On the surface apparent reflectance exploitation: Entangled Solar induced Fluorescence emission and aerosol scattering effects at oxygen absorption regions

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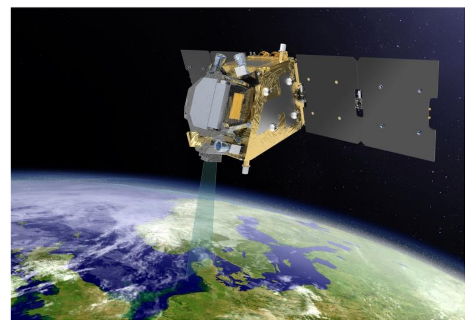
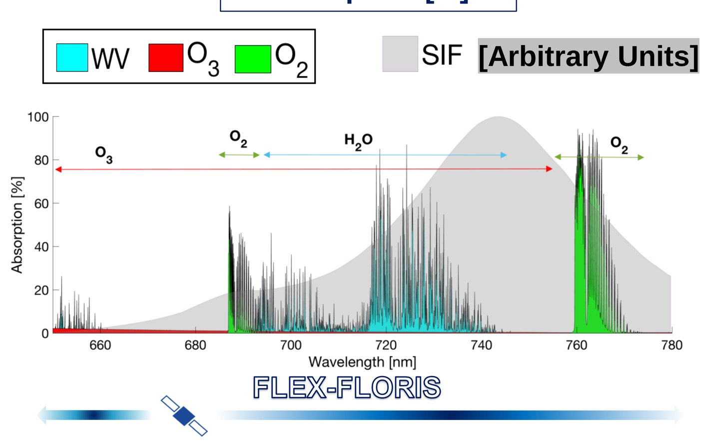
Introduction

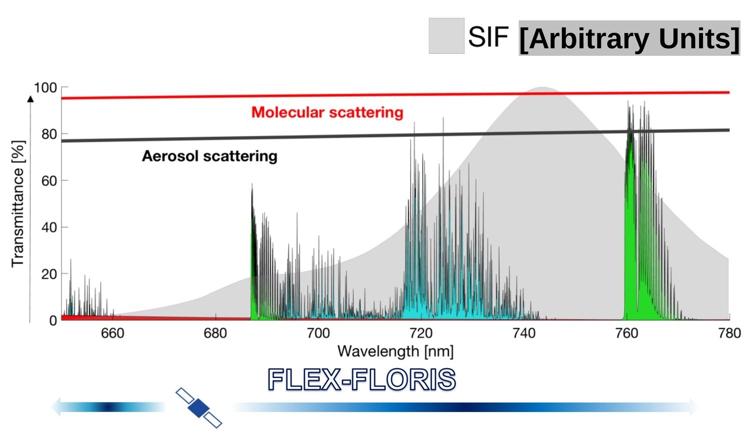


Artist's rendition of the **Fluorescent Explorer** satellite. [Credit: Thales Alenia Space/Briot]

Monitoring vegetation photosynthetic activity and its link with the carbon cycle at a global scale is a leading breakthrough that the scientific community has been seeking in recent years. Pursuing this goal, one of the most important advances in the last decade has been the measurement of the Solar Induced Fluorescence (SIF) at a satellite scale. Current satellite-derived SIF estimations provide SIF measured at certain specific wavelengths depending on the retrieval strategy and the instrument capabilities. However, for the time being, no global observations of the total spectrally resolved and integrated SIF signal have been yet achieved. In a near-future context, spectrally resolved SIF estimations will be provided by missions such as the FLuorescence EXplorer (FLEX) from the European Space Agency.

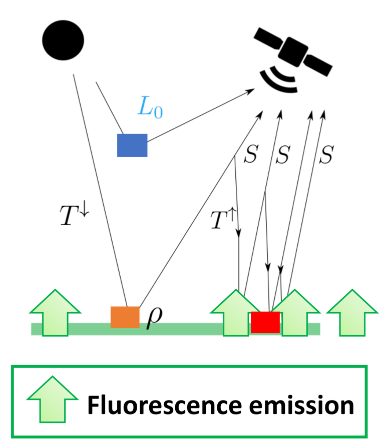
When disentangling the total SIF contribution, emitted between 650-800 nm, from the acquired satellite signal, molecular and aerosol absorption and scattering effects must be carefully accounted for. Particularly, within the oxygen absorption features, the characterization of the aerosol scattering effects represents the most critical step prior to the SIF estimation.





