Ocean Observations

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ATOC 5051

You now know as much as Nansen did

- We have covered the Navier-Stokes eqtns.
- You have basic scientific training
- So, what now? What would you do to try to understand the physics of the ocean? What would you measure and how?

The Old Days.

- For hundreds of years, sailors had been keeping logbooks and learning navigation
- But, in the late 1700s, two thing happened:
- 1) B. Franklin and others started using the logbooks scientifically (1769)
- 2) The Harrison clock was built (1760), allowing sailors to know their longitude as well as latitude. Made famous by J. Cook.

Franklin's Gulf Stream (1769)

Cook's Voyages: 1st (1768-1771)

Cook's Voyages: 2nd (1772-1775)

Cook's Voyages: 3rd (1776-1779)

Now that Science was active in the sea…1800s boomed

- Logbooks were analyzed, famously by Maury
- Instruments were developed (current meters, moorings, tide gauges, reversing thermometer, reversing water bottle, messengers, bathythermograph)

And the cruises: Beagle

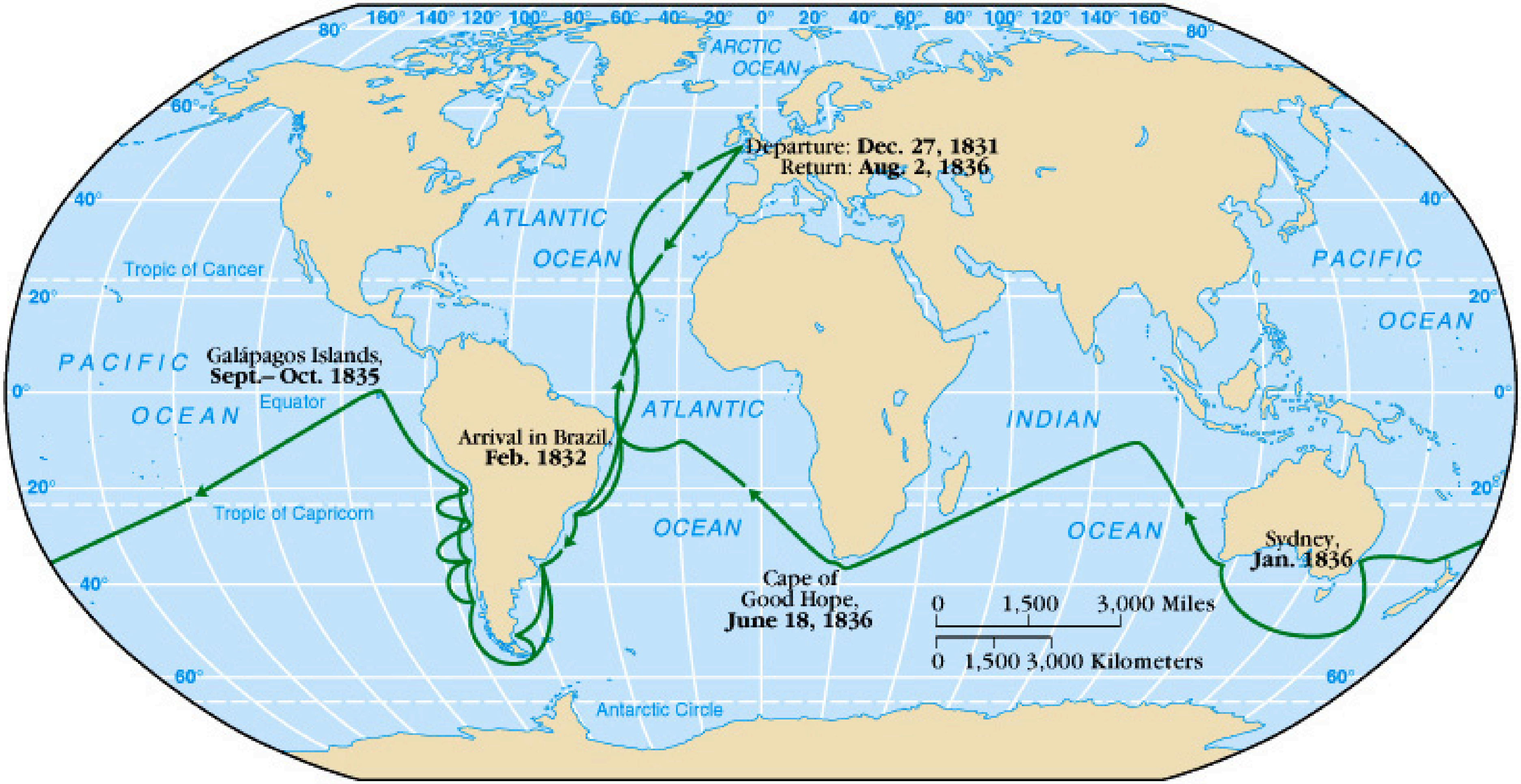


Fig. 1-11. Voyage of the H.H.S. Beagle
December 1831 – August 1836

And the cruises: Challenger

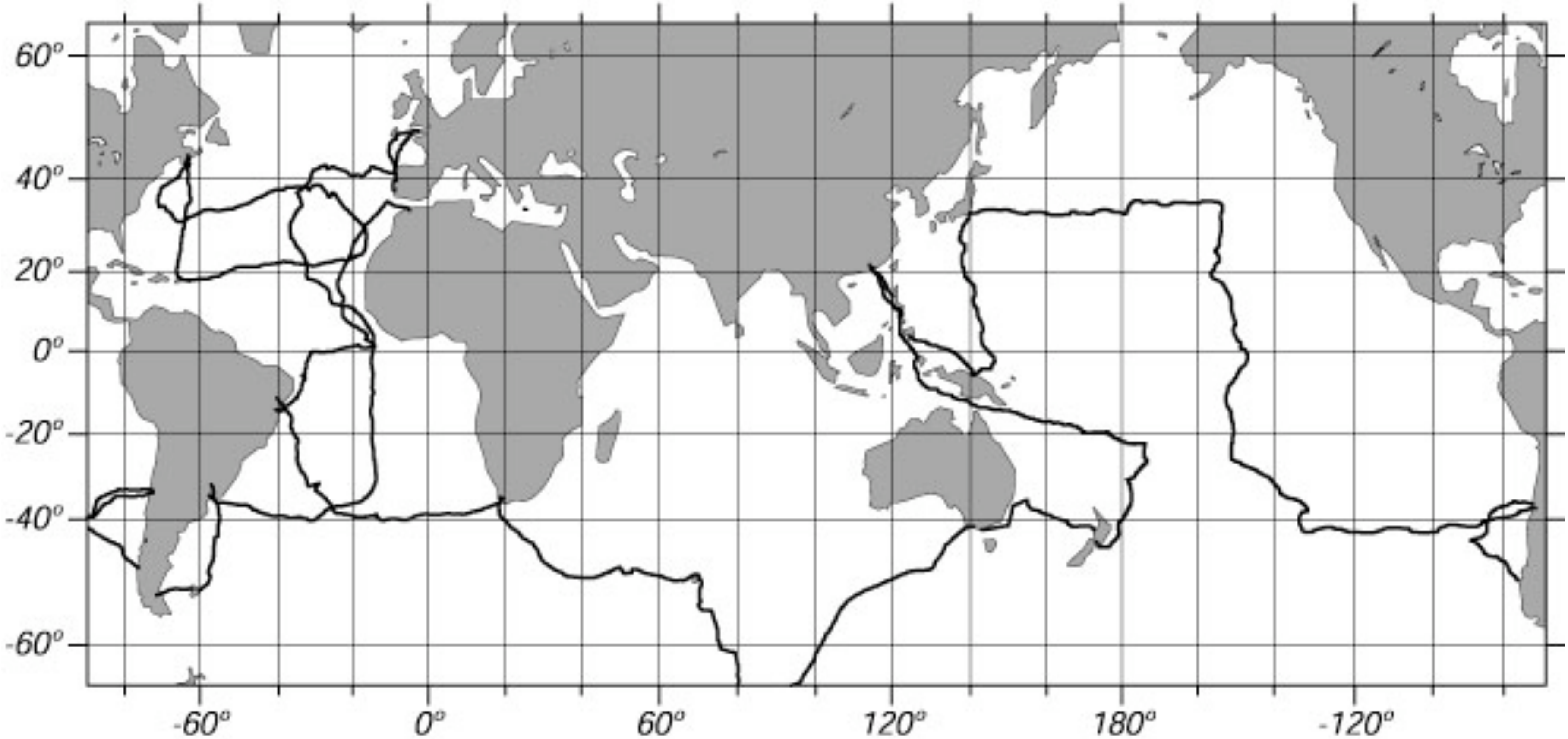
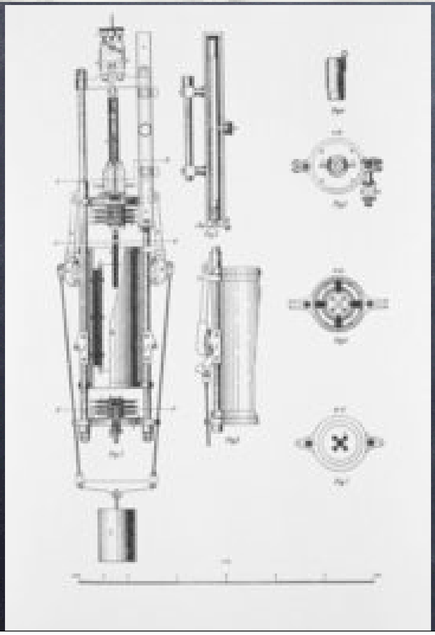
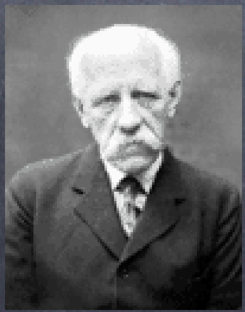


Figure 2.1 Example from the era of deep-sea exploration: Track of the H.M.S. *Challanger* during the British Challanger Expedition 1872-1876. From Wust (1964).

And the cruises: Challenger

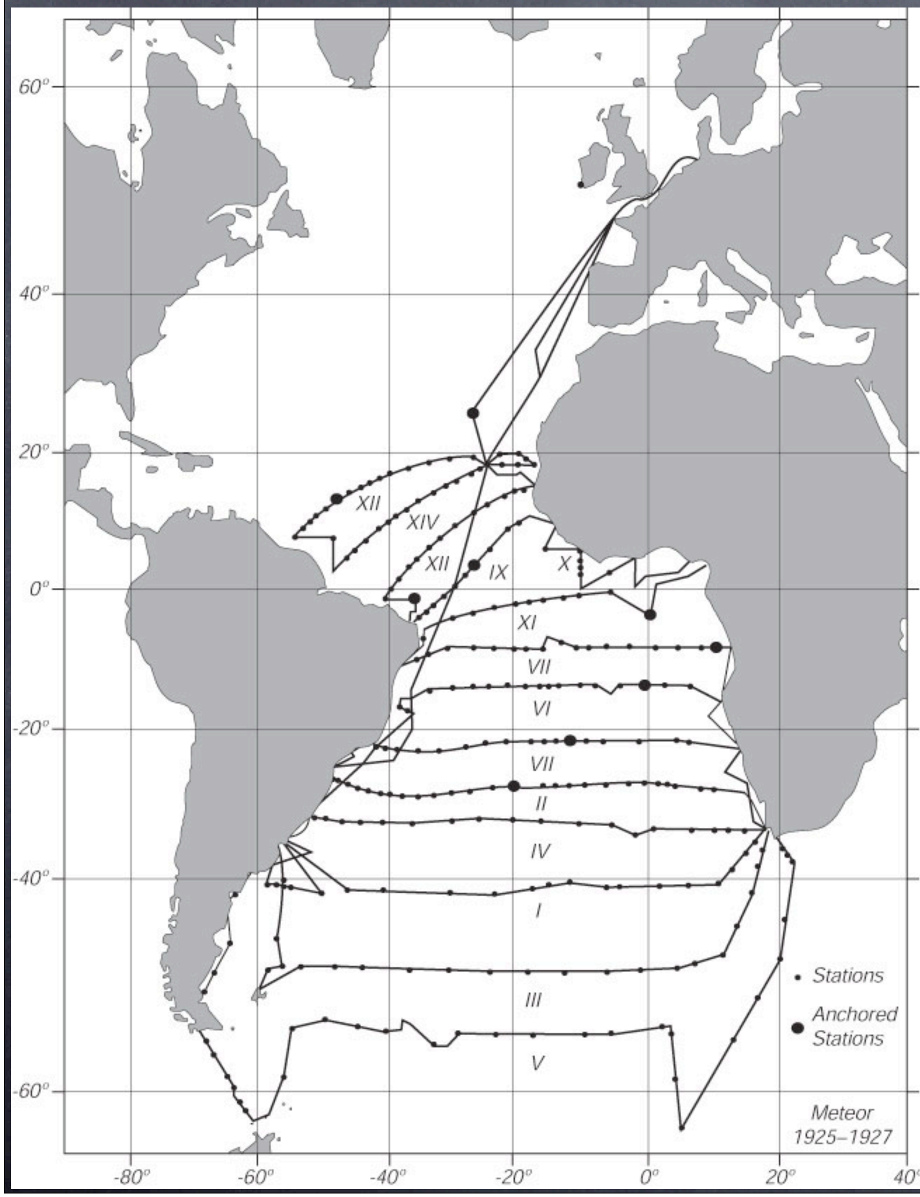
The Cruises: The Fram (1893-1896)

