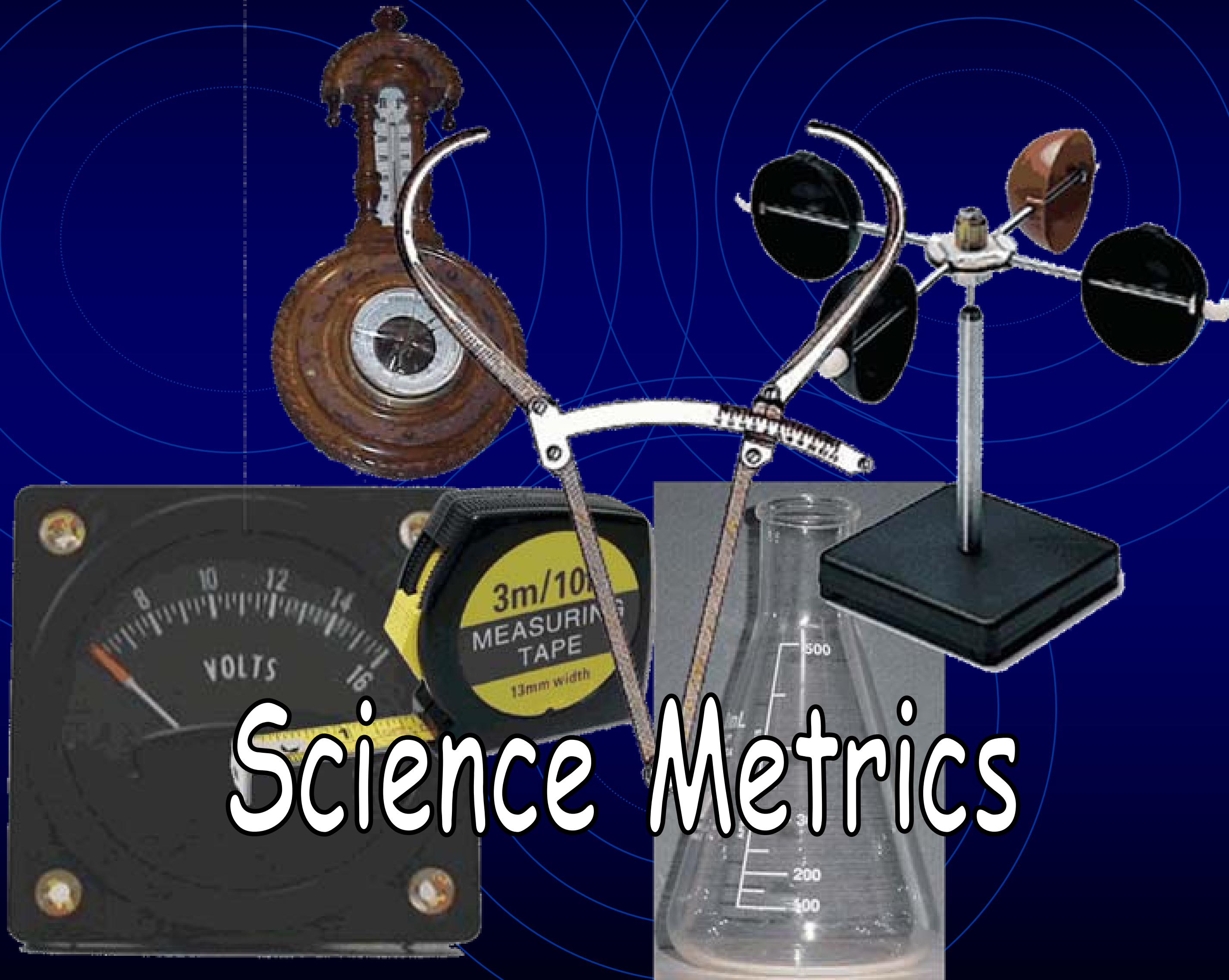
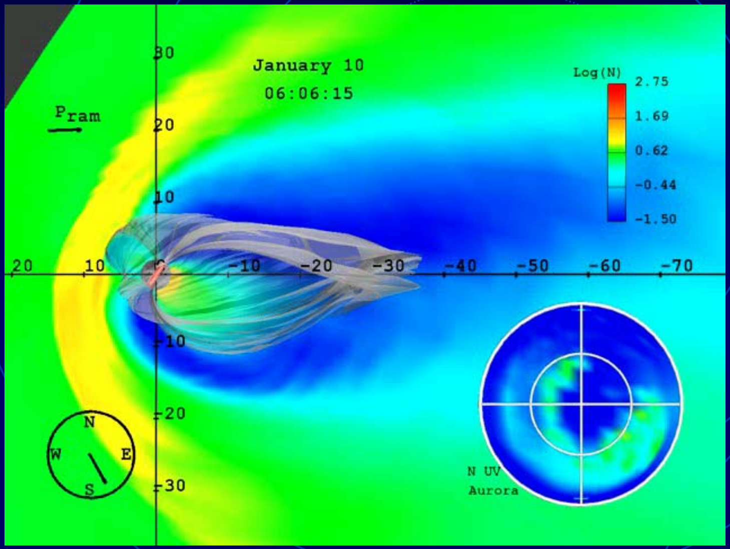
Measuring Space Weather Models



