Earth Moon Planet (2009) 104:25–27
DOI 10.1007/s11038-008-9246-y

Monitoring the Dynamics of the Ionosphere–Plasmasphere System by Ground-Based ULF Wave Observations

Massimo Vellante · Matthias Förster · Michael Pezzopane · Norbert Jakowski · Tie Long Zhang · Umberto Villante · Marcello De Lauretis · Bruno Zolesi · Werner Magnes

Received: 11 January 2008 / Accepted: 1 August 2008 / Published online: 17 December 2008

Abstract Cross-spectral analysis of ULF wave measurements recorded at ground magnetometer stations closely spaced in latitude allows accurate determinations of magnetospheric field line resonance (FLR) frequencies. This is a useful tool for remote sensing temporal and spatial variations of the magnetospheric plasma mass density. The spatial configuration of the South European GeoMagnetic Array (SEGMA, $1.56 < L < 1.89$) offers the possibility to perform such studies at low latitudes allowing to monitor the dynamical coupling between the ionosphere and the inner plasmasphere. As an example of this capability we present the results of a cross-correlation analysis between FLR frequencies and solar EUV irradiance (as monitored by the 10.7-cm solar radio flux F10.7) suggesting that changes in the inner plasmasphere density follow the short-term (27-day) variations of the solar irradiance with a time delay of 1–2 days. As an additional example we present the results of a comparative analysis of FLR measurements, ionospheric vertical soundings and vertical TEC measurements during the development of a geomagnetic storm.

M. Vellante (✉) · U. Villante · M. De Lauretis
Dipartimento di Fisica, Università dell'Aquila, L'Aquila, Italy
e-mail: massimo.vellante@aquila.infn.it

M. Vellante · M. Pezzopane · U. Villante · M. De Lauretis · B. Zolesi
Consorzio Area di Ricerca in Astrogeofisica, L'Aquila, Italy

M. Förster
GeoForschungsZentrum, Potsdam, Germany

M. Pezzopane · B. Zolesi
Istituto Nazionale di Geofisica e Vulcanologia, Rome, Italy

N. Jakowski
Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institut für Kommunikation und Navigation, Neustrelitz, Germany

T. L. Zhang · W. Magnes
Institut für Weltraumforschung, Graz, Austria

Keywords ULF waves · Field line resonance · Remote sensing · Solar activity · Plasmasphere · Ionosphere

1 Introduction

The knowledge of the composition and concentration of the plasma populating the Earth's magnetosphere, its spatial structure and its temporal variations, represent an essential information for understanding the complex dynamic processes which take place in the magnetosphere. However, in situ measurements by satellites are generally limited only to particular regions. So far, the most economic and efficient method for determining the electronic density of the magnetospheric plasma has been the technique based on the ground recording of VLF whistlers propagating along the geomagnetic field lines (Park 1972). An alternative technique is based on the ground recording of ULF waves and in particular on the detection of resonant oscillations of the geomagnetic field lines (FLR). This technique, which was introduced in the eighties by Baransky et al. (1985), consists in comparing measurements of the north-south geomagnetic component at two stations nearly aligned along a same geomagnetic meridian and closely separated in latitude (typically 1–3°). The standard procedure identifies the resonant frequency f_R of the field line midway the two recording stations as the frequency where the phase difference is maximum (Waters et al. 1991). The estimated f_R is then used to derive estimates of the equatorial plasma mass density which scales as $\rho_{\mathrm{eq}} \propto f_R^{-2}$. The spatial configuration of the SEGMA array (Vellante et al. 2002) is particularly suitable for the application of this technique for detecting FLRs. Indeed, the array is composed of four stations approximately equispaced in latitude between 36° and 42° CGM latitudes which allow to determine f_R at three different magnetic shells: $L = 1.61$, 1.71, 1.83. It allows to monitor the dynamics of the inner magnetosphere and in particular the dynamical coupling between the ionosphere and the plasmasphere. Two prominent results, recently obtained by using data from SEGMA, are reported in the next section.

