Refining Boundary Conditions for SEP Trapping in the Salammbô Radiation Belt Dynamics Code

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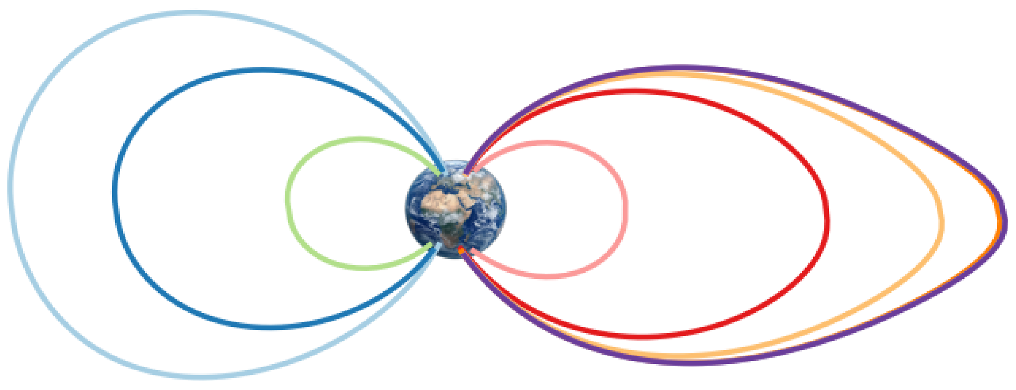
Introduction and Motivation



Earth's proton radiation belt presents persistent hazards to satellite operations, such as solar panel aging for energies ~10MeV. Its long-term evolution evolves rapidly during geomagnetic storms, which can empty or refill the proton belt populations. It is therefore essential to accurately model SEP as well as proton injection and losses during storms to have a representative estimate of fluxes in Earth Radiation Belts.

The Salammbô code (ONERA, [1]) simulates proton belt 100keV-800MeV dynamics. However, its outer boundary conditions (BCs) need to be refined and are discussed here. Future work during the thesis will focus on ~MeV energy proton injection (phenomena influenced by electric fields) as well as SPAND and CRAND processes injecting protons through interactions with Earth's upper atmosphere.

Goal

Improve the determination of the shielding limit for SEP injection in Salammbô through magnetic latitude dependence and new source terms (not only BCs).

Methodology

Particle phase space given by coordinates (L^*, MLT, α_{eq}, α, φ) and energy E_c.

Pitch Angle at equator, linked to maximum magnetic latitude for trapped particles

Pitch Angle

Gyration phase

Magnetic drift shell with a radius indexed by L*

This magnetic field line is at a magnetic longitude given by MLT at a given date.

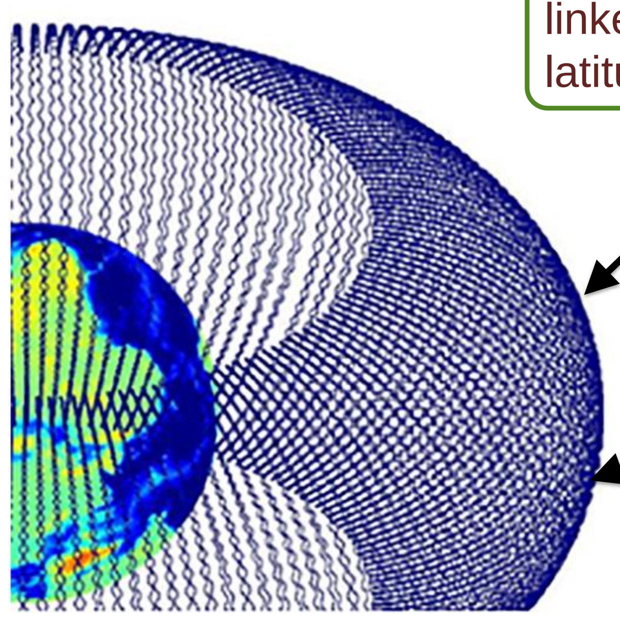


Figure from [4]. Motion of a trapped proton with energy E_c = 1 MeV

MASHCode [2,3]

Sampling the phase space at time t and then integrating the trajectories backward in time to determine the origin of the particles.

Origin = Magnetopause? Averages over (MLT, α, φ)

Proportion of particles coming from the magnetopause f(Kp, Dst, L*, E_c, α_{eq}) using the Tsyganenko-89 BOBERG (T89Bob) magnetic field configuration for given Kp and Dst indices [5].

Existing → Salammbô BCs: Injection of satellite fluxes at L* such that f = 0.5

This L* value is called the shielding limit.