In the context of the FLEX/Sentinel-3 tandem mission concept, this work presents a novel technique that refines any a priori aerosol characterization process through the exploitation of the high spectral resolution surface apparent reflectance signal at the oxygen absorption regions. Within the absorption features, SIF contribution on satellite-derived surface apparent reflectance generates a characteristic peaky spectrum. However, these peaks can be simultaneously distorted through the atmospheric correction process due to inaccuracies in the aerosol characterization among other secondary sources. The presented technique improves the accuracy of any a priori aerosol retrieval by distinguishing distortions on surface apparent reflectance inferred by errors on the aerosol optical thickness, the Angstrom exponent, the asymmetry of the scattering and the single scattering albedo.

Theoretical basis



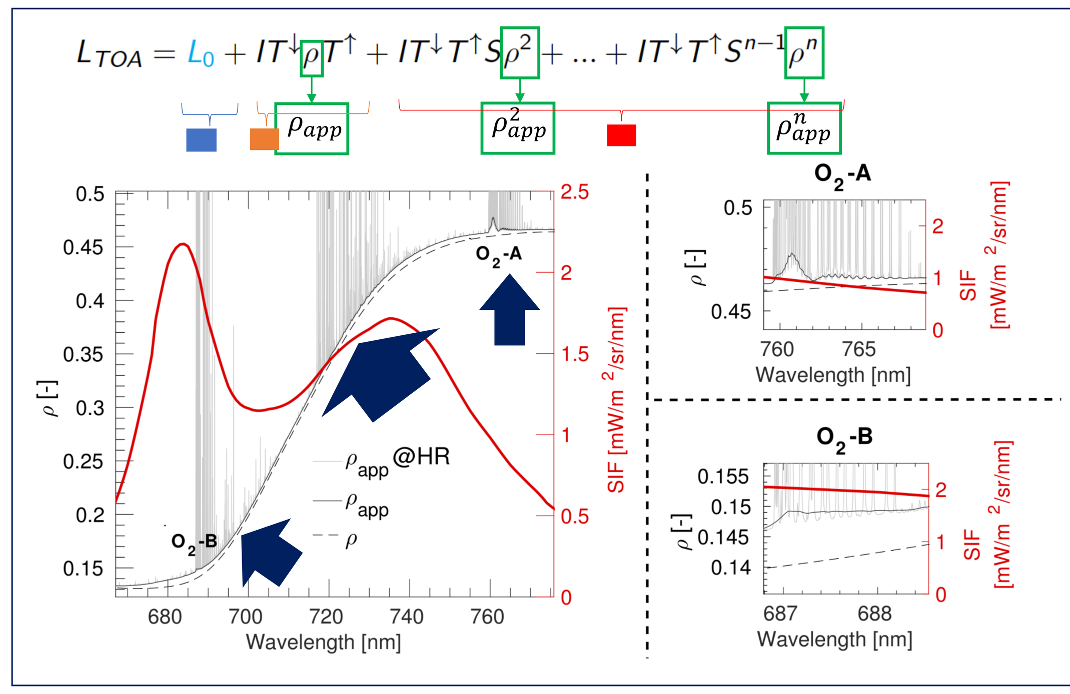
Radiance at satellite level (L_{TOA}) can be described as the contribution of different sources:

- Radiance scattered by the atmosphere (L_0)
- Radiance reflected by the surface and transmitted to the sensor
- Radiance reflected by the surface, backscattered by the atmosphere, reflected by the surface and transmitted to the sensor

$$L_{TOA} = L_0 + IT^{\downarrow}\rho T^{\uparrow} + IT^{\downarrow}T^{\uparrow}S\rho^2 + \dots + IT^{\downarrow}T^{\uparrow}S^{n-1}\rho^n$$

When adding the contribution of the emitted SIF; TOA radiance can be formulated as

$$L_{TOA} = L_0 + IT^{\downarrow}\rho_{app}T^{\uparrow} + IT^{\downarrow}T^{\uparrow}S\rho_{app}^2 + \dots + IT^{\downarrow}T^{\uparrow}S^{n-1}\rho_{app}^n$$

