

# THE VERSATILE ELECTRON RADIATION BELT (VERB) CODE: OVERVIEW

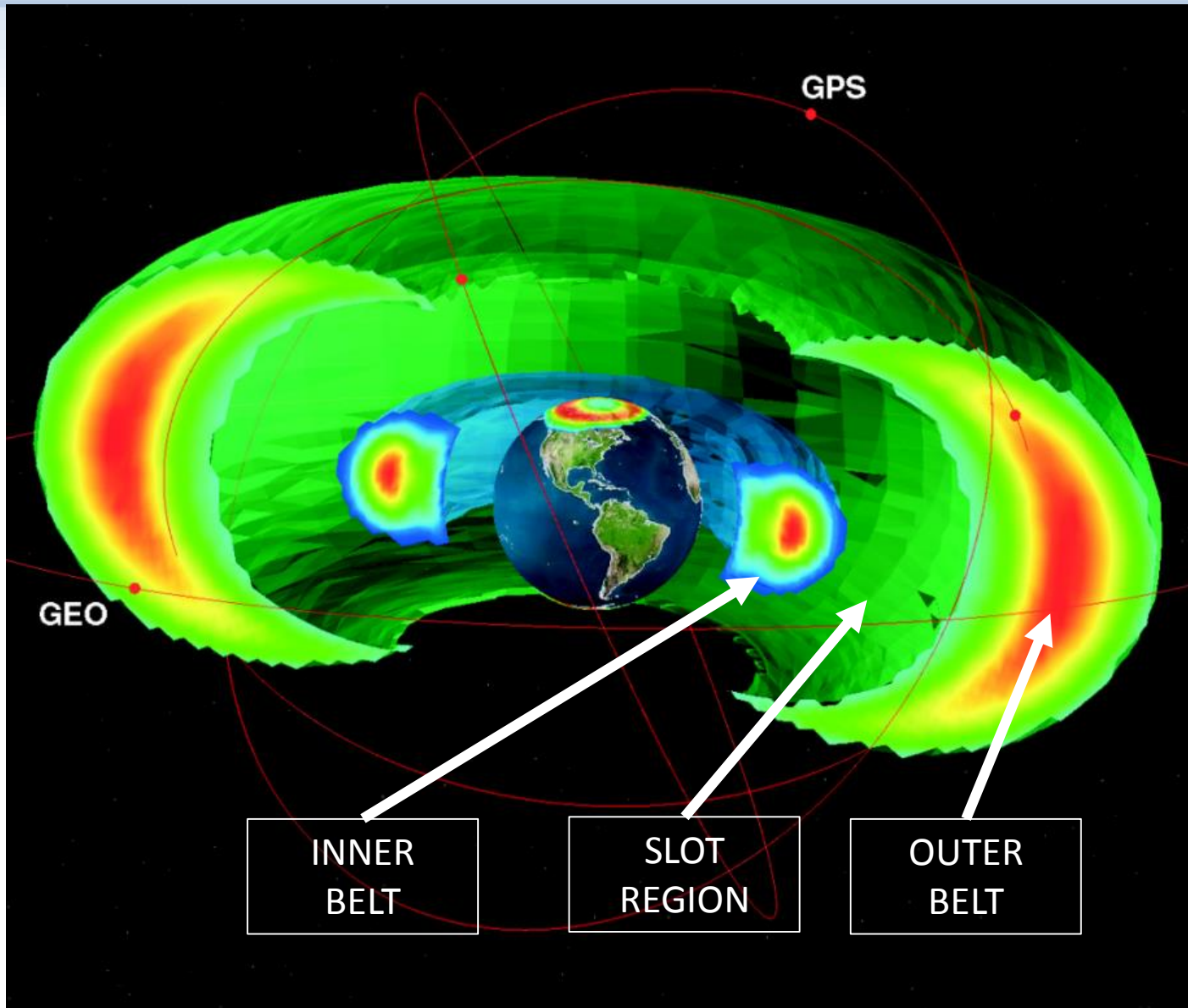
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1. University of California, Los Angeles, CA, USA
2. Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences Potsdam,  
Germany

