ΜΕΤΕΩΡΟΛΟΓΙΑ.— **Variance Spectrum Analysis of the Time - Latitude Distribution of Zonal Average Annual Excess Precipitation Totals over the Northern Hemisphere,** *by Christos S. Zerefos and George B. Cosmas**. Ἀνεκοινώθη ὑπὸ τοῦ Ἀκαδημαϊκοῦ κ. Ἠλία Μαριολοπούλου.

A B S T R A C T

Variance spectrum analysis was applied to zonal averages of annual excess precipitation totals in 8 latitude belts of the Northern Hemisphere using Xanthakis' (1972, 1975) data in order to test on a global scale the significance of the various periods involved in these time series. It is shown that these spectra can be represented by a first-order autorregressive model since red noise criteria are surprisingly met. Significant peaks at about 10 to 11 years are evident only in the high-latitude belts 50° - 80° and in the zone 20 - 30° Northern latitude. Higher harmonics of the eleven-year solar cycle are evident in the Northern equatorial zone 0 - 10° as well as in the latitude zone 20 - 30° N. In the middle latitude zones 30° - 50° N there is no evidence of solar cycles in the data studied. In all latitude belts under study, several peaks exceeded their 99% confidence limits. Our results strongly confirm Xanthakis' (1972) earlier findings on significant solar activity and precipitation links.

Meteorological periodicities and solar triggering effects on the earth's lower atmosphere has been an attractive subject to hundreds of investigators in the past. As the statistical methods and their applications to Meteorology begun to improve, more sophisticated and relatively strict mathematical approaches to this so old solar-weather problem were published, especially in the last two decades (see, for example, Lamb, 1972). In the light of power spectrum analysis, otherwise known as variance spectrum analysis, several Meteorological time series were tested in searching «significant» solar activity 11-year periods. However, the

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* ΧΡ. Σ. ΖΕΡΕΦΟΥ – Γ. Β. ΚΟΣΜΑ, **Φασματικὴ ἀνάλυσις τῆς κατὰ πλάτος καὶ εἰς τὸν χρόνον κατανομῆς τοῦ ὑπὲρ τὸ κανονικὸν ἐτησίου μέσου ζωνικοῦ ὕψους τοῦ ὑετοῦ εἰς τὸ Βόρειον Ἡμισφαίριον.**

contradictory results so far obtained led Meteorologists suspicious on that subject and since no physical mechanism on solar-weather controls is presently accepted, the problem is still open to a wide variety of speculations.

Inspite of the above mentioned difficulties, there are some indications of apparent free-atmosphere responses to solar activity components (Zerefos, 1975) and of surprisingly significant solar-precipitation relations (Xanthakis, 1972, 1975). Thus, Xanthakis (1972) showed that, at least in the high-latitude Northern zones, precipitation is strongly correlated with solar activity. Xanthakis' results were obtained in the following way: First, all stations with annual precipitation records were collected from «World Weather Records», to have long-period of available data. Next, care was exercised in selecting these data in order to compute zonal averages of rainfall totals, derived from a combination of data from a large number of available stations. However, since the number of these stations varied gradually over the years, Xanthakis studied the «behaviour» of each station in relation to the overall zonal average in such a way that zonal averages were relatively insenstitive to changes of station network and to missing or incomplete observations. Names and geographical coordinates of the stations used are to be published in Xanthakis (1975).

In his earlier paper Xanthakis (1972) introduced a new parameter which replaced annual precipitation totals at a given station. This parameter is simply the yearly total precipitation departure from a minimum total annual precipitation value (R_0) defined as the lowest yearly total rainfall amount observed at a given station during a long period (period of available records mentioned above). Zonal averages of these departures ($\overline{R - R_0}$) were then calculated for each year at 10 deg. Northern latitude belts from the equator to the pole. Calculated correlation coefficients between ($\overline{R - R_0}$) and solar activity indices (Wolf numbers and the areas index) showed that close correlation (positive or negative) existed between $\overline{R - R_0}$ and solar activity only in either the high Northern latitude belts ($\varphi \geqslant 50^\circ$ N) or the Northern equatorial zone ($0^\circ \leqslant \varphi \leqslant 10^\circ$ N). In the remaining Northern zones, this correlation was poor or even insignificant as, for example, was observed in the latitude belt 30° - 40° N.

The striking results discussed above were the stimulus for the pre-

sent work which is concerned with the application of variance spectrum analysis to Xanthakis' data in order to analyze statistically the time series involved in his earlier investigations. Another reason to search for significant periodicities in Xanthakis' $\overline{R - R_0}$ values was the work by Dehsara and Cehak (1970). These authors investigated variance spectra of annual precipitation totals at 92 stations and they found spectral peaks mostly near periods of 6 years and with very long periods, though most of the spectra studied could be approximated by a first-order autorregressive model (Markovian process). More recently (Xanthakis, personal communication and unpublished material), it was found that $\overline{R - R_0}$ filtered to remove short-period oscillations displayed long periodic variations.

Zonal average $\overline{R - R_0}$ data for 8 latitude belts were used in the present study to be tested for non-randomness through power spectrum analysis. These data were kindly supplyied to us by Professor Xanthakis to whom we express our appreciation for the helpfull discussions.

Figures 1 to 8 show the $\overline{R - R_0}$ variance spectra for each 10 deg. latitude zone under study. For a given latitude belt maximum time lag used in the computation of the spectrum, was chosen to be the one third of the entire length of each zonal record, in order to get enough resolution in the spectra under investigation.

