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Interplanetary Orientation Leading Intense Geomagnetic Storms

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Abstract:- The present work focuses on finding the relation between strong, moderate and small geomagnetic storms based on disturbed storm time index and the orientation of interplanetary magnetic field. In this work the data selected is from year 2015 to 2018 and classification of the geomagnetic storms is done on the basis of Dst (ring current) as intense geomagnetic storms (Dst<-100 nT), moderate geomagnetic storms (-99nT ≤ Dst≤ -80 nT) and small geomagnetic storms (-79nT ≤Dst ≤ -60 nT).The Dst index datawas obtained from the World Data Centre for Geomagnetism, WDC-Kyoto. The solar parameters; solar proton density (Np), solar proton speed (Vp), solar proton temperature(Tp) and vertical component of Interplanetary Magnetic Field (IMF_z) of the same duration are taken fromAdvance Composition Explorer (ACE) spacecraft, as given by the ACE Science Centre. During this period 9 intense geomagnetic events, 11 moderate geomagnetic storms and 5 small geomagnetic activities are observed.From these data sets a total of 10 events were selected for the study, out of which 5 are intense geomagnetic storms, 3 are moderate geomagnetic storms and 2 are small geomagnetic storms. In case of intense geomagnetic storms disturbed storm index (Dst) lag behind interplanetary magnetic field (IMF) by 10 hours, for moderate geomagnetic storms disturbed storm index (Dst) lag behind interplanetary magnetic field (IMF) by 4hours and disturbed storm index(Dst) lag behind interplanetary magnetic field (IMF) by 16hours in small geomagnetic storms. ThusDst index is following the southward orientation of vertical component of interplanetary magnetic field as consequential of varied solar parameters.

Keywords:- *Solar Proton Density, Solar proton Temperature, Solar proton speed, IMF and Dst index.*

I. INTRODUCTION

Magnetic storms have two basic causes; the Sun sometimes emits a strong surge of solar wind called a coronal mass ejection. This gust of solar wind disturbs the outer part of the Earth's magnetic field, which undergoes a complex oscillation. This generates associated electric currents in the near-Earth space environment, which in turn generates additional magnetic field variations all of which constitute a "magnetic storm"[1]. Occasionally, the Sun's magnetic field directly links with that of the Earth. This direct magnetic connection is not the normal state of affairs. When it occurs, charged particles traveling along magnetic field lines can easily enter the magnetosphere, generate currents, and cause the magnetic field to undergo time dependent variation [2]. Sometimes the Sun emits a coronal mass ejection at a time when the magnetic field lines of the Earth and Sun are directly connected. When these events occur, we can experience a truly large magnetic storm [3]. The solar wind (stream of charge particles) emitted from the corona of the Sun carrying along it some magnetic field from the sun to interplanetary space, these give rise to interplanetary magnetic field that interact with earth magnetosphere leading to geomagnetic storms of different magnitude depending on the intensity of solar wind ion parameters[4]. Hence,when earth is engulfed by abnormal interplanetary structures, characterized by sudden increases in magnetic field B, geomagnetic storms occurs due to these sudden impact as indicated by increased in solar geomagnetic disturbances indices (DST, Np, Tp, Vp, IMF_Z).Therefore, interplanetary orientation have significant impact on super intense geomagnetic storms[5].

II. DISTURBED STORM INDEX (DST) INDEX

The Disturbance Storm Time (Dst) index is a measure of geomagnetic activity used to assess the severity of geomagnetic storms. It is expressed in nanotesla and is based on the average value of the horizontal component of the Earth's magnetic field measured at four near-equatorial geomagnetic observatories. It measures the growth and recovery of the ring current in the Earth's magnetosphere. The lower these values get, the more energy is stored in Earth's magnetosphere. It provides data on the strength of the ring current created by solar protons and electrons around Earth. The ring current around Earth generates a magnetic field that is diametrically opposed to Earth's magnetic field, i.e., as the difference between solar electrons and protons increases, Earth's magnetic field weakens. The Earth's magnetic field is weakened if the Dst number is negative. This is especially true during solar storms [6].Due to solar wind (stream of charge particles) emitted from the corona of the Sun carrying some magnetic field from the sun to interplanetary space, which give rise to interplanetary magnetic field that interact with earth magnetosphere leading to geomagnetic storms of different magnitude depending on the intensity of solar wind ion parameters. For future studies super intense geomagnetic storms need to be included to ascertain its variability to intense, moderate and small geomagnetic activities.

III. THE INTERPLANETARY MAGNETIC FIELD (IMF)

The interplanetary magnetic field (IMF) is a part of the Sun's magnetic field that is carried into interplanetary space by the solar wind. The interplanetary magnetic field lines are said to be "frozen in" to the solar wind plasma. Because of the Sun's rotation, the IMF, like the solar wind, travels outward in a spiral pattern that is often compared to the pattern of water sprayed from a rotating lawn sprinkler. The IMF originates in regions on the Sun where the magnetic field is "open"--that is, where field lines emerging from one region do not return to a conjugate region but extend virtually indefinitely into space[4]. The direction (polarity, sense) of the field in the Sun's northern hemisphere is opposite that of the field in the southern hemisphere. (The polarities reverse with each solar cycle). The interplanetary magnetic field (IMF) plays a huge rule in how the solar wind interacts with Earth's magnetosphere. The heliosphere current sheet is long the plane of the Sun's magnetic equator, the oppositely directed open field lines run parallel to each other and are separated by a thin current sheet known as the "interplanetary current sheet" or "heliospheric current sheet" [7]. The current sheet is tilted (because of an offset between the Sun's rotational and magnetic axes) and warped (because of a quadrupole moment in the solar magnetic field) and thus has a wavy, "ballerina skirt"-like structure as it extends into interplanetary space, because the Earth is located sometimes above and sometimes below the rotating current sheet, it experiences regular, periodic changes in the polarity of the IMF. These periods of alternating positive (away from the Sun) and negative (toward the Sun) polarity are known as magnetic sectors [8].The IMF is a vector quantity with three directional components, two of which (Bx and By) are oriented parallel to the ecliptic. The third component--Bz--is perpendicular to the ecliptic and is created by waves and other disturbances in the solar wind. When the IMF and geomagnetic field lines are oriented opposite or "antiparallel" to each other, they can "merge" or "reconnect," resulting in the transfer of energy, mass, and momentum from the solar wind flow to magnetosphere The strongest coupling with the most dramatic magnetospheric effects occurs when the Bz component is oriented southward. The IMF is a weak field, varying in strength near the Earth from 1 to 37nT, with an average value of approximately 6nT [9].

IV. GEOMAGNETIC STORM

The Earth's magnetosphere is created by our magnetic field and protects us from most of the particles the sun emits. When a CME or high-speed stream arrives at Earth it buffets the magnetosphere. If the arriving solar magnetic field is directed southward it interacts strongly with the oppositely oriented magnetic field of the Earth. The Earth's magnetic field is then peeled open like an onion allowing energetic solar wind particles to stream down the field lines to hit the atmosphere over the poles. At the Earth's surface a magnetic storm is seen as a rapid drop in the Earth's magnetic field strength. This decrease lasts about 6 to 12 hours, after which the magnetic field gradually recovers over a period of several days [10].The disturbance storm time (Dst) describes the strength of the ring current and provides a reliable measurement for the impact of geomagnetic storms. The ring current occurs when charged particles of the solar wind enter the inner magnetosphere and move along the geomagnetic field lines in a westward direction around Earth. The magnetic field of this ring current impacts the field strength on Earth's surface. This impact is described with Dst and provided at hourly resolution through the World Data Centre for Geomagnetism in Kyoto [8]. Geomagnetic activity described by Dst is correlated with the strength of solar wind features and, thus, can be predicted based on their measurements [11].A geomagnetic storm is defined by changes in the Dst (disturbance – storm time) index. The Dst index estimates the globally averaged change of the horizontal component of the Earth's magnetic field at the magnetic equator based on measurements from a few magnetometer stations. Dst is computed once per hour and reported in near-real- time. During quiet times, Dst is between +20 and −20 nano-Tesla (nT) [12].

