Remote Sensing of Environment 115 (2011) 1380–1386

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

Validation of the MetOp-A total ozone data from GOME-2 and IASI using reference ground-based measurements at the Iberian Peninsula

M. Antón [a,*], D. Loyola [b], C. Clerbaux [c], M. López [d], J.M. Vilaplana [e], M. Bañón [d], J. Hadji-Lazaro [c], P. Valks [b], N. Hao [b], W. Zimmer [b], P.F. Coheur [f], D. Hurtmans [f], L. Alados-Arboleda [a]

[a] *Departamento de Física Aplicada, Universidad de Granada, Granada, Spain*
[b] *Remote Sensing Technology Institute (IMF), German Aerospace Center (DLR), Wessling, Germany*
[c] *UPMC Univ. Paris 06; Univ. Versailles St-Quentin; CNRS/INSU, LATMOS-IPSL, Paris, France*
[d] *Agencia Estatal de Meteorología (AEMet), Madrid, Spain*
[e] *Estación de Sondeos Atmosférico "El Arenosillo", INTA, Huelva, Spain*
[f] *Spectroscopie de l'atmosphère, CQP, Université Libre de Bruxelles, Brussels, Belgium*

ARTICLE INFO

Article history:
Received 6 September 2010
Received in revised form 17 December 2010
Accepted 29 January 2011
Available online 5 March 2011

Keywords:
Ozone
Validation
MetOp-A
GOME-2
IASI
Brewer spectrophotometer

ABSTRACT

One of the most important atmospheric composition products derived from the first EUMETSAT Meteorological Operational satellite (MetOp-A) is the total ozone column (TOC). For this purpose, MetOp-A has two instruments on board: the Global Ozone Monitoring Experiment 2 (GOME-2) that retrieves the TOC data from the backscattered solar ultraviolet–visible (UV–Vis) radiance, and the Infrared Atmospheric Sounding Interferometer (IASI) that uses the thermal infrared radiance to derive TOC data. This paper focuses on the simultaneous validation of the TOC data provided by these two MetOp-A instruments using the measurements recorded by five well-calibrated Brewer UV spectrophotometers located at the Iberian Peninsula during the complete 2009. The results show an excellent correlation between the ground-based data and the GOME-2 and IASI satellite observations (R^2 higher than 0.91). Differences between the ground-based and satellite TOC data show that the IASI instrument significantly overestimates the Brewer measurements (about 4.4% when all five ground-based stations are jointly used). In contrast, the GOME-2 instrument shows a slight underestimation (~1.6%). In addition, the absolute relative differences between the Brewer and GOME-2 data are quite smaller (about a factor higher than 2) than the Brewer–IASI absolute differences. The satellite viewing geometry (solar zenith angle and the view zenith angle) has no significant influence on the Brewer–satellite relative differences. Moreover, the analysis of these relative differences with respect to the ground-based TOC data indicates that GOME-2 instrument presents a slight underestimation for high TOC values. Finally, the IASI–GOME-2 correlation is high (R^2~0.92), but with a mean relative difference of about ±6% which could be associated with the bias between UV–Vis and infrared spectroscopy used in the retrieval processes.

1. Introduction

Monitoring the evolution of the ozone layer has become a subject of major concern both by the scientific community and the general public from a wider perspective, including the close relationship between the ozone layer changes and the global climate change (World Meteorological Organization, WMO, 2006). With the most advanced atmospheric models predicting global ozone recovery only on the next decades, it is of great scientific and societal importance to maintain a global long-term record of accurate ozone measurements (Loyola et al., 2009).

There are several instruments on board satellites which have been designed for retrieving ozone and other trace gases in the atmosphere, providing daily images of the global total ozone column (TOC) with uniform spatial coverage. These satellite instruments are a very useful tool for understanding the geographical and temporal distribution and variability of the ozone on a global scale. In this context, the Meteorological Operational satellite program (MetOp) from the European organization for the exploitation of METeorological SATellites (EUMETSAT) foresees a series of three polar-orbit platforms which will be launched sequentially every 5 years in order to provide continuous meteorological observations for at least 15 years (2006–2020). The first of these satellites (MetOp-A) was launched in October 2006 and the MetOp-B and MetOp-C are expected to be flying in 2012 and 2016, respectively. The main objective of the MetOp mission is to deliver continuous and long-term datasets supporting operational meteorology, global weather forecasting and climate monitoring (Edwards et al., 2006).

