline{R - R_0}$'s corresponding to the two zones 50^0 - 60^0 (upper curve) and 60^0 - 70^0 (lower curve).

In the latitude zone 50^0 - 60^0, the long-term variation seems to be composed mainly from two periodic changes: one with period of 88 years and amplitude of 100 mm and another with period of 44 years and amplitude of 50 mm. During the interval 1902 - 1918, a third variation, with period of

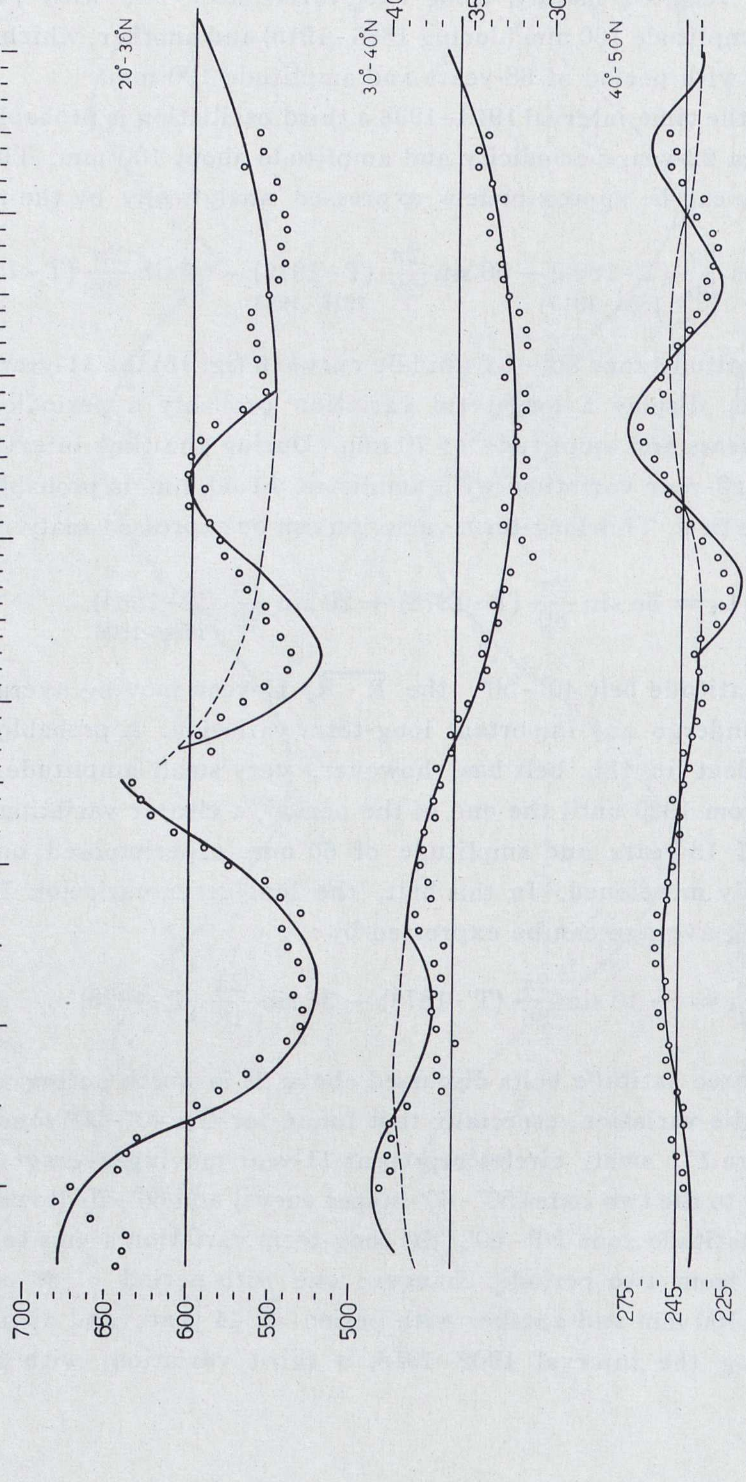

Fig. 16. The small circles represent the 11-year moving average of $R - \overline{R}_0$ - values in the latitude zones 20° - 30° N (upper), 30° - 40° N (middle) and 40° - 50° N (lower). The continuous curve represents the long-term variation L_t expressed by the relations (3), (4) and (5) respectively.

16 years and amplitude of 100 mm, is probably added to the others. The composite of these long-term periodic changes can be expressed analytically as:

$$\left.\begin{aligned} L_t = &- 50 \sin \frac{2\pi}{88} (T - 1881) - 40 \sin \frac{2\pi}{44} \underset{1881 - 1947}{(T - 1881)} - \\ &- 40 \sin \frac{2\pi}{16} \underset{1902 - 1918}{(T - 1902)} - 30 \sin \frac{2\pi}{8} \underset{\substack{1888 - 1896 \\ 1918 - 1926 \\ 1948 - 1956}}{(T - 1888)} \end{aligned}\right\} \quad (6)$$

The analytical expression (6) shown in figure 17 (a) by a continuous curve, has a maximum (280 mm) in the year 1947. If we suppose that equation (6) applies as well after the 1950, then, by virtue of the first two periodic components, we expect a rainfall zonal-minimum around the end of the present century (1991 - 2000) similar to that which occured at the end of the 19th century (1895 - 1900).

Finally, in the latitude zone 60° - 70° (fig. 17b), the course of $\overline{R - R_0}$ can also be approximated as a composite of three variations given by the relation:

$$L_t = - 40 \cos \frac{2\pi}{32} \underset{1882 - 1922}{(T - 1882)} + 40 \sin \frac{2\pi}{80} \underset{1918 - 1958}{(T - 1918)} - 40 \sin \frac{2\pi}{12} \underset{1938 - 1956}{(T - 1938)} \quad (7)$$

From the above analysis we can conclude that, disregarding the Northern equatorial zone 0° - 10° and the zone 10° - 20° N, where the 40-year periodicity seems to be rather stable, in all of the remaining Northern latitude belts the observed periodicities were found to be unstable with respect to their periods and amplitudes. In addition, during different time intervals, superimposed terms with shorter periods but appreciable amplitudes alter the overall course of the 11-year moving average values. Because of the random appearance of these superimposed variations we are not in the position to extrapolate in time the above mentioned analytical expression 1 - 7, to forecast the long-term $\overline{R - R_0}$ tendencies after the 1960's, which is obviously a task of great partical importance. However, only in the two latitude belts 0° - 10° and 10° - 20°, where only one or two variations are evident during the period we studied, coult one try to extrapolate the results obtained for these zones. Indeed, regarding the 0° - 10° belt, we can assume that the 40-year periodicity phase reversal by 180° in 1943 can be extrapolated and thus we

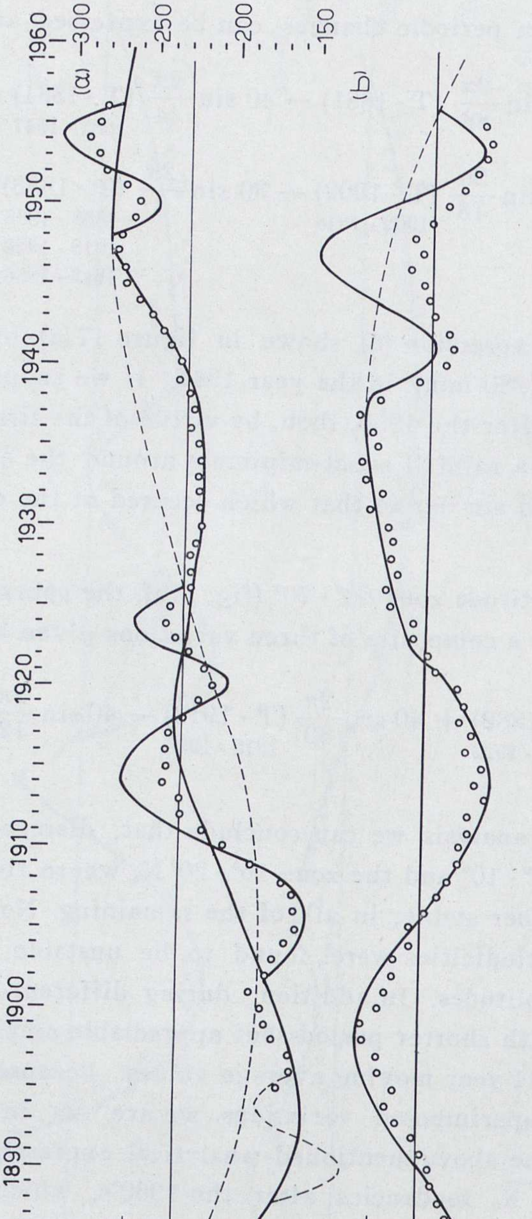

Fig. 17. The small circles represent the 11-year moving average $\overline{R - R_0}$-values for the latitude belts 50°-60° N (upper) and 60°-70° N (lower), respectively. The continuous curves represent the long-term variations L_t expressed by the relations (6) and (7) respectively.

should expect a minimum around the year 1973, similar to that observed in 1913. Similarly, in the zone 10° - 20°, under the assumption that the 40-year periodicity is retained, we should expect a maximum to occur in the year 1968.

Table 2 shows the periods of the L_t-variation observed with the above described method in the different Northern latitude zones under investigation.

TABLE 2.

Zones	Period (in years) of L_t-variations				
0° - 10° N	12			40	
10° - 20° »		16		40	
20° - 30° »			22	36	88
30° - 40° »			22		80
40° - 50° »		18		36	
50° - 60° »		16	22	44	88
60° - 70° »	12			32	80
70° - 80° »		16	22		

It is worth noting that the amplitude of these periodic changes reaches its maximum value in the latitude belt 10° - 20° and its minimum value in the latitude belt 30° - 50°.

b) Southern Hemisphere.

The application of the 11-year moving average method to the $\overline{R - R_0}$-values for the different Southern latitude zones reveals variations with periods similar to those found in the Northern hemisphere. However, comparing the corresponding latitude zones of the two hemispheres, we can see a different behaviour in the long-term variation.

In figure 18 the small circles represent 11-year moving average $\overline{R - R_0}$-values for the zones 0° - 10° S (upper curve) and 10° - 20° S (lower curve).

The long-term variation in the Southern equatorial zone (0° - 10° S) is probably produced by two superimposed variations, one with a 44-year period and an amplitude of 80 mm and another having a period of 22 years and an amplitude of 140 mm. In fig. 18 (a) the first variation is shown by the dashed curve, while the 22-year periodicity (with an almost double amplitude) is shown by the continuous curve.

The analytical representation of these L_t - variations, in that latitude zone, can be approximated by the relation:

$$L_t = 40 \sin \frac{2\pi}{44} (T - 1876) - 70 \sin \frac{2\pi}{22} (T - 1876) \qquad (8)$$

Worth noting is the fact that, in the Southern equatorial zone 0° - 10° S, the ovserved variations have constant periods and amplitudes during the whole period under investigation (1885 - 1960). This constancy in period and amplitude is not observed in the corresponding Northern equatorial zone (0° - 10° N), where the 40-year periodicity probably shows a phase reversal from 1943 onwards.

There are also differences between these zones, regarding the amplitude of the variations observed. Thus, in the Southern equatorial zone, the amplitude of these long-term changes is more than double that in the corresponding Northern equatorial zone.

In the latitude zone 10° - 20° (fig. 18b) the course of $\overline{R - R_0}$ 11-year moving averages is rather unclear. There appears to be a long-term variation with a period of 88 years and with an amplitude of about 120 mm, on which other shorter-period variations are superimposed. The most evident of these is a 28-year variation, evident during the period 1895 - 1923. These long-term L_t - variations can be expressed by the relation:

$$L_t = 60 \cos \frac{2\pi}{88} (T - 1879) - 70 \sin \frac{2\pi}{28} \underset{1895 - 1923}{(T - 1895)} \qquad (9)$$

The continuous curve in fig. 18b shows approximately the 88-year periodicity, the dashed curve referring to the 28-year variation. The high standard deviation of the 11-year moving averages $\overline{R - R_0}$ as well as lack of sufficient data resulted in uncertainties in the long-term course of $\overline{R - R_0}$ in this particular latitude zone.

The course of the 11-year moving averages $\overline{R - R_0}$ in the two latitude zones 20° - 30° and 30° - 40°, shown in fig. 19a and 19b respectively, is rather strange. Simple sinusoidal variations of 12-year duration are evident in

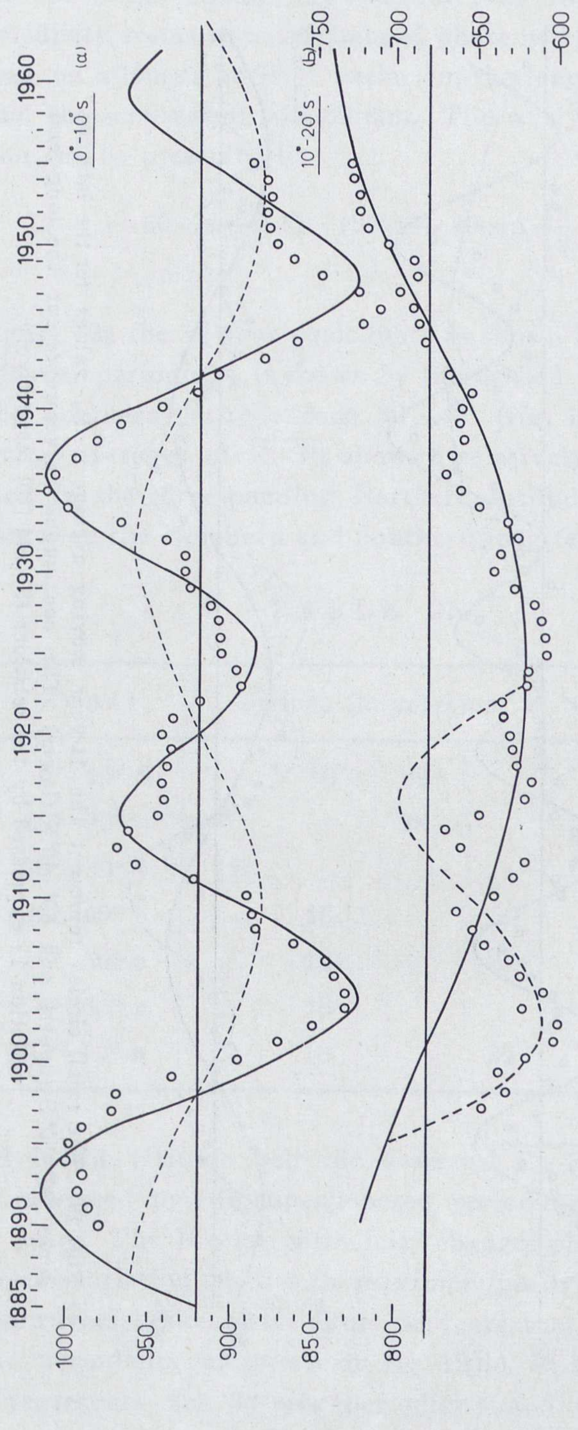

Fig. 18. The small circles represent the 11-year moving average $\overline{R} - R_0$ - values for the latitude zones 0° - 10° S (upper) and 10° - 20° S (lower). The continuous curves represent the long-term variations L_t expressed by the relations (8) and (9) respectively.

