Karlsruher Institut für Technologie

# Analysis of stable water isotopes in tropospheric moisture during the West African Monsoon

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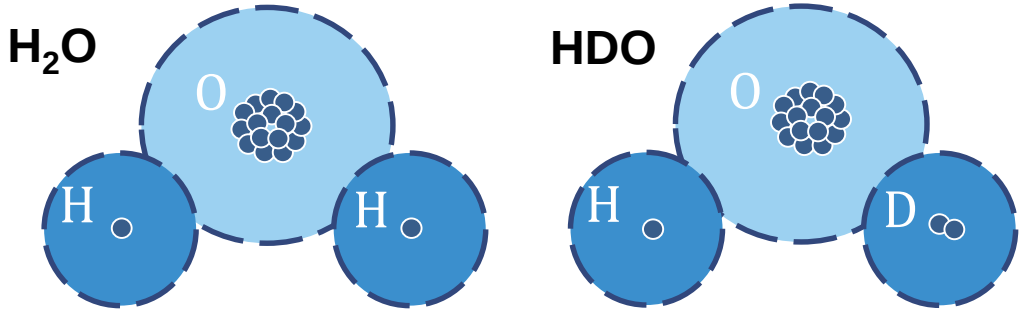
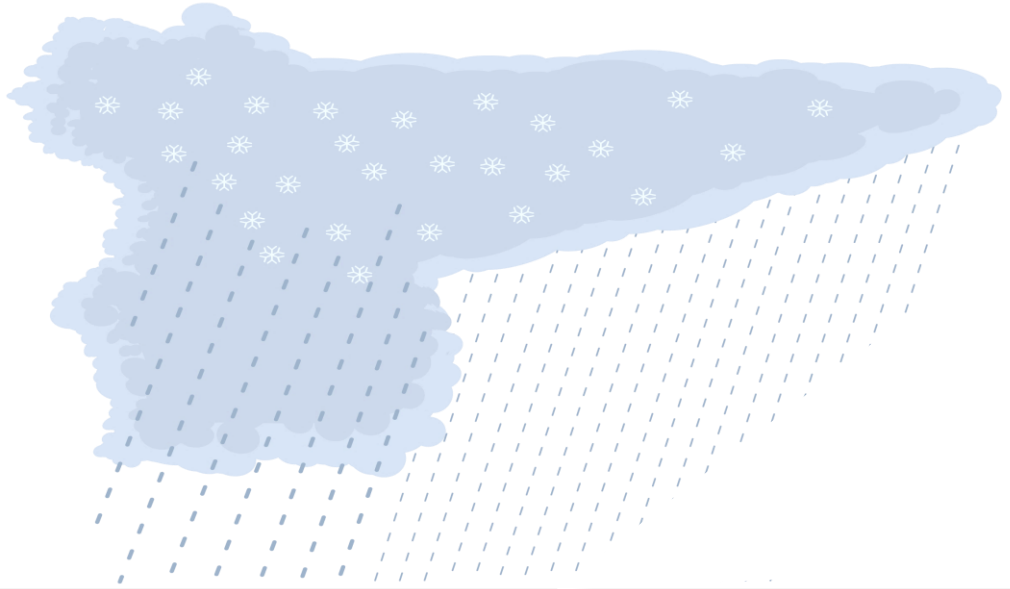
Institut of Meteorology and Cliamte Research, Atmospheric Trace Gases and Remote Sensing



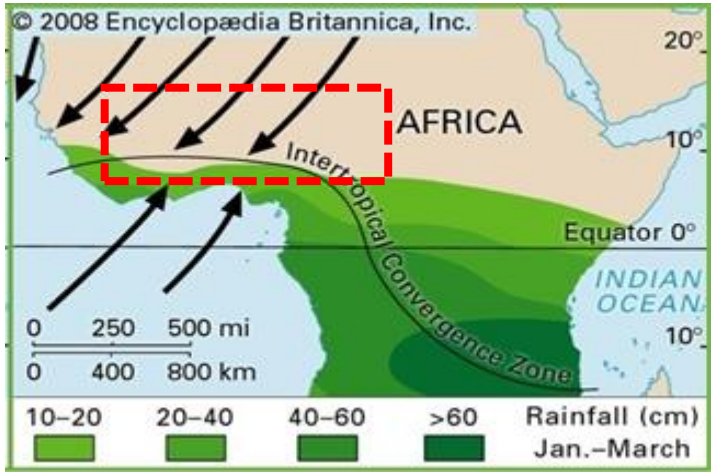



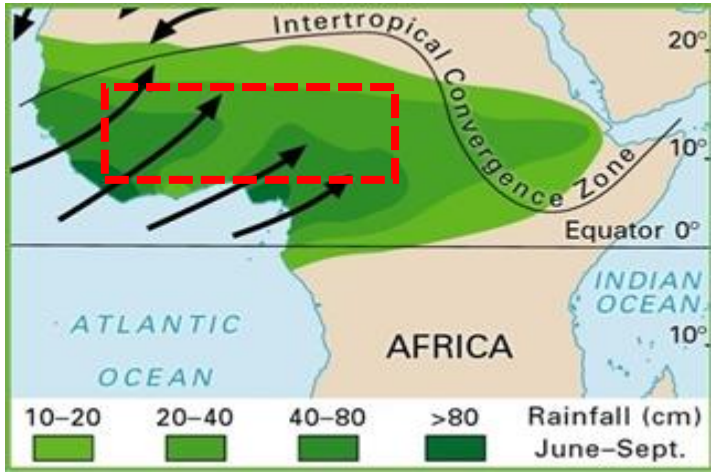
*“Water vapour ($H_2O$) in the atmosphere is a key component of the Earth’s hydrological cycle, critical in shaping the global environment and supporting life on Earth as we know it.”*
Climate Change Initiative, ESA[1]

# **Sahel zone** in West Africa as region of the extremes …

[2]

[3]



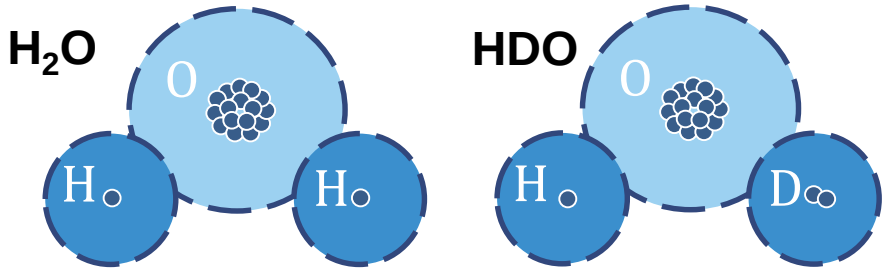




[4]

… where even climate models reach their limits (OECD Report, 2016).

**Analysis of isotopic composition in water vapour as promising diagnostic for atmospheric processes**

# Water isotopes in the troposphere




$$\delta D = \left( \frac{HDO/H_2O}{R_{vsmow}} - 1 \right) * 1000$$

with $R_{vsmow} = 0.031\ \%$

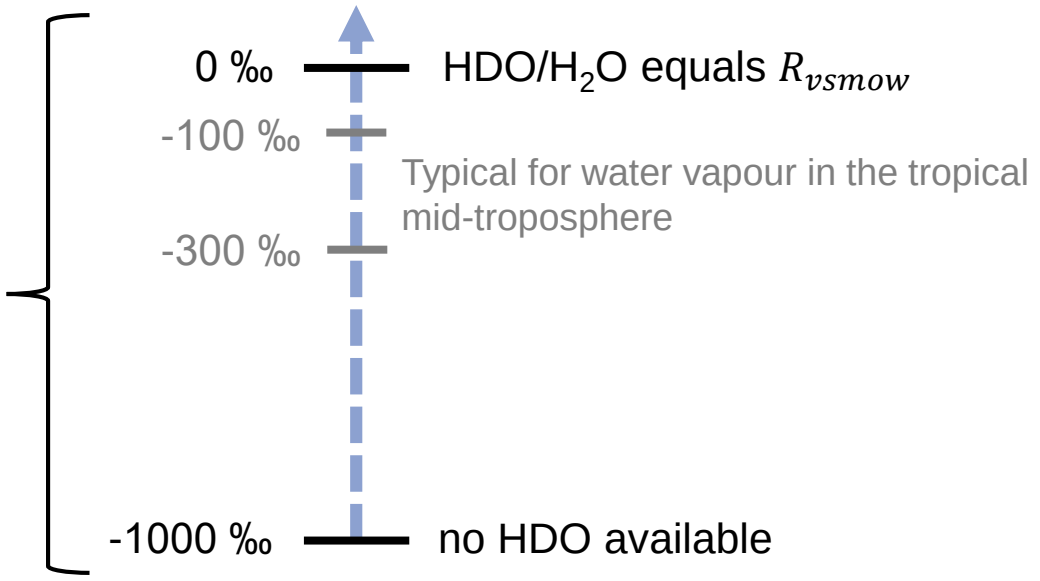
**Increased molecular mass**

**Reduced saturation vapour pressure**

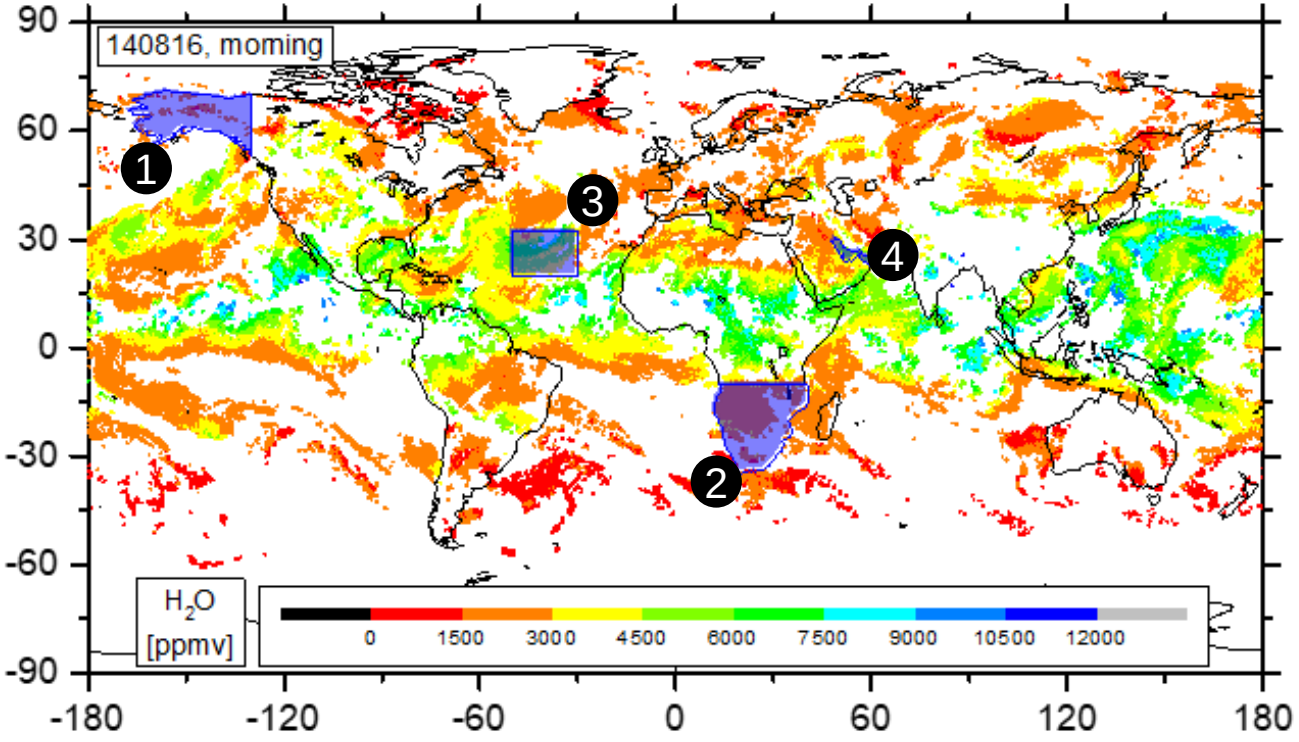
**Equilibrium fractionation**

- Lighter isotopes evaporate preferentially.
- Heavier isotopes condensate preferentially.

