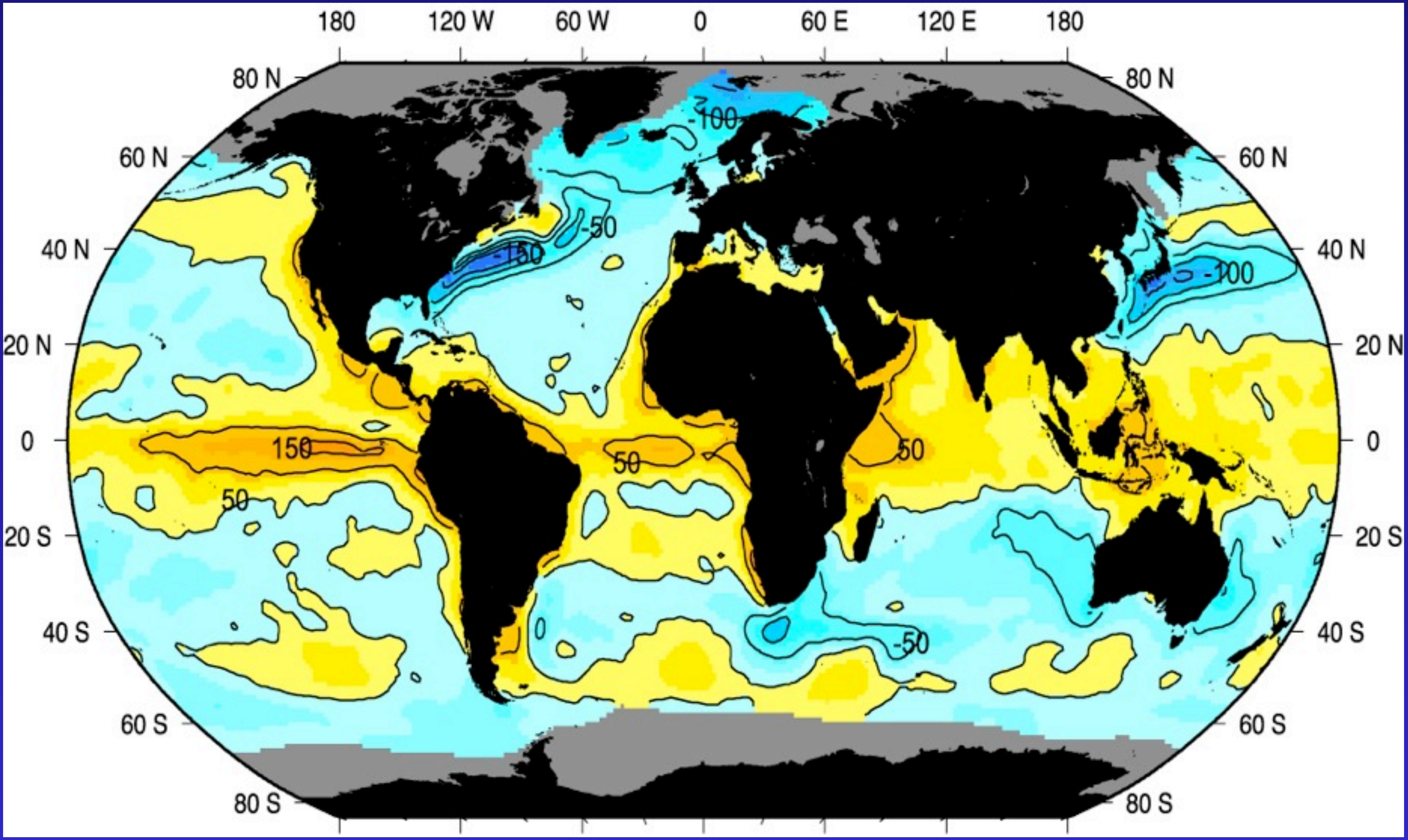
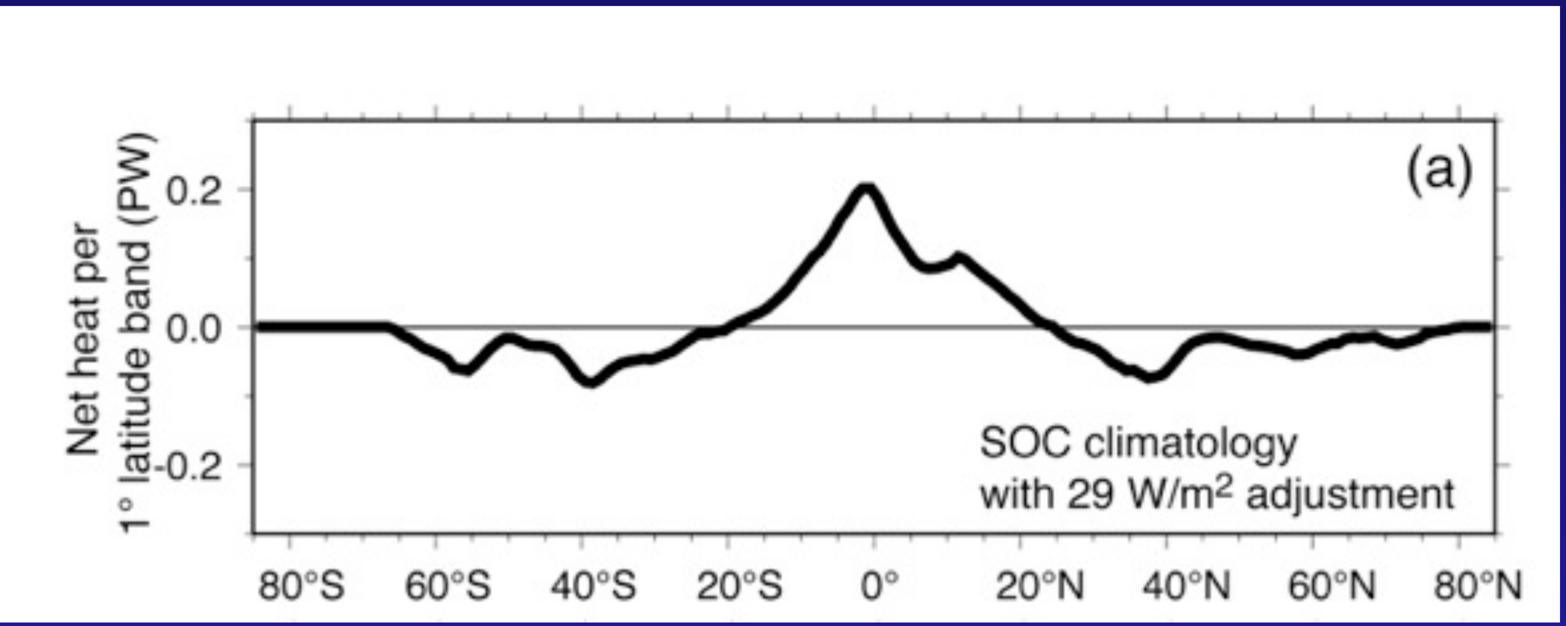
Surface heat flux (W/m^2) into ocean

