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RESPONSE OF GEOMAGNETIC VARIATIONS AND 30 MHz RIOMETER ABSORPTION, AT INDIAN ANTARCTIC STATION MAITRI, TO CONDITIONS OF "ZERO" AND "HIGH" SOLAR WIND

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ABSTRACT

Variations in the 30 MHz cosmic radio noise signal, and in the Y, X, Z fluxgate magnetometer traces recorded at the Indian Antarctic station MAITRI (geom. 62°.8 S, 52°.8 E, L = 4.8) are compared for the "zero solar wind" day of 11 May 1999 ($\Sigma Kp = 2_o$), the very Quiet day 22 Dec 1999 ($\Sigma Kp = 1_o$), and the very Disturbed day 18 May 1999 ($\Sigma Kp = 31_o$). Interplanetary magnetic field and solar wind parameters from the WIND satellite for these days are also examined, in order to understand what factors cause Maitri to change from a location influenced by Sq currents, to one influenced by Auroral electrojet currents. It is observed that it is not only negative Bz and high solar wind velocity which play a role in causing pronounced magnetic disturbance at this just-sub-auroral location but also high ion density and high ion dynamic pressure in the solar wind. The observations reflect on the changes which occur in the size of the geomagnetosphere and in the size of the auroral oval as a consequences of changes in the Interplanetary medium.

1. INTRODUCTION

The period 10 – 12 May 1999 has been designated by the International community as one of "zero solar wind" (Le et al. 2000). In space science parlance, this would refer to conditions of very low ion density in the solar wind, accompanied as well by very low solar wind speeds. Both ion density and speed of the solar wind were lowest on 11 May 1999, causing it to be referred to as "the day when the solar wind almost disappeared". Solar wind velocity Vx on 10 May 1999 ($\Sigma Kp = 9_o$) was between 380-440 km/sec, on 11 May ($\Sigma Kp = 2_o$) it was at its lowest, namely 200-400 km/sec and on 12th May ($\Sigma Kp = 16_+$) it was back to around 400 km/sec. On another very quiet day 22 Dec 1999 ($\Sigma Kp = 1_o$), Vx had values 260-290 km/sec. In contrast, the highly disturbed day of 18th May 1999 with its ΣKp of 31_o, showed solar wind speeds of 500-700 km/sec. Thus at first sight, the geomagnetic disturbance in the environment of Earth seems to be almost directly related to the speed of the solar wind.

For Earth, Snyder et al. (1963) from Mariner 2 satellite data, established the following emperical relationship between solar wind speed and the daily sum Kp value:

$$V_{sw} = 8.44 \ \Sigma Kp + 330 \text{ (km/sec)} \qquad (1)$$

Since solar magnetic field lines are embedded in the outflowing solar wind (thereby producing the Interplanetary Magnetic Field (IMF), it is also natural to expect the IMF to play a role in the state of magnetic activity of planetary magnetospheres. Wilcox et al (1967) related the 3 hrly Kp index to the intensity B of the IMF thus:

$$Kp \approx \frac{|B|}{3} \quad \text{where } |B| \text{ is the magnitude of the total IMF in nT} \qquad (2)$$

Ballif et al. (1967) pointed out that Kp was related to transverse fluctuations in the solar wind. A very systematic study of the relationship between the solar wind electric field and geomagnetic activity has been made by Ondoh (1998). The latitudinal and longitudinal extents of the auroral field-aligned currents as a function of Bz and By has been discussed by Friis-Chistensen and Lassen (1991).

It has been known for half a century that the solar wind represents the expansion of the gaseous solar corona into interplanetary space (Chapman 1954; 1959). This solar wind shows large time variations in velocity, density and pressure at 1AU (Sun-Earth distance), and these variations are known to be related to magnetic field structures on the Sun (Woo and Habbal 1999; Karpen 1999). Coming closer to Earth, the day 11 May 1999 stood out as a day of very low solar wind density ($<1/cm^3$) at 1AU, and hence earned the research attention of several workers. Le et al. (2000a) from the WIND and IMP 8 satellite observations note, that on this day the geomagnetosphere had a highly dipolar structure and there was some ring current, but very little magnetopause current. A subsequent work by Le et al. (2000b) suggests that on the same day, 11 May 1999, with its weak, northward directed IMF, there were upstream waves in the foreshock, but the bow shock was extremely weak, possibly due to very low (an order of magnitude less) power in the waves. While Le et al. (2000a) observed weak field-aligned currents in both northern and southern high latitudes, Farrugia et al. (2000) from NOAA-12 satellite observations on 11 May 1999, show distinct asymmetry between particle precipitation patterns in the northern and southern auroral ovals. While the northern oval received energy fluxes of 3-4 $ergs/cm^2/sec$ and average energy of about 4keV, the southern oval showed marked absence of precipitation.

