SWFL: AFRL Efforts to Provide Actionable SWx Info to DoD

29 April 2010

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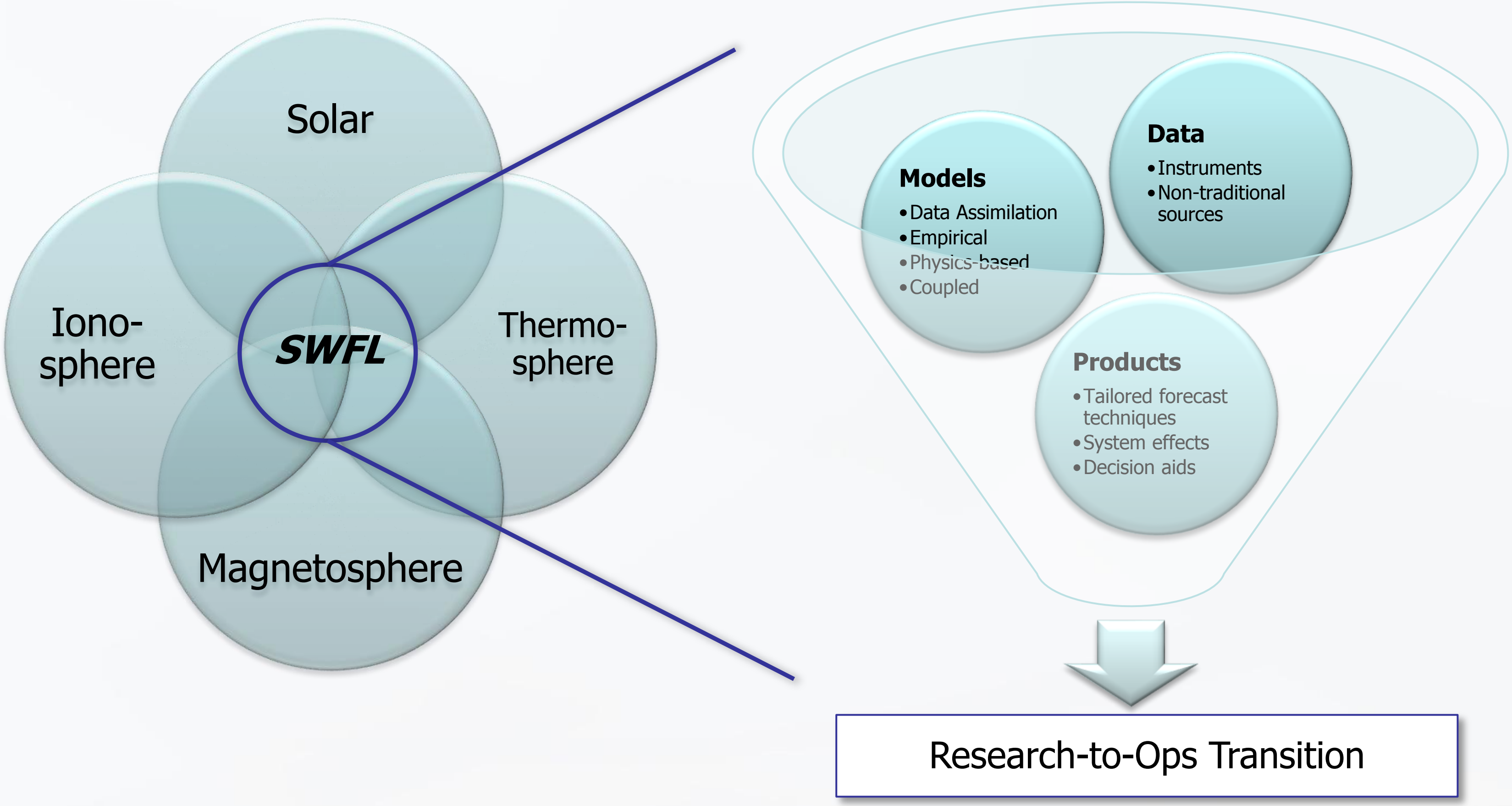
THE AIR FORCE RESEARCH LABORATORY
LEAD I DISCOVER I DEVELOP I DELIVER

Overview: Space Weather Forecast Lab (SWFL)



SWFL Aimed at Getting the Best Space Weather Products to the Warfighter

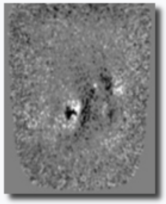
Data: Solar/Coronal Assimilation

Arge, et al., *"New Global Solar Magnetic Field Maps Using ADAPT"*

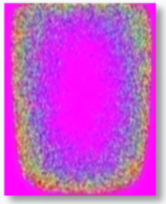
ADAPT

Input Data

Solar Magnetogram Data



Magnetic Field



Variance

Intelligent Front End

Import & Select Data for Data Assimilator

Data Assimilator

Initial Conditions

Forecast Step: use the WH model to calculate forecast

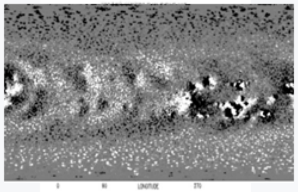
Analysis Step: combine observations with forecast

Assimilation Results

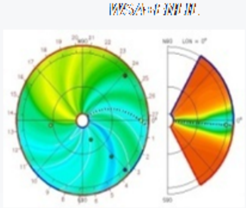
Modeling/Forecasting Applications

Improved Solar Synoptic Maps

Coronal & Solar Wind Models



Global Magnetic Field



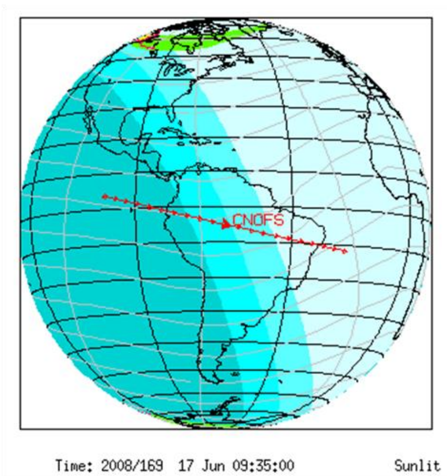
WSA-ENLIL Solar Wind

Data: C/NOFS and SSAEM

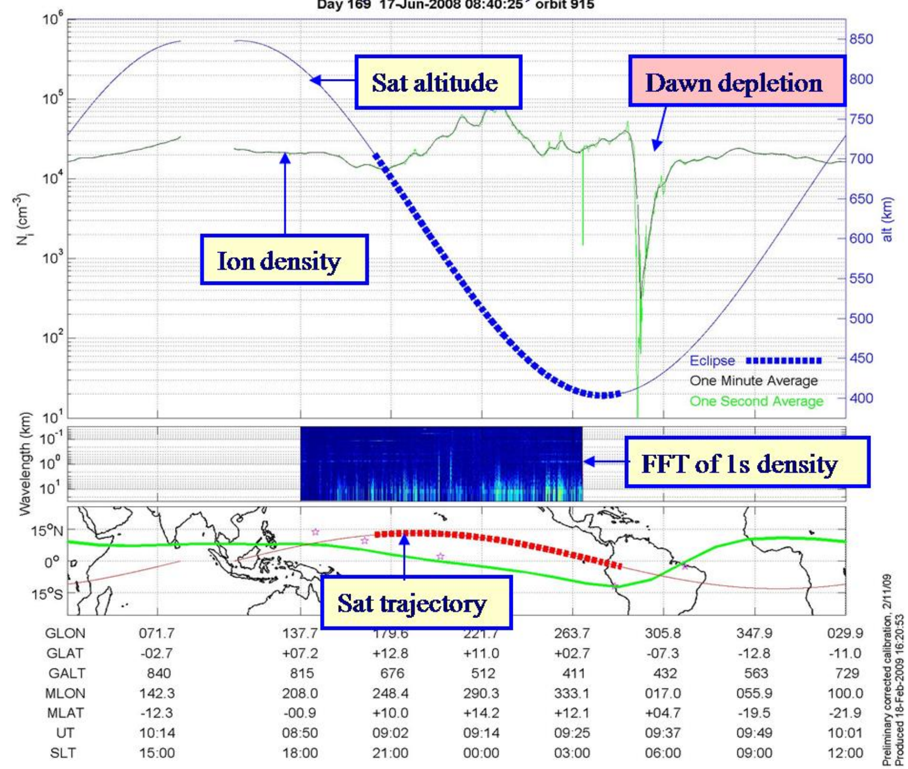
de La Beaujardiere, et al., *"C/NOFS Science Results and Plans for a Follow-on Mission"*

