

Advanced Methods in Oceanography: Observations

Florian Sévellec (Lecture 1):
Background and Hydrography

Lecture outline

This double-lecture will set out

Part 1:

- (1) a brief motivation for monitoring/observing the ocean;
- (2) how the ocean has historically been observed using hydrographic sections;

Part 2:

- (3) Different instruments and their potential for monitoring

Observing vs. monitoring

There are several reasons why we might want to **observe a system**, for example:

- ???

Observing vs. monitoring

There are several reasons why we might want to **observe a system**, for example:

- to test a hypothesis
- to gather the exploratory data necessary to form a useful hypothesis
- to map the system

Observing vs. monitoring

There are several reasons why we might want to **observe a system**, for example:

- to test a hypothesis
- to gather the exploratory data necessary to form a useful hypothesis
- to map the system

We **monitor a system** if we think...?

Observing vs. monitoring

There are several reasons why we might want to **observe a system**, for example:

- to test a hypothesis
- to gather the exploratory data necessary to form a useful hypothesis
- to map the system

We **monitor a system** if we think it might change, that such changes will have important impacts, and that we need to recognize these changes before their impacts are realized.

The variable and changing ocean?

Oceano:

"-logy" ???

"-graphy" ???

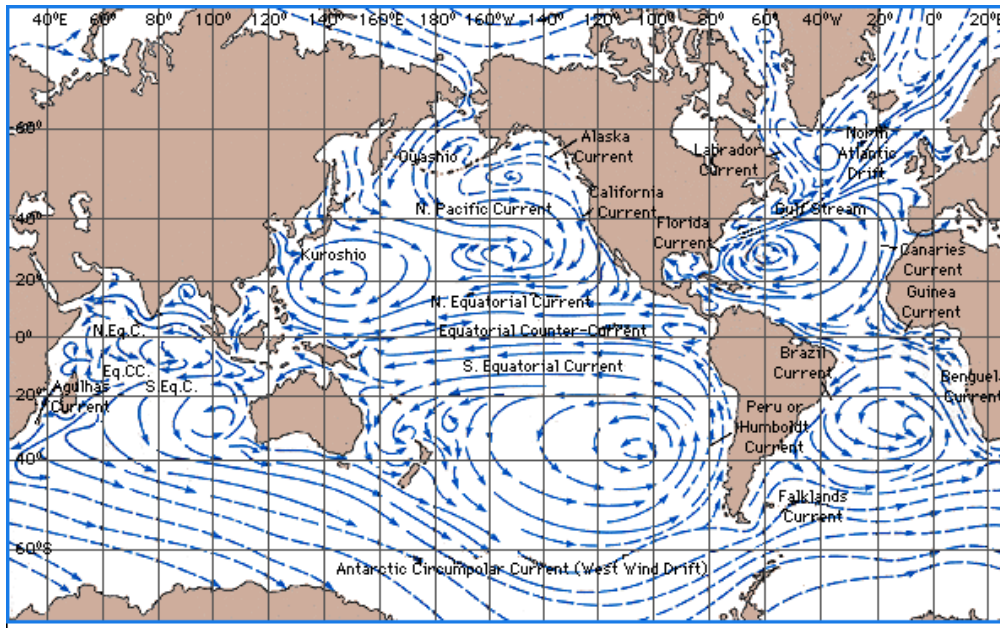
The variable and changing ocean?

Oceano:

"-logy" - study of / research into

"-graphy" - drawing of / writing on

Do ocean-scientists study or draw maps?

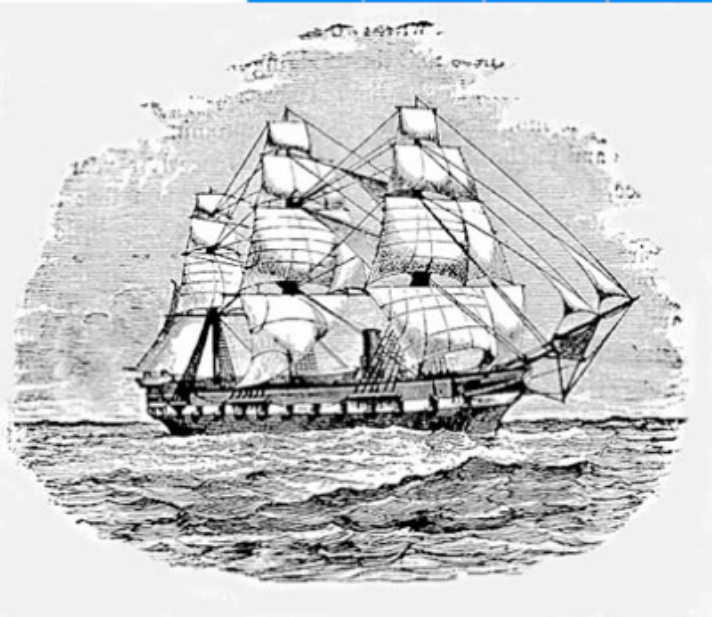


Source: The Open University (1995), *Ocean Circulation*, Pergamon Press.

Franklin-Folger map of the Gulf Stream made in 1769



The variable and changing ocean?



HMS
Challenger,
1872-1876



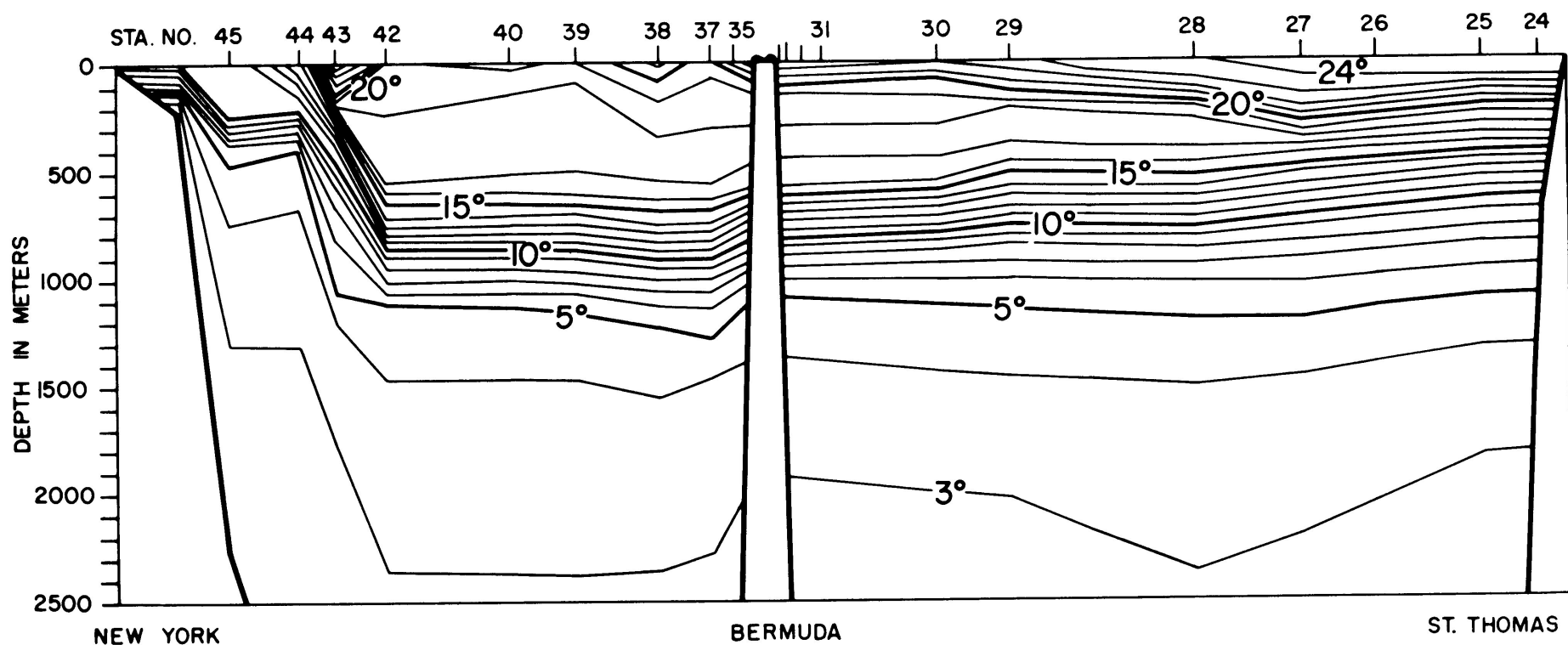
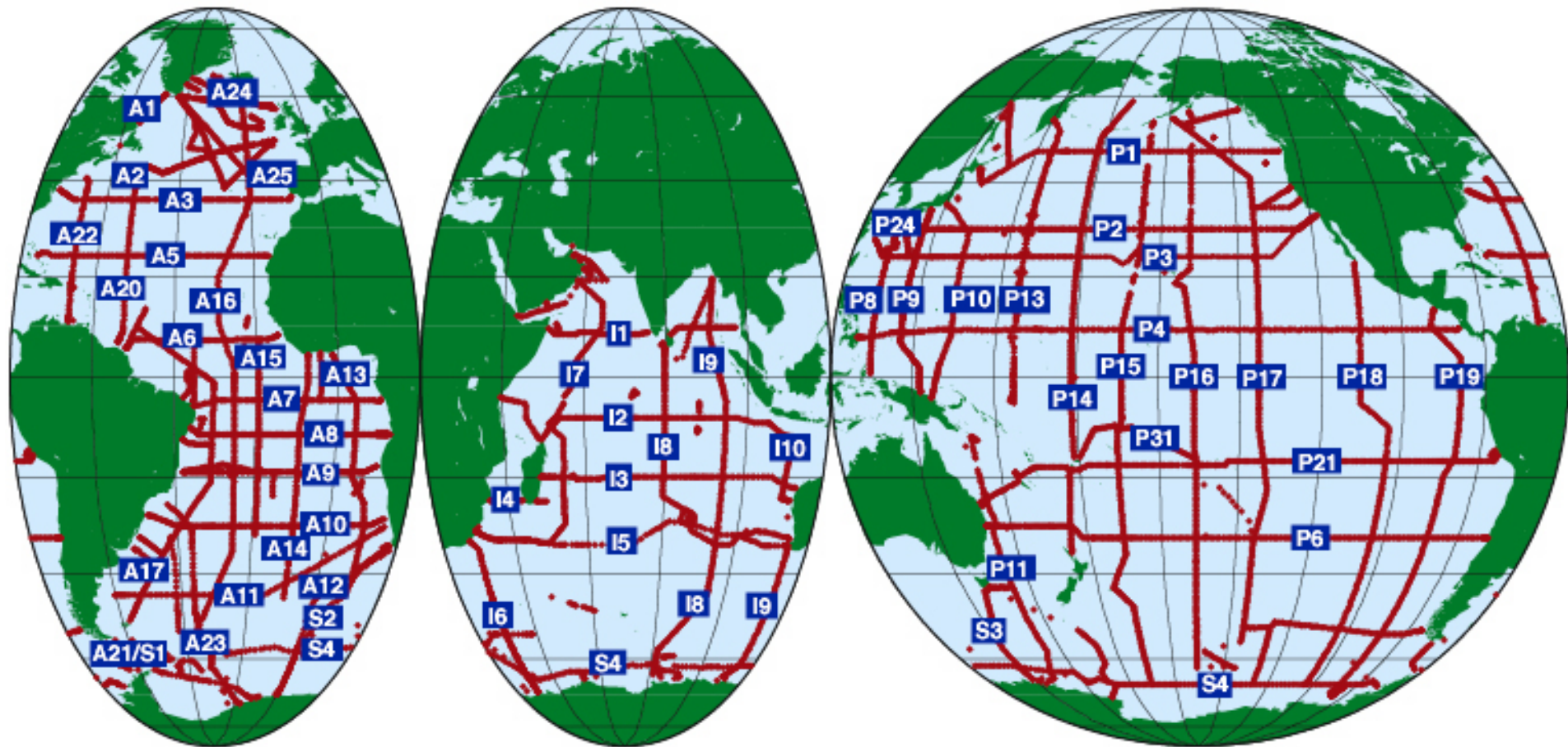


Figure 32. Temperature, °C, on *Challenger* section from the Virgin Islands to Bermuda to New York, March–May 1873.

HMS Challenger observations show subsurface Gulf Stream structure for first time and also identify “18° Water”

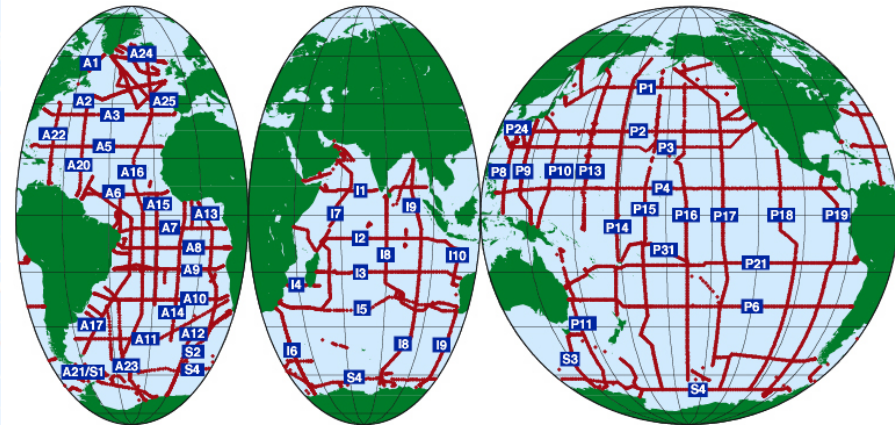
The variable and changing ocean?

The World Ocean Circulation Experiment



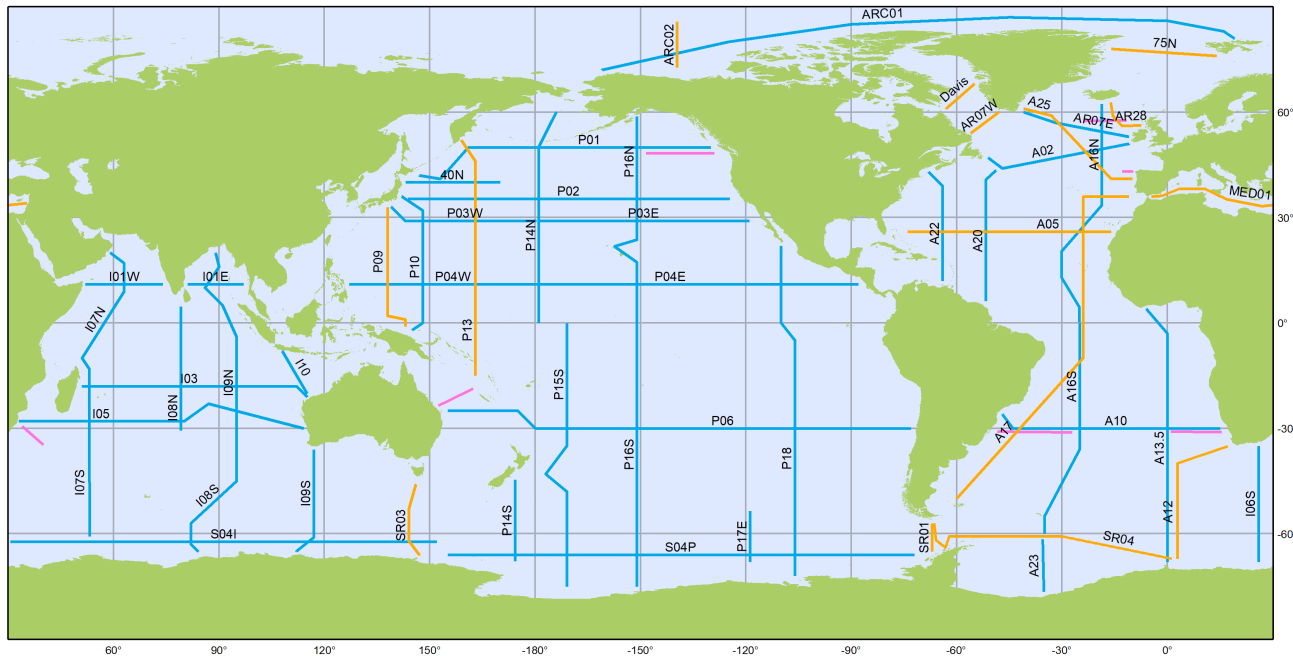
The variable and changing ocean?

From the dawn of modern oceanography until the "WOCE era" (the World Ocean Circulation Experiment took place mainly in the 1990s), there was a tendency – through necessity – to view the ocean as time invariant.



