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Statistical bias correction for creating coherent total ozone record from OMI and OMPS observations

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ABSTRACT

A long-term coherent total column ozone (TCO) record is essential to ozone layer variability assessment, especially the detection of early signs of ozone recovery after years of depletion. Because of differences in satellite platforms and instruments design, calibration, and retrieval algorithms, however, significant cross-mission biases are observed between multiple sensor TCO observations in the common time–space domain. To attain a coherent TCO record, observed cross-mission biases should be accurately addressed prior to the data-merging scheme. In this study, a modified statistical bias correction method was proposed based on the quantile-quantile adjustment to remove apparent cross-mission TCO biases between the Ozone Monitoring Instrument (OMI) and Ozone Mapping and Profiler Suite (OMPS). To evaluate the effectiveness of this modified algorithm, the overall inconsistency (OI), a unique time-series similarity measure, was proposed to quantify the improvements of consistency (or similarity) between cross-mission TCO time series data before and after bias correction. Common observations during the overlapped time period of 2012–2015 were used to characterize the systematic bias between OMPS and OMI through the modified bias correction method. TCO observations from OMI during 2004–2015 were then projected to the OMPS level by removing associated cross-mission biases. This modified bias correction scheme significantly improved the overall consistency, with an average improvement of 90% during the overlapped time period at the global scale. In addition to the evaluation of consistency improvements before and after bias correction, impacts of cross-mission biases on long-term trend estimations were also investigated. Comparisons of derived trends from the merged TCO time series before and after bias correction across 38 ground-based stations indicate that cross-mission biases not only affect magnitudes of estimated trends, but also result in different phases of trends. Further comparisons of estimated seasonal TCO trends before and after bias correction at the global scale suggest that trends derived from the bias-corrected time series are more accurate than those without bias correction. Overall, the bias correction scheme developed in this study is essential for preparing an accurate long-term TCO record representative of trend analysis to support future assessment of ozone recovery at the global scale.

1. Introduction

Ozone is an important atmospheric component that plays a key role in atmospheric chemical and radiation processes, despite its smaller concentration compared to the well-mixed carbon dioxide in the atmosphere (Jöckel et al., 2006; McPeters, Bhartia, Haffner, Labow, & Flynn, 2013). Broadly, atmospheric ozone can be divided into two portions depending on its location in the atmosphere: stratospheric ozone in the Earth's upper atmosphere and tropospheric ozone in the lower atmosphere. Unlike ozone in the troposphere, which adversely impacts human health, natural vegetation growth, and crop yield, stratospheric ozone protects life on Earth from the sun's harmful ultraviolet (UV) light by absorbing the high frequency radiation through a photochemical process. This process modifies the chemistry of the stratosphere and produces heat that in turn changes atmospheric dynamics (McPeters et al., 2013).

Compared to the "bad ozone" at the Earth's surface, "good ozone" in the stratosphere draws more scientific attention because of the dramatic ozone depletion over Antarctica and its profound climatic effects on the global environment since the late 1970s. As a result of the abundant release of anthropogenic chlorofluorocarbons into the atmosphere, an expanding Antarctic ozone hole has been observed during each austral spring in the past decades. Scientific investigations indicate that the

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depleted Antarctic ozone layer has played a critical role in the Southern Hemisphere (SH) climate changes, and that these effects are not confined just to the vicinity of Antarctica but extend over much of the SH, even reaching the tropics (e.g., Reason, 2005; Son, Tandon, Polvani, & Waugh, 2009; Thompson et al., 2011; Kang, Polvani, Fyfe, & Sigmond, 2011; Ding, Steig, Battisti, & Küttel, 2011; Feldstein, 2011; Fyfe, Gillett, & Marshall, 2012; Gillett, Fyfe, & Parker, 2013; Gonzalez, Polvani, Seager, & Correa, 2013; Manatsa, Morioka, Behera, Yamagata, & Matarira, 2013). Owing to the implementation of the Montreal Protocol and its amendments since 1989, emissions of ozone depleting substances into the atmosphere have been significantly reduced. Subsequently, ozone layer depletion has decelerated and has begun to recover since the mid-1990s (WMO, 2003). Modeling experiments indicate that the ozone layer would recover to its 1980s conditions by the 2050s, which in turn may result in significant climatic changes (e.g. Arblaster, Meehl, & Karoly, 2011; Perlwitz, 2011; Perlwitz, Pawson, Fogt, Nielsen, & Neff, 2008; Barnes, Barnes, & Polvani, 2014; Previdi & Polvani, 2014).

