Space Weather Technology, Research, and Education Center
Space Weather Testbed Development

Dr. Thomas Berger
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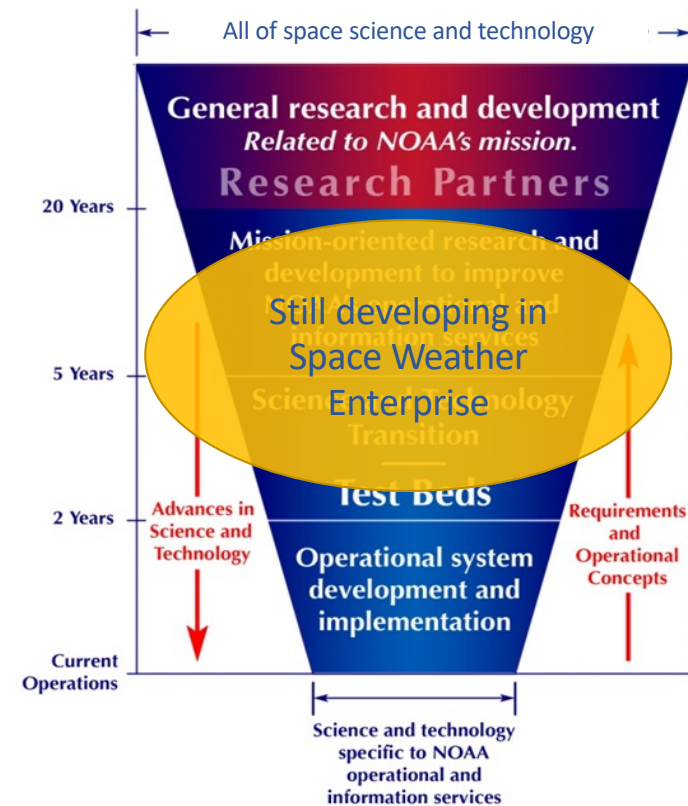
Enrico Camporeale, Wendy Carande, Tim Fuller-Rowell, Delores Knipp, Jenny Knuth, Greg Lucas, Sebastijan Mrak, Chris Pankratz, Julia Putt, Eric Sutton

Harrison Bourne, Steve Taylor

SWx TREC

College of Engineering
& Applied Science
UNIVERSITY OF COLORADO **BOULDER**

CU LASP
Laboratory for Atmospheric and Space Physics
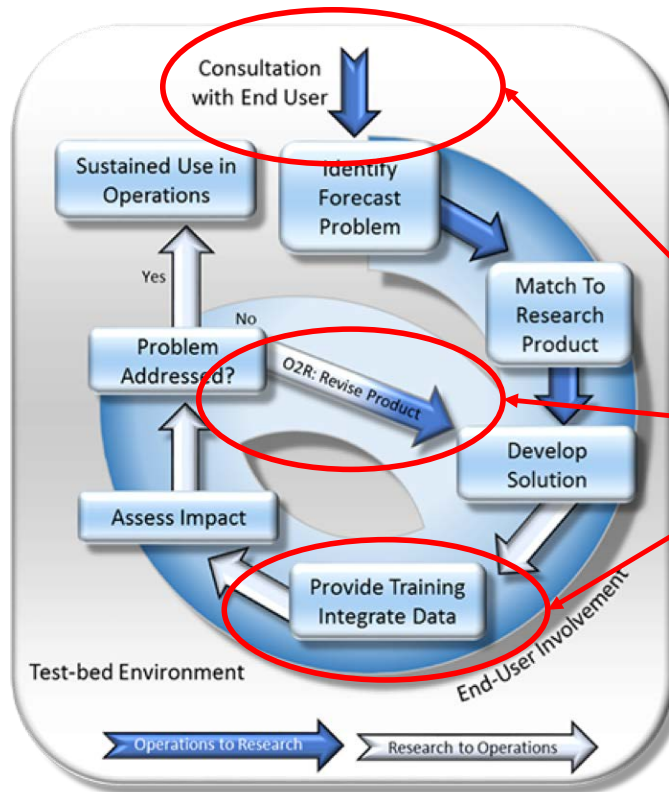University of Colorado **Boulder**

Space Weather Forecasting is decades behind Terrestrial Weather Forecasting. Why?

- **Lack of Observations**

- **Lack of "Full System" Coupled Models**

- **Research-to-Operations (R2O) link is weak**
  - Models are designed for research
  - Tools for data visualization & model interaction are often afterthoughts
  - Researchers and Forecasters have no common platforms for dev/ops transitions

- **Operations-to-Research (O2R) feedback is weak**
  - No community access to operational models for education or development purposes
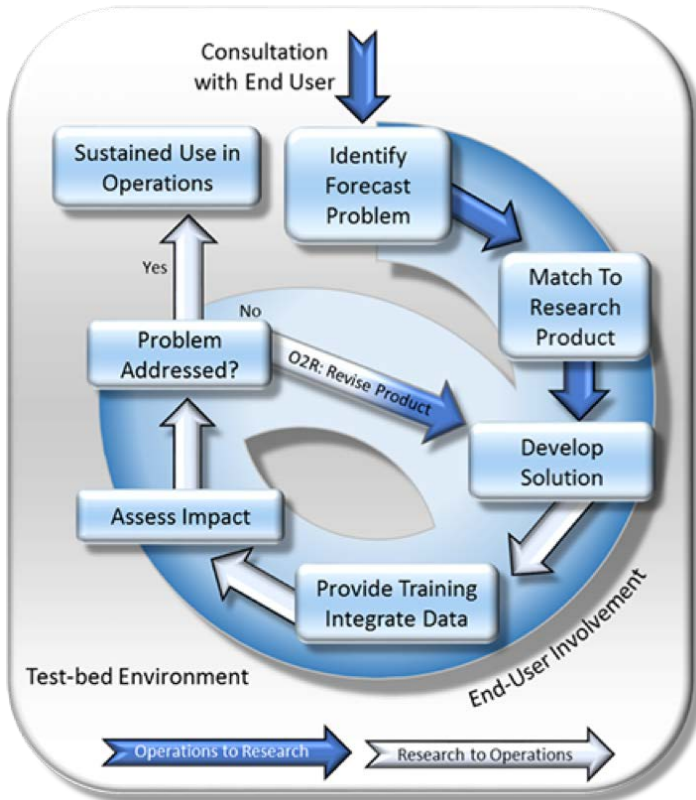 - Forecasters and Researchers have no common platforms for dev/ops transitions

