Towards quantifying model error from spectral radiative transfer models

➡ An application to **PROSPECT** model

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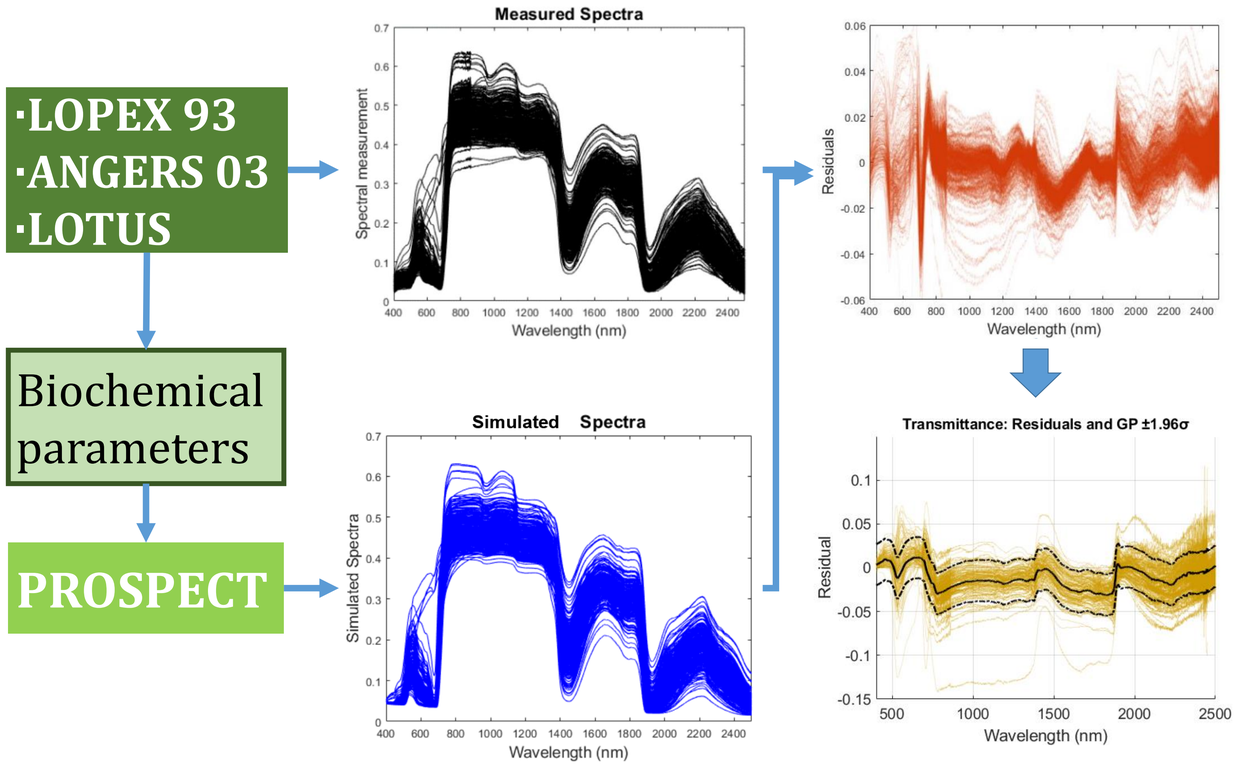
Abstract

Radiative Transfer Models (RTMs) are essential tools for interpreting Earth Observation data, but their internal uncertainties are often ignored. While recent efforts in uncertainty quantification have focused on propagating measurement errors, the structural uncertainty of the models themselves remains unexplored. In this work, we assess the inherent uncertainty in the PROSPECT leaf model by comparing model outputs generated using ground-truth biochemical parameters to measured spectral signatures. We model the residuals using a zero-mean Gaussian Proces, allowing us to characterize the spectral uncertainty of the model across a range of conditions. This approach offers a practical route towards integrating model error into uncertainty-aware EO applications.

PROSPECT spectral uncertainty as a GP:

A modeling strategy



PRE-PROCESSING steps

a) Estimation of N parameter for LOTUS.

b) Estimation of anthocyanin for LOPEX and ANGERS.

c) Removal of senescent leafs.

d) Outlier detection on the residuals.

· A total of **633 spectral samples** remain (reflectance and transmittance) from 400 to 2500 nm.

MODELING APPROACH

1. Use ground-truth input parameters $\vec{\theta}$ to generate model predictions of reflectance $\rho(\lambda)$ and transmittance $\tau(\lambda)$:

$$\mathcal{M}_x(\vec{\theta}), \text{ with } x \in \rho,\ \tau$$

2. Compute the **residuals** between model and measurements:

$$r_x(\lambda) = x_{meas}(\lambda) - \mathcal{M}_x(\vec{\theta})$$

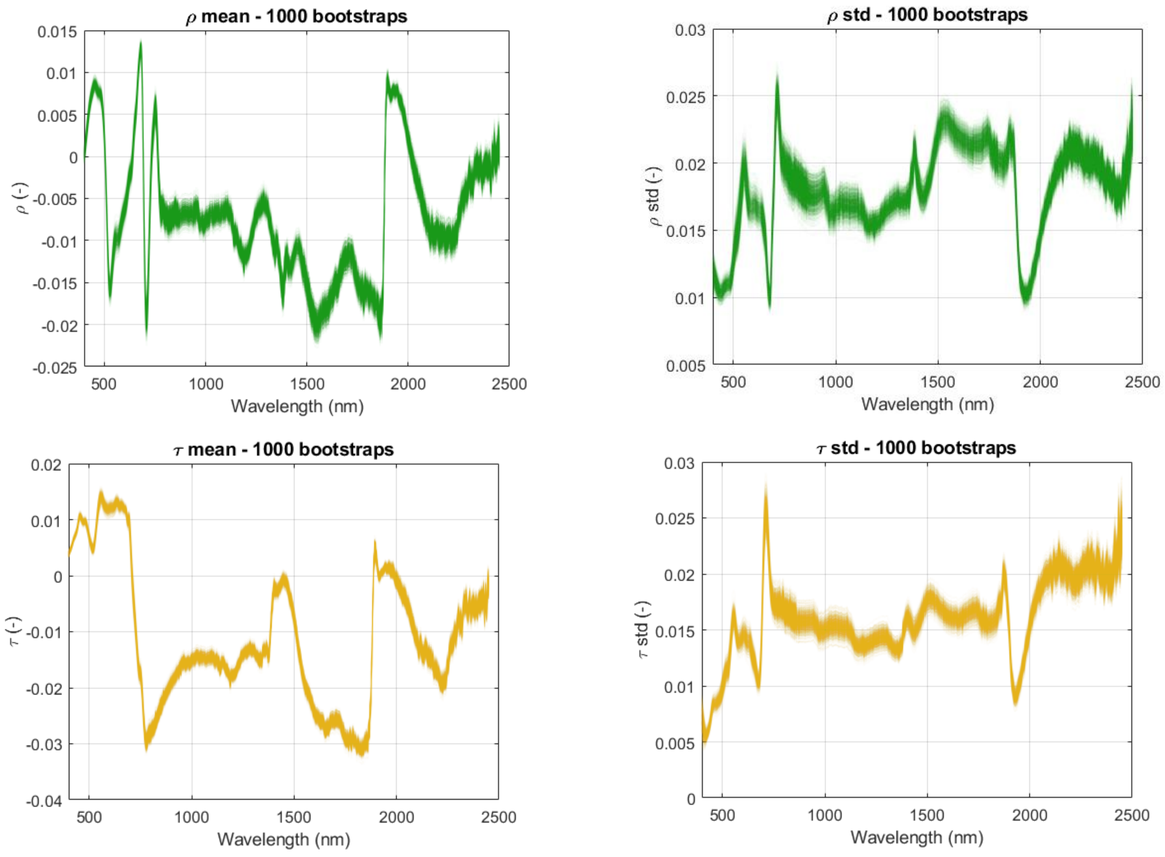
3. Fit two independent **zero-mean Gaussian Processes** across all samples:

$$r_x(\lambda) \sim \mathcal{GP}\left(0,\ k_x(\lambda, \lambda')\right)$$

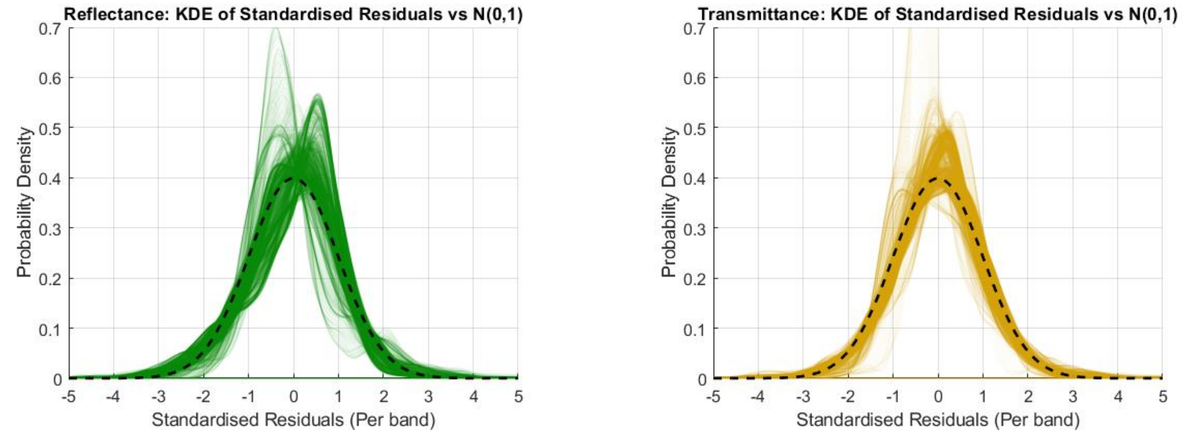
4. The two GPs encode the model uncertainty:
   - · GPs capture **smooth and structured** residuals.
   - · Posterior GP variance serves as a spetral **estimate of model error**.