V. INTERPLANETARY MAGNETIC FIELD AND INTENSE GEOMAGNETIC STORMS

Geomagnetic storms are large disturbances in the Earth's magnetosphere, usually measured through the ring current Dst index, and produced by enhanced solar wind-magnetosphere energy coupling through the magnetic reconnection mechanism. Intense geomagnetic storms are defined when the peak value of this index reaches ≥-100 nT, while extreme storms (also called great magnetic storms or superstorms), are usually defined when Dst reaches values of ≥-250[13]. These very intense events can occur in any part of the solar cycle and have dramatic consequences for space weather.

VI. METHODOLOGY

The present work focuses on finding the relation between strong, moderate and small geomagnetic storms based on disturbed storm time index and the orientation of interplanetary magnetic field. In this work the data selected is from year 2015 to 2018 and classification of the geomagnetic storms is done on the basis of Dst (ring current) as intense geomagnetic storms (Dst< -100nT), moderate geomagnetic storms (-99nT ≤ Dst ≤ -80nT) and small geomagnetic storms(-79nT ≤ Dst ≤ -60nT).The Dst index data and solar parameters; solar proton density (Np), solar proton speed (Vp), solar proton temperature(Tp) and vertical component of Interplanetary Magnetic Field (IMF_z) of the same data duration are collected from World Data Centre, Kyoto Japan and Advanced Composition Explorer (ACE) hourly average definite multi spacecraft interplanetary parameters data. During this period 9 intense geomagnetic events, 11 moderate geomagnetic storms and 5 small geomagnetic activities are recorded.From these data sets a total of 10 events were selected for the study, out of which 5 are intense geomagnetic storms, 3 are moderate geomagnetic storms and 2 are small geomagnetic storms.

VII. RESULT AND DISCUSSION

S/N	YEAR	MONTH	DAY	DST INDEX (nT)	DST TIME (UTC)	MAX. NP (cm^{-3})			MAX.TP(°K)			MAX.VP (km/s)			IMF_Z(nT)		
						Date	Time(UTC)	NP Value	Date	Time(UTC)	TP Value	Date	Time(UTC)	VP Value	Date	Time(UTC)	Value
1	2015	MARCH	17	-222	23:00	17	4	33.52	17	11	6.17E+05	18	21	737.92	17	13	-28.557
2	2015	JUNE	23	-204	05:00	22	18	59.43	24	17	8.47E+05	23	17	808.31	22	18	-39.435
3	2015	OCTOBER	07	-124	23:00	7	12	28.68	7	19	6.82E+05	7	20	840.94	7	13	-18.41
4	2015	DECEMBER	20	-155	23:00	20	12	38.45	19	16	2.60E+05	19	20	502.04	20	22	-18.911
5	2016	JANUARY	01	-110	01:00	31	13	30.66	31	6/8	2.58E+05	31	8	501.07	31	19	-16.202
6	2016	OCTOBER	13	-104	24:00	13	2	23.00	14	23	2.27E+05	14	15	445.77	13	15	-21.169
7	2017	MAY	28	-125	08:00	27	19	59.364	29	20	1.33E+05	27	22	407.08	28	0	-20.196
8	2017	SEPTEMBER	08	-122	02:00	7	6	15.89	8	1	8.82E+05	8	7	855.47	7	23	-31.621
9	2018	AUGUST	26	-175	07:00	26	12	27.61	27	18	3.13E+05	27	18	643.23	26	4	-17.038

Table 1: Intense geomagnetic storms (DST≤-100nT)

