# New insights into the hydrological cycle from IASI δD distributions across the globe

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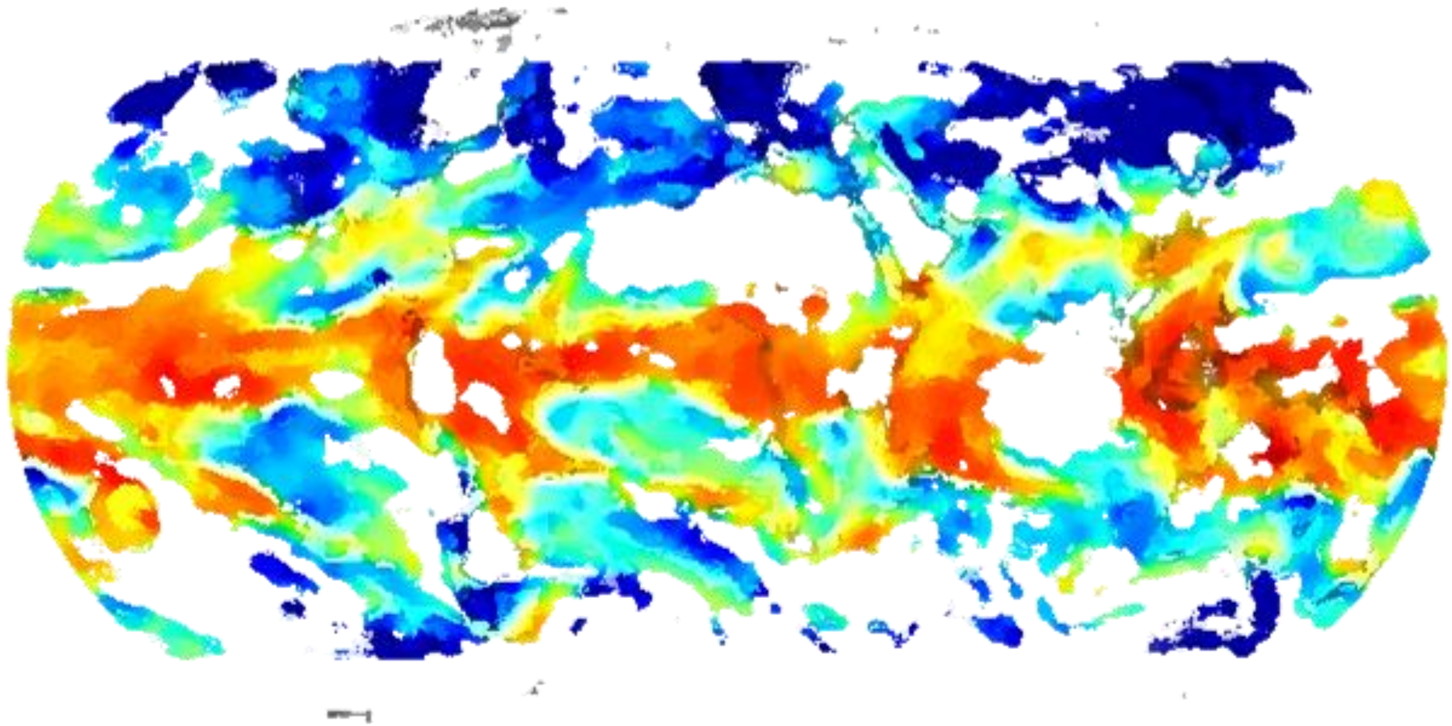
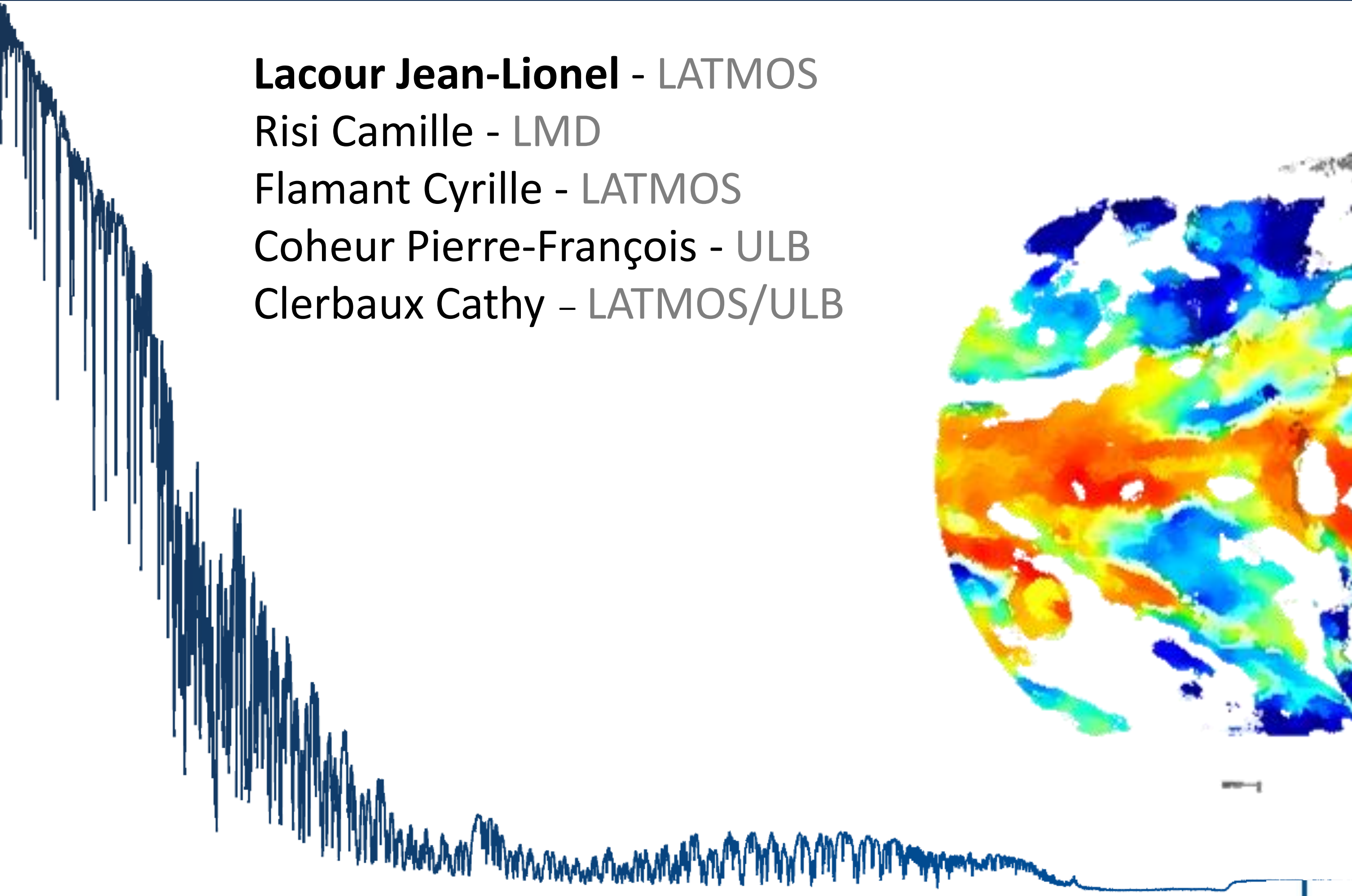
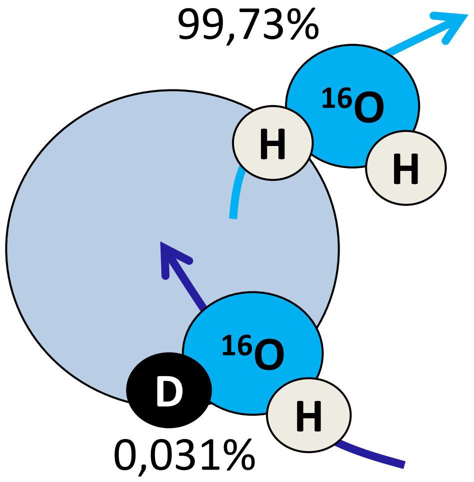




IASI 2016 April 11-15, Juan Les Pins

# Water isotopologues




- Water isotopologues – *$H_2{}^{16}O$, HDO, $H_2{}^{18}O$* – have different vapour pressures
- $H_2{}^{16}O$ preferentially evaporates
- HDO preferentially condenses
- Every phase change is recorded in the isotopic ratio δD

$$\delta D = 1000 \times \left( \frac{HDO / H_2{}^{16}O}{SMOW} - 1 \right)$$

*Standard Mean Oceanic Water*

The isotopic ratio tells us :

- about the degree of rainout of an airmass from its origin above the ocean
- about different sources of water vapour (oceanic/continental)
- about the different processes affecting the airmasses

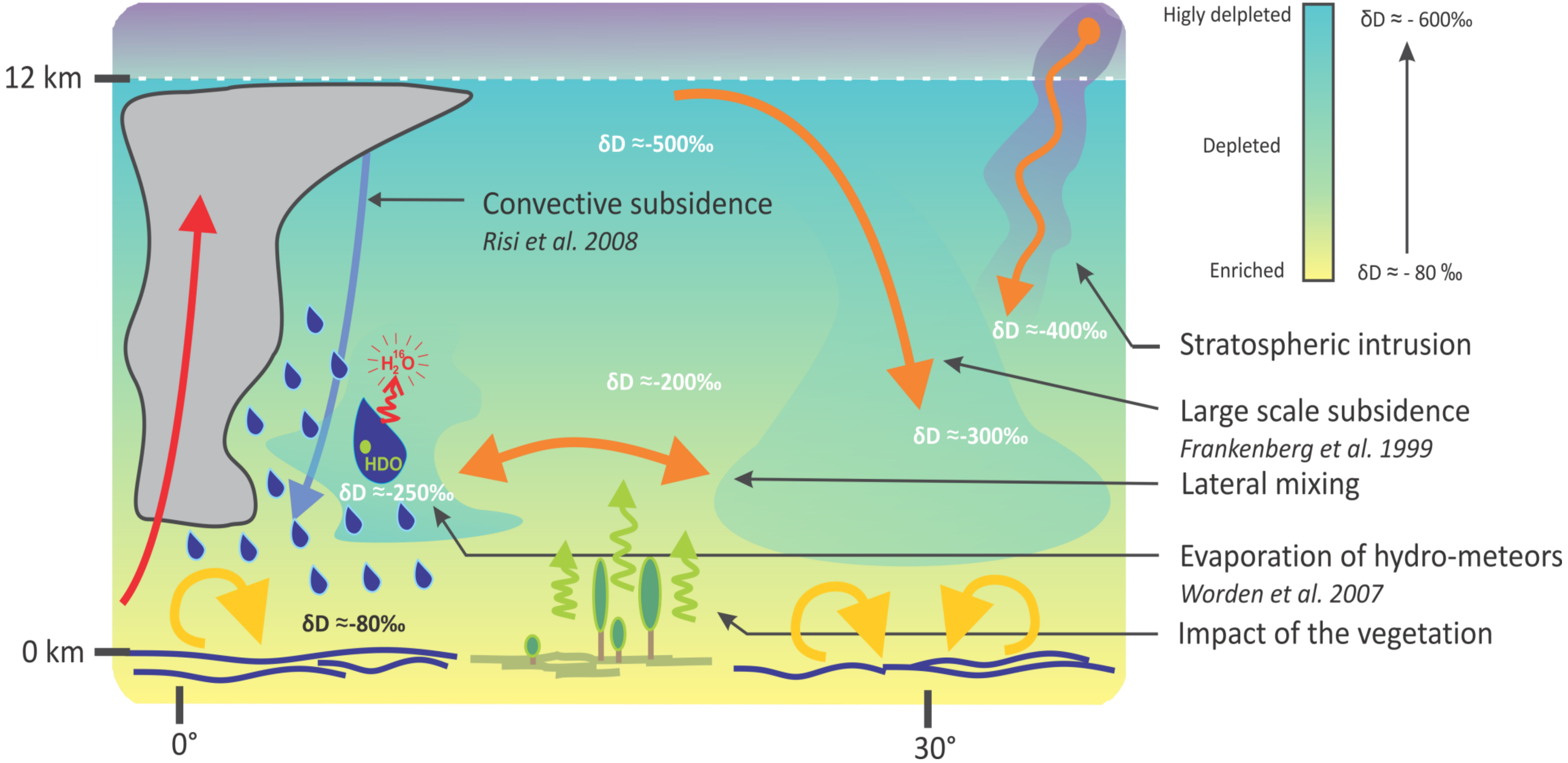
Constraints on the hydrological cycle uncertainties

