Are general circulation models representing processes controlling tropical and subtropical free tropospheric relative humidity properly?

The added value of water vapor isotope measurements.

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1 Introduction

1.1 Goal

Evaluating the representation of processes controlling tropical and subtropical free tropospheric relative humidity (RH) in atmospheric general circulation models (GCMs) is crucial to assess the credibility of predicted climate changes ([3]). The goal of this study is to **design diagnostics to detect and understand biases** in the representation of these processes.

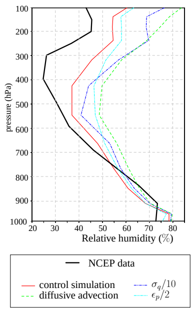
As RH is the net result of a subtle balance between many different processes, RH observations are not sufficient by themselves to evaluate simulated processes controlling it. As the isotopic composition of water vapor is sensitive to phase changes during the water cycle, we explore here the **added value of water stable isotope measurements** to design diagnostics to detect and understand biases in the representation of processes controlling RH.

1.2 Method

GCMs commonly feature a moist bias in the free troposphere ([1]). We intercompare 4 simulations using the isotope-enabled GCM LMDZ ([2]): one using the AR4 version, and 3 tests exhibiting a moist bias for different reasons:

1. Excessive diffusion during water vapor transport (simple upstream scheme rather than second order advection scheme)
2. Underestimated subgrid-scale variability of water vapor (standard deviation of the humidity probability distribution σ_q divided by 10 in statistical cloud scheme)
3. Excessive condensate detrainment (precipitaton efficiency ϵ_p divided by 2 in convective scheme)

We investigate **how these possible reasons for a moist bias can be detected by evaluating the simulated 3D isotopic distribution** and its temporal variations against 4 satellite datasets (SCIAMACHY, TES, ACE, MIPAS), 4 ground-based remote sensing datasets and various in-situ measurements. For all model-data comparisons, outputs were co-located and applied averaging kernels if any.



RH profiles for our different LMDZ simulations

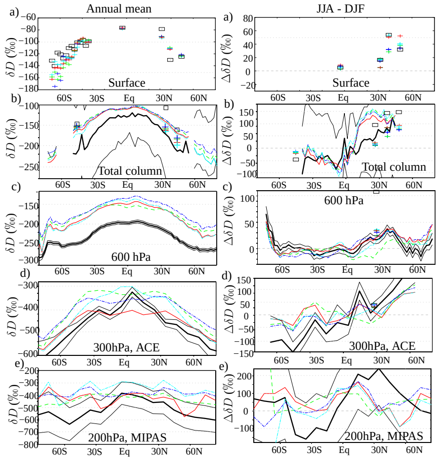
2 Multi-dataset evaluation of the simulated isotope distribution

2.1 Zonal averages

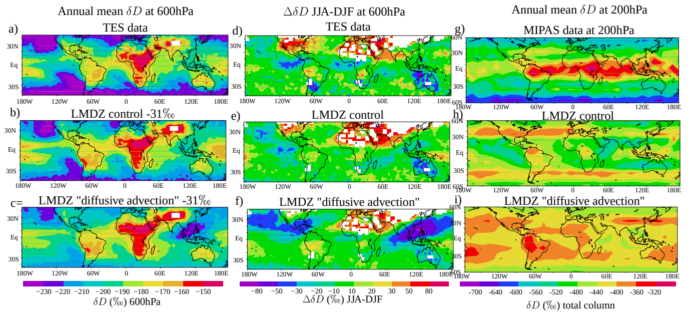
δD measures the enrichment in HDO relatively to sea water in ‰.

Zonal mean of annual mean (left) and seasonal variations (right) of δD at different levels in the different datasets. a) surface vapor from in-situ measurements. b) total column vapor compared to SCIAMACHY and ground-based FTIR over Wisconsin, Oklahoma and New-Zealand. c) At 600hPa compared to TES. d) Between 400 and 300hPa compared to ACE. e) At 300 compared to ACE. f) At 200hPa compared to MIPAS. Lines represent the satellite datasets and markers the ground-based datasets. The ground-based FTIR data at Izana has been added at 800hPa (b), 600hPa and 300hPa.

- 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.



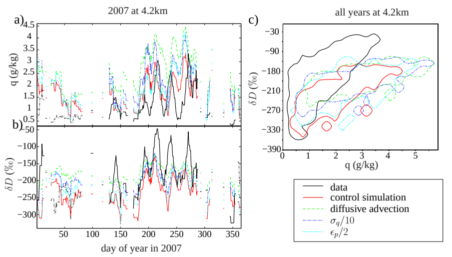
2.2 Spatial patterns



a-c: Annual mean δD at 600hPa measured by TES and simulated by LMDZ for the control and diffusive advection simulations. d-f: Same for JJA-DJF at 600hPa measured by TES. g:i: Same for δD at 200hPa measured by MIPAS.

