Temperature and humidity in IPCC AR4 models: An assessment using AIRS observations

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SUMMARY

Temperature and humidity fields in coupled climate models are compared with those derived from AIRS observations. We included NCEP and ERA-40 reanalysis data sets also in the comparison. Temperature simulations in the models show a colder bias within 2 K except for the tropopause regions outside the tropics (Figure 1). Models also show a larger warm bias in the southern polar regions. Reanalysis temperature fields agree within 1 K with AIRS data which is the expected goal of accuracy for AIRS temperature data.

Most of the models and reanalysis data show a dry bias in the lower troposphere and wet bias in the upper troposphere (Figure 2). This is consistent with the results presented in [1] in which they described it as a dipole with less moisture in the models below 800 hPa and more moisture above compared to AIRS data.

AIRS relative humidity has a dry bias due to a flaw in the method of calculation. Figure 4 shows difference in RH compared to AIRS data. Differences are up to 40 %RH which is physically unrealistic. A comparison with ERA-40 shows that the differences are within 10 %RH as shown in the bottom panel of Figure 5. Therefore RH product in AIRS data set must be used with caution.

The extent to which these biases may impact the climate sensitivity of the model, based on our current knowledge of temperature and humidity feedbacks is examined. In particular we show that the model-simulated response of water vapor to a warming climate is remarkably robust across models (Figures 6 and 7).

1 Introduction

In this study, we compare AIRS temperature and humidity retrievals to that simulated from 16 different models using the archive of climate model simulations compiled for the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC). Because the mass of water vapor is tightly coupled to temperature through the Clausius-Clapeyron (C-C) relation, the use of specified SST in GCM simulations heavily constrains the model response. For this reason, we consider only fully coupled ocean-atmosphere model simulations in which the ocean temperature is a predicted quantity.

2 Temperature

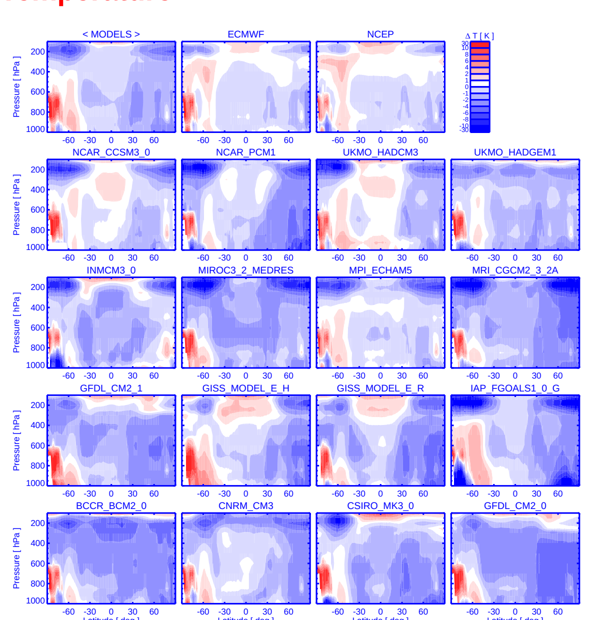

Figure 1. *Vertical structure of difference in zonal averaged temperature ($\Delta T = T_{model} - T_{AIRS}$) for different coupled GCMs and reanalysis data set. Top-left panel shows ΔT for the mean model.*

