



FLARECAST



TESTING PREDICTORS OF ERUPTIVITY USING PARAMETRIC FLUX EMERGENCE SIMULATIONS

<http://flarecast.eu/>

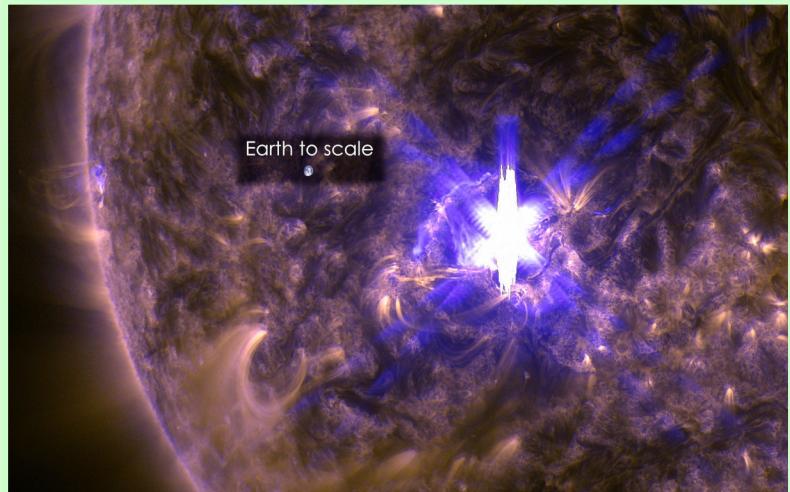
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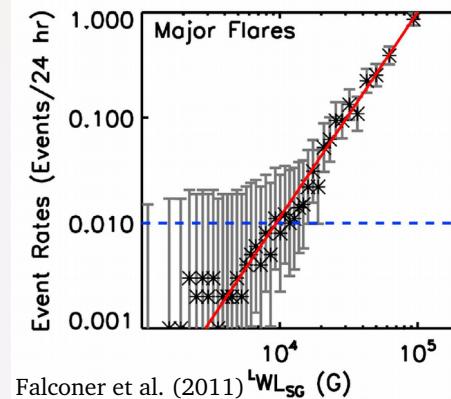
Eruptivity predictors

Solar flares → correlated with size and complexity of Active Regions



Flare prediction → Empirical variation of magnetic parameters

$$WL_{SG} = \int (\nabla B_z) dl$$



- But ...**
- None of these parameters provided a clear eruptivity criterion
 - The predictability of the parameters has been only barely tested on simulations

Objectives :

Testing the reliability of the magnetic parameters used in flare predictions, using parametric MHD simulations

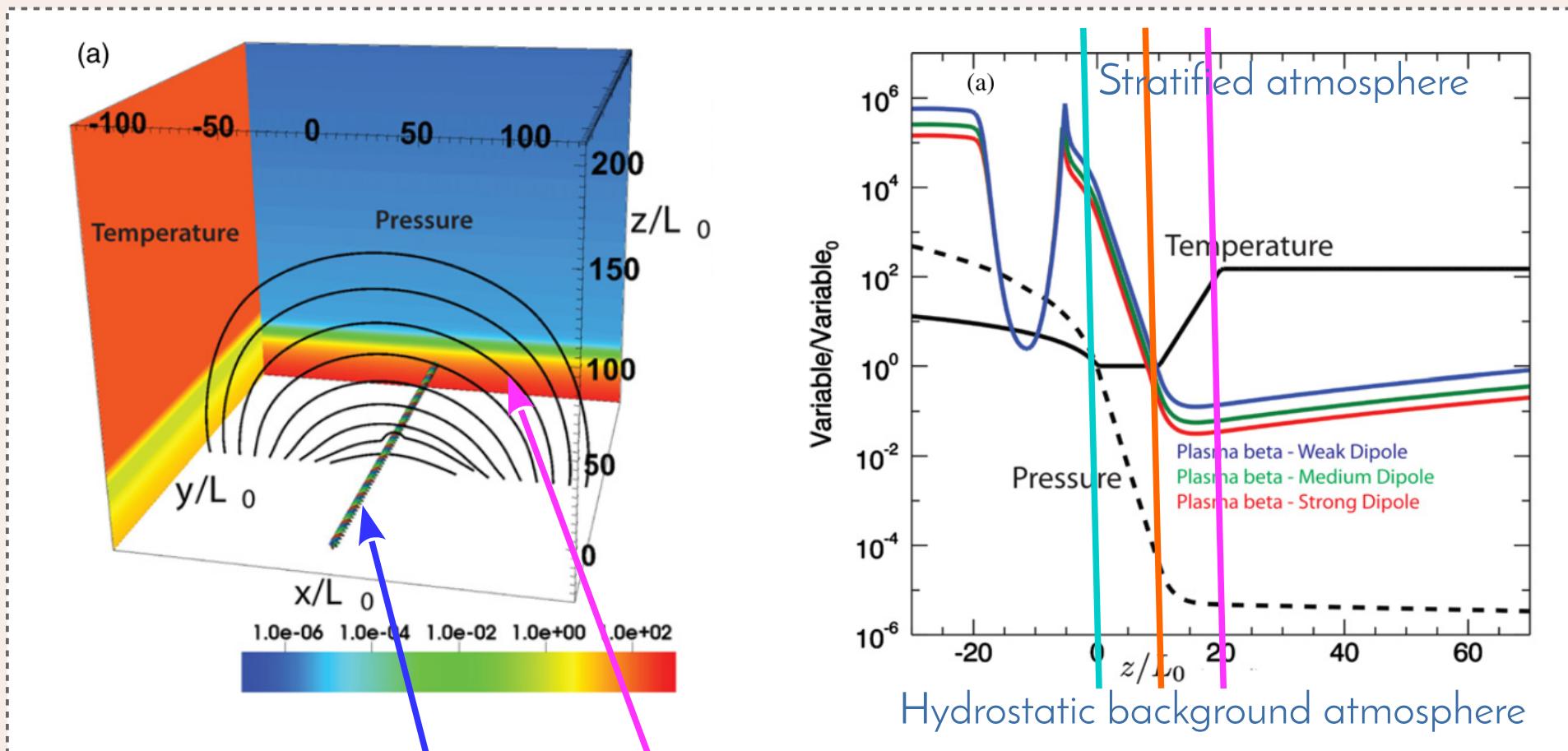
MHD Parametric Simulations



Flux emergence 3D visco-resistive simulations

in a stratified atmosphere + coronal arcade

Leake et al (2013, 2014)



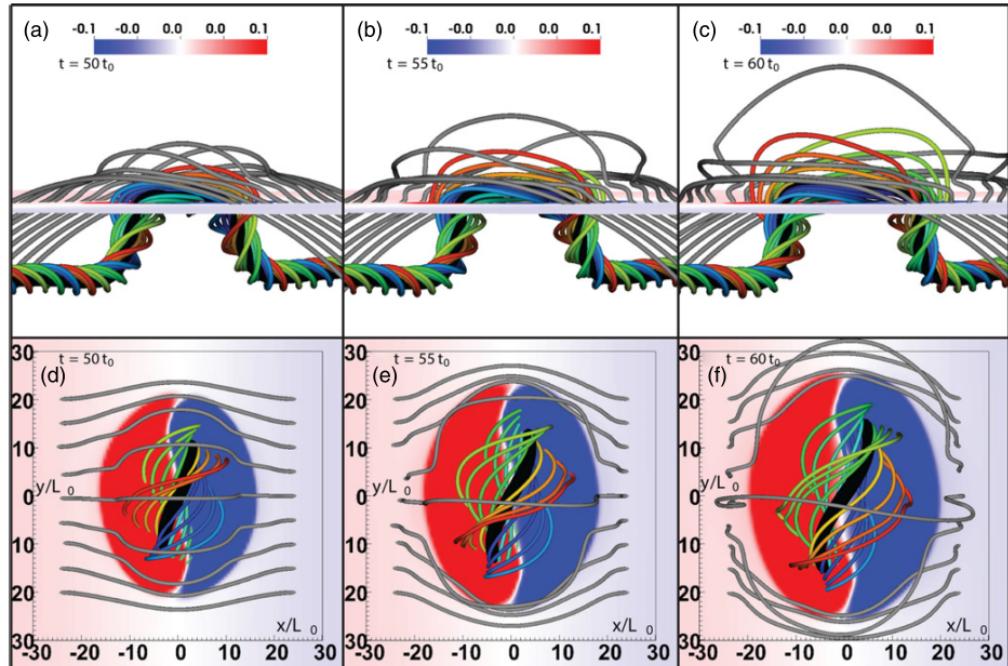
Twisted flux tube superimposed
in the convection zone

