ΠΡΑΚΤΙΚΑ ΤΗΣ ΑΚΑΔΗΜΙΑΣ ΑΘΗΝΩΝ

ΣΥΝΕΔΡΙΑ ΤΗΣ 6ΗΣ ΙΟΥΝΙΟΥ 1980

ΠΡΟΕΔΡΙΑ ΓΕΩΡΓΙΟΥ Ε. ΜΥΛΩΝΑ

ΑΣΤΡΟΝΟΜΙΑ. – **Influence of solar proton event on upper stratospheric temperatures,** *by J. Xanthakis - C. Zerefos - S. Sehra - C. Repapis - C. Poulakos* *. Ἀνεκοινώθη ὑπὸ τοῦ Ἀκαδημαϊκοῦ κ. Ἰ. Ξανθάκη.

A B S T R A C T

The temperatures of the stratosphere above 35 - 40 km at high latitudes were significantly lower than expected following the abnormal solar activity of August 1972. The observed cooling is possibly associated with larger-scale ozone reductions of the upper stratosphere over the polar cap related to the same solar proton event (Heath et al., 1977). Tentative model calculations of the expected stratospheric cooling rates due to earlier proposed catalytic destruction of ozone by nitrogen oxides produced by the solar event were found to be in reasonable agreement with the observations.

1. INTRODUCTION

Measurements with the backscattered ultraviolet (BUV) experiment on the Nimbus 4 satellite, have shown large-scale reductions in the ozone content above the 4 mb pressure surface ($\sim$38 km) over the polar cap associated with the major solar proton event of 4 August, 1972 (Heath et al., 1977). These measurements provide the only evidence of a

* Ι. ΞΑΝΘΑΚΗ - Χ. ΖΕΡΕΦΟΥ - S. SEHRA - Χ. ΡΕΠΑΠΗ - Κ. ΠΟΥΛΑΚΟΥ, **Ἡ ἐπίδρασις ἡλιακῆς ἐκλάμψεως πρωτονίων ἐπὶ τῆς θερμοκρασίας τῆς ἀνωτέρας στρατοσφαίρας.**

direct solar effect on stratospheric ozone which has been observed up to now. The maximum ozone density reduction amounted to about 20 %.

In summer radiation is the dominant term in the energy budget of the stratosphere and reductions in the ozone amount schould be reflected in the temperature of the ozone layer. Thus, the previously cited ozone reductions which refer to summertime should also be reflected in observations of mean temperatures at high latitudes and the altitudes of interest. In this report we present of a significant cooling that took place in the upper stratosphere at high latitudes in late summer of 1972, based on the available rocketsonde data.

2. DATA

Rocketsonde monthly mean temperatures and standard deviations of daily temperatures for each month of the period July through October, 1972 were taken from the Upper Atmosphere Tabulations of World Data Center A (WDC-A) at 5 km height intervals from 25 km to 60 km. Corresponding longer term means and standard deviations were also taken from the same source and they refer to the four-year period 1969 - 1972. Use was also made of the Russian Bulletin, Results of Rocket soundings of the Atmosphere, which included daily soundings at the two rocket stations Heiss and Volgograd. Monthly means and standard deviations as well as the corresponding long-term summaries were computed by us.

Table I identifies the stations whose data were investigated at the first place and shows the available number of data points for each station and month at the 40 km level. We decided to exclude from our analysis those stations possessing less than four observations in any one of the months under study in the year 1972. According to this criterion results from Heiss, Volgograd, Barking Sands and Kwajalein are not shown in this report *. We also excluded Fort Sherman because of the reported extremely high standard deviations in September 1972. Following the before mentioned objective criteria, we were left with 8

* Although Ft Churchill possesses only 4 observations in July 1972, this station was not excluded because of its very complete records in the subsequent months August, September and October.

TABLE I

Rocket stations and number of soundings in July, August, September and October for 1972 (upper row) and 1969 - 1972 (lower-row).