Dawn N_e Depletion

- **Example of N_e dawn depletion at 05 LT**
- **Just before the E-region sunrise**
- **Unexpected result**



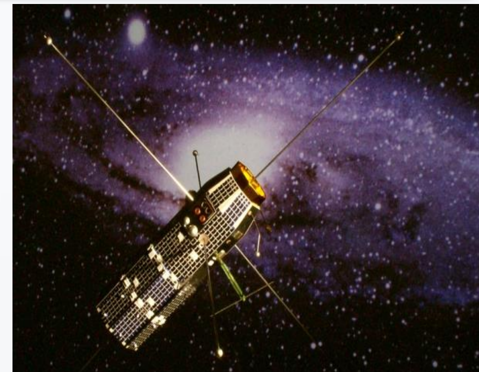
PLP data, 17Jun 08, orbit 915



From De La Beaujardiere et al. GRL, 09

Data: C/NOFS data into PBMOD

Roth, *"A Case Study of PBMOD with assimilation of C/NOFS Electric Field Data*

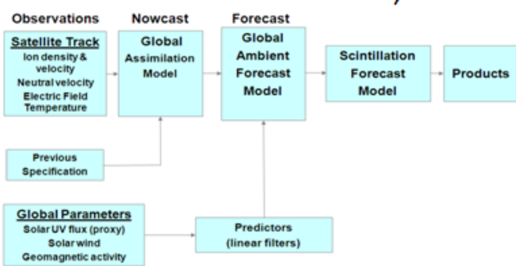


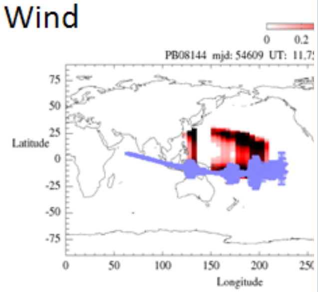
PBMOD

Physics Based Model (PBMOD) is a low-latitude ionospheric plasma density and radio scintillation model developed for C/NOFS.

Model Components:

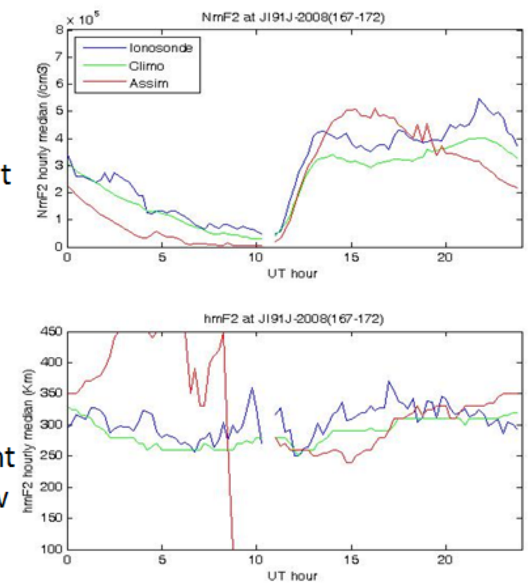
- **Embedded Models**- Solar UV Flux, Neutral Densities, Winds and Temperatures, Plasma Temperatures, Plasma Velocity (including Neutral-wind Dynamo, Penetration Electric Fields)
- **Assimilation-** Electric Field, Neutral Wind





Results

These plots give the local-time variation of the profile parameters averaged over the six day test period, showing that the largest deviations of the assimilated model happened at night, when the fields were largest and most structured. This is also the time, however, when interpretation of the ionosonde measurements might be least reliable (because of low densities and multiple species effects).



Data: Ionospheric Utility

Bishop, et al., *"On the Relative Utilities of Data Types for Assimilation by Global Ionospheric Models"*

The 7 'Grouse' Equation Terms
[The grouse is a game bird]

The Utility of each data type is given by the product:

$$\text{Utility} = \text{NUM} \times \text{REL} \times \text{QAL} \times \text{LEN}^2 \times \text{MER} \times \text{4D} \times \text{APP}$$

Table 1.1: Interpretation of the terms in the Grouse Equation

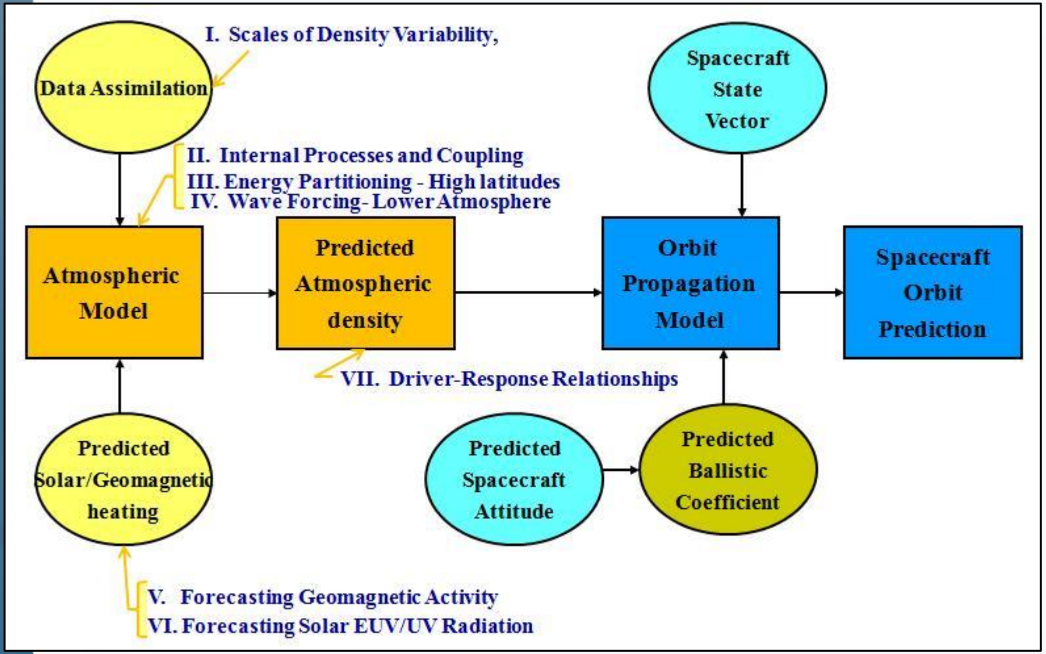
Symbol	Interpretation
NUM	The **Number** of systems providing this data type
REL	**Reliability** - The probability that the observing system will provide an observation at the expected time and place
QAL	The **Quality** of the data type (quality control and uncertainties)
LEN	The characteristic length covered by each observation (the **spatial correlation** length)
MER	The **Merit** of the observation. [If the data type is the only one that provides information for a specific region, its (relative) merit is very high.]
4D	Four-dimensional space-time coverage, or **[4] coverage**
APP	The **Applicability** of the data type to the current version of GAIM

