Reconstruction of GPS phase scintillation during a geomagnetic substorm: Data fusion of GPS, All-Sky Camera and PFISR observations

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Introduction

The Earth's ionosphere has a profound effect on radio signals propagating through it. Global Positioning System (GPS) signals experience the ionosphere as a highly structured plasma medium, which alters the signals in an unpredictable way. Variations in the signals phase and amplitude are due to small-scale variations in the plasma electron density, i.e. plasma irregularities, which are magnetic latitude dependent.

In the auroral region, it is known that these plasma irregularities generally affect only the signals phase, which is a direct measurement of GPS receivers. Signal phase variations $\Delta\Phi$ are directly proportional to Total Electron Content *TEC*, and inversely proportional to the speed of light *c* and the radio frequency *f*.

$$\Delta\Phi = \pm\frac{40.3}{cf}TEC\ [cycles]$$

GPS receivers are in particular sensitive to high frequency variations of the signals phase, also referred to as phase scintillation, which affects receiver performance and, in extreme cases, causes operation outages. In the auroral region, the most intense source of GPS phase scintillation is due to auroral particle precipitation, which causes sudden enhancements in *TEC*, as well as being a source of several plasma instabilities.

2D space-time localization of high latitude GPS scintillation is enabled by auroral optical luminosity, which provides a convenient information-bearing signal for advancing our general understanding of radio signal scintillation. The additional inclusion of an incoherent scatter radar, like the Poker Flat Incoherent Radar (PFISR), gives us an opportunity to fully reconstruct the phase scintillation in space and time.

In this poster, we present a joint analysis of GPS, all-sky camera (ASC) and PFISR field-aligned observations with high temporal resolution, during a step-like expansion of an auroral westward traveling surge (WTS).

Methodology

- GPS observables were obtained by The Mahali GPS receiver array, consisting of nine solar-powered GPS receivers as a 10 – 20 km baseline distance array, in the vicinity of the Poker Flat Research Range (PFRR), Alaska. We use a carrier phase on L1 band to obtain the phase scintillation via detrending and high-pass filtering process.

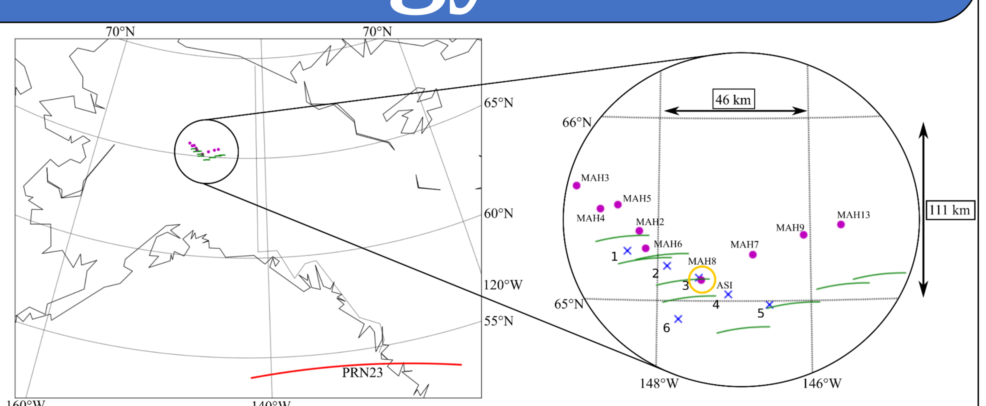


Figure 1: The Mahali GPS receiver array (magenta dots) in Alaska with PFRR all-sky camera and PFISR (yellow circle). PFISR beams (blue crosses) at the mapping altitude are shown with the GPS receiver-satellite lines-of-sight (green lines).

- In conjunction with the GPS phase scintillation, we use the green line (558 nm) emission brightness images, obtained from the PFRR ASC that covered the array's field-of-view. The temporal resolution of ASC at particular wavelength is 12.5 seconds. Merged GPS-ASC observations are used to obtain a spatial correlation between auroral optical emissions and GPS scintillation activity.
- In addition to merged GPS-ASC observations, PFISR was running the Themis 36 multi-beam experiment with several beams co-aligned with GPS lines-of-sight. Here we present merged GPS-ASC-PFISR observations at high temporal resolution. The radar's received power is used to spatially associate the position of GPS phase scintillation with respect to the auroral precipitation flux tube.
- All observations were collected in the magnetic field-aligned direction, with an GPS elevation angle of ~75°!

