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Predicting geo-effectiveness of CMEs with EUHFORIA coupled to OpenGGCM

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euhforia

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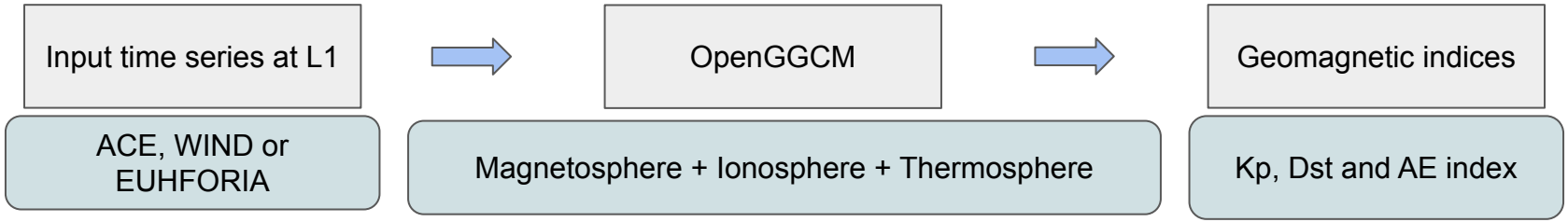
EUHFORIA + OpenGGCM



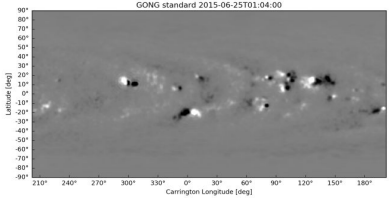
- We perform OpenGGCM simulations to predict geomagnetic activity caused by CME events.
- OpenGGCM simulations are driven by solar wind data at L1 from
  - in-situ observations: OMNI (*Reference for comparison*)
  - MHD Simulations: EUHFORIA (with unmagnetised Cone CME and flux rope Spheromak CME)
- We compare the geomagnetic indices predicted by OpenGGCM using different inputs with measured data.

EUropean **H**eliospheric **FOR**ecasting **I**nformation **A**sset (EUHFORIA)

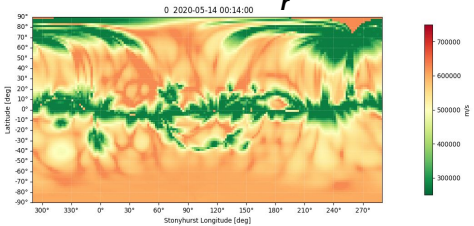
Pomoell & Poedts, 2018

Corona: Semi-Empirical WSA model

Synoptic Magnetogram (1 R_{sun})



v_r



PFSS model (1 - 2.6 R_{sun})

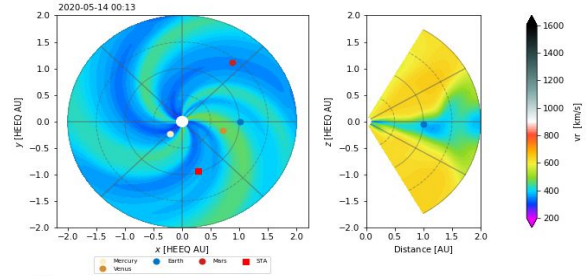
SCS model (2.3 R_{sun} - 0.1 AU)

MHD parameters (0.1 AU) using empirical relations

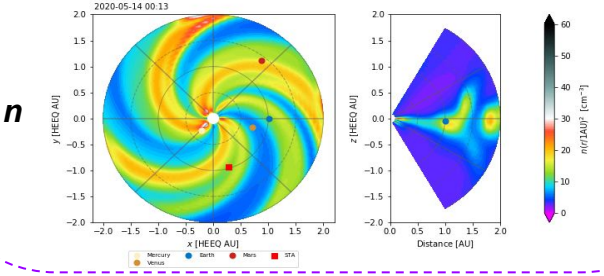
Heliosphere: time dependent ideal MHD model

Evolves MHD parameters ***v***, *n*, ***B***, *T* (0.1 - 2.0 AU)

v



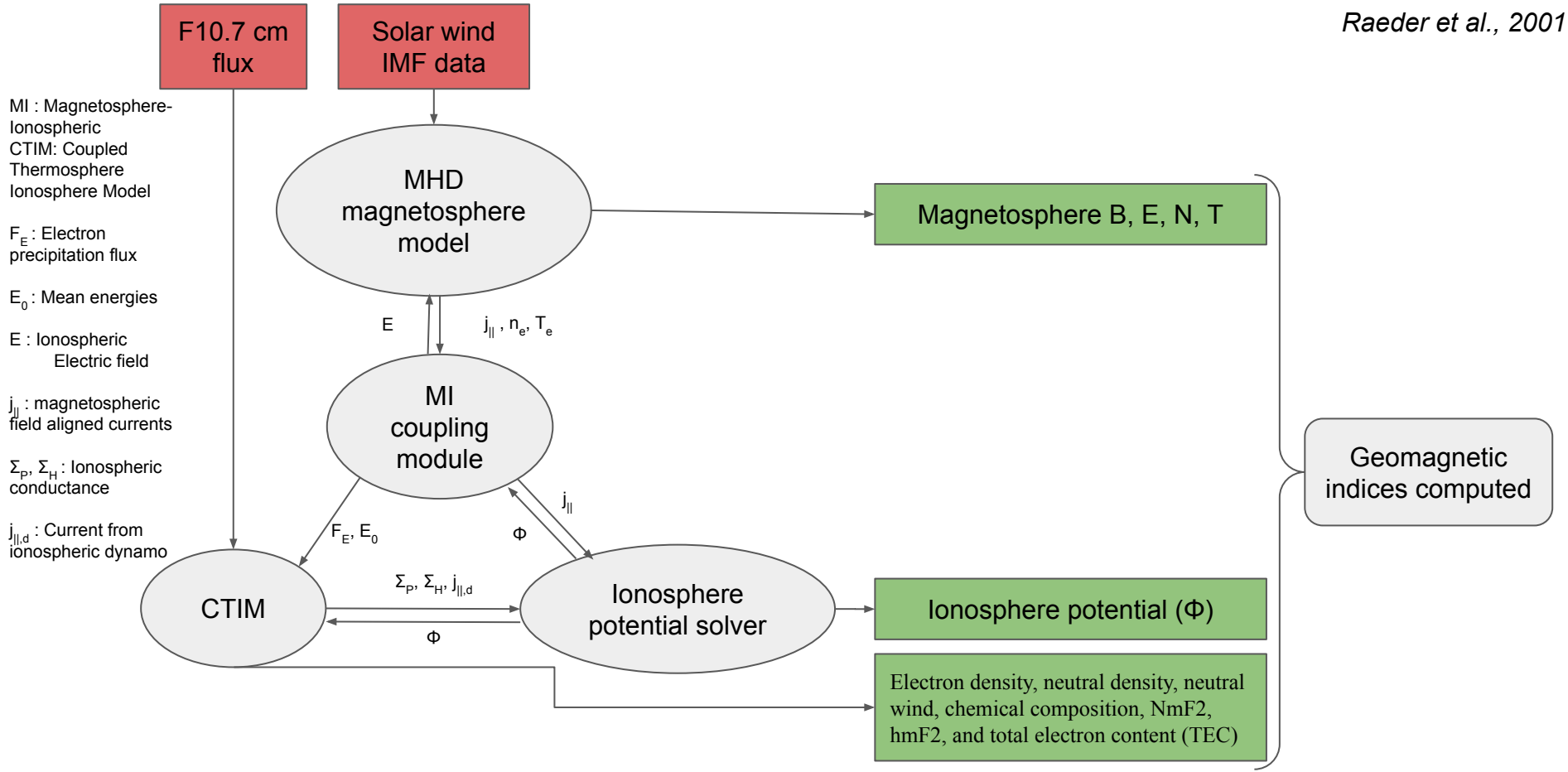
n



Solar wind relaxation → CME insertion @0.1 AU → Forecasting

Open Geospace General Circulation Model (OpenGGCM)

Raeder et al., 2001

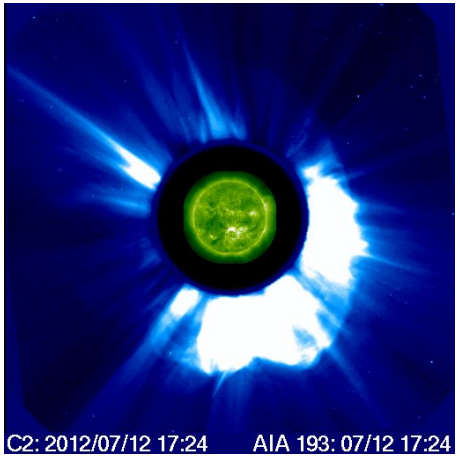


Test case: Event 2012-07-12

Textbook event: Hu+2016; Gopalswamy+2017; Marubashi+2017 & more

Remote observations

- Fast Earth-directed halo CME
- Single CME event
- Good STEREO position for 3D reconstruction



https://cdaw.gsfc.nasa.gov

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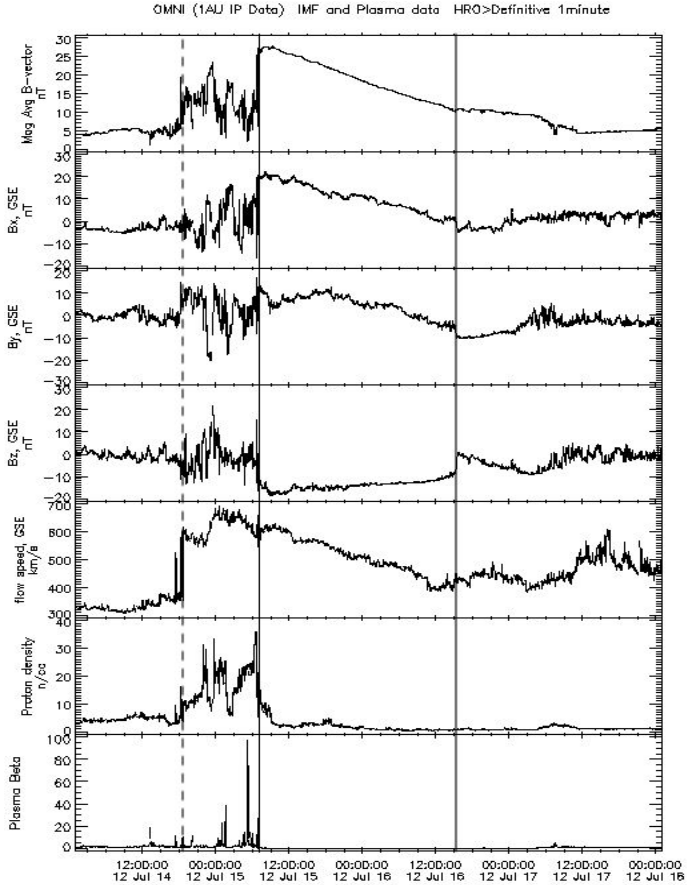
In-situ (@ L1)

- Clear CME/ICME association
