Modeling Magnetospheric Impact on the Ionosphere: Status and Challenges for the Upcoming Solar Cycle

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Overview

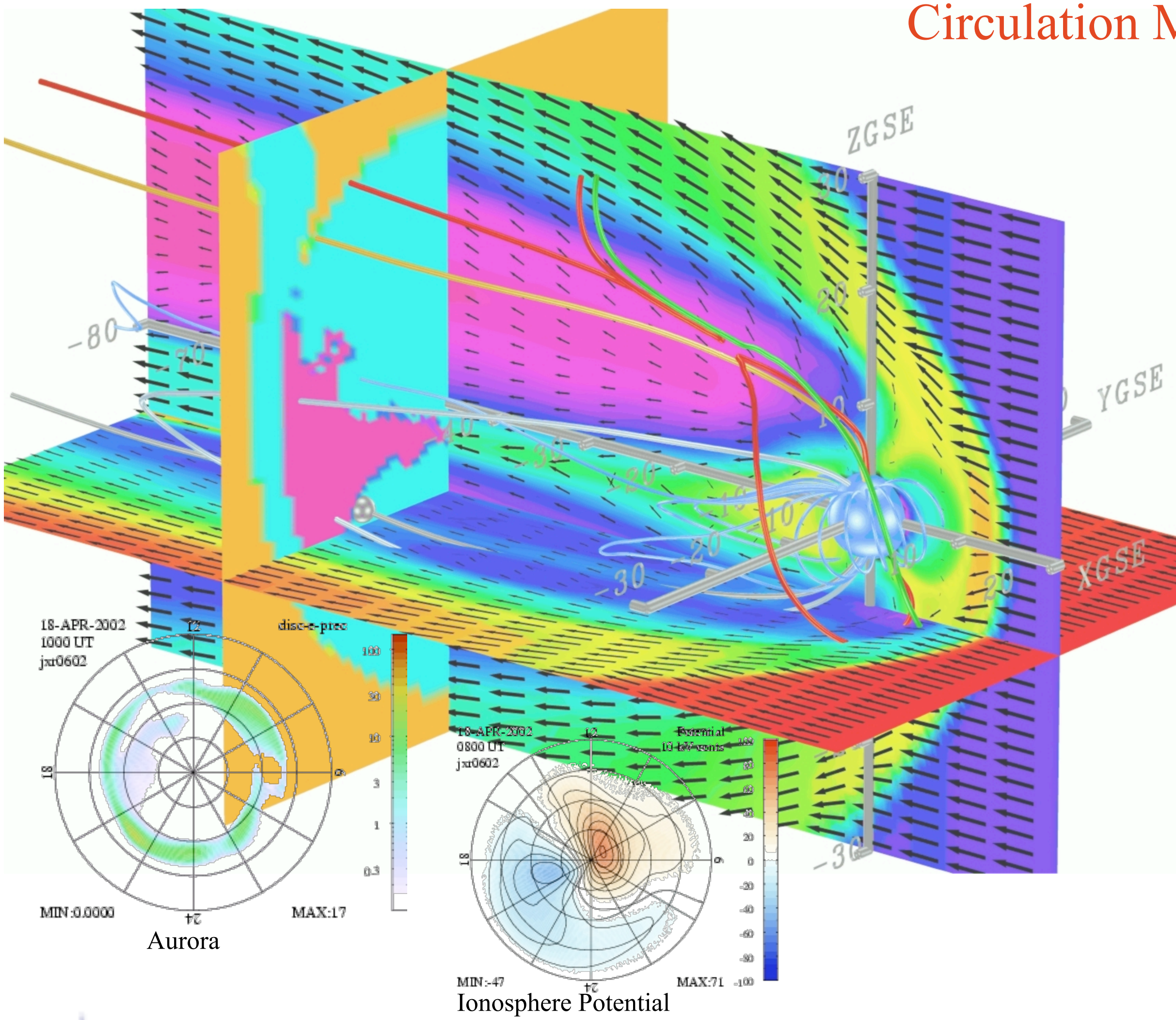
- What drives the ionosphere?
- Magnetospheric input.
- How can we forecast?
- Bridging the valley of death.

What drives the ionosphere?

- Light! There would not be much of an ionosphere without solar UV/EUV/X-ray: ionization, heating.
- Energy input from the magnetosphere:
  - Poynting flux.
  - Electron precipitation.
  - Proton precipitation.
- Tides and waves propagating upward from the atmosphere.
- Stars: nighttime starlight and gamma ray bursts.

OpenGGCM: Global Magnetosphere Modeling

The Open Geospace General Circulation Model:



- Coupled global magnetosphere - ionosphere - thermosphere model.
- 3d Magnetohydrodynamic magnetosphere model.
- Coupled with NOAA/SEC 3d dynamic/chemistry ionosphere - thermosphere model (CTIM).
- Coupled with inner magnetosphere / ring current models: Rice U. RCM, NASA/GSFC CRCM.
- Model runs on demand (>300 so far) provided at the Community Coordinated Modeling Center (CCMC at NASA/GSFC). http://ccmc.gsfc.nasa.gov/
- Fully parallelized code, real-time capable. Runs on IBM/datastar, IA32/I64 based clusters, PS3 clusters, and other hardware.
- Used for basic research, numerical experiments, hypothesis testing, data analysis support, NASA/THEMIS mission support, mission planning, space weather studies, and Numerical Space Weather Forecasting in the future.
- Funding from NASA/LWS, NASA/TR&T, NSF/GEM, NSF/ITR, NSF/PetaApps, AF/MURI programs.

