Temperature Variations as Revealed by Climate Model Simulations of the Upper Troposphere and Lower Stratosphere

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Objective

The objective of this study is to investigate and better understand temperature variations in the upper troposphere & lower stratosphere (UTLS) using coupled Atmosphere-Ocean Climate Models (AOGCMs). Results are compared with observational datasets, including radiosonde temperatures and satellite data from microwave sounding units.

Methodology

Monthly temperature data from sixteen AOGCMs were used to produce:

- global and regional time series of surface and upper air temperature anomalies.
- vertical temperature trends.
- vertical temperature averages.

Trend values are calculated from a linear least squares analysis with trend uncertainties computed using the standard error, where autocorrelation is employed to account for non-randomness of temperature data.

In addition, models with and without the inclusion of ozone depletion forcing are separated and then averaged to understand how well models perform in representing vertical temperature distribution, especially in the UTLS.

Models used

- Output from sixteen state-of-the-art AOGCMs submitted to the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC AR4).
- Model simulations of the 20th & 21th centuries are evaluated.

Model	Responsible organization
Bcc-cm1 (China)	Beijing Climate Center
Bccr-bcm2.0 (Norway)	Bjerkness Center for Climate Research
ccsm3 (USA)	NCAR's Community Climate System Model
cgcm3.1 (Canada)	Canadian Center for Climate Modeling and Analysis
cnrm_cm3 (France)	Centre National de Recherches Meteorologiques
csiro_mk3.0 (Australia)	CSIRO Atmospheric Research, Australia
echam5 (Germany)	Max Planck Institute for Meteorology
gfdl_cm2.0 (USA)	NOAA Geophysical Fluid Dynamics Laboratory
gfdl_cm2.1 (USA)	NOAA Geophysical Fluid Dynamics Laboratory
giss_er (USA)	NASA Goddard Institute for Space Studies
inm_cm3.0 (Russia)	Institute for Numerical Mathematics
ipsl_cm4 (France)	IPSL/LMD/LSCE
miroc3.2_m (Japan)	CCSR/NIES/FRCGC, medium resolution
mri_cgcm2.3.2a (Japan)	Meteorological Research Institute
ncar_pcm1(USA)	Parallel Climate Model, NCAR
ukmo_hadcm3 (UK)	Hadley Centre for Climate Prediction, Met Office

Comparison of models with observations

I. Global time series temperature anomalies

Almost all models show a statistically significant global mean surface temperature increase over the past three decades.

