Examining Water Vapour Residency Times from Observational and AMIP Ensembles

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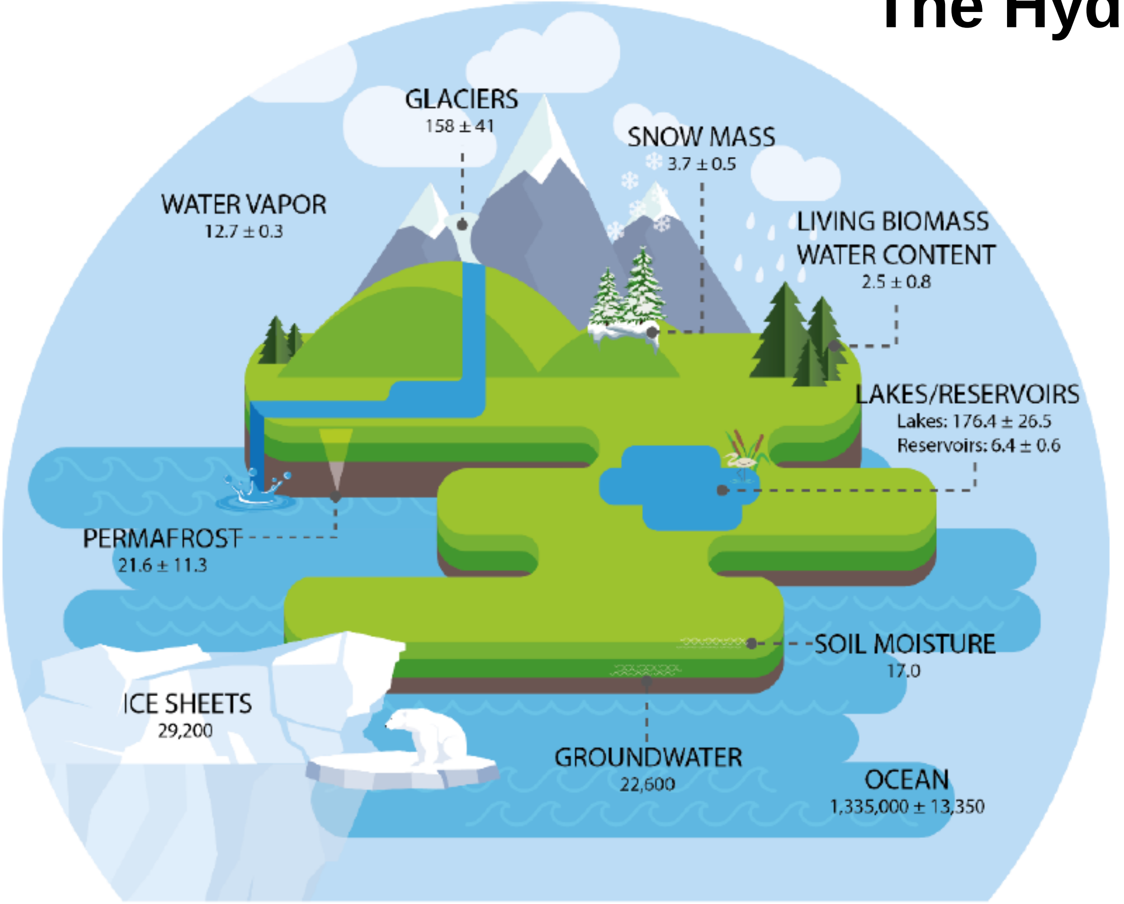
Overview

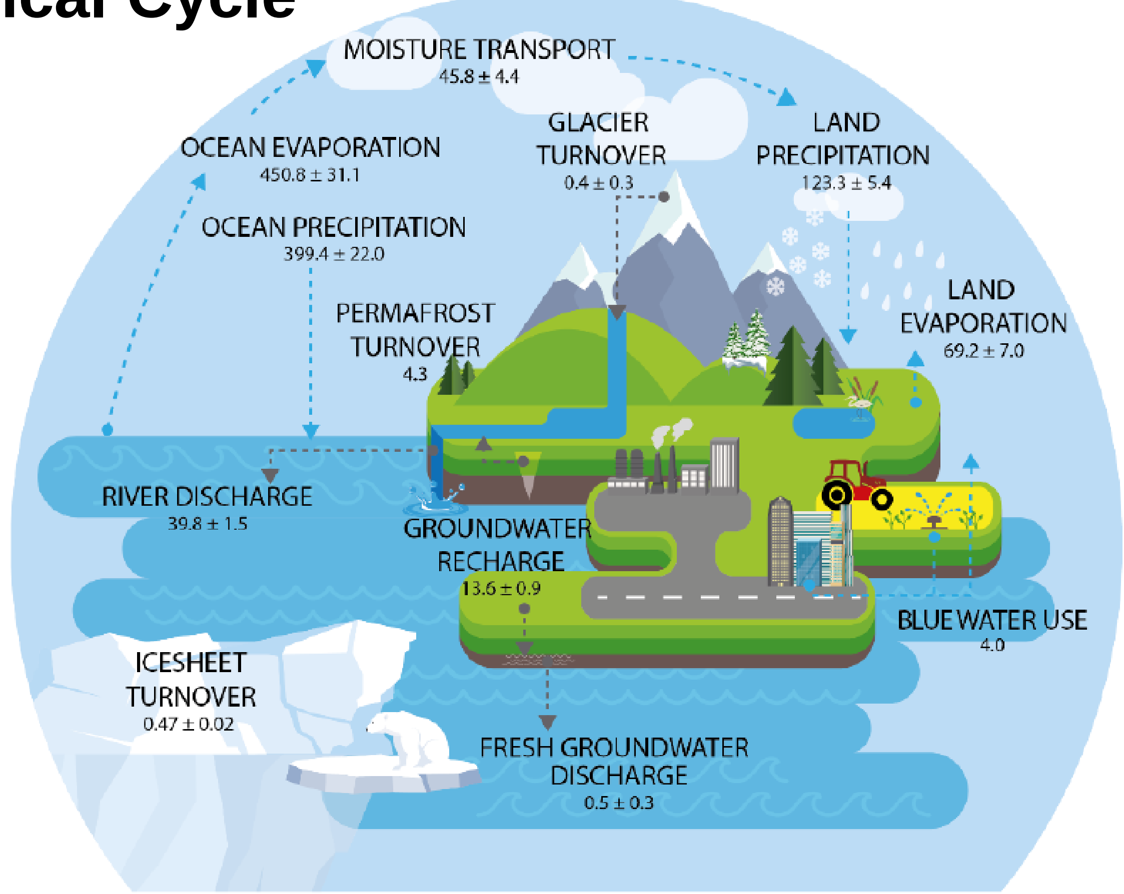
- Motivation
- Method
- Datasets
- Results
  - PDFs
  - Time series analysis
  - Convective regions
  - Trends
- Future challenge
- Conclusions

Motivation

The Hydrological Cycle



GLOBAL WATER STORAGES



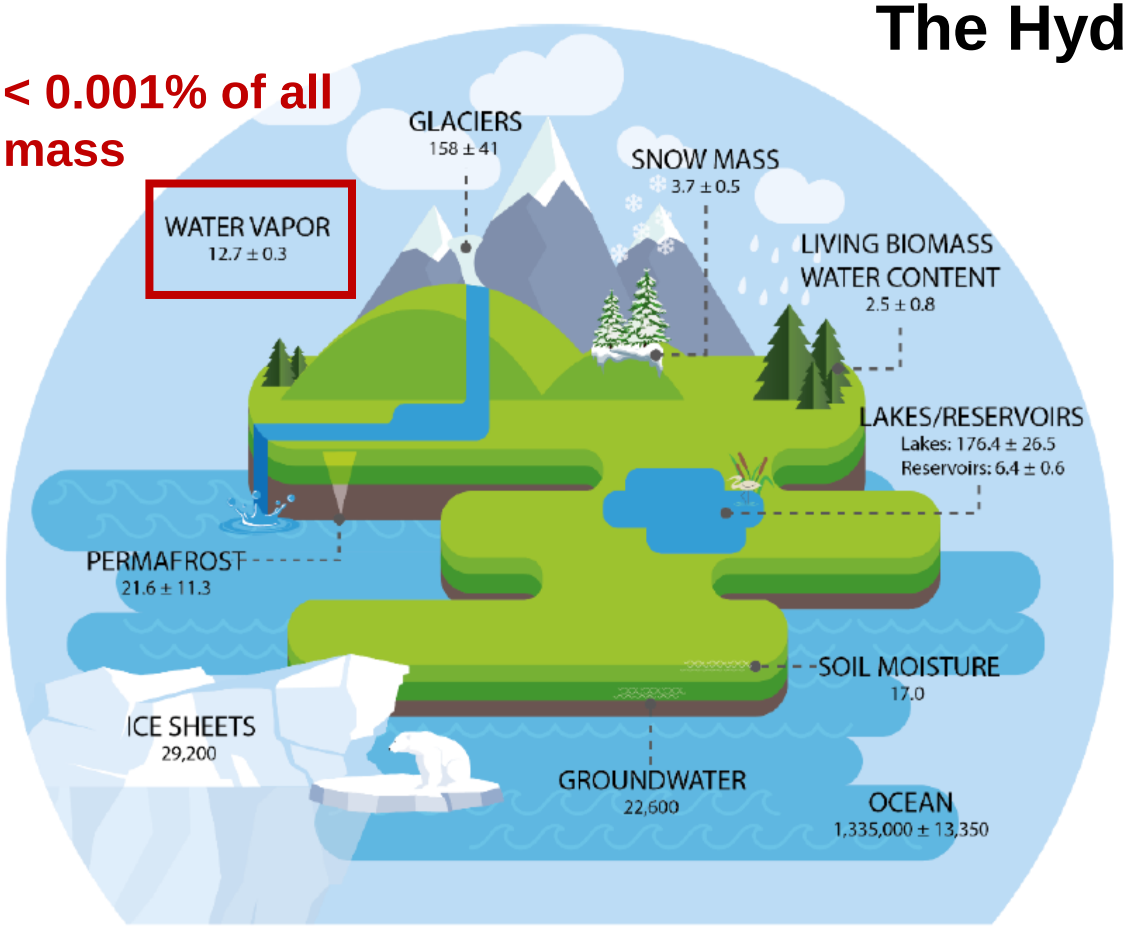
GLOBAL WATER CYCLE FLUXES

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

Motivation

The Hydrological Cycle

< 0.001% of all mass



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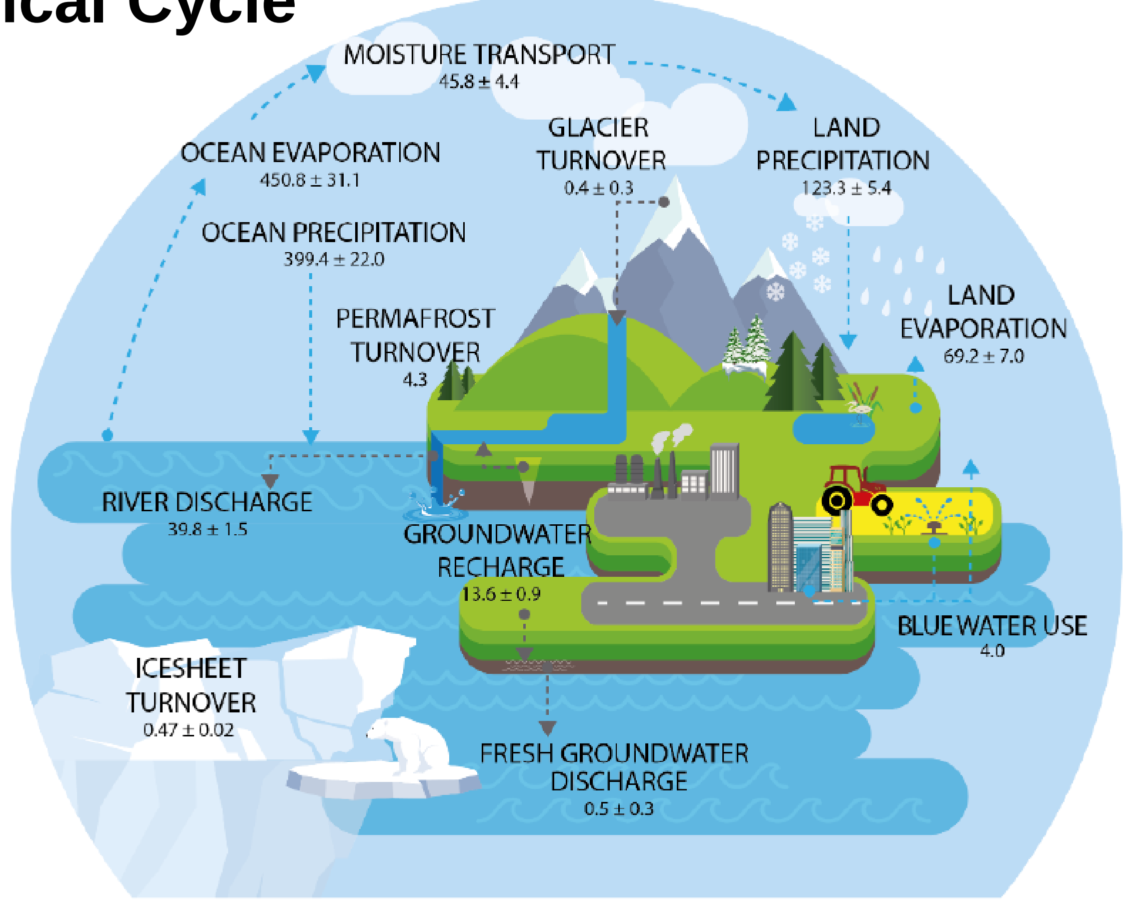

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(Water Vapour Residence Time)

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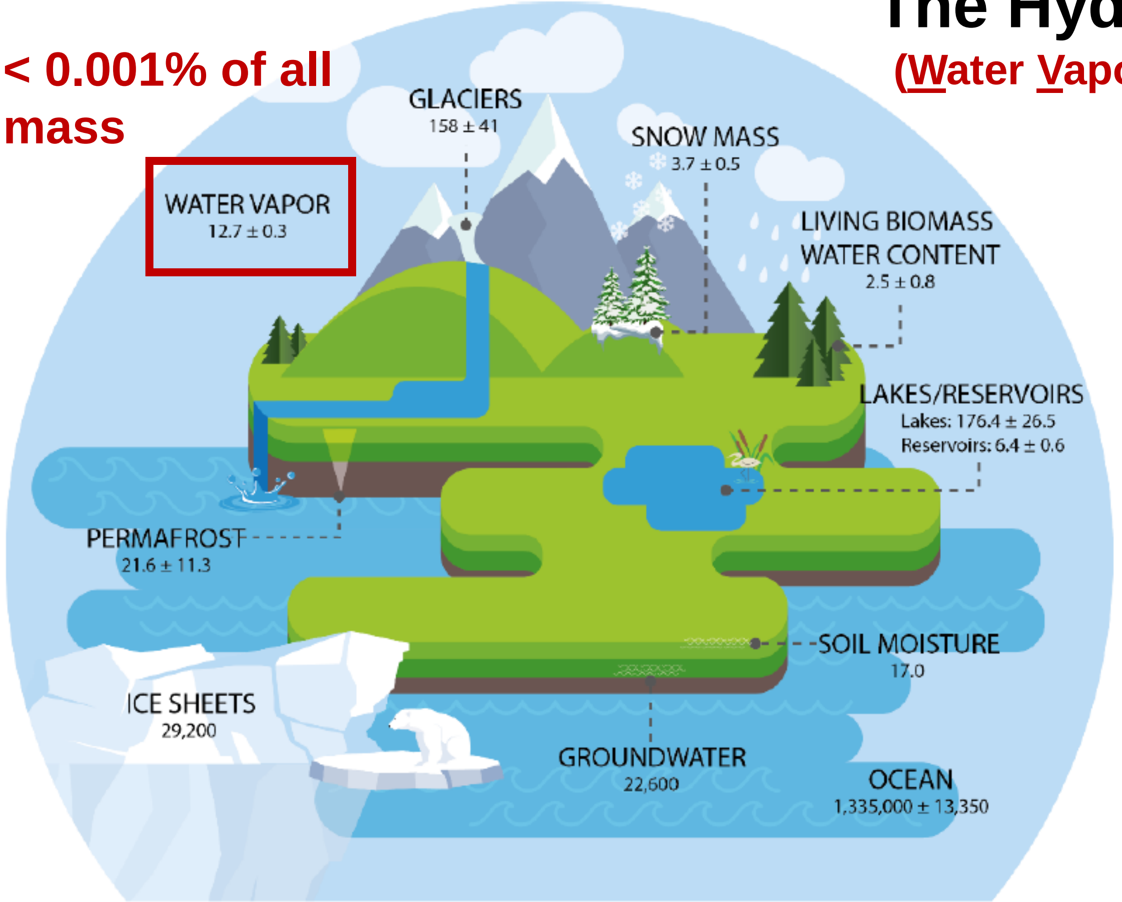
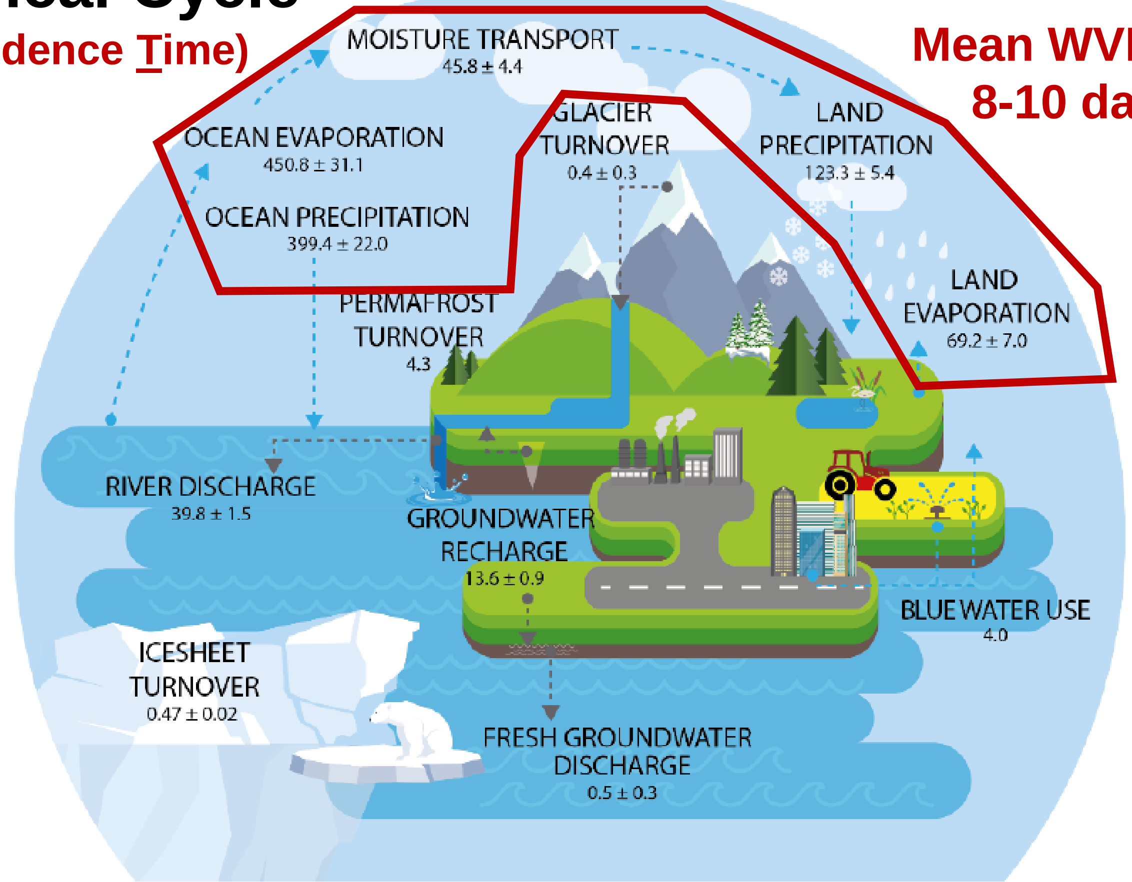


GLOBAL WATER STORAGES

Mean WVRT 8-10 days



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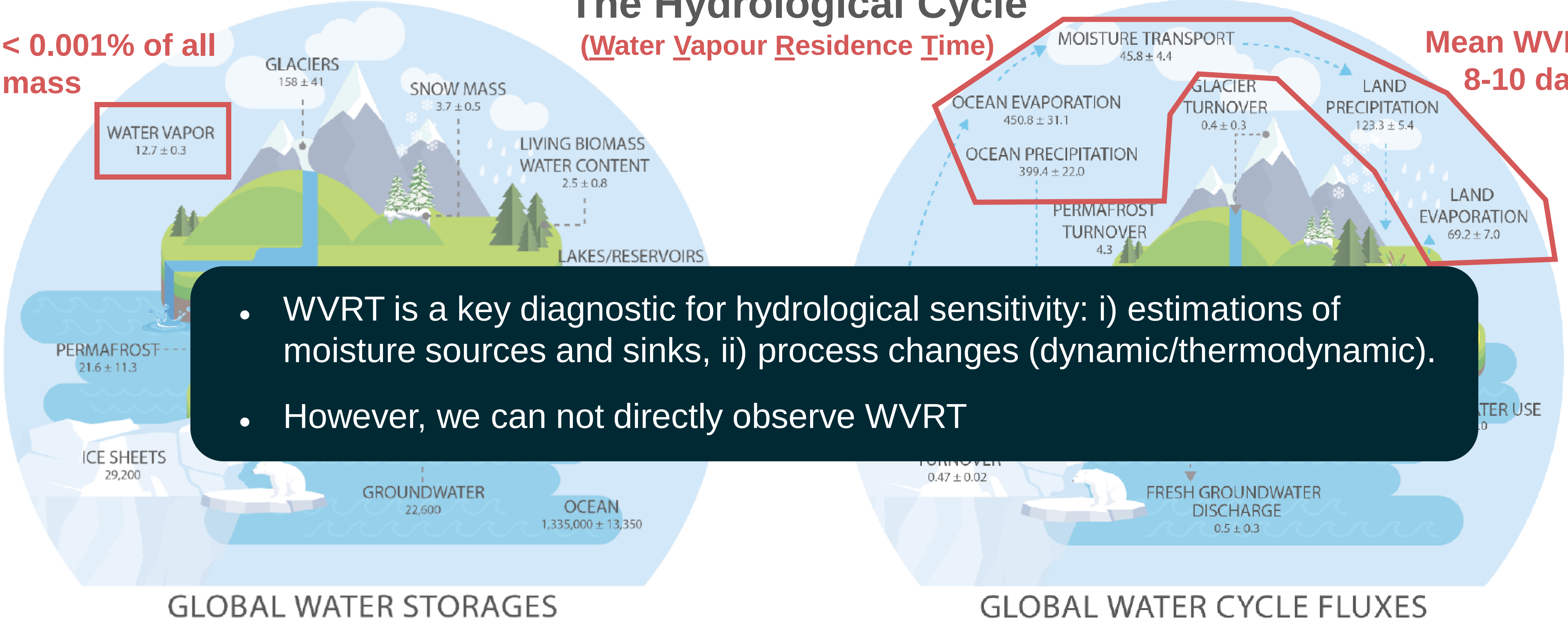


< 0.001% of all mass

Mean WVRT 8-10 days

- 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

Method

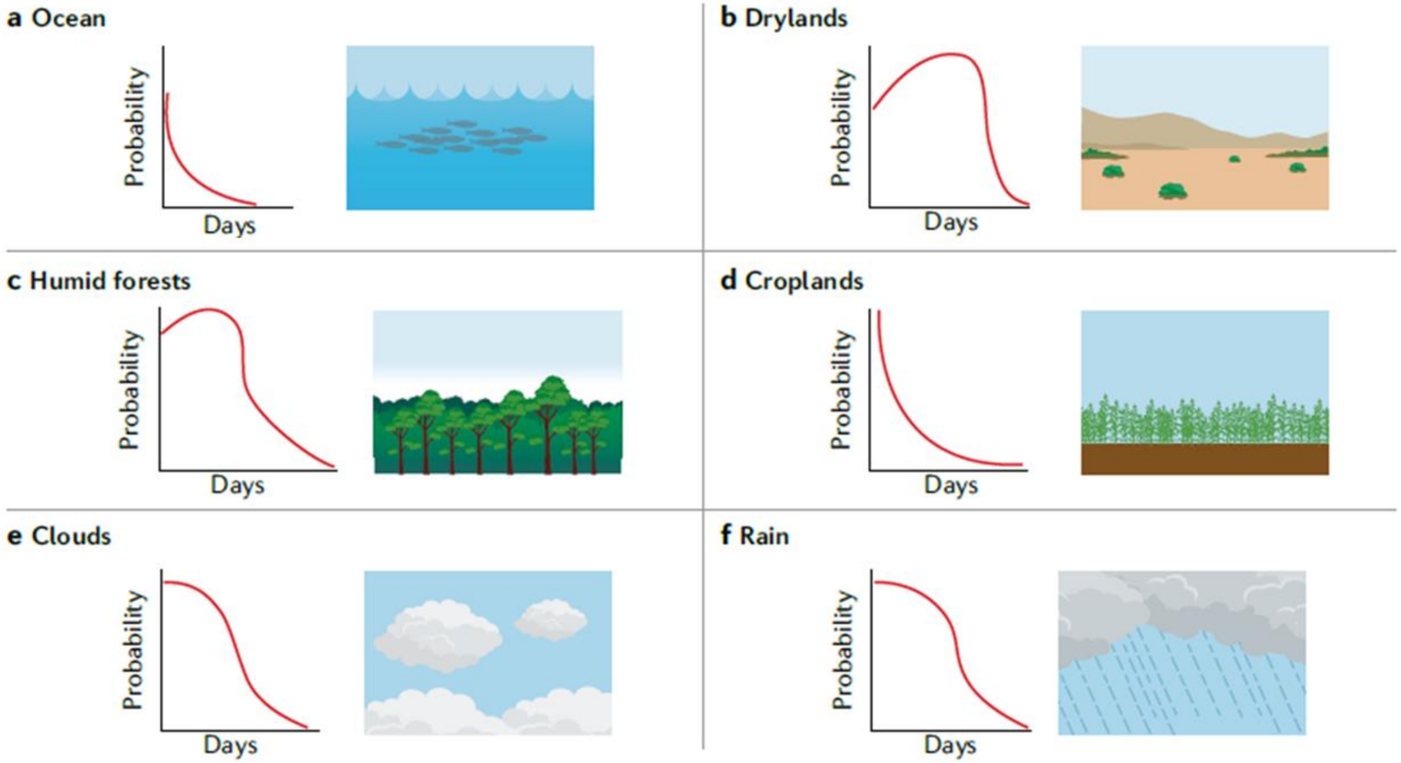
- Use a number of metrics to estimate WVRT, ranging in complexity. This study uses long established turnover time (TUT) method:

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

$$= \frac{\boldsymbol{kg\, m^{-2}\, m}}{\boldsymbol{kg\, m^{-2} day^{-1} m}}$$

$$= \boldsymbol{days}$$

- 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.

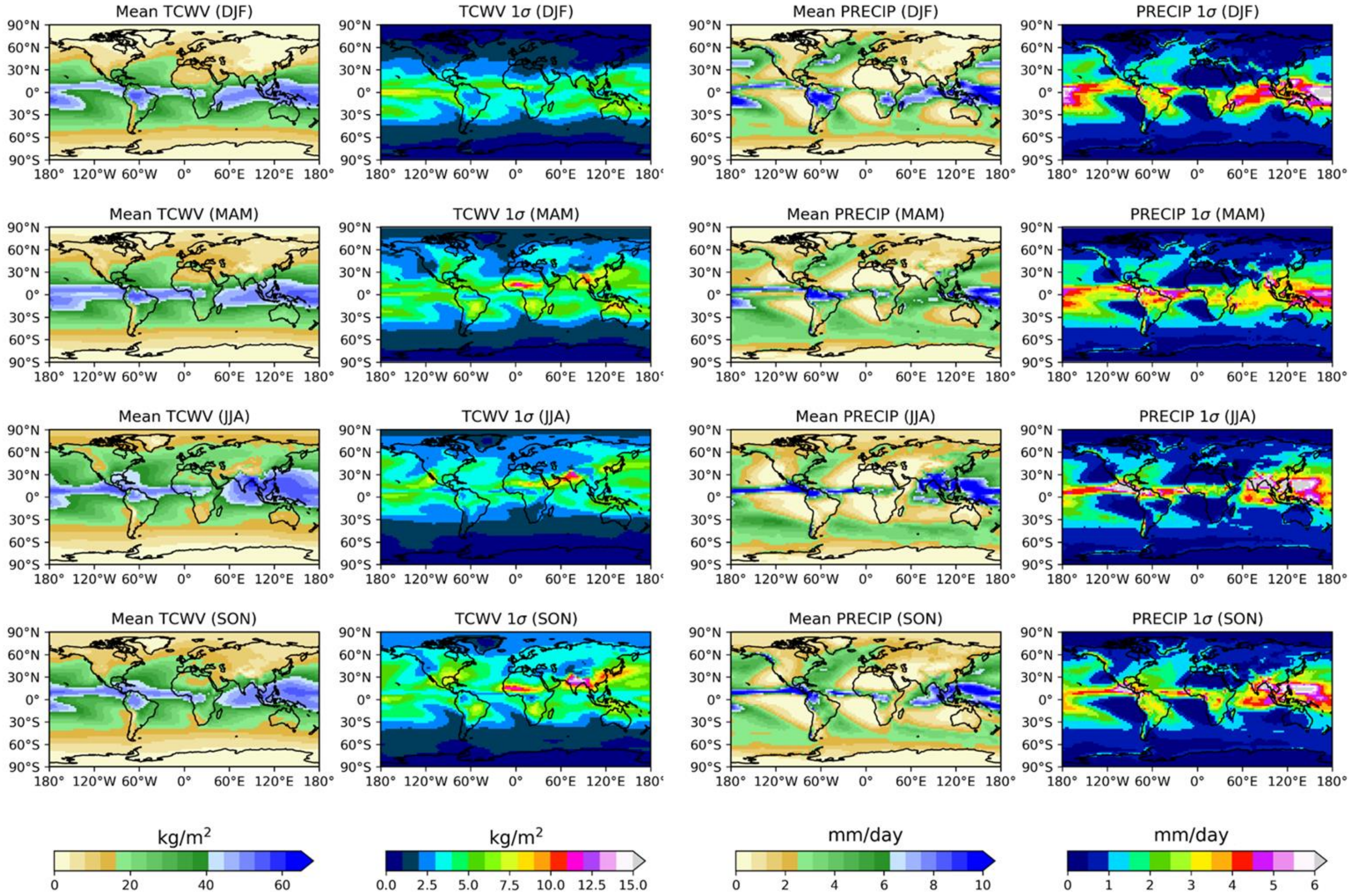


Adapted from Gimeno et al., 2021

Datasets

- Ensembles of TCWV and precipitation (prw, pr) from satellite observations, reanalysis and AMIP models.
- Satellite and reanalysis TCWV records are taken from G-VAP archive.
- Observational precipitation records include: CMAP, GPCP (v2.3), IMERG (V06B), PERSIANN-CDR and HOAPS (v5) as well as corresponding reanalysis.
- All records are monthly means, pre-processed to G-VAP common grid format.

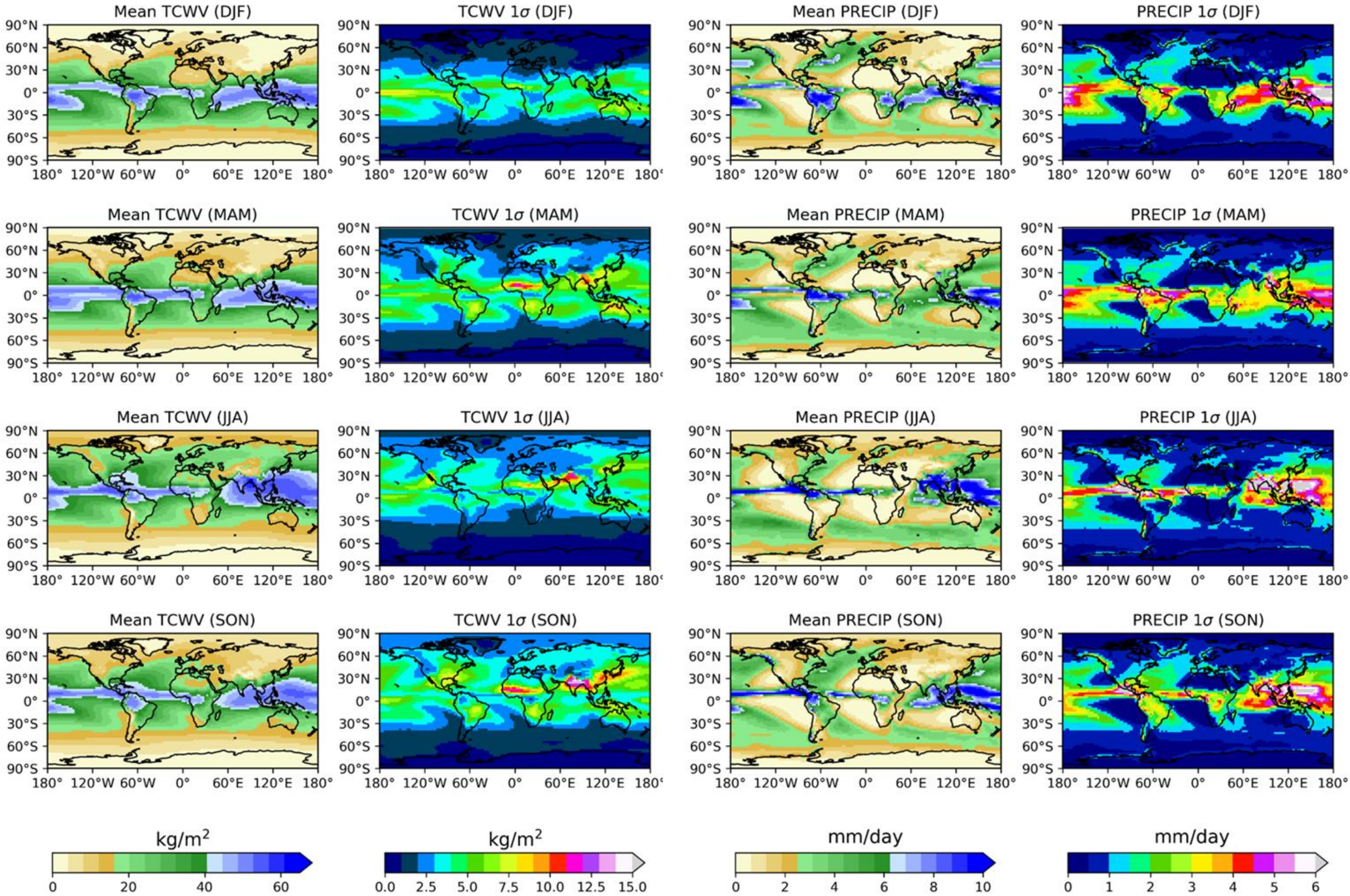
AMIP Ensemble



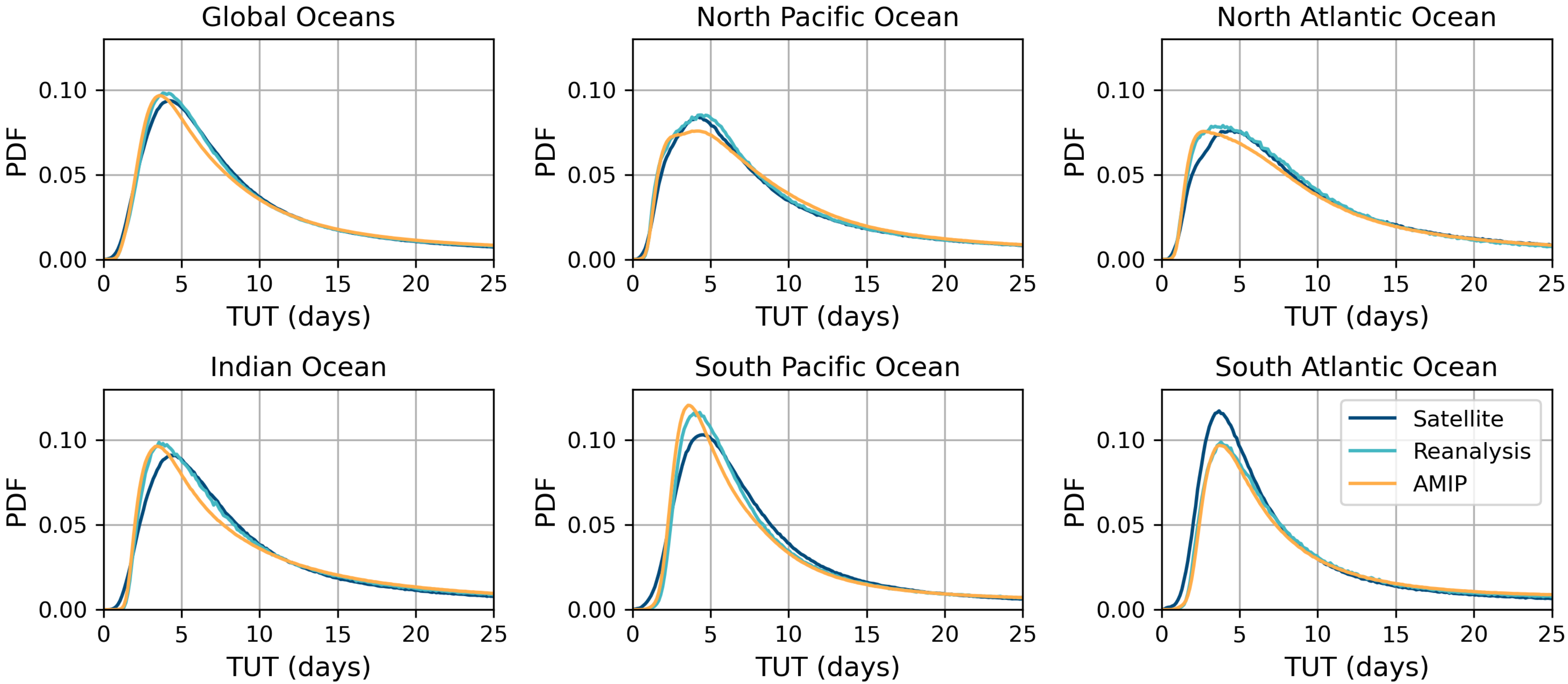
Datasets

- Analysis is performed over global ice free oceans between ±60°.
- Further subdivided into 5 major ocean regions (N/S Atlantic/Pacific & Indian).
- Filter for low precipitation (< 0.275 kg/m^2/day).
- Ensemble median is calculated from all time series.
- TUT is calculated from median of PDF (Sodemann, H., 2020).

AMIP Ensemble



Data Record PDFs



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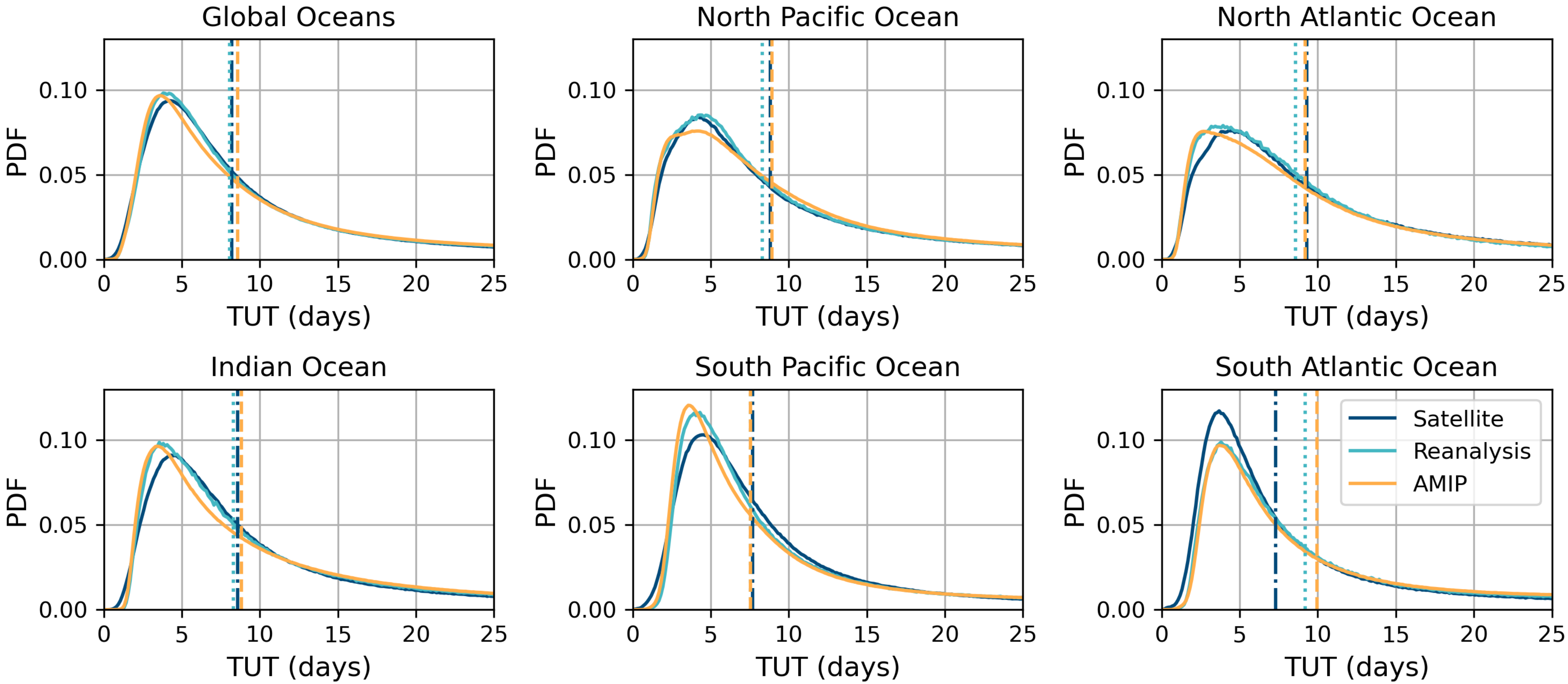

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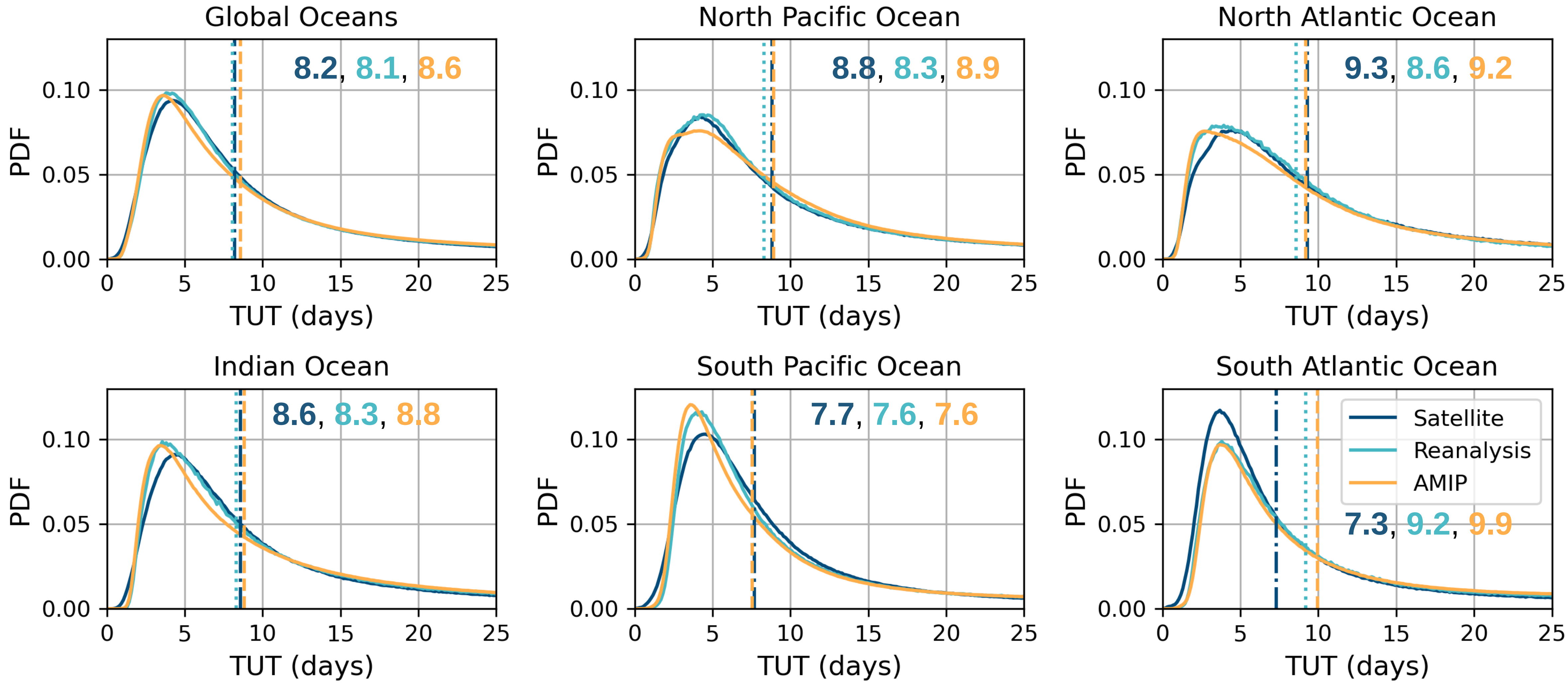

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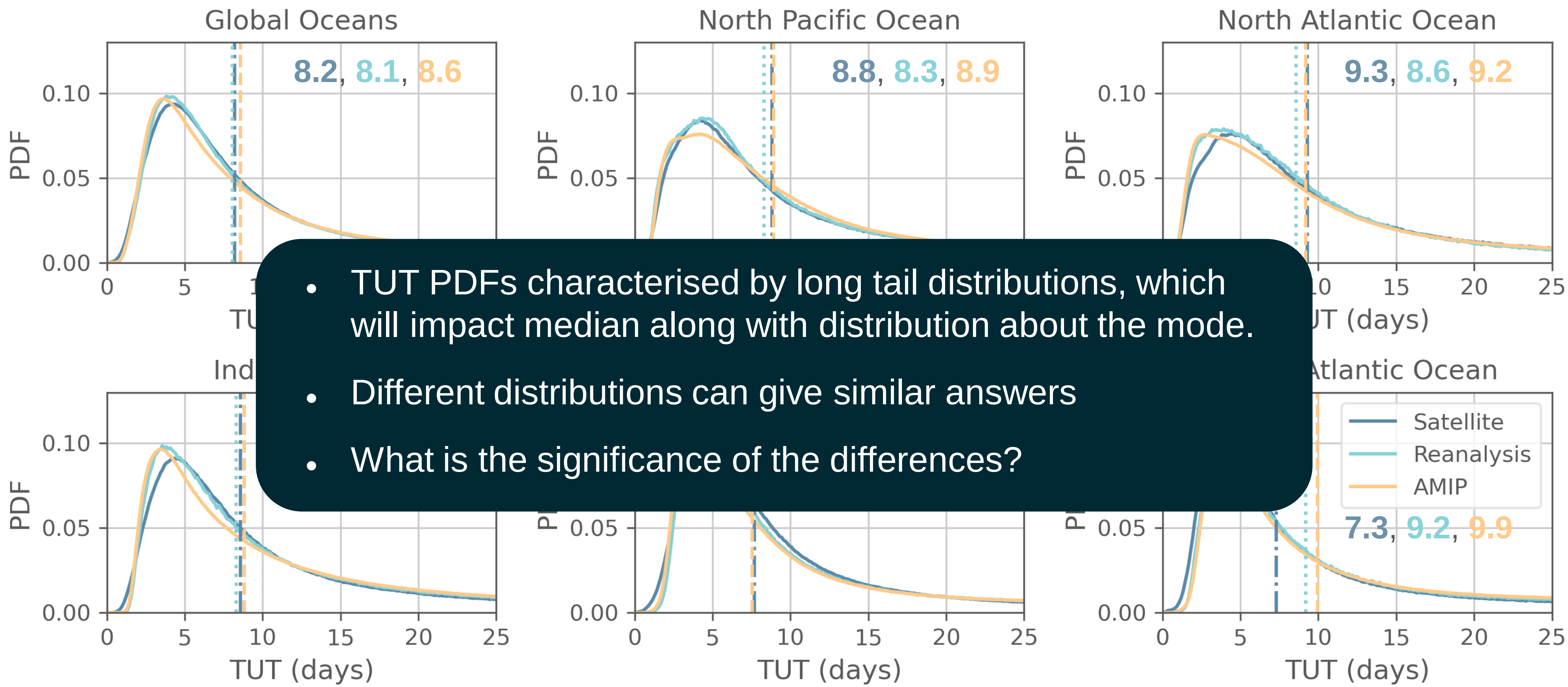
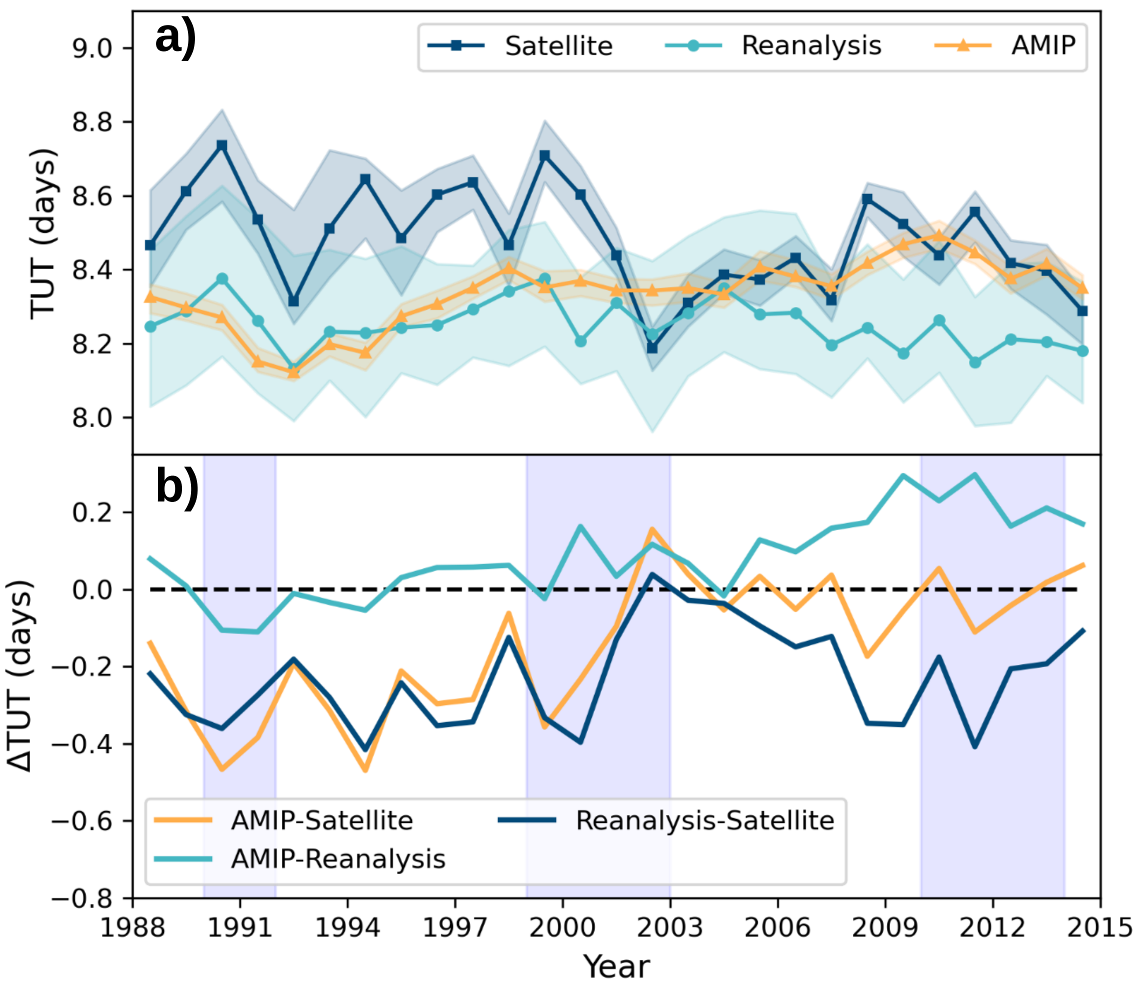


- TUT PDFs characterised by long tail distributions, which will impact median along with distribution about the mode.
- Different distributions can give similar answers
- What is the significance of the differences?

TUT: Annual time series

- Shaded regions are 95% confidence interval about the median
- Sharp gradient in satellite TUT around 1990-92, 1999-2003, 2010-2014 (transition from strong La Nina -> El Nino)
- Mean ΔTUT (1988-2000) relative to satellite obs = 0.32 days (7.5 hrs) ~ CO2x2 forcing (PDRMIP)
- 2001-2014 mean ΔTUT of just over 2.5 hrs (0.11 days) ~ CH4x3

Median Annual Turnover Time Calculated from Ensembles for Global Ice Free Oceans betwenn ±60°



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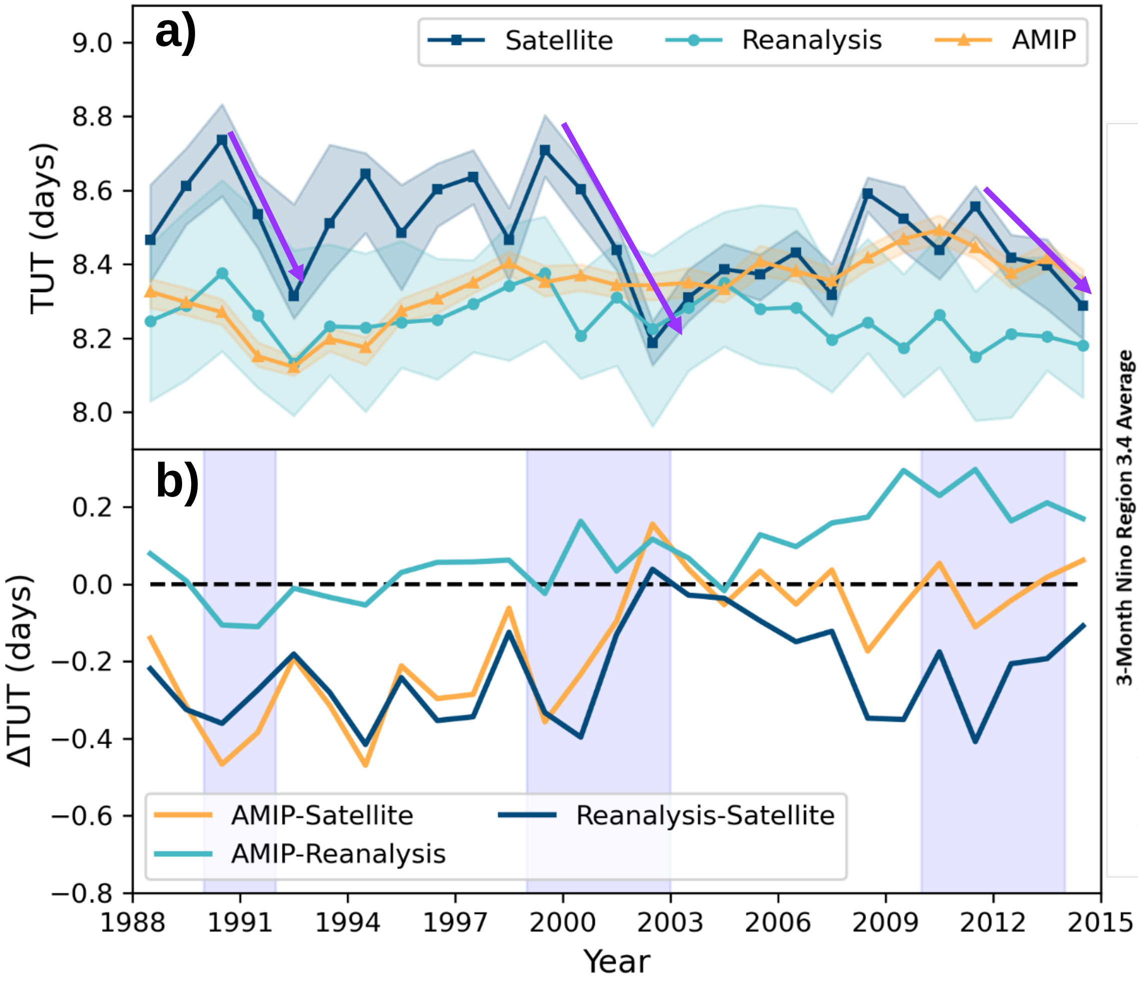

Index (ONI)

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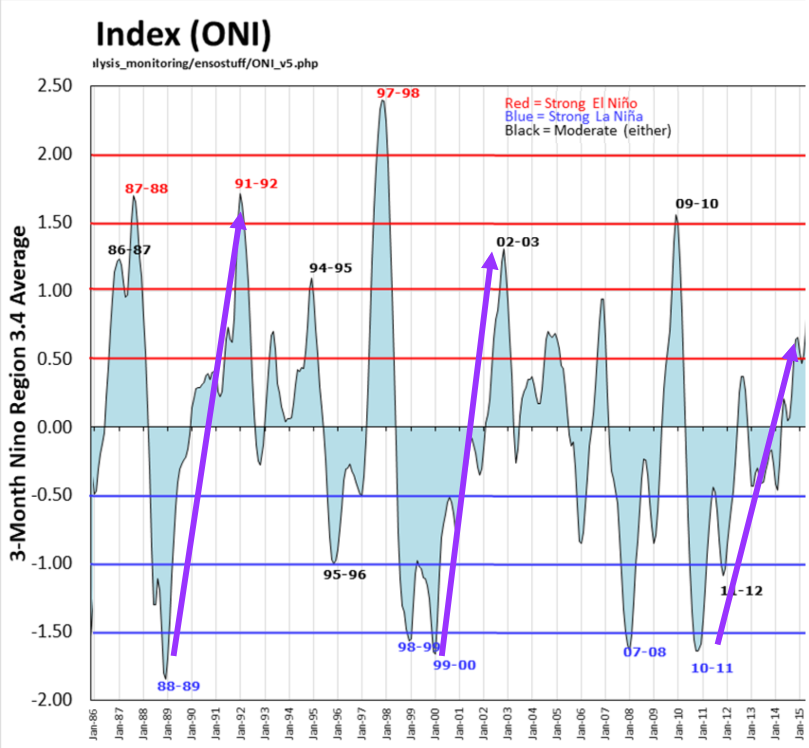

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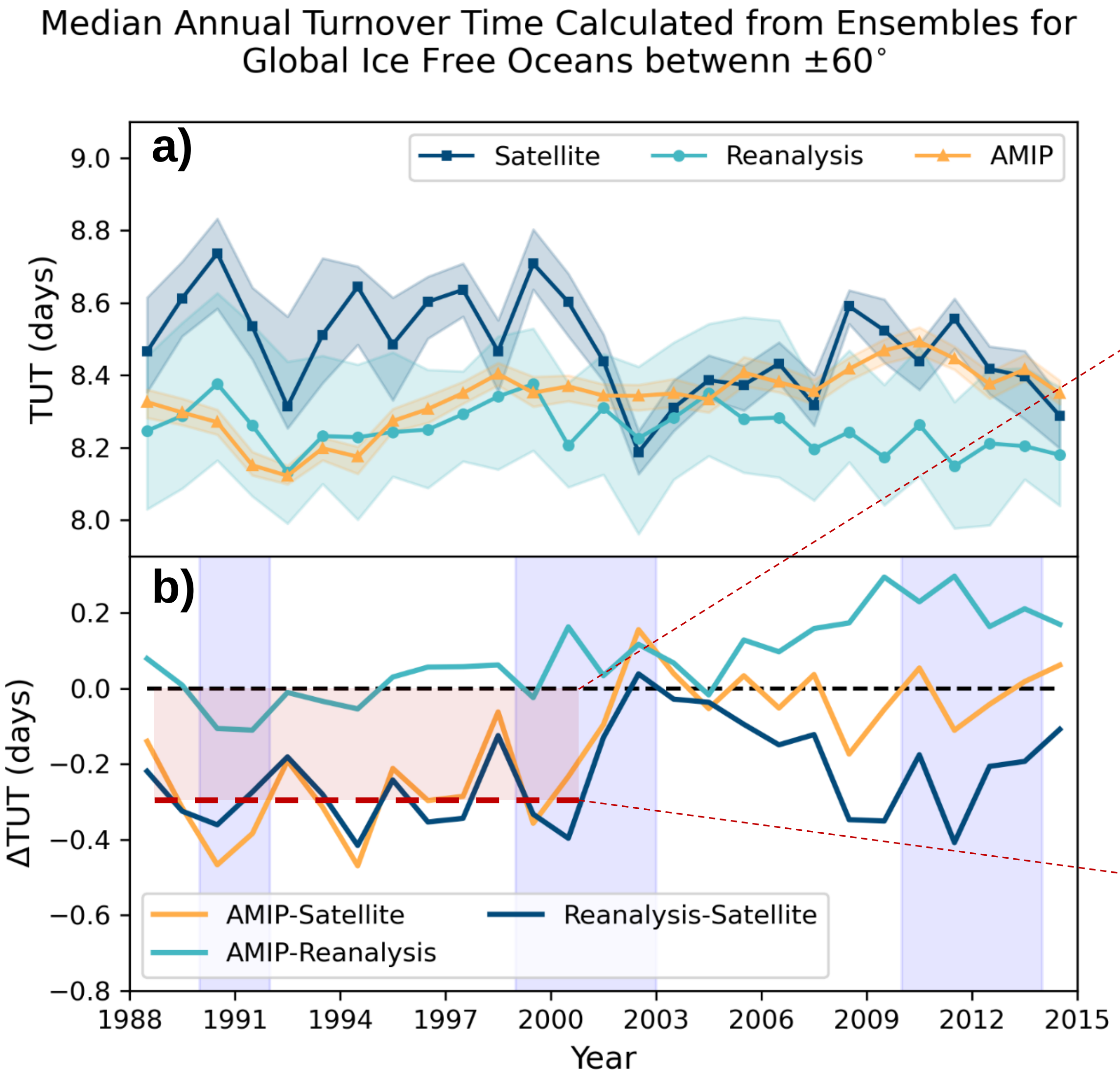
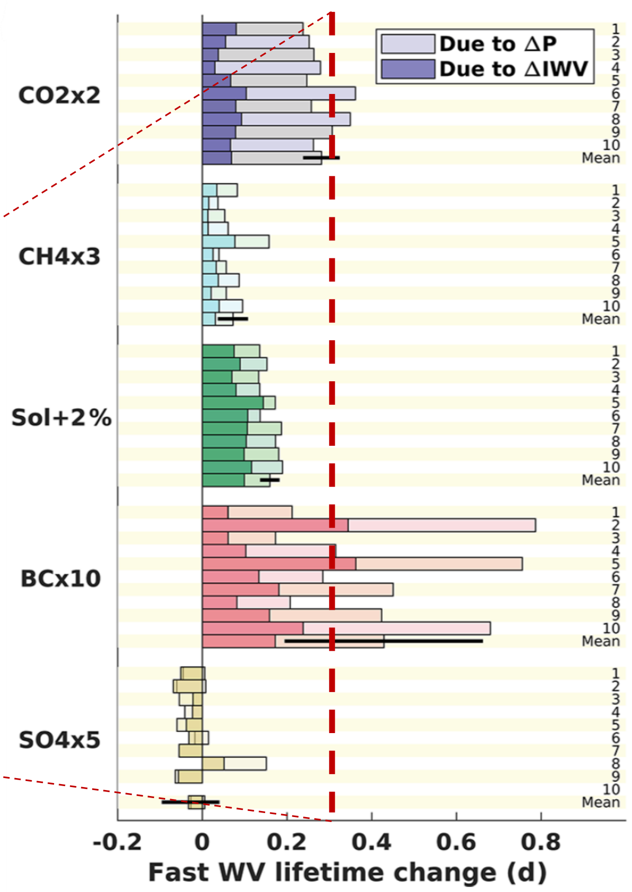


Median Annual Turnover Time Calculated from Ensembles for Global Ice Free Oceans betwenn ±60°

Results from PDRMIP



(Figure taken from Hodnebrog et al., 2019)

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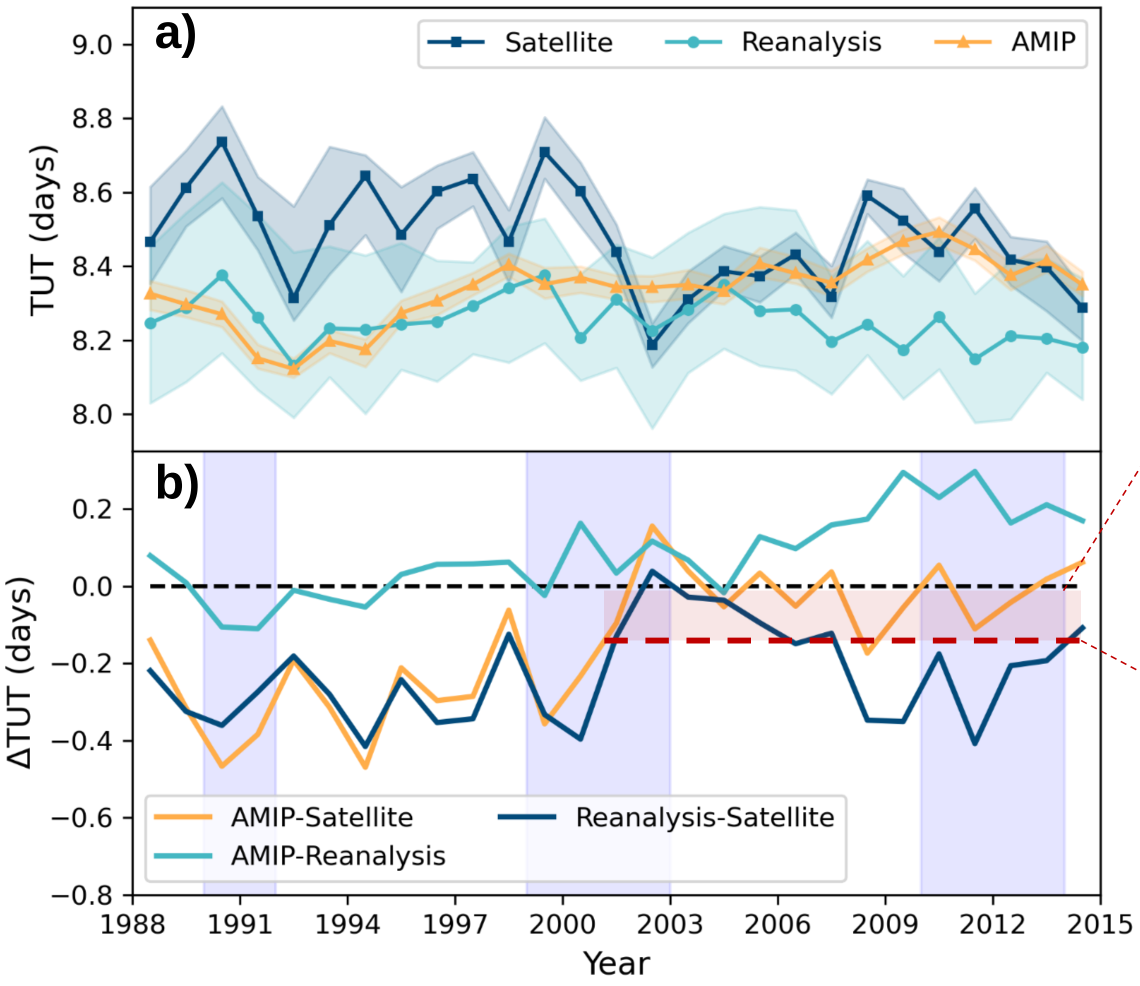

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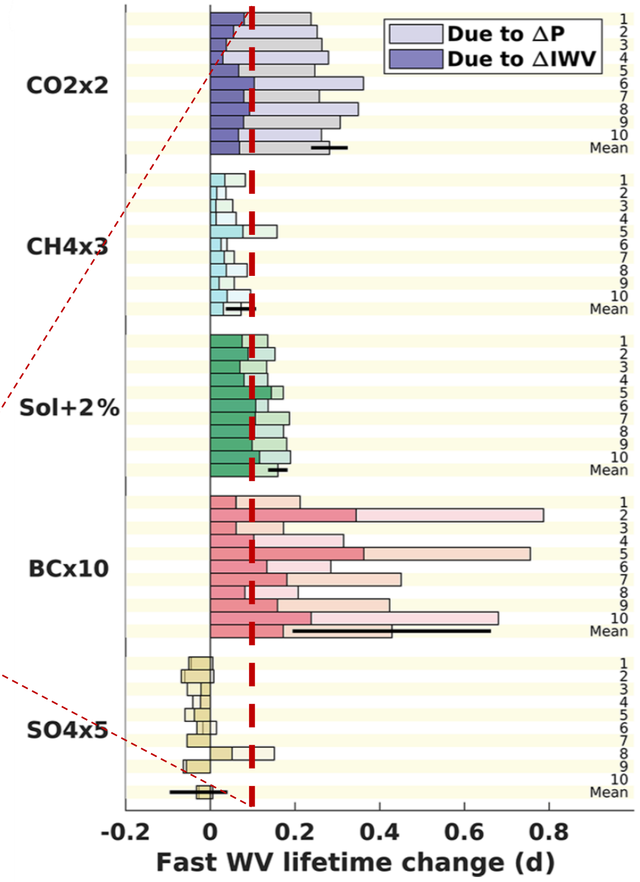

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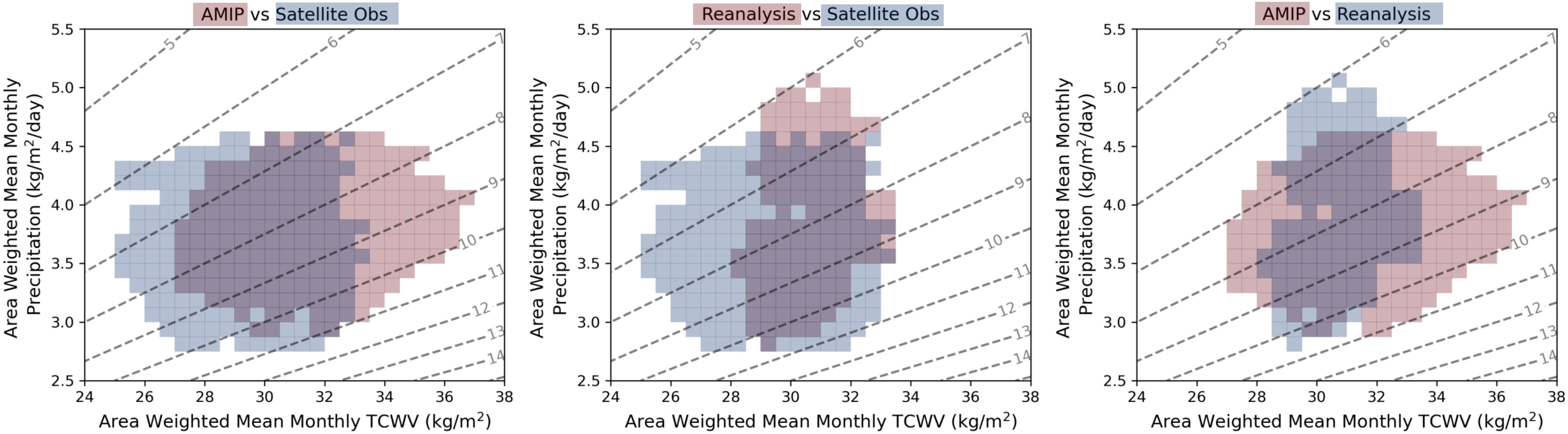

- AMIP has members with ‘wetter’ atmospheres relative to satellite and reanalysis
- Reanalysis has narrow TCWV range but higher precipitation values

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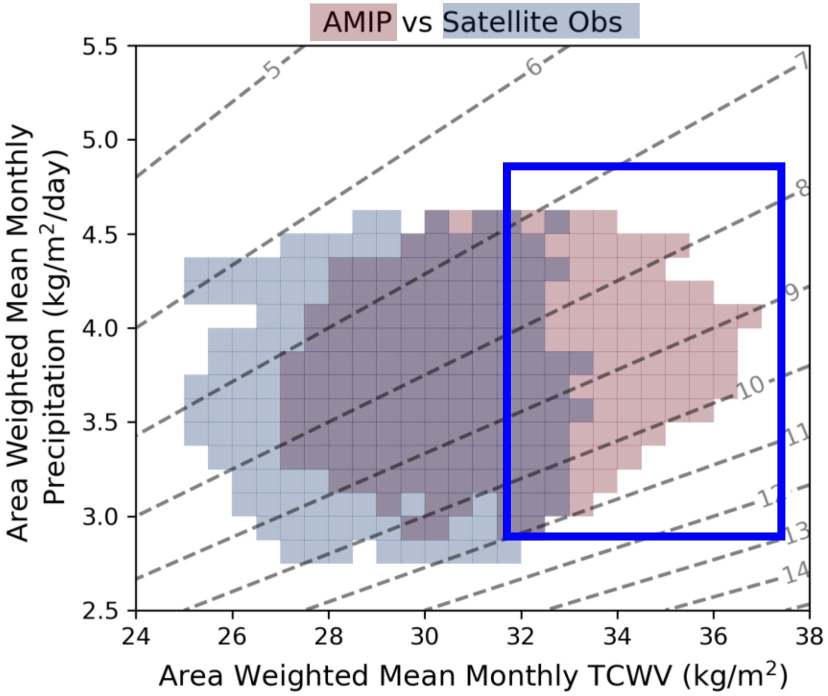

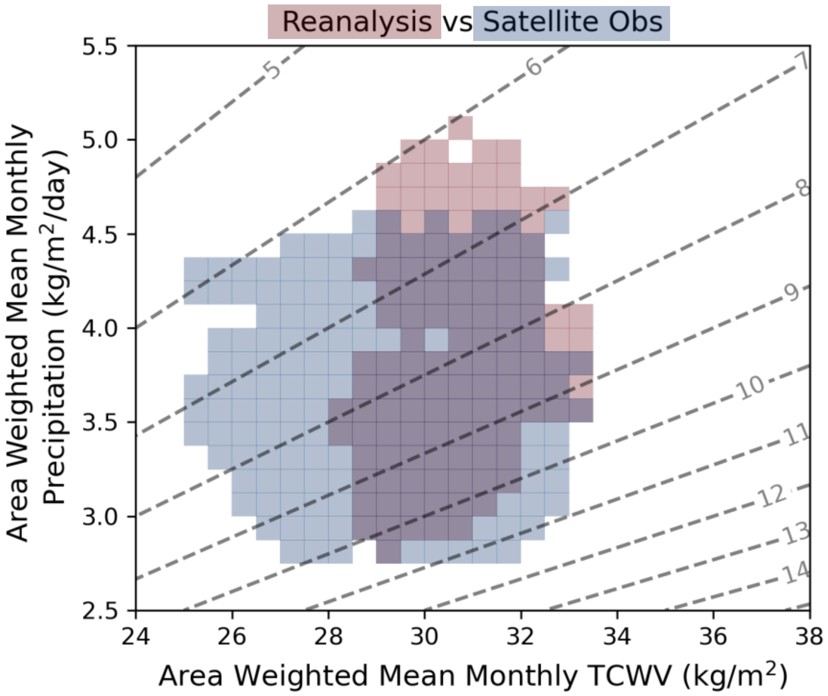

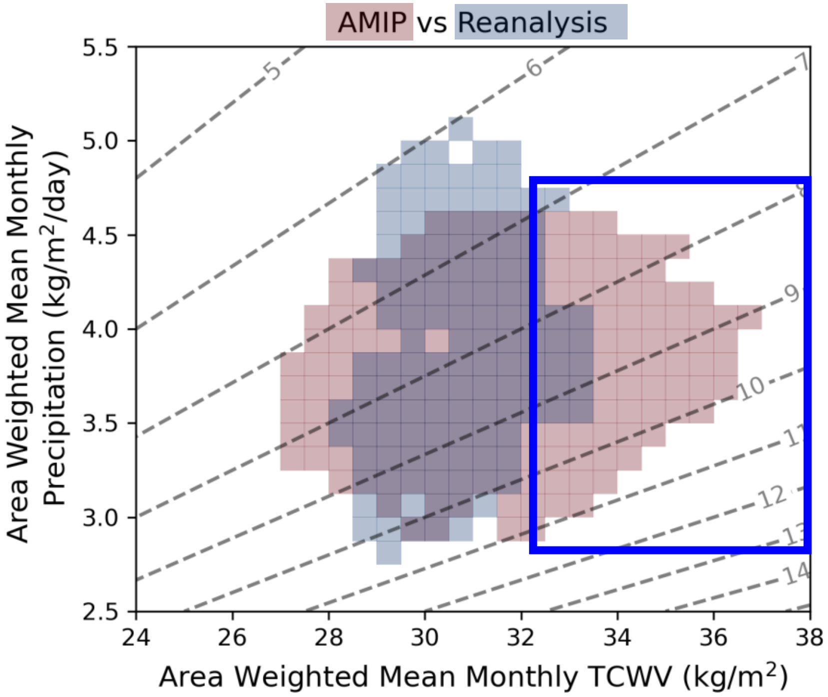

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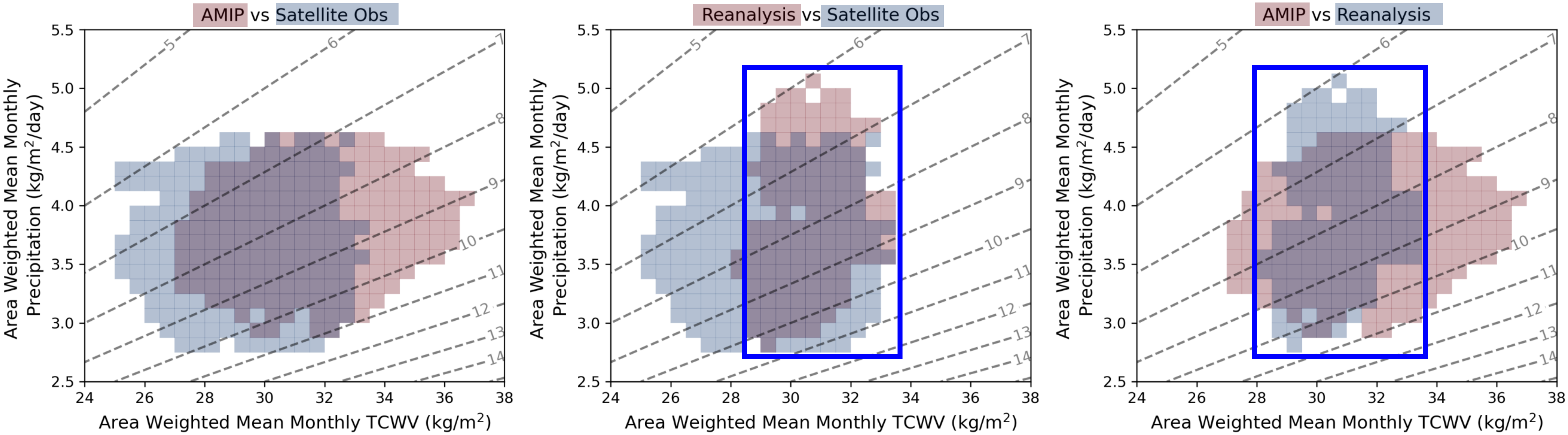

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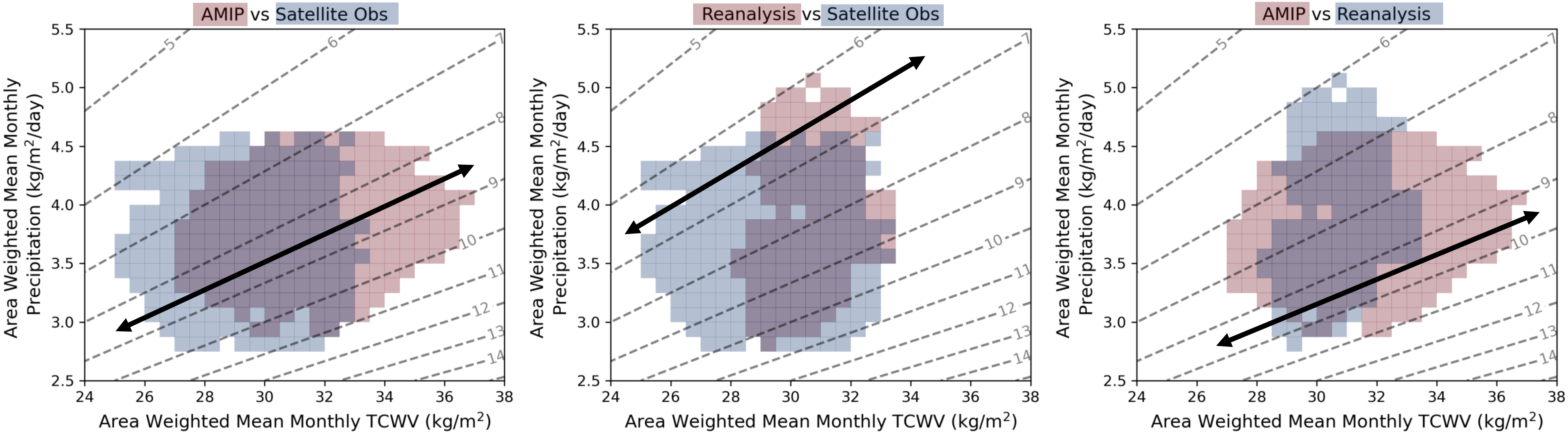
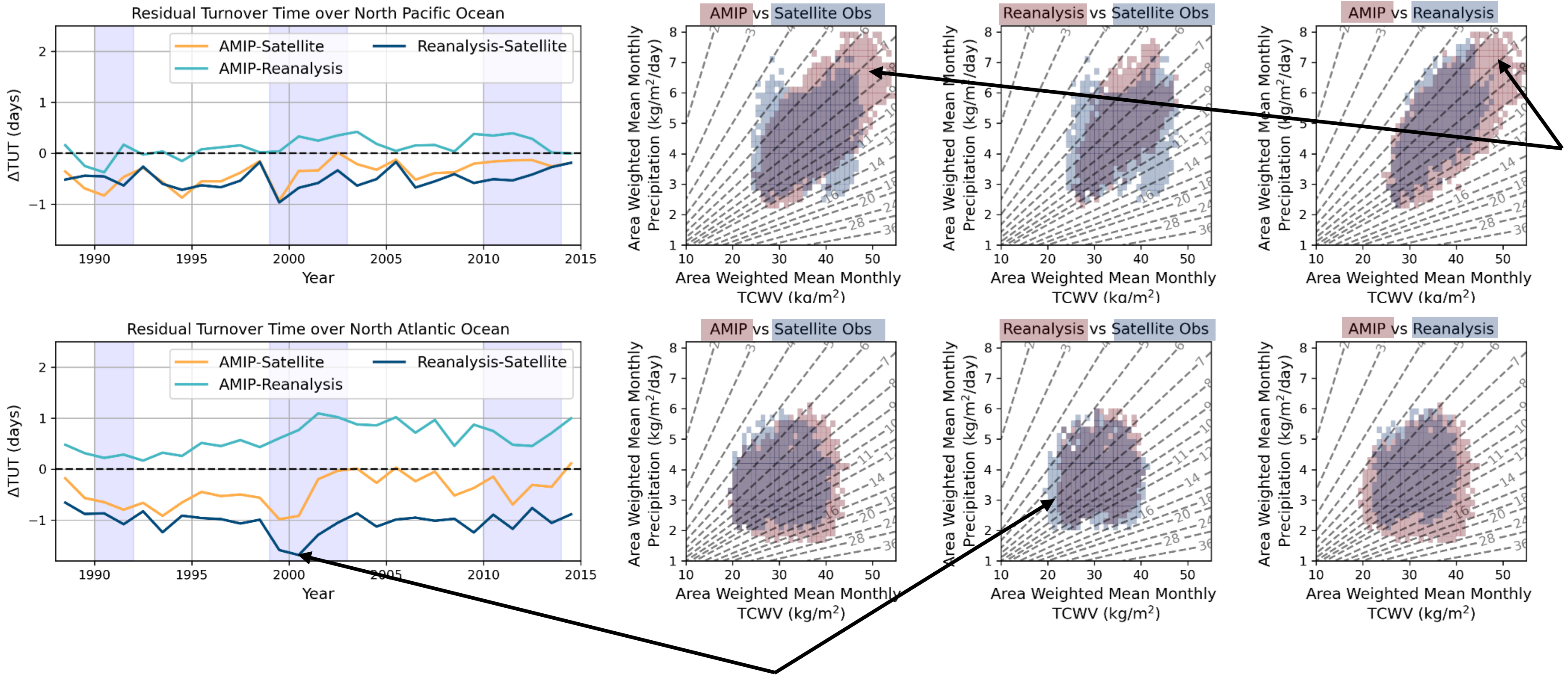


- Different distributions lay along similar TUT gradients, differences are coming from uncertainties around atmospheric moisture pathways

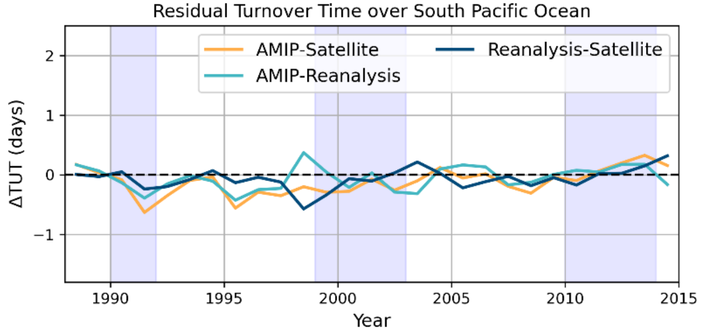
TUT: Annual time series

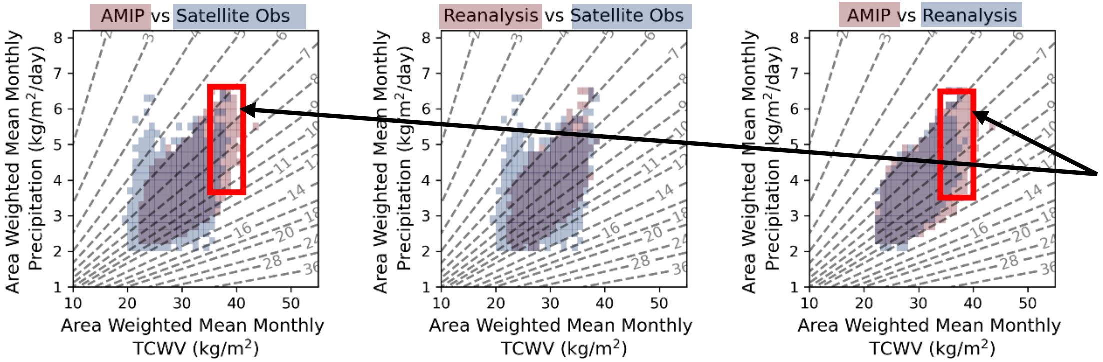


AMIP shows much wetter atmosphere with higher precipitation in North Pacific

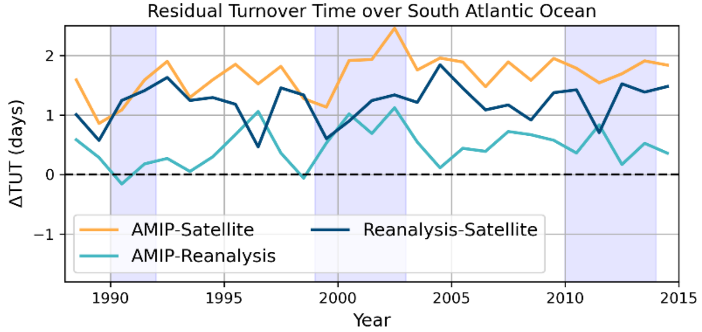
Differences in lower end TCWV and precipitation between reanalysis and Satellite observations bigger impact over North Atlantic

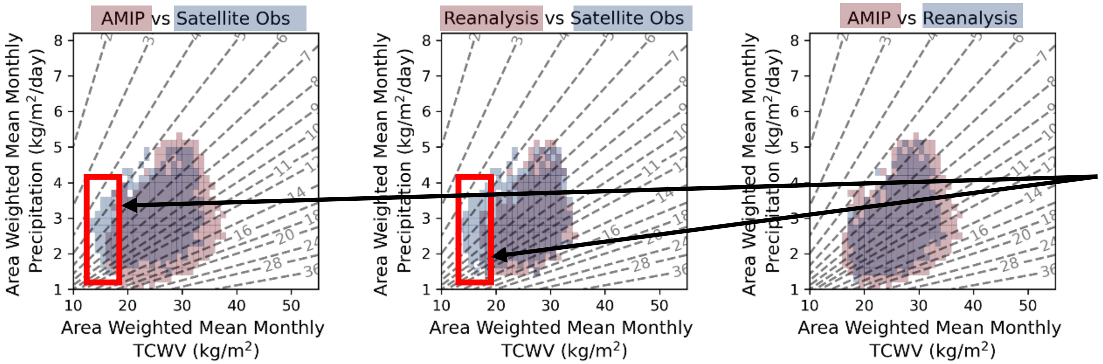
TUT: Annual time series



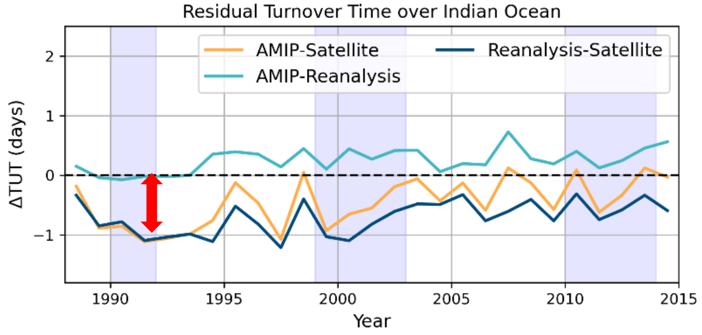


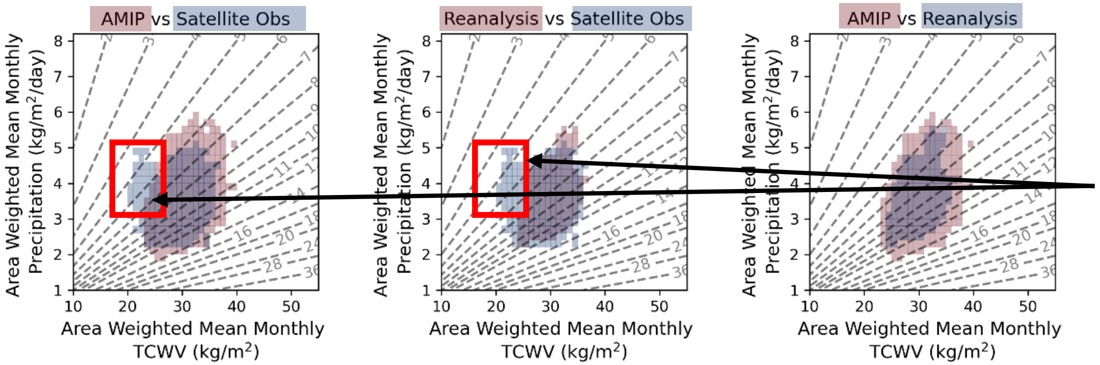
South Pacific best performing region from residuals, although wetter distribution for AMIP





Asymmetry to the Atlantic, again precipitation range in dry atmospheres dominate residuals



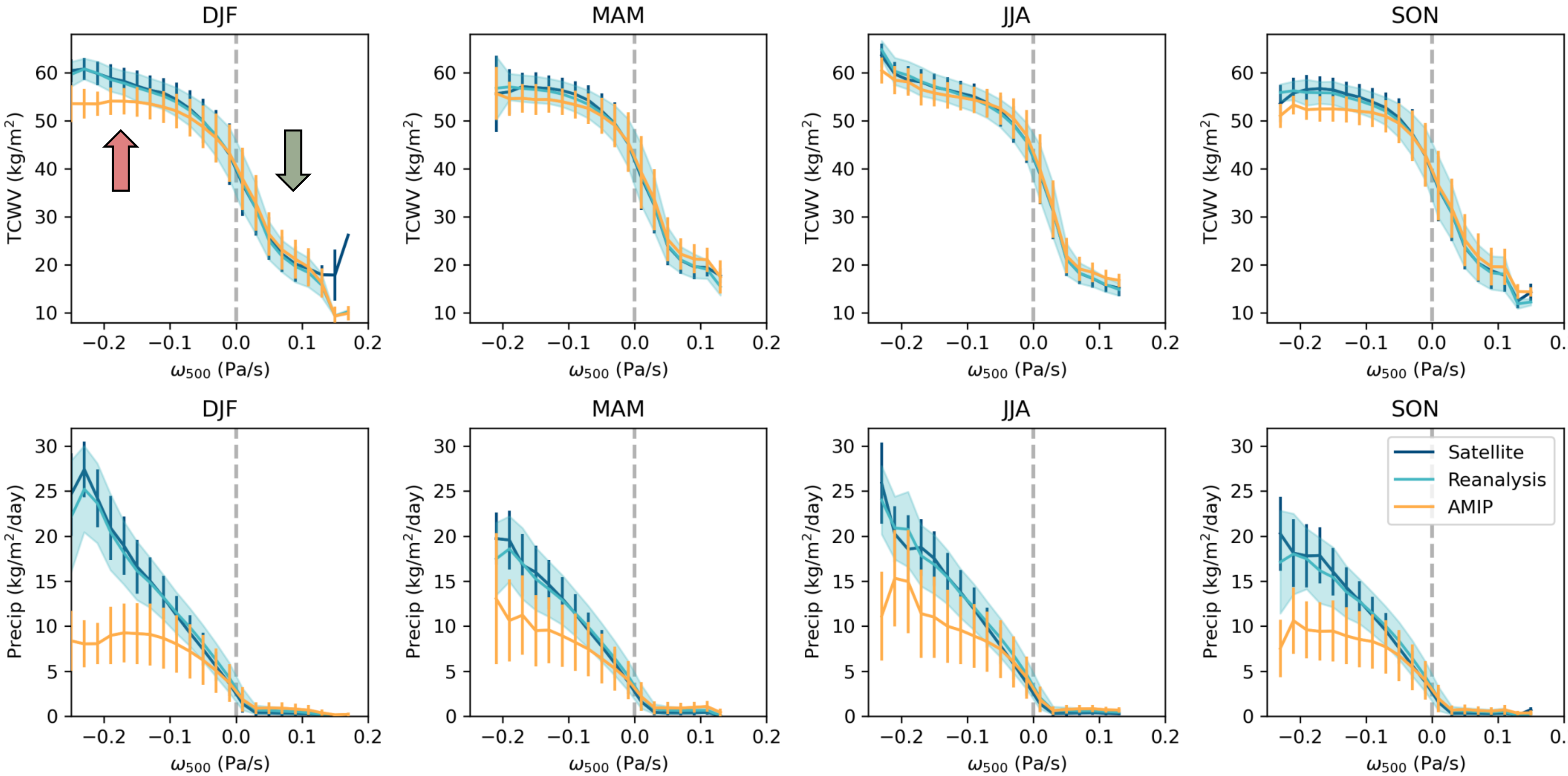


Medium to high precipitation range for TCWV between 20-25 kg/m2 in satellite obs driving large residuals (-1 day) in Indian ocean

Convective Regions

Ascending air masses

Descending air masses



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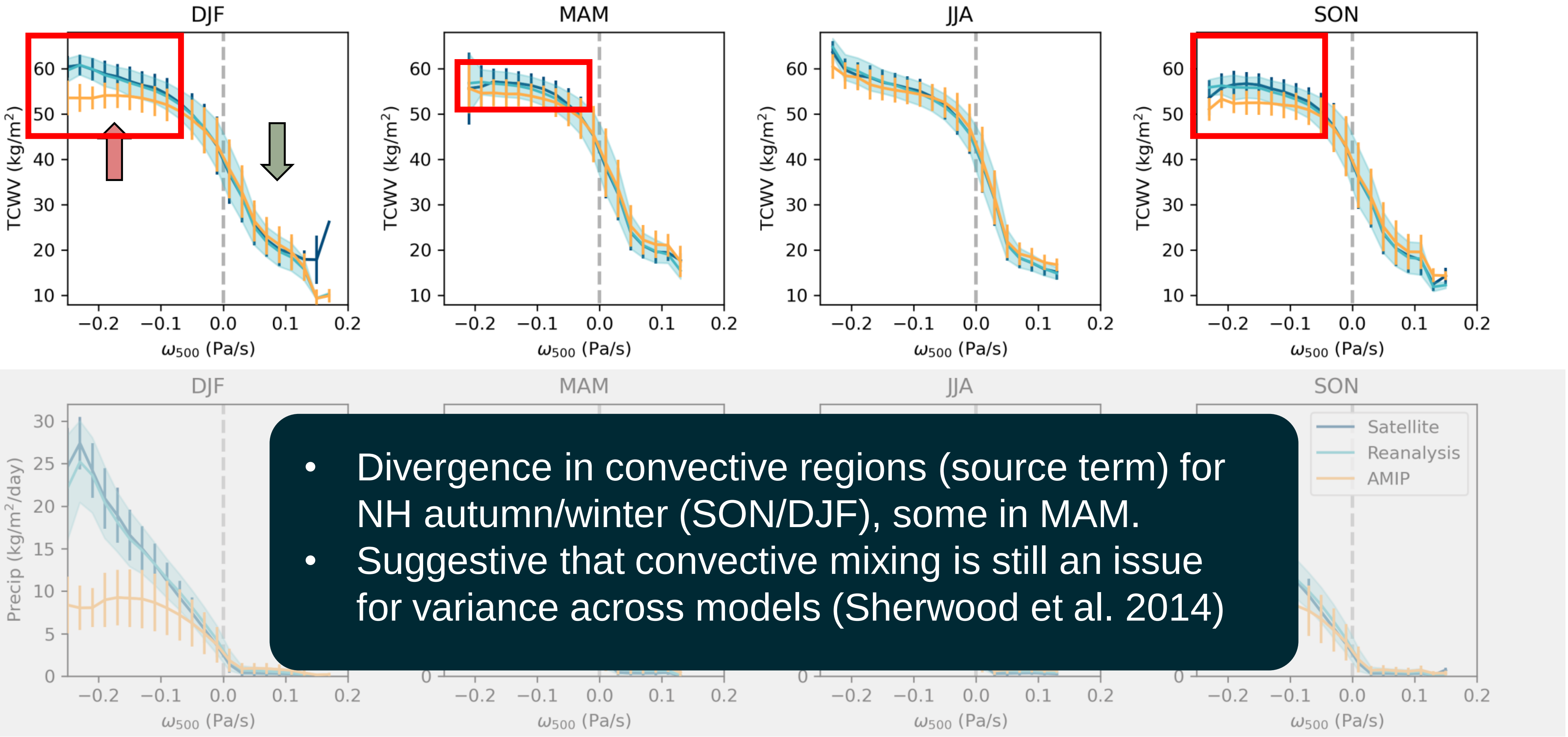

- Divergence in convective regions (source term) for NH autumn/winter (SON/DJF), some in MAM.
- Suggestive that convective mixing is still an issue for variance across models (Sherwood et al. 2014)

Convective Regions

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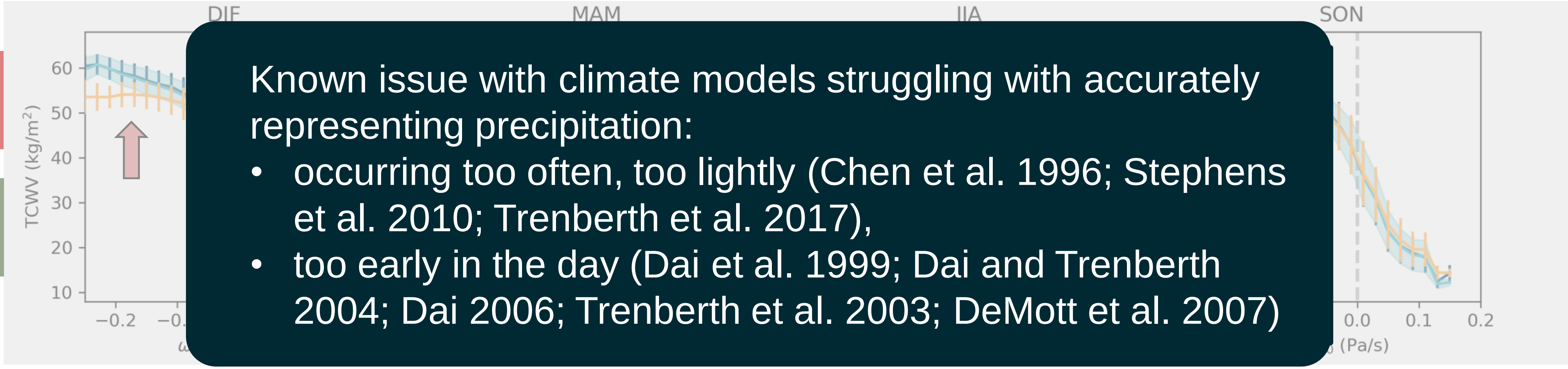
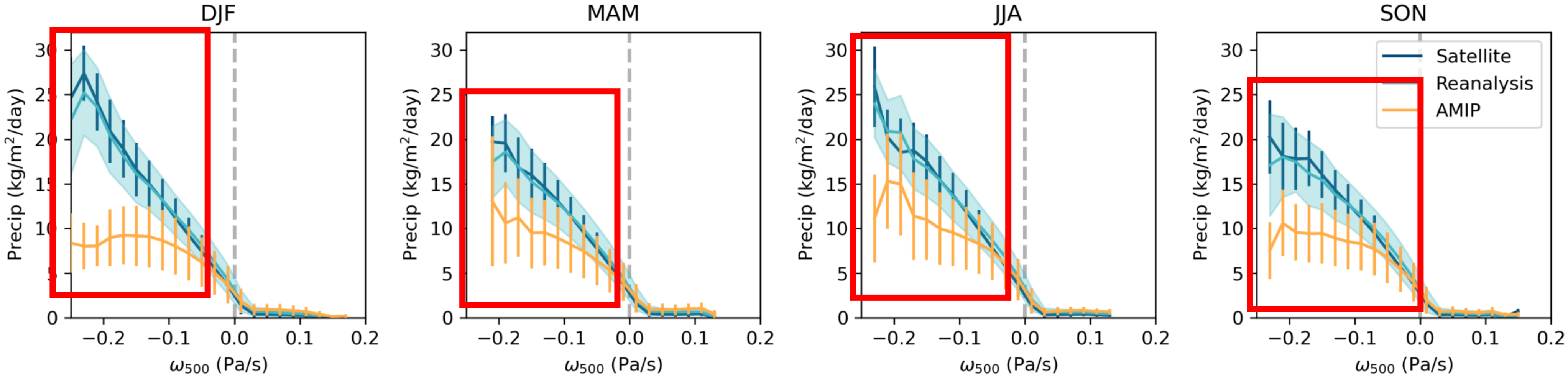


Known issue with climate models struggling with accurately representing precipitation:

- occurring too often, too lightly (Chen et al. 1996; Stephens et al. 2010; Trenberth et al. 2017),
- too early in the day (Dai et al. 1999; Dai and Trenberth 2004; Dai 2006; Trenberth et al. 2003; DeMott et al. 2007)



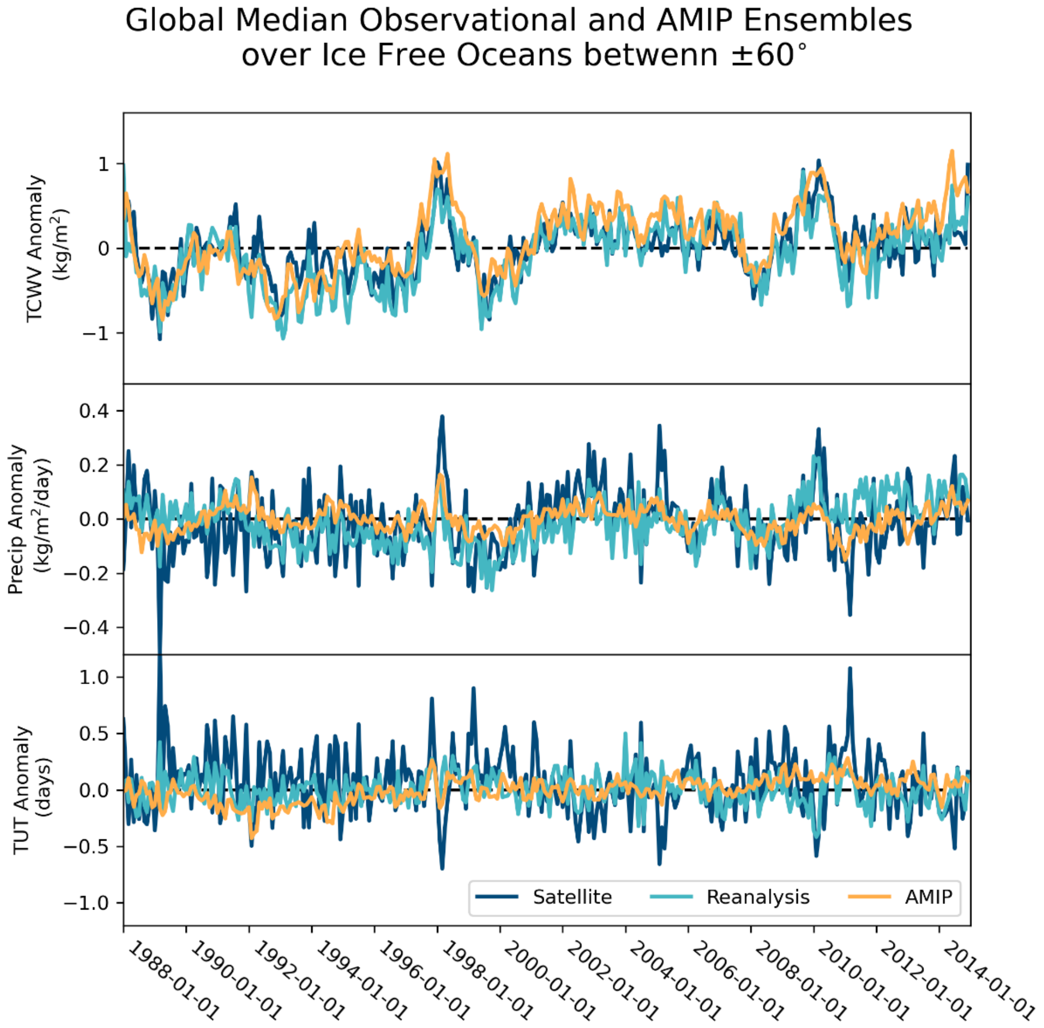
Ensemble Anomalies/Trends

- Trend analysis uses approach from G-VAP which uses a level shift regression model (Weatherhead et al. 1998, Mieruch et al. 2014):

$$Y_t = \mu + \ \omega X_t + \epsilon_t$$

- Fits 4 frequencies (asymmetric fitting of the annual cycle) and ENSO strength simultaneously.

	Trend in Ensemble Median		
	Satellite	Reanalyis	AMIP
TCWV (kg/m²/decade)	0.15±0.10	0.21±0.27	0.28±0.23
precip (kg/m2/decade)	0.37±0.31	1.01±0.31	-0.2±0.16
TUT (hours/decade)	-0.8±1.75	-0.4±1.02	2.15±1.6



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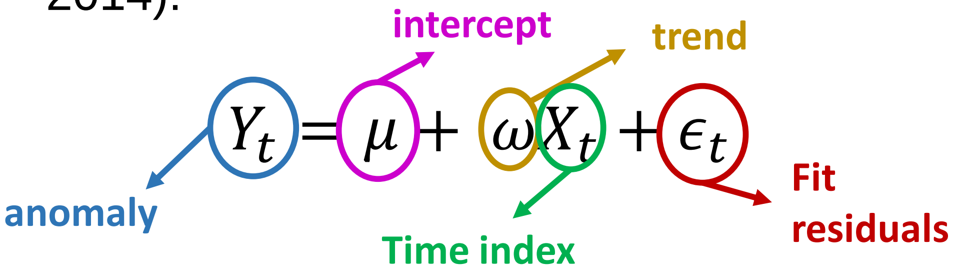

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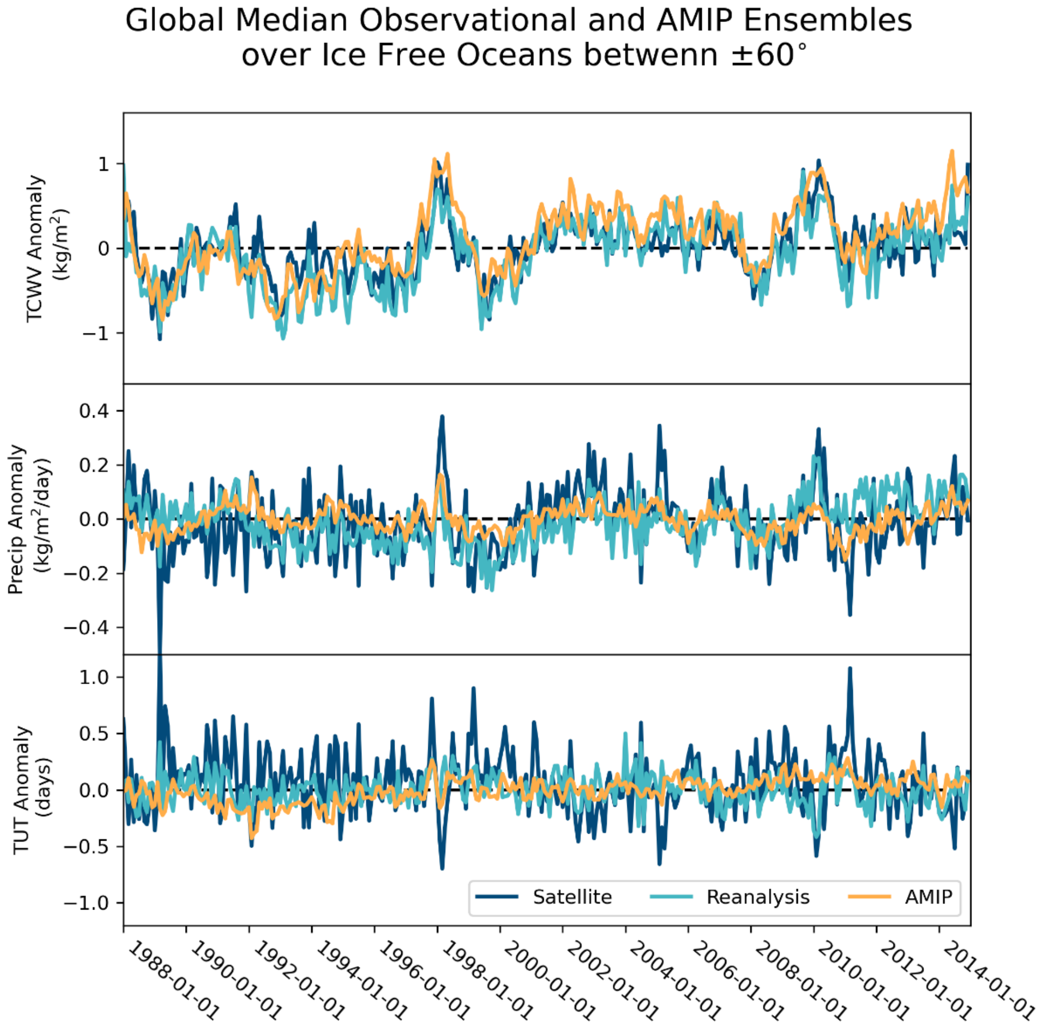

Global Median Observational and AMIP Ensembles over Ice Free Oceans betwenn ±60°

Ensemble Anomalies/Trends

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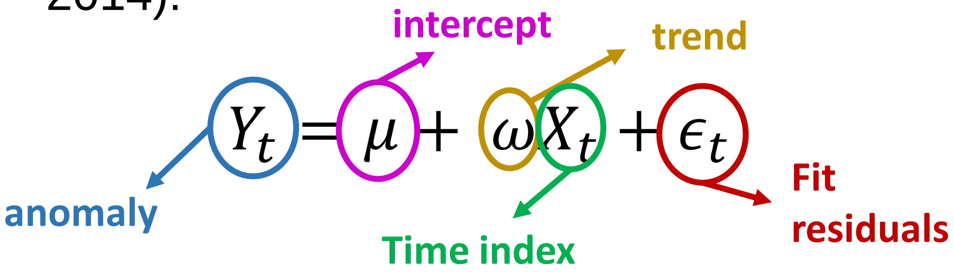

intercept

trend

$$Y_t = \mu + \omega X_t + \epsilon_t$$

anomaly

Time index

Fit residuals

- Fits 4 frequencies (asymmetric fitting of the annual cycle) and ENSO strength simultaneously.

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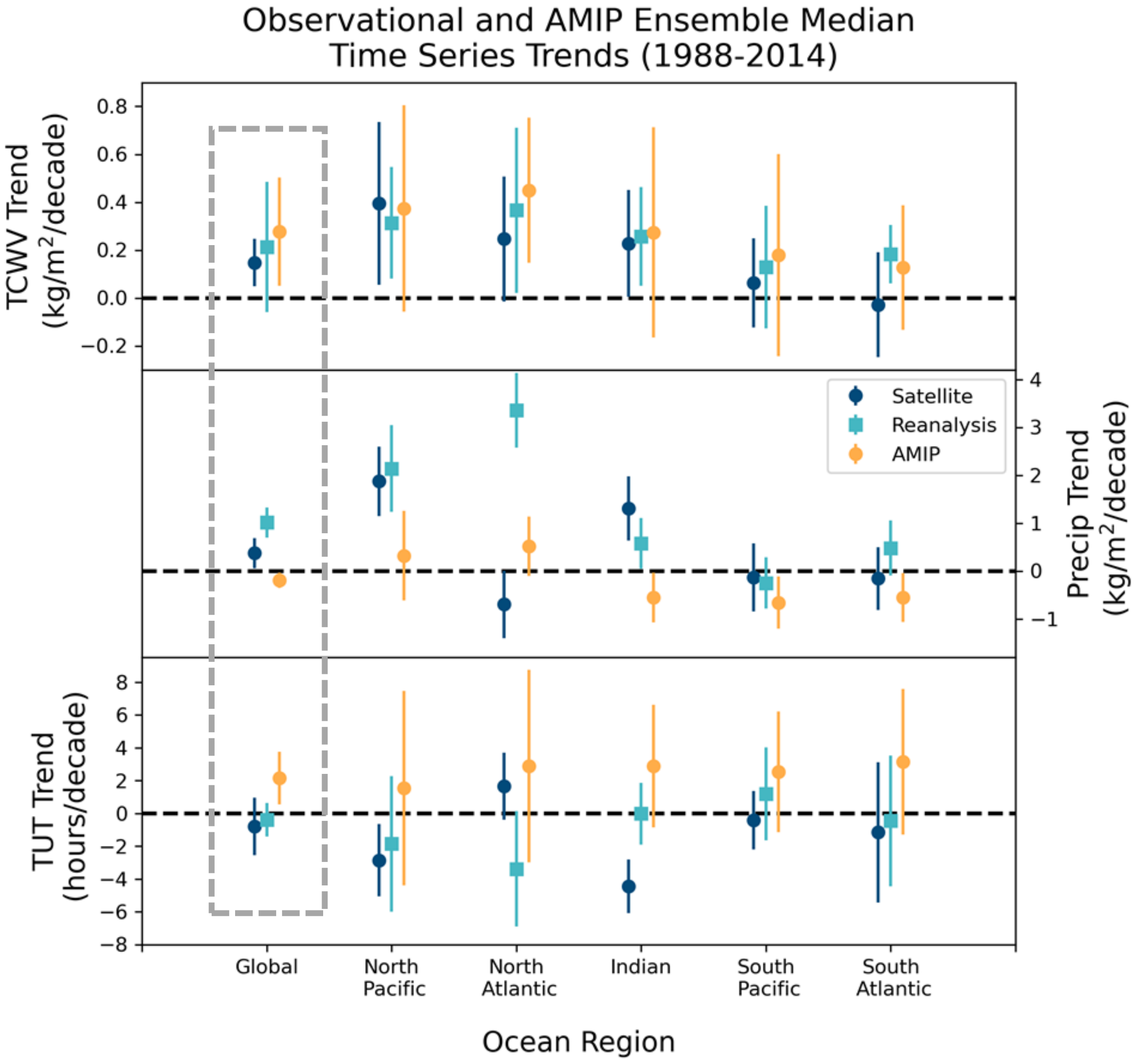
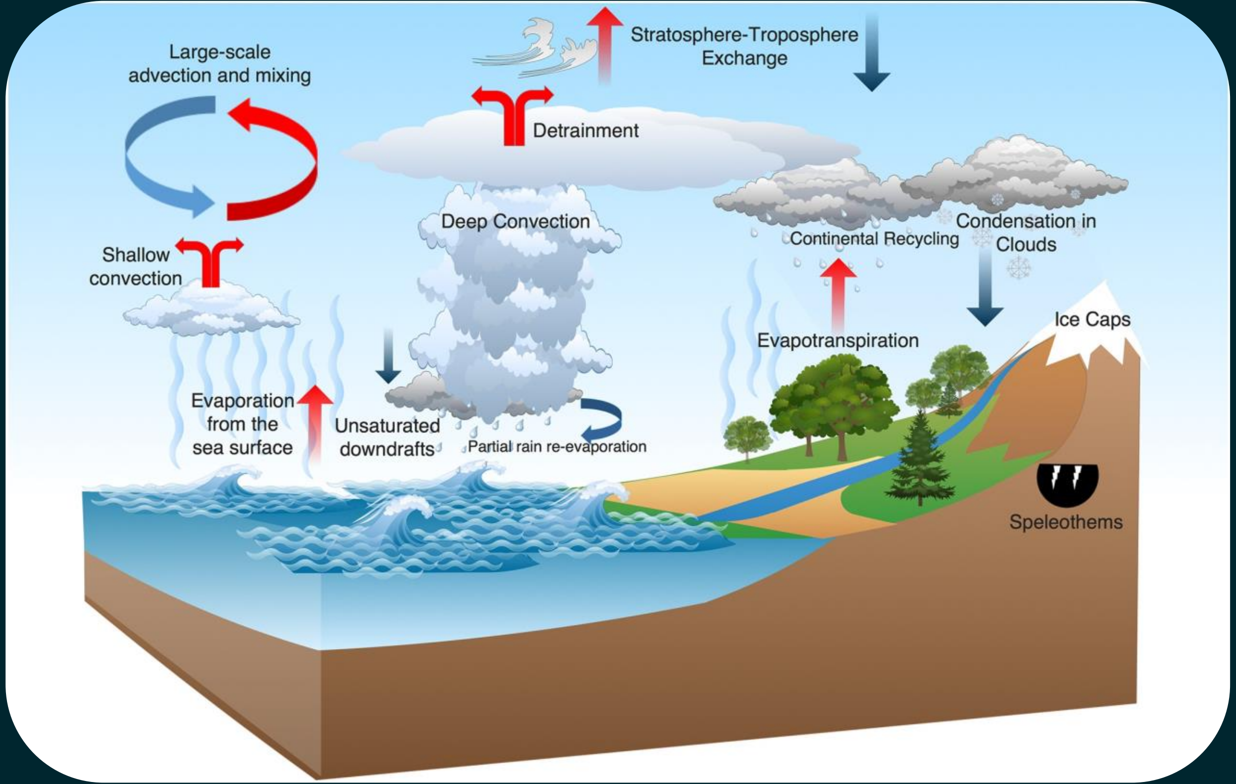

Observational and AMIP Ensemble Median Time Series Trends (1988-2014)

Future Challenge

- Biases in TCWV and precip relative to one-another can be significant when thought of in terms of transport (TUT). Small differences in TUT can be equivalent to significant forcing, e.g. 7.5hrs ~ CO2x2.
- Greater constraint of moisture pathways and the representation of TCWV and precip in models are intrinsinctly linked.
- Consistent climate quality data sets needed, especially when we look backwards.
- Development of new datasets – stable water vapour isotopologues can give information on air parcel history.

Atmospheric moisture pathways



Adopted from Galewski et al. (2016)

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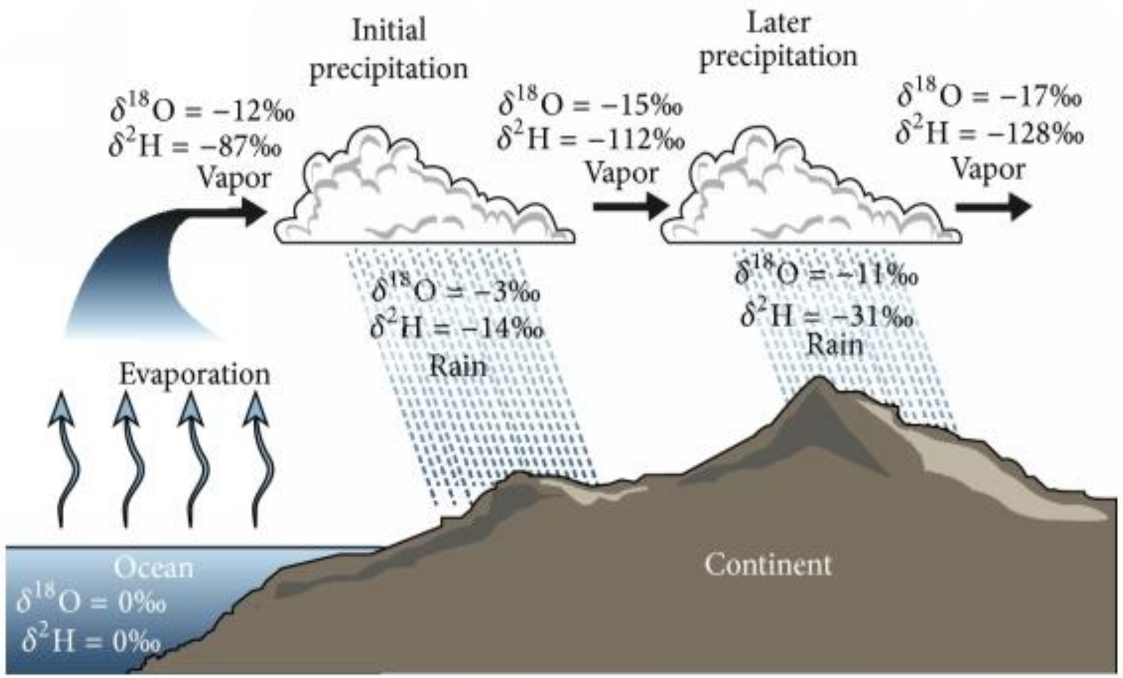
Water vapour pairs {H2O, δ} can provide information on evaporation, condensation, and precipitation.



(Figure taken from Xi, X., 2014.)

Summary

- Analysis of TUT in AMIP records between 1988-2014 show median differences of between 2.5-7.5 hrs relative to satellite observations (global ice free oceans).
- These differences occur from biases relating to moisture pathways/transport, with TUT especially sensitive to precipitation.
- These differences have greater complexity a regional scales.
- Known issues around convective precipitation still present in AMIP models, which is suggestive that convective mixing between lower & mid- troposphere could be driving some of this behaviour.
- AMIP ensemble median trends in TUT show a general slowing of the hydrological cycle, which is not observed in the satellite or reanalysis records
- Internationally there is a lot of work on producing and analysing climate quality long term satellite records (e.g. GEWEX, ESA CCI) – key activities
- New efforts around stable water vapour Isotopolgues from both satellite observations and models will help to constrain uncertainty in atmospheric pathways.

Thanks For listening

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@DrTimJTrent