

Topical Discussion Meeting report

[Template]

A Topical Discussion Meeting aims at active participation or interaction between the participants. The participants work and discuss on a predefined theme or problem heading towards an outcome or target. A working meeting is a 1h informal afternoon meeting with NO abstract submission form and therefore NO poster contributions.

Name of the meeting: TDM5 ESA Space Weather Modelling Roadmap

Convener/s: Stefaan Poedts, Maria Elena Innocenti, Jorge Amaya

Secretary: Jorge Amaya

Date – Time – Room: October 28th, 2025, 17:00 – 18:00, Studion

of attendees (approximate): 40+

Speakers, if any (names and institution):

Panellists:

Rui Pinto – IRAP/CNRS

Jens Pomoell – University of Helsinki

Christian Möstl - GeoSphere Austria, Austrian Space Weather Office

Form of TDM: ~~Event Impact~~ | **Panel Forum** | ~~Service/Project Feedback~~ | ~~Other~~

Objective of the TDM

The TDM5 session aimed to gather inputs from the community for the compilation of a roadmap for space weather modelling over the next decade and beyond. The roadmap will focus on bridging current gaps in data, modelling approaches, and community integration. The session sought to identify needs and requirements to enhance model accuracy, operational readiness, and resource allocation for the advancement of space weather prediction capabilities

Discussion highlights

The TDM5 session convened experts to address the evolving landscape of space weather modelling, emphasizing the necessity for more real-time data and the integration of new missions such as ESA SHIELD. Participants highlighted the critical need for additional in-situ measurement points, recognizing that while remote sensing (e.g., PUNCH mission) offers partial solutions, in-situ data remains indispensable for model precision. The ESA mission SHIELD was highlighted as a very interesting and useful opportunity. The discussion underscored persistent challenges in uniting the solar and planetary modelling communities, citing differences in language, tools, and resources as barriers to effective collaboration.

A recurring theme was the imperative to close gaps between different modelling approaches, particularly by integrating more real data into physics-based models and leveraging artificial intelligence and machine learning (AI/ML) to enhance these frameworks. The group acknowledged that the proliferation of models and data necessitates increased resources, and that real-time data storage presents logistical difficulties. It was noted that models, predominantly forward in nature, accumulate errors, and efforts must focus on identifying and reducing them.

Time dependence in modelling was identified as an emerging trend, with ensemble modelling for active regions cited as a promising avenue. However, the inclusion of more physics in models often results in slower computation, raising questions about operational feasibility. The consensus was

that limitations are more closely tied to pipeline creation than to the underlying physics, and that ensemble approaches, already successful in weather forecasting, could be adapted for space weather with sufficient resources.

The interplay between empirical and physics-based models was explored, with the suggestion that these paradigms may eventually converge as empirical models grow more complex and physics-based models become faster. AI/ML was recognized as a tool for optimizing processing chains and parameterizing physics-based models, though its effectiveness is constrained by the availability of high-quality data. The potential of physics-informed AI to surpass traditional models in accuracy was discussed, alongside the caveat that AI/ML solutions are typically limited by their training data and may lack generalizability.

Participants drew parallels with the evolution of weather forecasting, noting that space weather modelling currently faces similar challenges to those encountered in meteorology two decades ago. The concept of digital twins was proposed as a future direction, though the creation of fully coupled model chains remains a formidable challenge. The group emphasized that space weather differs fundamentally from terrestrial weather, particularly in terms of data availability and process complexity, and that resource constraints are more pronounced.

Uncertainty quantification (UQ) emerged as a central concern, with the recognition that, unlike in weather forecasting, space weather models often lack well-defined error bars. Progress in UQ was acknowledged, but the need for greater computational power and investment was stressed. The feasibility of “backward propagation” studies was debated, with the consensus that such approaches are limited by the scarcity of measurement points and the need for robust magnetic field models.

The discussion also addressed the risks associated with data access, particularly the reliance on critical datasets such as NOAA solar wind data. The potential for alternative data sources, including ground-based reconstructions and open data initiatives from China, was considered. The idea of deploying satellites in strategic orbits to achieve comprehensive coverage was raised, though practical constraints were noted.

Data assimilation was identified as a valuable but underutilized technique, and the importance of providing both quiet and active time forecasts to end users was emphasized. The group agreed that reduced models, trained on full physics-based simulations, could offer practical benefits. The necessity of combining AI and physics-based approaches was reinforced, with the expectation that a competitive ecosystem of models would drive progress.

Finally, the session concluded with a call to view the challenge not solely as a modelling problem but as a community endeavour, requiring coordinated resources, training, and the cultivation of new talent.

Main conclusions of the meeting

1. The advancement of space weather modelling over the next 10 to 15 years hinges on the integration of diverse data sources, the convergence of physics-based and AI/ML approaches, and the systematic reduction of uncertainties.
2. Managing uncertainties can be achieved by integration of data from new missions, systematic use of data assimilation in models, integration of advanced AI/ML techniques, ensemble scenario evaluation, and tracking of systemic error propagation between models.
3. Achieving operational readiness will require significant investments in computational resources, data accessibility, and community coordination, with an emphasis on training and

interdisciplinary collaboration.

4. The community must prioritize the development of robust, adaptable models and foster an environment where innovation in both methodology and infrastructure is actively supported.

Annexes

The exact notes of the meeting with detailed discussions can be found in the recorded video, or can be requested to the conveners.