Observations

- Presented are observations of GPS scintillation activity during successive WTS passages across the sensors field-of-view.
- There are 4 intervals of auroral activity that represented here, first as optical activity mapped on geographical map, then as joint observations of GPS scintillation activity and co-aligned PFISR beams and line-of-sight green line brightness.

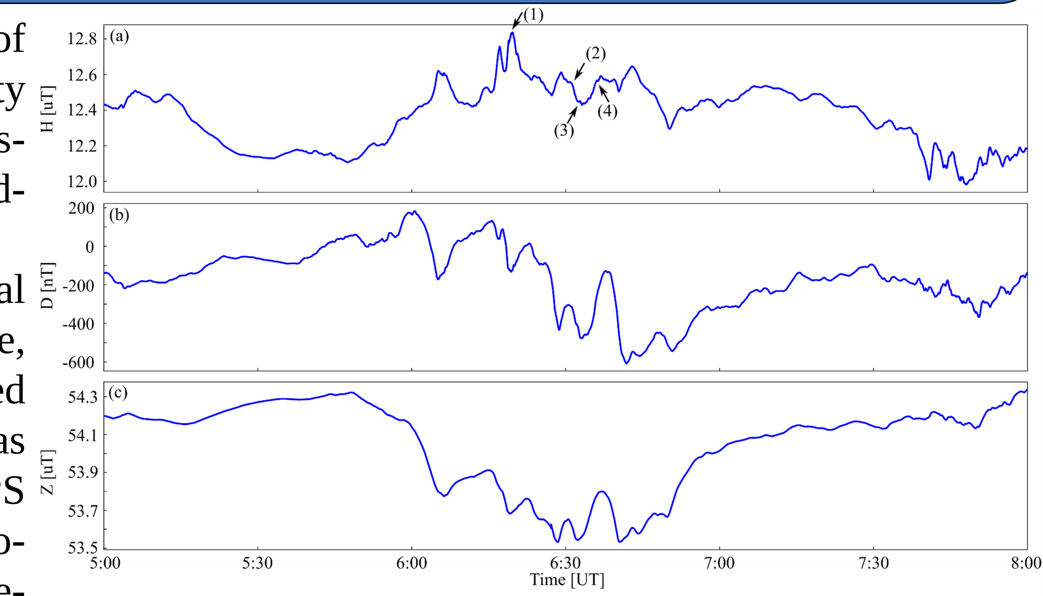
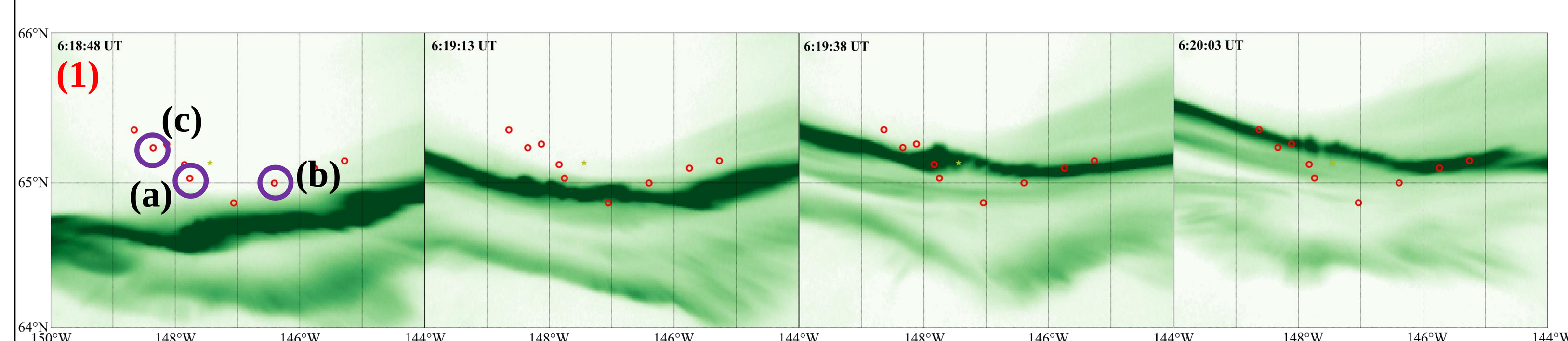


Figure 2: Magnetogram (variations in HDZ components) from the PFRR fluxgate magnetometer for the event. Enumerated events within the dashed lines marks the six successive passages of the WTS. Enumerated are four events presented below.



