Using water vapor isotopic measurements to evaluate moist and cloud processes in general circulation models

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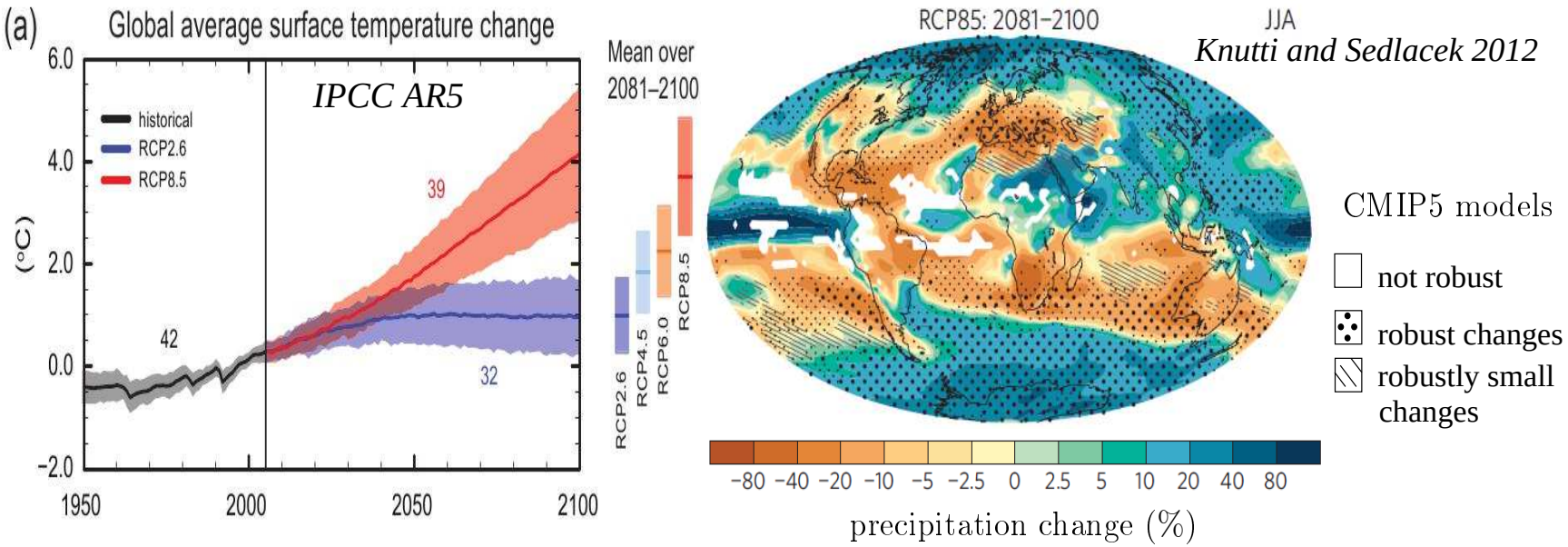
Moist and cloud processes in climate models

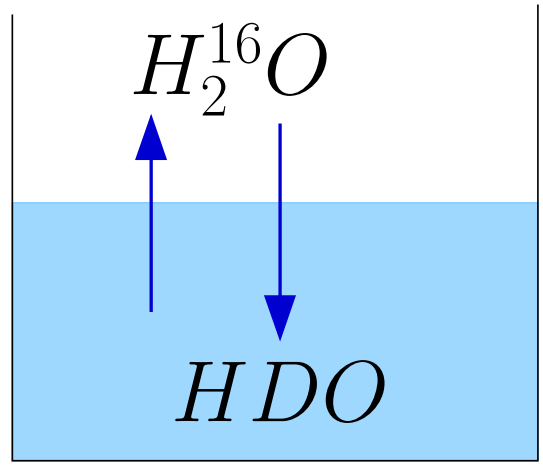


- Sources of spread? Temperature: cloud feedbacks (*Bony et al 2004, Dufresne et al 2008, Vial et al 2014*)
- For precip: convective parameterizations, cloud feedbacks? (e.g. *Kang et al 2008, Frierson and Hwang 2012*)

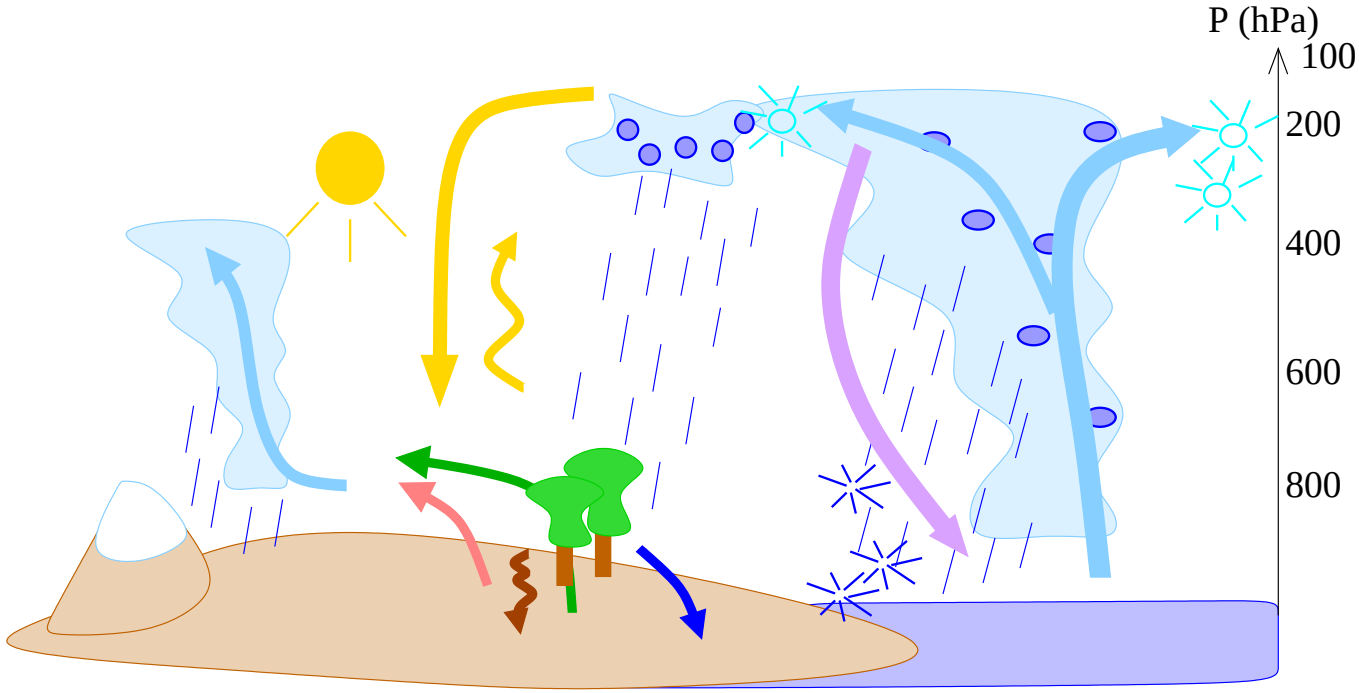
⇒Need to better evaluate these processes in models

Water isotopes

- $H_2^{16}O$, HDO, $H_2^{18}O$ ...
- $\delta D = (HDO/H_2O/R_{sea\ water} - 1) \cdot 1000$ in ‰
- fractionation during phase changes
  $\Rightarrow$ tracers if the water cycle



What can we use isotopes for?



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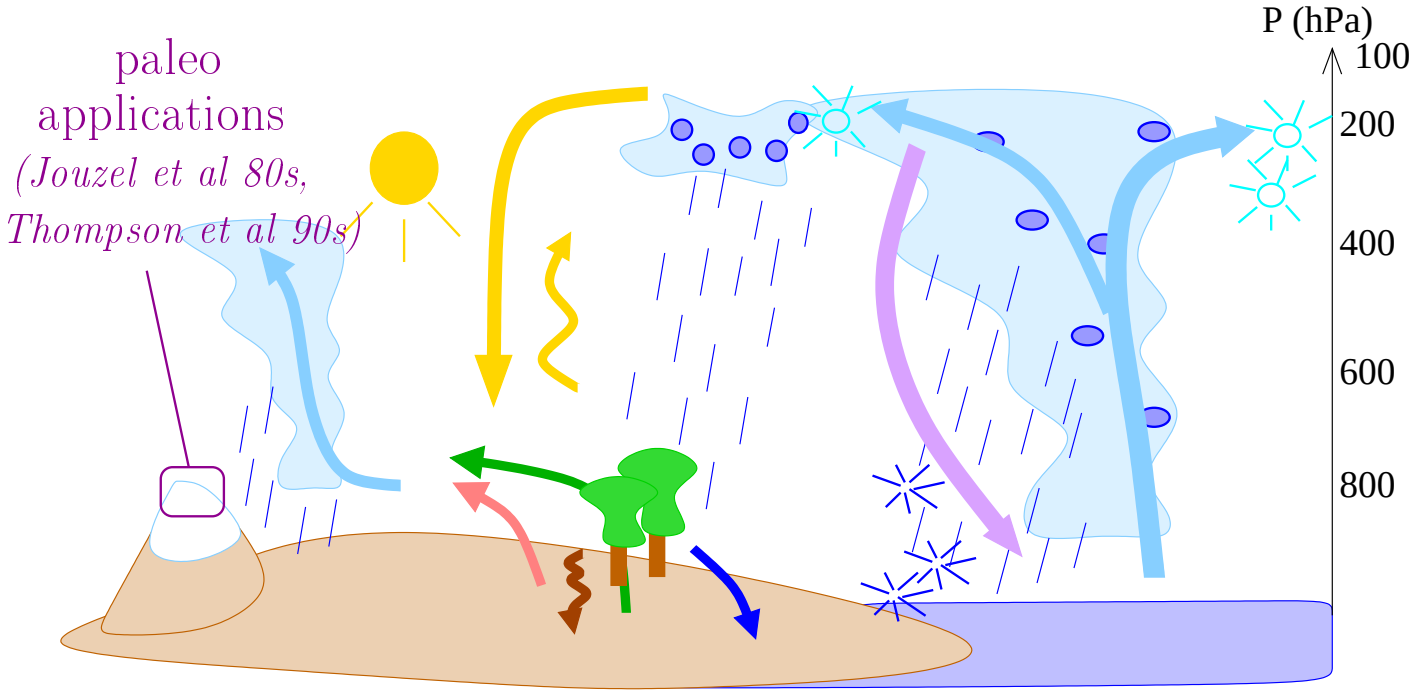

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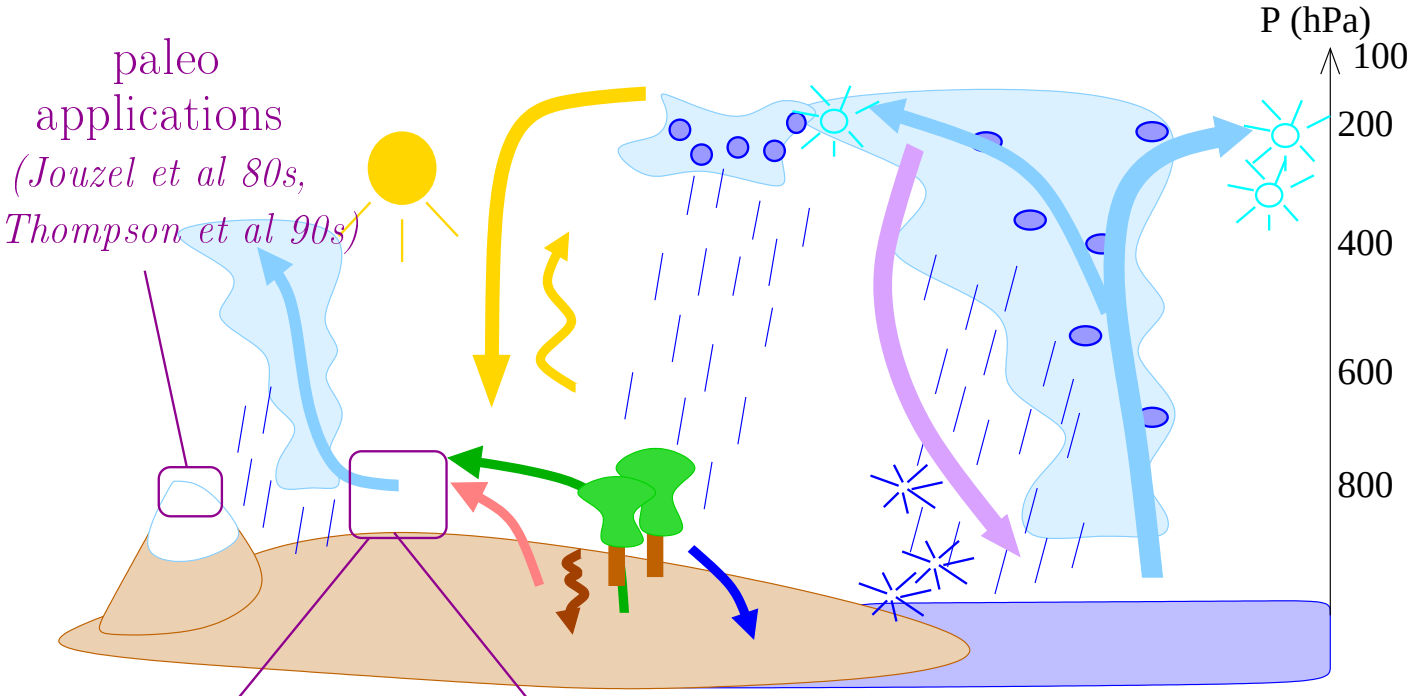

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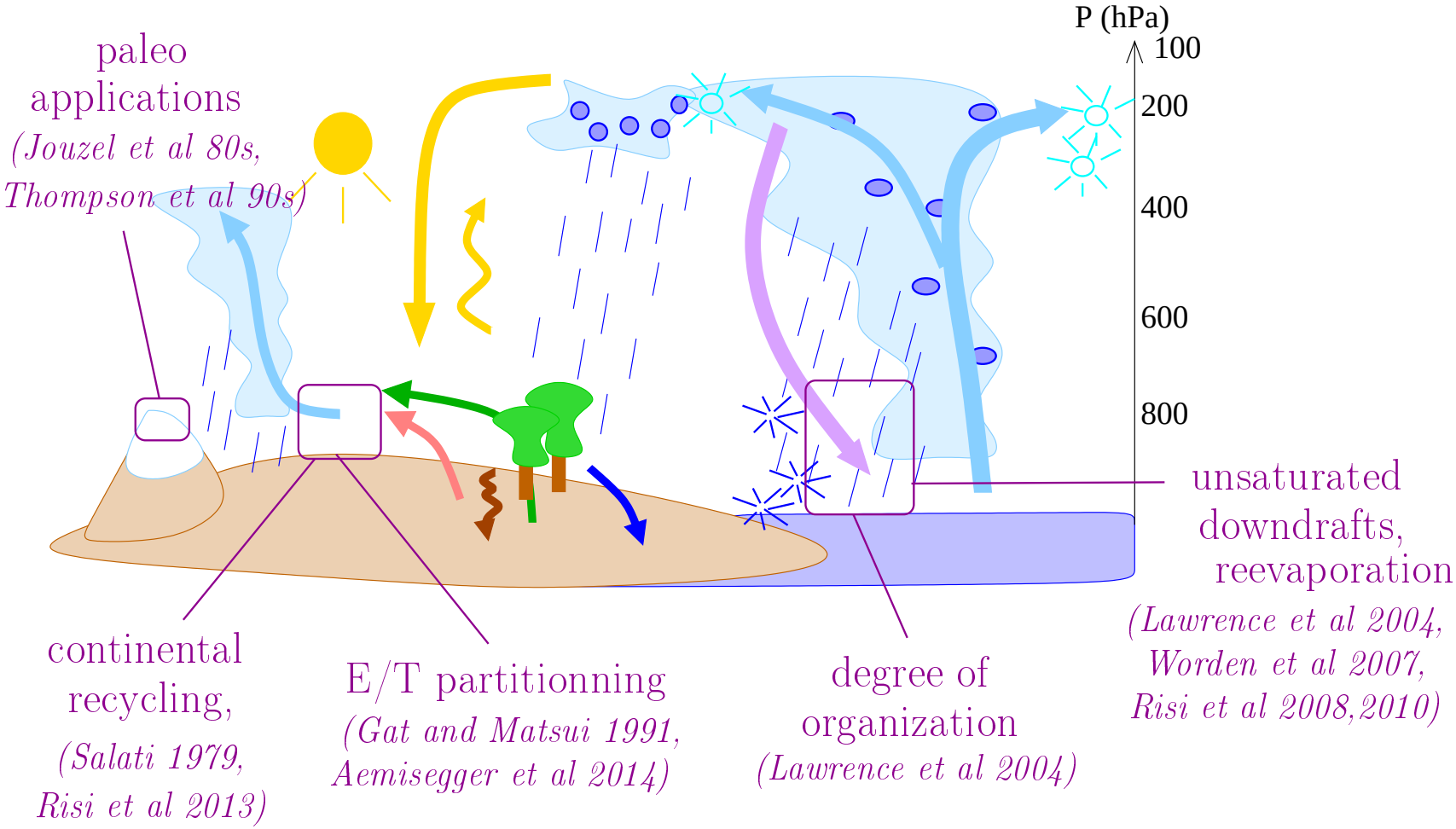

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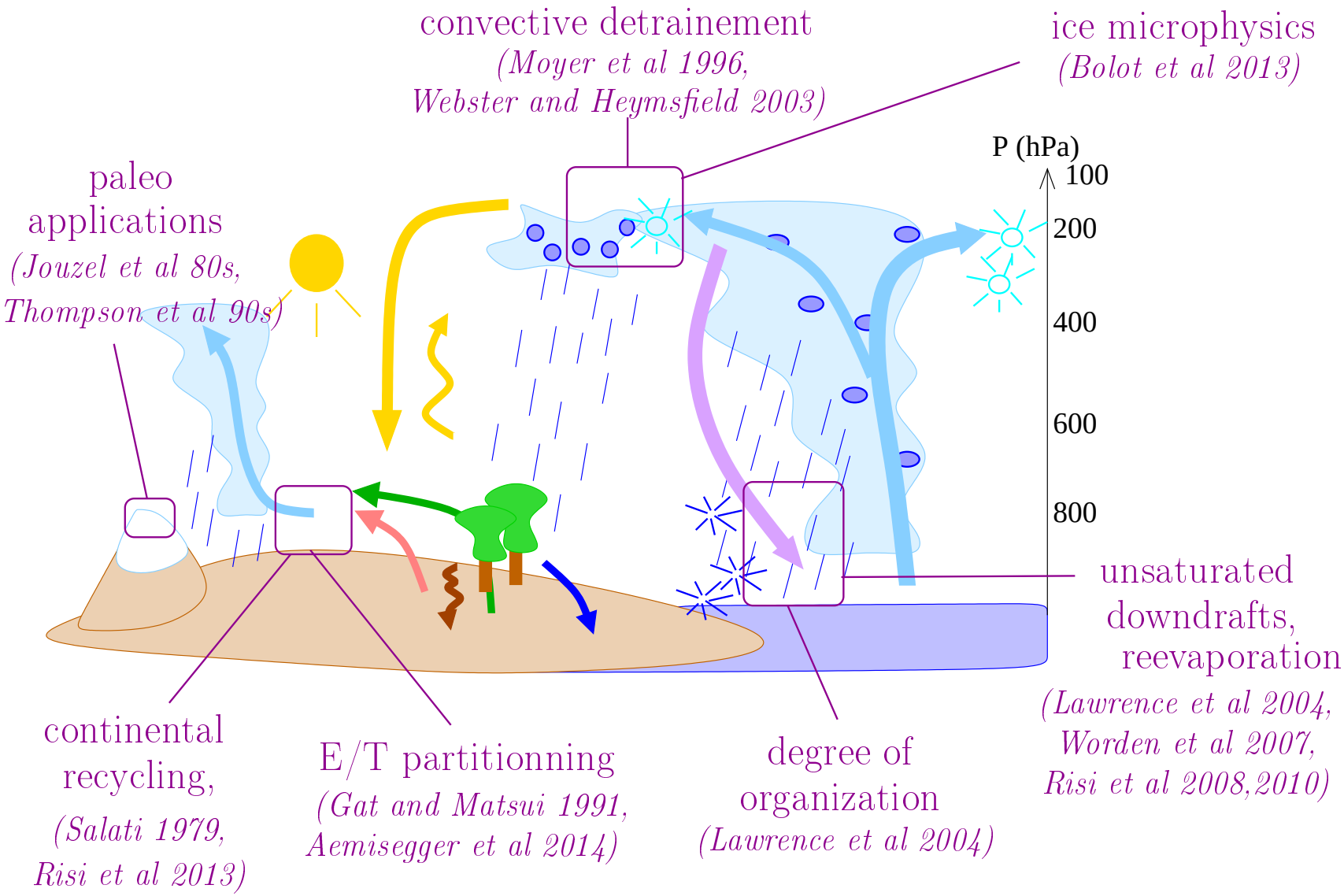

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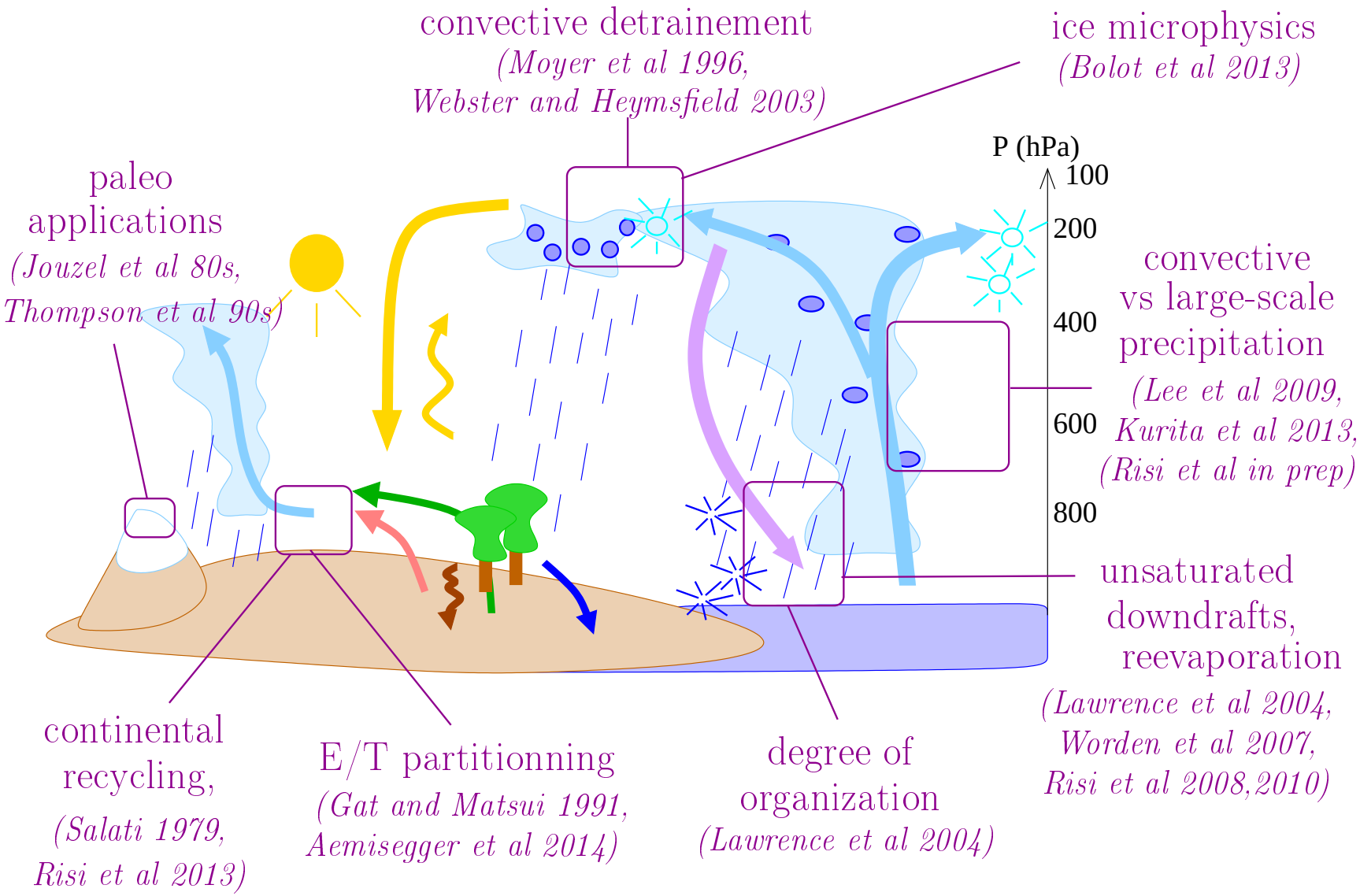