$\delta D =$

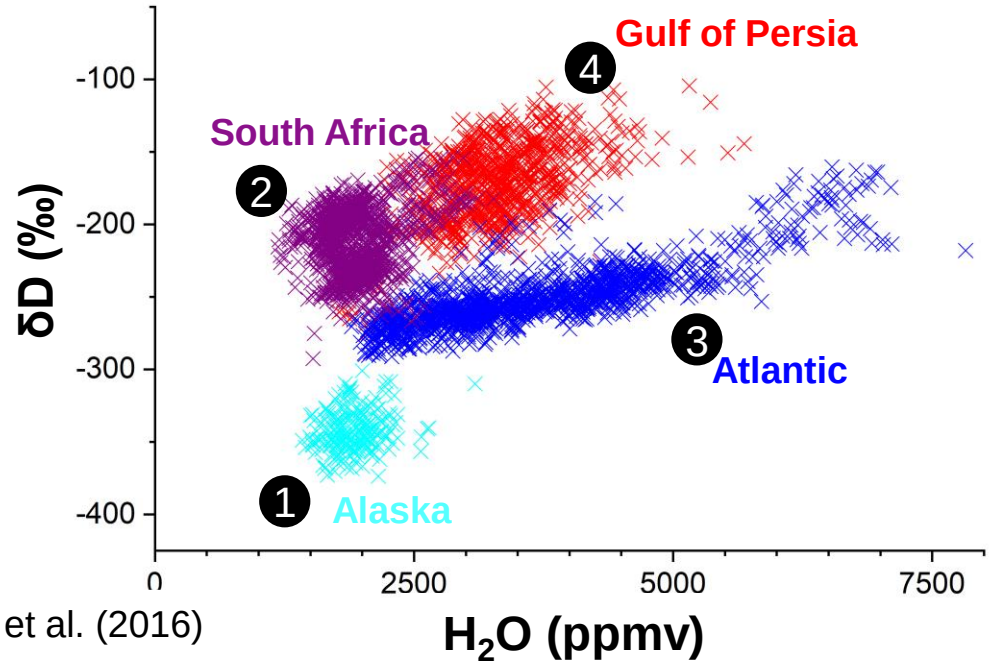


# $H_2O$ and δD in tropospheric water vapour




Global $H_2O$-distribution in mid-tropospheric water vapour

Pairwise analysis of $H_2O$ and δD in water vapour



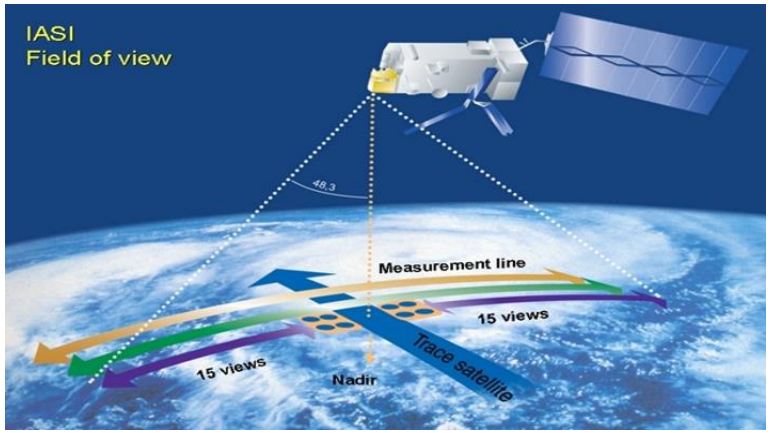

Schneider et al. (2016)

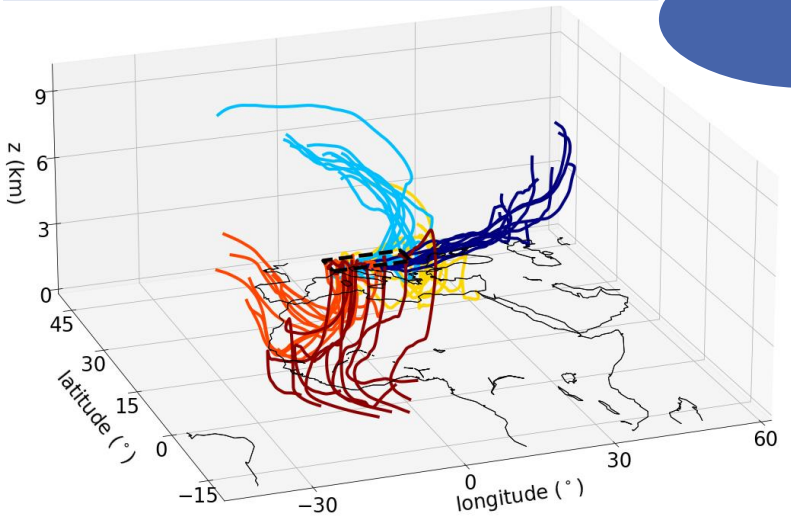
**Different regimes in {H2O, δD} phase space due to different prevailing moisture processes in each region**