Repeating WOCE?

GO-SHIP = Global Ocean Ship-based Hydrographic Investigations Program
There is an ongoing global ocean monitoring programme to effectively reoccupy the WOCE Hydrographic Sections on a decadal time scale to document how water mass properties are changing with time.



GO-SHIP

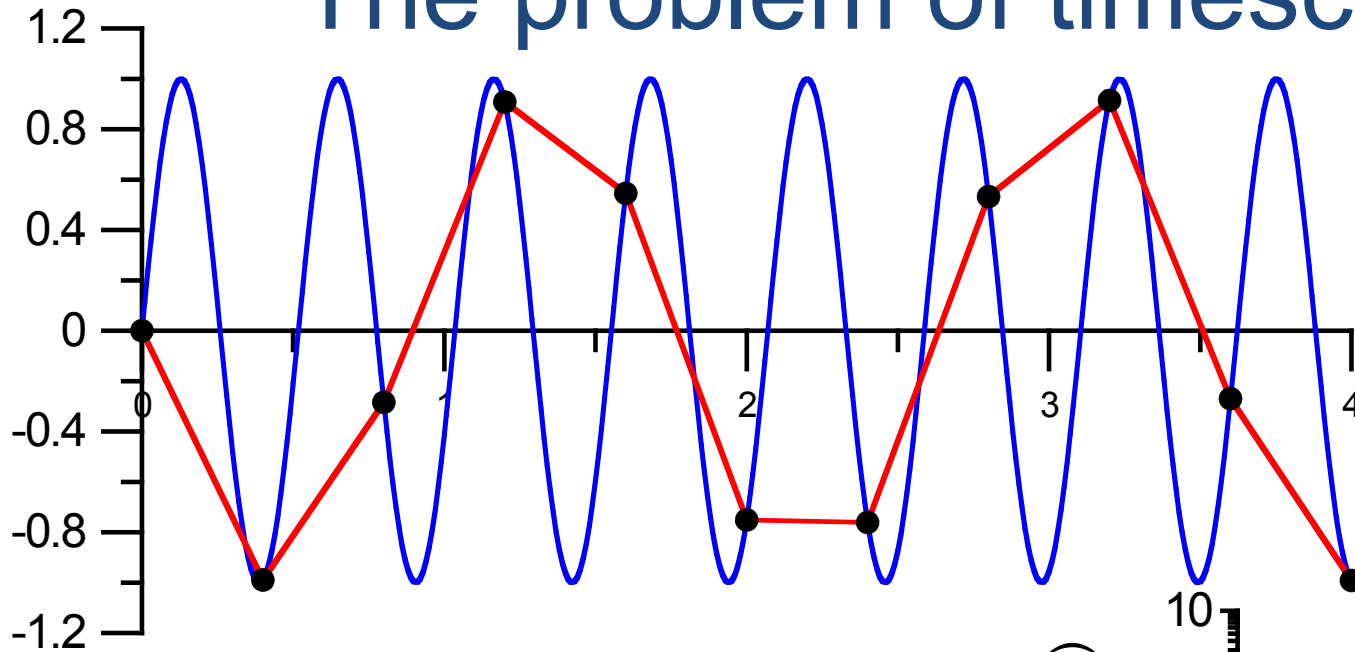
Reference Lines of 2012-2023 Survey

August 2019

- Decadal full GO-SHIP (all level 1 data requirements met): 40
- High frequency GO-SHIP (reduced data requirements, but with decadal full GO-SHIP occupation): 15
- Associated GO-SHIP (GO-SHIP similar data requirements off regular lines): 7



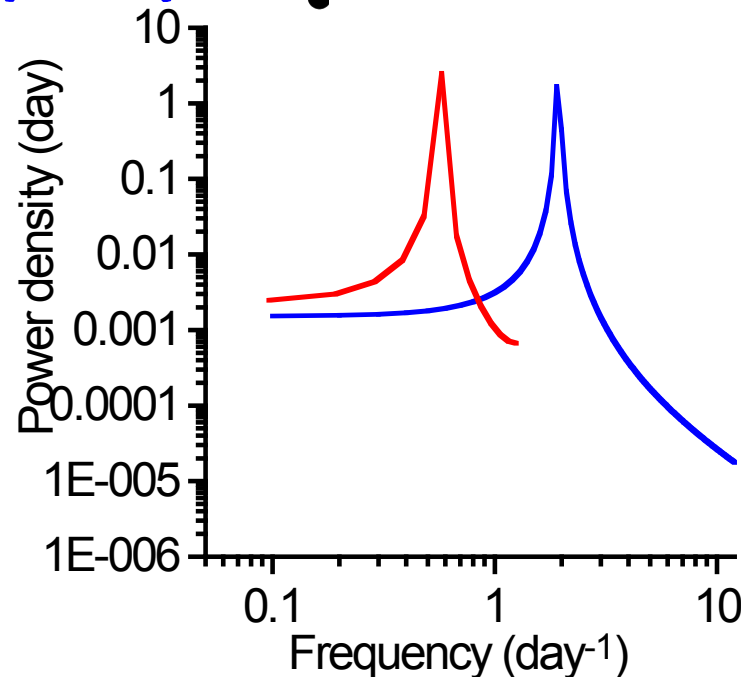
The problem of timescales

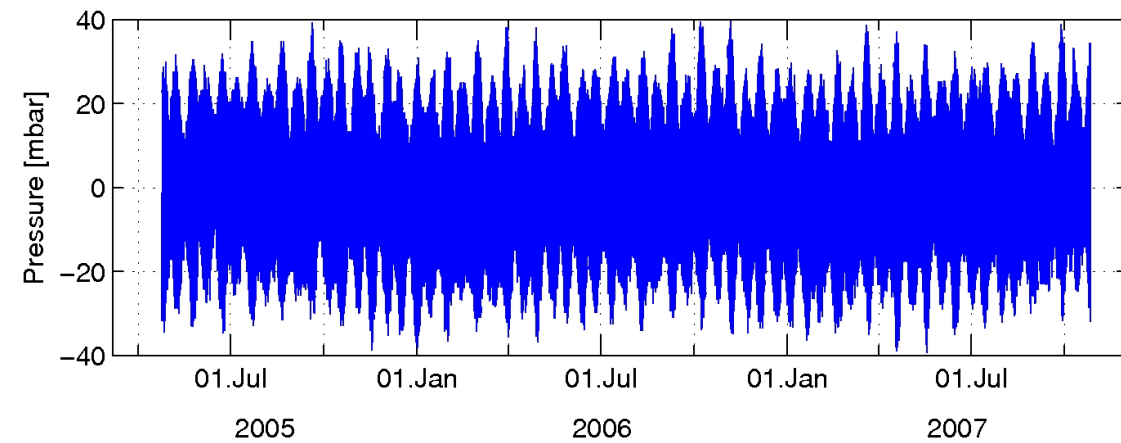


Aliasing a signal:

Blue line = well-resolved

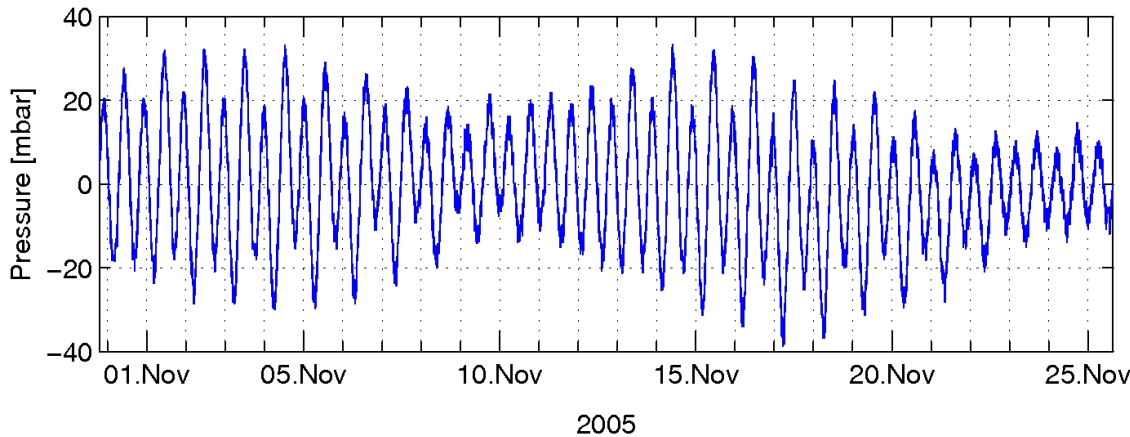
Red line = poorly resolved →
apparent existence of low frequency
signal



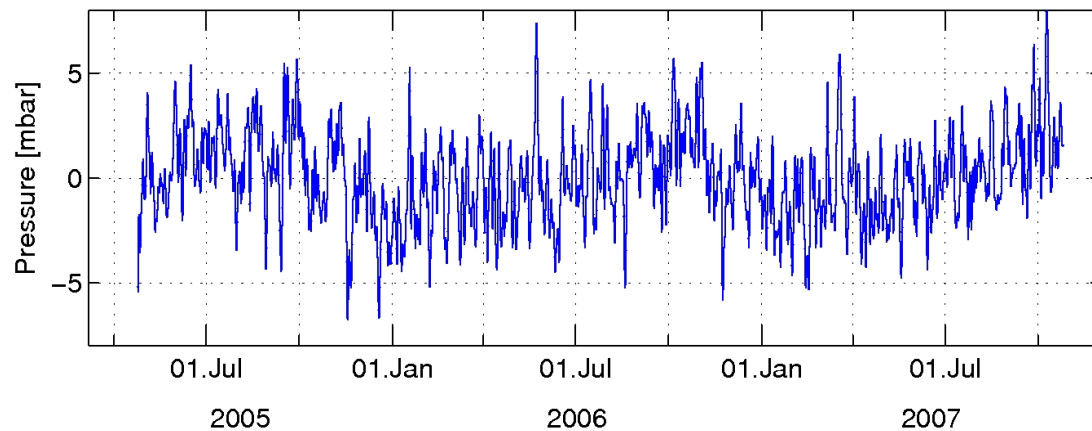


The distinction between variability and a real change depends on the timescale of interest.

30 month record



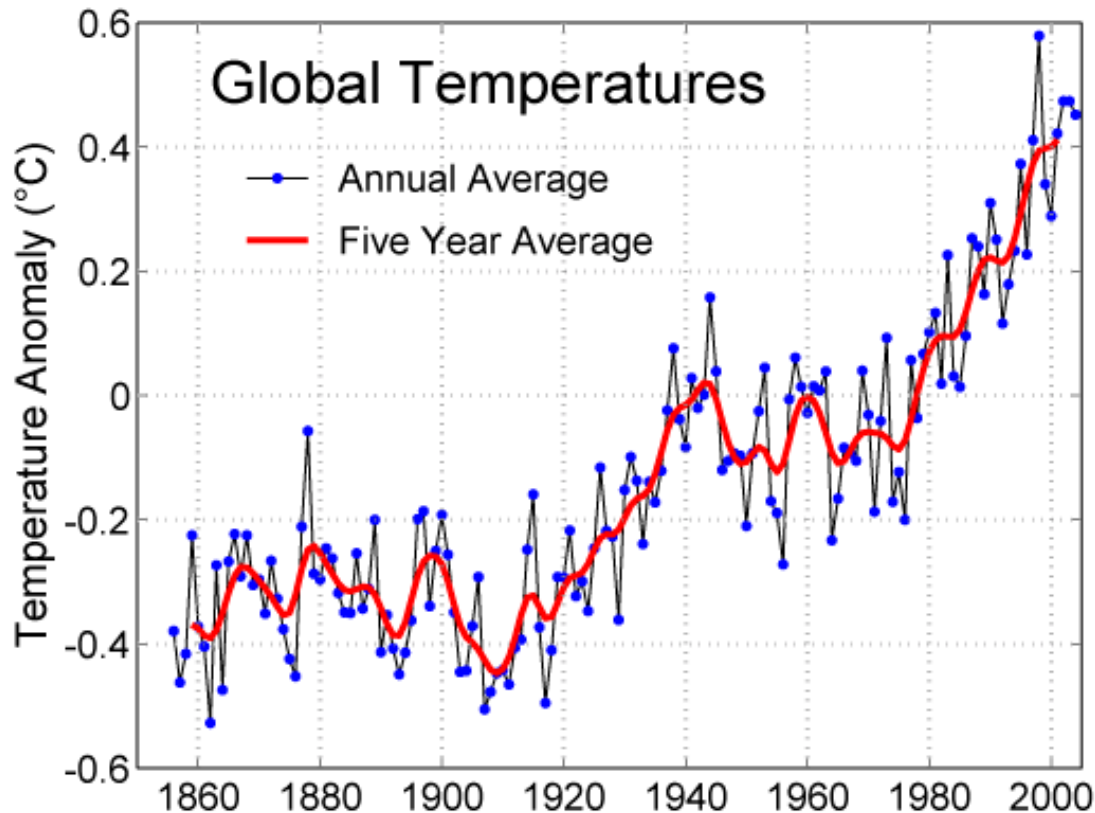
1 month shows tides



30 month
(2-day low-pass filtered)
to show low frequency
variability including
seasonal cycle

Bottom pressure time series

Variability versus change



Global mean surface atmospheric temperatures show interannual and decadal variability, which is associated with e.g. ENSO, volcanic dust input, overlying a long-term trend, which is associated with anthropogenic greenhouse gas emissions.

What aspects of the ocean might
change...

... and why should we care?

We do **or** would like to monitor...

Some examples:

- **Sea level** (coastal populations & ecosystems)
- **Ocean heat content** (the Earth is out of energy balance; most of the excess heat is stored in the ocean)
- **Sea surface temperature** (e.g. tropical cyclones)
- **Meridional overturning circulation** (Atlantic and European climate; carbon cycle)
- **Arctic sea ice** (ecosystems; albedo feedback; indigenous populations; MOC; trade routes)
- **Ocean pH** (ecosystems; fisheries; atmospheric CO₂)
- **Marine productivity** (ecosystems; fisheries; atm. CO₂)
- **Anthropogenic CO₂ uptake** (atm. CO₂)

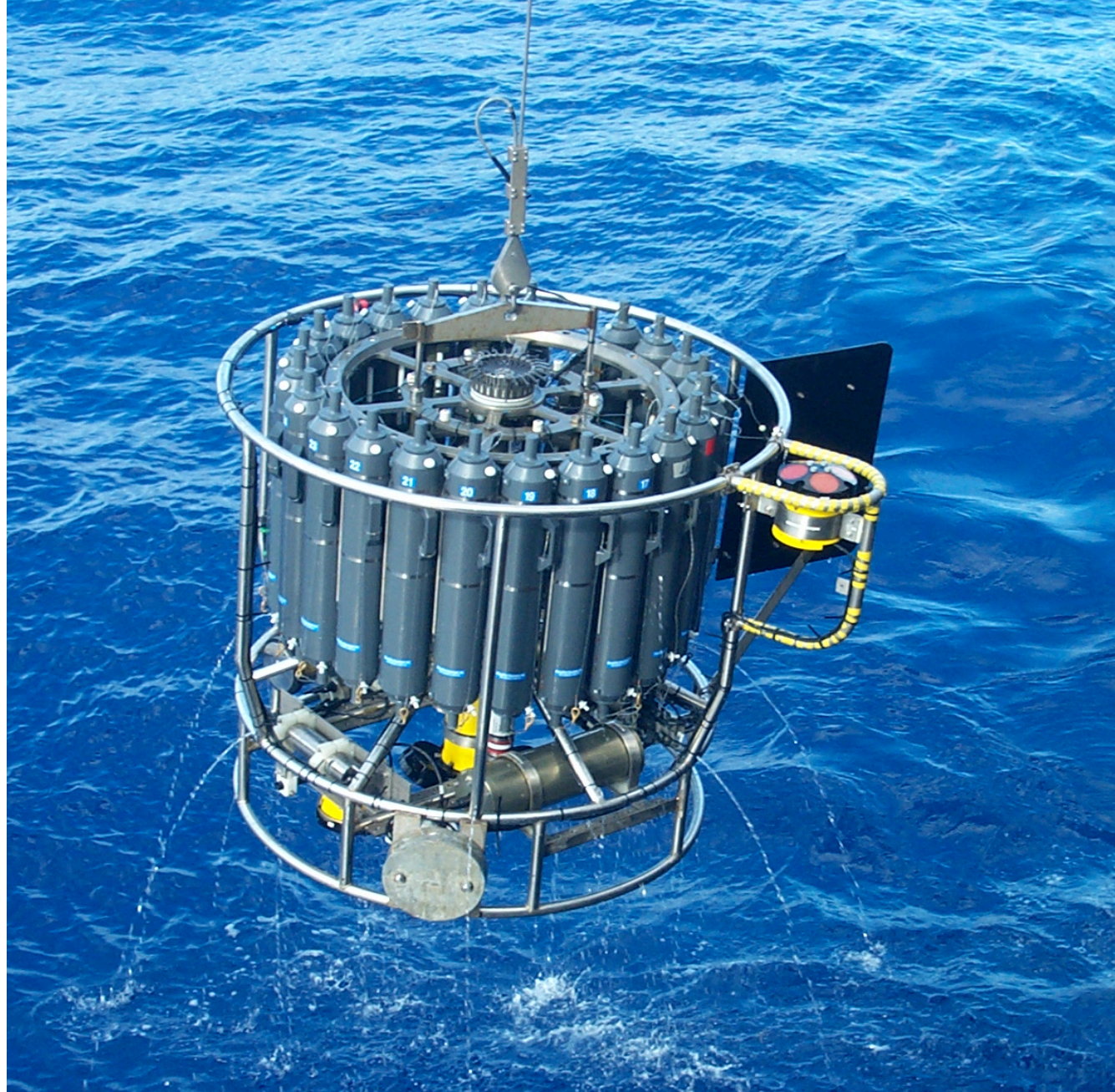
Goals, methods, and these lectures

- The best research programmes start with a scientific problem and then choose the methods that are best suited to solving that problem.
- However, you need to know what methods for observing the ocean are available, before you attempt to design a monitoring system.
- In keeping with this, this lecture is devoted principally to observational tools, and the remaining lectures principally to specific problems.