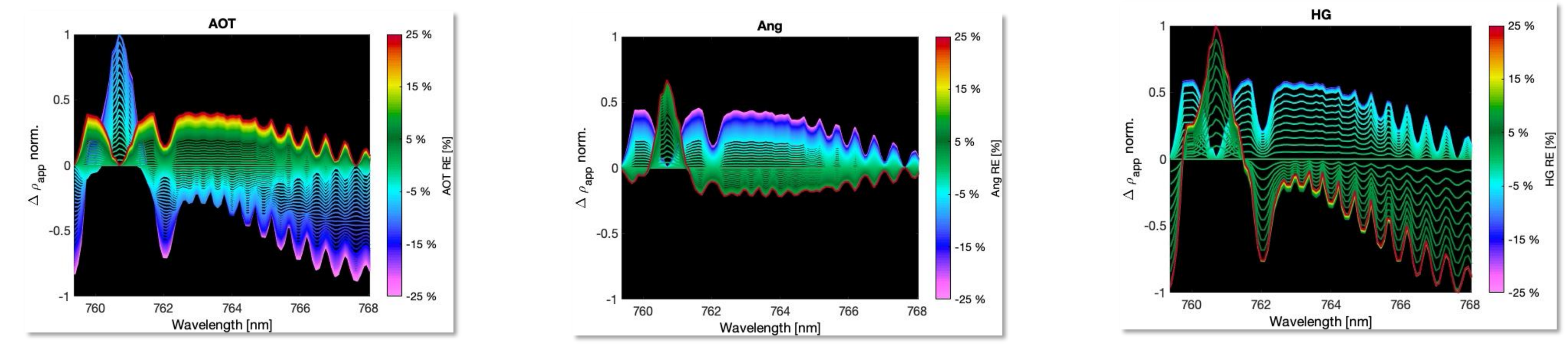


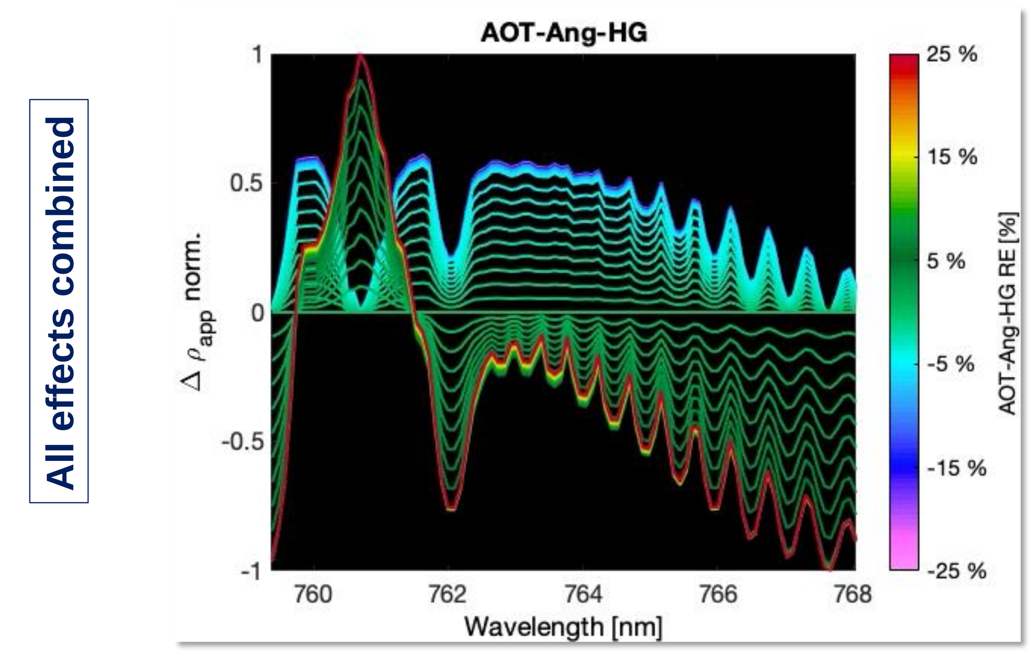
ρ_{app} peaks can be distorted due to inaccuracies on the aerosol characterization; which is typically one of the major sources of uncertainty in an atmospheric correction process.

