Astroclimes - describing the capabilities of our synthetic transmission spectra code for measuring atmospheric CO_2

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Introduction

Carbon dioxide (CO_2) and methane (CH_4) are the main culprits for the global rise in average temperature, which drives climate change. As such, it is crucial to accurately and reliably measure the amount of said gases in the atmosphere so that we can better understand and model climate change, as well as guide governmental policies for alleviating its impact.

There are many networks in place that carry out such work, for example the Global Monitoring Laboratory (GML), which carry out in-situ observations in four baseline observatories across the world. For measurements of the column-averaged dry air mole fraction of CO_2, (XCO_2), satellites such as NASA's OCO-2 and OCO-3 and ESA's GOSAT and GOSAT-2 have been employed.

This project proposes a new method to measure the amount of greenhouse gases in the Earth's atmosphere which uses spectroscopic astronomical observations. Our measurement approach is like that of the satellites, but we do not rely on sunlight for our observations, and instead use light from telluric standard stars.

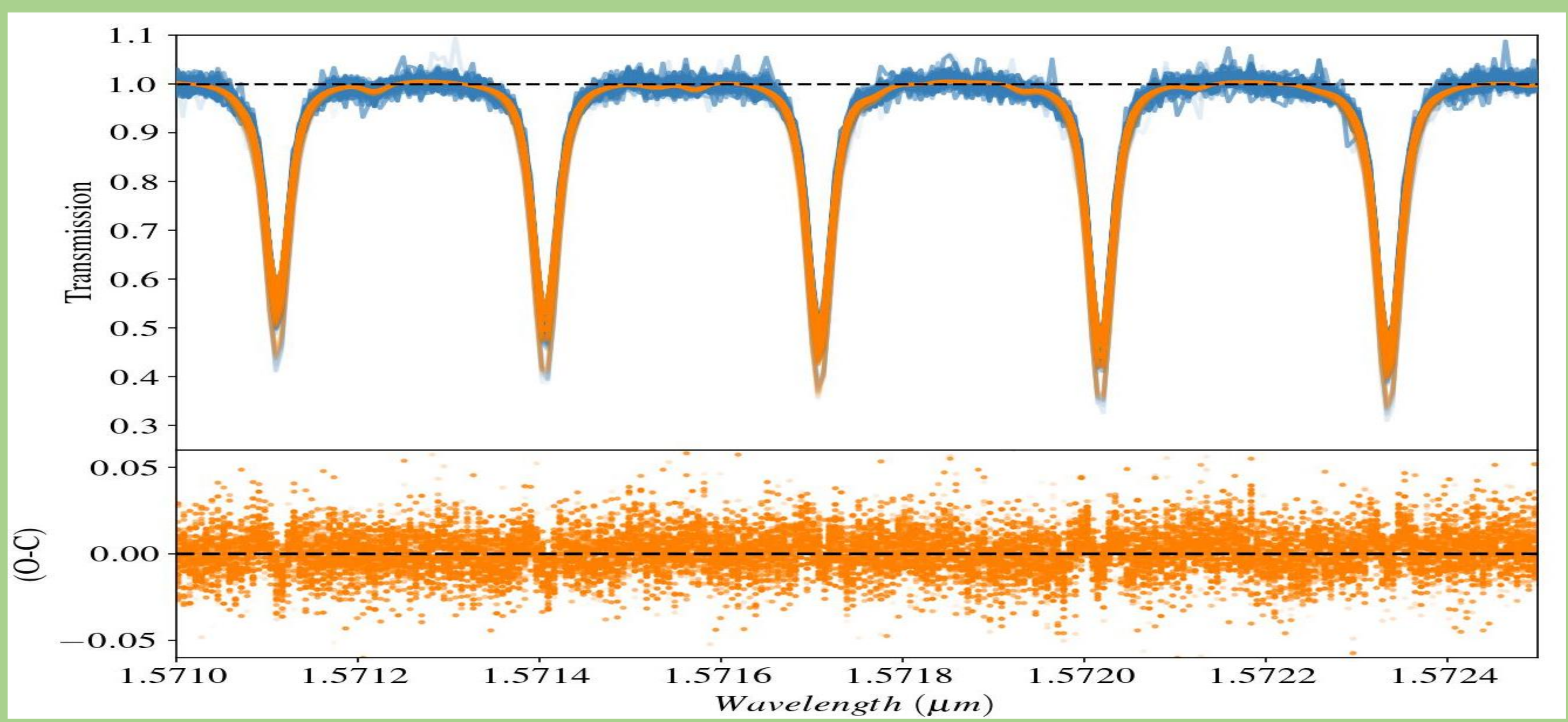

Figure 1: Comparison between the 66 model spectra and their respective observational spectra, zoomed in on some CO_2 lines.