- ICME: Shock+sheath+Magnetic cloud (flux-rope)



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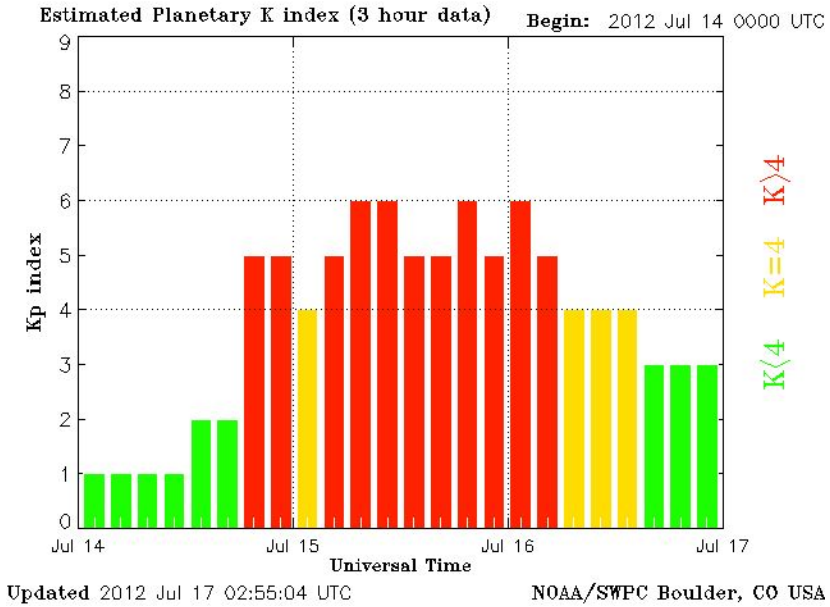
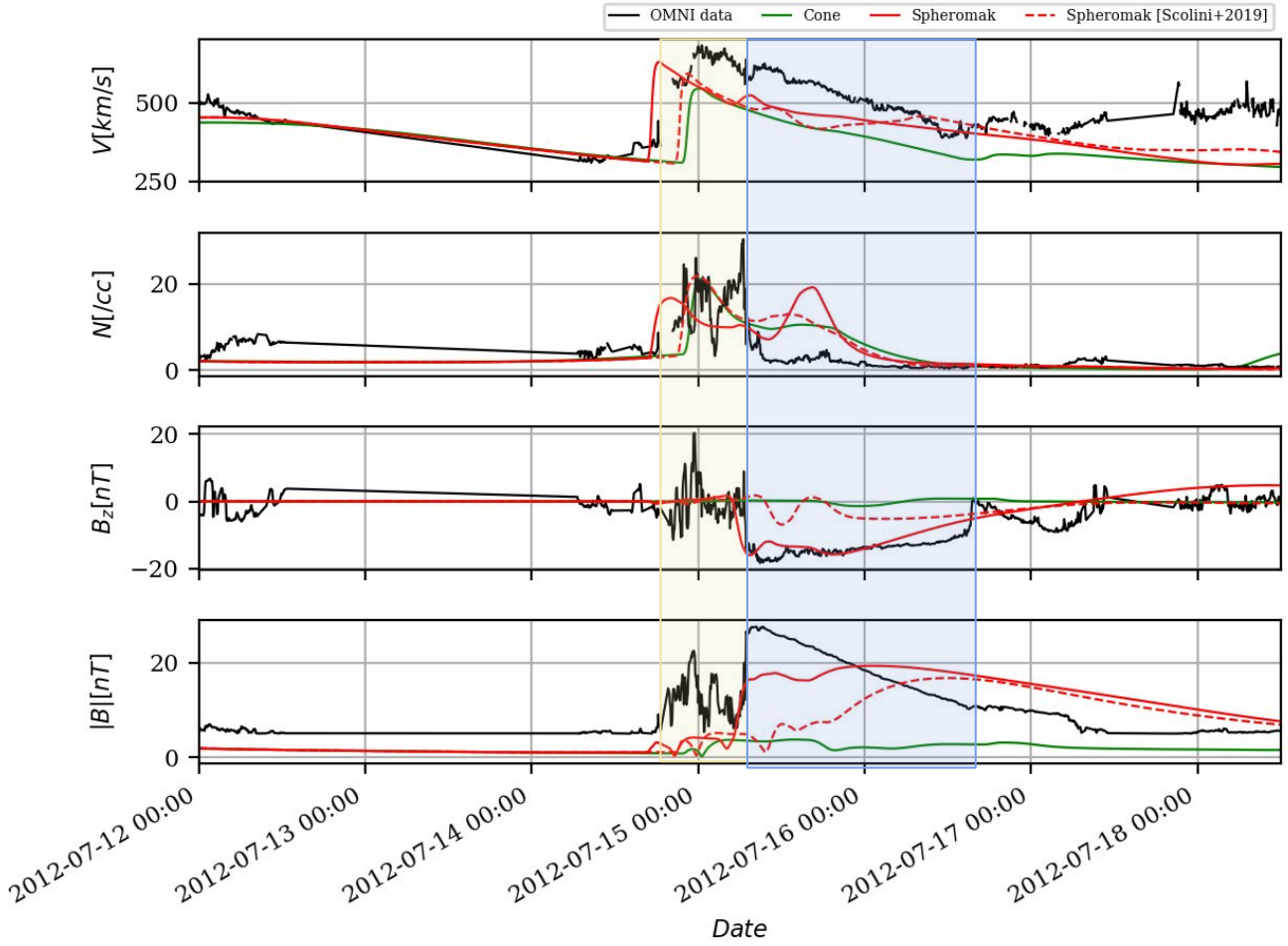
@ Earth

- Moderate geomagnetic storm (prolonged southward Bz)

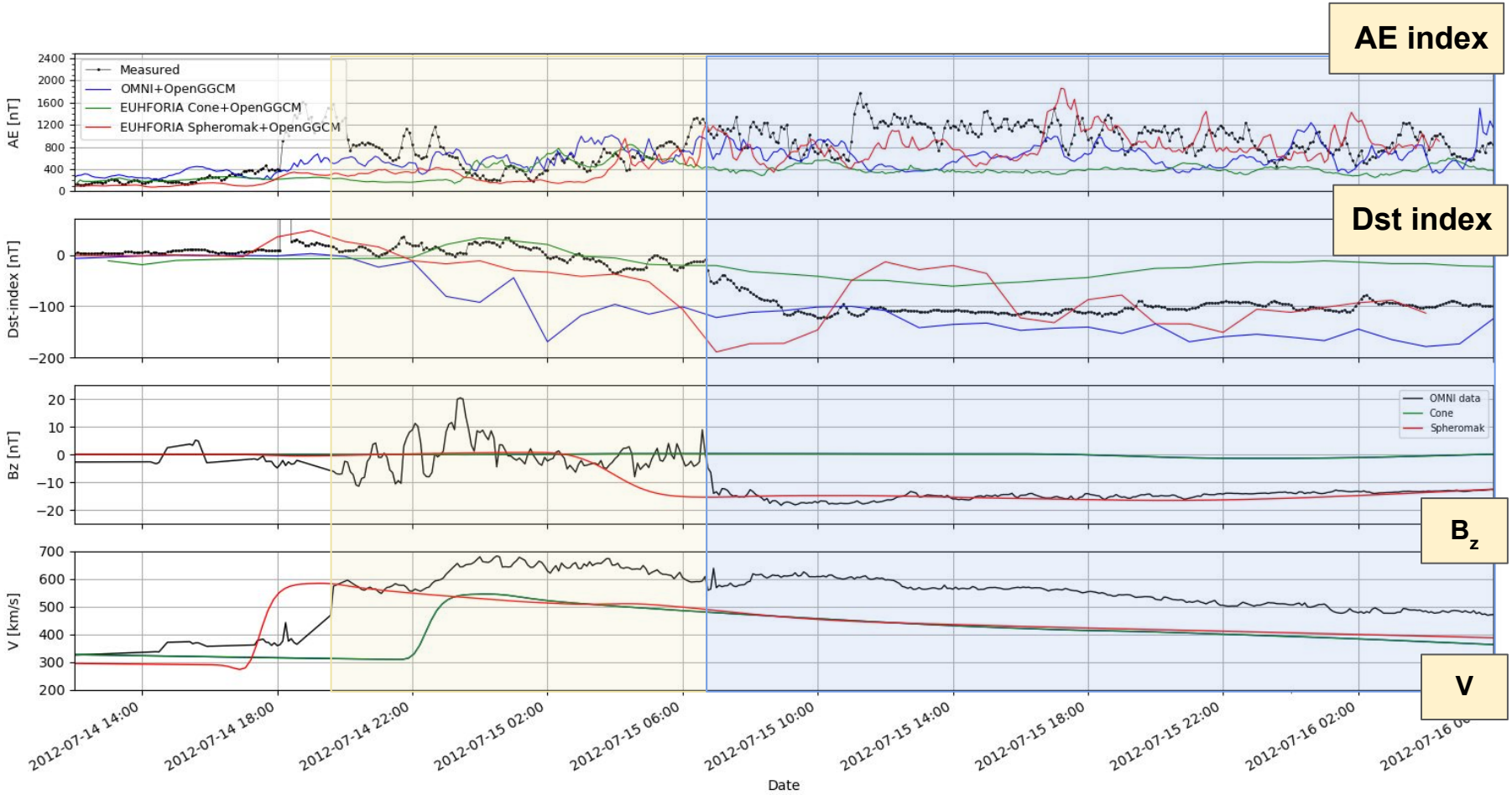


Event 2012-07-12 @Earth



- **Arrival time, speed** and **number density** peaks reproduced at Earth.
- Flux rope CME modelling upgraded as compared to Scolini et al., 2019