The purpose of this work is to examine how the 30 MHz Riometer (RIO) and the fluxgate magnetometer (FM) at the just-sub-auroral Indian Antarctic Station MAITRI (MAI) (geomag lat. 62°.8 S Long 52°.8 E, L value = 4.8) responded to velocity and ion density changes in the solar wind, and the IMF, during the periods of 'slow' and 'fast' solar wind mentioned above, namely 10-12 May 1999, 18 May 1999, and 22 Dec 1999. It may be noted that at MAI, LMT differs from UT by 1 hr.

2. OBSERVATIONS

The left-hand side (LHS) of Figure 1 shows the 30 MHz Riometer (RIO) absorption, and the Y, X and Z variation patterns at MAI on 11 May 1999. Below this are the 3 hrly Kp values for this day. It is a magnetically very quiet day, as the 3 hrly Kp value never rose above 0+. The AU, AL and AE records for this day were examined and all three indices are calm, with values never rising above 100 nT. The RIO trace shows the normal diurnal variation in absorption, with definite noise superposed on it between 09-12 UT. It must be remembered that this is a winter month for Antarctica with total absence of solar radiation, but the signal is quite strong. RIO records for the same day at the nearby Antarctic Station SYOWA BASE (geog. Lat. 69^0 S, $39^0.58$ E, Geomagn. $70^0.17$ S, $81^0.23$) show the same feature, and hence the signature is suggestive of a 30 MHz radio noise source of celestial

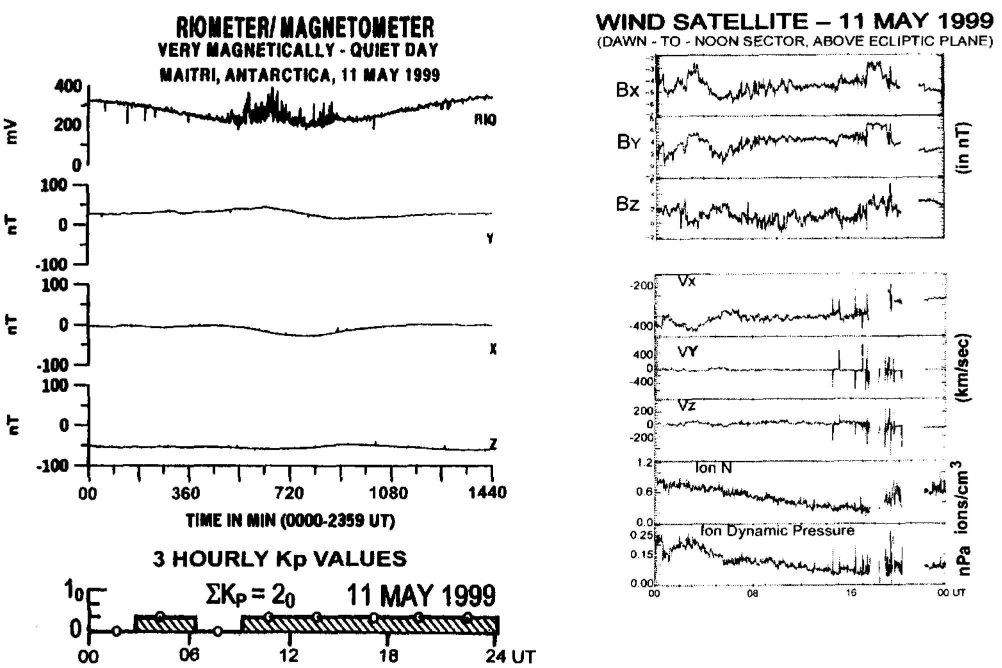

Fig. 1. 30 MHz Riometer and geomagnetic Y, X and Z variations at Maitri for the disturbed day of 11 May 1999, "the day the solar wind almost disappeared". Note the very low values of the 3 hrly Kp index on this day. The right hand shows the IMF components and solar wind velocities; note the very low Vx of 200-400 km/sec, and absence of any substantial southward Bz.