In situ observations: hydrography

CTD-ROSETTE

- Conductivity
- Temperature
- Depth
- (+ ADCP)



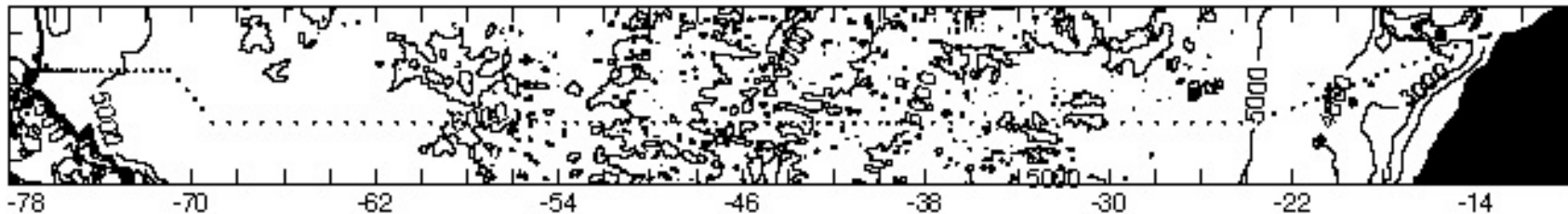
The Niskin bottles:

- calibrate the CTD results (especially for salinity), and
- give other information (Oxygen, CFC, *etc.*)

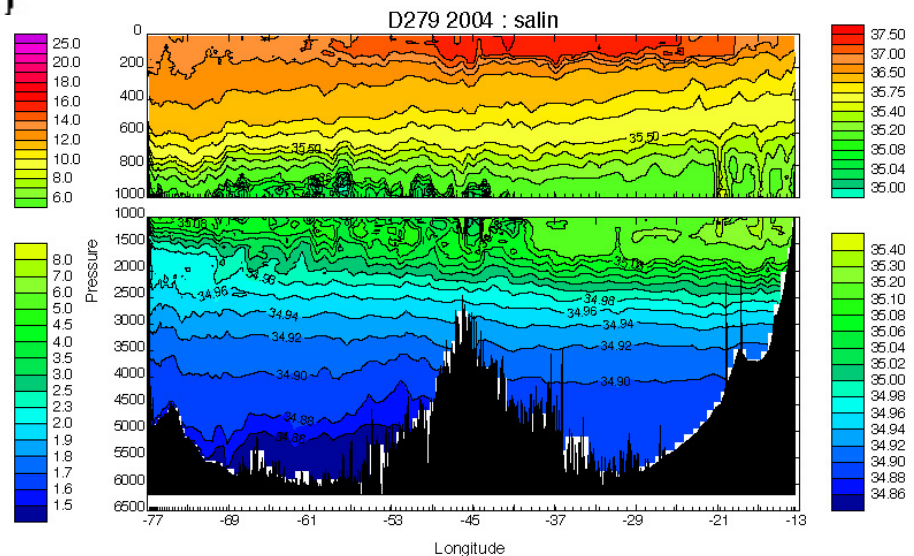
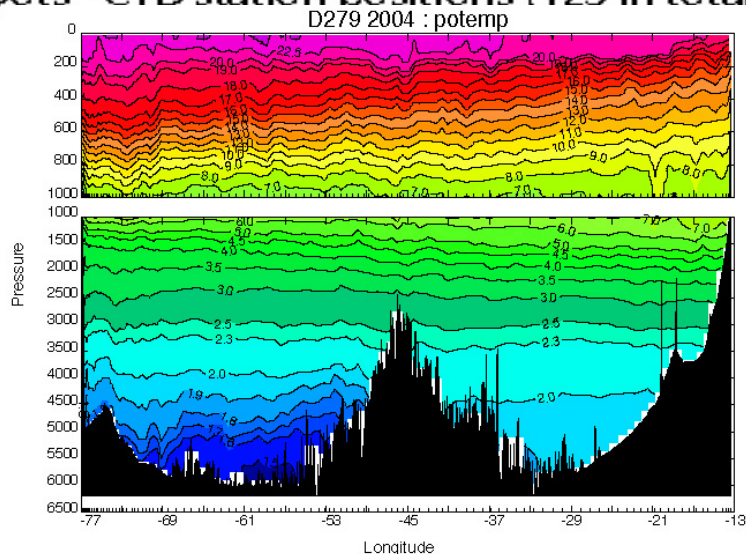
The cost of hydrographic sections

- Hydrographic Stations along 26° N – O(100) for 6000 km section
- In deep water, 6-10 stations per day.
- Ship time, $O(10^4 \text{ €})$ per day.

Transatlantic Section



Dots - CTD station positions (125 in total)



How much hydrographic data do we have?

Do we have the ability to cover space and time with CTD?...

How much hydrographic data do we have?

Do we have the ability to cover space and time with CTD?...

Obviously, but unfortunately, no.

Expendable Bathymermographs (XBTs)

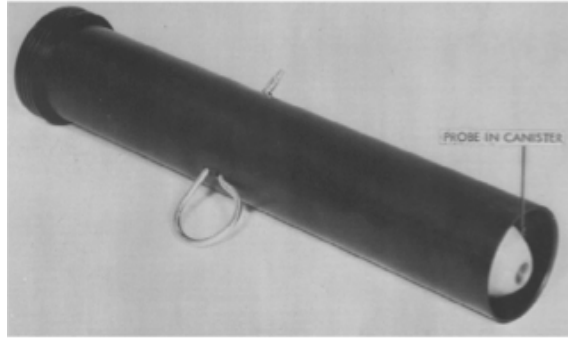
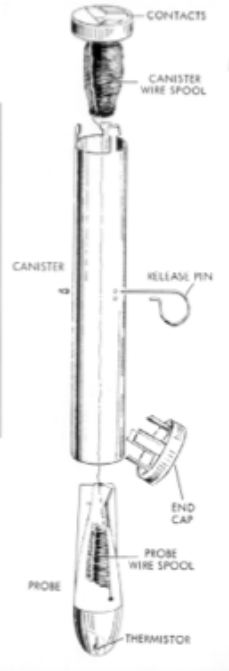


Fig. 1: XBT diagrams: Bathythermograph (probe) and exploded view.



- XBTs are a fast method of obtaining a temperature (and sometimes salinity) profile, but still depend on a ship being in the location of interest.

image: NOAA

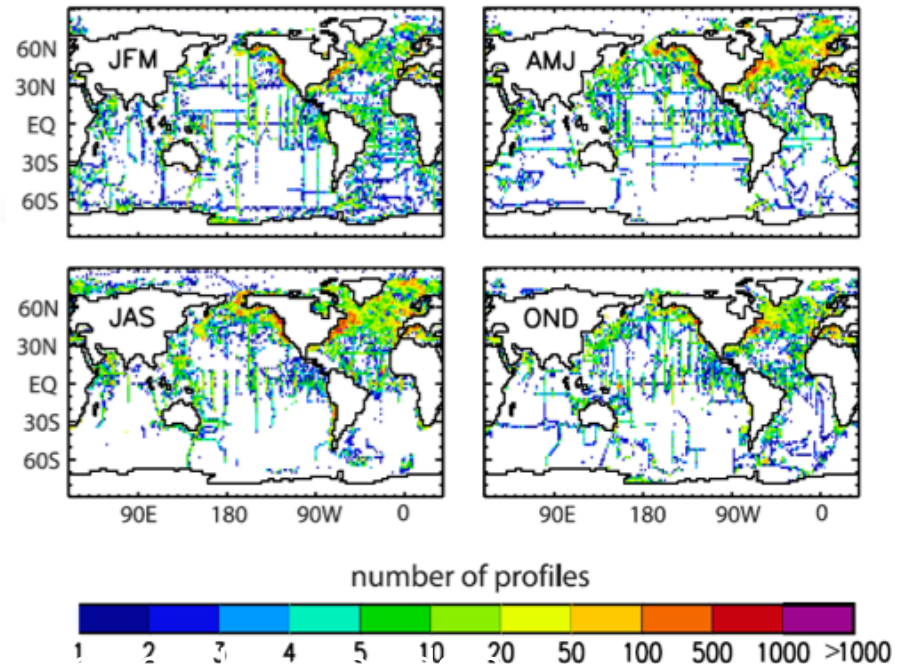


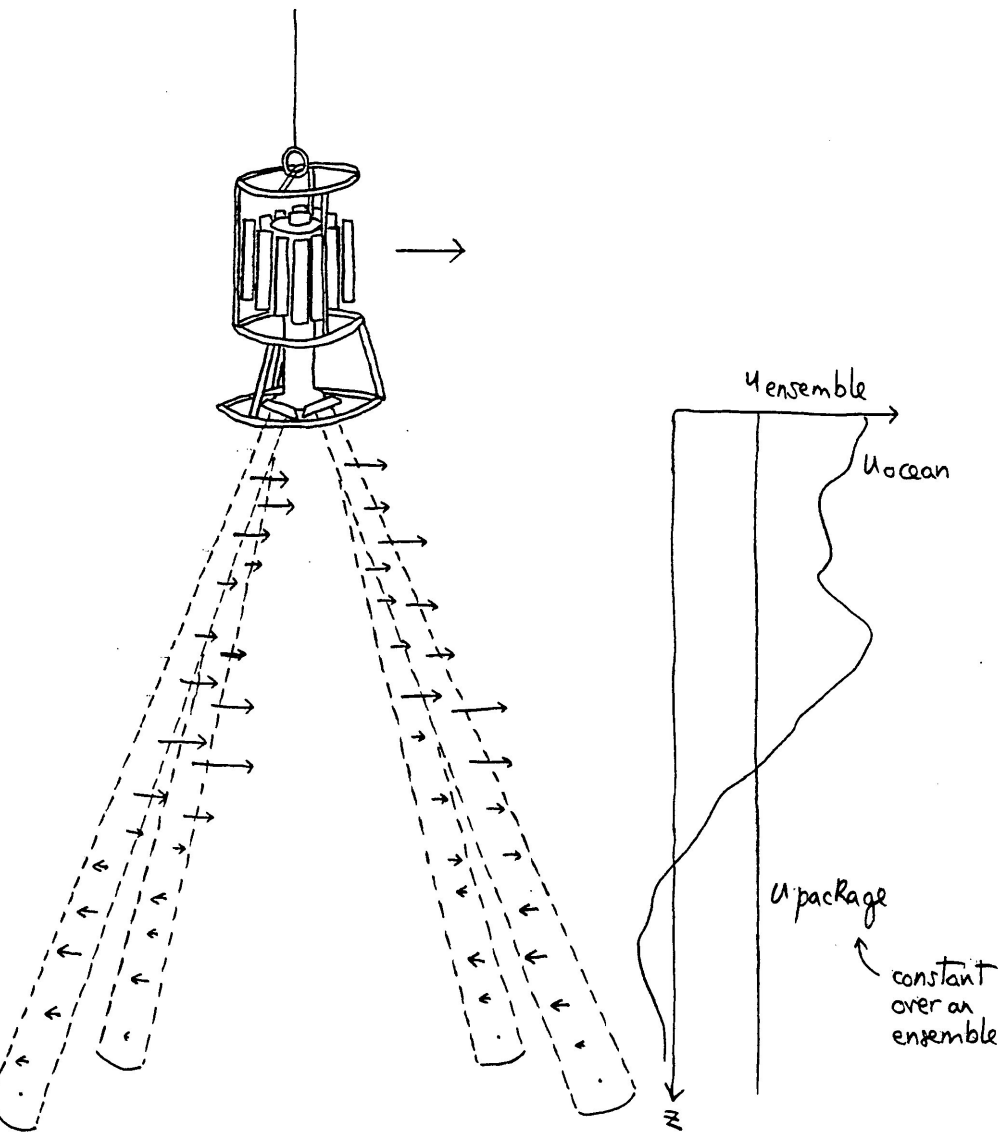
Figure 1. Number of (a) temperature profiles and (b) temperature-salinity profiles, in each 2° by 2° mesh box, from the NODC and WOCE databases. JFM, AMJ, JAS, and OND are the four seasons, respectively, January-February-March, April-May-June, July-August-September, and October-November-December. This also gives a confidence index for the field of MLD computed from those data.

Temperature & salinity profiles:
de Boyer Montegut et al. (2004)

Expendable Bathymermographs (XBTs)

- A problem with XBTs is data quality. This is generally sufficient for determining mixed layer depth, but deep observations require greater precision both for depth and temperature/salinity. **This greatly limits their value for monitoring.**
- The depth of XBT profiles is limited by the length of wire trailed from the ship, usually much less than the bathymetric depth.

In situ observations:
(lowered) acoustic Doppler
current profilers

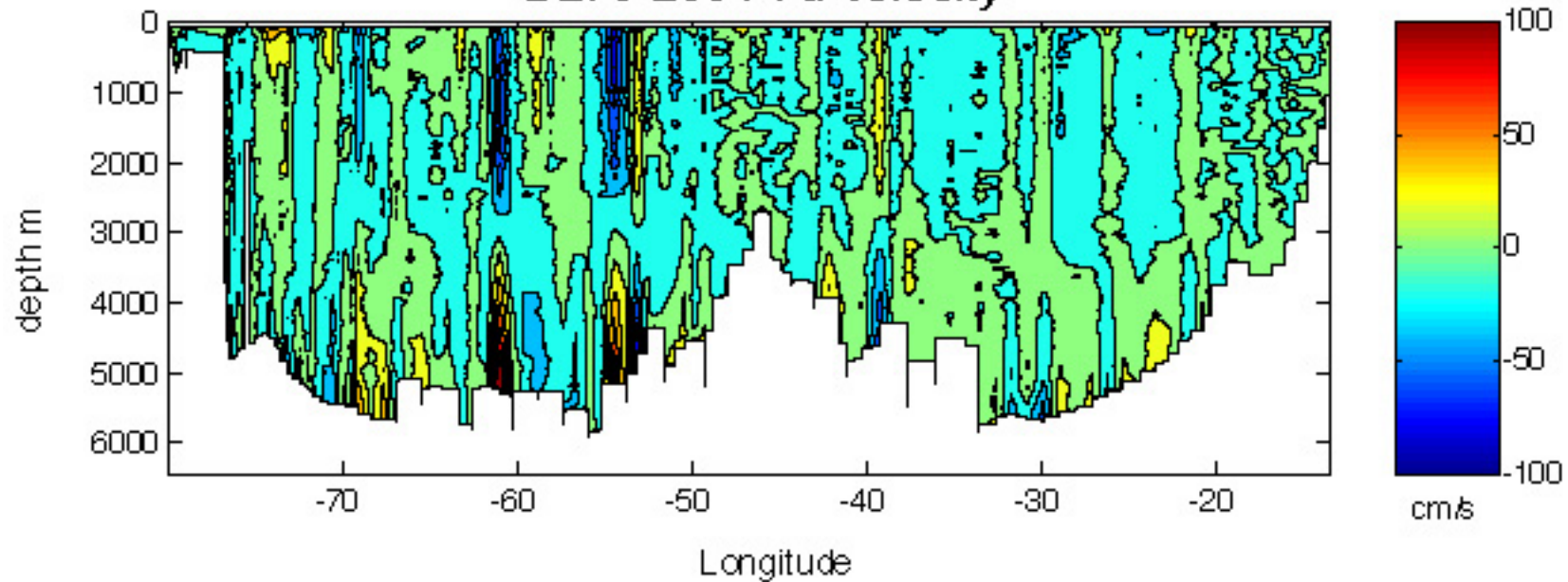


ADCPs send acoustic signals and detect changes in frequency in the signal reflected from particles (due to the Doppler effect).

