Evaluating land surface hydrological processes and land-atmosphere feedbacks using water isotopic measurements

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1 Introduction

1.1 Ultimate goals

- Climate models show dispersion in the response of land surface precipitation and hydrology to climate and land use change ([1, 3]). What processes are responsible for this dispersion? What part of the "hydrological response chain" (fig 1) is most critical?
- Models also show dispersion in land-atmosphere feedbacks at intra-seasonal scale due to dispersion primarily in the $q_{sol} \rightarrow ET$ link and secondarily in the $ET \rightarrow P$ link ([2]). Are there observational constrains of these feedbacks? Are they relevant to assess the credibility of land hydrological response to climate and land use change?

1.2 Method

- **Sensitivity tests** with the LMDZ GCM coupled to the ORCHIDEE land surface model.
- Water stable **isotopic observations** to better evaluate land-atmosphere feedbacks and associated processes.

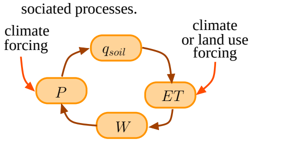


Fig 1. "Hydrological response loop" to atmospheric or land use forcing and land-atmosphere feedback chain. P=precipitation, q_{soil}=soil humidity, ET=evapo-transpiration, W=precipitable water.

2. Land-atmosphere feedbacks on precipitation

- Focus on intra-seasonal scale to look at perturbations within a background large-scale circulation and to compare with observations.
- Water tagging in LMDZ-ORCHIDEE ([4]) to quantify intensity of land-atm feedbacks.

2.1 Quantifying land-atm feedbacks in the model

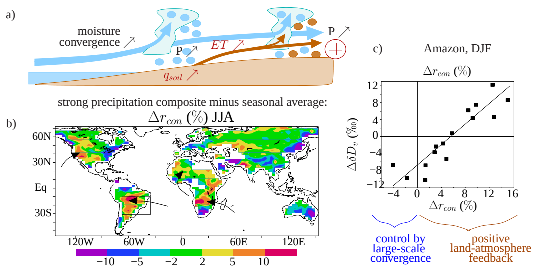


Fig 2. a) When feedbacks are positive, the fraction of vapor from continental recycling (r_{con}) increases during precipitation events. b) difference of r_{con} between precipitation events and the seasonal average, used as a proxy for land-atm feedbacks. c) Example over the Amazon: difference in water vapor δD (measuring the enrichment in HDO relatively to sea water in ‰) as a function of difference in r_{con}.

- Positive feedbacks in most monsoon regions.
- During precipitation events, δD anomaly is all the more enriched as land-atm. feedbacks are positive

$\Longrightarrow$Use of $d\delta D/dP$ or $d\delta D/dW$ as a proxy for land-atm. feedbacks (fig 2c).

2.2 Dispersion in land-atm feedbacks and isotopic constraint

Sensitivity tests to land surface and atmospheric representation: fig 3, 4.

- land-atm feedbacks are sensitive to land surface representation.
- $d\delta D/dW$ over land minus ocean observed by GOSAT (*Frankenberg et al in prep*) = observational constrain of land atmosphere feedbacks.

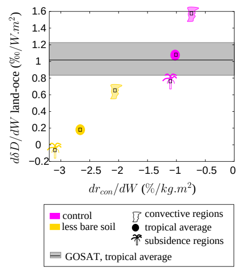


Fig 3. $d\delta D/dW$ over land minus ocean as a function of dr_{con}/dW (direct proxy for land-atm feedbacks) in tropical average and for different dynamical regimes, for the sensitivity tests run with water tagging.
$\Longrightarrow d\delta D/dW$ over land minus ocean = observable proxy for land-atm feedbacks

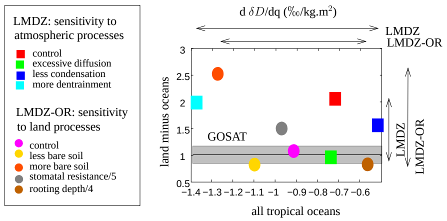


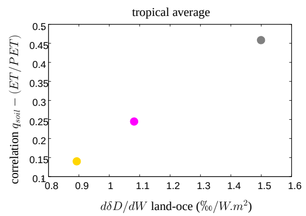
Fig 4. $d\delta D/dW$ over land minus ocean as a function of $d\delta D/dW$ over ocean simulated in tropical average by different sensitivity tests.

