Open Call for Ideas for

New data products, tools and services for Swarm

Template

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In order to facilitate 'cross pollination' between ideas and research groups, the Proposer(s) declare in submitting this idea, that the Swarm DISC may publish the name(s) of the proposer(s) and the title of the idea. Please indicate below (select Yes or No) whether DISC can also publish the entire content of the submitted idea:

Publish the entire content *Yes*

Product/Tool/Service Idea

Title: Swarm meets Movement Ecology: using magnetic satellite data to study animal migratory navigation

Product/Tool/Service Description (2 pages maximum)

- *Description of proposed product/tool/service*

Migratory animals use information from geomagnetic field to navigate across long distances; however, how they are able to do this is still not completely understood (Mouritsen 2018). In the last few years, on-animal tags with GPS trackers now allow detailed tracking of individual animals throughout their lifetime. For the study of geomagnetic navigation, tracking data need to be linked to accurate information on magnetic field at the position and time of each GPS point. This has not been possible until recently with the development of new tools based on Swarm data.

We previously developed a data fusion tool called MagGeo (Benitez Paez et al. 2021), which employs a bespoke spatio-temporal interpolation of Swarm measurements to calculate values of the geomagnetic field at the location and time of each GPS point on the trajectory of a tracked animal. We first find all Swarm points within a spatio-temporal kernel of the GPS point (Figure 1). This kernel is geographically defined by a circle on the surface of the Earth, which is larger towards the Equator and smaller towards the Poles. This is to account for Swarm orbits and ensure that we find approximately the same number of Swarm points around each GPS point. We then calculate the spatial and temporal distance of each Swarm point from the GPS point and use this in weighted interpolation of magnetic values. We use geomagnetic values from CHAOS-7 model at the location of each satellite point but interpolate residuals, which represent the external part of the field. We interpolate residuals from all Swarm points in the kernel and add the result to the modelled value of the field at the location and altitude of the tracked animal. We do this for measurements in all three dimensions in the NEC coordinate system separately. In our accuracy assessment with data from INTERMAGNET stations, we found that our method has an average absolute error in total intensity of 21.6nT. This is likely at the lower end of what migrating animals can probably sense (20-200nT) and shows that our tool can support the study of animal responses to real geomagnetic conditions.

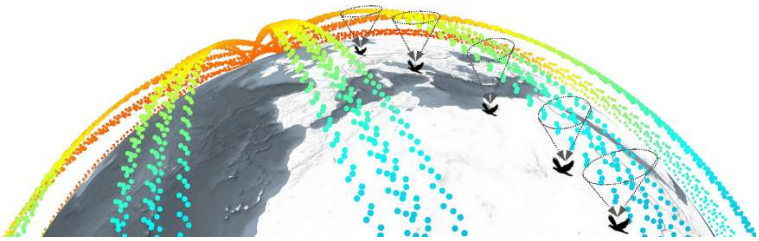


Figure 1. Spatio-temporal fusion of Swarm data with GPS tracking data: we select Swarm measurements using a spatio-temporal kernel around the GPS tracking point, and then employ a spatio-temporally weighted interpolation method to calculate geomagnetic values at the GPS point (i.e. animal location).

In addition to annotating GPS points with values of geomagnetic field, our tool also provides data from the CHAOS-7 model as well as Kp values that can be used for studies of animal behaviour. In Benitez Paez et al. (2021) a short case study used Kp to investigate if migratory birds are affected by geomagnetic storms. We found that greater white-fronted geese (*Anser albifrons*) change speed and direction of their migratory flights during periods with a high Kp – something that no one has ever been able to observe before and which would be impossible without the fusion of Swarm and animal tracking data.

