Data Assimilation for Prediction and Reanalysis of the Radiation Belts

Yuri Shprits[1,2]

Graduate students and postdoctoral scholars: Dmitri Subbotin[1], Marianne Daae[1], Ksenia Orlova[1], Kyung-Chan Kim[1], Binbin Ni[1], Xudong Gu[1], Adam Kellerman[1], Tatiana Podladchiva[2], Nikita Aseev[1], Irina Zhelavskaya[1]

Undergraduate students: Lois Frost, Aadit Patel, Adam Brown, Xin Wei, Brian Zhu, Lusine Kamikyan, David Meyer, Sharon Xu, Akshat Mahajan, Marco Perez-Guzman

Collaborators: Maria Spasojevic[3], Dmitri Kondrashov[1], Michael Ghil[1,5], Richard Horne[5]

[1]GFZ Potsdam and University of Potsdam

[2] Institute of Geophysics and Planetary Physics, UCLA, Los Angeles, CA

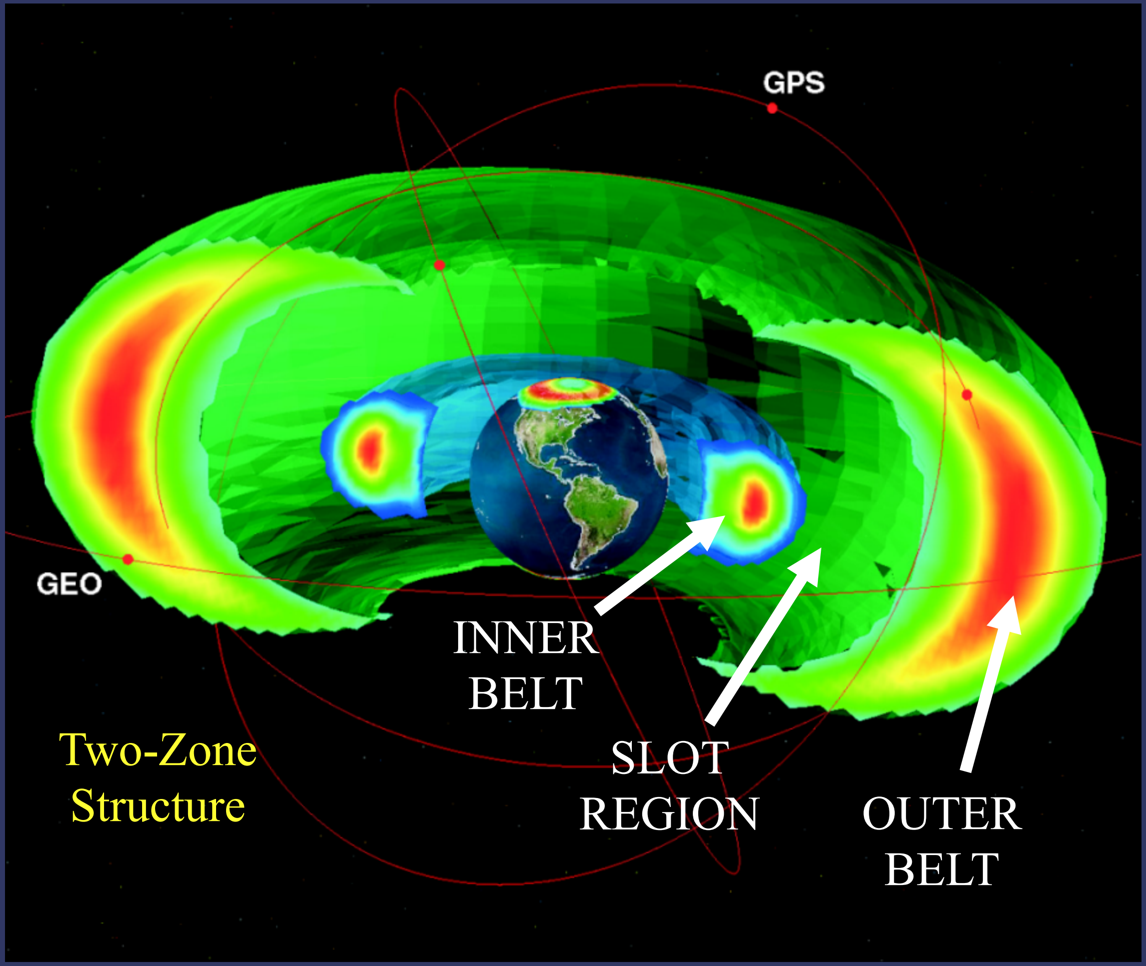
[3]EAPS, MIT, Cambridge, MA

[4] Stanford University, Stanford, CA

[5] École Normale Supérieure, Paris, France

[5] British Antarctic Survey, Cambridge, UK

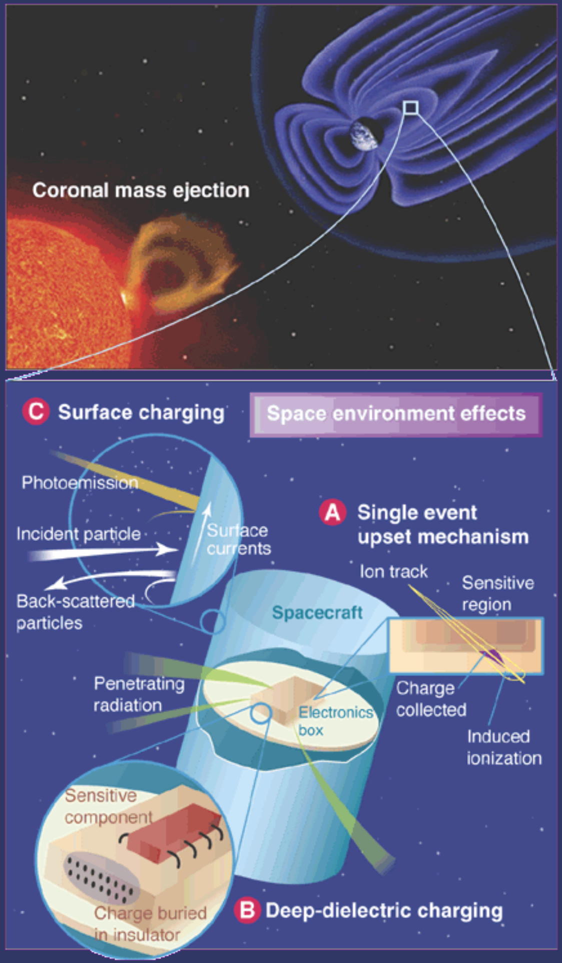
Radiation Belts – Two-Zone Structure



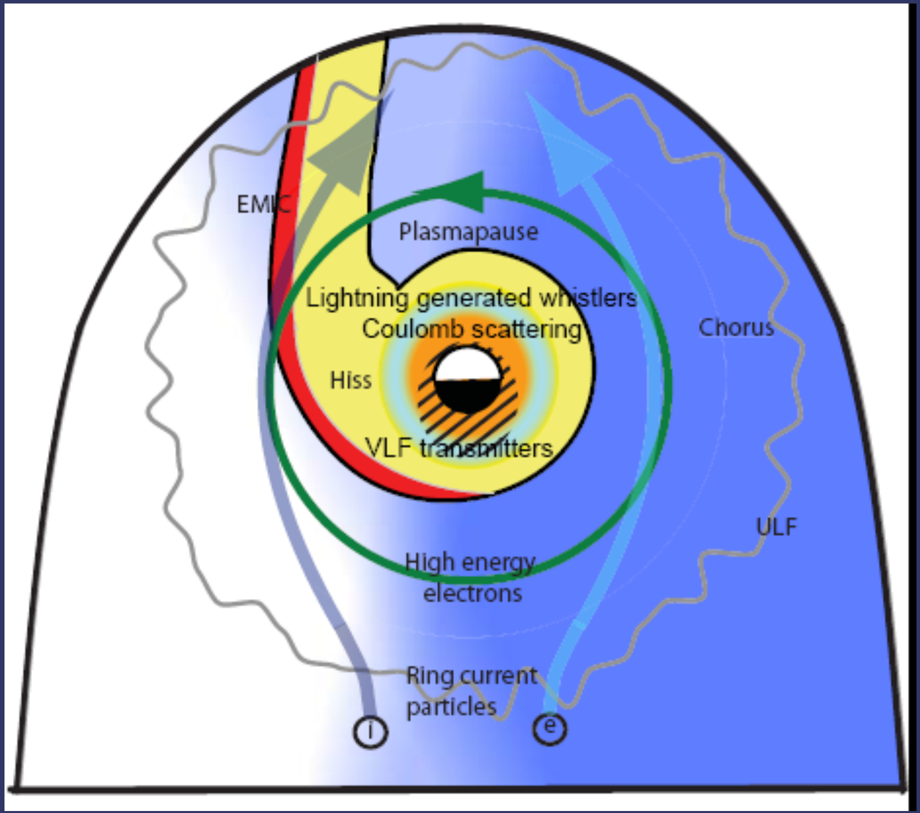
- Radiation belts – two donut-shaped regions of high radiation encompassing the Earth.
  - energies >100 keV
  - two-zone structure
- Inner belt: fairly stable.
- Outer belt: can change on the time scale of an hour.

Increased Interest in Ionizing Radiation