Science Metrics

Dynamics on multiple scale sizes: both time and space



How do we create a metric that will help us understand how well a model is capturing the relevant physical processes?

A Metric Should:

- Compare a model output with a measured value **in as direct a fashion as possible.**
  - BEWARE: bad data are common.
- Be meaningful (but ‘meaningful’ may be different when looking at operational metrics vs science metrics).
- Be well defined so that everyone can agree on how it is to be calculated.
- Require little additional effort to calculate. The model output should either be a natural output of the code, or require minimal additional computational effort.

Ops metrics vs Science metrics

- Operational metrics should be based on measurements that are likely to continue to be made (e.g. regular measurements of Fof2). Science metrics can use historical data.
- Science metrics must be open to everyone. Ops metrics may include classified data.
- Science metrics need to cover the range of physics addressed by the model. Ops metrics need to cover the range of effects of importance to users.

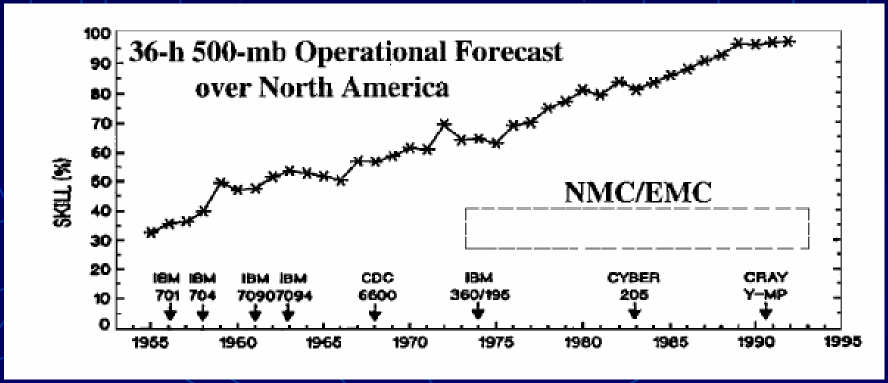
A few additional comments from the NSWP Implementation Plan

- Although there is remarkable overlap between parameters that are important to the application community and scientifically important parameters, the overlap is not 100%. For example, ring-current ions are an important element of magnetospheric physics but have little direct effect on present technological systems.

- Scientific metrics should have a scale that encompasses both presently available scientific algorithms and the best that we could hope for by the end of the NSWP. Present algorithms are not good enough to make useful predictions of all aspects of space weather and might thus score zero on some application metrics. There is also a chance that our ability to predict some parameters will, by the end of the NSWP, exceed what is needed for present technologies. A good scientific metric should encompass both extremes.

Science vs Ops Metrics [2]

- Ops metrics should show us, over the long term, that we are making progress toward serving the user community.
- Science metrics should show us that we are improving our physical understanding.



Long-term record of skill in the 36-hour, 500-mb operational forecast over North America from the Numerical Meteorological Center (now the Environmental Modeling Center). (From McPherson, 1994.)