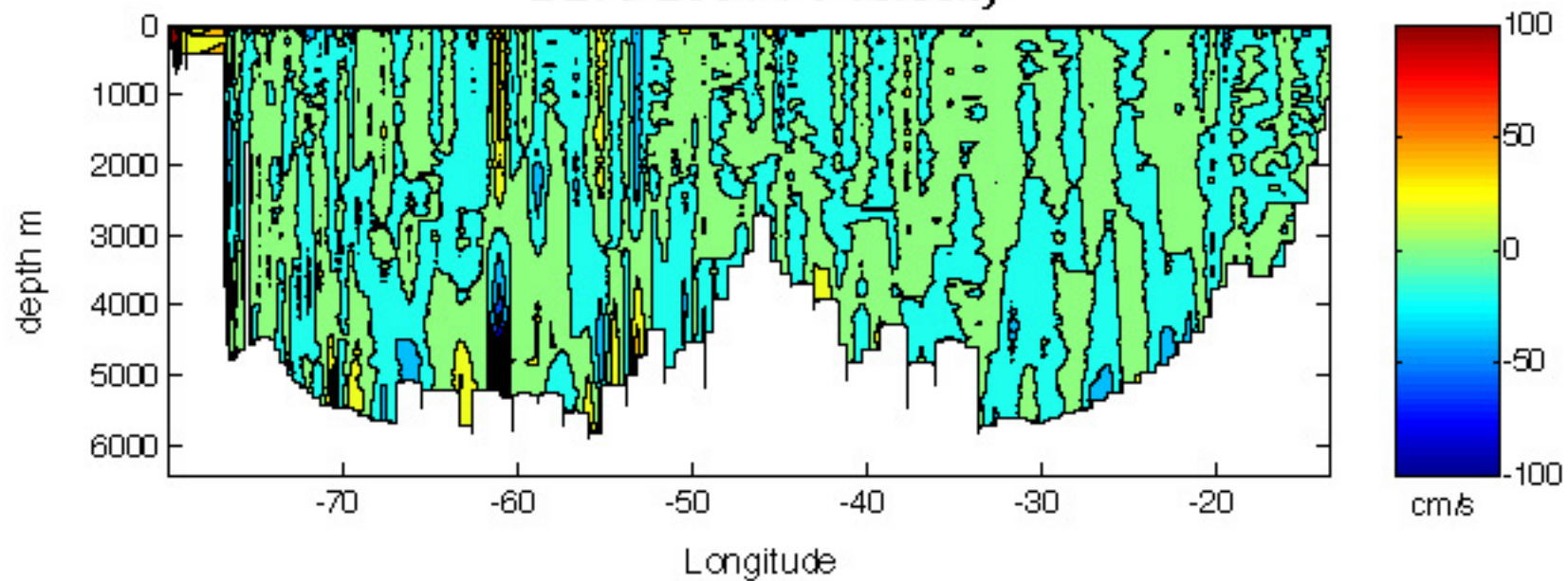
This gives the velocity of the particle **relative** to the ADCP. Obtaining absolute velocities from lowered ADCPs is more complex than for shipboard ADCPs (where GPS gives ship velocity) because of package motion.

Figure 2.3 A cartoon showing what the LADCP is measuring on each ping. The instrument profiles about 300m of the water column on each ping; this is an ensemble. The velocities are collected in bins of length 16m and each velocity contains a component from the ocean current plus a component from the motion of the instrument itself. The component of velocity due to the motion of the instrument must be the same in each bin of an ensemble, therefore by differentiating the measured velocities over an ensemble the motion of the instrument is removed. The ensemble shears are then strung together, demeaned and integrated up over the complete depth of the cast to give relative velocities.

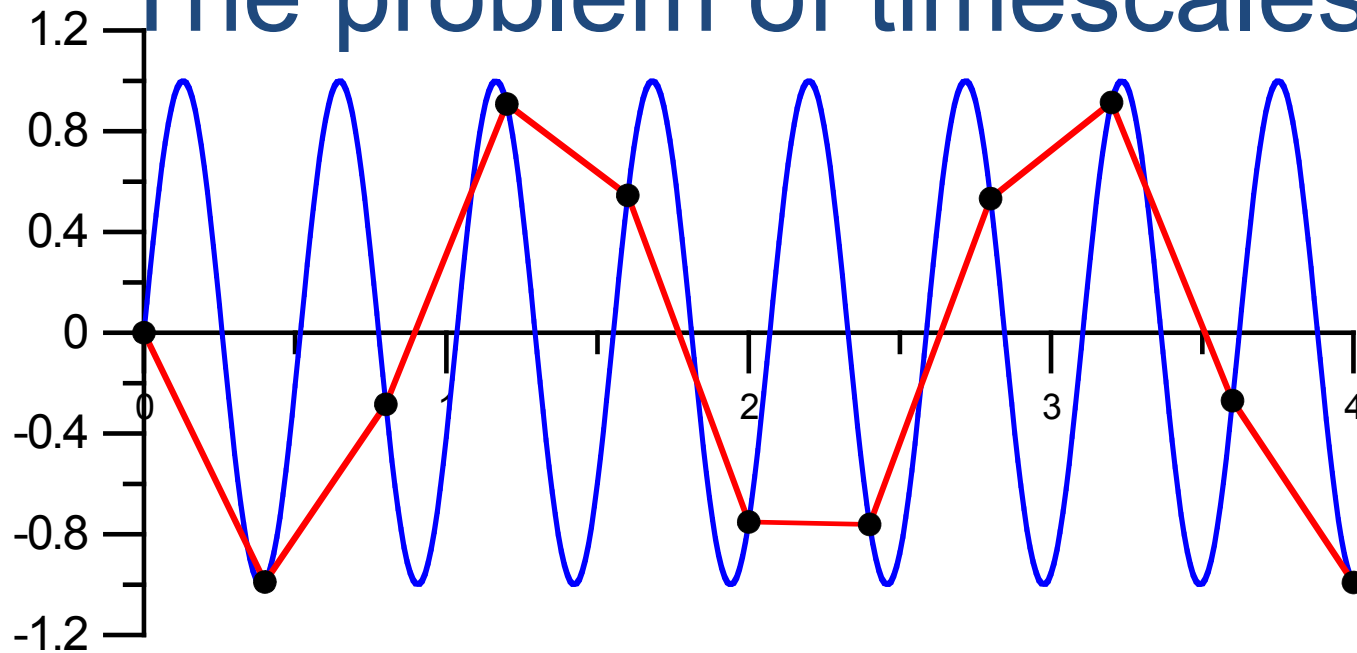
D279 2004 : u velocity



D279 2004 : v velocity



The problem of timescales (again)



Velocity shows much greater variability on very short ($<$ inertial period) timescales than hydrographic data, due to inertial oscillations, tides, turbulence, and barotropic processes that do not show up in temperature or salinity.

For this reason, baroclinic velocities are usually calculated directly from hydrography, using the geostrophic approximation.

Can we extend time series
backward in time?

History of monitoring

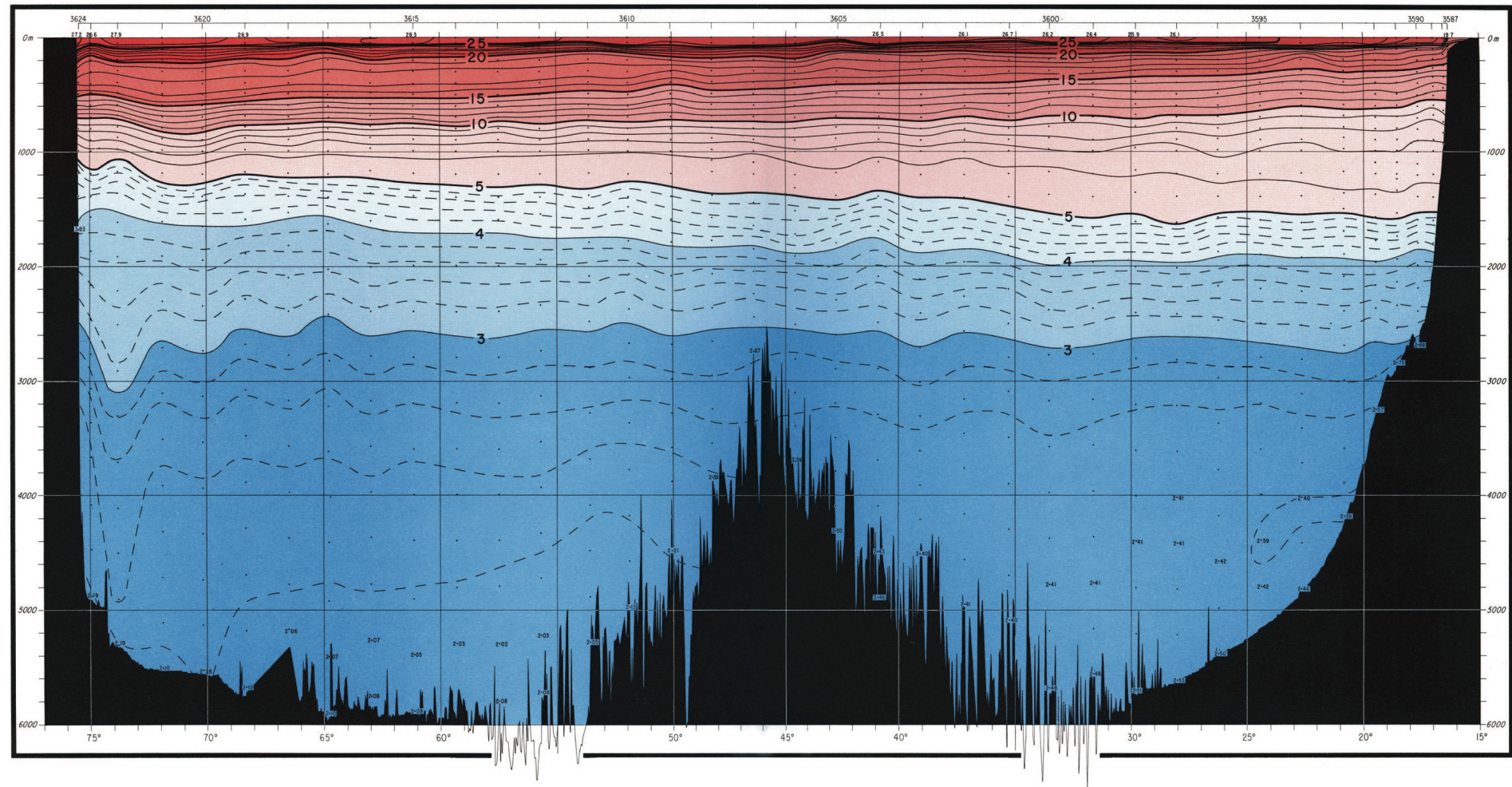
Until the last ~2 decades or so, little subsurface oceanography has been conducted with the goal of monitoring in mind.

Some exceptions:

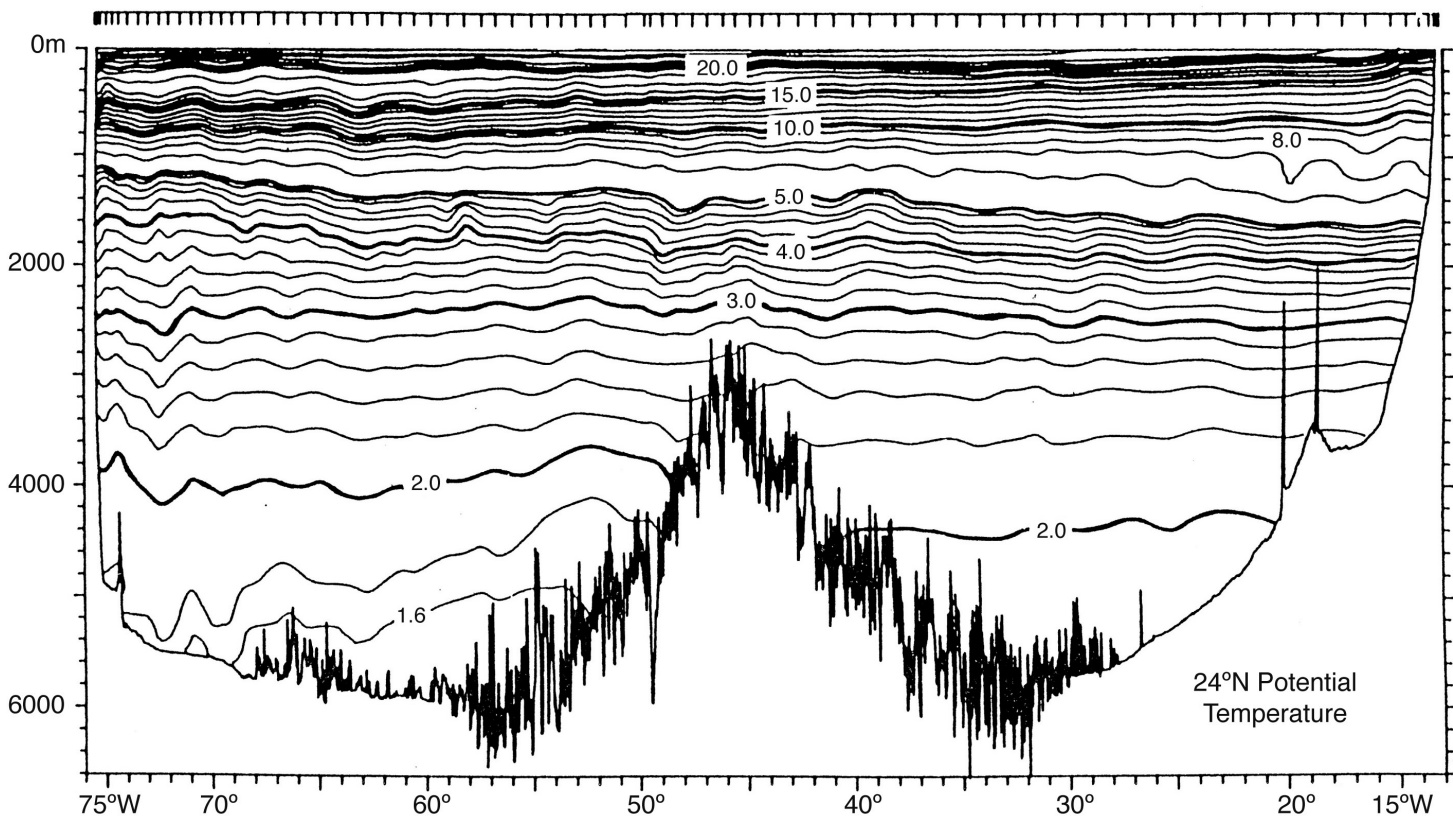
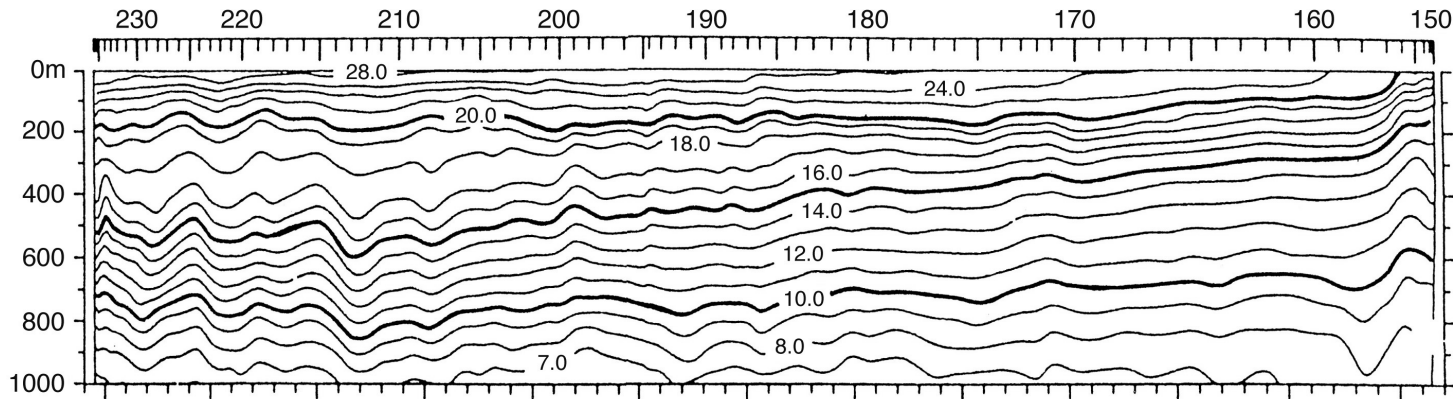
- Florida Strait transport (with the aid of a communications cable)
- Atlantic Meridional Transect (AMT), which is not made up of full-depth stations.
- Drake Passage transport
- Norwegian Sea: Ocean weather ship station M (was to be 13th of an array; hence "M")

These are mainly opportunistic projects: e.g. a ship in transit from north to south (AMT) or to an Antarctic base (Drake Passage).