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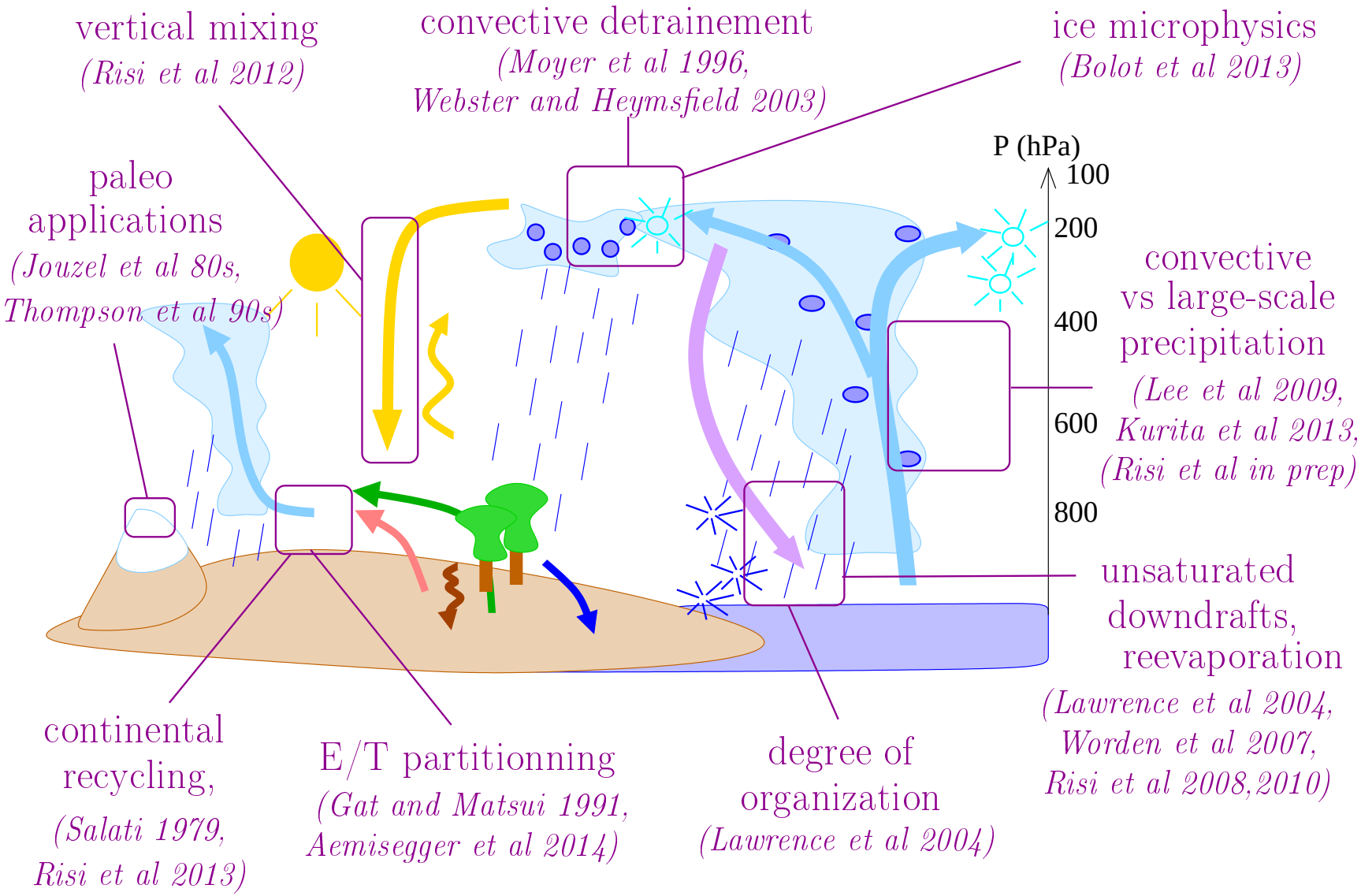
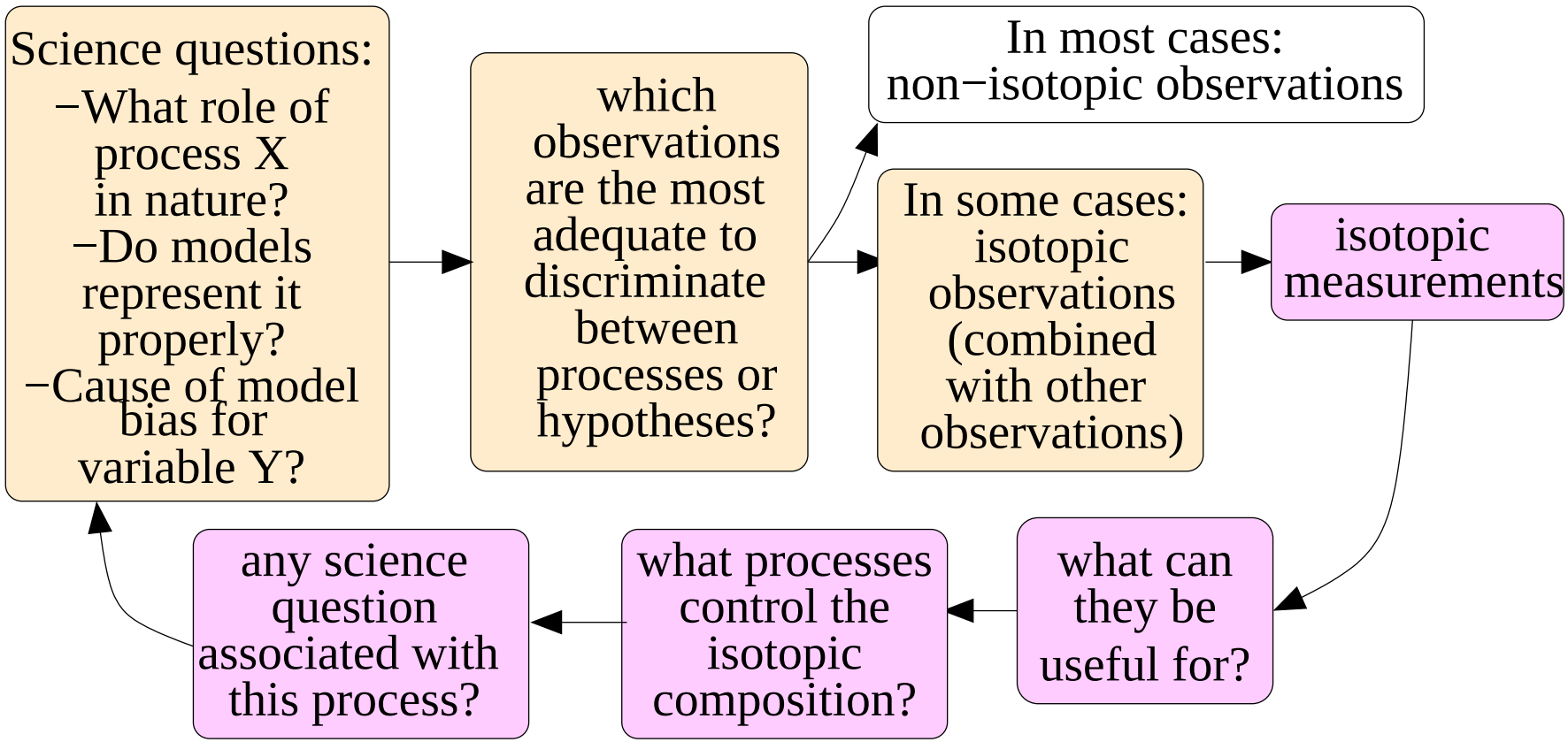


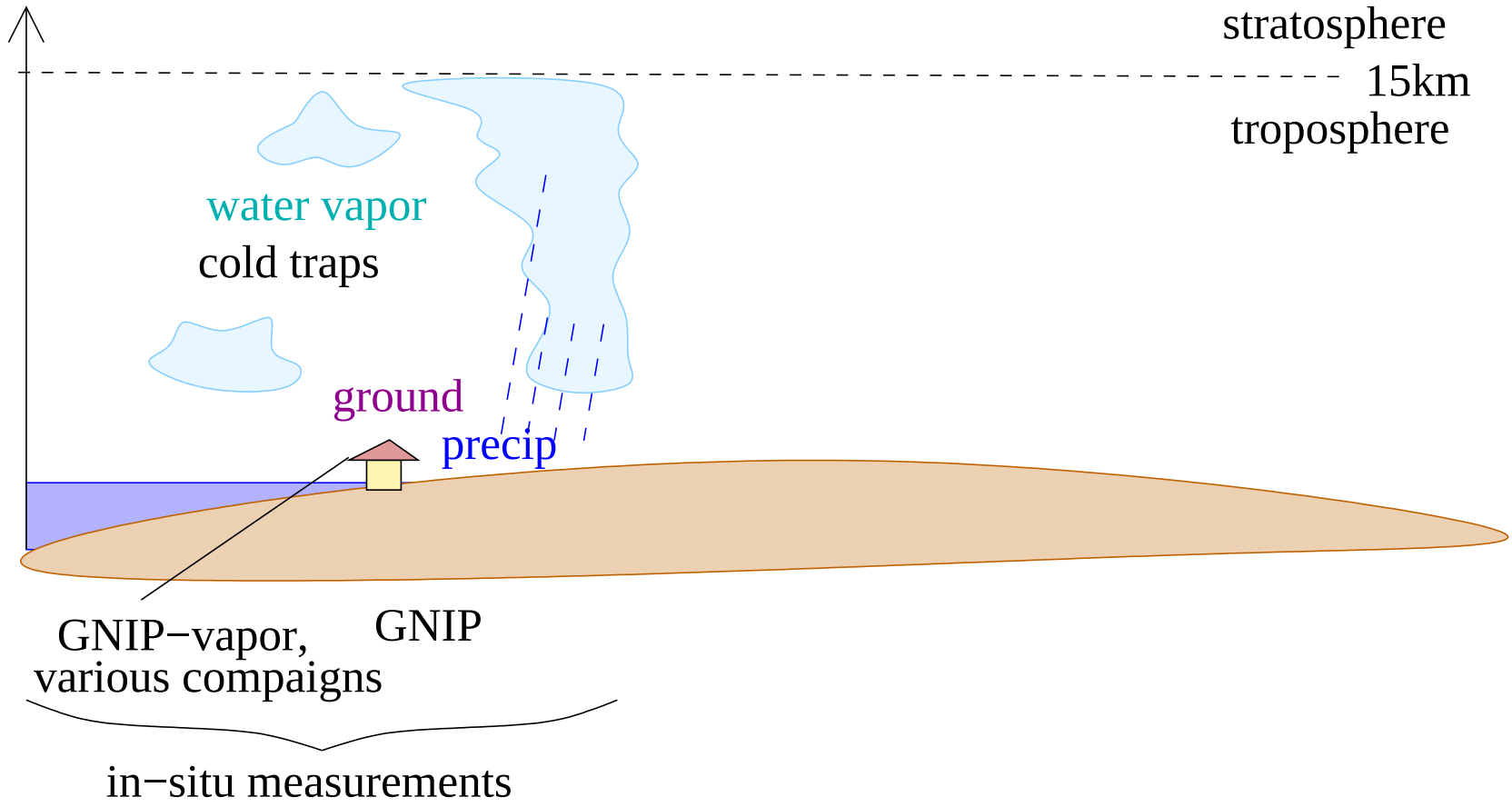
Why do we want isotopes to be useful?



Seminar outline and summary

1. recent developments in water vapor isotopic measurements and models
2. Upper troposphere: δD sensitive to moistening by convective detrainment
3. Mid-troposphere: what does the δD-precipitation link says about the model physics?
   - 3.1 δD reflects shallow vs deep convective mixing and associated large-scale circulation
   - 3.2 δD reflects convective vs large-scale precipitation and associated heating profiles
4. During MJO events: mid-tropospheric δD evolution reflects the relative timing of different cloud types and associated moistening and dehydrating processes

Measurements



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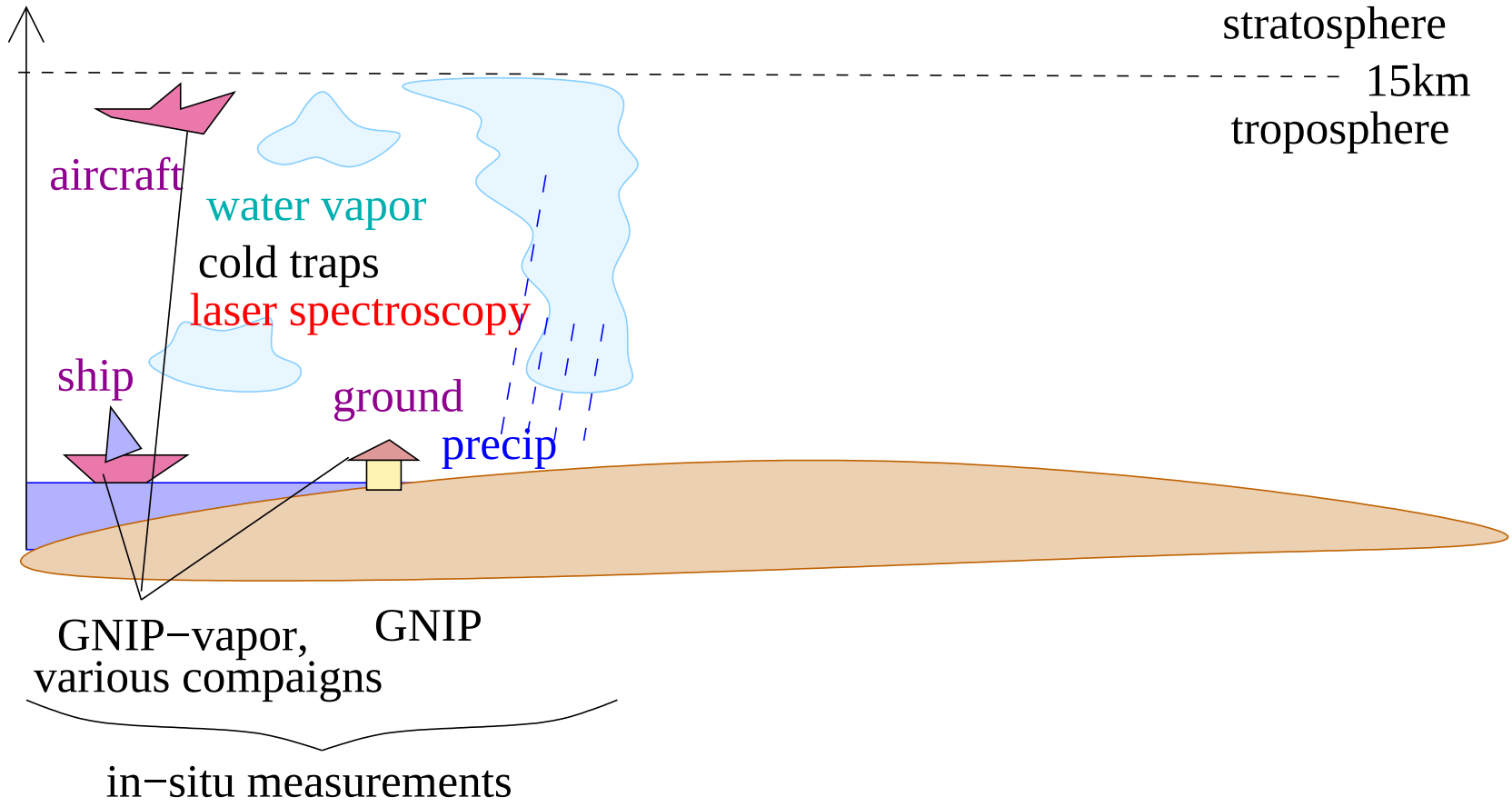

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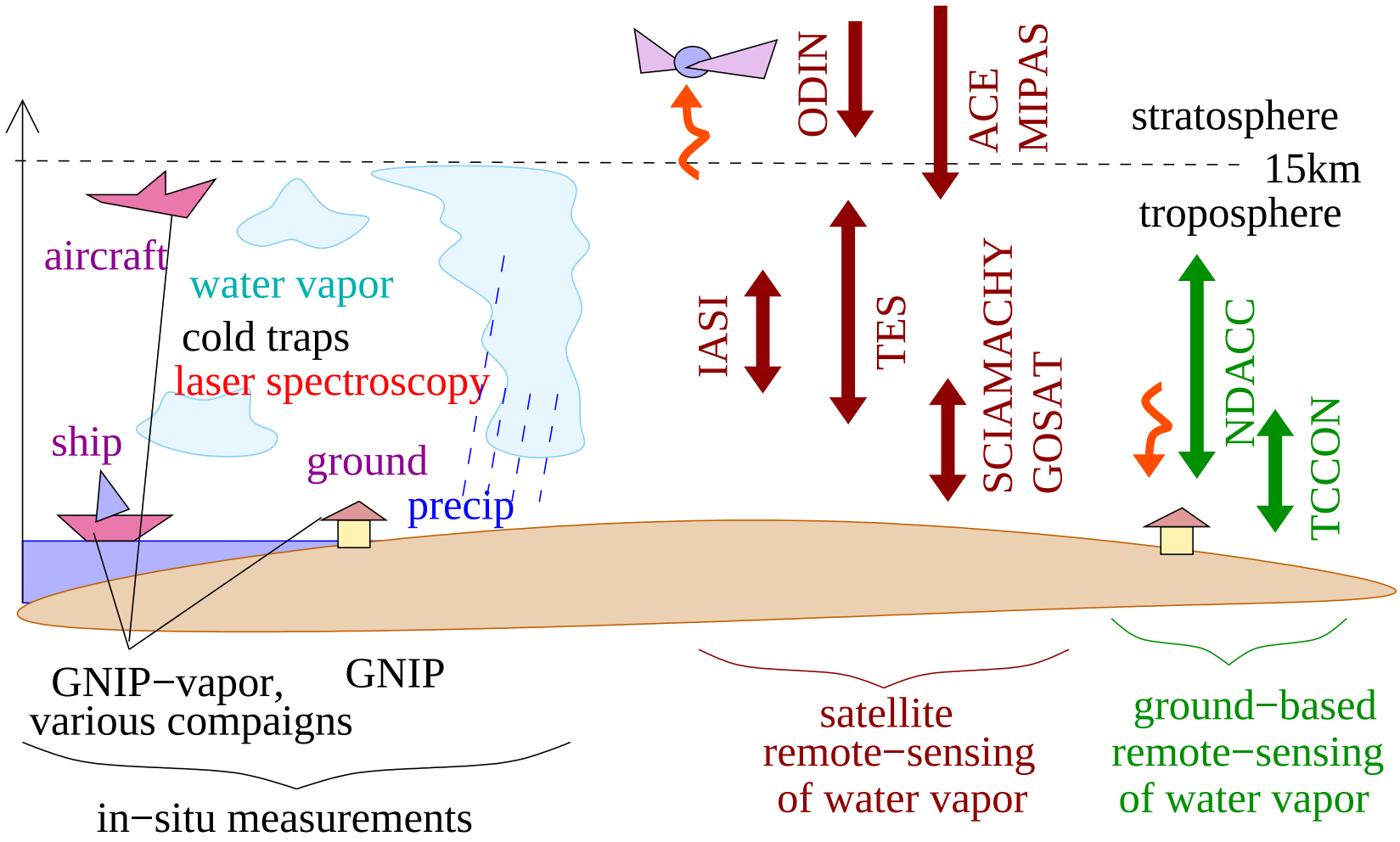