Methodology

Spectroscopic ground-based observations are plagued with spectral lines that originate from molecules in the Earth's atmosphere, the so-called **telluric lines**. Normally, astronomers want them removed from their analysis, but we aim to study them. For that, we employ the synthetic transmission method, in which a model telluric spectra is generated based on atmospheric profiles (Figure 2), spectral line databases and solving the radiative transfer equation. Additional effects such as Rayleigh scattering, aerosol scattering, and collision-induced absorption (CIA) are also included.

This model spectra is then compared to the observational spectra, and an MCMC is run with the abundances of the desired molecules defined as the free variables until the best fit is found (Figure 1).

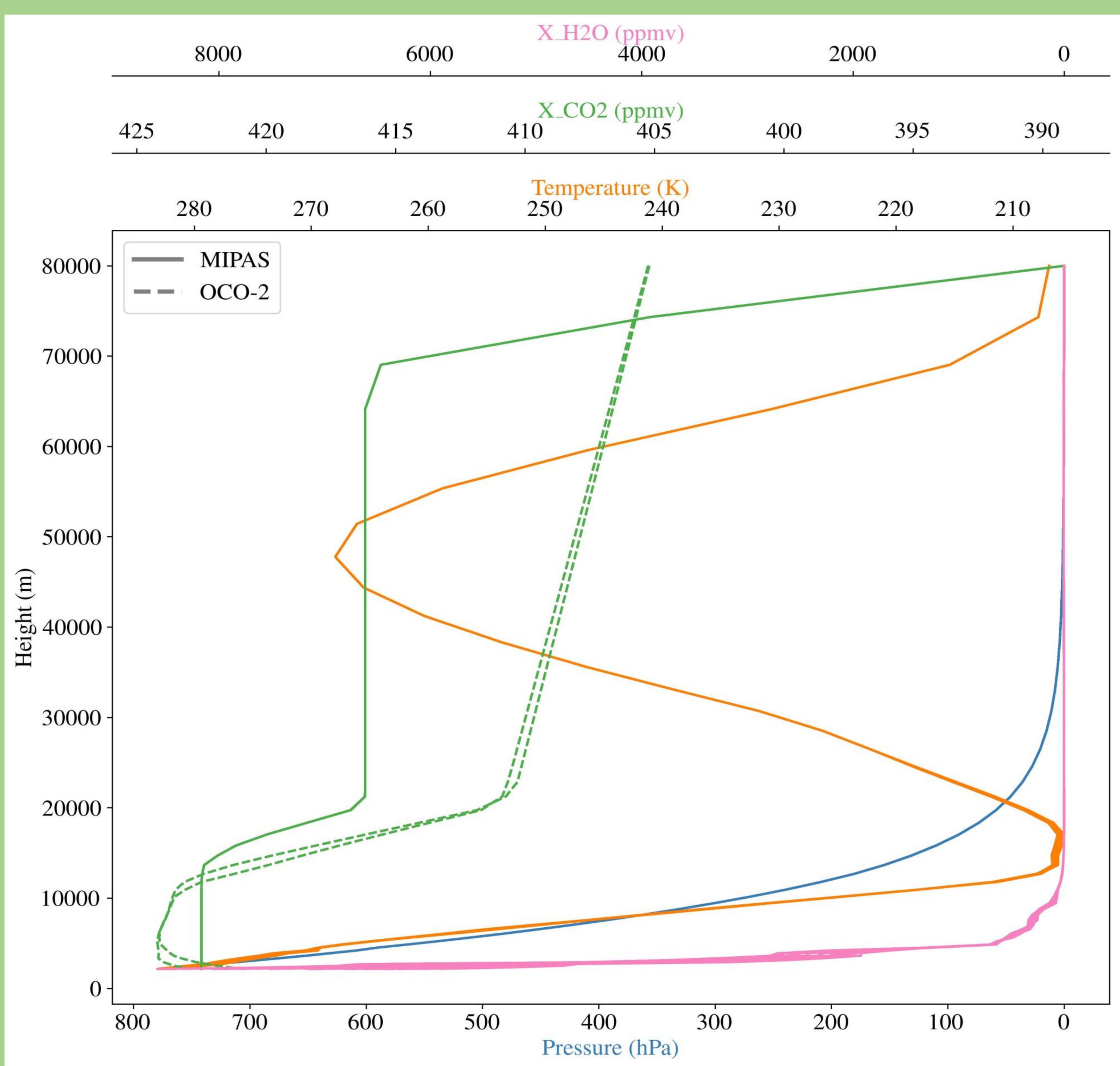

Figure 2: Pressure, temperature and abundances of CO_2 and water as a function of height, obtained by the combination of site data, weather balloon data and the MIPAS and GDAS atmospheric profiles. An additional CO_2 profile was also used, which comes from OCO-2 (dashed green line).

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Key messages

- Our new method was able to accurately reproduce the ESO Sky Model's reported PWV values, except in the extreme cases where PWV=20mm,30mm.
- The resulting XCO_2 values are consistently higher than the reported values from OCO-2 and OCO-3, potentially due to a calibration issue.
- The fits to the observational spectra show that the algorithm looks promising in removing telluric lines, an aspect which will be tackled in future work.

Model validation

To test our model, we compared it to the telluric model from the ESO Sky Model Calculator. Models were generated for each of the PWV values available, with a resolution of R=300000 and a wavelength range of 1.0-1.8µm, while all other parameters were kept as their default values. The goal was to see if we could reproduce the reported PWV values by running our fitting algorithm (Figure 3).