Red noise criteria were met in all of the 8 spectra under study (figs. 1 to 8), that is, each $\overline{R - R_0}$ value depends only on its immediate predecessor. It is the first time so far that red noise criteria are so clearly met in a world-wide precipitation study (see also Dehsara and Cehak, 1970). Red noise (simple Markov) continua together with their appropriate 95% and 99% confidenee limits are shown in figs. 1 to 8, added to the corresponding spectra.

Figure 9 summarizes the results obtained in figs. 1 through 8. The horizontal axis in that figure has periods in years, which when significant at the 95% C. L. are shown by the dashed areas, and when they exceed the 99% C. L. they are shown by cross-dashed areas.

From all the above mentioned figures it appears that significant peaks with period of about 10 to 11 years are evident only in the high-latitude belts 50° - 80° deg. and in the latitude belt 20° - 30° deg. Northern latitude. Higher harmonics of the eleven year solar cycle are evident in

the Northern equatorial zone $0^{\circ} - 10^{\circ}$ N as well as in the latitude zone $20^{\circ} - 30^{\circ}$ N. In the middle latitude belts $30^{\circ} - 50^{\circ}$ N there is no evidence of solar cycles in $\overline{R - R_0}$ values. It is remarkable, however, that in all latitude zones under study, several peaks exceeded their 99% confidence limits.

Following the above discussion we can conclude that the evidence of solar activity and precipitation links, originally found by Xanthakis' correlations, is strongly confirmed through the application of power spectrum analysis. It is worth noting that the high correlations in this earlier work were found in all, but the two high latitude zones, not from precipitation data of the entire record of each zone, but separately for different sub-periods of the record as a whole, since, phase reversals were observed in these time series. So, we were not at all expecting to prove so remarkably the above mentioned 11-year solar cycles in the zonal average annual excess precipitation totals $\overline{R - R_0}$ on a global scale. Our results are encouraging for further research on that topic. Finally, no physical causation of the previously discussed findings can be given here, and we leave it as a fascinating problem for future work.

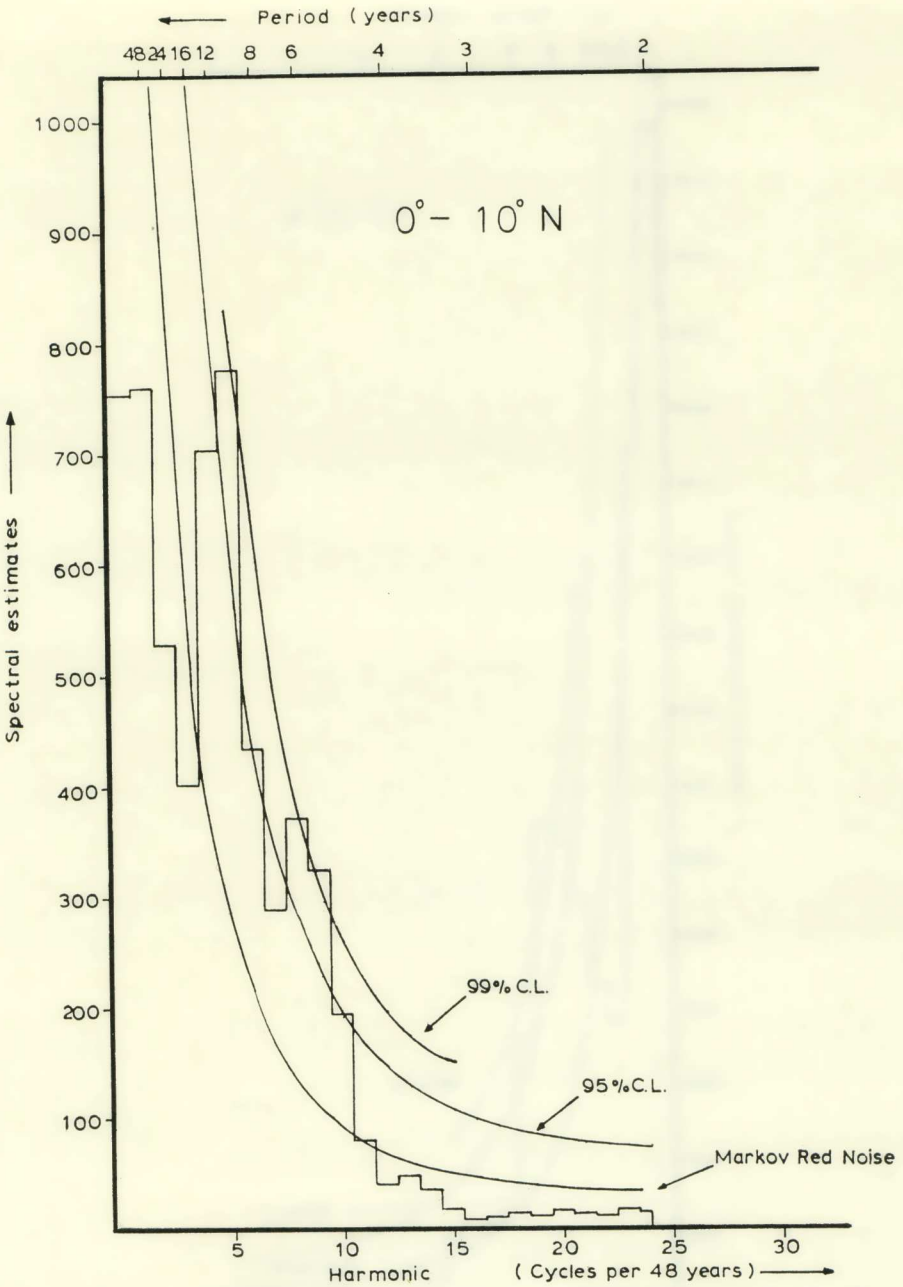

Fig. 1. Power spectrum of zonal average yearly excess precipitation totals in the Northern equatorial zone 0° - 10° N. Maximum lag of analysis equals the $^1/_8$ of the length of the record. Red noise and associated 95 % and 99 % confidence limits are added.