Yellow: heating. Blue: cooling.



This is the annual mean (total for all seasons)

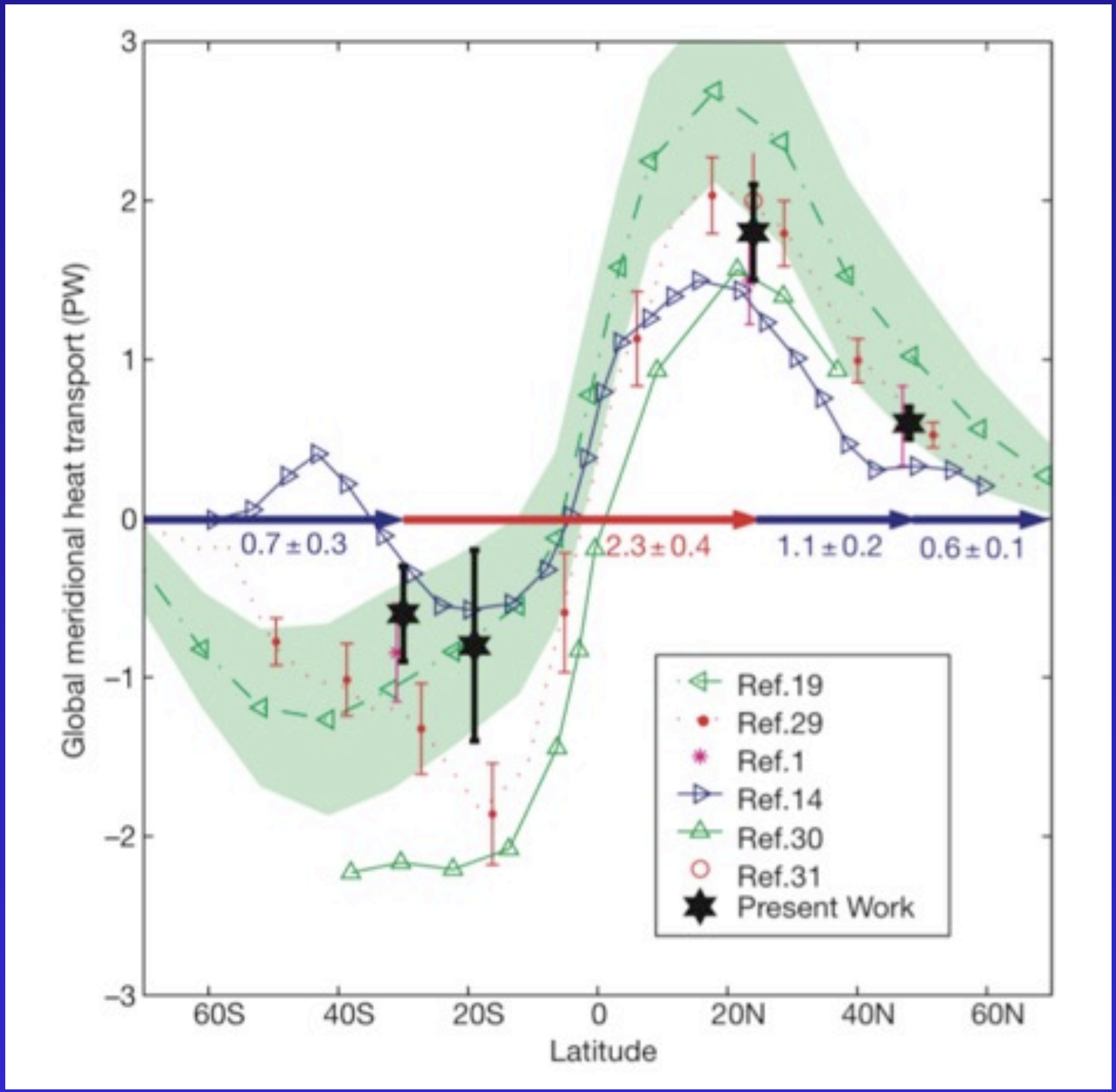
DPO Figure 5.16



Data from Josey et al., 1999; Grist and Josey, 2003

Zonally averaged heat flux into the ocean.

