Low-Altitude Mapping of Ring Current and Radiation Belt Results

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DREAM: The Dynamic Radiation Environment Assimilation Model

• Developed by LANL to quantify risks from natural and nuclear belts
• Uses Kalman Filter, satellite observations, and physics model
• Couples ring current, magnetic field, and radiation belt models
• Goals: Specification, Prediction, Understanding
Why Data Assimilation?

Sparse and/or Heterogeneous Observations

Complex Physical System

Global, Real-Time Data-Driven Solution
DREAM Computational Framework

Radiation Belt Observations
- Archival Data
- Real Time Observations
  - Data Pre-Processing

Radiation Belt Data Assimilation
- Phase Space Density Calculation
- Data Assimilation Engine
- Magnetic Invariant Calculations
- Particle Flux Reconstruction

Physics-Based Radiation Belt Model
- Radial Diffusion
- Energization
- Scattering & Precipitation
- Solar Wind Driving
- Geomag. Activity...
- High Altitude Nuclear Explosion (HANE)

Global Magnetic Field Model
- RAM: Self-Consistent Inner Magnetosphere Model
- Empirical Magnetic Field Model

User Requirements
- Real-Time & Forecasting
- Specification & Anomaly Resolution
- Climatology & System Design

Environmental Conditions, Forecasts, Warnings, Statistics, Assessments, etc.
Flux vs $L^*$, Time (1 MeV)

- HEO Observations (validation set)
- DREAM Model
- CRRES-ELE Model
- AE-8 Model

Distribution at $L^* = 6$

- Observations
- DREAM
- CRRES-ELE
- AE-8
Validation 2: Average Flux vs Altitude
Validation 3: Prediction Efficiency
testing variation around the mean

\[ PE = 1 - \frac{\sum (\text{model} - \text{obsv})^2}{\sum (\text{obsv} - \langle \text{obsv} \rangle)^2} \]
Validation 4: Average absolute error

DREAM gives ~10x improvement

Cumulative Error

\[ \sum (|\text{model} - \text{obsv}|) \]
Connecting DREAM to LEO (and LEO to DREAM)

- LEO observations are critical: auroral, MeV electrons, MeV ions and NPOES instruments (post Nunn-McCurdy) are deficient
- LEO informs not only the local space weather conditions but also global models of surface charging, internal charging, dose, etc
- Extrapolating trapped particle models to LEO is challenging
The Opportunities and Challenges of LEO

- LEO is heavily populated and an important region to predict
- LEO satellites provide global coverage at high cadence
- LEO measures ionospheric input
- But, only a small fraction of particles reach LEO
- Field asymmetries such as the SSA
- Time and activity-dependent precipitation

$\alpha = 10^\circ, 20^\circ, 30^\circ$
POLAR and SAMPEX: 2 MeV electron flux
POLAR and SAMPEX on the same scale
The flux ratio varies from $0.1$ to $10^{-5}$ with Time, L, Activity.
POES: Ratio of precipitating/trapped flux can be better understood in physical context.
The RAM-SCB provide further information on coupling of trapped fluxes to LEO & the ionosphere.
RAM-SCB calculates EMIC & Whistler wave growth, amplitude, & wave-particle interactions

EMIC Wave Gain

EMIC Wave Amplitude

Plasmaspheric Electron Density
Precipitating 1 MeV electron and 100 keV ion fluxes as a function of L, LT, and time
RAM-SCB and the SW Modeling Framework

1-way coupling has been demonstrated
2-way is in development
Realistic calculation of ring current is the first step for calculation of Region 2 currents

- BATSRUS ~ zero Dst
- RAM-SCB - stronger RC than SWMF (BATSRUS+RCM)
- Including O+ implies fewer ions and weaker Dst
- E-field very strong in recovery phase – will change with shielding
- Tail current (> 6.6 $R_E$) not included (~ 30% of Dst?)
RAM-SCB equatorial B field is much lower and has more structure than SWMF

Artifacts at L<3.5 are due to imperfect model grid matching
Realistic calculation of ring current pressures and B produce very realistic R2 currents

- 3D equilibrium code calculates currents from pressure gradients and force-balanced B-field
- much sharper resolution (field line inter-distance increases toward Earth)
- SWMF – R-1 currents; very small R-2 currents no shielding
- RAM-SCB: R-2 currents at lower latitudes; some R-1 currents higher
DREAM at LEO: Conclusions

- Extrapolating global radiation belt models to LEO is complex.
- Assimilating LEO fluxes into a global model could produce large ($>10^3$) errors if not done properly.
- “Properly” means considering dependence on energy, local time, geomagnetic activity, magnetospheric regions…
- Local pitch angle information hugely helps understand different behavior in trapped, bounce-loss, & drift-loss cones.
- LEO measurements (if any) help more than just LEO satellites.