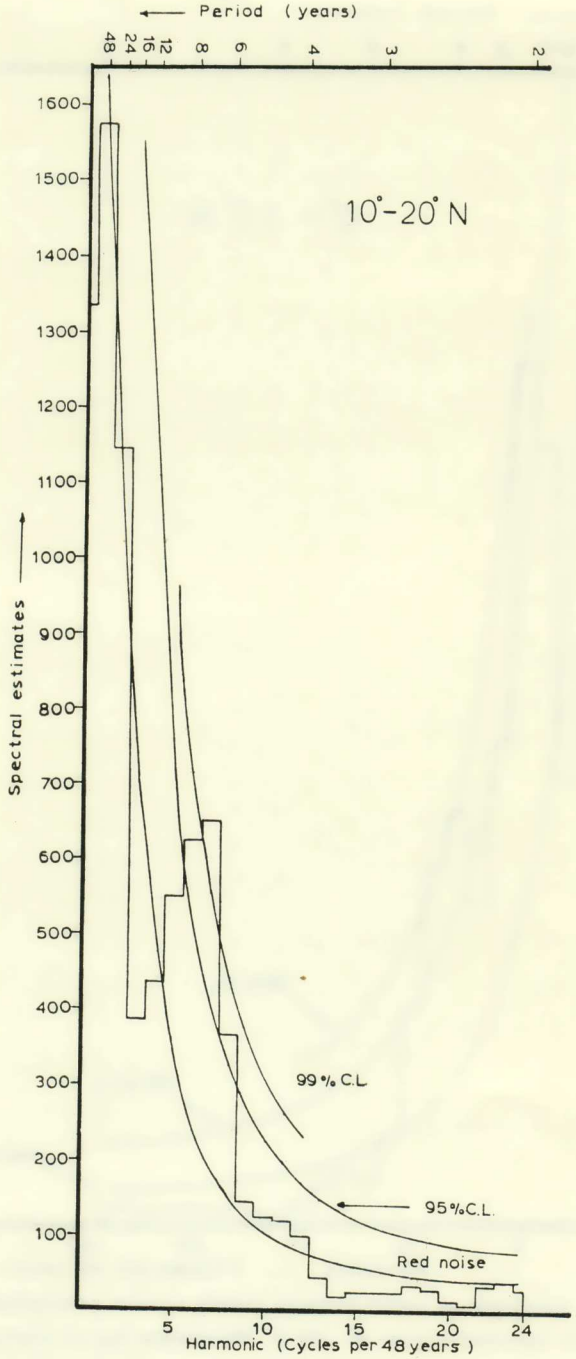

Fig. 2. Same as fig. 1, but for the 10° - 20° N latitude zone.

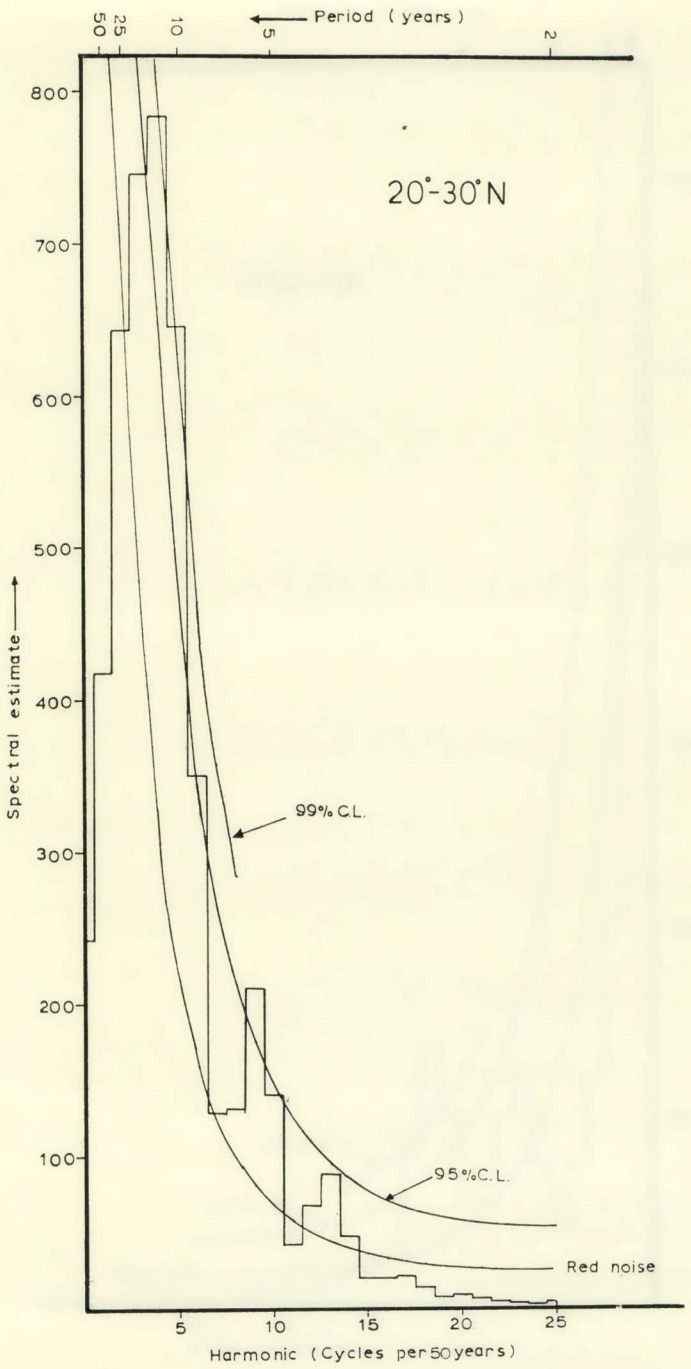

Fig. 3. Same as fig. 1, but for the 20° - 30° N latitude zone.

