DREAM

The Dynamic Radiation Environment Assimilation Model

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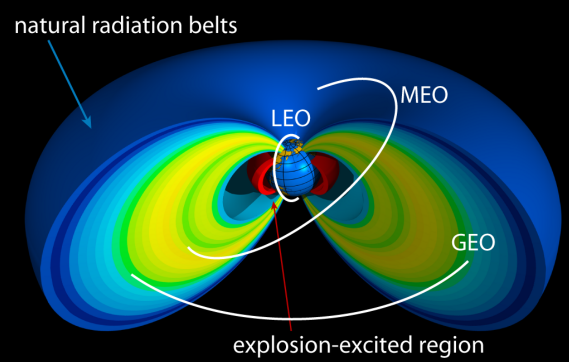

Los Alamos
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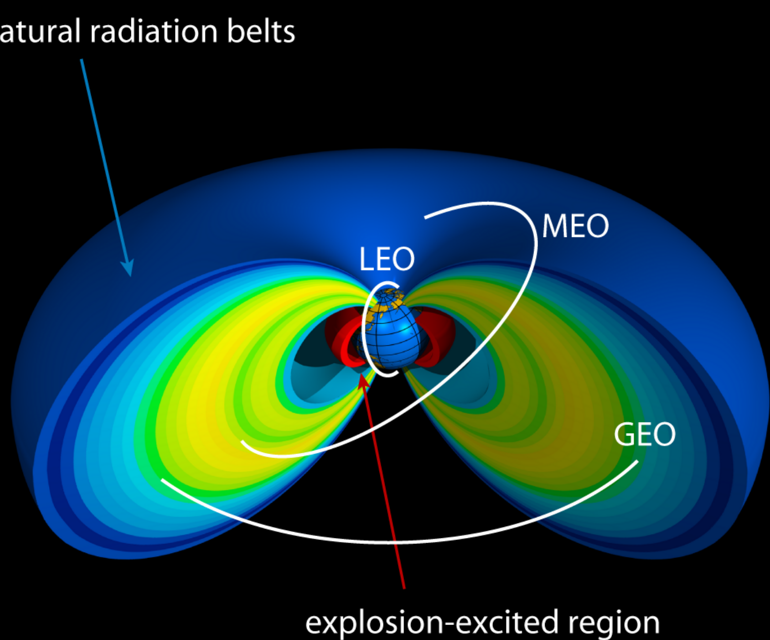
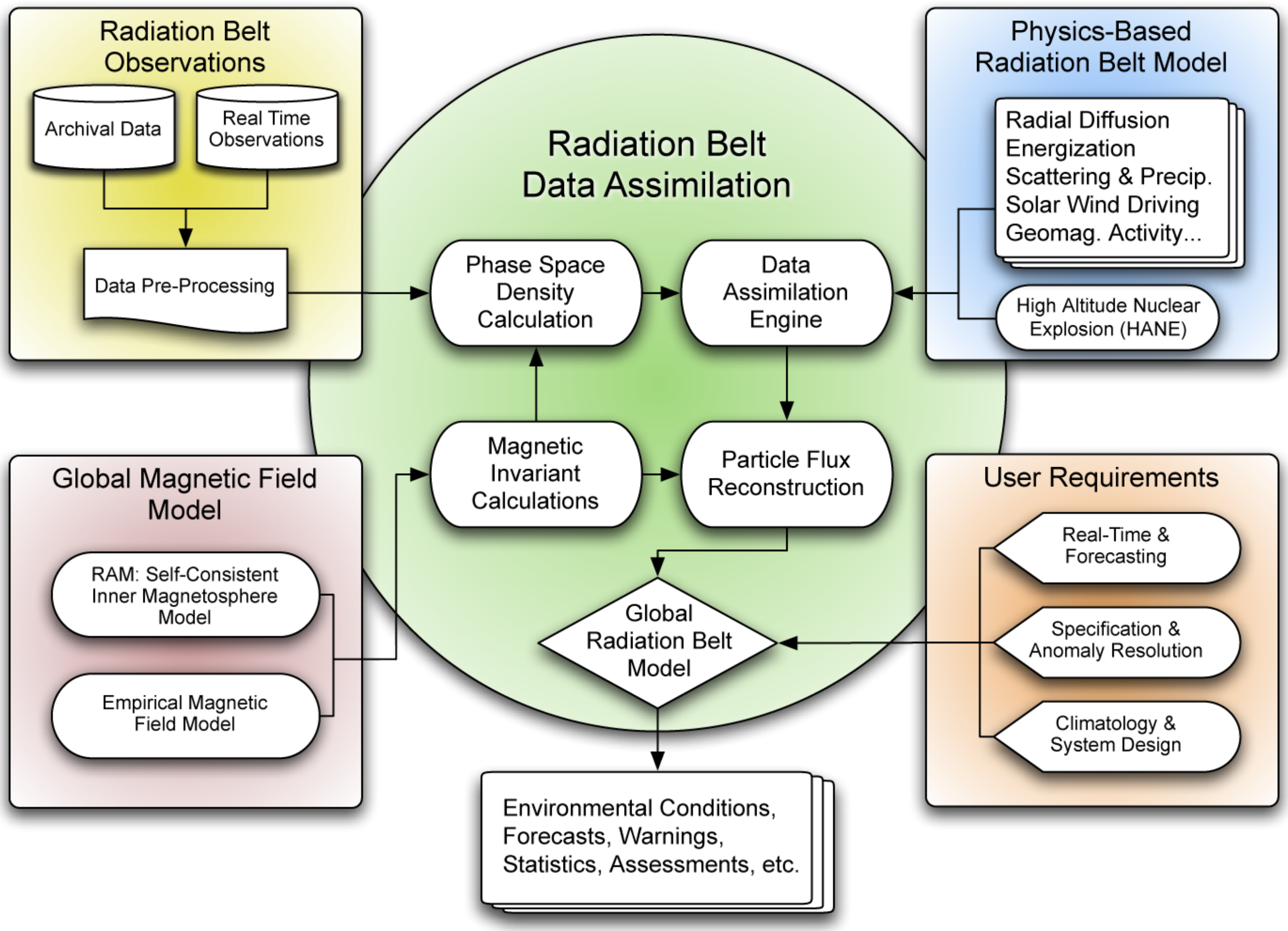
DREAM: The Dynamic Radiation Environment Assimilation Model

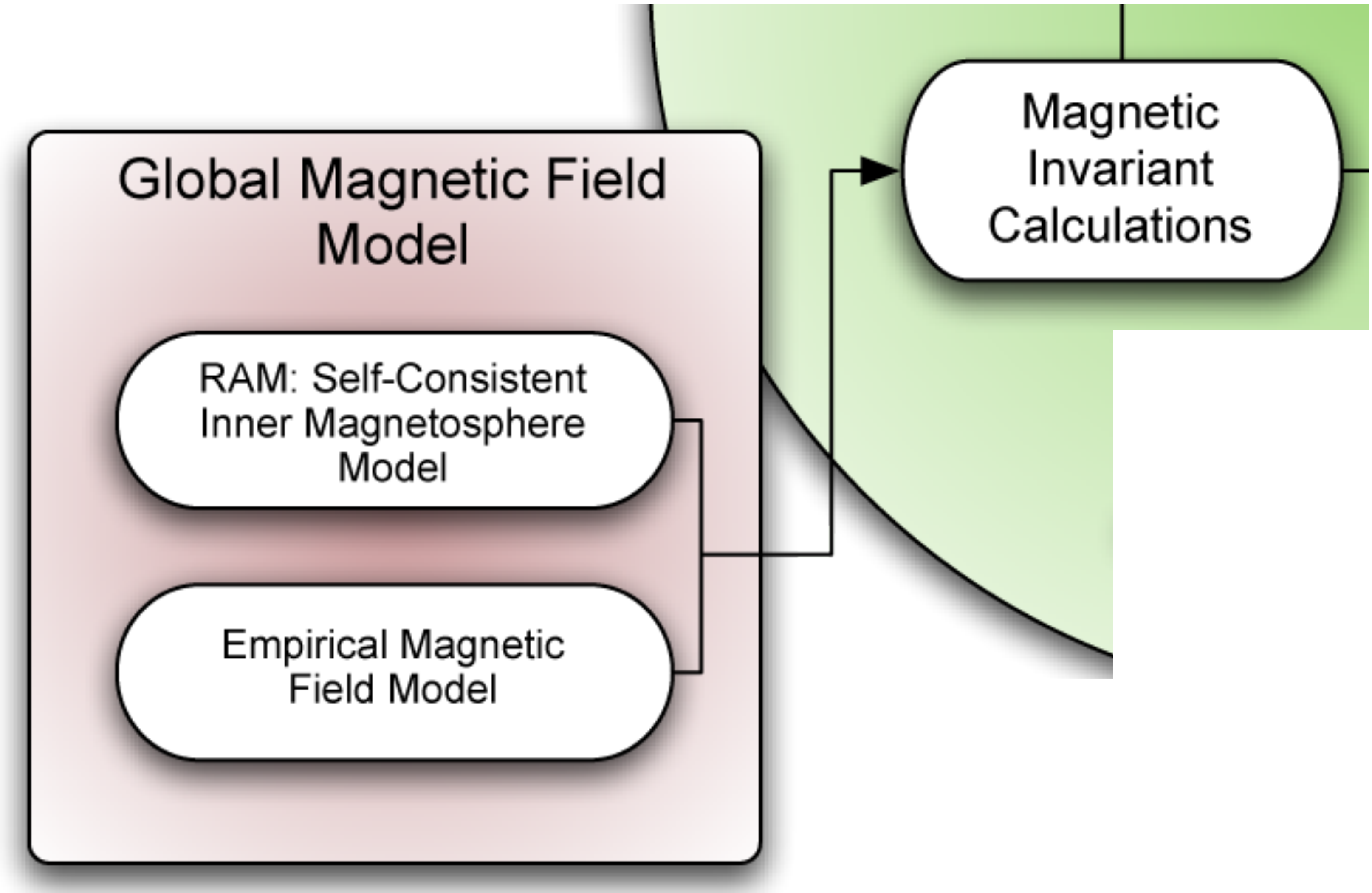


- Developed by LANL to quantify risks from natural and artificial belts
- Uses Data Assimilation with GEO, GPS and other observations
- Couples ring current, magnetic field, and radiation belt models
- Goals: Specification, Prediction, Understanding

