CHIME-Oriented Analysis of Aleatoric Uncertainty Propagation in GPR-based L2B vegetation retrieval models

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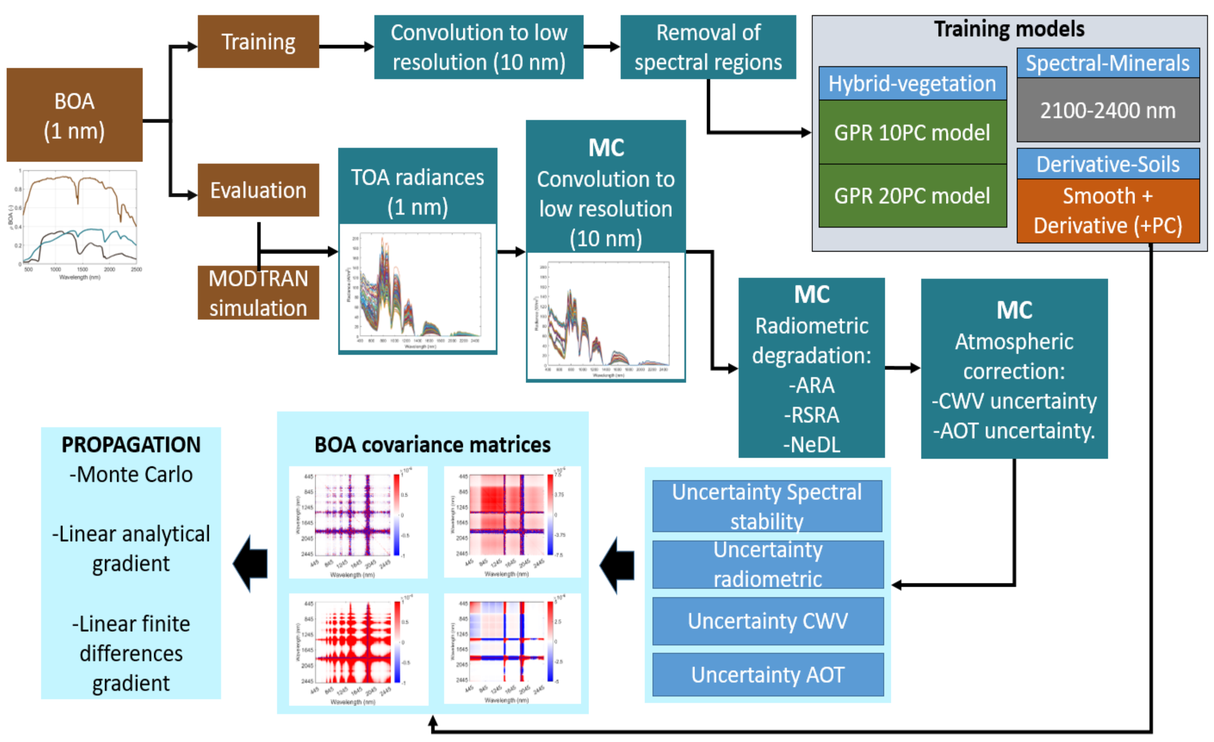
Abstract

The upcoming launch of the Copernicus hyperspectral imager CHIME will produce an unprecedented stream of data. Specifically, bottom-of-atmosphere reflectance (L2A product) serves as the fundamental source of information for the upper level products, i.e. L2B biophysical products. The present work explores the impact of the uncertainties of L2A on the L2B biophysical products, in particular LAI, LWC, SOC and kaolinites abundance. The retrieval of these variables ingest BOA reflectances into different algorithms which core MLRA is GPR. Thus, in the present work, BOA reflectances and its spectral covariances are generated in a CHIME context. Then, these uncertainties are propagated through the different processing chains via Monte Carlo and compared against the results obtained with linear uncertainty propagation.