Temperature ("25 N") in 1957

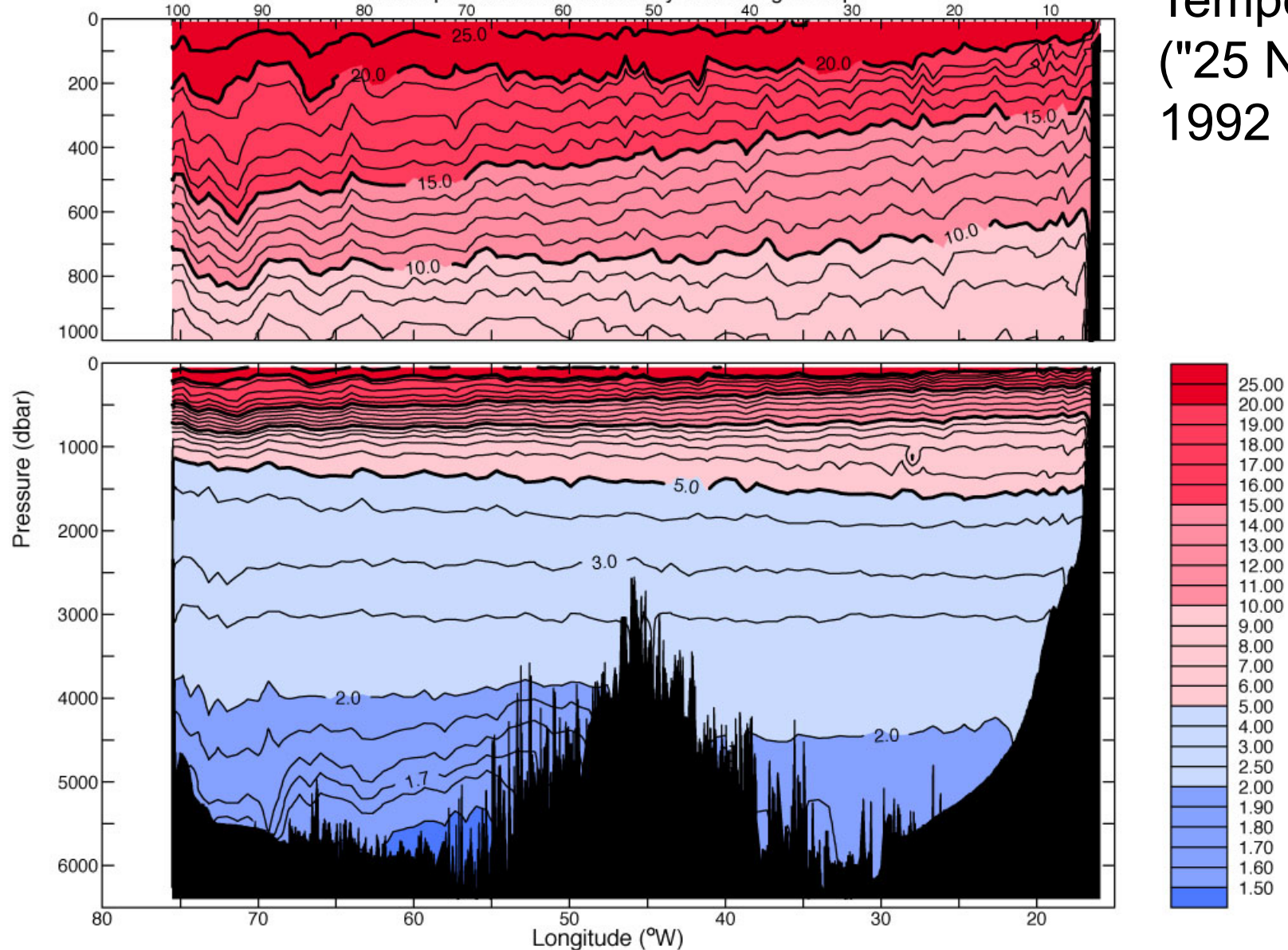


Temperature ("25 N") in 1981



Zonal section of potential temperature ($^{\circ}\text{C}$) across $24^{\circ} 30'\text{N}$ in the Atlantic from hydrographic stations taken aboard BIO Hesperides in Jul-Aug 1992

Station positions are indicated by ticks along the top

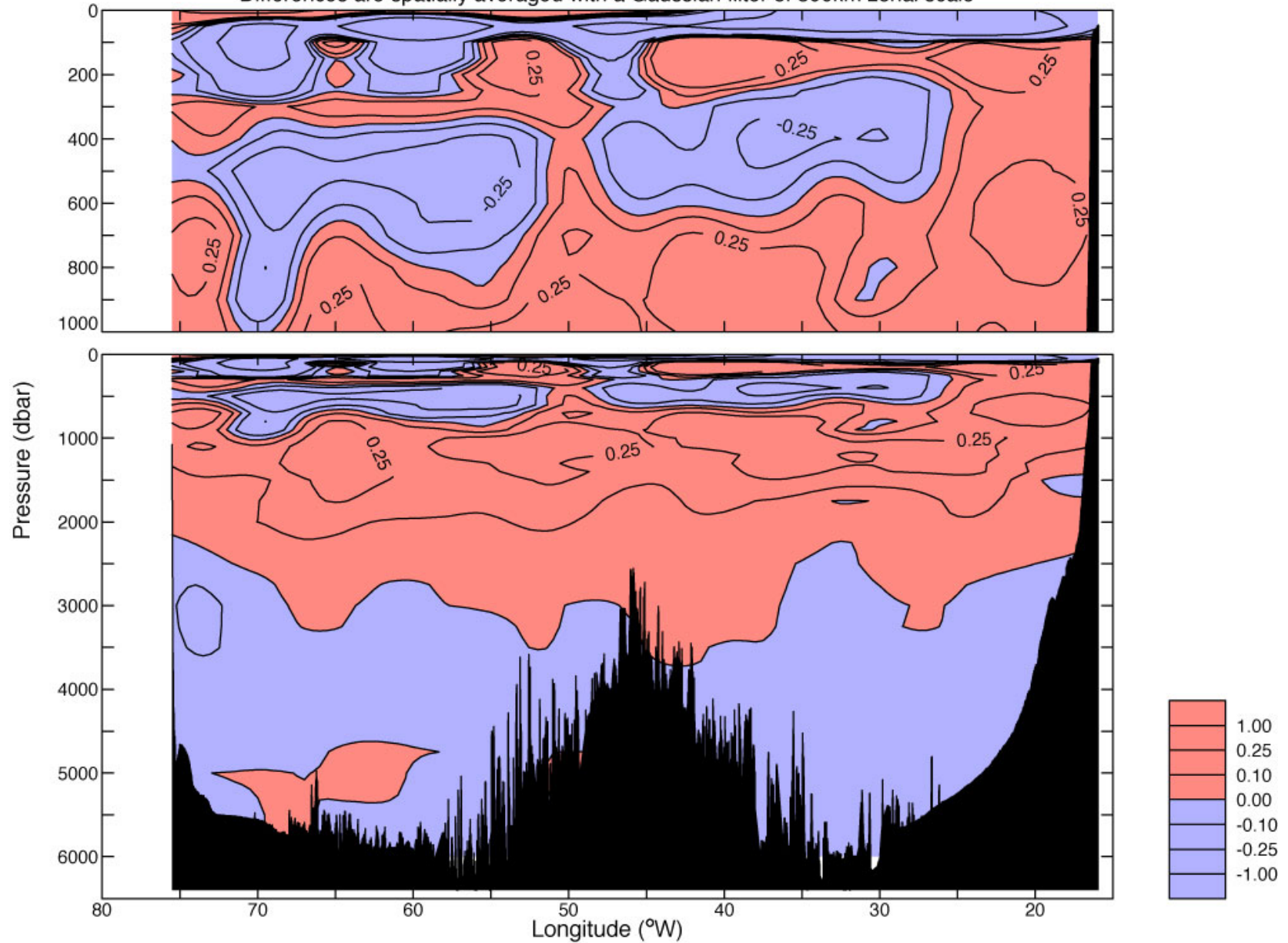


Temperature
("25 N") in
1992

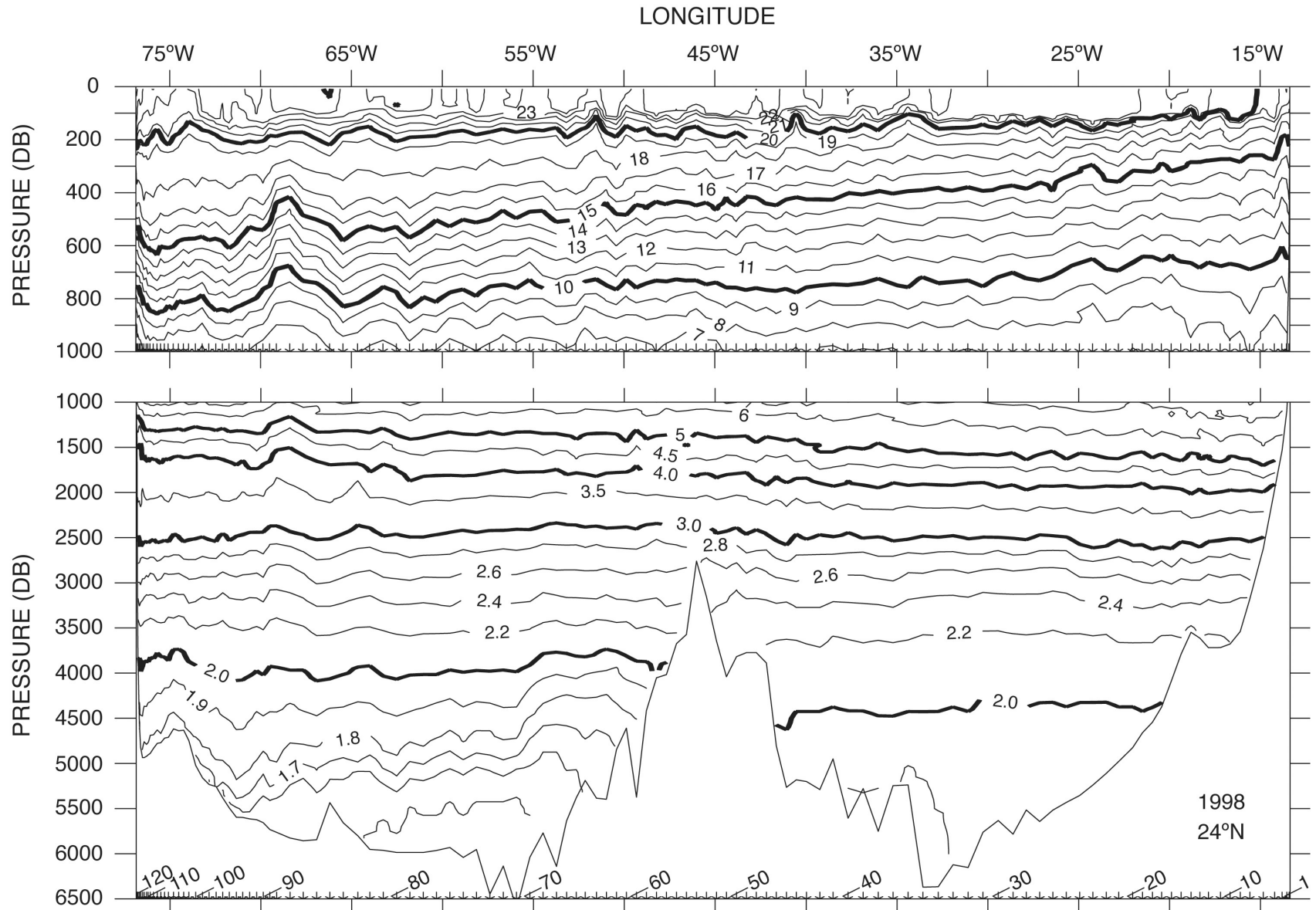
Bryden, Griffiths, Lavin, Parrilla et al 1996

Pattern of potential temperature change ($^{\circ}\text{C}$)
over the period 1957 to 1992 across $24^{\circ} 30' \text{N}$ in the Atlantic

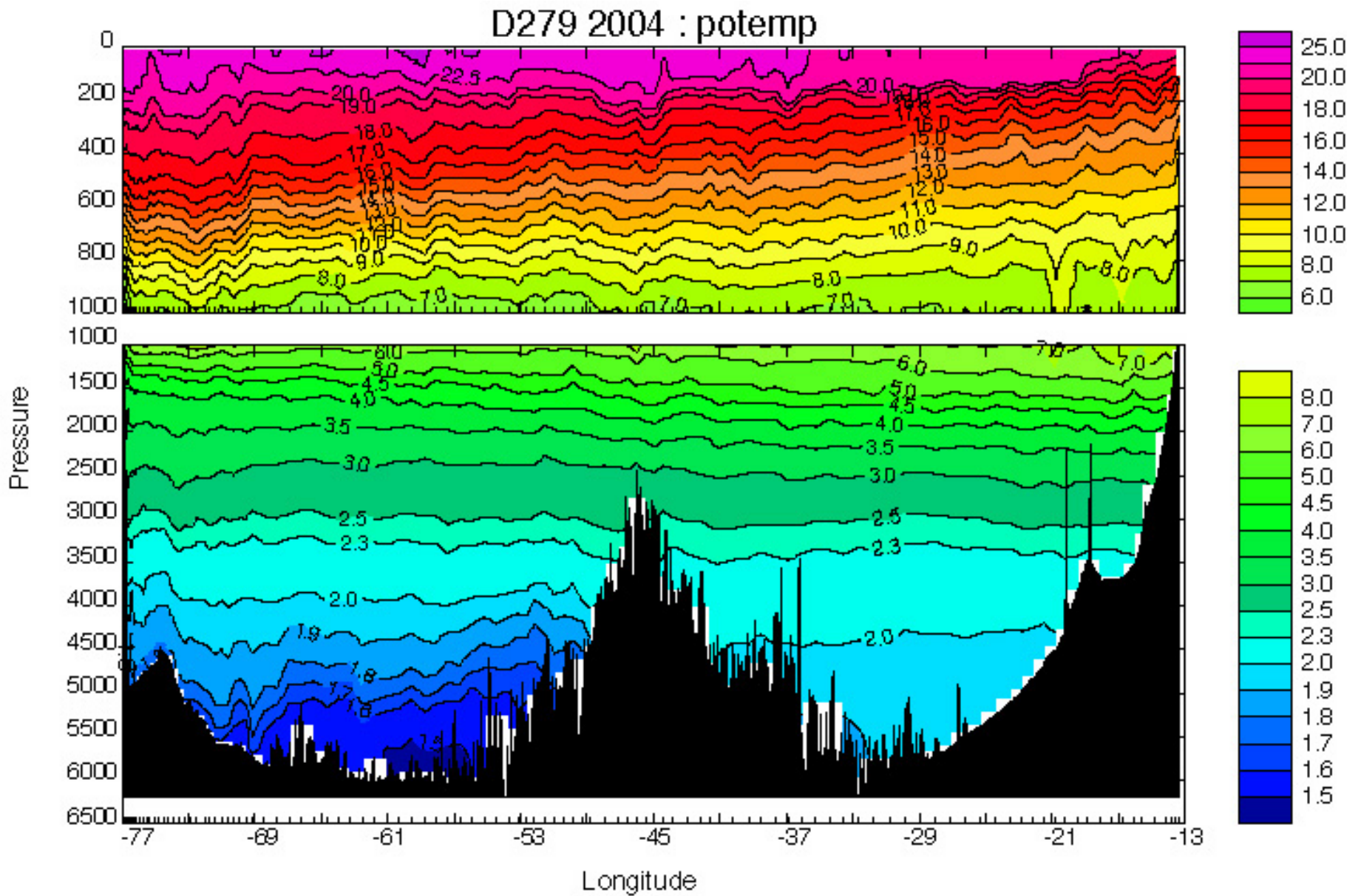
Differences are spatially averaged with a Gaussian filter of 300km zonal scale