- IMF rotations in all magnetic field components of flux rope well-captured
- Flux rope model enhances the predictions of **B** and **B_z** by around 48% and 46% as compared to Cone CME

Geomagnetic indices from OpenGGCM



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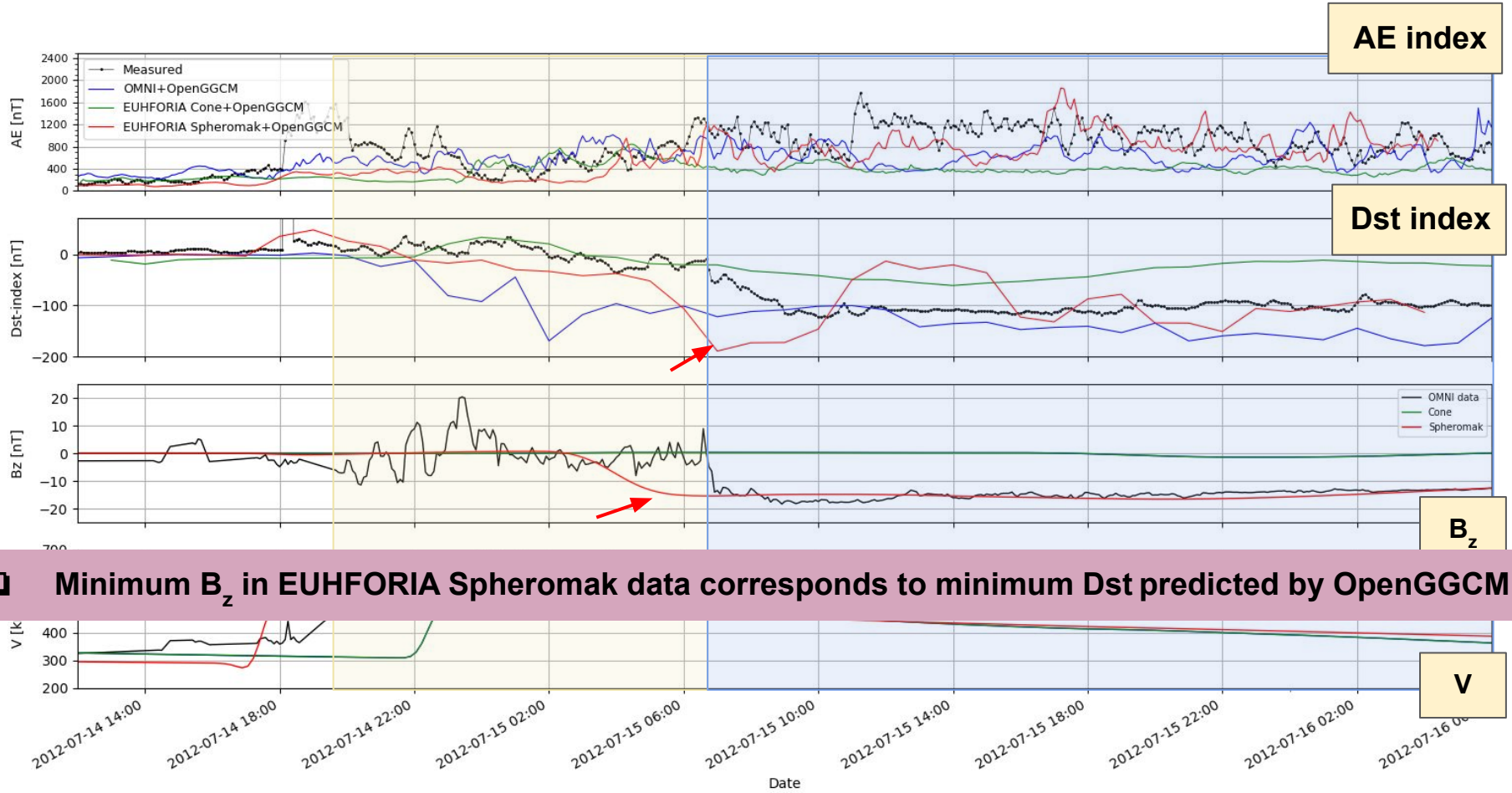

