# Precipitation Isotope Variations in Inland Antarctica Contributed by Episodic Warm and Moist Air Intrusion from Mid-Latitudes —For a Better Understanding of Paleoclimate

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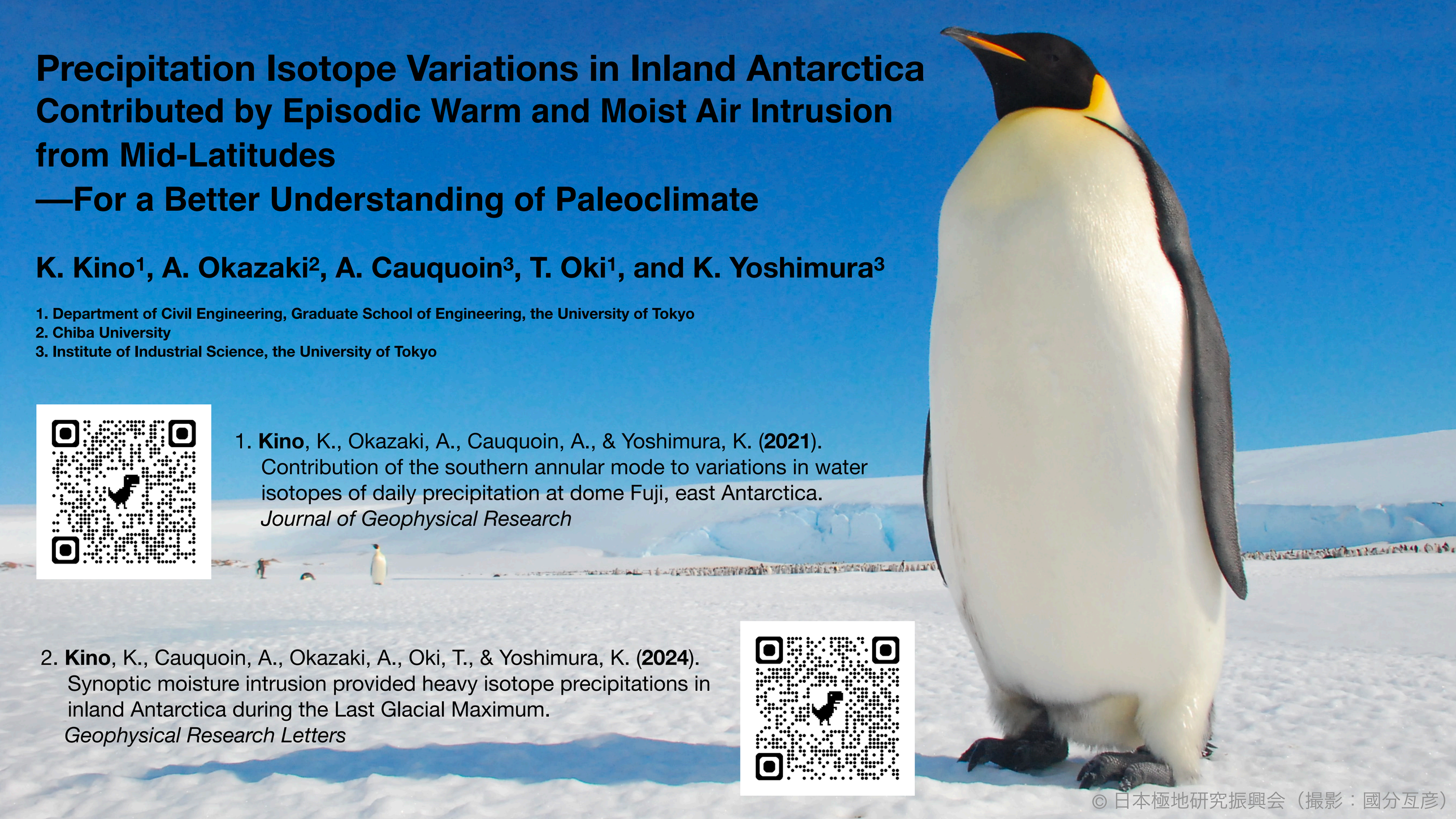
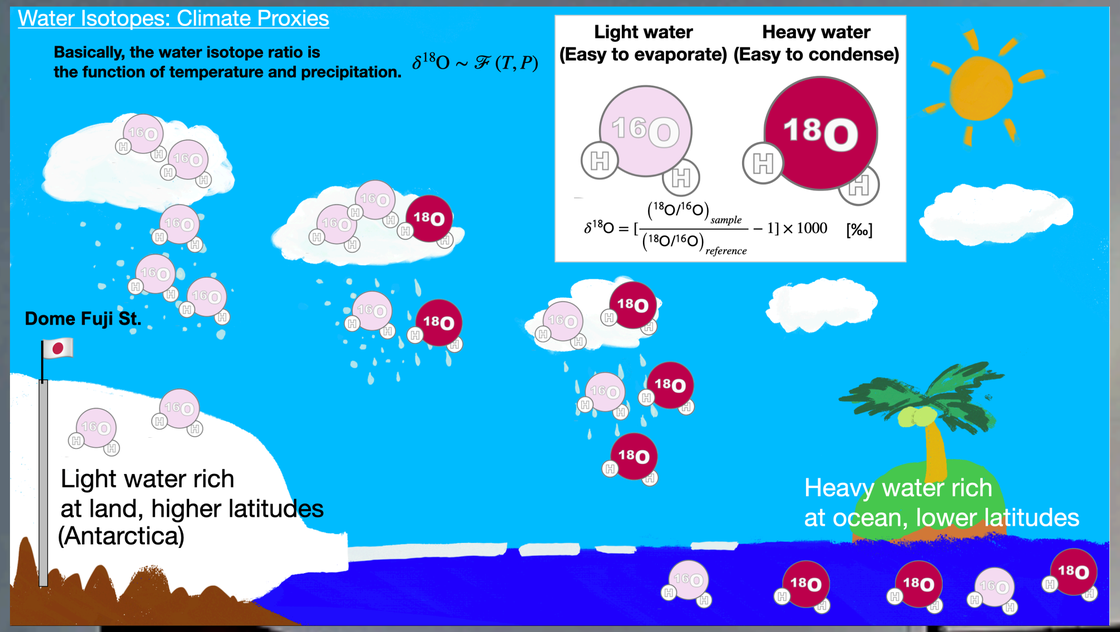
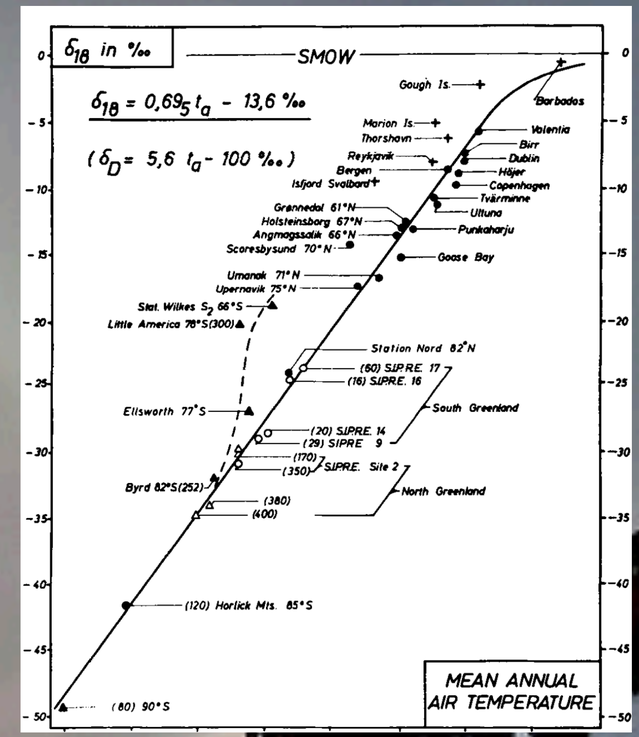