DREAM Computational Framework

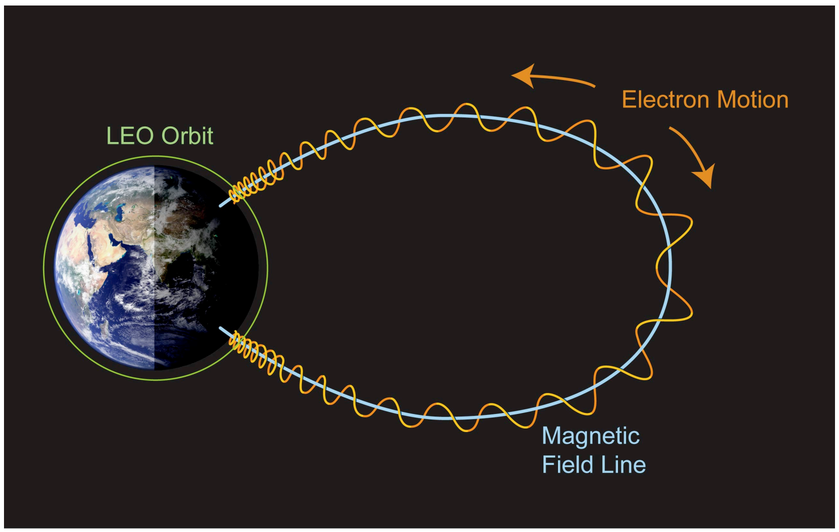


DREAM Computational Framework

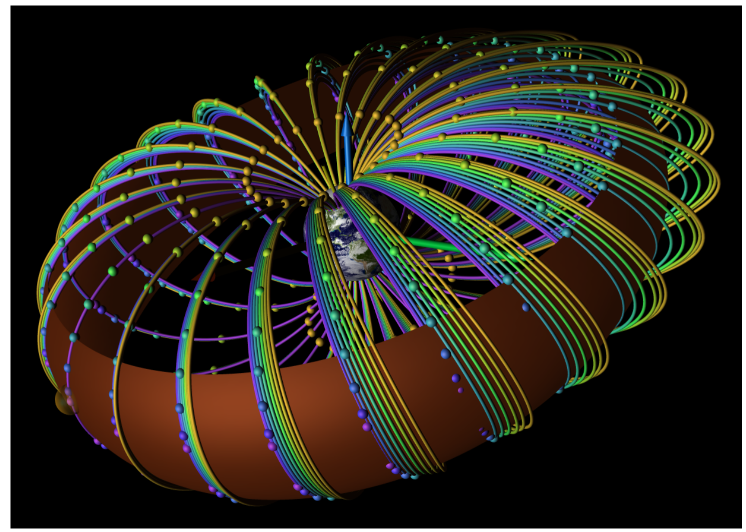


"Magnetic Invariants" define electron motion in the radiation belts

Bounce Motion
Along a Field Line

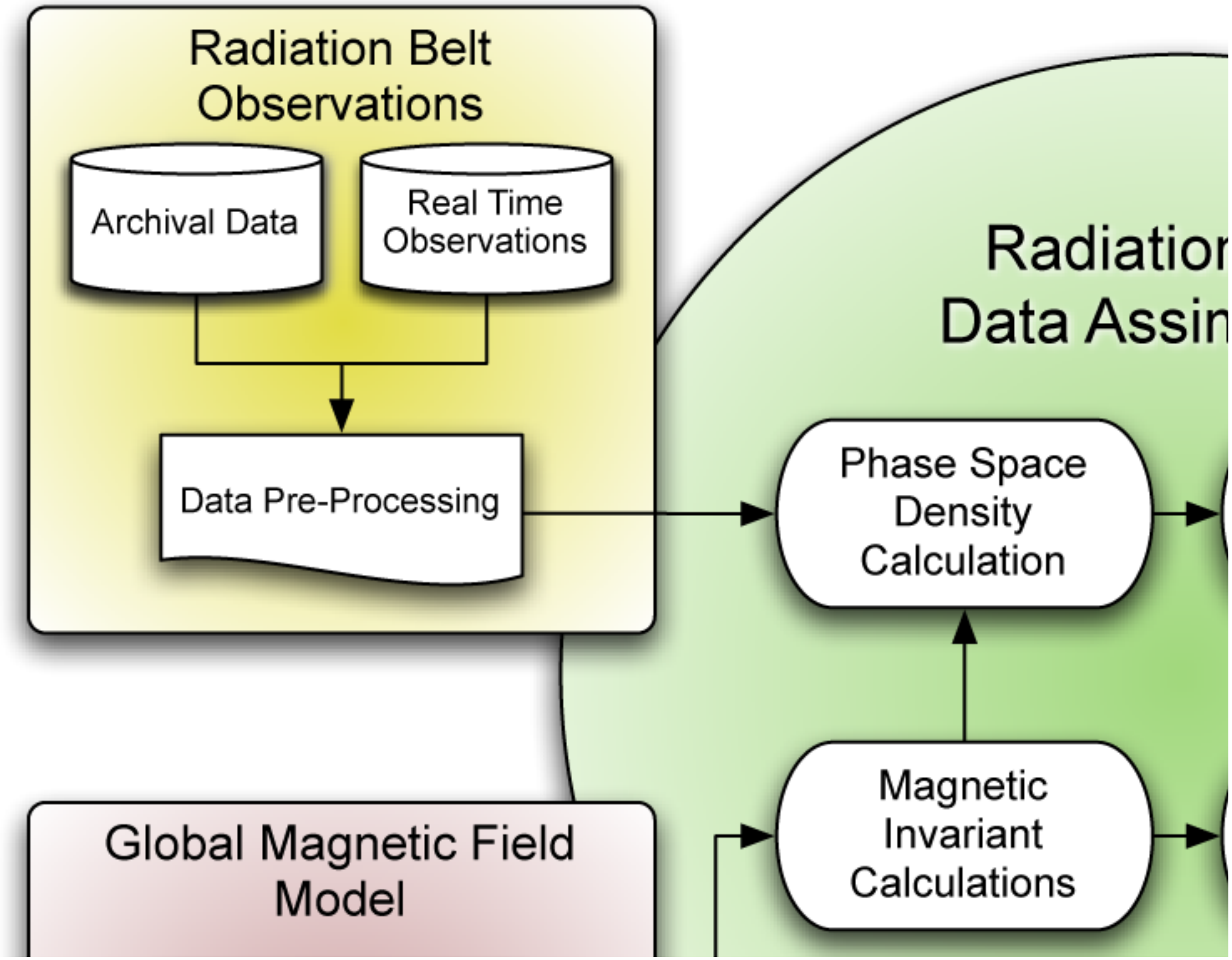


Drift Motion
Around the Earth



- DREAM calculates the magnetic invariants associated with gyro, bounce, and drift motions as a first step to calculating radiation belt electron dynamics.
- Can use either statistical models (e.g. T89, T04) or complex magnetically self-consistent physics models (e.g. RAM-SCB).

Observations + Magnetic Invariants => Phase Space Densities



Observations are in Flux
Physical equations use phase space density

Phase Space Density (PSD)

