TESTING PREDICTORS OF ERUPTIVITY USING PARAMETRIC FLUX EMERGENCE SIMULATIONS

http://flarecast.eu/

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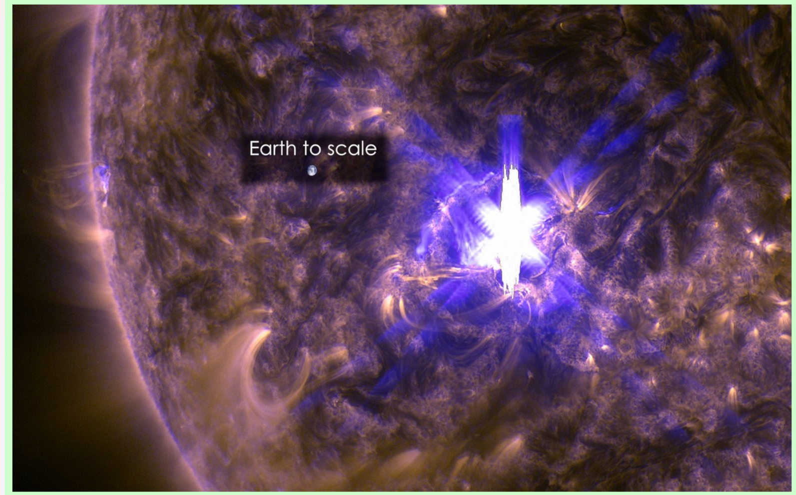
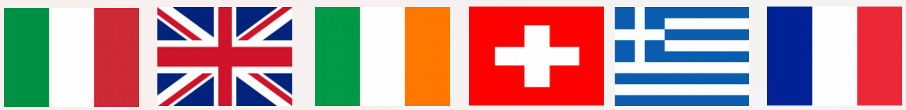
The Flarecast project

What?

Provides an on-line, automatic flare forecasting tool, based on state-of-the-art flare prediction methods



Who?



A European consortium of 9 institutions

How?

- Automatic extraction of Active Region magnetic properties
- Comparison with past solar activity – Machine learning/Data mining

FLARECAST top-level objectives

01 To understand the drivers of solar flare activity and improve flare prediction

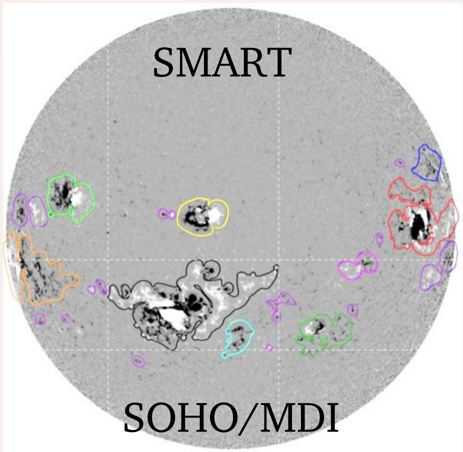
02 To provide a globally accessible flare prediction service

03 To engage with space weather end users and inform policy makers/ public

How Flarecast works?

Machine learning

Past Solar Activity

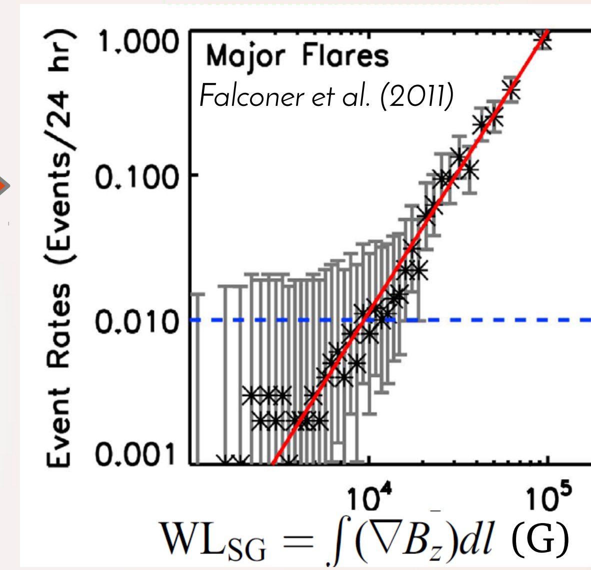


State-of-art algorithms

machine learning and data mining

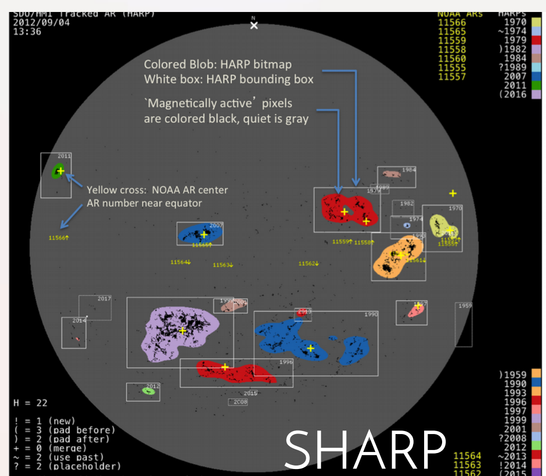
Automatic extraction of about 50 magnetic parameter

Eruptivity criterion



Primary Data source: SDO/HMI data, vector magnetograms
Quasi real time

Using the SHARP pipeline
+GOES X flares properties
+ (?) AIA (?)

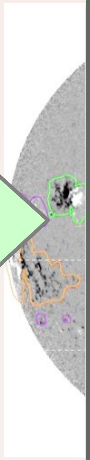


Predictions!

How Flarecast works?

Machine le

Past Solar Activity



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Primary Dat
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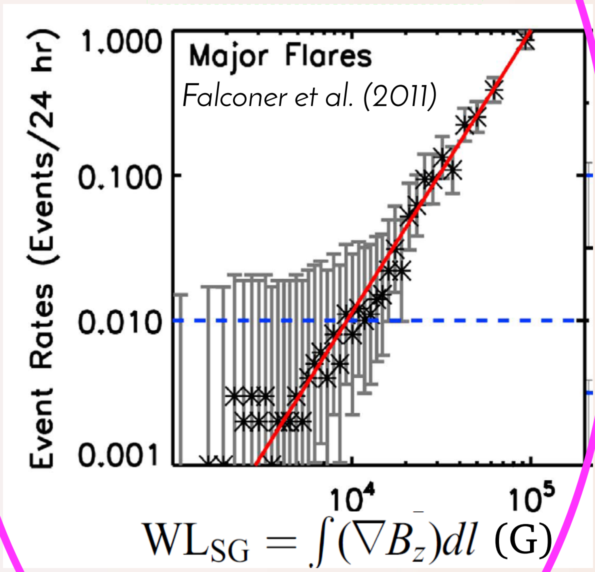
Using the
+GOES X
+ (?)

→ To understand the physical processes involved in solar flares
→ Instabilities?

→ To determine the observables eruptivity criteria

Work package 6 :
Explorative research

Eruptivity criterion

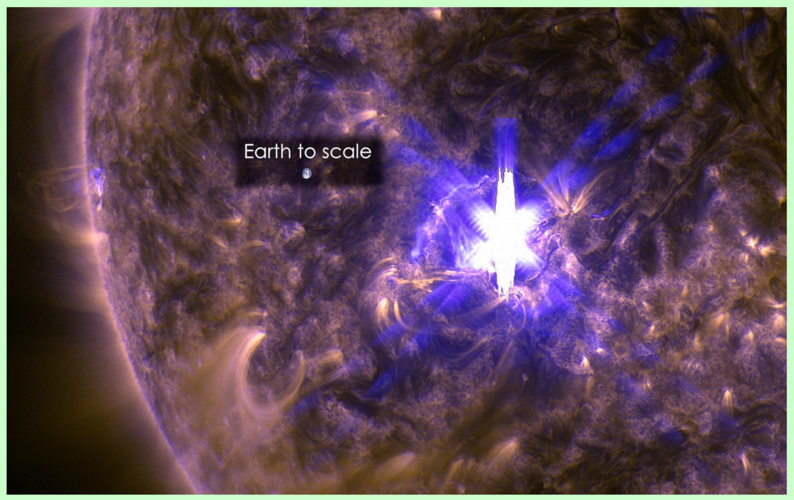


Predictions!

