Project Details

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Program Element: Focused Science Topic

Topic: Pathways of Cold Plasma through the Magnetosphere

Project Title:
Understanding plasmaspheric refilling: an investigation using machine learning models and physics-based simulation

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Summary:
Science description
The plasmasphere consists of cold plasma (~1 eV) at mid- to low- L-shells surrounding the Earth. The plasmaspheric density and composition strongly influence energetic particle scattering and acceleration, wave propagation, wave-particle interactions. Therefore, it is essential to understand the plasmaspheric dynamics, i.e., the plasmaspheric erosion and refilling under various geomagnetic conditions. However, previous studies are limited by the lack of in-situ satellite measurements of the cold plasma at ideal locations and at any time. For example, satellite measurements following the motion of flux tubes are essential but missing how flux tubes are refilled. To resolve this issue, machine-learning (ML-) based models of the cold plasma, including total plasma density and different ion species, will be developed to provide global and time-dependent reconstructions of the cold plasma and ion species at any location (e.g., following any flux tube, or on the equatorial plane), and at any time (e.g., during the storm recovery phase). In addition, a physics-based model of the ionosphere, plasmasphere, and electrodynamics (IPE) will be compared to the ML-modeled semi-observations to aid in interpretation and study the mechanisms governing plasmaspheric refilling.
The main goal is to understand the typical characteristics and governing mechanisms of the cold electrons and ion species during plasmaspheric refilling using machine learning models and physics-based simulations.
The main objective is to answer the overarching science question: how are the cold electrons and various ion species refilled under different geomagnetic activity?
Specific science questions that will be addressed are:
1. How is the total electron density of the plasmasphere refilled?
2. How are the different ion species (H+, He+, and O+/N+) refilled?
3. What are the physical mechanisms controlling the refilling for each particle population?
Methodology
The proposed project will use in-situ data from the HOPE and EMFISIS instruments onboard NASA's Van Allen Probes; solar wind conditions and geomagnetic indices as driving conditions; machine-learning models of total plasma density and ion species, and physics-based IPE model. Specifically, to address:
1.Q1 and Q2: the refilling rates of the total plasma and ion species will be evaluated using the ML-modeled densities along flux tubes at different locations and different phases of geomagnetic activity.
2.Q3: the contribution of physical mechanisms will be evaluated using the physics-based IPE model, whose results will be cross-validated with and matched ML-modeled semi-observations.
The uncertainty of the ML-based model will be evaluated as a function of locations. The uncertainty of the IPE model will be quantified using sensitivity analysis.
Relevance
Our study focuses on the cold plasmasphere and its drainage plume, which is the targeted plasma population of the FST target. Our project contributes to FST #3, objective 1 (refilling of the plasmasphere, &and factors controlling these sources), objective 2 (the evolution of the plasmasphere), and objective 4 (determination of the properties and controlling factors of the low-energy electron and ion populations) in section 3.2. Our study uses machine learning models and physics-based simulations, which fits the types of investigation in section 3.3. The ML-based models will contribute semi-observations with uncertainties to the FST team, which serves as a comparison basis to validate first-principle models. The IPE model will provide the evolution of cold electrons and ions species in the plasmasphere under different geomagnetic activities. The metrics of success will be the model performance of the empirical model and IPE model. The milestones include the development of the ML-based model, model application to event studies, and comparison to the IPE model to understand the physical mechanisms of plasmaspheric refilling.

Publication References:

no references