Magnetopause and bow shock models with machine learning

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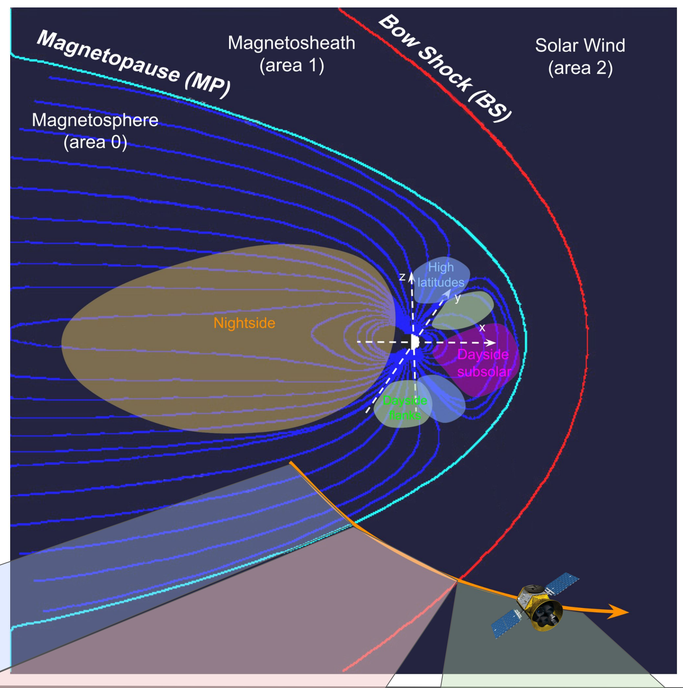
1 - Magnetopause and Bow Shock, Analytical models make assumptions

- Magnetopause (MP) : frontier between the magnetopshere and the interplanetary medium.
- Bow Shock (BS) : limit where the solar wind starts to be influenced by the Earth's magnetic field.

The MP and BS are very important to model because



Analytical models are :

- Fast
- Easy to use

BUT

They assume:

- Symetries
- No inter-correlation between parameters

Machine Learning models allow us to remove these assumptions.

We can use machine learning because we now have huge amounts of data.

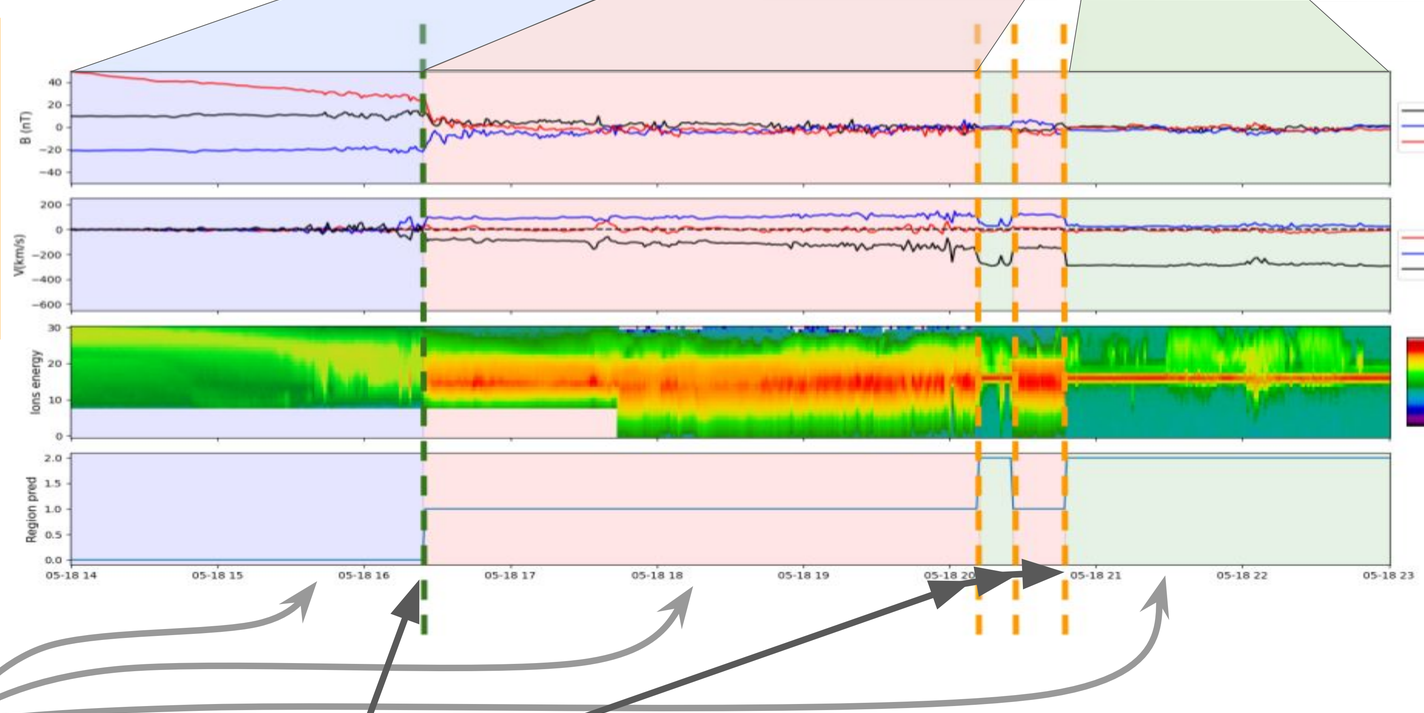
2 -New BS and MP models from machine learning, pipeline