Peaks in the surface apparent reflectance (ρ_{app}) are specially noticeable on the strongest absorption features

Analyzing the spectral distortion on the surface apparent reflectance due to distinct aerosol optical properties:

- Distortion normalized between [-1,1] to ease the comparison of the spectral features associated with each aerosol optical property studied





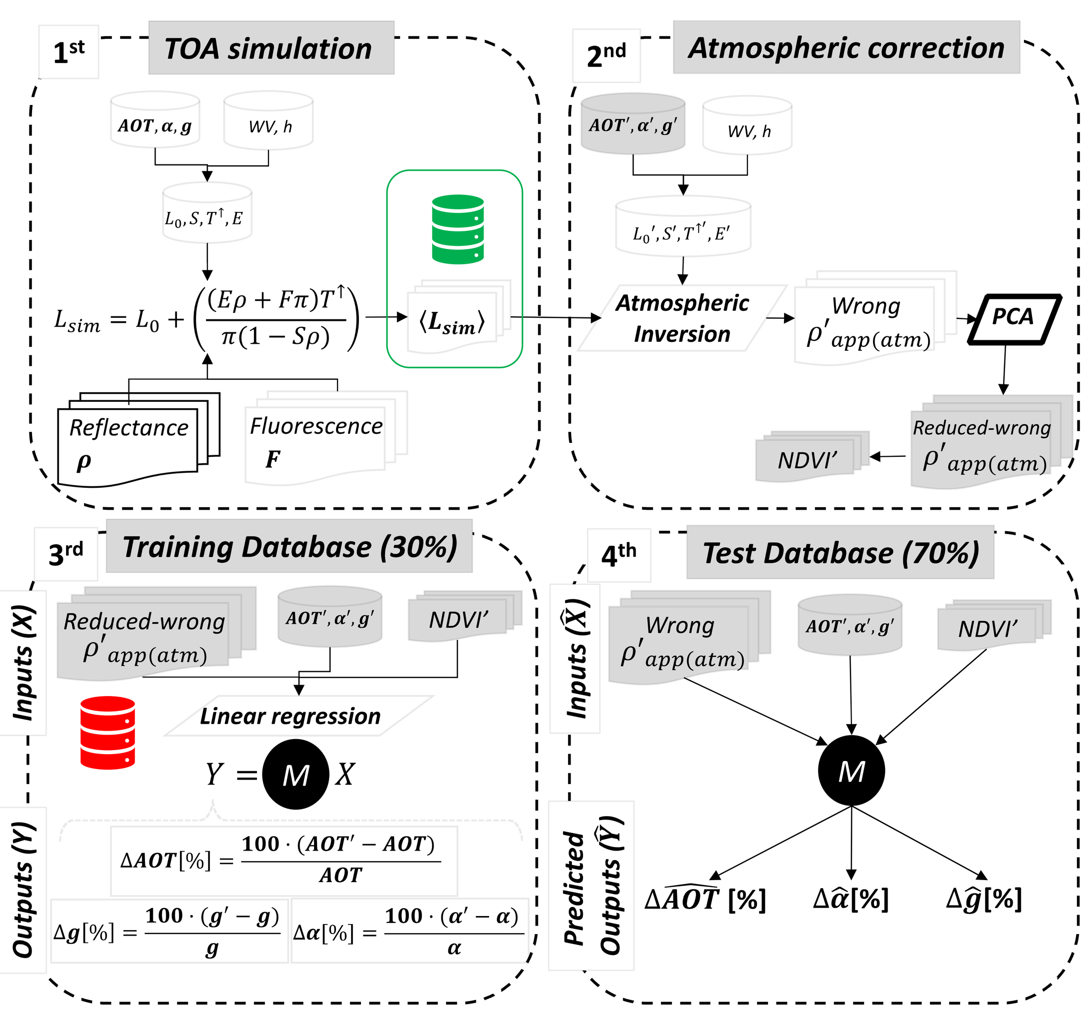
Settings for illustration
ρ = 0.5 [-]
SIF = 0 mW/m²/sr/nm

- Would it be possible to infer errors associated with the aerosol optical properties by analyzing the spectral distortion pattern generated at the oxygen regions in ρ_{app} ?

