Drop of Solar Wind at the End of the 20th Century

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Abstract Variations in the solar wind (SW) parameters with scales of several years are an important characteristic of solar activity and the basis for a long-term space weather forecast. We examine the behavior of interplanetary parameters over 21–24 solar cycles (SCs) on the basis of the OMNI database (https://spdf.gsfc.nasa.gov/pub/data/omni). Since changes in the parameters can be associated with both changes in the number of different large-scale types of SW and with variations in the values of these parameters at different phases of the solar cycle and during the transition from one cycle to another, we select the entire study period in accordance with the Catalog of large-scale SW types for 1976–2019 (see the site http://www.iki.rssi.ru/pub/omni, [Yermolaev, Nikolaeva, et al., 2009, https://doi.org/10.1134/s00100952509020014], which covers the period from 21 to 24 SCs) and in accordance with the phases of the cycles, and average the parameters at selected intervals. In addition to a sharp drop in the number of interplanetary coronal mass ejections and associated sheath types, there is a noticeable drop in the value (by 20%–40%) of plasma parameters and magnetic field in different types of solar wind at the end of the 20th century and a continuation of the fall or persistence at a low level in the 23–24 cycles. Such a drop in the solar wind is apparently associated with a decrease in solar activity and manifests itself in a noticeable decrease in space weather factors.

1. Introduction

It is well known that the Sun has variable activity, and the study of solar activity variation and its effect on the Earth on a scale of 1–100 years is one of the main tasks of solar and solar-terrestrial physics (e.g., Bhargawa & Singh, 2021; Christensen-Dalsgaard, 2021; De Jager, 2005; Gopalswamy et al., 2020; Hathaway, 2015; Sasikumar Raja et al., 2019; Schwander et al., 2017; Schwenn, 2006; Usoykin, 2017). In the literature, in addition to the well-studied solar cycles of Schwabe (11 years) and Hale (22 years), the possibility of the Sun approaching the minimum of the Gleissberg (about 90 years) cycle, the so-called grand minimum, is widely discussed (Dreschhoff et al., 2015; Feynman & Ruzmaikin, 2011; Nagovitsyn et al., 2021; Svalgaard et al., 2005; Zolotova & Ponyavin, 2014). These variations in solar activity are manifested along the entire chain of solar-terrestrial connections: in the interplanetary medium, in the magnetosheath, in the magnetosphere, in the ionosphere and in the lower regions of the Earth (Bazilevskaya et al., 2021; Dmitriev et al., 2009; Gopalswamy, Yashiro, et al., 2015; Hajra et al., 2021; Li et al., 2016; Love, 2021; Miroshnichenko, 2018; Ogurtsov & Jungner, 2020; Oh & Kim, 2013; Yermolaev et al., 2012 and references therein). In this work, the main attention is paid to the study of the solar wind (SW).

Direct experimental study of the solar wind began at the beginning of the space age and has been one of the main tasks of space physics. There are three main reasons for this attention. First, the large-scale (with scales of more than 10⁶ km at 1 AU) solar wind structures are born on the Sun, do not have time to undergo noticeable modification along the way from the Sun to the Earth, and contain information about the structure and processes on the Sun. Second, small-scale (with scales less than 10⁶ km) solar wind phenomena are locally induced and allow plasma processes in the absence of collisions of charged particles with each other and with the walls of space laboratory to be studied (e.g., Verscharen et al., 2019; Zelenyi & Milovanov, 2004 and references therein). Third, the solar wind is the main agent that transfers disturbances from the Sun to the Earth’s magnetosphere and excites perturbations of the magnetosphere-ionosphere system, that is solar wind is the causes of various phenomena of space weather (e.g., Tsurutani & Gonzalez, 1997; Yermolaev et al., 2005, 2021 and references therein). Thus, the measurement of parameters of the solar
wind on different scales is an important method for investigating the physics of the Sun, the physics of the heliosphere, and for solar-terrestrial physics.

