Journal of Atmospheric and Solar-Terrestrial Physics 71 (2009) 143–157

Contents lists available at ScienceDirect

Journal of Atmospheric and Solar-Terrestrial Physics

journal homepage: www.elsevier.com/locate/jastp

PMSE and E-region plasma instability: In situ observations

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ARTICLE INFO

Article history:
Received 6 June 2008
Received in revised form
2 October 2008
Accepted 6 October 2008
Available online 17 October 2008

Keywords:
PMSE
E-region
Plasma instability

ABSTRACT

From 29 June to July 6, 2003, the ROMA-Svalrak (Rocketborne Observations of the Middle Atmosphere at the Svalrak facilities) sounding rocket campaign took place at Ny-Ålesund (Spitsbergen, geographical coord. 79°N, 12°E, geomagnetic coord. 76°N, 110°E). Three sounding rockets were launched to study neutral air turbulence and small scale plasma dynamics around polar mesosphere summer echoes (PMSE). During all three flights both PMSE and plasma instability events were observed. It is known that small-scale field aligned structures in the E-region plasma density can be created by unstable electromagnetic waves. The mechanism responsible for creating the structures causing radar echoes (PMSE) is believed to be neutral air turbulence in the presence of heavy charged particles. E-region plasma irregularities recorded during the last rocket flight (labeled RO-MI-03) were observed only during the upleg of the trajectory but not during the downleg. Also, on the upleg there was no clear spatial separation between PMSE and the plasma instability regions. In the current paper we consider this transition region in detail.

1. Introduction

Strong ionospheric currents in the height region from 90 to 120 km at high latitudes are known as the auroral electrojet. These currents produce plasma irregularities and can lead to plasma instabilities, that is plasma waves that grow exponentially or faster. Plasma irregularities in the auroral electrojet region have been studied for over six decades both theoretically and experimentally (for reviews on both theory and observations see Fejer and Kelley, 1980; Kelley, 1989; Fejer et al., 1991; Sahr and Fejer, 1996; Fejer, 1996).

The two primary plasma instabilities in the E-region are the two-stream and gradient drift instabilities. The two-stream instability is the fundamental mechanism responsible for direct generation of short wavelength irregularities in the electrojet plasma. The driving force for the two-stream and gradient drift instabilities is the electric field.

Strong radar echoes, known as polar mesosphere summer echoes (PMSE), are commonly observed at polar latitudes at heights between ~84 and 92 km (Cho and Kelley, 1993; Hall and Röttger, 2001; Röttger, 2001). In our current understanding (summarised in, e.g., Rapp and Lübken, 2003, 2004), inhomogeneities in the refractive index which cause such radar echoes are due to electron density irregularities which are produced by neutral air turbulence in the presence of heavy charged (ice) particles.

These different types of structures (PMSE and plasma instabilities) created by different physical mechanisms differ in wavelength, spectral shape and are usually spatially separated from each other.

From 29 June to 6 July 2003, the European sounding rocket campaign ROMA-Svalrak (Rocketborne Observations of the Middle Atmosphere at the Svalrak facilities) took place at Ny-Ålesund (Spitsbergen, geographical

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1364-6826/$ - see front matter
doi:10.1016/j.jastp.2008.10.003

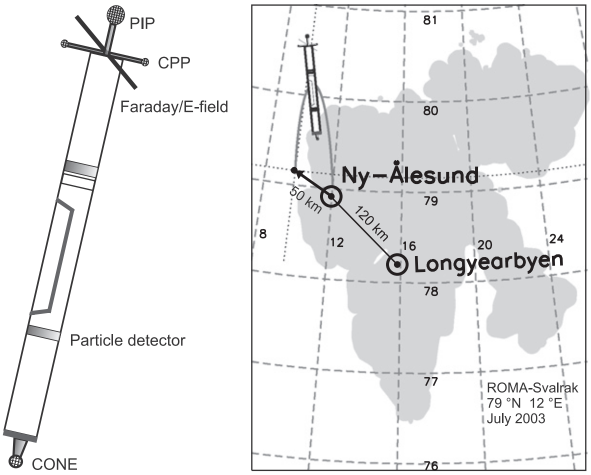

Fig. 1. Left panel: Sketch of the payload. The first rocket carried probes for the E-field measurements whereas the second and the third payloads were equipped with the Faraday antennas. For the acronyms see the text. Right panel: Map of Svalbard. Rockets were launched from Ny-Ålesund in the North–West direction. The bold arrow shows the horizontal projection of the rocket trajectory. Ground-based instruments: SOUSY radar and IAP lidar were located at Longyearbyen. Ground-based magnetometers were operating at Ny-Ålesund and Longyearbyen. The distance between Ny-Ålesund and Longyearbyen is $\simeq 120$ km, and the distance between Ny-Ålesund and the rocket impact point is $\simeq 50$ km.

