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Exploring long term climate variability in the Quaternary with iCESM1.2

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Climate Model

- Oxygen-18 and Deuterium tracking in all model components of the Community Earth System Model 1.2 (Nusbaumer et. al.; Wong et al.; JAMES, *in review*)
  - Developed by NCAR, CU, OSU, and UW-M
  - Fully coupled 2° atm / lnd and 1° ocn / ice

Model Simulations

- 10 runs with different orbits, CO_2, and land ice
  - Initialized from equilibrium climate simulations

Run Type	Obliquity (°)	Longitude of perihelion (°)	Eccentricity	CO_2 (ppm)	Ice sheets
Preindustrial	**23.441**	**102.72**	**0.0167**	**284.7**	**0 ka BP**
Low obliquity	22.079	---	---	---	---
High obliquity	24.48	---	---	---	---
WS perihelion	---	90	0.0493	---	---
SS perihelion	---	270	0.0493	---	---
AE perihelion	---	0	0.0493	---	---
VE perihelion	---	180	0.0493	---	---
0 Eccentricity	---	---	0	---	---
Low CO_2	---	---	---	142	---
Ice Maximum	---	---	---	---	21 ka BP

Reconstruction Techniques

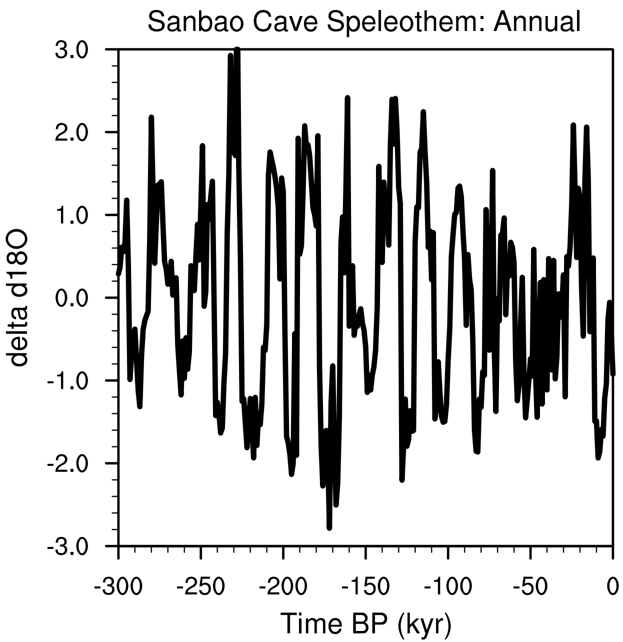
- Linear combinations of end-member forcing experiments well replicate many aspects of long term variability (Erb et al., 2015)
  - $\Delta X_{ti} = (\Delta X_{orbit} * Orbit_{ti}) + (\Delta X_{GHGs} * GHG_{ti}) + (\Delta X_{ice} * SL_{ti})$
  - Can the same technique work for water isotopes?

Example Applications

- China Speleothem $\delta^{18}O$ Records
  - Sanbao Cave (Cheng et al., 2009)
- Antarctic Ice Core δD Records
  - Fuji Dome (Kawamura et al., 2007) / Vostok (Petit et al., 2001) / Epica Dome C (Jouzel et al., 2007)
- North Atlantic Deep Water $\delta^{18}O$ Records
  - Benthic Foram Records (Lisiecki and Raymo, 2005)