One of the goals of such studies is to study the variations in solar wind parameters on large time scales exceeding a year. These scales include variations in parameters at different phases of the solar cycle and variations at different cycles. Several similar studies have been carried out (see, e.g., Bruno et al., 1994; Dmitriev et al., 2009; Gopalswamy, Tsurutani, & Yan, 2015; Larrodera & Cid, 2020; Li et al., 2016; Nakagawa et al., 2019 and references therein). However, such studies have several disadvantages: (a) The study of the solar wind lasts for only a short period (usually 2 neighboring cycles are compared), although there are measurements for more than 4 solar cycles that are available for analysis (e.g., OMNI base of solar wind parameters https://spdf.gsfc.nasa.gov/pub/data/omni), (b) There is a lack of selection of the solar wind for its individual types. In most works, if a selection is made according to the types of solar wind streams, the selection is only according to the magnitude of the bulk speed (without additional analysis of the connection of these streams with solar structures and/or phenomena), for the so-called fast and slow streams (see e.g., Bruno et al., 1994; Kasper et al., 2007; Larrodera & Cid, 2020 and references therein). This does not allow the change in the number of different types of SW and the change in parameters in these different types of SW to be separated on these scales.

As shown by numerous experiments at a distance of ~1 AU, the solar wind at scales >10^6 km is structured, that is, it contains types of streams or regions in which the characteristic parameters either change little or change according to known relations. Some types of streams form on the Sun. These types include both quasi-stationary and disturbed types. Quasi-stationary types are fast (or High Speed Streams [HSS] of solar wind) streams from coronal holes, slow streams from coronal streamers, and also the heliospheric current sheet (HCS), the region of the change in the direction of the interplanetary magnetic field (IMF) in the slow type. The disturbed type that is born on the Sun is the body of the coronal mass ejections (CMEs), interplanetary CMEs (ICMEs), which are usually subdivided into magnetic clouds (MC) with high and regularly varying IMF and ejecta with lower and less regular IMF. Another part of the types of streams is formed along the path from the Sun to the Earth. These types are compression regions before the fast stream, corotating interaction region (CIR), which may be formed with the periodicity of the Sun's rotation, since a coronal hole on the Sun can live for several revolutions of the Sun, and also the compression region of Sheath, which is formed before the fast ICME. If the leading edges of both types of pistons (HSS and ICME) move faster than the preceding solar wind by more than the magnetosonic speed, then shocks form in front of the CIR and Sheath. When the velocity of the trailing edge of the ICME is lower than the velocity of the incident SW stream, a reverse shock wave can be formed in a similar way. If the trailing edge of the ICME or HSS moves faster than the next SW, then a decompression region (the so-called Rarefied region) may form. The Rarefied regions and reverse shocks are rarely formed. The origin, formation and dynamics of large-scale SW types have been extensively and reported in detail in the literature (see e.g., Borovsky & Denton, 2016; Cane & Richardson, 2003; Gopalswamy, 2006; Gosling & Pizzo, 1999; Jian et al., 2006; Kilpua et al., 2017; Regnault et al., 2020; Yermolaev, Nikolaeva, et al., 2009, 2015; Zurbuchen & Richardson, 2006 and references therein). Based on the OMNI solar wind measurement database (http://omniweb.gsfc.nasa.gov, King & Papitashvili, 2005), we have created a living catalog of large-scale solar wind phenomena since 1976 (the site with web addresses ftp://ftp.iki.rssi.ru/pub/omni or http://www.iki.rssi.ru/pub/omni and the paper by Yermolaev, Nikolaeva, et al., 2009). In this work, we use the identification of SW types of this catalog.

In this paper, we investigate long-term variations in solar wind parameters on scales from the characteristic sizes of large-scale solar wind structures (several hours or 10^7 km) to larger sizes, including both variations within the solar activity cycle and variations from the 21st to the 24th solar cycle. In contrast to previous works, for the first time, we take into account the change in the number of various large-scale phenomena of the solar wind in different phases and in different cycles of solar activity and perform a separate averaging of the solar wind parameters in the corresponding phenomena.
2. Data and Methods

In this work, we use two sources of information.

