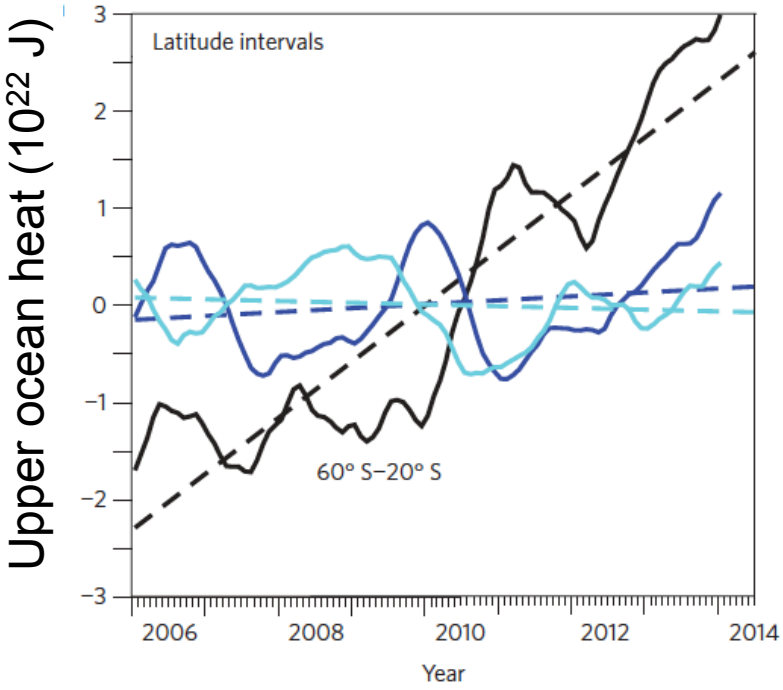
Long-term warming (and freshening) trends in the Southern Ocean from Argo

Sarah Gille

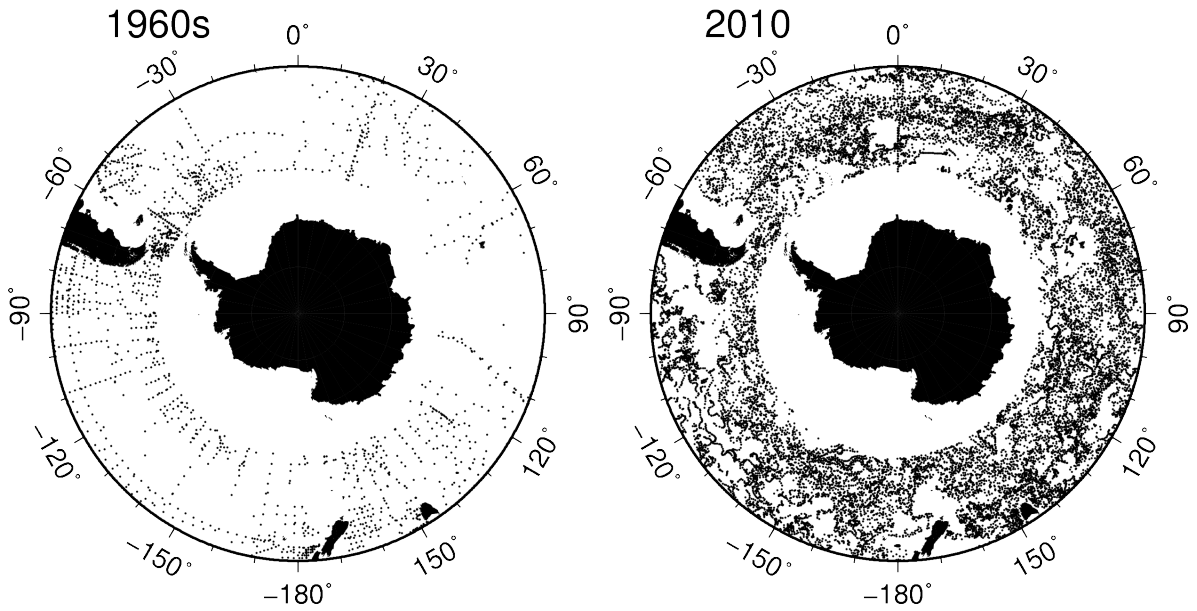
With input from many others including Neil Swart, John Fyfe, Matt Mazloff, Uriel Zajaczkovski

Scripps Institution of Oceanography



(Roemmich et al, *Nature Climate Change*, 2015)

Before Argo…. How much do we know?

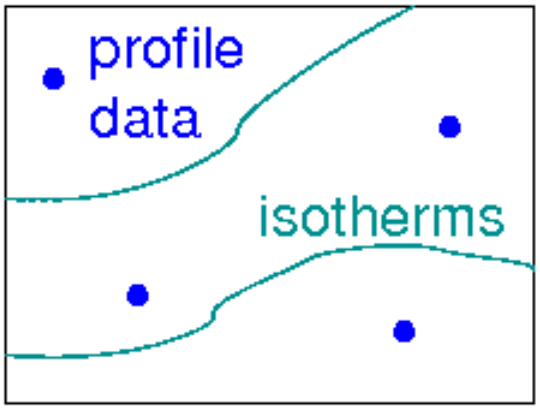


Measurements at 1000 m: Before Argo, too gappy to map easily.

- What do floats and historic data together tell us about pre-Argo heat and freshwater change?
- What mechanisms account for change?

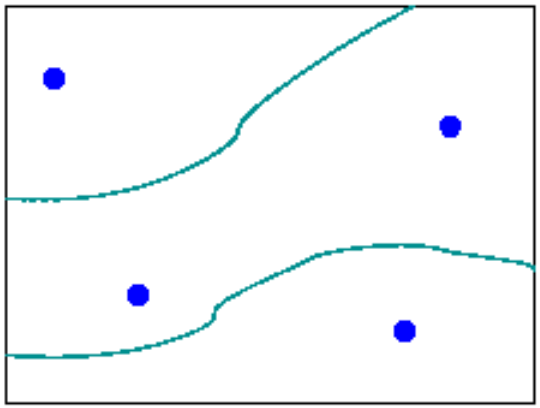
How do we assess change in T or S?

Historic data

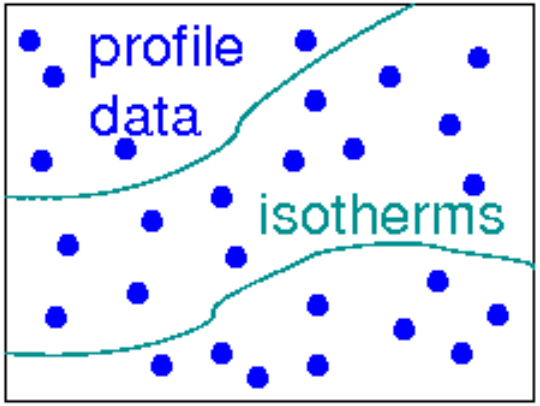


Data too sparse to map.

Use individual points.