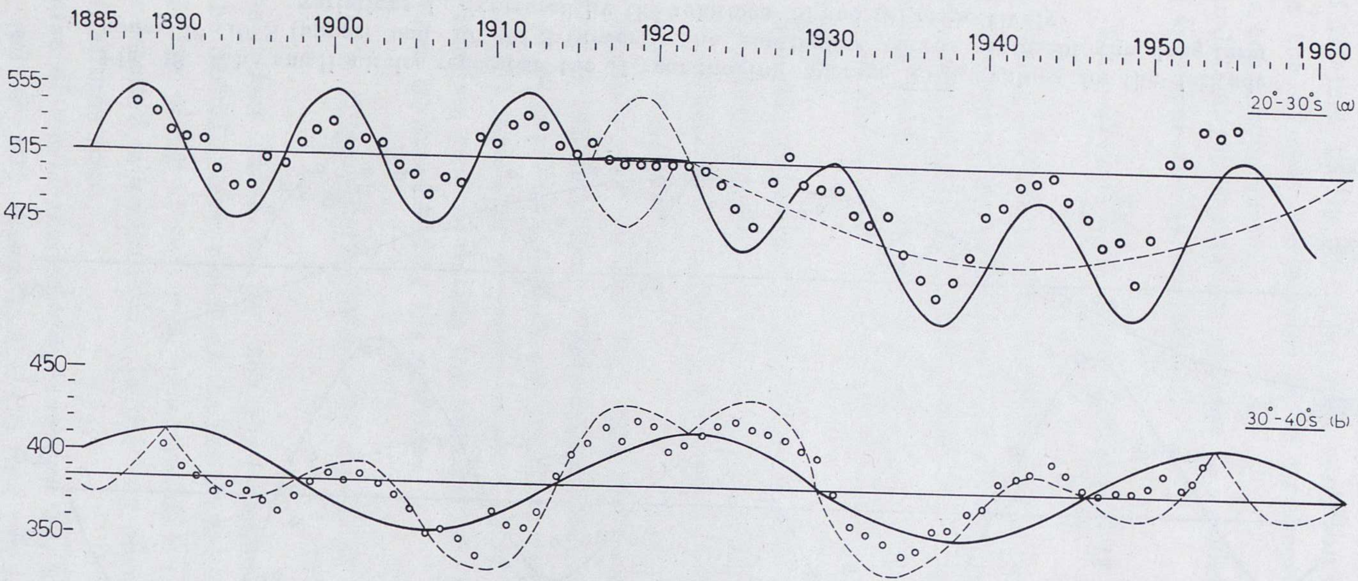

Fig. 19. The small circles represent the 11-year moving average $\overline{R - R_0}$ - values for the latitude zones 20° - 30° S (upper) and 30° - 40° S (lower). The continuous curves represent the long-term variation L_t expressed by the relations (9) and (10) respectively.

fig. 19a (20° - 30° zone) during the time interval 1885 - 1921. Later on, this 12-year periodicity seems to have changed phase by 180° and it is found to be superimposed on a longer periodic variation, the length of which is probably 80 years and the semi-amplitude 60 mm. The analytical expression of this L_t - variation can be presented by:

$$L_t = -60 \sin \frac{2\pi}{80} (T - 1922) + 40 \sin \frac{2\pi}{12} \underset{\substack{1885 - 1921 \\ 1916 - 1958}}{(T - 1885)} \qquad (10)$$

In figure 19a the 12-year periodicity is shown by the continuous curve while the 80-year periodicity is shown by the dashed curve.

In the Southern latitude zone 30° - 40° (fig. 19b), the course of the 11-year moving averages of $\overline{R - R_0}$ shows a relatively small range. This was also observed in the corresponding Northern latitude zone (apart from the difference between the Northern and Southern long-term courses).

TABLE 2b.

Zones	Periods (in years) of L_t - variations				
0° - 10° S		16	22	44	
10° - 20° »			28		88
20° - 30° »	12				80
30° - 40° »		16		32	
40° - 50° »		18		36	80
50° - 60° »		18			88
60° - 70° »	12	18		32	

Indeed in this latitude belt the observed $\overline{R - R_0}$ long-term variation are probably produced by two superimposed periodic variation with periods of 16 and 32 years. The 16-year periodicity changes phase by 180° after 1922 when the 32-year variation reaches its maximum positive value. It is probable that this phase reversal takes place every 32 years, that is, during the maxima of the 32-year periodicity as shown in fig. 19(b). In that figure the continuous curve represents the 32-year periodicity and the dashed curve the

16-year periodicity. The following relation gives an approximate expression of this long-time variation:

$$L_t = 30 \sin \frac{2\pi}{32} (T - 1882) - 30 \sin \frac{2\pi}{16} \underset{\substack{1890 - 1922 \\ 1954 - 1956}}{(T - 1890)} + 30 \sin \frac{2\pi}{16} \underset{\substack{1922 - 1954 \\ 1986 - 2018}}{(T - 1922)} \qquad (11)$$

From the above discussion it follows that there are considerable differences in the long-term variations of precipitation between the corresponding latitude zones of the two hemispheres. The common feature of these long-term variations is the large amplitudes found in the equatorial latitude belts and the small amplitudes found in mid-latitudes (30^0 - 50^0) in both hemispheres. As regards the long-time variations, with the greatest frequency there are those with periods of 80 - 88 years, evident in a total of 8 zones in the two hemispheres, and those with 40 - 44 year periodicities, evident in 4 latitude belts. The so-called Brückner's 32 - 36 year periodicity appears in 3 Northern and 3 Southern belts. It should be noted here that the components which appear with most frequency are those with lengths of 22, 32 - 36, 40 - 44 and 80 - 88 years (see Table 2b), obviously multiples of the 11-year cycle.

4. CORRELATIONS BETWEEN THE DIFFERENCES $(\overline{R - R_0}) - L_t$ AND THE TWO INDICES OF SOLAR ACTIVITY

Folloving the above discussion we can tentatively propose that the $\overline{R - R_0}$ - values, filtered by means of the well known 11-year moving average method, display long periodic changes most of which have lenghts of 18, 22, 32 - 36, 40 - 44 and 80 - 88 years. These L_t - variations were presented in the previous sections by the analytical formulae 1 to 11, significantly influence the course of $\overline{R - R_0}$ - values during the 11-year solar activity cycle.

Solar activity link's if any, with precipitation totals would be more promising when the long periodic variations L_t were removed from the $\overline{R - R_0}$ - values, assuming that the L_t - variations are more likely to be of terrestrial origin.

As will be shown later, the correlation coefficients between solar activity and the $(\overline{R - R_0}) - L_t$ variable, which we call the «11 year component of the mean zonal annual precipitation», are found to be higher than those obtained by using $\overline{R - R_0}$ alone. This is shown in the following tables 3 and 4 which present the correlation coefficients of $\overline{R - R_0}$ and $(\overline{R - R_0}) - L_t$ with the two solar activity indices. The time intervals used for the computation of each of the correlation coefficients, are shown in the last column of tables 3 and 4.

TABLE 3.

Correlation coefficients of $\overline{R - R_0}$ and $(\overline{R - R_0}) - L_t$ with the two solar activity indices (I_α and W.N) in the Northern hemisphere zones.

Zones	$\overline{R - R_0}$		$(\overline{R - R_0}) - L_t$		Time intervals
	I_α	W.N	I_α	W.N	
0° - 10° N	+0.83	+0.75	+0.86	+0.77	1888 - 1917
»	−0.72	−0.62	−0.87	−0.79	1918 - 1960
10° - 20° N	−0.35	−0.37	−0.90	−0.72	1888 - 1907, 1918 - 1960
»	+0.90	+0.89	+0.94	+0.92	1908 - 1917
20° - 30° N	−0.31	−0.24	−0.76	−0.74	1885 - 1908
»	+0.34	+0.26	+0.77	+0.67	1909 - 1960
30° - 40° N	−0.01	0.00	−0.03	−0.01	1885 - 1960
40° - 50° N	−0.64	−0.70	−0.70	−0.73	1885 - 1910
»	+0.47	+0.49	+0.59	+0.60	1911 - 1960
50° - 60° N	−0.72	−0.67	−0.80	−0.74	1890 - 1904
»	+0.68	+0.76	+0.90	+0.80	1905 - 1960
60° - 70° N	−0.65	−0.61	−0.91	−0.74	1885 - 1960
70° - 80° N	+0.74	+0.64	+0.86	+0.74	1913 - 1970

From these tables we conclude that in the high-latitude zones ($\varphi \geqslant 60°$ N and $\varphi \geqslant 50°$ S) the correlation between the 11-year component of the mean zonal annual precipitation $(\overline{R - R_0}) - L_t$ and the solar activity indices does retain its sign (positive or negative) during the whole period under study. In the equatorial and in the mid-latitude zones, the correlation changes sign more than once during the period under investigation 1885 - 1960. In both hemispheres the correlation almost disappears in the 30° - 40° latitude zone.

From tables 3 and 4 it also follows that for all latitude zones in both hemispheres, the correlation coefficients found between the $(\overline{R - R_0}) - L_t$-values and the two solar activity indices are generally higher than those found between $\overline{R - R_0}$ and the same indices.

TABLE 4.

Correlation coefficients of $\overline{R - R_0}$ and $(\overline{R - R_0}) - L_t$ with the two solar activity indices (I_α and W.N) in the Southern hemisphere zones.

Zones	$\overline{R - R_0}$		$(\overline{R - R_0}) - L_t$		Time intervals
	I_α	W.N	I_α	W.N	
0° - 10° S	+0.73	+0.74	+0.81	+0.77	1885 - 1903, (1916/17), (1938 - 1943)
»	−0.70	−0.58	−0.86	−0.75	1904 - 1960
10° - 20° S	+0.75	+0.66	+0.92	+0.98	1900 - 1902, 1907 - 1914
»	−0.80	−0.73	−0.62	−0.56	1895 - 1960
20° - 30° S	+0.62	+0.49	+0.86	+0.73	1883 - 1951
»	−0.71	−0.54	−0.76	−0.73	1936/37, 1952 - 1960
30° - 40° S	−0.65	−0.66	−0.63	−0.62	1886 - 1917
»	+0.07	+0.01	+0.17	+0.28	1918 - 1960
40° - 50° S	+0.85	+0.86	+0.88	+0.76	1916 - 1939
»	−0.60	−0.59	−0.87	−0.74	1909 - 1915, 1940 - 1960
50° - 60° S	−0.83	−0.70	−0.93	−0.79	1901 - 1960
60° - 70° S	−0.70	−0.68	−0.87	−0.77	1914 - 1960

In figure 20, continuous vertical straight lines refer to the correlation coefficients found between $(\overline{R - R_0}) - L_t$ and the area index I_α, while the dashed lines represent the corresponding correlation coefficients found by using the Wolf numbers in each of the latitude zones under study. The 1% confidence level is also shown in that figure as a latitude-histogram.

From that figure we can see that, except for the latitude zone 30° - 40°, all correlation coefficients are statistically significant to a better than 0.01 confidence level on a global scale. Generally, the correlation coefficients obtained with the areas index are higher than those found with the Wolf Numbers.

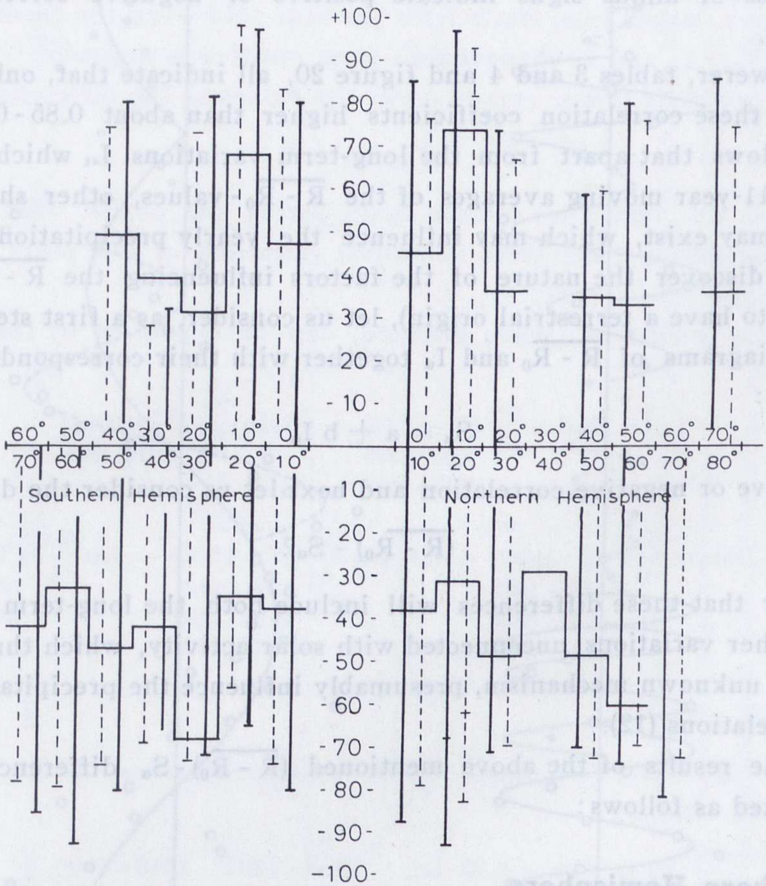

Fig. 20. The continuous vertical straight lines refer to the correlation coefficients found between $(\overline{R - R_0}) - L_t$ and the area index I_α, in each of the latitude zones. The dashed lines represent the corresponding correlation coefficients found by using the Wolf Numbers. The 1 % confidence level is shown as a latitude-histogram.