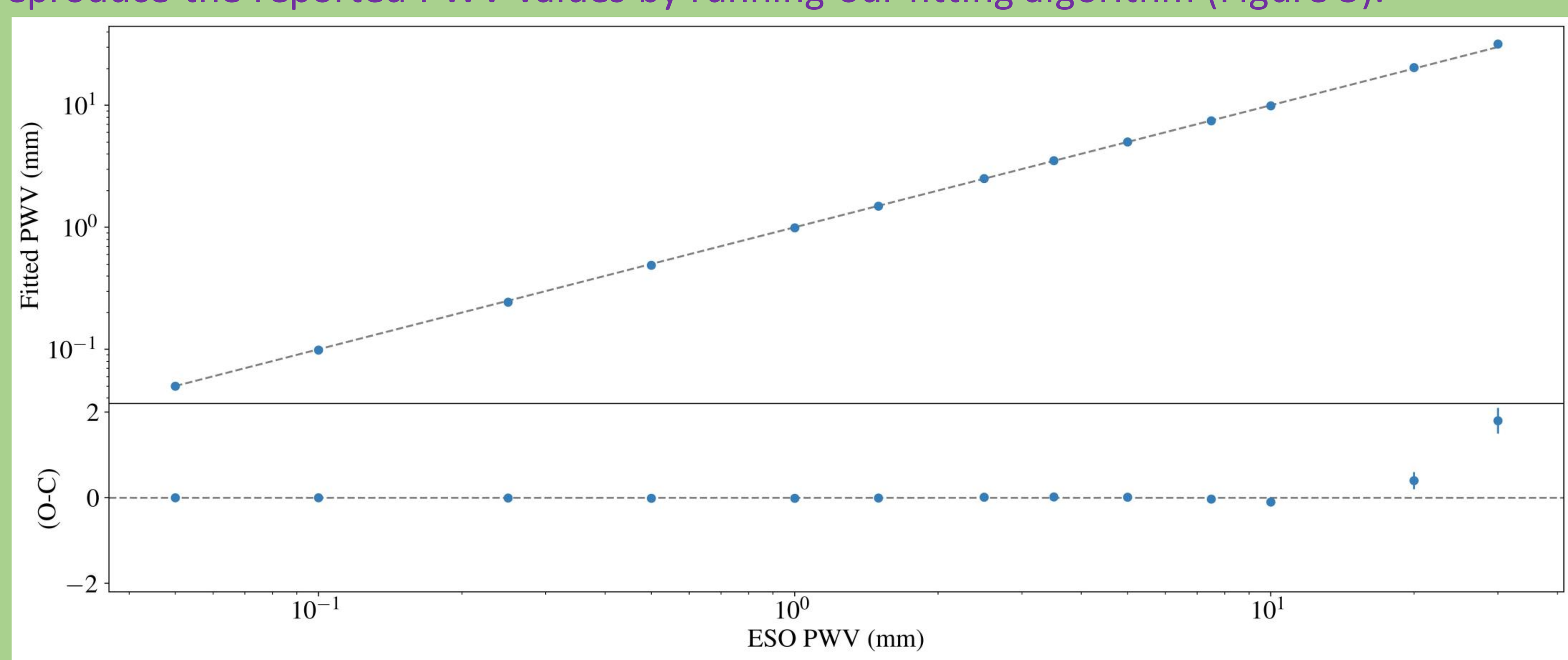

Figure 3: PWV values retrieved from fitting our model to the ESO Sky Model compared to the reported ESO PWV values.

Fit to observational data

New observations of HR5676 were carried out with the CARMENES instrument at the Calar Alto Observatory. Alongside this new spectroscopic data, a weather balloon was launched to obtain a local atmospheric profile and a CO_2 sensor was placed next to the telescope.

The 66 spectroscopic observations were analysed with our algorithm, once with the MIPAS CO_2 profile and then with the OCO-2 retrieved CO_2 profile. These yielded ground-level CO_2 values, as well as column-averaged dry air mole fractions of CO_2, XCO_2, which are shown compared to the measured sensor values and the reported OCO-2 and OCO-3 values in Figures 4 and 5, respectively.