Station	Lat.	Long.	July	Aug.	Sept.	Oct.
Heiss	80.4° N	58.0° E	3	2		4
			38	33		30
Poker Flats . .	65.1° N	147.5° W	9	11	5	—
			24	34	16	
Fort Churchill .	58.7° N	93.8° W	4	11	9	12
			17	34	37	38
Primrose Lake .	54.8° N	110.1° W	—	7	6	5
				33	27	20
Volgograd . . .	48.6° N	44.4° E	—	4	7	4
				13	29	33
Wallops Isl. . .	37.8° N	75.5° W	10	10	7	21
			38	45	45	54
Point Mugu . .	34.1° N	119.1° W	12	10	8	9
			68	53	49	59
White Sands . .	32.4° N	106.5° W	13	15	12	19
			34	35	55	48
Cape Kennedy .	28.5° N	80.5° W	14	9	8	9
			54	42	43	39
Barking Sands .	22.0° N	159.8° W	12	11	4	9
			61	67	51	46
Fort Sherman .	9.3° N	80.0° W	11	6	5	8
			36	37	13	28
Kwajalein . . .	8.7° N	167.7° E	4	3	6	—
			27	36	38	
Ascension Isl. .	8.0° S	14.4° W	12	10	10	10
			42	36	38	41

stations possessing on the average the order of 10 observations per month, more or less uniformly distributed in each of these months in 1972. Most of these observations were made in sunlight and we have chosen to accept the rocketsonde data as published without attempting further corrections. For the most part the data we used are based on

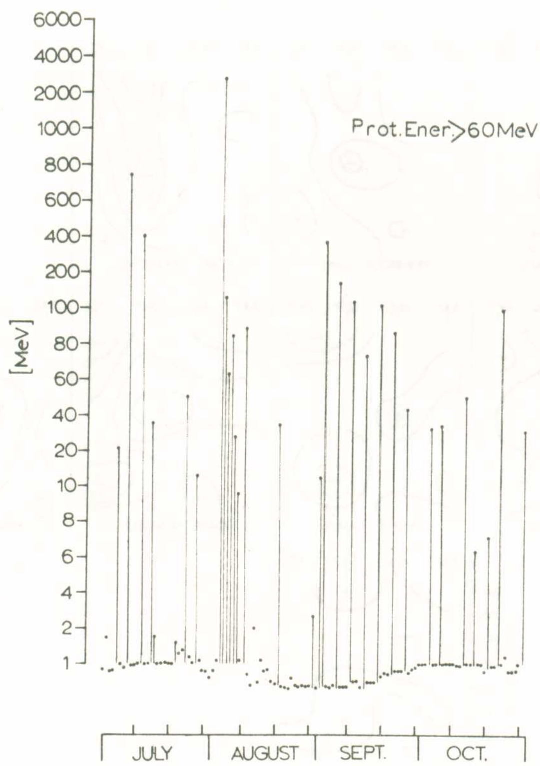

Fig. 1. Solar proton fluxes for proton energies greater than 60 MeV as measured by Explorer for July up to October, 1972.

the Datasonde system since a changeover to that observational system was instituted in 1969 (Quiroz, 1979, and Angell and Korshover, 1978).

The solar proton fluxes as measured by Explorer were taken from the Comprehensive Reports of solar activity and it is shown in Fig. 1. We can easily see from that figure the abnormally higher solar proton flux that was associated with the Ground Level Event (GLE) in early August, 1972.

3. RESULTS

At a given station and level, we calculated the departure of the monthly mean temperature for the summer months of 1972 from the corresponding four-year monthly mean temperature (1969 - 1972) and the significance of each monthly departure was tested through student's-t

Fig. 2. Isolines of 1972 monthly mean temperature departures from long-term (1969 - 1972) mean. Shaded regions are significant at better than 95 % confidence levels.

test. Isolines of these monthly temperature departures are shown in Fig. 2, where shaded regions indicate temperature departures significant at the 95 % confidence level.

