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Small-scale structure of midlatitude sporadic-*E* seen with GPS total electron content observations

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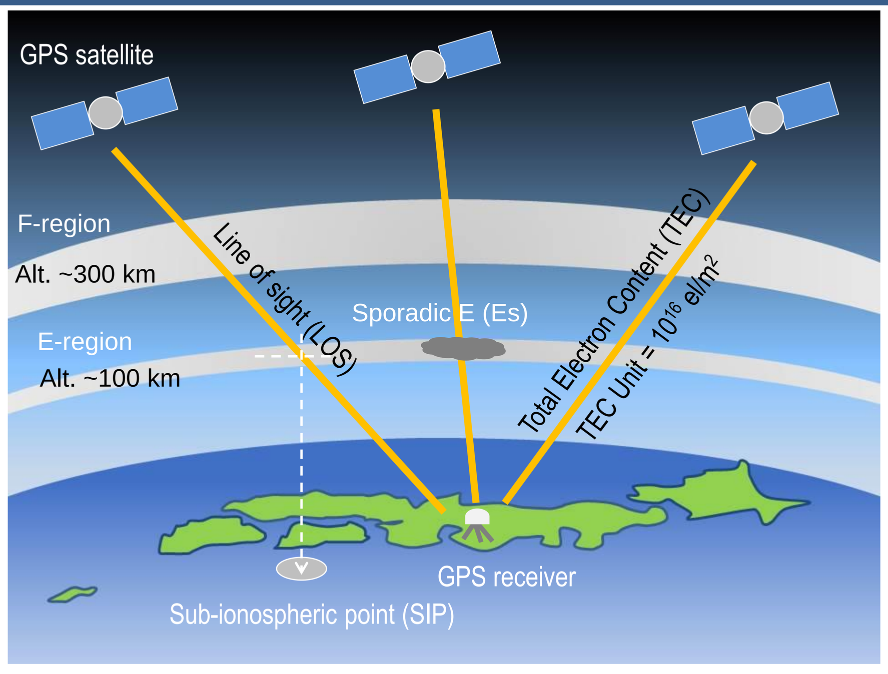
Method : GPS-TEC observation for sporadic-*E* detection



Sporadic-*E* is a densely ionized plasma patch that sporadically appears at an altitude of ~100 km (E-region of the ionosphere).

Advantages of GPS-TEC observation
A dense GPS array in Japan enables two-dimensional imaging of horizontal shapes of sporadic-*E* (Maeda and Heki, *Radio Sci.*, 2014).

Detection threshold foEs ≈ 17 MHz (Ne ≈ 3.6 x 10^{12} el m^{-3})
Favorable for daytime observation without MSTID.
Resolution Space ~25 km
time 30 s

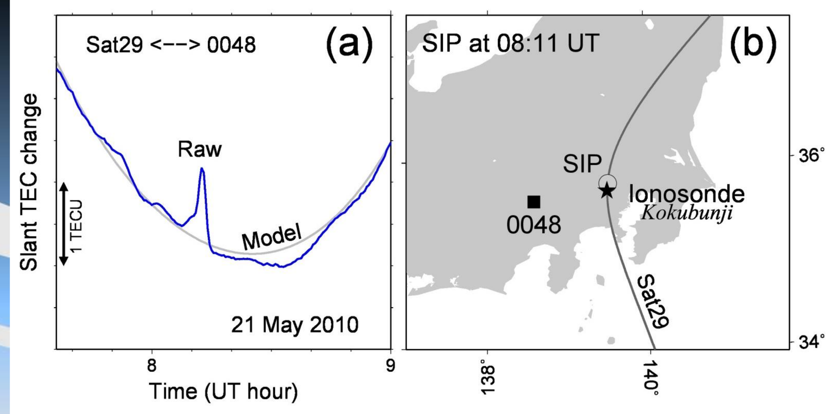


Fig.1 a. Time series of slant TEC (observed / model)
b. SIP at 08:11 UT (when TEC pulse was observed)