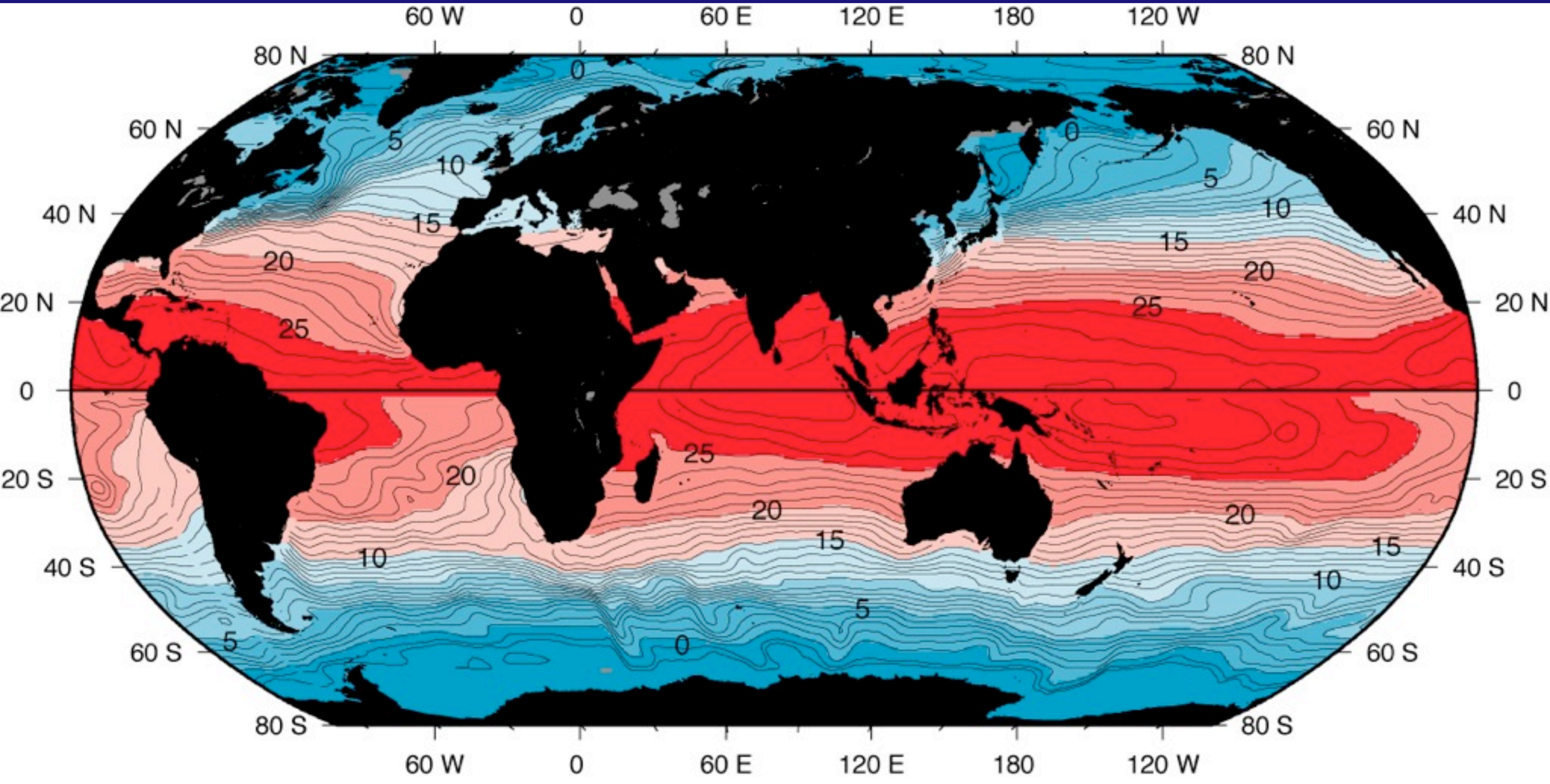
Why doesn't the equator just get hotter and hotter?



Ocean circulation transports heat poleward: famous "conveyor belt" or thermohaline circulation (more in November).