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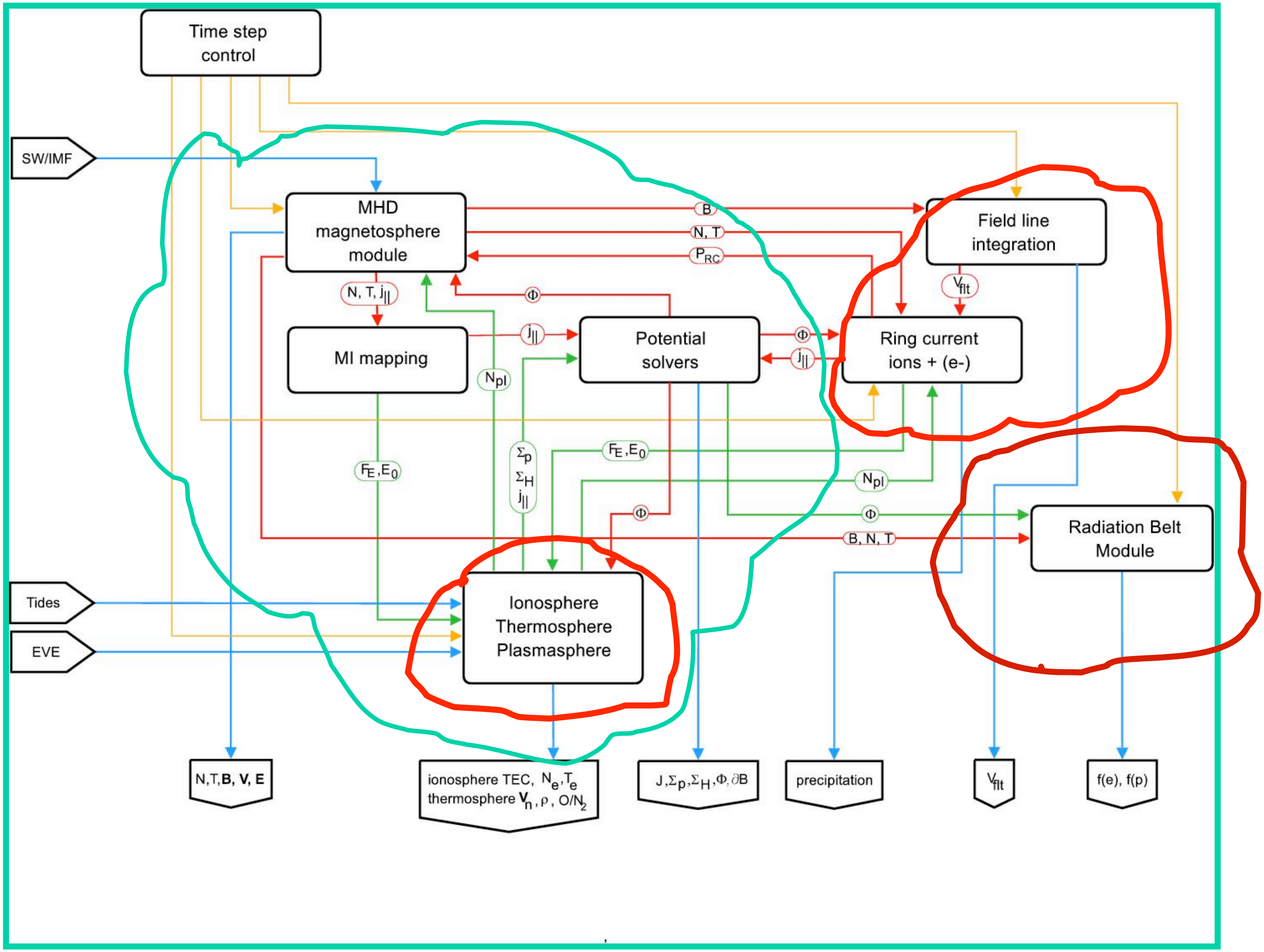
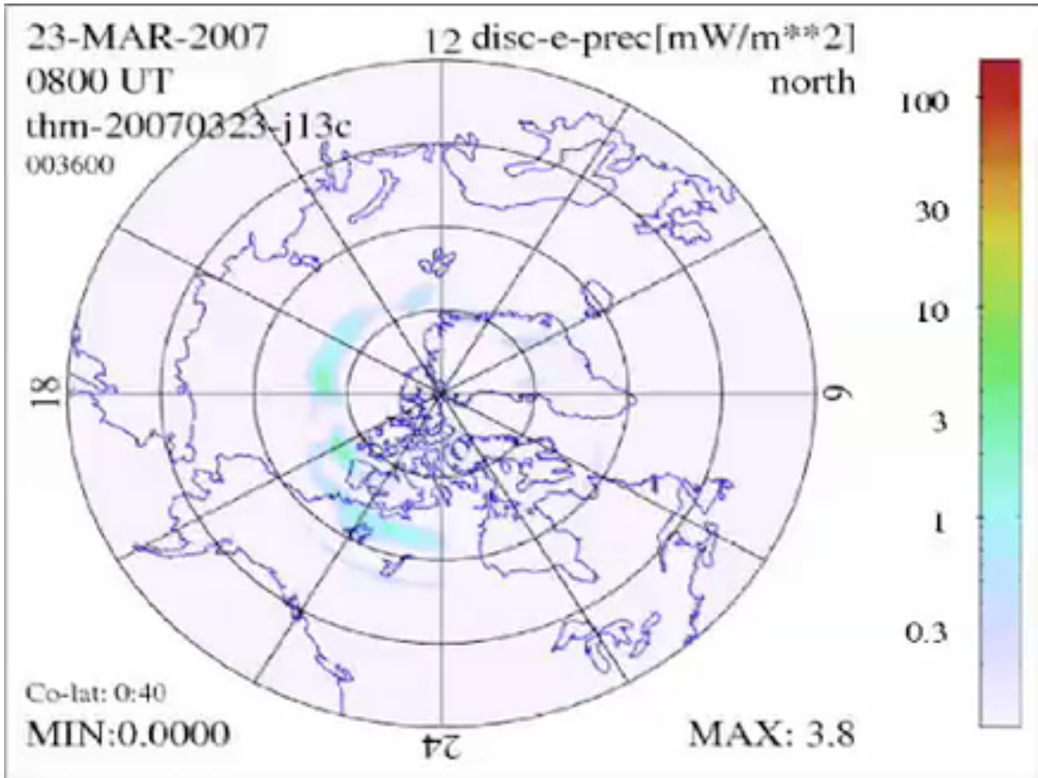
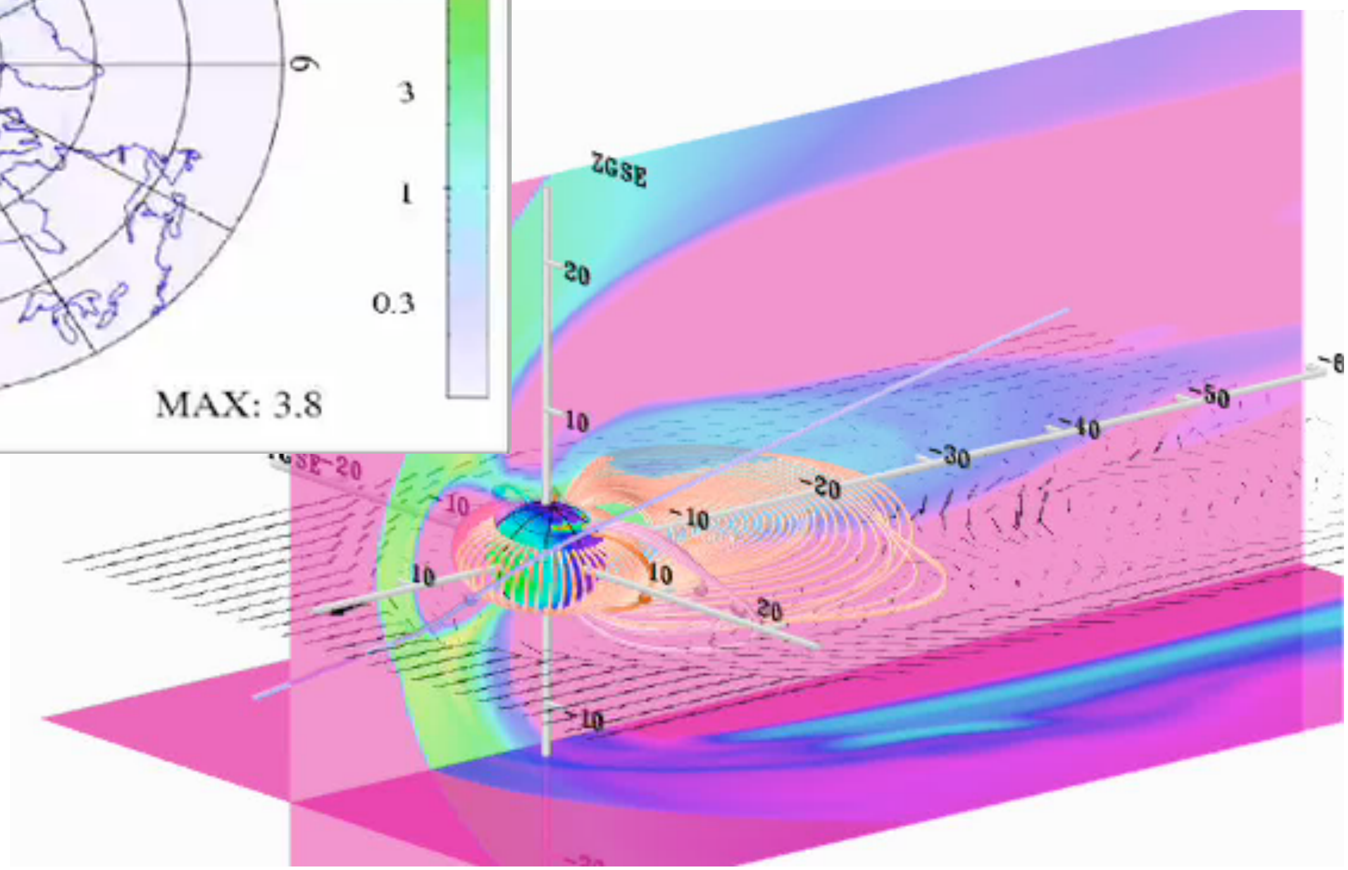
Model Data Flow



