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Validation of integrated water vapor from OMI satellite instrument against reference GPS data at the Iberian Peninsula

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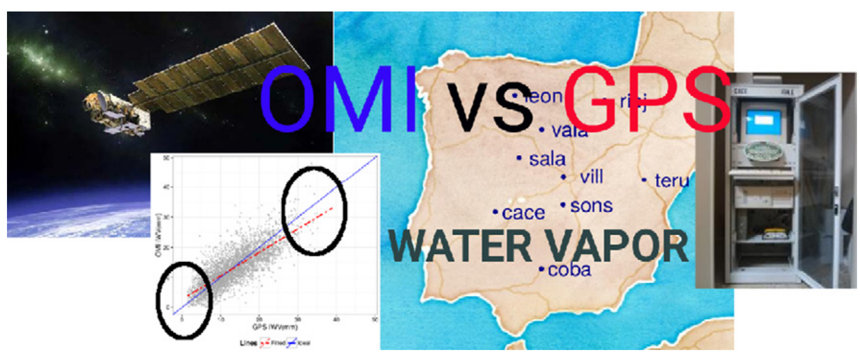
HIGHLIGHTS

- Version 1.0 OMI IWV product is promising, in fairly good agreement with GPS data.
- OMI data can sometimes be unrepresentative to possible extreme local IWV values.
- Low IWV data show great variability (~ 100%) and overestimation (~ +40%).
- High IWV data show less variability and underestimation (~−20%).
- Seasonal and SZA dependence of OMI-GPS differences is mainly related to IWV.

GRAPHICAL ABSTRACT



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ABSTRACT

This paper shows the validation of integrated water vapor (IWV) measurements retrieved from the Ozone Monitoring Instrument (OMI), using as reference nine ground-based GPS stations in the Iberian Peninsula. The study period covers from 2007 to 2009. The influence of two factors, - solar zenith angle (SZA) and IWV -, on OMI-GPS differences was studied in detail, as well as the seasonal dependence. The pseudomedian of the relative differences is −1 ± 1% and the inter-quartile range (IQR) is 41%. Linear regressions calculated over each station show an acceptable agreement (R^2 up to 0.77). The OMI-GPS differences display a clear dependence on IWV values. Hence, OMI substantially overestimates the lower IWV data recorded by GPS (~40%), while underestimates the higher IWV reference values (~20%). In connection to this IWV dependence, the relative differences also show an evident SZA dependence when the whole range of IWV values are analyzed (OMI overestimates for high SZA values while underestimates for low values). Finally, the seasonal variation of the OMI-GPS differences is also associated with the strong IWV dependence found in this validation exercise.

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1. Introduction

Water vapor is the most important greenhouse gas on Earth, and plays a key role in the hydrological cycle (Myhre et al., 2013). Additionally, it provides latent heating when it condenses, and, according to general circulation models (Colman, 2003), it represents a positive climate feedback.

However, water vapor is also one of the most variable gases in the troposphere, both spatially and temporally (Myhre et al., 2013; Ortiz de Galisteo et al., 2011, 2014). Therefore, in order to assess climate change, knowledge of the spatio-temporal distribution of water vapor is fundamental. Since ground-based observations cannot provide a uniform global coverage (being specially scarce over polar and oceanic regions), it is necessary to use satellite measurements to improve spatial cover.

Water vapor is usually quantified using the column-integrated amount of atmospheric water vapor (IWV), equivalent to condensing all the water vapor in the atmospheric column and measuring the height that it would reach in a vessel of unit cross section; it can be measured in superficial density (g/mm^2) or in length (height) units (mm).

Over the years, multiple remote-sensing techniques have been developed to measure IWV both from ground sites and from space platforms. Among them, we find microwave radiometers (Jones et al., 2009; Turner et al., 2007), sun-photometers (Ichoku et al., 2002), Lidar (Turner et al., 2002), satellite measurements (Bennouna et al., 2013; Román et al., 2015; Wang et al., 2014), Global Positioning System (GPS) (Ortiz de Galisteo et al., 2011) and radiosounding (Jakobson et al., 2005; Torres et al., 2010).

Among ground-based water vapor instruments, GPS receiver stations are one of the most powerful techniques to measure IWV. It has been widely studied, as in Pany et al. (2001) and De Haan et al. (2002) (tested against a numerical model), and Ortiz de Galisteo et al. (2010) (for GPS antenna corrections). One of its main advantages is the independence of meteorological events, such as cloudiness or precipitation, along with the possibility of high temporal resolution (up to a few minutes) and low cost of the receivers, allowing a dense coverage (Köpken, 2001).