# Water isotopologues - numbers



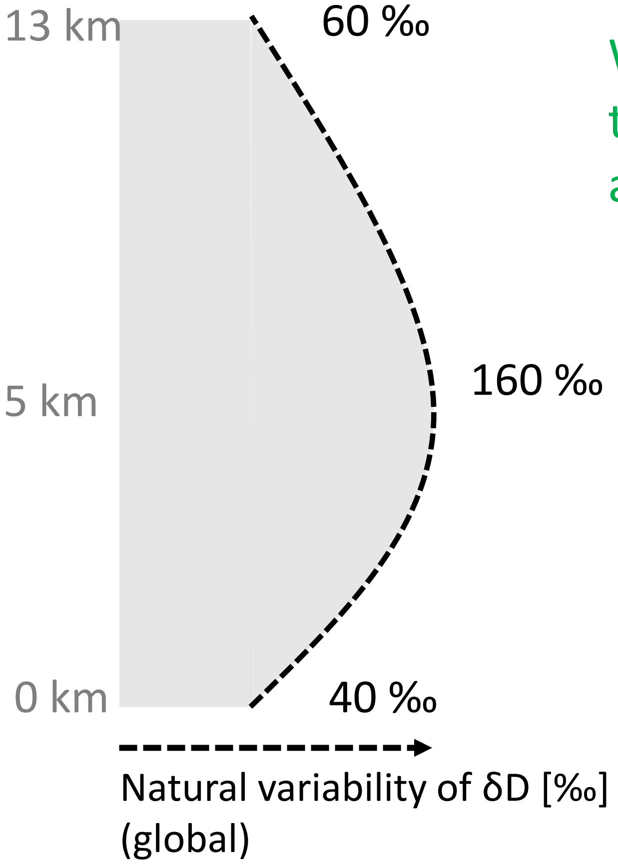
$$\delta D = 1000 \times \left( \frac{HDO / H_2{}^{16}O}{SMOW} - 1 \right)$$

δD = 0 ‰ in the ocean
~ - 80 ‰ above the ocean
~ - 500 ‰ at the tropopause



# Remote sensing of δD – The challenge

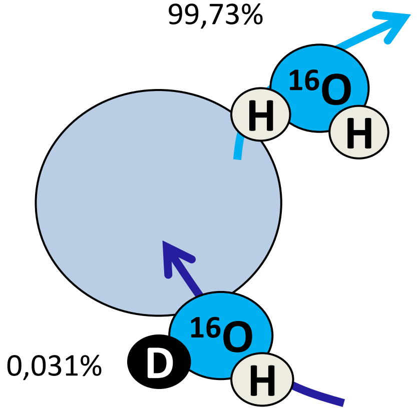
$$\delta D = 1000 \times \left( \frac{HDO/H_2{}^{16}O}{SMOW} - 1 \right)$$




- Variability of water vapour is large!
- Small variations of the isotopic ratio!

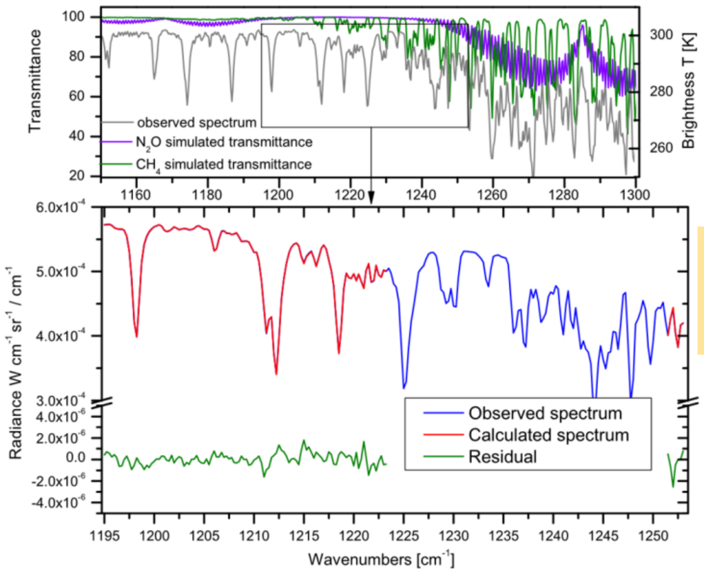
We need a methodology that is **sensitive** over the wide dynamical range of water variations and **precise** to capture isotopic variations

- Depending on the altitude range a precision between 10 and 50 ‰ is needed
- 10 ‰ ~ a variation of 1 % of $H_2O$



# Retrieval methodology

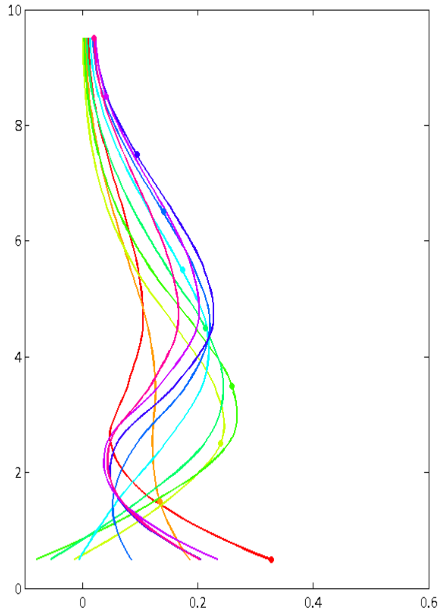


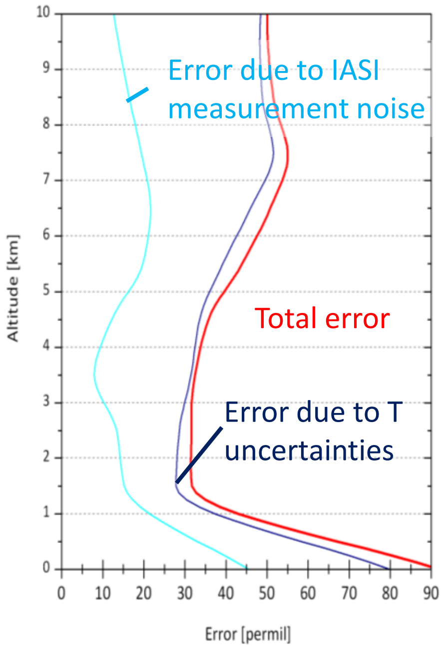



OEM with a constraint on log(HDO/H2O)

*[Worden et al., 2006; Schneider et al.,2006]*

- Short spectral range 1195-1253 cm-1
- Full inversion on the 10 first layers of the atmosphere
- Temperature profiles from EUMETSAT L2
- cloud flag < 10 %






δD profiles with 1-2 DOFS

→ Vertical sensitivity is limited (generally in the free tropopshere) *[Lacour et al., 2012]*

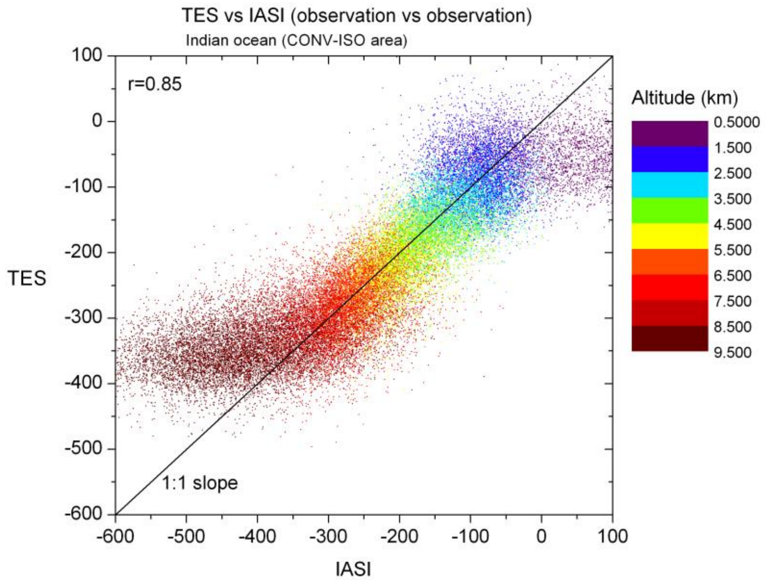
Error of 38 permil for an individual measurement

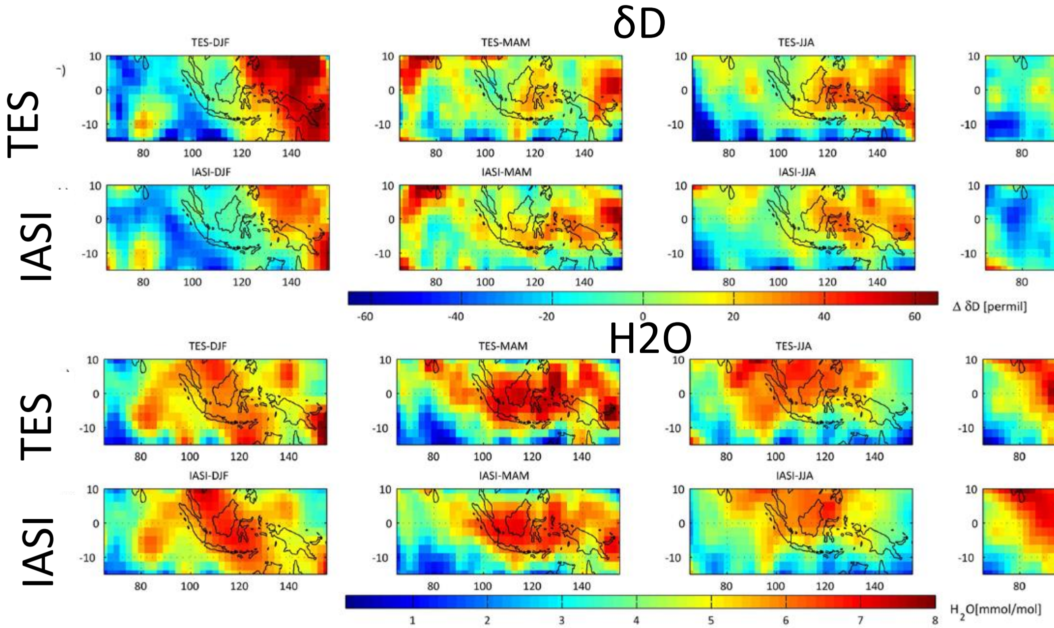
# Cross validation

- Cross-validated against TES and ground-based FTIRs (MUSICA)

  *[Lacour et al., 2015 AMT]*

- Cross validation of $H_2O$, δD but also of the relationship $H_2O$- δD



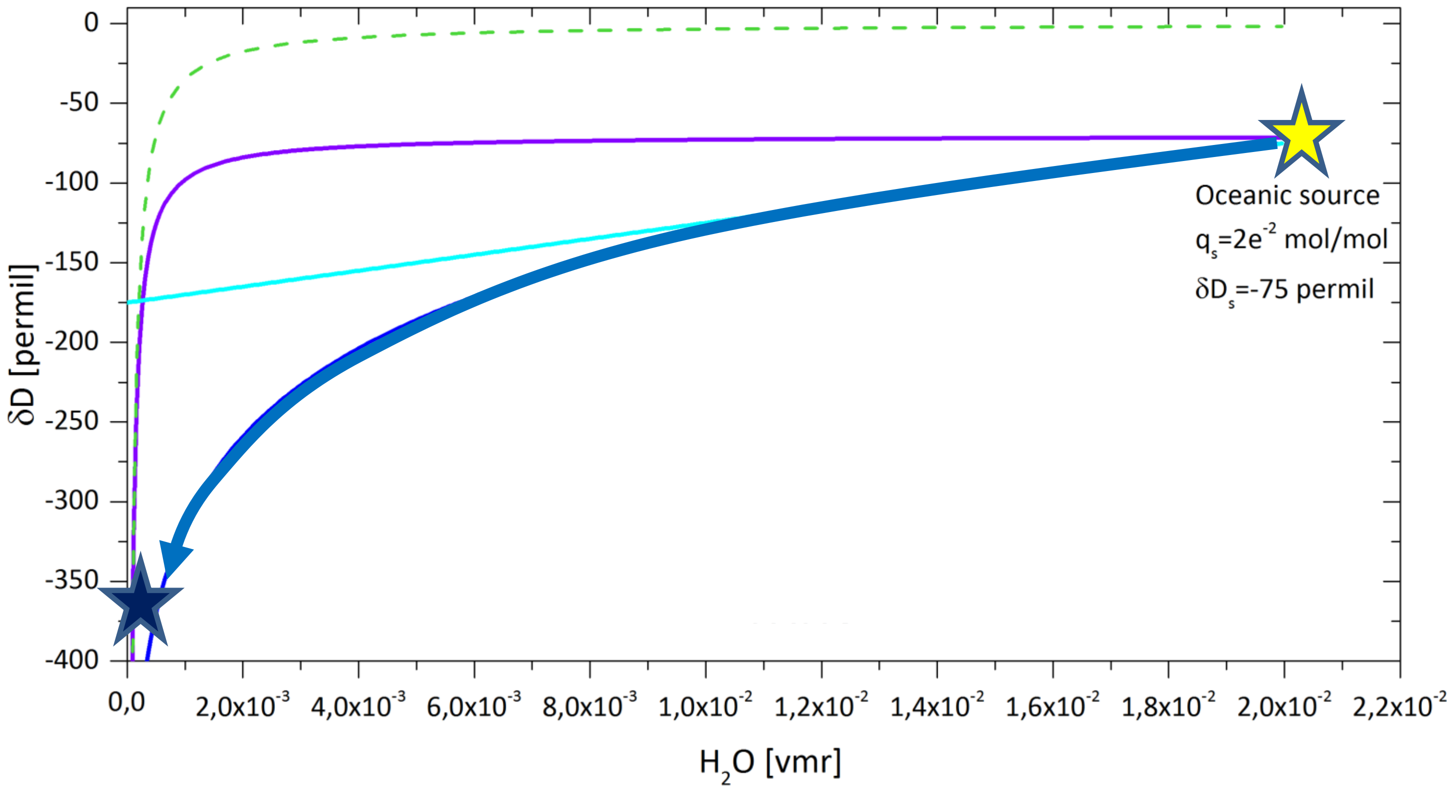




- With a better spectral resolution (0.1$cm^{-1}$) TES can provides estimates of δD in the boundary layer
- IASI Sensitivity to δD decreases for high water vapour contents