origin. The Y, X and Z magnetogram traces are very calm with very little variation, suggestive of Sq current focus behaviour. This would imply that on this magnetically quiet day, the auroral oval has retreated poleward, with the Sq current loop expanding to higher latitudes. When this happens, a sub-auroral station would find itself located in the vicinity of the center of the Sq current loop (i.e. the Sq focus) rather than well northwards of it. Concepts of elementary physics indicate that such an Sq focus location would experience practically no variation in X, Y and Z components.

The total field value B (figure not shown here) of the IMF was around 5 nT. Bx has values of –2 to –6 nT, and Bz has intermittent negative values of only 0 to –2 nT. Solar wind velocities are very low indeed with values of Vx between 200 – 400 km/sec. The satellite coordinates indicate that the WIND was located in the dawn to noon sector near the ecliptic plane. The ion density and ion pressure values from the WIND satellite are also shown for this day of "zero" solar wind. Ion densities fell from a value of 0.8/cm^3 to about 0.3/cm^3 from 00 – 18 UT before rising slightly. Ram pressure (defined as mNV^2) too had very low values, dropping from about 0.20 nPa (nano Pascals) at 00 UT, to about 0.05 nPa at 18 UT. In summary, the IMF and Interplanetary (IP) parameters suggest that on this day solar charged particles from the "solar wind" could not have penetrated Earth's environment deep enough to cause Geospace disturbance. This is borne out by the work of Farrugia et al. (2000), which shows that the GOES 8 satellite observed the geomagnetic field to be highly dipolar on 11 May 1999.

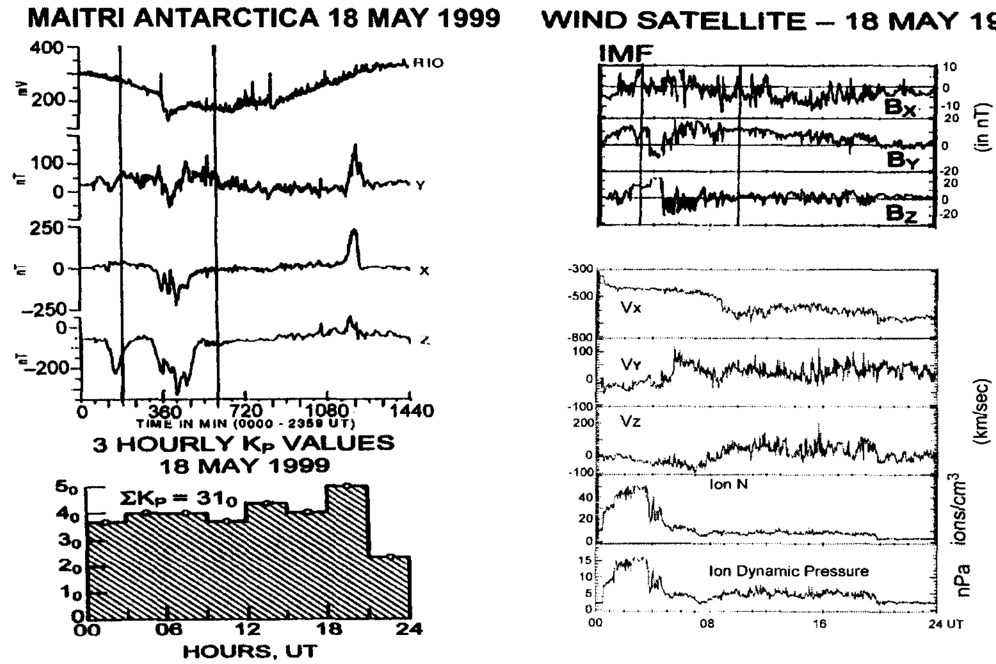

Fig. 2. 30 MHz Riometer and geomagnetic Y, X and Z variations at Maitri for the disturbed day of 18 May 1999. Note in contrast to Fig.1, the highly disturbed RIO, Y, X and Z traces, the high 3 hrly Kp values exceeding 4, the very high solar wind speeds of 500-700 km/sec, and the negative Bz which occurs over a substantial part of the day. Vertical lines demarcate time-interval where Bz had a substantial negative component.

