Modeling the dynamic variability of sub-relativistic outer radiation belt electron fluxes using machine learning

Donglai Ma[1], Xiangning Chu[2], Jacob Bortnik[1], Seth G. Claudepierre[1,4], W. Kent Tobiska[3], Alfredo Cruz[3], S. Dave Bouwer[3], J. F. Fennell[4], J. B. Blake[4]

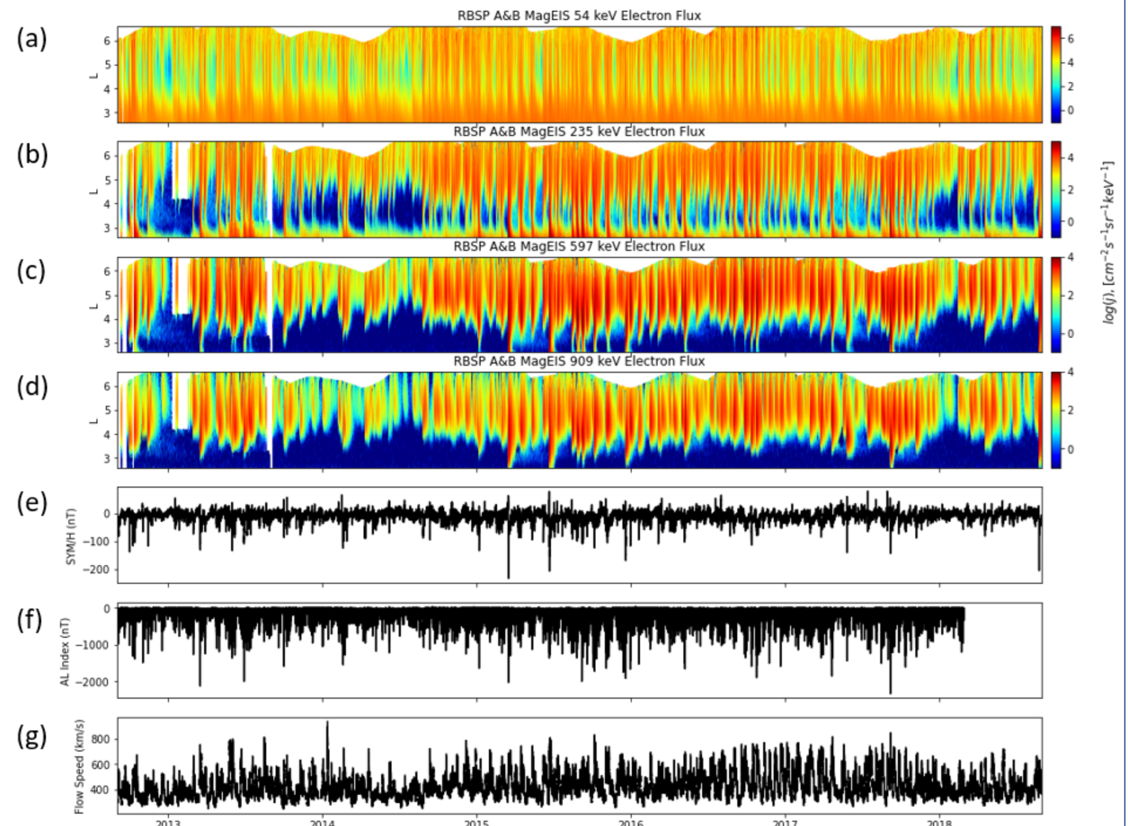
[1]University of California at Los Angeles (UCLA) [2]University of Colorado Boulder [3]Space Environment Technologies, Pacific Palisades [4]Space Sciences Department, The Aerospace Corporation

Abstract

- We present a set of neural network models that reproduce the dynamics of electron fluxes in the range of 50 keV ~ 1 MeV in the outer radiation belt.
- The models take satellite position, and a time-history of geomagnetic indices, and solar wind conditions in different length time windows as inputs.
- The models are then trained on electron flux data from the Magnetic Electron Ion Spectrometer (MagEIS) instrument on Van Allen Probes and **reproduce the dynamic variation of electron fluxes in different energy channels.**
- The model results show **high overall correlation coefficients** (0.78~0.92) on both the test dataset, and an out-of-sample 30-day period from February 25 to March 25 in 2017, when a geomagnetic storm took place.
- The model is able to **capture electron dynamics such as intensifications, decays, and dropouts, as well as the MLT dependence of the lower energy (~<100 keV) electron fluxes during storms.** The models have reliable prediction capability and can be used for a wide range of space weather applications.