1. Hourly data of OMNI base parameters for 1976–2019 (https://spdf.gsfc.nasa.gov/pub/data/omni/low_res_omni, King & Papitashvili, 2005),
2. Intervals of different types of SW of the catalog of large-scale phenomena (ftp://ftp.iki.rssi.ru/pub/omni/ or http://www.iki.rssi.ru/pub/omni, Yermolaev, Nikolaeva, et al., 2009) created on the basis of the OMNI database.

On the one hand, when creating our catalog, we use the same criteria that were used by other authors to identify the types of SW (e.g., Tsurutani et al., 2006; Wimmer-Schweingruber et al., 2006; Zurbuchen & Richardson, 2006), and therefore, the results are in good agreement with each other (e.g., Lepping et al., 2003, 2017; Jian et al., 2008; Richardson & Cane, 2012). On the other hand, unlike other works that identified only individual types of SW, in our catalog, each 1-h measurement point is associated with one of the above types of SW. Due to the small number (less than 2% of the total analysis time) of rarefaction regions (Borovsky & Denton, 2016), the statistical reliability of the parameters associated with them is low. Therefore, the areas of rarefaction were excluded from the results.
Figure 1a shows the annual data of the OMNI database that are available for analysis. Before the launch of the solar wind monitors WIND and ACE in the 21st and 22nd solar cycles (Figure 1a), the data coverage was about 40%, and in the 23rd and 24th cycles it was about 100%. Figure 1b and Table 1 show the division of the entire 1976–2019 interval into sub-intervals by phases of 21–24 cycles. The solar wind parameters were averaged separately for different types of solar wind and for different phases of solar cycles.

Most of the parameters have a very large scatter, and for them the standard deviation turns out to be close to the average value. However, due to a sufficiently large number of measurements of parameters for various types of solar wind (with the exception of MC for which the number of points was an order of magnitude less than for other types of SW), the statistical error (i.e., the standard deviation divided by the square root of the number of measurement points) turns out to be an order of magnitude smaller, and the time variations described below on the scales of the phases of solar cycles and cycles are of sufficient statistical significance (Bendat & Piersol, 1971). The largest scatter is observed for the proton temperature $T$, and since it has a lognormal distribution (Burlaga & Lazarus, 2000; Dmitriev et al., 2009), we averaged the logT value.

## 3. Results

At the beginning of this section, we present data characterizing solar and magnetospheric activity for the period under study. Then we consider the parameters of the solar wind, selected according to SW types and averaged over the scales of the phases of solar cycles.

### 3.1. A Brief Overview of Solar and Magnetospheric Activity for the Period 21–24 Solar Cycles

Figure 2 presents an overview of data on solar and magnetosphere activity for the 44-year interval 1976–2019. This interval includes 1635–2225 Carrington rotations of the Sun (~27 days) and four maxima of 21–24 solar cycles. The left panel shows the temporal variations in the number of solar X-ray flares of strong M (6,344 events) and extreme X (494 events) classes on the visible side of the Sun. The right panel represents moderate ($-100 < \text{Dst}_\text{min} < -50$ nT; 280 events) and strong ($\text{Dst}_\text{min} < -100$ nT; 280 events) magnetic storms. The ratio of the number of flares to the number of storms is about seven. After excluding flares located far above 45° from the Sun-Earth line, the ratio is approximately three. In the literature, cases are considered when flares of a weaker class C are considered as a possible solar source of disturbances in the magnetosphere. Thus, the number of flares significantly exceeds the number of magnetic storms. This is the main reason for the large number of false alarms for storm forecasts made from observations of solar flares.