1. **Kino**, K., Okazaki, A., Cauquoin, A., & Yoshimura, K. (**2021**). Contribution of the southern annular mode to variations in water isotopes of daily precipitation at dome Fuji, east Antarctica. *Journal of Geophysical Research*

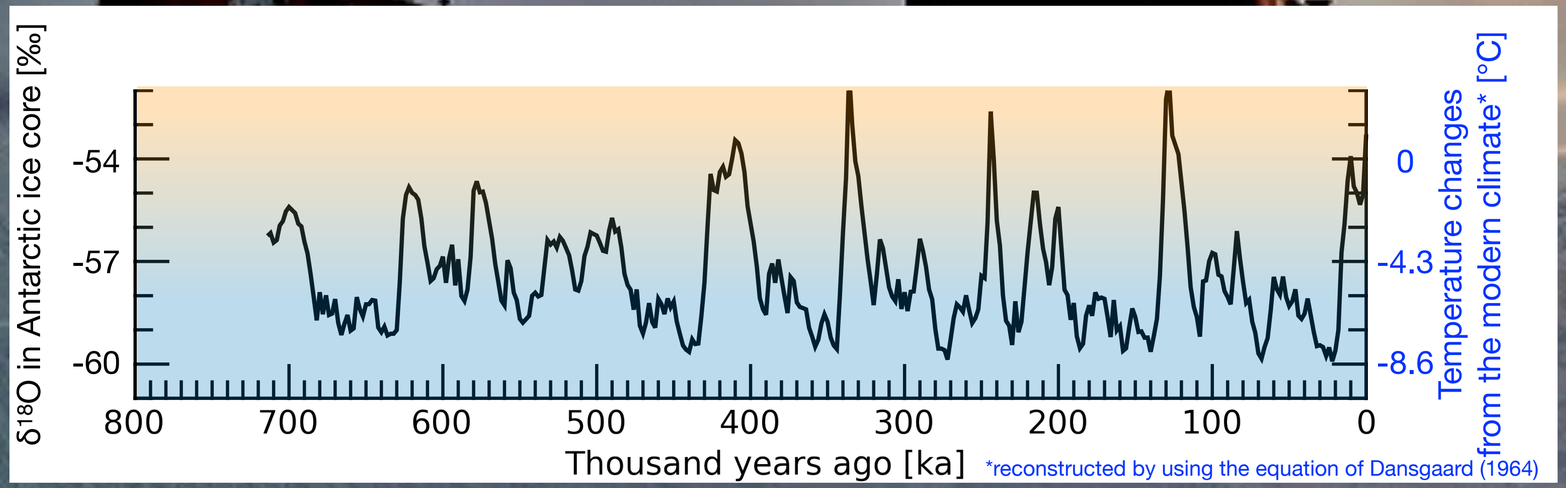
2. **Kino**, K., Cauquoin, A., Okazaki, A., Oki, T., & Yoshimura, K. (**2024**). Synoptic moisture intrusion provided heavy isotope precipitations in inland Antarctica during the Last Glacial Maximum. *Geophysical Research Letters*

# Diamond dust (clear-sky precipitation)
# has been assumed to be the main cause of precipitation in inland Antarctica.
# → Antarctic ice cores should record the mean climate.



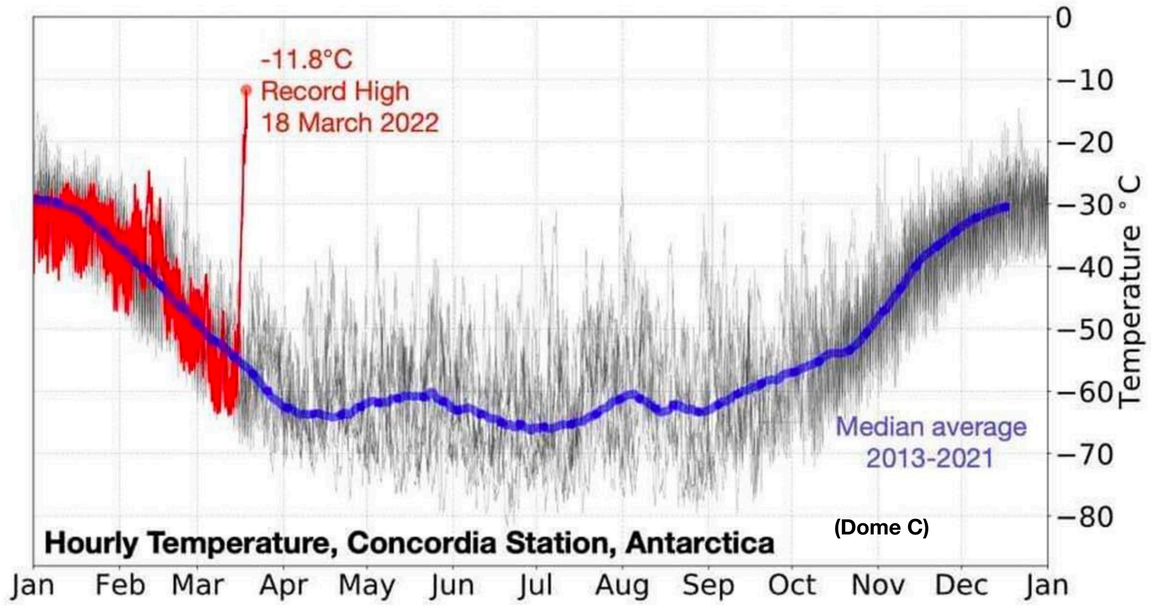

(Dansgaard, 1964)

