Operational specification and forecasting advances for [1]Dst, thermospheric (LEO) [2]densities, and [3]aviation radiation dose and dose rate

Advances In Space Weather Observations, Modeling, and Applications

AMS 2014

February 4, 2014

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3 areas of improvements for operational users

1. **Aviation radiation environment specification**
   - ARMAS real-time radiation data from aircraft
2. **Dst forecasting**
   - ENLIL/Rice “stream A” Dst forecasts
   - Anemomilos “stream B” Dst forecasts
3. **Thermospheric density forecasting**
   - JB2008 and HASDM densities

1. Aviation radiation environment specification

ARMAS real-time measurements from aircraft

– utilizes airborne micro dosimeters
– calibrated to TEPC in NSRL, LANSCE, LLUMC beams
– makes dose and dose rate measurements in real-time
– transmits data to the ground via Iridium for data integration with NAIRAS
– distributes the updated information via *SpaceWeather* app with 15-minute latency (aircraft-to-app)
– http://sol.spacenvironment.net/~ARMAS/index.html

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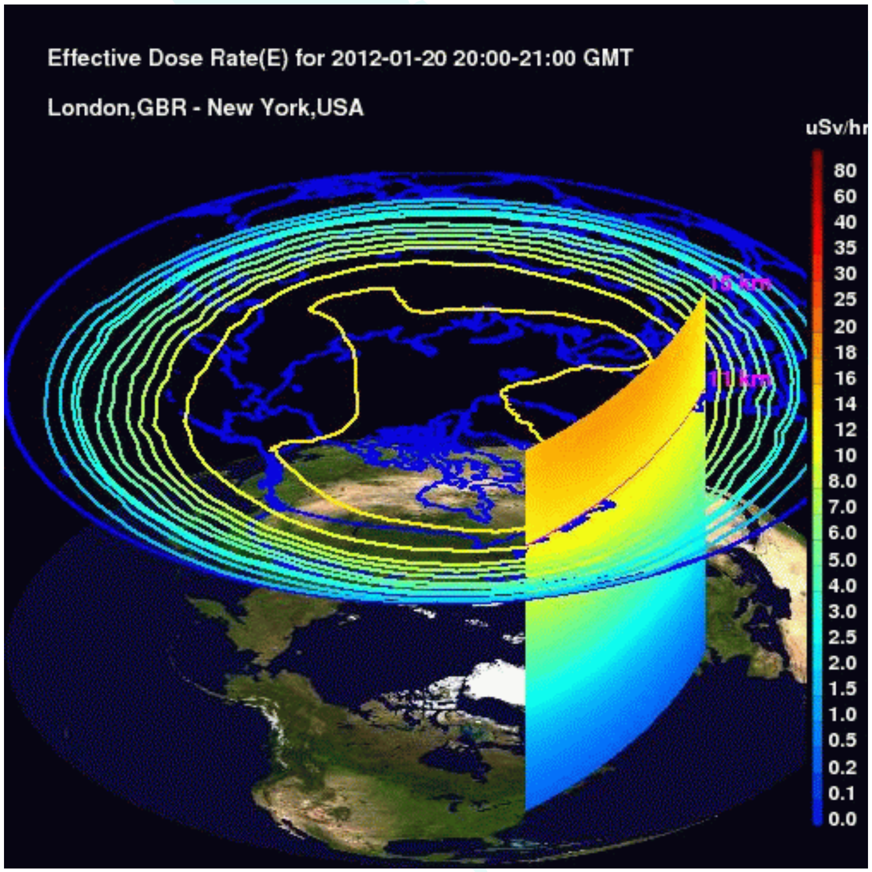
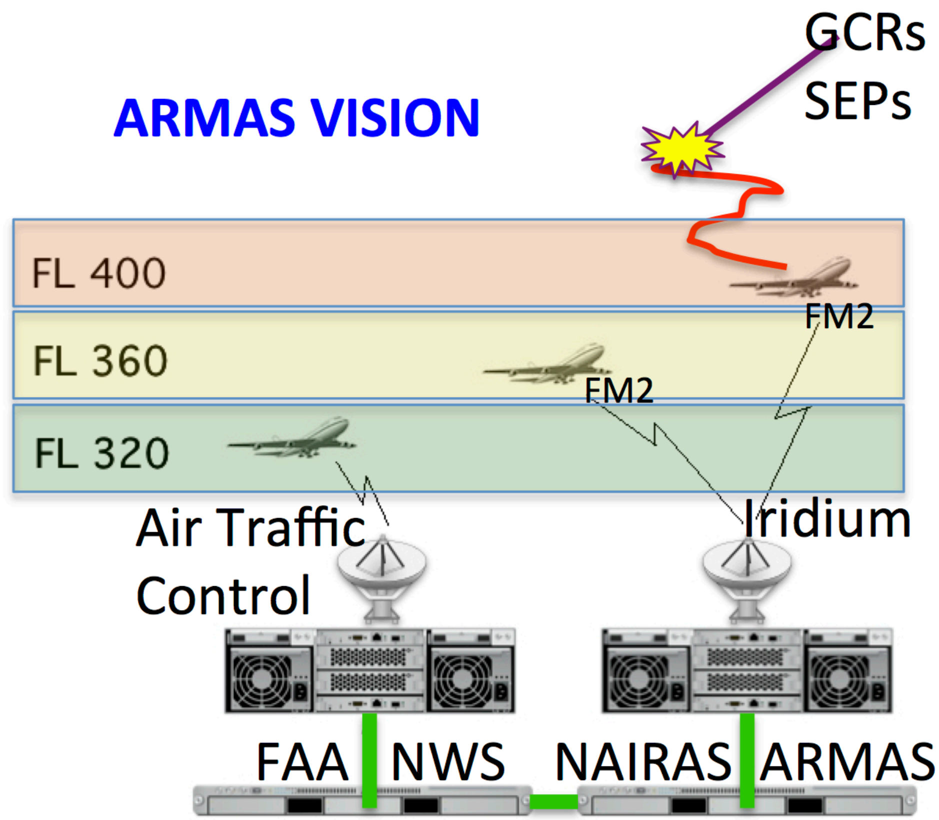
Real-time aviation radiation specification

NAIRAS



ARMAS



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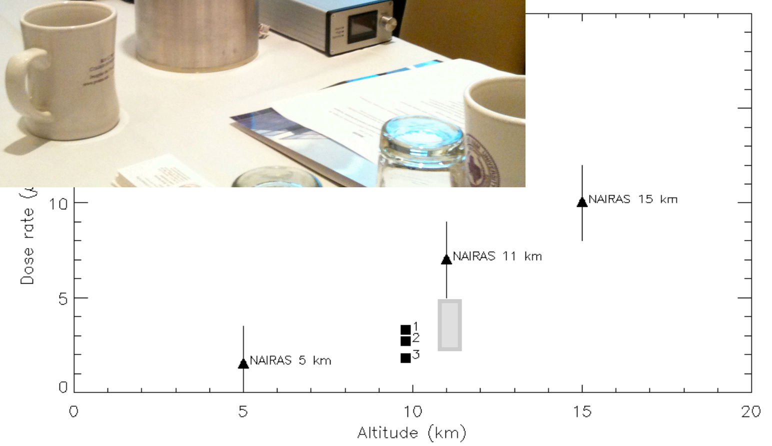
ARMAS SBIR Phase I, II *real-time* successes