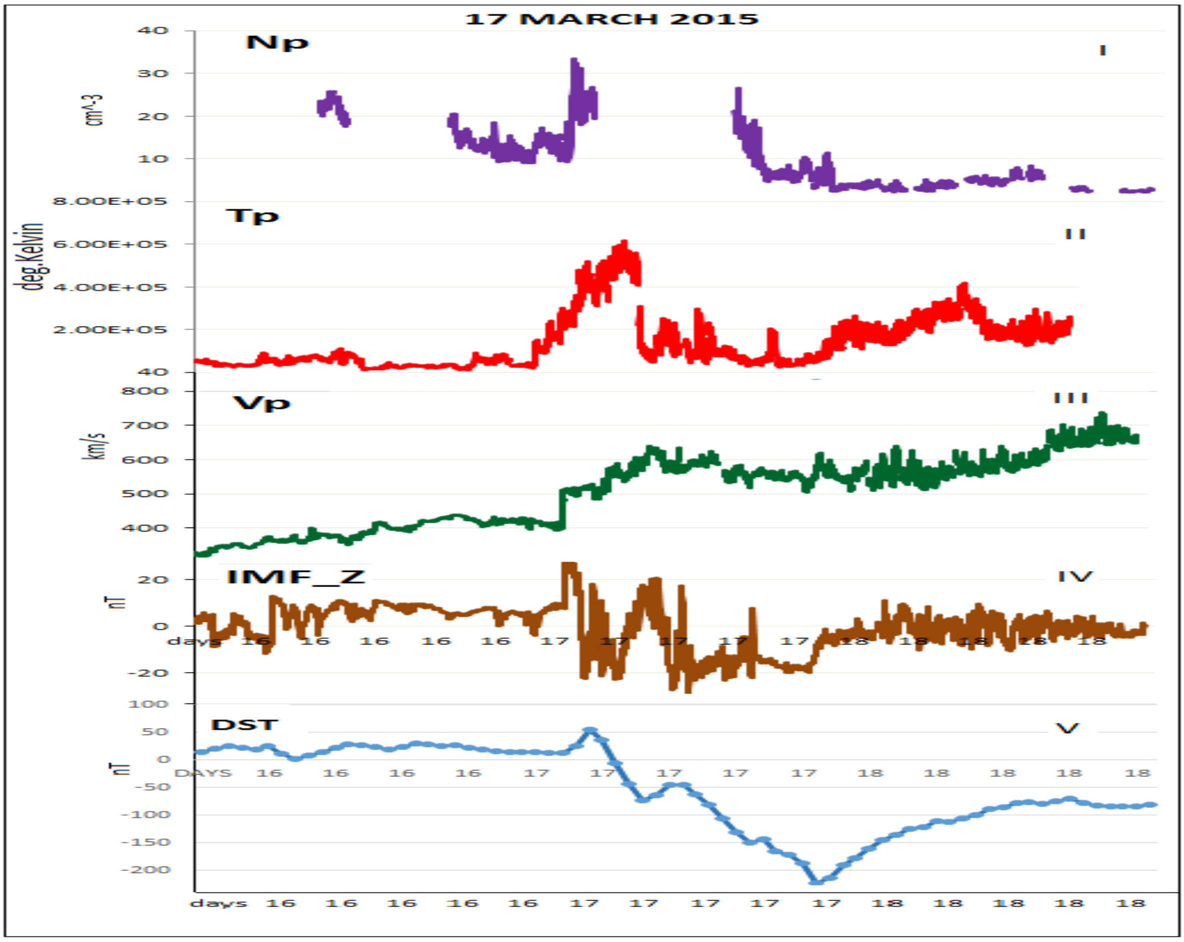

Fig. 1: Intense geomagnetic storms for 17th March 2015

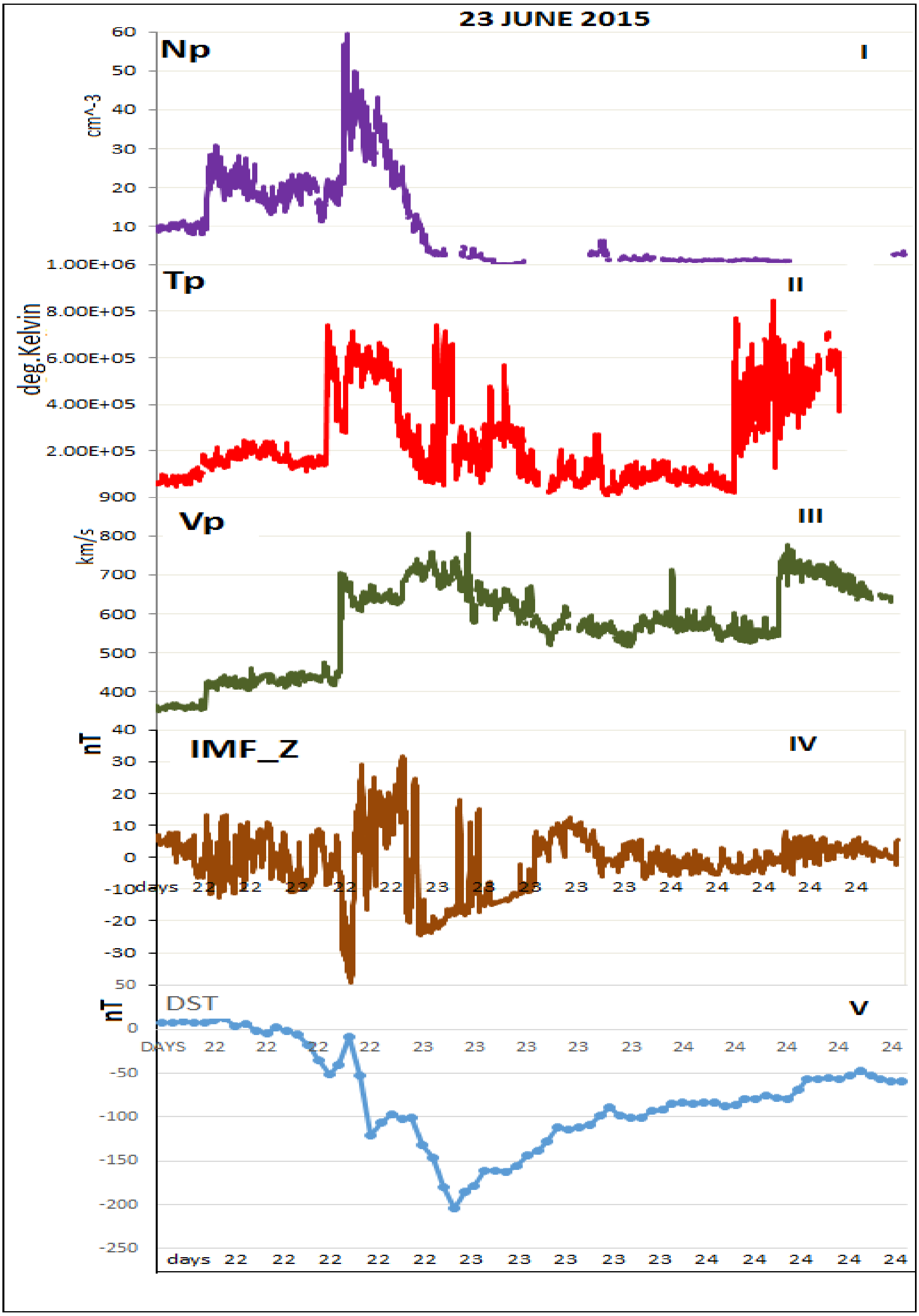

Fig. 2: Intense geomagnetic storms for 23rd June 2015