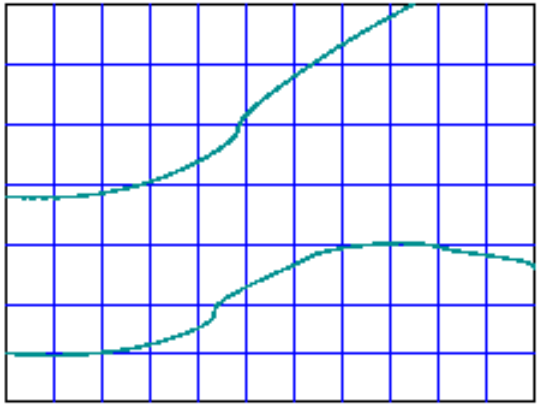


Since 2004

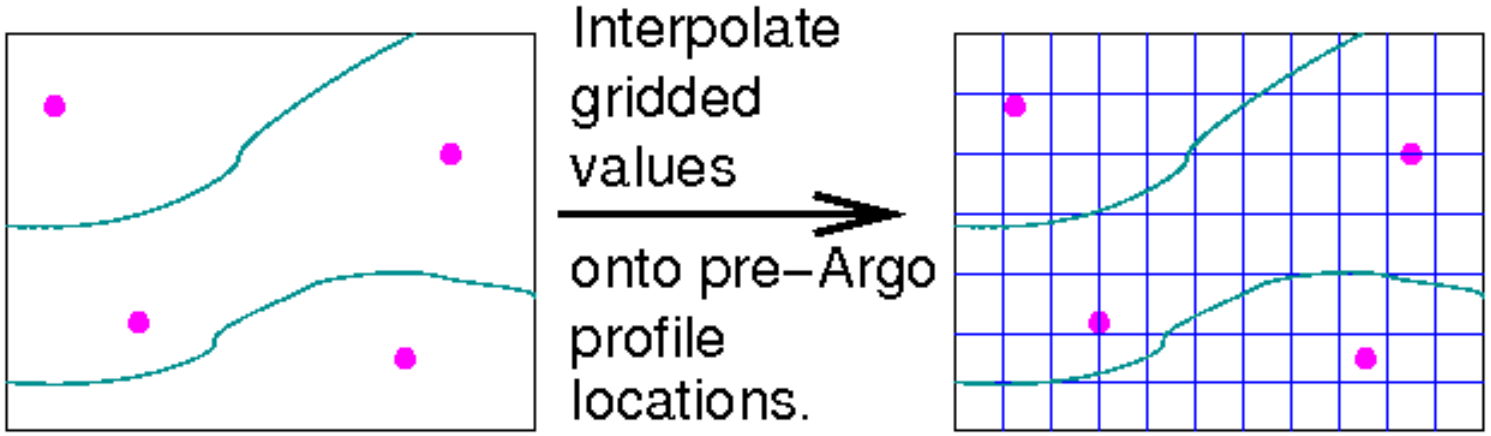


Data comparatively dense.

Objectively map to grid.



How do we assess change in T or S?



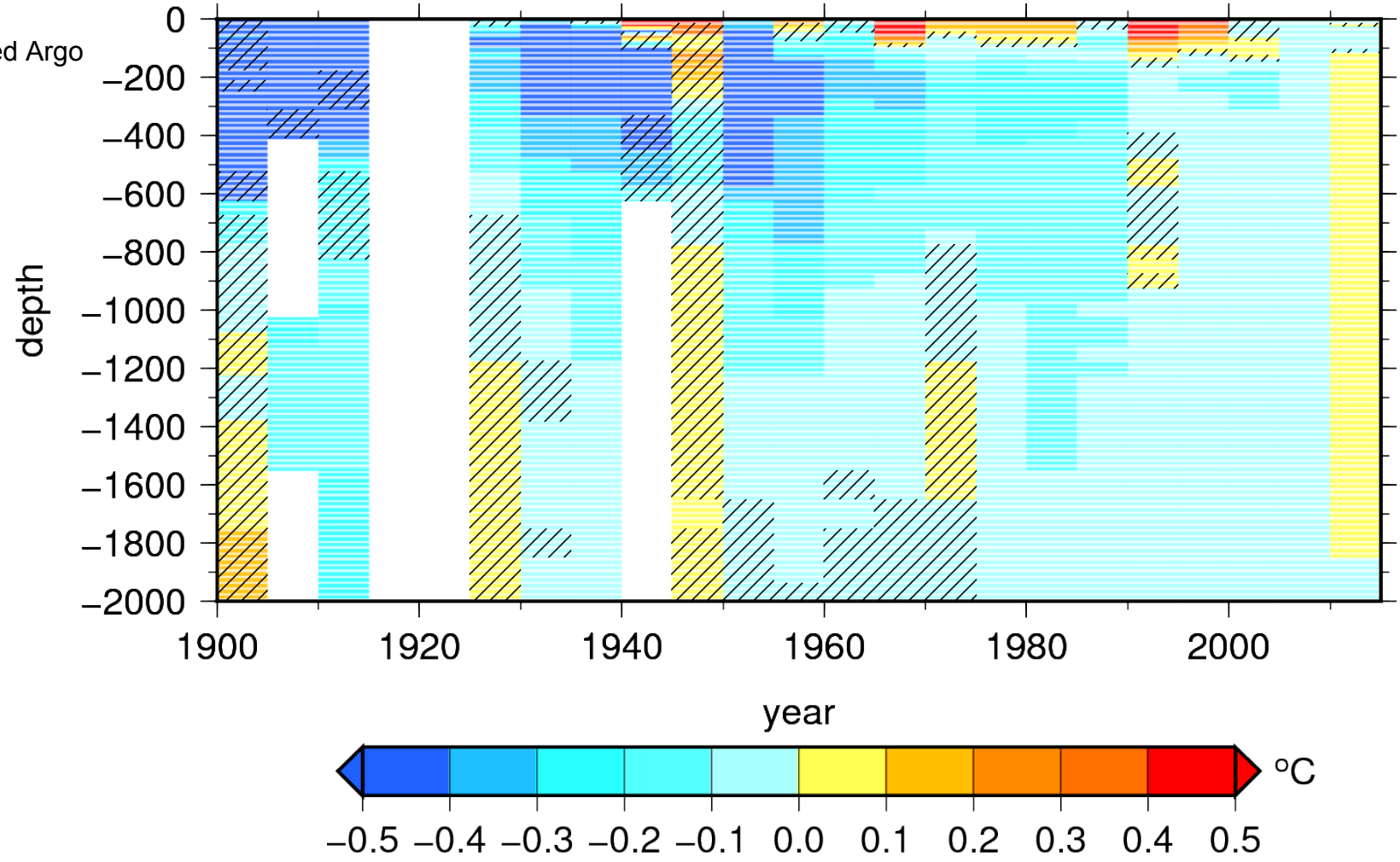
Use Roemmich and Gilson (2009) climatology for Argo era

- Compute $T_{profile} - T_{mapped\ Argo}$ or $S_{profile} - S_{mapped\ Argo}$.