Unfortunately, ground-based measurements cannot resolve the spatial structures of global water vapor fields, and coverage is restricted mainly to land areas. Satellite observations are more suitable for weather forecasts and climate studies, due to high accuracy and high spatial resolution of IWV products. There are, however, two major drawbacks in polar orbiting satellite observations (Diedrich et al., 2016). First, most areas are sampled only once per day (or even less), depending on latitude and swath width of the instruments. Secondly, clouds are opaque in the visible and NIR spectra and therefore satellite IWV data under cloudy conditions are not reliable. Therefore, to reassure the quality of the IWV data derived from satellite instruments, validation exercises using reference measurements are required.

Numerous satellite instruments provide IWV data which have been widely inter-compared against reference ground-based measurements, namely, Global Ozone Monitoring Experiment-2 (GOME-2) (Grossi et al., 2015; Kalakoski et al., 2016; Noël et al., 2008; Román et al., 2015), MODerate-resolution Imaging Spectroradiometer (MODIS) (Bennouna et al., 2013; Chang et al., 2015; Gao and Li, 2008; Li et al., 2003; Ningombam et al., 2016; Prasad and Singh, 2009; Román et al., 2014), Meteosat (Hanssen et al., 2001; Schroedter-Homscheidt et al., 2008), MEdium Resolution Imaging Spectrometer (MERIS) (Diedrich et al., 2016; Li et al., 2006) or SCIAMACHY (Bovensmann et al., 1999; Noël et al., 2005; Schrijver et al., 2009). Additionally, the Ozone Monitoring Instrument (OMI) also provides IWV data using the retrieval algorithm proposed by Wang et al. (2014). However, to our knowledge, only one validation exercise using the IWV product from OMI can be found in literature (Wang et al., 2016) and that paper presented comparisons on a global scale using reference data that are different from those used in the present work.

This paper focuses on the validation of the IWV data obtained from the OMI satellite instrument using as reference the GPS IWV data recorded at nine stations in the Iberian Peninsula, covering the period 2007–2009. The main objective of this paper is to quantify the differences between IWV obtained from OMI and GPS, considered as reference, in order to improve the understanding of the quality and accuracy of the OMI IWV data.

The paper is organized as follows. Datasets are described in Section 2. Section 3 shows the methodology to carry out the study. Results are presented in Section 4, and, finally, conclusions are drawn in Section 5.

2. Data

2.1. OMI data

OMI (Levelt et al., 2006) was launched on 15 of July 2004 onboard NASA Earth Observing System (EOS) Aura satellite into a Sun-synchronous polar orbit. Developed by the Netherland's Agency for Aerospace Programs (NIVR) and the Finnish Meteorological Institute (FMI), OMI UV/Vis spectrograph samples the whole planet daily at 1330 local time (LT).

The OMI IWV data used in this study are the first version of Smithsonian Astrophysical Observatory (SAO) OMH2O level 2 retrievals which uses the SAO operational retrieval algorithm presented in detail in González Abad et al. (2015).

The visible channel (349 nm –504 nm) of OMI covers several water vapor spectral bands. These bands are weak compared with bands at longer wavelengths. Using the 7ν and $6\nu + \delta$ polyads between 430 –480 nm helps to avoid non-linearity due to saturation. Another feature that makes this retrieval valuable and unique among satellite retrievals is the more uniform albedo over the globe making results over land and water consistent. Despite albedo uniformity, validation analysis carried on by Wang et al. (2016), showed a significant bias (around 5% lower) of SAO OMH2O version 1 compared to in-situ measurements over the oceans.

The retrieval follows these steps: (1) direct fitting of Slant Column Density (SCD) using a semi-empirical model considering several gases (water vapor, ozone, nitrogen dioxide, O_2-O_2, glyxoal, liquid water), the Ring effect, the water Ring effect, 3rd order closure polynomials, wavelength shift, under-sampling correction, and common mode. (2) SCD conversion to Vertical Column Density (VCD) by dividing SCD by the Air Mass factor (AMF). AMF are calculated using radiative transfer calculations saved in look-up-tables (LUT) at 442 nm. LUTs are dependent on viewing geometry (solar zenith angle (SZA), viewing zenith angle (VZA) and relative azimuth angle (RAA)) and surface properties (pressure and albedo). It is important here to mention that AMF is notably sensitive to cloudiness (Wang et al., 2016). Finally, VCD can be converted easily to IWV multiplying by a factor (molecular weight of water divided by Avogadro constant). A full description of the retrieval set up can be found in Wang et al. (2014).

Following the guidelines provided by Wang et al. (2014) for OMH2O quality the cloud fraction had to be lower than 0.1, cloud top pressure greater than 500 HPa, air mass factor greater than 0.75 and retrieval root mean square (RMS) value for the fitting Slant Column Density lower than 0.005. Moreover, only pixel whose *maindataqualityflag* flag were equal to 0 were chosen, and pixels affected by the row anomaly (Wang et al., 2014) have been rejected as well.

2.2. GPS data

GPS IWV data used in this work were derived from ground-based GPS measurements of zenith total delay (ZTD) using tropospheric

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