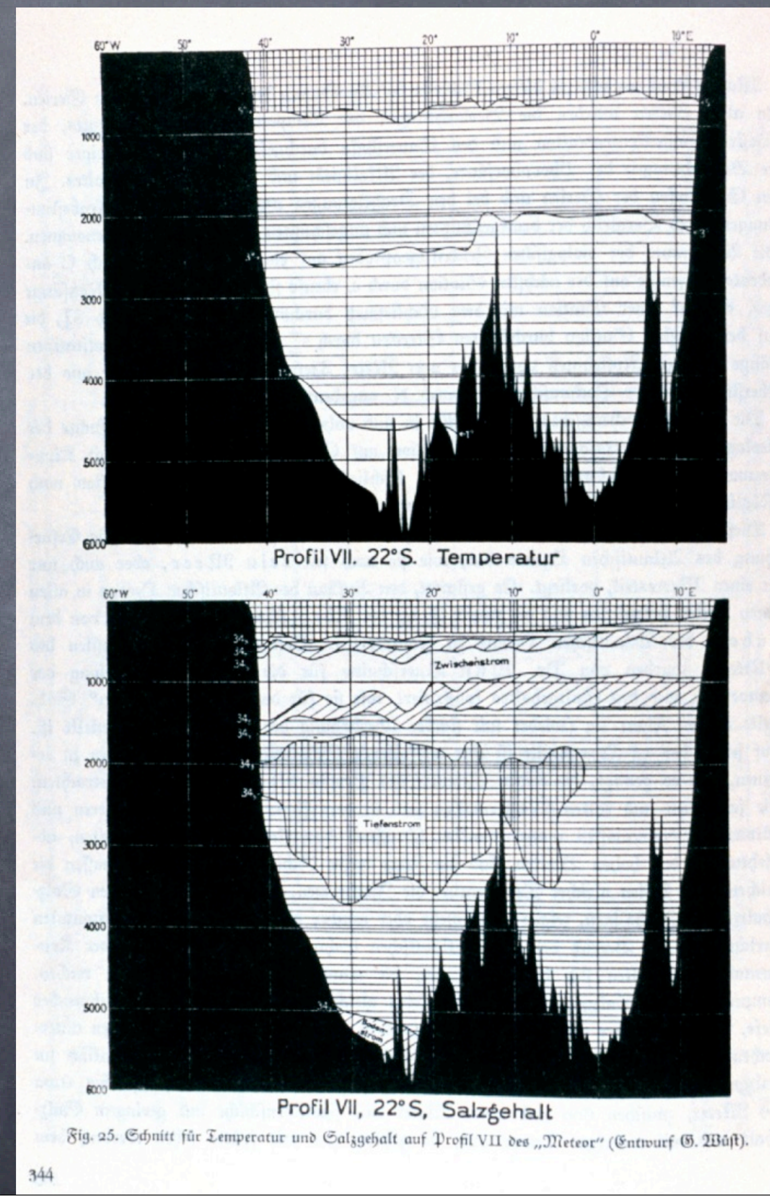




Norwegian explorer, oceanographer, statesman, and humanitarian who led a number of expeditions to the Arctic (1888, 1893, 1895–96) and oceanographic expeditions in the North Atlantic (1900, 1910–14). For his relief work after World War I he was awarded the Nobel Prize for Peace (1922).

20th-Century Science: The Meteor (1925-1927)





20th-Century Science: The Meteor (1925-1927)

Abb. 332. Präsentieren der Sicherheitswache beim Passieren brasilianischer Kriegsschiffe.

20th-Century Science: The Atlantis (1931-1964)

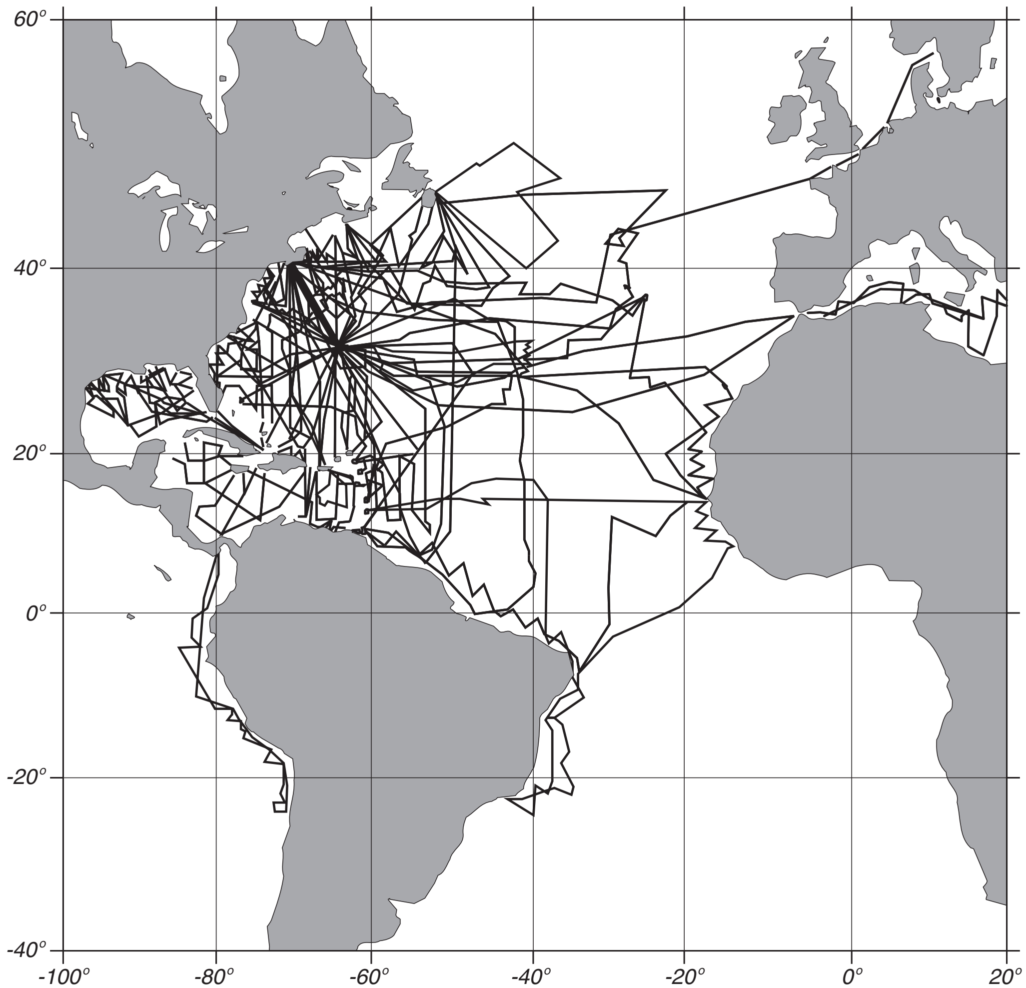


Figure 2.3 Example from the era of new methods. The cruises of the R/V *Atlantis* out of Woods Hole Oceanographic Institution. After Wust (1964).

IGY 1957-1958

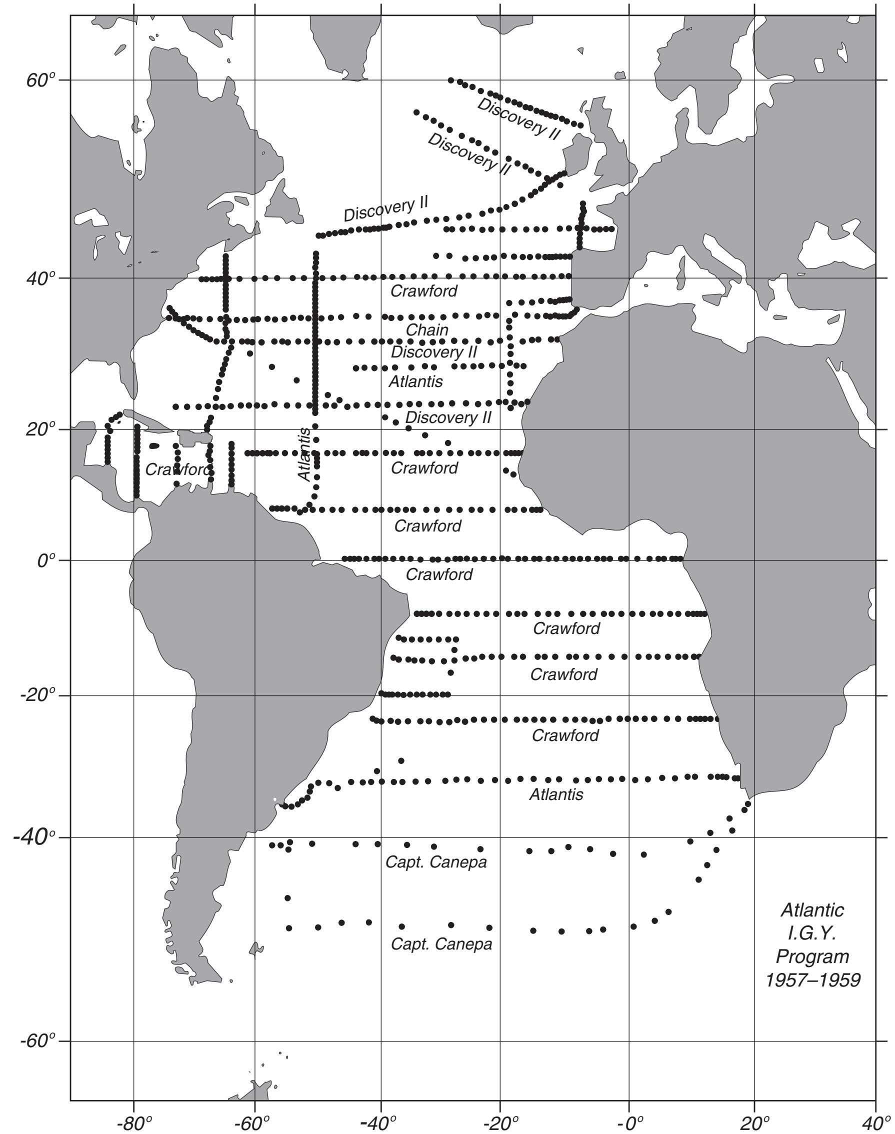


Figure 2.4 Example from the era of international cooperation . Sections measured by the International Geophysical Year Atlantic Program 1957-1959. After Wust (1964).

A Lull until WOCE

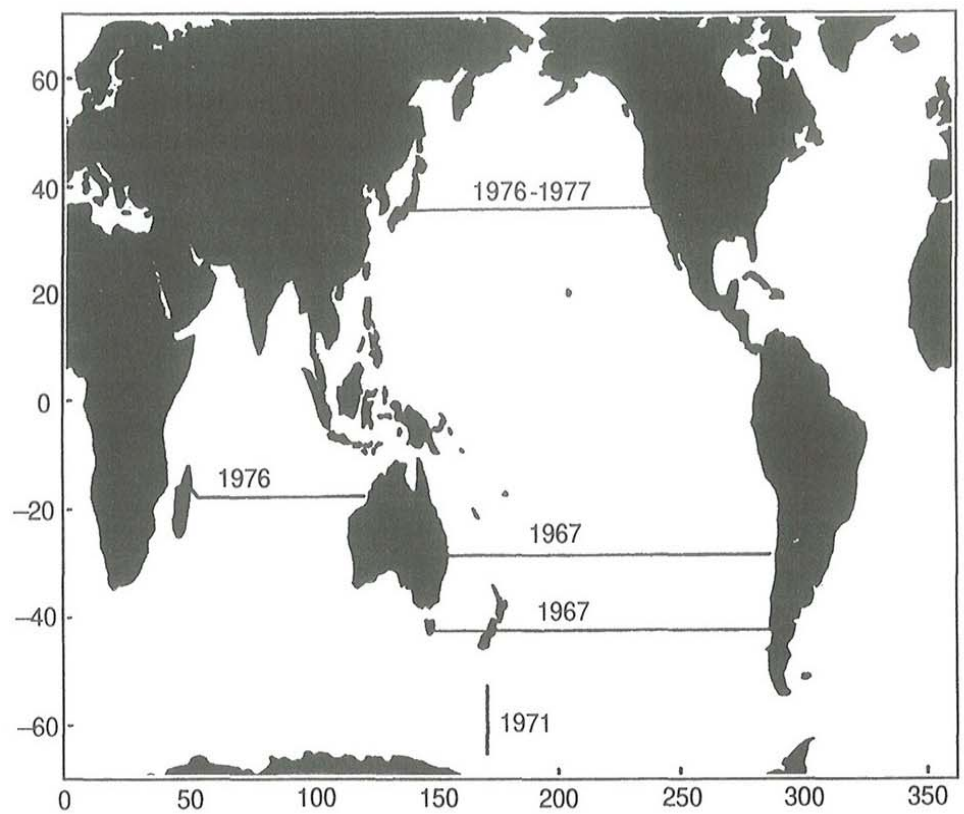


Fig. 2.1.1 The very few trans-oceanic hydrographic sections obtained during the period following the IGY (1958–59) and preceding the WOCE design period. This latter coincided with the resurvey of the North Atlantic (early 1980s), which to some extent marked a return to large-scale physical oceanography following the mesoscale, and other process programmes that dominated the 1960s and 1970s.

