# Report on the Workshop "Swarm in Space Physics", 5 May 2006 at the 1st Swarm International Science Meeting, Nantes


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## ABSTRACT

The Swarm constellation's combination of precision measurements of geomagnetic fields, electric fields, and plasma parameters will provide an unprecedented view of the terrestrial ionosphere and its coupling to the thermosphere and magnetosphere. Swarm will realize maximum scientific return by a) operating at the highest temporal resolution available at all latitudes – from polar to equatorial, b) including modeling as an integral part of the mission from the early stages, and c) by coordinating with ground-based instrument arrays to the maximum extent possible.


## WORKSHOP OVERVIEW

As part of the 1st Swarm International Science Meeting, a special 3-hour session on "Swarm in Space Physics" was organized by the authors in order to identify and discuss opportunities the Swarm mission offers for space physics research, including:

- Identification of key science goals,
- Specialized instrument operating modes,
- Combination of Swarm observations with observations, both ground- and space-based,
- Utilization of Swarm observations to create and validate models, and
- Requirements and wishes for Swarm data products, data distribution, and instrument modes.

With only three hours, some of the above topics were only touched upon, however the Workshop did lead to several conclusions as described below. The Workshop was divided into two halves, the first focusing on Magnetosphere-Ionosphere-Thermosphere (MIT) science, and the second on Space Weather.

During the MIT portion, three invited discussion leaders presented overviews on each sub-topic, followed by a short discussion.

*William Liu* of the Canadian Space Agency began with an overview of magnetospheric/high-latitude science, arguing that our present understanding of the ionosphere represents the greatest uncertainty in magnetospheric physics. This conclusion stems from knowledge that the ionosphere provides mass to the magnetosphere, it acts as a dynamic energy sink to the magnetosphere, and it determines the closure of magnetospheric currents (see accompanying paper in these proceedings). Improvements in magnetospheric physics will therefore require 3-D (height-resolved) ionospheric models supported by high-resolution, height-resolved ionospheric measurements. Dr. Liu, who chairs the International Living With a Star program, thanked ESA for its contribution of Swarm to sun-earth system studies.

*Paul Kintner* of Cornell University then spoke about the mid- and low-latitude ionosphere, showing animated sequences of massive, mesoscale perturbations in total electron content (TEC) measured over Japan and North America by GPS networks. These perturbations are associated with magnetic storms, and are large and dynamic enough to cause failures in communications and navigation systems, including GPS. However, the physical causes and geographical extent of these disturbances remain unknown. During the discussion the point was raised that while Swarm is probably not an optimum tool for identifying and mapping such disturbances, Swarm will provide key measurements that will allow physical mechanisms to be clarified. An important conclusion from this discussion was that the ionosphere is highly structured at all latitudes, not just in the auroral zone, and the onset, duration and locations of disturbances are unpredictable at present. In order for Swarm to be able to contribute to new understanding in this area, it is inadvisable to meet Swarm telemetry constraints by sacrificing temporal resolution at lower and middle latitudes in order to support higher rates at high latitudes.

*Hermann Lühr* of GFZ Potsdam then led a discussion on thermospheric science, specifically addressing Swarm Level-2 products relevant to this topic. The point was made that ionospheric conductivity is perhaps not a good level-2 product for Swarm, since it can be calculated relatively easily using other data products from Swarm. Instead, the eventual level-2 product list should include quantities that exploit Swarm's multi-point capabilities, including field-aligned currents, and Poynting flux, along with thermospheric winds and density gradients. Aaron Ridley (Michigan) added that ground-based Fabry-Perot interferometer chains could complement thermospheric wind measurements from Swarm, and that planning has been initiated in North America for such a chain.

The second half of the Workshop began with an overview by *Therese Moretto* stressing the need to include physics-based models and theory with Swarm measurements, along with other datasets, both ground-based and space-based.

*Michael Hesse* (NASA GSFC) then gave a short presentation on the Community Coordinated Modeling Center (CCMC). The CCMC serves as a free and open archive of many space physics models relevant to MIT science that can be run on request, and could serve as a valuable resource for Swarm. The CCMC can be accessed at “ccmc.gsfc.nasa.gov”.

It was generally agreed that, concerning the space physics science goals of Swarm, it is necessary to extend the measurements with models. Swarm will provide important model parameters/inputs such as field-aligned currents, electric fields and thermospheric winds. Such parameters are key measurements for the interface between magnetospheric and ionospheric models, the combination of which is currently a high priority in the international modeling community. Swarm could also therefore play an important role for model validation. To explore and ensure the best utilization of Swarm in combination with models, it was suggested to invite modelers to future Swarm science workshops – or to hold a dedicated workshop on the modeling aspects.

Similarly, it was widely acknowledged that answering the important space physics science questions identified for the Swarm mission will require the combination of Swarm measurements with a wealth of other ground based and satellite observations. Specifically, the possibility of continued operation of the extended Canadian ground-based program that is currently being implemented for the NASA THEMIS mission was discussed and was found to be highly desirable. It was also agreed that the use of existing Ørsted and CHAMP data together with other data sets should be strongly encouraged. This will help not only in building up the necessary expertise for exploring the joint data sets but also in defining in detail the science questions to be addressed with Swarm. It was suggested that this be made a priority topic in future Swarm workshops.

## CONCLUSIONS AND RECOMMENDATIONS

The Workshop concluded with a summary of key scientific objectives and suggestions for space-physics-related studies and data products. The key scientific questions identified were:

- The role of small-scale structures in the energy budget and coupling of the M-I-T system,
- causes and sources of plasma disturbances that can affect communication and navigation signals, and
- electrodynamics of the aurora and associated current systems.

Concerning level-II data, a data center facility providing high-level data products was considered very useful. A key output of the Swarm mission will of course be the next-generation model of the geomagnetic field, including both internal and external field sources. It will be most helpful to the space physics community if this model can be separated into constituent parts, including both the internal and external fields resulting from sources such as the ring current, Sq currents, and auroral field-aligned currents.

Level-II data product definitions will be refined in future discussions, however a list of additional candidates discussed during the Workshop included:

- FAC intensity and location
- Global convection potential
- Density error bars
- Poynting flux
- Electric field divergence
- Plasma-pressure gradient
- Neutral density gradients
- Neutral winds and wind gradients
- Auroral electrojet tracking
- Ionospheric conductivities

Additionally, it was noted during the Workshop that the Swarm, Ørsted, CHAMP, and SAC-C data will continue to be valuable references long after the missions are completed, and a long-term archive of these data should be pursued.

Finally, the workshop participants emphasized the high degree of spatial and temporal structure of ionospheric electric and magnetic fields and plasma structures during active periods, noting that such structure can occur at all latitudes. The telemetry allocation currently planned for Swarm limits key parameters to spatial resolutions of 4 km, whereas during active times the ionosphere is known to be structured on scales at least an order of magnitude smaller than this. Accurate and timely characterization of the active ionosphere has important applications for global navigation, communications, satellite tracking, radiation hazards, and electromagnetic induction, in addition to the basic science of ionospheric and magnetospheric current systems that are a primary focus of the Swarm mission. The participants therefore encourage ESA to pursue opportunities for additional downlink capability (for example with additional ground stations in cooperation with NOAA) through which higher continuous measurement rates can be supported.