Sanbao Cave Reconstruction

- $\delta^{18}O$ linear combination: good frequency but low amplitude



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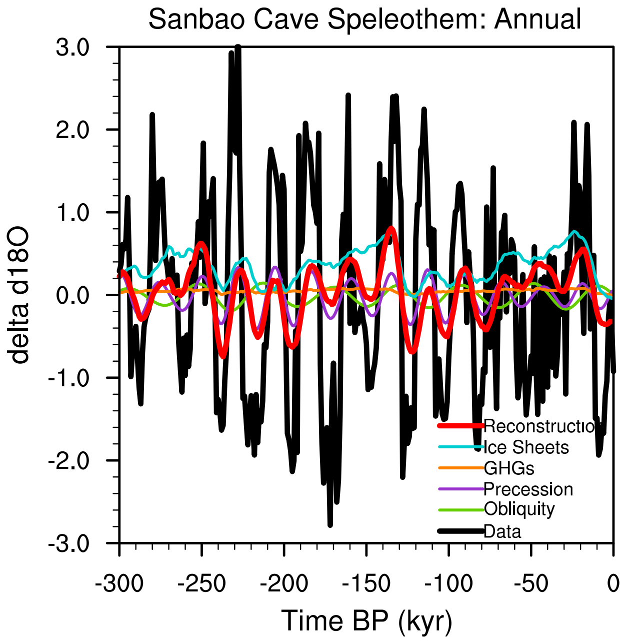
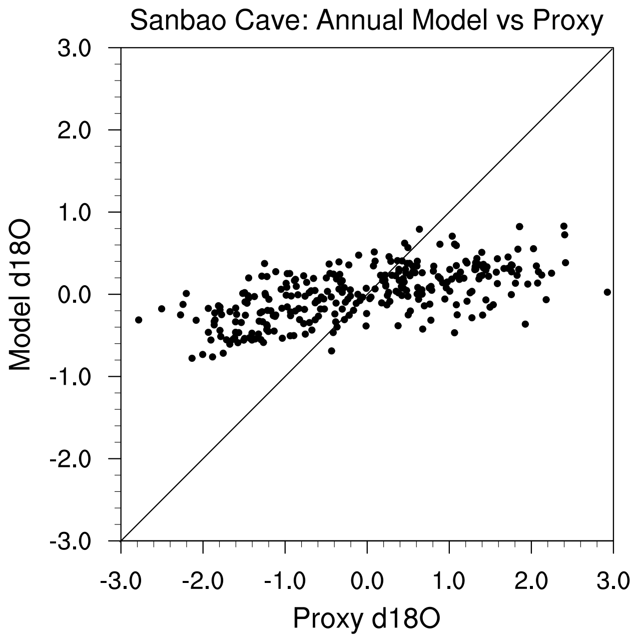
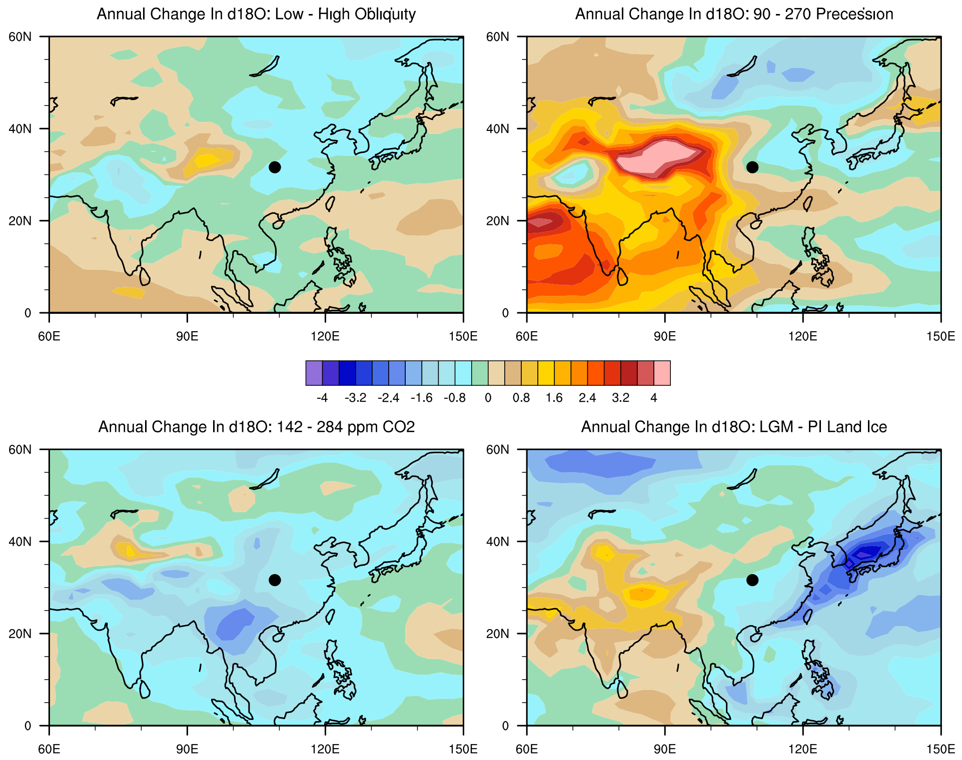




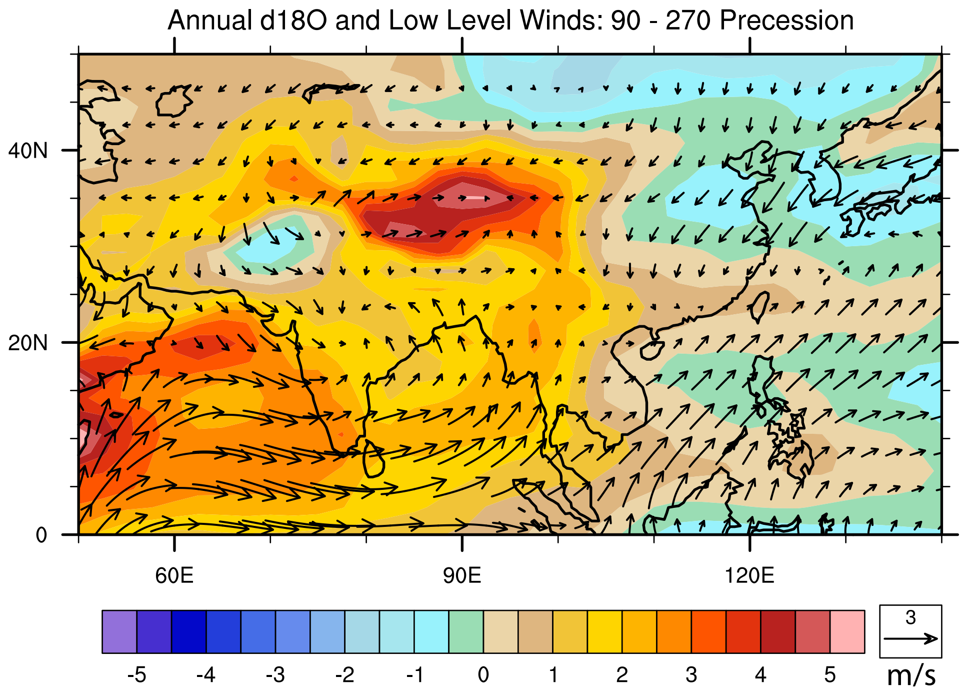
Sanbao Cave Reconstruction

- Model bias?
  - Strong $\delta^{18}O$ gradients in region
- Cave water sourced from higher altitudes?



