Examining Water Vapour Residency Times from Observational and Model Ensembles

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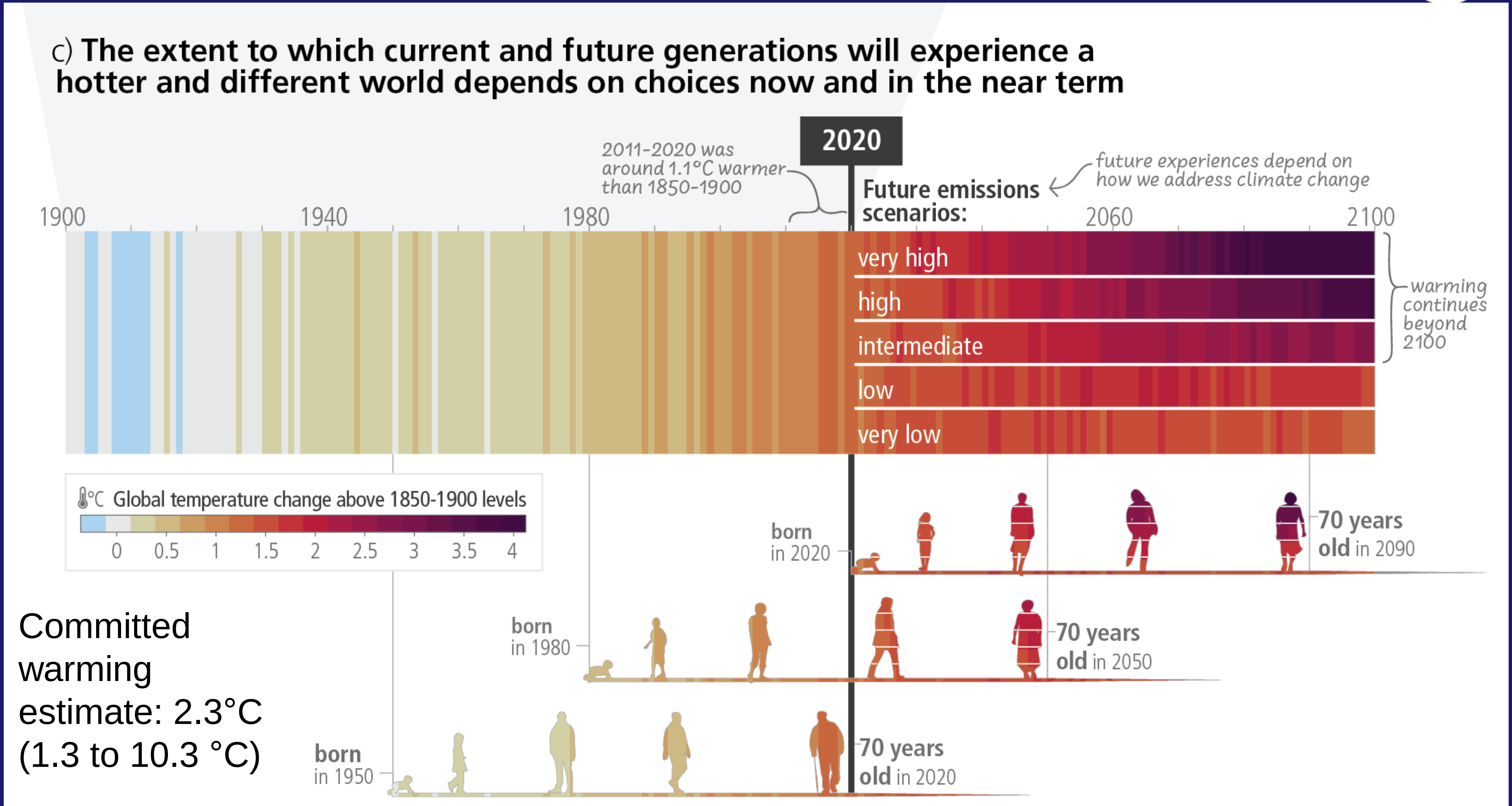
Motivation



Committed warming estimate: 2.3°C (1.3 to 10.3 °C)

Source: Figure SPM.1 IPCC AR6 Synthesis Report

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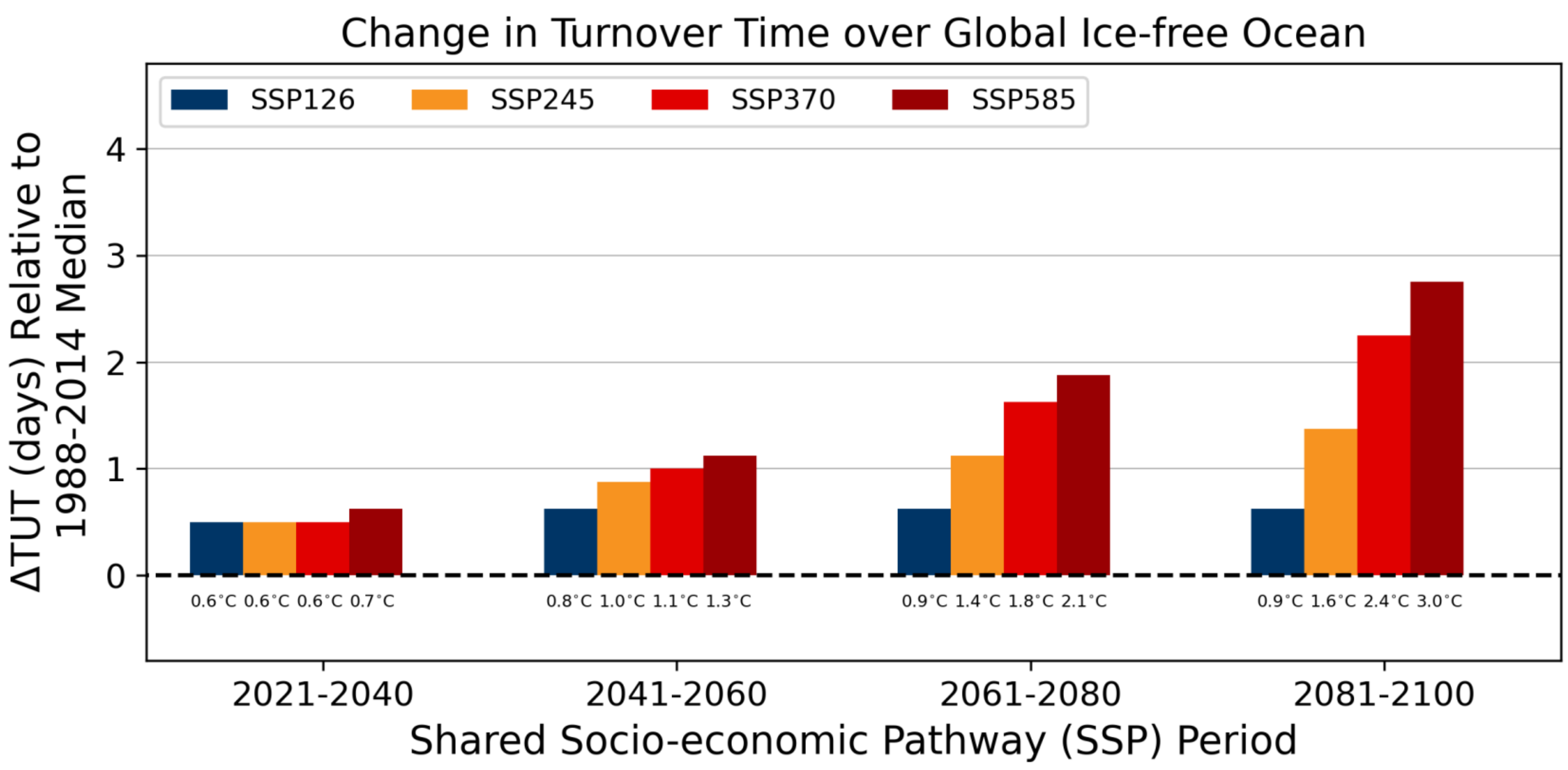
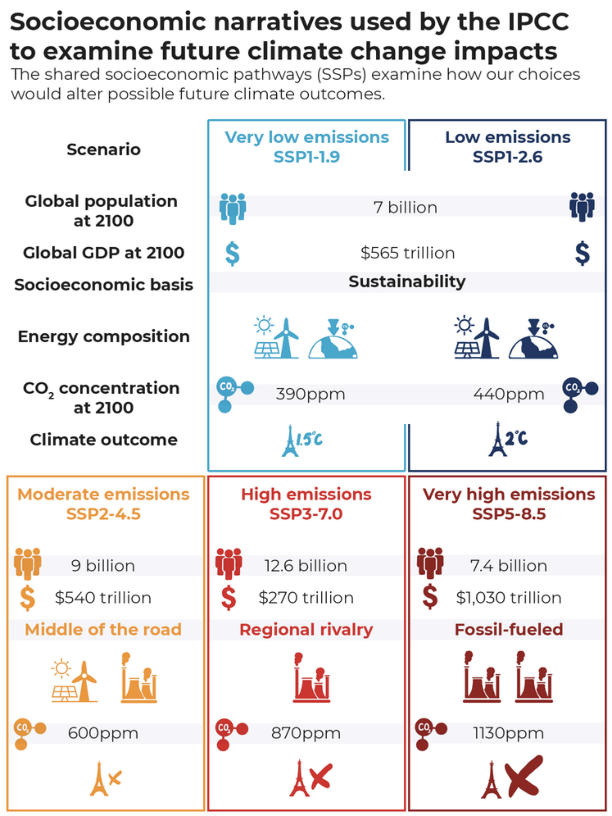
Motivation

- WVRT changes due to future warming scenarios from CMIP6 from an ensemble of 19 models.
- Results show a slowing of hydrological cycle by ~0.5 days relative to 1988-2014 median under Paris agreement (ΔT< 2K). Further slowing under higher emission scenarios.