Coronal magnetic dipole

MHD Parametric Simulations



Parametrization of the simulations



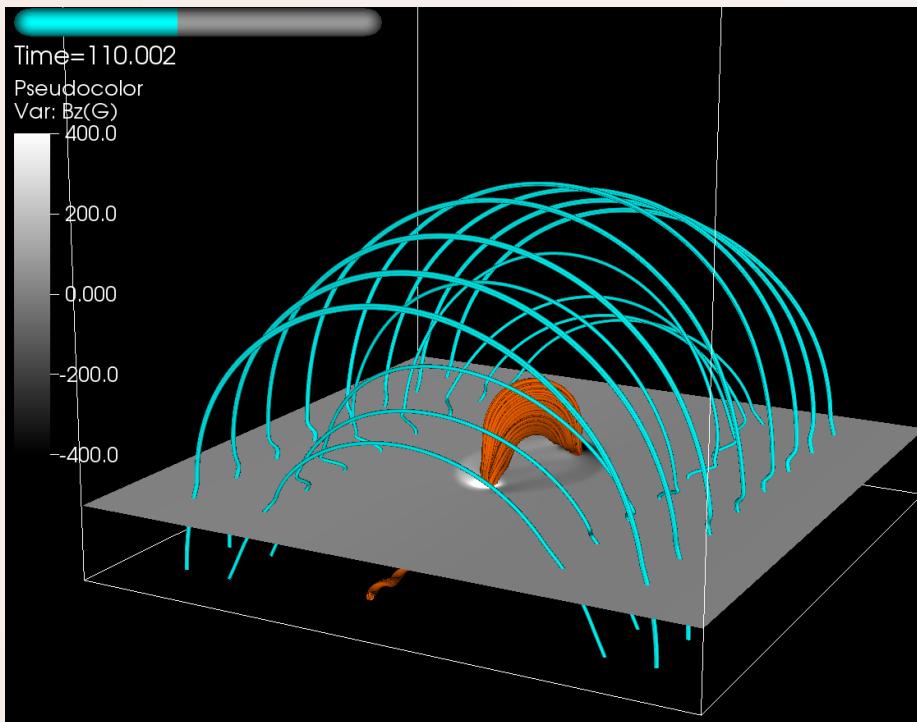
- **Orientation** of the dipole:
 - favoring magnetic reconnection
- **Strength** of the dipole:
 - Strong (SD) - 26 G
 - Medium (MD) - 19.5 G
 - Weak (WD) - 13 G
 - No Dipole (ND) (Max B at $z = 0$)

Eruptive and non-eruptive simulations only differ by the dipole orientation, favoring or not reconnection
Dipole strength only impacts trigger time in eruptive cases

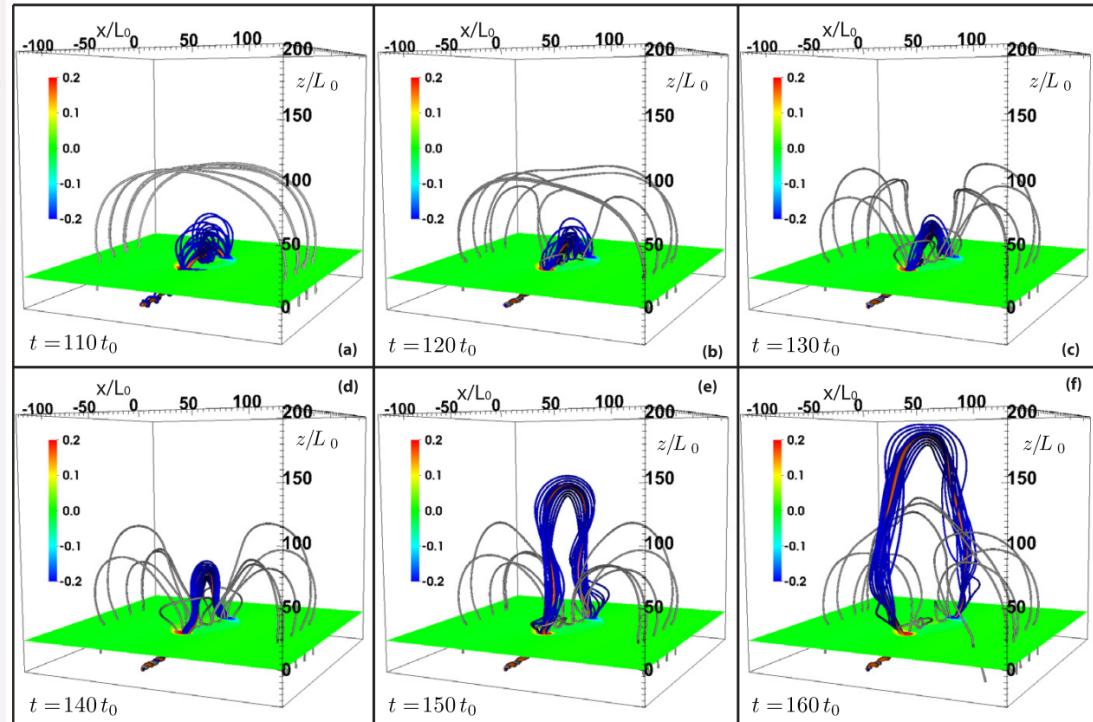
MHD Parametric Simulations



4 non-eruptive simulations



3 eruptive simulations



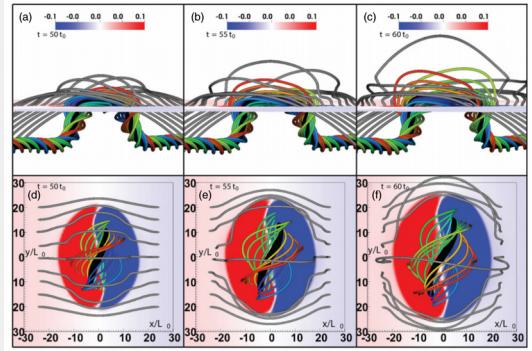
Parametric simulations: **orientation** and **strength** of the coronal arcade is varied

Eruptives vs. non-eruptive simulations: **orientation** du dipole → favor the **magnetic reconnection process** or not

Dipole **strength**: only slightly impact the eruptive flare **trigger time**

Simulation Analysis

We analyse the simulations as real data



1.

3D MHD simulations +
time evolution

2.

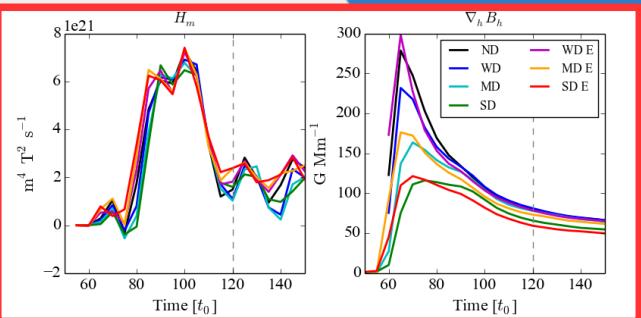
Magnetogram
time series for
each simulation

4.

Time evolution of
predictors for the 7
simulations

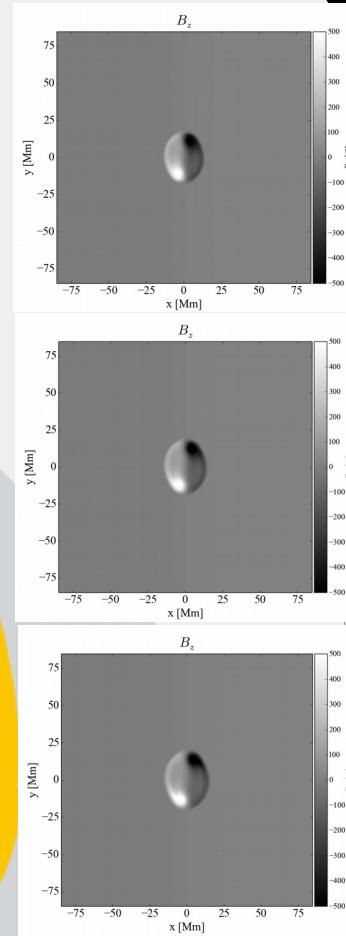
Computation of
magnetic
parameters
(~100)

3.



