Can we assess the credibility of future relative humidity changes predicted by climate models using present-day observations?

The added value of water vapor isotope measurements.

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1 Introduction

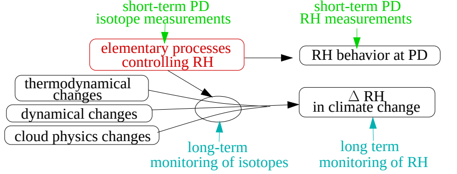
1.1 Goal

Tropical and subtropical free tropospheric relative humidity (RH) impacts the longwave outgoing radiation, the cloud distribution and modulates deep convection. Therefore, predicting future RH changes as climate changes (ΔRH) is crucial to predict not only the water vapor feedbacks, but also cloud feedbacks and regional changes of precipitation ([5]).
How can we assess the credibility of ΔRH predicted by climate models?

If RH is a function of n processes F_i, including tropospheric thermal structure, large-scale dynamics, mixing during transport, cloud macro- and micro-physics, then $\Delta RH = \Sigma_{i=1}^{n} \Delta F_i \cdot \frac{dRH}{dF_i}(F_1, ...F_n)$: ΔRH depends on the balance of thermodynamical, dynamical and cloud physics changes (ΔF_i), and the response to each of these changes is modulated by processes controlling RH ($\frac{dRH}{dF_i}$).

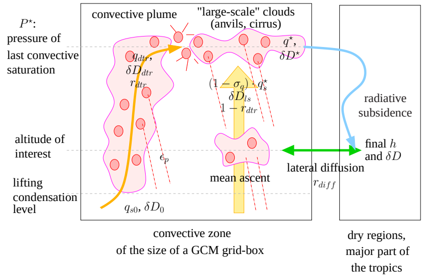
1. How do processes controlling RH at play at present-day (PD) impact ΔRH?
2. How can we evaluate the representation by GCMs of these processes?
3. How can we check that simulated ΔRH results from the correct combination of thermodynamical, dynamical, and cloud physics changes?

For questions 2 and 3, we explore the added value of isotope measurements:


short-term PD
isotope measurements
short-term PD
RH measurements
elementary processes
controlling RH
RH behavior at PD
thermodynamical changes
dynamical changes
cloud physics changes
Δ RH
in climate change
long-term
monitoring of isotopes
long term
monitoring of RH

1.2 Method

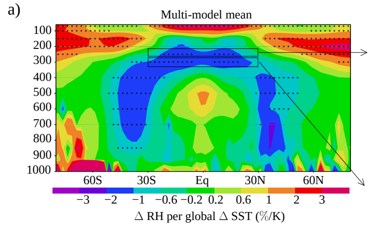
1. We inter-compare several PD and 4xCO_2 simulations with the isotope-enabled GCM LMDZ ([4]), including tests exhibiting a PD moist bias for different reasons (poster 1) to investigate how mis-representation of RH processes impact ΔRH predictions;
2. inter-compare 10 CMIP3 climate models to explore the link between PD climate and predicted ΔRH;
3. interpret our results using a simple theoretical framework. For simplicity, we consider only thermodynamical changes (ΔSST, lapse rate change ΔΓ) and increase in convective detrainment height as factors forcing ΔRH. We leave for future work the role of poleward shift of jets ([2]) and changes in shallow or deep convection. Our assumptions best applies to the upper troposphere (UT) ([1]).

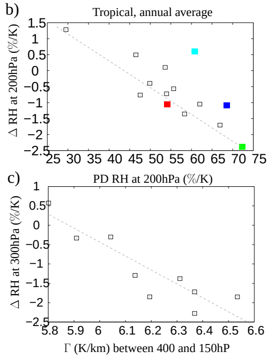


Simple theoretical model to interpret our sensitivity experiments. We assume characteristic profiles of specific humidity and isotope composition q_{dtr} and δD_{dtr} in convective plumes, depending on the precipitation efficiency ϵ_p in convective clouds and on the humidity and isotope composition at the lifting condensation level q_{s0} and δD_0. Though not realistic, large-scale mean ascent constitutes a second source of vapor significant in GCMs. The humidity and δD in the convective zone, $q^\star$ and $\delta D^\star$, depend on q_{dtr}, δD_{dtr}, the subgrid-scale variability of water vapor in anvils and stratiform clouds (σ_q), the proportion of air coming from convective detrainment r_{dtr} and a large-scale condensation rate. q and δD are then conserved during subsidence, until they mix with moister air by lateral diffusion.

For numerical applications, we took parameters from our LMDZ simulations when readily diagnosticable, otherwise optimized them.

2 How do processes controlling RH impact ΔRH predictions?





a) Zonal, annual, multi-model mean of ΔRH in CMIP3 $2 \times CO_2$ experiments, normalized by ΔSST. Stippling shows where multi-model ΔRH exceeds inter-model standard deviation of ΔRH. b) ΔRH as a function of PD RH at 200hPa c) ΔRH at 300hPa as a function of PD Γ.