Pre-ARMAS: post flight thermoluminescent and etched track detector analysis

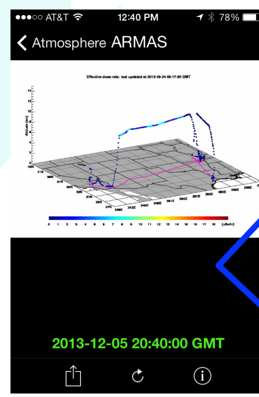
ARMAS Phase I

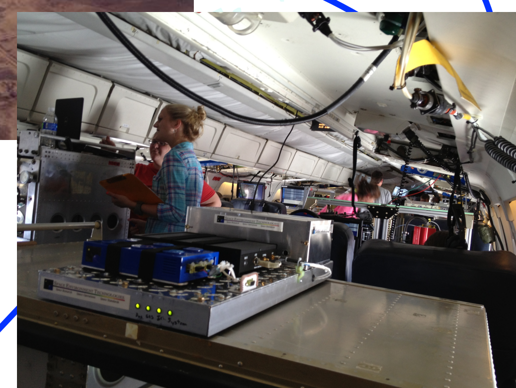
- TEPC - 7 commercial flights
- 2011–2012



ARMAS Phase II

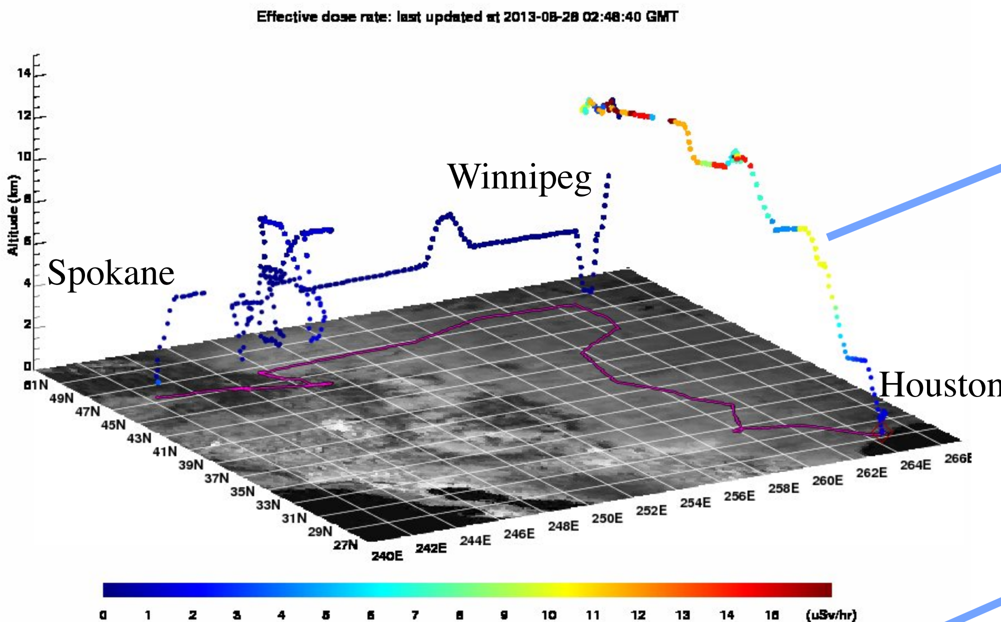
- µDos - 29 Dryden DC-8 flights
- 2013

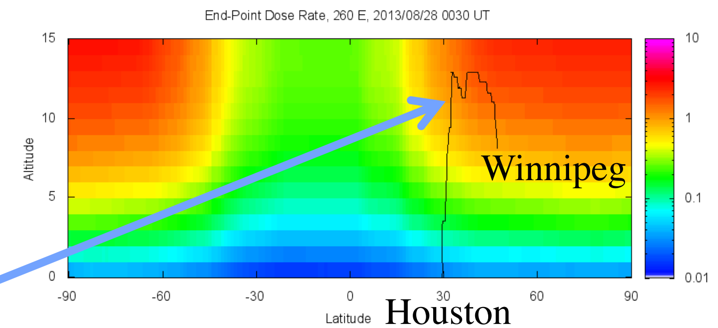


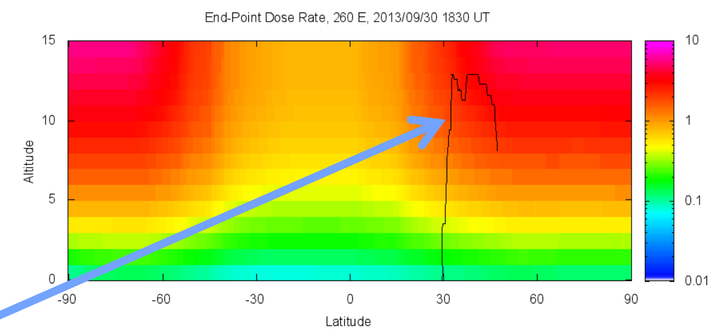


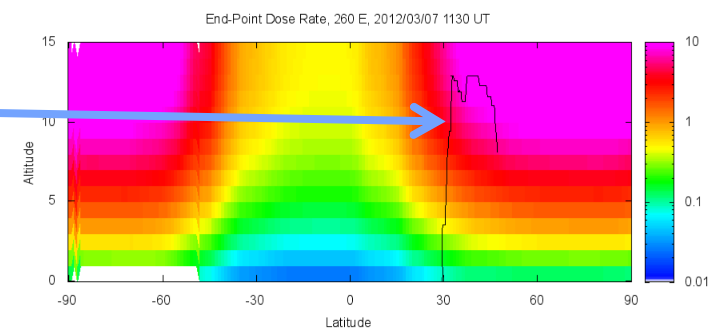
Tobiska *et al.* http://spaceweather.usu.edu http://spacewx.com *SpaceWeather* app