Added value of IASI δD observations

# Applications of IASI δD retrievals

Interpretation of δD et H2O observations
-> Simple models [Noone et al.,2012]




Rayleigh Model

Added value of IASI δD observations

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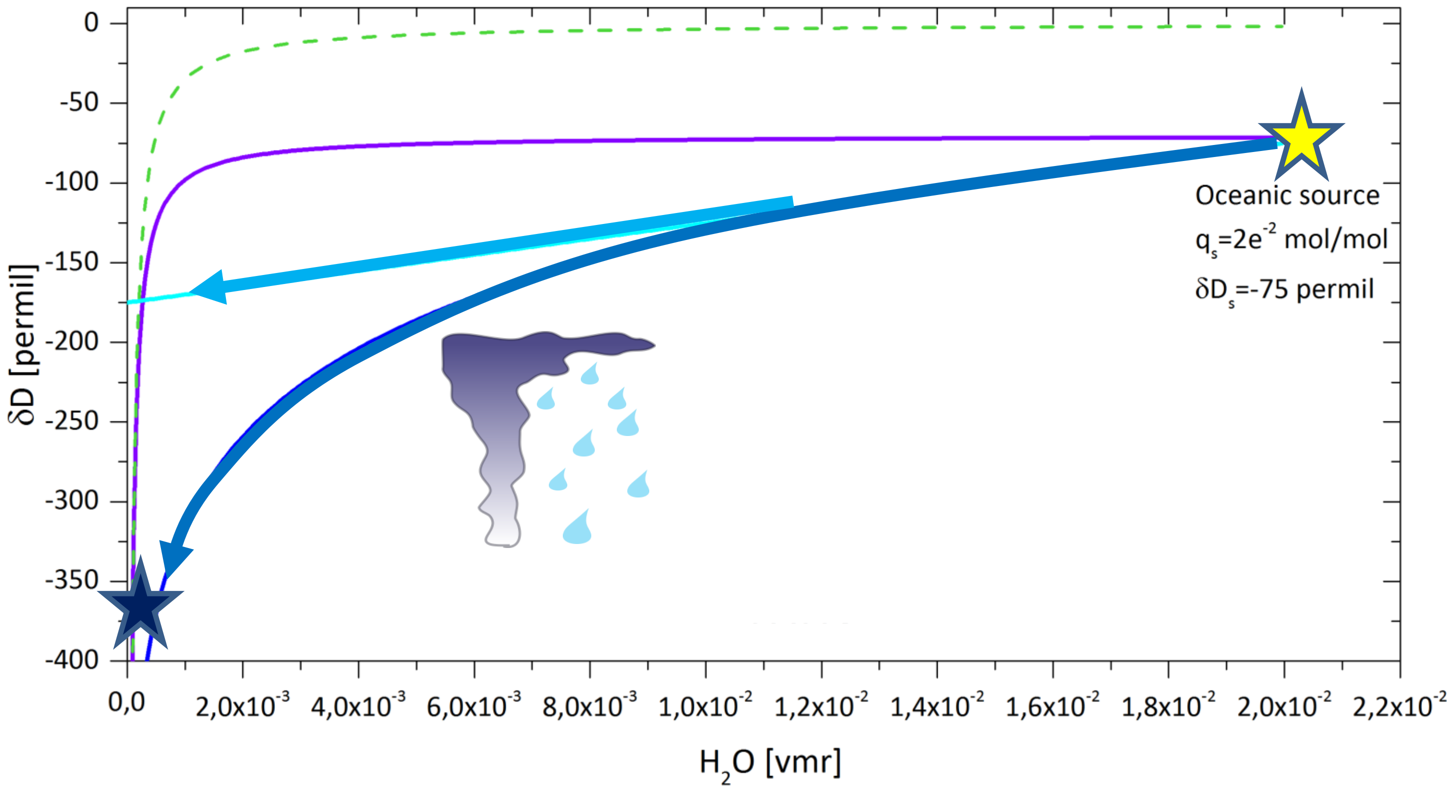
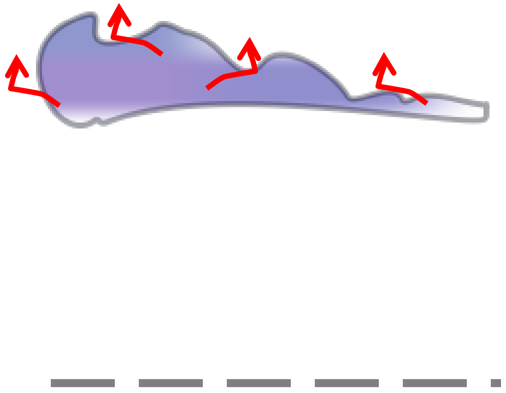



Pseudo-adiabatic model



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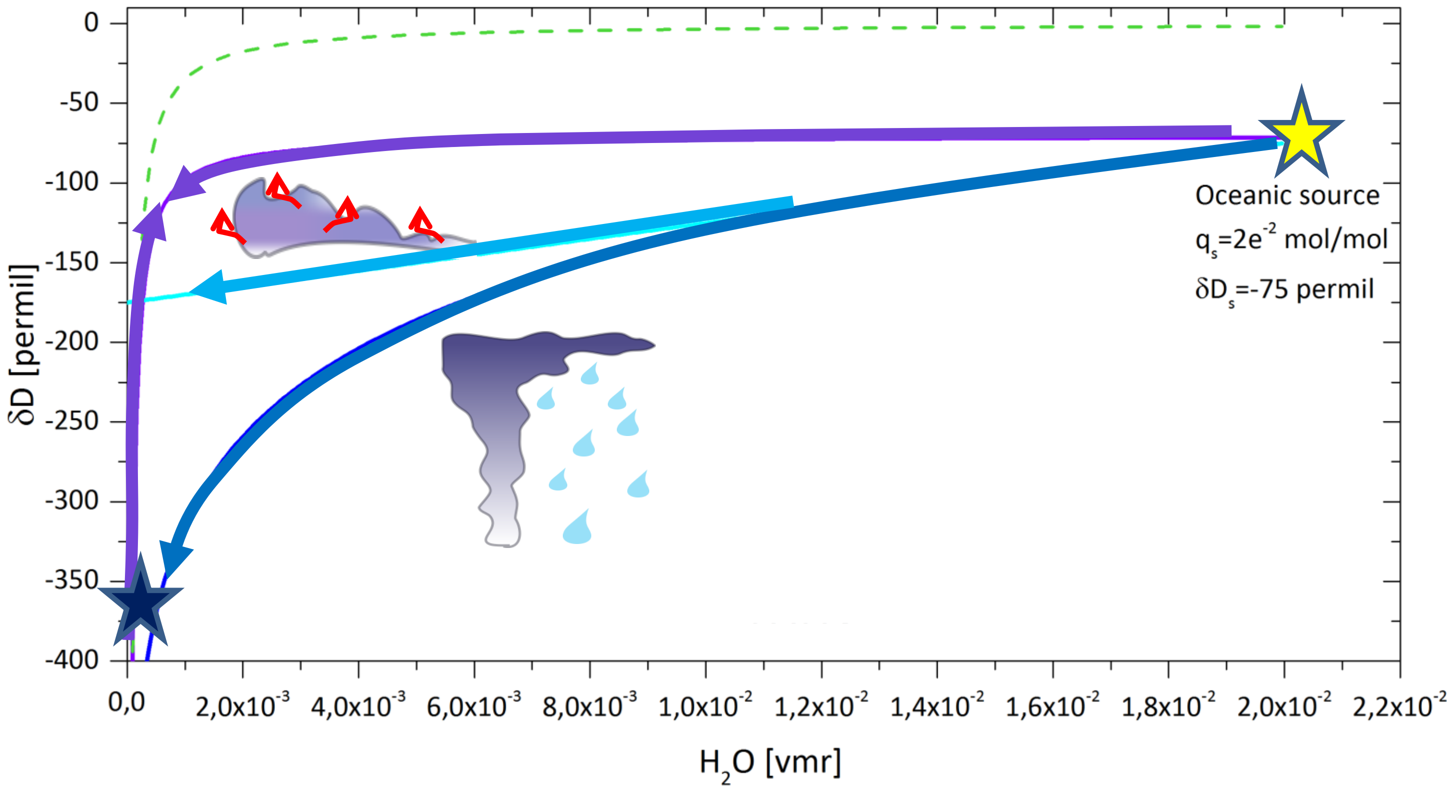
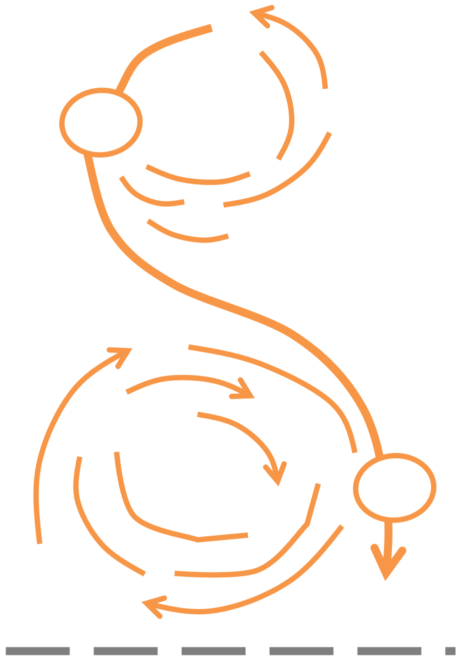



