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Polar and ecliptic solar wind during solar maximum

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ABSTRACT

In this papers we would like to explore observations of solar wind in both the polar and equatorial regions simultaneously at the same time during 23rd solar maximum, in order to compare the similarities and difference in solar wind between two regions. The observed period roughly coincides with polarity reversal phase. The comparative study relates polar and eduatorial solar wind using observed data. The polar wind has been extensively investigated by Ulysses, the first spacecraft to perform in-situ measurements in the high-latitude heliosphere and ecliptic solar wind observed by ACE were used to examine solar wind parameters. The solar wind parameters-temperature, density ,speed and solar magnetic field are taken for evaluation. This study elucidates the solar wind variations in equatorial, southern and northern hemisphere in maximum phase. But slow and fast solar winds are characterized in southern polar hemisphere but fast wind is prevails in northern polar hemisphere.

Introduction

During periods of solar maximum, the dominant component of the solar wind plasma appears to be slow solar wind. (Wang et.al 2011). The solar wind varies in density, velocity and temperature, and magnetic field properties with the solar cycle, heliographic latitude, radial distance and differential rotational effects. As is well known, the ecliptic solar wind is pattern of fast and slow streams and the development of compression and rarefaction regions are typical features of the ecliptic wind. A completely different environment in which to study compressive fluctuations is offered by the polar solar wind, a fast and steady flow observed at high heliographic latitudes. The velocity gradients in polar wind are much weaker than those typical of the ecliptic wind (Neugebauer et al., 1995). Rather, its (polar wind) presence in the high-latitude heliosphere is dramatically dependent upon the phase of the solar activity cycle (McComas et al., 2002b, Bavassano et al., 2004a). In the present analysis the nearly the solar wind from the polar and equatorial will be used to investigate how the compressive fluctuations behave during solar maximum in both hemispheres.

Since early 1992, the ESA/NASA Ulysses spacecraft has been in a 6.2 year near polar orbit which takes it to maximum heliolatitudes of -80^{o} to +80^{0}. During 2000 – 2001, period co-incident with solar maximum, the eccentricity of ulysses's second orbit leads to a very rapid scan around perihelion from high southern to high northern lattitudes. One of the striking features of the solar activity cycle is the reversal of polarity of the polar magnetic field. Ulysses observation of solar wind three dimensional structure in its second polar orbit (McComas et al., 1998). The only opportunity to investigate the properties of the high-latitude solar wind around solar maximum is offered by the Ulysses plasma measurements south to north through the perihelion. orbit is entirely different from its first polar orbit (McComas et al., 2002a).

A steady, fast wind at high latitudes and a slower and more variable wind at low latitudes are observed in its second polar Around perihelion, it performs a pole to pole scan in only 10.5 months. The first of these was near solar minimum, but the second coincided with solar maximum, recording in-situ the global distribution of open magnetic flux while the solar magnetic field reversal took place.

Coverage of solar wind observation was limited prior to operation of the Advanced Composition Explorer (ACE) at the L1 point in 1997. The three major solar wind monitoring platforms currently around Earth's orbit include ACE (Nagatsuma et al., 1989). In the present study we will analyse Ulysses data with data collected at the same time by ACE, 1998.1 to 1998.3 Ulysses and ACE are at similar latitudes and observed similar speeds. After 1998.3 Ulysses moves to larger latitudes than ACE and again sees somewhat higher speeds. But from 1999.0 to 1999.6 both Ulysses and ACE observe very similar speed probes. [McComas et al., 2000]. The investigated period roughly covers the suns magnetic Polarity reversal (Bavassano et al., 2004a)

This study examine the solar wind parameters in polar and equatorial regions during 23rd solar maximum. During 2000 September to 2001 January Ulysses covers southern polar hemisphere and during 2001 September-December Ulysses covers northern polar hemisphere. Various parameters, such as solar wind velocity, proton density, proton temperature and mean magnetic field, fluctuate in this scenario (Shollykutty, John et al., 2009). Solar wind parameters under study are the plasma velocity (V), the proton number density (N) in cm^{-3}, the proton temperature (T) in kelvin, the magnetic field magnitude (B) in Nano Tesla.