Southern Ocean warming since 1900

$T_{profile} - T_{mapped\ Argo}$

Using all data in climatology

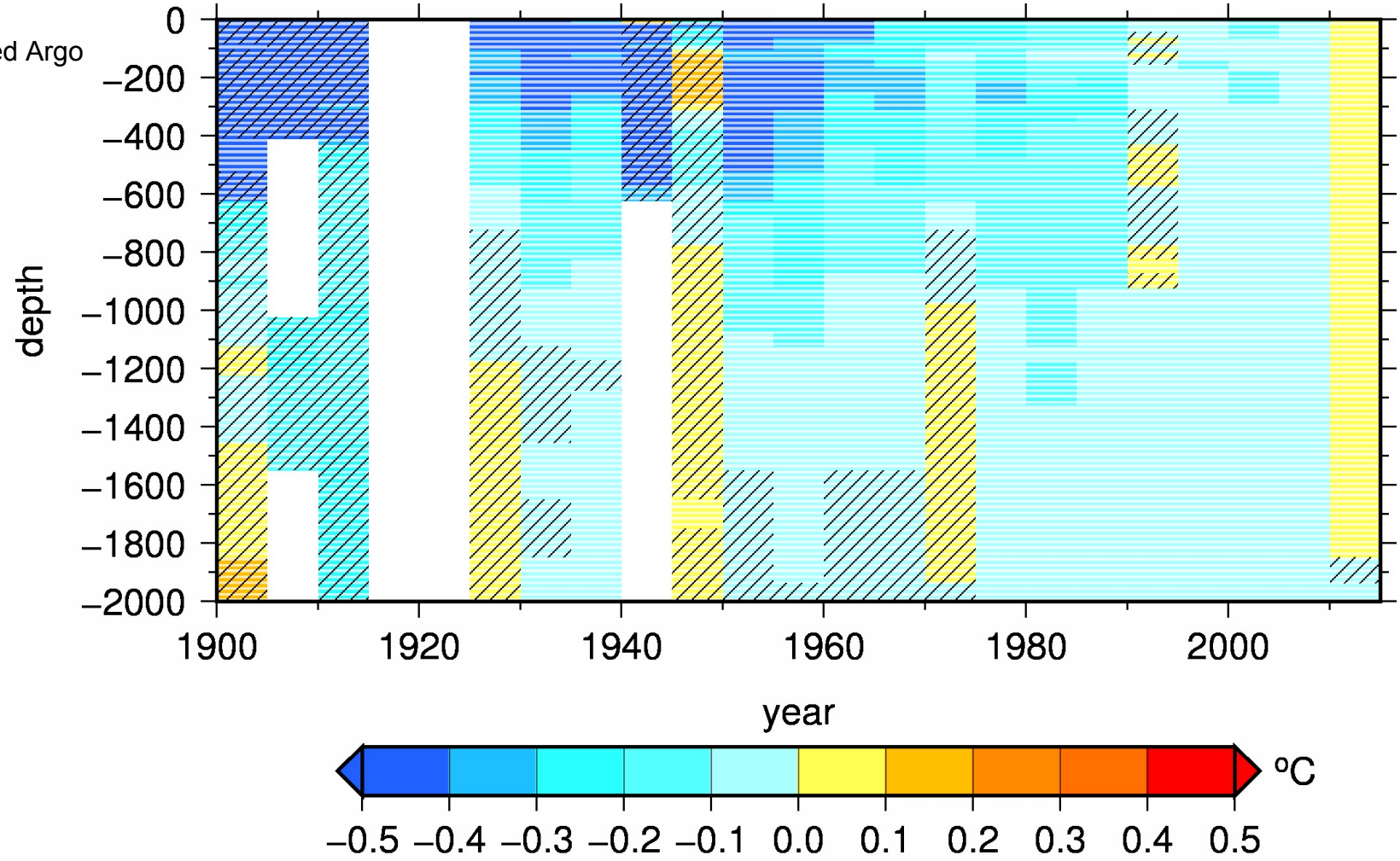


Historic hydrographic data minus modern Argo data, 40-60 S. (Gille et al, in prep)