Sanbao Cave Reconstruction

- Circulation changes are important for signals (Liu et al., 2012)



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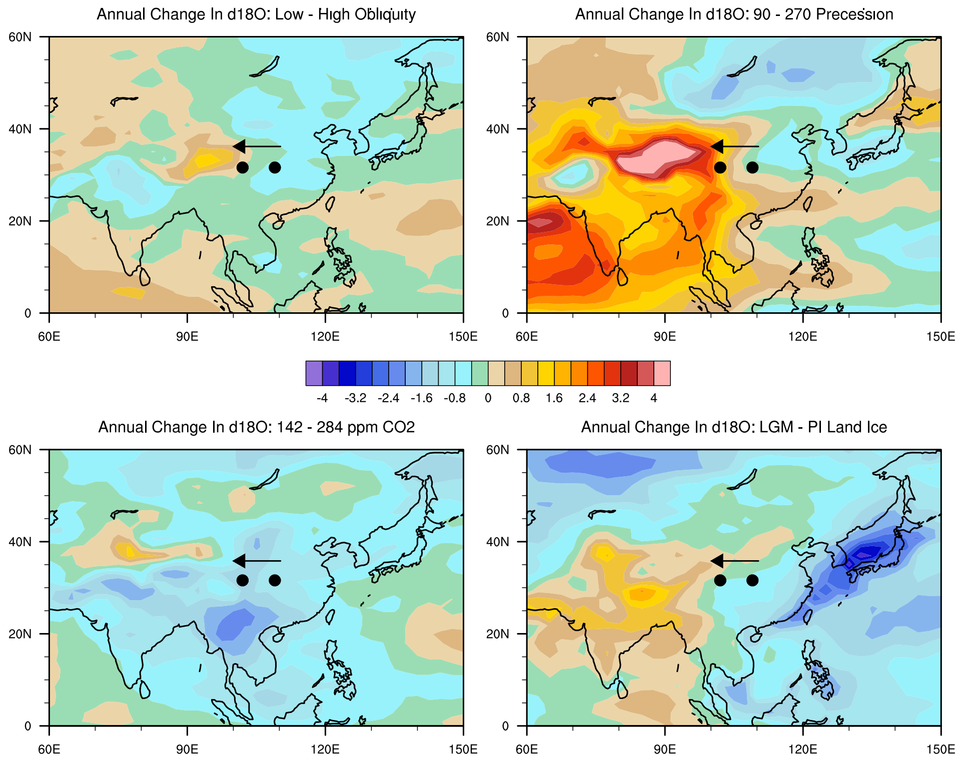

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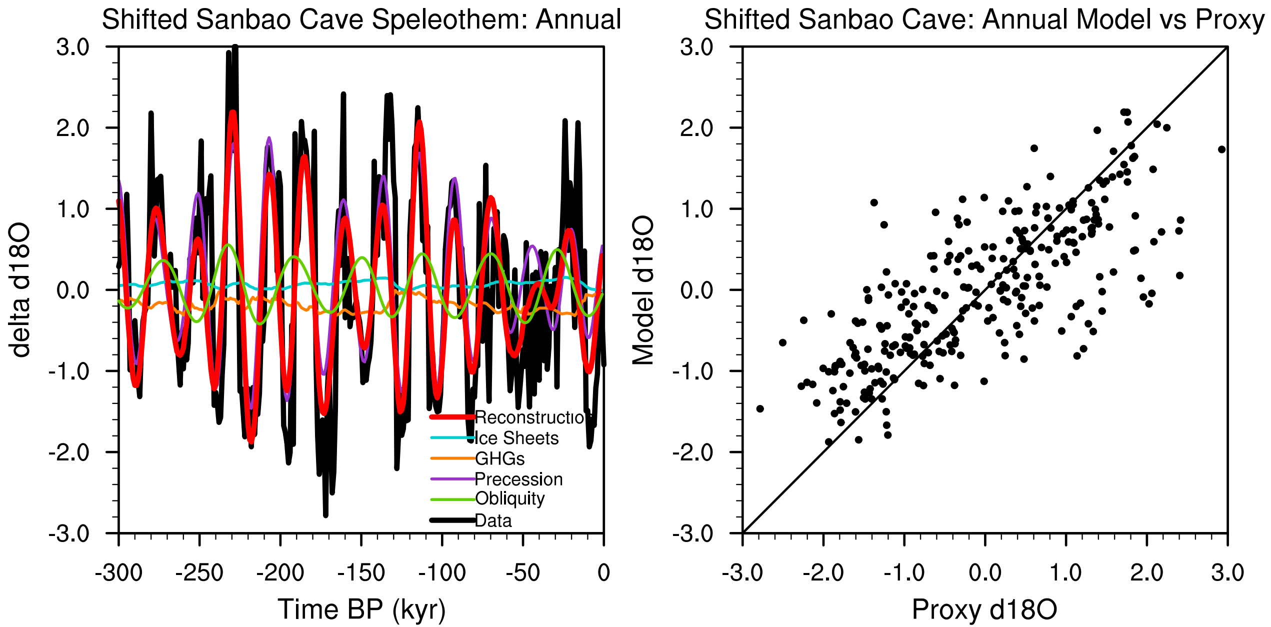

