Space Radiation Climatology: A New Paradigm for Inner Magnetosphere Simulation and Data Analysis

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GEM Inner Magnetosphere Tutorial,

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FG9 Wiki: http://virbo.org/wiki/index.php/GEM2007

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Outline

- What are Climatology and Reanalysis?
- What are they good for?
- How will Reanalysis change the way we study the Inner Magnetosphere?
- What challenges must be met?
- FG9: Space Radiation Climatology

What is Climatology? I

- **In some contexts, climatology is just an average model of the environment, with or without indications of the variability of the environment: a farmer's almanac for the space environment**

Past Weather Check

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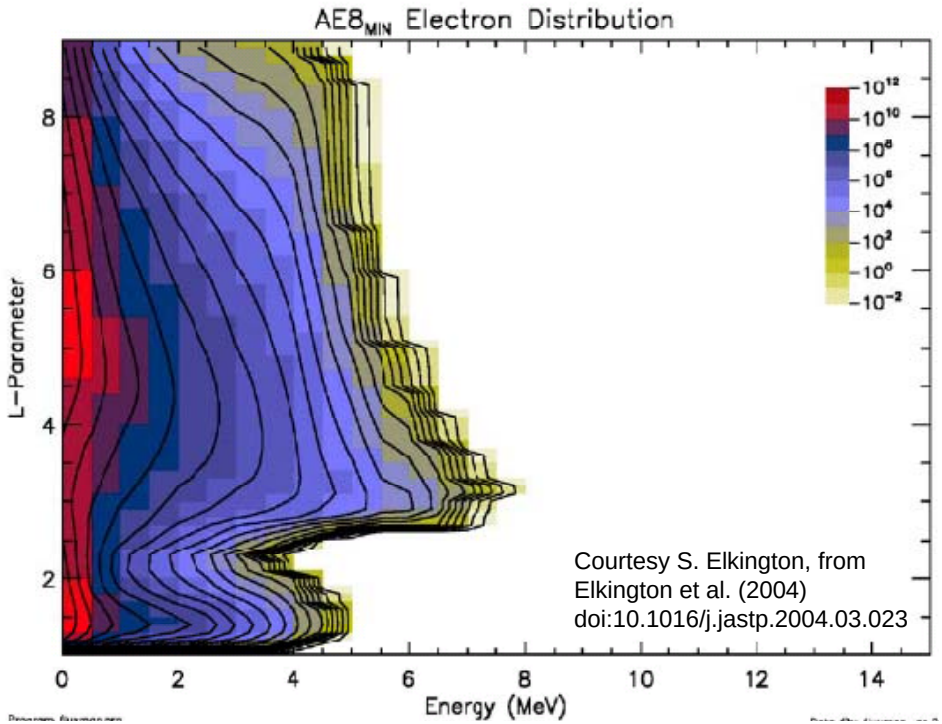
Yesterday, 5/13/2007 in VIENNA, VA

High Temperature:	Low Temperature:	Precipitation:
Actual: 70°F	Actual: 45°F	Actual: Trace
Normal: 74°F	Normal: 49°F	Normal: 0.14 in
Record: 88°F	Record: 32°F	Record: 1.31 in

Past 24 Hours | Past Month | Typical Weather



Courtesy S. Elkington, from Elkington et al. (2004) doi:10.1016/j.jastp.2004.03.023

- **We typically see climatology in the nightly weather report: today's high/low as compared to normal and records (above)**

- **We typically use climatology as initial or boundary conditions (right) or for long-term specifications**

Weather Graphics Courtesy of AccuWeather, Inc., 385 Science Park Road, State College, Pennsylvania 16801, (814) 237-0309, Other Weather Products Available, © 2007