ARMAS flight 18 example









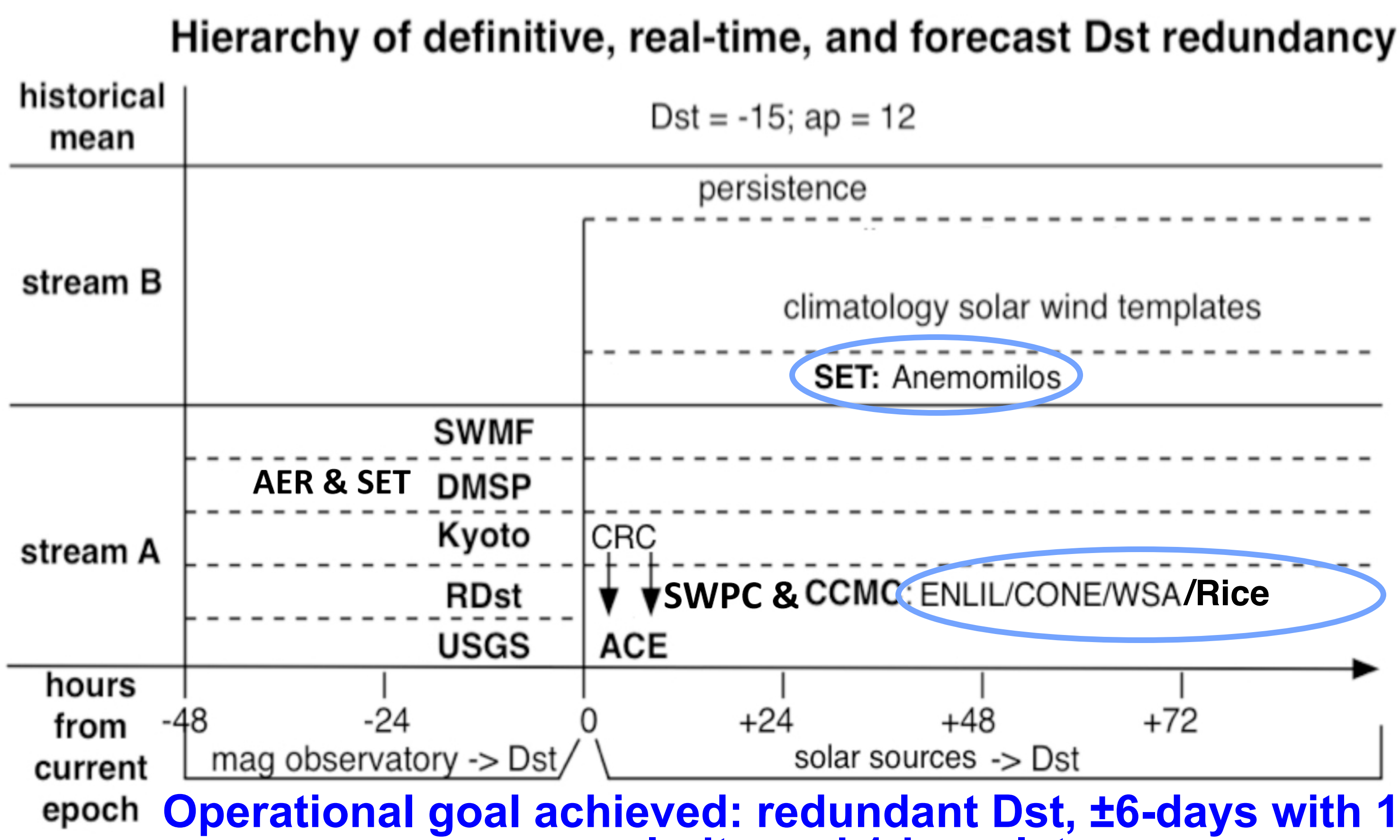
- **Top:** ARMAS flight 18 (August 28, 2013)
- **Middle:** S2 event (September 30, 2013)
- **Bottom:** S3 event (March 7, 2012)

Related Citation: Tobiska, W. K., B. Gersey, R. Wilkins, C. Mertens, W. Atwell, and J. Bailey (2014), U.S. Government shutdown degrades aviation radiation monitoring during solar radiation storm, *Space Weather*, 12, doi 10.1002/2013SW001015

2. Dst forecasting

- Primary (stream "A"): ENLIL/Rice Dst forecasts
- Backup (stream "B"): Anemomilos Dst forecasts
- http://sol.spacenvironment.net/~sam_ops/index.html?
- Citation: Tobiska, W. K., D. Knipp, W. J. Burke, D. Bouwer, J. Bailey, D. Odstrcil, M. P. Hagan, J. Gannon, and B. R. Bowman (2013), The Anemomilos prediction methodology forDst, SpaceWeather, 11, 490–508, doi:10.1002/swe.20094.

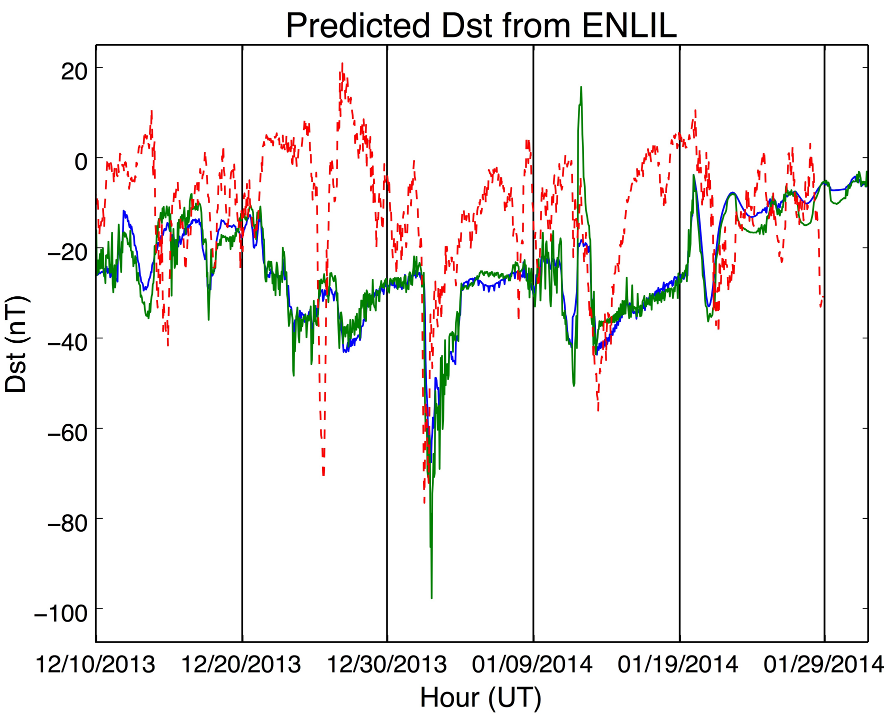
Operational Dst requirement: -48 to +72 hours with 3-hour granularity, 3-hour latency

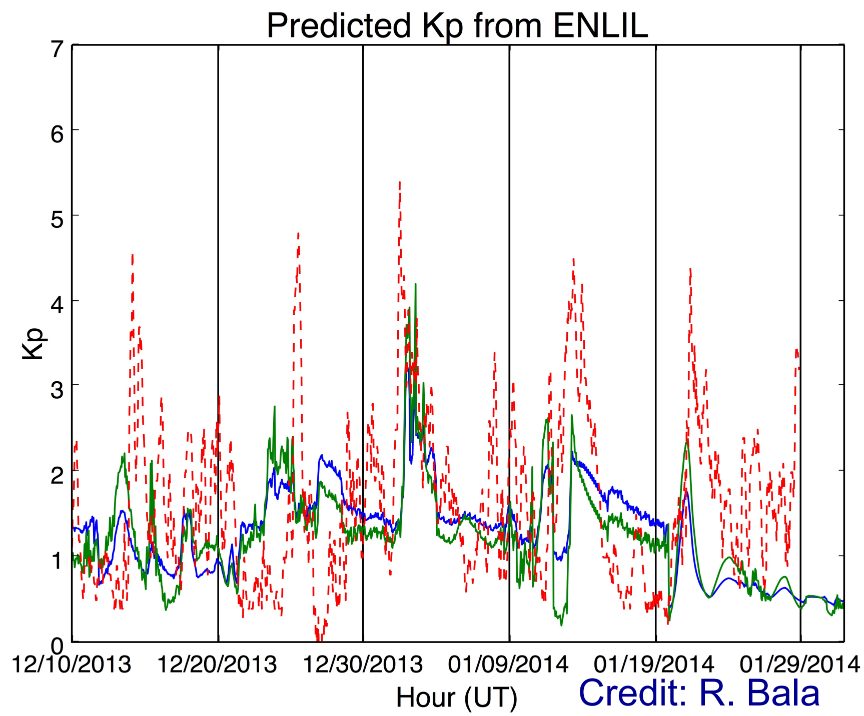


Operational goal achieved: redundant Dst, ±6-days with 1-hour granularity and 1-hour latency