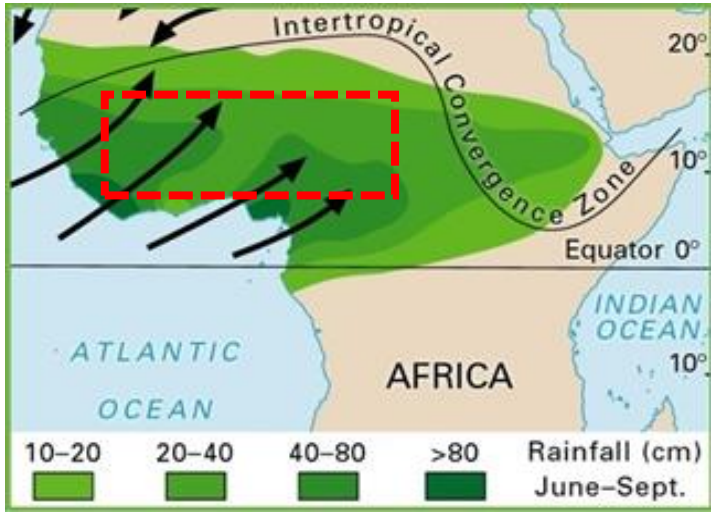
## Remote Sensing Data

## Model-Based Framework

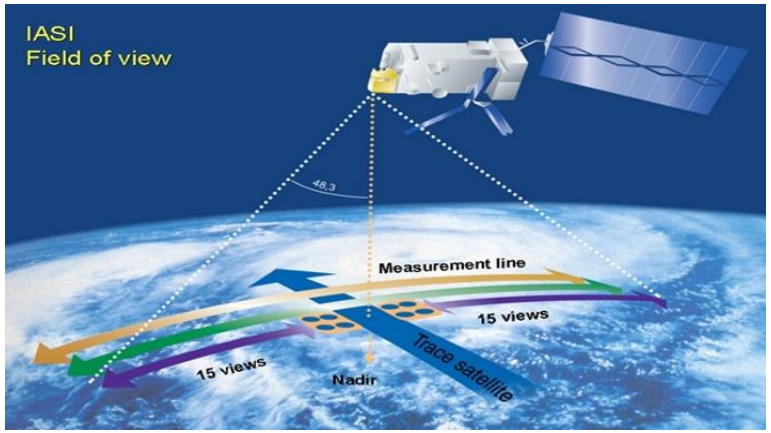
## Process Identification



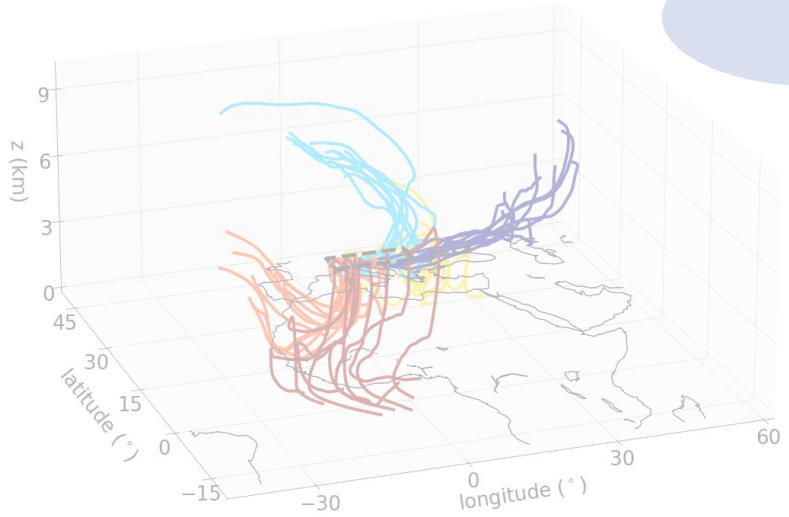



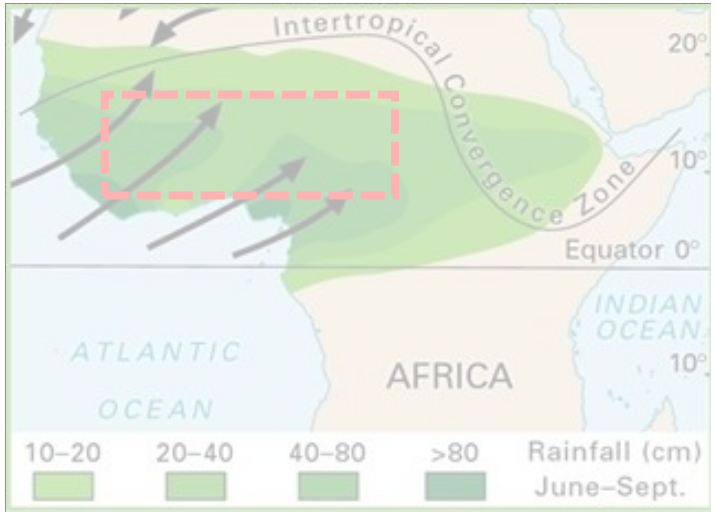
## Remote Sensing Data



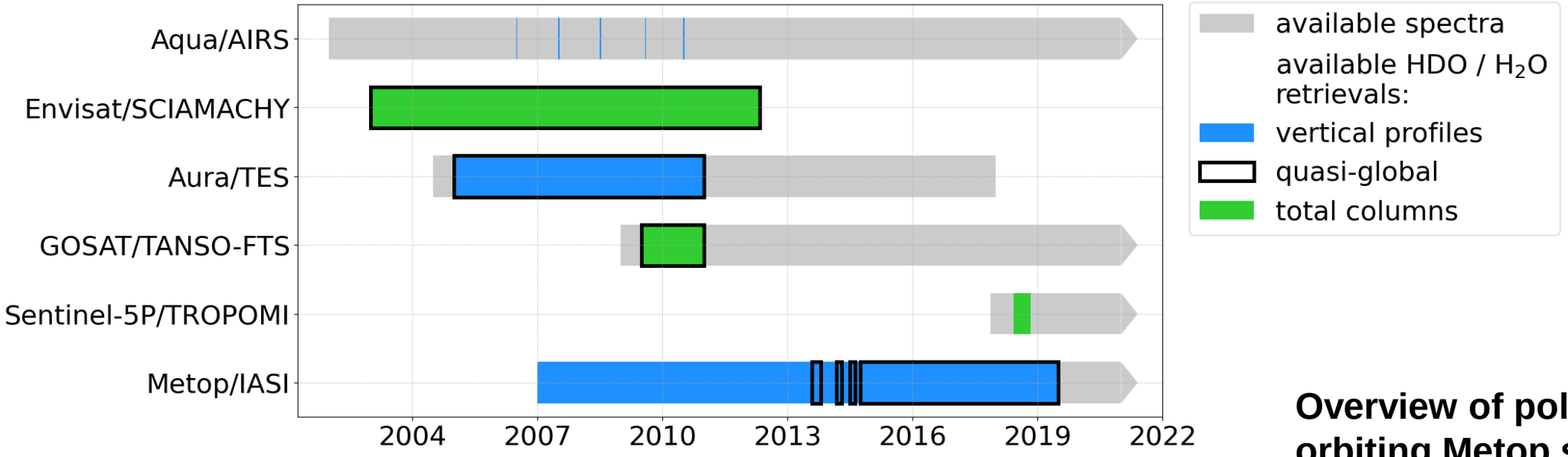

## Model-Based Framework




## Process Identification



# Remote sensing with Metop/IASI

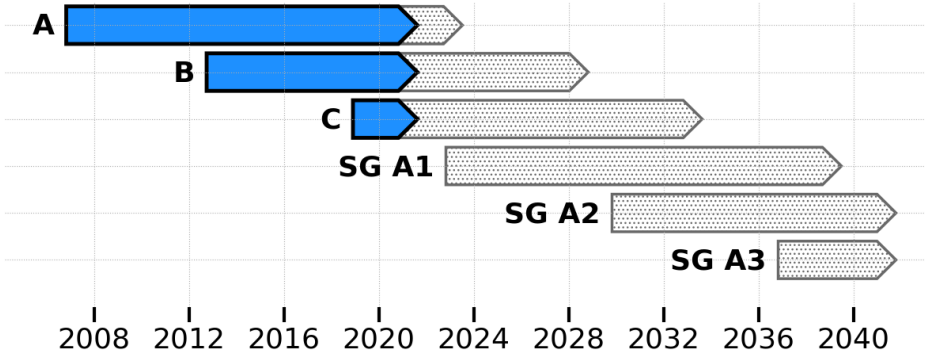



## Overview of referenced tropospheric HDO/$H_2O$ datasets from space

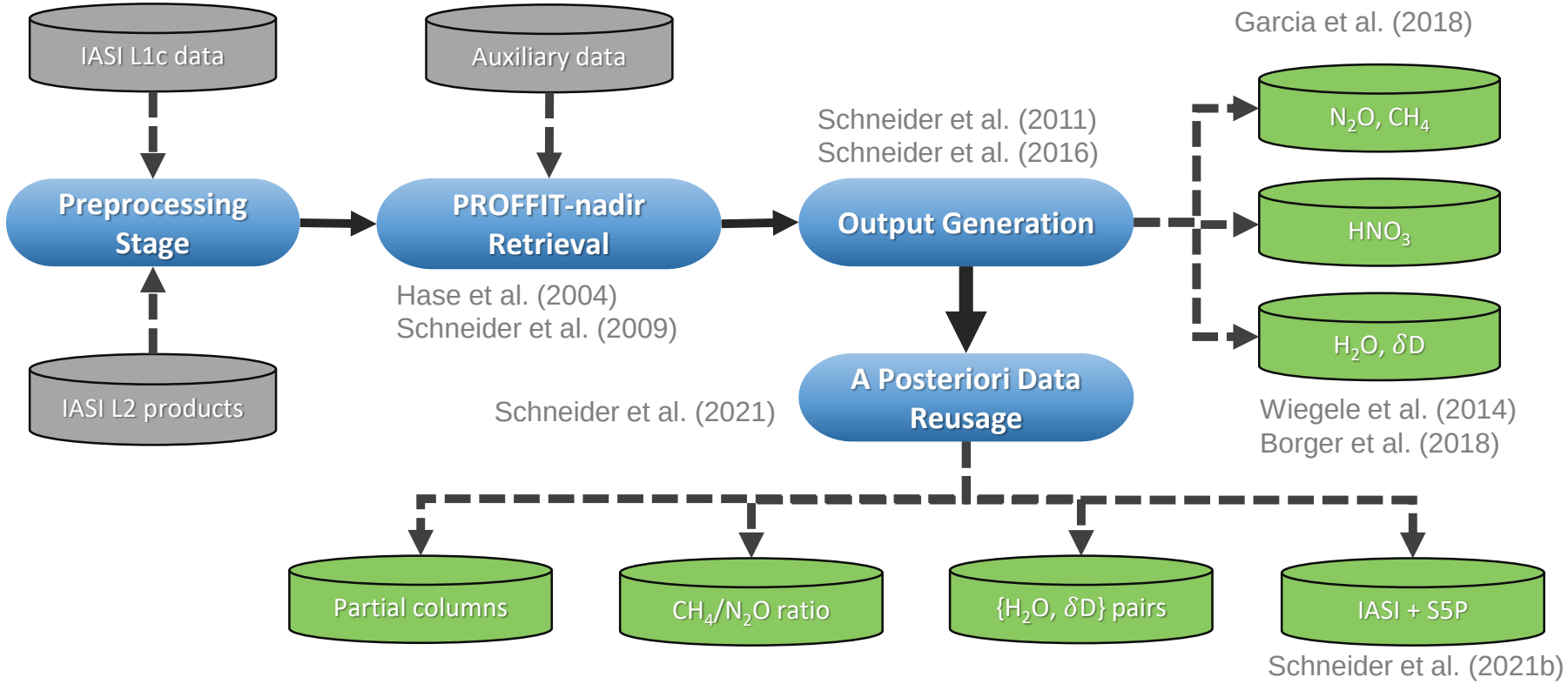
- Further Aqua/AIRS data available monthly and globally, but not yet referenced in literature
- Lack of continuous, daily and global HDO/$H_2O$ datasets

➢ **Generation of new Metop/IASI product**

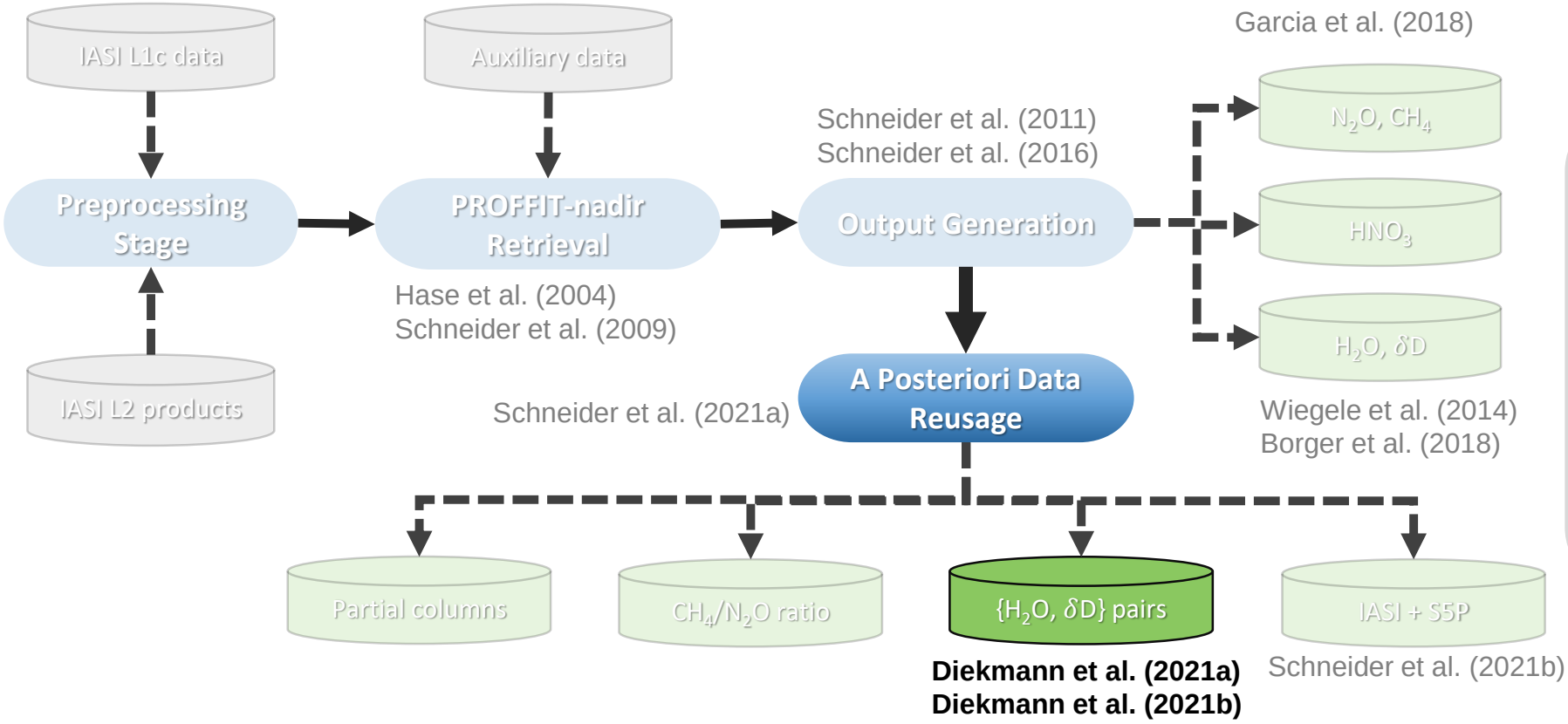
## Overview of polar-orbiting Metop satellites