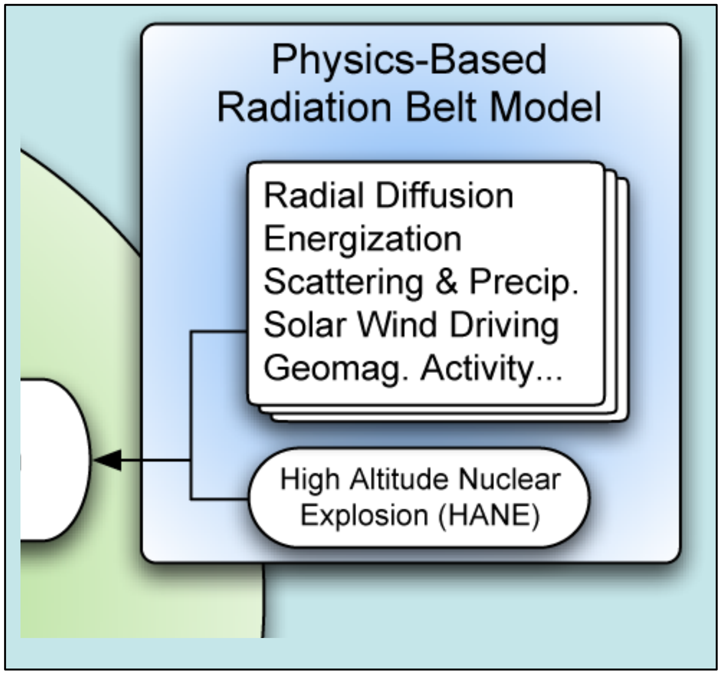
$$f = \frac{j}{p^2}$$

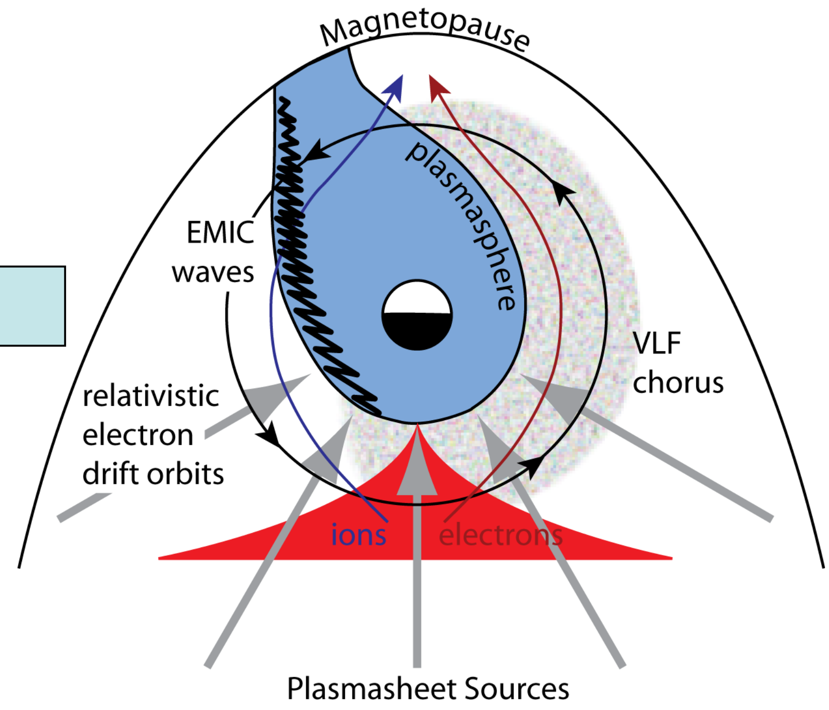
Model for PSD Evolution
e.g. Radial Diffusion

$$\frac{\partial f}{\partial t} = L^2 \frac{\partial}{\partial L}\left(\frac{D_{\mathrm{LL}}}{L^2}\frac{\partial f}{\partial L}\right)$$

- The conversion from flux (as a function of energy, pitch-angle and location) to PSD (as a function of the three magnetic invariants) is a critical step in radiation belt modeling
- This conversion must also be reversed at the end to get predictions in physically-relevant quantities (e.g. to get dose).

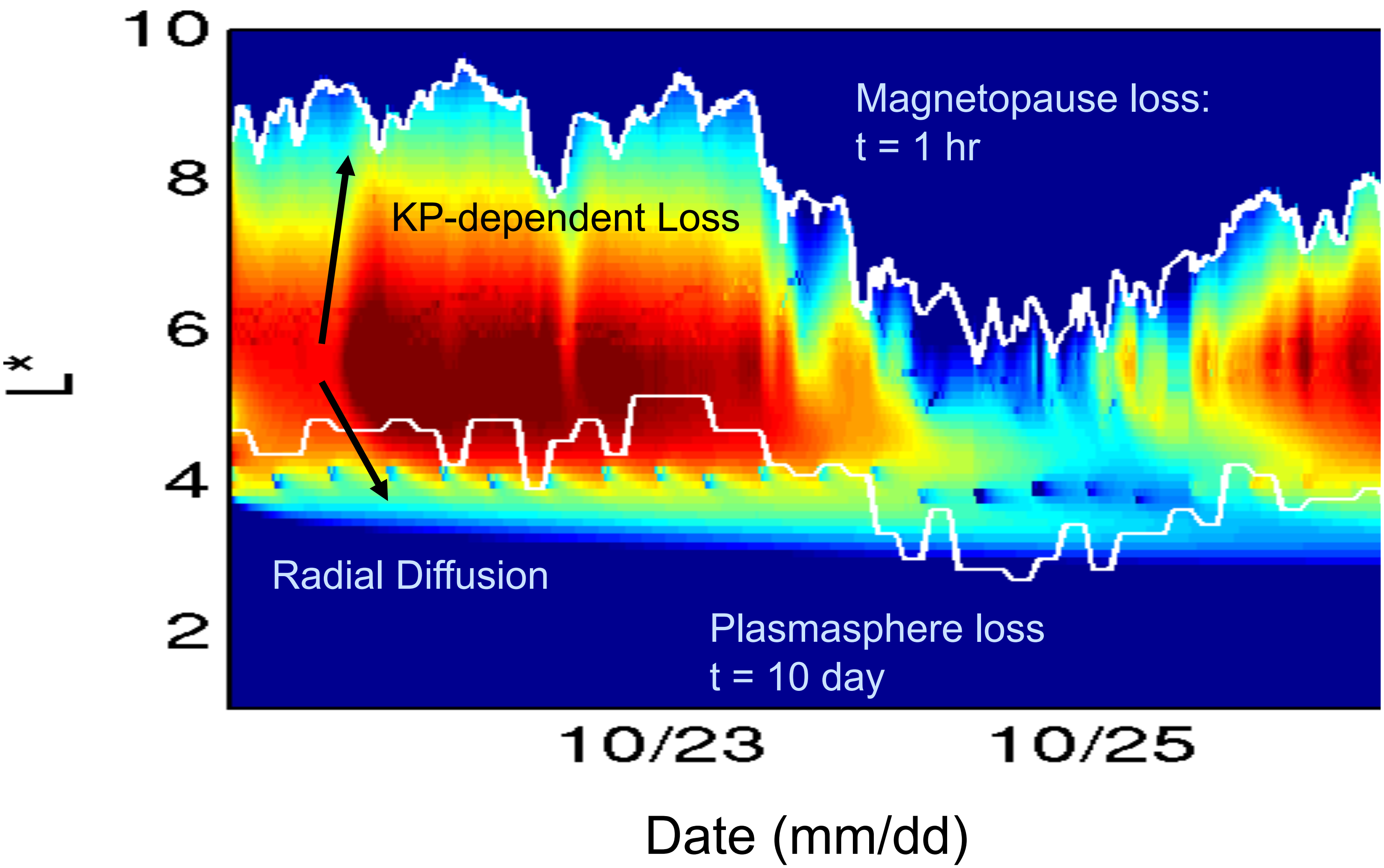
DREAM Computational Framework
Physics Models



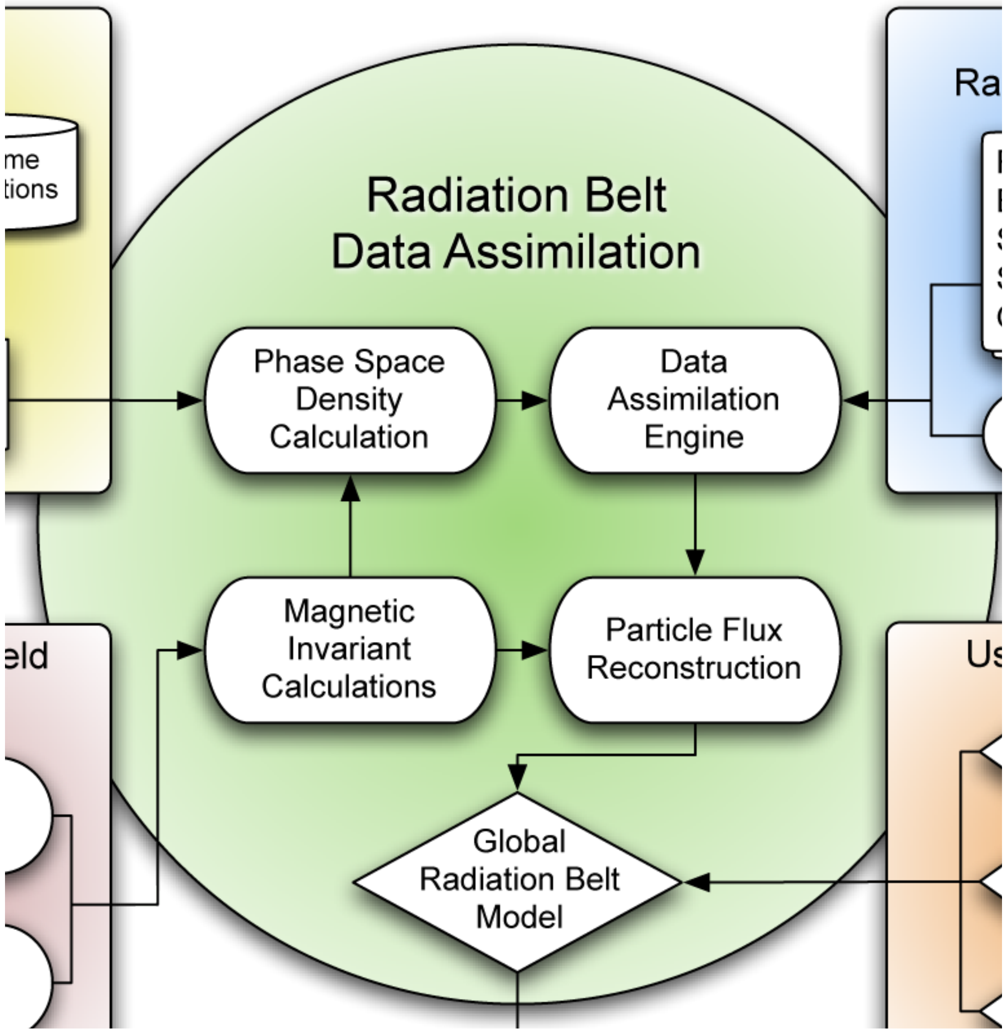


- DREAM can use physics models with various levels of physical and computational complexity
- But, physics models alone can not yet make accurate predictions