X 7 simulations

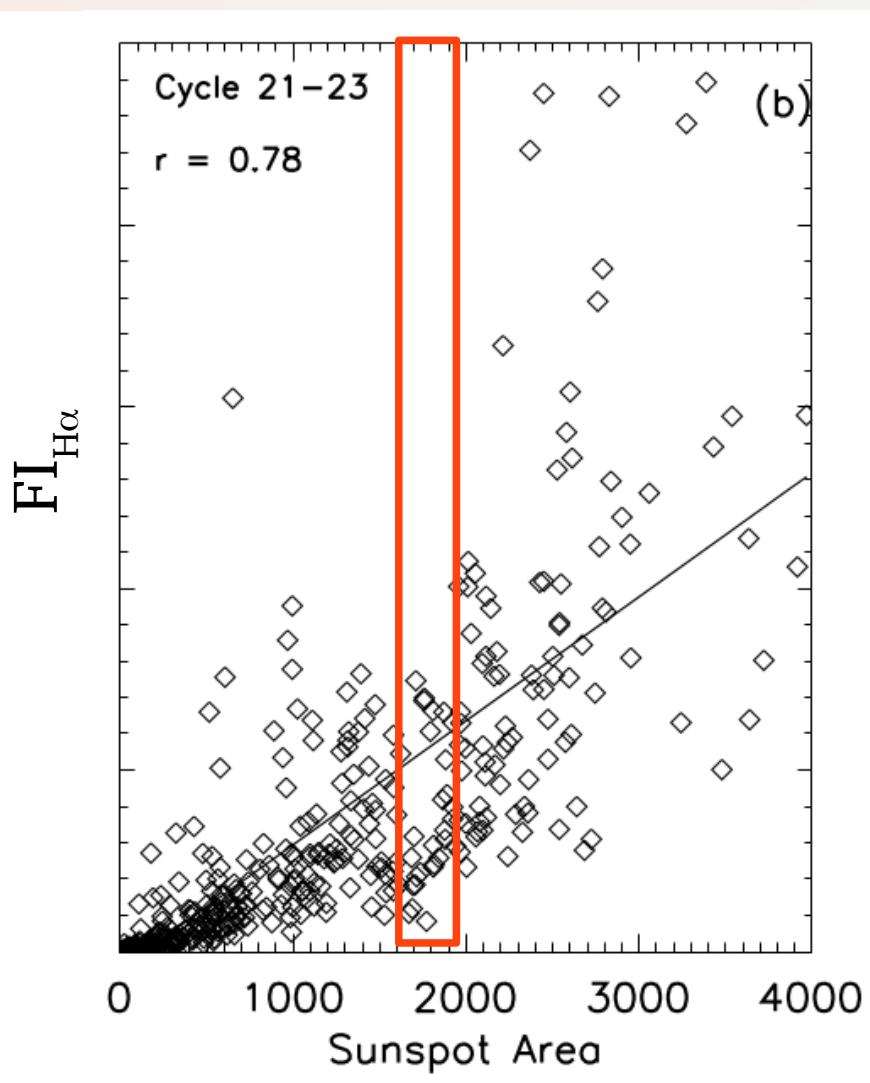
Strong Dipole (SD, SD E)
Medium Dipole (MD, MD E)
Weak Dipole (WD, WD E)
No Dipole (ND)



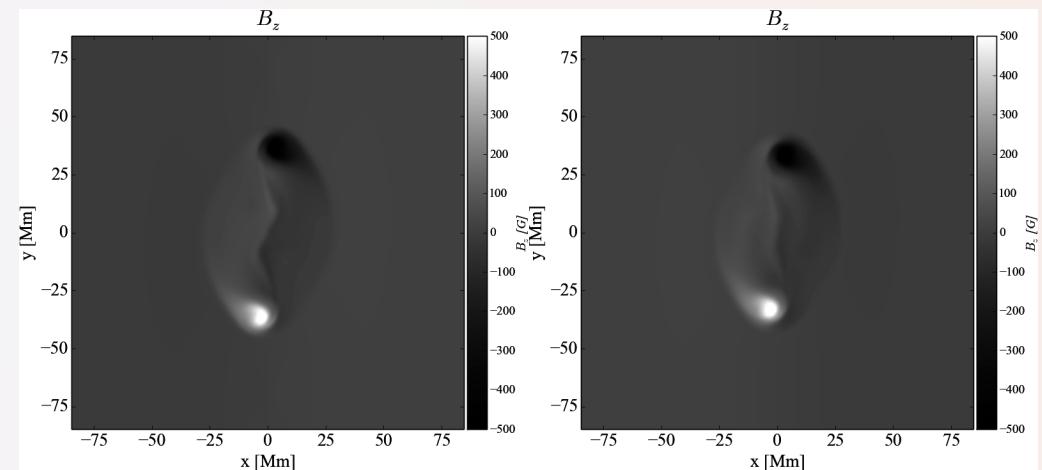
Limitations



Flaring index correlated with Active Region size



Our simulations:
Similar size → similar flux → very similar magnetograms



→ Very similar case study.
But we can still investigate the potential differences observables between eruptive or quiet ARs

Tested & Developed Parameters



Magnetic Field

$B, B_z, B_h, B^{pot}, B_z^{pot}, B_h^{pot}$,

Gradients : $\nabla_h B, \nabla_h B_z, \nabla_h B_h$

Fluxes : $F_{tot}, F_{net}, F_+, F_-$

Free energy: r_e (Leka 2003)

Magnetic helicity : H_m (Pariat 2009)

Polarity Inversion Line properties (PIL)

$L_s, L_{ssm}, L_{sgm}, WL_{ss}, WL_{sg}$ (Falconer 2008)

L_{sc}, WL_{sc} ----- **NEW** -----

$L(\Psi > 80^\circ), L(\psi > 80^\circ)$ (Leka 2003)

R value (Schrijver 2007)

Magnetic field geometry

Inclination angle: γ

Twist parameter: α

Shear angles: ψ, Ψ

$A(\Psi > 80^\circ), A(\psi > 80^\circ)$
(Leka 2003)

Currents

$J_z, J_z^{ch}, J_z^h,$

$I_{tot}, I_{net}, I_+, I_-$

I_{direct}, I_{return}

(Leka 2003)

Lorentz forces

F_x, F_y, F_z, F

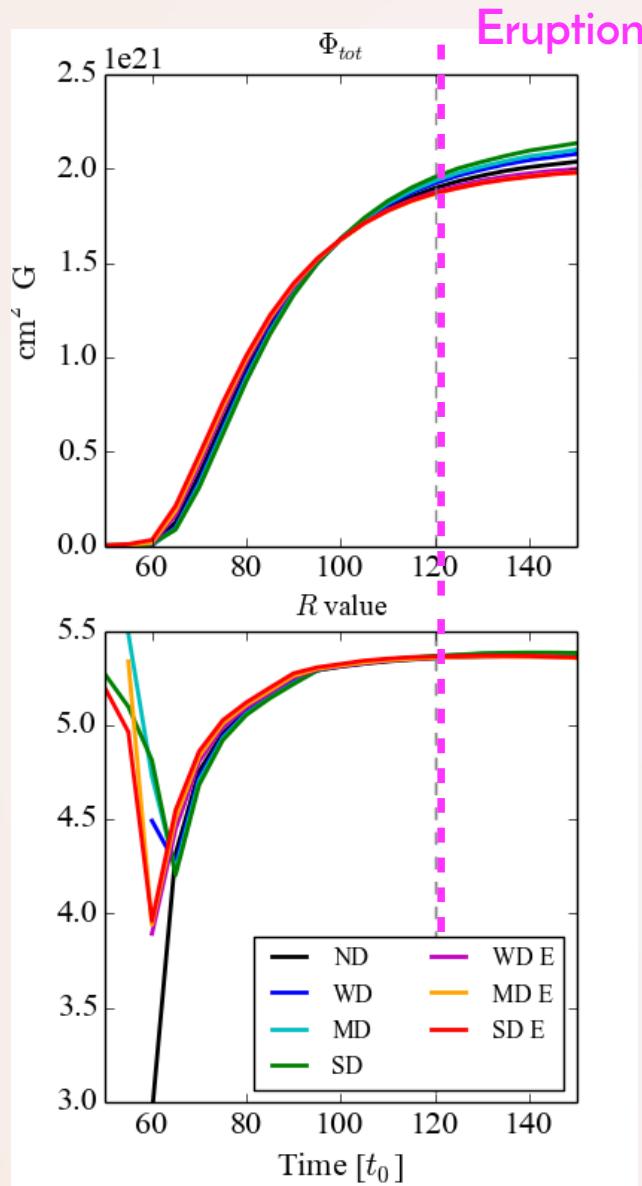
$\delta F_x, \delta F_y, \delta F_z,$

(Fisher 2012)

