Simulations of tropospheric/stratospheric ozone with the Canadian Middle Atmosphere Model

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Abstract: The Canadian Middle Atmosphere Model (CMAM) is based on a vertically extended (lid near 95 km) version of the 3rd generation Canadian GCM. A gas-phase stratospheric chemistry mechanism (CH_4, N_2O, halocarbons, NO_x, HO_x, inorganic Cl and Br) and a description of heterogeneous processing on PSCs is included in CMAM and the model ozone field is interactive with the GCM radiation scheme. The model in the above described state has been extensively exercised and has participated in both rounds of the Chemical Climate Model Validation (CCMVal) model intercomparison project where it has been shown to compare favourably with other current-generation CCMs. An updated version of CMAM has recently been completed including additional model components to simulate the chemistry of the troposphere such as lightning NOx emissions, wet and dry deposition and cloud-corrections for photolysis rates. The chemistry of non-methane hydrocarbons are not yet included, though results from a year-2000 timeslice experiment show the model is capable of representing the general features of the global distribution of ozone throughout the atmosphere.

Timeslice experiments using combinations of present-day and pre-industrial sea-surface temperatures and sea-ice (SST/SIC) together with present-day and pre-industrial emissions of CO and NOx and present-day and pre-industrial levels of ozone depleting substances (ODSs) are used to explore the interactions between climate, tropospheric and stratospheric ozone changes. The changes in tropospheric ozone column from pre-industrial to present-day are comparable with earlier estimates, considering the AR5 historical pre-cursor emissions used here. Changes in strat-trop exchange of ozone, when using pre-industrial SSTs/SIC, have a significant impact on the model simulated pre-industrial tropospheric ozone and significantly reduce the pre-industrial to present-day increase in ozone simulated by the model. While the increase in tropospheric ozone column from pre-industrial to present-day would be larger if not for the effects of ODSs.

<u>Stratospheric CMAM</u>

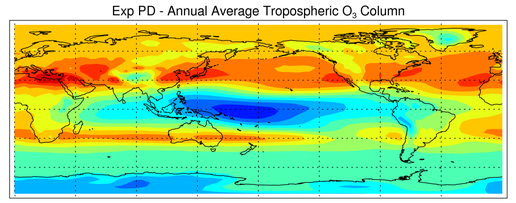
- T31, 71 levels, lid at 95 km
- no chemistry calculated on model levels below 400 hPa
- specified lower boundary condition (mixing ratio) for source gases (N_2O, CH_4, halocarbons)
- look-up table of clear-sky photolysis rates with constant surface albedo (0.3)
- constant dry deposition velocity for certain species

<u>Tropospheric extension of CMAM</u>

- T47, 71 levels, lid at 95 km
- chemistry calculated on all model levels
- specified lower boundary condition for source gases
  - specified emission fluxes for CO and NOx
  - NOx emission from lightning
- look-up table of clear-sky photolysis rates with local surface albedo
  - correction to account for clouds
- multiple resistance calculation of dry deposition velocities
- solubility-based wet removal by stratiform and deep convection precipitation
- N_2O_5 hydrolysis on tropospheric aerosols

the same chemical mechanism is currently used in both versions

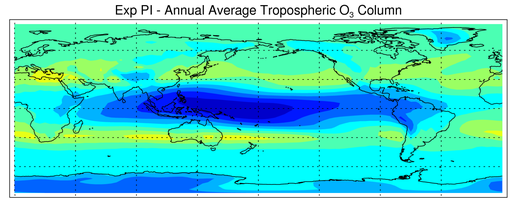
Annual average tropospheric column ozone from the different experiments



PD - Present Day Tropospheric Ozone Column

- year 2000 emissions from AR5 database
- year 2000 CH_4(1.76 ppmv), N_2O (316 ppbv)
- year 2000 ozone depleting substances (3.4 ppbv Cly)
- year ~2000 SST/SIC from HadISSTs

