Real-time Assimilative Modeling for the Earth's Radiation Belts Using DREAM

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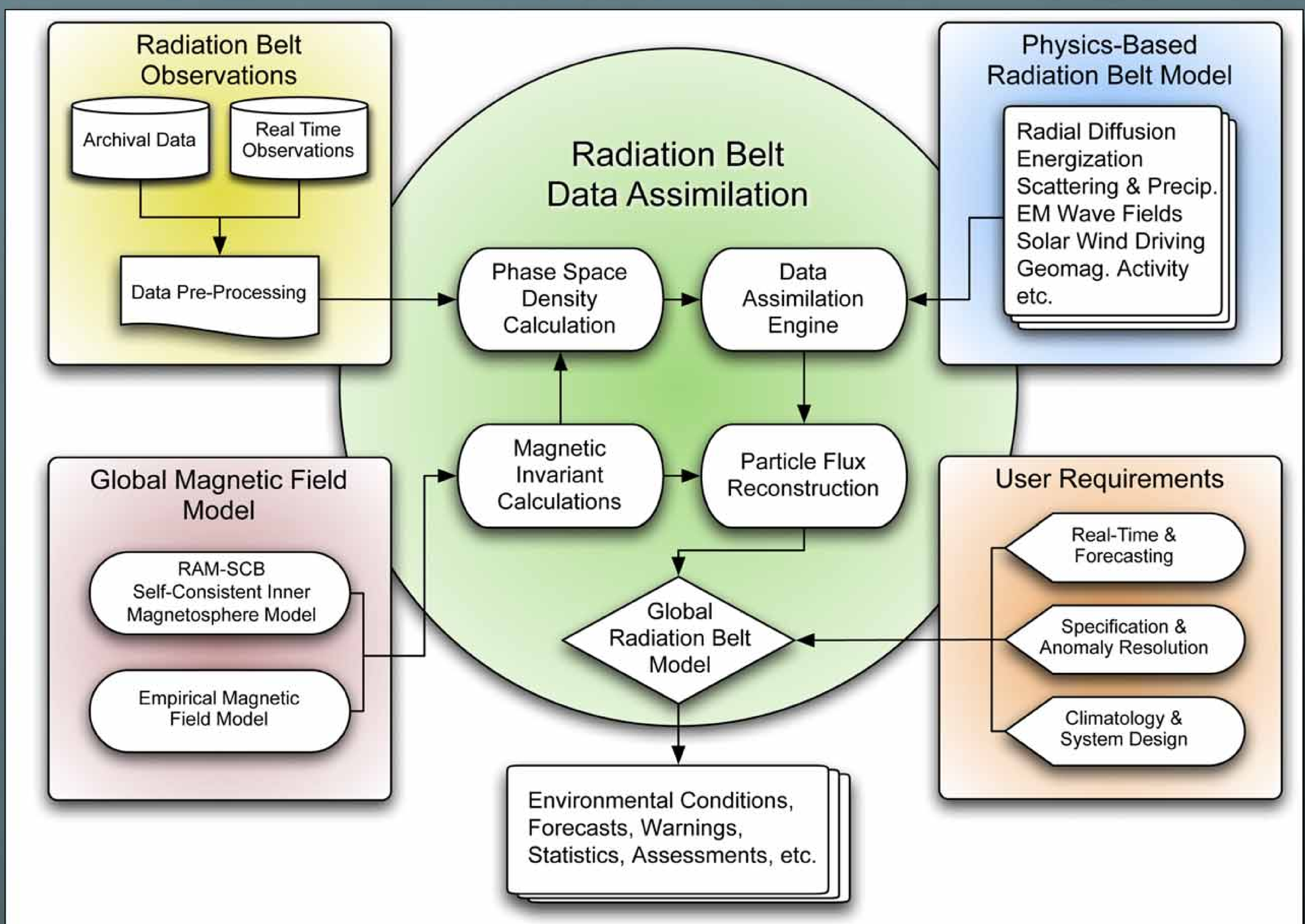
The Dynamic Radiation Environment Assimilation Model (DREAM) is a data-assimilative model of the Earth's radiation belts that has, until recently, been used primarily as a research tool to understand radiation belt dynamics and to develop Kalman filter techniques for application to magnetospheric modeling. More recently, the emphasis of the DREAM program has shifted toward implementation of a real-time operational prototype for testing and validation at the Air Force Research Laboratory's (AFRL) Space Weather Forecast Laboratory (SWFL) and NASA's Community Coordinated Modeling Center (CCMC). The transition has required significant effort, funding, and shifting of priorities that serve as a recent example of the opportunities and challenges of transitioning a model from research to operations (R2O).