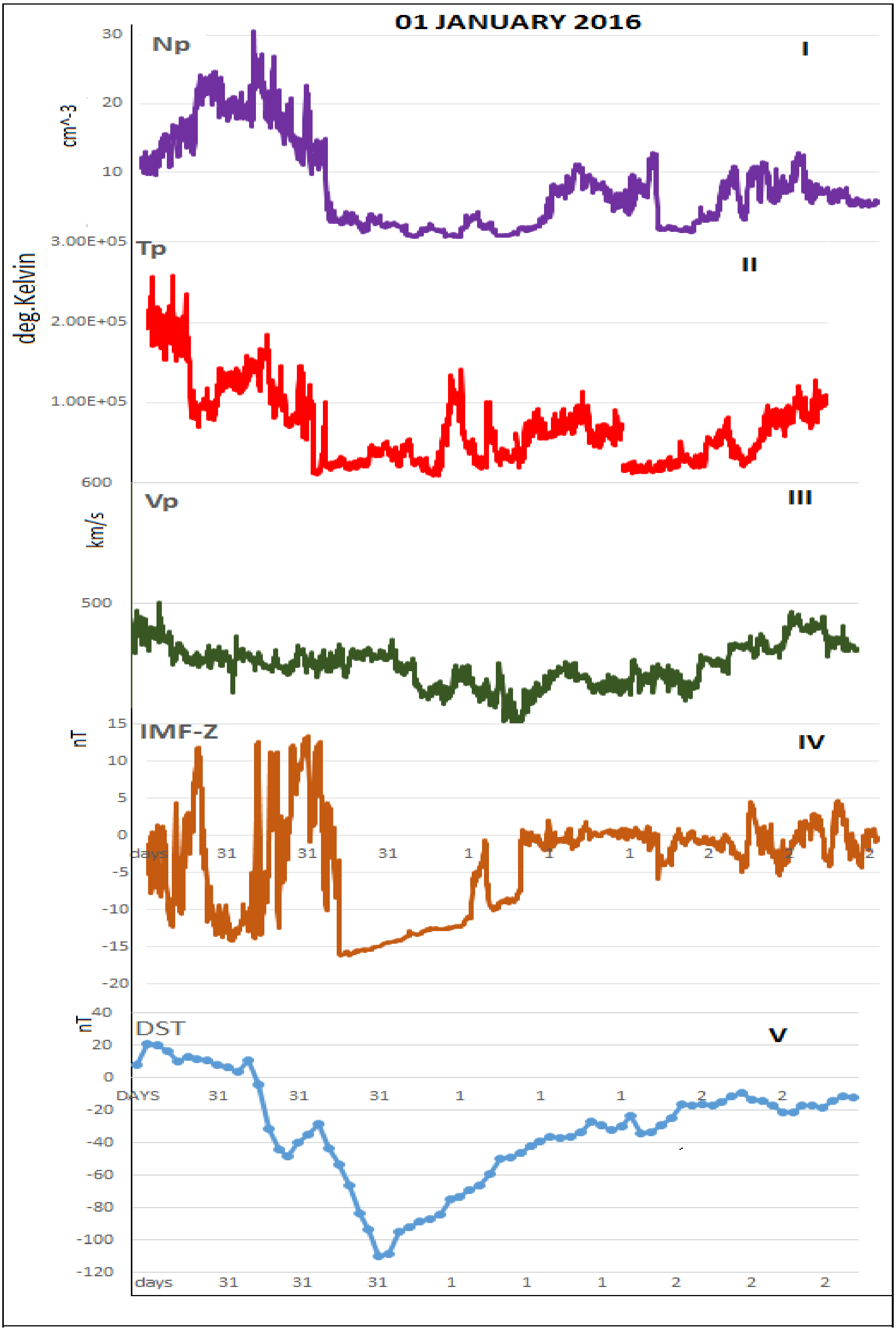

Fig. 3: Intense geomagnetic storm for 1st January 2016

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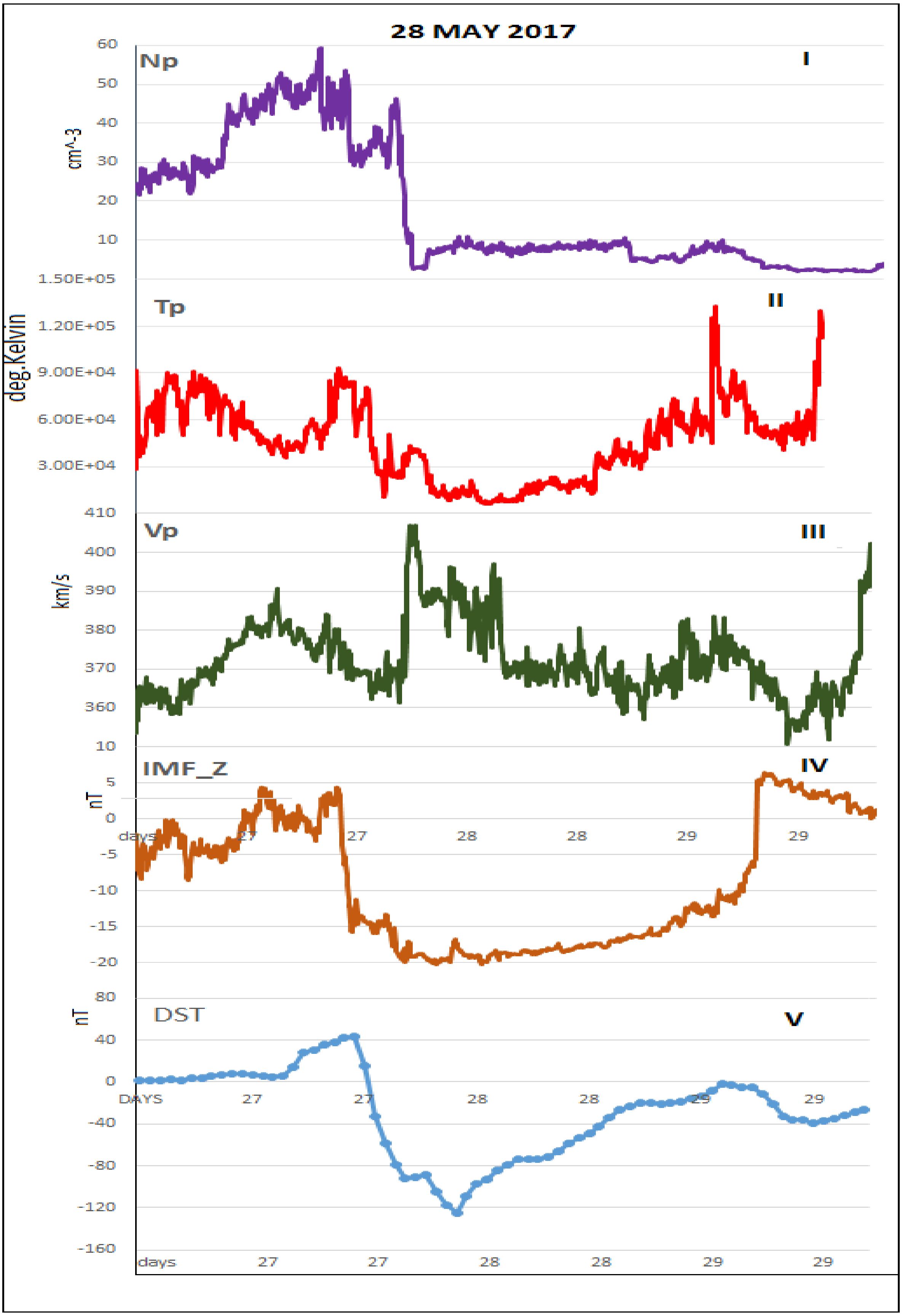