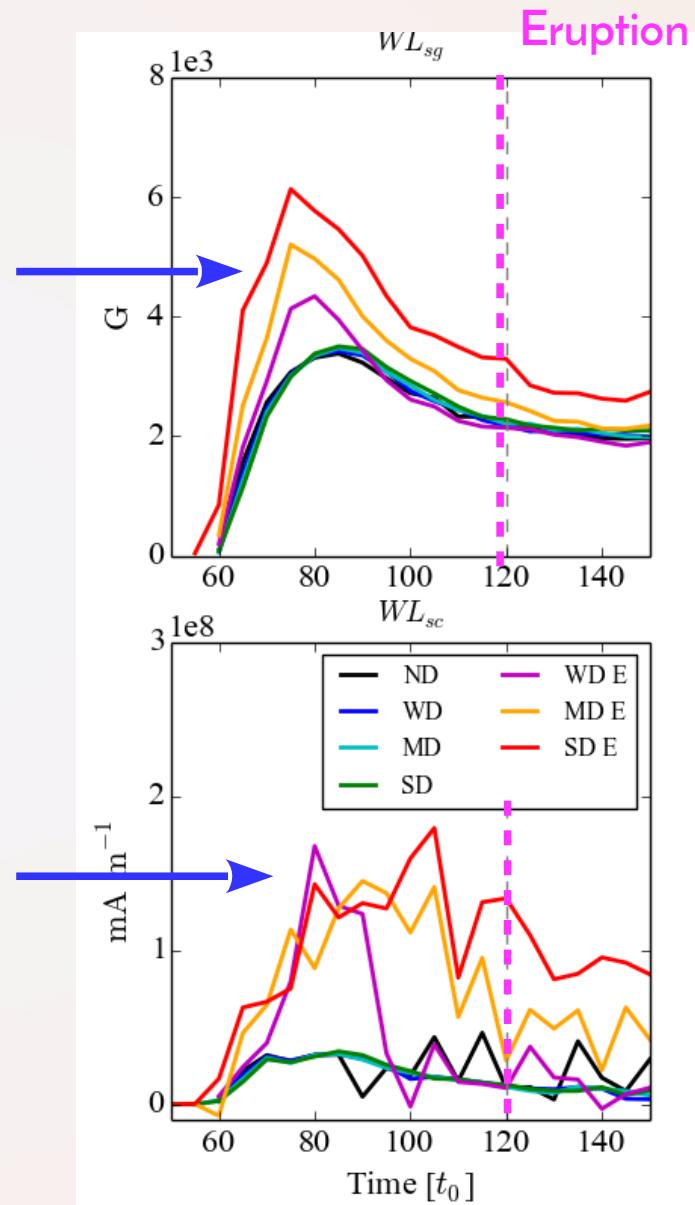
For each parameter X, the four moments $\mu(X), \sigma(X), \varsigma(X)$ et $\kappa(X)$ are also computed, averaged over the whole AR

Looking for one or more parameter able to **discriminate** the **ERUPTIVE** and **STABLE** simulations,
i.e. different behavior as a function of the eruptive nature, using **ONLY** 2D surface
magnetograms, and **BEFORE** the eruptions.

Pre-eruptive signatures : What we are looking for?



Same behavior for all the simulations



Different behavior, according to the eruptive/stable nature of the simulations

Pre-eruptive signatures



99 parameters → **only the 6 parameters related to the PIL** show a detectable eruptive signature

$$L_{ss} = \int dl_{\text{MPIL}}, \text{ with } B_h > B_h^{th}; \psi > \psi_{th}$$

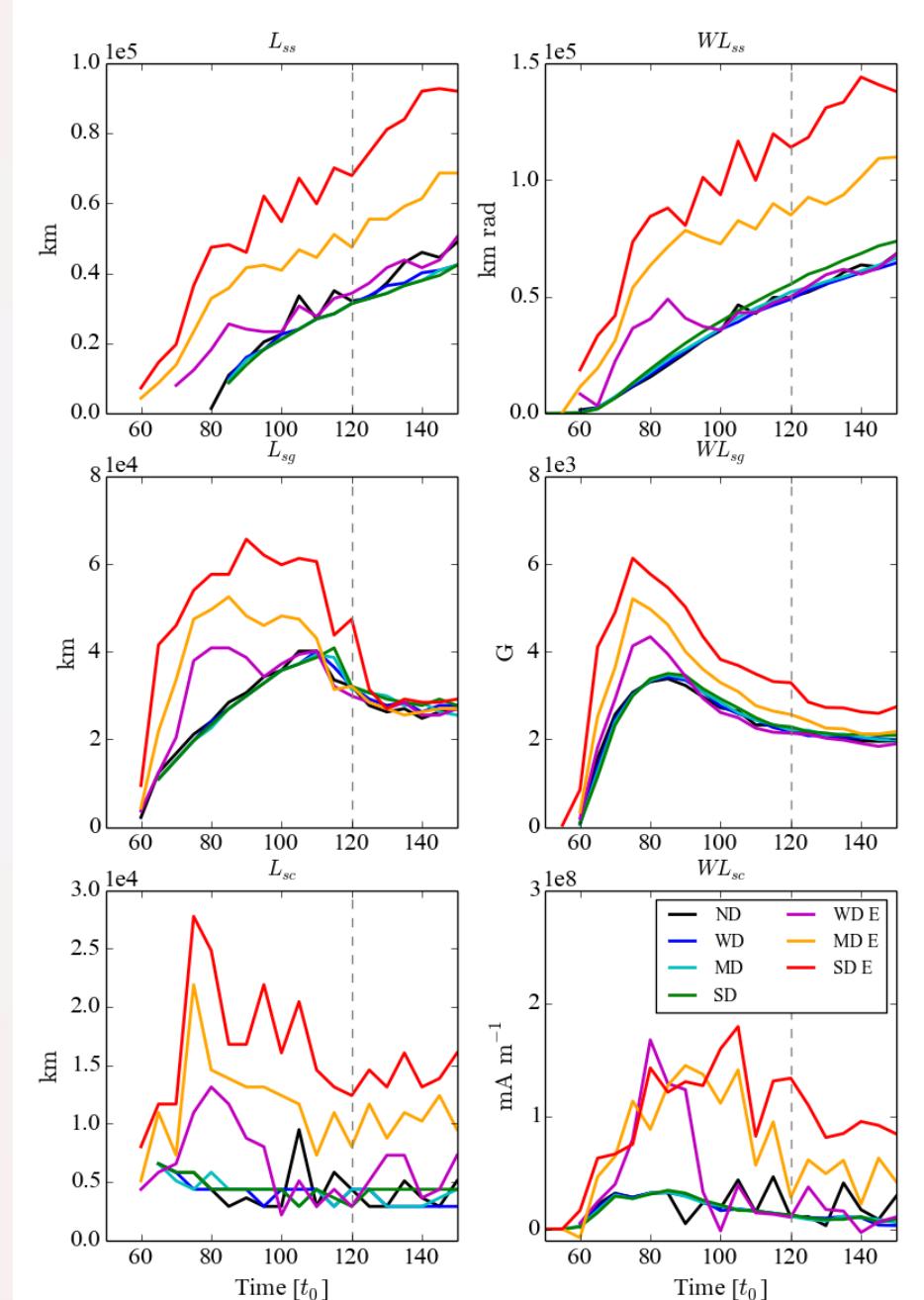
$$L_{sg} = \int dl_{\text{MPIL}}, \text{ with } B_h^{pot} > B_h^{th}; \nabla_h B_z > \nabla_h B_z^{th}$$

NEW $L_{sc} = \int dl_{\text{MPIL}}, \text{ with } B_h > B_h^{th}; J_z > J_z^{th}$

$$WL_{ss} = \int \psi dl_{\text{MPIL}}, \text{ with } B_h > B_h^{th}$$

$$WL_{sg} = \int \nabla_h B_z dl_{\text{MPIL}}, \text{ with } B_h^{pot} > B_h^{th}$$