Aerosol characterization refinement

Methodology

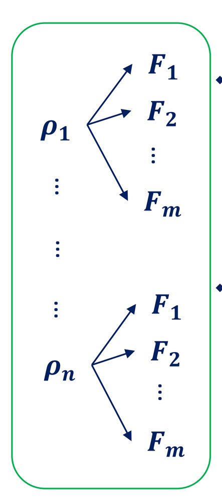
A simple simulated exercise was performed to evaluate until what extend training distortions appearing in ρ_{app} due to aerosol inaccuracies would be able do predict errors in the aerosol characterization as part of the atmospheric correction technique?



Original methodology proposed in Sabater et al. 2017

Dataset

A set of ~10^8 distinct L_{TOA} radiance spectra were simulated by combining surface reflectance (ρ) and fluorescence (F)



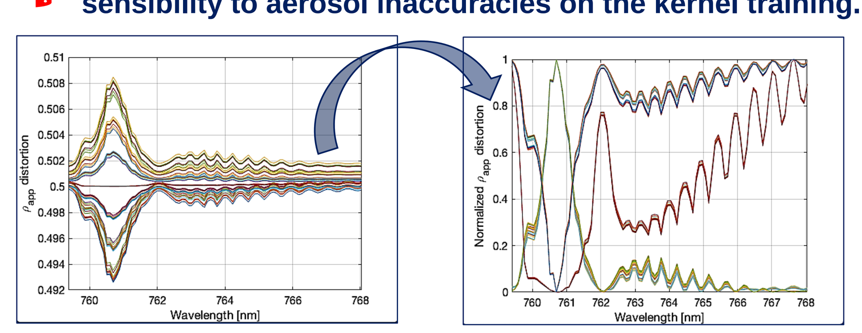
- Combining all possible distinct fluorescence (F) with reflectance (ρ) spectra at surface level.
- Only simulating oxygen regions, to simplify the process. This could allow to approximate the F spectra

Combined with distinct values of :

- AOT,
- Angstrom exponent,
- asymmetry parameter (Henyey-Greenstein), and
- Single Scattering Albedo (SSA) values

~10^8 distinct L_{TOA} spectra

Normalize spectral distortions in ρ_{app} to enhance the sensibility to aerosol inaccuracies on the kernel training.



Example of distortions produced when over/underestimating aerosol optical properties over a flat reflectance spectrum (ρ) of 0.5 [-].

Normalized spectral distortions produced when over/underestimating aerosol optical properties over a flat reflectance spectrum (ρ) of 0.5 [-].