Fig. 4: Intense geomagnetic storm for 28th May 2017

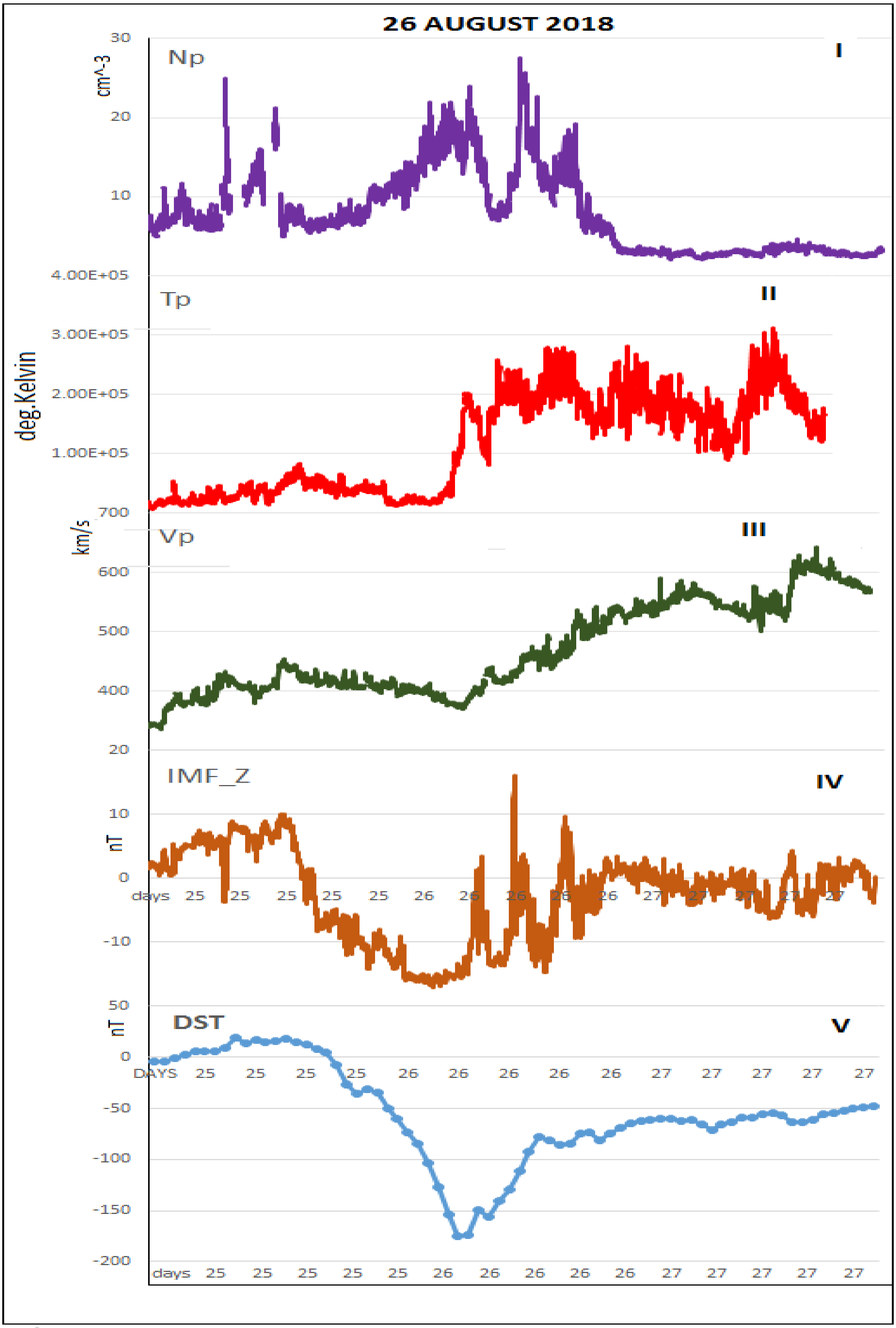

Fig. 5: Intense geomagnetic storm for 26th August 2018

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In each of the above figures there are five panels, panel I is proton density (N_p) in cm^{-3},panel II is proton temperature (T_P) in degree Kelvin, panel III is proton speed (V_p) in km/s, panel IV and V are vertical component of the interplanetary magnetic field (IMF_Z) and disturbed storm index (DST) respectively, both measured in nT. In figure 1 first panel depicts solar proton density (Np) varying with value ≈ 33.52 per cm cubic on 17TH march 2015 at 04UTC, second panel depicts solar proton temperature (Tp) varying with value ≈ 6.17E+05 deg. Kelvin on same date at 11UTC, third panel represent solar proton speed (Vp) varying with value ≈ 737.92 km/s on 18TH march 2015 at 21UTC,thenfourth panel depicts Interplanetary magnetic field (IMF_Z) varying with value ≈ -28.557nT on 17TH march 2015 at 13UTC,fifth panel represents geomagnetic storm (Dst) varying with value ≈ -222nT onthe same day at 23UTC but lags behind IMF by 10hours. In figure 2 first panel depicts solar proton density (Np) varying with value ≈ 59.43 cm^{-3} on 22nd June 2015 at 18UTC, second panel depicts solar proton temperature (Tp) varying with value ≈ 8.47E+05 deg. Kelvin on 24th June 2015 at 17UTC, third panel represent solar proton speed (Vp) varying with value ≈ 808.31 km/s on 24th June 2015 at 17UTC,then fourth panel depicts Interplanetary magnetic field (IMF_Z) varying with value ≈ -39.435 nT on 22nd June 2015 at 18UTC, fifth panelis geomagnetic storm (Dst) varying with value ≈ -204nTon same day at 05UTC but lags behind IMF by 11hours. In figure 3 First panel depicts solar proton density (Np) varying with value ≈ 30.66 cm^{-3}on 31stDecember 2015 at 13UTC, second panel depicts solar proton temperature (Tp) varying with value ≈ 2.58E+05 deg. Kelvin on 31stDecember 2015 occurs twice at 06UTC and 08UTC, third panel represent solar proton speed (Vp) varying with value ≈ 501.07 km/s on 31st December 2015 at 08UTC, thenfourth panel depicts Interplanetary magnetic field (IMF_Z) varying with value ≈ -16.202nT on 31stDecember 2015 at 19UTC ,fifth panel is geomagnetic storm (Dst) varying with value ≈ -110nT on same day at 01UTbut lags behind IMF by 6 hours. In figure 4 first panel