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A statistical study of space hurricanes in the Northern Hemisphere

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The space hurricane is a newly discovered large-scale three-dimensional magnetic vortex structure that spans the polar ionosphere and magnetosphere. At the height of the ionosphere, it has a strong circular horizontal plasma flow with a nearly zero-flow center and a coincident cyclone-shaped aurora caused by strong electron precipitation associated with intense upward magnetic field-aligned currents. By analyzing the long-term optical observation onboard the Defense Meteorological Satellite Program (DMSP) F16 satellite from 2005 to 2016, we found that space hurricanes in the Northern Hemisphere occur in summer and have a maximum occurrence rate in the afternoon sector around solar maximum. In particular, space hurricanes are more likely to occur in the dayside polar cap at magnetic latitudes greater than 80°, and their MLT (magnetic local time) dependence shows a positive relationship with the IMF (interplanetary magnetic field) clock angle. We also found that space hurricanes occur mainly under dominant positive IMF By and Bz and negative Bx conditions. It is suggested that the stable high-latitude lobe reconnection, which occurs under the conditions of a large Earth's dipole tilt angle and high ionosphere conductivity in summer, should be the formation mechanism of space hurricanes. The result will give a better understanding of the solar wind–magnetosphere–ionosphere coupling process under northward IMF conditions.

KEYWORDS

space hurricane, polar ionosphere, polar cap aurora, magnetosphere–ionosphere coupling, high-latitude lobe reconnection

1 Introduction

The auroral oval is an elliptical auroral band around the Earth's magnetic pole, which is slightly squashed on the Sun side and stretched on the night side. The region surrounded by the polar boundary of the auroral oval is called the "polar cap". Most auroras occur in the auroral oval. However, some of them are observed in the polar cap in the form of an arc or spot called a "polar cap arc" or "polar cap spot" (Zhu et al., 1997; Hosokawa et al., 2011; Kullen, 2013). Several kinds of high-latitude auroras have been discovered and named based on their shapes and locations of occurrence, such as transpolar arcs (TPAs), the polar cap arc (15MLT-PCA), cusp spot, and high-latitude dayside aurora (HiLDA) (e.g., Berkey et al., 1976; Ismail, et al., 1977; Fear and Milan, 2012; Frank et al., 1982; Frey et al., 2002; Frey et al., 2003; Milan et al., 2005; Korth et al., 2004; Zhang et al., 2016; Zhang et al., 2020; Han et al., 2020). Among them, the 15MLT-PCA, cusp spot, and HiLDA can also be classified as dayside auroras because they are related to processes in the dayside magnetosphere, especially at the dayside magnetopause (Frey et al., 2019).

The cusp spot is a type of auroral spot that occurs in the cusp with proton precipitation and is related to lobe reconnection during the northward IMF (Sandholt et al., 1996; Milan et al., 2000; Frey et al., 2002; Østgaard et al., 2005). HiLDA is another type of auroral spot that occurs at a much higher geomagnetic latitude and is formed by the strong precipitation of field-aligned accelerated electrons during the northward IMF and positive IMF by conditions (Frey et al., 2003; Frey et al., 2004; Carter et al., 2018). 15MLT-PCA, defined by Han et al. (2020), is a special polar cap arc extending from the poleward edge of the auroral oval, which is frequently observed in the ~1500-MLT sector both in the Northern and Southern hemispheres.

Recently, Zhang et al. (2021)have reported a large-scale magnetic vortex structure near the north magnetic pole in low solar activity and low geomagnetic activity conditions. Many features have been revealed from DMSP satellite observations, including a circular horizontal plasma flow with shears, a nearly zero-flow center, and a coincident cyclone-shaped aurora caused by strong electron precipitation associated with upward field-aligned currents (FACs). Therefore, it is analogically named as "space hurricane." The geomagnetic condition, by traditional measures, which excludes the high-latitude polar cap, is extremely quiet. However, the space hurricane opens a strong energy transport channel from the solar wind to the Earth's magnetosphere and deposits a large amount of convection and particle energy into the polar cap ionosphere, which relates the space hurricane to the high-latitude lobe reconnection process. Since this new type of large-scale magnetic vortex structure and its major auroral disturbances have only recently been recognized, its characteristics in terms of its occurrence versus solar cycle, season, universal time, and the IMF are so far unknown. In addition, its association with the high-latitude lobe reconnection mechanism also needs to be further verified by statistical surveys.