I) Gather data from satellites with different orbites: Themis, MMS, Cluster, Double Star, Geotail, IMP8 & Artemis

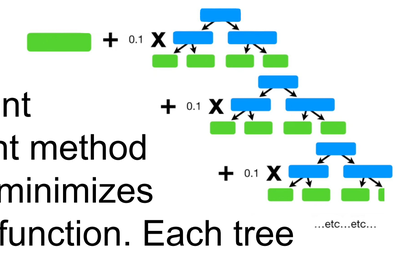
II) Predict the region (SW, MSH or MSP) on this data, with a Gradient Boosting Classifier (Nguyen et al., 2022)

III) Detect crossings (change of regions) (Michotte de Welle et al.) This gives **~20 000 BS** crossings and **~ 30 000 MP crossings.**

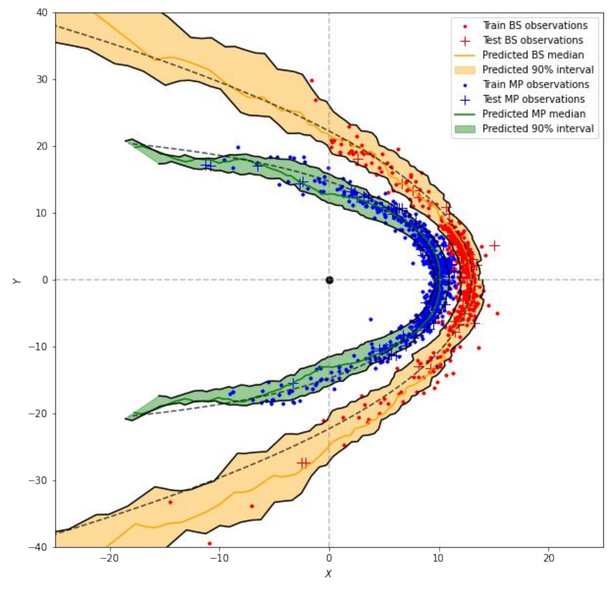
III) Build a database with the position of the crossings and the corresponding solar wind.
The features are : theta, phi, Pd, Ma, Np. Tp, Pm, Bx, By, Bz, B, Vx, Vy, Vz, V, COA, CLA, tilt. Predicted value : R.
& **Fitting of the model**



GRADIENT BOOSTING



Gradient descent method which minimizes a loss function. Each tree approaches the residuals between dataset and predictions at the previous iteration.

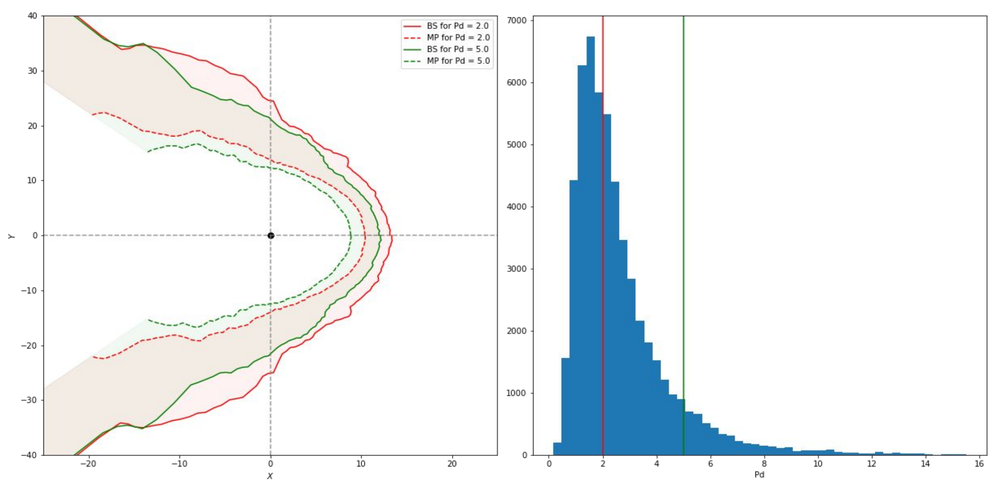


3 - Results

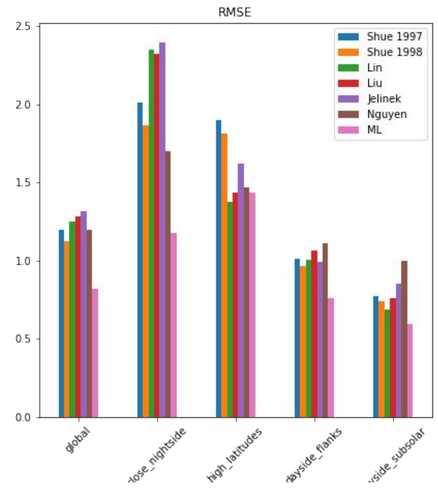
Achieved goal : Predict both frontiers depending on upstream solar wind data, by making less assumptions.

