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The ISL Langmuir probe experiment processing onboard DEMETER: Scientific objectives, description and first results

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Abstract

The DEMETER Langmuir probe experiment, called ''Instrument Sonde de Langmuir'' (ISL), has been designed for in situ measurements of the bulk parameters of the ionospheric thermal plasma. The ISL instrument is comprised of two sensors: (i) a classical cylindrical sensor and (ii) a spherical sensor with its surface divided in seven segments: six spherical caps electrically isolated and the rest of the sphere which is used as a guard electrode. The two main parameters measured by ISL are the electron density and temperature; they are obtained with a 1 s time-resolution. In addition, the ion density and its variation can be derived from the current-voltage characteristics of the probe, but it requires an a-priori knowledge of the ion composition and a more sophisticated processing than the one currently implemented. The novel design for the spherical sensor has been called the segmented Langmuir probe (SLP). The SLP current can be measured individually on each of the seven segments, thus providing angular sensitivity to the ram direction of the incoming ion flow. The SLP was flown for the first time onboard the DEMETER satellite for in-flight validation of this novel concept, but the main sensor used routinely during the mission is the cylindrical probe. The design of the instrument and the analysis technique for the cylindrical probe are described. A brief description of the SLP and of its capabilities is provided. An overview of the currently available ISL data products on the DEMETER Mission Science Data Centre is given. Selected examples of some ''classical'' ionospheric features as being observed by ISL are discussed.

Keywords: Ionospheric plasma; Perturbations; Electron density; Temperature

1. Introduction

The global behaviour of the upper atmosphere and particularly of the ionosphere depends on the amount of solar radiation impinging on it. Daily and seasonal variations are reasonably well modelled in current ionosphere models. It is well known that there are natural perturbations in the ionospheric plasma connected with magnetic storms, particle precipitation from the radiation belts, etc., but no model exists that allows to predict such perturbations. Although there is observational evidence that solid-earth events such as earthquakes and volcanic activity generate atmospheric perturbations by direct coupling between the perturbed solid-earth surface and the atmosphere, the mechanisms of seismicity–ionosphere coupling are poorly understood. Correlations between tropospheric and ionospheric parameter variations have been observed for almost 50 years (Bauer, 1957; Bauer, 1958a, b), and similar mechanisms may be at work during a seismic event. Care must be exercised not to interpret these natural effects as seismogenic events as discussed, for example, by Afonin et al. (1999). The main scientific objectives of DEMETER (detection of electro-magnetic

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emissions transmitted from earthquake regions) are to study the disturbances induced in the Earth ionosphere by seismic and by volcanic activity (Parrot et al., 2005). The second objective of DEMETER is the global monitoring of the Earth's electromagnetic environment and the study of the effects of the anthropogenic activities on the ionosphere. One possible mechanism, often invoked, is that the upward propagating atmospheric perturbations couple with the ionosphere, and produce a detectable perturbation in the ionospheric parameters (Ondoh, 1999).

The specific scientific objectives of the DEMETER Langmuir Probe Instrument (ISL: Instrument Sonde de Langmuir) are to map the bulk plasma parameters (primarily electron density and temperature) and to study their variations associated with solid-earth events and other sources of perturbations. ISL is a Langmuir probe swept in voltage. A complete voltage sweep is performed in 1 s, thus allowing to obtain a current–voltage (I–V) characteristic every second. Bulk plasma parameters extracted from the analysis of the I–V characteristics are obtained with 1 s time resolution, corresponding to about 7 km spatial resolution on the 700 km altitude DEMETER orbit. ISL is also capable of monitoring the spacecraft potential and its variations with a time resolution of better than 100 ms. Here, we provide a description of the ISL instrument and illustrates the instrument capabilities to study ionospheric perturbations. In this preliminary paper, no attempt will be made to correlate the ionospheric perturbations observed with seismic events. A proper study, that will be undertaken once sufficient data has been accumulated, will be based on a statistical evaluation of the large amount of data that DEMETER is expected to acquire over its lifetime (currently planned for 2 years). This paper should be seen as an overall description of the ISL instrument capability and illustrating the ISL data products available on the server of Mission Science Data Centre after routine analysis. However, due to the inherent difficulty to perform routine processing of Langmuir Probe raw data, it is highly advisable to refer to the raw data for a detailed investigation of the observed effects.

In Sections 2 and 3 we describe in detail the ISL instrument design and we provide an overview of its flight operations. In Section 4 we present the data analysis method and describe briefly the ISL data products available to the DEMETER guest investigators through the Mission Science Data Centre server (Lagoutte et al., 2005). Examples of the preliminary ISL scientific results are described in Section 5. Concluding remarks are given in Section 6.

2. The ISL instrument description

2.1. Background information on the Langnuir probe and specifically about ISL

A Langmuir Probe (LP), in its simple form, is a conductor immersed in a plasma with a bias voltage applied to it. The principle of the measurement technique is to vary the bias voltage and to measure the current collected as a function of the applied voltage, i.e. to acquire the current-voltage (I–V) characteristic of the probe. The analysis of the I–V characteristics provides information concerning the plasma density and temperature. The Langmuir Probe has been extensively used in space plasma diagnostic for more than 40 years (for a recent review, see for instance Brace, 1996; see also Brace et al., 1971, 1973; Bering et al., 1973; Chapkunov et al., 1976). When a conductor immersed in a plasma is biased, it acquires a space charge based on the relative flux of electrons and ions to the conductor. In a typical ionospheric plasma, in addition to the ambient ions and electrons, photoelectron and secondary particles emitted by the probe surface contribute to the overall current collected by the probe.

When the bias voltage is negative, the probe collects an ion current and repels electrons from the ambient plasma. Conversely, for a positive voltage, it collects an electron current and repels ions. The response of the LP is obtained by acquiring the I–V characteristic, much in the same way as we obtain the I–V characteristic of a diode. The analysis of the I–V characteristic provides the following plasma parameters, with their expected values along the DEMETER orbit indicated for reference:

- electron density (N_e): 10^8–$5.10^{11}\,m^{-3}$,
- electron temperature (T_e): 600–10000 K,
- ion density (N_i): (note that it requires knowledge of the ion composition and of the effective ion collection area): same as N_e ,
- spacecraft potential (V_s): $\sim\pm3V$.

A standard LP sensor is a single electrode which can be either a plane, a cylindrical, or a spherical electrode. Under ionospheric conditions, a Langmuir Probe is typically biased within the range ±5 volts with respect to the satellite body, i.e. the virtual electrical ground. A typical I–V characteristic is shown in Fig. 1, in both a linear–linear and linear–log scale. The principle theory of the LP is well established when the plasma conditions are such that the Debye Length is much larger than the dimensions of the electrode. Then, the so-called Orbit-Motion-Limited theory applies for calculating the I–V response of the LP (Langmuir and Moth-Smith, 1924). A numerical solution has been developed for a non-flowing thermal plasma by Laframboise (1966). No complete theory exists for calculating the response of a LP under ionospheric conditions, which includes magnetic field effects and the bulk motion of the plasma. Approximate theories can however be used under ''ideal'' plasma conditions, i.e. Maxwellian distributions, that allow analyzing the probe response and retrieving the plasma parameters with acceptable accuracy ($\pm15\%$ for T_e and $\pm30\%$ for N_e are generally accepted numbers for a Langmuir probe). It should also be noted that, in addition to the relative drift effects between the plasma and the sensor (due to orbital