We now examine variations on 18 May 1999 with ΣKp of 31_o. Three hourly Kp values remained at values of 4_o and above, over the whole day. All the auroral indices AU, AL and AE were found to be very disturbed on this day at exactly the time when MAI shows marked magnetic disturbance (i.e. 03-09 UT and 19-22 UT); the AE index rises above 500 nT during these intervals. The magnetometer at MAI registers marked disturbance at all hours of the day, with the X component registering the signature of a Westward Auroral Electrojet (WAE) during 04-10 UT, and that of an Eastward Auroral Electrojet (EAE) during 19-22 UT. The sharp changes in Z to negative values during 04-10 UT suggest the position of the AE currents to be equatorward of MAI. A clear RIO absorption event is seen during 03-09 UT; it is accompanied by variations in the Y component of the type caused by field-aligned currents (fac) which could accompany the high energy particle precipitation events causing the RIO absorption. The positive bay in Y during 19-22 UT is not accompanied by any prominent RIO event. This would suggest that the Y, X and Z variations for this event are associated more with a north-south directed ionospheric current, rather than with any fac accompanying energetic particle precipitation. Comparison with Syowa Base variations at 19-22 UT, suggest that both locations see a pronounced Harang Discontinuity feature.

The RHS of Figure 2 shows that negative Bz is seen during 04-10 UT with values between 0 to –20 nT. This occurs exactly at the time when RIO, Y, X, and Z at MAI all show clear absorption/magnetic disturbance effects. The solar wind velocity (lower RHS of Figure 2) is very high on this day; Vx has a value of ~ 500 km/sec up to 10 UT and beyond that steadily increases to ~ 700 km/sec. The ion Pressure (mNV^2) of ions in the solar wind from the WIND satellite data shown in Fig. 2, has very high values between 5-15 nPa during 00-05 UT, and this later drops to average values of about 5-6 nPa till 20 UT. The ion density too had very high values of 25-50 ions/cm^3 during 00-05 UT, and then dropped to values of about 8-10 ions/cm^3 till 20 UT. It is these high values of Ram pressure, which have possibly had a major influence on the Y, X, Z and RIO variations. A similar situation could have contributed to the X, Y and Z changes seen between 18-20 UT, when the ion density had values of 8-10 /cm^3 and solar wind had speeds exceeding 600 km/sec, Bz had a mild negative component (0-10 nT) at this time. The CANOPUS magnetometer array in the northern auroral Canadian zone reflects the magnetometer changes shown by MAI i.e. major variations over (04-10 UT) and limited variations around 20 UT (Rostoker 2001; private communication). The WIND satellite on this day was located in the Dawn-Noon time sector with respect to Earth, below the plane of the ecliptic.

We now present the RIO, Y, X and Z variations at MAI for a day which was even quieter than 11 May 1999, namely 22 Dec 1999, with a ΣKp of 1_o (Figure 3). A perusal of the AU, AL and AE indices for this day shows very calm traces, never rising beyond 100 nT. This is a summer month for Antarctica with solar UV present over all 24 hours of the day. The LHS of Figure 3 shows that the traces RIO, Y, X and Z are all very calm, and as in Figure 1, resemble variations at a southern Sq focus location. The 3 hourly Kp index remained at a value of 0 over 00 – 12 UT, and thereafter over 12-24 UT, at 0_+, which suggests very magnetically quiet conditions indeed. These are ideal conditions for the retreat of the auroral oval polewards, and the poleward expansion of the southern Sq current loop as seen for 11 May 1999 (Fig. 1).

The RHS of Figure 3 shows that on this day, the Bx component of the IMF does not exceed 5 nT, and Bz had negative values of 0 to –7 nT over the interval 14-19 UT. It may be noted that exactly at this time, the X and the Z components record a ripple of magnetic disturbance. Over most of the day, Bz has mainly positive values.