# Remote sensing with Metop/IASI



# Remote Sensing with Metop/IASI

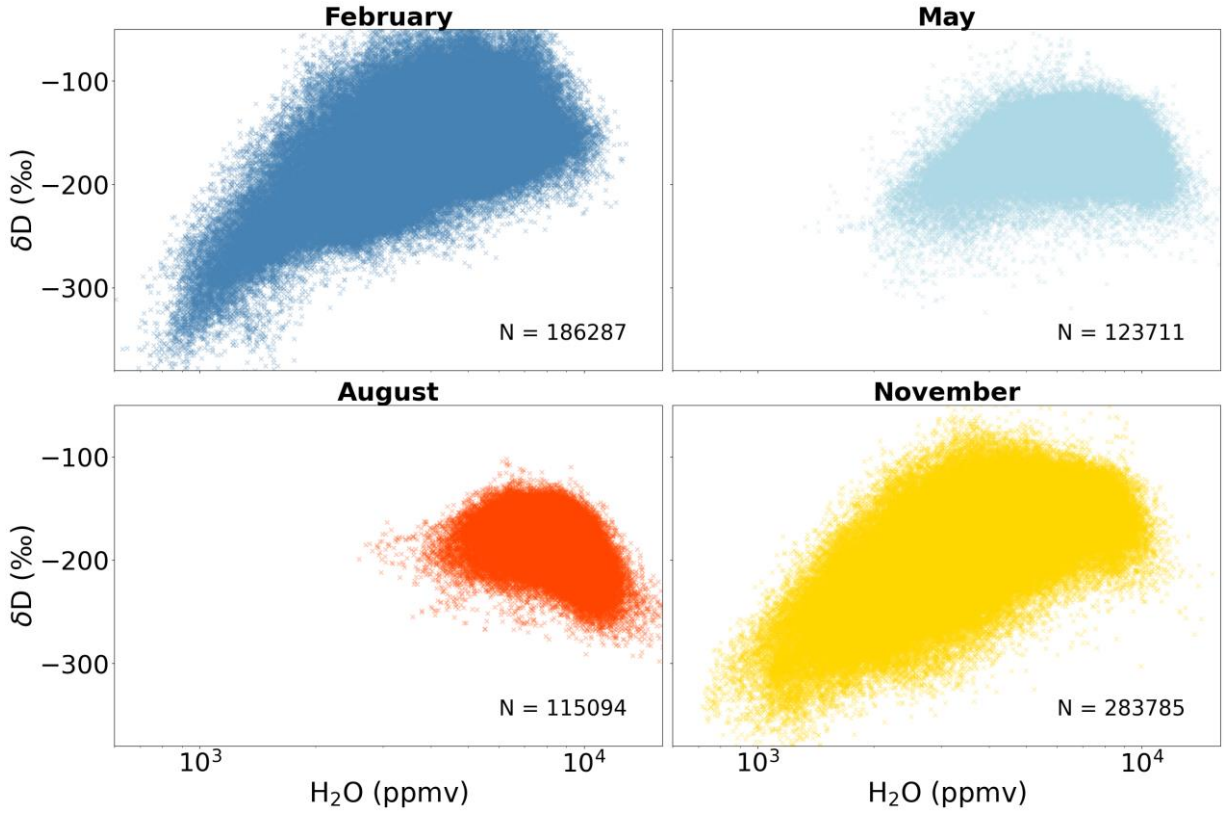


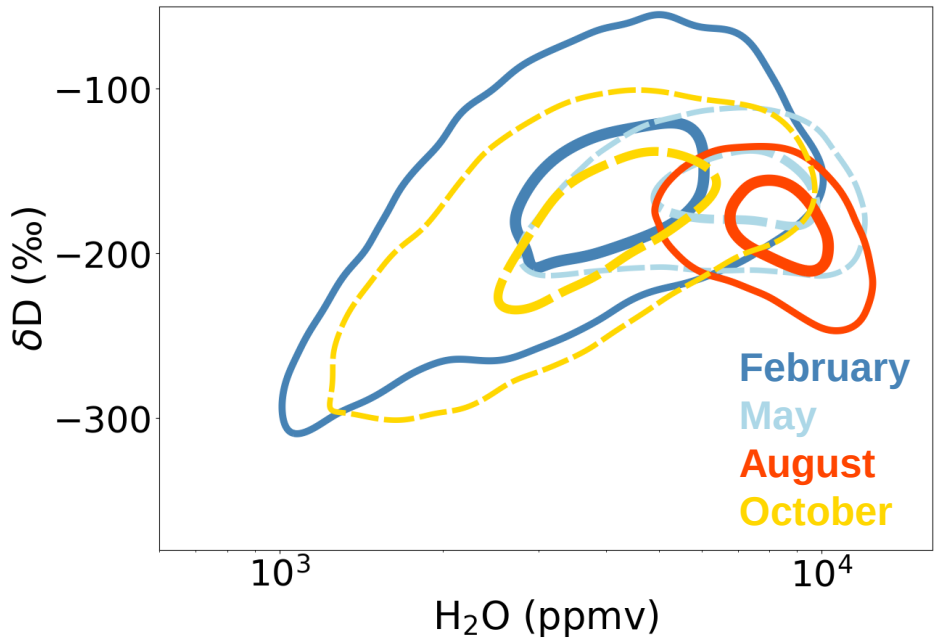

**Quasi-operational Post-Processing for optimal $\{H_2O, \delta D\}$ data**

- focus on mid-troposphere ($z = 4km$)
- Oct. 2014 – Jun. 2019
- Globally, twice daily
- Around 300 000 – 400 000 observations per day

# Climatologies with Metop/IASI

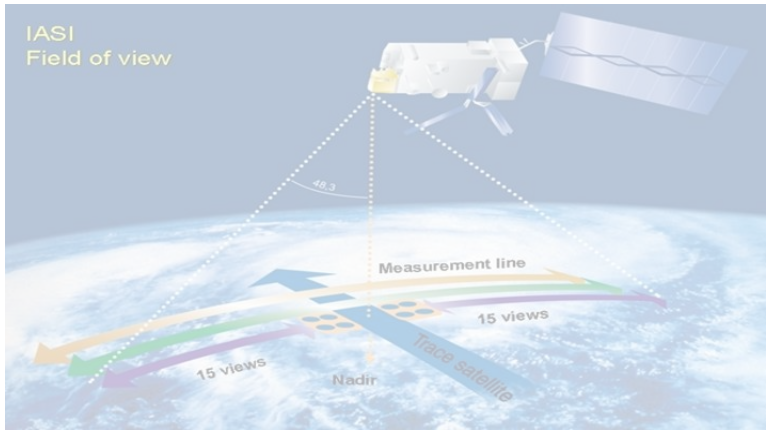
**IASI data over the Sahel averaged for 2015 – 2018**



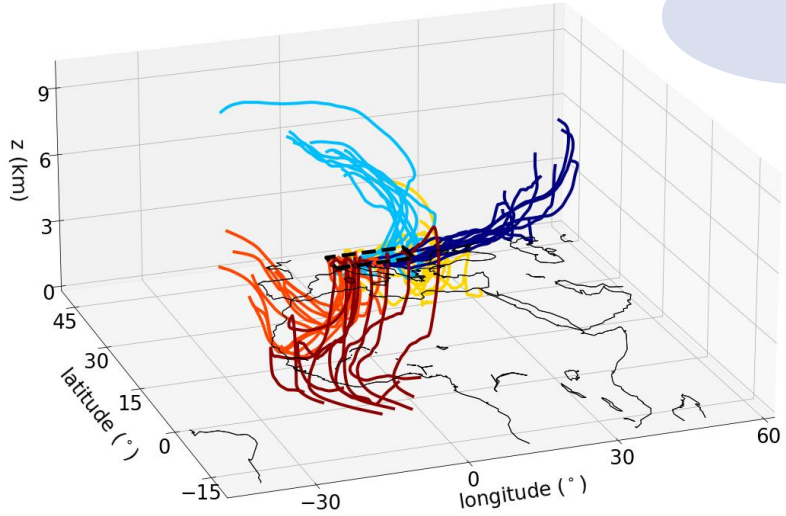




- Correlation of H2O and dD during winter
- Anticorrelation during summer
- Which processes account for the observed saisonality?

