

The Need for Real-Time Radiation Belt Measurements at MEO

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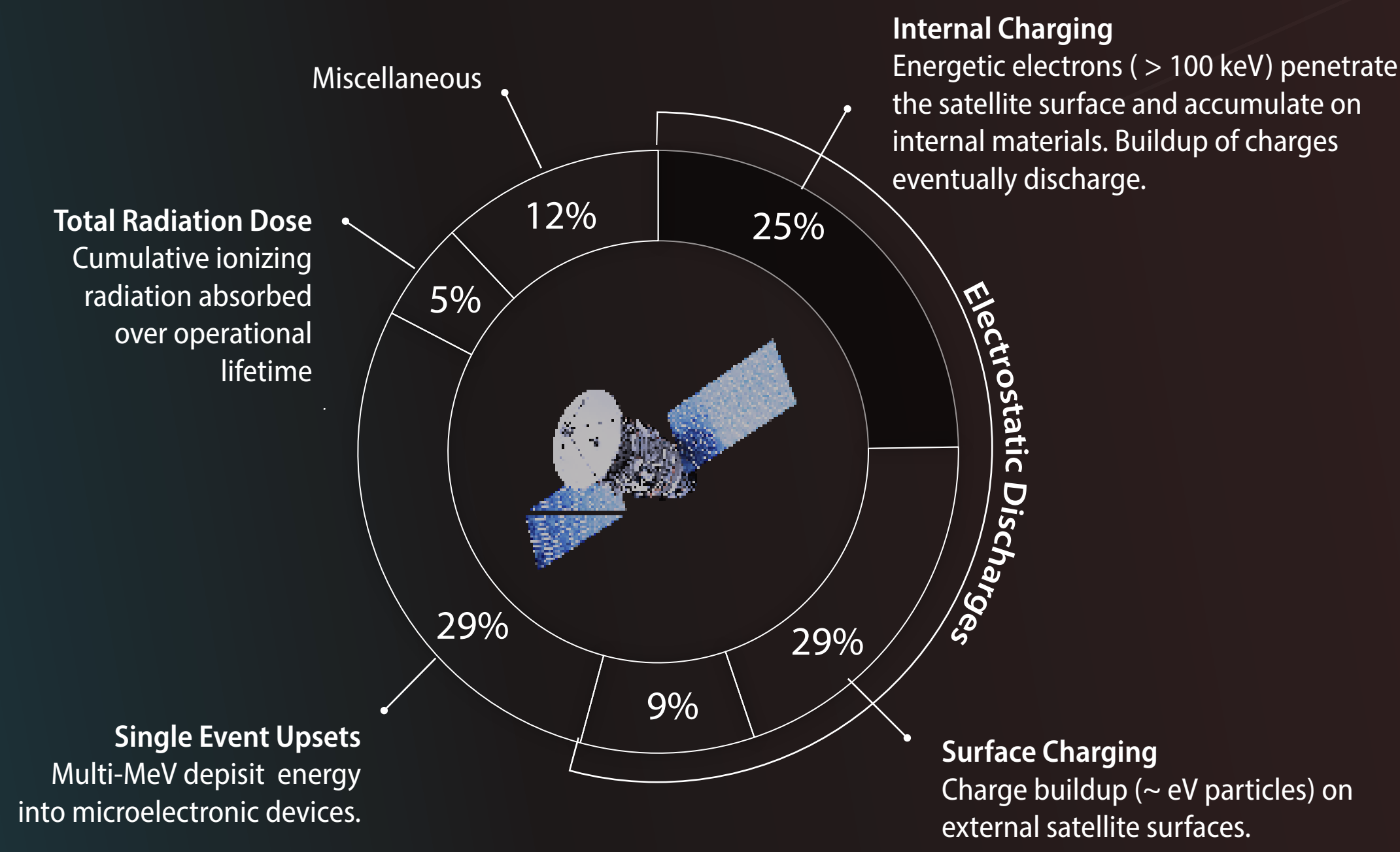


