

Statistical Analysis of Jump in Solar Wind Plasma Parameter and Coronal Mass Ejections with Shock Related Geomagnetic Storms

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Abstract

Coronal Mass Ejections (CMEs) are the drastic solar events in which huge amount of solar plasma materials are ejected into the heliosphere from the sun and are mainly responsible to generate large disturbances in solar wind plasma parameters and geomagnetic storms in the geomagnetic field. We have studied geomagnetic storms, ($Dst \leq -90nT$) observed during the period of 1997-2012 with Coronal Mass Ejections and disturbances in solar wind plasma parameters (velocity). We have inferred that most of the geomagnetic storms are associated with halo and partial-halo Coronal Mass Ejections (CMEs). The association rate of halo and partial halo coronal mass ejections are found 75 % and 25 % respectively. Further, we have concluded that geomagnetic storms are closely associated with the disturbances in solar wind plasma parameters. We have determined a positive correlation between the magnitudes of geomagnetic storms and speed of CMEs with correlation coefficient 0.26. Further Positive co-relation has been found between the speed of CMEs and peak velocity of jump in solar wind plasma velocity. Statistically calculated co-relation coefficient is 0.31 between these two events. Again there is a Positive co-relation has been found between the speed of CMEs and magnitude of jump in solar wind plasma velocity with correlation coefficient 0.20. Furthermore, we observe the positive correlation between the magnitude of geomagnetic storms and the peak value of JSWV events and statistically calculated co-relation co-efficient is 0.42 between these two events. We have concluded that geomagnetic storms are mainly caused by Coronal Mass Ejections and disturbances in solar wind plasma parameters that they generate.

Introduction

Coronal Mass Ejections (CMEs) are the drastic solar events in which huge amount of solar plasma materials are ejected into the heliosphere from the sun and are mainly responsible to generate large disturbances in solar wind plasma parameters and geomagnetic storms in the geomagnetic field. CMEs from the Sun drive solar wind (SW) disturbances in terms of the magnetic field, speed, and density, which in turn cause a geomagnetic disturbance in Earth [1]. Several investigators have studied geomagnetic storms with various solar features, solar wind parameters and inferred that CMEs which are the energetic solar features and associated with active regions are responsible for the most geoeffective solar wind disturbances and, therefore, the largest storms and are well associated with geomagnetic storms [2,3,4,5]. Mcallister and Crooker [6] have studied the effects of solar and heliospheric phenomena on the geomagnetic field. Gopalswamy [7] has studied the role of halo and partial halo CMEs in producing geomagnetic storms.

Experimental Data

In this investigation, hourly Dst indices of geomagnetic field have been used over the period 1997 through 2012 to determine onset time, maximum depression time, the magnitude of geomagnetic storms. This data has been taken from the NSSDC Omni web data system which has been created in late 1994 for enhanced access to the near earth solar wind, magnetic field and plasma data of omni data set, which consists of one hour resolution near earth, solar wind magnetic field and plasma data, energetic proton fluxes and geomagnetic and solar activity indices. The data of coronal mass ejections (CMEs) have been taken from SOHO – large angle spectrometric, coronagraph (SOHO / LASCO) and extreme ultraviolet imaging telescope (SOHO/EIT) data. To determine disturbances in solar wind plasma parameters, hourly data of solar wind plasma velocity has been used and these data have also been taken from Omni web data also.

Data Analysis and Results

The association between geomagnetic storms of magnitude $< -90nT$ and coronal mass ejections (CMEs), and disturbances in solar wind plasma parameters for the period 1997 to 2012 are given in Table No.1. We have 54 geomagnetic storms in our list in which we have no data of CMEs for the association. From the data analysis, it is observed that 48 out of 54 (88.88%) geomagnetic storms $< -90nT$ are found to be associated

with coronal mass ejections. We have 54 geomagnetic storms in our list in which the CME data for the association is available for 48 geomagnetic storms. We have further observed that the majority of related CMEs are halo CMEs. We have 48 geomagnetic storms, which are associated with coronal mass ejections out of which 36 geomagnetic storms (75.00%) are related to the halo coronal mass ejections. Only 12 out of 48 (25.00%) geomagnetic storms are found to be associated with partial halo coronal mass ejections.