- Radiation is hazardous to satellite electronics & humans in space
- Miniaturizations of satellite electronics makes satellites more vulnerable than ever before.
- Electric orbit rising satellites spend a long time in heart of the belts.



Competition Between Acceleration and Loss



Inward radial diffusion driven by the ULF magnetic fluctuations.

Energy and pitch angle scattering due to resonance interactions with different waves.

Combined effect of losses to magnetopause and outward radial diffusion.

[Shprits et al., 2008; Review JASTP]

3D Fokker Planck Equation Including the Mixed Diffusion Terms

RADIAL DIFFUSION

$$\frac{\partial f}{\partial t} = L^{*2} \frac{\partial}{\partial L^*}\bigg|_{J_1,J_2} \frac{1}{L^{*2}} D_{L^*L^*} \frac{\partial f}{\partial L^*}\bigg|_{J_1,J_2} +$$

$$+\frac{1}{p^2}\frac{\partial}{\partial p}\bigg|_{L,\alpha_0} p^2 \left(D_{pp}\frac{\partial f}{\partial p}\bigg|_{L,\alpha_0} + D_{p\alpha_0}\frac{\partial f}{\partial \alpha_0}\bigg|_{L,p} \right) +$$

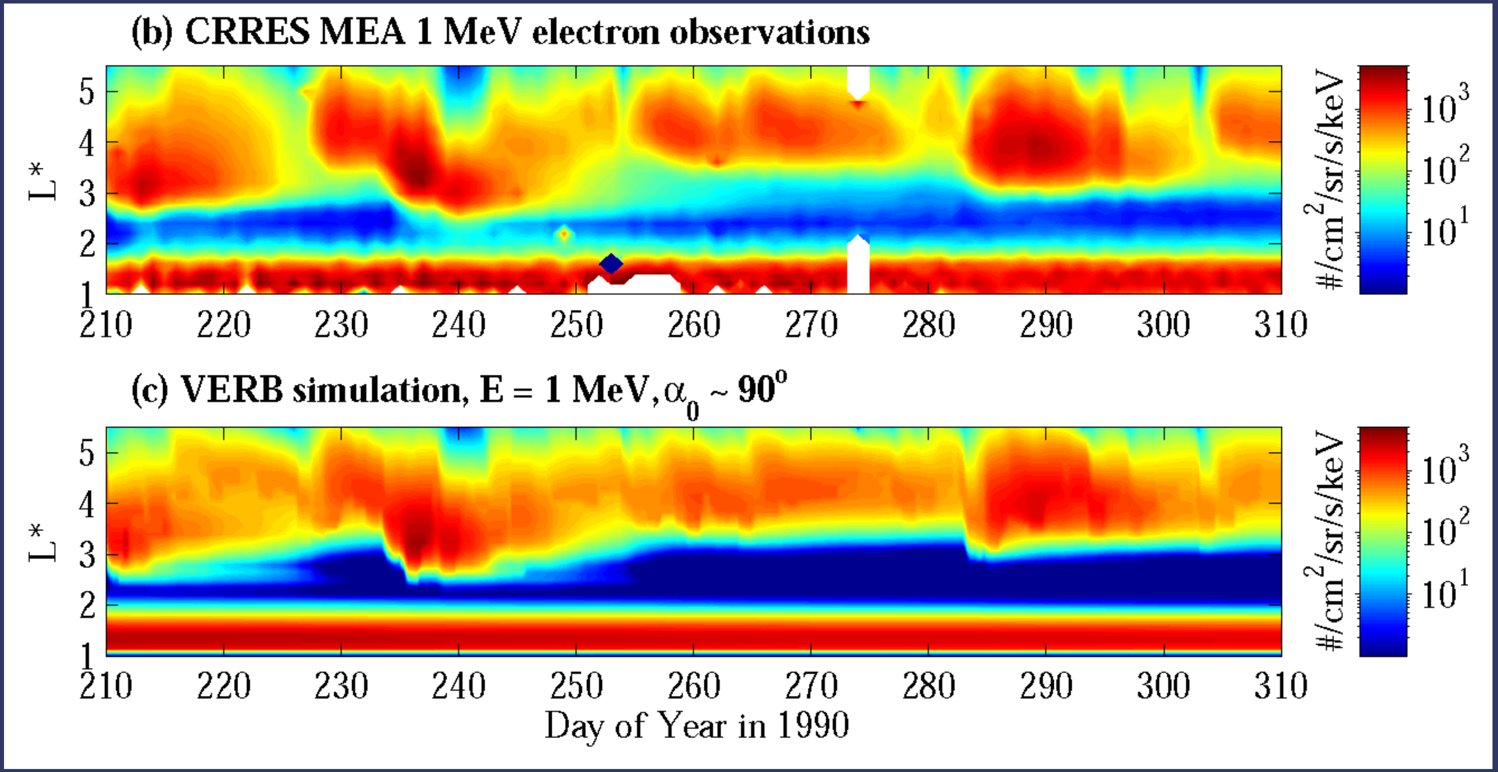
$$+\frac{1}{T(\alpha_0)\sin(2\alpha_0)}\frac{\partial}{\partial \alpha_0}\bigg|_{L,p} T(\alpha_0)\sin(2\alpha_0) \left(D_{\alpha_0 p}\frac{\partial f}{\partial p}\bigg|_{L,\alpha_0} + D_{\alpha_0\alpha_0}\frac{\partial f}{\partial \alpha_0}\bigg|_{L,p} \right) +$$

