Trying to constrain tropical precipitation projections and convective/cloud processes using water isotopic measurements: from paleo to daily time scales

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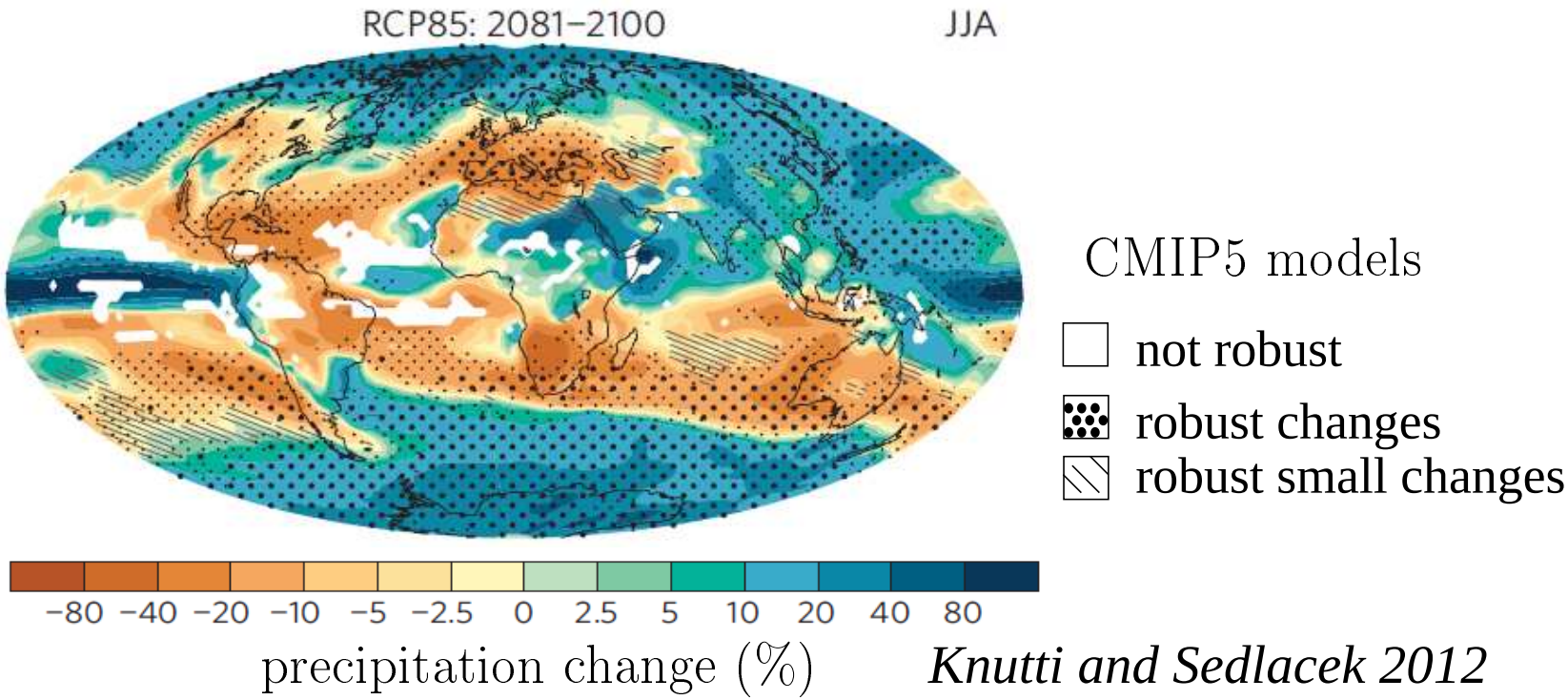
with the contribution of: Sandrine Bony, Christian Frankenberg, Valérie Masson-Delmotte, You He, Jean-Lionel Lacour, Boutheina Oueslati, Obbe Tuinenburg, Françoise Vimeux, John Worden

UCLA, October 21, 2014

Spread in precipitation projections



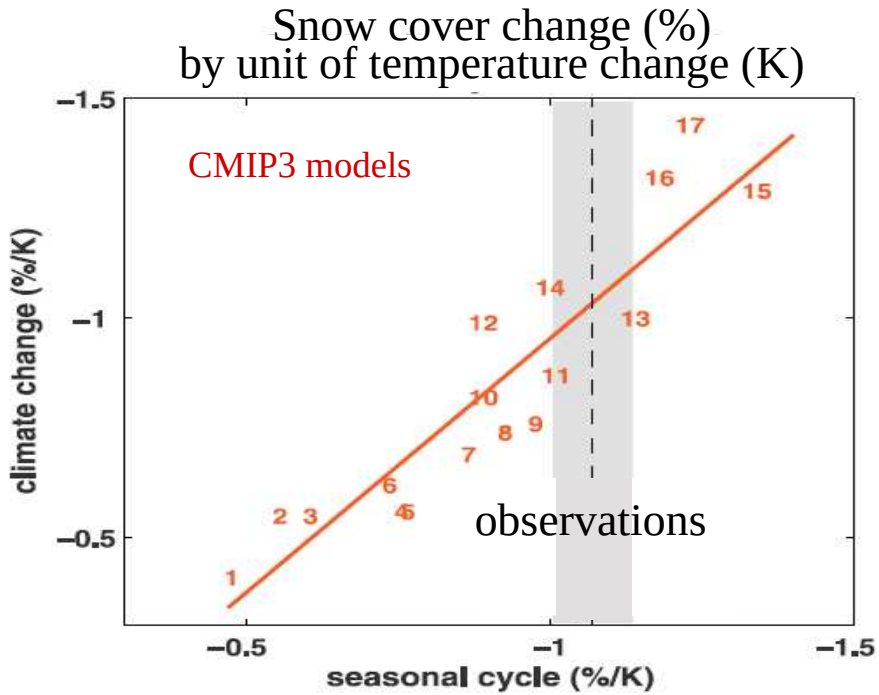
Knutti and Sedlacek 2012

- Sources of spread? convective parameterizations, cloud feedbacks? (e.g. *Kang et al 2008, Frierson and Hwang 2012*)

⇒How can we assess the credibility of precipitation projections?

Observational constraints?

- School case: *Hall and Qu 2006*: snow albedo feedback



- Conditions for good observational constraints:
  1. link between projected behavior and observable behavior
  2. common physical processes
  3. observations with precision finer than model spread

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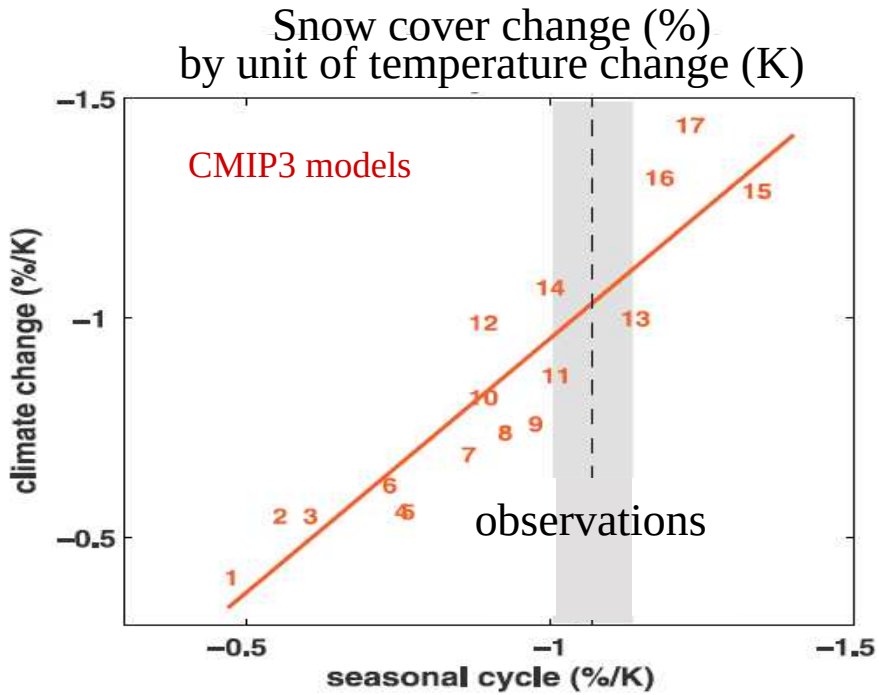


- Conditions for good observational constraints:
  1. link between projected behavior and observable behavior
  2. common physical processes
  3. observations with precision finer than model spread
- Use paleo constrains? (e.g. *Hargreaves and Annan 2009*, *Braconnot et al 2012*)

Seminar outline and summary

1) if a model is better for the past, is it more cedible for the future?
$\Rightarrow$ work in progress on links past/future changes using CMIP5 archive, some encouraging results

2) Are there archives of past precipitation changes?
$\Rightarrow$ are tropical paleo archives of precipitation isotopes ($H_2^{18}O$) proxy for precip? or of temperature?
$\Rightarrow$ work in progress, but complex: model-dependent

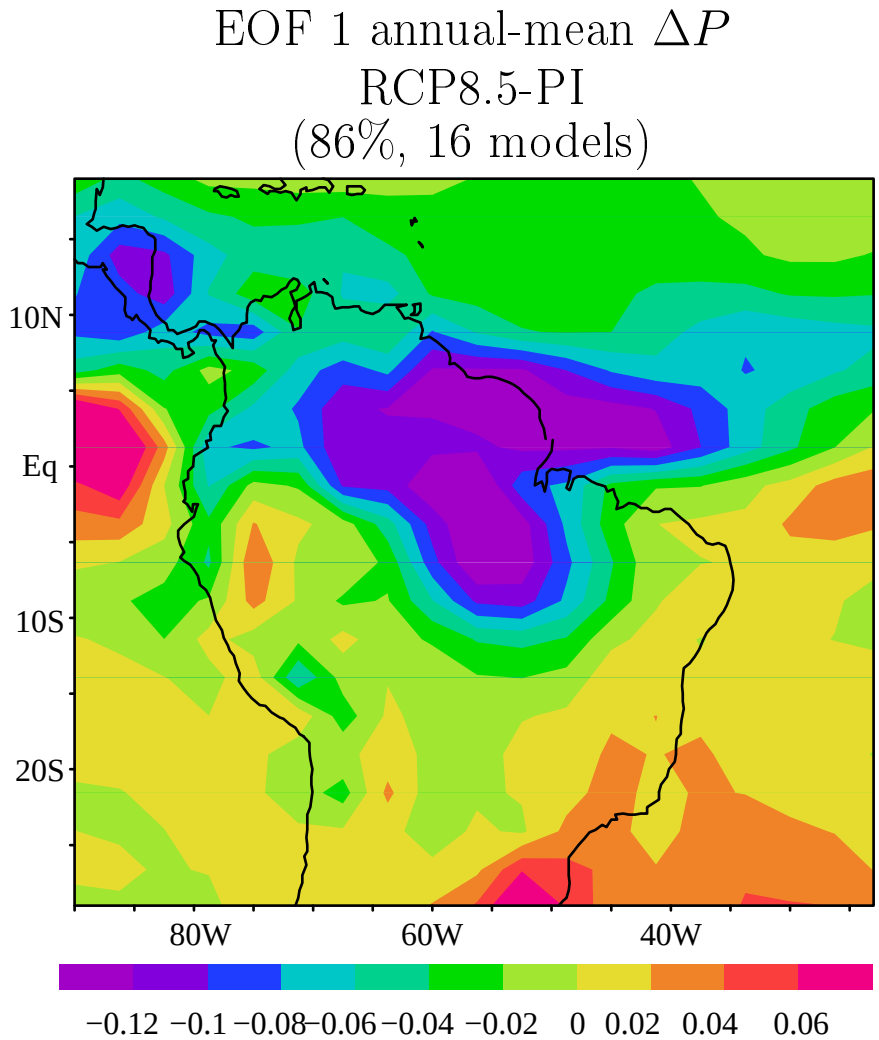
3) Link between precipitation rate and isotopic composition?
$\Rightarrow$ work in progress using recent satellite measurements
$\Rightarrow$ link depends on the details of convective/cloud processes, e.g. stratiform, deep and shallow convection
$\Rightarrow$In turn, use isotopes to better constrain these processes in models? e.g. work in progress on the MJO

1) Link between past and future precipitation changes

- CMIP5 archive: for the 1st time for the same model:
  - climate change scenraios (RCP)
  - Last Glacial Maximum (LGM) (7 models)
  - Mid Holocene (MH) (10 models)
  - idealized simulations
- Precipitation patterns are complex $\Rightarrow$ need to look more regionally

$\Rightarrow$ here: study for South America

Multi-model EOF of future precip changes



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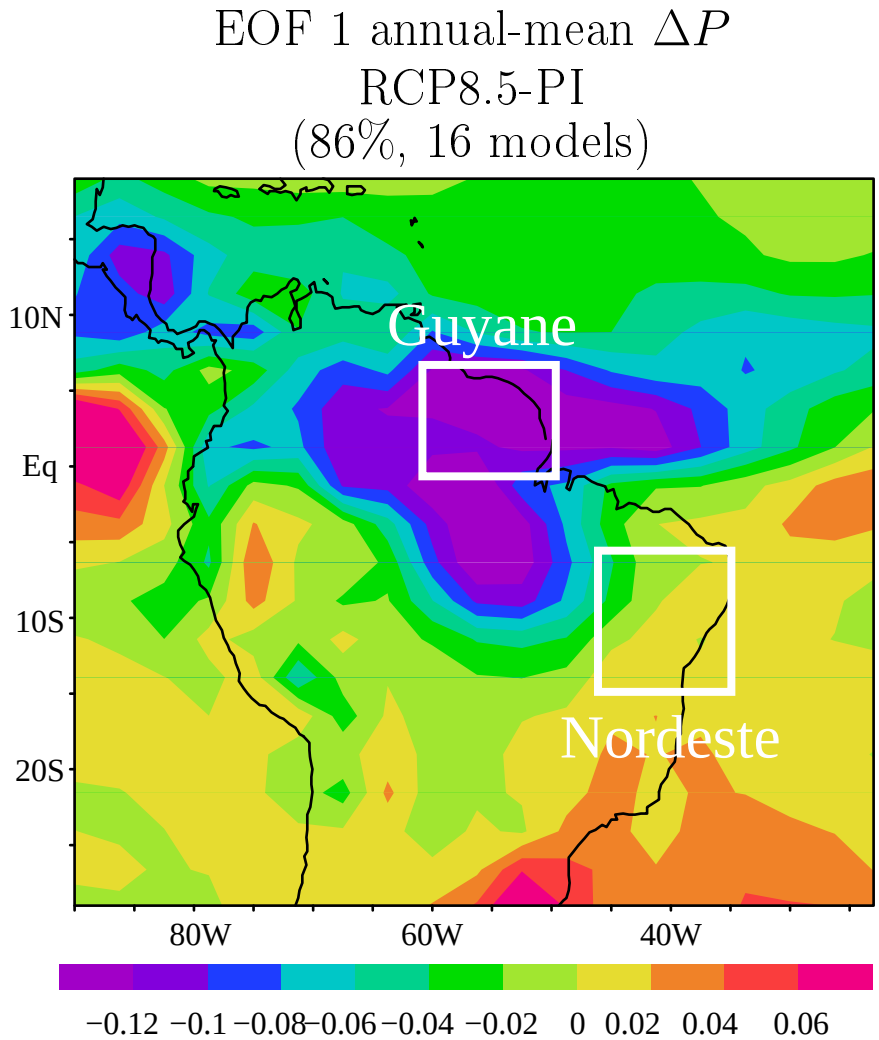
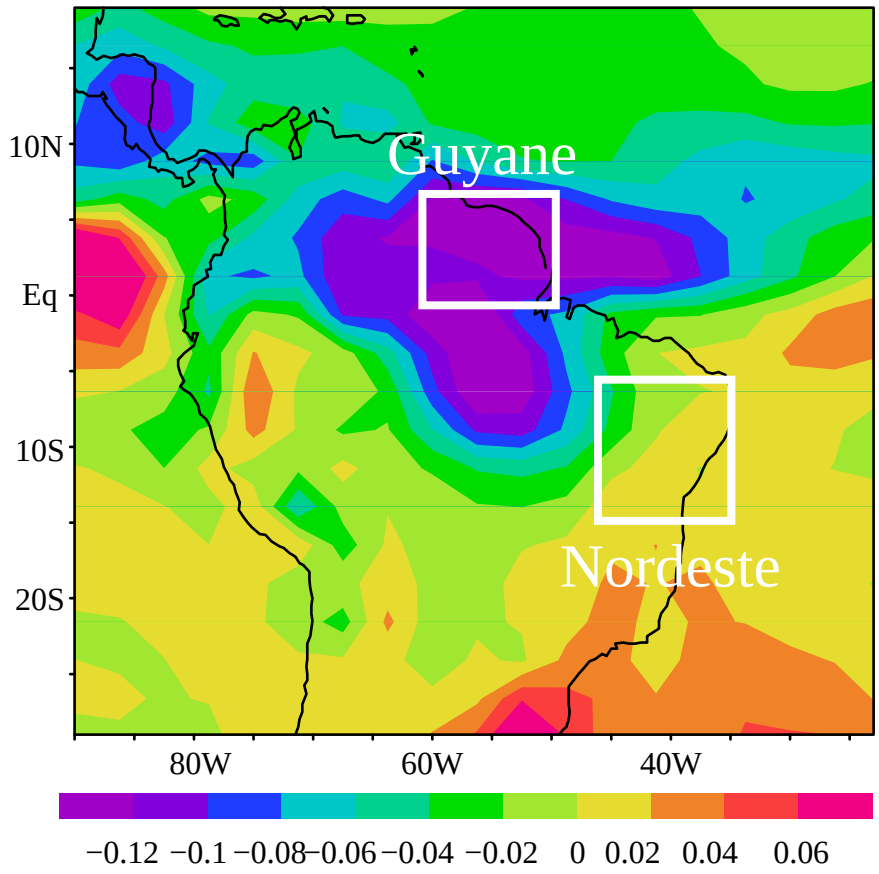
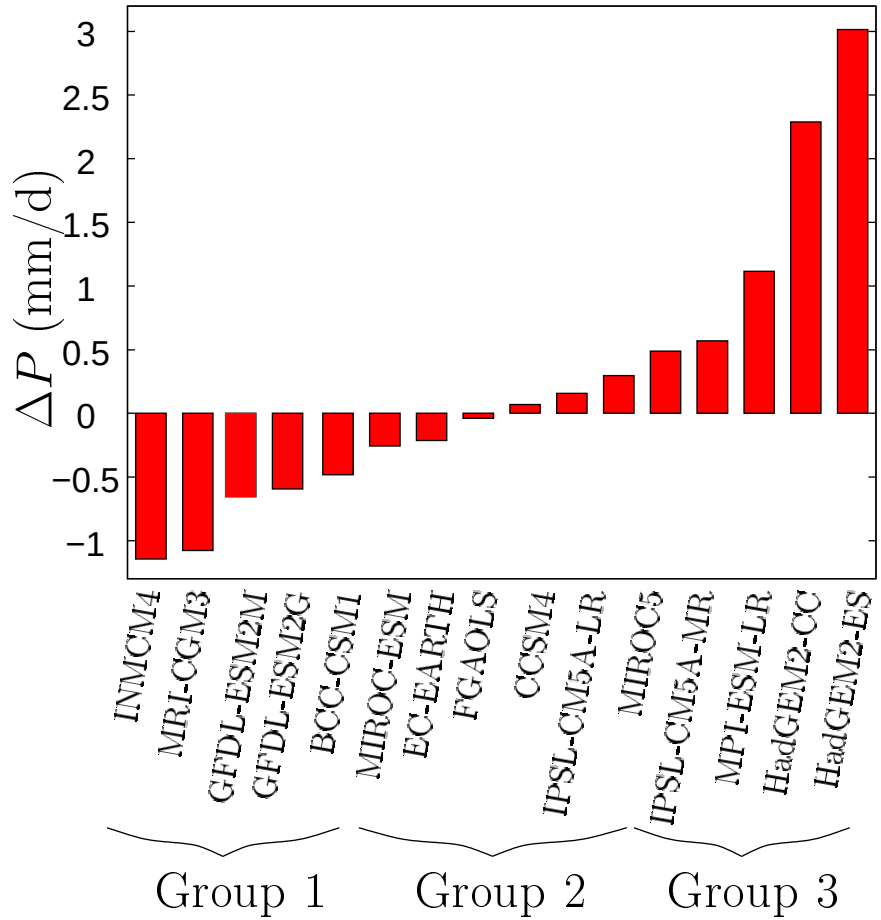