Southern Ocean warming since 1900

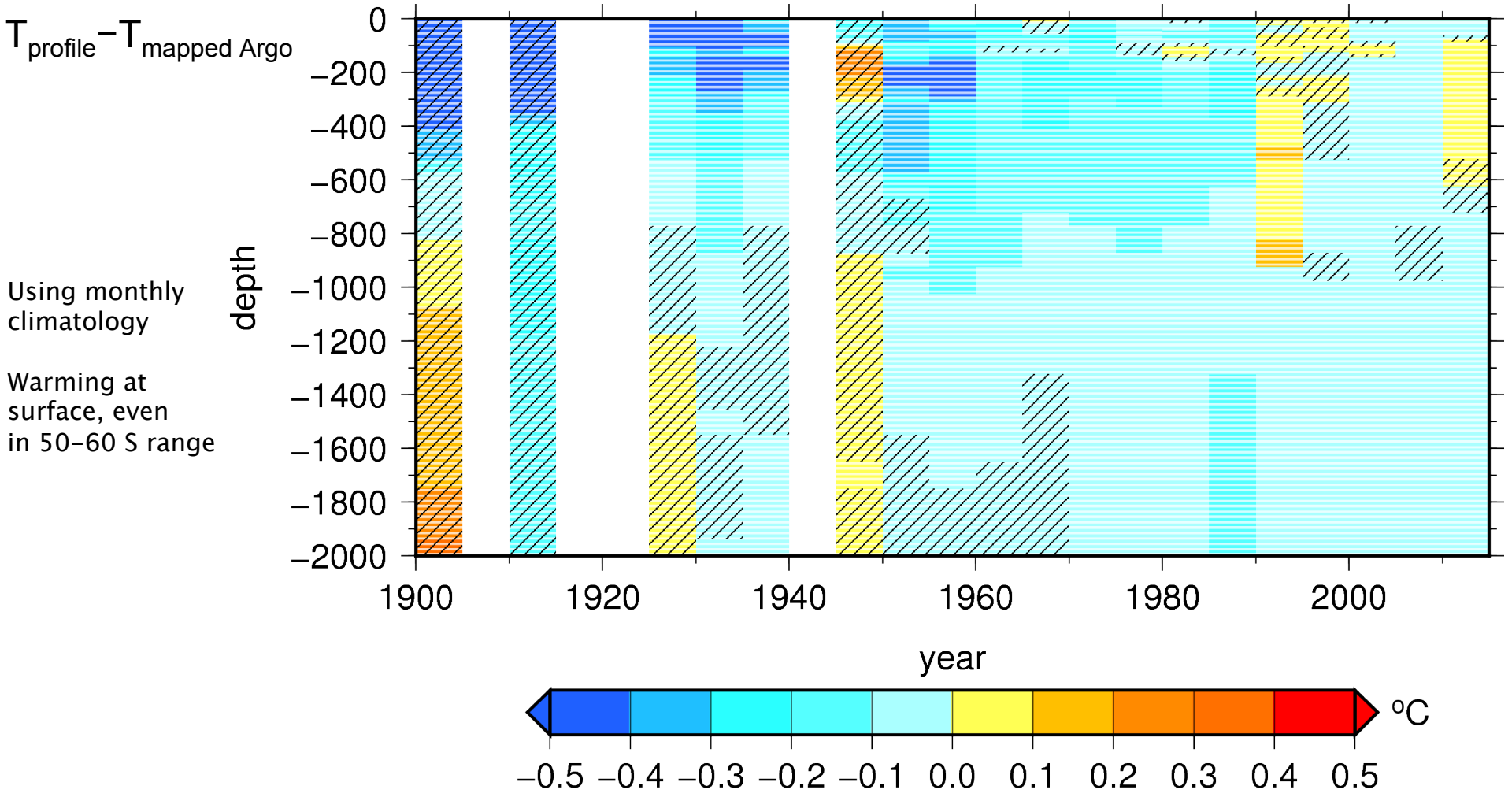
$T_{profile} - T_{mapped\ Argo}$

Using monthly climatology



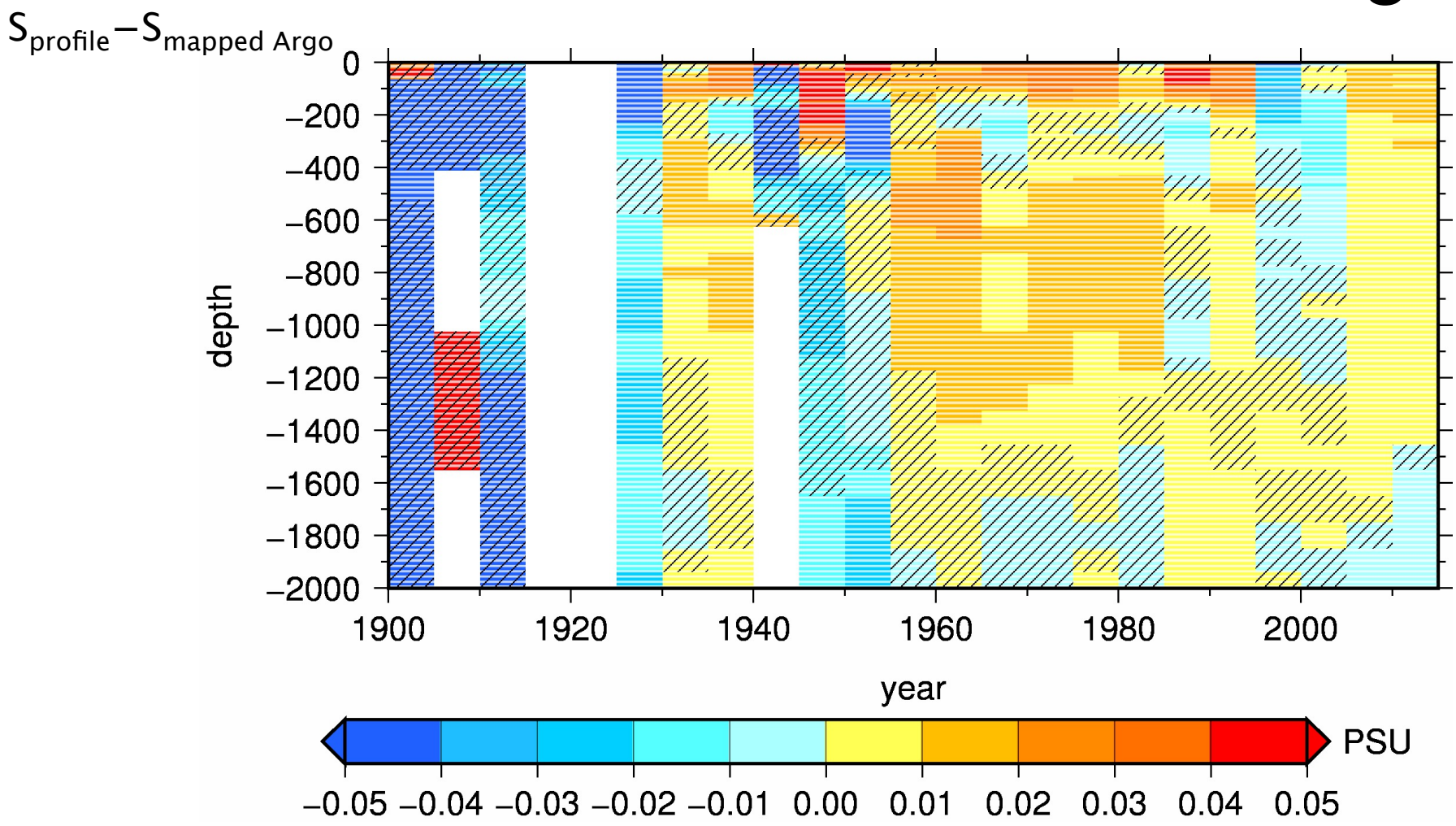
Historic hydrographic data minus modern Argo data, 40-60 S. (Gille et al, in prep)

Southern Ocean warming since 1900



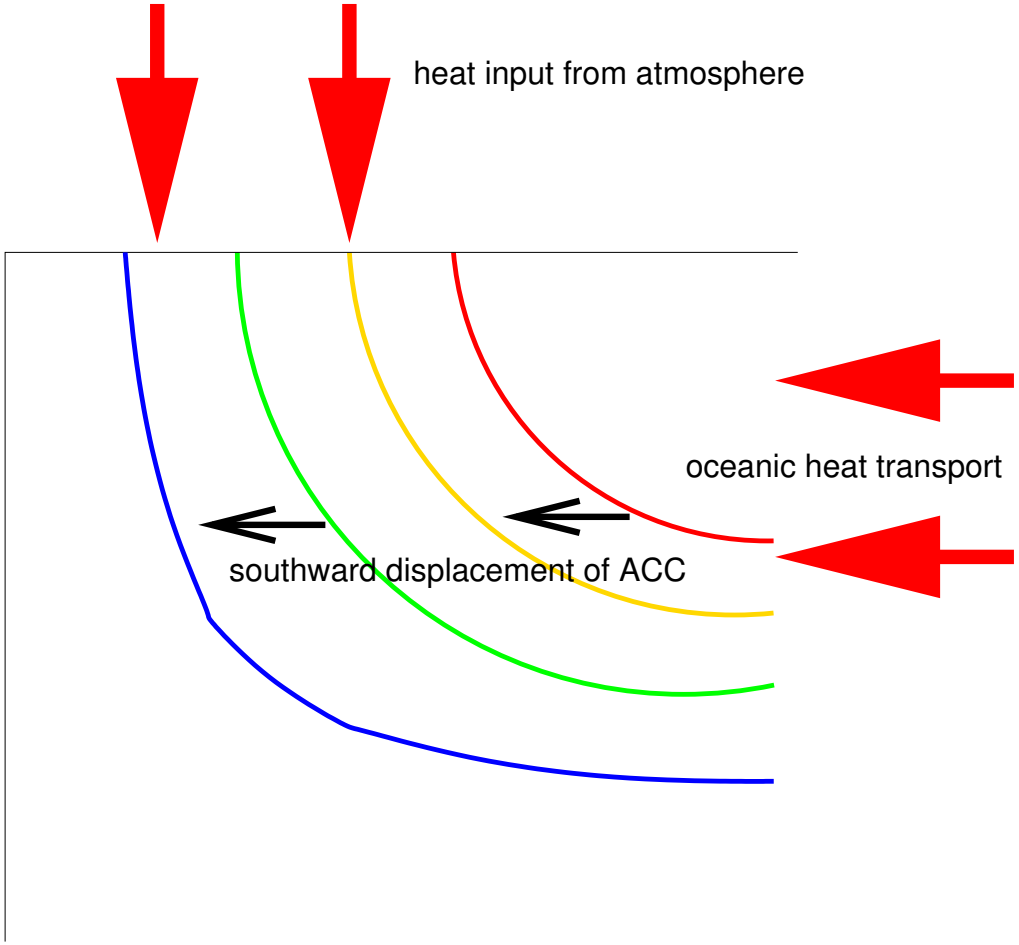
Historic hydrographic data minus modern Argo data, 50-60 S. (Gille et al, in prep)

Southern Ocean also freshening



Historic hydrographic data minus modern Argo data, 40-60 S.(Gille et al, in prep)