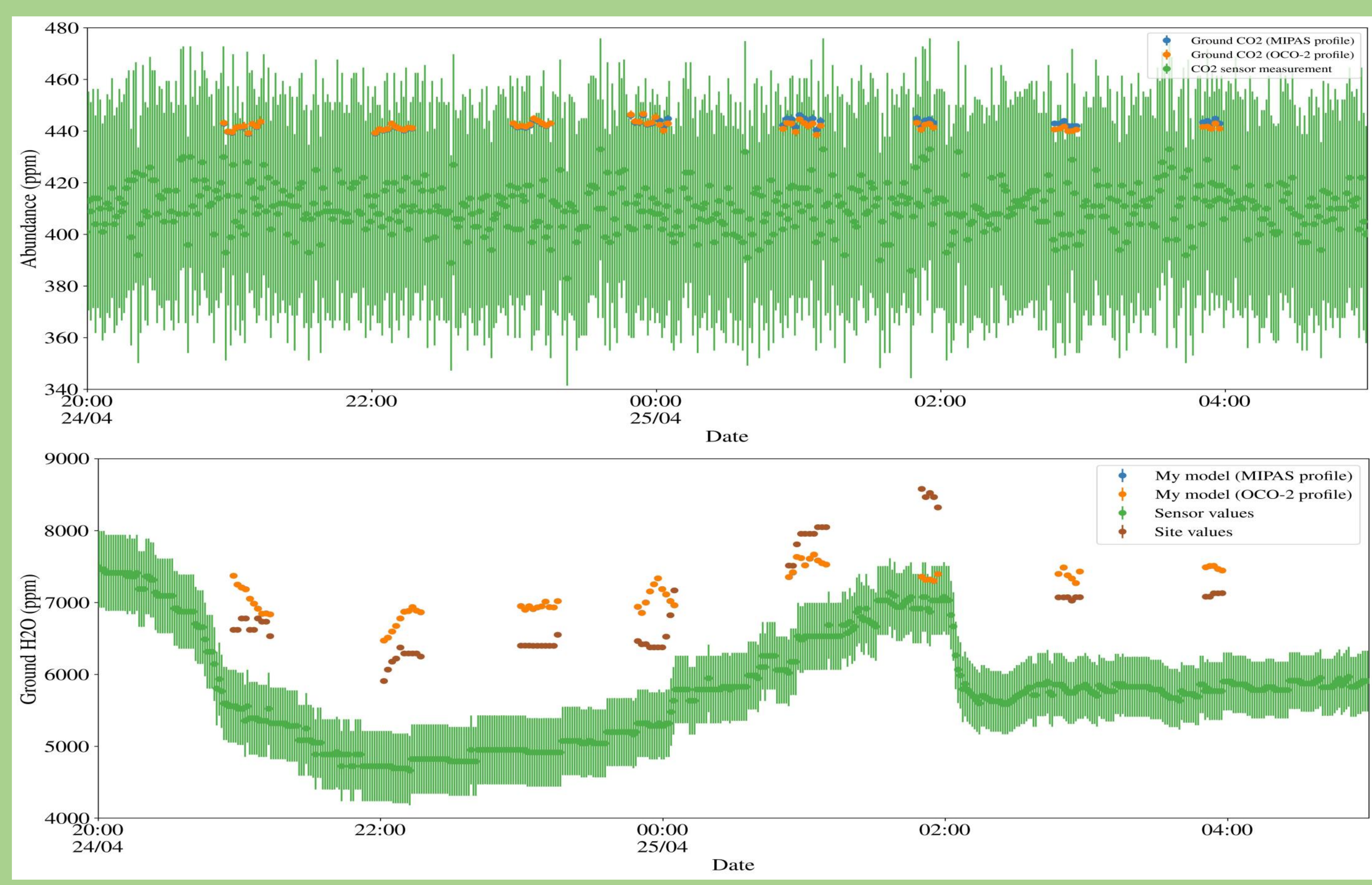

Figure 4: Top: ground level CO_2 abundance retrieved from our analysis using the MIPAS CO_2 profile (blue) and the OCO-2 CO_2 profile (orange) compared to the sensor measurements (green). Bottom: same thing for H_2O instead, with the measurements from