- Excessive advection over-estimates the depeting effect of convection and underestimates the depleting effect of dehydration from the tropics to the subtropics

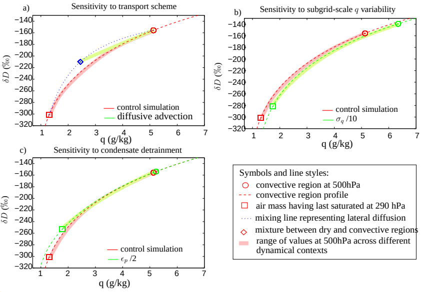
2.3 Intra-seasonal variations in the subtropics



Daily specific humidity q (a) and vapor δD (b) at 4.2km retrieved by the ground-based FTIR at Izana (soild black) and simulated by the 4 versions of LMDZ, during the year 2007. c) Probability density function for the joint q-δD distribution (iso-contour encompassing 98% of data points) from all years of data.

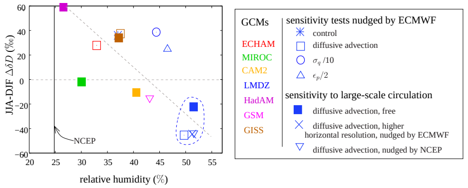
- Excessive diffusion during advection underestimates the depleting effect of dehydration without affecting the amplitude of dehydration too much
- Subgrid-scale variability affect the variability in humidity without affecting the depleting effect of dehydration too much
- Condensate detrainment affects the mean δD and q.

3 Interpretation



Interpretation of our simulation results using a simple theoretical model (see poster 2): example at 500hPa. q and δD range from values characteristic of a convective region at this level (circle) to values characteristic of the convection region at the maximum altitude of the last saturation (square), assuming that this air then slowly subside conserving q and δD ([4]). a) If lateral diffusion takes place between convective and dry subsiding regions, dry regions are re-moistenened and strongly enriched. b) If the subgrid-scale variability of water vapor, σ_q, decreases, a smaller proportion of air condenses in the large-scale condensation scheme. Air is moister and more enriched. c) When a higher proportion of condensate is allowed to detrain rather than precipitate, convective regions are moistened and strongly enriched.

4 Generalization to 7 isotope-enabled GCMs



a) 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. Sensitivity tests to the nudging and resolution are packed together to highlight their similar behavior.

- in the upper-troposphere, excessive diffusion during advection seems to be a widespread cause of moist bias in GCMs.

5 Conclusion

We can use **water vapor isotope measurements as observational diagnostics to understand the reasons for a moist bias in a GCM**:

Reason for moist bias	Observational test to detect this bias
Excessive diffusion during water vapor transport	Reversed δD seasonality troughout the free troposphere Convection depletes the vapor throughout the free troposphere Underestimated intra-seasonal subtropical variability of δD due to underestimated q-δD slope
Underestimated subgrid-scale variability of water vapor	Underestimated intra-seasonal subtropical variability of δD due to underestimated dry extrema
Excessive condensate detrainment	Overestimated δD in the upper troposphere

Inter-comparing 7 isotope-enabled GCMs suggests that **excessive diffusion during water vapor transport is a common cause of moist bias in GCMs**.

References

[1] V. O. John and B. J. Soden. Temperature and humidity biases in global climate models and their impact on climate feedbacks. *Geophys. Res. Lett.*, 34:L18704, doi:10.1029/2007GL030429, 2007.

[2] C. Risi, S. Bony, F. Vimeux, and J. Jouzel. Water stable isotopes in the LMDZ4 General Circulation Model: model evaluation for present day and past climates and applications to climatic interpretation of tropical isotopic records. *J. Geophys. Res.*, in press:doi:10.1029/2009JD013255, 2010.

[3] S. C. Sherwood, W. Ingram, Y. Tsushima, M. Satoh, P. L. V. M. Roberts, and P. A. O'Gorman. Relative humidity changes in a warmer climate. *J. Geophys. Res.*, *115*, 115:D09104, doi:10.1029/2009JD012585, 2010.

[4] S. C. Sherwood, E. R. Kursinki, and W. G. Read. A distribution law for free-tropospheric relative humidity. *J. Clim.*, 19:6267–6277, 2006.