European Space Weather Week 2025

# Global Validation of the Data-Assimilative VERB-3D Code for the Radiation Belts

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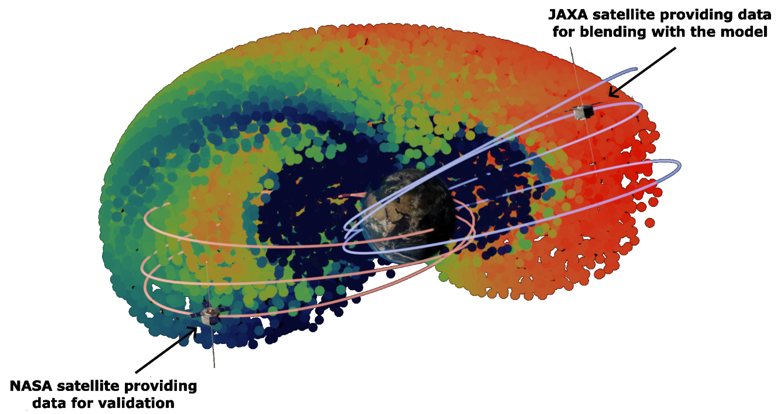
# 1. Motivation and Objectives

- We use data-assimilation (Kalman Filter) to blend sparse measurements with the physics-based model VERB-3D in order to fill the gaps and construct a reliable data set




- We want to validate the Data-Assimilative scheme using two independent datasets, **assimilating Arase with the model** and **comparing it** afterwards against the **Van Allen Probes**

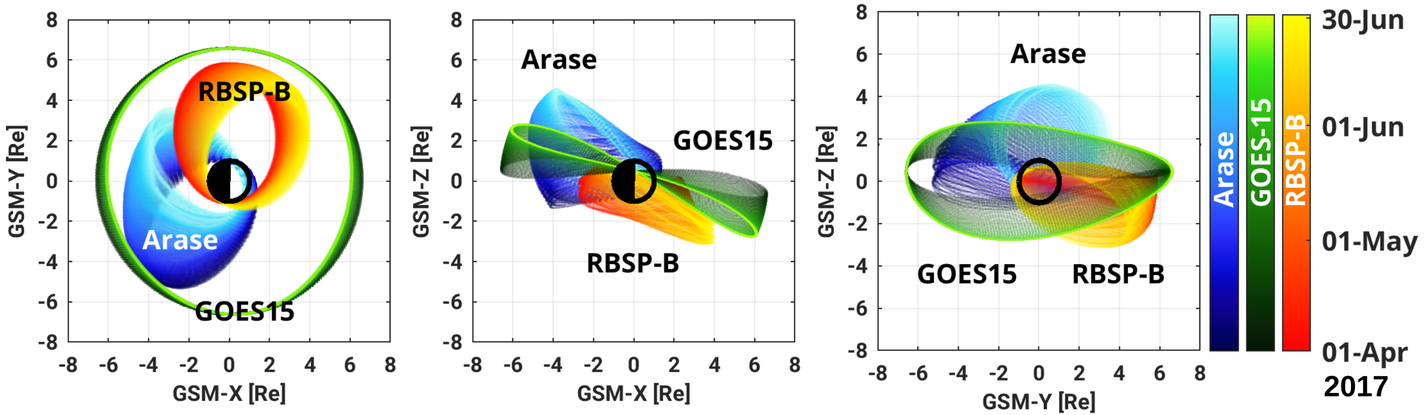
# 2. Satellite data

Satellite observations are limited due to spatial coverage, and individual data sets can be noisy and incomplete

