Upper-Tropospheric and Lower-Stratospheric Ozone from Assimilation of EOS-Aura Data into GEOS-5

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Abstract

Accurate knowledge of the abundance, structure and variability of ozone fields in the Upper Troposphere – Lower Stratosphere (UTLS) is critical to our understanding of Stratosphere – Troposphere Exchange processes, radiative forcing and the tropospheric ozone budget. Data assimilation provides a unique opportunity to generate a representation of global ozone fields by combining satellite observations with general circulation model output in a manner that is consistent with atmospheric dynamics. In this paper we present validation results of an eight-year long assimilation of data from the Ozone Monitoring Instrument (OMI) and the Microwave Limb Sounder (MLS), both on the EOS-Aura satellite, into the GEOS-5 Data Assimilation System (GEOS-DAS) developed at NASA's Global Modeling and Assimilation Office (GMAO) in collaboration with NCEP. This version of GEOS-DAS uses state-dependent background error variances for ozone, which help resolve sharp tracer gradients in regions of high variability. In particular, we will demonstrate that sharp ozone gradients in the vicinity of the tropopause are correctly represented in this assimilation allowing studies of cross-tropopause ozone transport.

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EOS-Aura Ozone Data

The Ozone Monitoring Instrument (OMI) provides information on the total ozone column by measuring backscattered solar radiation. The ground pixel size at nadir scan position is 13×24 km^2.
The OMI data are assimilated using efficiency factors which account for variable sensitivity of the retrievals to different layers of the atmosphere. The a priori information is effectively removed by the observation operator.

The Microwave Limb Sounder (MLS) provides information on the chemical composition of the stratosphere during day and night. This is retrieved from measured microwave emissions from the atmospheric limb. Ozone profiles from MLS (~260 hPa – 0.14 hPa, vertical resolution ~3 km) constrain the stratospheric ozone in the data assimilation system.

We assimilate OMI version 3 and MLS version 2.2 retrieved ozone product.

GEOS-5 Data Assimilation System

The Goddard Earth Observing System - 5 (GEOS-5) Data Assimilation System uses the 3-DVAR Gridpoint Statistical Interpolation algorithm with an Incremental Analysis Update scheme, in which analysis increments are added to the model integration as additional forcing terms. This leads to smooth transport.
The present experiment uses GEOS-5.7.2 DAS at a 2°×2.5°horizontal resolution with 72 l layers. It spans eight years of Aura data, 2005 - 2012. Ozone is assimilated along with meteorological data from satellite-borne instruments as well as conventional data sources as described in *Rienecker et al. (2011, J. Of Climate).*

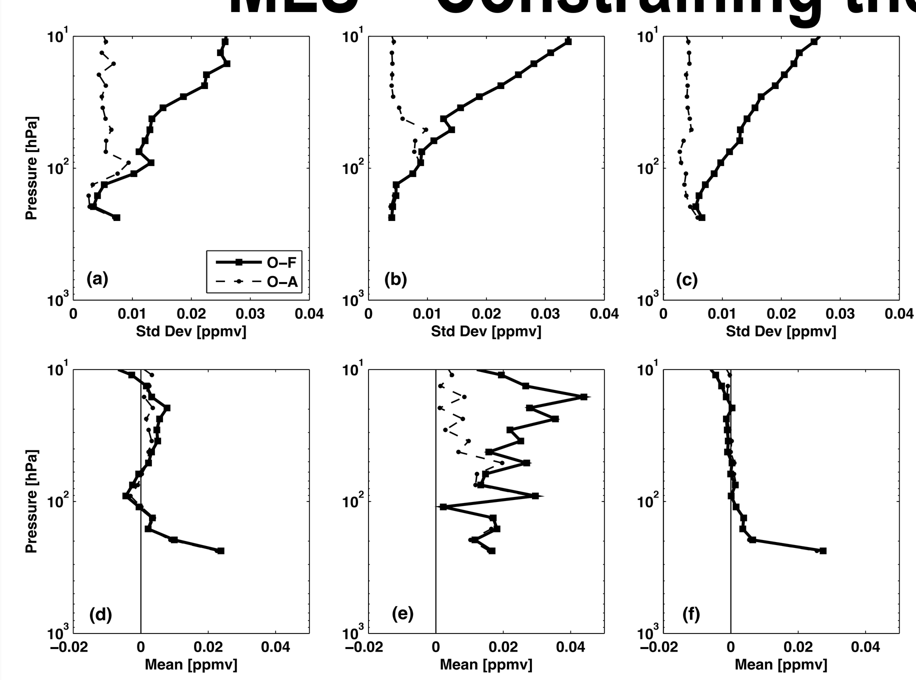
Information from the data is distributed around an observation location using a prescribed background error correlation matrix. In some cases this may lead to excessive smoothing of the assimilated fields, particularly in the presence of sharp gradients. In order to alleviate this problem we use state-dependent background error variances for ozone:

$$\sigma = \alpha \times [O_3]_{[mol/mol]}$$

where α is a tunable parameter.