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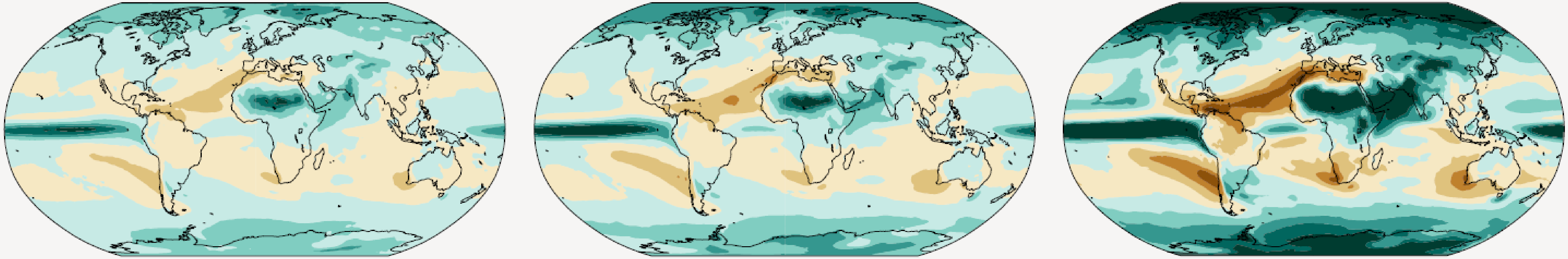
Motivation

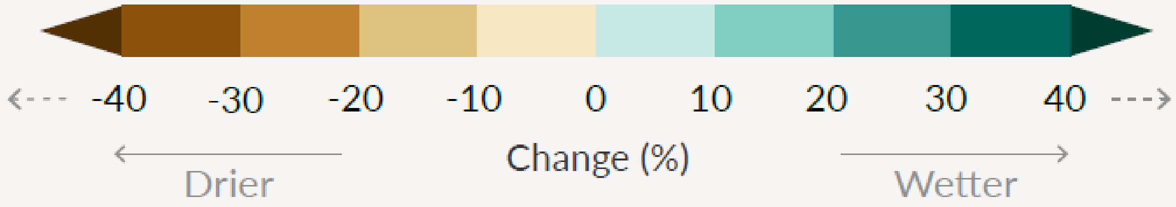
c) Annual mean precipitation change (%) relative to 1850-1900

Precipitation is projected to increase over high latitudes, the equatorial Pacific and parts of the monsoon regions, but decrease over parts of the subtropics and in limited areas of the tropics.

Simulated change at **1.5 °C** global warming | Simulated change at **2 °C** global warming | Simulated change at **4 °C** global warming



Relatively small absolute changes may appear as large % changes in regions with dry baseline conditions



IPCC AR6 (2021)

changes in WVRT → changes in atmospheric moisture pathways → changes in global precipitation patterns

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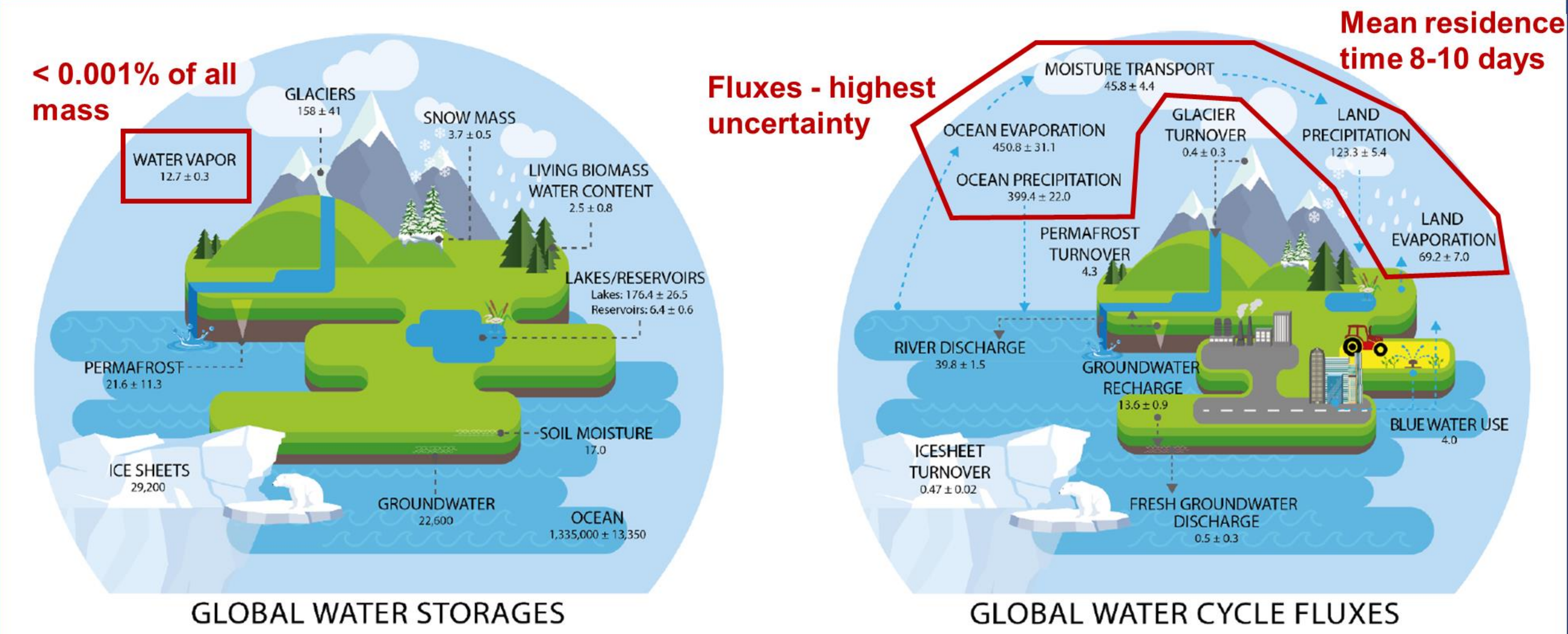
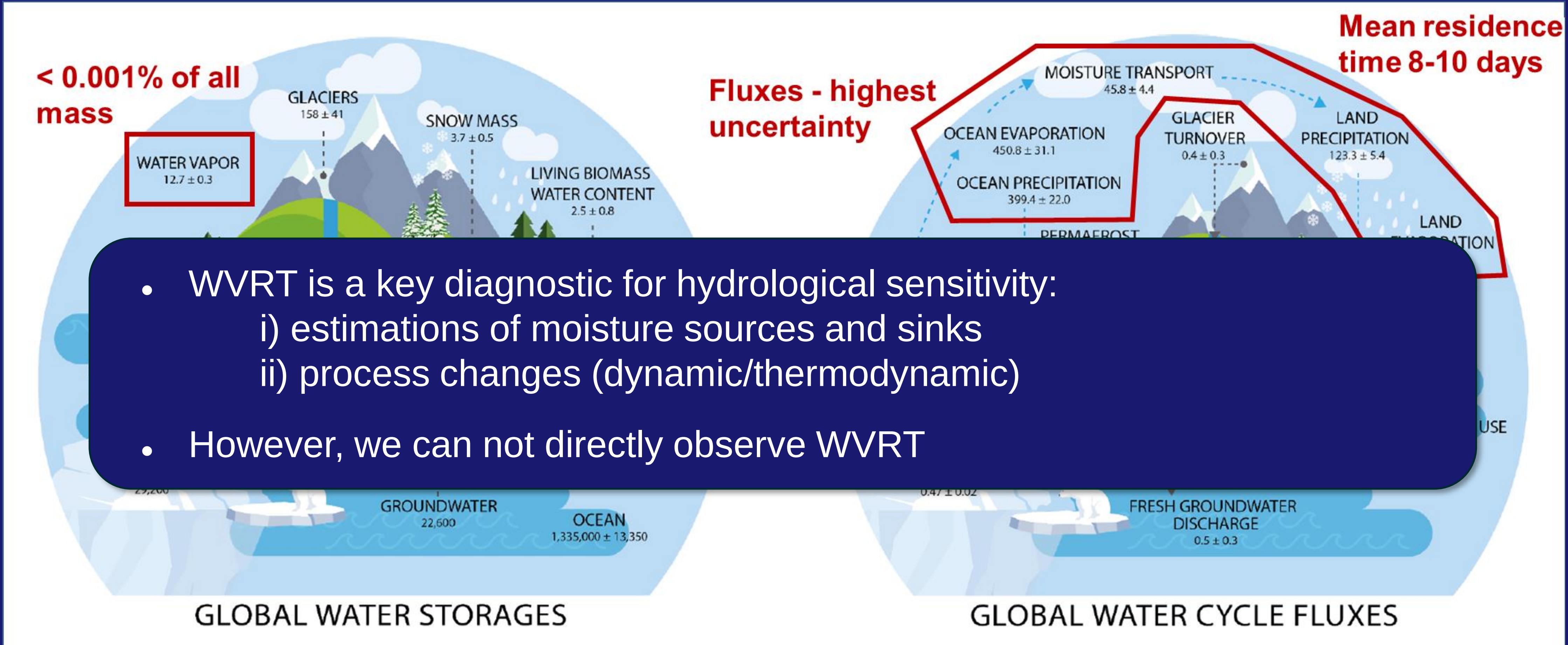
The Hydrological Cycle



Images taken from Dorigo et al. (2021), all values are in 10^3 km^3

The Hydrological Cycle



- WVRT is a key diagnostic for hydrological sensitivity:
  - i) estimations of moisture sources and sinks
  - ii) process changes (dynamic/thermodynamic)
- However, we can not directly observe WVRT