DREAM is still in the early stages of transition to real-time operations but we do not see any significant obstacles to success.



DREAM consists of a variety of modules that allow flexibility, adaptability, and use of the model for a variety of purposes ranging from basic scientific discovery to real-time operational predictions.

The core of DREAM is an ensemble Kalman filter data assimilation module.

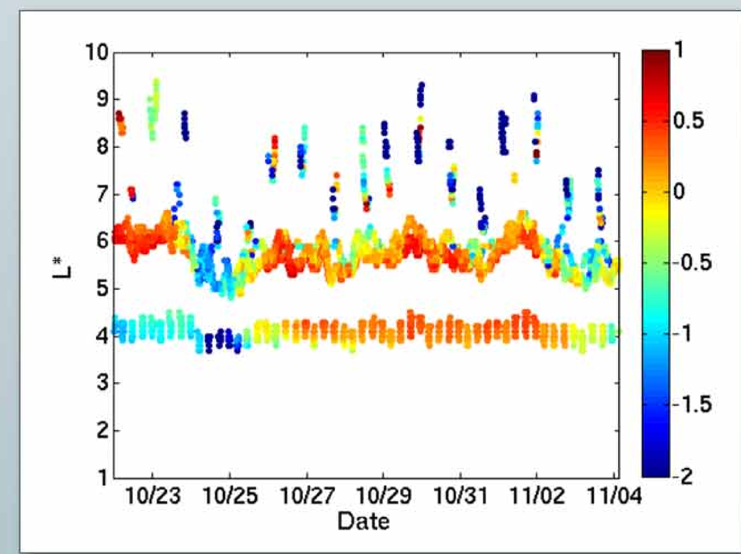
Both real-time and archival data can be assimilated. There are no inherent limits on the types of data, the number of satellites, or their orbits.

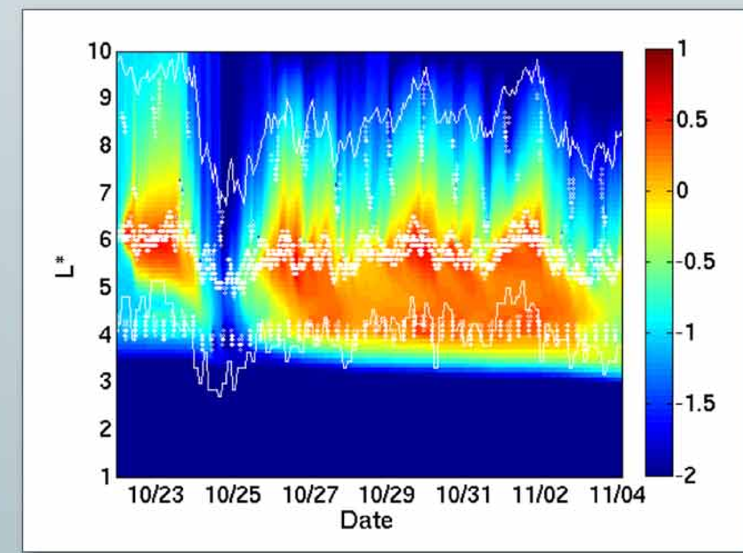
Fluxes must be converted to phase space density using magnetic invariants derived from global magnetic field models. An important component of DREAM is the RAM-SCB model but other field models can also be used.

