UNDERSTANDING OCEAN SALINITY: RESULTS FROM ARGO

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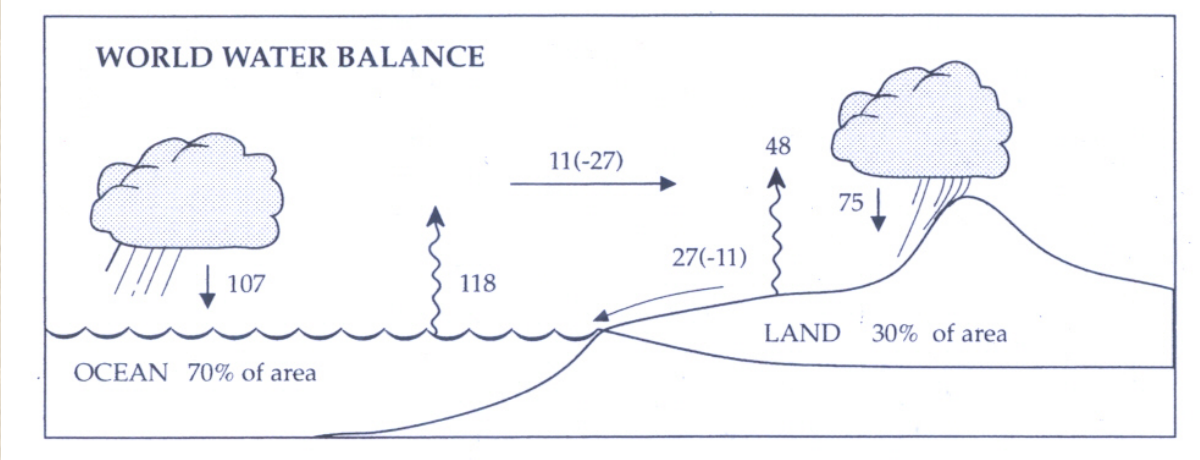
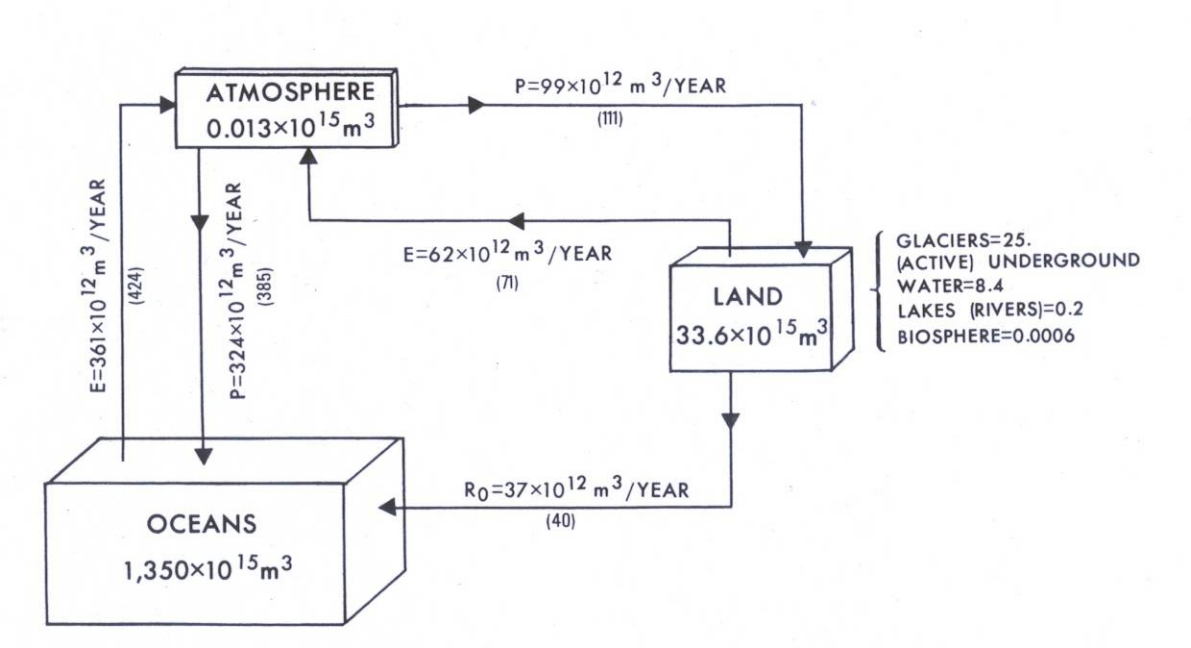
Ocean salinity: what is it, and why are we interested?



(Hartmann, 1994)



(Peixoto and Oort, 1992)

Ocean salinity: classical and modern

$$S = \frac{M_S}{M_S + M_W} = \frac{1}{1 + \left(\frac{M_W}{M_S} \right)}$$

classical definition of salinity

salinity is tied to the hydrological cycle

Ion	‰ by weight	[°/₀₀ = parts per thousand]	
chloride, Cl^-	18.980	negative ions (anions) total	= 21.861‰
sulphate, SO_4^{2-}	2.649		
bicarbonate, HCO_3^-	0.140		
bromide, Br^-	0.065		
borate, $H_2BO_3^-$	0.026		
fluoride, F^-	0.001		
sodium, Na^+	10.556	positive ions (cations) total	= 12.621‰
magnesium, Mg^{2+}	1.272		
calcium, Ca^{2+}	0.400		
potassium, K^+	0.380		
strontium, Sr^{2+}	0.013		
		overall total salinity	= 34.482‰

the chemical composition of seawater

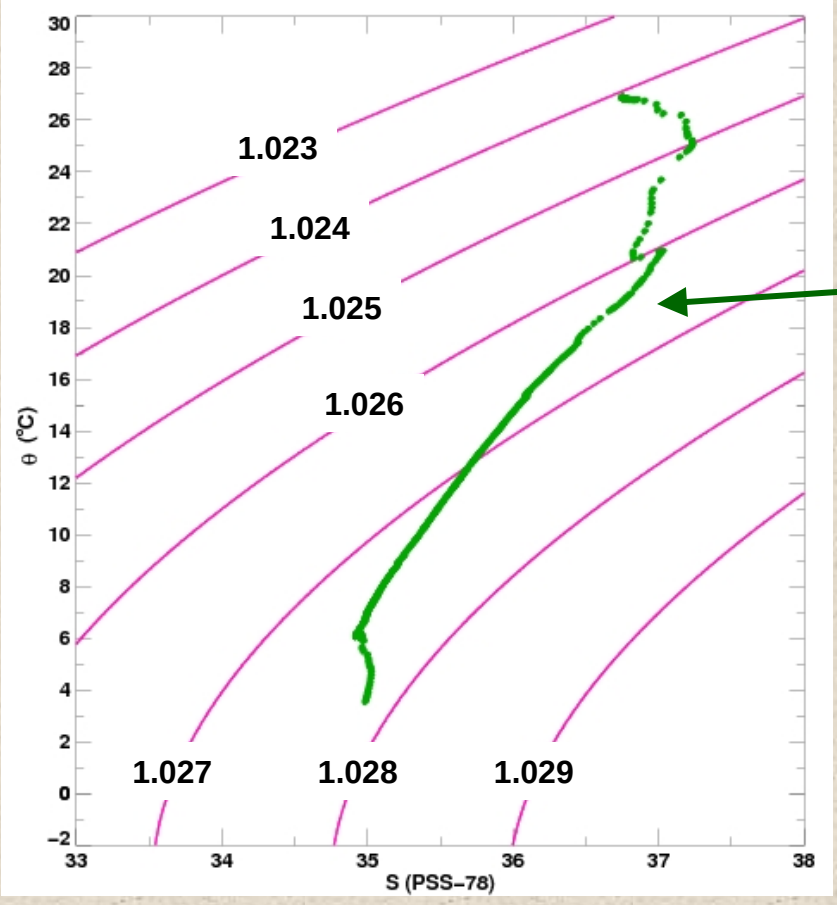
Perhaps surprisingly, the proportions of the major constituents of seawater are approximately constant nearly *everywhere in the deep ocean*.

$$C = C(S, T, p) \rightarrow S = S(C, T, p)$$

modern definition of salinity; the 1978 Practical Salinity Scale

$$\rho = \rho(S, T, p)$$ **the modern equation of state for seawater**

the density (mass) distribution determines the flow, via Newton's Laws



Data from UW float 6889 (WMO 5903283) in the subtropical N. Atlantic

$$S = \frac{M_S}{M_S + M_W}$$

classical definition of salinity

$$\frac{\partial S}{\partial t} + \underset{\sim}{u}_H \cdot \nabla S + w \frac{\partial S}{\partial z} = \text{sources} - \text{sinks}$$

average this over a surface mixed layer of thickness *h* :

$$h \frac{\partial S}{\partial t} = -\langle \underset{\sim}{u} \rangle h \cdot \nabla \langle S \rangle - \nabla \cdot \int_{-h}^{0} \underset{\sim}{u} S \, dz - \left(\langle S \rangle - S_{-h} \right) \left(\frac{\partial h}{\partial t} + \underset{\sim}{u}_{-h} \cdot \nabla h + w_{-h} \right) + \left(E - P \right) S_o + \text{SSM}$$

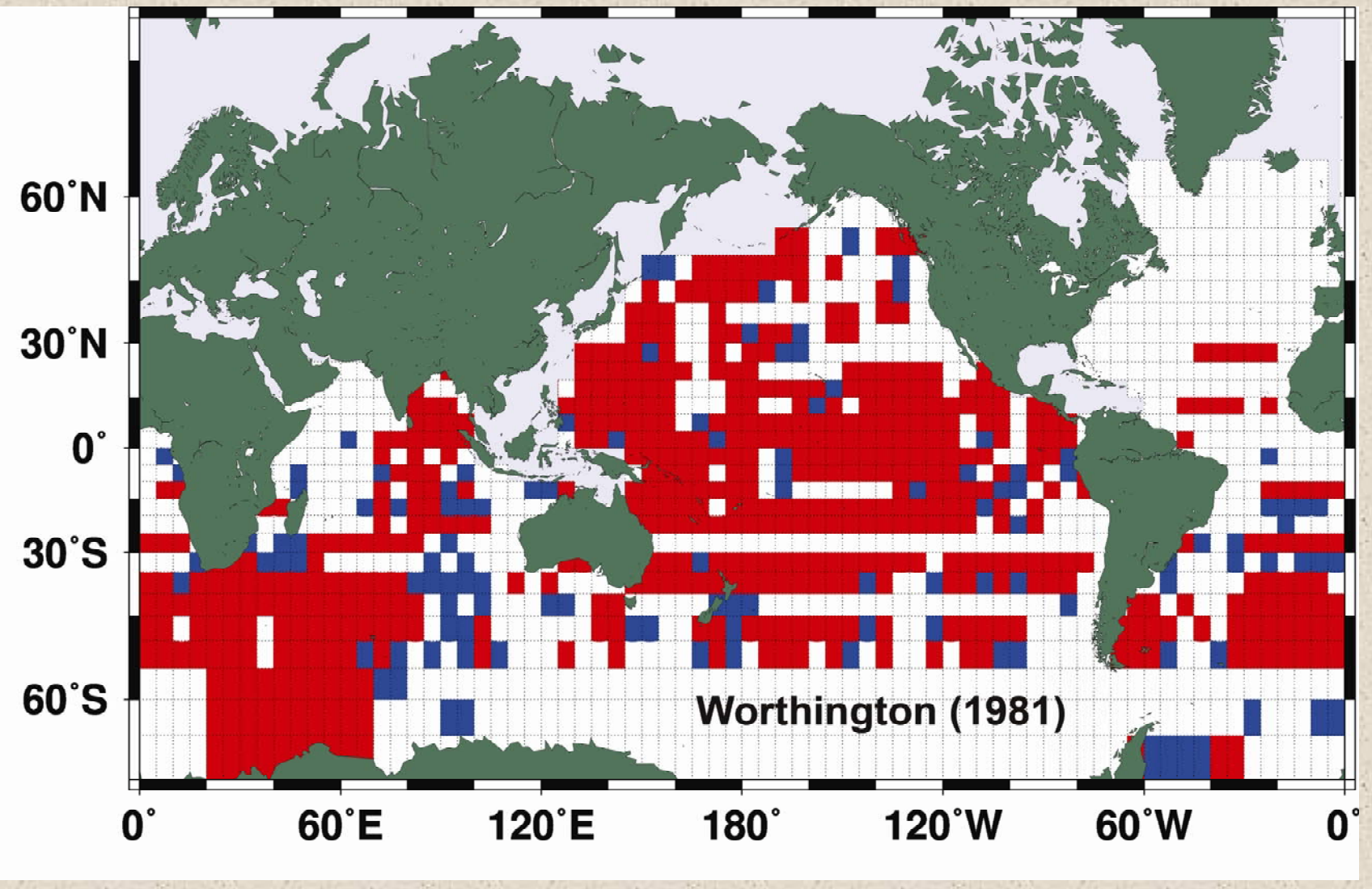
advection of vertically-averaged salinity by the average flow