SHARP

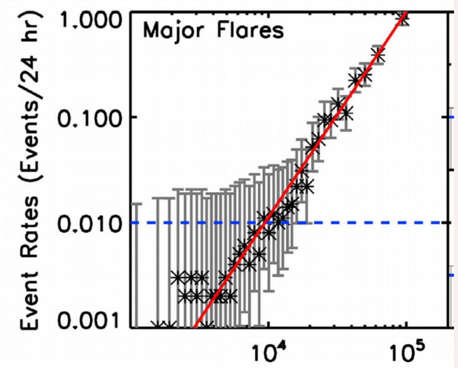
Eruptivity predictors

Solar flares → correlated with size and complexity of Active Regions



Flare prediction → Empirical variation of magnetic parameters

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



Falconer et al. (2011)

But ... → None of these parameters provided a clear eruptivity criterion

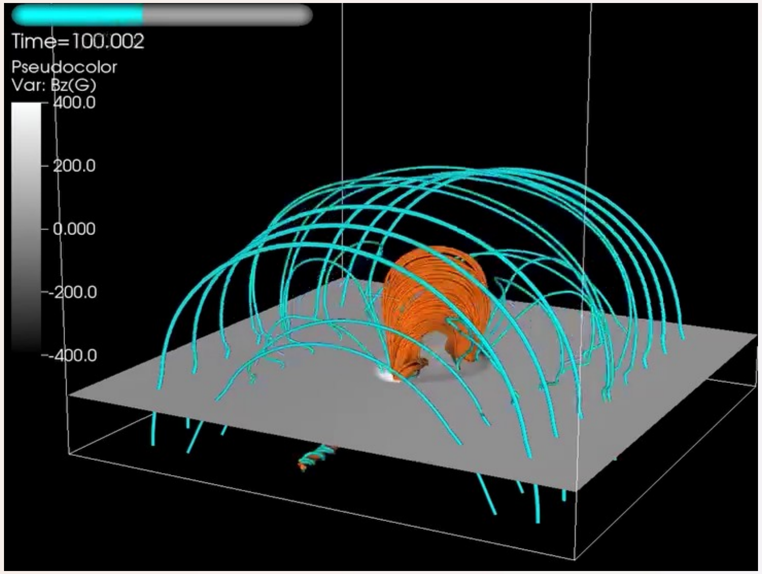
→ The predictability of the parameters has been only barely tested on simulations

Objectives :

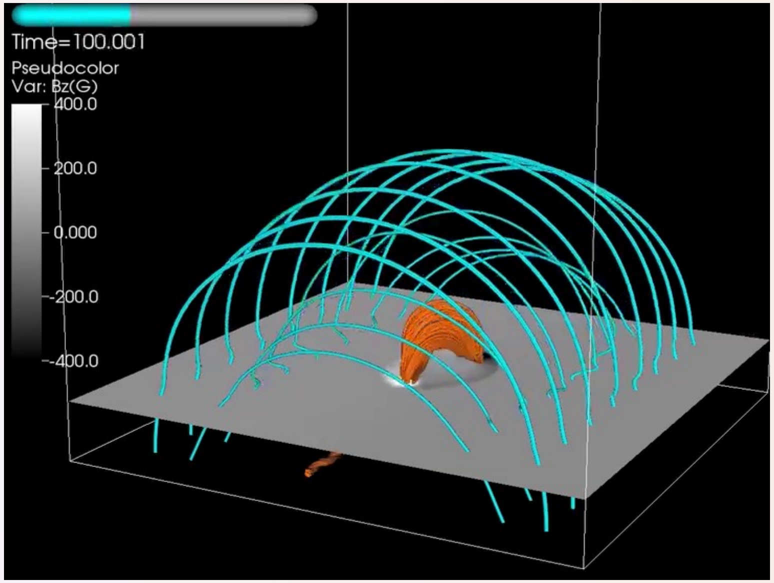
Testing the reliability of the magnetic parameters used in flare predictions, using parametric MHD simulations

MHD Parametric Simulations

4 eruptive simulations



3 eruptive simulations

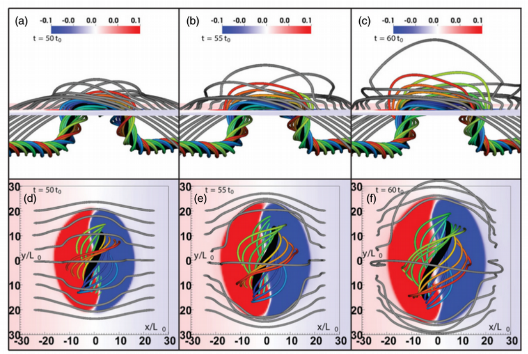


Parametric simulations: **orientation** and **strength** of the coronal arcade is varied

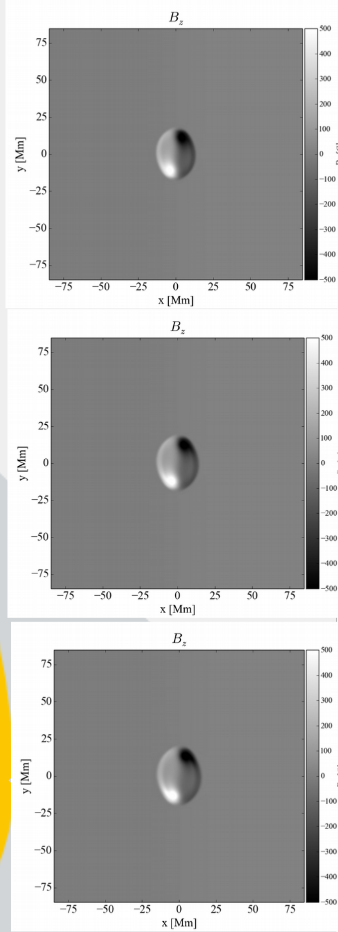
Eruptives vs. non-eruptive simulations:
orientation du dipole → favor the **magnetic reconnection process** or not
Dipole **strength**: only slighlty impact the eruptive flare **trigger time**

Simulation Analysis

We analyse the simulations as real data



1. 3D MHD simulations + time evolution

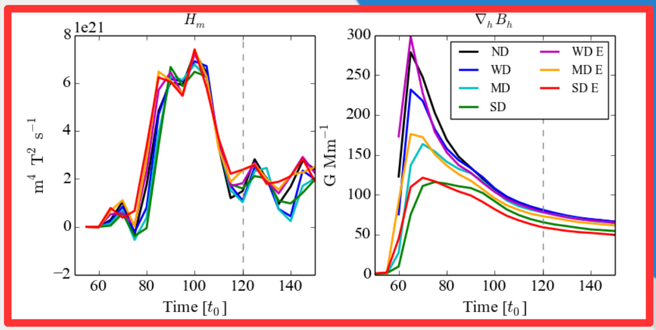


2. Magnetogram time series for each simulation

3. Computation of magnetic parameters (~100)

4. Time evolution of predictors for the 7 simulations

Eruptive signature ???



X 7 simulations

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

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 : $\mathbf{F}_{tot}$, $\mathbf{F}_{net}$, $\mathbf{F}_{+}$, $\mathbf{F}_{-}$

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 ----

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

R value (Schrijver 2007)

Magnetic field geometry

Inclination angle: γ

Twist parameter: α

Shear angles: ψ, Ψ

$A(\Psi > 80°)$, $A(\psi > 80°)$

(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

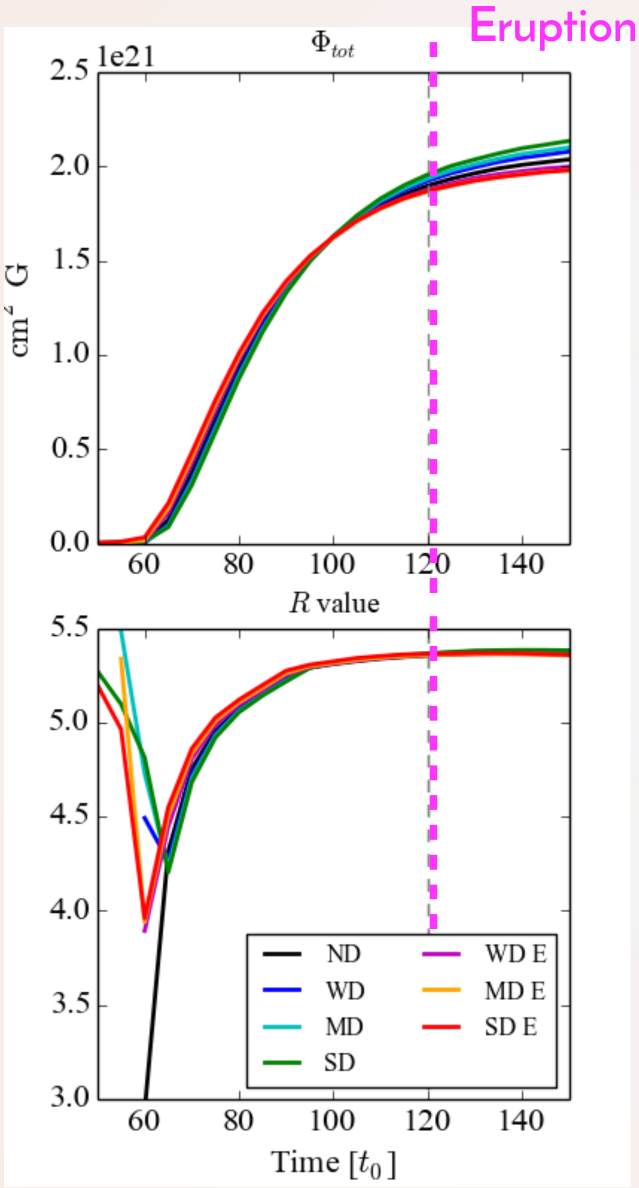
δF_x, δF_y, δF_z

(Fisher 2012)