Phase Space Density as a function of L* and Time

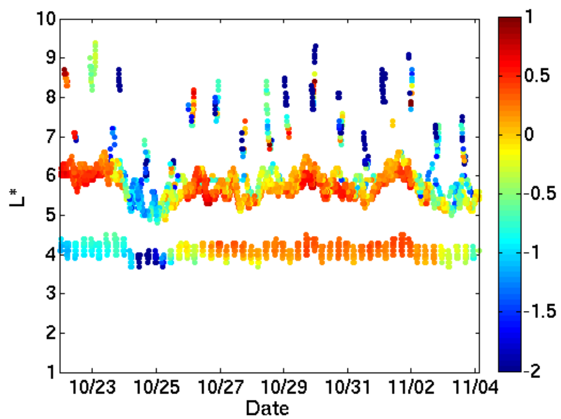


DREAM Computational Framework
Data Assimilation

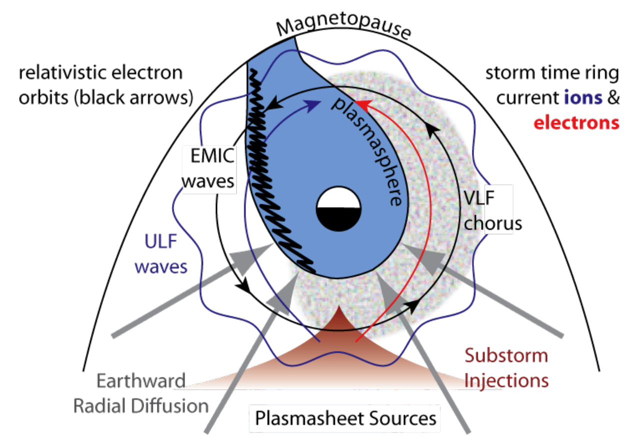


Data Assimilation turns sparse observations into global, data-driven solutions

Sparse and/or Heterogeneous Observations



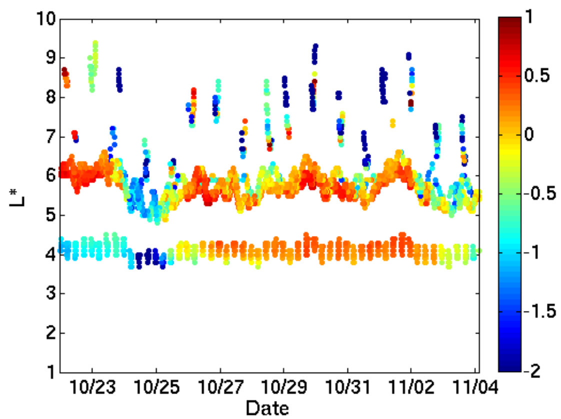
Complex Physical System



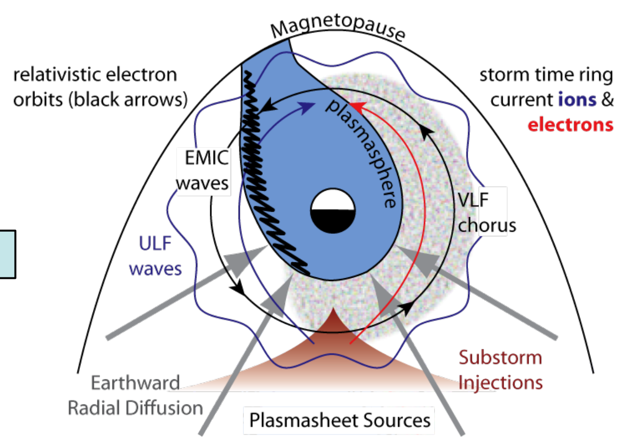
- Data Assimilation methods such as Kalman Filtering are techniques to combine physical models with sparse or conflicting data to produce optimized global solutions. The assimilation, or ‘reanalysis’, gives information not present in the model or measurements alone

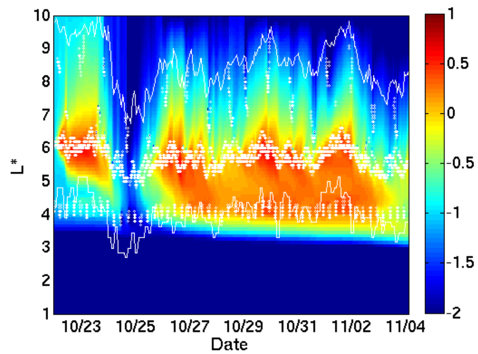
Data Assimilation turns sparse observations into global, data-driven solutions