Mixing Model



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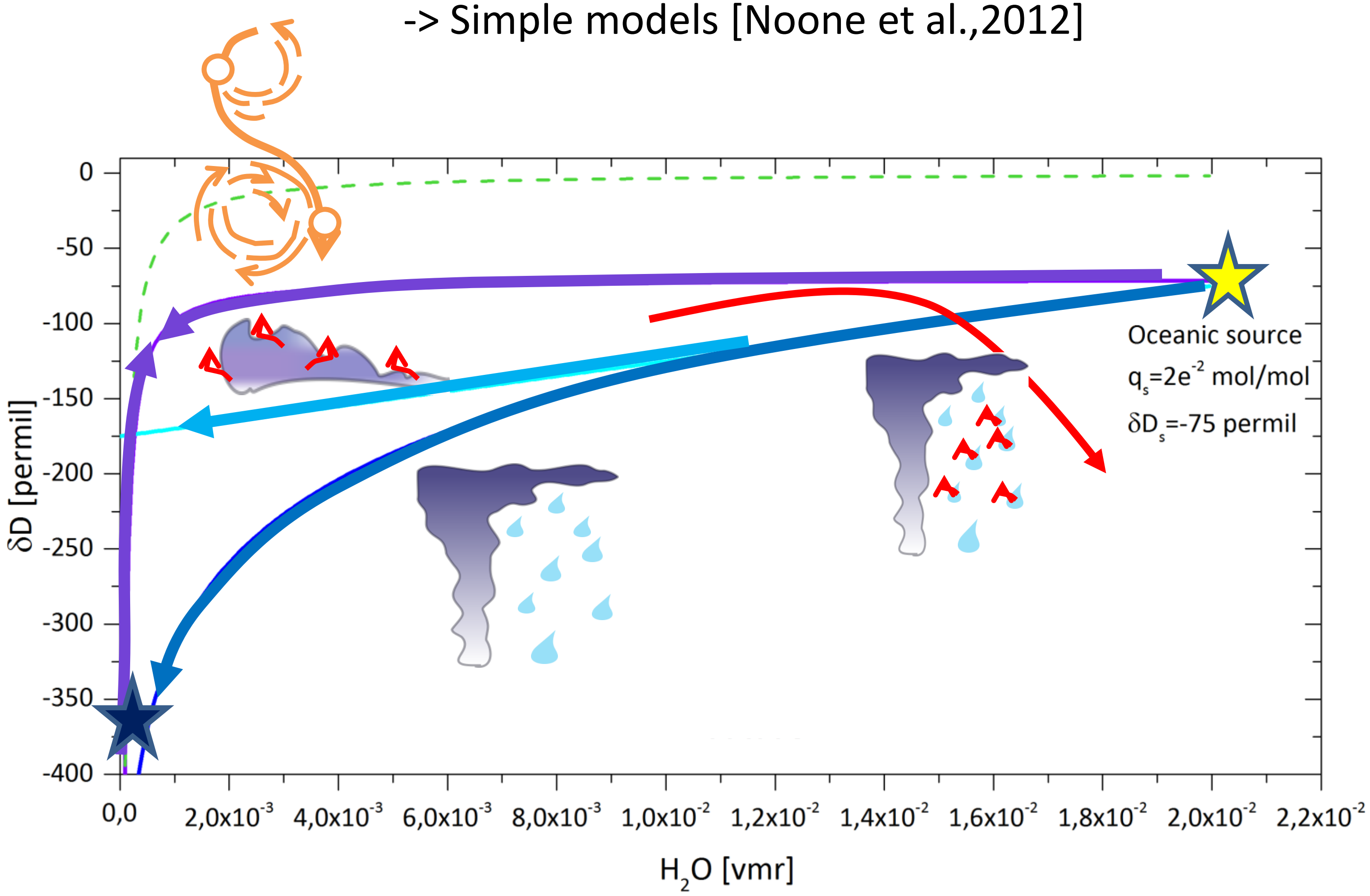
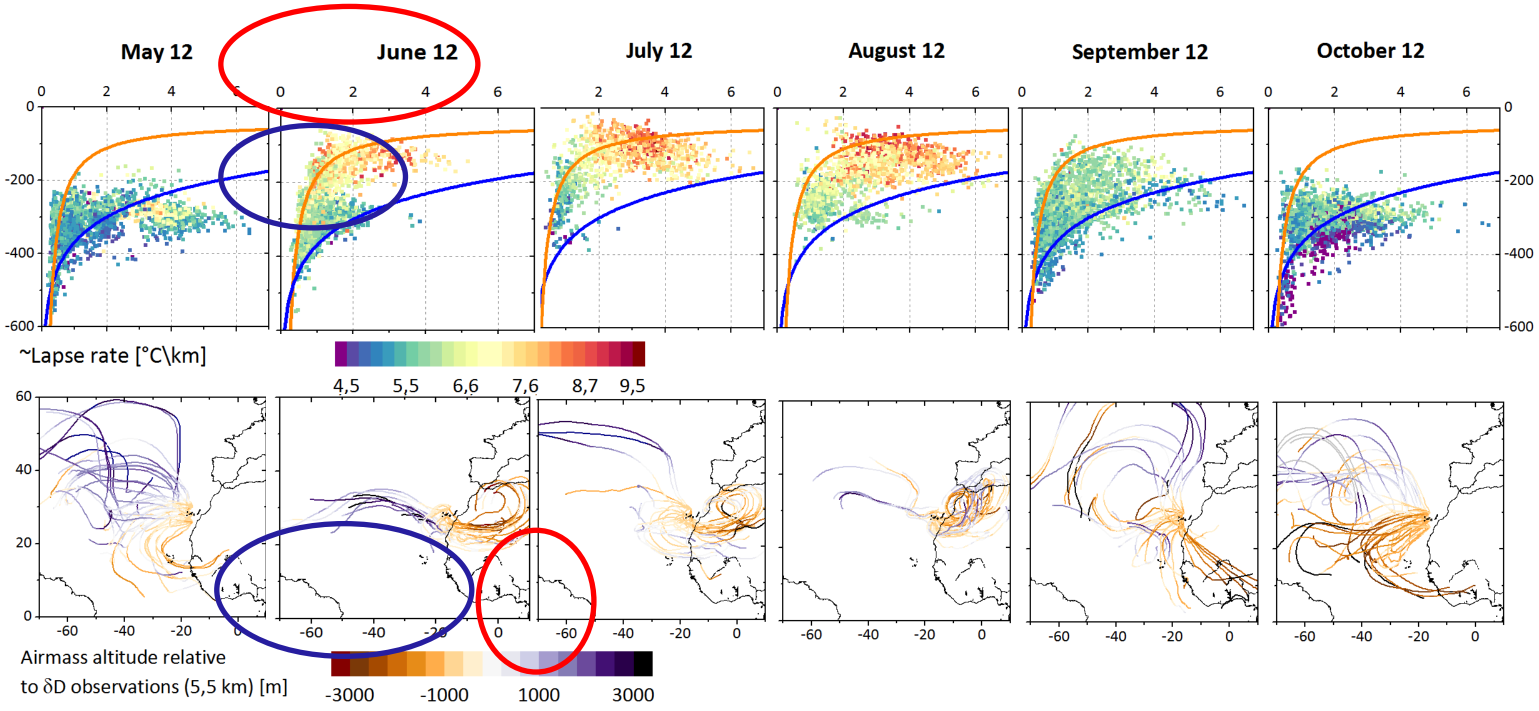



Re-evaporation of rain drops

# North Atlantic – Influence of the Sahara

## Temporal variations at Izana – North Atlantic

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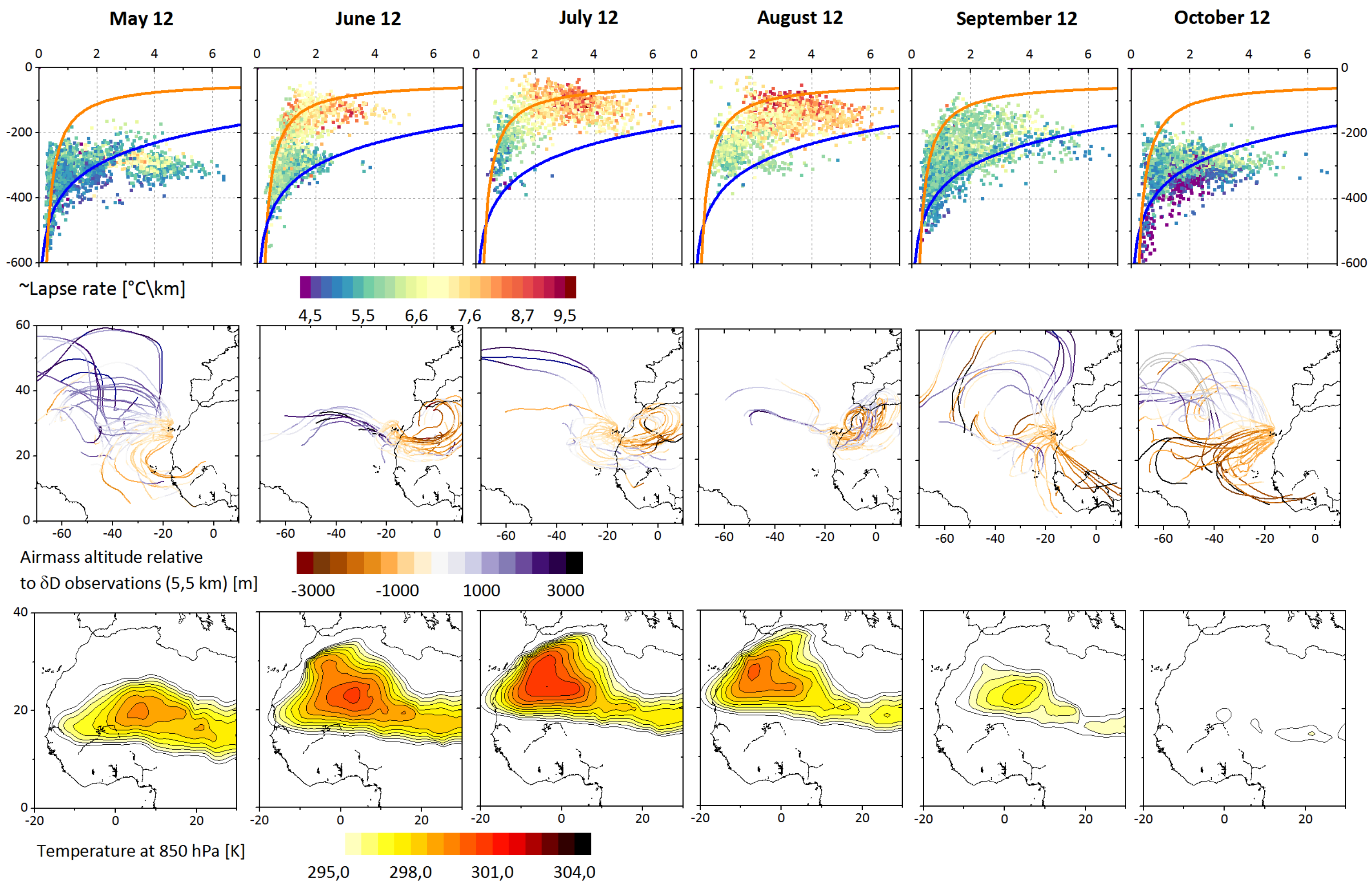
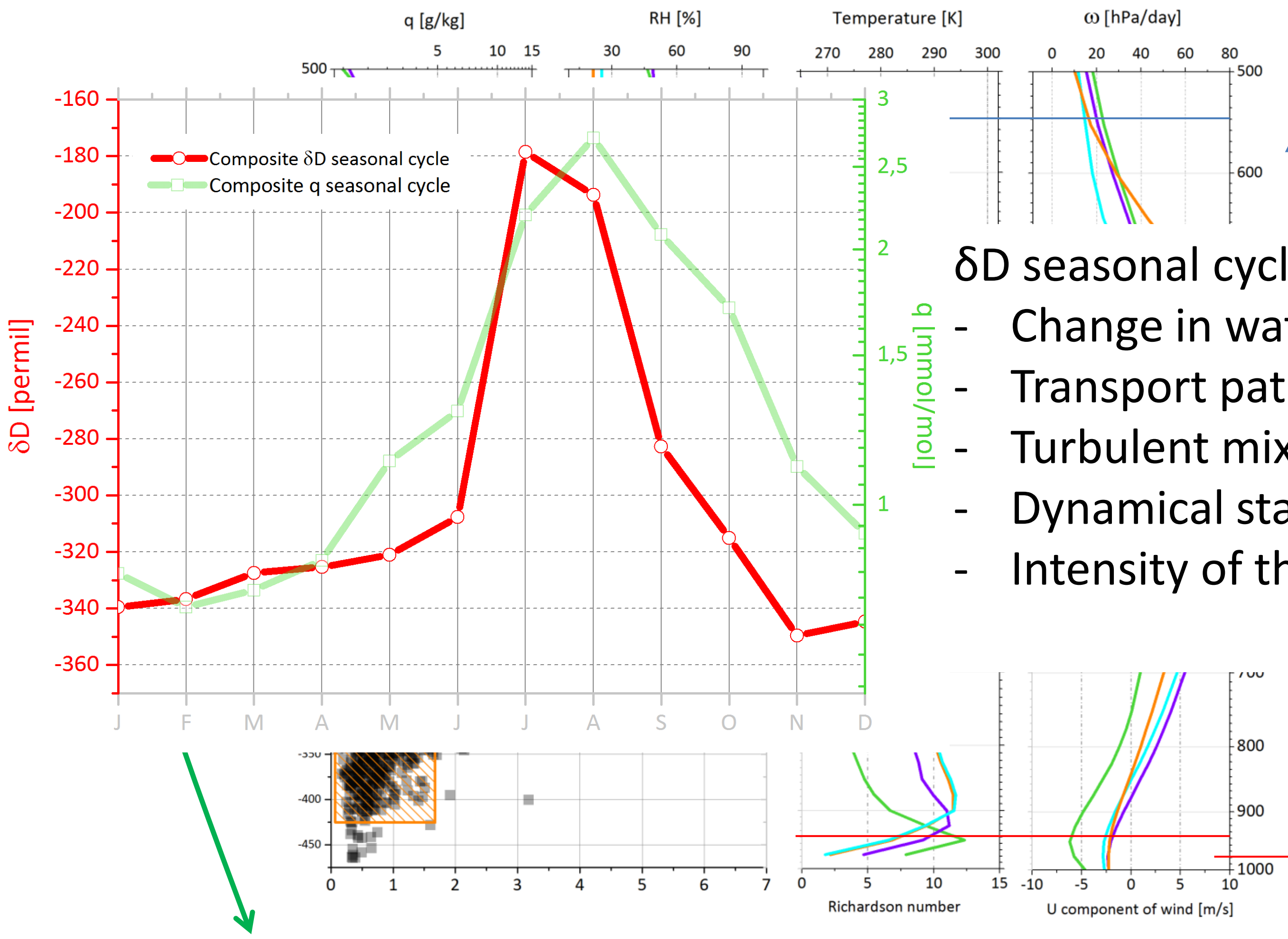



Added value of IASI δD observations

# North Atlantic – Influence of the Sahara

## Dynamical state of the atmosphere




δD seasonal cycle is controlled by:

- Change in water sources
- Transport pathways
- Turbulent mixing
- Dynamical state of the atmosphere
- Intensity of the Saharan Heat Low