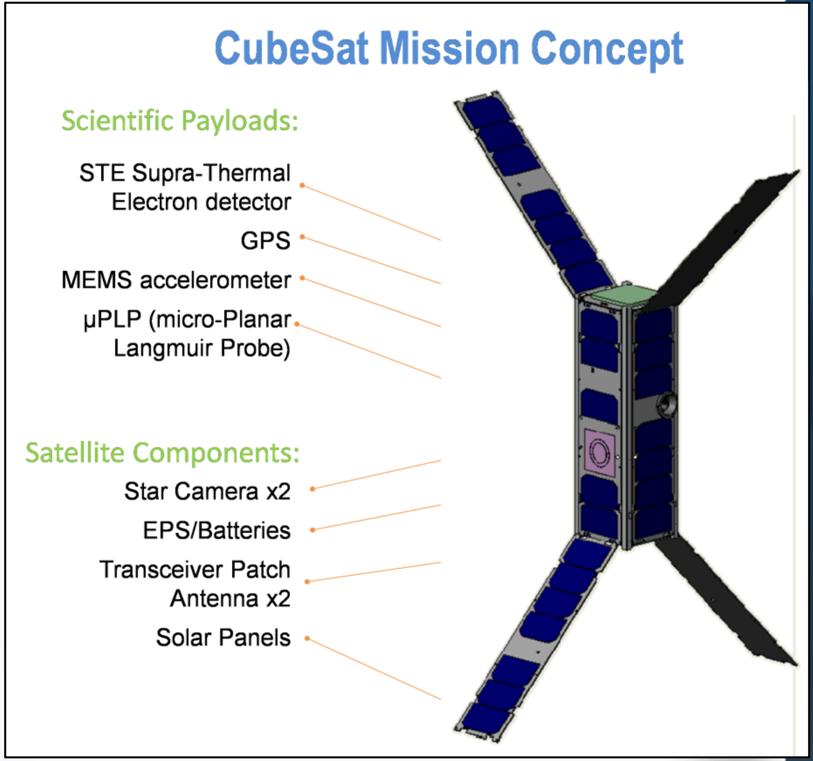
Ranked Utilities of Data Types, Based on Default Grouse Terms

Data Type	Qty of Systems	Ranked Utility
GPS Slant TEC	100	1725
Radio Occultation TEC	6	785
Topside Ionosonde Profile	1	310
Digisonde Profile	50	85
DMSP/SSIES Electron Density	3	26
DMSP/SSUSI Disk UV Radiance	2	21
In Situ Electron Density	1	9
DMSP/SSUSI Limb UV Radiance	2	3
Low Power Ionosonde Peak Parameters	1	0.01

Data: CubeSats for Drag

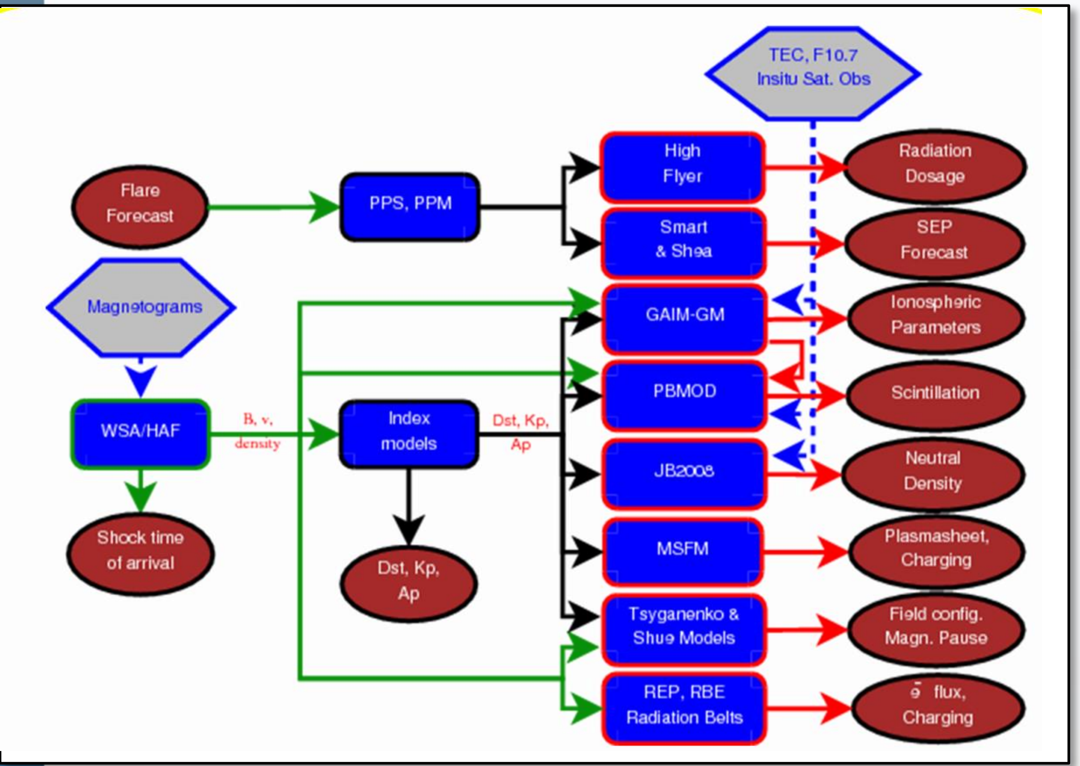
Sutton, et al., *"A CubeSat Constellation to Investigate the Atmospheric Drag Environment"*