- *Description of current state of the art and level of maturity of proposed algorithm*

The algorithm in Benitez Paez et al. (2021) is mature and has been tested and validated by our team. We performed an evaluation of the interpolation method (Iyer et al. 2022) and two studies of geomagnetic navigation of migratory birds (Zein et al. 2023, Zein et al. – under review) using the tool. However, MagGeo is written in Python as a Jupyter Notebook and, as such, it has had a very low uptake in the target community (movement ecology). Ecologists are not proficient in Python; they either use R or do not have coding skills. The main effort for this project is therefore to *improve and re-design* the MagGeo tool to be more accessible to ecologists and thus promote use of magnetic satellite data in an entirely new scientific community.

- *Data input needs (e.g. type of data from Swarm and/or other, frequency, auxiliary information)*

We require Level1b 1Hz data from start of mission to the present, as well as field models (e.g. CHAOS) and the Kp index. The code will be flexible to allow data from other related missions (e.g. MSS-1 and NanoMagSat) to be incorporated, assuming the file formats are consistent and access can be obtained via VirES.

- *Expected output (e.g. frequency of delivery, suggested strategy for data delivery)*

Output 1: We will re-develop MagGeo as a Python library, starting from existing tool, but incorporating the following improvements: 1) migration from the current Jupyter Notebook mode to API functionality for ease of installation and scalability to large trajectory data sets, 2) improved support for both sequential and parallel computation of magnetic field values, 3) improved data handling and visualisation functionalities, 4) new improved interpolation methods (Iyer et al. 2022), and 5) improved documentation. The package will be disseminated using the Python Package Index (PyPI.org), one of the main repositories for Python libraries. Geomagnetic data will be delivered on demand from VirES system, as already in the original MagGeo tool.
Output 2: The new Python library will be used to create a MagGeo MoveApp. MoveApps (moveapps.org, Kölzsch et al. 2022) let developers create their analysis workflows via code wrappers, which are presented as apps that can be linked in a visual environment, without the user needing to know how to code. This is aimed to increase visibility among ecologists who are not proficient in coding.
Output 3: We will also create a maggeo R package that will call the Python implementation from output 1. This output will increase uptake among those ecologists who are confident in R, but do not know Python. The maggeo package will be disseminated via the Comprehensive R Archive Network (CRAN) repository.
Output 4: We will provide online workbooks in Python and R and MoveApp workflows to allow starting examples for ecology studies. We will also promote the tool via ecology workshops and conferences.

- *Scientific/application benefits, complementarity with other relevant ESA and non-ESA activities including opportunities for new scientific activities based on implementation of the proposed product*

Traditional navigation studies in ecology employ laboratory and displacement experiments, by raising animals in a lab under specific magnetic conditions, or moving them to a different location, and then observing if they correct for the direction once released. These experiments are only able to provide information on the direction of departure and not on what happens during the actual migration. More recently, tracking studies provide detailed location data, but there was, until now, no way to find what geomagnetic conditions animals experienced during the migration and how they reacted to these conditions. Implementing MagGeo in a way that will allow a broader community of ecologists access geomagnetic information will therefore, for the first time, allow study of geomagnetic navigational behaviour in the wild.

- *Expected user community*

The target user group are movement ecologists who study animal migration. This spans almost the entire movement ecology community, since migration is a common behaviour found in terrestrial, aerial and marine realms. Ecologists are also at the forefront of publishing and sharing data – their main data portal, Movebank.org, contains data from thousands of researchers, and these are the users that we are targeting with our tool. Movebank currently holds over 6.1 billion animal locations from 200,000 animals of over 1300 species, where 11 million new data points are added each day. MoveApps (see output 2) were designed to support analysis of these data. In addition, this target community is also growing, since recent miniaturisation of tags means that much smaller animals can be tagged. For example, most of migratory birds are small and could not be tagged until miniature tags, such as ICARUS tags (Krondorf et al. 2022) came to the market. This means that more researchers will now be able study migratory navigation of their chosen (small) species and our tool will provide access to geomagnetic data to this growing user group.

- *References*

Benitez Paez F, Brum Bastos VdS, Beggan CD, Long JA and Demšar U, 2021. Fusion of wildlife tracking and satellite geomagnetic data for the study of animal migration. *Movement Ecology*, 9:31.

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