Raising awareness of Application of AI in Space Weather Science & Prediction

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NASA HQ & NASA Goddard Space Flight Center

ISWI Steering Committee Meeting
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Artificial Intelligence and Heliophysics/Space Weather

The Problem: Heliophysics research is becoming an increasingly important area, thanks to our growing reliance on high-tech infrastructure, such as GPS/GNSS systems and power grids, sensitive electronics on satellites, exposure to aviation radiation and exploration of deep space pertaining to passengers and crew and astronaut health respectively, which can be heavily impacted by space weather events.

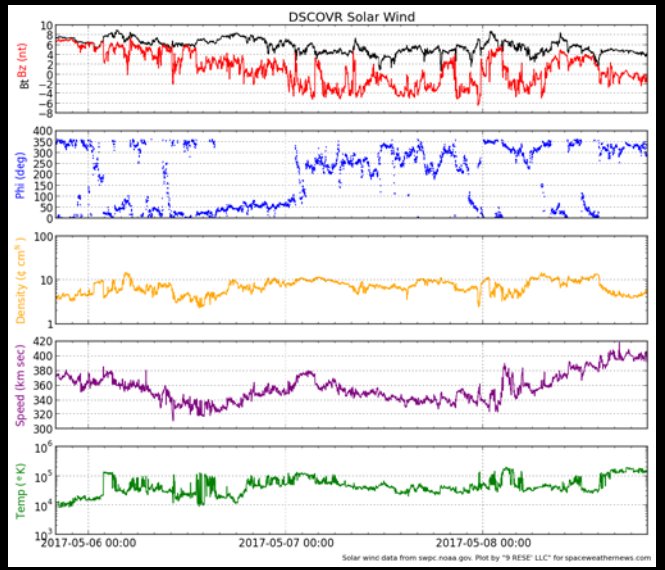
The Opportunity: In light of the evolving data landscape that defines our understanding of the space weather system, the heliophysics community faces both an exciting opportunity and an important imperative to harness new advances in data-driven sciences (e.g. AI) and technologies (e.g. High Performance Computing, GPU). These new techniques are opening the way to take a fresh look at ways in which solar events, such as flares and coronal mass ejections, might have a subtle but measurable effect on terrestrial systems, including weather patterns and even seismic activity.

FDL FRONTIER DEVELOPMENT LAB

FDL is a public / private research partnership between NASA, the SETI Institute and leaders in commercial AI and private space.

Over the past five years FDL has demonstrated a model for breakthrough AI application over a highly accelerated time period - and commercial and international partnership.

SOLAR WIND DATA



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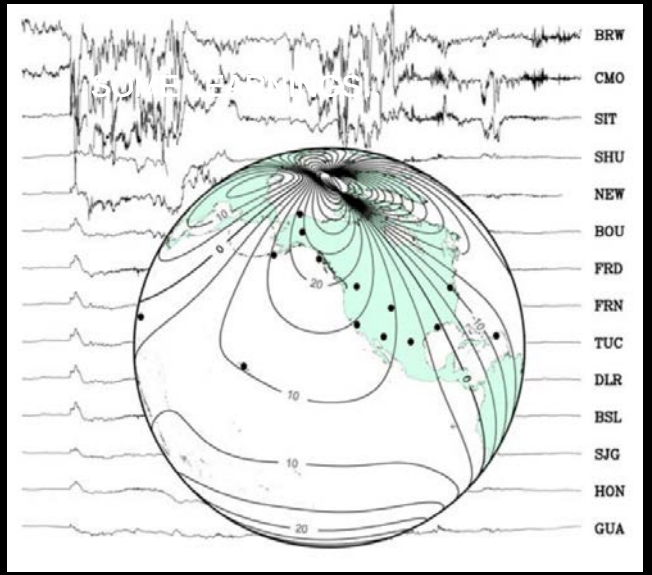
GEOMAG DATA



