Neural network modeling of solar- and atmospheric-driven ground magnetic perturbations at mid-latitude

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Introduction

Ground magnetic measurements made at magnetic observatories measure a superposition of magnetic fields from several sources, e.g.,

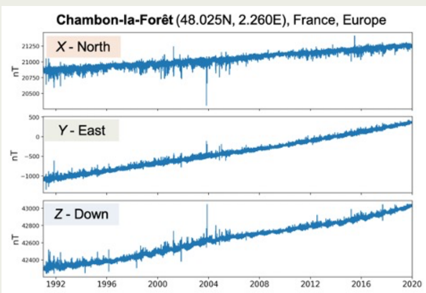

Fig 1. Magnetic measurements over 1991 – 2019 at the magnetic observatory Chambon-la-Forêt (CLF).

- Earth's intrinsic magnetic field, or "main field", accounting for the secularly increasing variation.
- Solar-quiet (Sq) current systems powered by the solar irradiance.
- Complex solar-magnetospheric-ionospheric coupling, e.g., via auroral and equatorial electrojets at high- and low-latitudes, respectively.

Magnetic activity indices derived from ground magnetic observatories measure the intensity of the Sun-magnetosphere-ionosphere and neutral atmosphere coupling. The *Kp* index derived from several mid-latitude observatories has been the most widely used for space weather operation. However, its time cadence (3h) and intensity scale (0 to 9) are rather crude. Moreover, it is challenging to determine a 'baseline' representative of the quiet variations in the absence of solar storms.

The problem: depending on how the 'baseline' is defined, the **magnetic activity indices** can *overestimate* or *underestimate* the intensity of the perturbations, with serious impacts in operational space weather.

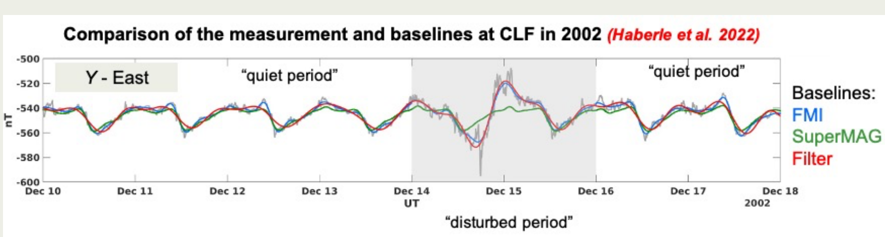

Fig 2. Example of magnetic measurements at CLF on Dec 10 – 18, 2002, and the baselines representative of quiet variations for the east component.

Prior work: the filter baseline

In an effort to derive a new magnetic activity index, **Haberle et al. (2022)** proposed to decompose the magnetic measurements to determine a baseline:

$$f_{FB} = f_{>24} + f_D$$

Above-diurnal filter

Dominated by the secular variation due to change of Earth's intrinsic magnetic field (Fig 1) and perturbations of solar origins.

Daily filter

Dominated by the solar-quiet (Sq) variations owing to Sq current in the ionosphere and tidal waves.

The filter baseline represents the quiet periods (in the absence of solar storms) rather well. However, during the perturbed periods, the filter baseline varies with the storm variations. Thus, the perturbation intensity can be underestimated similar to the FMI method (Fig 2).

Scope & Goal

To derive a robust magnetic activity index, as a first step, we consider:

- How can we model the intensity of ground magnetic perturbations owing to the solar- and atmospheric-origins?
- How can we define a baseline that robustly represents the quiet variation for both quiet (no solar storms) and disturbed periods?

We focus on magnetic data from CLF, France, Europe, at mid-latitude.

