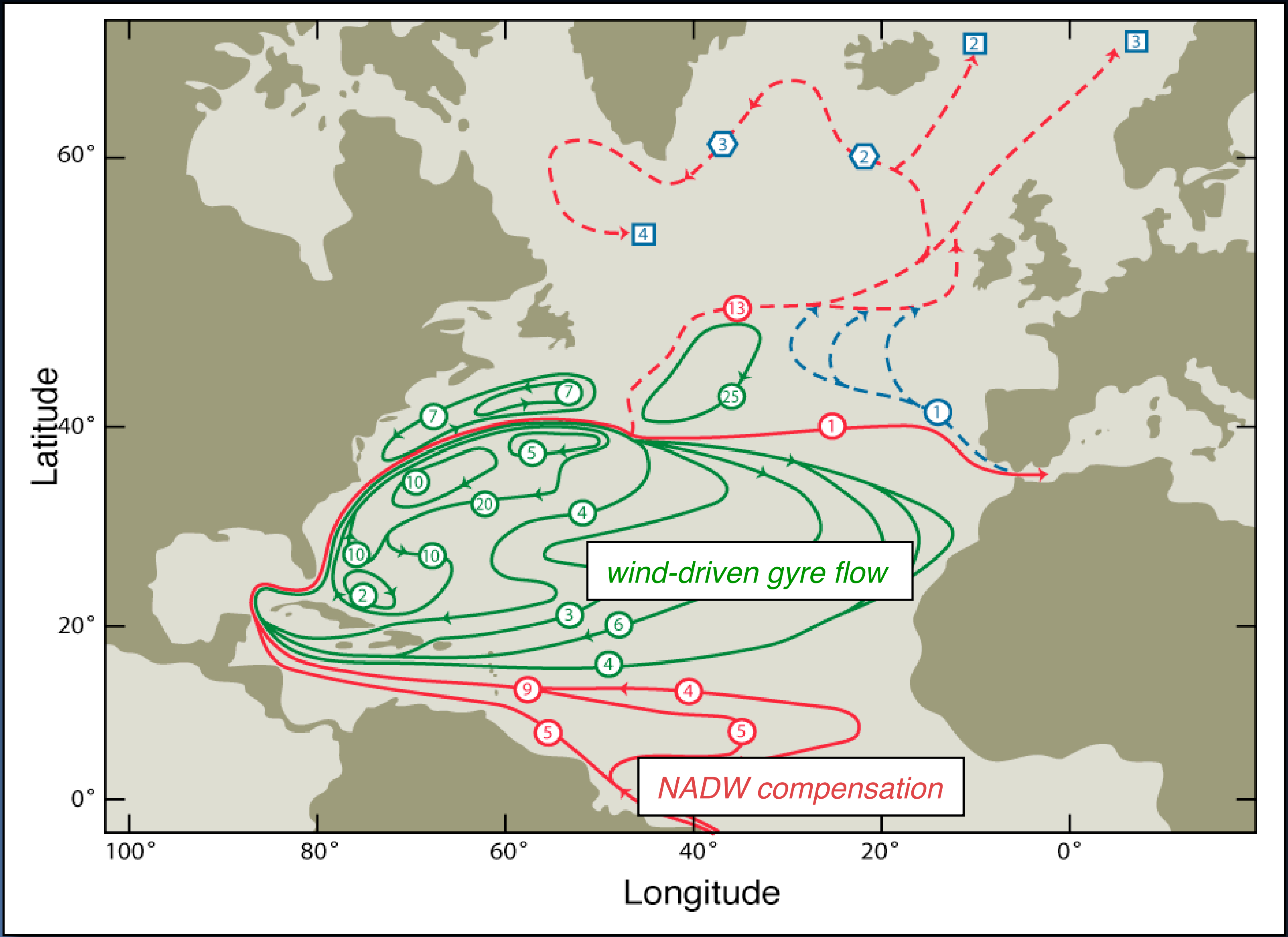
Gulf Stream Temperature, Salinity, and Transport during the Last Millennium

David Lund - University of Michigan

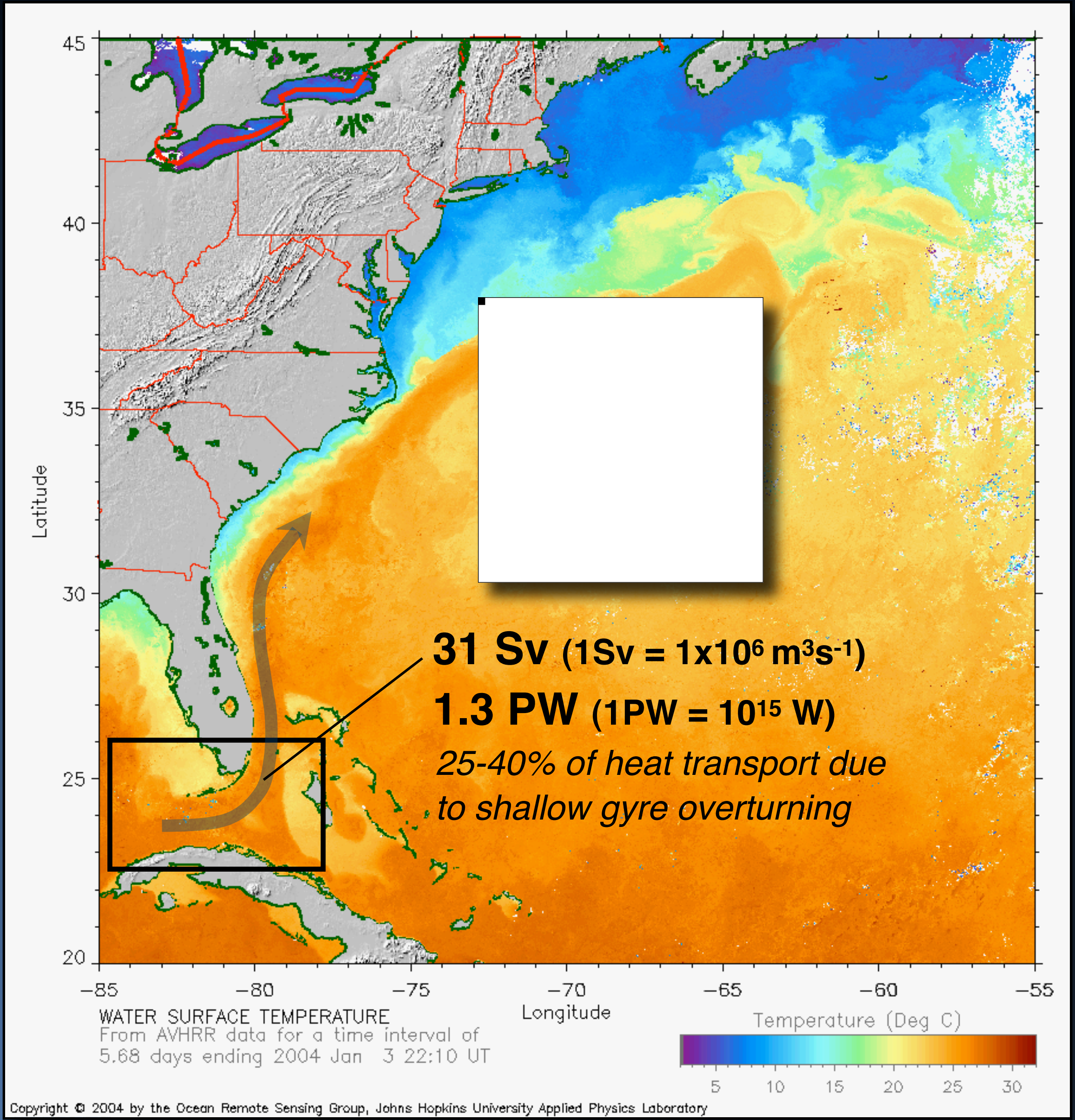
- Part I – Geostrophic estimation of Gulf Stream flow
  - *- Gulf Stream strength varied by ~10%*
  - *- Weaker vertical shear and transport during Little Ice Age*
  - *- Consistent with timing of North Atlantic cooling*
- Part II – Sea-surface temperature and salinity
  - *- Gulf Stream salinity increased during LIA*
  - *- Likely due to southward migration of the Inter-Tropical Convergence Zone*
- Part III – Linking the oceanic circulation and ITCZ

North Atlantic surface circulation



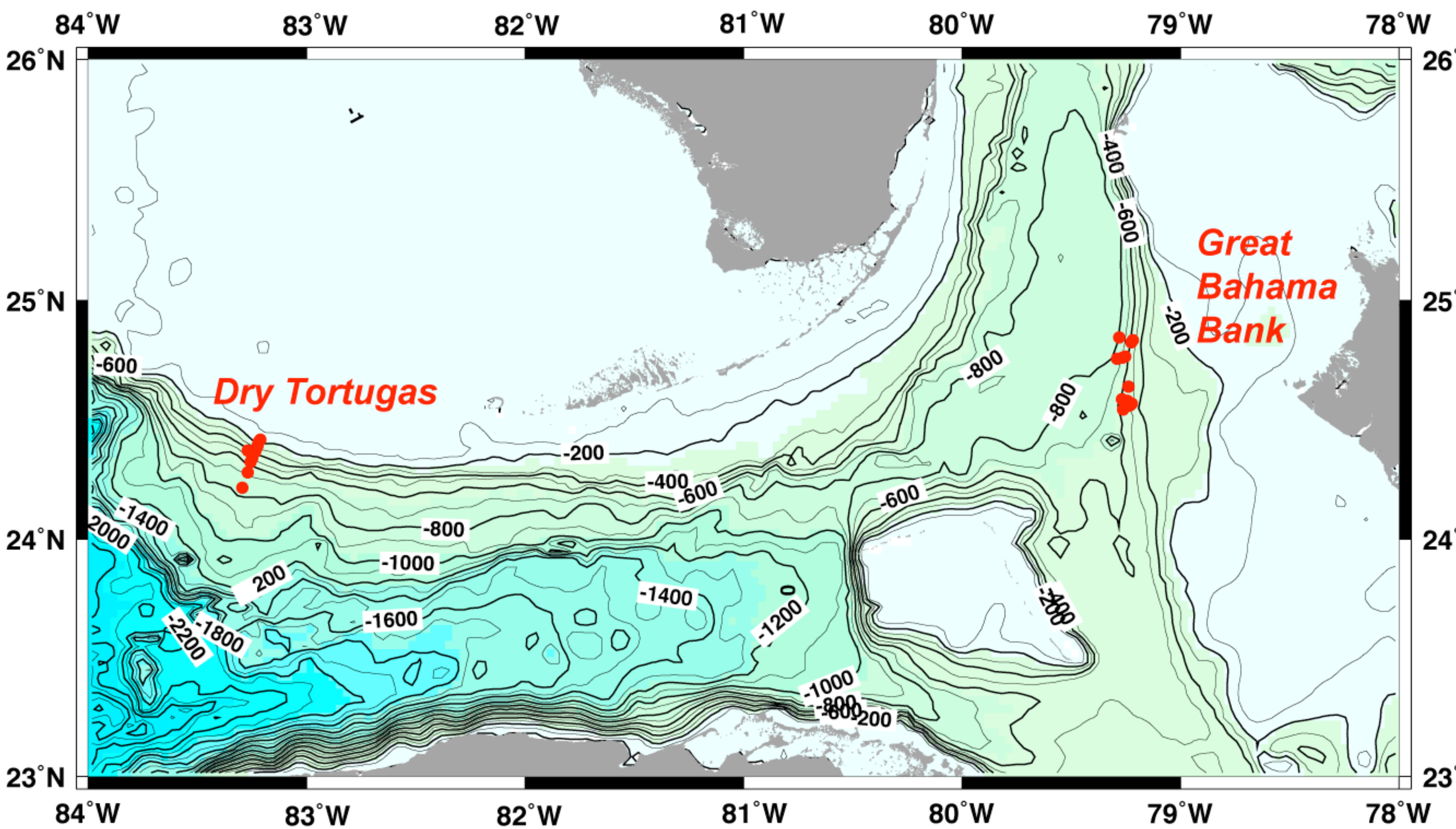
Schmitz, 1996

Gulf Stream volume and heat transports



Talley, 1999
Schmitz, 1996
Larsen, 1992

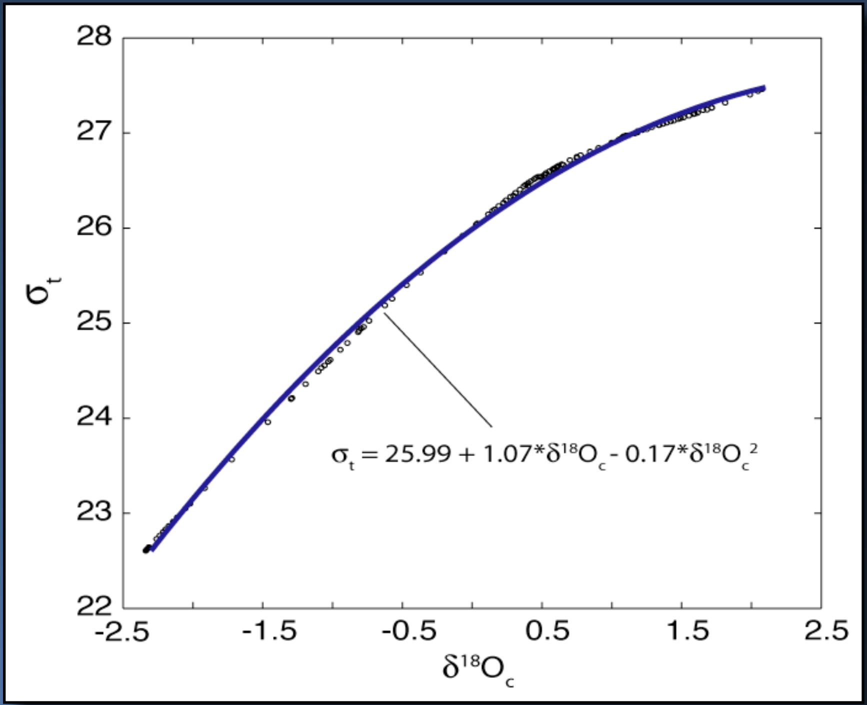
Location of core sites in Florida Straits

