Retrieval of atmospheric CH_4 profiles from hyperspectral infrared satellite observations: an inversion approach based on Physically Informed Neural Network

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ABSTRACT

Monitoring atmospheric methane (CH_4) is crucial due to its significant impact on climate and air quality, with a radiative effect tens of times greater than carbon dioxide (CO_2) and 60% of emissions being anthropogenic. A major concern is the thawing Antarctic permafrost, which holds an estimated 540 Gt of CH_4, potentially causing severe global warming if released. Unlike CO_2, whose atmospheric cycle and vertical profile are well-characterized by satellite and ground observations, CH_4 vertical profiling, cycle, and distribution remain more uncertain.

Satellite observations in the NIR, MIR, and TIR enable continuous global monitoring of CH_4, which has several absorption bands in the IR region, and modeling it while accounting for temperature and other atmospheric constituents is crucial to understanding its spatial and temporal variability, and better constraining sources and sinks. To take full advantage of satellite data, techniques need to be developed to speed up retrievals, and in this regard, artificial intelligence plays a key role.

In this context we present the first results of the PRIN-MVP[(*)] (Methane Vertical Profiling) project, which aims at developing an innovative retrieval scheme to derive CH_4 vertical profiles from satellite data, guided and validated by circulation modeling. The methodology is based on Physics-Informed Neural Networks (PINNs), which include equations to physically constrain the output parameter.

We present the inversion methodology developed for and applied to IASI data, already extensively used to retrieve CH_4 column abundances. The PINN training set consists of about 500000 clear sky spectra, simulated by the σ-IASI/F2N radiative transfer model, and other ancillary information on a specific area of interest. The dimensionality of the spectra is reduced through Principal Component Analysis (PCA) in the region of interest for methane, which is constrained through a new approach based on Averaging Kernel's analysis which we will present. To reduce noise and dimensionality, PCA was also applied to atmospheric profiles, creating a projection basis for each altitude on spatial points in the area of interest, corresponding to a different layer of the σ-IASI/F2N pressure grid.

The study aims at demonstrating the power of PINNs for estimating full, self-consistent CH_4 profiles. In this sense, we will show the results obtained by PINNs by comparing them with ground-truth profiles.

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