the observatory's weather station included as well (brown).

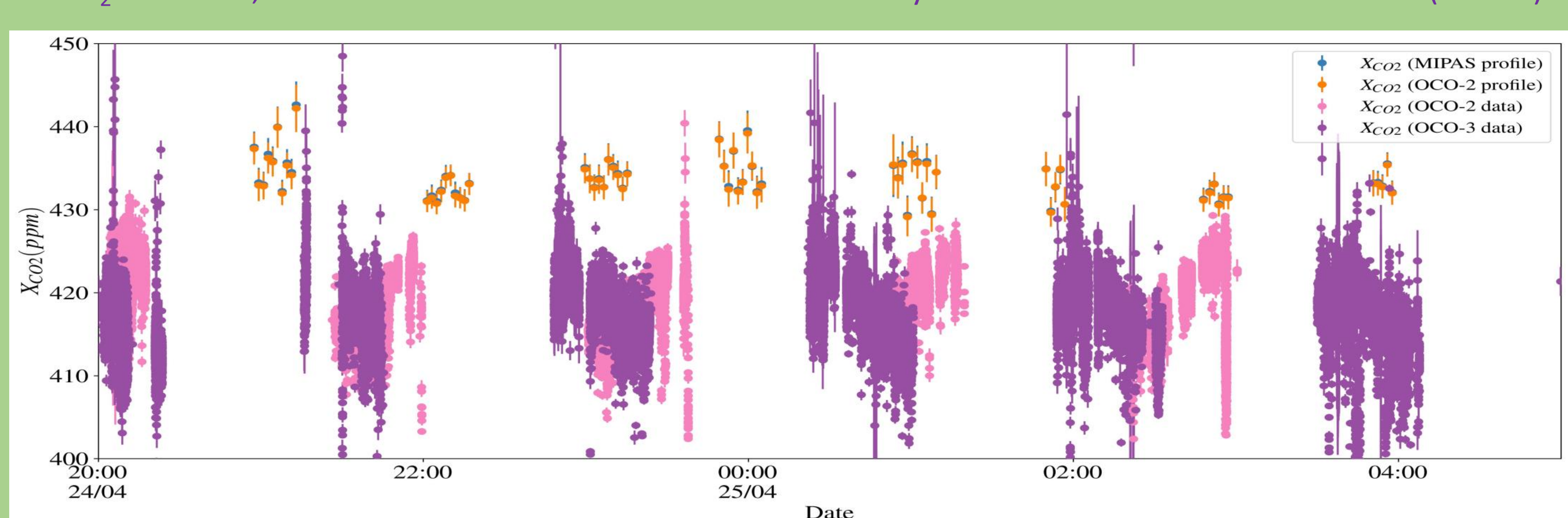

Figure 5: XCO_2 values retrieved from our analysis compared to XCO_2 from OCO-2 and OCO-3. It should be noted that these measurements were taken at similar times, but not at similar places.