Project Aims

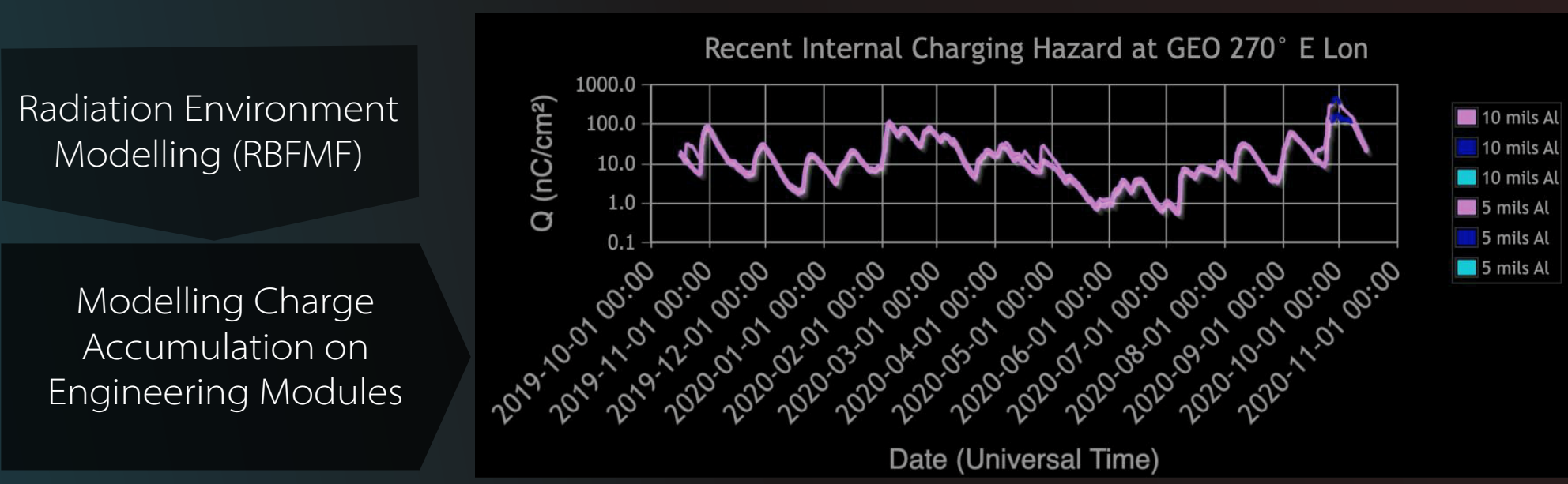
To evaluate the accuracy of an outer radiation belt environment specification model at MEO and GEO trajectories.

1. Motivation: Satellite Anomaly Attribution

Satellite anomalies are unexpected deviation in a satellite's operation, ranging from minor malfunctions to component damage or system failure. Anomalies can be caused by environmental conditions like space weather (Koons et al., 1999).



Electrostatic discharges due to internal spacecraft charging are a primary cause of satellite anomalies. SatCAT allows operators to monitor the real-time and long-term effects of internal spacecraft charging due to radiation belt electrons.

