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Multiscale Geoeffectiveness Forecasting using SHEATH and DAGGER

Vishal Upendran
[vishal@lmsal.com]

Bay Area Environmental Research Institute
Lockheed Martin Solar and Astrophysics Laboratory
Frontier Development Lab

FDL-X HELIO 2023 MULTISCALE GEOEFFECTIVENESS
A MULTISCALE 'SUN-TO-MUD' GIC FORECASTING SCHEME

RESEARCHER

MICHAEL JOHN HEYNS

TIMEZONE: BST

RESEARCHER

SAHITI YERRAMILLI

TIMEZONE: EST

FACULTY

BANAFSHEH FERDOUSI

TIMEZONE: EDT

RESEARCHER

RAMAN MUKUNDAN

TIMEZONE: CET

FACULTY

ANGELOS VOURLIDAS

TIMEZONE: ET

FACULTY

VISHAL UPENDRAN

TIMEZONE: PDT

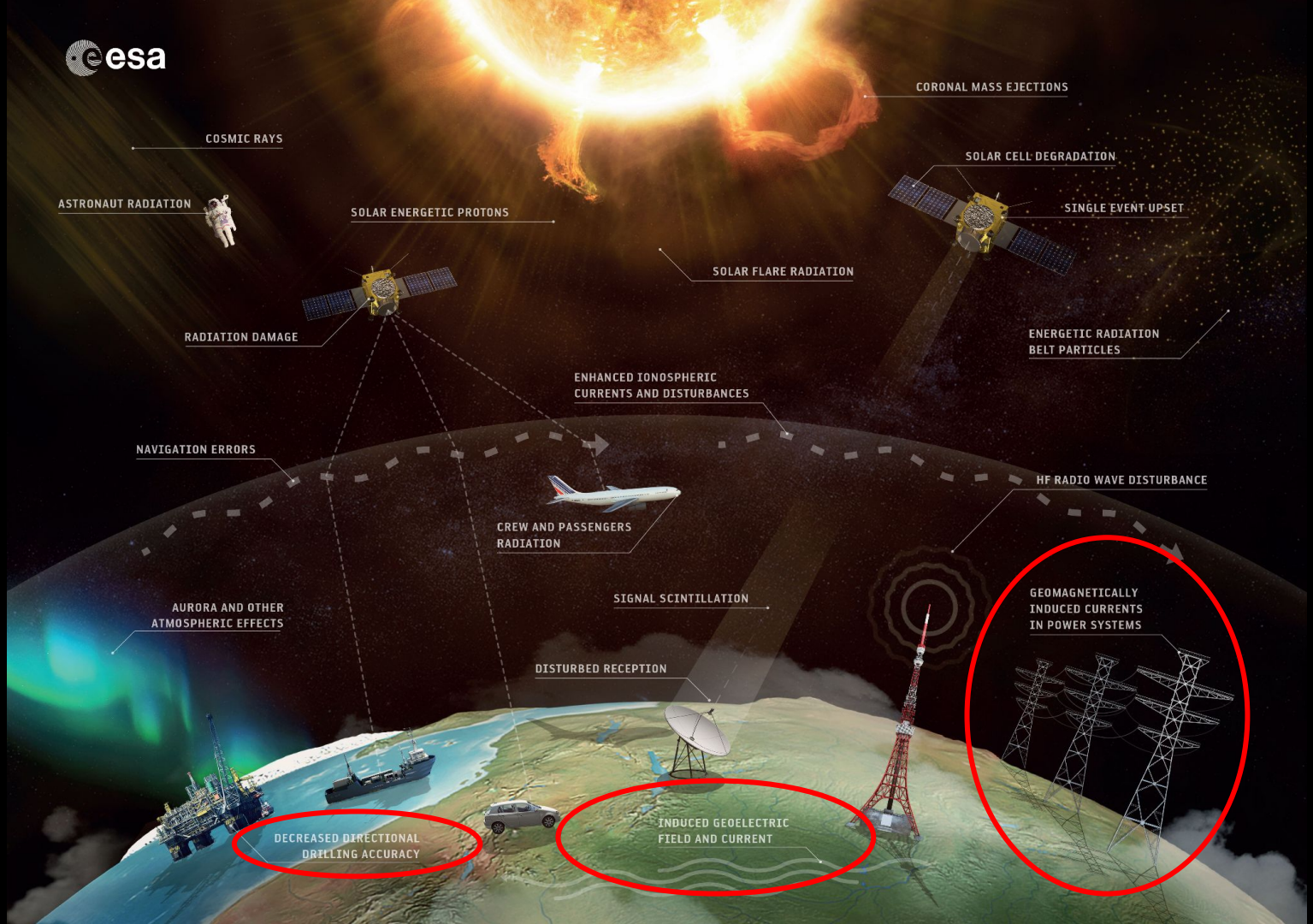
.. and the FDL 2020 team + external collaborators!