Observation minus Forecast Statistics

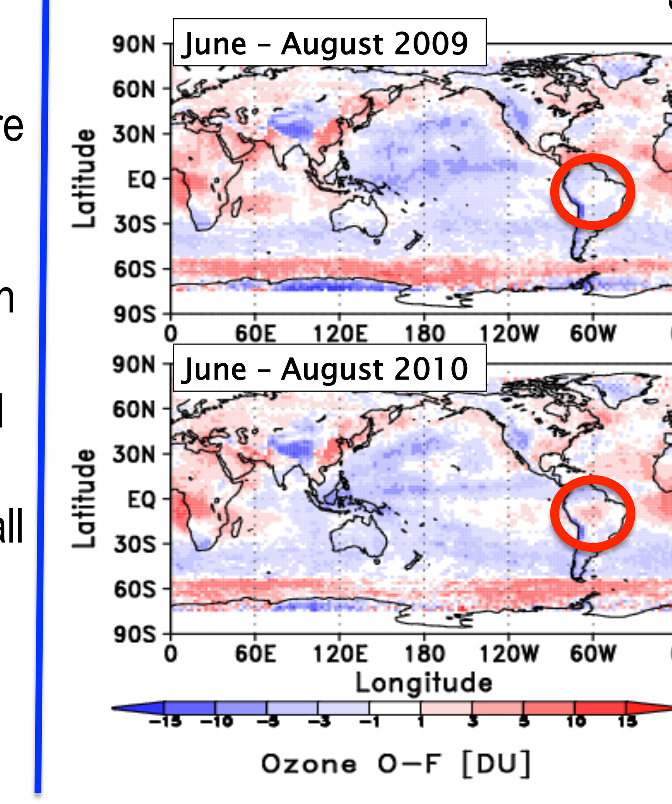
MLS – Constraining the Stratosphere



Mean (top) and standard deviation (bottom) of MLS observation minus forecast and observation minus analysis residuals

- Analysis corrects for forecast errors through the stratosphere (O-A is smaller than O-F).
- At the lowest two MLS layers, where observations are known to be biased high and have large errors, the O-A is biased high.
- O-F standard deviation is small - stratospheric ozone is well constrained by MLS data

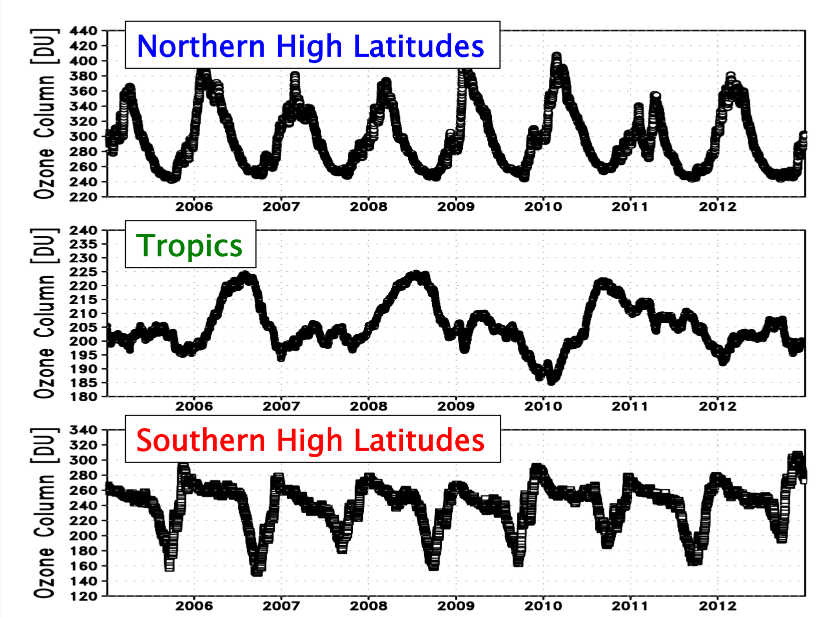
OMI – Extracting Tropospheric O_3 Information



With the stratosphere constrained by MLS observations, the total ozone column from OMI observations provide information about tropospheric ozone.

- Positive O-Fs over land – the data partly compensate for the lack of ozone sources in the model
- Negative values over regions of deep convection – possible correction of model transport errors
- Biomass burning in the Amazon: much higher fire counts reported in 2010 than in 2009
- South of 60°S (high solar zenith angles) – OMI data and efficiency factors are less accurate