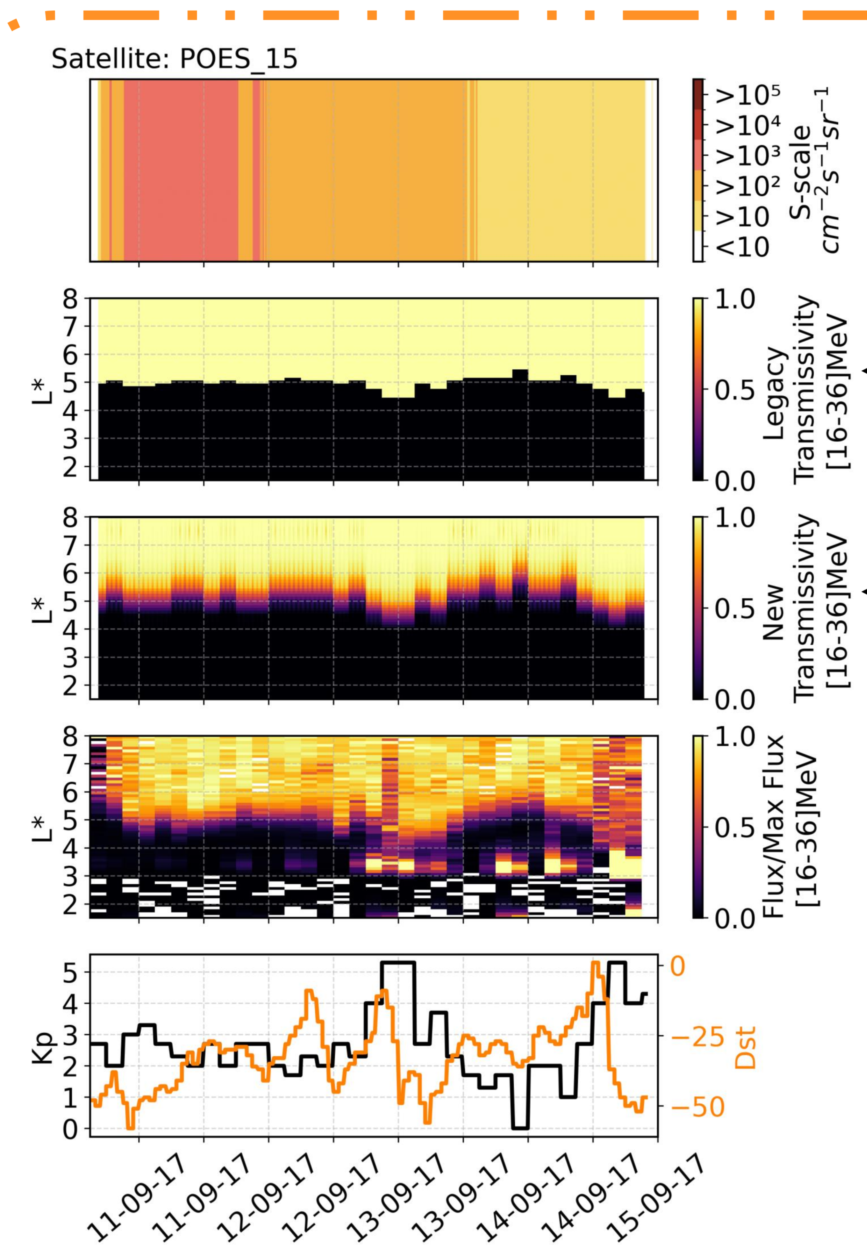
To come → New BCs and source terms to implement

First steps

It is well known that the transmissivity f depends on (L*, MLT, E_c) and on the geomagnetic configuration.
We also find that:

1. The transmissivity function **depends on the parameter α_{eq}**.
2. For a same α_{eq} ,particles have easier access to the equatorial region.
3. Sampling of the phase space should be performed **in 6D** in order to accurately determine f.

September 2017 storm (relatively low Kp)

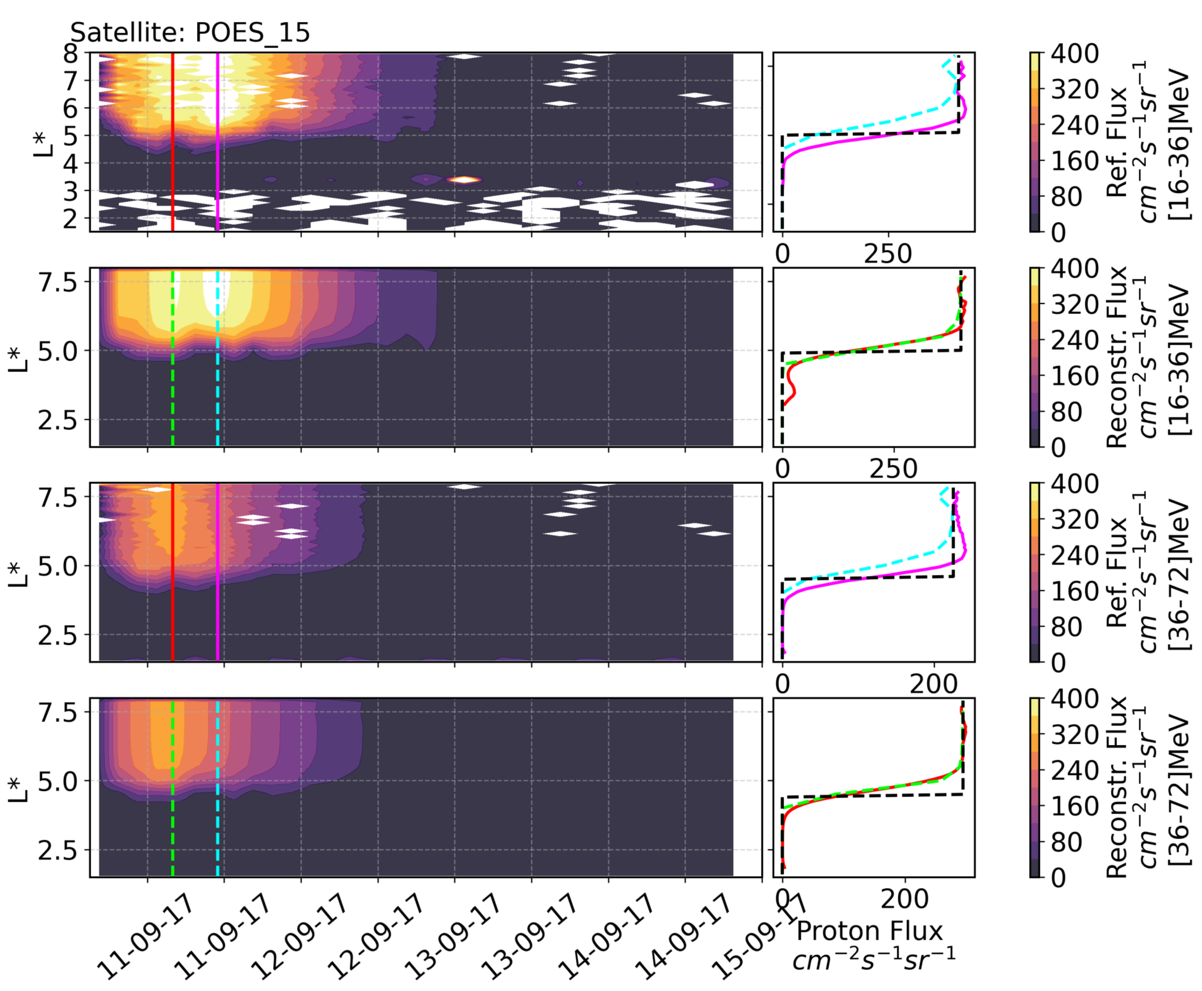


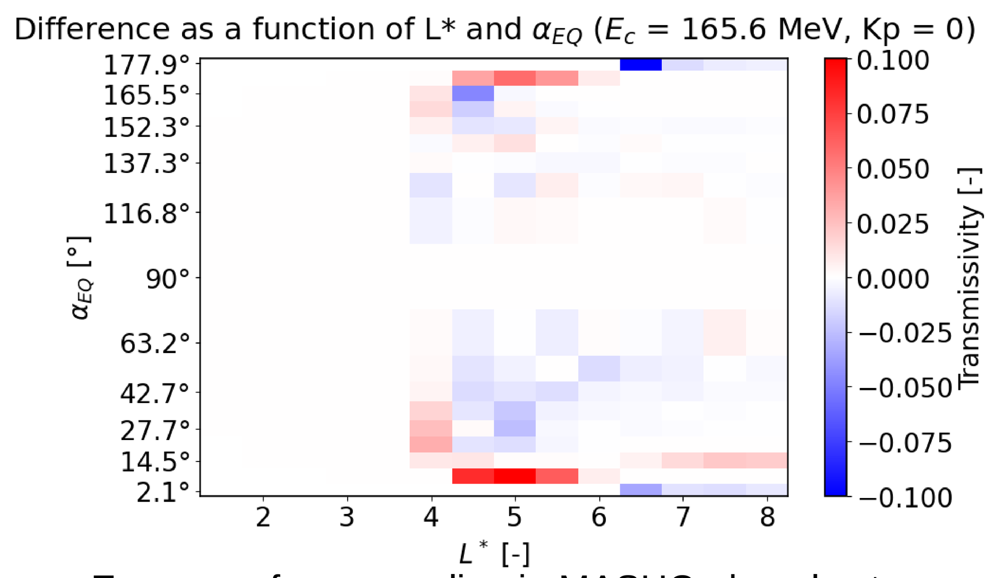
Former model did not depend on energy for large Kp and was only sampled at equator for low Kp.