Multi-model EOF of future precip changes

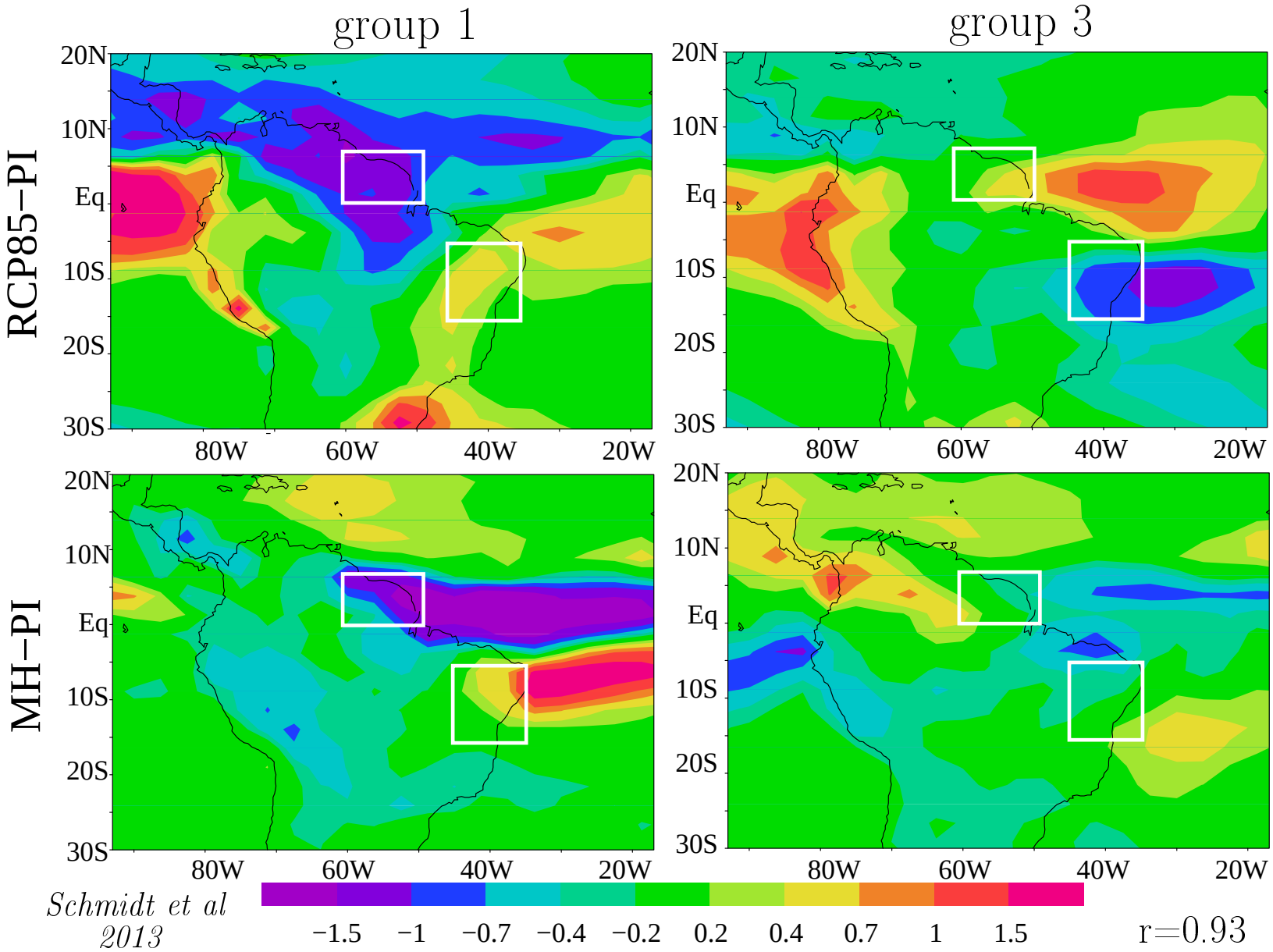
EOF 1 annual-mean ΔP
RCP8.5-PI
(86%, 16 models)



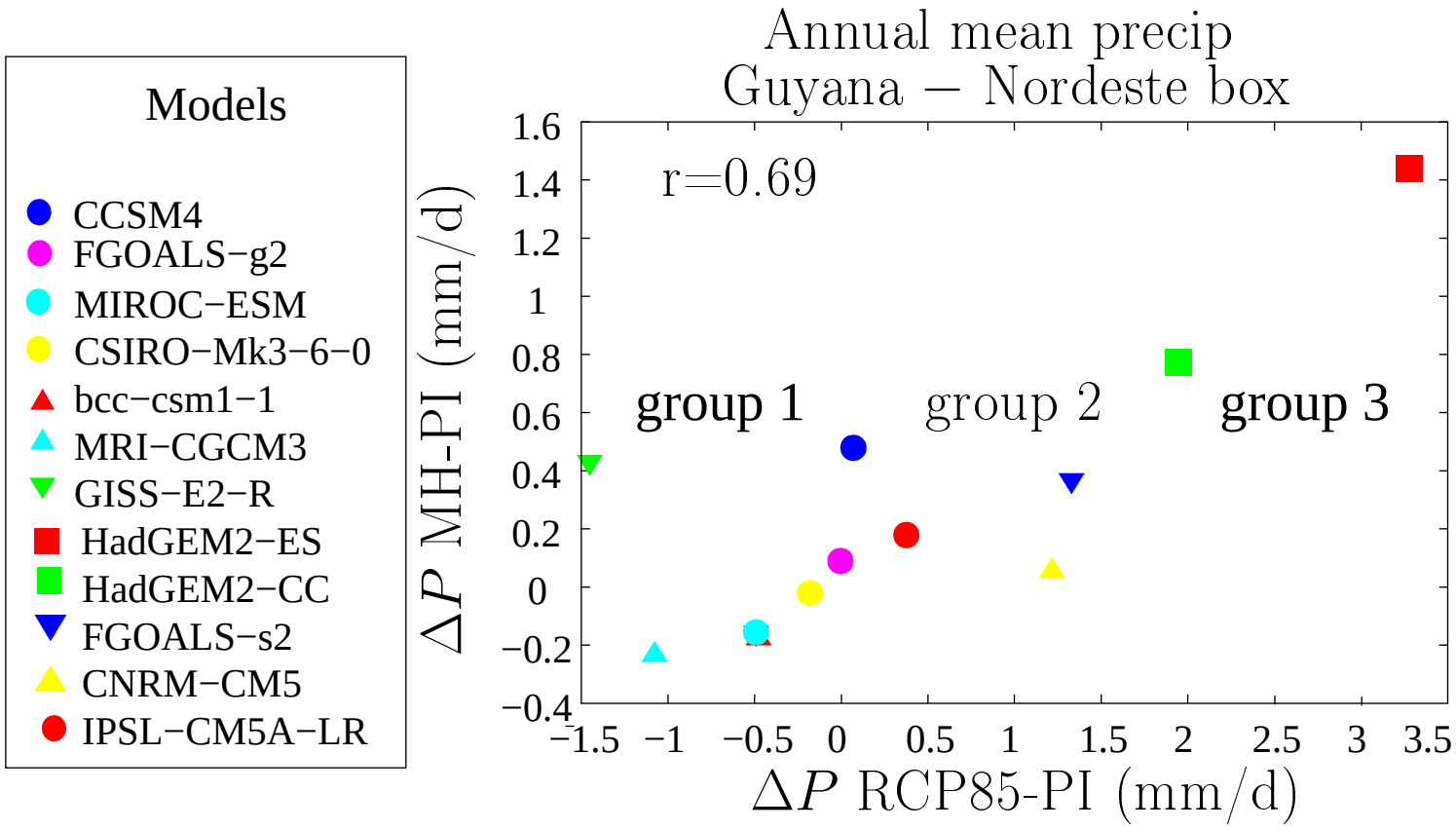
Guyane-Nordeste
RCP8.5-PI precip change



Link between future climate and MH



Use MH obs to constrain projections?



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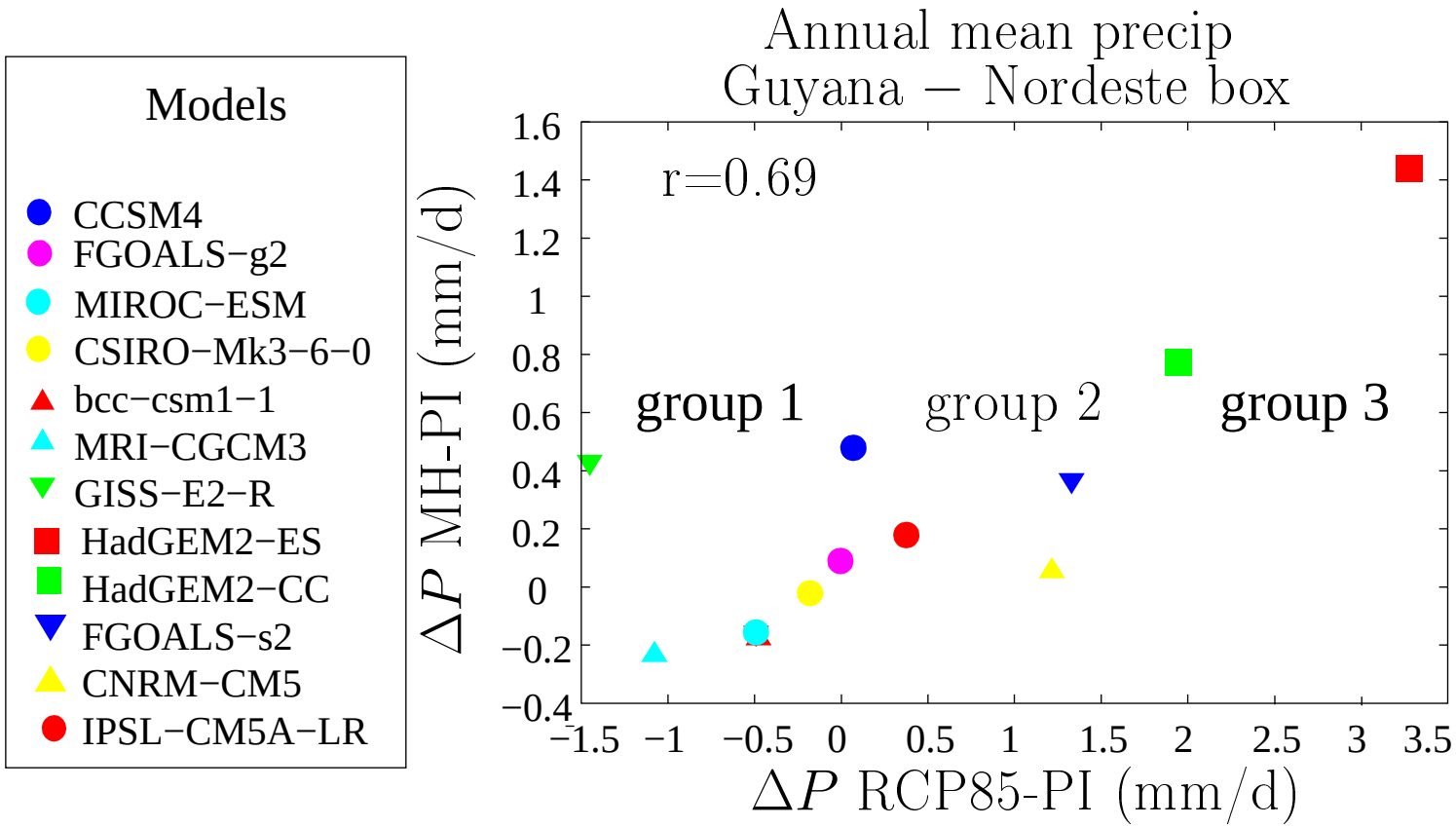
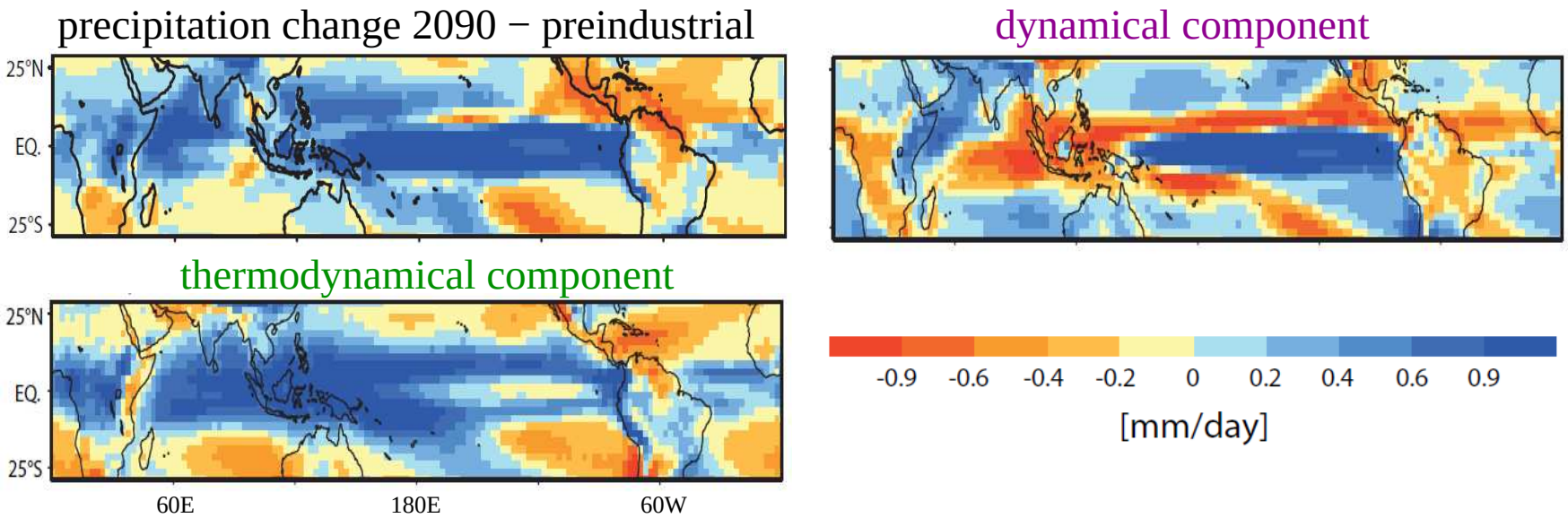


- Are there common mechanisms?
  - present-day pattern? e.g. double ITCZ less frequent in group 1
  - physical mechanisms? ⇒ *Bony et al 2013* decomposition

Decomposing precipitation changes into dynamic and thermodynamic effects

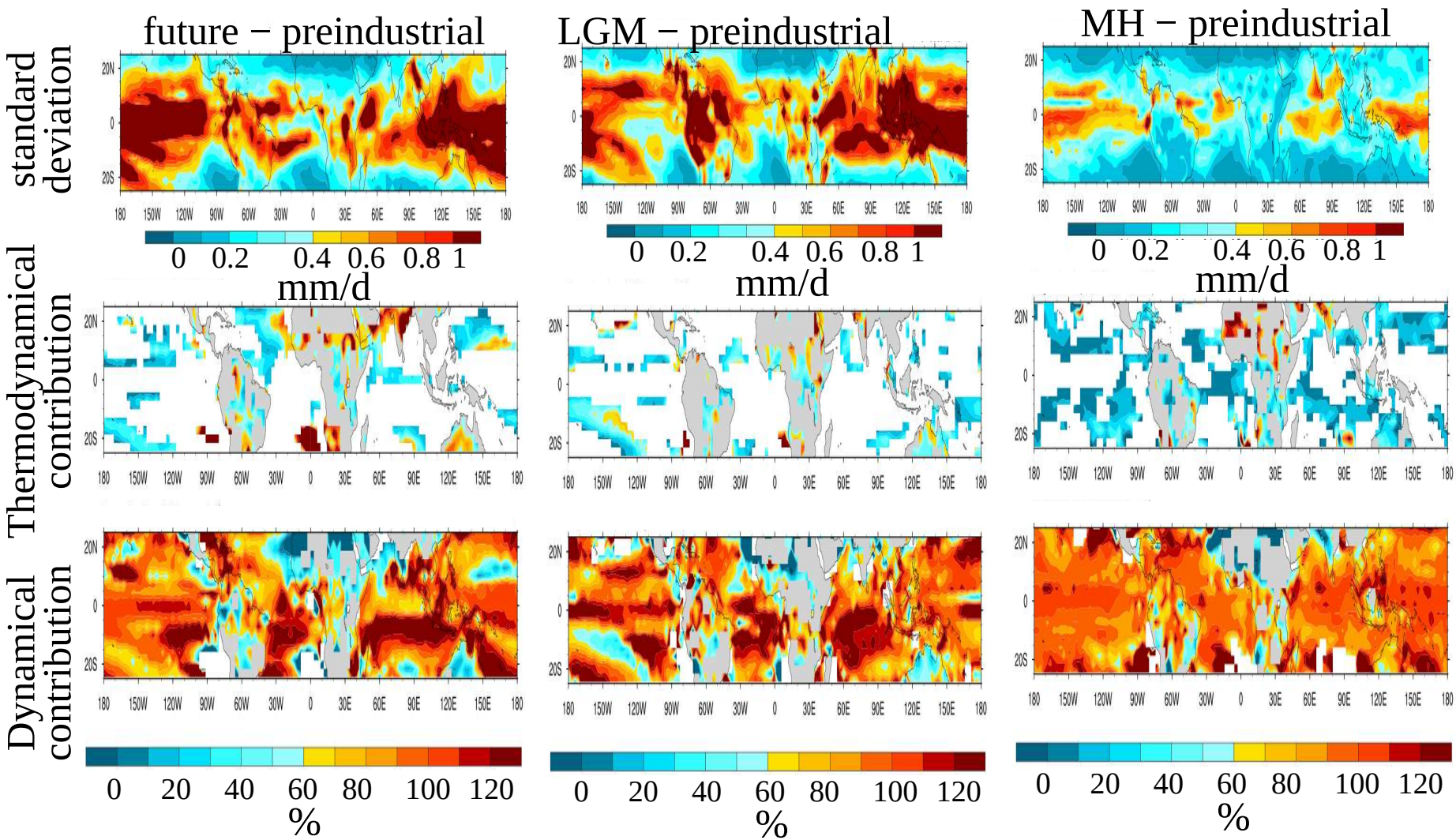
$$\Delta P = \Delta P_{dyn} + \Delta P_{ther} \text{ with } \Delta P_{dyn} = \Gamma_q \cdot \Delta\bar{\omega}$$



Which contribution contributes to the spread? Mechanisms similar in paleo and in future?

Spread in precipitation projections?

- Work in progress by Boutheina Oueslati



Summary on past/future links

- Some encouraging results in some regions: models that show a common behavior for future climate also show a common behavior for past climates
- Need to work more on understanding mechanisms
- Dynamical changes dominate the spread (except on the Sahel), and dominate correlations between past/future when exists

$\Rightarrow$Is it easier to find past/future links for a specific contribution to precipitation change?

Summary on past/future links

- Some encouraging results in some regions: models that show a common behavior for future climate also show a common behavior for past climates
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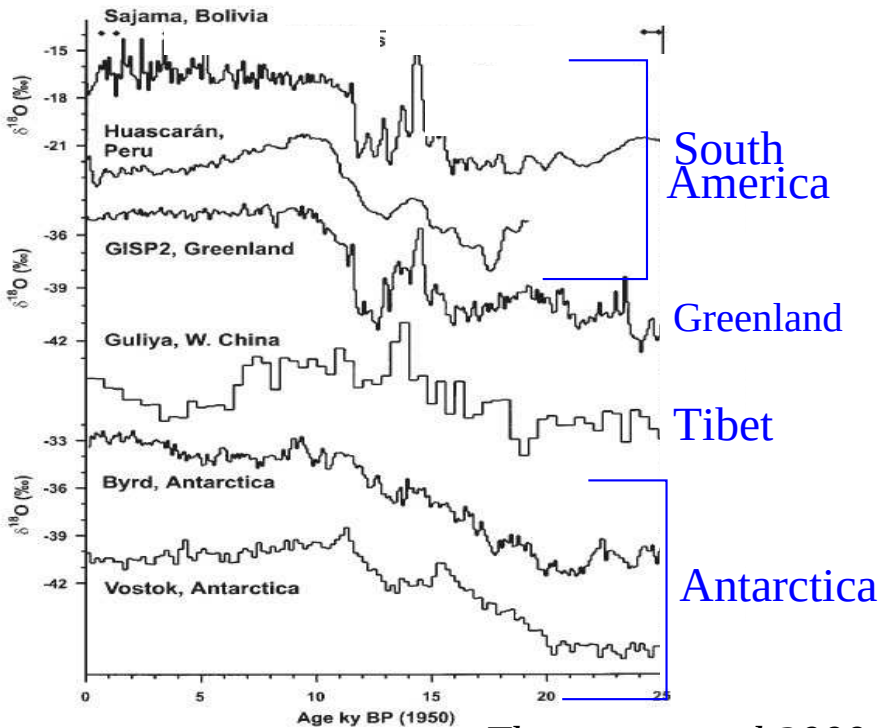
$\Rightarrow$Is it easier to find past/future links for a specific contribution to precipitation change?

- Availability of precipitation archives?

What does $\delta^{18}O_p$ records?