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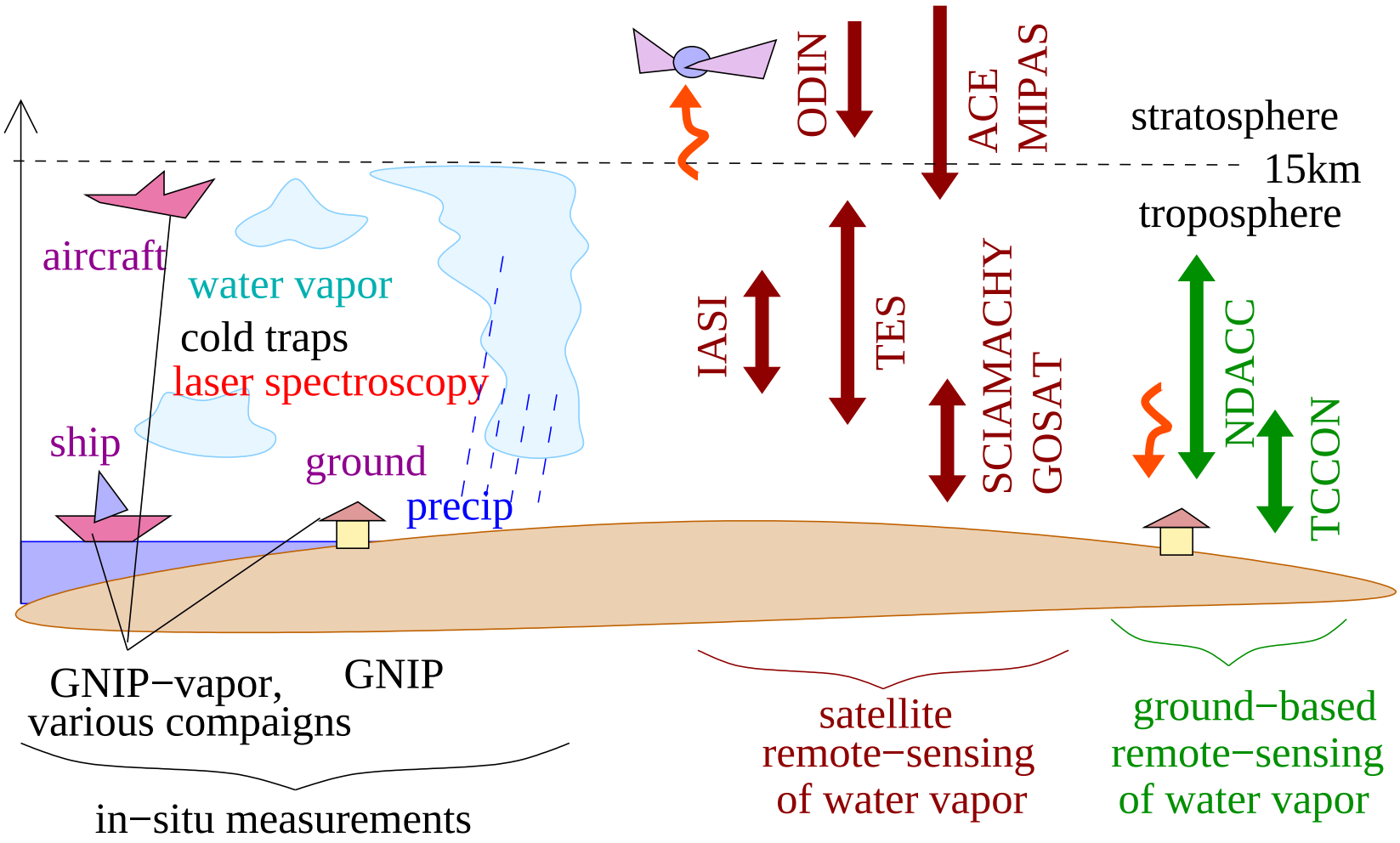
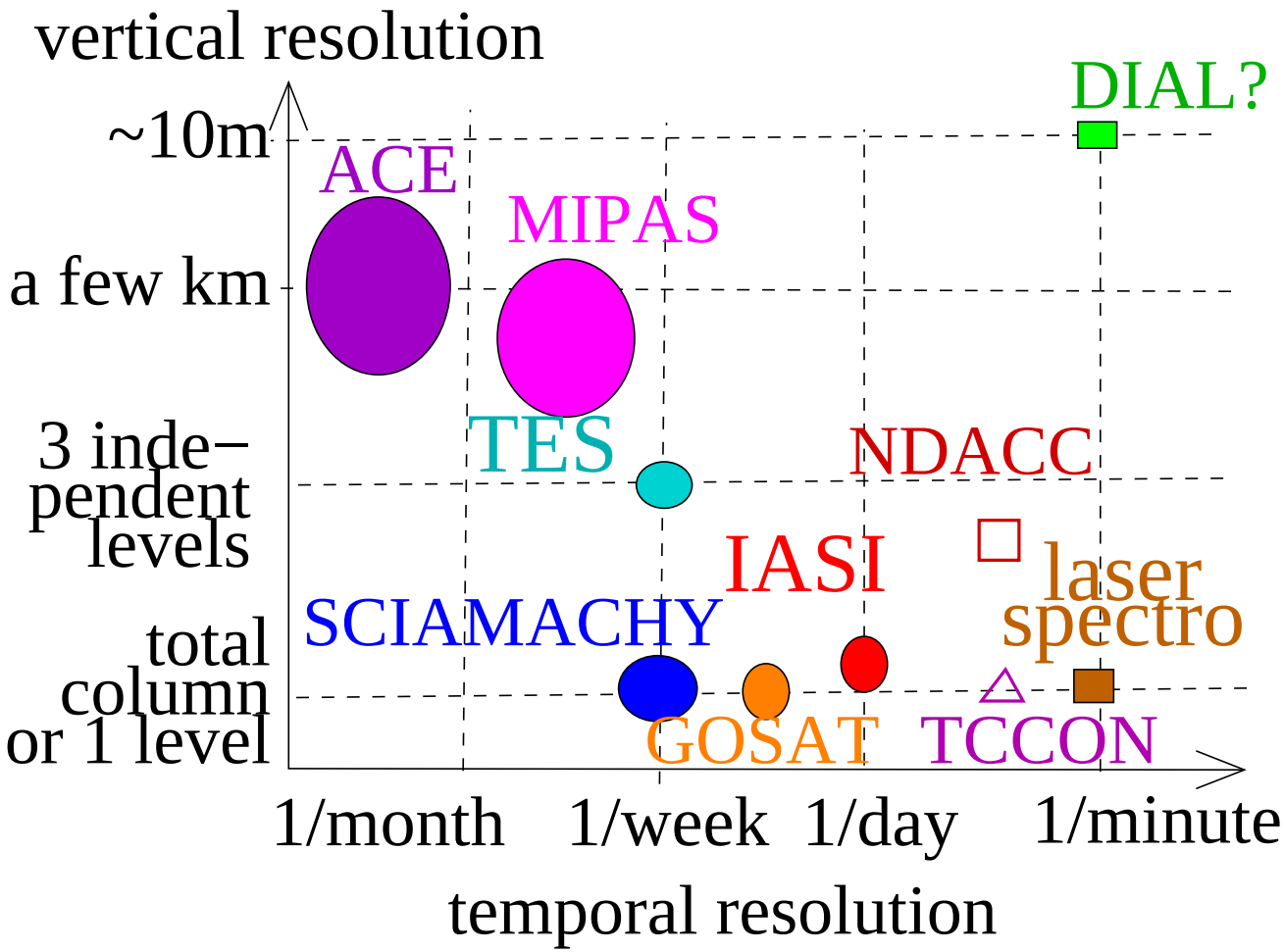


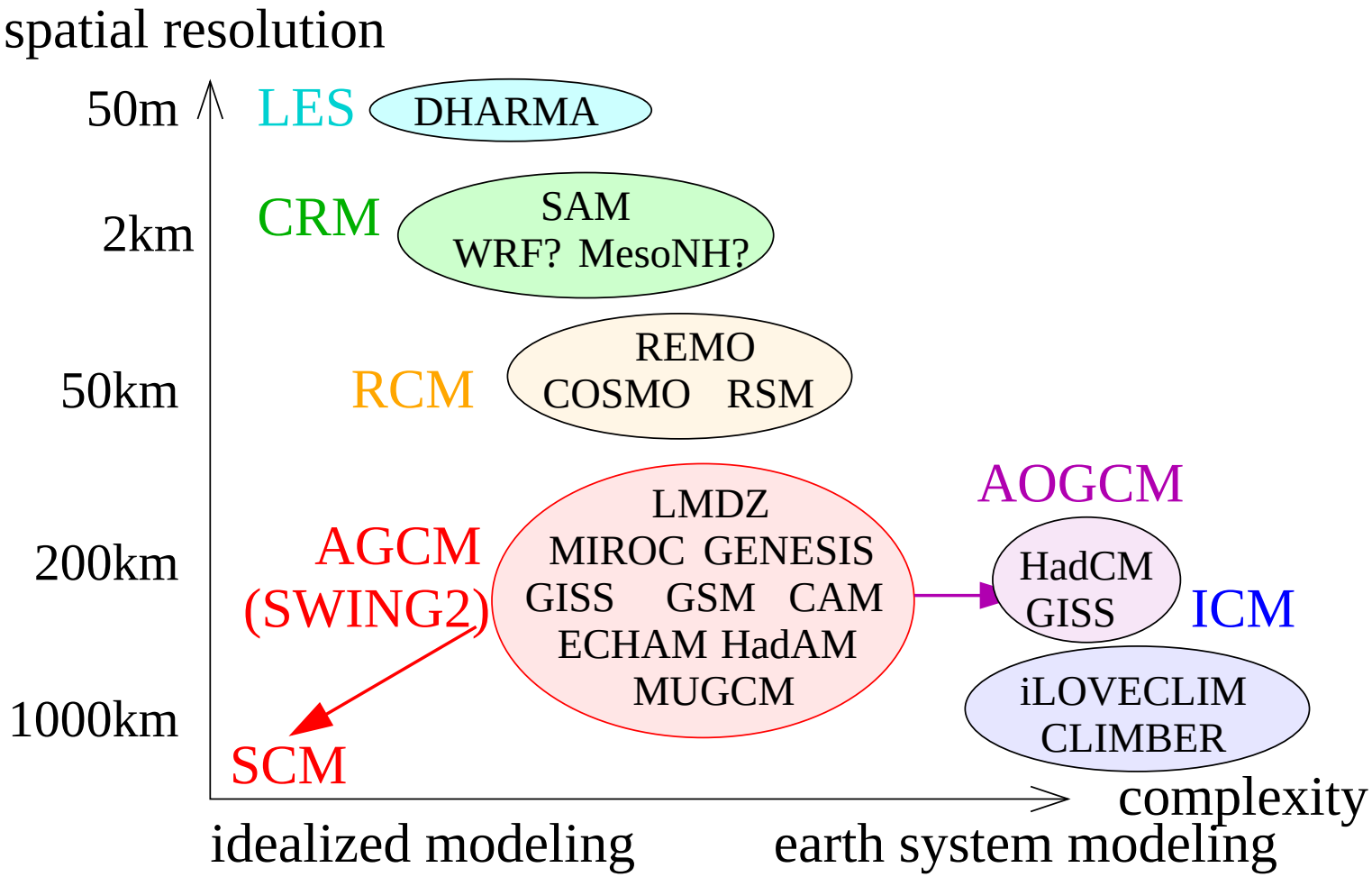
- TES: weekly vertical profiles of δD
- IASI: 2 daily global coverage of δD

Diversity of measurements

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



Numerical models



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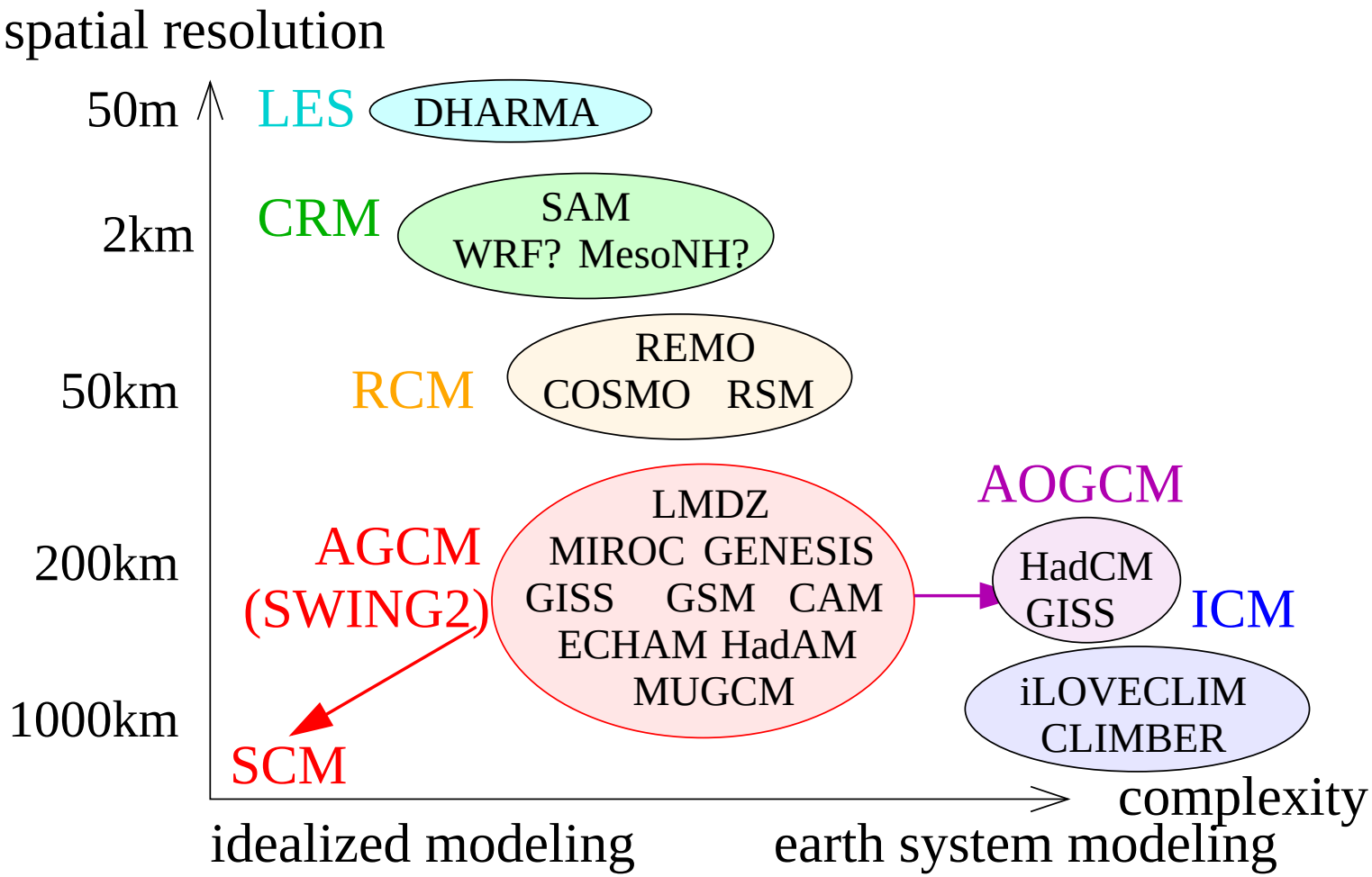
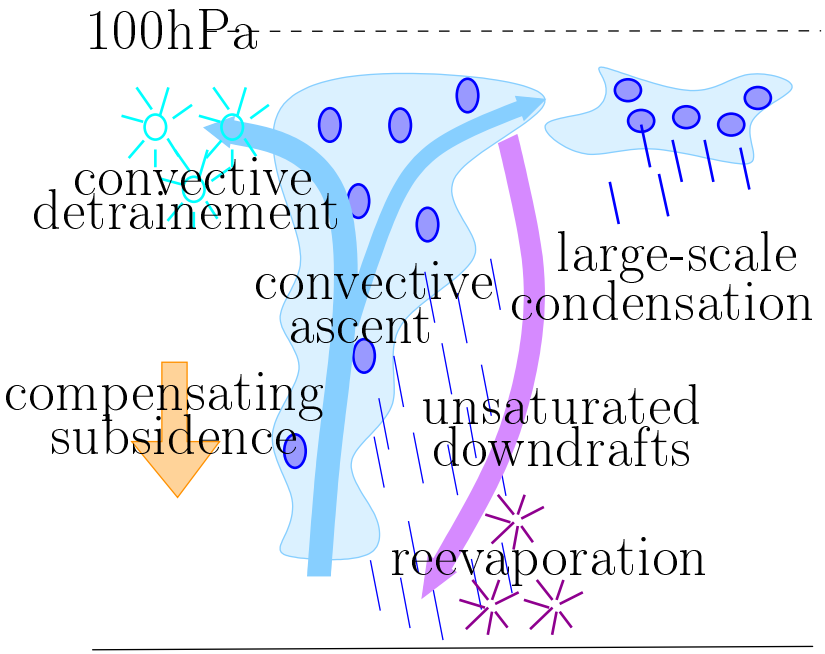
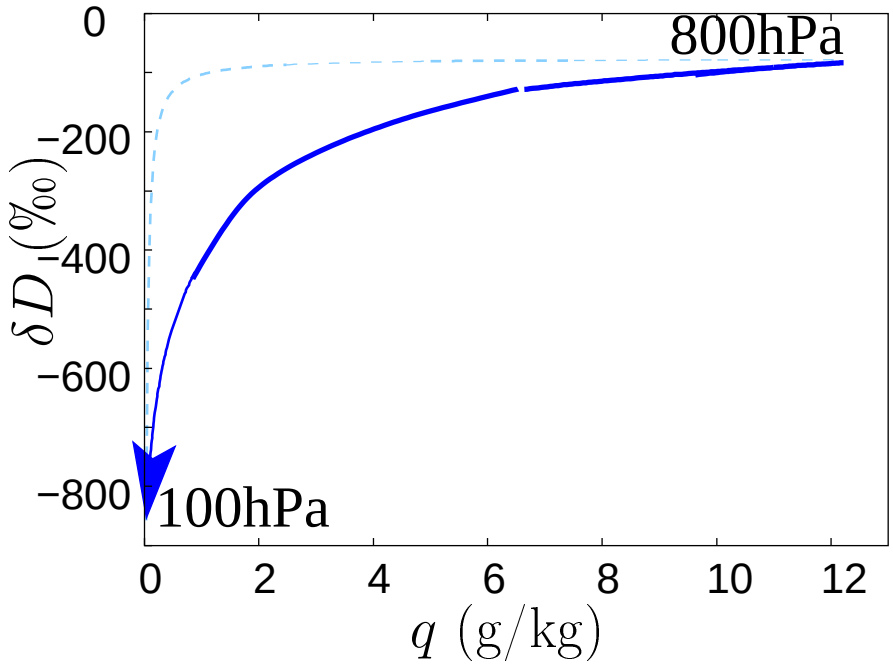


- Here: LMDZ model, SWING2

Theoretical framework: q-δD

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

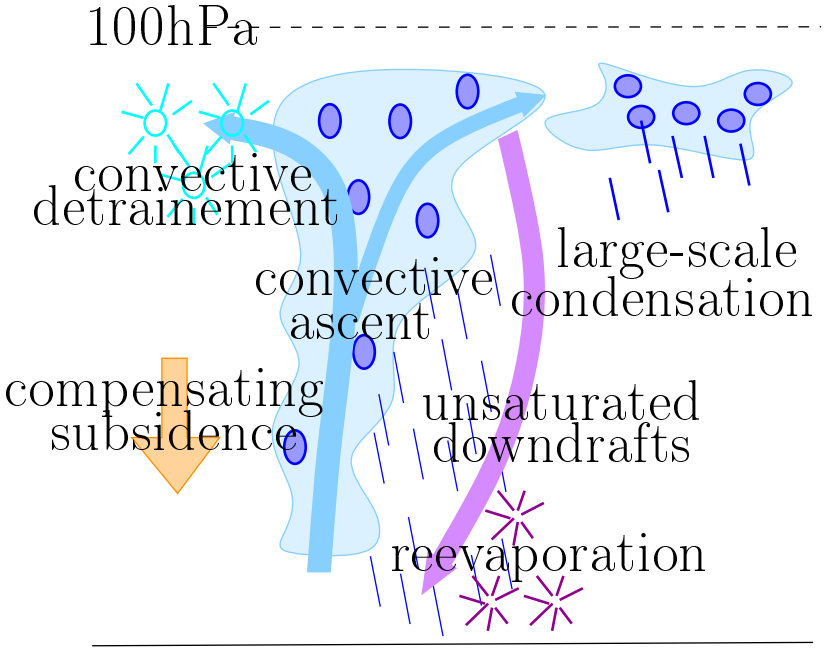


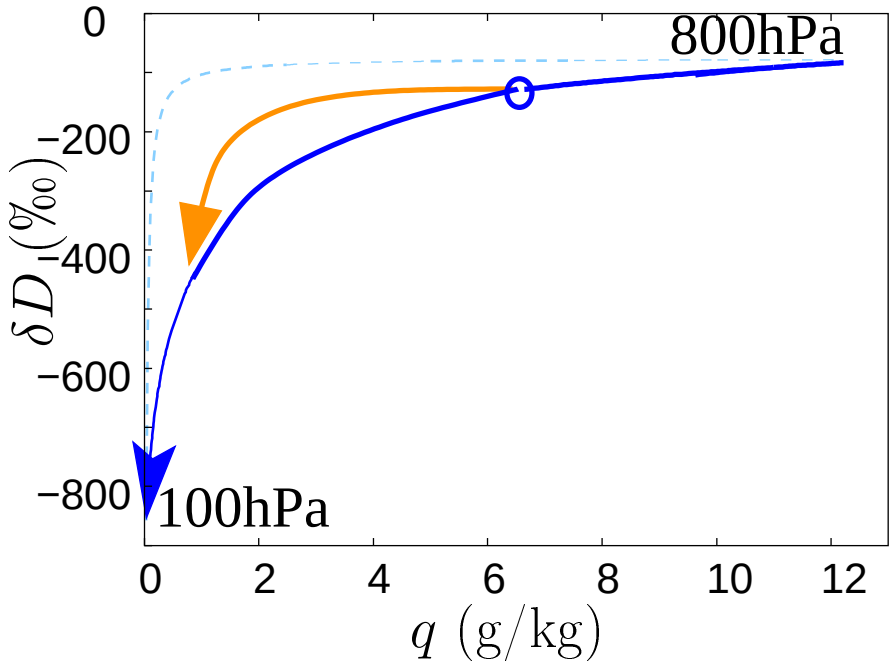


large−scale condensation

Theoretical framework: q-δD

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





large−scale condensation

subsidence

Theoretical framework: q-δD

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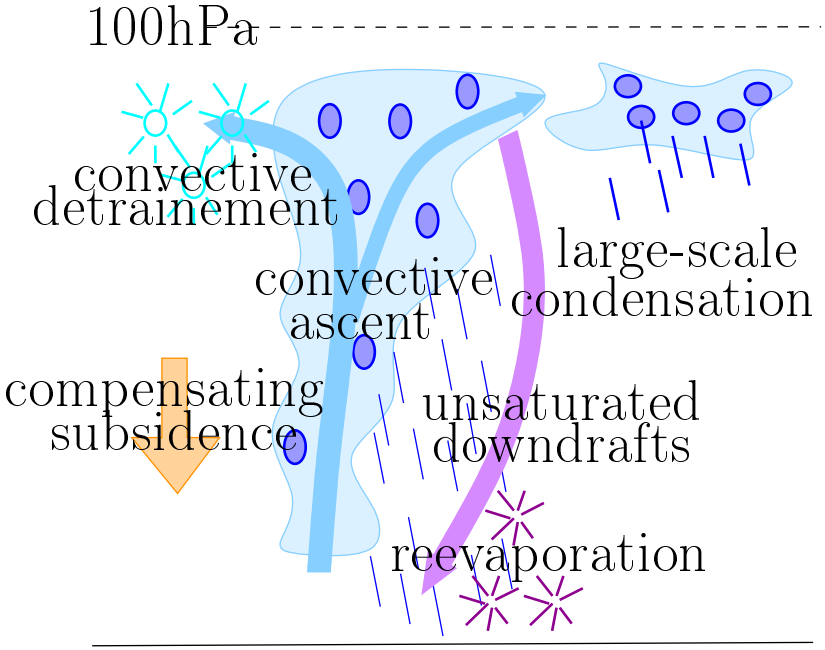