Data analysis

The hourly averaged values of solar wind parameters and magnetic field were derived from data returned by Ulysses's SWOOPS instrument and magnetometer (Bame et al., 1992, Balogh et al., 1992, Bame et al., 1992) were utilized for carrying out this work.

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In Advanced Coronal Explorer (ACE) satellite, we mainly utilised hourly averaged values of solar wind parameters and magnetic field from SWEPAM and ACE MAG data respectively for our studies. ACE SWEPAM provides solar wind proton density, proton temperature and proton velocity data. ACE MAG provides the interplanetary magnetic field data.

Observation and Discussion

The hourly averaged values of solar wind parameters and magnetic field of the Ulysses and ACE observations have been used to investigate the fluctuations in the high (polar) and low (equatorial) wind. The parameters under study are ma velocity (V), the proton number density (N) in cm^{-3}, the proton temperature (T) in kelvin, the magnetic field magnitude (B) in nano Tesla.

The time interval investigated in this work ie; Ulysses observation from the latitudinal scan around perihelion coincides with the polarity reversal phase of solar magnetic field. In the second polar pass, Ulysses passes southern hemisphere first, then moves through northern hemisphere. These time periods are used to study polar and equatorial solar wind during solar maximum. Since ACE was in halo orbit at L1 and Ulysses was at polar region, the time changes with respect to both spacecrafts observations are slightly different of solar rotations. At higher latitudes, poleward of 35°, Ulysses was almost continuously immersed in the extremely uniform high speed solar wind from the polar coronal holes [Phillips et al., 1996; McComas et al., 2000a]

Figure 1 shows solar wind velocity, radial distance and heliolattitude distance plotted with respect to time, covering both southern and northern polar phases Ulysses in its second out-of-ecliptic orbit and ACE observations for ecliptic orbit.

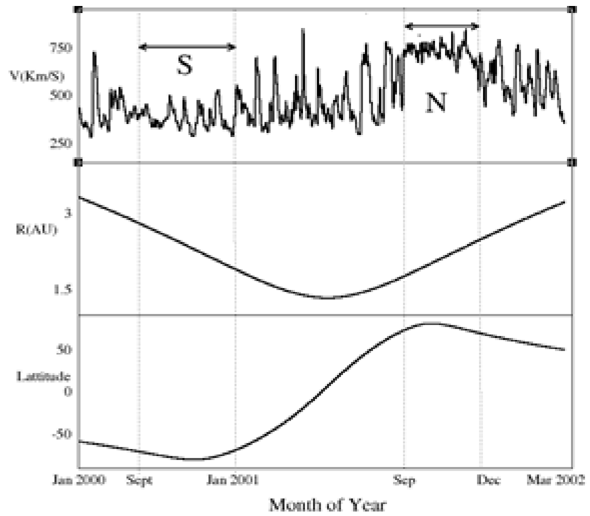

Fig. 1. The solar wind velocity V (in km/s) and the Ulysses heliographic latitude λ (in degrees) and heliocentric distance r (in astronomical units, au.) are plotted vs. universal time (u.t.) for the investigated interval.

Thick bars in the top panel and dashed vertical lines indicate the investigated intervals (S and N) from the southern and northern pass, respectively. Each interval corresponds to a high-latitude cut of the Ulysses orbit. Due to the asymmetry between the northern and southern orbital leg, the same time length does not correspond to the same latitudinal range in the two hemispheres.

Figure 2 shows the solar wind plasma parameters and magnetic field variation at solar maximum variation Observed by ulysses during its second polar orbit in southern polar hemisphere and corresponding ACE observation.