ENLIL/Rice Prime Dst Forecast and ACE Comparison

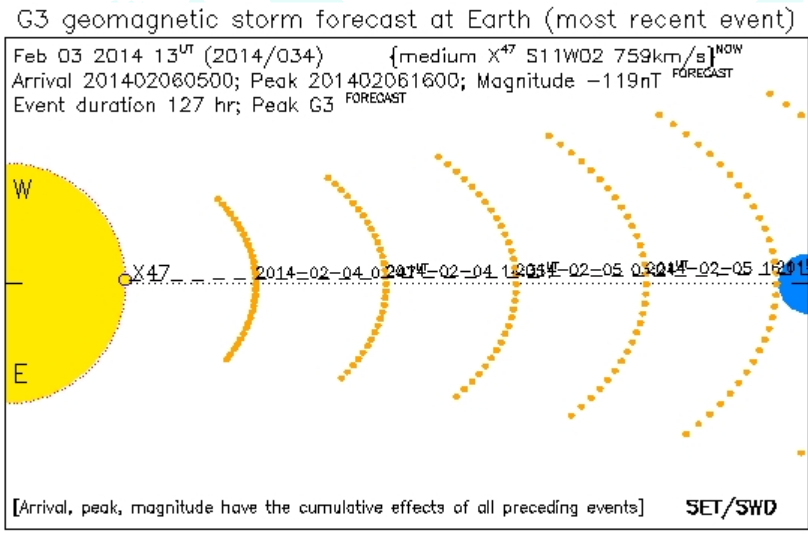
- ACE near-realtime predictions are plotted here in red
- http://mms.rice.edu/realtime/forecast.html
- ENLIL/Rice models under predict but largely in line with the trend and are within acceptable range
- Magnetospheric activity on the New Year's day is well captured

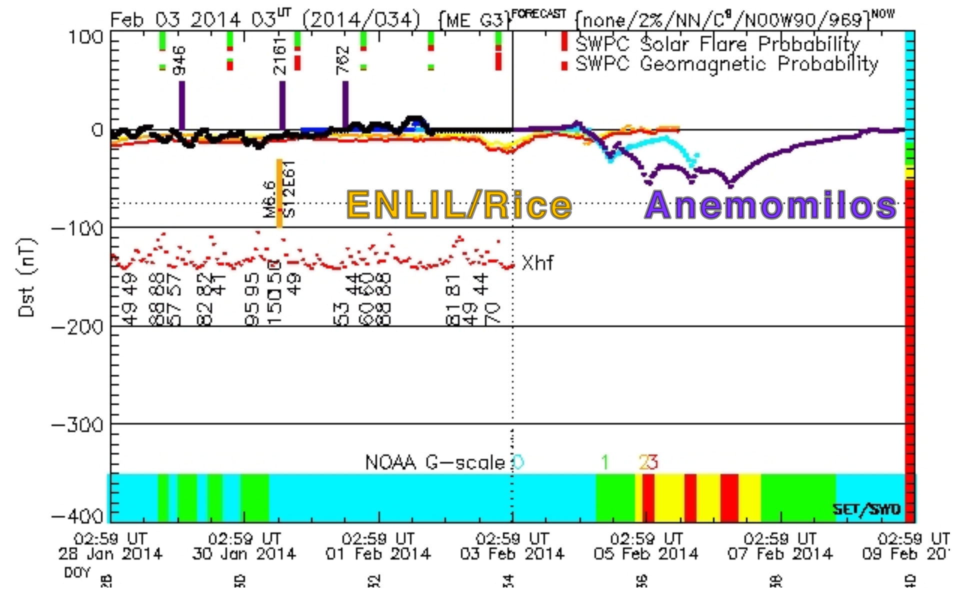




Credit: R. Bala

SET's operational Dst forecasting



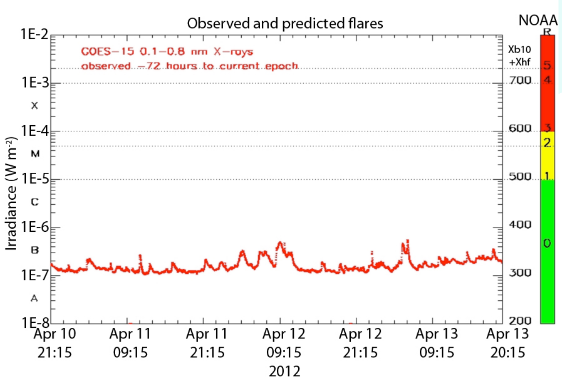


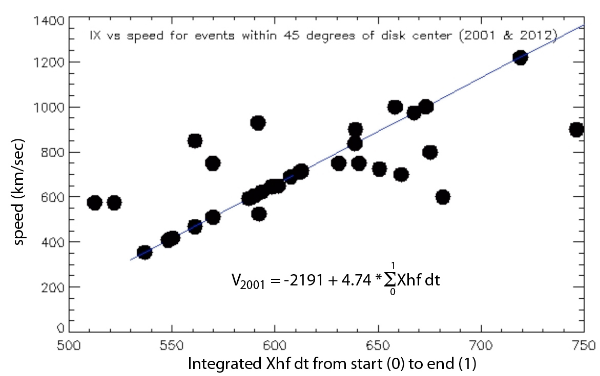
- *Anemomilos* is the Greek word for "windmill"
- The data-driven deterministic algorithm uses **3 solar observables** to identify geoeffective events: **http://sol.spacenvironment.net/~sam_ops/index.html?**
- It has a **15-minute cadence**, **1-hour time granularity**, **144-hour prediction** window (+6 days), and 1-hour latency
- Most flare events above a certain irradiance threshold, occurring within defined solar longitude/latitude regions and having sufficient liftoff velocity of ejected material, will produce a geoeffective Dst perturbation

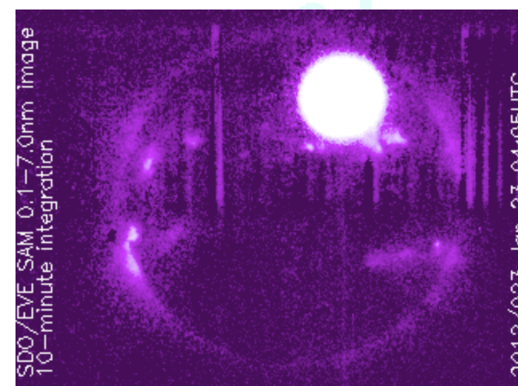
Anemomilos Basis

Three solar observables are used for operational Dst forecasting: flare magnitude, integrated flare irradiance, and event location

- Magnitude is a proxy for ejecta quantity (mass) and, combined with speed derived from the integrated flare irradiance, represents the kinetic energy
- Speed is estimated as line-of-sight velocity for events within 45° radial of solar disk center
- Solar disk, not limb, observable features are used for predictive techniques based on SDO/EVE/SAM centroid of flare event





