ΑΣΤΡΟΝΟΜΙΑ.— **Remarks on High Latitude Air Temperature Ranges and Solar Activity,** *by Christos S. Zerefos* and *John Xanthakis**. Ἀνεκοινώθη ὑπὸ τοῦ Ἀκαδημαϊκοῦ κ. Ἰω. Ξανθάκη.

S U M M A R Y

Annual temperature ranges at the vicinity of solstices (DT_s) in the high-latitude belt 60 - 70°N were correlated with sunspot numbers and the areas index during the period 1880 - 1960. Statistically significant correlation coefficients, at the 0.05 confidence level, were found at time lags of 8 and 14 years after the corresponding solar activity indices. The correlation between DT_s and solar activity during the first three years of the declining solar cycle was found to be highly significant ($r = -0.76$). In continental stations, DT_s averaged over successive sunspot periods, were found to be strongly correlated with correspondingly averaged solar activity indices ($r = -0.87$) confirming earlier findings which, however, were based on different data samples (Xanthakis, 1956). Continental and coastal 11-year averaged DT_s displayed exactly opposite courses during the successive sunspot cycles, the coastal 11-year averaged DT_s being unrelated to the long-term solar activity course. Previously reported high correlations between long-term solar activity changes and other air temperature range parameters were not substantiated.

Z U S A M M E N F A S S U N G

In der vorliegenden Arbeit wurde die Korrelation des Jährlichen Temperaturwechselns, in der Zone zwischen 60 - 70°N, in der Nähe der Sonnenwende (DT_s), mit zwei Indizien der Sonneaktivität, während der Periode 1880 - 1960, durch Zeitverschiebungen von 0 bis 23 Jahre, bestimmt. Statistisch wurden die Korrelationskoefficienten (Sicherheit 0.05) bei Zeitverschiebungen am 8 und 14 Jahr, gefunden. Die Korrelation zwischen DT_s - Werte und Sonneaktivität, während der ersten drei Jahren, nach der Aktivitätsmaximum, weisst eine Statistische Sicherheit

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grosser als 99 % auf. Der Mittelwert von der DT_s für der Kontinentalstationen als Durchschnitt der jeweilige Aktivitätsperioden hängen stark von der entsprechenden Aktivitätsindizien ab ($r = -0.87$), dies Ergebnis bestätigt früheren Arbeiten von Xanthakis (1956) allerdings auf anderen Daten bezonen. Die Kontinentale und die Küstenstationen DT_s (11-Jahre Durchschnitt) zeigen gegenseitigen Durchlauf, während der jeweilige Aktivitätsperioden. Die Küstenstationen zeigen keine Korrelation im bezug mit dem langfristigen Durchlauf der Sonneaktivität. Frühere Ergebnisse über grosse Korrelationen zwischen langfristigen Aktivitätsvariationen und anderen Parameter der Temperaturbereichen, wurden nicht bestätigt.

1. INTRODUCTION

Solar weather controls has been the attractive pole for many colleagues in the past. We shall not try to start revewing their findings and suspicions since their (in many cases contradictory) results are discussed fairly extensive in several places (see for example Lamb, 1972).

An early study by one of us (Xanthakis, 1956) showed that some yearly air temperature range parameters, averaged over successive sunspot periods, displayed a close correlation with the corresponding average Wolf numbers during twelve successive solar cycles. These temperature ranges, symbolized as DT_s, DT_e and X are defined as follows:

$$DT_s = T_s - T_s', \quad DT_e = (T_e - T_e')/2 \quad \text{and} \quad X = DT_e - (DT_s)/2$$

where T_s and T_s' represent the mean air temperatures at the vicinity of solstices (June/July and December/January) and T_e, T_e' are the mean air temperatures at the vicinity of equinoxes (March/April and September/October) respectively.

A statistical study of DT_s (Zerefos, 1974) showed that this parameter was found to be a rapidly oscillating atmospheric element with different behaviour in coastal and continental stations. Spectral analysis showed that coastal DT_s displayed significant quasi-biennial oscillations while continental DT_s had significant periodicities with approximate length of 3.5 years which could be a higher harmonic of the approximately 11-year solar cycle. Another interesting property of DT_s is that, by definition, it is probably a function of «continentality» which is supported by the smaller values and standard deviations found for coastal as compared to those for continental stations.

