Deciphering Chinese speleothems with an isotope-enabled climate model

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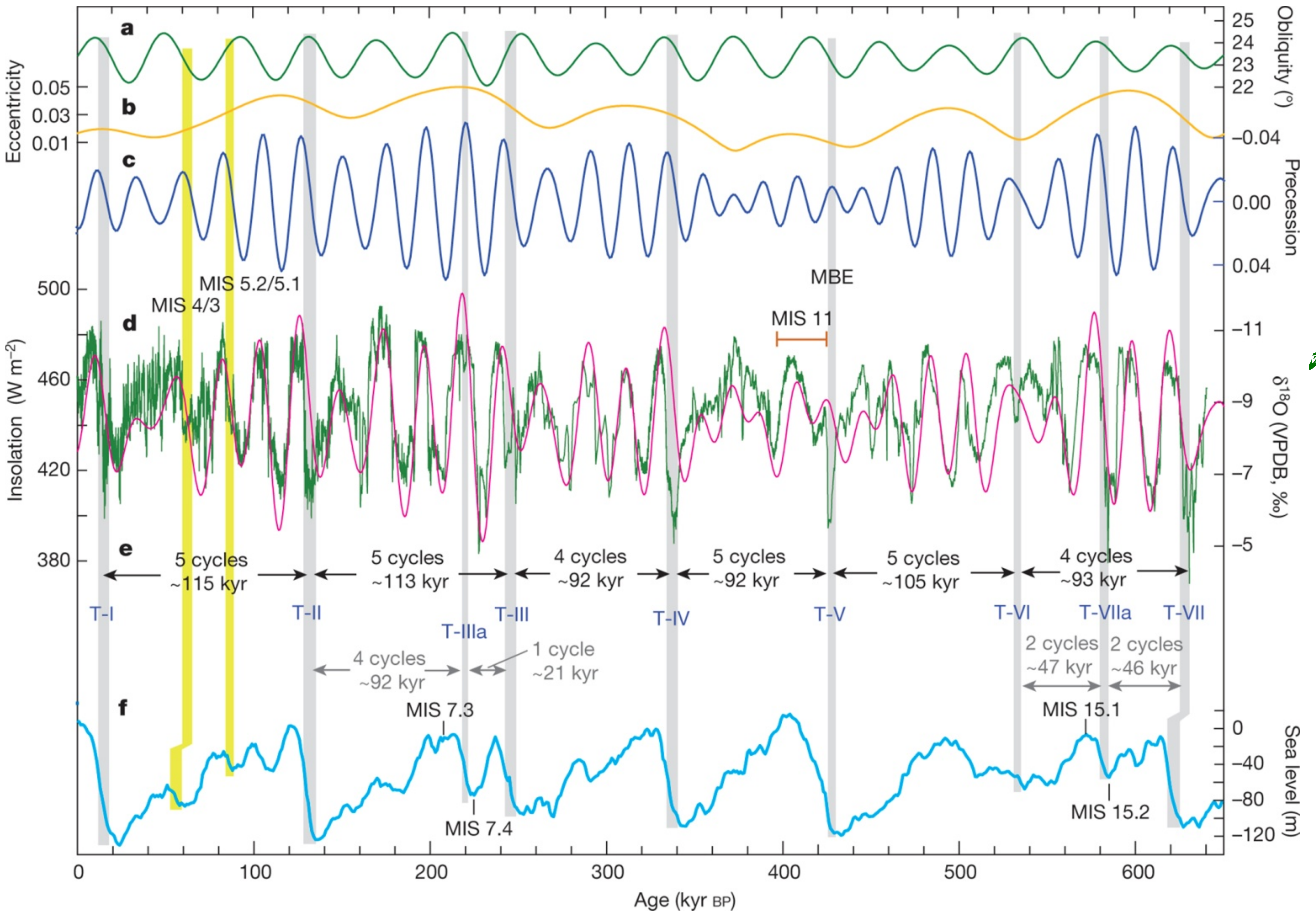
Asian speleothem δ18O

Composite of Chinese speleothem records over the last 600 kyrs



What is that?

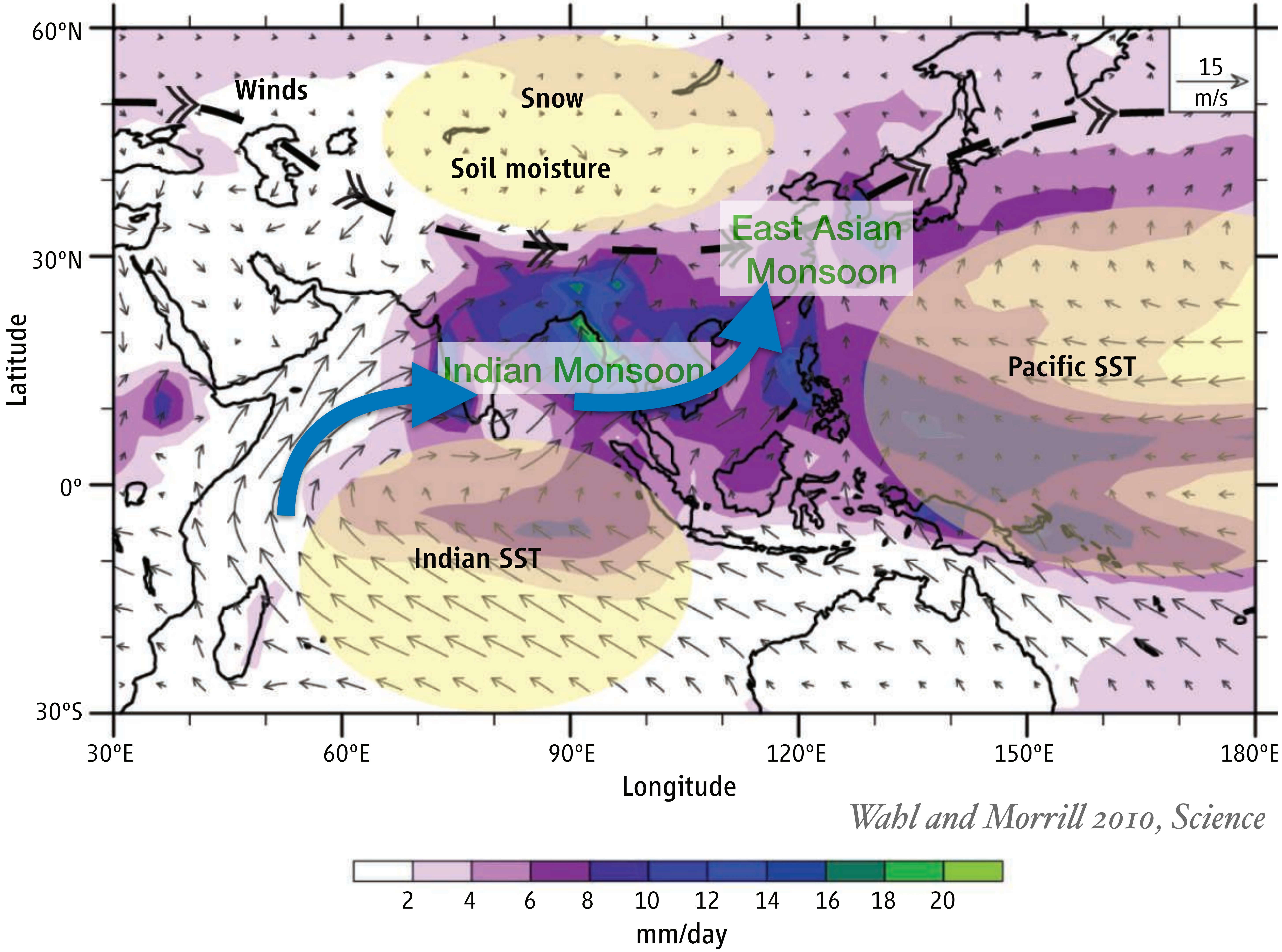
Monsoon intensity

Cheng et al. 2016, Nature

Speleothem δ18O has been widely used to investigate hydroclimate variability, particularly for studies of the Asian monsoon

The Asian monsoon

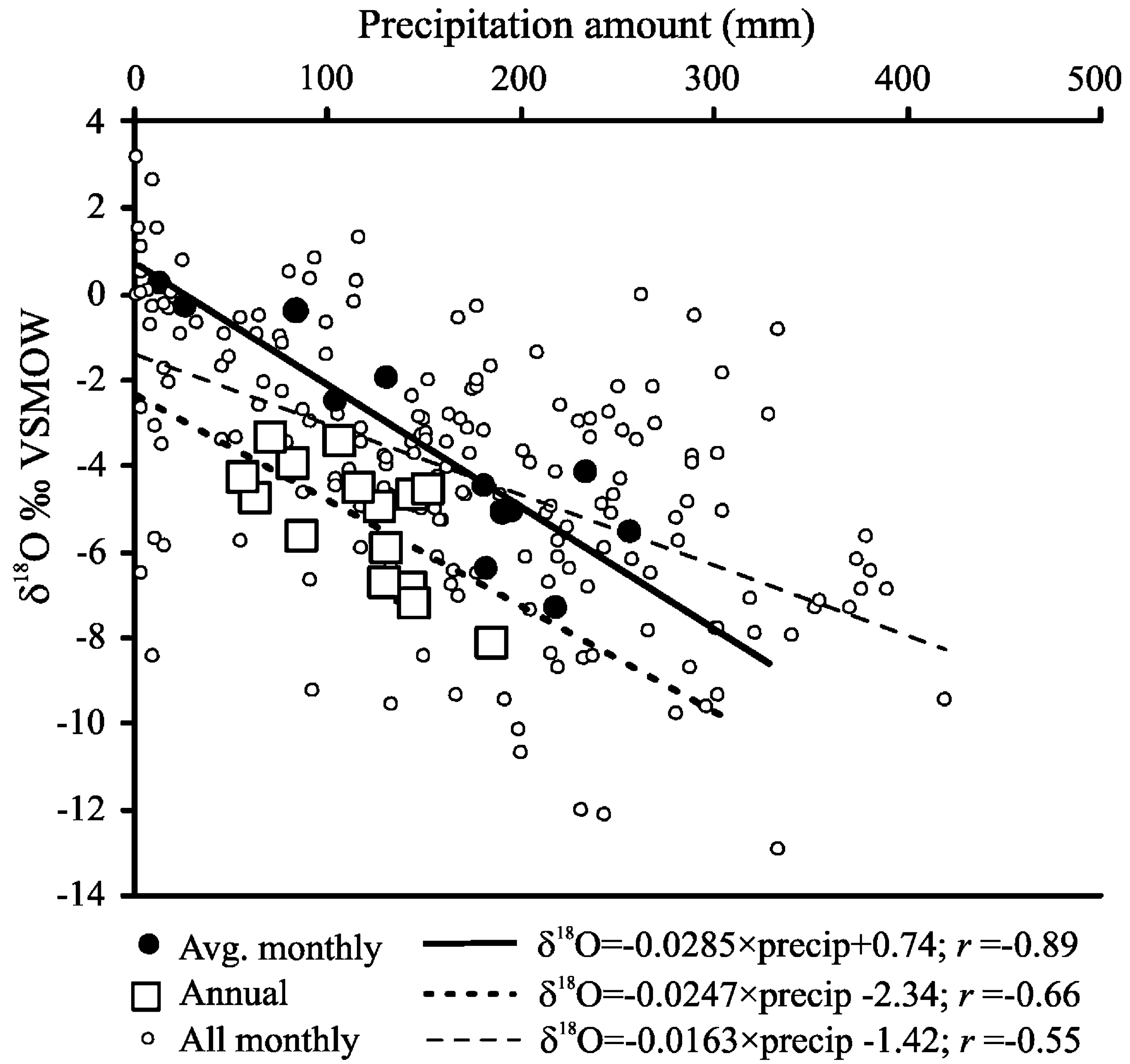
Circulation? Precipitation?



Wahl and Morrill 2010, Science

Interpretation of precipitation δ18O

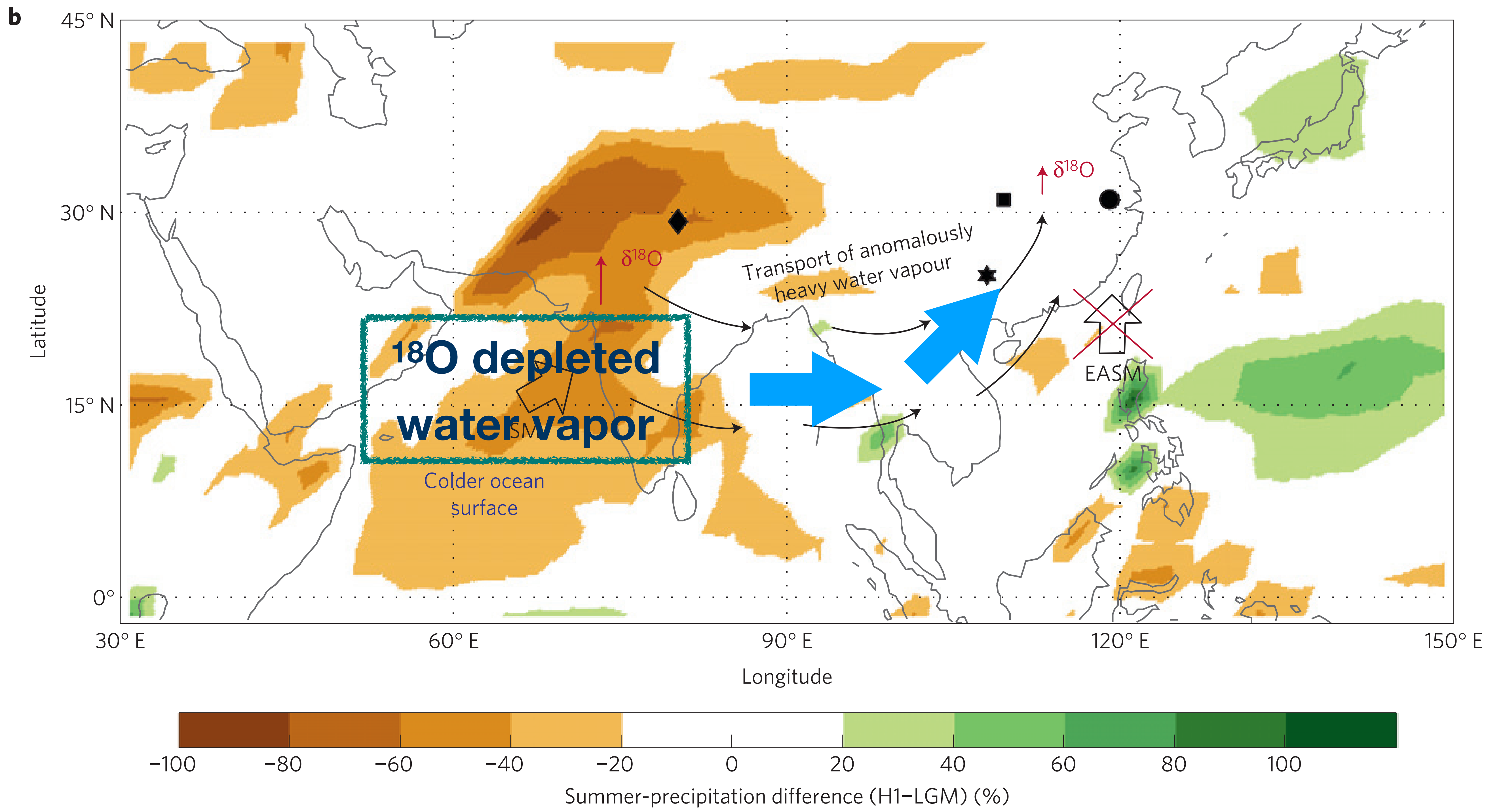
Amount effect



Lachniet and Patterson, 2006 (J. Hydro.)

