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Solar Wind Dynamic Pressure Dependency on the Plasma Flow Speed and Imf Bz During Different Geomagnetic Activities

Olufemi B ADEBESIN *, Oluwole S IKUBANNI, Stephen J KAYODE

ABSTRACT [ENGLISH/ANGLAIS]

In this paper, the dependency of the solar wind dynamic pressure P (nPa) on the plasma flow speed (km/s) and the Interplanetary Magnetic Field (IMF) Bz during the initial and main phase, as well as during peak plasma flow speed (Vmax) values of 9 'Intense' (-250 nT ≤ peak Dst < -100 nT) and 11 'very intense' (peak Dst < -250 nT) geomagnetic storms had been presented. Moreover, this work ascertains the difference in the dependency of the dynamic pressure with the aforementioned parameters during 'intense' (I) and 'very intense' (V-I) storms. The results revealed that (i) the solar wind dynamic pressure is highly dependent on the southward IMF Bz during the main phase of a storm, mostly when the plasma flow speed value is very large, i.e. exceeding the 550km/s ambient value, and the Dst < -250 nT, (ii) the dynamic pressure enhancement during enhanced solar wind speed flow, and under a southward Bz that flows steadily would always produce an intense storm, (iii) for 'intense' conditions, IMF Bz is the most important factor to be considered during storm onset, whereas the flow speed is the most considered factor with regards to 'very intense' storms; when considering their dependency with the dynamic pressure, and (iv) the more the intensity of a storm, the larger the simultaneous enhancement in dynamic pressure.

Keywords: Solar wind dynamic pressure, geomagnetic storms, Interplanetary Magnetic Field, plasma flow speed

RÉSUMÉ [FRANÇAIS/FRENCH]

Dans cet article, la dépendance de l'énergie solaire P vent pression dynamique (NPA) sur la vitesse d'écoulement du plasma (km / s) et le champ magnétique interplanétaire(FMI) Bz pendant la phase initiale et principale, ainsi que lors de la vitesse d'écoulement pic plasmatique (Vmax) des valeurs de 9 'intense' (-250 nT ≤ pic Dst<-100 nT) et 11 «très intense» (pic Dst <-250 nT) orages géomagnétiques ont été présentés. En outre, ce travail détermine la différence de la dépendance de la pression dynamique avec les paramètres ci-dessus au cours de «intenses» (I) et «très intense»(VI) des tempêtes. Les résultats ont révélé que: (i) la pression dynamique du vent solaire est très dépendante sur le sud Bz FMI au cours de la phase principale d'une tempête, la plupart du temps lorsque la valeur de la vitesse d'écoulement du plasma est très grand, c'est à dire supérieure à la / 550 km s la valeur ambiante, et le Dst <-250 nT,(ii) l'augmentation de la pression dynamique au cours de renforcement de l'écoulement du vent solaire vitesse, et en vertu d'un Bz qui coule vers le sud progressivement serait toujours produire un orage intense, (iii) pour «intense» conditions, le FMI Bz est le plus important facteur à considérer lors de survenue de l'orage, alors que la vitesse d'écoulement est considéré comme le facteur le plus en ce qui concerne des tempêtestrès intenses des; lors de l'examen de leur dépendance à la pression dynamique, et (iv)plus l'intensité d'une tempête, la plus grande de la l'amélioration simultanée de la pression dynamique.

Mots-clés: Vent solaire pression dynamique, orages géomagnétiques, champ magnétique interplanétaire, la vitesse d'écoulement du plasma

Affiliations:
Department of Physics, College of Science & Engineering, Landmark University, Omu Aran, Kwara State, NIGERIA

Email Address for Correspondence/ Adresse de courriel pour la correspondance: f_adebesin@yahoo.co.uk

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INTRODUCTION

The earth's magnetosphere is a highly dynamic structure that responds quite dramatically to changes in the dynamic pressure of the solar wind and the orientation of the interplanetary magnetic field (IMF). Its ultimate source of energy is the interaction with the solar wind. Some of the energy extracted from this interaction goes directly into driving various magnetospheric processes, while some is stored in the magnetotail, to be released later in substorms. The principal means by which energy is transferred from the solar wind to the magnetosphere is a process known as "reconnection", which occurs when the IMF is oriented anti-parallel to the orientation of the earth's field lines. This orientation allows interplanetary and geomagnetic field lines to merge, resulting in the transfer of energy, mass and momentum from the solar wind to the magnetosphere.

The variations of solar wind dynamic pressure are known to affect the energy and momentum transfer from the solar wind to the magnetosphere-ionosphere system. To this respect, two important factors are the rise time and the duration of the pressure perturbation. For short rise times strong transient perturbations are observed both in the magnetosphere and in the ionosphere until a new location of the magnetopause boundary is established. [1] and references therein. On the other hand, the duration of a pressure perturbation determines whether the effects will be localized or global. If the duration is long enough to engulf most of the magnetosphere in the solar wind region of enhanced/reduced pressure, the pressure variation causes typical global increases of the geomagnetic field strength measured at the geostationary orbit, and on the ground at equatorial and middle latitudes, which are usually called Sudden Commencements (SC) or Sudden Impulses (SI), depending on whether they are followed by a geomagnetic storm (SC), or not (SI); in such cases, often one refers to the pressure variation itself as an SI,

The solar wind dynamic pressure P_{sw} could be regarded as a function of the solar wind particle density, and is expressed mathematically as

$$P_{sw} = Nm_p v^2 \qquad (1)$$

where N is the solar wind particle density, m_p the proton mass, and v the flow speed or solar wind velocity

This paper is however targeted at investigating the dependency of the solar wind dynamic pressure on the plasma flow speed and Interplanetary Magnetic Field (IMF) Bz in GSM; during the onset or initial phase and the main phase of Geomagnetic storms, as well as during peak plasma flow speed values for the intense storms under investigation.

