On the source of the anomalous June 23, 2020 Pc5 waves detected at both ground and satellite data

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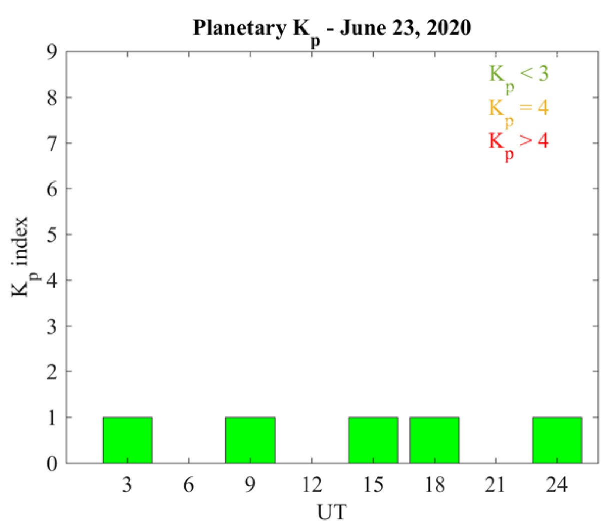
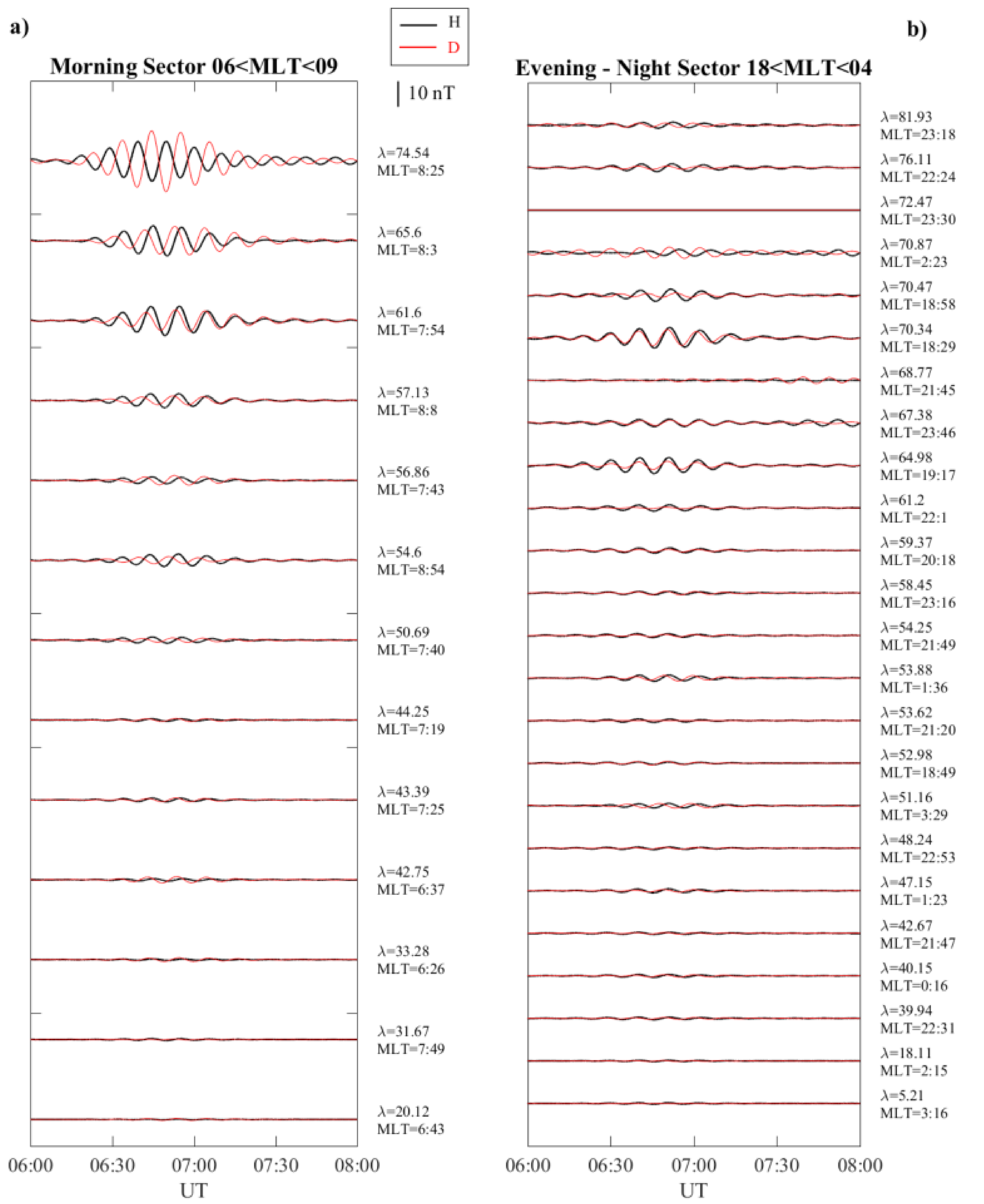
Introduction.