advection of salinity by the sheared part of the horizontal flow

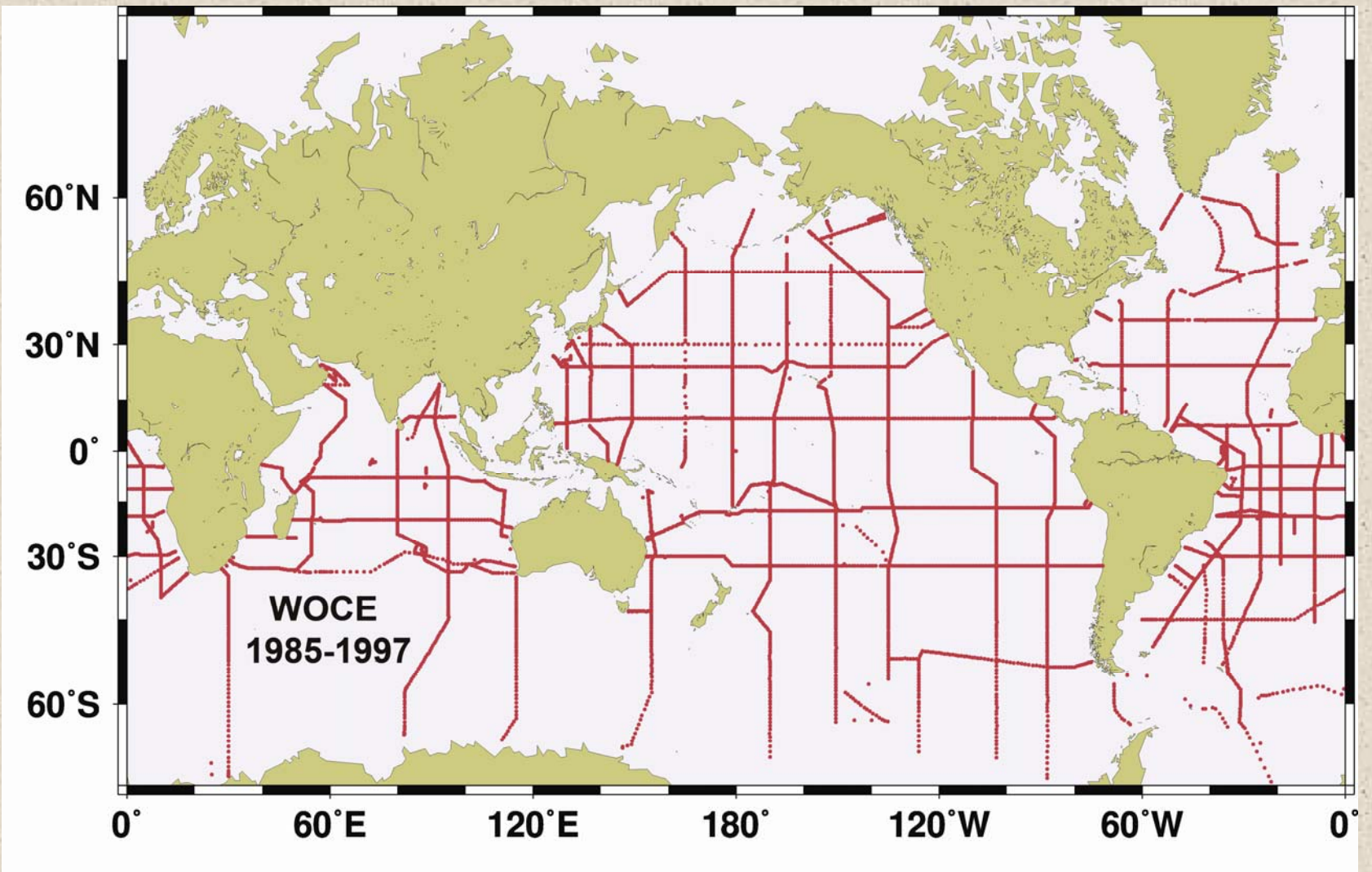
entrainment/detrainment and/or obduction/subduction of salinity through the base of the mixed layer

change of salinity at the sea surface through evaporation and/or precipitation

small scale mixing

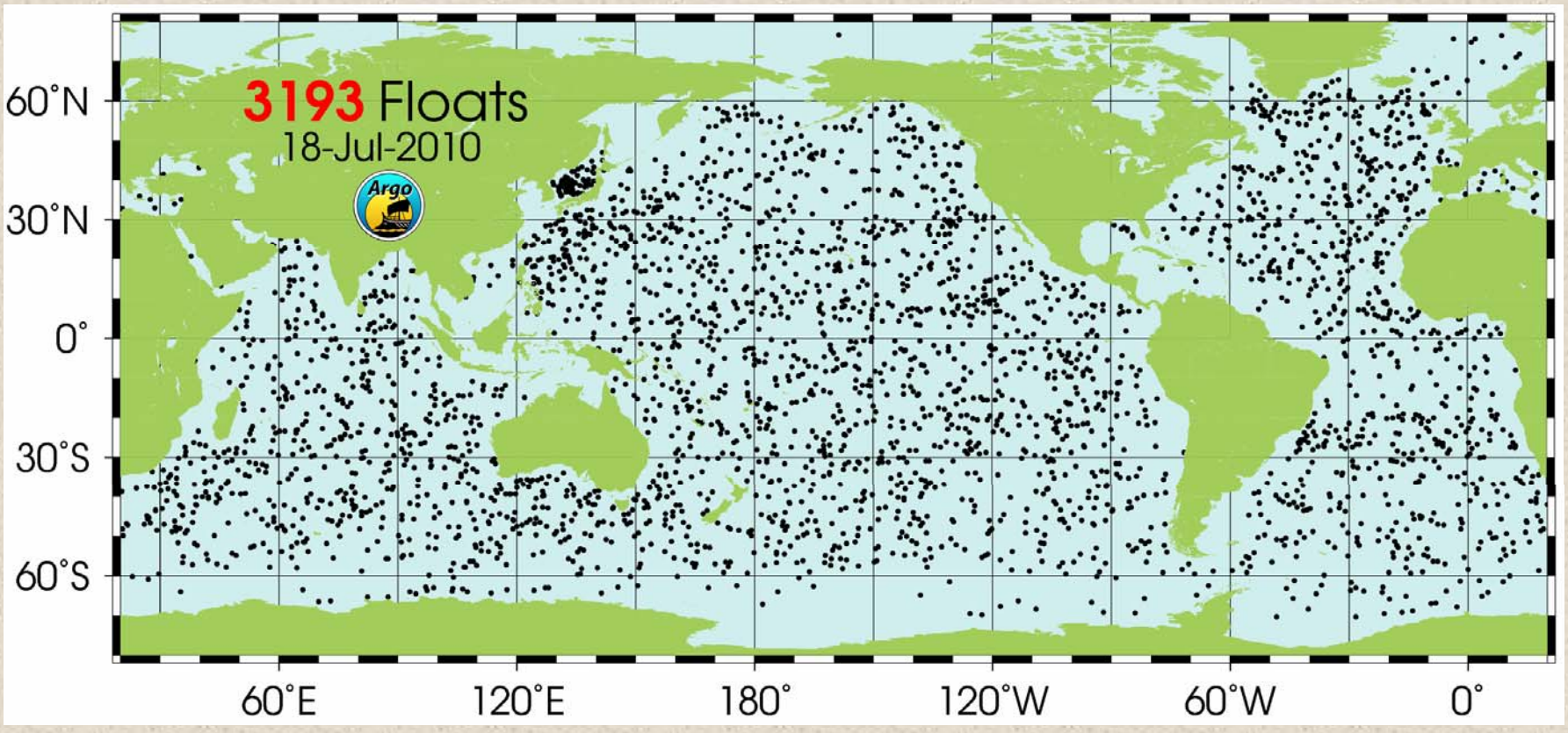


High Quality *T* and *S* Coverage in the 20th Century



WOCE hydrographic sections, 1985-1997

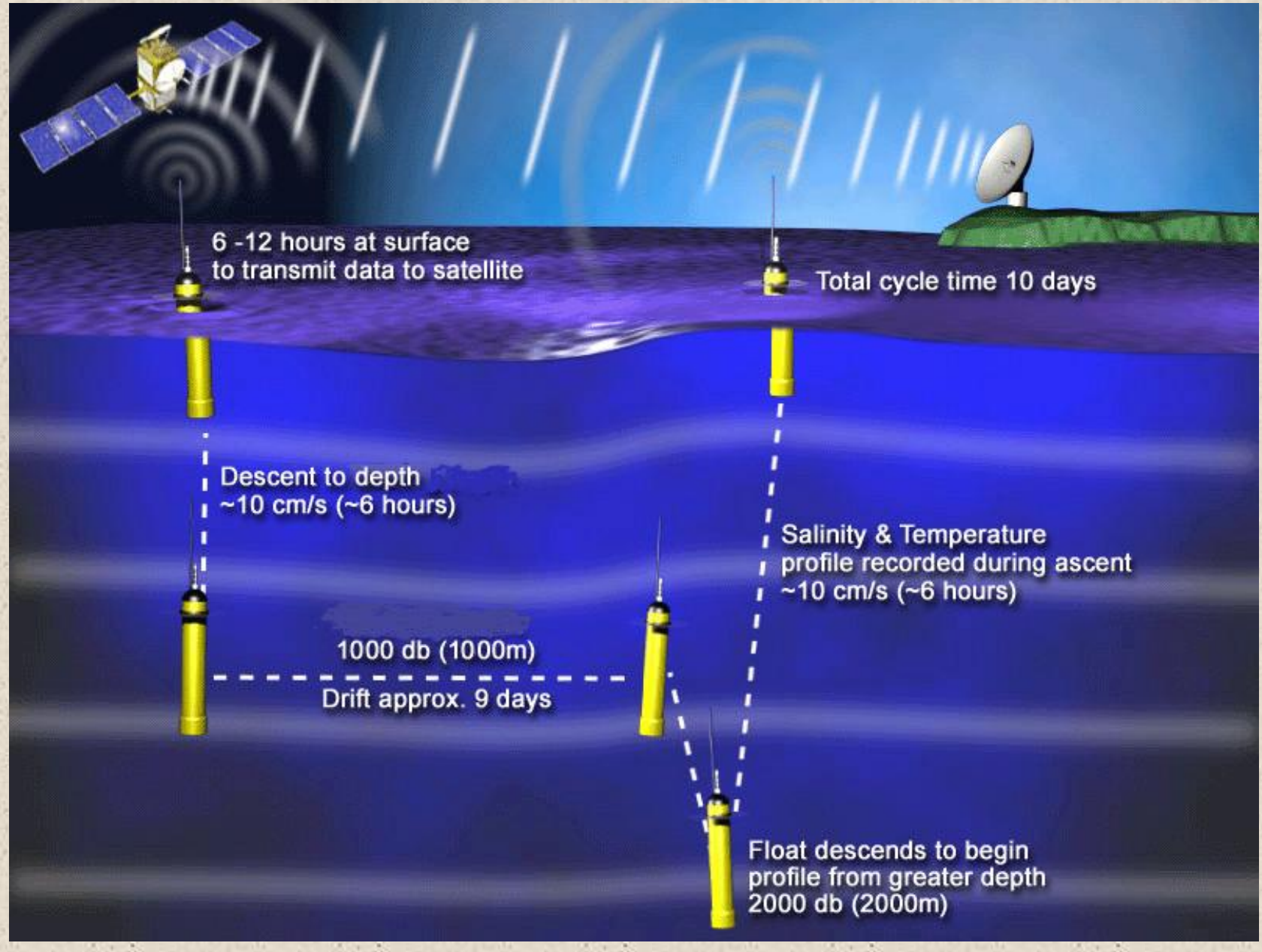
The Argo Float Array



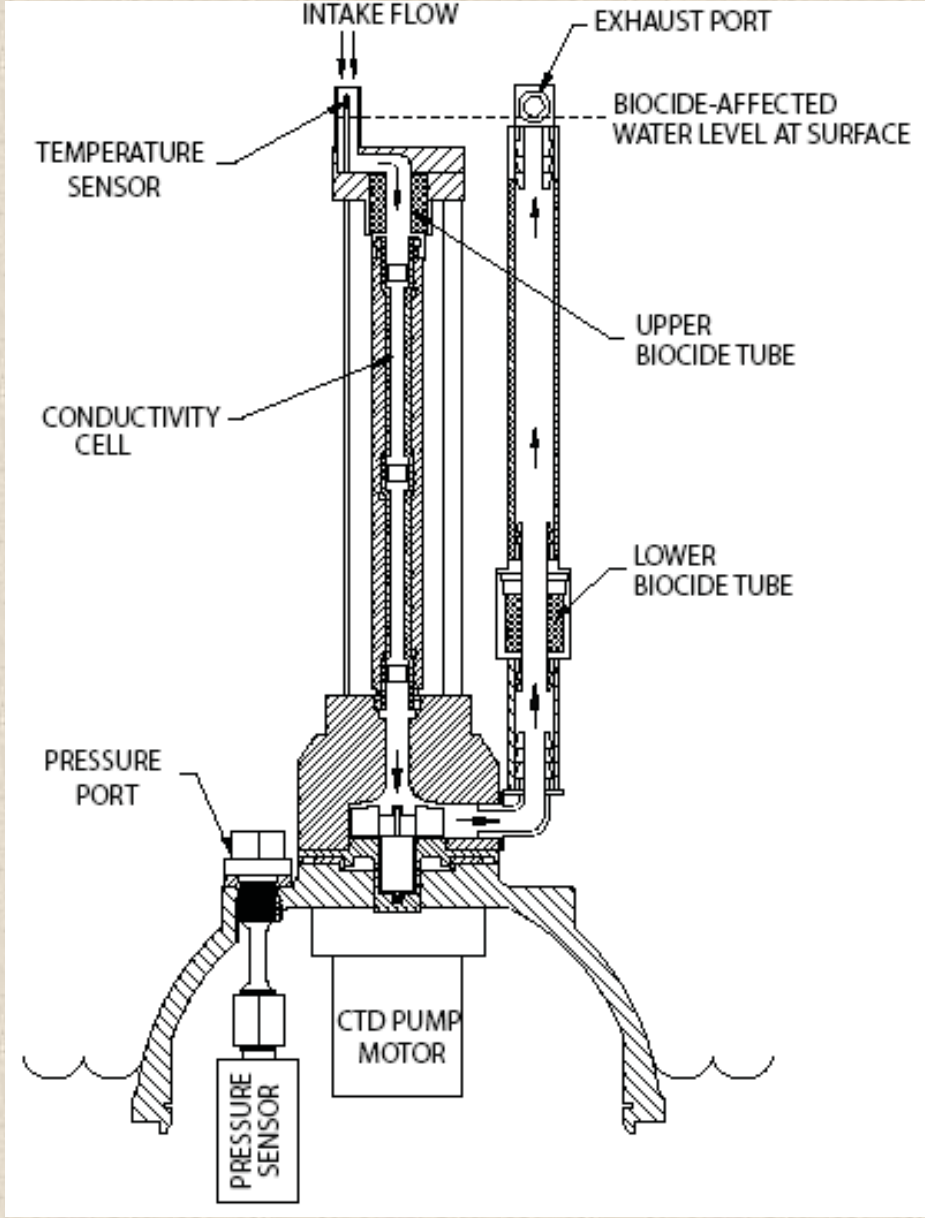
27 countries, ~800 floats/year deployed
UW: ~120 floats/year

canonical Argo mission:
0-2000 m; *T*, *S*, *p* **(0.005 °C; 0.01 PSU ; 2.5 dbar)**
Δt = 10 days
4-5 years/200-250 profiles

All data are publicly available with 24 hours of collection.

