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INTERCORRELATED SATELLITE OBSERVATIONS RELATED TO SOLAR EVENTS

Edited by V. Manno and D. E. Page

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VARIATIONS OF SOLAR WIND FLUXES OBSERVED ON BOARD VENERA-5 AND VENERA-6 FROM JANUARY 21 TO MARCH 21 1969 AND PULSATIONS OF THE EARTH'S ELECTROMAGNETIC FIELD CAUSED BY THESE VARIATIONS

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Abstract. This paper describes the preliminary results of comparison of data obtained from recording of solar wind fluxes on board Venera-5 and Venera-6 from January 21 to March 21, 1969 and from recording of pulsations and short-period disturbances of the earth's electromagnetic field at the Soviet Observatory 'Borok' ($\Phi = 53°$, $\Lambda = 123°$). The considerable increases of solar wind fluxes as a rule were accompanied by considerable disturbances of the earth's electromagnetic field so that there is no doubt about their causality.

1. Some Information on Solar Wind Measurements Carried out on Venera-5 and Venera-6

On each of the spacecraft launched to Venus in January 1969 a flat four-electrode integral trap was installed which made it possible to register positive ions with energies $E > 50$ eV. On the way from the earth to Venus the collector currents of the traps were measured; the results of measurements were conserved in a memorizing device, information from which was recorded on the earth during radiotelemetric transmissions.

The collector current of a trap of the type used, is always lower than the current created by ion fluxes affecting the trap. This is accounted for by photoemission of electrons from the suppressor grid [1]. The trap orientation to the sun during the measurements was practically constant; in such a case one can consider the above-mentioned photoemission as constant. But the trap collector currents varied to a great extent during the observations, giving evidence of occasional considerable increases of the solar wind ion fluxes. It is easy enough to determine variations of the ion fluxes ΔN_i with sufficient confidence but determination of the absolute values of ion fluxes is more difficult because of the necessity of taking into account the above-mentioned photoemission. That is why, in this preliminary paper, only values of ΔN_i above some level N_{i0} are given. The value N_{i0} (10^8 cm^{-2} sec^{-1} in order of magnitude) is not defined more precisely here.

2. On Earth's Electromagnetic Field Pulsations and Their Registration at the Observatory 'Borok'

For comparison with the observations of solar wind fluxes from Venera-5 and Venera-6 the record of electromagnetic field pulsations of P_c-type and its variations over longer

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periods [2] were used. According to recent ideas the P_c-type pulsations result from the interaction of solar wind fluxes with the outermost region of the subsolar part of the magnetosphere. The available experimental data give evidence that the values and periods of these pulsations depend both on the physical parameters of the magnetosphere in which magnetohydrodynamic waves propagate (radius of subsolar part of magnetosphere, space distribution of plasma density and magnetic field) and on the parameters of the interplanetary plasma interacting with it (bulk velocity and density of solar plasma, magnitude and direction of interplanetary magnetic field).

It is supposed that plasma parameters have a tangential discontinuity at the shock wave front, which may be unstable and responsible for the generation of surface waves; i.e. conditions may occur under which the amplitude of surface waves can increase considerably.

Waves generated at the magnetospheric boundary surface are transformed to magnetohydrodynamic waves by means of different processes. These waves propagate through the magnetosphere to the lower boundary of the ionosphere, and can create standing waves in 'magnetospheric resonators'. Magnetopause – plasmapause and plasmapause – lower boundary of the ionosphere serve as the walls of these resonators. It is worth noting that as the quality of these resonators is low ($Q \sim 5$–10) the life-time of these waves must completely depend on the time during which some solar wind inhomogeneity is interacting with the magnetosphere.

As the lower boundary of the ionosphere is separated from the earth by a non-conducting region, the magnetohydrodynamic waves in the ionosphere induce electromagnetic waves in this region. That is why magnetohydrodynamic waves in the magnetosphere can be detected on the surface of the earth by means of measurements of pulsations of electric and magnetic fields which are fluctuating synchronously.