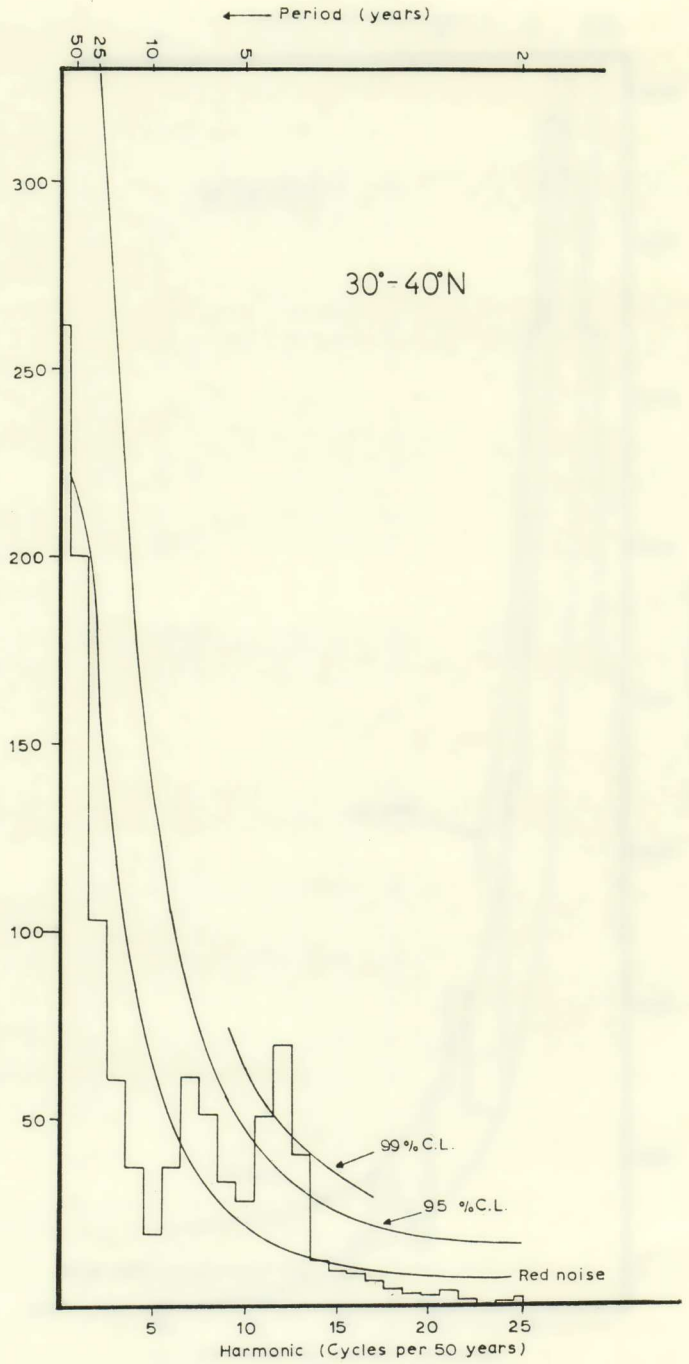

Fig. 4. Same as fig. 1, but for the 30° - 40° N latitude zone.