## **Acknowledgments**

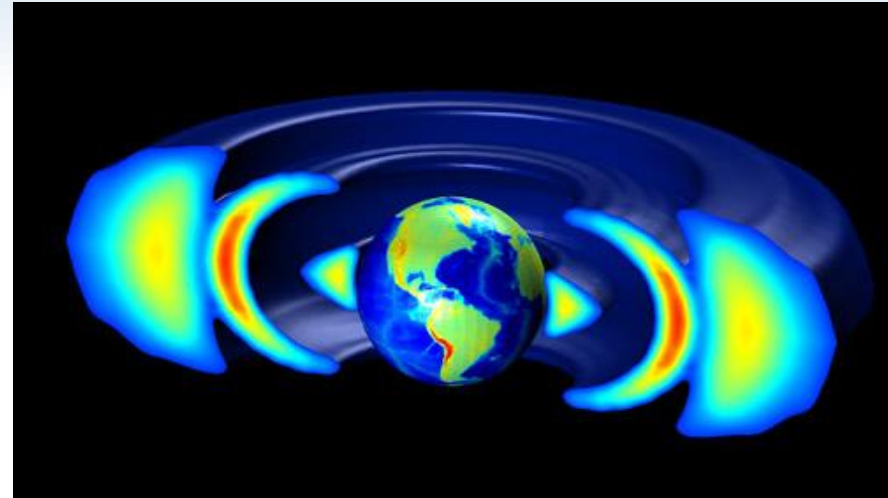
D. Subbotin, N. Aseev

# Radiation Belts



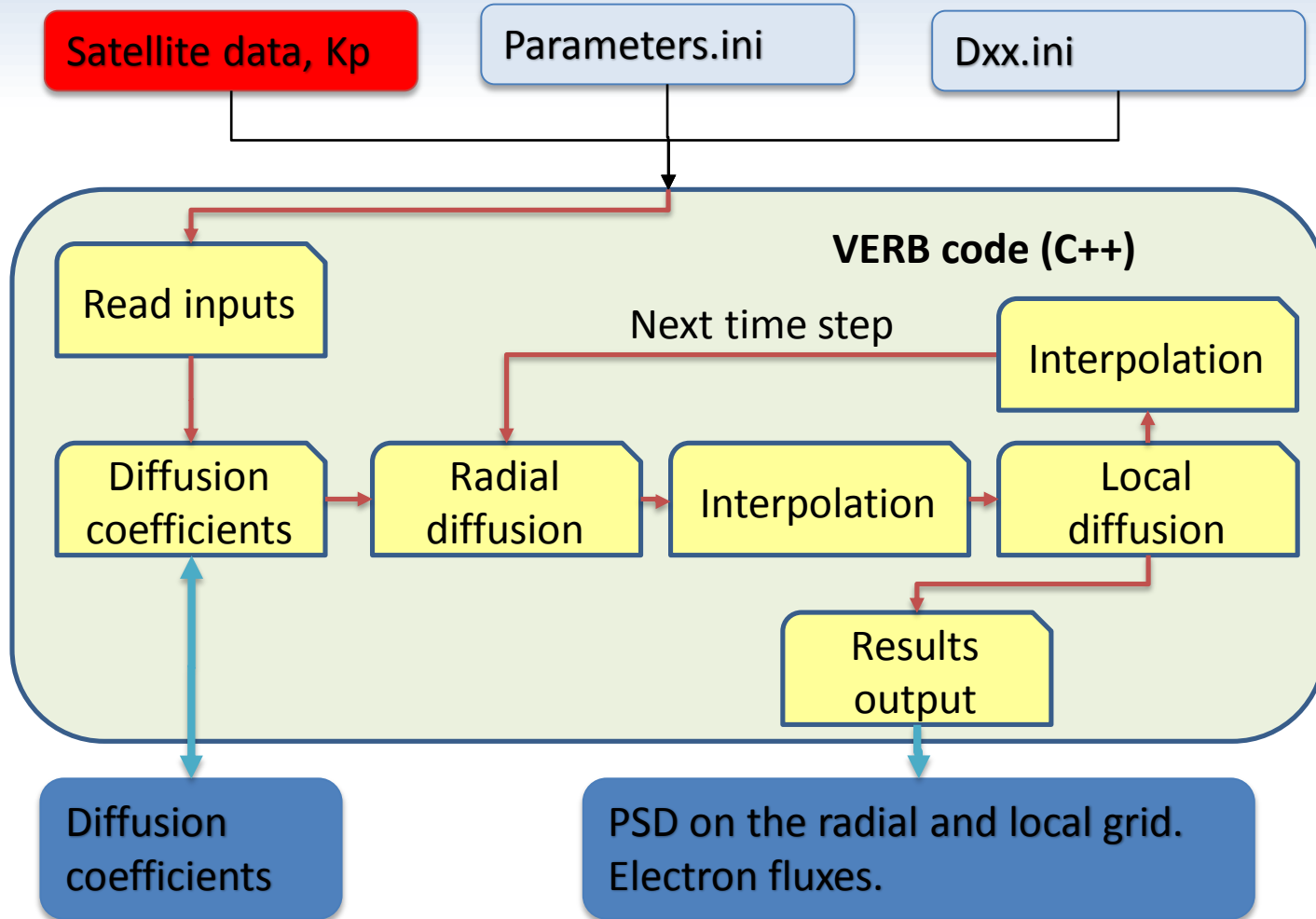
# VERB code

- The Versatile Electron Radiation Belt (VERB) code is designed to model the dynamics of the radiation belts.
- It includes various physical processes and can reproduce the dynamics of relativistic and ultrarelativistic electrons.
- 3D VERB code allows to obtain the dose at various orbits and can be used for deep dielectric charging calculation.
- The VERB code has been validated in the number of sensitivity tests, examples and long-term simulations during CREES and Van Allen Probes operation periods.



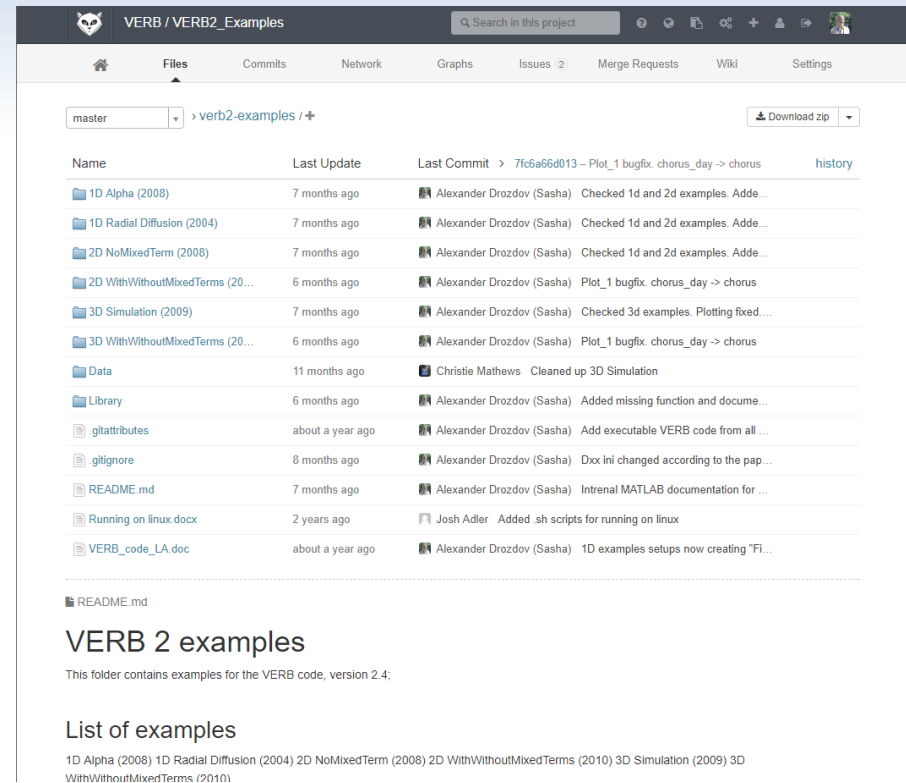
*Shprits et al., 2013*

# VERB code scheme



The VERB code uses an unconditionally stable, implicit scheme and the operator-splitting method to numerically solve the Fokker-Planck equation.

# The code development



The screenshot displays a Git repository interface for 'VERB / VERB2\_Examples'. The top navigation bar includes 'Files', 'Commits', 'Network', 'Graphs', 'Issues 2', 'Merge Requests', 'Wiki', and 'Settings'. The current view is 'Files' for the 'master' branch, showing a directory structure under 'verb2-examples / +'. A table lists files and folders with columns for Name, Last Update, and Last Commit. Below the table, the 'README.md' file is expanded, showing the text 'VERB 2 examples' and 'This folder contains examples for the VERB code, version 2.4;'. A 'List of examples' section follows, listing files like '1D Alpha (2008)', '1D Radial Diffusion (2004)', etc.