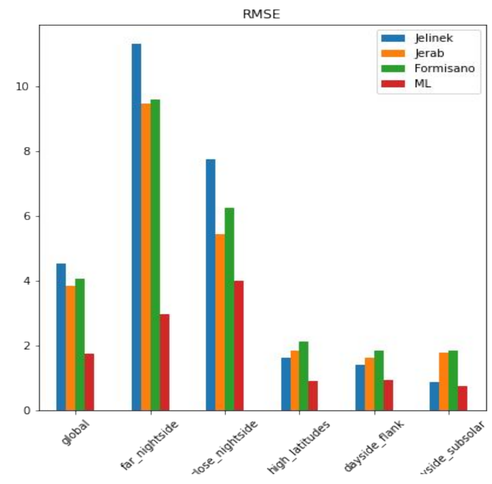
BS and MP for mean solar wind conditions:

Bx	By	Bz	Np	Vx	Vy	Vz	Tp	Pd	Beta	Ma	B	V	COA	CLA	time	sat	tilt	Pm
2.57	-3.59	4.08	8.18	-391.3	33.294685	-11.388099	98138.0	2.53	1.31	7.3	6.011605	392.879037	1.129064	-0.7216	2017-10-21 15:48:00	MMS	-0.015888	0.014379

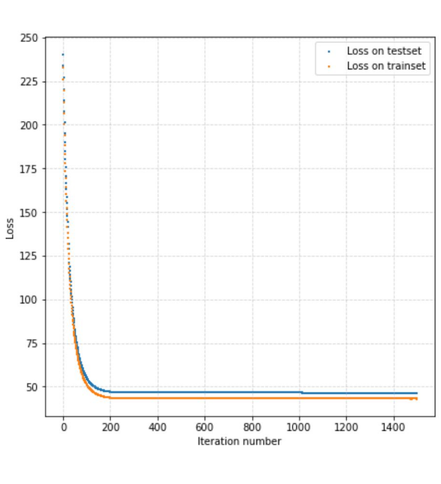


We have **better RMSE than analytical models.**





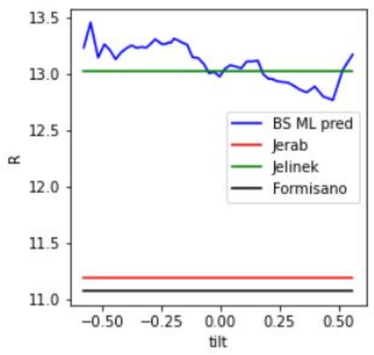
We have a robust model



Having made no assumptions allows us to see effects that are interesting but still to check and investigate.

→ A dependance on new parameters. It seems that the tilt of the dipole could have an effect on the shape of the frontiers. (Lu et al., 2019)

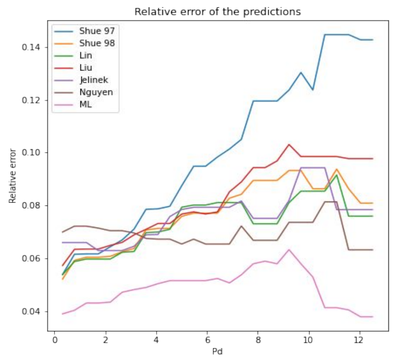
Position of the Bow shock at the subsolar point



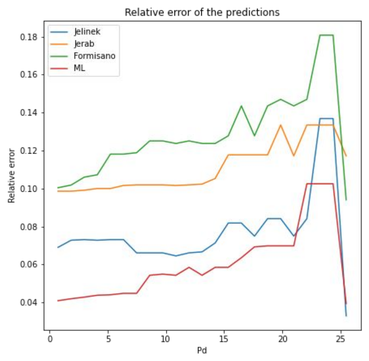
→An asymmetry between quasi-parallel and quasi_perpendicular sides of the bow shock : the quasi-perpendicular side seems slightly farther from the Earth. (Walsh et al., 2012)

→Good validity of our model on a wider range of parameters. This can be due to a broader dataset or to the use of machine learning. We should fit again analytical models with our new complete dataset of crossings.

Magnetopause



Bow Shock



4 - Perspectives

Gives a more accurate shape and position of the MP and BS. This allows to know better the position of satellites compared to the frontiers and thus a better normalization. Useful for example in the work of Michotte de Welle et al, In review. (cf talk Michotte de Welle et al.).

5 - References

Jerab et al., 2005; Jelinek et al., 2012; Formisano et al., 1979; Shue et al., 1997; Shue et al., 1998; Lin et al., 2010; Liu et al.,2015; Nguyen et al., 2021; Nguyen et al., 2022; Wang et al., 2013; Walsh et al., 2012; Lu et al., 2019; Michotte de Welle et al., In review