$$+Sources - Losses$$

PITCH ANGLE DIFFUSION RESULTS IN LOSS INTO THE ATMOSPHERE

ENERGY DIFFUSION RESIULTS IN LOCAL ACCELERATION

Validation of the Versatile Electron Radiation Belt (VERB) Code for Over 100 Days in 1990

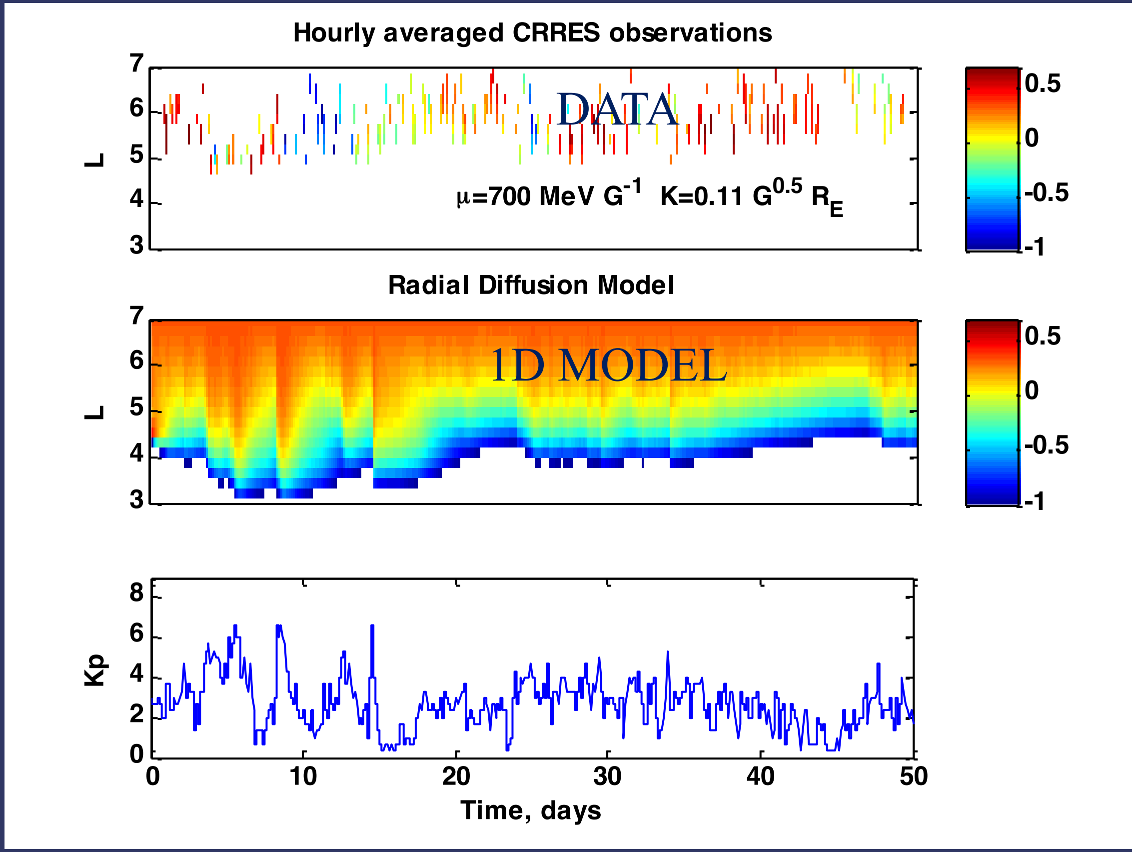


Boundary conditions from observations around GEO.

Radial diffusion, chorus and hiss waves are parameterized by Kp.

[Shprits et al., 2008; Kim et al., 2010]

Comparison of the Observations and the Radial Diffusion Model



Observations are sparse.