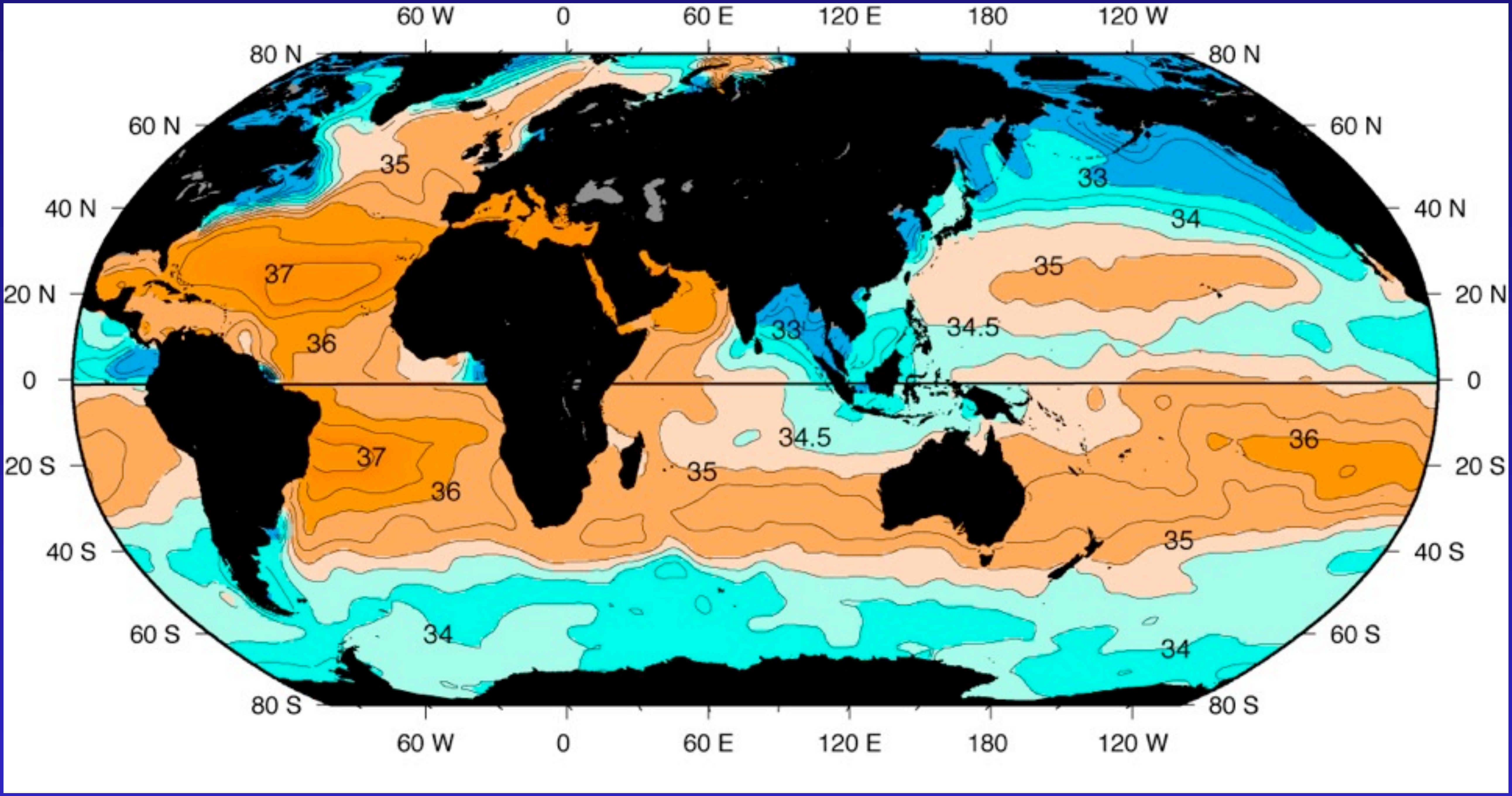
Ganachaud and Wunsch, 2000, 2003

Surface temperature (°C)

