

Water isotopes for atmospheric water cycle applications

Camille Risi

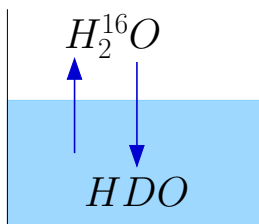
LMD/IPSL/CNRS

+ some thoughts from David Noone

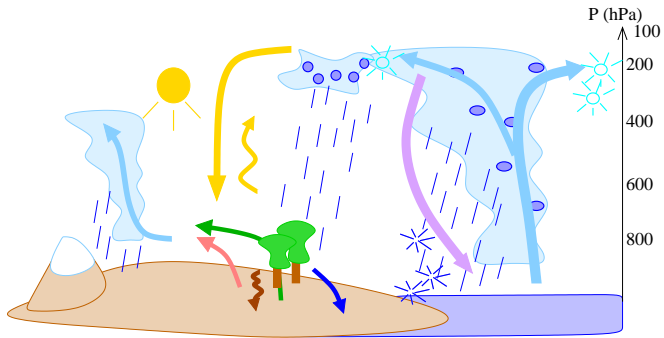
The Hague, July 2014

Water isotopes

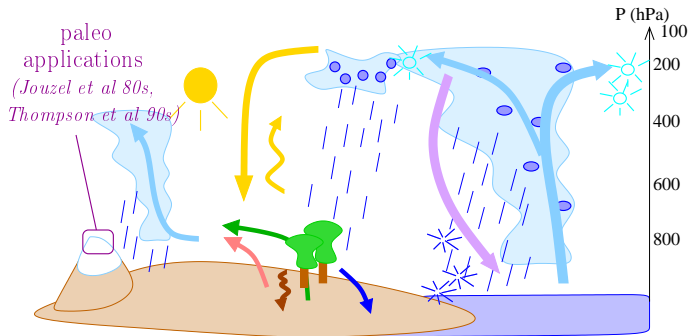
- ▶ $H_2^{16}O$, HDO , $H_2^{18}O$...
- ▶ fractionation during phase changes
⇒ tracers of the water cycle



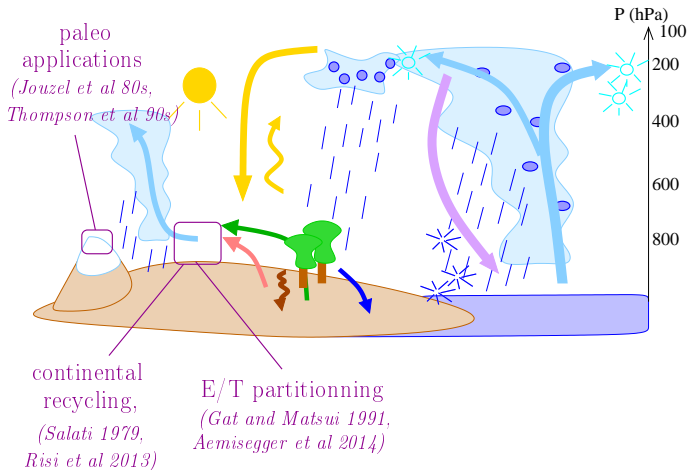
What can we use isotopes for?



