H_2O, CO_2, and CH_4 Monitoring at Astronomical Telescope Sites

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Introduction

In ground-based astronomical observations, molecules in the Earth's atmosphere absorb the light of celestial objects at certain wavelengths, so-called „telluric lines". These telluric absorptions are variable and depend on both, the physical properties of and on the amount of molecules in the atmosphere. To take this influence into account, astronomers observe „Telluric Standard Stars" (TSS), bright and hot stars, which have hardly any intrinsic spectral features near the telluric lines. From the TSS spectra, templates of these telluric lines are built, which are used to correct astronomical observations. Yet, these TSS spectra contain information on the chemical composition of the Earth's atmosphere during the time of observation. Modern astronomical telescopes are equipped with state-of-the-art spectrographs reaching high sensitivities in a broad range of wavelengths, leading to a widebcoverage of emission/absorption lines of various molecules. As telescope sites are built in areas with good and stable weather conditions, the temporal coverage of TSS observations is very high.

Data set

The European Southern Observatory[f] (ESO) has one of the largest telescope sites in the dry Atacama desert in Chile, the Very Large Telescope at the Cerro Paranal. One of the most versatile instruments mounted there is ‚X-Shooter', a medium resolution spectrograph (R=3000-18000) covering the entire wavelength range from the ultra-violett (>0.3µm) to the near-infrared (<2.5µm) with one shot. Thus, spectral features of H_2O, CO_2, and CH_4 are visible. For our investigations, we have taken all available TSS observations starting from October 2009, when X-Shooter went into operation, to February 2013. We selected a total number of 1172 high-resolution (R>7700) measurements (on average ~28 per month). These spectra were used to determine the amount of CO_2 by calculating a monthly mean of the column density.

Method

Having a spectrum at hand, it is possible to determine the chemical composition of the Earth's atmosphere at the time of observation. We have developed an iterative algorithm [1],[2], which calculates the molecular column densities on the basis of the radiative transfer code LBLRTM[c] [3]. This code requires an atmospheric profile (created by refining a standard model[a] with the time dependent GDAS[b] model, and on-site measurements of P, T, and relative humidity), and the line database HITRAN[d] [4]. With the help of a Levenberg-Marquard χ^2 minimisation algorithm (Cmpfit[e] package), spectral features are fitted by scaling the corresponding molecular profile. The best-fit profile (see Fig. 1) is used to determine the column densities. We have compared our findings with ESRL/NOAA provided flask measurements from Easter Island[g] [5], which is at a similar latitude as Cerro Paranal.

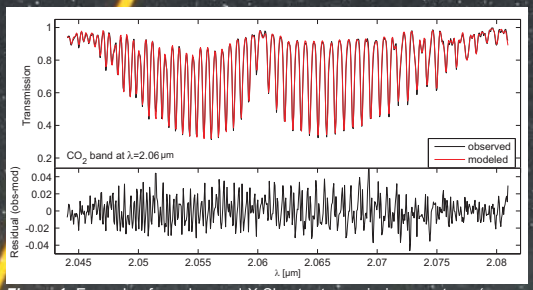

Figure 1: Example of an observed X-Shooter transmission spectrum (upper panel, black line) and the best fit (red) retrieved with our algorithm for the CO_2 band at λ=2.06µm. The lower panel shows the residual.

Preliminary CO_2 results

Figure 2 shows the monthly mean CO_2 concentration of the Easter Island measurements[g] (red), and the results of the fits of the X-Shooter spectra (black). The annual increase k of the concentration is visible in both data sets, although the Paranal data show a lower increase of 1.27±0.09 ppmv/yr compared to the 1.91 ppmv/yr from Easter Island. This deviation probably results from the comparably short period of available X-Shooter spectra, and statistical and systematic errors therein. The errors result from, e.g., the absolute calibration of the Co_2 profile, pressure measurement, limited resolution of the X-Shooter spectra (separation between line/continuum), variation of the not-well known instrumental profile (particularly in the line wings), and the start parameters for the fitting algorithm. Therefore, further investigations and comparisons with other ground based / satellite data have to be conducted, e.g. TCCON network [6]. In addition, an extension to higher resolution spectrographs, e.g. CRIRES (R~100000), could minimise instrumentally induced systematic errors.

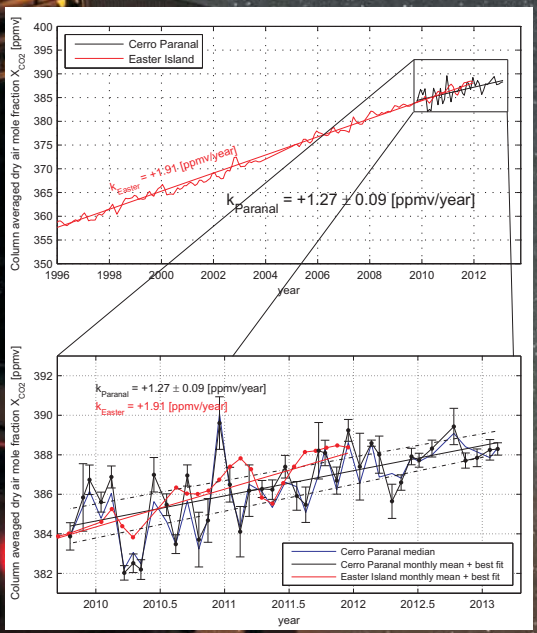

Figure 2: Comparison of CO_2 column densities obtained from astronomical spectra and ground based flask measurements from Easter Island [5]. The dry air mole fraction data of the latter were converted from ground based to column averaged.

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References:
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[2] Molecfit User Manual VLT-MAN-ESO-19550-5772 + references therein
[3] Clough et al. 2005, JQSRT 91, 233
[4] Rothman et al. 2009, JQSRT 110, 533
[5] Conway & Masarie, 2012, Atmospheric Carbon Dioxide Dry Air Mole Fractions from the NOAA ESRL Carbon Cycle Cooperative Global Air Sampling Network, 1968-2011, Version: 2012-08-15[5]
[6] Wunch et al, 2011, Phil. Trans. R. Soc. A, 386, 2087

Links:
[a] http://www.atm.ox.ac.uk/RFM/atm/
[b] Global Data Assimilation System: http://ready.arl.noaa.gov/gdas1.php
[c] Line-By-Line Radiation Transfer Model: http://rtweb.aer.com/lblrtm_frame.html
[d] High-resolution transmission molecular absorption database: http://www.cfa.harvard.edu/HITRAN/
[e] CMPFIT: http://www.physics.wisc.edu/~craigm/idl/cmpfit.html
[f] ESO: http://www.eso.org
[g] ESRL/NOAA: ftp://ftp.cmdl.noaa.gov/ccg/co2/flask/month/ http://www.esrl.noaa.gov/gmd/ccgg/globalview/

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