In this paper, we investigate the statistical properties of space hurricanes by using 12 years of continuous observations from the DMSP F16 Special Sensor Ultraviolet Spectrographic Imager (SSUSI) over the Northern Hemisphere. We find that the space hurricane has the same observational features as the HiLDA reported in previous studies, except for its obvious rotor structure in the auroral morphology (Frey et al., 2003; Frey et al., 2004). We also find that the space hurricane shares some common observational features with 15MLT-PCA reported in Han et al. (2020), although 15MLT-PCA is an auroral arc. In addition, the statistical results imply that the stable high-latitude lobe reconnection mechanism, which occurs under the conditions of a large Earth's dipole tilt angle and high ionosphere conductivity in summer, is likely to be the formation mechanism of space hurricanes. The results are important for fully understanding the auroras occurring in the polar cap and the coupling of solar wind energy into the magnetosphere–ionosphere system during the northward IMF.

2 Data and methodology

2.1 Data

The DMSP/SSUSI instrument (https://ssusi.jhuapl.edu/gal_Aur) provides horizon-to-horizon line scan images at five simultaneous far ultraviolet wavelengths (Paxton et al., 2002). Each orbital crossing of a DMSP satellite generates two auroral image swathes in the Northern and Southern hemispheres. Most of the image swathes cover the dayside of the polar cap and part of the auroral ovals on both the dawn and dusk sides (Ma et al., 2020). In this paper, DMSP F16/SSUSI observations from 2005 to 2016 in the Lyman–Birge–Hopfield short (LBHS) band (a wavelength of 140–150 nm) are used to find space hurricane events in the Northern Hemisphere. In addition, the 1-min OMNI data (https://omniweb.gsfc.nasa.gov) are used to get the solar wind, IMF, and geomagnetic indices. Meanwhile, considering the distance from the bow shock nose to the ionosphere, the OMNI data have been lagged by 7 min (Liou et al., 1998). The sunspot number used in this paper is a 1-month resolution from the public Sunspot Index and Long-term Solar Observations (SILSO) website (https://sidc.be/silso/datafiles).

2.2 Methodology

Figure 1 shows a typical space hurricane event observed by the SSUSI in the Northern Hemisphere during the DMSP passes from 06:00 to 11:30 UT on 17 June 2011. A bright auroral spot (more than 1,000 km in diameter) appears in the polar cap near

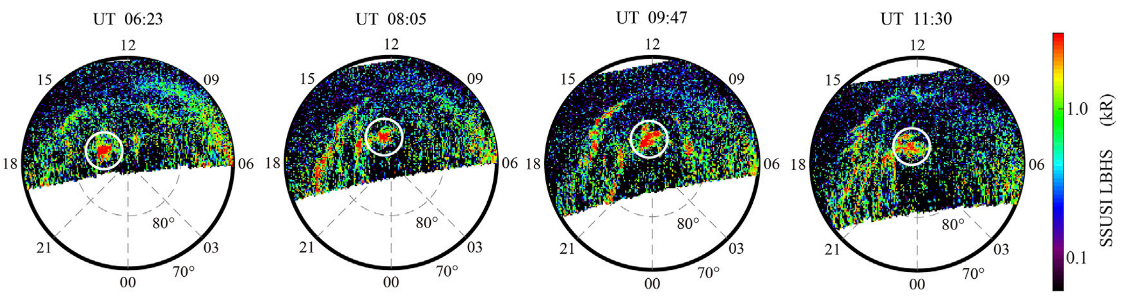

FIGURE 1
Typical space hurricane event observed by the DMSP F16/SSUSI in the Northern Hemisphere on 17 June 2011. The white circle marks the space hurricane.

the north magnetic pole. The biggest difference between the space hurricane and 15MLT-PCA defined by Han et al. (2020) using the DMSP/SSUSI is the auroral shape. In other words, the space hurricane is a bright auroral spot rather than an arc, and it is separated from the auroral oval.

By analyzing the features of the typical space hurricane event (see Figure 1) and following the procedure in Zhang et al. (2021), we propose the following criteria for selecting the space hurricane event from the SSUSI observations: 1) an auroral spot occurs in the polar cap, 2) the spot has an area of at least 10 pixels with luminosity greater than 0.1 kR, and 3) the bright spot is detached from or has a tendency to detach from the auroral oval. Once all criteria are satisfied, the event is counted as a space hurricane event. In addition, we take every image of the space hurricane and examine its features in detail to find the time when the SSUSI instrument begins to show the space hurricane, which we identify as the space hurricane start time.