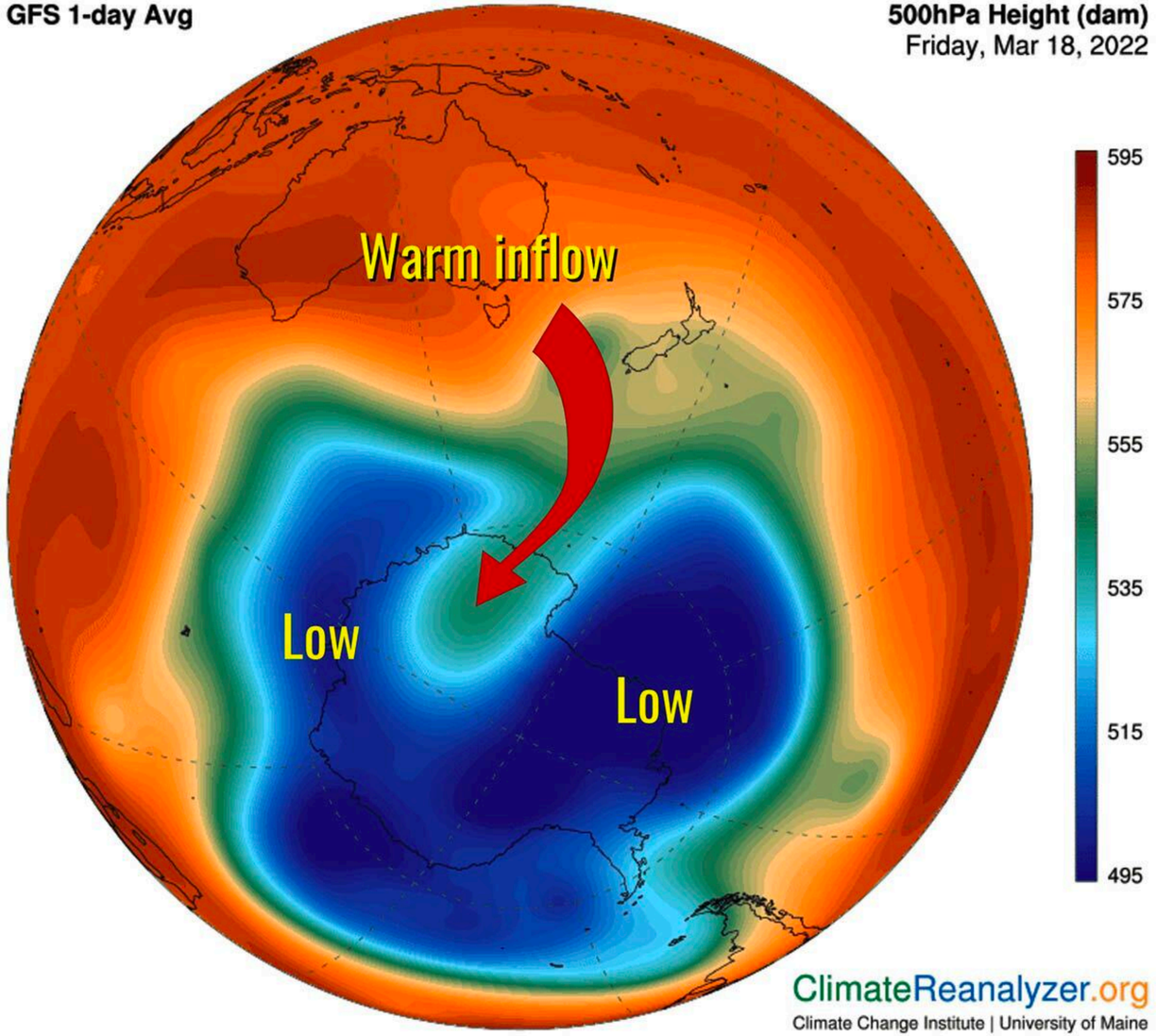



## Empirical isotopic thermometer

$$\delta^{18}O \sim kT_{local}$$

**Recent observations have revealed the contribution of extreme precipitation events to total precipitation in Antarctica.**



# Issues: Revising the ice core-based past temperature reconstruction

(2024/3/8) Kanon KINO

**Traditional view** $\delta^{18}\mathrm{O} \sim kT_{local}$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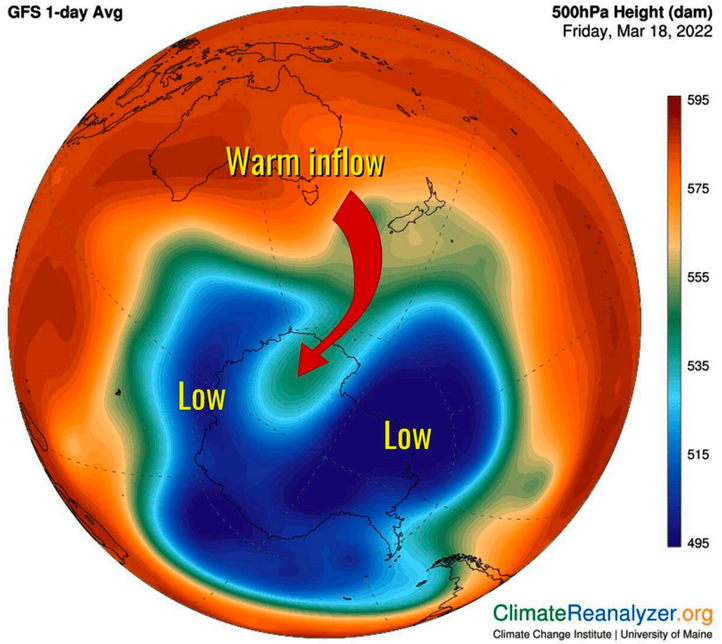
**Updated view** $\delta^{18}\mathrm{O} \sim \mathcal{F}(T, P)$

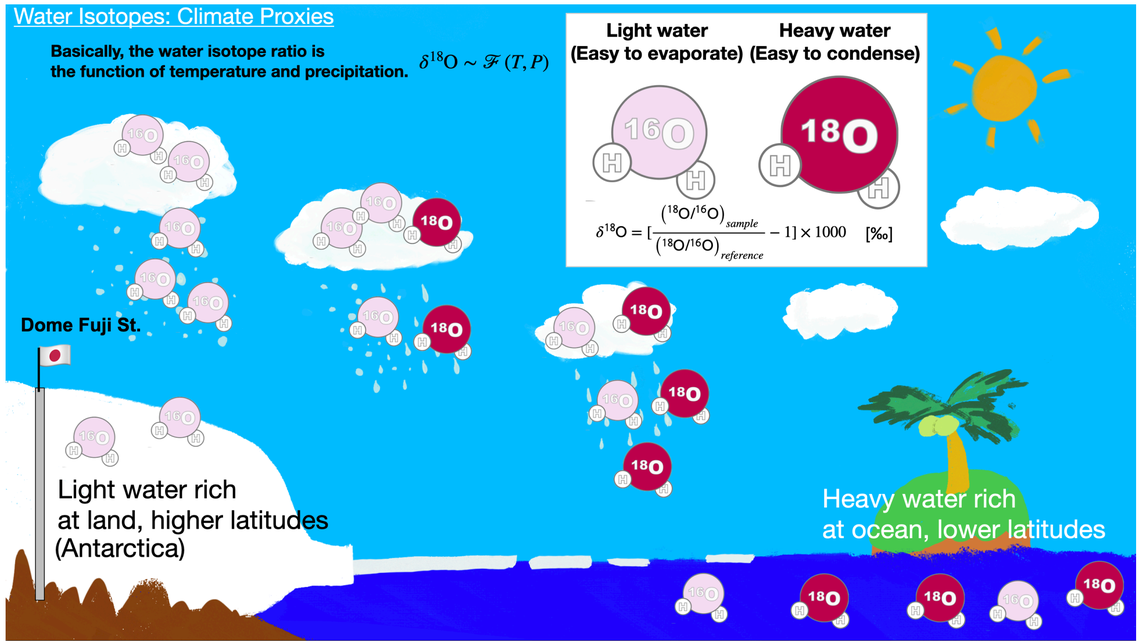
Precipitation weighting effect cannot be ignored.