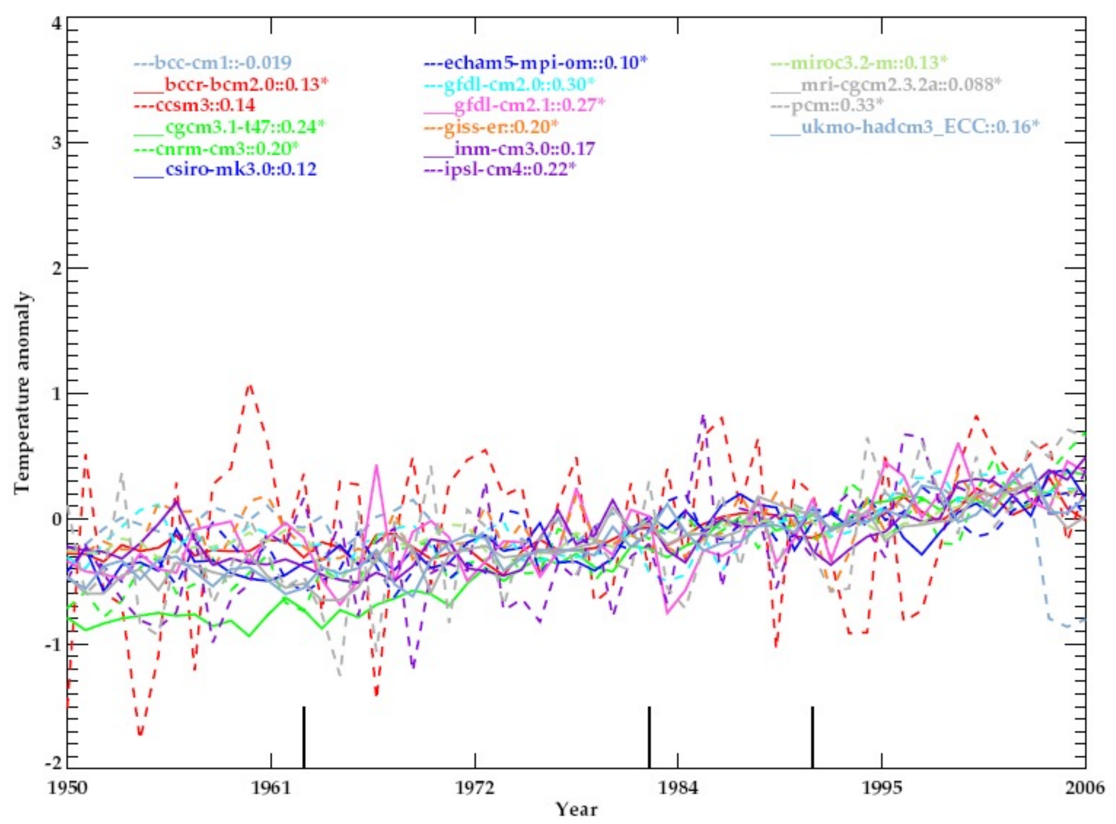

Fig. 1. Annual global mean surface temperature anomalies with respect to 1979–2005 from the IPCC models. Statistically significant trends at the 95% level are indicated with a * symbol.

In the lower stratosphere, models show:

- a statistically significant decrease in temperature.
- an increase in stratospheric temperature for about 2 years following major volcanic eruptions.
- an overestimation of temperature response due to volcanic aerosols.