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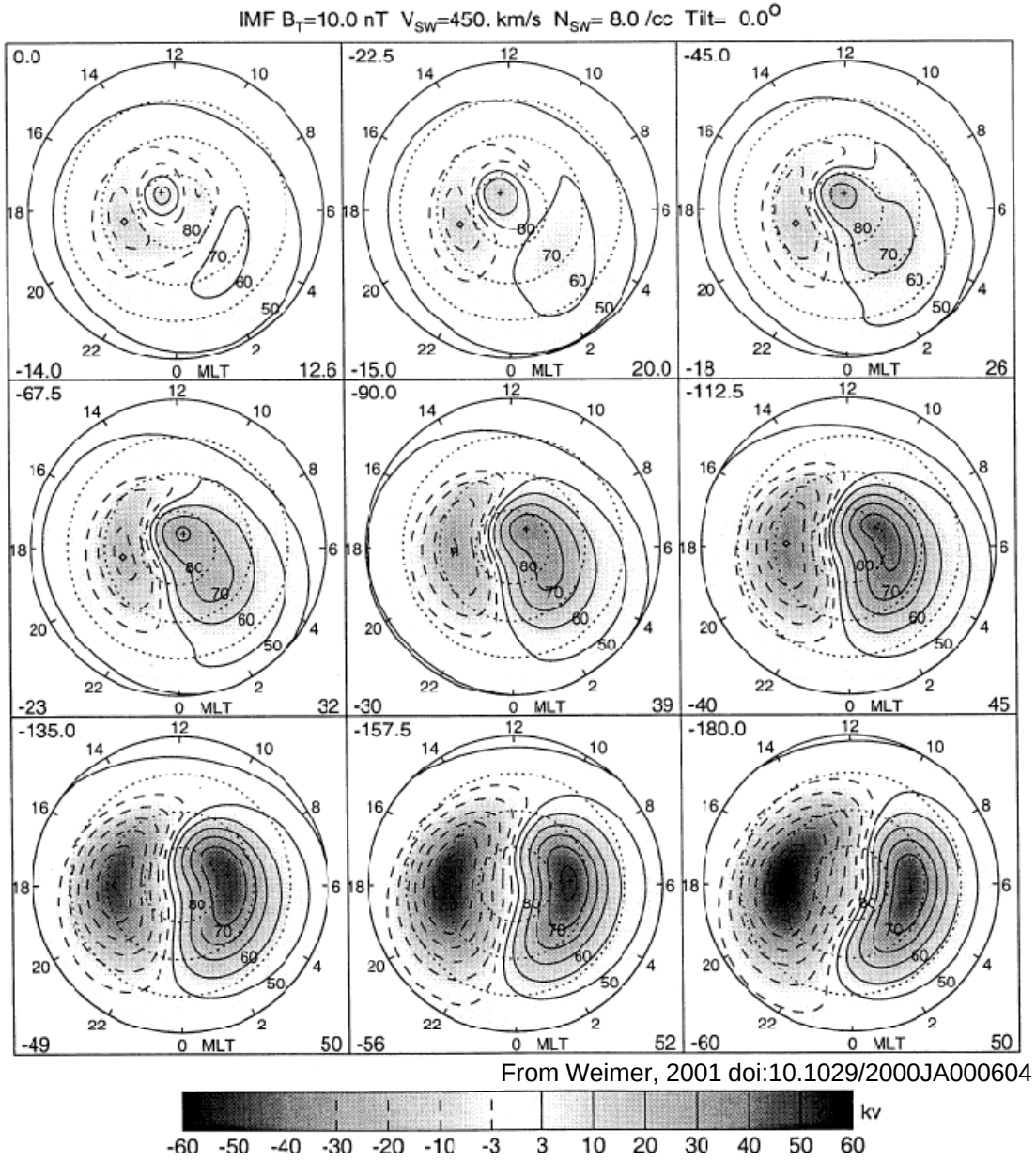


From Weimer, 2001 doi:10.1029/2000JA000604

Figure 2. Electric potential patterns for negative IMF B_Y at IMF clock angles from 0° to 180° at -22.5° steps. All other input conditions are fixed with B_T=10 nT, V_{SW}=450 km s^{-1}, n_{SW}=8 cm^{-3}, and zero tilt angle. Contours around the negative potentials are drawn with the dashed lines, and solid lines are used for positive contour levels. The clock angle is shown in the upper left of each box, and the minimum and maximum potentials are noted in the lower left and right corners. The locations of the minimum and maximum potentials are indicated with the diamonds and pluses. A solid line shows the location of the flexible low-latitude boundary.

What is Climatology? II

- In more sophisticated cases, we obtain parametric descriptions
- For example, Weimer potential maps (left) reveal the "typical" behavior of the polar cap potential pattern for various Solar Wind/IMF conditions
- These kinds of parametric maps can be very useful in establishing systematic variation of the magnetosphere to upstream driving
- Parametric climatologies can also be used as boundary conditions for dynamic simulations