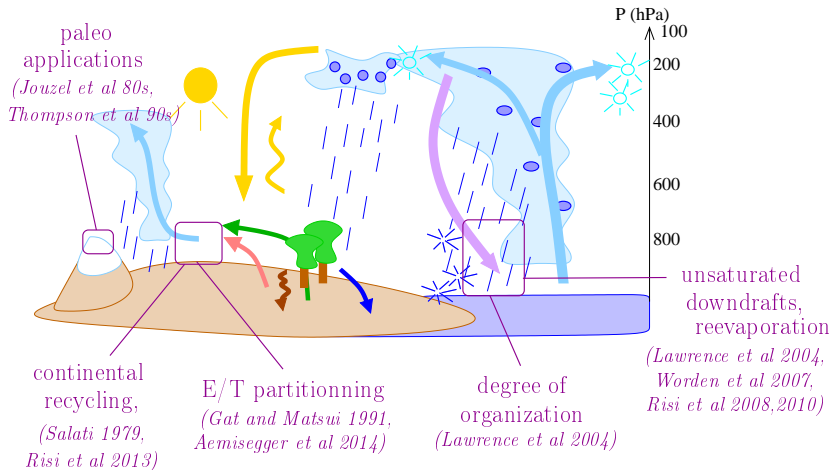
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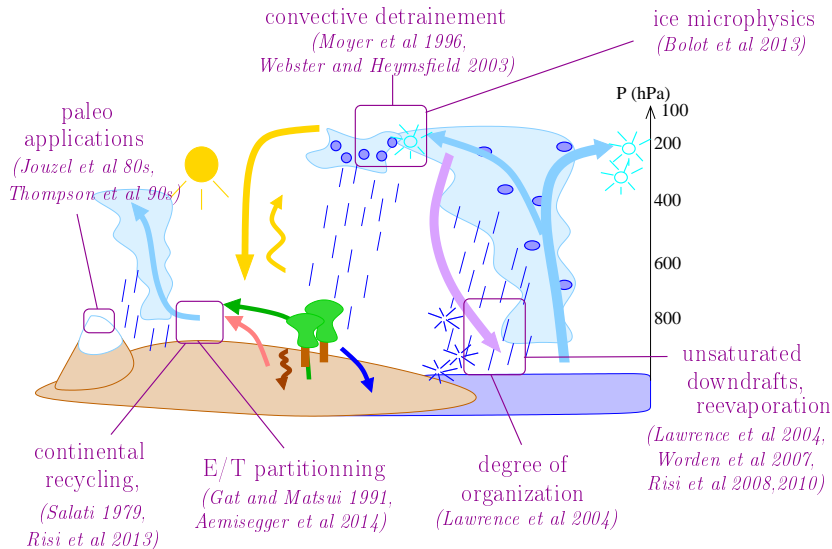
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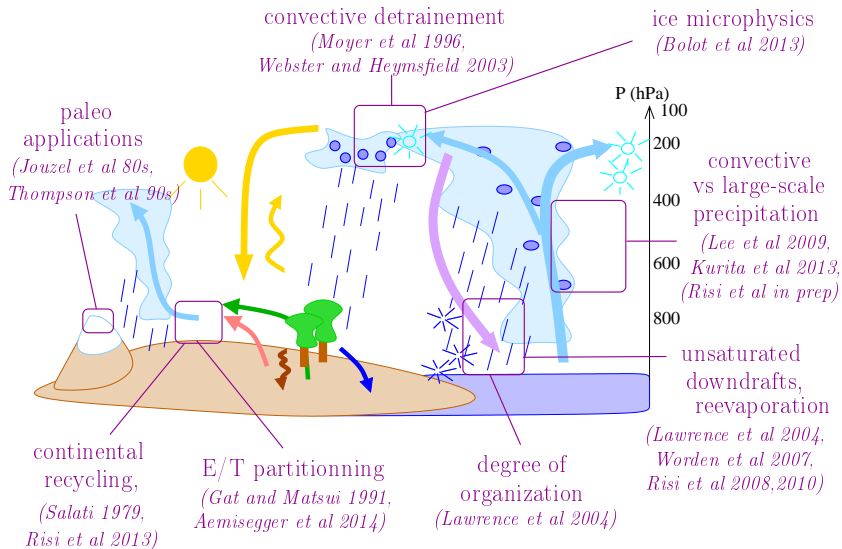
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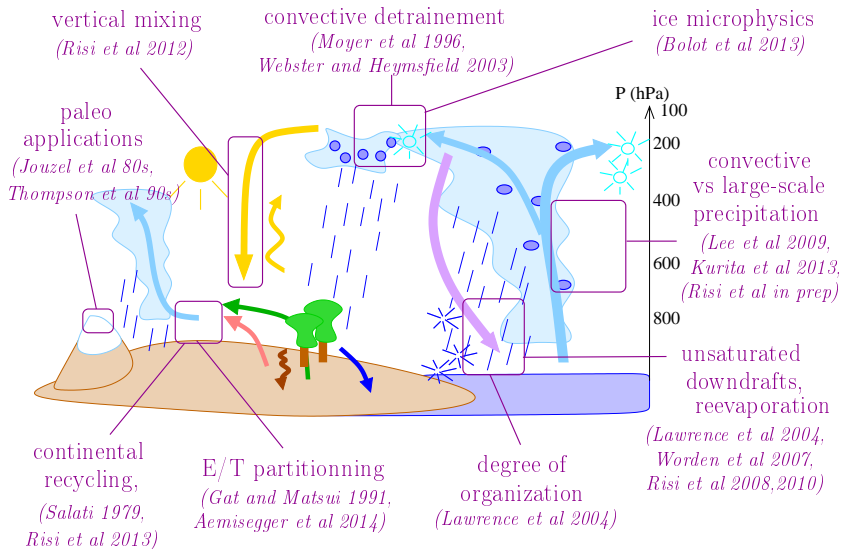
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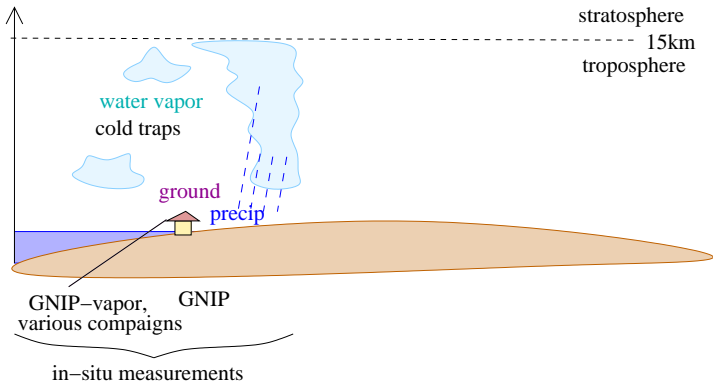
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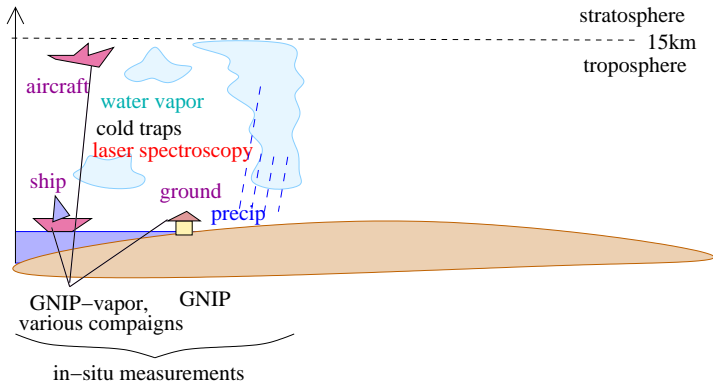
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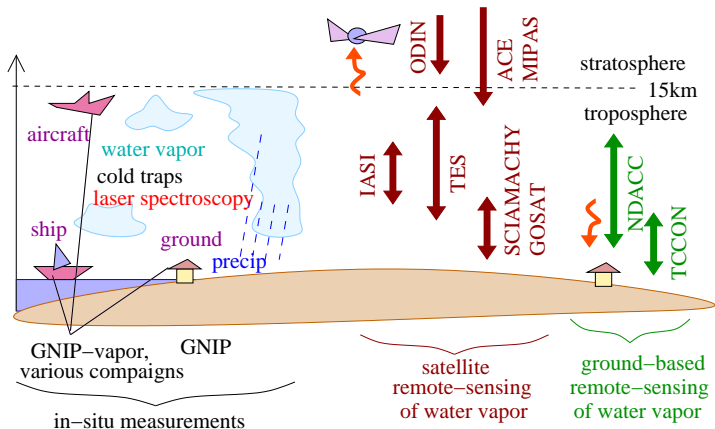
Opportunities: new measurements