The Visible Driver: Aurora

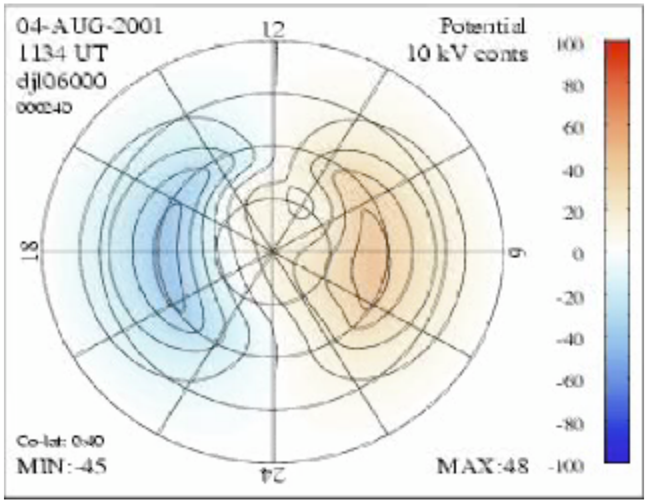


Aurora and Westward Traveling Surge

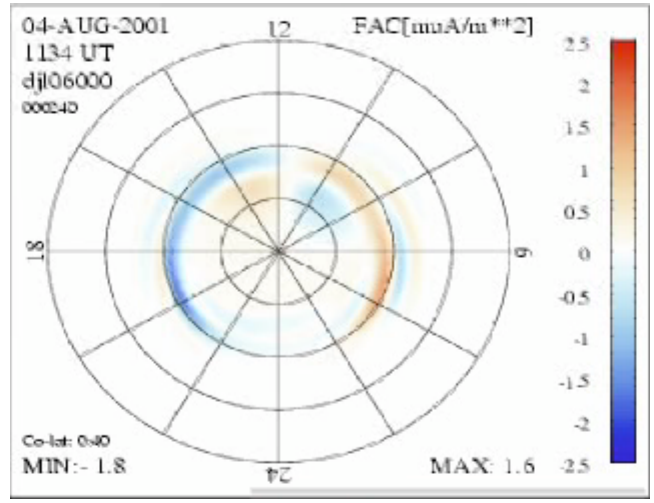


Force balance breakdown before tail reconnection onset

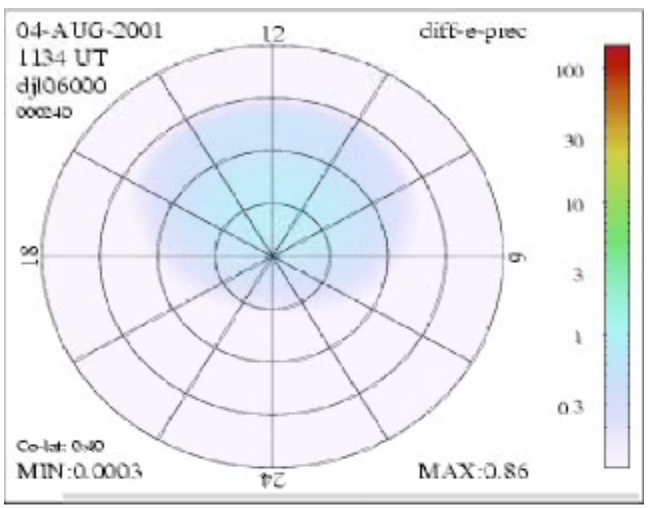
The Magnetospheric Drivers



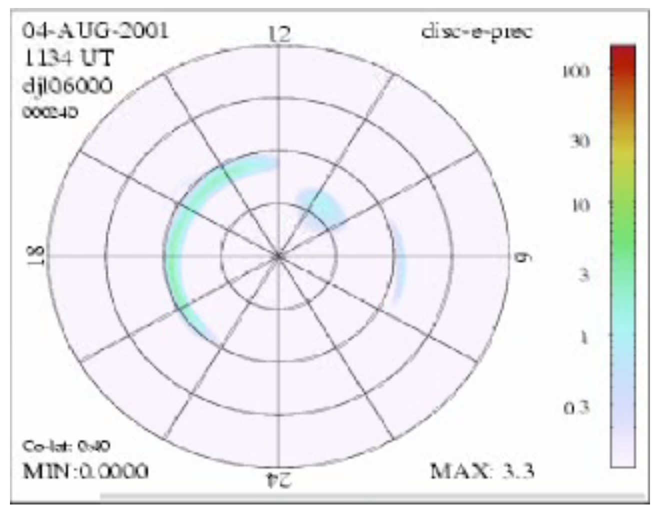
Potential



Field-aligned Current



Diffuse e- precipitation



Discrete e- precipitation

Challenges

- Forecasts require SW/IMF forecasts/nowcasts. L1 measurements only give ~30-60 min lead time; less when it gets interesting.
- Model needs to run in real-time or faster.
- Since L1 measurements are off the sun-Earth line (often 50+ RE) and/or since SW/IMF predictions are error-prone → ensemble predictions are necessary → need for extensive computer resources.
- Validation in an operational setting is essential → need feedback to improve model.

Real-time and ensemble runs: 40 PS3 Cluster

- 40 PS3 from Best Buy + GB Ethernet switch + PC head node + cables + monitor – games ~$24k.
- New firmware, Linux, MPI libs etc.
- Uses 5 kW of power, though.
- Motivates middle-schoolers, newspaper writers.

Page A2 • NEW HAMPSHIRE UNION LEADER, Monday, June 23, 2008

UNH's supercomputer to predict 'space weather'

Advanced math: By combining 40 PS3 gaming consoles, the institute created a computer that, in theory, can perform 8 trillion calculations per second.

By CLYNTON NAMUO
Union Leader Correspondent

DURHAM — Video-game nerds rejoice: Researchers at the University of New Hampshire have bundled 40 Playstation3 game consoles to form a supercomputer they will use to help predict "space weather."

Associate physics professor Jimmy Raeder said he and other researchers at UNH's Institute for the Study of Earth, Oceans and Space have combined the gaming systems into a supercomputer that, theoretically, can perform 8 trillion calculations a second.

"The gaming industry is insatiable," Raeder said. "The more computational power they have, the more realistic they can make the games."