3 Specific Humidity

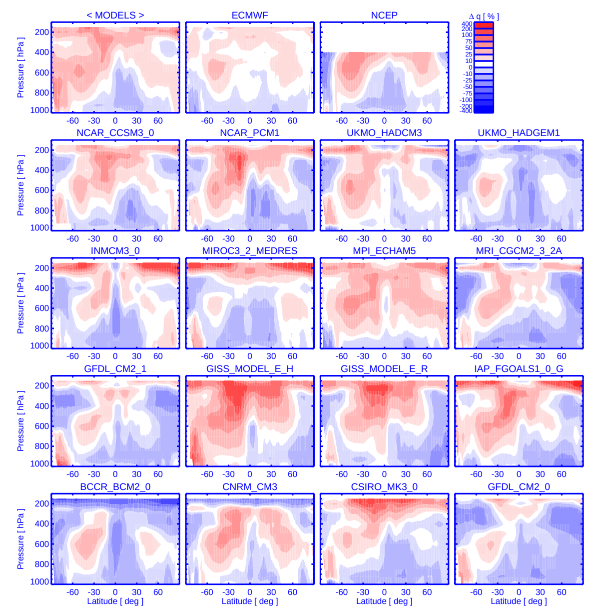

Figure 2. *Vertical structure of difference in zonal averaged specific humidity ($\Delta q = \frac{q_{model} - q_{AIRS}}{q_{AIRS}}$) for different coupled GCMs and reanalysis data set. Top-left panel shows ΔT for the mean model. The values are given in percent. In AIRS data, water vapor mixing ratio (MMR) is a layer mean quantity, i.e., the reported value at a level is the mean value of the atmospheric layer above this level. For example, MMR at 1000 hPa is the mean of MMR of the layer between 1000 and 925 hPa. For comparison, we converted MMR to specific humidity (q) using the formula, $q = \mathrm{MMR}/(1+\mathrm{MMR})$. The layer mean MMR (or q) in AIRS data are calculated assuming the logarithm of MMR varies linearly with logarithm of pressure. This assumption allows us to calculate layer mean q from model and reanalysis data by 'simply' taking mean of logarithm of q at adjacent levels and then exponentiating it.*

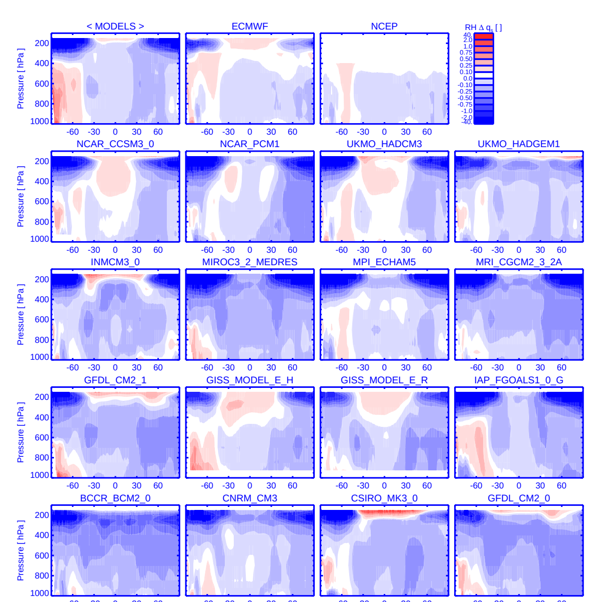

Figure 3. *Vertical structure of zonal averaged $\frac{\mathrm{RH} \times \Delta q_s}{q}$ for different coupled GCMs and reanalysis data set, where $\Delta q_s = q_s^{model} - q_s^{AIRS}$ and RH is the relative humidity in the models.*

4 Relative Humidity

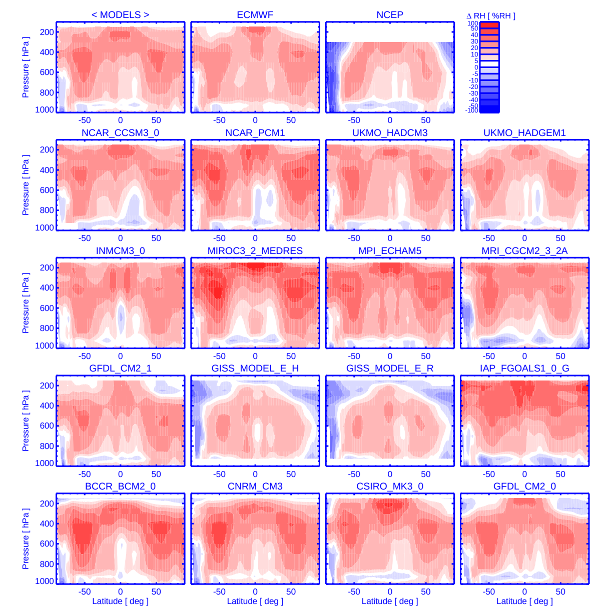

Figure 4. *Vertical structure of difference in zonal averaged relative humidity ($\Delta \mathrm{RH} = \mathrm{RH}_{model} - \mathrm{RH}_{AIRS}$) for different coupled GCMs and reanalysis data set. Relative humidity in AIRS data is computed by taking ratio of MMR and saturation mass mixing ratio (SMMR), where as explained before, MMR is a layer mean quantity, but SMMR is calculated using retrieved air temperature profile which is a level quantity and therefore SMMR is also a level quantity. Thus taking ratio of layer mean value to level value would thus produce a dry bias in RH values because level SMMR will be larger than layer SMMR due to a positive lapse rate in the troposphere. This makes it impossible to make a direct comparison of RH between models and AIRS data and would lead large biases as shown in this figure.*