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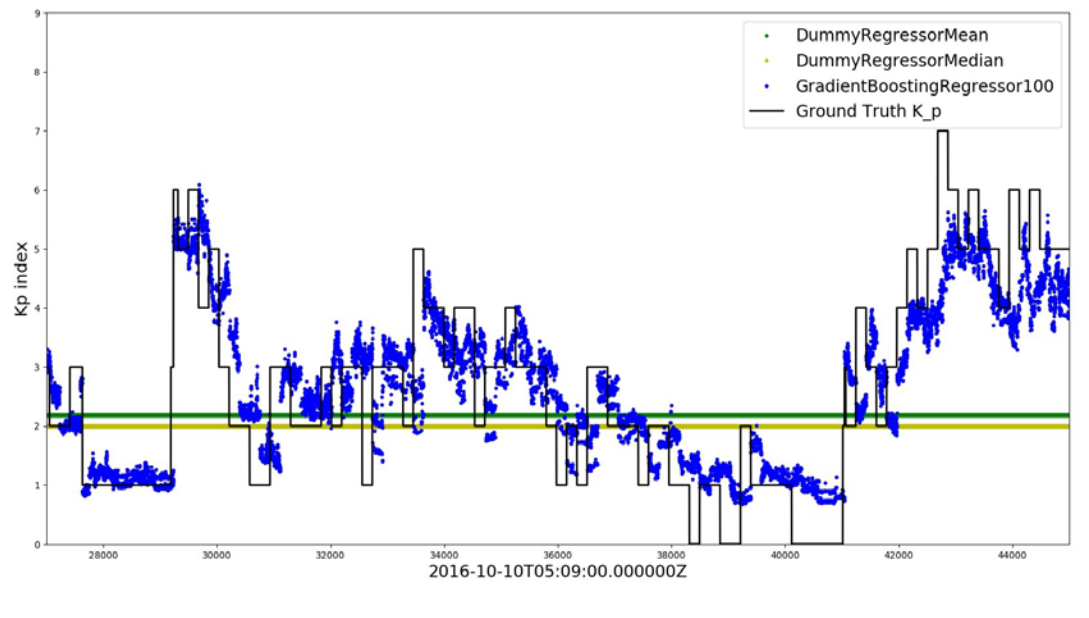
“STING”

(Solar Terrestrial Interactions Neural Network Generator)

Kp Index

Refers to a range of geomagnetic activity levels within a 3-hr interval each day.



STING is able to predict Kp 3 hours in advance.

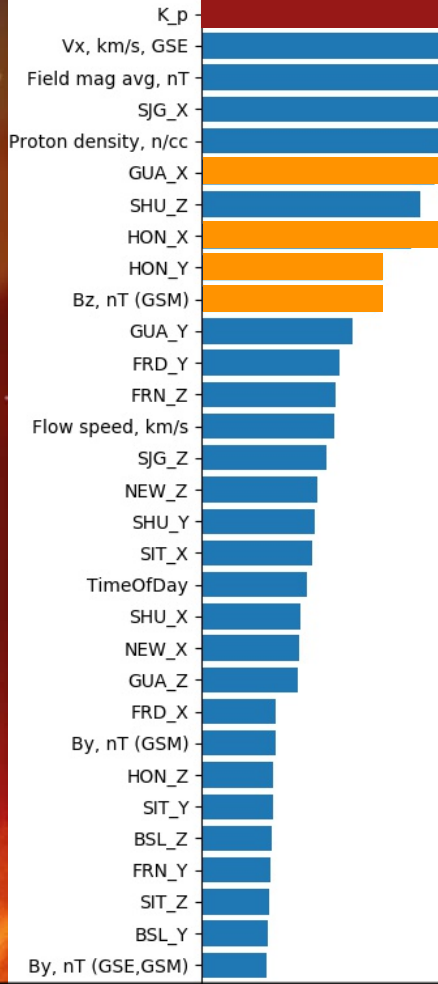
Accurately predicting the variability of Earth's geomagnetic fields in response to solar driving.