Dansgaard, 1964 (Tellus)

Water vapor transport



Pausata et al. 2011 (Nat. Geo.)

Which factor dominates?
What about other factors?

What controls precipitation δ18O?

Interannual

Orbital

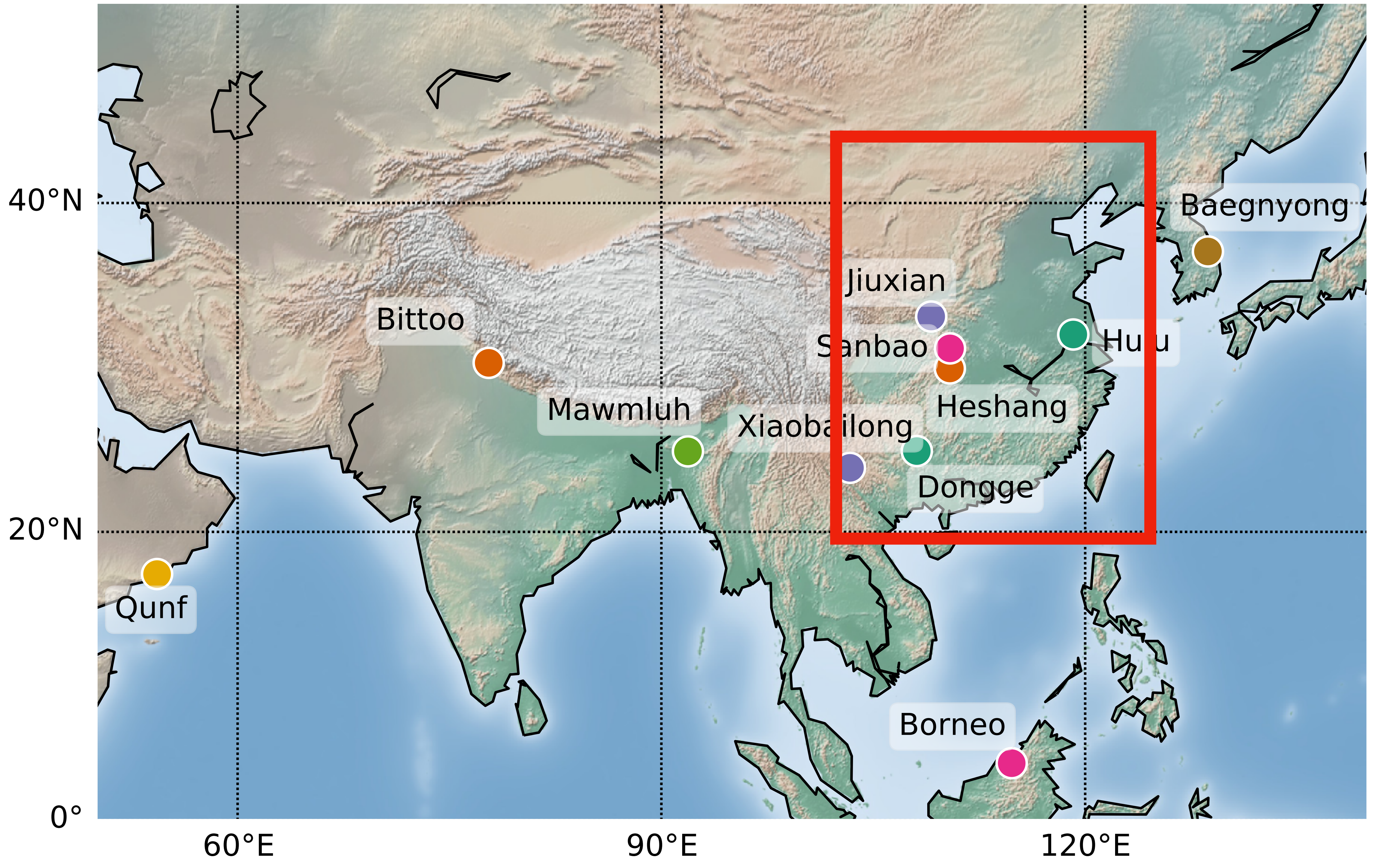
$\delta^{18}O_P$

★ Source composition

★ Rainout

★ Condensation

★ Source location

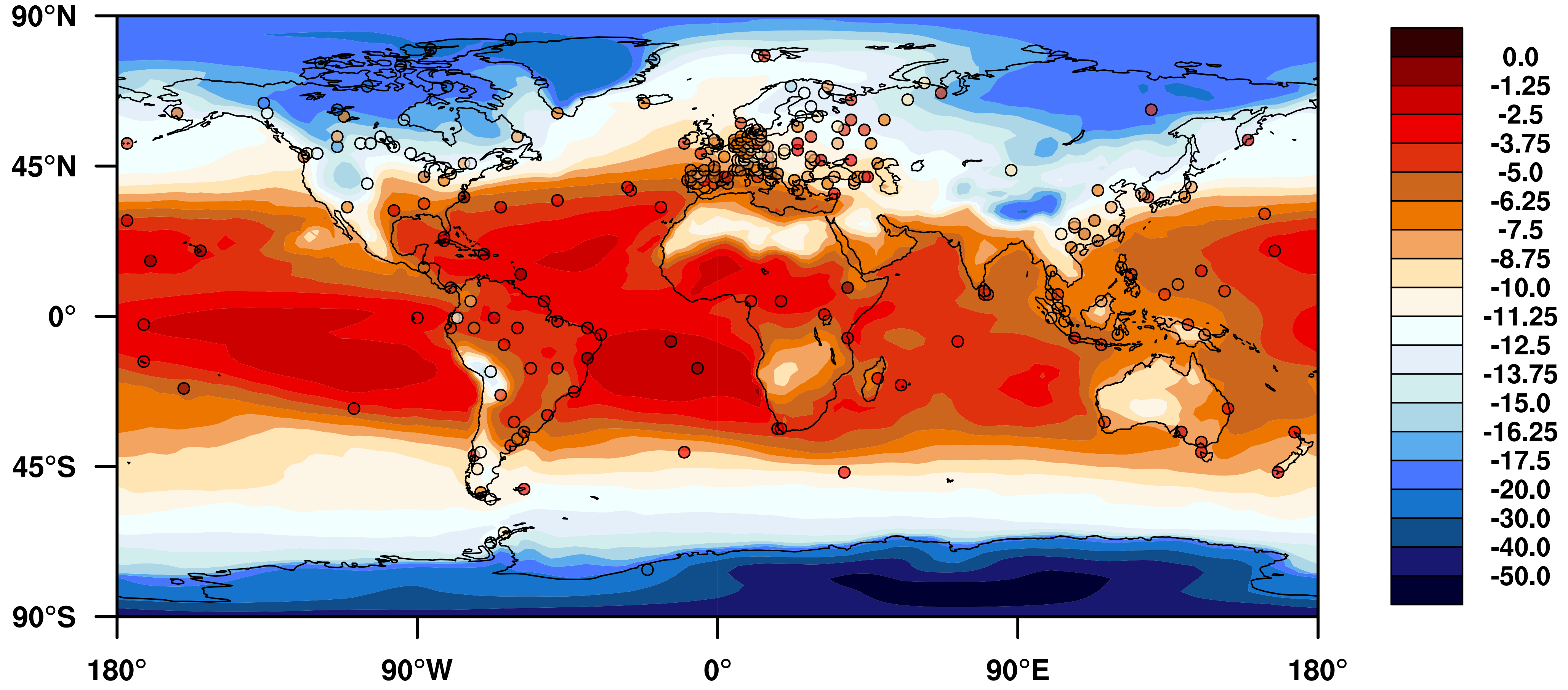


East Asian Monsoon region

Model setup and experimental design

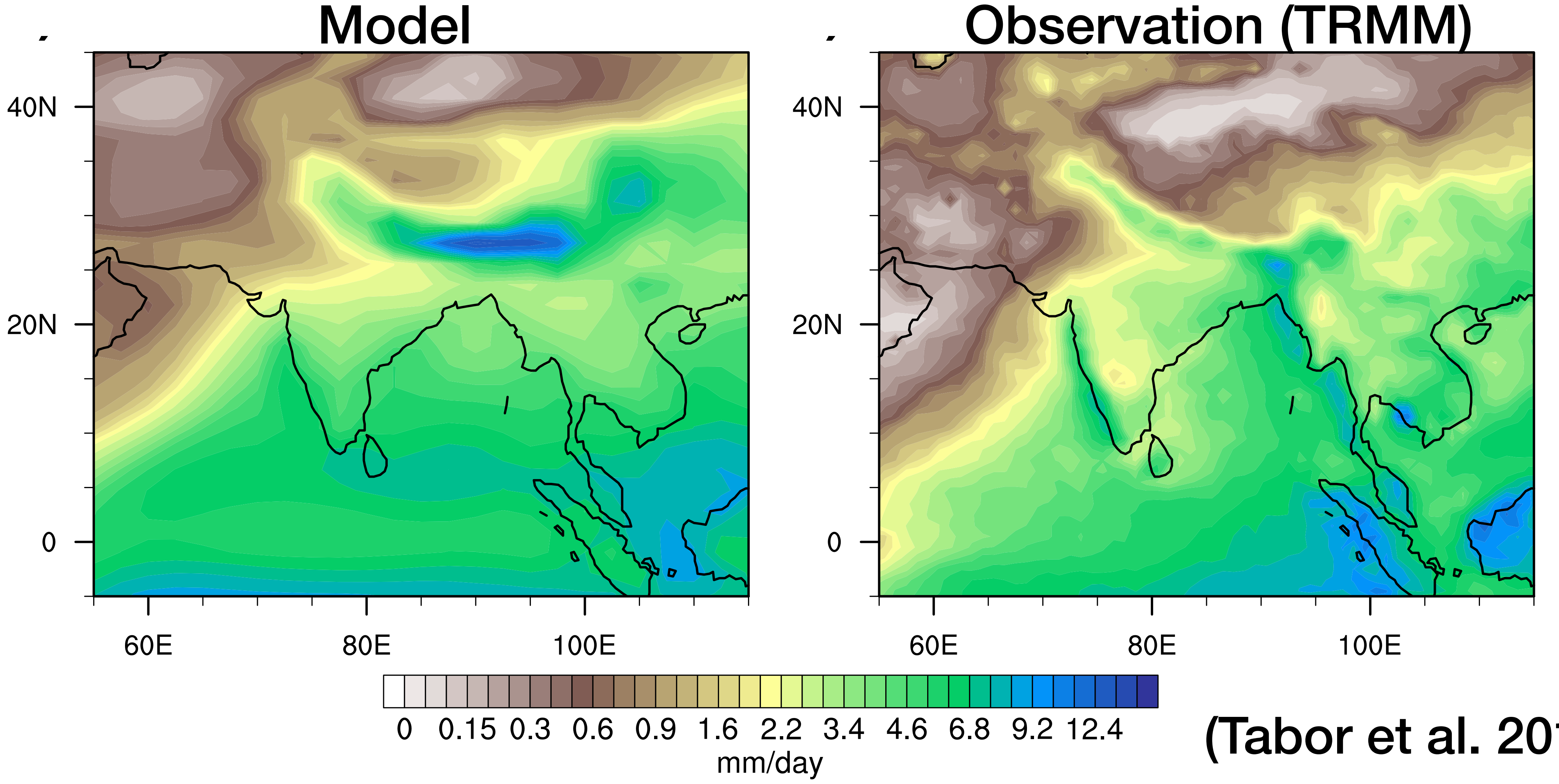
Model: iCAM5

Model precipitation δ^{18}O vs. GNIP data



(Nusbaumer et al. 2017)

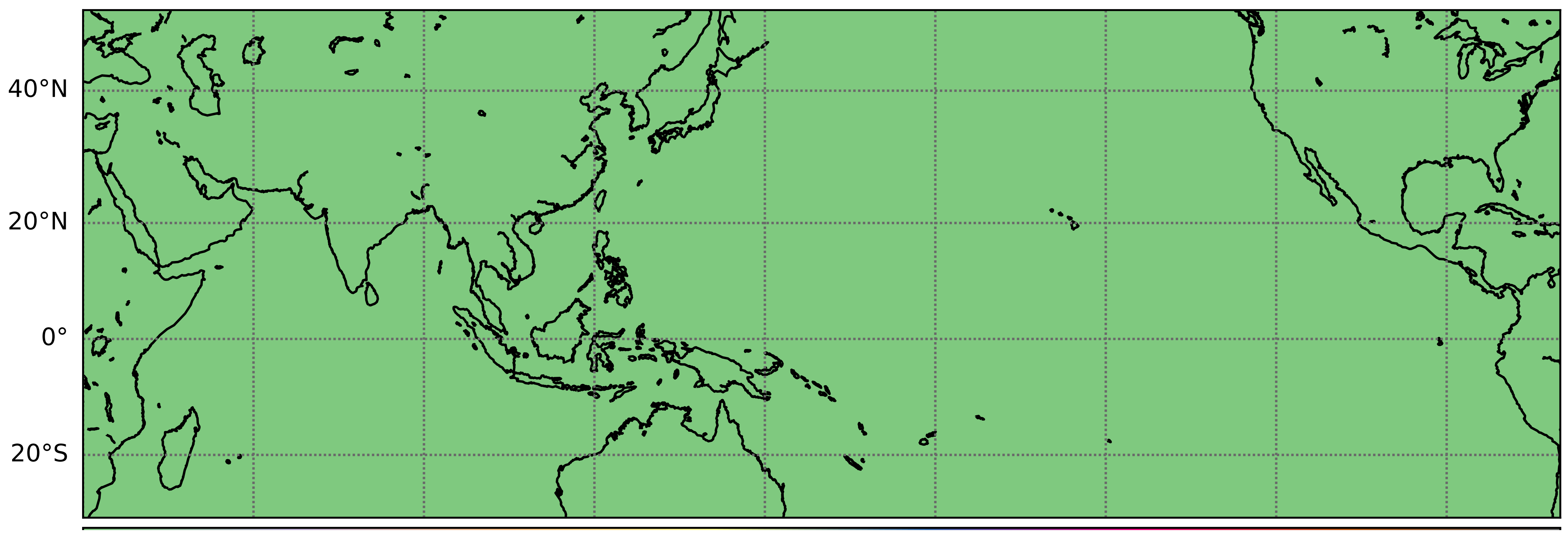
JJAS precipitation



(Tabor et al. 2018)