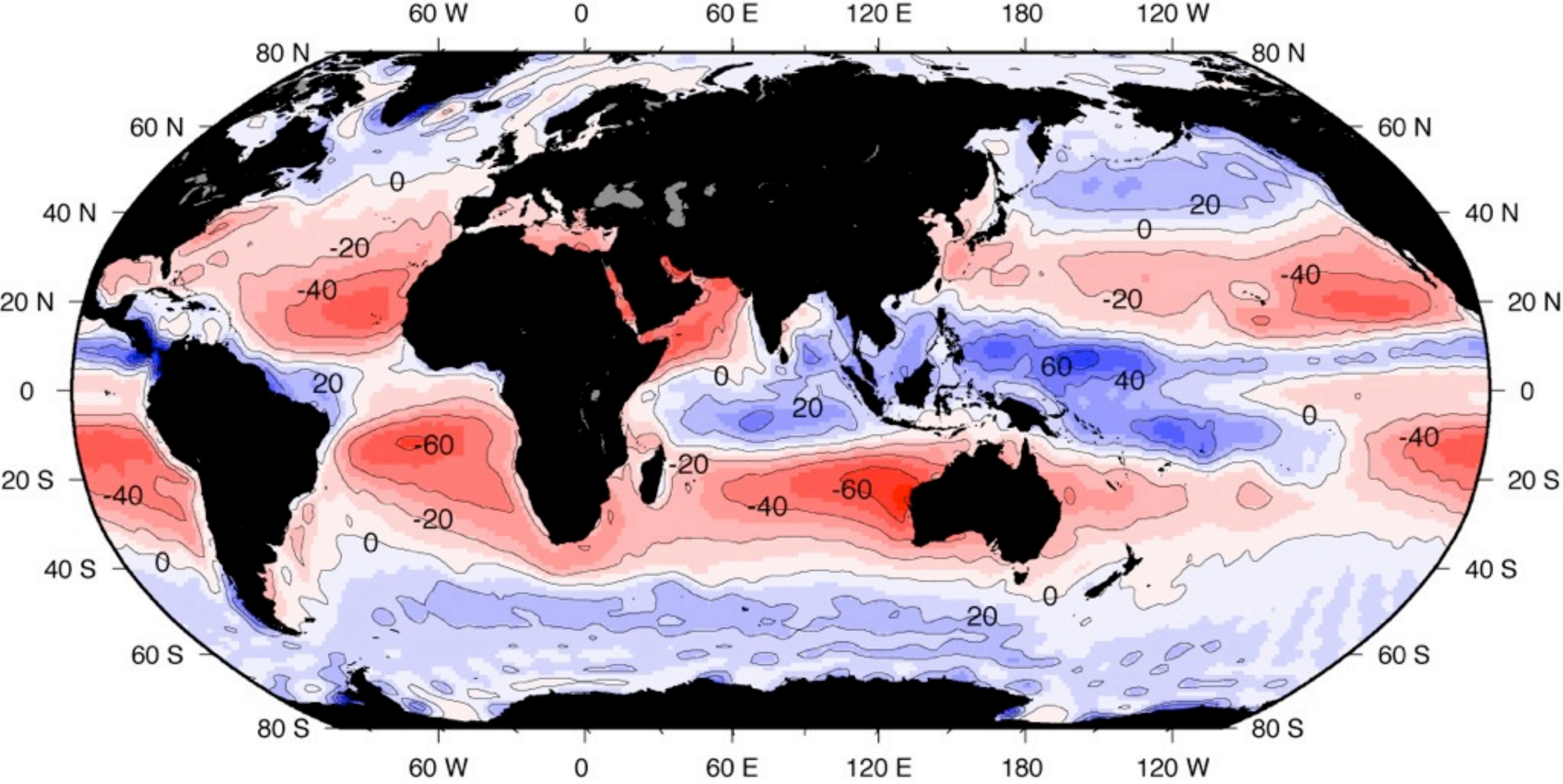


DPO Figure 4.1: Winter data from Levitus and Boyer (1994)

Surface salinity



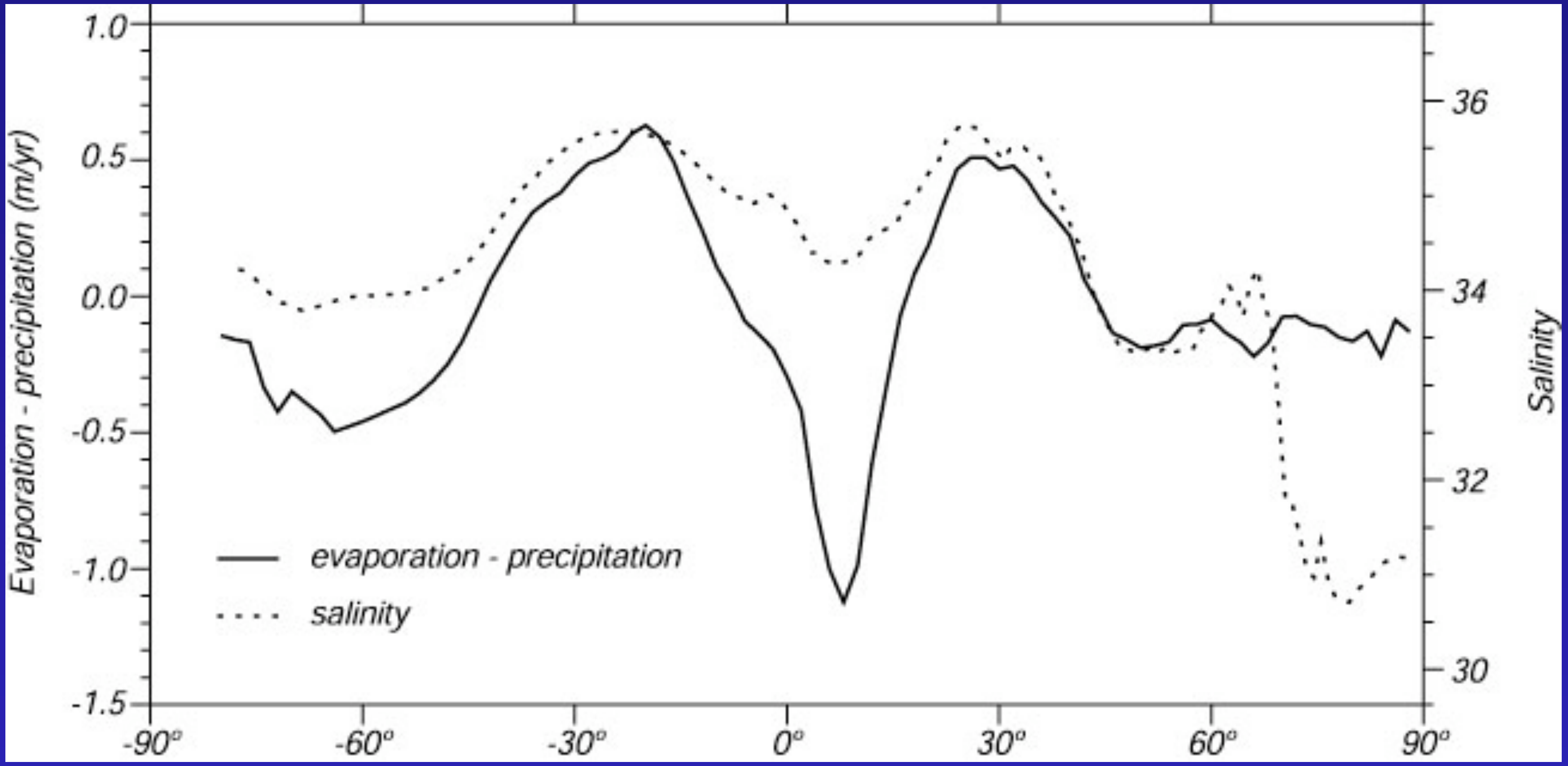
Precipitation minus evaporation (cm/yr)