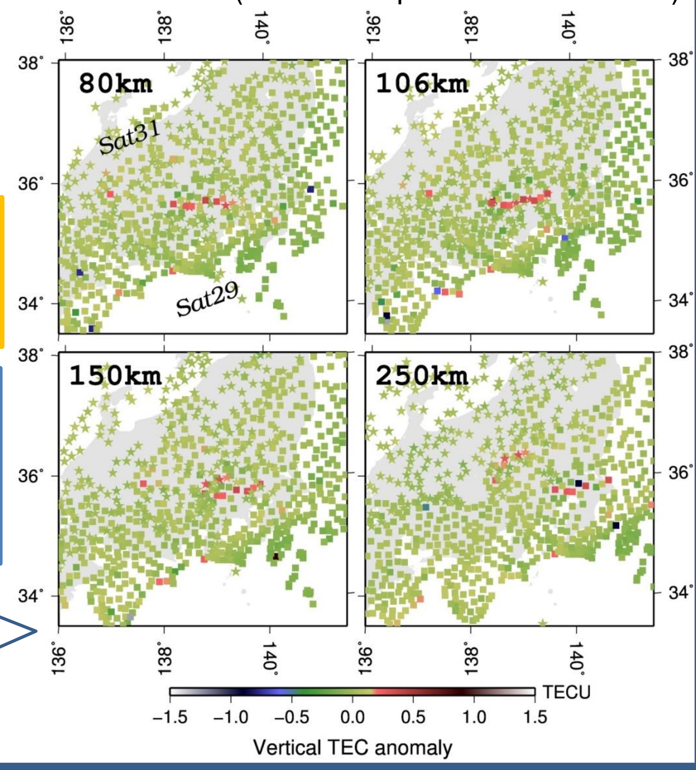
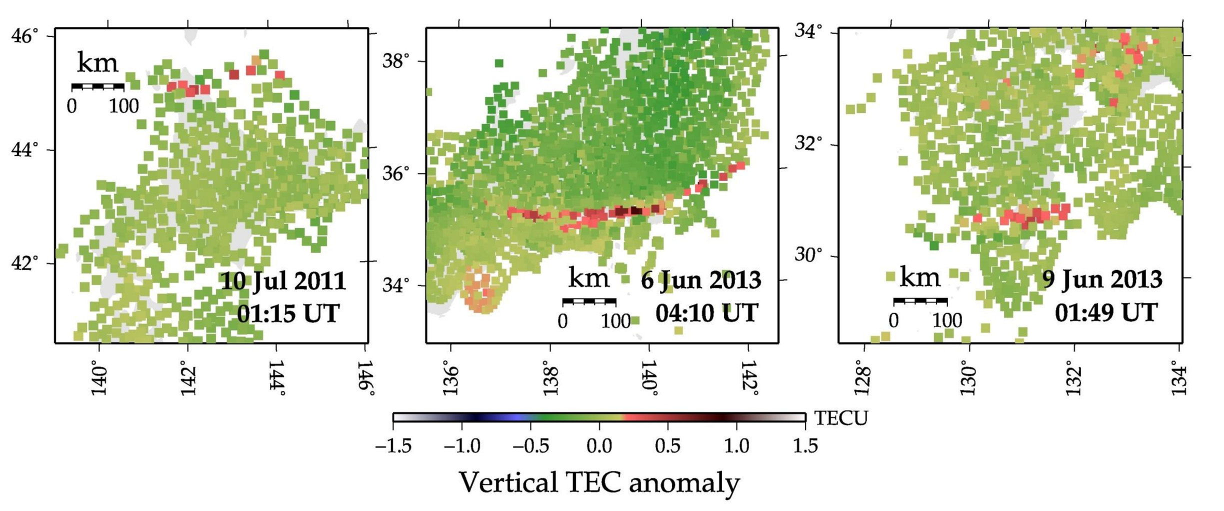


Fig.2 Altitude constraint by using two satellites. The anomaly regions imaged by two satellites coincide at a correct altitude, i.e., 106 km.