But, Still little Data:

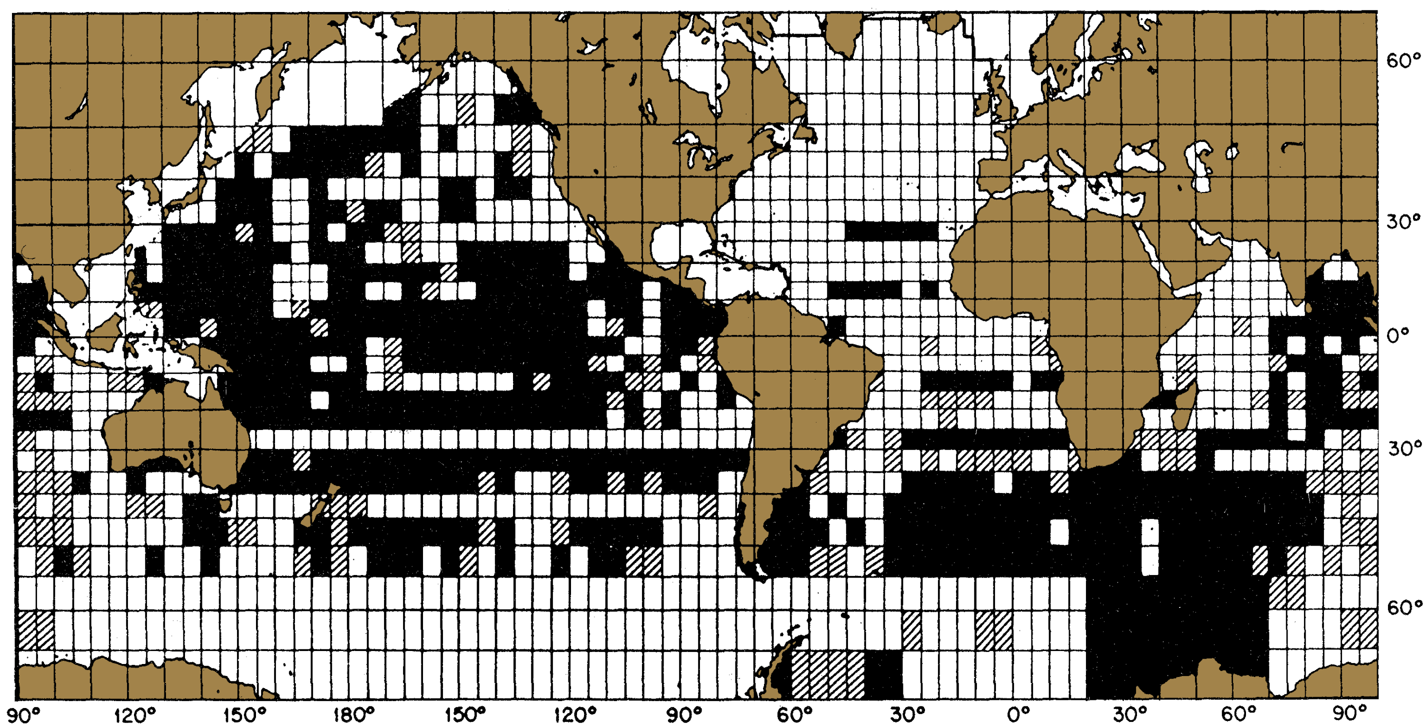


Fig. 2.3. World wide distribution of oceanographic stations of high data quality shortly before 1980. Unshaded 5° squares contain at least one high-quality deep station. Shaded 5° squares contain at least one high-quality station in a shallow area. Black 5° squares contain no high-quality station. Adapted from Worthington (1981)

The WOCE Era:
1980-2002

- WOCE (World Ocean Circulation Experiment)
- Set out to measure all time and space scales
- Global coverage
- Repeat Sections
- Moorings, Drifters, Ships, Satellites, Numerical Models, Data Assimilation,...

A traditional view...

Ruddiman, 2001

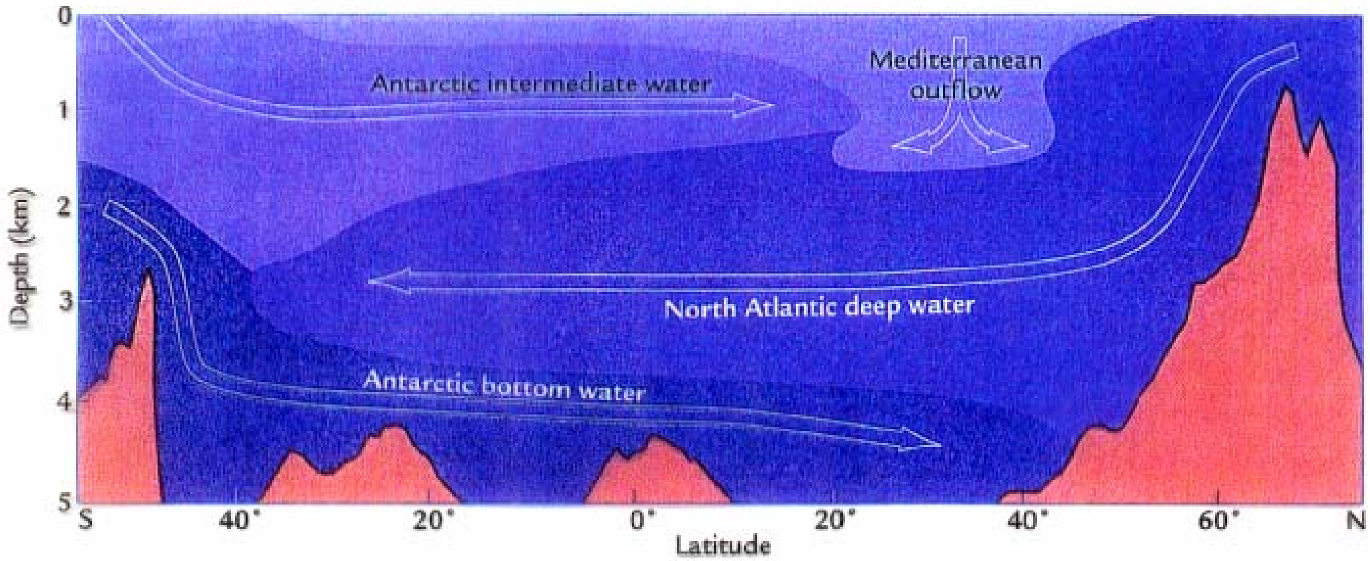
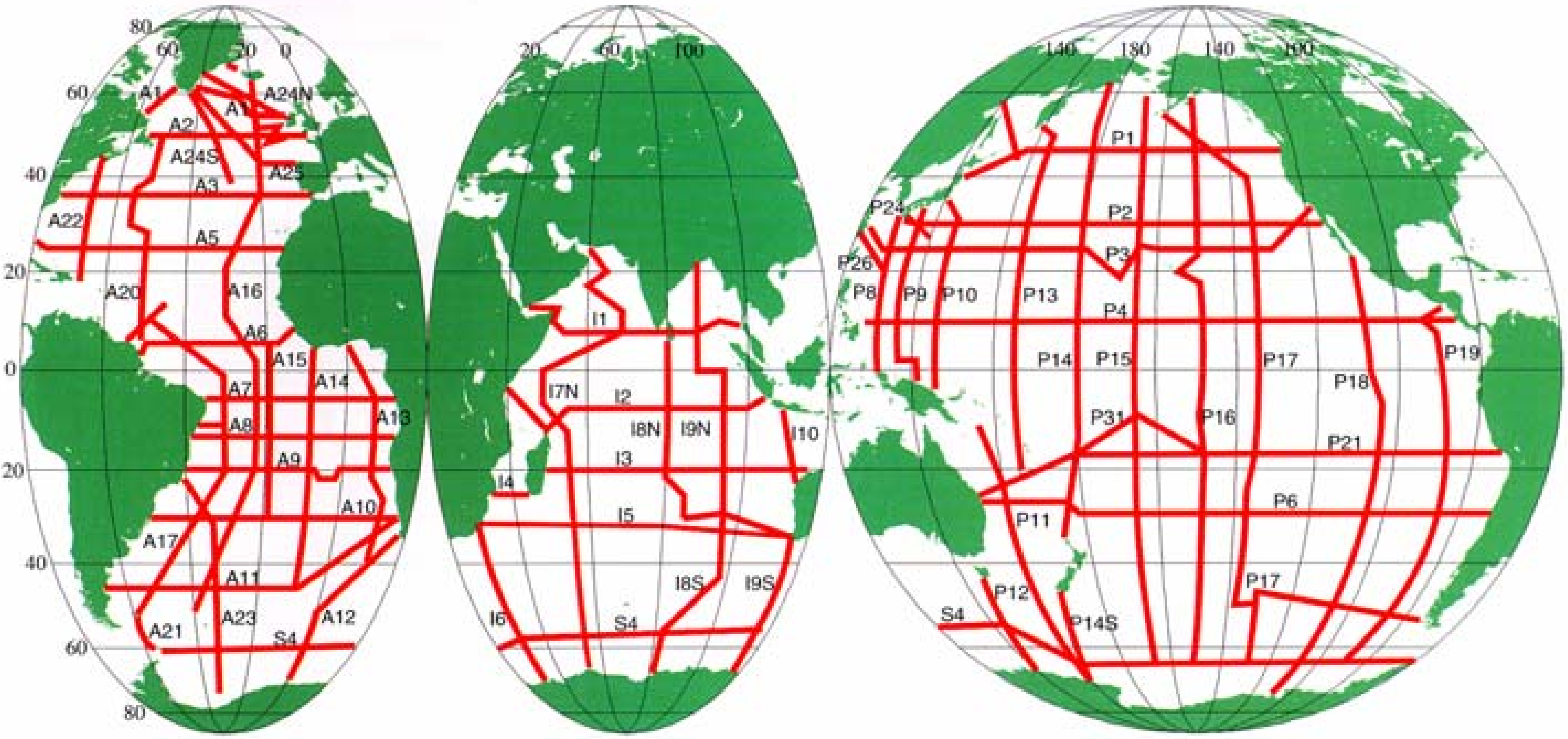


FIGURE 2-26 Deep Atlantic circulation Water filling the North Atlantic basin comes from sources in the high-latitude North Atlantic, the Southern Ocean near Antarctica, and (at shallower depths) the Mediterranean Sea. (Adapted from E. Berner and R. Berner, *Global Environment* [Englewood Cliffs, N.J.: Prentice-Hall, 1996].)

WOCE Hydrographic Program One-Time Survey



CTD Measures:

Conductivity

Temperature

Pressure

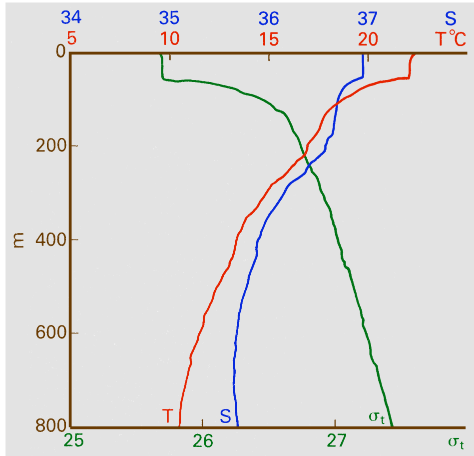


Fig. 2.1.

An example of the basic CTD data set. Temperature *T* and salinity *S* are shown against pressure converted to depth. Also shown is the derived quantity σ_t.

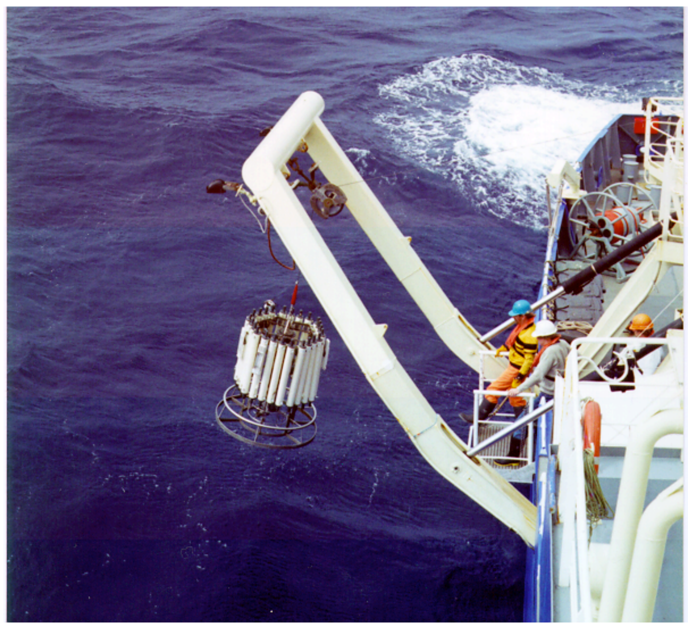


Fig. 2.2. A CTD is retrieved after completion of a station. The instrument is mounted in the lower centre, protected by a metal cage to prevent damage in rough weather. Above the CTD are 24 sampling bottles for the collection of water samples. The white plastic frames attached to some of them carry precision reversing thermometers.