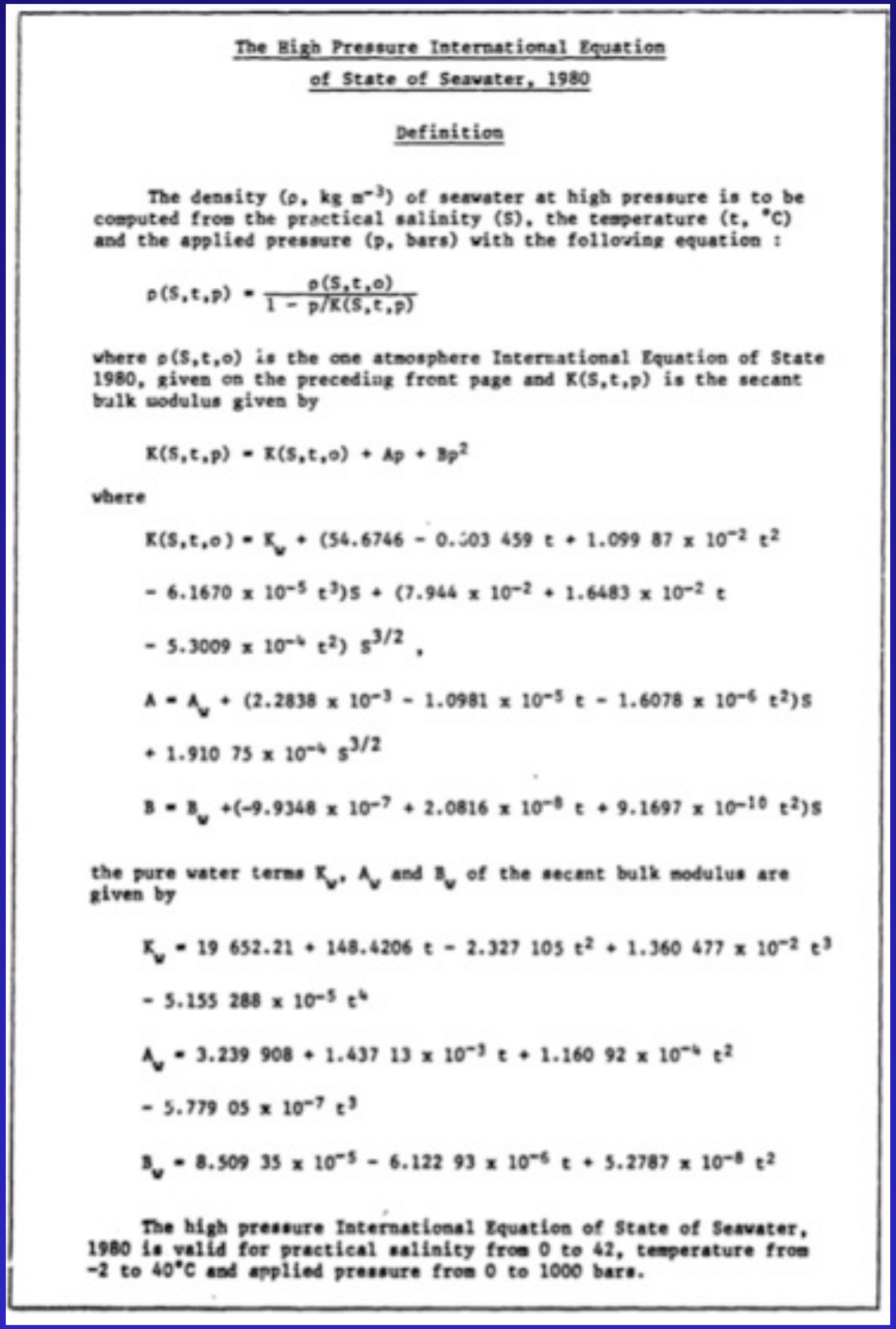
Salinity is set by freshwater inputs and exports since the total amount of salt in the ocean is constant, except on the longest geological timescales

NCEP climatology DPO 5.4

Zonally averaged E-P and Salnity



Equation of state for density: ϱ (T,S,p).