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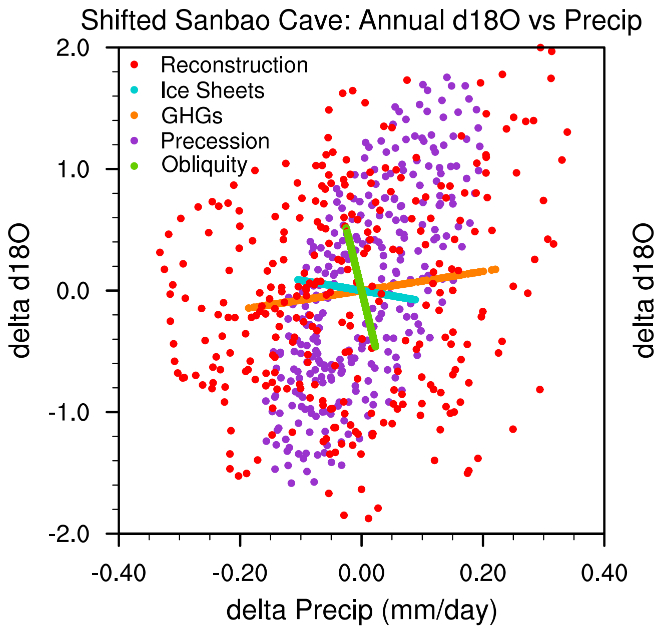
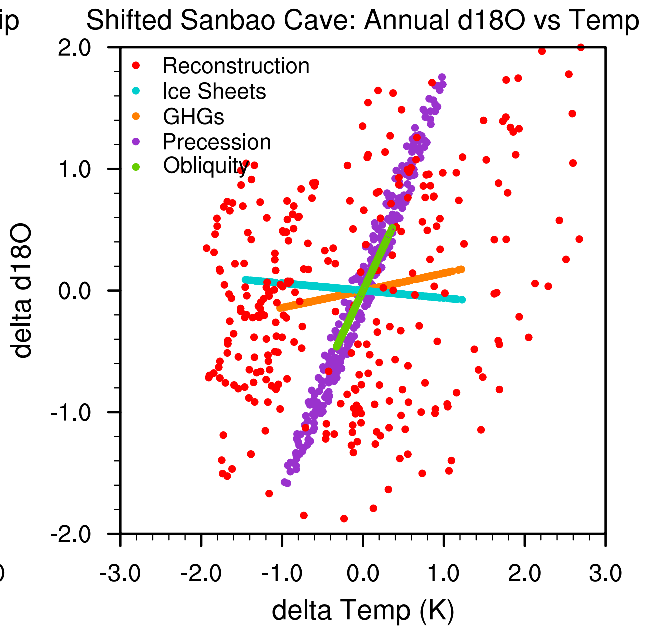
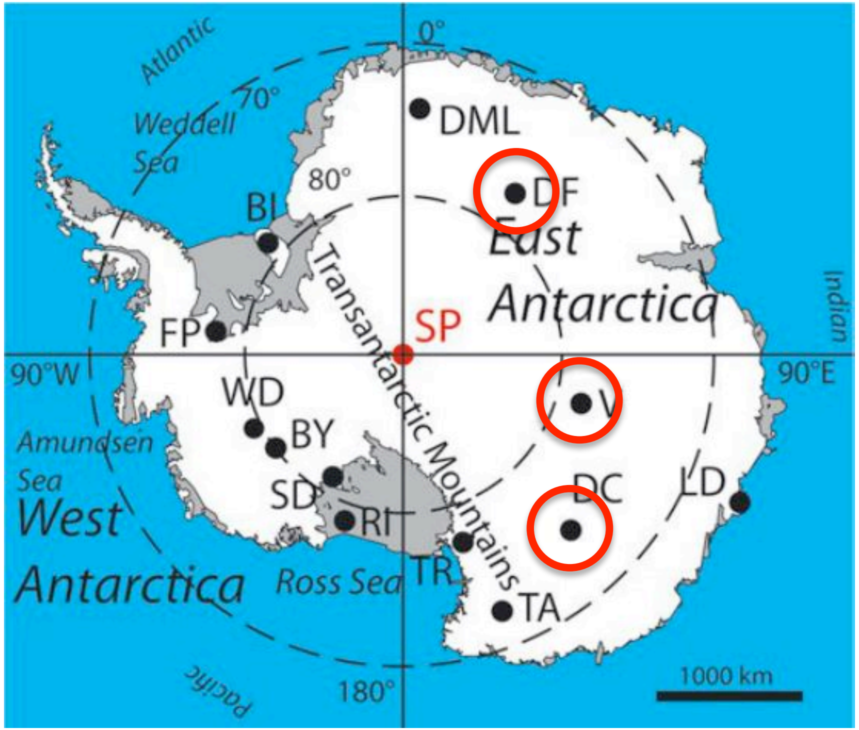
Sanbao Cave Reconstruction