What is Climatology? III

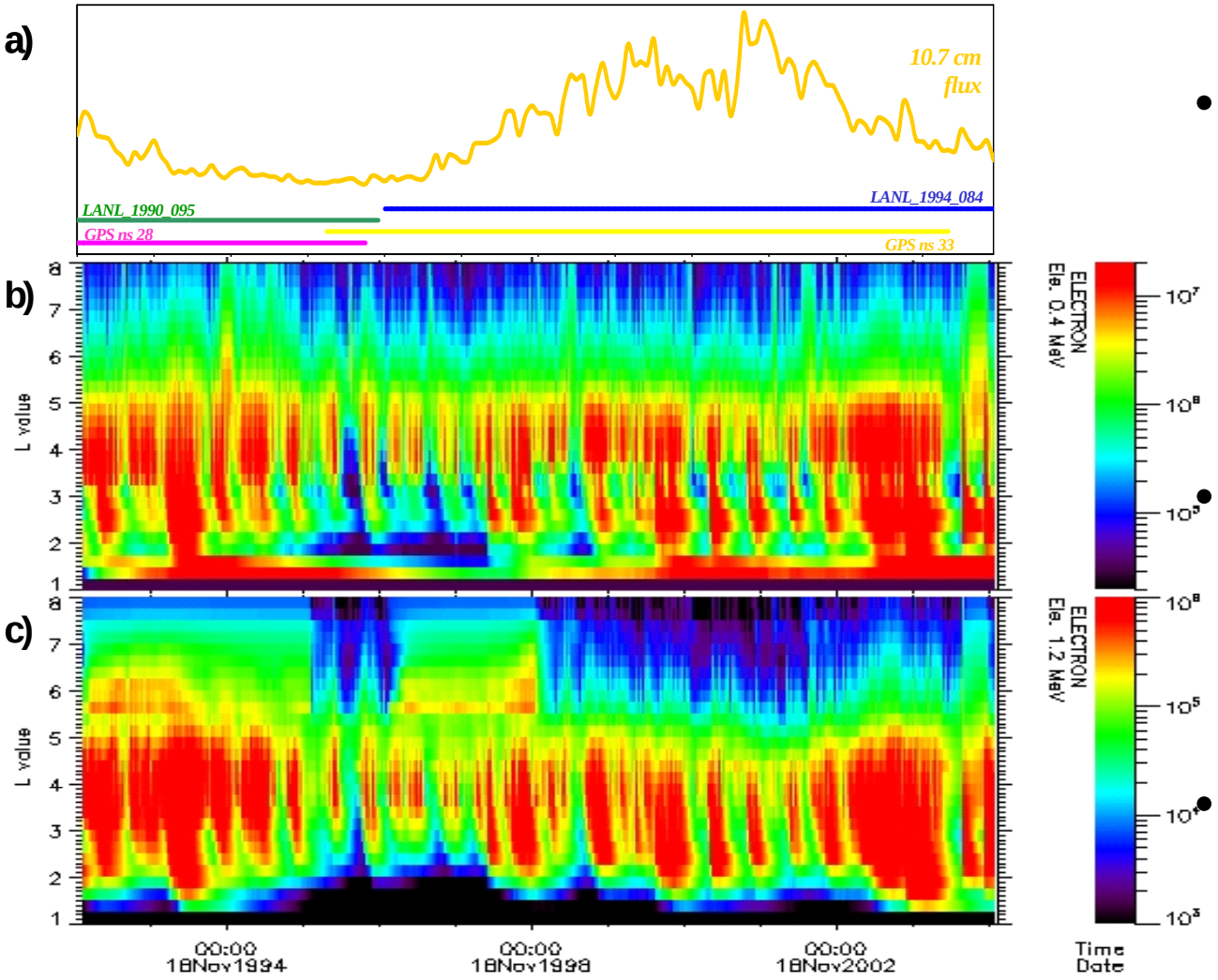


Figure courtesy S. Bourdarie (ONERA)

- In the most sophisticated case, “reanalysis climatology”, we obtain a global specification of the environment over a long time scale (e.g., one or more solar cycles) for an actual time interval
- In this example, the Salammbo electron radiation belt model is run for 11 years driven by LANL GEO and GPS observations
- It’s still a work in progress, but it’s already revealing interesting intra-cycle variation

What is Reanalysis? I

- **Reanalysis is the creation of a spatially and temporally continuous description of the environment through the appropriate combination of observations, physical laws and statistical models**
- **Data assimilation often plays a fundamental role in combining observations and physics-based simulations**
- **Thus, one can imagine Reanalysis as a multi-year or multi-decade data-assimilative simulation run: "The Mother of All Event Studies"**
- **The resulting data set is often called "a reanalysis" and it provides the state of the environment in a series of snapshots on a fixed grid at a fixed time step for a very long time**