Panagiotis Tigas
Evangelos Paouris
Teo Bloch
Siddha Ganju
Mark Cheung
Asti Bhatt
Ryan McGranaghan
Yarin Gal

Proxy/Input

Geomagnetic Field

Direct Effect



What do stakeholders need?

Forecasts need to be:

- **Fast** – Near-instant run time and **minimal computational expense**
- **Localized** – Able to timeously & accurately forecast **local effects** due to fine scale driving
- **Actionable** – Sufficient **lead time** with an estimate of **uncertainty**

Geomagnetic disturbances and their drivers are highly localized

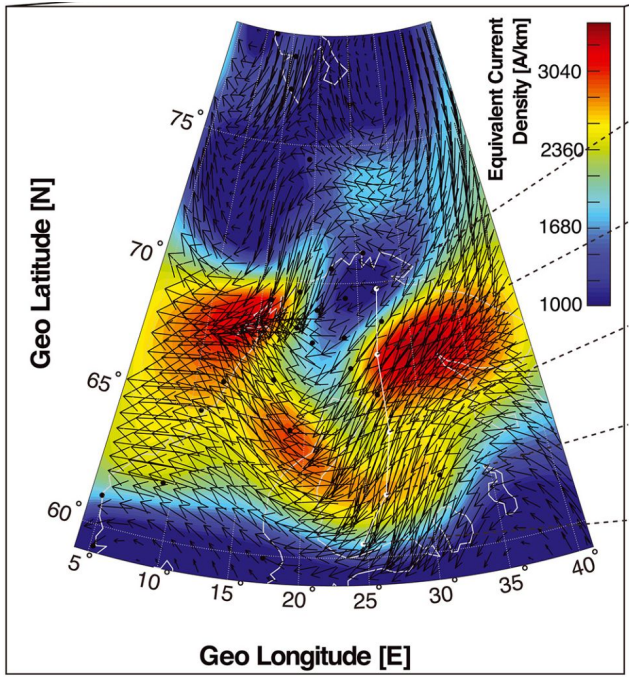
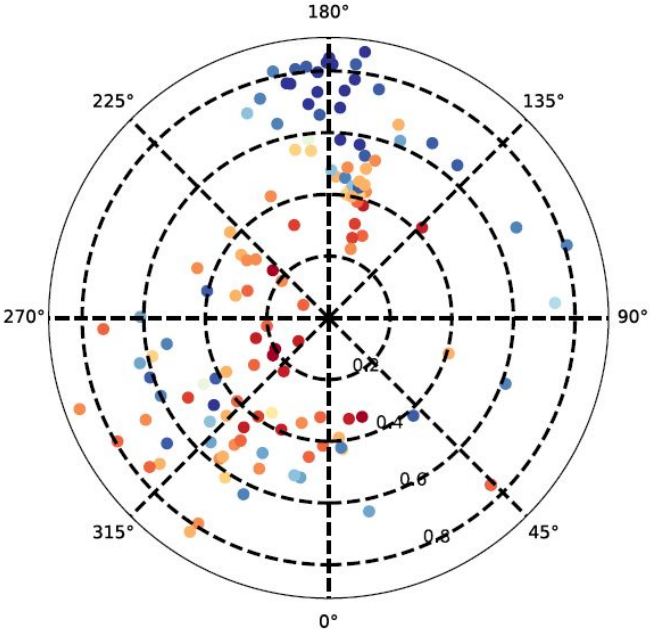