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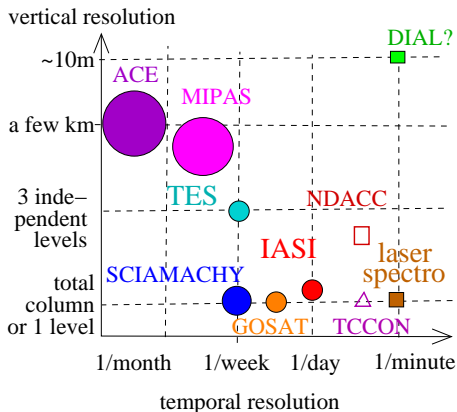


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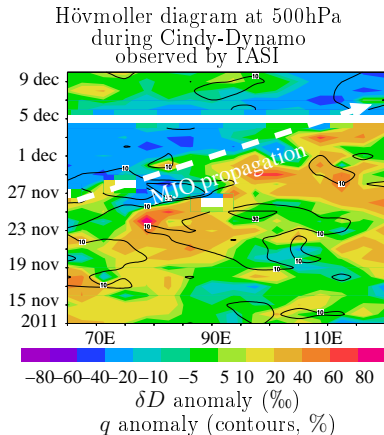
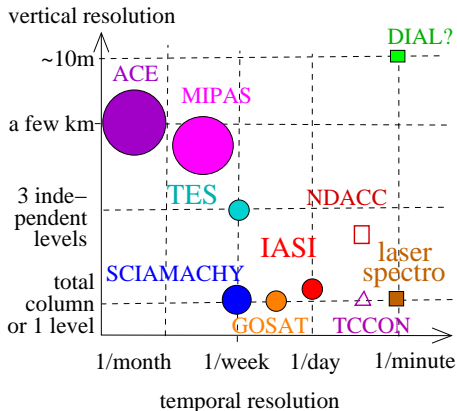
Opportunities: diversity of measurements

- ▶ different altitudes, temporal resolution, vertical resolution, precision, spatial resolution and coverage...



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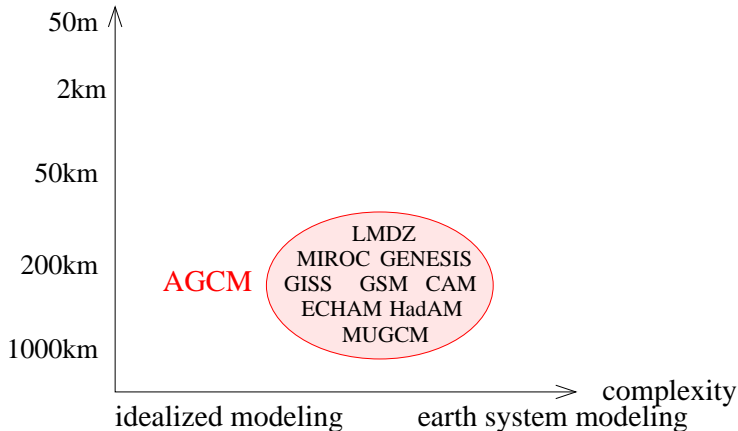
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Opportunities: numerical models