Sparse and/or Heterogeneous Observations



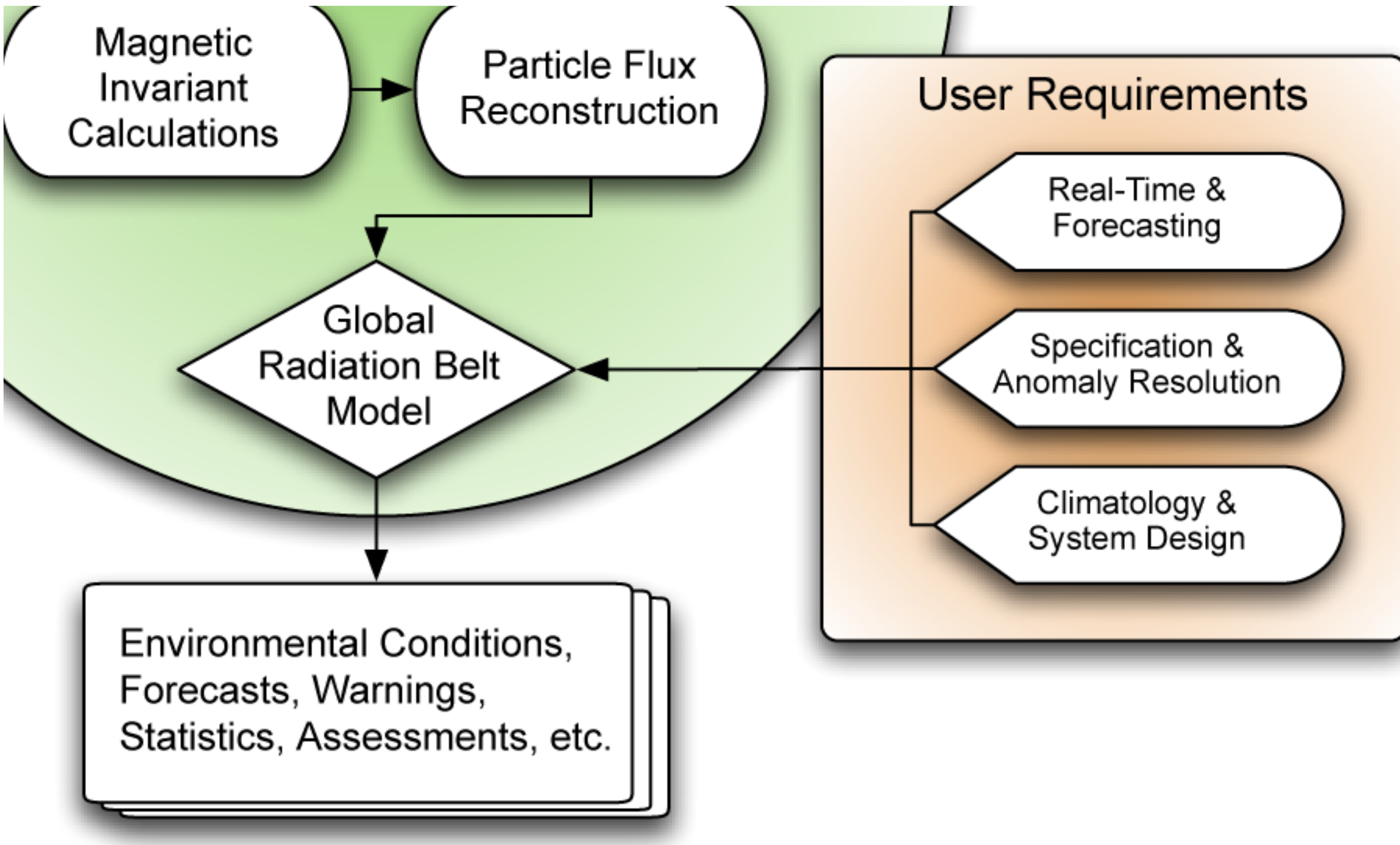
Complex Physical System





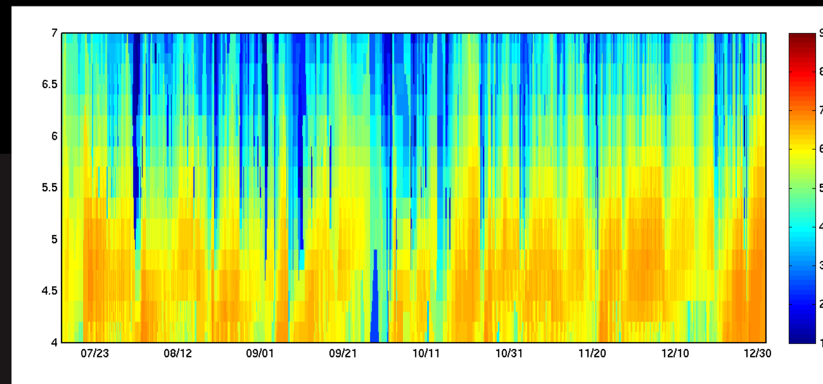
Global, Real-Time Data-Driven Solution

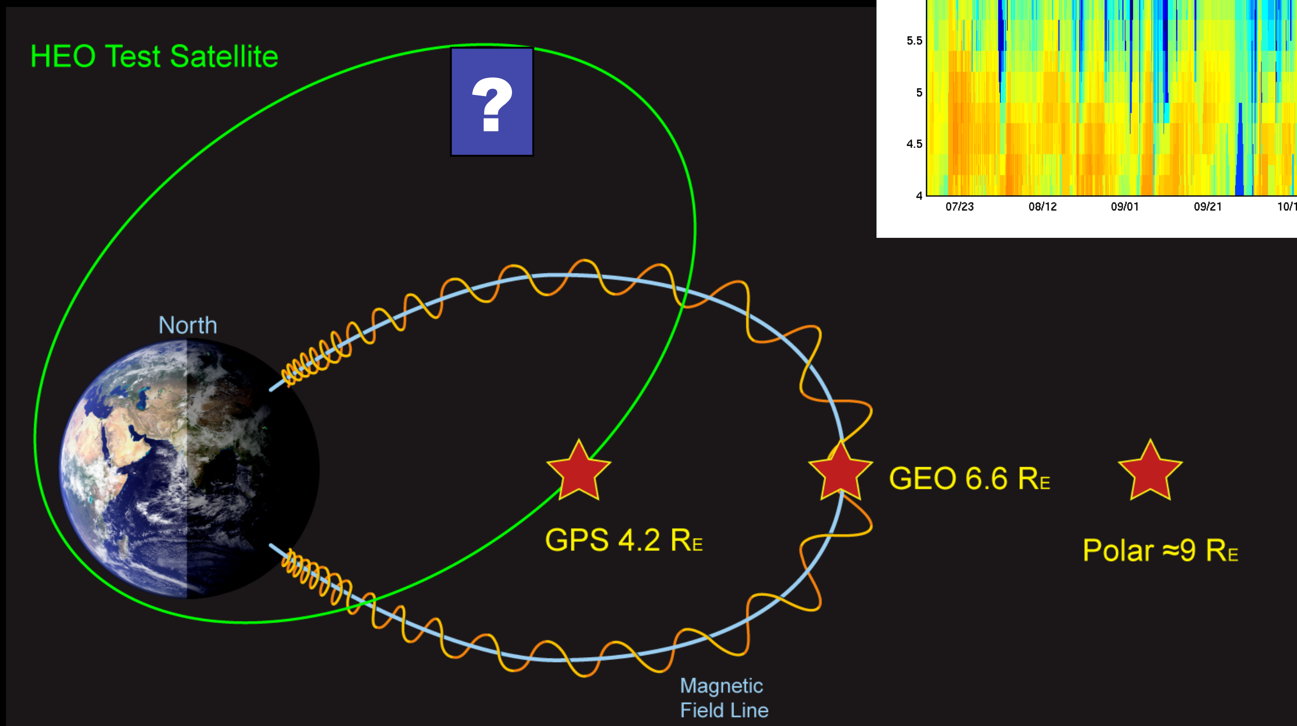
DREAM Computational Framework Validation and Applications