- Forcings have different local temp and precip relationships



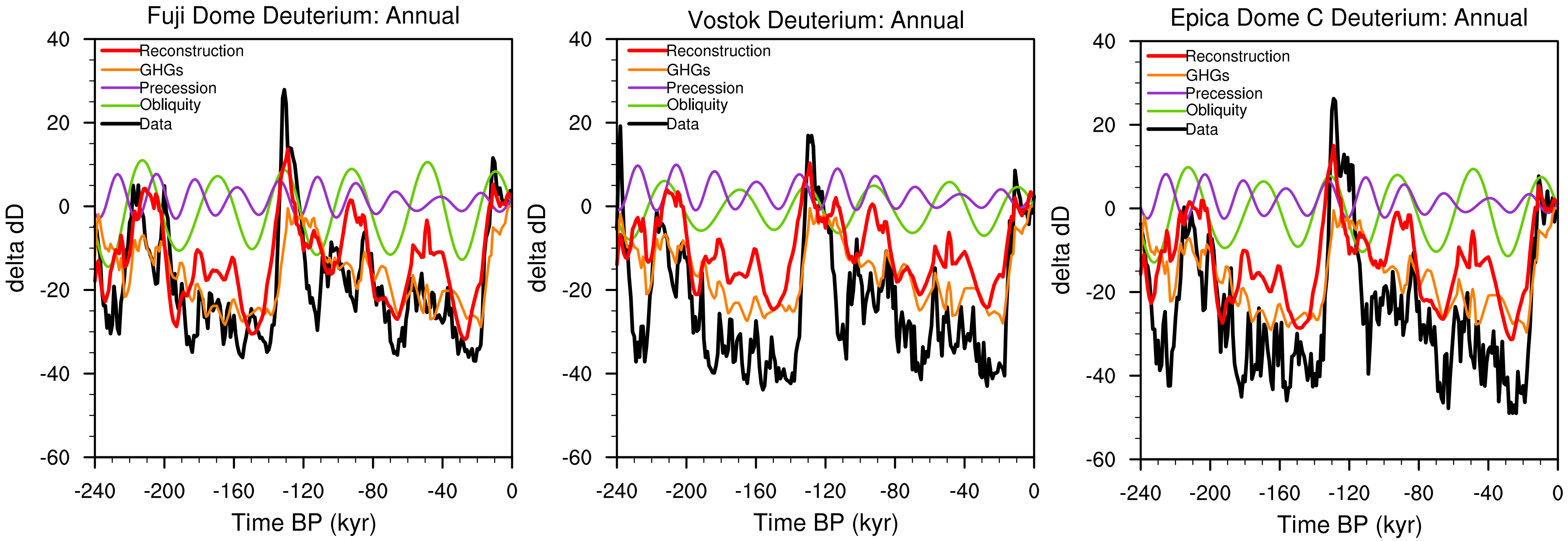


Ice Core Reconstructions



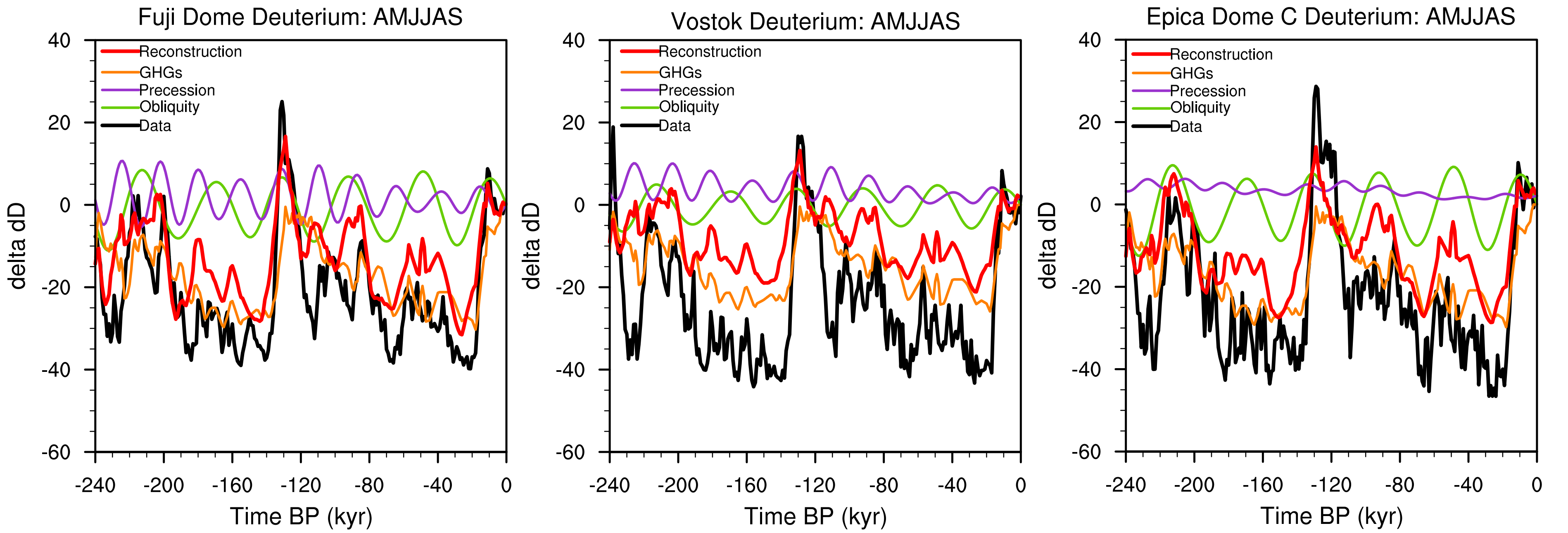
Ice Core Reconstructions

- HDO well captured by model simulations without land ice forcing



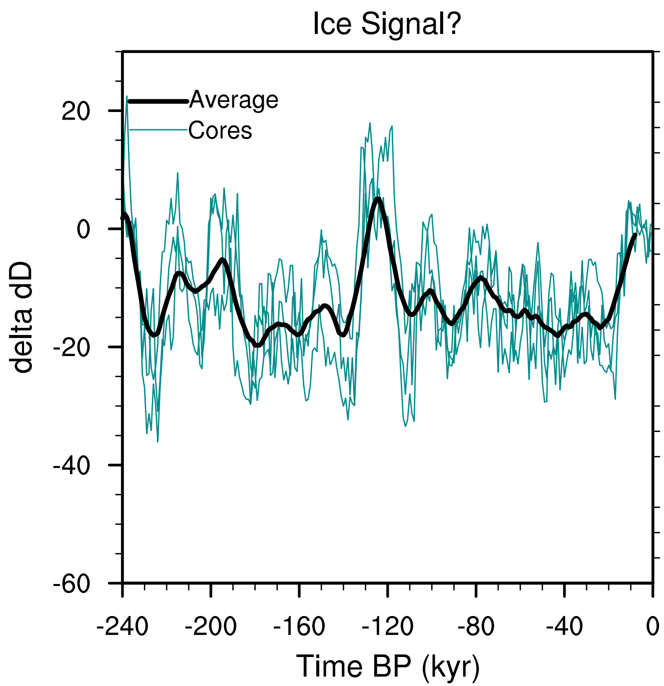
Ice Core Reconstructions

- Amplitude match especially good in Winter months