Large-scale structure (Frontal structure)



Characteristics
- frontal shape
- E-W alignment
- length ~100 km
- width ~20 km

Fig.3 Horizontal shapes of sporadic-*E* layers observed over **a**. Wakkanai (45N), **b**. Kokubunji (35N), and **c**. Yamagawa (30N). Frontal structures with typical elongation in the east-west (E-W) direction are evident regardless of occurrence latitude. Lengths are in the range of ~50-500 km with an average of ~160 km (Maeda and Heki, *EPS*, 2015).

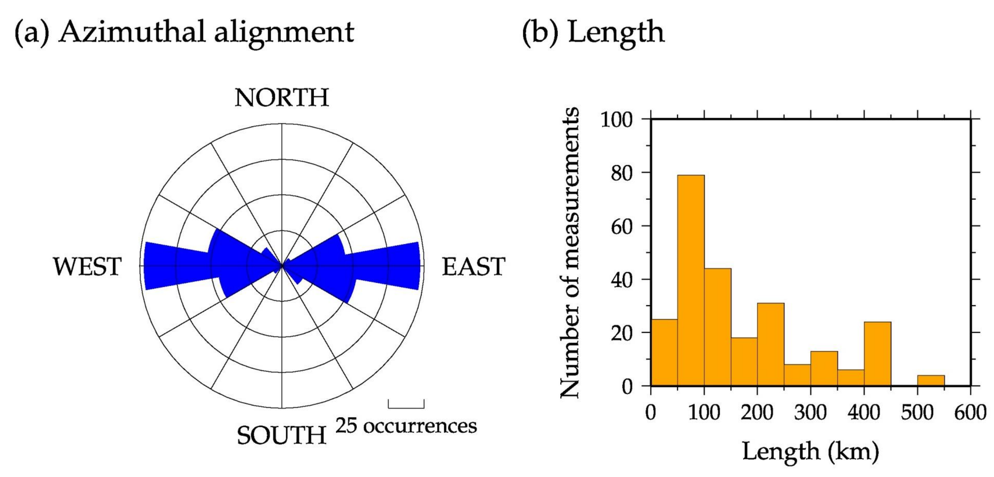
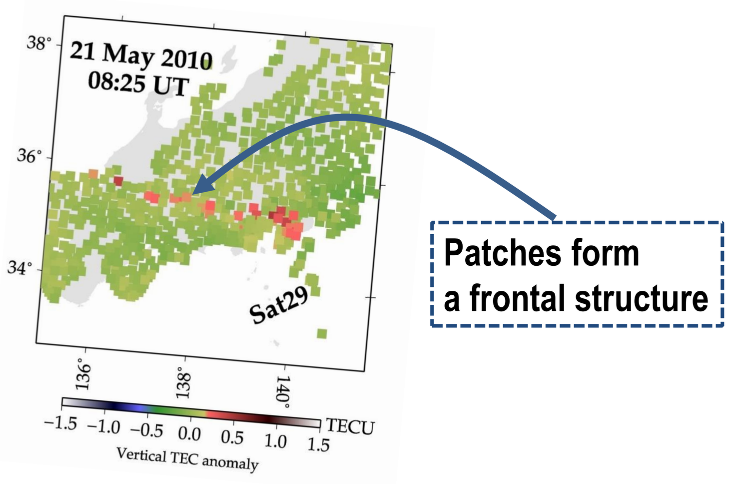


Fig.4 a. Rose diagram showing the number of azimuth alignment of frontal structures observed during 2010. In most cases structures prefer to elongate in the east-west (E-W) direction. Not a single case is observed which has a perfect north-south alignment. **b.** Histogram showing the number of length observed during 2010. The median length is approximately 100 km.