Prediction of flux in different satellite orbits

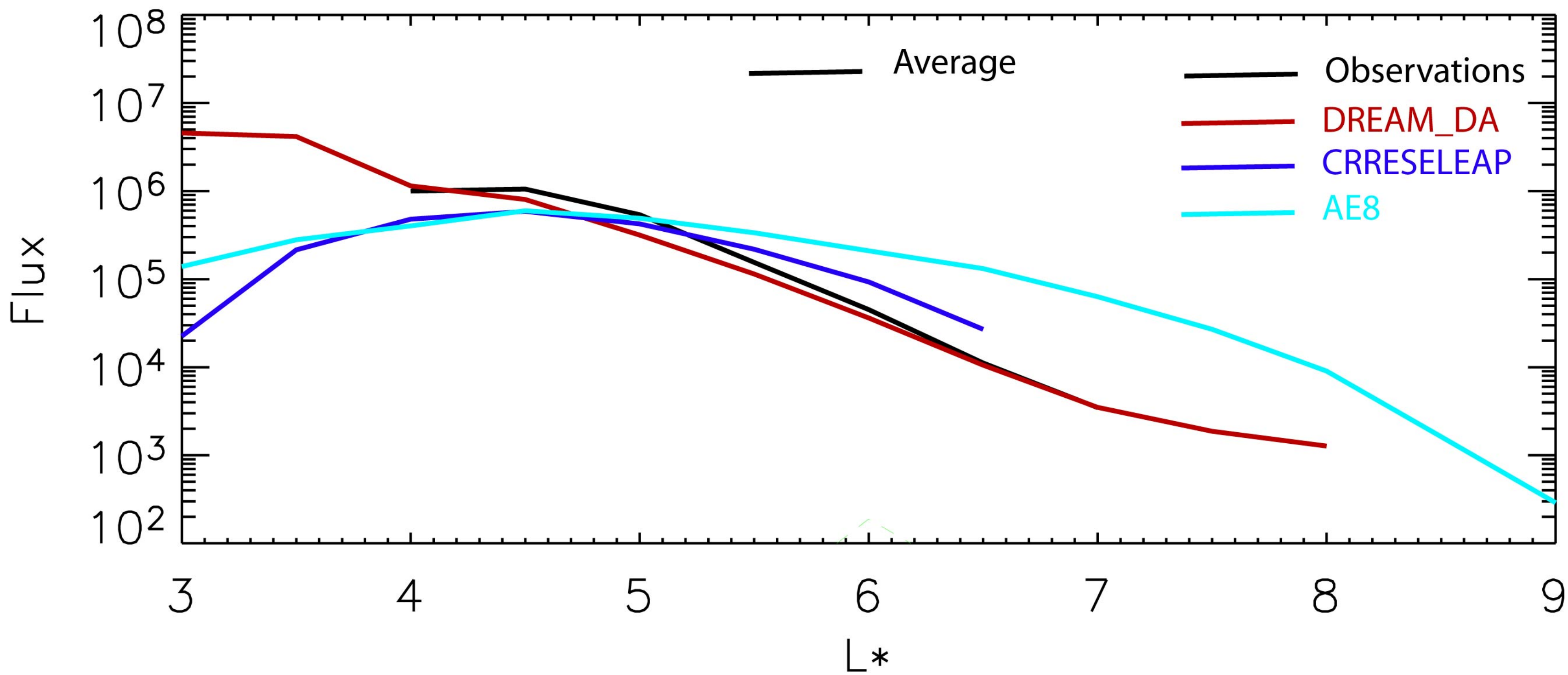
~ 1 MeV electron flux at HEO-3



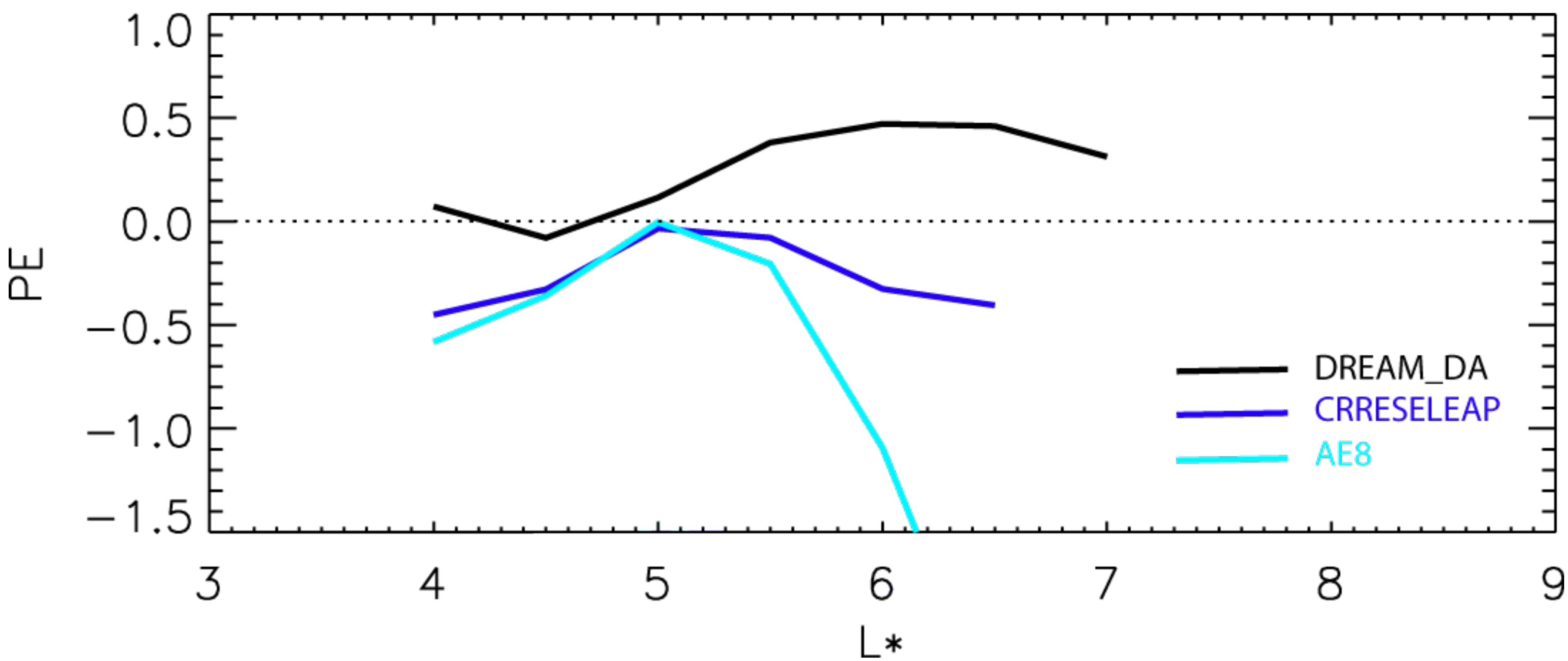


HEO is a different orbit and is not used as input to DREAM

Validation 1: Average Flux vs Altitude

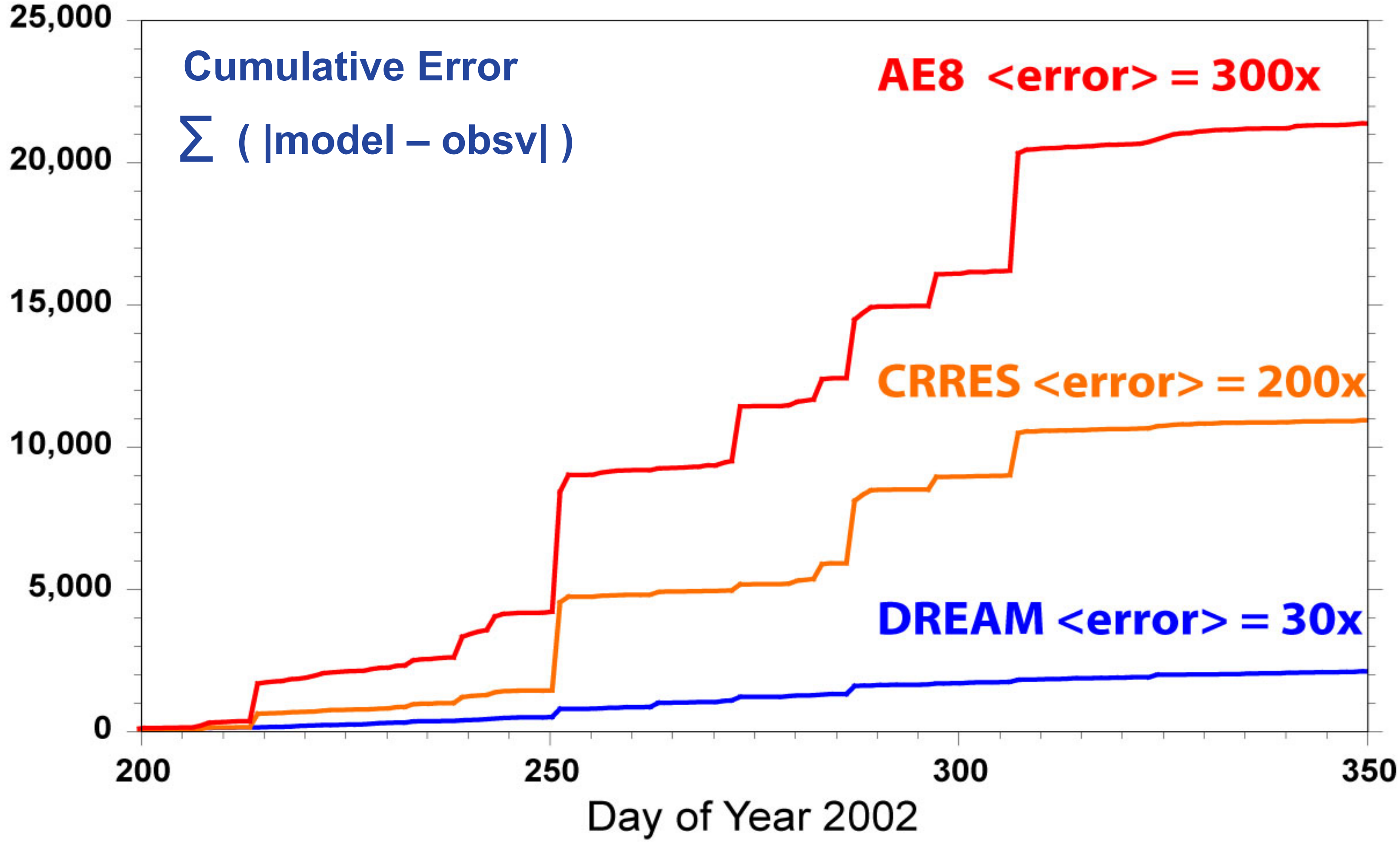


Validation 2: Prediction Efficiency testing variation around the mean



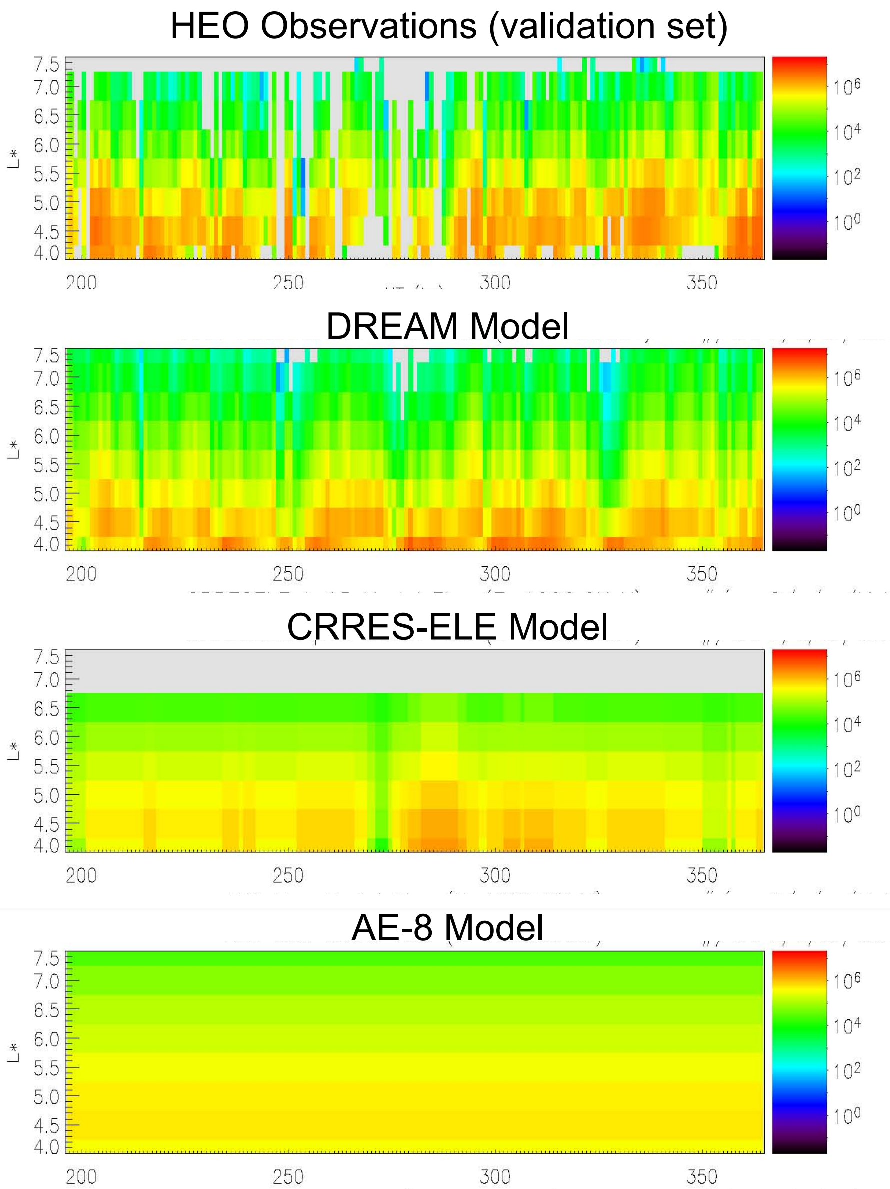
$$PE = 1 - \frac{\Sigma\ (\text{model} - \langle \text{obsv} \rangle)^2}{\Sigma\ (\text{obsv} - \langle \text{obsv} \rangle)^2}$$