The above mentioned findings and Bray's (1966) observation of an apparently significant in-phase relationship between long periods of high or low solar activity and prevailing surface temperature levels, together with a small but significant quasi-biennial periodicity in the solar disturbance found by Shapiro and Ward (1962), led us to investigate further the behaviour of DT_s and the previously mentioned air temperature range parameters in relation to solar activity.

TABLE I

No	Station	Lat.	Long.
1	Bergen	60° 24′	05°19′ E
2	Bodo	67° 17′	12°24′ E
3	Haparanda	65° 50′	24°09′ E
4	Helsinki	60° 10′	24°57′ E
5	Archangel	64° 35′	40°36′ E
6	Ust - Zylma	65° 27′	52°10′ E
7	Berezon	63° 56′	65°04′ E
8	Surgut	61° 15′	73°24′ E
9	Turukhansk	65° 47′	88°04′ E
10	Yakutsk	62° 01′	129°43′ E
11	Verkhoyansk	67° 33′	133°24′ E
12	Godthaab	64° 11′	51°43′ W
13	Jacobshavn	69° 13′	51°02′ W
14	Ivigtut	61° 12′	48°10′ W
15	Angmagsalik	65° 37°	37°33′ W
16	Stykisholm	65° 05′	22°46′ W
17	Vestmano	63° 24′	20°17′ W
18	Grimsey	66° 33′	18°01′ W
19	Teigarhorn	64° 41′	14°22′ W
20	Thorshavn	62° 03′	06°45′ W

2. DATA

A rather homogeneous sample of mean monthly air temperatures for 20 stations was collected from «World Weather Records». These stations are located in the latitude belt 60° - 70° N and in almost continuous operation during the period 1880 - 1960 (see their list in table I). The reason for choosing this particular latitude belt was to include as many stations as possible in the Northernmost latitudes for which there are indications of atmospheric responses to solar events (Zerefos, 1973). Solar activity data were taken from Waldmeier's Zurich sunspot numbers and from a list by Poulakos and Tritakis (1972) we took the values of the areas index of solar activity. The areas index is simply defined as the half of the sum of the square roots of the total areas of sunspots and faculae, corrected for foreshortening (Xanthakis, 1969).

3. RESULTS

Zonally averaged yearly DT_s in the latitude belt 60° - 70° N were first computed using all stations as well as for coastal and continental stations separately during the period 1880 - 1960. We then calculated lag correlation coefficients between the above mentioned zonally averaged DT_s and the two indices of solar activity, namely the Zurich sunspot numbers and the areas index I_a. Time lags used ranged from 0 to 23 years. Lag correlation coefficients for all stations between average DT_s and/or sunspot numbers and I_a indices and corresponding .05 and .01 confidence levels are shown in figure 1.

From fig. 1 it appears that significant correlations are only found at lags 8 and 14 (at the .05 conf. level) the shape of that curve being the result of correlating two periodic elements. It should be noted that when these calculations were repeated for continental and coastal stations separately, significant peaks at the .05 level were found at lags 8 yrs for continental and 14 yrs for coastal stations.

Although the above mentioned correlations were generally low (but significant) it seemed worth while to go further and to investigate the correlation between DT_s and solar indices for the three successive years following the first sunspot peak. The reason to choose these particular three years was the well-known preference of the more drastic solar events to follow by approximately 2 to 3 years the first sunspot maximum (Papagiannis et al., 1972). This correlation was found to be highly significant ($r = -0.765$) suggesting that the position of active centers on the solar disk must be considered seriously in searching solar-weather links and not the absolute values of the solar indices, since the same result was not reproduced when we repeated these calculations for the ascending branch of solar activity.