SPACE WEATHER
MISSION 01

IBM LOCKHEED MARTIN

SOLAR-TERRESTRIAL INTERACTIONS

SOLAR-TERRESTRIAL INTERACTIONS
FRONTIER DEVELOPMENT LAB 2017



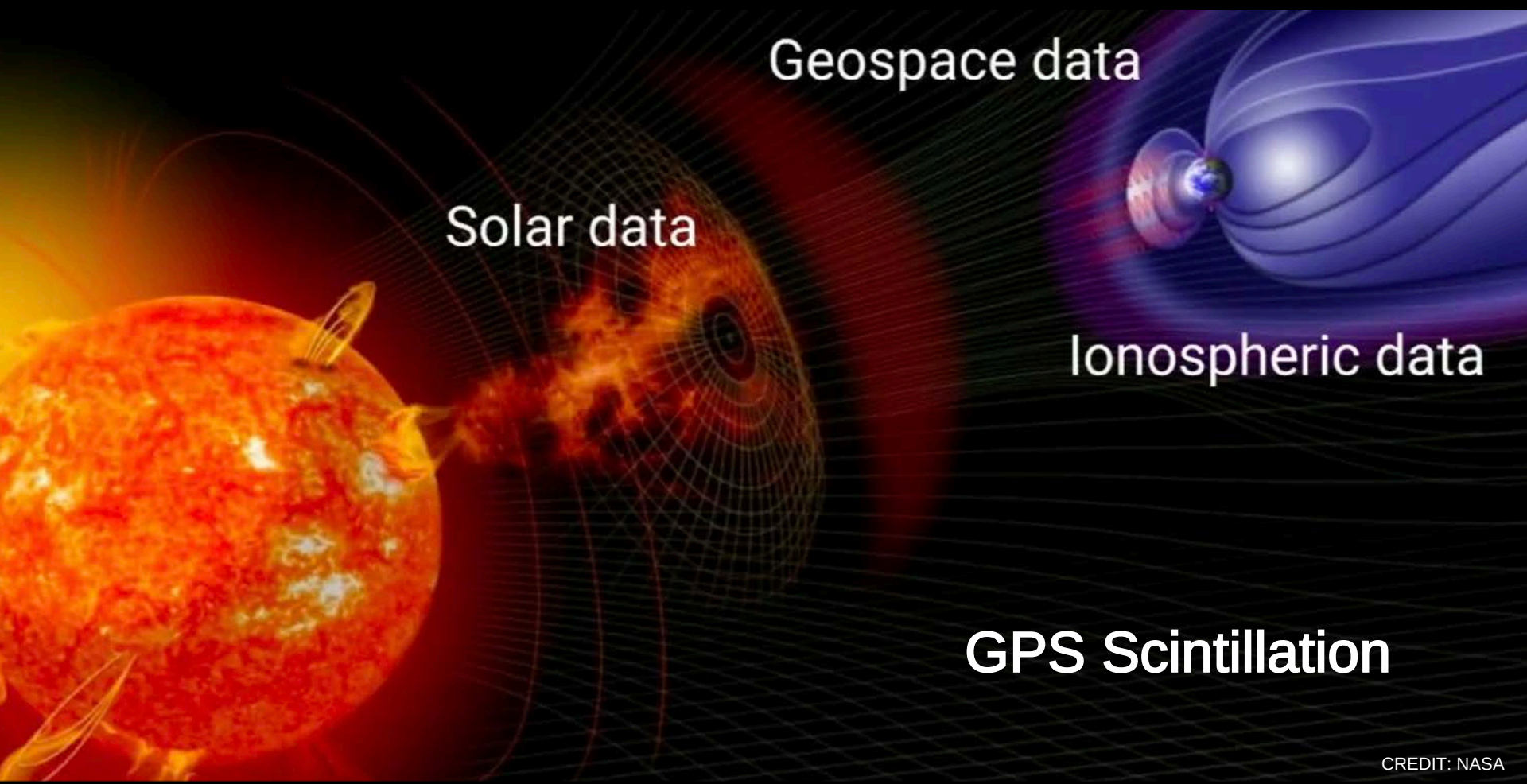
Other important predictors:

- Solar wind magnetic field strength and Bz,
- Solar wind speed and proton density,
- **Unexpected Result:** N-S component of the geomagnetic field at low latitude stations (Guam, Hawaii, Puerto Rico). **This points to the importance of the magnetospheric ring current.**

Machine learning extracted important physical parameters without prior knowledge of the system.

- **In the process STING discovered the imprint of the magnetospheric ring current in precursors of geomagnetic storms - an example of an AI derived discovery.**