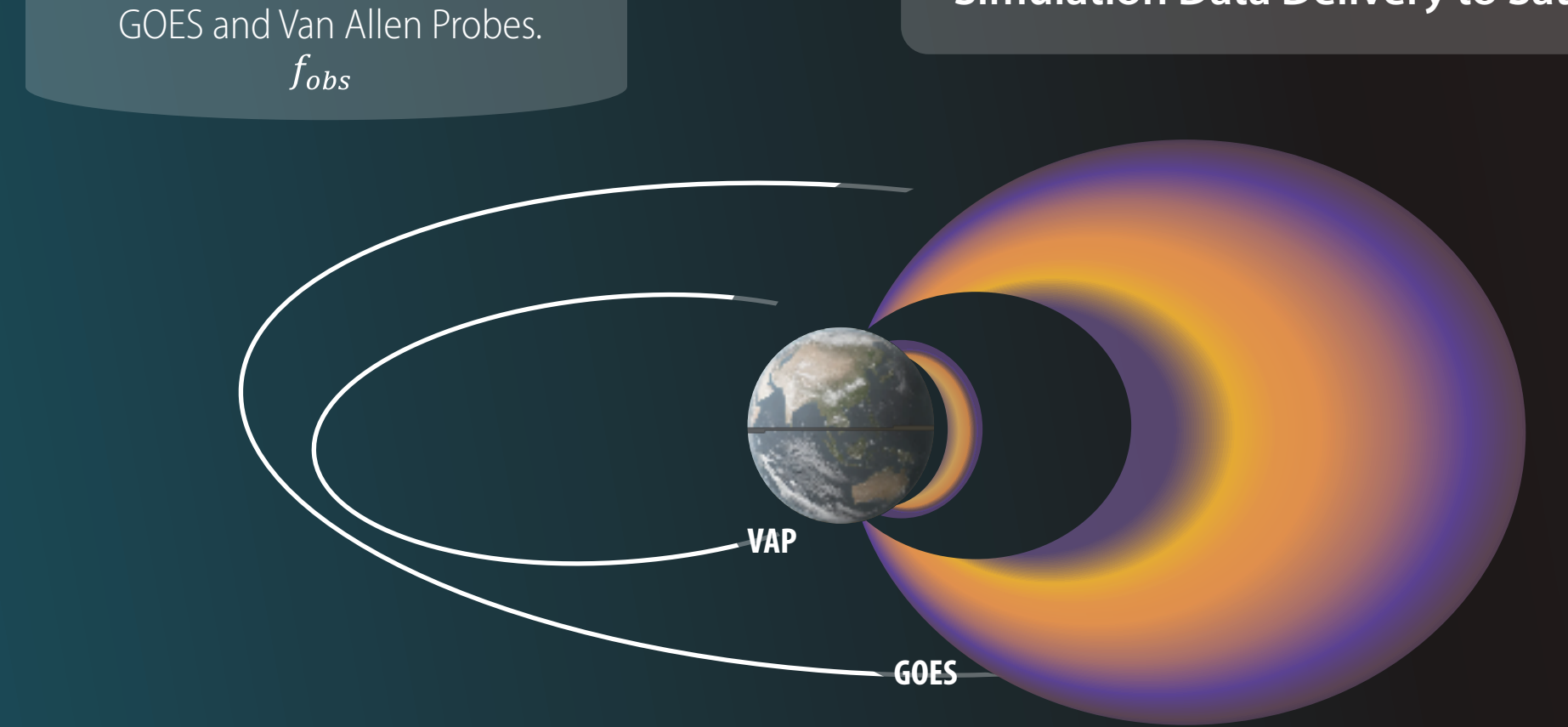
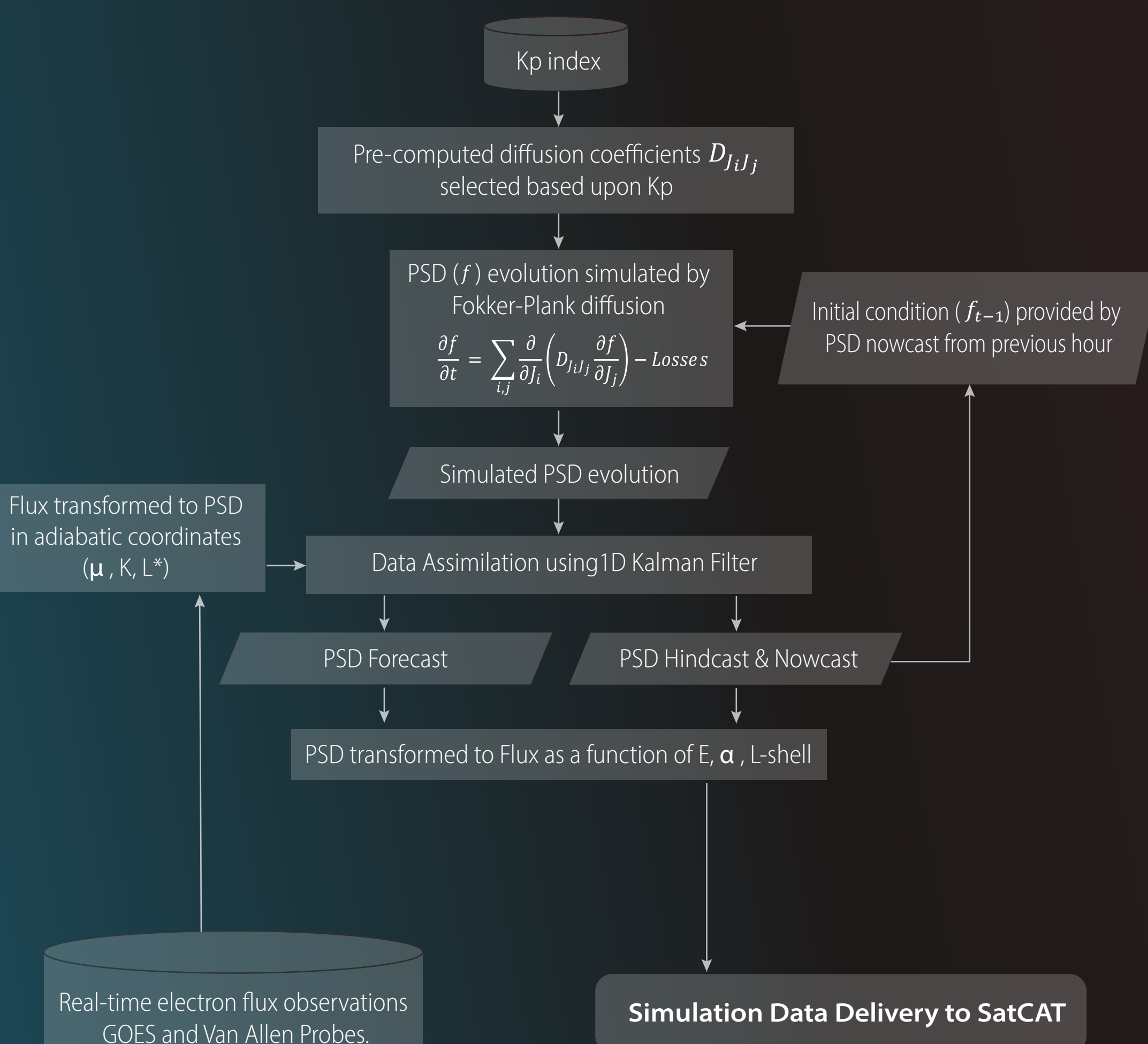