Temperature ("25 N") in 1998



Temperature ("25 N") in 2004



Cunningham, 2004

2004-1957 Temperature and Salinity Difference

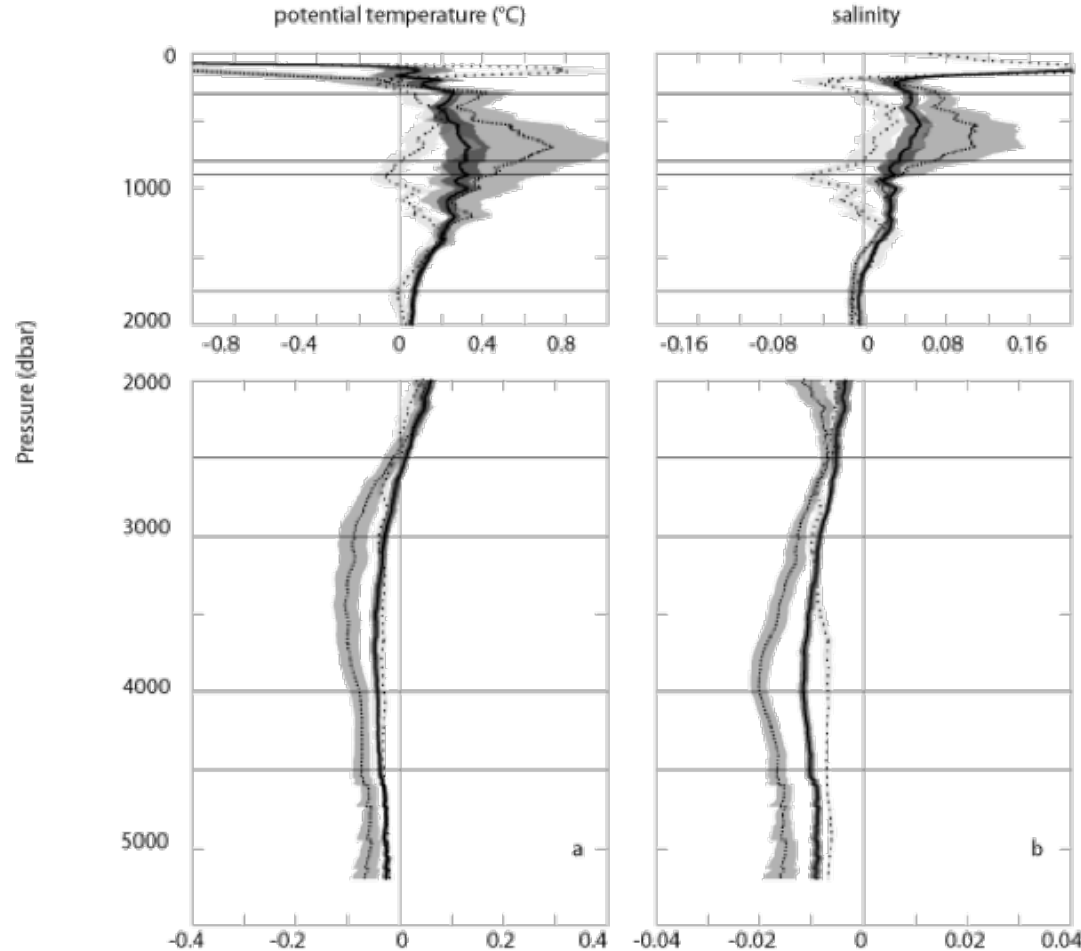
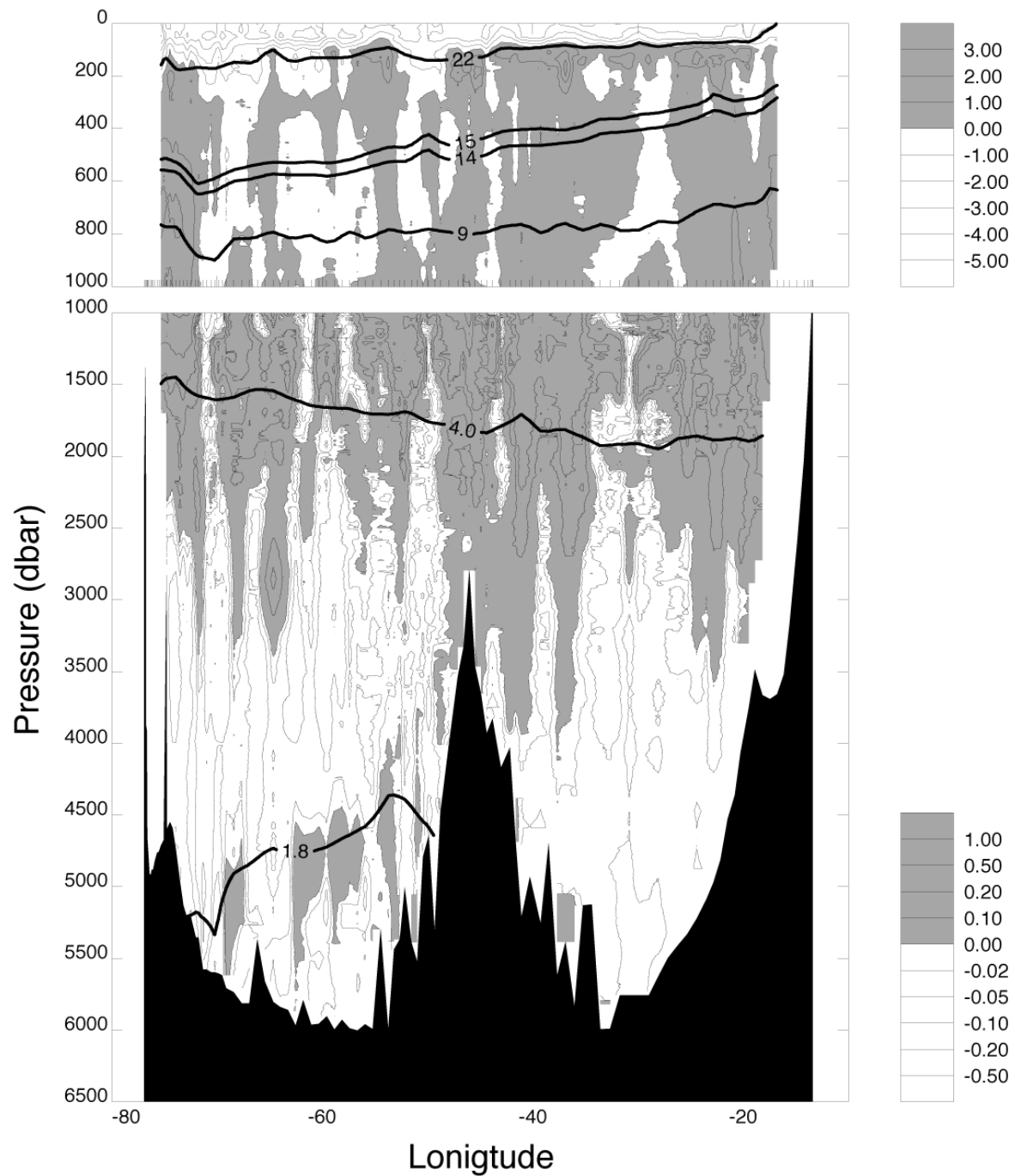
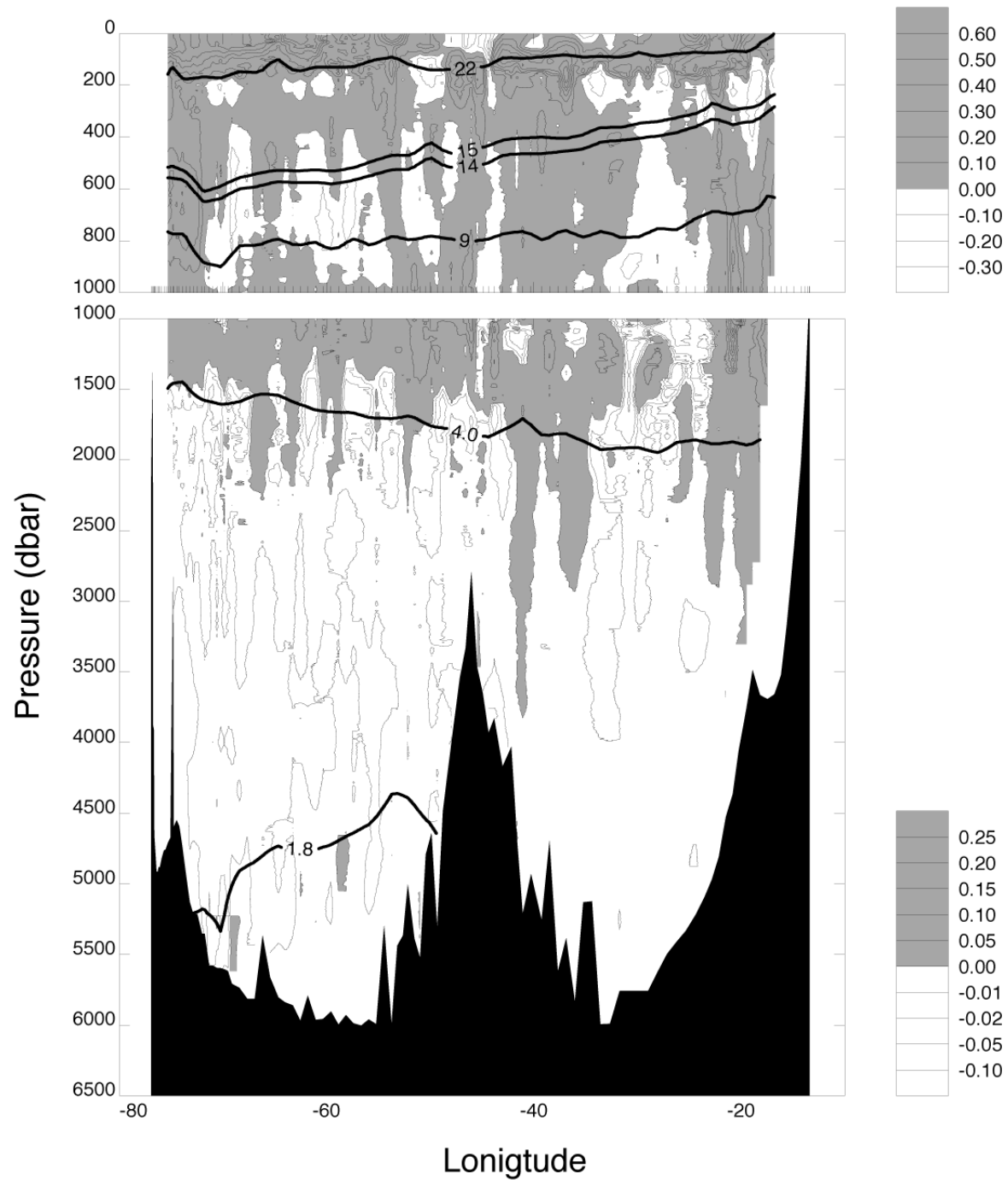


Figure 2. (a) Potential temperature and (b) salinity change from 1957 to 2004 averaged zonally on pressure surfaces (2004–1957) plotted against pressure. Shading shows ± 1 standard error of the mean zonal difference. Full transatlantic section (solid); 65 to 75°W (dashed); 25 to 35°W (dotted). The water mass layers are: thermocline, 300 to 800 dbar; Intermediate Water, 900 to 1750 dbar; upper North Atlantic Deep Water, 1750 to 2500 dbar; western basin lower North Atlantic Deep Water, 3000 to 4000 dbar; eastern basin lower North Atlantic Deep Water, 3000 dbar to sea-bed; and western basin Antarctic Bottom Water, 5000 dbar to sea-bed.

2004 - 1957 : Potential Temperature difference



2004 - 1957 : Salinity difference



Concluding remarks

- Effective monitoring systems depend on **both** adequate frequency of observation, and adequate length of time-series.
- Before ~2000, **subsurface** observational studies were rarely optimized for monitoring.
- This presents a major weakness for oceanographers until existing timeseries become long enough (decades).
- Meanwhile, it is imperative to maximize the value of historical data.

Part 2:

Different instruments and
their potential for monitoring

Outline

In this lecture we will explore available unmanned instruments, and their potential for monitoring:

- a) Moored instrumentation
- b) Argo floats
- c) Drifters
- d) Gliders
- e) Autonomous Underwater Vehicles (AUVs)

a) Moored instrumentation

Moored Instrumentation

Deploy instruments in the deep sea for extended period
Recover them using acoustic releases after a year to obtain

Time series measurements of ocean currents, temperature, salinity, bottom pressure made in spatial arrays of moorings

Temporal evolution of (physical) ocean parameters

- Cycles (diurnal, seasonal, tides)
- Sustained long-term (climate) change
- random variations
- representativeness of measurements taken at a certain location and time

Seagauge (Seabird Inc.) bottom pressure recorder

Purpose :

➔ Pressure of water column at sea floor

Principle :

➔ Quartz crystal oscillation frequency

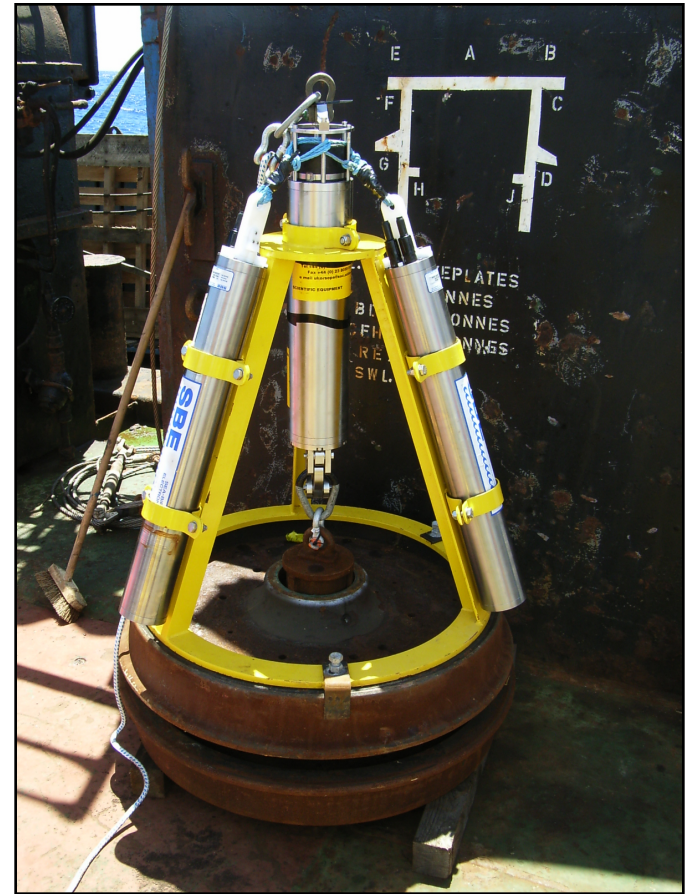
Technical specification

➔ range : 0 to 7000 dbar

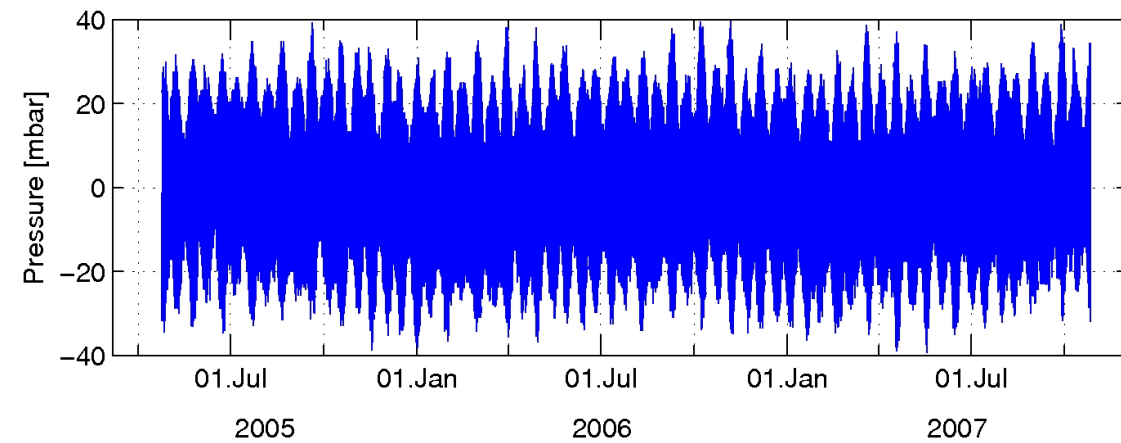
➔ accuracy : 0.7 dbar

➔ resolution : 0.0003 dbar (0.3 mm)