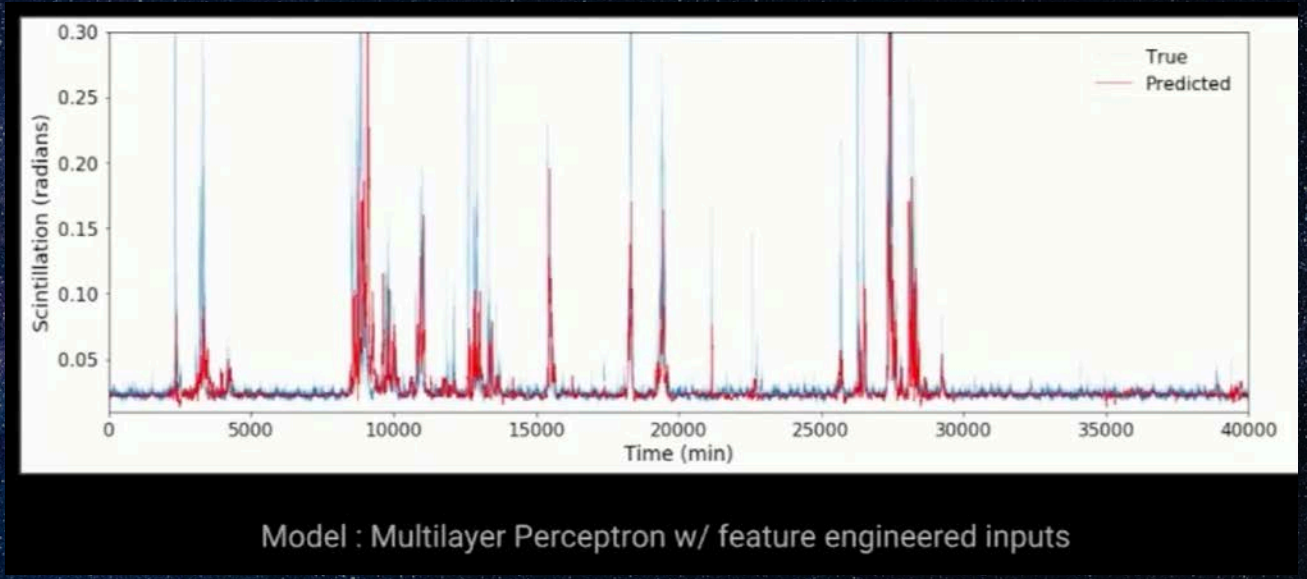
FDL


Geospace data
Solar data
Ionospheric data
GPS Scintillation
CREDIT: NASA

Build data-driven model to forecast GPS disruptions here

Canadian High Artic Ionospheric Network (CHAIN) GPS Receivers

GPS Scintillation



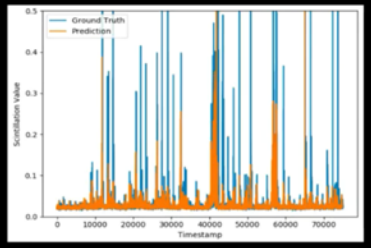
Model : Multilayer Perceptron w/ feature engineered inputs

Predict GPS disruptions 1 hour in advance

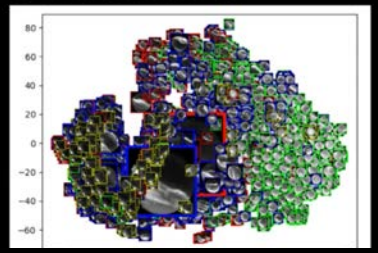
Improved forecasting metrics by 70%

Disturbances can be forecast 1 hour in advance!

- Accurate predictions within ± 5 min
  - +15% improvement in predicting timing
  - Magnitude prediction with 17% error - new benchmark
- Realtime Performance



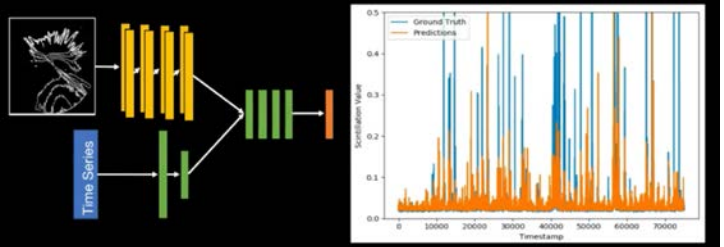
Discrete structures in aurora are more important for GPS disturbances!



...which agrees with Physics

The bigger the image the more significant the GPS disturbances

Can auroral images improve our predictive model?