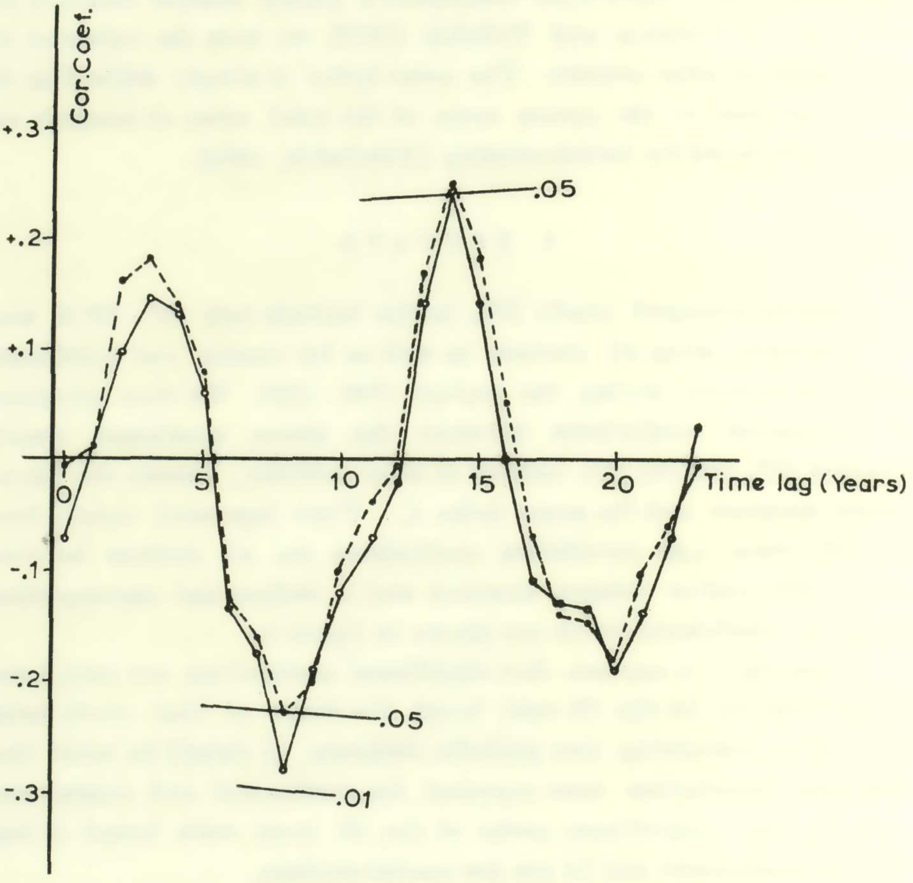

Fig. 1. Lag correlation coefficients of zonal avevage DT_s (20 stations) with sunspot numbers (continuous line) and with the areas index (dashed line).

Returning to Xanthakis' earlier work (1956) we averaged the above mentioned zonal DT_s over successive sunspot cycles (8 cycles) and correlated them with corresponding solar activity indices averaged over the same successive solar cycles. Correlation coefficients were found quite encouraging: —0.76 with sunspot numbers and —0.72 with I_a index. Following the different properties of DT_s for coastal and continental stations, discussed in the Introduction, we decided to divide the averaged over successive sunspot cycles DT_s into two groups corre-

