Remote Sensing of Environment 209 (2018) 648–659

Contents lists available at ScienceDirect

Remote Sensing of Environment

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

Accuracy of satellite total column ozone measurements in polar vortex conditions: Comparison with ground-based observations in 1979–2013

J. Kuttippurath*, P. Kumar, P.J. Nair, A. Chakraborty

CORAL, Indian Institute of Technology Kharagpur, 721302 Kharagpur, India

ARTICLE INFO

Keywords:
Ozone recovery
Satellite measurements
Polar vortex
Ground-based measurements
Solar zenith angle
TOMS
OMI
SAOZ
DOAZ
Dobson
Brewer

ABSTRACT

This study presents the first detailed long-term analysis of satellite and ground-based Dobson, Brewer, SAOZ (Système D'Analyse par Observations Zénithales) and DOAS (Differential Optical Absorption Spectrometer) measurements inside the Antarctic vortex for the 1979–2013 period. In general, the satellite measurements show a good agreement with ground-based measurements at all stations (correlation coefficient > 0.95). The average relative difference between ground-based and satellite measurements is about ± 1–3% and the mean bias error (MBE) is within ± 4 DU, depending on the satellite instrument and ground-based station. The satellite measurements show good stability over their operational period, for which the estimated drifts are about ± 0.1–5%/decade and are statistically insignificant for most instruments. The Nimbus TOMS (Total Ozone Monitoring Spectrometer) and OMI (Ozone Monitoring Instrument) measurements are stable over the period, but the Earth Probe-TOMS measurements show deterioration after 2000. Also, most satellite instruments show no dependency on satellite solar zenith angle (SZA), but reveal significant dependency on stratospheric temperature. In addition, the mean relative difference shows larger variation with lower total column ozone (TCO). This long-term and multi-instrument comparison exercise would help both ground-based and satellite measurement community to better analyse accuracy of the TCO measurements from the instruments and examine the stability of their long-term measurements. In addition, the SZA and temperature dependency assessment would also help the ozone observation community to use better absorption cross-sections for TCO retrievals.

1. Introduction

The Antarctic ozone hole has been a global environmental problem of great significance. The ozone loss in the polar region was first observed in early 1980s and significant loss in ozone has been observed thereafter (Farman et al., 1985). It was found that the ozone loss was due to the man-made chlorofluorocarbon substances in the atmosphere, but a reduction in ozone depleting substances is also observed in recent years in the Polar Regions (e.g. Rinsland et al., 1989). Therefore, a corresponding increase in ozone is also expected in the Antarctic (e.g. Kuttippurath et al., 2013; Solomon et al., 2016) and hence, monitoring the changes in ozone layer with high accuracy is exceedingly warranted in that region (e.g. Bai et al., 2015; Kuttippurath et al., 2015).

Atmospheric ozone is currently measured from the ground and space by a number of methods, and all employ the principle of interaction of radiation with ozone at different wavelength regions (e.g. Kuttippurath et al., 2010; Hassler et al., 2014; Nair et al., 2015). While the satellite measurements provide global coverage, measurements from the ground are essential to validate them to ensure their quality and long-term stability (Orphal et al., 2016). With the most advanced atmospheric models predicting full ozone recovery only in the next decades (e.g. Austin and Wilson, 2006; WMO, 2014); it is of great scientific and societal importance to maintain a global long-term data of accurate ozone measurements (e.g. Loyola et al., 2009; McPeters et al., 2015; Nair et al., 2015; Kuttippurath and Nair, 2017).

