On the radiative forcing of global-mean temperature trends in the middle atmosphere

Andreas I. Jonsson
Dept. of Physics, University of Toronto, Toronto, Canada, andreas.jonsson@utoronto.ca

Victor I. Fomichev
Dept. of Earth and Space Science and Engineering, York University, Toronto, Canada, victor@nimbus.yorku.ca

Abstract

Global-mean temperature trends in the middle atmosphere can be explained by changes in the radiative energy budget forced by atmospheric composition changes. Here, we analyze past and future temperature trends and changes in radiative heating agents in model simulations performed with the Canadian Middle Atmosphere Model (CMAM). We identify two periods of near-linear changes: 1970-1990, during the period of ozone depletion, and 2010-2040, during the period of ozone recovery. Using a 1D radiative-convective model (RCM) it is shown that the past and future temperature trends can be understood as a combination of effects from changes in CO_2, O_3 and H_2O. The results confirm the generally accepted view that while enhanced CO_2 acts to cool the middle atmosphere, temperature trends are modulated by long-term changes in O_3 concentrations: Halogen-induced ozone depletion in the past has led to enhanced cooling whereas ozone recovery in the future will reduce the CO_2 effect. Increases in H_2O, mainly due to surface trends in CH_4, provide additional cooling in the lower stratosphere. The importance of changes in the 9.6 um O_3 band cooling and in the mesospheric NIR CO_2 heating is also analyzed.

Motivation

- What is the impact of climate change and CFC-induced ozone changes on the global-mean temperature of the middle atmosphere?
- Do we understand the changes occurring in the past?
- How do future trends compare to past trends?
- What is the importance of cooling in the 9.6 μm O_3 band and heating in the mesospheric NIR CO_2 bands?
- Are trends in temperature, O_3 and H_2O consistent and understandable in terms of the forcings: CO_2, CFC, CH_4 and N_2O?

Outline

- Time series of temperature, O_3 and H_2O, and changes in the radiative energy budget from transient runs with the CMAM have been analyzed.
- Analyzing annual and global mean fields reduces the effect of changes in dynamics.
- A 1D radiative-convective model (RCM) has been used to analyze the individual effects of changes in the forcing agents in the past (1970-1990) and the future (2010-2040).

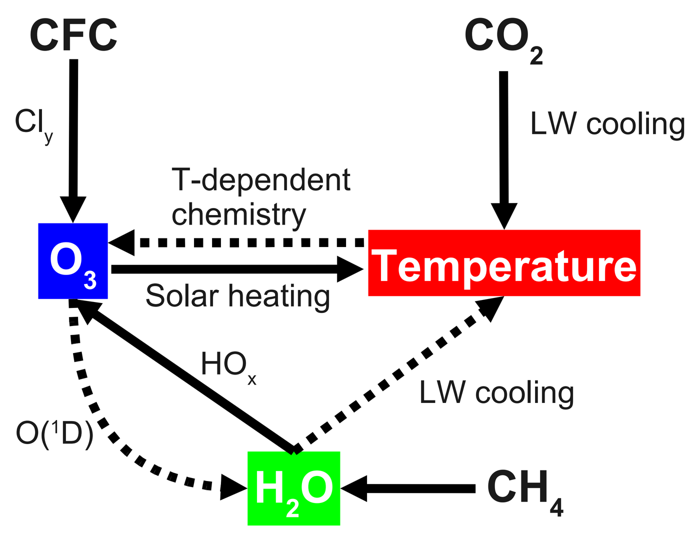
Model and Simulations

- CMAM: interactive chemistry-climate model
  - Vertical domain: 71 levels from the ground to ~95 km
  - Horizontal resolution: T32
  - 98 gas phase, 35 photolysis and 12 heterogeneous reactions
- Ensemble of 3 simulations
  - covering 1950 – 2100
  - prescribed SSTs and sea ice from 3 realizations of a coupled atmosphere-ocean GCM run
  - no QBO, solar cycle or volcanic aerosol effects (for the simulations considered here)
- GHG loading from IPCC scenario A1B (IPCC, 2000) and halogen loading from WMO scenario Ab (WMO, 2003)