Name	Last Update	Last Commit
1D Alpha (2008)	7 months ago	Alexander Drozdov (Sasha)
1D Radial Diffusion (2004)	7 months ago	Alexander Drozdov (Sasha)
2D NoMixedTerm (2008)	7 months ago	Alexander Drozdov (Sasha)
2D WithWithoutMixedTerms (2010)	6 months ago	Alexander Drozdov (Sasha)
3D Simulation (2009)	7 months ago	Alexander Drozdov (Sasha)
3D WithWithoutMixedTerms (2010)	6 months ago	Alexander Drozdov (Sasha)
Data	11 months ago	Christie Mathews
Library	6 months ago	Alexander Drozdov (Sasha)
gitattributes	about a year ago	Alexander Drozdov (Sasha)
gitignore	8 months ago	Alexander Drozdov (Sasha)
README.md	7 months ago	Alexander Drozdov (Sasha)
Running on linux.docx	2 years ago	Josh Adler
VERB_code_LA.doc	about a year ago	Alexander Drozdov (Sasha)

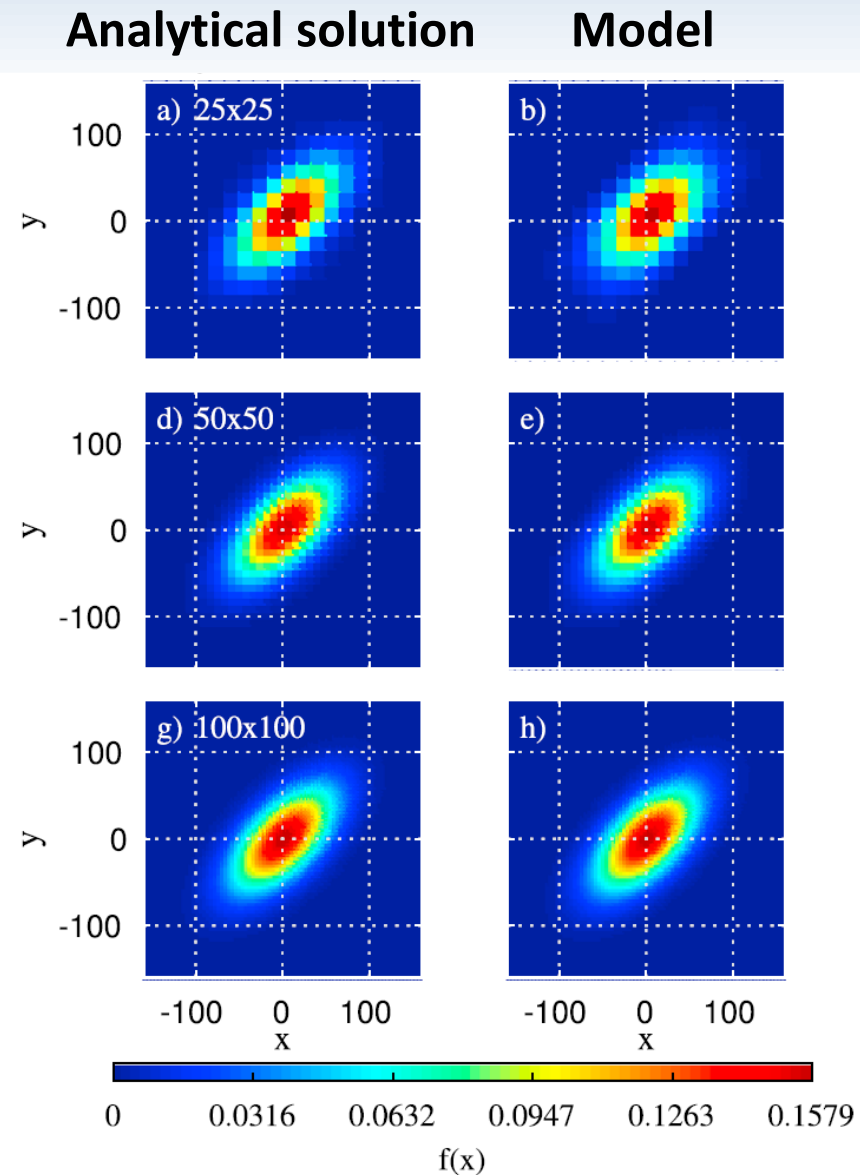
**VERB 2 examples**  
This folder contains examples for the VERB code, version 2.4;

**List of examples**  
1D Alpha (2008) 1D Radial Diffusion (2004) 2D NoMixedTerm (2008) 2D WithWithoutMixedTerms (2010) 3D Simulation (2009) 3D WithWithoutMixedTerms (2010)

- **The VERB code has been developed using git and svn version control systems. The tests, examples and supporting libraries are also under version control.**
- **The VERB code is cross-platformed and can be compiled for Windows, MAC and Linux systems using cmake built system.**
- **The code can be executed on the multiprocessor clusters.**