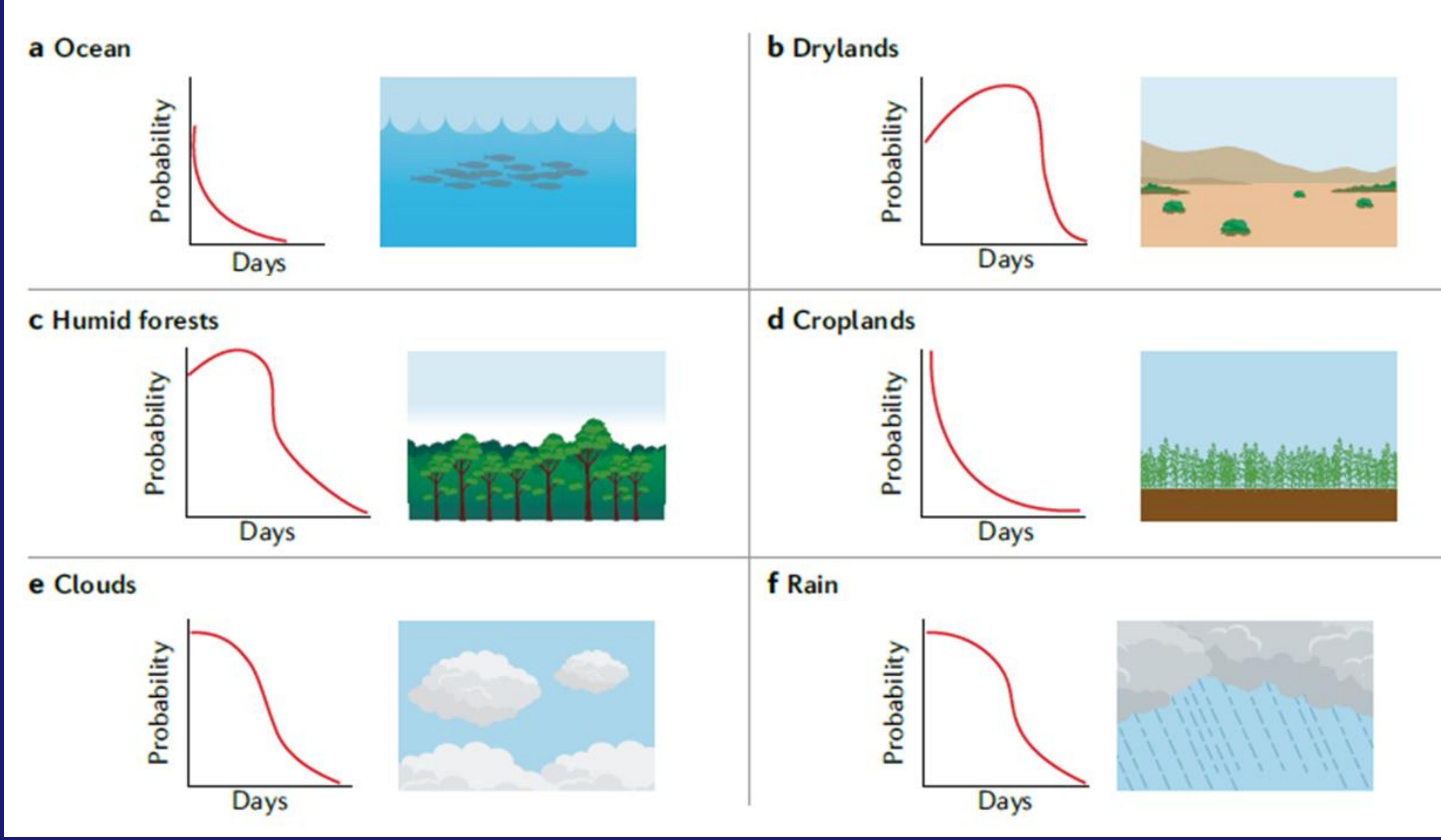
Images taken from Dorigo et al. (2021), all values are in 10^3 km^3

Estimating WVRT

- This study uses long established turnover time (TUT) method to estimate WVRT:

$$\mathbf{TUT} = \frac{\boldsymbol{TCWV \times Area}}{\boldsymbol{precipitation \times Area}} = \boldsymbol{days}$$

- WVRT estimates also vary (e.g. 4-5, 8-10 days), this is due to substantial spatial variability, whether the mean or median is used, and how these regions are sampled for the calculation.
- Expected changes to TCWV and precipitation (ice-free ocean) due to warming (CC) alter TUT of water vapour by roughly 8-12 hours/K (0.3-0.5d/K).



Adapted from Gimeno et al., 2021

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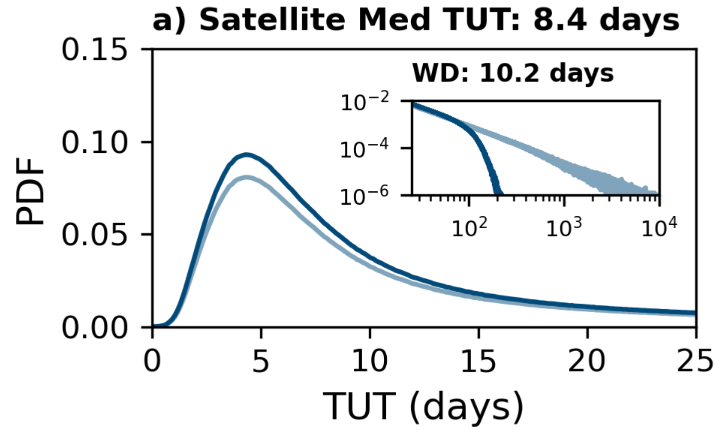
WVRT estimates for 1988-2014



- PDFS characterised as skewed distributions with long tails
- Inclusion of ‘drizzle’ (noise threshold on obs) impacts the tail length and add noise.
- Results in differences in TUT estimates

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- Estimates for global ice-free ocean (±60° latitude)

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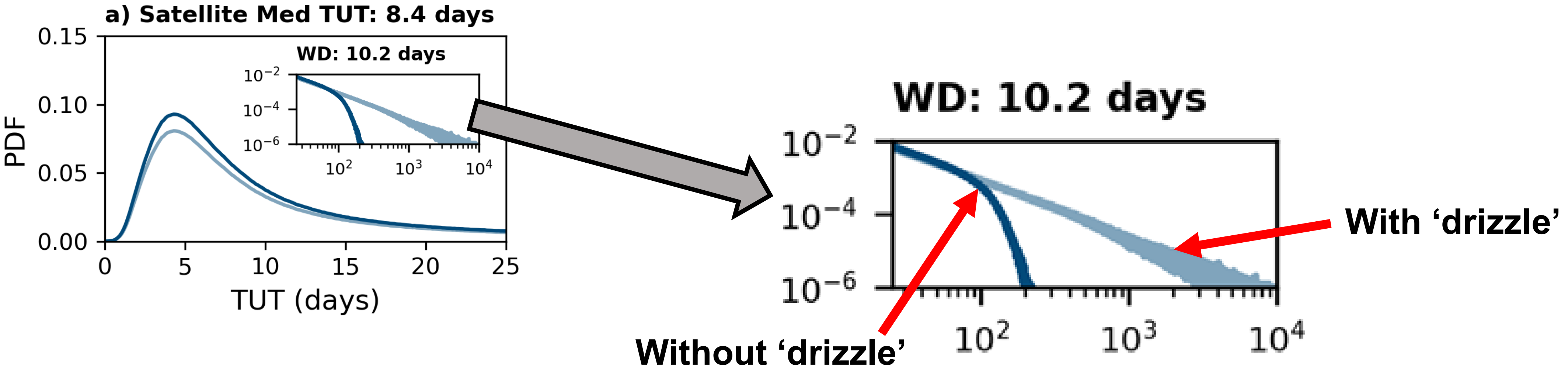

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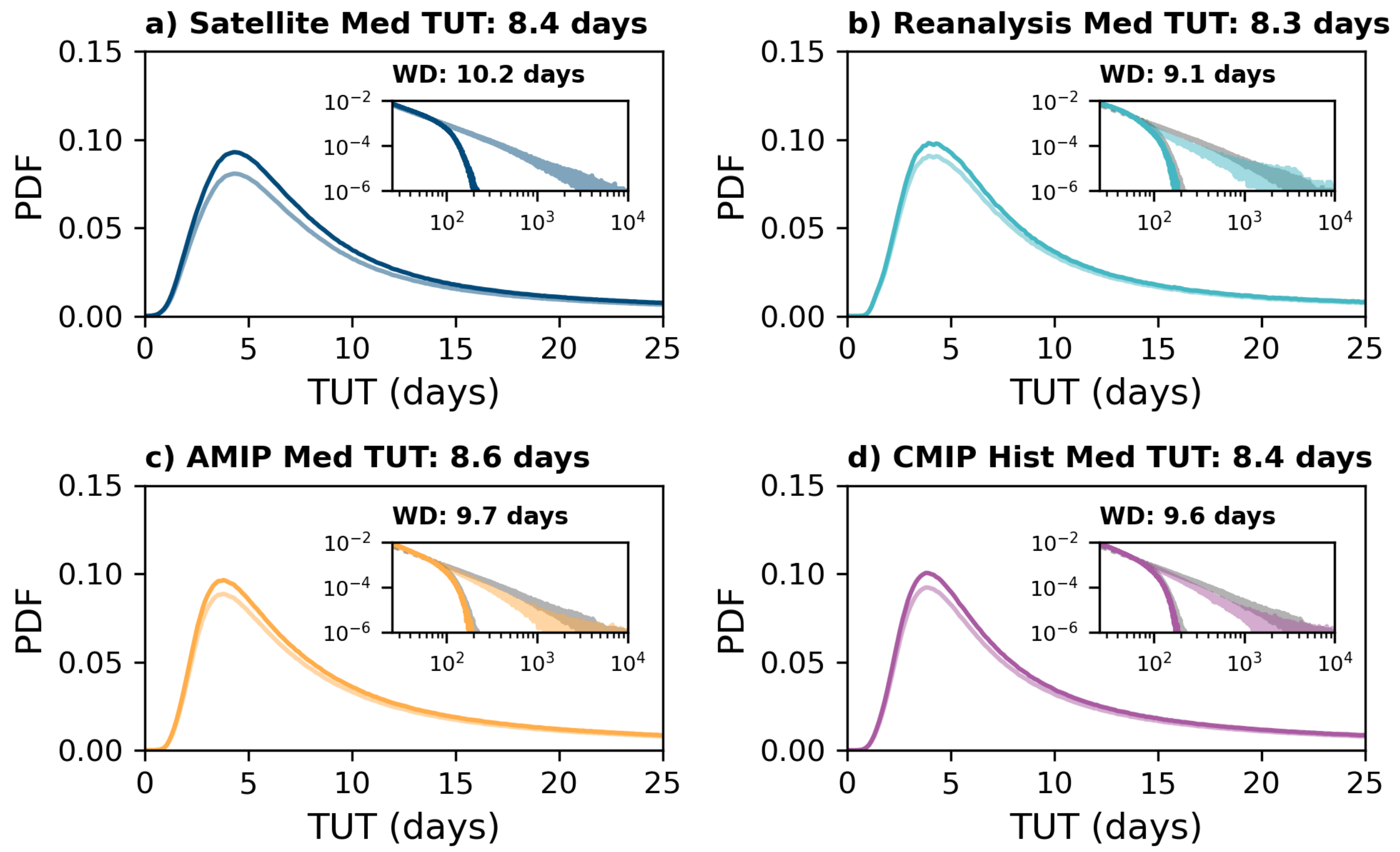