- Thompson et al 2000 $\longrightarrow$ temperature proxy



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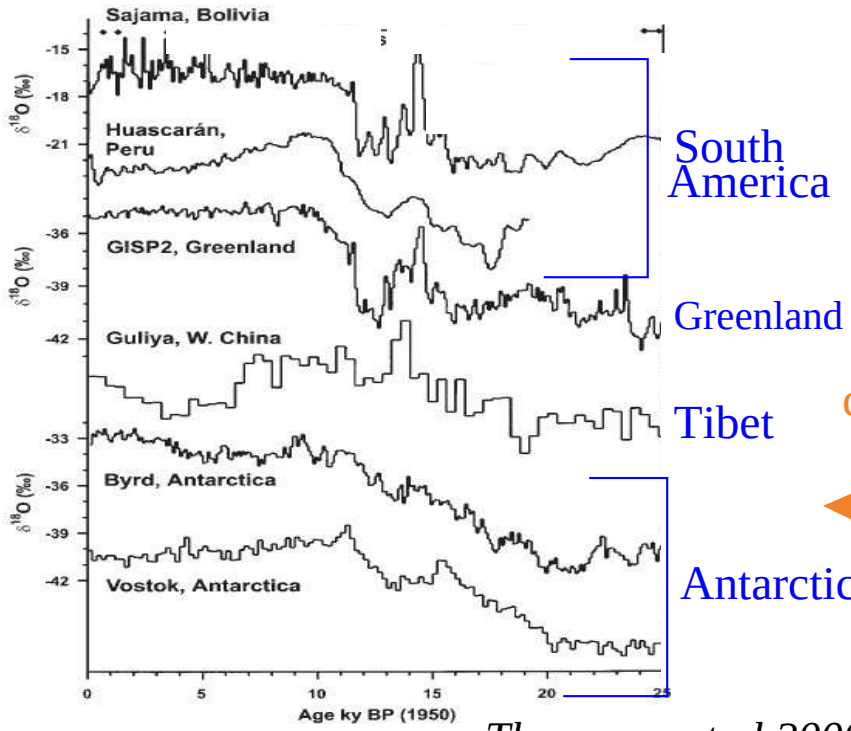

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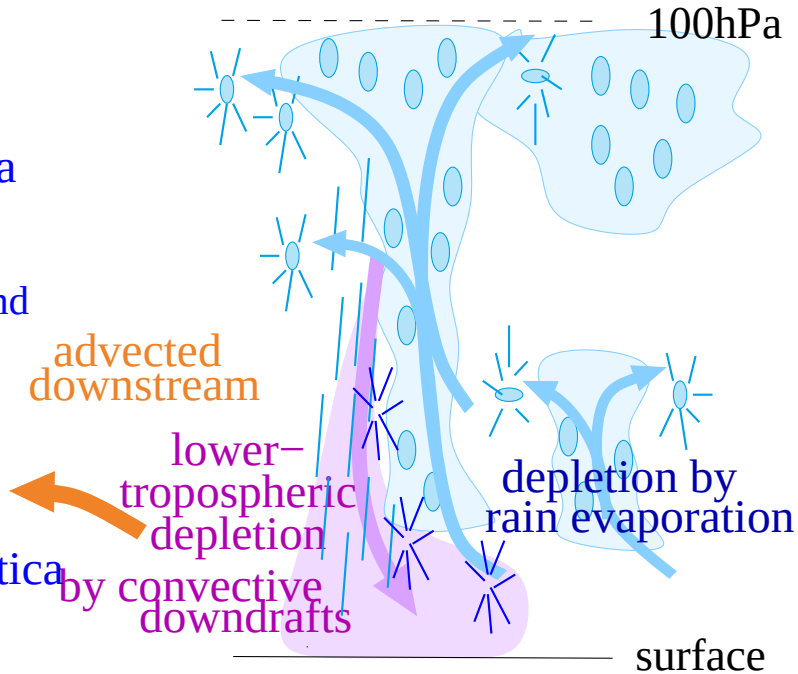

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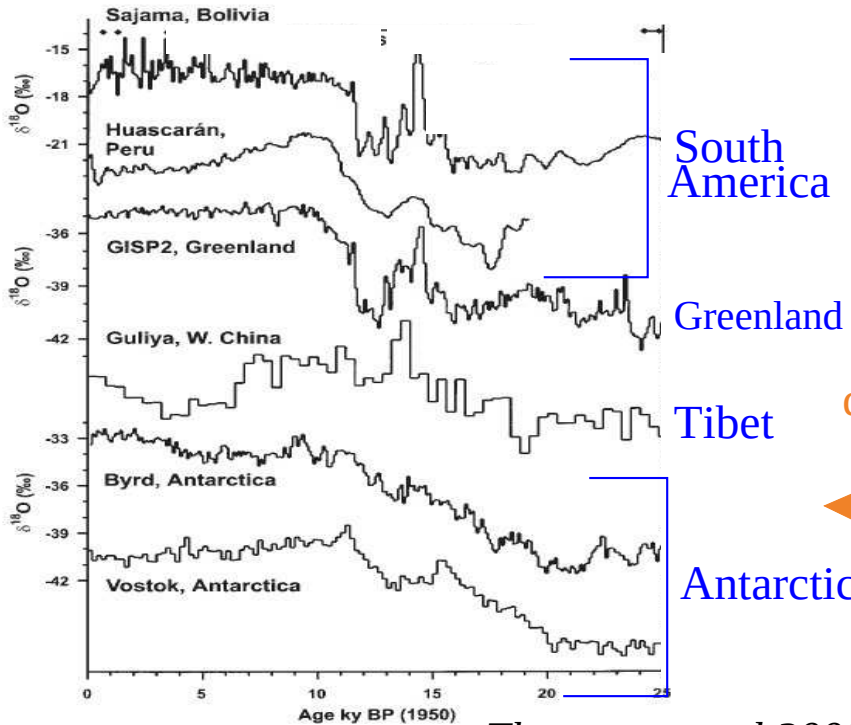

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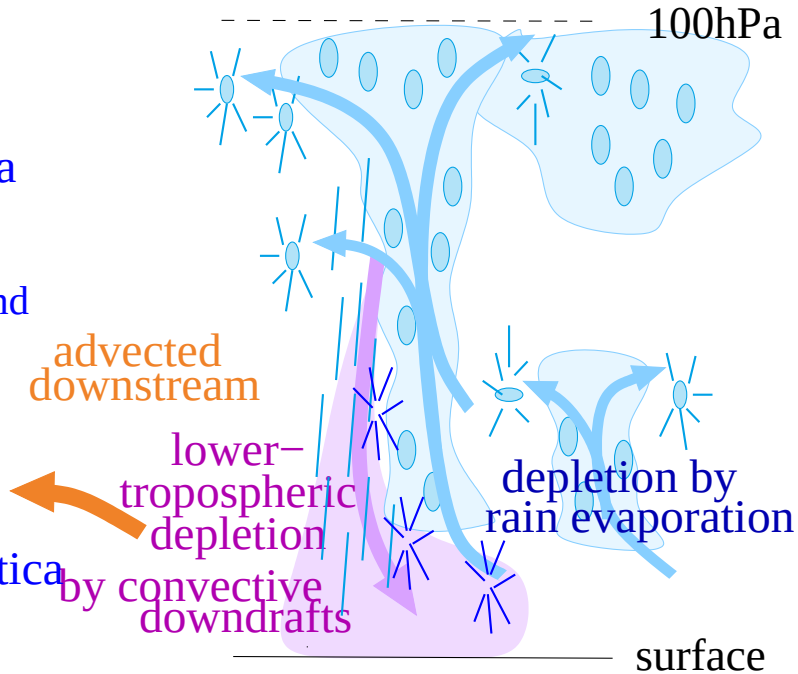


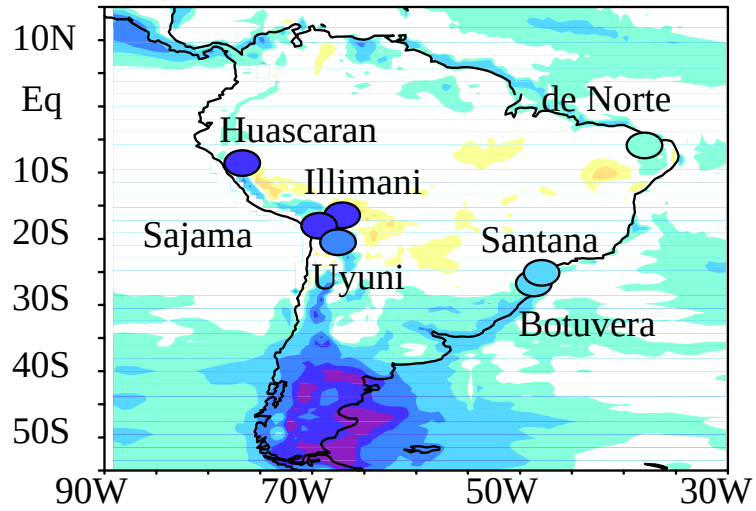
Risi et al 2008

$\Longrightarrow$ Use LMDZ GCM with isotopes (*Risi et al 2010*):
11 different climates (e.g. LGM, MH); 4 different model physics

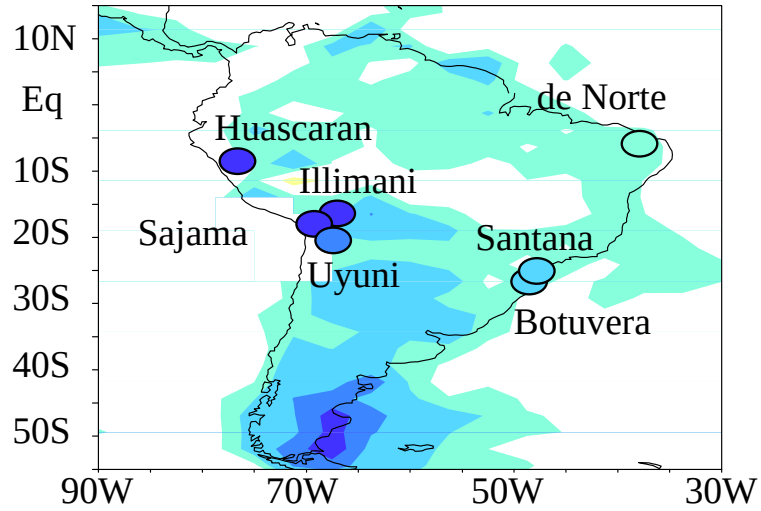
Paleo simulations with LMDZ-iso

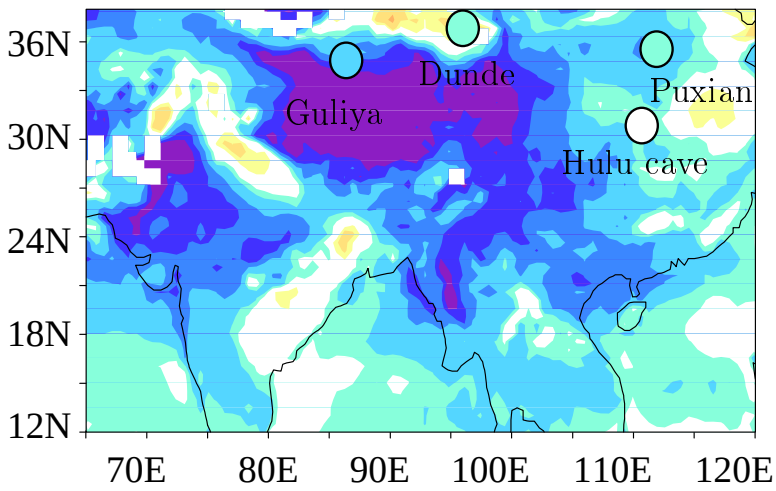
Last glacial maximum - present

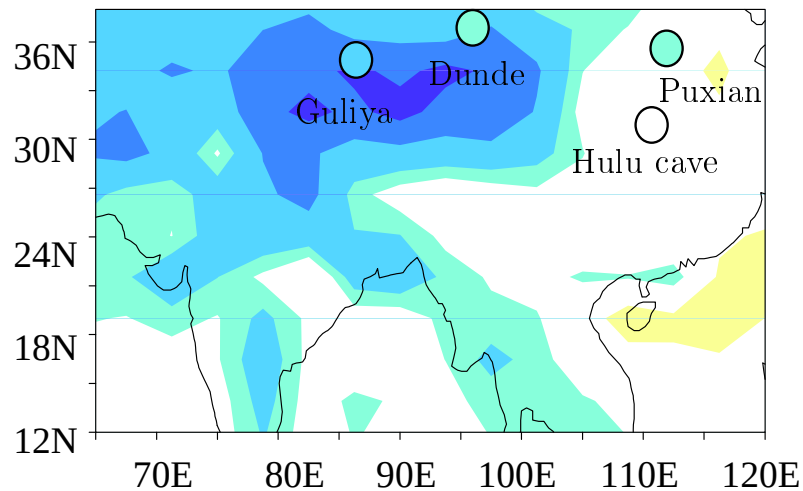
LMDZ zoom 50km resolution

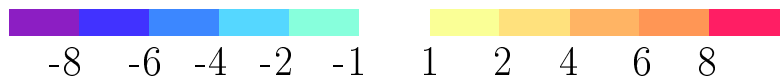


LMDZ 2.5x3.75



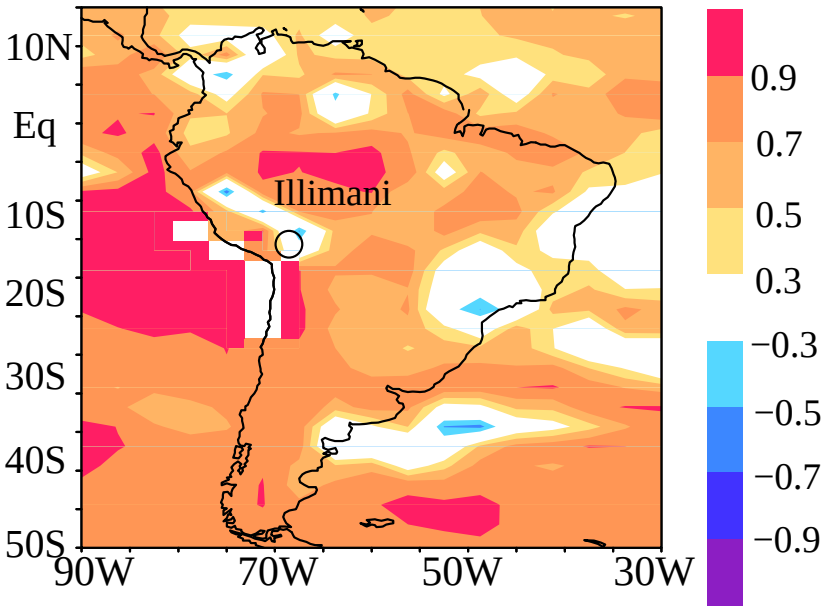




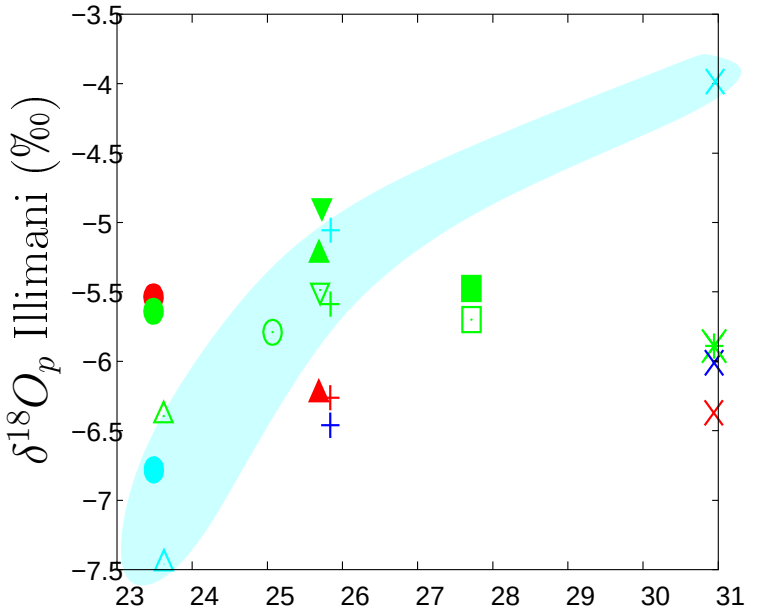


$\Delta\delta^{18}O$ (‰) (corrected for sea water)

Is $\delta^{18}O_p$ a proxy for temperature?



correlation between tropical mean SST and $\delta^{18}O_p$



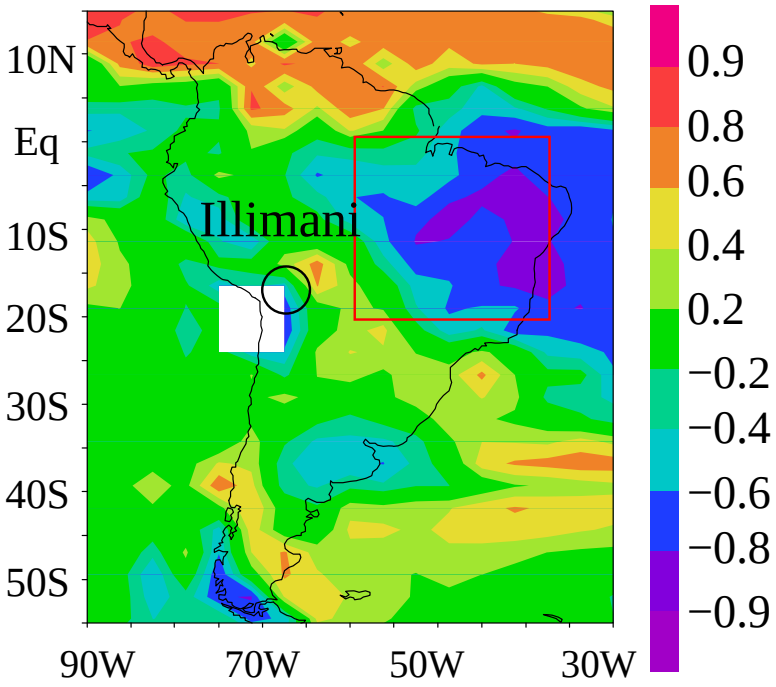
tropical-mean (30°S-30°N) SST (°C)

Climates:	
+ present−day	○ LGM climap
× 4xCO2 IPSL	● LGM IPSL
✳ 2xCO2 IPSL	△ LGM IPSL THCoff
□ 2xCO2 ECHAM	▲ MH IPSL
■ 2xCO2 MIROChi	▽ Eemien IPSL
	▼ Eemien IPS THC+

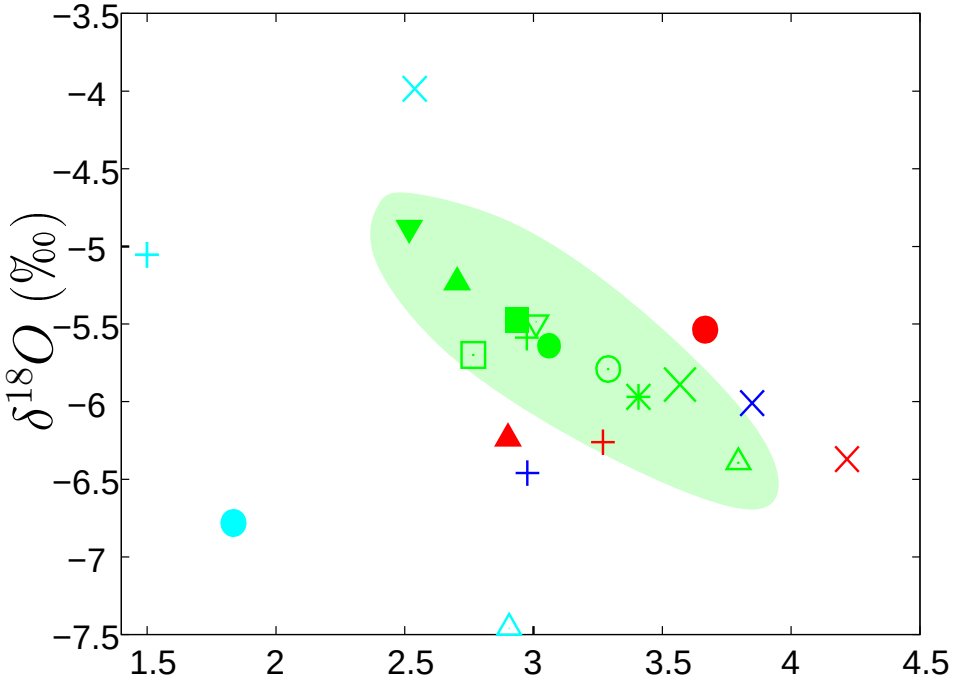
Model versions
- control
- less diffusion
- more detrainment
- less condensation
- 50 km resolution

- temperature = significant control at paleo time scales
- but sensitive to model physics

Is $\delta^{18}O_p$ a proxy for precipitation?



correlation between $\delta^{18}O_p$ at site and precipitation around



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Model versions
- control
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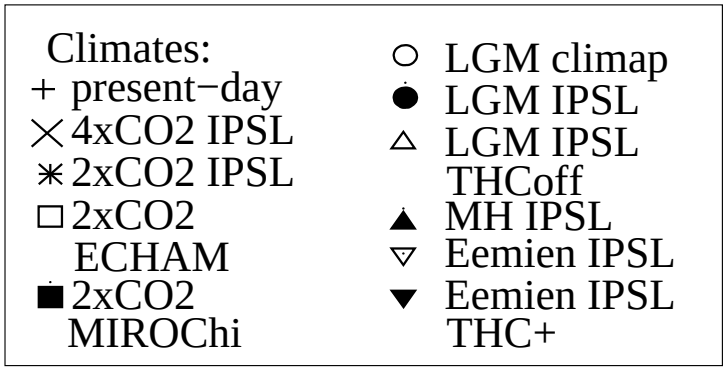
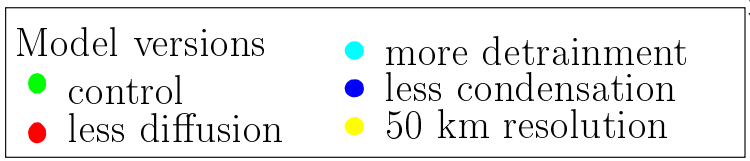
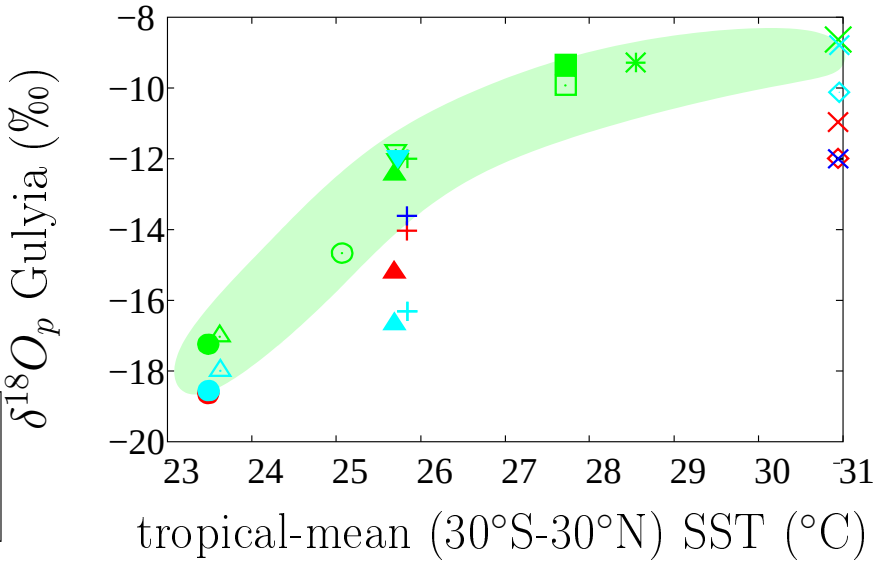
- 50 km resolution

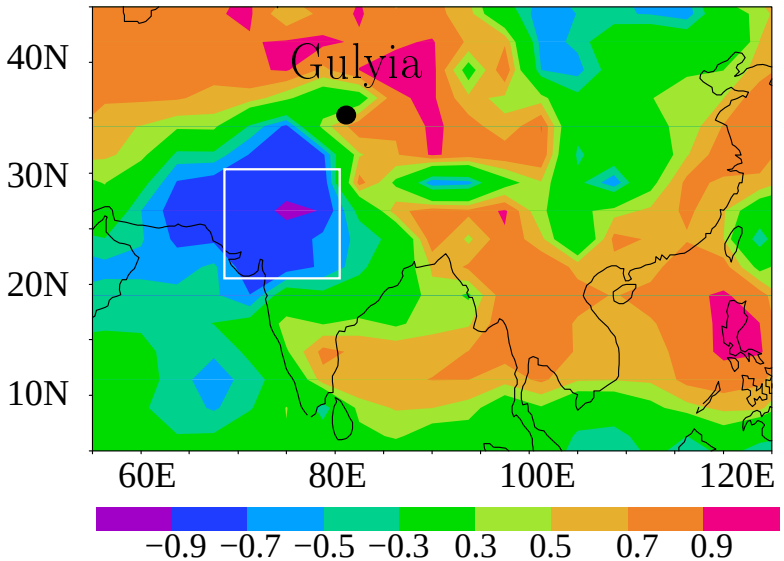
- $\delta^{18}O_p$ influenced by past regional precipitation changes
- but sensitive to model physics

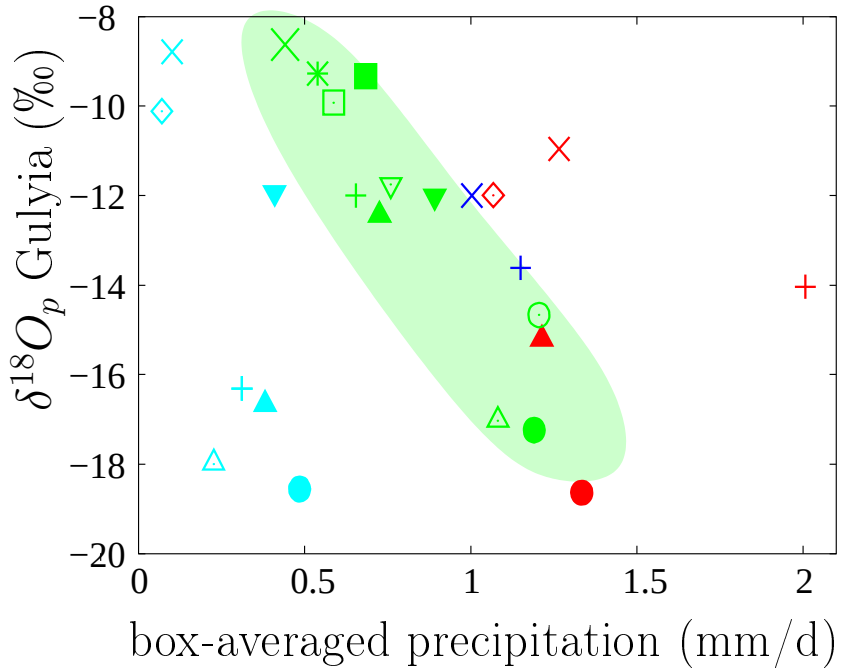
And in other regions?