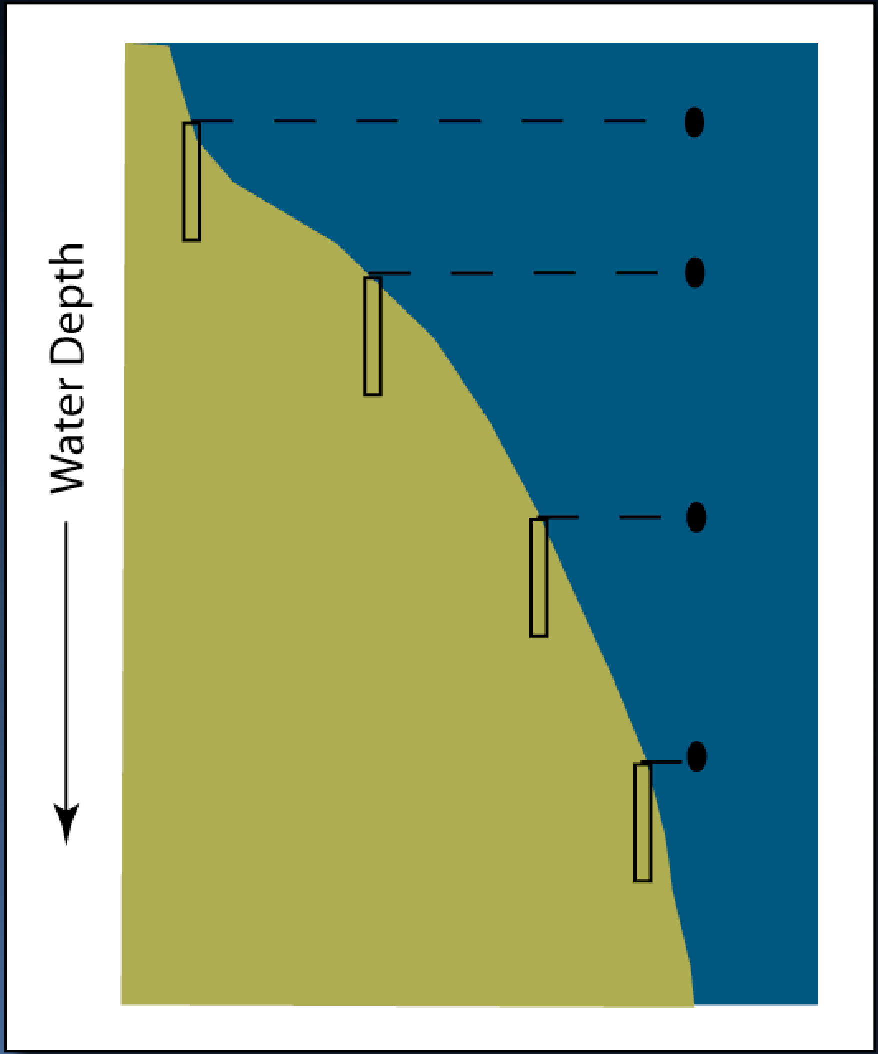


Core retrieval and sampling

Benthic foraminiferal $\delta^{18}O$ and density

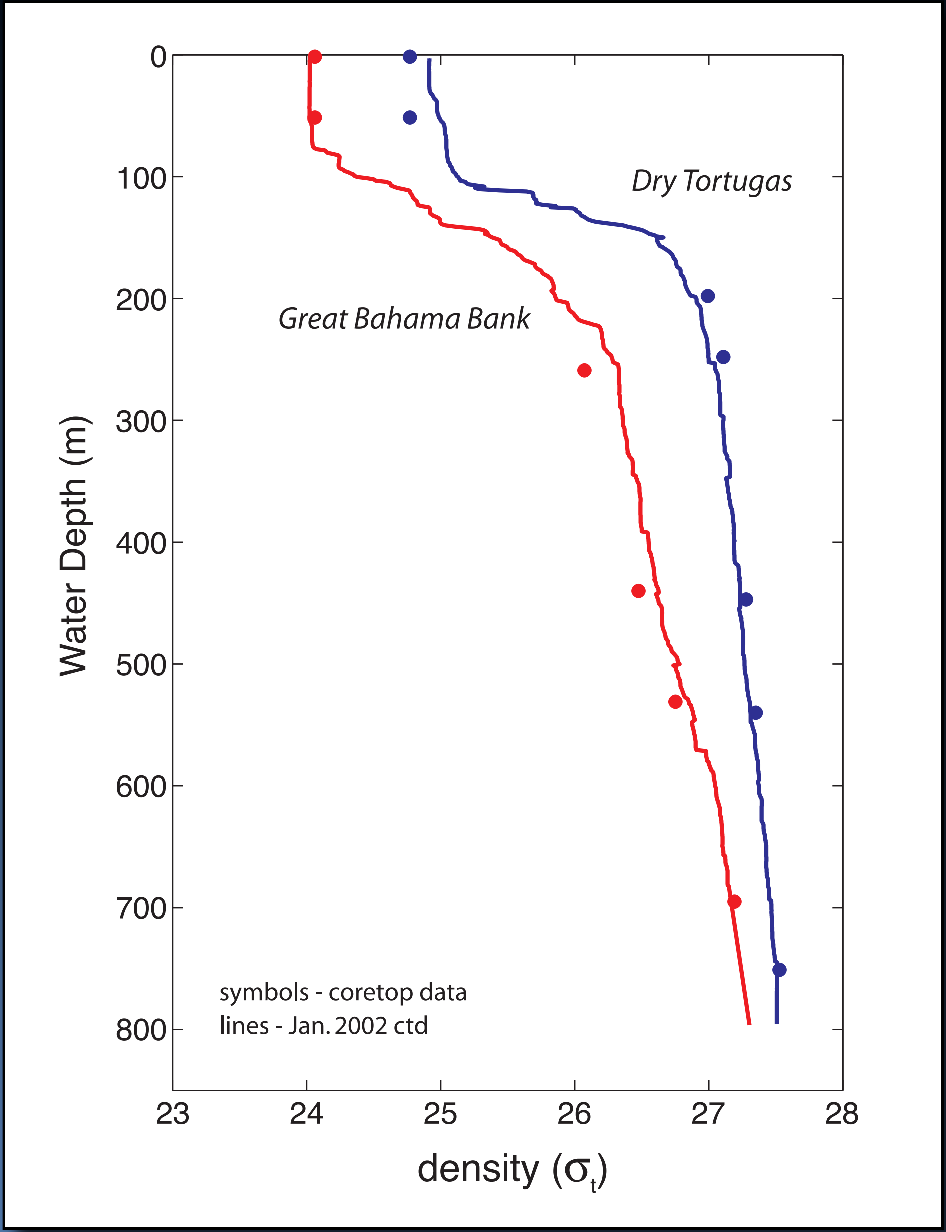
increasing S and decreasing T causes sea water density AND foraminiferal $\delta^{18}O$ to increase





after Lynch-Stieglitz et al., 1999

Foraminiferal density estimates match modern observations



Lund et al., 2006

Estimating Gulf Stream transport

Modern techniques

- current meters ~ 29-31 Sv *Pillsbury, 1890; Schott et al., 1988; Leaman et al., 1995*
- submarine cable estimates of 29 Sv (Jan) to 33 Sv (July)
  Wertheim, 1954; Baringer and Larsen, 2001
- geostrophic estimates ~ 28-30 Sv *Montgomery, 1941; Schmitz and Richardson, 1968*

Geostrophic estimation (using thermal wind equations)

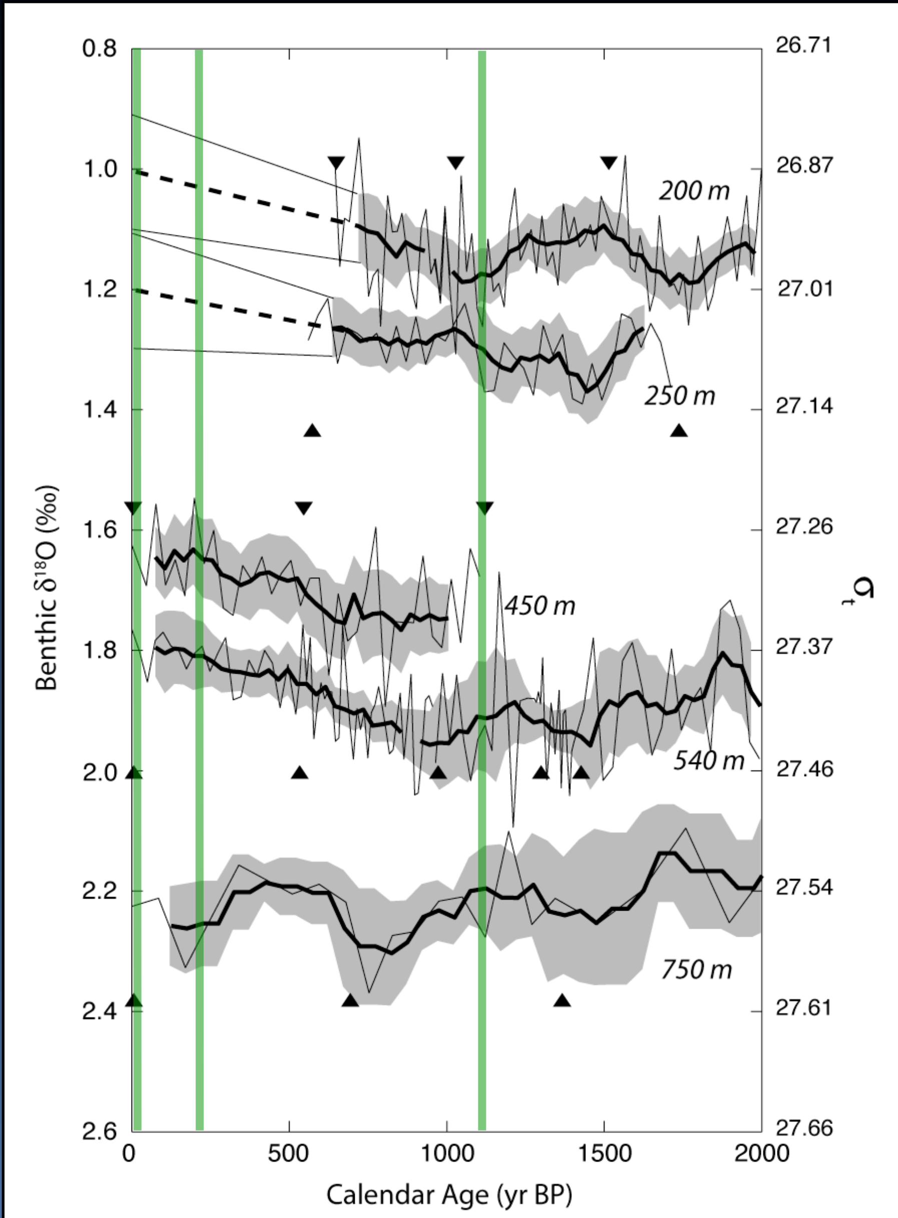
$$\frac{\partial v}{\partial z} = -\frac{g}{\rho_o f}\frac{\partial \rho}{\partial x}$$

$$\frac{\partial u}{\partial z} = \frac{g}{\rho_o f}\frac{\partial \rho}{\partial y}$$