The solar wind parameters and magnetic field observation of Ulysses in its second polar orbit in northern hemisphere and ACE are shown in figure 3

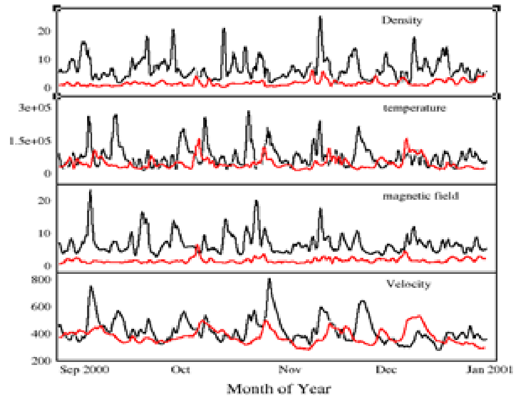

Fig 2. From bottom to top, solar wind velocity V(Km/S), Magnetic field B(nT), Temperature T(K), Density N(Kg/cm3) for southern hemisphere for Ulysses (red) and ACE(black).

The analysed interval spans from day 252, 2000 to day 16, 2001 in southern polar hemisphere for Ulysses and corresponding ACE observation as follows.

As already noticed by previous studies (e.g. Horbury and Balogh, 2001), at the time of Ulysses observations the southern polar wind velocity was more modulated by corotating features than the northern one, especially in the outer region.

The velocity profile is quite variable for both polar and ecliptic wind. The velocity is varying between 280 Km/s and 880 km/s for ecliptic wind and for polar wind this is varying between 285 Km/s and 535 km/s.At small scales, velocity variations are relatively small and spiky. Magnetic field varies up to 20 nT for ecliptic wind whereas 3 nT for polar wind. Polar wind is cooler than observed ecliptic wind. The density of solar wind particle associated with ecliptic wind is more than polar wind. Large number of coronal mass ejections can be observed in ecliptic wind than the polar wind. Ulysses observes a fast, steady southern wind from the southern and northern polar coronal holes during its first out-of-ecliptic observations. There is so such events are encountered in second southern polar pass, which took place in solar maximum. The steady fast polar solar wind shows, polar coronal holes are disappearing in southern hemisphere during solar maximum.

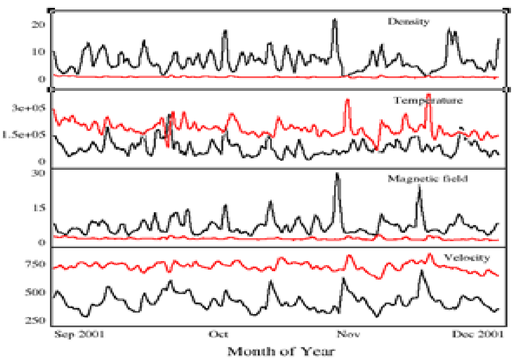

Fig 3. From bottom to top, solar wind velocity V(Km/S), Magnetic field B(nT),Temperature T(K), Density N(Kg/cm3) for northern hemisphere for Ulysses (red) and ACE(black).

The analysed interval spans from day 246, 2001 to day 346, 2001 in northern polar hemisphere,as in figue 3 by Ulysses and corresponding ACE observation as follows.

The velocity profile is quite variable for both polar and ecliptic wind. The velocity is varying between 270 Km/s and 650 km/s for ecliptic wind and for polar wind this is varying between 600 Km/s and 885 km/s. .At small scales, velocity variations are relatively small and spiky. Ulysses was immersed in the high-speed polar solar wind stream in which only an inward magnetic field polarity was observed. Magnetic field varies up to 20 nT for ecliptic wind whereas 2 nT for polar wind. Polar wind is cooler than observed ecliptic wind. The density of solar wind particle associated with ecliptic wind is more than polar wind. Large number of coronal mass ejections can be observed in ecliptic wind than the polar wind.

The polar solar wind is a fast, tenuous and steady flow that, with the exception of a relatively short phase around the Sun's activity maximum, fills the high latitude heliosphere.

The variations of solar wind in polar region are much smaller than in ecliptic wind. So both winds have significant effect in heliosphere. Polar winds can produce appreciable effects in large distance, showed that at the time of Ulysses observation, especially in outer region, corotating features modulate the southern wind velocity more than that of northern wind.