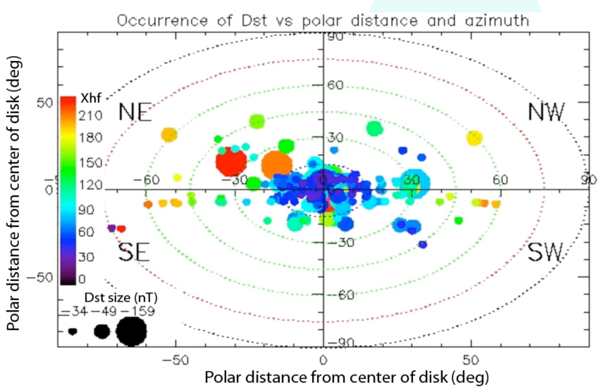


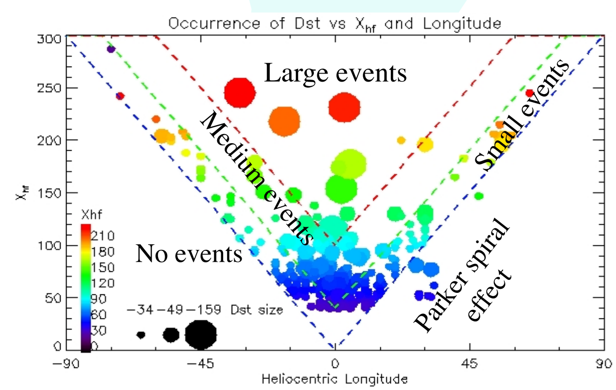
Anemomilos geoeffectiveness of location

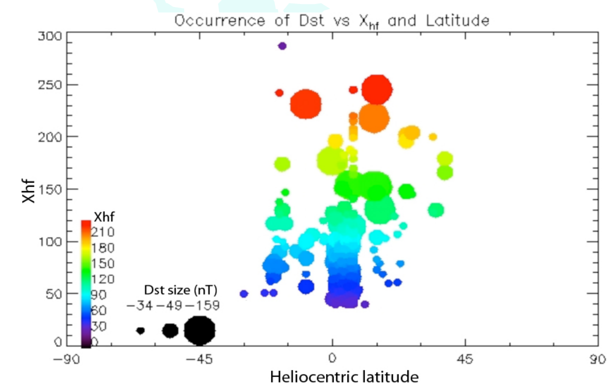
Occurrence of Dst vs Xhf in solar latitude & longitude (25 months)

- 2001 (Jan-Jul), 2005 (Mar-Sep), 2011-2012 (Dec-Nov)

Resulting Dst event size can be sorted by Xhf size and flare longitude/latitude







3. Thermospheric density forecasting

- HASDM provides derived, accurate, global densities (2000–)
- JB2008 is an empirical thermospheric density model that is used for real-time operational forecasts of accurate densities for satellite drag using solar & geomagnetic drivers
  - Solar drivers are the four indices and proxies S10, M10, Y10, F10
  - Geomagnetic drivers are the two indices ap and Dst
- Related Citations and data/model locations:
  - IS 14222 Earth Atmosphere Density, ISO, Geneva, 2013
  - JB2008: http://sol.spacenvironment.net/~JB2008/index.html
  - CIRA: http://spaceweather.usu.edu/htm/cira
  - SIP: http://www.spacewx.com/solar2000.html
  - *SpaceWeather* app: http://spacewx.com/iPhone.html
  - http://spacewx.com/Space_Weather_Now.html

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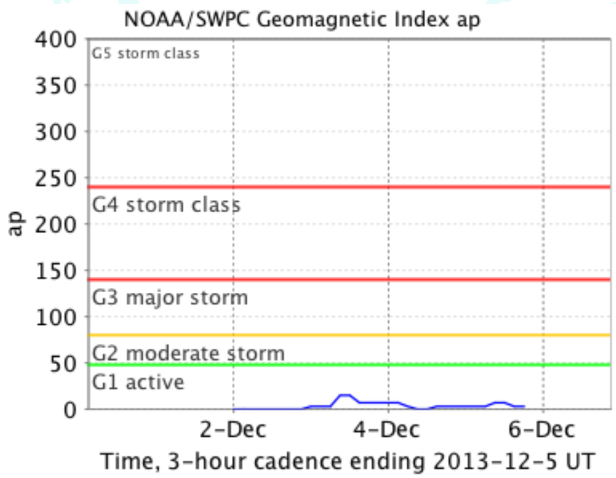
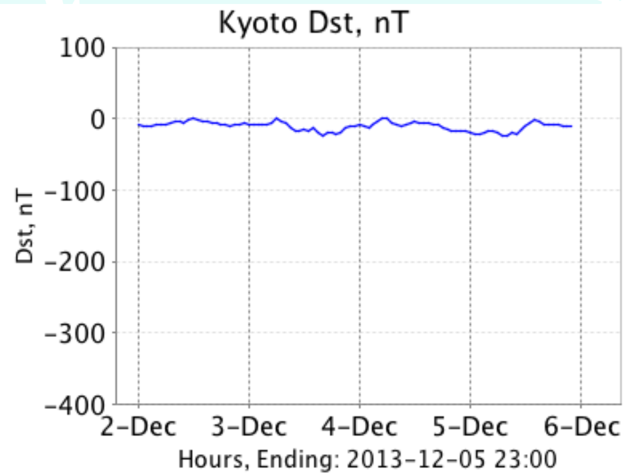
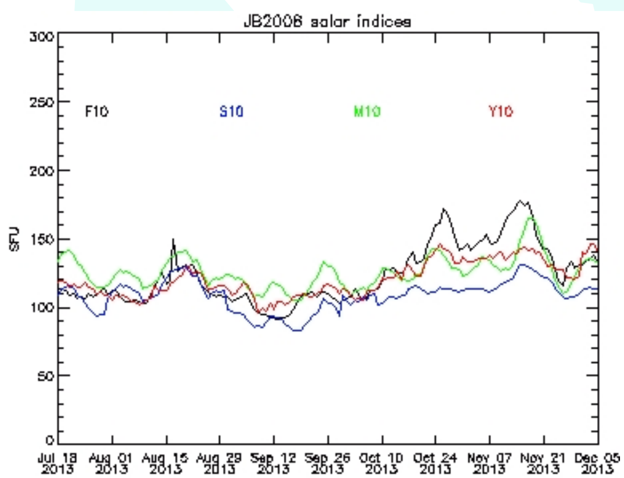
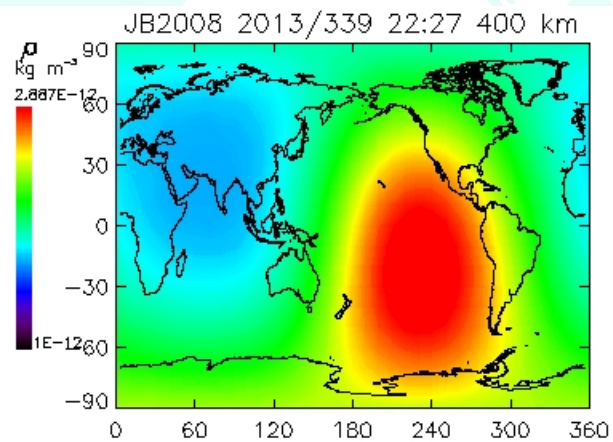
JB2008 Indices