- Minimum B_z in EUHFORIA Spheromak data corresponds to minimum Dst predicted by OpenGGCM

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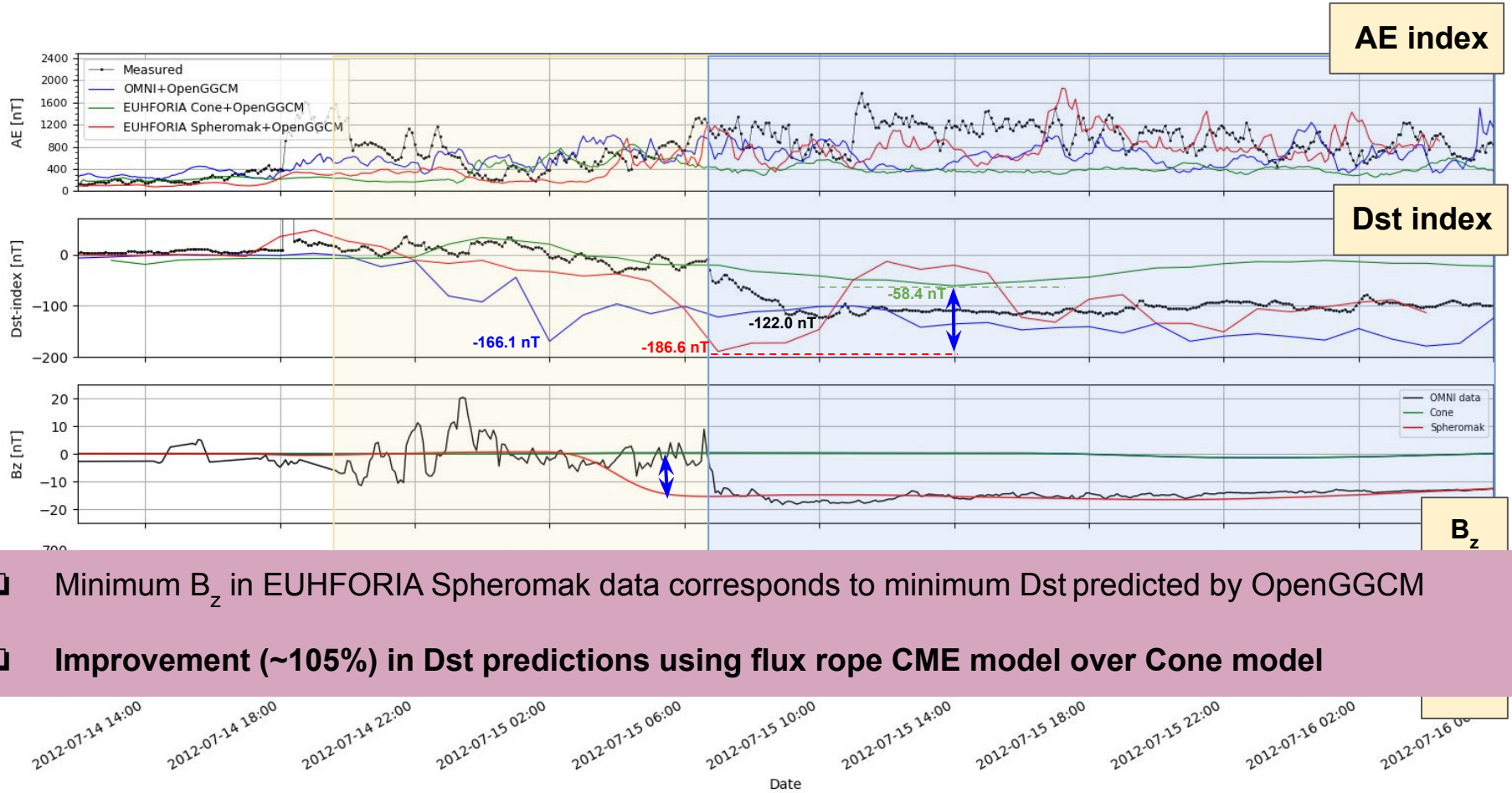
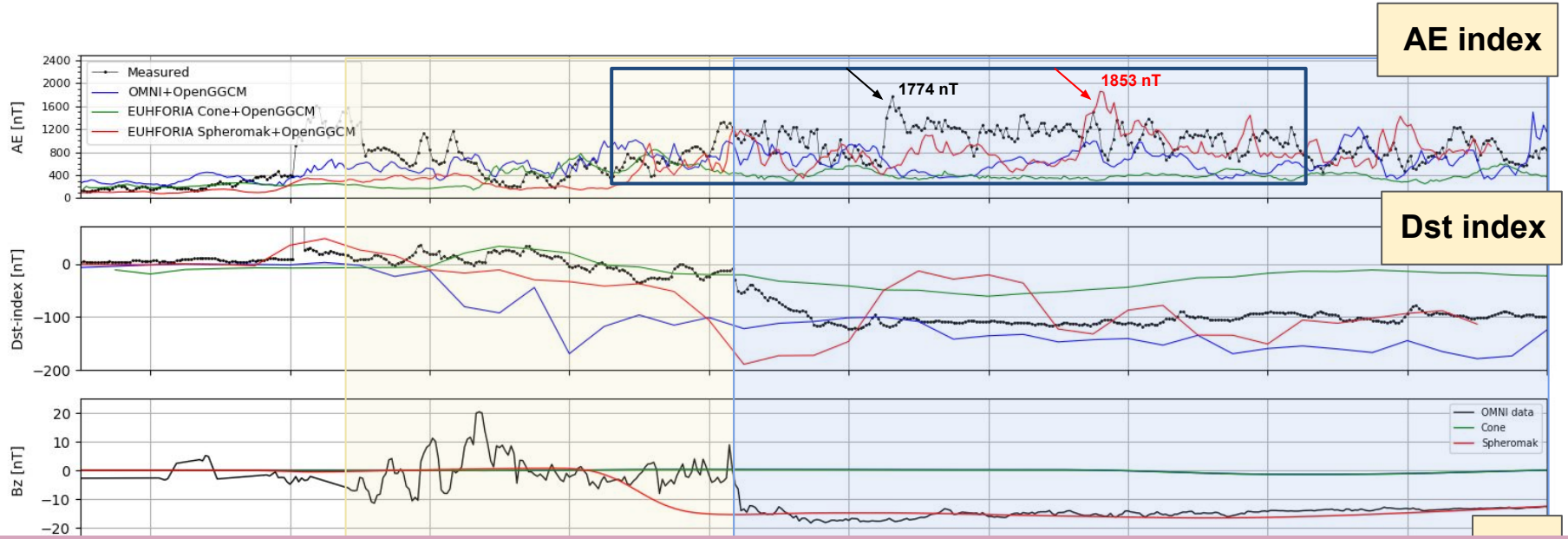