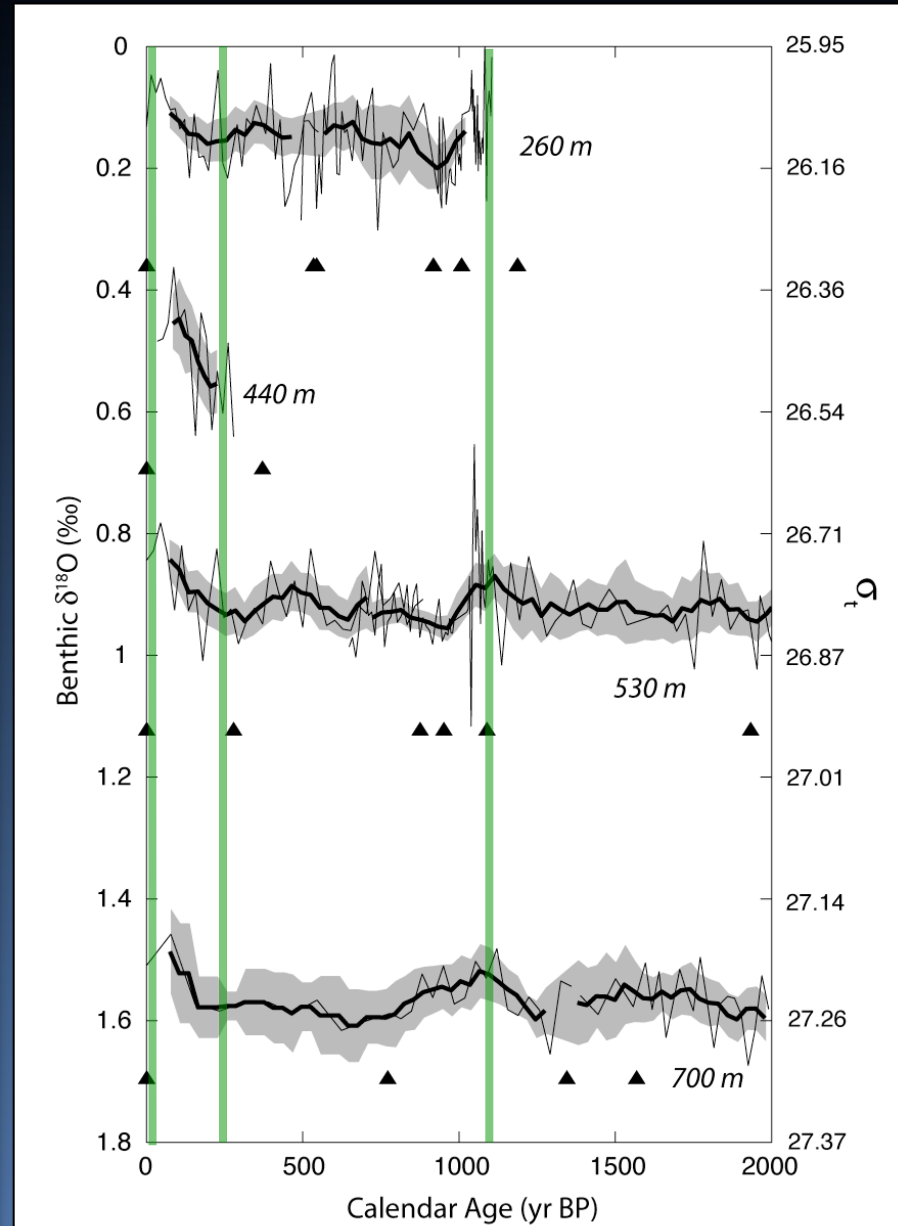
---> vertical current shear is proportional to horizontal density gradient

* *transport can be calculated only if velocity at a given depth is known*

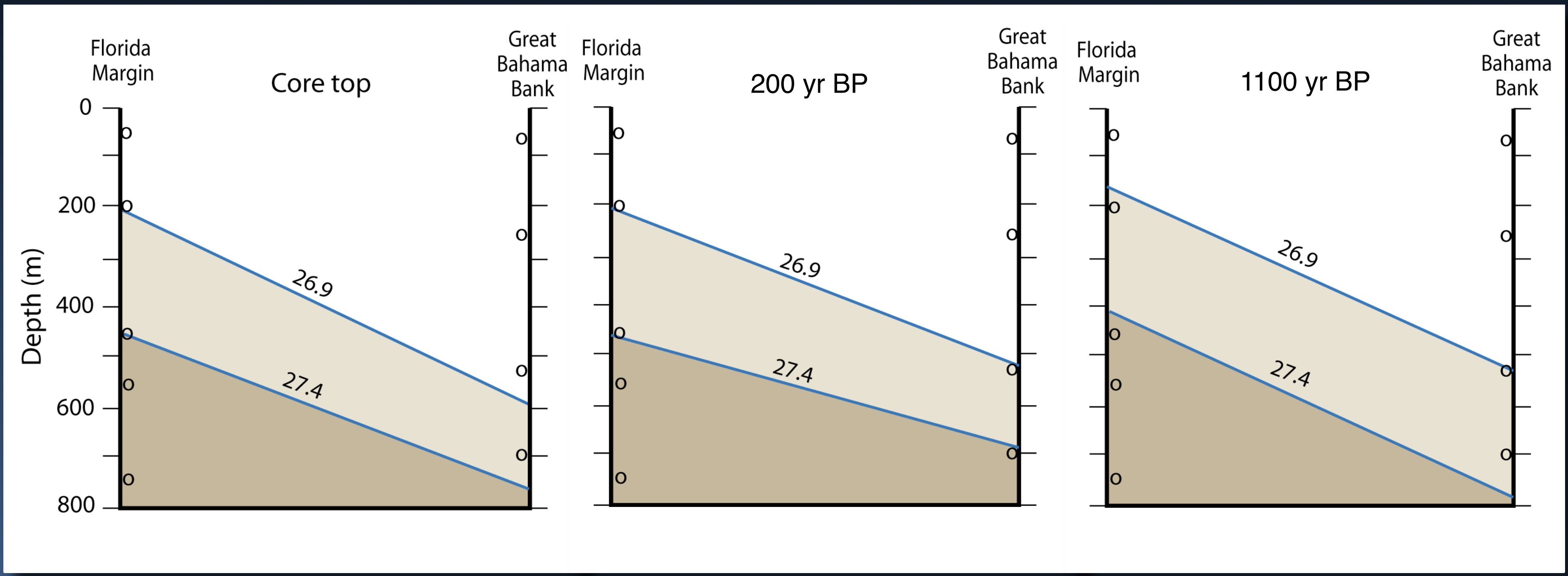
Dry Tortugas $\delta^{18}O$



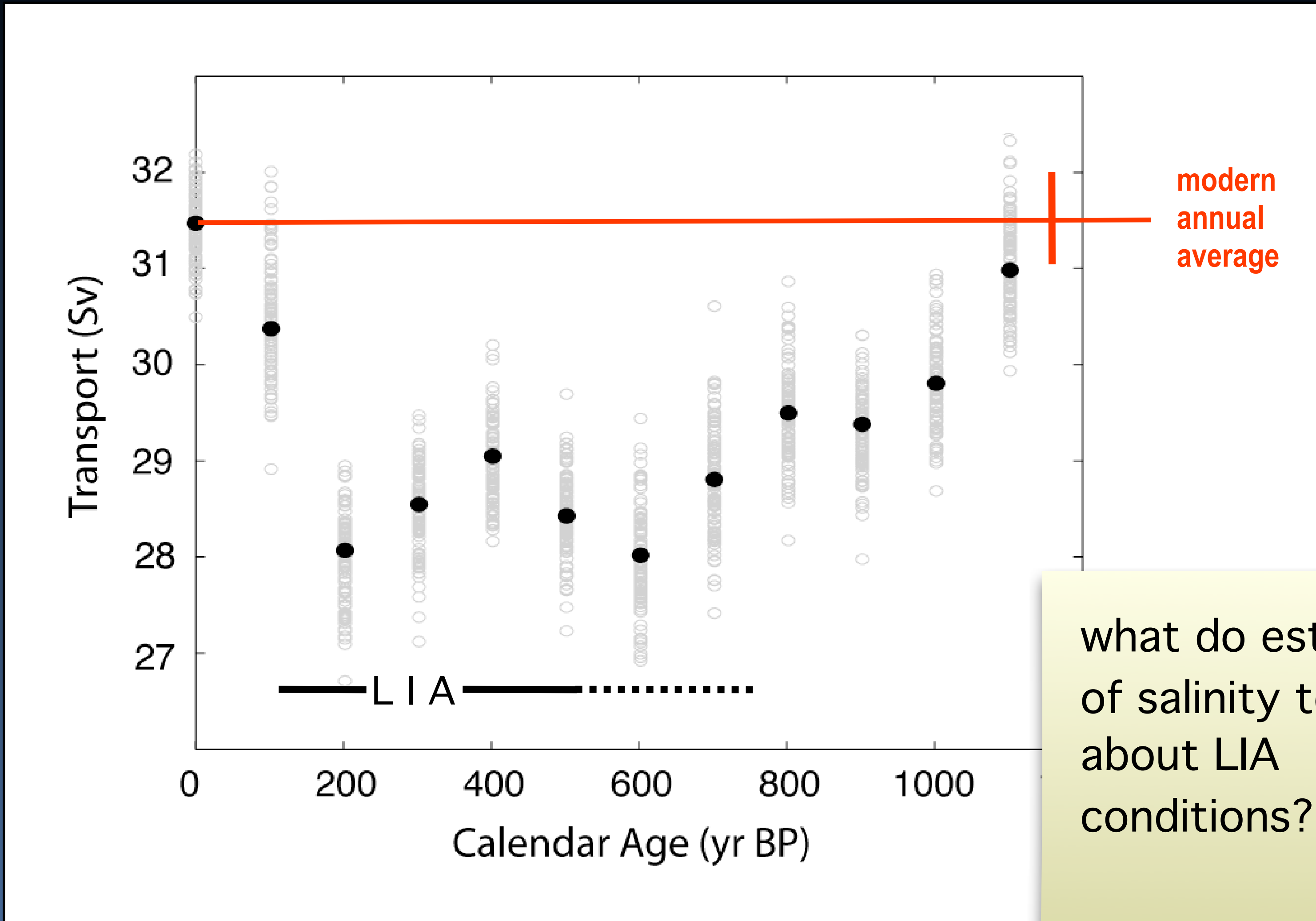
Bahamas $\delta^{18}O$



Florida Current density cross-sections



Lower Gulf Stream transport during Little Ice Age

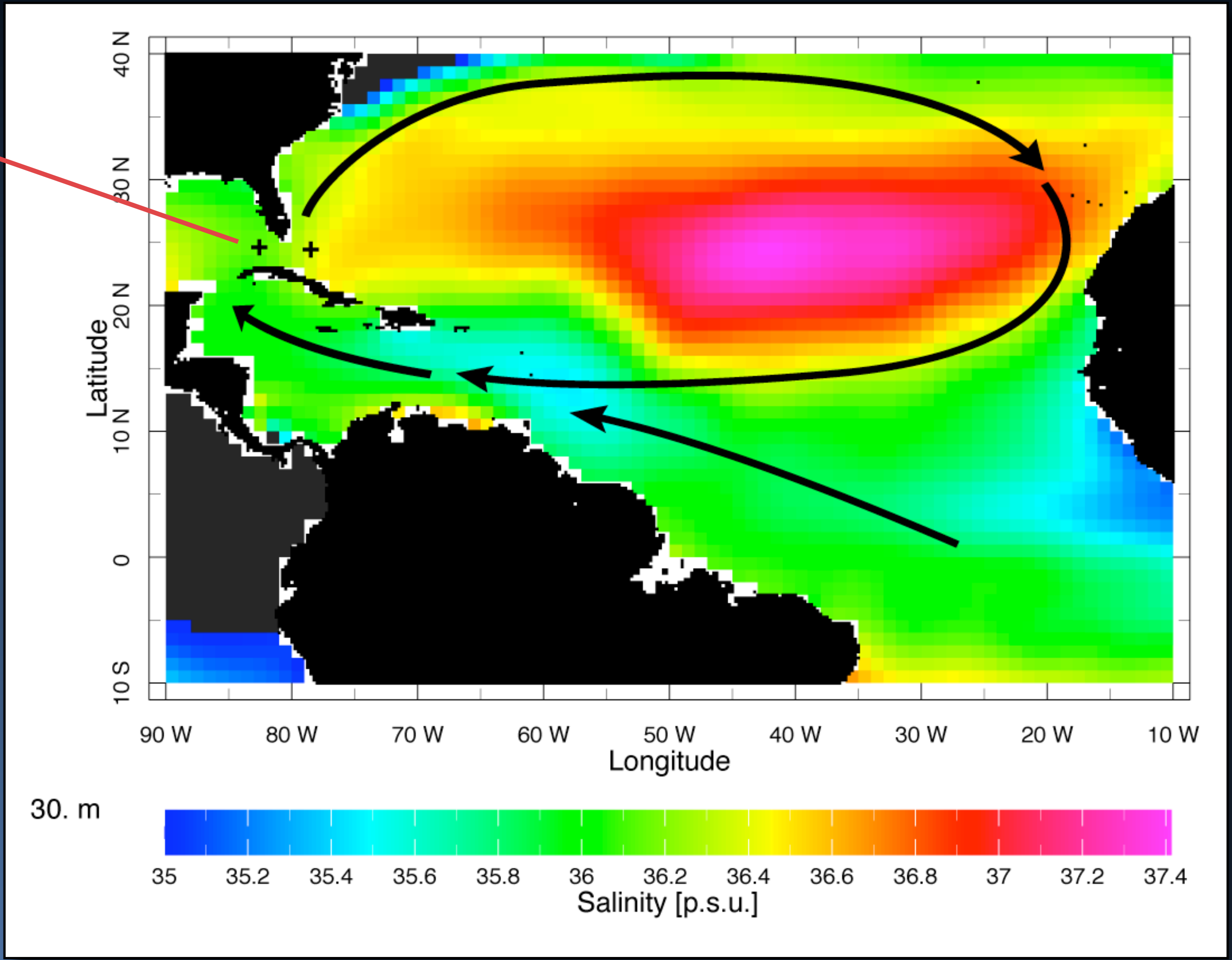


what do estimates of salinity tell us about LIA conditions?

