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In-situ electron and ion measurements and observed gravity wave effects in the polar mesosphere during the MaCWAVE program

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Abstract. Langmuir probe electron and ion measurements from four instrumented rockets flown during the MaCWAVE (**M**ountain **a**nd **C**onvective **W**aves **A**scending **VE**rtically) program are reported. Two of the rockets were launched from Andøya Rocket Range, Norway, in the summer of 2002. Electron scavenging by ice particulates produced reductions of the electron density in both sharp narrow (≈1–2 km) layers and as a broad (≈13 km) depletion. Small-scale irregularities were observed in the altitude regions of both types of electron depletion. The scale of the irregularities extended to wavelengths comparable to those used by ground-based radars in observing PMSE. In regions where ice particles were not present, analysis of the spectral signatures provided reasonable estimates of the energy deposition from breaking gravity waves.

Two more instrumented rockets were flown from Esrange, Sweden, in January 2003. Little turbulence or energy deposition was observed during one flight, but relatively large values were observed during the other flight. The altitude distribution of the observed turbulence was consistent with observations of a semidiurnal tide and gravity wave instability effects as determined by ground-based lidar and radar measurements and by falling sphere measurements of the winds and temperatures (Goldberg et al., 2006; Williams et al., 2006).

Keywords. Atmospheric composition and structure (Aerosols and particles) – Meteorology and atmospheric dynamics (Middle atmosphere dynamics; Turbulence)

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1 Introduction

The state of the polar mesosphere is influenced by a number of energy sources that can be driven either globally or locally. The MaCWAVE (Mountain and Convective Waves Ascending VErtically) program was designed to determine the connection between some of the possible energy sources and the corresponding responses in the mesosphere and lower thermosphere (MLT). While tidal forces can directly influence the MLT, another common mechanism for the transport of energy is through gravity waves, which propagate upwards from the Earth's surface. There can be many possible sources of gravity waves, such as topography, wind shear, convection, geostrophic adjustment, wave-wave interaction, energetic particle precipitation, etc. (Fritts, 1993; Fritts and Alexander, 2003). Tropospheric convective activity, which commonly occurs during the summertime, was the planned source for the summer MaCWAVE launch sequences that were conducted from Andøya Rocket Range in northern Norway. This location was chosen because of the availability of ground-based radar and lidar support facilities, which provided important data about the state of the atmosphere at the time of the rocket launches.

Gravity waves can also be generated by the movement of winds over orographic features such as a mountain range. The winter MaCWAVE program was designed to investigate this source mechanism and consisted of rocket launches from Esrange in northern Sweden. Prevailing winds across the mountain range located to the west of the launch range were expected to create gravity waves whose effects would be seen in the MLT. Both the summer and winter MaCWAVE programs included a large number (∼25 and 20) of meteorological rockets for the determination of the winds and temperatures over four separate 12-h intervals.

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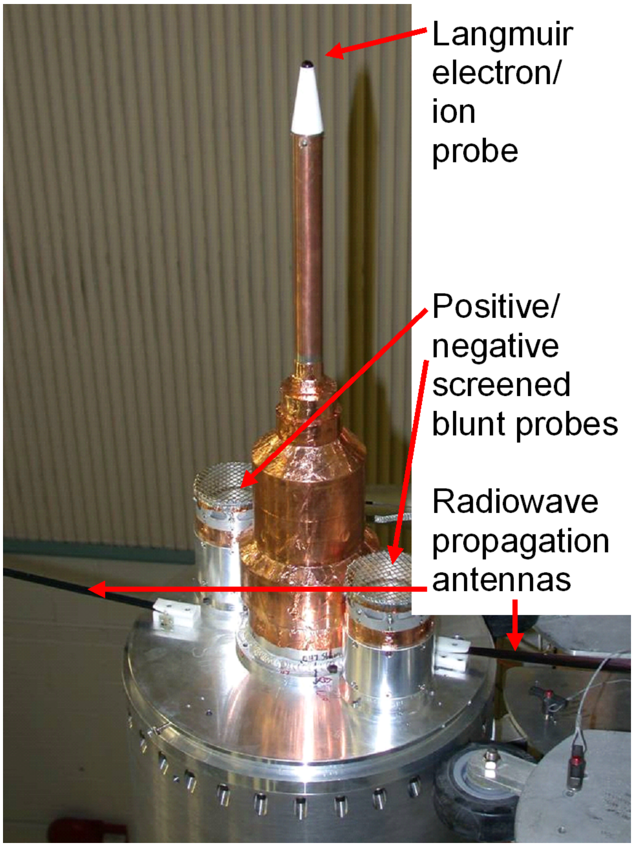