➔ max. depth : 6800 m

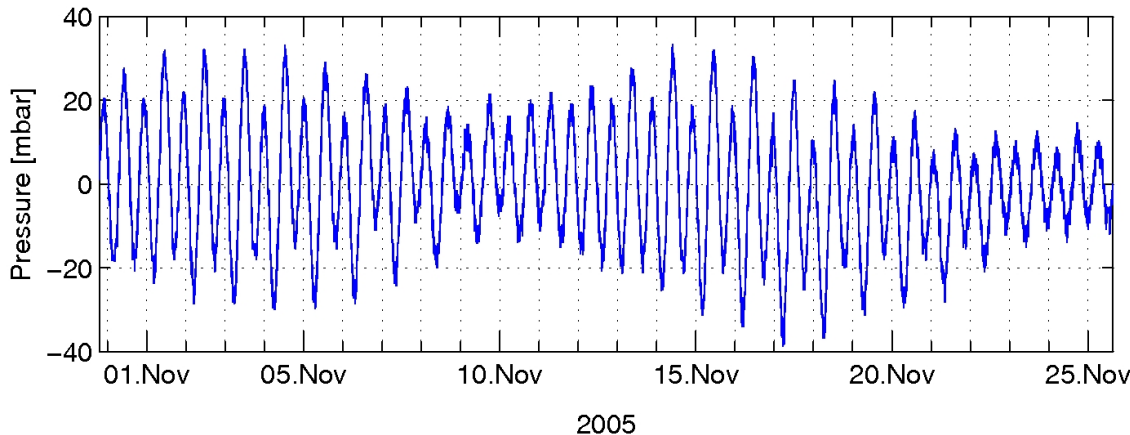


2 Seagauge sensors
Mounted on a lander frame

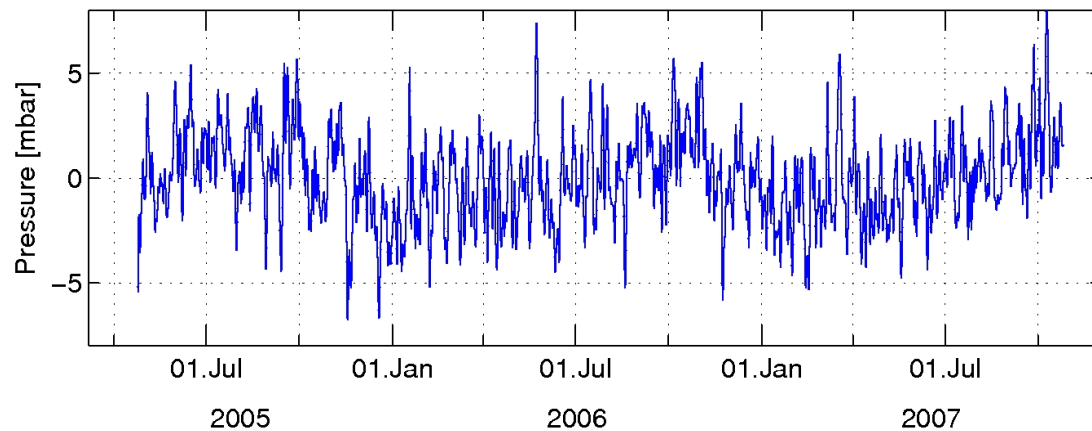


Bottom pressure time series

30 month record



1 month shows tides



30 month
(2-day low-pass filtered)
to show low frequency
variability including
seasonal cycle

RCM-11 current meters

Purpose: speed and direction of flow

Principle:

- speed: acoustic Doppler frequency shift
- direction : magnetic compass

Technical specification of Aanderaa RCM-11

- Range : 0 – 300 cm/s
- Accuracy : 1% in speed
5° in direction
- Resolution : 0.3 cm/s in speed
0.35° in direction
- Sampling : 1 – 120 minute interval
- max. Depth: 6000 m



Seabird MicroCAT Conductivity, temperature, pressure (CTD) sensor

Purpose:

- temperature and salinity
- density

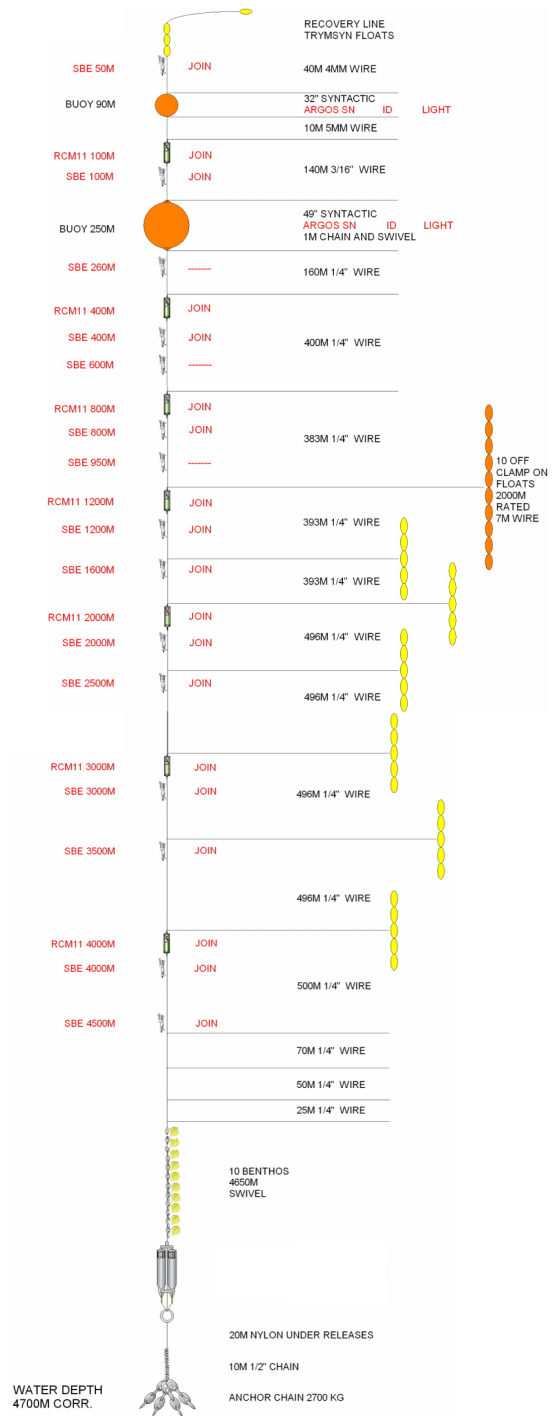
Principles:

- temperature : thermistor
- conductivity : seawater cond. cell
- pressure : deflection of metal diaphragm



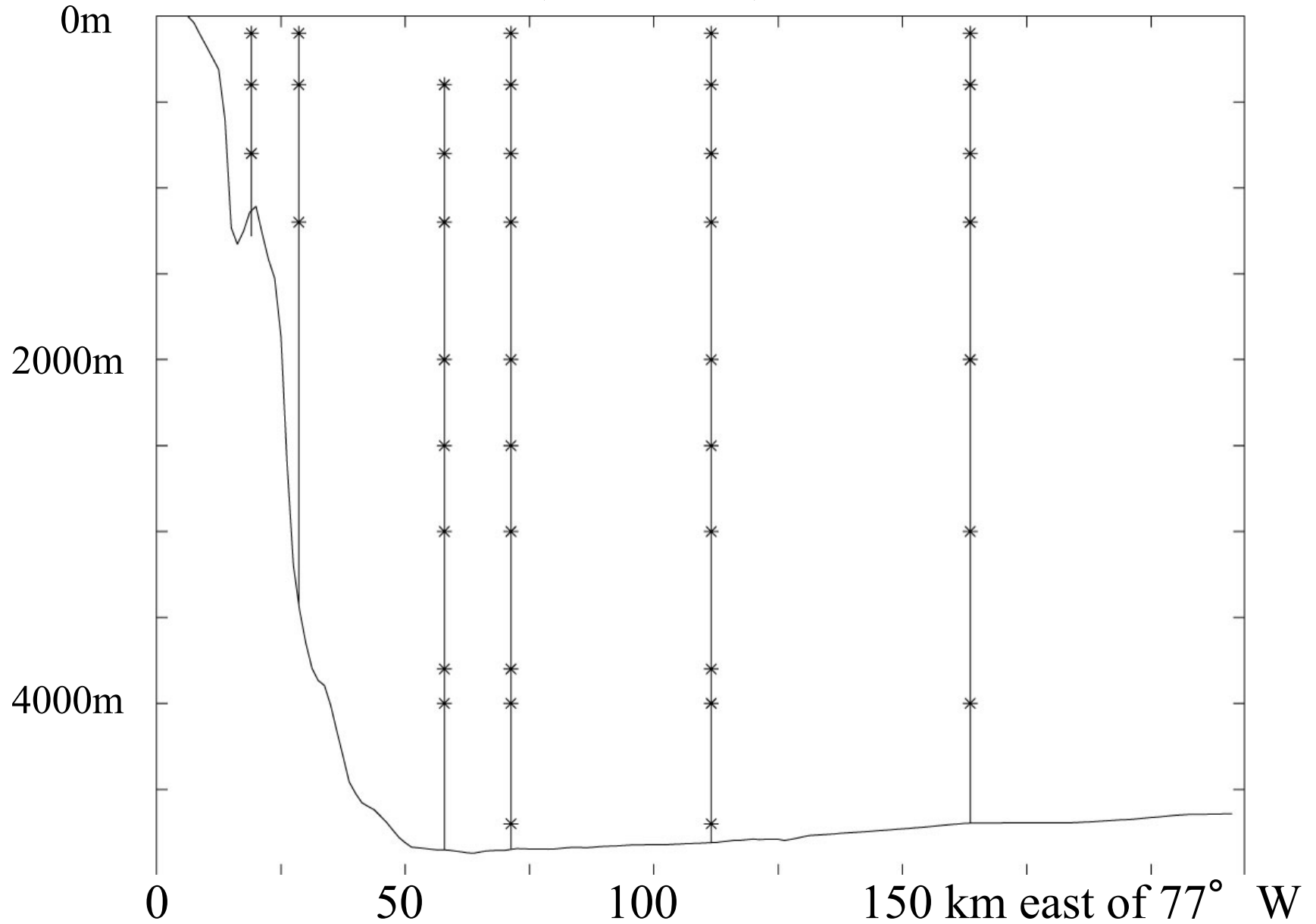
Technical specifications

- Range : T: -5 to 35° C | C: 0 to 7 S/m | P: 0 to 7000 dbar
- Accuracy : T: 0.002° C | C: 0.0003 S/m | P: 0.1% of full scale
- Resolution : T: 0.0001° C | C: 0.00001 S/m | P: 0.002% of full scale
- max. Depth: 7000 m
- Sampling : 10 sec to 2 hours

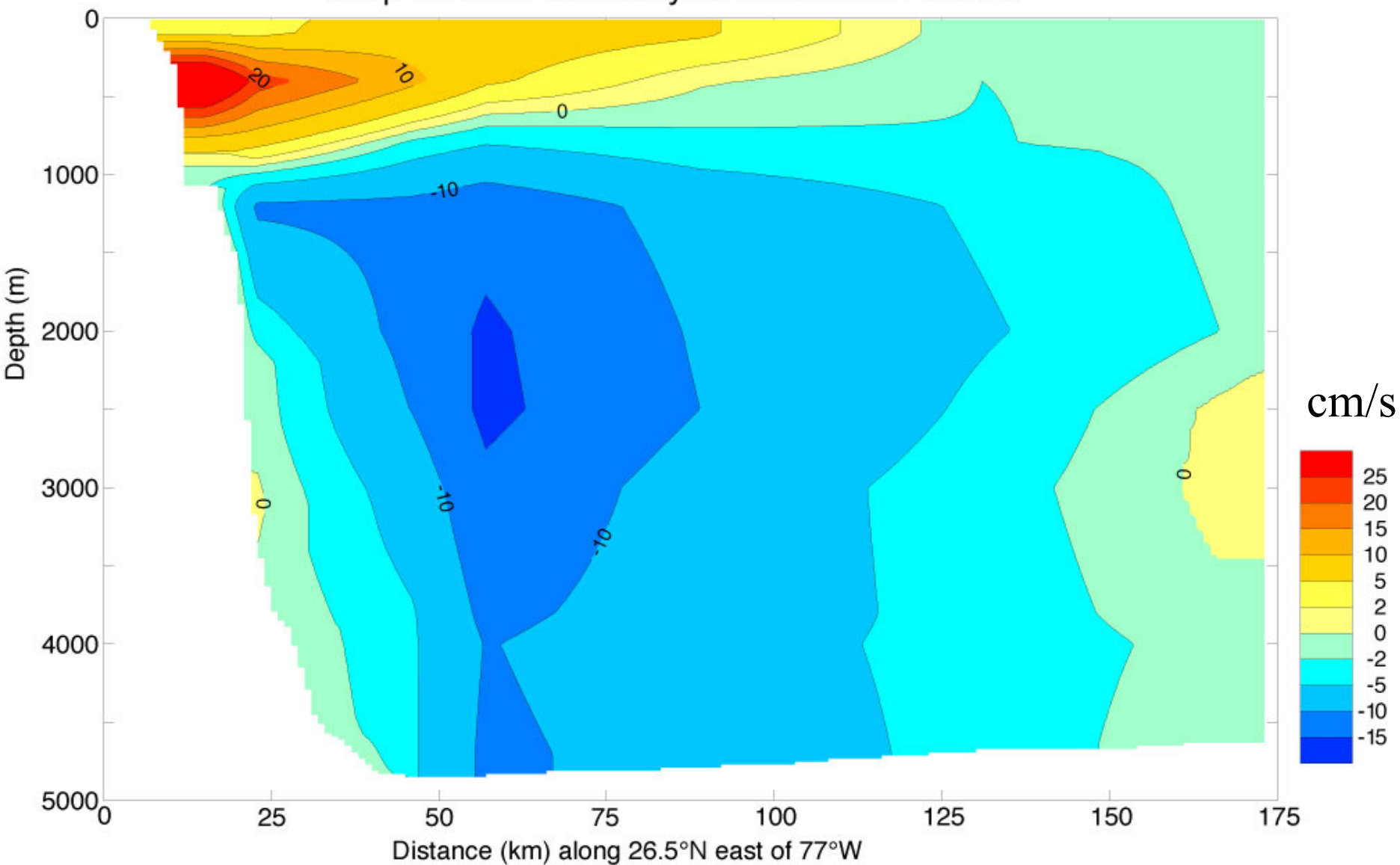


We can deploy several instruments on a mooring, enough so we can define the vertical structure of the variability