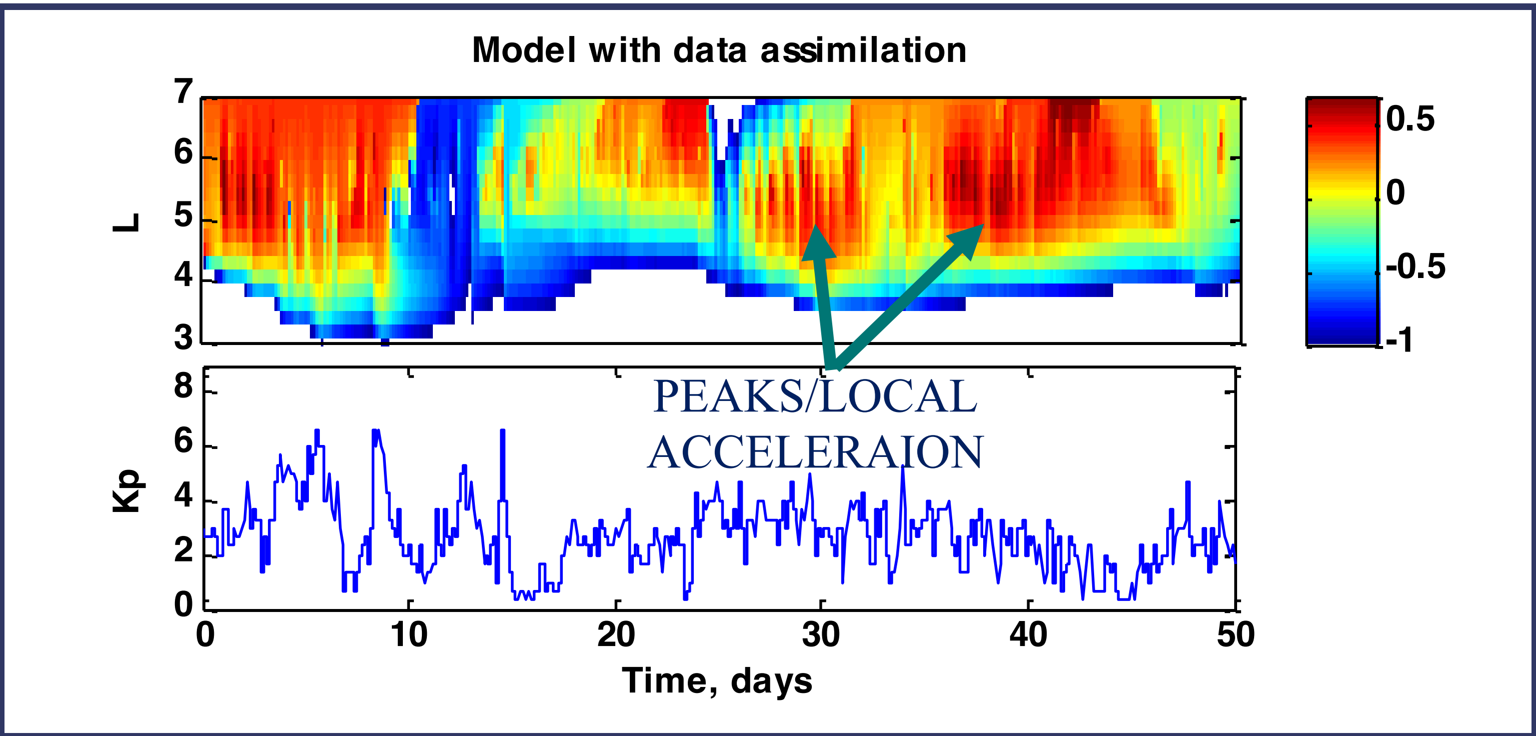
Model is continuous but may be missing essential physics .

L is approximately the distance from the Earth.

Kp is the index of geomagnetic activity.

[Shprits et al., 2007]

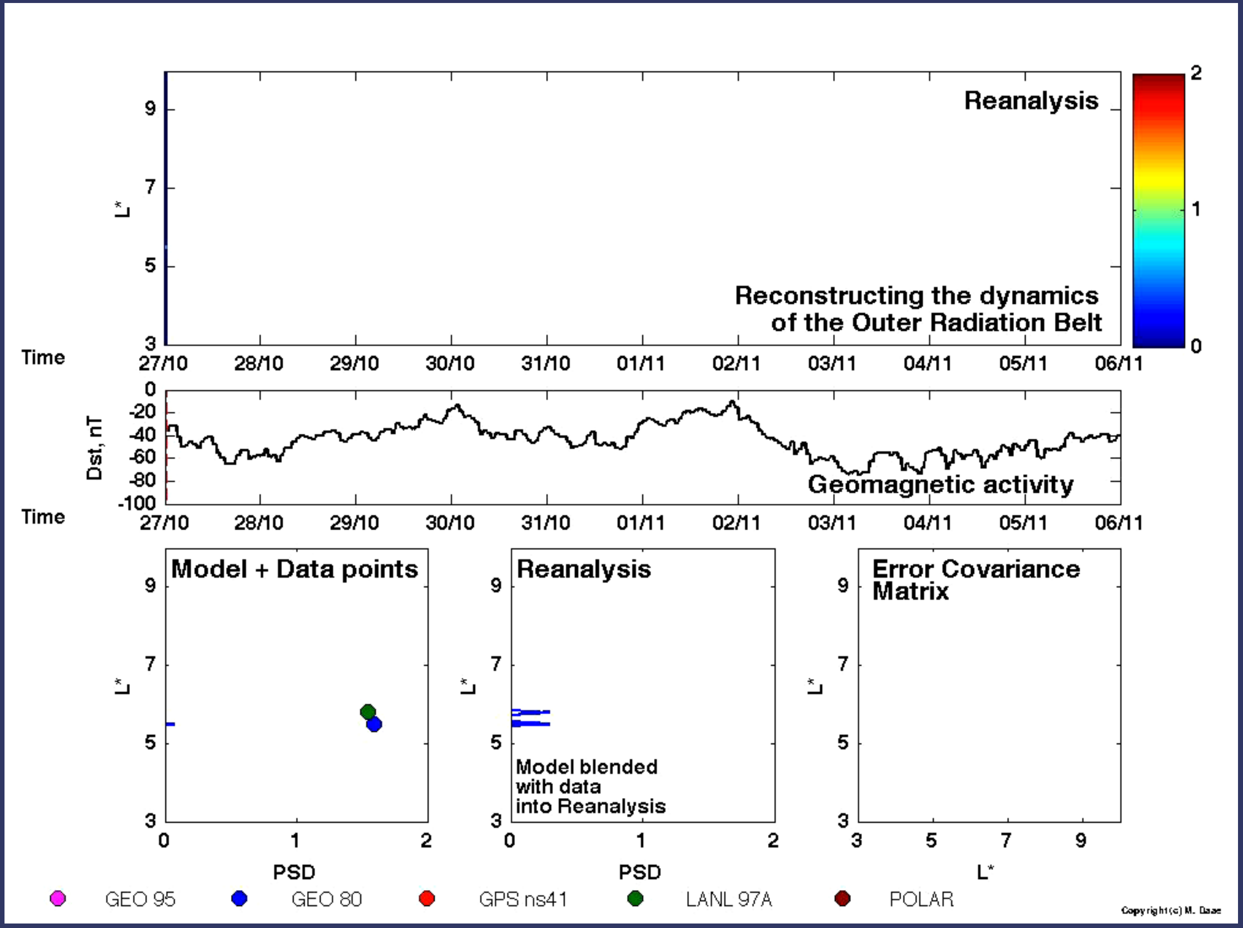
Data Assimilation/Peaks in Phase Space Density



Data assimilation can fill in spacio-temporal gaps.
Data assimilation shows building up peaks in Phase Space Density.