ENHANCED PREDICTABILITY OF GNSS DISTURBANCES

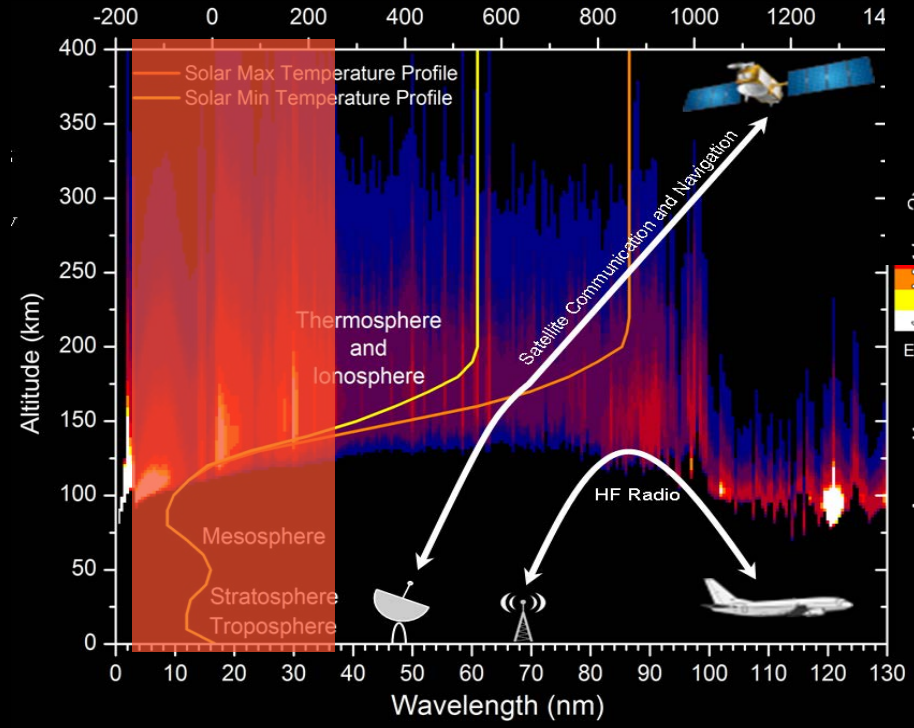
Results overview:

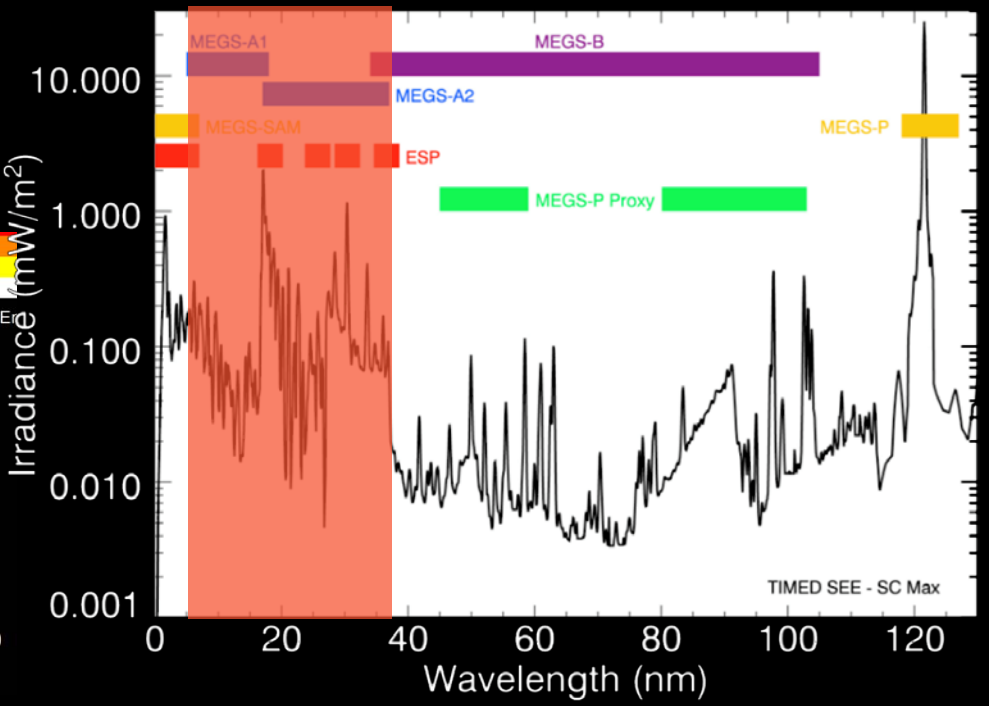
- The team used a novel machine learning approach of bringing together auroral imagery and solar-magnetosphere-ionosphere observations to improve the predictability of GPS/GNSS signal disruptions.
- By using ML techniques to understand auroral structures, they achieved 15% improvement over the state of the art and instantaneous results.

EUV Variability Experiment (EVE)

Observational blackout in the most energetic part of the EUV spectrum

EUV spectrograph.
EUV spectral irradiance.
MEGS-A suffered electrical fault in 2014 and is no longer operational.