Ice Core Reconstructions

- Can model / proxy mismatch information Antarctic ice volume evolution?
  - Response similar to Antarctic ice volume simulations (Pollard and DeConto, 2009)



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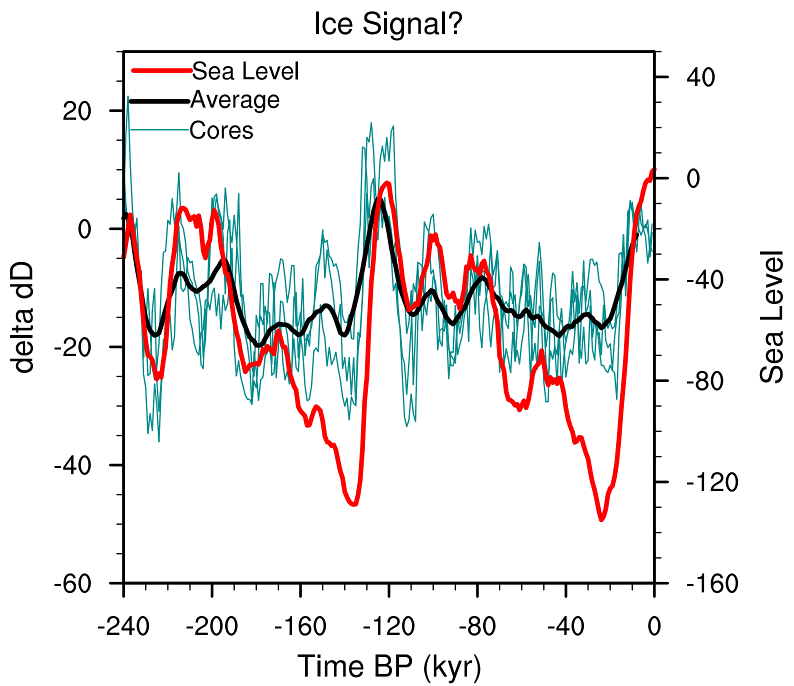

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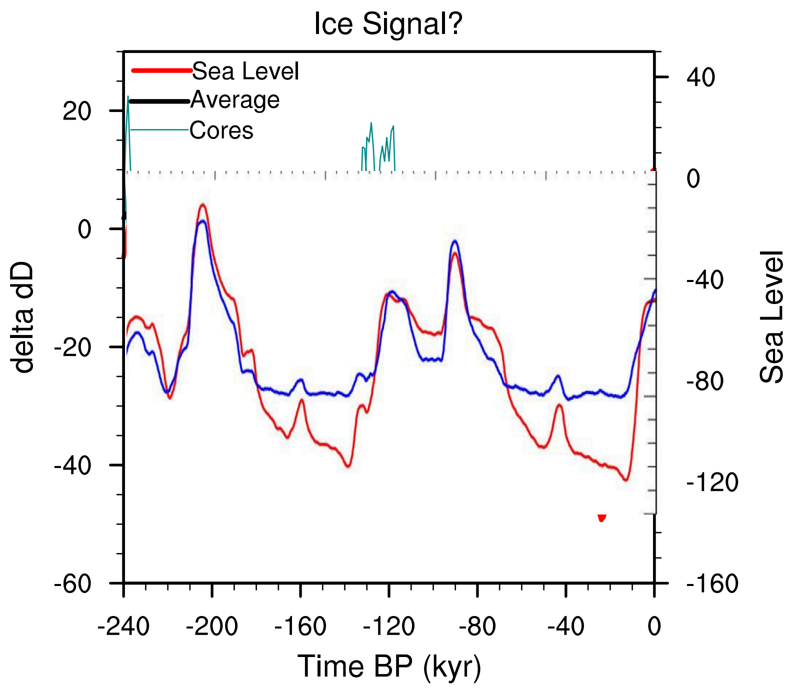