**Van Allen Probes:** Launched on August 2012 and deactivated October 2019.

**Arase:** Launched on December, 2016 ***and counting!***

**GOES:** Launched in 2006 and 2010.



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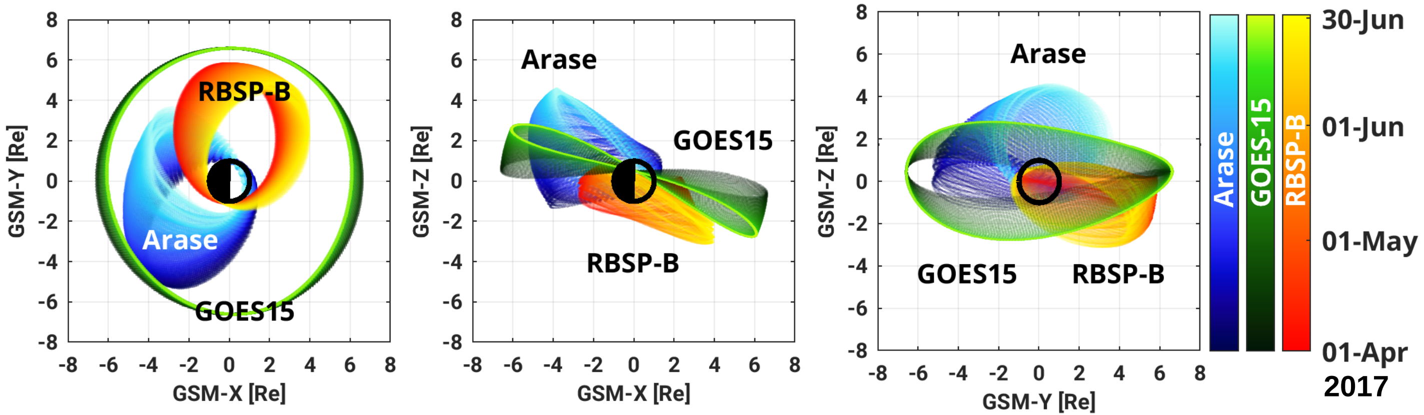
**To ensure that they do not exhibit systematic differences we adjust to the same reference frame**



# 3. Satellite data harmonization

Minimize discrepancies between different instruments, so datasets can be reliably used together for validation purposes, ensuring they are consistent and comparable.

## > Identifying magnetic conjunctions

We match ***electron-flux observations at magnetic coordinate conjunctions*** using pitch angle resolved data:

$$(1) \qquad \Delta t \leq 30\,\mathrm{min}$$

$$(2) \qquad \Delta L^\star \leq 0.1,\ L^\star > 3$$

$$(3) \qquad \Delta MLT \leq 1$$

We interpolate the ***VAP*** measurements in energy to match the ***Arase*** energy channels using linear interpolation in logarithm of energy.

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## > Correction of the dataset