Lund et al., 2006

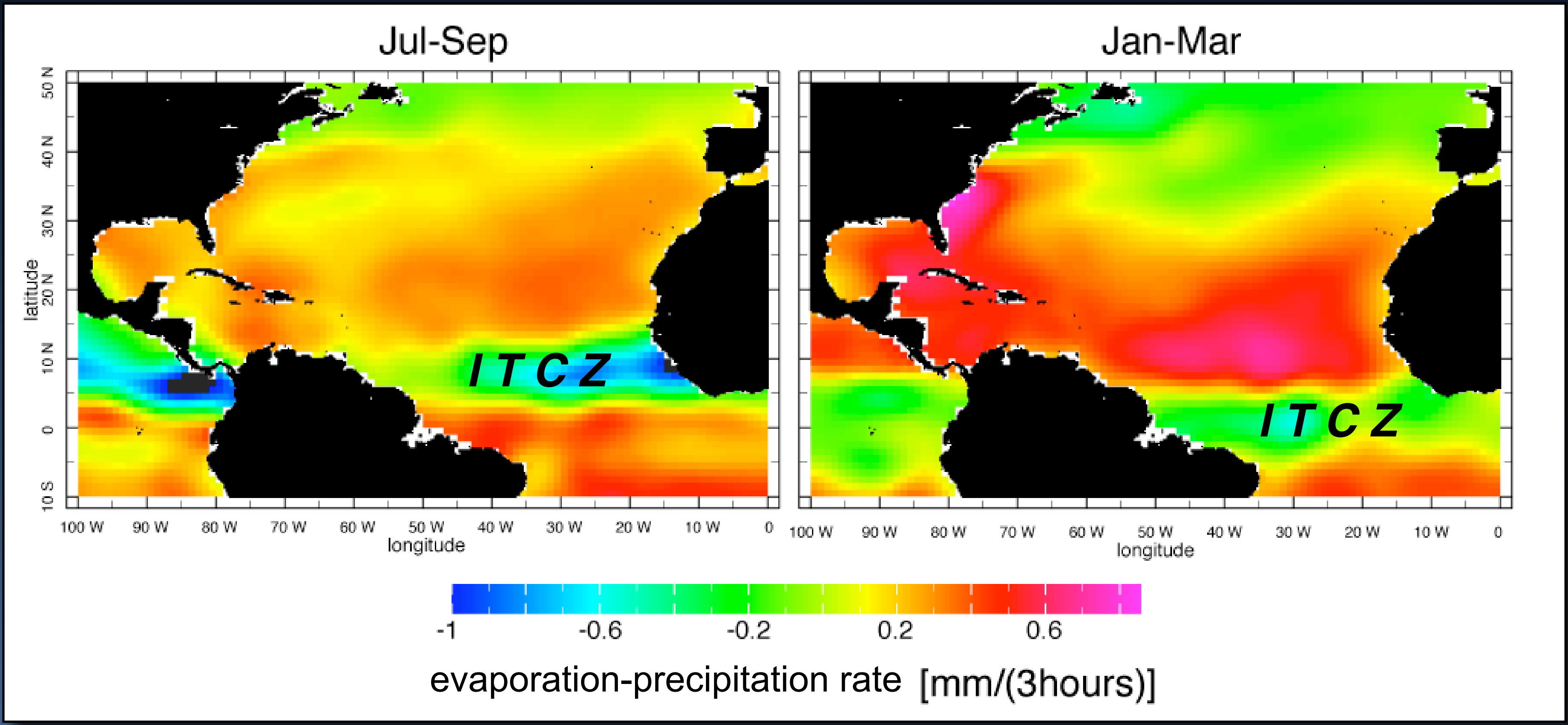
Dry Tortugas reflects tropical Atlantic salinity

Dry Tortugas
salinity= 36.0
79ggc and 62mc



Levitus, 1994

North Atlantic surface salinity controlled by evaporation-precipitation rate



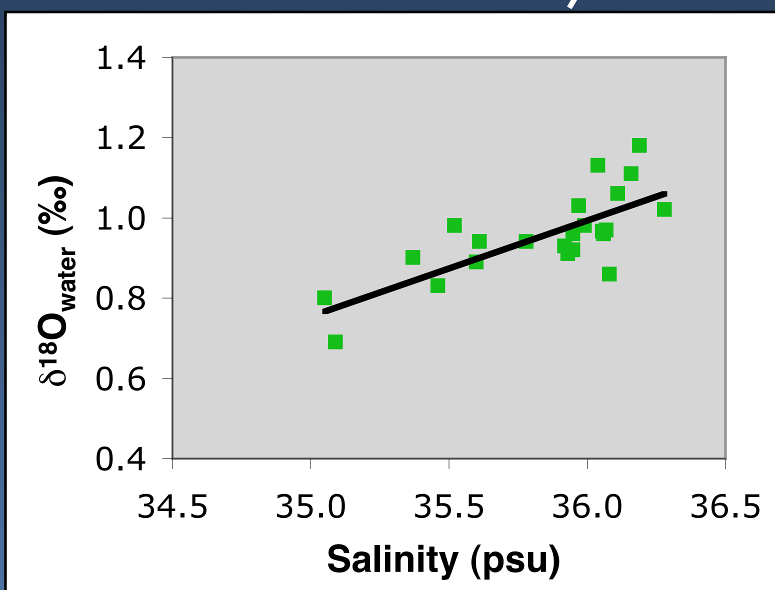
daSilva et al., 1994

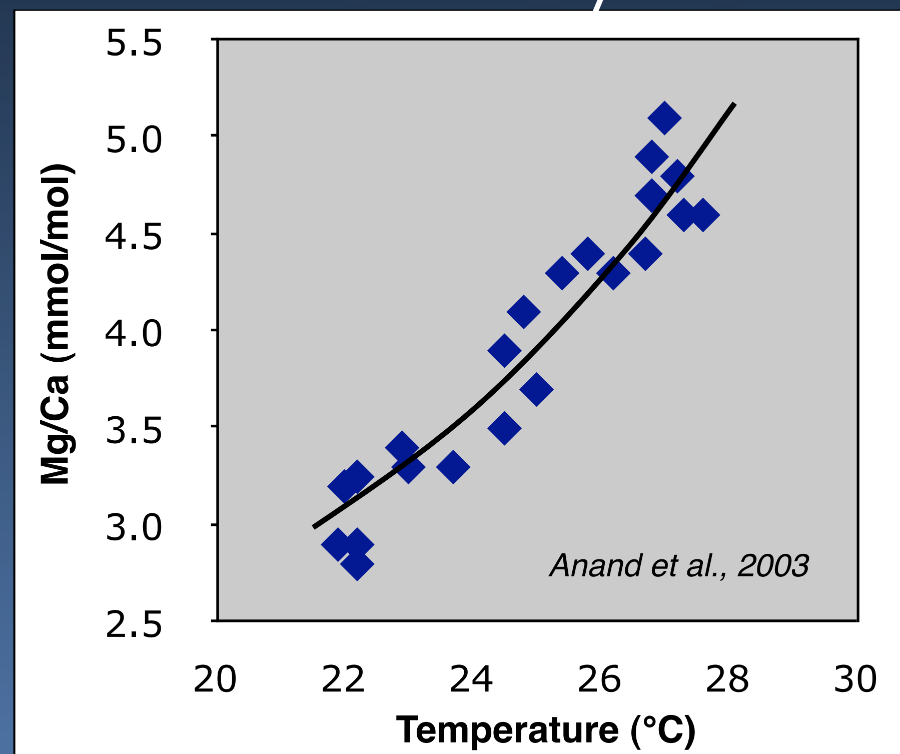
Calculating surface salinity using planktonic foraminifera

$$\delta^{18}O_{calcite} = \delta^{18}O_{water} - 0.20(SST) + 2.98$$

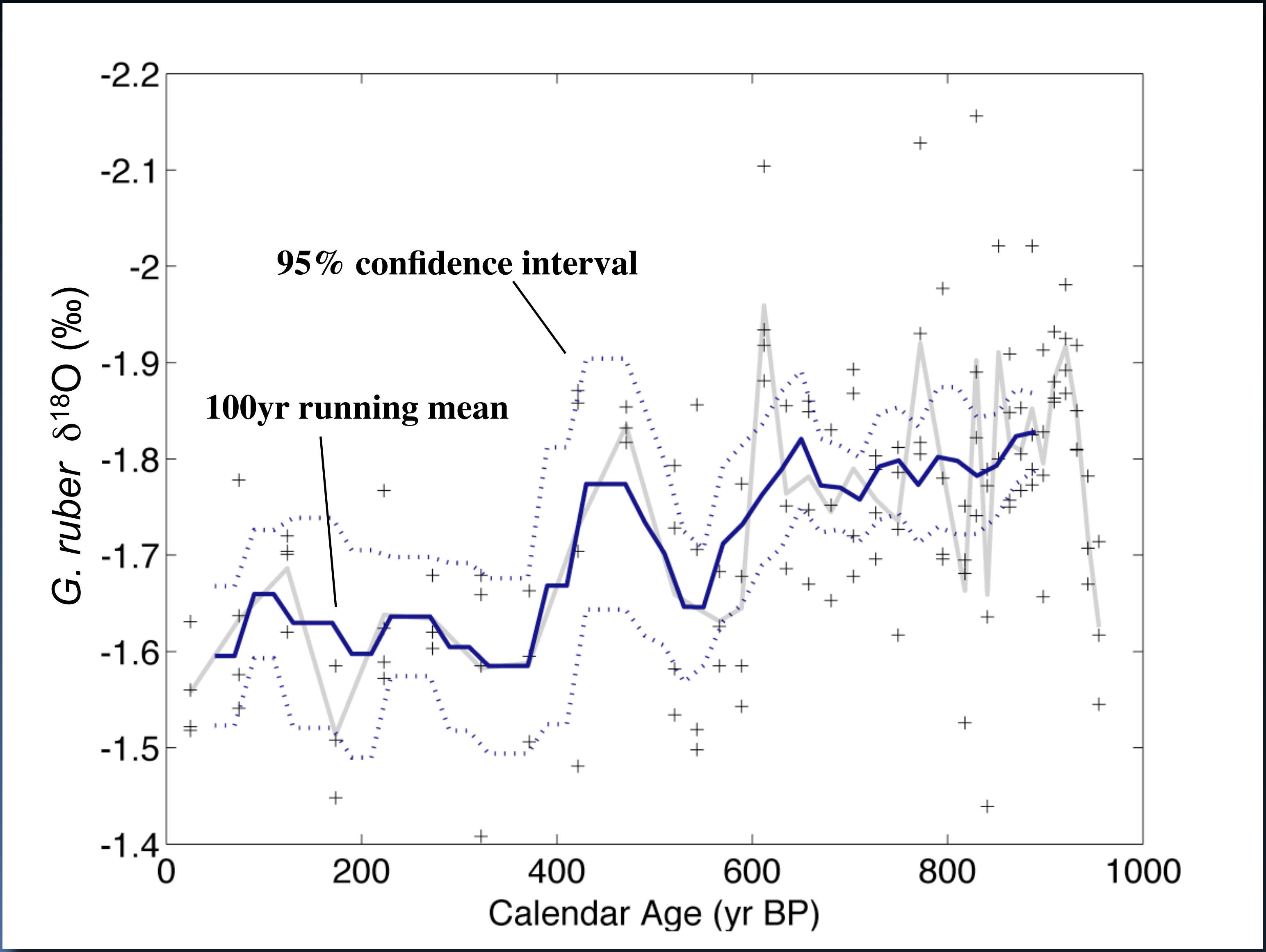
Kim and O'Neil, 1997
Lynch-Stieglitz et al., 1999