Raeder and his associates will use the supercomputer's vast power to study what's commonly referred to as space weather, or the sun's interaction with the Earth's magnetosphere. The sun periodically produces solar flares and solar wind that interacts with earth in many ways and can interfere with satellites, ground communication and even cause power outages, he said.

"Satellites can die because of space weather effects," he said.

The supercomputer will also be used to study Aurora, known also as the Northern or Southern Lights depending on where they occur. Raeder said researchers eventually hope to be able to predict space weather much in the same way meteorologists predict regular weather.

And like regular weather, the study of space weather requires increasingly complex calculations. This is where the PS3-powered supercomputer comes in handy, Raeder said.

The console, introduced during 2006 holiday shopping season, is well-known in gaming circles for its cutting-edge graphics, which is made possible by an advance computer chip designed specifically for the system called the cell broadband engine.

Raeder said the chip itself is the key to the system's performance. By combining 40 PS3s, the UNH researchers have created a supercomputer that, in theory, can perform 8 trillion, or 8 thousand billion, calculations per second. Take that H&R Block.

That computing power pales in comparison to a recently announced supercomputer called "Roadrunner," created by scientists at the Los Alamos National Laboratory in New Mexico. That computer combined hundreds of PS3 chips to form the fastest supercomputer on earth.

Raeder said Roadrunner is the first supercomputer to achieve a petaflop, or one quadrillion calculations per second. That's 10 to the 15th power or one thousand trillion calculations per second.

"It's just absolutely mind blowing," Raeder said.

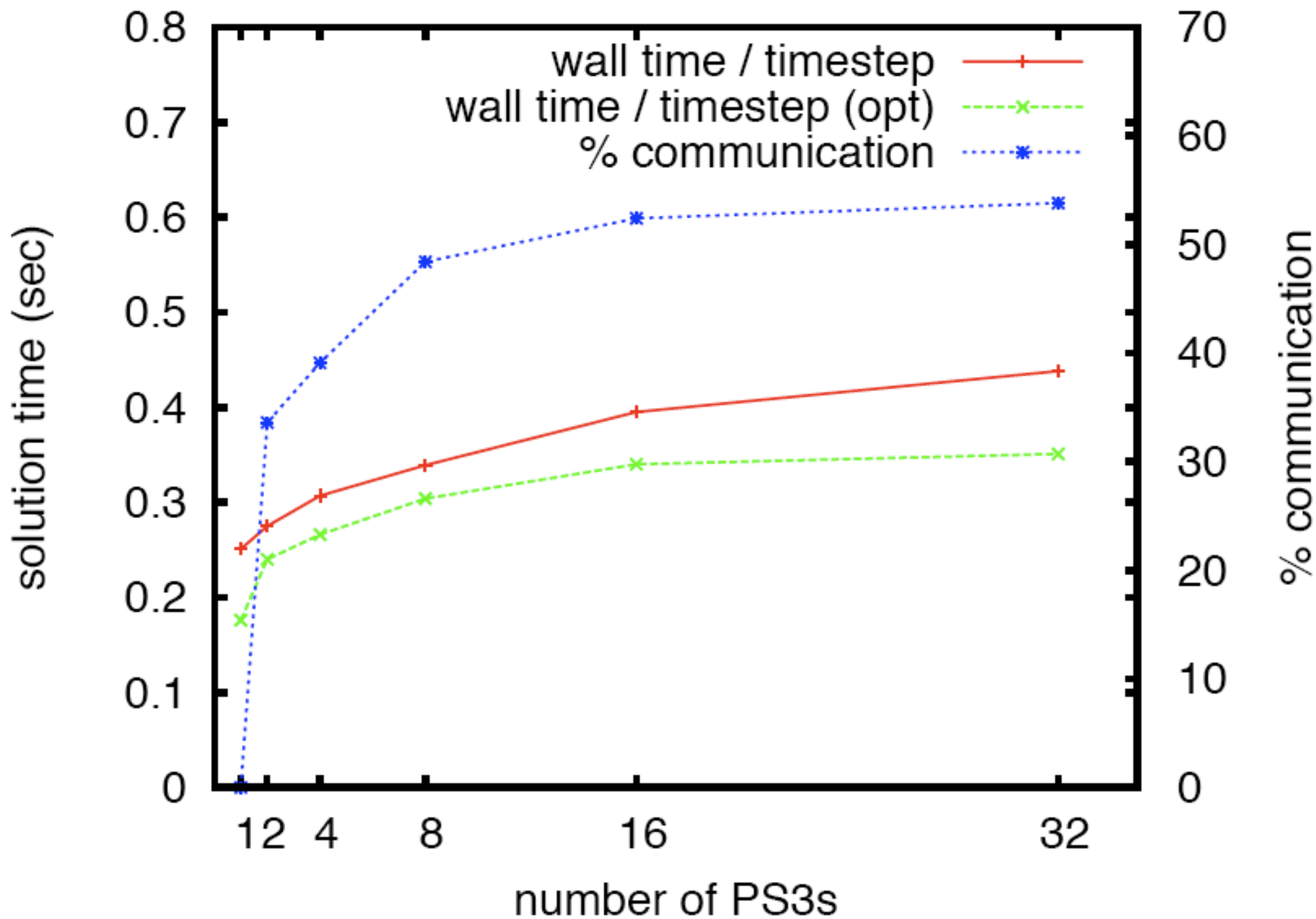
Roadrunner cost about $133 million, but Raeder and his associates spent only $24,000, including the cost of the systems and the parts necessary to combine them, to construct their scaled-down version. The UNH endeavor is being funded with a four-year $1.5 million National Science Foundation grant.