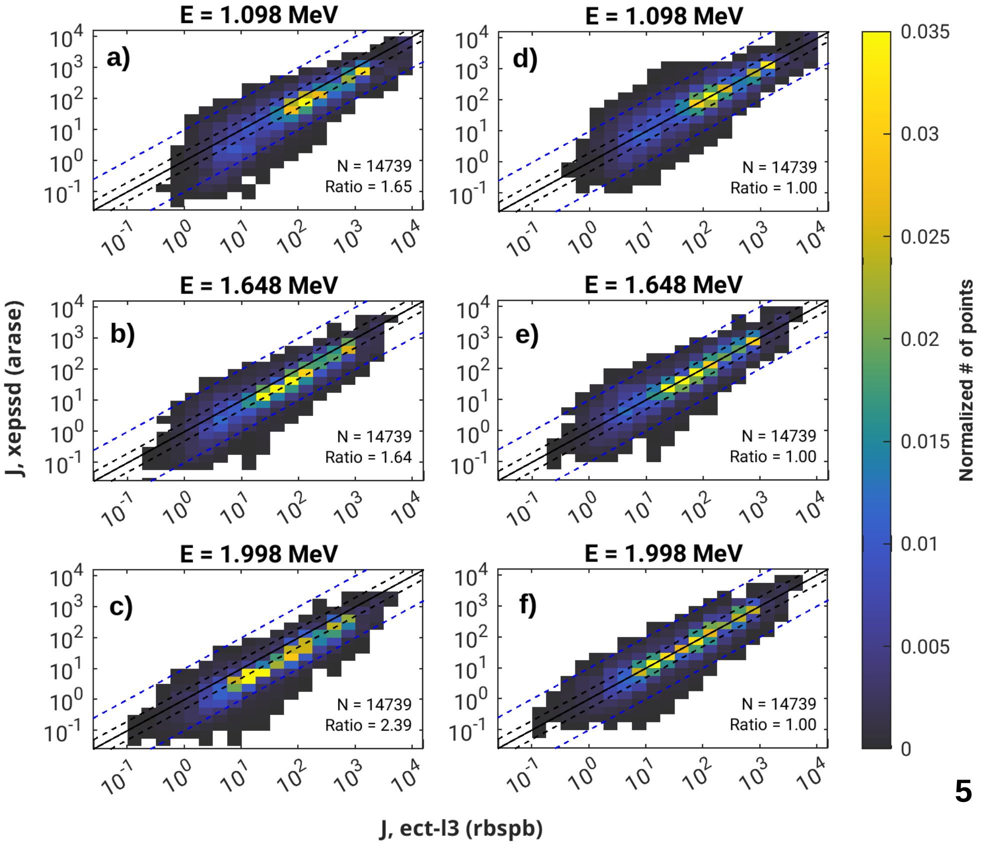
We adjust the datasets using the following ***factor*** that depends only on the energy channel:

$$ratio\,(E) = \frac{j_{\mathrm{VAP}}}{j_{\mathrm{Arase}}}$$

# 3. Satellite data harmonization

- Between Arase and Van Allen Probes

- Intercalibration for magnetic conjunctions shows a good agreement



# 4. The VERB-3D Code

The 3D Versatile Electron Radiation Belt Code (VERB-3D) describes the evolution of the Radiation Belts by solving the Fokker-Plank equation, in terms of radial distance (L), relativistic momentum (p), and pitch angle (α) as:

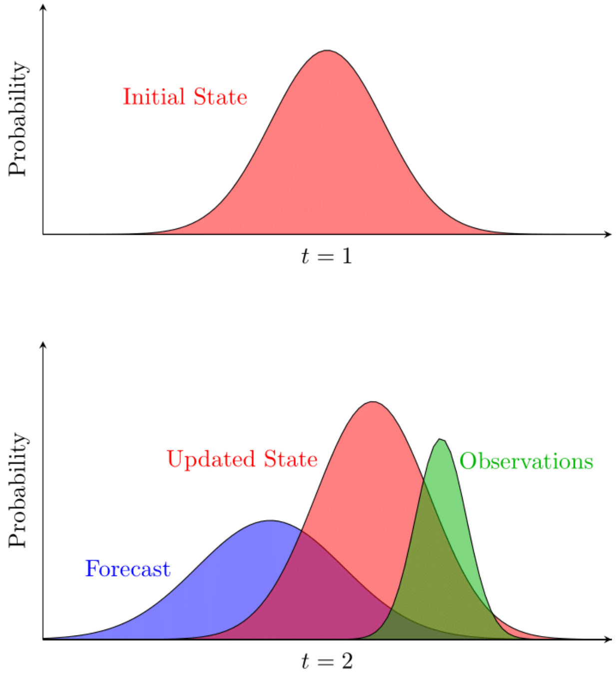
$$\frac{\partial f}{\partial t} = \underbrace{L^{*2} \frac{\partial}{\partial L^*}\bigg|_{\mu,J} \left( \frac{1}{L^{*2}} D_{L^*L^*} \frac{\partial f}{\partial L^*}\bigg|_{\mu,J} \right)}_{\text{Radial diffusion}} + \underbrace{\frac{1}{p^2} \frac{\partial f}{\partial p}\bigg|_{\alpha_0,L^*} p^2 \left( D_{pp} \frac{\partial f}{\partial p}\bigg|_{\alpha_0,L^*}\right.}_{\text{Energy diffusion}} \underbrace{\left. + D_{\alpha_0 p} \frac{\partial f}{\partial \alpha_0}\bigg|_{p,L^*} \right)}_{\text{Mixed diffusion}} +$$

$$\underbrace{+ \frac{1}{T(\alpha_0)\sin(2\alpha_0)} \frac{\partial}{\partial \alpha_0}\bigg|_{p,L^*} T_{\alpha_0} \sin(2\alpha_0) \left( D_{\alpha_0\alpha_0} \frac{\partial f}{\partial \alpha_0}\bigg|_{p,L^*}\right.}_{\text{Pitch-angle scattering}} \overbrace{\left. + D_{\alpha_0 p} \frac{\partial f}{\partial p}\bigg|_{\alpha_0,L^*} \right)}^{\text{Mixed diffusion}} - \frac{f}{\tau}$$

where *f* is the phase space density, α the equatorial pitch angle, p the relativistic momentum and L* indicates the location of the drift paths of energetic electrons. The code includes chorus an hiss waves.

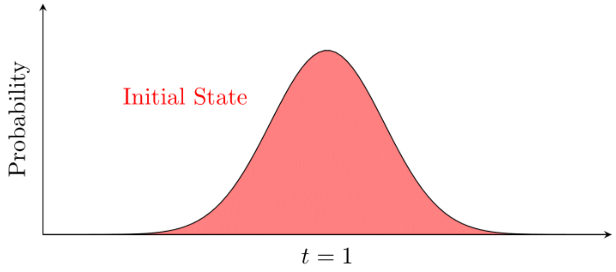
# 5. Validation: the Kalman Filter

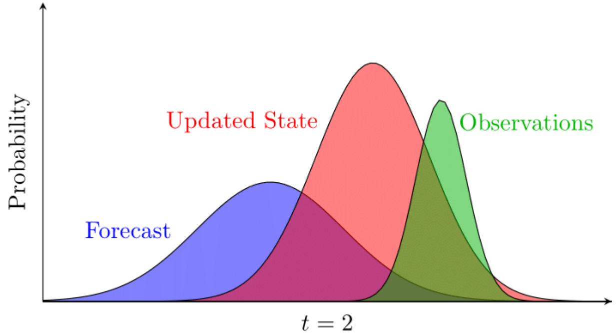
- The **Kalman Filter** can blend sparse measurements with physics-based models (**VERB-3D**)



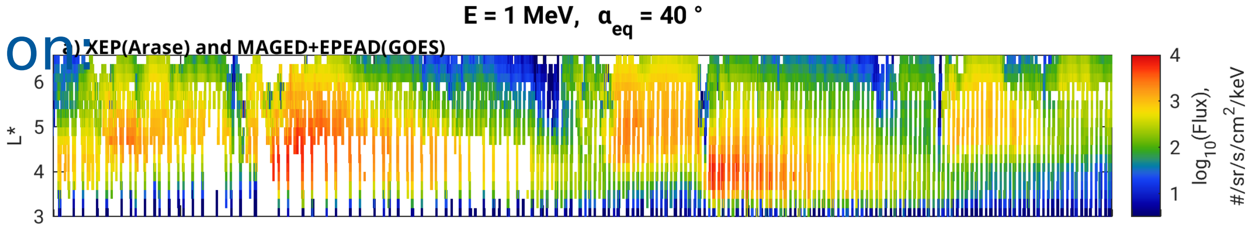
# 5. Validation: the Kalman Filter

- The **Kalman Filter** can blend sparse measurements with physics-based models (**VERB-3D**)
- We assimilate Arase and GOES measurements into the VERB-3D code
- We validate against Van Allen Probes observations, which are **not** used for data assimilation
- Time: from **April to June of 2017.**



