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Drivers of the variability of ionospheric plasma observed by the Swarm satellites

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The ionosphere is a highly complex plasma containing electron density structures with a wide range of spatial scale sizes. Large-scale structures with horizontal extents of tens to hundreds of km exhibit variation with time of day, season, solar cycle, geomagnetic activity, solar wind conditions, conditions in the neutral atmosphere and location. Whilst the processes driving these structures are well understood, the relative importance of these driving processes is a fundamental, unanswered question. These large-scale structures can also cause smaller-scale irregularities that arise due to instability processes and which can disrupt trans-ionospheric radio signals, including those used by Global Navigation Satellite Systems (GNSS). Ionospheric effects pose a substantial threat to the integrity, availability and accuracy of GNSS services. Strategies to predict the occurrence of plasma structures are therefore urgently needed.

Swarm is ESA's first constellation mission for Earth Observation (EO). It initially consisted of three identical satellites (Swarm A, Swarm B, and Swarm C), which were launched into Low Earth Orbit (LEO) in 2013. Initially the spacecraft flew in a string-of-pearls configuration before the final constellation of the mission was achieved on 17 April 2014. Swarm A and C form the lower pair of satellites, flying in close proximity an at altitude of 462 km Swarm A and C, whereas Swarm B was at 511 km. The configuration of the Swarm satellites, their near-polar orbits and the data products developed, enable studies of the spatial variability of the ionosphere at multiple scale sizes. In this paper three Swarm data products are used, which represent the variability of the ionosphere at spatial scale of 100km, 50km and 20km.

The technique of Generalised Linear Modelling is used to identify the dominant driving processes of large-scale structures in the ionosphere at low, middle, auroral and polar latitudes at each of the scale sizes discussed. The statistical relationships between the ionospheric structures and proxies for the driving processes are determined in each region and scale size. The variations between regions and scale sizes are discussed, with a particular focus on the European sector. Predictive models for these ionospheric structures at low, middle, auroral and polar latitudes are created and the goodness-of-fit of these models is determined.

These models of the plasma structures are deterministic. However, there are also random variations in the ionospheric structures which cannot be captured by these models. The variability which is not captured by these models is quantified. This variability can be due to a missing driving process, a poorly specified driving process or the stochastic component. These results therefore provide an upper limit on the magnitude of the random component of ionospheric variability at these altitudes and scale sizes.

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