- Minimum B_z in EUHFORIA Spheromak data corresponds to minimum Dst predicted by OpenGGCM
- **Improvement (~105%) in Dst predictions using flux rope CME model over Cone model**

Geomagnetic indices from OpenGGCM



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- **AE index corresponding to negative B_z region reproduced with flux rope CME (~57% better than Cone)**

Geomagnetic indices from OpenGGCM

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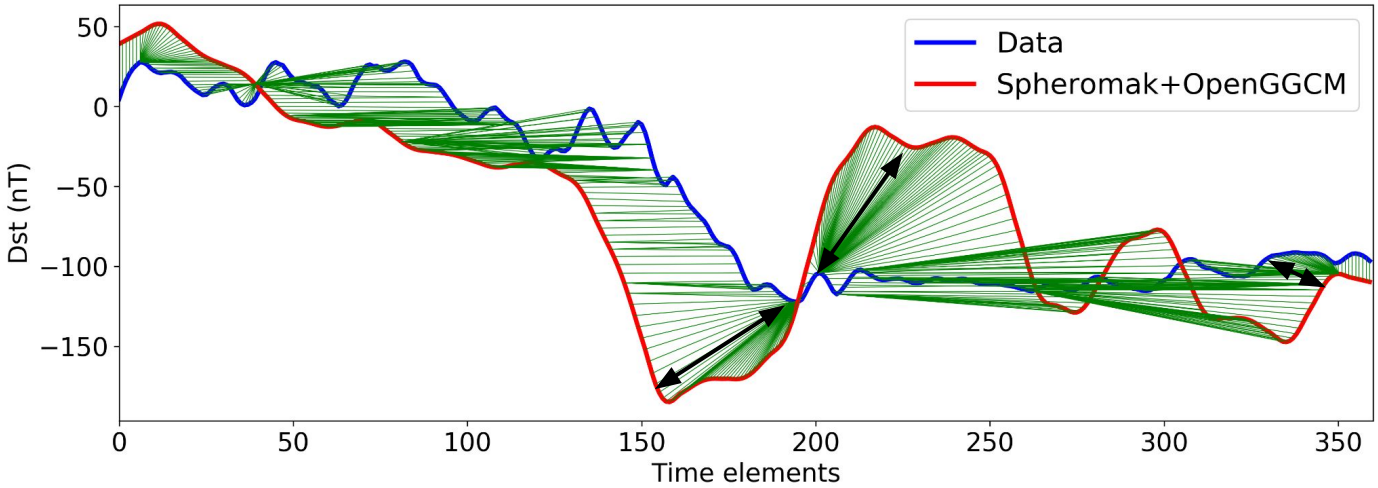
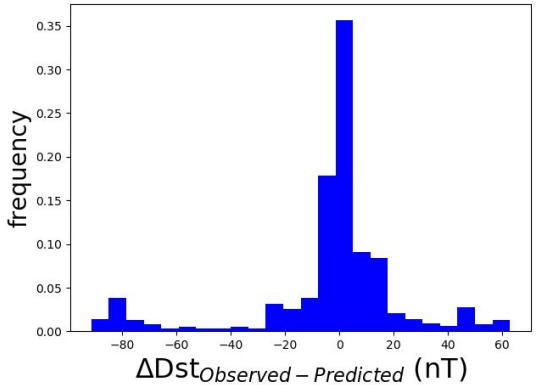
- Improvement (~105%) in Dst predictions using flux rope CME model over Cone model
- AE index corresponding to negative B_z region reproduced with flux rope CME (~57% better than Cone)
- **EUHFORIA(Spheromak)+OpenGGCM performing well as compared to the reference model**

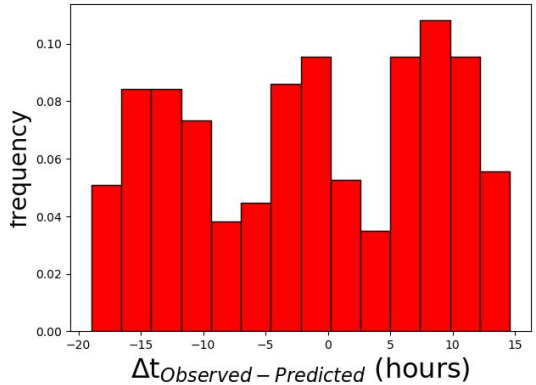
Metric: Dynamic Time Warping (DTW)

➔ DTW (*Gorecki and Łuczak, 2013; Keogh and Pazzani, 2001, and references therein*) measures similarity between two sequences that have a similar patterns but differ in time.

➔ Sequences are warped in non-linear manner to match each other
- ◆ Optimal alignment of time-dependent sequences
- ◆ Algorithm copes with time deformations







- Initial and main phase of the storm mapped successfully
- Time gaps computed
- Additional abrupt extrema in modelled data mapped reasonably with data

Quantification of shifts in time and amplitude between the maps

Samara et al, 2021 (in preparation)

Conclusion

- Successful coupling of EUHFORIA with OpenGGCM
- Validation with observed CME event of 12 July 2012
  - Flux rope (Spheromak) CME performs as good as reference model and significantly better than Cone CME
  - AE and Dst indices predicted with comparable magnitude to measured data
- Application of advanced metric, Dynamic Time Warping (DTW) for assessing the coupling

EUHFORIA(Spheromak)+OpenGGCM w.r.t	Δmax(AE) %	Δmin(Dst) %
OMNI+OpenGGCM (reference)	26	7

	Δt_max(AE) [hr]	Δt_min(Dst) [hr]
EUHFORIA(Spheromak) +OpenGGCM w.r.t observed data	6	-3

Limitations & Future work

- Underestimation of B_z with EUHFORIA hinders prediction of geomagnetic indices with OpenGGCM - Need improvement in observations-based modelling of CMEs
- Solar wind before CME arrival in simulations has smooth temporal fluctuations - does not replicate AE variations accurately
- OpenGGCM simulations are not fully stable, abrupt oscillations in Dst observed. To be studied further.
- EUHFORIA+OpenGGCM coupling has to be validated further with more events and a detailed assessment of its performance to be performed using DTW (*Maharana et al*, *in preparation*)

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Thank you

Questions?

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