Space-based instruments provide continuous and global measurements, but they require thorough validation with other independent measurements for assessing their accuracy and making corrections to retrieval algorithms (e.g. Bhartia and Wellemeyer, 2002; Balis et al., 2007a). It is a regular exercise that the ground-based and satellite measurements are checked with respect to dedicated field campaign measurements, such as in Lauder in 1992 and in Cabauw in 2009 (e.g. Vaughan et al., 1997; Roscoe et al., 1999; Vandaele et al., 2005; Roscoe et al., 2010). The Total Ozone Mapping Spectrometer/Ozone Monitoring Instrument (TOMS/OMI) aboard different satellites have been thoroughly validated over the years, tropics and mid-latitudes in particular. For instance, studies using satellite measurements show Total Column Ozone (TCO) differences of about 3% with different ground-

* Corresponding author.
E-mail address: jayan@coral.iitkgp.ernet.in (J. Kuttippurath).

https://doi.org/10.1016/j.rse.2018.02.054
Received 12 March 2017; Received in revised form 27 January 2018; Accepted 22 February 2018
0034-4257/ © 2018 Elsevier Inc. All rights reserved.

based measurements (GBM) (Fioletov et al., 2008; Antón et al., 2009, 2010; Hendrick et al., 2011). Balis et al. (2007b) showed that the average deviation is < 2% between Earth Probe TOMS (EP-TOMS) and GBMs, as estimated for 18 places in Europe, Canada, Japan, the United States, and Antarctica in 1996–2004. McPeters et al. (2008) found a difference of about 0.4%–1.1%, when OMI measurements were compared to Brewer and Dobson GBMs from 76 stations in the northern hemisphere in 2004–2006. Buchard et al. (2008) reported that the agreement between ground-based and OMI measurements at two French sites is within 5% for the period October 2004–September 2005. Ialongo et al. (2008) compared the OMI and ground-based measurements in Rome and found a systematic difference of about +1.8% during the period 2004–2006. The comparison between Brewer and OMI measurements at five Spanish stations showed an underestimation of the latter by 2% in 2005–2007 (Antón et al., 2009). Zhang et al. (2017) found that most satellite measurements overestimate the Brewer measurements at Zhongshan in Antarctica, with about 0–4% in 1993–2015.

In Antarctica, there are several ground-based instruments, which are capable of measuring TCO. These instruments include spectrometers of Dobson, Brewer, Système D'Analyse par Observations Zénithales (SAOZ) and Differential Optical Absorption Spectroscopy (DOAS) (e.g. Kuttippurath et al., 2010). Most of these instruments have observations for several decades, but some are not validated thoroughly. In addition to this suite of instruments, there are also a number of satellite measurements available for several decades. These satellite measurements are mostly globally validated, and thus provide a general idea of the bias of measurements at different latitude regions. However, as the dynamics and chemistry are different in polar vortex conditions as compared to other latitude regions, these global validations are not sufficient to deduce accurate biases of the measurements inside the vortex (e.g. Zhang et al., 2017). Furthermore, since the ozone recovery studies in Polar Regions are primarily based on measurements inside the vortex (Nash et al., 1996; Hauchecorne et al., 2002), thoroughly validated measurements (both ground and satellite-based) are necessary for the long-term trend analyses.

We, therefore, examine the satellite measurements inside the Antarctic polar vortex for the past 34 years and analyse their accuracy and stability. Since the accuracy of most satellite TCO measurements is not examined yet in vortex conditions, as most validation exercises are (both ground and satellite-based instruments) limited to averages in time (e.g. few years) and space (e.g. latitudinal averages or a few ground-based stations), we use the TOMS (flown on different satellites during the period 1979–2004) and OMI (2005–2013) measurements inside the Antarctic polar vortex for this analysis.

Since we are discussing the polar ozone in vortex conditions, the measurements during May–November are exploited from 11 Antarctic stations. A detailed comparison between GBM and satellite data is performed to deduce the bias and drift in satellite or ground-based measurements at different stations. Furthermore, as the absorption cross-sections depend on temperature and solar zenith angle (SZA), we investigate the dependency of retrieved measurements on temperature and SZA. This is particularly important in the context that the World Meteorological Organization/Global Atmosphere Watch - International Ozone Commission had constituted a committee - ACSO (Absorption Cross Sections of Ozone; http://igaco-o3.fmi.fi/ACSO/, 2009) - to review the ozone cross-sections and to find the impact of ozone cross-sections on retrievals from different satellite and ground-based instruments, and henceforth, the results from this study can also be used for further analyses and assessment reports. On top of these, according to the Global Climate Observing System (GCOS, http://www.wmo.int/pages/prog/gcos/Publications/gcos-154) requirements, satellite measurements with absolute error smaller than 5 DU, total uncertainty < 2% and a long-term drift/stability within 1%/decade qualify as a parameter for the climate change assessment. Henceforth, we examine the quality of the TOMS and OMI data in this study.