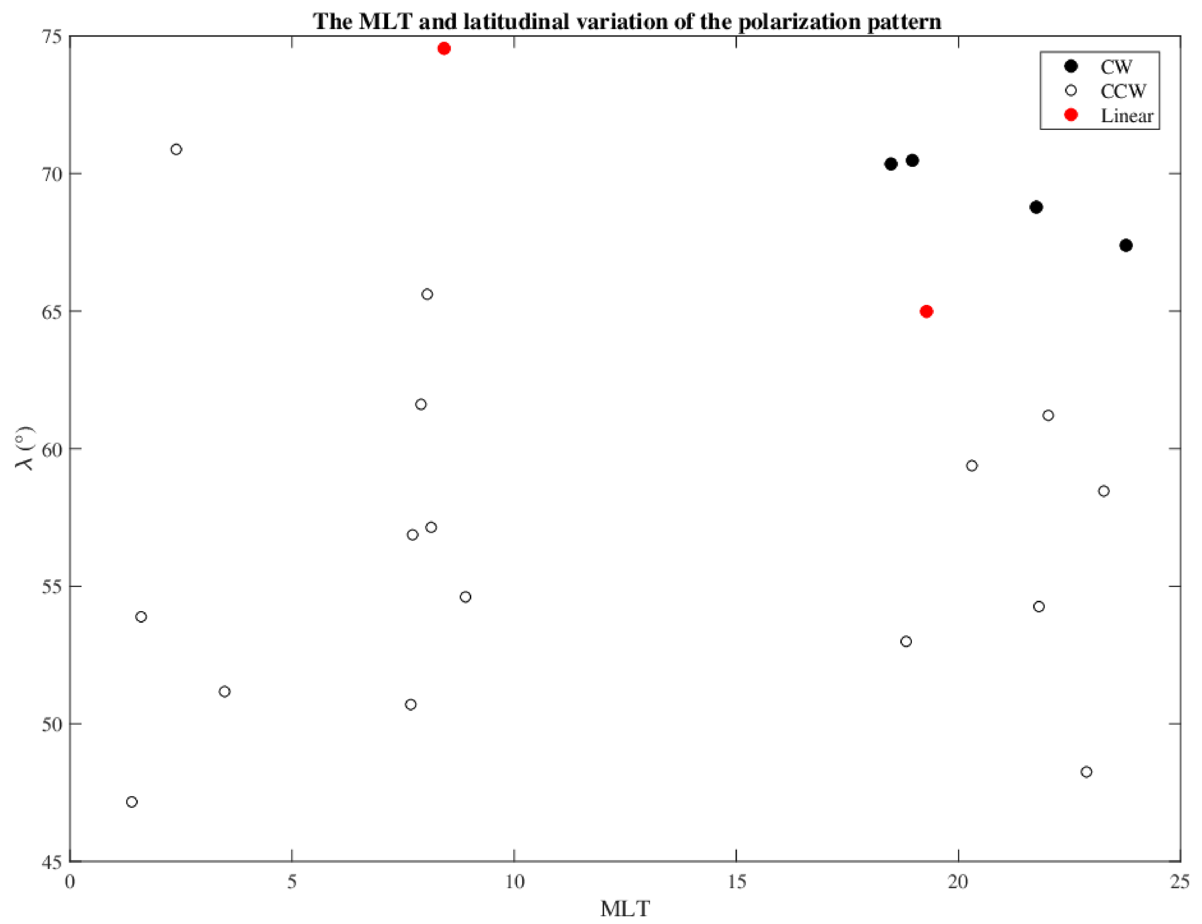
We examine the characteristics of ULF waves observed in the magnetosphere and at ground on June 23, 2020 during super solar quiet geomagnetic conditions. A highly monochromatic and large-amplitude wave at f = 1.67 mHz was observed between 6:10 and 7:00 UT at CSES LEO satellite orbit and across a wide longitudinal range of ground stations from low to high latitudes. We found the possible driver of such global ULF wave activity in the impact of a Tangential Discontinuity intersecting the bow shock quasi-parallel to it. As a consequence, a foreshock bubble (FB) was generated, producing pressure pulses which in turn generates Pc5 waves in magnetosphere. The combination of the long period of these pulsations, their extended duration, the latitude-independent frequency, and the small azimuthal wave number suggests the occurrence of a global magnetospheric waveguide mode. The amplitude and cross-phase analysis of the wave activity on the ground and the polarization pattern indicate that the waveguide mode coupled to the field line resonance (FLR) occurs at different latitudes at different local times. Such FLRs occurred at latitudes smaller than usually observed at the same frequency, suggesting a significant reduction of the local field line eigenfrequencies as compared with usual values. The analysis of LEO satellites confirms the slight enhancement of energetic particle precipitations in the slot region casued by the ULF wave activity.