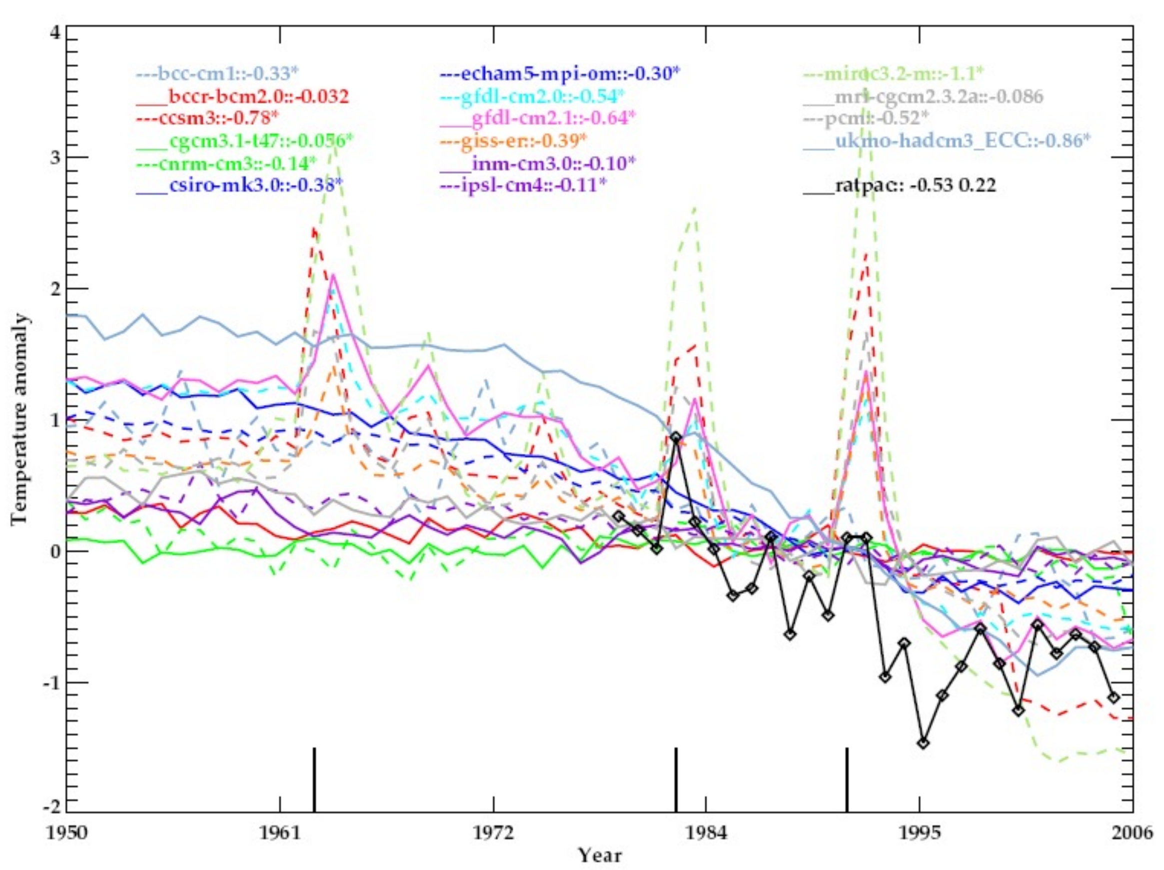

Fig. 2. Annual global mean temperature anomalies at 50 hPa with respect to 1979–2005 from the IPCC models.

II. Global vertical temperature trend

The vertical distribution of model temperature trends are compared with observations.