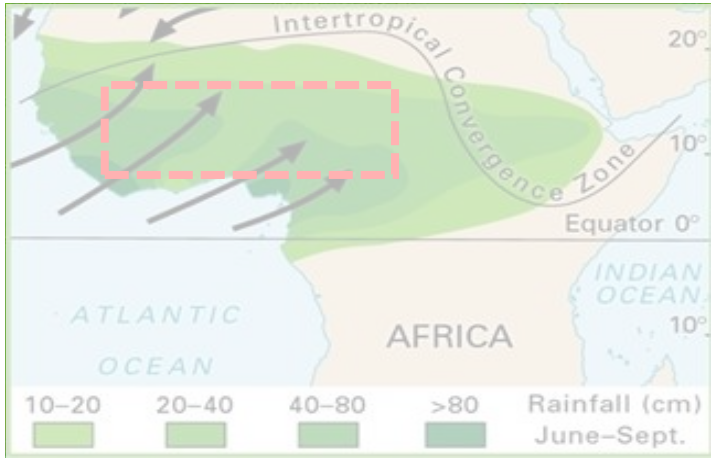
## Remote Sensing Data



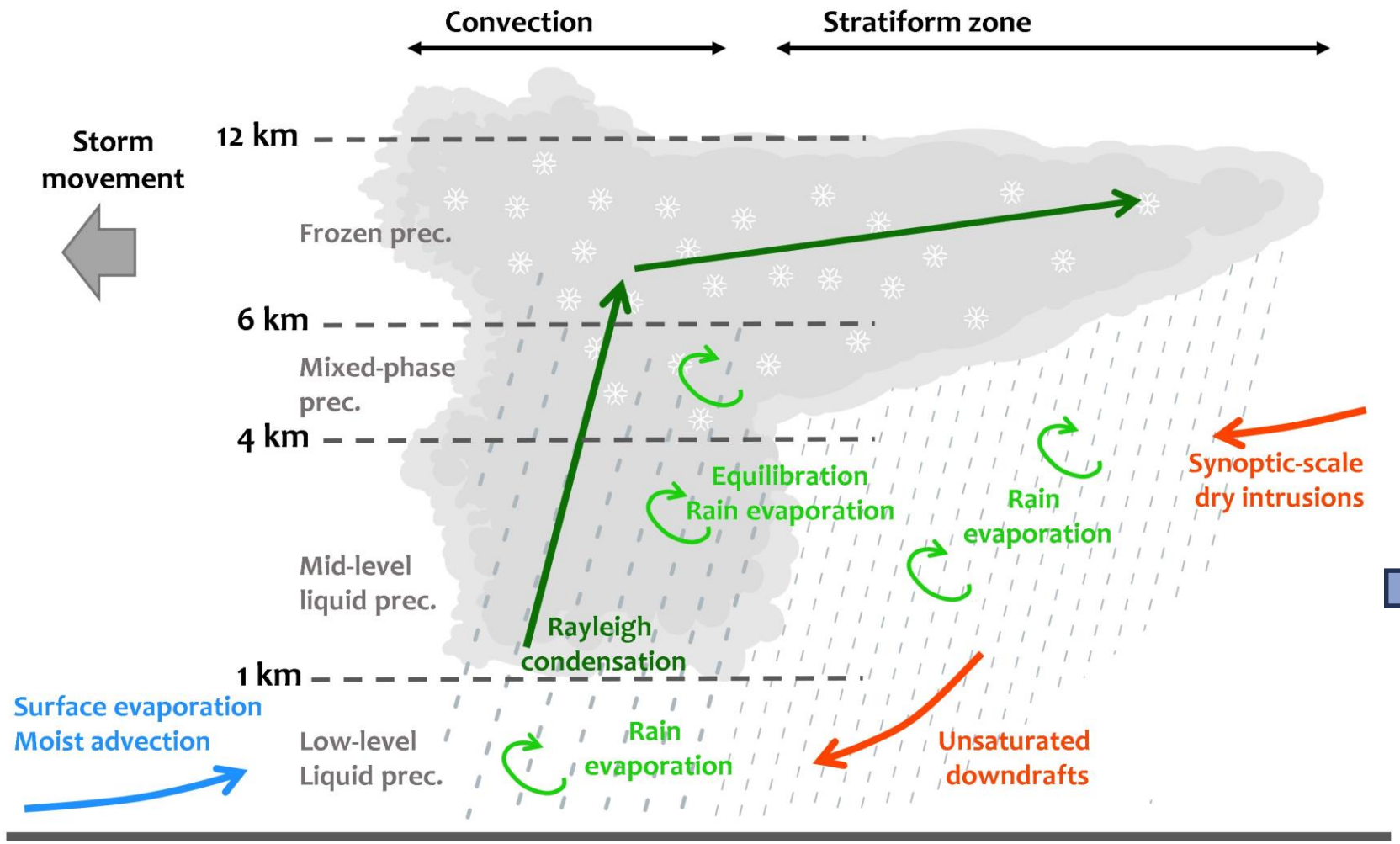

## Model-Based Framework




## Process Identification



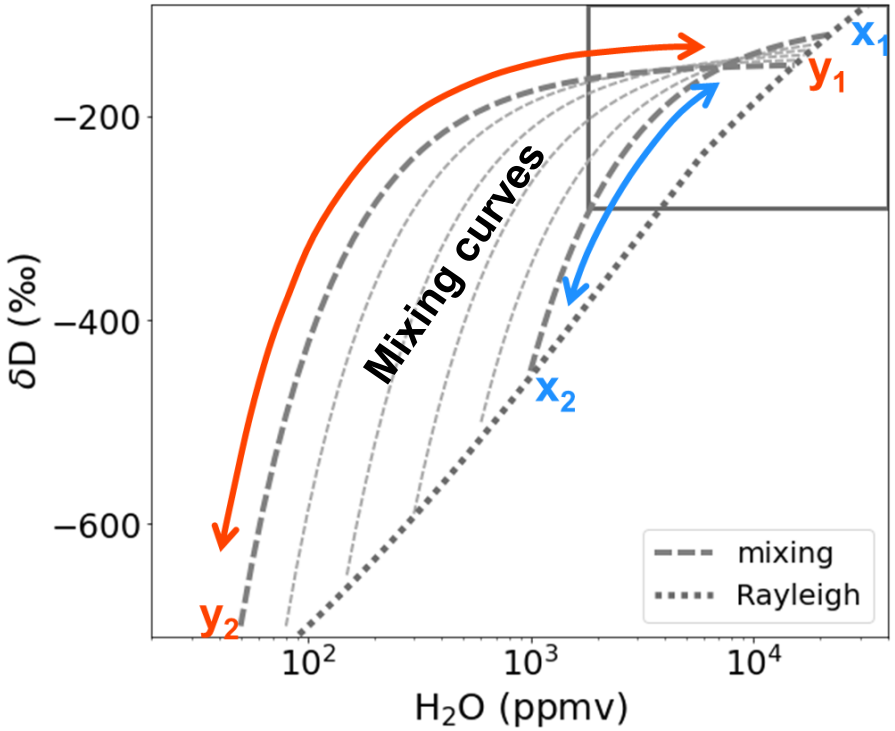
# Relevant moisture processes for $H_2O$ and δD

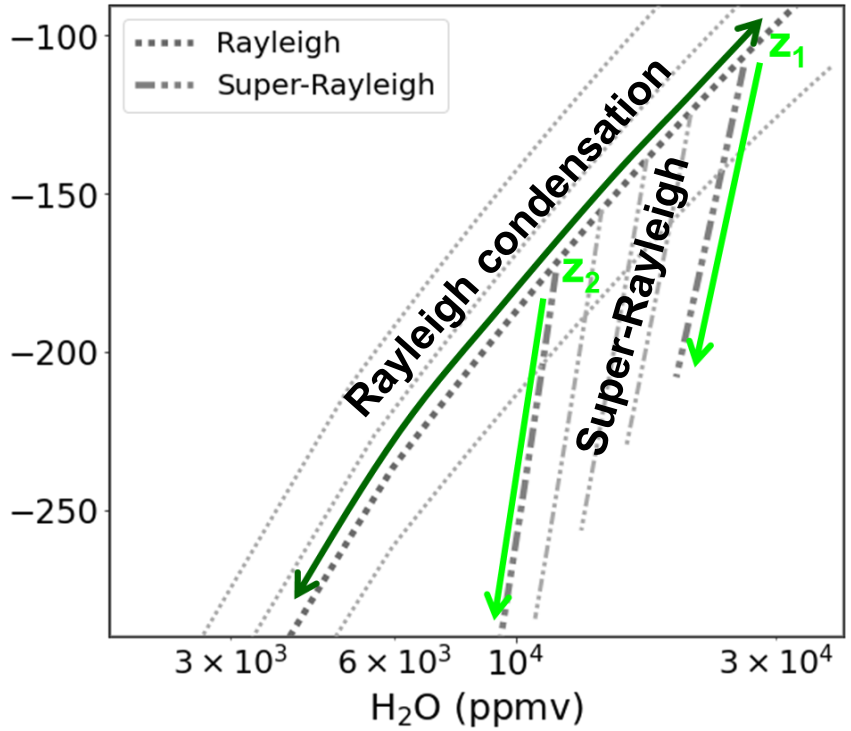



Schematic overview of prevailing moisture processes within a convective squall line event during the West African Monsoon

**How do these processes reflect in the {$H_2O$, δD} phase space?**

# $H_2O$ and δD along air mass trajectories



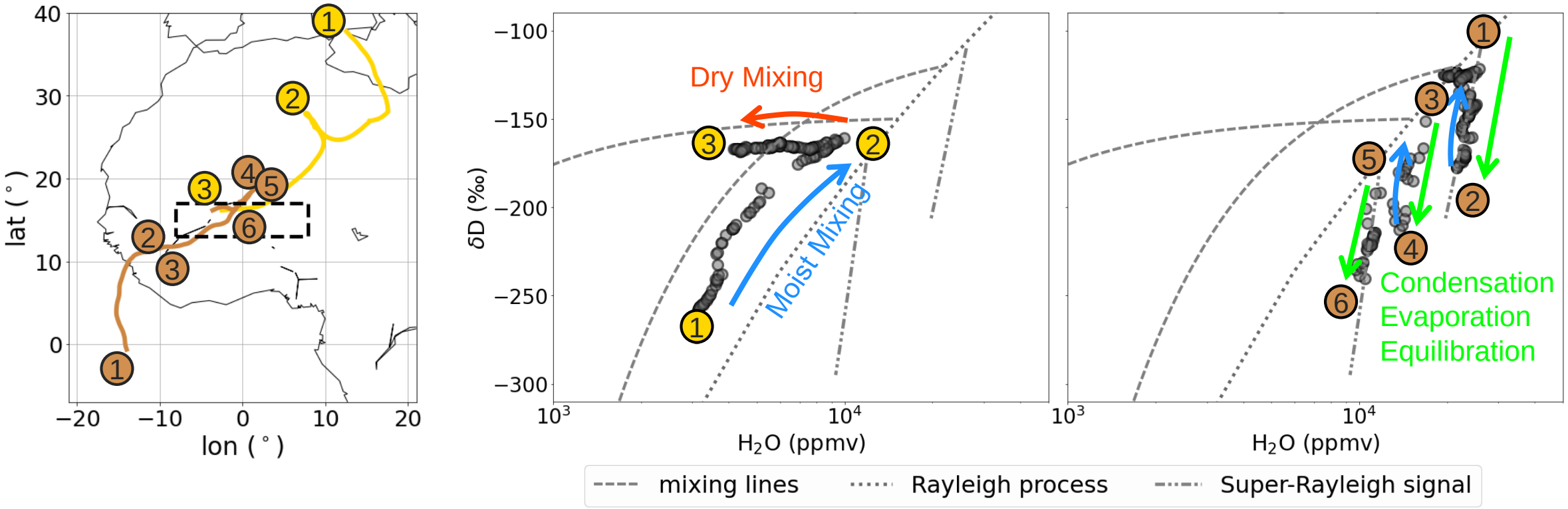

Theoretical process curves developed in Noone (2012), for describing effects of idealized processes to $H_2O$ and δD in water vapour

**Mixing of air masses**
Mixing curves for air mass mixing without fractionation

**Rayleigh Condensation**
Rain condensation during moist adiabatic ascent

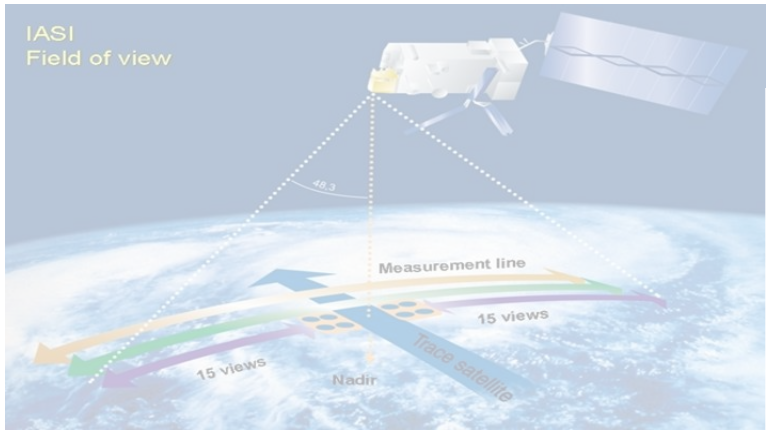
**Super-Rayleigh Signals**
Special case of Rayleigh condensation, which is overlaid by partial rain evaporation and equilibration