All of space science and technology

General research and development
Related to NOAA's mission.
Research Partners

20 Years

Mission-oriented research and development to improve ...informations services

Still developing in Space Weather Enterprise

5 Years

Science ...nology Transition

Test Beds

2 Years

Advances in Science and Technology

Operational system development and implementation

Requirements and Operational Concepts

Current Operations

Science and technology specific to NOAA operational and information services

The R2O-O2R Problem is Well Studied in Terrestrial Weather

Terrestrial Weather R2O-O2R System
Jedlovec et al., 2013

Generally weak or entirely missing in SWx Forecasting enterprise

We need Space Weather Developmental Testbeds

Terrestrial Weather R2O-O2R System
Jedlovec et al., 2013

Research Model
Algorithm Development

Code Review & Update

Developmental Testbed
Simulated Operational Environment

Operational Requirements

O2R Forecaster Feedback

Operational Testbed
Actual Operational Environment

Operational Validation

Operational Forecasting Offices
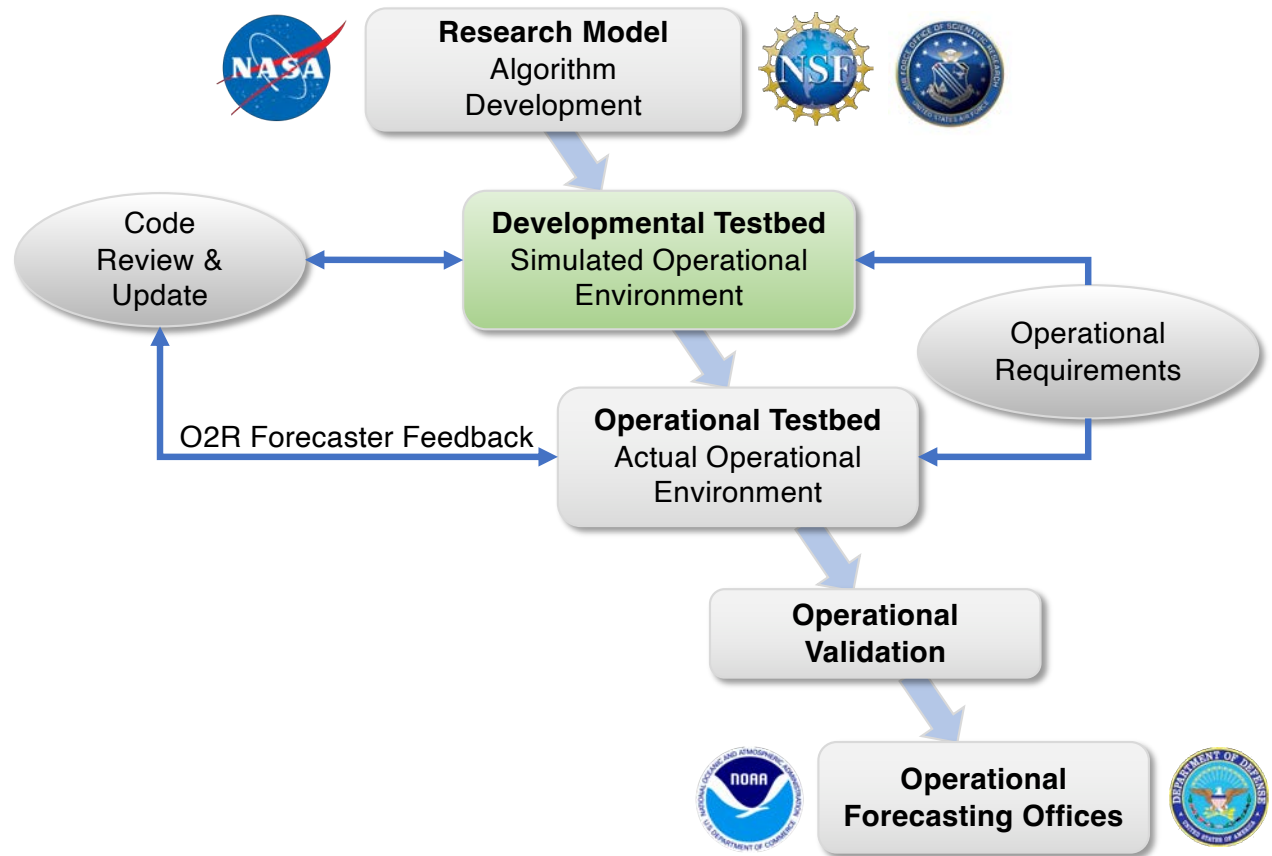
Operational Space Weather Forecasting Models

What's Missing?
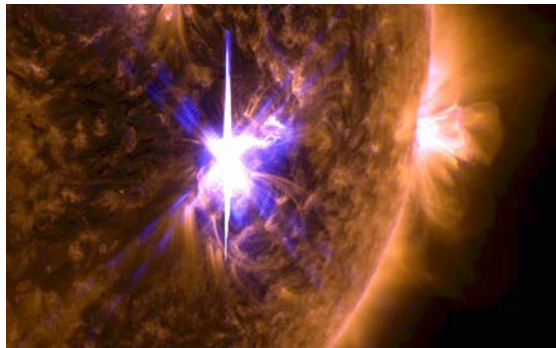
Solar Eruption Warning System
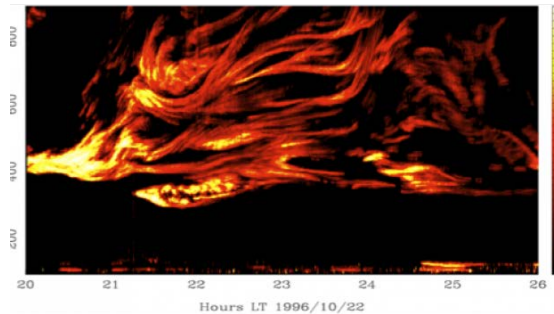3—12-hour warning of flare & CME events
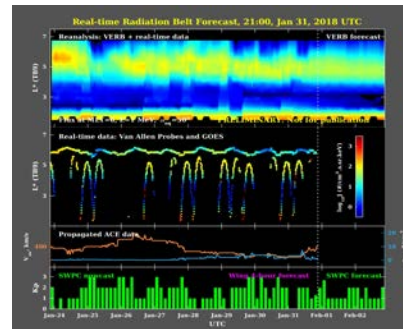
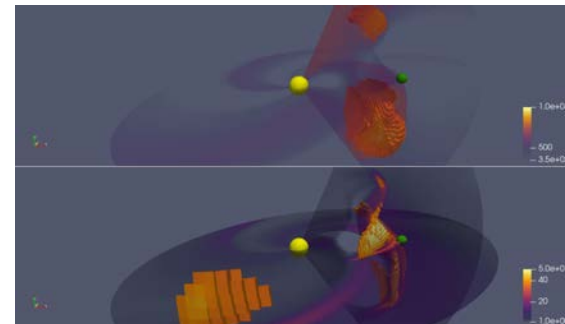VERB model, courtesy A. Kellerman (UCLA)