It is convenient to observe electric field pulsations by recording the potential differences created by telluric currents induced in a well-conducting surface layer of the earth. At the observatory 'Borok' records of telluric currents are made by means of devices with much broader amplitude-frequency characteristics than those used to record the magnetic field (these devices enable one to record oscillations with periods from 10 sec to over 1h practically without distortion of amplitudes). For our preliminary comparison with solar wind data the most interesting feature was the general level of the electromagnetic field disturbance in a broad frequency band; that is why the telluric currents records were used for this purpose. The registration of telluric currents was carried out continuously on photopaper, moving with a speed of 90 mm per hour; the scale of the electric field horizontal components was the following:

the North–South direction

$$E_x = 0.036 \text{ mv/mm km}$$

the West–East direction

$$E_y = 0.131 \text{ mv/mm km}.$$

Such sensitivity corresponds to registration of similar magnetic field variations of magnitude ~0.08–0.1 γ/mm. So in the following comparison the records were used with a sensitivity exceeding the sensitivity of the standard magnetograms by more than an order of magnitude.

3. Results of the Observations and Brief Discussion

The results of the Venera-6 observations of solar wind ion fluxes for the period considered are presented in Figure 1 (the upper graph). Directly underneath the time intervals corresponding to increases of ion fluxes during which ΔN_i reached maximum value, equal to or more than 3×10^8 cm^{-2} sec^{-1} are marked. The lowest diagram shows time intervals during which pulsations and short-period disturbances of electromagnetic field were observed at the observatory 'Borok'. Only those with indices of disturbance level $E_d > 1$ are shown. The dimensionless index E_d was defined as the ratio of the maximum amplitude of the pulsations horizontal component of the electric field (equal to $\sqrt{(E_x^2 + E_y^2)}$) during one hour to its value averaged over a year from the 'Borok' data.

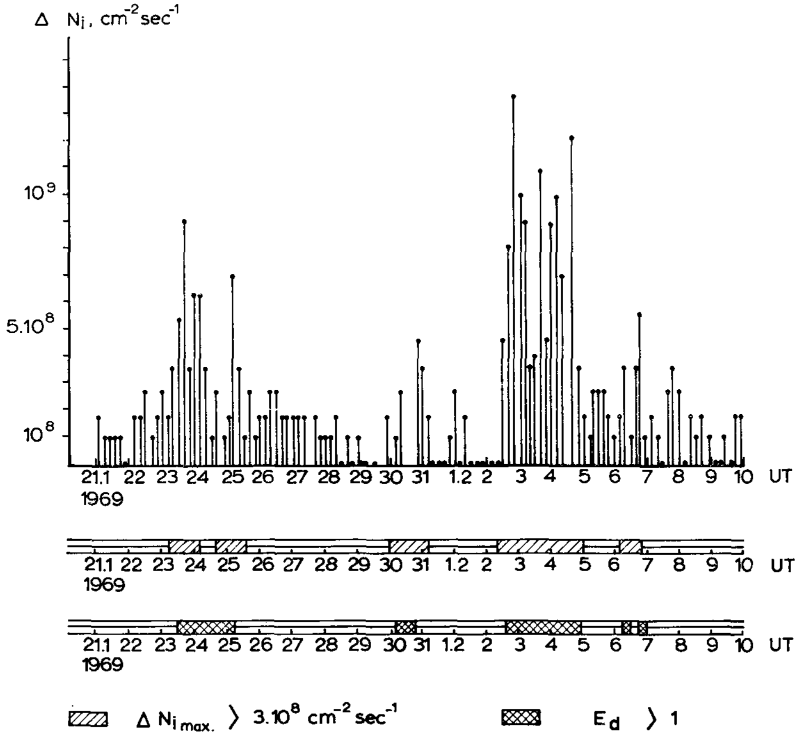

Fig. 1a.