On June 23, 2020 (SSQ day) a strange 10 minutes oscillations (Pc-5 waves) was found in every magnetometer on a global scale.
Such oscillations are called“pulsation continuous” or “Pc” for short.
Pc waves are essentially flutters propagating down the flanks of Earth’s magnetosphere excited by the solar wind.
Pc waves are distinguished by the peculiar frequency: Pc-3 (10 – 100 mHz); Pc-5 (0.1 – 10 mHz).
In general Pc-5 are excited by two possible drivers:
1. waves with the same frequency in the solar wind parameters (resonance phenomena);
2. Impact of discontinuities (CIR, IP shocks, and so on) onto the magnetopause.

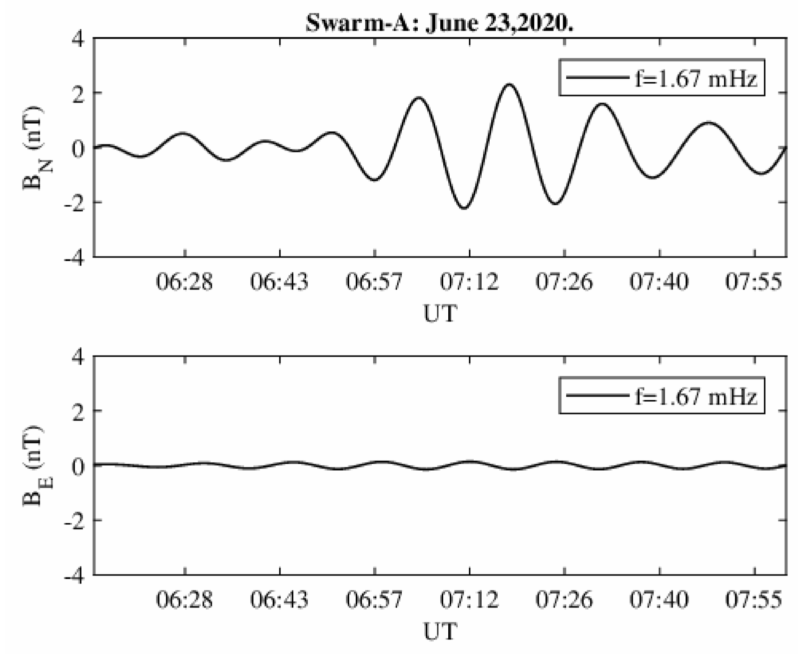


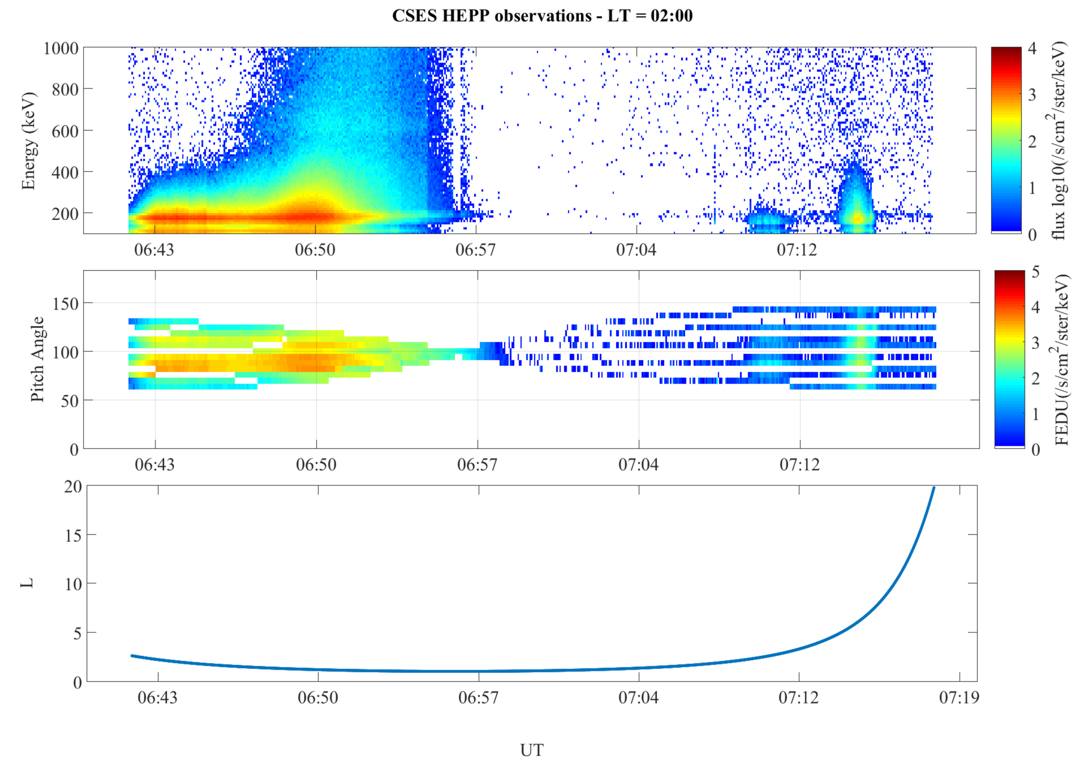


The ground-based data have been organized into two LT sectors: the morning sector (06:00–18:00 LT, panel a) and the night sector (18:00–06:00 LT, panel b). The power spectra (not shown) revealed a peak centered at f = 1.67 mHz in both sectors. This latitude-independent frequency was used for coherence, amplitude, and cross-phase analyses for the ground measurements. The coherence, cross-phase and amplitude ratio (not-shown) confirms the FLR signature at 74.54° of latitude in the morning sector and at 70.34° in the nighside sector.



The polarization pattern (open circles identify CCW polarization, black circles identify CW polarization, and red circles identify linear polarization) as a function of magnetic LT and latitude clearly reveals a reversal at λ=65° in nigh sector and some evidence for a similar feature at λ=75° in dayside sector. According to theoretical models, such a polarization pattern can be interpreted as an effect of the resonant coupling between compressional and Alfvén modes(Southwoodet al., 1974), which predicts a polarization reversal at the latitude of the resonant field line. The polarization profile is consistent with the one proposed by (Piersanti et al. 2011) who interpreted such behavior in terms of a resonance line shifting to a lower latitude moving toward the dark hemisphere because of the MLT dependence of the length of the local field line (Waters et al. 1996).