Science vs Ops metrics

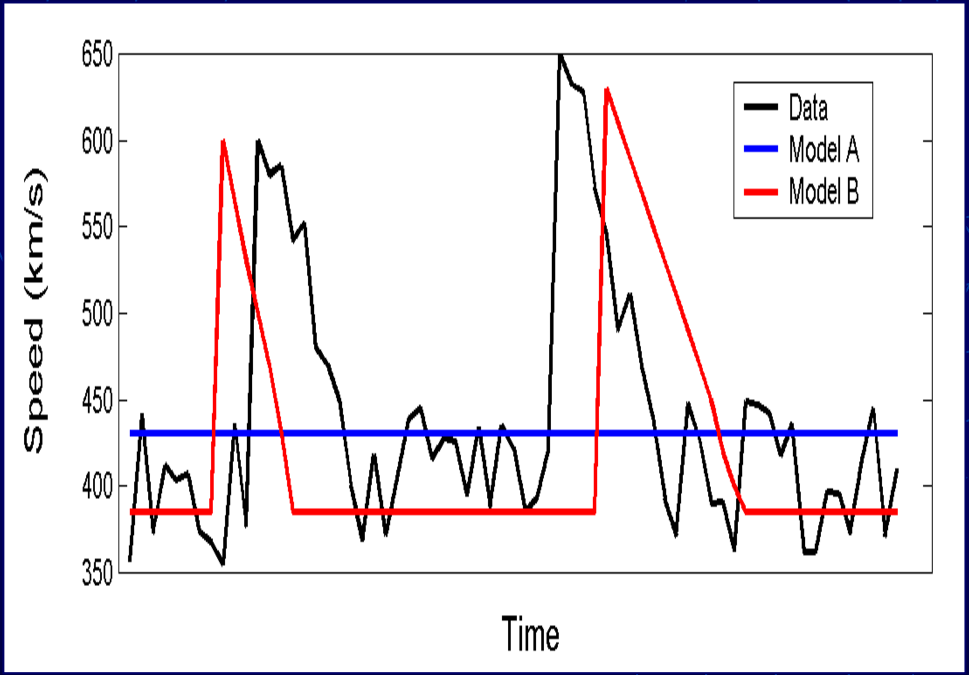


Figure taken from CISM poster by Mathew Owen and provided to me by Harlan Spence.

- Model A might be preferable to model B for operational purposes, whereas B is clearly superior from a science standpoint.
- How do we define two metrics, comparing the same parameters, but giving one result for Ops and the other result for science?

- Suppose we have a global MHD model for the magnetosphere with an adjustable parameter for the efficiency for energy transfer from the solar wind to the magnetosphere.
  - Use the model to calculate Φ_{PC} and compare with DMSP measurements.
  - Calculate the metric and over a large body of data you can fine-tune the adjustable parameter to get the best result. IS THIS OK?
    - YES, with qualifications
    - For operations this is definitely OK. For science, you have to ask yourself: is the best fit value for the parameter telling us about how the solar wind couples to the magnetosphere, or is the problem somewhere else entirely?

- This leads to another point (mentioned previously). We need more than one metric for a model. We need enough metrics to cover the important physical understanding.
  - Do we get Φ_{PC} right?
  - Do we get the large scale magnetospheric convection pattern right?
  - Do we get the field-aligned currents right?
  - Do substorms occur approximately when they should? And where they should?
  - Do we get extreme cases right?

A look at the metrics recommended in the NSWP Implementation Plan

- Ionosphere and Thermosphere
- Magnetosphere-Ionosphere
- Solar-Interplanetary

Ionosphere-Thermosphere
Key Physical Parameters

- Priority I
  - Electron density, ***including intrinsic variability***
  - Neutral mass density, ***including intrinsic variability***
  - Amplitude of the electron density irregularities
- Priority II
  - Neutral and ion composition
  - Thermospheric winds and temperatures
  - Low-latitude ion drifts
- Priority III
  - Electron and ion temperature
- Priority IV
  - Minor species

IT Metrics

Category	Parameter	Place	Time	Cadence	Data
F-region ionosphere	NmF2, hmF2	Low, mid and high latitudes	Noon,Midnight, dawn, and dusk	Hourly	Ionosonde or ISR
High-latitude structure	N_e (~800 km)	Orbit plane of polar satellite	Every orbit	Every orbit	DMSP
Pre-reversal enhancement	Peak magnitude of vertical ion drift	Magnetic equator	16-20 LT	Daily	ISR (Jicamarca)
Scintillation/ ionospheric irregularities	σ_ϕ and S_4 at 250 MHz and 1 GHz	Between ±20 deg. Magnetic latitude	18-04 LT	Daily	Satellite to ground receivers (e.g. GPS)
TEC	Peak TEC and latitude of equatorial ionization anomaly		Every orbit of observation	Every orbit of observations	TOPEX

Major features of the M-I coupled system

FEATURE	Includes
Magnetic field configuration	Global magnetic structure, including dayside, tail; ground magnetic variations
Electric field configuration	Ionospheric and magnetospheric. Represents effects of solar wind/magnetosphere coupling,, magnetospheric convection
Auroral precipitation	Precipitation from polar cusp, plar cap, main auroral zones and plasma sheet
Trapped energetic particles	Includes ring current and inner and outer radiation belts, from 1 keV to 100 MeV
Cold particles	Plasmasphere, plasmapause, suprathermal ions
Plasma sheet, PSBL	KeV electrons and ions that extend into the tail
Magnetopause	Shape and postion, reconnection, transfer processes, boundary layers
Waves and small-scale effects	Cause particle loss by pitch-angle scattering, allow magnetic reconnection, accelerate auroral particles