A detailed analysis of solar and magnetospheric data is beyond the scope of this article. Here, we would like to draw the reader’s attention only to the following facts. These two parameters demonstrate both phase variations within a cycle and a change (a decrease in the number of disturbed events on the Sun and in the Earth’s magnetosphere) during a sequential transition from the 21st to the 24th cycle, and when they are averaged over several Carrington rotations, they have a good correlation. However, it is difficult to find a point-to-point correspondence between data on the left and right panels. This confirms the well-known fact that magnetic storms are not directly generated by solar flares (Gosling, 1993) and indicates that solar-magnetosphere relationships are more complicated (Gonzalez et al., 1999; Yermolaev et al., 2005, 2012, 2021).

Figure 3 presents an overview of the disturbed solar wind phenomena for the same time periods of 21–24 solar cycles. The left panel shows the CIR slots (green slots, 1,369 events), and the right panel shows Sheath (black, 1,012 events), Ejecta (blue, 1,776 events), and MC (red, 217 events). Gray intervals correspond to other types of solar wind, and white intervals correspond to no measurements. The average annual (averaged over several Carrington rotations) numbers of Sheaths and ICMEs on the right panel demonstrate a similar behavior of the parameters in Figure 2 with phase variations and a decrease in the number of disturbed
Figure 2. Time variations in solar X-ray flares (on the left) and magnetic storms (on the right) for the period 1976–2019.
events with an increase in the cycle number, while CIRs on the left panel are distributed more evenly in time, without an explicit dependence from the phase of the cycle and without a decrease during the 23 and 24 cycles. The relationship between interplanetary drivers and magnetic storms is beyond the scope of this work. Therefore, we note here that the geoeffectiveness (the ratio of the number of magnetic storms to the

Figure 3. Time variations in disturbed solar wind phenomena: CIR (on the left) and Sheath, Ejecta, and MC (on the right) for the period 1976–2019.
number of interplanetary drivers of a certain type) for the period 1976–2019 differs little from the geoeffec-
tiveness we obtained earlier for the period 1976–2000 (Yermolaev et al., 2012).

3.2. Average Parameters in Solar Wind

Table 2 presents several parameters of solar wind and Dst index averaged over solar cycles 21–24 (top to bottom) for three quasi-stationary (HCS, SLOW with speed $V \leq 450$ km/s and FAST with $V > 450$ km/s) and four disturbed (CIR, Sheath, Ejecta and MC) types of solar wind as well as for ALL (without SW type selection) solar wind data. These cycle-averaged data are shown by red open squares in Figures 4–7 (see below).

Table 2 shows that, for all solar cycles, the ratios between the parameters averaged over the cycle in different types of SW remain approximately the same. A number of parameters, such as speed $V$ and relative temperature $T/\text{Temp}$, do not change as the cycle number increases. However, all other parameters (density $N$, magnitude of IMF $B$, relative content of helium $Na/Np$) as well as parameters depending on the IMF, density and temperature (beta parameter, thermal pressure $NkT$ and kinetic pressure $mNV^2$) have a clear tendency to decrease. The average amplitude of the Dst index also falls.

Two facts should be noted. On the one hand, in some cases the decline is non-monotonic. This may be due to data gaps in cycle 21 and 22 and the quality of the OMNI database. On the other hand, in most cases, the differences between the mean values exceed the statistical error (except for the cases of MC, which were recorded significantly less than other types of SW).

Figures 4–7 present time profiles of parameters of solar wind plasma and IMF averaged over phases of solar cycles (Table 1 and Figure 1b): minimum—black circles, rising phase—blue triangles, maximum—purple squares, declining phase—green inverted triangles, without selection with phases—red open squares. The parameters $N$, $V$, $B$, $T/\text{Temp}$ and $T$ for 3 quasistationary types of solar wind (HCS, Slow, and Fast) and solar wind without type selection and for 4 disturbed types of solar wind (CIR, Sheath, Ejecta, and MC) are shown in Figures 4 and 6, respectively. The parameters $NkT$, $\beta$, $Na/Np$, $Dst$ and $mNV^2$ are presented in Figures 5 and 7.

