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Abstract
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Towards a machine learning retrieval of solar-induced fluorescence from DESIS data

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Challenge

One of the most important biophysical parameters to assess and monitor plant health is the solar-induced fluorescence (SIF) emitted during photosynthesis. Over the last decades, SIF retrieval with on-ground and airborne spectrometers (such as HyPlant) has successfully helped study fluorescence at high spatial resolution, but with limited spatial and temporal coverages. Using data from current and future space-borne spectrometers has the potential to monitor fluorescence over extended regions with high temporal frequency. In this respect, the DESIS imaging spectrometer operating on the International Space Station can play a decisive role given its spectral (3.5 nm) and spatial (30 m) resolutions, spatial coverage and revisit times. In this contribution, we report on our on-going effort to develop a machine learning (ML) approach to SIF retrieval in the O_2-A absorption band tailored to the DESIS instrument.

Methodology

The starting point of our work consists in the simulation of at-sensor radiance spectra in the O_2-A band taking into account atmosphere, geometry, surface and sensor aspects in detail. The radiative transfer in the atmosphere is modelled using MODTRAN6 and considerable effort is put into simulating realistic spectra based on expert knowledge of the DESIS spectrometer. We developed a general-purpose simulation tool and used it to carry out a comprehensive sensitivity analysis in order to identify the key parameters for SIF retrieval in the O_2-A band as well as their ranges. An extensive set of databases of simulated at-sensor radiance spectra for DESIS was then generated encompassing a wide range of atmosphere conditions, observation geometries, surface parameters and sensor characteristics. The multi-dimensional input space consists of 12 dimensions and was sampled with different methods (uniform grid, random and Halton) so that the complex interplay between the input parameters is suitably captured. A sequence of databases of increasing complexity was prepared to aid the learning process, with the final databases containing over 10 million spectra. The realistic nature of these spectra was ensured through comparison to real data from DESIS and HyPlant in order to control any domain gap between simulation and data.

Results

Two applications of the simulated databases described above are explored in our work. First, we trained a forward simulator of at-sensor radiances using simple ML methods. Our results show that fourth-degree polynomials are both fast and accurate ML simulators. In fact, typical computation times are 10–20 µs per spectrum (instead of minutes for the full simulation) and the at-sensor radiance errors amount to less than 0.1 mW/m^2/sr/nm across the O_2-A band (less than 10% of a typical SIF signal). The proposed ML simulator can be instrumental for SIF retrieval by enabling fast simulation of large datasets and by its integration in self-supervised inversion schemes (see submission by Buffat et al.). These applications are currently not feasible with a full-fledge simulation.

Second, we designed a multi-layer perceptron with residual links and trained it on the simulated data to retrieve SIF from DESIS in the O_2-A band. The model predicts SIF pixelwise and its performance is validated with DESIS/HyPlant coincident datasets from 2020 and 2023. The figure below shows a SIF map retrieved by our model for part of a DESIS scene. The SIF estimates are fairly well correlated with the HyPlant retrieval based on a traditional method and show some dependency on surface reflectance. The results are still preliminary and more work is needed for a full validation of the method. However, our findings are promising for the final goal of retrieving SIF from DESIS data with a robust ML approach.

Outlook for the future

The DESIS imaging spectrometer has been continuously delivering high spectral resolution measurements from the International Space Station since 2018 and will likely continue to do so in the next years. Although not designed specifically for SIF retrieval, DESIS has suitable spectral properties for the task and a large catalogue of data from around the world. Our preliminary results suggest that an ML method trained on realistic simulations can in fact retrieve SIF from DESIS at-sensor radiance spectra around the O_2-A band. If it turns out that such SIF retrieval can be made reliably on a routine basis, then the existing and future DESIS data will automatically enable the mapping of fluorescence from any land site in the globe at high spatial resolution, frequent revisit times and at different local times.

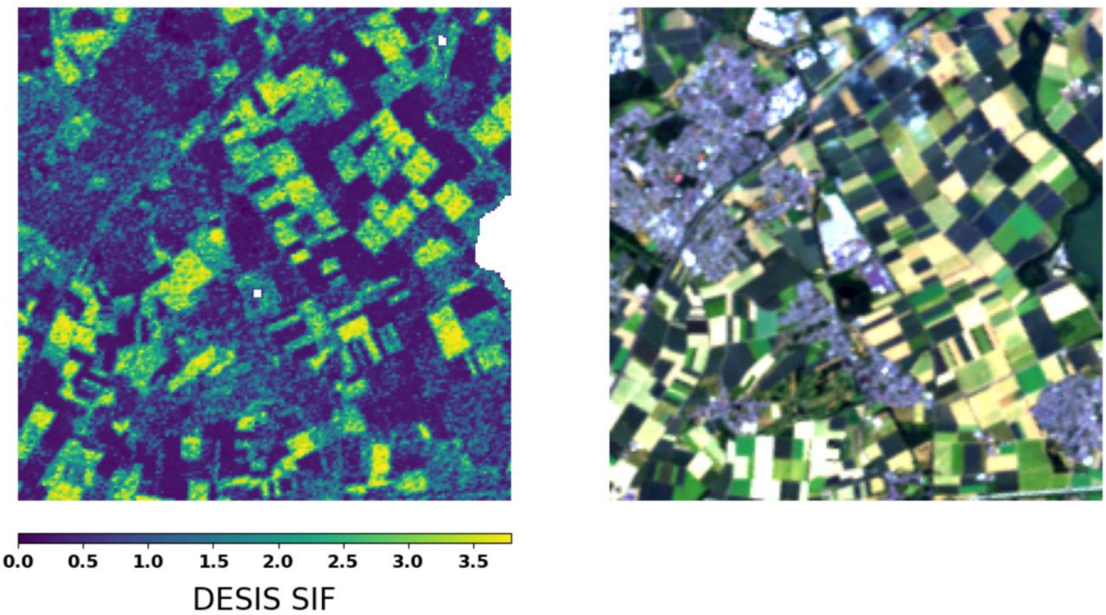

Figure DESIS SIF retrieval preliminary results. The left panel shows the SIF retrieved by the proposed ML model (in units of mW/m^2/sr/nm), while the right panel is the corresponding true color composite based on DESIS reflectances.