Radiation Belt Forecasting Model
Energetic particle flux at any orbit of interest

Thermospheric Neutral Density Forecasting
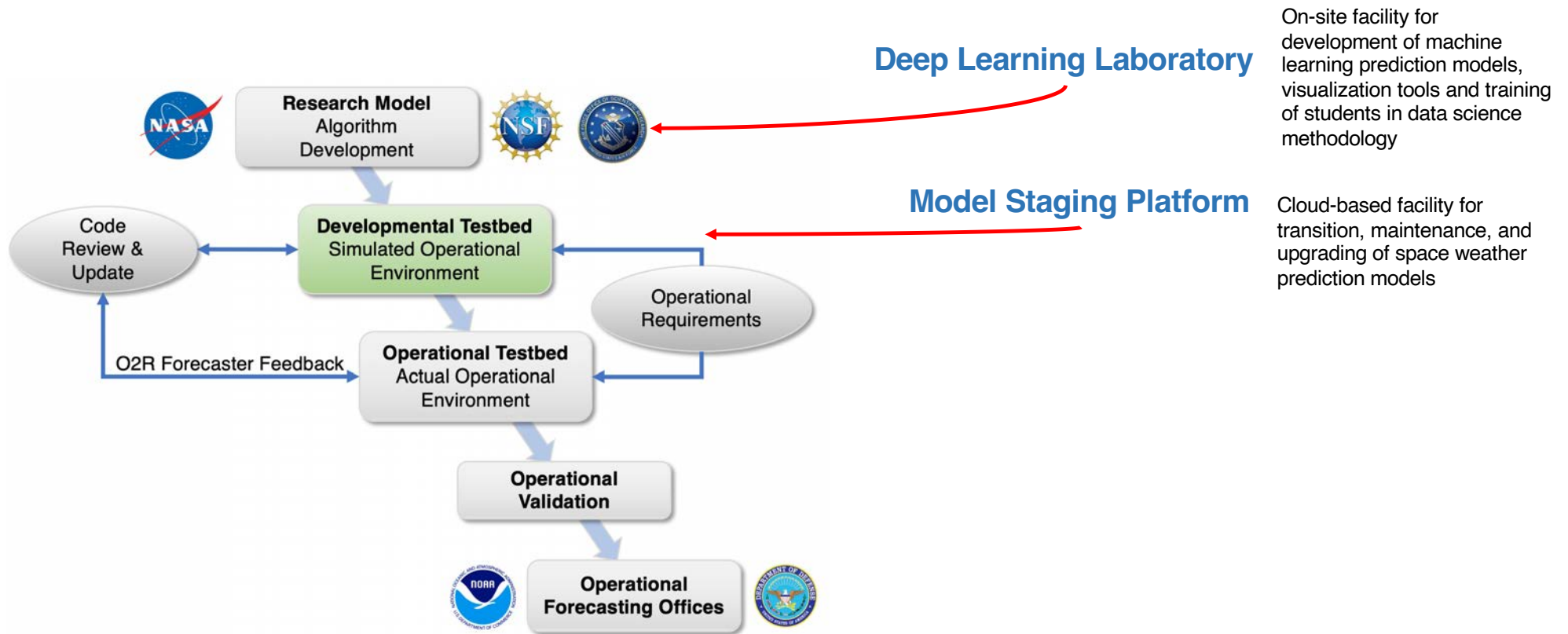LEO satellite drag prediction

Ionospheric Scintillation Forecasting Model
Warning and Alert system for NavComm users

Better visualization tools for Forecasters
CU/LASP 3D Solar Wind and CME visualization shown here

The University of Colorado Solution
## SWx TREC Deep Learning Laboratory (DLL) & Model Staging Platform

Deep Learning Laboratory

On-site facility for development of machine learning prediction models, visualization tools and training of students in data science methodology

Model Staging Platform

Cloud-based facility for transition, maintenance, and upgrading of space weather prediction models

The SWx TREC Deep Learning Laboratory was enabled through AFOSR and NASA support

AFOSR DURIP (Fall 2020)

- GPU server purchase: Lambda Labs Hyperplane system – "Birkeland"
- Barco VideoWall for visualization tool development

NASA/Heliophysics Space Weather Quantified Uncertainty (SWQU) grant (PI: Enrico Camporeale)

- Additional Lambda Labs GPU server purchase – "Alfven"

Barco video wall system
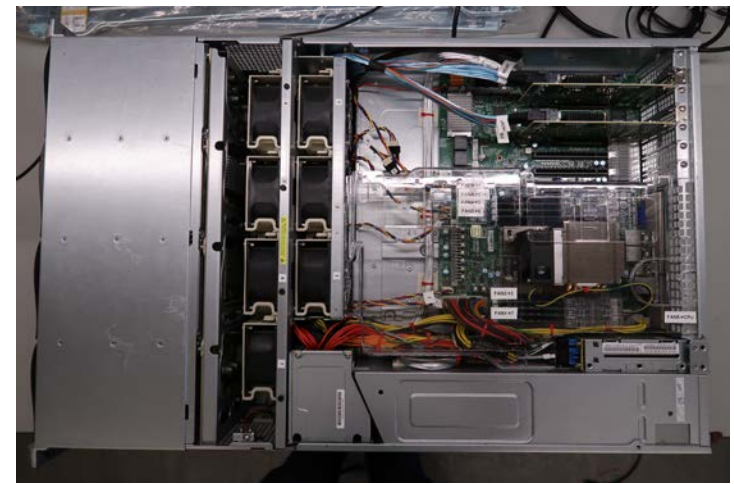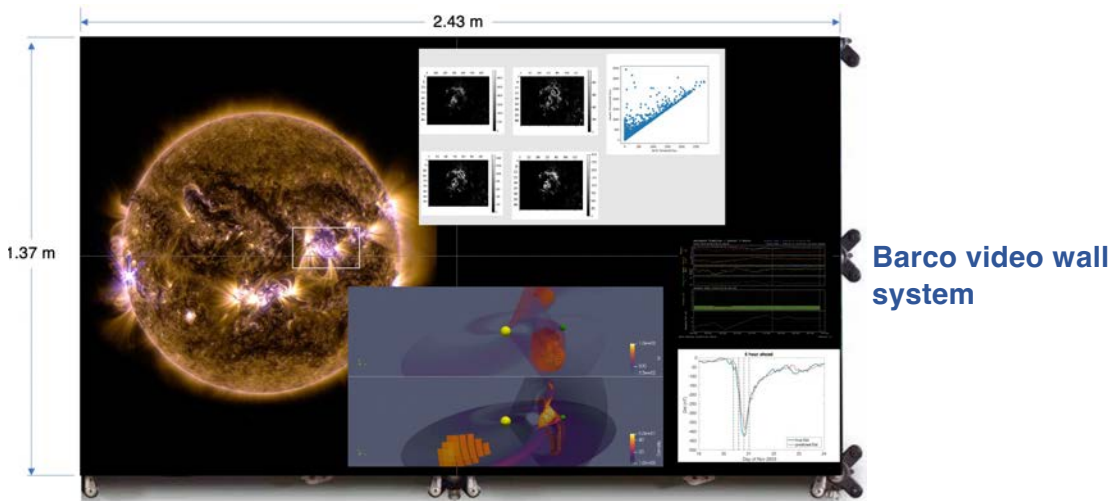
Lambda Labs Hyperplane systems

