Measuring the amount of precipitable water vapour with VISIR

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1 Introduction

Water is one of the main constituents of the atmosphere. It is mainly concentrated in its lower layers. When meteorological conditions allow an optical or infrared telescope to observe, water in the atmosphere can be found either in condensed form (liquid: droplets, in most clouds or solid: ice crystals in cirrus clouds) or as water vapour. The condensed forms will significantly degrade the quality of optical and Near Infra-Red (NIR) observations, while a significant amount of water vapour will negatively affect NIR and, more importantly, Mid-Infra-Red (MIR) observations, as can be seen `http://www-atm.physics.ox.ac.uk/group/mipas/atlas/`.

To quantify the amount of water vapour along a line of sight across the atmosphere, the commonly used quantity is the amount of precipitable water vapour (PWV). It is defined as the equivalent to the liquid precipitation that would result if all the water vapour in the column is condensed, and is expressed in mm.

Variations of the PWV during the night will influence the sensitivity and conversion factor (the relation between the number of detected photons and the flux above the atmosphere) of observations in the MIR, in a way that depends on the passband of the filter used. Therefore, time expensive observations of standard stars are necessary if accurate estimations of these quantities are required. In addition, before starting observations of a science target, it would be advantageous to know the sensitivity that can be reached. In service mode observations, this allows the night astronomer to select which instruments to use or which OBs are most suited to the current conditions. In visitor mode, the visiting astronomer can best schedule the time to execute a given observation.

Therefore, it would be useful to assess the relationship between the sensitivity and conversion factor, on one hand, and the observing conditions, such as the PWV, on the other hand. Hence, a reliable and fast method to determine the PWV is needed.

At ESO, the WWW page developed by Marc Sarazin and Andre Erasmus (`http://www.eso.org/gen-fac/pubs/astclim/forecast/meteo/ERASMUS/l_p_f0.html`) provides an estimate of the PWV over the ESO observatories. This value is based on Upper Tropospheric Humidity derived from 6.7 μm images obtained by the GOES satellite, surface relative humidity and on the European Centre for Medium-Range Weather Forecasting model

Other methods include radiometers[1], in particular, as support to sub-millimeter observatories (APEX, ALMA[2]), as a high-accuracy ($\approx 10^{-6}$ mm) is required; sky dips[1] that are also expensive in terms of execution time ; or measurement of absorption lines in stellar spectra (see contribution by Thomas-Osip et al.).

Here we describe a method based on short exposure VISIR sky spectra.

2 PWV based on VISIR sky spectra

Since December 2005, we have regularly obtained 10 s, 19.5 μ medium–resolution spectra of the sky using VISIR when it is in use. The wavelength coverage corresponds to the Q3 filter. The execution time required to produce such spectra is actually dominated by the set-up of the instrument.

The data are obtained in burst mode (see the VISIR user manual). The planes of the produced cube are averaged. The resulting frame is divided by a flat-field obtained with the telescope at zenith. The sky spectrum is obtained by averaging 37 columns in order to obtain a high S/N while not being too affected by the spectrograph distortion.

These spectra are then fitted with a model spectrum based on the Reference Forward Model (RFM), a line-by-line modeling Fortran code, developed by Anu Dudhia (Oxford) to analyze data from MIPAS on-board ENVISAT (see `http://www.atm.ox.ac.uk/RFM`). It uses the HITRAN'2004 Database (Version 12.0) [3], which includes individual line parameters for 1,734,469 spectral lines for 37 different molecules. Other components of RFM include an 'Atmospheric profile' describing mean pressure, temperature, and concentration of H_2O, CO_2, etc... for typically 50 layers of the atmosphere.

The 19.5 μ VISIR spectra are however dominated only by the H_2O lines. Corrections to the 'tropical' atmospheric profile are made based on the atmospheric pressure and temperature at the observatory at the time of the observation. The data are then fitted by a least square method by adjusting the amount of water vapour with a unique factor for all atmospheric layers. In practice, this only affects the lower layers.

Figure 1 shows some examples and their best fit.