[Shprits et al. 2007]

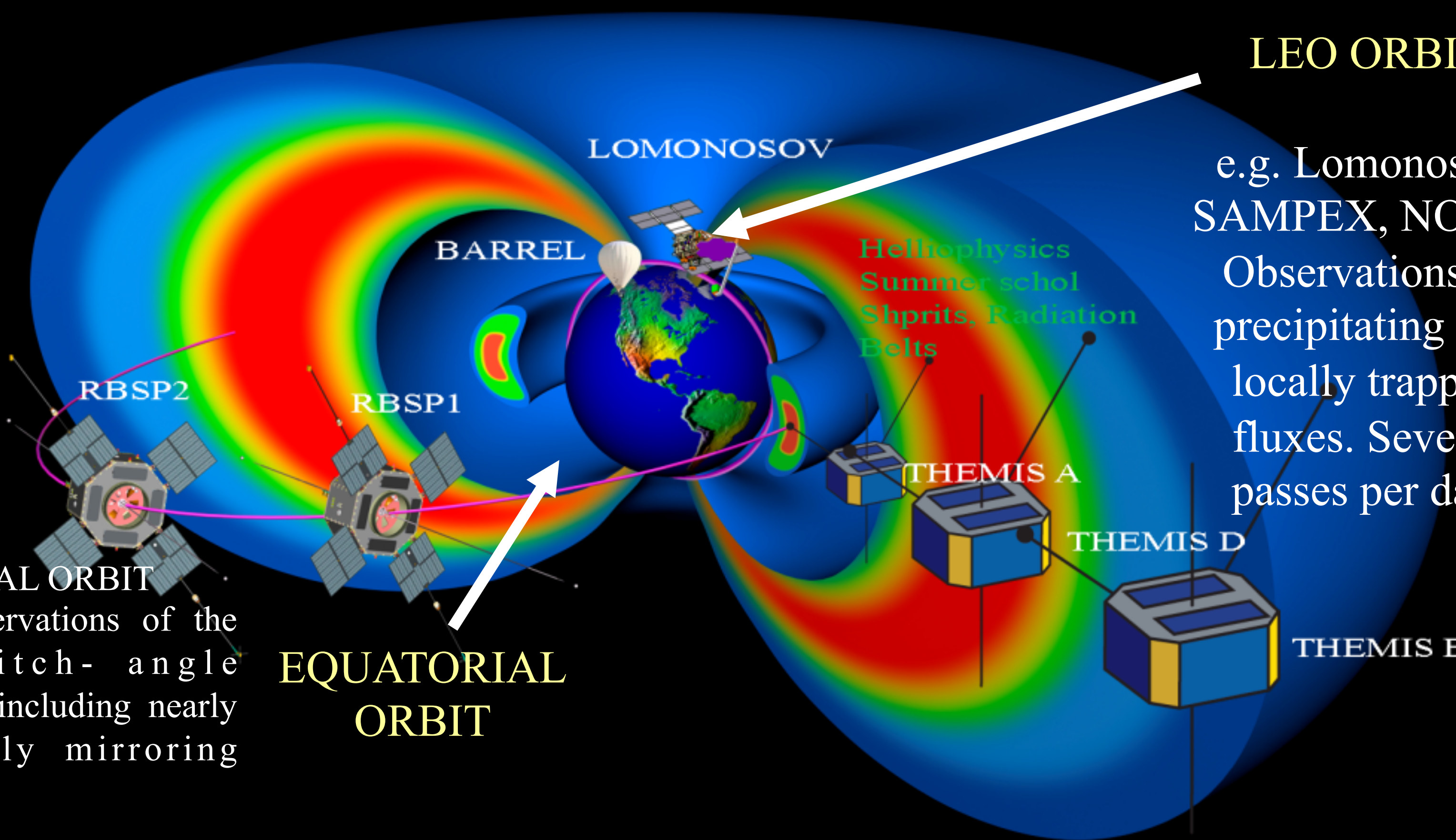
Data Assimilation



Data is blended with the model according to the underlying structure of data and model errors.

Data from 5 spacecraft is assimilated and radial profile of PSD is dynamically reconstructed.

Multi-Point Observations



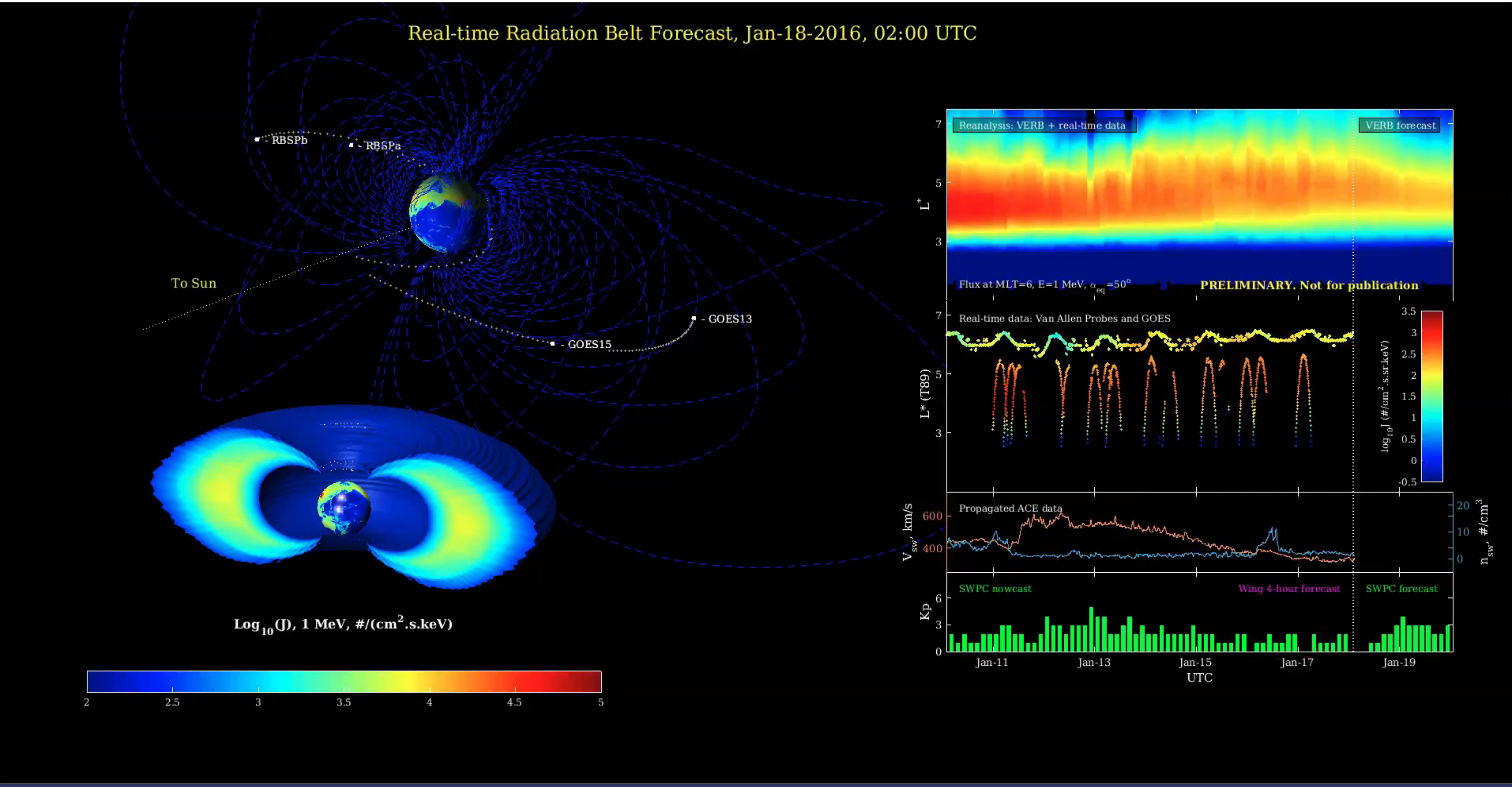
LEO ORBIT

e.g. Lomonosov, SAMPEX, NOAA. Observations of precipitating and locally trapped fluxes. Several passes per day.