Image: Dimmock et al., 2019

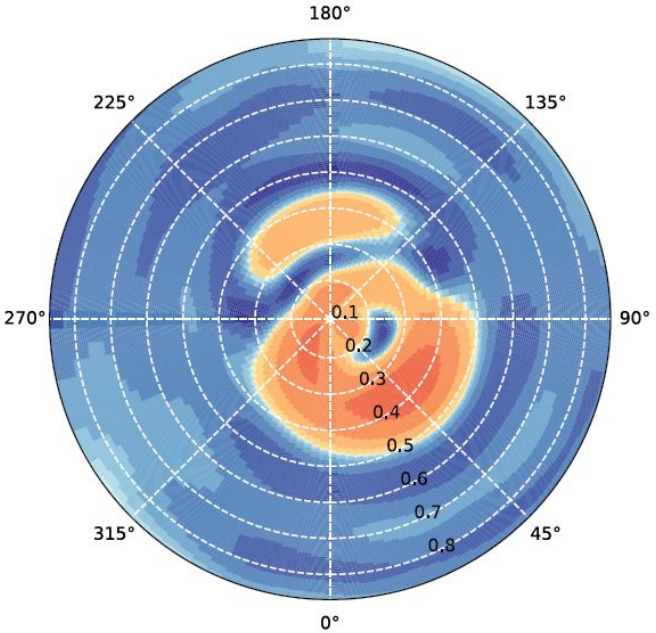
Deep leArninG Geomagnetic pErtuRbation (DAGGER)

DAGGER-V1— FDL 2020

Targets: SuperMAG Geomagnetic Field Measurements

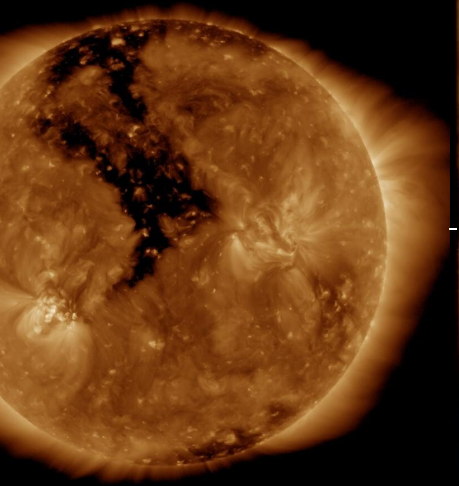


Predictions: Global Spherical Harmonic Basis Estimates of Geomagnetic Field



Examples from Upendran et. al., 2022

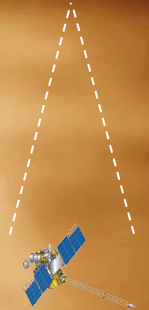
Adaptive Forecast Refinement



Sun:
Remote sensing

Propagation time: ~days
Length scales: 1000s of km to millions of km

SHEATH + DAGGER:
Low fidelity, high lead time forecasts

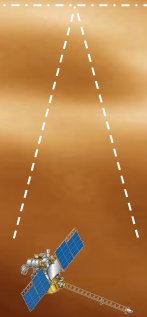


L1

Credits: NASA SVS; data from Craig DeForest, SwRI

Adaptive Forecast Refinement

Propagation time: ~minutes
Length scales: 100s - 1000s of km



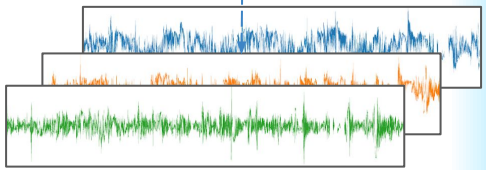
L1

DAGGER++
High fidelity, low lead time forecasts using contextual magnetospheric state

SHEATH

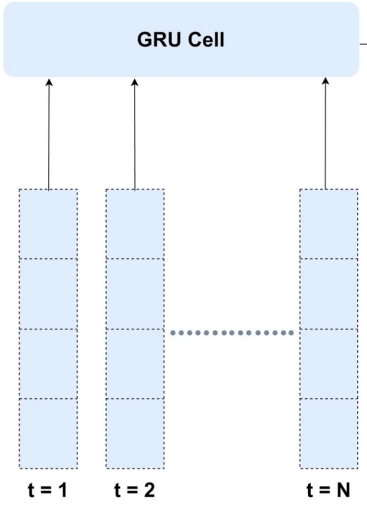
Coronal hole & active region masking, feature generation