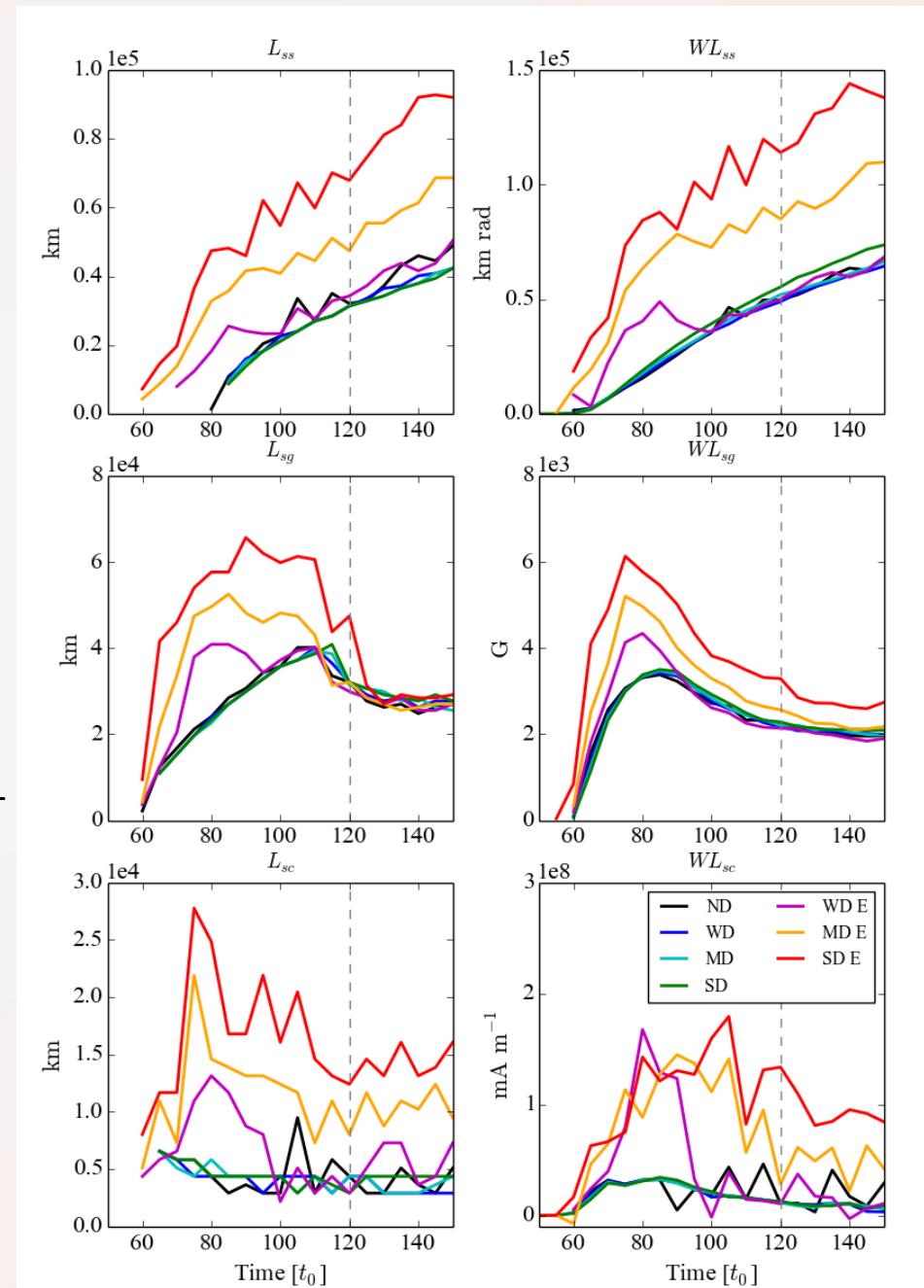
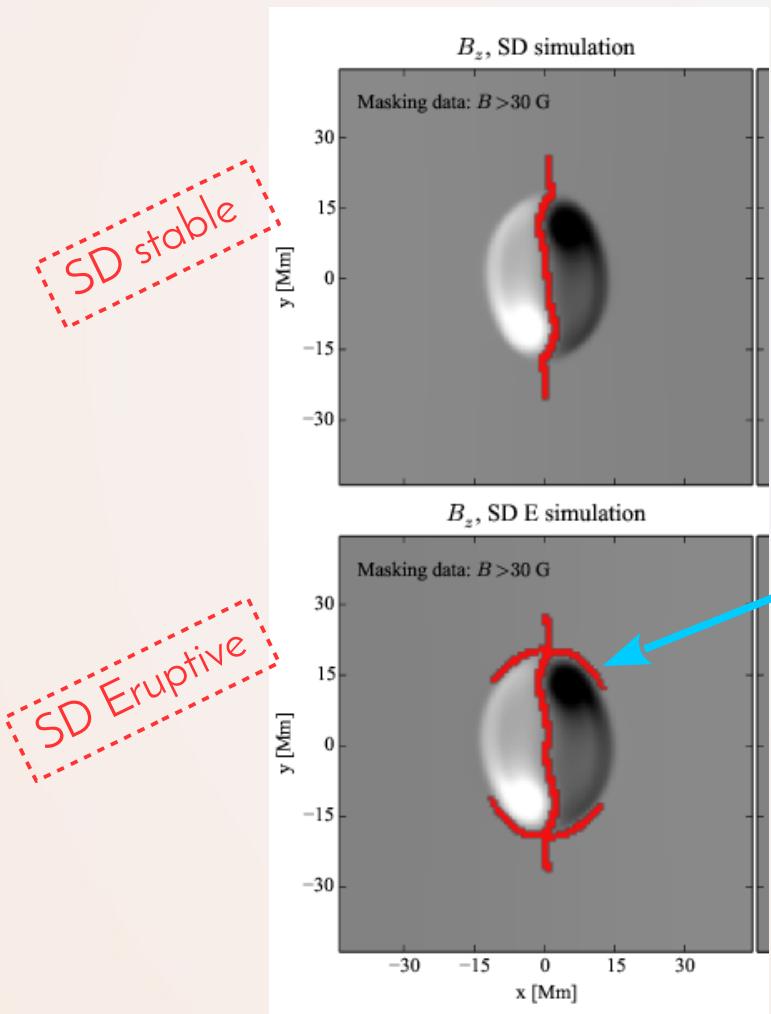
NEW $WL_{sc} = \int J_z dl_{\text{MPIL}}, \text{ with } B_h > B_h^{th}$



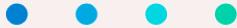
Pre-eruptive signatures



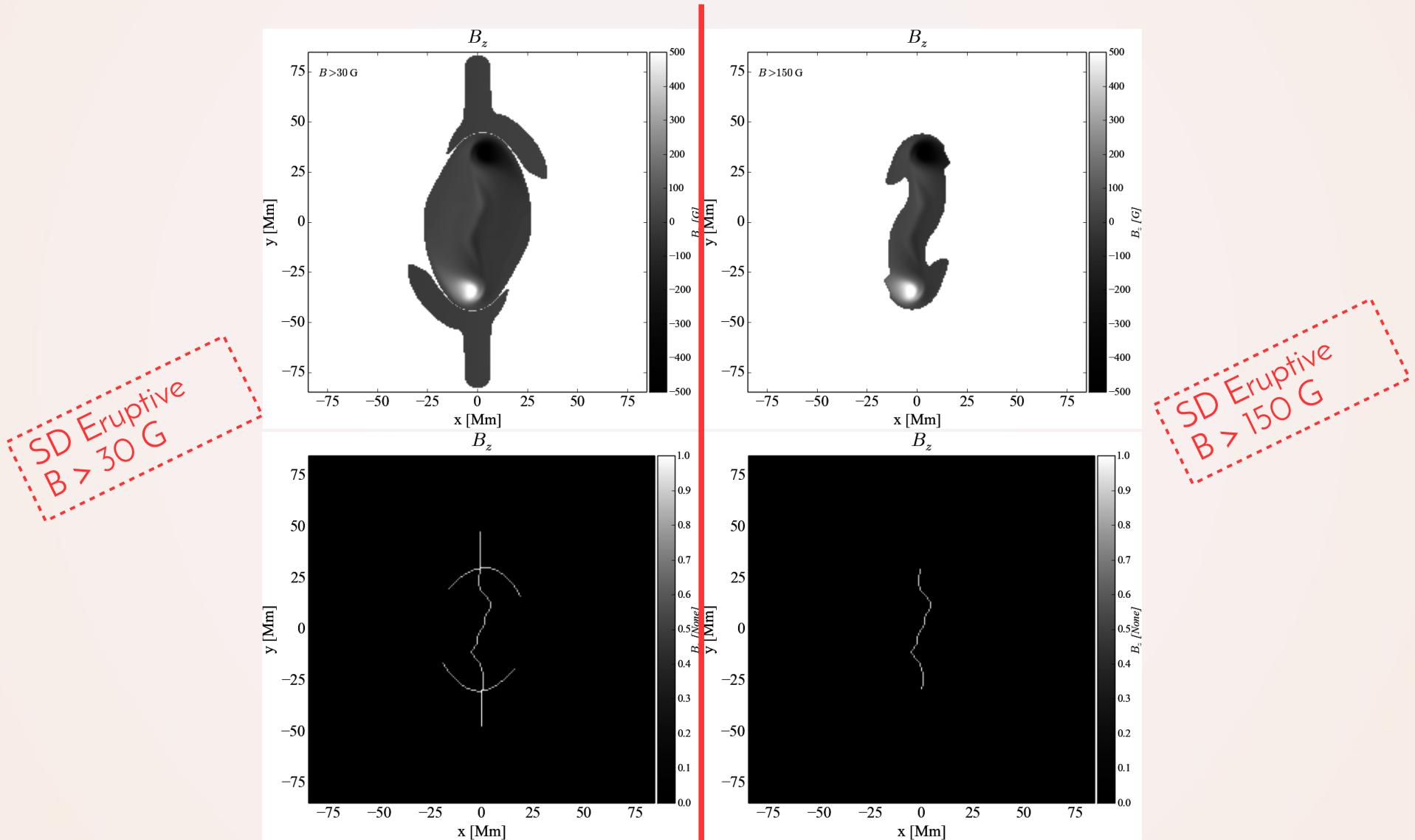
99 parameters → **only the 6 parameters related to the PIL** show a detectable eruptive signature