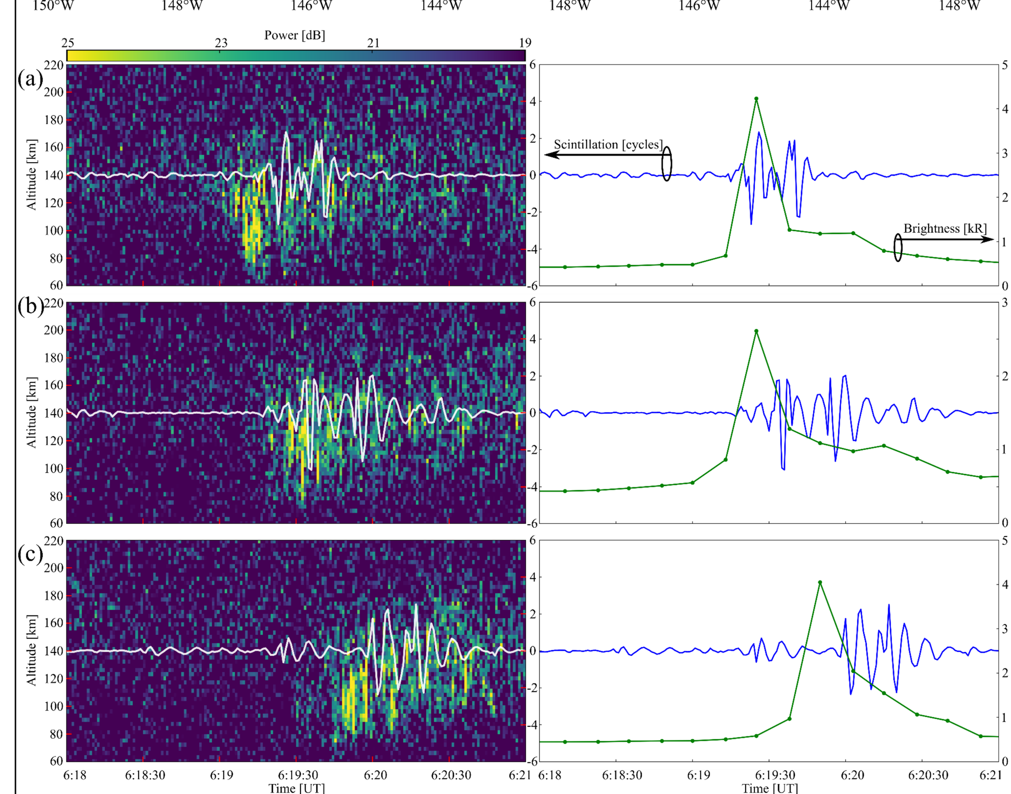
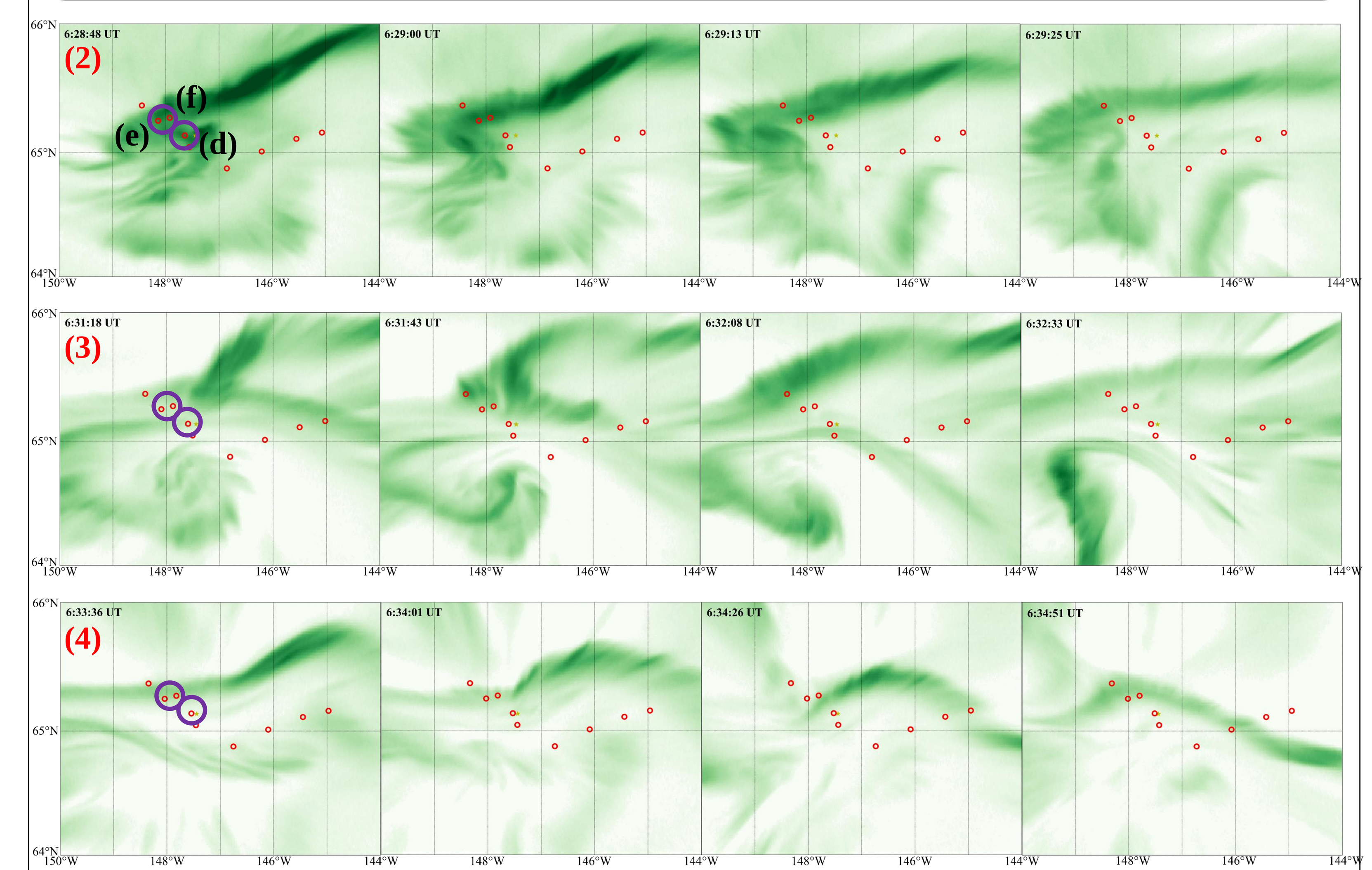