In an earlier work by [2], in identifying the variation between Dst and IMF Bz during 'intense' and 'very intense' geomagnetic storms, it was observed that 'very intense' storms are more likely to experience shock in the interplanetary magnetic field region faster than 'intense storms with a flow speed > 400 km/s. It was also observed that 'intense storms recover faster than the 'very intense ones. However in another work by [3] while investigating the roles being played by both interplanetary and geomagnetic parameters in general in the generation of 'intense' and 'very intense' storms and their geoeffectiveness, it was argued that all 'very intense' storms are likely to have a plasma flow speed greater than 550 km/s within the storm interval, but not all flow speed greater than 550 km/s are 'very intense' storms. Hence, this paper is also set to ascertain whether there is going to be a difference in the dependency of the dynamic pressure with the aforementioned parameters during intense' (-250 nT ≤ peak Dst < -100 nT) and 'very intense' (peak Dst < -250 nT) geomagnetic storms.

THE SIGNIFICANCE OF SOLAR WIND DYNAMIC PRESSURE IN THIS STUDY

The effect of the Interplanetary Magnetic Field (IMF) Bz component on magnetospheric activity has been extensively documented in the past. The activity minimizes under northward IMF (Bz $\geq$ 0), while it increases with increasing magnitude of southward IMF (Bz < 0) as evidenced, for example, by both the AE index and the cross-polar-cap potential [4] and the references therein. On the other hand, much less attention has been given to the effect of the solar wind dynamic pressure on magnetospheric activity, and therefore its role has not been clearly established. In recent years several studies have assessed the response of the magnetosphere to changes in the solar wind dynamic pressure [5, 6] and references therein. A notable feature in many of these studies is the dependence of the pressure-induced magnetospheric response to the preexisting IMF orientation. A pressure enhancement occurring under steady southward IMF conditions produces a prominent and easily observable response. In contrast, under northward IMF (or near-zero IMF Bz) a similar dynamic pressure change induces a weaker response in the magnetosphere.

Sudden enhancements of solar wind dynamic pressure have been shown to have very different effect on all magnetospheric current systems under northward or southward IMF. [7] and references therein. For southward IMF, all current systems exhibit an increase in magnitude and strong correlation with the solar wind density, while when the IMF is northward their response is weaker. The geosynchronous magnetic field also exhibits different behavior for different IMF orientations after a solar wind pressure front impact. [6] showed that for southward IMF the field undergoes a general compression on the dayside and a strong dipolarization-like change on the nightside. For northward IMF a compression of the entire magnetosphere was observed with a few cases of depression near midnight.

DATA, PLOTS AND OBSERVATIONS

The paper is aimed at investigating the dependence of the solar wind dynamic pressure on the plasma flow speed and Interplanetary Magnetic Field (IMF) Bz in GSM; during the onset or initial phase and the main phase of Geomagnetic storms, as well as during peak plasma flow speed values for the 20 geomagnetic storms under investigation. Moreover, to also ascertain whether there is going to be a difference in the dependency of the dynamic pressure with the aforementioned parameters during 'intense' (-250 nT ≤ peak Dst < -100 nT) and 'very intense' (peak Dst < -250 nT) storms. The Interplanetary and Solar wind parameters data used in this work are 1-hour averages from NASA NSSDC OMNI data set. The testing tool for the analysis is the Pearson correlation coefficient.

The OMNI database includes a compilation of the hourly resolutions of the IMF Bz, solar wind plasma data, and some solar and geomagnetic activity indices. It is a convenient and widely used source for the study of geomagnetic storms. On the overall, 9 'intense' and 11 'very intense' storms are being considered. However, two of the storms are double steps (i.e Oct 3-5, 2001 and Oct 20, 1989 storms) thereby having two minimum peak values for Dst (nT). The storm dates and their corresponding Interplanetary and Solar wind parameters values are highlighted in Table 1. The plot interval spans five days (the storm day, two days before and two days after the storm). On the whole, only four storm dates are discussed extensively under this section because of space consideration – 2 'Intense' storm dates (Figures 1 & 2), and 2 'very intense' storm dates (Figures 5 & 7). However, the other storms observational values are also summarized in Table 1. Note that the line XX' marks Storm sudden commencement (SSC), line YY' marks point of minimum peak Dst value, and PP' marks point of maximum flow speed (i.e Vmax).

July 15-16, 2000 Storm

Figure 1 shows the response of Geomagnetic and Solar wind parameters for July 13-17, 2000. This kind of event, according to [8] is known as the 'Bastilla event', in which case it consists of an interplanetary shock driven by a magnetic cloud, whose intense magnetic field rotates from south to north smoothly. While the Bz is pointing southward, it causes a very intense fall in the Dst value, reaching its minimum peak value of -301 nT. It should be noted that immediately after the shock, as indicated by line XX'; there was a sudden rise in the plasma temperature, plasma density and the plasma dynamic pressure, as well as an increase in the value of the flow speed to ~880 km/s. On July 13 the solar wind shows a fairly flat, although high, speed with a falling density and temperature. The dynamic pressure goes from over 6 nPa near 1800 UT to around 2 nPa towards the end of the day.

On the 14th day, the plasma parameters stay fairly flat until about 1530 UT when there is a clear forward shock with a speed increase to over 700 km/s. This is followed by a sudden density increase and temperature decrease near 1700 UT. At the end of the day, the dynamic pressure is around 17 nPa. On the 15th, there is a declining speed until a large forward shock arrives near 1400 UT. This shock is clearly identified by the abrupt and strong speed increase from about 600 km/s to over 900 km/s. This shock has a strong density and stronger temperature enhancement. The dynamic pressure reaches about 43 nPa . At 1600 UT there is a further increase in the speed, while the density and temperature have declined markedly. Unfortunately, there is a tracking gap after 2000 UT. On the 16th day, the speed continues to be quite high, with a substantial decrease around 0140 UT and lasting until 0210 UT. During this decrease the density also falls, resulting in a dynamic pressure drop to below 1 nPa. The pressure afterwards is about 6.5 nPa. At 0500 UT, IMP first enters the magnetosheath. However, there are still occasional solar wind periods until as late as 1311 UT, when the dynamic pressure is down to over 5 nPa

September 22, 1999 Storm

The plot of the response of the Interplanetary and Solar wind parameters is indicated in Figure 2. It spans September 20 through 24. The Bz plot shows that there was a southward turning of Bz between 00:00UT on September 21 and 02:00UT on September 22 to a first minimum value of -7.5nT indicating that the IMF has experienced over 20 hours of southward component. It thereafter experiences northward turning up till around 17:00UT on September 22. It should be noted that the Storm Sudden Commencement (SSC) which is an indicative of the arrival of a shock in the Interplanetary medium must have triggered the depression of Dst beginning from 18:00 UT and caused the sharp southward turning of Bz at 18:00UT of the same day to a minimum peak value of -15nT. At around 20:00UT, Bz had rotated northward again attaining a -4nT value, fall shortly, and continues in the northward direction again throughout September 23 and 24.