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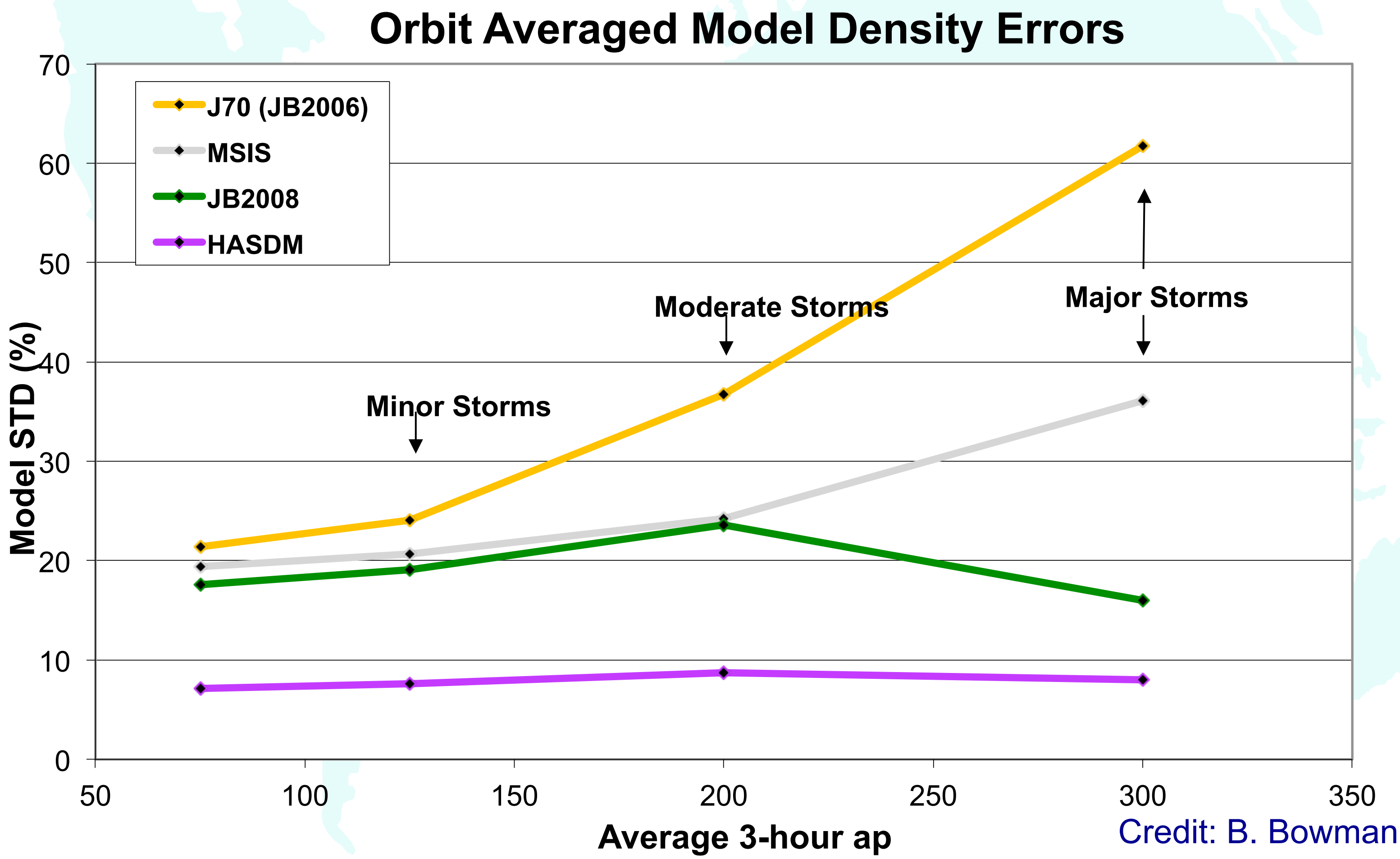
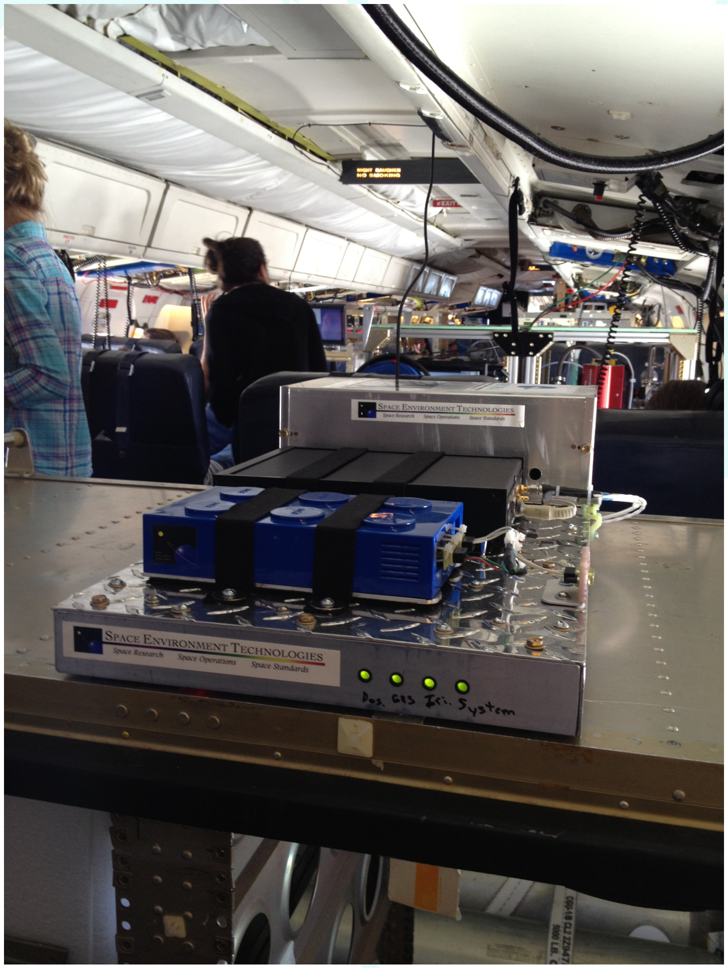
Orbit Average Density Error for Geomagnetic Storms



Credit: B. Bowman

Backup slides

ARMAS Dryden DC-8 flights June – September 2013



DC-8 FM1 prototype setup

- 29 ARMAS flights
- demonstrated real-time downlink of dose rate from commercial aircraft altitudes
- Iridium link to ground
- integration into NAIRAS
- distribution to users
- 15-minutes latency

ARMAS real-time dose collection success

ARMAS SBIR objectives - COMPLETE

- ✓ dose rate measurements to be made using dedicated, calibrated micro-dosimeters on aircraft
- ✓ real-time downlink of data via Iridium satellite link
- ✓ data integration into NAIRAS radiation dose rate

ARMAS schedule

- ✓ **2011**: 7 TEPC flights validated NAIRAS
- ✓ **2012**: 2 dosimeters' purchased, PCB assembled
- ✓ **2013**: Fe ion, neutron, and proton beam comparisons with TEPC and 29 Dryden DC-8 flights for real-time downlink demonstration for dose rate along aircraft flight path
- • **2014**: real-time dose database app for air crew, frequent flyers, and prenatal fetuses; DC-8 flights Q3-Q4

Rice real-time models of Kp, Dst and AE

- Near near-realtime predictions models based on neural network
- Uses empirical coupling functions as sequential time inputs generated using ACE data to feed the neural networks
- Predicts Kp, Dst and AE (short-term) over1-hour and 3-hour periods (subject to prevailing solar wind conditions)
- Subscribers to their network receive free “alerts” for values exceeding pre-defined thresholds

$$\mathrm{Kp};\ \mathrm{Dst}^*_{t+1} = f\,(\Phi_{t=0}, \Phi_{t=-1}, \ldots, \Phi_{t-8})\ \text{and}$$

$$\mathrm{Kp};\ \mathrm{Dst}^*_{t+1} = f\,(\Phi_{t=0}, \Phi_{t=-1}, \ldots, \Phi_{t-8};\ \mathrm{Press}_{t=0}\ \mathrm{Press}_{t=-1}, \ldots, \mathrm{Press}_{t-8})$$

Dst^* is pressure corrected

Bala and Reiff [2012]