What is Reanalysis? II

Sparse observations along spacecraft track

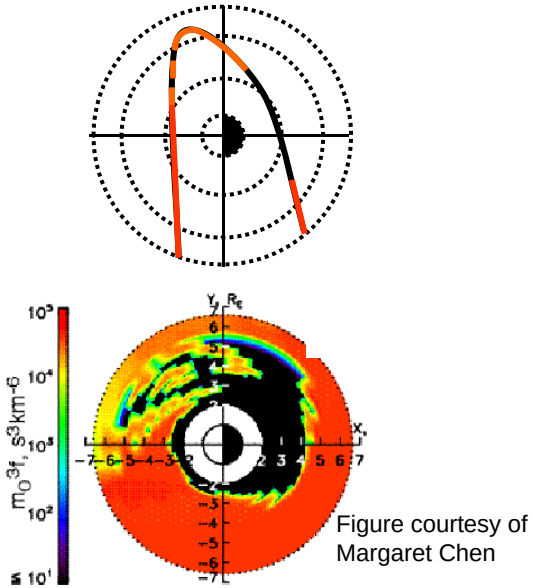


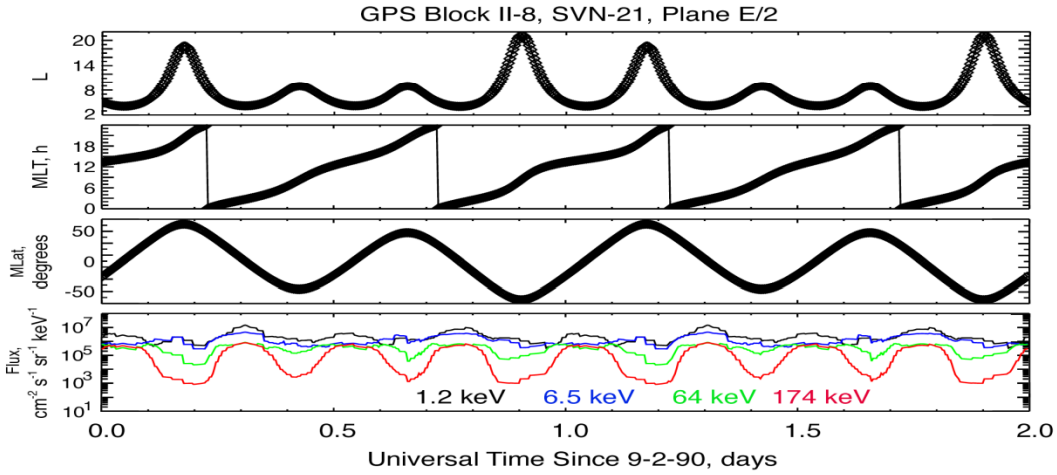
Figure courtesy of Margaret Chen

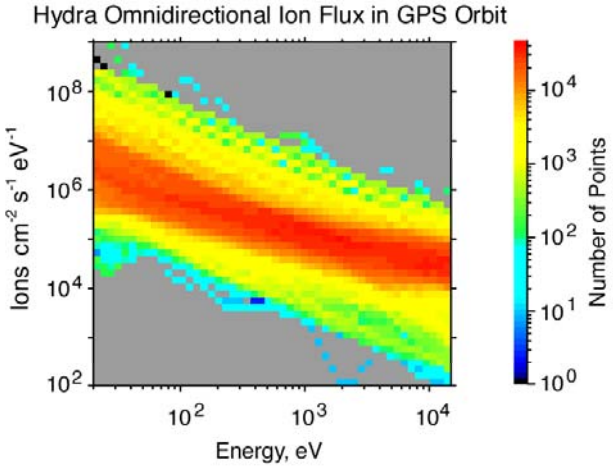
3 MeV/G (33 keV at 3 R_E) Protons

Data assimilation adjusts physics-based numerical simulation or statistical model to match observations: fills in spatial gaps

The Goal of Reanalysis:

Run data assimilative model for a full solar cycle





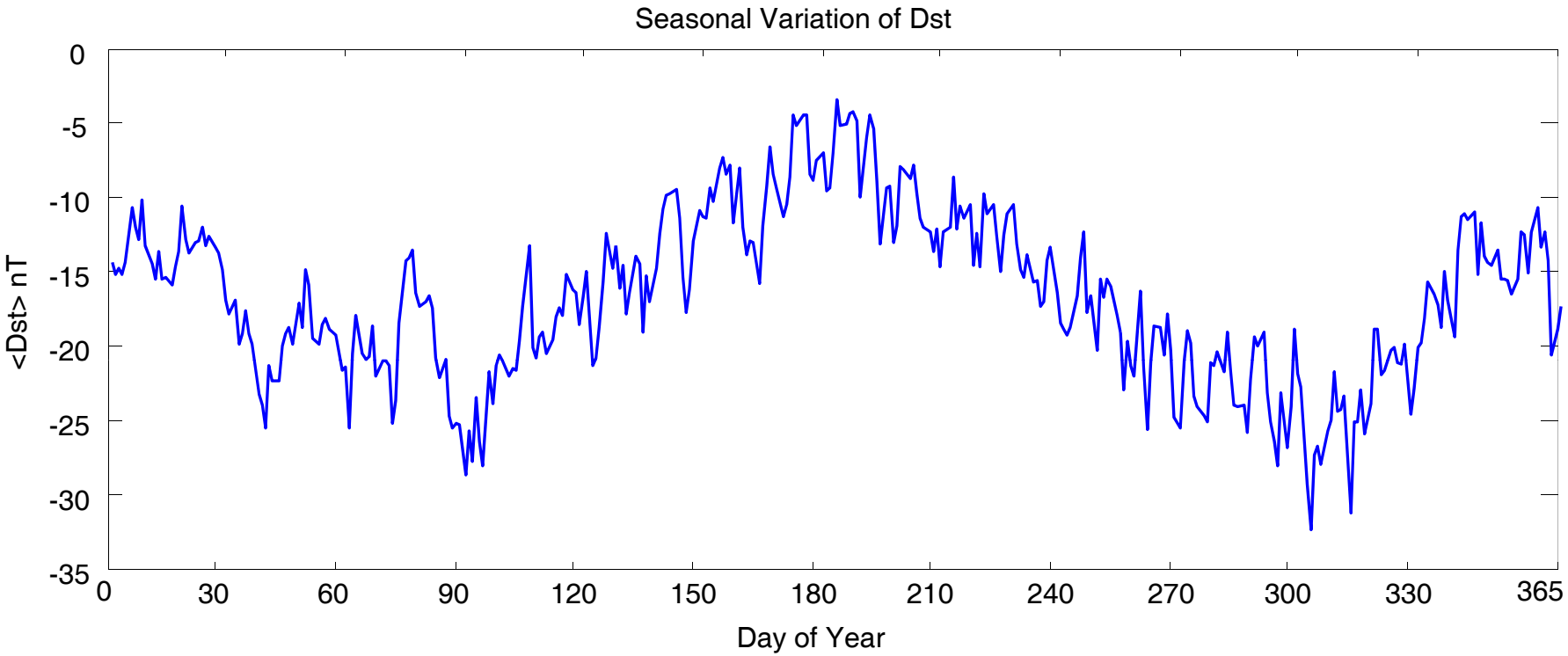
In this demonstration, a GPS vehicle is flown through a climatology of hot proton flux (Roeder et al. doi:10.1029/2005SW000161)

What are Climatology and Reanalysis good for?