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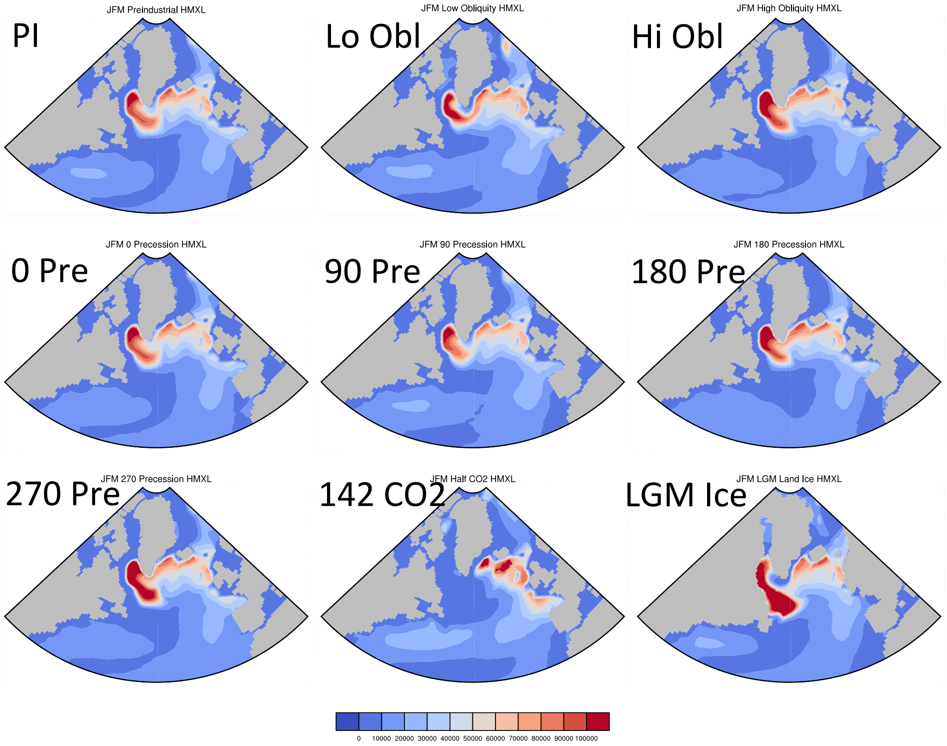
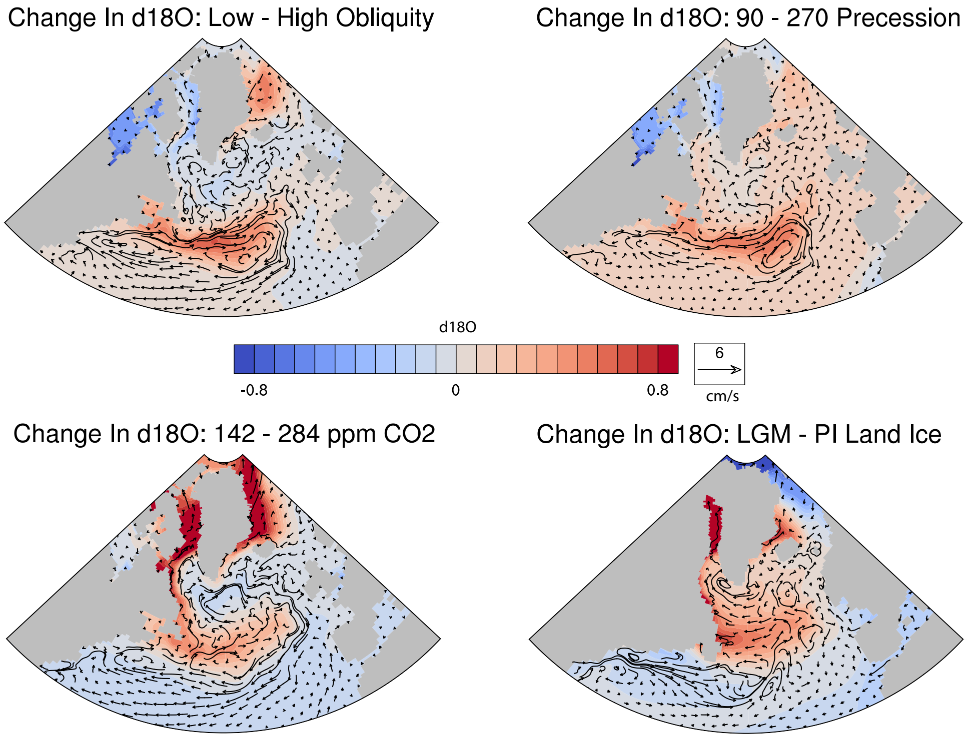
Deep Water Signals

