Process-evaluation of tropospheric humidity simulated by general circulation models using water vapor isotopic observations, and implications for climate feedbacks

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1 Introduction

1.1 Ultimate goals

- Climate models frequently show a moist bias in the mid and upper tropical/subtropical troposphere compared to different datasets (e.g. [4]). What are the mis-represented processes responsible for this bias? What is the consequence of this bias on climate change projections?
- Climate models exhibit dispersion in climate sensitivity, whose main reason is the dispersion in cloud feedbacks (e.g. [1]). What processes are responsible for this dispersion, and are there observational constraints for the representation of these processes?

1.2 Method

- **Sensitivity tests** with the LMDZ GCM that exhibit a moist bias for different reasons, and also turn out to exhibit different climate sensitivities.
- Use of water stable **isotopic observations** of water vapor to better evaluate convective, cloud and transport processes.

2 Simulations

- Control: AMIP-like simulations with winds nudged by ECMWF, from 1960 to 2011, with AR4 version of LMDZ, 2.5°×3.75°×19 levels, equipped with isotopes ([7]).
- Sensitivity tests exhibiting increased moist bias (figure 1):
  - "diffusive advection": Van Leer scheme replaced by simple upstream scheme
  - "σ_q/10": sub-grid-scale variability in water vapor reduced by 10 in cloud scheme
  - "ϵ_p/2": precipitation efficiency reduced by 2 in convective scheme.

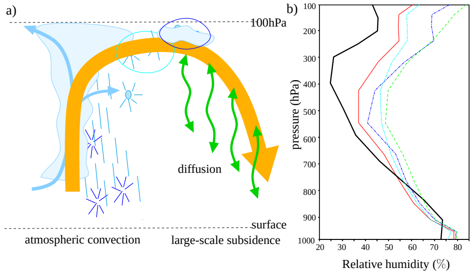


Fig 1. a) Illustration of different processes controlling relative humidity (RH) in the tropical atmosphere, and how they are affected by our sensitivity tests. b) RH profiles for our sensitivity tests, in tropical average and compared to AIRS.

3 Isotope-based observational diagnostics

3.1 In LMDZ

- Comparison of our tests with a wealth of satellite, ground-based and in-situ data, accounting for spatio-temporal sampling and instrument sensitivity ([8])
- When the moist bias is due to excessive diffusion, the δD seasonal cycle throughout the subtropical troposphere is reversed or underestimated compared to observations (figure 2)
- When the moist bias is due to excessive convective detrainment, convective conditions are associated with a strong depletion of the mid troposphere (figure 3).

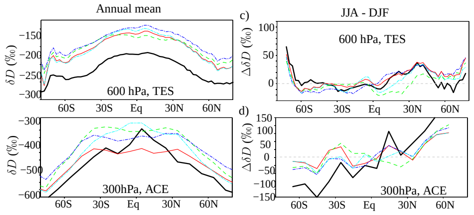


Fig 2. Zonal mean of annual mean (left) and seasonal variations (right) of δD (measuring the enrichment in HDO relatively to sea water in ‰) at 600hPa compared to TES ([12]), b) Between 300hPa compared to ACE ([5]).

- Disagreement and scatter increases with height
- Equator to poles gradients are underestimated, subtropical δD is too enriched
- Excessive advection leads to reversed seasonality in free troposphere
- Excessive condensate detrainment leads to too enriched δD values.

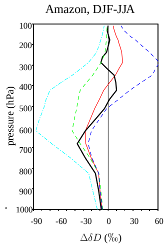


Fig 3. Seasonal variation of δD profiles in the Amazon compared to new TES profiles ([11]).

- Convection associated with lower-tropospheric depletion due to unsaturated downdrafts ([6]) and upper-tropospheric enrichment due to condensate detrainment (e.g. [10])
- Excessive condensate detrainment leads to strong mid-tropospheric depletion

3.2 Application to other isotopic GCMs

SWING2: 7 isotopic GCMs

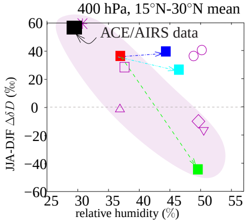


Fig 4. Relationships between annual mean RH (30°S-30°N) and seasonal variation of δD (15°N-30°N) at 400hPa , for the different SWING2 simulations and our sensitivity tests.

- large-scale circulation nudging and horizontal resolution has a small influence on RH and isotopes compared to model physics
- Applying the subtropical diagnostic suggests that the most freaquent reason for the moist bias is excessive vertical diffusion (figure 4)
- Increasing vertical resolution can slove this problem (not shown)

4 Implications for climate projections

4.1 RH changes

Control simulations with climatological SSTs, climate change simulations with SST anomalies from the IPSL coupled model in a 4×CO_2 experiment.

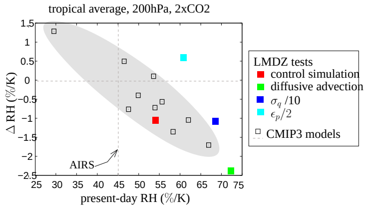


Fig 5. Annual, tropical average change in RH as a function of present-day RH in the UT, for our sensitivity tests and CLIP3 simulations.

- When advection is excessively diffusive, the upper-tropospheric drying in climate change is overestimated.
- Comparison with CMIP3 models support the excessive vertical diffusion is responsible for the moist bias and leads to overestimated drying in climate change.

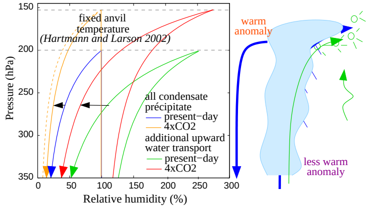


Fig 6. Schematic explaining why (1) if all condensate precipitates, the UT dries as SST increases ([3]) and (2) if condensate is retained or additional water is transported upward, the drying is larger.

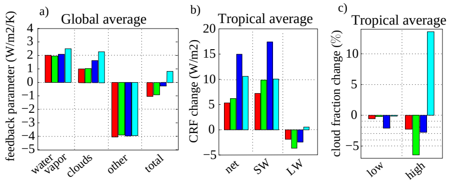
- stronger drying in "diffusive advection".
- In ϵ_p/2, a large drying arise if the winds are nudged to present. The moistening is due to UT circulation change.

4.2 Implications for climate feedbacks

Feedback decomposition using the radiative kernel method ([9])

- The magnitude of water vapor feedbacks reflect RH changes but the dispersion is overwhelmed by cloud feedbacks
- Differences in cloud feedbacks are due to:
  - The stronger decrease in low clouds in σ_q/10 ([2]), leading to positive short-wave cloud feedback
  - The increase in high cloud in ϵ_p/2, leading to positive long-wave cloud feedback.

Fig 7. a) Feedback parameters, b) change in cloud radiative forcing (CRF) and c) change in cloud cover, for our sensitivity tests.



5 Conclusion

- Depending on the representation of convective, cloud and transport processes, cloud feedbacks and hence climate sensitivity is very different.
- Water vapor isotopes can help evaluate the representation of these processes.

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