UNH's PS3-driven supercomputer has enough computing power to match the UNH institute's other supercomputer, which weighs 8,000 pounds and cost $750,000. Plus, even with the modifications, the PS3 machines can still play video games, Raeder said.

From left, University of New Hampshire researchers Kai Germaschewski, Andrew Foulks, Joachim Raeder and Doug Larson show off the 40 Playstation 3 game consoles they linked to form a supercomputer.

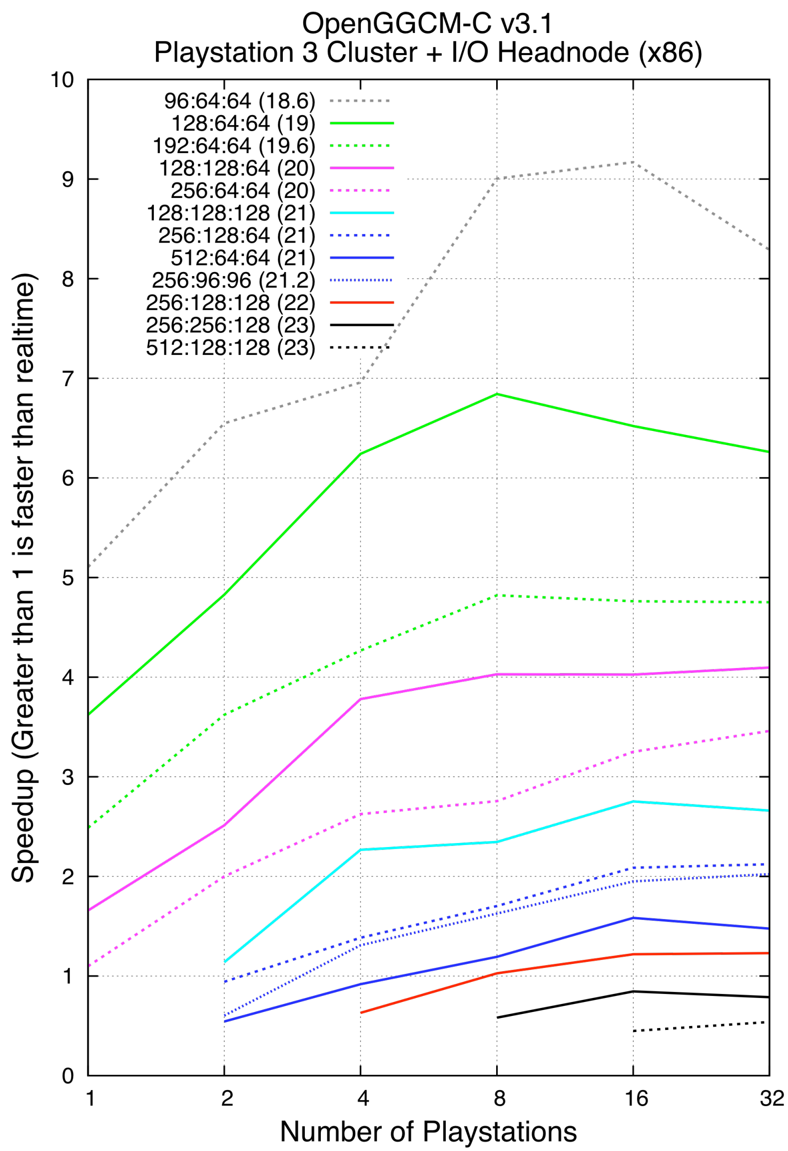
COURTESY

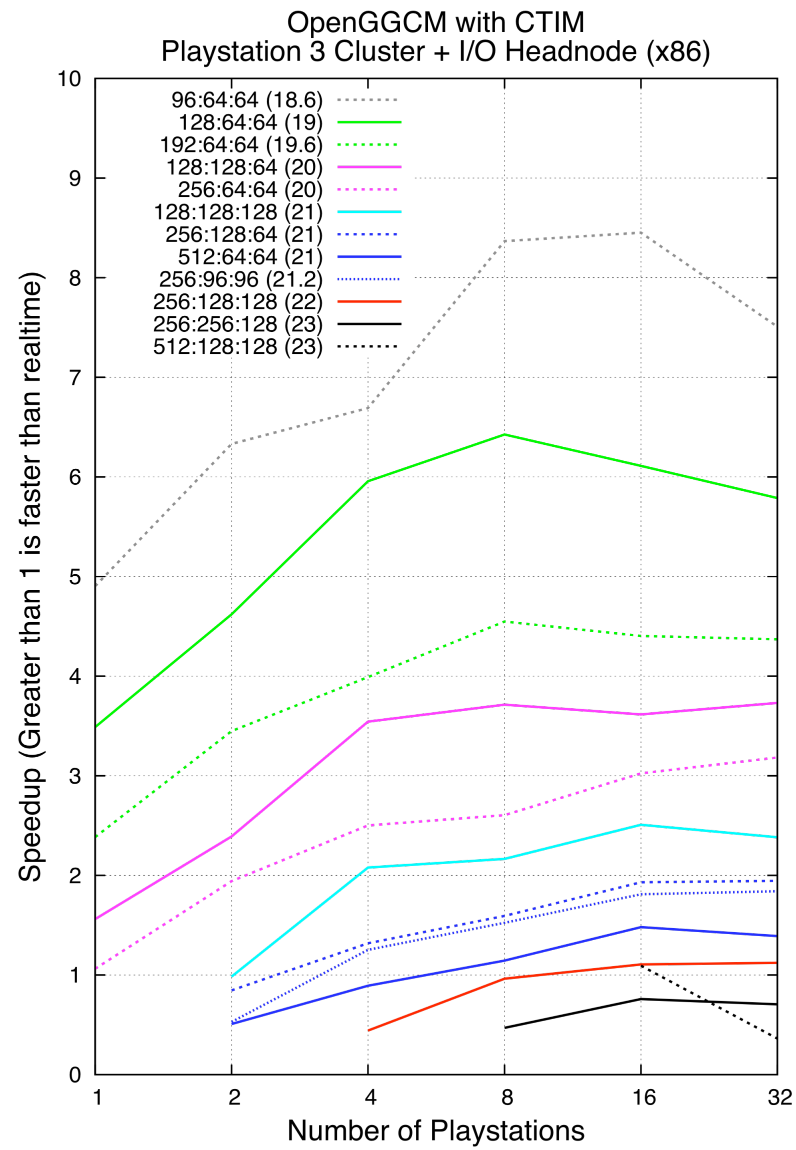
Scaling with number of PS3's



Weak scaling on 40 PS3 cluster: Not perfect. Too much time spent on inter-node communication (GB Ethernet switch). New QS22 IBM Cell blade cluster should be much better. Cluster (42 nodes / 84 CBE, NSF CISE funding + IBM donation) expected in May 2009.