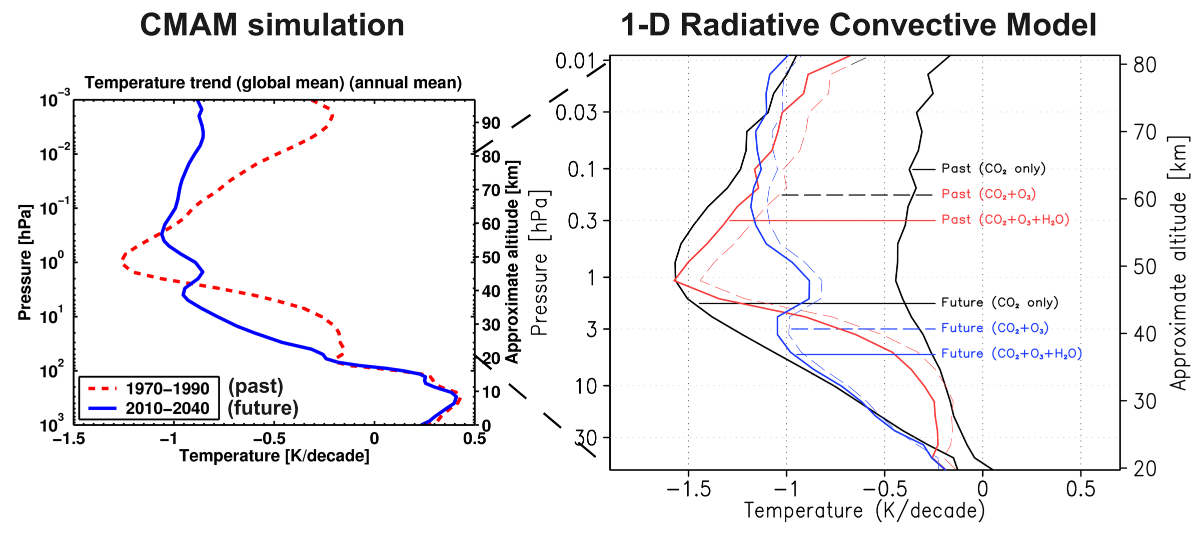
Conclusion

- Global-mean temperature trends in the middle atmosphere can be explained by changes in the radiative energy budget forced by the atmospheric composition changes.
- The middle atmosphere temperature decreases in response to the CO_2 increase, but past and future trends are different due to the modulation of O_3 changes on solar heating rates.
- H_2O cooling is more important in the past than in the future.
- Changes in the 9.6 μm O_3 band cooling and in the mesospheric NIR CO_2 heating play an essential role in determining past and future temperature trends.

Radiative-photochemical interactions in the middle atmosphere



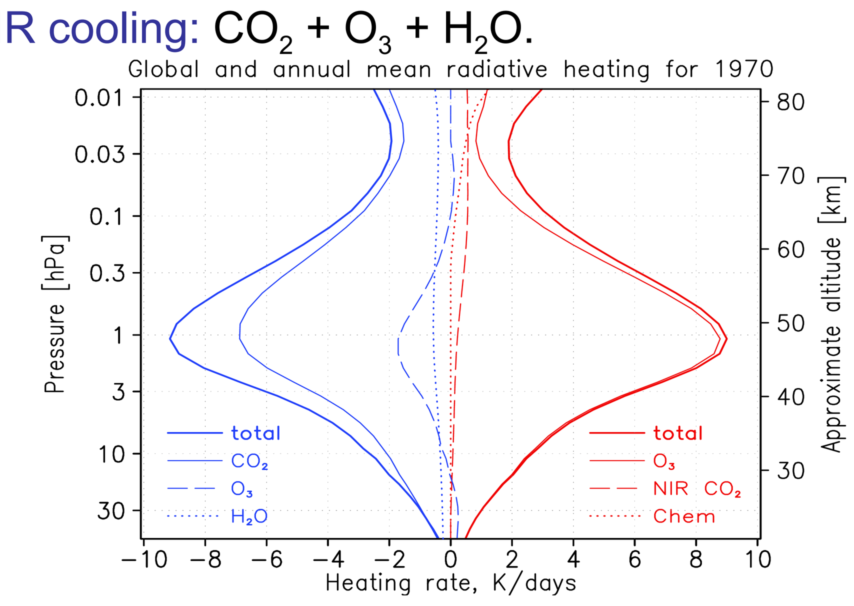
Attribution of past and future global-mean temperature trends