5. THE DIFFERENCES $(\overline{R - R_0}) - S_\alpha$

If the 11-year component of $\overline{R - R_0}$ (that is the $(\overline{R - R_0}) - L_t$) were dependent only on the 11-year solar activity, then a linear relation would exist between this component and the solar activity, expressed, for example by a relation of the form:

$$(\overline{R - R_0}) - L_t = a \pm b\ (I_\alpha \text{ or } WN)$$

where plus or minus signs indicate positive or negative correlations respectively.

Howerer, tables 3 and 4 and figure 20, all indicate that, only in a few cases are these correlation coefficients higher than about 0.85 - 0.90. From this it follows that apart from the long-term variations L_t which appeared from the 11-year moving averages of the $\overline{R - R_0}$-values, other shorter periodicities may exist, which may influence the yearly precipitation totals. In order to discover the nature of the factors influencing the $\overline{R - R_0}$-values (assumed to have a terrestrial origin), let us consider, as a first step, the dispersion diagrams of $\overline{R - R_0}$ and I_α together with their corresponding regression lines:

$$S_\alpha = a \pm b\ I_\alpha \qquad (12)$$

for positive or negative correlation and next let us consider the differences:

$$(\overline{R - R_0}) - S_\alpha .$$

It is clear that these differences will include both the long-term variations L_t and other variations unconnected with solar activity, which through some currently unknown mechanism, presumably influence the precipitations totals via the relations (12).

The results of the above mentioned $(\overline{R - R_0}) - S_\alpha$ differences, can be summarized as follows:

a) Northern Hemisphere.

Zone $0^0 - 10^0$ N.

In figure 21 (upper curve) the small circles represent the differences $(\overline{R - R_0}) - S_\alpha$, where:

$$\left.\begin{aligned} S_\alpha &= 690 + 4.2\ I_\alpha, \quad 1887 - 1917 \\ S_\alpha &= 877 - 4.8\ I_\alpha, \quad 1918 - 1960 \end{aligned}\right\} \qquad (13)$$

The continuous line shows the long-term variations L_t resulting from the 11-year moving average $\overline{R - R_0}$-values (see also fig. 15 (a)). The 180^0 phase

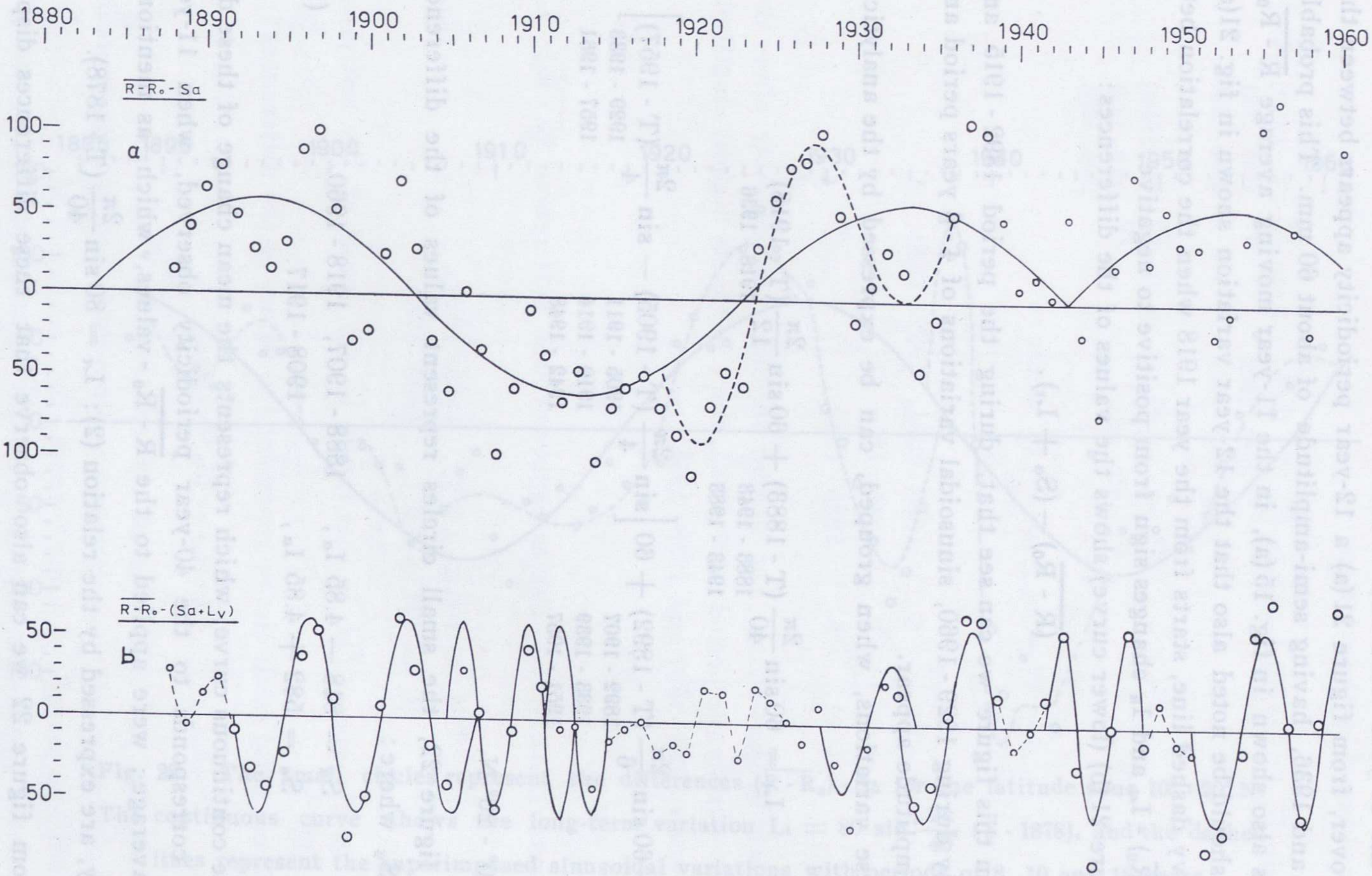

Fig. 21. (a) The small circles represent the differences $(\overline{R - R_0})$ - $S\alpha$. The continuous curve shows the long-term variation L_t and the dashed curve a 12-year periodicity. (b) The small circles represent the differences $(\overline{R - R_0})$ - $(S\alpha + L_t)$ and the continuous curves shown the sporadic sinusoidal variations W.

change in the 40-year variation which occurred after 1943, is more evident here. Moreover, from figure 21 (a) a 12-year periodicity appears between the years 1918 and 1936, having semi-amplitude of about 60 mm. This probable variation is also shown in fig. 15 (a), in the 11-year moving average $\overline{R - R_0}$-values. It should be noted also that the 12-year variation shown in fig. 21(a) by the heavy dashed line, starts from the year 1918 when the correlation between $(\overline{R - R_0}) - L_t$ and I_α changes sign from positive to negative.

Figure 21 (b) (lower curve) shows the values of the differences:

$$(\overline{R - R_0}) - (S_\alpha + L_t).$$

From this figure we can see that, during the period 1892 - 1915 and sporadically during 1929 - 1960, sinusoidal variations of 4 - 6 years period and constant amplitude appear.

These variations, when grouped, can be expressed by the analytical relation:

$$L_t = 60 \sin \frac{2\pi}{40} \underset{\substack{1883\,-\,1943 \\ 1943\,-\,1983}}{(T - 1883)} + 60 \sin \frac{2\pi}{12} \underset{1918\,-\,1936}{(T - 1918)} \qquad (5,1)$$

$$W = -60 \sin \frac{2\pi}{6} \underset{\substack{1892\,-\,1907 \\ 1933\,-\,1939 \\ 1951\,-\,1957}}{(T - 1892)} + 60 \left[\sin \frac{2\pi}{4} \underset{\substack{1905\,-\,1911 \\ 1910\,-\,1914 \\ 1942\,-\,1948}}{(T - 1905)} - \sin \frac{2\pi}{4} \underset{\substack{1929\,-\,1933 \\ 1957\,-\,1961}}{(T - 1957)} \right]$$

Zone 10° - 20° N.

In figure 22, the small circles represent values of the differences $(\overline{R - R_0}) - S_\alpha$ where:

$$S_\alpha = 818 - 4.85\, I_\alpha, \quad 1888 - 1907, \ 1918 - 1960$$
$$S_\alpha = 582 + 4.85\, I_\alpha, \quad 1908 - 1917. \qquad (14)$$

The continuous curve, which represents the mean change of these differences, corresponds to the 40-year periodicity observed, when 11-year moving average; were applied to the $\overline{R - R_0}$ - values, which, as mentioned previously, are expressed by the relation (2): $L_t = 80 \sin \frac{2\pi}{40} (T - 1878)$.

From figure 22 we can also observe that these differences display sinusoidal variations (superimposed in L_t - variation) with different amplitudes

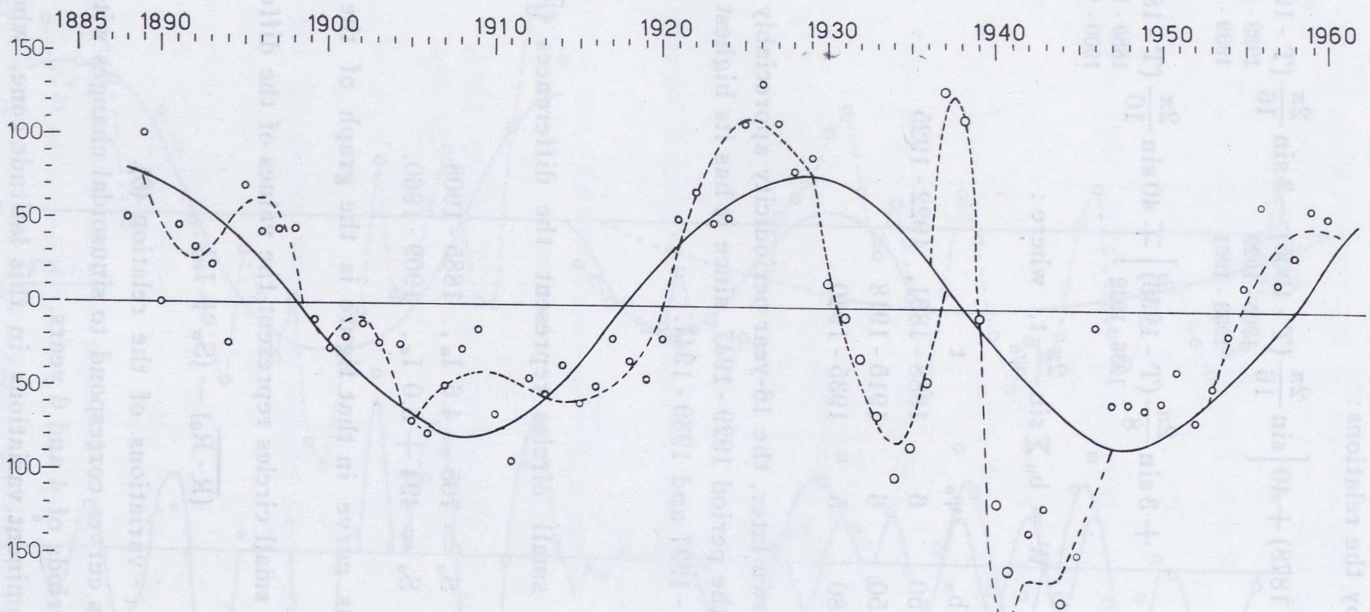

Fig. 22. The small circles represent the differences $(\overline{R - R_0}) - S_\alpha$ for the latitude zone 10° - 20° N. The continuous curve shows the long-term variation $L_t = 80 \sin \frac{2\pi}{40} (T - 1878)$, and the dashed lines represent the superimposed sinusoidal variations with periods of 8, 10 and 16 years.

and periods (dashed lines). Thus, the observed variations in this latitude belt can be approximated by the relations:

$$(5,2)\quad L_t = 80\sin\frac{2\pi}{40}(T-1878) + 40\Big[\underset{\substack{1905-1929\\1953-1961}}{\sin\frac{2\pi}{16}(T-1905)} - \underset{\substack{1929-1937\\1939-1947}}{3\sin\frac{2\pi}{16}(T-1929)} + \underset{1936-1942}{3\sin\frac{2\pi}{8}(T-1936)}\Big] \mp \underset{\substack{1889-1899\\1900-1905}}{40\sin\frac{2\pi}{10}(T-1889)}$$

$$W_\circ = b_n \sum \sin\frac{2\pi}{\psi_n} t, \quad \text{where:}$$

b_n	ψ_n	t
−50	6	1888 - 1891, 1922 - 1925
+50	6	1915 - 1918
+80	5	1935 - 1940.

As it will be shown later, the 16-year periodicity appreciably alters the $\overline{R-R_0}$ course during the period 1929 - 1947, since it has its highest amplitude during the years 1929 - 1937 and 1939 - 1947.

Zone 20° - 30° N.