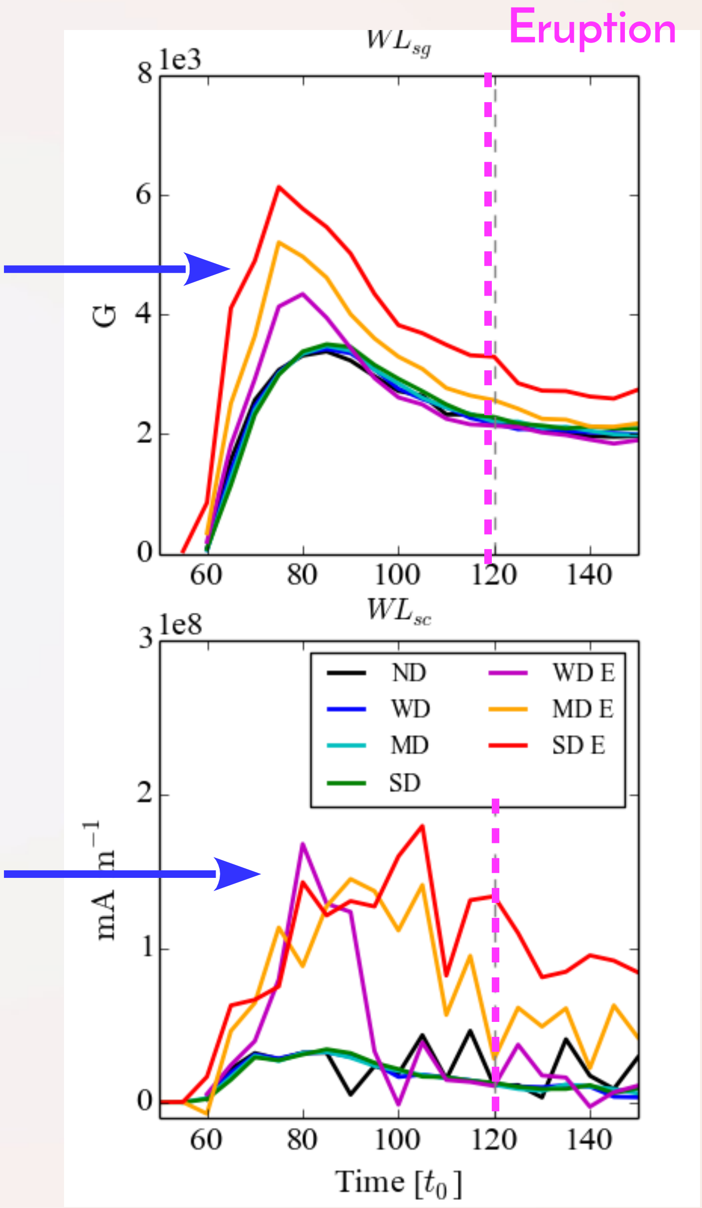
For each parameter X, the four moments $\mu(X)$, $\sigma(X)$, $\varsigma(X)$ et $\kappa(X)$ are also computed, averaged over the whole AR

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

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

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

NEW

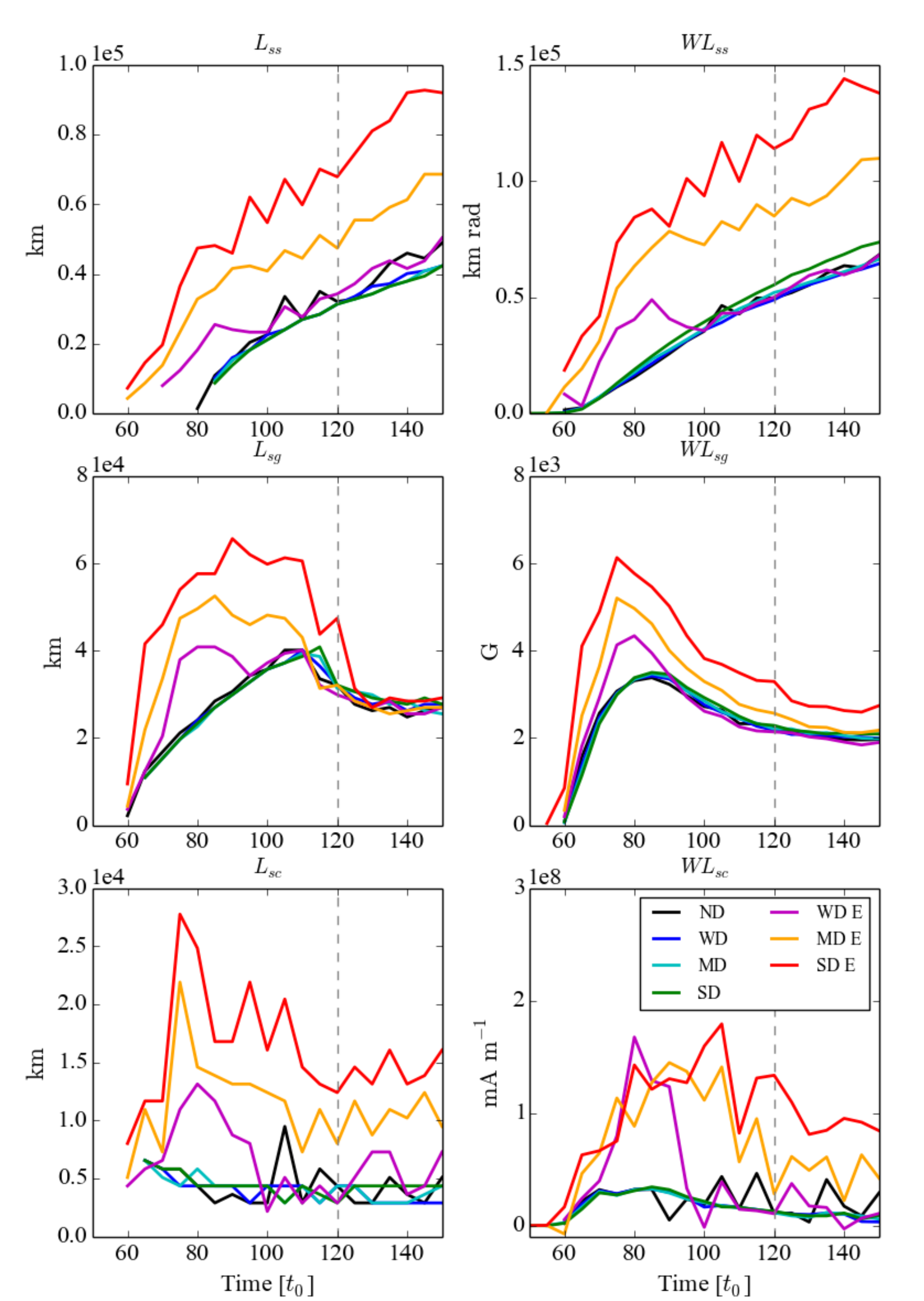
$$L_{sc} = \int dl_{\mathrm{MPIL}}, \text{ with } B_h > B_h^{th};\ J_z > J_z^{th}$$