5 Comparison with ECMWF

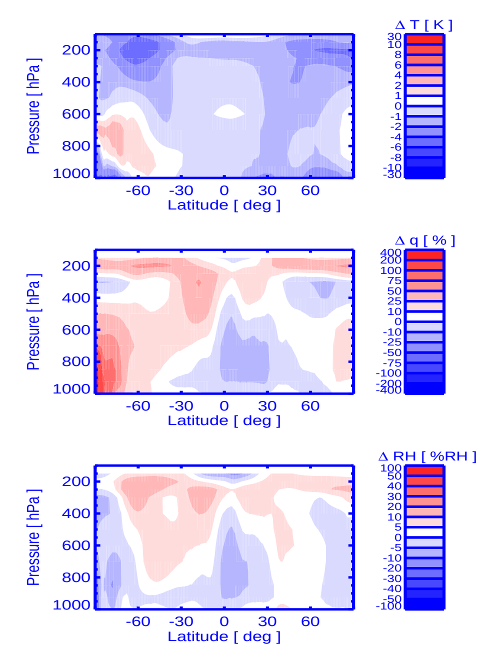

Figure 5. *Mean model biases compared to ECMWF reanalysis data set. Note that ΔRH is within 10%RH in this case.*

6 Specific humidity response

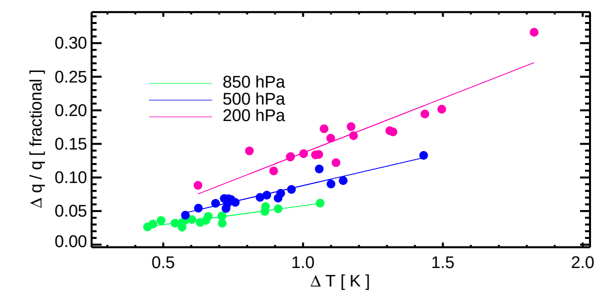

Figure 6. *Fractional change in specific humidity with respect to change in temperature at 850, 500, and 200 hPa. Although the magnitude of biases differ in models, the response in specific humidity is robust across the models at all levels. This indicates that the biases do not have a direct bearing on the simulated feedback values.*

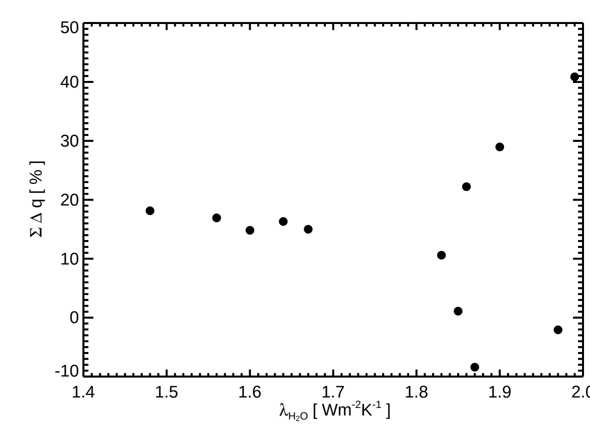

Figure 7. *Sum of specific humidity biases as a function of water vapor feedback values. Δq is summed between 850 and 200 hPa for the entire latitude range and thus it represent an integrated quantity of the bias in specific humidity for each model. Water vapor feedback values (λ_{H_2O}) is taken from Soden and Held (2006) [2]. λ_{H_2O} values do not depend on the biases in the models.*

7 Conclusions

- Temperature biases are within 2 K at most of the regions. Tropopause regions outside the tropics show large biases.
- Models show large biases in specific humidity and the magnitude of bias varies across the models
- model-simulated response of water vapor to a warming climate is remarkably robust across models
- the model-simulated biases have little direct impact on the strength of the feedbacks in these models
- Relative humidity values reported in AIRS data have large dry biases

References

[1] Pierce, D. W. et al. (2006), Three-dimensional tropospheric water vapor in cou- pled climate models compared with observations from the airs satellite system, *Geophys. Res. Lett.*, **33**, L21701, doi:10.1029/2006GL027060.

[2] Soden, B. J. and I. M. Held, (2006), An assessment of climate feedbacks in coupled ocean-atmosphere models, *J. Climate*, **19**(14), 3354-3360.