Figure 2 shows the interplanetary conditions, solar wind parameters, and geomagnetic indices provided by OMNI for the space hurricane event in Figure 1 (the gray-shaded period). An outstanding feature in Figure 2B is the relatively stable northward IMF condition (IMF Bz > 0) with a strong positive By component and a small negative Bx component for more than 6 h. In addition, Figures 2E,F show that the period of interest is geomagnetically quiet between the two periods of enhanced activity associated with variable IMF with periods of Bz < 0. In Figures 2B–D, the average solar wind speed is relatively high (V = ~500 km/s) and the number density (around 7 cm^{-3}) indicates a high dynamic pressure of around 3.5 nPa. We have checked and confirmed that the properties shown in Figure 1 and the IMF conditions shown in Figure 2 are valid for all our space hurricane events.

To examine the favorable solar wind and IMF conditions for the occurrence of a space hurricane, we also need to compare the space hurricane to background conditions. For each event, the space hurricane condition is defined as a 30-min average of the OMNI data taken immediately before our identified event start time (Han et al., 2020). The background condition is also the 30-min average value of the OMNI data taken immediately before the center time of each DMSP satellite orbit in the Northern Hemisphere. This space hurricane condition and background condition are based on the fact that when the DMSP/SSUSI observes a space hurricane, the satellite is basically very near to the center of its transpolar orbit.

3 Statistical results

Here, we present the statistical dependence of the space hurricane on geophysical conditions such as location, time of the day and season, and solar conditions such as the solar cycle, solar wind, IMF components, and IMF clock angle.

3.1 Solar–geophysical conditions

Using the method discussed in Section 2.2, we identified 329 space hurricane events (see Supplementary Table S1) from SSUSI observations on the DMSP F16 satellite in the Northern Hemisphere from 2005 to 2016. Taking these events into account, we show the statistical dependencies of space hurricanes in Figure 3. Figure 3A shows the yearly occurrence of the space hurricane overlapped with the sunspot number. It indicates a clear correlation between the occurrence of the space hurricane and the sunspot number, although the occurrence does not reflect the double peak in solar activity. Figures 3B,C show the monthly and UT distributions of the observed space hurricane events from 2005 to 2016, indicating that the space hurricane occurs mainly in summer months and more frequently during 09–16 UT. After calculating the annual and diurnal variation of the solar elevation angle (blue curve) and Earth's dipole tilt angle (red curve) shown in Figures 3B,C, we can see that the summer months and 09–16 UT, which have a high occurrence of space hurricanes, correspond to the large solar elevation angle and large dipole tilt angle.