Analysis of the data shows the following:

1. The velocity $V$ in quasi-stationary types of SW changes little both with a change in the cycle phase and with an increase in the cycle numbers. In the disturbed types of SW, the changes are slightly larger. The largest scatter is observed in MC, the number of which is small and the statistical significance is small. However, it can be noted that in Sheath, Ejecta, and MC, the speed is slightly slower in the minimum phase of cycle 22, and has a maximum in the declining phase of cycle 23.

2. The density $N$ in quasi-stationary types of SW and CIR depends little on the phase of the cycle, while in Sheath and MC, there is an increase in the differences for the phases of the cycle: in Sheath, $N$ increased during the declining phase in cycles 22 and 24, while in MC, it has a more chaotic spread, apparently associated with the small statistics of the measurements.

3. The measured and relative temperatures of protons, $T$ and $T/\text{Temp}$, have little dependence on the phase of the cycle for different types of solar wind, but decreases with an increase in the cycle.

4. The magnitude of the magnetic field $B$ in all types of solar wind depends on the phase of the cycle, has a maximum value at the maximum of the cycle, a minimum at the minimum of the cycle, and an intermediate value in the rising and declining phases.

5. Thermal $NkT$ and dynamic $mNV^2$ pressures, which depend on the parameters $V$, $N$, and $T$, behave in a similar way and depend little on the phase of the cycle. Somewhat unexpected was the excess of both pressures in Sheath during the declining phase in all 4 cycles.

6. Parameter $\beta$, which is also a dependent parameter on $B$, $N$, and $T$, depends weakly on the phase of the cycle, while in all types of SW, it is a maximum at the minimum and a minimum at the maximum of the cycle.

7. The relative helium abundance $Na/Np$ depends on the phase of the cycle: in all cycles, the minimum is observed in the minimum phase, and the maximum value is at the maximum (except for cycle 23, in which the maximum is observed at the declining phase, and, for Sheath, Ejecta, and MC, a local and rather sharp minimum is observed at the maximum phase).
|                  | HCS   | SLOW  | FAST  | ALL (Without SW type selection) | CIR    | Sheath | Ejecta | MC     |
|------------------|-------|-------|-------|---------------------------------|--------|--------|--------|--------|
| \(N, \text{cm}^{-3}\) | 11.7 ± 6.2 | 9.7 ± 6.5 | 5.4 ± 4.3 | 8.2 ± 6.5 | 11.8 ± 9.0 | 13.1 ± 10.1 | 6.9 ± 4.7 | 9.5 ± 7.1 |
| \(\nu^{*10^3}, \text{km/s}\) | 3.7 ± 0.6 | 3.8 ± 0.4 | 5.4 ± 0.8 | 4.3 ± 0.9 | 4.6 ± 0.9 | 4.7 ± 1.1 | 4.3 ± 0.8 | 4.7 ± 1.1 |
| \(B, \text{nT}\) | 1.9 ± 2.0 | 6.7 ± 2.9 | 7.5 ± 3.8 | 7.5 ± 3.6 | 9.9 ± 4.1 | 9.9 ± 4.9 | 7.0 ± 2.9 | 13.5 ± 5.1 |
| \(T/\text{Exp}\) | 1.5 ± 0.7 | 1.6 ± 0.9 | 1.5 ± 0.8 | 1.6 ± 0.9 | 2.3 ± 1.1 | 2.2 ± 1.1 | 1.1 ± 0.8 | 1.1 ± 1.0 |
| \(\text{Log}_{10} T, \text{K}\) | 4.7 ± 1.9 | 6.7 ± 3.0 | 7.4 ± 3.6 | 7.0 ± 3.6 | 10.2 ± 4.2 | 9.6 ± 4.8 | 7.0 ± 3.0 | 14.3 ± 5.6 |
| \(\text{NkT}^{*10^2}, \text{nPa}\) | 0.9 ± 0.7 | 0.94 ± 0.8 | 1.5 ± 2.0 | 1.19 ± 1.7 | 2.67 ± 2.0 | 3.14 ± 3.6 | 0.61 ± 0.8 | 1.01 ± 1.6 |
| \(\beta, \text{10}^{-1}\) | 0.67 ± 0.5 | 0.64 ± 0.8 | 1.08 ± 2.1 | 0.90 ± 1.8 | 2.24 ± 0.8 | 2.80 ± 5.1 | 0.32 ± 0.5 | 0.47 ± 1.7 |
| \(\text{Na/Np}^{*10^2}\) | 0.60 ± 0.4 | 0.53 ± 0.6 | 0.93 ± 1.7 | 0.74 ± 1.2 | 1.88 ± 1.8 | 2.03 ± 3.7 | 0.26 ± 0.3 | 0.35 ± 0.7 |
| \(\text{Dist}, \text{nT}\) | 11.20 ± 10.3 | 5.95 ± 5.5 | 7.03 ± 4.6 | 6.40 ± 6.7 | 7.63 ± 5.5 | 7.95 ± 7.3 | 2.27 ± 2.5 | 0.89 ± 2.0 |