Table 1
The ground-based stations in Antarctica with their latitude (Lat.), longitude (Lon.), type of instrument used for measurements (Inst.) and measurement period (Period) considered in this study. The measurements inside the Antarctic vortex from May through November as available from each instrument are considered. The position of stations is illustrated in Fig. 1.

Stations	Lat.	Lon.	Inst.	Period
Arrival Heights	77.8°S	166.7°W	Dobson	1988–2013
Belgrano	77.9°S	34.6°W	Brewer	1993–2013
Faraday	65.3°S	64.3°W	Dobson	1979–2013
Halley	75.6°S	26.8°W	Dobson	1979–2013
Marambio	64.2°S	56.7°W	Dobson	1987–2013
Neumayer	70.7°S	8.3°W	DOAS	1999–2012
Rothera	67.6°S	68.1°W	SAOZ	1996–2013
Syowa	69.0°S	39.6°E	Dobson	1979–2013
Zhongshan	69.4°S	76.4°E	Brewer	1993–2013
San Martin	68.07°S	67.08°W	Brewer	2002–2010
South Pole	89.9°S	24.8°W	Dobson	1979–2013

2. Total column ozone measurements

2.1. Ground-based measurements

2.1.1. Dobson spectrometer

Dobson spectrometer is a double quartz-prism monochromator and it permits simultaneous measurements at two wavelengths in the UV region, where absorption at one wavelength is more as compared to the other (Dobson, 1957). The instrument sequentially measures a series of wavelength pairs, and comparison of the absorption for each pair of wavelengths allows for the estimation of TCO, with the weighted mean average of the individual estimates giving the final TCO. The most common wavelength pair, used for more than 98% of instruments, is the double pair: 305.5/325.4 and 317.6/339.8 nm (Komhyr et al., 1993). The absorption cross-sections from Paur and Bass (1985) are used for measurements. Individual observations are performed by looking at the direct sun in clear sky conditions and measurements with SZA < 84° can be performed. The total error of Dobson measurements is about 3% (e.g. Hendrick et al., 2011). The Dobson measurements at South Pole, Syowa, Marambio, Arrival Heights, Halley and Faraday are used. Further details about the stations are given in Table 1.

2.1.2. Brewer spectrometer

The instrument consists of a single diffraction grating, and 5 precision milled exit slits, mounted at the focal plane of the instrument. The slits correspond to wavelengths 306.3, 310.1, 313.5, 316.0 and 320.0 nm optimised for measuring ozone and SO_2. A Fabry lens, placed just behind the exit slits, produces a reduced image of the diffraction grating on a 10 mm diameter photocathode of a photomultiplier tube. The slits are sampled sequentially by moving a mask in front of them. As the slits are never moved, the wavelength calibration is very stable. The resolution of the Brewer instrument is 0.6 nm compared to 0.9-3.0 nm of the Dobson instruments. The Brewer spectrophotometers make use of the same principle as that of Dobson for TCO observations. Therefore, the uncertainty of a well-calibrated Brewer instrument is similar to that of the Dobson, about 2–3% (Basher, 1985; Scarnato et al., 2010). Measurements at Belgrano, San Martin and Zhongshan are performed with Brewer instruments and are considered.

2.1.3. SAOZ

The SAOZ instruments are zenith sky ultra-violet visible (UV–Vis) spectrometers with a resolution of 1 nm looking at sunlight scattered at zenith during twilight, which measure ozone in the Chappuis band (450–650 nm) at high SZA between 86° and 91° every morning and evening (Pommereau and Goutail, 1988; Kuttippurath et al., 2013). Various SAOZ observations, in general, agree within 3%, for which the main source of uncertainty is the air mass factor used in the retrieval.

Download English Version:

https://daneshyari.com/en/article/8866665

Download Persian Version:

https://daneshyari.com/article/8866665

Daneshyari.com