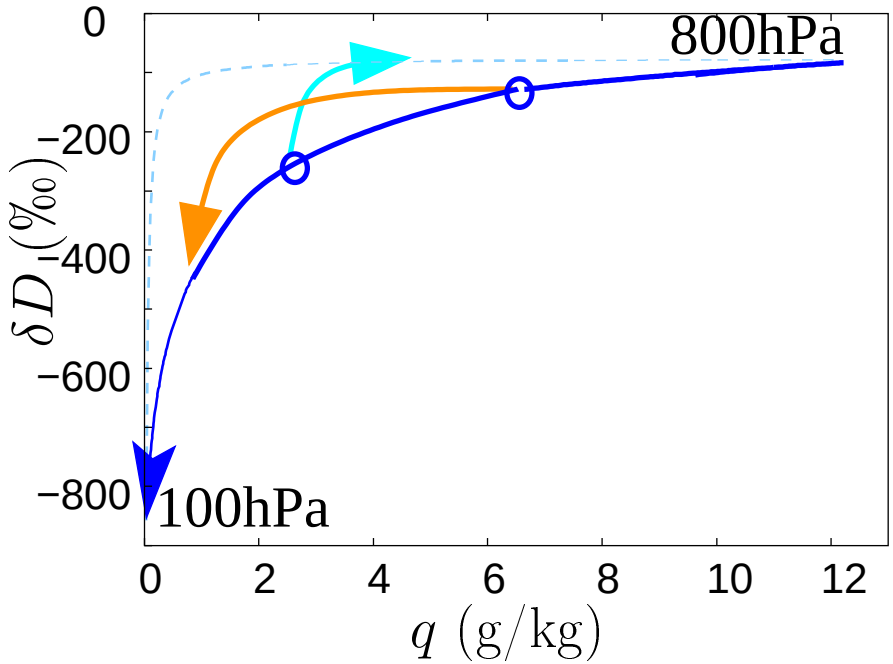

large−scale condensation
detrainment
subsidence

Theoretical framework: q-δD

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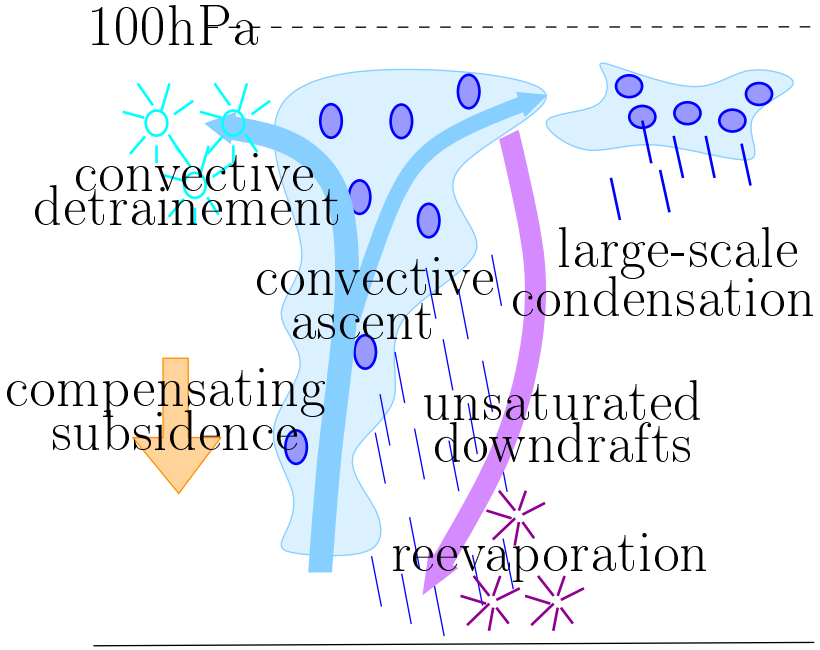

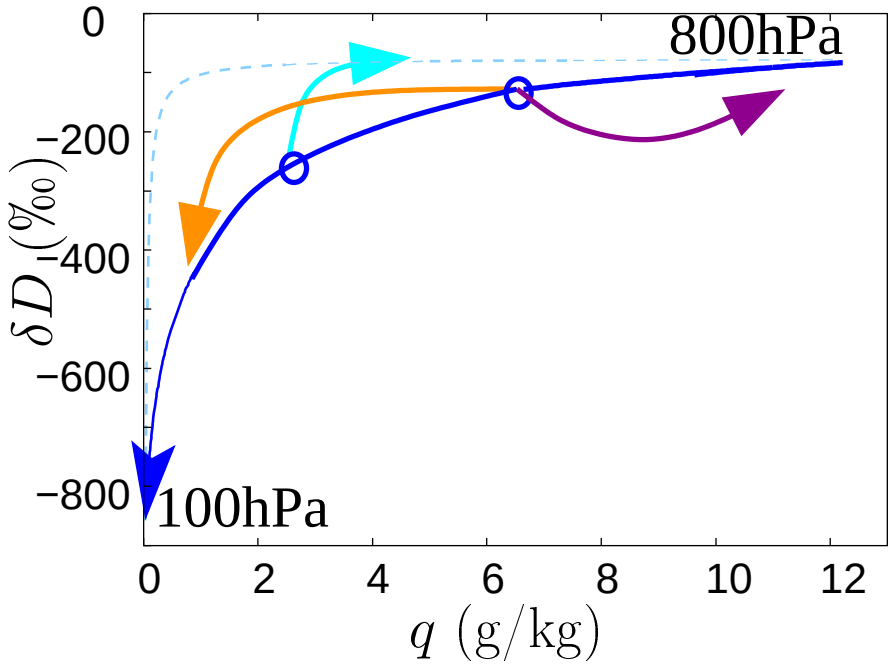

large−scale condensation
detrainment
subsidence
rain reevaporation

Theoretical framework: q-δD

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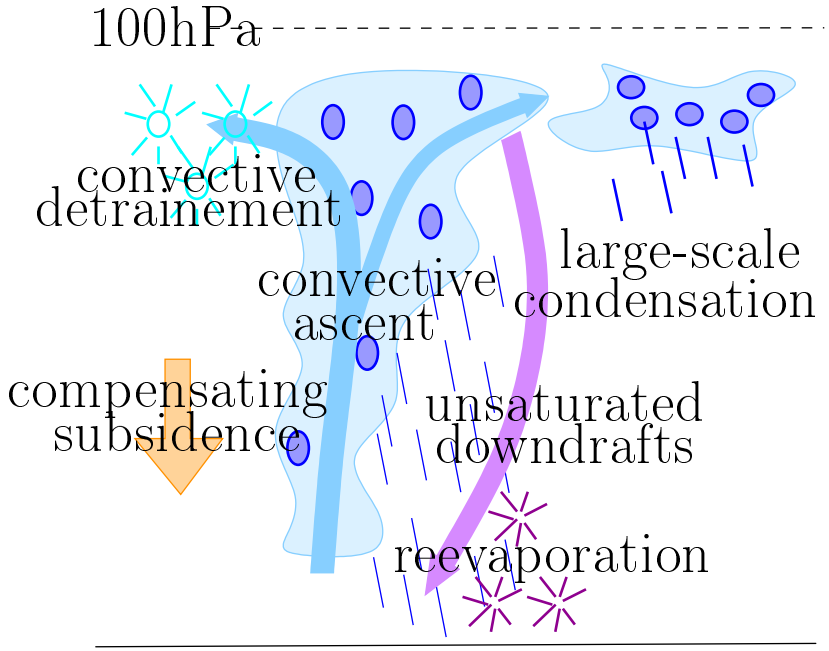
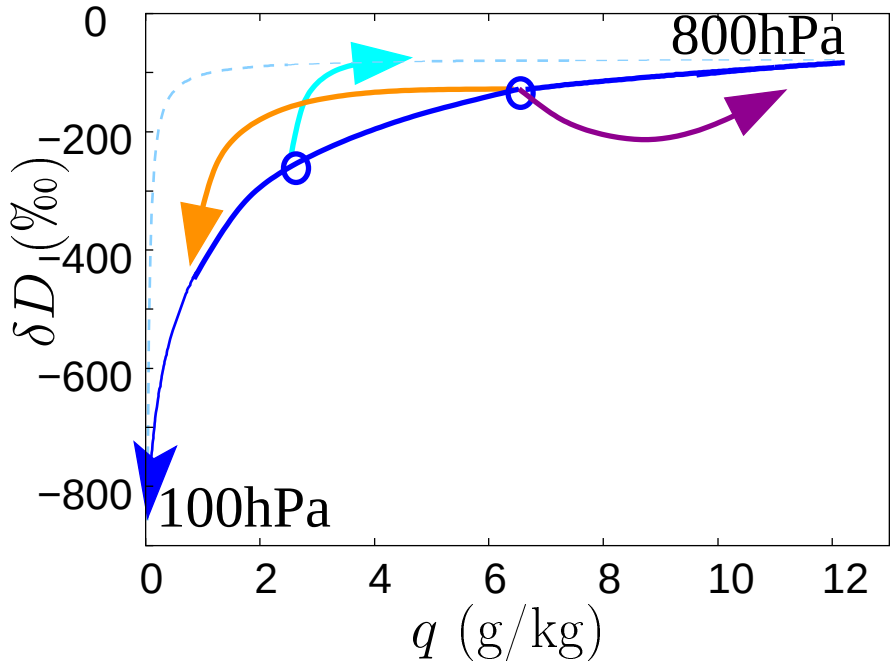


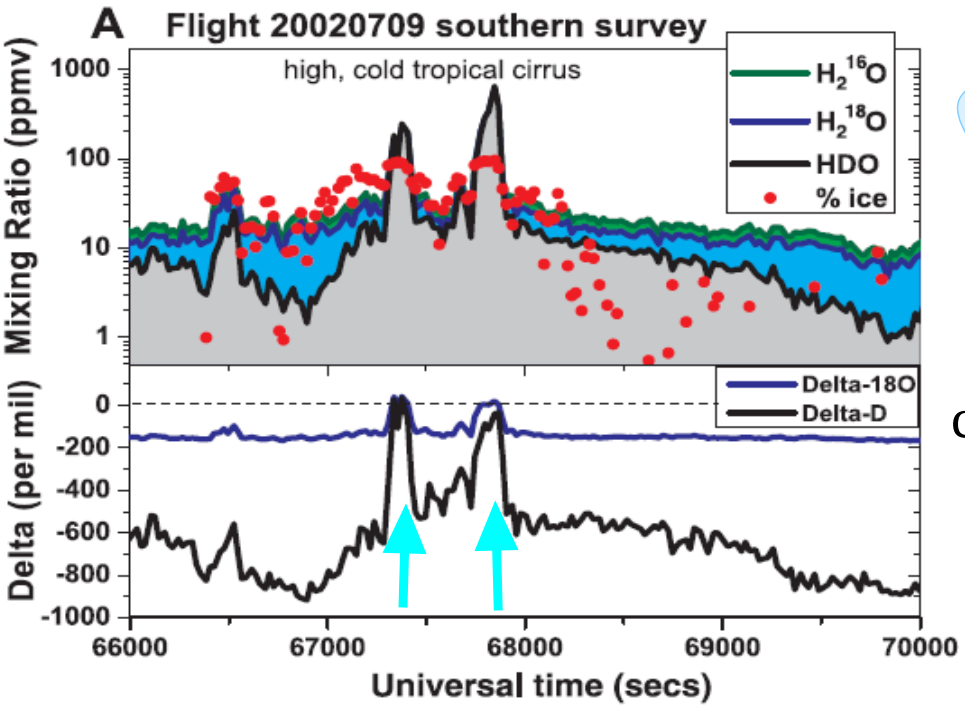


large−scale condensation
detrainment
subsidence
rain reevaporation

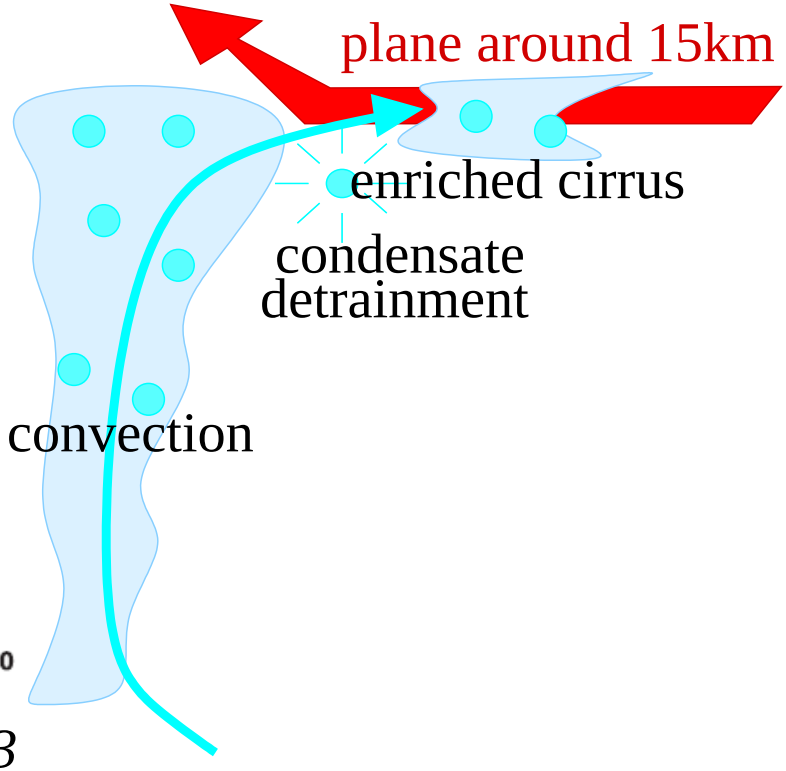
- limitation: need to bridge gap between this simple framework and numerical modeling

Isotopes in the upper troposphere

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



Webster & Heymsfield 2003



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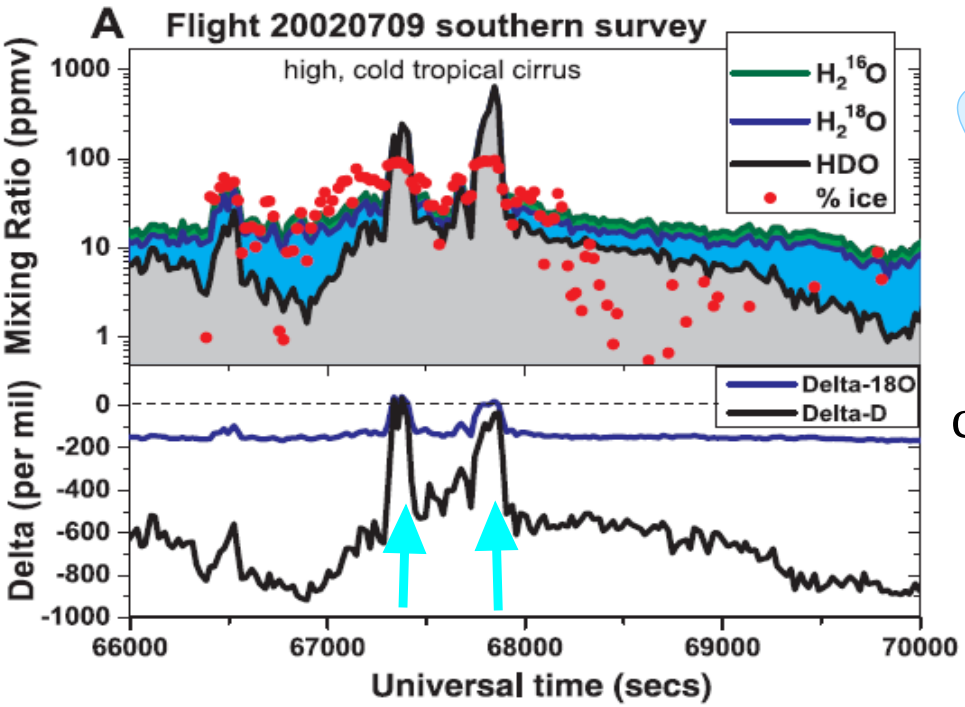

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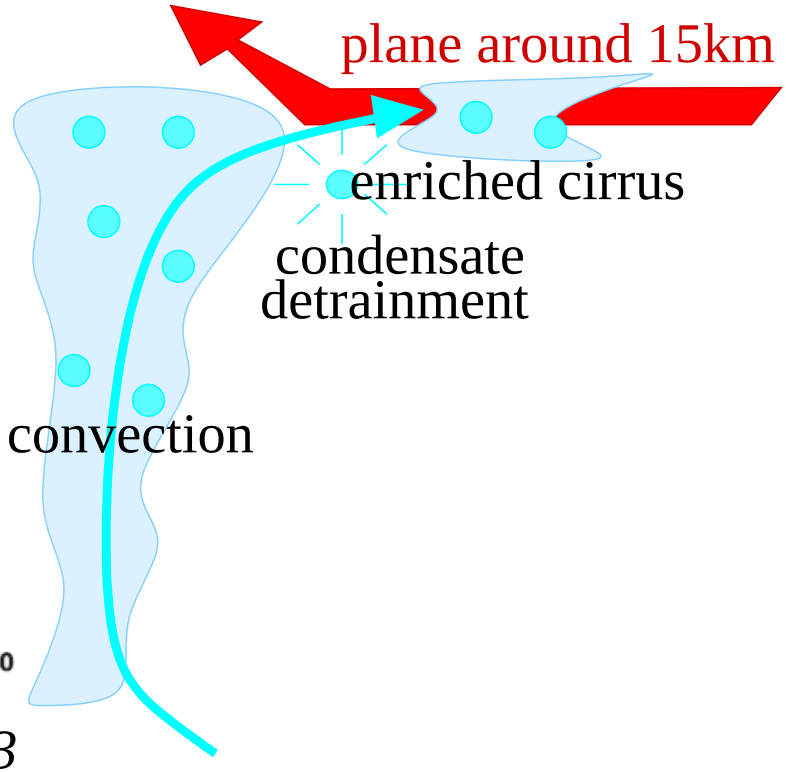
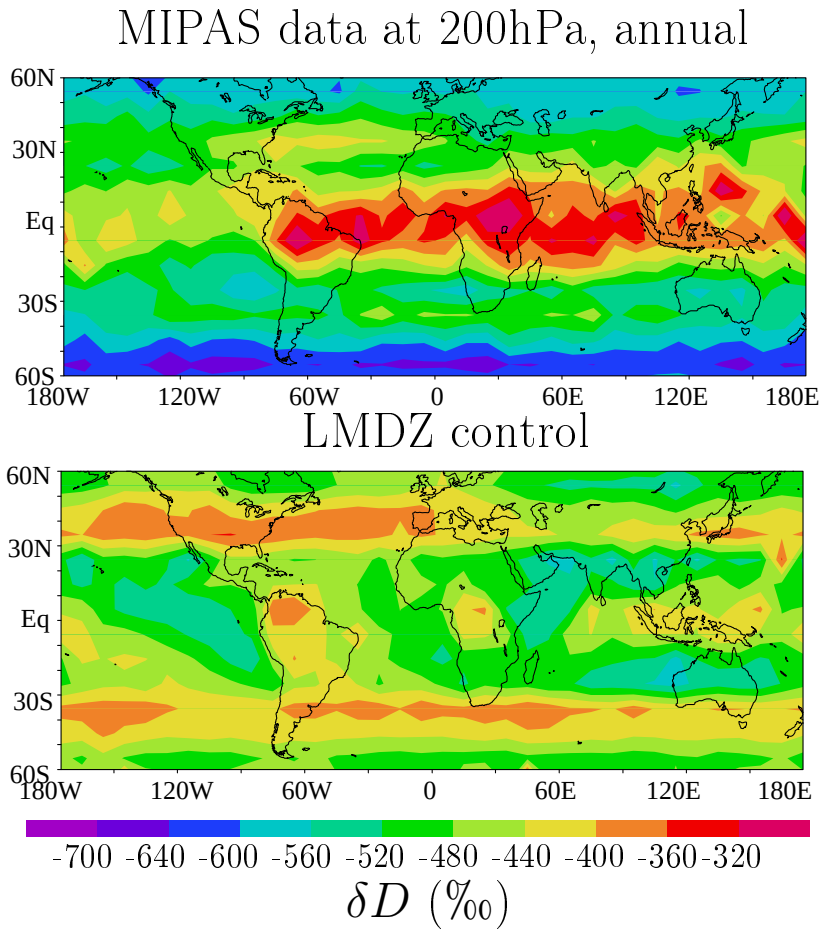


- Limitation: isotopes consistent with some convective injection of water through the tropopause layer. But how to make quantitative estimations?

Convective detrainment in upper troposphere



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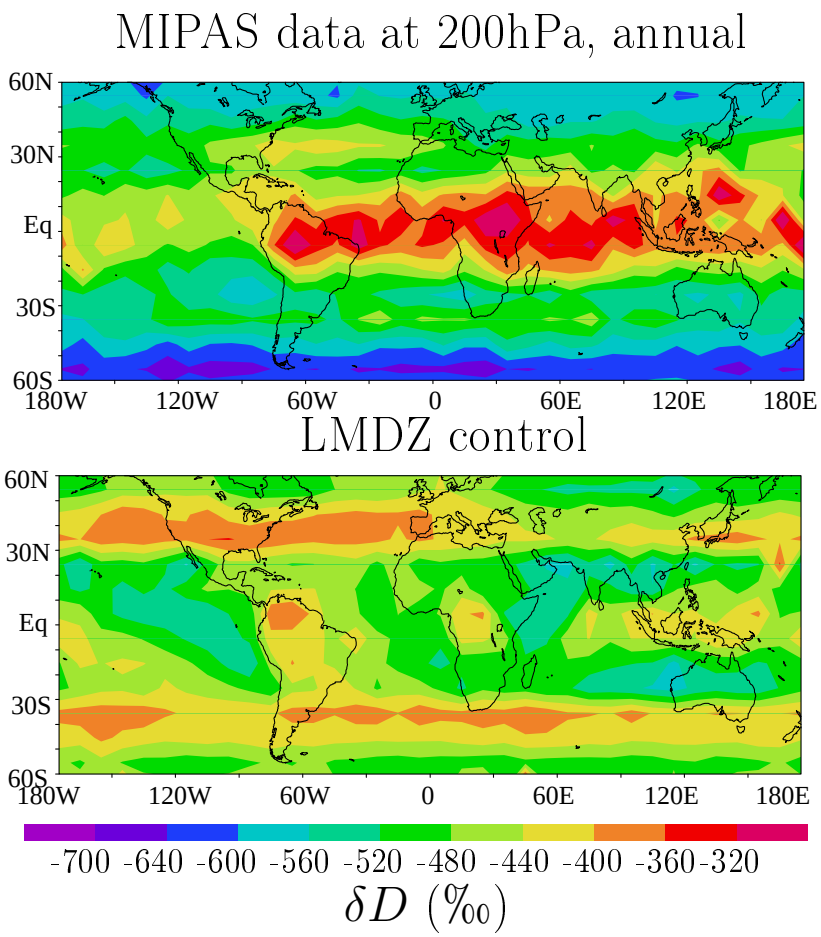