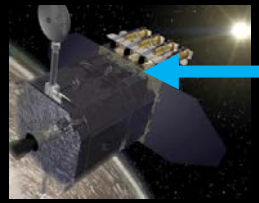


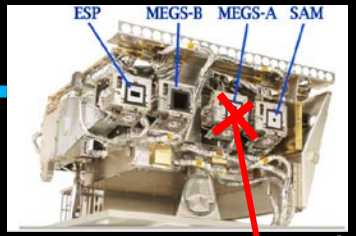


FDL 2018 Case Study

"*RESURRECT*" SDO MEGS-A observations

NASA Solar Dynamics Observatory (SDO)





Mal functioned in 2014

AI model reduced mean error of spectral irradiance prediction to 2.83%

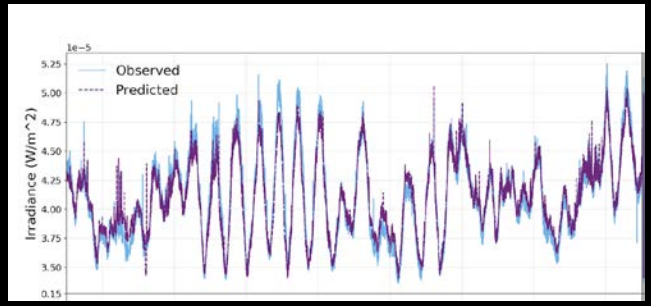
- **Need:** Measurement of solar spectral irradiance is needed for satellite orbit boost planning. Currently, this can be difficult because the MEGS-A module on SDO stopped functioning in 2014.

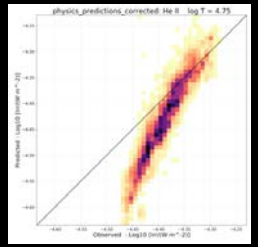
- **Goal:** The SDO AIA EUV imager co-observed with MEGS-A from 2011 to 2014 -- Can we use this data overlap to train a deep learning model to "virtually resurrect" the MEGS-A instrument and fill the observational gap left by the MEGS-A failure, thereby improving spectral irradiance prediction?

- **Methodology:** Develop a machine learning model using 2011/2014 data, test the accuracy using 2012/2013 data. After training and testing over 1000 machine learning configurations, the best implementation was found to be a Residual neural net model augmented with a Multi-Layer Perceptron.

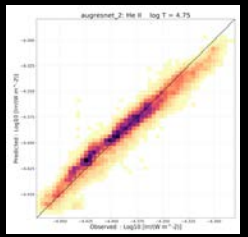
- **Findings:** The neural net model significantly improved upon physics based models, **reducing mean error from 7.46% to 2.83%.** This improved accuracy may constitute a scientifically useful virtualization of MEGS-A.