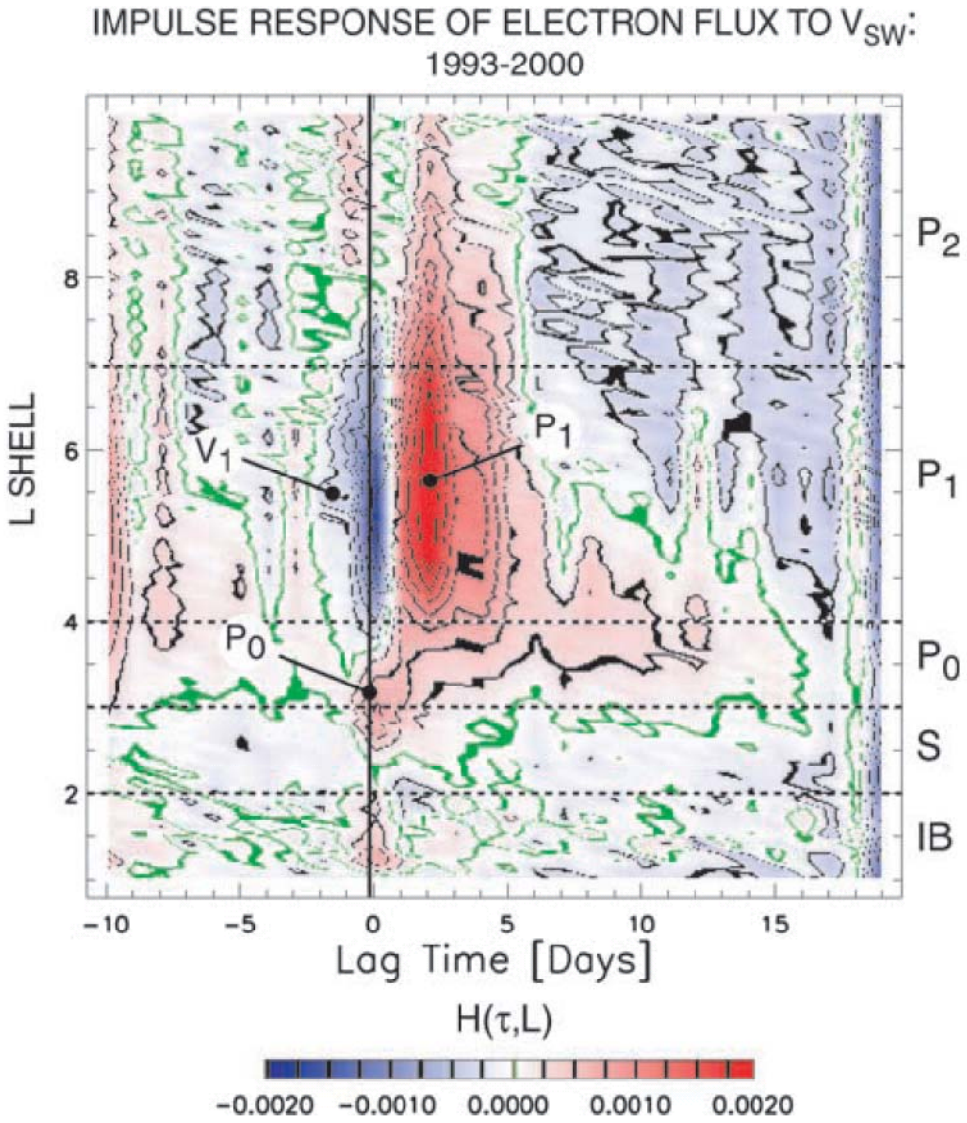
- **Simple Climatology:**
  - **Initial and boundary conditions for simulations**
  - **Space environment specifications for spacecraft design and mission planning (intended use of AE-8 and AP-8)**
  - **Identification of statistical relationships between different aspects of the space environment (e.g., Russell-McPherron effect)**

- **Reanalysis Climatology:**
  - **Initial and boundary conditions appropriate for actual, specific historical events**
  - **Space environment specifications for spacecraft design and mission planning**
  - **Combines “all” available measurements into common resource**
  - **Consistent framework for comparison of simulations**
  - **Testbed for space weather forecast models**
  - **Weakly coupled collaboration (e.g., use AMIE reanalysis to drive ring current reanalysis, to compute magnetic field for computation of adiabatic invariants of energetic particles)**
  - **Standardized, global grid for time series and multivariate data analysis**
  - **The mother of all event studies**

Uses of Climatology I



The Russell-McPherron Effect is a climatological result with a physical implication: the systematic relationship between magnetic activity and season implicates dayside magnetic reconnection as a major cause of magnetic activity



From Vassiliadis et al. (2005, doi:10.1029/2004JA010443)