$$\delta^{18}O_{water} = \delta^{18}O_{calcite} - 2.98 + 0.20(SST)$$



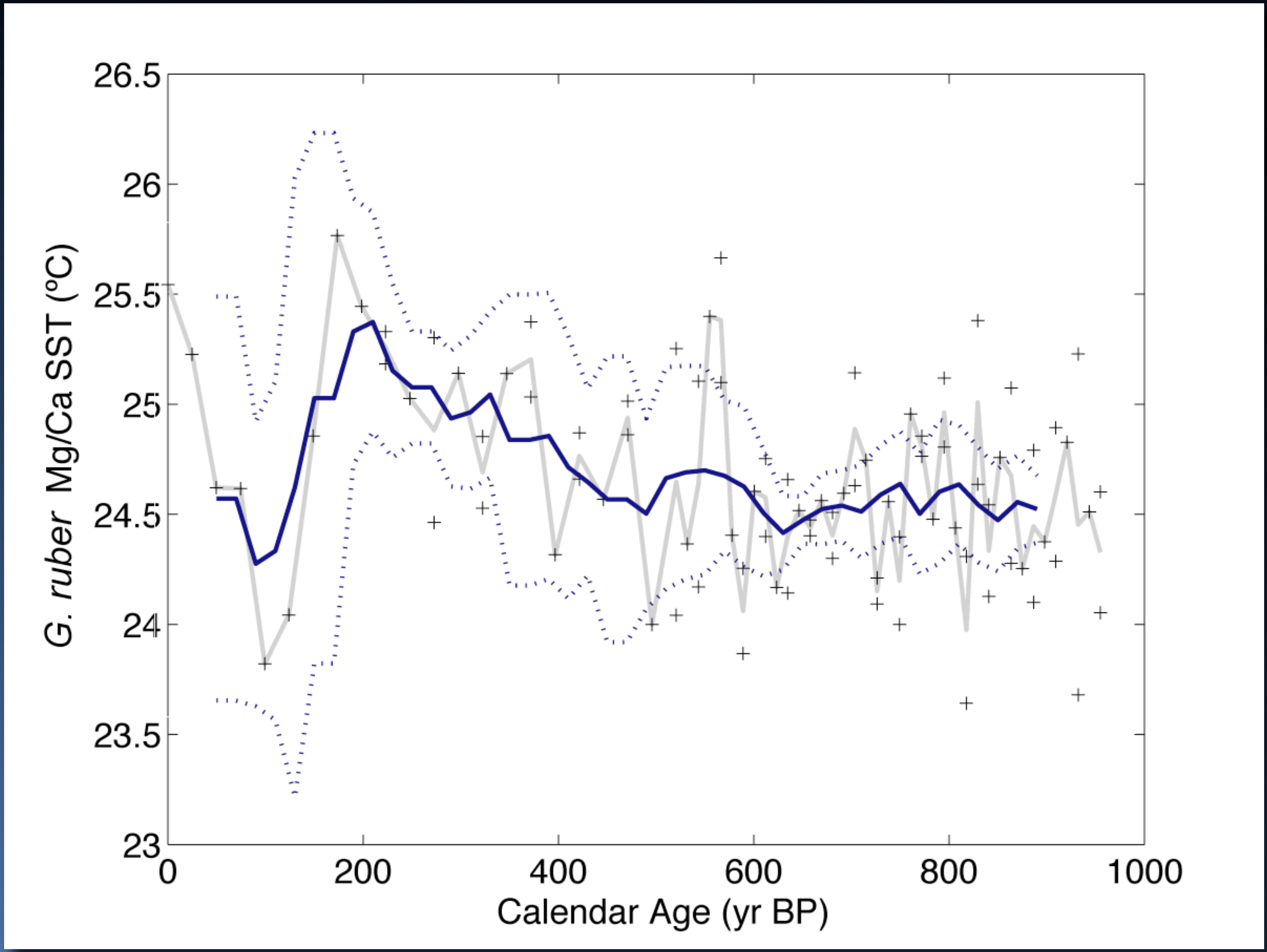


Dry Tortugas $\delta^{18}O_{calcite}$ increased during LIA



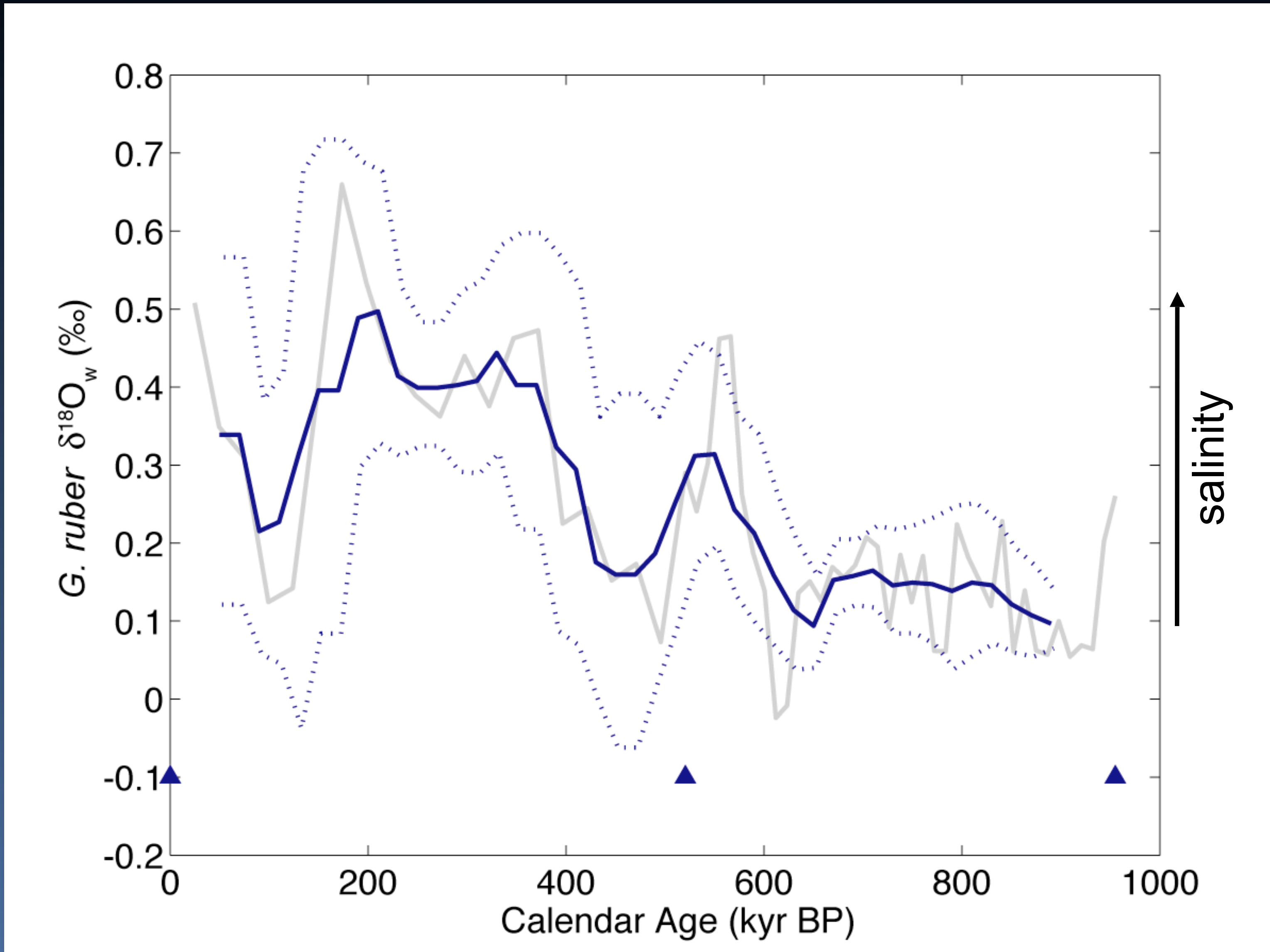
Lund and Curry, 2006

Dry Tortugas sea surface temperature increased during LIA



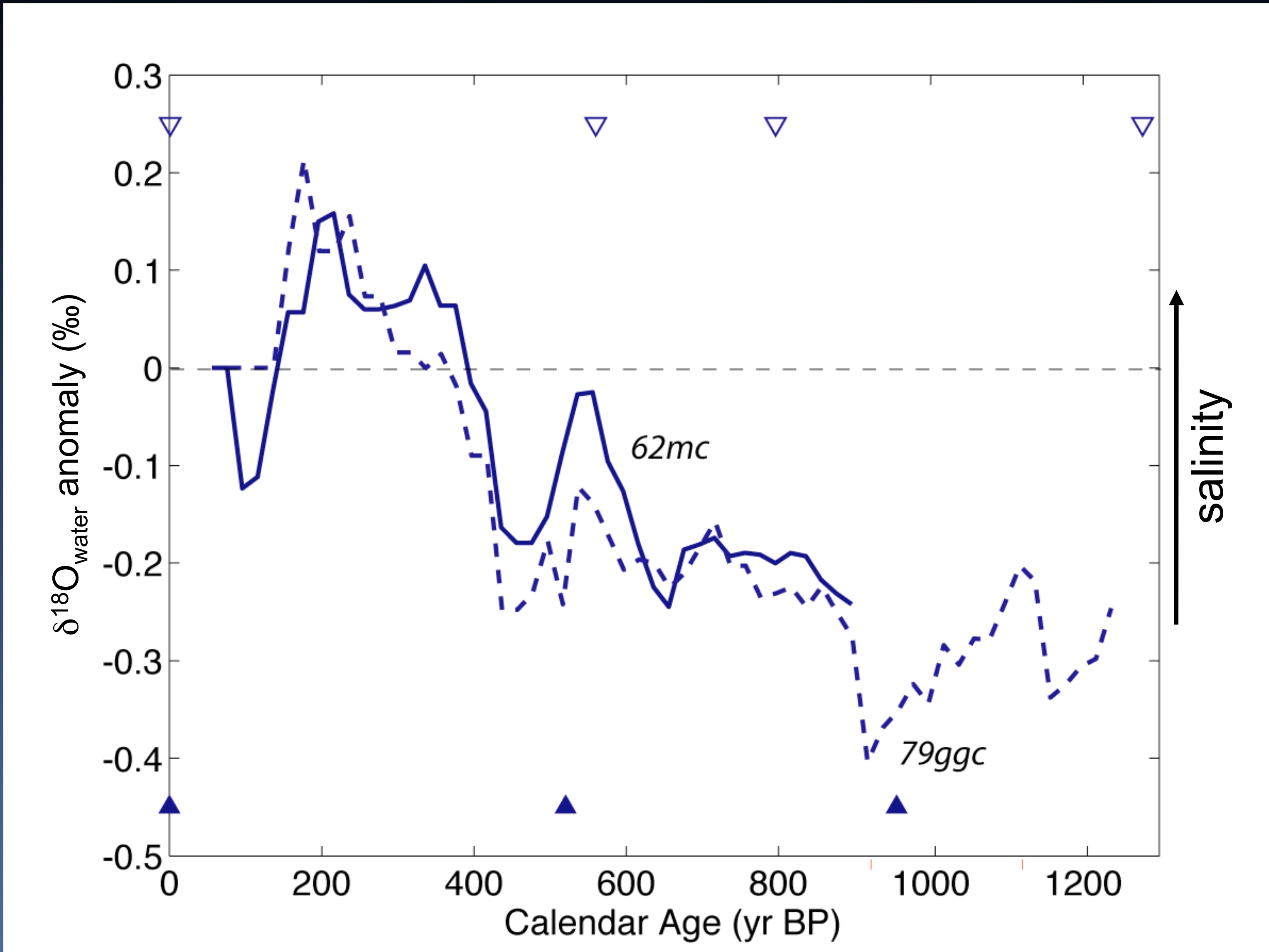
Lund and Curry, 2006

Dry Tortugas $\delta^{18}O_w$ increased during LIA



Lund and Curry, 2006

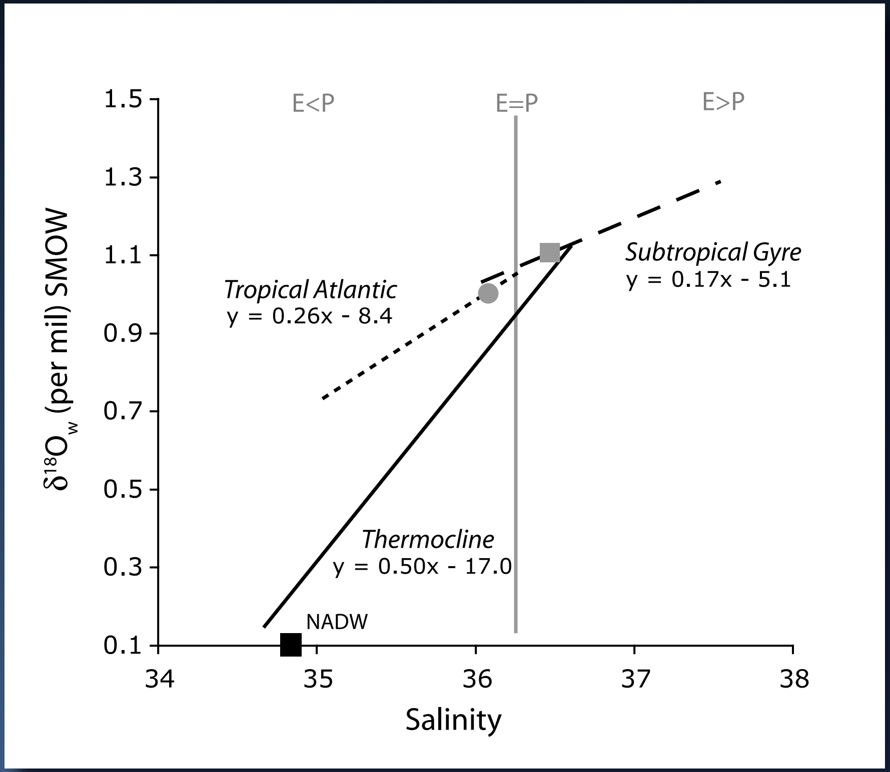
Dry Tortugas $\delta^{18}O_w$ record is replicable



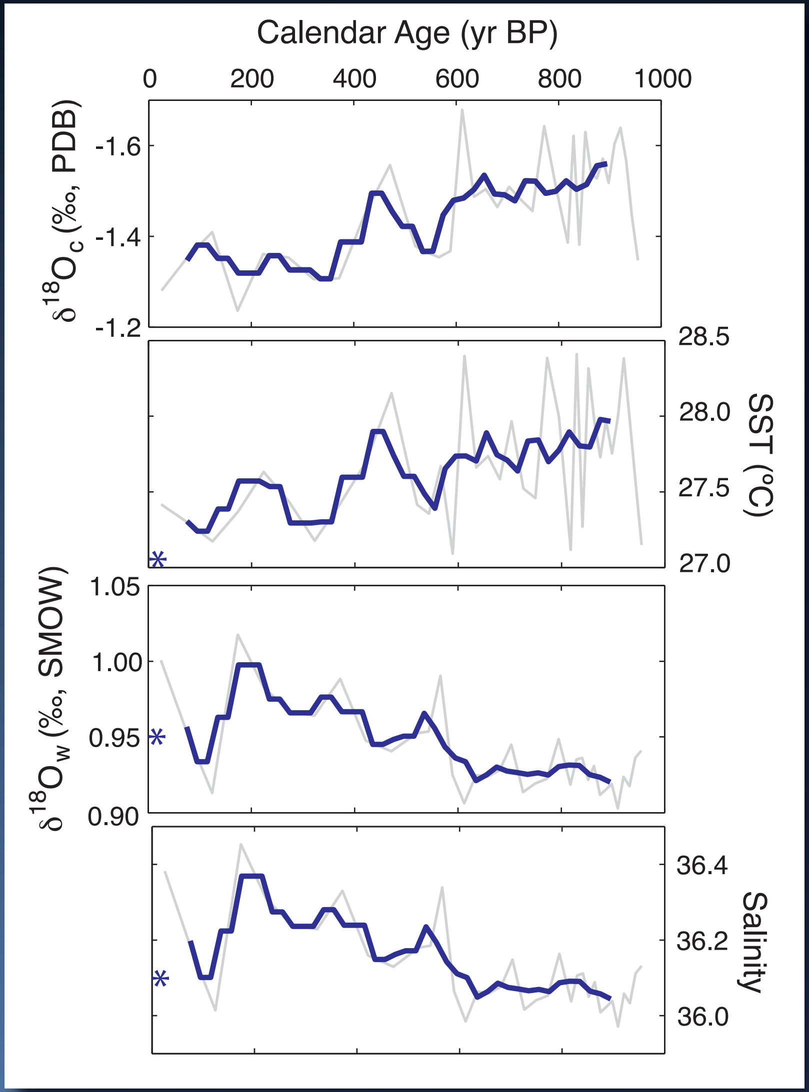
The magnitude of $\delta^{18}O_w$ variability is due to either:

A) influence of thermocline water

or B) incorrect Mg/Ca calibration

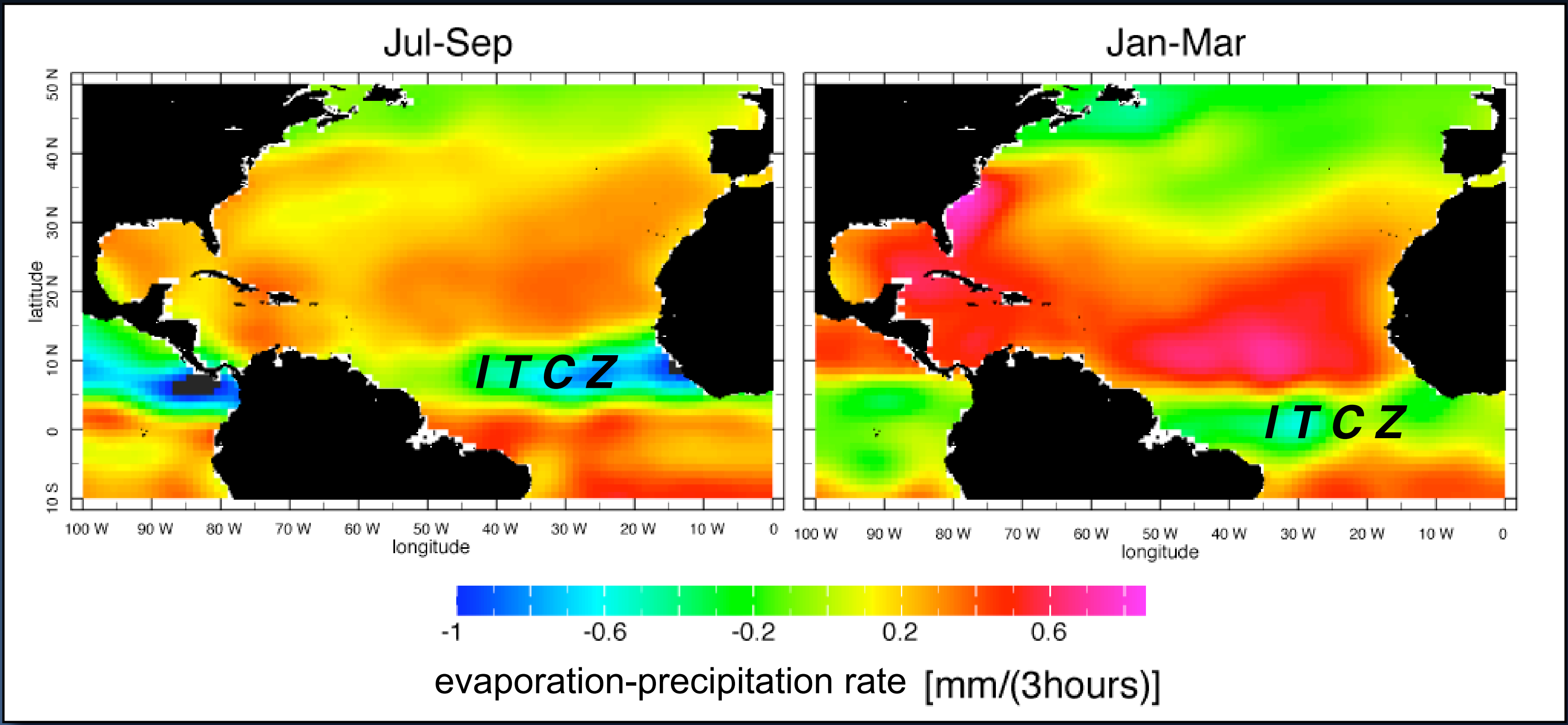


Schmidt, 1999
Craig & Gordon, 1965



based on multivariate equations of deMenocal et al., 2007

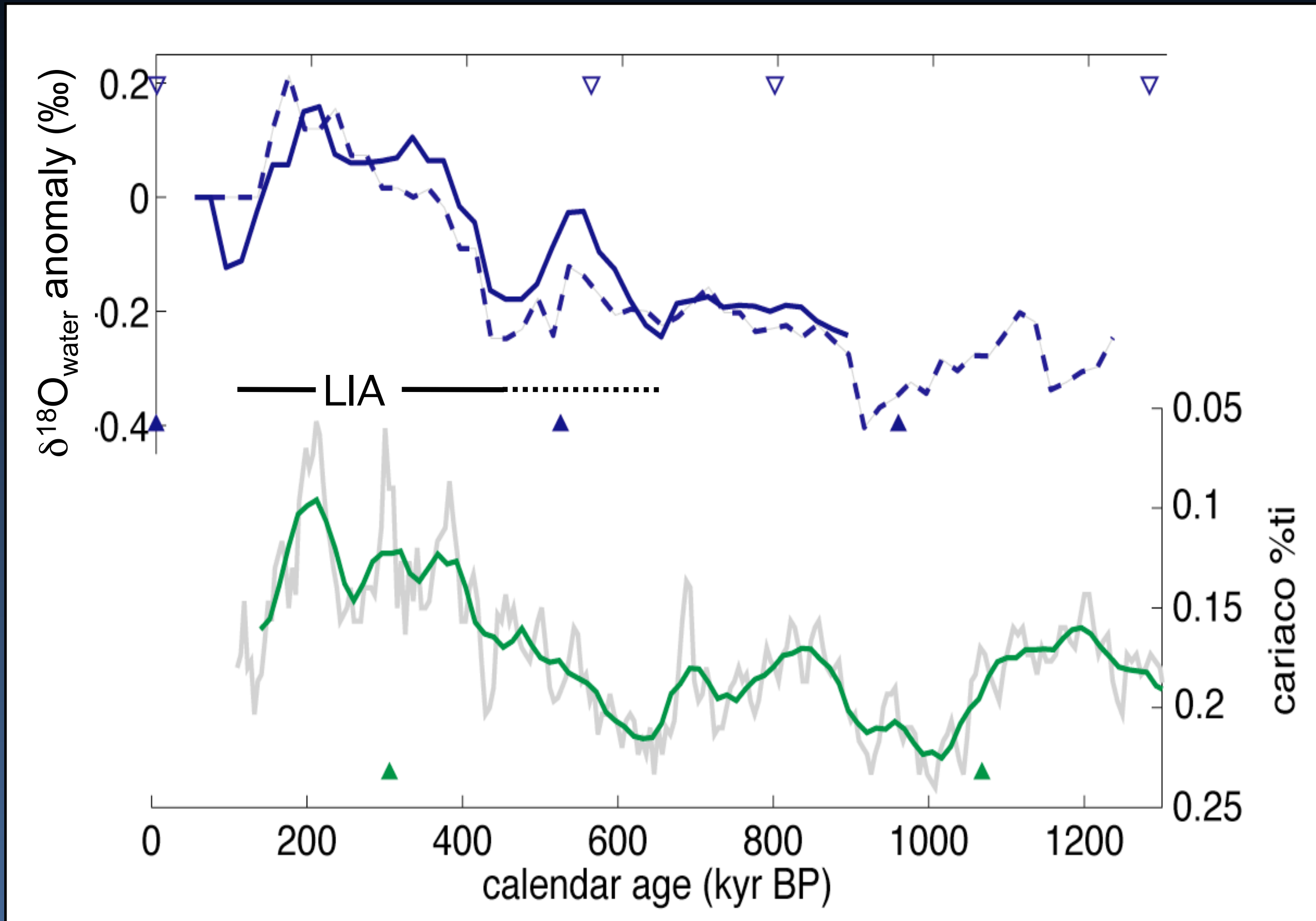
Higher LIA salinity driven by southward ITCZ migration