# $H_2O$ and δD along air mass trajectories

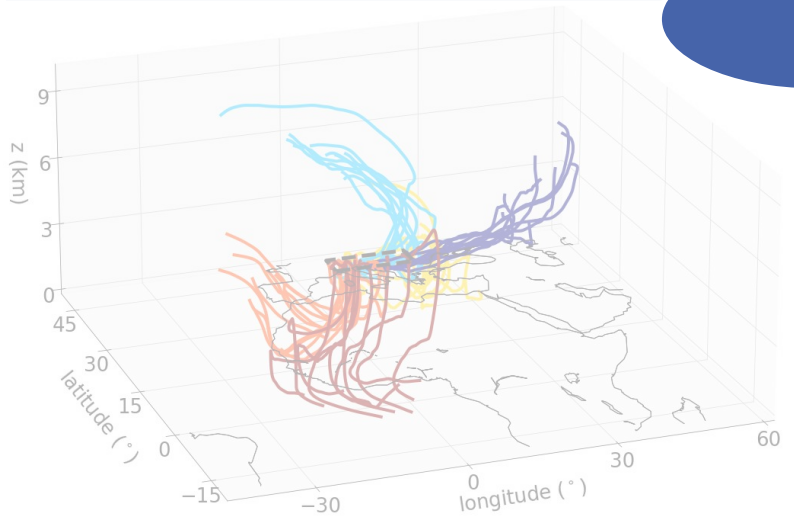



**Identification of moisture processes along trajectories:**
Diekmann et al., 2021c

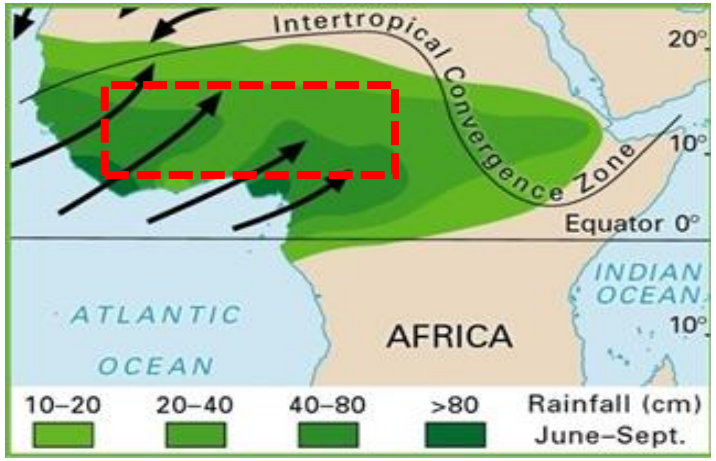
## Remote Sensing Data




## Model-Based Framework

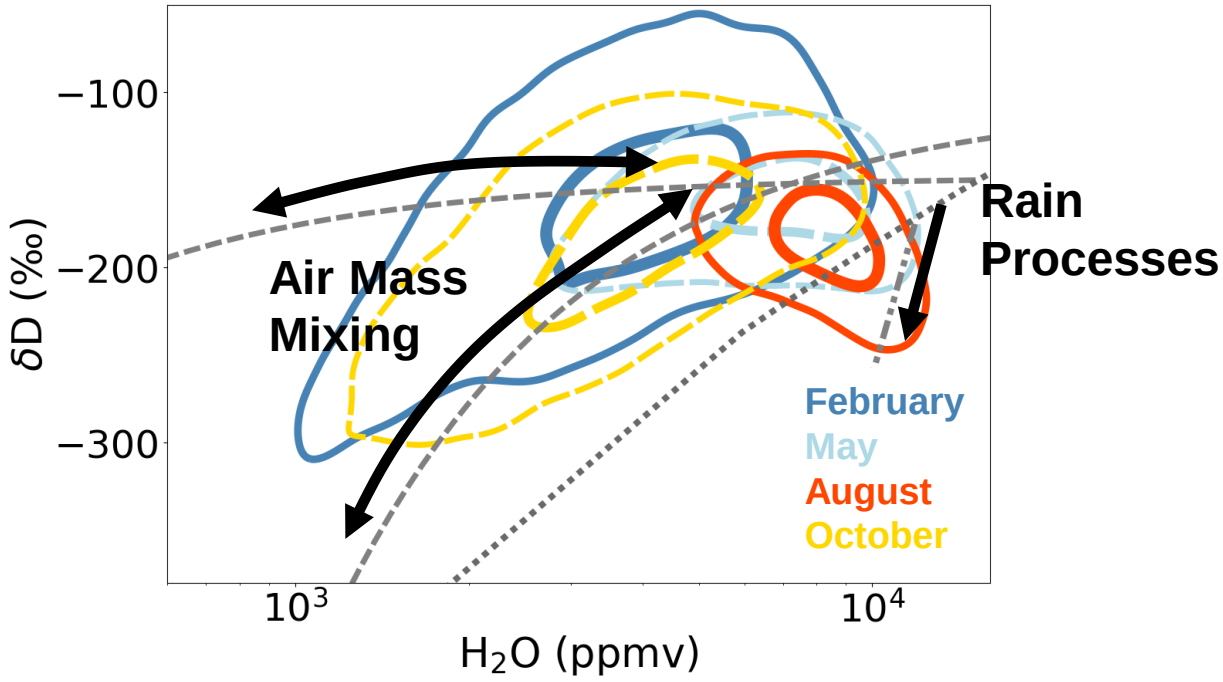


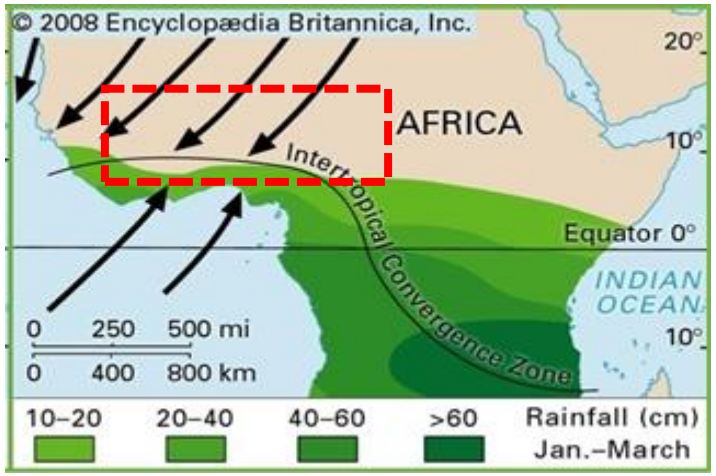

## Process Identification



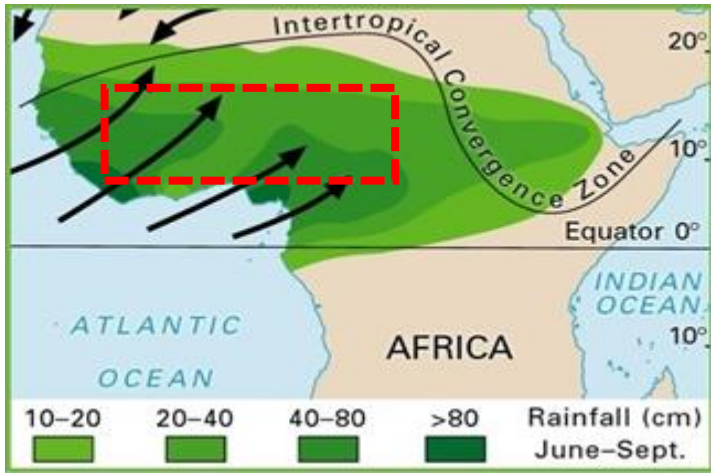
# Annual cycle over the Sahel

**IASI data, over the Sahel, averaged for 2015 – 2018**



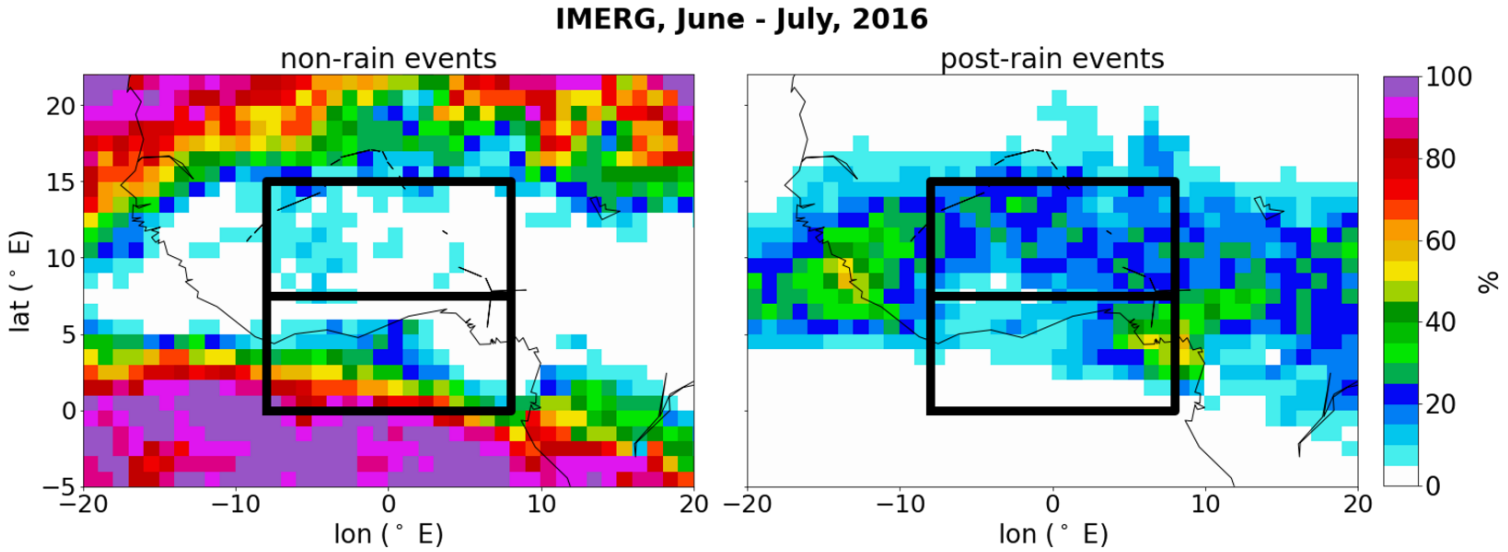

**Winter**
Mixing of dry Saharan air into the Sahel

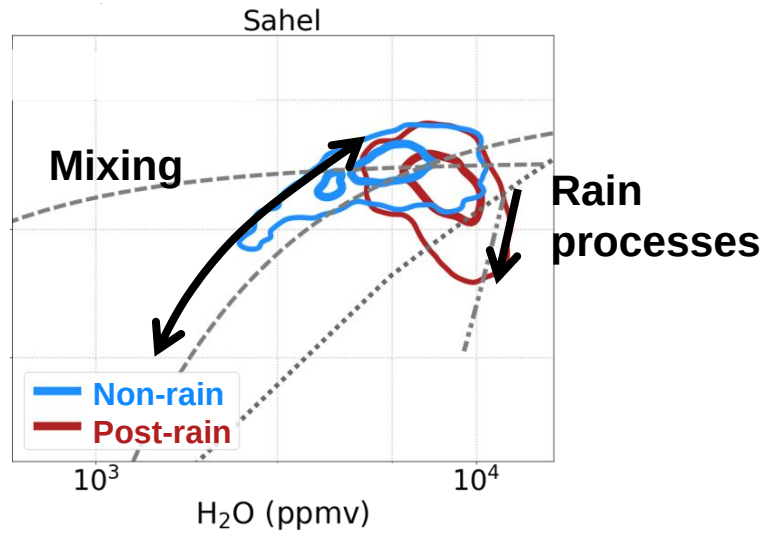



**Summer**
Moist monsoon winds induce strong rainfalls over the Sahel

# Clustering of IASI observations

## Sorting of IASI data into non-rain and post-rain events using GPM IMERG rainfall data




- **Air masses without rain impact (non-rain) show strong mixing signals**
- **Air masses affected by rain show strong Super-Rayleigh signals**