Figure 3: Passage of the first WTS over the sensors field-of-view, formed as a poleward moving auroral arc. Below are presented selected co-aligned observations from GPS, ASC and PFISR. Combination of MAH6-PRN23 line-of-sight with PFISR beam 6 (a), MAH7-PRN23 line-of-sight with PFISR beam 5 (b), and MAH4-PRN23 line-of-sight with PFISR beam 1.

- Auroral particle precipitation during the first WTS caused impact ionization that penetrated below 80 km in altitude.
- All GPS receivers experienced severe phase scintillation during this time period, with L1 scintillation amplitude exceeding 2 cycles.
- Chosen co-aligned lines-of-sight from figure 3 show repeatable and persuasive pattern of mutual relationship between auroral precipitation flux tube and scintillation activity.
- Phase scintillation abruptly arises after the passage of the most intense precipitation and is always found on the tube's trailing edge!
- Green line brightness is derived from mapping of the raw ASC image to an altitude of 120 km. Comparison between line-of-sight brightness and PFISR reflected power from figure 3 shows that 120 km is a good mapping assumption.
- Figure 4 presents a series of related WTS expansions over the sensors field-of-view. The series formed highly structured, stratified amorphous glowing auroras expanding in the east-west direction.
- The selected observables show highly localized phase scintillation activity, generally uncorrelated with optical emissions and PFISR altitude profiles of ionization.
- Phase scintillation was monitored only during the events (2) and (4), and none during the event (3). Despite the PFISR profiles look similar as well as optical structures (flow, shape and intensity).
- The only obvious distinction between the events is in the Horizontal *H* component of magnetic field from the magnetogram in figure 2.