Impact of observation pre-processing

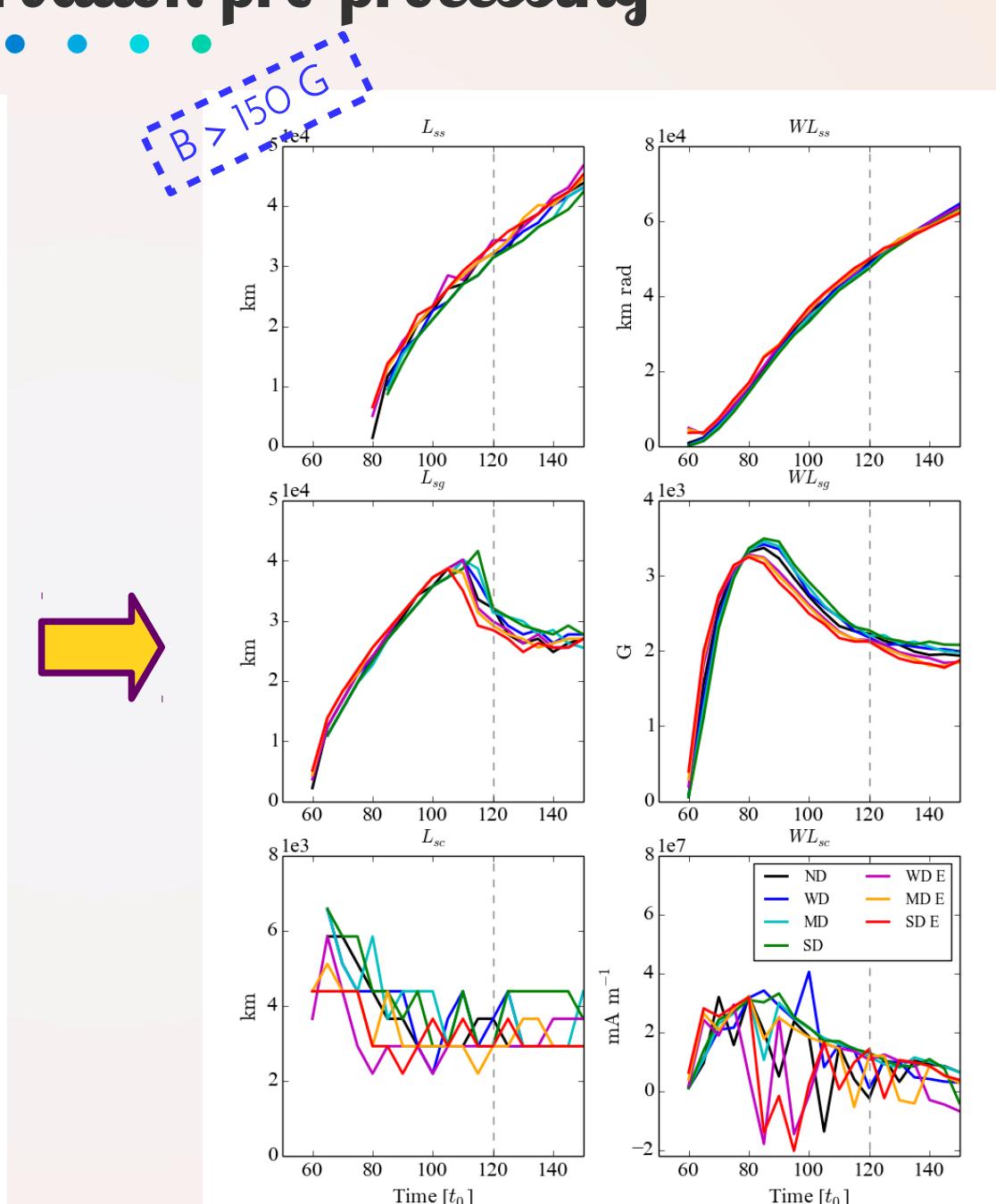
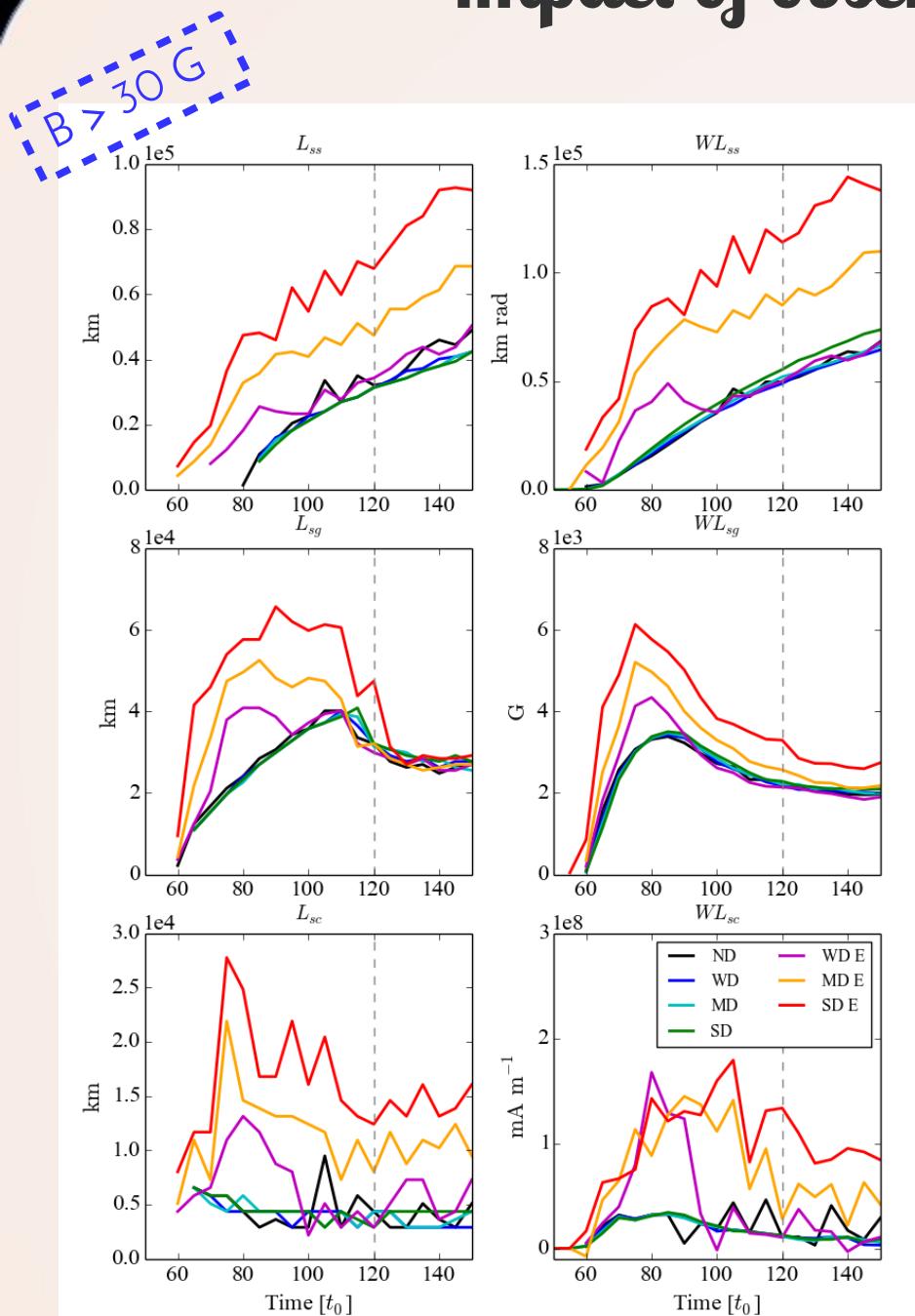