Water-tagging experiment: Trace moisture and water isotopes

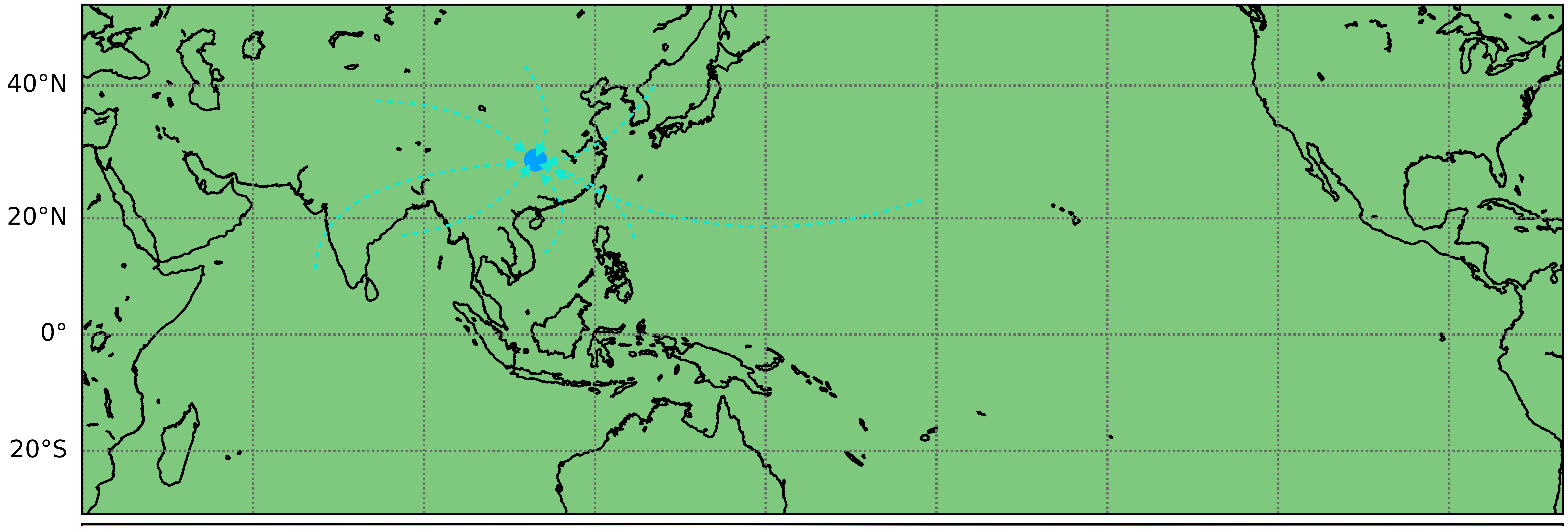
Tagging regions (32)



- Forced by SST/sea ice observations (Hurrell et al. 2008) from 1953 to 2012 (60 years)
- Model resolution: 1.875°×2.5°, 30 vertical levels

Decomposing precipitation δ18O changes

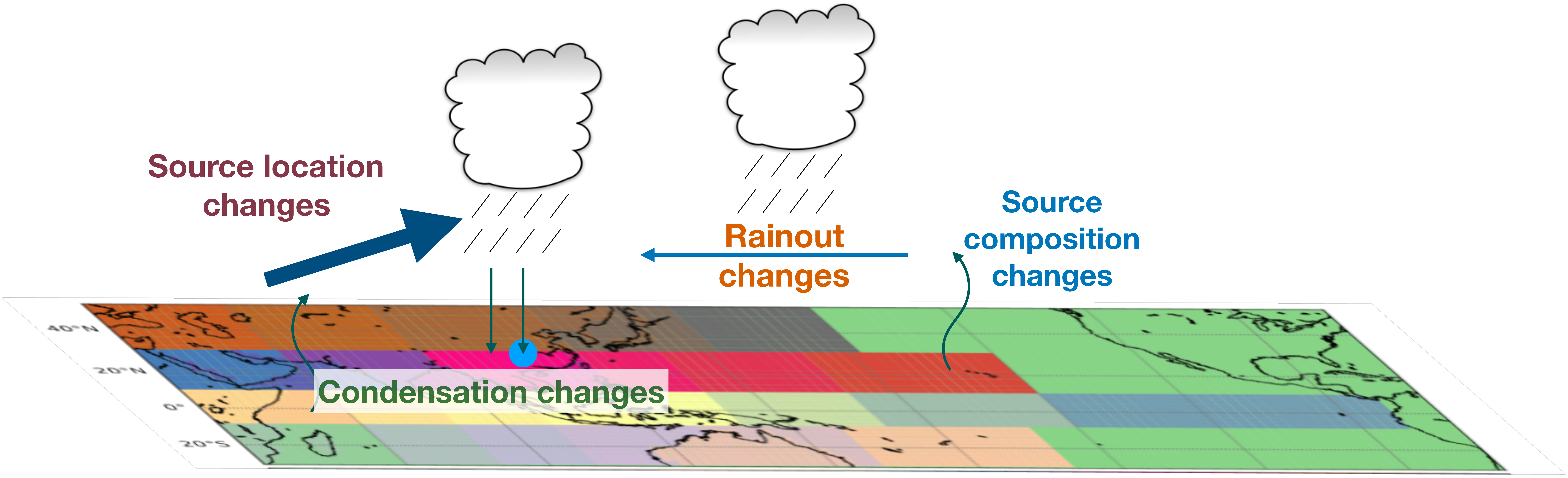
$$\delta^{18}\mathrm{O}_p = \sum_{i=1}^{N} \delta^{18}\mathrm{O}_{P_{sink}i} \times \frac{p_i}{p_{total}}$$



(Note: Colors just represent different tagging regions)

Decomposing precipitation δ18O changes

$$\Delta(\delta^{18}O_p)$$



Decomposing precipitation δ18O changes

$$\delta^{18}\mathrm{O}_p = \sum_{i=1}^{N} \delta^{18}\mathrm{O}_{P_{sink}i} \times \frac{p_i}{p_{total}}$$

For each tagged region:

$$\Delta(\delta^{18}\mathrm{O}_p)_i = \Delta(\delta^{18}\mathrm{O}_{P_{sink}i} \times \frac{p_i}{p_{total}}) = \Delta\left[(\delta^{18}\mathrm{O}_{P_{sink}} - \delta^{18}\mathrm{O}_{wv_{sink}}) + (\delta^{18}\mathrm{O}_{wv_{sink}} - \delta^{18}\mathrm{O}_{wv_{source}})_i + (\delta^{18}\mathrm{O}_{wv_{source}})_i\right] \times (\frac{p_i}{p_{total}})$$

$$+\delta^{18}\mathrm{O}_{P_{sink}i} \times \Delta(\frac{p_i}{p_{total}})$$

- Condensation changes: $(\delta^{18}\mathrm{O}_{P_{sink}} - \delta^{18}\mathrm{O}_{wv_{sink}})$
- Rainout changes: $(\delta^{18}\mathrm{O}_{wv_{sink}} - \delta^{18}\mathrm{O}_{wv_{source}})_i$
- Source composition changes: $(\delta^{18}\mathrm{O}_{wv_{source}})_i$
- Source location changes: $+\delta^{18}\mathrm{O}_{P_{sink}i} \times \Delta(\frac{p_i}{p_{total}})$

High $\delta^{18}\mathrm{O}_p$ - Low $\delta^{18}\mathrm{O}_p$

(Tabor et al. 2018)

Tabor, C. R., Otto-Bliesner, B. L., Brady, E. C., Nusbaumer, J., Zhu, J., Erb, M. P., et al. (2018). Interpreting precession-driven δ18O variability in the South Asian monsoon region. *Journal of Geophysical Research: Atmospheres*, 123, 5927–5946. https://doi.org/10.1029/2018JD028424

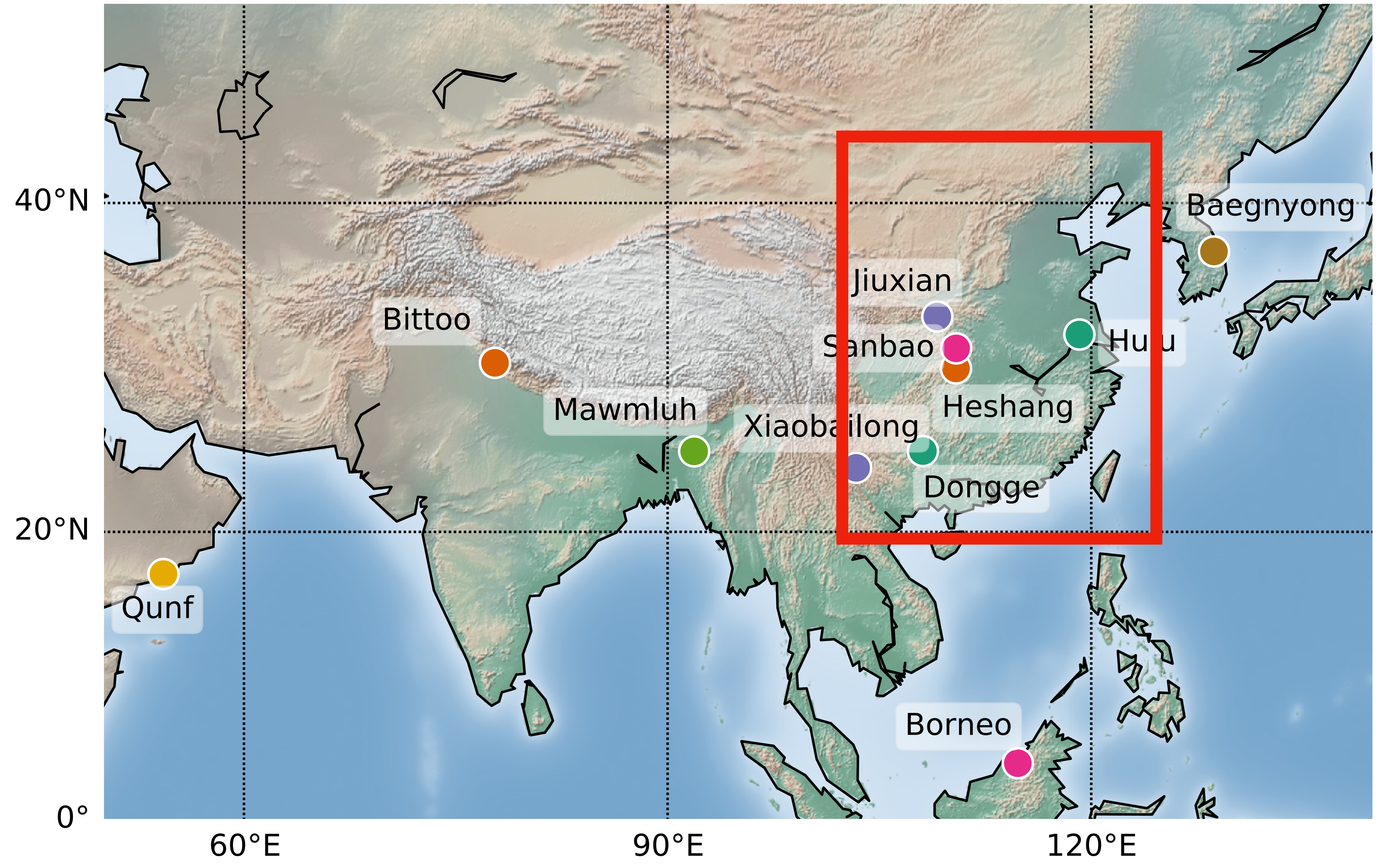
What controls precipitation δ18O?

Interannual

Orbital

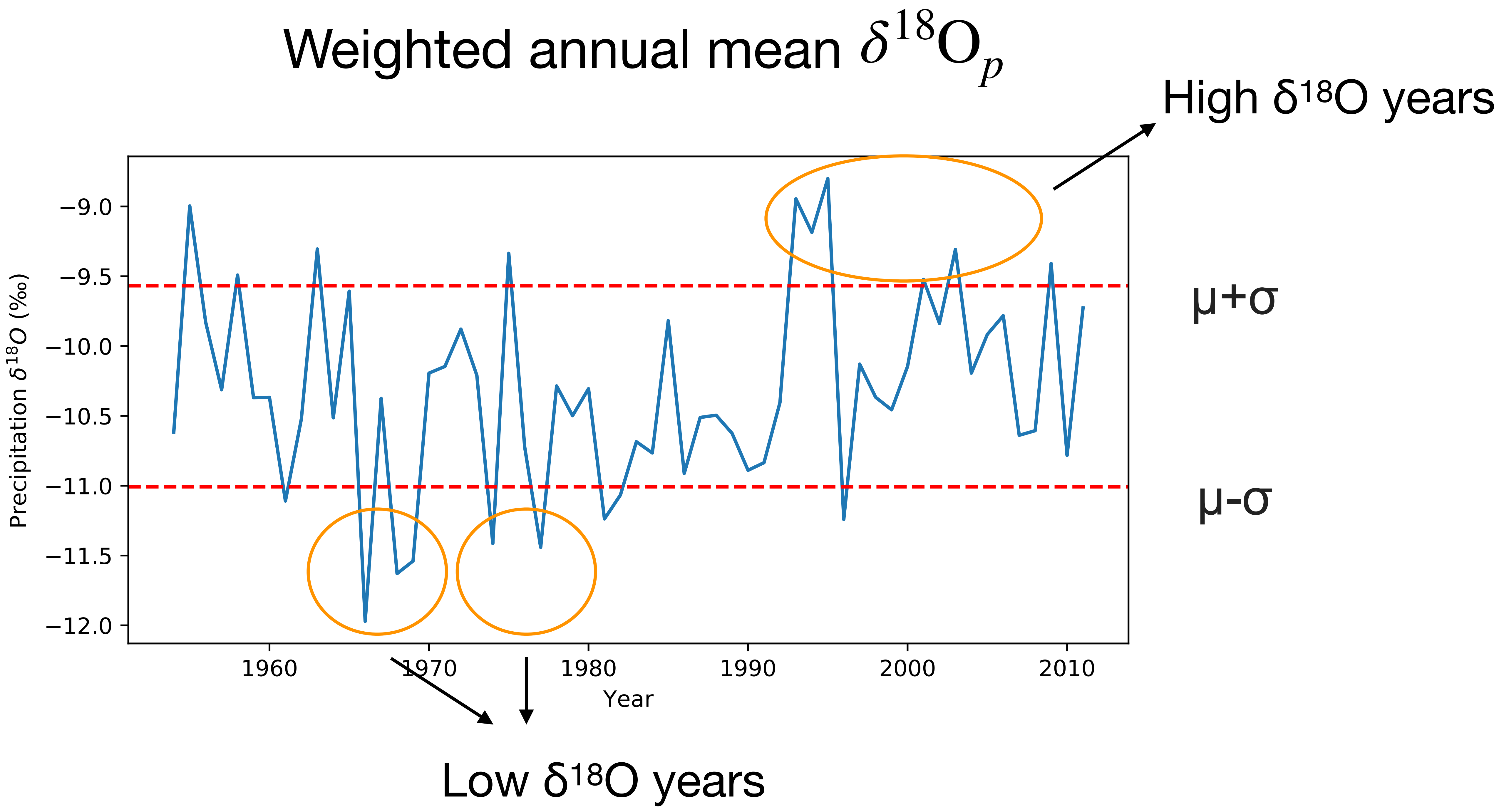
$\delta^{18}O_P$

- ★ **Source composition**
- ★ **Rainout**
- ★ **Condensation**
- ★ **Source location**