Summary on the interpretation of paleo isotopic records

- At paleo time-scales and especially during LGM, temperature is a major control in LMDZ
- Also relationship with upstream precip
- But sensitive to the model physics

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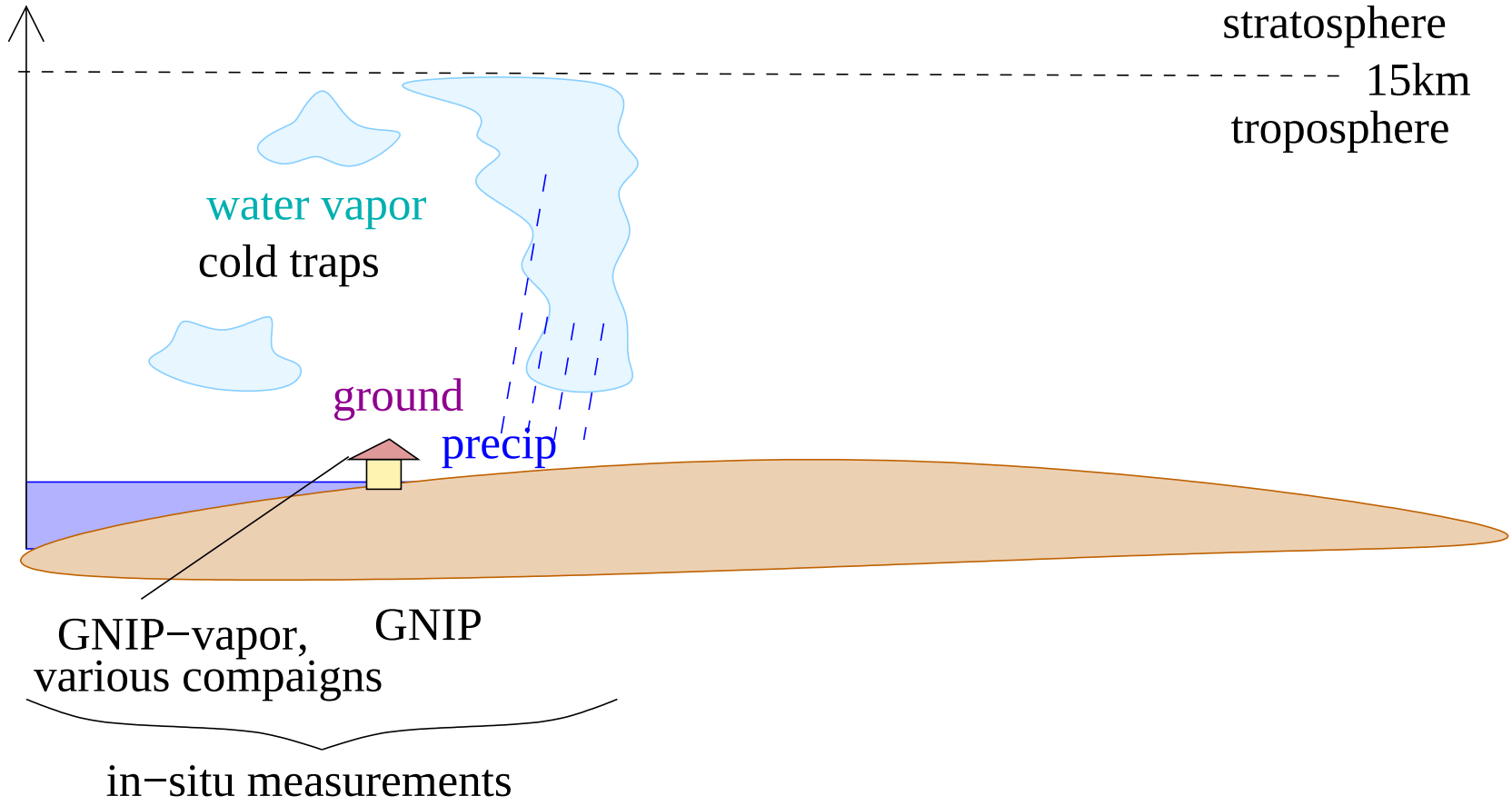
$\Longrightarrow$ Which physics is the most realistic?

$\Longrightarrow$ use present day measurements to better test climate-$\delta^{18}O$ relationships?

Use present-day measurements?



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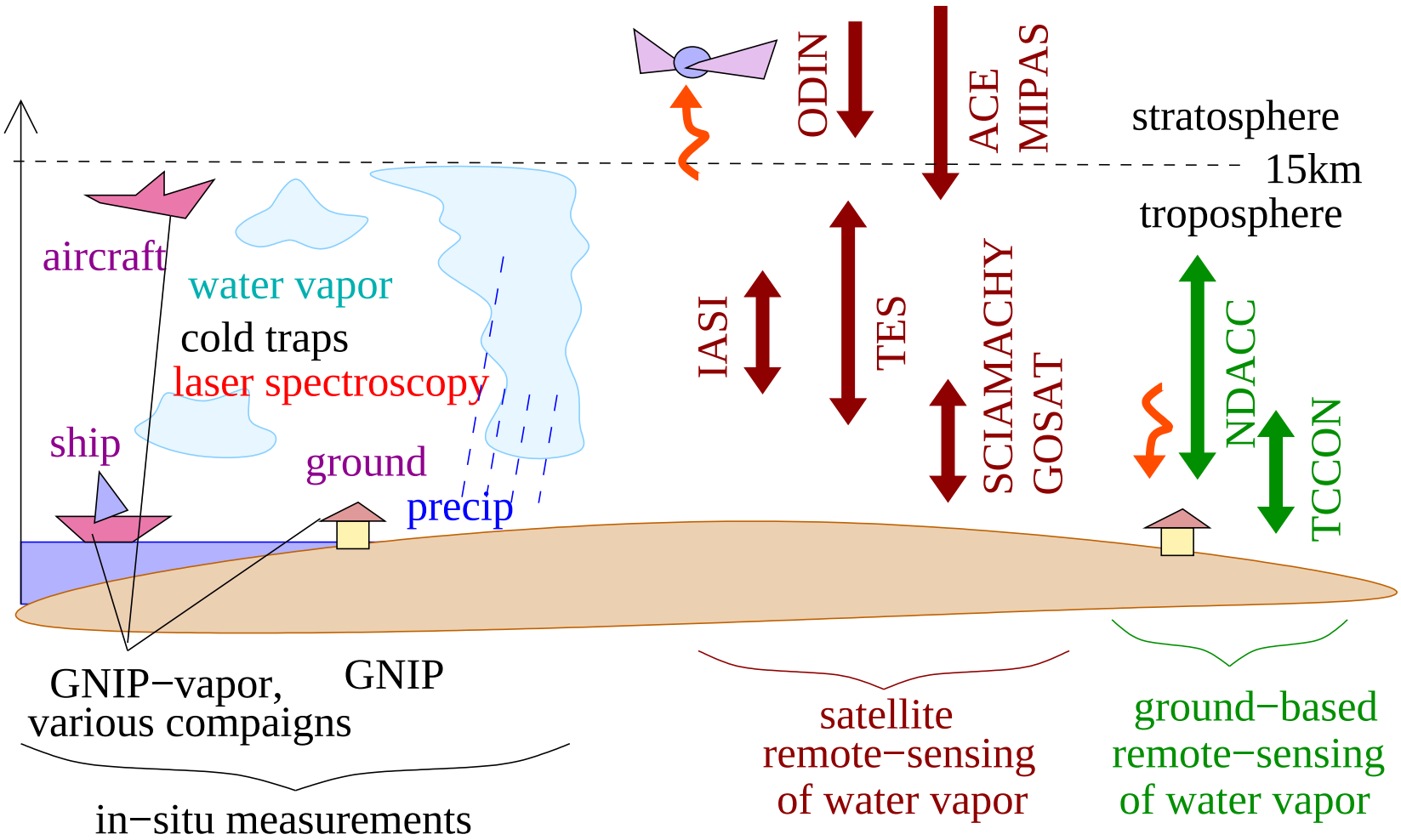

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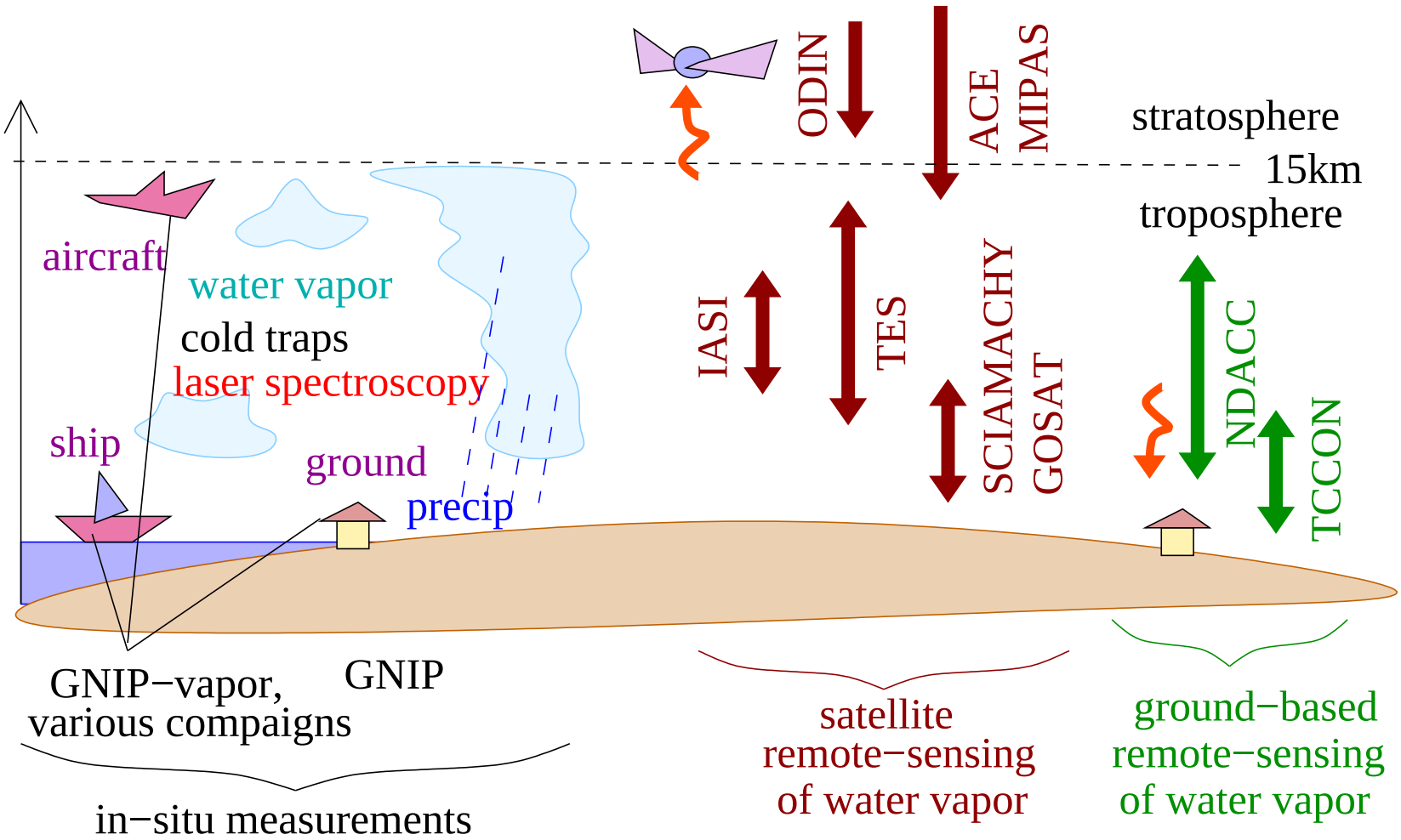
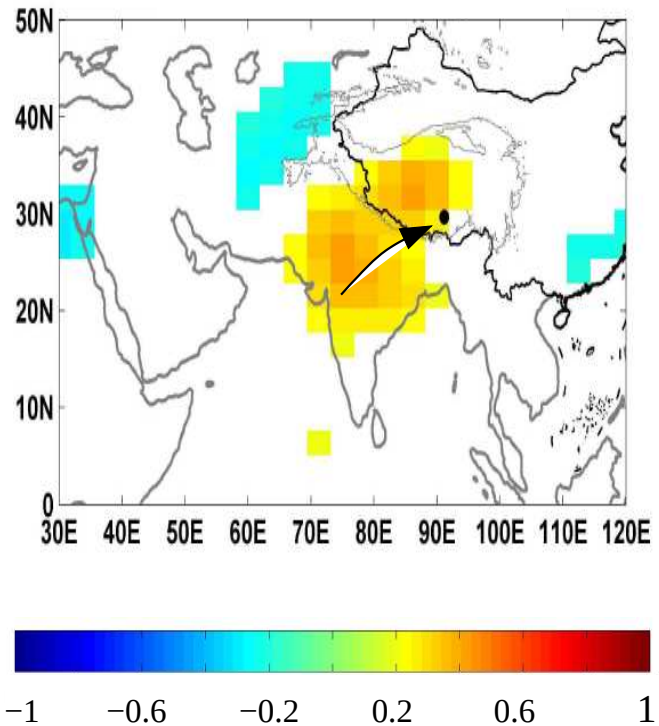


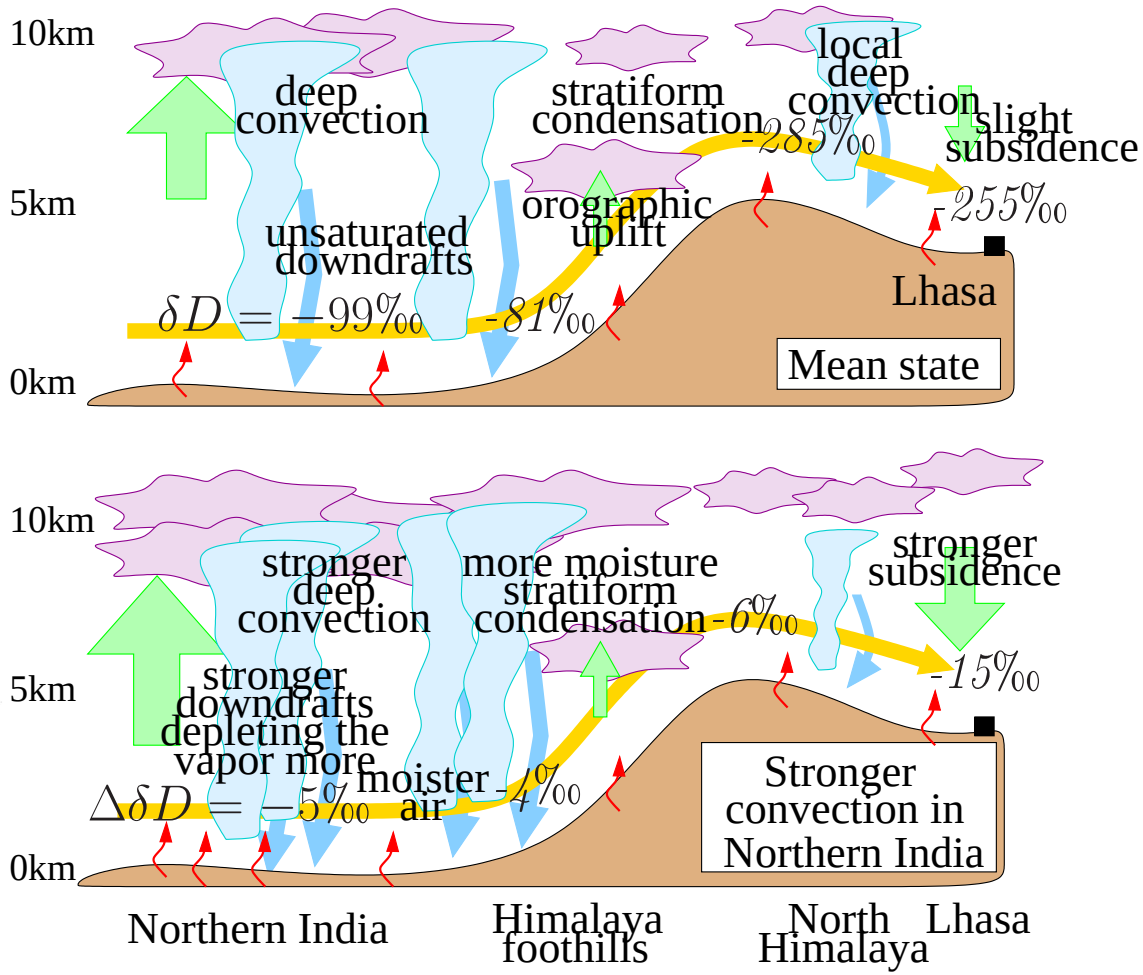
- TES: weekly vertical profiles of δD
- IASI: 2 daily global coverage of δD

Case study: what controls $\delta^{18}O_p$ in Lhasa?