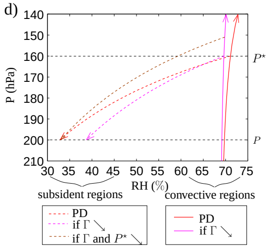
- Obvious links between ΔRH and PD RH are rare ([3])
- Moist GCMs simulate more negative ΔRH at 200hPa. This is consistent with a moist bias due to excessive lateral diffusion.
- GCMs with a strong Γ simulate more negative ΔRH at 300hPa

Common key for sections 2 and 3:

□ CMIP3 models

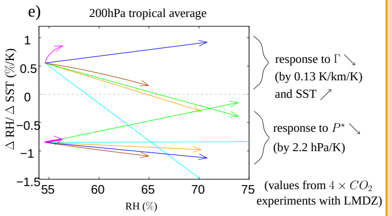
LMDZ tests
🟥 control simulation
🟩 diffusive advection
🟦 σ_q /10
🟦 $\epsilon_p/2$

Effect of processes controlling RH
→ Precipitation by convection ↗
→ ϵ_p ↘ (/2)
→ σ_q ↘ (/10)
→ diffusion during transpport ↗
→ $P^\star$ ↗
→ Γ ↘



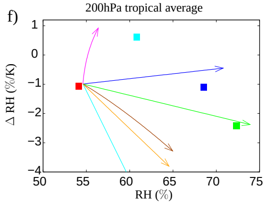
How ΔΓ and $\Delta P^\star$ affect RH at 200hPa in our simple theoretical model

- decrease in Γ dries convective regions where condensate is detrained, but moistens subsident regions
- decrease in $P^\star$ dries subsident regions



Theoretical response of RH at 200hPa to thermodynamical changes and to an increase in detrainment height, as a function of RH.

- macro- and micro-physical processes controlling RH impact ΔRH significantly
- The higher the impact of condensate detrainment on the UT vapor budget (lower ϵ_p, stronger lateral diffusion), the more negative ΔRH (as in fig a)
- The lower the Γ, the less negative ΔRH (fig c)
- Since the effects of Γdecrease and $P^\star$ decrease on RH nearly balance each other, ΔRH is very sensitive to the relative contributions of these 2 changes.



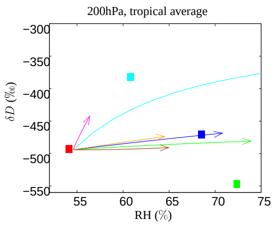
Checking our theoretical framework against our LMDZ sensitivity tests

- Our simple framework captures the more negative ΔRH when a moist bias is due to excessive lateral diffusion, and the small impact on ΔRH of underestimated σ_q.
- The more negative ΔRH when condensate detrainment is excessive is counter-acted by the lower convective contribution to precipitation in our excessive condensate detrainment simulation .

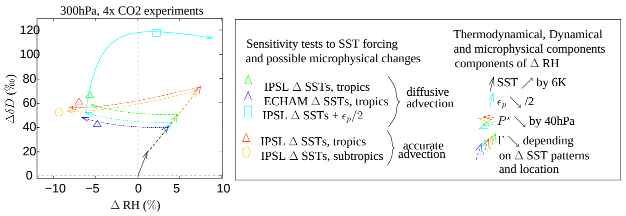
3 How can we evaluate processes controlling RH?

δD measures the enrichment in HDO relatively to sea water in ‰.
δD as a function of RH in our LMDZ sensitivity tests and predicted by the theoretical framework. Our framework captures the isotopic signature of excessive condensate detrainment and of underestimated σ_q .

- Each reasons for a moist bias impact δD differently
- More on poster 1.



4 How can we check that ΔRH results from the right combination of reasons?



ΔδD as a function of ΔRH at 300hPa in 4xCO2 LMDZ experiments with different processes at PD, different SST patterns and/or with the addition of possible microphysical changes. Our theoretical framework predicts qualitatively the trajectories of ΔδD versus ΔRH in the different experiments.

- If long-term δD observations are available in addition to RH and T, the relative contributions of thermodynamical (ΔSST, ΔΓ), dynamical ($\Delta P^\star$) and microphysical (ϵ_p) changes can be disentangled.

5 Conclusion

- Projected ΔRH in the upper-troposphere are significantly sensitive to (1) processes controlling RH at present-day (PD), including cloud micro- and macro-physics, and (2) the balance of thermodynamical vs dynamical changes.
- The diversity of how GCM handle RH processes and predict the balance of changes makes it difficult to find clear relationships between PD variables and ΔRH ([3]).
- How a PD moist bias affects ΔRH projections depends on the reason for the bias. Water stable isotopes measurements combined with RH measurements can help diagnose this reason.
- Long term monitoring of RH and δD may constitute an additional diagnostic to check the credibility of simulated ΔRH.

References

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