- ▶ more and more numerical models with isotopes

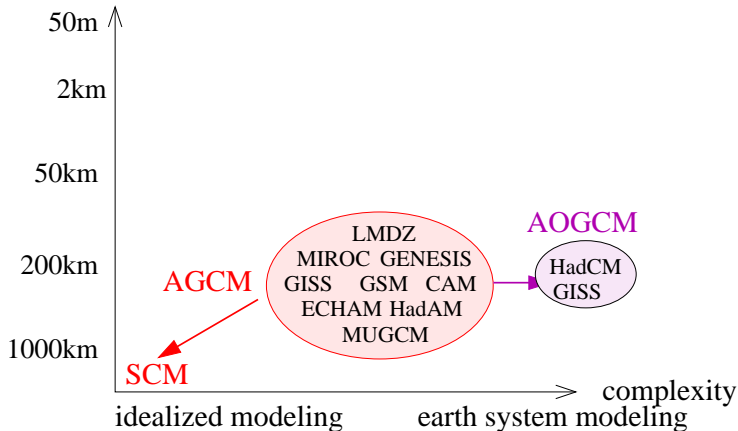
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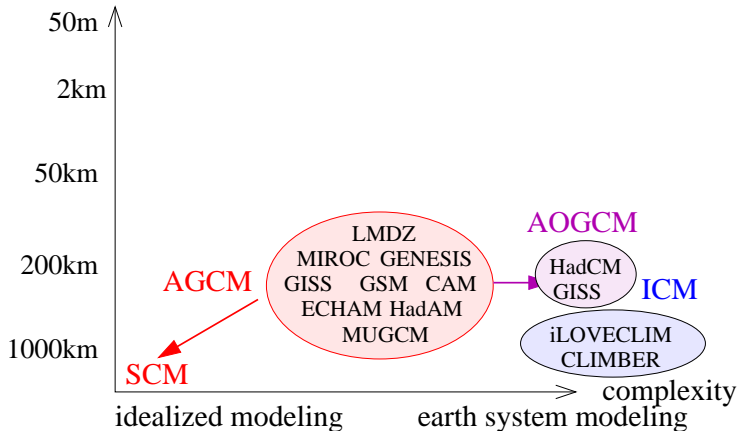
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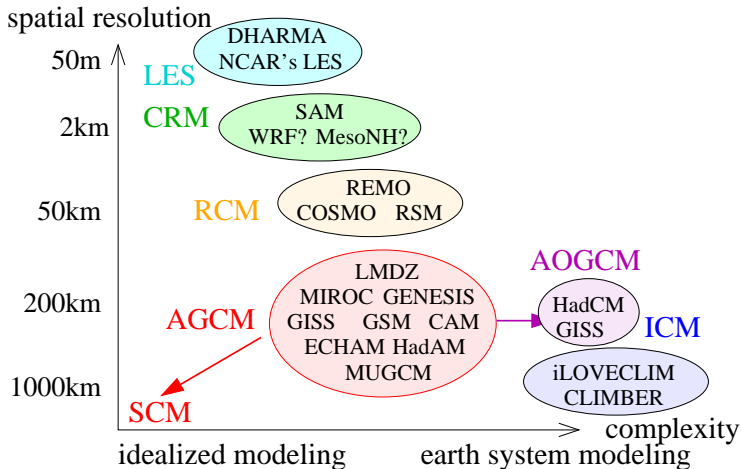
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Opportunities: use GCM simulations

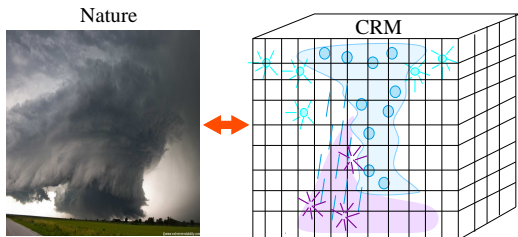
- ▶ isotopic simulators to compare with observations:
 - ▶ take into account spatio-temporal sampling & instrument sensitivity (*Risi et al 2012, Field et al 2012*)
 - ▶ forward proxy modeling of paleo archives (e.g. *Kanner et al 2013, Caley et al 2014*)

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- ▶ Model intercomparison projects with isotopes:
 - ▶ why?
 - ▶ check robustness of simulated results
 - ▶ detect/understand model biases (*Risi et al 2012*), evaluate/improve GCMs (*Field et al subm*)
 - ▶ SWING 1 & 2 Intercomparison project
 - ▶ AMIP simulations, monthly outputs, $\simeq 9$ GCMs
 - ▶ limitations: daily outputs? Paleo simulations?
 - ▶ To go further:
 - ▶ CMIP6 with isotopes? PMIP?
 - ▶ SWING3? GEWEX?