XBT (eXpendable bathythermograph)

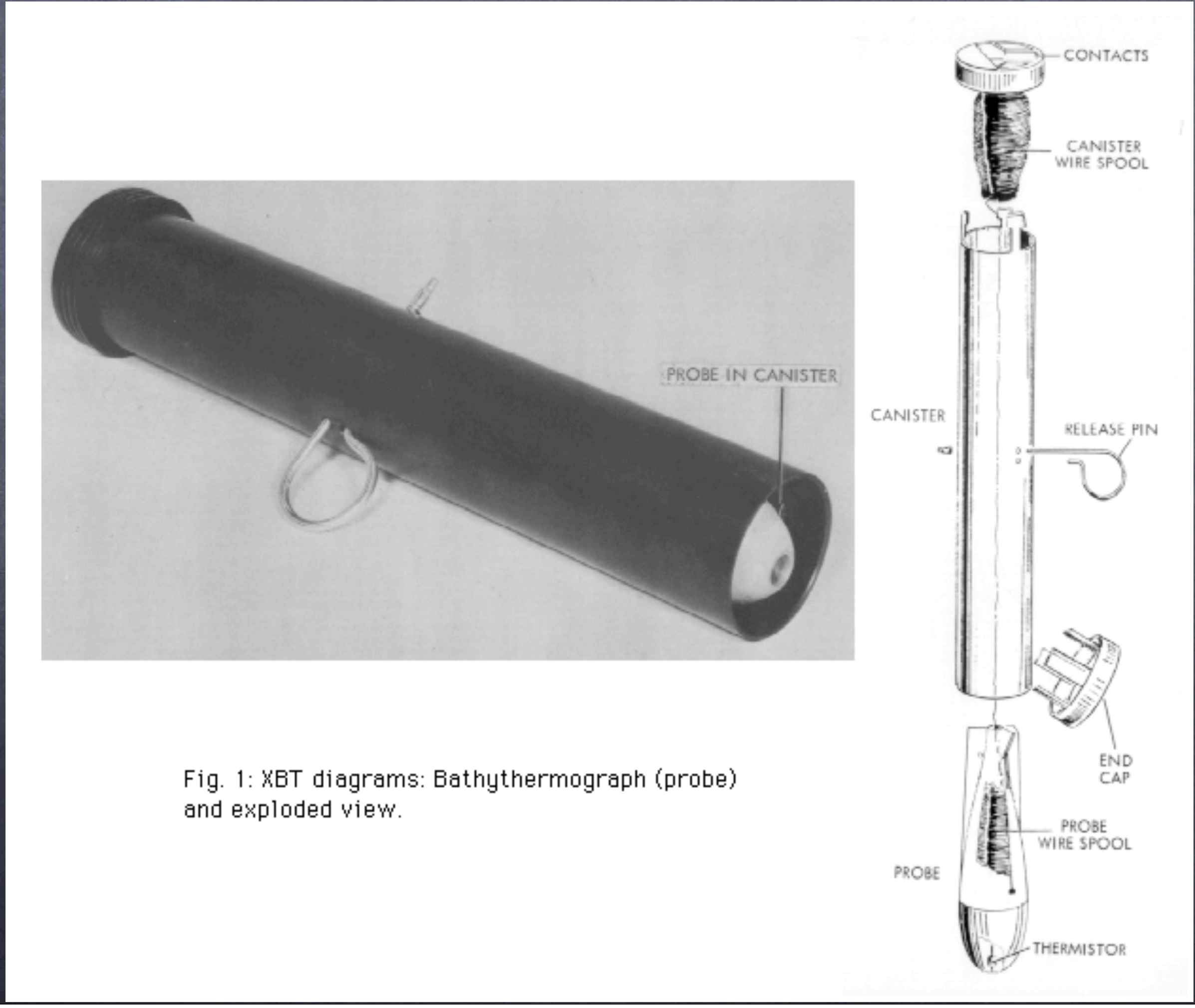
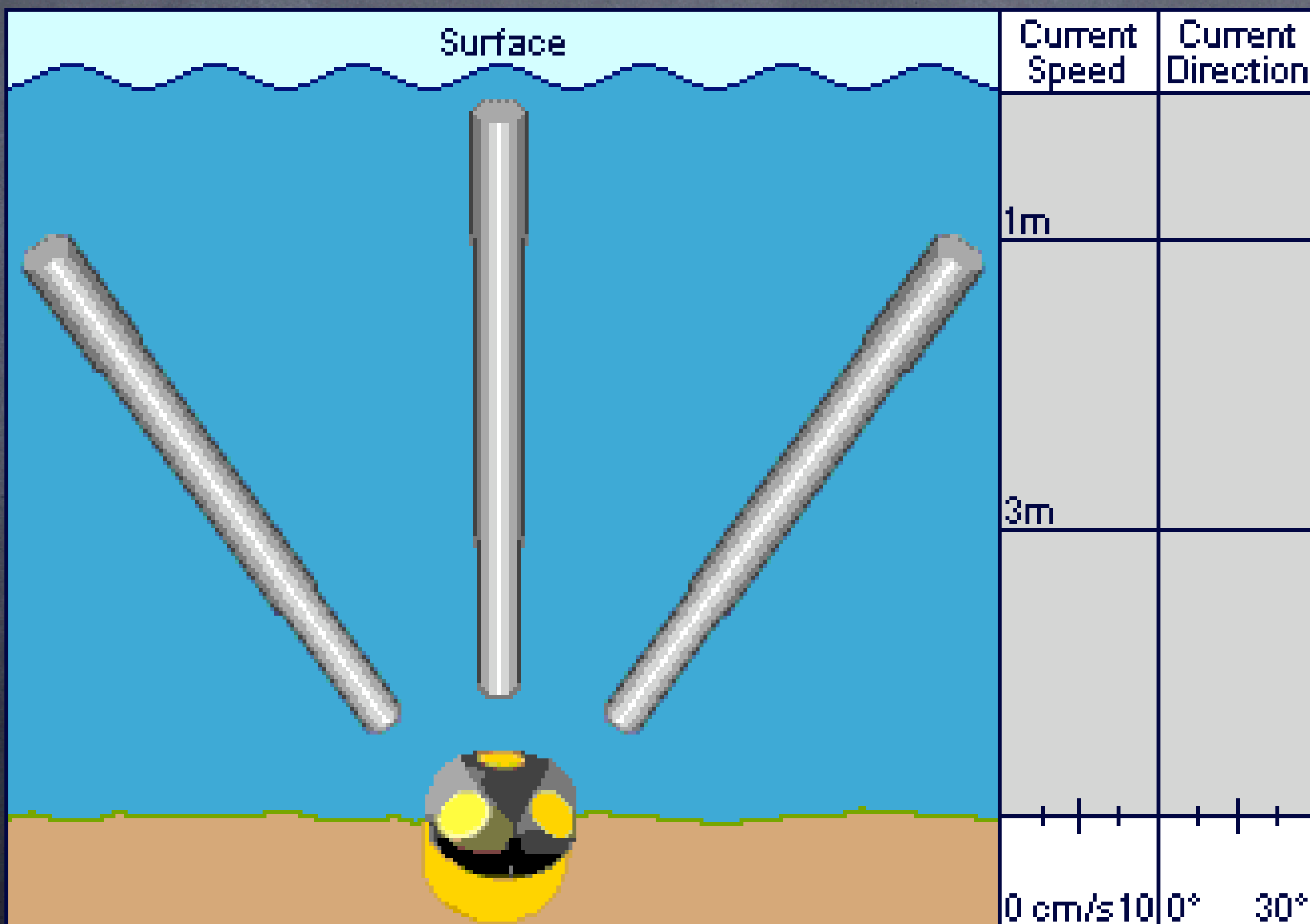


Fig. 1: XBT diagrams: Bathythermograph (probe) and exploded view.

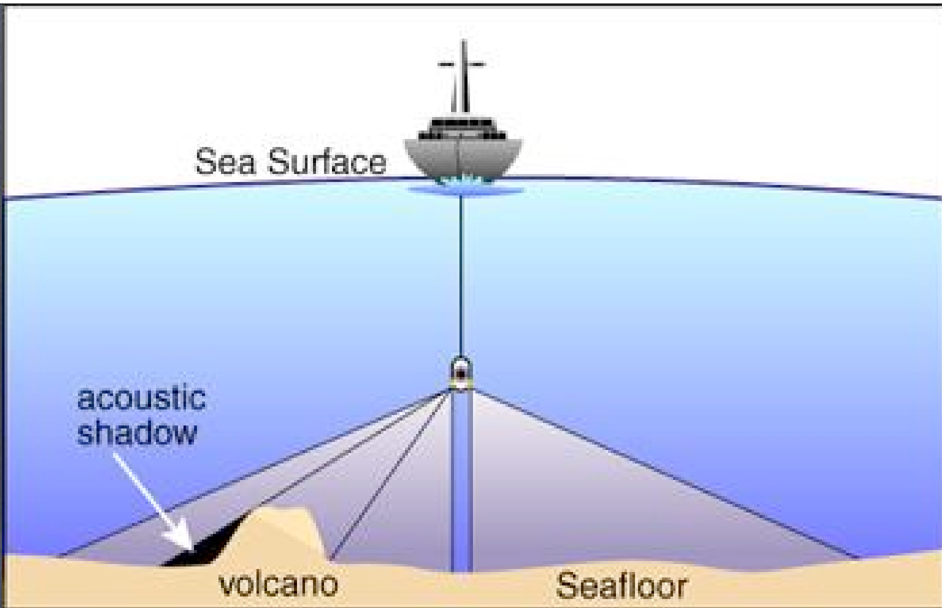
ADCP (Acoustic Doppler Current Profiler, Shipboard or mooring)

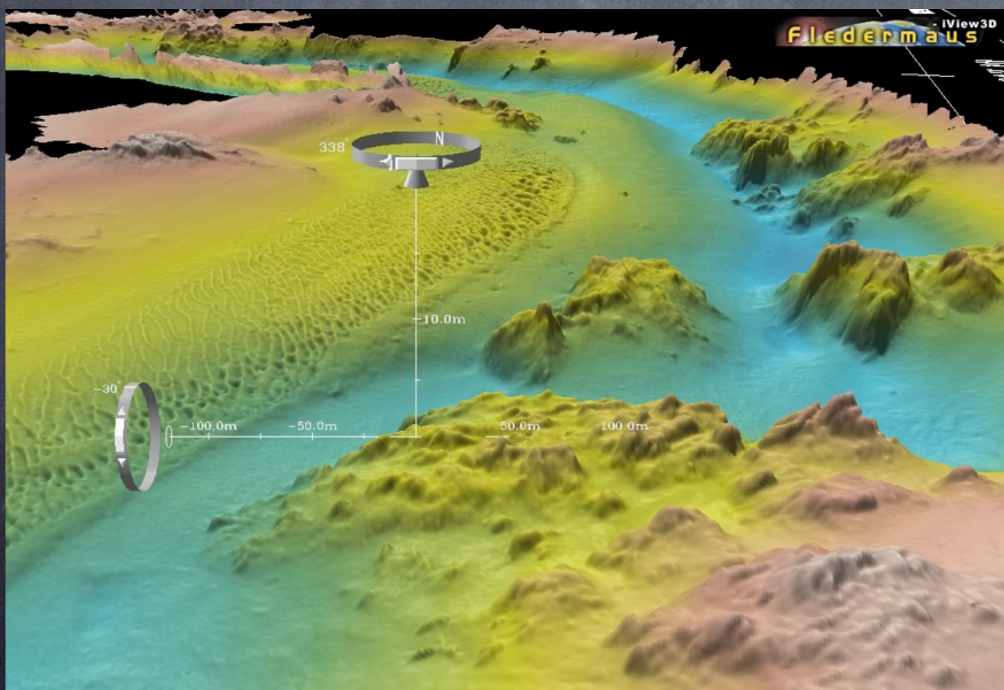


GPS (Global Positioning Satellites)