The plasma temperature plot shows a relatively low temperature. However, with effect from 07:00UT on September 22, there came along an abrupt rise in temperature to a peak value of 275000K, drops a while and then rose again to its second consecutive peak values of 325000K at 19:00UT on September 22. Thereafter,

Table 1: This table shows the storm dates and their corresponding Interplanetary and Solar wind parameters values showing (i) solar wind dynamic pressure values and corresponding flow speed, IMF Bz in GSM during the Storm Onset period (ii) with the Dst minimum peak values during the Storms Main phase and (iii) during Peak flow speed period. Note: N/A stands for unavailability of data during the period

						Storm Onset Values			Main Phase Values				At Peak V(km/s) Values			
Storm Date	Plot internal	Peak Dst (nT)	Nature	Step	H.Position	P (nPa)	V (km/s)	Bz (nT)	P (nPa)	V (km/s)	Bz (nT)	Dst (nT)	P (nPa)	V (km/s)	Bz (nT)	Dst (nT)
1-Oct-2002	29 Sept-3 Oct	-176	Intense	Single	N13E45	N/A	296	-1.8	5.64	396	-15.8	-176	5.66	516	-1.5	-73
3-Apr-1990	1-5 Apr	-187	Intense	Single	-	1.43	488	-0.8	9.65	573	-0.1	-187	4.09	616	6.2	-93
3-5 Oct 2001	2-6 Oct	-148	Intense	Double	-	3.11	507	4.1	3.60	465	-9.8	-148	5.03	573	4.1	-116
		-166	Intense		-	3.11	507	4.1	1.48	520	-12.5	-166	5.03	573	4.1	-116
6-Apr-2000	4-8 Apr	-287	V .Intense	Single	N16W66	9.00	368	-15.3	10.62	567	-25	-287	1.72	625	5.1	-161
8-Sep 2002	6-10 Sept	-181	Intense	Single	N09W28	1.12	357	-6.2	4.40	506	-10.1	-181	7.38	550	-21.5	-138
8-Nov-1991	5-9 Nov	-354	V. Intense	Single	-	N/A	N/A	0.0	N/A	N/A	-21.8	-354	6.06	628	N/A	-258
11-Apr-2001	9-13 Apr	-271	V. Intense	Single	S21W04	6.74	612	-6.2	7.36	721	-8.9	-271	12.92	832	-6.9	-14
14-Jul-1982	12-16 July	-325	V. Intense	Single	-	28.70	928	-6.5	N/A	N/A	-5.7	-325	9.97	986	-9.6	-313
15-May-2005	13-17 May	-263	V. Intense	Single	N12E12	0.00	510	5.0	N/A	878	-10.7	-263	N/A	926	25.8	-197
20-Oct-1989	18-22 Oct	-202	Intense	Double	-	1.45	487	-1.9	3.76	638	-4.4	-202	3.36	918	-4.4	-156
			V. Intense		-	N/A	N/A	N/A	N/A	N/A	-7.2	-268	3.36	918	-4.4	-156
20-Nov-2003	18-22 Nov.	-422	V. Intense	Single	N00E18	1.88	441	-1.1	10.79	550	-17.7	-422	7.06	703	-24	-100
21 Mar 1990	19-23 Mar.	-136	Intense	Single	-	15.23	489	-12.5	N/A	N/A	6.4	-136	4.85	594	11.4	-98
22 Sept. 1999	20-24 Sept.	-173	Intense	Single	-	13.39	538	-15.0	7.09	588	-4.9	-173	17.8	594	-13.8	-127
22 Oct. 1999	20-24 Oct.	-237	Intense	Single	-	5.27	472	-2.2	11.18	548	-20.1	-237	2.74	676	1.6	-166
22 Oct. 2001	20-24 Oct.	-292	V. Intense	Single	N16W18	N/A	312	-31.6	N/A	N/A	-7.2	-292	1.88	716	-5.4	-173
31 Mar. 2001	29 Mar-2 Apr	-387	V. Intense	Single	N19W75	22.04	703	-21.6	17.99	644	-19.4	-387	2.31	809	-5.3	-161
29 Sept. 1978	27 Sept-1 Oct	-224	Intense	Single	-	4.99	610	4.5	2.02	821	-24.3	-224	3.87	906	-18.6	-121
30 Oct. 2003	28 Oct-1 Nov	-353	Intense	Single	S21E88	3.95	607	-13.4	N/A	N/A	-13.9	-353	1.73	1189	19.6	-241
15 Dec. 2006	13-17 Dec	-146	Intense	Single	S06W24	8.51	896	-2.2	0.79	737	-8.6	-146	8.51	896	-2.2	2
15-16 Jul 2000	13-17 July	-301	V. Intense	Single	N17E01	30.15	858	-8.5	4.30	1012	8.3	-301	17.65	1107	-23.7	-281

plasma temperature decreased gradually to a value less than 50000K and even through September 23, 1999. The plasma density plot shows negligible effect until around 18:00UT on September 21 to a value of ~15.0/cm^3. This increase, according to [3] and the reference therein signifies the arrival of a shock in the interplanetary medium. However, beginning from around 11:00UT on September 22, there was a rapid increase in the density which gets to a peak value of 46.3/cm^3 at 13:00UT. This appears to indicate the presence of CME ejecta containing a magnetic cloud.