Fig. 1. Variations of solar wind ion fluxes measured on board Venera-6 for the period from January 21 to March 21, 1969 (upper graph). The time intervals corresponding to ion fluxes increases during which ΔN_i reached maximum value $\Delta N_{i_{\max}} > 3 \times 10^8$ cm^{-2} sec^{-1} are marked lower; the time intervals during which pulsations and short-period disturbances with indices $E_d > 1$ were observed at the observatory 'Borok' are shown at the bottom of the graph.

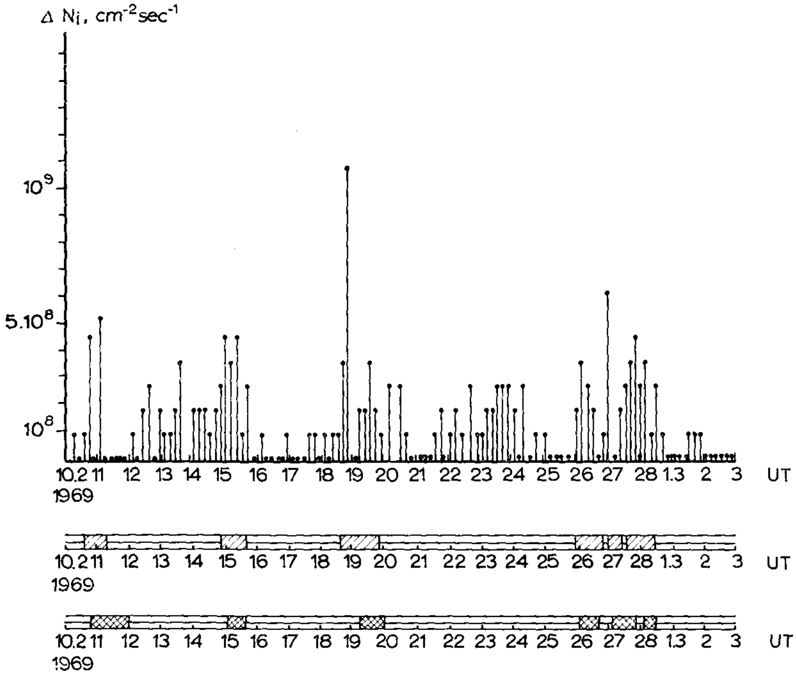
Δ N_i, cm^{-2}sec^{-1}
10^9
5.10^8
10^8
10.2 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 1.3 2 3 UT
1969
10.2 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 1.3 2 3 UT
1969
10.2 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 1.3 2 3 UT
1969

Fig. 1b.

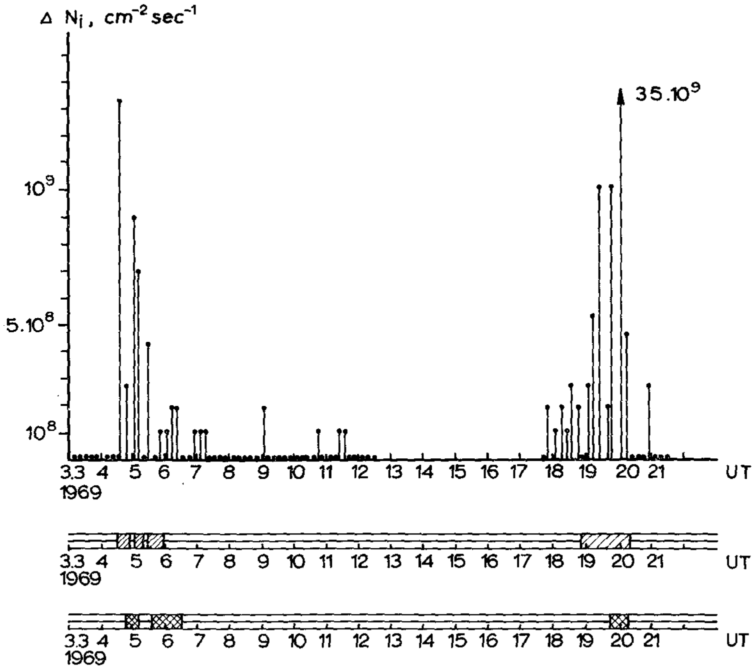
Δ N_i, cm^{-2}sec^{-1}
35.10^9
10^9
5.10^8
10^8
3.3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 UT
1969
3.3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 UT
1969
3.3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 UT
1969

Fig. 1c.