Advanced Navigation

Side-Scan Sonar: Detailed Mapping

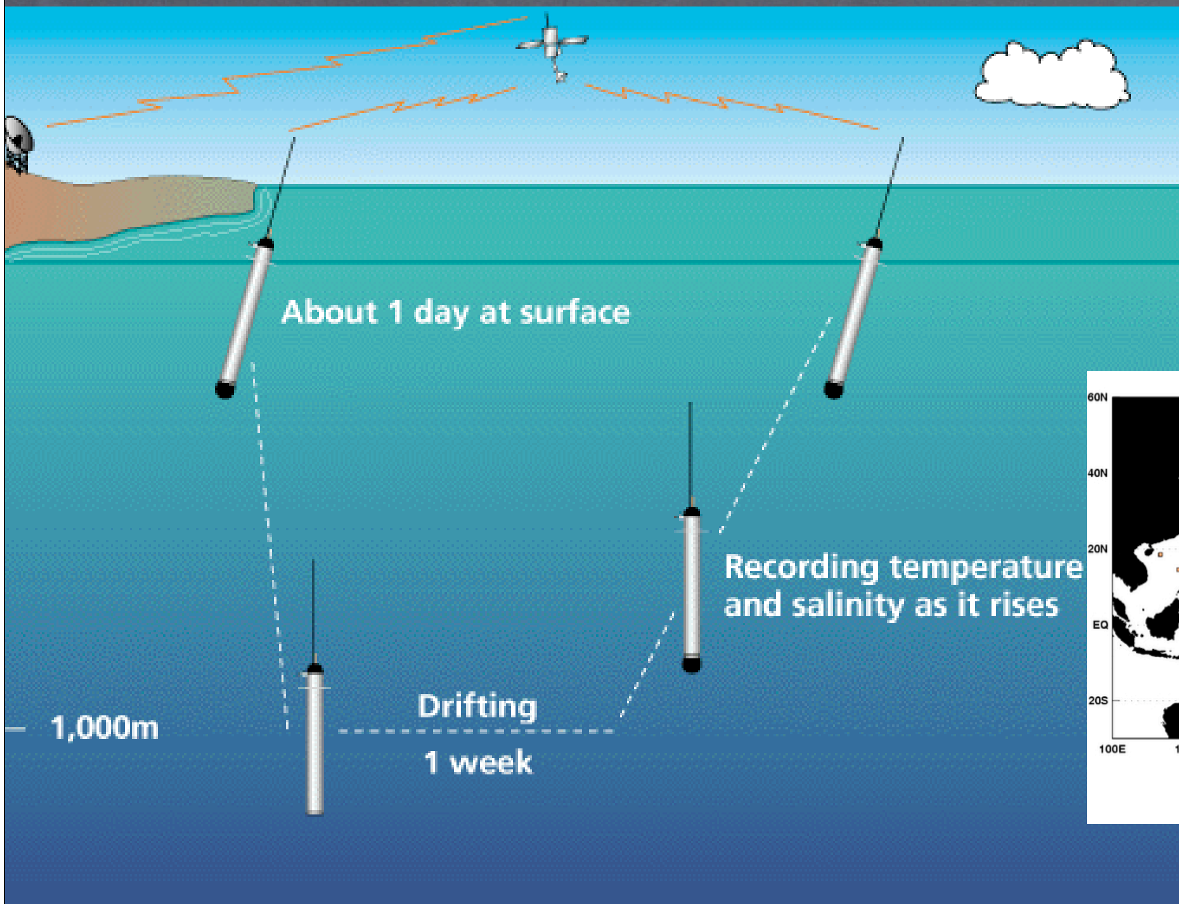


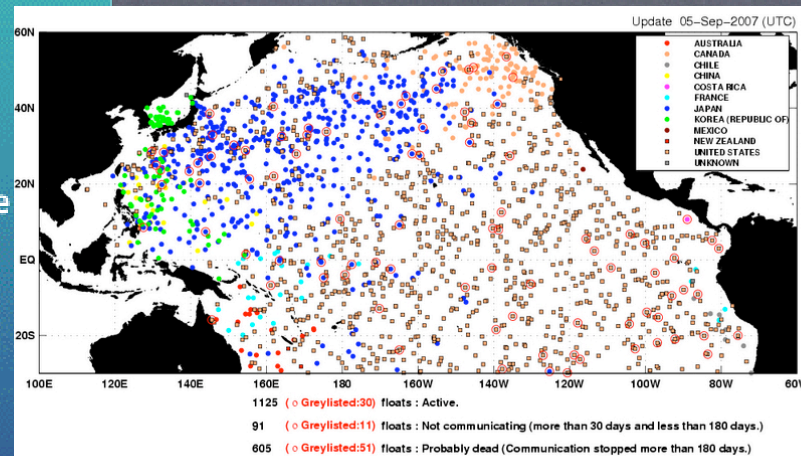


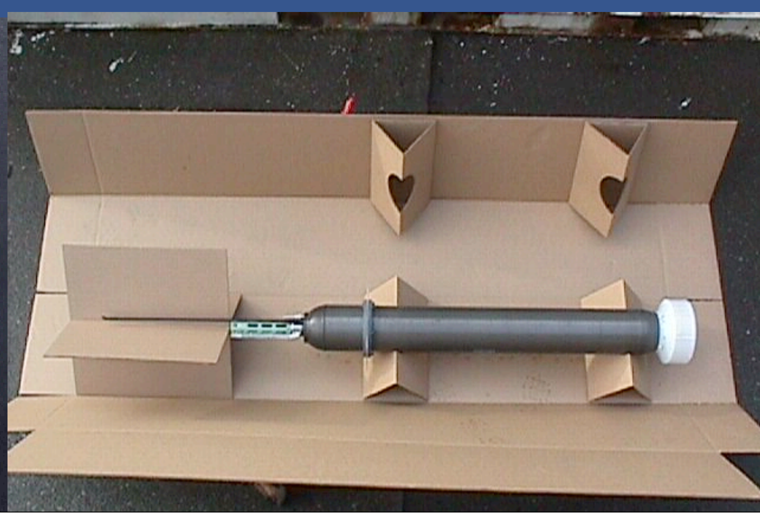
Submarine Canyons

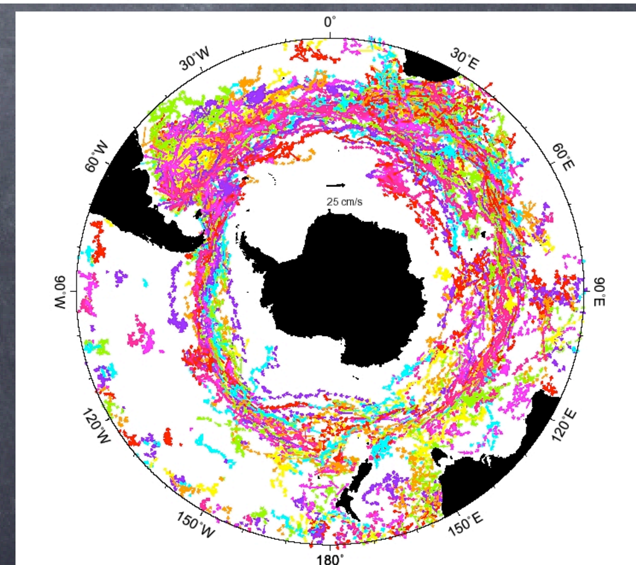
Shipwreck

Automated Floats









Satellite Altimetry

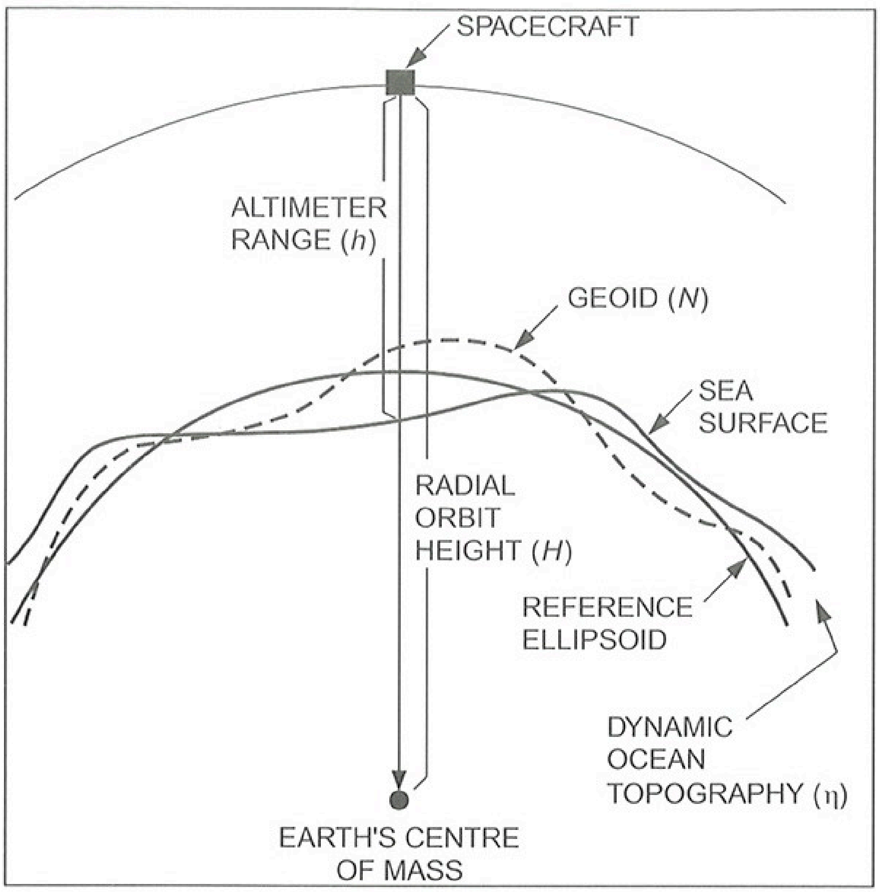


Fig. 3.3.1 Measurement geometry of satellite altimetry.

Other Satellites
Ocean Color (T & Chl)
Rainfall
Wind Scatter
Geoid

Directly Observe Theorized Waves

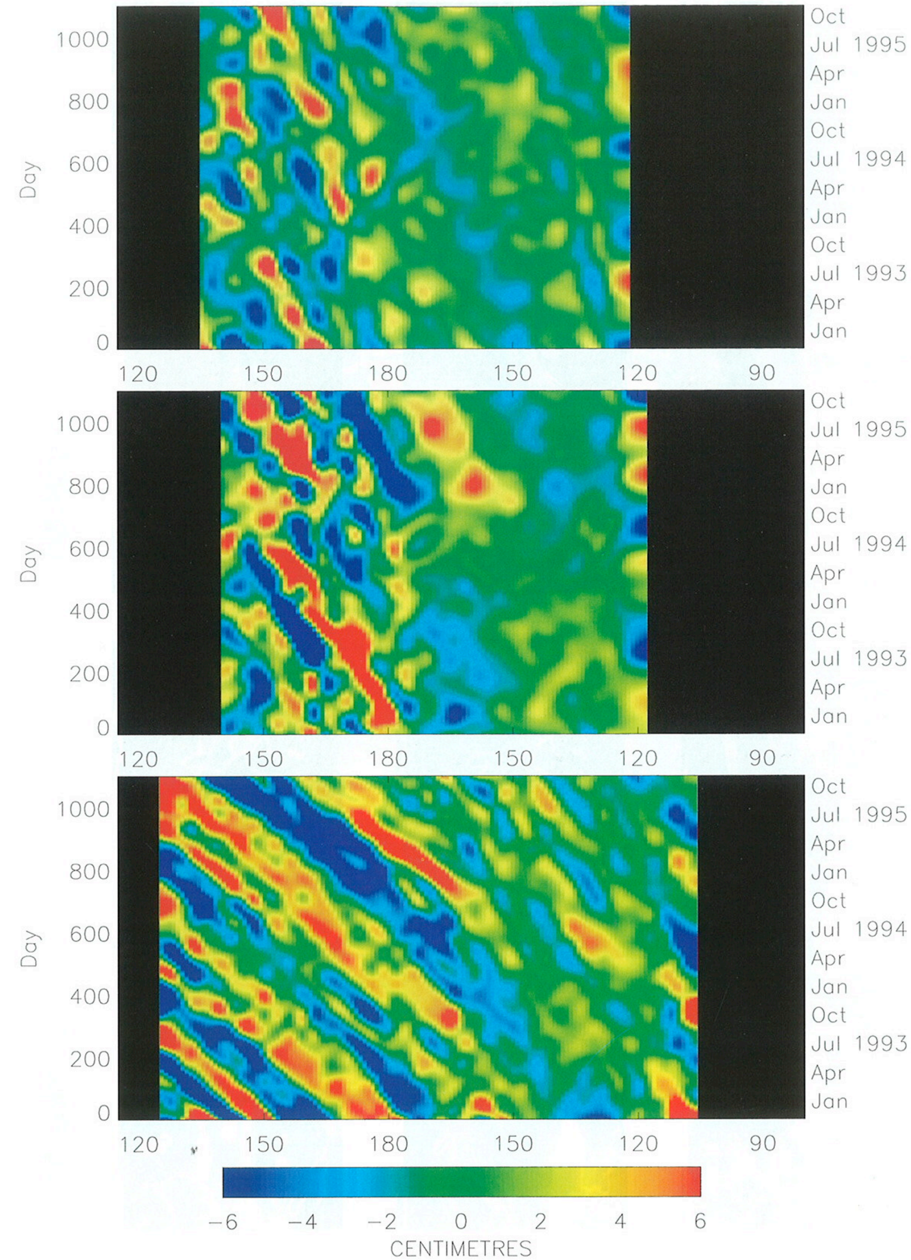


Plate 3.3.7 (see p. 153) Time–longitude sections of sea level observed by T/P in the North Pacific Ocean along 39°N (top), 32°N (middle), and 21°N (bottom). From Chelton and Schlax (1996).

Directly Observe Eddies: Validate Models

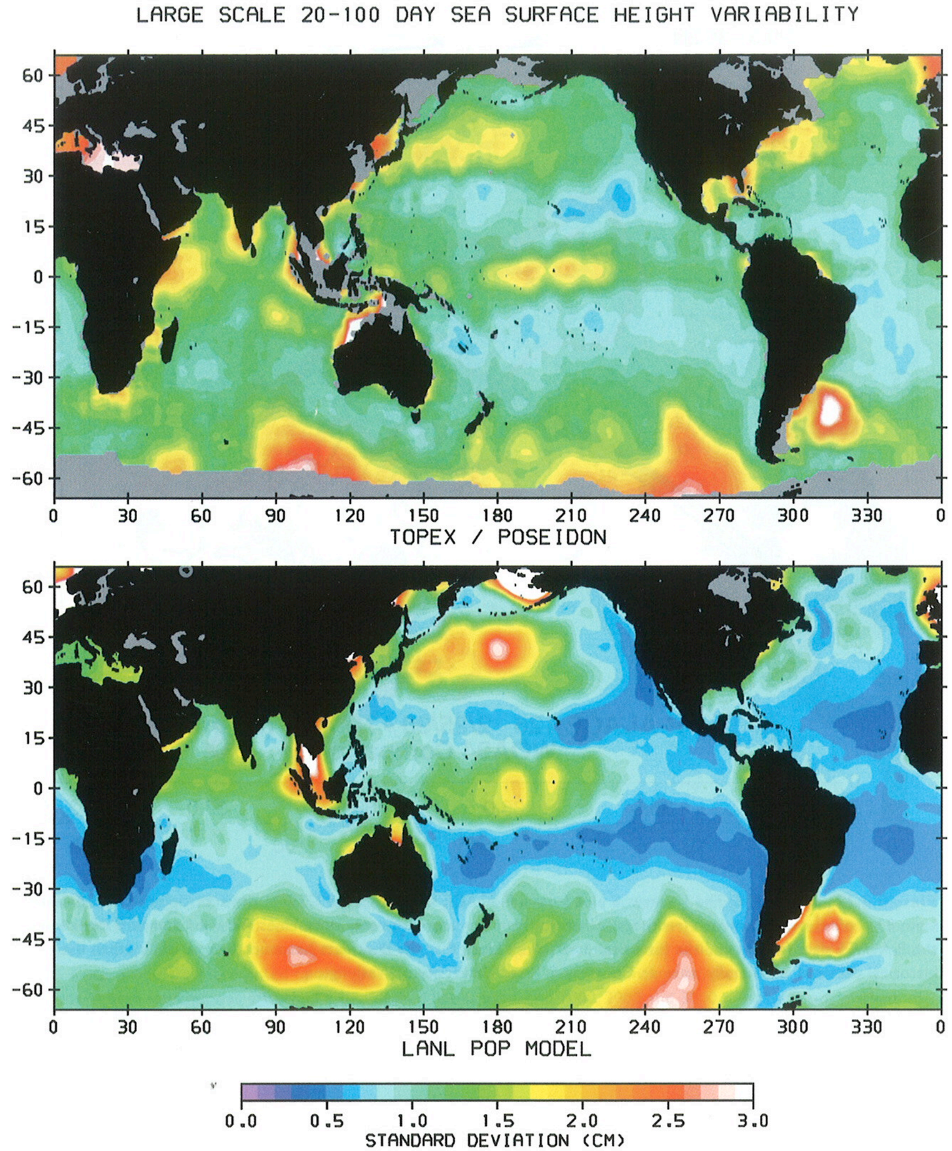


Plate 3.3.5 (see p. 152) Root-mean-square variability of sea surface height measured by T/P (top) and simulated by the ocean general circulation model developed by the Parallel Ocean Program of the Los Alamos National Laboratory (bottom). Both were filtered to retain energy at spatial scales larger than 1000 km and temporal scales shorter than 100 days. From Fu and Smith (1996).