# Process analysis of West African Monsoon

**Robust distinction between air masses that were affected by rain processes and that only experienced air mass mixing**

**Evaluation of IASI data**

- Interpretation of annual variability
- Impact of different monsoon phases
- Impact of individual rainfall events

**Evaluation of isotope-enabled atmospheric models**

- Global model ICON-ART$_{iso}$
  - Impact of horizontal resolution
- Regional model COSMO$_{iso}$
  - Impact of convective treatment

| Plattform | Typ | Region | Δx | Zeitraum | Spezifikationen |
|---|---|---|---|---|---|
| **IASI** | Spaceborne sensor | Global | 12 km | Oct. 2014 – Juni 2019 | - |
| **LAGRANTO** | Trajectory model | Sahel | - | “ | - |
| **ICON-ARTiso** | Global model | Global | 160 km | Jan. 2017 – Dec. 2019 | Free-running |
| | “ | Global | 80 km | “ | “ |
| | “ | Global | 80 km | “ | “, incl. 2-way nesting |
| | “ | Afrika | 40 km | “ | “, 2-way nesting |
| **COSMOiso** | Regional Model | Africa | 14 km | Juni – Juli 2016 | Nudged to ERA-interim param. Convection |
| | “ | “ | “ | “ | expl. Convection |
| | “ | “ | 7 km | “ | “ |
| **GPM IMERG** | Rainfall product | Global | 0.1° | “ | 30min – rain |
| | “ | “ | “ | Jan. 2015 – Dec 2018 | Monthly averaged rain |

## Remote Sensing Data

- Novel multi-annual and global dataset of mid-tropospheric {$H_2O$, δD} data

## Model-Based Framework

- Air mass trajectory analysis for attributing characteristic {$H_2O$, δD} signals to transport and rain processes

## Process Identification

- Synergy of satellite and model data
- Variability of {$H_2O$, δD}-Paaren over West Africa from annual to convective scale
- Identification of key processes of the mid-tropospheric moisture during the monsoon

# Ongoing and planned projects

| Project | Objectives |
|---|---|
| MOTIV (DFG)<br>2016 – 2021 | Generation of MUSICA IASI {$H_2O$, δD} data (**Schneider et al. 2021a**, **Diekmann et al. 2021a**)<br>Model- and satellite-based analysis of moisture transport pathways over West Africa (**Diekmann et al. 2021c**) and over the Northern Atlantic (**Dahinden et al. 2021**)<br>Data-driven analysis of {$H_2O$, δD} – distributions (**Ertl et al., in prep.**) |
| TEDDY (DFG)<br>2019 - 2022 | Assimilation of MUSICA IASI {$H_2O$, δD} data into numerical weather prediction models (**Toride et al. 2021**, **Khosrawi et al., in prep**.) |
| S5P+I H2O-ISO (ESA)<br>2019 – 2021 | Generation and validation of H2O and δD total column products from Sentinel-5P/TROPOMI data (polar-orbitint satellite, since 2017 in orbit)<br>Model- und satellite-based evaluation of TROPOMI H2O and δD total column products |
| EUREC4A-iso (ERC)<br>2016 - 2022 | Multi-Platform-Analysis of water isotopes over Barbados, Jan.-Feb. 2020<br>Provision of MUSICA IASI {$H_2O$, δD} data |
| Planned activities | Combination of MUSICA IASI {$H_2O$, δD} data with new TROPOMI products, for obtaining global water isotope distributions with vertical profile information (analogous to $CH_4$ in **Schneider et al., 2021b**)<br>Model-based evaluation of new combinded IASI/TROPOMI product (ICON-$ART_{iso}$, …) |

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# Thanks for your attention!

# References


- Hase et al. (2004): https://doi.org/10.1016/j.jqsrt.2003.12.008
- Schneider et al. (2009): https://doi.org/10.1016/j.jqsrt.2009.04.011
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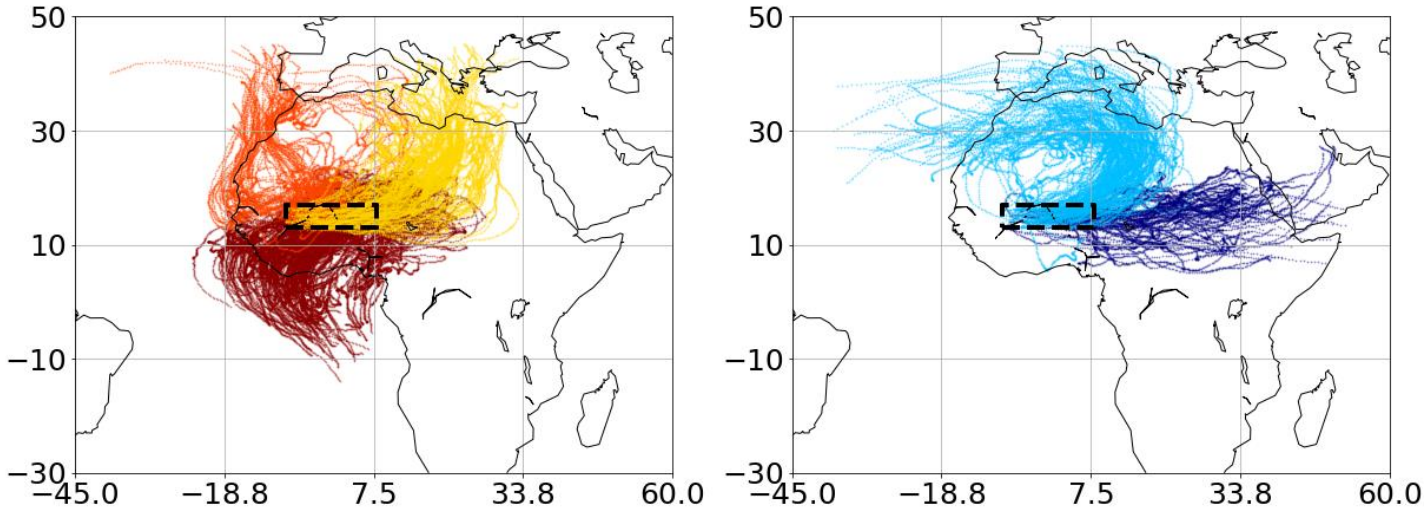
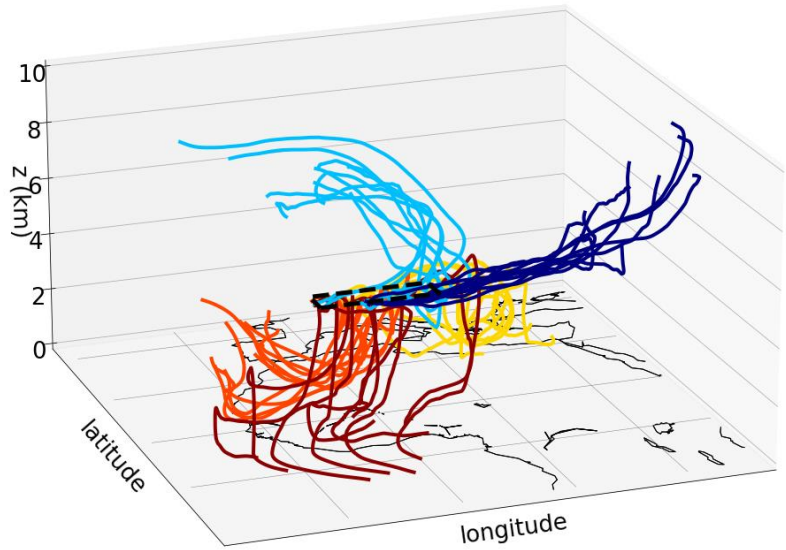
- Pfahl et al. (2012): https://doi.org/10.5194/acp-12-1629-2012
- Wiegele et al. (2014): https://doi.org/10.5194/amt-7-2719-2014
- Schneider et al. (2016): https://doi.org/10.5194/amt-9-2845-2016
- Borger et al. (2018): https://doi.org/10.5194/amt-11-4981-2018
- Eckstein et al. (2018): https://doi.org/10.5194/gmd-11-5113-2018
- Garcia et al. (2018): https://doi.org/10.5194/amt-11-4171-2018
- Toride et al. (2021): https://doi.org/10.1029/2020GL091698
- Dahinden et al. (2021): https://doi.org/10.5194/acp-2021-269
- Schneider et al. (2021a): https://doi.org/10.5194/essd-2021-75
- Schneider et al. (2021b): https://doi.org/10.5194/amt-2021-31
- Diekmann et al. (2021a): https://doi.org/10.5194/essd-2021-87
- Diekmann et al. (2021b): https://dx.doi.org/10.35097/415
- Diekmann et al. (2021c): https://doi.org/10.1002/essoar.10506628.1

# Graphics and citations

- [1] https://climate.esa.int/en/projects/water-vapour
- [2] https://www.humanosphere.org/world-politics
- [3] https://www.flickr.com/photos/oxfam/8006487509
- [4] https://www.oecd-ilibrary.org
- [5] https://www.britannica.com/science/West-African-monsoon