Two of the instruments on board MetOp-A are the Global Ozone Monitoring Experiment 2 (GOME-2) (Munro et al., 2006) and the

---

* Corresponding author at: Departamento de Física Aplicada, Universidad de Granada, 18006 Granada, Spain. Tel.: +34 924 289536; fax: +34 924 289651.
E-mail address: mananton@unex.es (M. Antón).

0034-4257/$ – see front matter © 2011 Elsevier Inc. All rights reserved.
doi:10.1016/j.rse.2011.01.018

Infrared Atmospheric Sounding Interferometer (IASI) (Clerbaux et al., 2009, 2007). Both sensors retrieve total ozone column and ozone profile information with a high spatial and temporal resolution, but while the GOME-2 instrument obtains the total ozone from the backscattered solar ultraviolet–visible (UV–Vis) radiance emerging at the top of the atmosphere, the IASI instrument retrieves it from the thermal infrared radiance (TIR) resulting from the interaction between the Earth's thermal emission and the atmosphere.

To ensure the quality of the satellite TOC observations, the comparison of these satellite data with reliable ground-based ozone measurements has proven to be a crucial activity (WMO, 1999). In this context, the Spanish Agency of Meteorology (AEMet) has accumulated nearly twenty years of experience in measuring TOC with Brewer spectrophotometers. All instruments from the Spanish Brewer network follow the same protocol of calibration and are biannually calibrated by comparison with the traveling references Brewer #017 from the International Ozone Services (IOS) and Brewer #185 from the Regional Brewer Calibration Centre — Europe (RBCC-E). Comparisons with these traveling reference instruments confirm the reliability of the Spanish Brewer calibration (Redondas et al., 2002, 2008). When Brewer spectrophotometers are properly calibrated and regularly maintained, as is the case of the entire Spanish Brewer Network, the TOC records obtained through direct sunlight (DS) measurements can potentially maintain an estimated accuracy of 1% over long time intervals (WMO, 1996). Thus, the instruments of this network have been successfully used to perform exhaustive validation exercises of diverse satellite total ozone datasets (Antón et al., 2010a, 2009a,b, 2008, 2010).

Several validation exercises on the GOME-2 total ozone data have been performed using ground-based spectrophotometers (e.g., Antón et al., 2009a; Balis et al., 2007, 2008). Loyola et al. (in press) showed that the GOME-2/MetOp-A total ozone data (GDP 4.4 version) slightly underestimates ground-based TOC data by about 0.5% to 1.0% over the middle latitudes of the Northern Hemisphere. In addition, some studies have focused on the comparison of the IASI TOC data with ground-based measurements recorded by spectrophotometers, e.g. Boynard et al. (2009), who showed that IASI ozone retrievals present a positive bias of about 3% compared to both GOME-2 and ground-based measurements. These works confirm the need of a continuous validation effort of the GOME-2 and IASI total ozone data using reliable ground-based measurements is required in order to assess its quality and accuracy.

The main objective of this paper is to report on a detailed validation of the MetOp-A TOC data derived from the GOME-2 and IASI instruments, using as reference spatially and temporally co-located ground-based measurements from the well established Spanish network of Brewer spectrophotometers. The period of study covers the period January–December 2009. The observed discrepancies are quantified and their likely origins examined in detail. Although this work is focused on a regional scale (Iberian Peninsula), it provides new insights into the accuracy of the satellite retrievals since to the best of our knowledge, no simultaneous comparisons between these two instruments flying aboard the MetOp-A satellite and ground-based data have been published to date. In addition, this paper presents the first validation of the IASI total ozone data derived from the new operational retrieval software called FORLI (Fast Optimal Retrievals on Layers for IASI).

The paper is organized as follows. The satellite and ground-based measurements are described in Section 2. Section 3 introduces the validation methodology. The results and discussion are presented in Section 4. Finally, Section 5 summarizes the main conclusions.

