Estimating ozone radiative forcing based on satellite observations

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ABSTRACT

Recently available satellite measurements, such as those from the Tropospheric Emission Spectrometer (TES) on the NASA EOS Aura platform, are providing for the first time, global datasets of the distribution of trace gases in the lower atmosphere. One application of this data is in constraining physical and chemical processes in numerical models. Presented here are initial results from a study of the impact of constraining the global tropospheric ozone distribution, with ozone profiles retrieved from T ES, on the radiative forcing in a general circulation model. Ozone data from TES are first assimilated into a version of the Geophysical Fluid Dynamics Laboratory's chemistry-climate model AM2-Chem in which the model dynamics are constrained by nudging to NCEP reanalyses. The assimilated ozone field is then used to constrain the radiation calculation in AM2-Chem, with no dynamical constraints imposed, to assess the impact on the radiative forcing through changes to the outgoing longwave radiation and model dynamics (T, u, v, w etc).

INTRODUCTION

Ozone is an important trace gas, making a significant contribution to the chemical and radiative state of the lower atmosphere. Increases in tropospheric ozone are estimated to provide the third largest increase in direct radiative forcing since the pre-industrial era and contribute a radiative forcing of 0.35 W/m2 to the climate system (IPCC, 2001). Currently, climate models produce a range of results for the impact of tropospheric ozone, reflecting uncertainties in the chemistry and sources of tropospheric ozone. Satellite observations of the global distribution of ozone in the troposphere are challenging due to its extreme local variability and low abundances compared to the stratosphere. The Tropospheric Emission Spectrometer (TES) is the first dedicated satellite instrument from which the global tropospheric ozone distribution can be measured and is described in the next section. Presented here are initial results from model simulations aimed at better quantifying the global radiative impact of tropospheric ozone through constraints imposed from recent satellite observations.

AM2-CHEM – GLOBAL CIRCULATION MODEL

- The AM2-Chem model is a general circulation model with a full representation of tropospheric chemistry based on the MOZART-2 chemical transport model (Horowitz et al., 2003; Tie et al., 2004). The model is described by Anderson et al. (2003).
- The model has a horizontal resolution of 2 degrees latitude and 2.5 degrees longitude with 24 vertical levels with nine vertical levels in the lowest 1.5 km above the surface, whereas there are five levels in the stratosphere. The vertical resolution in the upper troposphere is approximately 2 km.
- Ozone fields and radiation calculation in model can be specified based on climatology.

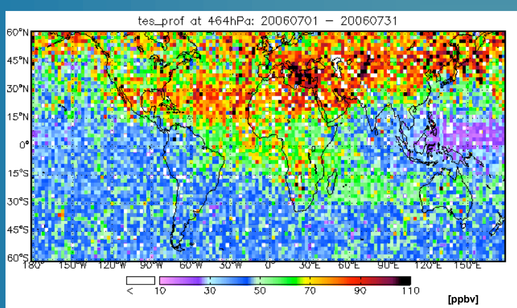


Figure 1. TES Global Observations, July 1-31 2006

TES ASSIMILATED OZONE

- The ozone field in the AM2-Chem radiation calculation is constrained through assimilation of ozone data from the TES instrument.
- TES is high-resolution infrared Fourier Transform spectrometer that was launched onboard the NASA EOS Aura satellite in on July 14, 2004.
- The Aura satellite is a polar sun-synchronous orbit with a repeat cycle of 16 days and a 1.43 pm ascending node.
- It can measure spectral radiances from 3.3-15 μm and a nadir footprint of 8 km x 5 km.
- TES provides accurate tropospheric profiles of temperature, water vapour, ozone, carbon monoxide, and surface temperatures.
- Ozone profiles from TES used in the AM2-Chem simulation are assimilated using a sub-optimal Kalman filter, which adjusts the model field with a weighted difference between the model and observed states (Parrington et al., 2007).

EXPERIMENTAL METHODOLOGY

To investigate the radiative impact of the tropospheric ozone distribution in the AM2-Chem model, two simulations are performed. Firstly, a standard simulation is performed in which the model is allowed to run for one month, outputting monthly mean global fields of temperature and OLR. In this simulation, the radiation calculations in the model are based on an ozone climatology, derived from ozonesonde and satellite observations. A second simulation, similar to the first, is performed but with the ozone field used in the model radiation calculations constrained with the TES observations. This TES assimilated ozone field was also generated with the AM2-Chem model with constraints imposed on the model dynamics by nudging to NCEP re-analyses.