The High Pressure International Equation

of State of Seawater, 1980

Definition

The density (ρ, kg m^{-3}) of seawater at high pressure is to be computed from the practical salinity (S), the temperature (t, °C) and the applied pressure (p, bars) with the following equation :

$$\rho(S,t,p) = \frac{\rho(S,t,o)}{1 - p/K(S,t,p)}$$

where $\rho(S,t,o)$ is the one atmosphere International Equation of State 1980, given on the preceding front page and $K(S,t,p)$ is the secant bulk modulus given by

$$K(S,t,p) = K(S,t,o) + Ap + Bp^2$$

where

$$K(S,t,o) = K_w + (54.6746 - 0.603\,459\ t + 1.099\,87 \times 10^{-2}\ t^2$$

$$- 6.1670 \times 10^{-5}\ t^3)S + (7.944 \times 10^{-2} + 1.6483 \times 10^{-2}\ t$$

$$- 5.3009 \times 10^{-4}\ t^2)\ S^{3/2}\ ,$$

$$A = A_w + (2.2838 \times 10^{-3} - 1.0981 \times 10^{-5}\ t - 1.6078 \times 10^{-6}\ t^2)S$$

$$+ 1.910\,75 \times 10^{-4}\ S^{3/2}$$

$$B = B_w + (-9.9348 \times 10^{-7} + 2.0816 \times 10^{-8}\ t + 9.1697 \times 10^{-10}\ t^2)S$$

the pure water terms K_w, A_w and B_w of the secant bulk modulus are given by

$$K_w = 19\,652.21 + 148.4206\ t - 2.327\,105\ t^2 + 1.360\,477 \times 10^{-2}\ t^3$$

$$- 5.155\,288 \times 10^{-5}\ t^4$$

$$A_w = 3.239\,908 + 1.437\,13 \times 10^{-3}\ t + 1.160\,92 \times 10^{-4}\ t^2$$

$$- 5.779\,05 \times 10^{-7}\ t^3$$

$$B_w = 8.509\,35 \times 10^{-5} - 6.122\,93 \times 10^{-6}\ t + 5.2787 \times 10^{-8}\ t^2$$

The high pressure International Equation of State of Seawater, 1980 is valid for practical salinity from 0 to 42, temperature from −2 to 40°C and applied pressure from 0 to 1000 bars.

Or, use seawater matlab routines (google), or nice online equation of state calculator:

http://fermi.jhuapl.edu/denscalc.html

Linearized equation of state

$$\partial\rho \approx \rho \times [-\alpha\partial T + \beta\partial S + \gamma\partial p]$$

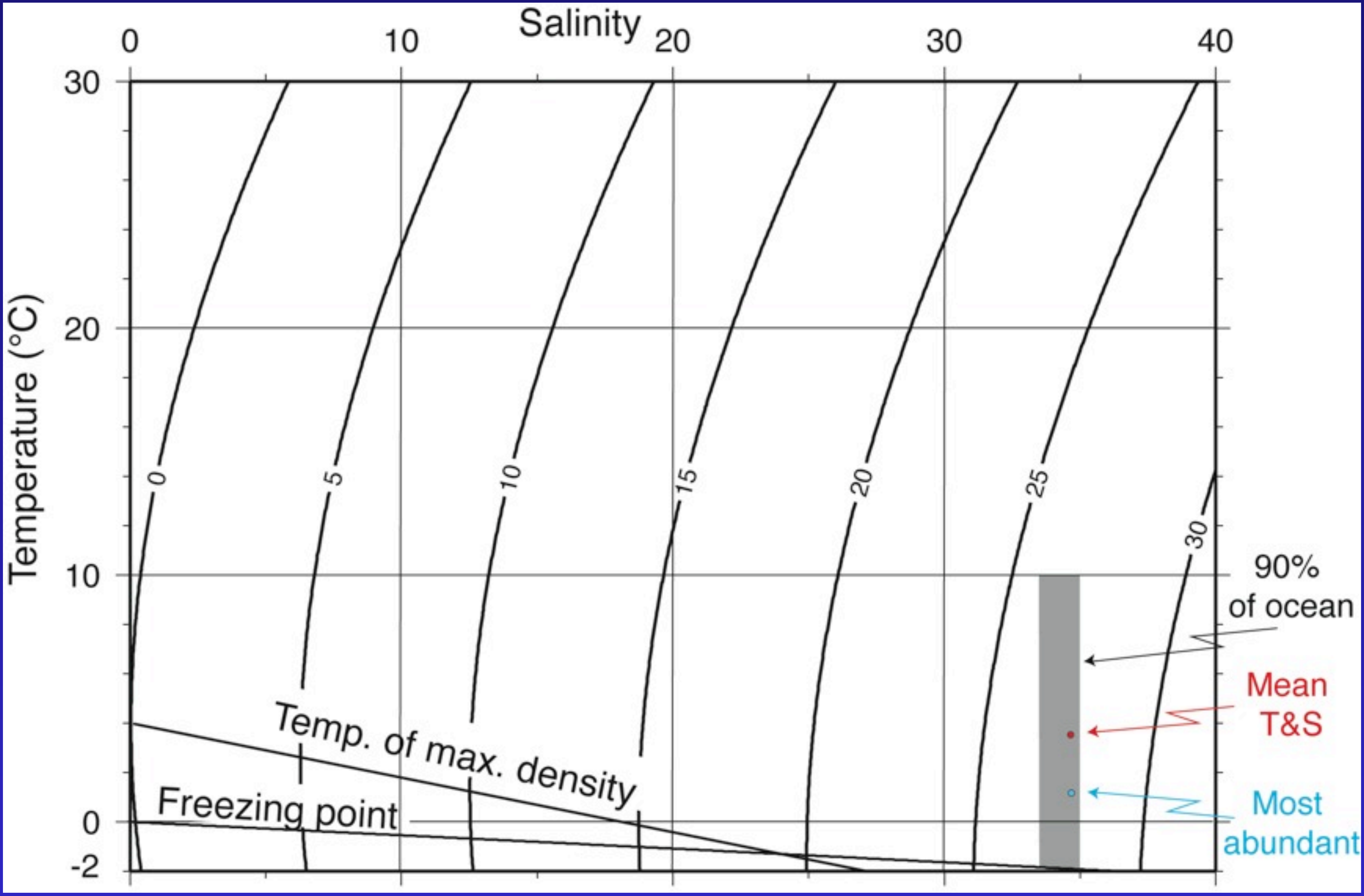
thermal expansion coefficient ~
3×10^{-4} [°C^{-1}] at surface

So a net increase of 2 °C will change density by...?