coord. 79°N, 12°E, geomagnetic coord. 76°N, 110°E, see Fig. 1). The primary scientific aim of this campaign was the study of small scale processes related to neutral and plasma dynamics in the upper mesosphere and lower thermosphere/ionosphere. Three sounding rockets were launched while ground-based measurements were performed with a VHF radar monitoring PMSEs, a potassium lidar for the detection of noctilucent clouds, and magnetometers which gave evidence for disturbances of the auroral electrojet. In addition, the continuously operating SuperDARN HF radar network measured the line-of-sight velocity of F-region ionospheric irregularities.

The different instruments onboard the sounding rockets provided simultaneous and high resolution measurements of neutral air density and temperature, electron density and temperature, and positive ion density. The radar observations were continuously conducted throughout the entire campaign period while the potassium lidar was always operated when weather conditions permitted.

2. Experimental technique

Fig. 1 shows schematics of the payload (left panel) and of the ground-based stations at Svalbard (right panel) employed during the ROMA-Svalrak campaign. The first payload (RO-MI-01 launch) carried probes for electric field measurements which were replaced by Faraday antennas (see below) for the last two flights (RO-MI-02 and RO-MI-03).

2.1. Rocketborne instruments

The positive ion probe (PIP) mounted in the front of the payload is an electrostatic probe, developed by the Norwegian Defence Research Establishment (FFI). It consists of two concentric spherical grids with diameters of 8 and 10 cm. The outer grid is at payload potential. The inner grid is negatively biased (-7 V) relative to the rocket body and, it therefore, collects positive ions. The PIP sensor measures ion density fluctuations on spatial scales as small as 10 cm and with a precision better than 0.1%. Together with the radio wave propagation experiment described below, the PIP sensor further allows us to derive absolute ion densities. For a detailed description of the PIP instrument, the reader is referred to Blix et al. (1990).

In the rear, the payload was equipped with the CONE (= COmbined measurements of Neutrals and Electrons) instrument (see Giebeler et al., 1993). Basically, the CONE sensor is a spherical ionisation gauge for the measurement of neutral density and is surrounded by a negatively biased grid (to shield the gauge from ambient electrons) and a positively biased spherical grid which is connected to a sensitive electrometer to measure electrons. The measurement of both neutrals and electrons are made at very high spatial resolution and high precision (i.e., altitude resolution $\geqslant 10$ cm; precision better than 0.1%). Hence these measurements allow for the detection of small scale fluctuations in both species that arise due to processes like neutral air turbulence (Lübken et al., 2002) or plasma instability processes (see below). In addition, the height profile of neutral number densities can be integrated assuming hydrostatic equilibrium to yield a temperature profile at $\sim$200 m altitude resolution and an accuracy of $\sim$3 K (Rapp et al., 2001, 2002). The electron current measured by the outermost grid of the CONE sensor can also be converted to absolute electron number densities by normalising it to the absolute (but spatially coarse) electron number densities derived from the radio wave propagation experiment described below.

The radio wave propagation experiment yields a high precision electron density measurement. Basically, this is realised by transmitting a radio signal from the ground and receiving it by a pair of antennas on the rocket. The theoretical basis and practical application of this technique are described for example in Bennett et al. (1972) and Smith (1986). The transmitted linearly polarised electromagnetic wave may be considered to be the resultant of two circularly polarised waves with equal electric field vectors rotating in opposite directions. When propagating through the ionospheric plasma these two waves differ in absorption and phase velocity. The difference in absorbtion causes the resultant wave to become elliptically polarised (differential absorption). In addition, the difference in phase velocity causes the major axis of the polarisation ellipse to rotate as the wave propagates (Faraday rotation). Since both differential absorption and Faraday rotation directly depend on the electron number density along the path of the radio signal through the ionosphere, the height resolved measurements of both quantities can be used to precisely derive the electron number density profile at a typical vertical resolution of $\sim$1 km (defined by the rocket velocity and the rocket spin rate). Importantly, these measurements are not influenced by unwanted effects due to the