Table 2: Average Values and Standard Deviations of Parameters for Different Types of Solar Wind in 21–24 Solar Cycles
Figure 4. Time profiles of parameters $N$, $V$, $B$, $T/T_{\text{exp}}$, and $T$ (top to bottom), averaged over the phases of the solar cycle (see the legend under the figure) for three types of solar wind (HCS, Slow and Fast) and solar wind without type selection (see titles at the top of the panel columns).
Figure 5. The same as in Figure 4 for parameters $NkT$, $\beta$, $Na/Np$, $Dst$, and $mNV^2$. 
Figure 6. The same as in Figure 4 for parameters for four types of solar wind (CIR, Sheath, Ejecta, and MC).
Figure 7. The same as in Figure 5 for parameters for four types of solar wind (CIR, Sheath, Ejecta, and MC).
8. The average value of the Dst index depends weakly on the phase of the cycle; nevertheless, there is a slight tendency that the dip of the index is greater (magnetic storms are stronger) at the maximum phase in all types of SW.

4. Discussion and Conclusions

Thus, the analysis of the parameters of plasma and IMF was carried out, averaged both by the types of the solar wind and by time on the scales of phases and complete solar cycles from 1976 to 2019 in the ecliptic plane near the Earth. Along with the well-known fact that the number of disturbed ICME (and Sheath associated with ICME) solar wind types has significantly decreased over the last 2 cycles, it was shown that CIR events are distributed more evenly in time, without an obvious dependence on the phase of the cycle and without a decrease for 23 and 24 cycles (see Figure 3). In addition, it was shown, for the first time, that most of the parameters for different types of SW decreased noticeably at the end of the 20th century during the transition from the 22nd to the 23rd cycle. In particular, Table 2 and Figures 4–7 show the time profiles of the solar wind parameters for different types of SW and allow us to draw the following conclusions.

1. The average velocity \( V \) did not change over a period of 21–24 cycles in different types of solar wind.

2. The density \( N \), the absolute \( T \) and relative \( T/T_{expt} \) temperatures, the magnitude of the IMF \( B \), the relative helium abundance \( Na/Np \), as well as the parameters dependent on the IMF, the density and temperature (beta parameter, thermal pressure \( NkT \) and kinetic pressure \( mNV^2 \)) decreased markedly (by 20%–40% in different types of SW) during the minimum phase between 22 and 23 cycles and remained low in 23–24 cycles. Thus, the activity of the Sun and its impact on the heliosphere dropped markedly during this period.

3. The parameters \( V, N, T, T/T_{expt}, NkT, mNV^2 \) and \( \beta \) are weakly dependent on the phase of the solar cycle.

4. Parameters \( B \) and \( Na/Np \) differ more strongly in different phases of the cycles and significantly decrease in 23–24 cycles.

5. A drop in the average IMF \( B \) in cycles 23–24 correlates with a decrease in the dip in the Dst index (i.e., with a decrease in the average magnetospheric activity).