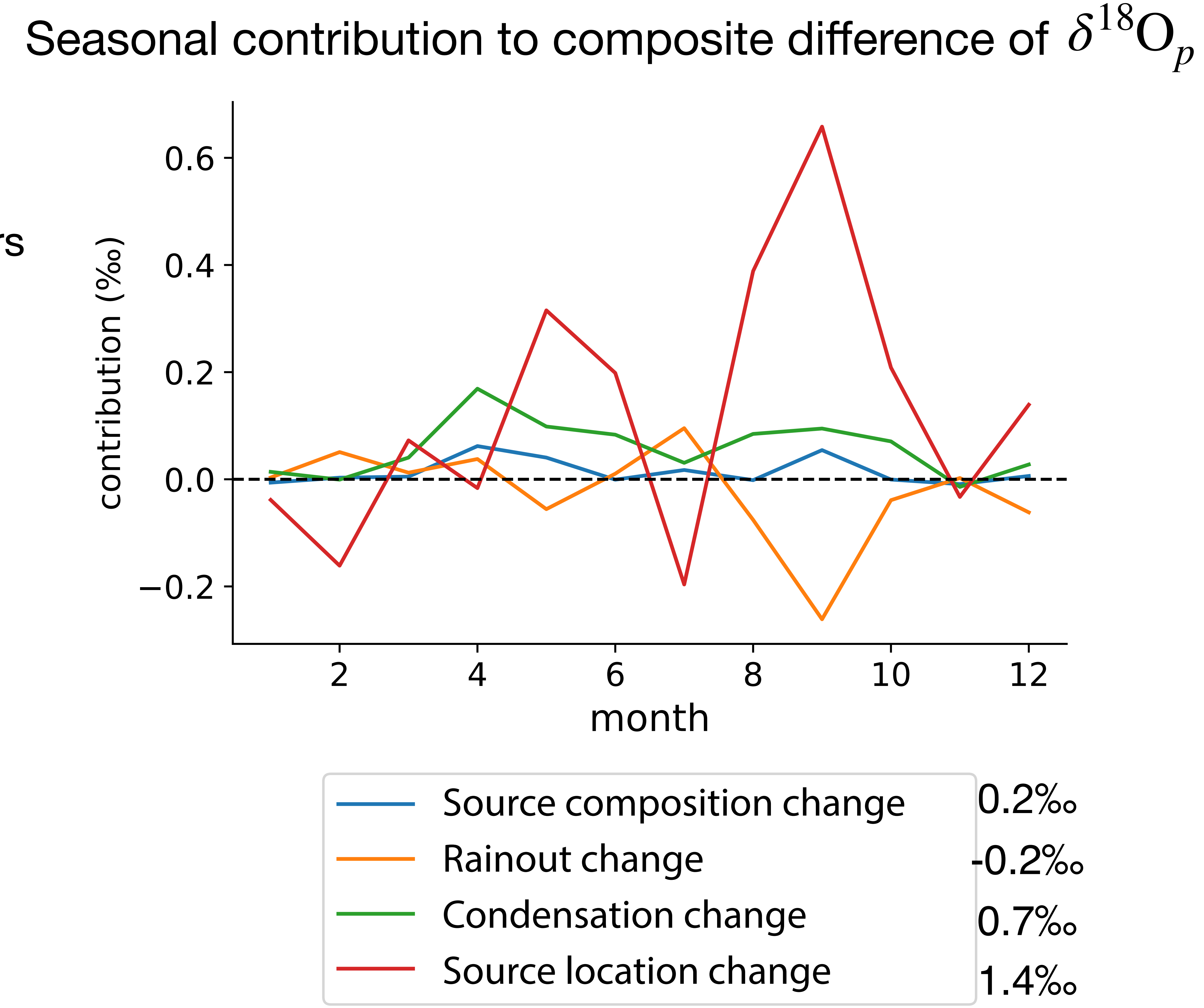


East Asian Monsoon region

Interannual variability of $\delta^{18}O_p$ in East Asia

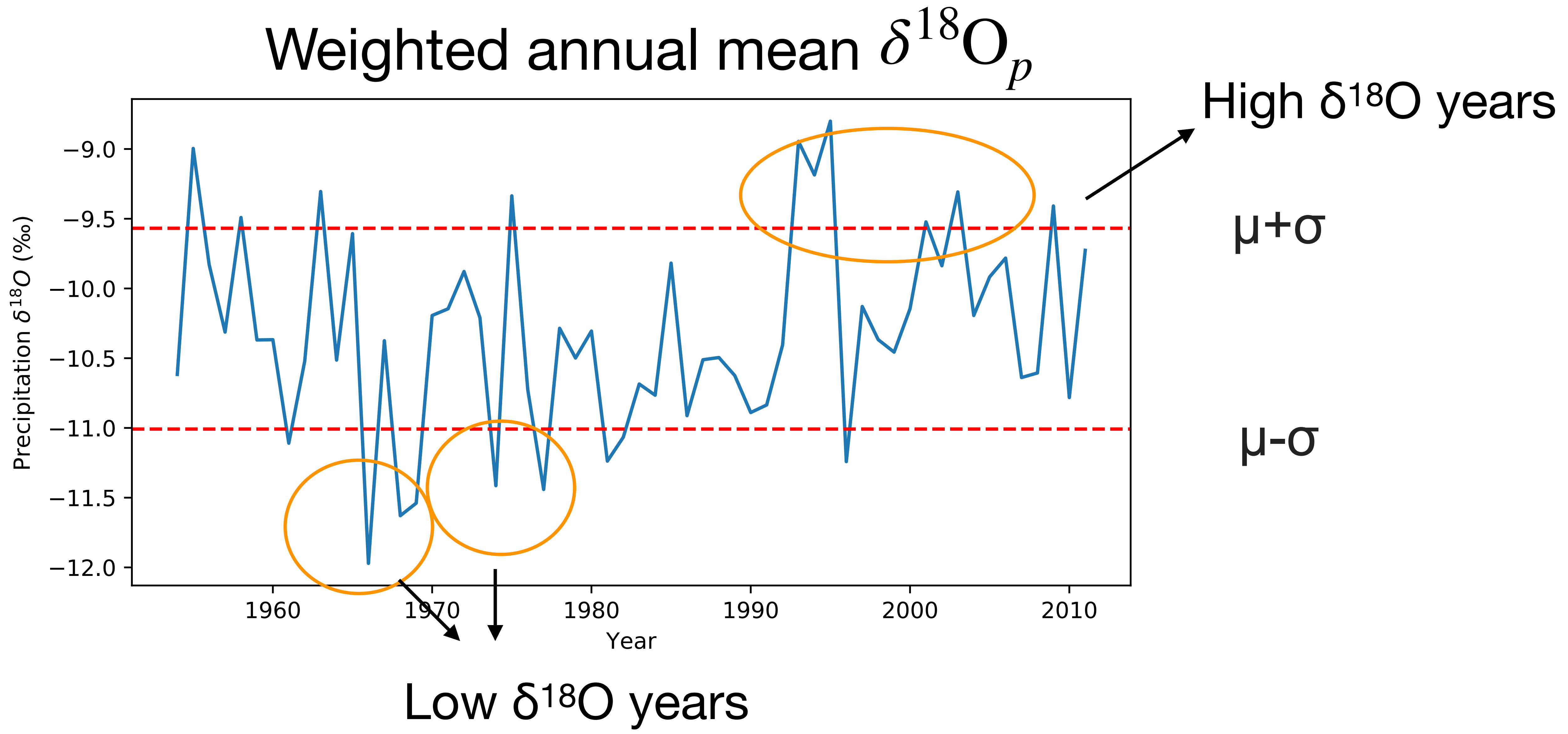


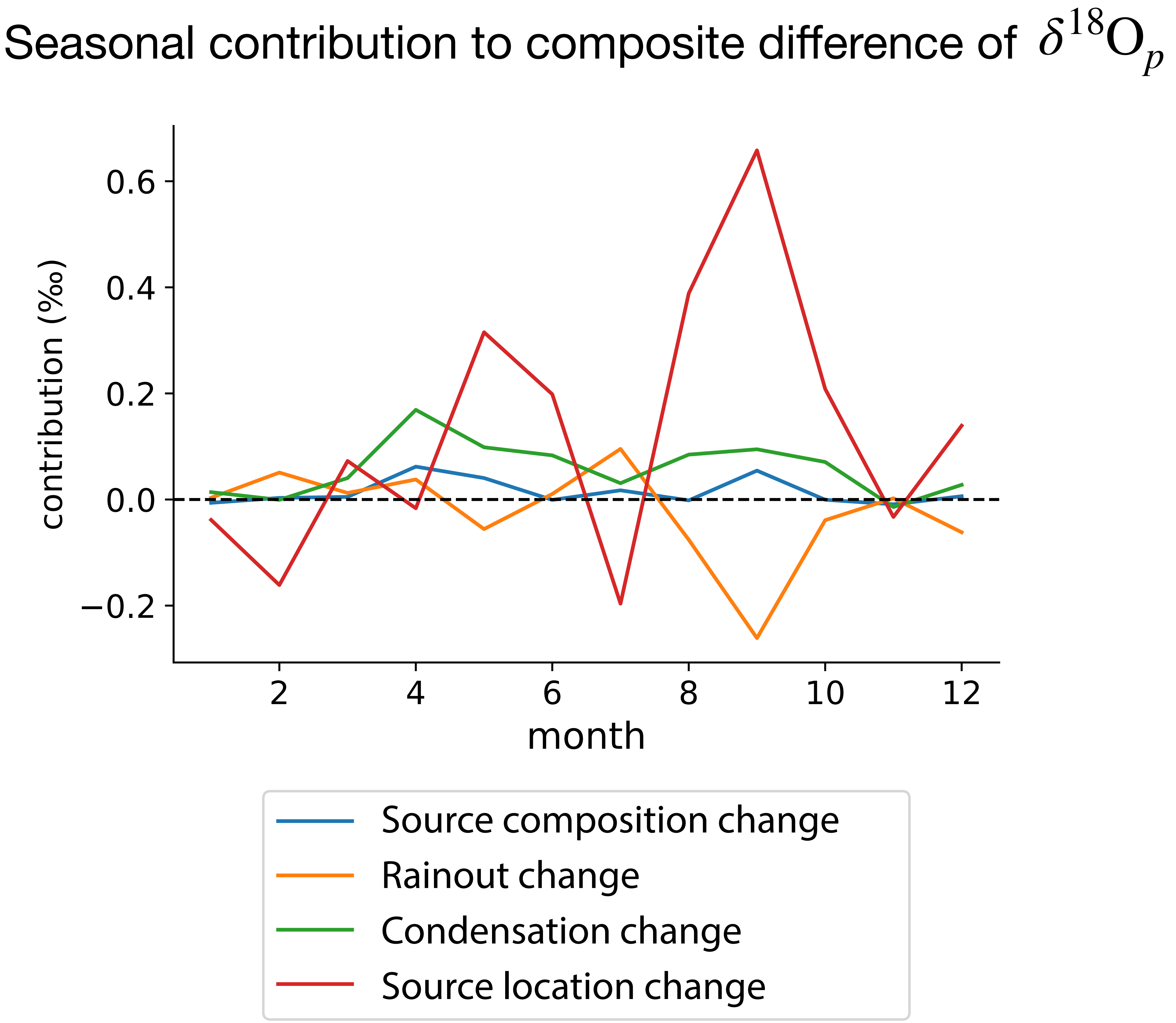
Difference: 2.1‰

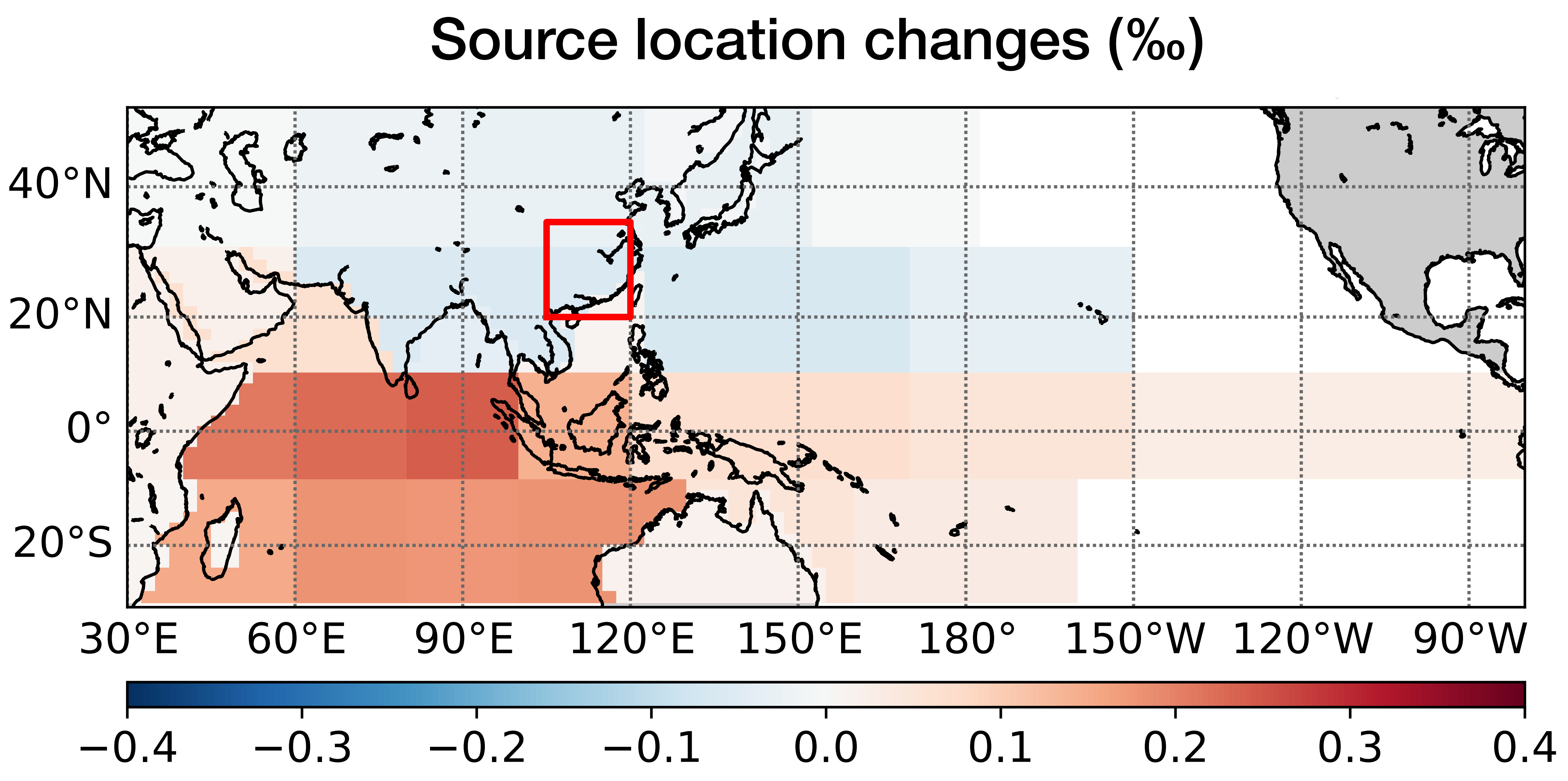


Result #1: Interannual variability is dominated by moisture source location changes