depicts solar proton density (Np) varying with value ≈ 59.364cm^{-3}on 27th May 2017 at 19UTC, second panel depicts solar proton temperature (Tp) varying with value ≈ 1.33E+05 deg. Kelvin on 29th May 2017 at 20UTC, third panel represent solar proton speed (Vp) varying with value ≈ 407.08 km/s on 27th May 2017 at 22UTC,thenfourth panel depicts Interplanetary magnetic field (IMF_Z) varying with value ≈ -20.196nT on 28th May 2017 at 0UTC ,fifth panel is geomagnetic storm (Dst) varying with value ≈ -125nT on same day at 08UTC but lags behind IMF by 8 hours. In figure 5 first panel representssolar proton density (Np) varying with value ≈ 27.61 cm^{-3}on 26th August 2018at 12UTC, second panel depicts solar proton temperature (Tp) varying with value ≈ 3.13E+05 deg. Kelvin on 27th August 2018 at 18UTC, third panel represent solar proton speed (Vp) varying with value ≈ 643.23 km/s on 27th August 2018 at 18 UTC,fourth panel depicts Interplanetary magnetic field (IMF_Z) varying with value ≈ -17.038nT on 26th August 2018 at 04UTC ,fifth panel followed by geomagnetic storm (Dst) varying with value ≈ -175nT on same day at 07UTC but lags behind IMF by 3 hours.

S/N	YEAR	MONTH	DAY	DST INDEX(nT)	DST TIME (UTC)	MAX NP (CM^-3)			MAX TP (°K)			MAX VP (KM/S)			IMF_Z(nT)		
						Date	Time(UTC)	Value	Date	Time(UTC)	Value	Date	Time(UTC)	Value	Date	Time(UTC)	Value
1	2015	JANUARY	07	-99	12:00	7	20	26.13	6	3	3.55E+0.5	6	0	551.96	7	8	-20.971
2	2015	MARCH	19	-88	01:00	18	14	8.55	18	15	4.20E+05	18	21	737.92	18	13	-10.68
3	2015	JUNE	25	-86	16:00	25	11	9.624	24	22	7.09E+05	24	2	713.22	25	6	10.576
4	2015	AUGUST	16	-84	08:00	15	10	30.12	15	18	2.89E+05	17	0	599.57	15	10	-21.438
5	2015	AUGUST	27	-92	21:00	27	3	21.565	28	17	1.02E+05	26	3	429.98	28	17	-16.341
6	2015	SEPTEMBER	09	-98	13:00	10	21	29.591	10	23	1.39E+05	8	0	571.86	9	7	-10.073
7	2015	NOVEMBER	07	-89	07:00	6	22	12.972	6	23	6.94E+05	7	2	708.47	6	22	-16.872
8	2015	DECEMBER	31	-93	24:00	31	13	30.644	31	4	3.49E+05	31	8	501.07	31	19	-16.202
9	2016	JANUARY	20	-93	17:00	19	10	30.374	19	9	8.12E+04	19	9	395.39	19	9	-10.722
10	2016	MARCH	06	-98	22:00	7	15	29.846	7	16	1.21E+05	7	15	422.35	6	22	-17.995
11	2016	MAY	08	-88	09:00	9	5	21.439	9	10	5.61E+05	10	23	726.61	8	6	-12.845

Table 2: Moderate geomagnetic storms index (-99 ≤ Dst ≤ -80)

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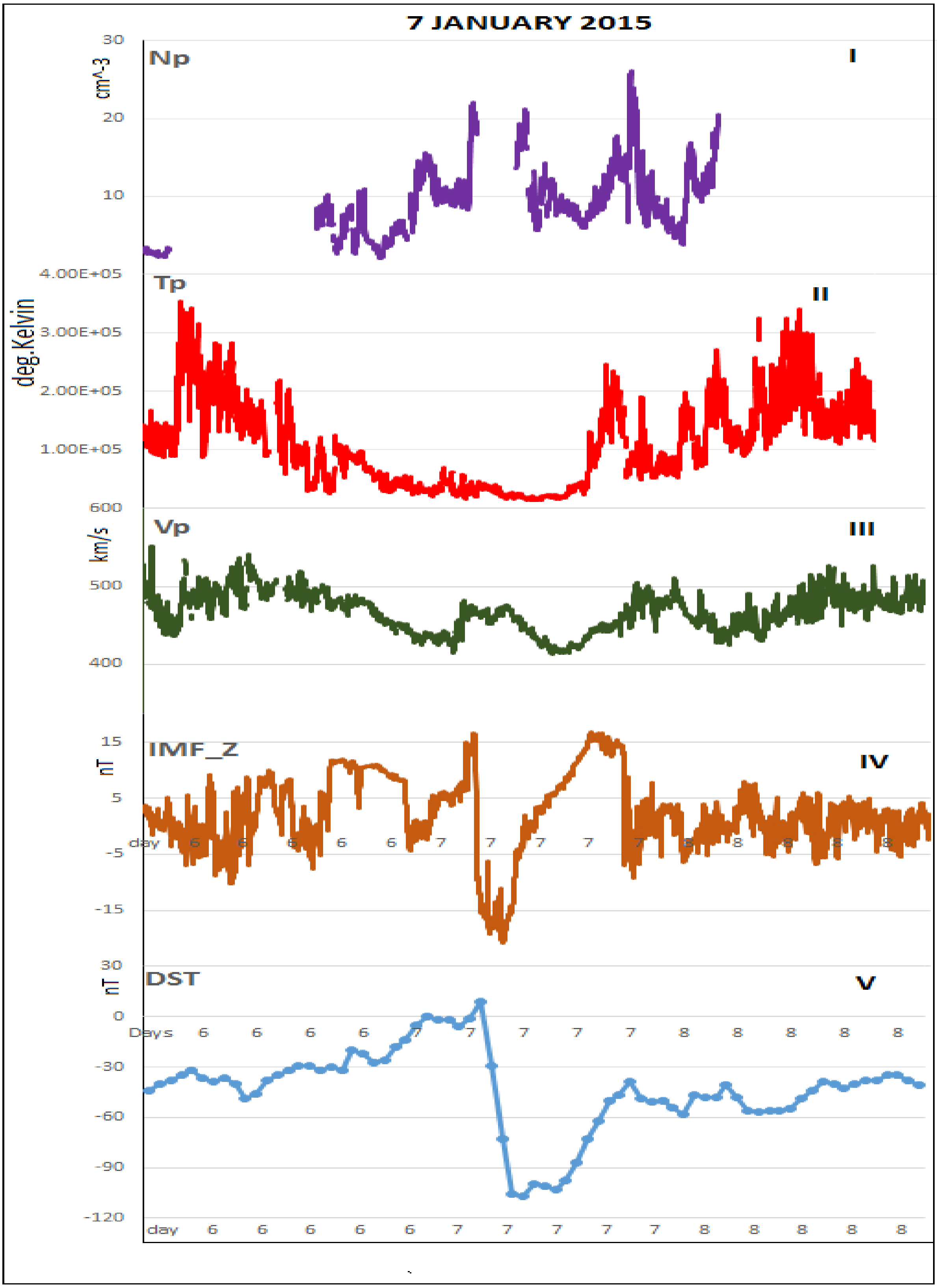