In this paper universal time is given in all cases.

From 9 h March 12 to 17 h March 17 measurements were not carried out. A graph on which the data obtained from Venera-5 are plotted in a similar manner is very much like that given in Figure 1 and is not presented here. It differs from the graph given in Figure 1 in some details, because the spacecraft were at the distance of some millions of kilometers from one another and the times of ion flux measurements on both spacecraft were different.

In Figures 2, 3 and 4 samples of telluric currents data records used for this investigation are presented. The upper curve corresponds to the component of the horizontal electric field E_x (in the direction North–South), and the lower one to E_y (in the direction West–East).

Figure 2 corresponds to very small pulsations of the electromagnetic field of the earth during the day 3.8.1969 ($\Delta N_i \sim 0$, $E_d \sim 0$, see Figure 1).

Figure 3 corresponds to the sudden commencement of an electromagnetic storm (transition from quiet to disturbed state at 1^h58^m 2.26.1969).

In Figures 4a and 4b transitions from disturbed to quiet states corresponding to the days 2.27 and 2.28.1969 are shown.

One must bear in mind that, as the registration of telluric currents was continuous, the beginning and the end of any event could be determined using these records with an error of some minutes. The variations of solar wind fluxes were measured only once every 4 h, that is why variations with shorter period could not be revealed and beginnings and ends of disturbances could be determined with correspondingly low accuracy.

Let us return to the graphs in Figure 1.

One can see that the periods when the solar wind ion fluxes were comparatively low as a rule correspond to periods with low level of the earth's electromagnetic field pulsations ($E_d \leqslant 1$). During all periods under consideration there were 10 cases of substantial increases of N_i ($\Delta N_i \gtrsim 3 \times 10^8$ cm^{-2} sec^{-1}) with duration more than 8 h each.

Each of these time intervals (including the interval following the event on February 25, 1969) is accompanied by a time interval with a disturbed and pulsating earth's electromagnetic field. In all cases mentioned, beginnings of the increases of N_i observed on spacecraft located between the sun and the earth preceded the commencements of the periods of the disturbances and pulsations of the earth's electromagnetic field.

A consideration of the earth current records within these two months showed that in daytime the considerable increases of pulsations and short-periodic disturbances of the earth's electromagnetic field did not occur even within the four-hour intervals between the ΔN_i measurements taken during the periods of low N_i values recorded on the spacecraft. Only the long period marked enhancements of the solar wind fluxes (about half-day or more) seem to cause the earth's electromagnetic field pulsations with large amplitudes.

It should be noted that comparison between N_i-values and K_p-indices (shown on

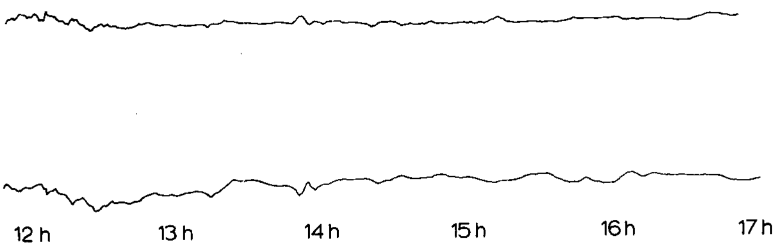

Fig. 2. An example of telluric currents data records from the observatory 'Borok'. The upper curve corresponds to the component value of horizontal electric field E_x (in the direction North–South), and lower one to E_y (in the direction West–East). The state of the earth's electromagnetic field 3.8.1969 is very quiet ($\Delta N_i \sim 0$, $E_a \sim 0$).

