Role of stratospheric ozone changes in the global carbon uptake, as simulated by the CMCC-Carbon Earth System Model

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1. Introduction, Motivation

Observed changes in the SH climate over the past decades are reported as a shift in the Southern Annular Mode, especially during SH summer. Model studies have found that during austral summer these changes can be mostly attributed to stratospheric ozone depletion. Coupled-climate-carbon-model simulations have reported that associated trends in surface winds can have an impact on the air-sea CO_2 fluxes over the Southern Ocean through ventilation of carbon rich deep water. It is expected that summer SH circulation changes will be weaker or even reversed for the next 50 years due to stratospheric ozone recovery partially offsetting changes due to greenhouse gases increase. Here, stratosphere-troposphere coupling in the Southern Hemisphere (SH) is examined in high and low top versions of the CMCC-Carbon Earth System Model.

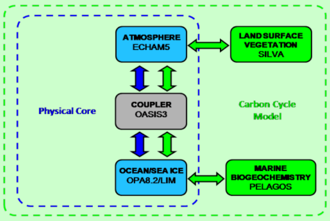
Purpose: Role of troposphere-stratosphere dynamical processes in the connection between stratospheric ozone depletion/recovery, SH climate changes, and global carbon uptake.

Methodology: In this work two sets of simulation reproducing the historical climate and one future scenario including stratospheric ozone changes are performed and analysed. The simulations are performed with the CMCC Carbon Earth System Model (CESM) that includes processes related to the biological and geochemical parts of the carbon cycle. One set of simulations is done with the high-top version of the model, which includes a well-resolved stratosphere and has top at 80km; the second set uses the low-top version of the same ESM (top at 10km).

Implications: The link between stratospheric O_3 and ocean may imply the need to incorporate a well-resolved dynamical stratosphere for SH climate projection/prediction

2. Model and Simulations

CMCC-CESM Carbon Cycle Earth System Model



Stratospheric Component: Top at 80 km, 39 vertical levels

Resolution:
HIGH-TOP: Atm: T31L39 ~3.75x3.75deg
LOW-TOP: Atm: T31L19
Ocean: 2 deg X 31 levels

HIGH-TOP: Momentum conserving orographic and non-orographic gravity wave scheme [Manzini et al., 2006]; Parameterization of methane oxydation

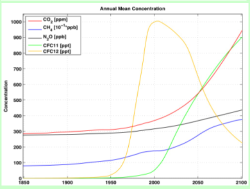
Here we analyse two sets of simulations reproducing the historical climate and a future scenario

Simulations	Years
Historical	1850-2005
RCP8.5	2006-2100

FORCINGS	
SOLAR CYCLE	YES
WMGHG	CMIP5*
O3	CMIP5
VOLCANOES	NO
AEROSOLS	Anthropogenic SO4, CMIP5

* CO2, CH4, N2O, HFCs, PFCs, SF6, CFCs, HCFCs, Halons, CCl4, CH3Br, CH3Cl

Greenhouse gas concentrations for 1850-2005 and for the 2006-2100 CMIP5 RCP8.5 scenario



THE OZONE TRENDS

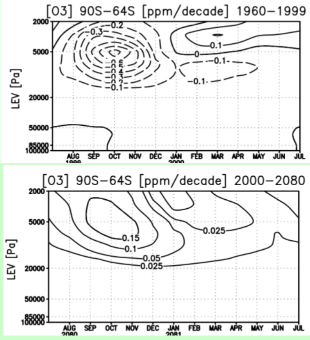


Figure 1: Linear trend of the monthly mean O_3 integrated between 64S and 90S [ppm/decade] applied as an external forcing to the simulations. Linear trends are calculated for the period 1960-1999 (top) and 2000-2080 (bottom)

3. Long-term changes in the historical simulation

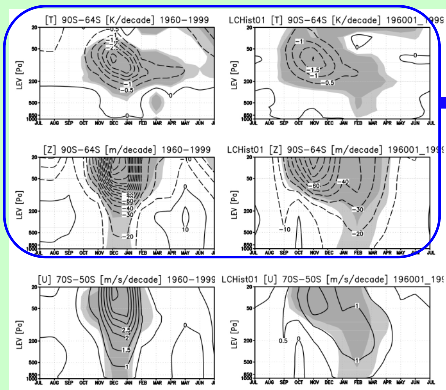
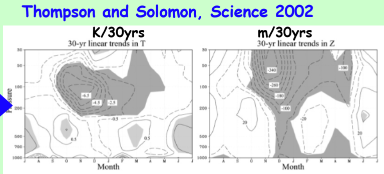