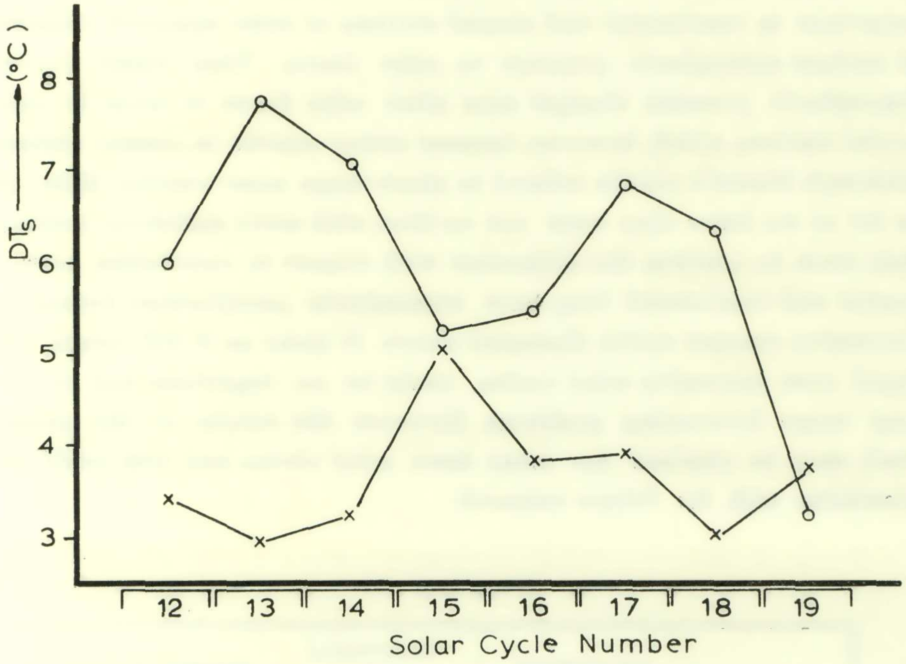

Fig. 2. Mean zonal DT_s averaged over successive solar cycle periods for continental (upper curve) and coastal stations (lower curve).

sponding to coastal and continental stations respectively. The results are shown in fig. 2, where the upper curve refers to continental and the lower curve to coastal stations.

From fig. 2 we can easily see that averaged DT_s over a solar cycle period display an exactly opposite course between continental and coastal stations during the successive solar cycles under study. This result was not reproduced when five year (instead of the approximately 11-year) average of DT_s were calculated. Rather remarkable correlation coefficients were found between the above mentioned average DT_s for continental stations (upper curve in fig. 2) and the corresponding solar activity indices: —0.84 with sunspot numbers and —0.88 with I_a index, both being highly significant at the .01 confidence level. However, similar correlations for coastal DT_s were found to be insignificant ($r = 0.30$).

Mustel and his coworkers (1969) were the first to discuss a different behaviour in continental and coastal stations of some apparent responses of surface atmospheric pressure to solar flares. They found uniform atmospheric pressure changes soon after solar flares to occur in continental stations which, however, became rather chaotic in coastal stations. Although Mustel's results refered to short-range solar-weather links and as far as we know they were not verified with strict statistical methods, they seem to confirm the difference with respect to correlation between coastal and continental long-term atmospheric peculiarities during the successive sunspot cycles discussed above. It looks as if DT_s range, averaged over successive solar cycles, could be an important tool in very long range forecasting problems. However the results of the present work must be checked for many more solar cycles and this could be a promising task for future research.

TABLE II

	All stations		Continental stations		Coastal stations	
	W	Ia	W	Ia	W	Ia
«Range X»	+0.42	+0.30	+0.53	+0.62	—0.22	—0.38
Te′ - Te	—0.02	—0.02	—0.02	—0.01	—0.03	—0.05
T	+0.24	+0.37	+0.20	+0.30	+0.37	+0.51

The correlation analysis discussed above was repeated for range X, DT_e as well as for the yearly air temperatures (T). Correlation coefficients thus obtained were found to be insignificant even at the .05 level. Table II shows for comparison these correlations which refer to the averaged over the successive solar cycles X, DT_e and T. It was indeed discouraging to find out that «range X» was almost non correlated with solar activity and not to confirm in our data Xanthakis' earlier findings who has found the correlation coefficient between X and Wolf numbers, shifted a sunspot period with respect to each other, to be about $+0.90$. It should be noted here that he used a widely spread number of stations located in a great variety of latitudes and longitudes, from the near East to the U. S., instead of the «narrow» latitude zone used in the present study. It would be suggestive to investigate range X for the whole Northern Hemisphere in relation to long-term solar activity changes in order to be statistically confident that such a solar-terrestrial link exists or not.

4. CONCLUSIONS

The results of the correlation analysis discussed in the previous paragraph, may be summarized as follows :

1) The time series of continental DT_s, shifted 8 years with respect to solar activity indices, are correlated with the solar disturbance significantly, only at the .05 confidence level. When continental DT_s were averaged over successive solar cycle periods, they were found to be strongly correlated with corresponding solar activity indices the correlation coefficient being highly significant ($r = -0.87$) in agreement with Xanthakis' (1956) earlier findings discussed in the Introduction.