Interannual variability of $\delta^{18}O_p$ in East Asia



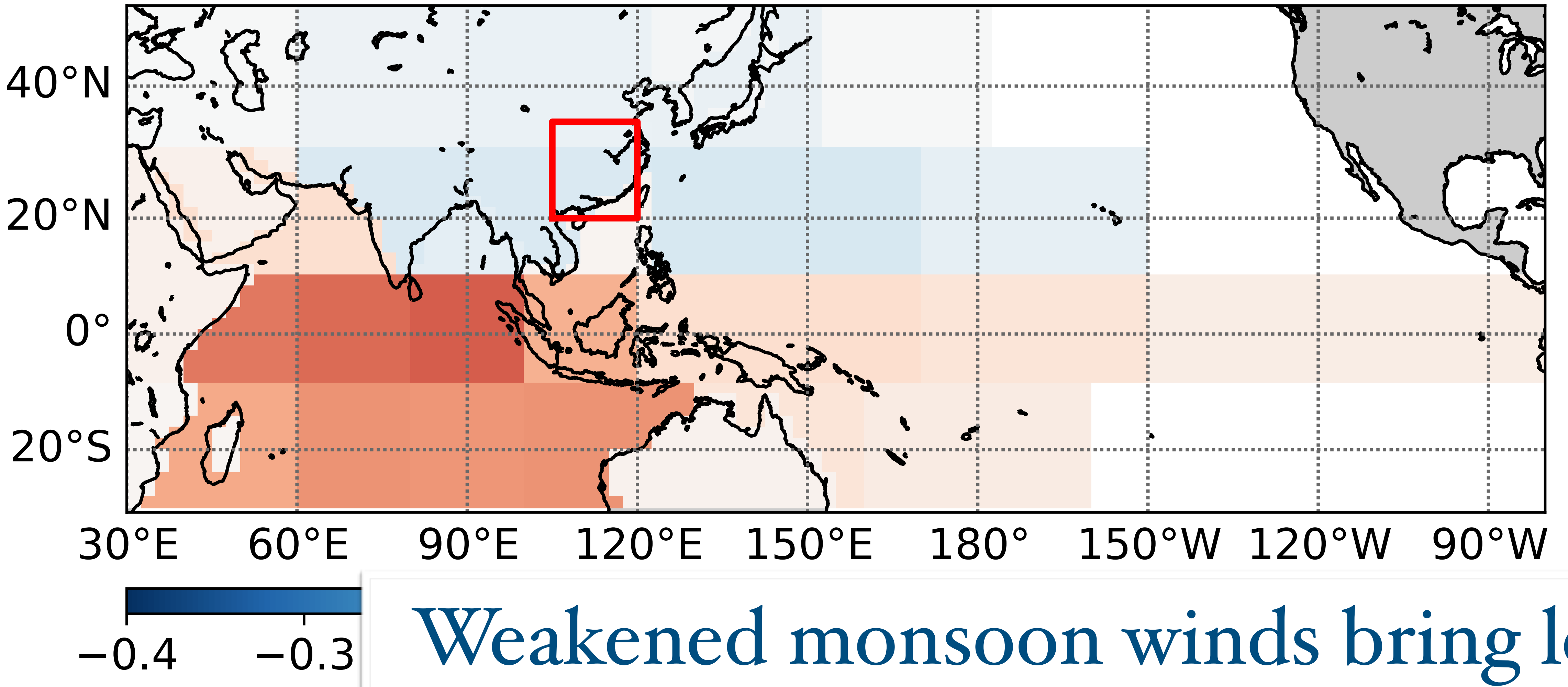




Interannual variability of $\delta^{18}O_p$ in East Asia

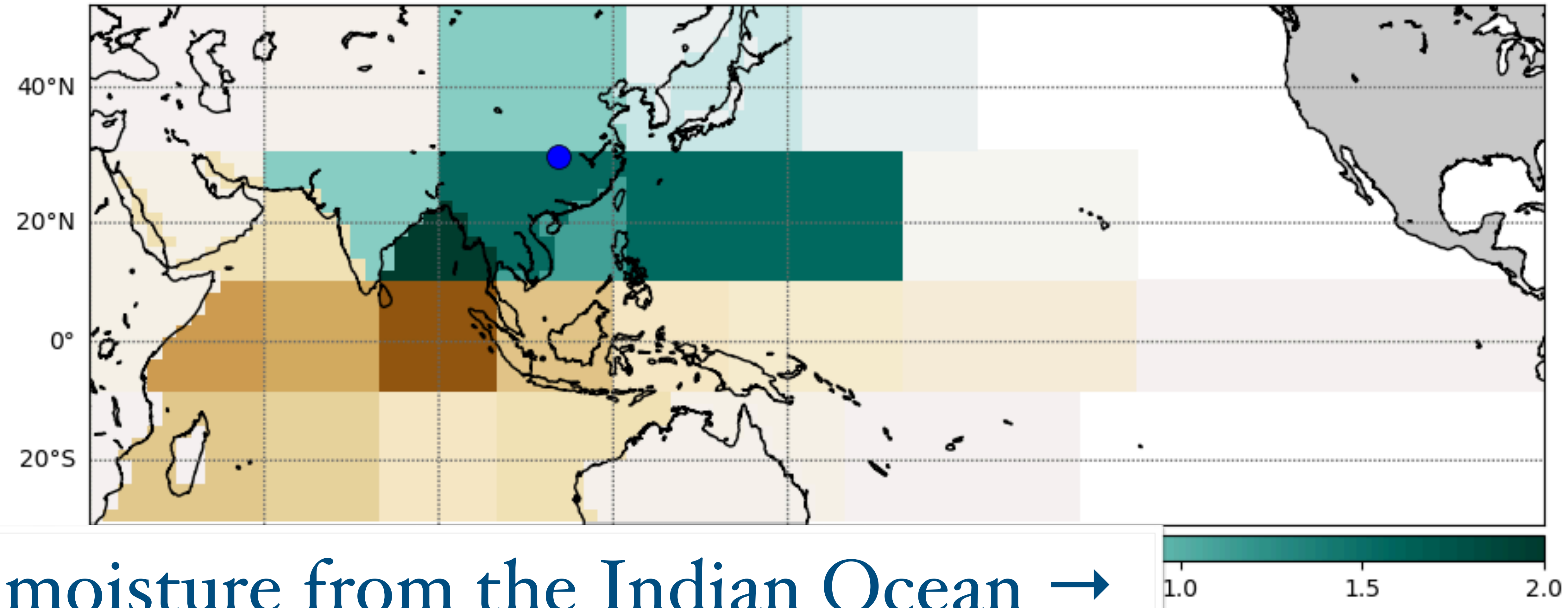
$$\delta^{18}O_{P_{sink} i} \times \Delta\left(\frac{p_i}{p_{total}}\right)$$

Source location changes (‰)

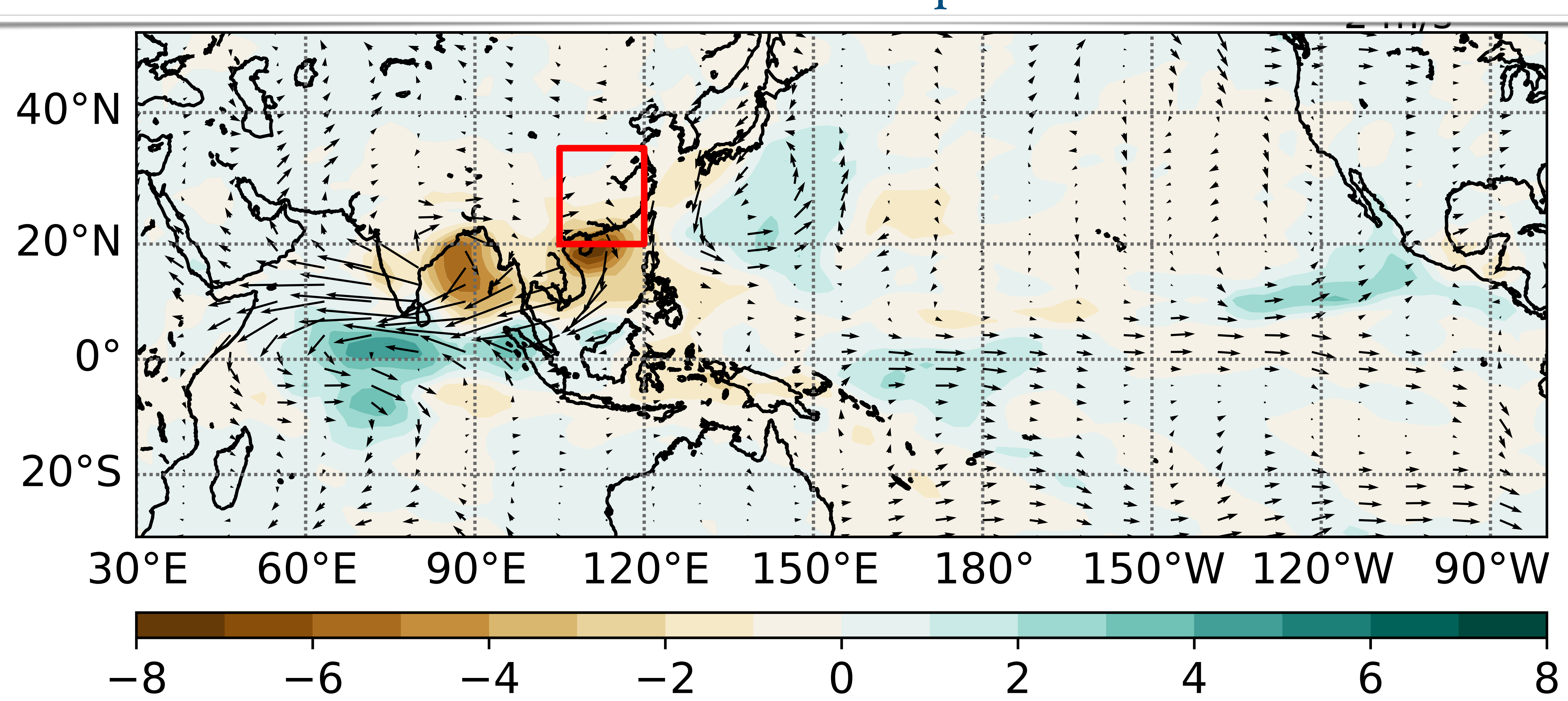


$$\Delta\left(\frac{p_i}{p_{total}}\right)$$

Change of precipitation contribution (%)



Weakened monsoon winds bring less moisture from the Indian Ocean → Enriched $\delta^{18}O_p$ in China



(mm/day)

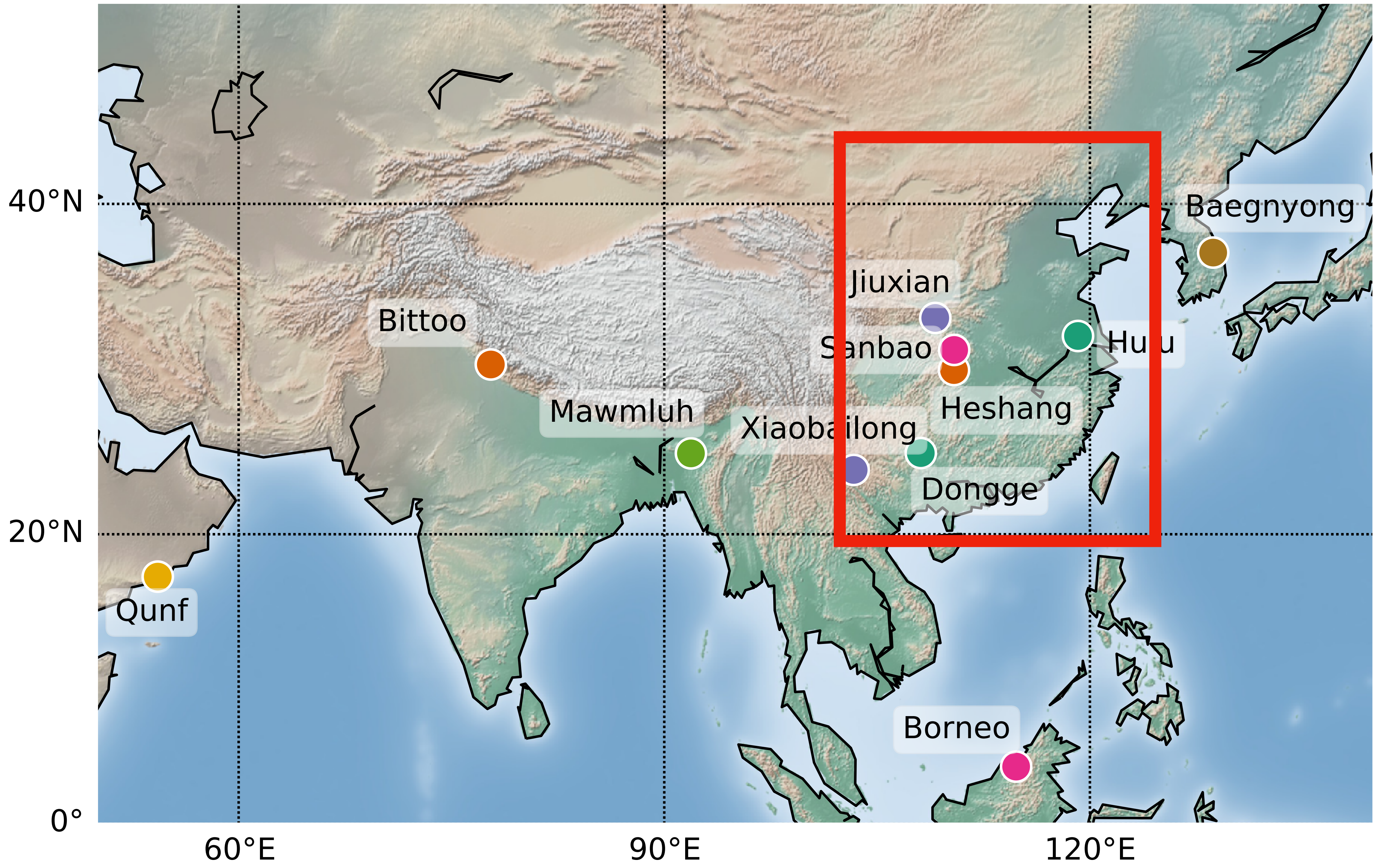
What controls precipitation $\delta^{18}O$?

Interannual

Orbital

$\delta^{18}O_P$

- ★ Source composition
- ★ Rainout
- ★ Condensation
- ★ Source location



East Asian Monsoon region

What controls precipitation $\delta^{18}O$?