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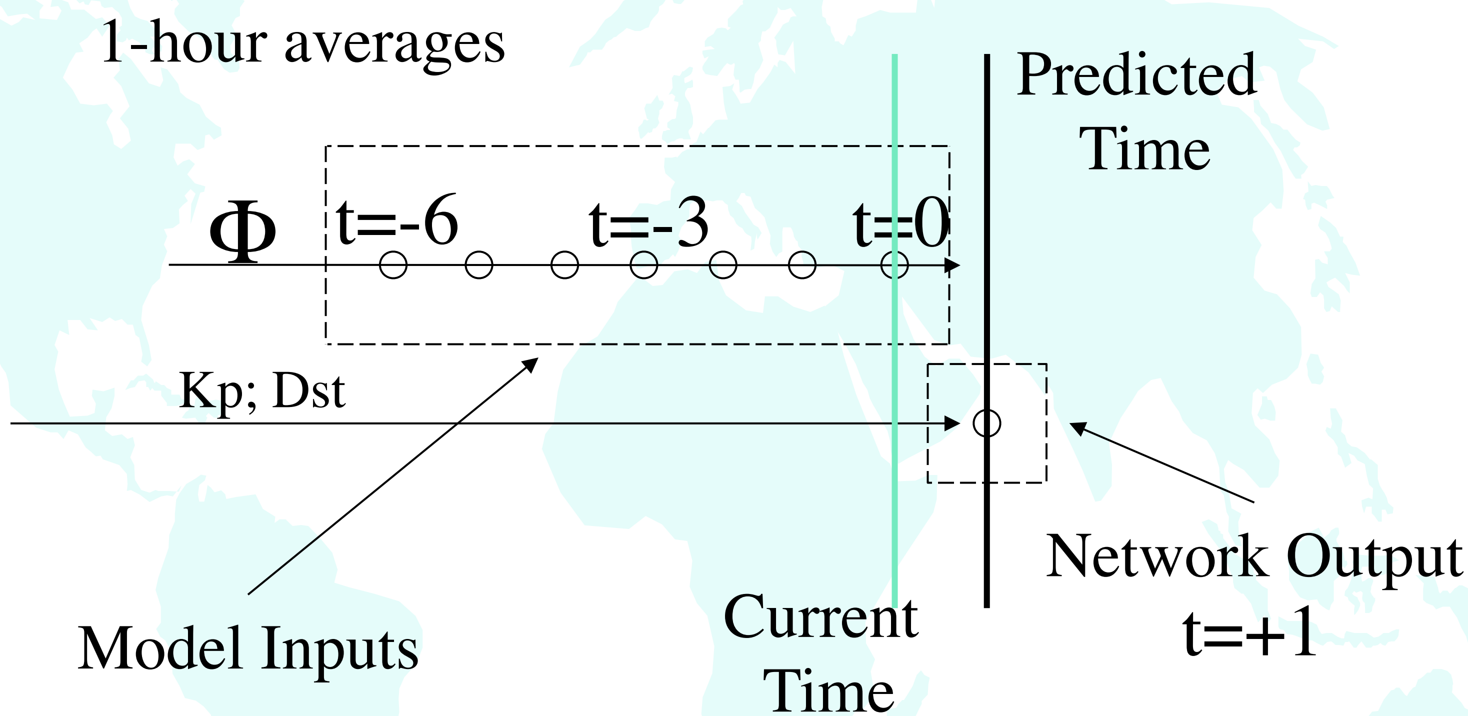
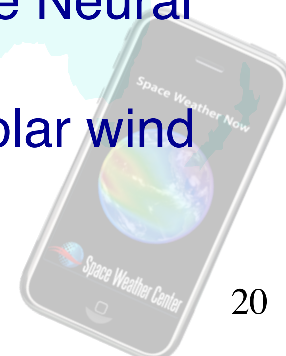
ENLIL/Rice Prediction model representation



- Enlil-based prediction models are extensions of the existing Rice Neural Network models
- For each valid prediction, approximately 9 hours of preceding solar wind inputs are needed.

