IMAGING AURORAL DENSITY STRUCTURE USING TRANSIONOSPHERIC HF WAVES

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ABSTRACT

It is planned to observe HF waves from coordinated ground transmitters such as the SuperDARN radars and the CADI ionosondes using the Radio Receiver Instrument on the enhanced Polar Outflow Probe (ePOP) small satellite when it makes an orbital pass through the nearby ionosphere. Measurable quantities such as the direction of arrival and the delay time of signal waves will be used to "image" large-scale ionospheric structures. Oblique scatter from irregularities embedded in the structure will be investigated. Such measurements will be coordinated with simultaneous observations of backscatter and reflection at the ground facilities.

INTRODUCTION

Backscatter from high-latitude irregularities of density and reflections from overdense ambient plasma are the bases of widely used and convenient techniques for the observation of high-latitude ionospheric dynamics. Research using these techniques has been based on assumptions about scatter or reflection that are difficult to confirm definitively. For instance, the interpretation of HF backscatter data has proceeded on the assumption that radar echoes arise from aspect-sensitive coherent backscatter as represented by the Bragg condition. This assumption has been expedient because independent measurement in-situ of spontaneously created structure that scatters or reflects HF waves observed simultaneously on the ground is a scenario that is difficult to conceive, let alone arrange. At radar spatial resolution scales, it has been possible to compare HF backscatter with incoherent scatter radar and ionosonde measurements, to test the accuracy of plasma parameter measurements. Convection speeds in the auroral ionosphere measured with these techniques have been shown to agree.

The details of scatter and reflection are yet to be explored in situ. The operation of a spaceborne HF radio receiver at the same frequency as a ground radar can address this situation. Such a coordinated observation could provide "sky truth" and hence an improved picture of the relation between decameter periodicity in density and the gradients in larger scale structure (> 1 km) that produce the scatterers.

EXPERIMENT CONCEPT

The irregular high-latitude ionosphere can produce dramatic effects on electromagnetic (EM) waves passing through it. Waves can be refracted, scattered, amplified, damped or decomposed through nonlinearity, depending on the local state of the medium. An important goal of ePOP is to exploit these observable effects as the basis of investigation of fluid processes like the gradient-drift instability occurring around the peak of the ionospheric F region where density irregularities form. The interpretation of HF coherent backscatter to the ground from such regions has been based on the notions of ray-optics propagation to and from regions of irregularity where aspect-sensitive scatter returns some of the incident wave energy back to the radar.

It is planned to observe waves from ground HF transmitters such as the Super Dual Auroral Radar Network (SuperDARN) radars and the Canadian Advanced Digital Ionosondes (CADI) using the Radio Receiver Instrument (RRI) on the enhanced Polar Outflow Probe (ePOP) [1] small satellite when it makes an orbital pass through the nearby topside ionosphere. The objective will be to use measurable quantities such as the direction of arrival and the delay time of signal waves to "image" large-scale ionospheric structures. Such measurements will be coordinated with simultaneous observations of backscatter or reflection at the ground facilities. The investigations will include searches for oblique scatter to the spacecraft from the irregularities. Particle detectors on ePOP will measure the small-scale density fluctuations of the irregularities when the spacecraft flies through possible locations of HF scattering..

The goals of this experiment include, in HF coherent backscatter, an improved understanding of the physics of radio-wave scatterers. It is hoped that this will lead to new tests of the theory of plasma-fluid instabilities and the irregular density structure that they create. In ionosonde data analysis, the imaging of structure will provide a training tool for the interpretation of signatures in conventional swept- and fixed-frequency recordings that have been familiar yet not fully understood. The receiver will also be programmed to observe spontaneous plasma-wave emissions that are created in auroral dynamics processes that are closely connected with the density structures revealed by the imaging process.

Fig. 1 illustrates the imaging process in the case of an ePOP pass over a CADI. The CADI is located at the origin and radiates vertically with a beamwidth of about 60°. Orbital motion allows ePOP to sweep a range of ray directions and thereby probe the shape of F-region localized structures, such as ionospheric "blobs" like the one shown in Fig. 1. The rays are at 1° increments of elevation angle. A number of effects on the rays can be seen: focusing, defocusing, and group-delay effects (the rows of "+" signs on the rays show wave packet location reached at constant delay). The raypath picture is sensitive to the relative geometry, probing frequency, and electron densities. Measurement of the wave parameters listed on Fig. 1 permit fitting the observations to ionospheric structures. Preflight simulations may help to establish whether the fitting of the flight data is best done by sorting through a library of numerical results, or by using a more analytical approach.