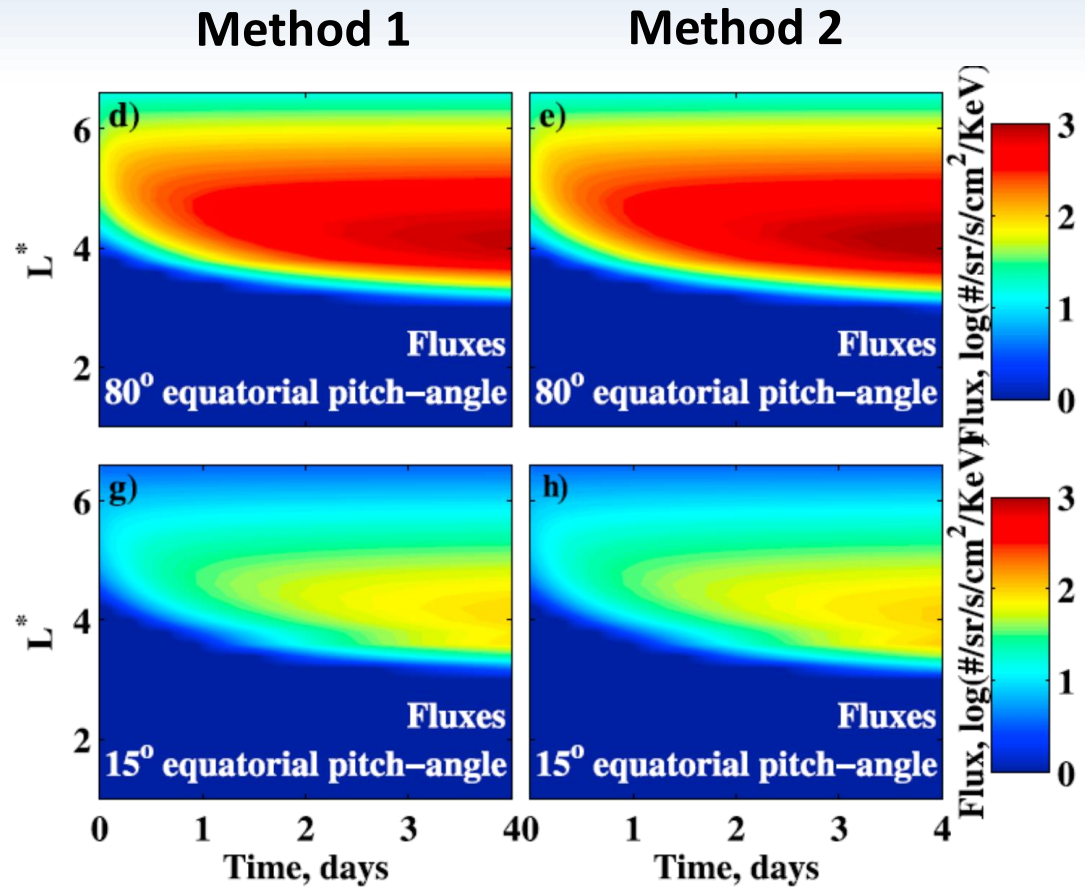
# Verification

The comparison shows that the VERB code numerical solution of the two-dimensional diffusion equation with mixed terms converges to the analytical solution.



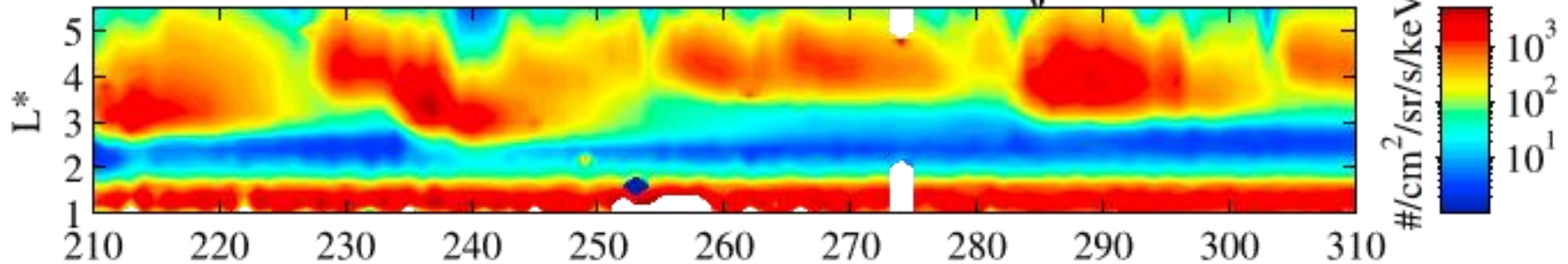
# Verification

The comparison of the simulations with two-grid method (Method 1) and new single-grid methods (Method 2) produce similar result.

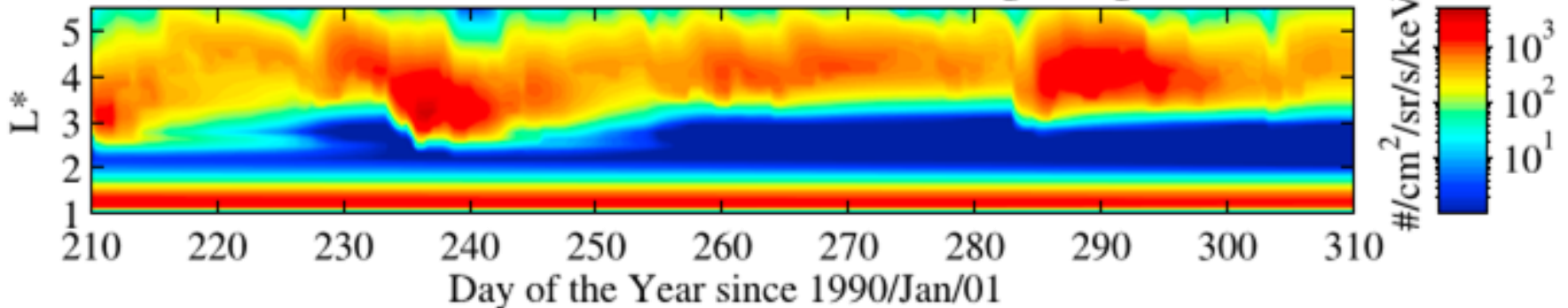


# Validation

(a) CRRES MEA electron observations,  $E = 1 \text{ MeV}$ ,  $\alpha_0 \sim 90^\circ$



