Topical Discussion Meeting report

Name of the meeting: Present and future of hybrid physics-data-driven approaches in space weather forecasting applications
Convener: Sabrina Guastavino
Secretary: Francesco Marchetti
Data – Time – Room: 22/11/23, 11:45 – 12:45, Guillaumet Room
Nr of participants: about 60
Form of TDM: Panel forum

Objective of the TDM

The purpose of this topical discussion meeting is to discuss opportunities from, and limitations of, physics-driven machine learning, aiming toward a constructive debate and potential future courses of action.

Discussion highlights

The discussion begins with the convener introducing the speakers.
Panellist members:

- Michele Piana. Affiliation: Department of Mathematics, University of Genova, Italy
- Manolis K. Geourgeoulis. Affiliantions: Johns Hopkins University Applied Physics Laboratory, Maryland, USA and RCAAM of the Academy of Athens
- Enrico Camporeale. Affiliation: Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, CO, USA
- Veronique Delouille. Affiliation: Royal Observatory of Belgium, Belgium

In addition, the convener gave a brief presentation of the topic and some possible discussion questions. In detail, the main questions are the following two

How to plug physics in ML?

- physics-based loss design
- data interpretability
- network structures

How to embedd ML in physics-based models?

- estimation of parameters
- data engineering
- improving physics-based models by learning

A possible list of space weather applications has been listed: active region classification, flare forecasting, flare nowcasting, prediction of Time-of-Arrival (ToA) and Speed-of-Arrival (SoA) for coronal mass ejections (CMEs), prediction of space weather impact on the magnetosphere, identification of correlations between coronal holes and solar wind transients.

We report below some of the highlights of the discussion.

Manolis K. Georgoulis: Physics in itself needs to be codified: from magnetic field to coded data and metrics, that depend on large parameter spaces. Then you need to distinguish between flaring/no-flaring regions in time, which is complicated, therefore machine learning helps. But extreme events are really rare, so machine learning is in trouble and not really interpretable very often. That's why we need physics

Enrico Camporeale: go beyond physics vs ML, that is in reality also physics models are somehow black box because they are complex and approximated via many parameters.

Veronique Delouille: PINN take into account physics into ML and it works, with geomagnetic storms you can use ML in quite times and switch to the model during the storm.

Michele Piana: with FLARECAST, we realized that the number of features that matter is small. If you account for physics, what will happen? More parameters or less parameters will be involved? It is also important to agree on how to validate our approaches, construction of implementation paradigms. We could try to use ML to unveal new physical models, or to constrain physical parameters.

Audience:
- Indeed we are approximating our systems: the math is good enough for incorporate physics? Well, ML can provide some uncertainty quantification that helps in dealing with this. For sure we could add errors to our ML models to be more realistic

- PB-ML is exciting, but the approximation of certain quantities should be related to the uncertainty quantification of other parameters. This is really promising.

- PINN are good because they can actually deviate and escape from PDE that might be not really effective in some situations. They allow to get rid of some preprocessing needed in numerical simulations (e.g. adjust boundary conditions)

- Pay attention to correlated features generated by physics-based procedures. On the other hand, indeed when you have a ML model that takes as input features of different dimensions, what are they really doing?

- Using physics-based features then you could drive your attention to related tasks (e.g. regression of energy data in place of classification)

- In cardiology they use DL to constrain parameters in Navier-Stokes, is there something similar for MHD in space forecasting? MHD is an incomplete set, not complex enough. But at the same time, few data are at disposal to include large sets of physical equations.

- Statistical potential is also high in driving the definition of flares and properties related.

- Exploit as SW community the fact that ML communities are hungry for applications

Main conclusion of the meeting

We report the main conclusions in the following four messages.

- Try to do what is done in different areas, that is validation paradigm that are shared to evaluate algorithms, and if they are not good understand why

- AI never replace scientist, scientist using AI will replace scientist, so become fluent in AI

- AI is important in constructing projects, so get in touch with an expert, it is fundamental in some aspects

- We need infrastructure: benchmark datasets. We are in an era of pluralism and the general landscape is not clear. We should avoid the fact that pluralism becomes cachophony, let us agree on experiments to compare numbers.

Annexes

Minutes of meeting: 62 min
Panelists: Manolis Georgoulis, Enrico Camporeale, Veronique Delouille, Michele Piana
Number of participants: about 60

The introductory presentation is attached to the paper.

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MIDAgroup

Topical Discussion meeting

Organizers:

Sabrina Guastavino & Francesco Marchetti

European Space Weather Week 2023 (ESWW23), Tolouse

November 20-24th, 2023

Università di Genova

Panellists

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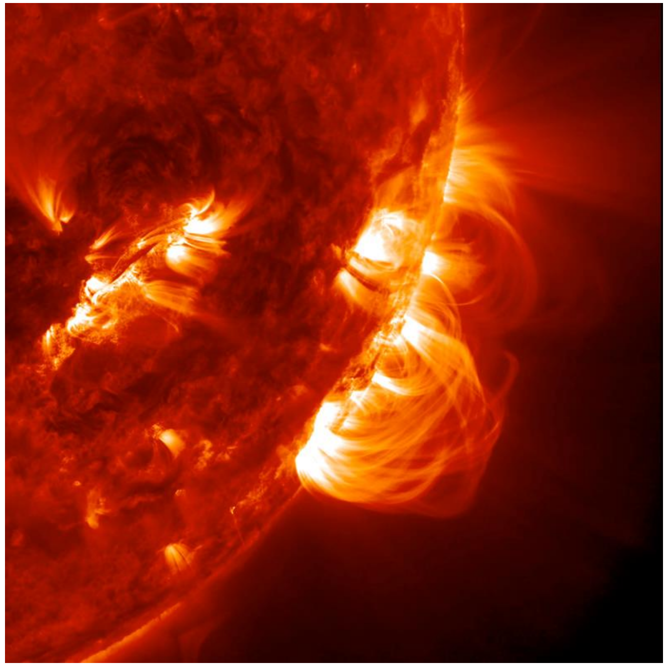
How to forecast space weather events?

Two main courses of action:

- **Physics-based approach**: physical models, as magnetoidrodynamics (MHD) equations, are used to simulate the behaviour of such events



- **Data-driven approach**: artificial intelligence which learns to predict space weather events from historical data archives

Promising approach

Physics-driven artificial intelligence

Discussion points

- Pros and cons of physics-based and artificial intelligence methods
- Opinion on physics-driven AI techniques

How to plug physics in ML?
- physics-based loss
- data interpretability
- network structures

Keywords:
- Physics-informed ML
- Physics-driven ML
- Explainable ML models

How to embedd ML in physics-based models?
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Space weather applications:

active region classification
flare forecasting
flare nowcasting
prediction of Time-of-Arrival (ToA) and Speed-of-Arrival (SoA) for coronal mass ejections (CMEs)
prediction of space weather impact on the magnetosphere,
identification of correlations between coronal holes and solar wind transients.