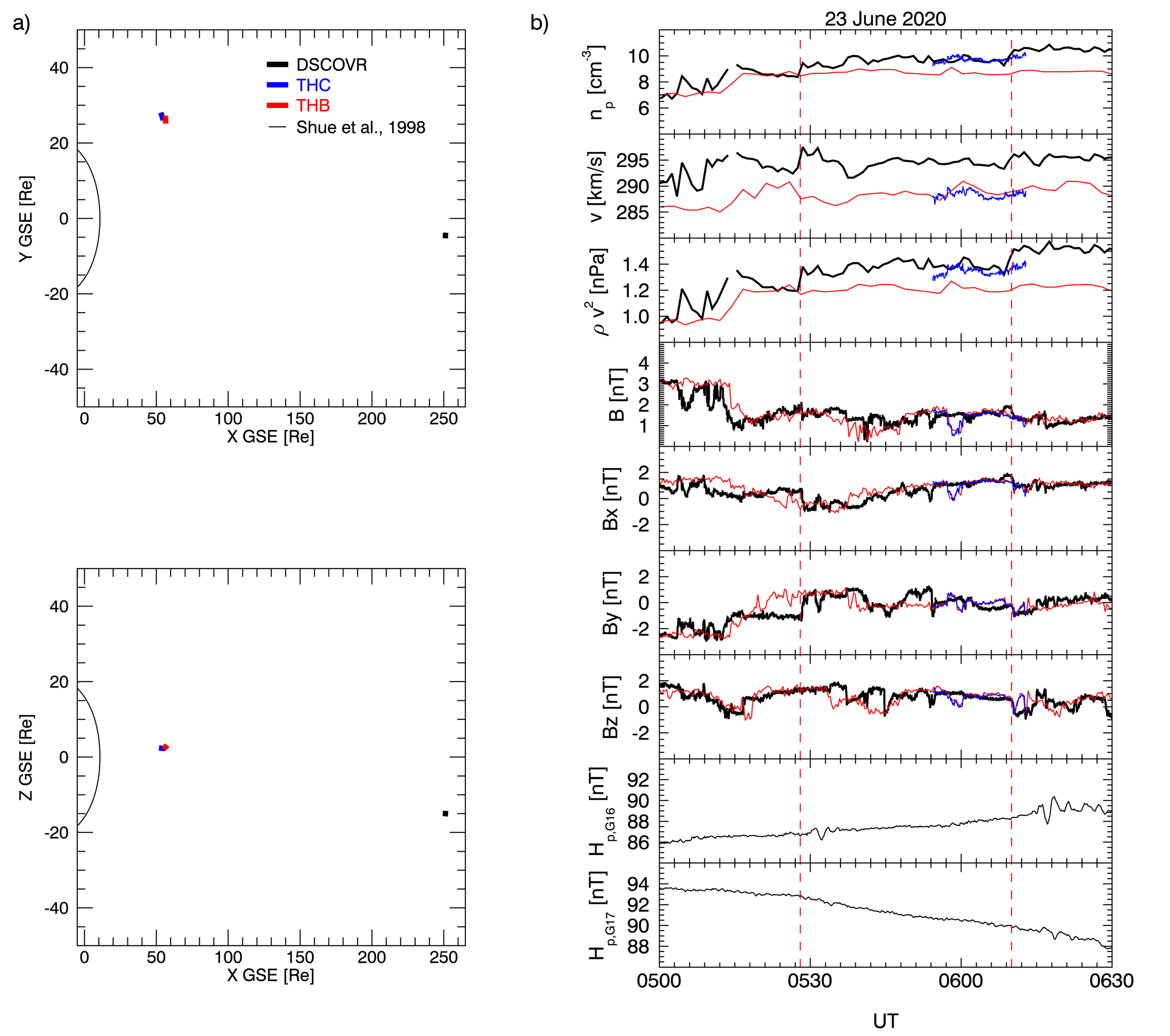


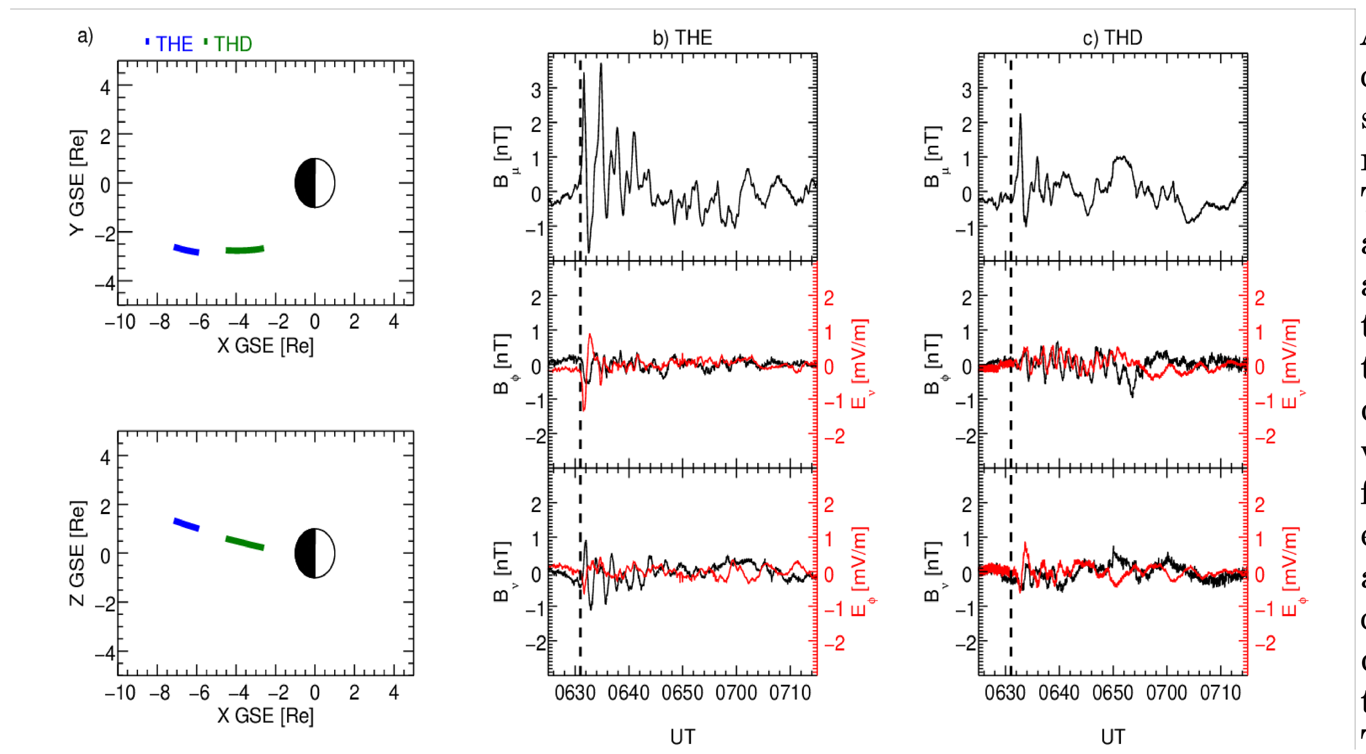
Left panel) A Pc5 wave activity is clearly seen along both the north-south (B_N - upper panel) and east-west (B_E - lower panel) components of Swarm-A satellite. As expected for LEO satellites orbits B_N attain larger amplitudes than B_E (Balasis et al., 2015). The Pc5 wave activity started at 06:24 UT. The maximum amplitude at SWARM is observed around 7:20 UT, later with respect the maximum amplitude observed at ground magnetometer at around 6:50 UT. Such amplification might be related to the resonant latitude region. In fact, its geomagnetic position corresponds to λ=73.57° and MLT=2:10 which are coherent with the ground polarization pattern.