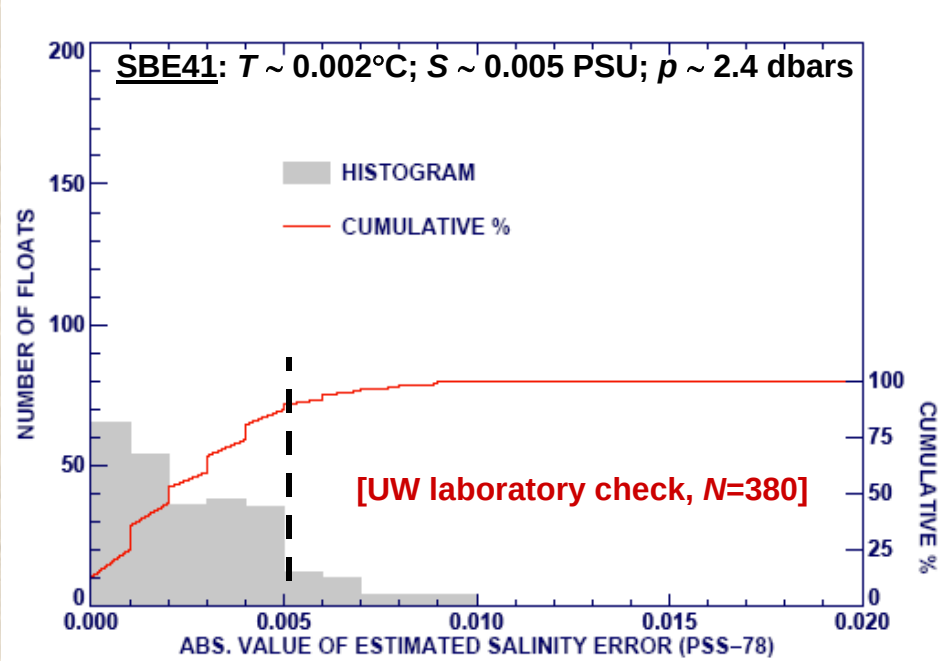


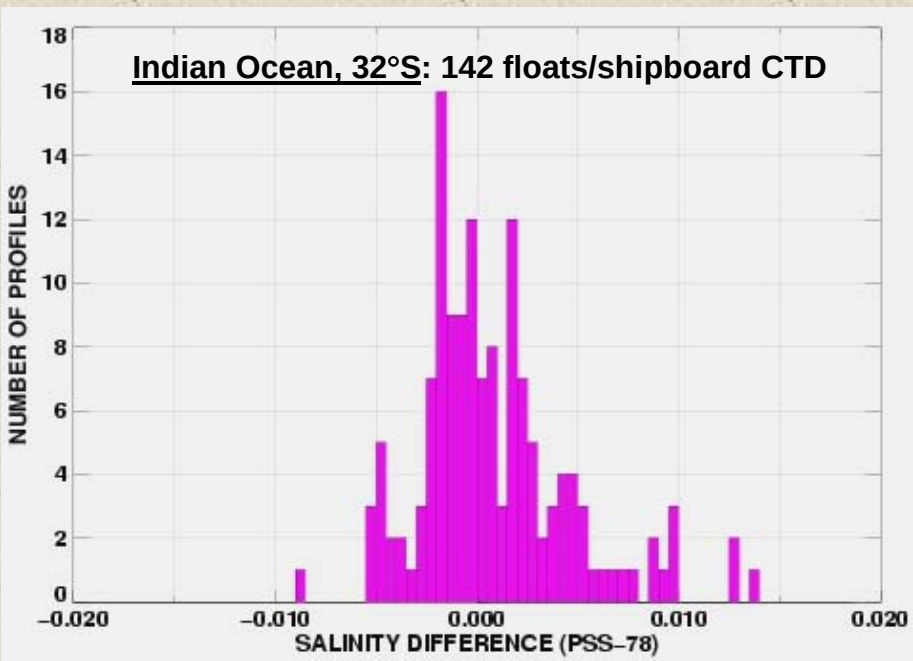
Schematic of a typical Argo mission (200-250 profiles)



(T, S, p) ~ (0.005 °C, 0.005 PSU, 2.5 dbar)

SBE CTD performance in Argo: generally excellent



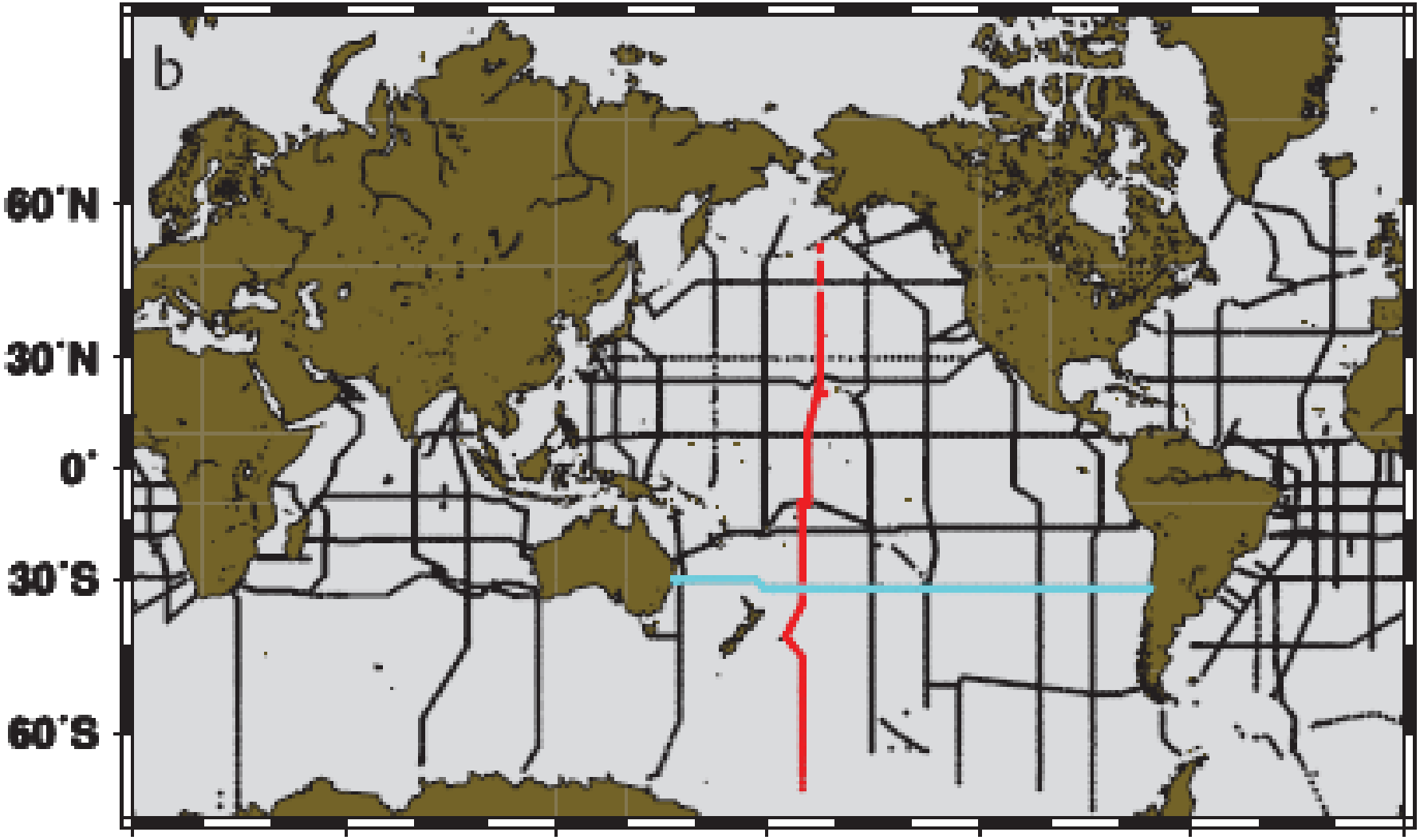


Results from recovered floats

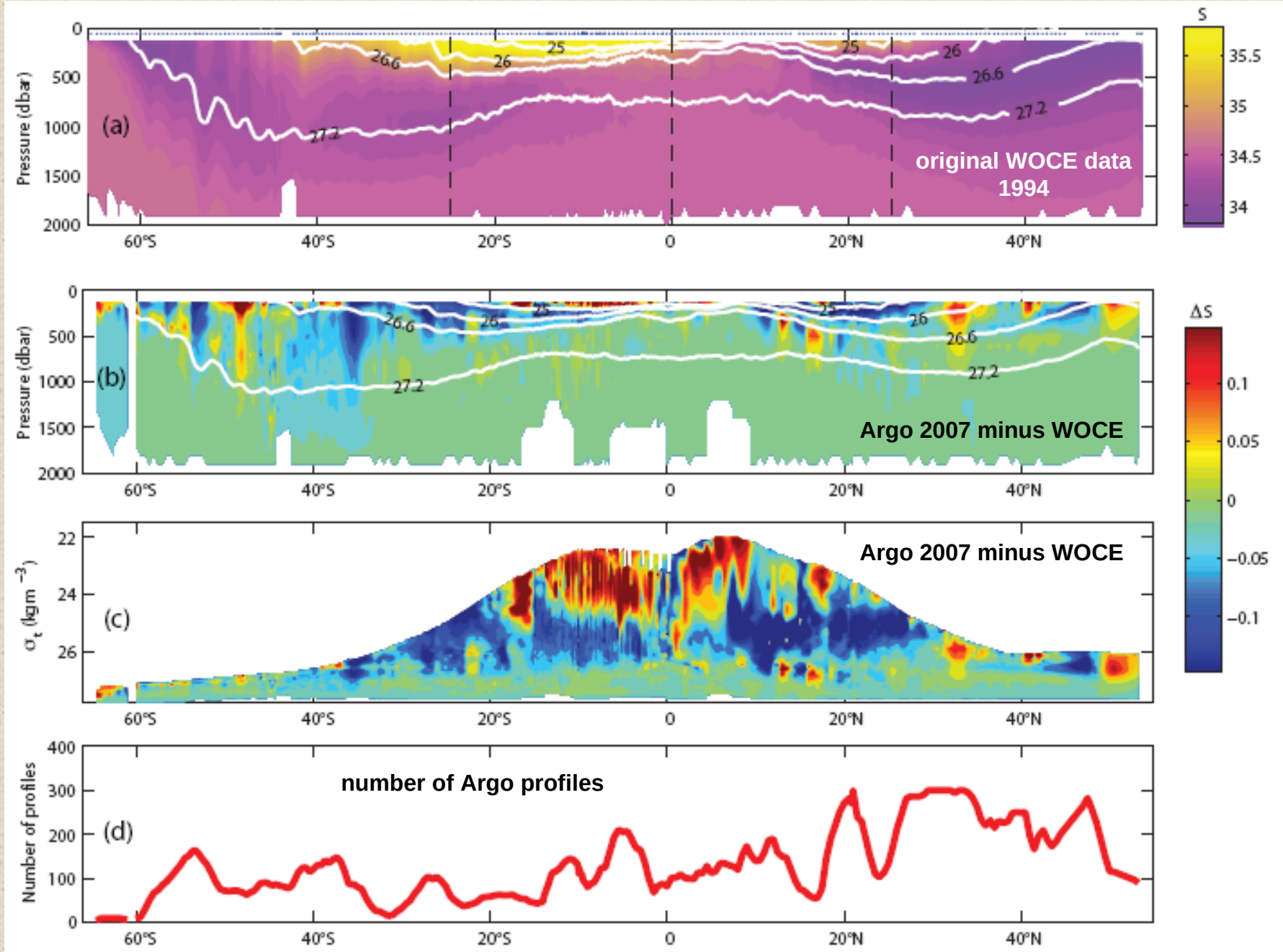
FLOAT	TIME (days)	ΔT (°C)	ΔS (PSS-78)	Δp (decibars)
29045*	840	0.00136	-0.0074	4.68
2900056*	730	0.00158	-0.0074	5.92
29051*	900	0.00100	-0.0125	0.72
41862†	1096	0.00030	-0.0060	0.06