M-I Metrics

Category	Parameter(s)	Place	Averaging Interval	Data
High latitude ionospheric electric field	Component of E along track of polar orbiting satellite	~1000 km altitude, from dawn-dusk orbit	100 km along s/c track	Drift meter on DMSP
Auroral electron flux	Latitude-integrated energy and number fluxes	~1000 km altitude, from nightside auroral zone crossings	100 km along s/c track	Precipitating electron flux from DMSP or NOAA spacecraft
Magnetic indices	AE, Dst, Kp	Ground stations	Time resolution of index	Ground magnetometers
Magnetospheric electron fluxes	Fluxes of >10 keV and > 1 MeV electrons	Geosynch orbit	15 minutes	LANAL and NOAA spacecraft

Solar-Interplanetary Metrics

Solar EUV	Intensity of strong spectral lines; integrated EUV flux	L1	1 day	SOHO, or other satellite at L1
Solar x-rays	Intensity of 0.1 – 0.8 nm flux	Earth orbit	1 hour	GOES
Solar protons	Proton flux	Geosynch orbit or L1	1 hour	GOES, ACE or other L1 monitor
Solar Wind	N, P, Vx, Bx, By, Bz	L1 solar-wind monitor	5 minutes	ACE, or other L1 monitor
Disturbance departure times from the Sun	Time when disturbance leaves Sun	Solar observing telescopes		SOHO, Mauna Lea, etc.
Solar wind transit times	Transit time from Sun to Earth	L1 solar wind monitor		ACE or other L1 monitor

Science Metrics

- Compare the metrics adopted by CISM with those from the NSWP Implementation Plan
  - How has our thinking changed since the Implementation Plan was done?

Ionosphere-Thermosphere

CISM
Center for Integrated Space Weather Modeling

- E-, F-region heights
- E-, F-region Peak Densities
- Nothing on structure, scintillation, TEC

NSWP

- hmF2, but ignores E-region
  - E-region is where electrojet currents are important.
- NmF2
  - E-region ignored
- High-latitude structure, scintillation, TEC

IT metrics comparison

- CISM adds in some very important physics, that of the E-region.
- CISM does not identify any thermosphere metrics
- CISM does not include structure and scintillation
    - Scintillation effects are very important, but also very difficult to model.

Magnetosphere-Ionosphere

CISM

- Polar cap potential
- Polar cap boundary
- Field-aligned currents
- Particle Precipitation
- Magnetic indices (in OPS metrics)

NSWP

- High-latitude ***E*** along DMSP track.
- Missing
- Auroral electron flux
- Magnetic indices

M-I metrics comparison

- CISM adds field-aligned currents, which are very important for understanding M-I coupling
- CISM dispenses with the various magnetic indices in their science metrics
  - But we have to admit that indices are still heavily used, by both the science and operations communities.
  - But CISM has the E-region metrics that are missing from the NSWP list.

Magnetospheric metrics

CISM

- Magnetic field
- Ring current/rad belt particle fluxes
- Magnetopause location

NSWP

- Mentioned as an important feature of a model, but not a priority metric
- Magnetospheric electron fluxes
- Mentioned as an important feature of a model, but not a priority metric

Neither CISM nor NSWP have much to say about the magnetotail.

Solar-Interplanetary metrics

CISM

- Solar Wind/IMF at L1
- Shocks and CMEs at L1 (in OPS)
  - Speed, arrival time, Bz, duration
- SEP Properties (in OPS)
  - Rise time, peak flux, duration, cut-off

NSWP

- Solar Wind/IMF at L1
- Solar wind transit times
- Disturbance departure times from the Sun
- Solar proton flux