2. The Radiation Belt Forecasting Model and Framework

The Radiation Belt Forecasting Model and Framework (RBFMF) provides hourly hindcasts (previous 8 days) and forecast (future 2 days) of the electron radiation environment in real time.

Diffusive modelling of the radiation belt is combined with real-time data inputs from GOES and Van Allen Probe beacon data.

Diffusion coefficients are modelled for wave-particle interactions with ULF (Brautingham & Albert 2000), Lower-band chorus (Shprits et al., 2007; Li et al., 2007), and plasmaspheric hiss (Spasojevic et al., 2015) waves.



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Citation:
Staples, F., Kellerman, A., & Green, J. (2024). On the performance of a real-time electron radiation belt specification model. *Space Weather*, 22, e2024SW003950. <https://doi.org/10.1029/2024SW003950>

References:
Brautingham & Albert (2000) *J. Geophys. Res.*, S.P., 105(A1) DOI: 10.1029/1999JA900344; Li et al. (2007) *J. Geophys. Res.*, S.P., 112(A10) DOI: 10.1029/2007JA012368; Shprits et al. (2007) *J. Geophys. Res.*, S.P., 112(A12) DOI: 10.1029/2007JA012579; Spasojevic et al. (2015) *J. Geophys. Res.*, S.P., 120(12) DOI: 10.1002/2015JA021803; Tsyganenko (1989) *Plan. and Spc. Sci.*, 37(1) DOI: 10.1016/0032-0633(89)90066-4.

3. Validation Method

The 10-hour hindcast is validated against a dataset of PSD observations from 32 individual satellites from the Van Allen Probes, GOES, THEMIS, Cluster, MMS and GPS constellation.

Multi-Mission Observations:
Observations are converted to adiabatic coordinates using the IGRF and Tsyganenko (1989) field model, then intercalibrated to Van Allen Probe B and bias corrected GOES 15 data. PSD observations are interpolated across μ and K , and averaged into L^* and time bins to match the resolution of the simulation.

Statistical Evaluation:
Error and bias is quantified using the median symmetric accuracy

$$MSA = 100 (\exp(M(|\log_e(Q_i)|)) - 1)$$

and signed symmetric percentage bias

$$SSPB = 100 \operatorname{sgn}(M(\log(Q_i))) (\exp(M(|\log(Q_i)|)) - 1)$$

where Q_i is the ratio between the hindcast and observation (Morley et al., 2018).

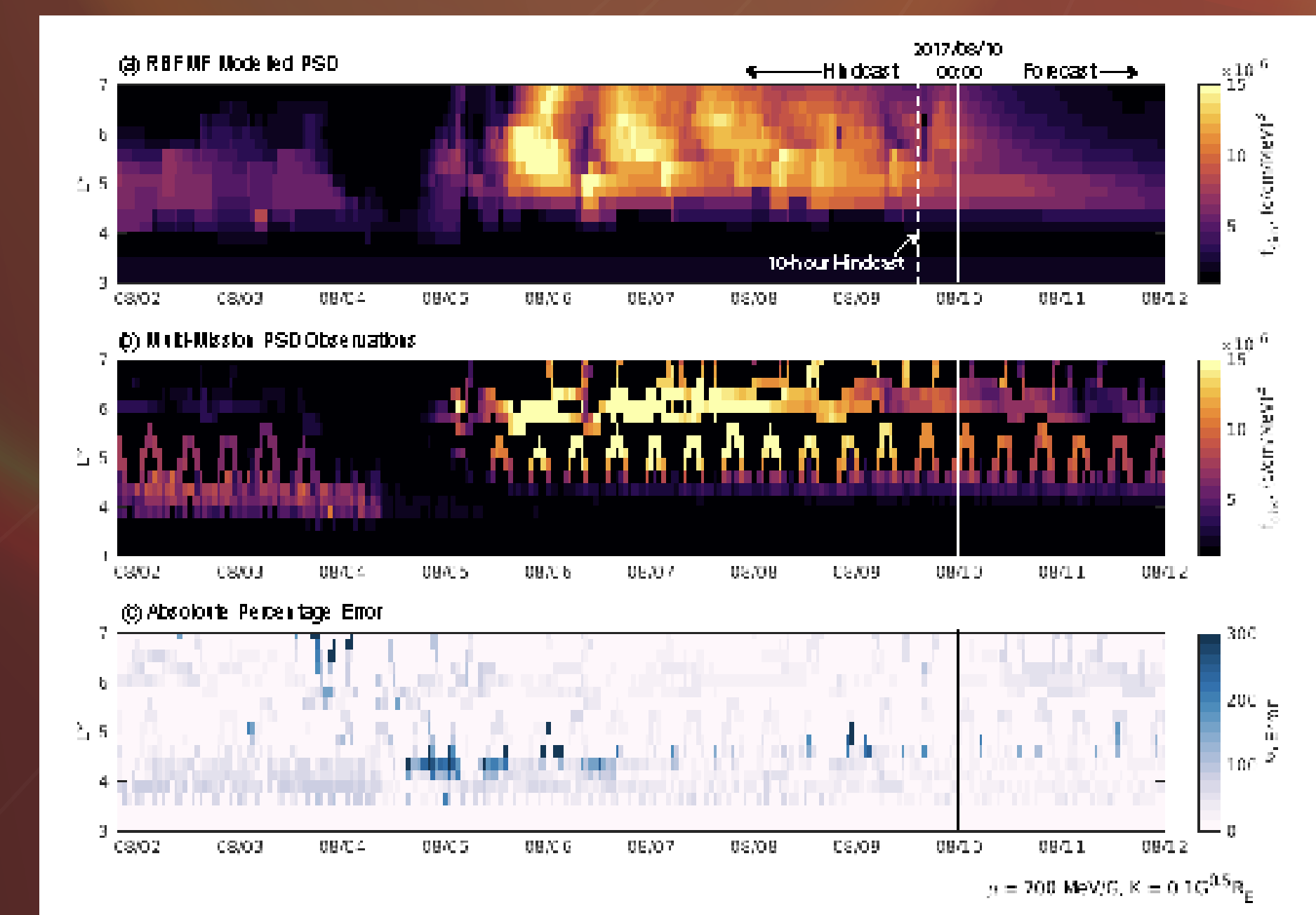
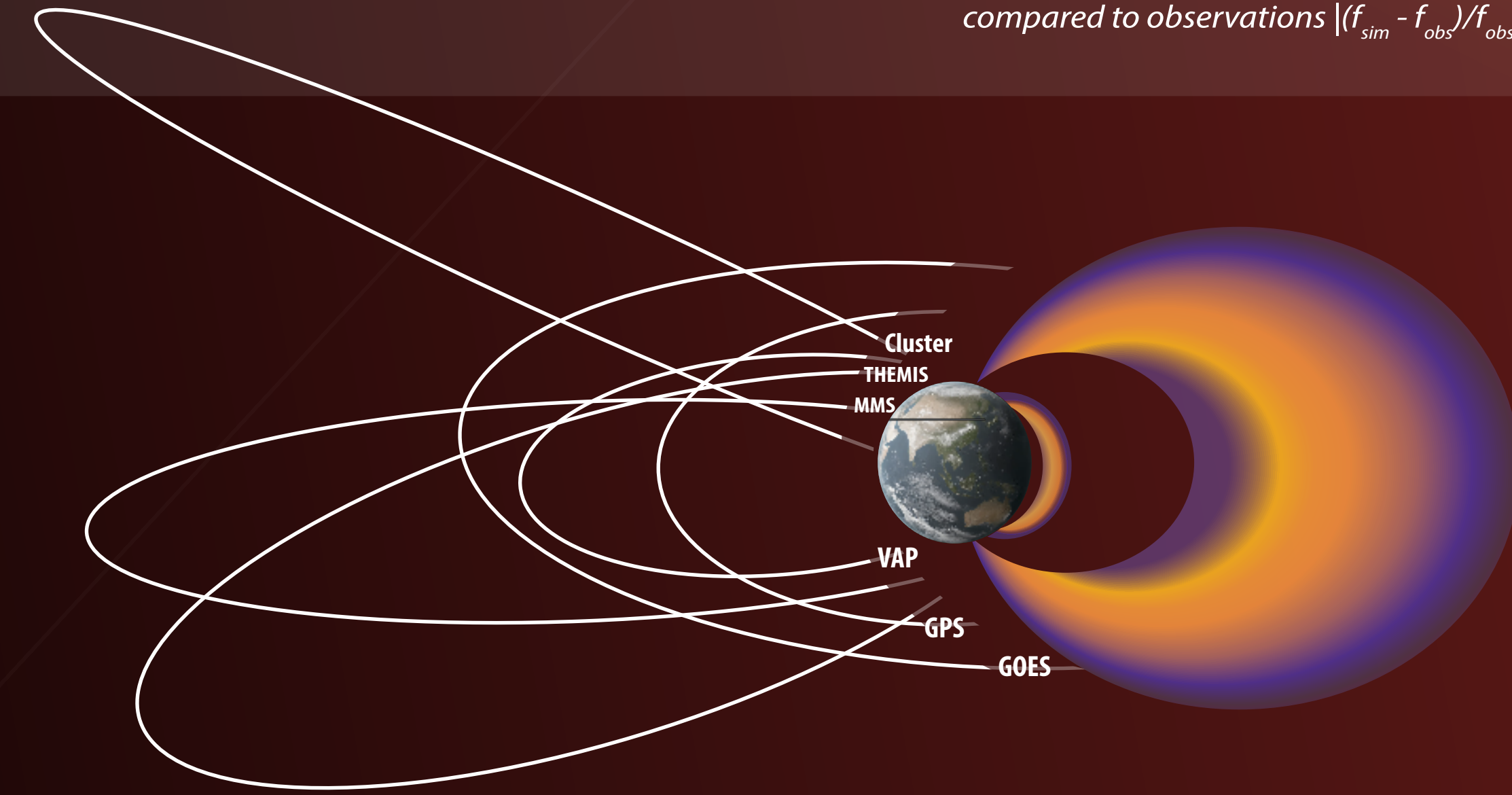


