**Background & Challenge**

The ionosphere, especially the E-region (~100 km) and the F-region (~300 km), has been extensively studied due to its role in supporting radio wave propagation and the performance of GPS/GNSS satellites. Large-scale variations, such as Es (sporadic-E), often exhibit frontal structures with a preferred alignment in the east-west direction. These structures are important for understanding the propagation of radio waves and the functionality of GPS/GNSS systems.

**Method: GPS-TEC Observation for Sporadic-E Detection**

Advantages of GPS-TEC observation in detecting fronts include its ability to capture two-dimensional imaging of horizontal structures. The technique involves combining GPS data with ionosonde data to identify and image the frontal structures.

**Summery**

GPS-TEC observations successfully detect and image 2-D horizontal shapes of sporadic-E patches over Japan. Es often shows frontal structure with a preferred alignment in the east-west direction. Frontal structures sometimes propagate to north and south. Close analyses of TEC data revealed small-scale structures and indicate that gradients and Kelvin-Helmholtz instabilities play important roles in the formation of daytime Es patches.

**Large-scale structure of sporadic-E over Japan**

- **Horizontal structure**
  - Frontal shape
    - Length ~160 km
    - Width ~20 km

- **Vertical TEC anomaly**
  - TECU

- **Fig. 2** Vertical TEC anomaly maps showing horizontal structures of Es patches that appear in three different latitude regions: a, Wakkanai (~49° N, Hokkaido) ~35° N, and e, Frankagawa (~37° N, Japan). Frontal structures are common with lengths ranging from 100 to 500 km.

**Small-scale structure**

- **Fig. 6 & 7** Es movement. QT structure is clearly observed with the GPS station 0580 while other stations show irregular TEC changes. The location of QT is shown as an orange circle in the SIP map. In this case, one of the QT structures is isolated in the central part of the region. The horizontal expansion of the QT structure is ~10 km.

**Discussion: Formation of Es patch**

- **Gradient-drift instability**
  - Gradientes and wind shear are responsible for the formation of Es patches. When a strong wind shear is present, small patches are undulated, and the wind direction is to the north of the undulated trailing edge of the frontal structure.

- **Kelvin-Helmholtz (KH) instability**
  - It is widely accepted that the formation of Es patches is attributed to Kelvin-Helmholtz instability. This instability arises when there is a difference in density between two layers, leading to the formation of wave-like structures. In the case of Es patches, the wave-like structures are characterized by the movement of plasma clouds in a propagating direction.

**References**


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