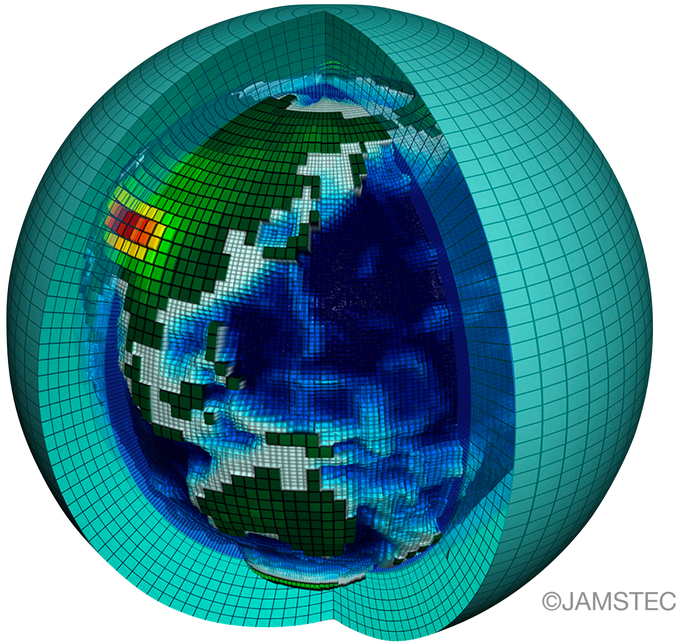



Q1. How did the synoptic-scale phenomena affect Antarctic precipitation isotopes **in the modern climate?**

Q2. How did the synoptic-scale atmospheric circulations affect Antarctic precipitation isotopes **in the past climate (paleoclimate)**?

# An isotope-enabled atmospheric climate model: MIROC5-iso (Okazaki and Yoshimura, 2017; 2019) was used.




Details

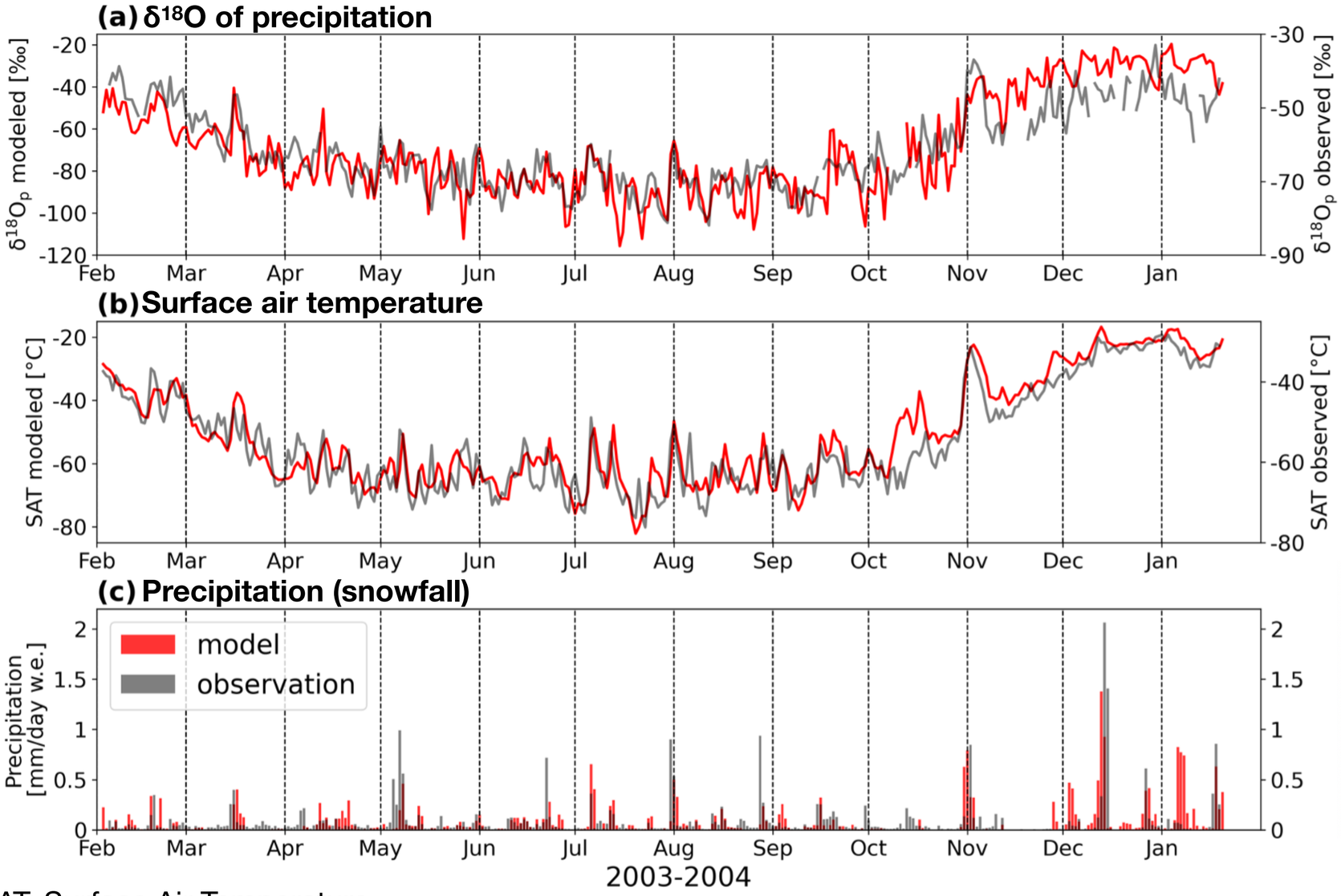
*Modern climate
- Forced by monthly climatological sea surface conditions from HadISST.
- The horizontal winds were nudged toward JRA-25 reanalysis as per the rerun of Okazaki and Yoshimura (2019).
- Model resolution: T42L40 (128x64x40 grids; ~200–300 km).
- Analyzed period: 1981–2010
- Daily SAM index was calculated based on Marshal and Thompson (2016)

*Paleoclimate (the Last Glacial Maximum)
- Following PMIP4 protocol (Kageyama et al., 2021)
- Ice sheet & topography; 21ka of GLAC-1D (Briggs et al., 2014; Ivanovic et al., 2016; Tarasov et al., 2012)
- Sea surface temperatures and sea ice concentrations were given by Paul et al. (2020) and Sherriff-Tadano et al. (2023)
- $\delta^{18}O_{sea\ ice}$ was set to 0 and 1‰ in PI and LGM, following Werner et al. (2018)
- Model resolution: T42L40 (128x64x40 grids; ~200–300 km).
- Quasi-equilibrium 30-year was analyzed after sufficient spin up.