# 6. Validation:



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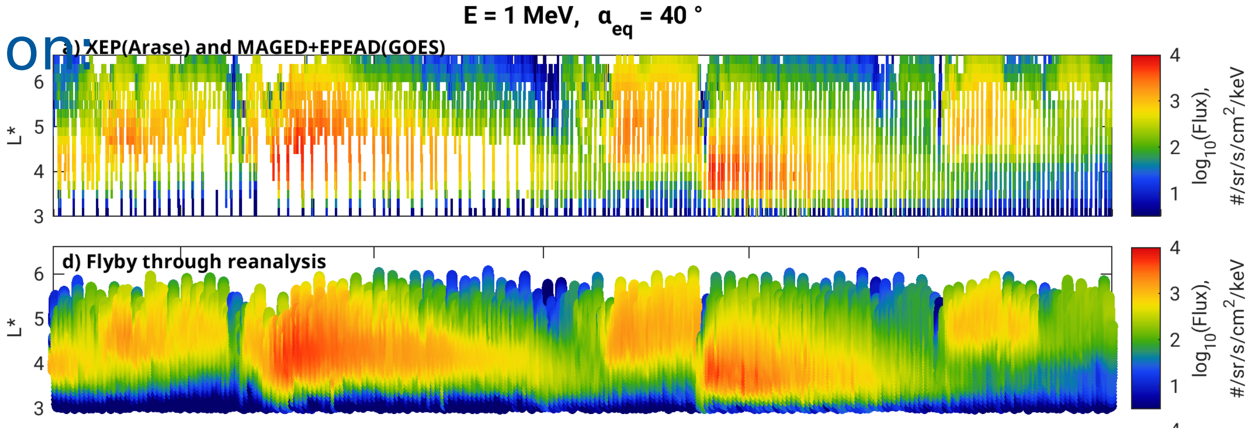

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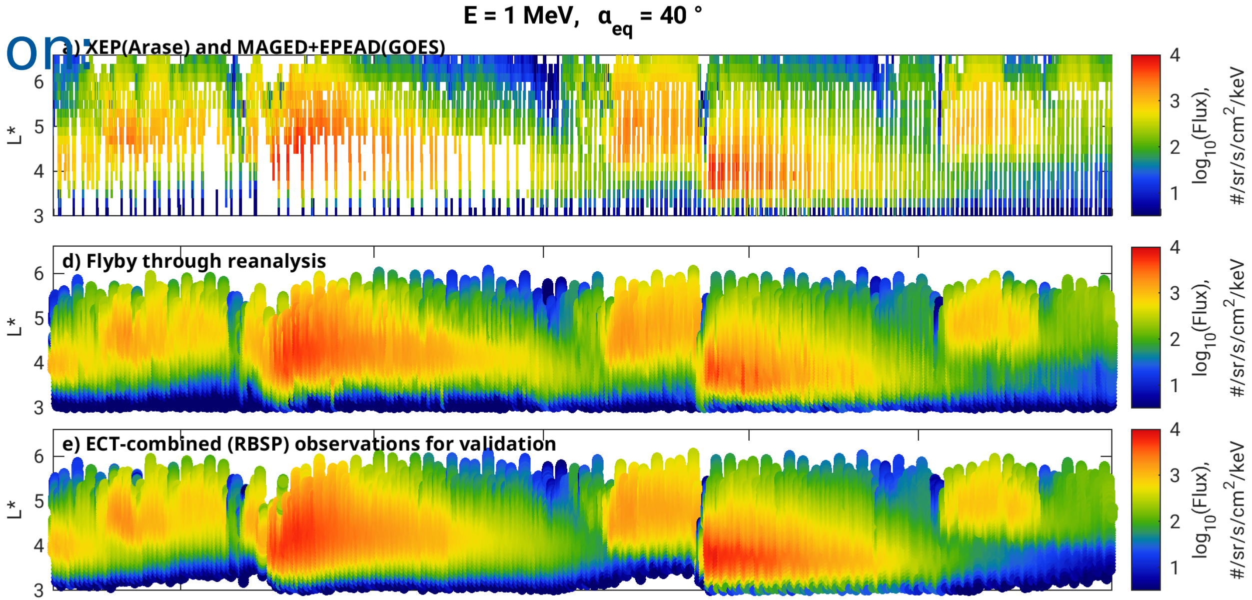