(e) VERB simulation with radial + chorus + hiss + lightning + VLFs

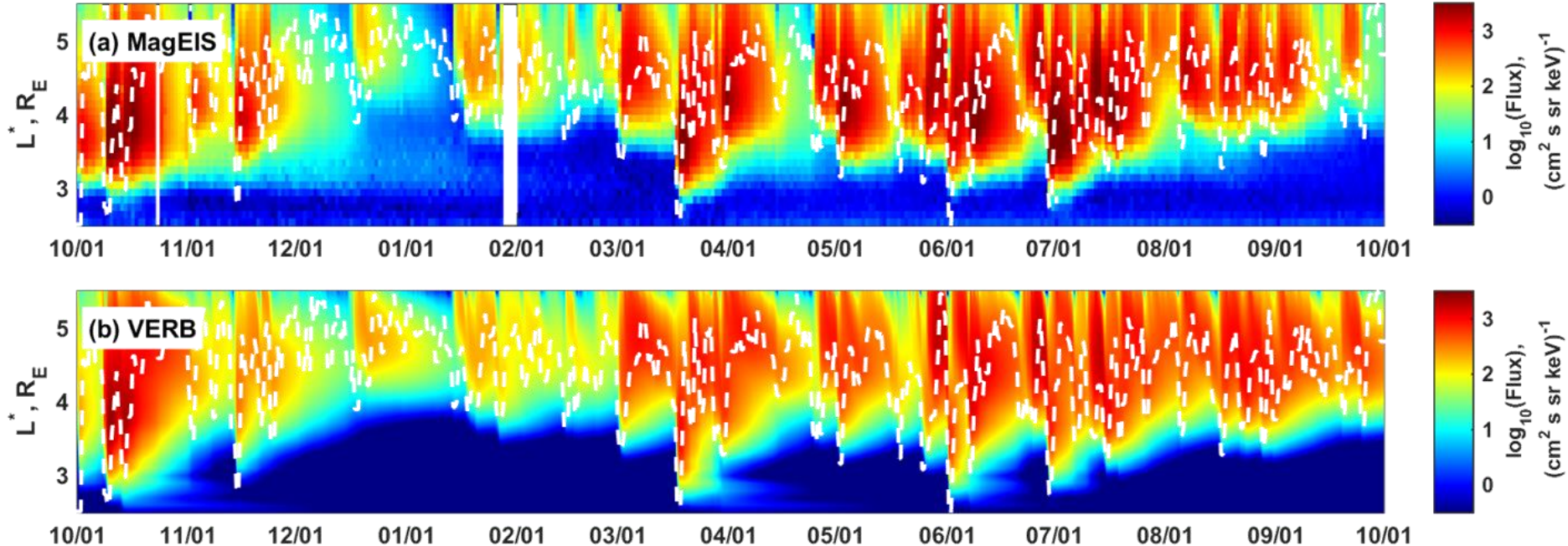


The comprehensive 100-day VERB code simulations provide a qualitative agreement with the observations during the CREES period.



# Validation

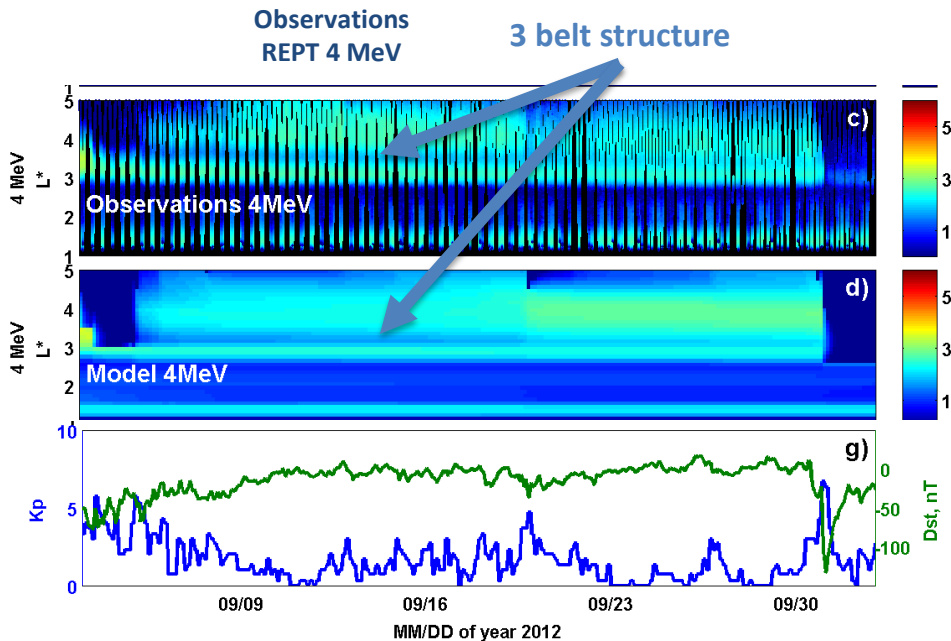
Flux, Energy = 0.9 MeV,  $\alpha_{\text{loc}} = 85^\circ$



*Drozdo et al., 2015*

**The one-year VERB code simulations provide a qualitative agreement with the observations during the Van Allen Probes period.**