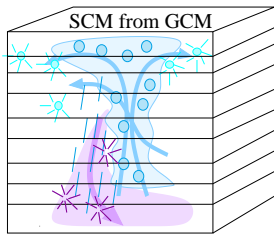
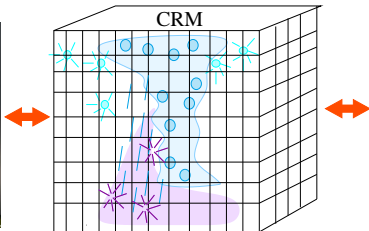
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- ▶ to compare more easily to observations (*Yoshimura et al 2010*)
- ▶ to study processes, e.g. SAM (*Blossey et al 2010, Moore et al 2014*)



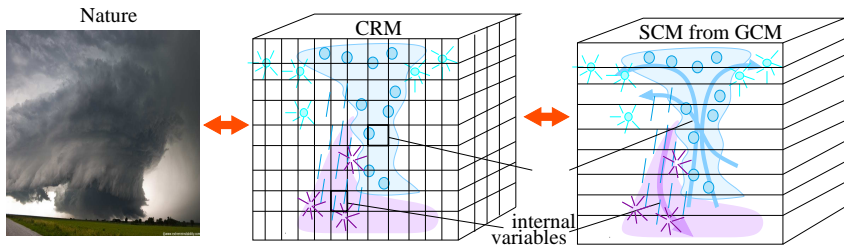
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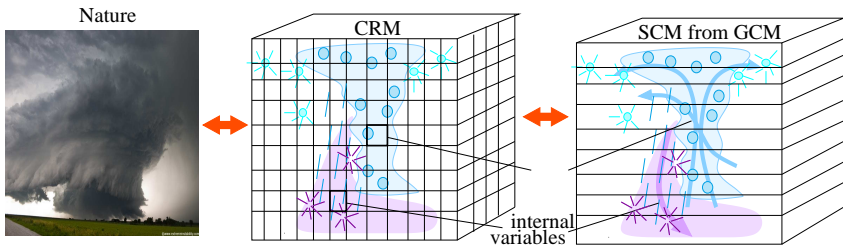
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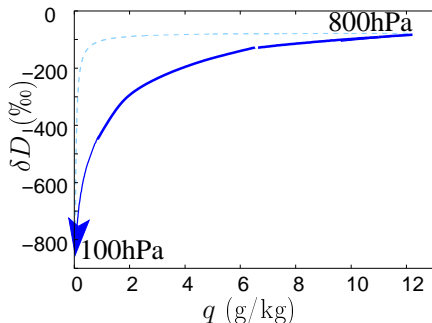
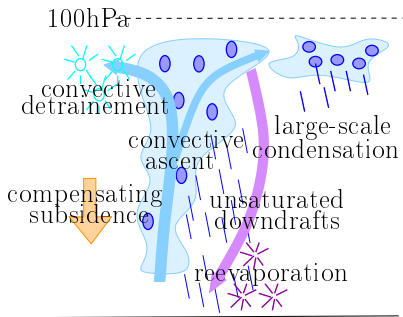
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- ▶ Define cases for CRM/SCM intercomparison project?
 - ▶ idealized (radiative convective equilibrium)
 - ▶ campaign: e.g. Cindy Dynamo?

Theoretical framework: q - δD

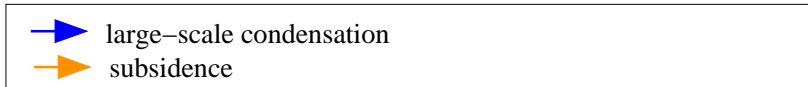
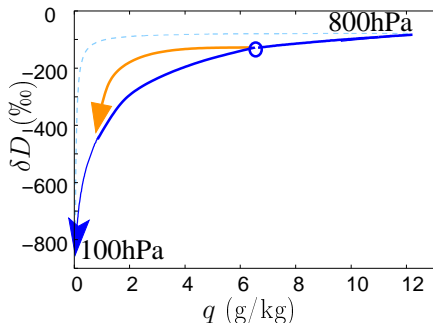
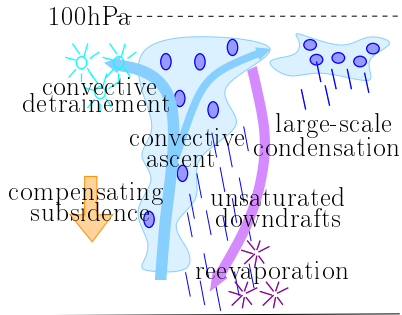
- Moistening and dehydrating processes (*Worden et al 2007*)