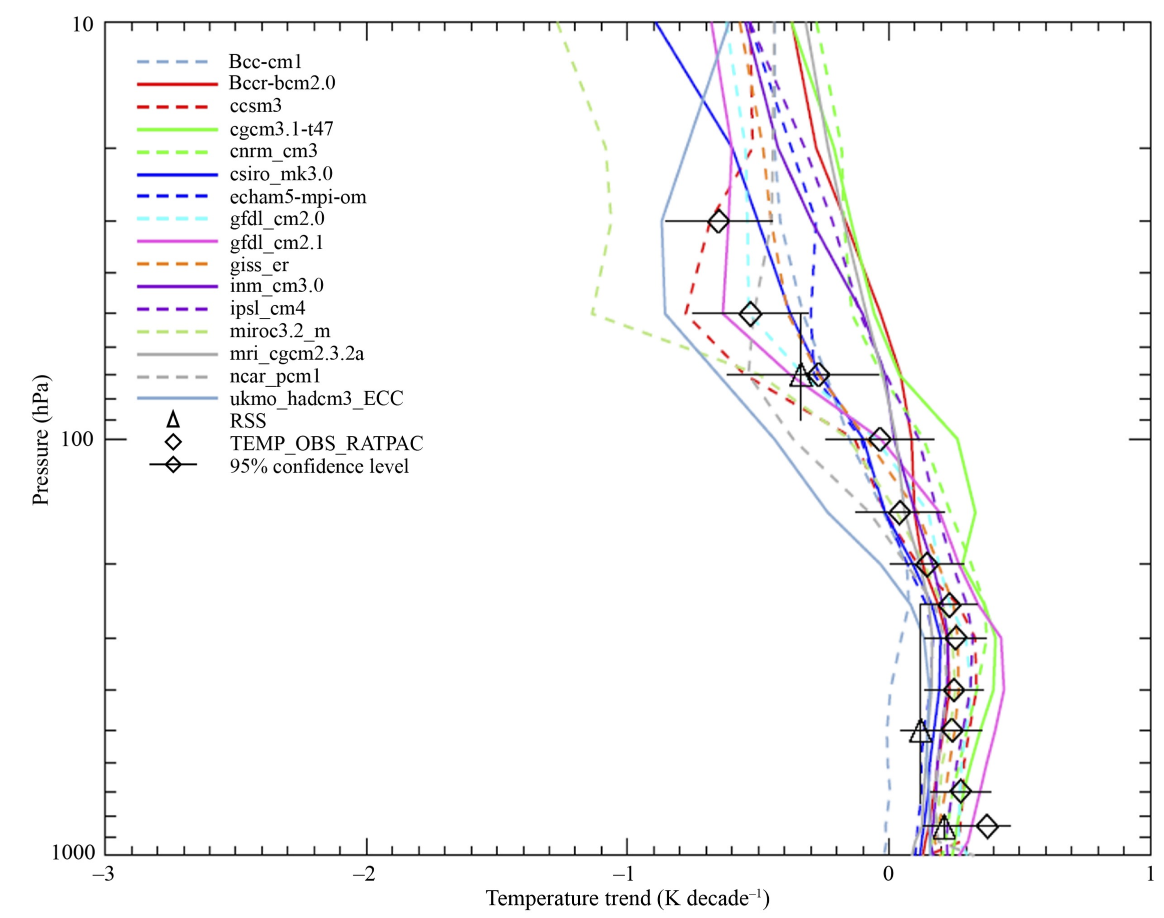

Fig. 3. Globally averaged IPCC vertical temperature trends compared with radiosonde (RATPAC) and satellite (RSS) observations between 1979–2005. Horizontal thin lines represent uncertainty at the 95% confidence level.

III. Temperature trend analysis

Models with and without inclusion of ozone depletion are averaged and compared with observations.

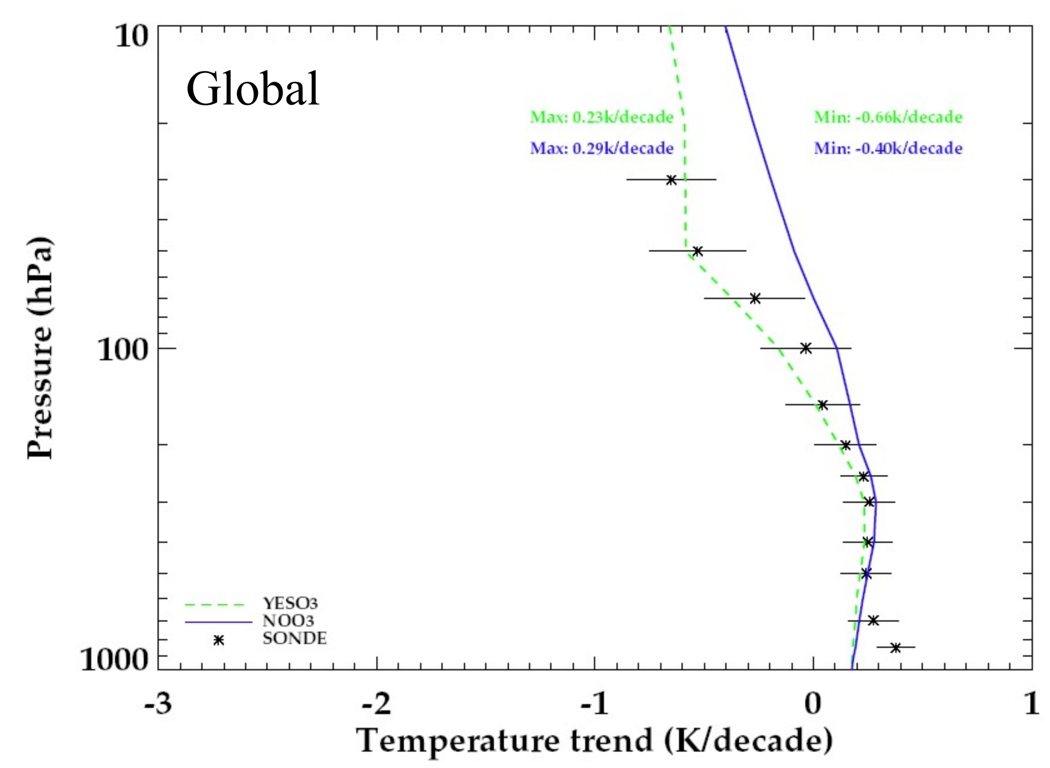

Fig. 4. Average temperature trend from IPCC with and without ozone depletion compared with radiosonde observation dataset.