From Fig. 2, the following conclusions can be made :

1. The high-latitude stations Poker Flats, Primrose Lake and Ft Churchill all show a statistically significant cooling in September, 1972.

This cooling is strongest between 40 and 45 km. The cooling rates we observe are much greater than the «normal» seasonal cooling rates at this time of the year. A further example on that point is seen in Fig. 3, which shows the time series of individual soundings in two levels as compared to the seasonal trend (dashed-line) from July to November 1972 at Ft Churchill (vertical bars are two times the standard deviation).

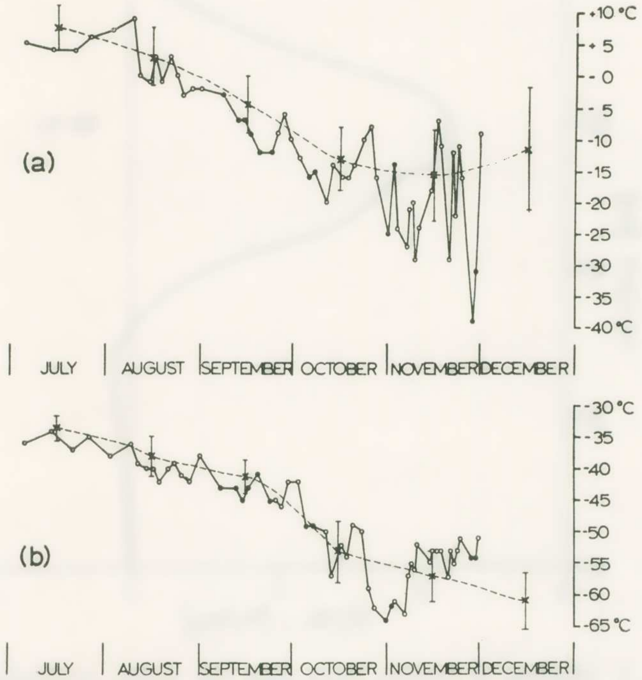

Fig 3. Time series of temperature for Fort Churchill rocket-soundings from July up to December 1972, at 50 km (a) and at 30 km (b). Dashed lines are the seasonal trends, crosses are the monthly means and vertical bars are the two times the standard deviations.

2 The midlatitude stations Wallops Isl., Point Mugu, White Sands and Cape Kennedy, despite their large geographical separation all show a similar pattern which consists of a more or less significant cooling in October. The same pattern was also evident at the Russian station Volgograd (not shown here).

3. The low-latitude station Ascension Island shows departures of less than one degree affter the event. The same holds for the other two

low-latitude stations which were excluded from our analysis because of their small data base.

From the above discussion one is tempted to try to relate the observed significant high altitude-latitude cooling to the flare induced ozone reductions reported by Heath et al. (1977). Assuming that the

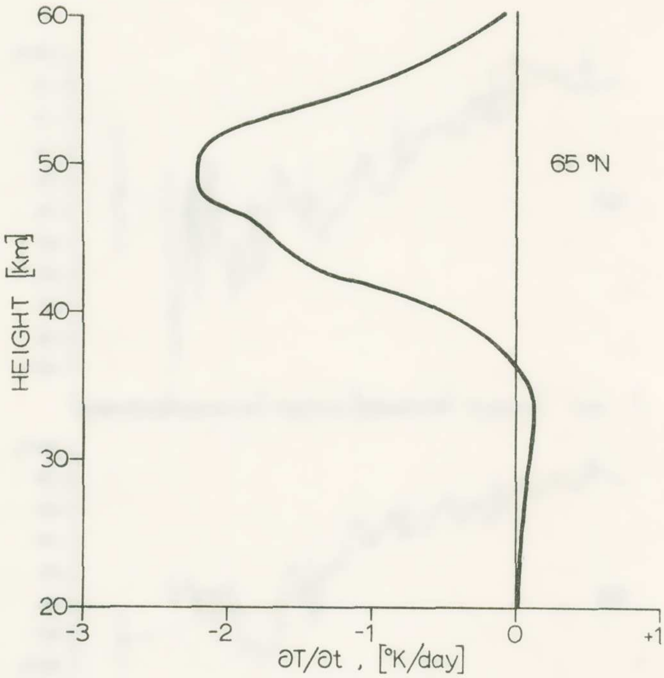

Fig. 4 Heating or cooling rates after the model calculations by Zerefos and Crutzen, 1975.