- Work by You He: weekly, JJAS, Lhasa, TES+LMDZ
- precip $\delta^{18}O$ varies follows vapor δD $\Rightarrow$focus on vapor



Correlation between δD at Lhasa at 500 hPa observed by TES and OLR 2 days before



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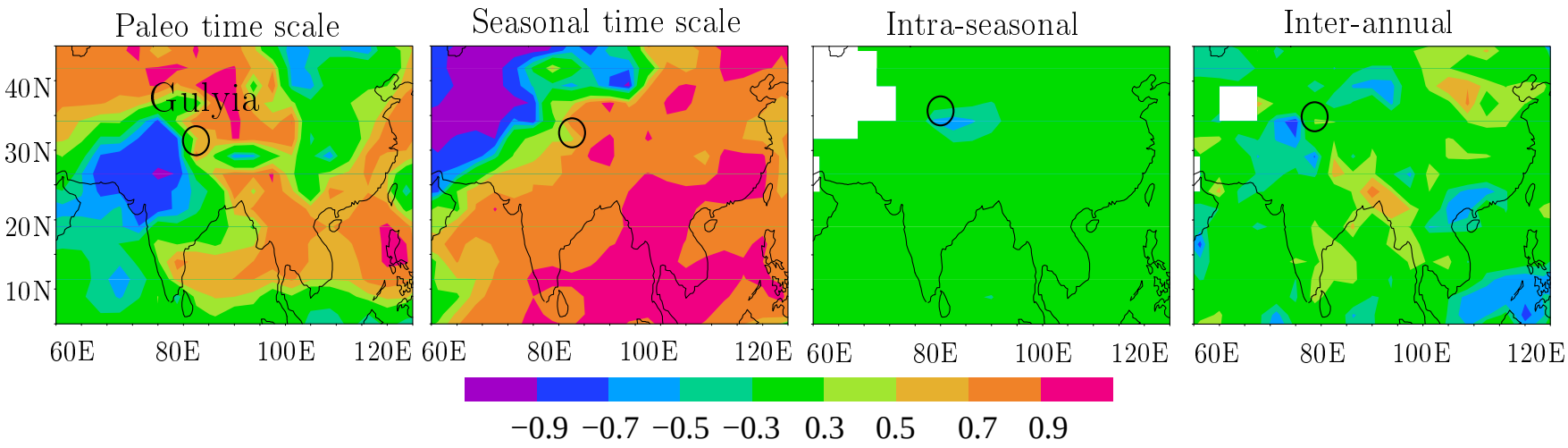

correlation between $\delta^{18}O_p$ at Gulyia and precipitation around

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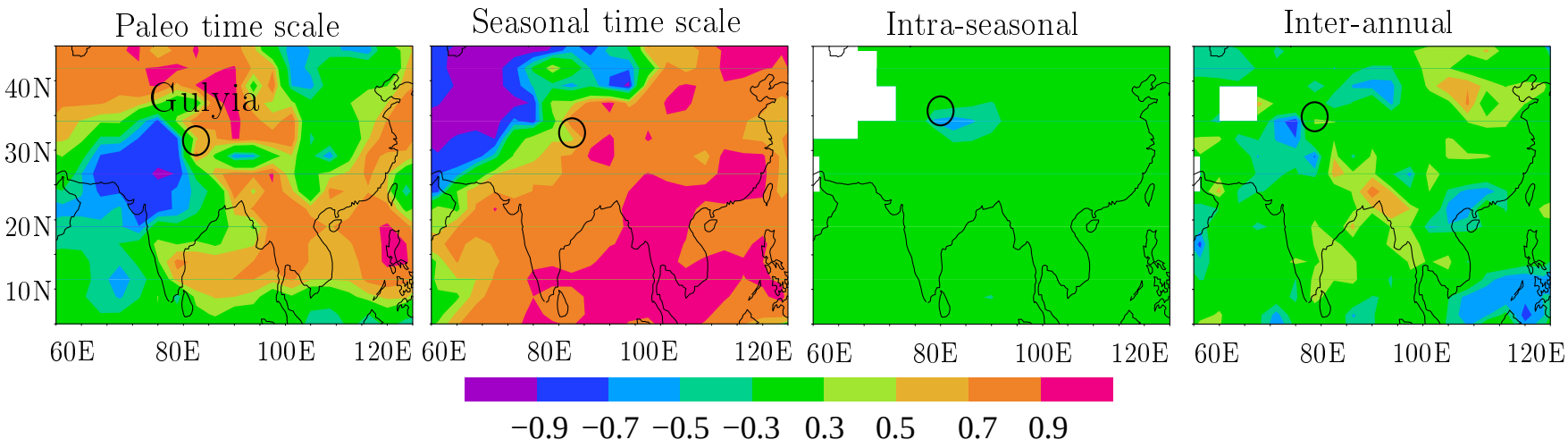

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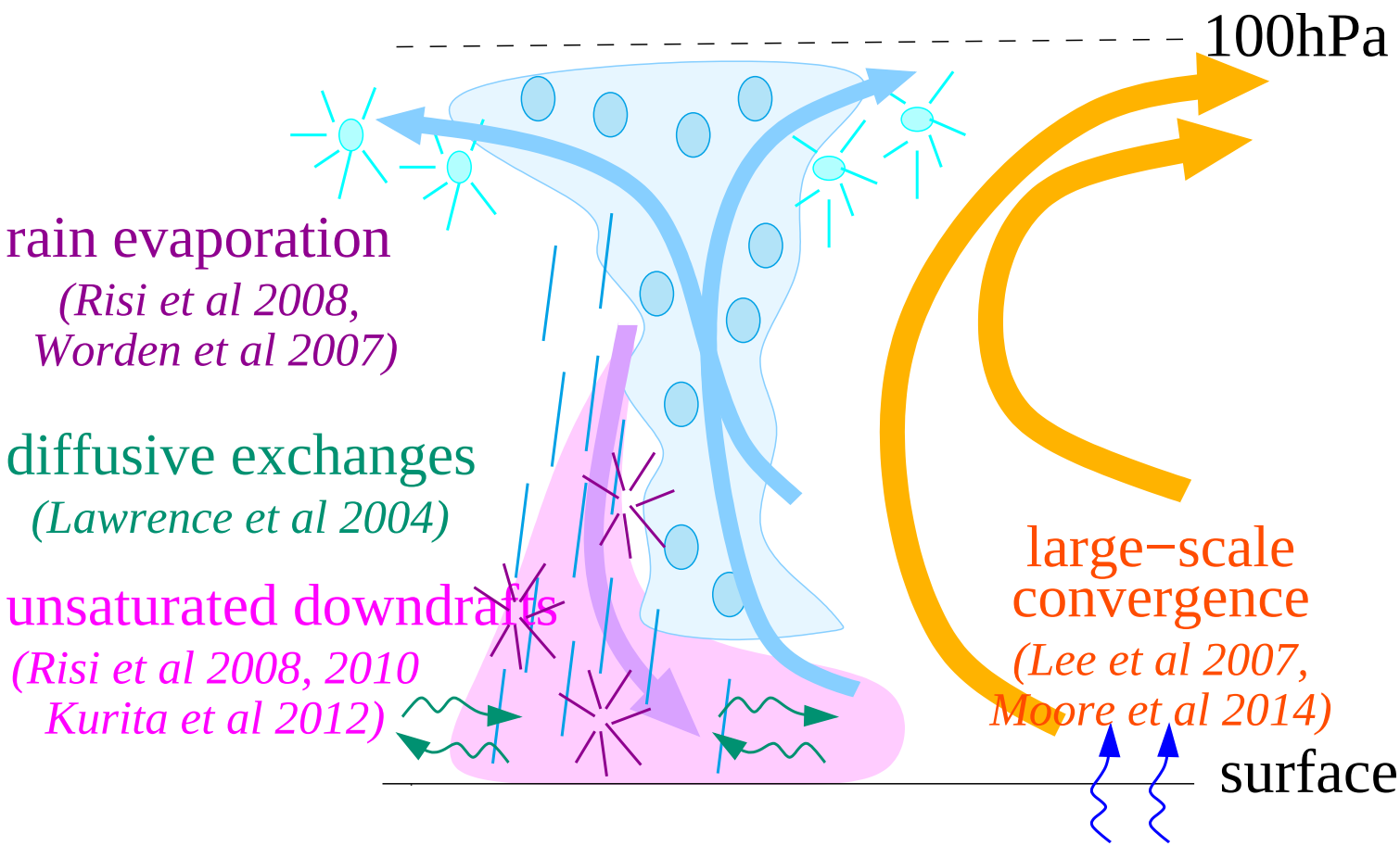
$\Longrightarrow$Understanding daily controls not enough for paleo controls

- work in progress: are some sensitivity tests more realistic at daily time scales?
  Do we expect them to be more realistic for paleo time scales?

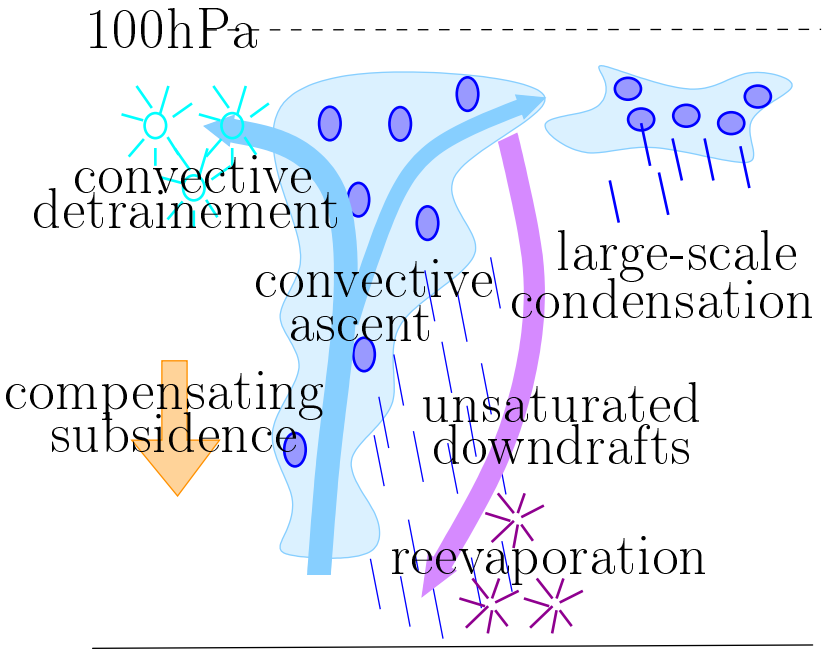
Why is the link between isotopes and convection so sensitive to the model physics?

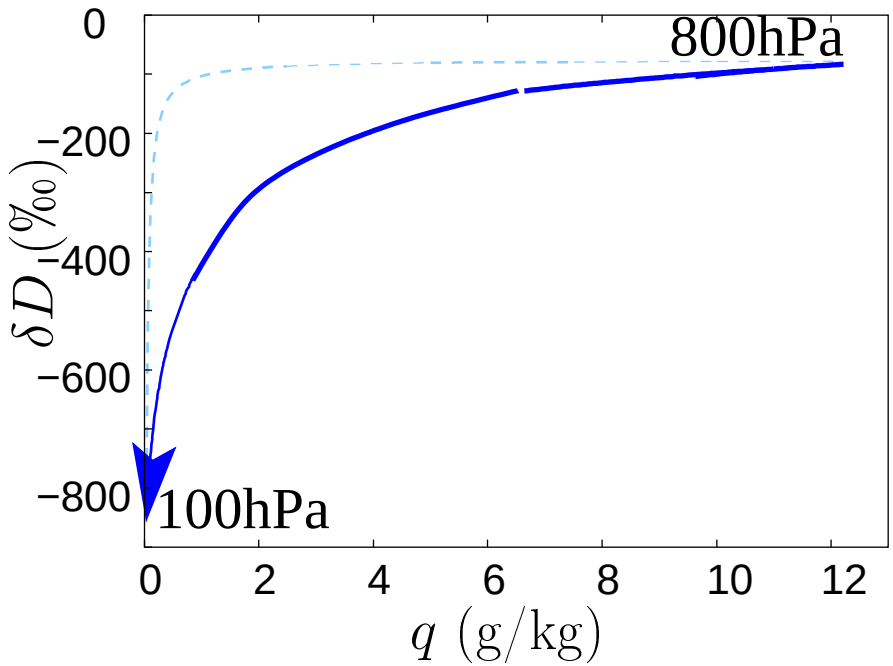
What causes the amount effect?



Theoretical framework: q-δD

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





large−scale condensation

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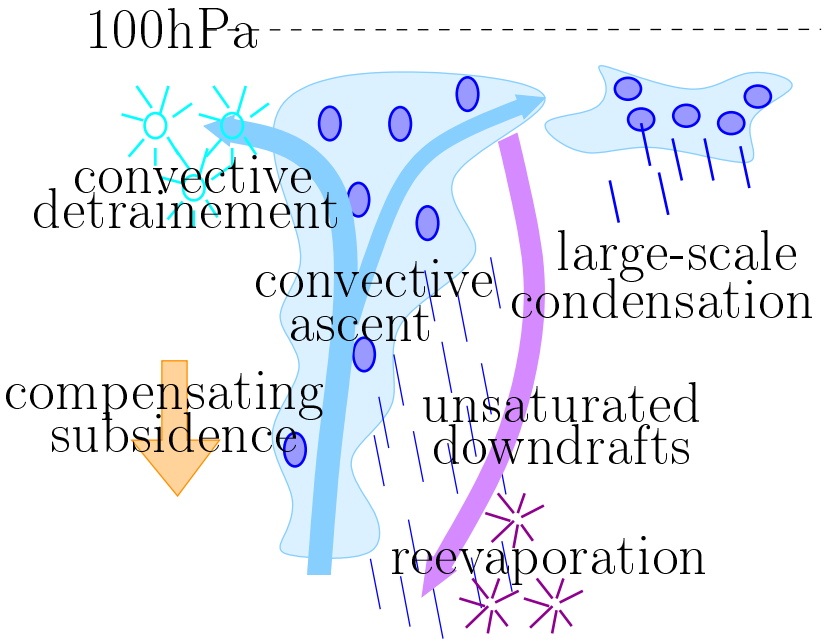

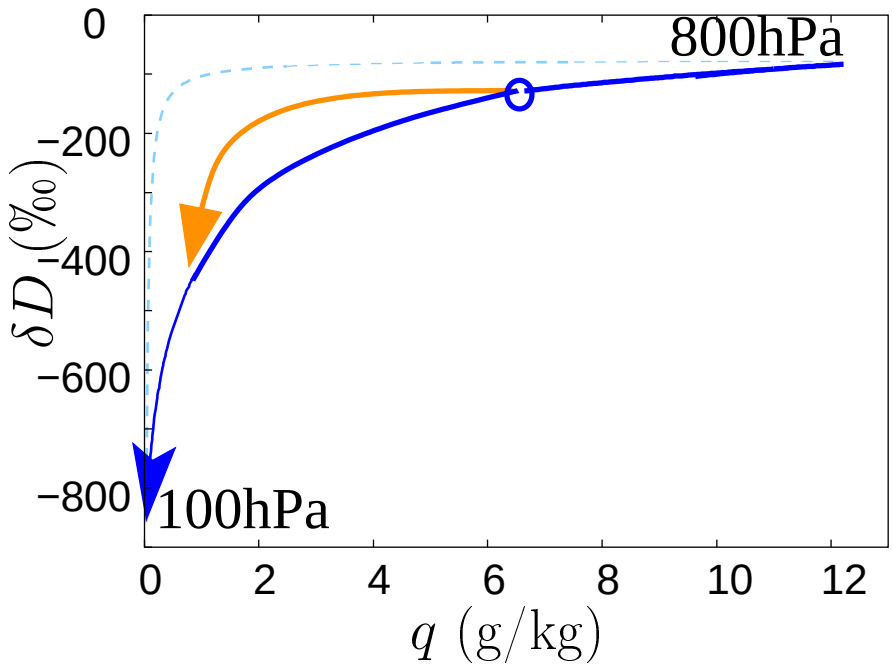

large−scale condensation

subsidence

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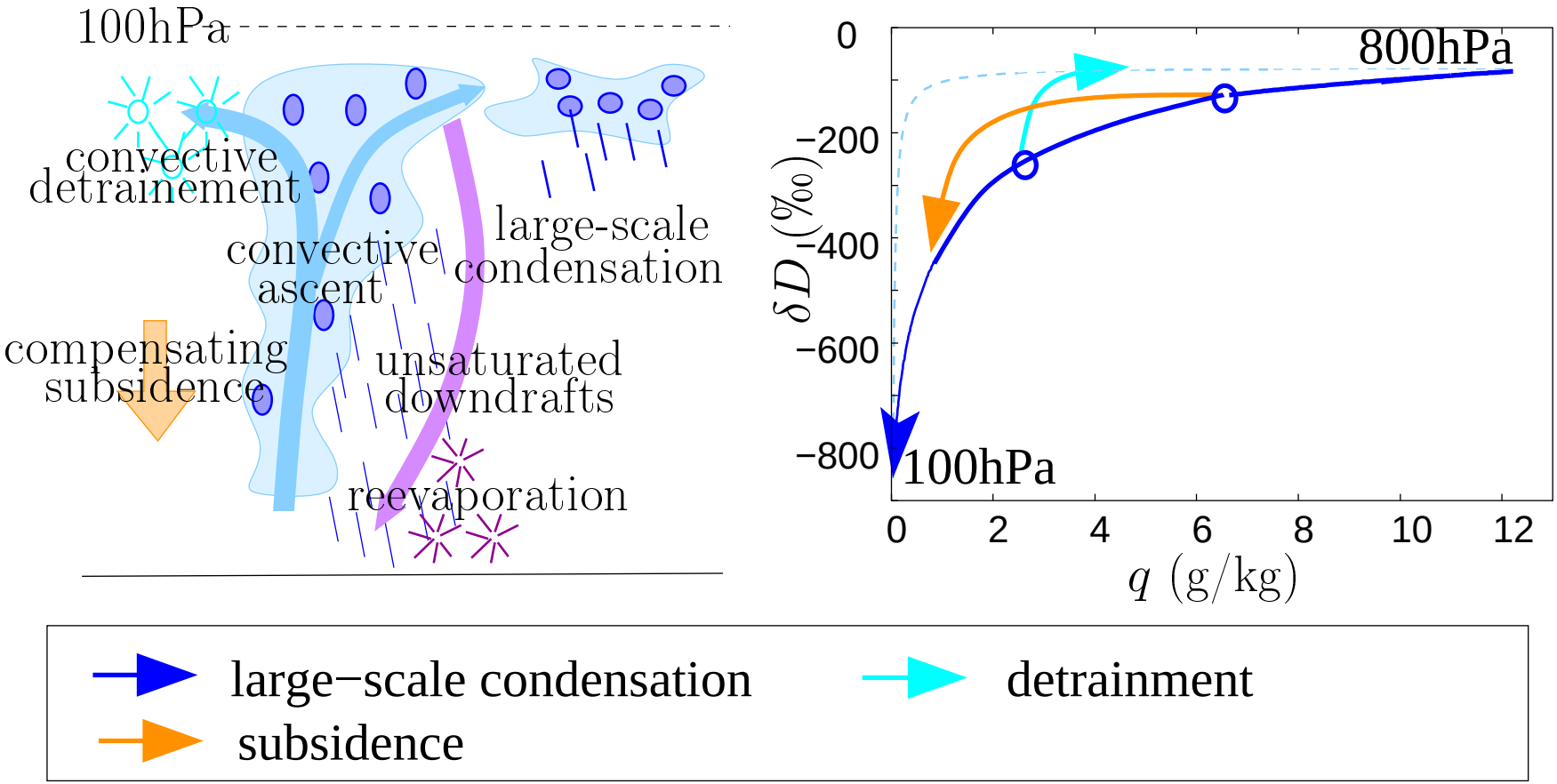

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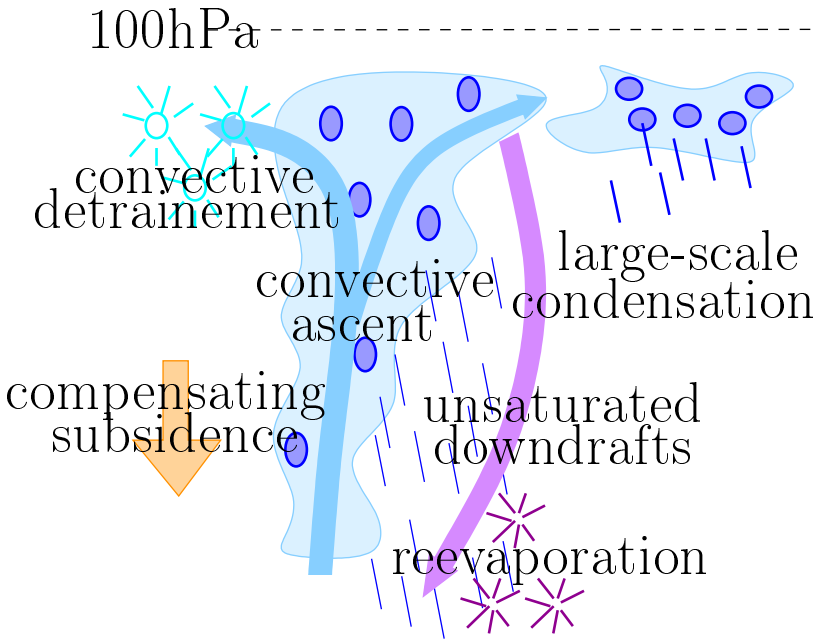
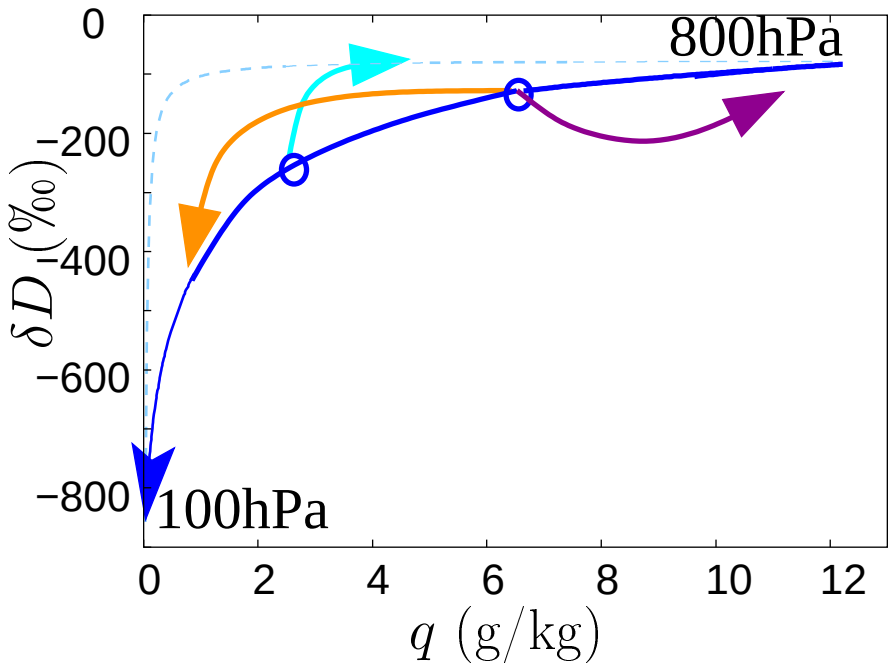
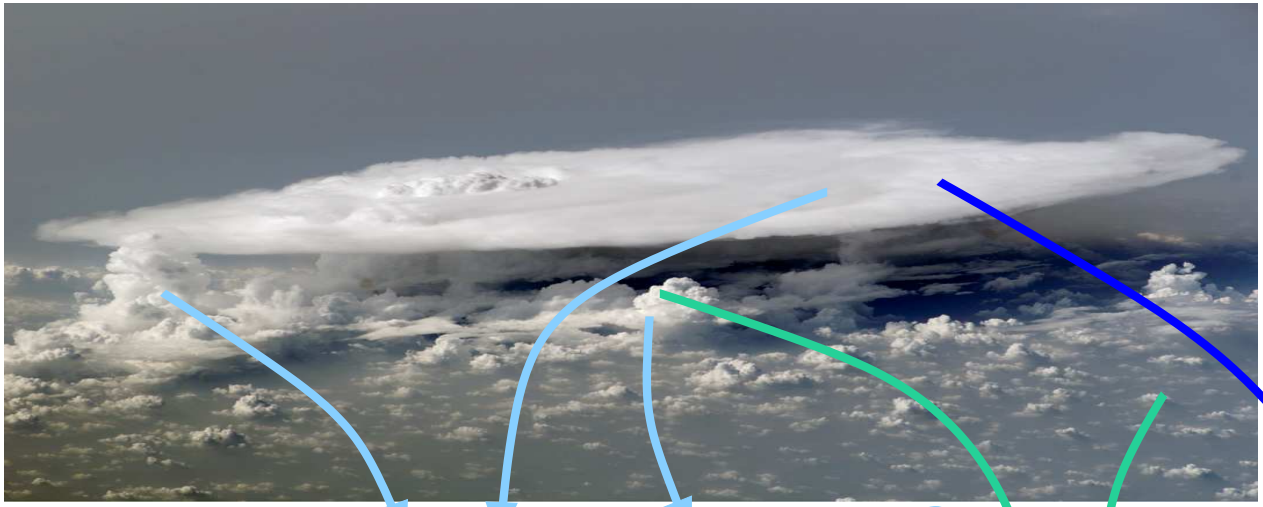
- Moistening and dehydrating processes *(Worden et al 2007)*