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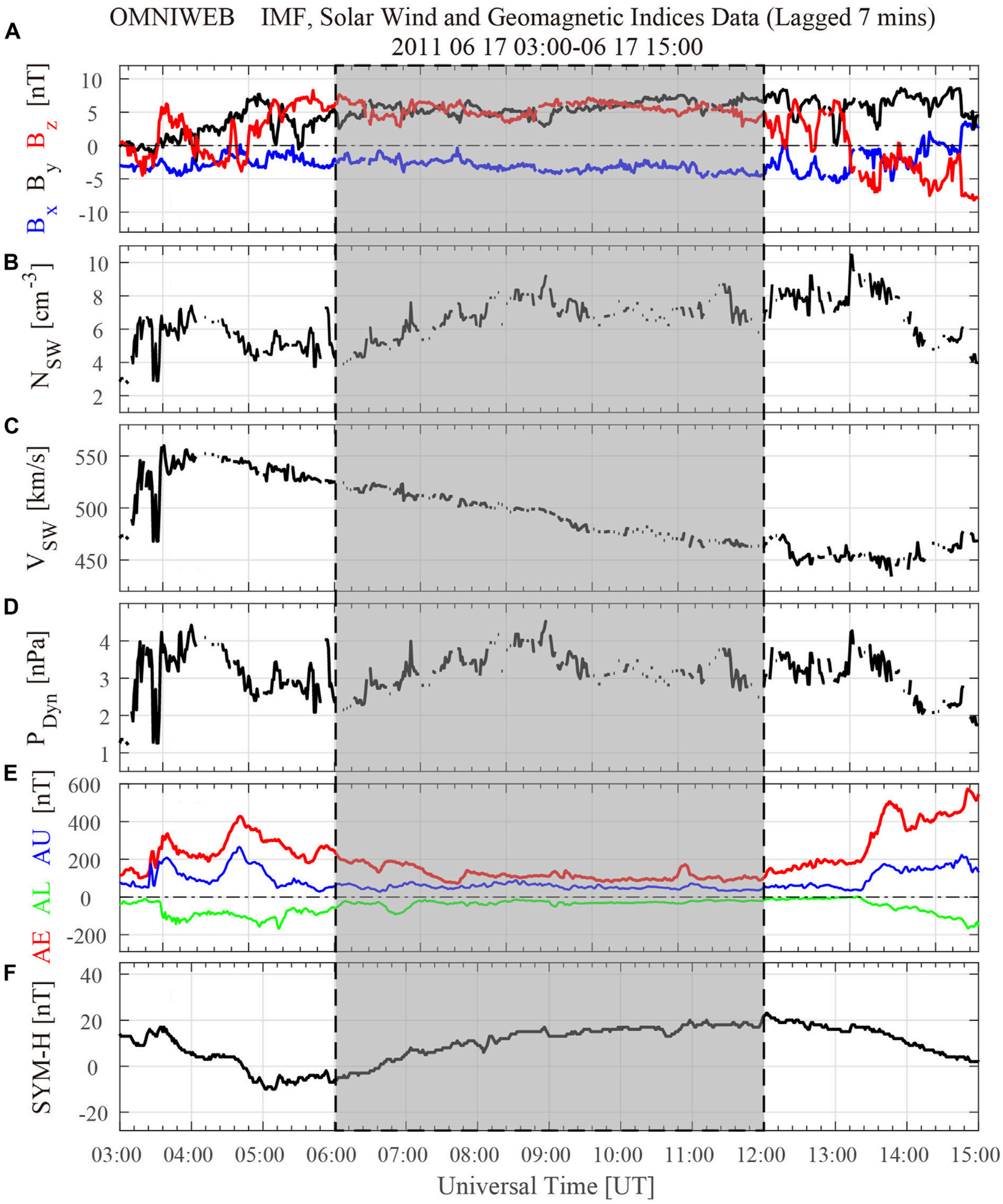

FIGURE 2
Overview of the interplanetary conditions and geomagnetic indices on 17 June 2011. **(A)** IMF components in geocentric solar magnetosphere (GSM) coordinates; **(B)** solar wind proton density; **(C)** solar wind speed; **(D)** solar wind dynamic pressure, PDyn; **(E)** provisional auroral electrojet indices: red, blue, and green lines are for AU, AL, and AE; and **(F)** provisional SYM-H geomagnetic index.