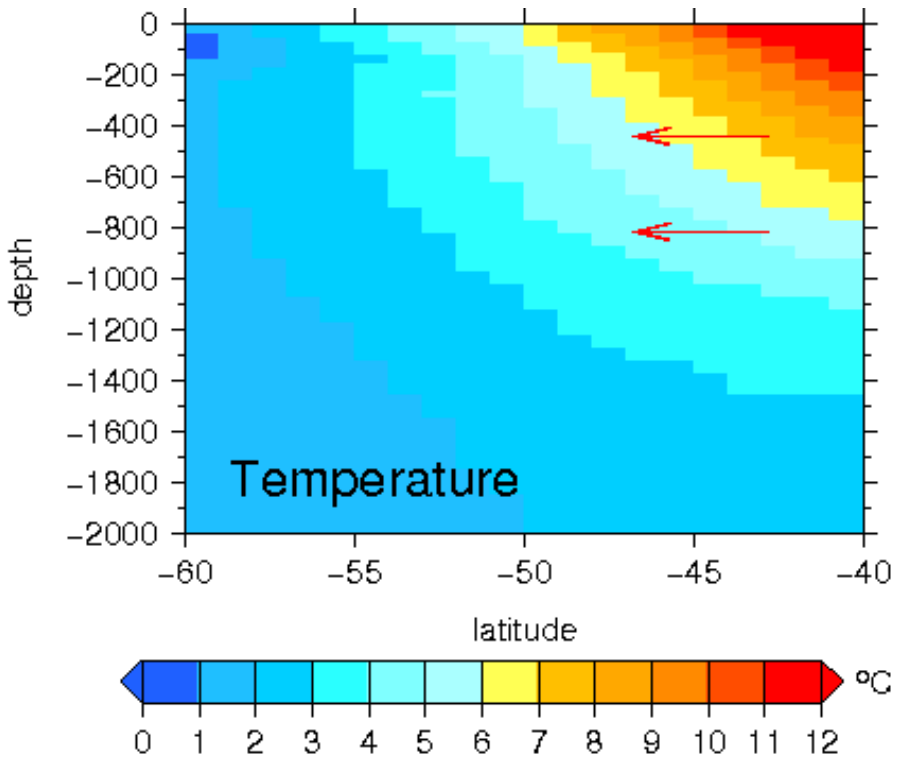
Mechanisms for Southern Ocean change

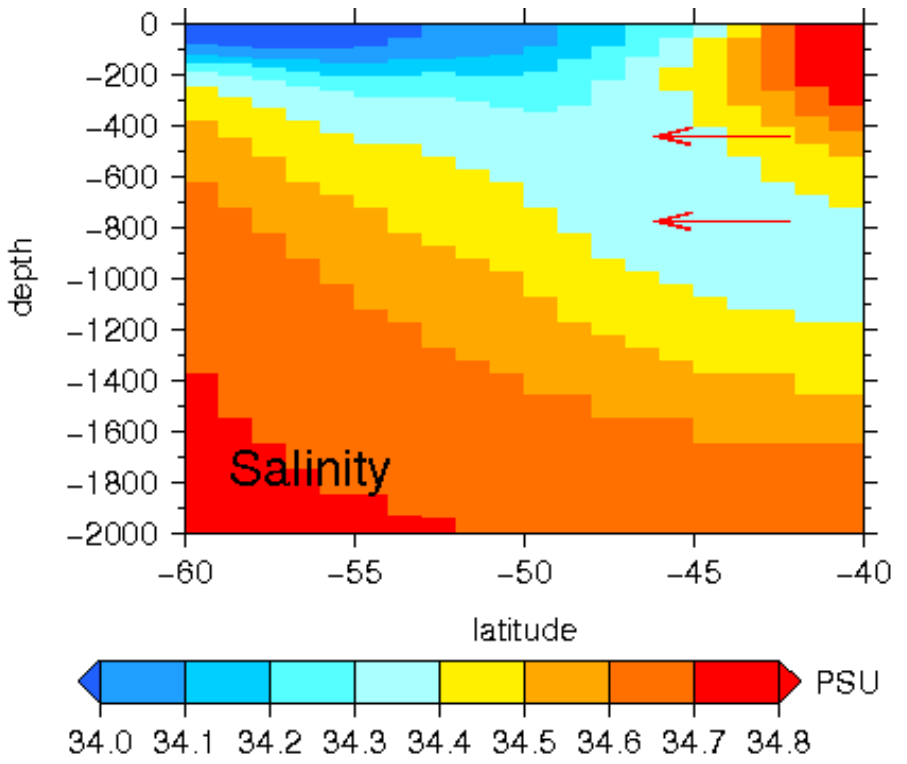


For full Southern Ocean (south of 40S)

- Advection (by mean flow or eddies)?
- Air-sea fluxes (heat and evaporation minus precipitation)?

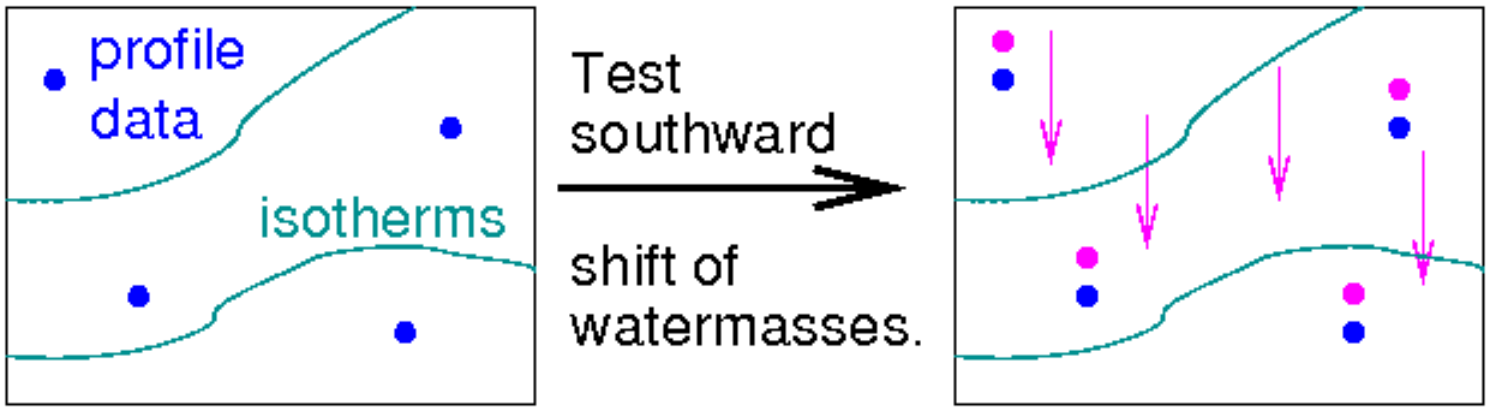
What if water masses have shifted south?





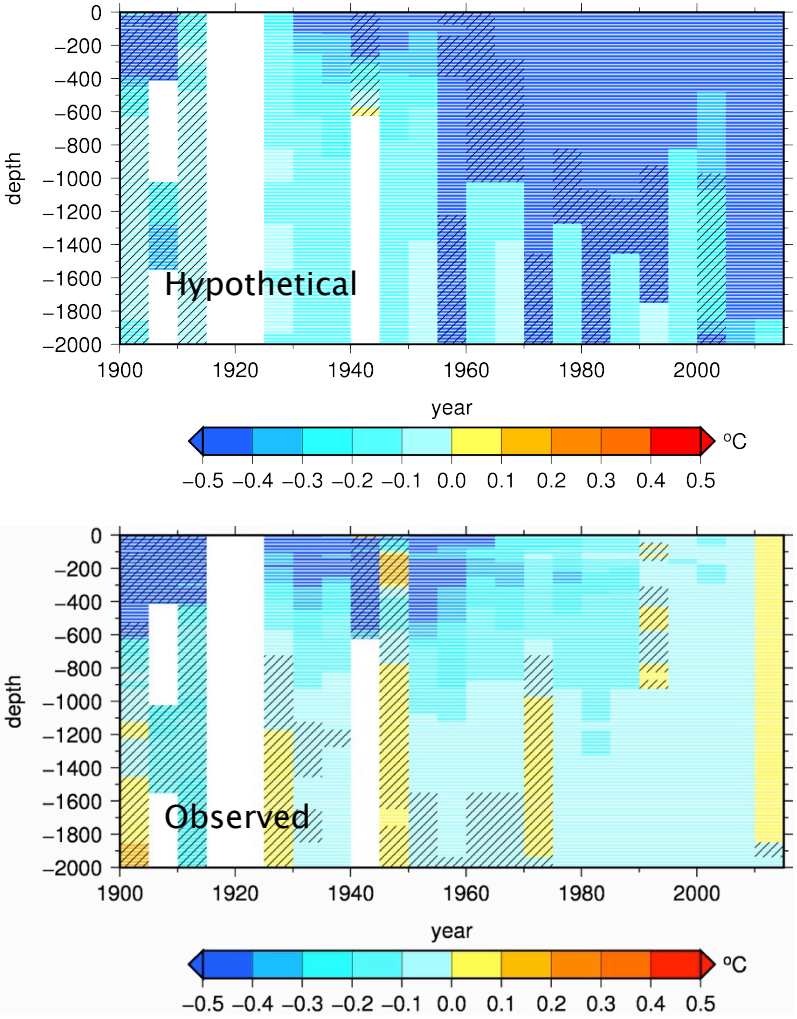
Mean meridional T and S sections

Meridional shifts in water masses?