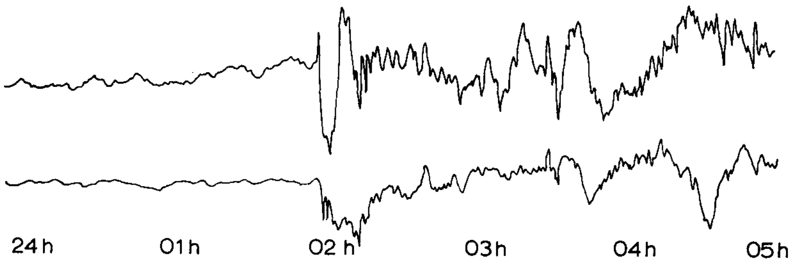

Fig. 3. An example of telluric currents data records corresponding to sudden commencement of electromagnetic storm (the transition from quiet to disturbed state at 1^h58^m 2.26.1969).

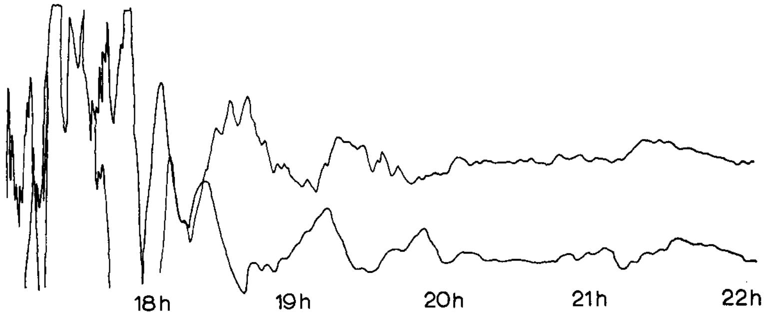

Fig. 4a. An example of telluric currents data records corresponding to the transition from disturbed to quiet state 2.27.1969.

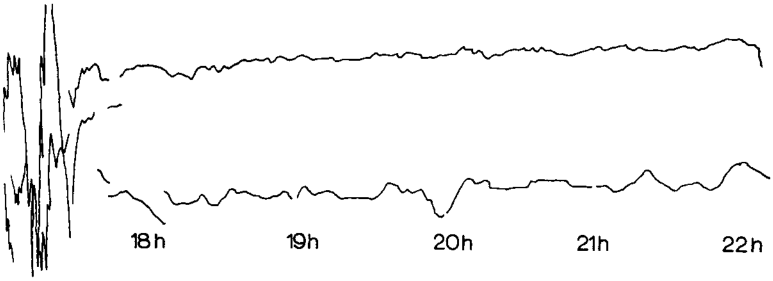

Fig. 4b. The transition similar to the one shown in Figure 4a for 2.28.1969.

Figure 1) reveals that there is no satisfactory correlation between these data (although the values of $N_i \gtrsim 10^9$ cm^{-2} sec^{-1} generally corresponds to $K_p \sim 5$).

The good agreement of ΔN_i-values with the results of the registration of pulsations and disturbances with short periods of the earth's electromagnetic field together with the poor correlation with K_p-indices may be related to the fact that K_p-indices are defined from the data of a standard magnetograph network whereas the registration of pulsations is made, as was pointed out in Section 2, with instruments of higher sensitivity.

4. On the Events of February 25–27, 1969

As it is known a number of solar flares were observed on February 25 (including those at 9^h20^m (class 2B, 14N, 36W), 16^h59^m (1N, 13N, 41W), 19^h43^m (1N, 13N, 43W). On February 26 a solar flare was observed in the same part of the solar disk at 04^h46^m (1B, 13N, 46W). On February 27 a flare was registered at 14^h08^m (2B, 14N, 65W) [3].

At 01^h58^m on February 26 a world magnetic storm Sc began (its commencement can be seen from the telluric currents records on Figure 3). At 00^h38^m on February 27 the magnetic storm Sc which was registered by a number of observatories began [3] and was represented by enhancements of the amplitudes of the telluric current pulsations. In both cases the indicated disturbances were preceded by increases of ΔN_i-values observed on Venera-5 and Venera-6. In addition on February 25 the solar flares were observed aboard Venera-5 and Venera-6 with devices aimed to observe protons of energy $\leqslant 30$ MeV at ~ 10 h. These appeared in the form of a sharp enhancement of the particle counting rate followed by gradual decrease and the second sharp enhancement of the same energy particle fluxes was observed on February 27 at ~ 20 h. The detailed data of these measurements are given in the paper of Vernov *et al.*, this volume, p. 53.