2) The time series of yearly coastal DT_s shifted 14 years with respect to solar activity are correlated with solar indices only at the .05 confidence level. However when coastal DT_s were averaged over successive solar cycle periods they were found to be insignificantly correlated with corresponding solar activity indices.

3) Coastal and continental stations display an exactly opposite course as far as 11-year DT_s averages are considered. This peculiar property was not reproduced when DT_s over other than the approximately 11-year solar activity period.

4) During the first three years of the descending branch of the solar cycle, it was found that the averages of DT_s for all stations were highly correlated with the corresponding solar activity indices ($r = -0.765$).

5) Previous findings on high correlations between temperature ranges X and X and DT_e averaged over solar cycle periods, and cor-

responding solar activity indices, which were based on different data samples, were not substantiated. Also, as evidenced from our correlations, there is no preference to use either sunspot numbers or the areas index in correlations involving temperature range parameters, since correlation coefficients found with the one or the other were not statistically different.

As mentioned in the Introduction, continental and coastal DT_s have different properties, the former displaying an almost 3.5-year oscillation and higher standard deviations than the latter for which quasi-biennial oscillations are also evident. While the quasi-biennial oscillations of coastal DT_s are to be considered as a fundamental terrestrial period, in which the sea probably plays an important role (see for example Lamb, 1972, pp. 249 - 50) our results do not suggest any solar triggering at least during the long range course of successive sunspot cycles. On the other hand, the approximately 3.5-year oscillation found in continental DT_s can probably be considered as a higher harmonic of the 11-year solar cycle and a speculation arose on a possible triggering effect of solar origin, which is supported by the highly significant long-term solar and DT_s correlations found in continental stations.

Before ending this note, we should point out that computations on hemispheric scale are needed before drawing any further conclusions or practical aspects useful in long and very long range forecasting problems.

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Ὁ Ἀκαδημαϊκὸς κ. **Ι. Ξανθάκης**, παρουσιάζων τὴν ἀνωτέρω μελέτην, εἶπε τὰ ἑξῆς:

Ἔχω τὴν τιμὴν νὰ ἀνακοινώσω εἰς τὴν Ἀκαδημίαν ἐργασίαν τοῦ κ. Χρήστου Ζερεφοῦ καὶ ἐμοῦ ὑπὸ τὸν τίτλον «Ἡλιακὴ Δραστηριότης καὶ Θερμοκρασία τοῦ Ἀέρος εἰς τὴν Ζώνην Γεωγραφικοῦ Πλάτους 60° - 70° N.».

Εἰς προηγουμένην ἐργασίαν μου εἶχον μελετήσει τὰς μέσας θερμοκρασίας τοῦ ἀέρος ἀνὰ ἡλιακὸν κύκλον, τὰς παρεχομένας ἐκ τῶν παρατηρήσεων διακοσίων πεντήκοντα (250) περίπου σταθμῶν τῆς Εὐκράτου Ζώνης τοῦ Βορείου Ἡμισφαιρίου.

Ἡ ἔρευνα αὕτη ἀπεκάλυψεν ὅτι ἡ μέση θερμοκρασία τοῦ ἀέρος κατὰ τὴν διάρκειαν ἑνὸς ἡλιακοῦ κύκλου, δηλαδὴ 11 ἐτῶν κατὰ μέσον ὅρον, δὲν παρουσιάζει οὐδεμίαν συσχέτισιν μὲ τὴν μέσην τιμὴν τῆς ἡλιακῆς δραστηριότητος κατὰ τὸν ἀντίστοιχον ἡλιακὸν κύκλον. Ἀντιθέτως, εἴς τινας τόπους τῆς Κεντρικῆς καὶ Βορειοδυτικῆς Εὐρώπης ποὺ ἐμελετήθησαν ἰδιαιτέρως, ἡ διαφορὰ τῶν μέσων θερμοκρασιῶν εἰς τὴν περιοχὴν τῶν ἡλιοστασίων, δηλαδὴ κατὰ τοὺς μῆνας Ἰούνιον - Ἰούλιον καὶ Δεκέμβριον - Ἰανουάριον, παρουσιάζει σαφῆ συσχέτισιν μὲ τὴν ἀντίστοιχον μέσην τιμὴν τῆς ἡλιακῆς δραστηριότητος κατὰ ἡλιακὸν κύκλον.