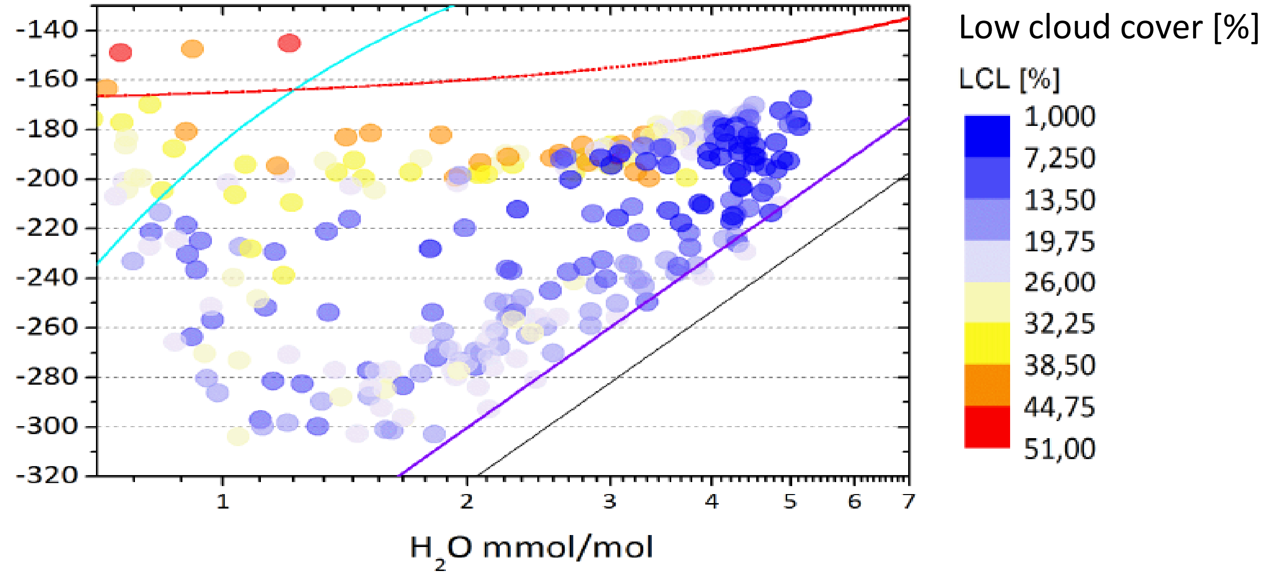
Saharan boundary layer

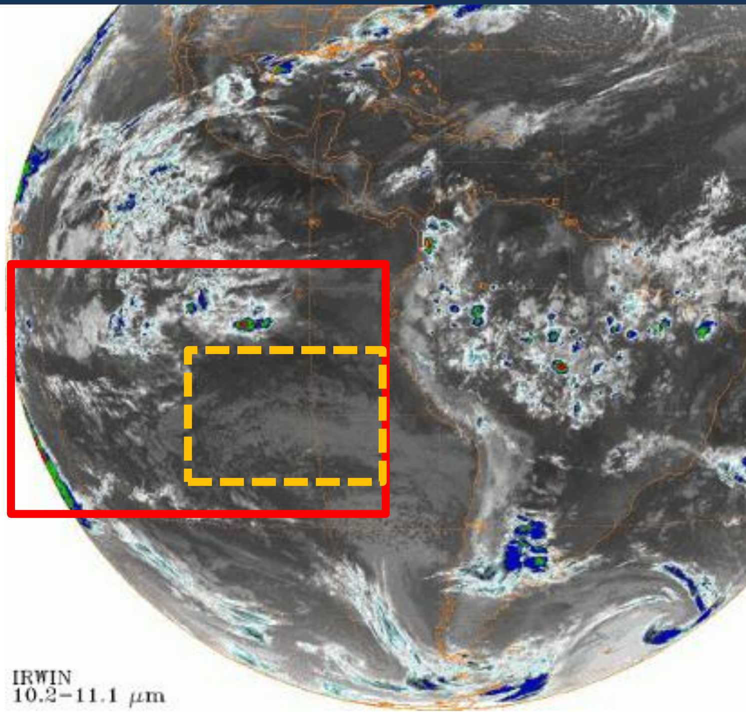
Marine boundary layer

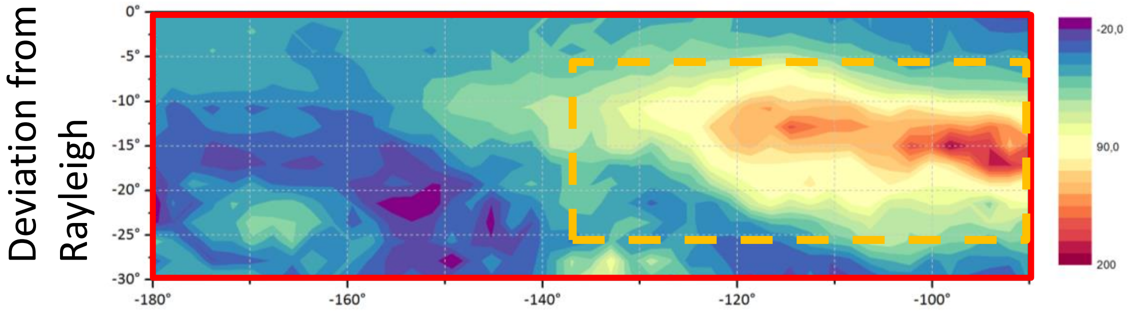
Corresponds to a deep turbulent boundary layer (up to 6 km)

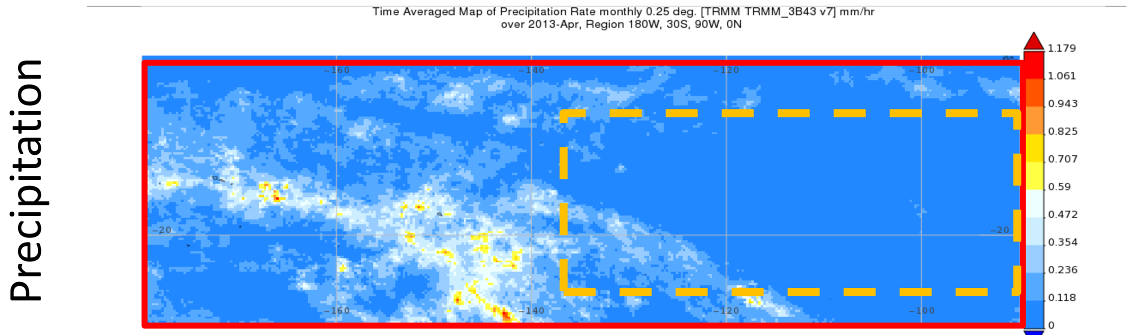
Added value of IASI δD observations

# South Pacific: influence of low clouds



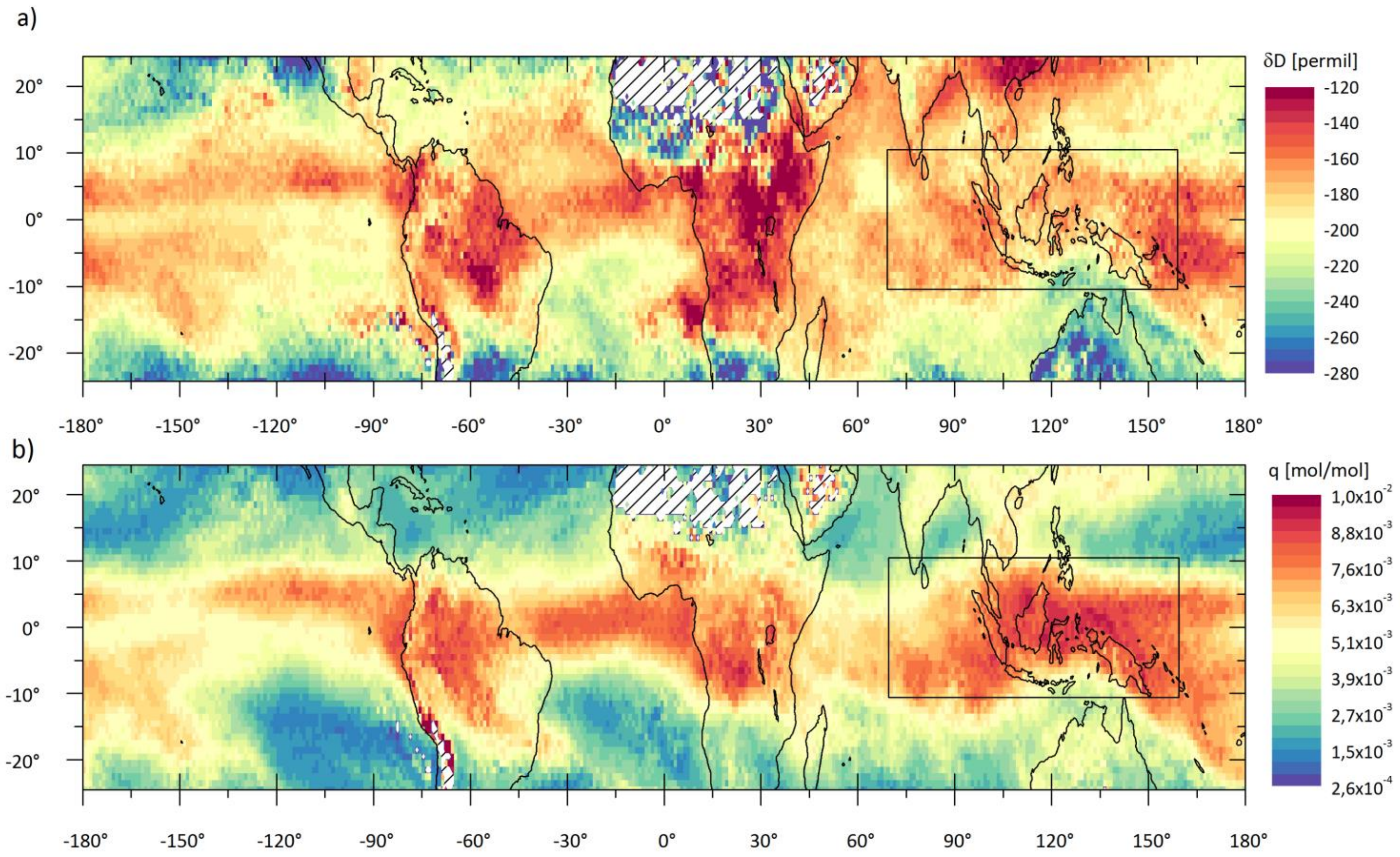

- Low clouds enrich the free troposphere
- Clear signature of the free tropospheric moistening by low clouds
- Climate sensitive areas where a small change in water vapour has an exponential impact on radiative budget

# Tropics: isotopic signature of convection's depth

Added value of IASI δD observations

δD at 4,5 km
IASI monthly averages

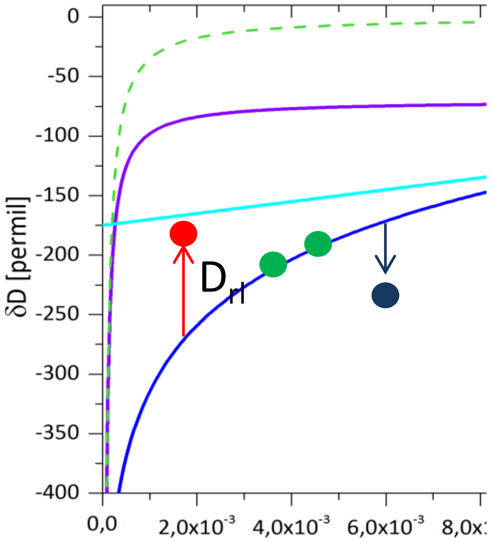
q at 4,5 km
IASI monthly averages




In convective areas, δD is sometimes enriched, sometimes depleted.
What could explain this different behaviours?
Intensity of convection? Depth of convection?

# Tropics: isotopic signature of convection's depth

- $D_{rl}$ = Deviation from what would be predicted by a Rayleigh model
- $r(\log(H_2O)\text{-}\delta D)$ = gives indication on the processes -> r<0 = amount effect

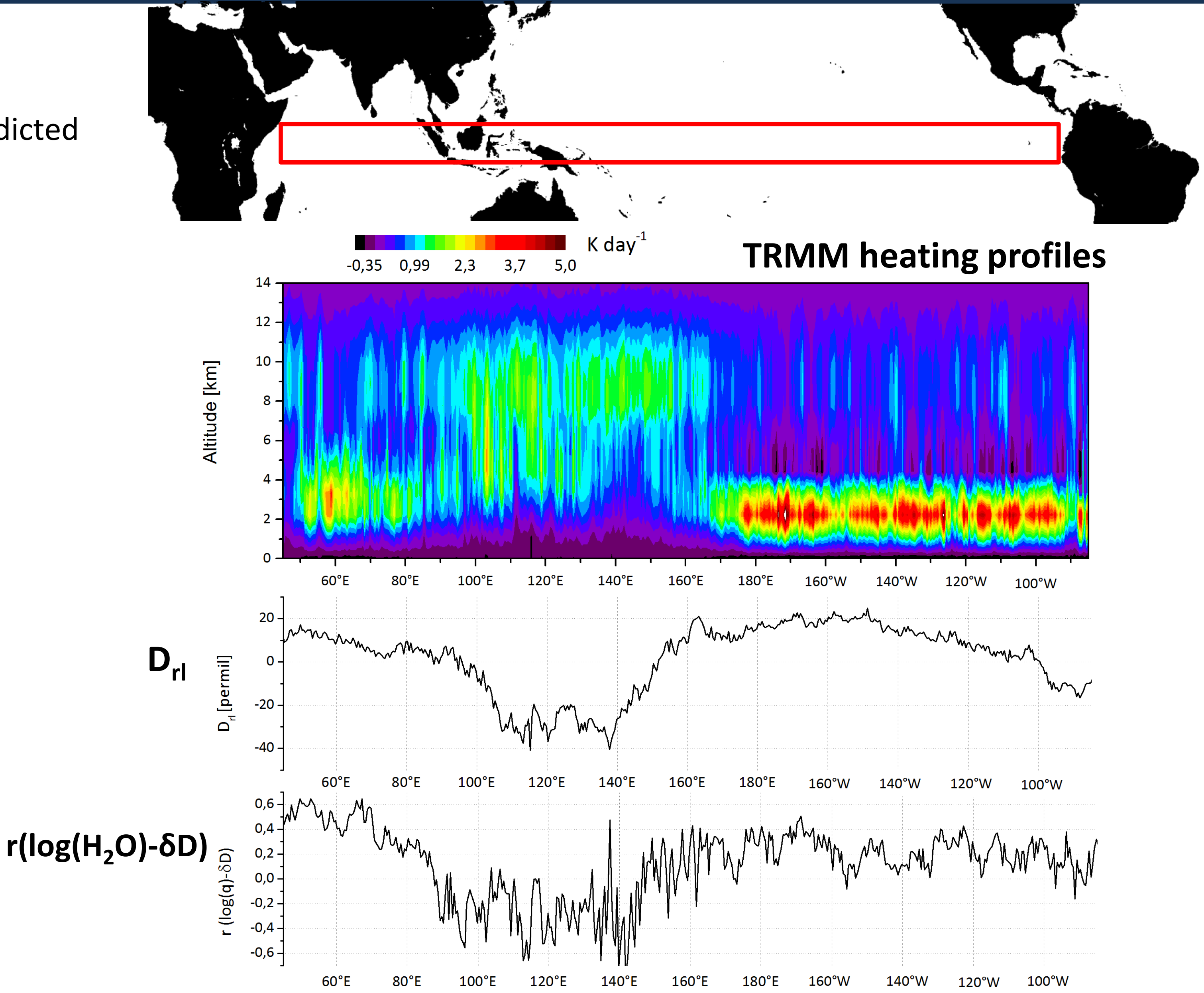



For a given source:

$D_{rl}$ = 0 advection

$D_{rl}$ > 0 enriching mechanisms

$D_{rl}$ < 0 depleting mechanisms



Added value of IASI δD observations

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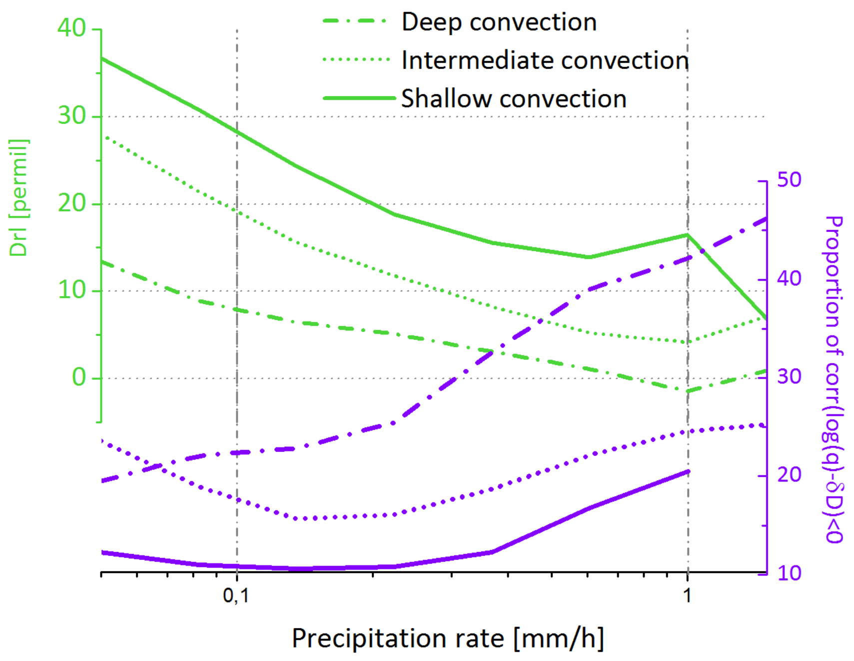
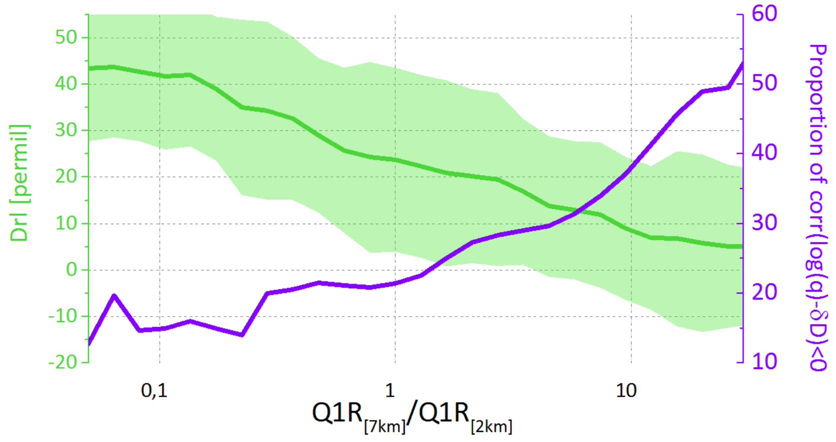



Shallow heating >> deep heating

deep heating >> shallow heating

- For any given convection intensity, the depth of convection is determinant in the isotopic composition of water vapour
  - Water vapour is more enriched when associated with shallow heating/convection
  - Water vapour is more depleted when associated with deep heating/convection
- Amount effect is more frequent in deep convective environment

➡ Convection's depth gives to water vapour a particular isotopic signature

# Tropics: isotopic signature of convection's depth

Climate implication:

- In GCM, shallow convection versus deep convection = result of multiple parametrizations specific to each model
- With consequences on:
  - Water vapour,
  - Chemical and aerosol transport,
  - Cloudiness (Cloud feedback)
  - Latent heating profiles – large scale circulation


- Sherwood et al., [2014] traced the uncertainty on climate sensitivity to the different ratios of deep and shallow convection in models

IASI δD observations could serve to evaluate the representation of shallow vs deep convection in climate models

# Conclusions and perspectives

- Distributions of δD at IASI resolution show well marked isotopic effects
- Many processes can be analysed under « the isotopic eye »

- Much more information in δD (record) than in $H_2O$ (Evapotranspiration, convection, air mass mixing, transport,…)

→ Powerfull tool to evaluate GCMs (about 10 isotope-enabled GCMs)

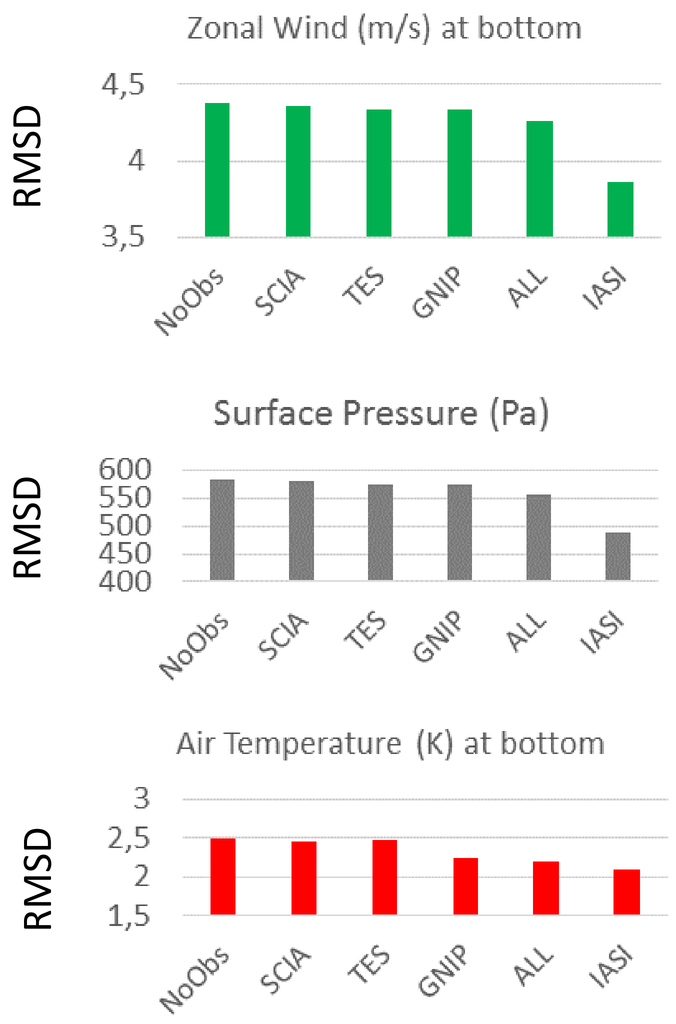
→ For weather forecasting?

*By assimilating δD observations [Yoshimura et al., 2014] showed that the assimilation of such obserbations constrain dynamic fields. The degree of improvement is proportional to the number of inputted data points.*

- Climate (past and future) applications

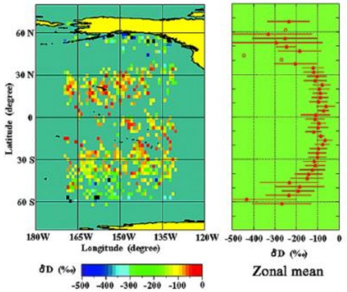
- Retrieval of δD in the tropics (one orbit) is now operationnal
- With an improved retrieval scheme

Yoshimura et al., 2014

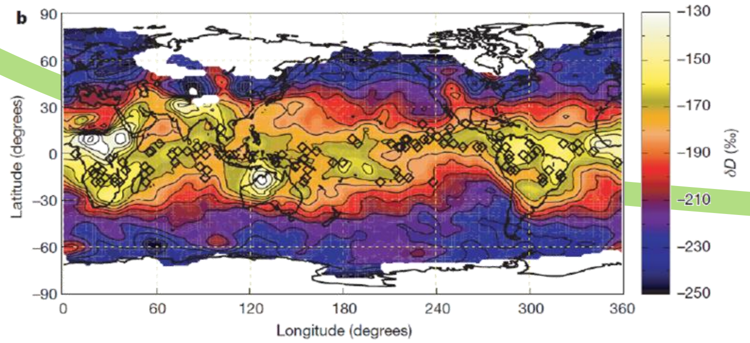


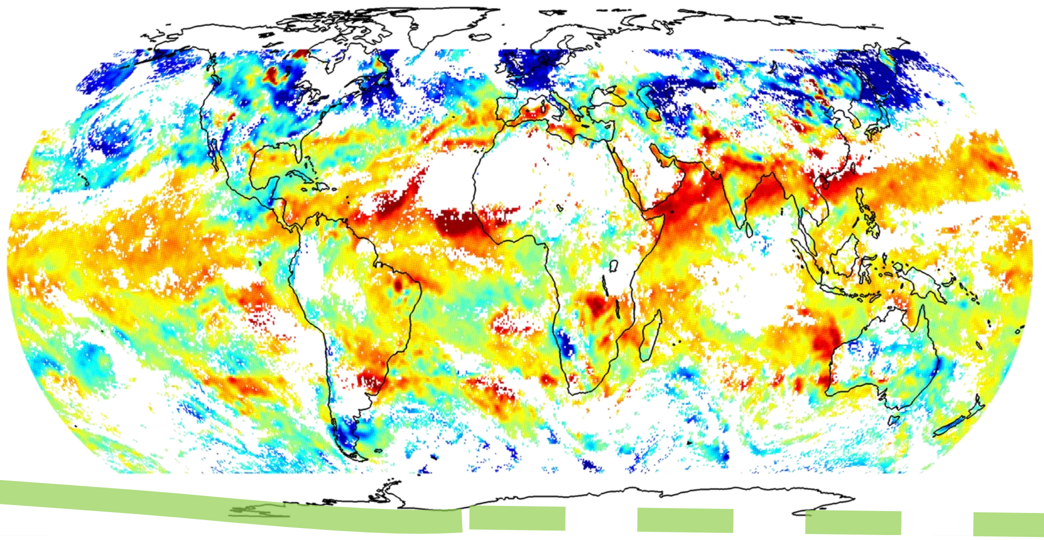
# Recent progress in remote sensing of δD

- 2004: Zakharov et al., *GRL* IMG/ADEOS



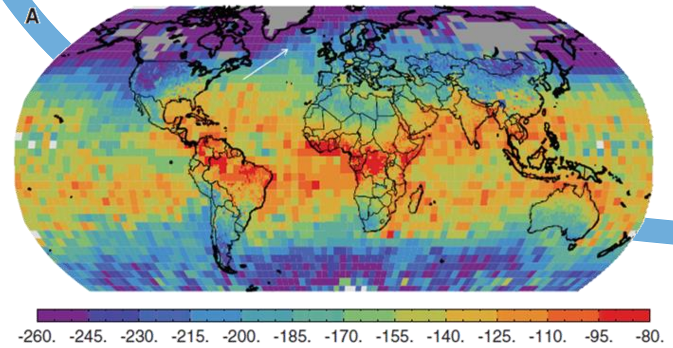

- 2006: Worden et al., *Nature* TES/AURA



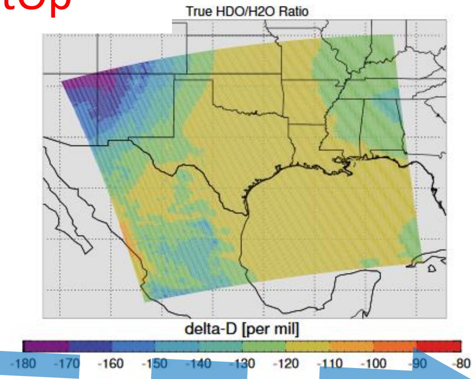



- 2012: Lacour et al., ACP IASI/MetOp
- 2011: Schneider et al., ACP IASI/MetOp
- 2009: Herbin et al., ACP IASI/MetOp