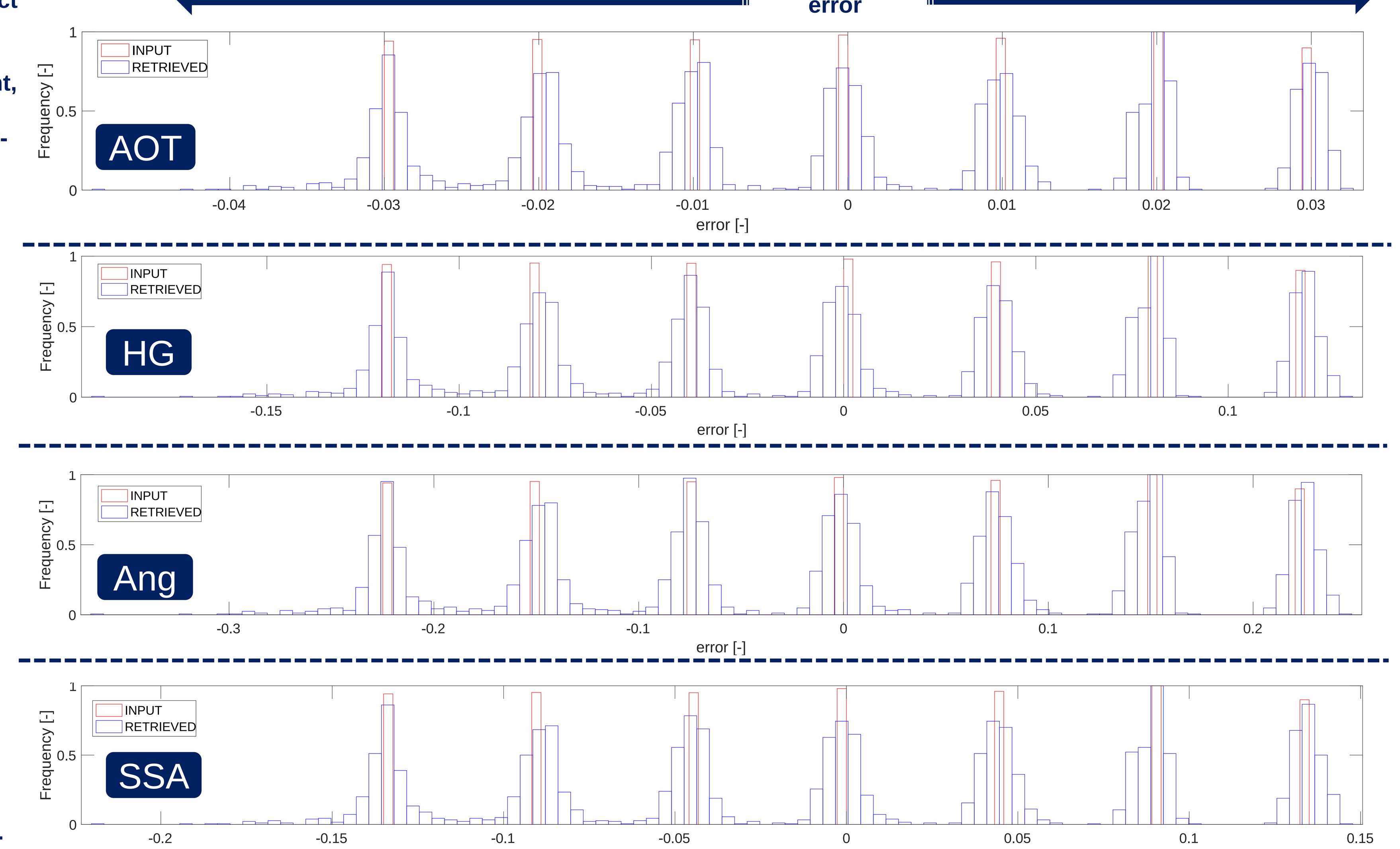
Results

Using the remaining database (70%) for testing. Histograms showing the input error in the aerosol characterization and the predicted error when applying the multivariate linear regression kernel (trained with the normalized spectra).

Predicted error in the aerosol characterization by the refinement technique.

Input error of the data.

Negative input error = Underestimation | Zero input error | Positive input error = Overestimation



Other aspects…

Since this technique is based on the exploitation of the absorption features, other aspects that can impact the spectral shape of the O_2 absorption bands needs to be also taken into consideration. For instance:

- The kernel (M) should be built for each specific instrument to minimize, as much as possible, residuals derived due to inaccuracies in the spectral calibration, i.e. in the characterization of the sensor spectral response function.
- Other aspects such as the accurate characterization of oxygen molecular density, i.e. total absorption; needs to be also properly accounted for. In this respect, while atmospheric oxygen molecular mixing ratio is stable and well-known, oxygen molecular absorption changes due to variations in the pressure and temperature conditions. These effects can be modelled, for instance, making used of the HITRAN molecular spectral database or using any atmospheric radiative transfer model (RTM) which accounts for these effects internally. Certainly, the final accuracy will also depend of the existing differences between the real and the assumed vertical temperature profile.
- Additionally, an accurate estimation of the surface elevation is also required. Inaccuracies in surface elevation disturbs both the optical path; which impact on the aerosol scattering effects on the O_2-B region, and on the surface pressure value.

Conclusions

Within the absorption features, solar-induced fluorescence contribution on satellite-derived ρ_{app} generates a characteristic peaky spectrum. However, these peaks can be simultaneously distorted through the atmospheric correction process due to inaccuracies in the aerosol characterization among other secondary sources. The exploitation of the spectral information of surface apparent reflectance (ρ_{app}) within the oxygen absorption features could be of high interest not only to estimate fluorescence but to accurate characterize the aerosol presence. The presented technique improves the accuracy of any a priori aerosol retrieval by distinguishing distortions on surface apparent reflectance inferred by errors on the aerosol optical thickness, the Angstrom exponent, the asymmetry of the scattering and the single scattering albedo.

Acknowledgement

Thanks to the **FluoSYN** postdoctoral research project funded by the Finnish Academy of Science (Suomen Akatemia) [Reference grant: 324091]

FLEX L1B to 519 L2 algorithm development study, Reference Tender: AO~1-8897~17~NL~MP.