Improved AI model



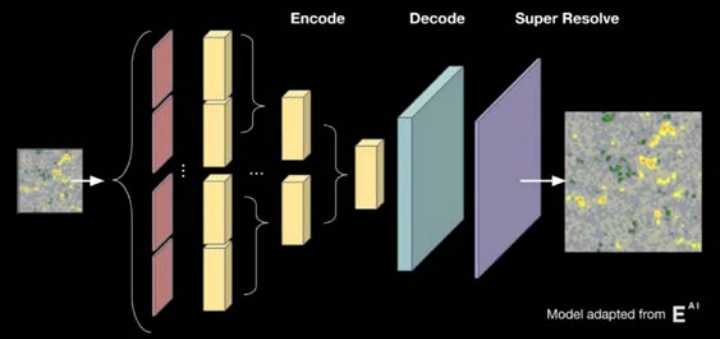


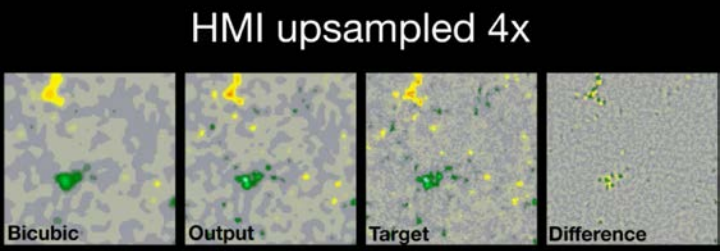
Plot of Predicted v.s Observed

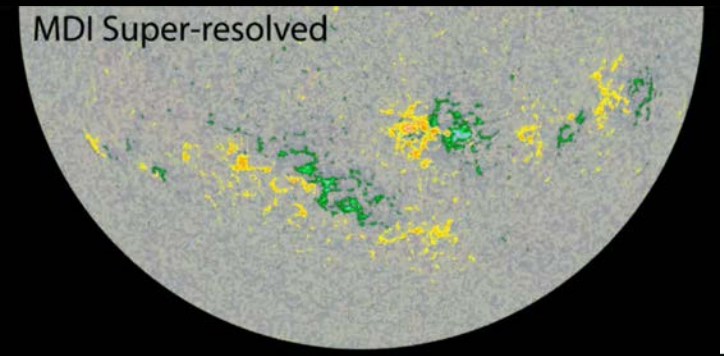


Physics-based model

Improved AI model





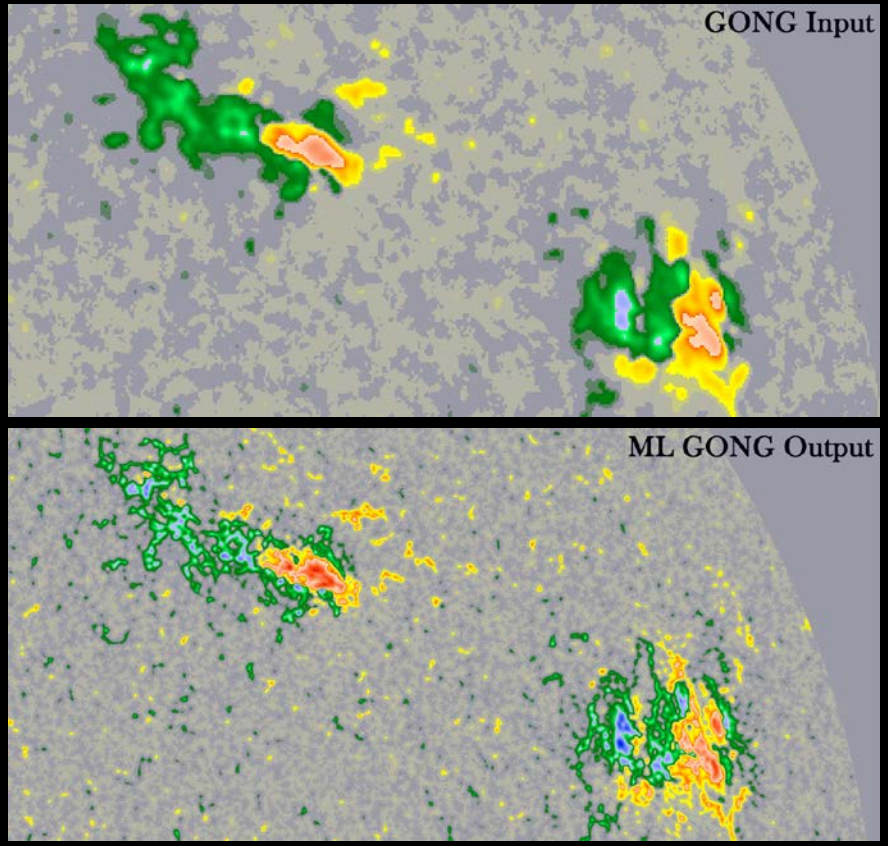


SUPER-RESOLUTION MAPS OF THE SOLAR MAGNETIC FIELD COVERING 40 YEARS OF SPACE WEATHER EVENTS

Results overview:

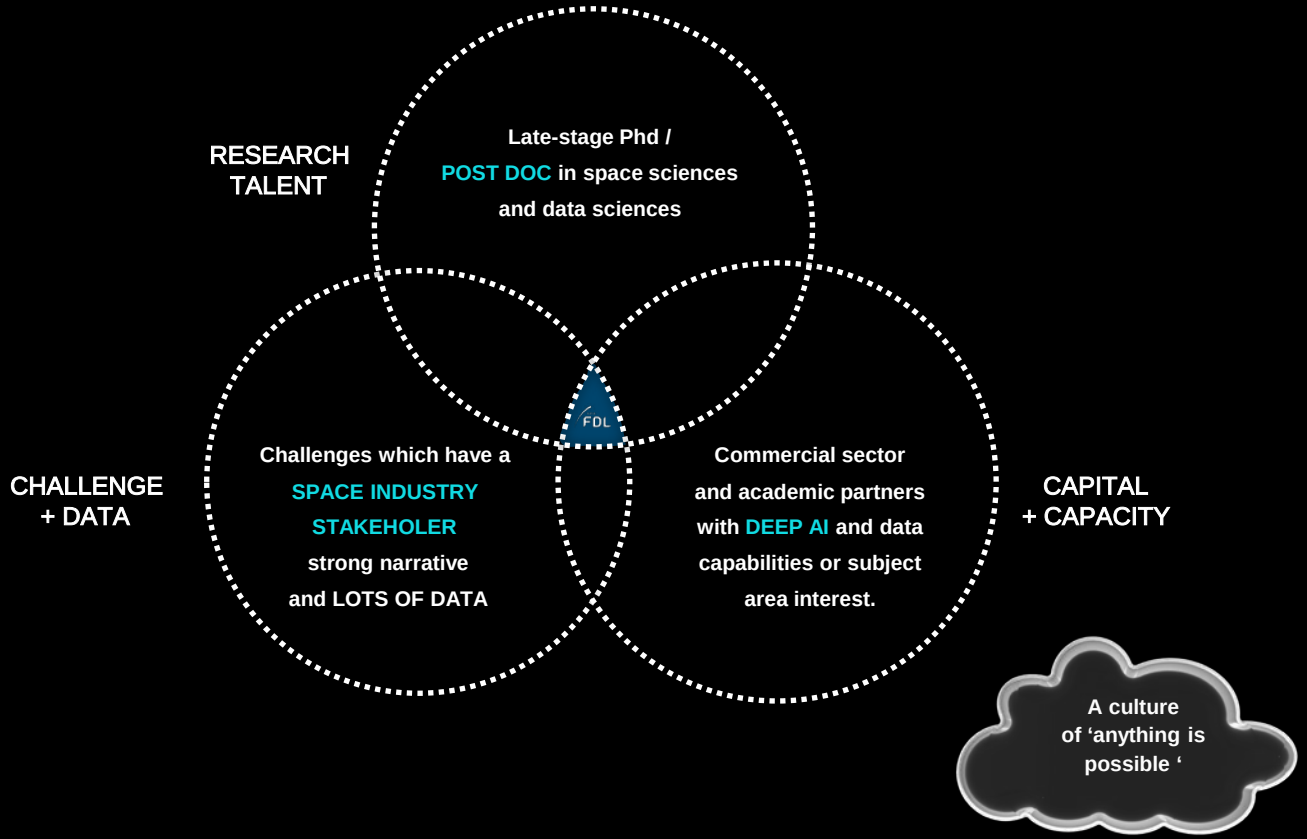
- Used state of the art deep neural networks to calibrate and super-resolve historical maps of the solar magnetic field.
- This addresses a problem that the heliophysics community has been unable to solve in 50 years and enables the study of both space weather and space climate evolution.

Super-resolution Maps of Solar Magnetic Field Covering 40 Years of Space Weather Events



NASA FDL

FRONTIER DEVELOPMENT LAB FORMULA



Quick Take Aways

Participation in ‘big science’ - new era of global problems requiring global thinking (and data) of which this project is a precursor.

Much of this data inform AI pipelines, both in terms of enhanced capabilities and ground truth. In turn, the ISWI initiative could be a unique on-boarding to cutting edge AI enhanced science and interdisciplinary collaboration, with multiple benefits.

Localized data capture could enable a new era of granular understanding of solar-terrestrial interactions; including fundamental insights on data such as UV, climate and atmospherics, ionsphere and thermosphere and others, informing local policy and guidance on space weather, public heath air quality and climate resilience, cancer.

Space-faring nations could receive crucial insights into space traffic management, human spaceflight and spacecraft operations.

Global users of satellite services, such as Star-link and GPS/GNSS could benefit with enhanced warnings and diagnosis of communications adversely affected by Space Weather.

The Sun, The Earth, and Near-Space, 2nd Edition

UCAR's COMET Program collaborated with NASA to create online interactive 2nd edition of Dr. John A. Eddy's book "The Sun, The Earth, and Near-Space"

- The COMET Program has over 25 years of experience developing media-rich, interactive, online lessons.
- Lessons widely used in university classrooms as supplemental material.
- Audience ranges from K-12 to university students, professionals, and decision-makers.
- COMET's MetEd website has over 650,000+ global users that will be able to access and view the Heliophysics lesson.

2nd Edition made possible with the assistance of:

Science Editors

- Dr. Nicholas Gross — *Instructor, Boston University*
- Dr. Philip Judge — *Senior Scientist, High Altitude Observatory at NCAR*

Lesson can be found at: meted.ucar.edu