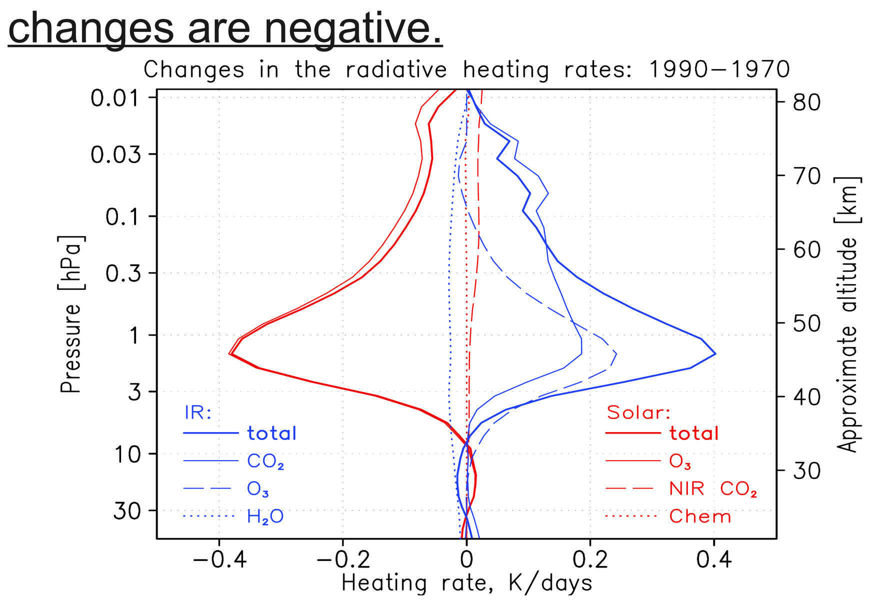
- The RCM was forced by changes in CO_2, O_3 and H_2O taken from the CMAM simulation.
- The CO_2 effect is stronger in the future than in the past, due to the faster CO_2 increase in the future.
- O_3 depletion/recovery enhances/reduces the cooling trend in the upper stratosphere and mesosphere
- The H_2O increase enhances the negative temperature trend by 0.1-0.15 K/decade in the past (or by ~30% near 10 hPa). The effect is much weaker (~0.05 K/decade) in the future.
- Net trends (due to CO_2 + O_3 + H_2O) from the RCM are similar to those from the CMAM.

Energy budget balance and changes

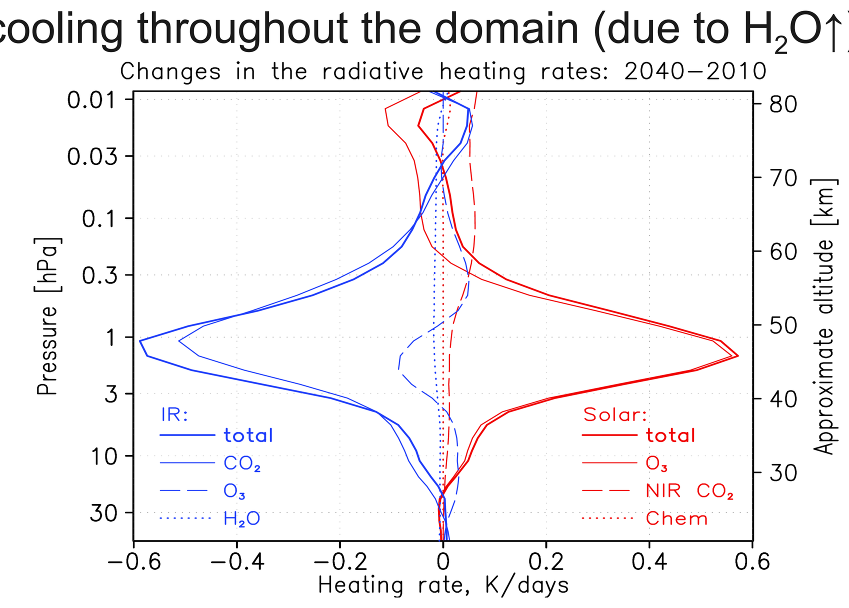
- Radiative balance (1970):
  - Solar heating: O_3 + NIR CO_2 + chemical heating (mesosphere).
  - IR cooling: CO_2 + O_3 + H_2O.



- Changes (1970-1990):
  - Solar heating: O_3 solar heating decrease ("self-healing" near 30 km); in the mesosphere partly compensated by NIR CO_2 heating increase.
  - IR cooling: Globally, IR cooling balances solar heating: comparable decrease in cooling by CO_2 (due to T↓, despite CO_2↑) and O_3 (due to both T↓ and O_3↓). Increase in H_2O cooling throughout the domain (due to H_2O↑). <u>Note, near 30 km only H_2O changes are negative.</u>



- Changes (2010-2040):
  - Solar heating: O_3 solar heating increase in the stratosphere and decrease in the mesosphere. The latter is compensated by an increase in NIR CO_2 heating.
  - IR cooling: Increase provided mainly by CO_2 (due to CO_2↑). Smaller changes for O_3 (T↓ and O_3↑ compensate each other). Small increase in H_2O cooling throughout the domain (due to H_2O↑).