Small-scale structure: N-S direction



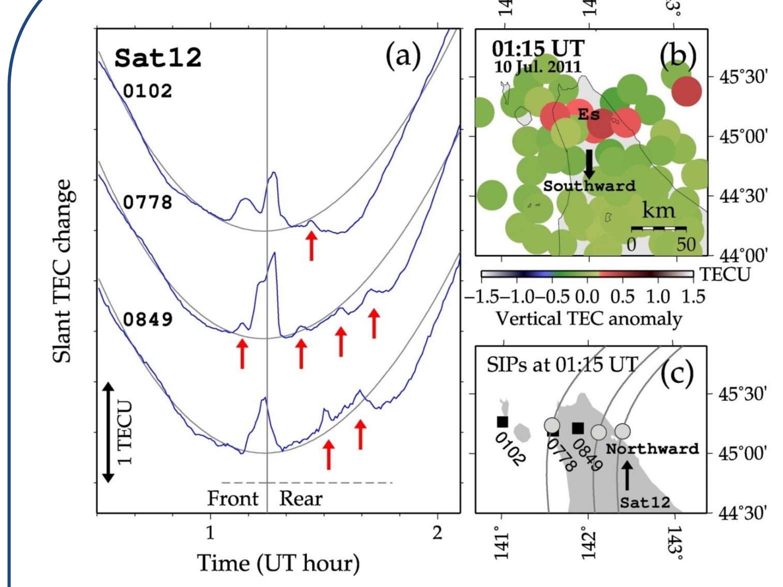


Fig.5 a. Slant TEC time series showing quasi-periodic TEC enhancement. Dominant peaks are accompanied by several small positive peaks. Since the frontal structure moved southward, the time period in the left/right of the vertical gray line at 01:15 UT represents the front/rear side of the structure (shown with horizontal dashed line. **b.** Vertical TEC anomaly map at 01:15 UT, showing a patchy frontal structure elongated in the E-W direction. **c.** SIPs of Satellite 12 and three GPS stations at 01:15 UT. Satellite 12 moved northward crossing the frontal structure during the time period shown in **a**.