2. Data

2.1. Satellite observations

GOME-2 is a nadir-viewing scanning spectrometer that covers the UV–Vis spectral range from about 240 to 790 nm, with a resolution varying from 0.26 to 0.51 nm. GOME-2 instrument has a swath-width of 1920 km with a constant ground pixel size of 80×40 km^2, resulting in a daily near global coverage at the equator. The current operational algorithm for the retrieval of total ozone column from the GOME-2 instrument is the GOME-2 Data Processor Version 4.4 (GDP 4.4). The GDP algorithm has undergone several years of progressive improvements since its first release in 1995 (Loyola et al., 1997, in press; Spurr et al., 2005; Van Roozendael et al., 2006). This retrieval algorithm uses two main steps to derive the total ozone column: the Differential Optical Absorption Spectroscopy (DOAS) least-squares fitting over the 325–335 nm fitting window for the retrieval of the slant ozone column, followed by the computation of a suitable Air Mass Factor (AMF) from the multiple-scattering radiative transfer code LIDORT (Spurr, 2008) to perform the conversion to the vertical column density. In addition, the GDP 4.4 includes two algorithms (OCRA and ROCCIN) for the treatment of clouds from GOME-2 measurements (Loyola et al., 2007).

IASI is a nadir-viewing Fourier Transform Spectrometer (FTS) designed to measure the spectrum emitted by the Earth-atmosphere system in the TIR spectral range from 3.62 to 15.5 μm with a resolution varying between 0.002 and 0.003 μm. This spectral range includes the strong absorption features from the ozone absorption band around 9.6 μm. Regarding the horizontal coverage, the IASI instrument has a swath-width of about 2200 km achieving global coverage. Each instantaneous field-of view (50 km × 50 km at nadir) is composed of a matrix of 2×2 circular pixels, with 12 km diameter footprint on the ground at nadir. TOC values are retrieved from the IASI spectra using the FORLI retrieval software which is based on the optimal estimation method described by Rodgers (2000). The FORLI software was initially developed to retrieve carbon monoxide (George et al., 2009; Turquety et al., 2009) and nitric acid (Wespes et al., 2009) concentrations, and was recently adapted to ozone. The FORLI code minimizes the difference between the observation and simulation by iteratively updating the state vector (set of unknown parameters) under constraints. For each observation the inputs are the corresponding IASI level 1C spectra and the IASI level 2 temperature and humidity profiles, as well as the IASI level 2 cloud cover. The direct computation of each spectrum is based on appropriate radiative transfer with speed-up approximations, and line-by-line computations saved in look-up tables which have a spectral oversampling of 100 (e.g. sampling of 2.5×10^{-4} cm^{-1}). These tables are pre-computed on a logarithmic grid in pressure (4.5×10^{-5} to 1.22 atm), a linear grid in temperature (162.8 to 322.64 K) and eventually a linear grid in humidity (for water vapor lines), and interpolated accordingly. The spectrum is processed when the cloud contamination of the pixel is lower than 13%. This threshold was empirically set up by looking to nearby pixel data that are not contaminated by clouds. The outputs are the ozone profile, the total ozone column, as well as the error covariance and averaging kernel matrices describing the vertical sensitivity.

Fig. 1 shows the averaging kernel (AK) profiles of both IASI and GOME-2 algorithms over Madrid for a specific date (10-June-2009). In addition, the experimental ozone profile recorded in this location for the same date has been added to the plot. This ozone profile was recorded using a balloon-borne ozonesonde which employs Electrochemical Concentration Cell (ECC) sensor and it is interfaced to Vaisala RS80-15G radiosonde. The figure shows that ozonesonde reached an altitude of 32 km. Moreover, the different vertical sensitivities of two satellite instruments can be clearly seen. On the one hand, the IASI instrument has a maximum sensitivity in the free troposphere between 5 and 10 km approximately. The vertical resolution of this instrument depends on the emissivity and thermal contrast at the location of the observation. The retrieved profiles are vertically correlated and the number of independent information ranges between 3 and 5. On the other hand, the sensitivity of GOME-2 instrument to the ozone density is strongly height dependent in the troposphere, presenting a maximum sensitivity in the stratosphere where the larger amount of ozone is located. Furthermore, the GOME-2 AK profile in the troposphere depends