Circulation changes in climate models related to the representation of the stratosphere

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Abstract

Coupled atmosphere ocean climate models typically resolve vertically only the troposphere and the lower stratosphere so that the tropospheric layers of the model are not directly exposed to numerical artefacts occurring at the upper boundary of the model.

Such "low top" models typically neglect or underestimate stratospheric variability, in the high latitudes as well as in the tropics. "Low top" models may simulate the lower stratospheric response to tropospheric dynamical forcing, but they likely distort any influence of the stratosphere on the troposphere. Indeed Boville had shown already in 1984 that baroclinic variability in the troposphere is sensitive to the dynamics of the stratosphere. More recent studies have shown feedbacks that are relevant on intra-seasonal time scales (Baldwin and Dunkerton, 2001) in high latitudes and inter-annual timescale in the tropics (Giorgetta et al., 1999).

Purpose: To evaluate the systematic influence of the stratosphere on the climate. Two coupled atmosphere ocean models that differs only in their representation of the stratosphere and mesosphere have been assembled: the first is the ECHAM5/MPIOM (T63L31) model with top of the atmospheric component at 10 hPa (the "low top" model); the second is the MAECHAM5/MPIOM (T63L47) model with top at 0.01 hPa (the "high top" model). These experiments are supported by two additional experiments using the "low top" and "high top" atmosphere models with identically prescribed lower boundary conditions for SST and sea ice, instead of the coupling to an identical ocean model.

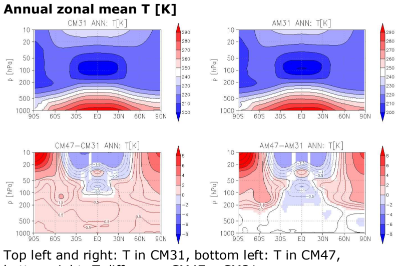
Results are reported for multi-decadal simulations performed with both climate models:

- Stratospheric cold temperature biases in the polar vortices are strongly reduced in the "high top" model. The **tropical UTLS and stratosphere is generally cooler** in the "high top" model. (→ 1.)
- **A nearly uniform warming is found in the troposphere** of the high top model with respect of the low top model. This warming is largest in the tropics (~0.5 K) and a cooling (~2 K) in the lower tropical stratosphere. (→ 1.)
- **Brewer Dobson and Hadley circulation** respond jointly to the changed stratospheric representation. Both are stronger in the "high top" model (→ 1).
- **Upper tropospheric and lower stratospheric differences are well approximated by the atmosphere only experiments**, where wave mean-flow interaction is changed in the stratosphere, thus **confirming the stratospheric origin of resulting tropospheric** changes in coupled experiments (→ 2).
- The dynamical changes are initiated by differences in the resolved wave mean-flow interaction in the stratosphere of the "low" and "high top" models (→ 3).

2. Coupled ocean vs. prescribed SST + sea ice

(differences are shaded where significant at the 95% conf. level)

Annual zonal mean T [K]



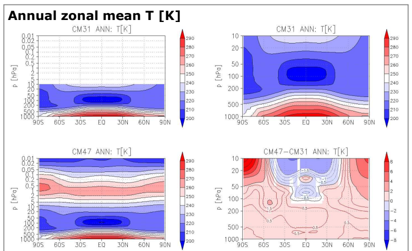
Top left and right: T in CM31, bottom left: T in CM47, bottom right: T difference CM47 – CM31

The "high top" model has warmer extratropics and colder tropics in the stratosphere and UTLS than the "low top" model. The tropospheric temperature between surface and ~300 hPa is nearly identical for prescribed SST and ice, but warmer in the "high top" model in the coupled simulations.

1. Low top vs. High top, coupled simulations

(Differences are shaded where significant at the 95% conf. level)

Annual zonal mean T [K]

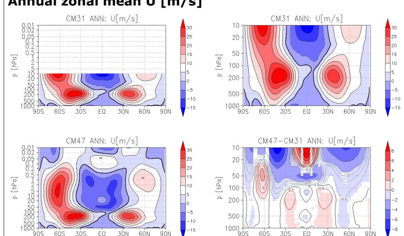


Top left and right: T in CM31, bottom left: T in CM47, bottom right: T difference CM47 – CM31

CM47 shows polar stratospheric warming, where the winter cold bias of CM31 is reduced, especially in the SH, and lower temperature in the tropical middle stratosphere.

The tropospheric temperature is increased by ~0.5K, with highest changes in the upper tropical troposphere and in the Arctic near the surface due to ice albedo feedback.