In figure 23(a), small circles represent the differences $(\overline{R-R_0}) - S_\alpha$, where:

$$S_\alpha = 705 - 4.6\ I_\alpha, \quad 1885-1908$$
$$S_\alpha = 494 + 3.0\ I_\alpha, \quad 1909-1960. \qquad (15)$$

The continuous curve in that figure is the graph of the analytical expression (3).

In figure 23(b) small circles represent the values of the differences:

$$(\overline{R-R_0}) - (S_\alpha + L_t)$$

where L_t are the L_t - variations of the relation (3).

The continuous curves correspond to sinusoidal changes with appreciable amplitude and periods of 4 and 6 years.

The more prominent variations in this latitude zone, when grouped, can be expressed by the relations:

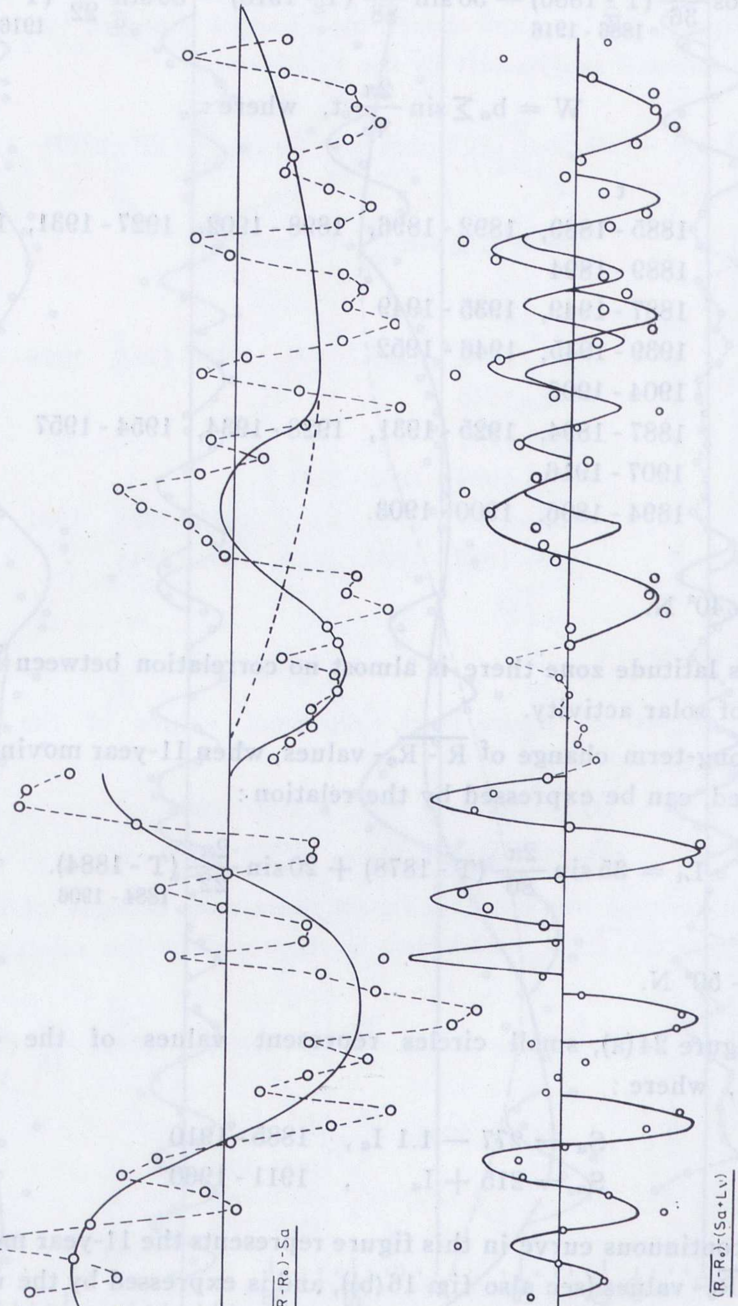

Fig. 23. (Upper) The small circles represent the differences $(\overline{R - R_0})$ - S_α for the 20° - 30° N latitude zone. The continuous curves show the long-term variations L_t. (Bottom). The small circles represent the differences $(\overline{R - R_0})$ $(S_\alpha + L_t)$ and the continuous lines show the sporadic sinusoidal variations W.

$$L_t = 80\cos\frac{2\pi}{36}(T - 1886) \underset{1886 - 1916}{} - 50\sin\frac{2\pi}{88}(T - 1918) - 50\sin\frac{2\pi}{22}(T - 1916) \underset{1916 - 1938}{}$$

(5,3)

$$W = b_n \sum \sin\frac{2\pi}{\psi_n} t, \text{ where :}$$

b_n	ψ_n	t
− 30	4	1885 - 1889, 1892 - 1896, 1898 - 1902, 1927 - 1931, 1956 - 1960
50	5	1889 - 1894
+ 30	4	1887 - 1949, 1935 - 1949
+ 50	6	1939 - 1945, 1946 - 1952
+ 60	4	1904 - 1906
− 60	6	1887 - 1894, 1925 - 1931, 1928 - 1934, 1954 - 1957
+ 80	6	1907 - 1916
− 80	6	1894 - 1896, 1900 - 1903.

Zone 30° - 40° N.

In this latitude zone there is almost no correlation between $\overline{R - R_0}$ and the indices of solar activity.

The long-term change of $\overline{R - R_0}$ - values, when 11-year moving averages are considered, can be expressed by the relation :

$$L_t = 35\sin\frac{2\pi}{80}(T - 1878) + 20\sin\frac{2\pi}{22}(T - 1884). \underset{1884 - 1906}{} \quad (5,4)$$

Zone 40° - 50° N.

In figure 24(a), small circles represent values of the differences $(\overline{R - R_0}) - S_\alpha$, where :

$$S_\alpha = 277 - 1.1\, I_\alpha, \quad 1885 - 1910$$
$$S_\alpha = 215 + I_\alpha \quad, \quad 1911 - 1960. \qquad (16)$$

The continuous curve in this figure represents the 11-year moving averages of $\overline{R - R_0}$ - values (see also fig. 16(b)), and is expressed by the relation (5). Small circles in figure 24(b) correspond to the value of differences :

$$(\overline{R - R_0}) - (S_\alpha + L_t).$$

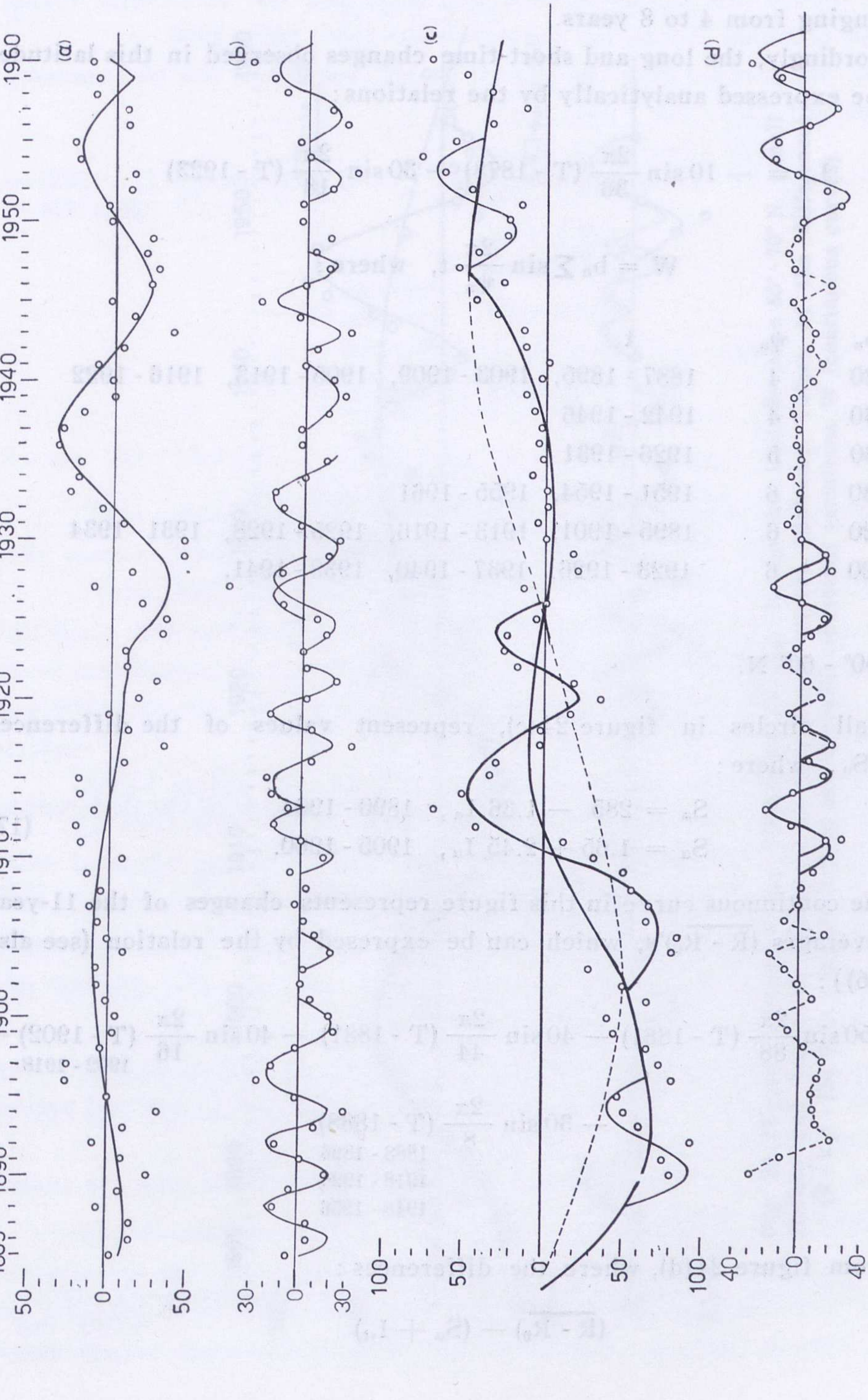

Fig. 24 (a) and (c). The small circles represent the differences $(\overline{R - R_0}) - S_\alpha$ for the latitude zones 40° - 50° N and 50° - 60° N respectively. The continuous curves represent the corresponding long-term variations L_t. (b) and (d). The small circles represent the differences $(\overline{R - R_0}) - (S_\alpha + L_t)$ for the latitude zones 40° - 50° N and 50° - 60° N respectively. The continuous curves show the corresponding sporadic sinusoidal variations W.

These differences display variations with constant amplitude and periods ranging from 4 to 8 years.

Accordingly, the long and short-time changes observed in this latitude zone can be expressed analytically by the relations:

$$L_t = -10\sin\frac{2\pi}{36}(T - 1878) - 30\sin\frac{2\pi}{18}(T - 1923)$$

(5,5)

$$W = b_n \sum \sin\frac{2\pi}{\psi_n} t, \quad \text{where:}$$

b_n	ψ_n	t
-20	4	1887 - 1895, 1903 - 1909, 1905 - 1913, 1916 - 1922
-30	4	1942 - 1946
$+30$	5	1926 - 1931
-30	6	1951 - 1954, 1955 - 1961
$+20$	6	1895 - 1901, 1913 - 1916, 1925 - 1928, 1931 - 1934
-20	6	1923 - 1926, 1937 - 1940, 1938 - 1941.

Z o n e 50° - 60° N.

Small circles in figure 24 (c), represent values of the differences $\overline{(R - R_0)} - S_\alpha$, where:

$$S_\alpha = 285 - 1.36\, I_\alpha, \quad 1890 - 1904$$
$$S_\alpha = 1.65 + 2.45\, I_\alpha, \quad 1905 - 1960. \qquad (17)$$

The continuous curve in this figure represents changes of the 11-year moving averages $\overline{(R - R_0)}$'s, which can be expresed by the relation (see also relation (6)):

$$L_t = -50\sin\frac{2\pi}{88}(T - 1881) - 40\sin\frac{2\pi}{44}(T - 1881) - 40\sin\frac{2\pi}{16}\underset{1902 - 1918}{(T - 1902)} -$$

$$- 30\sin\frac{2\pi}{8}\underset{\substack{1888 - 1896\\1918 - 1926\\1948 - 1956}}{(T - 1888).}$$

From figure 24 (d), where the differences:

$$\overline{(R - R_0)} - (S_\alpha + L_t)$$

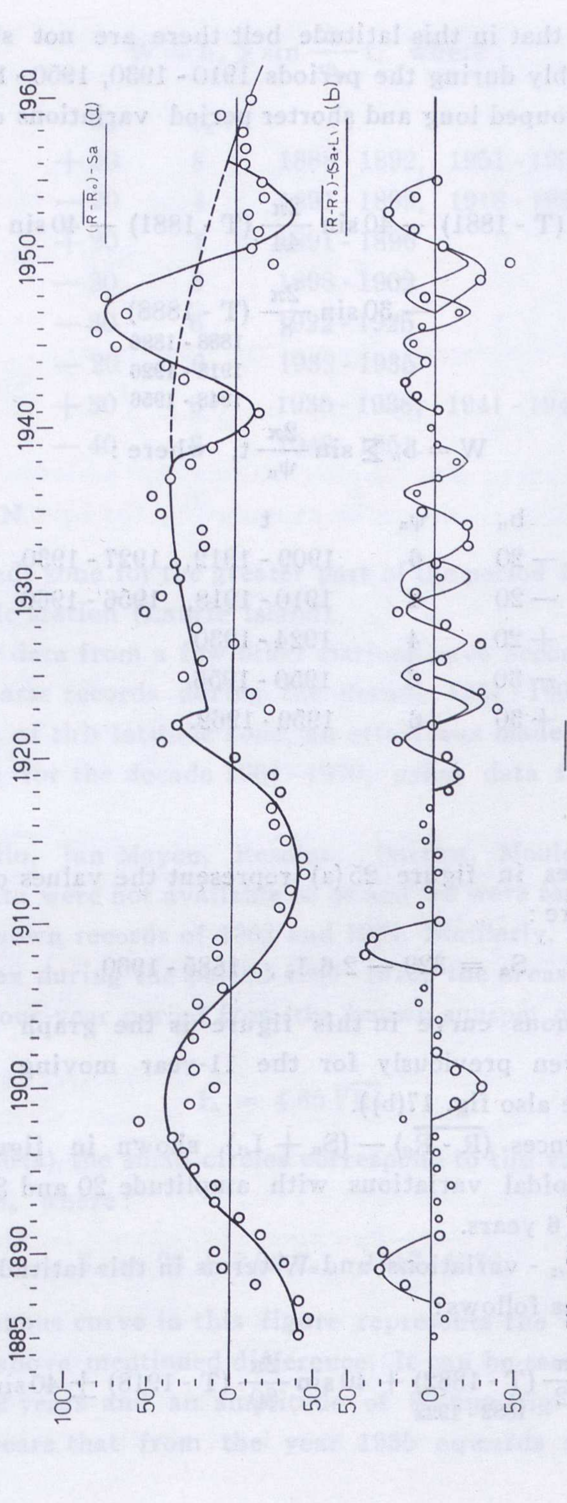

Fig. 25. (Upper). Values of the differences $\overline{(R - R_0)}$ - S_α for the latitude zone 60° - 70° N (small circles) and long-term variations L_t (continuous curve). (Bottom). Values of the differences $\overline{(R - R_0)}$ - $(S_\alpha + L_t)$ (small circles) and sporadic sinusoidal variations W (continuous curves).

are shown, we see that in this latitude belt there are not short-term variations except probably during the periods 1910 - 1930, 1950 - 1960.