Figure 1. (a) Simulated radiation belt PSD at 00UT on 10th Aug 2017 as a function of L^* over time for $\mu = 700$ MeV/G and $K = 0.1 G^{0.5} R_E$. Middle: Corresponding PSD observations taken by multi-mission dataset. Bottom: Percentage error of RBFMF compared to observations $|(f_{sim} - f_{obs})/f_{obs}| \times 100$.



4. Analysis

Overall Performance (2016-2018)

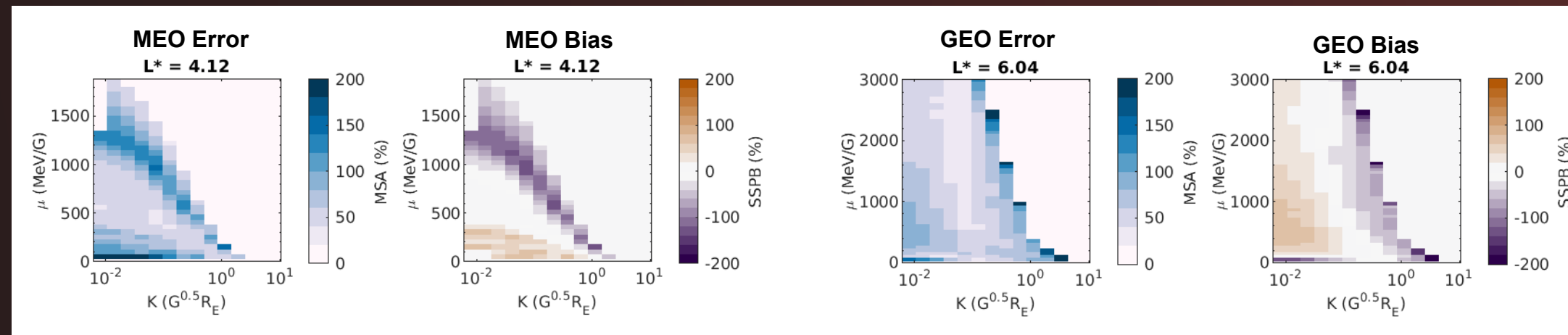


Figure 2: MSA (error) and SSPB (bias) between 2016-2019 are shown as function of μ and K at MEO (left) and GEO (right).

Storm-time Assessment

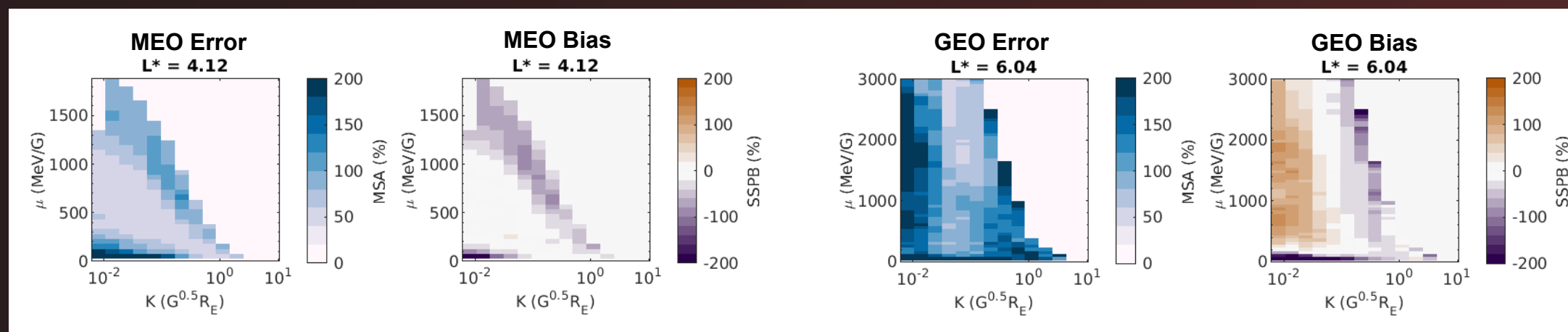


Figure 3: MSA and SSPB during geomagnetic storms occurring between 2016-2019. Storms are classified by Sym-H minima < -40 nT.