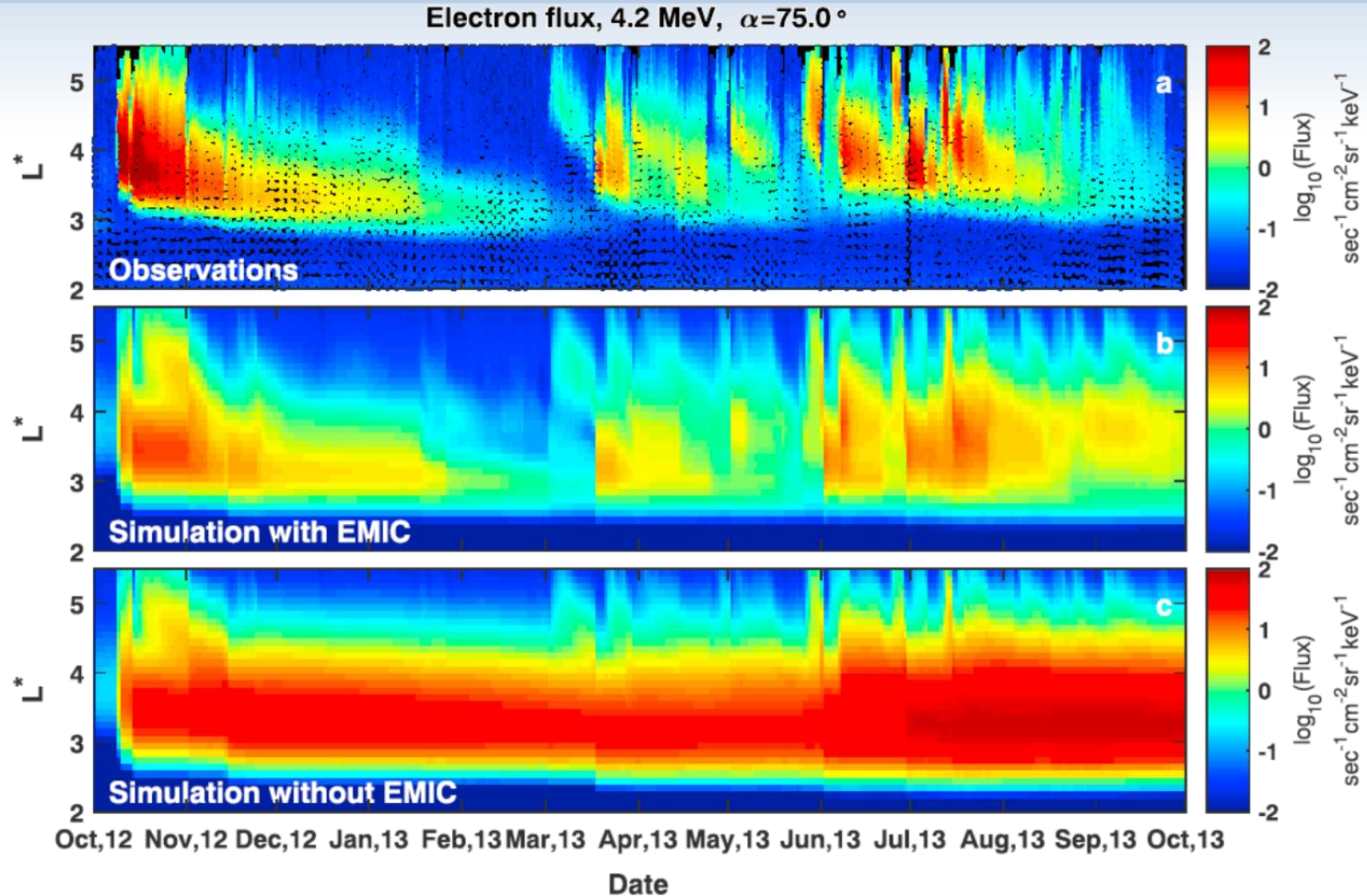
# Storm simulation



*Shprits et al., 2014, Nature Physics*

**The VERB code simulation with EMIC waves reproduces the third belt structure during September 2012.**

# Long-term simulation

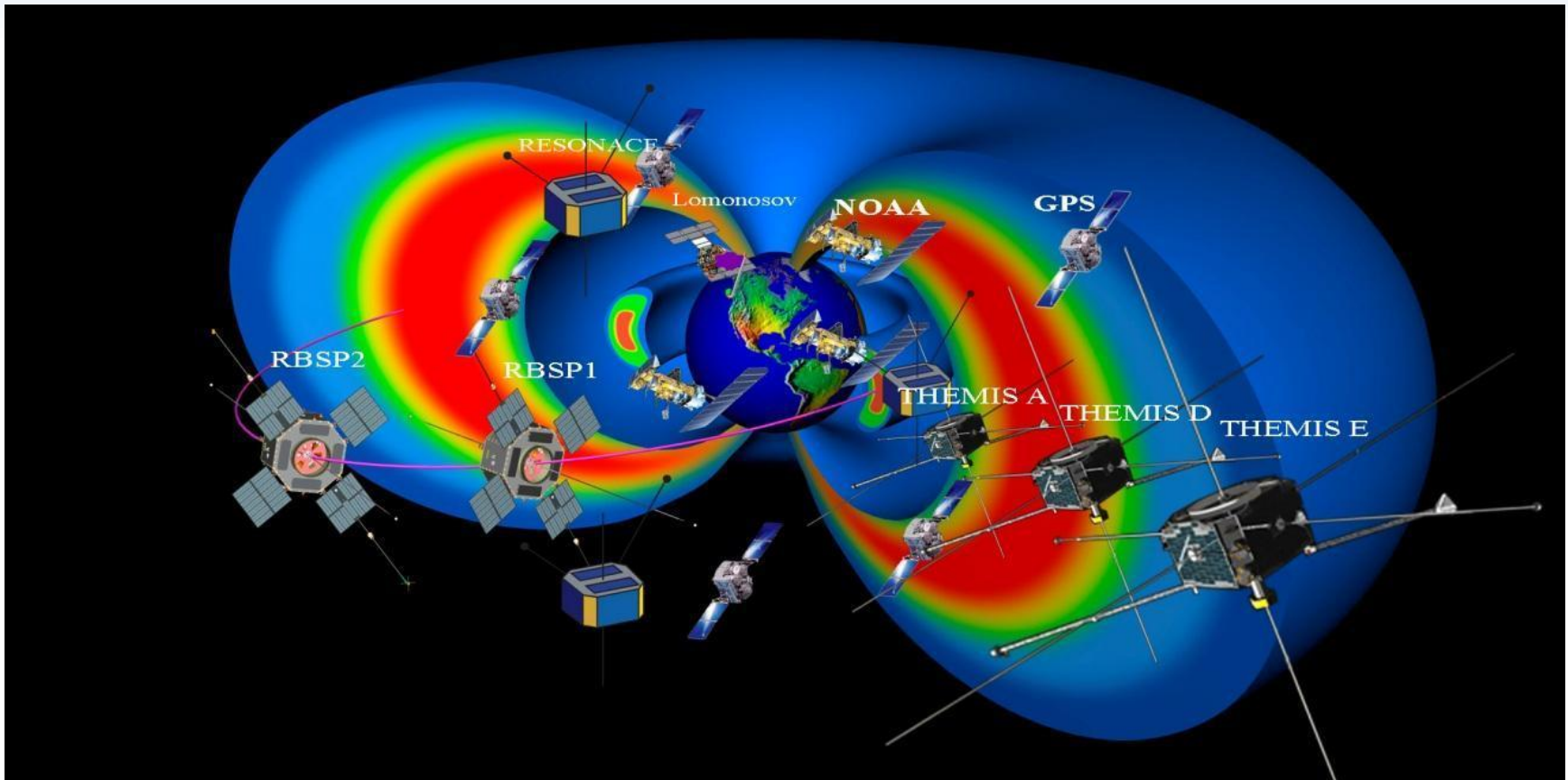


Recent long-term simulations includes EMIC waves.

*Drozdo et al. 2017*

The VERB code reproduces the dynamics of the ultrarelativistic electrons during one year of the Van Allen Probe observations.

