

2021 Virtual Swarm Science Workshop

INTRODUCTION

The **2021 Virtual Swarm Science Workshop (VS-SW)** on 28-29 June will bring together ESA and Swarm science experts to share and discuss the state-of-the science results and knowledge gained from Swarm-based ESA projects over the last 3 years, focussing on physics of the Earth's ionosphere, and its interactions with the lower atmosphere. The VS-SW will also contribute to the identification of a new science roadmap for Swarm extension phase, identifying the main science gaps and technical challenges to be tackled in the next 5 years, in order to *realise the best possible 4D reconstruction of the ionosphere, its dynamics and its interactions with the rest of the Earth/space systems based on an effective integration of Swarm data, other space/ground-based datasets, advanced models and latest digital technologies (e.g., ICT, AI).*

Seed questions:

1. What have we achieved since the 4Dionosphere workshop (see summary attached)? What are the main results and advances from your projects vs the challenges identified in the workshop?
2. Which are the main investigation that were not performed as part of your project that you would like to implement in the future? What are the main scientific priorities and needs where we can achieve a significant impact?
3. How can we build upon existing results and activities and move towards a community effort to develop the best possible SWARM-based description of the ionosphere and its dynamics and its interactions with the rest of the Earth/space systems?
4. What could be an ideal result of such an effort? A new advanced model? A combination of new advanced data and modelling results? What is feasible to achieve in 5 year?
5. What are the main science needs to characterise the quiescent time ionosphere: e.g., the variations of various quantities in time and space, under weakly driven conditions (non-storm times)?
6. What have we learned and what are the main science needs to better understand the asymmetries of ionospheric currents, conductivities, etc. between the two hemispheres: e.g., their origin, under quiescent and disturbed conditions, and their impact on the energy transfer between magnetosphere / ionosphere / thermosphere (MIT) system?
7. What have we learned and what are the main science needs to better understand fluctuations/irregularities/turbulence in the ionosphere: e.g., what are the more relevant features in Swarm electric and magnetic field data to differentiate among the various source mechanisms? Is it possible to predict their occurrence (fluctuations/irregularities/turbulence) according to the solar wind / interplanetary magnetic field conditions / season / local time / geographic location? What is their impact (fluctuations/irregularities/turbulence) on GPS signals?
8. How to better assess the influence of the local conditions in the lower atmosphere, and their impact on ionosphere dynamics?
9. What are the more relevant opportunities of Swarm data in synergy with other existing (e.g., Cluster, Solar Orbiter, etc) or planned missions?
10. What are the recommendations for ESA to foster a collaborative research effort towards such an ambitious goal?
11. What tools may be needed for the community... a 4Dionosphere community platform?

DRAFT AGENDA

DAY-1 (Start 9:00)

9:00 – Session 0 – Update from Swarm Mission status and Meeting objectives

- ESA presentations on mission status, scientific perspective and scope of this workshop [30 minutes]

9:30 – Session 1 – The variability of the Ionosphere: how to monitor geomagnetic activity, Ionospheric currents, ionospheric boundaries from s/c data [Chair Lorenzo Trenchi / scribe for this session]

Contributors and time slots:

- SIFACIT Objective 1: **Innovative methods to characterize Field-Aligned Currents with Swarm and potential / upcoming applications** [12 + 3 min questions]
- INTENS Objective 1: **Swarm-derived indices of magnetic storm and magnetospheric substorm activity** [12 + 3 min questions]
- EPHEMERIS Objective 1: **Monitoring plasmasphere dynamics through the observation of the mid-latitude ionospheric trough and other boundaries by Swarm (EPHEMERIS and PRISM projects)** [12 + 3 min questions]
- SIFACIT Objective 2: **Lessons learned from Swarm observations and MHD simulations of Joule heating** [12 + 3 min questions]
- OPEN DISCUSSION: more relevant open points, and how Swarm can contribute to address them [30 minutes]

Coffee break (11.00 – 11.15)

11:15 – Session 2 – Extreme events, driven from solar wind and/or perturbations from lower atmosphere [Chair Roger Haagmans / scribe for this session]

Contributors and time slots:

- COSTO: **Seismic ionospheric disturbances related to various earthquakes and tsunamis observed by Swarm and other LEOs, GNSS and ionosondes: new approaches for potential warnings** [12 + 3 min questions]
- ILGEW: **Lightning Generated ELF Whistlers** [12 + 3 min questions]
- HLAI: **Summary of results from the Swarm+ Ion Outflow project** [12 + 3 min questions]
- Swarm4Anom: **Global view of lightning spots as seen by Swarm** [12 + 3 min questions]
- VERA: **Swarm observations of the ionospheric response to the Southern Hemisphere sudden stratospheric warming in September 2019** [12 + 3 min questions]
- OPEN DISCUSSION: more relevant open points, and how Swarm can contribute to address them [30 minutes]