Stratospheric O_3 Column in Assimilation



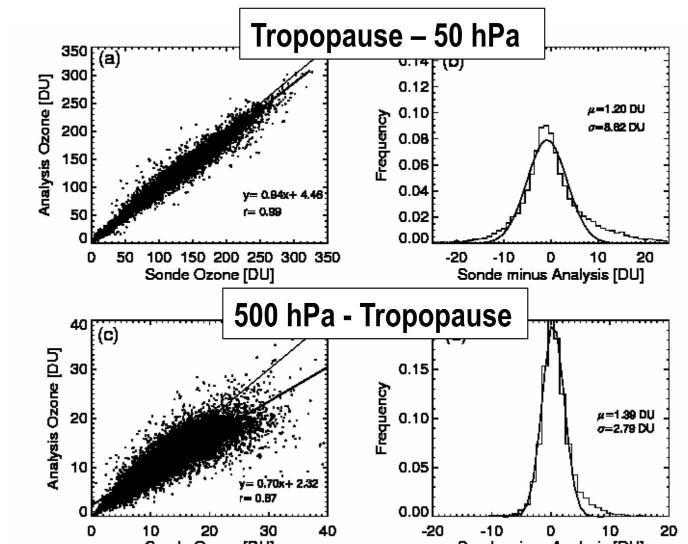
Analysis ozone integrated between the dynamical tropopause and the top of the model atmosphere, 6-hourly data, area-averaged in 3 latitude bands

Northern High Latitudes
- Spring maxima
- Interannual variability
- The 2011 'Arctic ozone hole'

Tropics
- Dominated by the Quasi-Biennial Oscillation

Southern High Latitudes
- Springtime ozone holes

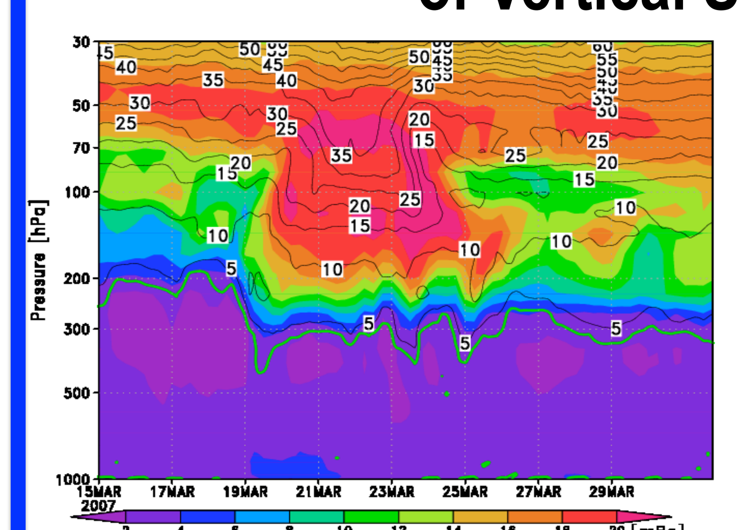
Comparison with ozonesondes



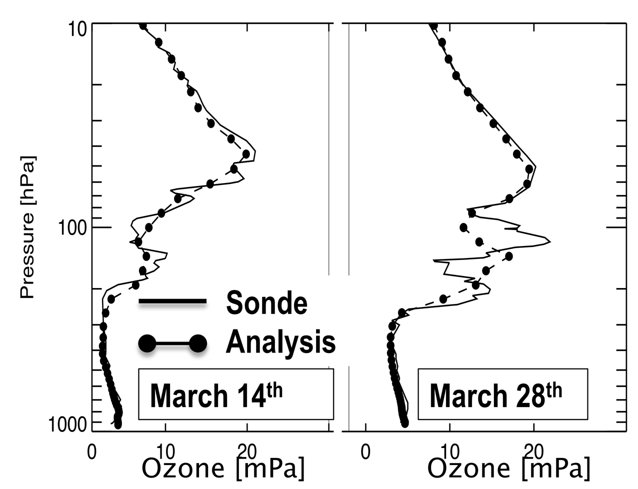
Left: scatter plots, vertically integrated analysis ozone vs. sondes. Right: the PDF of the differences (step) and Gaussian fit (smooth). All available sondes, 2005 – 2012. Ozone sondes: SHADOZ, WOUDC, NDACC

There is an excellent agreement in the lower stratosphere in terms of correlation, the mean and standard deviation of the analysis minus sonde differences. Analysis is biased low in the upper troposphere. This can be attributed to the absence of pollution-induced ozone sources in the model. The background upper tropospheric ozone is still well represented

Ozone Coupled with Dynamics – Representation of Vertical Structures



Evolution of ozone partial pressure (colors) and potential vorticity (contours) at the Hohenpeissenberg location (47°48'N, 11°E). . The 2 PVU line is bolder and shown in green.



Sonde and analysis ozone profiles at Hohenpeissenberg on two days in March 2007

The plots show the evolution of ozone and potential vorticity at a particular location in Germany in the second half of March 2007. A passage of an upper-level cyclone from north to south brings high PV and high ozone air from the north, resulting in a lowering of the dynamical tropopause (defined here as the 2 PVU surface). This example highlights the consistency of the dynamics and constituent transport in GEOS-5. The vertical ozone structures are in a fair agreement with ozonesonde data.

Summary

- **An analysis of EOS-Aura ozone data has been produced for 2005 – 2012 (continuing to the present)**
- **MLS profile data constrains the stratospheric ozone allowing the total column (OMI) observations to influence the tropospheric ozone column in assimilation**
- **Excellent agreement with ozonesondes in the lower stratosphere. Small low bias in the troposphere – need to include ozone sources (NO_x chemistry in the model)**
- **Evolution of assimilated ozone fields: tracer transport consistent with assimilated meteorology**