Improving our understanding of the ionosphere by using Swarm mission as a constellation

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ESA’s Swarm mission, consisting of three satellites, provides unique opportunities to improve our understanding of the ionospheric structures that cannot be achieved by single-satellite missions. In this study, we provide an overview of our recent work focusing on the ionospheric structures, based on observations of Swarm from the constellation perspective.

I: String of pearls formation

During the initial mission phase, when three satellites fly in a configuration as a string of pearls, is very useful to investigate the small-scale structures of equatorial plasma irregularities (EPIs) as well as the small-scale field-aligned currents (FACs) at auroral latitudes:

Cross-correlation has been performed of the plasma density and FACs between Swarm three satellites, we found:

- When the longitudinal separation between Swarm satellites larger than 0.4", no significant correlation was found any more. This result suggests that EPI structures include plasma density scale sizes less than 44 km in the zonal direction.
- A persistent period of small-scale FACs of order 10 s, while large-scale FACs can be regarded stationary for more than 60 s. Large-scale FACs are different on dayside and nightside. On the nightside the longitudinal extension is on average 4 times the latitudinal width, while on the dayside, particularly in the cusp region, latitudinal and longitudinal scales are comparable.

II: Side-by-side flying formation

The lower-pair flying Swarm A and C, with a longitudinal separation of 1.4", can well reflect the longitudinal (or local time) gradient of large-scale ionospheric structures, e.g., the equatorial ionization anomaly (EIA), equatorial electrojet (EEJ). In addition, the constellation provides an unique opportunity to check the assumptions and reliability of field-aligned currents calculation based on the single- and dual-satellite approaches.

By checking the systematic dependence of gradient between Swarm A and C, we found:

- At equinox months a fast decrease of the F region electron density is seen at the EIA trough region during the prereversal enhancement, while an increase is found meanwhile at crest regions. Afterward, a fast decrease of the EIA crest electron density occurs between 19:00 and 23:00 LT, with seasonal dependence.
- The ΔEIE, which can be considered as a high-pass filtered result of EEJ, although having much smaller values than the EEJ, exhibits clearly the local time gradient of the EEJ diurnal variation. This kind of high-pass filtering makes the tidal signatures in ΔEIE more prominent.

III: Counter-rotation formation

The counter-rotation period between Swarm A/C and B, provides also good opportunity to investigate the field-aligned scale length of post-sunset equatorial plasma bubbles (EPBs), as well as the propagation of upstream waves at ionospheric altitude.

Scale length of equatorial plasma bubbles

\[ d^2 = r^2 - \frac{r_0^2}{\cos^2(\Delta \phi)} + \frac{2 r r_0}{\cos(\Delta \phi)} \cos(\Delta \phi) \]

\[ \cos^2(\Delta \phi) = \cos^2(\phi_a) - \cos^2(\phi_b) \]

\[ \Delta \phi = \Delta \phi_a - \Delta \phi_b \]

\[ p = \frac{v_n}{v_{EIE}} \]

\[ a = \frac{a_n}{a_{EIE}} \]

\[ d = \frac{d_n}{d_{EIE}} \]

[Xiong and Lühr, 2023]

FACs calculated from Swarm dual-satellite are not affected by the far-field currents, e.g., the horizontal polar electrojet (PEJ). Our results reveal that the conventionally used FACs calculated with single-satellite approach underestimate the FACs' intensity.

- HIFAC derived from both approaches agree qualitatively, but the amplitudes of single-spacecraft results reach only about 70% of those from the dual-satellite.
- The radial current from single-satellite approach is contaminated by EEJ at American sectors due to large magnetic declination in this region.

References: