In the context of the ESA’s Solid & Magnetic Earth Science Cluster, the 4D Ionosphere initiative aims to advance the use of satellite data, particularly from the Swarm mission, along with additional space assets to contribute to the development of advanced dynamic models of Earth’s ionosphere, and its interactions with the magnetosphere, the lower atmosphere, and the other components of the Earth system. The Cluster includes several projects and activities that follow a community approach, fostering networking and collaborative research.

This poster outlines five new contributing research projects, kicked-off in January and February 2024. They jointly address different aspects of the ionosphere and, in particular, four main scientific challenges: 1) enhance the characterisation of the quiet ionosphere (QUID-REGIS); 2) enhance the observation and modelling of dynamic processes in the ionosphere such as irregularities, dynamics, and predictive capabilities – space weather (VIP-Dynamic); 3) enhance knowledge of the ionosphere – upper atmosphere/thermosphere coupling (JOIN); 4) improve the way to observe and model the ionosphere – magnetosphere coupling (FBURST). In addition, a novel activity has been launched to explore the potential of deriving ocean circulation information from geo-magnetic Swarm data (SFOID).

**QUID-REGIS**

**Quiet ionospheric Disturbances - Research based on Ground-based mesospheric and ionospheric data with Swarm data**

**Motivation**

The ion-aerion variability of quiet-time ionosphere is surprisingly high even during periods of negligible solar forcing. Relatively, well understood is the high-altitude where the solar wind is directly striking the high-latitude currents, connection electric field at polar auras, however, the current understanding does not allow to accurately model the ionospheric state during the quiet-time conditions also at mid- and low-latitude.

**Objectives**

The project contributes to a better understanding of the variability in the Swarm data during solar quiet periods by considering atmospheric dynamics in dynamics from below. The team aims to deliver a quantitative estimate of the lower atmosphere forcing in a potential source of ionospheric variability during solar quiet periods over a decade, taking advantage of measurements from a terrestrial-based ground-based network. The project team estimates the variability driven by the lower atmosphere from the Swarm data and the IRI model, for a better general baseline representation of Swarm.

**VIP-Dynamic**

**Swarm Space Weather: Variability, Irregularities, and Predictive capabilities for the Dynamic Ionosphere**

**Objectives**

- Develop a suite of Swarm-VIP-Dynamic models for capturing the ionospheric variability using ground-based scales, including small-scale variations.
- Predict key-quantities and demonstrate the operation of such models to operate in real-time environment.
- Use advanced near real-time modelling / probabilistic models / and machine learning methods.
- Evaluate the number of explanatory variables in the context of real-time predictions.
- Model densities, density gradients, amplitude of density variations.
- Improve previous models.

**JOIN**

**Joule heating effects on ionosphere-thermosphere coupling and neutral density**

**Objectives**

This project aims to study the auroral Joule heating and its consequences on the ionosphere-thermosphere (IT) system at high latitudes. The main objectives are:

1. Determine the global statistical distribution and variability of the high-latitude Joule heating during geomagnetic storms.
2. Consider spatial variability with observed large-scale atmospheric density variations at low Earth orbits (LEO).
3. Evaluate the effect of the JHI on the ionospheric magnetic field by directly comparing density measurements from two different satellites during co-orbitally periodic days between various LEO satellites at solar-orbit, see Figure 3.1.
4. Perform event studies of meso-scale Joule heating and density variations at auroral regions during conjunctions between Swarm satellites and incoherent scatter radars.

**FBURST**

**Mapping of field-aligned currents in the ionosphere and BURST bully flows in the magnetotail**

**Key Science Questions:**

- How do BFI influence FAC behavior?
- How do BFR modulate FAC-plume and spatial scales?

This project explores ionosphere-magnetosphere coupling using data from ESA missions (Cluster, Swarm), and non-ESA missions (e.g., MMS). It focuses on Burst Bulk Flow (BBF) events, mapping their magnetic position to footprints in the ionosphere. Using this, the team aims to determine the relationship between BFR and Field-Aligned Currents (FACs). The BBF database and footprint points will be publicly available for understanding the spatial impact of BBF events and their impact on the magnetotail dynamics, a higher resolution IMF-driven footprint.

**SFOID**

**Swarm for Ocean Dynamics Project**

Satellite magnetic field observations have the potential to provide information on dynamics, heat content and salinity throughout the ocean. With ten years of high-quality observations available from the Swarm satellites trio, there are now new possibilities for extracting this signal of interest. This project aims to retrieve the Ocean-Induced Magnetic Field (OIMF) signal, going to the next level of exploring an additional climate signal, and to incorporate this with the help of advanced numerical models.

- Dedicated processing of Swarm magnetic data with corrections for known magnetospheric and ionospheric signals.
- High resolution global modeling of the time-dependent internal field at Earth’s surface using this processed data.
- Spectral filtering to isolate the time-varying OIMF signal.
- Analysis of high-resolution numerical simulations based on 3D oceanic flows and conductivities.