Credit: R. Bala



Metadata

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:Missing_data: -999.0
:Run_Date_Time: 2014-01-27 19:20:33
:Source: NOAA/SWPC ESWDS 1-minute database
:Updated_by: Report_ENLIL_1hr_DBvec
:Data_time_zone: GMT
:Cadence: 1 hour
:Resolution: 1 hour
:version: v2.0
#ENLIL Solar Wind Data file produced by Space Environment Technologies/Space Weather Division
#Contact: spacenvironment@spacenvironment.net
#http://www.spacewx.com
# r = velocity outward (positive), km/s
# v_theta = north (positive)
# phi = west (postive)
#
#YYYMMDDhhmm YYYY-MM-DD hh:mm  JD b_r(nT) b_theta(nT) b_phi(nT) v_r(km/s) v_theta(km/s)
v_phi(km/s) (p/cm^3)  temp (K)  polarity(CG) Cloud  time_Arrival JD_arrival Days_to_Arrival
```

Data obtained from Enlil NOAA/SWPC ESWDS server

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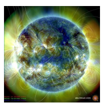
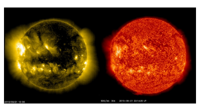
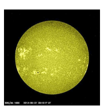
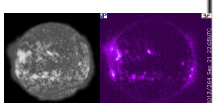
JB2008 Thermosphere Overview – Ops

Daily operational indices selected

- JB2008 additionally uses 81-day center smoothed indices
- JBH09 additionally uses 54-day backward smoothed indices

Index or proxy	Observing facility	Instrument	Observation time frame	Measurement cadence	Measurement latency	Operational availability
$F_{10.7}$	Penticton ground observatory	Radio tel-escope	1947-2013	3 times/day	Up to 24 hours	yes
$S_{10.7}$	SOHO, GOES	SEM, EUVS	1996-2013	15 seconds	Up to 24 hours	(a)
$M_{10.7}$	NOAA-16, 17, 18, SORCE, ERS-2	SBUV, SOL-STICE, GOME	1991-2013	2 times/day	Up to 24 hours	yes (c)
$Y_{10.7}$	GOES-12, UARS, SORCE, TIMED	XRS, SOL-STICE (2), SEE	1991-2013	1 minute, 16 times/day	Up to 10 min-utes, up to 48 hours	(b)

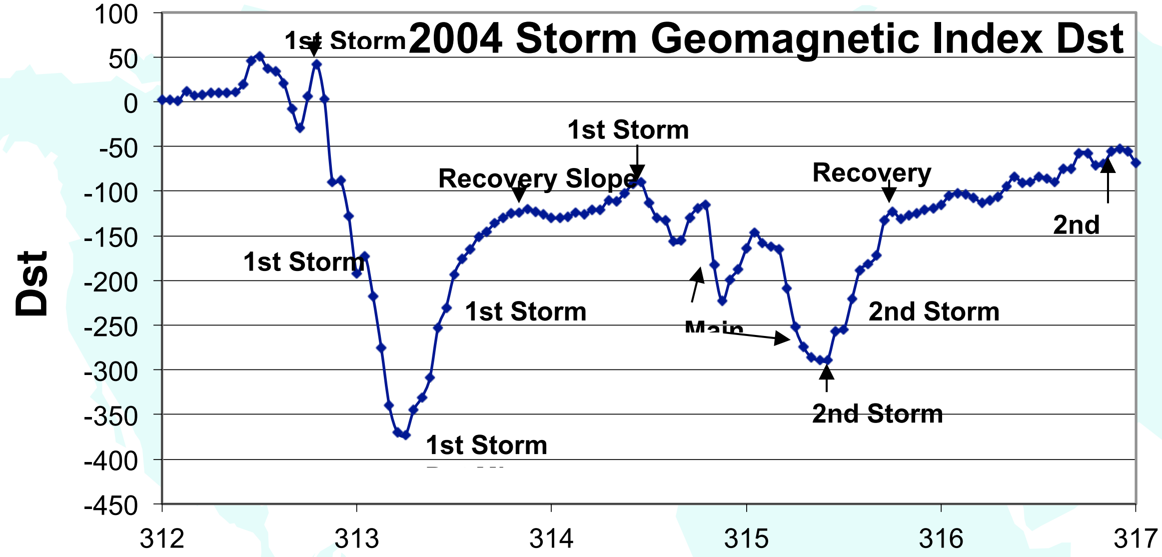
(a) SOHO/SEM is a NASA research instrument but provides daily irradiances on an operational cadence; GOES 13 EUVS B channel makes measurements in the same bandpass as SOHO SEM.

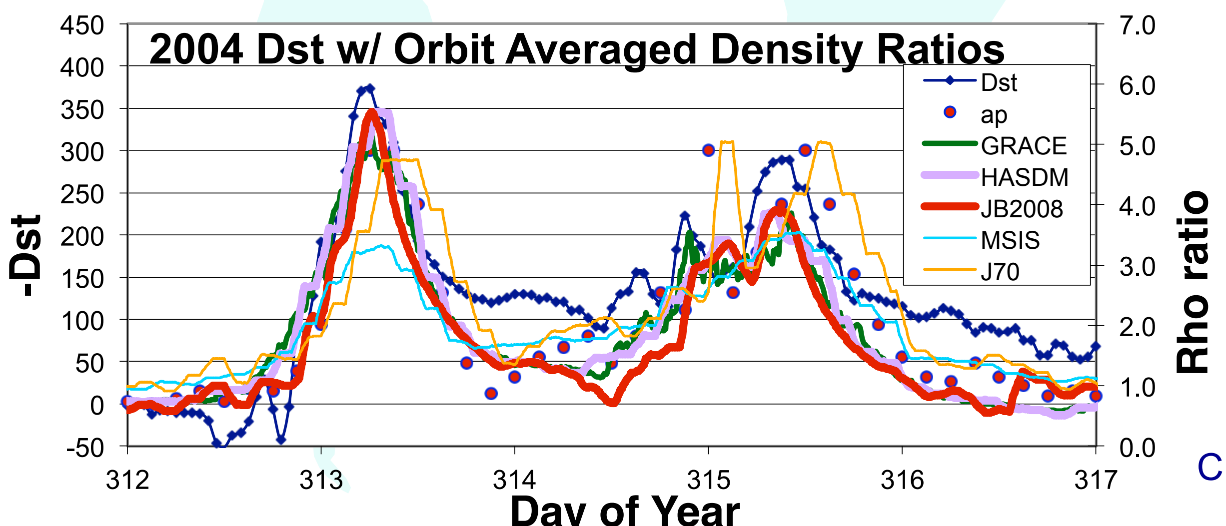
(b) GOES XRS is a NOAA operational instrument whereas TIMED/SEE and SORCE/SOLSTICE are NASA research instruments providing daily irradiances on an operational measurement cadence.

(c) UARS/SOLSTICE stopped in 2005; SORCE/SOLSTICE intends to provide data for several years.

Credit: ISO 14222

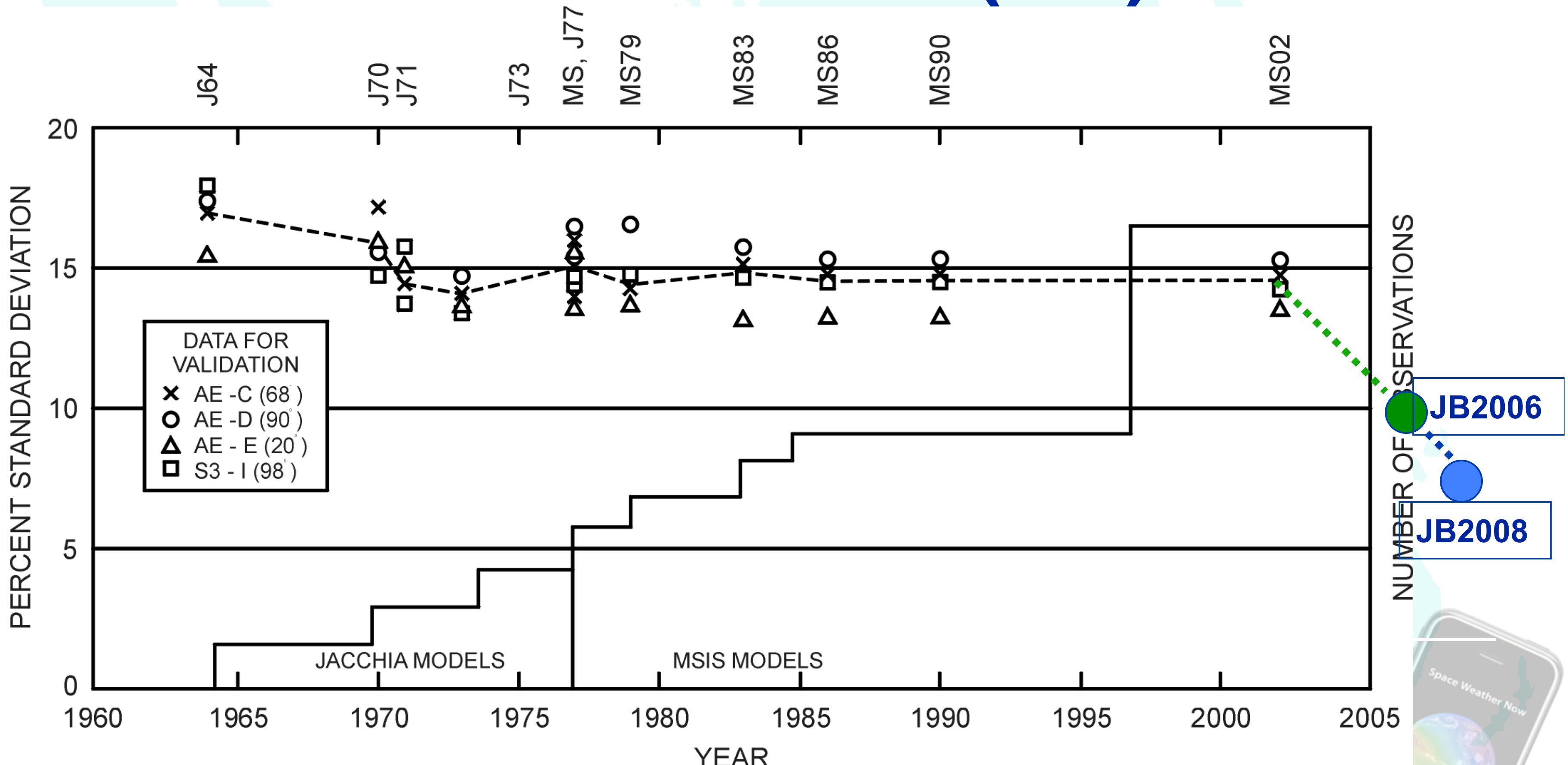
Storm-time Density Error comparisons





Credit: B. Bowman

Historical Density Model Errors at 350 km (1-σ)



Credit: F. Marcos