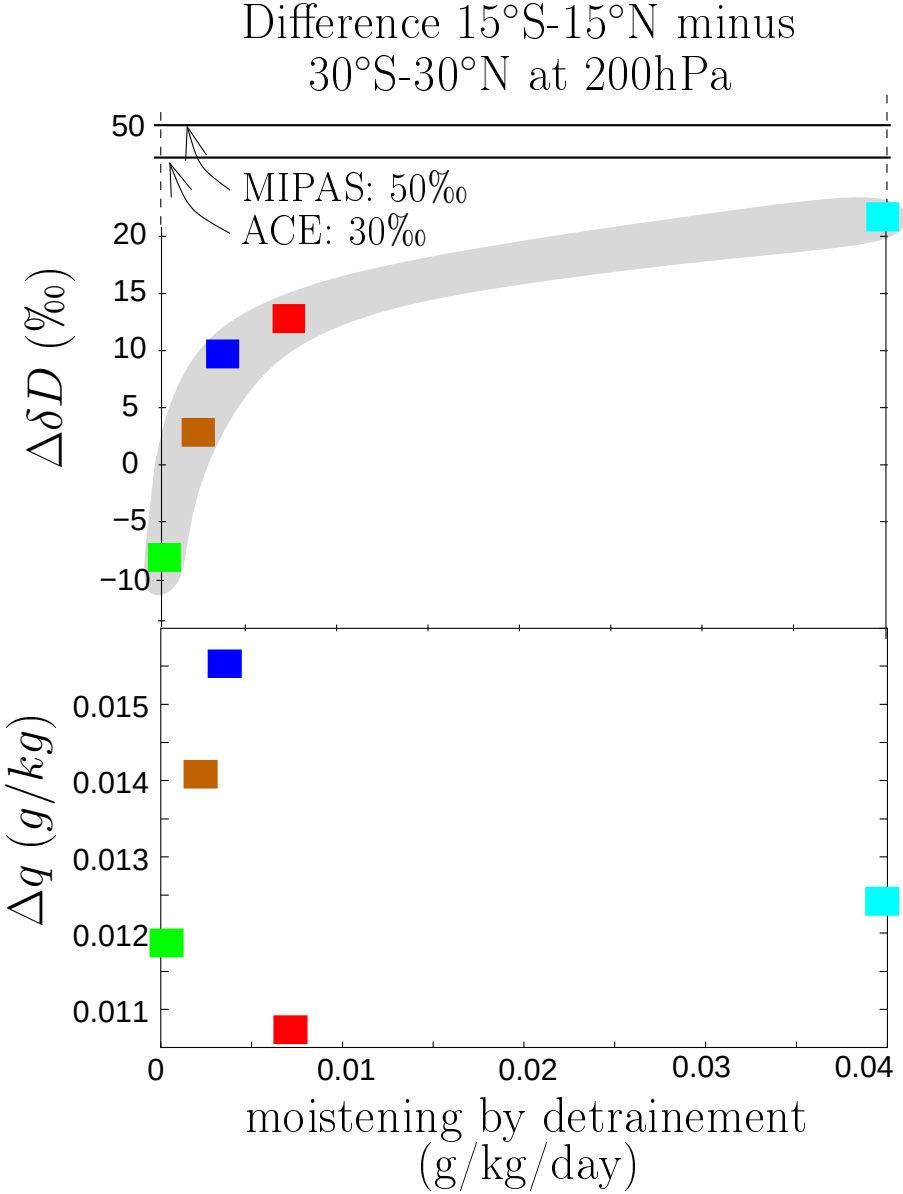

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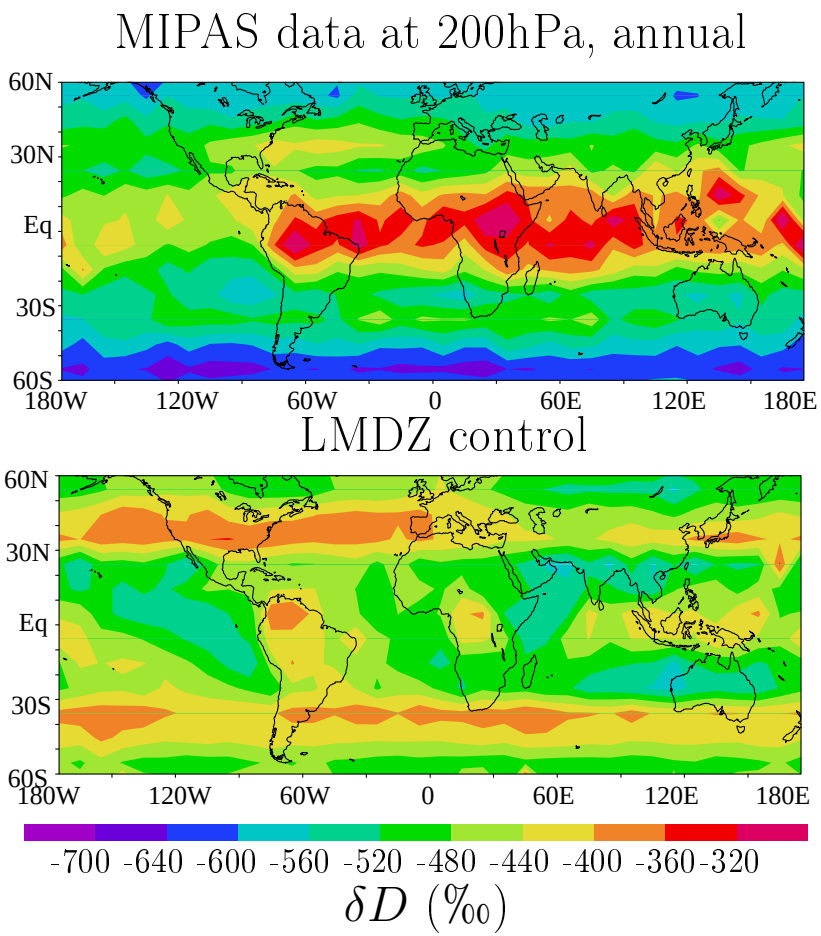

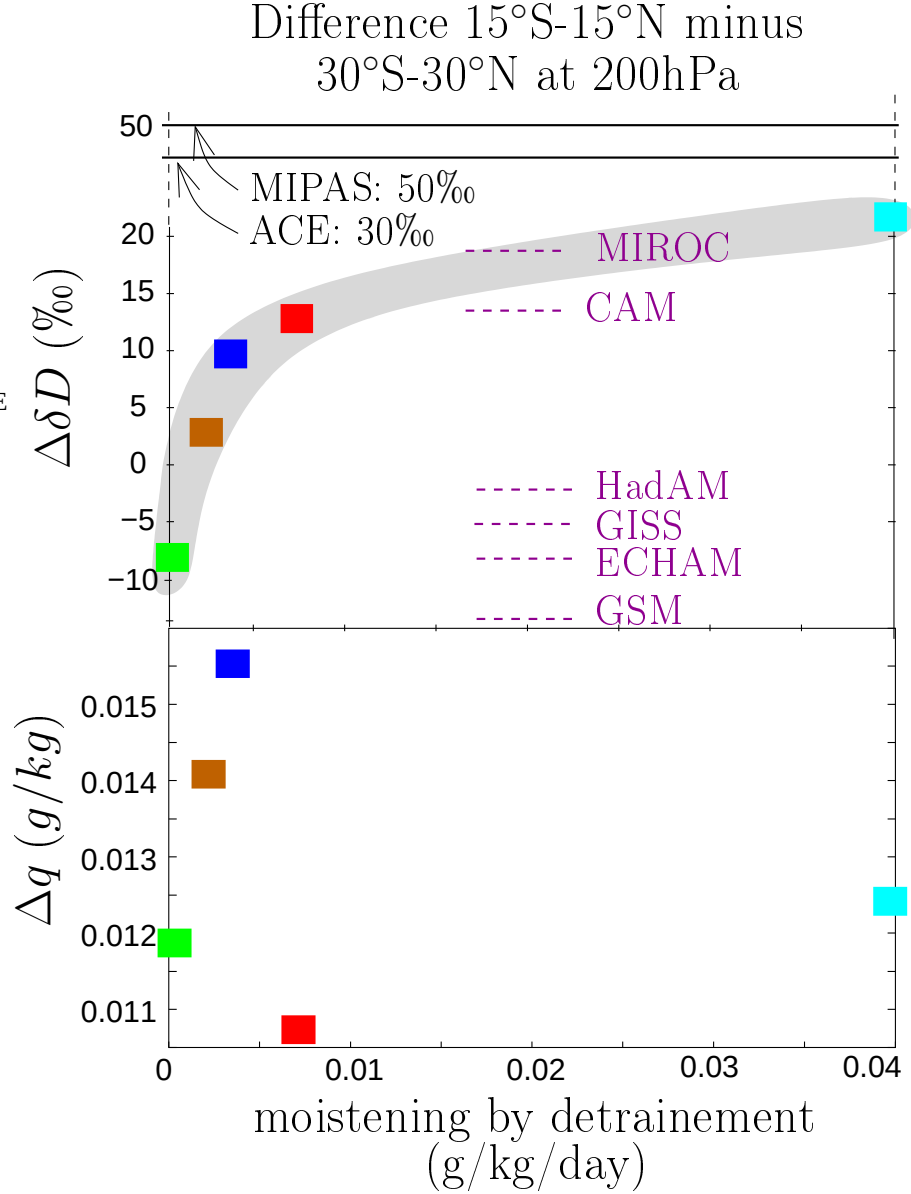

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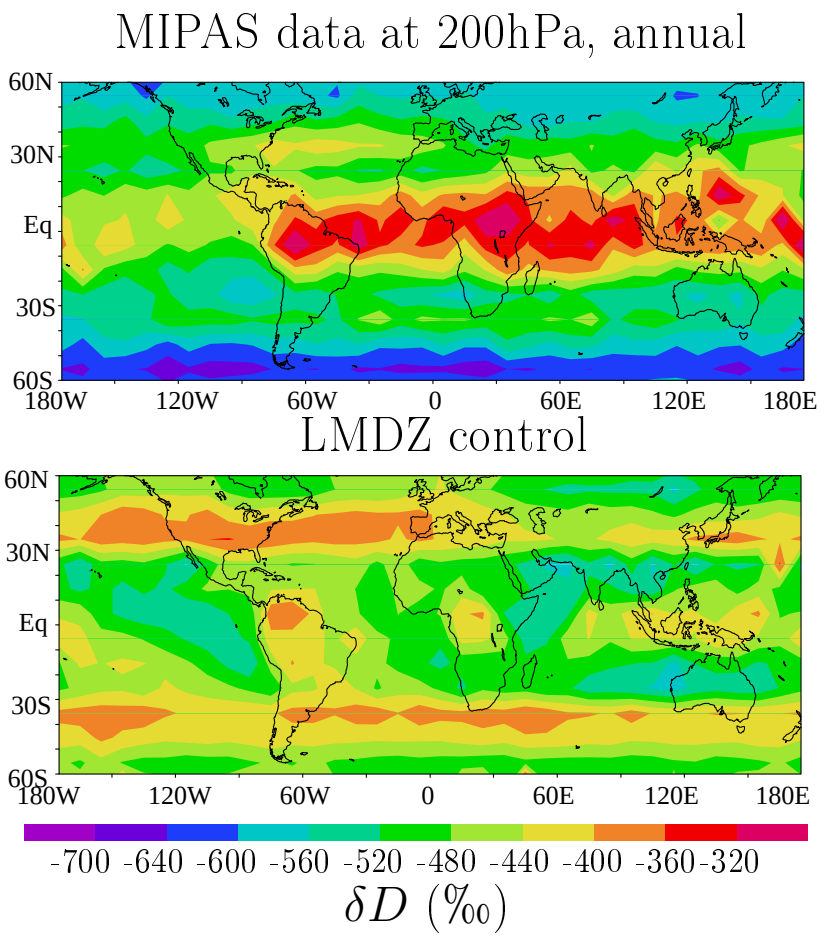
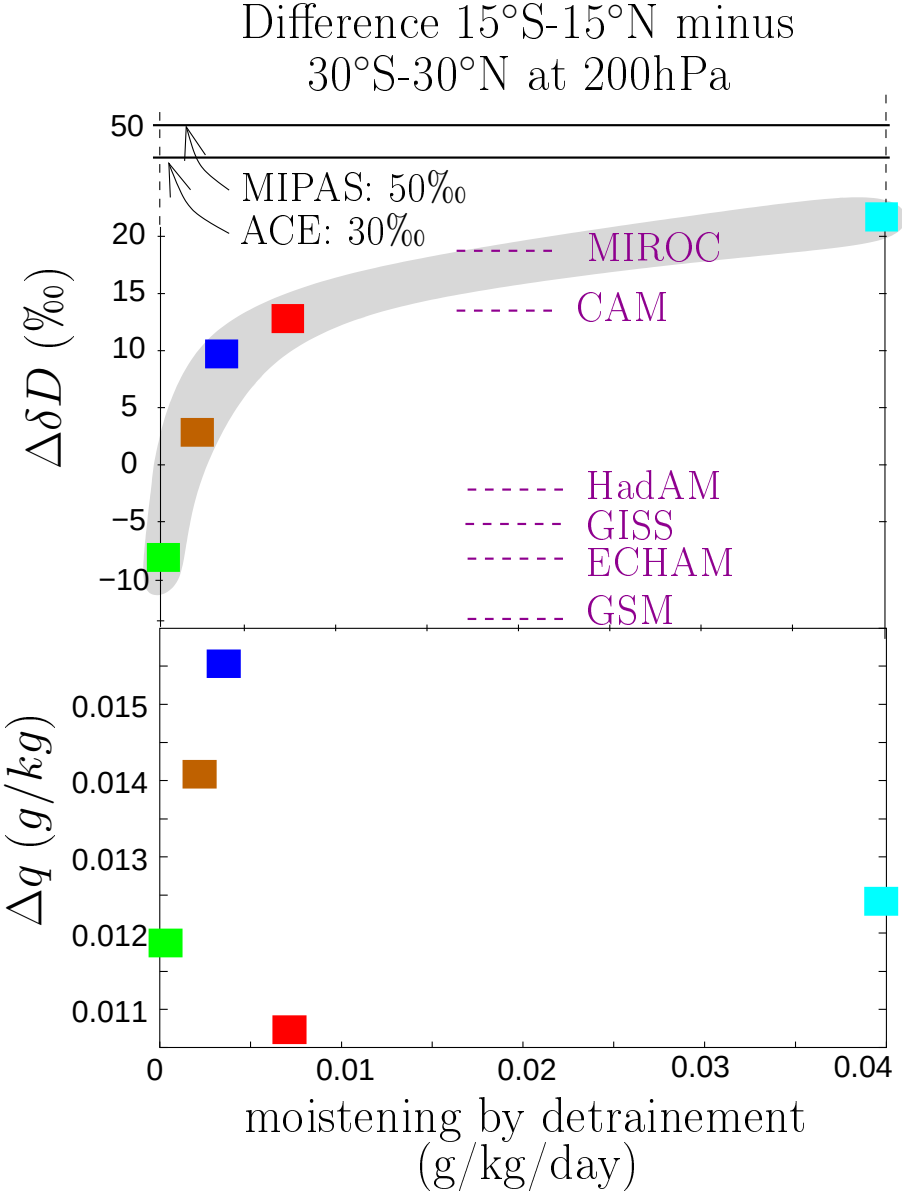
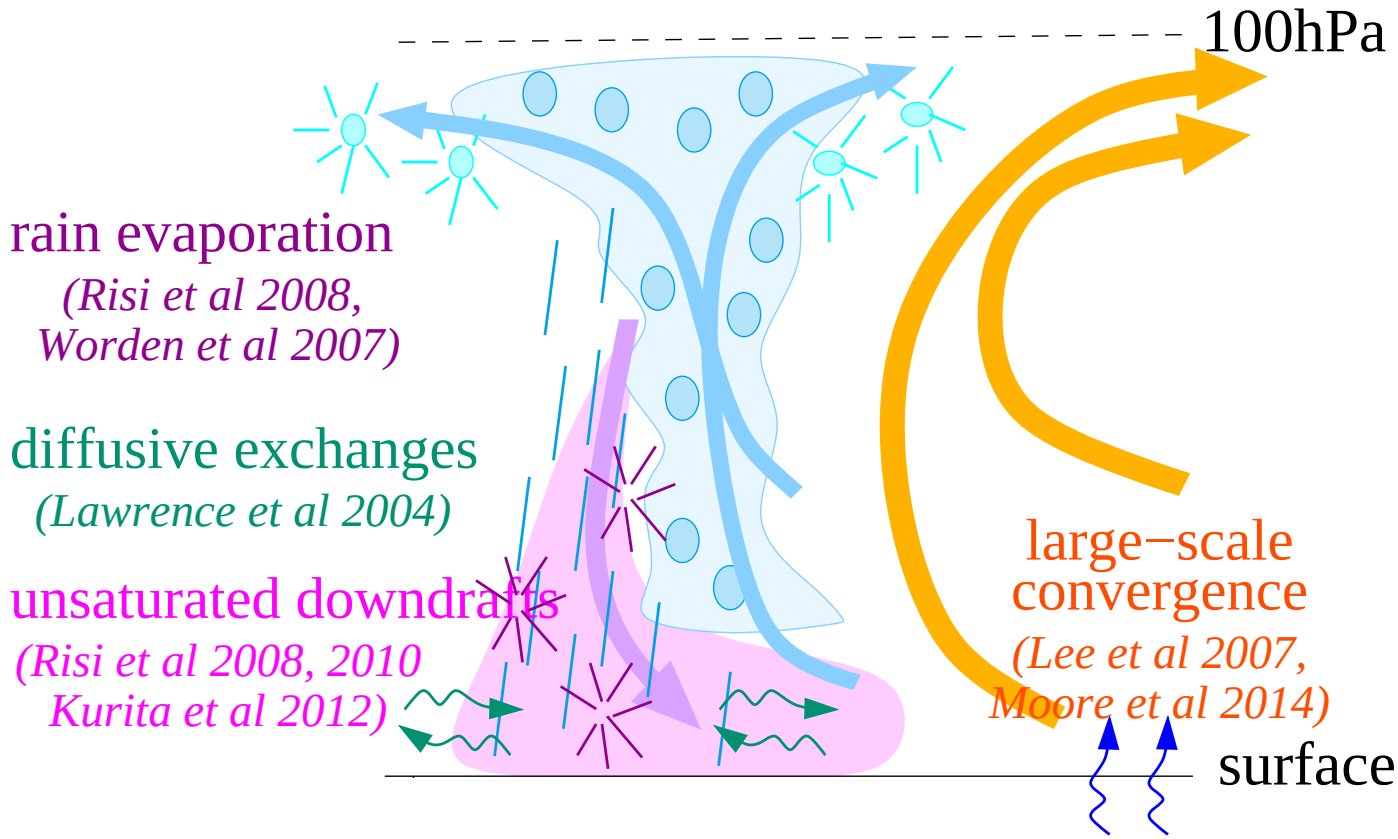




- what is missing? Correlation detrainment $\leftrightarrow$ updraft speed?

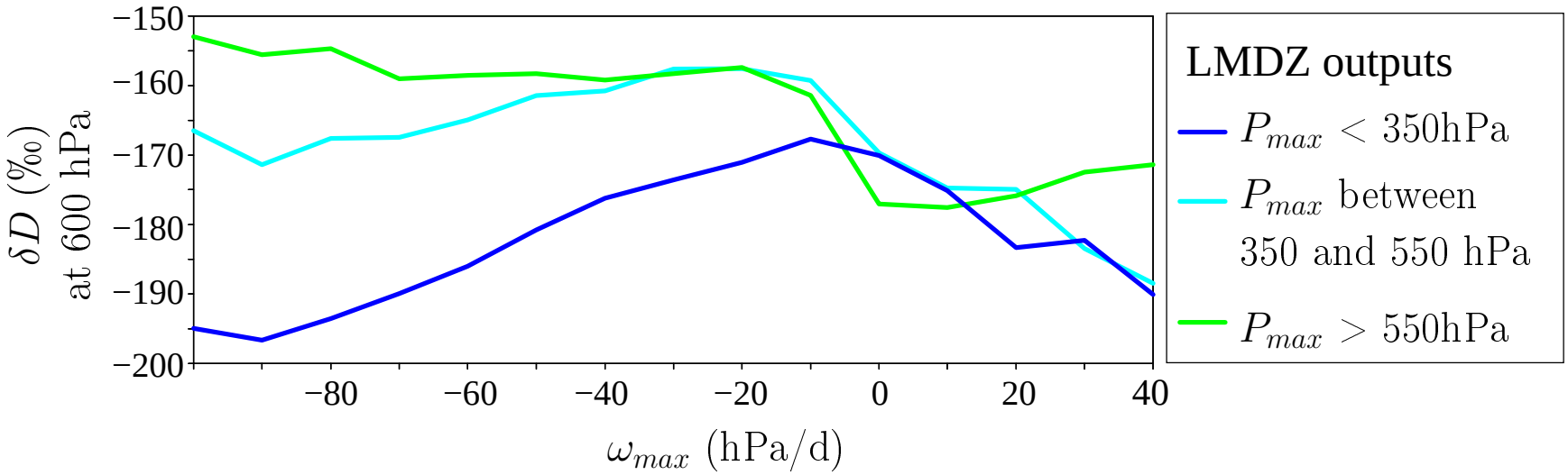
Lower and mid troposphere

- "amount effect": δD ↘ as precipitation ↘



- What does amount effect amplitude says about model physics?

Sensitivity to large-scale velocity profile



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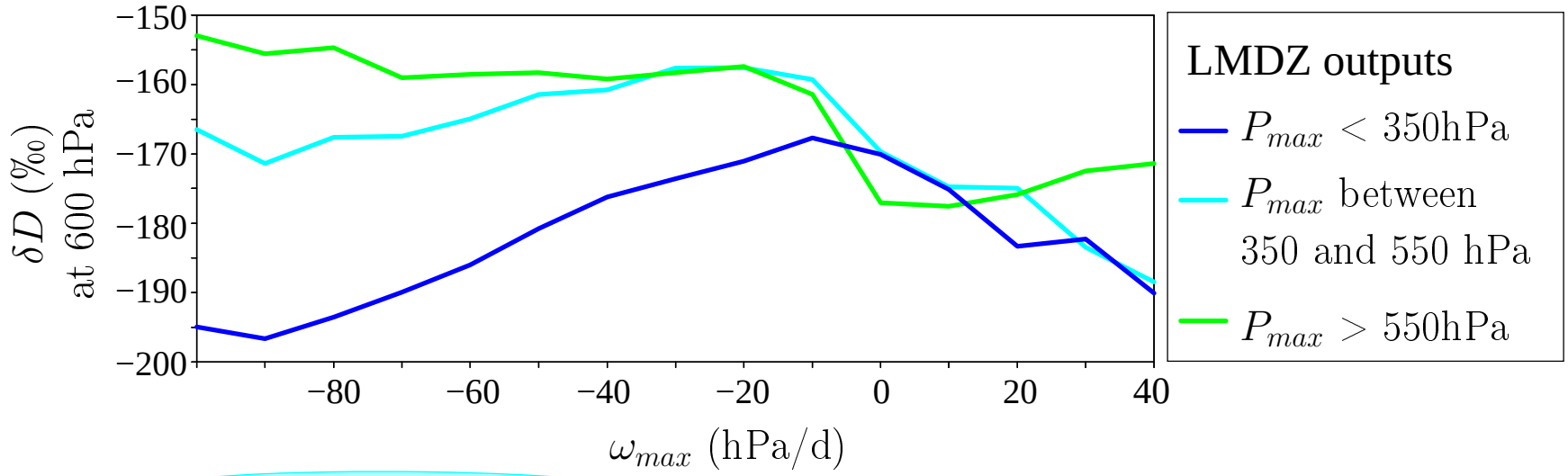