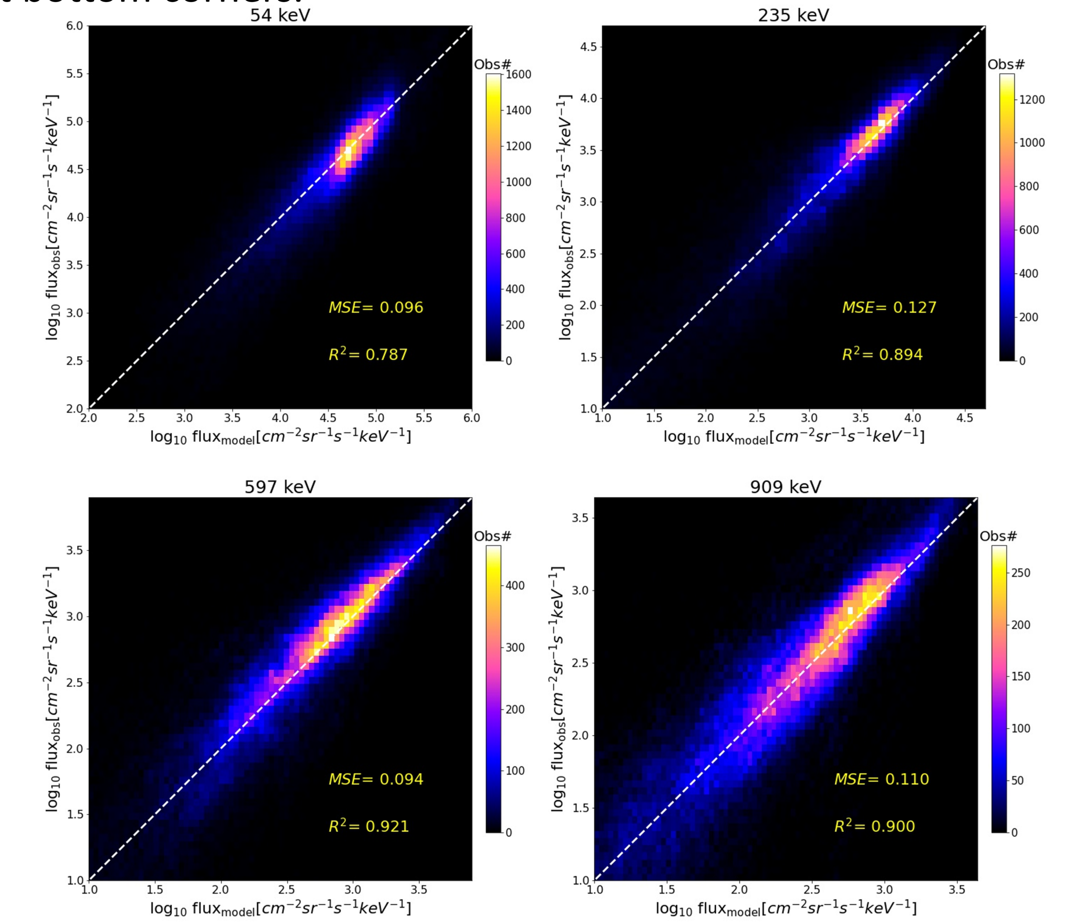
Data

- **MagEIS and OMNI data**
- Using four selected energy channels from the MagEIS instrument (54 keV, 235 keV, 597 keV and 909 keV shown in below Figure).
- The neural network model uses selected solar wind parameters as well as geomagnetic indices acquired from the OMNI data set as input parameters.