Table 2: This table shows observed Correlation coefficient values for Intense and Very-Intense Storm conditions

	ONSET		MAIN PHASE			PEAK FLOW SPEED		
	P vs V	P vs Bz	P vs V	P vs Bz	P vs Dst	P vs V	P vs Bz	P vs Dst
Intense	0.3018	0.7273	0.3481	0.1239	0.4826	0.1925	0.3987	0.1671
Very Intense	0.854	0.4013	0.6473	0.7349	0.6012	0.3371	0.6589	0.0971

The flow speed plot shows a moderate speed stream from 0000UT on September 21 to 12:00UT on September 22. The stream got to a peak value of 450km/s at 13:00UT on September 22. Thereafter, it maintains a steady value and then increases again to its second peak value of 590km/s at 20:00UT on September 22. It is obvious that throughout September 21 till 18:00UT on September 22, the flow speed never attained the 500km/s, in which case it could never met the criterion of fast solar winds. However, it should be pointed out that still yet, geomagnetic storm should occur at the solar wind speed shown in the plot.

The Dst plot indicates that beginning from 18.00UT of September 22, 1999, Dst was depressed sharply to a minimum peak value of 185nT at 19:00UT. Thereafter, Dst recovers rather gradually throughout the 23rd. However, the plot is indicative of a double step storm in which Dst reached its lowest value in the second step. The duskward electric field plot shows that starting from 00:00UT on September 21 to 15:00UT on September 22, the electric fields were less than 5.00mV/m. but as from 19:00UT on September 22, it began a gradual increase getting to a value of 10.00m V/m two hours later. Hence, these electric field conditions which gave Bz > 10nT are indicative of an intense storm. It was also observed that the dynamic pressure experiences its peak value at the instance the interplanetary medium experiences shock through the ring current intensification. This also coincides to the point of maximum flow speed value, as indicated by the line PP'

April 6, 2000 Geomagnetic Activity

Figure 3 is a composition of the solar and geomagnetic observations from April 4 to 8.The parameters are presented using the universal time. This is a kind of storm which originates from an interplanetary shock wave. This shock wave is being caused by a solar Coronal Mass Ejection (CME) as indicated by the plot of the Solar wind velocity in the fourth panel of figure 3. The solar wind was shown as it jumps from 375 km/s around 1400UT on April 6 to nearly 600km/s around 1900UT of the same day, marking the passage of an interplanetary shock wave caused by a CME. Immediately after the shock, as presented by line XX' on the figure, the Bz turns southward and is intensified because of a compression of the sheath region, and remaining like that for close to 16 hours. This makes the Dst reach its minimum peak value of approximately -287nT.

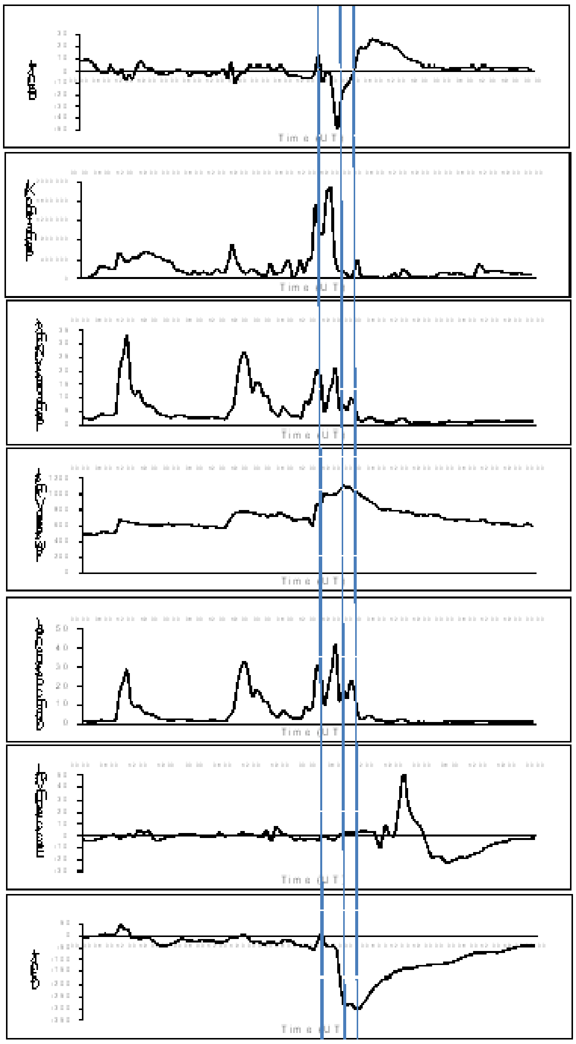
However, according to [8], no ejecta structure is observed after the shock, indicating that perhaps the probing satellite did not actually intercept the middle of the structure. It should be noted that sudden outburst of the solar wind dynamic pressure aggravated the rising in the value of the Plasma temperature, which rose to its maximum level. This also coincides with the Bz symmetry pointing southward as well as the increase in plasma flow speed. However, as the B_z (southward pointed) value becomes more negative, the associated geomagnetic activity increases.

September 8, 2002 Storm

The Response plot for September 8, 2002 was indicated in figure 4, and spans through Sept. 6-10. It should be noted that around 17:00UT of 7th September, when the IMF Bz recorded its minimum peak value of -22nT, both the plasma density, plasma temperature, plasma flow speed and the solar wind dynamic pressure first enhancement values, indicating a shock before the storm sudden commencement SSC. Furthermore, the abrupt northward rotation/orientation of Bz at 22:00UT on the 8th day is a reflective of the recovery state of the storm through September 9. This is also evident with the sharp fall in plasma temperature through this period. Observed that the Electric field value is not up to 5.00 mV/m, up till 16:00UT on September 7, confirming that Bz < 10nT.