Pre-processing → Masking of weak magnetic field areas (significant errors)



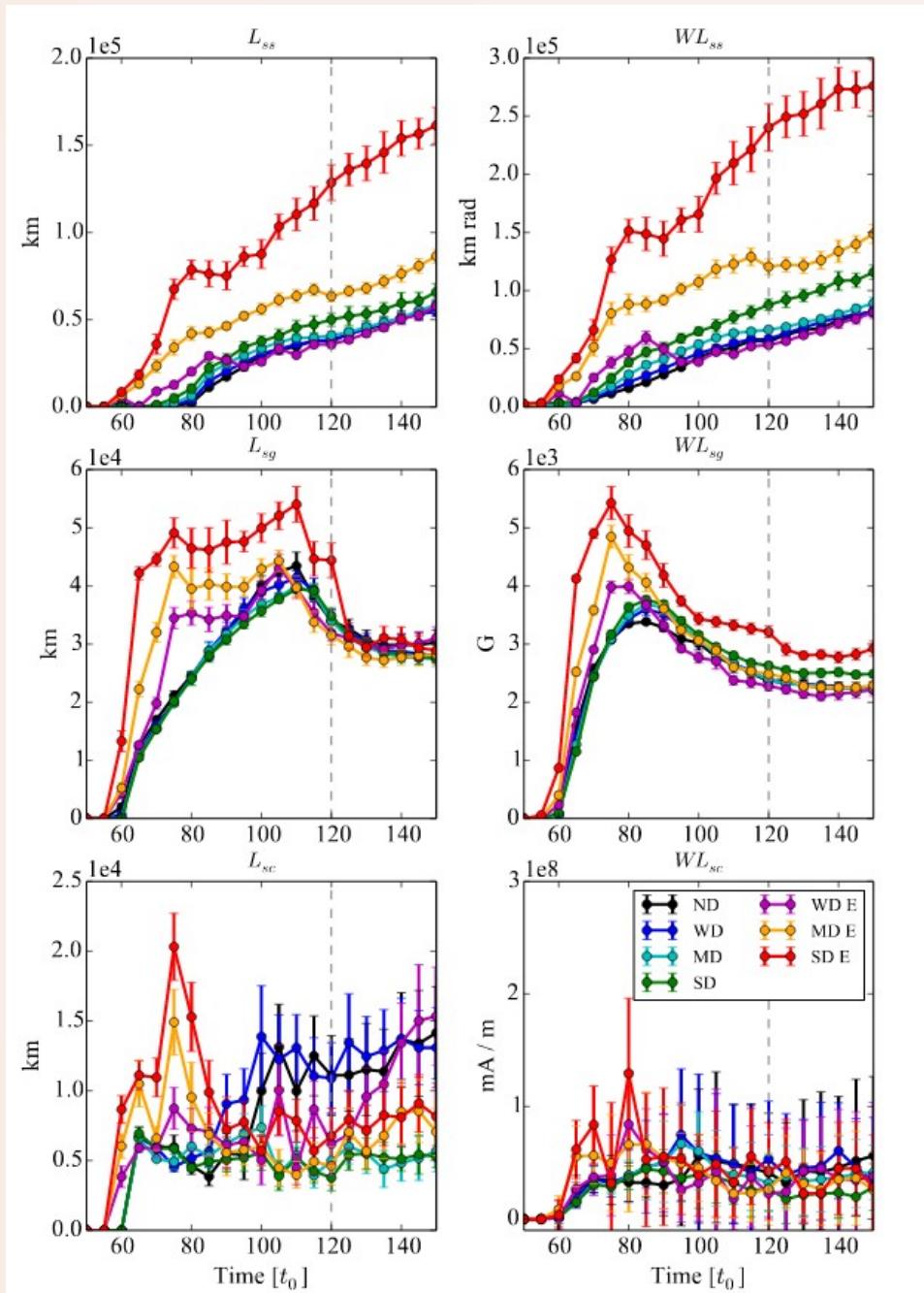
External edge of the PIL are no longer detected

Impact of observation pre-processing



High masking → pre-eruptive signatures are lost !

Impact of noises



Monte-Carlo scheme :

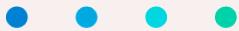
- Randomize the magnetograms
- Gaussian Perturbations

Error bars = standard deviation

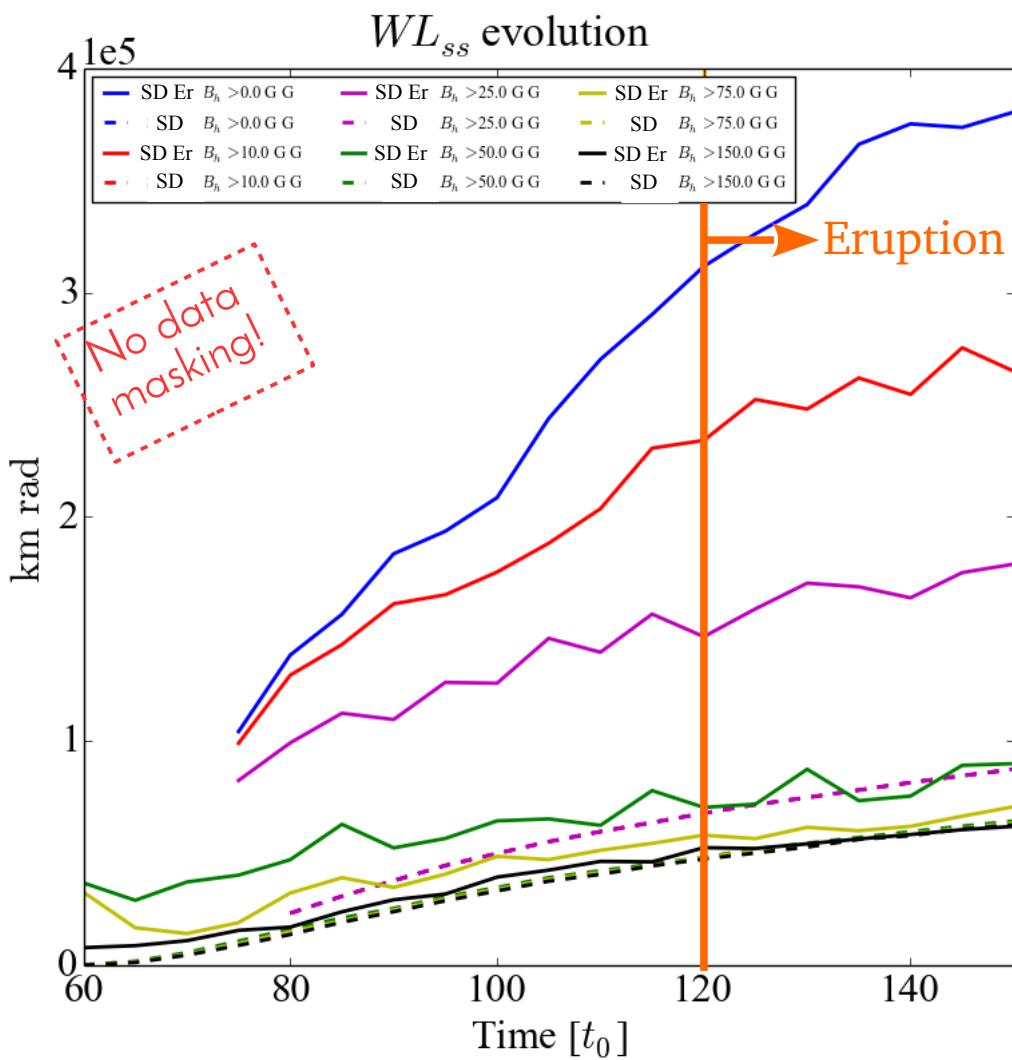
Simulated magnetic field measurements = mean value

The pre-eruptive signature
is still detectable

Impact of observation pre-processing



But the pre-eruptive signatures are even more sensitive to the physical threshold chosen in the calculations of each PIL parameters ...