Thus, the grouped long and shorter period variations can be expressed by the relations:

$$L_t = -50 \sin \frac{2\pi}{88}(T - 1881) - 40 \sin \frac{2\pi}{44}(T - 1881) - \underset{1902 - 1918}{40 \sin \frac{2\pi}{16}(T - 1902)} -$$

$$- \underset{\substack{1888 - 1896 \\ 1918 - 1926 \\ 1948 - 1956}}{30 \sin \frac{2\pi}{8}(T - 1888)} \qquad (5,6)$$

$$W = b_n \sum \sin \frac{2\pi}{\psi_n} t, \quad \text{where:}$$

b_n	ψ_n	t
— 20	6	1909 - 1912, 1927 - 1930
— 20	4	1910 - 1918, 1956 - 1960
+ 20	4	1924 - 1930
— 30	6	1950 - 1956
+ 30	6	1959 - 1962.

Zone 60^0 - 70^0 N.

Small circles in figure 25(a) represent the values of the differences $\overline{(R - R_0)} - S_\alpha$, where:

$$S_\alpha = 329 + 2.6\, I_\alpha, \quad 1885 - 1960. \qquad (18)$$

The continuous curve in this figure is the graph of the analytical expression (7) given previously for the 11-year moving averages of the $\overline{R - R_0}$ - values (see also fig. 17(b)).

The differences $\overline{(R - R_0)} - (S_\alpha + L_t)$, shown in figure 25(b), display sporadically sinusoidal variations with amplitude 20 and 30 mm and period ranging from 4 to 6 years.

Thus, the L_t - variations and W terms in this latitude zone are analytically expressed as follows:

$$L_t = -\underset{1882 - 1922}{40 \cos \frac{2\pi}{32}(T - 1882)} + 40 \sin \frac{2\pi}{80}(T - 1918) \pm \underset{\substack{+1904 - 1951 \\ -1938 - 1956}}{40 \sin \frac{2\pi}{12}(T - 1904)}$$

(5,7) $$W = b_n \sum \sin \frac{2\pi}{\psi_n} t, \text{ where :}$$

b_n	ψ_n	t
+30	8	1888 - 1892, 1951 - 1955
−20	4	1891 - 1899, 1918 - 1930
+20	4	1891 - 1896
−30	8	1898 - 1902
−30	6	1922 - 1925
−20	6	1932 - 1935
+30	6	1935 - 1938, 1941 - 1944
−40	6	1948 - 1951.

Zone 70° - 80° N.

This latitude zone for the greater part of the period 1913 - 1960 contains only one available station (Laurie Island).

Since 1950 data from a few other stations have become available to us, but these had sparse records during the decade 1951 - 1960. Because of the great importance of this latitude zone, an effort was made to supplement the available records for the decade 1961 - 1970, using data from the following stations :

Isford Radio, Jan Mayen, Resolute, Borrow, Mould Bay and Vardo.

In 1963 data were not available to us and we were forced to interpolate them from the known records of 1962 and 1964. Similarly, because of lack of data on area index during the period 1966 - 1970, the areas index I_α was calculated for this four-year period from the known sunspot number R by using the relation [**17**].

$$I_\alpha = 4.65 \sqrt{R}.$$

In figure 26 (a), the small circles correspond to the values oft he differences $\overline{(R - R_0)} - S_\alpha$ where :

$$S_\alpha = 93 + 2.02\, I_\alpha, \quad 1913 - 1970. \qquad (19)$$

The continuous curve in this figure represents the «mean» long-term variation of the above mentioned difference. It can be seen that this curve has a period of 22 years and an amplitude of 80 mm (fig. 26 (a)). From this figure it also appears that from the year 1935 onwards shorter variations (dashed curves) are superimposed on the long-term one. Thus, the long-term variations of the $\overline{(R - R_0)} - S_\alpha$ in this latitude zone, can be expressed by the relation :

$$(5,8)\quad L_t = 40\sin\frac{2\pi}{22}(T - 1911) + 30\sin\frac{2\pi}{10}\underset{1935 - 1950}{(T - 1935)} + 30\sin\frac{2\pi}{8}\underset{1951 - 1963}{(T - 1951)} - 30\sin\frac{2\pi}{16}\underset{1955 - 1971}{(T - 1955)}.$$

Figure 26 (b) represents values of the differences :

$$\overline{(R - R_0)} - (S_\alpha + L_t).$$

These differences also display alternating periodic variations, with lengths 6 and 8 years, which can be expressed by the relation :

$$W = -30\left[\sin\frac{2\pi}{8}\underset{1912 - 1916}{(T - 1912)} - \sin\frac{2\pi}{8}\underset{\substack{1926 - 1934\\1930 - 1938\\1963 - 1967}}{(T - 1926)}\right] + 20\left[\sin\frac{2\pi}{6}\underset{1942 - 1963}{(T - 1942)} - \sin\frac{2\pi}{6}\underset{1917 - 1920}{(T - 1917)}\right].$$

One remarkable thing in this latitude belt is the absence of longer than 22-year periodicity. This 22-year periodicity seems to continue throughout the whole period 1913 - 1970.

Of the remaining variations the more frequently observed are those with periods of 8 and 6 years, which, however, show amplitudes smaller than that of the 22-year periodicity.

The long-term variations L_t, revealed by applying the 11-year moving averages of the $\overline{R - R_0}$ values became also evident when the differences $\overline{(R - R_0)} - S_\alpha$ were used. These variations will subsequently be named as «probable primary periodicities».

Furthermore, the short-time sinusoidal change (symbolized as W) will be called «probable sporadic short-period variations».

As mentioned previously, primary periodicities L_t perceptibly influence the investigated correlation between $\overline{R - R_0}$ and the indices of solar activity under study (see also tables 3 and 4). As regards the sporadic variations W, these can be neglected only when they have small amplitude as compared to

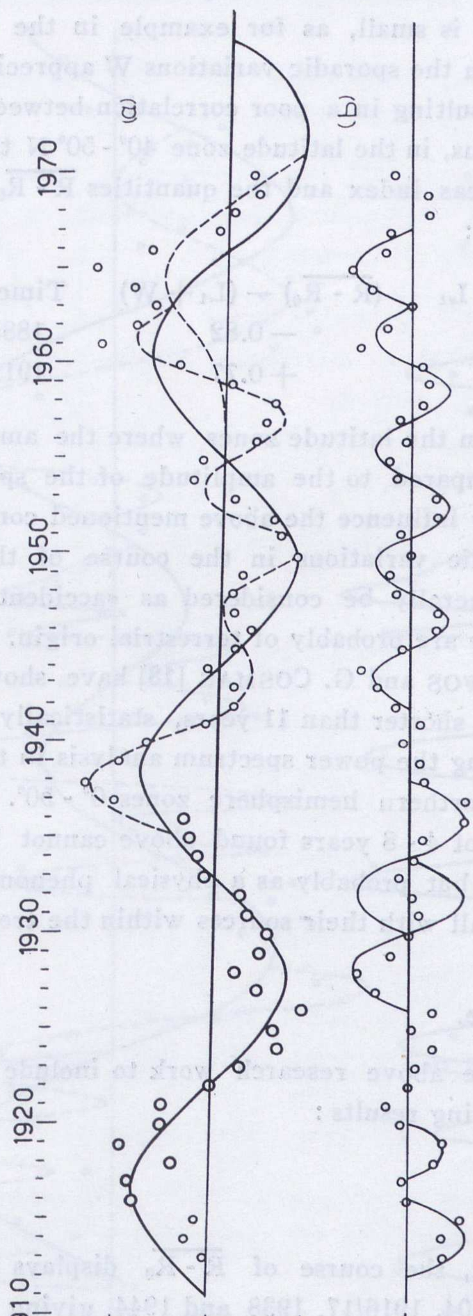

Fig. 26. (Upper) The small circles represent the differences $\overline{(R - R_0)} - S_a$ for the latitude belt 70° - 80° N. The continuous curve represent the 22-year variation and the dashed lines the superimposed shorter variations. (Bottom). The small circles represent the difference $(\overline{R - R_0}) - (S_a + L_t)$ and the continuous curve the sporadic oscillations W.

the amplitude of the 11-year variation of $\overline{R - R_0}$. However, when the amplitude of the $\overline{R - R_0}$ variation is small, as for example in the latitude belts 30° - 40° N and 40° - 50° N, then the sporadic variations W appreciably mask the 11-year $\overline{R - R_0}$ variation resulting in a poor correlation between $\overline{R - R_0}$ and the solar activity indices. Thus, in the latitude zone 40° - 50° N the correlation coefficients between the areas index and the quantities $\overline{R - R_0}$, $(\overline{R - R_0}) - L_t$ and $(\overline{R - R_0}) - (L_t + W)$ are :

$\overline{R - R_0}$	$(\overline{R - R_0}) - L_t$	$(\overline{R - R_0}) - (L_t + W)$	Time Interval
−0.64	−0.70	−0.82	1885 - 1910
+0.47	+0.59	+0.77	1911 - 1960.

On the other hand, in the latitude zones where the amplitude of the $\overline{R - R_0}$ variation is high compared to the amplitude of the sporadic pulses, the latter do not appreciably influence the above mentioned correlations.

The observed sporadic variations in the course of the «residuals» $(\overline{R - R_0}) - (S_\alpha + L_t)$ can generally be considered as «accidental» sinusoidal variations in $\overline{R - R_0}$ and they are probably of terrestrial origin.

Actually, CHR. ZEREFOS and G. COSMAS [**18**] have shown that there are variations with periods shorter than 11 years, statistically significant at less than 1% levels, by using the power spectrum analysis in the time series of $\overline{R - R_0}$ - values of the Northern hemisphere zones 0° - 50°. Consequently, the variations with periods of 4 - 8 years found above cannot be regarded as simply corrective meaning, but probably as a physical phenomenon, namely they are pulses of the rainfall with their sources within the troposphere.

b) Southern Hemisphere.

The extension of the above research work to include the Southern hemisphere gives the following results :

Zone 0° - 10° S.

In this latitude belt, the course of $\overline{R - R_0}$ displays abrupt phase changes during the years 1904, 1916/17, 1938 and 1944, giving rise to corresponding sign reversals of the correlation coefficients obtained with the indices of solar activity.

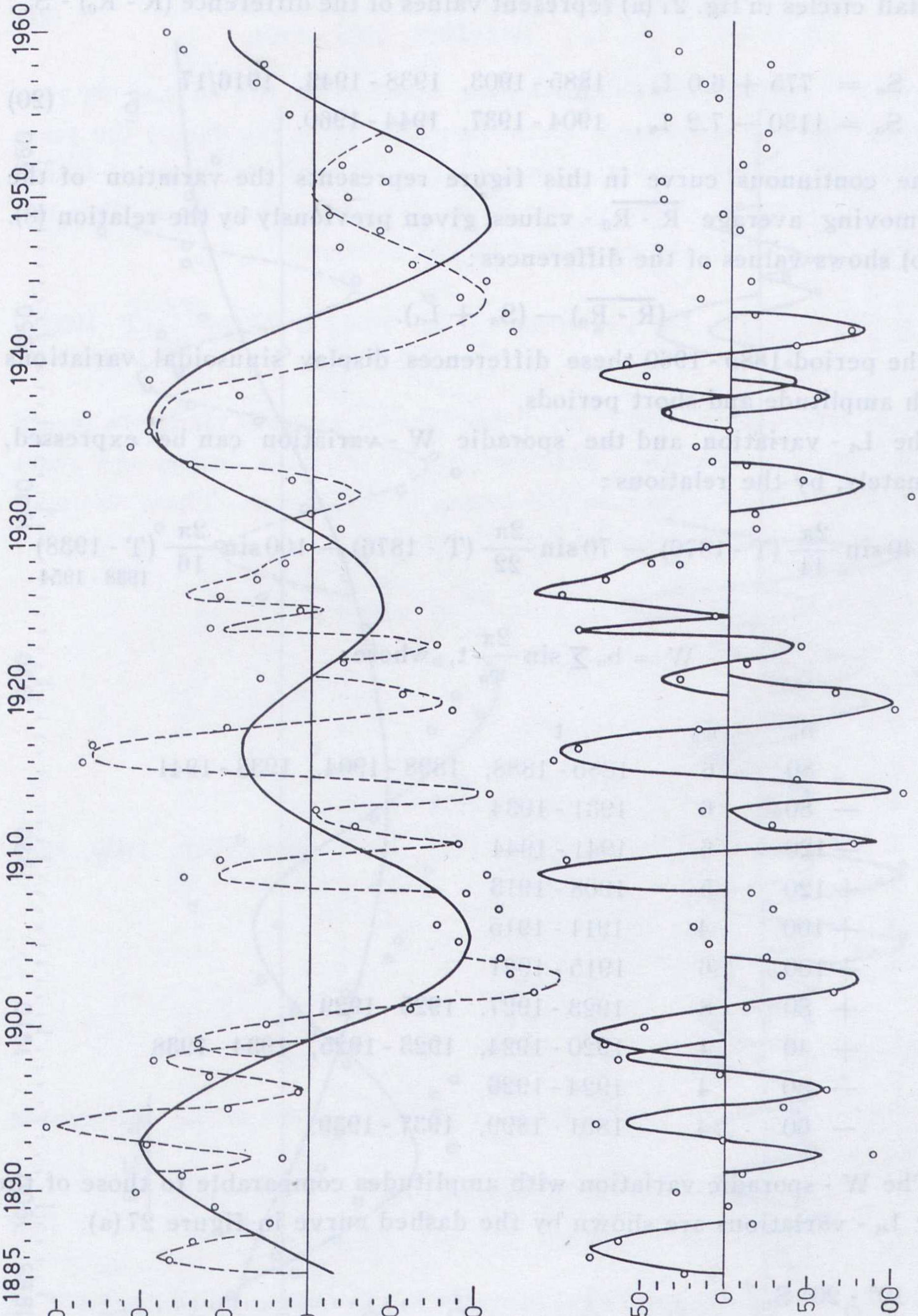

Fig. 27. (Upper). Small circles represent values of the differences $\overline{(R - R_0)} - S_\alpha$ for the latitude zone 0° - 10° S, while the continuous curve represents the mean variation of the 11 - year moving average $\overline{R - R_0}$ - values (long-term variation L_t). (Bottom). Small circles represent values of the differences $\overline{(R - R_0)} - (S_\alpha + L_t)$ and the continuous curves the sporadic oscillations W. These W - oscillations are shown in upper figure by the dashed lines.