daSilva et al., 1994

Coherent change in northern Venezuela precipitation

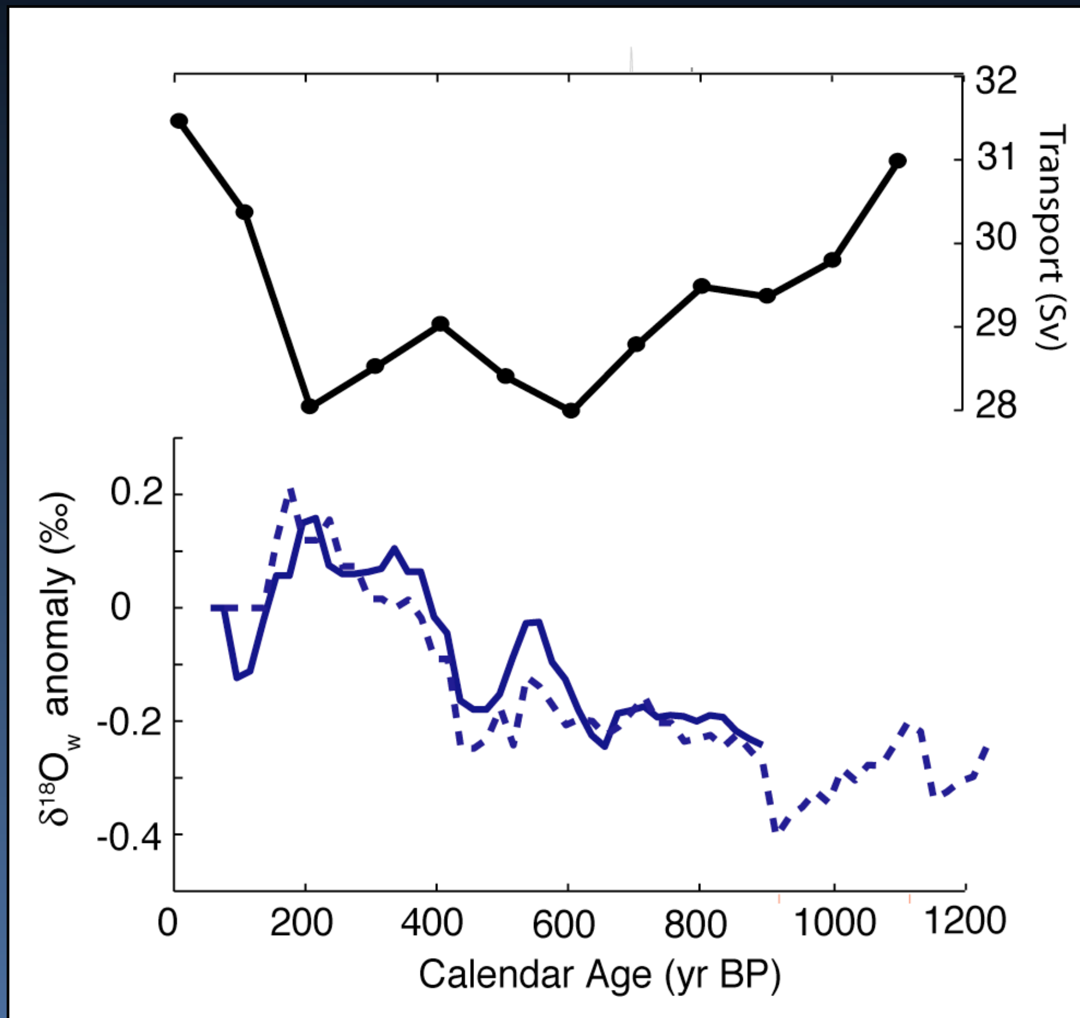
saltier northern tropical Atlantic



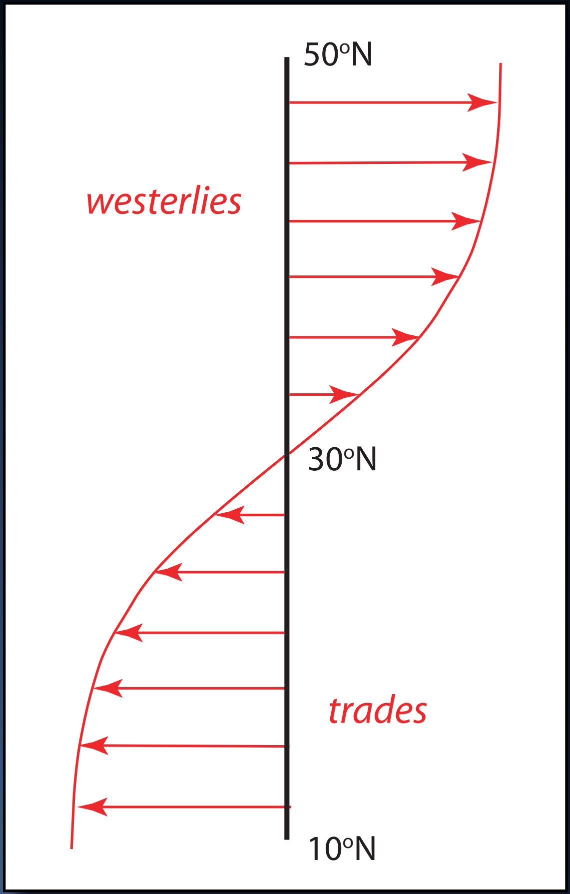
drier northern Venezuela

Haug et al., 2001

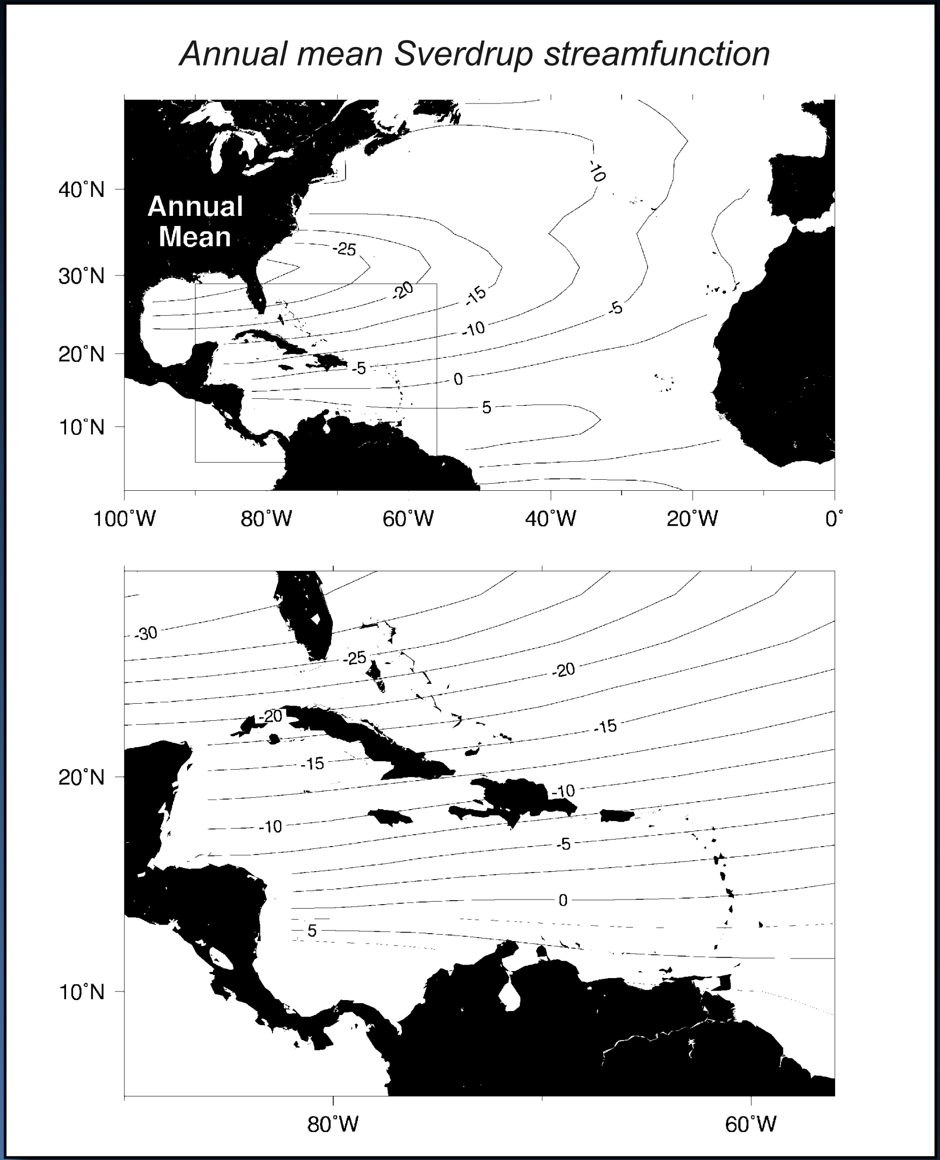
Gulf Stream characterized by low transport and high surface salinity during the Little Ice Age



A function of reduced windstress curl?

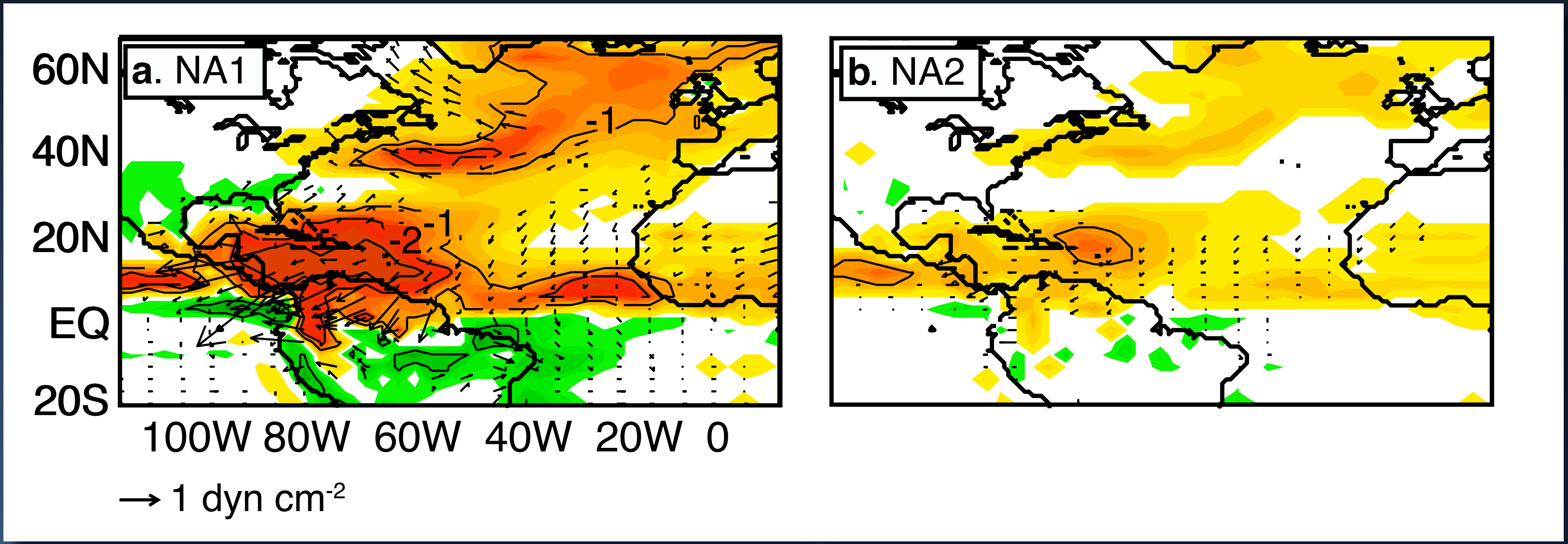


$$M_y \approx \frac{1}{\beta}\frac{\partial T_x}{\partial y}$$



Johns et al., 2002

Model results suggest curl increases when ITCZ migrates southward

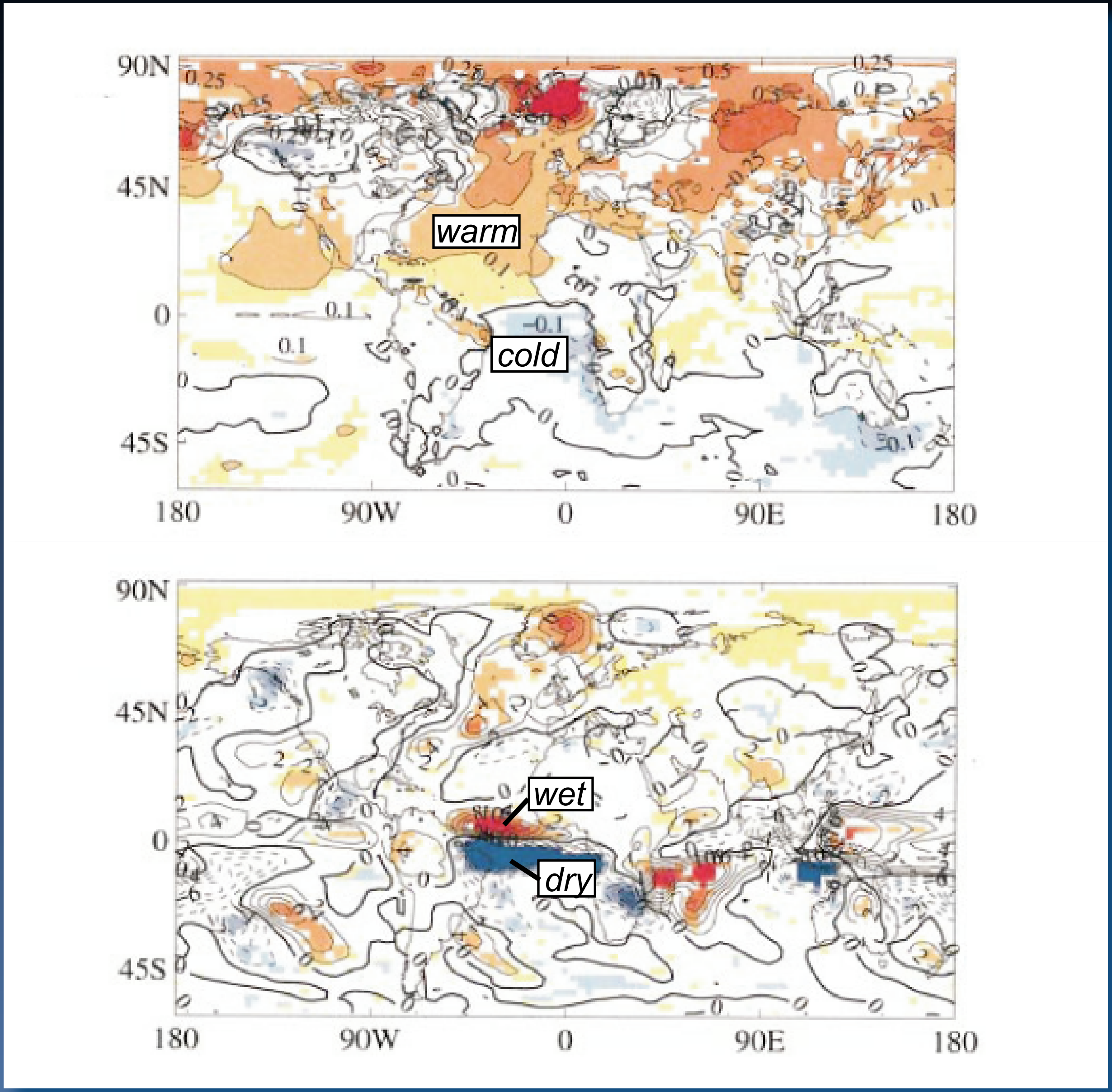


- forced NCAR CAM3 using SST anomalies from hosing experiment (Zhang & Delworth, 2005)

- SST anomalies scaled to simulate LIA observations

Saenger et al., 2009

A role for the MOC?



HadCM3 surface temp. (ºC) anomalies

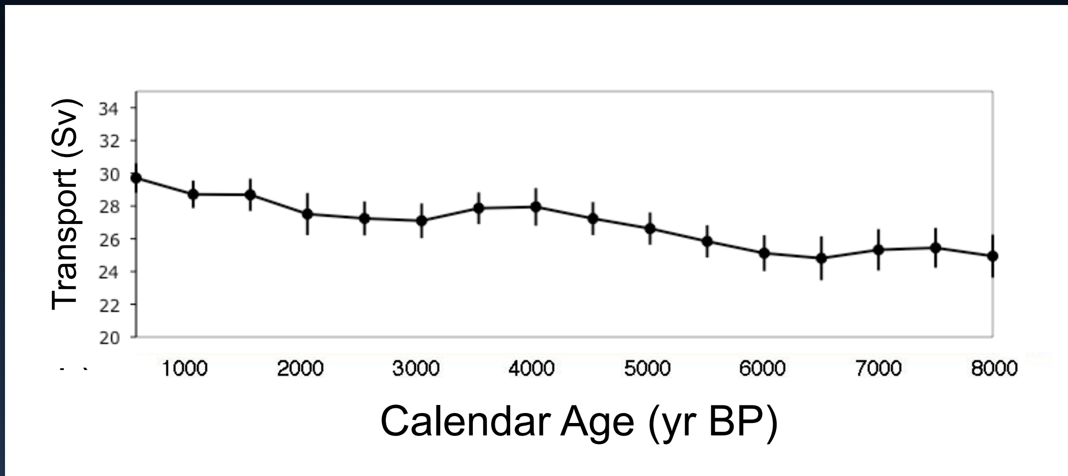
HadCM3 precipitation (cm/yr) anomalies

Vellinga and Wu, 2004

Conclusions

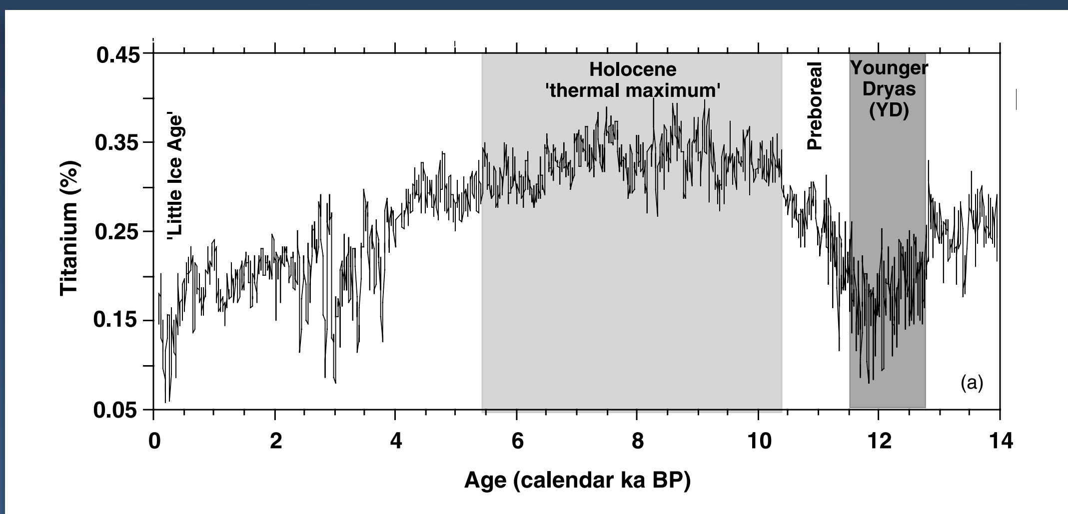
- *Gulf Stream transport varied by ~10% during the last millennium, but was 3±1 Sv lower during Little Ice Age*
- *Surface Gulf Stream salinity increased during the LIA, most likely due to southward ITCZ migration*
- *Simultaneous transport and salinity variability implies tight linkage between oceanic circulation and hydrologic cycle on centennial time scales*
- *Southward migration of wind-field would likely enhance flow, implying MOC was primary driver of LIA transport anomaly*