The values of solar plasma fluxes registered by Venera-5 and Venera-6 on February 25 were low, the pulsation and disturbances of the earth's electromagnetic field were also low according to the 'Borok' observatory data.

As for the February 26–28 time interval, the three main enhancements followed by decreases were observed both on the ΔN_i-graph and on the records of the earth electromagnetic field pulsations (Figure 1).

In Figure 5a the results of measurements of ΔN_i aboard the Venera-5 are given for the period February 25–28, 1969, and in Figure 5b the changes of hourly E_d-indices from the earth currents at 'Borok' observatory for the same time interval are presented. The results shown in Figure 5a give somewhat different ΔN_i data from the ΔN_i-values for the same time interval measured by Venera-6 (Figure 1) for the reasons mentioned above. It must be remembered when comparing Figures 5a and 5b that in Figure 5b – values determined from the maximum amplitude of pulsations of horizontal electric field components during one hour are given, but Figure 5a gives the instantaneous values of ΔN_i, which were measured once every four hours. With such an information on the changes of N_i, the moment at which the N_i-value is maximum can be missed because it can occur between two measurements.

Nevertheless in Figures 5a and 5b one can clearly see the above mentioned increases and decreases of solar wind fluxes and earth's electromagnetic field pulsations during the February 26–28 period.

We think that it is difficult to establish which of the numerous solar flares that occurred over the period of February 24–27 (in part they are noted in the beginning of this section) caused each of the enhancements of the solar wind flux, geomagnetic field disturbances and increase of pulsations observed over the time interval considered. Some considerations on the identification of the solar flares causing the magnetic storms Sc observed on February 25 and 27 are given in the paper of Vernov *et al.*, in the present volume, p. 53. We should like to note the following. If the above-mentioned magnetic storms Sc are caused by the arrival of shock waves fronts to the earth from interplanetary plasma (which in turn are created by solar plasma eruptions accompanying the flares) then it follows from the data shown in Figures 1 and 5a that the eruptions were continuous (lasting many hours). This is because in both cases the ΔN_i values reached the maximum only after many hours after the beginning of their increase which may be connected with the commencement of the storm.

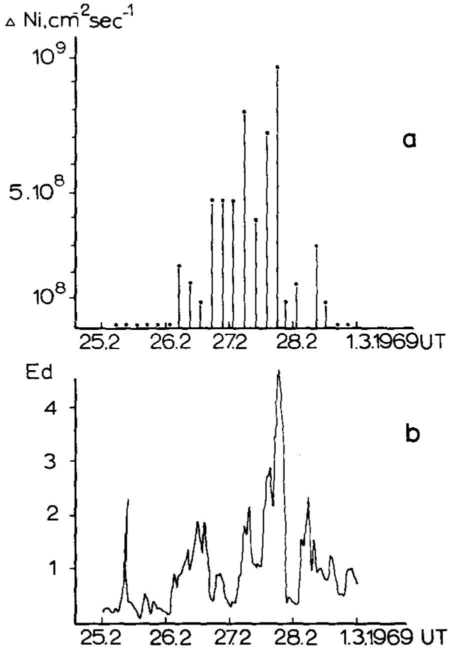

Fig. 5

Fig. 5. Variations of solar wind ion fluxes measured on board Venera-5 (upper graph) and the pulsations and short-period disturbances of earth's electromagnetic field from the observatory 'Borok' for the period February 25–28, 1969.

According to numerical calculations of Hundhausen and Gentry [4] pertaining to the phenomena related to the interplanetary plasma disturbances caused by solar flares, the maximum solar wind ion flux occurs during long disturbances not at the shock wave front (where the ion velocity is greatest) but sufficiently far beyond the front. One can see it from the values of velocities and concentrations of ions in Figure 3 [4].