Interannual

Orbital

$\delta^{18}O_P$

★ Source composition

★ Rainout

★ Condensation

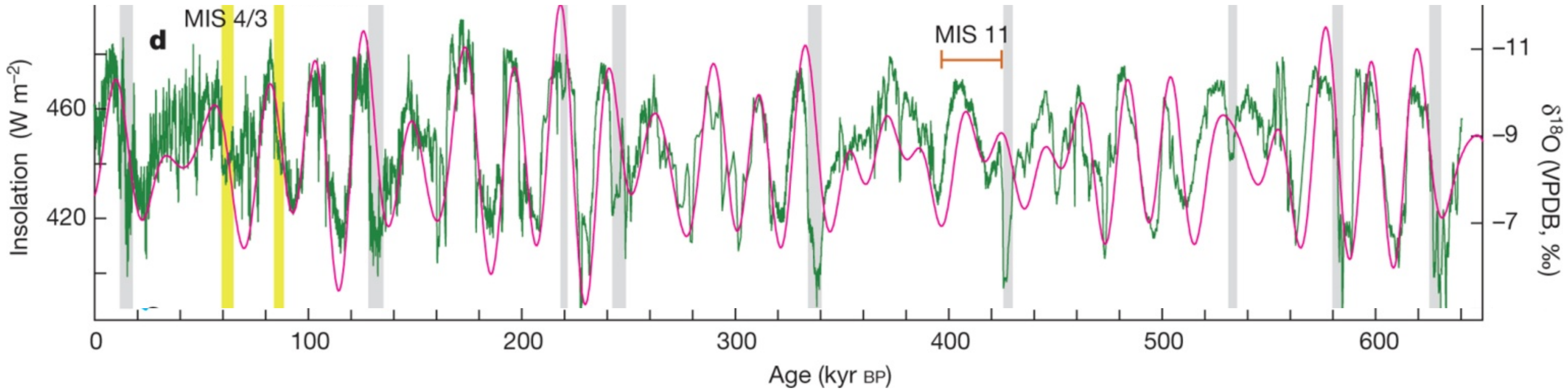
★ Source location

Precessional forcing experiments by iCESM (Tabor et al. 2018)

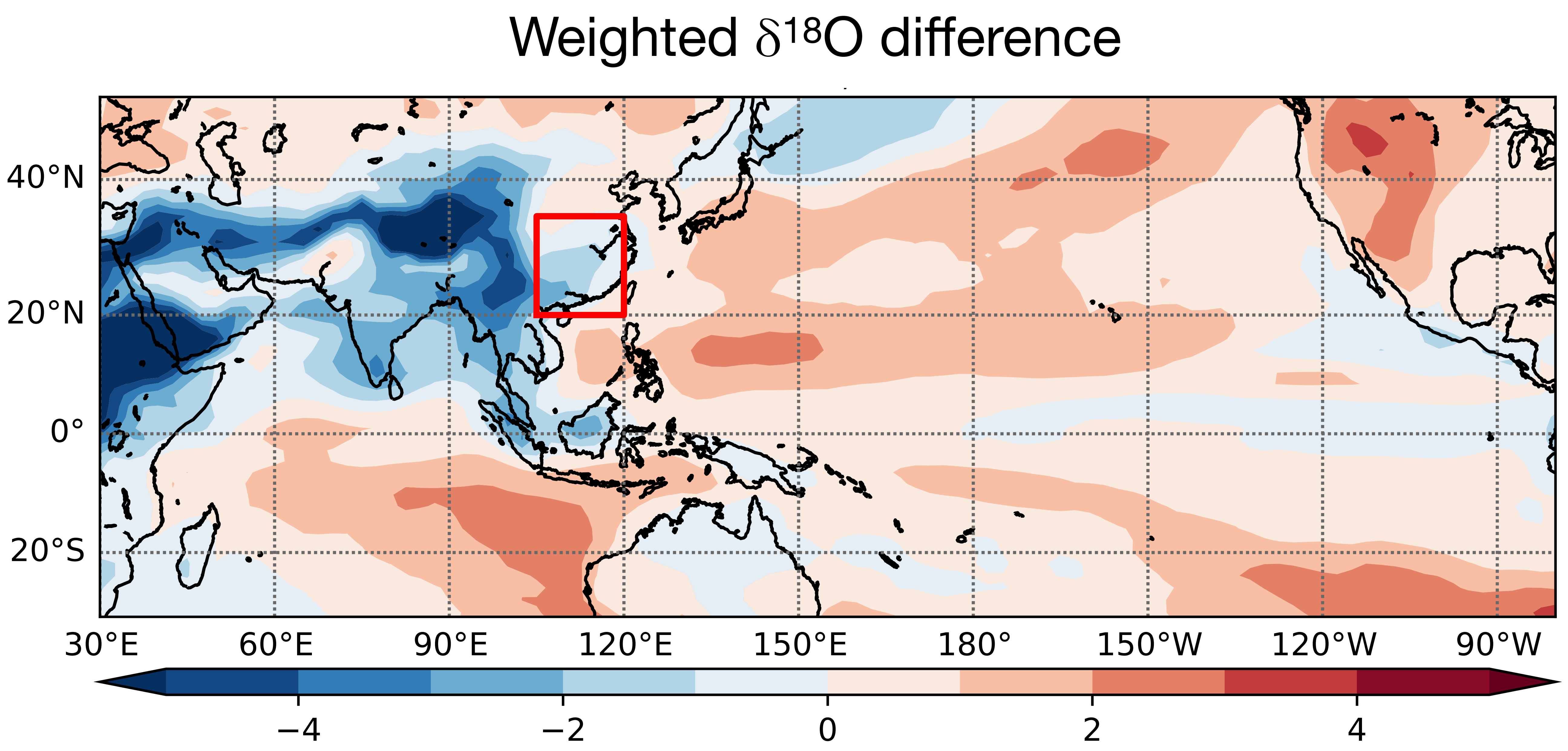
- Northern Hemisphere perihelion at summer solstice — precession minimum
- Northern Hemisphere perihelion at winter solstice — precession maximum

Tabor, C. R., Otto-Bliesner, B. L., Brady, E. C., Nusbaumer, J., Zhu, J., Erb, M. P., et al. (2018). Interpreting precession-driven δ18O variability in the South Asian monsoon region. *Journal of Geophysical Research: Atmospheres*, 123, 5927–5946. https://doi.org/10.1029/2018JD028424

Difference between Precession minimum and maximum



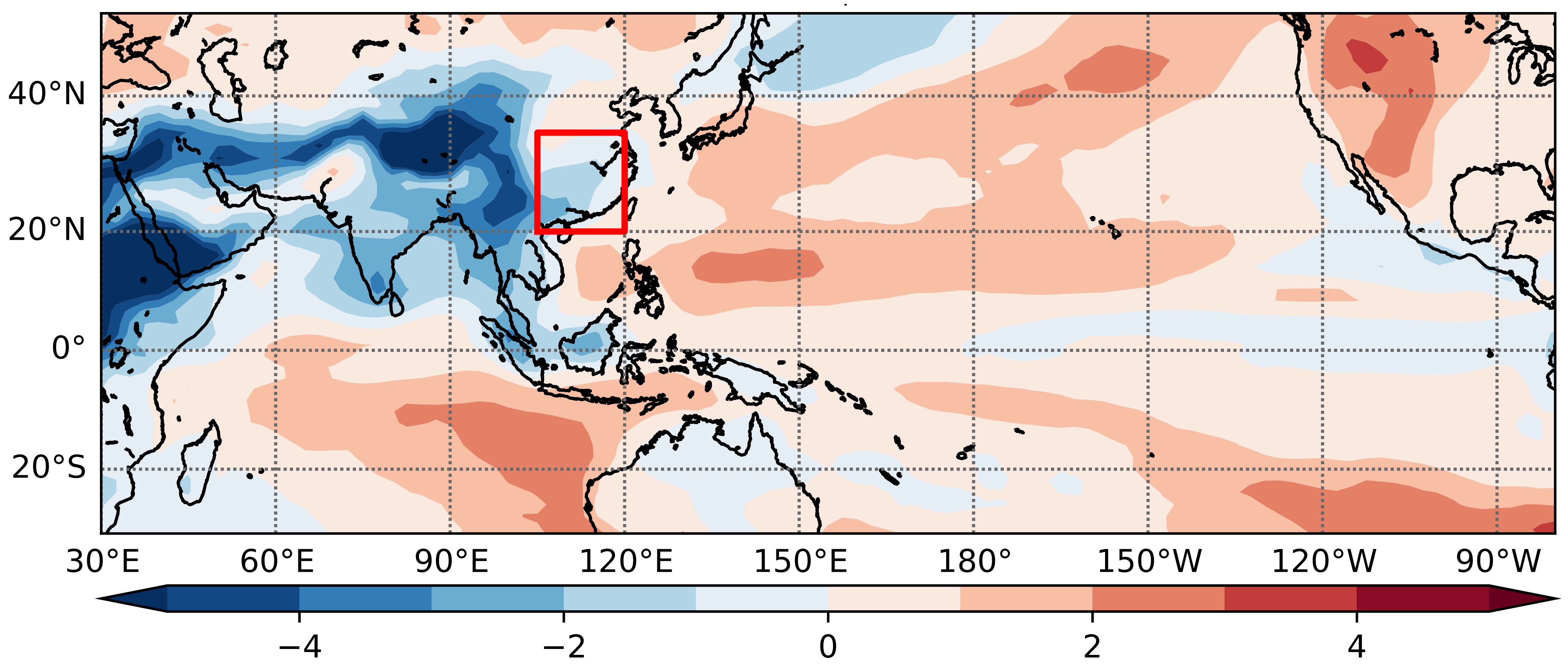
Precession minimum — Depleted δ18O



Mean δ18O difference: -1.6‰

Difference between Precession minimum and maximum

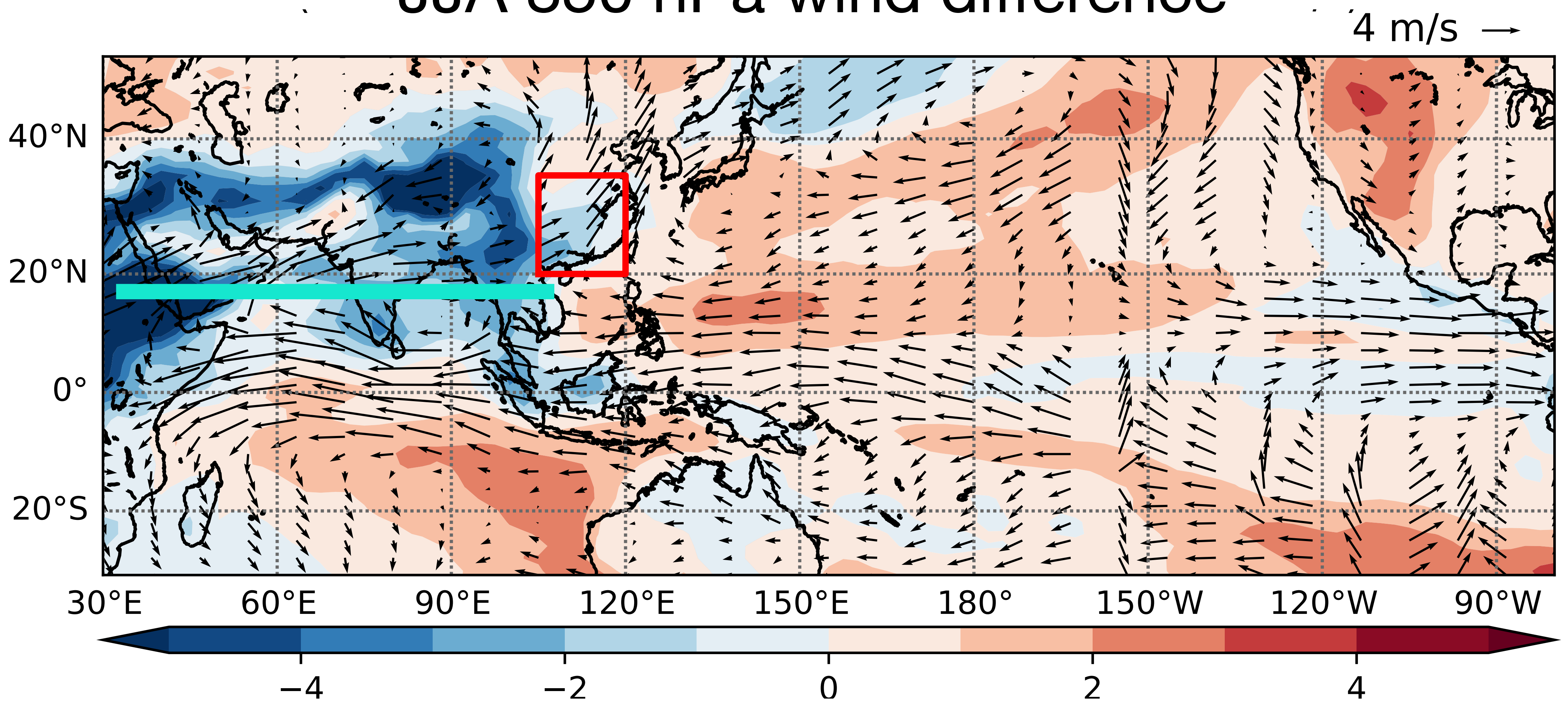
Weighted δ18O difference



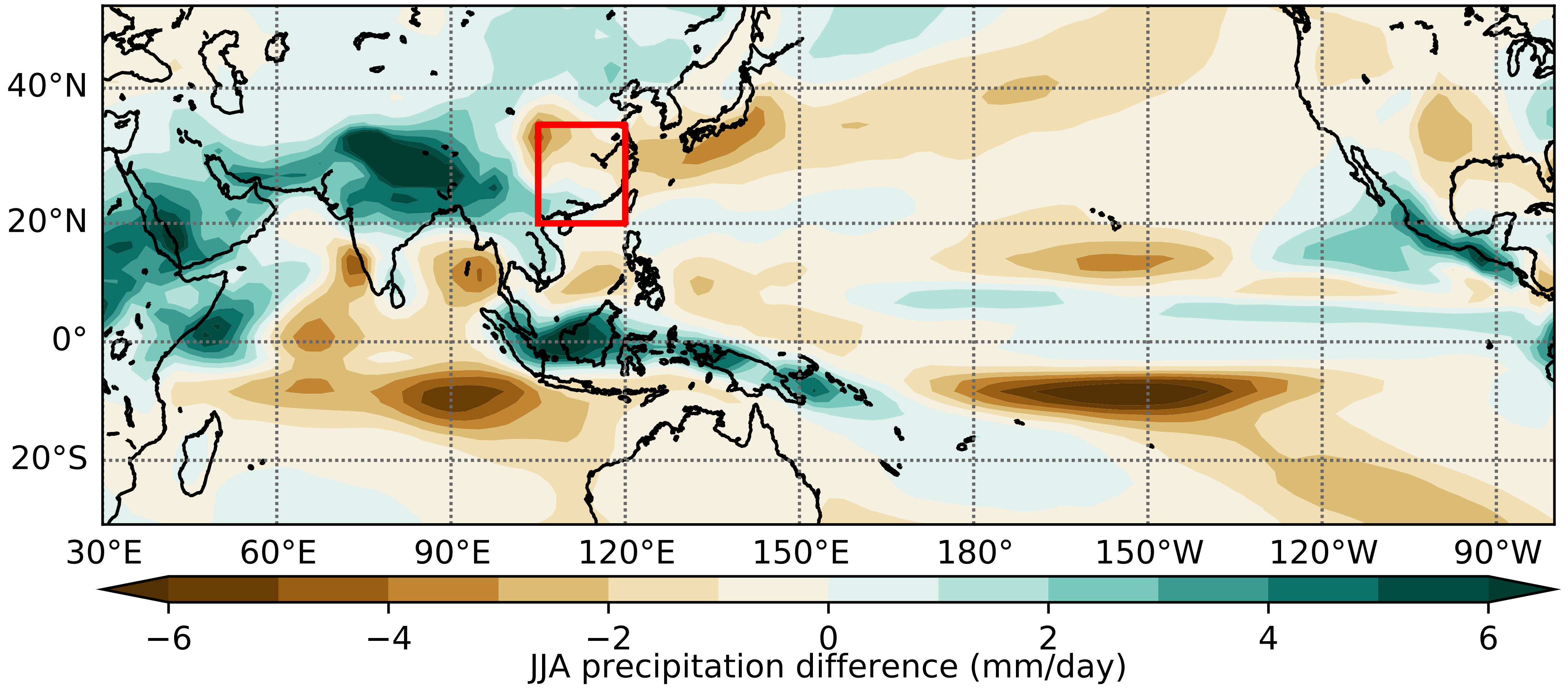
Mean δ18O difference: -1.6‰

Result #3: At orbital scales, depleted $\delta^{18}O_p$ in East Asia is associated with northward migration of the Asian monsoon winds