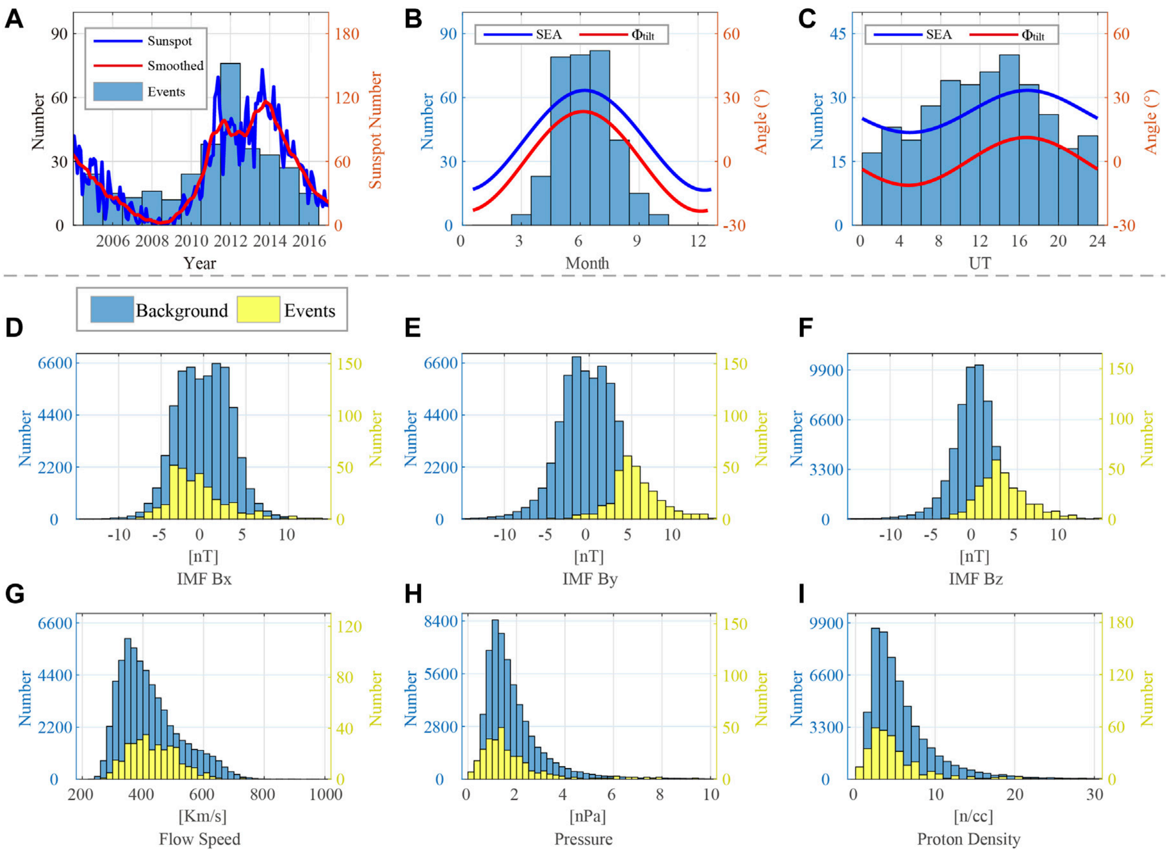

FIGURE 3
Dependence of the space hurricane observed by DMSP F16 from 2005 to 2016 on **(A)** years, **(B)** months, **(C)** universal time, **(D–F)** IMF (Bx, By, and Bz), and **(H–G)** solar wind (flow speed, dynamic pressure, and proton density) conditions. In panel **(A)**, the blue and red curves show the monthly and monthly smoothed values of the sunspot number, respectively. In panel **(B)**, the blue curve shows the annual variations of the solar elevation angle at the magnetic north pole (72.2°W, 80.1°N), and the red curve shows the annual variations of the Earth's dipole tilt angle. In panel **(C)**, the blue curve shows the diurnal variations of the solar elevation angle at the magnetic north pole on the summer solstice (June 21st), and the red curve shows the diurnal variations of the Earth's dipole tilt angle. In panels **(D–I)**, the blue bars represent the background conditions and the yellow bars represent the conditions in space hurricane events.

Figures 3D–I show the comparison between the space hurricane condition (yellow bars) and background condition (blue bars) in the IMF components Bx, By, and Bz and solar wind (flow speed, dynamic pressure, and proton density) parameters. The total number of backgrounds from 2005 to 2016 is 58436. It is clear that the favorable IMF condition for space hurricane formation is substantially different from the background condition. The space hurricane tends to occur under strong positive By, northward Bz, and negative Bx conditions. The space hurricane has a weak dependence on solar wind dynamic pressure and number density. As for the duration of a space hurricane event, it is hard to get an accurate duration due to the low time resolution of the DMSP/SSUSI (~101 min). A few space hurricanes can be observed by the DMSP F16 satellite on more than 10 consecutive orbits, which means these space hurricanes lasted at least 16 h. But many space hurricanes can only be observed two or three times in a row, indicating lifetimes of a few hours (see Supplementary Figure S2). Nearly half of space hurricane events can only be observed by one orbital period, meaning the space hurricane lasts no longer than ~202 min. If we define space hurricane events seen on adjacent satellite orbits of the DMSP F16 satellite as one continuous event, the 329 space hurricane events can be recorded as 147 individual hurricane events (see the second column of Supplementary Table S1).