In preparation for the ePOP radio science experiments with transionospheric propagation, the tracing of rays through ionospheric density models has permitted us to anticipate features of waves received at ePOP. Pulses emitted by ground transmitters with linear electric polarization will lead to O- and X-mode pulses at the spacecraft that are temporally shifted but not completely separated. The first and last parts of a single transmitted pulse will be interpreted upon reception as pure O- and X–mode waves, respectively. The wave vector **k** will be deduced from two components of the wave electric field through the amplitude and phase of the voltages induced on the crossed receiving dipoles of the RRI. In the middle of the pulse, where the O and X waves overlap, Faraday rotation effects may be used as a separate check on the component waves' characteristics. Data gathered during transionospheric propagation experiments involving the ISIS satellites in 1977-1978 may also be used to anticipate what happens to waves during transionospheric propagation.

These foregoing techniques will be valid for study of structures probed with either vertical propagation from CADIs or oblique propagation from SuperDARN radars. In the case of the latter, attempts will be made also to identify and locate coherent oblique scatter from dekameter-spaced field-aligned irregularities imbedded in the mesoscale structures.

EXPERIMENT DESIGN

Besides the radio science already discussed, ePOP has major scientific objectives of quantifying the micro-scale characteristics of plasma outflow in the polar ionosphere and of probing related micro- and meso-scale plasma processes at unprecedented resolution. This will include the exploration of the occurrence morphology of neutral-particle escape in the upper atmosphere. The science instrument payload will consist of 8 scientific instruments. These will include an imaging and rapid-stepping ion mass/energy/angle spectrometer, a time-of-flight neutral mass and velocity spectrometer, a suprathermal electron imager, a fast auroral imager, and the RRI. The particle instruments will be capable of measuring ion, electron, and neutral velocities at unprecedented temporal-spatial resolutions from an orbiting platform. In addition, the payload will include a differential GPS receiver, a fluxgate magnetometer, and a UHF radio beacon. These will be applied to the study of ionospheric tomography, of ionospheric electric currents producing magnetic field perturbations and of ionospheric irregularities, respectively.

The POP mission will entail a single micro-satellite in elliptic high-inclination orbit. The instruments will be carried on 70-kg bus having dimensions of a significant fraction of 1 m. The nominal perigee will be 300-500 km, the apogee between 1000 and 2000 km, and the orbital inclination in the range 65°-110°. A launch date in 2005 is targetted.