2.3 What processes are responsible for the dispersion?

We compare among our tests the correlations between different steps of the feedback loop (fig 1) at the intra-seasonal scale: P, infiltration,q_{soil}, ETP (=potential ET), ET/ETP , r_{con}, W.

Fig 5. $d\delta D/dW$ over land minus ocean (observable proxy for land-atm feedbacks) as a function of correlation between q_{soil} and ET/ETP , in tropical average.

- $q_{soil} \rightarrow ET$ link is critical

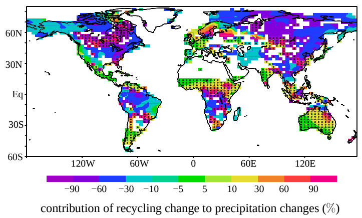


2.4 Relevance for climate change?

Climate change simulations with SST anomalies from the IPSL coupled model in a 4$\times CO_2$ experiment.

- land-atm feedbacks contribute to precipitation decrease and attenuate precipitation increase (fig 6).
- Work in progress: is it sensitive to the representation of land surface processes, and are the feedbacks consistent with those at intra-seasonal scale?

Fig 6. Contribution of land-atm feedbacks to precipitation change in a 4$\times CO_2$ experiment, quantified by water tagging ($(\Delta P/P)/(\Delta P_{oce}/P_{oce}) - 1$). E.g. -50% where precipitation increases means that land-atm feedbacks have attenuated the increase by half; +50% where precipitation decreases means that land-atmosphere feedbacks have amplified the decrease by 50%. Regions where precipitation increase (decrease) by more than 0.4mm/d are colored (colored and stippled).



3. Evapo-transpiration partitionning and $q_{soil} \rightarrow ET$ link

3.1 Evaluating evapo-transpiration partitionning using soil water isotopic measurements

Offline ORCHIDEE simulations on 10 sites spanning various hydroclimate conditions, numerous sensitivity tests.

- Soil water isotopic measurements can be used to evaluate the evaporation (E) vs transpiration (T) partitioning in models (fig 7).

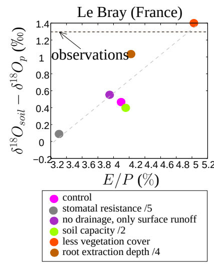


Fig 7. Example on the Bray site in Southern France: annual mean soil water $\delta^{18}O$ minus precipitation $\delta^{18}O$ as a function of annual mean E/P.

3.2 Implications for hydrological response to atmospheric forcing

Example on the Bray site: response to decrease of annual precipitation by half (fig 8).

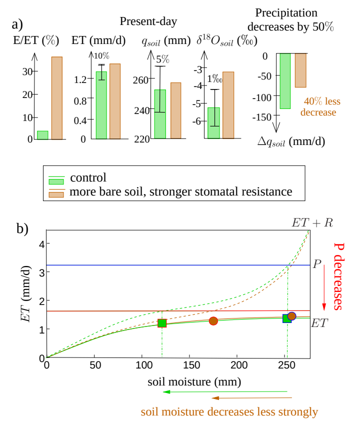


Fig 8. a) Comparison between the control (green) and a simulation with similar ET and q_{soil}, but with much higher E/ET (brown).

- Soil water $\delta^{18}O$ can identify model biases that are not obvious in ET or q_{soil} within measurement errors, but that impact hydrological response to climate change.

b) Functional relationship between ET and runoff as a function of q_{soil} in the control and higher E/ET test, and consequence for the response to precipitation decrease.

- E/ET impacts the $q_{soil} \rightarrow ET$ functional relationship, which controls the hydrological reponse to precipitation changes.

4 Conclusion

- Water isotopic measurements in water vapor can help evaluate the sign and intensity of land-atm feedbacks
- These feedbacks are very sensitive to the representation of land surface processes, in particular to $q_{soil} \rightarrow ET$
- $q_{soil} \rightarrow ET$ is sensitive to (among others) E/ET partitionning, which can be evaluated using water isotopic measurements in soil water.

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