* Deployed by Japan in the North Pacific † Deployed by the US in the North Atlantic

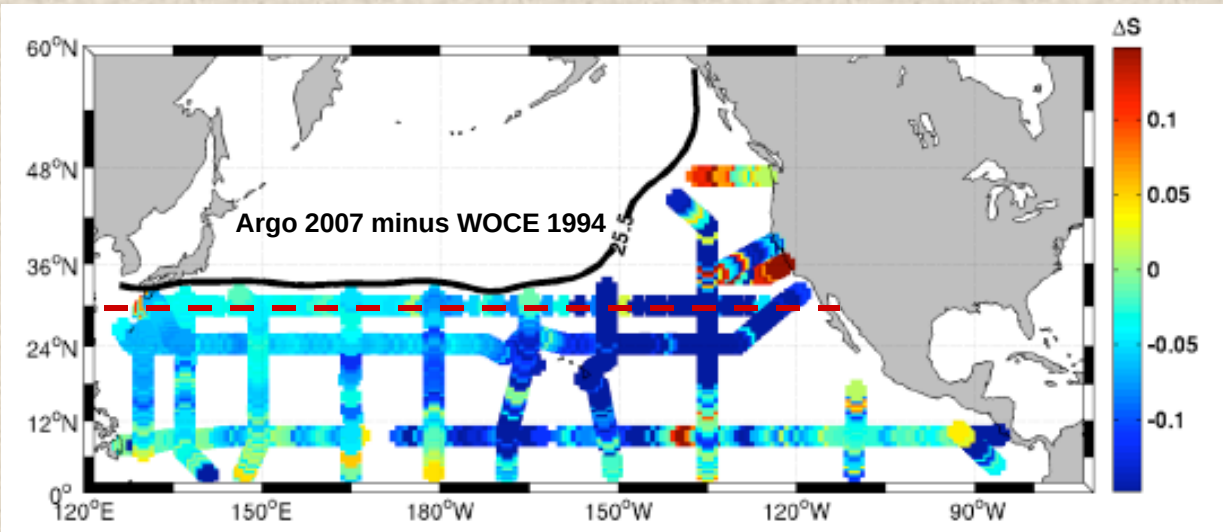
***DMQC results*:**
≤ 10 % adjusted

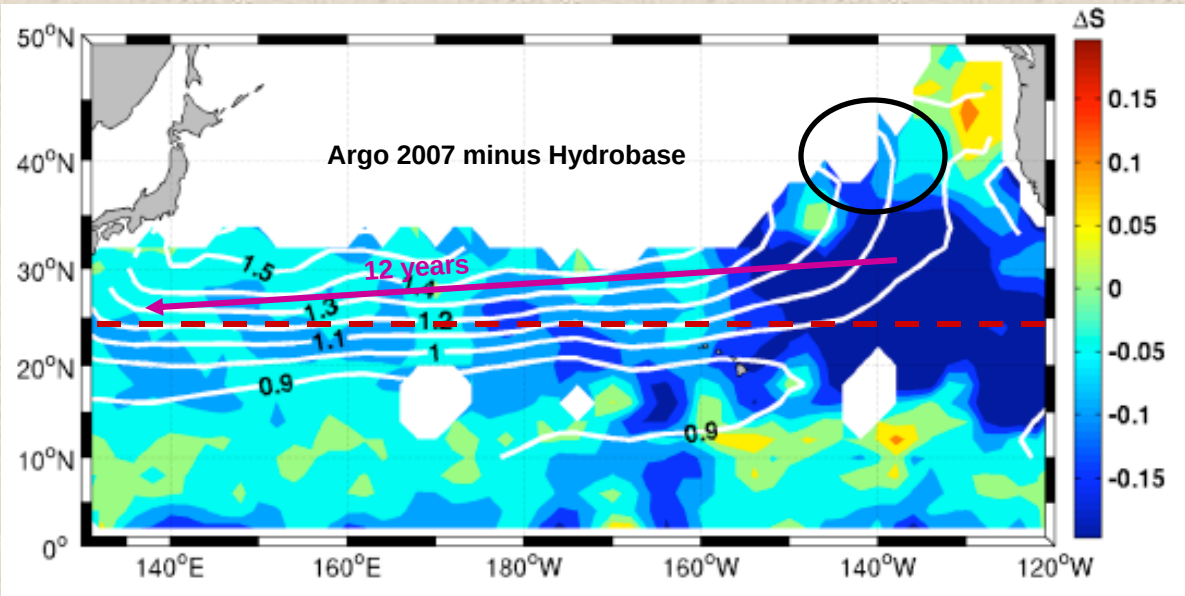


WOCE section P18 (red), 1994

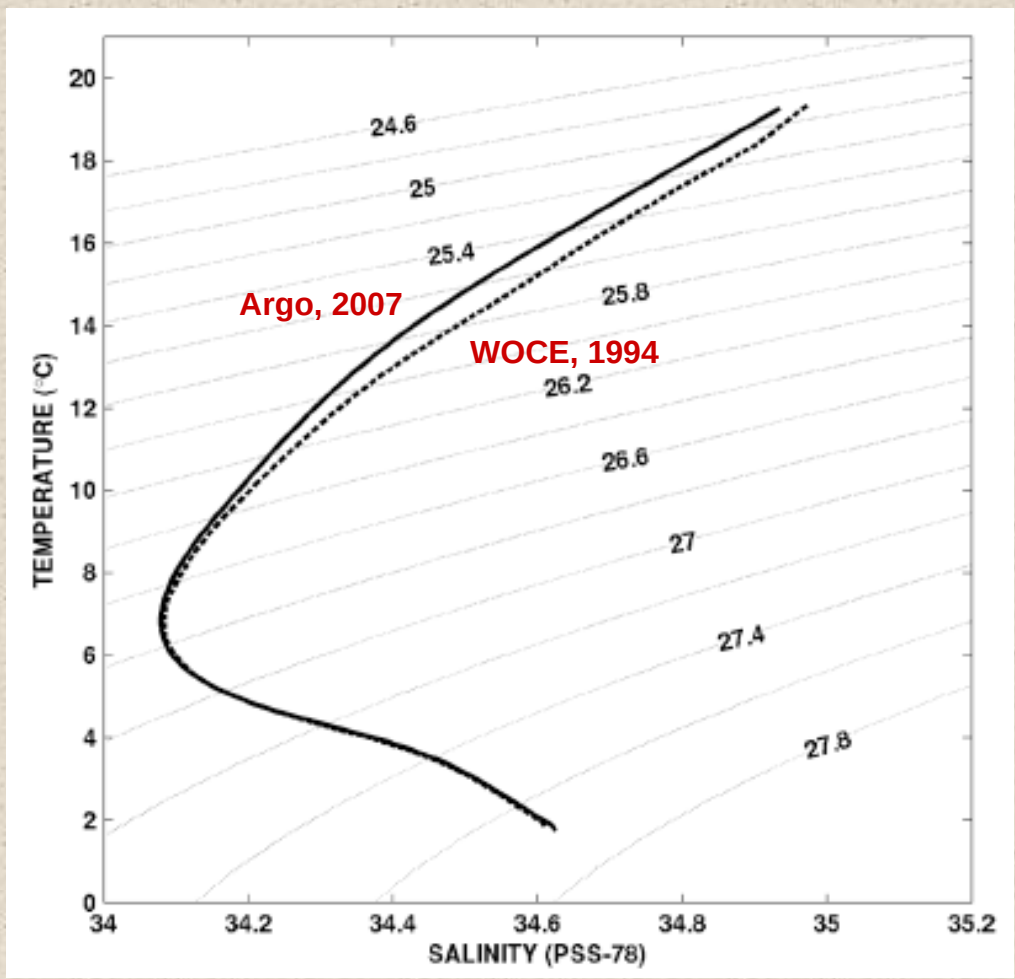


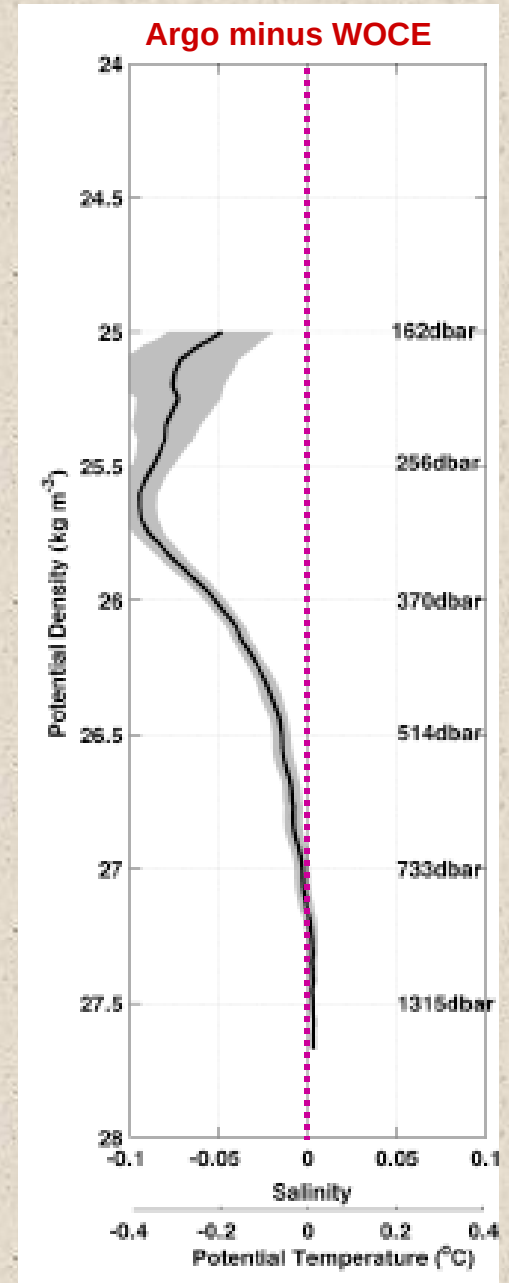
(Riser et al., 2008)





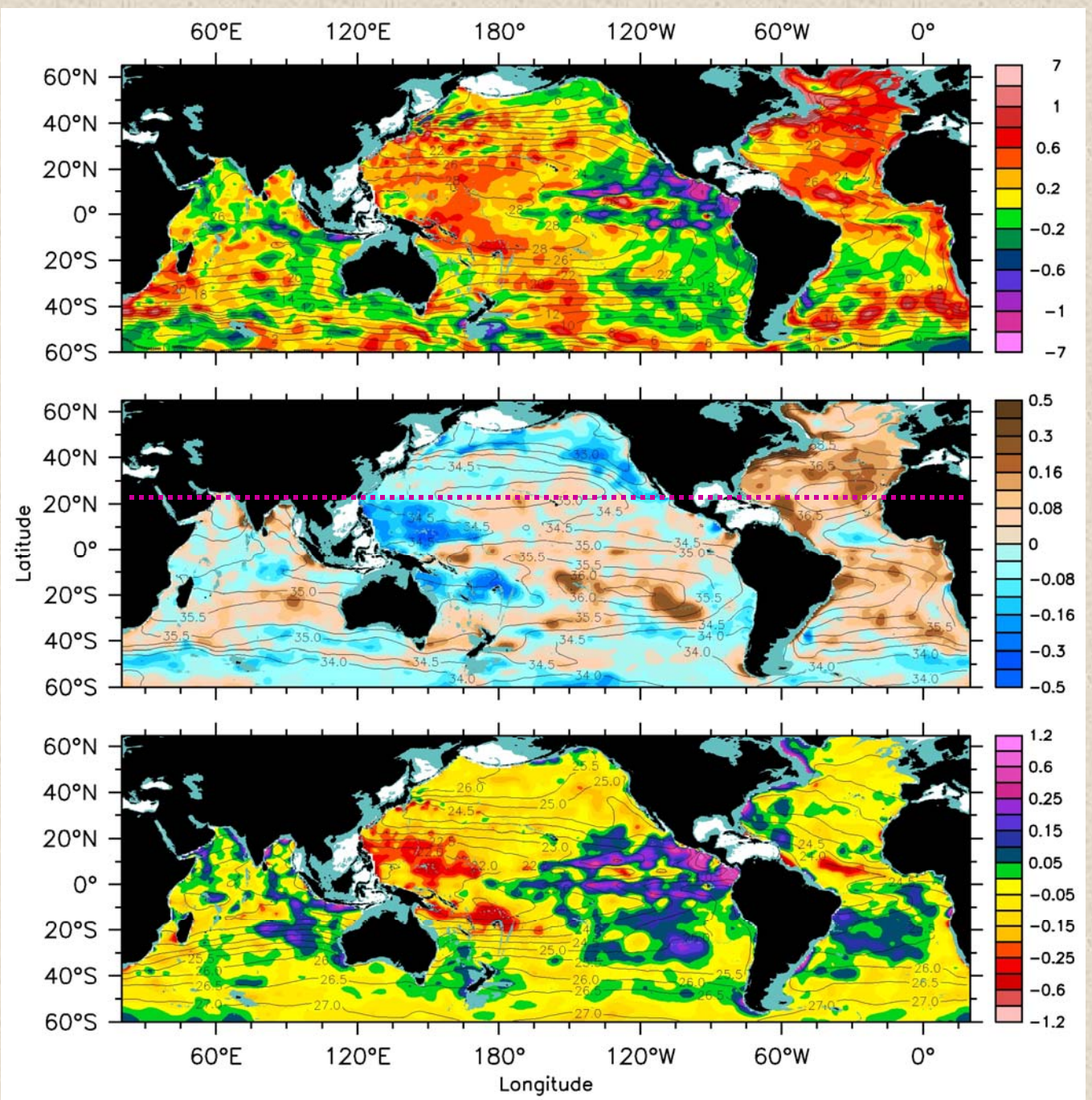
[Ren and Riser, 2010]