# Trajektorien über Westafrika



# Remote Sensing with Metop/IASI

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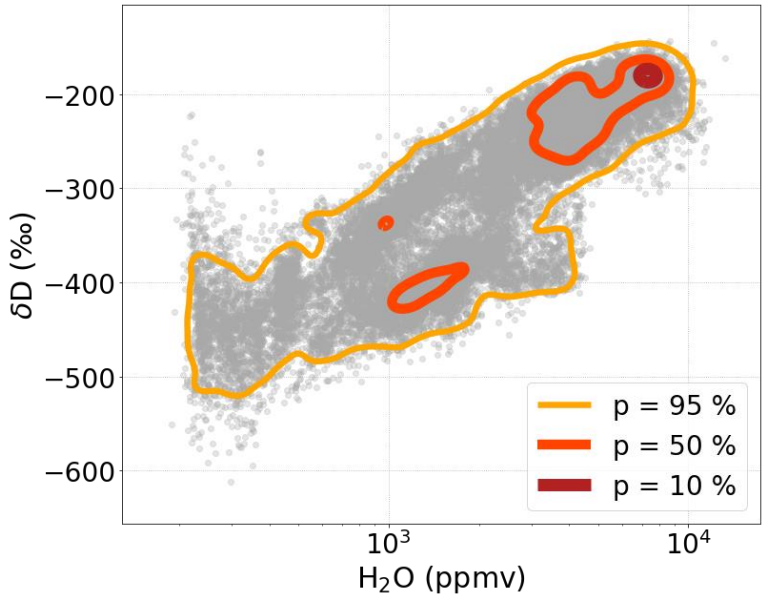
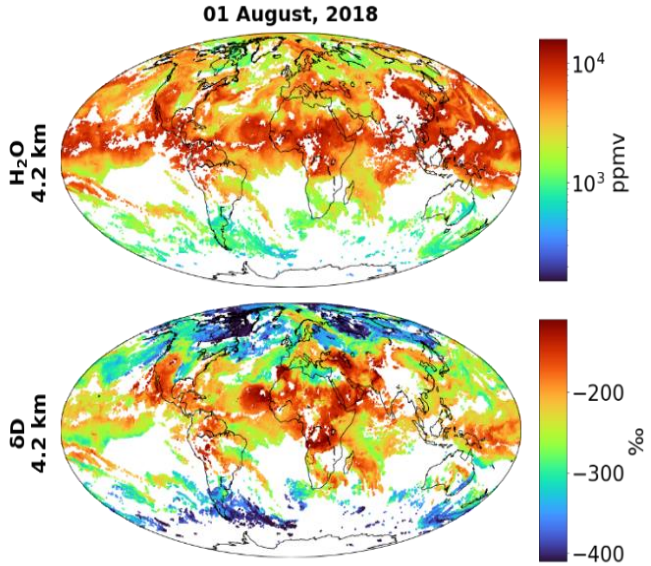
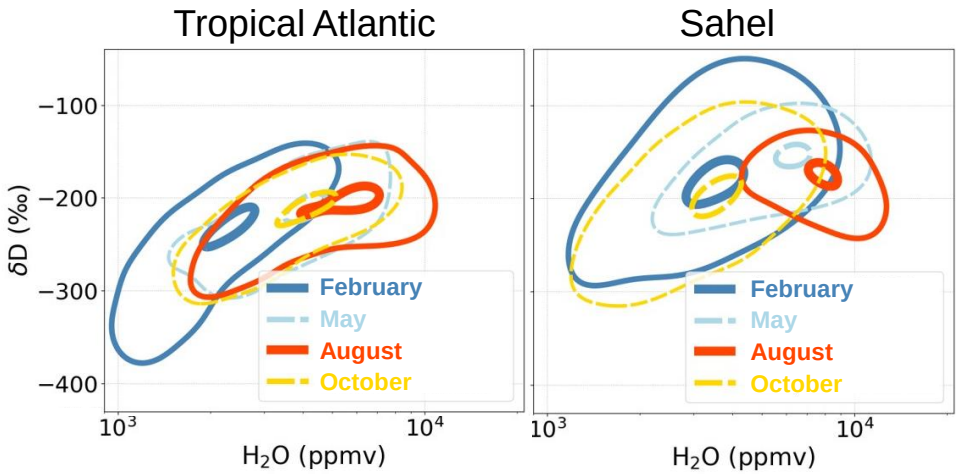
**Data along a single orbit**



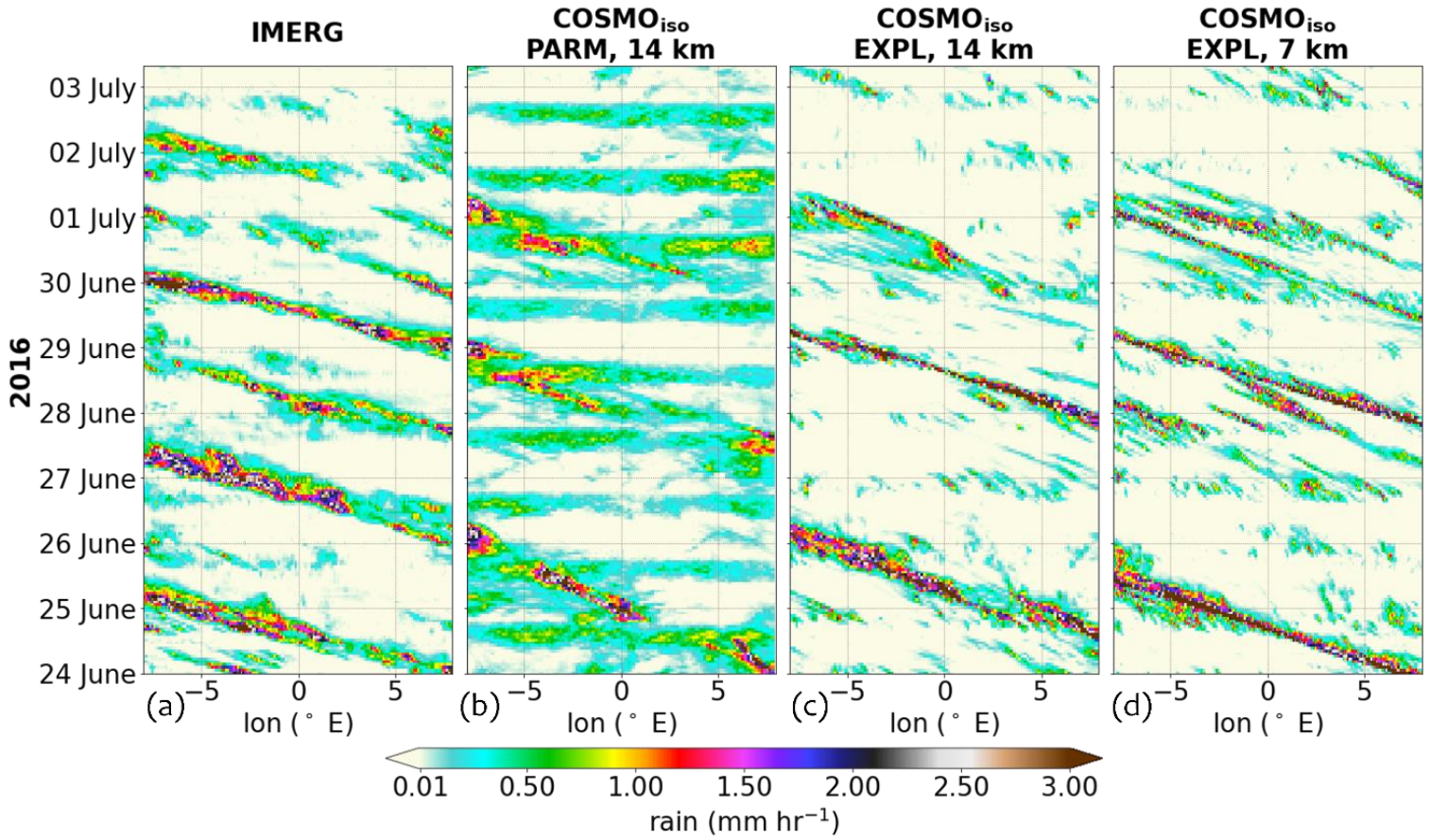

**Data for a whole day**



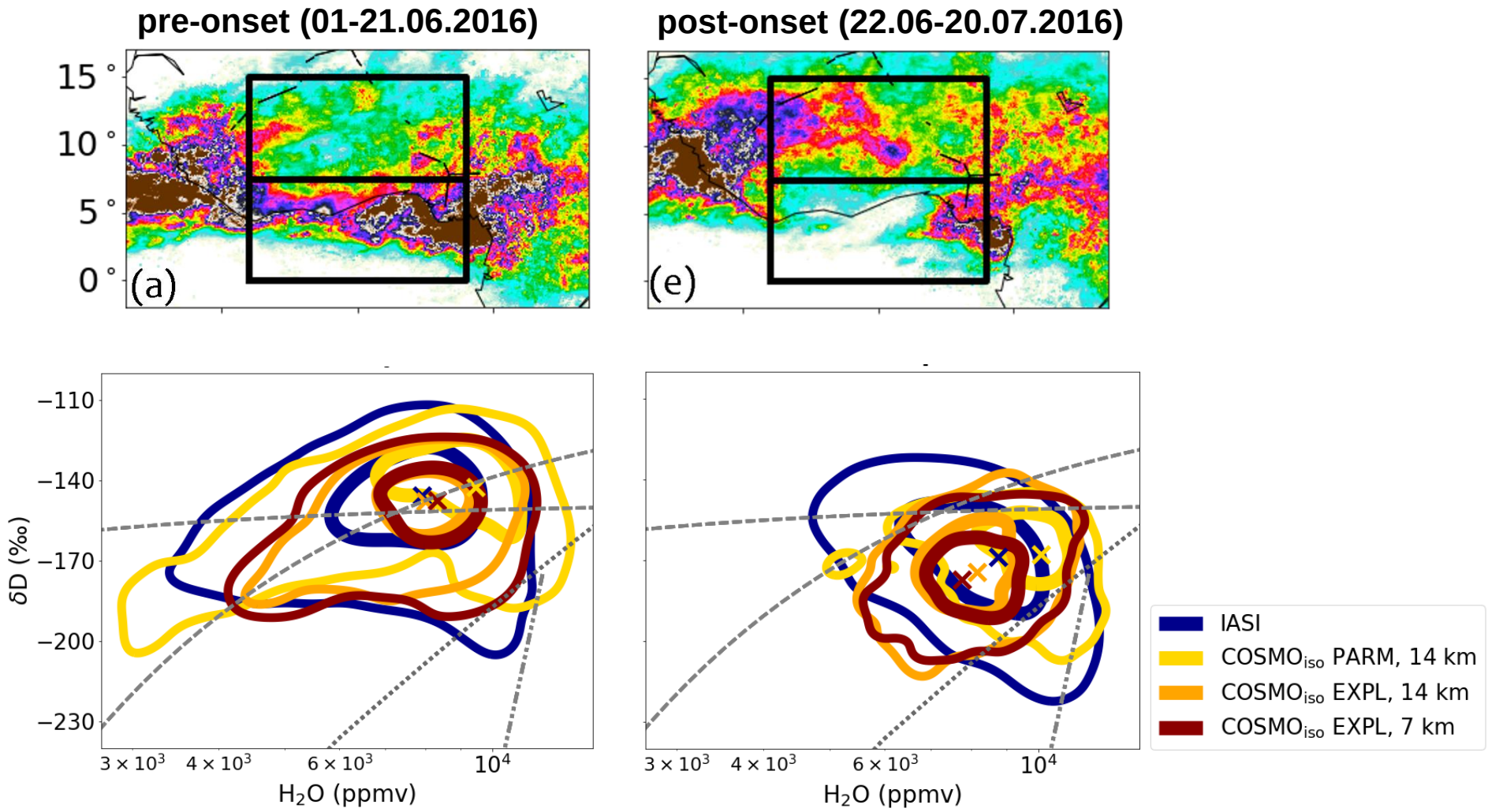

**Data for 2015 - 2018**



# Impact of convective treatment



# Impact of convective treatment



# Impact of horizontal resolution