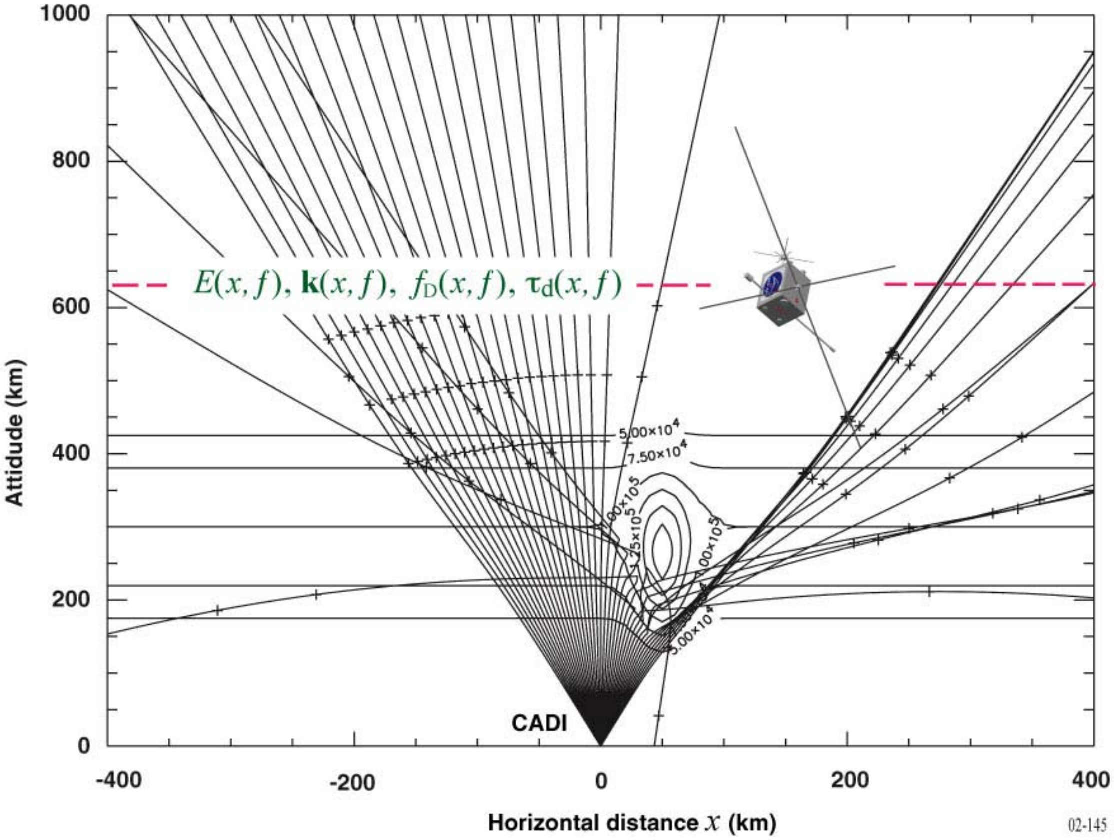

Fig. 1 The shape of a refracting density enhancement can be deduced from the history along the ePOP pass of various parameters of the CADI waves received at the spacecraft, such as the amplitude of the wave electric field $E(x,f)$, the direction of arrival of the wave vector $\mathbf{k}(x,f)$, the Doppler shift $f_D(x,f)$ or the signal time delay $\tau_d(x,f)$.

The POP Radio Receiver Instrument (RRI) will be a four-channel digital ELF-HF receiver. It will consist of a pair of crossed 6-meter dipoles with preamplifiers, and an electronics unit internal to the spacecraft. From below 100 Hz to about 3 MHz, the receiver will measure the electric fields of spontaneous waves. Between about 5 and 18 MHz, the receiver will measure the electric fields of waves from ground transmitters (CADI, SuperDARN, ionospheric heaters). The dynamic range of the receivers will be 120 dB above an input threshold of 1 μV and the bandwidth will be up to 30 kHz in each channel. The maximum output from the RRI will be four streams of 16-bit amplitude data, taken at precise intervals, for a maximum bulk output rate of 4 × 60 kHz × 16 bits = 3840 kbit s^{-1}. The RRI will have different operational modes, some with lower bandwidths, and some using only one dipole. The 30-kHz-bandwidth data will be recorded in relatively short periods (of the order of 100 s), given the limited spatial extent of radiation from the ground transmitters. The amplitude and relative phase of two components of an incoming electric field will be measured on the orthogonal dipoles. Current design calls for tubular antennas to be used to form the dipoles. The Universal Time of the rising edges of the transmitted pulses will be traceable to an absolute accuracy of better than 1 :s thanks to GPS-controlled clocks in the ground facilities. The timing of pulse sampling by the RRI will have the same absolute accuracy.

The RRI experiments will be carried out using agreed-upon frequencies in the ground SuperDARN and CADI transmitters. The science team will select the fixed frequencies on the basis of recent history of ionospheric parameters observed both by the ground facilities and ePOP. The CADI operational transmitting mode will interleave conventional swept-frequency ionograms and periods of about the same length of time during which the frequency is held fixed at one of several preprogrammed frequencies. The experiments discussed above are best carried out at altitudes below the highest acceptable perigee 500 km. Orbital predictions show that the spacecraft would intersect the latitude-longitude zones of targetted ground facilities a few to several times a day, providing passes lasting of the order of 100 s.

In addition to study of the formation and characteristics of density irregularities on various scales, the RRI will be used in related studies of plasma wave generation in the ionosphere. A variety of spontaneous wave phenomena, including ion cyclotron waves and lower-hybrid waves, will be detectable by the RRI at auroral latitudes. The coordinated measurement by the high-resolution ion and electron imagers on ePOP is expected to bring new understanding of the small-scale ion heating mechanisms. This will help to establish the role of ion wave-particle interactions for the ion bulk upflows at high latitudes. It is also planned to operate the RRI to record both ion and electron-wave fields when the spacecraft is in the vicinity of an ionospheric heater. In this investigation, the stimulation of parametric instabilities at HF will provide insight into the role of nonlinearities in limiting microphysical processes that influence bulk plasma characteristics.

REFERENCES

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