Lunch break (13.00 – 14.30)

14:30 – Session 3 – Understanding the origin and processes of ionospheric fluctuations / irregularities / turbulence / Alfvén waves and their impact on GPS signals [Chair Anja Stromme / scribe for this session]

Contributors and time slots:

- INTENS Objective 2: **Ionospheric turbulence: a challenge for GPS loss of lock understanding** [12 + 3 min questions]
- Swarm Polar Cap Patches: **Interhemispheric differences in ionospheric structuring at high latitudes** [12 + 3 min questions]
- EPHEMERIS Objective 2: **Magnetic field irregularities along the Swarm orbits - Introduction of a new intermittency index in the framework of the EPHEMERIS project** [12 + 3 min questions]
- SuperDARN ICEBEAR Collaboration – Turbulent E-region Aurora Measurements (SSIC-TEAM) project: **Results from A Swarm, Superdarn, and ICEBEAR Collaboration - Turbulent E-region Aurora Measurements** [12 + 3 min questions]
- SIEMIC: Swarm Investigation of the Energetics of Magnetosphere-Ionosphere Coupling **Alfvén Waves at Mid-Latitudes: Magnetosphere-Ionosphere Coupling, Interhemispheric Asymmetry and Radiation Belt Science** [12 + 3 min questions]

Coffee break (15.45 – 16.00)

- OPEN DISCUSSION: more relevant open points, and how Swarm can contribute to address them [30 minutes]

16:30 – Session 4 – Swarm contribution to Ionospheric models, and possible new developments [Chair Diego Fernandez / scribe for this session]

Contributors and time slots:

- Astrid Maute: **Potential use of Swarm data for the TIEGCM** [12 + 3 min questions]

DAY-2 (Start 9:30)

09:30 – Continuation of Session 4 – Swarm contribution to Ionospheric models, and possible new developments [Chair Diego Fernandez / scribe for this session]

- Alessio Pignalberi: **Improving the NeQuick topside representation by means of Swarm satellites data** [12 + 3 min questions]
- Bruno Nava: **NeQuick ionosphere electron density model** [12 + 3 min questions]
- Swarm-VIP: **Scale analysis – semi-empirical model** [12 + 3 min questions]
- OPEN DISCUSSION: more relevant open points, and how Swarm can contribute to address them [30 minutes]

Coffee break (10.45 – 11.00)

11.00 – Session 5 – Synergies with other existing or planned missions in the Sun-Earth connections domain [Chair Matt Taylor / scribe for this session]

Contributors and time slots:

- Erik Kuulkers: **INTEGRAL** [12 + 3 min questions]
- Raffaele Crapolicchio: **SMOS solar flux & TEC estimation** [12 + 3 min questions]
- Alex Hoffmann: **Daedalus** [12 + 3 min questions]
- Philippe Escoubet: **Cluster-Swarm-SMILE future synergies** [12 + 3 min questions]
- Arnaud Masson: **Cluster-SWARM pre-launch foreseen synergies and actual achievements** [12 + 3 min questions]
- Gauthier Hulot: **How NanoMagSat could contribute to ionospheric science beyond Swarm** [12 + 3 min questions]
- TBC [12 + 3 min questions]
- OPEN DISCUSSION: more relevant open points, and how Swarm can contribute to address them [30 minutes]

Lunch break (13.15 – 14.30)

14.30 – Session 6 – Achievement and next scientific challenges [Chair Roger Haagsmans / scribe for this session]

- Session chairs' summary [15 minutes per session – 75 minutes overall]
- Conclusion from ESA, and potentially interesting future activities:
 - Understanding the physical origin of irregularities in the ionosphere, their occurrence according to solar activity in view of the upcoming solar maximum, their link with turbulent dynamics and their impact on GPS signals
 - Assessing the asymmetries in the ionosphere between the two hemispheres, separating the ones caused by external drivers (asymmetries in magnetosphere, energetic particles, reconnection geometry) from the internal ones (magnetic dipole tilt effects, conductivity, ionospheric anomalies, neutral density, ...)
 - Implementing new geomagnetic indices from space, based on Swarm + platform magnetometers data, to monitor the intensity of the ionospheric currents at low and high geomagnetic latitudes, with the same accuracy in the two hemispheres, and with high time resolution.
 - Extreme events, driven from solar wind and/or perturbations from lower atmosphere/biosphere
 - Swarm measurements supporting future missions, and potential synergies with other existing or planned missions (with in ESA and in other agencies)
 - Others that came from discussions from various sessions...
- OPEN DISCUSSION