Solar wind regressor

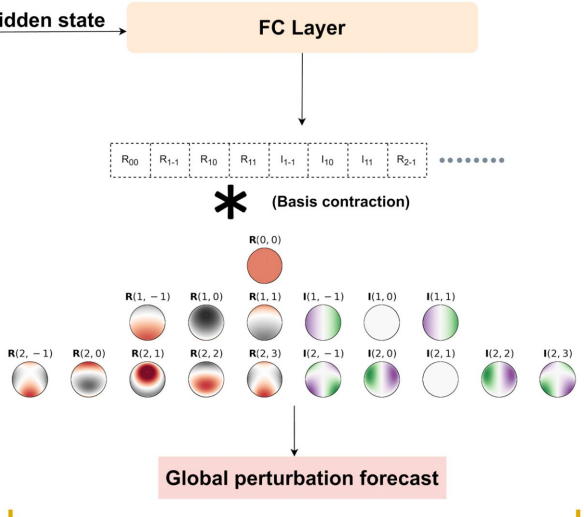


Solar wind forecasts: days in advance

DAGGER



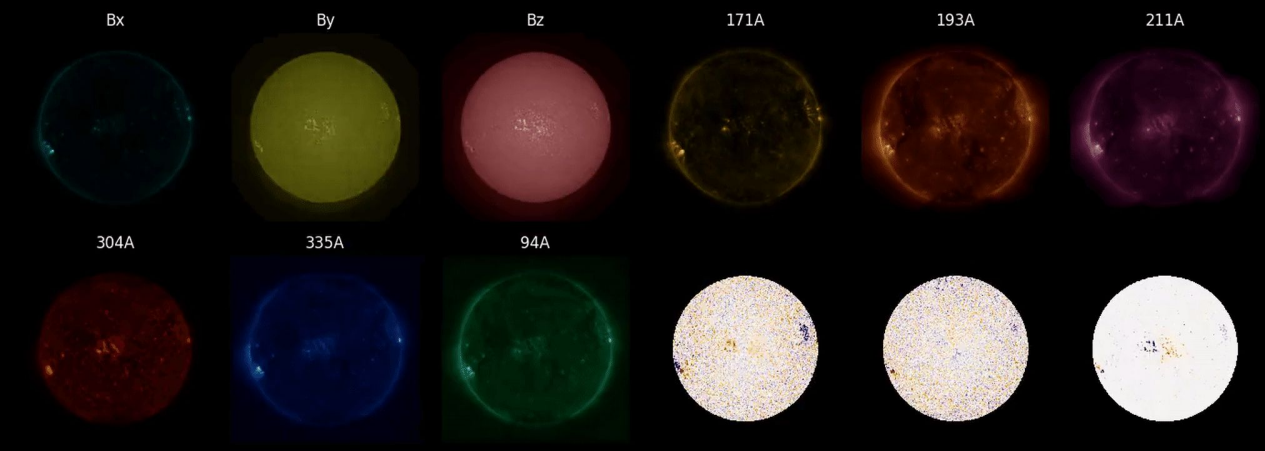
Hidden state



Solar wind encoder

Magnetospheric encoder

Global forecaster



FDL-X: Joint Study Event
Sept 27, 2017

SDOML Input

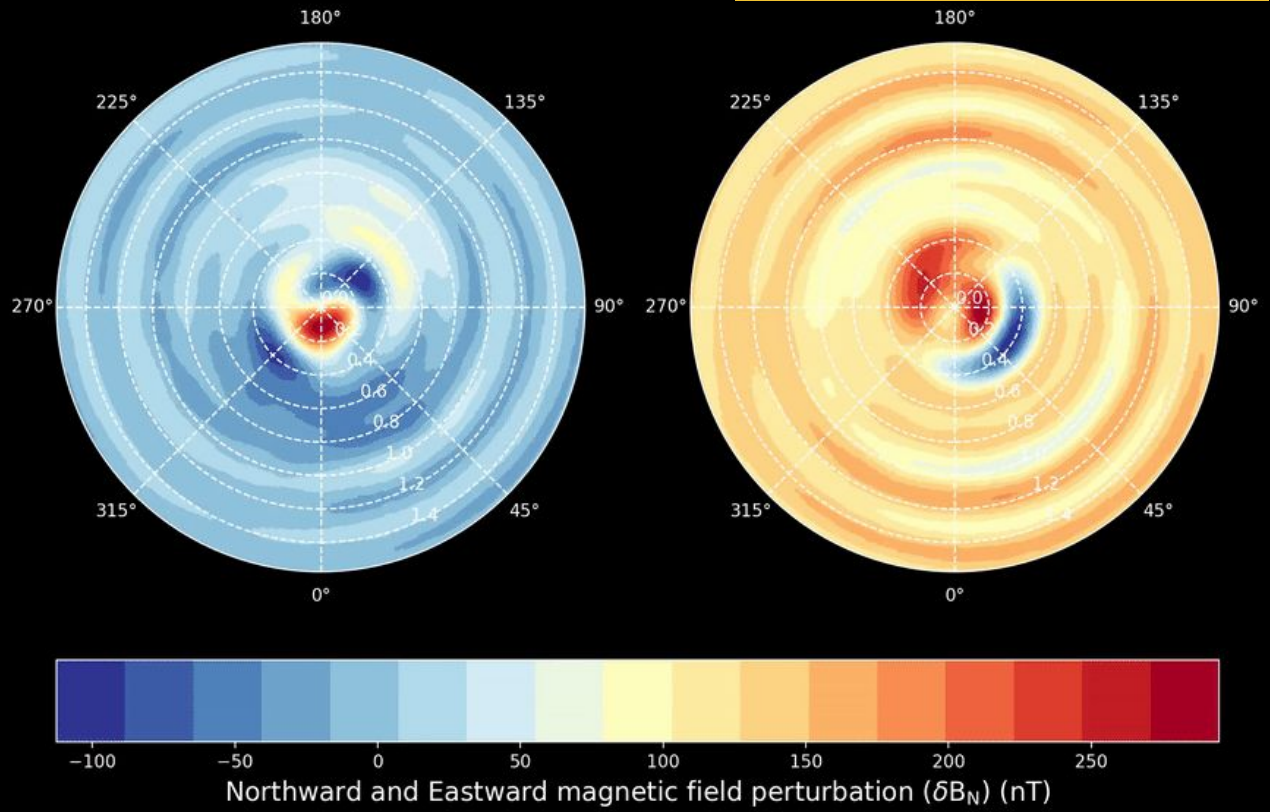
Solar wind forecast: multi-day ahead

SHEATH: Solar wind High-speed Enhancements And Transients Handler

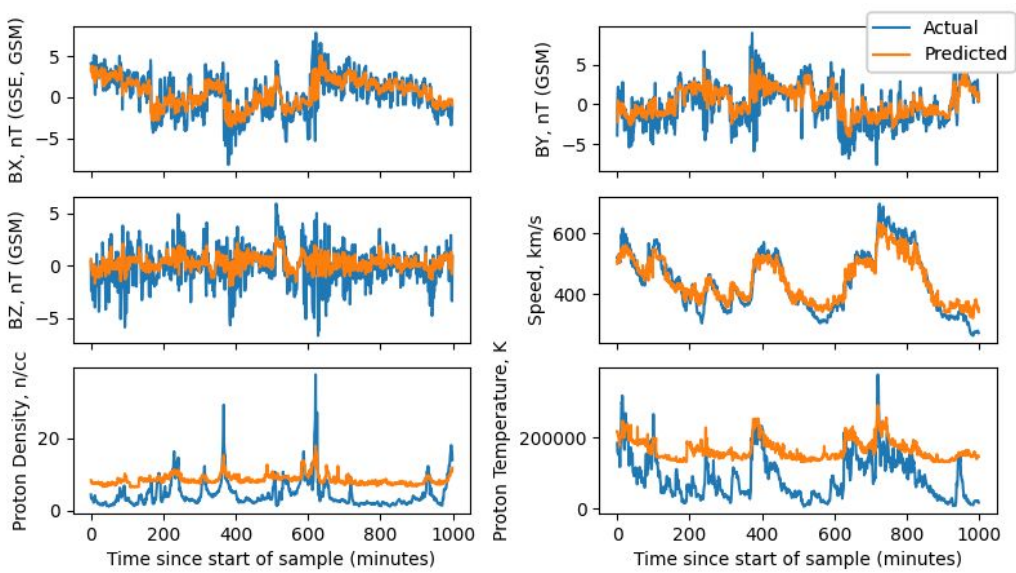