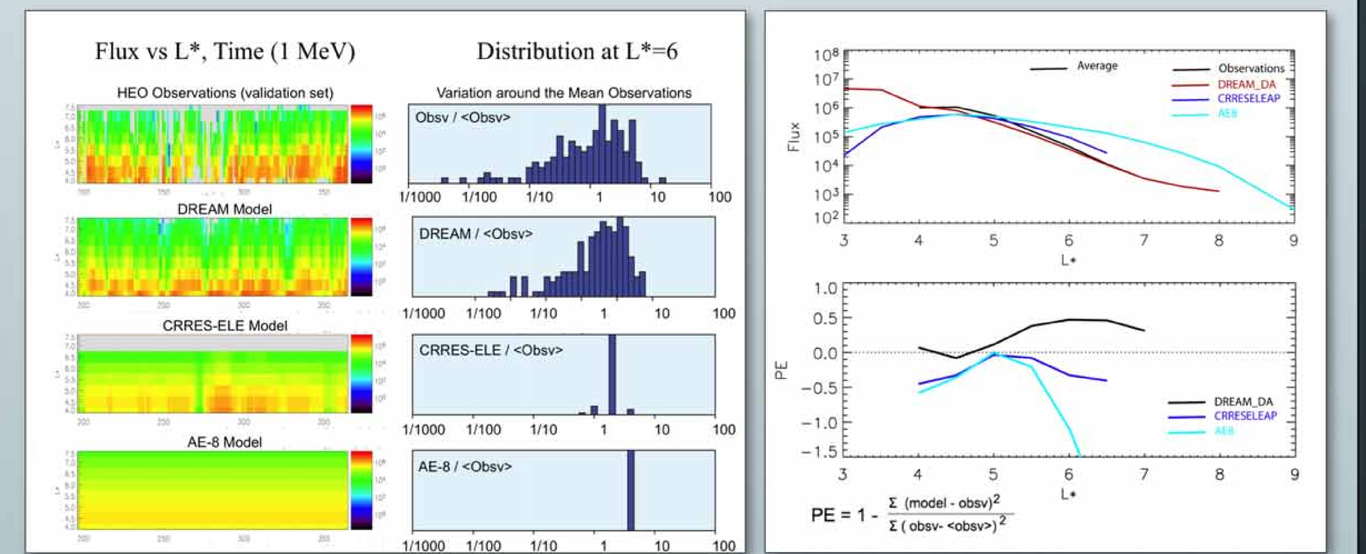
In data assimilation the data are not used as direct input or as boundary conditions. Rather, output is based on optimizing fidelity to both a physics model and the data (with uncertainties in both taken into account). Again, different physics models can be used for different applications.

DREAM output is a function of 3D spatial location, time, energy, and pitch angle. Therefore tools tailored to specific user requirements provide the most useful (and verifiable) space weather products.

DREAM: Research Applications and Model Validation







Step 1: Data Pre-Processing

- We convert flux to Phase Space Density at fixed magnetic invariants (μ, K, L*). The figure above shows PSD for K≈0 (e.g. near equatorial pitch angles) where data coverage is the most sparse.
- Research applications use all available data. This plot shows GPS, LANL/GEO and Polar data.
- Real Time applications typically have more limited data availability. Even data that is > 1 day old will still affect real time nowcast solutions though.
- DREAM will be able to assimilate RBSP data from the real time space weather broadcast or from the full research data sets