Here, we discuss in more detail the data on the magnitude of the magnetic field \( B \) and the helium abundance \( Na/Np \) in point (4). According to modern concepts (McComas et al., 1992; Owens et al., 2008; Svalgaard & Cliver, 2007; Webb & Howard, 1994), there is a minimum of the magnetic field, the so-called “The Floor in the Interplanetary Magnetic Field,” which does not vary during the solar cycle, and the measured magnetic field is the sum of this minimum field and the ICME field. We estimated the floor in IMF for the 1976–2000 interval, taking into account the contribution of the ICME during the minimum phases of 21 and 22 cycles, as a value of \( B = 4.65 \pm 0.6 \) nT (Yermolaev, Lodkina, et al., 2009). This value is consistent with earlier estimates, \( \sim 5 \) nT (Richardson et al., 2002) during 1972–2000 and \( \sim 4.6 \) nT (Svalgaard & Cliver, 2007) during the last 130 years, but contradicts the estimate \( 4.0 \pm 0.3 \) nT obtained at the end of cycle 23 (Owens et al., 2008). Therefore, we similarly made estimates of \( \sim 4.3 \) nT for cycle 23 and \( \sim 4.8 \) nT for cycle 24 with a standard error for both estimates of \( \sim 0.7 \) nT. Thus, our results confirm the decrease in the floor in IMF in cycle 23, obtained in Owens et al. (2008), but indicate its increase in cycle 24. Due to the uncertainty of the estimates obtained, the question remains whether the fall of the magnetic field \( B \) in 23 and 24 solar cycles is associated with a decrease in the floor in the IMF or with a decrease in the number of ICME events and with their contribution to the total magnetic field. Verifying the reliability of these results requires additional research.

An important fact is a significant drop in the helium abundance \( Na/Np \) in cycles 23–24 by an amount from \( \sim 1/4 \) to \( \sim 1/3 \) of the values in the corresponding types of SW in cycles 21–22. Since the change in the chemical composition in the solar wind corresponds to the same change in the composition of the upper solar atmosphere from where the solar wind emanates, this fact can be of great importance for the physics of the Sun. In addition, this decrease in the helium abundance may explain its extremely low content in the MC in papers by Owens (2018) and Huang et al. (2020) compared with the selection criteria for MC (\( Na/Np > 0.08 \)), which were developed on the basis of measurements in cycles 20–22 (Borrini et al., 1982; Hirshberg et al., 1972; Zurbuchen & Richardson, 2006).

It should be noted that although the magnitude of the decrease in parameters during 23 and 24 cycles relative to previous cycles is approximately equal to the magnitude of the change in parameters at different
phases of the solar cycle, it exceeds the statistical error and, therefore, is statistically significant. The above results on the decrease in parameters in 23–24 cycles were obtained for different physical quantities measured by various methods and different instruments on various spacecraft included in the OMNI database. This greatly reduces the likelihood that this decline is associated with some methodological effects and increases the reliability of the results and conclusions.

Thus, it was found that approximately at the minimum phase between the 22nd and 23rd solar cycles, all plasma parameters of the solar wind (with the exception of the velocity) and interplanetary magnetic field fell noticeably in each of the large-scale types of the solar wind and continued to decrease or remain low in 23–24 cycles. A noticeable decrease in magnetospheric activity and other manifestations of space weather is associated with this fact and a decrease in the number and intensity of interplanetary manifestations of CME. Since all measurements were carried out in the ecliptic plane, the observed fact can be explained not only by a decrease in the global activity of the Sun, but also by a change in the location of various types of solar wind sources at relatively low and high solar latitudes (e.g., Biso et al., 2020) which usually occurs when the direction of the solar global magnetic field changes in the solar cycle.

Data Availability Statement

Data on the identification of large-scale types of solar wind for 1976–2020 are available from the site of the Space Research Institute, Moscow, Russia, with web addresses ftp://ftp.iki.rssi.ru/pub/omni/ or http://www.iki.rssi.ru/pub/omni.

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