Fig. 6: Moderate geomagnetic storm for 7th January 2015

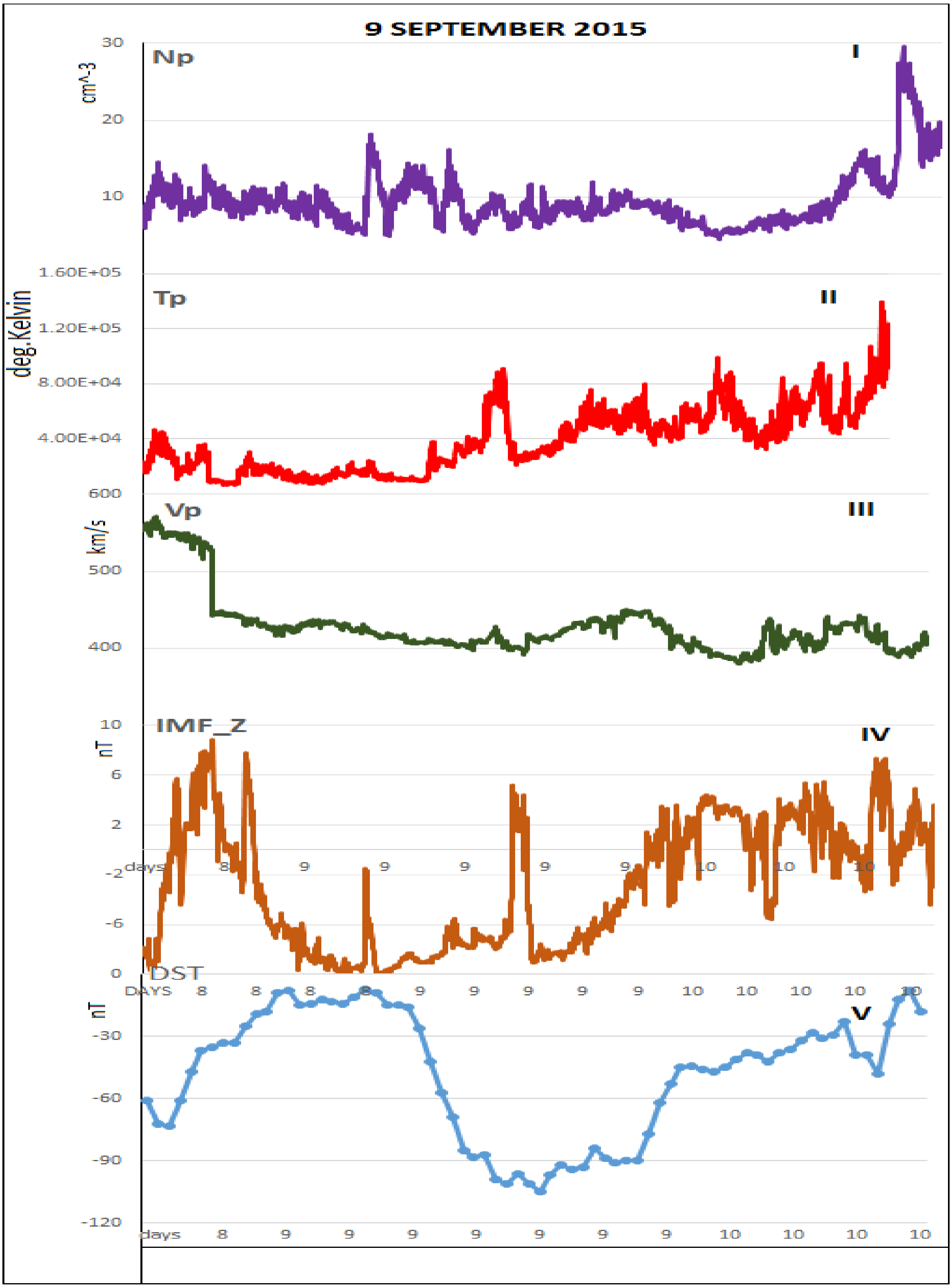

Fig. 7: Moderate geomagnetic storm for 9th September 2015

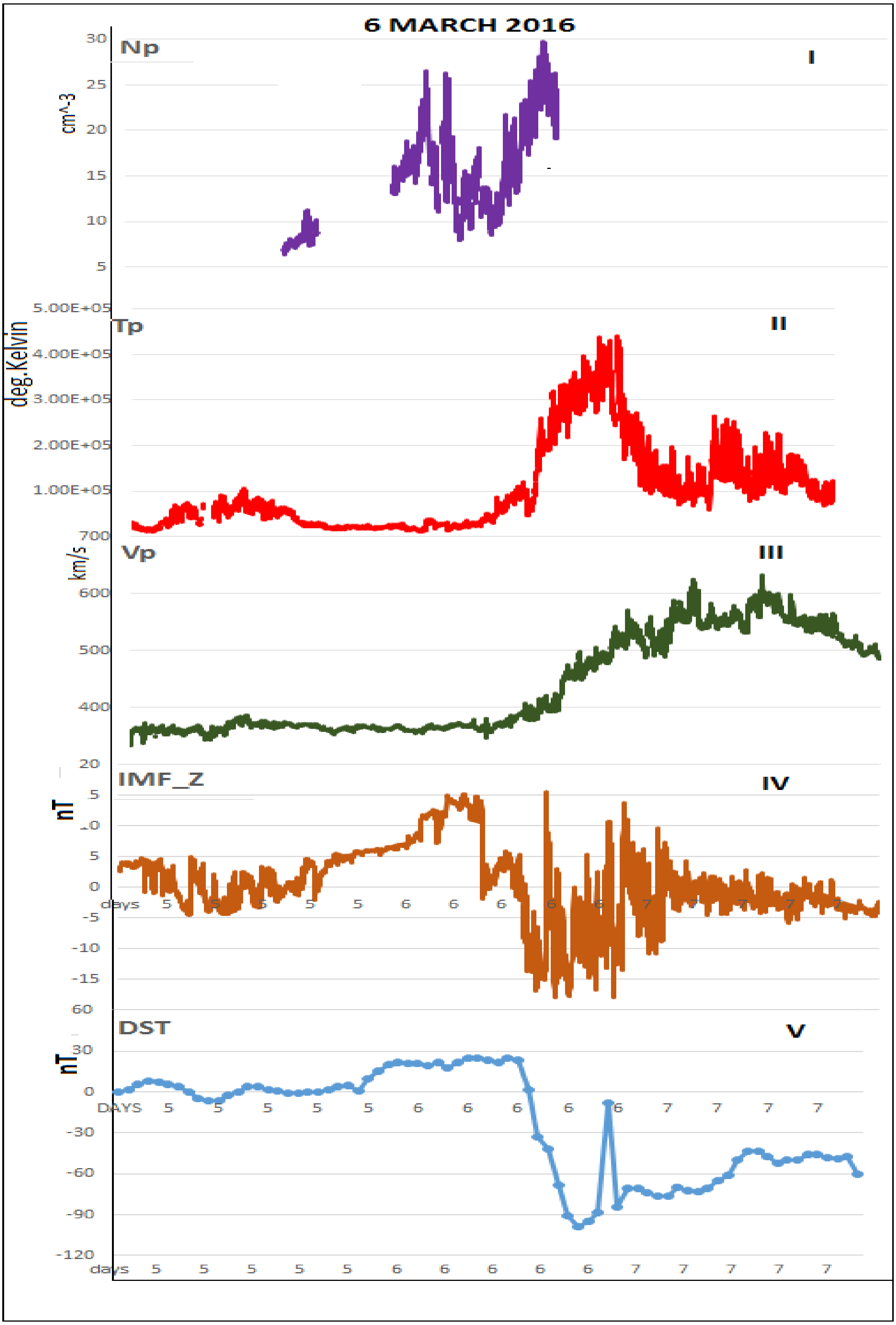

Fig. 8: Moderate geomagnetic storm for 6th March 2016

In each of the above figures there are five panels, panel I is proton density (N_p) in cm^{-3},panel II is proton temperature (T_P) in degree Kelvin, panel III is proton speed (V_p) in km/s, panel IV and V are vertical component of the interplanetary magnetic field (IMF_Z) and disturbed storm index (Dst) respectively, both measured in nT. Figure 6 is one ofmoderate geomagnetic storms presenting solar proton density (Np) varying with ≈ 26.13cm^{-3} on 7th January 2015 at 20UTC, solar proton temperature (Tp) varying with value ≈ 3.55E+05 °K on 6th January 2015 at 03UTC,solar proton speed (Vp) varying with value ≈ 551.96 km/s on 6th January 2015 at 0UTC,then Interplanetary magnetic field (IMF_Z) varying with value ≈ -20.971nT on 7th January 2015 at 08UTC, geomagnetic storm (Dst) follow IMF varying with value ≈ -99nT on the same day at 12UTC but lags behind IMF by 4hours. Figure 7 is also moderate geomagnetic storms with solar proton density (Np) varying with ≈ 29.591cm^{-3} on 10th September 2015 at 21 UTC,solar proton temperature (Tp) varying with value ≈ 1.39E+05 deg. °K on 10th September 2015 at 23 UTC,solar proton speed (Vp) varying with value ≈ 571.86 km/s on 08th September 2015 at 0UTC,then Interplanetary magnetic field (IMF_Z) varying with value ≈ -10.073nTon 9th September 2015 at 07UTC, geomagnetic storm (Dst) follow IMF varying with value ≈ -98nT on 09th September 2015 at 13UTC. The disturbed storm index (Dst) lags behind interplanetary magnetic field (IMF) by 5hours.Figure 8 presents solar proton density (Np) varying with ≈ 29.846cm^{-3} on 07th March 2016 at 15 UTC, solar proton temperature (Tp) varying with value ≈ 1.21E+05 °K on 07th March 2016 at 16UTC,solar proton speed (Vp) varying with value ≈ 422.35 km/s on 07th March 2016 at 15UTC,then Interplanetary magnetic field (IMF_Z) varying with value ≈ -17.995nTon 06th March 2016 at 22UTC, geomagnetic storm (Dst) follow IMF varying with value ≈ -98nT on 06th March 2016 at 22 UTC.The disturbed storm index(Dst) lags behind interplanetary magnetic field (IMF) by 0hours.

S/N	YEAR	MONTH	DAY	DST INDEX (nT)	DST TIME (UTC)	MAX Np (cm^{-3})			MAX TP (°K)			MAX VP (km/s)			B_gsm_z (nT)		
						Date	Time(UTC)	Value	Date	Time(UTC)	Value	Date	Time(UTC)	Value	Date	Time(UTC)	Value
1	2015	APRIL	16	-79	24:00	15	0	27.644	16	22	5.00E+05	17	4	734.87	15	8	-12.976
2	2015	MAY	13	-76	07:00	12	6	35.452	13	0	5.16E+05	14	1	755.09	12	23	-16.157
3	2015	JUNE	08	-73	09:00	7	13	27.723	8	10	4.63E+05	8	11	690.54	8	5	-20.029
4	2015	SEPTEMBER	20	-74	12:00	19	6	11.786	20	6	5.75E+05	21	5	628.79	20	5	-18.631
5	2016	AUGUST	23	-74	22:00	23	17	17.097	24	1	4.43E+05	24	1	654.12	23	19	-14.329

Table 3: Small geomagnetic storms (-79 ≤ Dst ≤ -60)