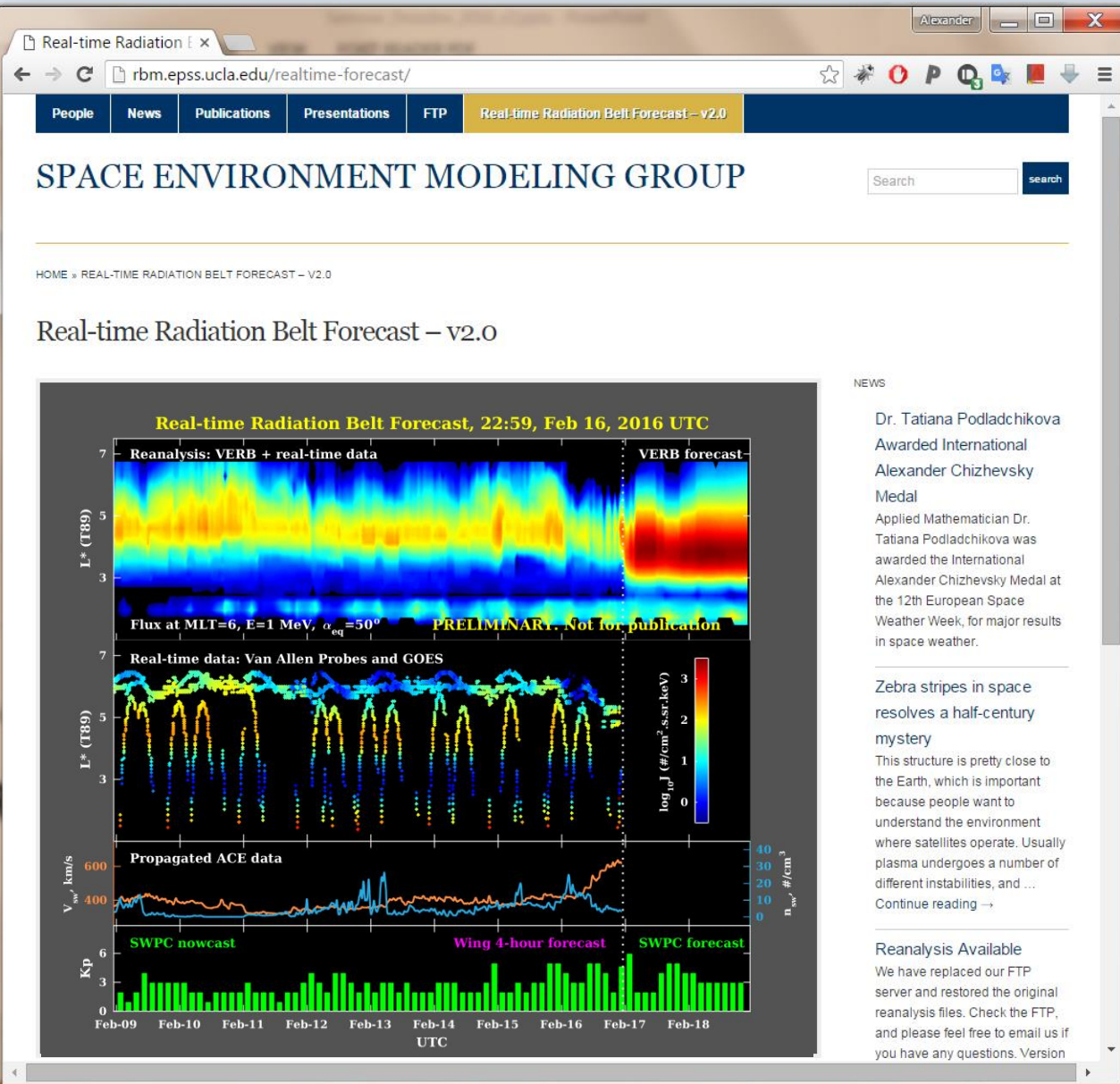
# Data Assimilation



The multipoint observations from various satellites can be included in the VERB code driven data assimilation to fill the spatial and temporal gaps. Data assimilation can be used in nowcast and forecast. *See more on Friday.*