# Observed extreme precipitation events at Dome Fuji Station, Antarctica

(2024/7/8) Kanon KINO

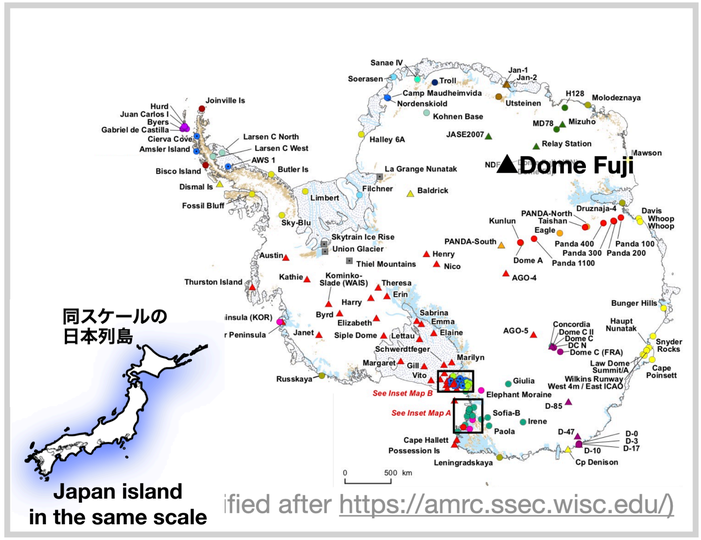
Large daily variations on the order of 10 °C/‰ in austral winter were mostly related to **blocking highs accompanied by extreme precipitation.**



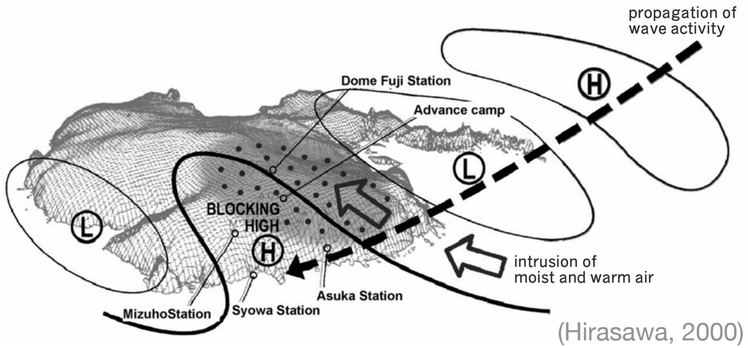

*SAT: Surface Air Temperature

*$\delta^{18}O_p$: $\delta^{18}O$ of precipitation

(Kino et al., 2021; Observation data from Fujita and Abe, 2006)




## Blocking highs




(Hirasawa, 2000)

# Winter warm bias due to the precipitation weighting

**Ice cores tend to record extreme precipitation events** and bias toward warm days**. (+11˚C in winter)**
→ We may not be able to reconstruct the annual mean temperature from ice cores.
**Similar biases were confirmed in the other ice core sites**, such as Dome C.

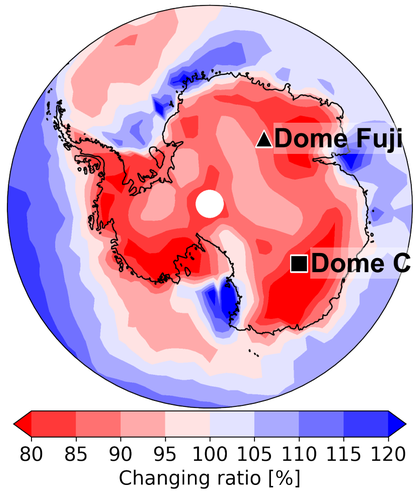
**With weighting**
(Realistic climatology)

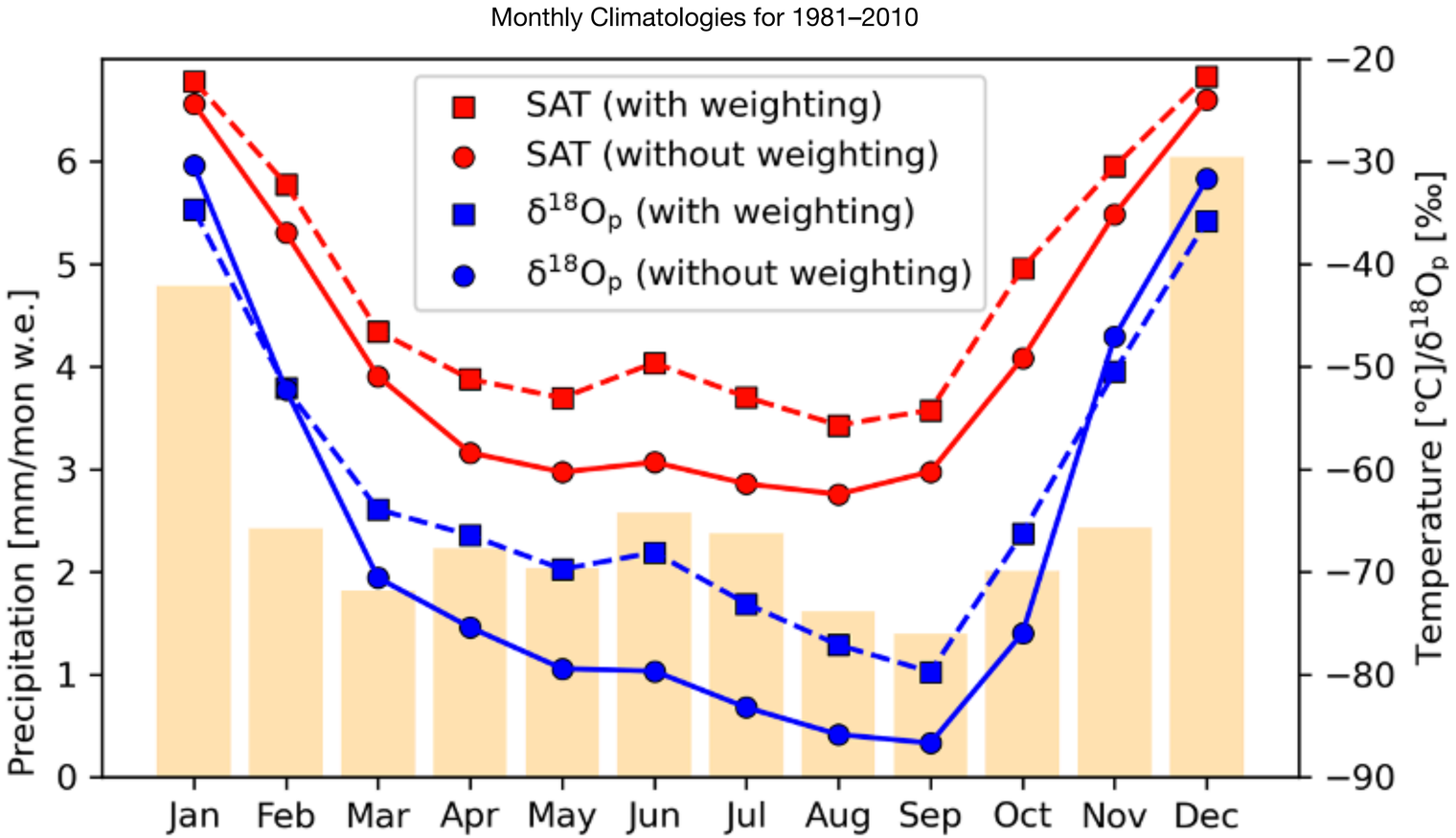
$$\delta^{18}\mathrm{O_p} = \frac{\sum \left( \delta^{18}\mathrm{O}_{\mathrm{p},d} \times P_d \right)}{\sum P_d}$$