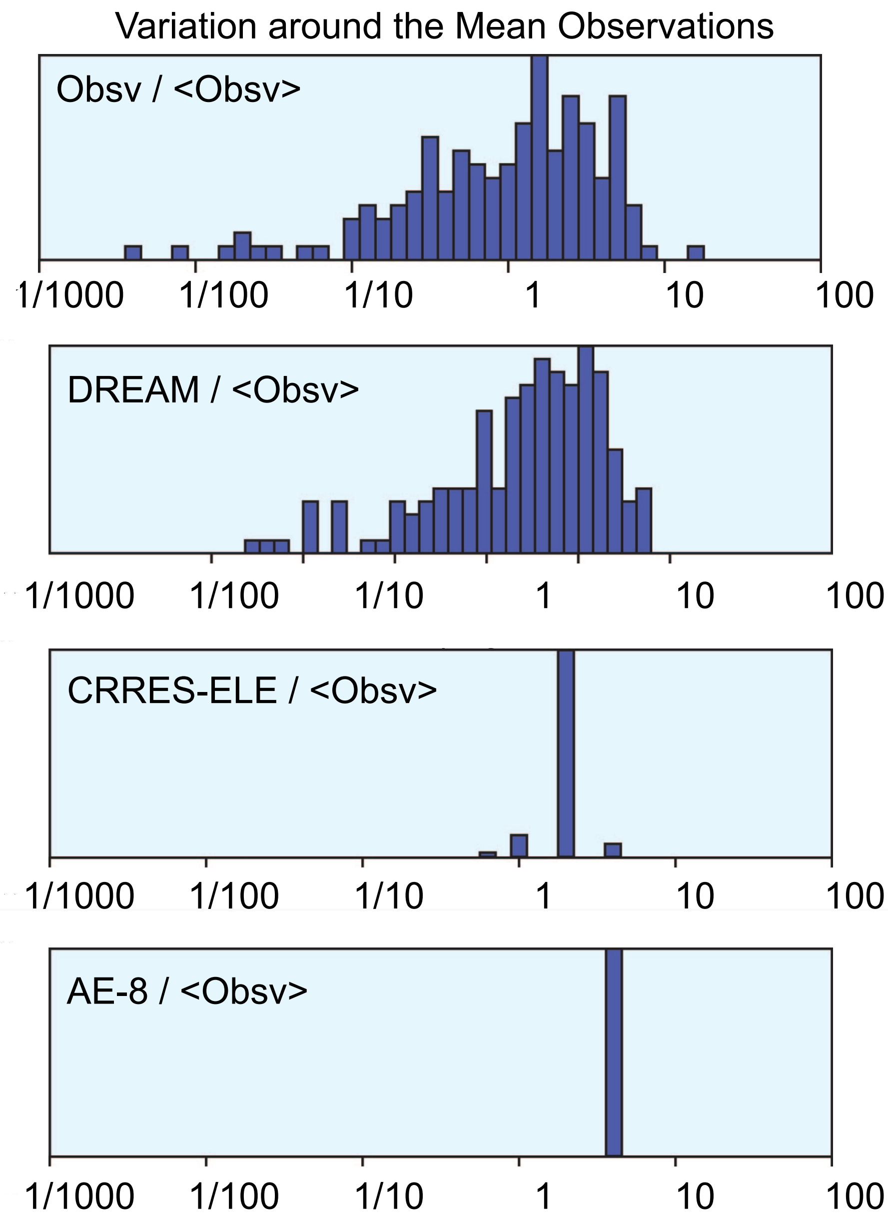
Validation 3: Average absolute error
DREAM gives ~10x improvement



Flux vs L*, Time (1 MeV)

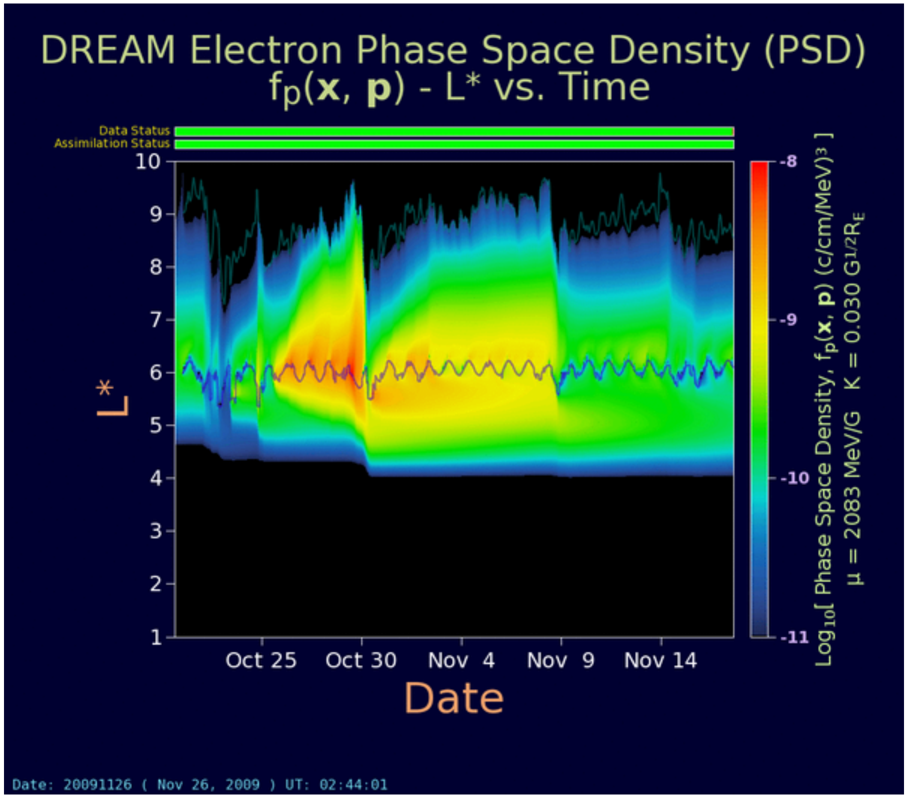
Distribution at L*=6





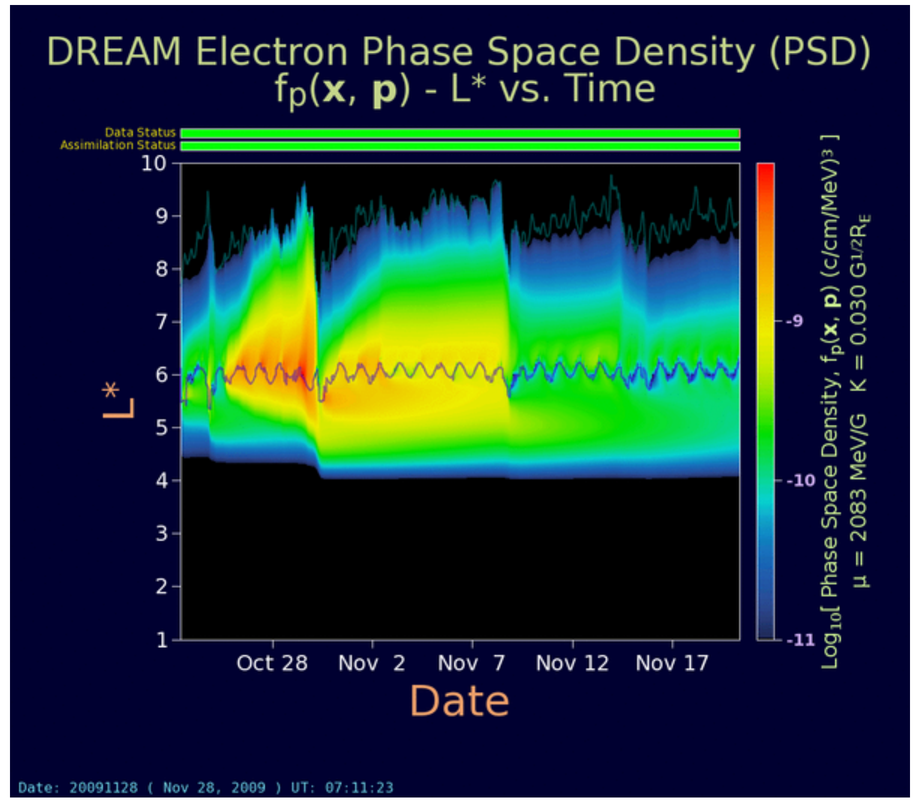
DREAM Real-Time Code

- Real-time version of DREAM currently running at LANL. See http://dream.lanl.gov. (iDREAM iphone app also available through itunes.)
- Installed for testing at AFRL R2O center in Albuquerque: SWFL
- Uses single GOES satellite input
- Forecasts can be produced using the nowcast + a physics model



DREAM at CCMC

- The real-time version of DREAM was also partially installed at CCMC.
- However, this effort was put on hold for a variety of reasons including: funding/manpower issues; the extremely limited number of data sources currently available for real-time data assimilation (LANL GEO data has been unavailable to the public since Jan 2008); a shift in emphasis (and funding) toward analysis of historical events; it would have merely duplicated existing implementations, etc..



DREAM Recoding Effort

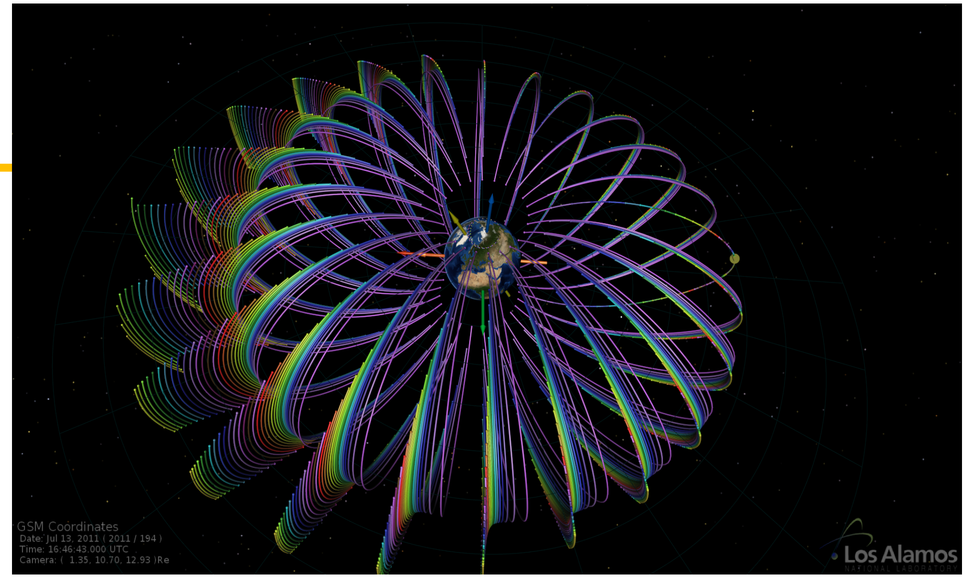
- The original DREAM real-time data-assimilation code was largely integrated into a GTK+ GUI in which the data assimilation was fed by a very limited number of hard-coded data input sources.
- The code has been completely rewritten to accommodate an arbitrary number of input data sources and to be able to compute Flux as a function of energy and pitch angle along arbitrary trajectories (e.g. to obtain dose on platforms that have no environmental sensors.)
- DREAM is now a highly modular set of programs written (mostly) in C and Python (RAM-SCB is FORTRAN.)
- I/O files are a mixture of HDF5 and JSON-enhanced ASCII and have ISTP-compliant meta-data tags that enable convenient visualization with autoplot.
- A lot of effort has also been spent on improving the LanlGeoMag library (upon which much of DREAM is built).