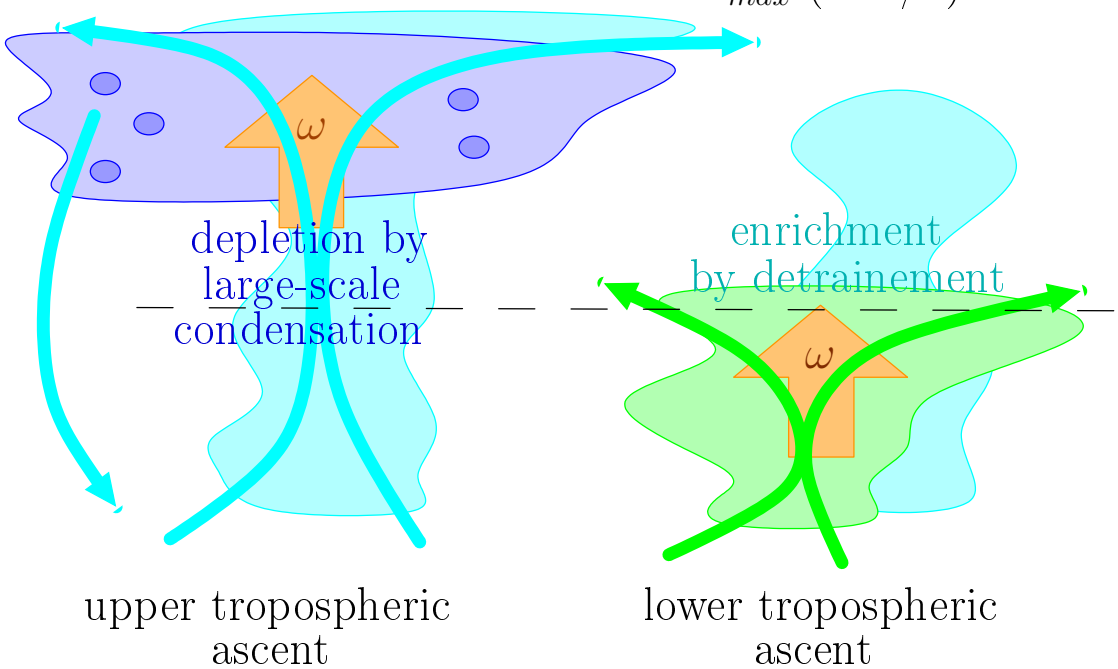

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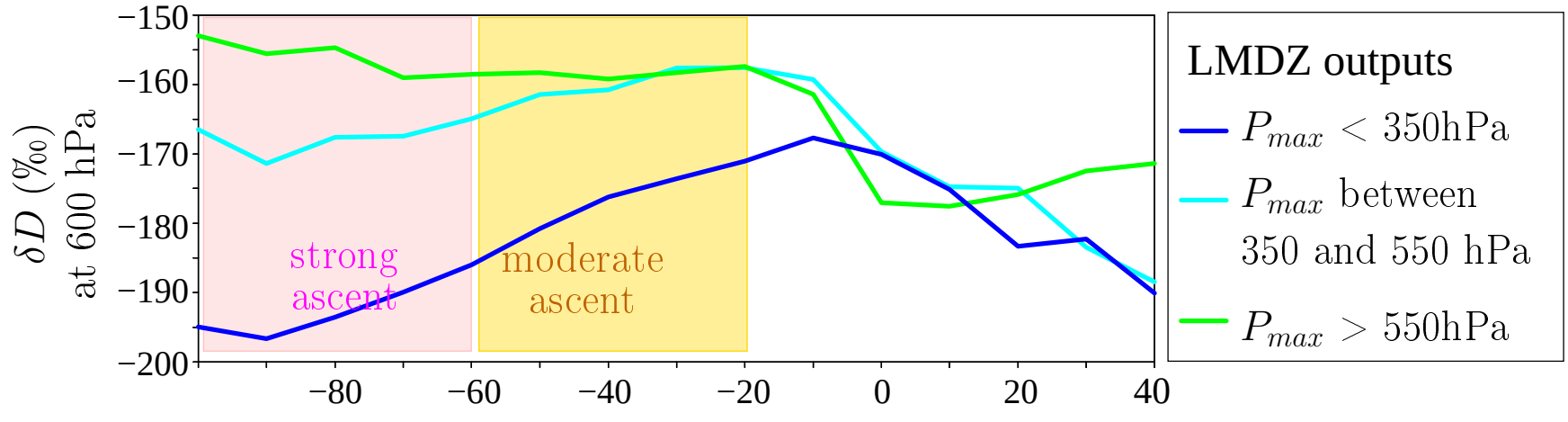
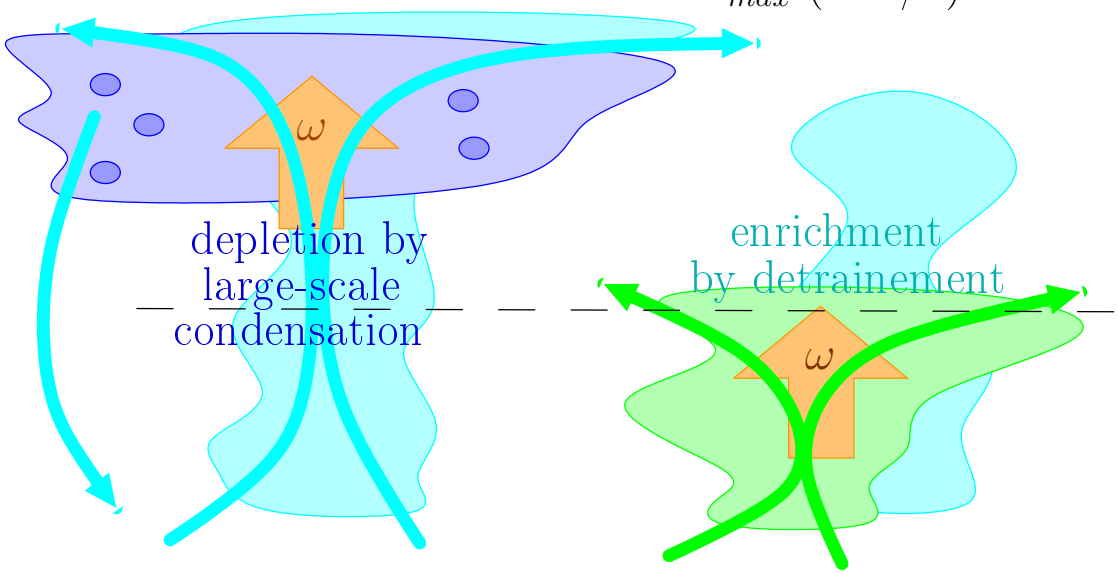
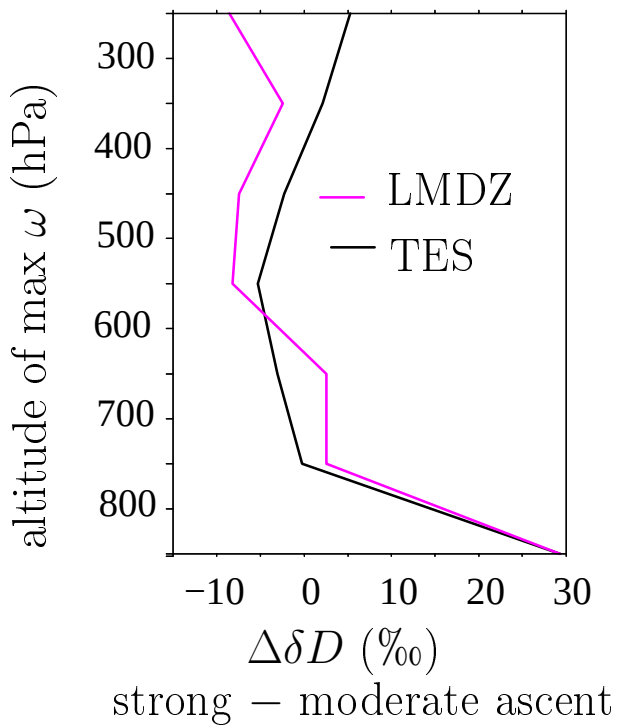
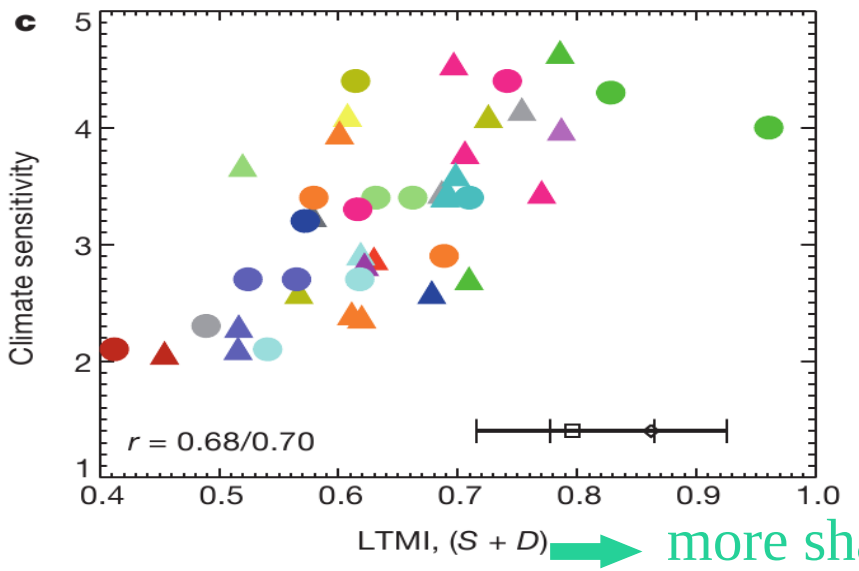






Implications

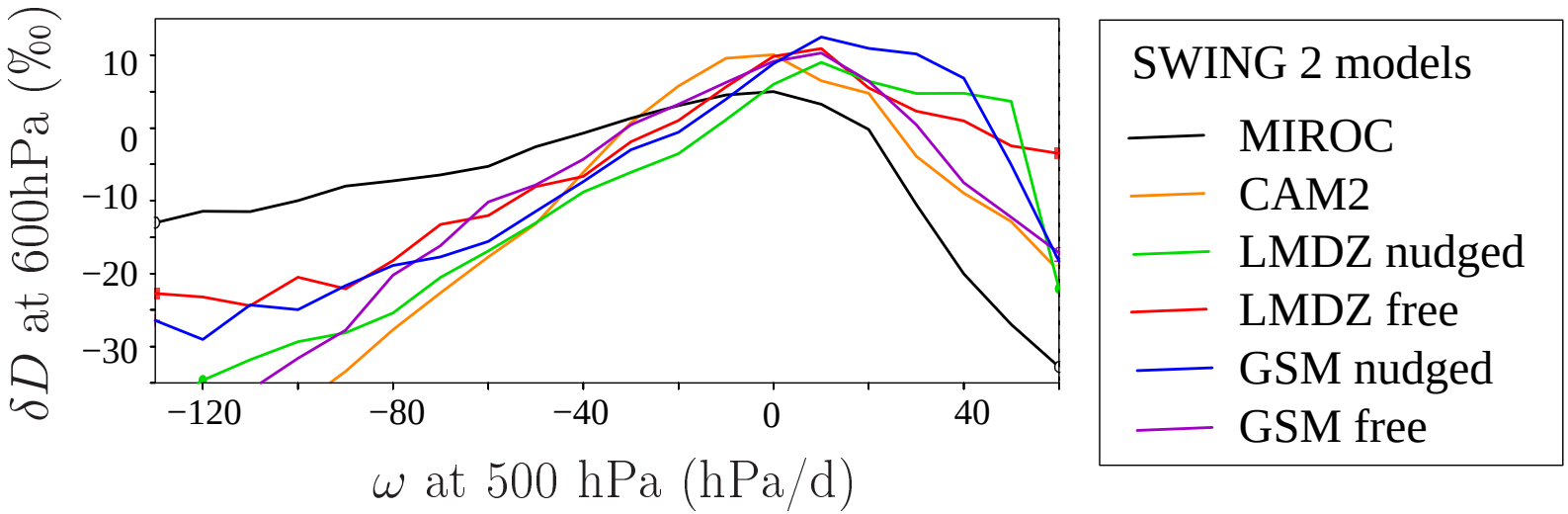
- Precipitation depletes the tropospheric vapor all the more as it is associated with top-heavy ascent
- amount effect amplitude reflects top-heaviness of circulation and associated latent heat profiles, i.e. conv vs shallow
- Key factor for cloud feedbacks? (*Sherwood et al 2014*)



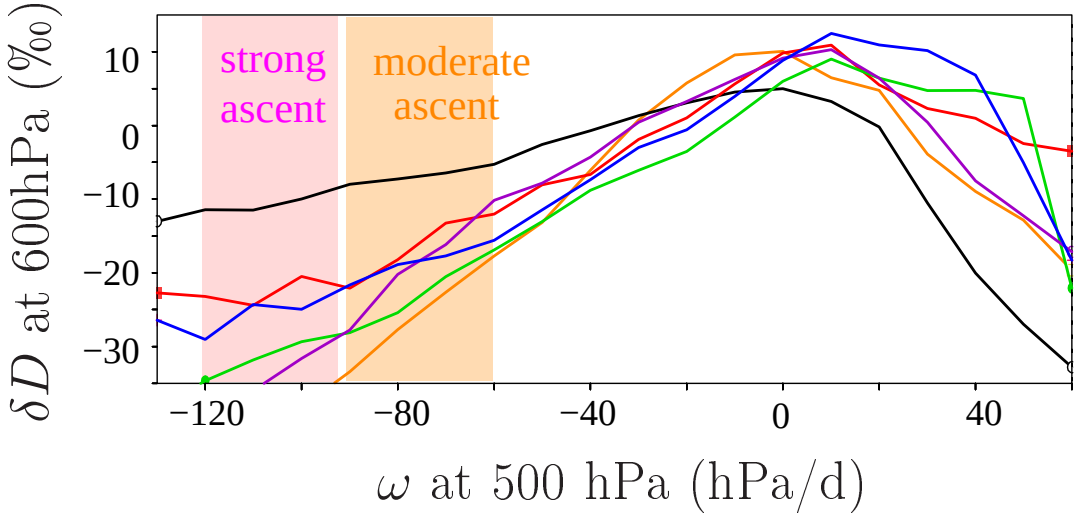
Sherwood et al 2014 → more shallow mixing

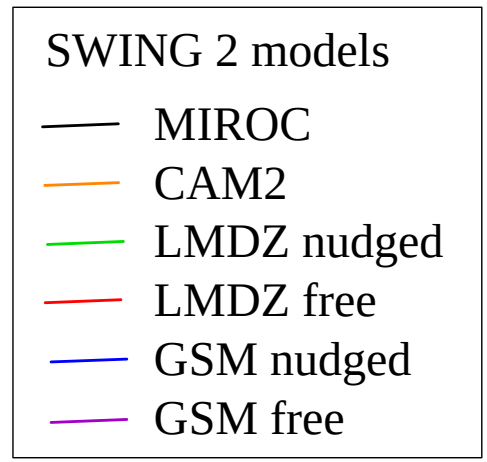
⇒use it evaluate deep vs shallow convective mixing and associated large-scale circulation?

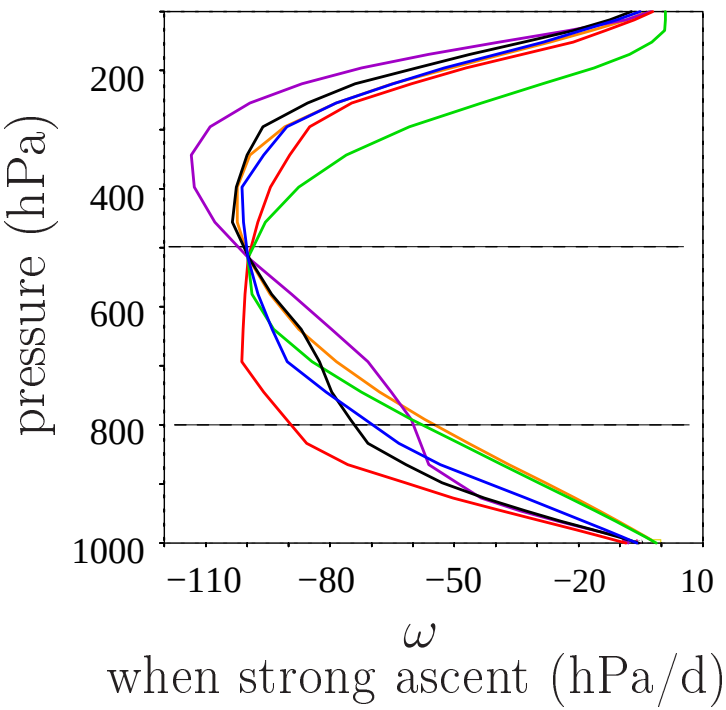
And across models?

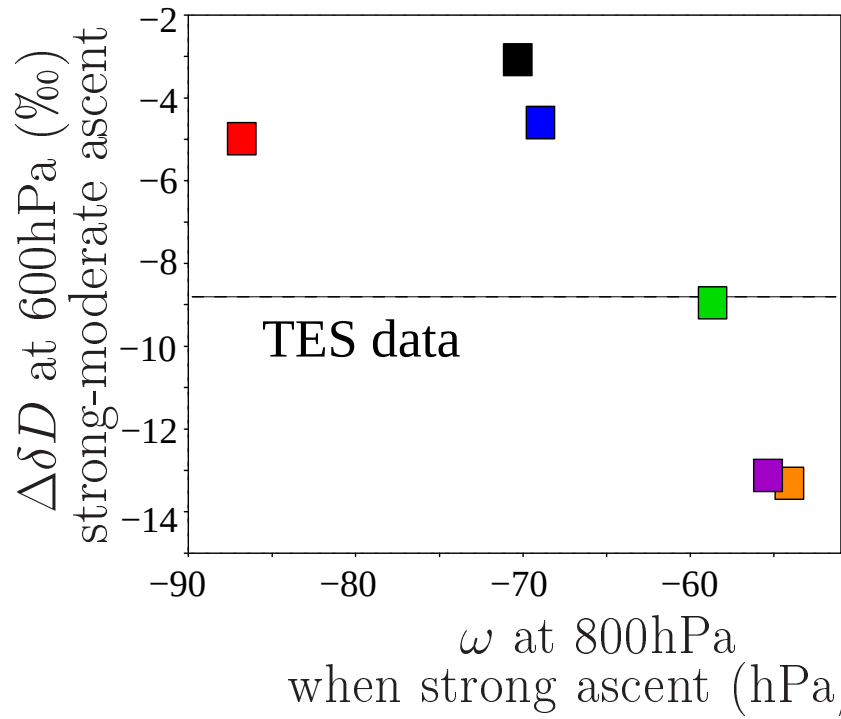


And across models?