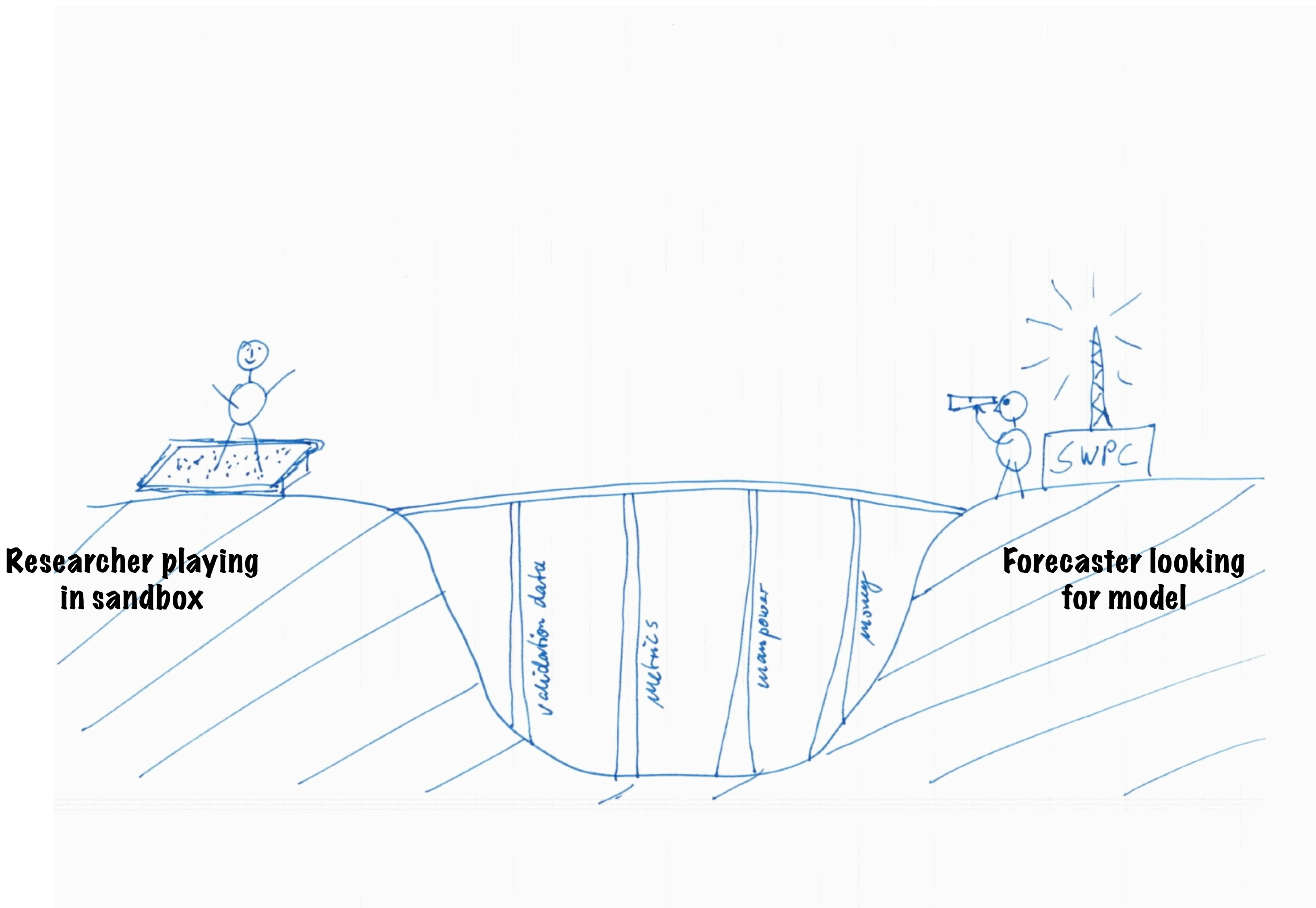
Scaling for PS3 cluster: Event of 31 August, 2001





Latest results: ~ factor 1.8 better!

Path to Operations: Valley of death



Validation

- **Should not be done by the model developers.**
- **Ideally should be done by different organizations.**
- **Requires extensive and stable data sets.**
- **Requires well thought out metrics.**
- **Requires substantial man power.**
- **Should provide feedback to the model developers.**
- **Needs to be done transparently.**
- **Ultimately needs to be an ongoing exercise even after transition to operations.**

Validation: Option 1

Modelers hand models to a ‘testbed’ or ‘prototyping’ center.