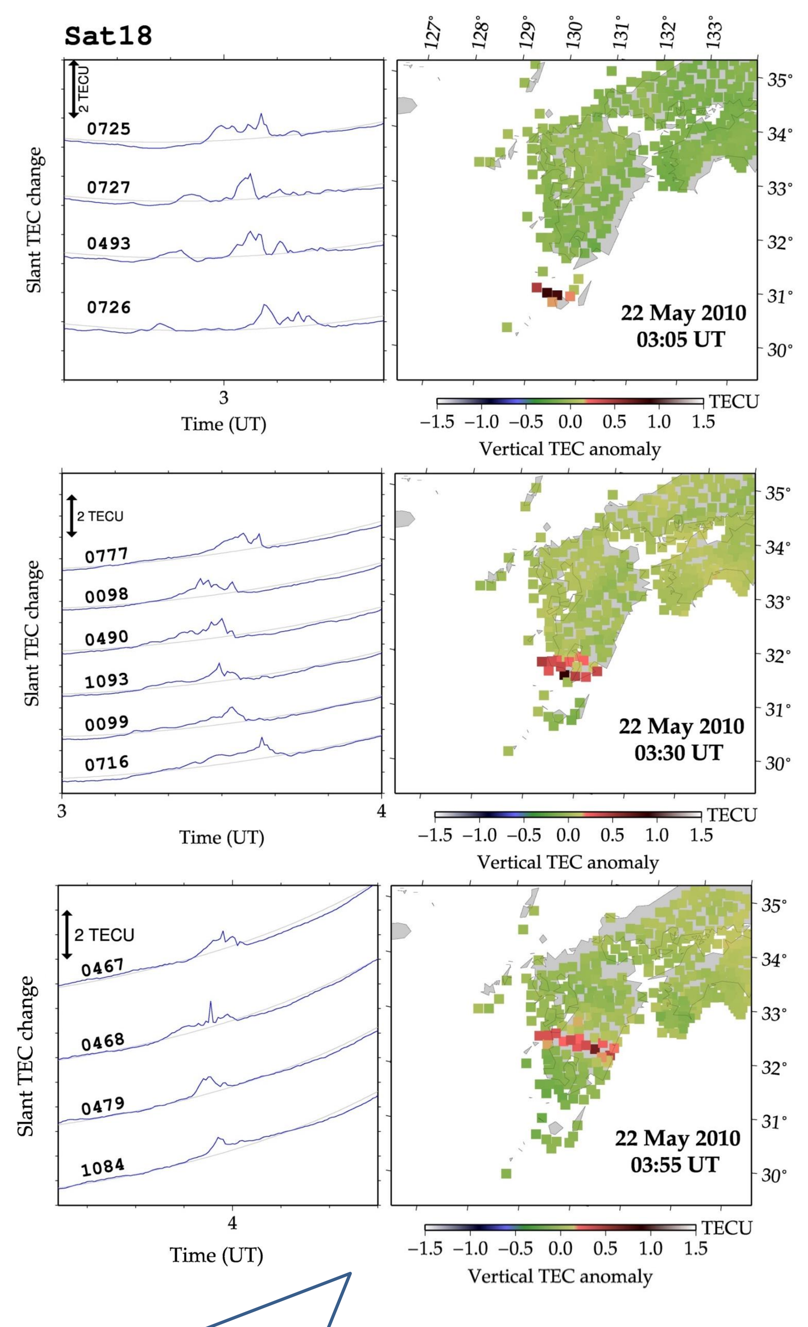
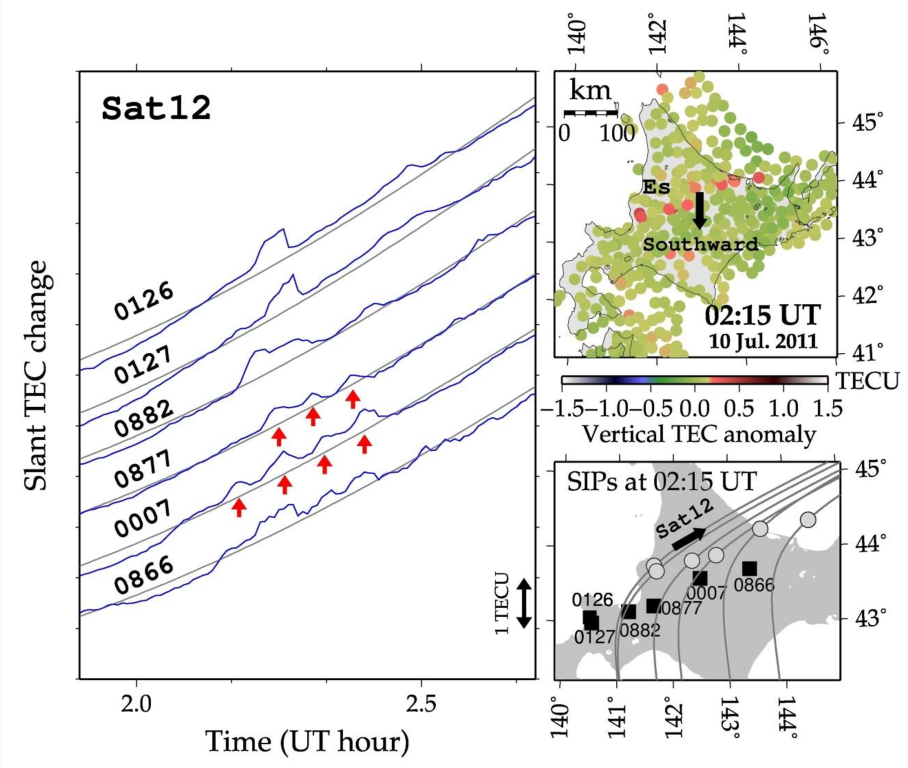


Fig.6. (**left**) Slant TEC time series showing QP TEC enhancement in the N-S section of the E-W frontal structure. Former time period shows the front side of the Es. (**right**) Vertical TEC anomaly maps showing the northward migration of the Es. Satellite 12 moved southward, crossing the frontal structure.

Summery

Small-scale structures are observed by GPS total electron content observations. They are characterized by quasi-periodic (QP) TEC enhancement, hence the QP horizontal separation of Es patches. Dominant frontal structure is often observed to accompany such QP structure in both N-S and E-W directions. Neutral shear instability, e.g., Kelvin-Helmholtz instability, is considered to be one of the most likely candidates for the generation of such QP structure.