Integrals along 24°N: the upper ocean has freshened

[Ren and Riser, 2010]



ΔT

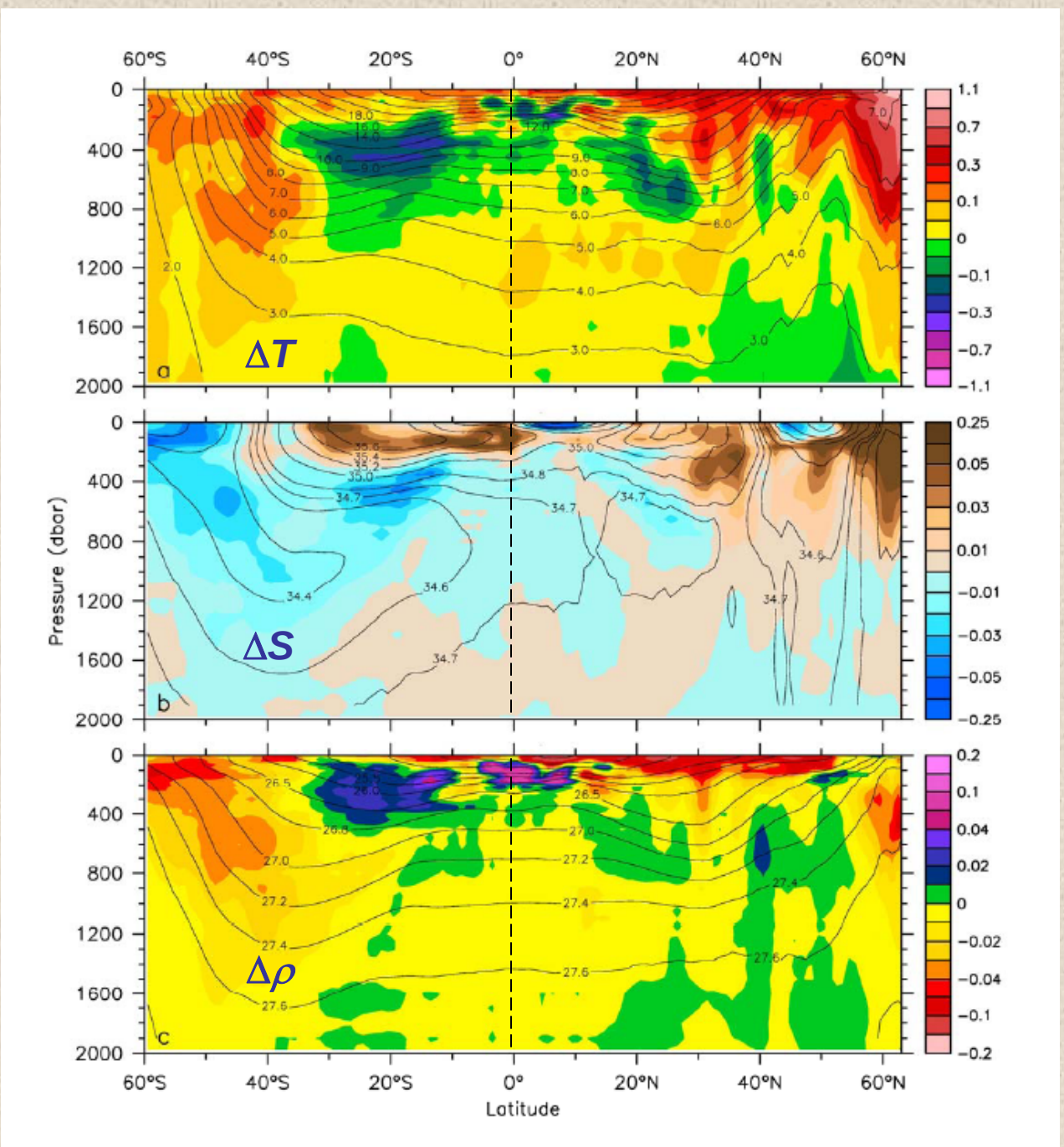
ΔS

$\Delta \rho$

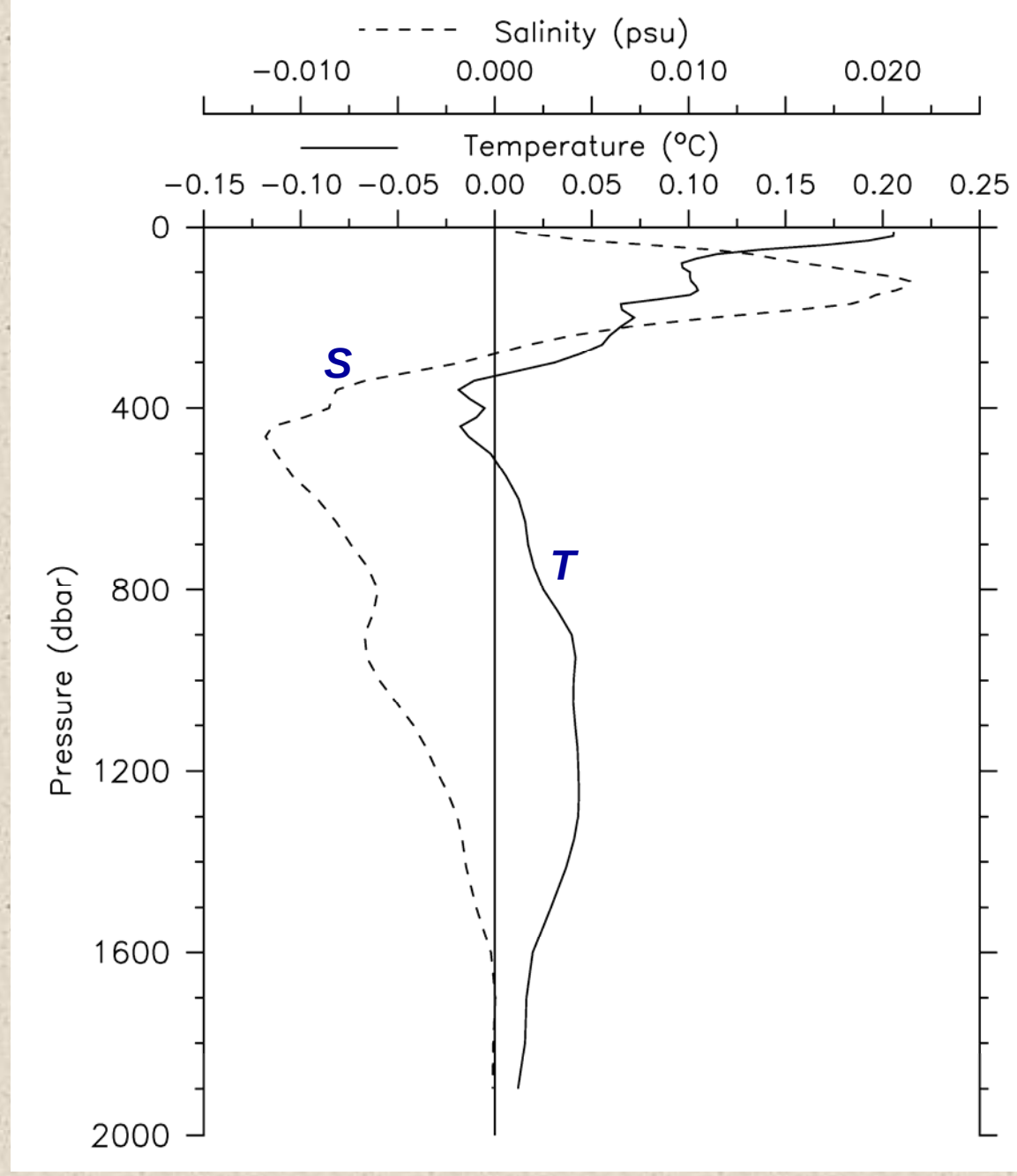
Upper ocean (~250 m), changes in the past 25 yr

[Roemmich and Gilson, 2009]

Average changes in temperature, salinity, and density in the world ocean as a function of latitude since the mid-1980s, determined using 2004-2008 Argo float observations



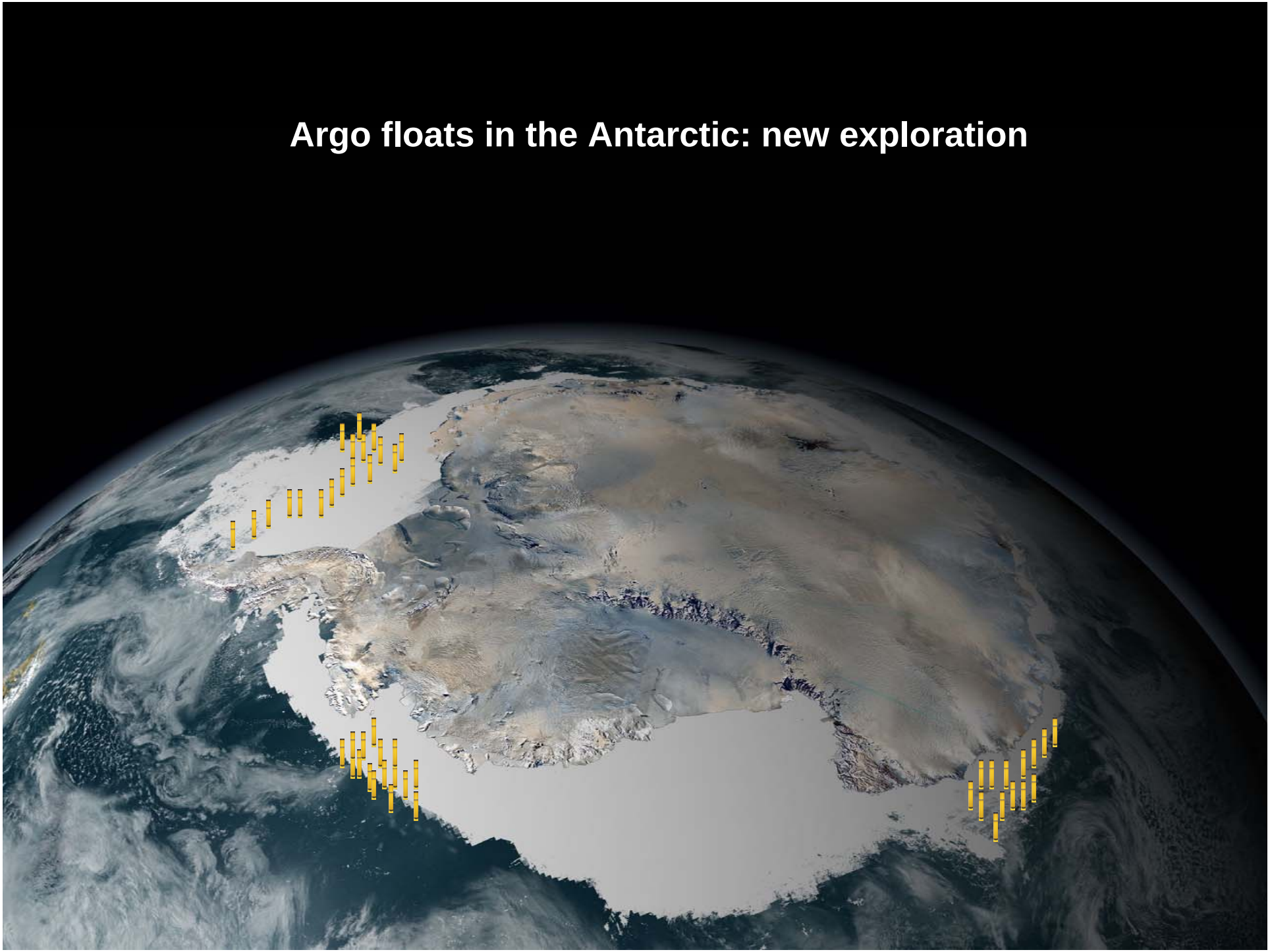
[Roemmich and Gilson, 2009]