Τὸ παράδοξον τοῦ πορίσματος τούτου εἶναι ὅτι ἡ συσχέτισις αὕτη καθίσταται σημαντικὴ εἰς τὸ ἐπίπεδον ἐμπιστοσύνης 99%, ὅταν αἱ δύο συσχετιζόμεναι μεταβληταὶ (θερμοκρασία ἡλιοστασίων καὶ ἡλιακὴ δραστηριότης) συγκρίνωνται μεταξύ των μὲ διαφορὰν φάσεως ἑνὸς πλήρους ἡλιακοῦ κύκλου, ἤτοι 11 ἐτῶν. Ἐν ἄλλοις λόγοις στατιστικῶς σημαντικὴ συσχέτισις παρατηρεῖται, ὅταν ἡ μέση τιμὴ τῆς ἡλιακῆς δραστηριότητος κατὰ τὸν ἡλιακὸν κύκλον 1901 - 1913 συσχετίζεται μὲ τὴν μέσην τιμὴν τῆς θερμοκρασίας εἰς τὴν περιοχὴν τῶν ἡλιοστασίων οὐχὶ κατὰ τὸν αὐτὸν ἡλιακὸν κύκλον, ἀλλὰ κατὰ τὸν ἑπόμενον 1913 - 1923. Ἡ ἑνδεκαετὴς αὕτη διαφορὰ φάσεως παραμένει ἀκόμη ἀνεξήγητος παρὰ τὴν διαρρεύσασαν εἰκοσαετίαν ἀπὸ τῆς ἀρχικῆς δημοσιεύσεως τῆς ἐργασίας ταύτης εἰς τὰ Archiv für Meteorologie, Wien καὶ τῶν σχετικῶν περιλήψεων ποὺ ἀνεδημοσιεύθησαν μεταγενεστέρως ὑπὸ σχολιαστῶν ἐγκρίτων ἀμερικανικῶν καὶ ρωσικῶν περιοδικῶν. Ἤδη μετὰ τὴν ἐπιτελεσθεῖσαν πρόοδον εἰς τὴν ἔρευναν τῆς ἡλιακῆς δραστηριότητος, εἰς τὴν ὁποίαν σημαντικῶς συνέβαλε τὸ Κέντρον Ἐρευνῶν Ἀστρονομίας καὶ Ἐφηρμοσμένων Μαθηματικῶν τῆς Ἀκαδημίας Ἀθηνῶν, ἐθεωρήσαμεν ἀναγκαῖον μετὰ τοῦ κ. Ζερεφοῦ νὰ ἐπανεξετάσωμεν τὸ πρόβλημα τοῦτο, στηριζόμενοι ἀφ᾽ ἑνὸς μὲν ἐπὶ ἄλλης βάσεως, χρησιμοποιοῦντες δὲ ἀφ᾽ ἑτέρου νέαν στατιστικὴν μέθοδον διάφορον τῆς προηγουμένης.