GPUs: 8x NVIDIA A100 SXM4 Tensor Core GPU (80GB) with NVLink/NVSwitch
CPUs: 2x AMD EPYC 7742 (64 Core, 2.25GHz)
Memory: 1 TB ECC RAM (16x 64GB 3200 MHz - total of 32 slots)
Operating System Drive: 2x 1.92TB M.2 NVMe (mdadm RAID 1 OS)
Extra Storage: 6x 15.36 TB
Chassis: 4U Rack (900L x 447W x 262.25H mm); 3000W 3+1 Redundancy

DLL GPU Servers Installed December 2021

AFOSR: "Birkeland"
NASA: "Alfven"

LASP Space Sciences Building

SWx TREC Facilities

- **Offices**
  - 3000 sq. ft. in new Aerospace Engineering building
    - 5 outer offices
    - Open collaboration space
    - Space Weather Model Staging Platform center

- **Computing**
  - 3 NVIDIA Titan-RTX GPU workstations
  - AFOSR DURIP & NASA SWQU:
    - 2 LambdaLabs 8xA-100 GPU servers
    - Barco VideoWall visualization/forecasting lab

- **Support**
  - College of Engineering and Applied Sciences (Staff & budget support)
  - Office of Contracts and Grants (Proposal support)
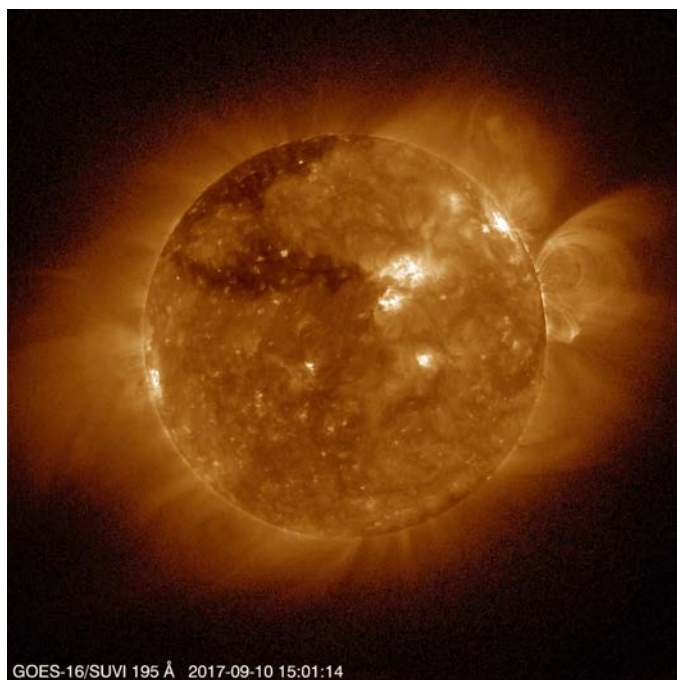 - Office of Industry Collaboration (Corporate outreach)
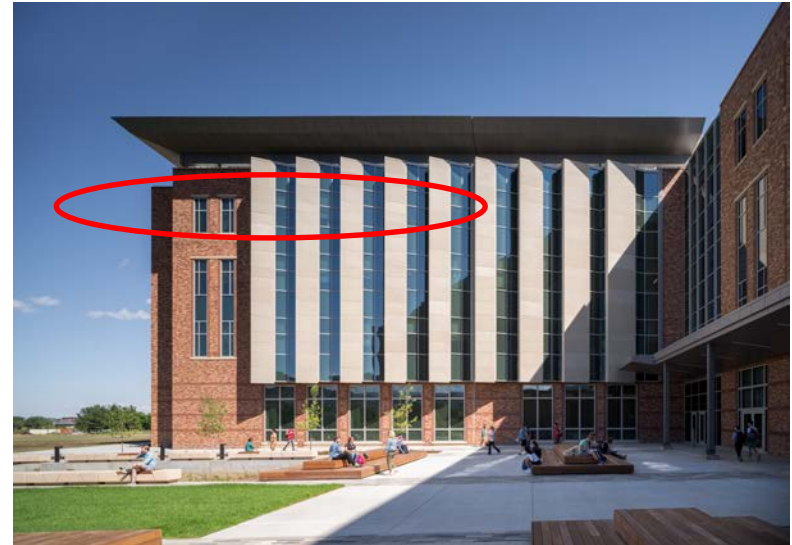
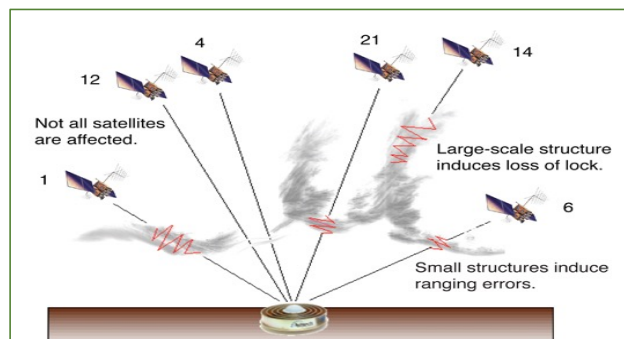# SWx Testbed Area in New Aerospace Engineering Building
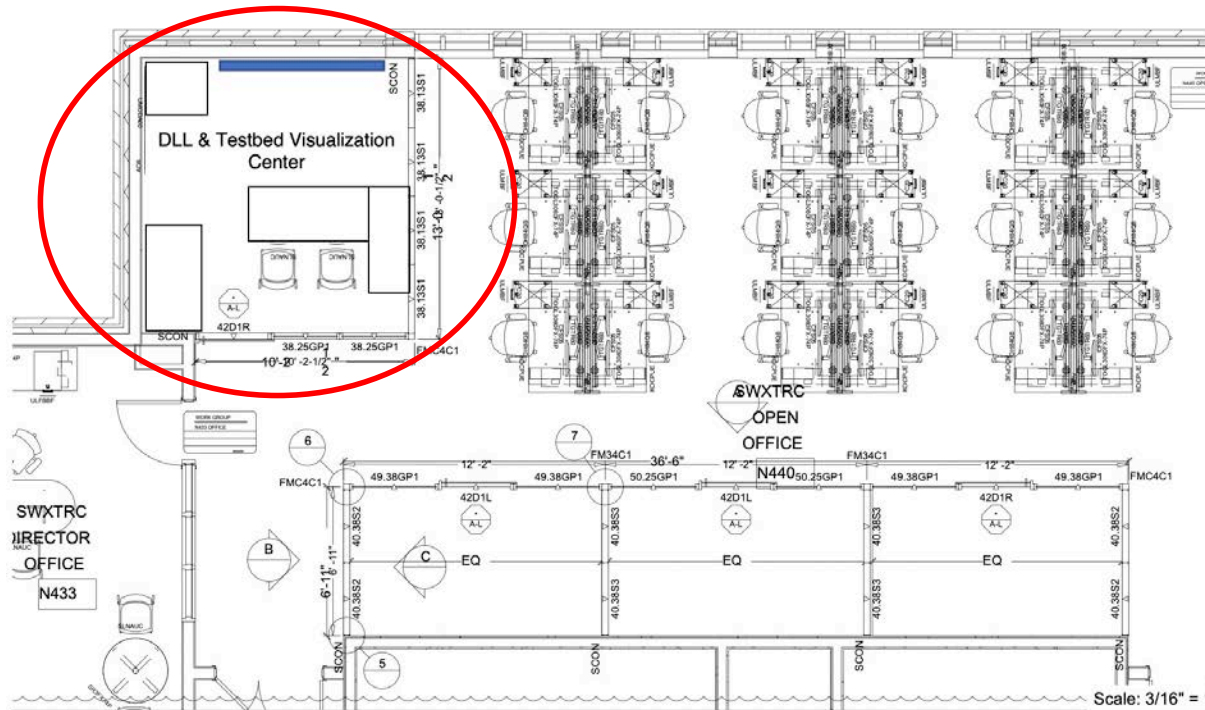
UNIVERSITY OF COLORADO BOULDER:
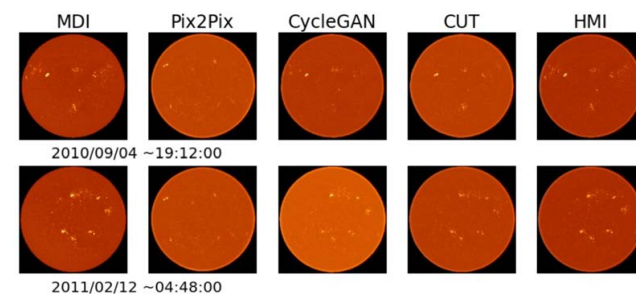AES - ARCHITECTURAL WALL - PHASE II