2 Experimental Results

2.1 Solar Activity Dependence

The analysis of four year (2001–2004) measurements of f_R across the SEGMA array has revealed a clear control by the solar EUV irradiance (as monitored by the F10.7 index) both on a solar cycle and day-to-day basis (Vellante et al. 2007). At $L = 1.61$, this control is expressed by the following relationship: f_R (mHz) = 94−0.21 F10.7. This result is interpreted in the following way: an increase of the solar EUV/X-ray radiation increases the ionization rate in the ionosphere; the produced ions diffuse along the local field line increasing the mass density; as a consequence the natural frequency of oscillation of the field line decreases. In addition, we find some evidence for a delay of 1–2 days between changes of the solar flux and corresponding changes of f_R. Similar delays were already found previously in ionospheric parameters and were attributed to the delay of the atomic oxygen concentration to follow solar radiation changes (Jakowski et al. 1991). In our case, some contribution may also come from the plasma diffusion along the flux tube.

2.2 Analysis of the Geomagnetic Storm of 3–4 April 2004

A comparative analysis of (a) FLR measurements at two station pairs of SEGMA ($L = 1.71$ and 1.83), (b) ionosounding measurements from the Rome station, and (c) vertical TEC measurements over north-Italy deduced from GPS signals of the European IGS network was conducted during the geomagnetic storm of 3–4 April 2004 (Villante et al. 2006). During the recovery phase of the storm (4 April) we observed at both L values a significant increase of f_R with respect to the pre-storm values of 3 April. This corresponds to an inferred decrease of the equatorial plasma mass density of about 40–50%. At the same time, both the ionosounding and TEC measurements revealed during April 4 a clear negative storm phase quantifiable also in this case as a decrease of about 50% in the ionospheric electron concentration. So the ionospheric depletion, probably caused by neutral composition changes which usually occur at middle latitudes during the storm development (Rishbeth 1998), was also reflected in a similar mass depletion in the plasmasphere.

3 Conclusions

The present results show that low-latitude ($L < 2$) plasmaspheric flux tubes may be considered to be, in a diurnal average sense, in a diffusive equilibrium with the underlying ionosphere, i.e. variations in ionospheric density which take place on time scales larger than ≈ 1 day are reflected in corresponding variations in the plasmasphere density. At higher latitudes, the ionosphere–plasmasphere interaction is expected to be less direct because of the increased filling time of the flux tubes which are very often depleted by magnetic disturbances. Therefore, also the short-term control of the solar irradiance on the plasmaspheric density should rapidly decrease with increasing L. There is indeed no mention in the scientific literature of the observation of such an effect from whistler measurements which are mainly obtained at $L > 2$. Therefore, our results demonstrate the usefulness of using the FLR technique for investigating the ionosphere–plasmasphere coupling.

References

L.N. Baransky, J.E. Borovkov, M.B. Gokhberg et al., Planet Space Sci. **33**, 1369–1374 (1985)

N. Jakowski, B. Fichtelmann, A. Jungstand, J. Atmos. Terr. Phys. **53**, 1125–1130 (1991)

C.G. Park, Radioscience Laboratory Technical Report 3454-1, Stanford University, California (1972)

H. Rishbeth, J. Atmos. Solar-Terr. Phys. **60**, 1385–1402 (1998)

M. Vellante, M. De Lauretis, U. Villante et al., ESA Special Publication 477, 487–490 (2002)

M. Vellante, M. Förster, U. Villante et al., J. Geophys. Res. **112**, A02205. doi: 10.1029/2006JA011909 (2007)

U. Villante, M. Vellante, P. Francia et al., Ann. Geophys. **24**, 1455–1468 (2006)

C.L. Waters, F.W. Menk, B.J. Fraser, Geophys. Res. Lett. **18**, 2293–2296 (1991)