### Instructions for use

#### Title
Possible shear instability in the daytime midlatitude sporadic-E observed with InSAR and GPS-TEC

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A coordinated observation of GPS total electron content (TEC) and space-borne interferometric synthetic aperture radar (InSAR) has been conducted to reveal both the large- and small-scale plasma structures of daytime midlatitude sporadic-E (Es). Both observations are used for the direct imaging of the plasma patches. GPS-TEC observations have shown a common frontal shape of Es elongated typically in the east-west (E-W) direction, while an interferogram derived from InSAR observation have revealed the small-scale (fine) structure of Es. Small-scale patches are aligned in the E-W direction which is the same azimuthal direction of dominant large-scale frontal structure. We speculate that the Kelvin-Helmholtz instability with the vertical shear of meridional winds is considered to be the most likely candidate for the generation mechanism of the small-scale plasma patches aligned in the zonal direction.

**Summary**

- Slant TEC
  - Fig. 1. Slant TEC time series (observed / modeled). Es leaves peculiar signature of pulse-like positive TEC enhancement in the slant TEC time series. By analyzing the slant TEC time series with the corresponding InSAR, small-scale structures can also be inferred with GPS-TEC observation.

- Altitude constraint
  - Fig. 2. Altitude constraint with 2 different satellites (i.e., Satellite 18 & 22). Changing the altitudes of ionospheric points (IPP) at 100 km (E-region) and at 300 km (F-region), two frontal (linear) structures elongated in the E-W direction coincide at 100 km (Fig. 2a) while gaps emerge at 300 km (Fig. 2b). This demonstrates that the frontal structure exists in the E-region of the ionosphere, hence the positive TEC anomaly is attributed to Es.

- Migration
  - Fig. 3. Vertical TEC anomaly map at 01:44 UT derived from GPS Satellite 18 when ALOS acquired the SAR image (red framed region). ALOS was on a descending orbit and observed Es looking the right side. Vertical TEC anomaly map shows a large-scale frontal structure which elongates over 250 km in the ENE direction. The SAR observation area corresponds to the eastern part of the frontal structure.

- Discussion
  - Kelvin-Helmholtz (KH) instability
    - In the present case, two plasma structures, i.e., the frontal patch and disc-shaped patches, are considered to be generated at the two nodes of K-H billows under the condition that the Richardson number is less than 0.25, making the neutral atmosphere unstable to the K-H instability. Since the axes of K-H billows are perpendicular to the shear direction, two structures which are aligned in the ENE-WSW direction are suggested to be caused by a wind shear in the NNO-SSE direction. Thus the K-H instability with the vertical shear of meridional winds is considered to cause ion perturbations in the neutral atmosphere, forming two K-H billows aligned in the zonal direction.

- Gradient-drift instability
  - In addition to the primary structuring of the two dominant structures, it is suggested that there could be a secondary instabilities operating in the southern disc-shaped patches. In Figure 4b, it is shown that disc-shaped patches are more structured than the frontal patch in terms of the development of undulation in the northern leading edge and large electron density gradient. Gradient-drift instability achieves the maximum growth rate when the direction of electron density gradient and the direction of Es patch movement are parallel. In this sense, plasma clouds in propagating Es with steep electron density gradient are supposed to be under the condition of gradient-drift instability.

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