3.2 Spatial distribution and the interplanetary magnetic field clock angle

To examine the spatial distribution of space hurricanes, we manually selected the center positions of these space hurricane events from SSUSI observation images. The space

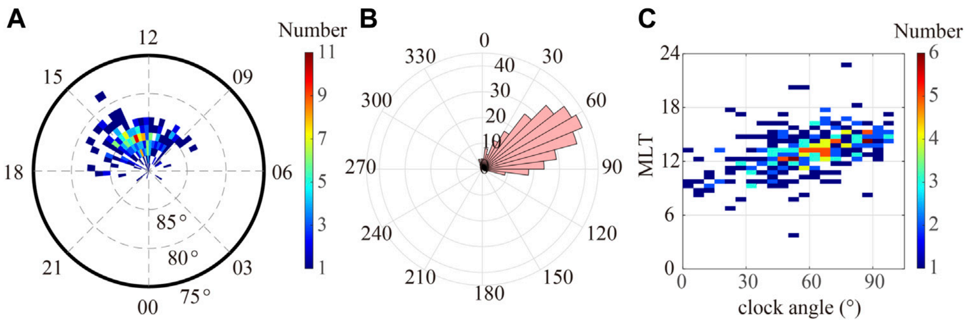

FIGURE 4
(A) MLAT-MLT distribution of space hurricane events (bin resolution 1° in MLAT and 24 min in MLT). **(B)** IMF clock angle (arctan (By/Bz)) distribution of space hurricane events. The numbers 10, 20, 30, and 40 indicate the frequency of space hurricane events in each clock angle interval (15°). **(C)** Variation of the IMF clock angle with the MLT location of the space hurricane (bin resolution 5° in the clock angle and 30 min in MLT).

hurricane center is considered the geometric center of the bright spot-like structure in the polar cap. Its distribution in the MLAT-MLT coordinate system is shown in Figure 4A. We can see that: 1) space hurricanes occur mainly in the afternoon sector around 13MLT and 2) at magnetic latitudes poleward of 80° MLAT with an average MLAT of ~85°.

In addition, we calculated the IMF clock angle (which is also a 30-min average value taken immediately before the 329 space hurricane events) and its dependence on the MLT distribution (see Figures 4B,C). In Figure 4B, the clock angle is above 45°, indicating that positive By is greater than positive Bz. Therefore, the IMF is northward and dominated by By when the space hurricane occurs, which is conducive to antiparallel magnetic reconnection with the lobe field line on the dusk side of the Earth's north pole at a high latitude (Lockwood and Davis, 1996; Frey et al., 2019). Figure 4C shows the relationship of the IMF clock angle with the MLT location of a space hurricane in the Northern Hemisphere. The location of the space hurricane shows a weak tendency to move duskward with an increasing IMF clock angle.

4 Discussion

In this paper, we have presented the observed statistical characteristics of the space hurricane, including 1) its persistent existence in the polar cap near the magnetic pole for tens of minutes to several hours; 2) its formation mainly under a dominant positive IMF By with Bx < 0 and Bz > 0 in the Northern Hemisphere in summer; 3) no clear dependence on solar wind parameters; 4) clear solar cycle dependence; 5) clear UT dependence with a high occurrence at 1,200–1600 UT; and (6) the MLT location varies with the IMF clock angle.

4.1 Interplanetary magnetic field conditions support lobe reconnection

Based on the DMSP/SSUSI observation and PPMLR-MHD (piecewise parabolic method with a Lagrangian remap to MHD) simulation, Zhang et al. (2021) proposed a space hurricane model. They considered that the space hurricane is formed by a high-latitude lobe reconnection under a northward IMF dominated by a positive BY component. The reconnection site is likely on the Earth's open magnetic field lines tailward of the cusp. After the reconnection between the IMF and Earth's magnetic field on the dusk side, the newly reconnected open field lines are draped by the solar wind to move dawn-ward and then tailward from the morning side to the afternoon side. In addition, the strong By component can produce a strong clockwise flow in the ionosphere, driving strong Pedersen currents that converge at the center of the hurricane and requiring a strong upward FAC to maintain current continuity. Therefore, the system sets up an upward FAC, accelerates the existing electrons into the ionosphere, and creates the auroral spots. Meanwhile, the magnetosheath ions precipitate into the cusp ionosphere along field lines to give the downward FACs.