- 2009: Frankenberg et al., *Sciences*, SCIAMACHY/ENVISAT



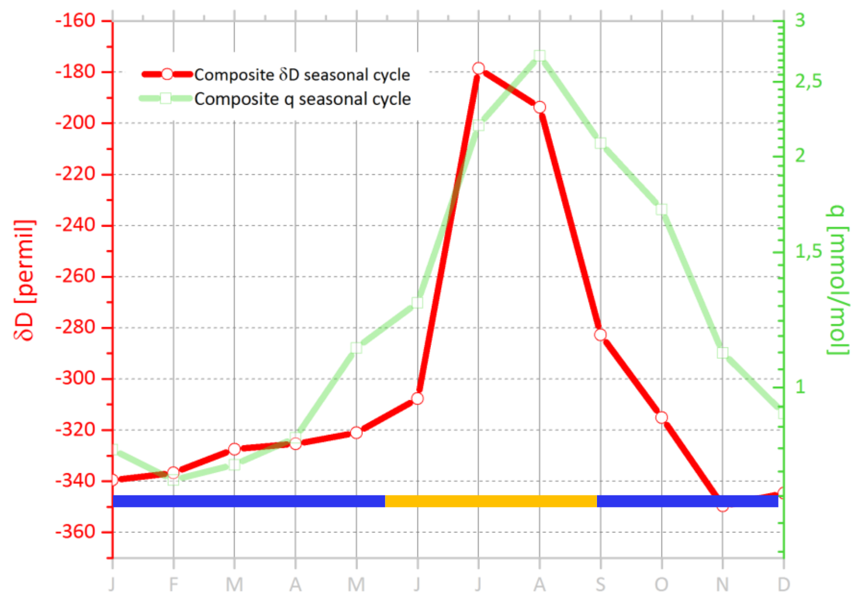

- 2013: Frankenberg et al., AMT GOSAT/SWIR
- 2013: Boesch et al., AMT GOSAT/SWIR




- 2016: Scheepmaker et al., AMT TROPOMI

# North Atlantic – Influence of the Sahara

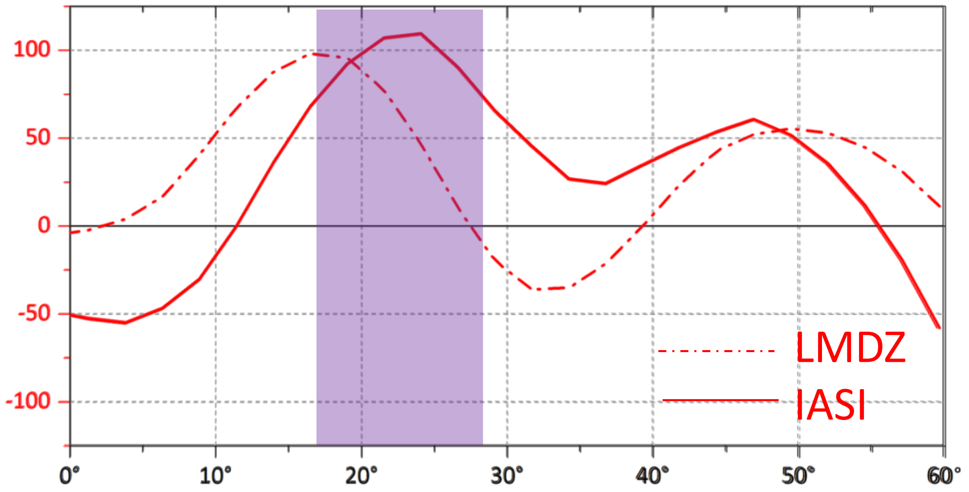
Added value of IASI δD observations



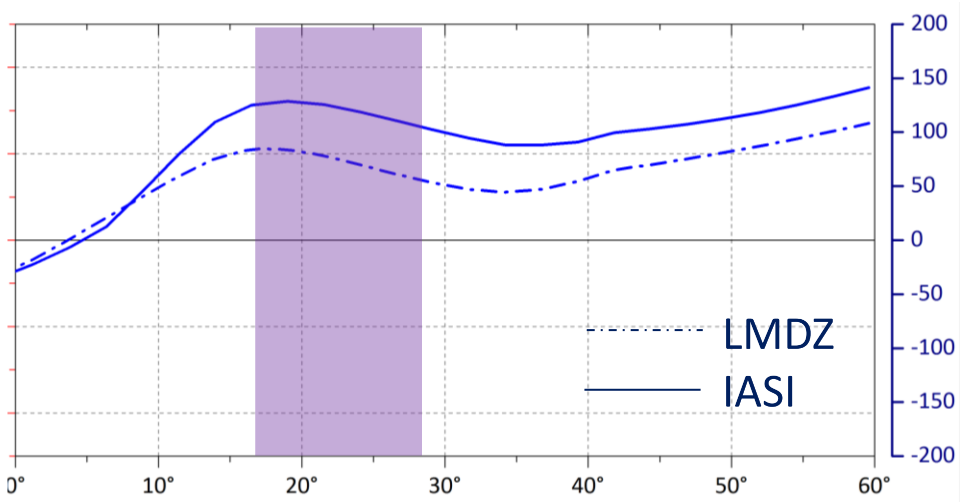

δD seasonal cycle is controlled by:

- Change in water sources
- Transport
- Turbulent mixing
- Dynamical state of the atmosphere
- Intensity of the Saharan Heat Low

δD seasonality (JA-DJ) [permil]



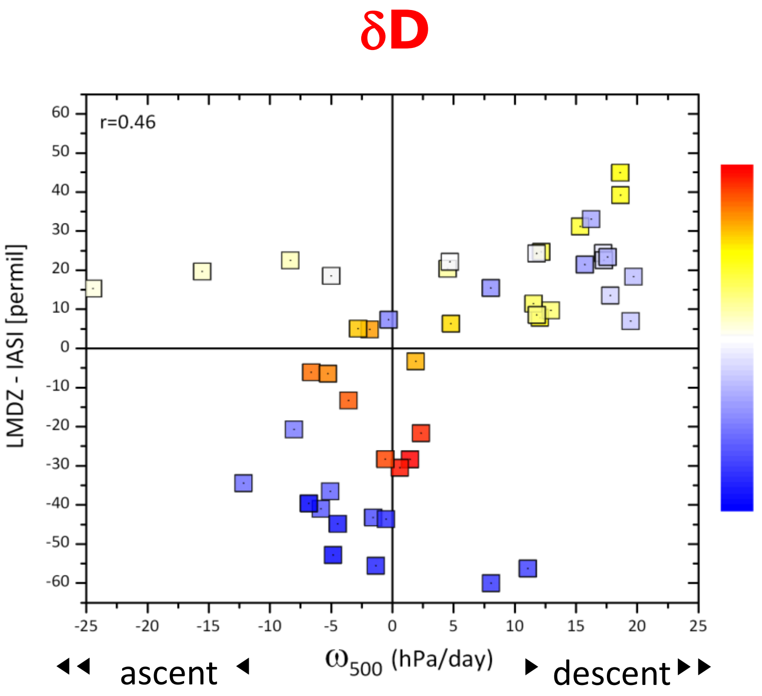

q seasonality (JA-DJ) [%]

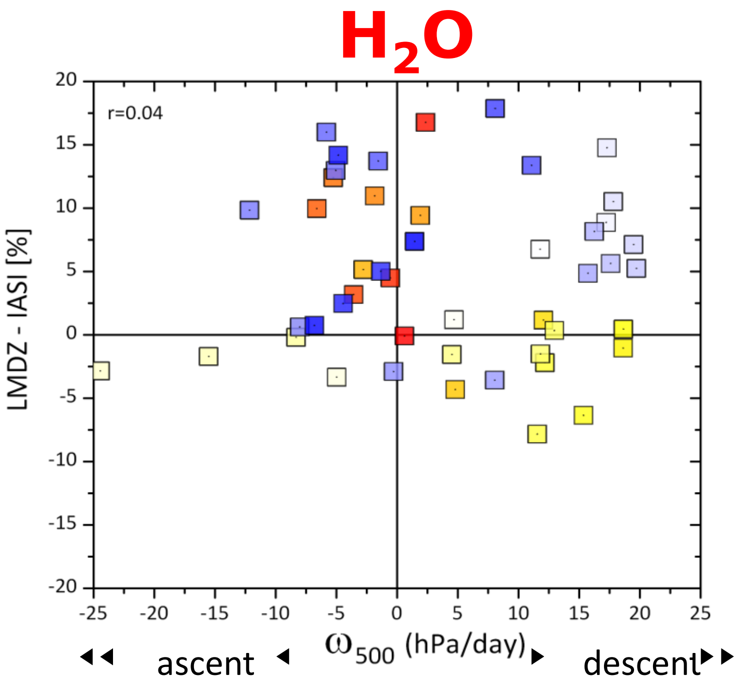


# δD to evaluate global climate models

- Isotopic composition of water vapour is sensitive to many processes: convection/transport/evapotranspiration/mixing …
- The capacity of a model to restitue δD reflects its ability to represent all these processes

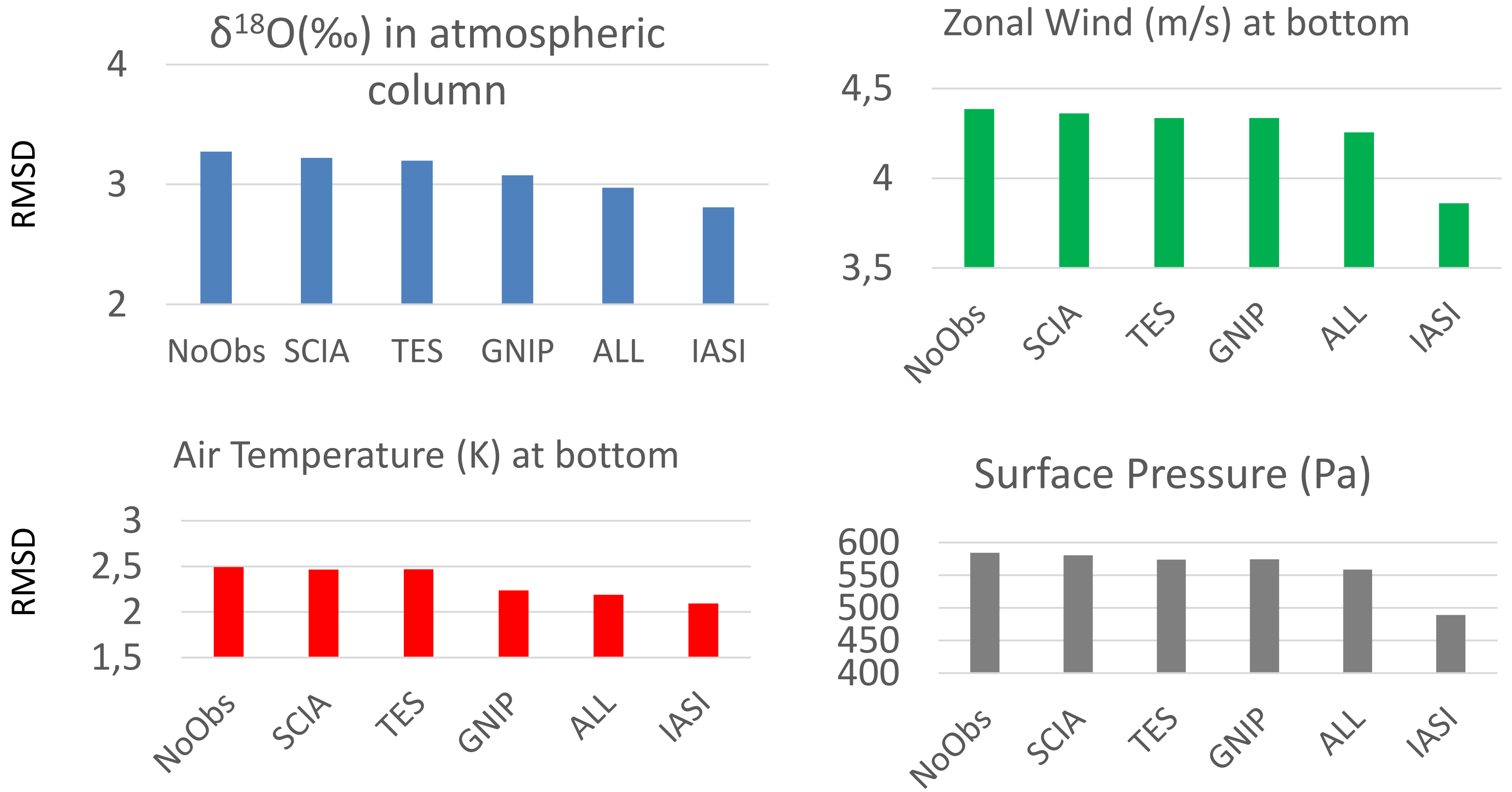
- Model evaluation against water vapour observations can be limited as
  - Different processes can have the same impact on H2O
  - Compensating effects in the models