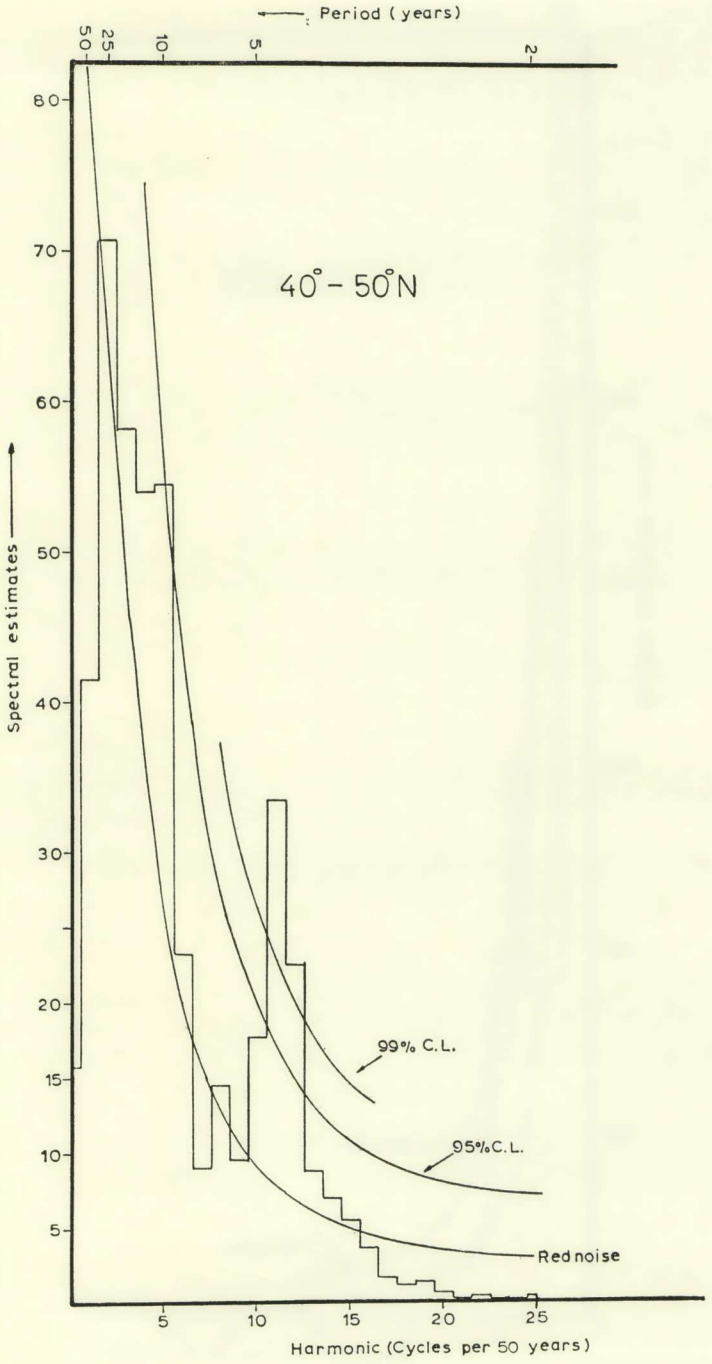

Fig. 5. Same as fig. 1, but for the 40° - 50° N latitude zone.

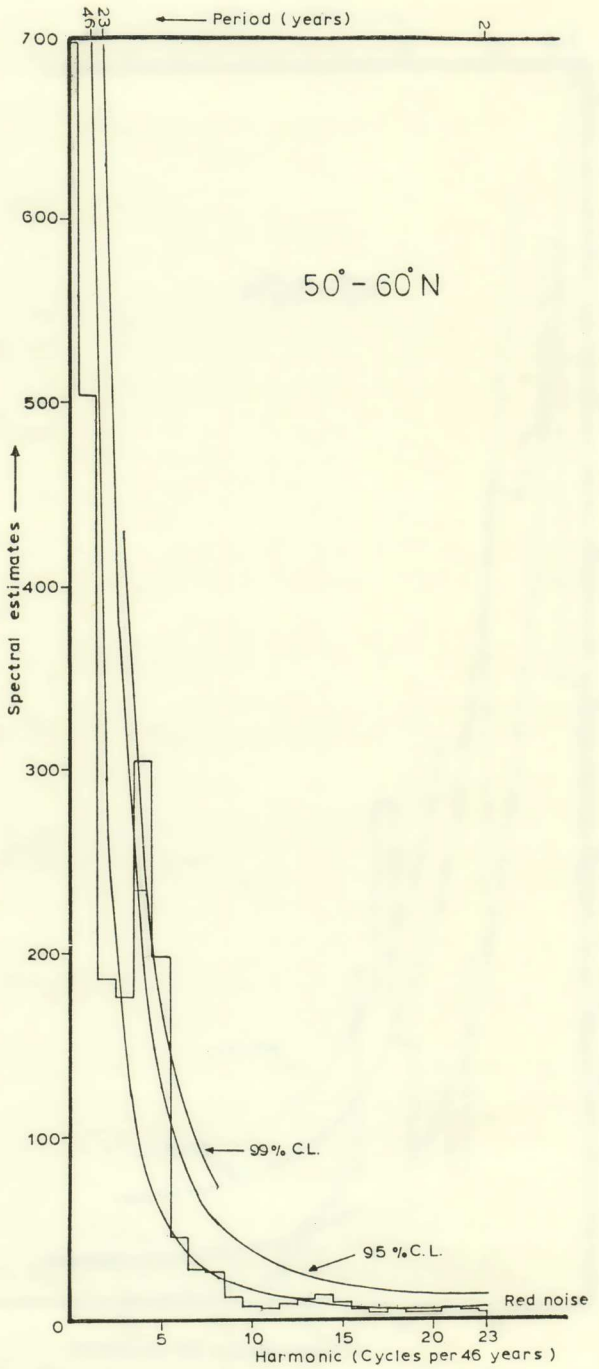

Fig. 6. Same as fig 1, but for the 50° - 60° N latitude zone.

