High-latitude plasma structure and scintillation

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[1] Observations of high-latitude plasma structure and scintillation are presented from the January 2001 scintillation campaign timeframe. Comparisons are made using the all-sky imager and two beacon-satellite ground receivers located at Sondrestrom, Greenland. The Coherent Ionospheric Doppler Receiver (CIDR) observes 150- and 400-MHz signals transmitted from low-Earth-orbiting satellites. The 250-MHz polar beacon-satellite system observes signals from highly elliptical orbiting satellites. F region patches, F region precipitation arcs, and auroral arcs were observed. Intermediate-scale structure was observed on the leading and trailing edges of patches prior to exiting the polar cap. Banded structure was observed across an F region arc. Additional beacon-satellite receivers in Greenland and Alaska provide a unique opportunity to study the spatial distribution and temporal evolution of patch structures and their associated scintillation.

INDEX TERMS: 2407 Ionosphere: Auroral ionosphere (2704); 2439 Ionosphere: Ionospheric irregularities; 2475 Ionosphere: Polar cap ionosphere; 2494 Ionosphere: Instruments and techniques; KEYWORDS: scintillation, beacon satellite, polar cap


1. Introduction

[2] Ionospheric scintillation affects positioning, communication, space tracking, and surveillance systems at high and low latitudes. Radio signals passing through the ionosphere are rapidly modulated in phase and amplitude, causing interruptions and errors in signal tracking. This results in position errors, reduction in available satellite-to-ground data transmission bandwidths, errors in target tracking, and poor-resolution surveillance. Aside from these direct effects, scintillation has an indirect effect. System errors can be attributed to scintillation by mistake, thus masking real problems and delaying their resolution. Knowledge of current ionospheric conditions and predictions about the development and evolution of plasma structures leading to scintillation effects are a critical element to mitigating system errors.

[3] With the proliferation of Coherent Ionospheric Doppler Receiver (CIDR) receivers, tracking Navy Ionospheric Monitoring Satellites (NIMS), and the launch of additional satellites carrying the Coherent Electromagnetic Radio Tomography (CERTO) beacon, especially those in low inclination orbits (e.g., PICOsat and CNOFS), the capability exists to utilize CIDR receivers in the study of ionospheric plasma structure and scintillation. The development and validation of using CIDR as an ionospheric scintillation instrument builds on previous studies using GPS total electron content (TEC) and tomography to specify a three-dimensional region of electron density interest [Coker et al., 2001, 1996; Bust et al., 2001]. The potential for using beacon receivers for scintillation studies at high latitudes has been demonstrated previously [Kersley et al., 1995; Fremouw et al., 2001].

[4] This paper focuses on the investigation of scintillation structures at high latitudes within the context of observed F region patches and arcs. For this study, comparisons are made between CIDR phase scintillations, a 250-MHz polar beacon-satellite system, and an all-sky camera in Greenland. The primary motivation for studying patches is to be able to specify and predict their scintillation effects on operational systems, including navigation, communication, and radar applications [Behnke et al., 1995; Reinking et al., 2001; Fremouw and Ishimaru, 1992]. The irregularity structure and scintillation effects associated with patches have previously been investigated [Kersley et al., 1995; Basu et al., 1994], as well as the climatology of...
scintillation effects [Secan et al., 1997; Fremouw and Secan, 1984].

2. Background

[5] Additionally, an initial study has demonstrated the scintillation capabilities of the CIDR receiver. This was accomplished by performing bench tests using a simulator and by comparing observations made at high latitudes from CIDR, a 250-MHz polar beacon-satellite system, and an all-sky camera in Greenland.

[6] Four CIDR receivers are deployed along the west coast of Greenland. The receivers typically collect data at a 1-Hz data rate, though capability exists to collect up to a KHz rate. For this study the receiver at Sondrestrom collected at a 10-Hz rate, corresponding to an approximately 400 m minimum scale size observable in the $F$ region. The CIDR scintillation observations sweep through a large geographic region in a relatively short timeframe, providing “snapshot” coverage of a large area. By themselves, these observations will help answer a number of important questions regarding scintillation structures, especially on the dayside of the polar cap and at equatorial latitudes, where optical cameras are unable to detect high-altitude structures. In the following section, observations of high-latitude plasma structure and scintillation are presented from the January 2001 scintillation campaign timeframe. Comparisons are made using the all-sky imager and beacon-satellite ground receivers located at Sondrestrom, Greenland. $F$ region patches, $F$ region precipitation arcs, and auroral arcs were observed. Patches, islands of high-density plasma traveling antisunward across the polar cap, occur in the dark polar region patches, and auroral arcs were observed.

Intermediate-scale structure was observed on the leading and trailing edges of patches prior to exiting the polar cap. Additional beacon-satellite receivers, distributed along the west coast of Greenland, provide an extended coverage area for tracking patches through the polar cap. Observations from the distributed receivers provide additional information on the spatial distribution and temporal evolution of patch structures and their associated scintillation.