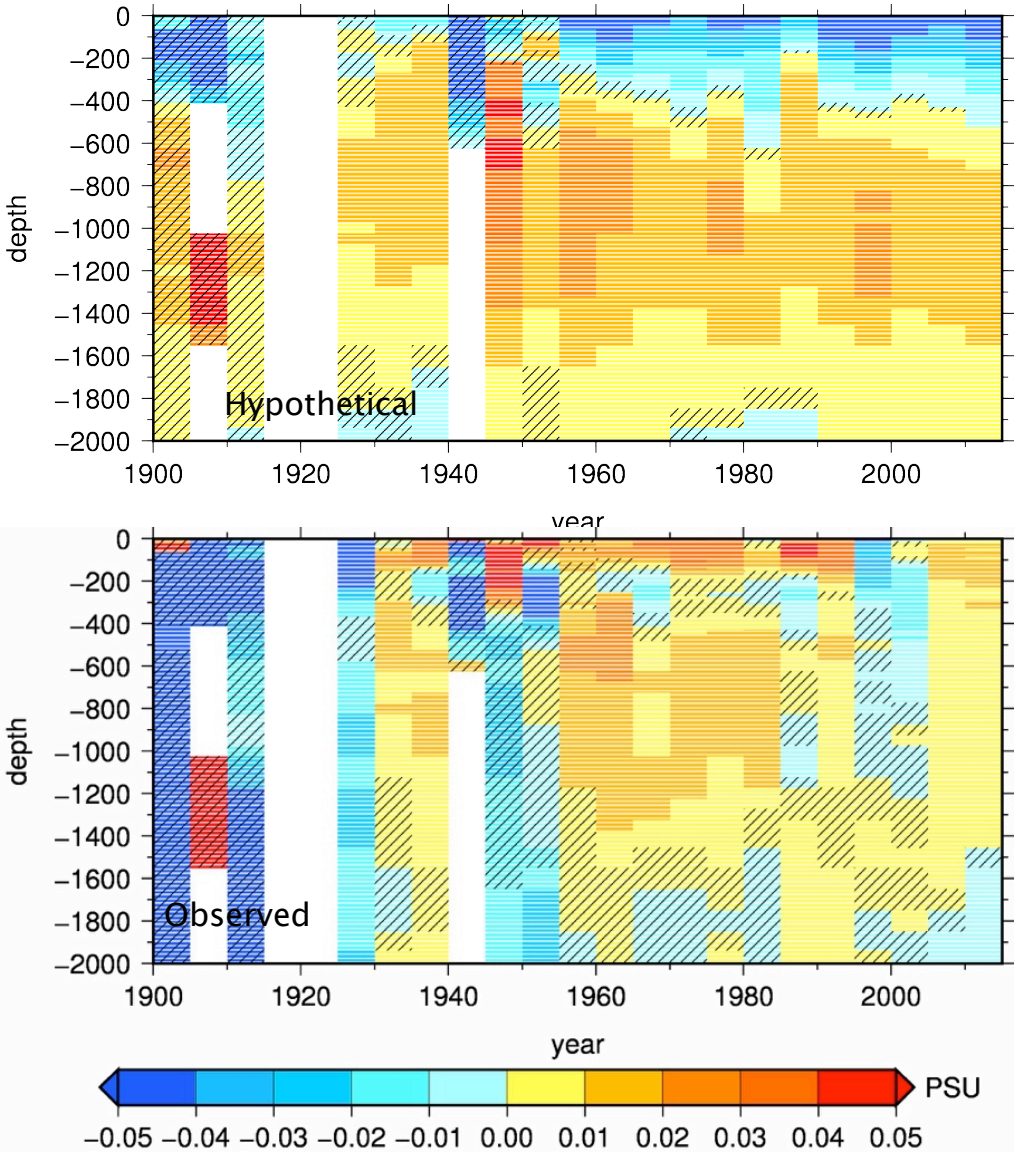
- Suppose that over time, water masses have shifted south by 1° latitude.
- Since historic sampling is variable, resulting changes in water mass properties could appear to vary in time.

Poleward shift implies warming



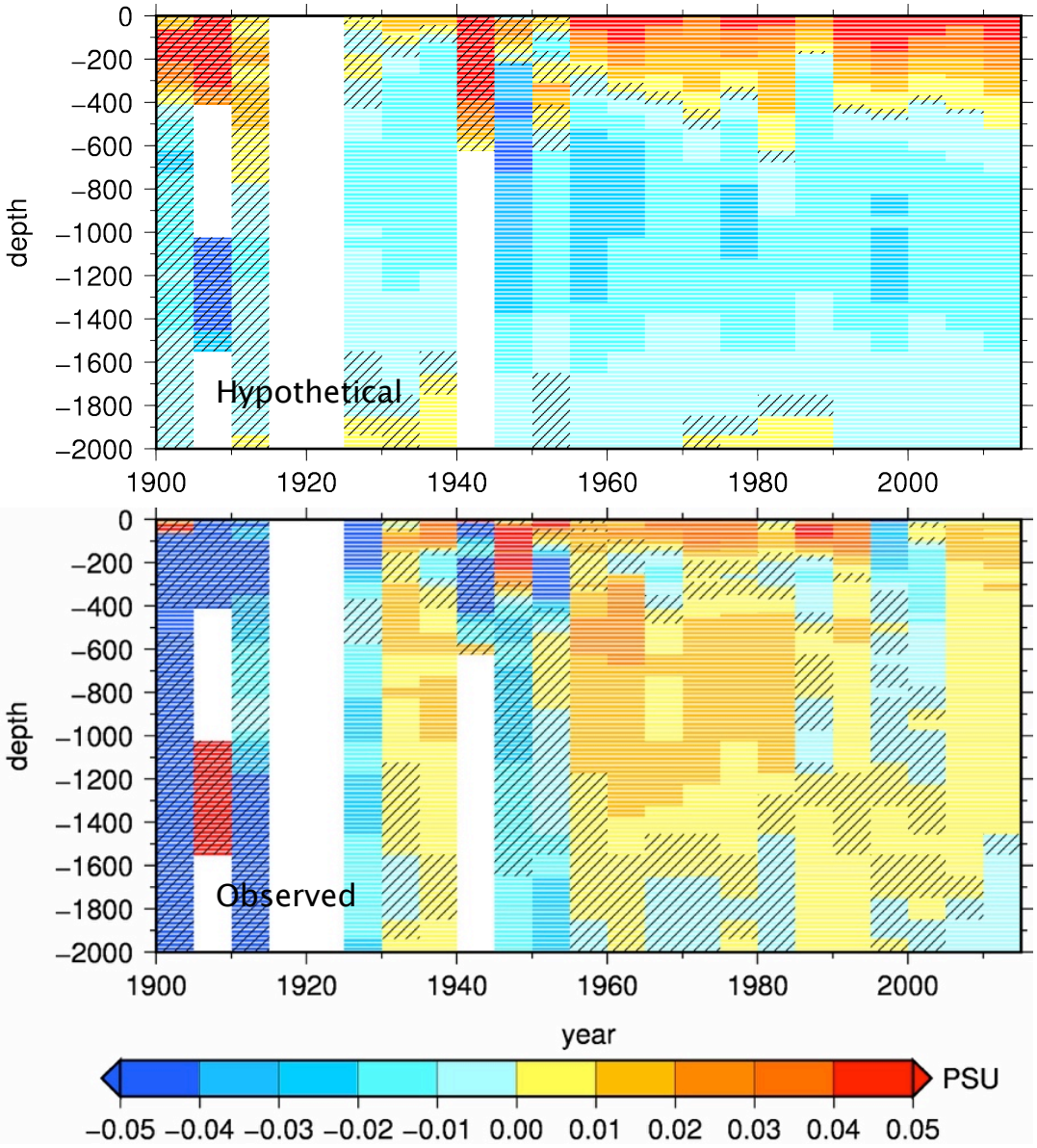
- 1° southward displacement.
- Watermass shift can't be uniform with depth: observed warming surface intensified relative to hypothesized warming due to southward shift.