FDL-X: Joint Study Event
Sept 27, 2017

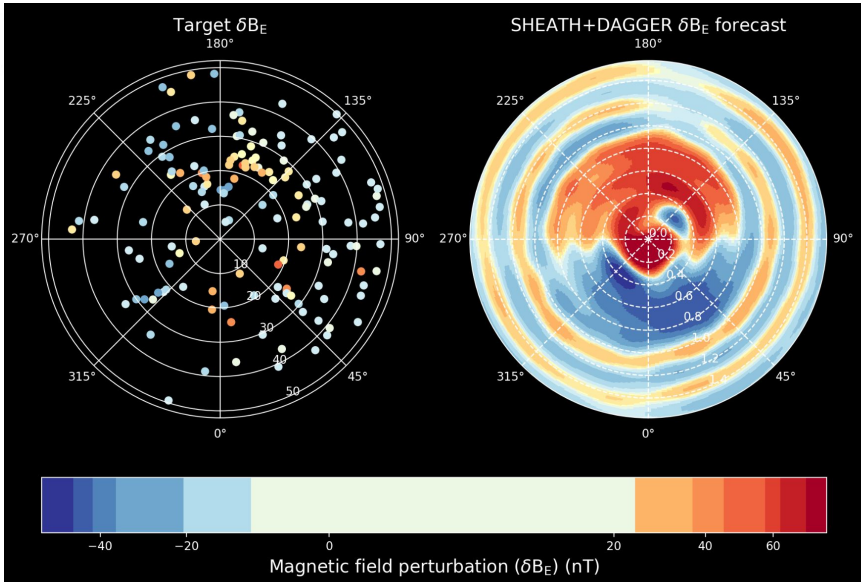
DAGGER forecast from SHEATH forecast

SHEATH& DAGGER Pipeline — Multi-Day Ahead Forecasts



SHEATH-DAGGER Pipeline — Multi-Day Ahead Forecasts





FDL-X: Joint Study Event
Sept 27, 2017

	Bx (nT)	By (nT)	Bz (nT)	v (km/s)	n_i (n/cc)	T_i (k)
Test MAE	1.9396	2.1187	1.5563	86.443	4.7149	1.095×10^5
Test RMSE	2.3849	2.7678	2.0726	98.665	5.4545	1.164×10^5

DAGGER++ : Enhancing DAGGER

Imbalanced Regression Correction