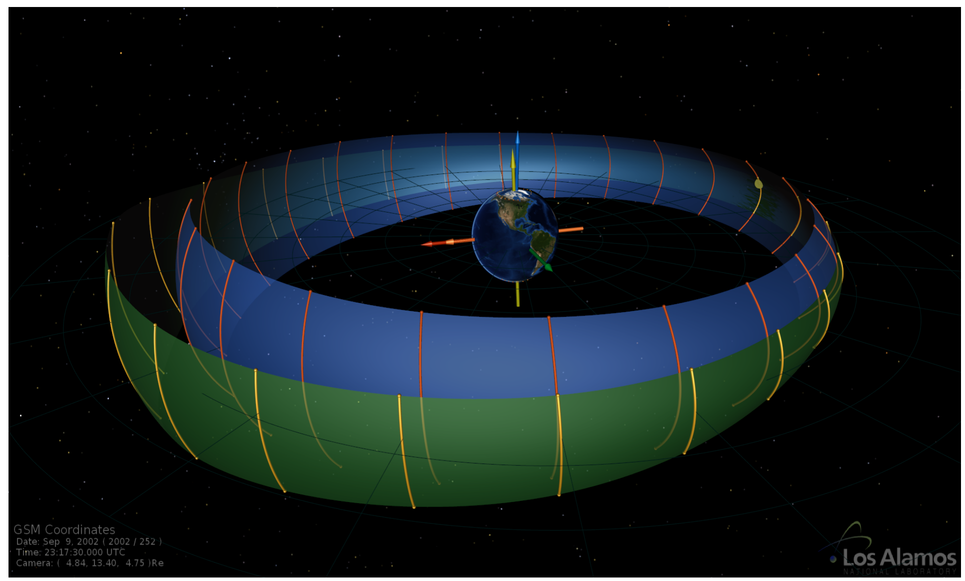
LanlGeoMag Library

- Extensive set of routines for highly accurate coordinate transformations (uses IUA-1976/FK-5 reduction theory with optional use of Earth Orientation Parameters), time system conversions, magnetic field models, magnetic field line tracing (including routines for unstructured grids like those resulting from RAM-SCB), magnetic invariant computations (e.g. I, K, L*, etc.), diffusion coefficients, Flux/ PSD conversion routines, orbit propagator/TLE utilities, and more...
- WGS84 Earth shape model used and all tracing routines respect the shape of the Earth. (Important for HANE research and computing bounce and drift loss cones correctly).
- Library is written in C, its thread-safe, and uses GNU autotools to make installation easy (and portable). Self documenting using doxygen.

LanlGeoMag Library

- Wrapped with Python (using ctypesgen) and will eventually be integrated into SpacePy.
- Extensive testing framework (unit tests, regression tests, etc.) on both C and Python sides.
- OpenGL visualization tools for drift shell tracing output.
- We are working to release this as open source (GPL or BSD).





Options for Installation of Latest Version of DREAM at CCMC

- DREAM can perform data assimilation using arbitrary combinations of input data for arbitrary time ranges and users can extract flux(E,a) profiles for arbitrary physical trajectories. However, the amount of pre-processed data needed to allow for this at CCMC would be prohibitive – at least to begin with.
- Instead, we intend to install the latest version of DREAM at CCMC together with a limited amount of pre-processed data input files for selected events of interest.
- Users could then (from cheapest to most computationally expensive):
  - fly arbitrary trajectories through the pre-computed data assimilation output
  - Re-run the data-assimilation with different combinations of data (e.g. leaving a data source out for testing)
  - Re-run everything with a different field model (B-field from RAM-SCB model could be available in the future) or other model parameters (e.g. different diffusion coefficients, etc.).
  - Upload and ingest additional datasets and then re-run everything.

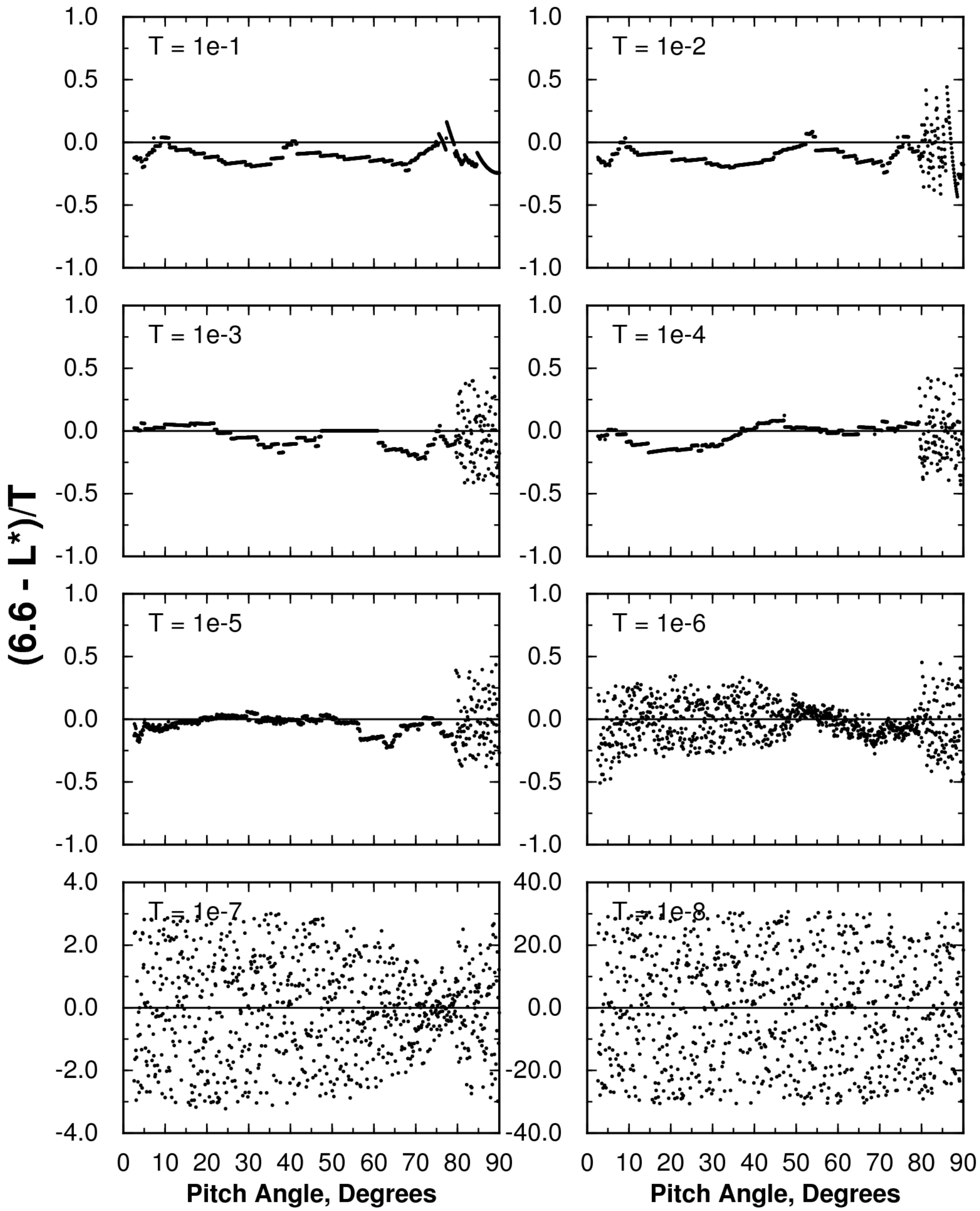
Options for Installation of Latest Version of DREAM at CCMC

- Another mode of operation that may be possible at CCMC could be to provide already-assimilated PSD output obtained from all of the current LANL GEO data sources. As noted earlier, none of the raw LANL GEO data has been available to the public since Jan 2008. Providing assimilated output may be an acceptable vehicle for releasing value-added output derived from this data.
- We will also transition the new code-base over to real-time operations within the coming year to facilitate real-time DREAM operations with RBSP data. (The RBSP/ECT SOC resides at LANL.)

On-going and future work

- Full integration of RAM-SCB, DREAM assimilation, and global MHD models. RAM-SCB is currently being coupled to SWMF. Magnetic fields will eventually couple back (1-way) to DREAM assimilation module.
- Extending the methods that we've demonstrated to other parts of the space environment such as the surface charging environment
- New physics models for acceleration, scattering, and loss. We are currently developing a 3D diffusion model (not yet integrated into an assimilative framework).
- Development of AE9 and a standard solar-cycle model as a baseline for forecasts and satellite design
  - Ongoing LANL/AFRL/NRO/Aerospace collaboration
- Visualization tools for SSA applications.

LanlGeoMag L Validation*



Difference between known and numerically computed values of L for a dipole field at 6.6 Re on the equator. (Other codes produce substantially biased results with this test.)*