Influence of Assimilated Data

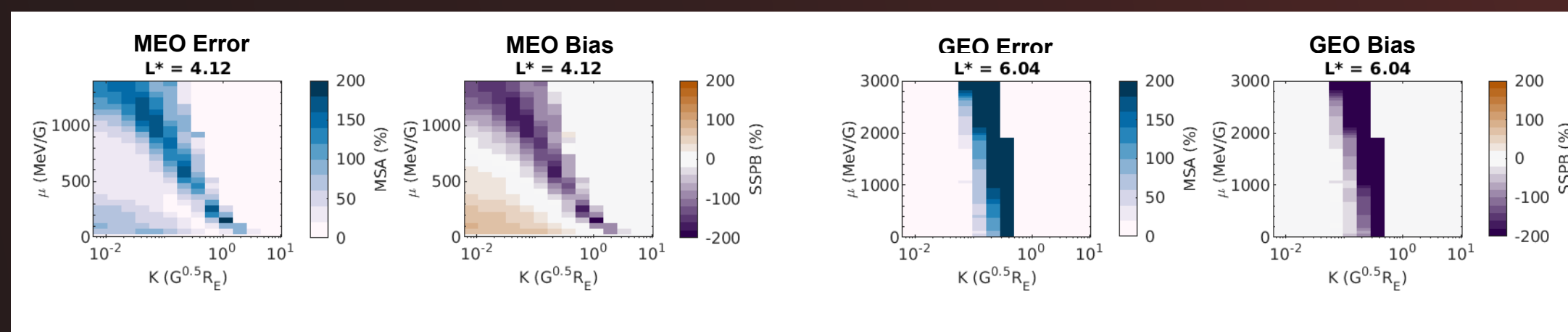


Figure 4: MSA and SSPB of the Van Allen Probe-B beacon data compared to the final Van Allen Probe-B science data product.

Post Van Allen Probe Decomission (2019 - 2020)

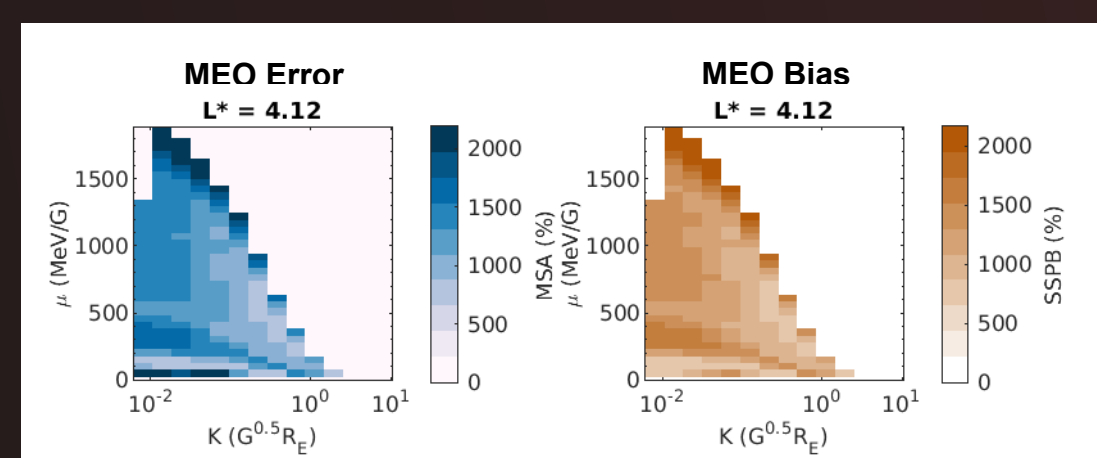


Figure 5: MSA and SSPB of the 10-hour hindcast as compared to GPS observations at MEO for the years 2019-2020.

Outer radiation belt error was < 150%.

> Error and bias depended strongly upon μ , K , and L^* : PSD at high μ ($E > 1$ MeV) was biased toward underestimation by up to 150%, and PSD at low μ ($E < 300$ keV) was biased toward overestimation by up to 70%.

> PSD at $\mu < 500$ MeV/G ($E < 700$ keV) was underestimated during storm times - associated with substorms.

> PSD of equatorial electrons ($K < 0.1 G^{0.5} R_E$) was overestimated at GEO - associated with magnetopause loss.

Van Allen Probe beacon data greatly influenced hindcast bias

> shown by matching relationships in bias when beacon data was tested against final science data.

Prediction accuracy significantly decreased when real time Van Allen Probe data were not available.

5. Conclusion

Data assimilation substantially improved the error and bias of radiation belt specification but strongly influenced error and bias.

Test new models of diffusion coefficients for Hiss, Chorus, and ULF waves.

Radiation Belt hindcasts were accurate within 150% at MEO and GEO from 2016-2018.

The physics based model must be improved now real-time Van Allen Probe observations are no longer available.

Future Model Development

Improve representation of storm time losses: EMIC wave scattering through new diffusion coefficients and improving the dynamic outer simulation boundary.

New missions providing real-time observations at MEO and GEO are required to enable accurate forecasting of the radiation environment.

Simulate substorm injections through updates to the inner simulation boundaries.