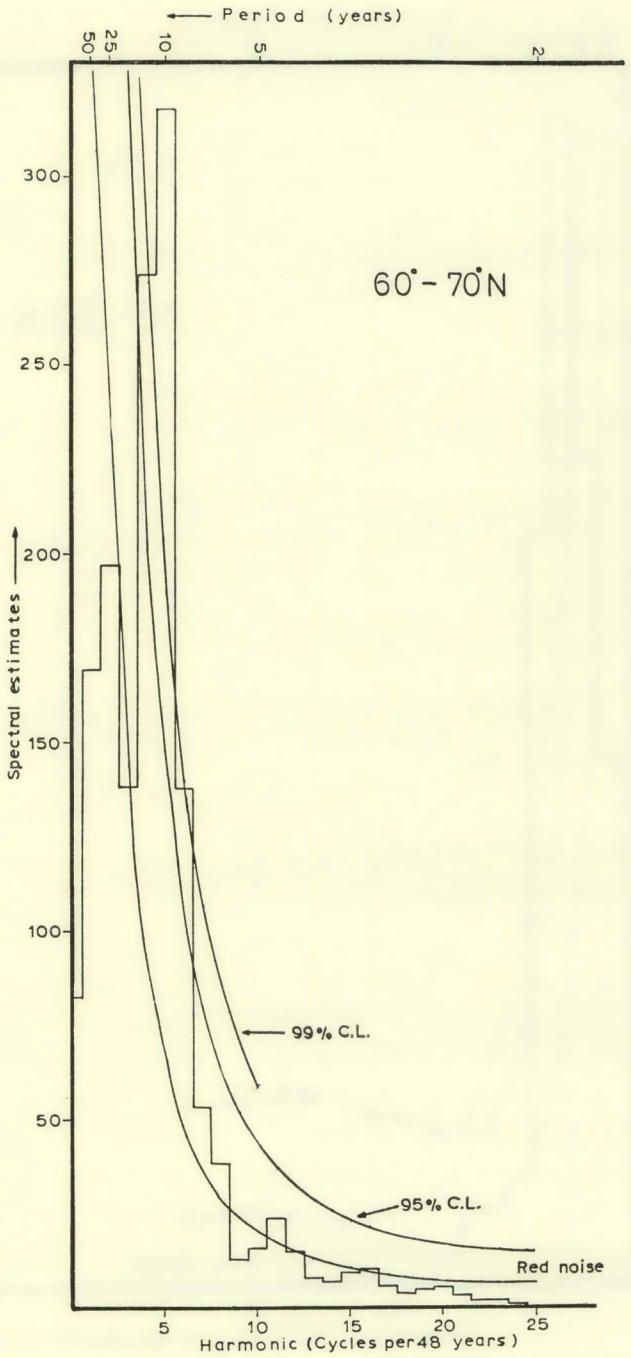

Fig. 7. Same as fig. 1, but for the 60° - 70° N latitude zone.

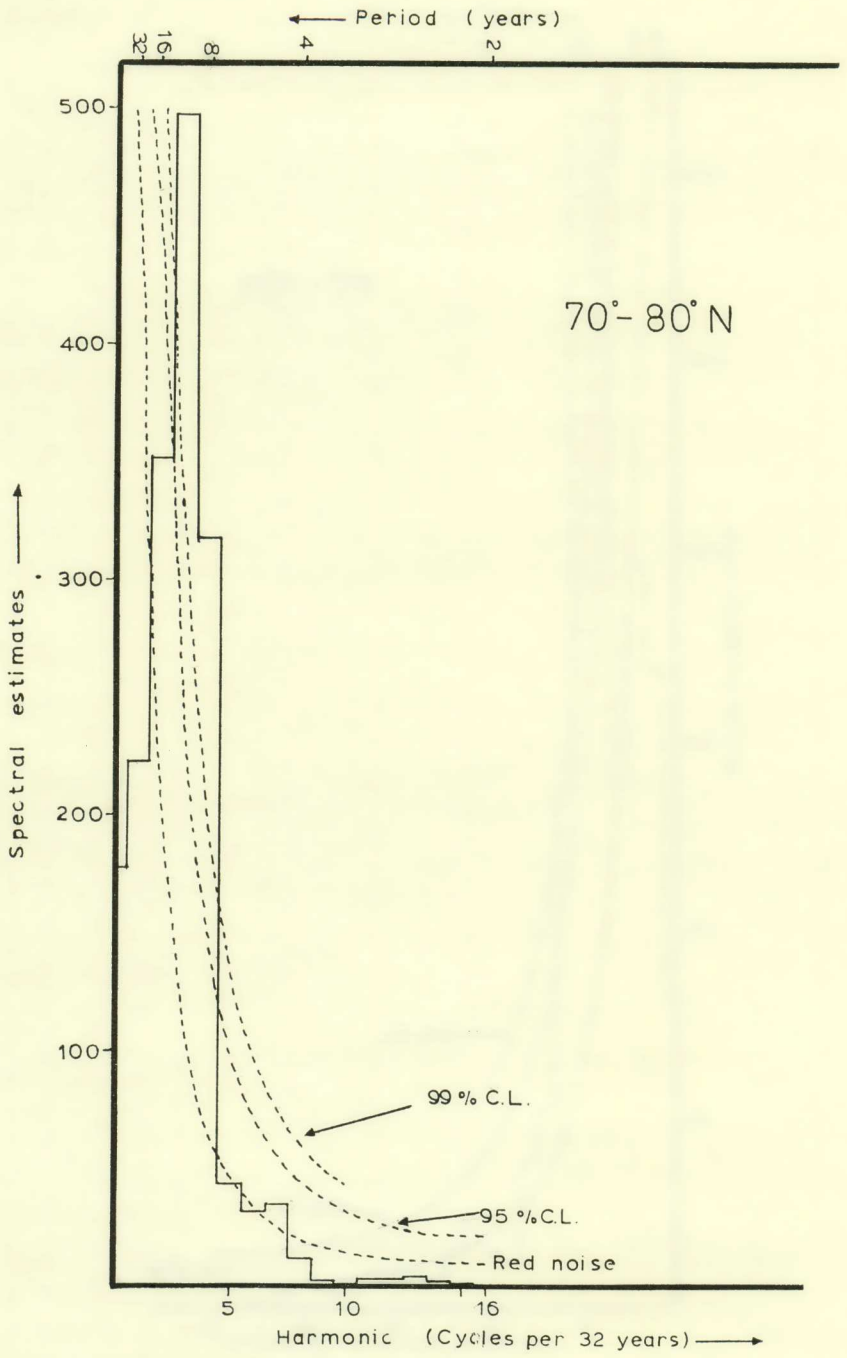

Fig. 8. Same as fig. 1, but for the 70° - 80° N latitude zone.