3. Results

[7] We present three comparisons between observations made by the all-sky imager using the 630.0-nm filter, the 250-MHz measurements, and phase scintillations from detrended 150-MHz CIDR phase measurements. Alternatively, the detrended 400-MHz CIDR phase measurements are used and scaled to 150 MHz. All the data are for the period of January 2001. Figure 1 compares an $F$ region patch ($B_z = -5$ nT) with observed phase scintillations from the CIDR at Sondrestrom. The upper panel presents a 630.0-nm all-sky image of the patch, with the NIMS satellite pass superposed over it. The open circles show regions of scintillation. The lower panel shows the sigma-sub-phi of the observed phase scintillation. The patch is traveling in the antisunward direction (south) toward the more luminous auroral region. This patch was one of several observed by the all-sky imager. Phase scintillations of up to 7 radians are observed along the leading and trailing edges of the patch. This observation is somewhat unusual in that the mechanism that produces scintillation in patches, the gradient drift instability [Crowley, 1996], predicts larger scintillation on the trailing edge of the patch. This same patch crossed the 250-MHz system line-of-sight (LOS) 20 min earlier, resulting in similarly elevated amplitude scintillation, S4 values 0.5–0.6. By the time the NIMS satellite intersects the 250-MHz system LOS, 250-MHz S4 values have fallen to 0.2 and the NIMS phase scintillation has also fallen to moderately low values (1–2 radians). The lower panel of Figure 1 shows the clear correlation between the observed phase scintillations and the patch region. The phase scintillation clearly rises at the low-latitude edge of the patch. While not as sharp a boundary, it also appears that the high-latitude boundary of the patch is again associated with increased phase scintillations.

[8] Figure 2 presents a comparison between an observed large stable auroral arc and the observed phase scintillations. The time history of 630.0-nm emissions shows that a large-scale brightness gradient advances from south to north in about 20 min. This is a classic substorm onset signature for magnetic local time (MLT) = 21 [Akasofu, 1977]. The sharp poleward edge of the structure is the boundary of the open and closed field lines in the polar cap/auroral zone transition [Doe et al., 1997; Gallagher et al., 1993]. The phase scintillation from CIDR shows that the more-significant scintillation occurs on the edges of the auroral arc. The 250-MHz system penetration point is also located along the poleward edge of this region, as indicated by the triangle in the top panel, where moderately high S4 values are consistent with results of the phase scintillation measurements from the satellite pass. It is also interesting to note the amount of spatial structure in the vicinity of the arc. The phase scintillations show three, and possibly four distinct structure peaks, near the equatorward boundary of the arc. A smaller scintillation peak is observed along the poleward boundary of the arc.

[9] Figure 3 presents comparisons between observed spatial scintillations and a premidnight soft $F$ region precipitation arc ($B_z = +5$ nT), where the Kelvin-Hemholtz instability is the mechanism responsible for producing scintillation [Crowley, 1996]. The satellite passes
Figure 1. An all-sky image of an $F$ region patch with a NIMS satellite pass superposed over it. See color version of this figure at back of this issue.
Figure 2. A large, relatively stable auroral arc is present as the satellite crosses over it. See color version of this figure at back of this issue.
Figure 3. A NIMS satellite pass crossing over a premidnight soft $F$ region precipitation arc. See color version of this figure at back of this issue.
over the arc and then over a quiet region between arcs at the point of closest approach to the 250-MHz system LOS. In this quiet region between arcs the phase scintillation from NIMS and amplitude scintillation from the 250-MHz system are at relatively low levels: 1–2 radians and S4 value 0.25, respectively. Phase scintillation is observed as the NIMS satellite passes over the arc, oscillating between 2 and 4 (sometimes 6) radians. Fifteen minutes earlier, this same arc crossed over the 250-MHz system LOS, resulting in elevated amplitude scintillation, S4 value 0.4. Note that for this case the phase scintillations occur across the entirety of the arc and again demonstrate smaller-scale structure within the overall spatially scintillating region.

4. Summary

[10] We have shown how the data from the CIDR receivers deployed in Greenland as a tomography array can be used as a spatial phase scintillation measurement instrument. The advantage of using the CIDR receivers, and low-Earth-orbiting satellites, is that we are able to obtain the horizontal variation in phase scintillation as the satellite passes by overhead. Polar orbiting satellites observe variations primarily in latitude. Thus the observed phase scintillations provide a spatial map in latitude of ionospheric fluctuations at high latitudes.

[11] Initial simulations were carried out on the CIDR at Applied Research Laboratories, University of Texas, Austin (ARL:UT) to demonstrate that the observations did indeed track phase scintillations. The CIDR does not record amplitude measurements and therefore cannot observe amplitude scintillations. A validation study with the 250-MHz polar beacon-satellite system at Greenland was completed and demonstrated the field utility of CIDR as a scintillation device.

[12] We have presented results from the validation study that compare spatial phase scintillations observed with the CIDR receiver to images from the all-sky camera. The results clearly demonstrate correlations between structures observed by the all-sky camera, the polar beacon-satellite system, and the CIDR observations. The spatial overlaying of the phase scintillations on the all-sky images clearly demonstrates the advantages of having spatial maps of scintillations. In Figure 1 the phase scintillations indicate small-scale structuring on both the leading and trailing edge of the patch. This kind of result, were it to hold up under increased analysis, could for a large number of cases have important consequences for the understanding of the underlying dynamics associated along the edges of patches. Similarly, Figures 2 and 3 show what appears to be small-scale structuring in the phase scintillations within larger scintillating regions. Increased analysis at small scales can potentially provide insight into the dynamic spatial scales of processes in the magnetosphere.

[13] For this study we only looked at a single CIDR located at Sondrestrom. However, all four receivers in the Greenland array can collect high-rate data and be analyzed for spatial scintillations. In such a study we would be able to map the latitudinal variations in phase scintillations from ~60–80 degrees geomagnetic latitude. Considering that the Greenland array sees 30+ passes per day, there is good potential for routine monitoring of spatial scintillations. In addition, a similar array exists in Alaska, and a five-receiver array will be deployed along the east coast this summer, coincident with the Millstone Hill incoherent scatter radar (ISR) and extending from northern Canada to Block Island.

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References


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