Right panel) A slight enhancement of energetic particle precipitations appeared at CSES LEO satellites (HEPP instrument). The pitch angle distribution (Figure 6b) shows that the energetic flux overwhelmingly dominates at pitch angles from 80°to 100°, peaking at around 90°. This region is commonly the slot region of radiation belt depicted by LEO satellites. At quiet geomagnetic condition usually it is invisible, but during the strong geomagnetic storm times, CSES can witness obvious slot region (Zhima et al., 2021). We speculate that the enhancement around the slot region might be induced by the ULF waves from the inner-magnetosphere.

Discussion

The extended period of super quiet geomagnetic conditions questions which is the driver of the global ULF mode. Looking at possible external mechanisms, the challenge was to properly identify the solar wind structure impacting the magnetosphere. To monitor the solar wind properties, we used data from the DSCOVR (X_{GSE}= 251.1 Re, Y_{GSE}=-4.5 Re, and Z_{GSE}=-15.0 Re) and THEMIS-B (X_{GSE}= 56.5 Re, Y_{GSE}= 26.7 Re, and Z_{GSE}= 2.7 Re). In THB measurements (right panels), we identified a sharp discontinuity in the IMF at 6:10 UT, ~12 minutes before the wave train. We identified a similar feature in the magnetic field measurements at DSCOVR ~71 minutes before. We found a general agreement of the large scale features, e.g. the slow increase of the solar wind density and dynamic pressure associated with a decrease in the IMF intensity at the beginning of the time interval for both DSCOVR and THB. The correspondence between the two small pressure jumps and the ULF wave activity suggest their possible role in triggering the magnetosphere dynamics.





At ~6:31 UT (black dashed lines—left panels), we clearly observed the onset of ULF waves at THE satellites, but at higher frequencies (~11mHz) with respect to the ground and SWARM observations. The two THEMIS satellites were almost aligned along the X_{GSE} direction during this time interval and observed the peak of the first fluctuation along the compressive component progressively from THE to THD, indicating a sunward propagation of the disturbance. These characteristics are compatible with Pi2 ULF waves, exhibiting properties of MHD fast mode waves when observed near the magnetic equator (Takahashi et al., 2003). A cross-spectral analysis of the poloidal component of B and toroidal component of E at THD (not shown), revealed evidence of a coherent wave at ~11.6 mHz with ~97° phase difference consistent with a standing toroidal wave mode. Note that, the ground observatories in the nightside showed wave activity very similar to the one observed at the THEMIS satellites. The abrupt onset of the Pi2 waves suggest a rapid reconfiguration of the magnetotail or bursty bulk flows as generation mechanism that might have been triggered by the short period of southward IMF. The SME and SML geomagnetic indices (not shown) provided by the SuperMAG collaboration manifested large values between 6:11 UT and 6:25 UT reaching at 6:22 UT a maximum value of ~208 nT and ~-181 nT, respectively. The large negative values of SML, suggested the occurrence of particle precipitation that are confirmed by the HEPP observations on-board CSES.

Conclusions.

In the solar wind, close to the estimated impact time on the magnetosphere of two small pressure pulses, associated with IMF component rapid variations, we observed wave activity in the night-side magnetosphere. For the interval of interest, the estimated time of arrival of the second pressure pulse is a few minutes late with respect to the onset time of the global ULF wave at about 6:22 UT. However, some stations in the dayside sector observed an isolated bump in the north-south magnetic field component at about 6:22 UT, that might be representative of the true impact time of the small solar wind dynamic pressure pulse that in turn might have triggered the global ULF wave. At the same time, the SME and SML geomagnetic indices reached maximum values suggesting the occurrence of particle precipitation. Shortly after, the abrupt onset of the Pi2 waves suggest a rapid reconfiguration of the magnetotail or bursty bulk flows.