Small-scale structure: E-W direction



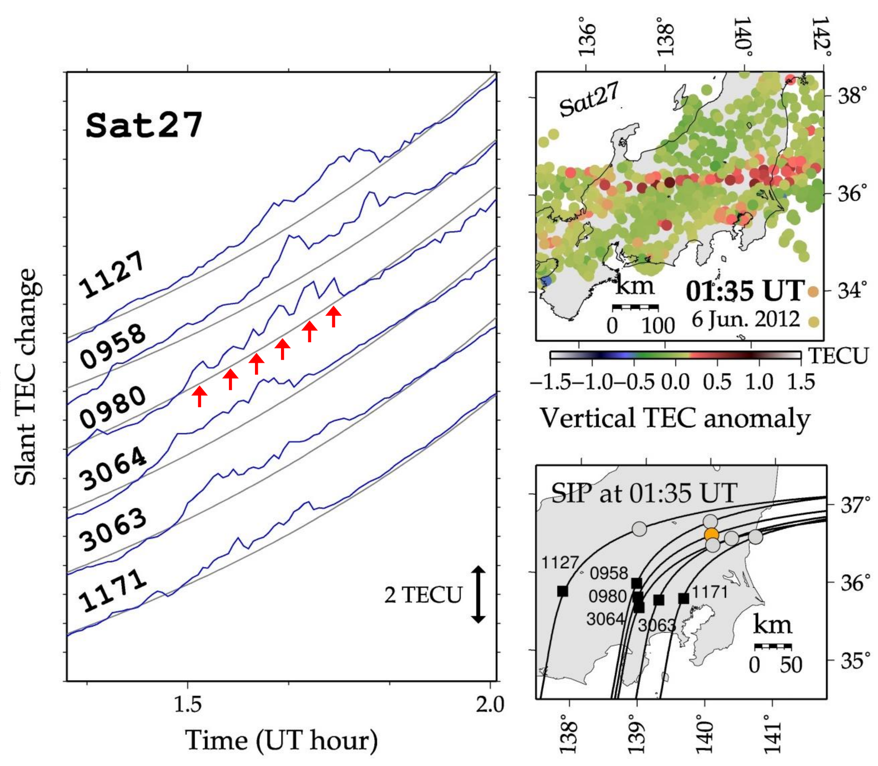


Fig.7 a. Slant TEC time series drawn by Satellite 12 and six GPS stations, showing typical QP TEC enhancement (especially clear with GPS station 0877 and 0007) **b.** Vertical TEC anomaly map at 02:15 UT, in which a frontal structure is evident. It elongates in the E-W direction. **c.** SIP positions with Satellite 12 and six GPS stations at 02:15 UT. SIPs moved east-northeastward, almost tracing the E-W elongation of the frontal structure.

These results demonstrates that QP TEC signatures are localized in the central part of the E-W elongation. The horizontal separation is ~15 km.

Fig.8 a. Another example of along-elongation QP structure observed over the central part of Japan. **b.** Vertical TEC anomaly map at 01:35 UT, showing an E-W frontal structure which was stationary during the observation. **c.** SIP positions with Satellite 27 and six GPS stations at 01:35 UT.