► large-scale condensation

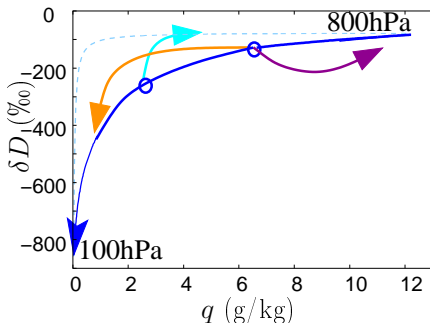
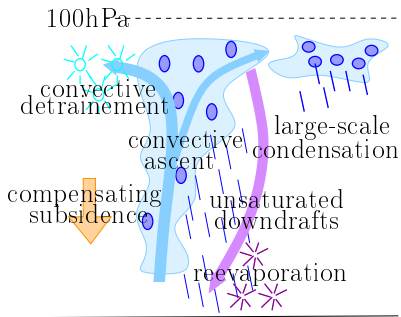
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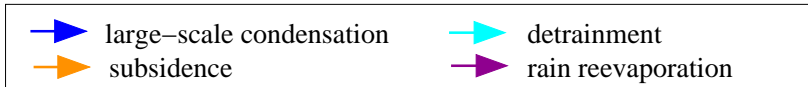
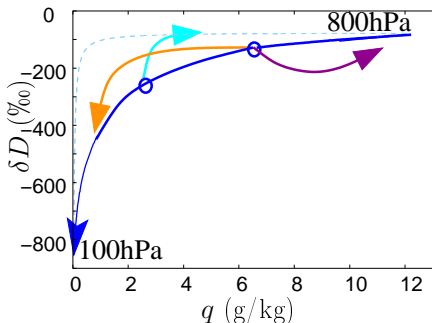
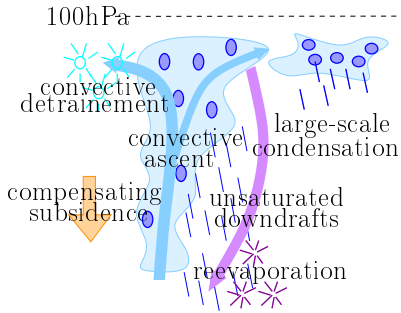


▶ large-scale condensation
▶ subsidence

▶ detrainment
▶ rain reevaporation

Theoretical framework: q - δD

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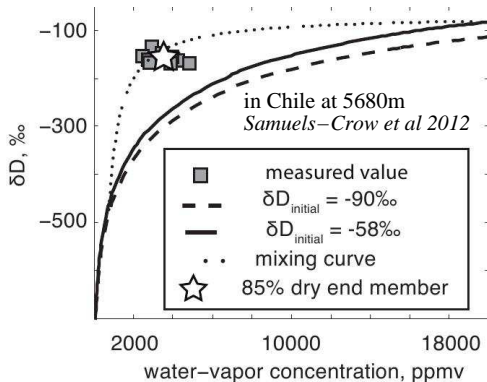


- limitation: need to bridge gap between this simple framework and numerical modeling

Examples of using isotopes to understand processes in nature

Example 1: Transport and mixing processes

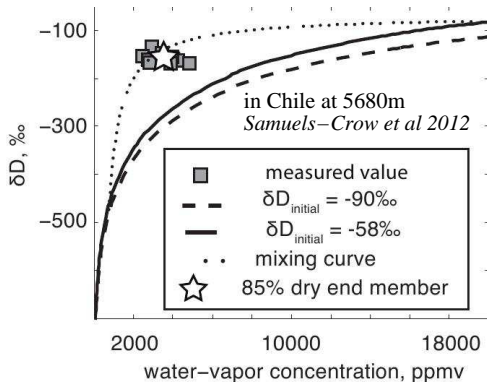
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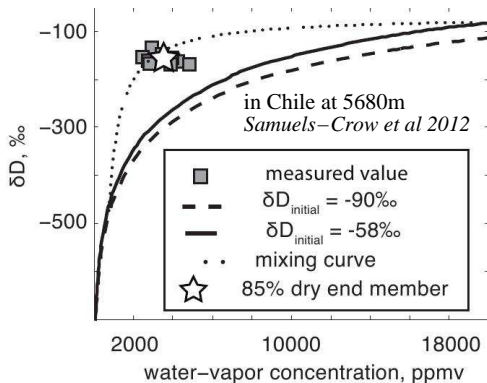


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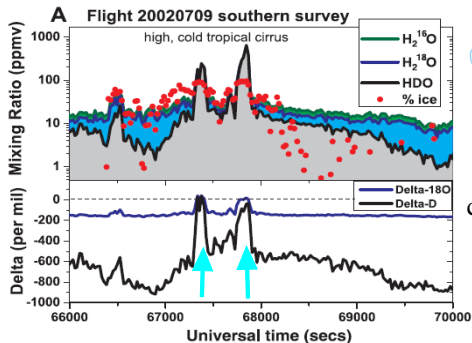
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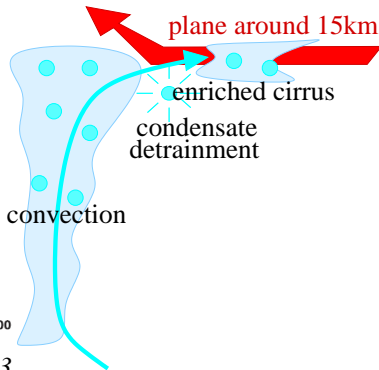
- ▶ Limitation: isotopes just consistent with what we already know (e.g. *Sherwood et al 1996*)
- ▶ But we are progressing... e.g. *Galewsky et al subm*: isotopes to distinguish between different hypotheses for moistening of stratospheric intrusions