Results

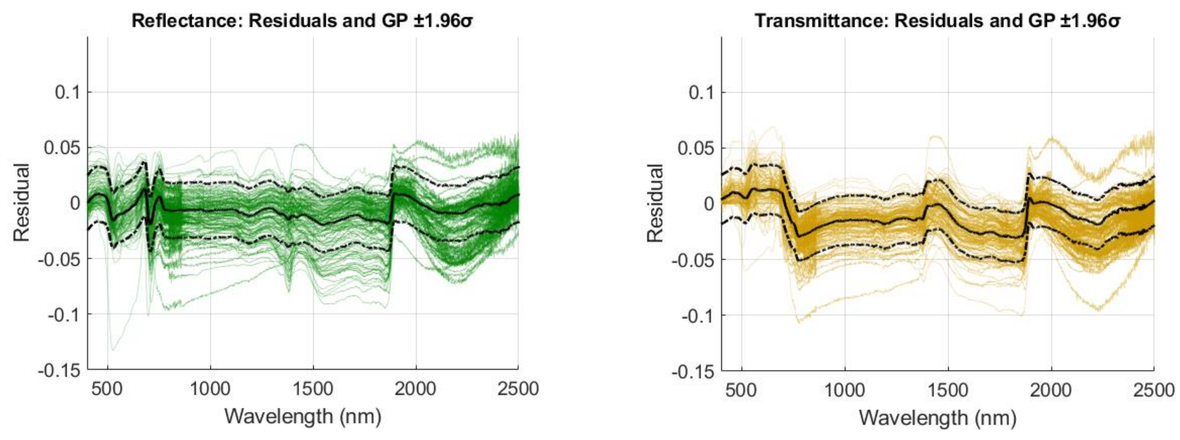
· Mean and variance for 1000 realizations of the training datasets.



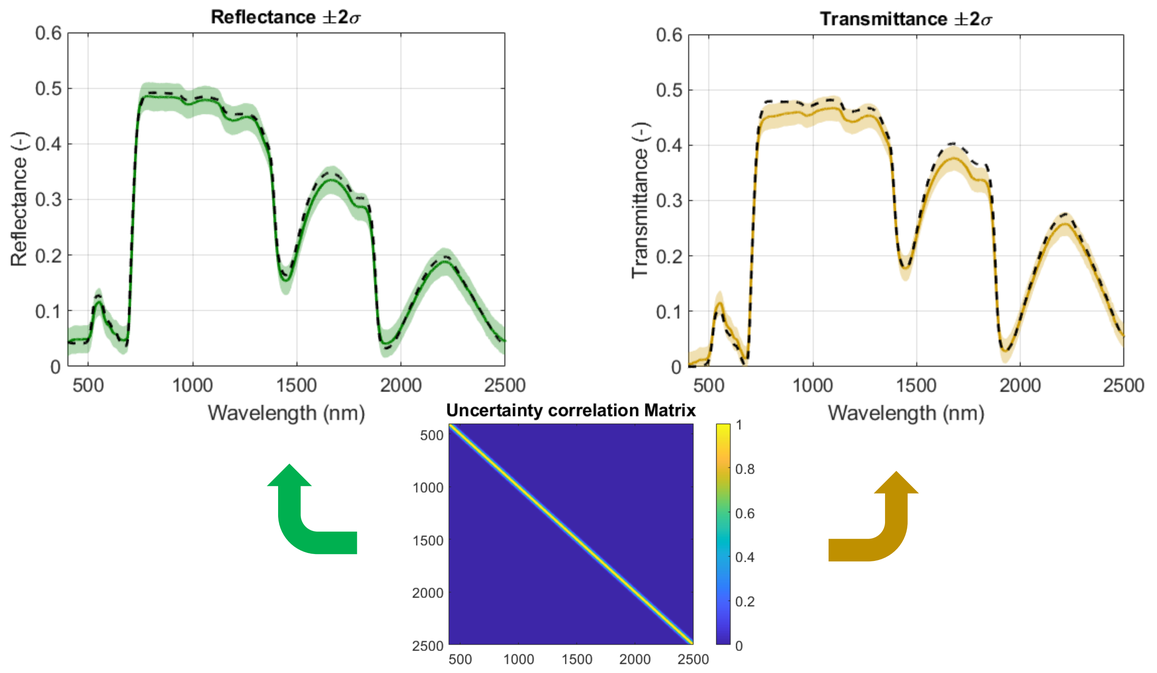
· Training residuals against $N(0,1)$



· Spectral plot of test residuals and dashed GP ±1.96σ interval.



· PROSPECT and PROSPECT with GP-error model.



Conclusions

- **Simple method** to quantify RTM uncertainty, demonstrated with **PROSPECT-PRO**.
- Adds **model error estimates** alongside observational uncertainty for inversion and simulation.
- Current model likely **underestimates uncertainty** due to wavelength-dependent bias in residuals.
- Working on **exemplary user-cases**: leaf biochemical parameter inversion.
- **Want to test on your data? Get in touch!**

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Funding

PANGEOS · cost EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY · erc · flexinel · LEVERHULME Centre for Wildfires, Environment and Society · LEO Laboratory for Earth Observation · King's College London · National Centre for Earth Observation NATURAL ENVIRONMENT RESEARCH COUNCIL · Universitat de València