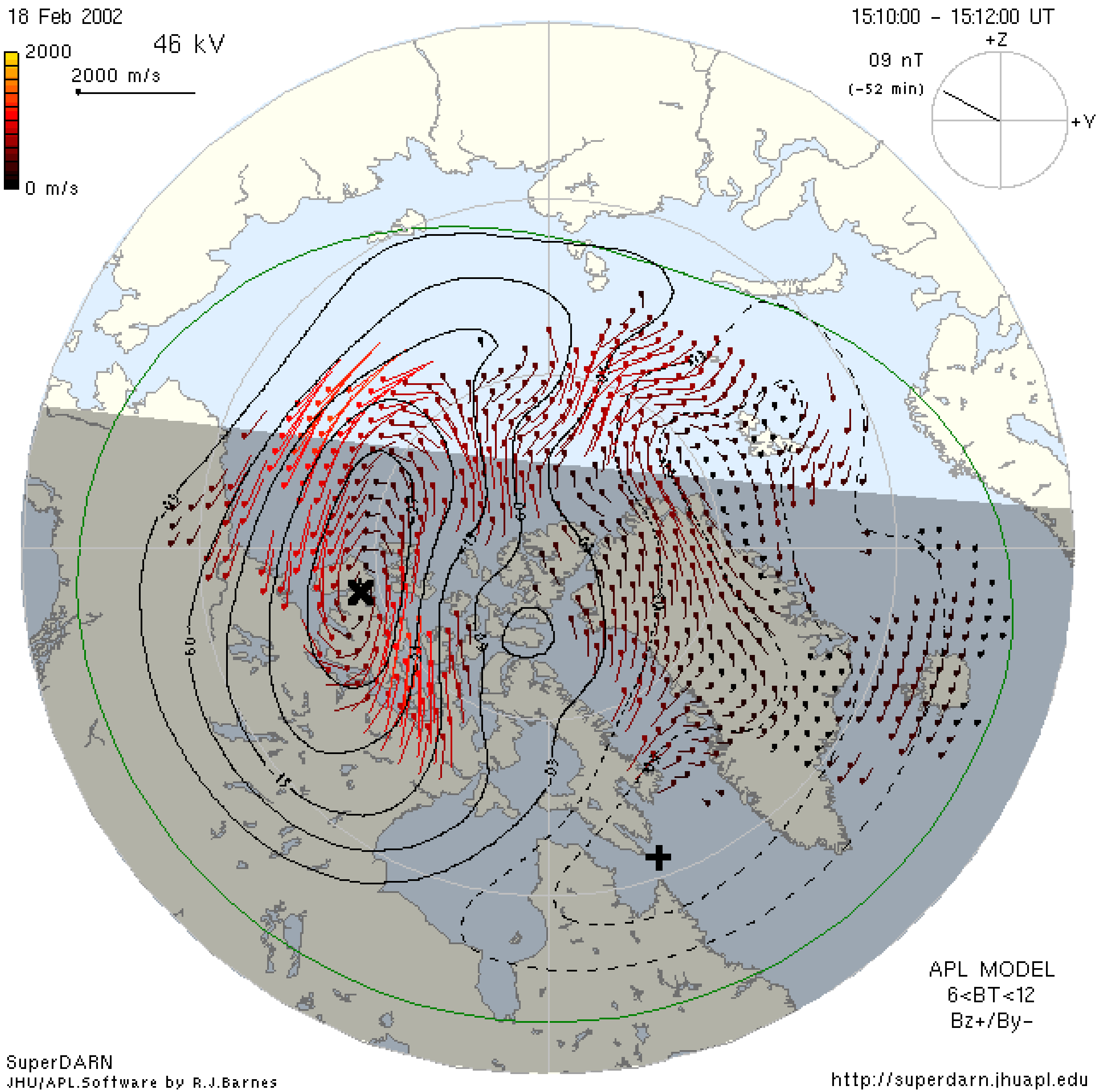
Solar-Interplanetary metrics [2]

- Coronal Hole Index
- White-light streamer belt index

- Solar EUV intensity
- Solar x-ray intensity

Polar Cap Potential
an alternative to DMSP

- DMSP pass once every 100 minutes and a single pass takes ~15 minutes.
  - This limits the number of measurement vs model comparisons that can be done.
  - It limits the comparison to a 1-D cut of the polar cap.
- If large amounts of radar data are available from SuperDARN and ISRs, then very reliable plasma drifts can be derived for long periods of time with a temporal resolution of 2 minutes.
  - This would allow a large number of measurement vs model points to be calculated.
  - The comparison could be made on a 2-D basis.


18 Feb 2002
46 kV
2000
2000 m/s
0 m/s
15:10:00 - 15:12:00 UT
+Z
09 nT
(-52 min)
+Y
APL MODEL
6<BT<12
Bz+/By-
SuperDARN
JHU/APL.Software by R.J.Barnes
http://superdarn.jhuapl.edu

Parameterization

- Total Potential Drop
- Minimum Potential
- Maximum Potential
- Orientation (angle γ)
- Cell Separation (orange + green line)
- Cell Size Ratio (orange/green)
- Positions (lat. & MLT) of Pot-max and Pot-min.