This conclusion is in qualitative agreement with the observational results of Figure 5.

The maximum ΔN_i value was observed about 12^h after magnetic storm Sc on February 27; the maximum electric field E_d disturbance occurred also at 21^h on the same day, i.e. a long time after the commencement of the geomagnetic disturbance.

5. Note on Solar Wind Fluxes Values

In the last few years the important characteristics of interplanetary plasma are under extensive and successful investigation. Those are the chemical composition, the variations of directions of the bulk velocity, the temperature anisotropy, the discontinuities of plasma parameters. We should like, however, to draw attention to the fact that some problems related to such an ordinary parameter as the value of integral flux of solar wind particles $N = nv$ still remain unclear.

There is no clear information on time and space variations of the solar wind particle flux in the excellent reviews on solar wind published recently by Axford [5], Ness [6] and Hundhausen [7].

It seems to be evident that the flux value should change inversely with the square of the distance from the sun and this was concluded by Snyder and Neugebauer [8] from the data of Mariner 2. But if one takes into account that, as a result of some misunderstanding in published data on solar wind ion flux values measured on Mariner-4 during the flight from the earth to Mars by the MIT group [10] these values were underestimated by the order of magnitude as related by Prof. A. Lazarus [9], then one may think that this conclusion is insufficiently supported by experiments.

It is not clear enough whether the quality of the plasma emitted by the sun (i.e. mean solar wind flux) changes with the phase of solar activity since the conclusion made in [11] is not supported by the preliminary Venera-5 and Venera-6 data.

It was pointed out previously that considerable magnetic storms sometimes occur during large variations of solar wind flux without substantial changes of the solar wind bulk velocity [12].

The comparison of results of different experiments, even when they are made simultaneously, presents a problem because of differences between methods and devices used for solar wind investigations and non-identity of data-processing procedures.

Considering that direct measurements of fluxes of solar wind particles N_i are interesting and important (this is supported by the data of this paper) one can conclude that every solar wind measurement must include determination of integral particle flux with the maximum obtainable precision.

Conclusion

There is a close relationship between the variations of solar wind ion fluxes ΔN_i and pulsations and short-periodic disturbances of the earth's electromagnetic field. The comparison between the ΔN_i measurements aboard Venera-5 and Venera-6 and the records of telluric currents and magnetic field pulsations of 'Borok' observatory revealed that increases of the amplitudes of earth's electromagnetic field pulsations ($E_d > 1$) corresponded to each case when $\Delta N_i \geqslant 3 \times 10^8 \text{ cm}^{-2} \text{ sec}^{-1}$. In future the simultaneous analysis of data on variations of solar wind fluxes and earth's electromagnetic field pulsations will be continued; in particular the behaviour of pulsations with different periods will be analysed.

The consideration of the results of ΔN_i registrations and the records of earth's electromagnetic field pulsations over the period of February 25–28, 1969, and taking into account the solar events data and results of energetic particles ($E \leqslant 30$ MeV) registration enable one to believe that during this period the earth's magnetosphere was affected by at least two shock wave fronts in interplanetary plasma (2.26.69 and 2.27.69) caused by solar flares. Each of these flares seemed to be accompanied by a long (with durations of many hours) cold plasma eruption and in each case the maximum flux values occurred rather far beyond the shock wave front (this is in qualitative agreement with [6]).

Together with the investigations of the fine details of the solar wind structure the vagueness related to space and time variations of solar wind integral flux values $N_i = n_i v$ and to their geophysical effects should be removed.

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Discussion

Question: What was the distance from the earth of the spacecraft on February 26?

Gringauz: Venera 6 at 3 million km at the beginning of the period and 17 million km at the end. Venera 5 was farther from the earth because launched some days earlier.

Question: Was the time lag corrected for in relating to the solar wind parameters and geomagnetic response?

Answer: No, observations refer to real time.