The velocity peaks observed during this interval generally are related to streams originating from small coronal holes. Even at these high latitudes, under the high-speed solar wind conditions, four coronal mass ejections (CMEs) were observed in the solar wind plasma. Even though the Sun has just barely passed through solar maximum, observations since early July 2001 (above $40° N) show fast polar coronal hole streams are again dominating the solar wind at high latitudes in the northern hemisphere. The fast winds produced by the huge polar coronal holes of Ulysses's first orbit are basically identical to these streams.

Slow solar winds are characteristics features of southern hemisphere solar wind during solar maximum. But in Northern hemisphere fast winds are prominent during solar maximum. Solar wind velocity, magnetic field, temperature and density are marginal in southern hemisphere ie; solar wind parameters are minimum. The solar wind velocity and temperature reaches peak values in northern hemisphere whereas solar wind magnetic field and density are its minimal value as compared with the ecliptic wind. This may be due to the polarity reversal happening during the polar reversal phase of magnetic field. The temperature is increased due to increased solar wind velocity. The slow solar wind in southern region and fast solar wind in northern hemisphere during solar maximum suggest that temporal variations affect the solar wind activity. Ecliptic solar wind has the same wind pattern during these different time periods of solar maximum shows radial dependence solar wind speed. Northern and southern polar wind and its corresponding ecliptic wind follows the same wind patterns suggesting uniform solar surface both in polar and ecliptic region.

Summary and Conclusion

Ulysses was the only one spacecraft which gives information about high latitude solar wind. For the present study, we investigated the variations of solar wind parameters at ecliptic regions and polar region for high activity phase of solar cycle 23 covered by Ulysses in its second out of ecliptic orbit.

The continued return of data from Ulysses provides invaluable and unique information on the high latitude solar wind during solar activity cycle. At smaller latitude separation. Particularly less than ~ 15 ° ACE and Ulysses frequently observe parts of the same stream structures. For high and low latitudes observed by both spacecraft, the peak intensity at ACE is always higher than at Ulysses. The typical duration of the events observed by Ulysses is longer than at ACE. Solar wind structure during Ulysses' near-maximum, second polar orbit is not so simple, well-ordered and that has been remarkably different from the observations during its first orbit. Comparison of solar wind observations from the ACE spacecraft, in the ecliptic plane at 1AU, and the Ulysses spacecraft as it orbits over the Sun's poles, provides valuable information about the latitudinal extent and variation of solar wind structures in the heliosphere.

The nature of fluctuations of plasma speed and plasma temperature are similar in polar and ecliptic region. Density of ecliptic solar wind is larger than 20 cm-3 whereas that of polar wind is less than 10 cm-3. In solar maximum, southern polar winds have the characteristics of slow solar wind that originates from more active regions of sun whereas northern polar winds have the characteristics of fast solar wind that emerges from magnetically open coronal holes. Velocity profile for low latitude lies between 280 km/s – 880 km/s during this more solar activity period and corresponding polar wind ranging from 285 km/s to 535 km/s in southern hemisphere. Also ACE observation showed that ecliptic wind ranging from 600km/s to 900 km/s and its corresponding Ulysses observation polar wind ranging from 270 km/s - 650 km/s in northern hemisphere. These are significant velocity variations because Ulysses observed solar wind at 5 AU and ACE observed solar wind at 1 AU. A small but significant hemispherical asymmetry exists, with the north polar hole being cooler than the southern one [Zhang et al., 2002]. The variation of proton density rises rapidly but falls slowly for polar and ecliptic winds. An unexpected result from Ulysses' solar maximum polar pass was that the solar wind speed and density were nearly constant with latitude, with the speed showing a slight decrease and the density a slight increase towards the solar pole. Solar wind parameters vary with changes in the solar cycle, with changes in heliolatitude. At solar maximum, all solar wind parameters have drastic variation. During solar maximum, solar wind parameters are found to be very erratic. The observed variations are in agreement with concepts of solar wind in its maximum phase.

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