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

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

NEW

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



Pre-eruptive signatures

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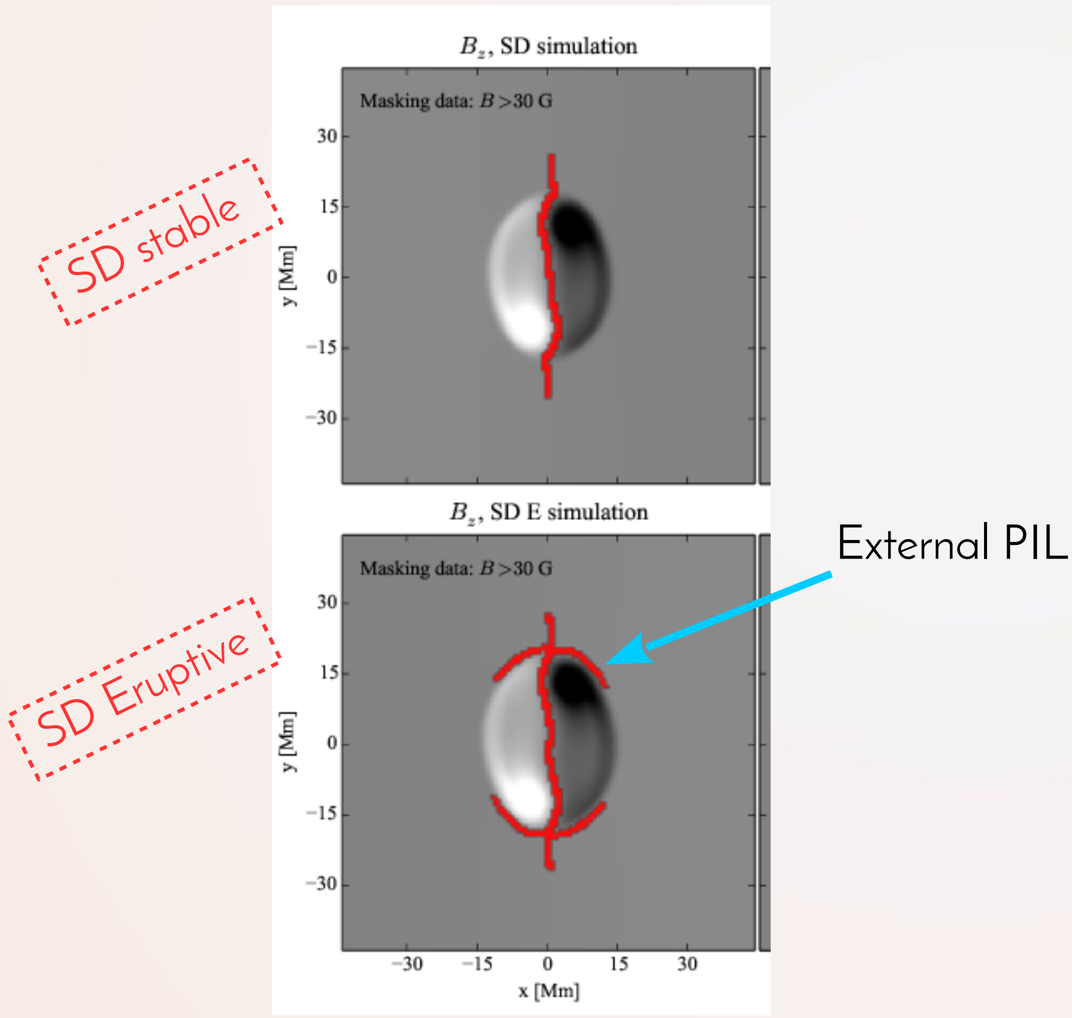
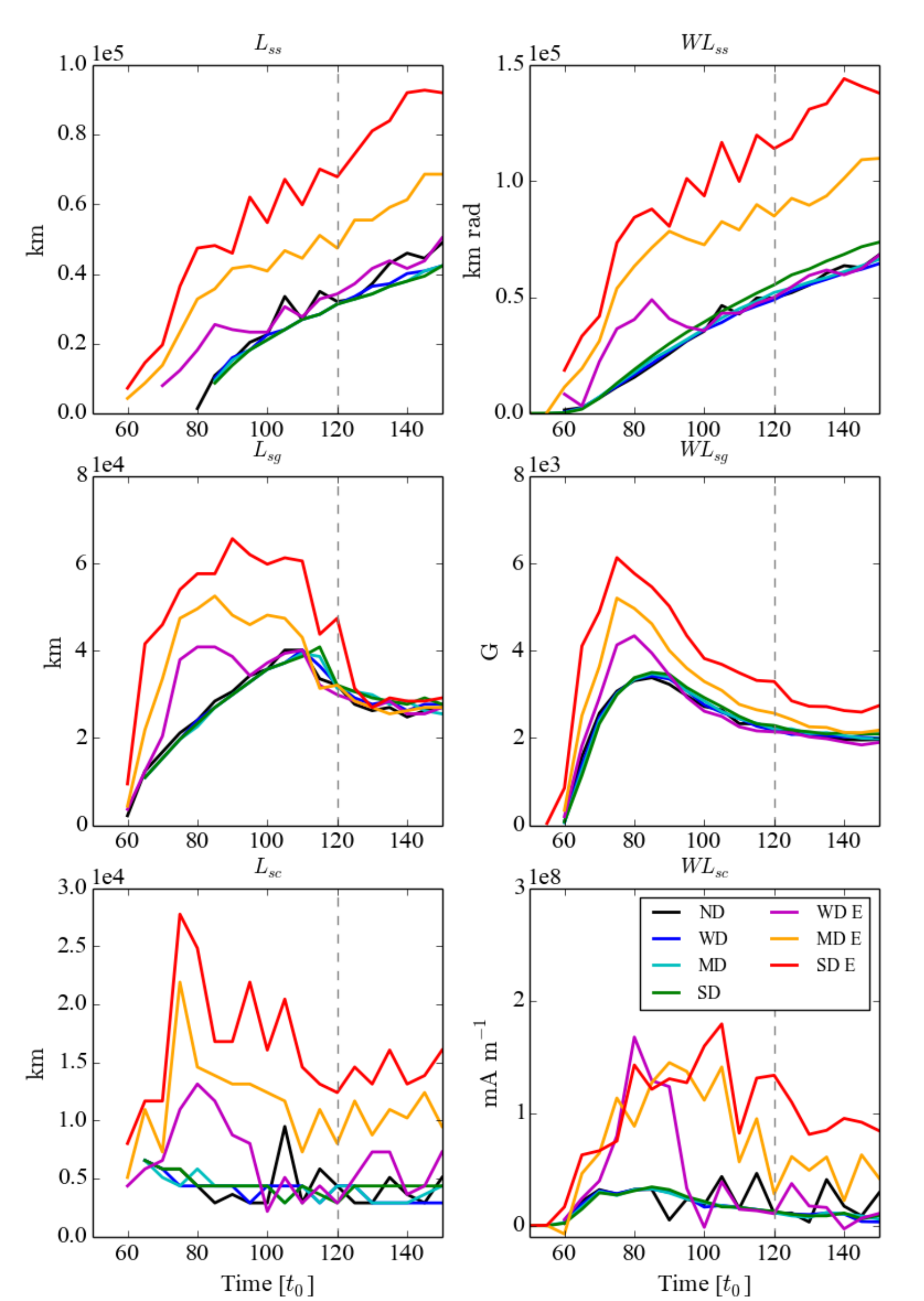
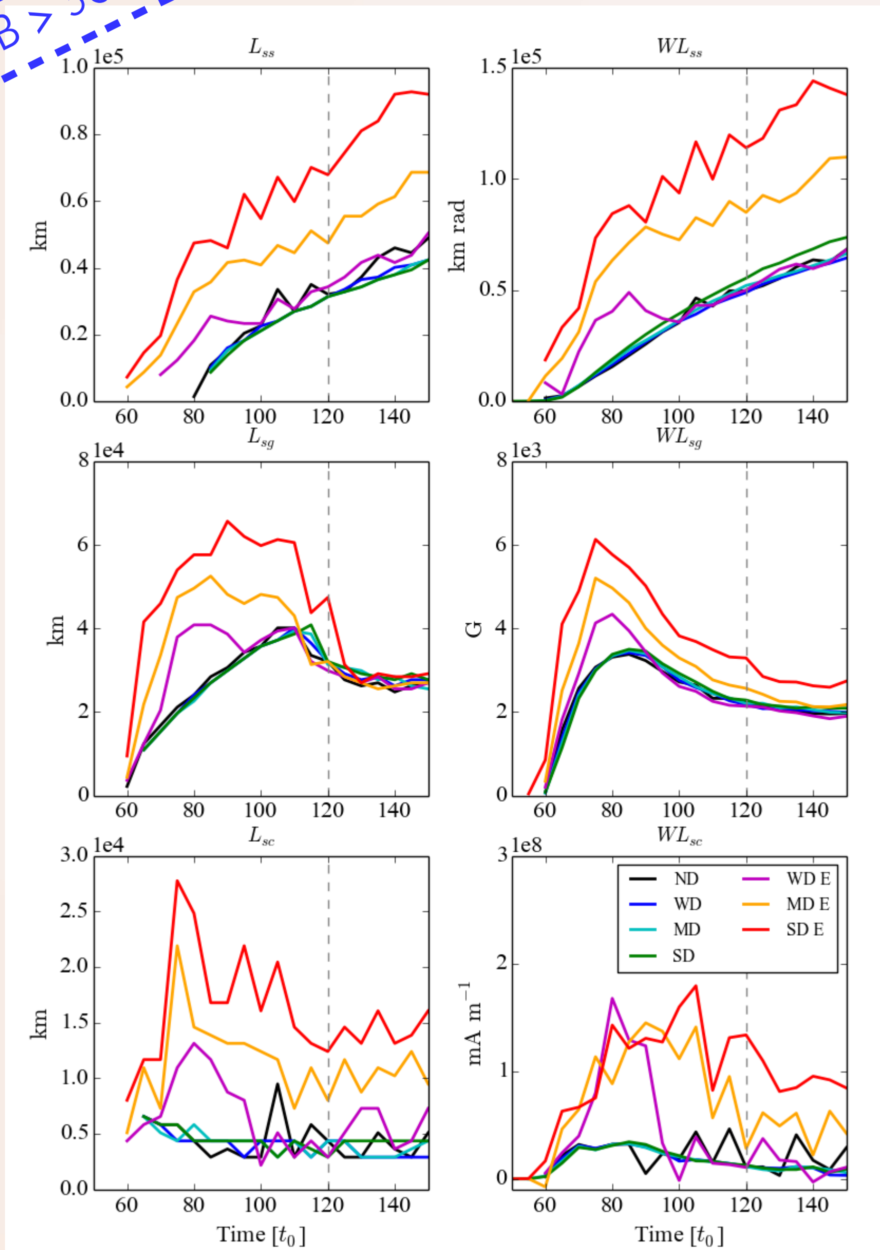