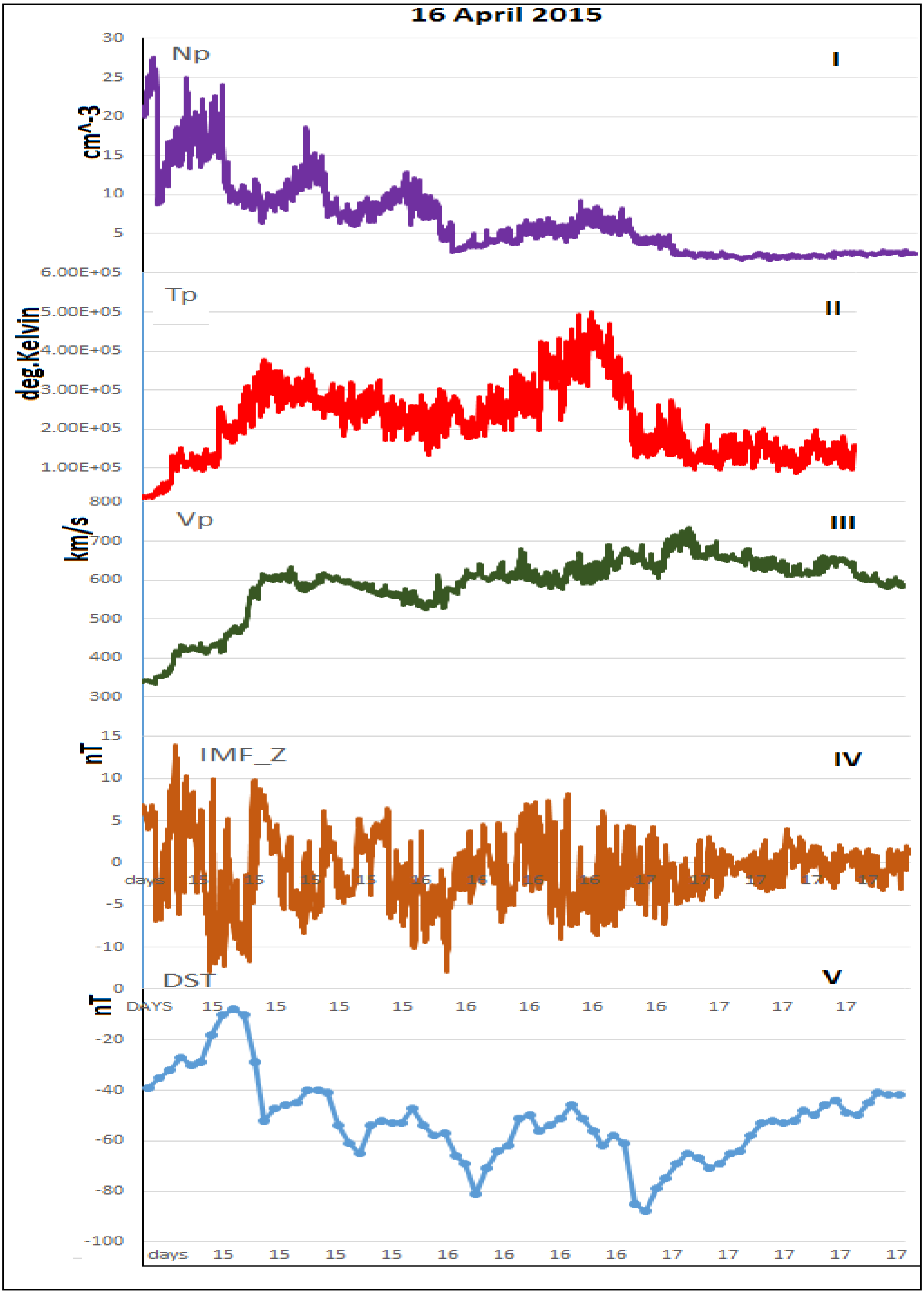

Fig. 9: Small geomagnetic storm for 16th April 2015

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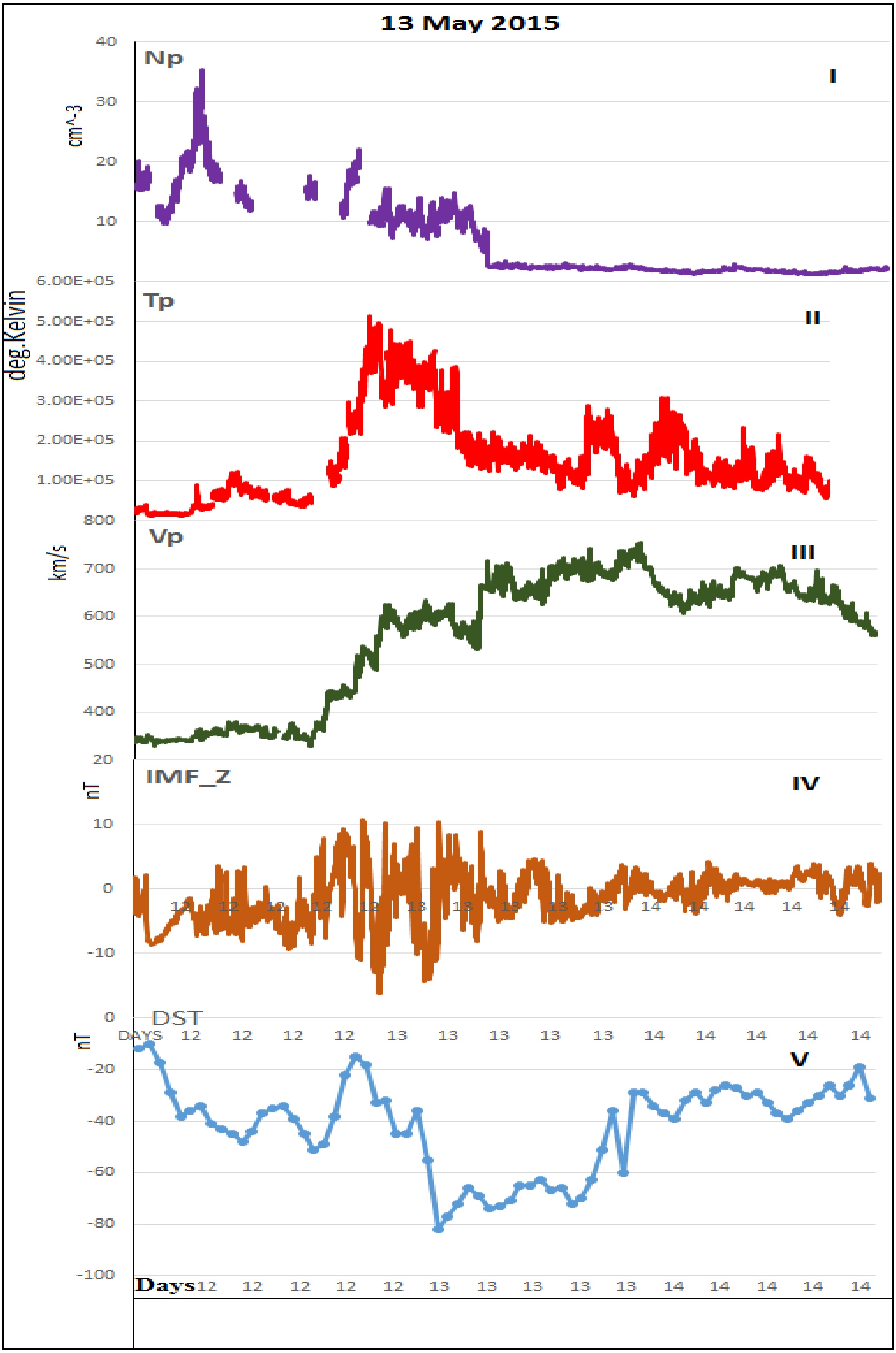

Fig. 10: Small geomagnetic storm for 13th May 2015

In each of the above figures there are five panels, panel I is proton density (N_p) in cm^{-3},panel II is proton temperature (T_P) in degree Kelvin, panel III is proton speed (V_p) in km/s, panel IV and V are vertical component of the interplanetary magnetic field (IMF_Z) and disturbed storm index (Dst) respectively, both measured in nT.Figure 9 is for a small geomagnetic storms. It shows solar proton density (Np) varying with ≈ 27.644cm^{-3} on 15 April 2015 at 0UTC, solar proton temperature (Tp) varying with value ≈ 5.00E+05 ^oK on 16 April 2015 at 22UTC,solar proton speed (Vp) varying with value ≈ 734.87kilometres per second on 17 April 2015 at 4UTC,then Interplanetary magnetic field (IMF_Z) varying with value ≈ -12.976nT on 15 April 2015 at 08UTC,geomagnetic storm (Dst) follows IMF varying with value ≈ -79nT on 16 April 2015 at 0UTC.Disturbed storm index(Dst) lags behind interplanetary magnetic field (IMF) by 16hour.Figure 10 is another small geomagnetic storm with solar proton density (Np) varying with ≈ 35.452 cm^{-3} on 13th May 2015 at 6 UTC, solar proton temperature (Tp) varying with value ≈ 5.16E+05^{o}Kon 13th May 2015 at 0UTC, solar proton speed (Vp) varying with value ≈ 755.09kilometres per second on 14th May 2015 at 1UTC, then Interplanetary magnetic field (IMF_Z) varying with value ≈ -16.157nT on 12th May 2015 at 23UTC, geomagnetic storm (DST) follows IMF varying with value ≈ - 76nT on 13th May 2015 at 07 UTCbut lags behind interplanetary magnetic field (IMF) by 8 hours.

VIII. CONCLUSION

Based on the data analysis it is found that Dst index is following the southward orientation of vertical component of interplanetary magnetic field with a range of 3-11UTC in intense geomagnetic storms, 0-5UTC in moderate geomagnetic storms and 8-16UTC in small geomagnetic storm. This means that the time delay between vertical component of interplanetary magnetic field and disturbed storm index is comparably highest in small geomagnetic storms and least in moderate geomagnetic storm. Thus the result obtained in this research shows clearly that the delay time between vertical interplanetary magnetic field and disturbed storm index can be used to predict the time interval between vertical interplanetary magnetic field and occurrence of storm, so that appropriate measures can be taken to avert or minimize its negative effects.

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