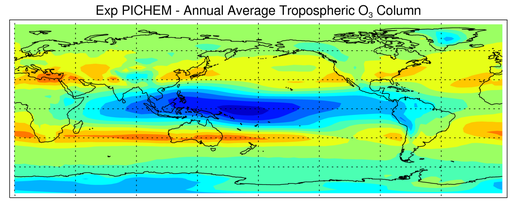
Global Avg. 29.8 DU



PI - Pre-Industrial Tropospheric Ozone Column

- year 1880 emissions from AR5 database
- year 1880 CH_4 (0.84 ppmv), N_2O (278 ppbv)
- year 1880 ozone depleting substances (0.5 ppbv Cly)
- year ~1880 SST/SIC from HadISSTs

Global Avg. 22.9 DU

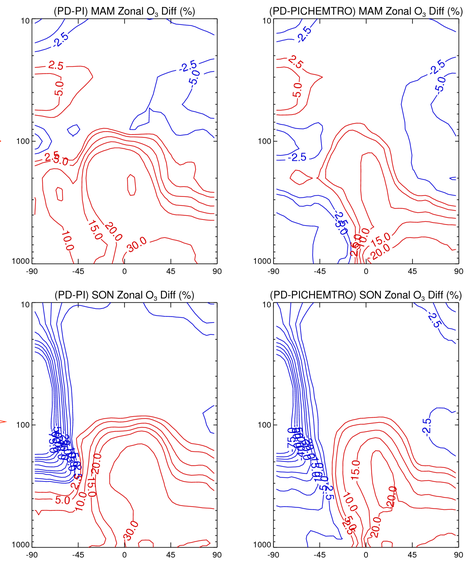


PICHEM - Pre-industrial Tropospheric Ozone Column

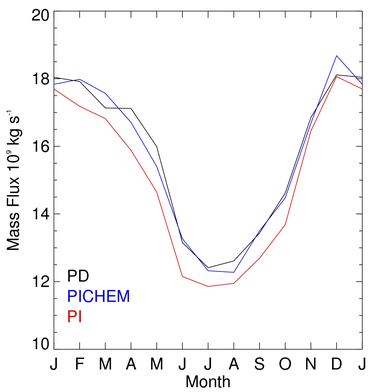
- year 1880 emissions from AR5 database
- year 1880 CH_4 (0.84 ppmv), N_2O (278 ppbv)
- year 1880 ozone depleting substances (0.5 ppbv Cly)
- year ~2000 SST/SIC from HadISSTs

Global Avg. 27.3 DU

Percentage change in zonally averaged ozone mixing ratio for March, April, May and expressed as a percentage of the present-day ozone. The left panel shows the change between the present-day and pre-industrial simulations. The right panel shows the difference between the present-day and pre-industrial simulation using present-day SST/SIC.



Same as the figure above, though for the September, October, November season.



The annual cycle in the downwelling mass flux at 100 hPa, calculated by integrating the downward component of the vertical residual velocity between 25° and the pole over both hemispheres.

The increase in the downwelling from the PI to PD simulations is likely associated with an increase in strat-trop exchange. The PICHEM simulation uses the same SST/SIC as the PD simulation and does not display an increase in downwelling. This likely accounts for a significant part of the difference in the ozone response shown above.

Figure 1. Colour contours present the annual average tropospheric ozone column from the year 2000 timeslice experiment. Data is averaged over the last eight years of a 20 year simulation with the tropopause defined by the WMO lapse rate definition. Also presented is a comparison of instantaneous ozone profiles extracted from the model at ozonesonde station locations (red lines) with the ozonesonde observations (black lines). Approximately 15 profiles are extracted from the model each month and this is compared with available ozonesonde data covering the period 1999-2008. The 'whiskers' on the data denote the 10th and 90th percentiles of the ozone mixing ratios from the model and observations over the season. Ozonesonde data are from the World Ozone and Ultraviolet Radiation Data Centre (WOUDC), courtesy of contributing agencies, and from the SHADOZ (Thompson et al. 2003) network. The efforts of the SHADOZ network and contributing agencies are gratefully acknowledged.

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