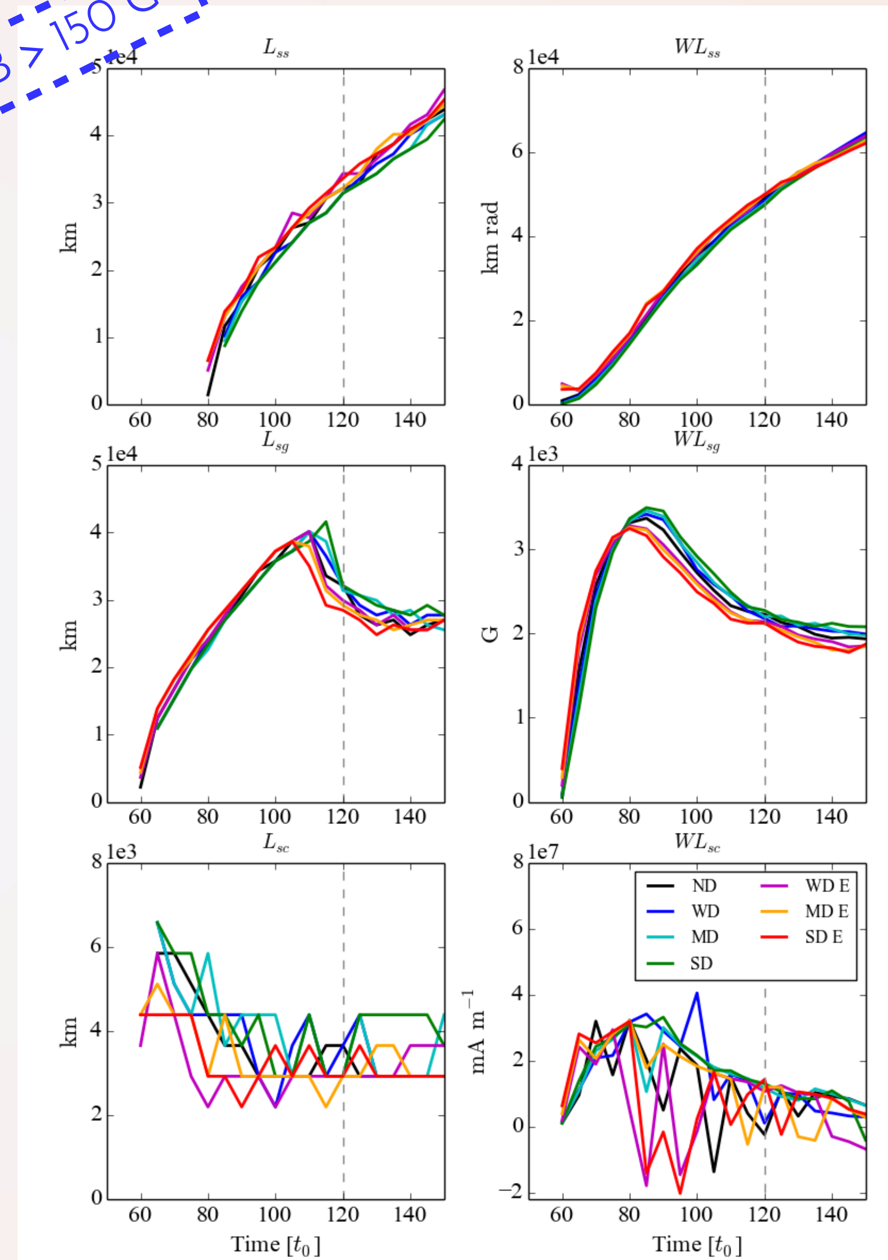


Impact of observation pre-processing

B > 30 G



B > 150 G

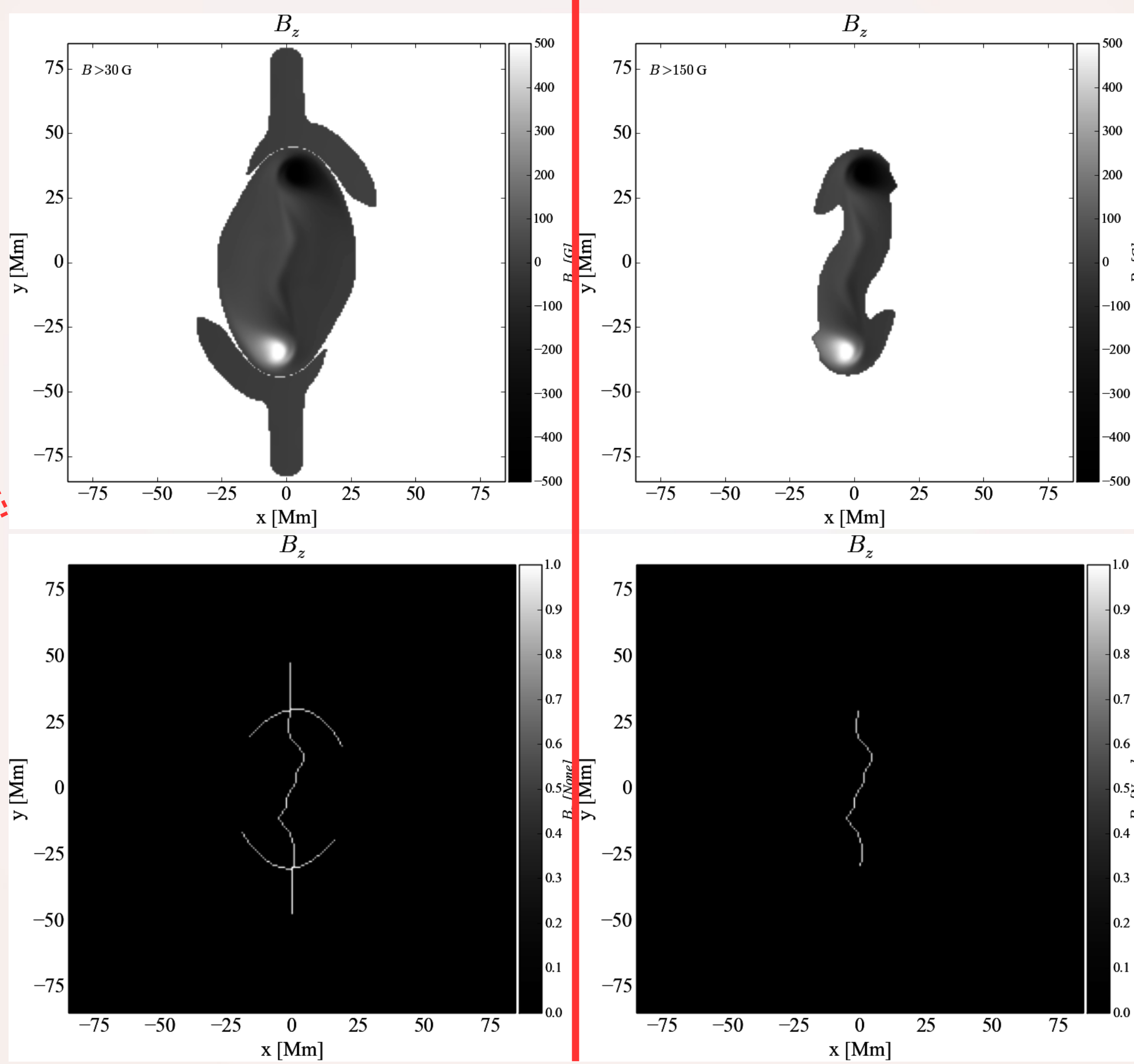


High masking → pre-eruptive signatures are lost !