associated upper stratospheric cooling is symmetric about the geomagnetic pole, it is probable that the subsequent cooling seen at moderate latitudes in October is due to air advected from higher latitudes.

Dütsch (1979) provides an extensive summary of mechanisms proposed to explain solar activity-ozone relations. We present here in Fig. 4 the results from the model calculations by Zerefos and Crutzen (1975) which are found in reasonable agreement with the observations presented in this study. That model is a time-dependent extension of the original model (Crutzen, 1970, 1974, Crutzen et al. 1975) and calculates the solar cosmic ray production of nitrogen oxides which subsequently act as deozonozers below 45 km. That model has been used by Zerefos and Crutzen (1975) to calculate stratospheric heating and/or cooling rates for the solar proton event investigated here.

From Fig. 4 we can see that following the August 1972 event, in comparison to undistributed conditions, a cooling is predicted to occur above about 36 km and a heating below that level due to the deeper penetration of the UV radiation as a result of the ozone reduction below 45 km. The peak of this cooling effect is expected to be located between 45 and 50 km, in reasonable agreement with the observations of Fig. 2. A cooling rate of 2 deg/day as that predicted at 50 km would be equivalent to a 10 deg. disturbance in the equilibrium temperature according to Dickinson's (1973) parameterization scheme
[a (50 km) $\sim$ 0.2 $(\text{day})^{-1}$] where a is his cooling coefficient. Insufficient knowledge of atmospheric transport at altitudes near 40 - 50 km makes it difficult to estimate the duration of such a disturbance.

The observed cooling in the upper stratosphere following a large proton event is not necessarily in conflict with evidence of a long-term, in-phase relation between upper stratospheric temperatures and the solar activity cycle as has been reported by Angell and Korshover (1978) and Quiroz (1979). Major solar proton events are rare and their possible influence on upper stratospheric temperatures, being transient in nature, would produce at high latitudes superimposed temperature variations perhaps deviating at times considerably from a more or less 11-year sinusoidal behaviour.

4. CONCLUSIONS

Following the major solar proton event which occured early in August, 1972 a significant cooling in the upper stratosphere at high latitudes is observed about one month after the event. The cooling has probably been advected to moderate latitudes by October, while there are no significant stratospheric temperature changes at low latitudes

The observed cooling is in agreement whith the only direct solar effect on the ozone layer that has been observed beyond any doubt, namely the ozone density decrease above 4 mb folloging the August 4, 1972 proton event (Heath et all 1977).

Model calculations of the expected stratospheric cooling rates following this particular event (Zerefos and Crutzen, 1975) are in reasonable agreement with the rocketsonde observations.

REFERENCES

J. K. Angell - J. Korshover, Recent Rocketsonde-Devited Temperature Variations in the Western Hemisphere, J. Atmos. Sci., 35, 1758-1764, 1978.

P. J. Crutzen, The Influence of Nitrogen Oxides on the Atmospheric Ozone Content. Quart, J. Roy. Meteor. Soc., 96, 320 - 337, 1970.

P. J. Crutzen - I. S. A. Isaksen - G. C. Reid, Solar Proton Events: Stratospheric Sources of Nitric Oxide, Science, 189, 457 - 459, 1975.

R. E. Dickinson, Method of Parameterization for Infrared Cooling Between Altitudes of 30 and 70 kilometers, J. Geoph. Res. 78, 4451 - 4457, 1973.