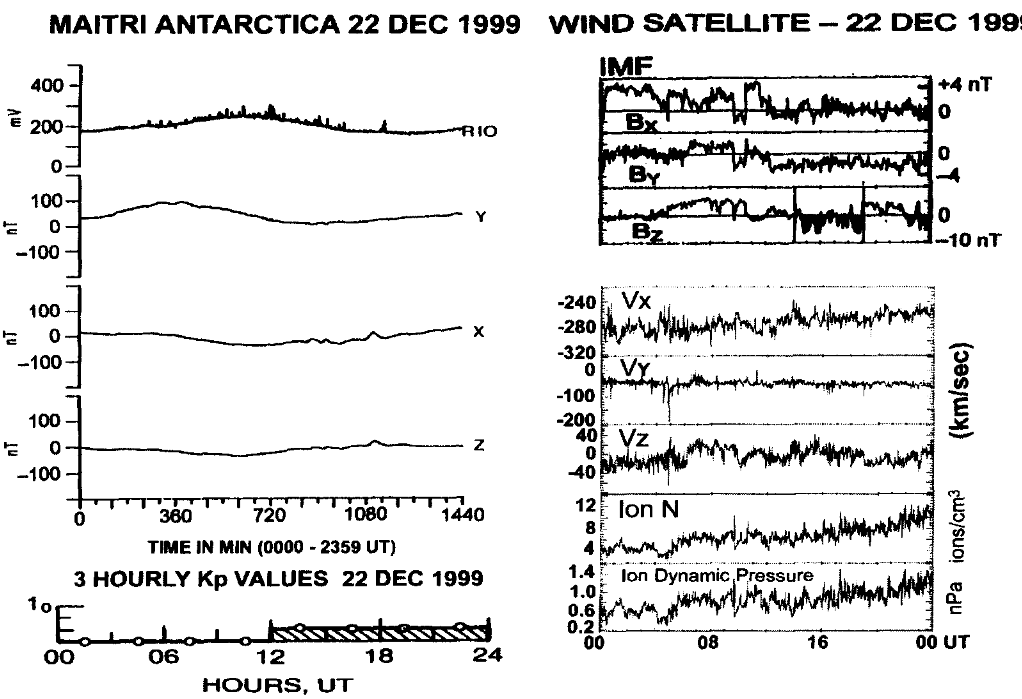

Fig. 3. 30 MHz Riometer and geomagnetic Y, X and Z variations at Maitri for an even magnetically quieter day, 22 Dec 1999. Again the 3 hrly Kp values are very low, RIO, Y, X, and Z traces very calm, the solar wind Vx component low (250-300 km/sec) and negative Bz seen for a few limited hours.

The lower part of the RHS of Figure 3 shows that the solar wind has very low values, with Vx dropping from about 280 km/s to about 250 km/sec over the day. The ion density on this day as registered by the WIND satellite, is of moderate value rising from 4 particles per cm^3 at 00 UT to about $10/cm^3$ by the end the day, and this rise accompanies the drop in solar wind speed. Ion pressure is also seen to rise from about 0.6 nPa to about 1.4 nPa over the day. Since the solar wind speed, ion density and ion dynamic pressure were very low (see Table 1) at 14-19 UT, the negative Bz could cause only a mild ripple of disturbance at MAI. The WIND satellite on this day is located in the Dawn-Midnight sector just below the plane of the ecliptic.

3. CONCLUSIONS

Table 1 summarises certain Geospace and Interplanetary parameters, namely Kp, Bz, Vx, N (ion density) and mNV^2 (ram pressure), which characterise the "zero solar wind" days 10-12 May 1999, the clearly Disturbed day 18 May 1999, and the very quiet day 22 Dec 1999. The LHS of Table 1 gives the average values of the parameters over the whole day, while the RHS of the table gives values during specific time-intervals when the RIO and the Magnetometer operating at MAI show disturbance.

It is clear that what really sets apart the "zero solar wind" days (10-12 May 1999) from the other days are the low values of ion density (as low as 0.3 to $0.8/cm^3$, never more than $3/cm^3$) and very low ion dynamic pressure (0.05 to 0.25 nano Pascals). A more magnetically quiet day (22 Dec 1999 with Kp = 1_o) but not a zero solar wind day, showed the ion density to be $4\text{-}10/cm^3$ and the ion dynamic pressure to be 0.6 to 1.2 nano Pascals, both of higher magnitude.