Observations



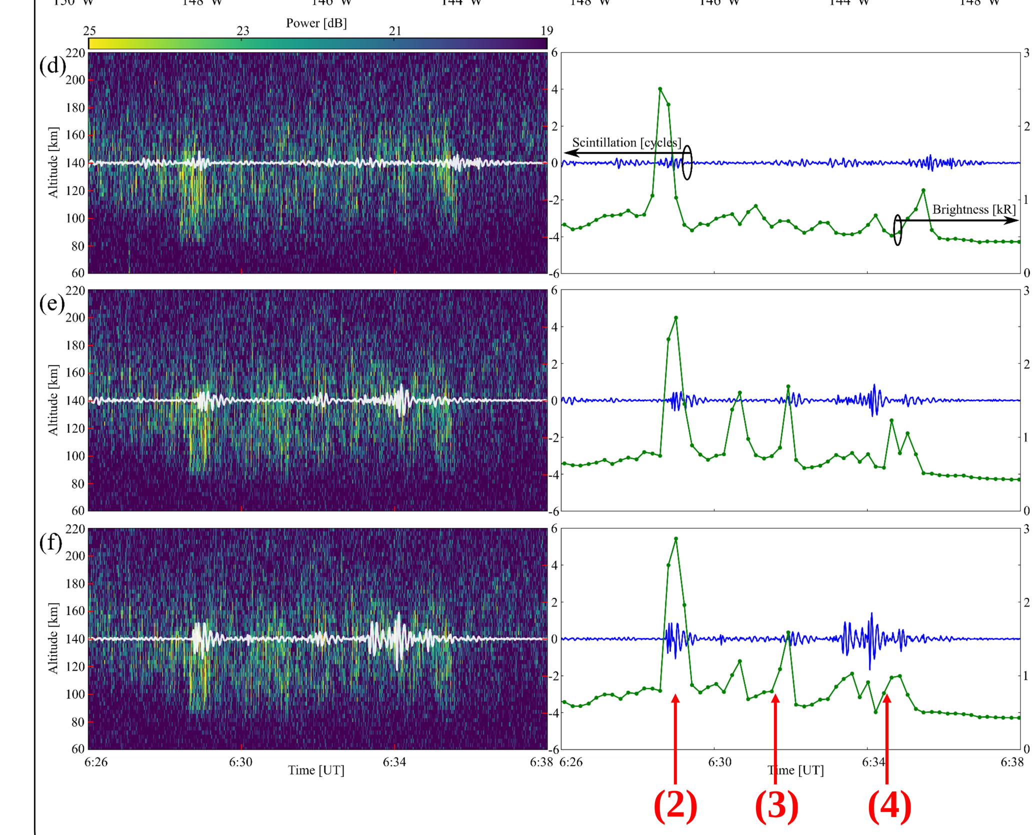


Figure 4: Passages of 3 successive auroral forms, marked as events (2)-(4) on the magnetogram. Co-aligned GPS scintillation, optical brightness and impact ionization is shown for three pairs of GPS-PFISR couples. Combination of MAH2-PRN23 line-of-sight with PFISR beam 3 (d), MAH4-PRN23 line-of-sight with PFISR beam 2 (e), and MAH5-PRN23 line-of-sight with PFISR beam 2.

- The finding that the phase scintillation is confined to the aurora's trailing edge suggests that gradient drift instability is the most probably mechanism for the irregularities. However, event (3) suggests that for the operation of such instabilities, sufficient electrodynamic activity is necessary.

Concluding remarks

- All observations shown here were obtained in the magnetic field aligned direction!
- Observations from the GPS array gave a repeatable and persuasive pattern of GPS phase scintillation activity in the presence of the WTS auroras. All phase scintillation activity was found on the auroras trailing edge!
- Phase scintillation activity is independent on the shape of the auroras. The whole study has shown that phase scintillation is found in the presence of auroral arcs, vortexes and amorphous glow.
- PFISR data explicitly shows that plasma irregularities responsible for phase scintillation operate in the E-region, around at altitude near 120 km.
- The discovery of scintillation activity on the auoras trailing edge suggests the gradient drift instability as the source of GPS phase scintillation.
- The scintillation quiet period during the event (3), suggests that sufficient electrodynamic activity is necessary for growth of favorable plasma instabilities.

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