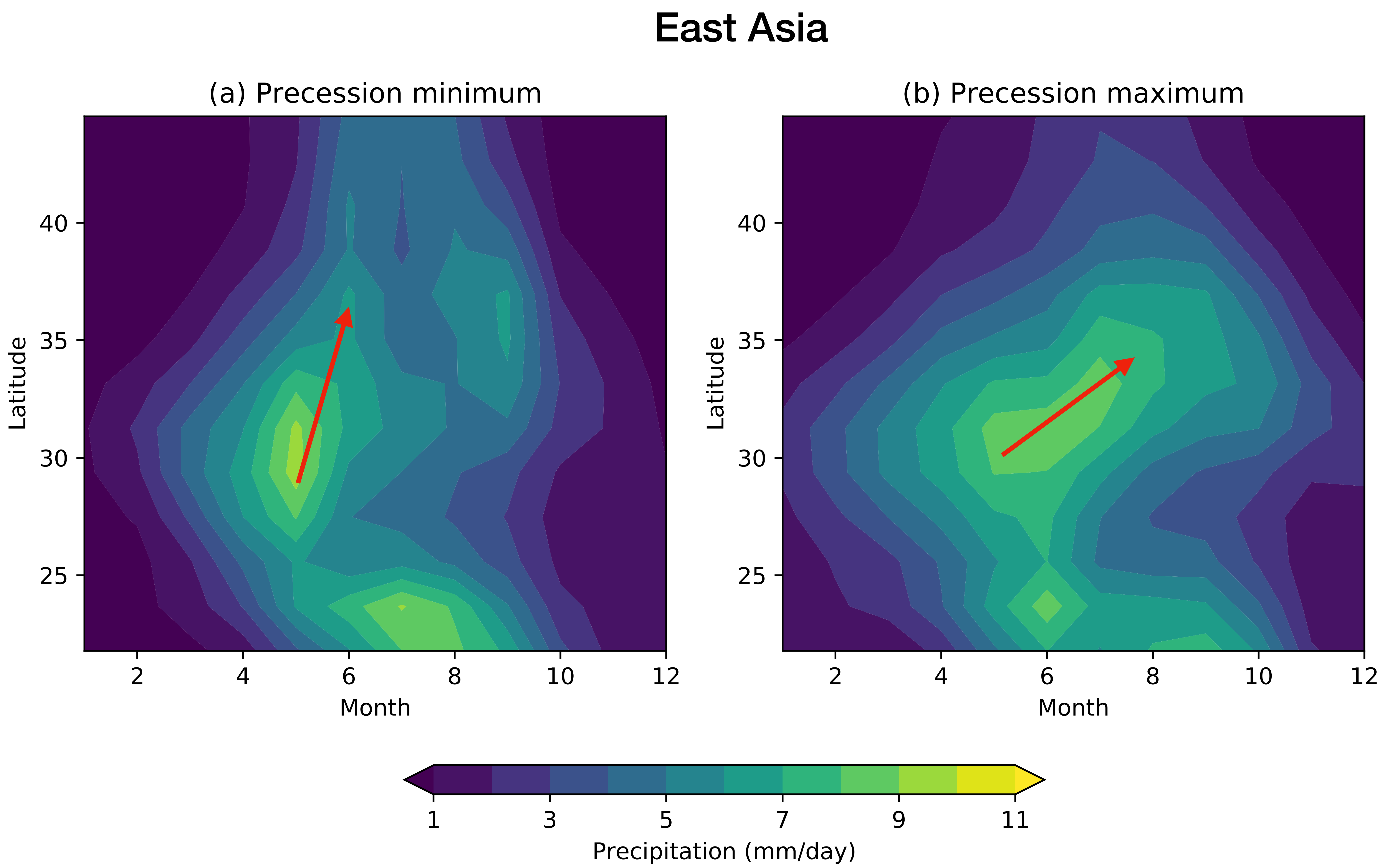
JJA 850 hPa wind difference



JJA precipitation difference



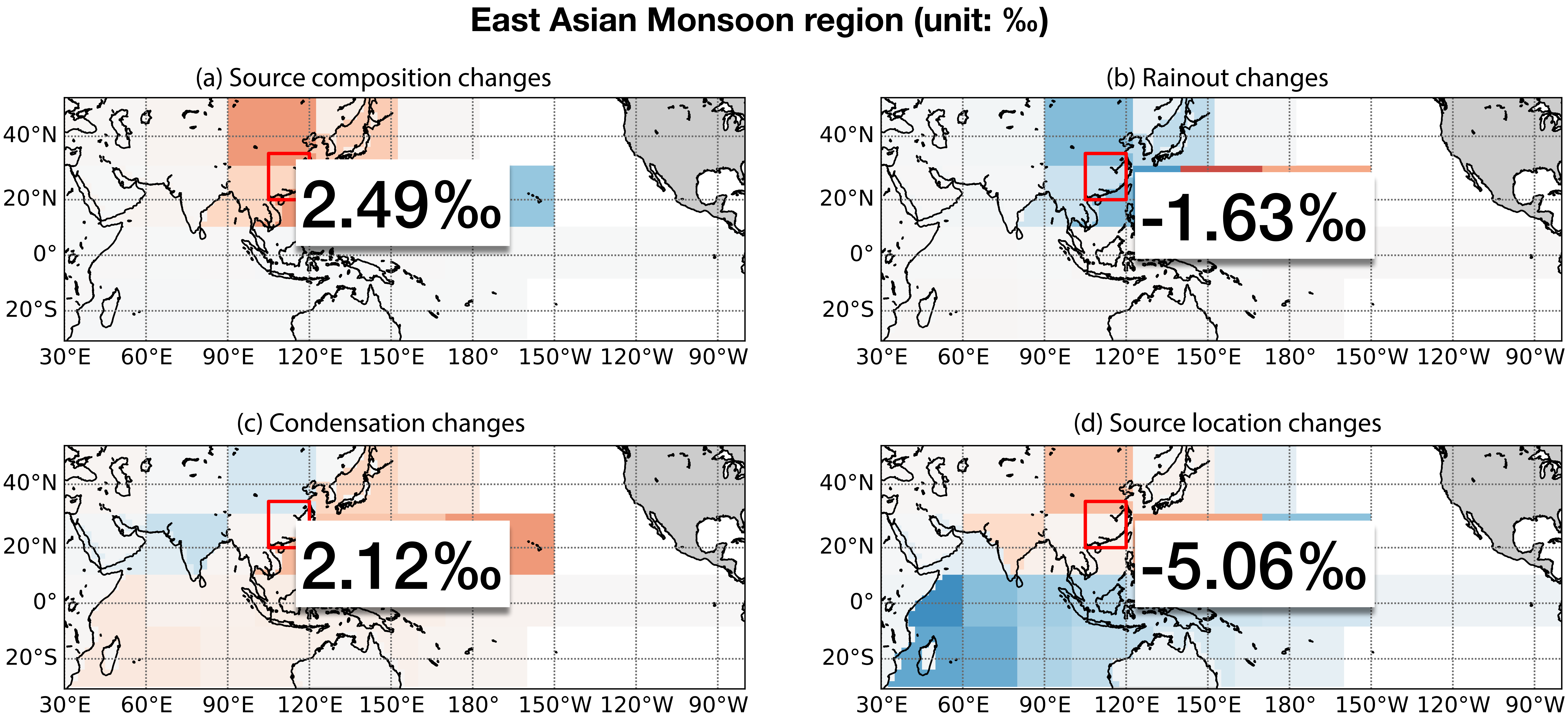
Precessional change of precipitation annual cycle



(Average between 100°E and 120°E)

Result #4: At orbital scales, depleted $\delta^{18}O_p$ in East Asia is associated with a shortened rainy season

What controls seasonal $\delta^{18}O_p$ change (JJA-DJF)? -2.08‰

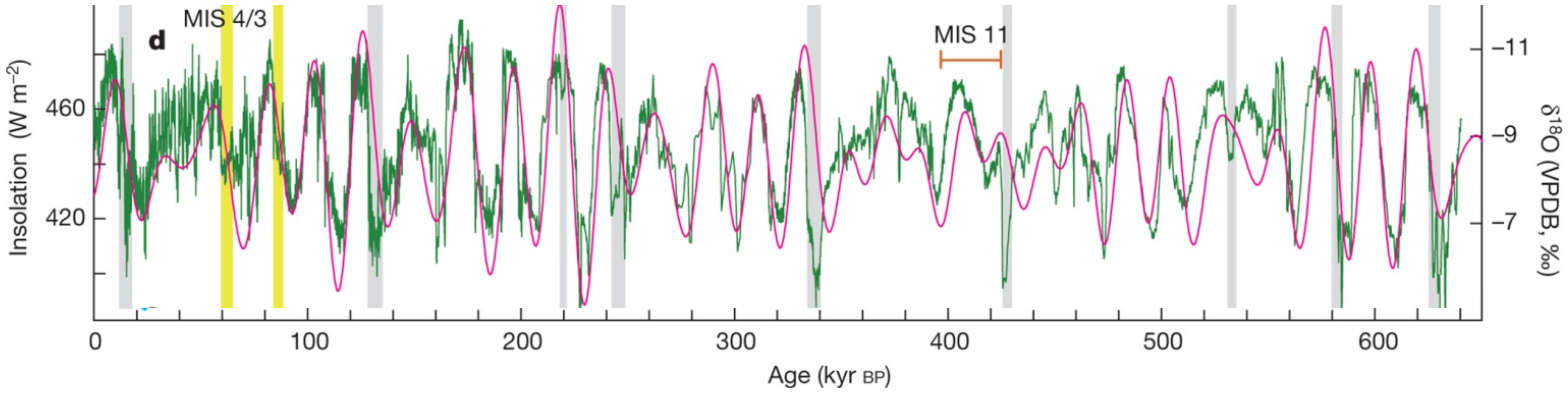


Result #5: At orbital scales, $\delta^{18}O_p$ variability in East Asia is dominated by moisture source location changes

Summary

In our experiments:

- ✳ Interannual variability in $\delta^{18}O_P$ is dominated by **moisture source location changes** for the East Asian monsoon region.
- ✳ At orbital scales, depleted $\delta^{18}O_P$ in East Asia is associated with **northward migration of the Asian monsoon winds**, resulting in:
  - ✦ Shortened rainy season
  - ✦ Decrease in precipitation amount (!)



Northward migration of monsoon winds

More moisture from the Indian Ocean

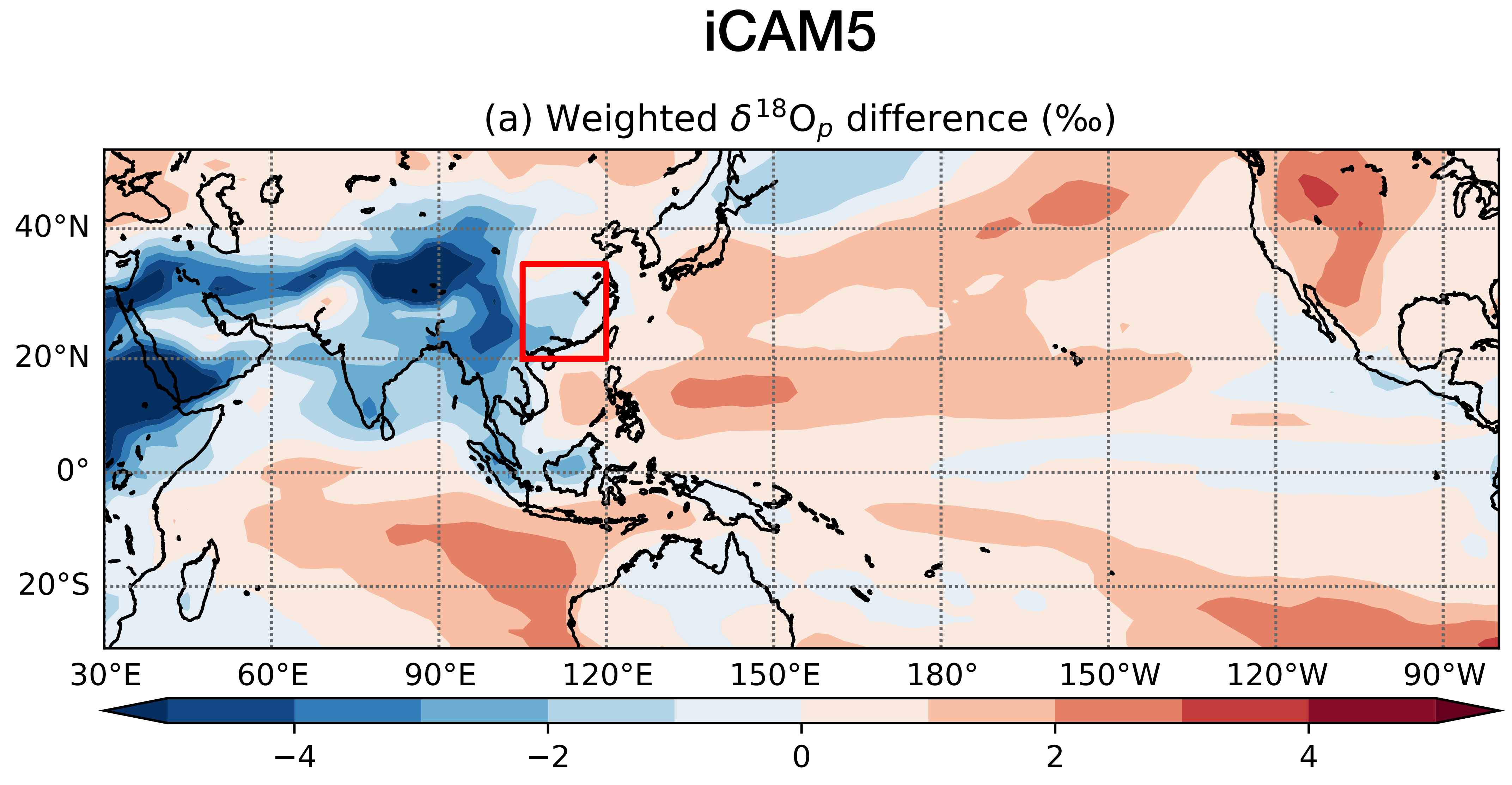
Questions?
Comments?