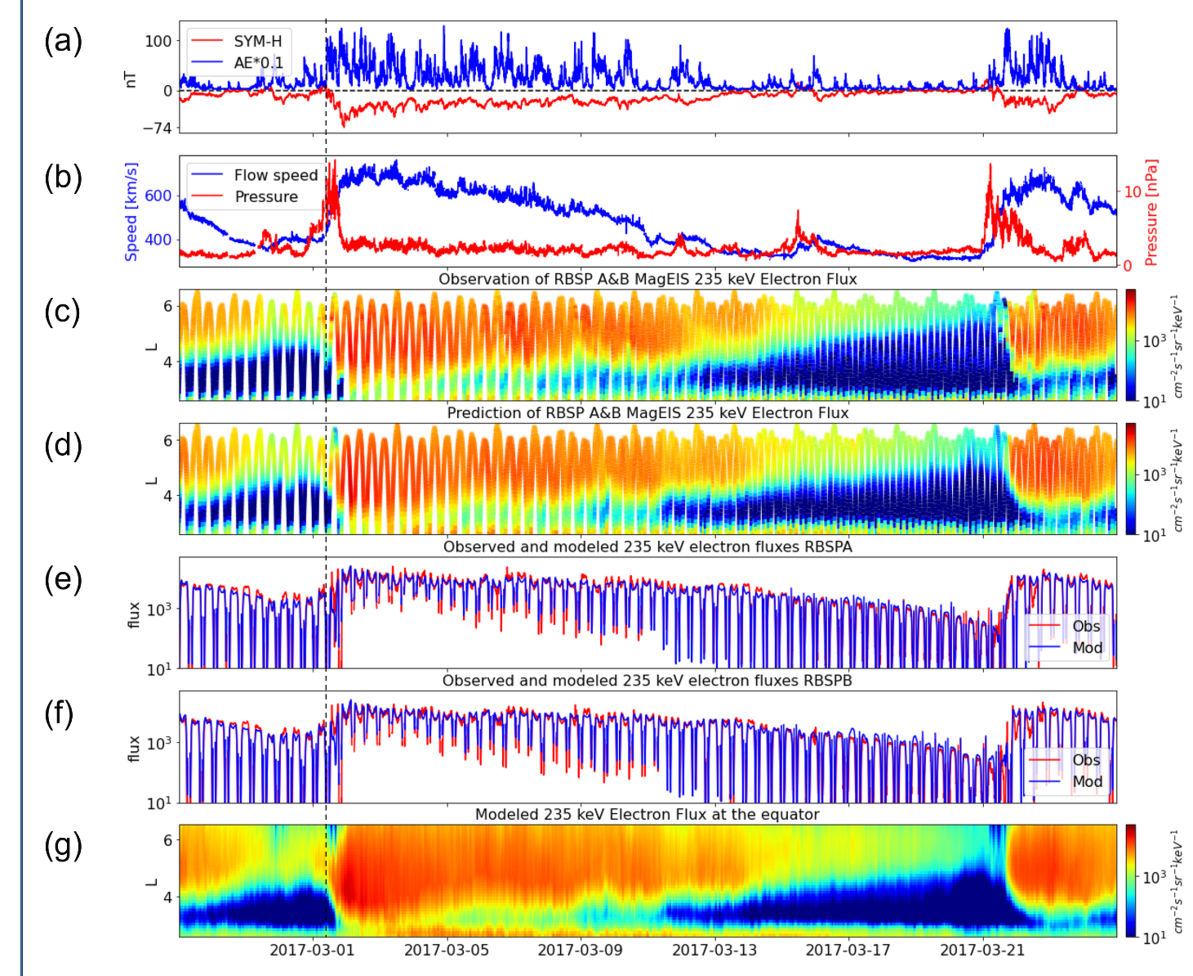


Method

Model performance on the test dataset for different electron energy channels, (a-d) test data at 54, 235, 597, and 909 keV. The white dashed line is the diagonal lines that indicate perfect agreement (y=x) between the observations and model results. The coefficient of determination R-squared and MSE are shown at the right bottom corners.