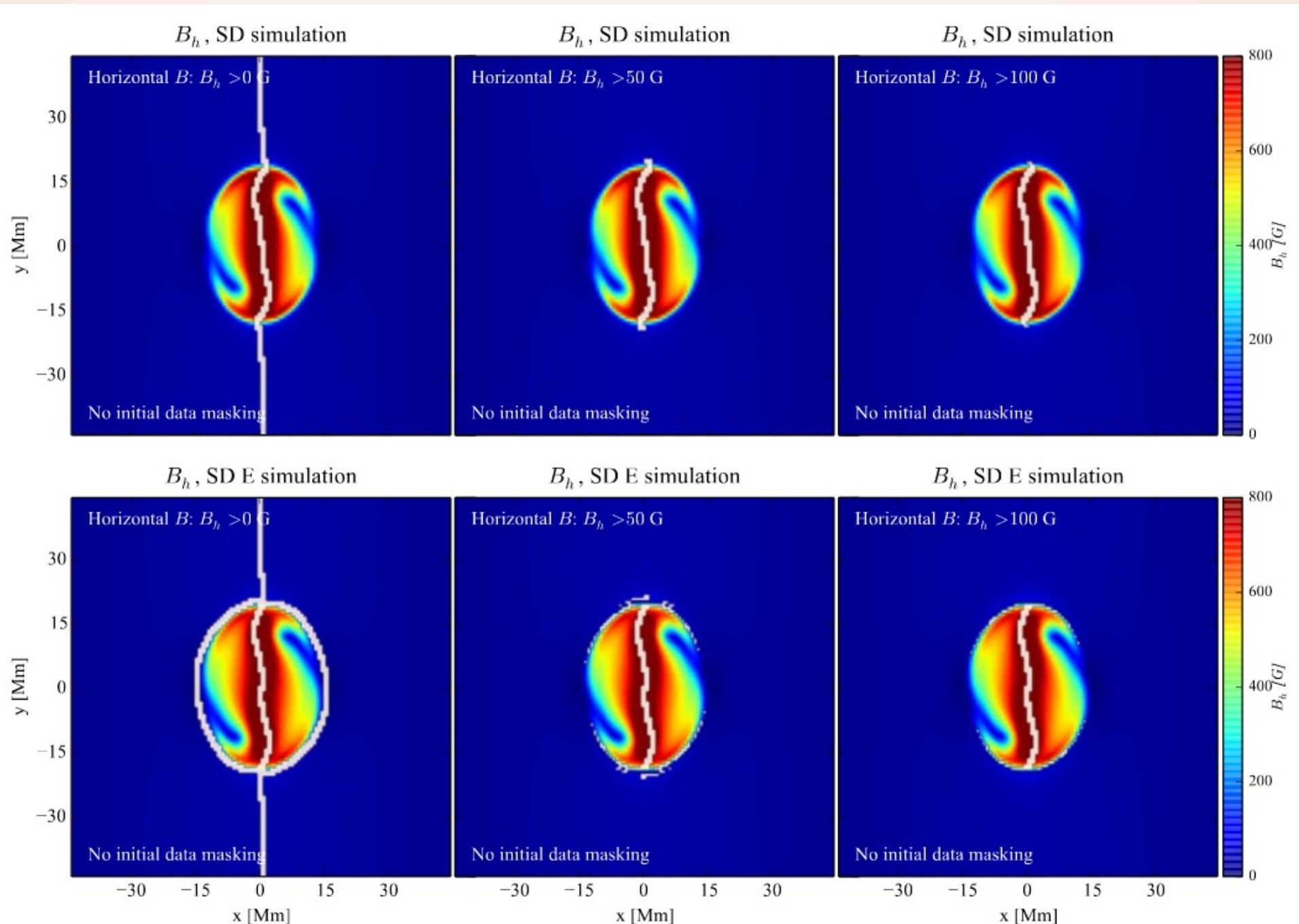
$$WL_{ss} = \int \psi dl \text{ where } B_h > 25 \text{ G}$$

Solid lines : eruptive simulations
Dashed lines : non-eruptive simulations

The pre-eruptive signature
is detectable only if
 $B_h < 50 \text{ G}$

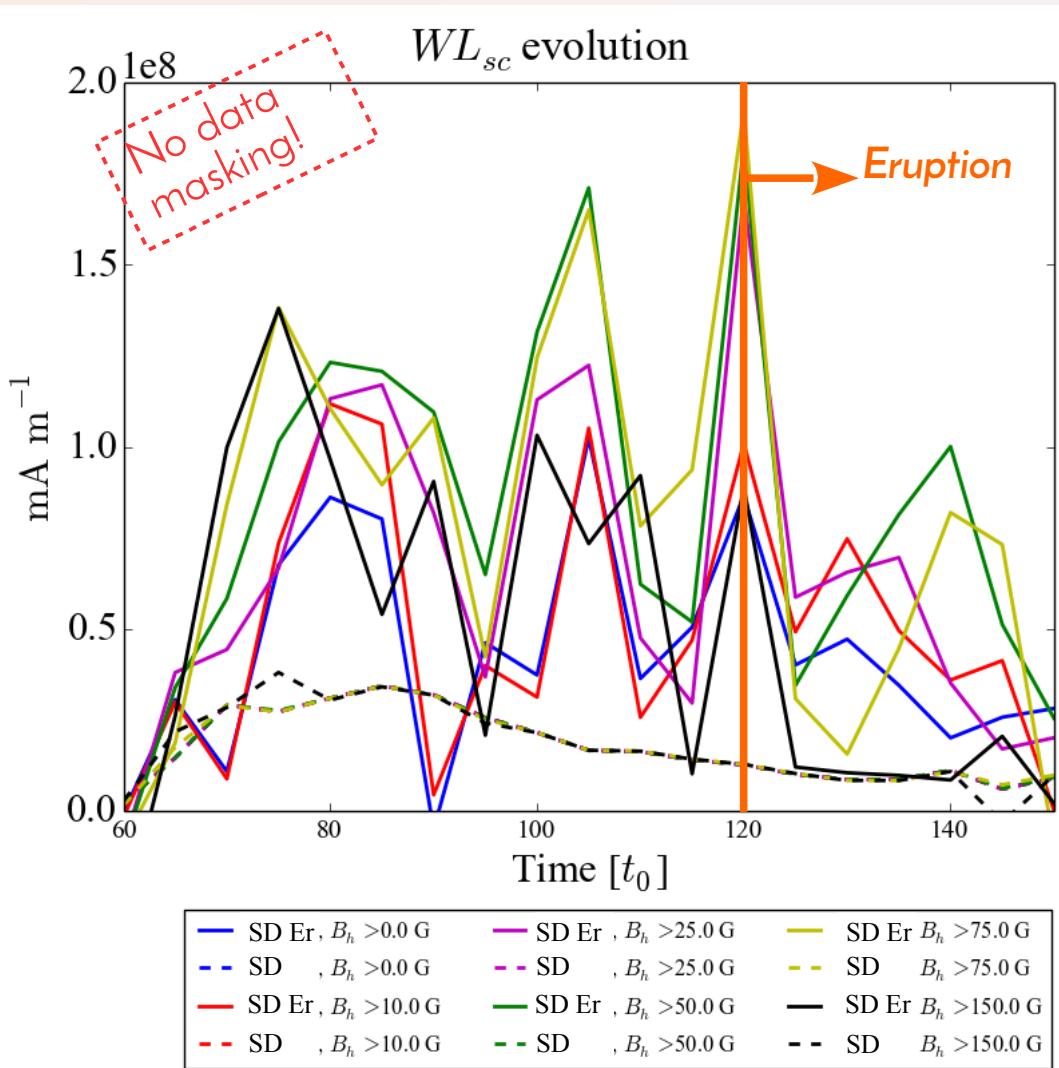
Physical threshold B_h

• • • •



Parametric study of WL_{sc}

• • • •



$$WL_{sc} = \int J_z dl \text{ where } B_h > 25 \text{ G}$$

Solid lines : eruptive simulations
Dashed lines : non-éruptive

Not very sensitive to the magnetic field threshold
→ Efficient eruptive proxy!

Conclusions



- ✓ Using parametric MHD simulations, we have tested the reliability of the parameters currently used in flare forecasting
- ✓ From the 99 tested parameters, only the properties related to the PIL (the Falconer parameters) presents a convincing pre-eruptive signature
- ✓ Development of two new quantities, related to current and PIL with strong eruptive potential
- ✓ But, the data pre-processing, i.e. the masking process strongly impact the detection of these signatures
- ✓ Parametric study of each Falconer parameter → investigation of their robustness
- ✓ WL_{sc} and WL_{sg} appear as the best eruptive proxies

Thank you!