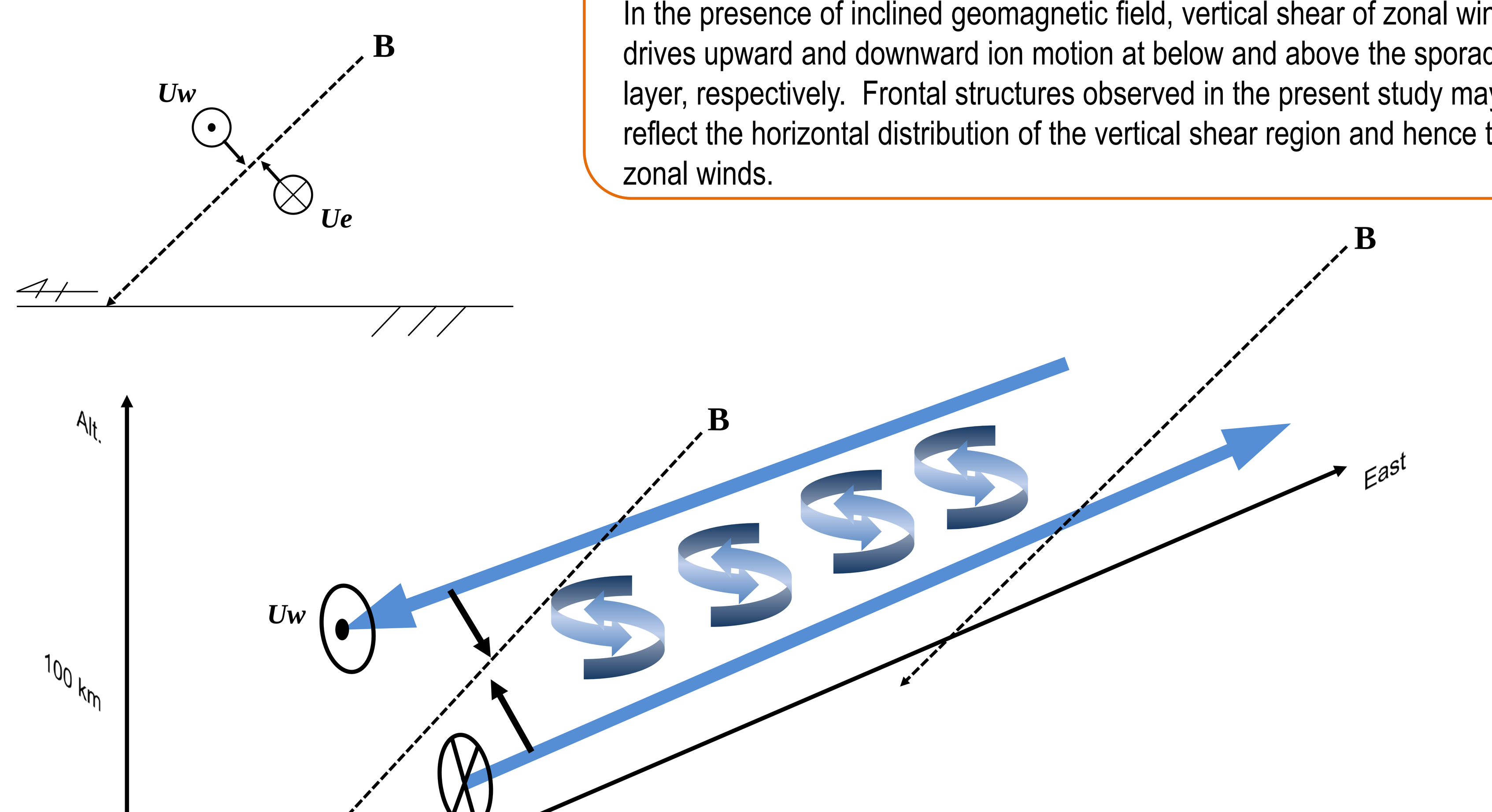
In **a**, QP TEC enhancement is clearly observed with the GPS station 0980 while other stations show irregular TEC changes. The location of SIP of 0980 is shown as an orange circle in the SIP map. In this case, either, the QP structure is quite localized in a small region. The horizontal spacing of the QP structures is ~10 km.

Discussion

Frontal structure

Horizontal distribution of zonal winds

In the presence of inclined geomagnetic field, vertical shear of zonal winds drives upward and downward ion motion at below and above the sporadic-*E* layer, respectively. Frontal structures observed in the present study may reflect the horizontal distribution of the vertical shear region and hence the zonal winds.



Pictorial image of a TMA trail in the *E*-region of the ionosphere observed during the SEEK-2 experiment conducted over southwestern Japan [*Larsen et al.*, 2005]

QP structure

Kelvin-Helmholtz (KH) instability

It is widely accepted that the formation of sporadic-*E* layers are attributed to zonal wind shear which often create favorable condition for shear instabilities such as Kelvin-Helmholtz (K-H) instability [*Larsen et al.*, 2005]. Zonal winds shear often satisfy Ri < 0.25 and becomes sensitive to K-H instability. This implies that eastward and westward winds may create wave-like structure or vortex structure that are responsible for QP TEC enhancement observed in this study (Fig.5-8). Zonal winds are considered to be the prime driver for the midlatitude sporadic-*E*, K-H instability may separate the dominant plasma cloud into a series of plasma patches, which sometimes observed as QP structure.

References

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