**Without weighting**
(Idealized climatology)

$$\delta^{18}\mathrm{O_a} = \frac{\sum \delta^{18}\mathrm{O}_{\mathrm{p},d}}{N}$$

$\delta^{18}\mathrm{O_p}/\delta^{18}\mathrm{O_a} \times 100$
(JJA)



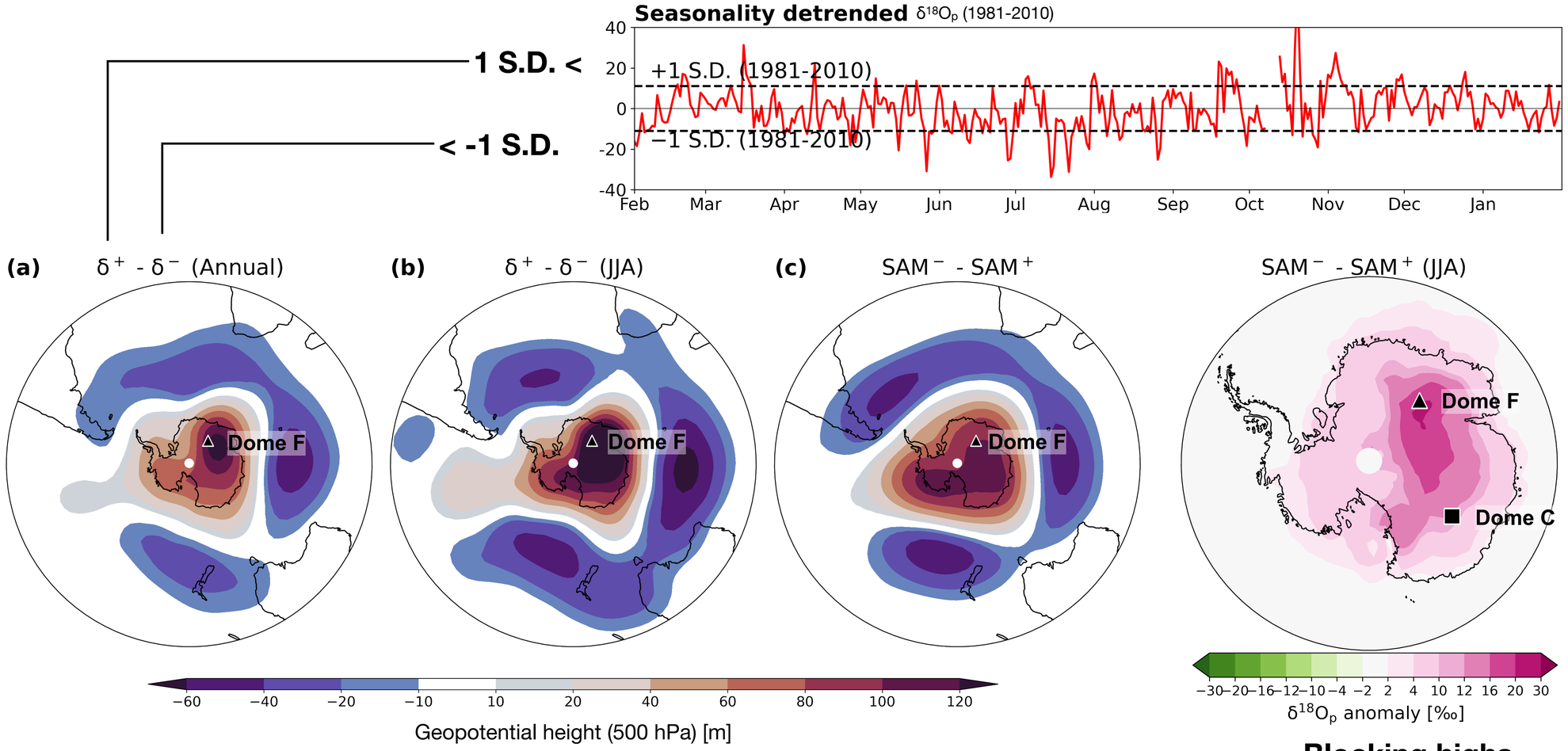




*SAT: Surface Air Temperature
*$\delta^{18}O_p$: $\delta^{18}O$ of precipitation

(Kino et al., 2021)

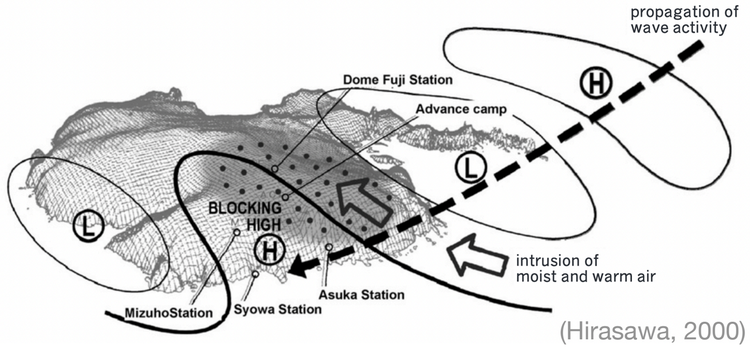
# The Southern Annular Mode drives daily $\delta^{18}O_p$ in Dome Fuji, but not at other sites