Impact of observation pre-processing

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

SD Eruptive
B > 30 G



SD Eruptive
B > 150 G

External edge of the PIL are no longer detected

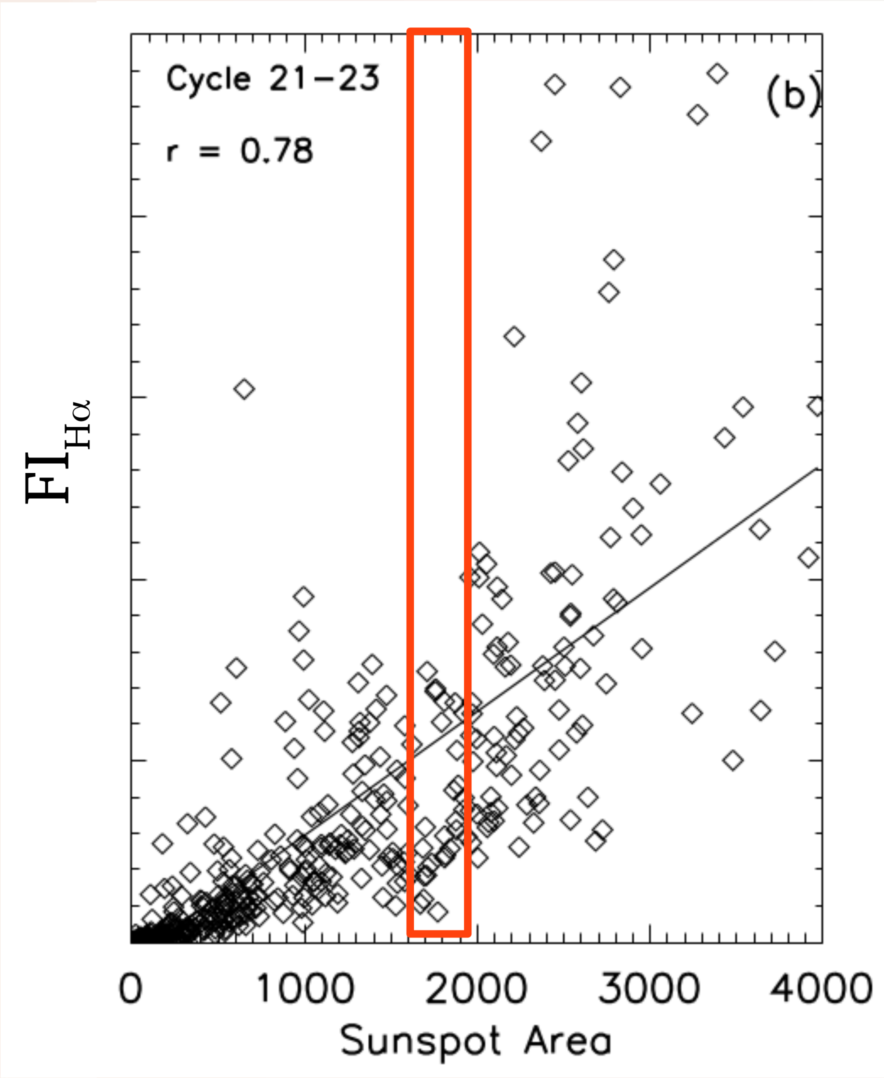
Conclusions

- ✔ 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
- ✔ We also carried out a parametric study of each Falconer parameter, based on the physical thresholds used → investigation of their robustness
- ✔ WL_{sc} and WL_{sg} appear as the best eruptive proxies

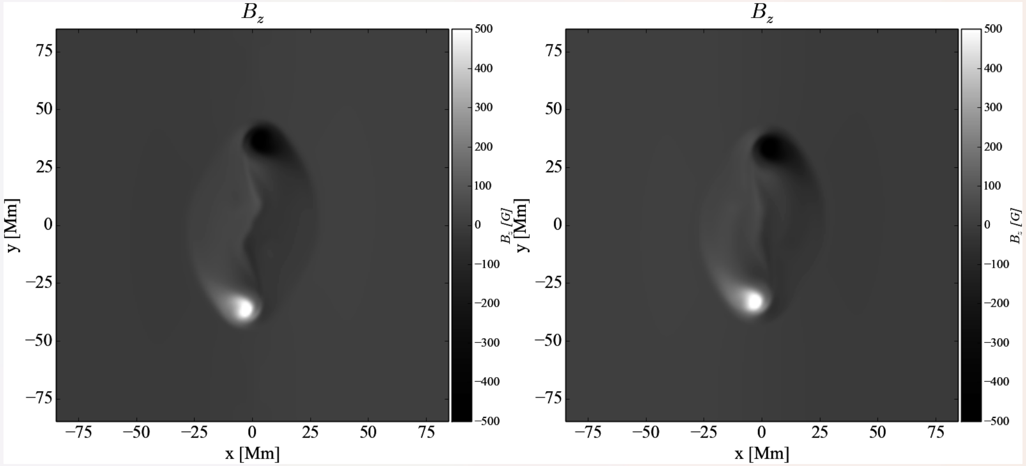
Thank you!

Limitations

Flaring index correlated with Active Region size



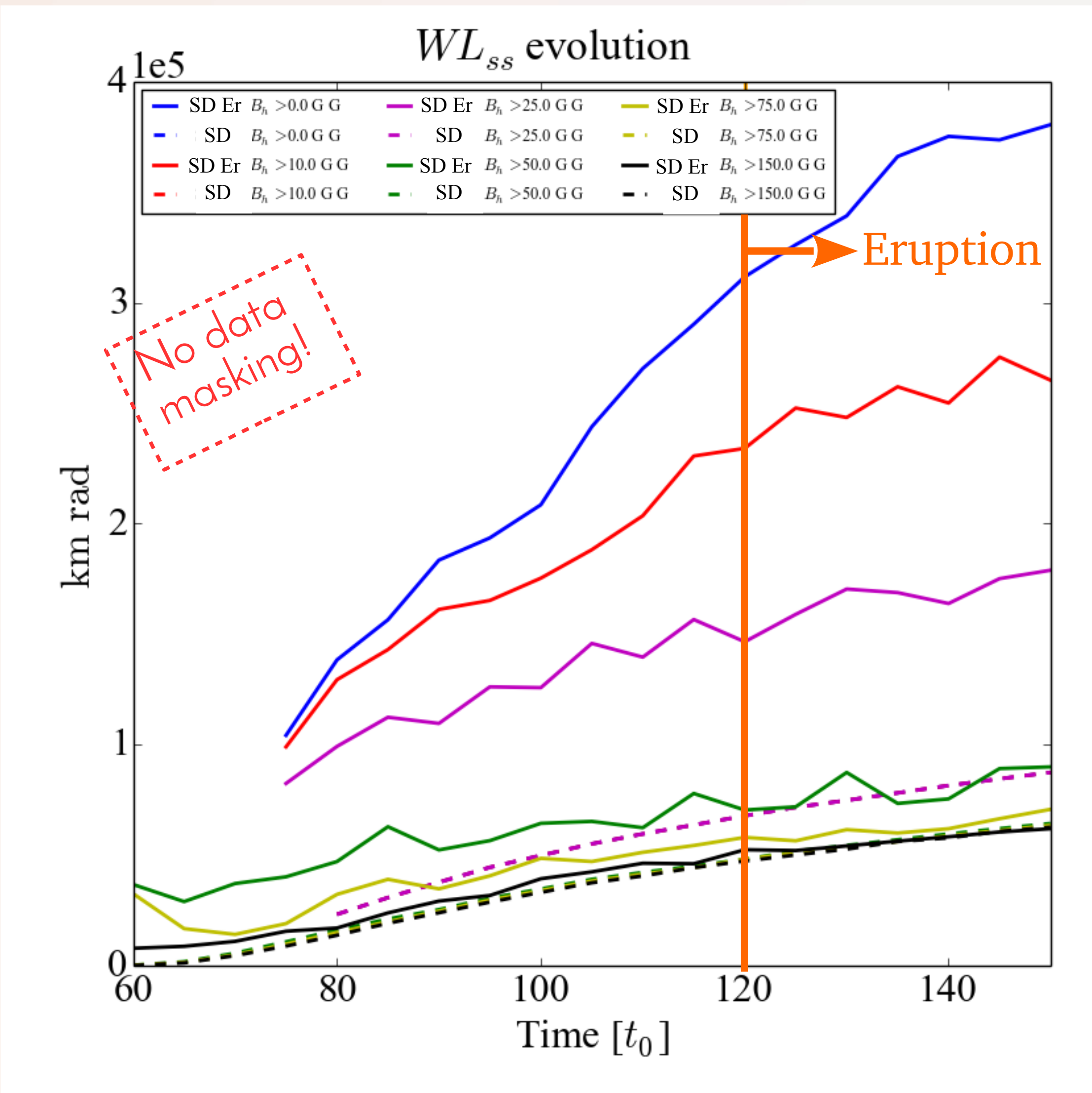
Our simulations:
Similar size → similar flux → very similar magnetograms



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

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 ...