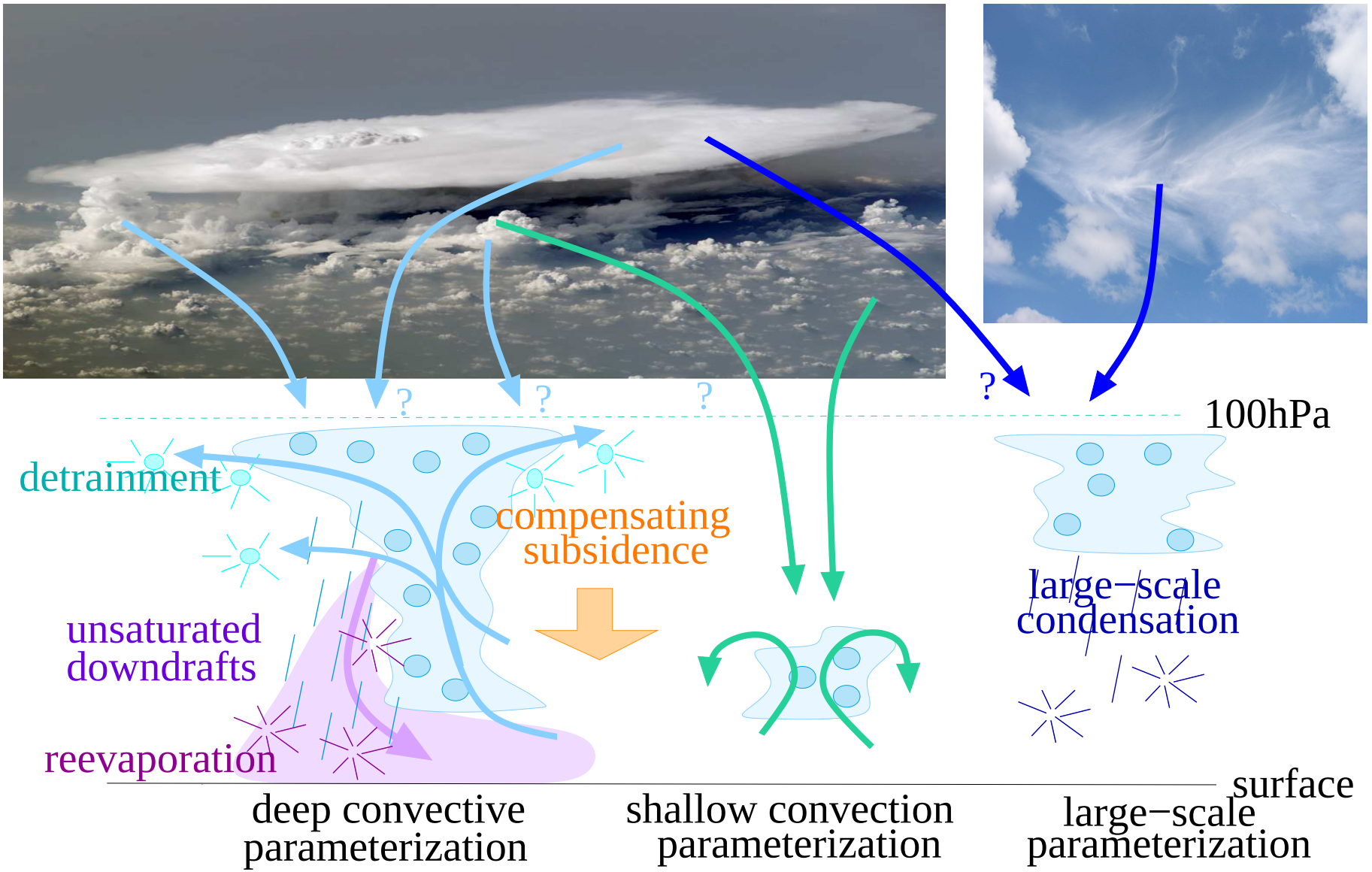








3) Convection vs large-scale schemes



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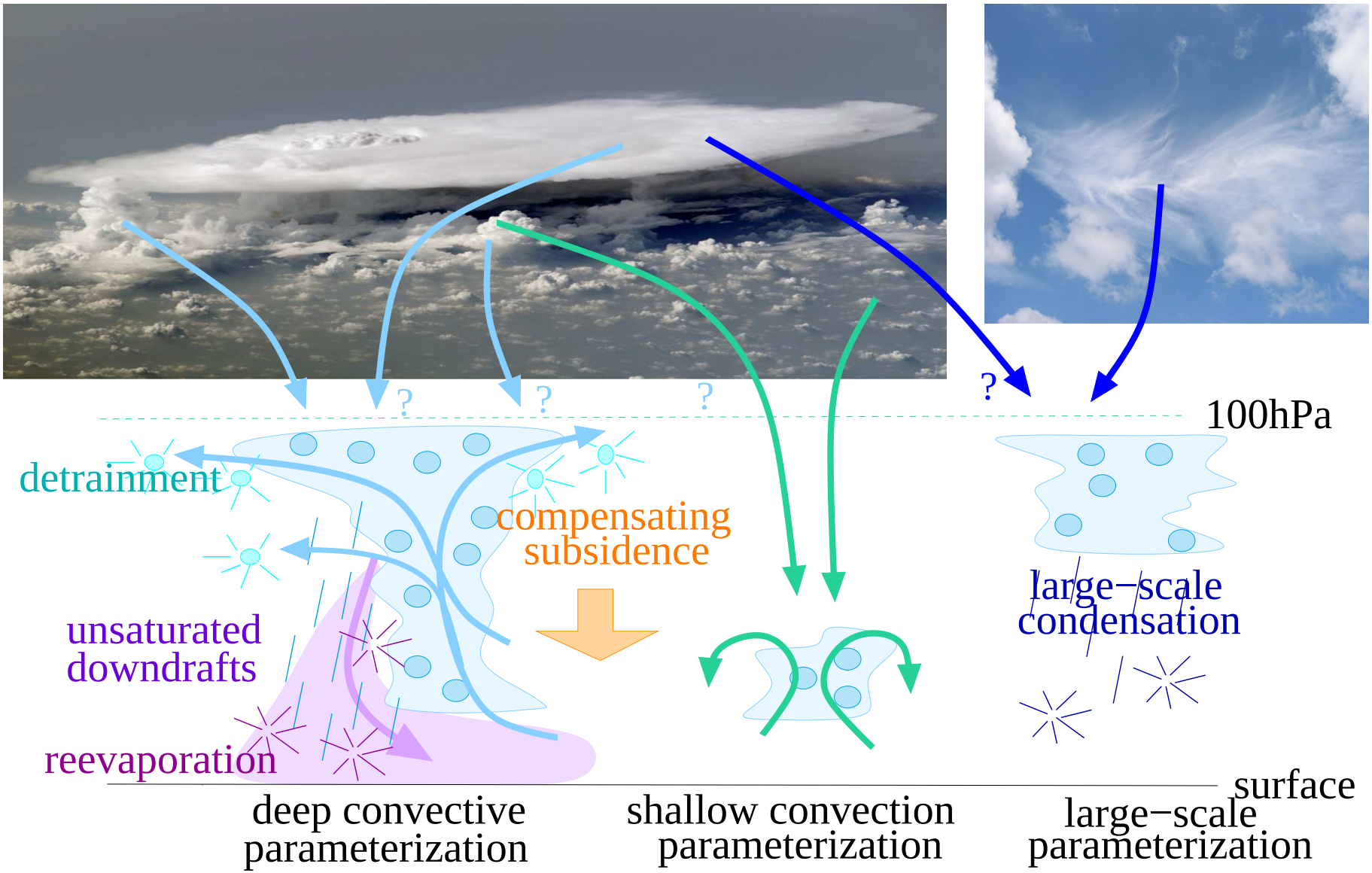
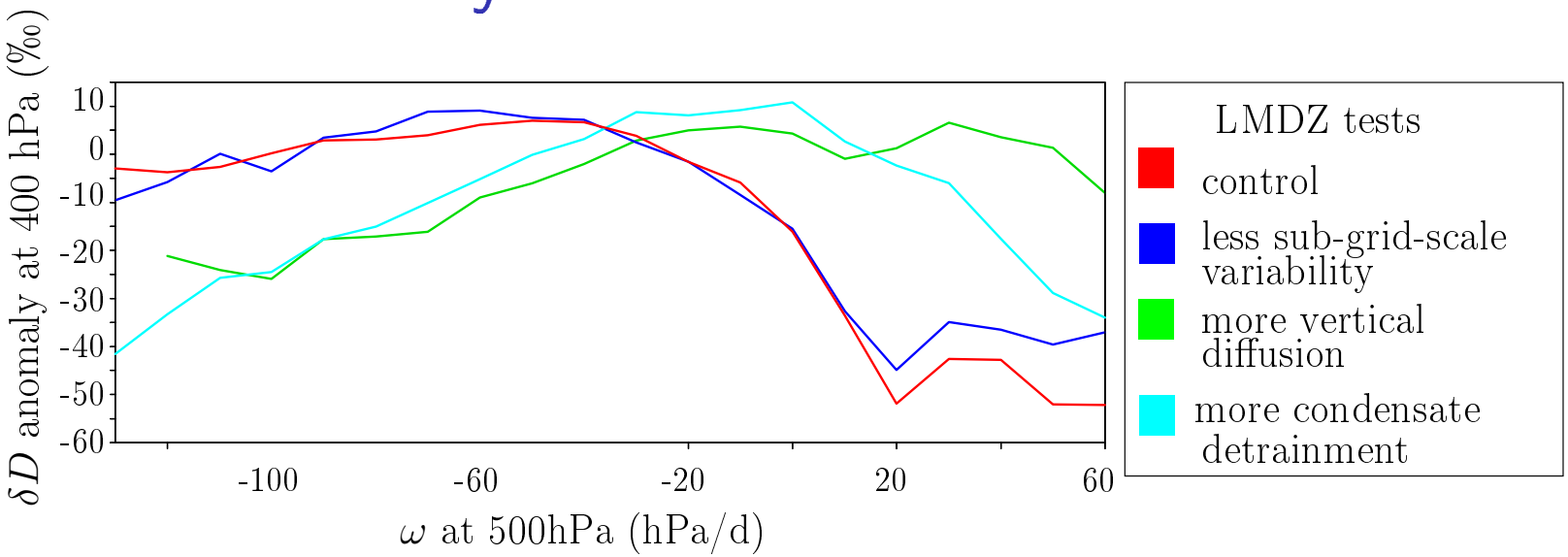


- conv vs large-scale precip arbitray

Sensitivity tests in LMDZ



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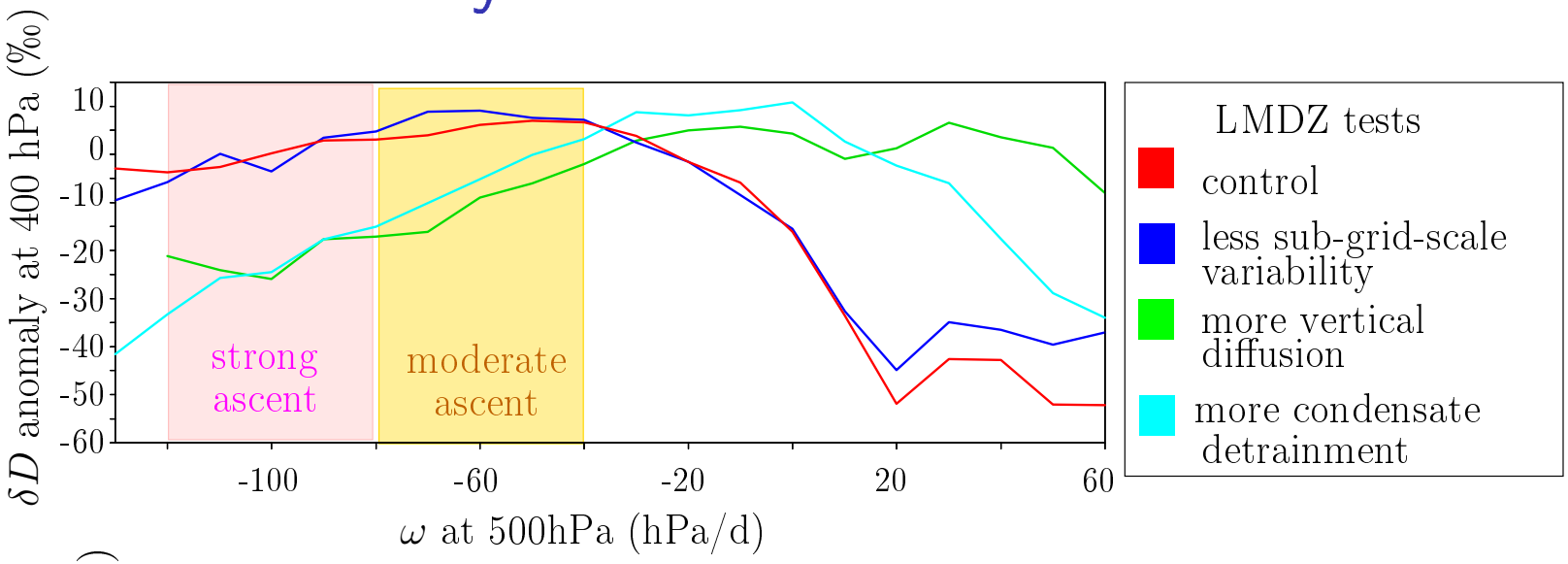
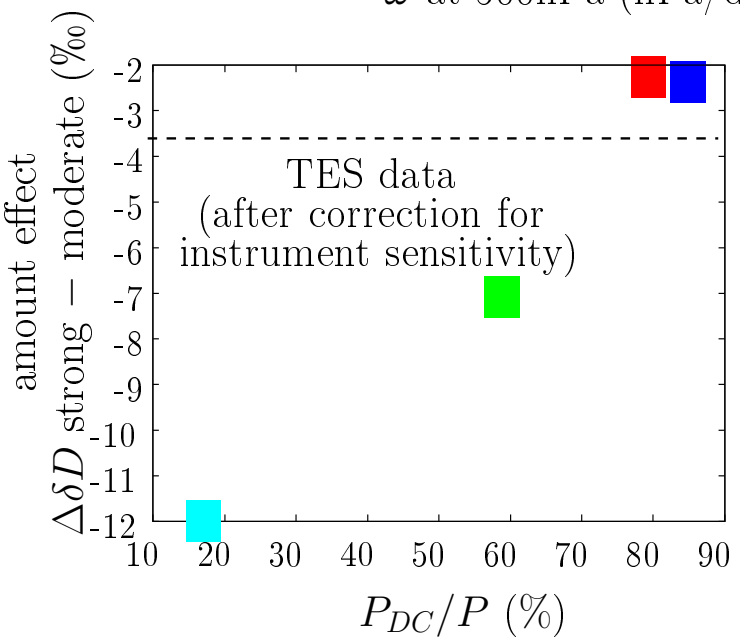
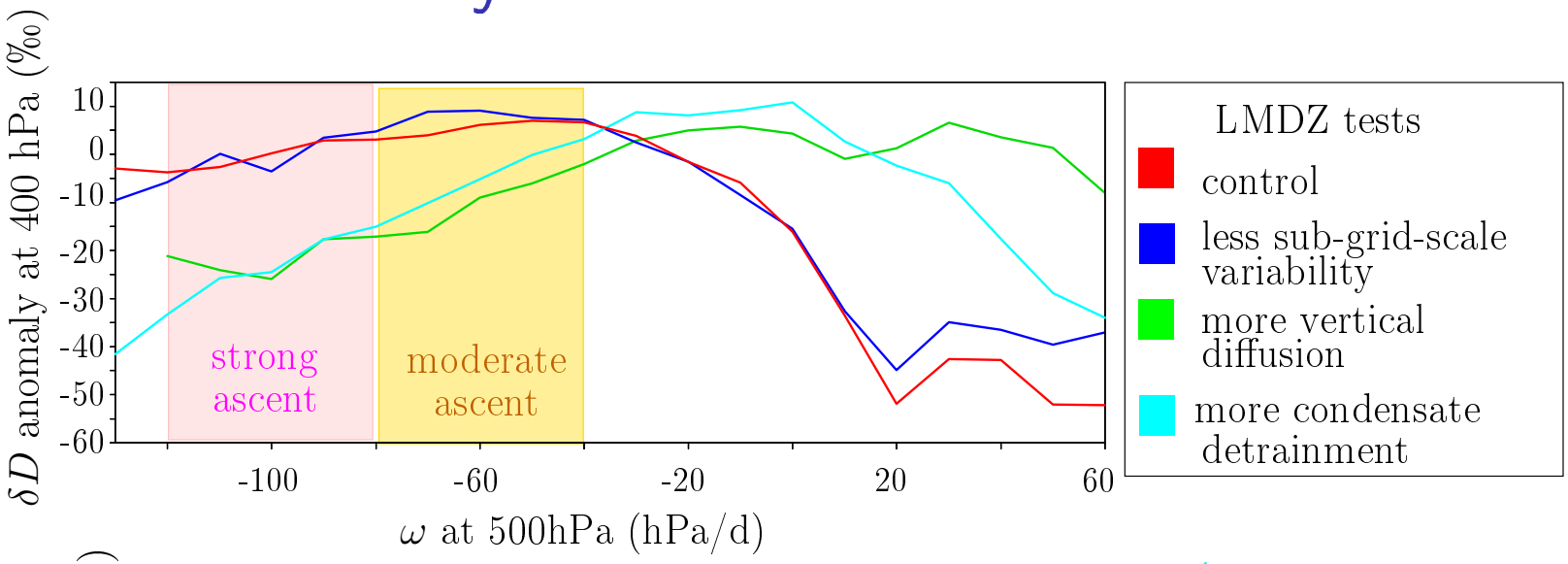
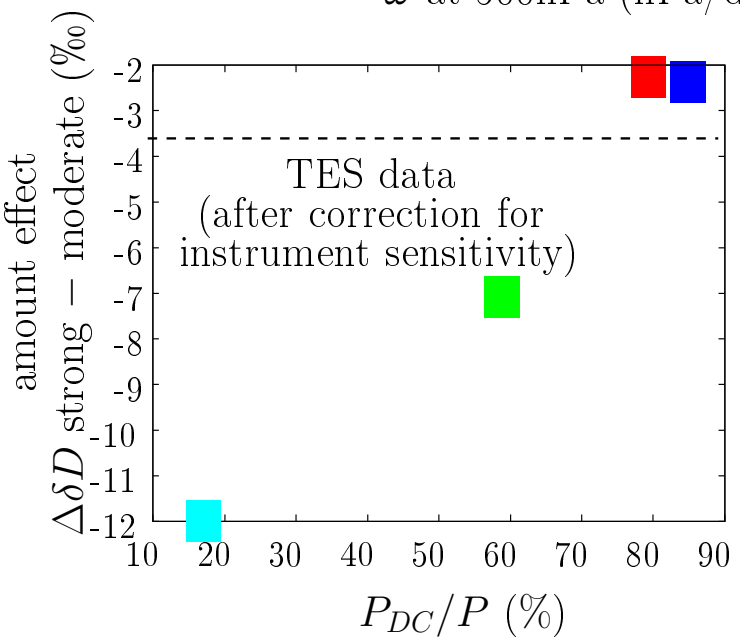
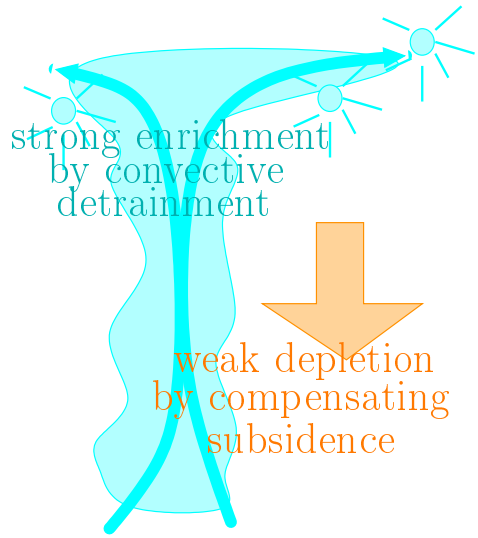


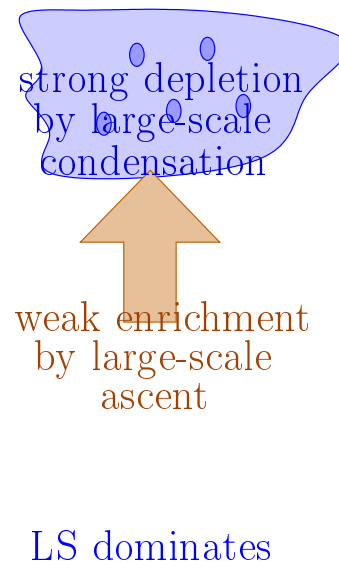


Sensitivity tests in LMDZ









Implications

- precipitating events deplete the tropospheric vapor all the more as it is associated with large-scale precipitation
- conv vs large-scale precipitation= arbitrary choice specific to each model, but with consequences on:
  - latent heating profiles $\Rightarrow$ large-scale circulation
  - cloudiness
  - water vapor, chemical and aerosol transport
  - intra-seasonal variability (*Kim et al 2012*)

$\Rightarrow$use water isotopes quantitatively to evaluate conv vs large-scale precip partitionning and underlying heating profiles?

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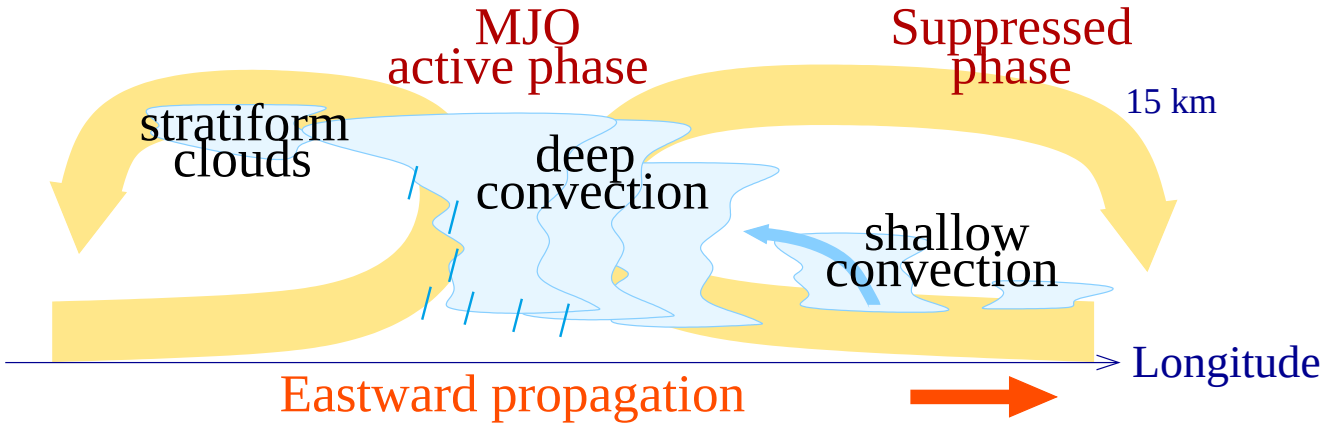
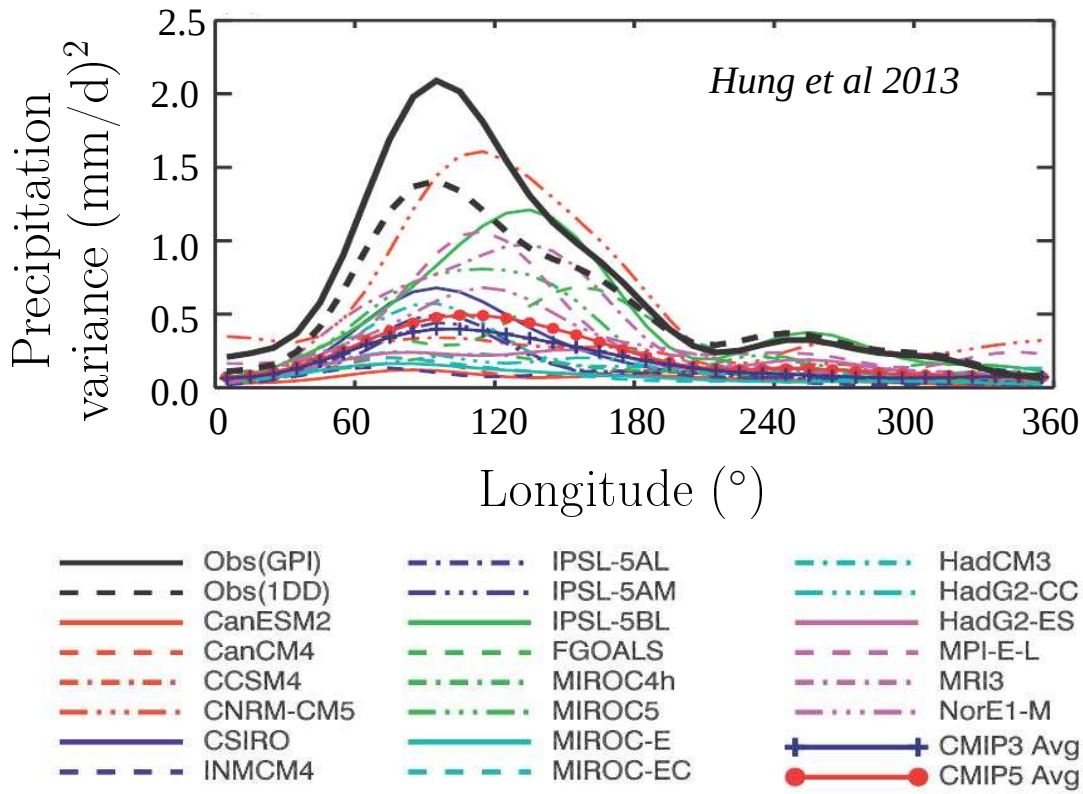
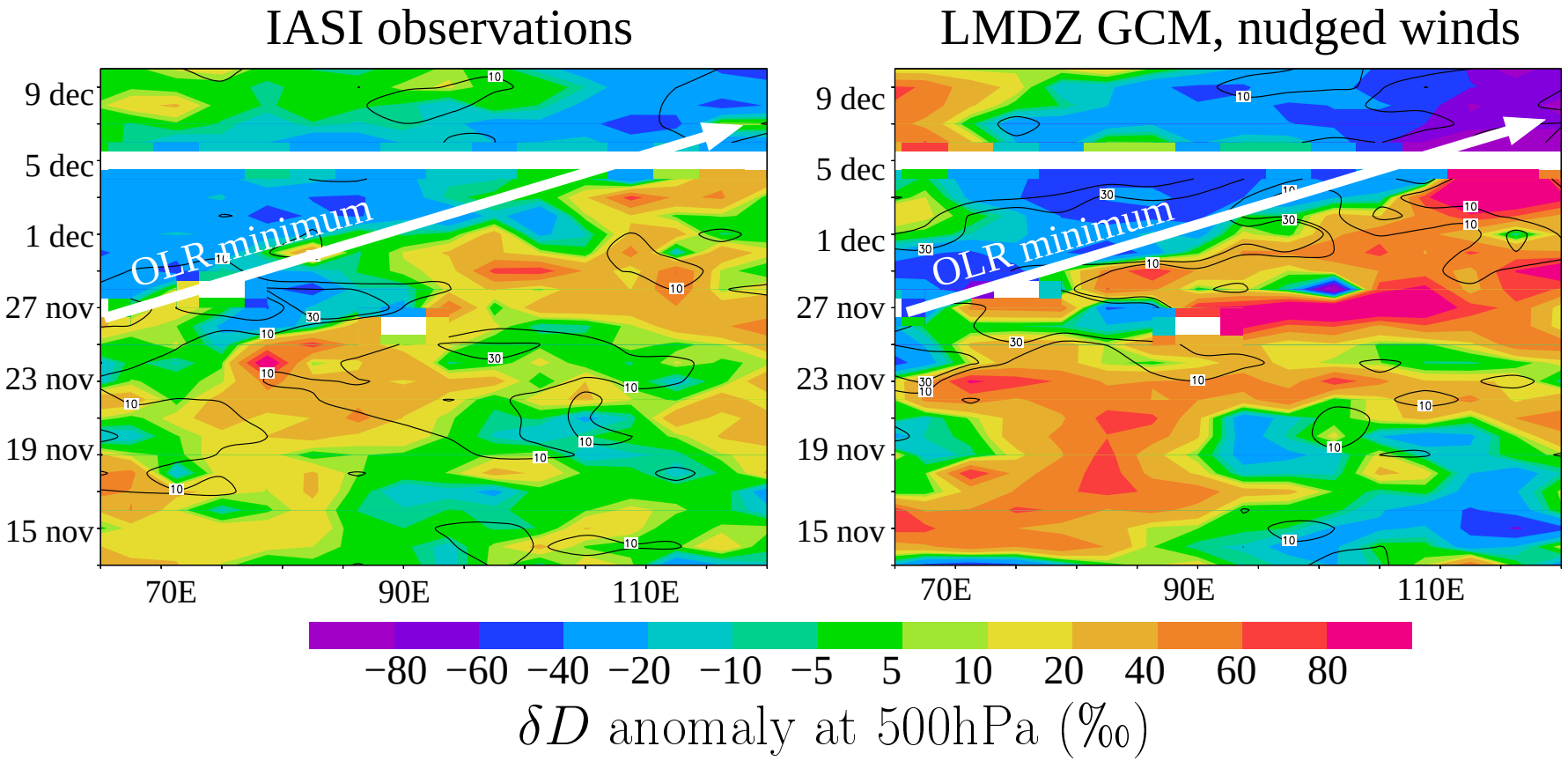
- work in progress with SCM
- Obbe Tuinenbourg's work: use water isotopes to evaluate sequence of cloud processes during the Madden-Julian Oscillation (MJO)?