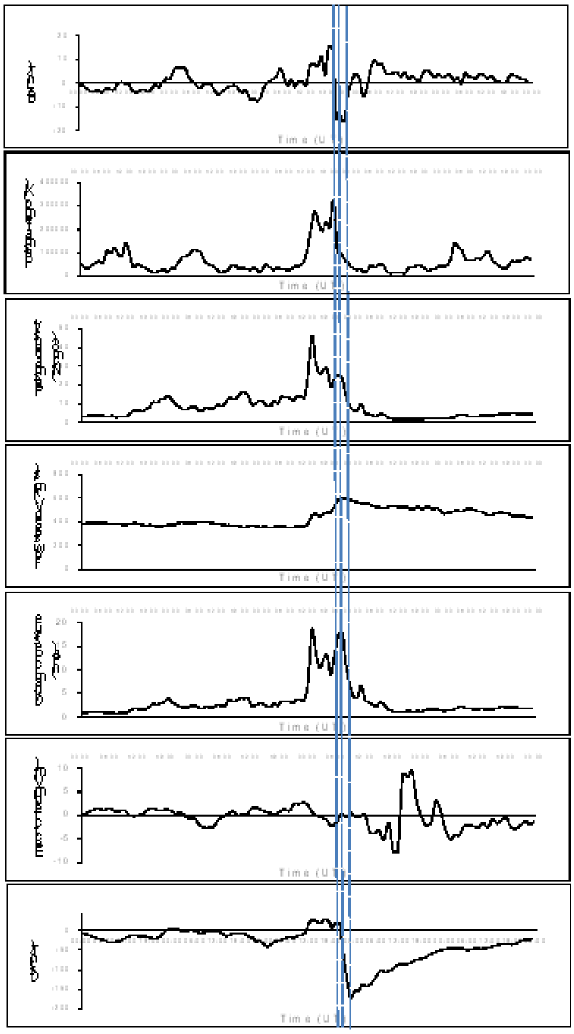
However, beyond this hour, the electric field began to record a rise attaining a peak value of 18.00m V/m at 17:00UT, decrease a while then begins to rise again getting to another significant value of 8.00 mV/m on September 7. It thereafter began to diminish again through the 10th day in an oscillatory manner. It should be noted that the point of the first electric field peak value coincides with a rise in plasma flow speed up to a value of 580km/s, indicating a major storm.

Figure 1: This figure shows response of Interplanetary and Solar wind parameters for July 13-17, 2000



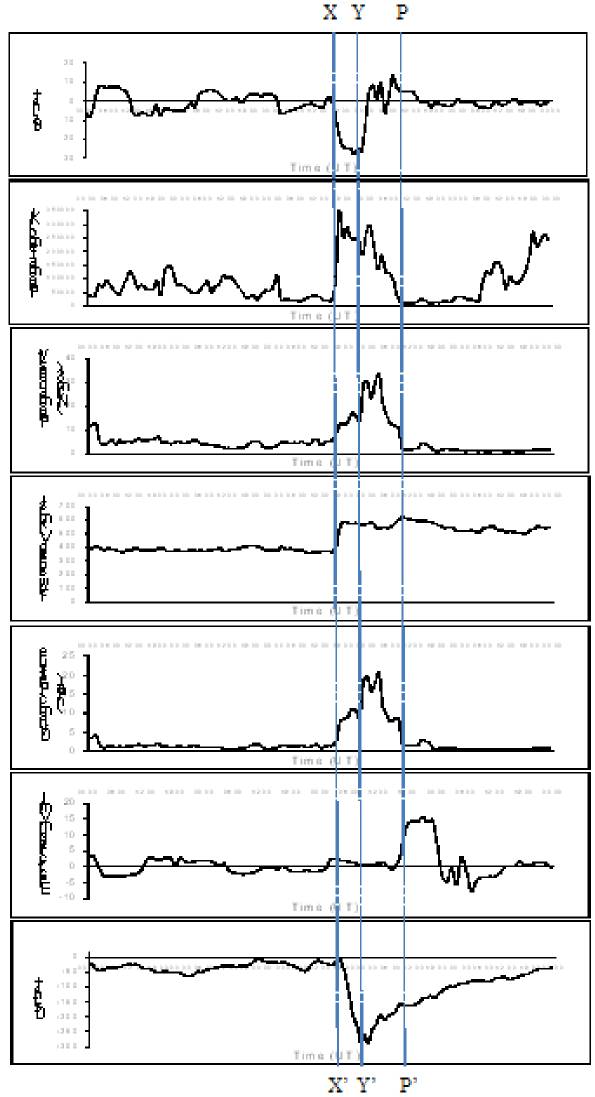
As regards the solar wind dynamic pressure, it was observed that there is going to be an increase of the solar wind/magnetosphere coupling efficiency, immediately after an abrupt increase in solar wind dynamic pressure during steady southward IMF configuration, which is the situation observed here (1st and 5th panels of Figure 4). Note that the Bz orientation was southward for more than 24 hours. The efficiency increase was observed even when the solar wind electric field was reduced after the pressure front, indicating that the sudden increase in pressure enhanced magnetospheric convection and partially balanced the effects of the decreasing Electric field.

Figure 2: This figure shows response of Interplanetary and Solar wind parameters for Sept. 20-24, 1999



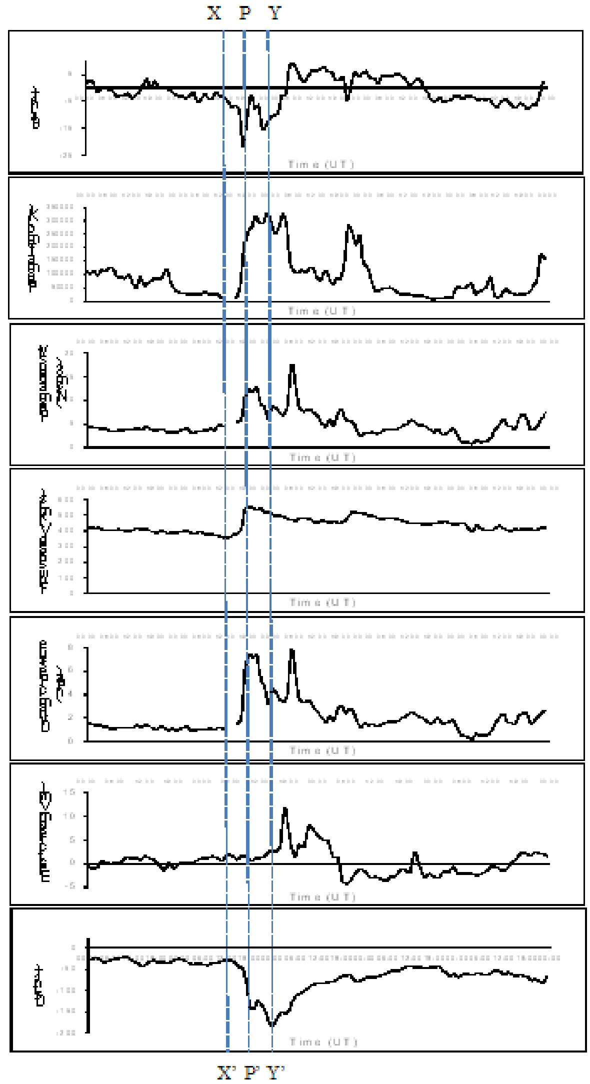
The storm time ring current index, Dst got to its first minimum value of -142nT around 18:00UT on September 7. It rotates northward shortly, and then southward again reaching a minimum peak value of -180nT at 00.00UT on September 8. It thereafter begins to recover until around 21:00UT when an abrupt decrease was noticed again to a value of -78nT and then continued with the recovery process. The two minima peak values observed is an indicative of a magnetic shock in the interplanetary medium. This is so because these two points coincides with a significant southward turning of Bz at this exact periods. However, the occurrence of a new major particle