- Data density difference between storm time and quiet time
- Adjust loss function weight per timestep for storm time data

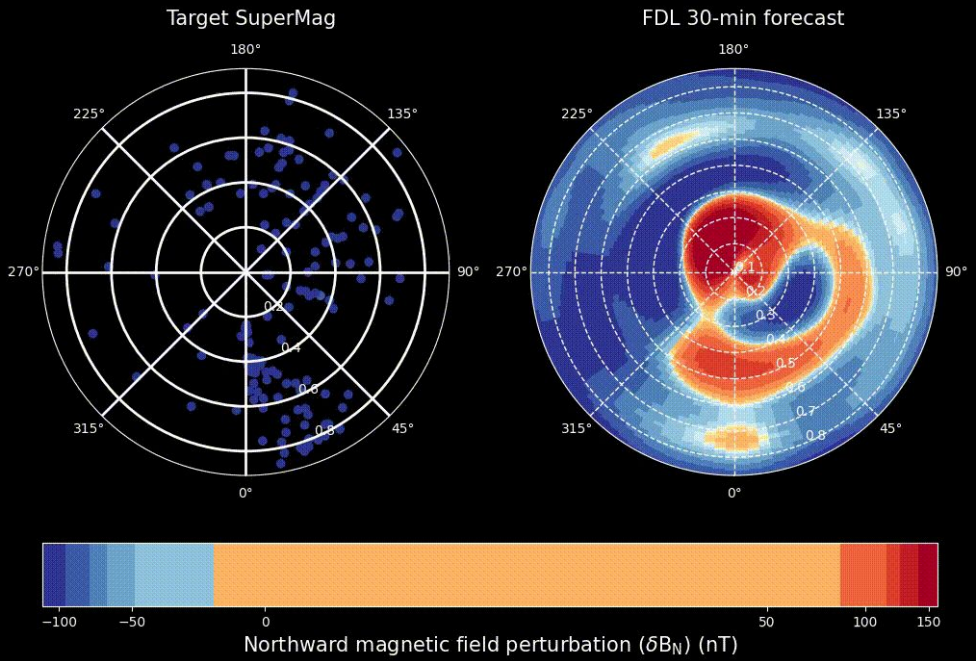
Geomagnetic Indices

- Improve accuracy through the inclusion of current state of geospace
- Incorporate additional features, i.e., SME, SMU/L, SMR

Ground Station Regularization

- Allow higher spherical harmonic orders to capture more localized signatures
- Adjust loss function weight per target by station density