Advantages:
- **Center personnel likely has expertise in metrics.**
- **Center maintains expertise in the validation data.**
- **Independent of modelers (ideally).**

Disadvantages:
- **Huge investment upfront for modelers and centers.**
- **Only few models can be tested at a time.**
- **Centers have initially no expertise in running a specific model: extensive modeler participation required.**
- **Models need to be ready before testing begins: blackboxing, documentation, etc.**
- **Possible conflict of interest if testbed center is also in the business of model development.**
- **Nobody ever gets tenure for validating a model. Not much in it for the modelers.**
- **Models may get prematurely blessed.**

Validation: Option 2

- **Modelers run their models in-house in prediction mode (endless real-time, ensemble, …, whatever they think is best).**
- **Model predictions are posted on the web: raw data and products requested by prediction centers.**
- **Prediction centers, testbeds, CCMC, … grab the predictions and produce their own metrics.**

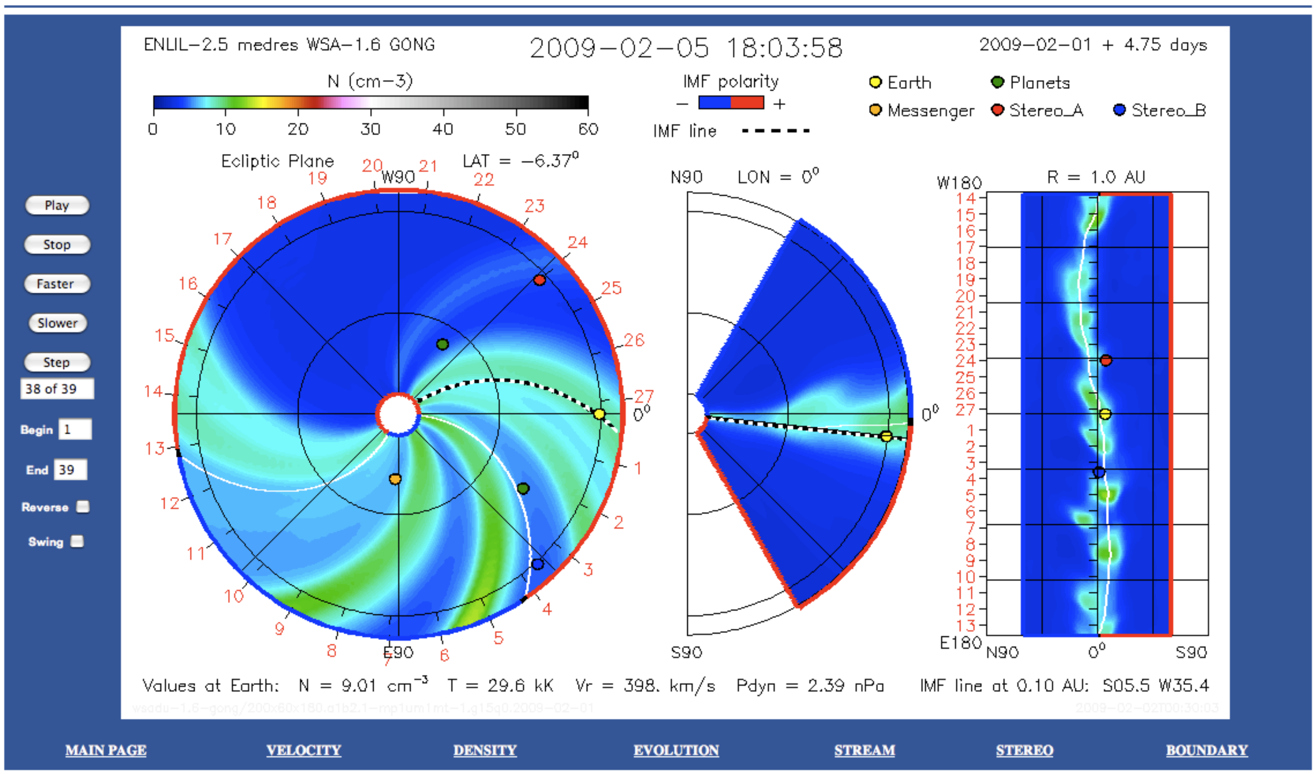
Validation: Option 2

- **Advantages:**
  - **No need for other institutions to install and "learn" the model.**
  - **No need to adhere to strict standards and blackboxing before model is validated (pitfall in traditional approach).**
  - **Provides "blind study" for modelers who do not know who might scrutinize their output.**
  - **No need for the modelers to deal with validation data.**
  - **Ensures continuity in model development.**
- **Disadvantages:**
  - **More players → need for coordination.**
  - **The transitioning itself is deferred.**

Example

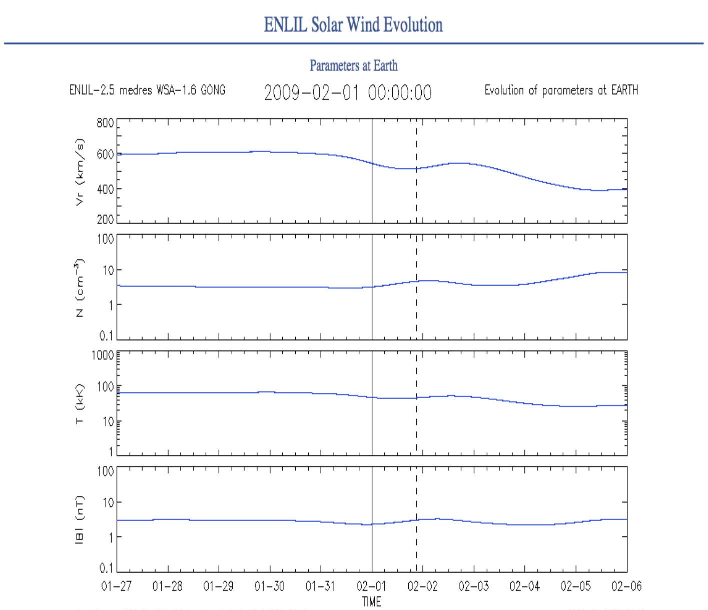
- **Dusan Odstrcil's ENLIL model provides such forecasts. Since there are virtually no observations between the corona and Earth longer term forecasts must be driven by solar observations.**

