Structure of Polar Cap Patches and Fast Shear Flows Following the CME Impact on 22 January 2012 Inferred from GPS Scintillation Spectra

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Polar cap patches are localized enhancements in ionospheric density which originate from solar EUV ionization on the dayside, enter the polar cap at the dayside cusp, convect anti-sunward at km/s velocities, and exit the polar cap near midnight to merge with sunward returning flow patterns. Plasma irregularities associated with polar patches are the leading cause of scintillations in L-band satellite signals such as GPS, and fast shear flows near the dayside cusp are thought to be integral to patch formation. In this paper, we report on the on the characteristics of polar cap patches and fast flows derived via analysis of the spectra of GPS scintillations recorded at Longyearbyen, Svalbard, following the CME impact on 22 January 2012. Following the interaction of the CME with the high latitude ionosphere, elevated GPS TEC values indicate the passage of patches through the cusp between 11-15 MLT, accompanied by significant GPS phase scintillations (σ_φ ~ 0.5 radians) but minimal amplitude scintillations ($S_4 < 0.05$). Examination of the scintillation spectra reveal that amplitude fluctuations were present, but not easily detected in the S_4 observations because the fluctuation power was concentrated at high frequencies. In fact, these amplitude spectra can be explained in terms of Fresnel filtering of the path integrated irregularity spectrum with a relatively high cutoff frequency (8 Hz). This filtering is consistent with weak scatter of the satellite signals by irregularities scanning past the ray path with an effective velocity ~ 3 km/s. Since the velocity of the satellite penetration point is negligible, by comparison, this scan velocity is attributed to fast plasma flow, presumably associated with shear flows near the cusp. To exploit the Fresnel filtering effect, we developed a technique to derive the flow velocity by reconciling the phase and amplitude spectra with weak scatter theory. We applied this approach to investigate the noontime entrance of patches into the dayside cusp and the midnight exit of patches from the polar cap. We find clear evidence of strong phase scintillations with reduced S_4 values in the presence of fast flows near the cusp, when the increasing Fresnel break frequency effectively suppresses the low frequency content in the amplitude fluctuations. The scan velocity increased from about 500-1000 m/s following the initial CME impact at ~6:00 UT, to sustained velocities between 1500-3000 m/s measured by GPS satellites whose ray paths intersected fast plasma flows near the cusp. In this sector, the phase spectral index (p) generally ranged between 2.4-2.8, with a tendency for somewhat larger values when the flow is faster. Weaker irregularities were detected in the outflow sector between 20-24 MLT, when p generally ranged from 2.6-3.0. The scan velocities measured in the outflow sector were slower, generally between 400-600 m/s. These velocity estimates compare favorably with ion drift measurements made by the DMSP satellites. Since our analysis technique is automated, it could potentially enable continuous monitoring of flow patterns in the polar cap using a relatively inexpensive GPS scintillation monitor. These measurements could then complement measurements from space-based platforms that sample the polar cap only intermittently and incoherent scatter radars which provide excellent diagnostics but cannot operate continuously.