Results — Station Regularization with Indices



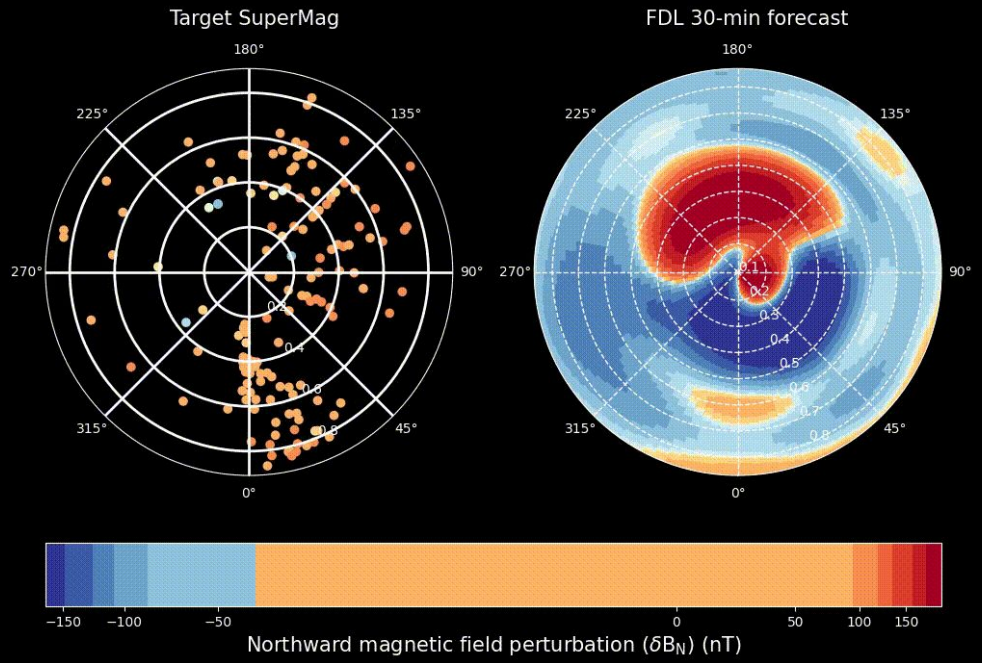
Best-Performing Stations

Station	MAE (nT)
SUA	49.56
C07	55.77
KUV	69.80

Worst-Performing Stations

Station	MAE (nT)
DIK	198.42
FRD	193.82
RAL	192.55

Results — Imbalanced Regression with Indices



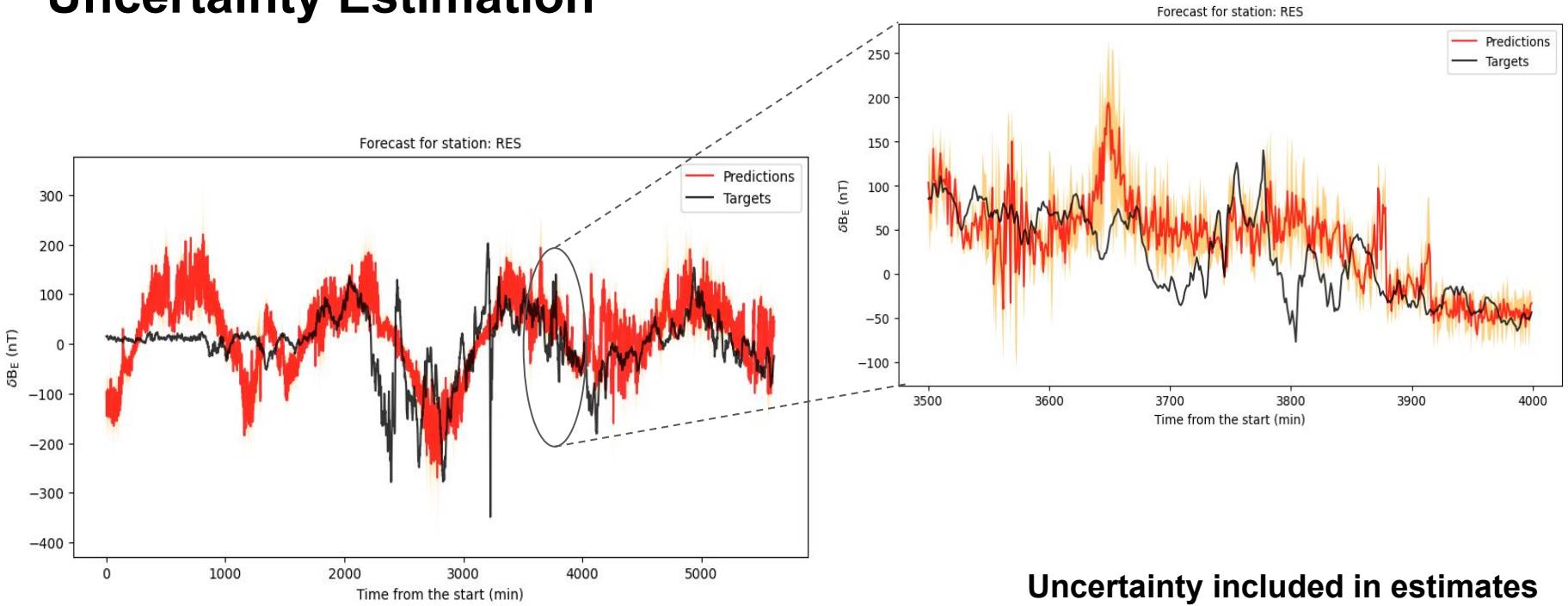
Best-Performing Stations

Station	MAE (nT)
SUA	17.67
C07	17.76
KUV	19.62

Worst-Performing Stations

Station	MAE (nT)
FRD	150.24
HAD	146
NVS	144.18

Uncertainty Estimation



Uncertainty included in estimates through deep ensembles

Multiscale Geoeffectiveness Results

SHEATH and DAGGER

Solar wind and IMF forecaster using physics-informed solar features, coupled to DAGGER geomag perturbation forecaster.

➔ **Forecast lead time:** several days.

DAGGER++

Updated, high TRL DAGGER model providing forecast uncertainties. Incorporates geomagnetic indices, station sparsity adaptation, and storm time statistic regularization.

➔ **Forecast lead time:** 10s of minutes at high fidelity.

Integrated pipeline

Integration with long term data source SDOML allows real-time data ingestion and operational deployment into the future.

Local forecasts, globally.