Current Deep Learning Research in Space Weather Prediction

Solar Eruption Prediction

Ionospheric Scintillation Prediction

Data Augmentation Experiments

Solar Flare Prediction with low False Positive Rates

Research by V. Deshmukh & K. van der Sande, supervised by T. Berger & N. Flyer

Experiment: 2-stage hybrid model
- Stage 1 = Convolutional Neural Network (CNN) probabilistic prediction model. **High skill, but high FPR.**
- Stage 2 = Extremely Randomized Trees (ERT) categorical classification model. **Used to lower FPR.**
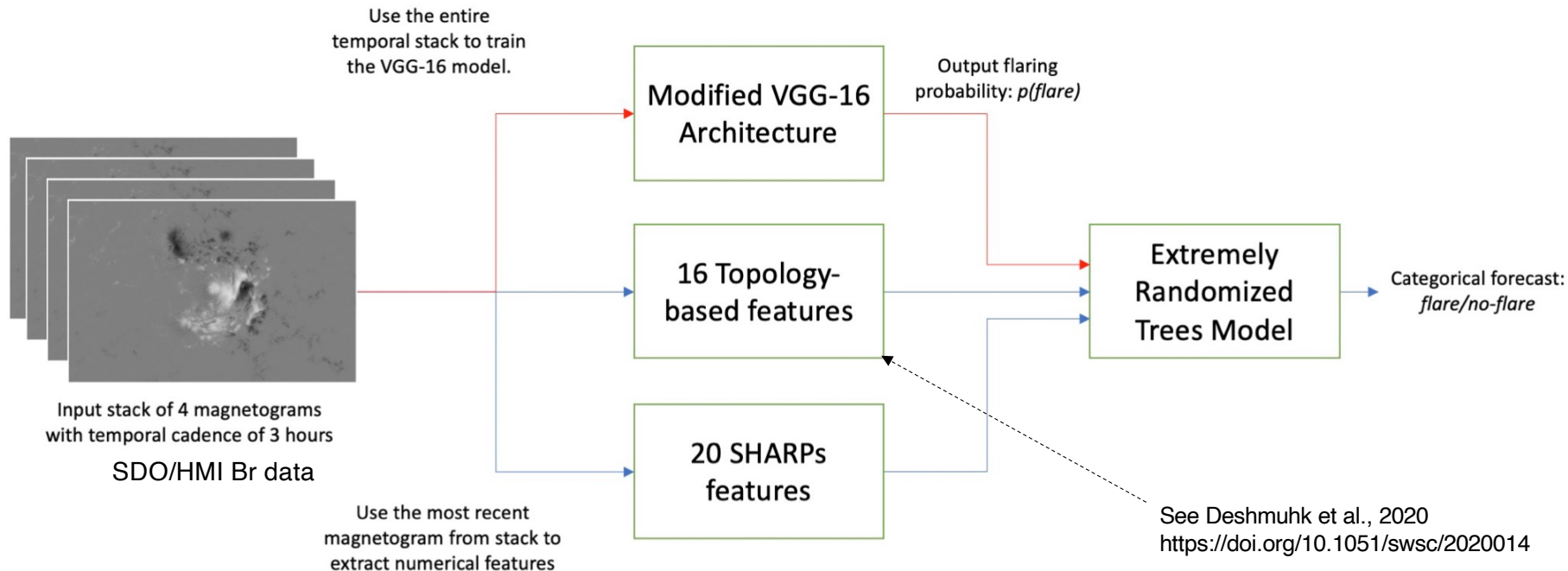
Hybrid CNN+ERT Architecture Outperforms CNN-only