- All (non-drizzle) TUTs within 0.3 days ~8hrs, increases to 1.1 days when drizzle is included
- No impact on mode, but impacts mode and mean TUT values. Median more robust (expected)

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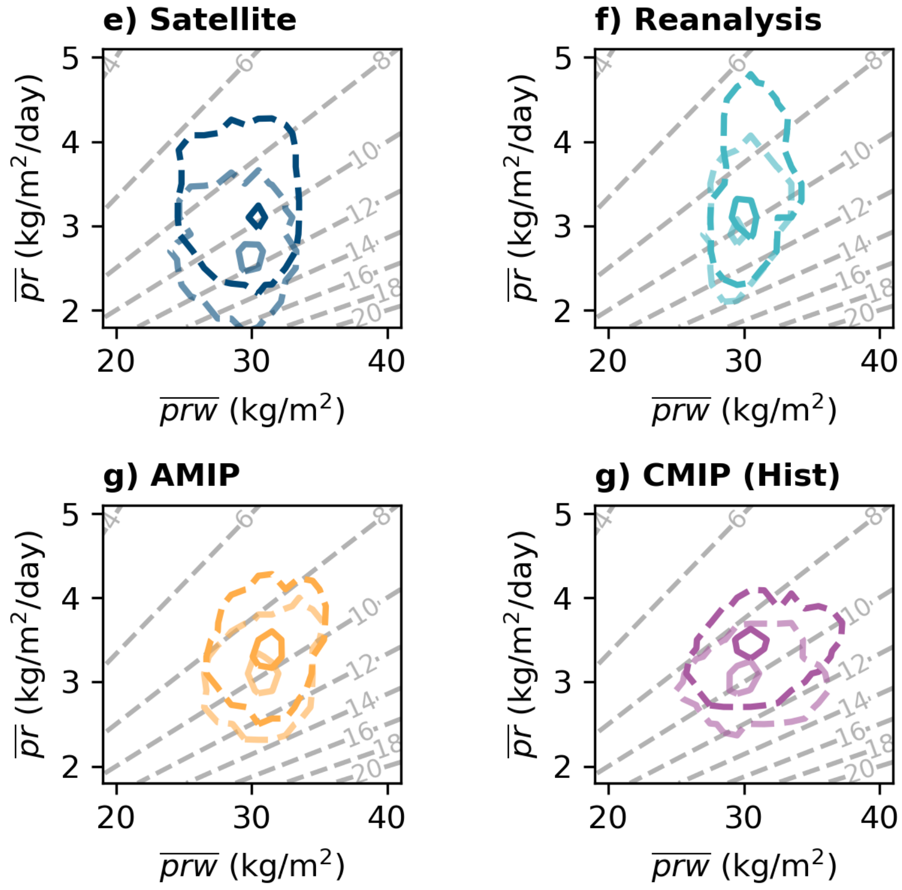
WVRT estimates for 1988-2014

- Can get the same TUT values for different conditions
- Reanalysis has broader precipitation range, lower variability in TCWV
- AMIP/CMIP models wetter atmospheres, lower precipitation seen in observations



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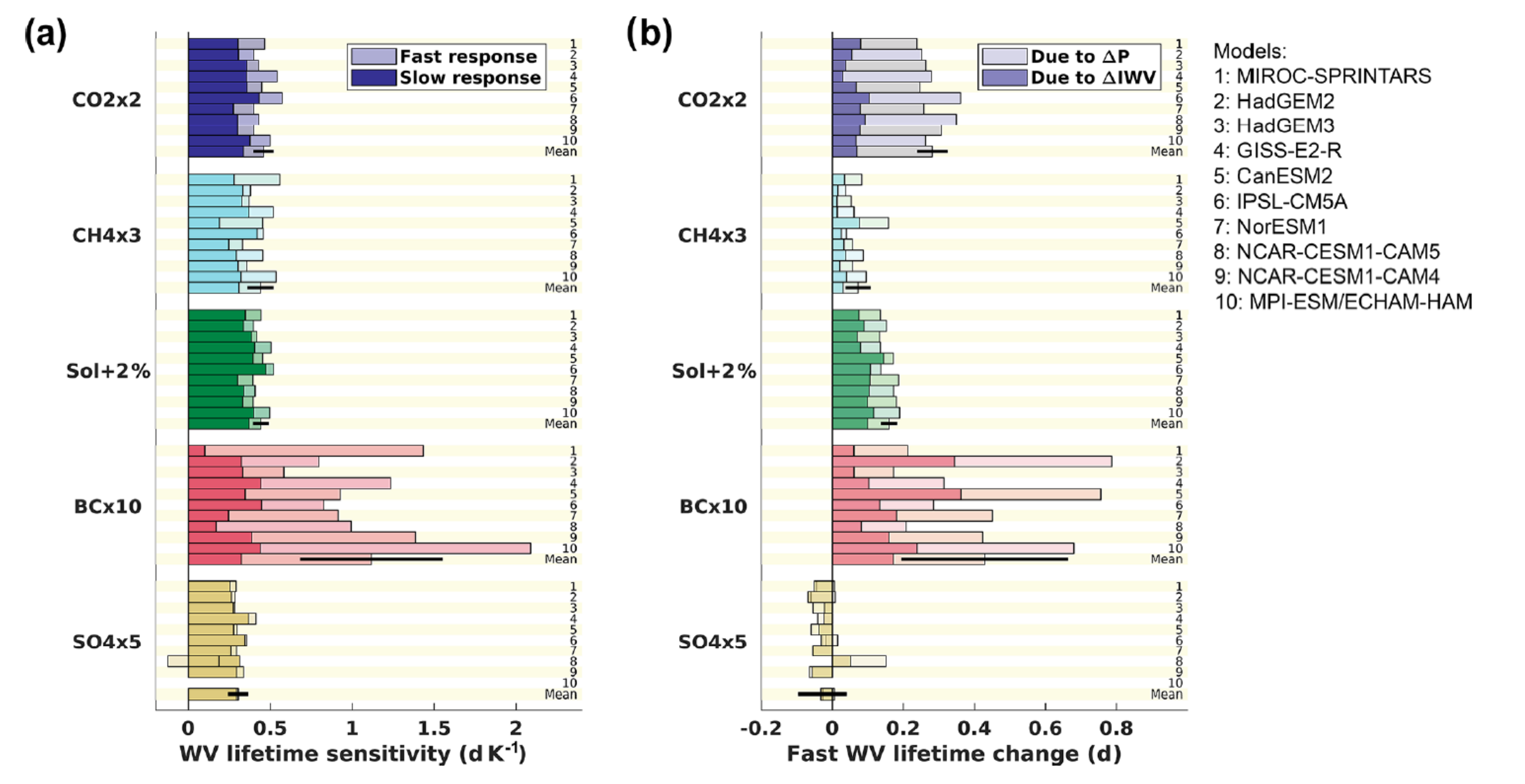
PDRMIP Results (AR5)

- Illustrate changes to TUT from individual climate drivers
- fast = rapid adjustments to an external forcing + radiative impacts before change in global & annual mean ΔTs.
- slow = total-fast



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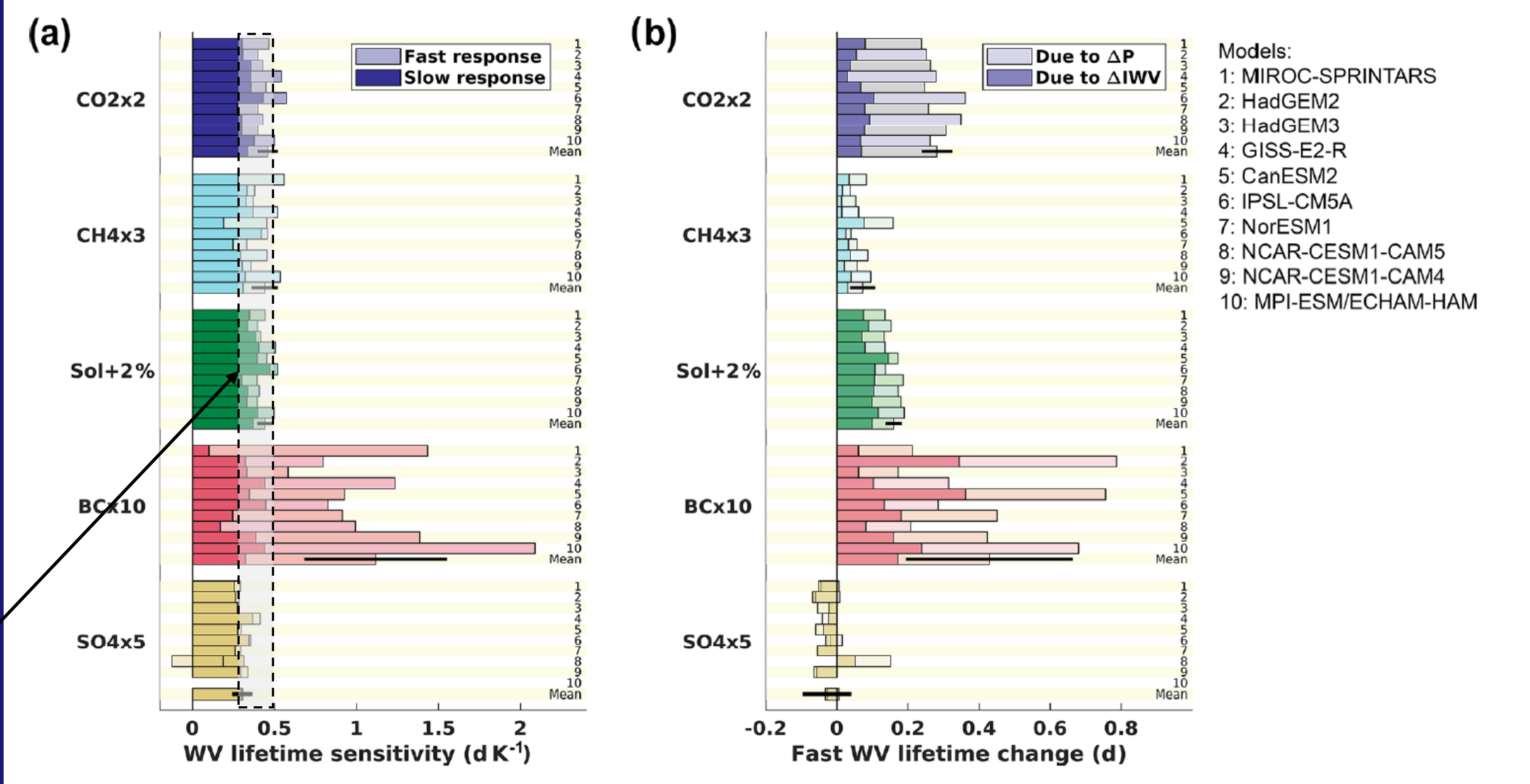
Estimate from CC