Poleward shift implies freshening at depth



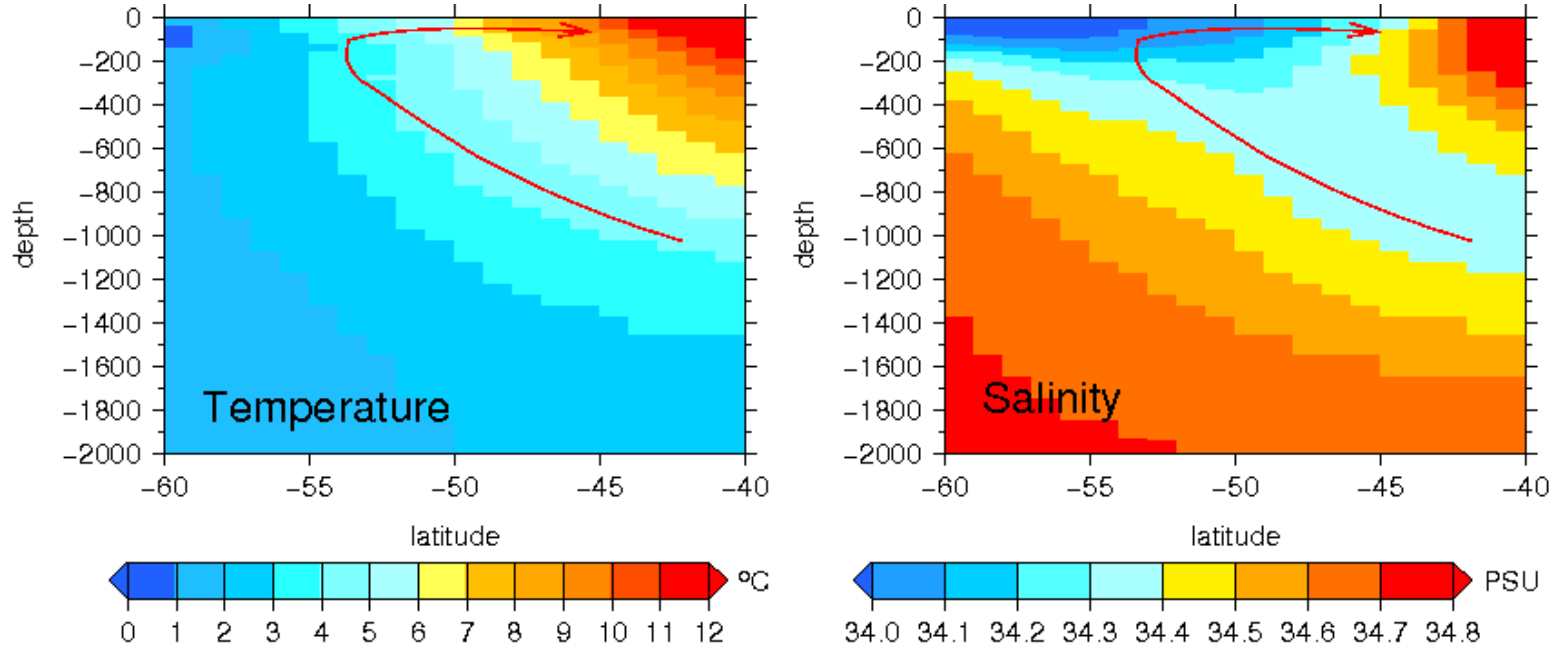
- Southward water mass shift would account for freshening at middepth…
- … but not freshening at surface.

Equatorward shift: freshening at surface



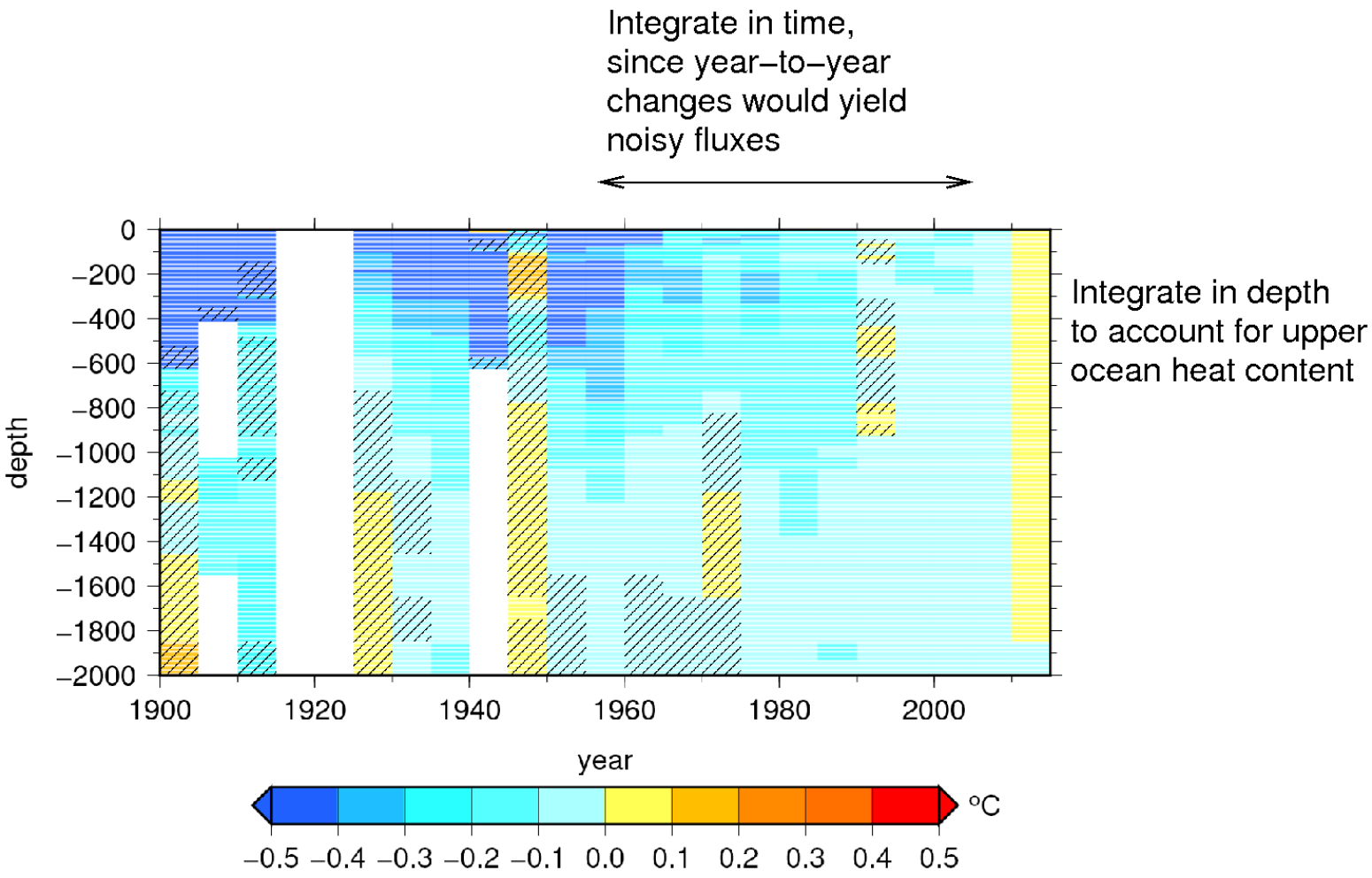
- Northward water mass shift would account for freshening at surface…
- ... but wouldn't explain temperature trends at surface (or subsurface salinity trends).