- Significant reduction in False Positives with only slight reduction in TP: much more reliable forecasting model
- Slightly lower TSS but **much** higher HSS compared to CNN alone
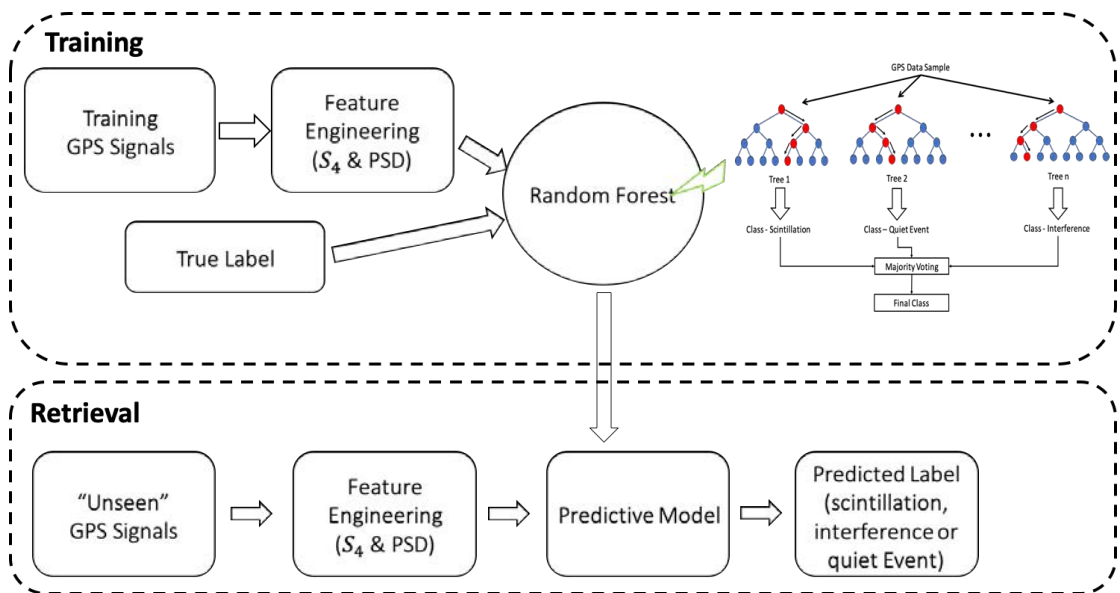

True Positives
(total over test set)

False Positives
(total over test set)
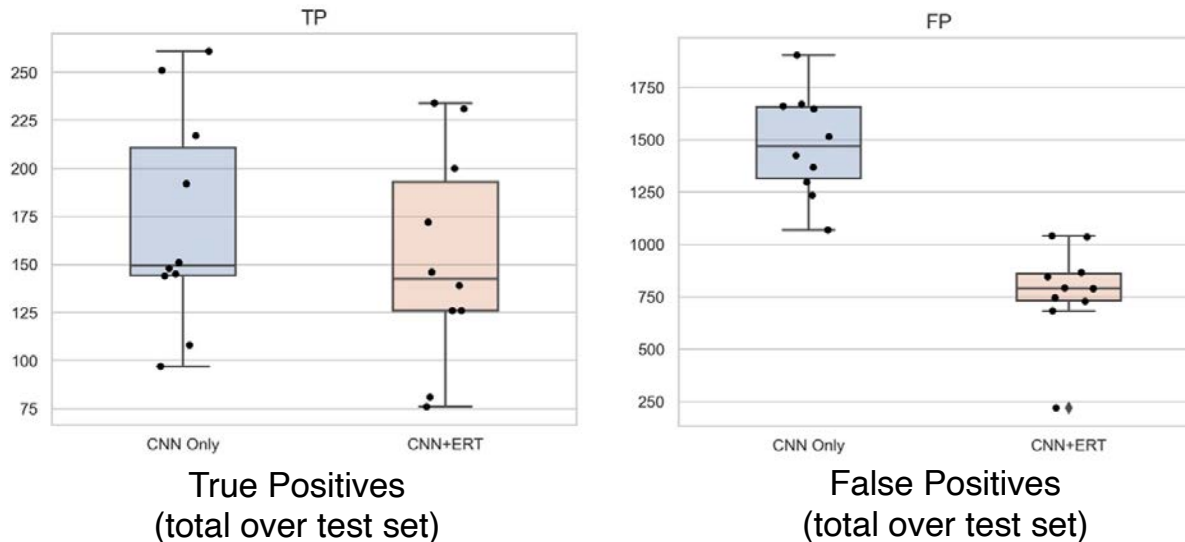
Dots indicate each of the 10 random seed trials

Prediction Metric	% Change in Metric after adding ERT stage
Recall	-12 ± 6.9
False Positive Rate	-48 ± 12.4
Accuracy	+3 ± 0.7
Precision	+69 ± 16.7
TSS	-8 ± 7.0
HSS	+56 ± 35.7

Model	TSS	HSS
CNN	0.68	0.17
CNN+ERT	0.62	0.26

Machine Learning Ionospheric Scintillation Prediction

Research supervised by J. Morton

Training

Training GPS Signals → Feature Engineering (S_4 & PSD) → Random Forest

True Label →

GPS Data Sample

Tree 1 — Class - Scintillation
Tree 2 — Class – Quiet Event
...
Tree n — Class - Interference

Majority Voting

Final Class

Retrieval

"Unseen" GPS Signals → Feature Engineering (S_4 & PSD) → Predictive Model → Predicted Label (scintillation, interference or quiet Event)