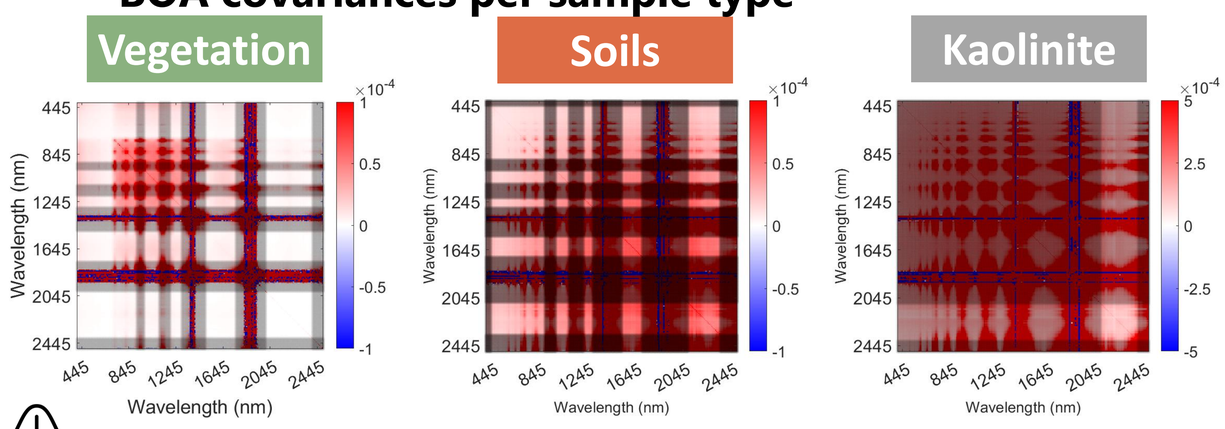
WORKFLOW & DATA GENERATION

High resolution BOA reference reflectances comming from PRO4SAIL (vegetation), spectral measurements (SOC) and spectral mixtures (kaolinites) is combined with MODTRAN to create TOA radiances. Then, convolution to sensor resolution is applied, introducing uncertainty on spectral calibration and radiometry. Finally, atmosphere is corrected introducing uncertainty in CWV and AOT. Thus, obtaining BOA reflectance and covariance.