Speed up of overturning circulation?

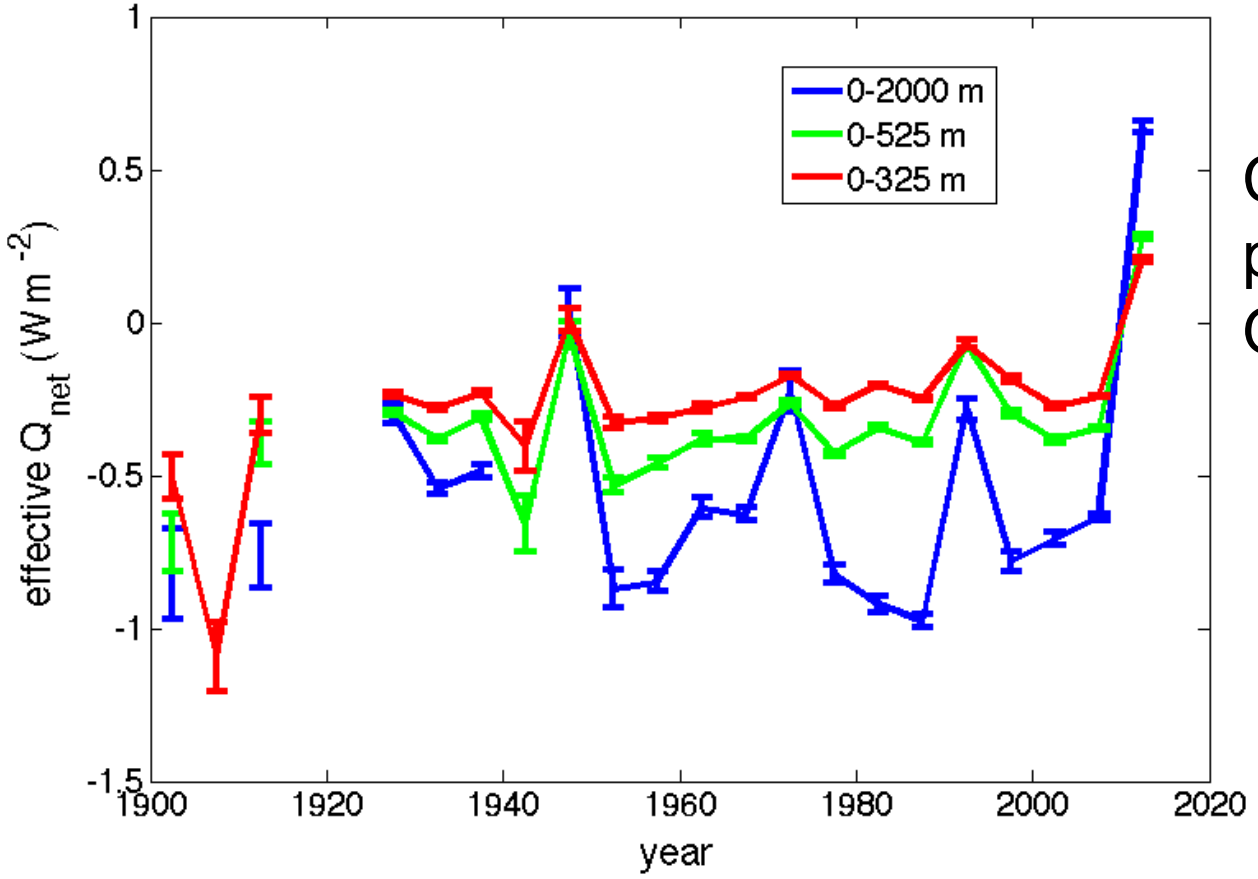


- Mid-depth water moving south; surface water moving north?
- But need surface fluxes to close temperature and salinity budgets in upper ocean.

Estimating net air-sea fluxes

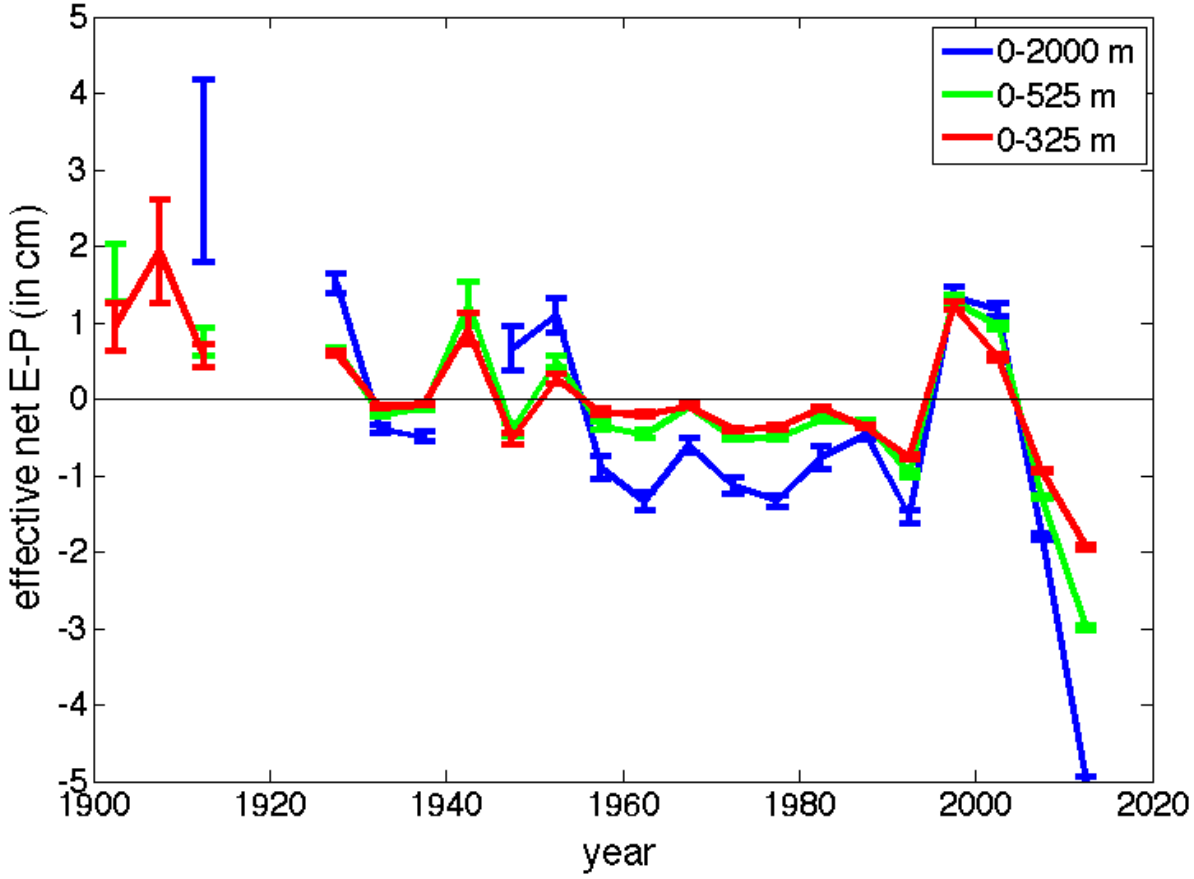


Suppose all warming from atmosphere



Consistent with persistent Q_{net} of O(0.5 W m^{-2}).

Suppose all freshening due to E-P



- Consistent with O(0.5) cm yr^{-1} freshwater input (0.01 Sv excess flux.)

Summary/Conclusions

- Historic data minus modern Argo records indicate Southern Ocean warming throughout 20th century and freshening since 1950s.
- To explain surface and subsurface trends, invoke advection plus surface fluxes.
- Is the freshwater from precipitation or melt?