Figure 3: This figure shows response of Interplanetary and Solar wind parameters for April 4-8, 2000



injection leads to a further development of the ring current with Dst index increasing for the second time. We may thus assumed the presence of both sheath field and the magnetic cloud field, and argue that both the sheath field and the cloud field have the proper orientation, and there is magnetic reconnection from both phenomenon resulting in a 'double storm'. This is so, as it is most likely that the first step of the storm was caused by the sheath Bz while the second was from the second magnetic cloud field. Thus, in the interplanetary region following CIR, the southward field components caused by these waves can cause magnetic reconnection, small injections of plasma into the magnetosphere and prolonged recovery phases of the storms. According to [9], events of this type are known as 'high intensity long duration, continuous AE activity (HILDCAA) events

Figure 4: This figure shows response of Interplanetary and Solar wind parameters for Sept. 6-10, 2002



DISCUSSION

When the interplanetary magnetic field (IMF) reaches the Earth with a southward orientation, magnetic reconnection between the Earth's magnetic field and IMF will take place. As a result, the Earth's magnetic field will be able to connect to the IMF directly, so that energetic particles in the solar wind are free to enter the magnetosphere along the magnetic field lines. If this process continues for several hours, the magnetic field, as well as plasma in the magnetosphere, will be strongly disturbed by the solar wind, and a geomagnetic storm or substorm will develop [10]. Geomagnetic storms are characterized by a depression in the H component of the geomagnetic field lasting over some tens of hours. This depression is mainly caused by the ring current encircling the Earth in a westward direction and can be monitored by the Dst index [11, 12]. In general, it is believed that the ring current gives the main contribution to the Dst index [13] and the reference therein.

Solar wind dynamic pressure enhancements can significantly compress the Earth's magnetosphere and lead to global changes in the magnetospheric and ionospheric currents, such as the Chapman-Ferraro (CF) current, region 1 (R1) field-aligned currents (FACs), cross-tail current, and the auroral electrojets [14]. Recently, [15] concluded that pressure enhancements also cause further intensification of the storm time preexisting partial ring current (PRC), provided that the interplanetary magnetic field (IMF) Bz has been southward for a while before the onset of the pressure enhancements. Shi [15] and Shi [16] inferred this response of the PRC from a nearly instantaneous ground dawn-dusk asymmetric perturbation in the north-south component (H) of the low-latitude to midlatitude geomagnetic field observed during the enhancement interval.

According to Wang [13] and the reference therein, on whether the solar wind dynamic pressure play a role in the injection of the ring current, it was observed that the ring current injection rate would increase during a period of enhanced solar wind dynamic pressure. Moreover, from the investigations of Wang [13], based on the most

Figure 5: This figure shows correlation plot showing the dependence of the dynamic pressure with (a) V and (b) Bz during storm onset for all storms. The cross bars represents the percentage error at 5% value

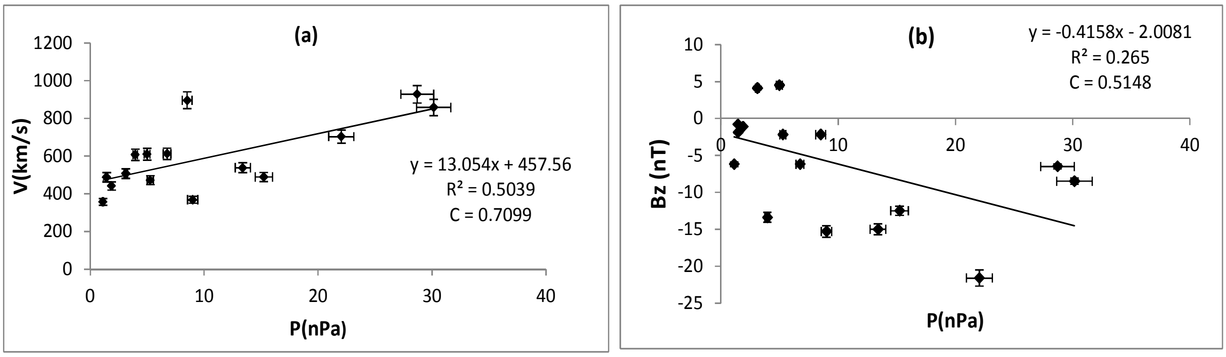


Figure 6: This figure shows correlation plot showing the dependence of the dynamic pressure with (a) V, (b) Bz and (c) Dst during storm main phase for all storms