Models: Baselining Current Capabilities

Young and Johnston: *A Baseline Space Weather Forecast Capability*



Environment or System Effect	Nowcast	Forecast	Operational model or data	Possible Next Generation Models	SWFL Project	Validation Metrics
Solar						
Flares	flares events, short-wave fade	M, X class probabilities	Data: GOES, USGS, SOON, RSTN, Human Forecast	Falconer model, Leka/Barnes, Balasubramaniam	Operational Model Assessment	Metric: Probabilistic forecast accuracy. Method: Briar Skill Scores and Contingency Tables
Radio Bursts	Solar Radio Event	None	GOES x-ray data, RSTN	Nothing Currently	Nothing Currently	None
CMEs	Nothing Currently	Nothing Currently	None	SMEI Data, SMEI-Tappin-Howard, SMEI-HAF WSA-Enlil-Cone	HAF Assimilation of SMEI Data	V, B, density time of arrival
Solar Energetic Particles	Energetic Particle Event, Polar Cap Absorbtion Event, Solar Radiation Dosage	Energetic Particle Event, Polar Cap Absorbtion Event	GOES particle and x-ray, RSTN, Riometer data, Model: PPM, PPS	REleASE, SEPSWM	Develop SEPSWM, Validate PPM/PPS, SEPSWM	Probability of Detection, false alarm rate, warning time
Solar Indices	F10.7, SSN	F10.7, SSN	Penticton F10.7, Recurrence	Nothing Currently	Nothing Currently	None
Magnetosphere						
Magnetic Storms	Geomagnetic Storming	Geomagnetic Storming	Data: ACE, GOES, DMSP,USGS Models: Real time Dst, HAF, WSA (NOAA)	WSA-Enlil, BATSRUS	Solar Wind Prediction Model Validation	Vsw, n, |B|, Bz, ϕ
Magnetopause Location	None	None	None	Shue et al., MHD	Shue et al. Validation	Satellite Observations
Radiation Belts	electron flux/fluence South Atlantic Anomaly	electron flux/fluence	GOES, RBE, REP	DREAM, DILBERT	Validate REFM, REP, Li, Flux_Pred, DREAM, RBE	e^- flux, fluence from various satellites
High Energy Particles	Radiation Dosage	Radiation Dosage	Data: Cosmic Ray History, neutron data Model: Hi Flier	SEUPE, NAIRAS	Validate Smart & Shea cutoff model	SAMPEX Cutoff Latitude
Magnetospheric Indices	Ap, Kp, Dst	Ap, Kp	USGS, UPOS Kp, Dst	WINDMI	Validate APL Kp model	Ap, Kp, Dst Observations
Ionosphere/Thermosphere						
Thermosphere	Thermospheric Density	Thermospheric Density	HASDM	JB2008	Validate JB2008	Insitu Density (CHAMP)
Ionosphere	TEC, Electron Profiles	TEC, Electron Profiles	Data: SCINDA, DISS, TEC Models: IONPRO and/or GAIM (Gauss Markov)	GAIM (Full Physics)	Validate GAIM	Vertical TEC (JASON), Insitu density (CHAMP), Ground Based GPS TEC, Radio Occultation,
Aurora	Auroral Oval	Auroral Oval	Data: DMSP, USGS Model: OVATION, Hardy	Combination of Ring Current and MHD models	Develop MHD based Radar Auroral Clutter	Under development
Ionospheric Indices	IACTIN, QE	QE	Data: DMSP Model: Empirical Models	GAIM(Full Physics), Combination of Ring Current and MHD models	Nothing Currently	None Identified
Satellite Communications	UHF Communications, signal fade	UHF Communications, signal fade	Data: SCINDA, DISS, TEC Models: WBMOD	PBMOD	Validate PBMOD	Scintillation: Magnitude, start and end times (6hr window), Signal Fade: Magnitude, hits
HF Communications	Polar Cap Absorption, HF Signal Fade, HF Point-to-Point	Polar Cap Absorption, HF Signal Fade, HF Point-to-Point	Data: SCINDA, DISS, TEC, USGS, GOES Models: GAIMCAP (Gauss Markov)	GAIMCAP (Full Physics)	Validate GAIM	Ground Based GPS TEC, QC Ionosonde data, Radio Occultation, Op. Metrics Not Identified
GPS Navigation	GPS Error	GPS Error	Data: SCINDA, DISS, TEC, USGS Models: GAIM (Gauss Markov)	GAIM(Full Physics)	Validate GAIM	Vertical TEC (JASON), Radio Occultation, Ground Based GPS TEC, Op. Metrics Not Identified

Model: Radiation Belt Fluxes

Nelson, et al., *"An Ensemble Forecast for Geosynchronous Radiation Belt Fluxes*

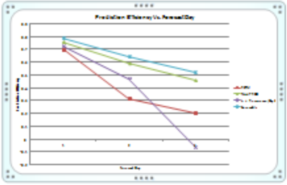
A Stochastic Ensemble Forecast Model for Geosynchronous Relativistic Electron Fluxes

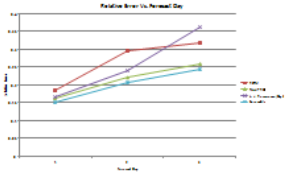
Steven Nelson[1,2], Shawn Young[1], Kara Perry[1,3], Alan Ling[1,4], Xinlin Li[5]
1 – USAF/AFMC/Air Force Research Laboratory 2 – University of New Mexico 3 – Institute of Scientific Research, Boston College
4 – Atmosphere and Environmental Research Inc. 5 – University of Colorado

Overview and Purpose

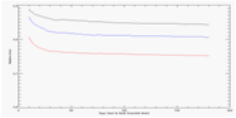
An ensemble model composed of three functional forecasting models (REFM, Li, FLUXPRED) has been developed to forecast >2 MeV electron flux at geosynchronous (GEO) orbit. A multivariate regression is done on these three independent forecasting methods to produce significantly better predictive results than any of the individual models alone. Additionally, a stochastic ensemble is created to provide probability results for forecasting. The purpose of the stochastic ensemble is to provide probabilistic guidance on the current level of trapped geosynchronous radiation to the decision makers.

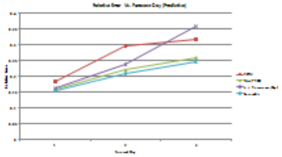
Historical Model





Predictive Model





Ensemble Model Weights

Day	REFM	FLUXPRED	LI
1	0.21121337	0.56028856	0.21717075
2	0.21554675	0.51705649	0.26255925
3	0.25810057	0.73634864	
3(Rec)	0.20887617	0.6271276	0.16510083

Model Performance Parameters

$$Skill\ Score = 1 - \frac{MSE}{\sigma^2}$$

$$MSE = \frac{\sum_{i=1}^{N}(P_i - T_i)^2}{N-1}$$

$$Relative\ Error = \frac{\sum_{i=1}^{N}|P_i - T_i|}{\sum_{i=1}^{N}|T_i|}$$

Conclusions

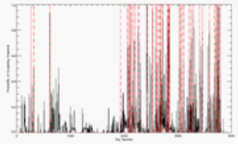
- The Historical Ensemble Model used regression coefficients based on 11 years of historical data and resulted in a lower relative error and a higher prediction efficiency than any individual model
- The Predictive Ensemble Model used regression coefficients based on the previous 81 days to create 1,-, 2-, and 3-day forecasts, resulting in a lower relative error and a higher prediction efficiency than any individual model.
- The Stochastic Predictive Ensemble Model generated one false negative and eight false positives (out of 159 events) for the 1-day forecast over 11 years, where we considered a false positive was a probability over 50% when an event did not occur, and a false negative is a probability below 50% when an event did occur. The Brier Score showed that the ensemble had superior results to any of the individual models.