- Can infer future deep water signal from areas of deep water formation



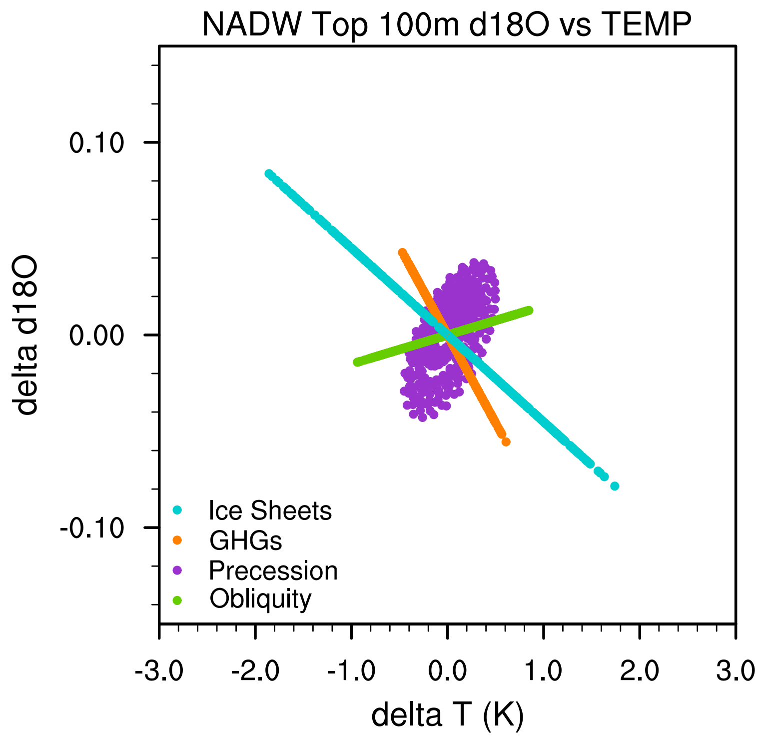
Deep Water Signals

- Small $\delta^{18}O$ variability in locations of NADW formation due largely to circulation changes



Deep Water Signals

- Linear theory unlikely a good assumption for NADW
- Signal dominated by land ice and CO_2
- Relationship between $\delta^{18}O$ and temperature depends on the forcing



Outlook

- Simulations can help us decompose signals in the isotopic records

- Use model outputs in specific proxy models

$$\text{base} = X_{0\text{ecc}},$$

$$\Delta X_{\text{obliq}} = \frac{\epsilon - \epsilon_{\text{preind}}}{\epsilon_{\text{high}} - \epsilon_{\text{low}}}(X_{\text{high}} - X_{\text{low}}),$$

$$\Delta X_{\text{ecc\_adjustment}} = \left(\frac{X_{\text{AE}} + X_{\text{WS}} + X_{\text{VE}} + X_{\text{SS}}}{4}\right) - X_{0\text{ecc}},$$

$$\Delta X_{\text{prec}} = \frac{e}{e_{\text{prec}}}\left\{\left[\frac{X_{\text{AE}} - X_{\text{VE}}}{2}\cos(\omega) + \frac{X_{\text{WS}} - X_{\text{SS}}}{2}\sin(\omega)\right] + \Delta X_{\text{ecc\_adjustment}}\right\},$$

$$\Delta X_{\text{orbit}} = \Delta X_{\text{obliq}} + \Delta X_{\text{prec}},$$

$$\Delta X_{\text{CO2}} = 5.35\ln\left(\frac{\text{CO2}}{\text{CO2}_0}\right)\left(\frac{\Delta X_{\text{HalfCO2}} - \Delta X_{\text{preind}}}{-3.71}\right),$$

$$\Delta X_{\text{CH4}} = (0.036[(\text{CH4})^{0.5} - (\text{CH4}_0)^{0.5}] - \{0.47\ln[1 + 2.01\times10^{-5}(\text{CH4}\times\text{N2O}_0)^{0.75} + 5.31\times10^{-15}\times\text{CH4}(\text{CH4}\times\text{N2O}_0)^{1.52}] - 0.47\ln[1 + 2.01\times10^{-5}(\text{CH4}_0\times\text{N2O}_0)^{0.75} + 5.31\times10^{-15}\times\text{CH4}_0(\text{CH4}_0\times\text{N2O}_0)^{1.52}]\})\left(\frac{X_{\text{HalfCO2}} - X_{\text{preind}}}{-3.71}\right),$$

$$\Delta X_{\text{GHGs}} = \Delta X_{\text{CO2}} + \Delta X_{\text{CH4}},$$

$$\Delta X_{\text{ice}} = \frac{\Delta\text{sealevel}}{\Delta\text{sealevel}_{\text{LGM}}}(X_{\text{IceSheets}} - X_{\text{preind}}),$$

$$\Delta X_{\text{total}} = \Delta X_{\text{orbit}} + \Delta X_{\text{GHGs}} + \Delta X_{\text{ice}}.$$