In this paper, the statistical characteristics (see Figures 3D–F, 4B) have shown that the space hurricane is present mainly under dominant positive IMF By, with Bx < 0, Bz > 0, and a large clock angle. This condition is suitable for lobe reconnection to occur between the dominant IMF By and Earth's magnetic field on the dusk side (Lockwood and Davis, 1996). In other words, the observed IMF conditions statistically support the high-latitude lobe reconnection mechanism of the space hurricane. These IMF dependences shown for space hurricanes are the same as for HiLDA (Frey et al., 2003), which has been explained by the multistep processes related to high-latitude magnetopause reconnection. It is suggested that the reconnection drives a pair of field-aligned currents flowing downward and upward, with the upward field-aligned current dominated by the electron precipitation form HiLDA (Frey et al., 2004). Although 15MLT-PCA also shows the same dependence on the positive IMF By and negative IMF Bx conditions as the space hurricane, the IMF Bz shows less control over the occurrence of 15MLT-PCA (Han et al., 2020; Feng et al., 2021). Han et al. (2020) explained 15MLT-PCA as the lobe reconnection which occurs in the tail lobe and far away from the cusp. The difference in their dependence on IMF Bz is likely to be the main reason for their different auroral shapes (Cai et al., 2021). For 15MLT-PCA, the clockwise convection cell is not well-formed due to the weaker lobe reconnection under the positive IMF By and Bz ~ 0, therefore forming the slender structure arc shape. Considering this IMF condition often occurs before the beginning or after the end of the space hurricane, we suggest the arc shape may correspond to the period when the high-latitude lobe reconnection begins and ends.

4.2 Temporal and spatial distribution

The seasonal and UT dependence of the space hurricane (see Figures 3B,C) is very similar to those of HiLDA and 15MLT-PCA. In the Northern Hemisphere, these three phenomena occur mainly in summer and more frequently a few hours after midday (Han et al., 2020; Frey et al., 2004). At present, there are two explanations. One is the high ionospheric conductivity in the sunlight hemisphere described by Frey et al. (2004), which considers the higher conductivity in the sunlit dayside polar cap as making the current closure between the upward FAC and downward FAC through the ionosphere easier and causing aurora (Shue et al., 2001). The other is the dipole tilt effect, where the large tilt angle can favor an effective accumulation of the solar wind energy flux somewhere in the summer lobe (Han et al., 2020). To study the relationship between these two effects and the occurrence of space hurricanes, we calculated the solar elevation angle and Earth's dipole tilt angle for each space hurricane event based on its date and location (the last two columns of Supplementary Table S1) and made a statistical histogram of the occurrence of the space hurricane and those two angles (see Supplementary Figure S1). It can be seen that the space hurricane mainly occurs during the period of the positive solar elevation angle (0°–40°) and large dipole tilt angle (mostly above 10°). The large solar elevation angle means higher conductivity in the polar cap. However, from Figures 3B,C and Supplementary Figure S1, it seems that the relative contribution of the two angles/effects to the occurrence of a space hurricane is still unknown.

The high MLAT location of the space hurricane and the high occurrence in the afternoon sector (see Figure 4A) are also similar to HiLDA and 15MLT-PCA. This can be understood from the location of the foot points of the newly reconnected open field lines and the reconnection site. In such a large positive IMF By condition, the formers are likely in the polar cap and the latter should mainly be on the dusk side (Zhang et al., 2021). Furthermore, we argued that the weak tendency for the dusk-ward movement of space hurricanes with the increasing IMF clock angle (see Figure 4C) is related to the extension of the reconnection site in the dayside magnetopause under the non-zero IMF By. Under positive/negative IMF By, the reconnection site extends toward dusk/dawn in the Northern Hemisphere (Luhmann et al., 1984; Park et al., 2006), and the open flux tubes are added asymmetrically to the magnetosphere (Cowley, 1981; Tenfjord et al., 2015; Milan et al., 2022). The evolution of polar cap aurora-like transpolar arcs is also modulated by IMF By, which is related to the night-side magnetotail process (Fear and Milan, 2012; Xing et al., 2018). The MLT distribution of 15MLT-PCA also shows a weak tendency of the dusk-ward movement with increasing IMF By magnitude (Feng et al., 2021). They think its dependence may be related to the IMF By modification of the low-latitude magnetopause reconnection location. Therefore, for similar reasons, the IMF clock angle may affect the MLT location of the space hurricane by changing the location of the magnetopause reconnection.