As the number of measurements increases, comparison with satellite data become possible. As can be seen in the left graph of Figure 2 the overall trend is similar between the values derived by the two methods. However, it is clear that in a large number of cases, the satellite data provides smaller PWV estimates compared to the VISIR ones. In particular, some short time scale events are just not seen by the satellite: the right graph shows a rapid decrease of PWV from the beginning to the end of the night started on February 26, 2006.

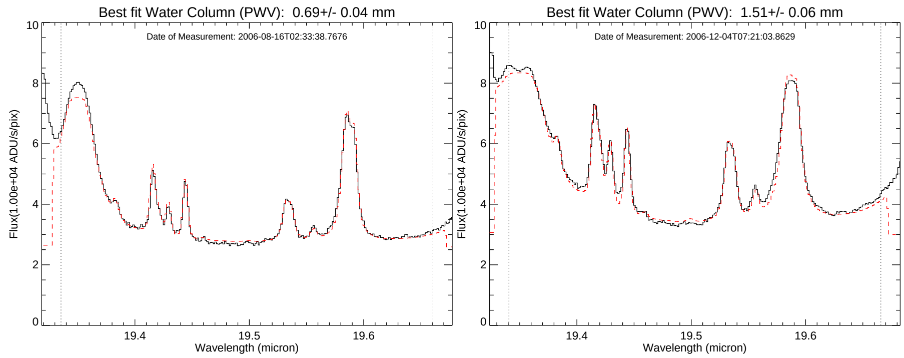

Fig. 1. Examples of sky spectra (black solid line) and their best fit (dash red line). The spectral range used for the fit is delimited by the vertical dotted lines.

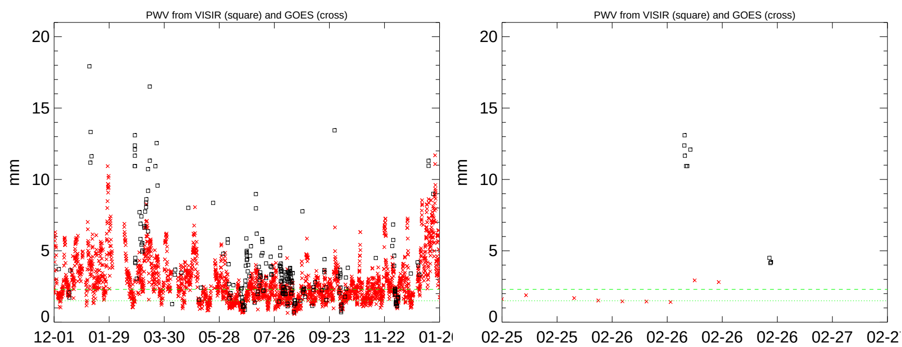

Fig. 2. Comparison between the GOES-based estimates of PWV (red cross) and the ones derived from the VISIR sky spectra (black 'x'). The left graph covers the whole period for which VISIR spectra have been taken. Overall trends are identical, although significant differences are present most of the time. On the other hand, the satellite based data are unable to detect short time scale events, such as the one displayed on the right graph.

Preliminary graphs showing the sensitivities and conversion factors as a function of the PWV are shown in Fig. 3 for PAH1, 4 for PAH2 and 5 for Q2. For PAH1, a significant dependence is put in evidence: the sensitivity getting worse for larger value of PWV, while at the same time the conversion factor decreases. Note that for PAH1, the graph shows the sensitivity divided by the FWHM of the PSF, since one expects that the sensitivity linearly depends on the FWHM. This dependence also exists for other filters, but is less important as most of the observations are diffraction limited.

As the PAH2 filter bandpass avoids any strong water vapour line, one expects only a weak dependence of the sensitivities and conversion factors on the PWV due to the larger continuum opacity for large PWV. Figure 4 confirms these theoretical predictions. On the contrary, for Q2, one expects a strong dependence, which is confirmed by the measurements.