It is also clear from the RHS of Table 1, that while negative Bz can cause a mild ripple of disturbance at just sub-auroral locations (e.g. at 14-20 UT of 22 Dec 1999), it must be accompanied by high solar wind speed (> 400 km/sec) for such a location to record even a mild event in RIO absorption and Y, X, Z magnetic variations (e.g. at 15-10 UT of 12 May 1999 listed in Table 1). Negative-positive turnings in Bz, with Vx exceeding 400 km/sec also seem to achieve this result (e.g. around 01:30 UT on 10 May 1999 in Table 1). This aspect has been pointed out by other workers (Russell et al. 2000). In contrast, for a clear disturbance event of large amplitude to be seen in RIO, Y, X, and Z at this just-sub-auroral station, the necessary and sufficient conditions are 1) prolonged negative Bz, and high solar wind (> 400 km/s) and 2) high ion density (> $10/cm^3$) and high ion dynamic pressure (> 6nPa). This is illustrated by the MAI events during 01-04 UT and 04-10 UT on 18 May 1999.

The RIO and Y, X, Z traces at the nearby Japanese Antarctic Station SYOWA BASE (SYO) were examined (but not shown here) for the same set of days, namely 11 May 1999, 18 May 1999 and 22 Dec 1999. Our observation was that while the magnetogram variations Y, X and Z were similar at MAI and SYO on the disturbed day 18 May 1999, suggesting clearly auroral oval locations for both (Baumjohann 1983), the situations differed on the magnetically very calm days. On 11 May 1999 and 22 Dec 1999 when the Kp and AE indices suggested the auroral oval to have retreated fully polewards, the Y, X and Z variations suggested the location of MAI to be near the southern Sq current focus, while SYO clearly experienced the signature of the southern Sq poleward current limb. The movement of a sub-auroral location like MAI into the auroral zone leaves magnetic signatures which are far more dramatic than those seen at the typical auroral location SYO. The ion density and ion pressure of the solar wind clearly influence this shift of sub-auroral MAI into the auroral zone, indicating thereby that the size of the geomagnetosphere, and the size of the auroral oval are dependent on these Interplanetary parameters.

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TABLE 1

Table showing values of the Kp index, IMF, Bz and Interplanetary parameters Vx, N (ion density) and mNV^2 (ion dynamic pressure) for the zero solar wind interval 10-12 May 1999, the highly disturbed day 18 May 1999, and the very quiet day of 22 Dec 1999.

AVERAGE VALUES OVER DAY						VALUES AT SPECIAL INTERVALS				
DAY	Sum Kp	Bz	Vx	N	mNV^2	3 hrly Kp	Bz	Vx	N	mNV^2
10 May 1999	9-	Mainly Positive -4 to +6 nT	380 to 460 km/s	1 to 4/cm^3	0.2 to 1.2 nPa					
Mild bay on magnetogram at ~1 : 30 UT						2o	South to North turn −2 to +2 nT	400 – 420 km/s	3/cm^3	0.9 nPa
11 May 1999	2o	Mainly Positive 0 to 4 nT	250 to 400 km/s	0.8 to 0.3/cm^3	0.05 to 0.25 nPa					
NO SPECIAL EVENT SEEN ON 11 MAY 1999										
12 May 1999	16+	Mainly Positive −5 to 8 nT	250 to 500 km/s	1-2/cm^3 till 15 UT, then rises	1-20 nPa up 15 UT then rises					
Mild RIO and Magnetometer event seen at MAI ~05 to 10 UT						5-	Prolonged Negative Bz between 0 and −5 nT	400 to 500 km/sec	~ 1 to 2 /cm^3	~ 1 nPa
18 May 1999	31o	Mainly Positive -17 to + 22 nT	400 to 650 km/s	10-50/cm3 till 05, UT then decreases to ~5/cm^3	3 to 15 nPa till 05 UT, then ~ 5 nPa					
RIO/MAG Events at MAI (01 – 04 UT) and (04 - 10 UT)						4o 4o	+ve Bz 15 -20 nT Sharp Negative Bz turn (-15 nT)	500 km/sec 500 km/sec	30 – 50 /cm^3 drops from 50 to 10 /cm^3	12-15 nPa drops from 10 to 3 nPa
22 Dec 1999	1o	Mainly +ve −7 to 7 nT	260 to 300 km/sec	4-10/ cm^3	0.6 to 1.2 nPa					
Mild ripple on MAI magnetograms at 14 – 20 UT						0+	-ve Bz of 0 to −7 nT	~260 km/s	6 - 8 /cm^3	~ 0.8 to 1.0 nPa

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