From the study of geomagnetic storms with disturbances in solar wind plasma parameters i.e. jump in solar wind plasma velocity, it is inferred that geomagnetic storms of higher magnitudes are found to be associated with such JSWV events, which have relatively higher jump magnitude of velocity. We have determined positive co-relation between magnitudes of geomagnetic storms and the peak value of jump in solar wind plasma velocity with correlation coefficient 0.42 (Figure-2).

To know the statistical behavior of shock related geomagnetic storms and CMEs we have plotted a scatter plot between the magnitude of geomagnetic storms and speed of CMEs and the resulting plot is shown in fig-3. We have observed the positive correlation between the magnitude of geomagnetic storms and the speed of associated CMEs with co-relation 0.26.

To see how the peak value of JSWV events is correlated with coronal mass ejections. We have plotted a scatter diagram between the speed of CMEs and peak value of associated JSWV events fig-4. From the trend line of the scatter plot between these two parameters, it may be concluded that there is a positive correlation between the peak value of JSWV events and speed of associated CMEs. Positive co-relation has been found between the speed of CMEs and peak velocity of jump in solar wind plasma velocity with co-relation coefficient 0.31.

To see how the magnitudes of JSWV events are correlated with speed of CMEs we have plotted a scatter diagram between the magnitude of jump in solar wind plasma velocity (JSWV) events and speed of associated CMES in fig-5. From the trend line of the scatter plot between these two parameters, it may be concluded that there is a positive correlation between magnitudes of JSWV events and speed of associated CMEs. Positive co-relation has been found between the speed of CMEs and magnitude of JSWV events with co-relation coefficient 0.20.

We have concluded that geomagnetic storms are mainly caused by Coronal Mass Ejections and disturbances in solar wind plasma parameters that they generate.

Table No.-1: Geomagnetic storms, CMEs, and Solar wind velocity.

| S. No. | Geomagnetic Storms $Dst \leq -90nT$ | | | | | Coronal Mass Ejections | | | | Solar wind velocity | | | |
|--------|-------------------------------------|------|-----|------|------------|------------------------|----------|-------------|-------|---------------------|------|------------------|--------------------|
| | DATE | Year | Day | Hour | Magni-tude | Date | Time | Type | SPEED | Day | Hour | Maximum velocity | Magn itude of jump |
| 1 | 10.01.1997 | 1997 | 10 | 2 | -101 | 06.01.1997 | 15:10:42 | Halo | 136 | 9 | 14 | 468 | 101 |
| 2 | 10.04.1997 | 1997 | 100 | 19 | -102 | 07.04.1997 | 14:27:44 | Halo | 878 | 99 | 19 | 473 | 196 |
| 3 | 15.05.1997 | 1997 | 135 | 5 | -115 | 12.05.1997 | 5:30:05 | Halo | 464 | 134 | 9 | 521 | 250 |
| 4 | 03.09.1997 | 1997 | 246 | 15 | -108 | 30.08.1997 | 1:30:35 | Halo | 371 | 245 | 21 | 560 | 252 |
| 5 | 30.12.1997 | 1997 | 364 | 2 | -95 | 26.12.1997 | 2:31:54 | Partia l | 197 | 363 | 4 | 394 | 112 |
| 6 | 17.02.1998 | 1998 | 48 | 11 | -114 | na | na | na | NA | 48 | 4 | 416 | 48 |
| 7 | 02.05.1998 | 1998 | 122 | 9 | -203 | 29.04.1998 | 16:58:54 | Halo | 1374 | 121 | 10 | 651 | 255 |
| 8 | 07.11.1998 | 1998 | 311 | 11 | -139 | 04.11.1998 | 7:54:06 | Halo | 523 | 310 | 21 | 639 | 256 |
| 9 | 28.02.1999 | 1999 | 59 | 17 | -94 | na | na | na | na | 59 | 4 | 412 | 76 |
| 10 | 16.04.1999 | 1999 | 106 | 15 | -156 | na | na | na | na | 105 | 15 | 462 | 89 |
| 11 | 12.09.1999 | 1999 | 255 | 7 | -103 | 10.09.1999 | 7:54:05 | Partia l | 1467 | 255 | 2 | 615 | 204 |