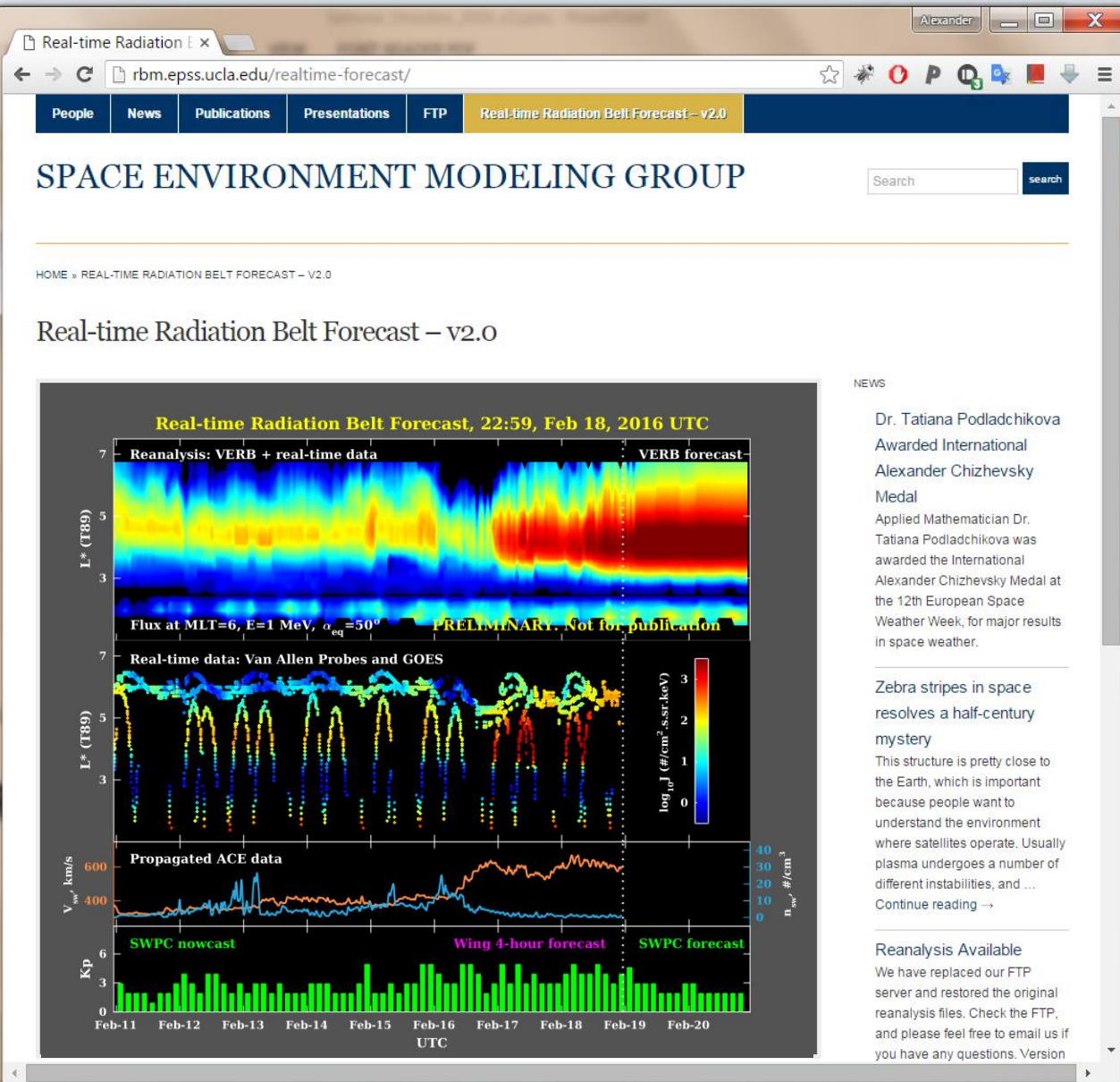
# Forecast

Real-time forecast of the electron radiation belt dynamics is available on <http://rbm.epss.ucla.edu>



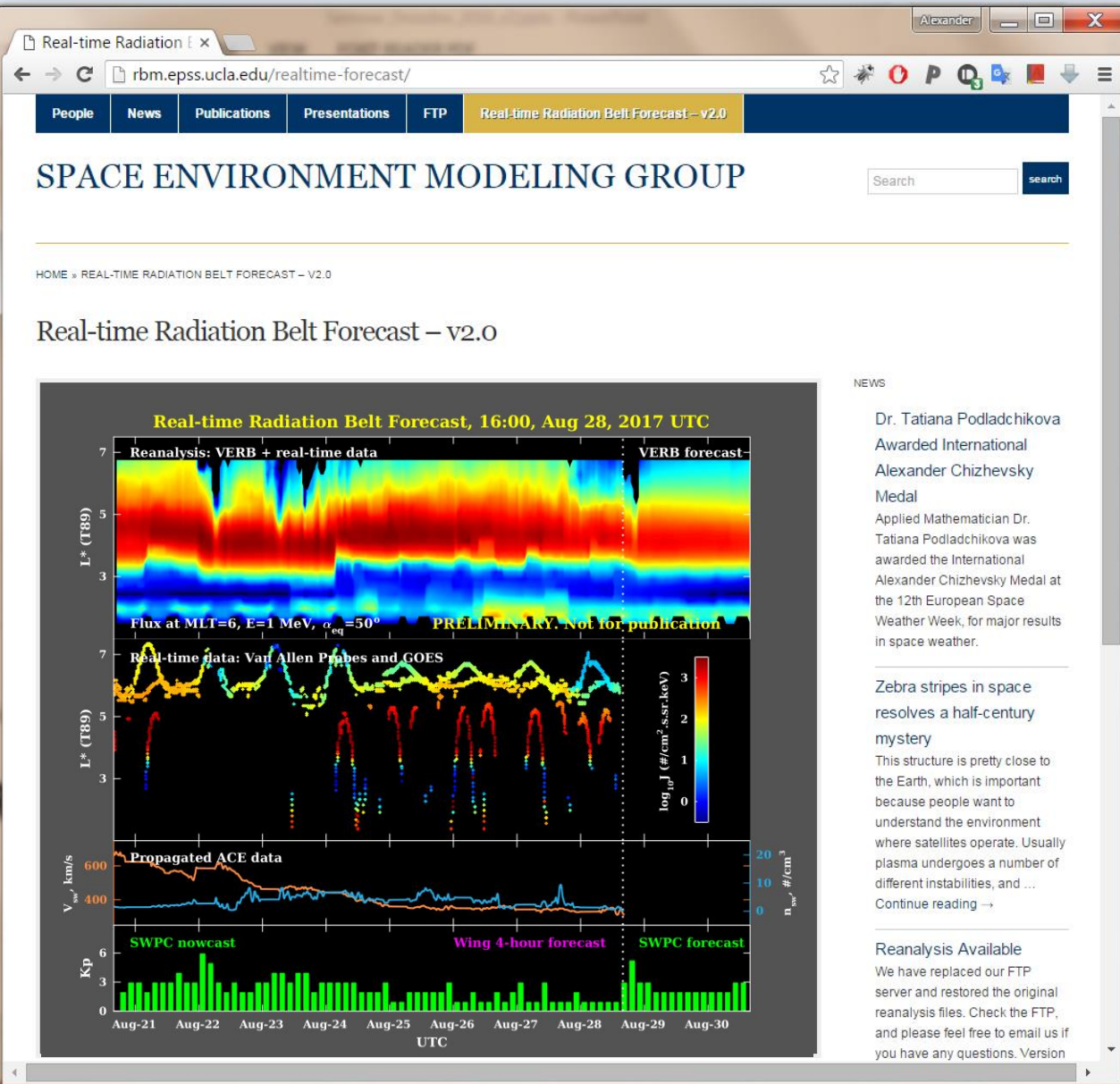
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## NEWS

Dr. Tatiana Podladchikova  
Awarded International  
Alexander Chizhevsky  
Medal

Applied Mathematician Dr. Tatiana Podladchikova was awarded the International Alexander Chizhevsky Medal at the 12th European Space Weather Week, for major results in space weather.

Zebra stripes in space  
resolves a half-century  
mystery

This structure is pretty close to the Earth, which is important because people want to understand the environment where satellites operate. Usually plasma undergoes a number of different instabilities, and ...  
Continue reading →

## Reanalysis Available

We have replaced our FTP server and restored the original reanalysis files. Check the FTP, and please feel free to email us if you have any questions. Version

# Conclusions

- **The Versatile Electron Radiation Belt (VERB) code can quantitatively reproduce the outer belt relativistic and ultrarelativistic energies.**
- **The VERB code supports multiprocessing calculations and can be compiled for different platforms.**
- **The VERB code has been validated during CREES and Van Allen Probes periods. The results of the validations are published in peer-reviewed journals.**
- **The VERB code can be used for reanalysis with data assimilation and in the real-time nowcasting and forecasting. *See more on Friday.***
- **The new improved version of the VERB code models the dynamics of low-energy electrons and can be used to estimate surface charging. *See more at the poster session.***