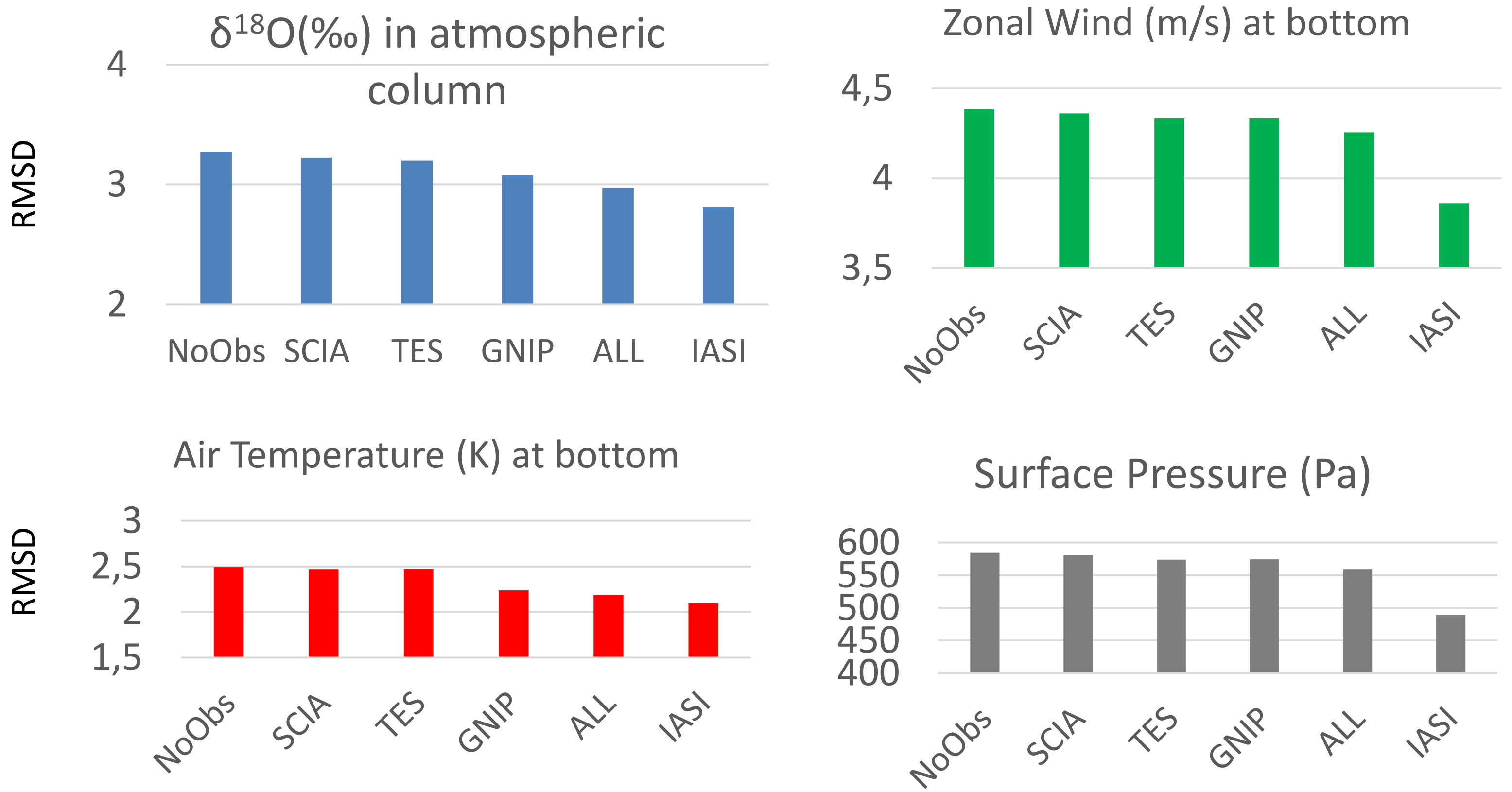



Yoshimura et al., 2015:

- First assimilation experiment of δD observations (TES, SCIAMACHY, GNIP, in situ)
- Positive score on T, P, wind fields



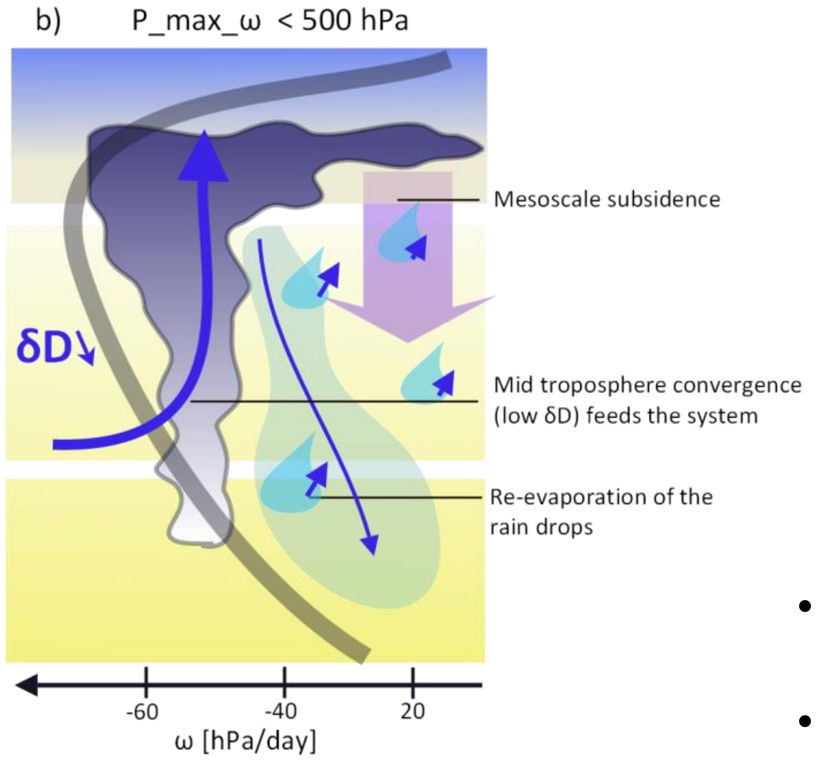

*"From OSSE, IASI's impact is much larger than those of TES, SCIAMACHY, and GNIP-vapor for not only δD, but also environmental variables (temperature, wind speed, pressure, etc.)"*



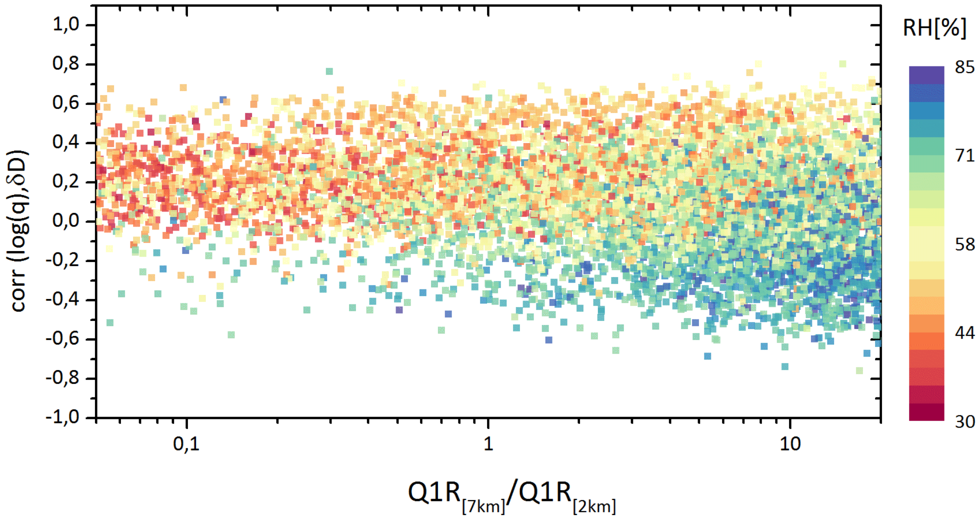
δ18O(‰) in atmospheric column
RMSD
4
3
2
NoObs
SCIA
TES
GNIP
ALL
IASI
Zonal Wind (m/s) at bottom
4,5
4
3,5
NoObs
SCIA
TES
GNIP
ALL
IASI
Air Temperature (K) at bottom
RMSD
3
2,5
2
1,5
NoObs
SCIA
TES
GNIP
ALL
IASI
Surface Pressure (Pa)
600
550
500
450
400
NoObs
SCIA
TES
GNIP
ALL
IASI

# Tropics: isotopic signature of convection's depth

- The mechanism responsible of the amount effect in precipitation has long been debated
- 3 mechanisms are commonly used to explain the depletion of the precipitations:




In the water vapour:

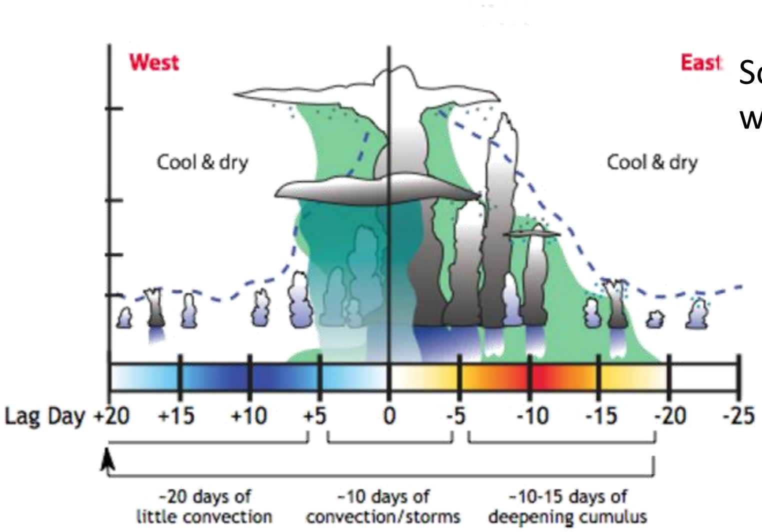



- Amount effect is more frequent in deep convective environment
- The anti-correlated pairs corresponds to very humid free troposphere
- The rain re-evaporation more efficient when RH increases

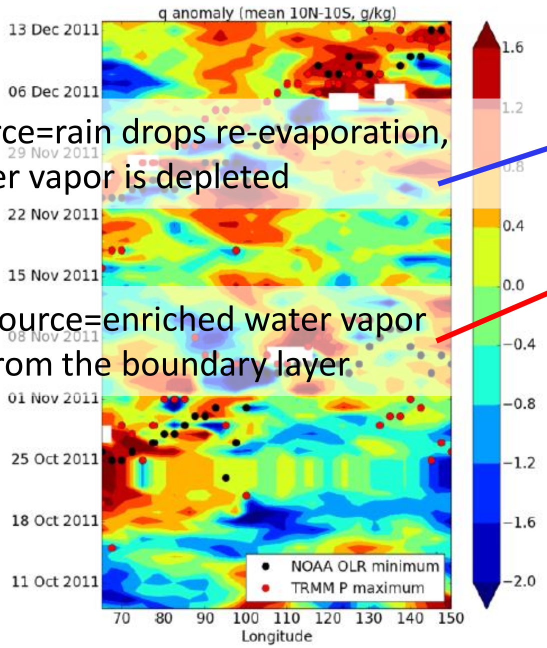
→ In the vapour, the amount effect is found associated with deep convective environment with high RH → rain re-evaporation mechanism

# Indian and Pacific Oceans – MJO

- MJO = principal mode of intra seasonal variability (30-60 days)
- Influence on global water cycle
- Persistant difficulties to simulate the water cycle in this region



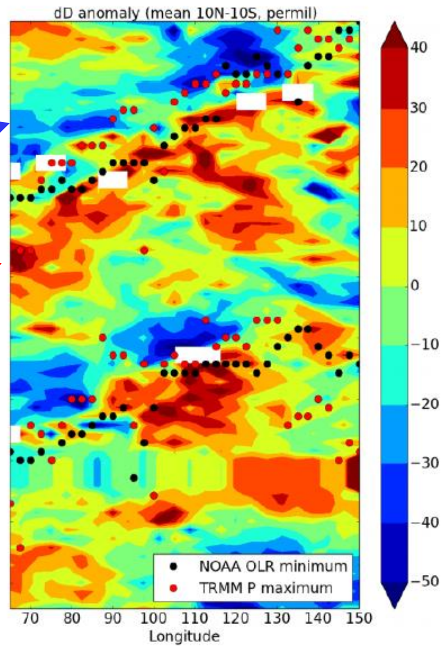

**$H_2O$**




Source=rain drops re-evaporation, water vapor is depleted

Source=enriched water vapor from the boundary layer

**δD**




Tuinenburg et al., JGR 2015