Interannual Variability Global Coverage

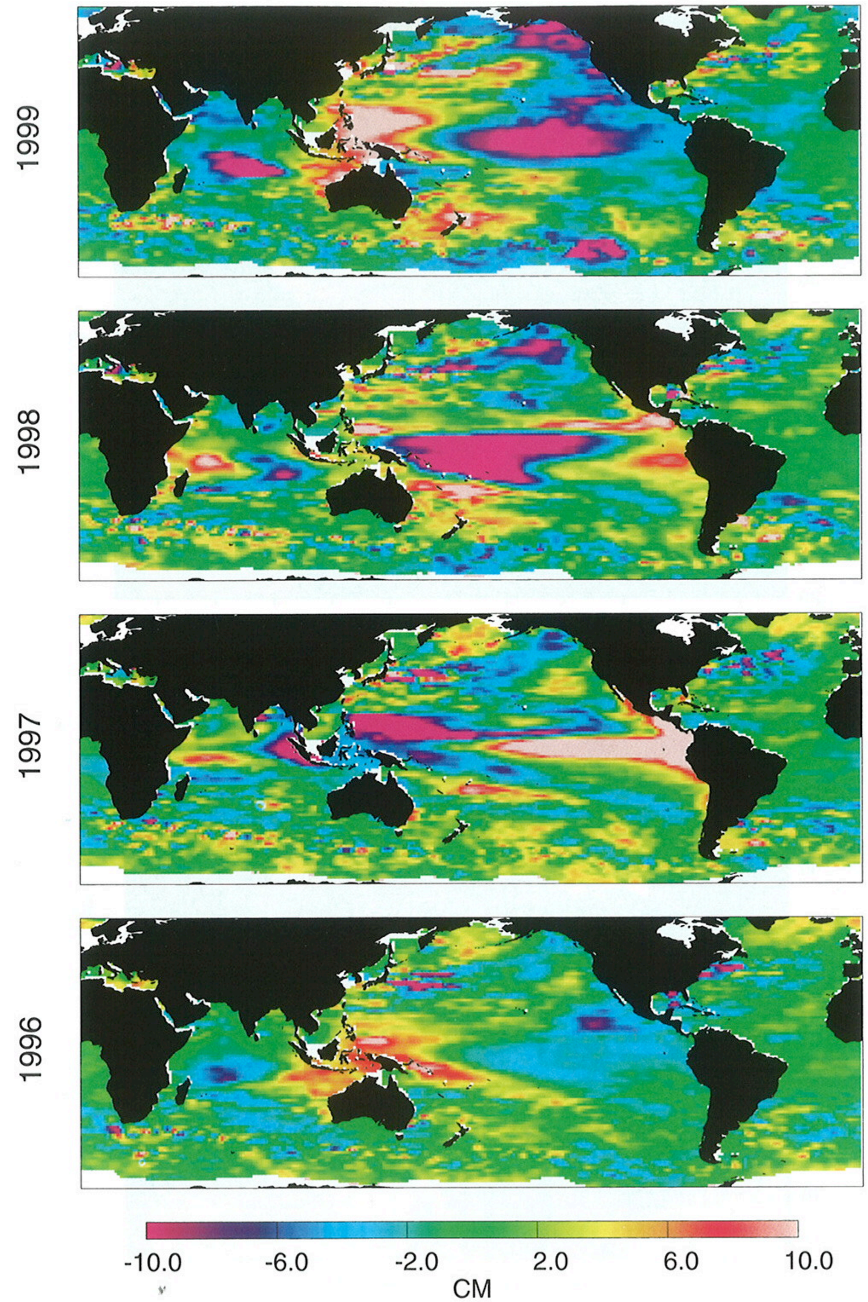
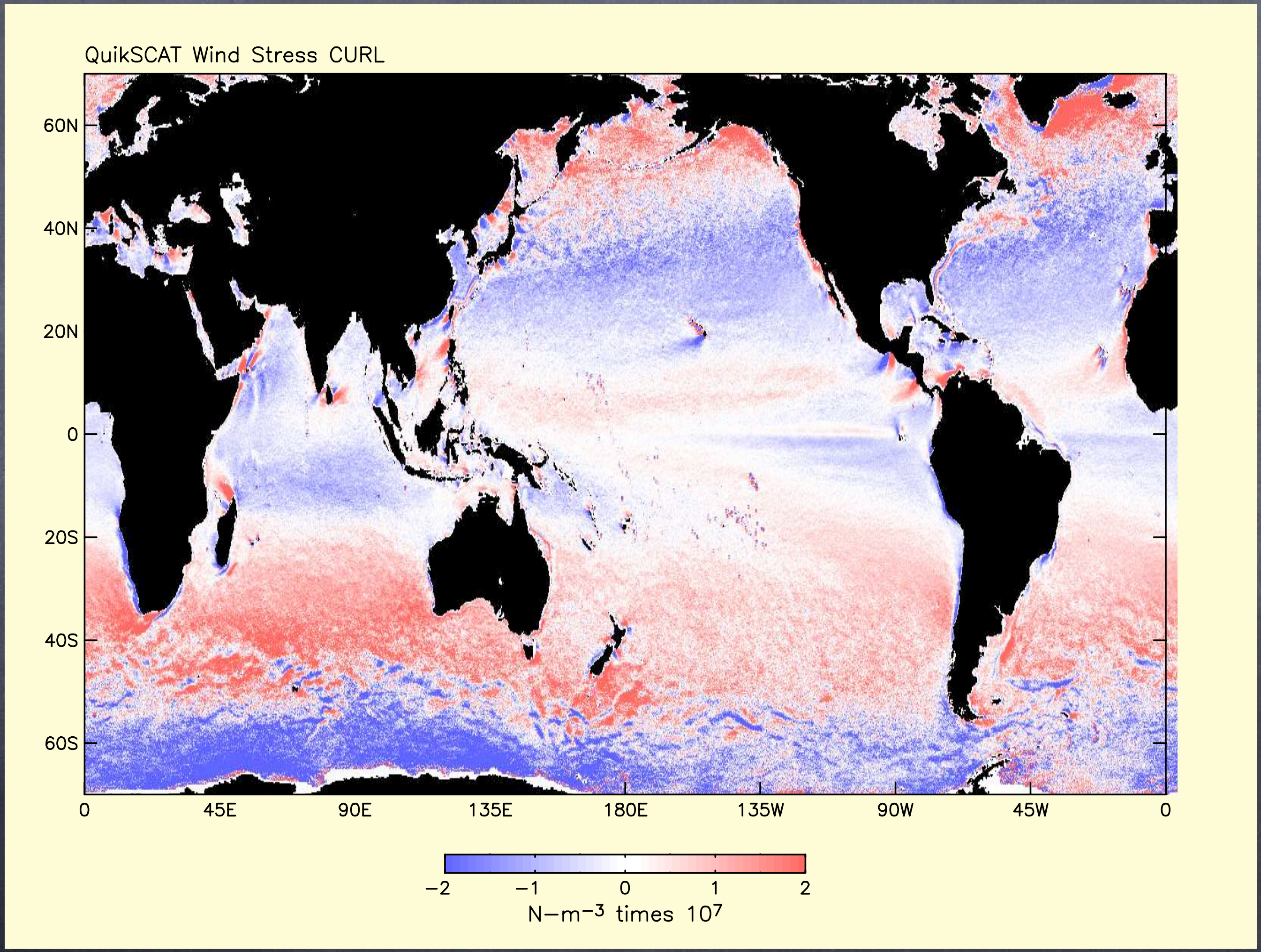
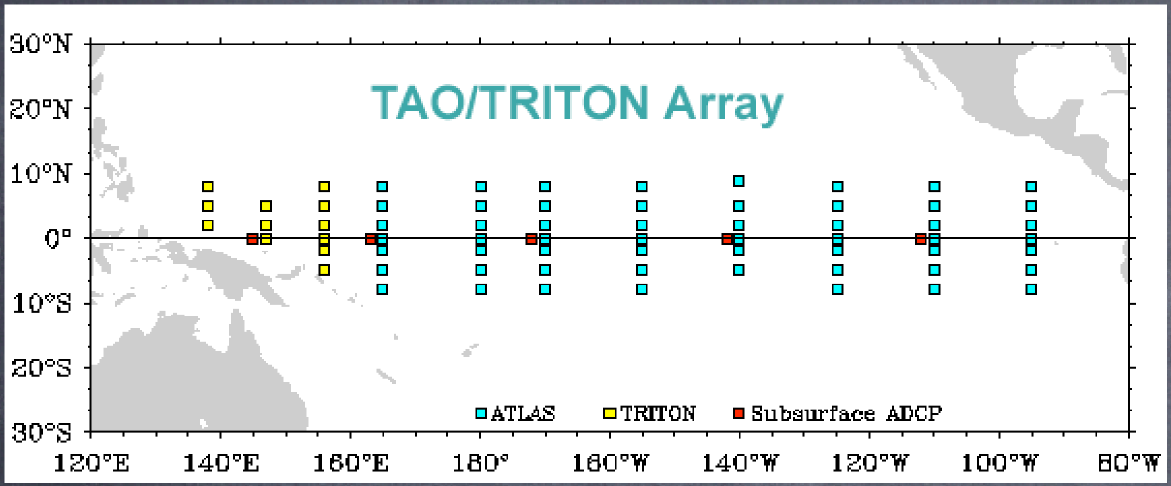


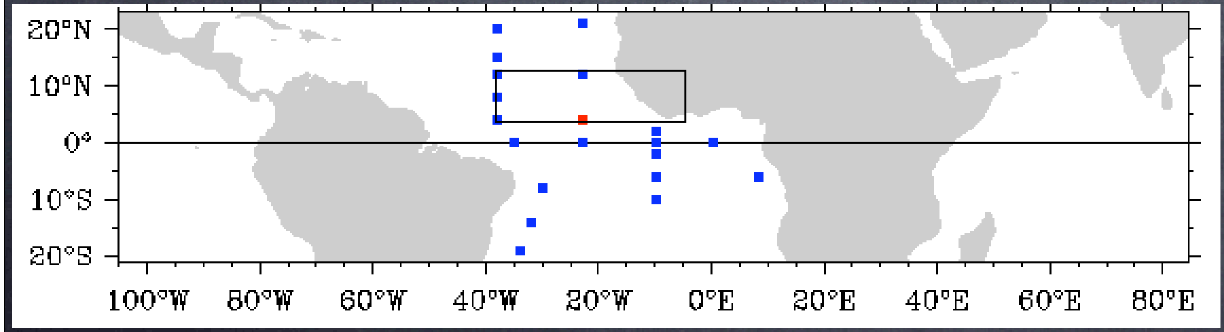
Plate 3.3.11 (see p. 159) Yearly averages of sea-level anomalies from the T/P data for 1996–99. The anomalies were computed relative to the 1993–96 mean.