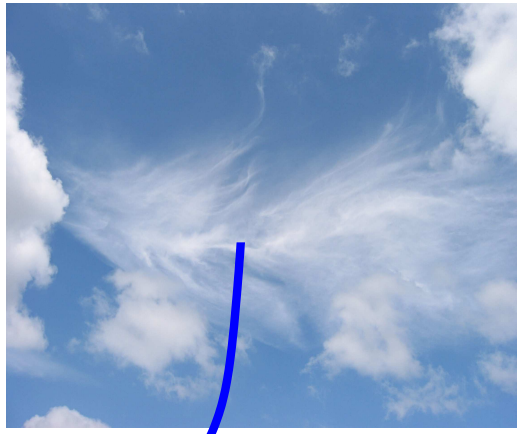




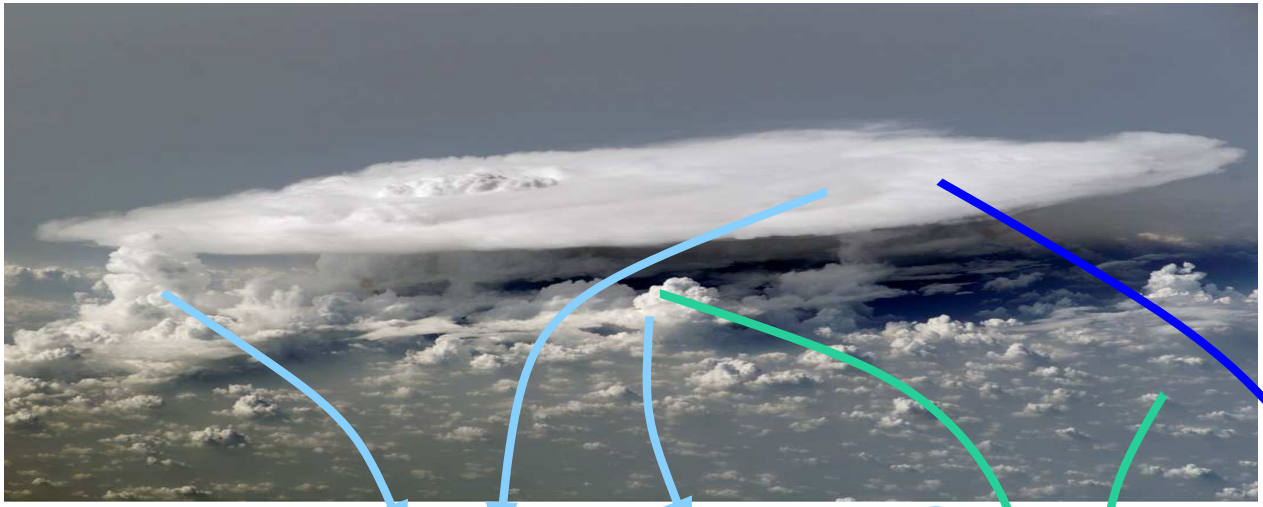
large−scale condensation
detrainment
subsidence
rain reevaporation