4.3 Particle precipitation

Based on the observations of the *in situ* plasma and current conditions when DMSP satellites pass through space hurricanes, Zhang et al. (2021) have identified many particle precipitation characteristics of the space hurricane including 1) a significant increase in the energy flux of electron precipitation without ion precipitation, 2) an upward FAC, 3) an elevated electron temperature, and 4) a clear inverted-V electron acceleration. Previous studies have pointed out that these characteristics can also be seen in HiLDA and the poleward side of 15MLT-PCA from DMSP or FAST observations (Frey et al., 2003; Han et al., 2020; Cai et al., 2021). The equatorward part of 15MLT-PCA, which connects to the auroral oval, has a different particle precipitation characteristic which is mainly ion precipitation with clear energy dispersion. It has been explained as the dragging effect caused by the newly reconnected tail lobe magnetic field lines moving toward the magnetotail under the action of the solar wind (Han et al., 2020).

Assuming that 15MLT-PCA is caused by the lobe reconnection proposed by Han et al. (2020), we can reasonably infer that the arc-shaped aurora should correspond to a similar arc-shaped upward field-aligned current region. However, this arc-shaped upward field-aligned current has been observed by the AMPERE (the Active Magnetosphere and Planetary Electrodynamics Response Experiment) FAC at the end of a space hurricane evolution stage (Zhang et al., 2021). Therefore, we suggest 15MLT-PCA may be the aurora form at the end of the space hurricane. It may correspond to the process of the auroral spot in the polar cap moving toward the equator and merging into the dusk-side auroral oval. In addition, when we select the events from DMSP/SSUSI images, sometimes, we see an auroral arc at 15MLT in the auroral oval that extends/shrinks to the polar cap before/after the appearance of the space hurricane when IMF Bz changes orientation during a long-duration period of positive By, also indicating that 15MLT-PCA may be the auroral form at the beginning or end of the space hurricane.

Finally, based on the observational results and statistical properties between HiLDA and the space hurricane, we believe that the space hurricane is a new type of HiLDA with arm characteristics. The high-latitude lobe reconnection is suggested to be its formation mechanism (Frey et al., 2004; Zhang et al., 2021). As for the space hurricane having better arm structures than previously defined HiLDA, it is likely due to improved spatial resolution of the observation equipment. The arm structures are difficult to identify in the lower spatial resolution ($1^{\circ} \times 1^{\circ}$) IMAGE/WIC (wideband imaging camera) from an altitude of thousands of kilometers (Mende et al., 2000) but can be clearly seen by DMSP/SSUSI from 860 km altitude. Of course, we also noticed that some space hurricane events do not have obvious arms, which may be related to specific solar wind and geomagnetic conditions.

5 Conclusion

Based on long-term DMSP F16/SSUSI observations from 2005 to 2016, we identified 329 space hurricane events in the Northern Hemisphere. Using these events, we found that the space hurricane has a clear IMF, solar cycle, and seasonal and UT dependencies. In the Northern Hemisphere, the space hurricane tends to occur in summer with a strong positive IMF By, northward Bz, and negative Bx. The space hurricane occurs mainly in the afternoon sector, with a maximum occurrence of around 13MLT. It occurs mainly near the magnetic poles at magnetic latitudes $>\sim 80^{\circ}$. In addition, the space hurricane shows a weak tendency to move duskward with the increasing IMF clock angle. These observational characteristics and statistical properties provide strong evidence for the high-latitude lobe reconnection mechanism proposed by Zhang et al. (2021) for the formation of the space hurricane.

We have also discussed the similarities and differences between the space hurricane and two other types of polar cap auroras: 15MLT-PCA and HiLDA. We suggest that 15MLT-PCA may be the aurora at the beginning or end of the space hurricane. Also, they may be the result of the high-latitude lobe reconnection under different interplanetary conditions (with Bz northward or not) and different evolutionary stages (stable or unstable). The space hurricane is likely a new type of HiLDA with arm characteristics. Insufficient spatial resolutions of the observation equipment may also cause the observed auroral forms to differ, especially for some space hurricanes where arm structures are inconspicuous.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/Supplementary Material.

Author contributions

Z-YX and Q-HZ designed and performed research. SL and Z-YX processed data and prepared the manuscript. Q-HZ contributed to the space hurricane definition and data interpretation. Y-LZ contributed to the DMSP SSUSI data analysis and interpretation. Z-YX, SL, Y-ZM, and X-YW participated in data processing and analysis. Z-YX, Q-HZ, Y-LZ, KO, LL, and BN participated in the scientific discussion and article revision. JL, YW, Z-XD, SD, and KX were involved in data analysis. All authors discussed the results and commented on the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fspas.2022.1047982/full#supplementary-material

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