EQUATORIAL ORBIT
Allows observations of the whole pitch- angle distribution including nearly equatorially mirroring particles.

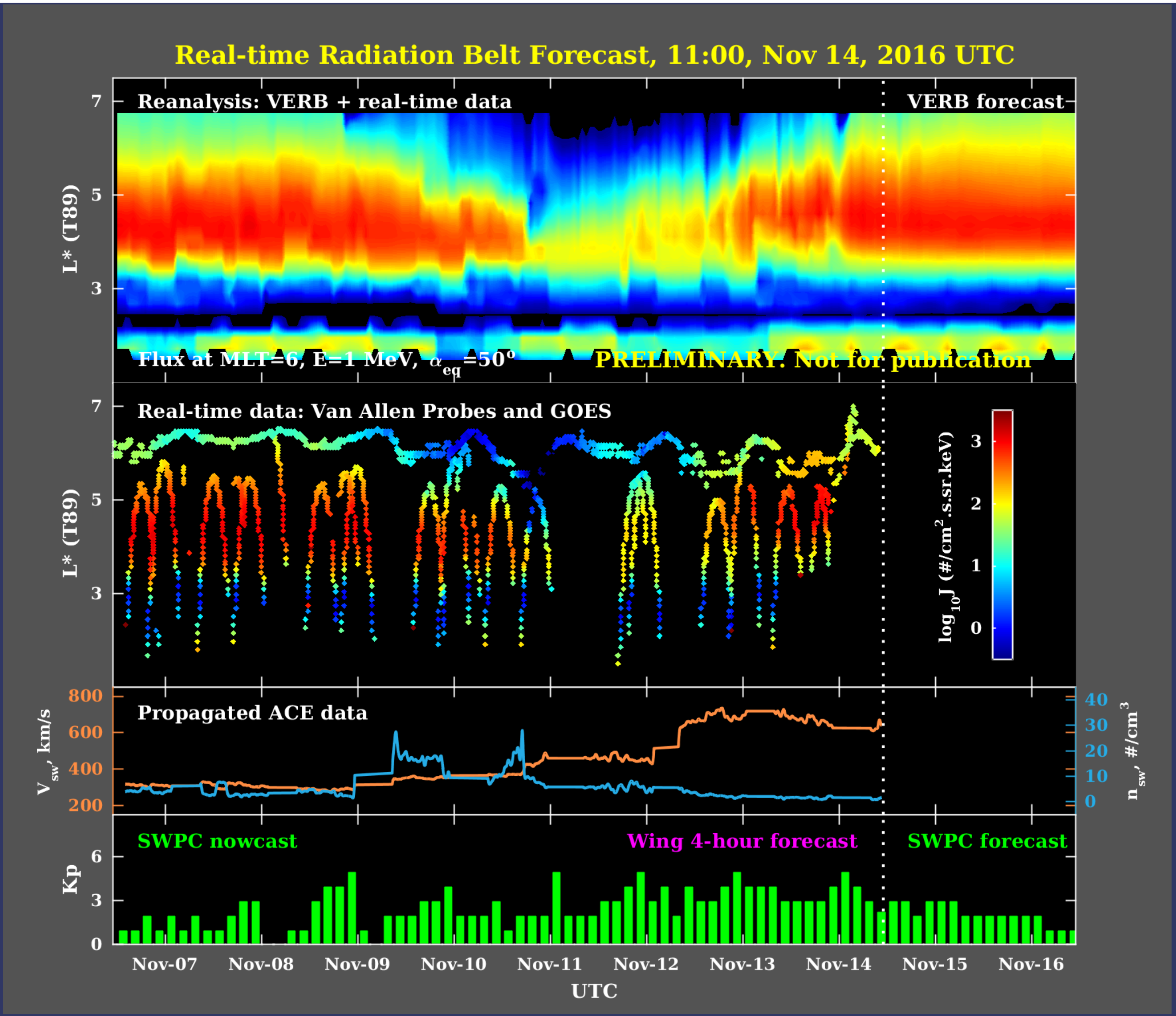
Radiation Belts Assimilative Forcast

Data from different satellites is blended with a physics-based model

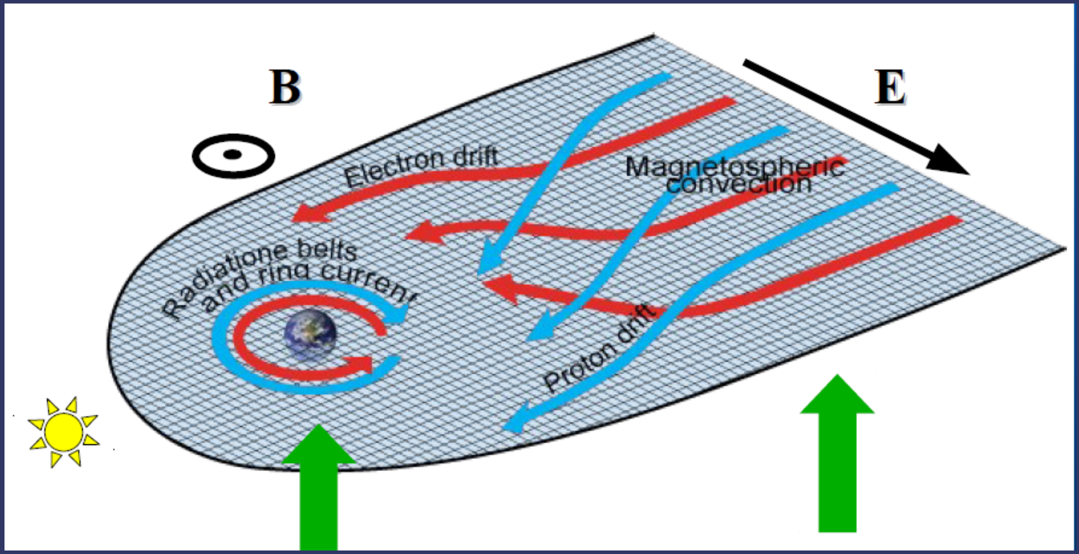


Radiation Belts Assimilative Forcast

http://rbm.epss.ucla.edu/realtime-forecast/