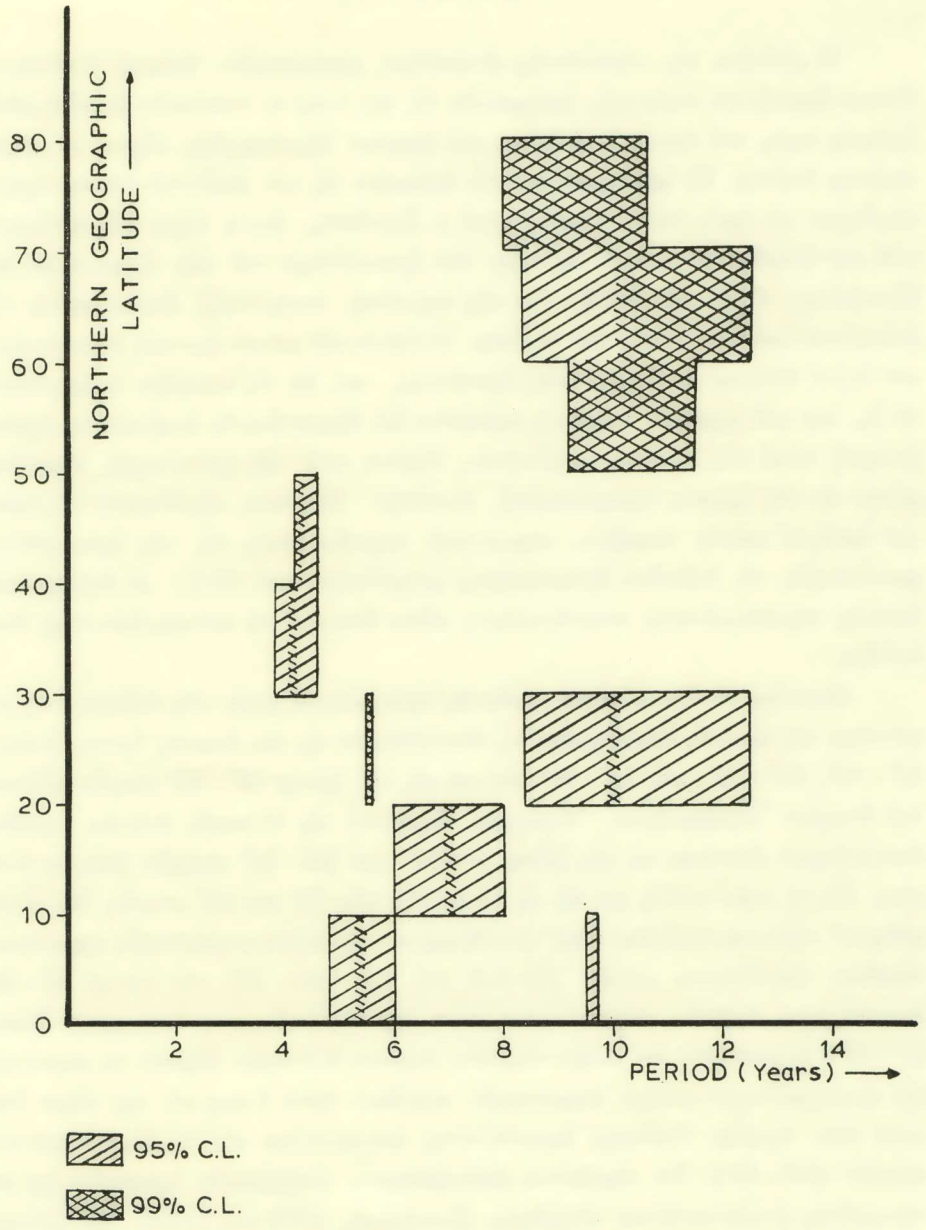

Fig. 9. The latitudinal distribution of significant periodicities revealed in figs. 1 to 8. Cross-dashed areas indicate periodicities significant at the 99 % confidence limit.

ΠΕΡΙΛΗΨΙΣ

Ἡ μέθοδος τῆς φασματικῆς ἀναλύσεως χρονοσειρῶν, γνωστὴ διεθνῶς ὡς Power Spectrum Analysis, ἐφηρμόσθη εἰς τὰς ὑπὲρ τὸ κανονικὸν ἐτησίας μέσας ζωνικὰς τιμὰς τοῦ ὑετοῦ εἰς 8 ζώνας τοῦ Βορείου Ἡμισφαιρίου, εὔρους 10 μοιρῶν πλάτους ἑκάστη. Τὰ χρησιμοποιηθέντα δεδομένα εἰς τὴν ἀνάλυσιν ταύτην προσεφέρθησαν εἰς ἡμᾶς ὑπὸ τοῦ καθηγητοῦ κ. Ξανθάκη, ἅτινα εἶχον ἤδη ἐπεξεργασθῆ καὶ ἐλεχθῆ ὑπ' αὐτοῦ ὡς πρὸς τὴν ὁμοιογένειαν καὶ τὴν ἀξιοπιστίαν των (Ξανθάκης, 1972 καὶ 1975). Διὰ τῆς παρούσης στατιστικῆς ἐπεξεργασίας τῶν δεδομένων τούτων εὑρέθη ὅτι τὸ ὑπὲρ τὸ κανονικὸν μέσον ζωνικὸν ἐτήσιον ὕψος τοῦ ὑετοῦ δύναται νὰ παρασταθῇ ἀρκούντως, καὶ δὴ εἰς ἐπίπεδον ἐμπιστοσύνης 99 %, διὰ τοῦ ἐρυθροῦ θορύβου, τοὐτέστιν διὰ Μαρκοβιανῆς διαδικασίας πρώτου βαθμοῦ, κατὰ τὴν ὁποίαν, ὡς γνωστόν, ἑκάστη τιμὴ τῆς χρονοσειρᾶς ἐξαρτᾶται μόνον ἐκ τῆς ἀμέσως προηγουμένης τοιαύτης. Ὡσαύτως εὑρέθησαν, ἐπὶ πλέον τοῦ ἐρυθροῦ τούτου θορύβου, σημαντικαὶ περιοδικότητες εἰς τὰς ἐρευνηθείσας χρονοσειράς, εἰς ἐπίπεδον ἐμπιστοσύνης μεγαλύτερον τοῦ 99 %. Αἱ ἐκπληκτικῶς ὑψηλῆς σημαντικότητος περιοδικότητες αὗται δυνατὸν νὰ συνοψισθῶσιν ὡς ἀκολούθως :