- At 10 hPa, models that include ozone forcing show 0.66 K/decade cooling rate whereas those that do not include show 0.40 K/decade over the 1979–2005 period.
- Models and observations agree well in the troposphere.
- Only models that include ozone depletion forcing agree with observations above the 70 hPa pressure level.

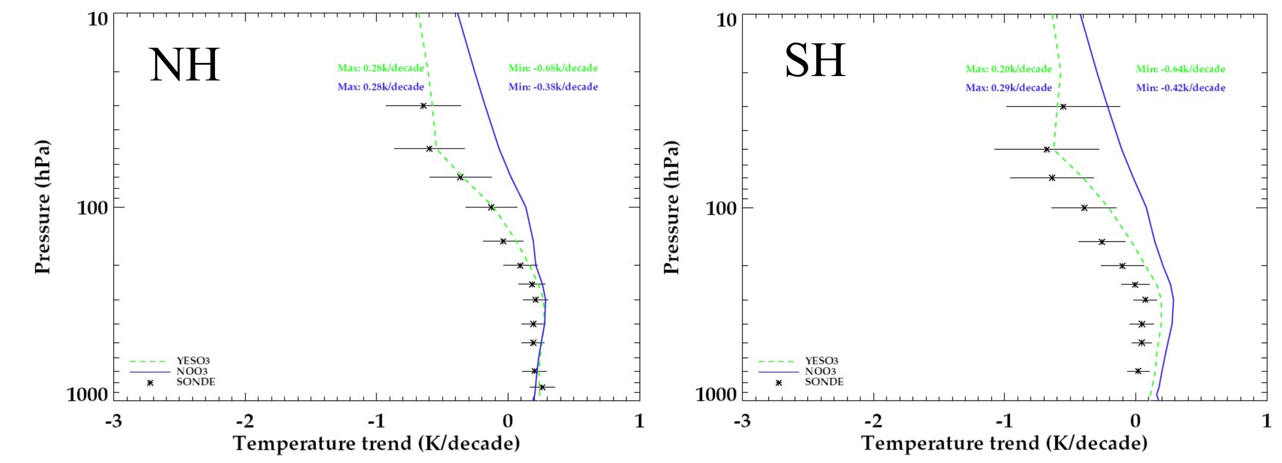

Fig. 5. As in Fig. 4 except for the Northern Hemisphere (left) and Southern Hemisphere (right).

Northern Hemisphere

- Above 250 hPa, models with ozone depletion forcing agree very well with RATPAC in the northern hemisphere.
- Below 250 hPa, all models agree with observations and show a warming trend.

Southern Hemisphere

- Less agreement between observations and models was observed in the SH as compared to NH, especially in the troposphere.
- Those models that include forcing due ozone depletion are closer to observations at all levels.

Summary

- Greater model to model variability (including the variability of models against observations) are observed in the stratosphere (Fig. 3).
- Models which include ozone radiative forcing agree better with observations.

In the troposphere, models show:

- disagreement with observations in the SH.
- agreement with observations in the NH.

At the surface, models show:

- less warming in the SH (0.20 K/decade).
- slightly greater warming in the NH (0.28 K/decade).

At 10 hPa, models show:

- slight difference in cooling rate between NH (–0.68 K/decade) & SH (–0.64 K/decade) is observed.

Future work

- Perform inter-comparison of model simulations in their ability to represent seasonal temperature variations. (*i.e.*, DJF, JJA, SON, and MAM) in different latitude ranges.
- Compare AOGCMs with simulations from Climate Chemistry Models (CCMs).

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