Particle Trajectories of Ring Current and Radiation Belt Particles



Stably trapped particles

Convection of the seed population of energetic electrons

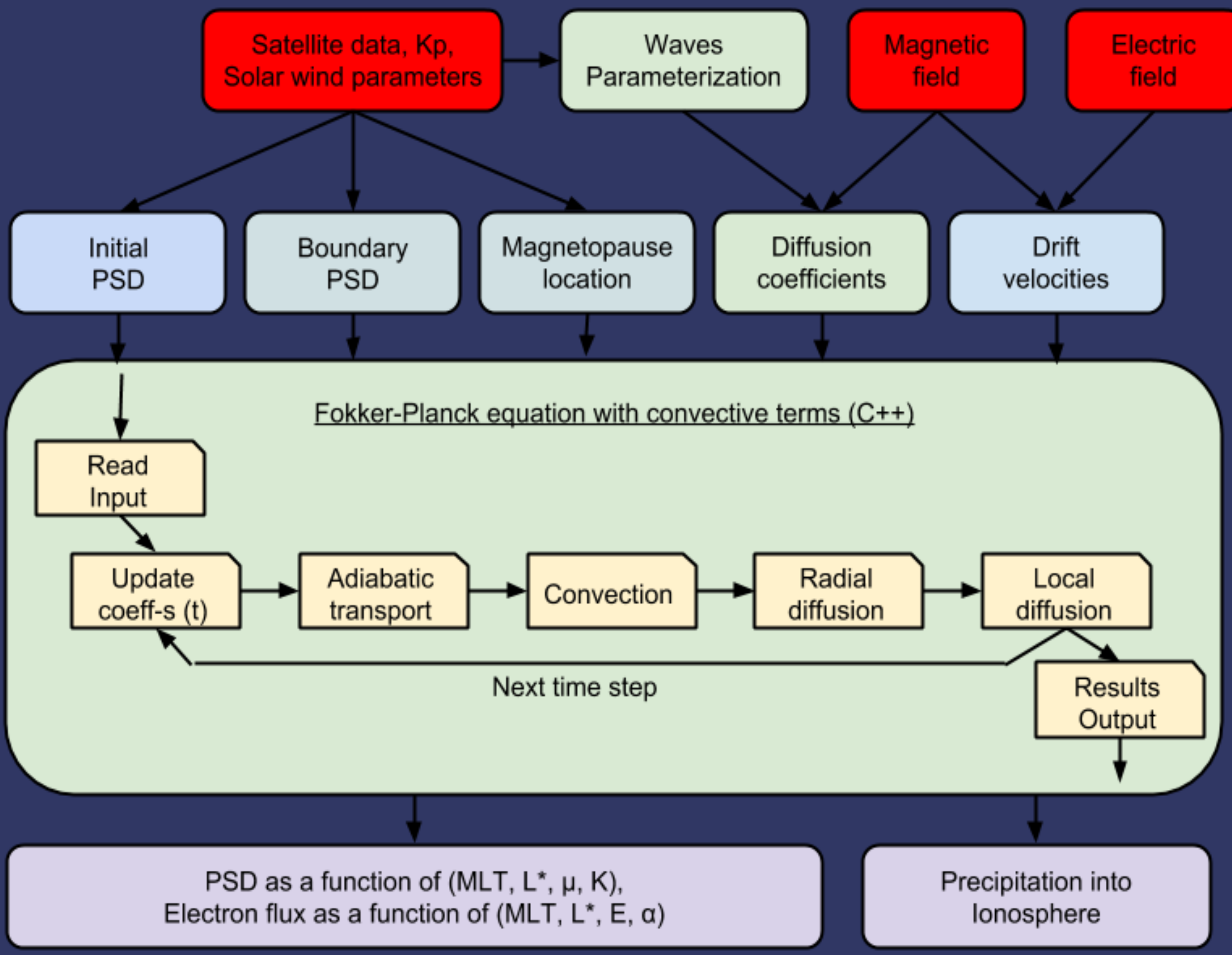
Drift of lower energy particles is dominated by ExB drift.

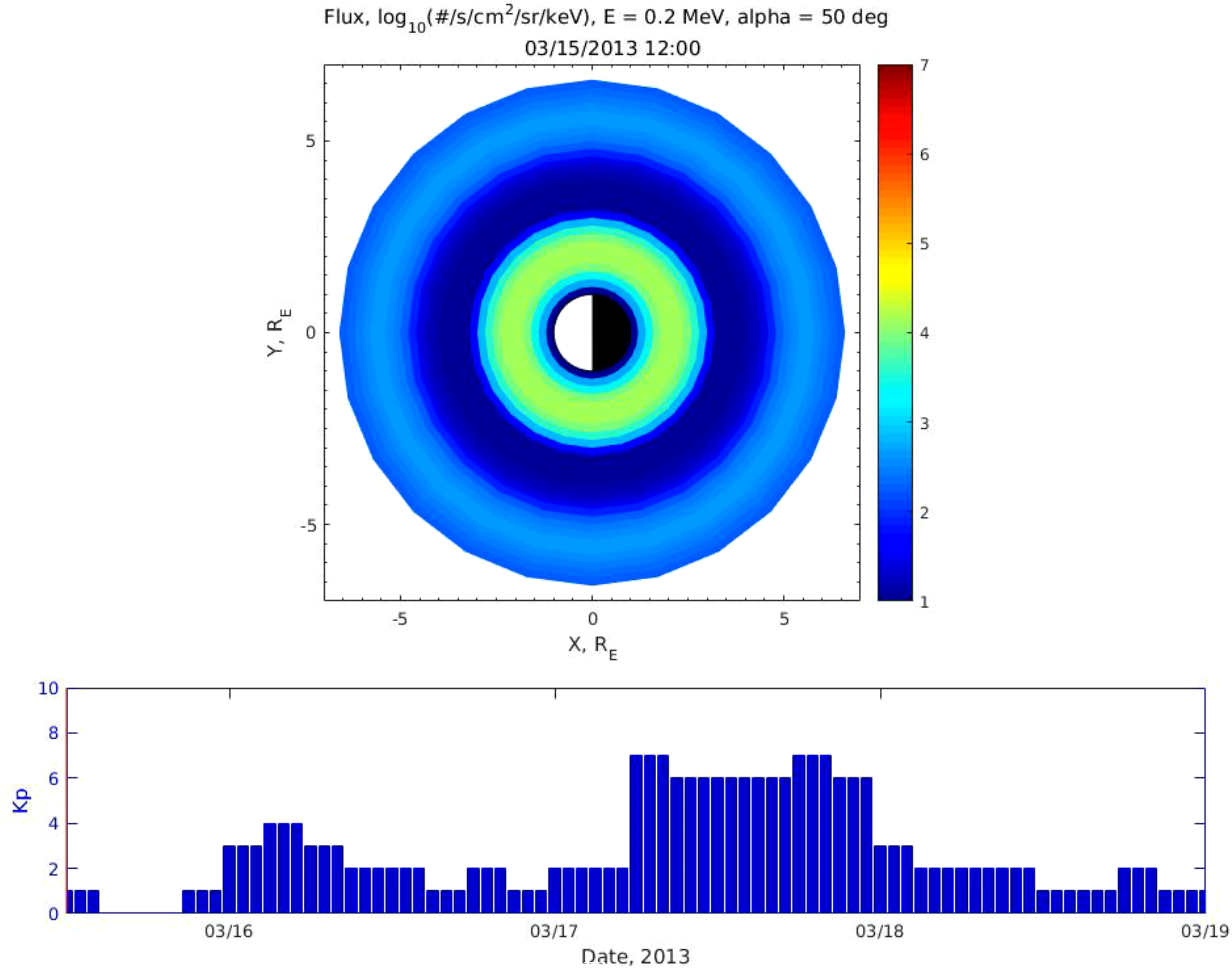
Radiation Belt particles are subject to the gradient and curvature drifts and will drift around the Earth.