Περίοδοι 10 ἕως 11 ἐτῶν, πιθανῶς σχετιζόμεναι μετὰ τῆς ἑνδεκαετοῦς κυμάνσεως τῆς ἡλιακῆς δραστηριότητος, ἀνευρέθησαν εἰς τὰς βορείας ζώνας πλάτους 50° - 60°, 60° - 70°, καὶ 70° - 80°, ὡς καὶ εἰς τὴν ζώνην 20° - 30° μοιρῶν πλάτους τοῦ Βορείου Ἡμισφαιρίου. Ἀνώτεροι ἁρμονικοὶ τῆς 11-ετοῦς περίπου περιόδου ἀνευρέθησαν ὡσαύτως εἰς τὰς ζώνας 0° - 10° καὶ 20° - 30° μοιρῶν βορείου πλάτους. Εἰς τὰ μέσα πλάτη καὶ δὴ εἰς τὰ μεταξὺ τῶν 30° καὶ 50° μοιρῶν, δὲν ἀνευρέθησαν «ἡλιακαὶ περίοδοι», ἀλλ' ἀντιθέτως αἱ εὑρεθεῖσαι στατιστικῶς σημαντικαὶ τοιαῦται κυμαίνονται μεταξὺ τῶν 3.5 καὶ 4.5 ἐτῶν. Εἰς τὴν ζώνην 10° - 20° ἐμφανίζονται περίοδοι περίπου ἑπτὰ ἐτῶν, εἰς δὲ τὴν βορείαν ἰσημερινὴν ζώνην (0° - 10°) ἐμφανίζεται καὶ ἑτέρα περίοδος περίπου 9.5 ἐτῶν. Πρέπει νὰ σημειωθῇ ὅτι τὸ μεγαλύτερον φάσμα σημαντικῶν περιόδων (ἀπὸ 8 ἕως 12 καὶ πλέον ἔτη) μετὰ λίαν ὑψηλῆς στάθμης ἐμπιστοσύνης ἀνευρίσκεται εἰς τὰ βορειότερα τῶν πλατῶν (50° - 80°). Τὰ εὑρεθέντα ἀποτελέσματα ἐπιβεβαιοῦν προγενέστερα καὶ προσφάτως ἀνακοινωθέντα εὑρήματα (Ξανθάκης, 1972 καὶ 1975). Τὰ ἡμέτερα εὑρήματα δεικνύουν ὅτι ὁ ὑπὸ τοῦ κ. Ξανθάκη εἰσαχθεὶς νέος δείκτης, ὅστις παριστᾷ τὸ ὑπὲρ τὸ κανονικὸν ἐτήσιον μέσον ζωνικὸν ὕψος τοῦ ὑετοῦ, εἶναι ὁ πλέον κατάλληλος εἰς τὸν κλάδον τῶν σχέσεων ἡλίου - ὑετοῦ, δεδομένου ὅτι ἕτεροι ἐρευνηταὶ εἰς ὀλίγας μόνον περιπτώσεις ἠδυνήθησαν νὰ εὕρουν ἑνδεκαετεῖς κυμάν-

σεις εἰς τὰ ἐτήσια ὕψη τοῦ ὑετοῦ εἰς διαφόρους σταθμοὺς τοῦ Βορείου Ἡμισφαιρίου. Δυστυχῶς ἡ πιθανὴ ὕπαρξις μακροτέρων περιόδων εἰς τὰ δεδομένα τὰ ὁποῖα ἐμελετήσαμεν δὲν εἶναι δυνατὸν νὰ προσδιορισθῇ διὰ τῆς φασματικῆς ἀναλύσεως, καθ' ὅτι ἡ μέθοδος αὕτη δύναται νὰ παράσχῃ πληροφορίας διὰ περιόδους τὸ πολὺ ἴσας πρὸς τὸ $^1/_3$ περίπου τῆς διατιθεμένης χρονοσειρᾶς. Τέλος δέον νὰ σημειωθῇ ὅτι οἱ εὑρεθέντες παλαιότερον ὑψηλοὶ συντελεσταὶ συσχετίσεως μεταξὺ τῶν δεικτῶν τῆς ἡλιακῆς δραστηριότητος καὶ τοῦ ὑπὲρ τὸ κανονικὸν ἐτησίου ζωνικοῦ ὑετοῦ (Ξανθάκης, 1972) δὲν ἀνεφέροντο δι' ὁλόκληρον τὴν χρονοσειράν, ἀλλ' ὑπελογίσθησαν οὗτοι διὰ διαφόρους ὑποπεριόδους ταύτης, τοῦτο δὲ ἐγένετο εἰς ὅλας τὰς ζώνας πλὴν τῶν ζωνῶν τῶν βορειοτάτων πλατῶν, λόγῳ τῆς κατ' ἐπανάληψιν ἐμφανίσεως ἀλλαγῶν φάσεως εἰς τὰς καθέκαστα χρονοσειρὰς ταύτας. Κατὰ ταῦτα, οἱ ἡμέτεροι ὑπολογισμοὶ οὐχὶ μόνον ἐπιβεβαιοῦν τὰς ἀνωτέρω συσχετίσεις, ἀλλ' ὑποδεικνύουν ὅτι οἱ παλμοὶ τῶν ὑπὲρ τὸ κανονικὸν ὑψῶν τοῦ ἐτησίου ζωνικοῦ ὑετοῦ εὑρίσκονται, διά τινος ἀγνώστου μηχανισμοῦ, ἐν στενῇ σχέσει μετὰ τῆς μεταβαλλομένης ἡλιακῆς δραστηριότητος.

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