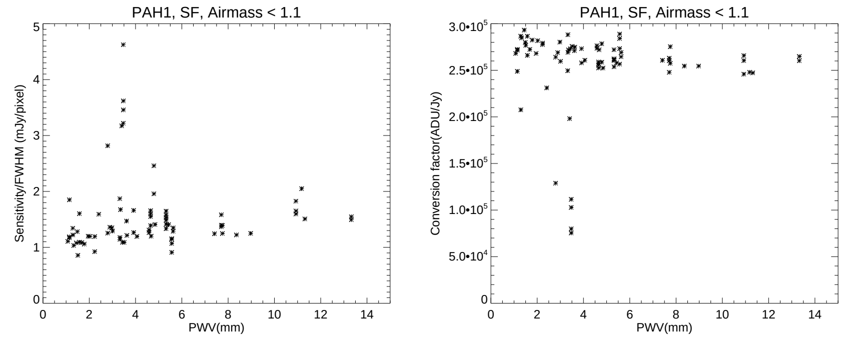

Fig. 3. Dependence of sensitivities and conversion factors on the PWV, for the PAH1 filter. In this case, the sensitivity has been divided by the FWHM in order to cancel its dependence on the seeing.

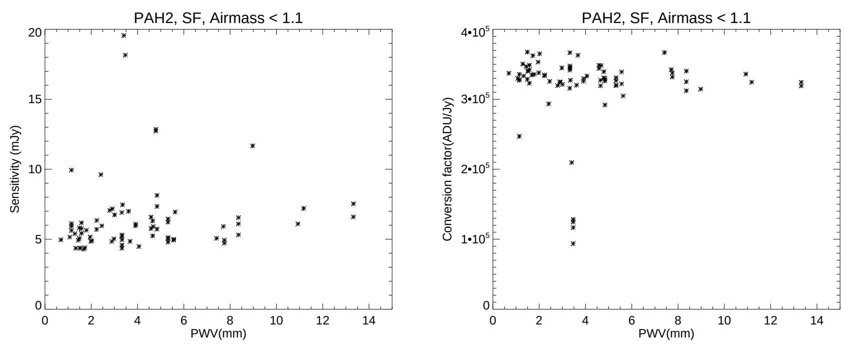

Fig. 4. Idem, for PAH2

3 Conclusion

We have demonstrated that the water vapour content of the atmosphere can be quickly estimated thanks to a 10 s sky spectrum. Significant differences are seen between a top-down (satellite–based) and the bottom-up estimates.

Clear dependences of the sensitivities and conversion factors on the PWV are put in evidence. Therefore, time expensive observations of photometric standards to determine the quality of the sky for MIR observations can be

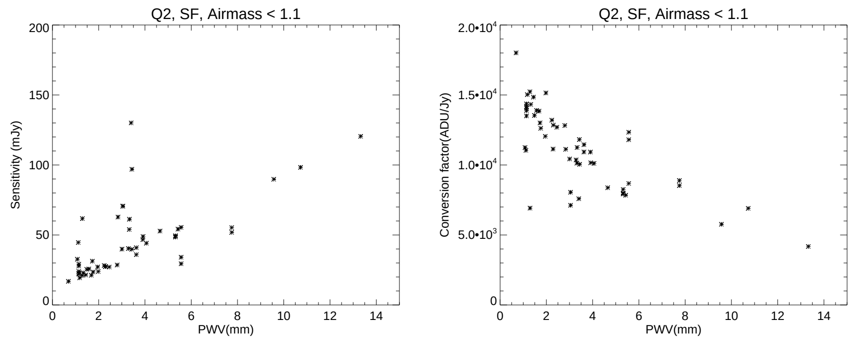

Fig. 5. Idem, for Q2

avoided. A paper describing these results as well as numerical relations for a larger set of filters is in preparation.

For the future, one could consider the possibility that the PWV becomes a constraint for observations in the MIR. This could be relevant for imaging as well as for spectroscopy, where some observations could critically depend on the width of some water vapour lines.

Accurate determination of the PWV as well as behavior of the PWV on a short time scale (minutes) to long time scale (months) are also important in the context of the selection of a site for the E-ELT.

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