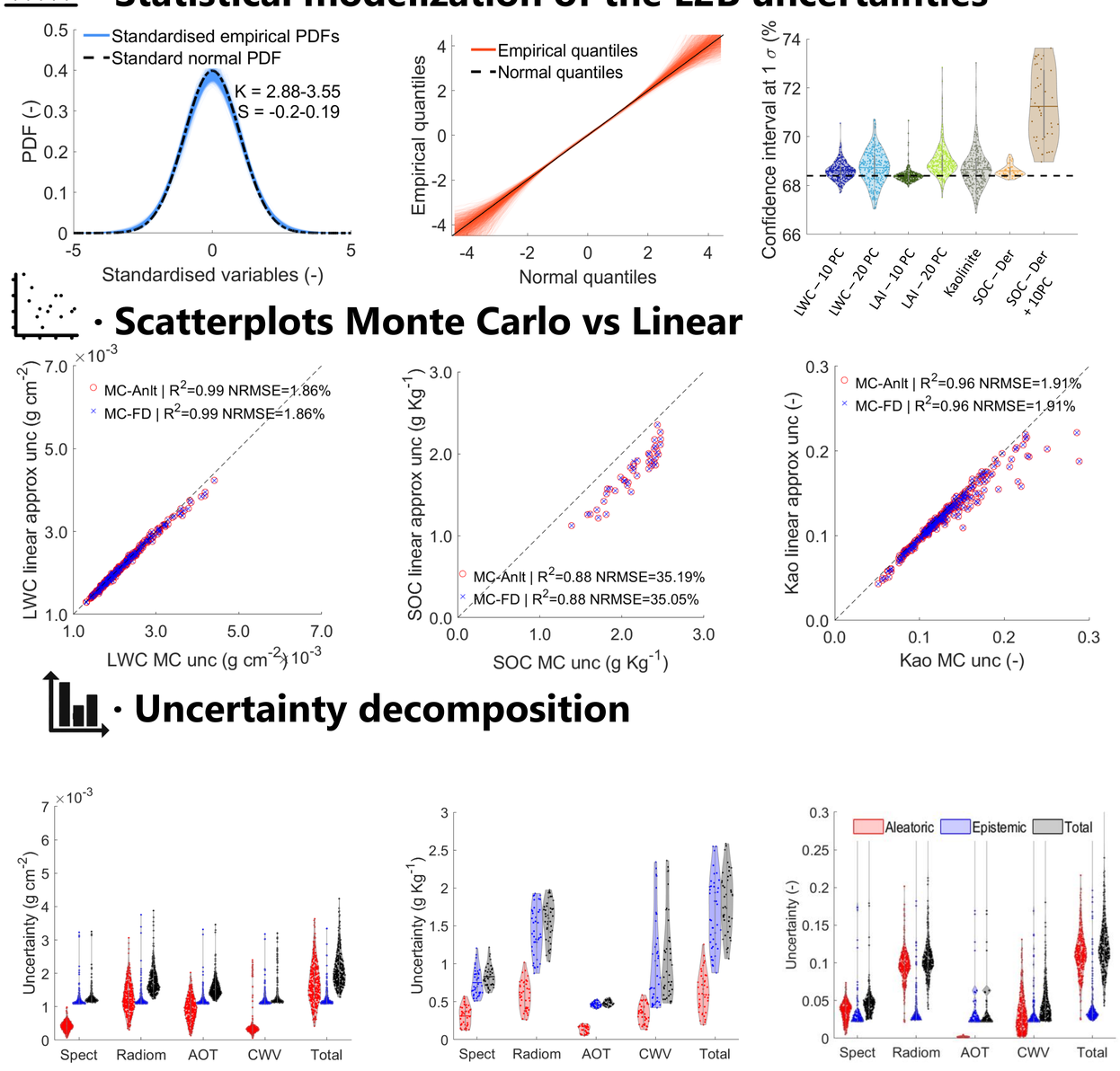


RESULTS & CHARACTERISATION

· BOA covariances per sample type



· Statistical modelization of the L2B uncertainties



· Scatterplots Monte Carlo vs Linear

· Uncertainty decomposition

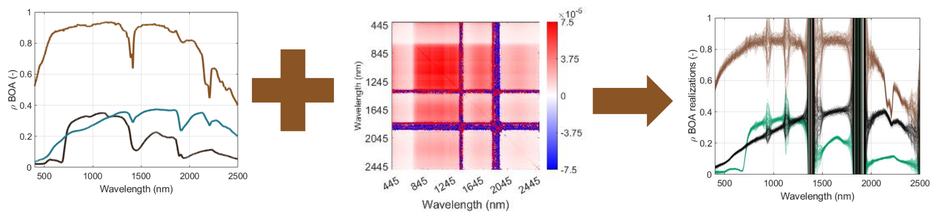
· Computation time

	MC (s)	Analytical grad (s)	Finite diff grad (s)
LAI - 10 PCs	5,00	0,04	0,09
LAI - 20 PCs	2,06	0,05	0,16
LWC - 10 PCs	5,11	0,05	0,10
LWC - 20 PCs	5,04	0,05	0,15
Kao - 30 bands	186,77	0,46	11,12
SOC - derivative	0,65	0,05	0,08
SOC – derivative 10 PCs	0,56	0,05	0,05

METHODS: Uncertainty propagation

Monte Carlo

$$p(y_*|x_*,\mathcal{D}) = \int p(y_*|x_*,\mathcal{D})p(x_*)dx_* \approx \frac{1}{N}\sum_{i=1}^{N} p(y_*|x_*^{(i)},\mathcal{D})$$



Linear

$$\sigma^2_{\text{total}} = \mathbb{E}\left(\sigma^2_{\text{GP}*}\right) + \text{Var}\left(\mu_{\text{GP}*}\right)$$

Epistemic component
GP predictive variance

$$Var(\mu_{GP*}) = J_{\mu_{GP*}} * \Sigma_x * J^T_{\mu_{GP*}}$$

Vegetation - PCA

Standarization

$$\Sigma_z = diag(\sigma^{-1}) * \Sigma_{r_{BOA}} * diag(\sigma^{-1})$$

PCA Dimensionality reduction

$$\Sigma_x = W * \Sigma_z * W^T + z * \Sigma_W * z^T$$

Soils - Spectral derivative

Gaussian Smoothing

$$\Sigma_{r_{smooth}} = S * \Sigma_{r_{BOA}} * S^T$$

Spectral derivative

$$\Sigma_{r'} = D * \Sigma_{r_{smooth}} * D^T$$

PCA reduction

Pure derivative $\Sigma_x = \Sigma_{r'}$

Mineral – Spectral window

Kaolinite retrieval exploits an specific absorptance window. Thus no operation is required:

$$\Sigma_x = \Sigma_{r_{BOA}}$$

CONCLUSIONS & TAKE HOME MESSAGE

- **Aleatoric** and **epistemic** uncertainty are **propagated** through GPR-based L2B retrieval schemes.
- **Linear approximation** shows good **agreement** with benchmark **Monte Carlo** propagation.
- Substantial **reduction** in **computational cost** via linear approximation.
- **PCA reduces** the contribution of the **aleatoric** uncertainty to the total uncertainty budget.

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