Model distinguishes between SWx scintillation and jamming interference
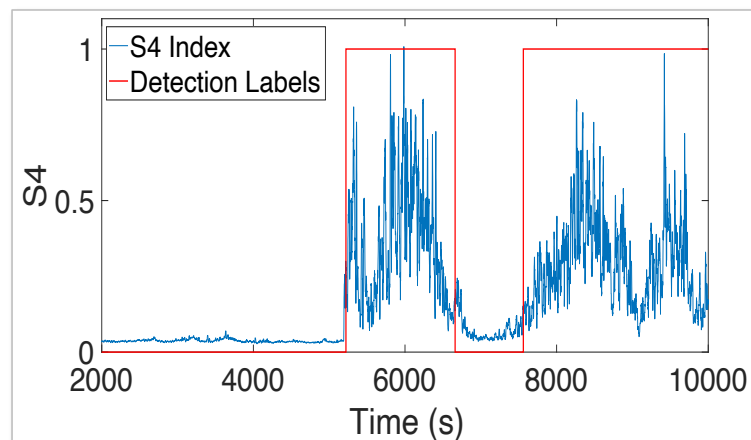
Algorithm	Accuracy
Linear SVM	94.6%
Gaussian SVM	94.4%
Logistic Regression	95%
Full-connected Neural Networks	94.2%
Random Forest	**97.2%**

Publications

1.Jiao, Y., J. Hall, Y. Morton, "Performance evaluation of an automatic GPS ionospheric phase scintillation detector using a machine-learning algorithm," Navigation, J. Institute of Navigation, 64(3):391-402, DOI: 10.1002/navi.188, Summer 2017.

2.Jiao, Y., J. Hall, Y. Morton, "Automatic equatorial GPS amplitude scintillation detection using a machine learning algorithm," IEEE Trans. Aero. Elec. Sys., 53(1): 405-418, DOI:10.1109/TAES.2017.2650758, Online ISSN 1557-9603, 2017.

# Generative Adversarial Network (GAN) Data Augmentation

Research by A. Liu, supervised by W. Carande
AGU2020 Poster: https://www.essoar.org/doi/10.1002/essoar.10510080.1
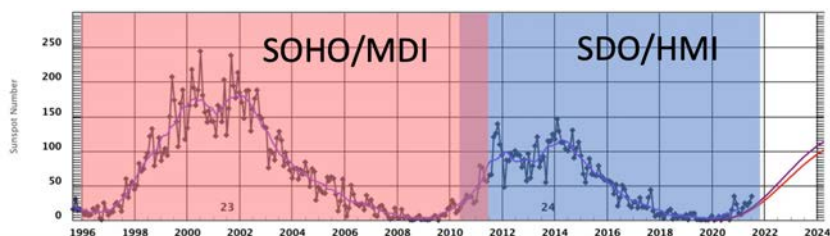
Problem: current flare prediction models are trained on the modern, high-resolution SDO/HMI magnetogram data.

SOHO/MDI magnetograms are lower resolution and cadence compared to modern SDO/HMI magnetograms. But MDI covers much more active Solar Cycle 23.

*Can we use GANs to upconvert MDI data to HMI resolution and cadence and **more than double the data available for solar eruption prediction?***
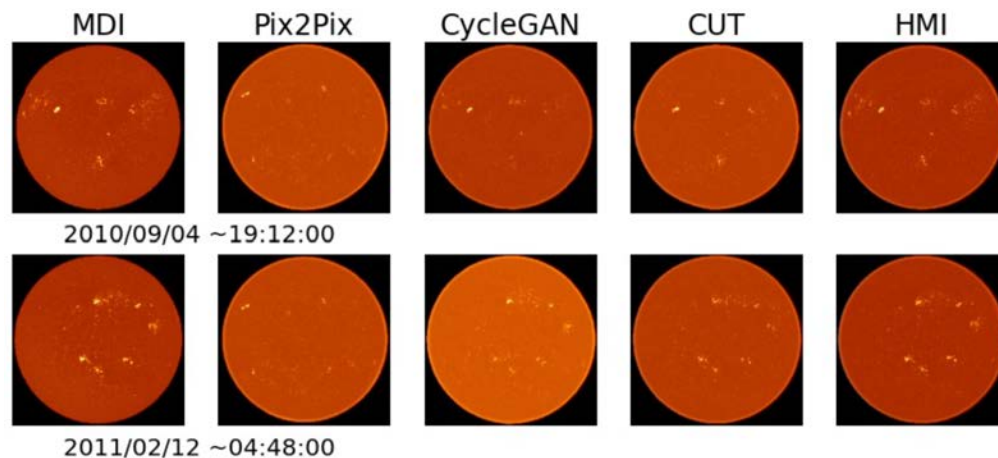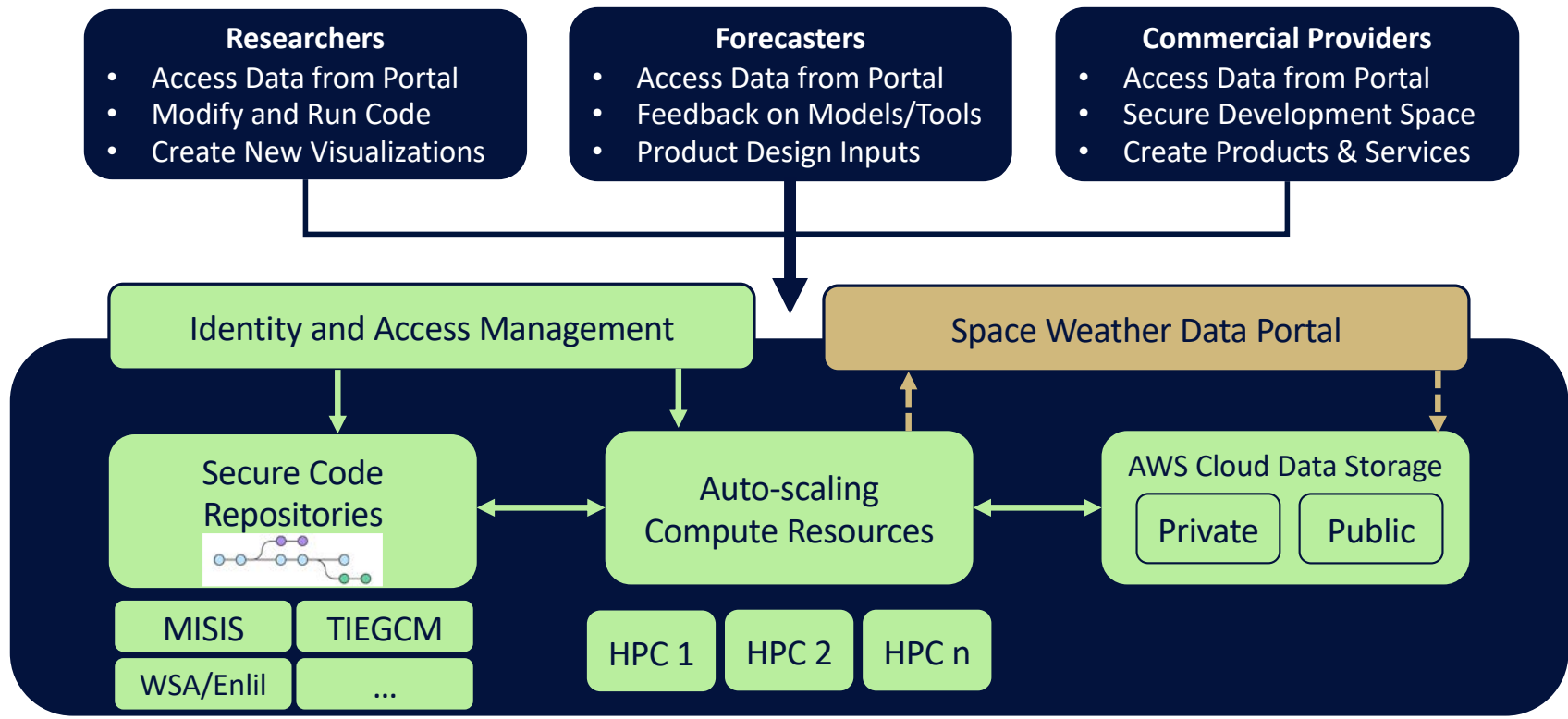