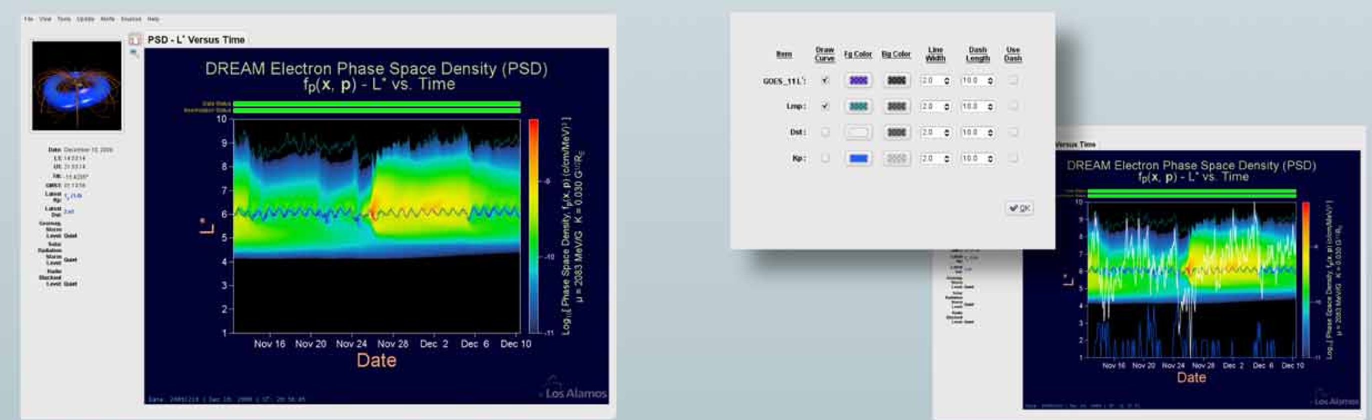
Step 2: Data Assimilation

- DREAM can use physics models of varying complexity. This plot shows a simple model described below. (White dots show data locations.)
- Boundaries: Plasmapause given by Kp-dependent Carpenter formula. The last closed drift shell (in L*) defines the outer boundary.
- Transport: Simple 1D diffusion. Assimilated data produce both inward and outward diffusion of either high or low phase space densities.
- Acceleration: We add a PSD source term that produces the same effects as acceleration but with amplitudes that are derived from data assimilation.
- Losses are specified differently in three regions. Fixed (10 day) loss inside the plasmasphere. Fast (~1 hr to 1 day) losses outside last closed drift shell. Kp-dependent losses between those boundaries.

Validation

- We have done extensive validation of DREAM using multi-satellite data assimilation
- Validation is done by comparing DREAM outputs to observations from satellites that (a) are not used as input data sets and (b) are in different orbits from the input satellites
- The plots above use GEO and GPS as input to DREAM. The validation data set is from HEO.
- The left plot shows that DREAM captures much of the intensity, structure, and dynamics of the radiation belts. We also show the distribution of fluxes at L*=6 normalized to the average observed flux. Both DREAM and the validation set show fluxes up to 10 times the average value and down to <0.01 of the average. The CRRES-ELE model shows little variation but nearly the right average value for this L* and validation period (2002). AE-8 is static so there is no variation but the average for this L* and validation period does not match the average observations.
- The right figures show validation metrics as a function of L*.
- DREAM reproduces the average flux and shape for the radial flux profile. CRRES-ELE and AE-8 do not have the correct radial flux profile and therefore match observations at only one L.
- Prediction Efficiency measures ability to predict variation around the mean. PE = 0 is no better than using an average flux as prediction. PE = 1 is exact prediction. Predictive models must have PE ≥ 0 in order to have value for operational predictions.

DREAM: Real Time Alpha Version



What is in the 'alpha version'?

- This version is currently installed and running in real time at AFRL's Space Weather Forecast Laboratory (SWFL) and at LANL (see http://leadbelly.lanl.gov/DREAM/). It will be installed at NASA's Community Coordinated Modeling Center (CCMC) in the very near future.
- The alpha version uses only one real time data input: GOES data courtesy NOAA SwPC. This limits the valid prediction region to approximately L > 5. (Note also the effects of single satellite diurnal variation.)
- A GUI enables overplotting of near-real-time parameters (e.g. Dst, Kp), manipulation of color tables, selection of past time intervals, choice of assimilated data sets, etc.
- The alpha version calculates PSD for only one mu and one K. (a 1D simulation volume).

What will be in the beta version?

- Multiple mu and K values will enable calculation of flux, pitch angle distributions and energy spectra (a 3D simulation volume). This will enable direct validation against other data sets as described above.
- We will incorporate multi-satellite data assimilation. Multiple GEO satellites give accurate PSD gradients near geosynchronous orbit. Even though GPS data are not available real time, even data several days old improves the nowcast – especially at L < 5. GPS data with latencies < 1 hr are possible in future.

Conclusions

- DREAM applies data assimilation techniques that have been widely used in meteorology (and other fields) to the Earth's radiation belts
- Assimilation of data in physics-based models produces information that has significantly more spatial coverage, accuracy and utility than either the data or model alone
- DREAM has been extensively validated using multi-satellite data assimilation, and was found to capture much of the intensity, structure and dynamics of the radiation belts
- Following 3+ years of development and testing in a research environment, DREAM has recently been implemented for real-time space weather applications
- Real-time applications impose some constraints on DREAM:
  - Developing infrastructure to reliably deliver and process real time data
  - Developing code that can be run completely unattended
  - Enabling fast, autonomous restart/retrieval of previously-calculated values
  - Implementing customizable outputs specific to the user's application

DREAM is currently in the early stages of testing and validation in an operational real-time setting. We see however no significant obstacles in fully transitioning the code from research to real-time operations in the near future.

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