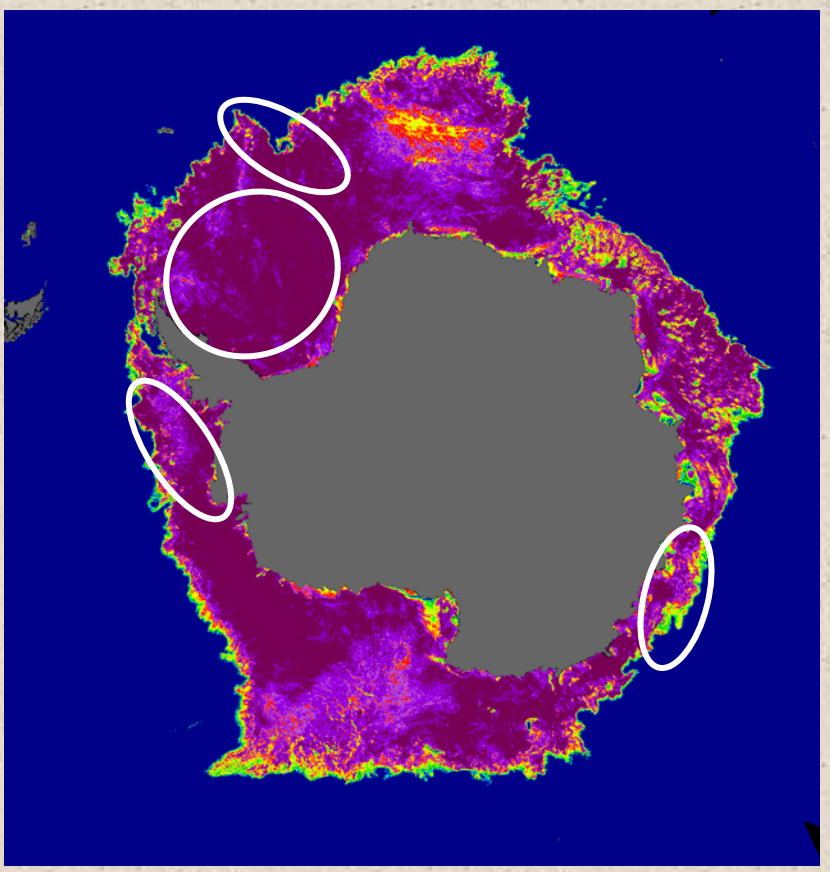


Globally-averaged changes over the past 25 years, using Argo and WOA data

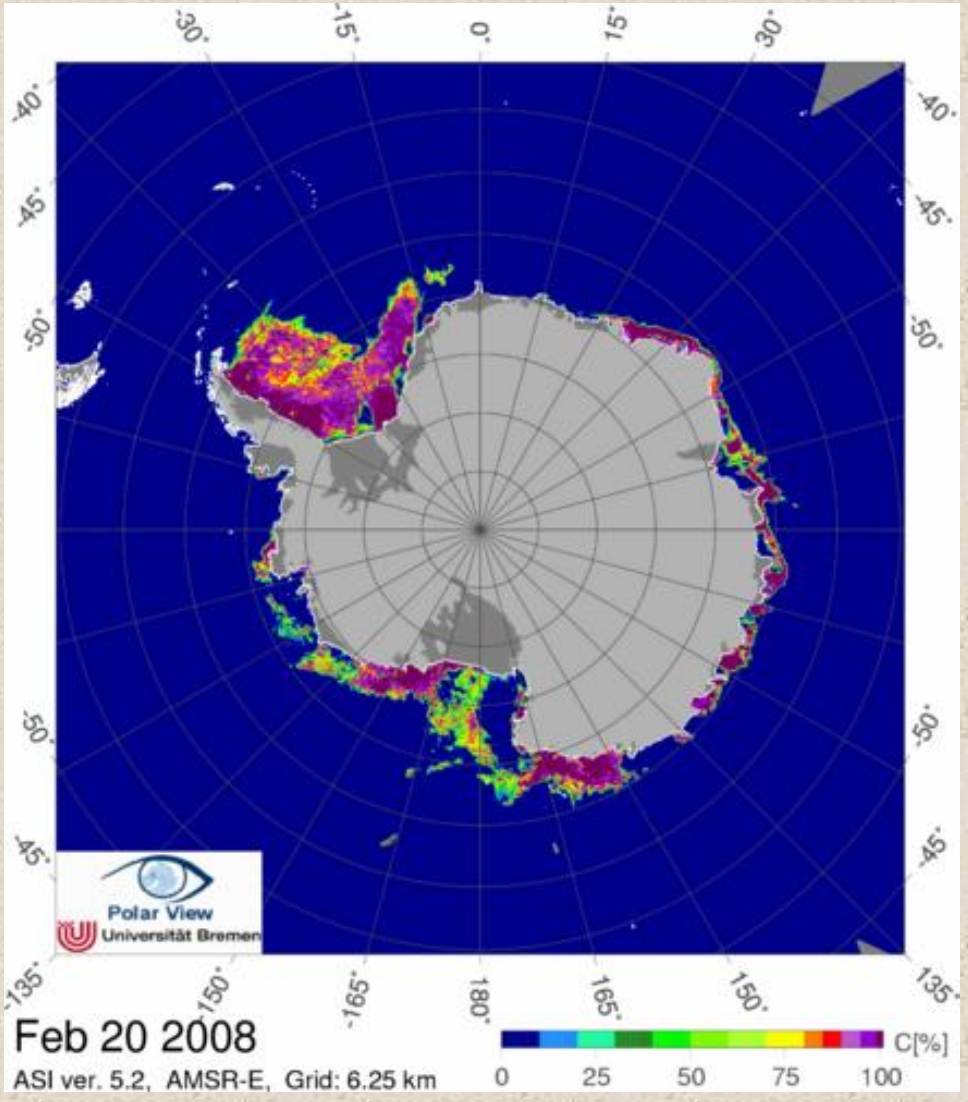
[Roemmich and Gilson, 2009]

Argo floats in the Antarctic: new exploration

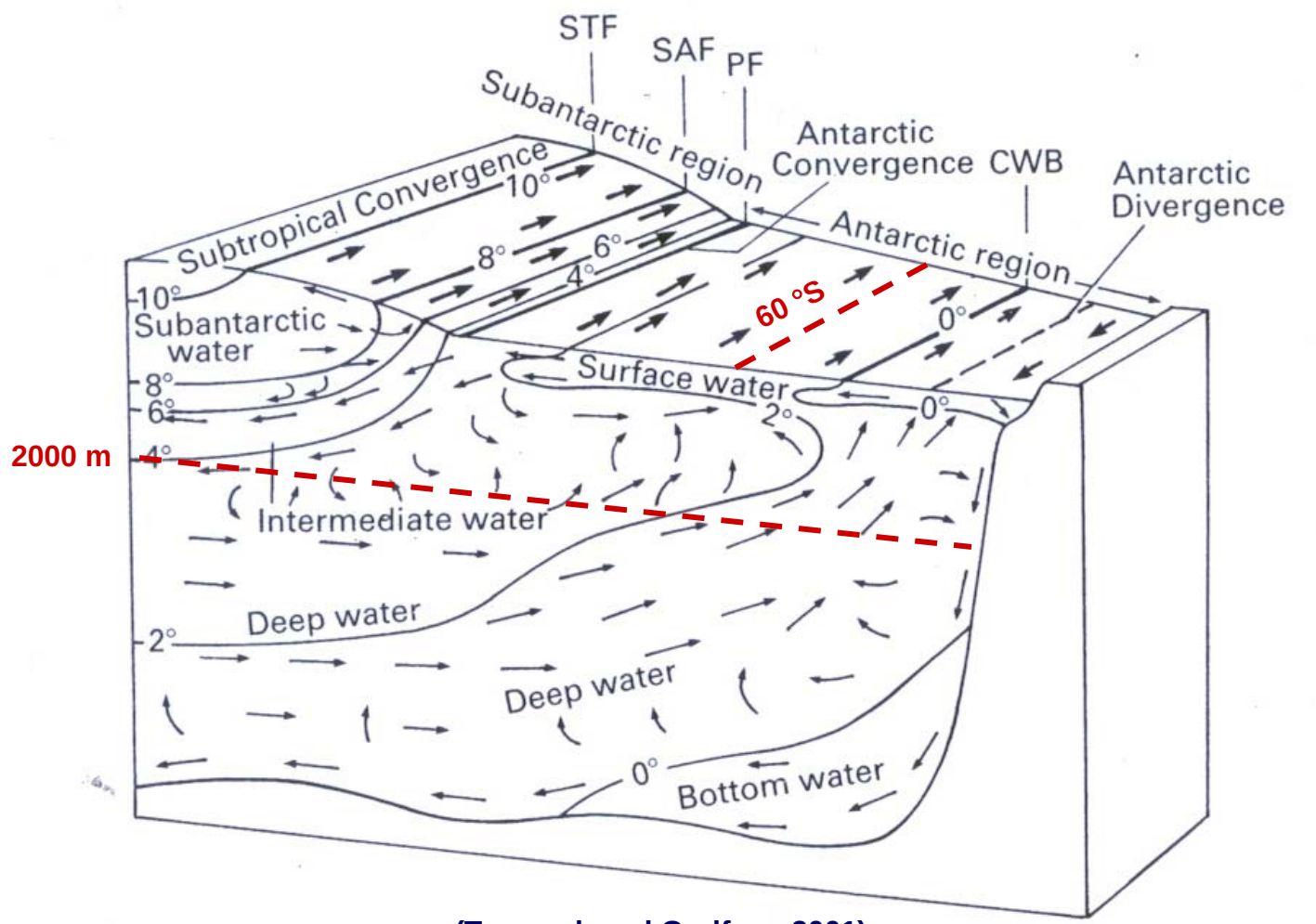




Aug 1 2007

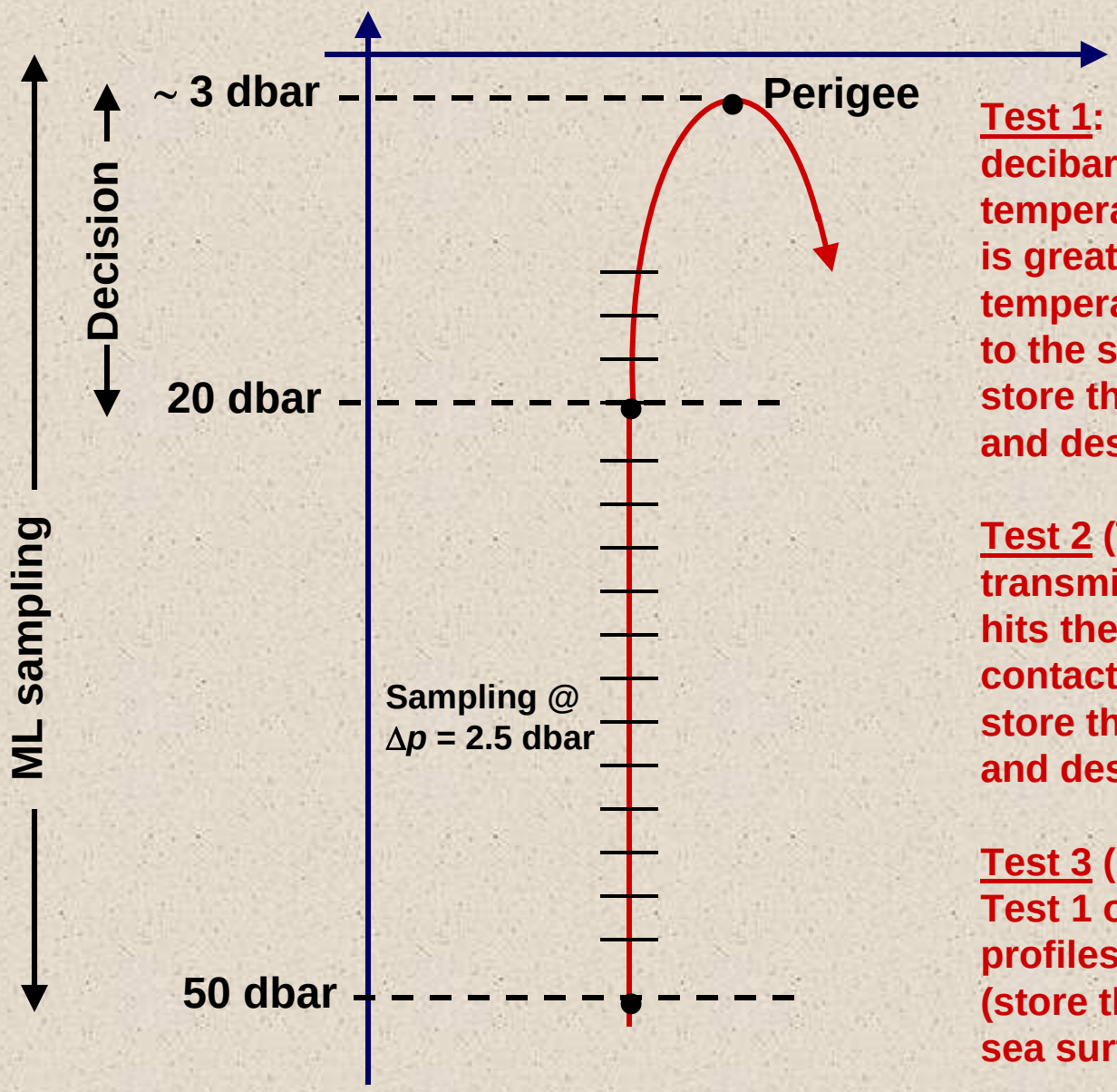


Antarctic sea ice cover: recent seasonal extremes



(Tomczak and Godfrey, 2001)

Antarctic/southern ocean floats can likely provide new insight into climate related variability, mixing, and circulation in the region.