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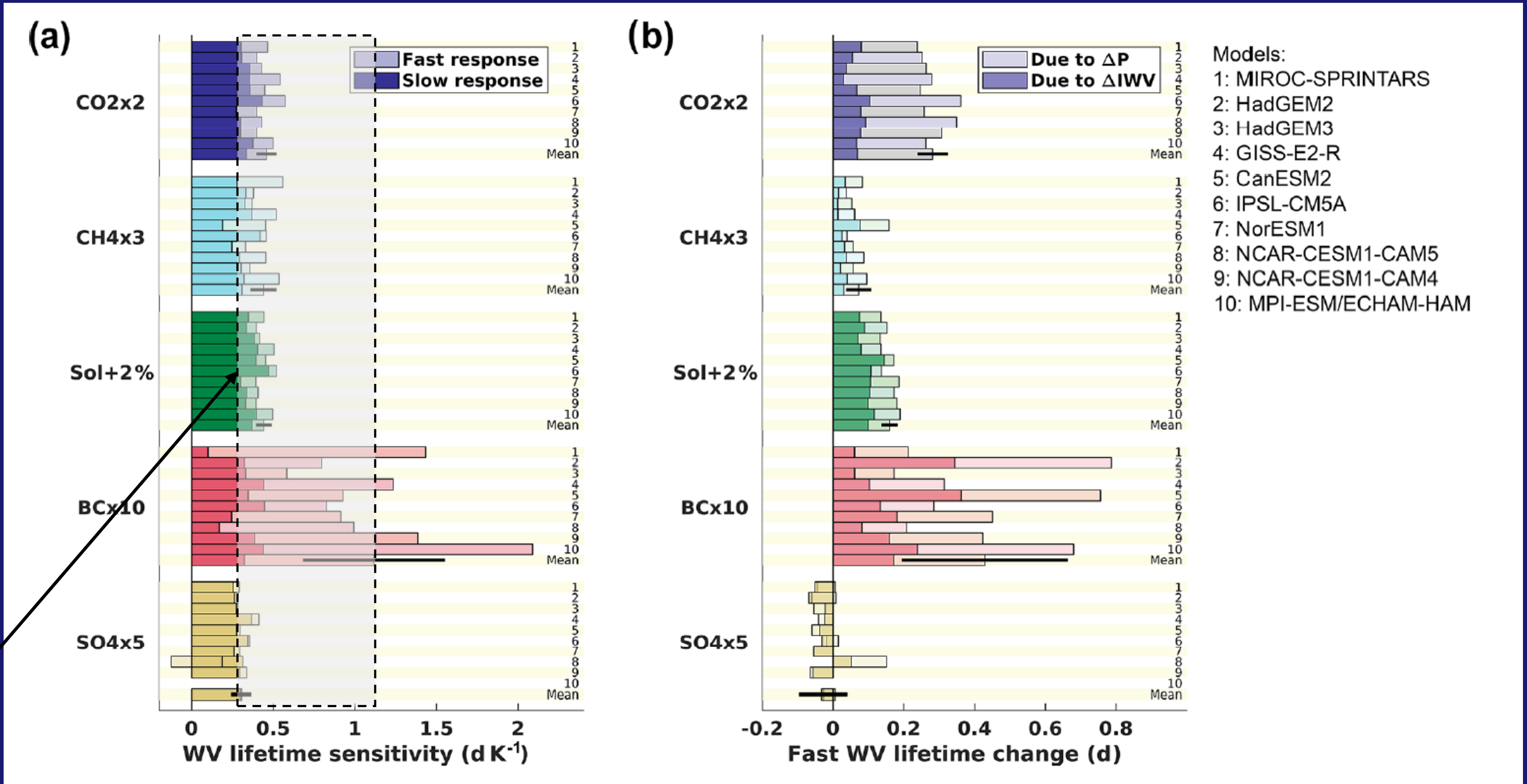
Uncertainty range between ensemble estimates



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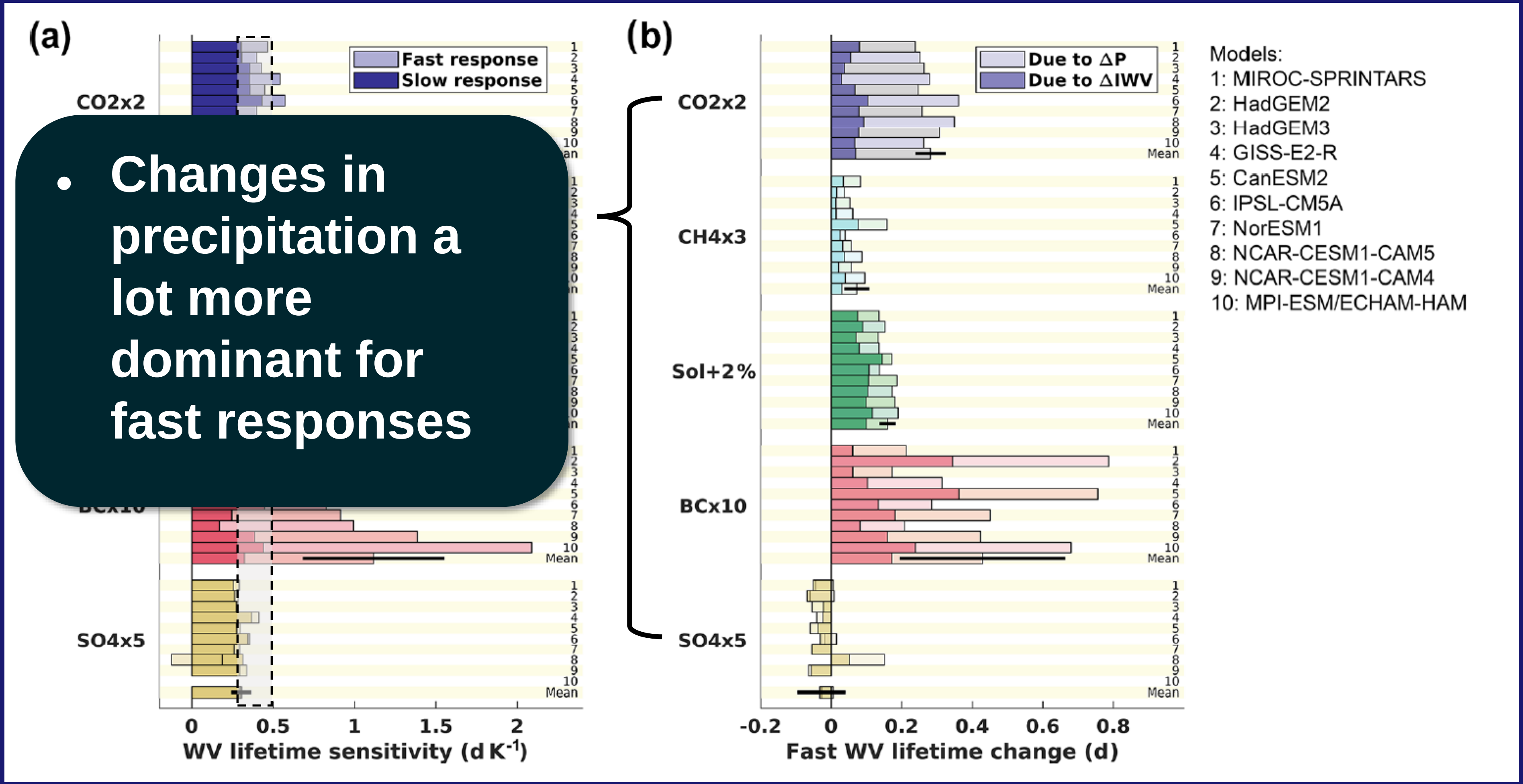

- **Changes in precipitation a lot more dominant for fast responses**

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Water isotopologues

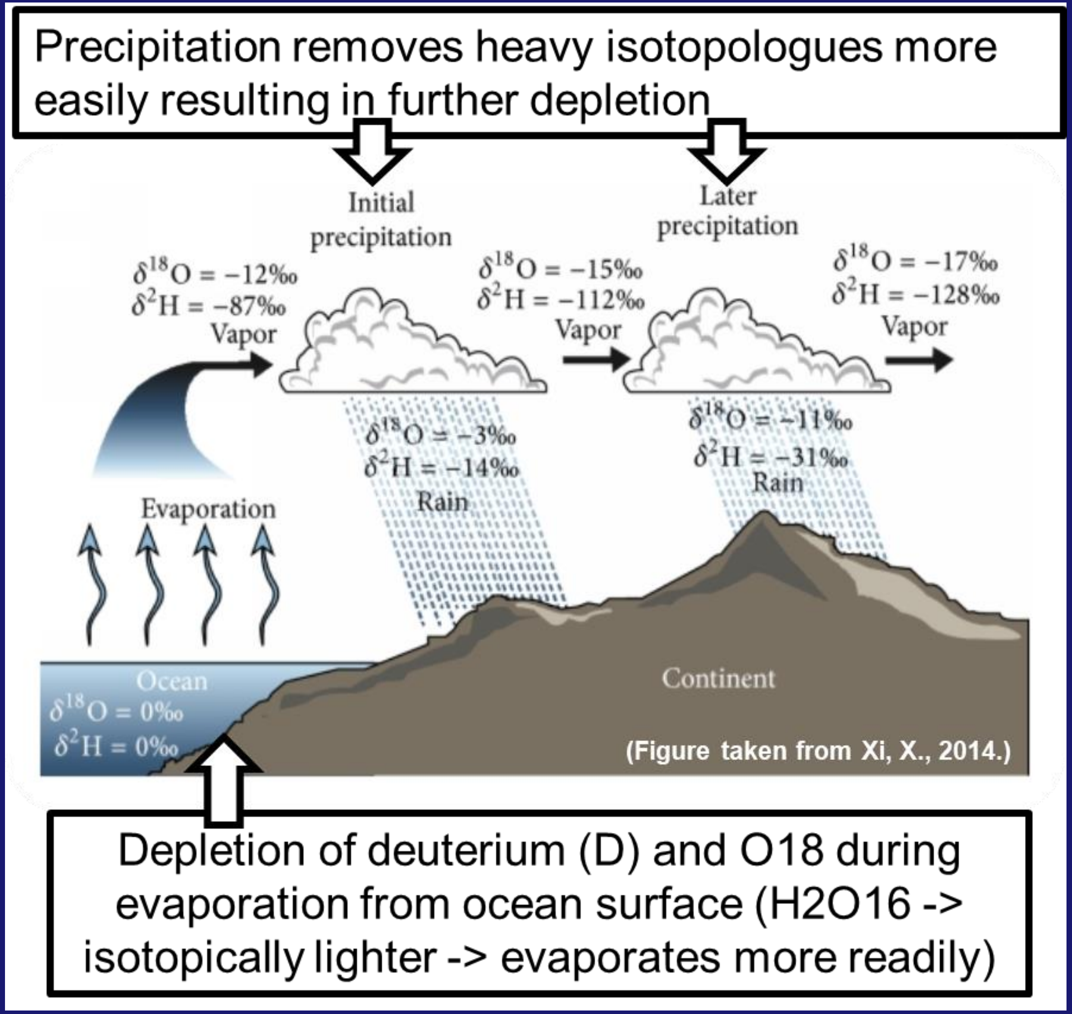
esa

- Satellite observations of stable water Isotopologues can provide global information on the moisture pathways or add an additional constraint.
  - IR – mid-tropospheric sensitivity
  - SWIR – column-averages with boundary layer sensitivity
- Water Isotopologues are given in δ (‰) notation:

$$\delta = \left[\frac{R_{satellite}}{R_s} - 1\right] \cdot 1000‰$$

$$R_s = \begin{cases} HDO/H_2O_{VSMOW} = 3.11 \times 10^{-4} \\ H_2O^{18}/H_2O_{VSMOW} = 2.0052 \times 10^{-3} \end{cases}$$

- Water vapour pairs {H2O, δ} can provide information on evaporation, condensation, and precipitation.



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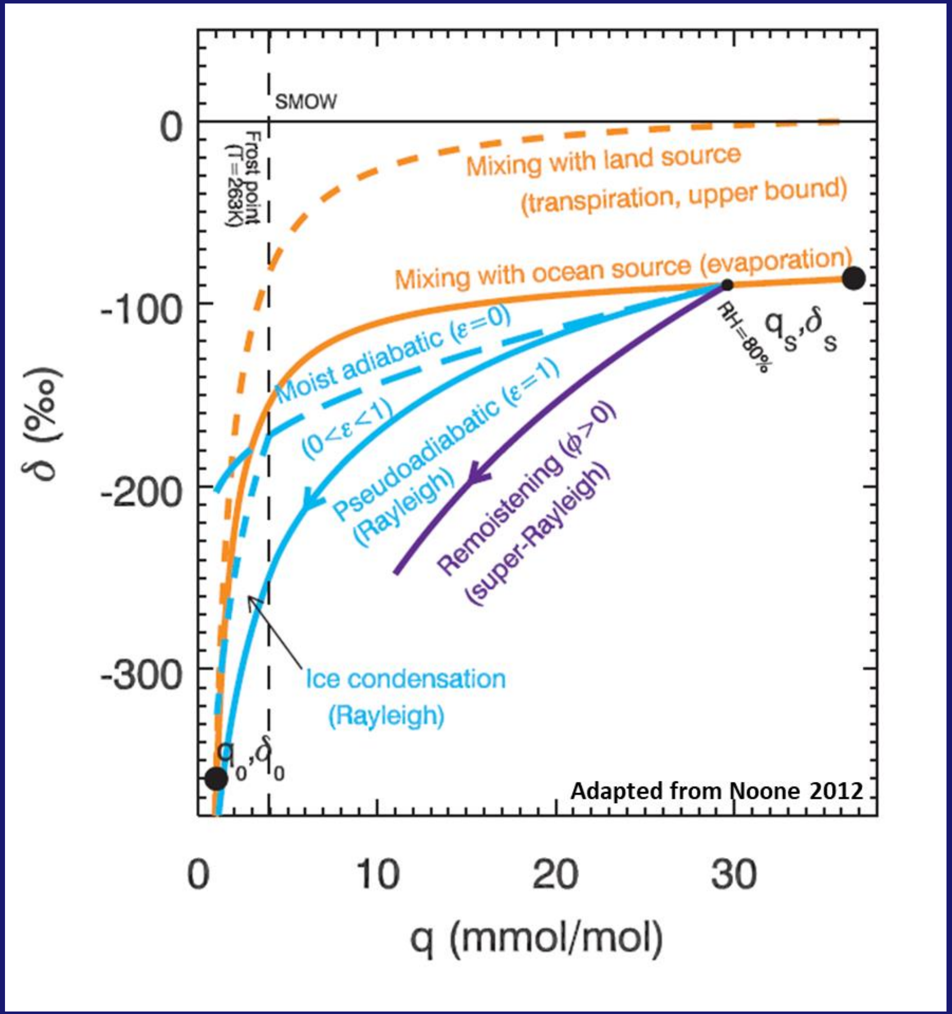
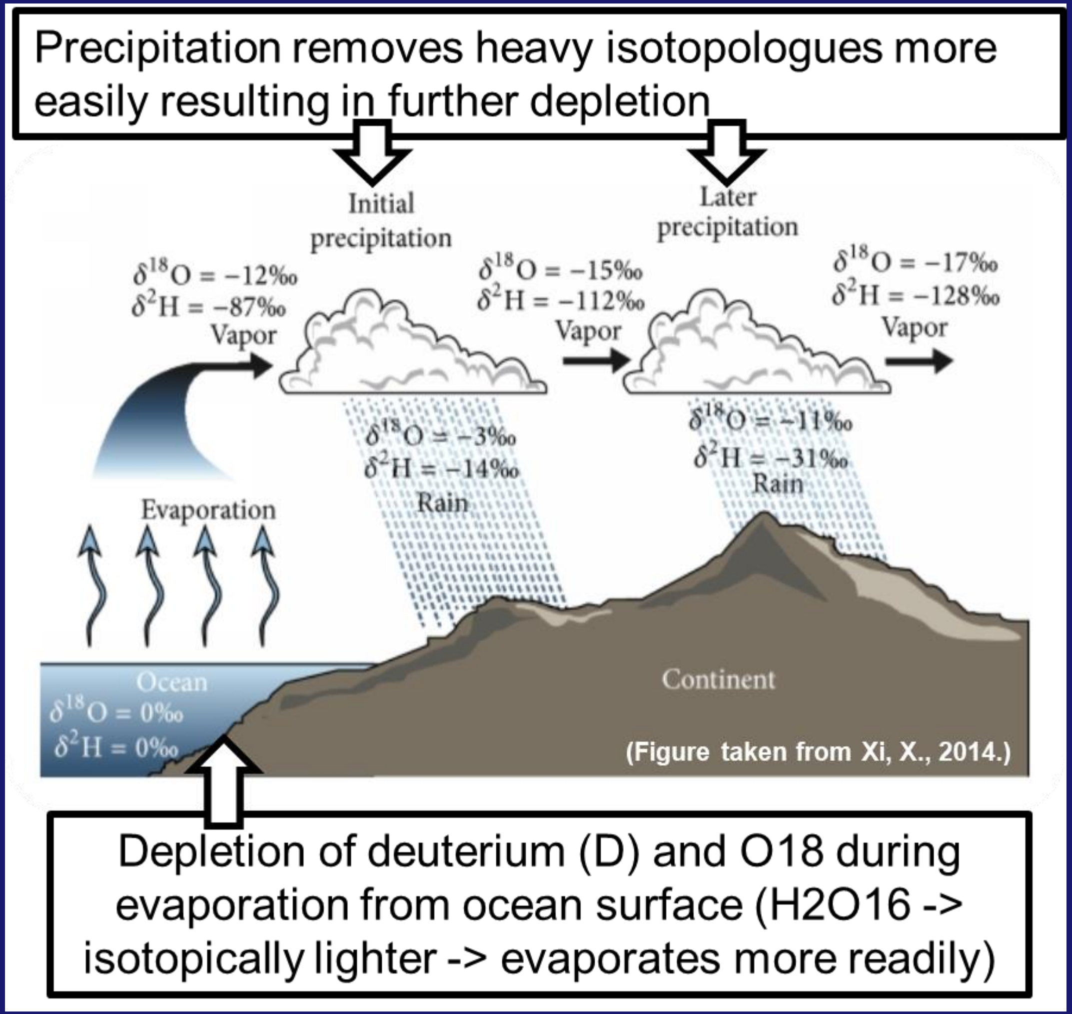
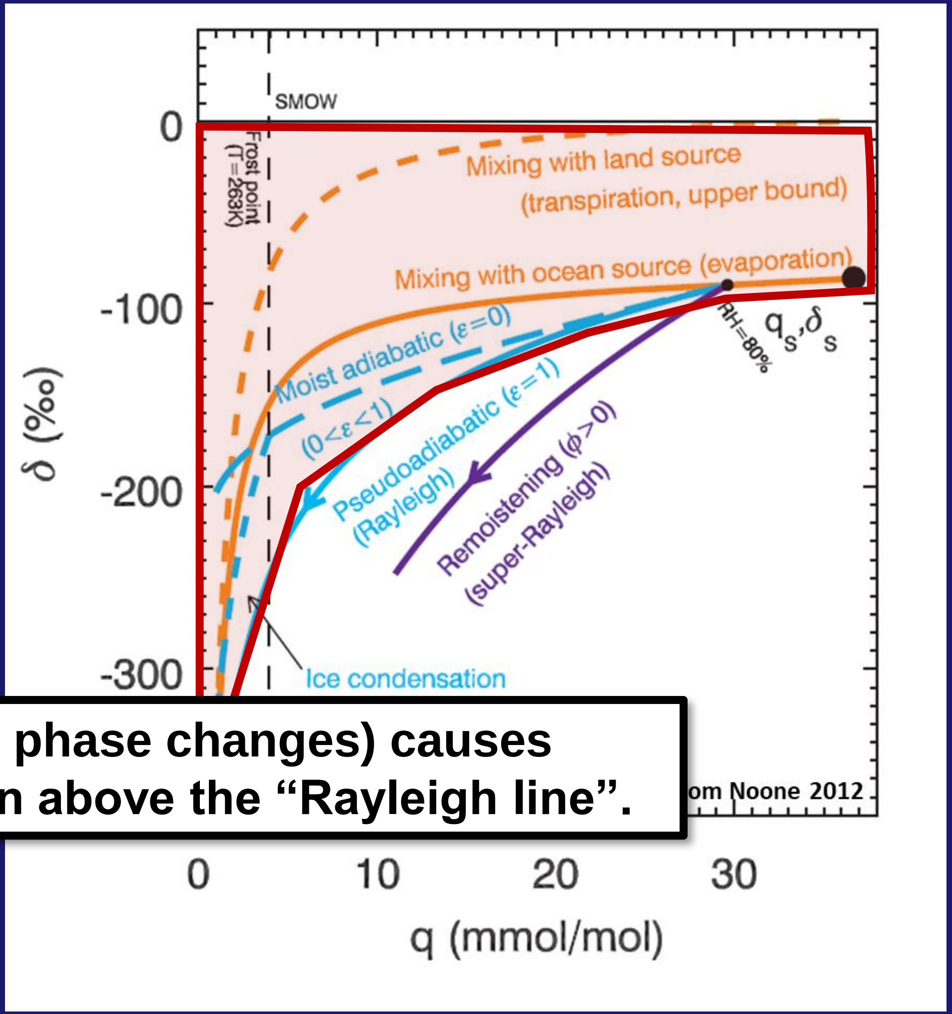
Water isotopologues



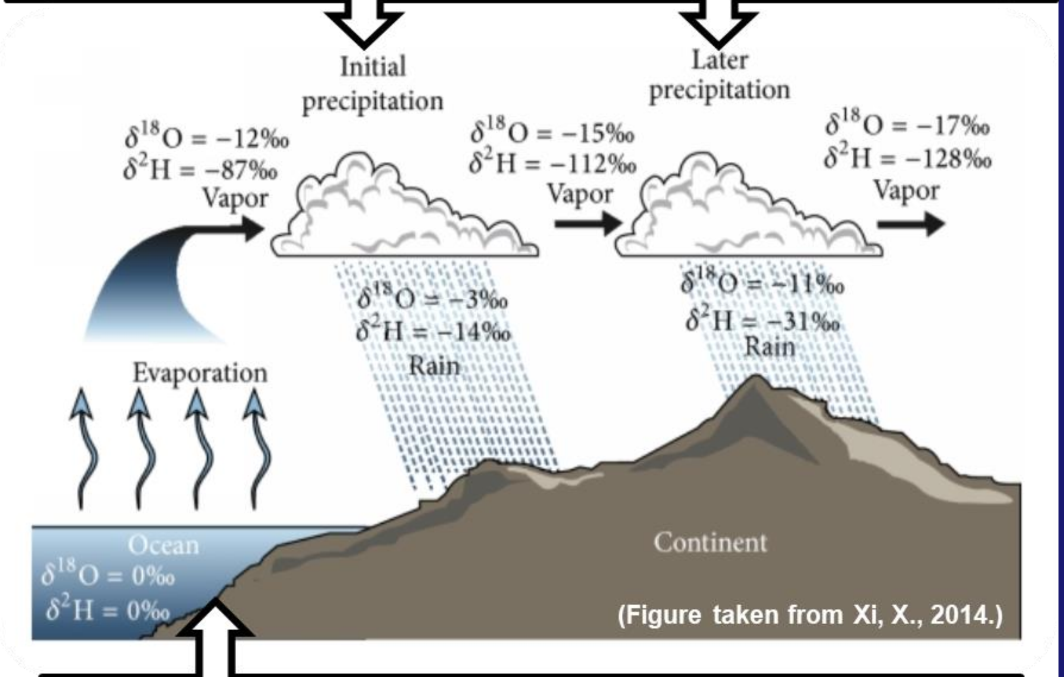


Water isotopologues



Mixing (no phase changes) causes distribution above the "Rayleigh line".

Precipitation removes heavy isotopologues more easily resulting in further depletion



Depletion of deuterium (D) and O18 during evaporation from ocean surface (H2O16 -> isotopically lighter -> evaporates more readily)

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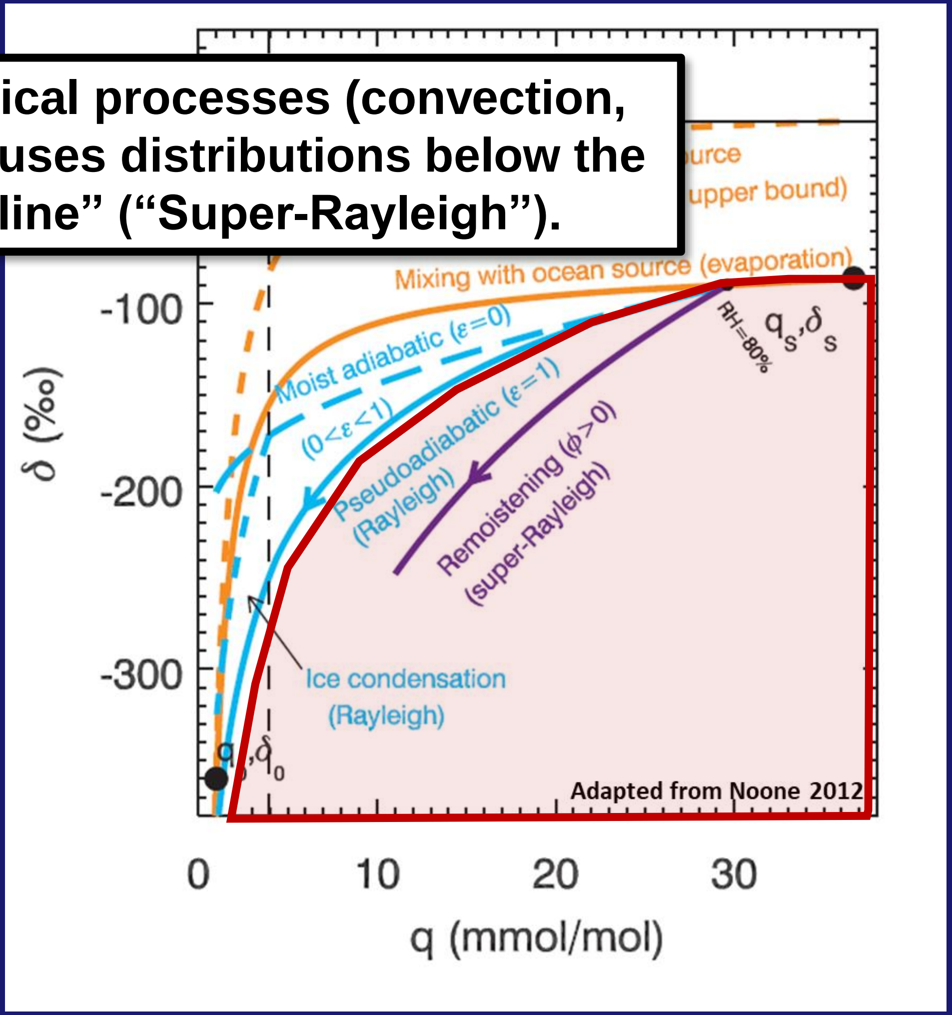
Water isotopologues

Microphysical processes (convection, clouds) causes distributions below the “Rayleigh line” (“Super-Rayleigh”).



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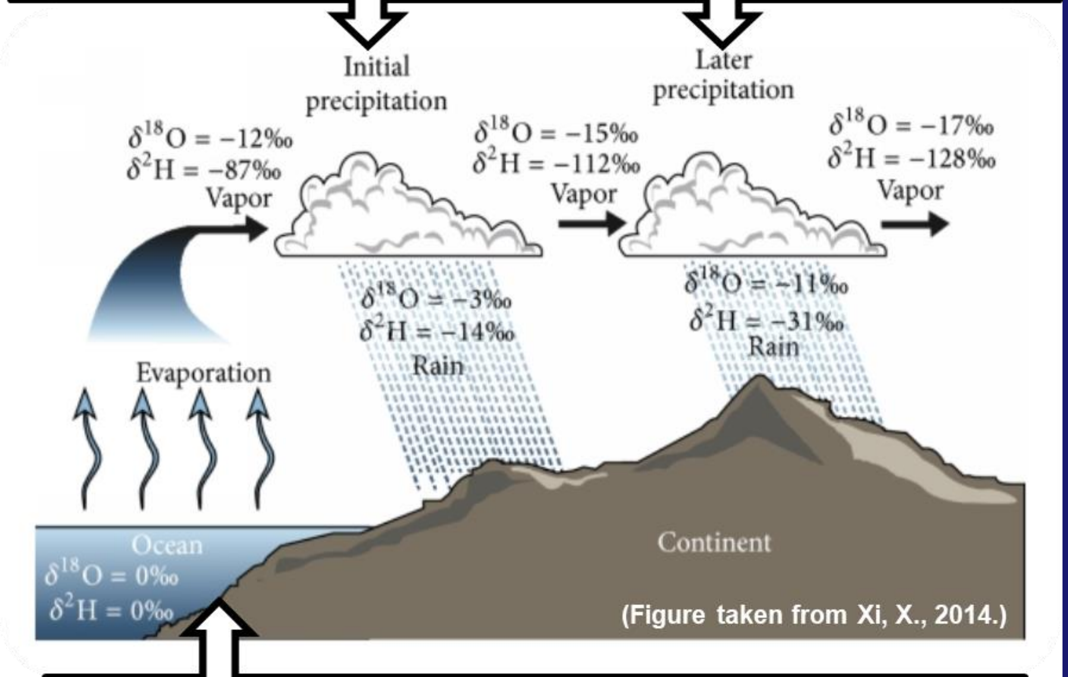

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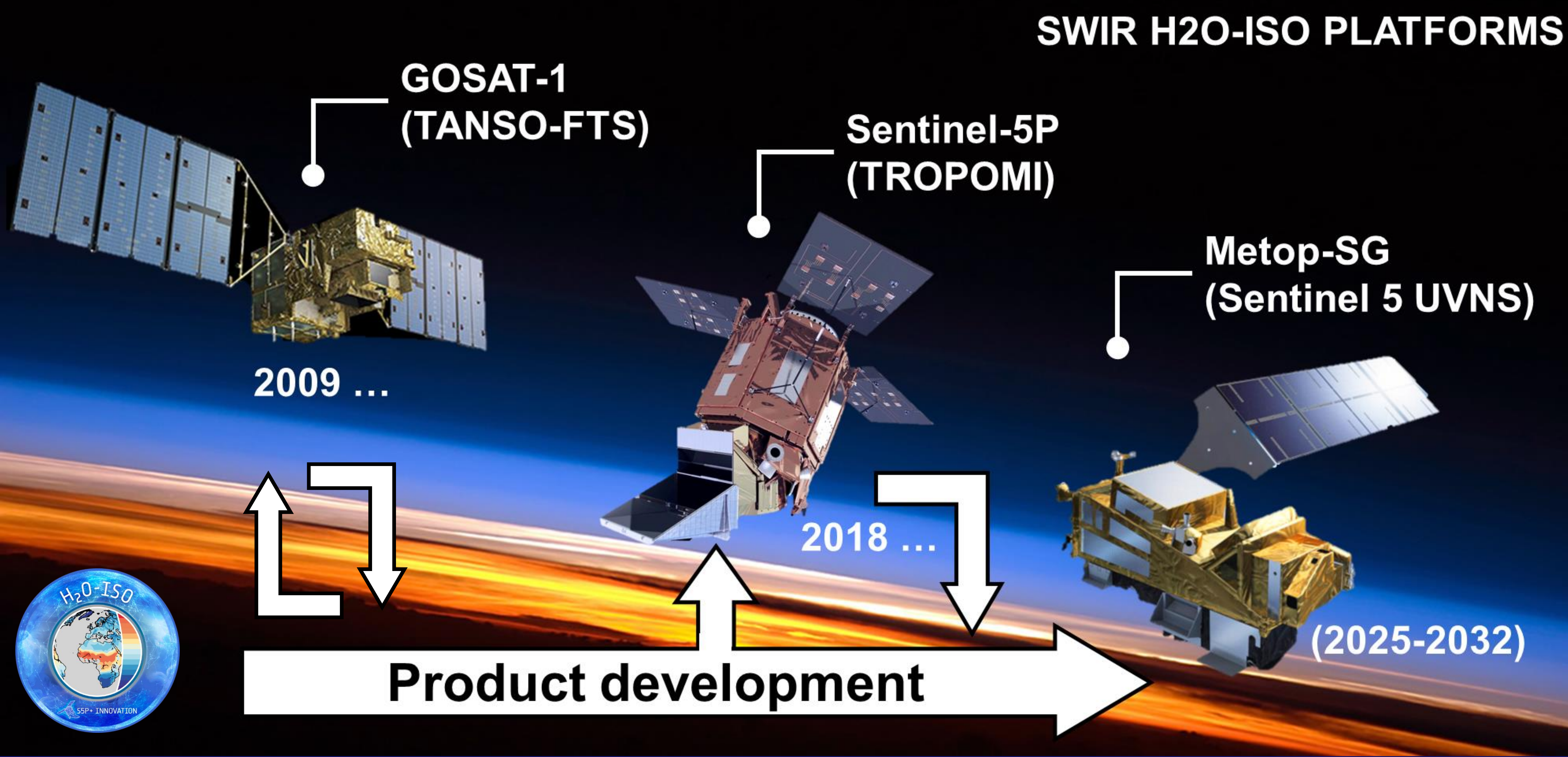

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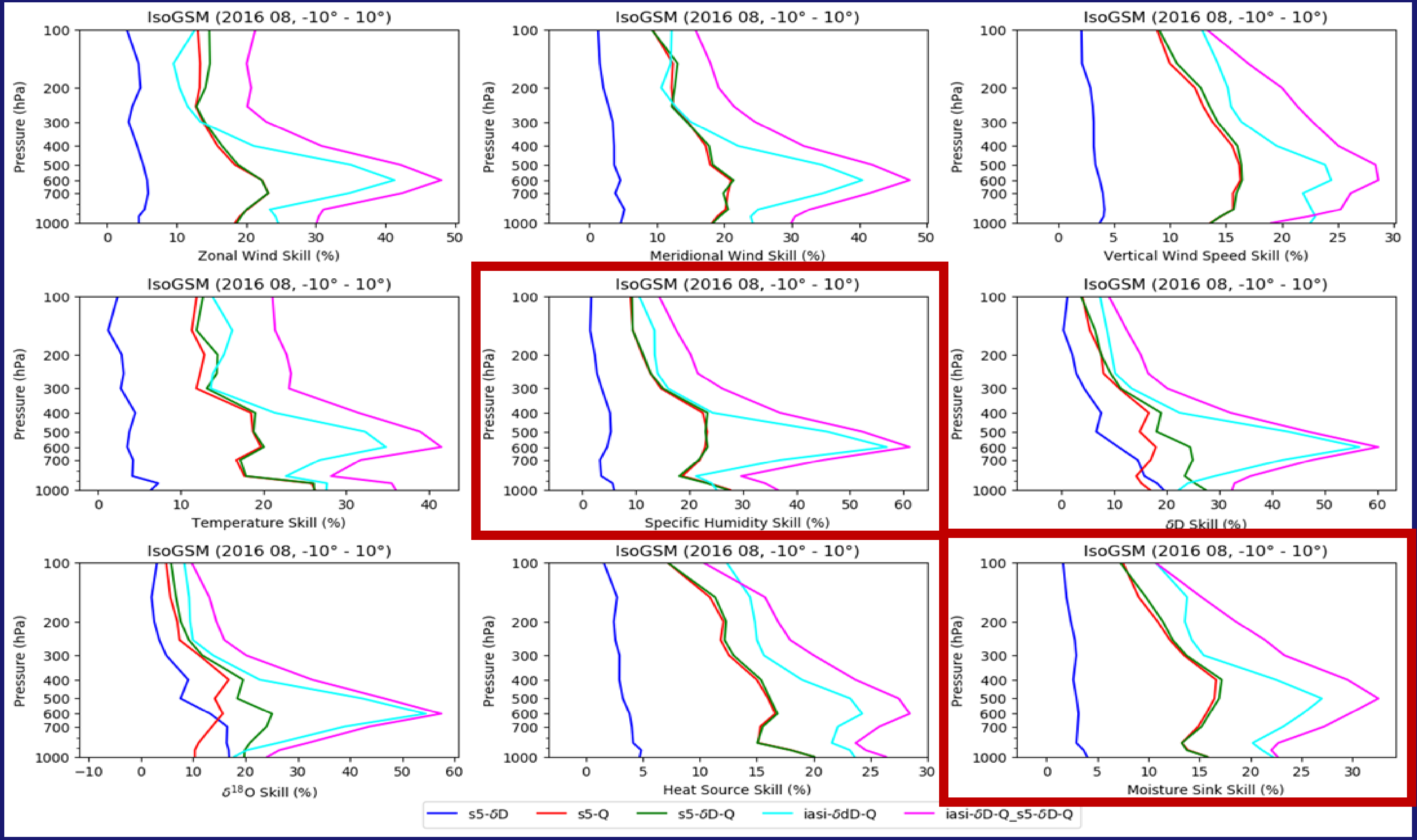
Water isotopologues: DA experiments



Key takeaway:

The highest improvements of about 35-45% are derived when S5P δD and q are assimilated together with MUSICA IASI δD and q

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Summary

- WVRT will increase under climate change, slowing the fast mode of the hydrological cycle, impacting global precipitation distributions.
- Current uncertainty between observations, reanalysis and climate models can be up to 1.1 days, signals we want to detect under Paris agreement are within the noise.
- **Challenge:** Reduce uncertainty in WVRT.
- **(one) Recommendation to ESA:** To continue to support the development of satellite stable water vapour isotopologue products.

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Thank you for listening

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