Small circles in fig. 27 (a) represent values of the difference $(\overline{R - R_0}) - S_\alpha$, where:

$$S_\alpha = 775 + 6.0\ I_\alpha, \quad 1885 - 1903, \quad 1938 - 1943, \quad 1916/17$$
$$S_\alpha = 1130 - 7.2\ I_\alpha, \quad 1904 - 1937, \quad 1944 - 1960. \qquad (20)$$

The continuous curve in this figure represents the variation of the 11-year moving average $\overline{R - R_0}$ - values, given previously by the relation (8). Fig. 27 (b) shows values of the differences:

$$(\overline{R - R_0}) - (S_\alpha + L_t).$$

During the period 1885 - 1960 these differences display sinusoidal variations with high amplitude and short periods.

The L_t - variation and the sporadic W - variation can be expressed, approximately, by the relations:

$$L_t = 40 \sin \frac{2\pi}{44} (T - 1876) - 70 \sin \frac{2\pi}{22} (T - 1876) - 100 \sin \frac{2\pi}{16} \underset{1938 - 1954}{(T - 1938)}$$

(5,10)

$$W = b_n \sum \sin \frac{2\pi}{\psi_n} t, \text{ where:}$$

b_n	ψ_n	t
80	6	1885 - 1888, 1898 - 1904, 1938 - 1941
— 80	6	1931 - 1934
— 120	6	1941 - 1944
+ 120	5	1908 - 1913
+ 100	4	1911 - 1915
+ 100	6	1915 - 1921
+ 80	8	1923 - 1927, 1925 - 1929
+ 40	4	1920 - 1924, 1923 - 1925, 1934 - 1938
— 80	4	1924 - 1926
— 60	4	1891 - 1899, 1937 - 1939.

The W - sporadic variation with amplitudes comparable to those of the primary L_t - variations are shown by the dashed curve in figure 27 (a).

Zone 10^0 - 20^0 S.

Small circles in figure 28 (a) correspond to values of the differences $(\overline{R - R_0}) - S_\alpha$, where:

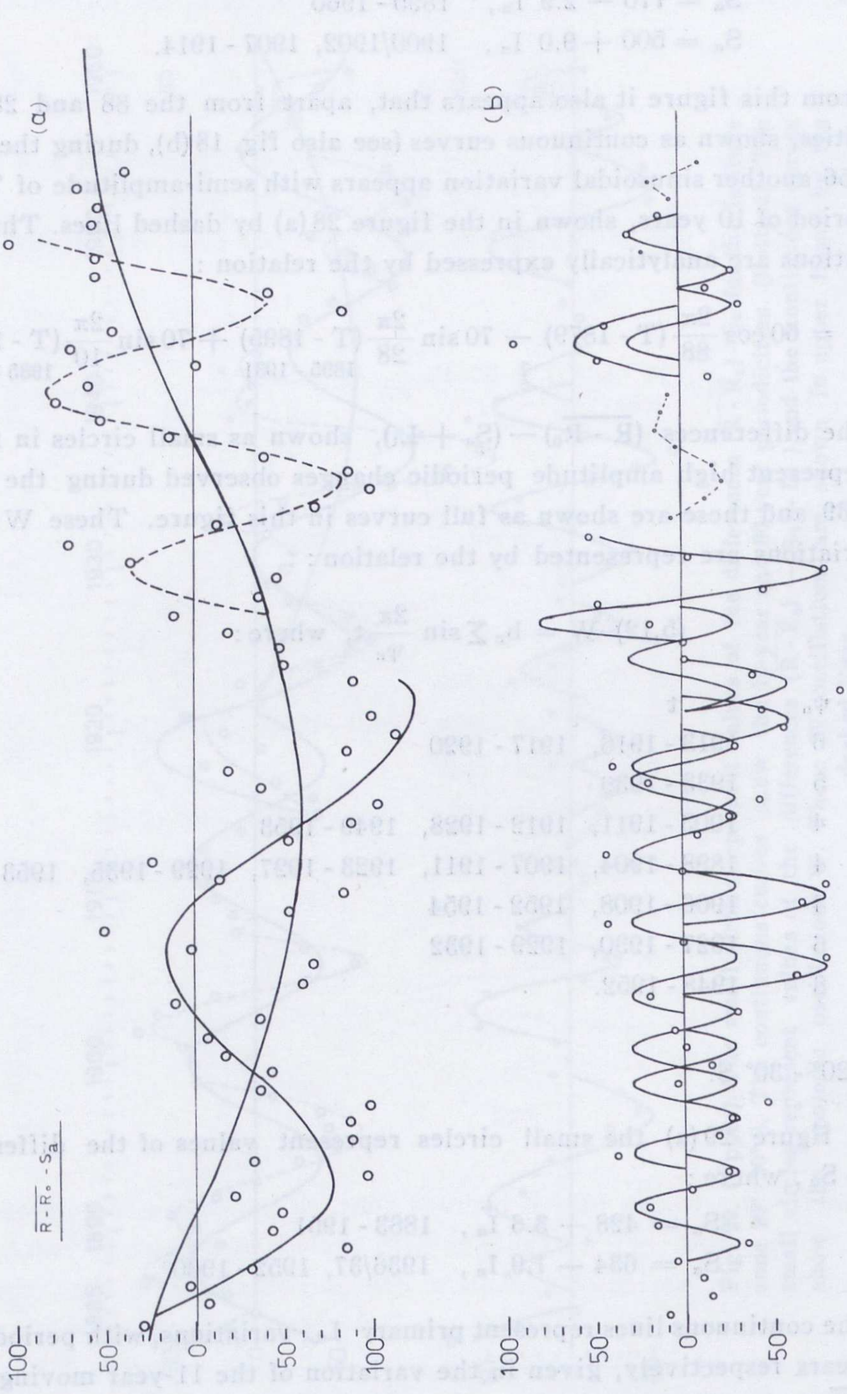

Fig. 28. (Upper). The small circles represent values of the differences $(\overline{R-R_0}) - S_\alpha$ for the latitude zone 10° - 20° S. The continuous curves show the 88-year and 28-year periodicities, while the dashed curve shown the 10-year periodicities. (Bottom). The small circles represent values of the differences $(\overline{R-R_0}) - (S_\alpha + L_t)$ and the continuous curves represent the sporadic oscillations W.

$$S_\alpha = 770 - 2.9\ I_\alpha, \quad 1895-1960$$
$$S_\alpha = 500 + 9.0\ I_\alpha, \quad 1900/1902,\ 1907-1914. \qquad (21)$$

From this figure it also appears that, apart from the 88 and 28-year periodicities, shown as continuous curves (see also fig. 18 (b), during the years 1935 - 1956 another sinusoidal variation appears with semi-amplitude of 70 mm and a period of 10 years, shown in the figure 28 (a) by dashed lines. Thus the L_t - variations are analytically expressed by the relation :

$$(5,11)\quad L_t = 60 \cos \frac{2\pi}{88}(T-1879) - \underset{1895-1931}{70 \sin \frac{2\pi}{28}(T-1895)} + \underset{1935-1956}{70 \sin \frac{2\pi}{10}(T-1935)}.$$

The differences $(\overline{R - R_0}) - (S_\alpha + L_t)$, shown as small circles in figure 28 (b), represent high amplitude periodic changes observed during the years 1910 - 1939 and these are shown as full curves in this figure. These W - sporadic variations are represented by the relation :

$$(5,12)\quad W = b_n \sum \sin \frac{2\pi}{\psi_n} t, \text{ where:}$$

b_n	ψ_n	t
−80	6	1913 - 1916, 1917 - 1920
−80	5	1933 - 1939
+30	4	1903 - 1911, 1912 - 1928, 1949 - 1953
−30	4	1898 - 1904, 1907 - 1911, 1923 - 1927, 1929 - 1935, 1953 - 1957
−90	4	1906 - 1908, 1952 - 1954
−60	6	1927 - 1930, 1929 - 1932
+60	8	1948 - 1952.

Zone 20° - 30° S.

In figure 29 (a) the small circles represent values of the differences $(\overline{R - R_0}) - S_\alpha$, where :

$$S_\alpha = 428 + 3.6\ I_\alpha, \quad 1883-1951$$
$$S_\alpha = 634 - 1.9\ I_\alpha, \quad 1936/37,\ 1952-1960. \qquad (22)$$

The continuous lines represent primary L_t - variations, with period of 12 and 80 years respectively, given in the variation of the 11-year moving average $\overline{R - R_0}$'s (see fig. 19 (a)).

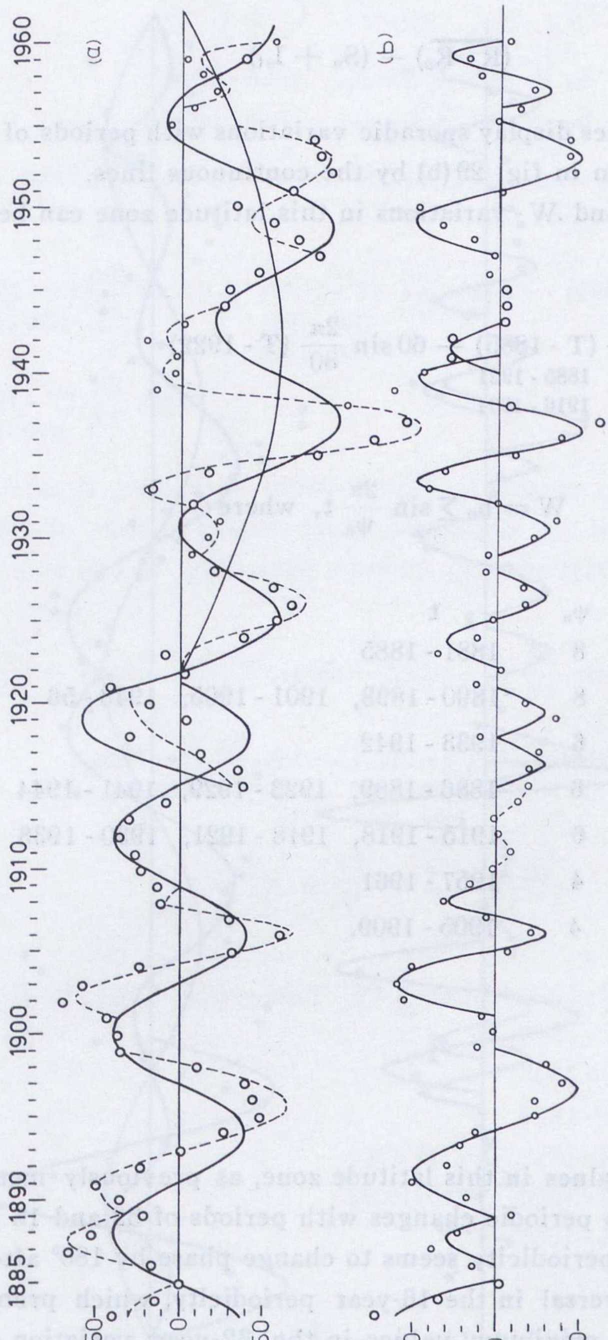

Fig 29 (Upper). The small circles represent values of the differences $(R - \overline{R_0}) - S_\alpha$ for the latitude zone 20°-30° S. The continuous curves show the 12-year and 80-year periodicities. (Bottom). The small circles represent values of the differences $(R - \overline{R_0}) - (S_\alpha + L_t)$ and the continuous curves show the sporadic oscillations W. These W - oscillations are shown in upper figure by the dashed lines.

Small circles in figure 29 (b) correspond to values of the differences:

$$\overline{(R - R_0)} - (S_\alpha + L_t).$$

These differences display sporadic variations with periods of 4, 6 and 8 years which are shown in fig. 29 (b) by the continuous lines.