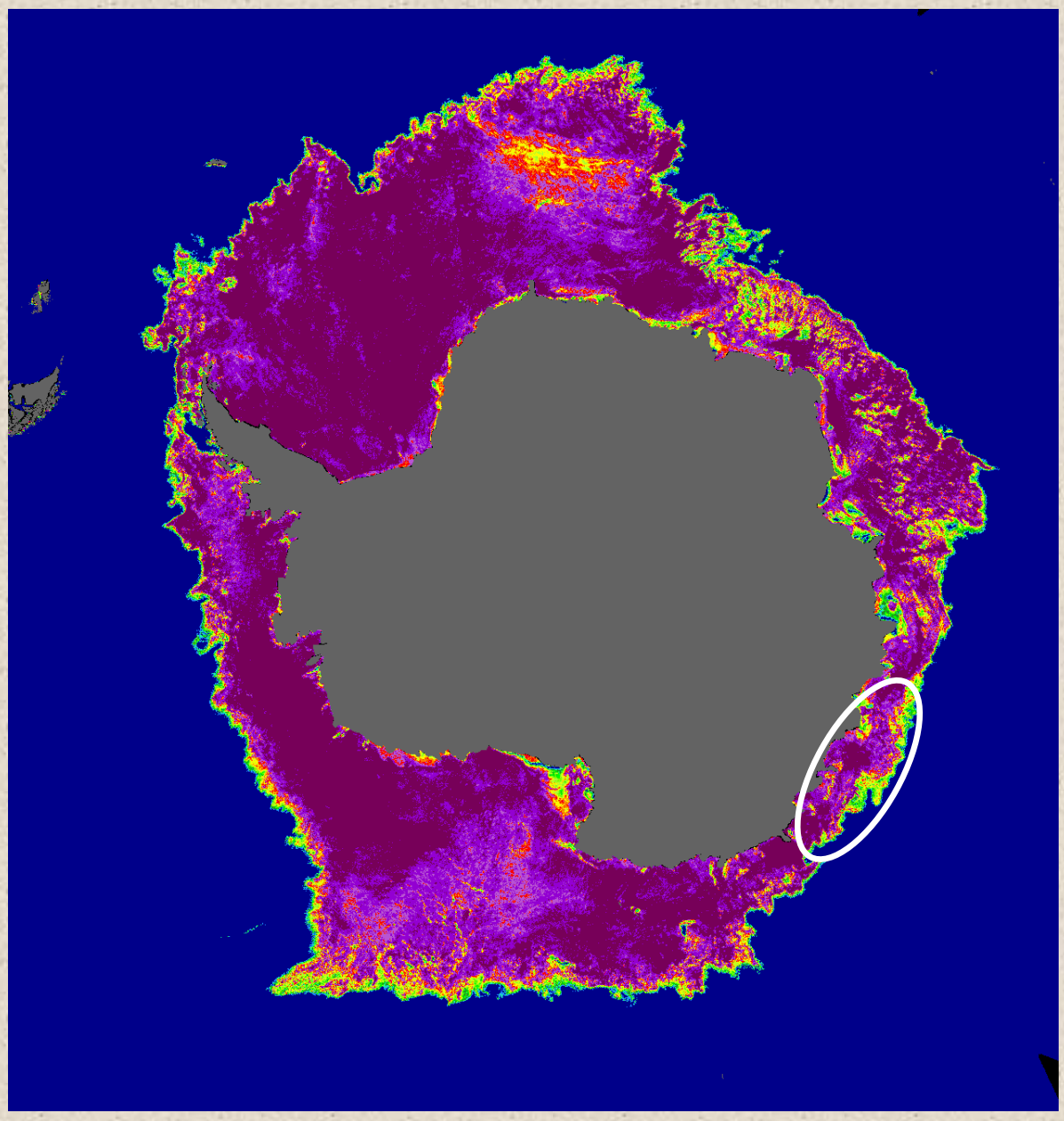
Schematic of the ice avoidance algorithm
(62 floats deployed; 85% working after 3 winters)

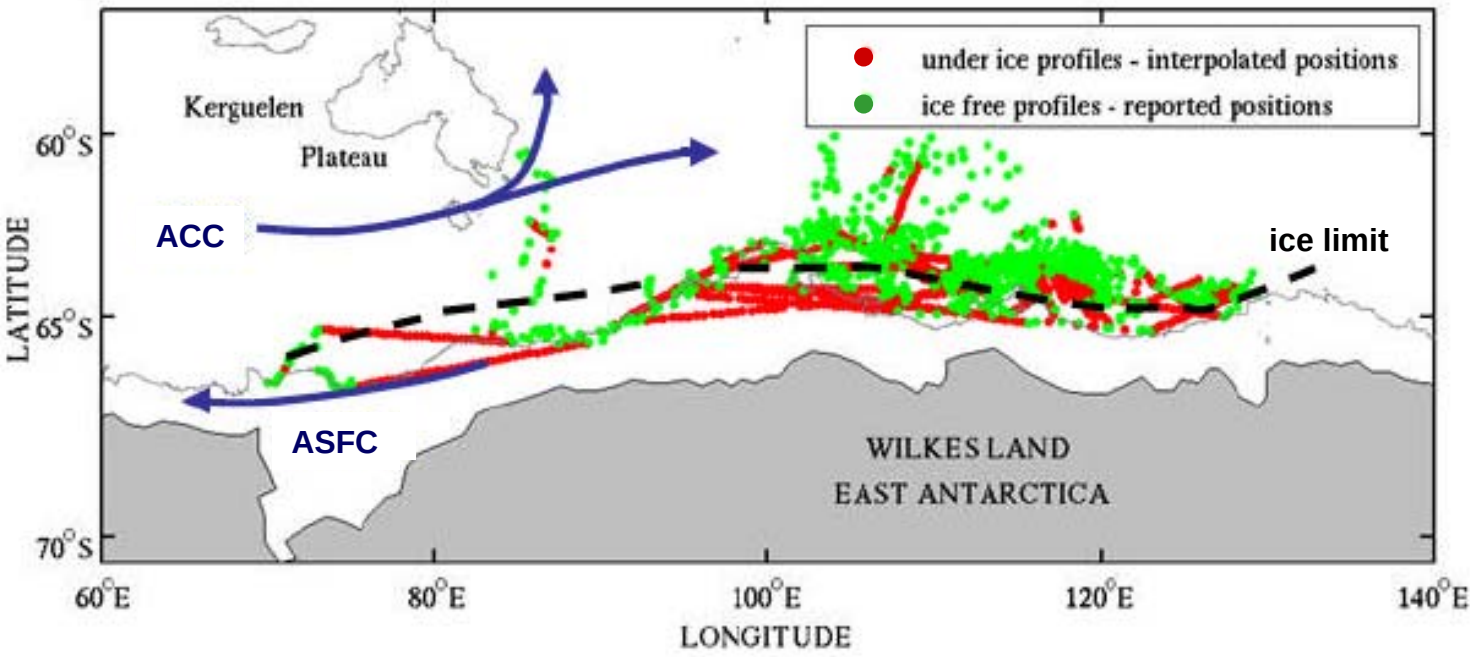
Test 1: Between 50 and 20 decibars compute the median temperature T_{ml}; if this temperature is greater than a threshold temperature T_{th} continue ascent to the sea surface. If $T_{ml} < T_{th}$, then store the profile, retract the piston and descend.

Test 2 (Test 1 fails): (a) No ice; transmit the profile. (b) The float hits the bottom of the ice; if no contact with a satellite in 2 hours, store the profile, retract the piston and descend.

Test 3 (ice breakup test): If either Test 1 or Test 2 fails on successive profiles, wait at least 2 more profiles (store them) before coming to the sea surface.

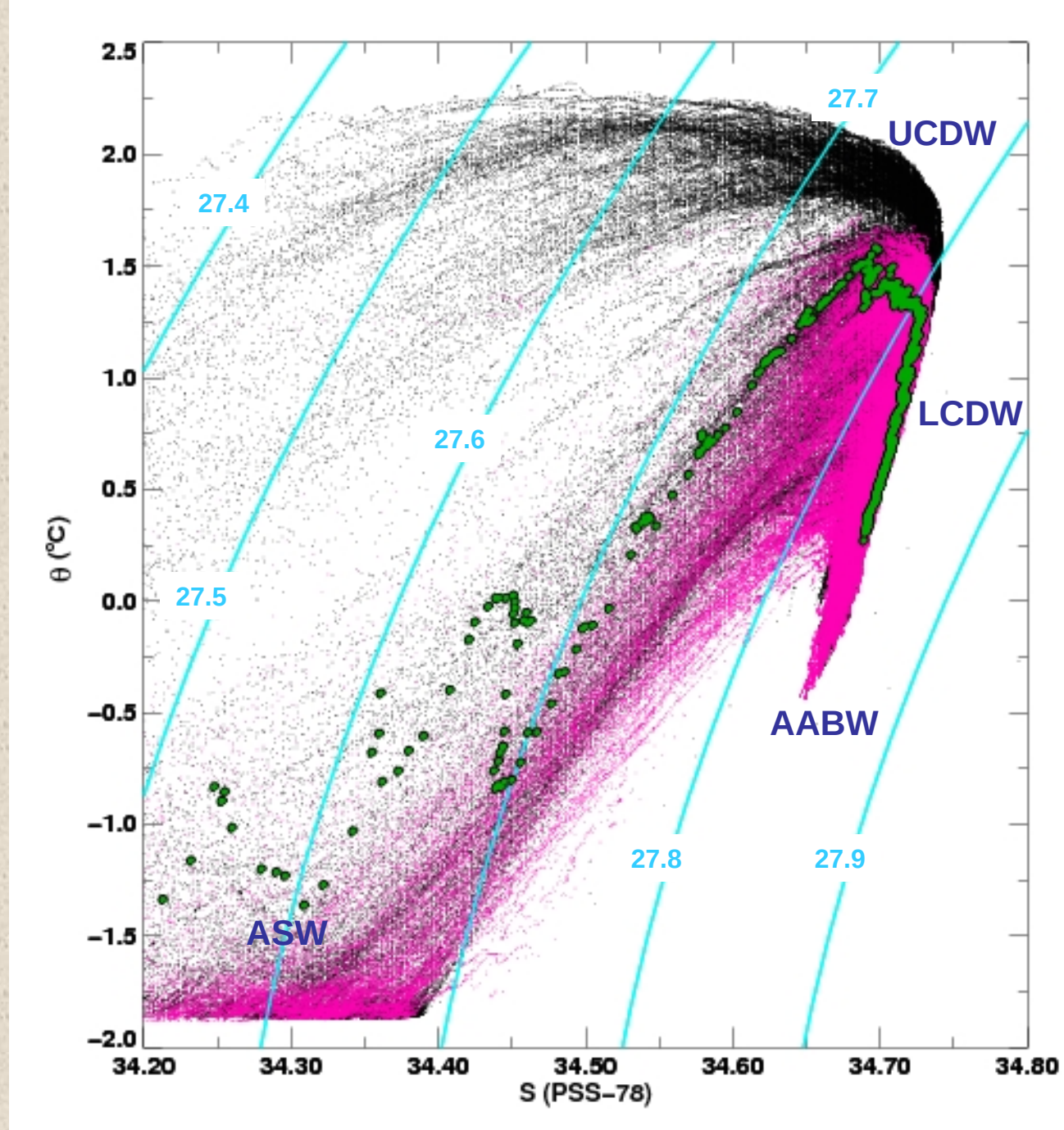
Test 4 (on or off test): In designated summer months, turn off Tests 1-3.