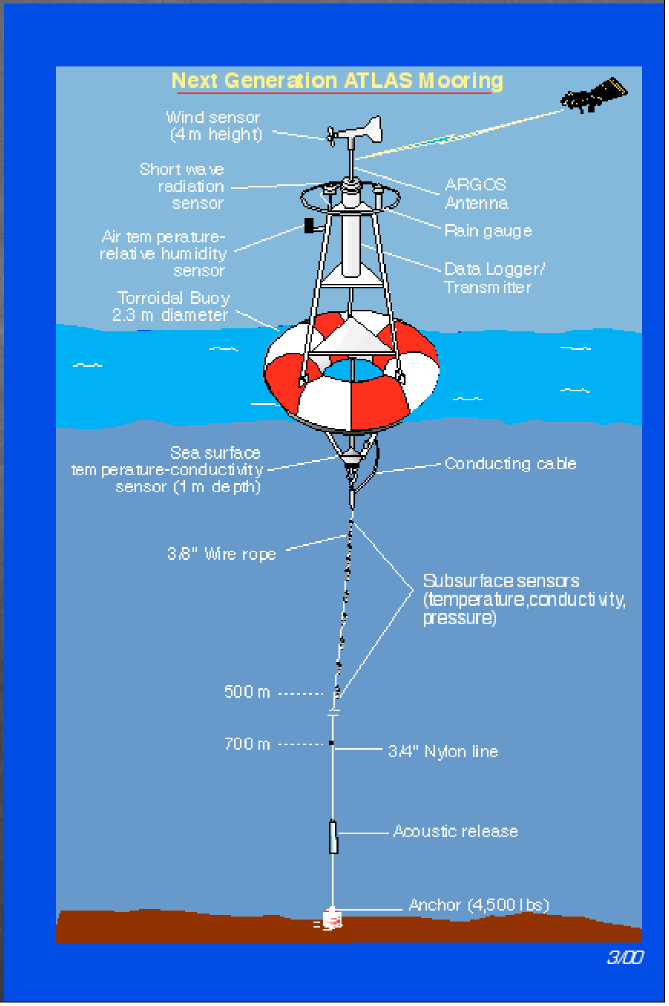
Detailed, High-res Wind Stress



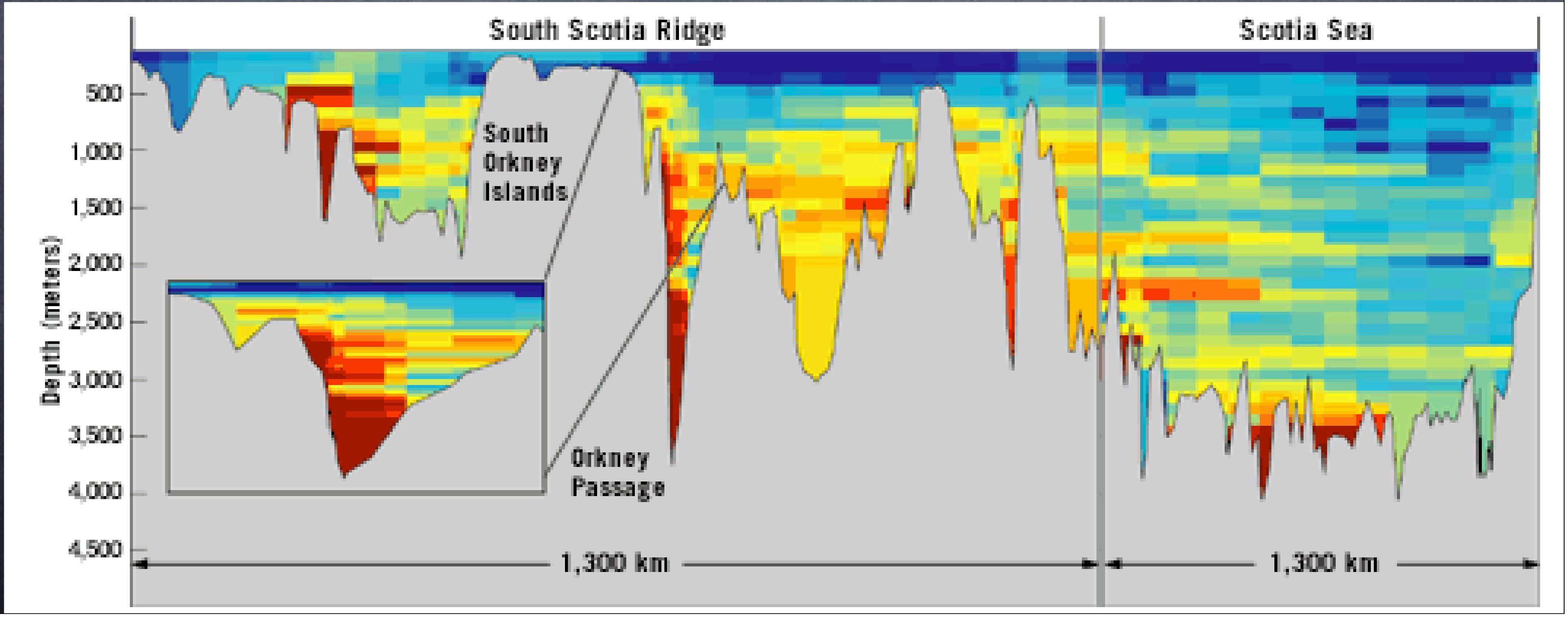
Moorings: TOGA/TAO/TRITON, PIRATA



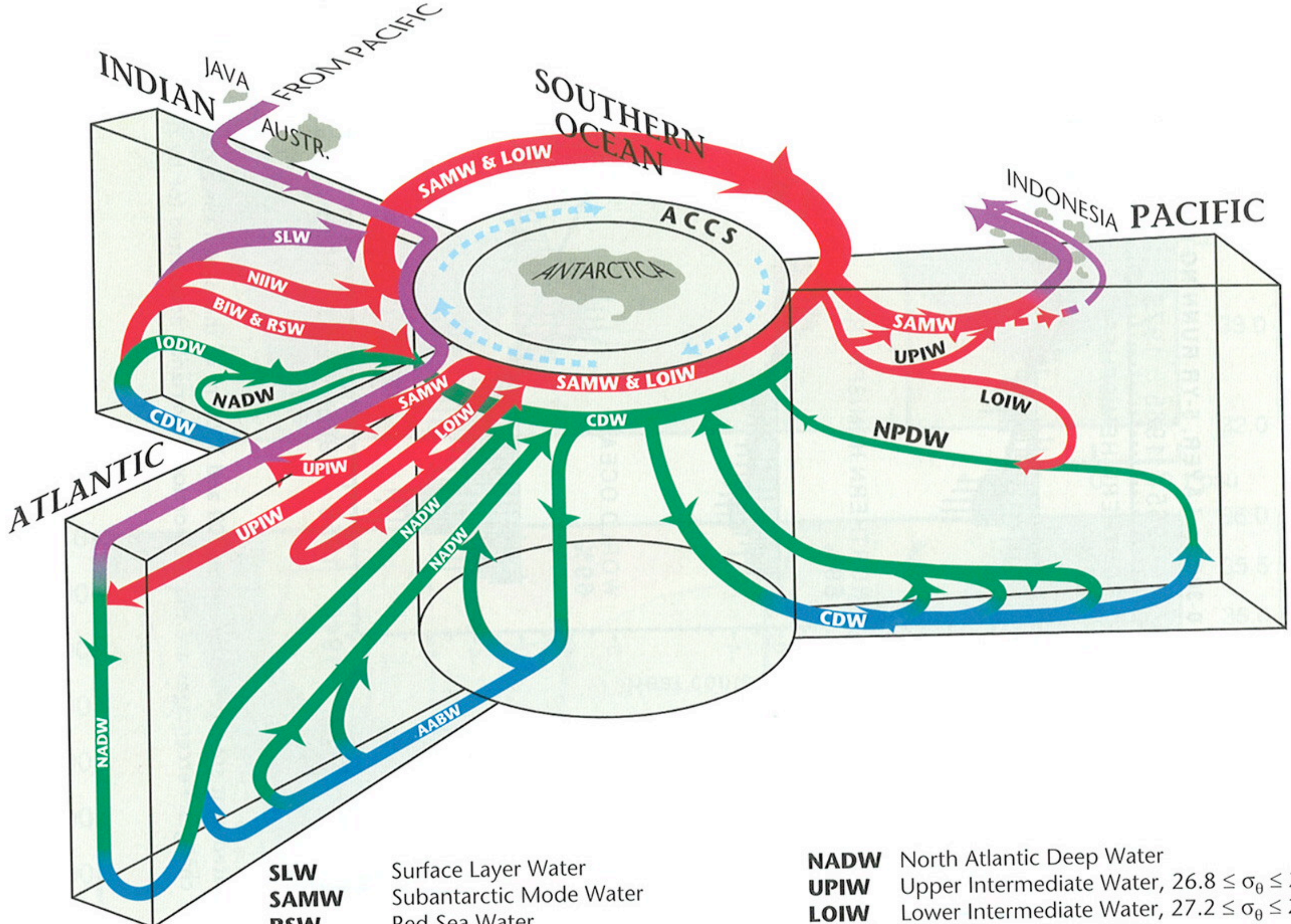




Microstructure Measurements



From this:
Franklin's Gulf Stream (1769)



SLW	Surface Layer Water	**NADW**	North Atlantic Deep Water
SAMW	Subantarctic Mode Water	**UPIW**	Upper Intermediate Water, $26.8 \le \sigma_\theta \le 27.2$
RSW	Red Sea Water	**LOIW**	Lower Intermediate Water, $27.2 \le \sigma_\theta \le 27.5$
AABW	Antarctic Bottom Water	**IODW**	Indian Ocean Deep Water
NPDW	North Pacific Deep Water	**BIW**	Banda Intermediate Water
ACCS	Antarctic Circumpolar Current System	**NIIW**	Northwest Indian Intermediate Water
CDW	Circumpolar Deep Water		

Plate 1.2.7 (see p. 22) A three-dimensional schematic showing the meridional overturning circulation in each of the oceans and the horizontal connections in the Southern Ocean and the Indonesian Throughflow. The surface layer circulations are in purple, intermediate and SAMW are in red, deep in green and near-bottom in blue. From Schmitz (1996b).

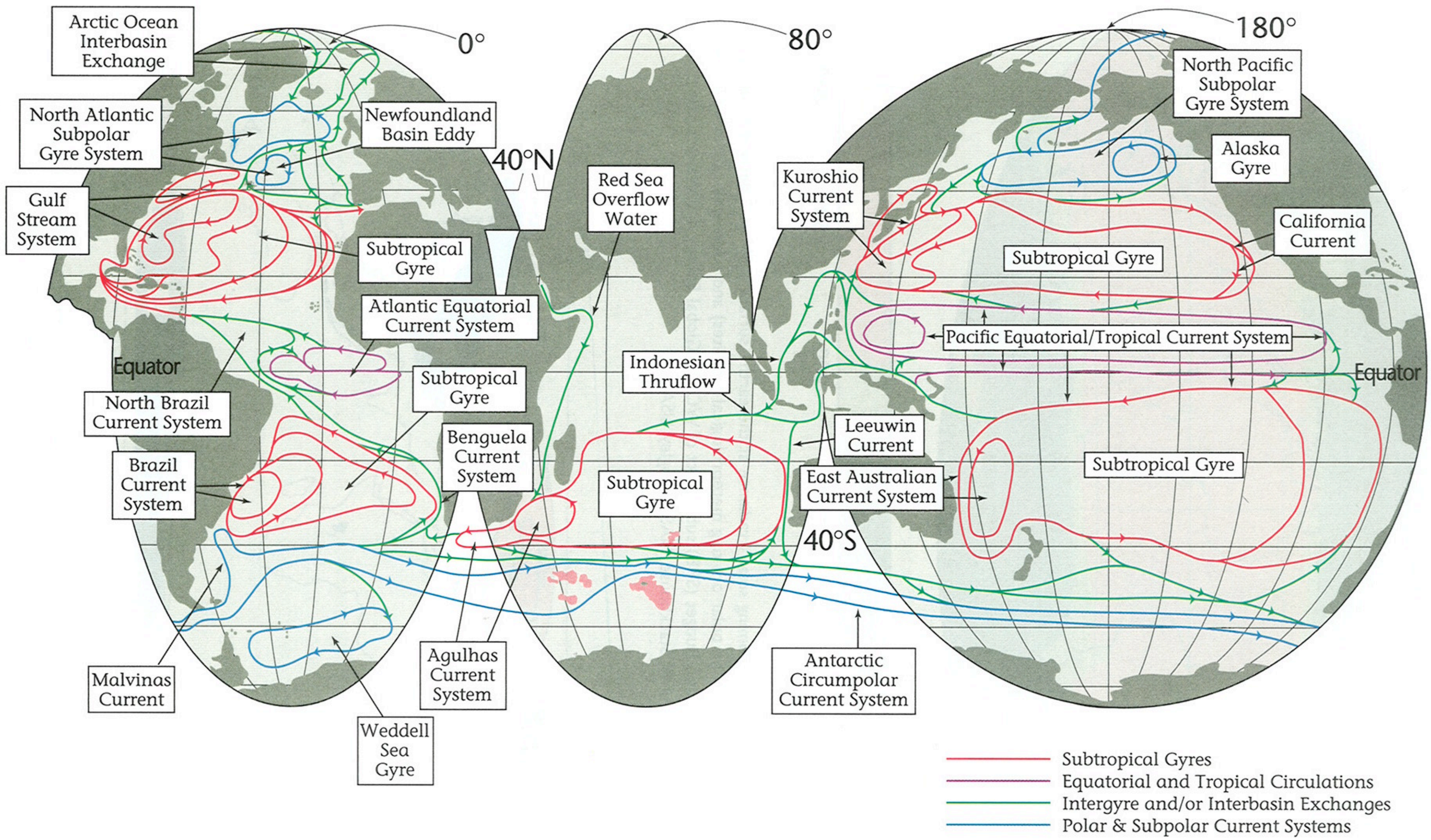
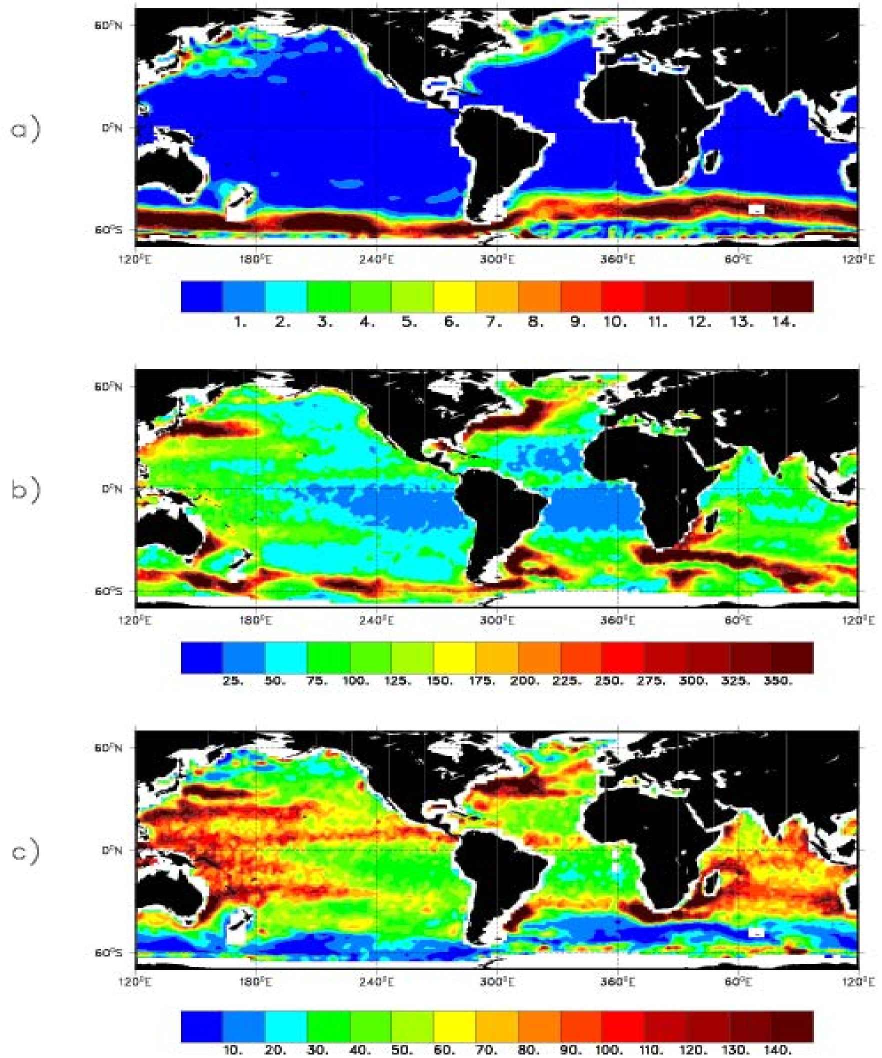


Plate 1.2.3 (see p. 18) A global schematic identifying the location and nomenclature for many of the major upper ocean current systems and the connections between these flow patterns (from Schmitz, 1996a).

But, Variable, Too!