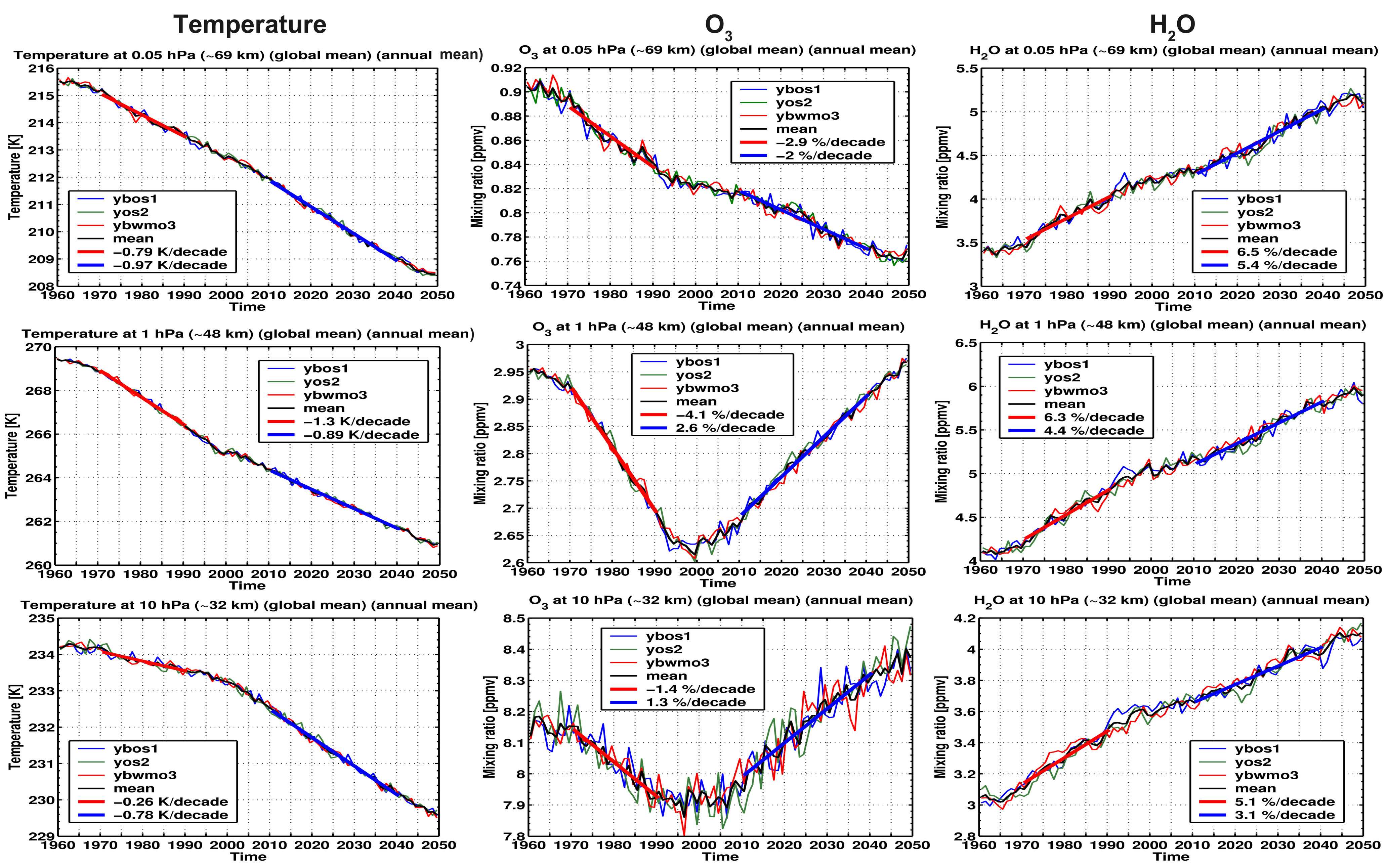


Global mean time series

Mesosphere: ~70 km

Stratopause: ~50 km

Stratosphere: ~30 km



Temperature decrease mainly due to CO_2 increase, but modulated by O_3 and H_2O changes, see energy budget analysis.

O_3 reduction and recovery due to CFCs (stratosphere) and H_2O (mesosphere).

H_2O increase throughout the domain is mainly due to CH_4 increase.

Surface forcings: