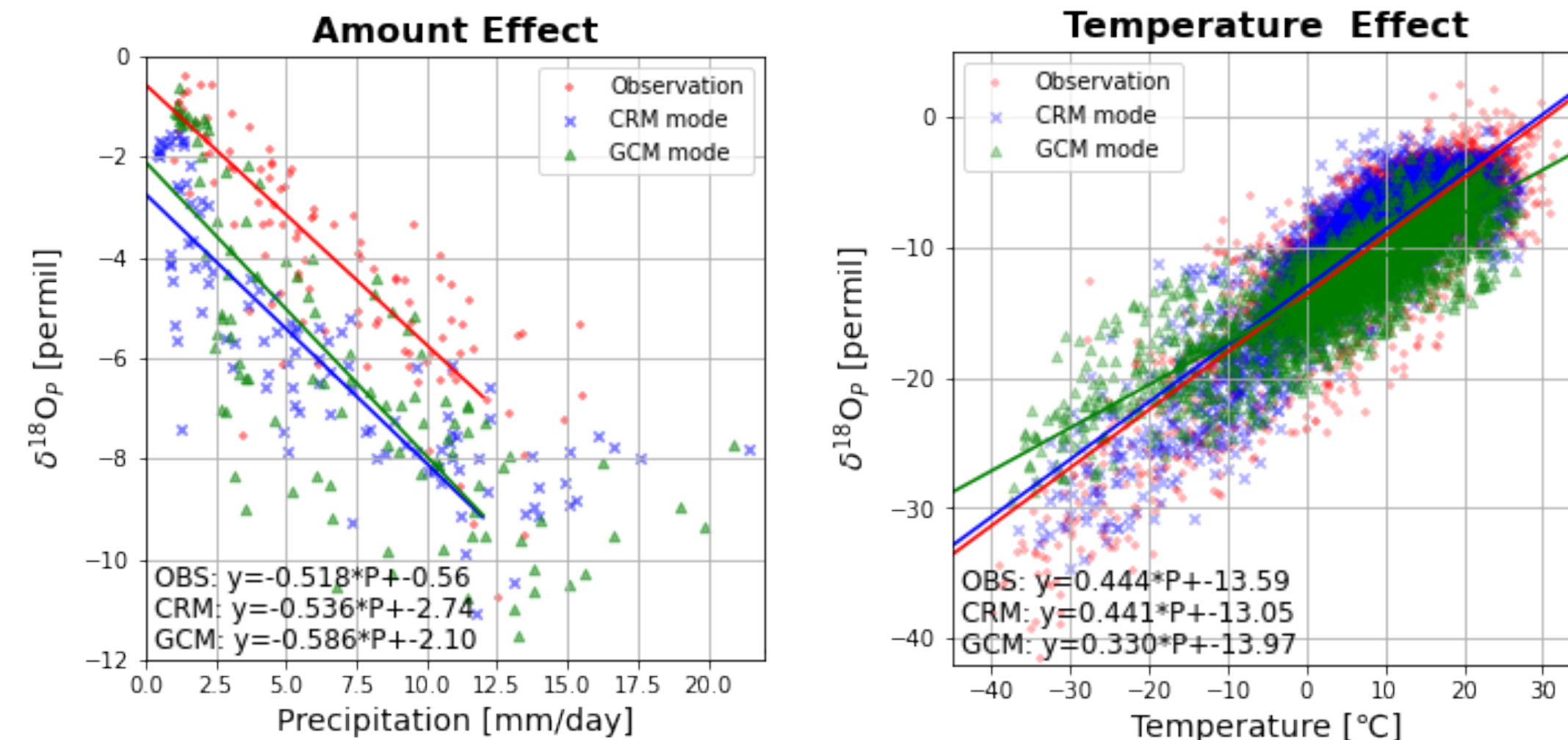
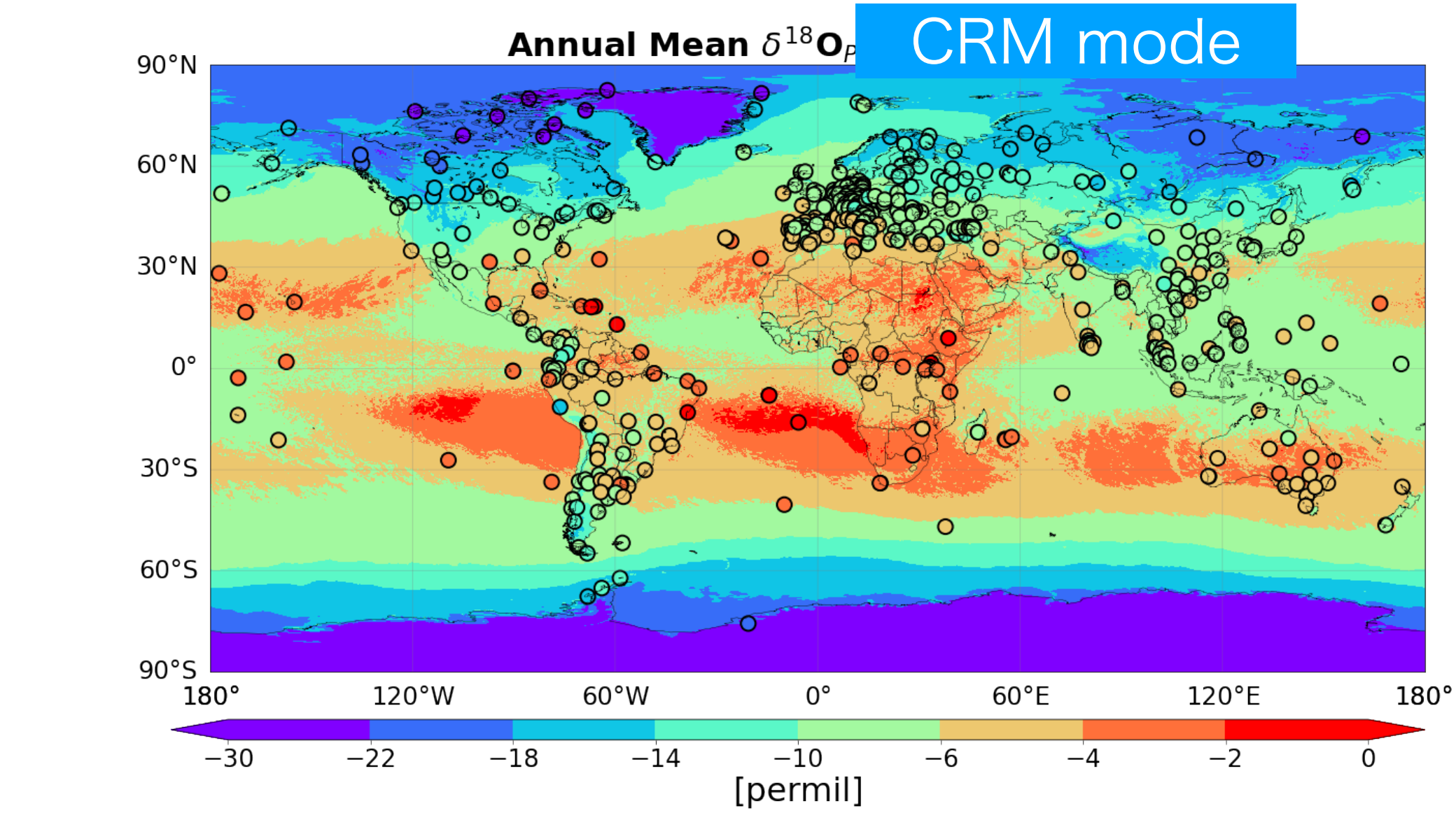


Stable isotopes in precipitation and water vapor simulated by isotope-incorporated NICAM

Masahiro Tanoue, Yuki Takano, Kei Yoshimura, and Hisashi Yashiro



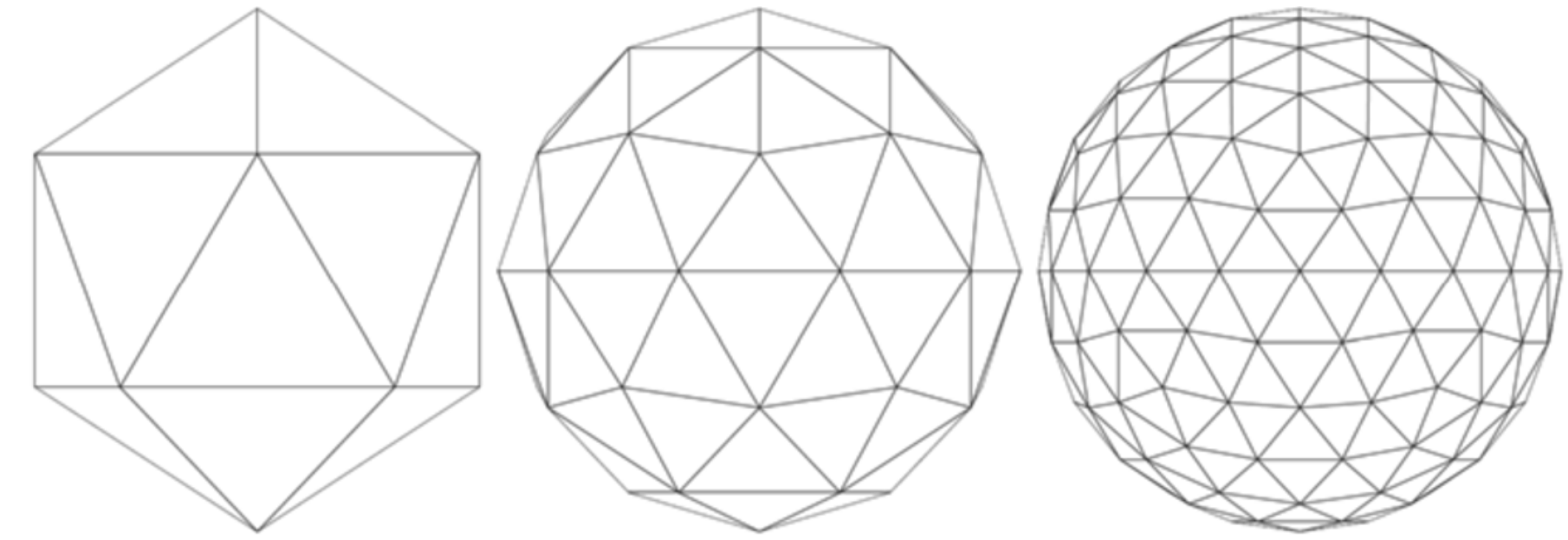
- Stable water isotopes (SWIs) were incorporated into NICAM (**isoNICAM**)
- Global CRM and GCM mode simulations were conducted.
- CRM mode simulation agreed well with observation :**
- Spatial patterns of annual mean and seasonal difference.
- Temperature and amount effects.

Introduction

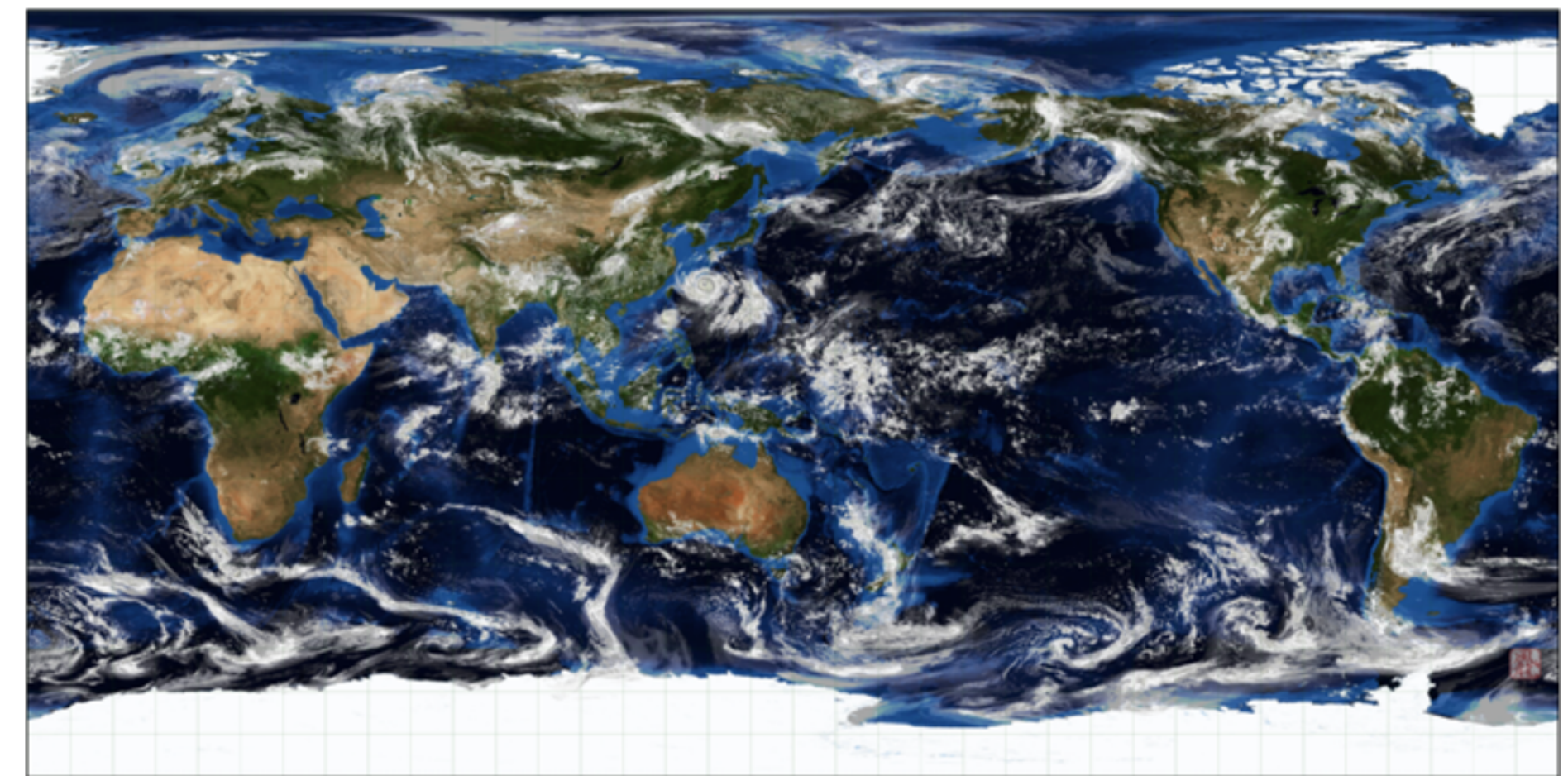
- The stable water isotopes (SWIs) ($\delta^{18}\text{O}$ and δD) are used as an indicator of the intensity of the atmospheric hydrological cycle due to their large variability in time and space.
- Although data about vapor isotope ratio with high frequency and high resolution are now available by satellite observations and spectroscopic analyses, **there is some room for discussion on the variability of isotope ratios in vapor and precipitation related to cloud microphysical processes.**
- Here, **we incorporated SWI tracer into the latest version of a global cloud system resolving model** (the Nonhydrostatic Icosahedral Atmospheric Model (NICAM)) (Sato et al., 2014), iso-NICAM, and investigated the contribution of cloud microphysical processes to the variability of isotope ratios in precipitation.

What is **NICAM**?

- NICAM is a Nonhydrostatic ICosahedral Atmospheric Model (NICAM), used as a Global Cloud Resolving Model (GCRM).
- NICAM applied Icosahedral grid system.
- **NICAM can simulate CRM (cloud resolving model) and GCM (general circulation model) modes.**
- A global simulation of less than 1.0 km mesh can be executed.

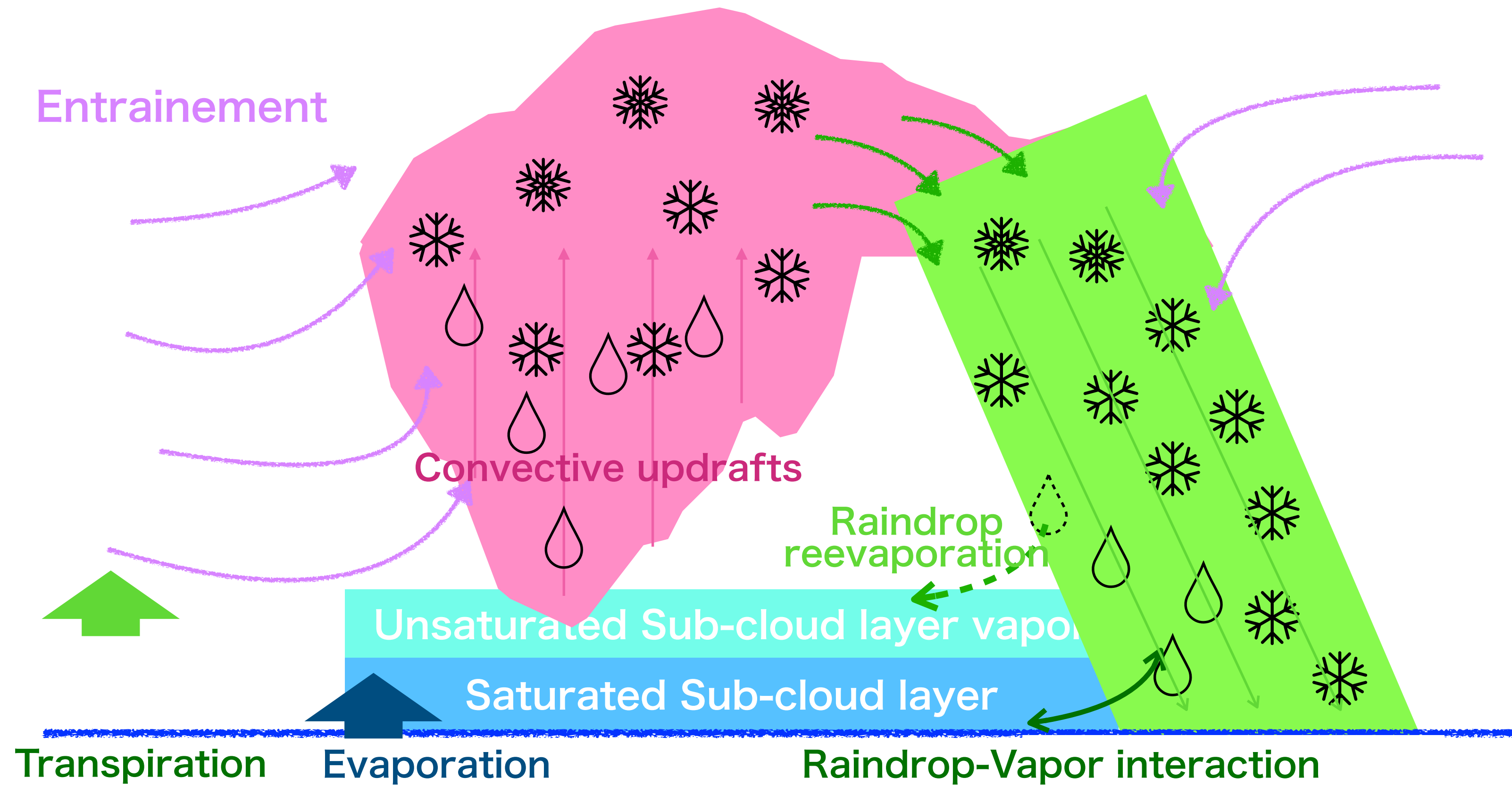


Icosahedral grids for grid division 0, 1, 2.
(Sato et al., 2014)



Cloud distribution simulated by the NICAM 870 m grid spacing experiment (Miyamoto et al. 2013).

SWI incorporated into NICAM



- SWIs were incorporated into model as predictive variables, indicating that SWIs parallel flow same as normal water (H_2^{16}O).
- During phase change, variability of SWIs differ with that of normal water (Fractionation).

Simulation design

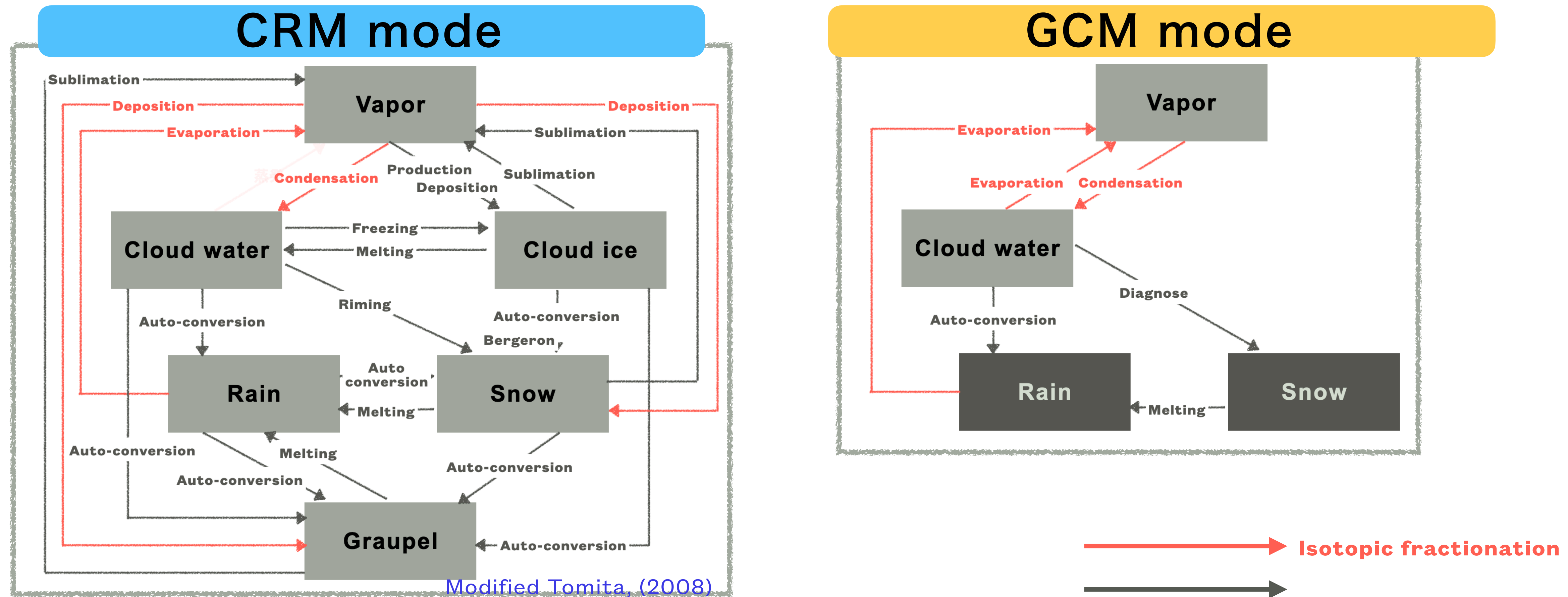
Exp. Name	Resolution	Cloud process	Convective process
GCM mode	GL07 (56 km), 78 layer	Large-scale condensation	CHIKIRA (Chikira & Sugiyama, 2010)
CRM mode	GL09 (14 km), 78 layer	NSW6 Roh (Roh and Satoh, 2017)	

- **Model** : NICAM (version 19.1) (Satoh et al., 2014)
- **Initial condition** : ERA5 (00Z 1 Jan. 2000)
- **Boundary condition** :
 - SST, ice mass, Ozone (Kodama et al., 2015) 。
 - Offline aerosol
- **Simulation period** : From 1 January 1979 to 31 December 1985

Isotope parameterization

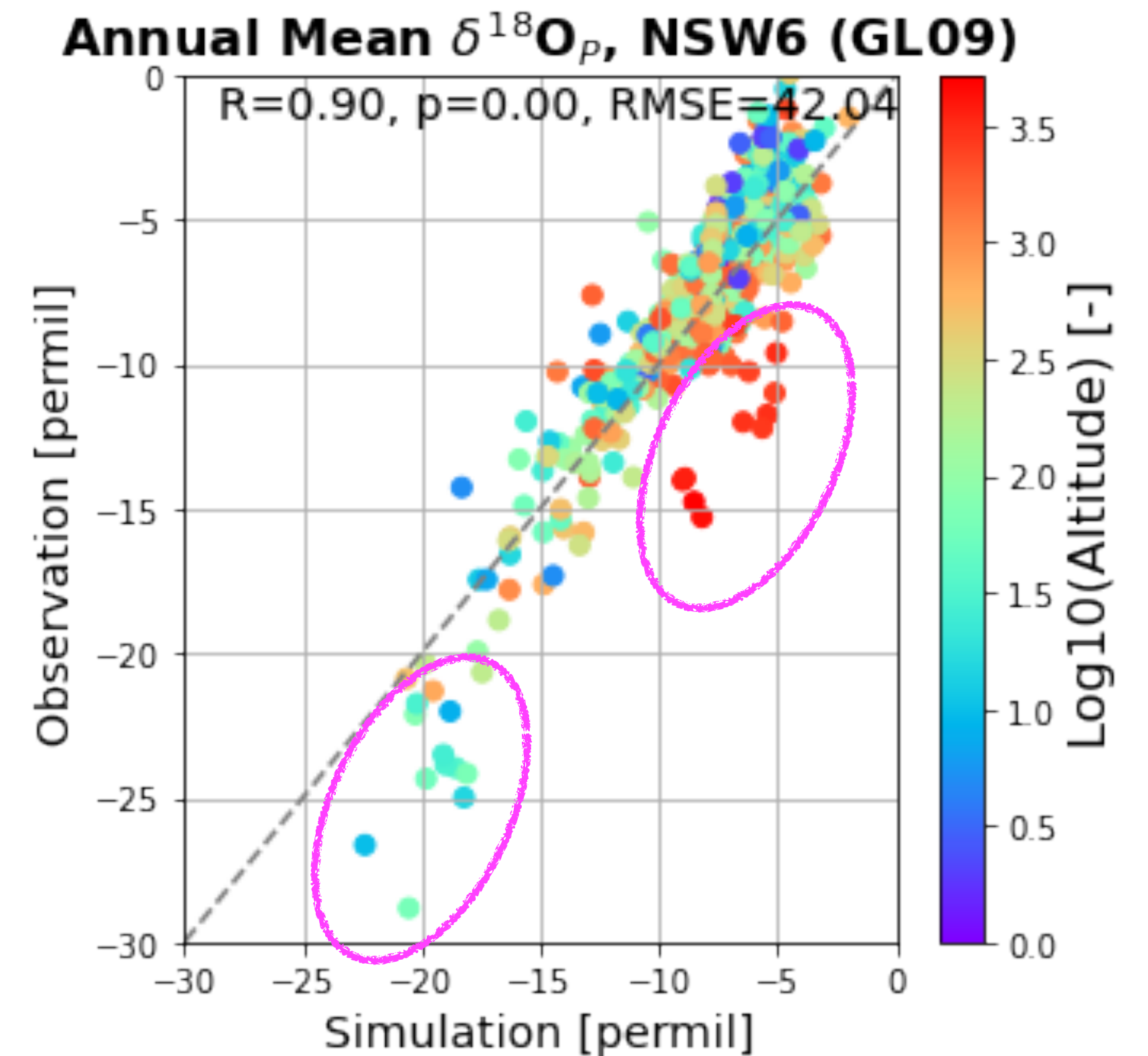
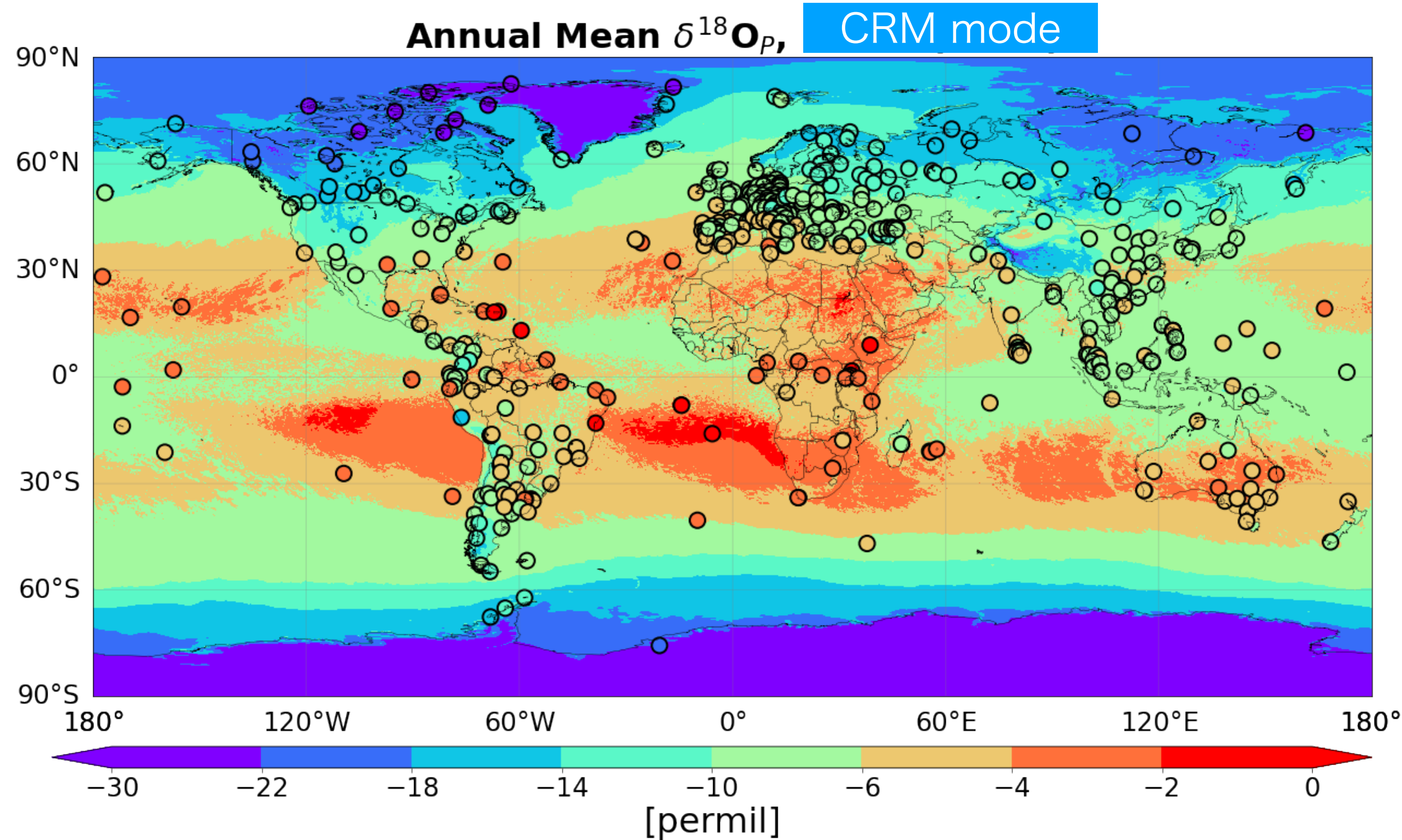
Equilibrium fractionation	Majoube (1971a; 1971b)
Molecular diffusivity	Merlivat (1978)
Ice crystal formation	Jouzel and Merlivat (1984); Blossy et al. (2010)
Open water evaporation	Merlivat and Jouzel (1979)
Raindrop evaporation	Blossy et al. (2010)
Surface isotopic reservoir	No fractionation
Seawater	Constant ($\delta^{18}\text{O} = \delta\text{D} = 0\text{‰}$)

Difference of cloud process



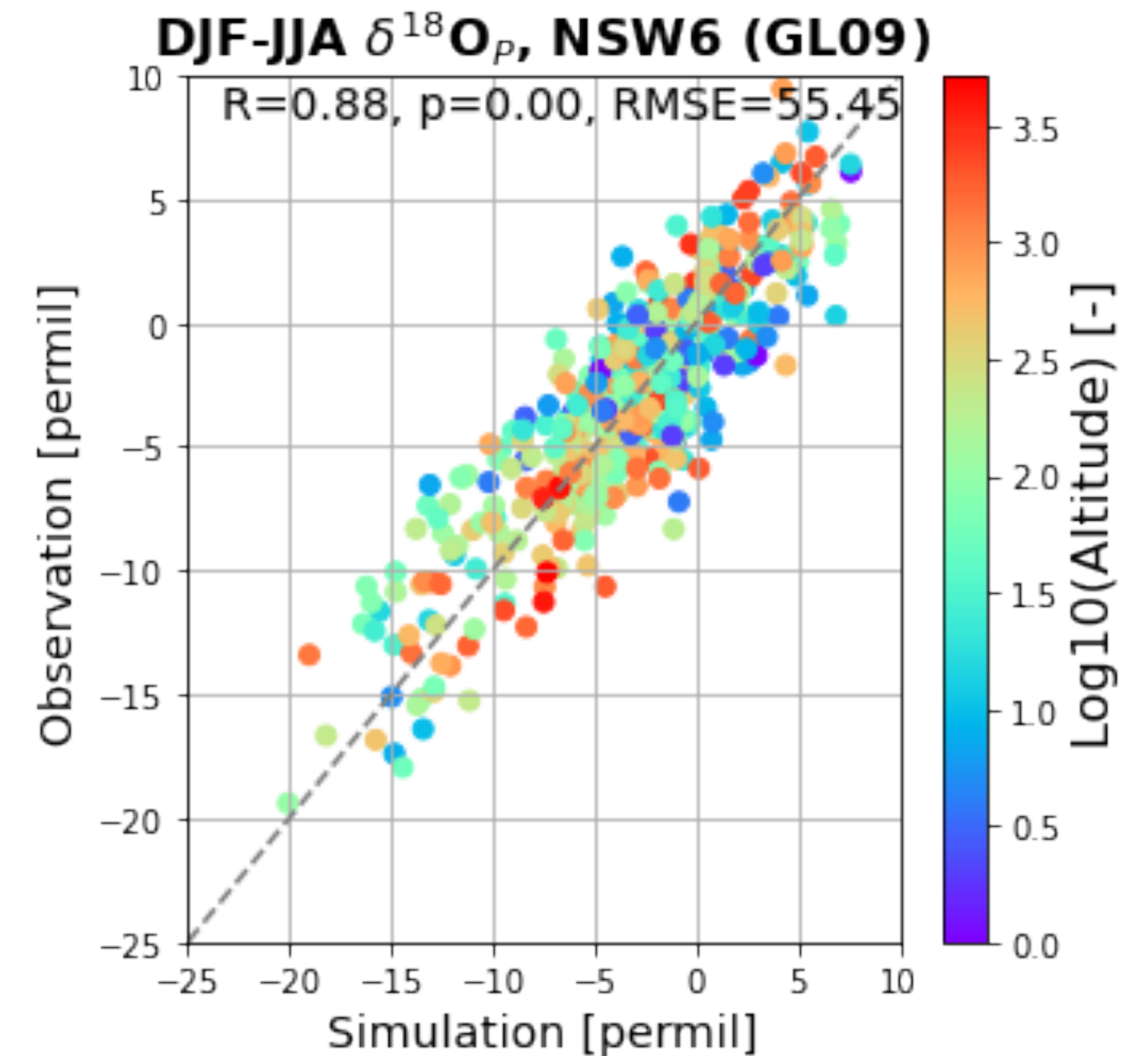
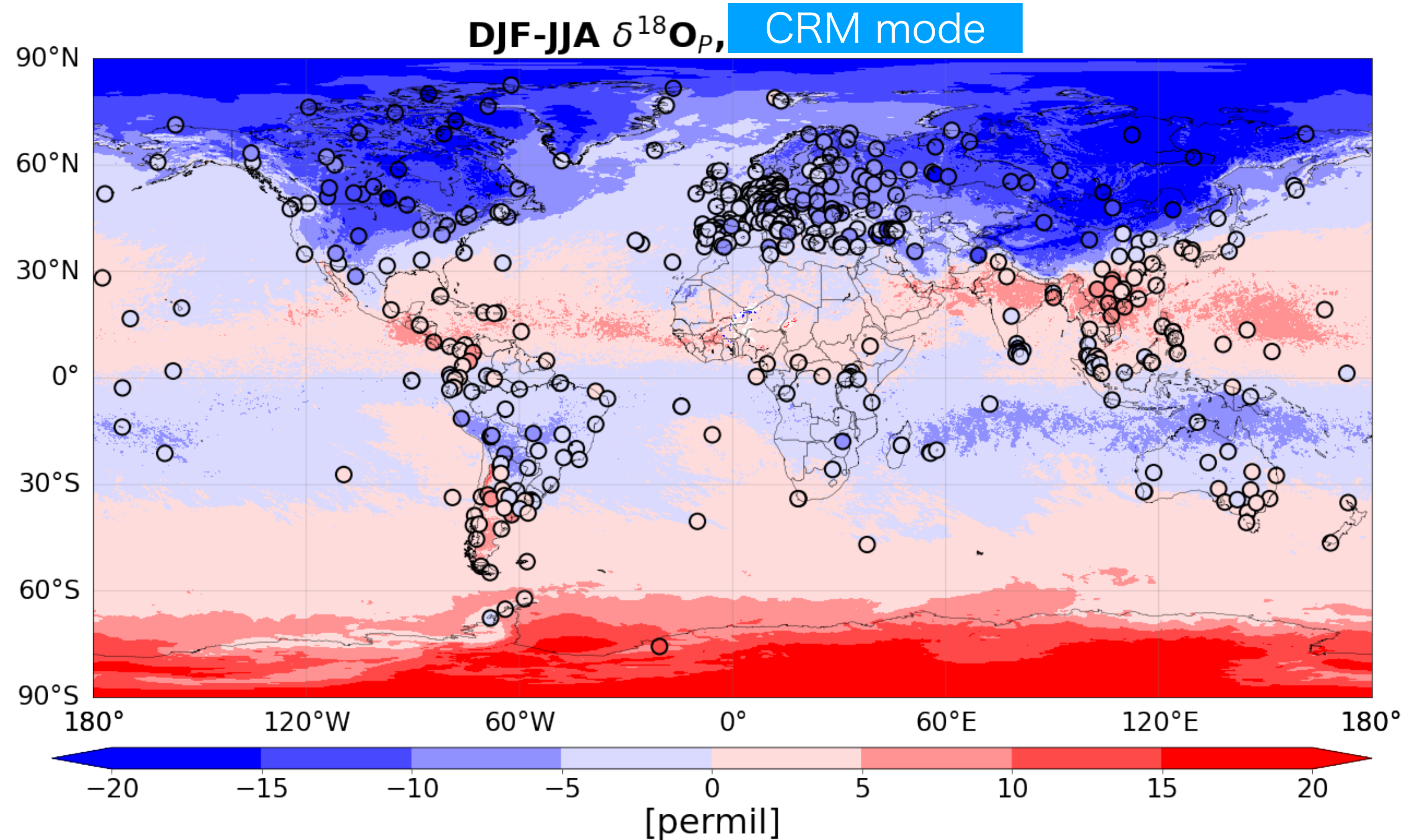
- CRM predicts 6 type of hydrometers, where GCM predicts 2 type.
- CRM explicitly calculate raindrop evaporation and solid sublimations.

Annual mean $\delta^{18}\text{O}$



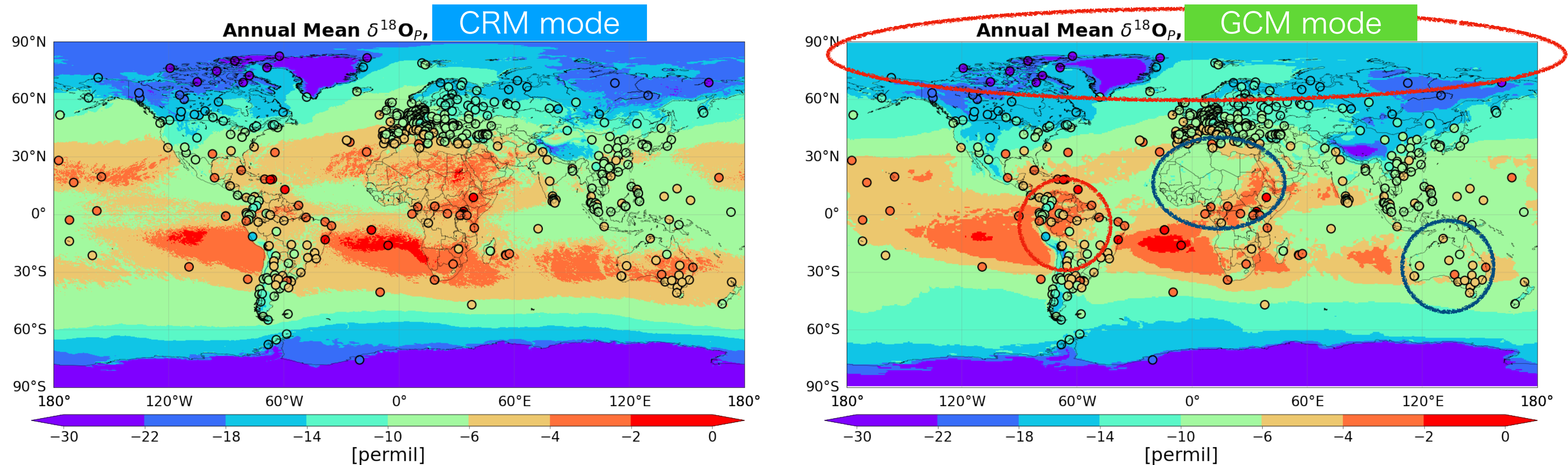
- The model captured spatial pattern of SWIs, except sites with high latitude or high altitude sites.

Seasonal difference of $\delta^{18}\text{O}$



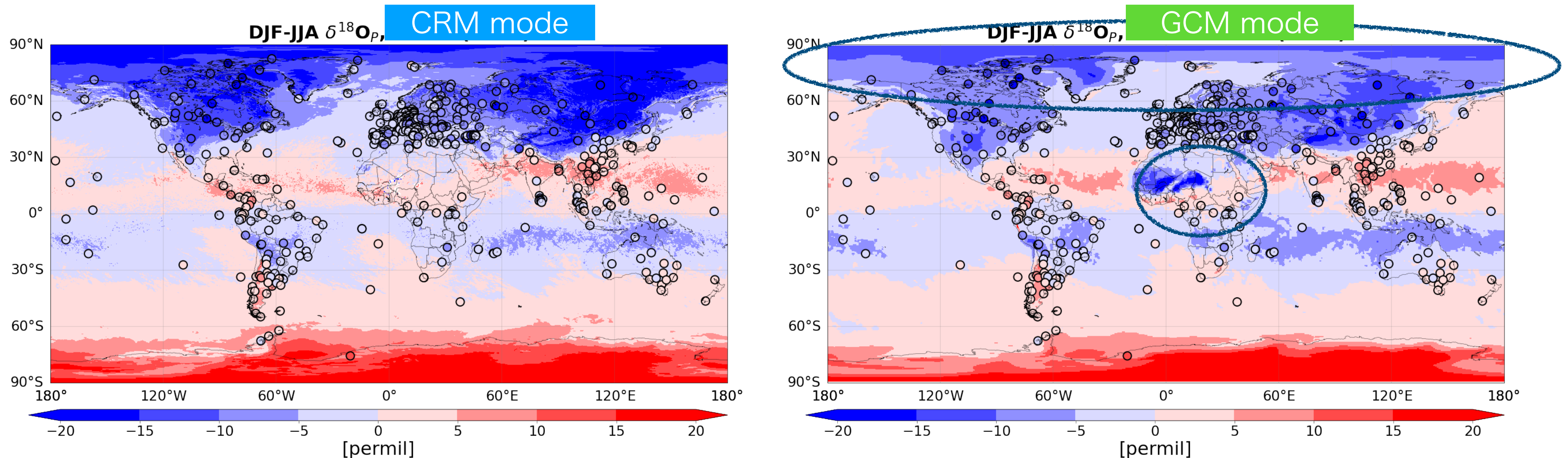
- The model well reproduce seasonal difference of $\delta^{18}\text{O}$.

Comparison between CRM and GCM



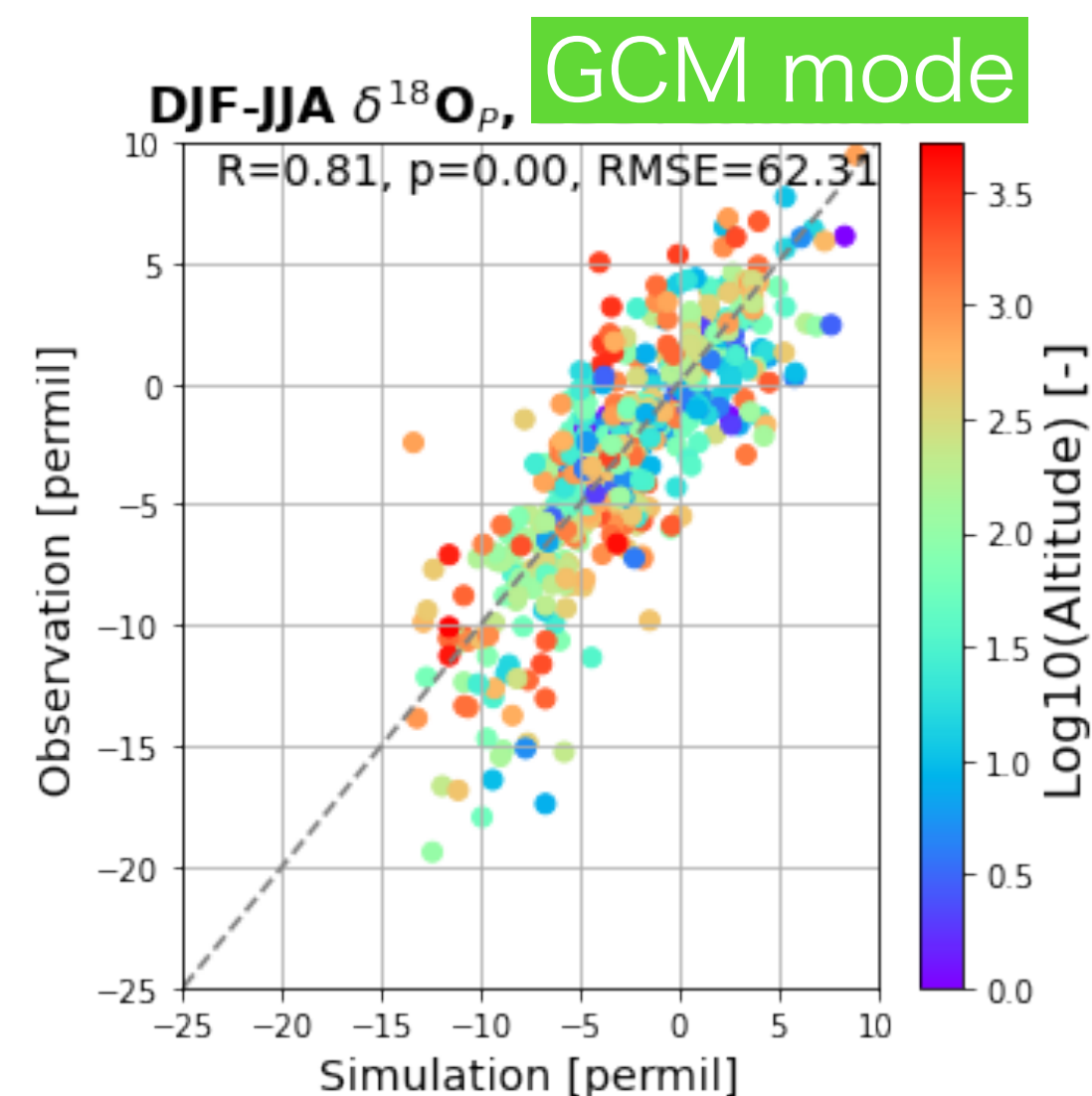
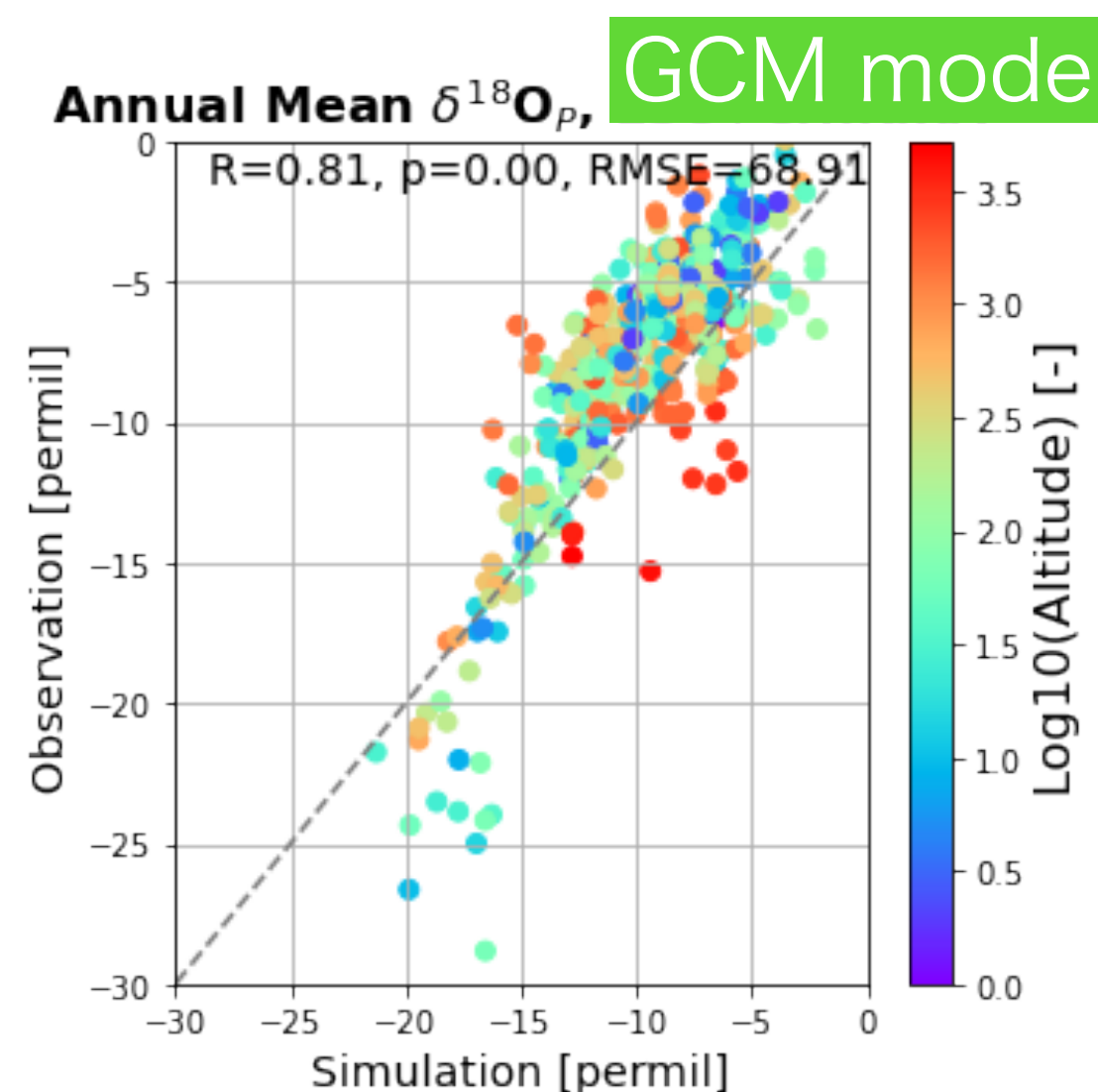
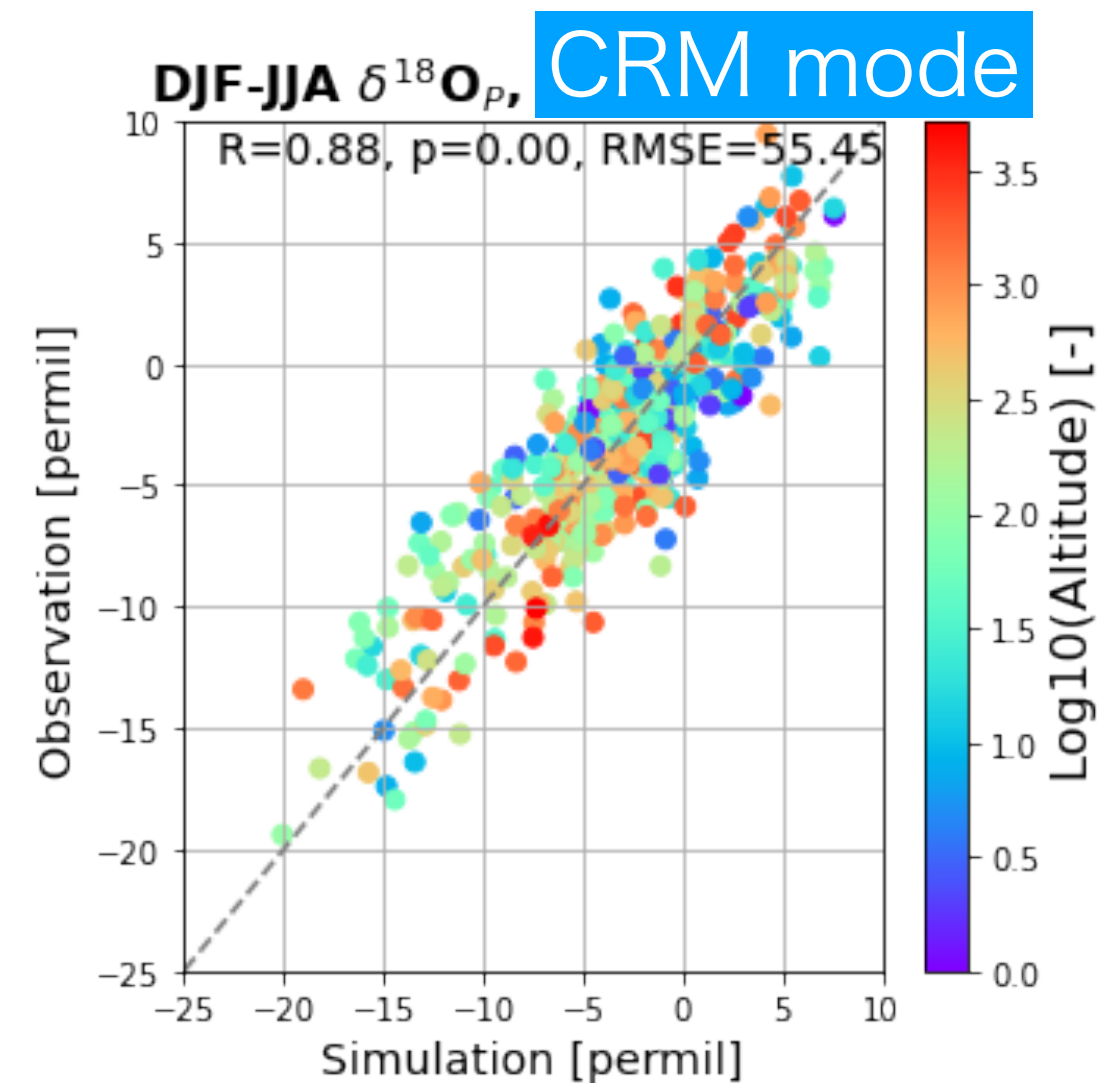
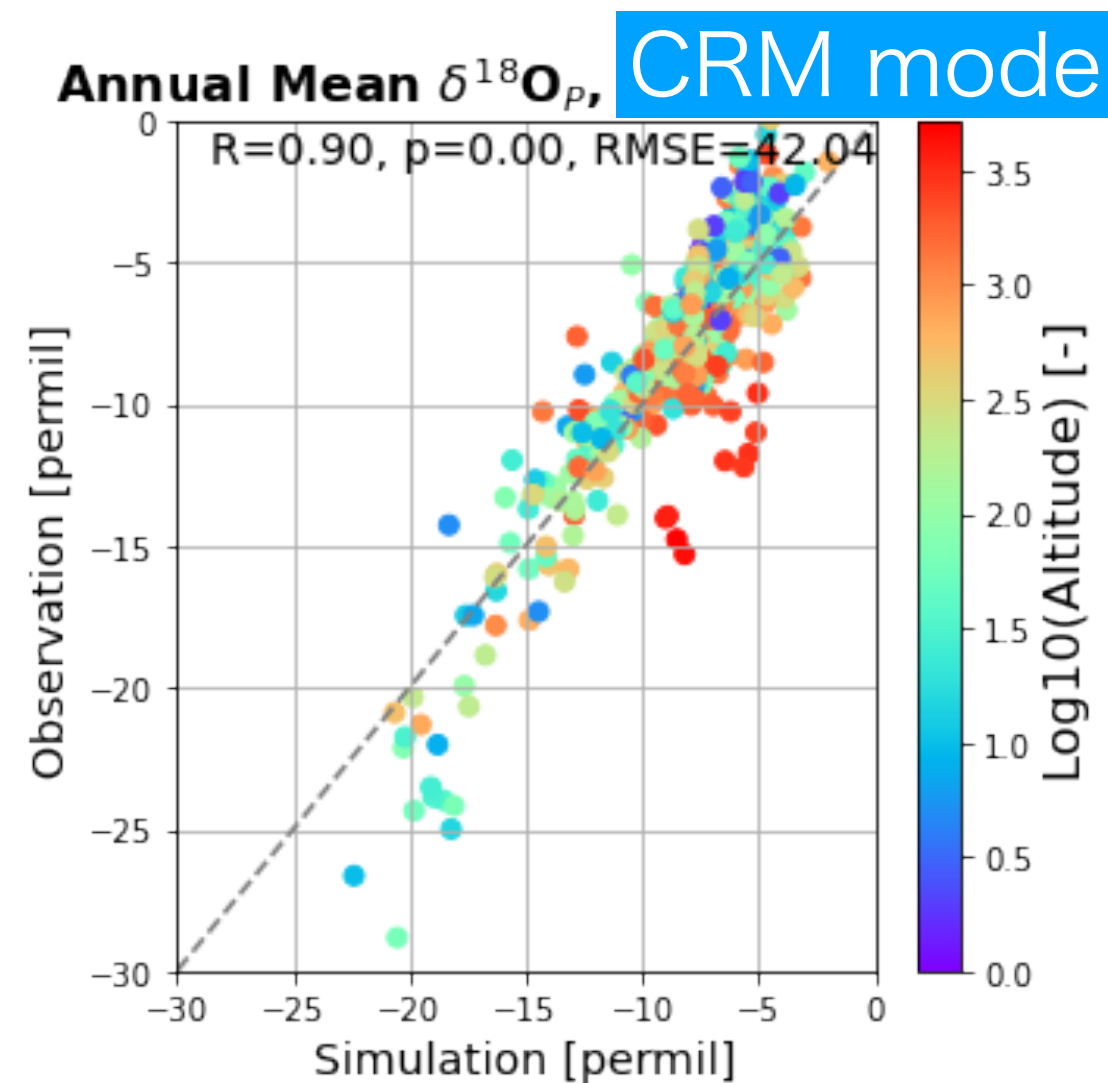
- The GCM mode also captured spatial pattern.
- However, there were some differences in Africa, Australia, South America and Arctic.

Comparison between CRM and GCM



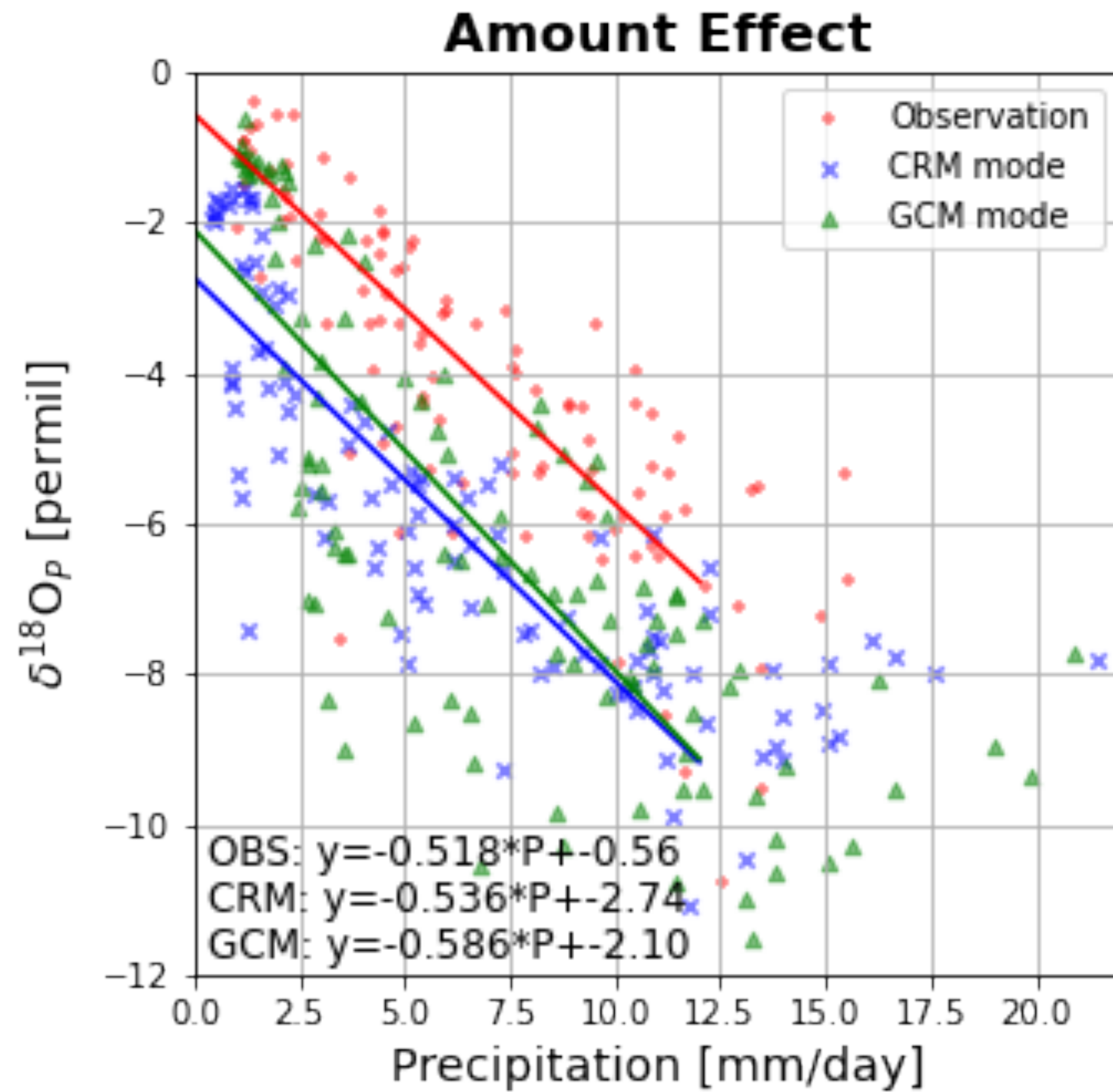
- Seasonal difference in CRM was larger than that in GCM, especially high latitude regions.
- Seasonal pattern in northern Africa was different between GCM and CRM.

Comparison between CRM and GCM



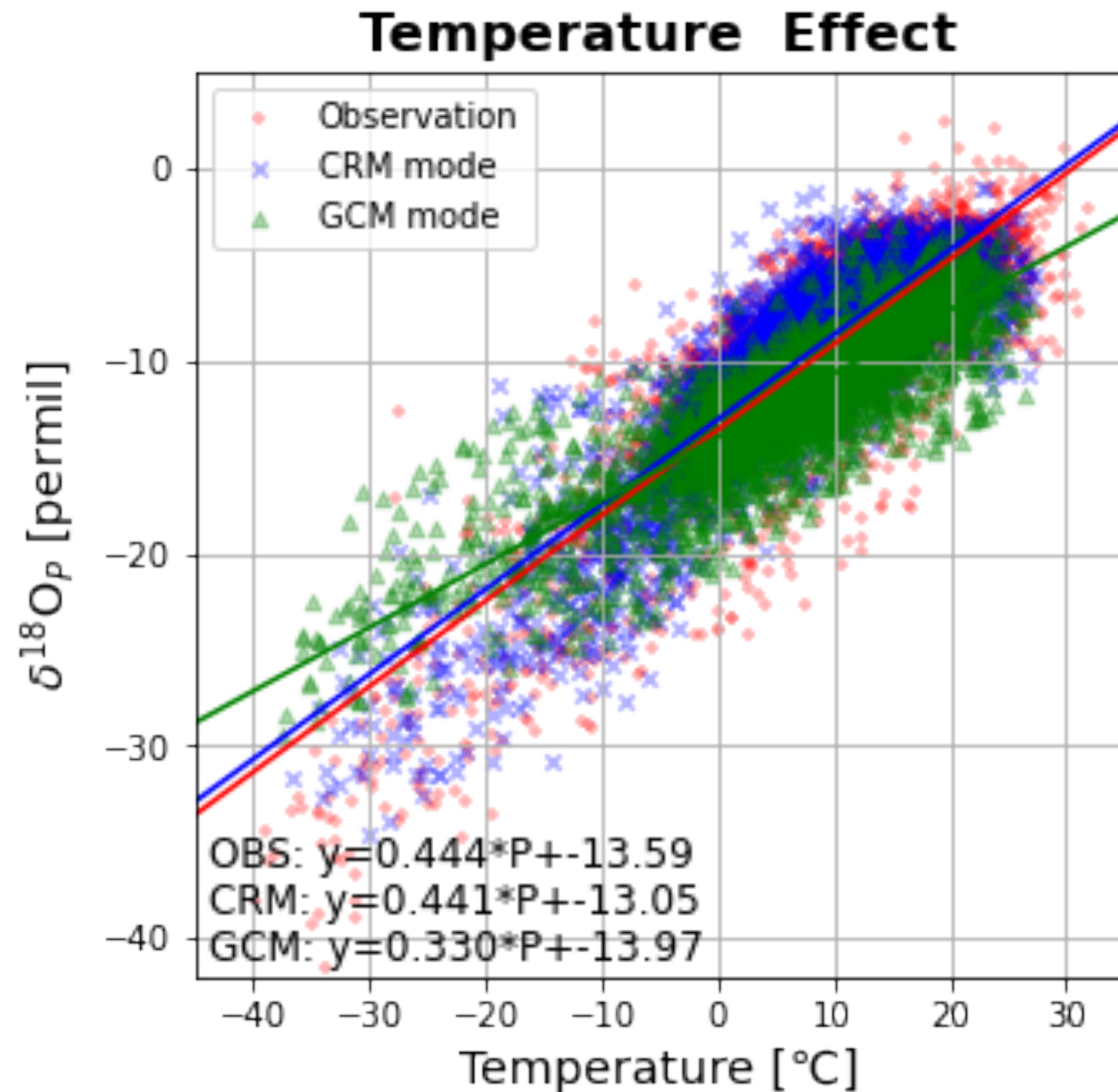
- Reproductivity of $\delta^{18}\text{O}$ in CRM mode was better than that in GCM mode.
- In high latitude regions, $\delta^{18}\text{O}$ values overestimated for the both modes.

Amount effect



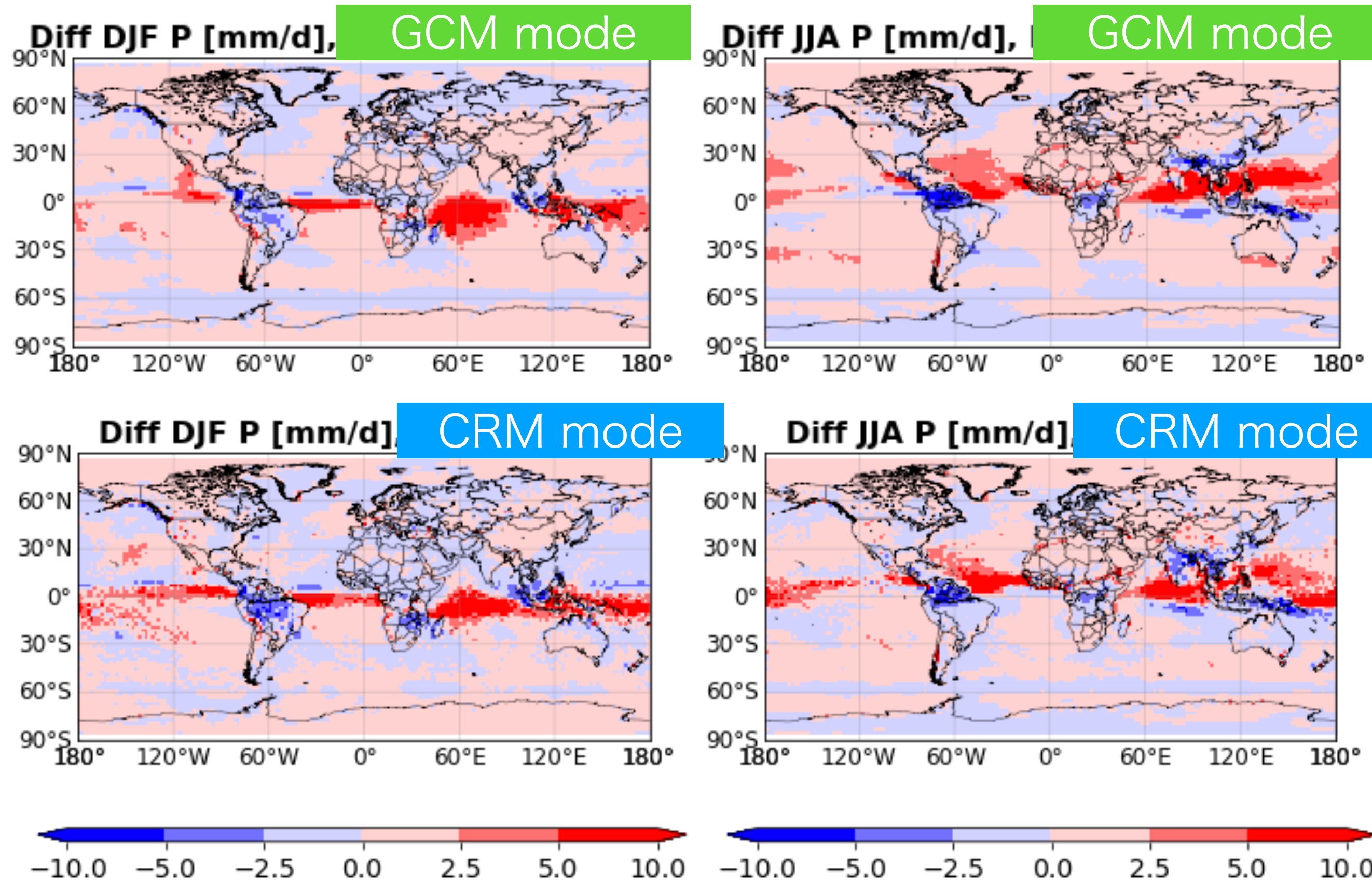
- Select 9 tropical ocean sites.
(same as Bony et al., 2008)
- Captured amount effect.
(decreasing ratio with increasing P)
 - **OBS** : **-0.518‰ / (mm d⁻¹)**
 - **CRM** : **-0.536‰ / (mm d⁻¹)**
 - **GCM** : **-0.586‰ / (mm d⁻¹)**
- Amount effect by **CRM** is closer to **OBS** than that by **GCM**.
- About 2‰ biases were found on the both simulations. The biases may be due to isotopic surface evaporation

Temperature effect



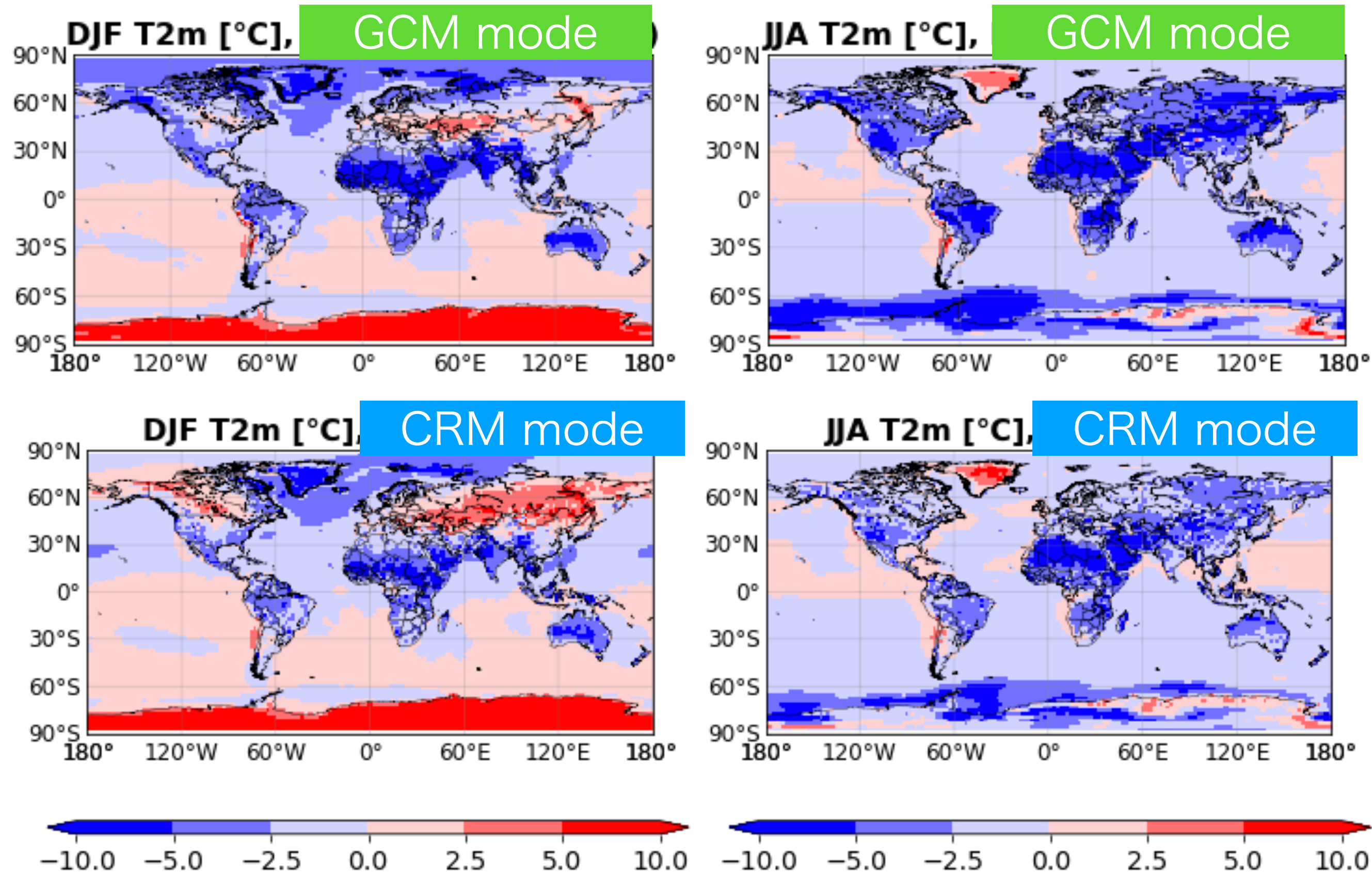
- Select mid- and high-latitude sites.
 - **Obs. : -0.444‰ / (mm d⁻¹)**
 - **CRM : -0.441‰ / (mm d⁻¹)**
 - **GCM : -0.586‰ / (mm d⁻¹)**
- CRM mode simulation well captured temperature effect.

Comparison of P with JRA55



- Precipitation overestimated in tropical regions, but underestimated over continents.
-> Stronger amount effect compared with OBS.

Comparison of T2m with JRA55



- T2m overestimated in Antarctic and Greenland in summer season.
->Overestimation of $\delta^{18}\text{O}$ in high latitude regions.
- The model underestimated in Africa, South Asia, Australia.

Summary

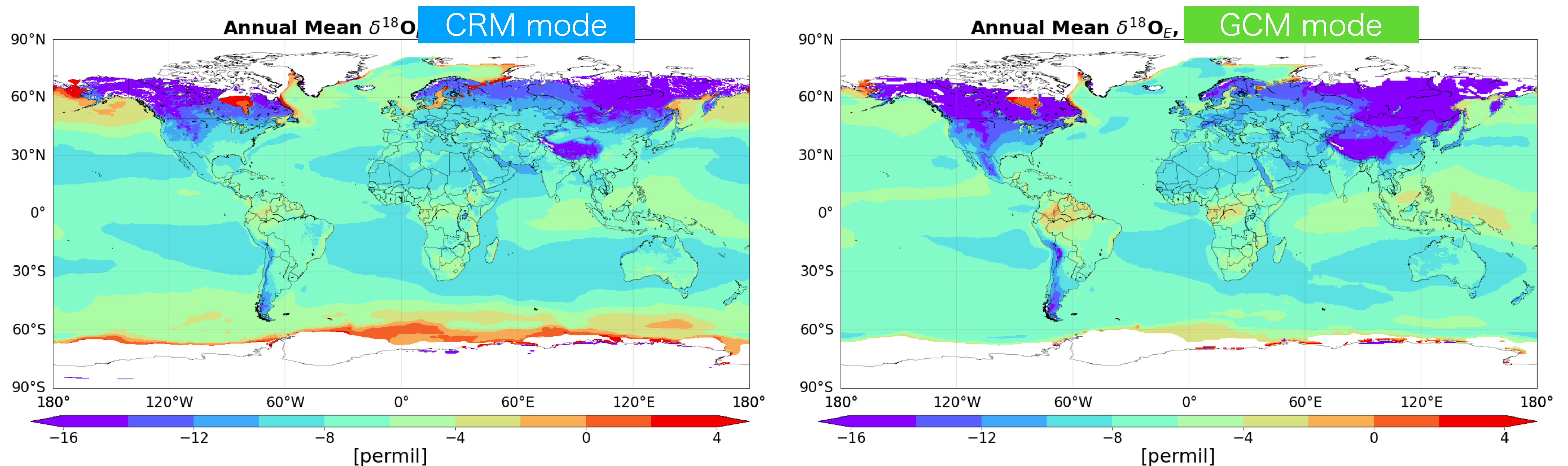
- CRM captured spatial pattern of annual mean and seasonal difference of precipitation isotopes. However, CRM overestimated values in high latitude and high altitude (>1000m) regions. Warm bias affected the overestimation in the high latitude region.
- In addition, temperature and amount effects in the CRM agreed well with those in observations. However, there are some biases in tropical precipitation, this may be due to isotopic surface evaporation.
- These results indicated that CRM is important for understanding variability and mechanism of precipitation isotopes across the world.
- Future Study:
 - Validation of simulated precipitation d-excess.
 - Validation of vapor isotope compared with satellite observation.

Reference

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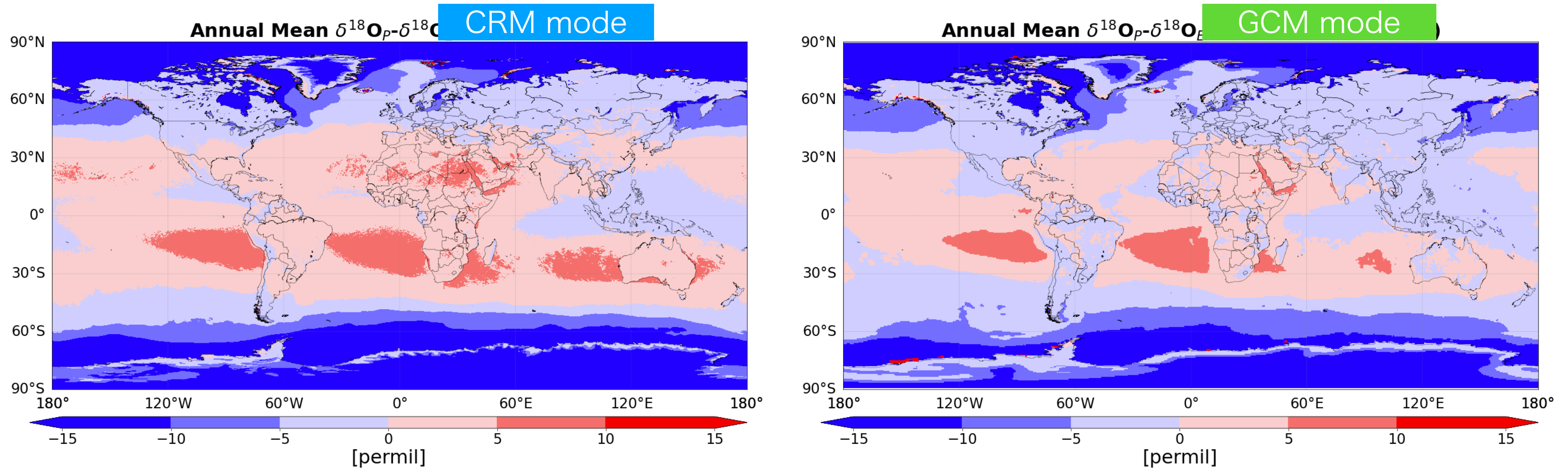
Supplement

Annual mean $\delta^{18}\text{O}$ in Evaporation



- Display grids with evaporation > 0.5 [mm/day]
- Annual patterns were similar between CRM and GCM modes. However, $\delta^{18}\text{O}_E$ in CRM mode was higher than that in GCM mode, especially in cold ocean region.

Annual mean $\delta^{18}\text{O}_\text{p} - \delta^{18}\text{O}_\text{e}$



- Spatial pattern of $\delta^{18}\text{O}_\text{p} - \delta^{18}\text{O}_\text{e}$ was similar.
- The difference was slightly higher in cold ocean region as well as dry regions (e.g., Sahel).