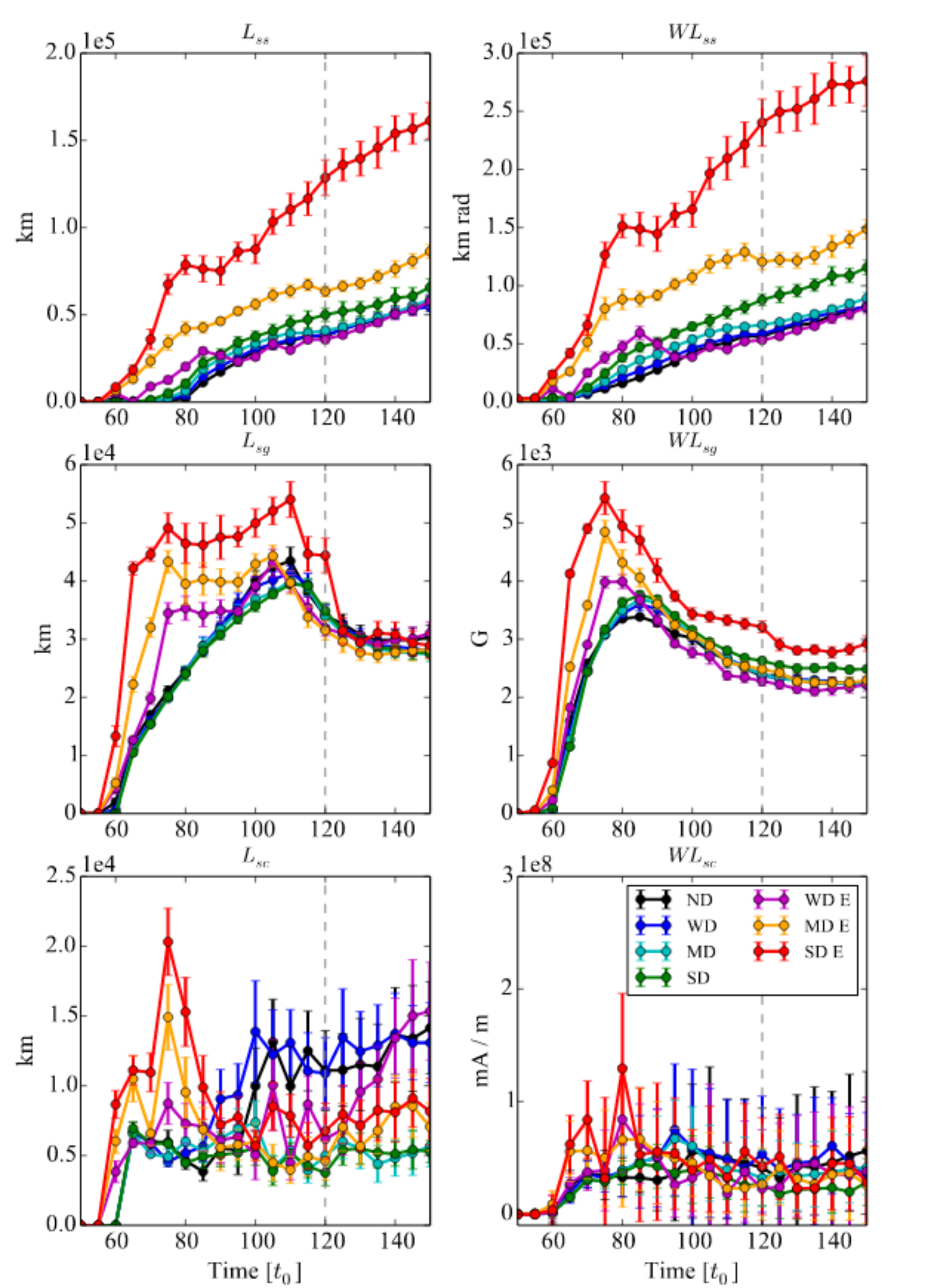


$$WL_{ss} = \int \psi \, dl \text{ where } B_h > 25\,\text{G}$$

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

The pre-eruptive signature is detectable only if B_h < 50 G

Impact of noises



Monte-Carlo scheme :