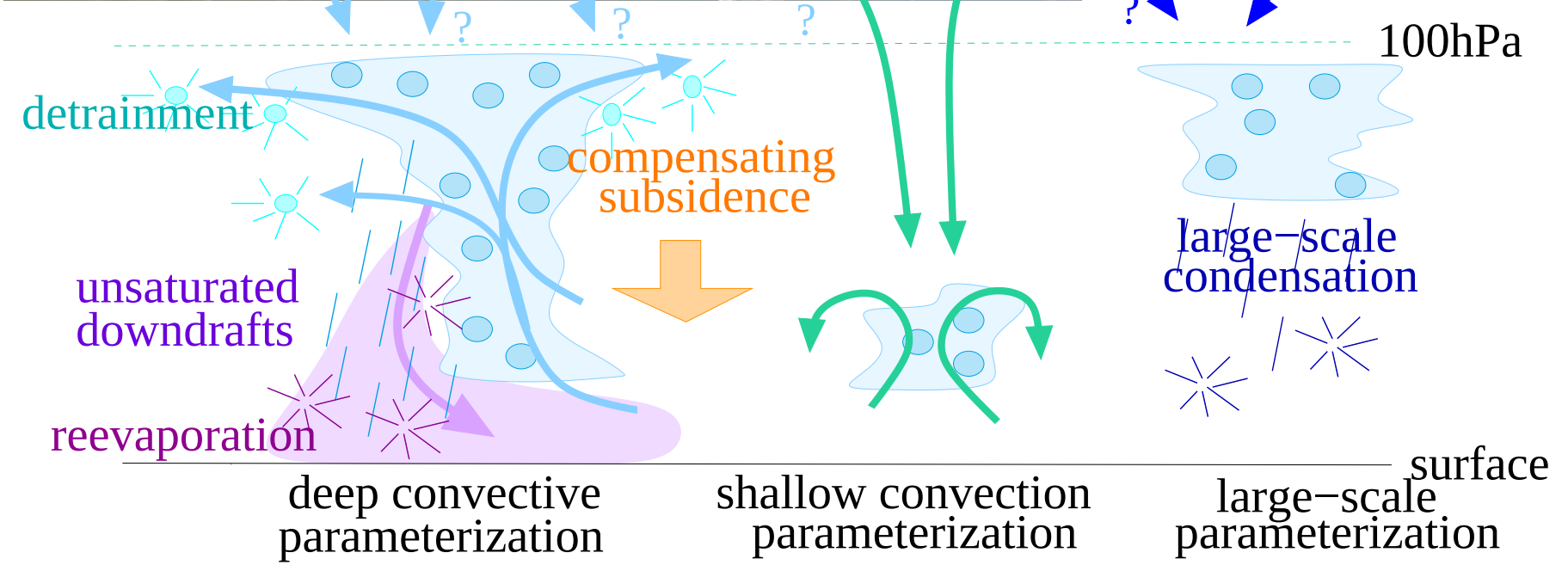
Convection vs large-scale schemes





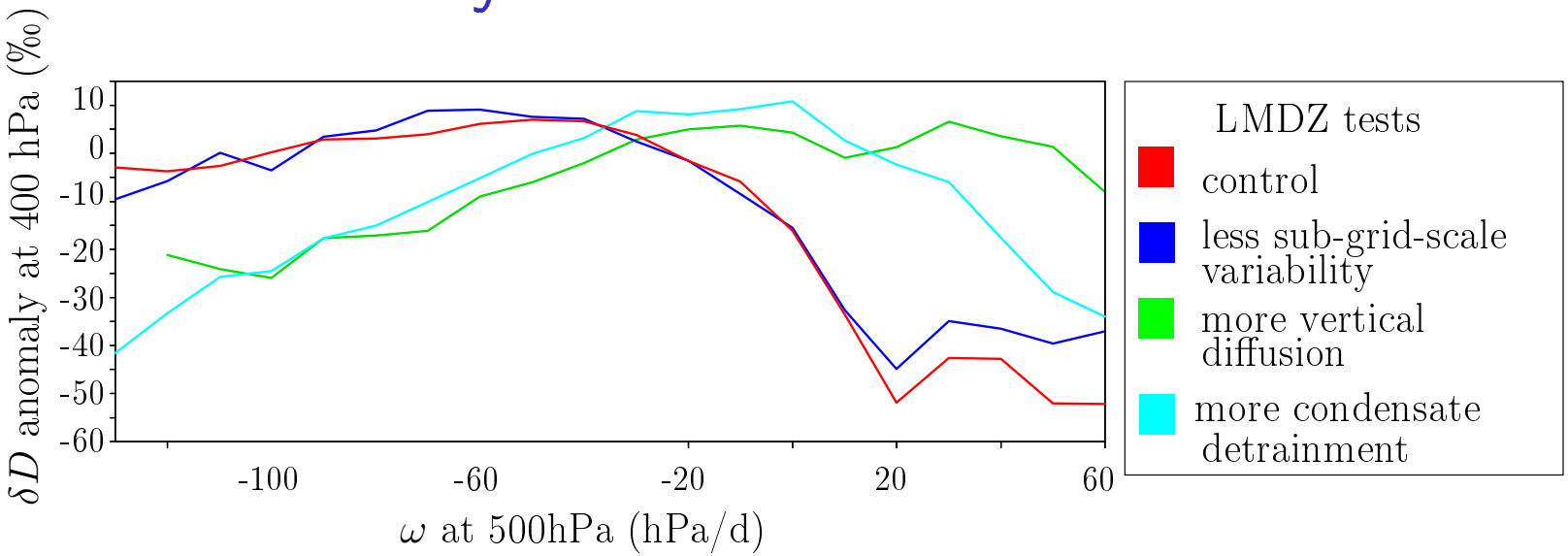
Convection vs large-scale schemes



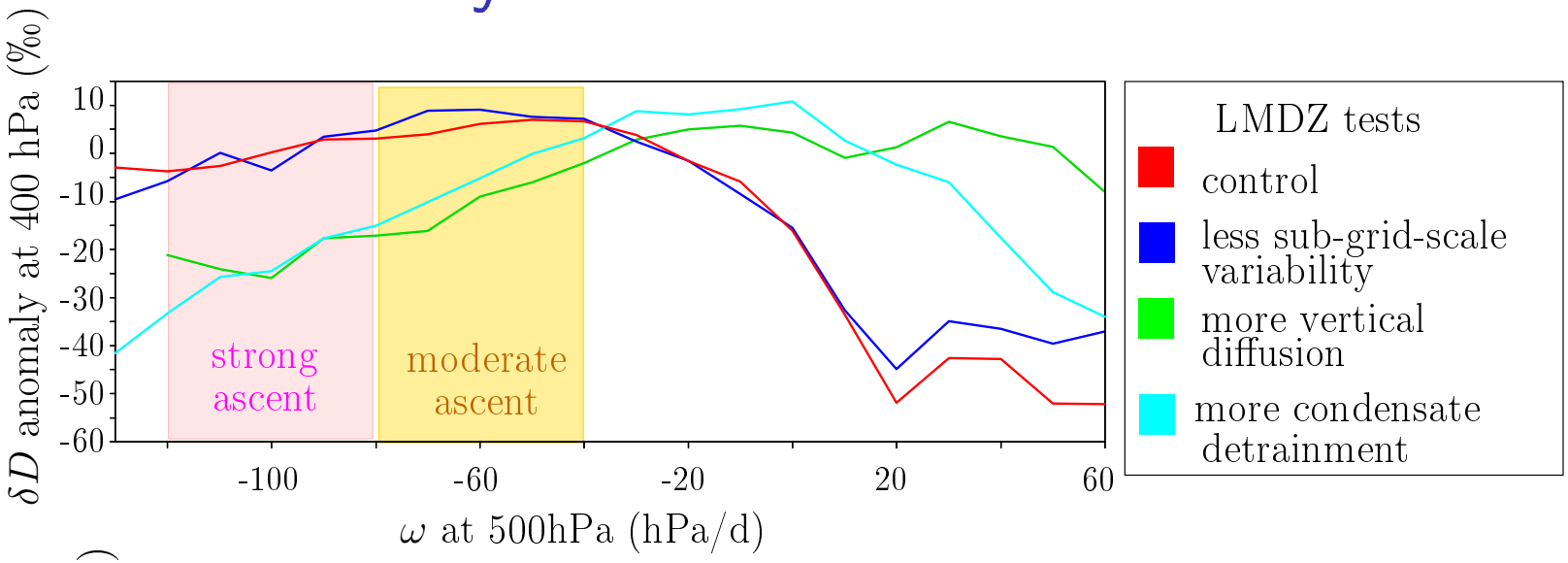


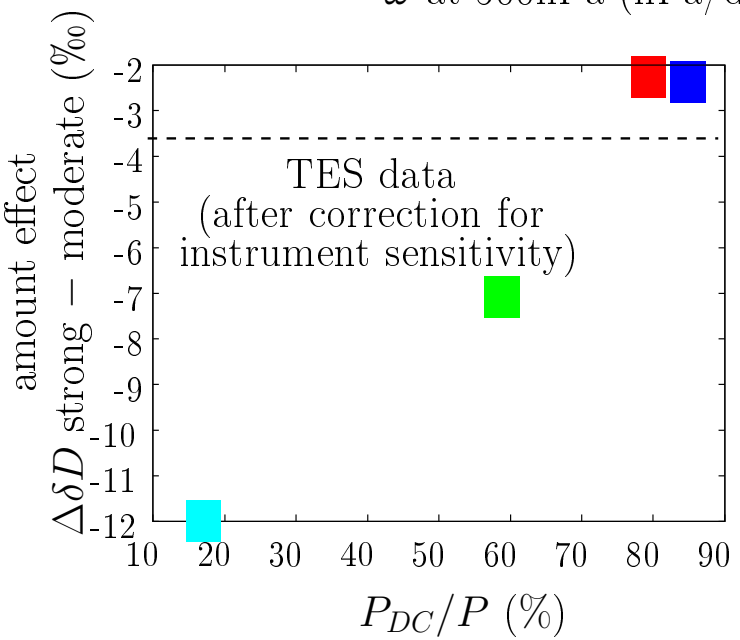
- conv vs large-scale precip arbitray

Sensitivity tests in LMDZ

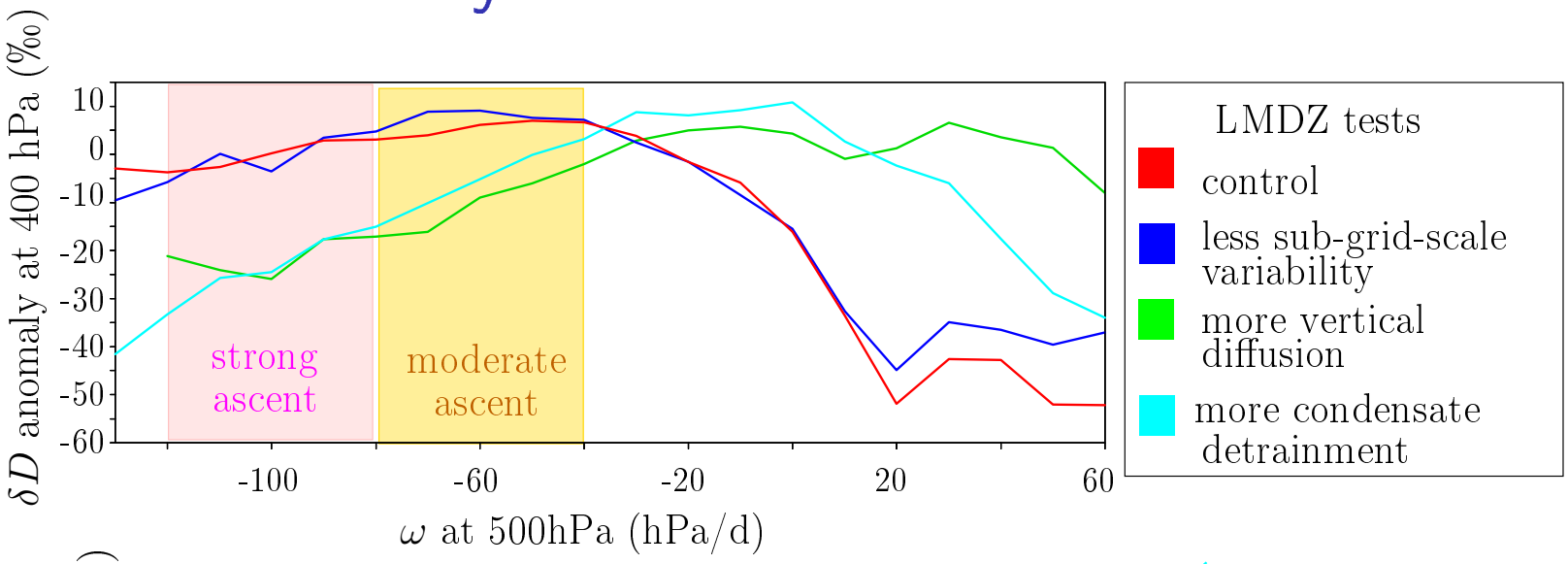


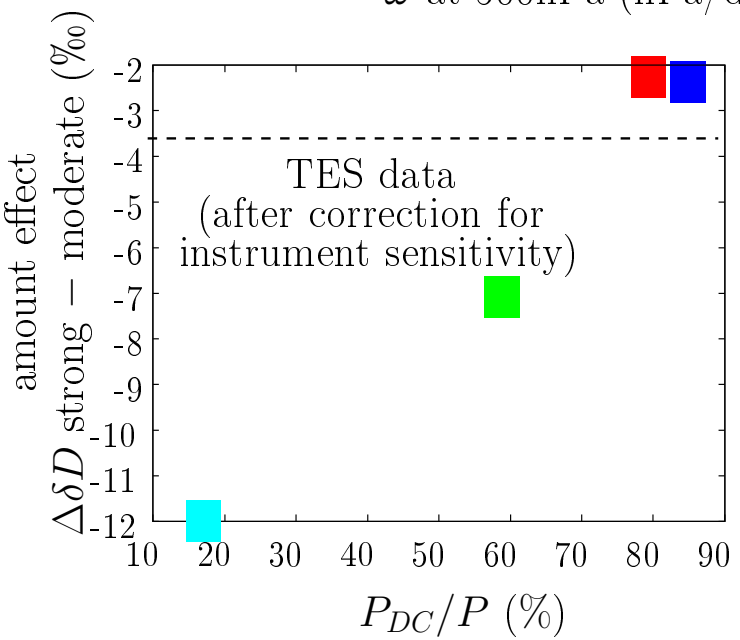
Sensitivity tests in LMDZ

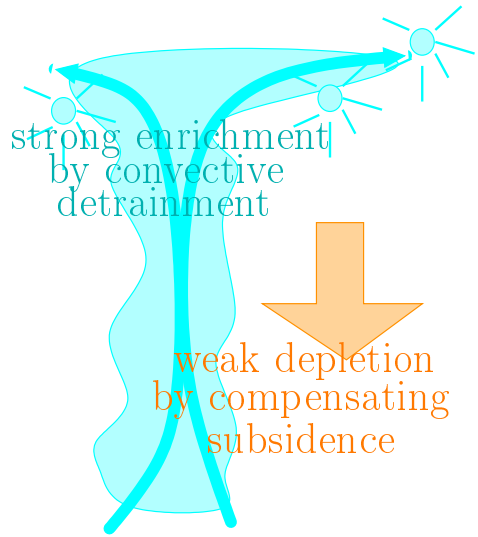




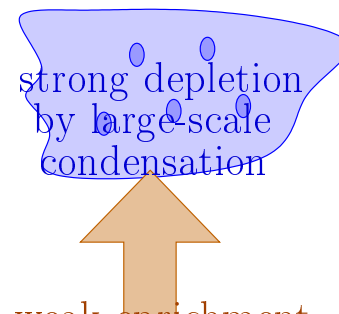
Sensitivity tests in LMDZ





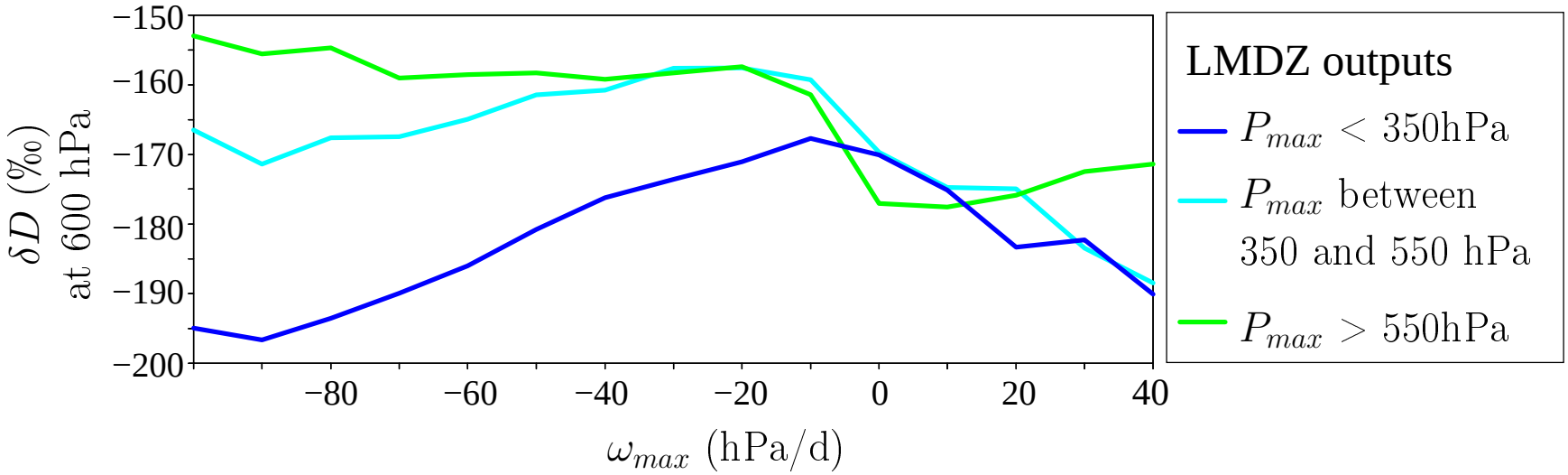


DC dominates

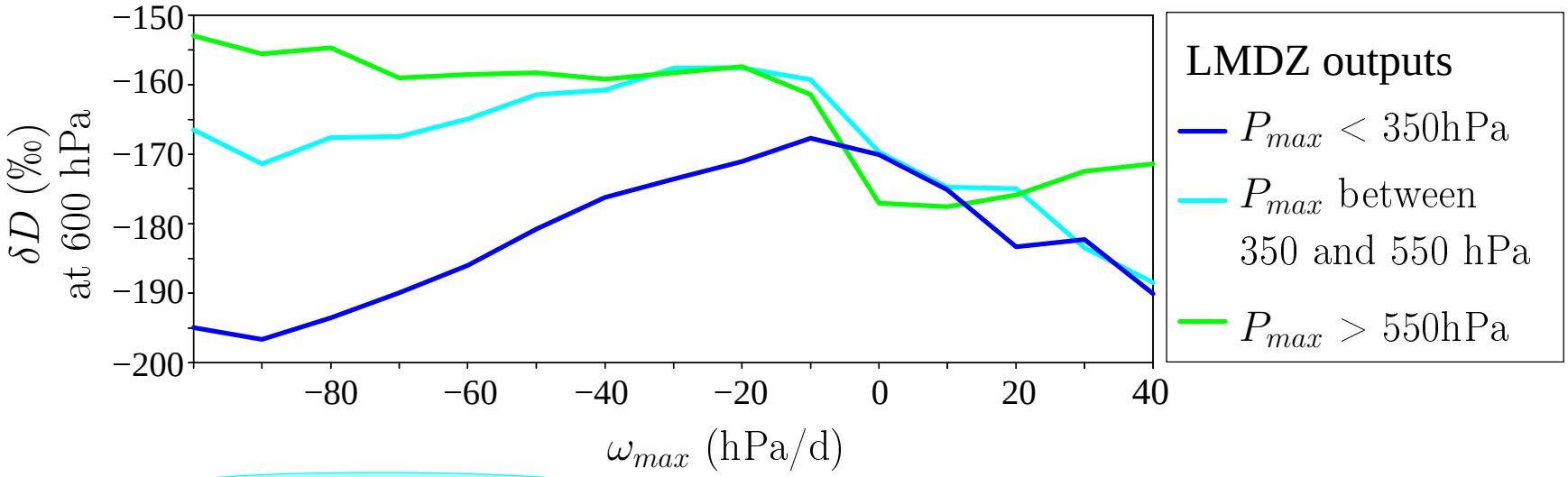


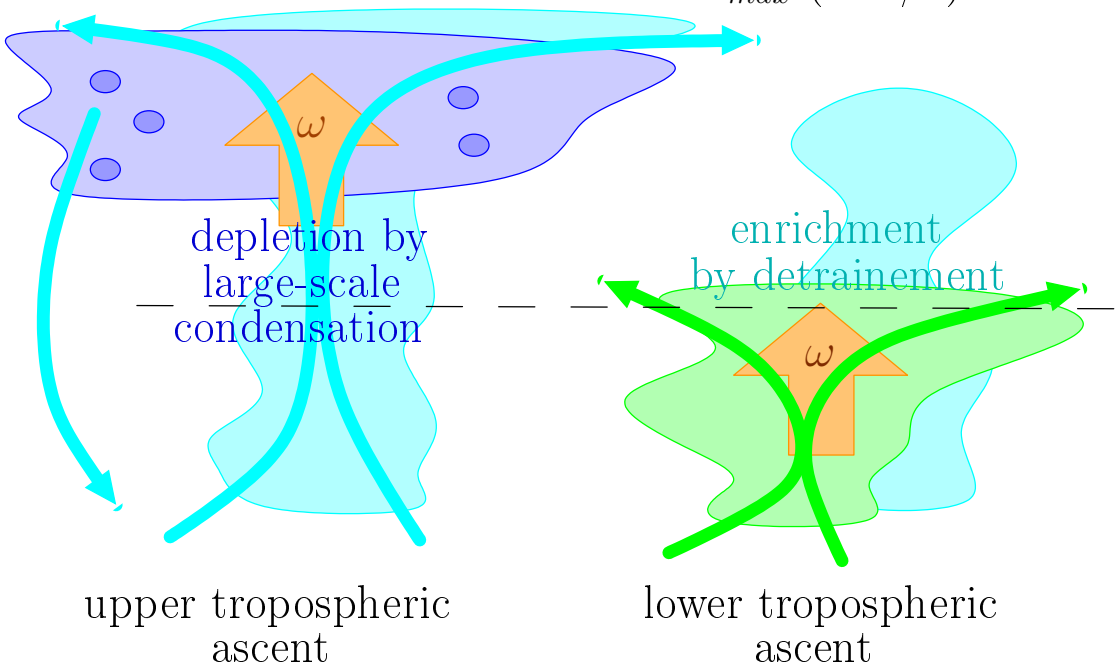
LS dominates

Sensitivity to large-scale velocity profile

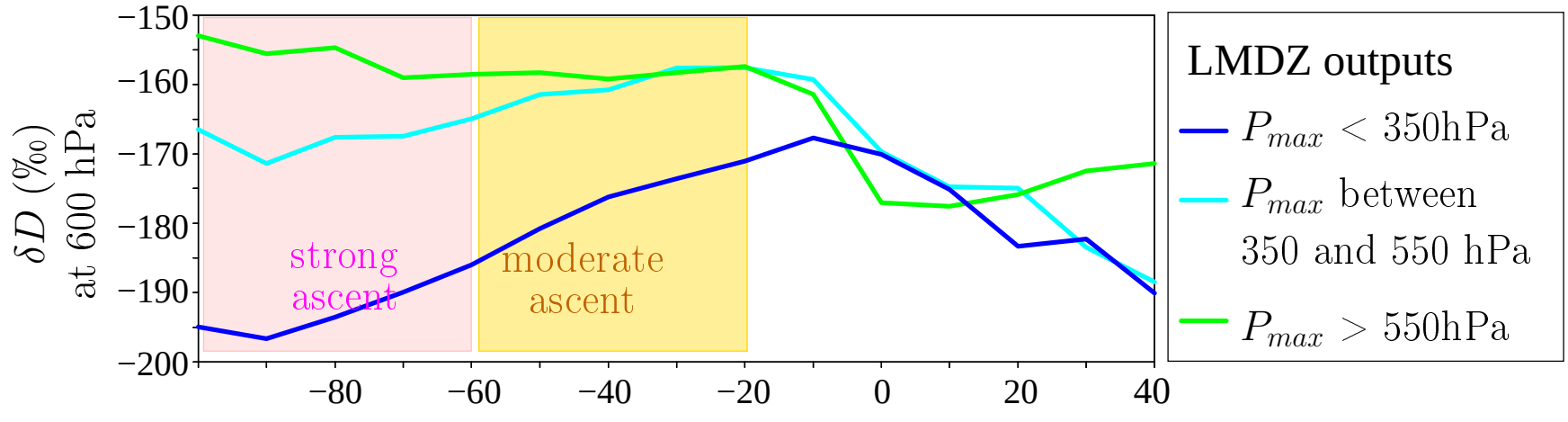


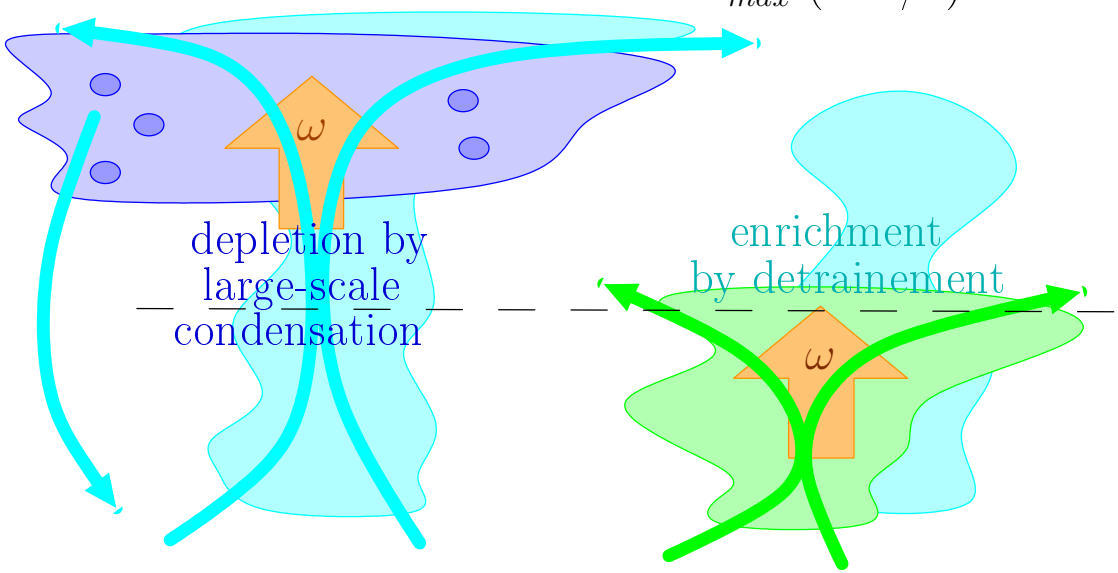
Sensitivity to large-scale velocity profile

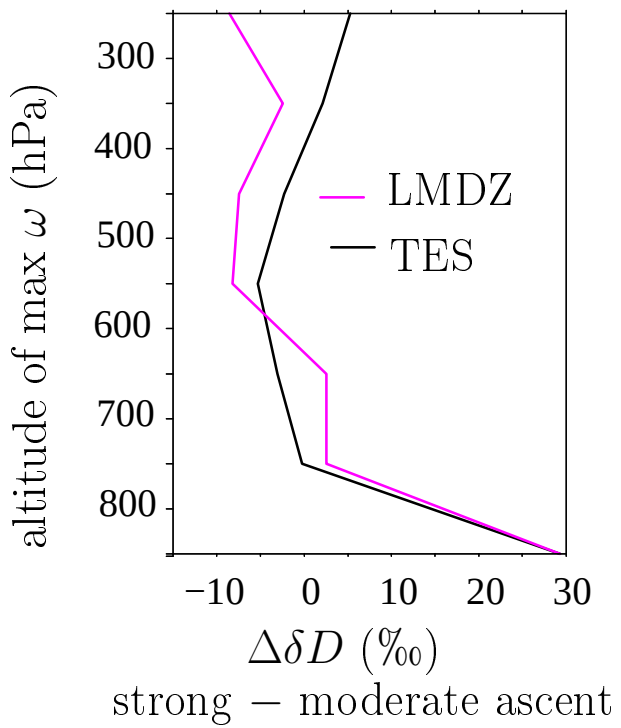




Sensitivity to large-scale velocity profile







Summary on convection-isotopes link

- link isotopes-convection complex
- precipitating events deplete the tropospheric vapor all the more as it is associated with large-scale precipitation

⇒use it to evaluate conv vs large-scale precip partitionning and underlying heating profiles?
Potentially key factor for intra-seasonal variability (*Kim et al 2012*)

- precipitating events deplete the tropospheric vapor all the more as it is associated with top-heavy ascent

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Key factor for cloud feedbacks (*Sherwood et al 2014*)

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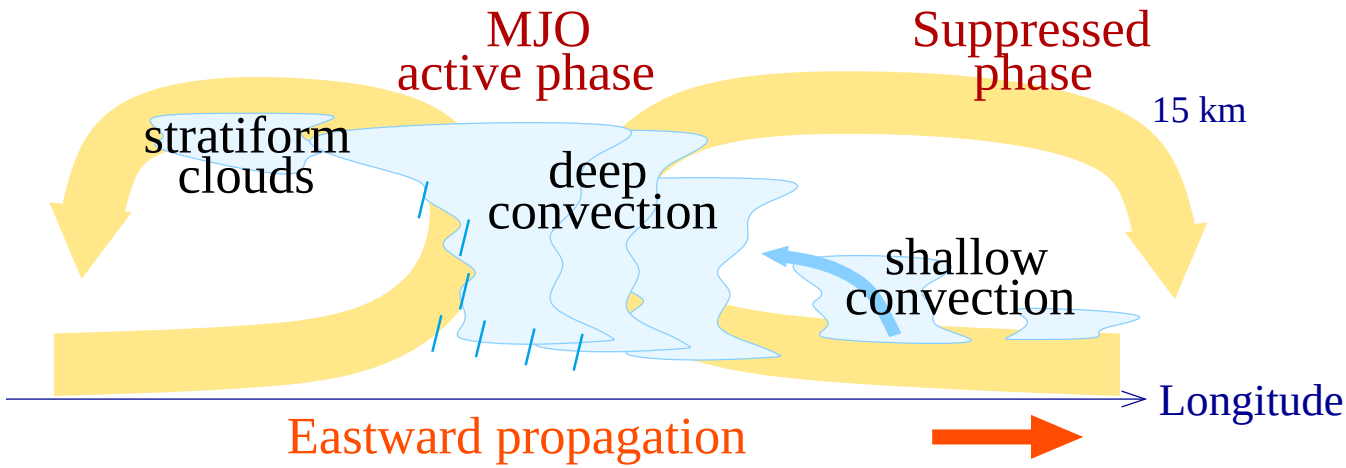
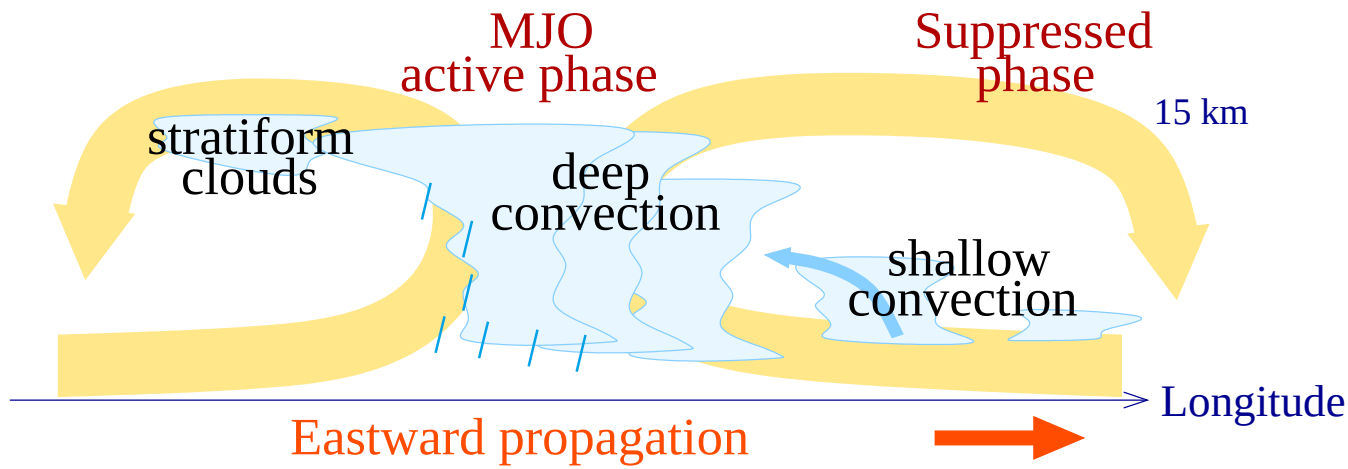
⇒use it to evaluate conv vs shallow and associated large-scale circulation?
Key factor for cloud feedbacks (*Sherwood et al 2014*)

⇒Use water isotopes to evaluate convective/cloud processes?
ex: during the Madden-Julian Oscillation (Obbe Tuinenburg's work)

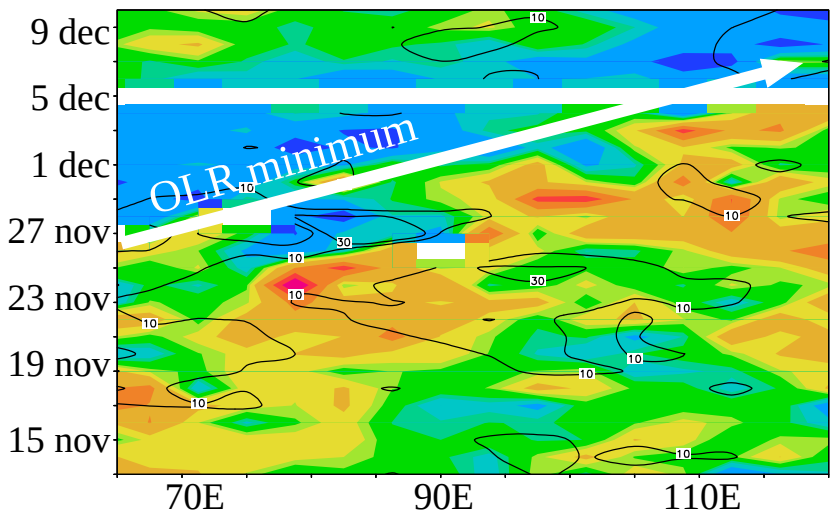
Isotopes during the MJO



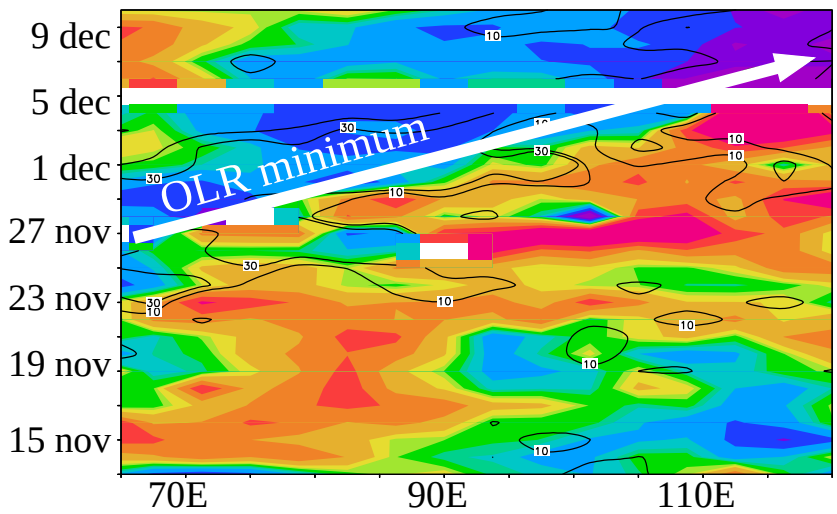
Isotopes during the MJO

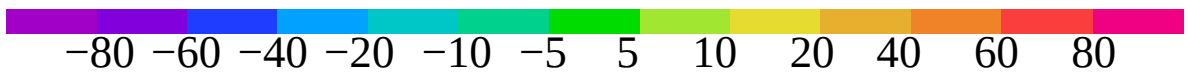


IASI observations



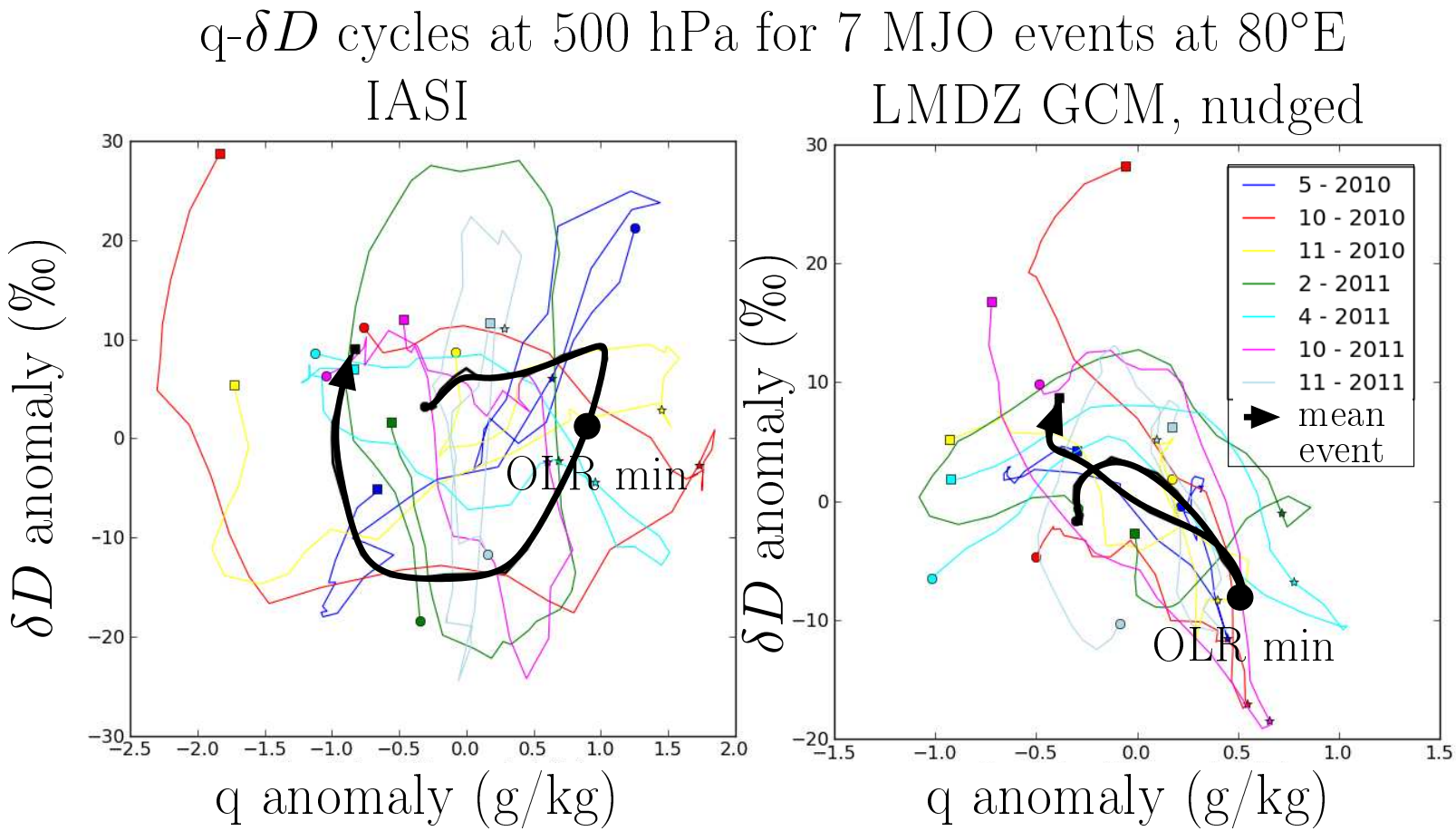
LMDZ GCM, nudged winds





δD anomaly at 500hPa (‰)