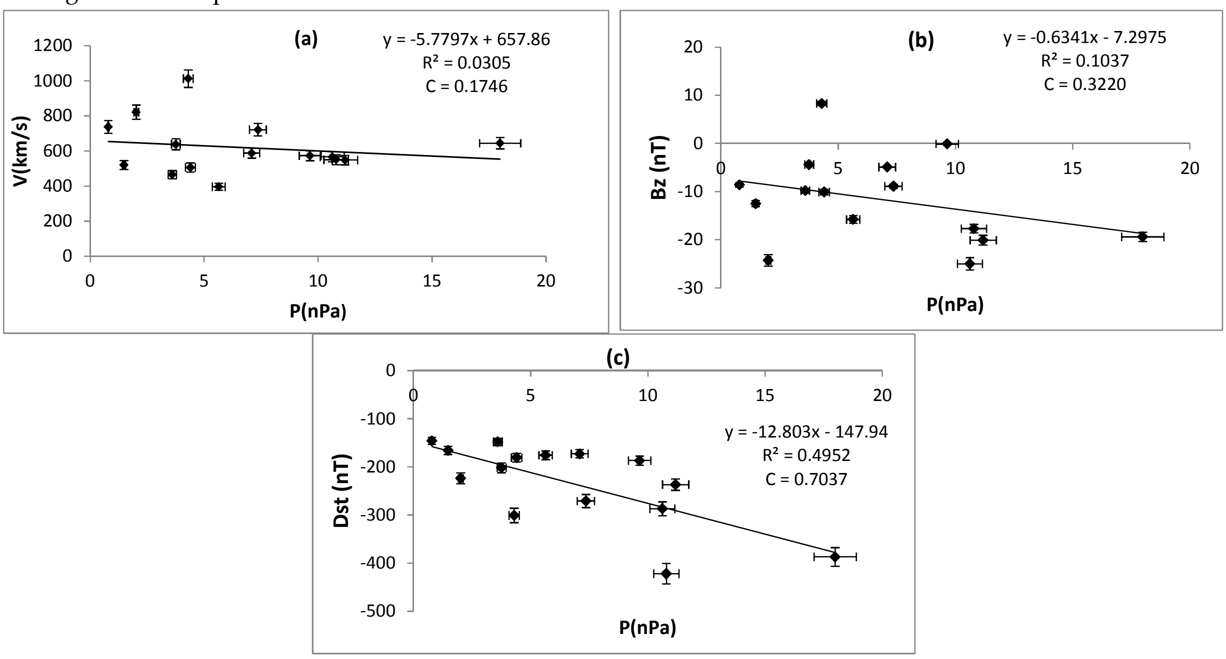
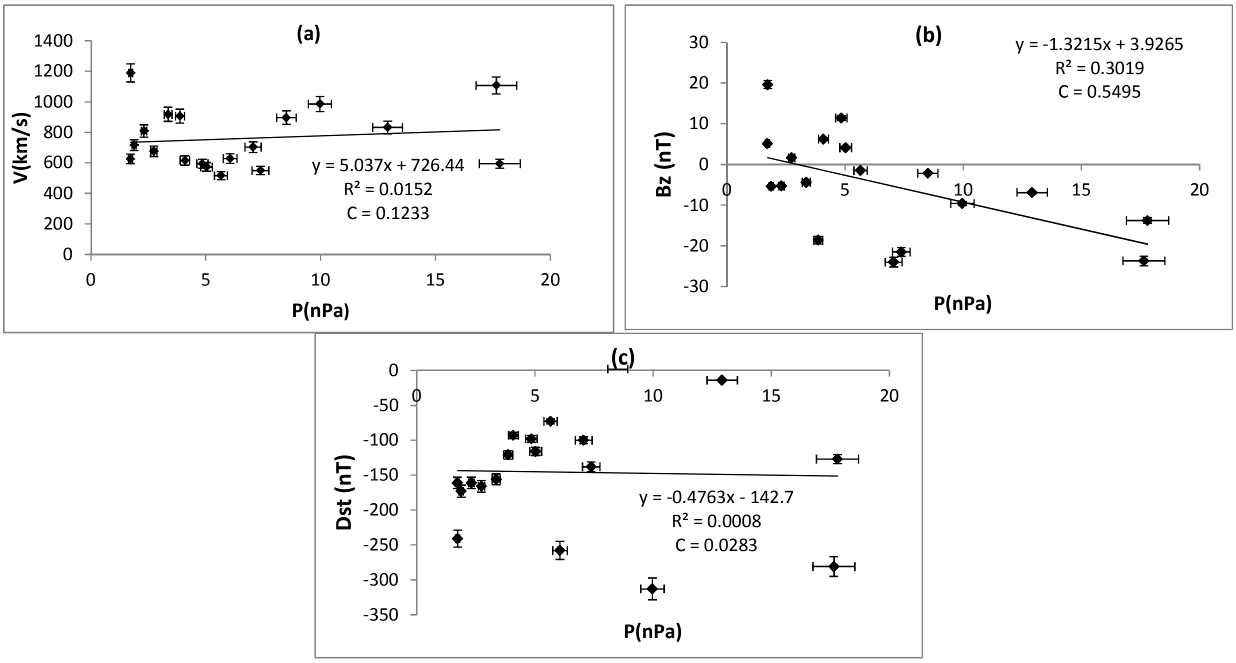


Figure 7: This figure shows correlation plot showing the dependence of the dynamic pressure with (a) V, (b) Bz and (c) Dst for Peak flow speed value for all storms



recent OMNI data set, from 1964 to 2001, it was discovered that the solar wind dynamic pressure does play an essential role in controlling the injection of the ring current, especially during strong magnetic storms. It was however concluded that the strength of the ring current injection is proportional to the solar wind dynamic pressure with a power index of 0.2 during southward IMF. This implies that the ring current injection increases when the magnetosphere is more compressed by high solar wind dynamic pressure. This assertion therefore makes it more interesting to delve into the present study of the dependence of the solar wind dynamic pressure (a ring current signature) on the mentioned parameters in the previous section during the different phases of geomagnetic activities.

Regarding the dependency of the solar wind dynamic pressure, it was observed that during the onset (or the initial phase) of all the twenty (20) magnetic storms under analysis, the Pearson correlation coefficient between the dynamic pressure and the plasma flow speed is very strong, attaining 70.9% correlation (figure 5). This could be attributed to the fact that the energetic particles coming from the Sun as part of the solar wind, which are free to enter the magnetosphere, and after a period of storage, are injected into the ring current of the system; of which majority of these particles are densely populated (i.e plasma density). Hence the plasma flow speed would automatically increase, and thereby increasing the dynamic pressure, since the dynamic pressure is a function of the plasma density and the plasma flow speed. However, Ionosphreric particles also contribute to the ring current and can even become the dominant source during main phase of major magnetic storms. Observe that the percentage correlation between the dynamic pressure and the IMF Bz is 51.48, which is good enough.