H. U. Dütsch, The Search for Solar Cycle-Relationships, J. Atmos. Terr. Phys., 41, 771 - 785, 1979.

D. F. Heath - A. J. Krueger - P. J. Crutzen, Solar Proton Event: Influence on Stratospheric Ozone, Science, 197, 886 - 889, 1977.

R. S. Quiroz, Stratospheric Temperatures During Solar Cycle 20, J. Geophys. Res., 84, 2415 - 2420, 1979.

C. S. Zerefos - P. J. Crutzen, Stratospheric Thickness Variations and their Possible Relation to Solar Activity, J. Geoph. Res., 80, 5041 - 5043, 1975.

ΠΕΡΙΛΗΨΙΣ

Εἰς τὴν παροῦσαν ἐργασίαν ἐμελετήθησαν αἱ διαφοραὶ ἀπὸ τὴν χρονικὴν τιμὴν τῶν μέσων μηνιαίων τιμῶν τῆς θερμοκρασίας τῆς στρατοσφαίρας πρὸ καὶ μετὰ τὸν Αὔγουστον 1972, ὁπότε συνέβη ἀσυνήθως ἰσχυρὰ ἐκπομπὴ ἡλιακῶν πρωτονίων προερχομένων ἀπὸ ἡλιακὰς ἐκλάμψεις.

Ἐχρησιμοποιήσαμεν τὰς διὰ πυραύλων μετρήσεις τῆς θερμοκρασίας τῆς στρατοσφαίρας εἰς διάφορα ὕψη μεταξὺ τῶν 20 καὶ 60 km. Τὸ πρῶτον ἀποτέλεσμα τῆς παρούσης ἐρεύνης ἀφορᾶ εἰς τὴν εὕρεσιν ἰσχυρᾶς ψύξεως τῆς ἀνωτέρας κυρίως στρατοσφαίρας ἡ ὁποία ἔλαβε χώραν κατὰ τὸν μῆνα Σεπτέμβριον εἰς τὰ βορειότερα γεωγραφικὰ πλάτη, ἐν συνεχείᾳ δὲ κατὰ τὸν Ὀκτώβριον, διεχύθη πρὸς τὰ μέσα γεωγραφικὰ πλάτη. Ἐδῶ πρέπει νὰ σημειωθῇ ὅτι εἰς τὰ χαμηλὰ πλάτη οὐδεμία σημαντικὴ μεταβολὴ τῆς θερμοκρασίας παρετηρήθη. Τὰ ἀνωτέρω

ἀποτελέσματα προέκυψαν ἐκ τῶν πυραυλοβολίσεων τῆς Ἀμερικανικῆς ἠπείρου. Δυστυχῶς αἱ ἀντίστοιχοι Ρωσικαὶ μετρήσεις διὰ πυραύλων εἰς τὸ βόρειον ἡμισφαίριον ἦσαν ἐλλειπεῖς κατὰ τὴν περίοδον ταύτην ἀλλὰ γενικῶς εὑρίσκονται ἐν συμφωνίᾳ μὲ τὰ ἀνωτέρω ἀποτελέσματα. Ἐξ ἄλλου ὁ Ρωσικὸς Σταθμὸς πυραυλοβολίσεων Molodezhnaya, εἰς τὸ πρόγραμμα τῶν μετρήσεων τοῦ ὁποίου συμμετέσχεν ὁ κ. Sehra, εὑρίσκεται κατὰ τὴν ὑπ' ὄψιν περίοδον εἰς τὸν πολικὸν χειμῶνα τοῦ νοτίου ἡμισφαιρίου καὶ οὕτω δὲν κατέστη δυνατὸν νὰ ἐπιβεβαιωθοῦν τὰ ἀνωτέρω εὑρήματα καὶ διὰ τὰς νοτίους πολικὰς περιοχάς.