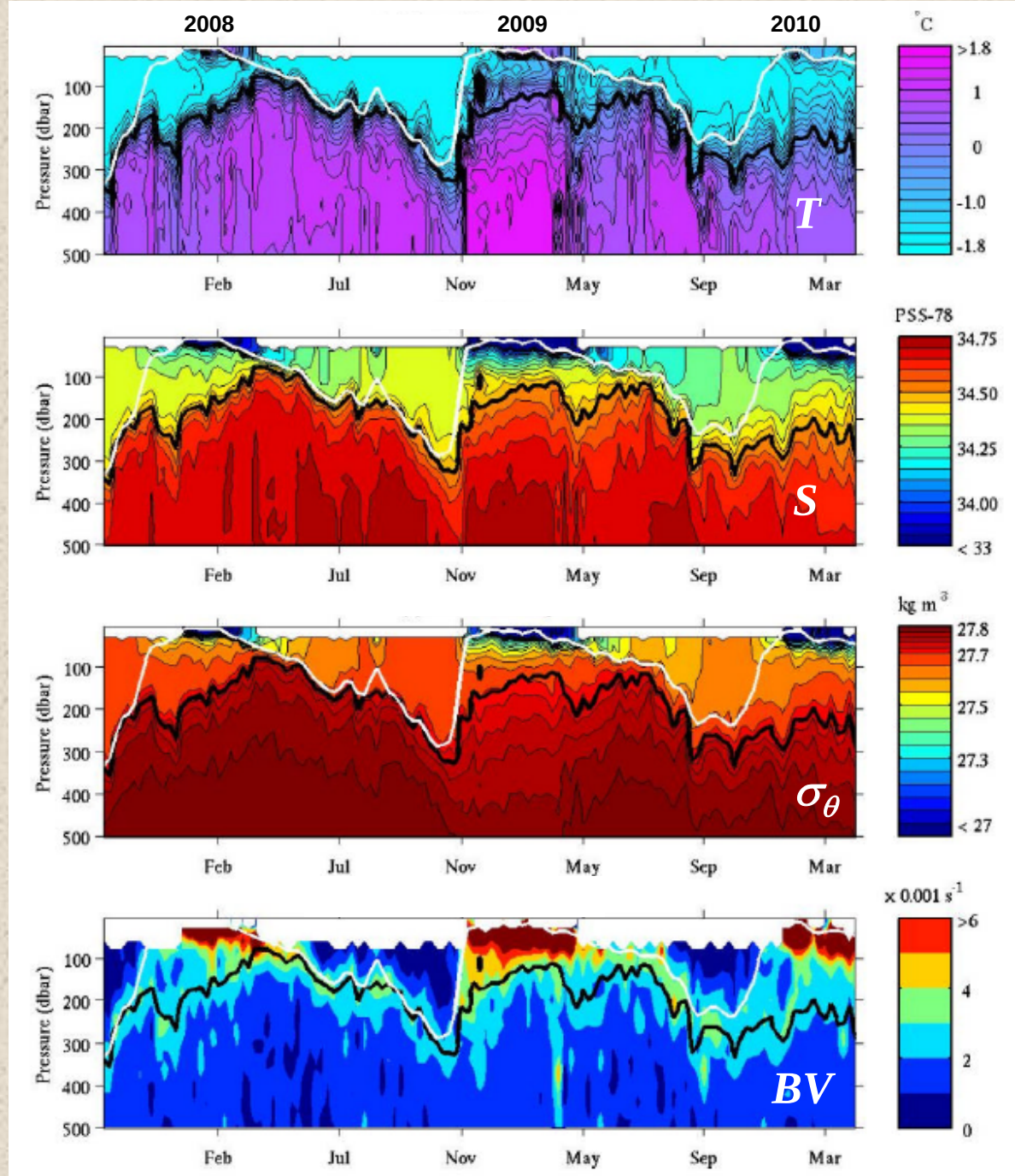


Wong and Riser, 2010

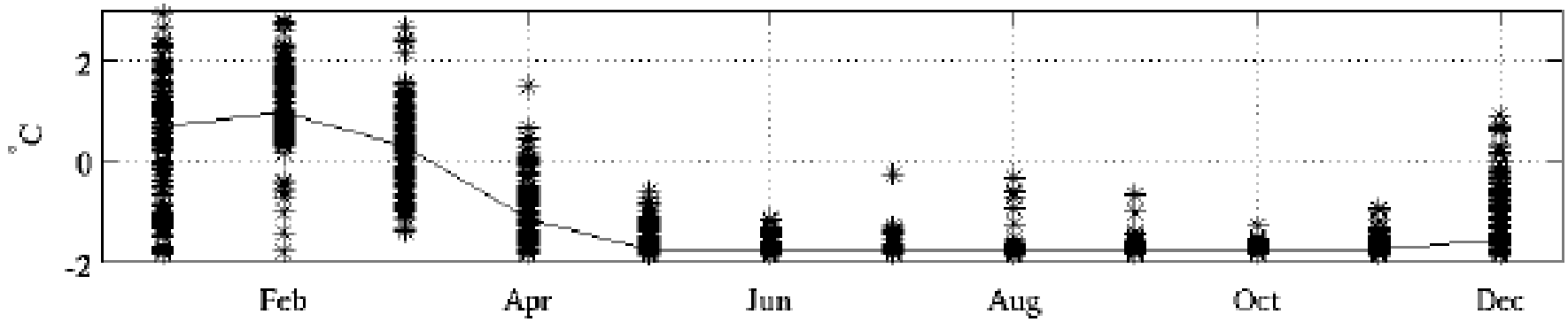
- depth 1000-2000 m
- depth > 2000 m
- UW float 5243 (prof. 65, 12/28/08)



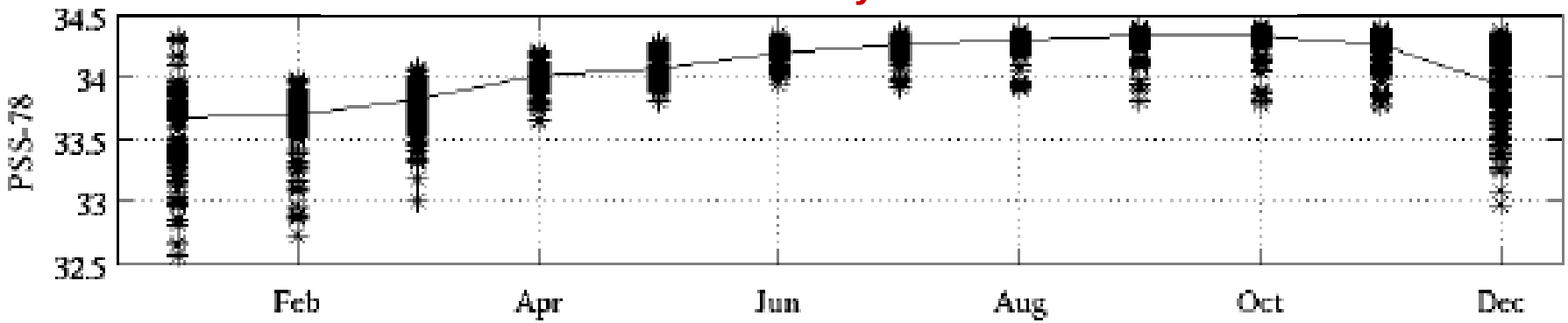
UW float 5243
WMO 2900126
10/7/07 – 3/15/10



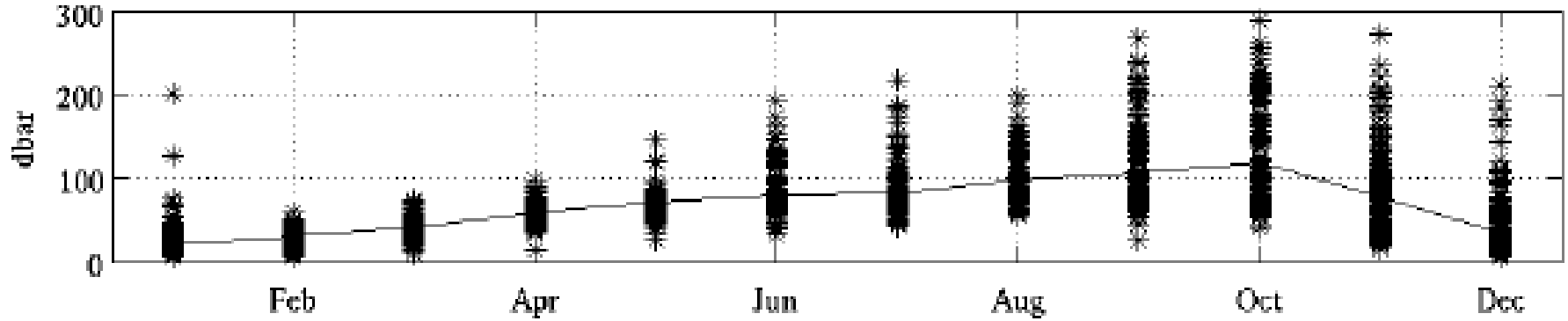
Potential Temperature

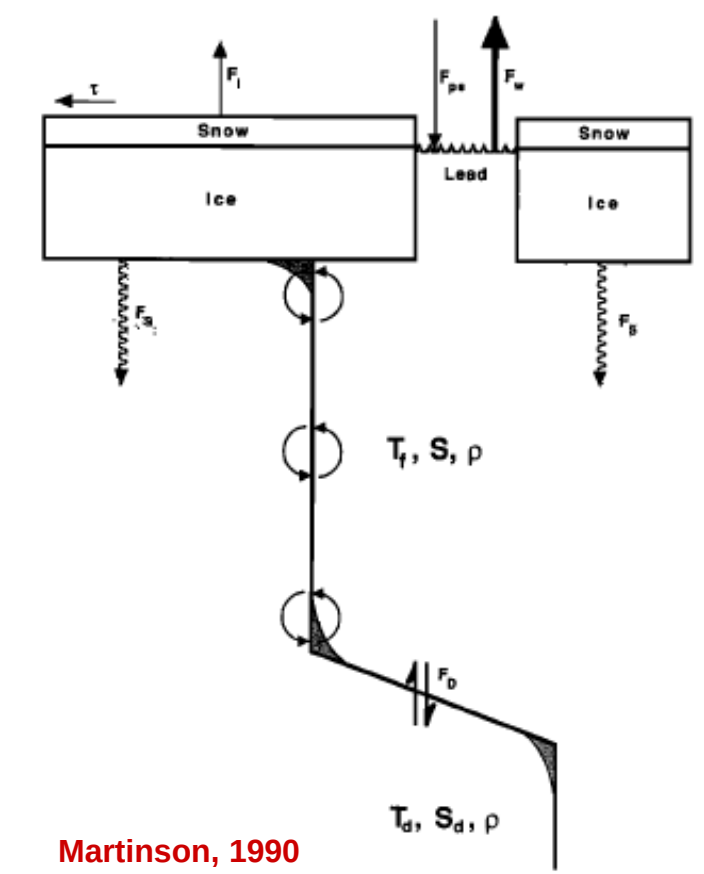


Salinity



Mixed Layer Depth



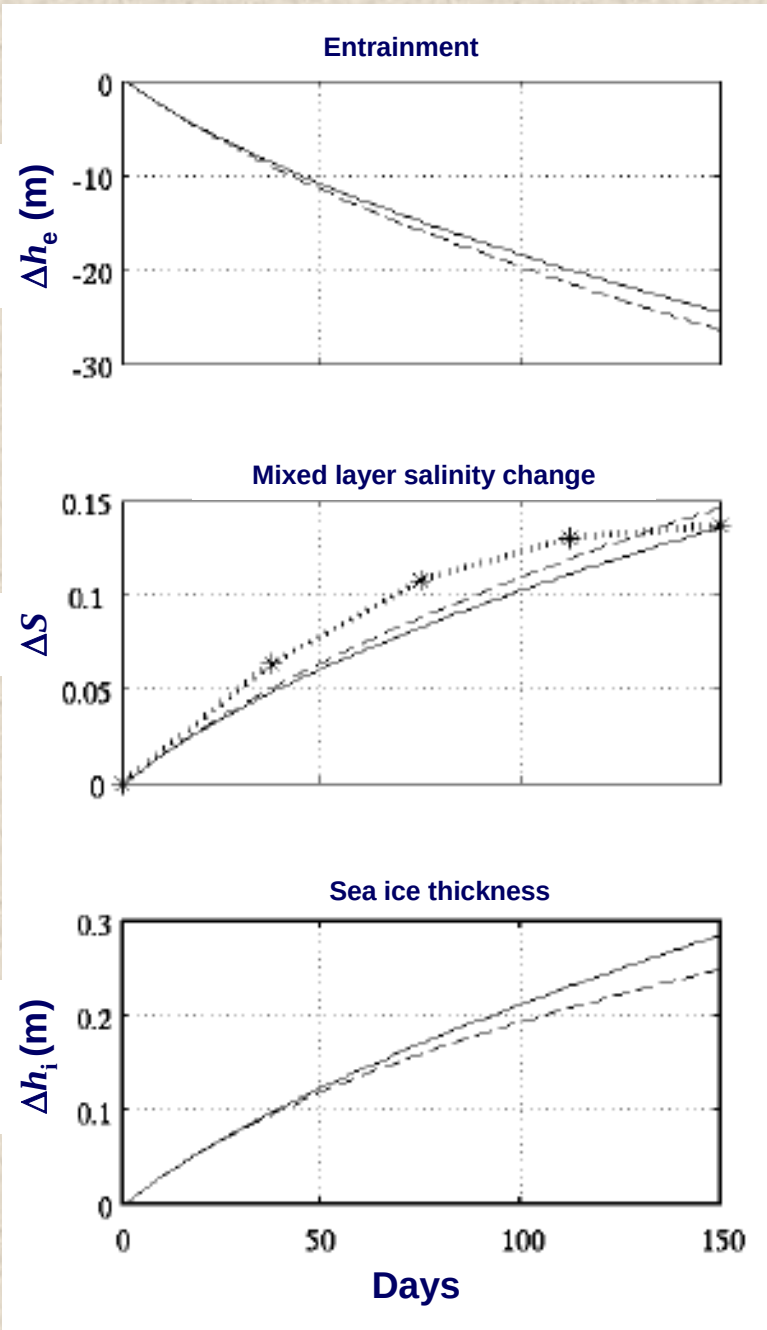


Martinson, 1990

$$\Delta h_e = \mu^{1/2} - (\mu + \theta t)^{1/2}$$

$$\Delta S = \frac{\nabla S}{\beta *}\left[\mu^{1/2} - (\mu + \theta t)^{1/2}\right]$$

$$\Delta h_i = \frac{\gamma \beta *}{A \sigma_i \lambda} \mathcal{F}_S t + \frac{\gamma}{A \sigma_i} \mu^{1/2} \nabla S \left[\mu^{1/2} - (\mu + \theta t)^{1/2}\right] + F_H t$$



Summary and Future Work

- Ocean salinity is an indicator of the ocean's role in the global hydrological cycle as well as a state variable for the ocean circulation. The salinity distribution is more than simply a measure of precipitation and evaporation.

- Over the past decade the Argo program has been successful in mapping the distribution of salinity in previously unexplored regions and in examining changes in the ocean salinity distribution over the past 2-3 decades.

- Careful analysis in models will be necessary in order to interpret the observed salinity changes.

- Argo will likely be an important contributor to Aquarius/SAC-D.

- Argo floats are now successfully measuring the circulation and property distributions under Antarctic ice and soon will be operating in the Arctic. In the near future Argo will begin to deploy floats with the capability of sampling to much deeper levels ($\geq$ 5000 m), which will greatly add to our knowledge of ocean variability but will be technically challenging and expensive.

- Estimates of decadal-scale variability are only beginning; the longer that programs like Argo continue, the more we will understand long-term ocean variability and the ocean's role in climate.