(2024/7/8) Kanon KINO



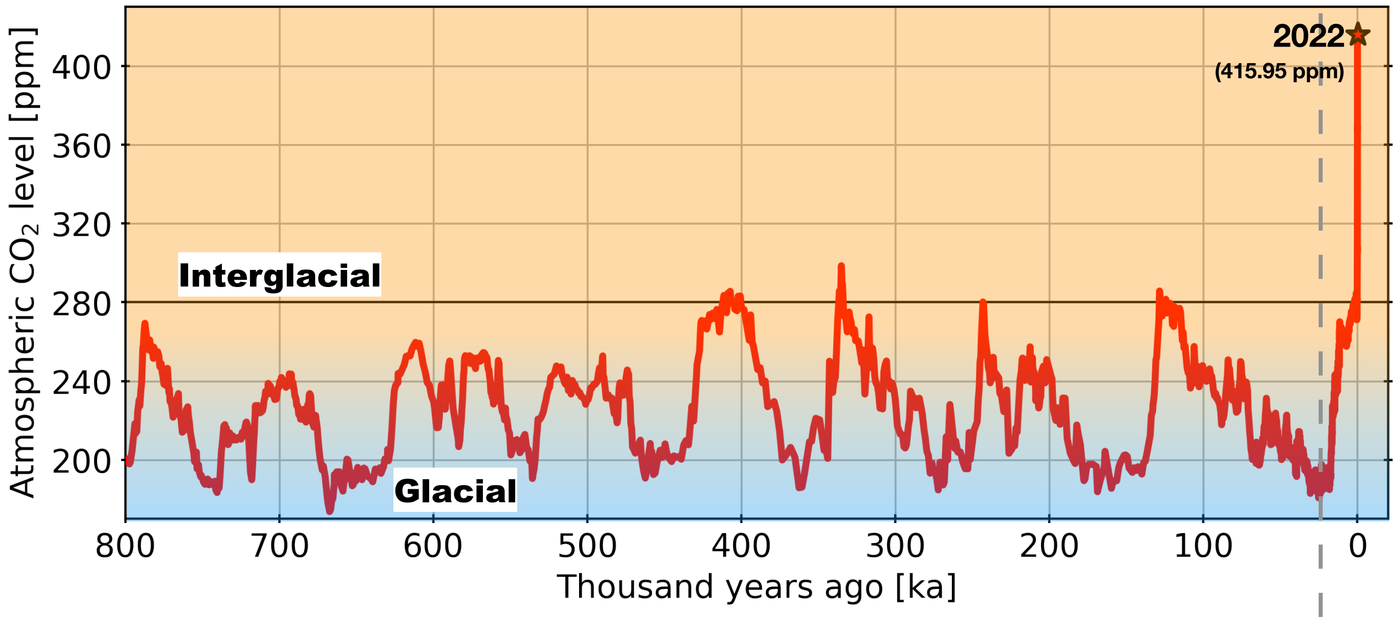

**Higher $\delta^{18}O_p$** at Dome Fuji linked to **SAM⁻** & **blockings.**
*Southern Annular Mode (SAM): indicator of southern westerly wind

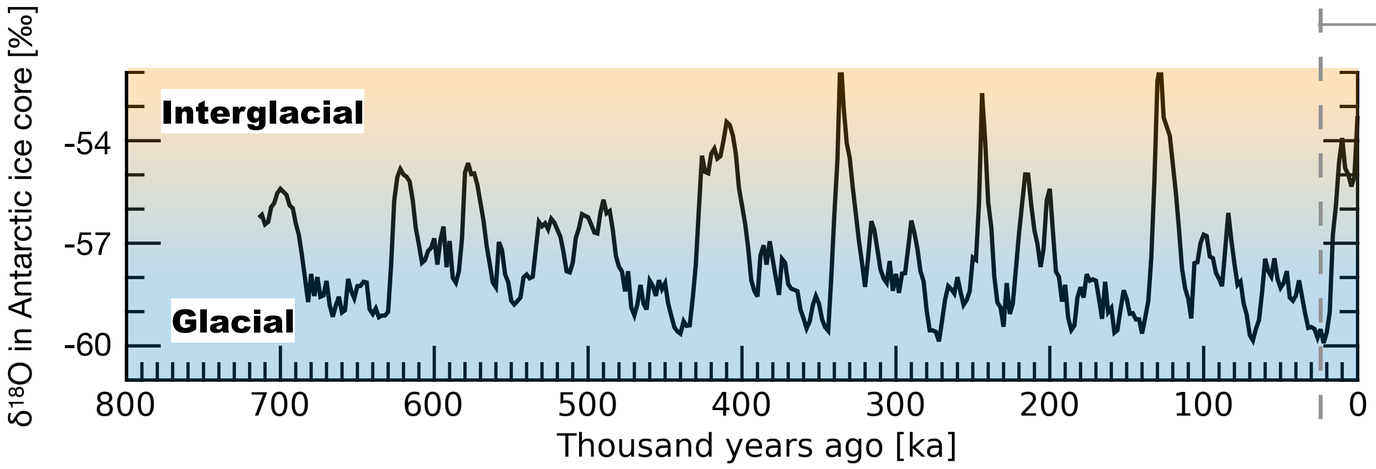
**Southern westerly wind plays an important role** in determining Antarctic $\delta^{18}O_p$, while its dominance depends on regions.




(Hirasawa, 2000)

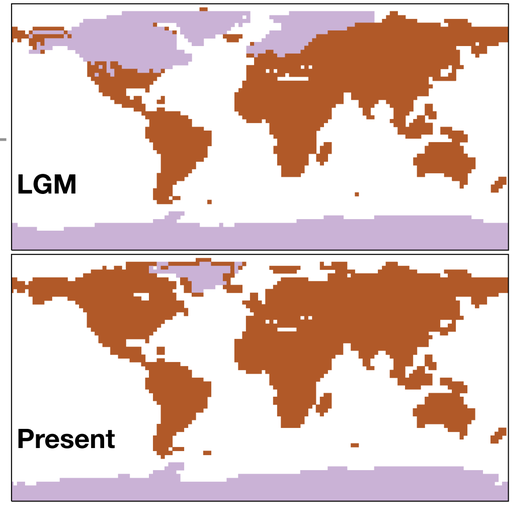
# It is essential to constrain the climate with very different $CO_2$ from the present. → Target: LGM