Methodologies

We consider applications of artificial neural networks to model the filter data from CLF (Fig 1). Two workflows (Fig 3) are developed. Using data from 1995 onwards, we train the neural networks using the walk forward training (Fig 4). Our independent parameters include:

- Solar wind, interplanetary field (IMF), F10.7 data upstream of Earth
- Geometrical data: the solar azimuth, solar longitude, and local time

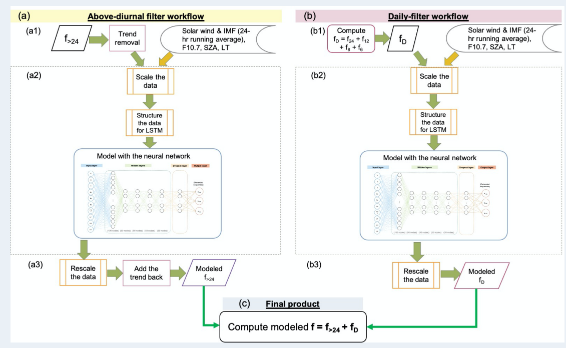

Fig 3. Workflow diagram for (a) the above-diurnal filter and (b) the daily filter to finally reproduce (c) the original filter data.

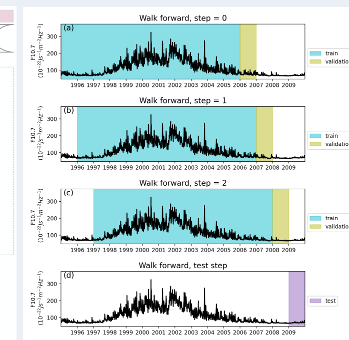

Fig 4. The model is trained and validated in several steps leading up to the test.

Key results

We show the modeling results for a quiet period and an active period of solar activities in 2009 (Fig 5) and 2012 (Fig 6), respectively. The modeling results using the neural networks show excellent agreement with the original filter data with high Pearson correlation coefficients (Pcc).

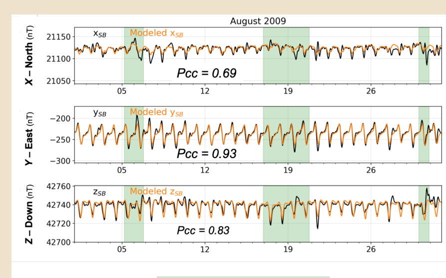

Fig 5. Comparison between the original FB (black) and modeling results (orange) in August 2009.

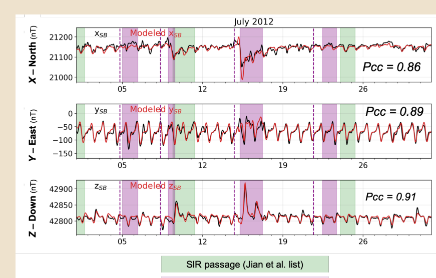

Fig 6. Comparison between the original FB (black) and modeling results (red) in July 2012.

To model the baseline that does not vary with geomagnetic storms, we consider excluding the solar wind and IMF data in our independent parameters for the neural networks. Fig 7 shows our modeling results.

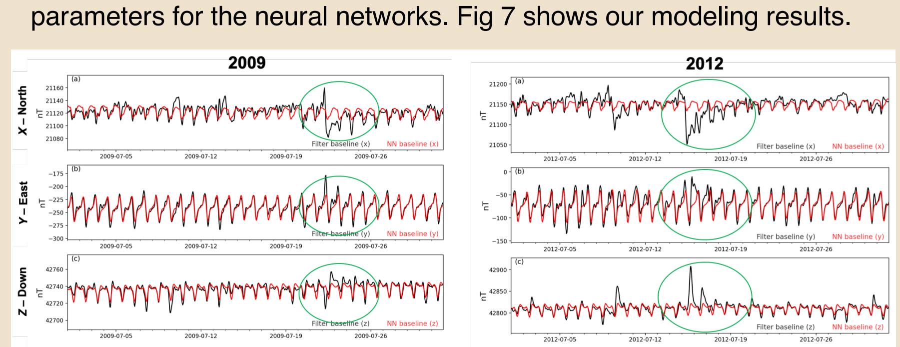

Fig 7. Comparison between the original FB (black) and our "baseline" (red) modeled using the neural networks when excluding the solar wind and IMF. Green circles mark geomagnetic storms; our baseline remains insensitive.

Summary

We demonstrate that neural networks can be used to model solar- and atmospheric-driven perturbations modulated by daily and seasonal variations as recorded at a ground magnetic observatory.

It can also be adapted to model the quiet variations when excluding the solar variabilities with important applications in the calculation of magnetic activity indices.

See our full work at:

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