Τὸ δεύτερον σκέλος τῆς παρούσης ἐρεύνης ἀφορᾶ εἰς τὴν ἑρμηνείαν τοῦ φυσικοῦ μηχανισμοῦ διὰ τοῦ ὁποίου ἡ ἡλιακὴ ἔκλαμψις πρωτονίων ὡδήγησεν εἰς τὴν παρατηρηθεῖσαν ψύξιν τῆς ἀνωτέρας κυρίως στρατοσφαίρας ὑπεράνω τῶν βορειοτέρων γεωγραφικῶν πλατῶν.

Ἡ φυσικὴ σύνδεσις τῶν δύο φαινομένων εἶναι πιθανὸν νὰ ὀφείλεται εἰς τὴν ἐπίδρασιν τῶν ἡλιακῶν πρωτονίων ἐπὶ τοῦ ὄζοντος τῆς στρατοσφαίρας. Πράγματι κατὰ τὴν αὐτὴν χρονικὴν περίοδον παρετηρήθη σημαντικὴ μείωσις τοῦ στρατοσφαιρικοῦ ὄζοντος ἀπὸ τὸν δορυφόρον NIMBUS-4 ὅπως ἐδημοσίευσαν προσφάτως οἱ Heath, Krueger καὶ Crutzer. Καθὼς ἡ θερμοκρασία ἰσορροπίας τῆς στρατοσφαίρας ἐξαρτᾶται, ἰδίως κατὰ τοὺς θερινοὺς μῆνας, ἐκ τῆς συγκεντρώσεως τοῦ στρατοσφαιρικοῦ ὄζοντος εἶναι λογικὸν νὰ δεχθῶμεν δοκιμαστικῶς τὸν ἤδη προταθέντα ἀπὸ τοὺς Ζερεφὸν καὶ Crutzen μηχανισμόν. Συμφώνως πρὸς τὸν μηχανισμὸν αὐτὸν τὰ ἡλιακὰ πρωτόνια παράγουν δευτερογενῶς ὀξείδια τοῦ ἀζώτου κατὰ τὴν εἴσοδον αὐτῶν ἐντὸς τῆς ἀτμοσφαίρας τὰ ὁποῖα ἀκολούθως δροῦν ὡς καταλυτικοὶ καταστροφεῖς τοῦ ὄζοντος εἰς ὕψη κυρίως κάτω τῶν 50 km. Ἐχρησιμοποιήσαμεν ὡς ἐκ τούτου ἓν κατάλληλον μοντέλο (πρότυπον) τὸ ὁποῖον ὑπολογίζει τὴν ἀναμενομένην μείωσιν τοῦ ὄζοντος εἰς τὰ βορειότερα πλάτη (ὅπου καὶ ἐκτρέπονται ὑπὸ τοῦ γεωμαγνητικοῦ πεδίου τὰ ἡλιακὰ πρωτόνια). Τὸ μοντέλλο αὐτὸ ἐν συνεχείᾳ ὑπολογίζει τὴν ἀναμενομένην ψύξιν τῆς στρατοσφαίρας συμφώνως πρὸς τὸν ἀνωτέρω μηχανισμόν. Ἡ σύγκρισις τῆς παρατηρηθείσης ψύξεως ἐκ τῶν πυραυλοβυλίσεων μὲ τὴν ἐκ τοῦ μοντέλου ὑπολογιζομένην ὁδηγεῖ εἰς ἐκπληκτικῶς παραπλήσια ἀποτελέσματα.

Ἐν συμπεράσματι, οἱ ἀνωτέρω μηχανισμοὶ εἶναι δυνατὸν νὰ ἑρμηνεύσουν τὰ πειραματικὰ εὑρήματα καὶ ἴσως νὰ ἀποτελέσουν ἀπαρχὴν τῆς ἑρμηνείας προγενεστέρων εὑρημάτων τοῦ ὁμιλοῦντος σχετικῶς μὲ τὴν ἐπίδρασιν τῆς ἡλιακῆς δραστηριότητος ἐπὶ τῶν φαινομένων τῆς τροποσφαίρας.