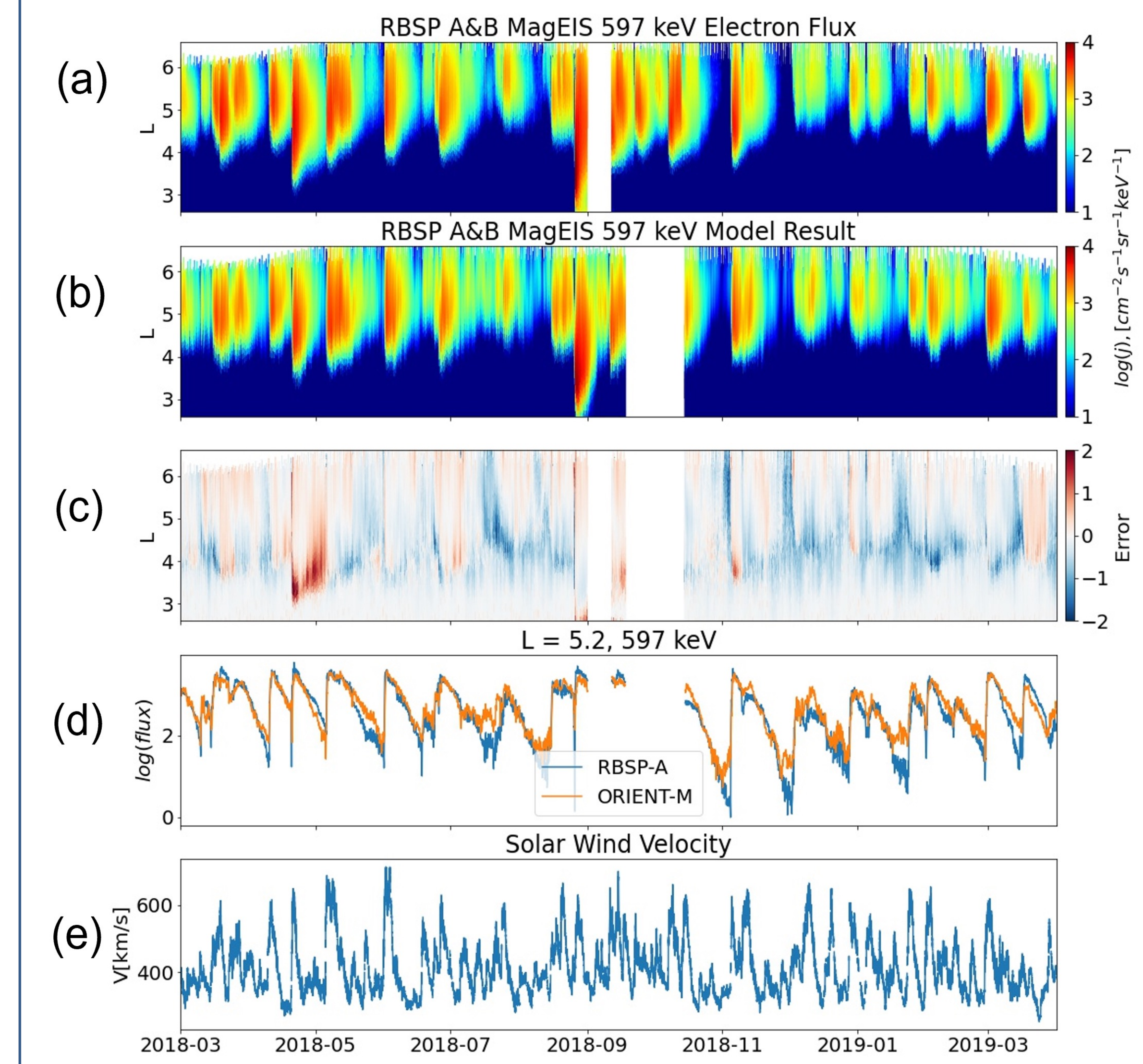


Short-term out-of-sample results



An example of the **235 keV** model results during the month-long period between February 25, 2017, and March 25, 2017 (a) geomagnetic indices Sym-H and AL; (b) The solar wind flow speed (Vsw) and pressure (Psw); (c-d) the observed and modeled 235 keV electron fluxes as a function of L shell and time; (e-f) the observed and modeled 235 keV electron fluxes along the trajectories of Van Allen Probes A and B; (g) the modeled 235 MeV electron fluxes on the equatorial plane.