Method: several different GAN models trained on overlap period during 2010—2011.

Model	Mean Abs Error	MSE
Pix2Pix	728.1717	0.001027
CycleGAN	608.7130	0.00745
CUT	623.8944	0.00074
Baseline	1007.9503	0.001288

Answer: *yes*, we can upconvert MDI to HMI data and use the data to train machine learning flare prediction models.

# Space Weather Model Staging Platform

Developed by G. Lucas, LASP

Researchers
- Access Data from Portal
- Modify and Run Code
- Create New Visualizations

Forecasters
- Access Data from Portal
- Feedback on Models/Tools
- Product Design Inputs

Commercial Providers
- Access Data from Portal
- Secure Development Space
- Create Products & Services

Current models
- TIE-GCM
- MSISe00 and 2.0
- IRI
- USGS E-field
- WSA/Enlil
- VECTOR

In progress
- WAM-IPE
- Glo-TEC & ROTI
- JB2008
- D-RAP
- SWMF Geospace

Identity and Access Management

Space Weather Data Portal

Secure Code Repositories

Auto-scaling Compute Resources

AWS Cloud Data Storage
- Private
- Public

MISIS TIEGCM
WSA/Enlil ...

HPC 1 HPC 2 HPC n

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LASP
Laboratory for Atmospheric and Space Physics
University of Colorado Boulder

3D Visualization of WSA/Enlil Solar Wind Model

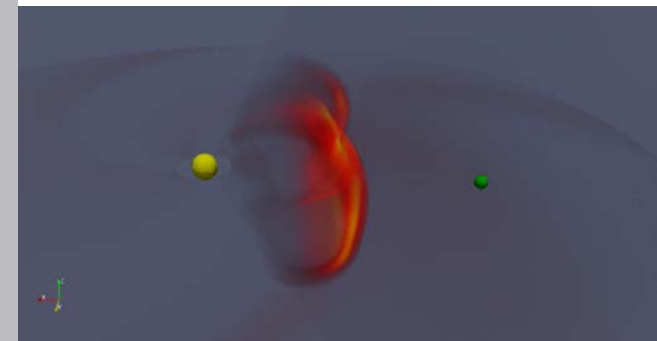Developed by G. Lucas under NASA SWx O2R grant (PI: Chris Pankratz, LASP)
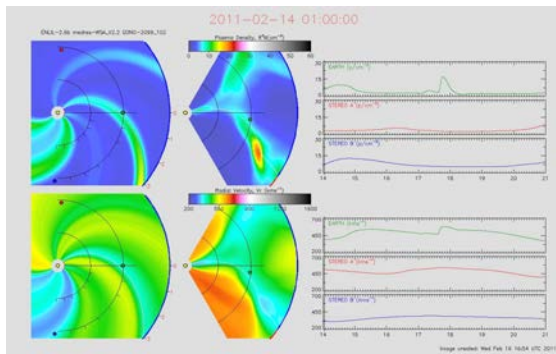
Legacy 2D visualization
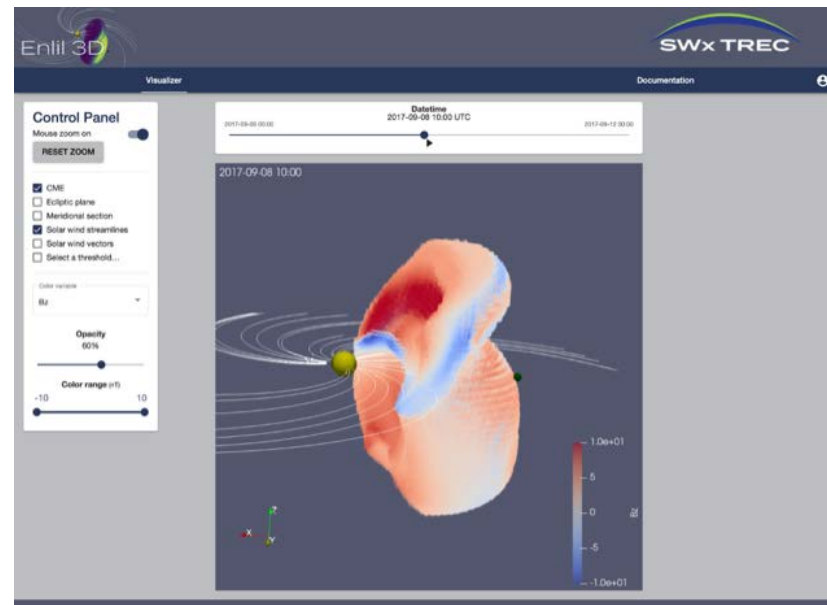
New 3D *interactive* visualization
https://enlil.swx-trec.com

In evaluation by
UK Met Office Space Weather
Operations Center (MOSWOC)

Looking Forward...

DLL

- Solar eruption prediction using both magnetogram and SDO/AIA coronal imagery
    - Requires large storage array (300 TB) and A100 GPU server
    - CNN and Self-Attention Network (SAN) architectures along with FPR suppression hybridization

- Ionospheric Scintillation Prediction for LEO Orbital Systems
    - Applications to Space Traffic Management during space weather events

- Install Barco video wall in SWx TREC office space

- Summer REU student Machine Learning and Data Science Bootcamp

Model Staging Platform

- Deploy 3D Enlil solar wind and CME visualization to operational testbeds

- Continue to add operational models to platform

https://www.colorado.edu/spaceweather