Thus, the L_t and W - variations in this latitude zone can be expressed by the relations:

$$L_t = 40 \sin \frac{2\pi}{12} (T - 1885) - 60 \sin \frac{2\pi}{80} (T - 1922)$$

(5,13) 1885 - 1921, 1916 - 1964

$$W = b_n \sum \sin \frac{2\pi}{\psi_n} t, \text{ where:}$$

b_n	ψ_n	t
60	8	1881 - 1885
40	8	1890 - 1898, 1901 - 1905, 1948 - 56
40	6	1933 - 1942
+30	6	1886 - 1889, 1923 - 1929, 1941 - 1944
−30	6	1915 - 1918, 1918 - 1921, 1930 - 1933
−30	4	1957 - 1961
+30	4	1905 - 1909.

Zone 30° - 40° S.

The $\overline{R - R_0}$ - values in this latitude zone, as previously mentioned (see fig. 19 b), display two periodic changes with periods of 32 and 16 years.

The 16-year periodicity seems to change phase by 180° after the year 1922. This phase reversal in the 16-year periodicity, which probably occurs during the years of maximum values in the 32-year variation (1890, 1922 and 1954) is shown in figure 30 (a) where the continuous curves represent the

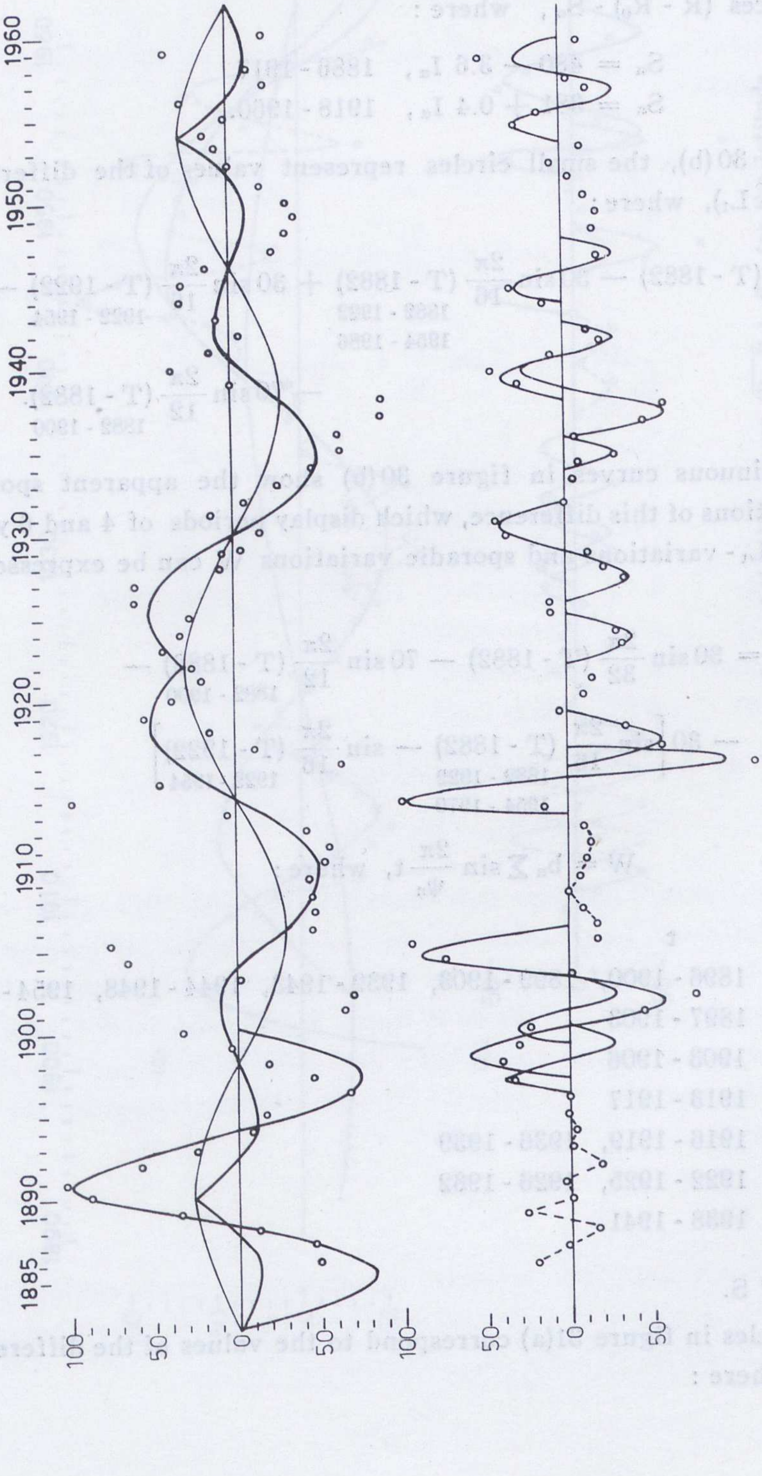

Fig. 30. (Upper). The small circles represent values of the differences $(\overline{R - R_0}) - S_\alpha$ for the latitude zone 30° - 40° S. The continuous curves represent the 12-year, 32-year and 16-year piriodicities respectively. (Bottom). The small circles represent values of the differences $(\overline{R - R_0}) - (S_\alpha + L_t)$ and the continuous curves show the sporadic oscillation W.

16-year and 32-year periodicities and the small circles correspond to values of the differences $\overline{(R - R_0)} - S_\alpha$, where :

$$S_\alpha = 480 - 3.6\ I_\alpha, \quad 1886 - 1917$$
$$S_\alpha = 381 + 0.4\ I_\alpha, \quad 1918 - 1960. \qquad (23)$$

In figure 30 (b), the small circles represent values of the differences $\overline{(R - R_0)} - (S_\alpha + L_t)$, where :

$$L_t = 30 \sin \frac{2\pi}{32} (T - 1882) - 30 \sin \frac{2\pi}{16} \underset{\substack{1882 - 1922 \\ 1954 - 1986}}{(T - 1882)} + 30 \sin \frac{2\pi}{16} \underset{1922 - 1954}{(T - 1922)} - 70 \sin \frac{2\pi}{12} \underset{1882 - 1900}{(T - 1882)}.$$

The continuous curves in figure 30 (b) show the apparent sporadic sinusoidal variations of this difference, which display periods of 4 and 6 years.

Primary L_t - variations and sporadic variations W can be expressed by the relations :

$$L_t = 30 \sin \frac{2\pi}{32} (T - 1882) - 70 \sin \frac{2\pi}{12} \underset{1882 - 1900}{(T - 1882)} -$$

$$(5,14) \qquad - 30 \left[\sin \frac{2\pi}{16} \underset{\substack{1882 - 1922 \\ 1954 - 1970}}{(T - 1882)} - \sin \frac{2\pi}{16} \underset{1922 - 1954}{(T - 1922)} \right]$$

$$W = b_n \sum \sin \frac{2\pi}{\psi_n} t, \text{ where :}$$

b_n	ψ_n	t
30	4	1896 - 1900, 1899 - 1903, 1939 - 1943, 1944 - 1948, 1954 - 1960
60	6	1897 - 1903
100	6	1903 - 1906
100	4	1913 - 1917
— 60	6	1916 - 1919, 1936 - 1939
— 40	6	1922 - 1925, 1926 - 1932
+ 40	6	1938 - 1941.

Zone 40° - 50° S.

Small circles in figure 31(a) correspond to the values of the differences $\overline{(R - R_0)} - S_\alpha$, where :

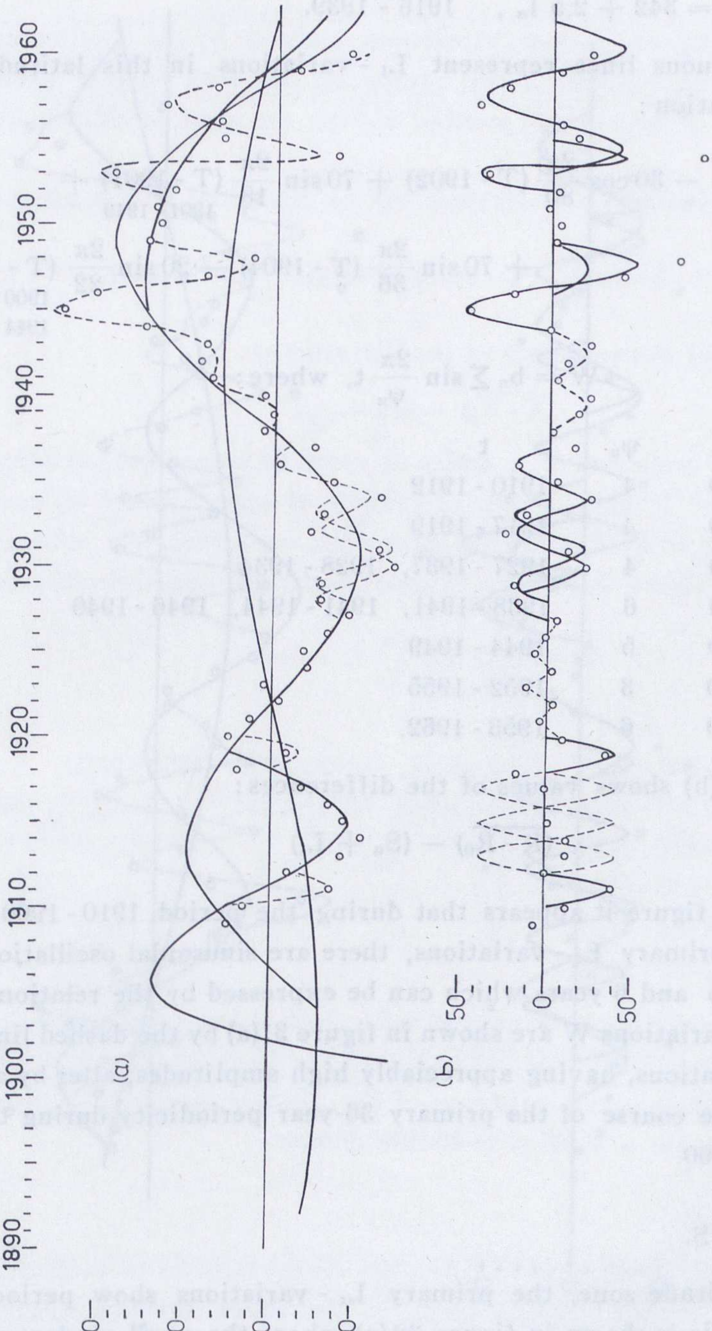

Fig. 31. (Upper) The small circles represent values of the differences $(\overline{R - R_0}) - S_\alpha$ for the latitude zone 40° - 50° S. The continuous curves represent the long-term variations L_t (80-year, 36-year and 18-year periodicities). (Bottom). The small circles represent values of the differences $(\overline{R - R_0}) - (S_\alpha + L_t)$ and the continuous curves show the sporadic W - oscillation. These W - values are shown in upper figure by the dashed lines.

$$S_o = 551 - 4.0\ I_\alpha, \quad 1908 - 1915, \quad 1940 - 1960$$
$$S_\alpha = 342 + 2.5\ I_\alpha, \quad 1916 - 1939.$$

The continuous lines represent L_t - variations in this latitude belt, given by the relation:

$$(5,15) \qquad L_t = -30 \cos \frac{2\pi}{80} (T - 1902) + 70 \sin \frac{2\pi}{18} \underset{1901 - 1919}{(T - 1901)} +$$
$$+ 70 \sin \frac{2\pi}{36} (T - 1904) - 20 \sin \frac{2\pi}{22} \underset{\substack{1900 - 1922 \\ 1944 - 1966}}{(T - 1900)}$$

$$(5,16) \qquad W = b_n \sum \sin \frac{2\pi}{\psi_n} t, \text{ where:}$$

b_n	ψ_n	t
-40	4	1910 - 1912
$+40$	4	1917 - 1919
$+20$	4	1927 - 1937, 1928 - 1934
-20	6	1938 - 1941, 1941 - 1944, 1946 - 1949
$+50$	5	1944 - 1949
$+50$	3	1952 - 1955
-40	6	1953 - 1962.

Figure 31 (b) shows values of the differences:

$$(\overline{R - R_0}) - (S_\alpha + L_t)$$

From this figure it appears that during the period 1910 - 1960, superimposed on the primary L_t - variations, there are sinusoidal oscillations with periods of 3, 4, 5 and 6 years which can be expressed by the relation (5,16). These sporadic variations W are shown in figure 31(a) by the dashed lines. The sporadic W - variations, having appreciably high amplitudes, alter by a significant amount the course of the primary 36-year periodicity during the time interval 1944 - 1960.

Zone 50° - 60° S.