How about volume? (mass conserved)

$$\text{Mass} = \varrho_1 V_1 = \varrho_2 V_2$$

Seawater density, freezing point



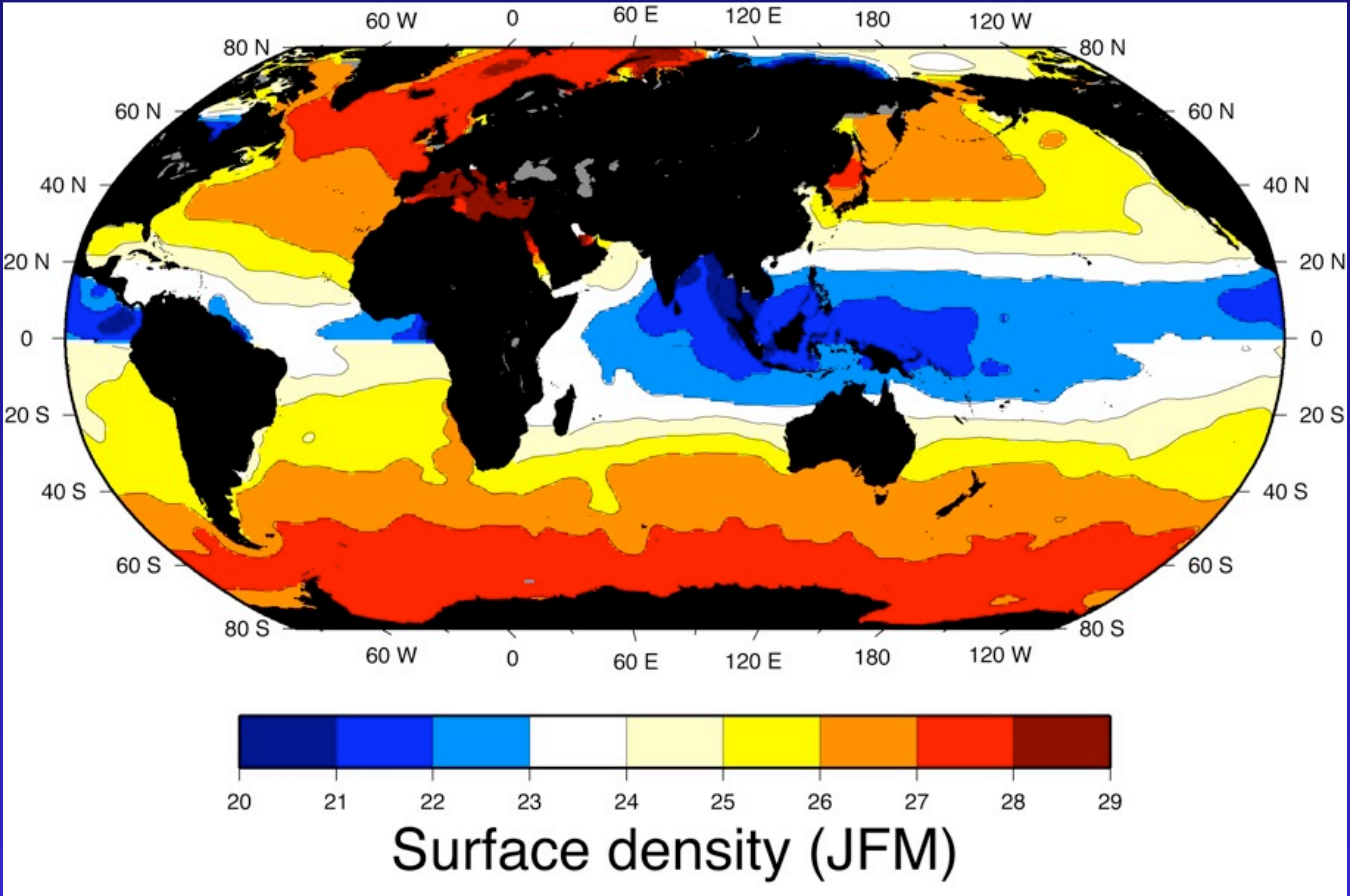
DPO Figure 3.1

Sea ice and brine rejection

- Why then does sea ice float? (because it is actually less dense than the seawater…)

- Brine rejection: as sea ice forms, it excludes salt from the ice crystal lattice.
- The salt drips out the bottom, and the sea ice is much fresher (usually ~3-4 psu) than the seawater (around 30-32 psu)
- The rejected brine mixes into the seawater below. If there is enough of it mixing into a thin enough layer, it can measurably increase the salinity of the seawater, and hence its density
- This is the principle mechanism for forming the densest waters of the world ocean.

Surface density (winter)



DPO Figure 4.16