Fig. 1. Instrument configuration for the Terrier-Orion rockets of the MaCWAVE program.

A large instrumented rocket was also included within each 12-h salvo. The primary data instruments of these Terrier-Orion rocket payloads were a pair of forward- and aft-mounted Langmuir probes. The probes' DC current data were used to determine the large-scale characteristics of the electron and ion densities. At the same time, high-gain AC channels were used to detect small-scale irregularities in the electron and ion currents. These AC data permitted determination of the energy dissipation when the gravity waves became unstable and deposited energy in the region. Goldberg et al. (2004; 2006) have provided overviews of the logistics and results of the MaCWAVE program. In this work we describe in detail the results from the Langmuir probe measurements.

2 Payload configuration

Each of the four instrumented MaCWAVE rockets carried essentially the same payload consisting of Langmuir probes, blunt probes, and a radio-wave propagation experiment (Fig. 1). A Langmuir probe was positioned on the central axis at each end of the payload to enable charge collection under both ram and wake flow conditions throughout essentially the entire flight. The front hemispherical collector was extended forward of the main body to ensure that the shock front from the payload structure would not perturb the aerodynamic flow at the collector. Multiple telemetry data channels were used to properly handle the wide dynamic range of the measured currents. The outputs of the logarithmic electrometers were processed by several different "DC" channels of different gain values. The data were also highpass filtered on the payload to reduce the effects of spin modulation and then transmitted to ground via multiple "AC" gain channels. The DC channels enabled the measurements of the electron and positive- and negative-ion currents/concentrations, while the AC channels were used to detect spectral features associated with encountered plasma density irregularities.

Because two of the flights were scheduled for launch during summertime conditions at a high latitude site, we expected that ice particles would be present. Therefore two screened blunt probes (Mitchell et al., 2001) were added to each end of the payload but located well behind the Langmuir probe. These instruments were used to identify altitude regions where large ice particles were present; such particles are not affected very much by the shock front from the more forward Langmuir probe. We have used DSMC (Direct Simulation Monte Carlo) computer modeling (Horányi et al., 1999; Mitchell et al., 2005) to determine the particle trajectories around the blunt probe structure. One blunt probe was biased at +2.5 volts, and the other at –2.5 volts. The alternate bias voltages help to identify the polarity of the ice particles that are found (Mitchell et. al., 2005).

5 Summary and conclusions

The combination of summer and winter flights has provided a number of opportunities for comparison of Langmuir probe electron and ion current measurements under various geophysical conditions. In the cold summer polar mesosphere, ice particle formation can produce sharp layer bite-outs in the electron density and/or broad regions of electron depletion. Both types of electron depletions are accompanied by plasma irregularities with scales smaller than a few meters. Although the occurrence of PMSEs seems to be associated with the regions of largest plasma density irregularities and bite-outs, small-scale irregularities can extend over a wider altitude region, where there is less severe electron depletion. At altitudes outside of the particle region (electron depletion region), plasma density irregularities can be used as a tracer of neutral turbulence. Another observation is that the positive ion density is increased in the electron bite-out regions.

The DC Langmuir probe current measurements illustrated large-scale gravity wave motion for both flights; however, for one flight the AC fluctuations indicated the presence of turbulence in only a limited altitude region. Turbulence was observed over a much larger altitude range for the second winter flight, and fairly large energy dissipation rates were inferred. This is consistent with the observation of a large-amplitude semidiurnal tide, which was deduced from data from falling spheres, radiosondes, and ground-based lidars that were an integral part of the MaCWAVE program.