In this latitude zone, the primary L_t - variations show periods of 18 and 88 years. This is shown in figure 32 (a) where the small circles represent values of the differences $(\overline{R - R_0}) - S_\alpha$, where:

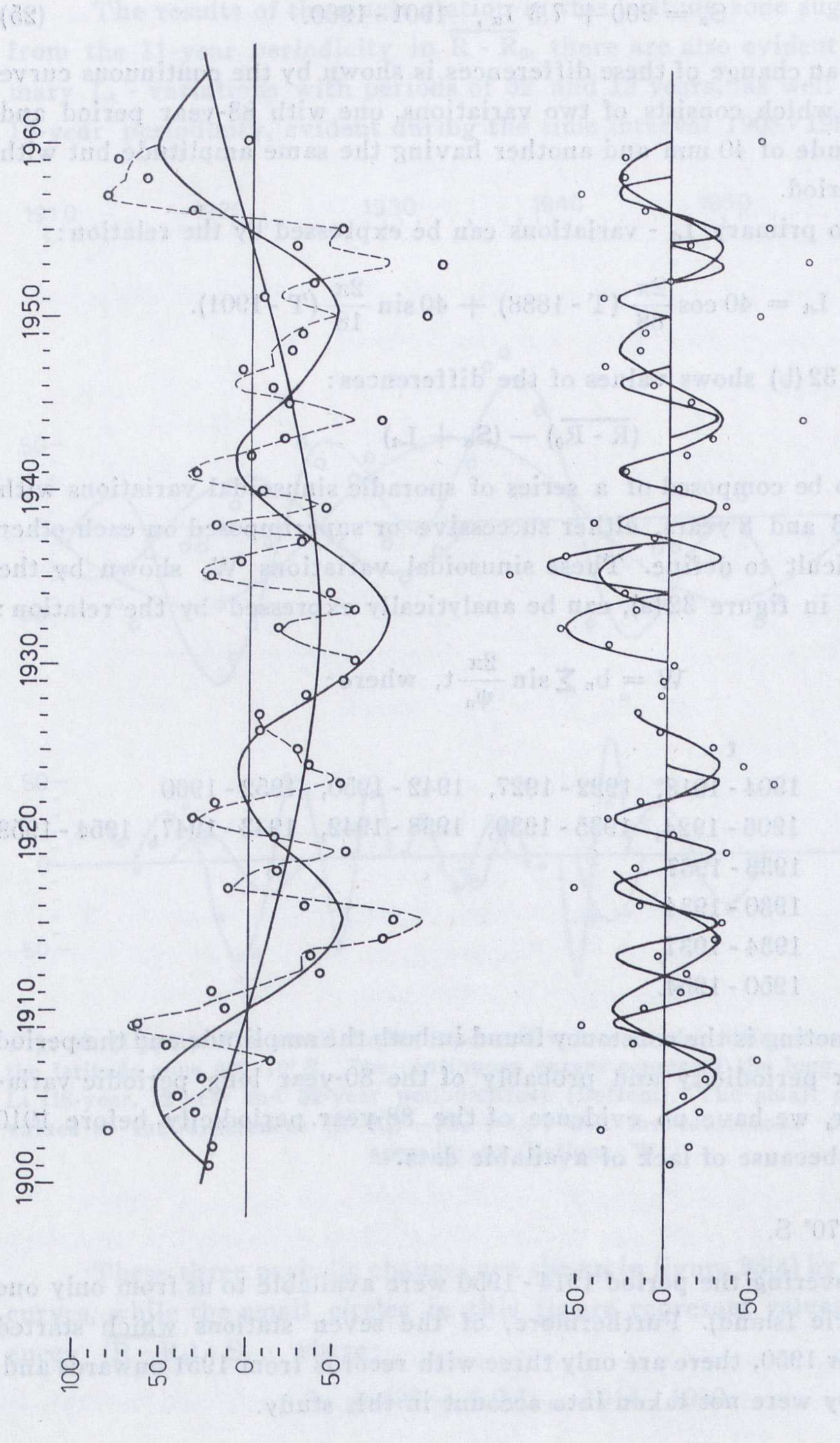

Fig. 32. (Upper). The small circles represent values of the differences $\overline{(R - R_0)} - S_\alpha$ for the latitude zone 50° - 60° S. The continuous curves represent the long term variation L_t (88-year and 18-year periodicities). (Bottom). The small circles represent values of the differences $\overline{(R - R_0)} - (S_\alpha + L_t)$ and the continuous curve shows the sporadic W - oscillation. These W - values are shown in upper figure by the dashed lines.

$$S_\alpha = 900 + 7.3\ I_\alpha, \quad 1901 - 1960. \tag{25}$$

The mean change of these differences is shown by the continuous curve in this figure which consists of two variations, one with 88-year period and a semi-amplitude of 40 mm and another having the same amplitude but with an 18-year period.

The two primary L_t - variations can be expressed by the relation:

$$(5,17) \qquad L_t = 40 \cos \frac{2\pi}{88} (T - 1888) + 40 \sin \frac{2\pi}{18} (T - 1901).$$

Figure 32 (b) shows values of the differences:

$$\overline{(R - R_0)} - (S_\alpha + L_t)$$

which seem to be composed of a series of sporadic sinusoidal variations with periods of 4, 6 and 8 years, either successive or superimposed on each other in a way difficult to define. These sinusoidal variations W, shown by the dashed curves in figure 32 (a), can be analytically expressed by the relation:

$$(5,18) \qquad W = b_n \Sigma \sin \frac{2\pi}{\psi_n} t, \quad \text{where:}$$

b_n	ψ_n	t
— 30	8	1904 - 1918, 1922 - 1927, 1942 - 1950, 1952 - 1960
— 30	4	1906 - 1924, 1935 - 1939, 1938 - 1942, 1943 - 1947, 1954 - 1958
40	8	1933 - 1937
60	8	1930 - 1934
70	6	1934 - 1937
30	4	1950 - 1954.

Worth noting is the constancy found in both the amplitude and the period of the 18-year periodicity and probably of the 80-year long periodic variation. However, we have no evidence of the 88-year periodicity before 1910 or after 1954 because of lack of available data.

Z o n e 60° - 70° S.

Data covering the period 1914 - 1950 were available to us from only one station (Lawrie Island). Furthermore, of the seven stations which started reporting after 1950, there are only three with records from 1951 onwards and, obviously, they were not taken into account in this study.

The results of the single station in this latitude zone suggest that apart from the 11-year periodicity in $\overline{R - R_0}$, there are also evident two other primary L_t - variations with periods of 32 and 12 years, as well as a transient 18-year periodicity, evident during the time interval 1908 - 1935.

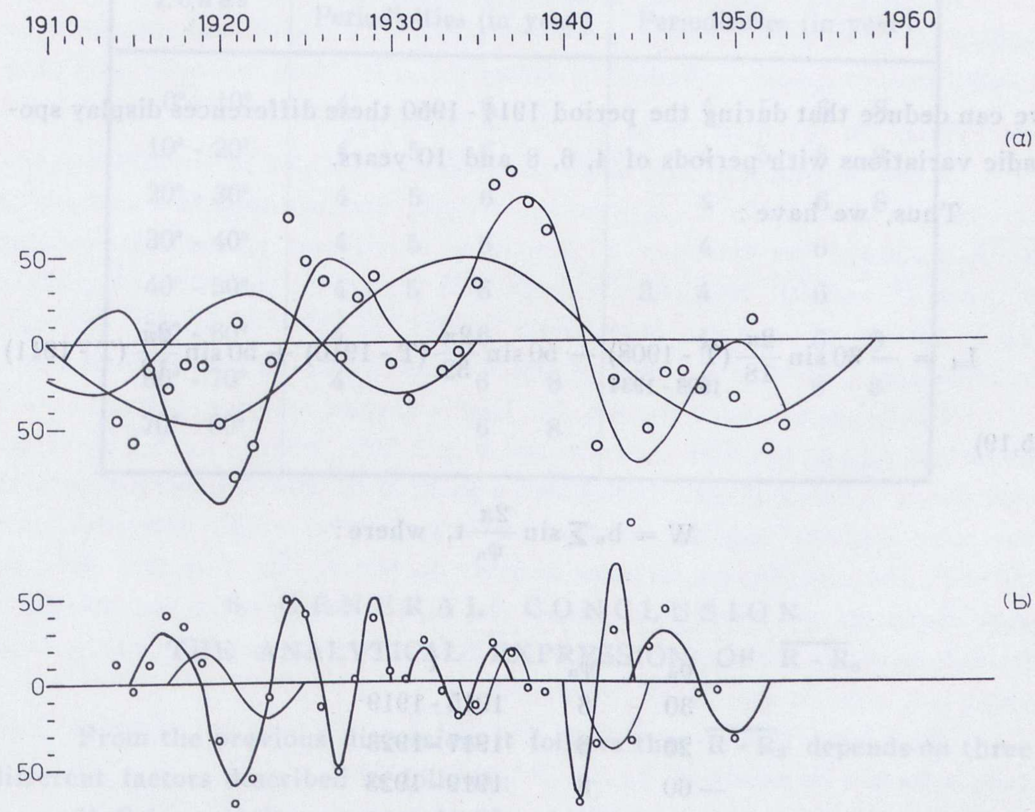

Fig. 33. (Upper). The small circles represent values of the differences $(\overline{R - R_0}) - S_\alpha$ for the latitude zone 60° - 70° S. The continuous curves represent the long - term variations L_t (18-year, 12-year and 32-year periodicities). (Bottom). The small circles represent values of the differences $(\overline{R - R_0}) - (S_\alpha + L_t)$ and the continuous curves show the sporadic oscillations W.

These three periodic changes are shown in figure 33(a) by the continuous curves, while the small circles in this figure represent values of the differences $(\overline{R - R_0}) - S_\alpha$, where:

$$S_\alpha = 497 - 6.0\, I_\alpha, \quad 1914 - 1950. \tag{26}$$

From figure 33 (b), in which the small circles represent values of the differences :

$$\overline{(R - R_0)} - (S_\alpha + L_t)$$

we can deduce that during the period 1914 - 1950 these differences display sporadic variations with periods of 4, 6, 8 and 10 years.

Thus, we have :

$$L_t = -30 \sin \frac{2\pi}{18} \underset{1908-1934}{(T - 1908)} - 50 \sin \frac{2\pi}{32} (T - 1910) + 50 \sin \frac{2\pi}{12} (T - 1911)$$

(5,19)

$$W = b_n \sum \sin \frac{2\pi}{\psi_n} t, \text{ where:}$$

b_n	ψ_n	t
30	8	1915 - 1919
20	8	1917 - 1923
— 60	8	1919 - 1923
50	6	1923 - 1926
— 50	4	1926 - 1930
20	4	1931 - 1937
20	4	1934 - 1938
— 70	4	1940 - 1944
— 40	8	1941 - 1945
30	8	1944 - 1952.

The long-term L_t - variations observed at the different latitude zones of the Northern and the Southern hemispheres are tabulated in table 5.

TABLE 5.

Sporadic W - variations observed in the different latitude zones of the Northern and Southern hemispheres.

Zones	Northern Hem. Periodicities (in year)				Southern Hem. Periodicities (in year)				
0^o - 10^o	4		6			4	5	6	8
10^o - 20^o	4	5	6			4	5	6	8
20^o - 30^o	4	5	6			4		6	8
30^o - 40^o	4	5	6			4		6	
40^o - 50^o	4	5	6		3	4		6	
50^o - 60^o	4		6			4		6	8
60^o - 70^o	4		6	8		4		6	8
70^o - 80^o			6	8					

6. GENERAL CONCLUSION
THE ANALYTICAL EXPRESSION OF $\overline{R - R_0}$

From the previous discussion it follows that $\overline{R - R_0}$ depends on three different factors described as follows :

1) Solar activity, expressed either by the area index (I_α) or the Wolf numbers (W. N). This solar activity influence can be analytically expressed by a linear relation of the form :

$$S_\alpha = C_{1,2} \pm K_{1,2} I_\alpha \tag{6,1}$$

where $C_{1,2}$ and $K_{1,2}$ represent two constants. Indices 1, 2 correspond to positive and negative correlations between the two variables $\overline{R - R_0}$ and I_α.

2) The long-periodic changes, which were symbolized previously by the symbol L_t (long-term variation).

These long-term variations L_t can be specified for each latitude zone by the values of the 11-year moving averages of $\overline{R - R_0}$ and, generally, represent the mean long-term trend of the $(\overline{R - R_0}) - S_\alpha$ changes. Both the amplitude and period of L_t's are different from zone to zone.

The more common periods, shown in tables 2 and 2b are those of 16 - 22, 32 - 36, 40 - 44 and 80 - 88 years.

3) Sinusoidal variations of short duration, which were previously symbolised as W. These short-period variations, with periods ranging between 4 and 8 years, appear sporadically during different time intervals and they are evident in the differences $(\overline{R - R_0}) - (S_\alpha + L_t)$.

It can be supposed that these short-term variations W are due to shorter periodic changes in $\overline{R - R_0}$ - values. Indeed, variance spectrum analysis of $\overline{R - R_0}$'s showed the existence of short-term significant periodicities evident between 0° and 50° Northern latitude [18] (Zerefos and Cosmas, 1975). These authors showed also that «solar cycles», do exist in all but the mid-latitude zones, the significance of which exceded the 99% confidence limit.

Of the above three factors, the first i. e. solar activity, plays the most important role in the high latitude zones ($\varphi > 50°$), where the $\overline{R - R_0}$ variation shows a clear 11-year period and a positive or negative correlation with the solar activity indices. On the contrary, in the middle latitude zones 30° - 50°, the contribution of solar activity to the $\overline{R - R_0}$ variation declines very distinctly and sometimes disappears, as, for example, in the 30° - 40° N latitude zone. In these zones, the two other factors L_t and W play the most important role in the $\overline{R - R_0}$ variation.

Following this examination, the $\overline{R - R_0}$ - values to the different latitude belts can be expressed by the general relation:

(6, 2) $$\overline{R - R_0} = S_\alpha + L_t + W$$

where:

$$S_\alpha = a_{1,2} \pm b_{1,2} I_\alpha$$

$$L_t = A_n \sum \sin \frac{2\pi}{\Omega_i} (T - T_0), \quad \Omega_i \geqslant 10 \text{ years}$$

$$W = b_n \sum \sin \frac{2\pi}{\psi_i} (T - T_0), \quad \psi_i \leqslant 10 \text{ years.}$$

The computed $\overline{R - R_0}$ - values, with the help of the relation (6, 2) are given for each latitude zone of the Northern and Southern hemispheres in tables 6 to 20. The numerical results of this analysis are shown graphically in figures 33 to 48.

In the second column of each table is written the number N of the available stations.

In the third column both observed values for $\overline{R - R_0}$ and those, by the formula $(\overline{R - R_0})_n = \frac{1}{4} [(\overline{R - R_0})_{n-1} + 2(\overline{R - R_0})_n + (\overline{R - R_0})_{n+1}]$ are shown.

In the fourth column S_α's are given. In the fifth column are listed the values of the L_t and W, while the sixth column shows the computed values of $\overline{R - R_0}$ from the relation (6, 2).

Finally, the last column shows the differences:

$$(\overline{R - R_0})_{obs} - (\overline{R - R_0})_{comp}$$

Afterwards, the results of the different components involved in $\overline{R - R_0}$ for each latitude zone are summarized.

Note: Graphical methods have been used for the calculation of S_α and W - variation. We will give more accurate values for S_α, W - variation and $(\overline{R - R_0})_{comp.}$ in a forthcoming publication by using the least - squares method and spectrum analysis.