Πρὸς τοῦτο διὰ νὰ ἐξαλείψωμεν τὸν παράγοντα τοῦ Γεωγραφικοῦ Πλάτους θεωροῦμεν μόνον τοὺς σταθμοὺς τοὺς διαθέτοντας μακρὰν σειρὰν παρατηρήσεων τῆς θερμοκρασίας τοῦ ἀέρος, τοὺς κειμένους ἐντὸς τῆς αὐτῆς ζώνης τῆς ἐπιφανείας τῆς γῆς, τῆς ὁριζομένης ὑπὸ τῶν παραλλήλων Βορείου Γεωγραφικοῦ Πλάτους 60° - 70°. Δεύτερον διὰ τὴν ἔκφρασιν τῆς ἡλιακῆς δραστηριότητος ἐκ παραλλήλου πρὸς τοὺς ἀριθμοὺς Wolf ἐχρησιμοποιήσαμεν τὸν ὑπ᾽ ἐμοῦ εἰσαχθέντα νέον δείκτην «τῶν ἐμβαδῶν», ὅστις ὡς ἐξαρτώμενος ἐκ τῶν ἐμβαδῶν τῶν κηλίδων καὶ πυρσῶν κέκτηται ἰδιάζουσαν φυσικὴν σημασίαν, καὶ τρίτον, ὅπερ καὶ σπουδαιότερον, ἀντὶ τῆς μέσης τιμῆς κατὰ 11ετῆ ἡλιακὸν κύκλον ἐθεωρήσαμεν αὐτὰς ταύτας τὰς ἐτησίας τιμὰς τόσον τῆς θερμοκρασίας τοῦ ἀέρος, ὅσον καὶ τῆς ἡλιακῆς δραστηριότητος. Τέλος ἀντὶ τῆς συνήθους στατιστικῆς μεθόδου ἐχρησιμοποιήσαμεν τὴν μέθοδον τῆς φασματικῆς ἀναλύσεως χρονοσειρῶν.

Τὰ πορίσματα τῆς νέας ταύτης ἐρεύνης δύνανται νὰ συνοψισθῶσιν ὡς ἀκολούθως :

1) Ἡ φασματικὴ ἀνάλυσις ἀποκαλύπτει στατιστικῶς σημαντικὰς συσχετίσεις μεταξὺ τῶν δύο μεταβλητῶν εἰς βαθμὸν ἐμπιστοσύνης 95%, ὅταν ἡ διαφορὰ φάσεως αὐτῶν εἶναι 8 ἢ 14 ἔτη, δηλαδὴ 11 ἔτη κατὰ μέσον ὅρον, ὅταν ἀντὶ τῶν

ἐτησίων τιμῶν λαμβάνωμεν τὰς μέσας τιμὰς κατὰ ἡλιακὸν κύκλον, ὅπως ἐπράξαμεν εἰς τὴν πρὸ εἰκοσαετίας ἔρευναν ἡμῶν.

2) Ἡ συσχέτισις μεταξὺ τῶν ἐτησίων θερμοκρασιῶν τοῦ ἀέρος κατὰ τὰ ἡλιοστάσια εἶναι πολὺ μεγαλυτέρα κατὰ τὰ τρία πρῶτα ἔτη μετὰ τὸ μέγιστον τῆς ἡλιακῆς δραστηριότητος, καὶ ἔτι μεγαλυτέρα, ὅταν θεωρῶμεν μόνον τοὺς ἠπειρωτικοὺς σταθμούς, οἱ ὁποῖοι παρουσιάζουν ἀρνητικὴν συσχέτισιν μὲ συντελεστὴν συσχετίσεως τῆς τάξεως τοῦ 99 % καὶ

3) Ἡ πορεία τῆς διαφορᾶς τῶν θερμοκρασιῶν εἰς τὴν περιοχὴν τῶν ἡλιοστασίων κατὰ ἡλιακὸν κύκλον εἶναι ἐντελῶς ἀντίστροφος μεταξὺ τῶν χερσαίων καὶ παραλίων σταθμῶν.

Οὕτω διὰ τῆς νέας ταύτης ἐρεύνης, ἥτις ἐγένετο ἐπὶ νέας βάσεως καὶ διὰ τῆς χρησιμοποιήσεως νέας ἀκριβεστέρας μεθόδου, ἐπιβεβαιοῦται ἀφ᾽ ἑνὸς μὲν τὸ περίεργον ἐξαγόμενον τῆς ἑνδεκαετοῦς διαφορᾶς φάσεως, ἀφ᾽ ἑτέρου δὲ ἀποκαλύπτονται καὶ νέαι ἀκόμη συσχετίσεις, καθὼς καὶ περιοδικότητες βραχείας περιόδου, μεταξὺ ἡλιακῆς δραστηριότητος καὶ θερμοκρασίας τοῦ ἀέρος κατὰ τὰ ἡλιοστάσια.