4) MJO so difficult to simulate?



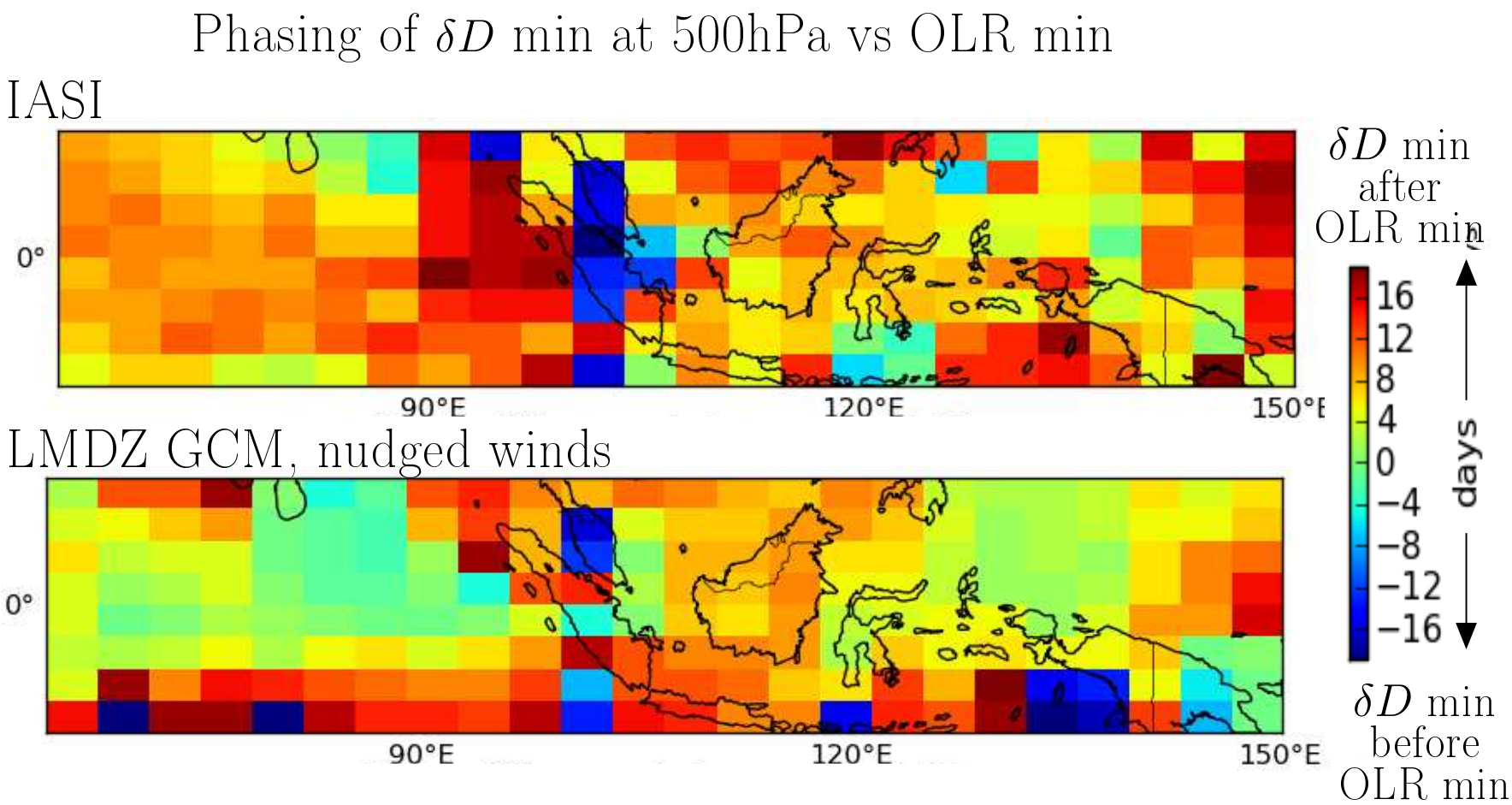


Cindy Dynamo campaign case



- Observed q max 0-1 days before OLR min
- Observed δD min 3 days after OLR min
- LMDZ captures this lag for this case

Statistical analysis for 2006-2007



- Observed δD min lags OLR min in Indian Ocean
- More complicated over Maritime Continent
- LMDZ δD to in phase with OLR

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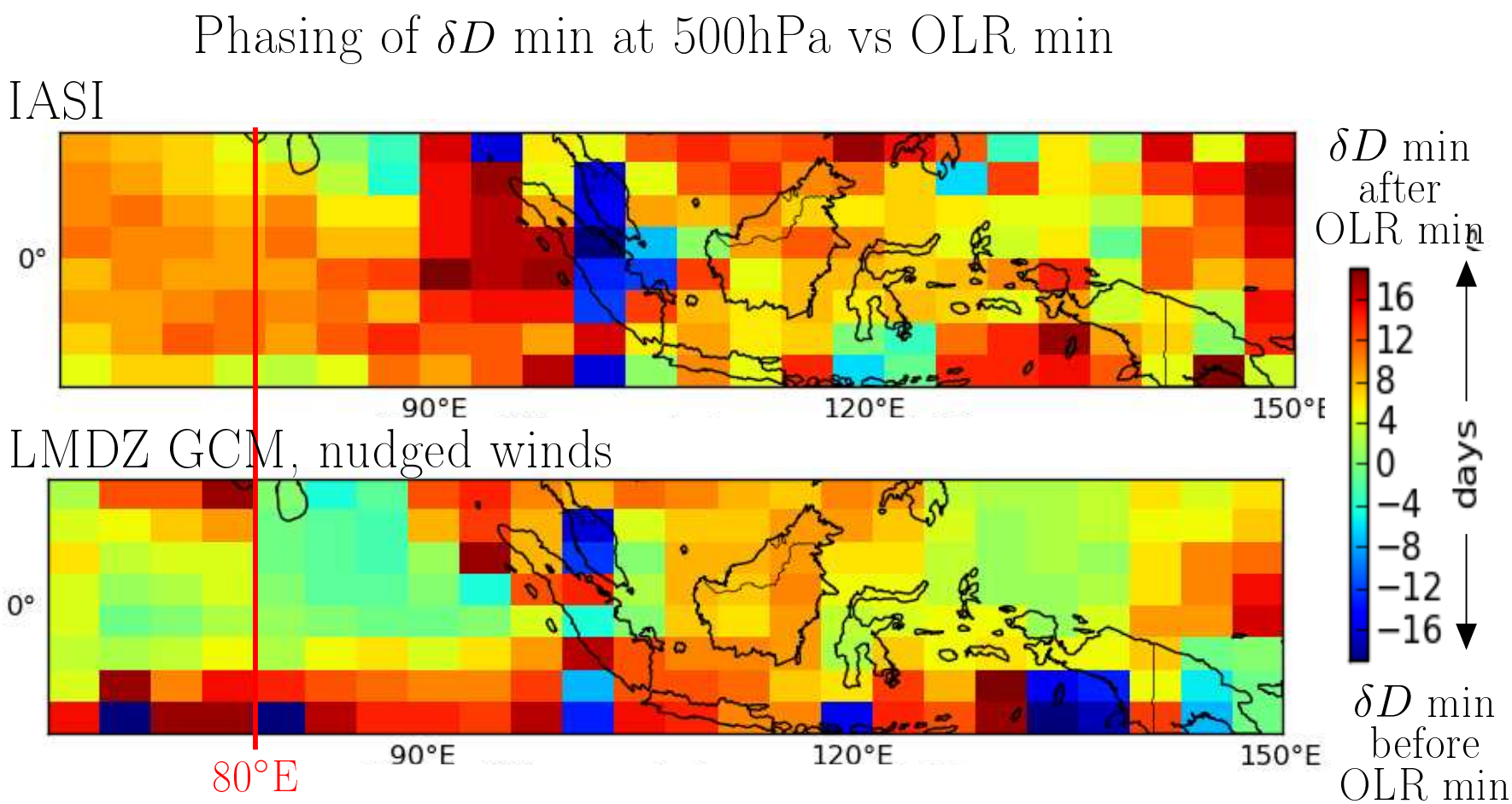

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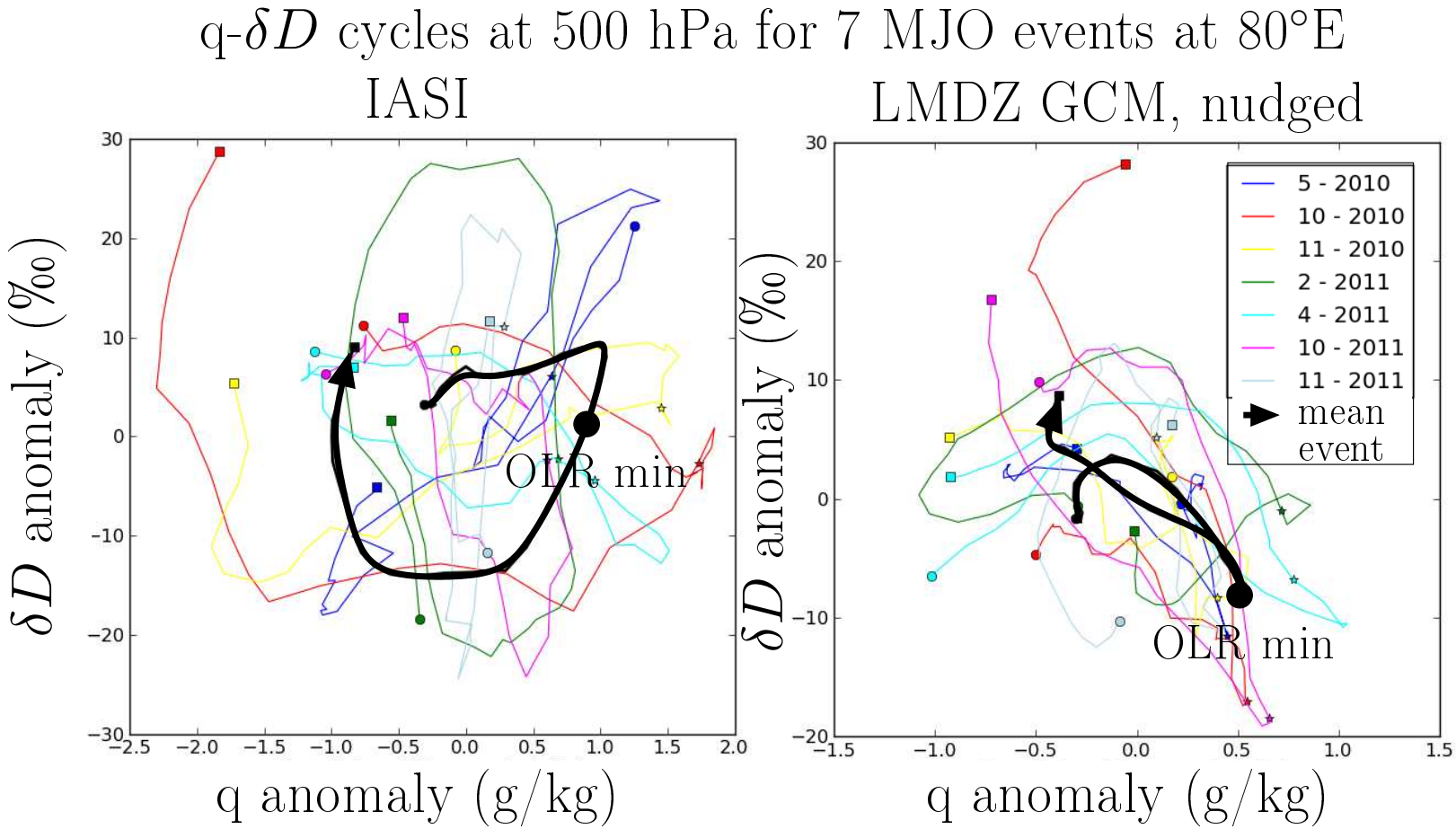
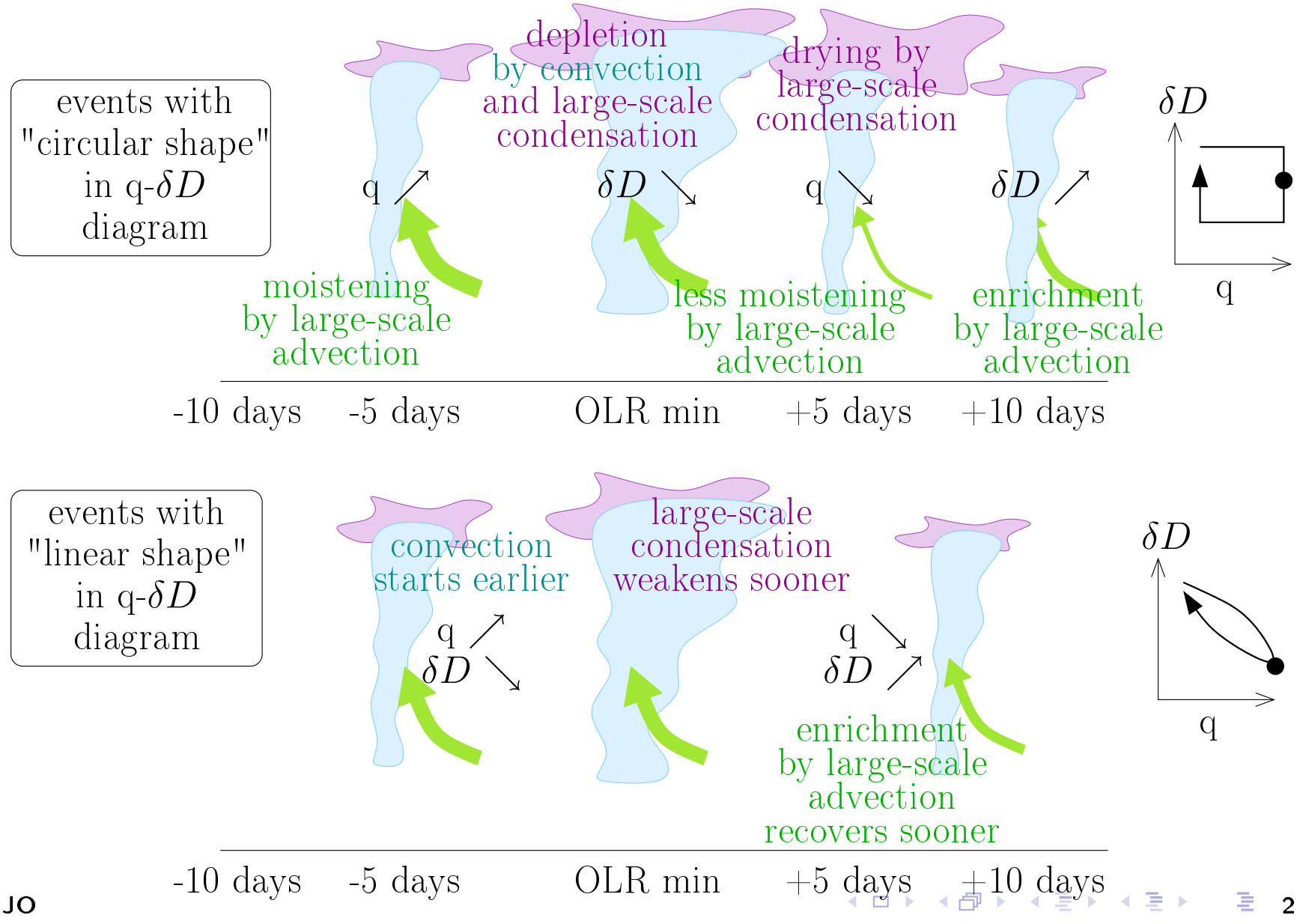
q-δD cycles in Indian Ocean



- Observations: "circular", clockwise shape
- LMDZ: sometimes circular, too often "linear": why?

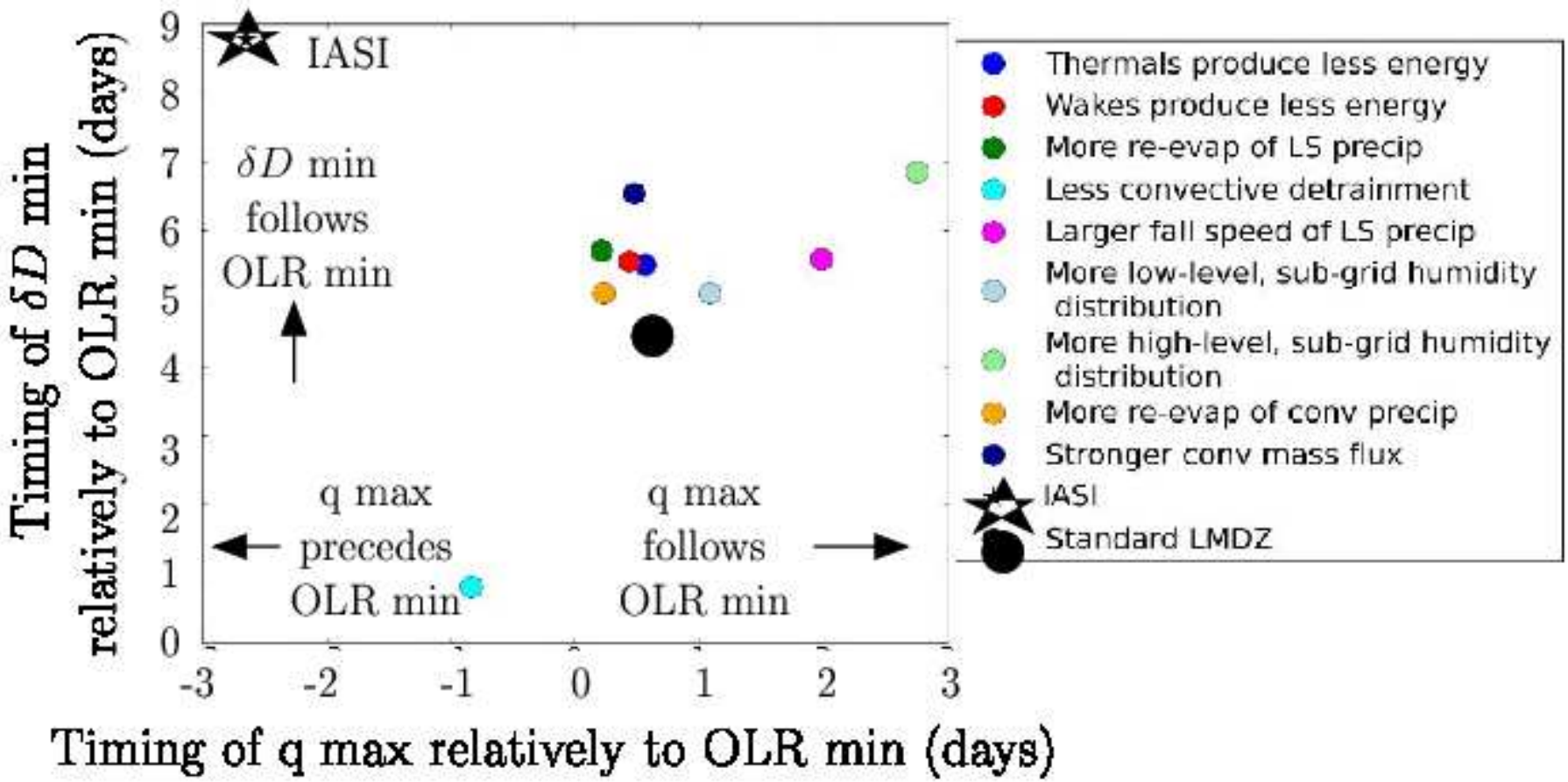
What determines $q - \delta D$ shape in LMDZ?



Preliminary summary on $q - \delta D$ cycles during the MJO

- Observed "circular shape" over Indian Ocean consistent with cloud evolution shallow $\longrightarrow$ deep $\longrightarrow$ stratiform
- What happens over the Maritime Continent?
- Still lot of work to fully understand both data and model behavior
- LMDZ too in phase:
  - convection triggers too soon?
  - Large-scale condensation not maintained long enough?
  - Large-scale advective enrichment recovers too soon?
- $q - \delta D$ useful for model evaluation? $\Rightarrow$ work in progress: analyze senstivity tests

Sensitivity tests with LMDZ



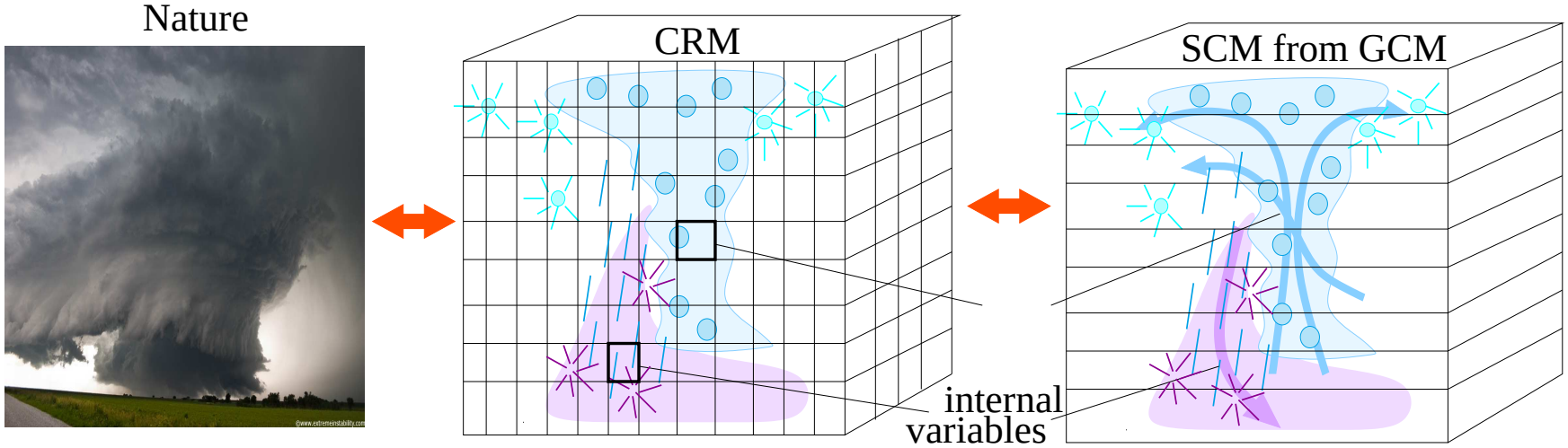
- $q - \delta D$ shape sensitive to convection/cloud parameters
- How to get closer to observations?

Summary on $q - \delta D$ cycles during the MJO

- $q - \delta D$ cycles during MJO: informs about the relative timing of shallow convection, deep convection, large-scale condensation and large-scale advection
- Potentially useful for model evaluation
- Still lot of work to fully understand both data and model behavior
- Exploit better the Cindy Dynamo campaign data?

General perspectives

- Bridge gap between simple theoretical $q - \delta D$ framework and more complex modeling
- Better exploit model hierachy: GCM vs SCM, with large-scale circulation as forcing or as a response (WTG).
- intercompare GCMs: add daily in SWING2?
- CRM/LES to study processes and to compare more easily to observations and to SCMs (conditional sampling)



- longer term: combine q, δD + chemical tracers: CO, O_3, ^{10}Be
  $\Rightarrow$ better characterize fluxes