FDL-X combines integrated AI pipelines, machine learning and domain science across heliophysics challenges. Please join us for presentations from all three teams.

Multiscale Geoeffectiveness Forecasting using SHEATH and DAGGER

Vishal Upendran
Tuesday 2:25 PM

Improving thermospheric drag modeling with EUV images: an FDL-X 2023 project

Tom Berger
Wednesday 1:45 PM

AIA is All You Need: SDO MEGS A&B virtualization via Convolutional Deep Learning

Daniel Gass
Tuesday 2:15 PM

A Scientific Cloud Computing Platform for Ingestion and Processing of SDO Data

Manuel Indaco
Wednesday 2:10 PM

AI Inference products, foundation models and multi-domain approaches to NASA Heliophysics.

FDL-X
James Parr
Wednesday 2:20 PM

Learn more at FDL.AI

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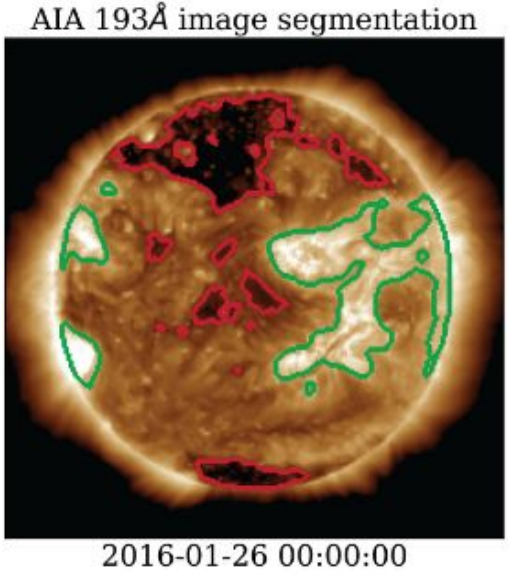
Extra slides

Segmentation scheme: Upendran *et al.* 2020

SHEATH

AIA 193 Å

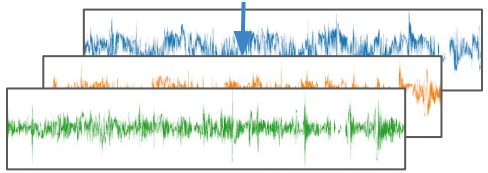
Gaussian Mixture Model



Coronal hole & active region segmentation

CH, AR fractional areas. Intensities, B fluxes in CH and AR.

XGBoost regressor



Solar wind forecasts: days in advance

SHEATH Feature importance