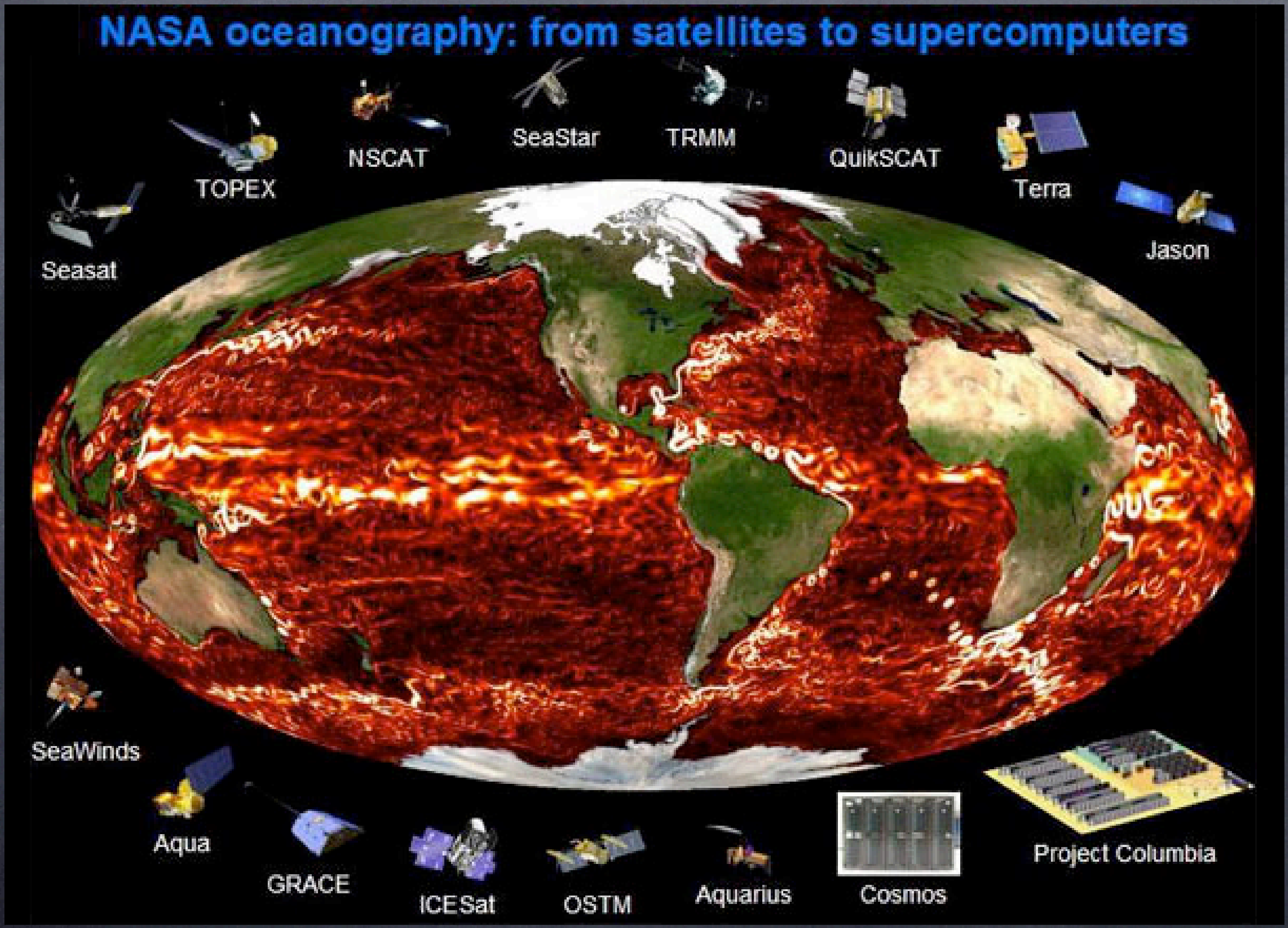


Mean KE

Eddy KE

Ratio:
Eddy KE/Mean KE

What to do with all of this stuff? Data Assimilation (ECCO)



The Quirks of Ocean Observation

- It is relatively easy to measure S, T, P, O2, etc.
- It was hard (now easy) to infer density from S, T, P
- It is very difficult to measure U, V
- It is slightly easier to measure dU/dz
- It is virtually impossible to measure W
- Subsurface observations are incredibly sparse and infrequent

Hydrostatic, Incompressible Eqtns.

So, using incompressibility and hydrostatic pressure, our equations are a little different:

$$\frac{D\mathbf{v}_h}{Dt} = -\frac{\nabla_h p}{\rho} + \nu \nabla^2 \mathbf{v}_h$$
$$\frac{dp}{dz} = -\rho g$$

Along with conservation of volume,

$$\nabla_h \cdot \mathbf{v}_h + \frac{\partial w}{\partial z} = 0$$

But, still 5 unknowns and 4 equations...

The Missing Ingredient
The Equation of State

$$\rho = f(p, \ldots)$$

For the ocean, pressure, salinity, and temp are the thermodynamic variables

$$\rho = f(p, S, T)$$

Often, A linearized EOS is OK...

$$\rho \approx \rho_0(1 - \beta_T(T - T_0) + \beta_S(S - S_0) + \beta_p(p - p_0))$$

$$\beta_T \approx 2(\pm 1.5) \cdot 10^{-4}\mathrm{K}^{-1}$$
$$\beta_S \approx 7.6(\pm 0.2) \cdot 10^{-4}\mathrm{psu}^{-1}$$
$$\beta_T \approx 4.1(\pm 0.5) \cdot 10^{-10}\mathrm{Pa}^{-1}$$

$$1\mathrm{bar} = 10^6\mathrm{dynes/cm}^2 = 10^5\mathrm{Pa}$$
$$1\mathrm{dbar} = 10^{-1}\mathrm{bar} = 10^5\mathrm{dyne/cm}^2 = 10^4\mathrm{Pa}$$

$$\frac{D\mathbf{v}_h}{Dt} = -\frac{\nabla_h p}{\rho} + \nu \nabla^2 \mathbf{v}_h$$

$$\frac{dp}{dz} = -\rho g$$

Along with conservation of volume,

$$\nabla_h \cdot \mathbf{v}_h + \frac{\partial w}{\partial z} = 0$$

But, still 5 unknowns and 4 equations...

Add the Equation of State:

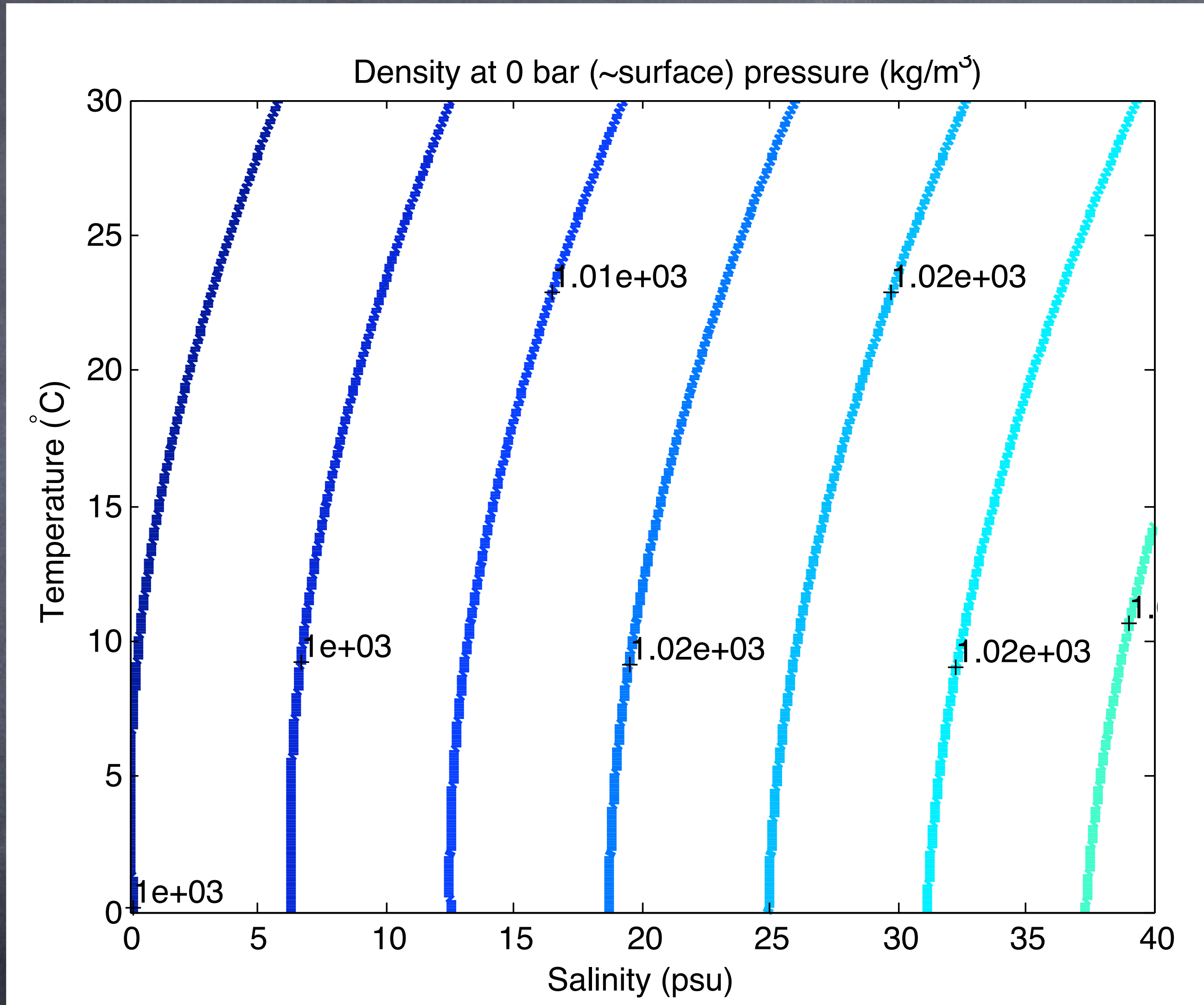
$$\rho = f(p, S, T)$$

Add the Conservation of Heat:
Add the Conservation of Salt/FreshH20

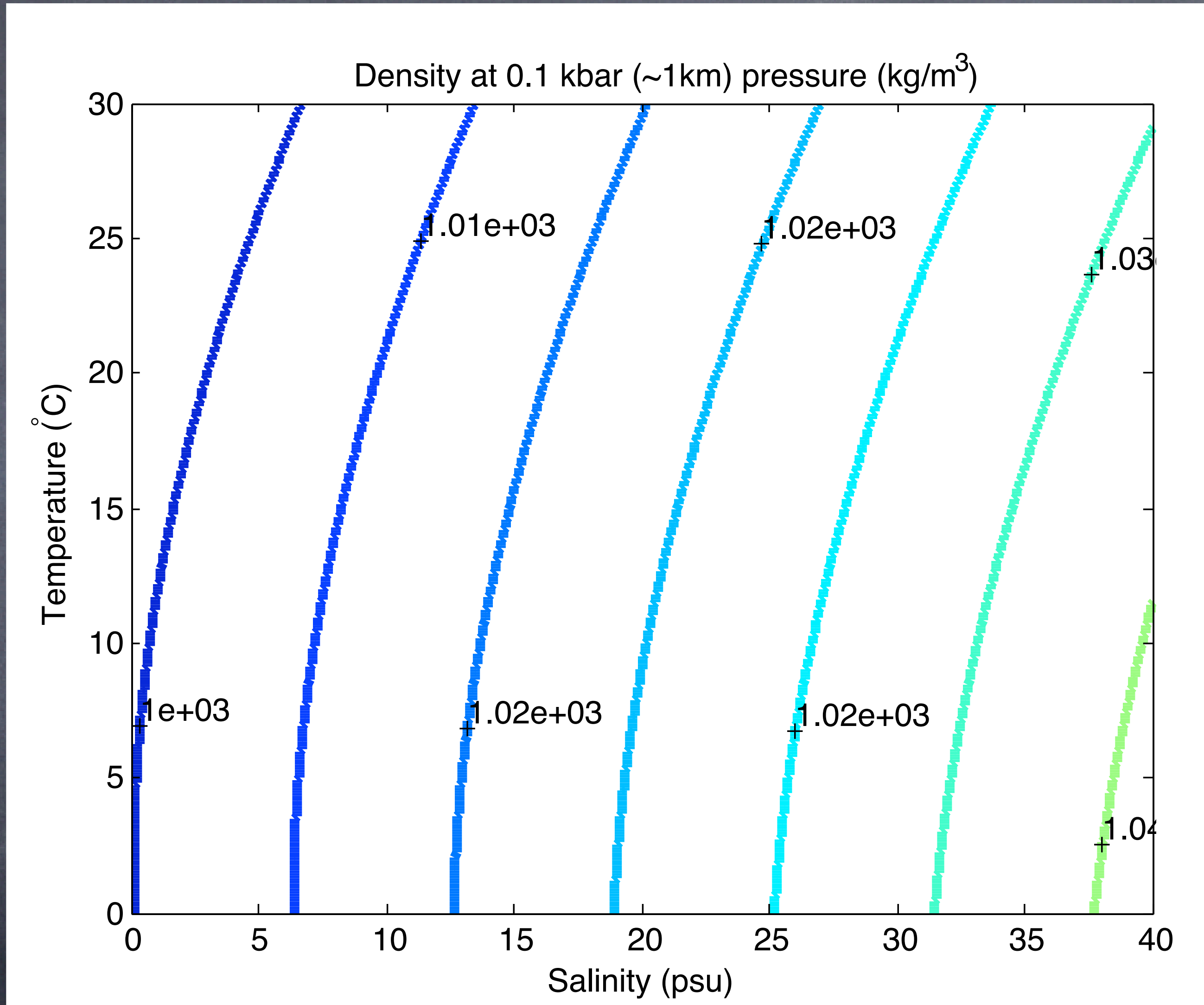
$$\frac{DT}{Dt} = \mathcal{T} \qquad \frac{DS}{Dt} = \mathcal{S}$$

These budgets will be next week...

Density at 0 m depth



Density at 1 km depth



Density at 10 km depth