To better predict future climate, investigations of mechanisms linking the regional climate changes to the observed ozone variability are needed, and therefore accurate long-term total column ozone (TCO) records are critical. These records are also essential to better understand earth system processes, to assess TCO variability and long-term trends, and to provide inputs to modeling efforts of Earth systems. Since the late 1970s, satellite-based TCO observations with high temporal resolution (e.g., daily) at the global scale have been available. Different satellite instruments and platforms have provided TCO observations since the 1970s (Fig. 1). These cross-mission sensors provide continuous TCO observations for long-term variability assessment. Because of differences in platforms and instruments design, calibration processes, center wavelengths, and retrieval algorithms, however, apparent cross-mission biases are observed between associated TCO observations. As reported by Kuttippurath et al. (2013), however, an ozone recovery rate of 1 to 2.6 Dobson Units (DU) per year was observed during 2000–2010 over Antarctica, which in turn suggests that even small drifts between TCO time series could result in apparent changes in ozone layer recovery speed. To create a consistent TCO record for the assessment of the long-term ozone variability, particularly the early signs of ozone recovery, cross-mission biases should be removed prior to the merging scheme. Generally, an advanced approach is to reprocess all the original radiometric datasets by applying different calibration corrections to each instrumental observation to guarantee that data from different instruments are consistent prior to the retrieval process through a same algorithm (McPeters et al., 2013). This approach is accurate because radiance calibration errors propagate nonlinearly, producing latitudinal and seasonal dependent errors in the retrieved ozone data (McPeters et al., 2013). One representative product using this approach is the Version 8.6 Solar Backscatter Ultraviolet (SBUV) Merged Ozone Data Set (MOD), which provides the longest available satellite-based time series TCO profile from a single instrument type (i.e., SBUV-type) (Frith et al., 2014; McPeters et al., 2013). A similar product was also created from European satellite sensor observations (e.g., Lerot et al., 2014). Although this approach is accurate, establishing a consistent calibration for different instruments requires efforts that can only be achieved by working with the original instrument teams. Moreover, the current Version 8.6 SBUV MOD is a zonal monthly mean gridded product with a spatial resolution of 5° globally, and both spatial and temporal resolutions are too coarse for regional analysis such as ozone-hole monitoring. In addition to the aforementioned reprocessing approach, data assimilation is another possible method capable of creating a long-term TCO record by incorporating TCO observations from satellite and ground-based instruments simultaneously. TCO records generated from these methods are always referred to as multi-sensor reanalysis ozone (e.g., Dragani, 2011; Van Der, J., Allaart, & Eskes, 2010, 2015).

In addition to the aforementioned complex approaches, statistical bias correction methods could be alternatives to removing cross-mission sensors biases. Most widely used statistical bias correction methods include simple approaches such as the delta-change and linear scaling (e.g.Vila, de Goncalves, Toll, & Rozante, 2009; Teutschbein & Seibert, 2012), and higher-skill methods such as the nonlinear regression (e.g. Teutschbein & Seibert, 2012; Bordoy & Burlando, 2013), Kalman

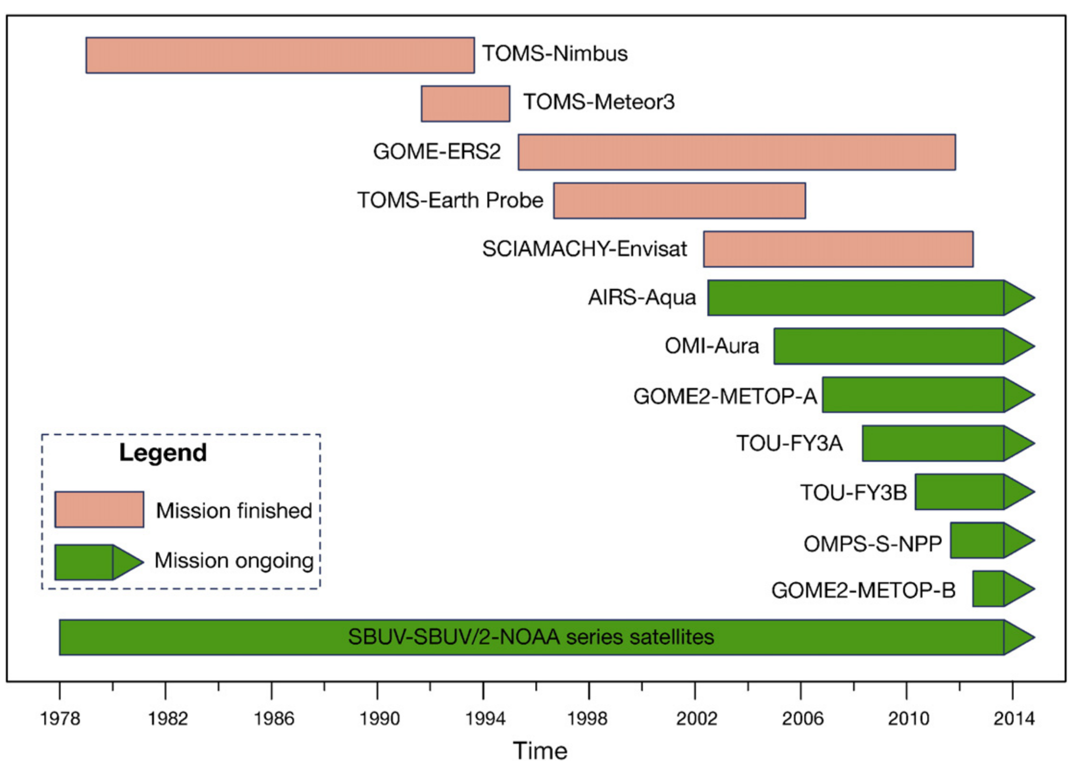

Fig. 1. Satellite instruments and platforms providing total ozone measurements since the 1970s.