Geophysical Research Abstracts
Vol. 21, EGU2019-8547-2, 2019
EGU General Assembly 2019

Reanalysis of radiation belt electron phase space density using four spacecraft and the VERB code

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The dynamical evolution of the radiation belts has been a subject of extensive research since their discovery in 1959. After decades of study, it is now known that they experience significant changes due to acceleration, loss and transport of particles trapped in the Earth's magnetic field. Since high-energy electrons can potentially cause spacecraft anomalies and damage satellite hardware, understanding and predicting fluxes in the radiation belts is of great importance to satellite operators, engineers, and designers.

Nevertheless, analysis of radiation belt observations presents major challenges. Satellite observations are often restricted to a limited range of L-shells, pitch angles, and energies. Additionally, observations at different L-shells are taken at different points along the spacecraft orbit and therefore at different times. Moreover, particle fluxes vary on short time scales, and observations from a single spacecraft do not allow for measuring the temporal variations on time scales shorter than the spacecraft orbital period. Analysis is further complicated by the fact that measurements are contaminated by errors, which are different for various instruments. As a consequence, to fill the spatiotemporal gaps and to understand the dynamics and dominant physical processes in the radiation belts as well as to create accurate models, observations should be combined with physics based dynamical models in an optimal way.

Numerical weather prediction faced similar problems to those mentioned in the 1970s. A methodology, usually referred as data assimilation, in which observations are combined with models in order to produce results close to the true values, was successfully applied. With the advent of space-borne observational data and the development of more sophisticated space-physics models, dynamical processes in the Earth's radiation belts can be analyzed and assessed using data assimilation methods as well.

In this study we implement a data assimilation tool using a split-operator sequential Kalman filter approach. Reanalysis of the electron radiation belt phase space density is obtained over the period October 2012 to October 2015 by combining sparse observations from the Van Allen Probes spacecraft and the Geostationary Operational Environmental Satellites 13 and 15 with the 3D Versatile Electron Radiation Belt (VERB) code. At first, radial profiles of electron fluxes are reconstructed, and the innovation vector is analyzed to show how the data is correcting for physical mechanisms absent in the model. Such processes (mixed pitch angle-energy diffusion, losses to the magnetopause, and scattering by Electromagnetic Ion Cyclotron waves) are then added in the reanalysis, and a validation against LANL GPS data is presented. Finally, major improvements with respect to the pure physics based model are discussed. It is demonstrated that the 3D data assimilative code provides a comprehensive picture of the radiation belts and is an important step toward performing reanalysis using observations from current and future missions.