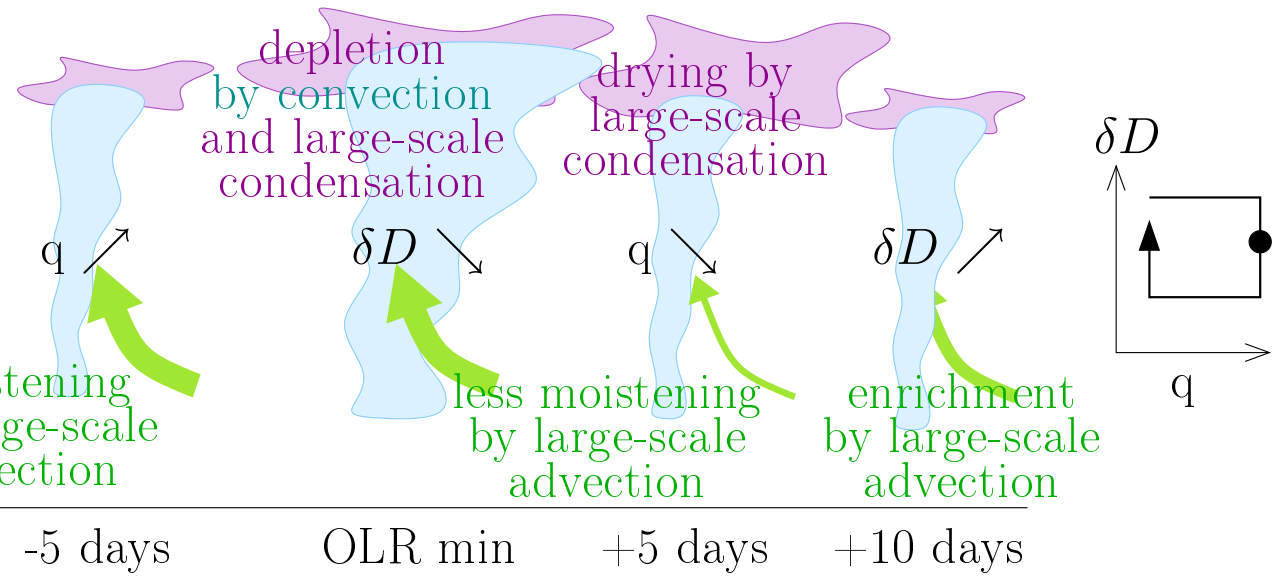
q-δD cycles in Indian Ocean



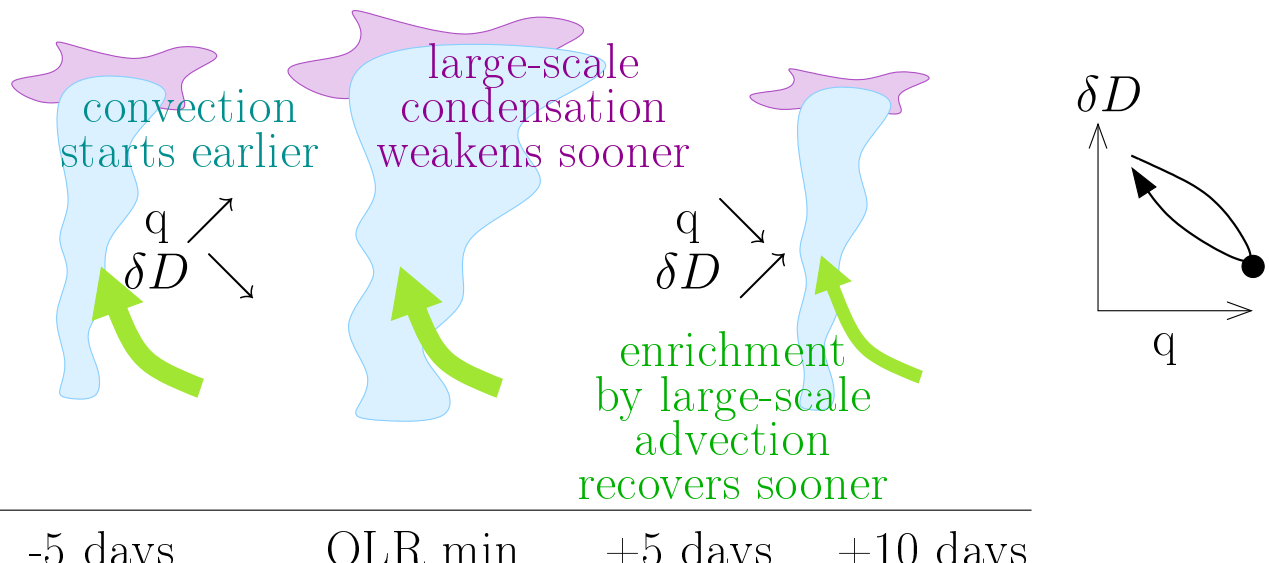
- Observations: “circular”, clockwise shape
- LMDZ: sometimes circular, too often “linear”: why?

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

events with "circular shape" in q-δD diagram



events with "linear shape" in q-δD diagram

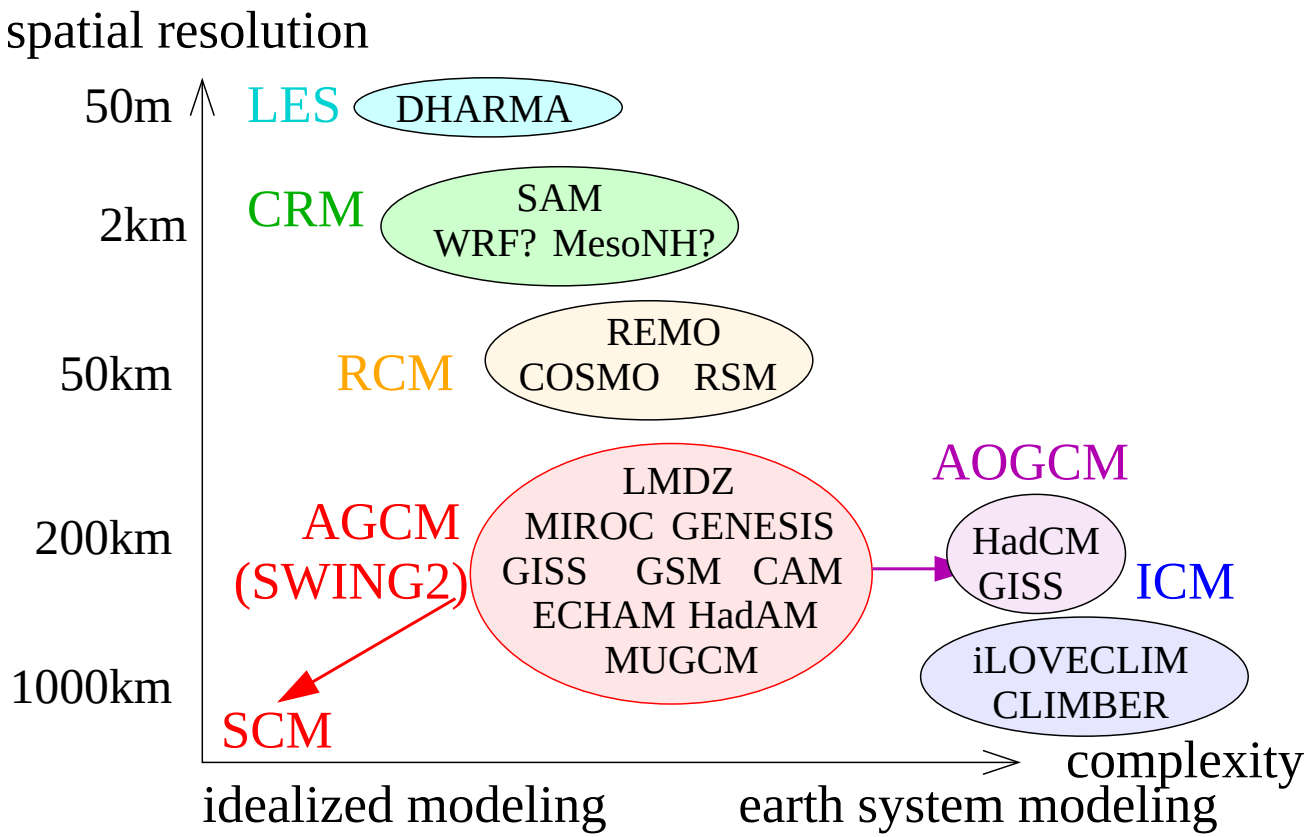


Summary on $q - \delta D$ cycles during the MJO

- Observed "circular shape" over Indian Ocean consistent with cloud evolution shallow $\longrightarrow$ deep $\longrightarrow$ stratiform
- 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

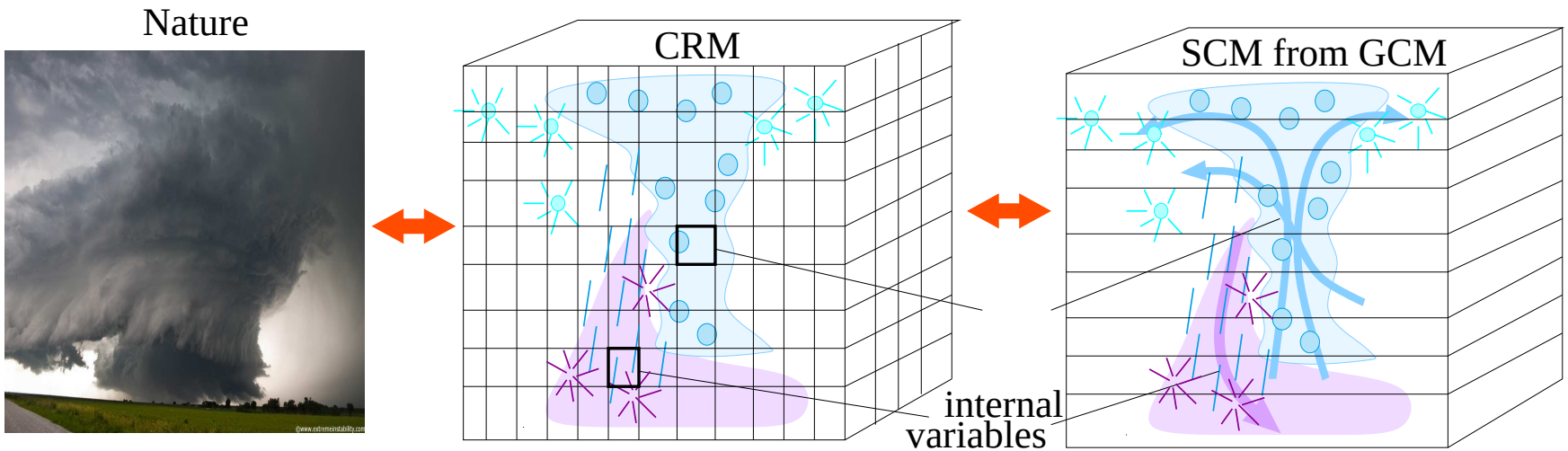
Perspectives (1/2)

- Bridge gap between simple theoretical $q - \delta D$ framework and more complex modeling
- Exploit model hierachy: numerical models with isotopes



Perspectives (2/2)

- CRM/LES to study processes and to compare more easily to observations and to SCMs (conditional sampling)



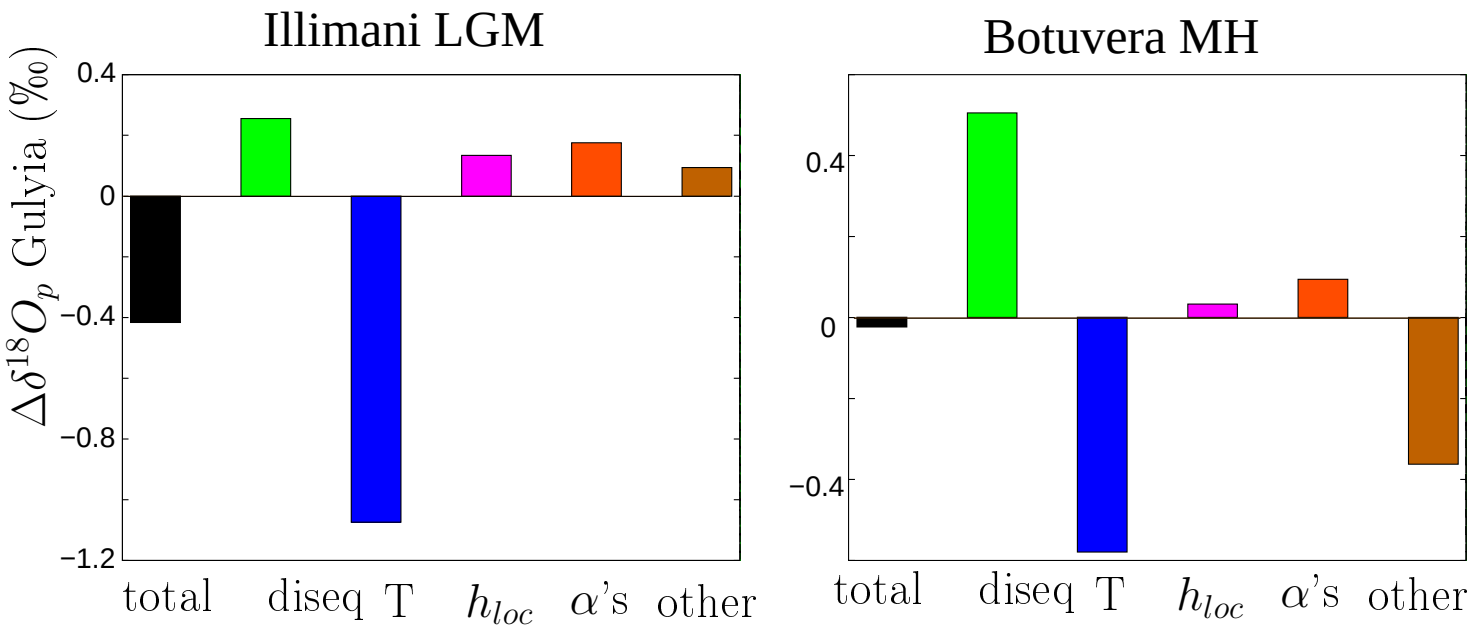
- intercompare GCMs
  - add daily outputs in SWING2?

Causes of $\delta^{18}O_p$ changes?

$$R_p = R_v + (R_p - \alpha_{loc} \cdot R_v) + (\alpha_{loc} \cdot R_v - R_v)$$

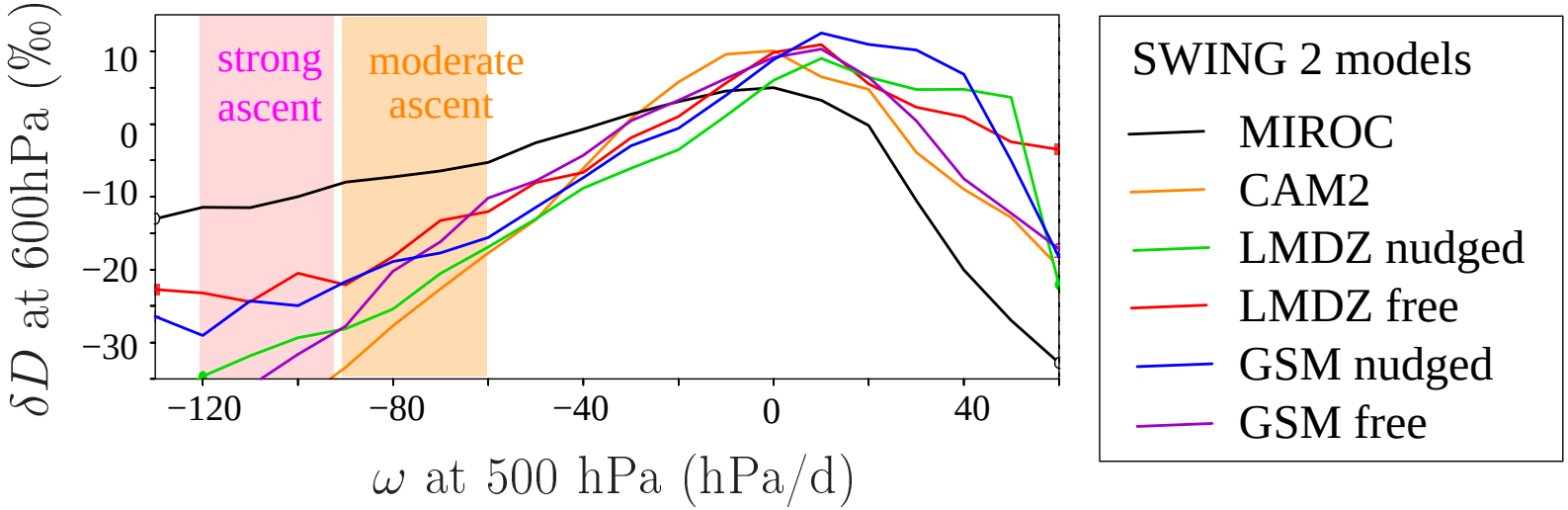
vap-cond diseq

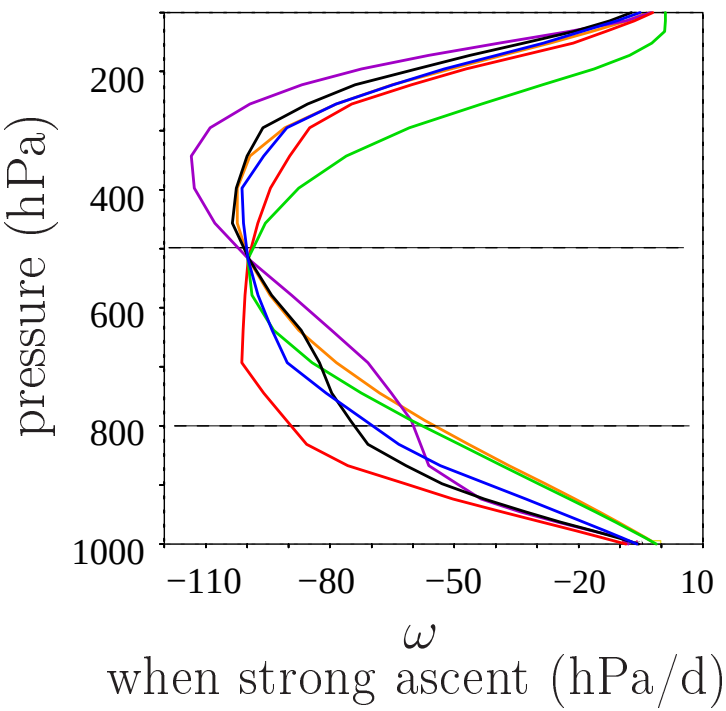
$$R_v = \underbrace{\frac{R_{oce}/\alpha_i}{\alpha_K \cdot (1-h_i)+h_i}}_{\text{initial vapor}} \cdot \underbrace{\left(\frac{h_{loc} \cdot q_s(T_{loc})}{q_s(T_i)}\right)^{\alpha_{loc}-1}}_{\text{distillation}} + \underbrace{\text{residual}}_{\text{e.g. upstream convection}}$$

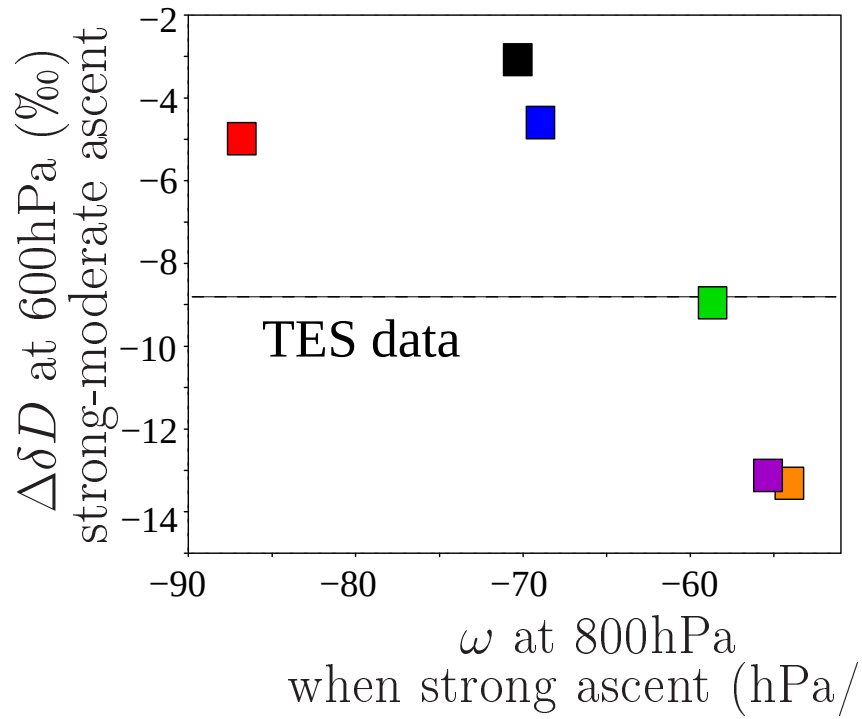


- importance of temperature effect

And across models?

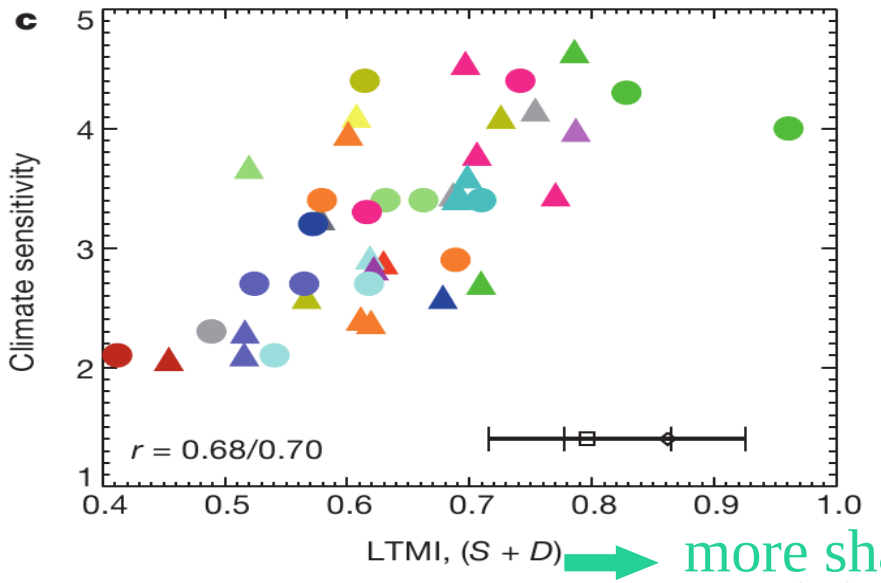






Implications

- 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*)



more shallow mixing

Sherwood et al 2014

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