New model depends on α_{eq} and will be injected in Salammbô as BCs and source terms.

Time and L* evolution of the transmissivity function f for the previous shielding model, the new model, and POES satellite observations (fluxes normalized by maximum L* fluxes). The first panel shows the time evolution of maximum proton fluxes in L*, and the last panel the evolution of Kp and Dst indices.

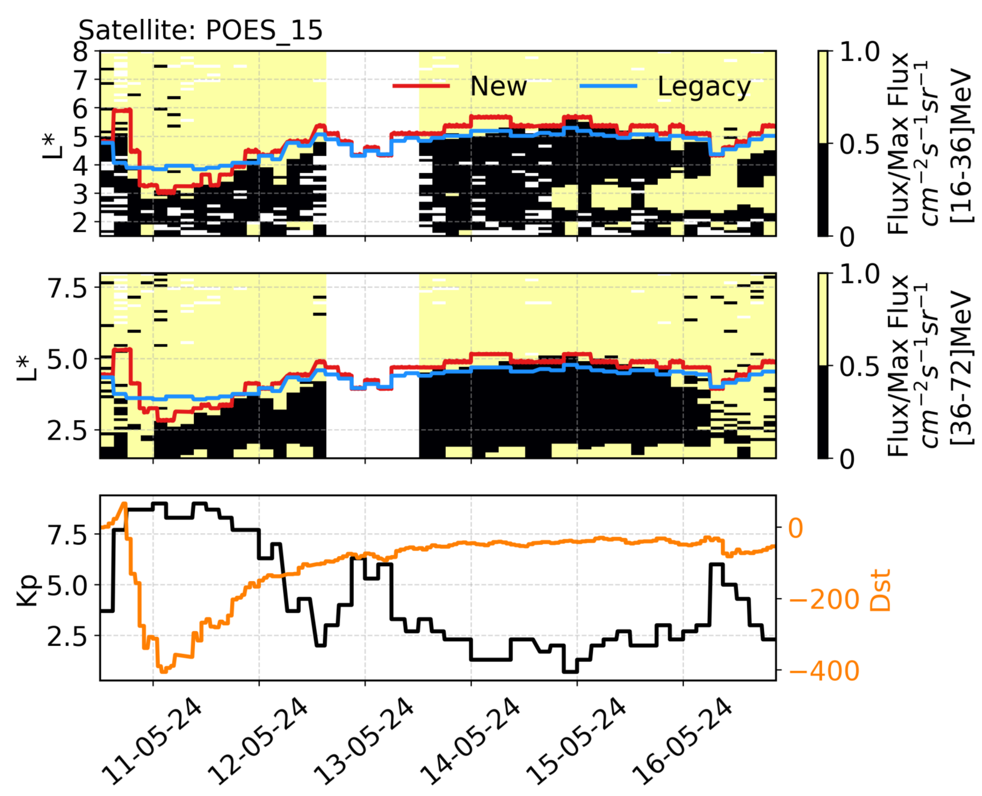
Time and L* evolution of POES satellite and reconstructed fluxes for two energy bands, with L* slices at two dates. Reference fluxes are shown in red/magenta, reconstructed in green/cyan, and previous model predictions in gray.





Error map from sampling in MASHCode only at equator versus the full 6D phase space case, with red (under-) and blue (10% over-estimation) regions.

Gannon Storm (large Kp and Dst)



Time and L* maps indicating where the POES-observed transmissivity function f exceeds 50%, with red and blue contours marking f =0.5 for the new and former models, respectively. Results are shown for two energy bands and demonstrate improved agreement with observations during high Kp and Dst storms.

Take-away message

Our study refines SEP trapping modeling in Earth's radiation belts by accounting for the 6D phase-space dependence of transmissivity as well as using upgraded numerical schemes and an updated magnetic field model for high Kp. Results show easier proton access to the equator. Next steps consist in injecting reconstructed fluxes as both BCs and source terms in Salammbô for validation against satellite data, and extending the model to lower energies (1-10 MeV).

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