**Last Glacial Maximum (LGM)**
**~ 20,000 years ago**

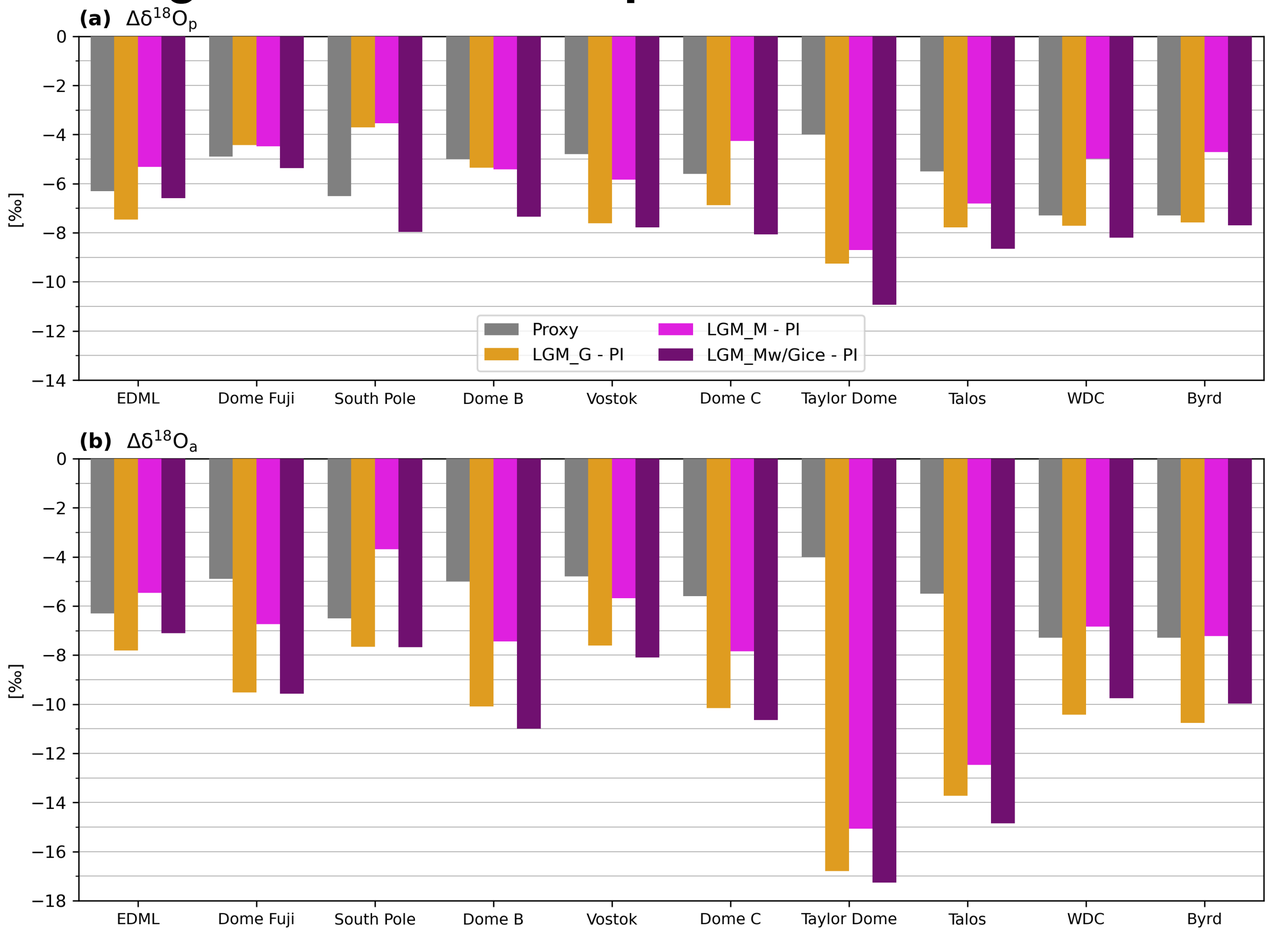

**Ice-sheet distribution**



# Precipitation weighting effect restrained $\delta^{18}O_p$ reduction from PI to LGM



## LGM might be colder than previous estimations!?



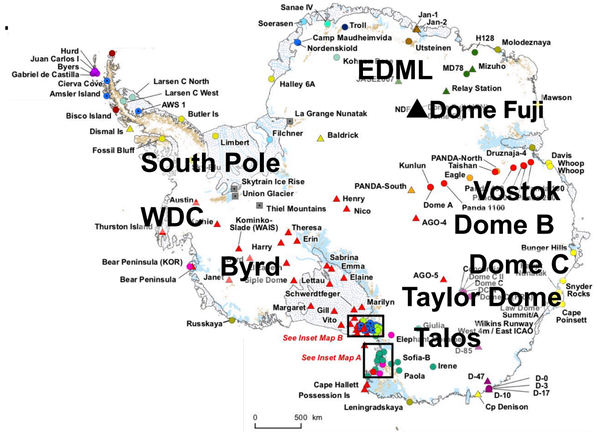

Proxy data were from Werner et al. (2018) and Steig et al. (2021).

**With weighting**
(Realistic climatology)

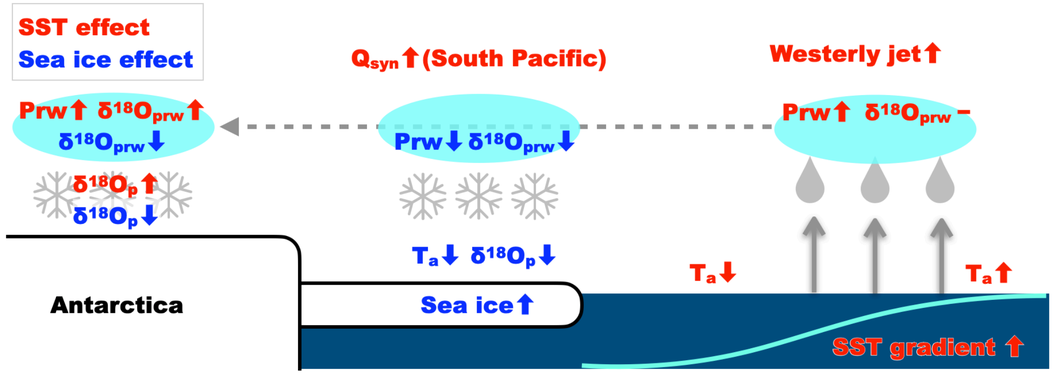
$$\delta^{18}O_p = \frac{\sum \left( \delta^{18}O_{p,d} \times P_d \right)}{\sum P_d}$$

**Without weighting**
(Idealized climatology)

$$\delta^{18}O_a = \frac{\sum \delta^{18}O_{p,d}}{N}$$




(Modified after https://amrc.ssec.wisc.edu/)


Synoptic-scale vapor ($\delta^{18}O$) transports toward inland Antarctica were well affected by the mid-latitude atmospheric circulations responded to sea surface conditions.

Q1. How did the synoptic-scale phenomena affect Antarctic precipitation isotopes **in the modern climate**?
**A1.** Synoptic-scale atmospheric circulations, namely blocking highs, play a crucial role in determining $\delta^{18}O_p$ inland Antarctica **through extreme precipitation events accompanied by abrupt warming**, resulting in **warm bias during austral winter in inland Antarctica.**

**Q2.** How did the synoptic-scale atmospheric circulations affect Antarctic precipitation isotopes **in the past climates, such as LGM** (last glacial maximum; ~21,000 years ago)?
**A2.** Basically, it is the **same as the modern climate**.

To simulate Antarctic $\delta^{18}O$ comparable to proxy records, **the accuracy of daily precipitation, including the moisture transport process, is essential**.
Then, we can revise the sensitivity of climate to changes in the atmospheric $CO_2$ level.

Our results indicated that **understanding of extreme meteorological events is beneficial for exploring paleoclimates and constraining climate sensitivity.**

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