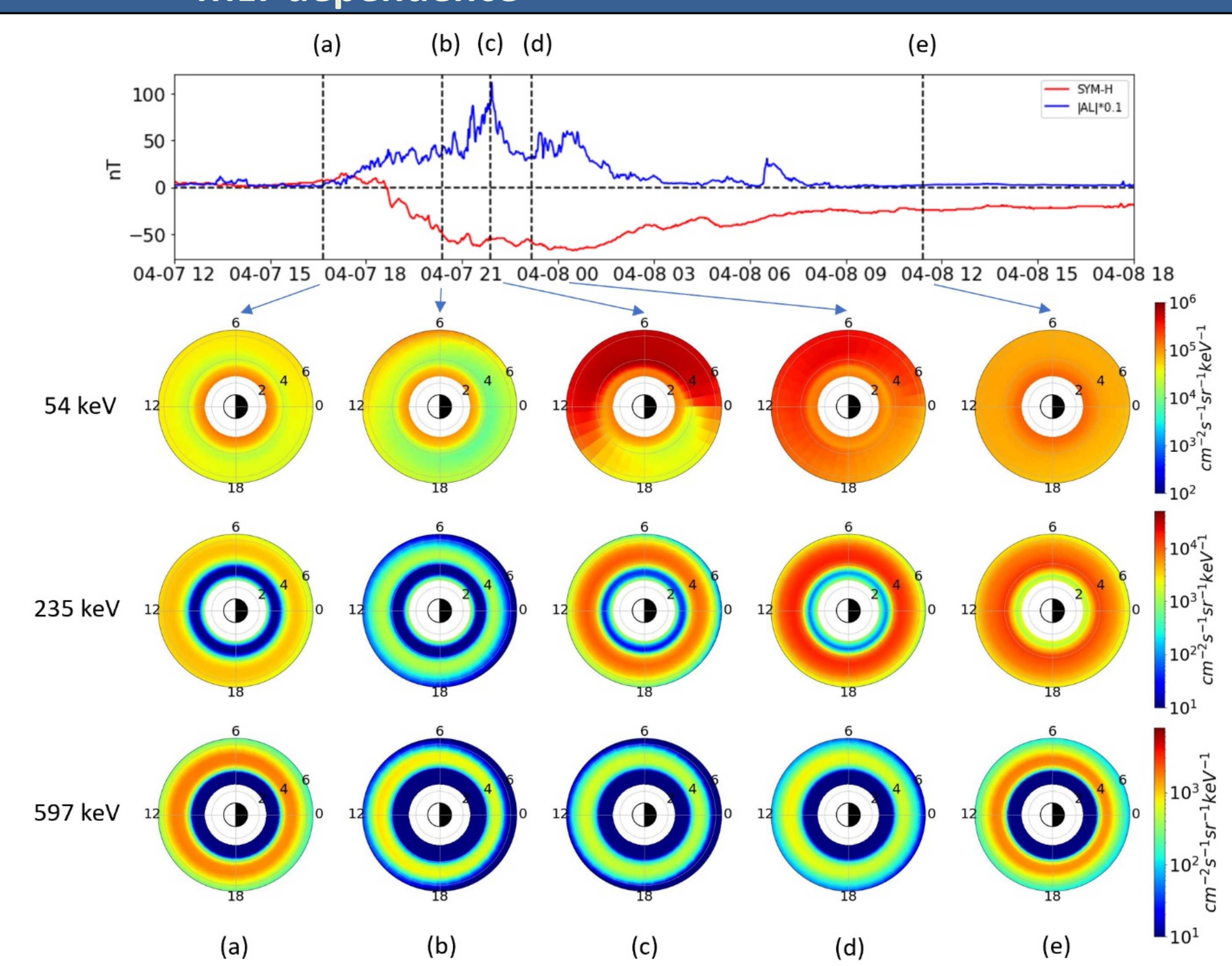
Long-term out-of-sample results



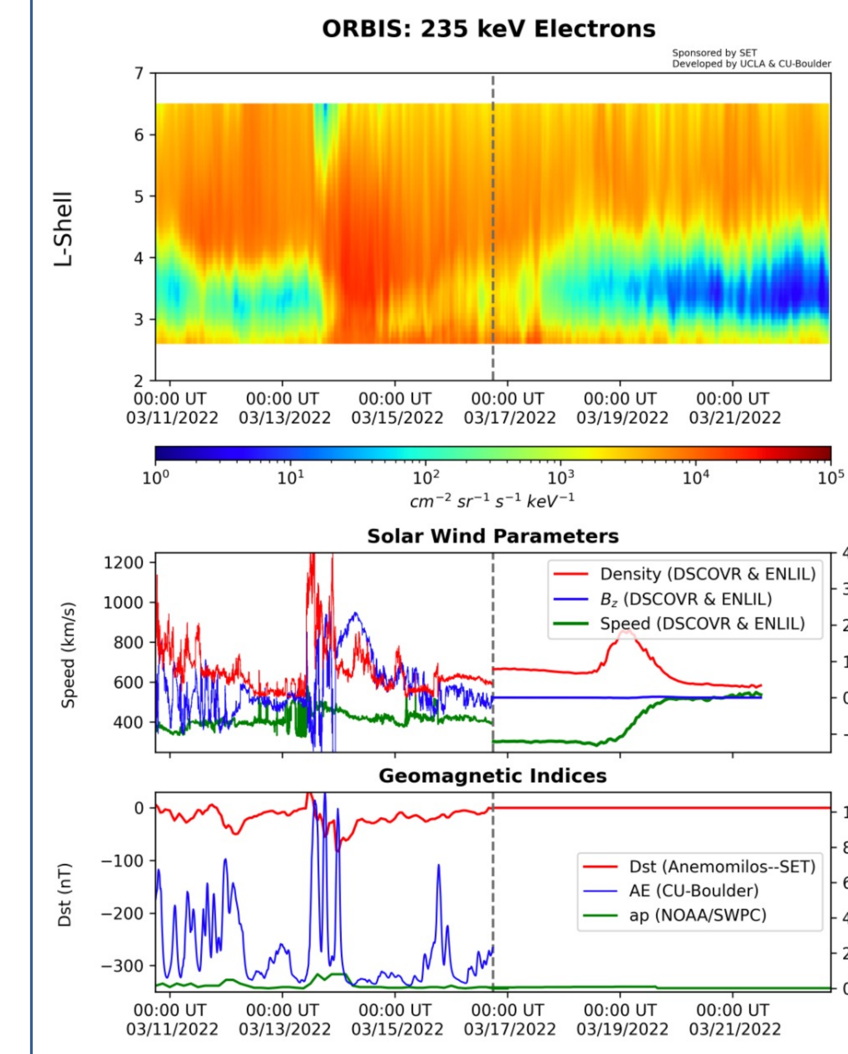
Model results produced along the Van Allen Probes' trajectories after March 2018 using the predicted AL index (lasp.colorado.edu/~lix) as input while the other inputs are obtained from the OMNI database. (a) The observed **597** keV electron fluxes along the trajectories of Van Allen Probes.(b) The 235 keV model results along the trajectories. (c) The differences between the observed and modeled electron fluxes. (d) comparison of observed and predicted flux at the fixed L-shell of 5.2 (e) solar wind velocity

MLT dependence

- A lower electron energies (tens to a few hundred keV), the energy-dependent magnetic drifts are far slower, the drift periods are longer and the loss timescales are shorter, such that the electron flux can vary dramatically within a limited range of MLTs.
- Figure shows the **modeled equatorial electron flux distribution variation for 54 keV, 235 keV and 597 keV** during the course of a geomagnetic storm that occurred on 8 April 2016.
- The model results show the distribution as function of L-shell and MLT which exhibit different dynamics for each of the different energy channels.
- At the peak of the geomagnetic activity (as measured by a minimum in the AL index) **the 54keV electron fluxes (time c) show significant MLT asymmetry in the electron flux enhancements,** which is observed predominantly at L ~ 3-6, and is a reflection of the Eastward drift of electrons around the Earth, as well as the rapid loss processes that remove the majority of the enhanced electron fluxes as they drift from the day through to the dusk sectors.



Realtime prediction



The ORIENT-R model has also been operationally deployed in real-time for usage by space-weather customers through a partnership with Space Environment Technologies (https://sol.spaceenvironment.net/orbis_ops) with a nowcast and prediction.

Contact

Donglai Ma
Graduate student
Department of Atmospheric and Oceanic Sciences, UCLA
Email: donglaima96@gmail.com, dma96@atmos.ucla.edu

Github: https://github.com/donglai96

Related Paper

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Chu, X., Ma, D., Bortnik, J., Tobiska, W.K., Cruz, A., Bouwer, S.D., Zhao, H., Ma, Q., Zhang, K., Baker, D.N. and Li, X., 2021. Relativistic electron model in the outer radiation belt using a neural network approach. Space Weather, 19(12), p.e2021SW002808.