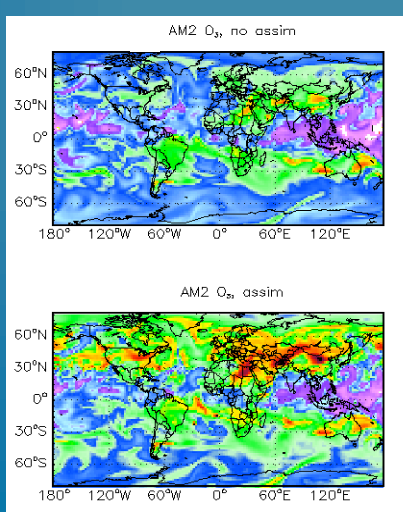


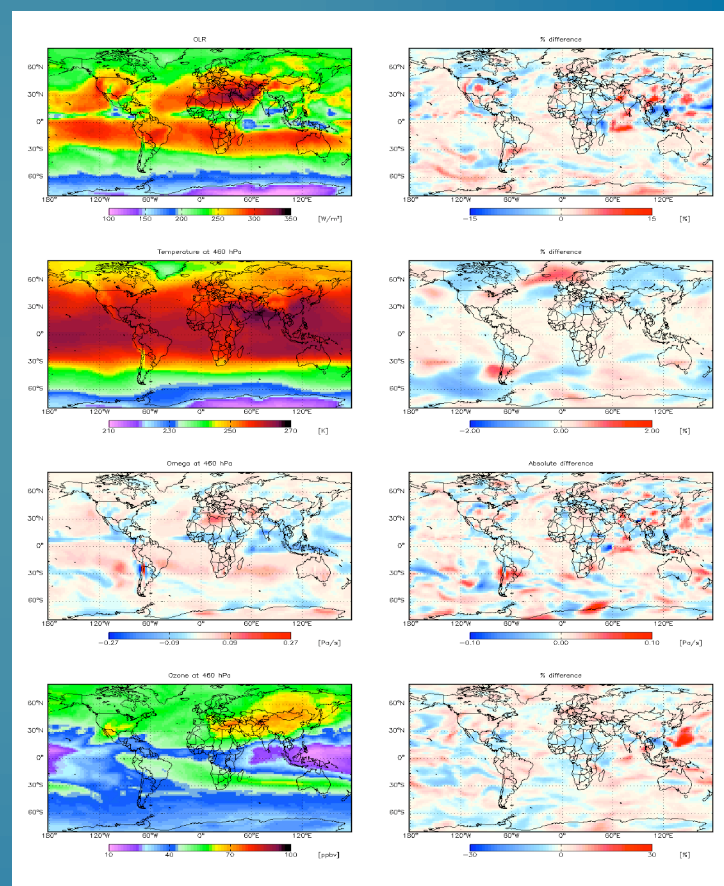
Figure 2: Ozone Concentrations in AM2-Chem before and TES assimilated ozone.

ACKNOWLEDGMENTS

The Centre for Global Change Science at the University of Toronto

RESULTS

- The left-hand column of Figure 3 shows monthly averaged global fields of the outgoing longwave radiation along with temperature, vertical transport (omega) and ozone at 460 hPa from the standard simulation. The right-hand column shows the differences between the TES assimilated and standard simulations.
- The TES assimilated ozone, which will have a different distribution to the climatology used in the standard simulation, has a global impact on the radiation calculation reflected by changes of between ±15% in OLR, ±2% in temperature, ±0.1 Pa/s in vertical transport, and ±30% in ozone.
- The ozone field shown does not interact with the radiation calculation in the model and reflects the change in the circulation patterns induced by the climate response. Changes in the ozone field are subject to the zonal and meridional winds, and the vertical transport, and indeed it is possible to identify some of the ozone changes with the omega changes.
- The changes in omega can also be identified with changes in the OLR, the largest changes in which are seen in the tropics over the western Pacific, southern Asia and the Indian ocean, along the ITCZ.
- The largest changes in temperature, up to 2%, are seen at mid-latitudes, whereas in the tropics, the changes are less than 0.5% relating to approximately 1K.



CONCLUSIONS AND FUTURE WORK

- Initial results show that the TES assimilated ozone affects the circulation in AM2 compared to the standard simulation in which an ozone climatology is used.
- The imposed ozone field has an impact on radiative forcing reflected in changes to the OLR and temperature, vertical transport and ozone distribution in the mid-troposphere.
- Assessment of the model response in the upper troposphere, where the radiative forcing is more sensitive to changes in the ozone abundance, is required to further understand the observed changes.
- Future work:
  - Better quantify the differences between the model simulations
  - Interpret response of tropospheric circulation to changes in temperature and OLR
  - Evaluate the radiative forcing of tropospheric ozone as observed by TES

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