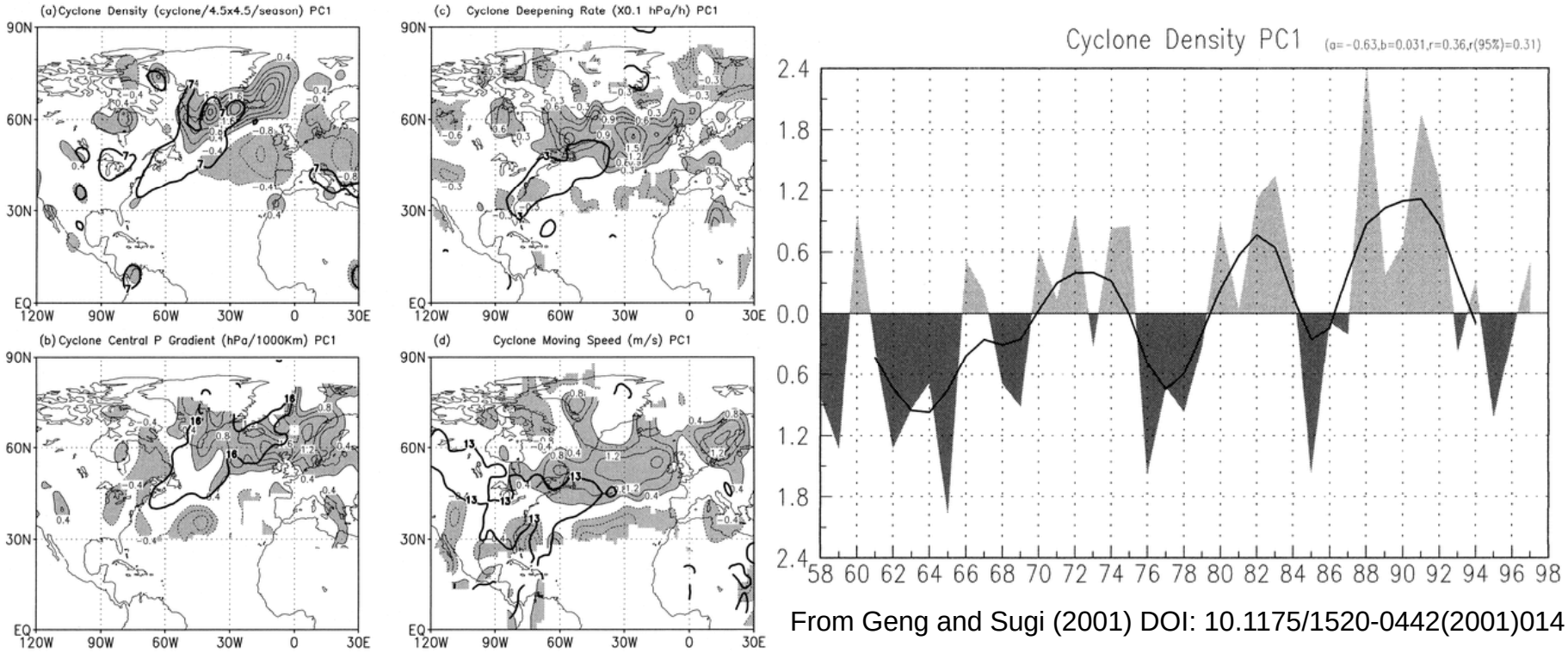
Uses of Climatology II

- A Reanalysis climatology enables multivariate time-series analysis: standard cadence and grid
- Has the potential to remove orbital and diurnal effects from observations
  - E.g., Polar's orbit changes from year to year
  - Ground-stations rotate under current systems (AL, Dst)
- Example at left from Vassiliadis reveals intriguing structure in long-term SAMPEX observations – can only do this now with flux in specific orbits, not global phase-space-density

How will Reanalysis change the way we study the Inner Magnetosphere?

- The NCAR/NCEP climate reanalysis is arguably the most-used data set in all of atmospheric science
- The reanalysis becomes a dataset in itself
  - Standardized
  - Physical units
  - Open to all
  - Shortcomings known by all (when openly discussed)
- Examples:
  - Need global magnetic field for your radiation belt study? Consult the ring current reanalysis
  - Need the plume location for your ring current study? Consult the plasmasphere reanalysis
  - Want to build a solar-wind driven empirical model of the radiation belts? Target the radiation belt reanalysis
- Reanalysis becomes the benchmark against which numerical simulations and forecasts can be tested

