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Whistlers in the ELF measured from LEO used to validate ionospheric models

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1 Extended Abstract

Satellites in Low Earth Orbits (LEO) are extremely useful for measuring the ever-evolving conditions of the ionosphere. With current technologies, both in-situ and remote sensing techniques can be applied to retrieve the plasma distribution around the satellite, particularly those using GNSS signals. These techniques, however, do not generally allow sounding the ionosphere directly below the LEO satellites. GNSS radio occultation, for instance, sense regions extending thousands of kilometres away from the satellite in the F region. It is therefore still critical to develop new techniques to allow sensing the ionosphere closer to the satellite position. This is particularly needed to establish an experimental link between the in-situ electron density measurements and the peak of the F2 layer. Here, we propose to use natural electromagnetic signals generated by lightning strikes to sound the ionosphere below the satellite orbital altitude close to its position. We use data from the European Space Agency (ESA) Swarm mission, acquired during campaigns of burst-mode acquisition of the Absolute Scalar Magnetometer (ASM) at a sampling rate of 250 Hz [1], which allow detecting magnetic signals in the Extremely Low Frequencies (ELF) travelling through the ionosphere. Swarm satellites are also continuously measuring the in-situ electron density using the Langmuir probes of the Electric Field Instrument (EFI). We developed specific algorithms to detect and characterise lightning-generated whistlers to obtain their dispersion. The measured dispersion depends on the ionospheric plasma distribution along the propagation path. In the ELF, the refractive index depends both on the electron density and the magnetic field. As a result, the propagation path is determined by the magnetic field direction and its length up to the Swarm satellites depends on the geomagnetic latitude. This length is longer at low latitudes, where Swarm satellites detect most of the whistler signals in the ELF. We studied the relation between the measured dispersion and the curved total root electron content along the path between the point where the lightning signal entered the ionosphere and the detection point. By using ray-tracing calculations, we were able to model the propagation path of whistler signals and obtain synthetic dispersions. Since the dispersion depends on the spatial distribution of ionospheric plasma, we developed a technique to adapt the background ionospheric model used for the simulation. We use the climatological IRI-2016 model as an initial baseline and the IRTAM, ionosonde-derived update of its parameters [2]. The topside up to Swarm altitude is adjusted by using the in-situ electron density measurements. These adaptations have been validated by comparing whistler dispersions measured near ionosonde locations with those computed using ray-tracing simulations. We present an extended validation study with whistlers observed during ASM burst-mode campaigns, mostly covering the period between 2019 and 2021, within 600 km from selected ionosondes at low latitudes. We extend the analysis to events located at further distance, by using the IRTAM model. The availability of whistler signals is currently based on one-week measurement campaign per month on two of the Swarm satellites. Their occurrence strongly depends on the local time of the satellite orbital plane. The future NanoMagSat mission will offer increased opportunities to continuously monitor whistler activity with a bandpass extending up to 800 Hz. This will further extend our ability to monitor the ionosphere and better constrain models in region where ground-based observations are not available.

References

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