Holocene variability in Gulf Stream transport



Transport increased
~ 4 Sv during Holocene

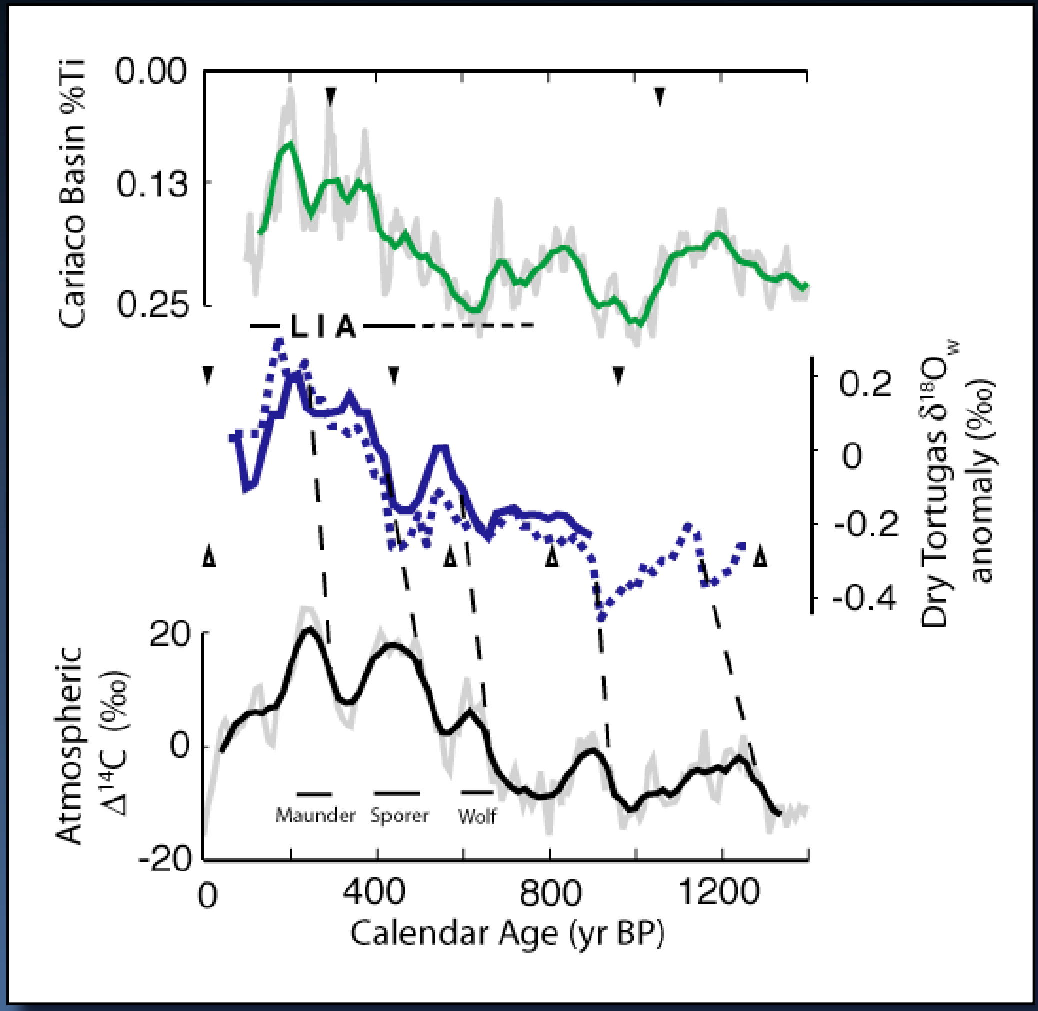
Lynch-Steiglitz, et al., in press



ITCZ migrated southward
during Holocene

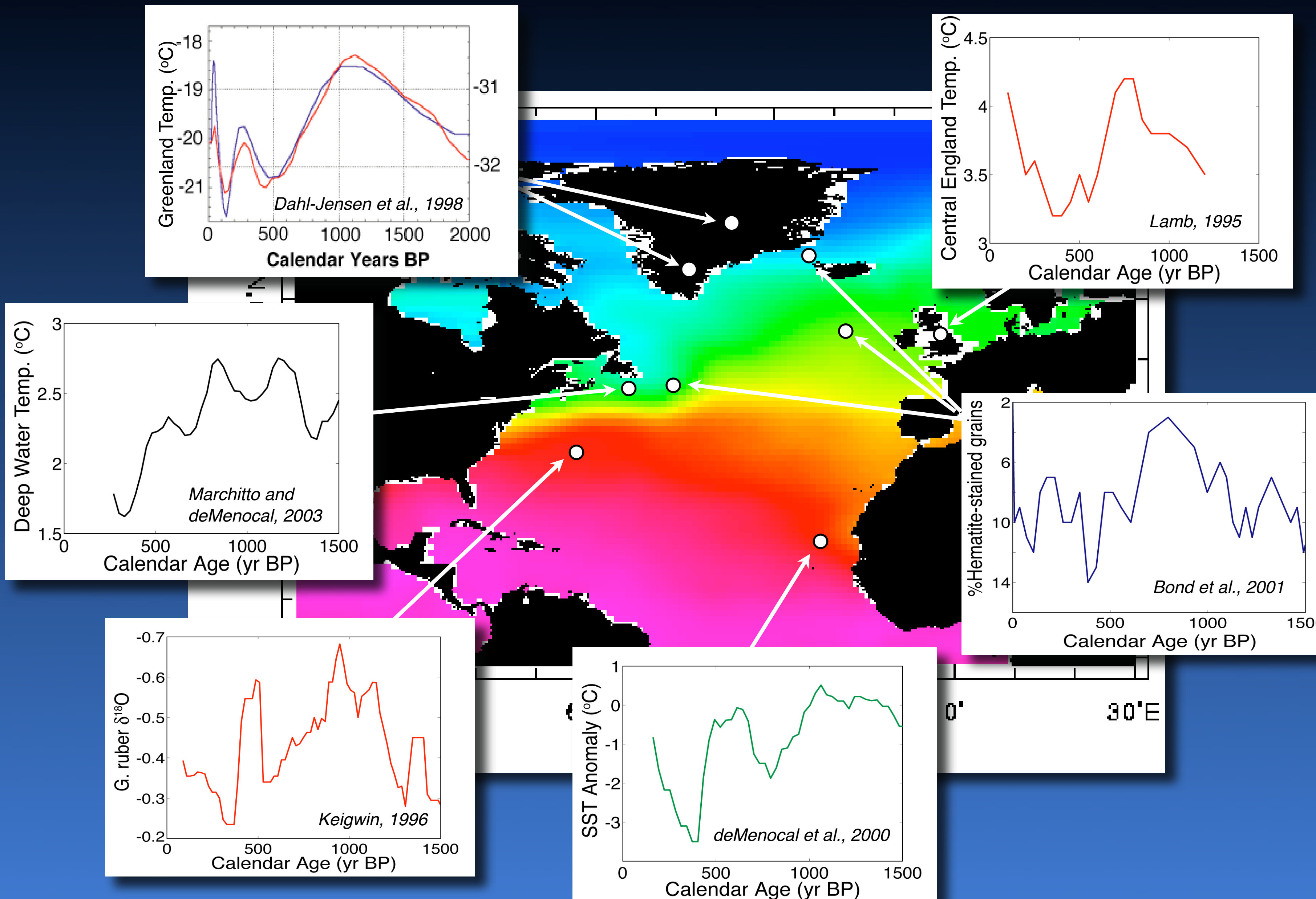
Haug et al., 2001

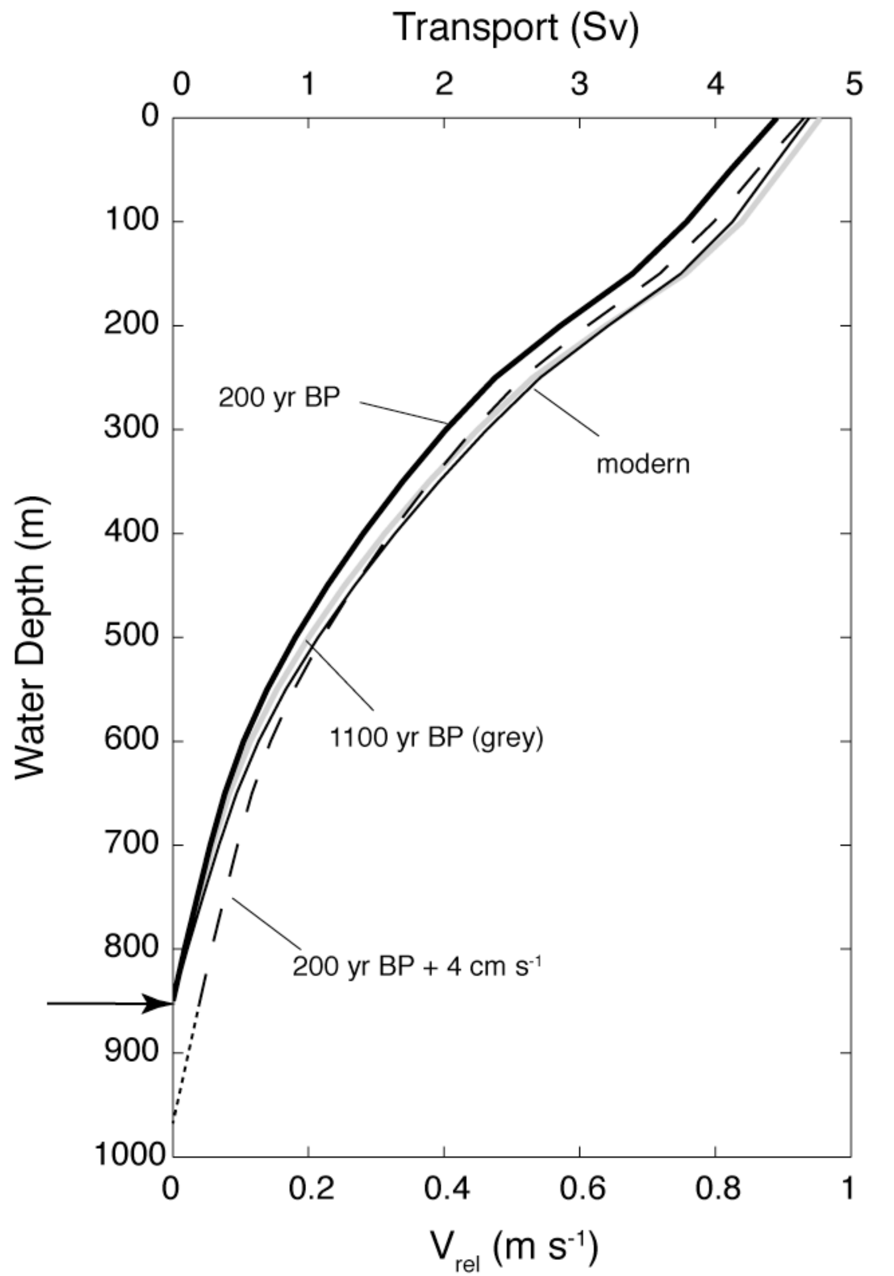
Dry Tortugas $\delta^{18}O_{water}$ record mimics $\Delta^{14}C_{atm}$



Lund and Curry, 2006

North Atlantic region cooled by ~1°C during LIA




Transport (Sv)
0
1
2
3
4
5
Water Depth (m)
0
100
200
300
400
500
600
700
800
900
1000
200 yr BP
modern
1100 yr BP (grey)
200 yr BP + 4 cm s-1
0
0.2
0.4
0.6
0.8
1
V rel (m s-1)