| | | | | | | | | | | | | | |
|----|------------|------|-----|----|------|------------|----------|-------------|------|-----|----|------|-----|
| 12 | 22.09.1999 | 1999 | 265 | 19 | -191 | 20.09.1999 | 6:06:05 | Halo | 604 | 265 | 2 | 602 | 250 |
| 13 | 21.10.1999 | 1999 | 294 | 23 | -257 | 19.10.1999 | 5:50:05 | Partia l | 753 | 293 | 23 | 678 | 342 |
| 14 | 22.01.2000 | 2000 | 22 | 14 | -98 | 18.01.2000 | 17:54:05 | Halo | 739 | 21 | 22 | 403 | 72 |
| 15 | 15.07.2000 | 2000 | 197 | 15 | -308 | 14.07.2000 | 10:54:07 | Halo | 1674 | 197 | 13 | 1107 | 497 |
| 16 | 15.09.2000 | 2000 | 259 | 19 | -221 | 12.09.2000 | 17:30:05 | Halo | 1053 | 259 | 1 | 401 | 78 |
| 17 | 13.10.2000 | 2000 | 287 | 14 | -100 | 11.10.2000 | 6:50:05 | Partia l | 799 | 286 | 16 | 469 | 155 |
| 18 | 28.10.2000 | 2000 | 302 | 20 | -142 | 25.10.2000 | 8:26:05 | Halo | 770 | 302 | 5 | 415 | 104 |
| 19 | 04.11.2000 | 2000 | 309 | 3 | -194 | 01.11.2000 | 16:26:08 | Halo | 801 | 308 | 17 | 559 | 231 |
| 20 | 10.11.2000 | 2000 | 315 | 7 | -102 | 08.11.2000 | 4:50:23 | Halo | 474 | 314 | 10 | 925 | 512 |
| 21 | 27.03.2001 | 2001 | 86 | 19 | -123 | 25.03.2001 | 17:06:05 | Halo | 677 | 85 | 19 | 644 | 325 |
| 22 | 31.03.2001 | 2001 | 90 | 3 | -413 | 29.03.2001 | 10:26:05 | Halo | 942 | 89 | 19 | 771 | 370 |
| 23 | 18.04.2001 | 2001 | 108 | 1 | -106 | 15.04.2001 | 14:06:31 | Partia l | 1199 | 107 | 23 | 518 | 162 |
| 24 | 17.08.2001 | 2001 | 229 | 12 | -149 | 15.08.2001 | 23:54:05 | Halo | 1575 | 229 | 9 | 599 | 264 |
| 25 | 25.10.2001 | 2001 | 298 | 10 | -162 | 22.10.2001 | 15:06:05 | Halo | 1336 | 298 | 7 | 449 | 95 |
| 26 | 05.11.2001 | 2001 | 309 | 18 | -314 | 04.11.2001 | 16:35:06 | Halo | 1810 | 308 | 18 | 426 | 114 |
| 27 | 24.11.2001 | 2001 | 328 | 6 | -223 | 22.11.2001 | 23:30:05 | Halo | 1437 | 327 | 12 | 1040 | 612 |
| 28 | 29.12.2001 | 2001 | 363 | 22 | -91 | 28.12.2001 | 20:30:05 | Halo | 2216 | 362 | 23 | 570 | 213 |
| 29 | 23.03.2002 | 2002 | 82 | 14 | -107 | 22.03.2002 | 11:06:05 | Halo | 1750 | 82 | 5 | 504 | 114 |
| 30 | 17.04.2002 | 2002 | 107 | 11 | -149 | 15.04.2002 | 3:50:05 | Halo | 720 | 107 | 6 | 611 | 286 |
| 31 | 11.05.2002 | 2002 | 131 | 13 | -103 | 08.05.2002 | 13:50:05 | Halo | 614 | 131 | 8 | 522 | 181 |
| 32 | 23.05.2002 | 2002 | 143 | 11 | -172 | 21.05.2002 | 21:50:05 | Partia l | 853 | 142 | 12 | 871 | 473 |
| 33 | 8/1/2002 | 2002 | 213 | 10 | -98 | 7/29/2002 | 23:30:05 | Partia l | 360 | 213 | 0 | 524 | 157 |
| 34 | 30.09.2002 | 2002 | 273 | 1 | -179 | 26.09.2002 | 1:31:44 | Partia l | 178 | 273 | 0 | 370 | 80 |
| 35 | 17.08.2003 | 2003 | 229 | 14 | -175 | 14.08.2003 | 20:06:05 | Halo | 378 | 229 | 13 | 530 | 105 |
| 36 | 20.11.2003 | 2003 | 324 | 2 | -417 | 18.11.2003 | 8:50:05 | Halo | 1660 | 324 | 2 | 703 | 262 |
| 37 | 03.04.2004 | 2004 | 94 | 14 | -113 | na | na | na | na | 93 | 17 | 515 | 143 |
| 38 | 22.07.2004 | 2004 | 204 | 18 | -115 | 20.07.2004 | 13:31:52 | Halo | 710 | 204 | 9 | 672 | 312 |
| 39 | 30.08.2004 | 2004 | 243 | 5 | -116 | na | na | na | na | 243 | 17 | 435 | 63 |
| 40 | 07.11.2004 | 2004 | 312 | 19 | -415 | 04.11.2004 | 9:54:05 | Halo | 653 | 312 | 2 | 730 | 418 |
| 41 | 28.05.2005 | 2005 | 148 | 11 | -155 | 26.05.2005 | 15:06:05 | Halo | 586 | 148 | 1 | 464 | 185 |
| 42 | 12.06.2005 | 2005 | 163 | 16 | -110 | na | na | na | na | 163 | 4 | 503 | 199 |
| 43 | 10.07.2005 | 2005 | 191 | 11 | -100 | 09.07.2005 | 22:30:05 | Halo | 1540 | 190 | 19 | 474 | 148 |
| 44 | 24.08.2005 | 2005 | 236 | 6 | -248 | 22.08.2005 | 17:30:05 | Halo | 2378 | 236 | 0 | 721 | 309 |
| 45 | 14.04.2006 | 2006 | 104 | 0 | -111 | 10.04.2006 | 6:06:04 | Partia l | 183 | 103 | 0 | 546 | 165 |
| 46 | 14.12.2006 | 2006 | 348 | 14 | -155 | 13.12.2006 | 2:54:04 | Halo | 1774 | 348 | 9 | 896 | 333 |
| 47 | 05.08.2011 | 2011 | 217 | 19 | -142 | 04.08.2011 | 4:12:05 | Halo | 1315 | 216 | 20 | 605 | 255 |
| 48 | 09.09.2011 | 2011 | 252 | 13 | -109 | 07.09.2011 | 18:48:05 | Partia l | 924 | 252 | 10 | 560 | 247 |
| 49 | 17.09.2011 | 2011 | 260 | 7 | -94 | 15.09.2011 | 0:00:06 | Partia l | 530 | 260 | 1 | 549 | 185 |

| | | | | | | | | | | | | | |
|----|------------|------|-----|----|------|------------|----------|-------------|------|-----|----|-----|-----|
| 50 | 26.09.2011 | 2011 | 269 | 13 | -136 | 24.09.2011 | 12:48:07 | Halo | 1915 | 269 | 9 | 704 | 374 |
| 51 | 24.10.2011 | 2011 | 297 | 21 | -157 | 22.10.2011 | 10:24:05 | Halo | 1005 | 296 | 21 | 534 | 223 |
| 52 | 07.03.2012 | 2012 | 67 | 0 | -140 | 05.03.2012 | 4:00:05 | Halo | 1531 | 66 | 4 | 592 | 231 |
| 53 | 23.04.2012 | 2012 | 114 | 15 | -119 | 19.04.2012 | 15:12:09 | Partia l | 540 | 113 | 20 | 501 | 205 |
| 54 | 17.06.2012 | 2012 | 169 | 0 | -151 | 14.06.2012 | 14:12:07 | Halo | 987 | 168 | 3 | 519 | 222 |

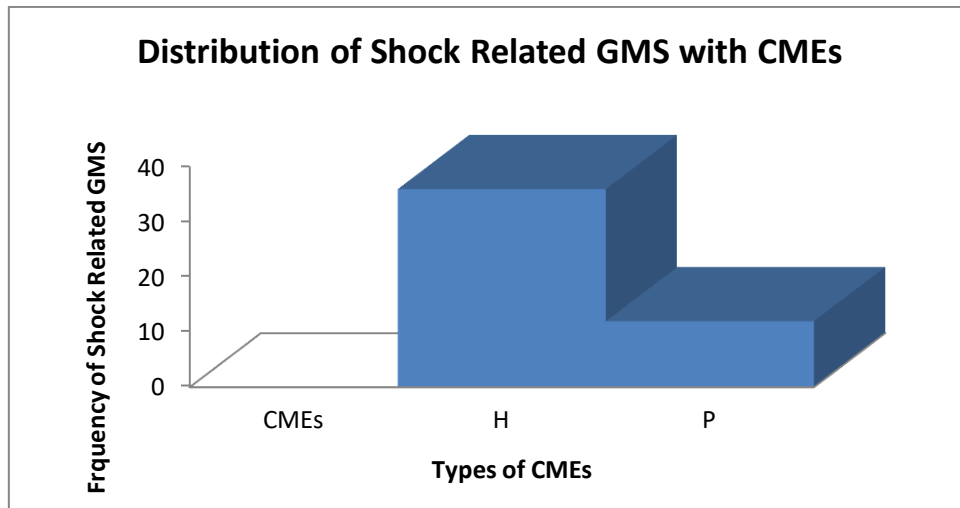


Figure-1 Distribution of shock related geomagnetic storms with coronal mass ejections.

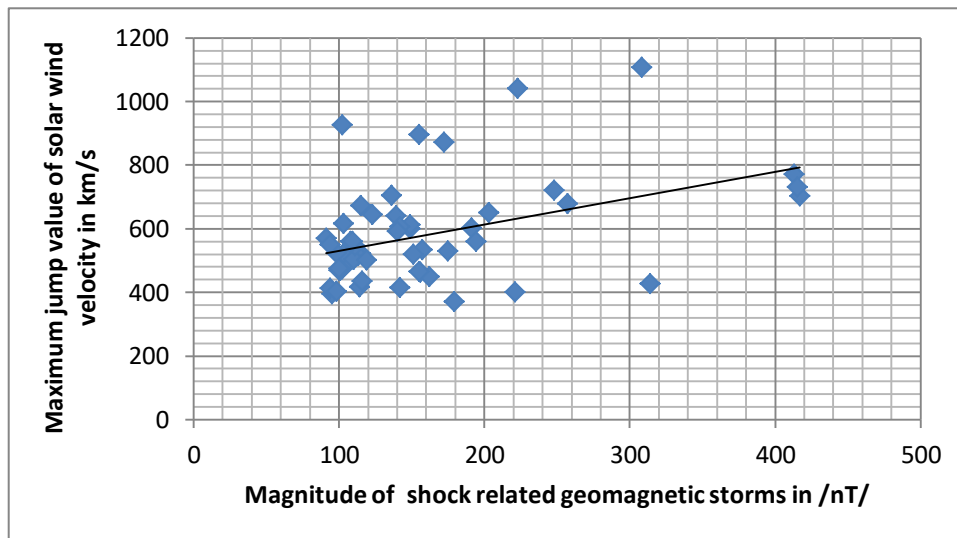


Figure-2 shows the scatter plot between magnitudes of shock related geomagnetic storms and the peak value of associated jump in solar wind plasma velocity.

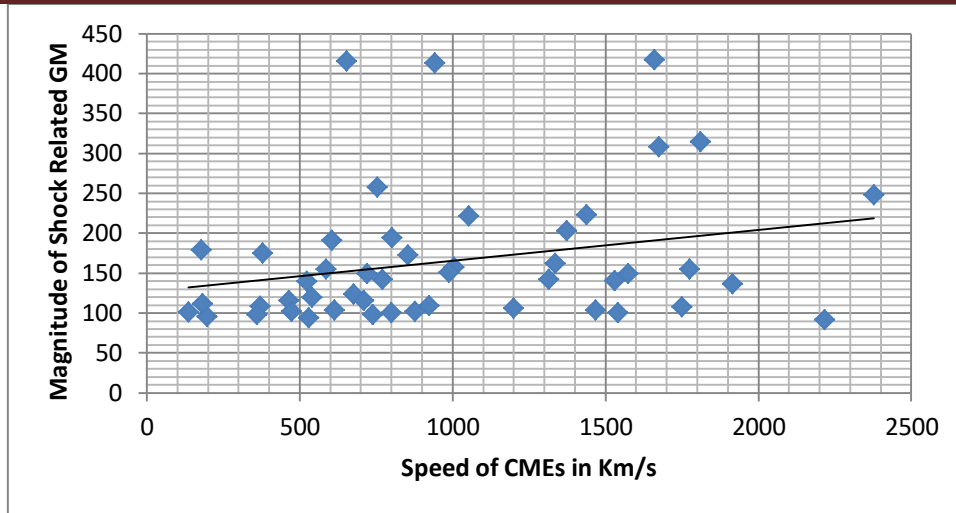


Figure-3 The figure shows a scatter plot between the speed of CMEs and magnitude of shock related geomagnetic storms.

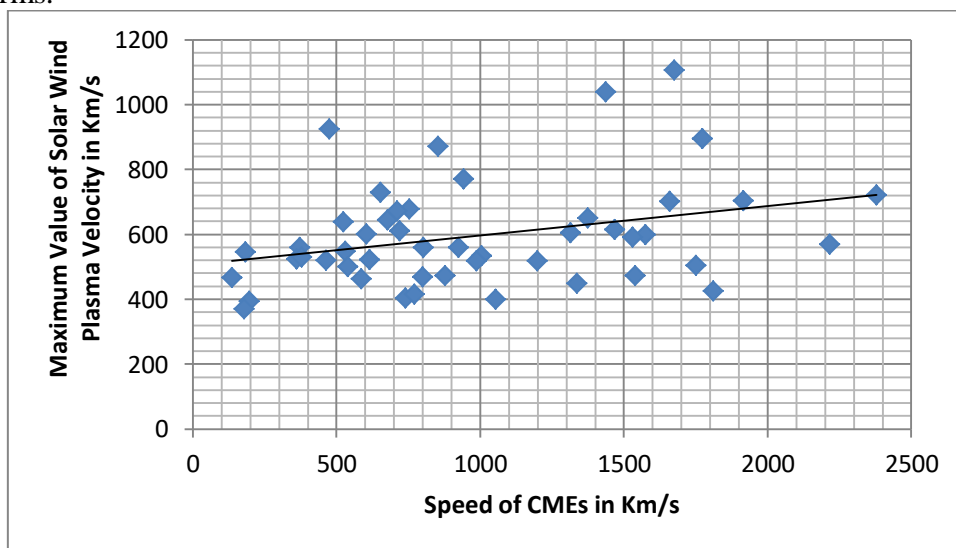


Figure-4 The figure shows a scatter plot between the speed of CMEs and peak value of JSWV events associated with shock-related GMS.

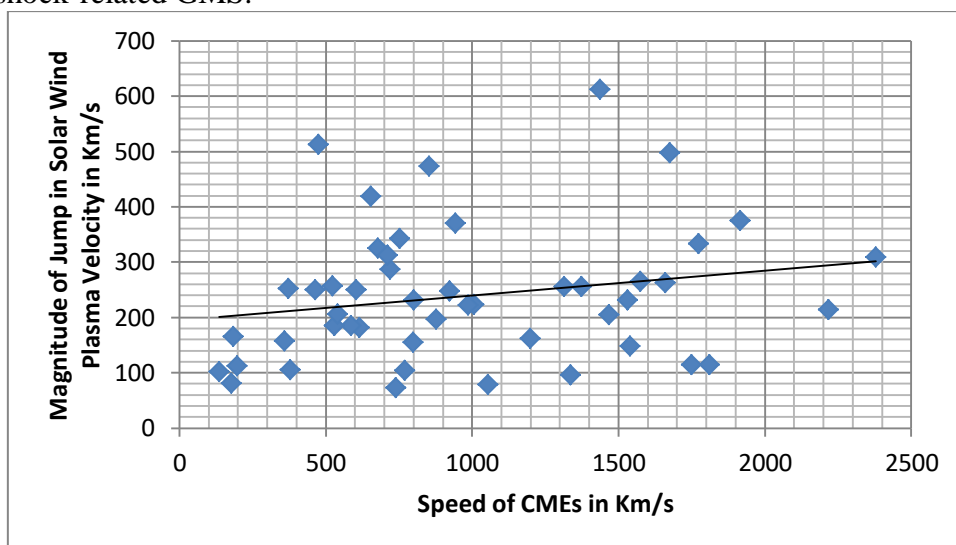


Figure-5 The figure shows a scatter plot between magnitudes of JSWV associated with shock-related GMS and speed of CMEs.

Conclusion

From our study 48 out of 54 geomagnetic storms $< -90\text{nT}$ have been identified as being associated with coronal mass ejections (88.88%), 36 out of 48 have been identified as being associated with halo coronal mass ejections and 12 out of 48 as being associated with partial halo coronal mass ejections. The association rates for halo and partial halo CMEs are found 75.00% and 25.00% respectively. The positive correlation between the magnitude of geomagnetic storms and the peak value of jump in solar wind plasma velocity suggest that coronal mass ejections and disturbances in solar wind plasma parameters play a crucial role in producing geomagnetic storms.

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