Stochastic Predictive Model

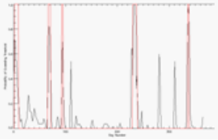
$$BS = \frac{1}{N}\sum_{i=1}^{N}(f_i - o_i)^2$$

Fluence Members	Ensemble BS	FLUXPRED BS	Percent better
fc1,fc2,fc3	0.032088428	0.032708181	1.894795067
fc1	0.018536201	0.021043204	11.91359928
fc2	0.027151828	0.030508025	11.00103006
fc3	0.034029049	0.034081569	0.154100887

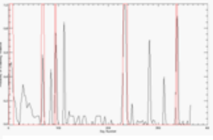
Fc1 Full Results



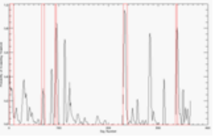
1/04-1/05 Day 1



Day 2



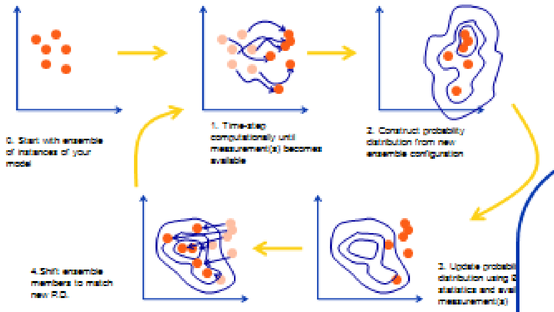
Day 3



Model: Ensemble Dst Forecast

Cable, et al., *"Data Assimilative Analysis of an Analytical Dst Behavioral Model*

Operation of the EnKF



Time-stepping the Dst Model

- **We use a semi-implicit, second-order scheme**

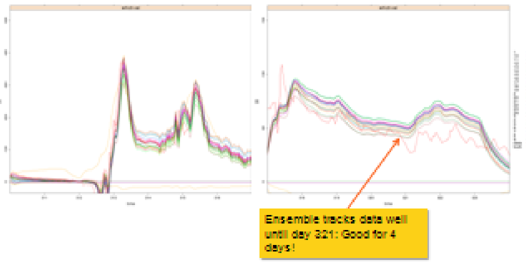
$$\frac{d\mathrm{Dst}}{dt} = \alpha_D \varepsilon_{VS}(t) - \frac{\mathrm{Dst}}{\tau_{RC}}$$

$$Dst^{n+1} = \frac{2-\Delta t/\tau_{RC}}{2+\Delta t/\tau_{RC}} Dst^{n} + \frac{\Delta t\, \alpha_D}{2+\Delta t/\tau_{RC}} \left(\varepsilon_{VS}(t^{n+1}) + \varepsilon_{VS}(t^{n})\right)$$

- Dst: time-stepped in model; measurements assimilated; shifted during assimilation
- τ_{RC} and α_D: constant from one Dst measurement to the next; no dire τ_{RC} or α_D measurements available; shifted during assimilation
- ε_{VS}: calculated from ACE data and fed directly into model as "given"; assimilation
- Δt: held constant at one hour; all measurements available hourly, so assimilation takes place after each time step of the model

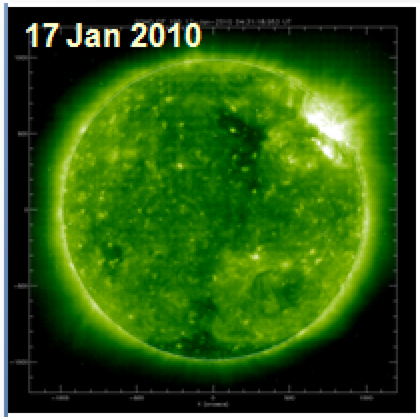
Predictive Runs

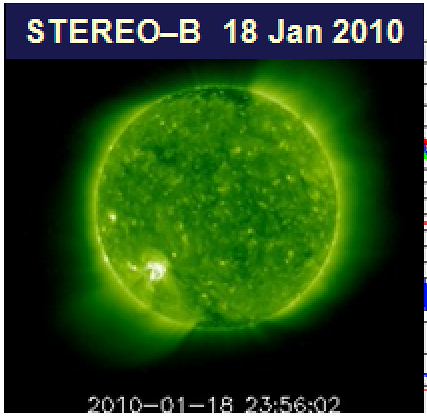
- EnKF derives parameters as:
  - α_D=-40[(nT/hr)/(mV/m)]
  - τ_{RC}=7.7 hr
- Use these parameters to do purely predicitve (i.e. no Dst measurements available) runs:

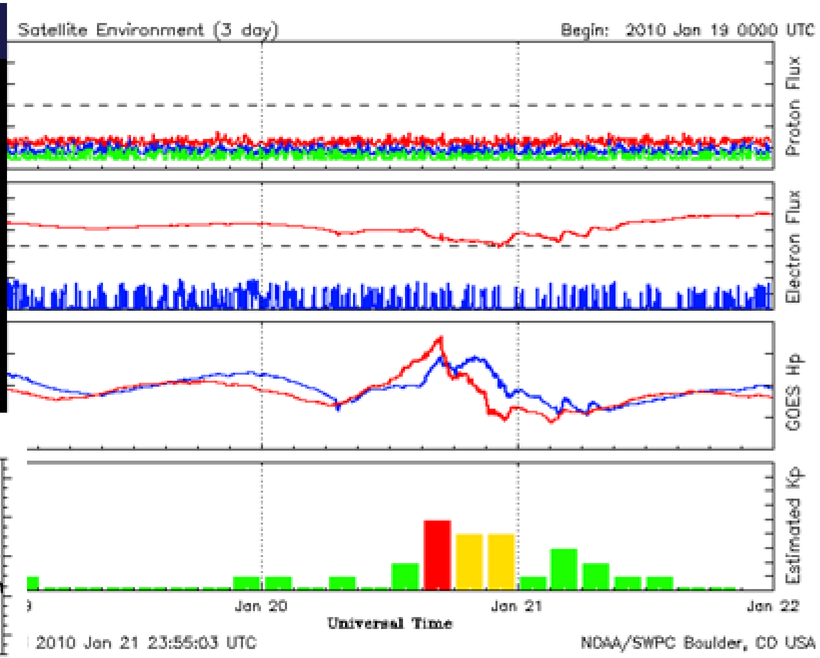


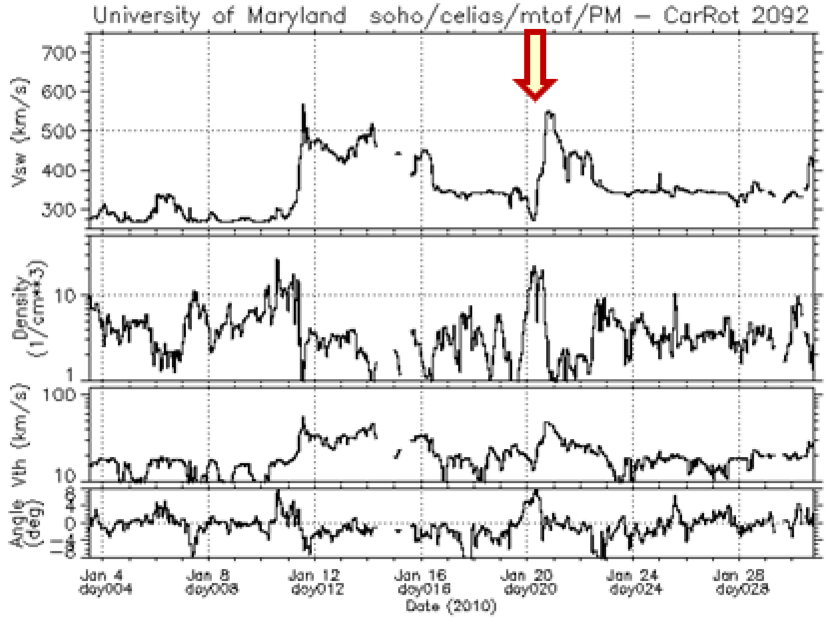
Model: Solar-Iono connections

Gentile, et al., *"Solar Wind Effects on Plasma Density Depletions"*







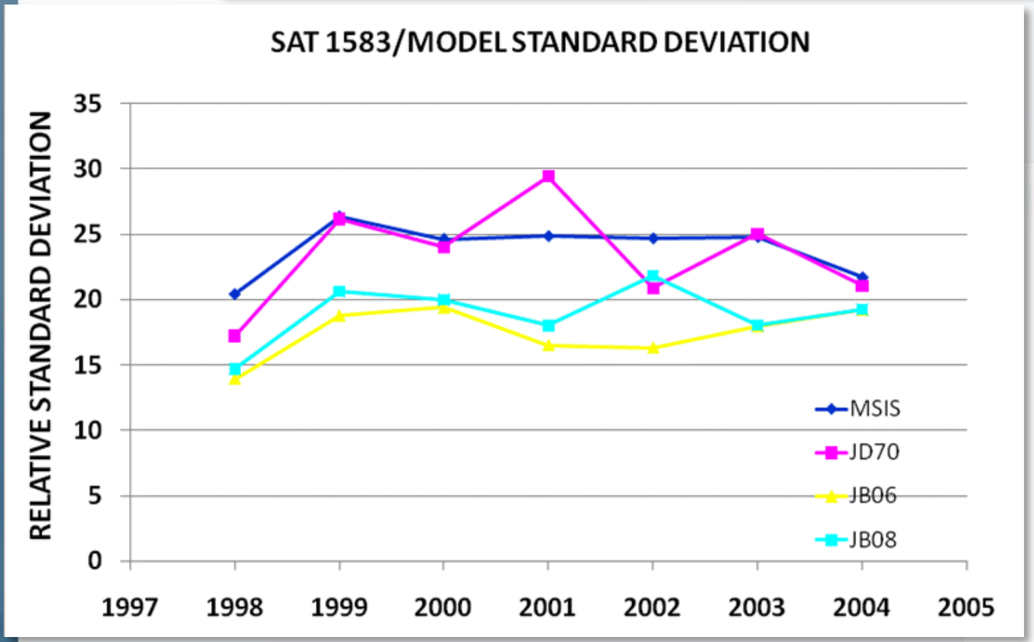


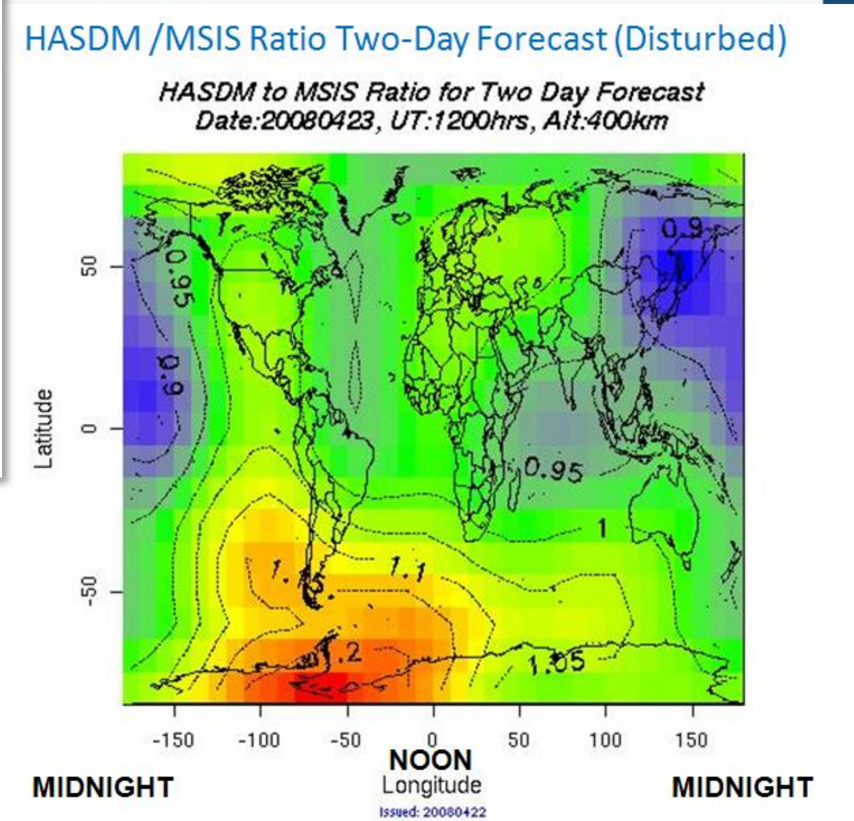
SMEI observed faint CME on 18 Jan 2010 beginning at ~ 10:26 am and lasting ~ 16 hours

Indicators of solar activity 20 January 2010

Model: Validation of Neutral Density Models

Wise, et al., *"Validation and Implementation of Neutral Density Models for SWFL"*

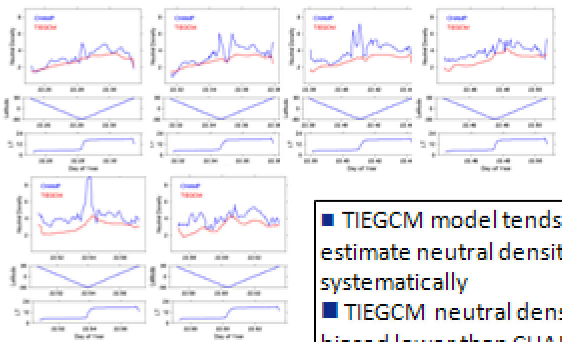




Models: Validation of TIEGCM

Lin, et al., *"Validation of Physics-based Neutral Density Modeling Using Thermosphere Ionosphere Electrodynamics Global Circulation Model"*

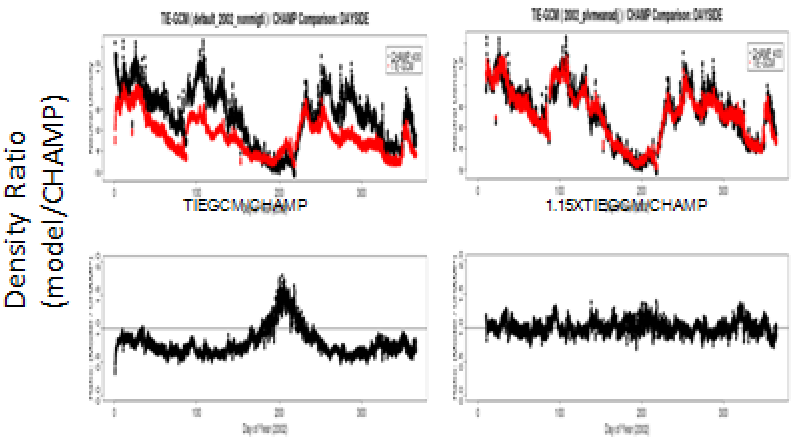
Validation of TIEGCM with CHAMP Measurements



- TIEGCM model tends to under-estimate neutral density systematically
- TIEGCM neutral density mean is biased lower than CHAMP values

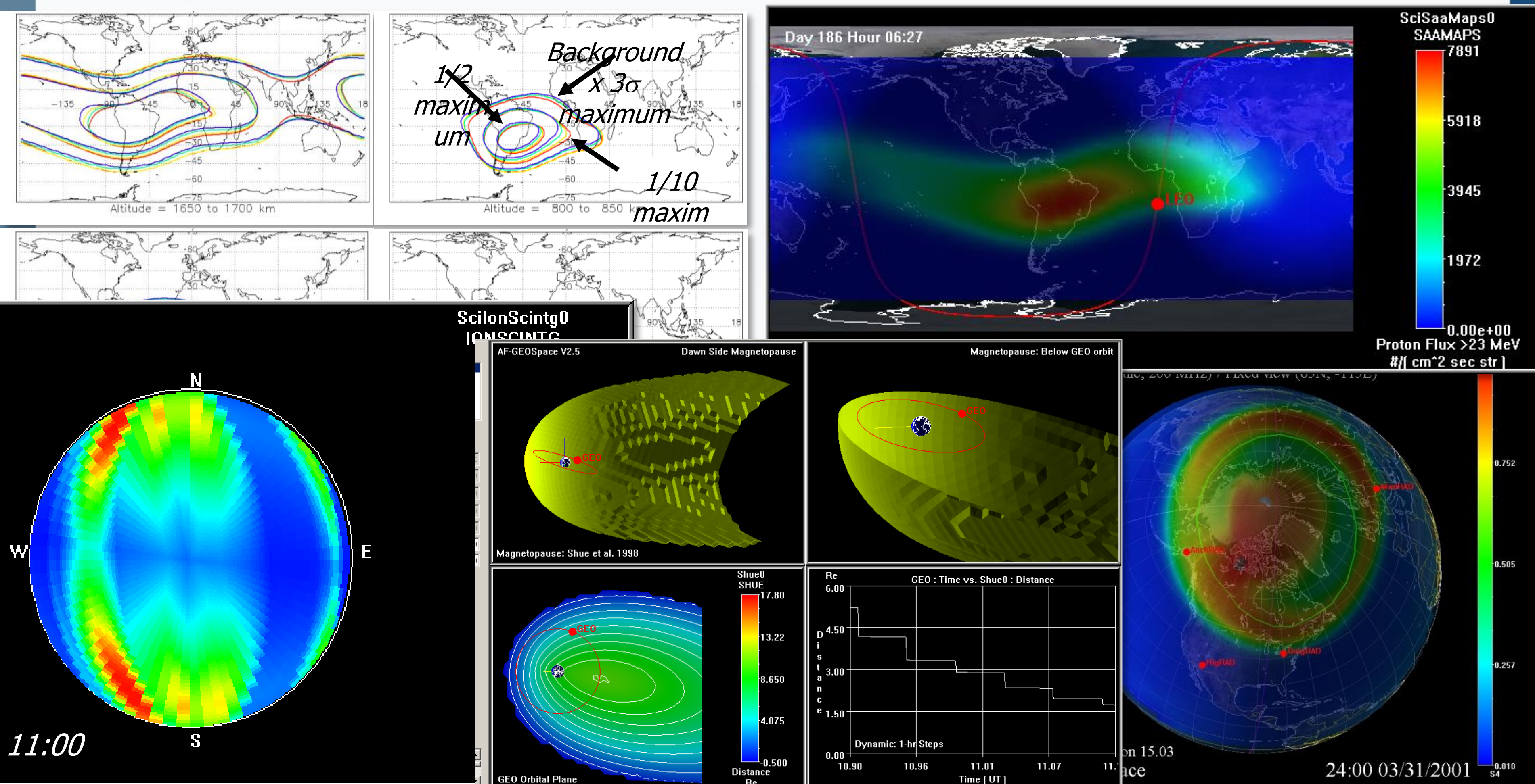
Dayside TIEGCM Results

constant eddy diffusivity ($5.0 \times 10^{-6}\ s^{-1}$) | CHAMP Equatorial Eddy Diffusivity



Model/Product: AF-GEOSpace

Hilmer, et al., *"AF-GEOSpace Version 2.5"*



Products: Hybrid CME Forecast

Johnston, *"AFRL SWFL: Constructing a Hybrid CME Forecast Methodology*

Forecaster Flowchart

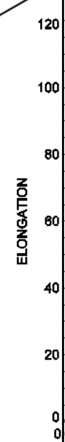
Solar event alert from coronagraph or other source (optional)

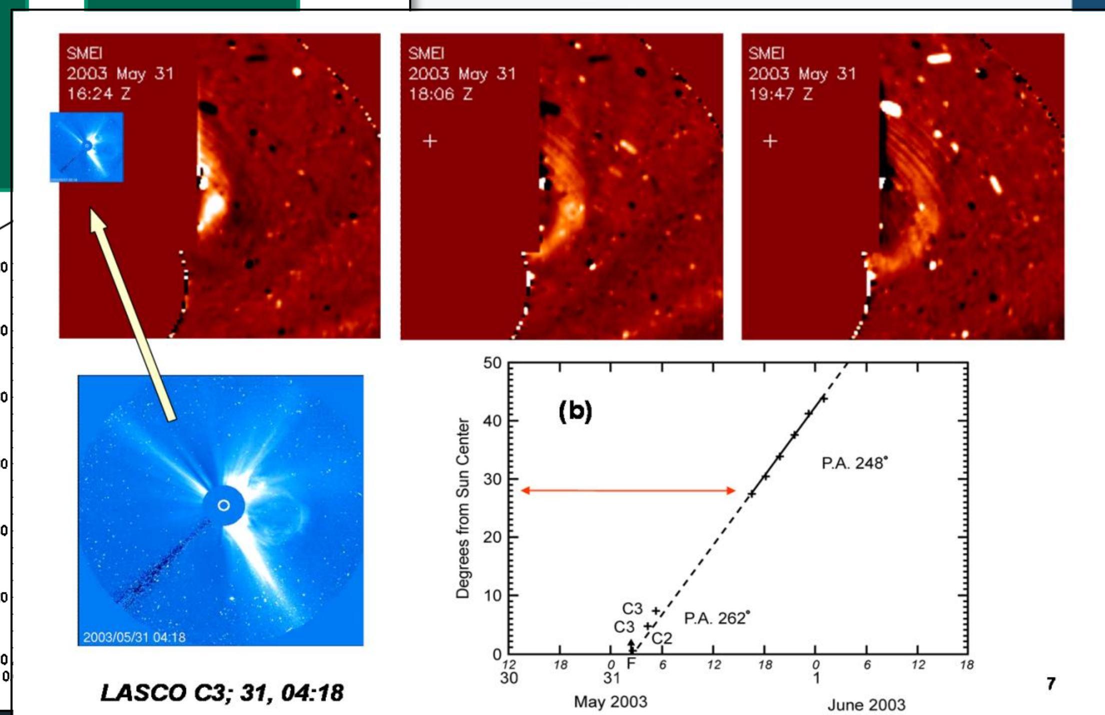
→ First detected in imager 20 ° - 30 ° from Sun (If not detected may be dim or back-sided)

↓ Forecaster measures position of leading edge of CME wavefront based on 3-4 images, makes initial speed estimate. Issues preliminary warning

→ Mid-course correction issued for event arrival time at Earth

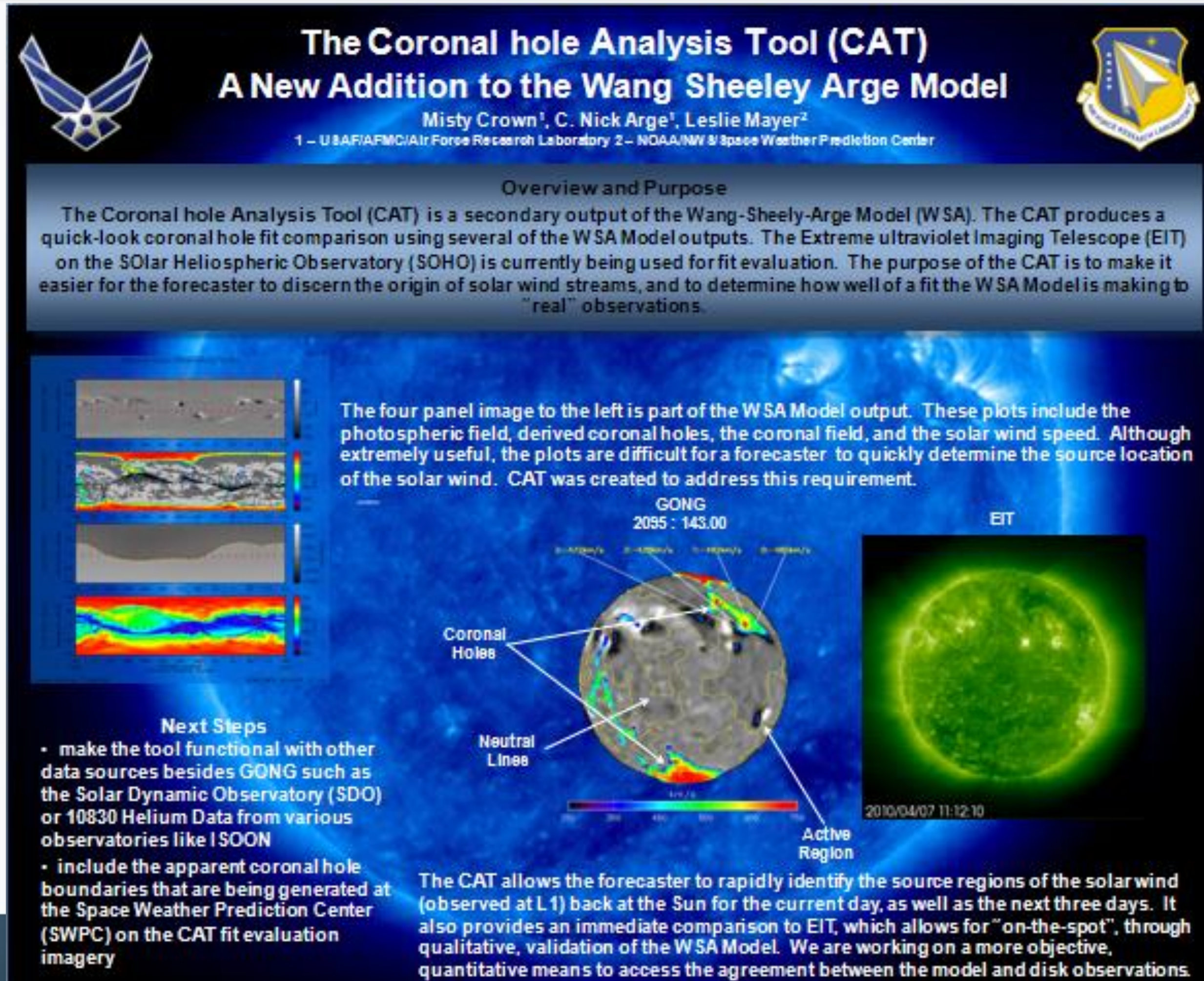
↓ At 0.5-0.75 A.U. from Sun, forecaster runs TH, HAF, or other model on all the images (position/time of wave front shape)





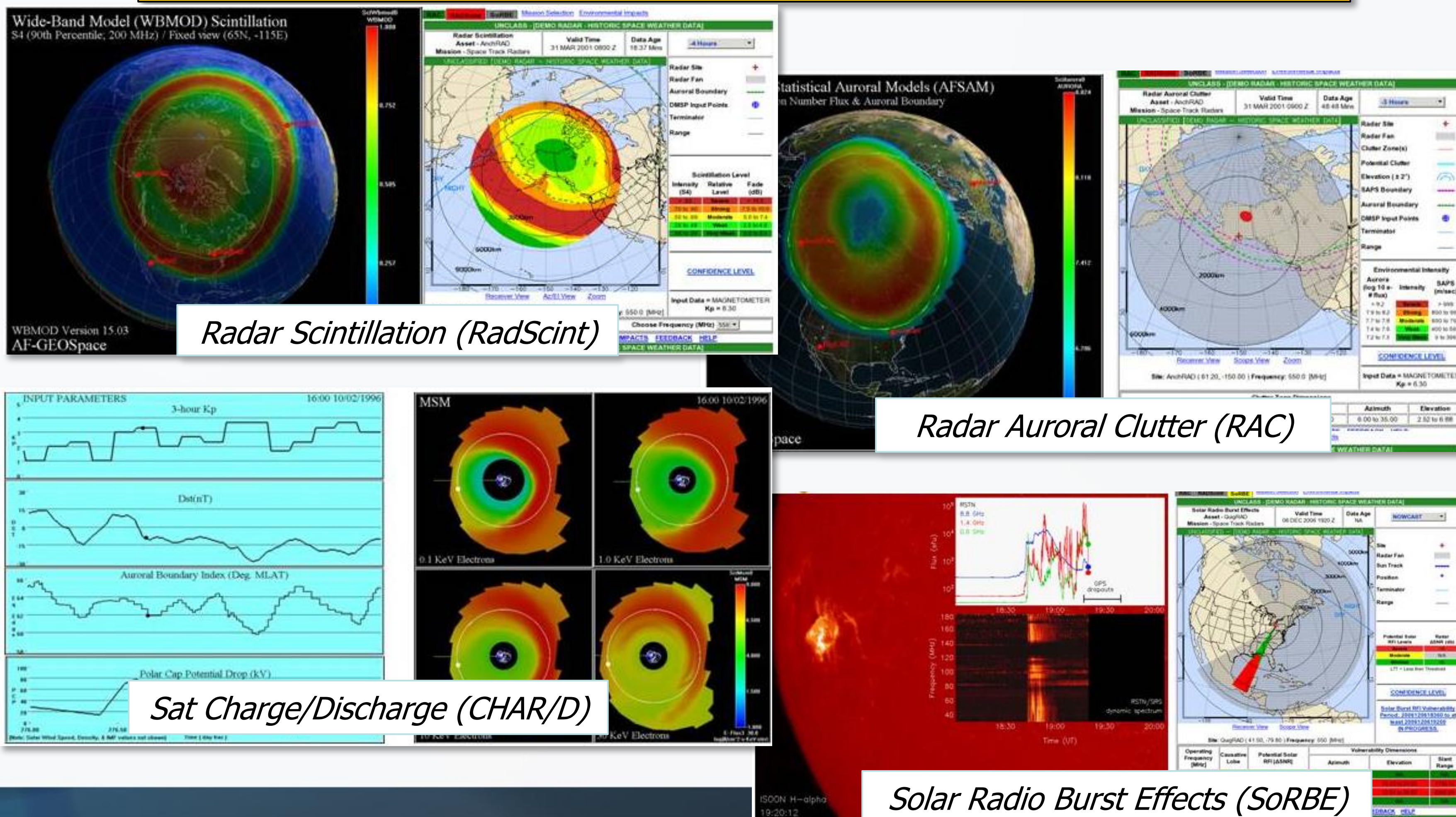
Products: Coronal Hole Tool

Crown, et al., *"Coronal Hole Analysis Tool (CAT): A New Addition to the WSA Model"*



Products: System Effects

Quigley, et al., *"Research-to-Operations: Models of SWFL and Products of SEEFS*



Conclusion

- AFRL Space Weather Center of Excellence is working on many pieces of the Space Weather puzzle
- The Space Weather Forecast Laboratory (SWFL) focuses efforts related to research-to-ops transition
- Details can be found at the Poster Session!