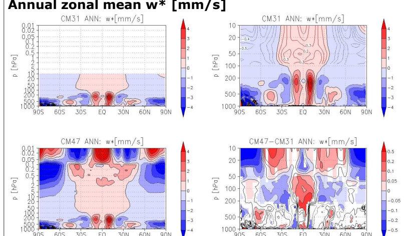
Annual zonal mean U [m/s]



Top left and right: U in CM31, bottom left: U in CM47, bottom right: U difference CM47 – CM31

Stratospheric winds are less westerly in CM47, except at the equator. Tropospheric wind changes are weak, due to the nearly horizontally uniform temperature difference, but still significant down to the surface in the subtropics and northern mid latitudes.

Annual zonal mean w* [mm/s]



Top left and right: U in CM31,
Bottom left: U in CM47, bottom right: difference CM47 – CM31

w* is increased near the equator in the troposphere and lower stratosphere, with compensating sinking in the mid latitudes of the lower stratosphere. Opposite changes occur in the middle stratosphere in mid latitudes. High latitudes show increased sinking in high latitudes from the winter circulation.

References

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Experimental design

- 4 simulations, **AM31, AM47, CM31, and CM47** using a 31 level "low top" or 47 level "high top" atmosphere GCM, either with prescribed SST and sea ice (AM) or coupled to an ocean GCM (CM), cf. Model description.

vertical resol. / *SST+ice*	**10 hPa**	**0.01 hPa**
Climatology 1979-1996	AM31	AM47
Ocean model	CM31	CM47

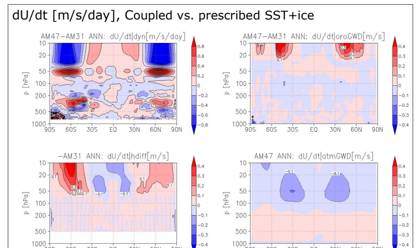
- *AM31* and *AM47* are run for 30 years
- *CM31* and *CM47* are evaluated for 100 years, taken from preindustrial control simulations, *CM31* is taken from the ECHAM5/MPIOM control simulation for IPCC AR4.
- *CM47* is started form an ocean state of *CM31* and finds a new equilibrium after 60 years of spinup.
- *CM47 – CM31*
  climate response to different stratospheres
- *AM47 – AM31*
  atmosphere only response to different stratospheres for fixed SST and sea ice boundary conditions
- *CM47 – AM47* and *CM31 – AM31*
  role of atmosphere ocean coupling for signal in troposphere

Model description

- *AM31*: ECHAM5(T63L31) (Roeckner et al., 2006)
- *AM47*: MAECHAM5(T63L47) (Manzini et al, 2006)
- *CM31*: ECHAM5(T63L31)/MPIOM(GR1.5L40) (Jungclaus et al., 2006)
- *CM47*: MAECHAM5(T63L31)/MPIOM(GR1.5L40)
- **ECHAM5(T63L31)** has a **"low top"** atmosphere that is resolved by 31 levels up to 10 hPa.
- **MAECHAM5(T63L47)** has a **"high top"** atmosphere that is resolved by 47 levels up to 0.01 Pa.
- ECHAM5 and MAECHAM5 have the same horizontal resolution, T63/1.9°x1.9°, and the **same vertical grid between surface and 100 hPa,** resolved by 26 levels.
- **Differences** exist in the **horizontal diffusion in the stratosphere** ($dx/dt = -(-1)^q \cdot K_x \cdot \nabla^{2q} x$) and in **parameterized gravity wave drag.**
- ECHAM5 has lower order hyper diffusion in the stratosphere: 2q=(6,4,2,2,2) at (90, 70, 50, 30, 10 hPa) to damp large scale waves near the model top, and 2q=8 at lower levels.
- MAECHAM5 has constant order 2q=8 at all levels, hence no damping of large scale waves
- MAECHAM5 hor. diff. has no effects on zonal means
- MAECHAM5 and employs the Hines parameterization for non-orographic gravity wave drag, which is not used in ECHAM5.

3. Low top vs. High top, prescribed SST+ice

dU/dt [m/s/day], Coupled vs. prescribed SST+ice



Resolved dynamics (top left) shows differences in dU/dt diagnosed as divergence of the EP flux, resulting from the different wave damping. Horizontal diffusion (bottom left) acts only in the low top model at 50, 30 and 10 hPa, where it decelerates U. Orographic gravity wave drag (top right) differs only substantially at 10 hPa, in the uppermost layer of the low top model. Non-orographic gravity wave drag (bottom right) is computed on ly in the high top model, and acts in the middle stratosphere. Overall, differences in resolved wave mean-flow interaction, resulting from wave damping by horizontal diffusion, and zonal mean effects of the horizontal diffusion are most important for the different tendencies.

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