Figure 2. The Linear trends of the monthly mean [T] and [Z] integrated south of 64S, and [U] integrated from 70 to 50S

Trends in observational datasets: Thompson and Solomon, Science 2002



Stratosphere:
(1) The trends in [90S-64S] geopotential height [Z] and temperature [T] show a decrease that peaks during the SH spring months but persists throughout the summer, as found in radiosonde data.
(2) The 1960-1999 T response to the imposed O3 change is larger for the High-Top than the Low-Top (max -3 K/decade for the HT and -2K/decade for the LT) and more similar to the observations (max -6.5/30 years thought for a different period: 1969-1998).

Surface: The [Z] trends and consequently the [U] trends at 70S-50S are found to reach the surface peaking in Nov-Dec for the HT (similar to observations) and later (Feb-Mar) for the LT.

SURFACE: The DJF SAM

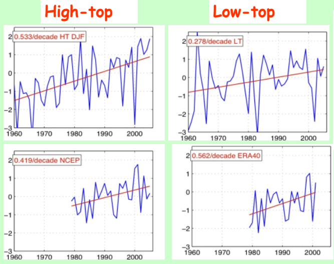


Figure 3. Time series of the SAM index (defined as the difference in standardized DJF sea level pressure between 40°S and 65°S after Gong and Wang [1999]). The anomaly is calculated wrt 1979-1999.

SURFACE: wind stress

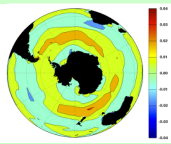


Figure 4. NDJ Zonal wind stress difference between High-top and Low-top, 1990-2005 average (Pa, positive clockwise).

Air-Sea Carbon Fluxes

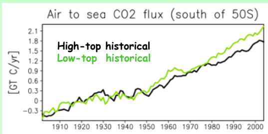


Figure 5 Integrated air to sea CO_2 flux (south of 50S) Units: Gt C/yr. The differences between HT and LT are of the order of 20%-25% between 1980 and 2005.

CONCLUSIONS

A set of simulations for the historical and one future scenario have been performed with the high-top and low-top CMCC Carbon Earth System Model (CESM).

Both model systems have an imposed O_3 trend (Figure 1).

In the stratosphere, they both have a similar response in T, but larger for the high-top (Figure 2)

Stratosphere-Troposphere: The dynamical response in Z and U is different. The high-top model is able to fully reproduce the observed trends in the tropospheric circulation patterns in NDJ in the SH whilst the low-top version shows a delayed response (JFM) (Figures 2) A stronger trend in the DJF SAM for the HT is found (Figure 3).

A role of the dynamical stratosphere can be implicated, related to the vertical resolution of the atmospheric model component, its vertical extension (location of the model top) and proper inclusion of dynamical stratospheric processes and their direct/indirect effects (e.g. parameterizations of unresolved gravity waves)

Consequences:

(1) Different response in the surface wind stress in the NDJ (Figure 4) and annual ocean carbon uptake (Figure 5), manifestation of a change in ocean circulation.

(2) Future climate projection and/or predictions for the next few decades need to take into account the evolution of O_3 recovery (Figures 6 to 8, ongoing work)

4. Long-term changes in the RPC8.5 scenario

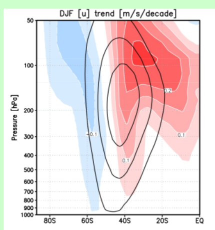


Figure 6. Long-term mean (black contour; 10m/s contours) and linear trend (colors; 0.25 m/s/decade contours) of DJF winds for the HT RCP8.5 scenario high-top 2000-2080

The SAM from the High-top

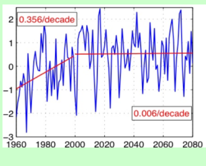


Figure 7. As Figure 4 for the historical + RCP8.5 scenario high-top

O3 and GHG no longer combine to produce strong positive SAM trends

Air-Sea Carbon Fluxes

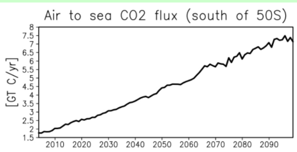


Figure 8 As Figure 6, but for the RCP8.5 scenario with the High-top (The Low-top is still running)

Possible role of the stratospheric ozone recovery on the CO_2 Southern Ocean uptake

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