Electrons –eastward,

Ions – westward.

Block Diagram Showing Data Exchange between the modules of the VERB 4D code




Flux, $\log_{10}$(#/s/cm^2/sr/keV), E = 0.2 MeV, alpha = 50 deg
03/15/2013 12:00
Y, R_E
X, R_E
5
0
-5
1
2
3
4
5
6
7
10
8
6
4
2
0
Kp
03/16
03/17
03/18
03/19
Date, 2013

PROGRESS

PRediction Of Geospace Radiation Enviroment and Solar wind parameterS

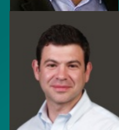
New EC Horizon 2020 funded project.

PARTICIPANTS

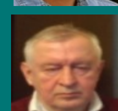
U. Sheffield


FMI

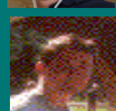

U.Warwick


GFZ/ U. of Potsdam


U. Michigan


SRI NASU


CNRS -LPC2E


IRF-L


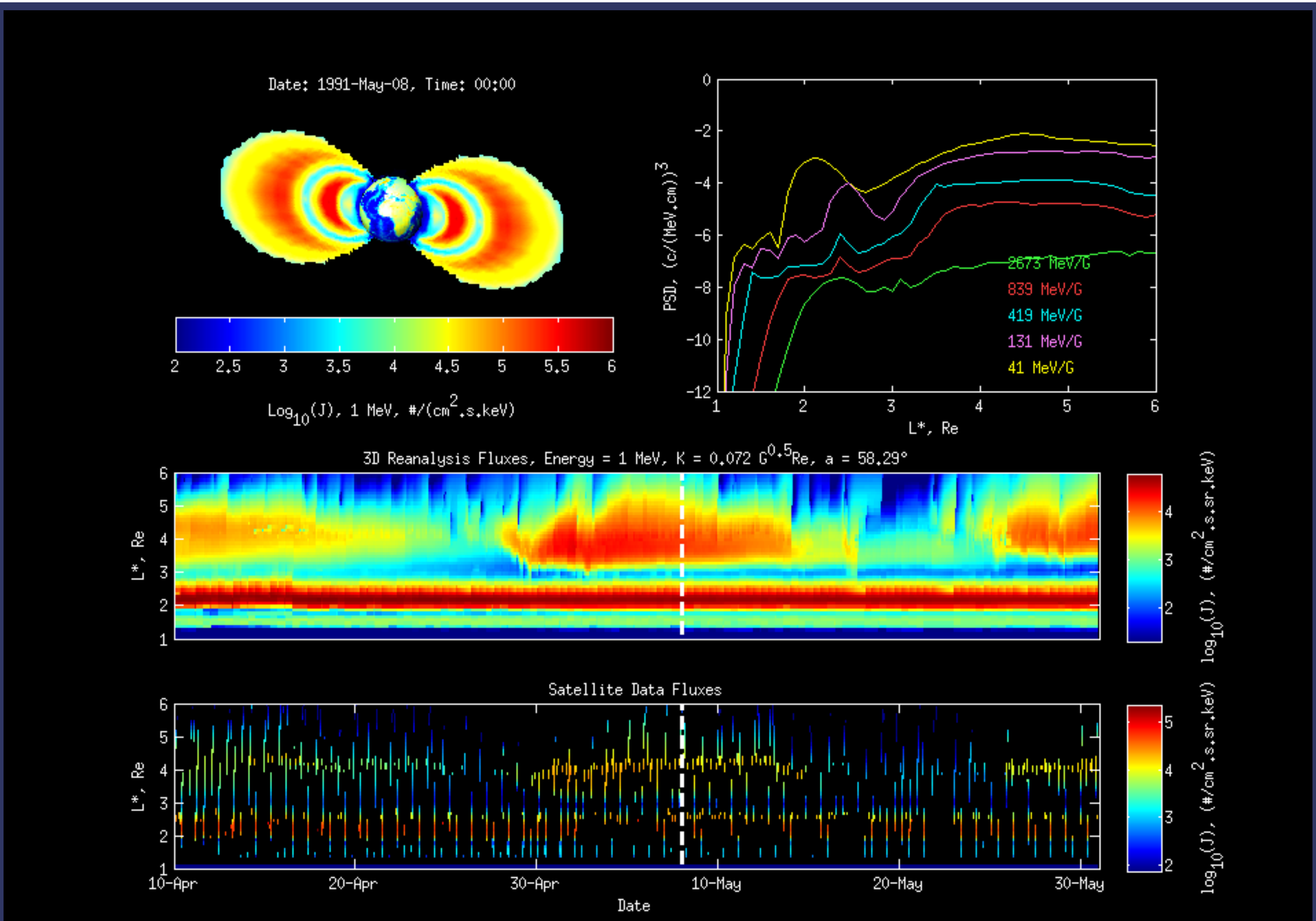
AIMS

- Development of a European Solar Wind model
- Models for the evolution of geomagnetic indices
- Statistical Wave models of wave activity
- Development and coupling of systems methodologies with physically based models
- Tools for robust, reliable forecasts for
  - geomagnetic indices
  - particle environment of the inner magnetosphere

Summary

- Data assimilation allows us to blend observations from various instruments on various spacecraft and allows us to accurately reconstruct the state of the radiation belts.
- Data assimilation will be curtial for space weather modeling, for combining data from the upcoming missions and developing models for forecasting, now casting and specification models.
- Data assimilation will significantly improve our ability to forecast the near-Earth radiation environment.
- Future work should include code coupling with neural networks, and validation of the newly developed VERB 4D that can model the entire inner magnetosphere.

Reconstruction of the State of the Radiation Belts Using 5 Spacecraft



Thank You