Example 2: troposphere-stratosphere exchanges

- papers from *Moyer, Kuang, Dessler, Sherwood, Sayres, Hanisco...*

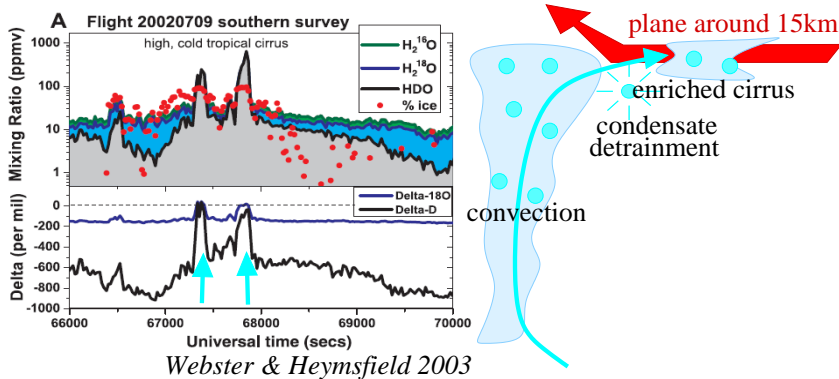


Webster & Heymsfield 2003



Example 2: troposphere-stratosphere exchanges

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- Limitation: isotopes consistent with some convective injection of water through the tropopause layer. But how to make quantitative estimations?

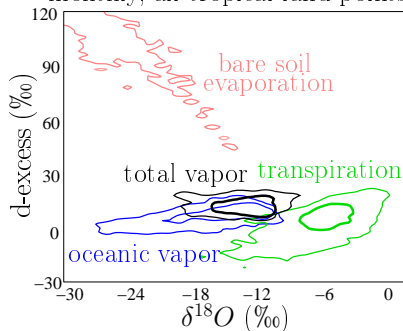
Example 3: Continental recycling

Water tagging:



Risi et al 2013

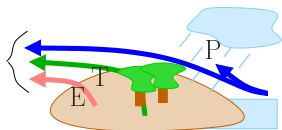
PDF of vapor composition
monthly, all tropical land points



- ▶ Use δD or $\delta^{18}O$ to quantify continental recycling (*Salati et al 1979, Risi et al 2013*)
- ▶ Use d-excess to quantify evaporation/transpiration: (*Gat et Matsui 1991, Aemessiger et al 2014*)

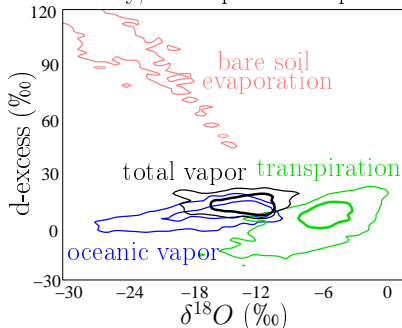
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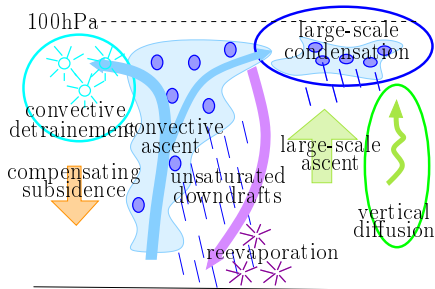
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- ▶ Limitation: how to extract continental recycling signal from all other processes? \Rightarrow isotope methods not very precise so far

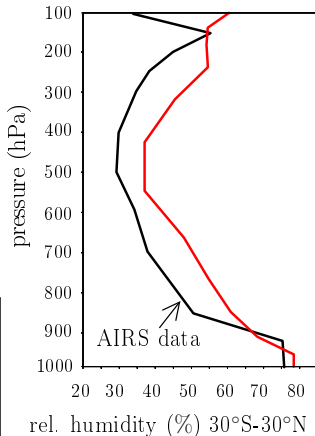
Isotopes to detect/understand biases, evaluate/improve/tune models

Ex 1: what causes the moist bias in GCMs?



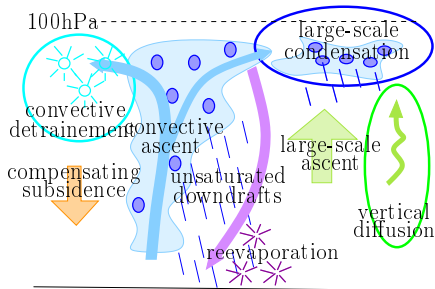
LMDZ:

■ Control



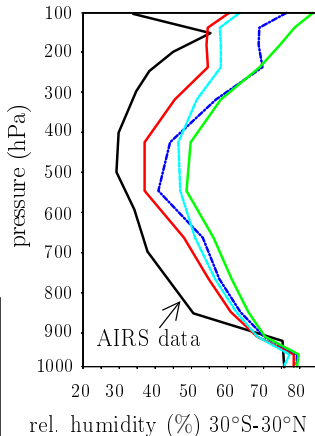
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LMDZ sensitivity tests:

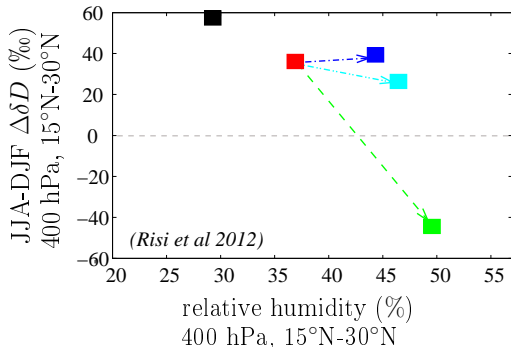
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- Excessive condensate detrainment
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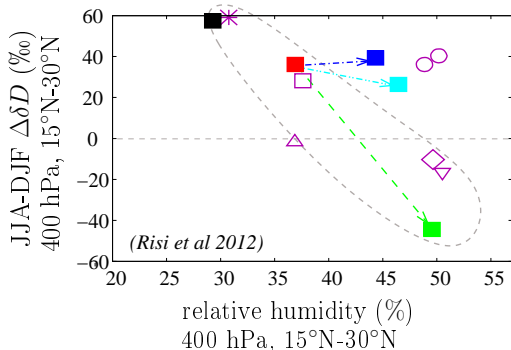
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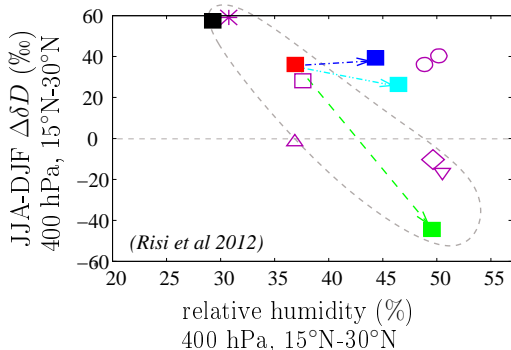
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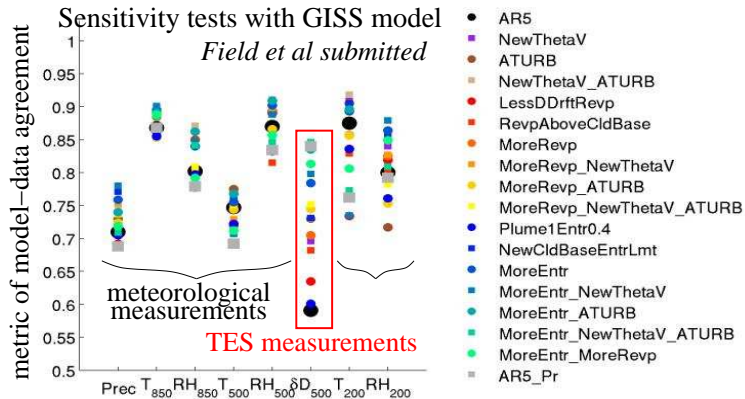
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- ▶ excessively diffusive advection = most frequent bias

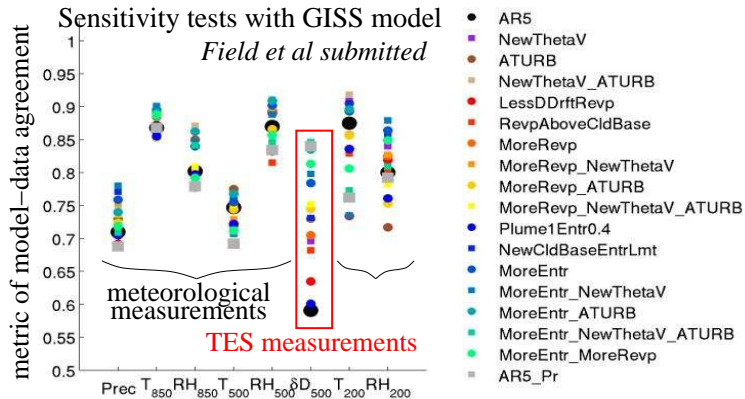
Example 2: Evaluate/improve/tune convection and cloud parameterizations

Lee et al 2009, Field et al submitted



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Lee et al 2009, Field et al submitted



- ▶ Limitation: isotopes not used operationally to improve models: more work before doing so safely...

Conclusion

- ▶ Isotopes potentially very useful to
 - ▶ quantify relative importance of moistening/dehydrating processes: e.g. mixing, convection, continental recycling...
 - ▶ detect/understand biases in models, evaluate/improve models
- ▶ But... difficult to make them actually/quantitatively useful
 - ▶ what controls water composition not well understood yet
 - ▶ lots of measurements exist but under-exploited
 - ▶ new modelling tools, but under-exploited
 - ▶ gap between numerical modelling and theoretical frameworks
- ▶ Possible solutions
 - ▶ More interactions between model-data, model-theory, hierarchy of models
 - ▶ Isotopes cannot answer everything: combine with meteo variables, clouds, chemical tracers (CO , O_3 , ^{10}Be) \Rightarrow data synergy (e.g. *Folkins et al 2006*, *Liu et al 2009*)
 - ▶ Intercomparison projects? something within GEWEX?
 - ▶ GCM: CMIP6 or SWING3?
 - ▶ SCM - CRM: idealized or campaign cases?