The correlation power is categorized based on the following range: Very strong (>65%), Good (50-64%), Weak (11-49%) and Insignificant (< 10%). During the main phase of all the storms (i.e the period during which the Dst reaches its peak minimum value), the dependency of the dynamic pressure with the plasma flow speed is rather insignificant, i.e., 17.5% (figure 6). This could be as a result of energy losses, and is explained in the following statement. According to [17] and the reference therein, the temporal variation the of the ring current is related to the injection of charged charged particles from the magnetotail and also to the energy lost by the circuit. However, a simple relationship describing this energy balance is given by

$$\frac{d}{dt}E(t) = U(t) - E(t)/\tau \qquad (2)$$

where U(t) is the rate of energy input and τ is the decay time. The main energy losses of the ring current are given by the following processes: (i) charge exchange, (ii) Coulomb scattering, (iii) resonant interactions with plasma waves [10], and (iv) flow-out ions. Each of these processes however depends rather strongly on several properties of the particles, such as the pitch angle, ion energy, composition, and location in the radiation belt. It was also noted that the percentage correlation between the dynamic pressure and the IMF Bz here is 32.2, which is also weak; and 70.87 for P versus Dst plot.

Regarding the correlation between the dynamic pressure and the flow speed when the Plasma flow speed is maximum, during the storm interval, it was observed that a weak dependency occurred between the two, as well as with Dst (figure 7), with an insignificant percentage. However, a rather interesting record is the strong 54.9% correlation between P and Bz. A better explanation for these is the Geomagnetic activity of April 6, 2000 (Figure 3) in which sudden outburst of the solar wind dynamic pressure aggravated the rising in the value of the Plasma temperature, which rose to its maximum level; and at the same time coincides with the Bz symmetry pointing southward as well as the increase in plasma flow speed. It was also observed that the Bz turns southward and is intensified because of a compression of the sheath region, and remaining like that for close to 16 hours, which in turn makes the Dst reach its minimum peak value of approximately -287nT. After the pressure pulse arrives the interplanetary magnetic field, the Dst strength increases and the Bz begins to have strong fluctuations in the north-south direction. However, it is well established that the Bz component of the IMF is the most important influence on the magnetosphere and high latitude ionosphere as it controls the fraction of the energy in the solar wind which is extracted by the magnetosphere [18] and references therein

On the basis of 'intense' (I) (-250 nT ≤ peak Dst < -100 nT) and 'very intense' (V-I) (peak Dst < -250 nT) storms, it was observed that during the storm onset (Table II), the correlation percentage between P and V (the flow speed) during I alone is 30.2%, which is rather weak. However a corresponding value during the same period (i.e storm onset) shows a very strong 85.4% for V-I storms. Moreover, the corresponding correlation percentage of the dynamic pressure versus IMF Bz between I and V-I storms during the storms onset are 72.7% and 40.1% respectively

During the main phase of the storm, the corresponding values of the correlation percentage of P versus V, and P versus Bz during 'intense' storms respectively are 34.8% and 12.4%. On the other hand, 'very intense' storms recorded 64.7% and 73.5% respectively during the same period. At the point of maximum flow speed (Vmax) during the storm period, the correlation percentage of the dynamic pressure P versus flow speed V, and P versus Bz during 'intense' storms are 19.2% and 39.9%. These two correlation values are rather weak. For 'very intense' storms, the values are 33.7% and 65.9% respectively. The observed 69.9% value shows a very strong relationship between the dynamic pressure and the IMF Bz. at high solar wind speed. According to [19], the intense interplanetary magnetic fields can be thought of as being associated with essentially two parts of a high-speed stream, the intrinsic ejecta (called driver gas fields), and the shocked and compressed fields and plasma due to the collisions of the high-speed stream with the slower solar wind preceding it. In the latter case, the compression is related to the strength of the shock and thus to the speed of the high-speed stream relative to the upstream (slow) solar wind. The higher the relative velocity, the stronger the shock and the field compression. However, if the shock runs into a trailing portion of a high speed stream, preceding it, exceptionally high magnetic fields may result, hence the reason for the high correlation value observed.

Note also the correlation percentage between the dynamic pressure and the ring-time magnetic index Dst during the main phase of the geomagnetic activities; which is 48.3% during I storms and 60.1% during V-I conditions. This could be explained on the basis of the results of [20], while investigating the effects of solar wind dynamic pressure P, and preconditioning in 88 large magnetic storms (Dst < −100 nT) occurring during solar cycle 23, he observed that there is always an increase in the Dst peak value when there is a large enhancement of the dynamic pressure during the main phase of a storm. Hence a more intense storm activity would always result in a simultaneous enhancement in P.

CONCLUSION

We have presented the dependency of the solar wind dynamic pressure P (nPa) on the plasma flow speed (km/s) and the IMF Bz during the onset and main phase of Geomagnetic storms, as well as during peak plasma flow speed values. We have employed 20 geomagnetic storms. It was observed that P versus V attained a significant value (above 70%) only during the onset of all the storms under analysis. This may be attributed to accelerated ring current intensification. During the main phase of all the storms, the dependency of the dynamic pressure with the plasma flow speed is rather weak, ie 17.5%; which could be as a result of energy losses in the ring current through: (i) charge exchange, (ii) Coulomb scattering, (iii) resonant interactions with plasma waves and (iv) flow-out ions. It was also noted that the %

correlation between P and the IMF Bz here is a little above 70.0. Regarding the correlation between P and V when the Plasma flow speed is maximum (Vmax), it was observed that a weak dependency occurred between the two. However, a strong correlation occurred between P and Bz.

On the basis of 'intense' and 'very intense' storms, it was observed that a good relationship existed between P and Bz (above 70%) only during storm onset for intense storms. The V-I storms also showed a good correlation percentage between P and V (>64%) during storm onset and main phase. It can therefore be suggested that

i. the solar wind dynamic pressure is highly geoeffective with the southward IMF Bz during the main phase of a storm, mostly when the plasma flow speed value is very large, i.e exceeding the 550km/s mark, and the Dst < -250 nT
ii. the dynamic pressure enhancement during enhanced solar wind speed flow, and under a southward Bz that flows steadily would always produce an intense storm, and
iii. For 'intense' conditions, IMF Bz is the most important factor to be considered during storm onset, whereas the flow speed is the most considered factor with regards to 'very intense' storms; when considering their dependency with the dynamic pressure.

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CONFLICT OF INTEREST

No conflict of interests was declared by authors.