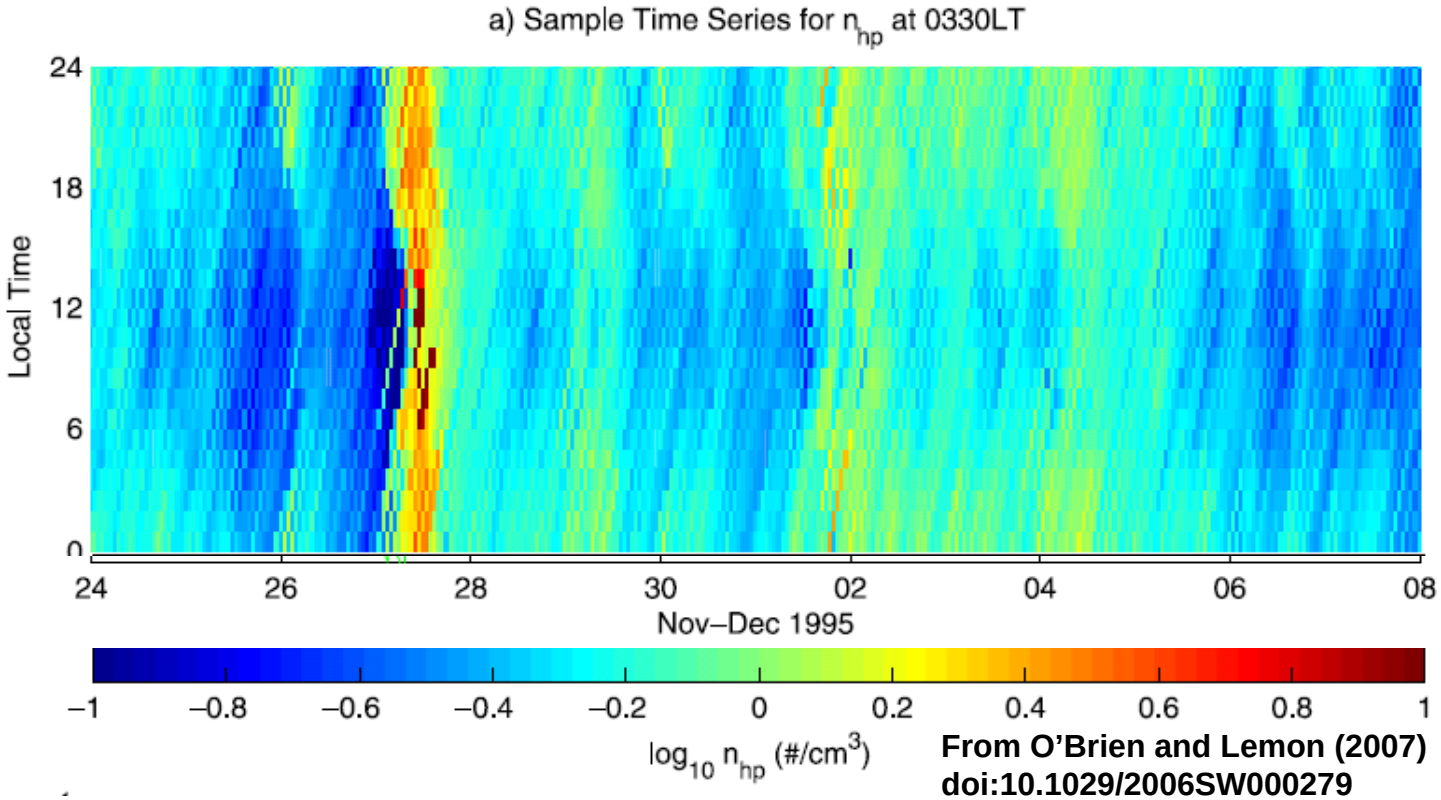
More examples: Climate Indexes



From Geng and Sugi (2001) DOI: 10.1175/1520-0442(2001)014

- **In this example North Atlantic Cyclone Density is subjected to principal component analysis**
- **A spatial pattern is revealed**
- **Much of the time evolution can be captured with a scalar index**
- **Is Dst the first principal component of the ring current? What about Asym-H?**

More Examples: GEO Plasma Boundary Condition



From O'Brien and Lemon (2007)
doi:10.1029/2006SW000279

- In this example, measurements from up to 6 LANL vehicles were used to reconstruct a 15+year history of plasma moments on a 1-hour grid in local time
- This GEO-plasma reanalysis can be used as a boundary condition for ring current simulations

What challenges must be met?

- Our observations are not calibrated to each other, and they rarely include a description of measurement error—they are not yet ready for data assimilation
- Long-term plasma observations are scarce inside GEO
- We have very little data in the inner belt (protons or electrons)
- We don’t have a large pool of radiation belt and plasmasphere models to choose from (we seem to have several ring current simulations)
- 3-D radiation belt codes are numerically unstable with off-diagonal diffusion terms—must simplify physics
- Electric-field effects shorten correlation lengths for <100 keV particles, making data assimilation very challenging at plasma energies
- Computer codes, even without data assimilation, may run too slowly and may not be able to simulate long intervals without developing instabilities
- And, of course, lots of physics remains unknown

FG9: Space Radiation Climatology

- **Chairs: Paul O'Brien and Geoff Reeves**
- **Objective: to produce data assimilative models and long-term reanalysis of the radiation and plasmas trapped in the inner magnetosphere**
- **Benefits to GEM:**
  - **Data assimilative models can support space weather forecasting and the GGCM**
  - **Reanalysis climatology enables data analysis to discover long-term cycles, solar wind coupling, etc**
  - **Reanalysis framework forces us to organize and standardize inner magnetosphere data**
  - **Reanalysis is an excellent test-bed for improving models: start at reanalysis initial condition and simulate forward using improved physics to see whether we can reproduce the reanalysis result *without* data assimilation**
- **Strategy and planning session TODAY after plenary**

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