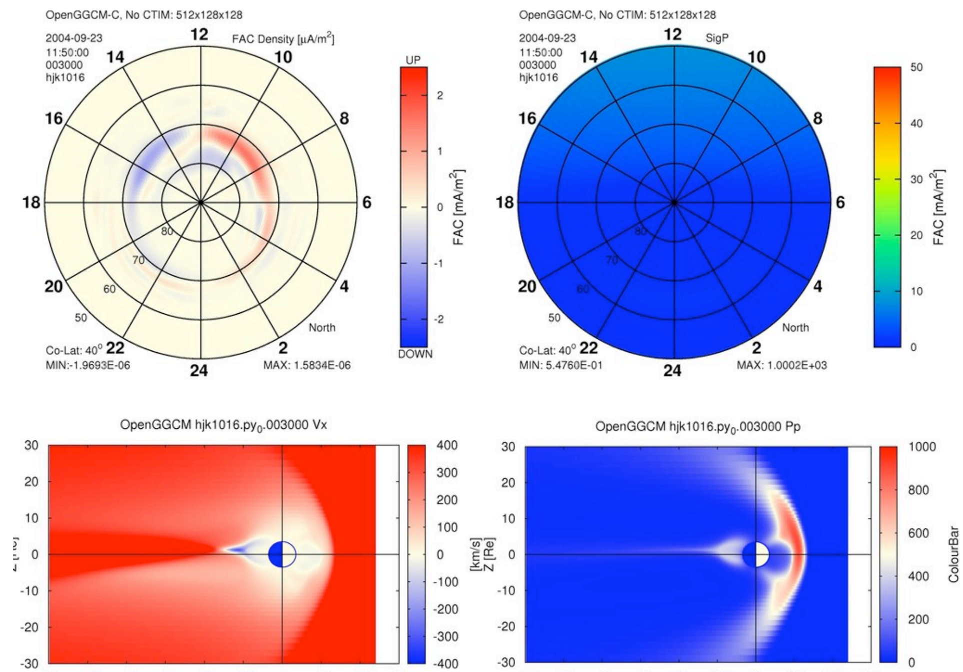
ENLIL Solar Wind Density



Real-time prediction plans for OpenGGCM

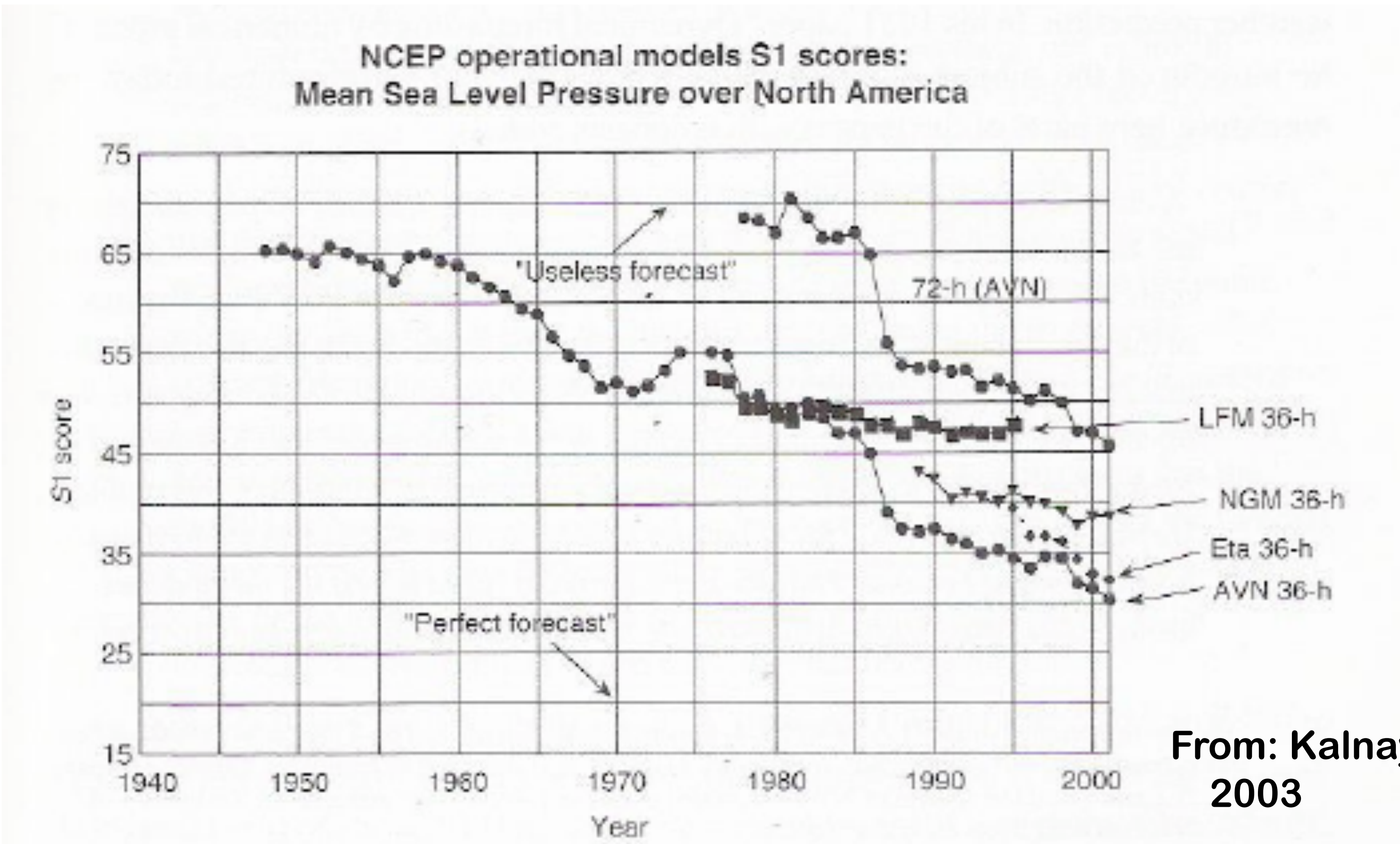
- **Produce continuous ENLIL SW/IMF predictions at Earth.**
- **Feed SW/IMF predictions into OpenGGCM to predict RB, ionosphere FAC, potential, precipitation,...., ground magnetic perturbations, KP,.....**
- **Continuously increase OpenGGCM resolution.**
- **Run multiple instances of OpenGGCM in parallel to produce ensemble forecasts, eventually ensemble Kalman filter (EKF).**
- **Provide forecasts on the web for other institutions to validate and estimate usefulness of the predictions.**
- **Even though ENLIL predictions are still very crude......**





Why?

- **Initial predictions will be lousy and probably worse than empirical models.**
- **BUT, one needs to start somewhere. Terrestrial weather predictions were laughable when they started but have now reached maturity (maybe).**



From: Kalnay, 2003

No Summary, just Homework Assignments

- Modelers:
  - Run your models in real-time.
  - Maintain web sites that post the real-time predictions.
  - Be responsive to centers' requests.
- Centers:
  - Make public what quantities you want to have predicted.
  - Use posted predictions to produce metrics evaluations.
  - Provide feedback to modelers. Everything should be transparent.
- Agencies:
  - Provide funding for modelers.
  - Provide funding for centers.
  - Provide funding for validation data.
- All:
  - Jackson, problem 7.13, due next Monday.