- Randomize the magnetograms
- Gaussian Perturbations

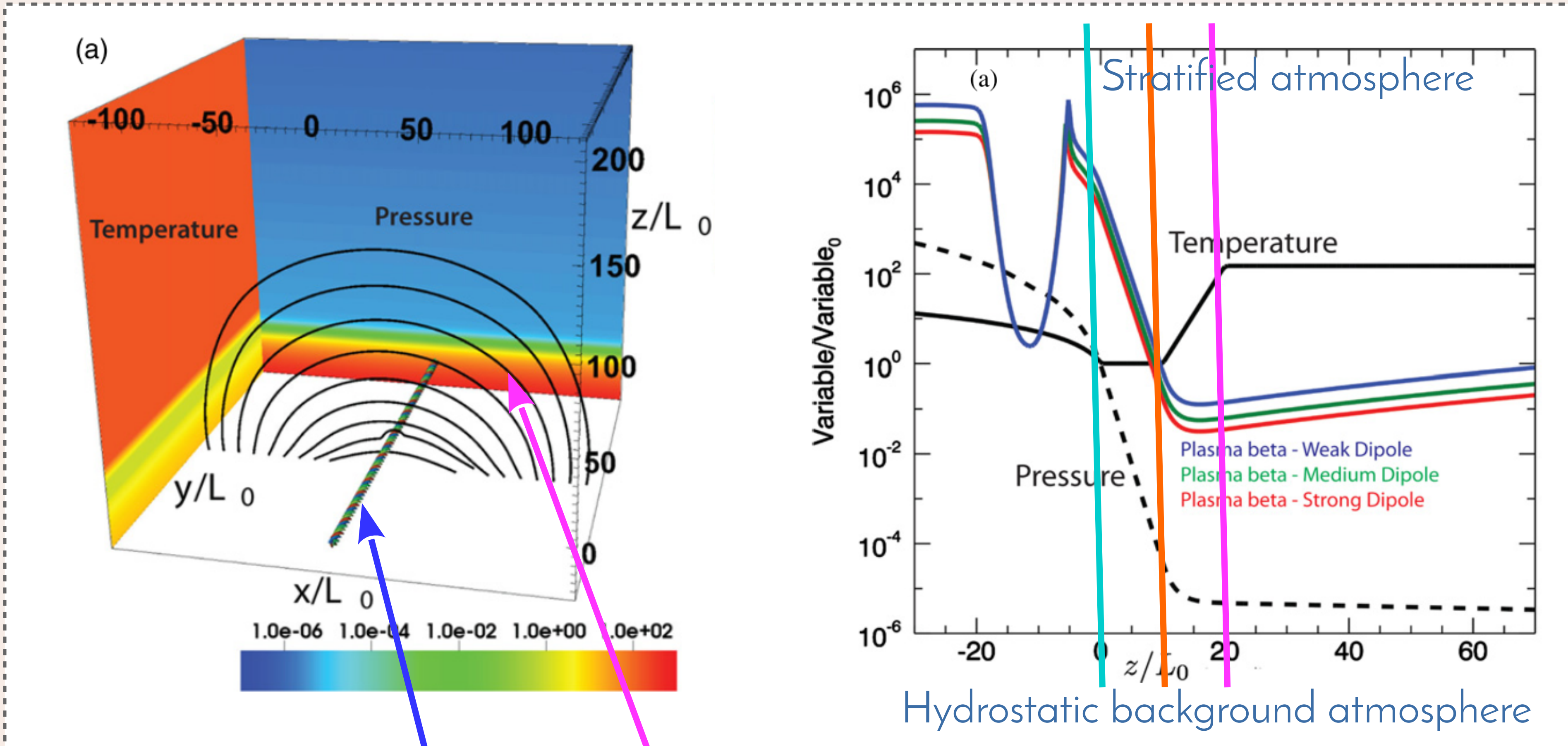
Error bars = standard deviation

Simulated magnetic field measurements = mean value

The pre-eruptive signature is still detectable

MHD Parametric Simulations

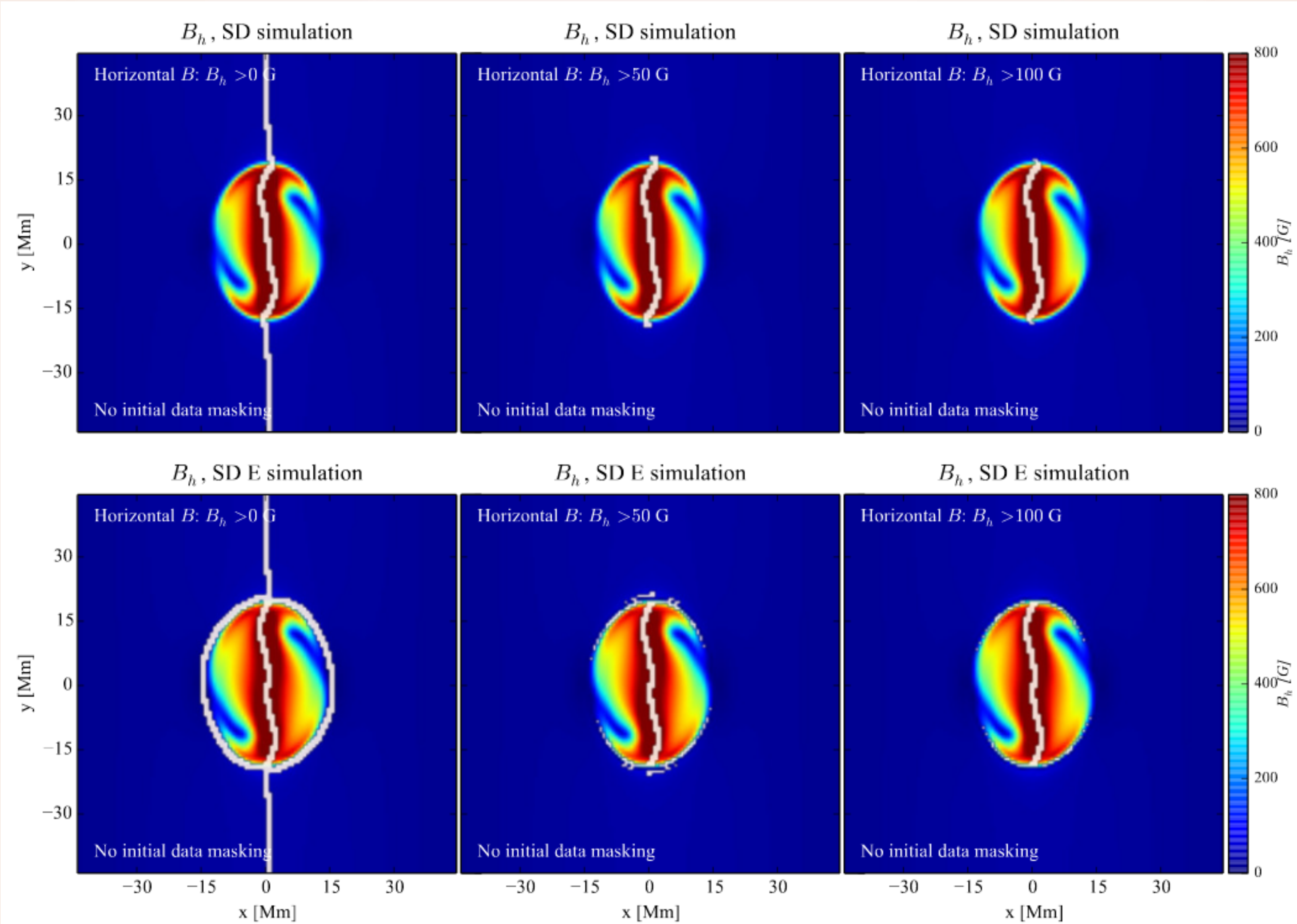
Flux emergence 3D visco-resistive simulations
in a stratified atmosphere + coronal arcade
Leake et al (2013, 2014)



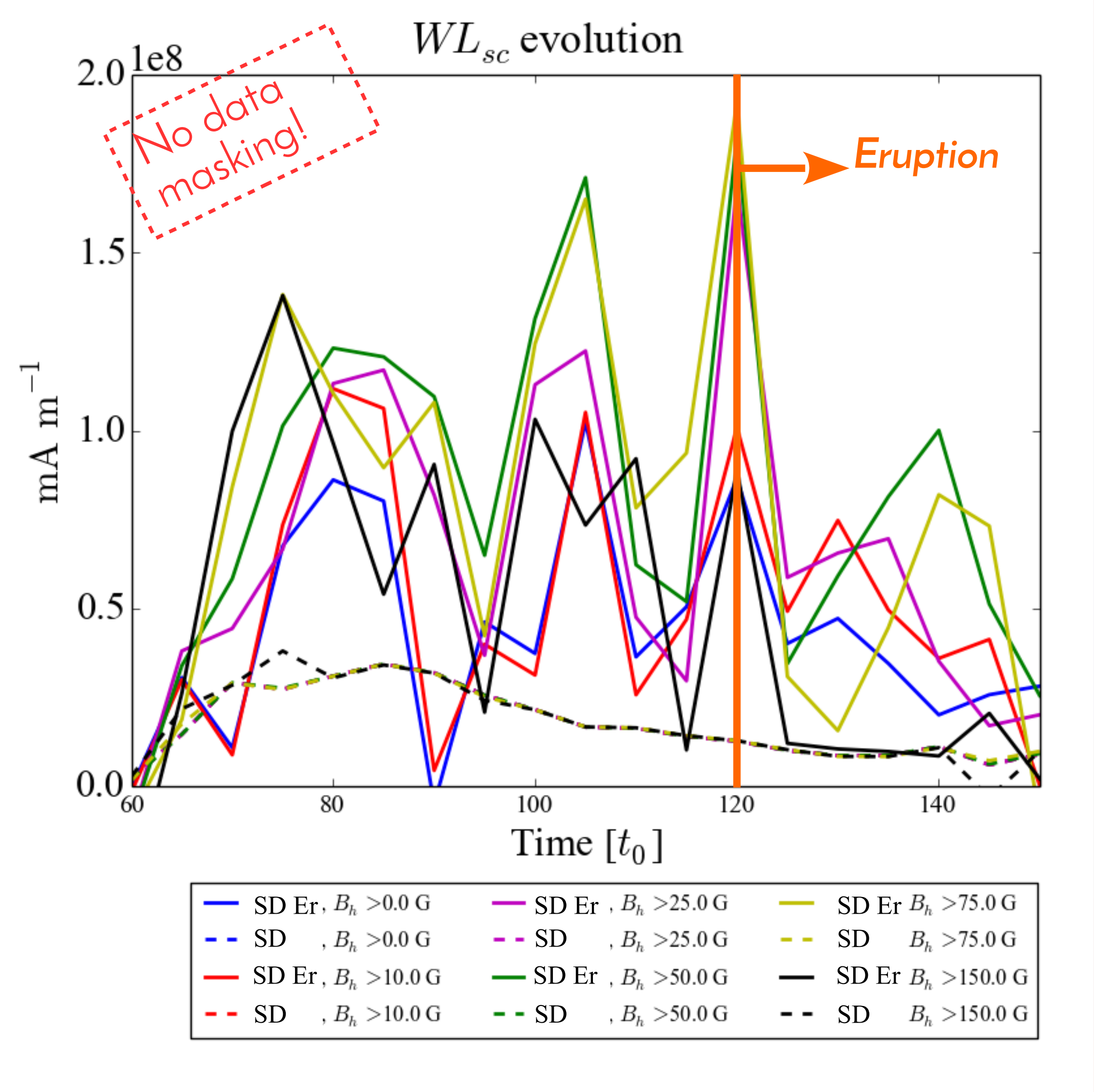
Coronal magnetic dipole

Twisted flux tube superimposed
in the convection zone

Physical threshold B_h



Parametric study of WL_{sc}



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

Solid lines : eruptive simulations
Dashed lines : non-éruptive

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