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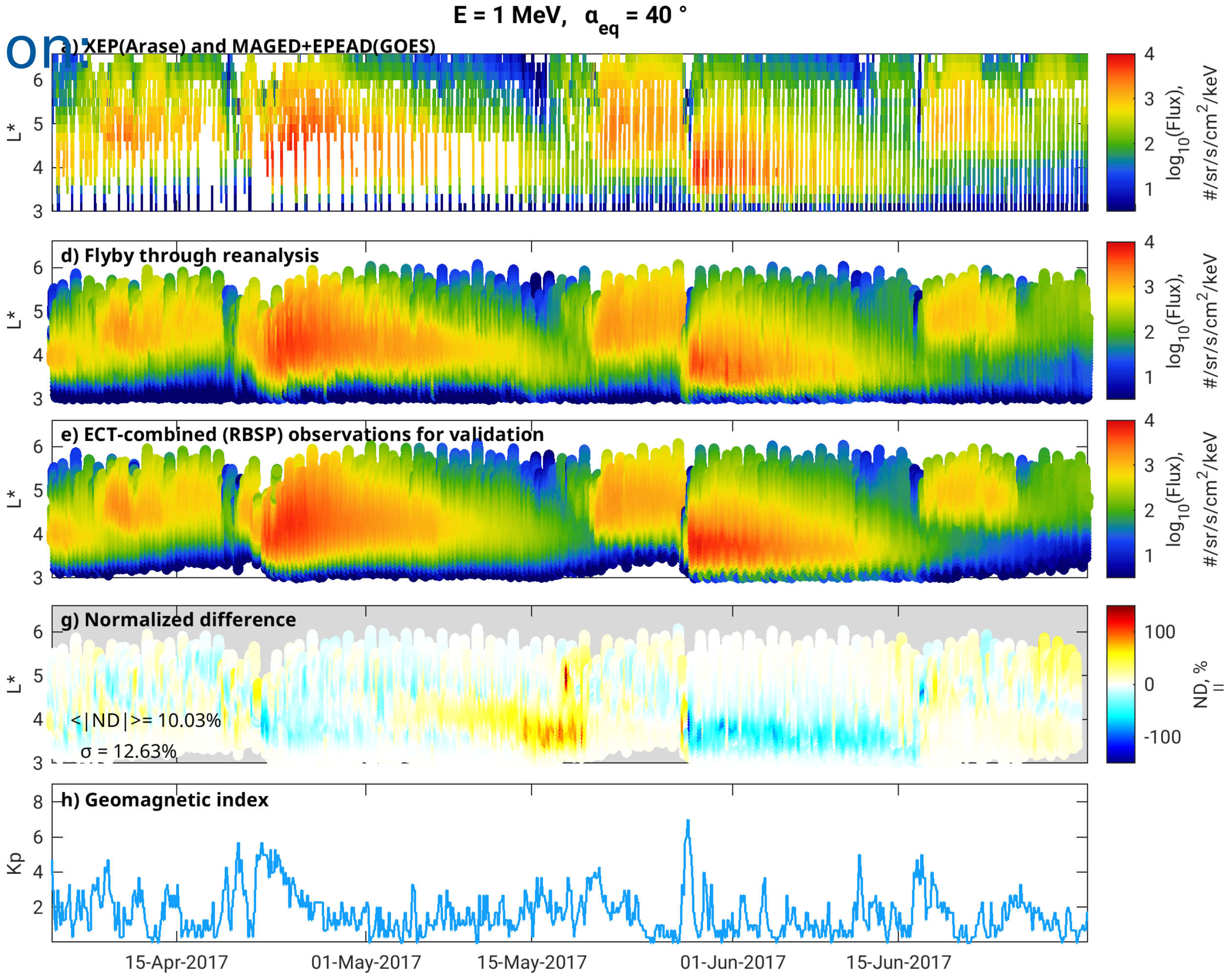