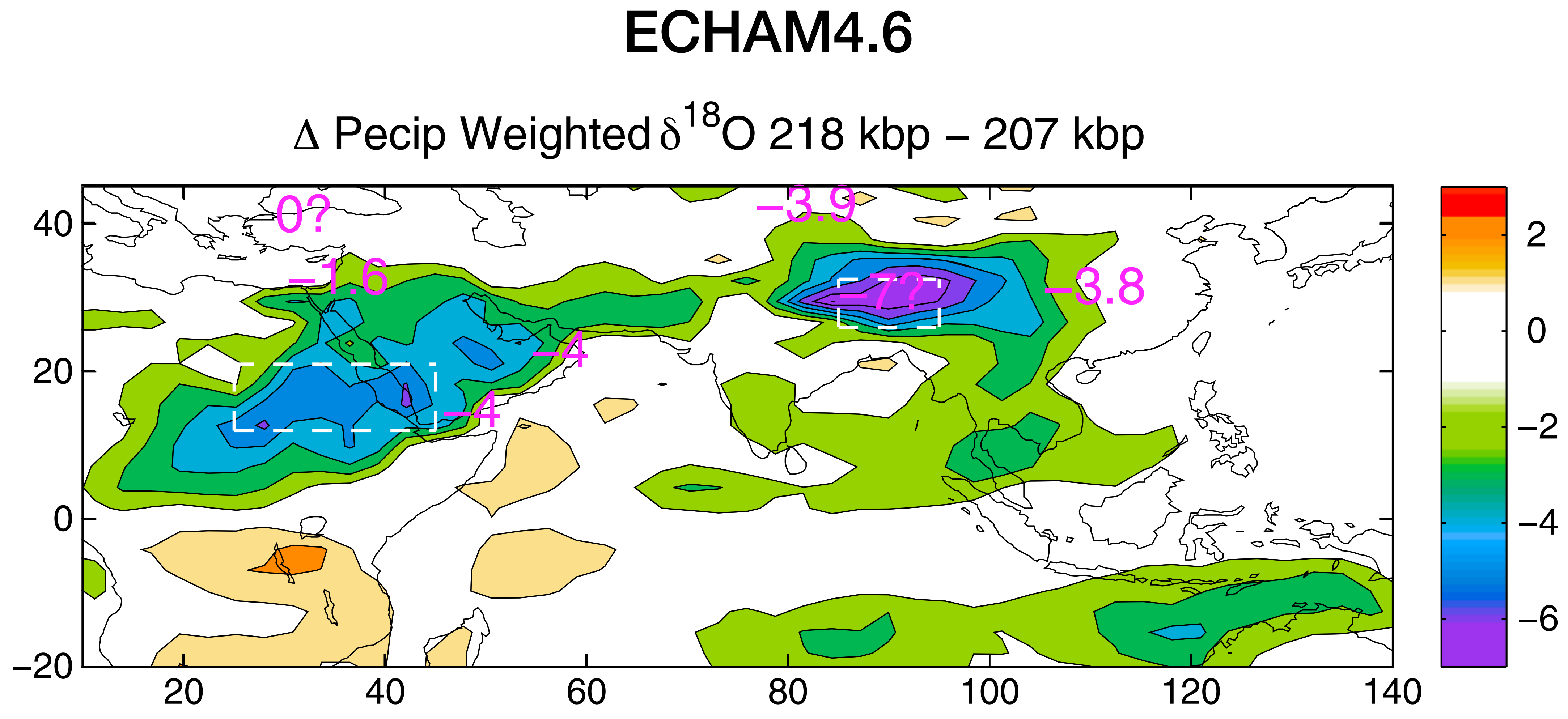
Email: jun.hu@rice.edu

Personal website:
https://junhu.info

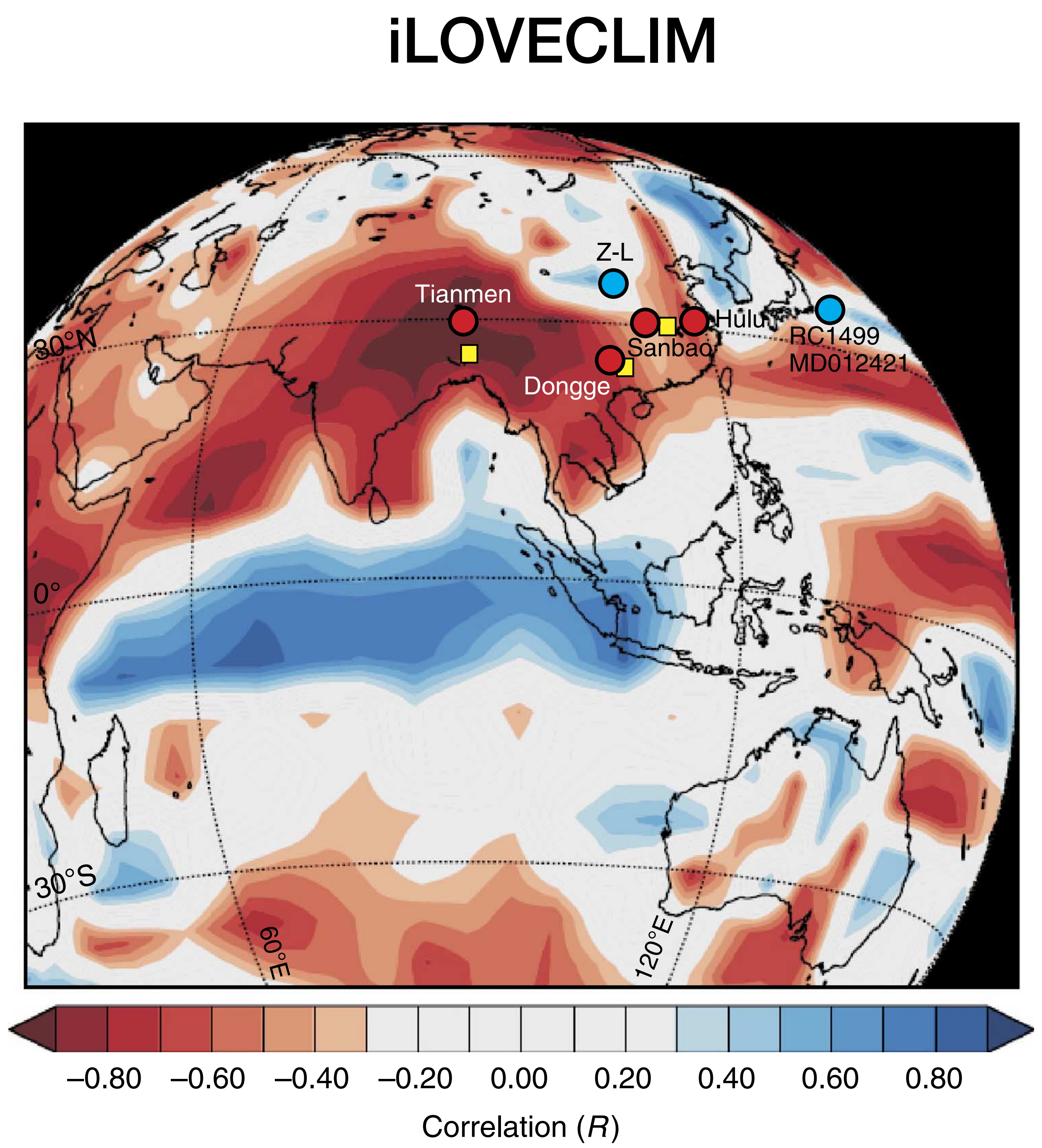
Github:
https://github.com/ClimateTools

A common model bias in East Asia?

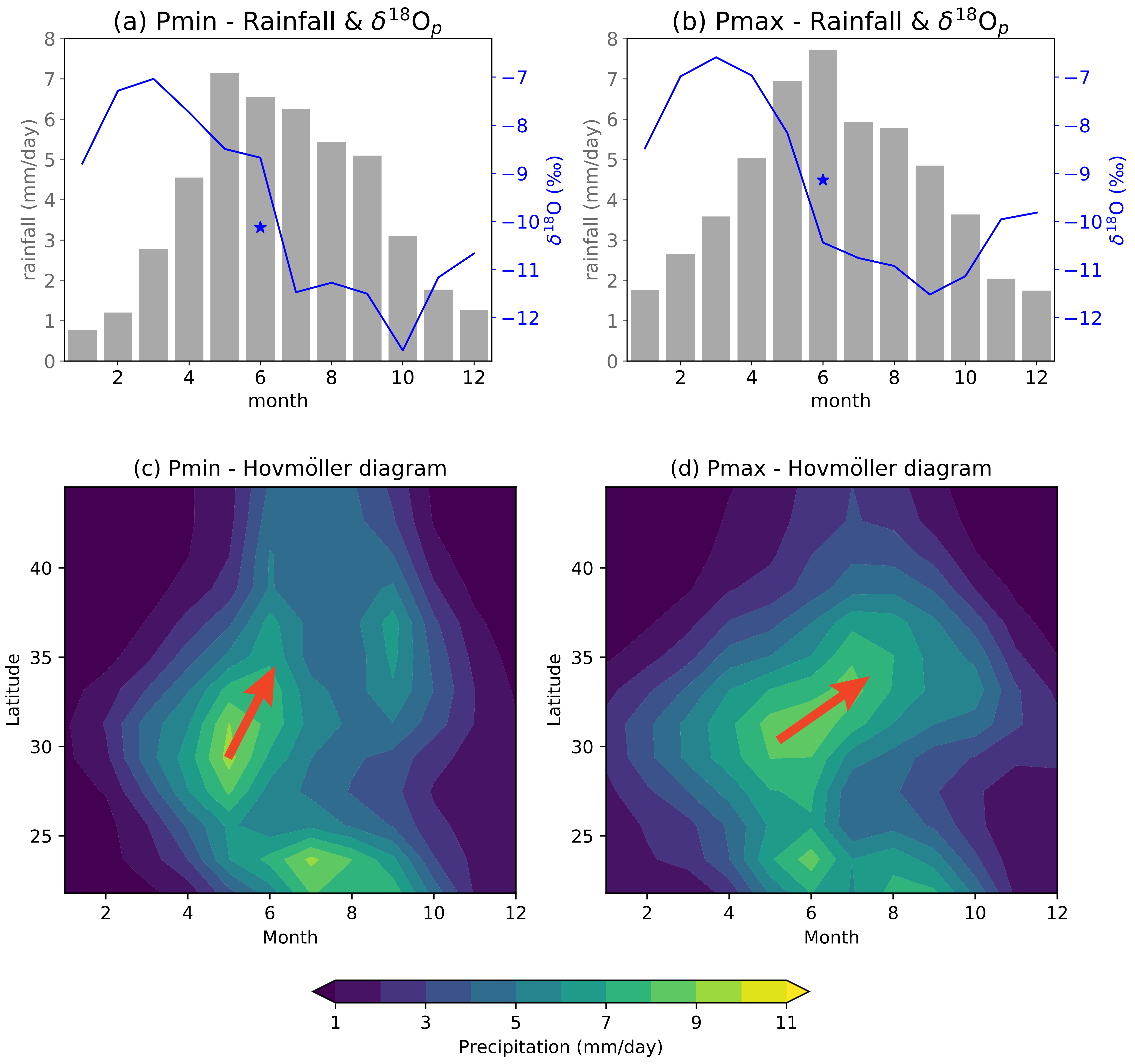




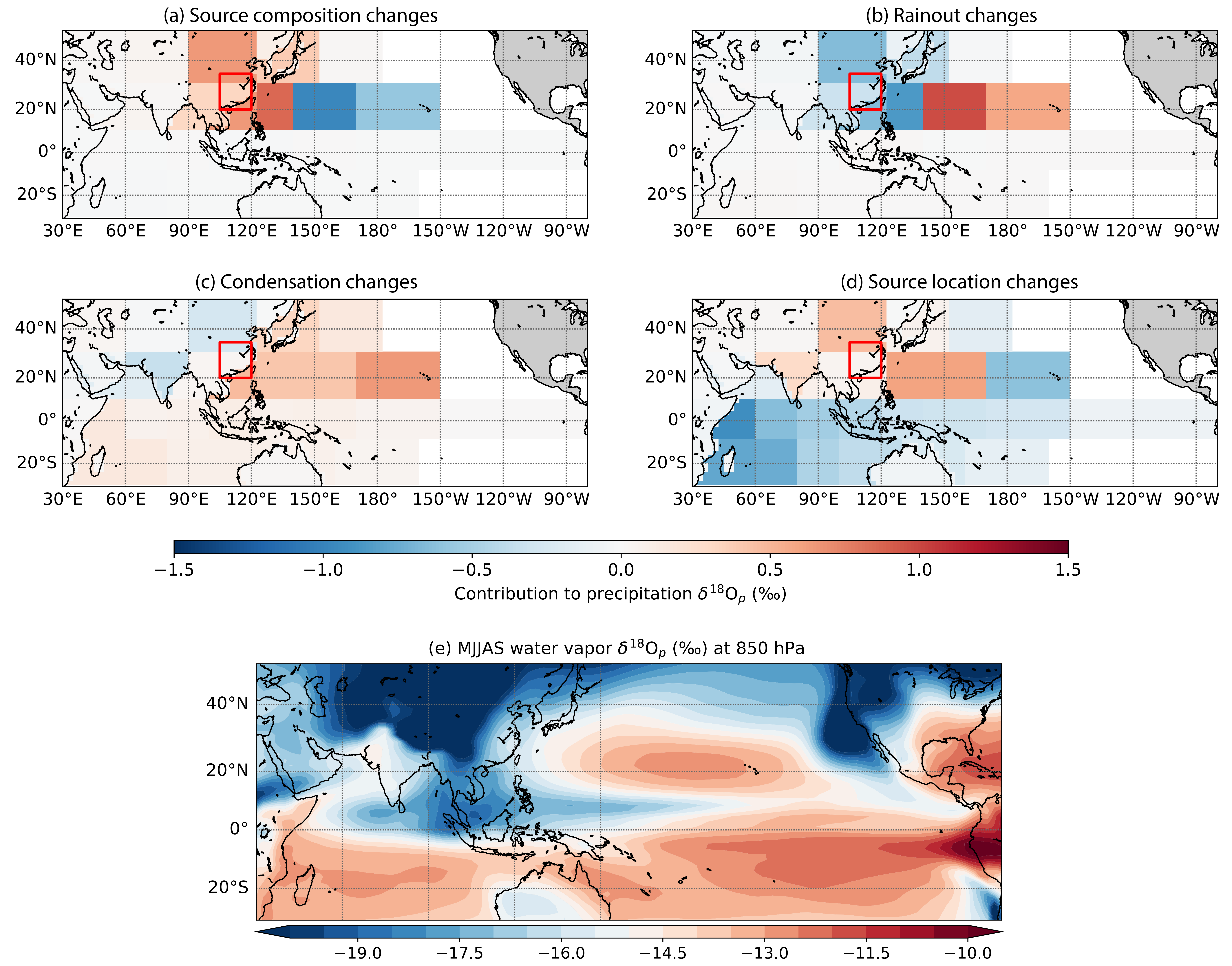
Battisti et al., 2014 (JGR-Atmosphere)



Caley et al., 2014 (Nat. Com.)



(a) Pmin - Rainfall & $\delta^{18}O_p$
(b) Pmax - Rainfall & $\delta^{18}O_p$
rainfall (mm/day)
$\delta^{18}O$ (‰)
month
(c) Pmin - Hovmöller diagram
(d) Pmax - Hovmöller diagram
Latitude
Month
Precipitation (mm/day)



(a) Source composition changes
(b) Rainout changes
(c) Condensation changes
(d) Source location changes
40°N
20°N
0°
20°S
30°E 60°E 90°E 120°E 150°E 180° 150°W 120°W 90°W
−1.5 −1.0 −0.5 0.0 0.5 1.0 1.5
Contribution to precipitation $\delta^{18}O_p$ (‰)
(e) MJJAS water vapor $\delta^{18}O_p$ (‰) at 850 hPa
−19.0 −17.5 −16.0 −14.5 −13.0 −11.5 −10.0