$$ND = \frac{j_{\rm obs}(L^*,t) - j_{\rm model}(L^*,t)}{\max_{8h} \frac{j_{\rm obs}(L^*,t)+j_{\rm model}(L^*,t)}{2}}$$

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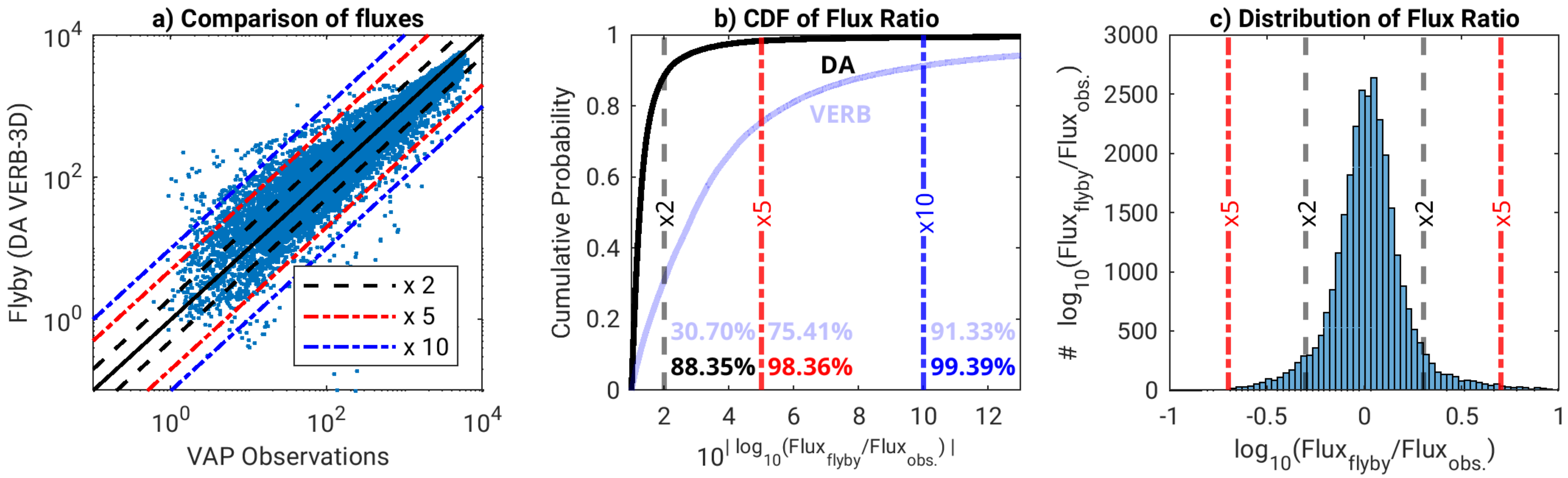
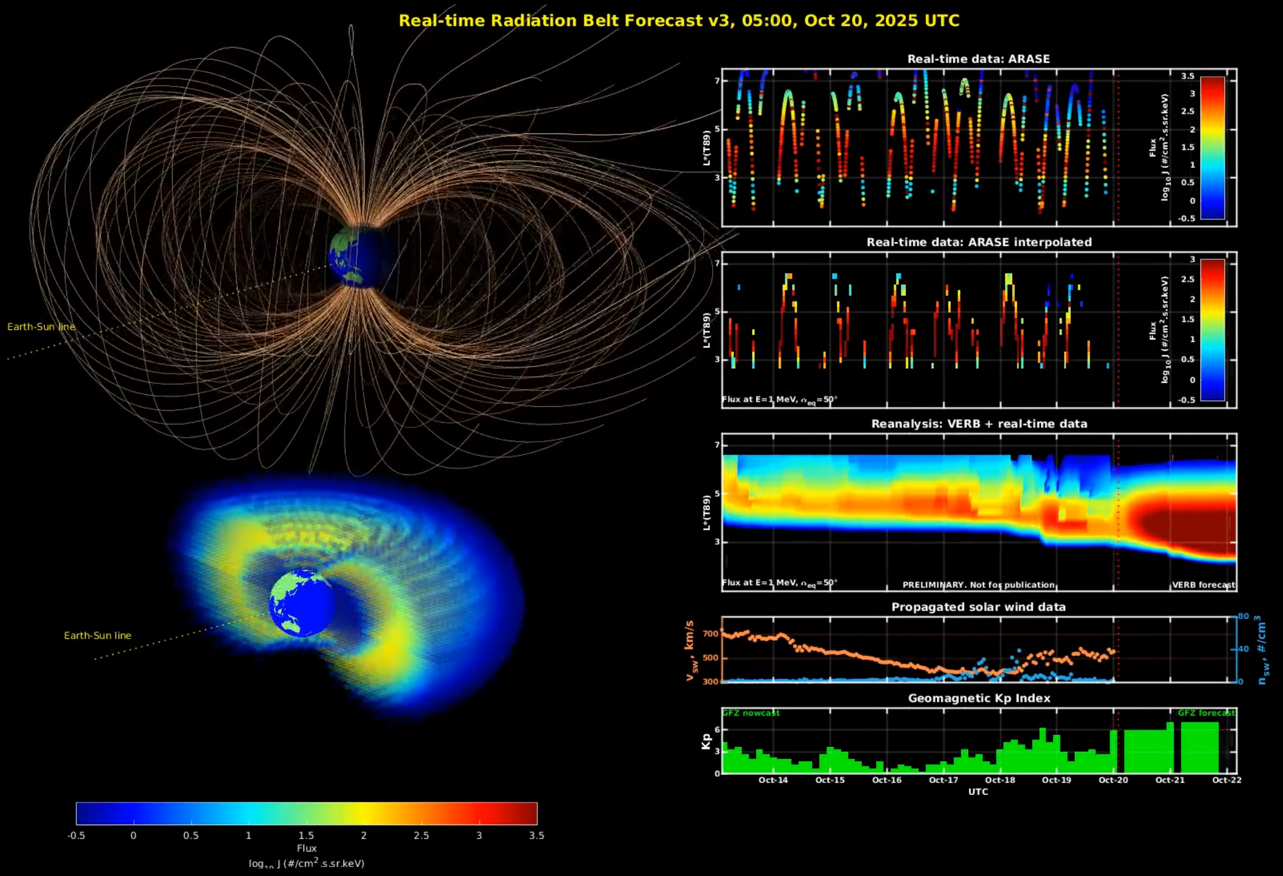
# 6. Validation:

**98% of the reanalysis falls within a factor of 2 when compared to the VAP observations!**



# 7. Radiation Belt Forecast




https://spaceweather.gfz-potsdam.de/products-data/forecasts/data-assimilative-radiation-belt-forecast

# 8. Conclusions

- Data assimilation provides to be a reliable technique for radiation belt reconstruction.

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- We sucessfully reproduce Earth’s radiation belts assimilating ARASE and GOES with VERB-3D.

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# 8. Conclusions

- Data assimilation provides to be a reliable technique for radiation belt reconstruction.
- We sucessfully reproduce Earth’s radiation belts assimilating ARASE and GOES with VERB-3D.
- The use of **two independent datasets** demonstrates great potential for space weather applications.

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