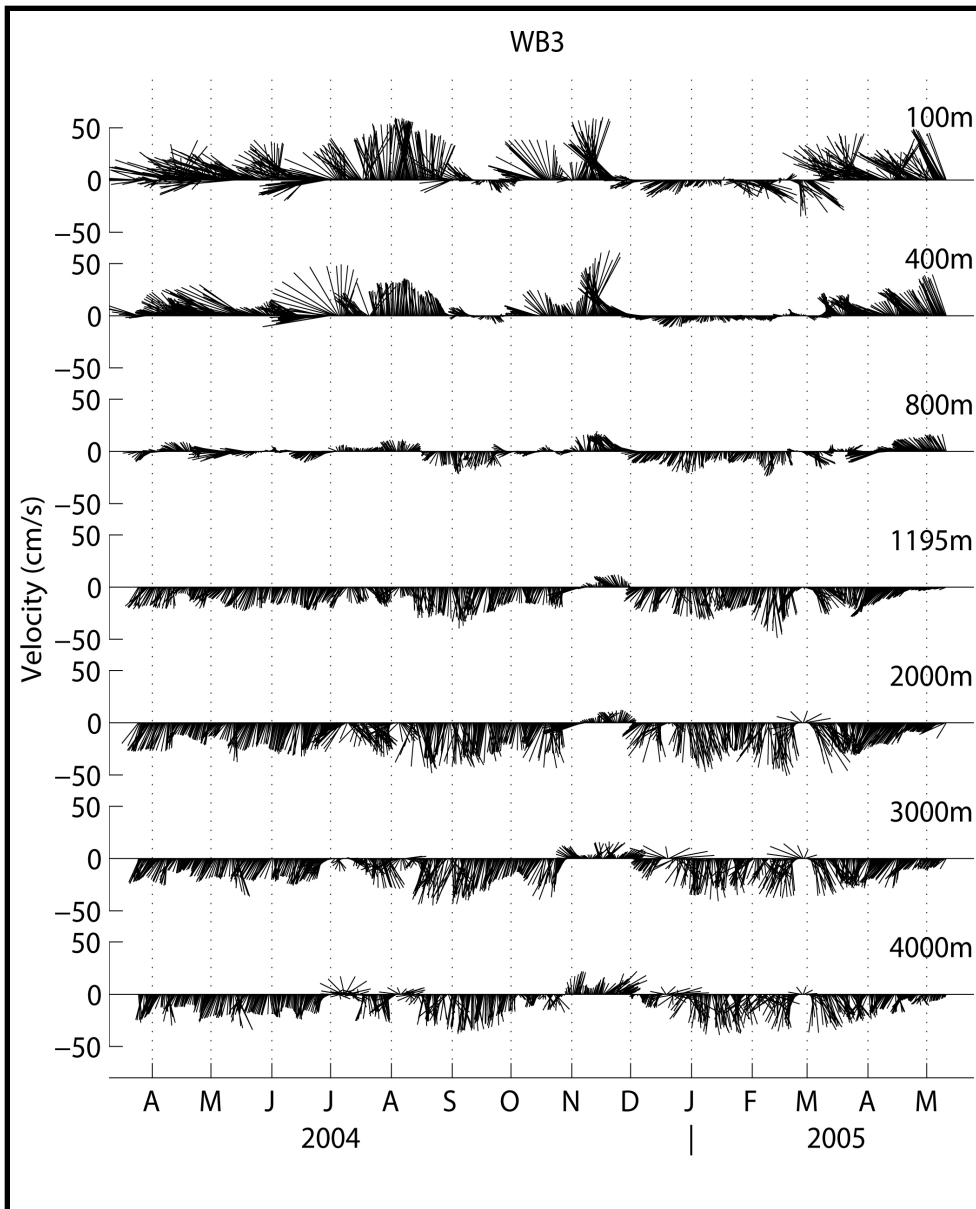
Mooring Array to measure Deep Western Boundary Current east of Abaco (Bahamas)



Deep Western Boundary Current east of Abaco



Current time series from a mooring in the subtropical west Atlantic



RAPID/MOCHA boundary
current mooring at 26.5 N

Scientific aims:

- Vertical structure of boundary currents

Antilles Current above 1000m
Deep Western Boundary Current
below 1000m

Johns et al. (2008)

Chemical measurements



To date, moorings have been principally used for physical observations.

A new, and still rarely used technology, is water sampling on moorings, such as AquaLAB, also used in Autosub.

Summary for Moored Instruments

- Modern sensors allow precise time series measurements of currents, temperature, salinity and bottom pressure
- Properties can be observed in remote places over long times
- Put out on moorings deployed in arrays, these observations define combined spatial and temporal variability of ocean circulation

b) Argo floats

Lecture 4 is dedicated to ARGO floats

c) Drifters



Global Drifter Programme

- Lagrangian drifters (like Argo floats, but drifter observations are made at the surface)
- Surface buoy and subsurface drogue (sea anchor) at ~15 m, attached by a long, thin tether
- Temperature and other properties measured at the buoy, transmitted to satellites
- Placed by Volunteer Observation Ships (VOS) and aircraft, as well as research vessels
- Administered by the Atlantic Oceanographic & Meteorological Laboratory (AOML)
- Incoming data are placed on the Global Telecommunications System (GTS) for distribution to meteorological services

Rick Lumpkin (AOML) on the Global Drifter Programme

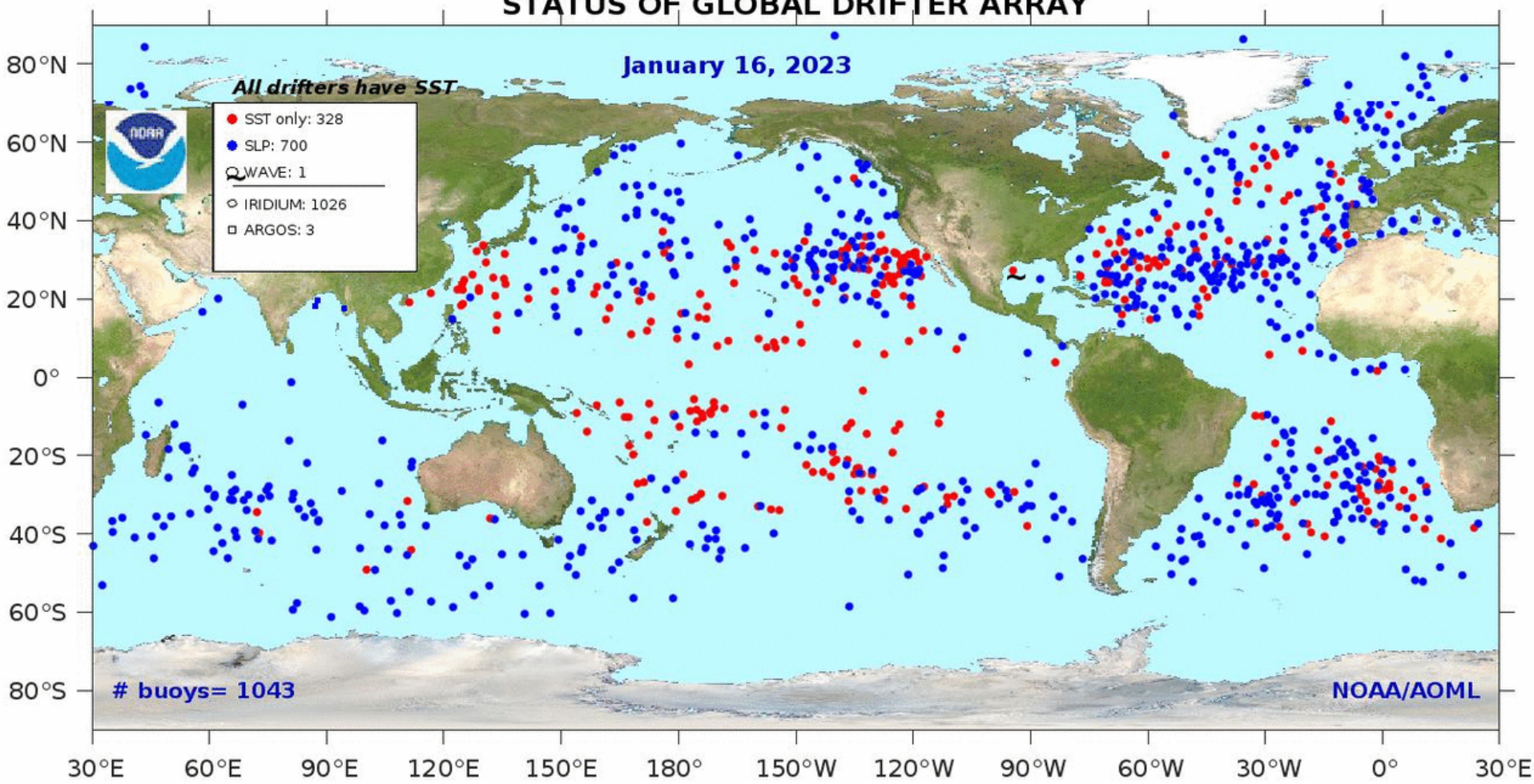
"The Global Drifter Program (GDP) is the principle component of the Global Surface Drifting Buoy Array, a branch of the Global Ocean Observing System(GOOS). Its objectives are to:

"Maintain a global 5x5 degree array of 1250 ARGOS-tracked surface drifting buoys to meet the need for an accurate and globally dense set of in-situ observations of mixed layer currents, sea surface temperature, atmospheric pressure, winds and salinity

"Provide a data processing system for scientific use of these data. These data support short-term (seasonal to interannual) climate predictions as well as climate research and monitoring."



STATUS OF GLOBAL DRIFTER ARRAY



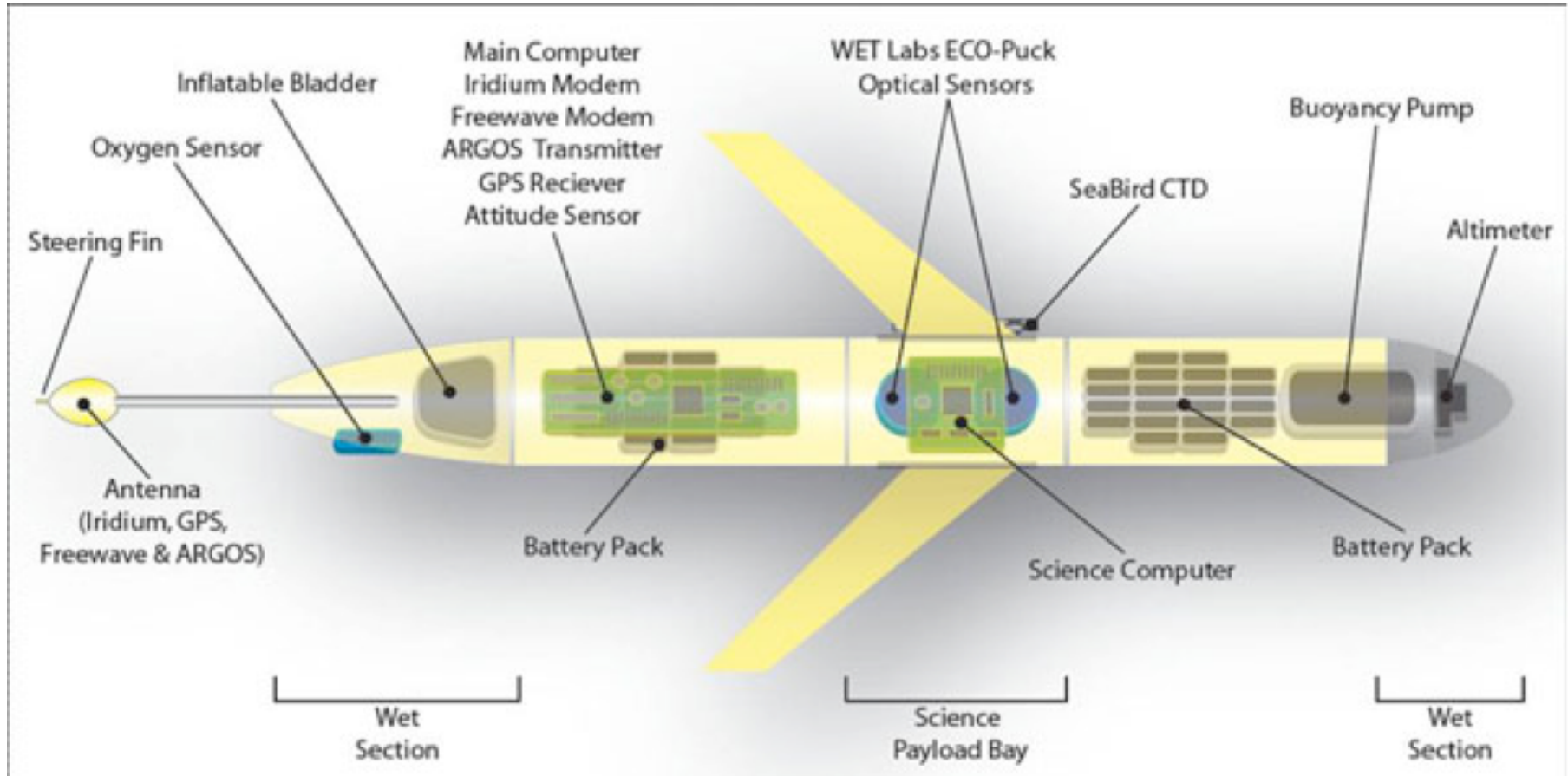
d) Gliders

Underwater gliders



No propeller !

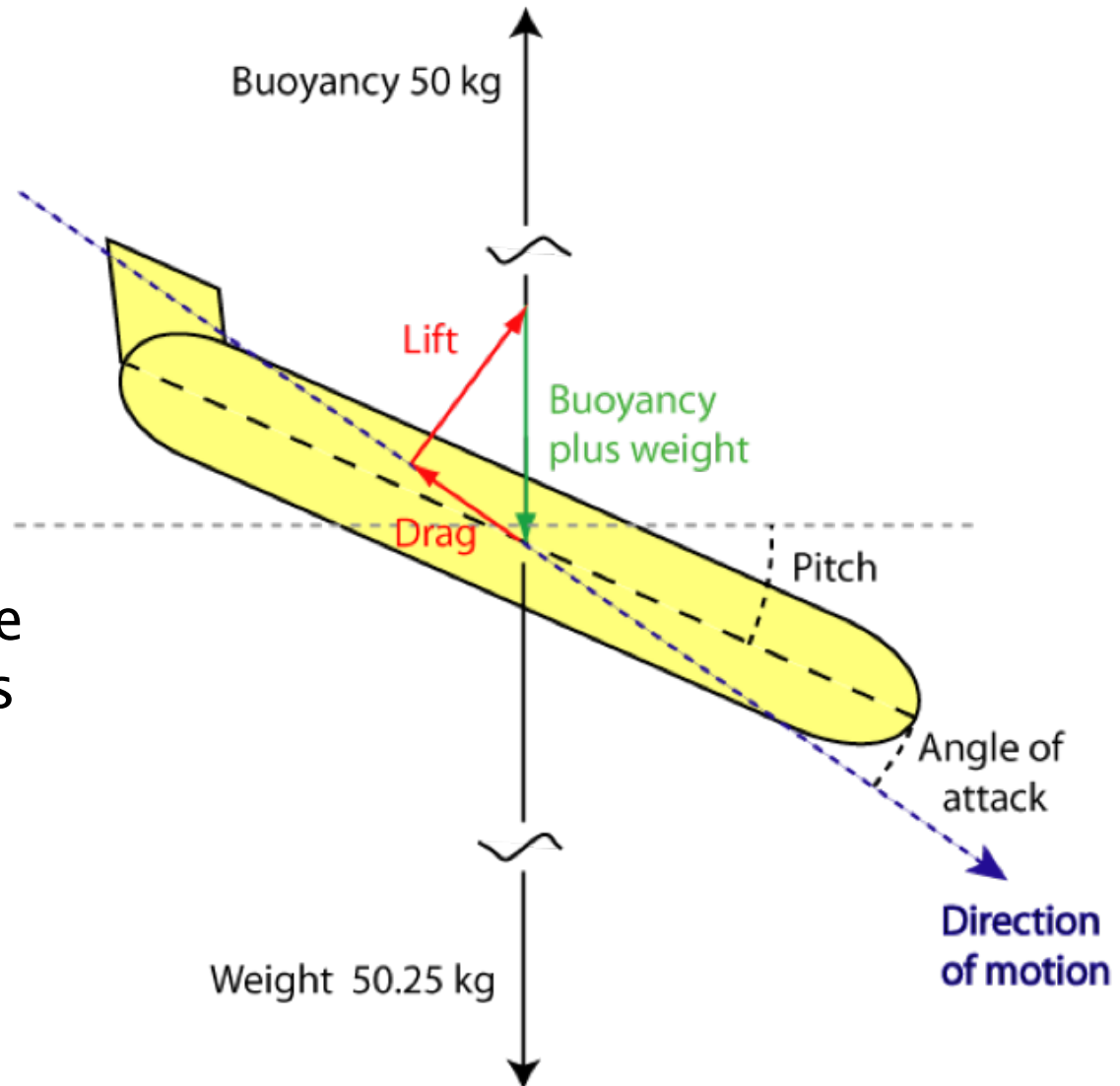
Inside a Slocum glider



Dive

In this picture the volume of the glider is such that the buoyancy is less than the weight and so the glider is descending.

An “angle of attack” is required to generate the “lift” force (which points upwards).

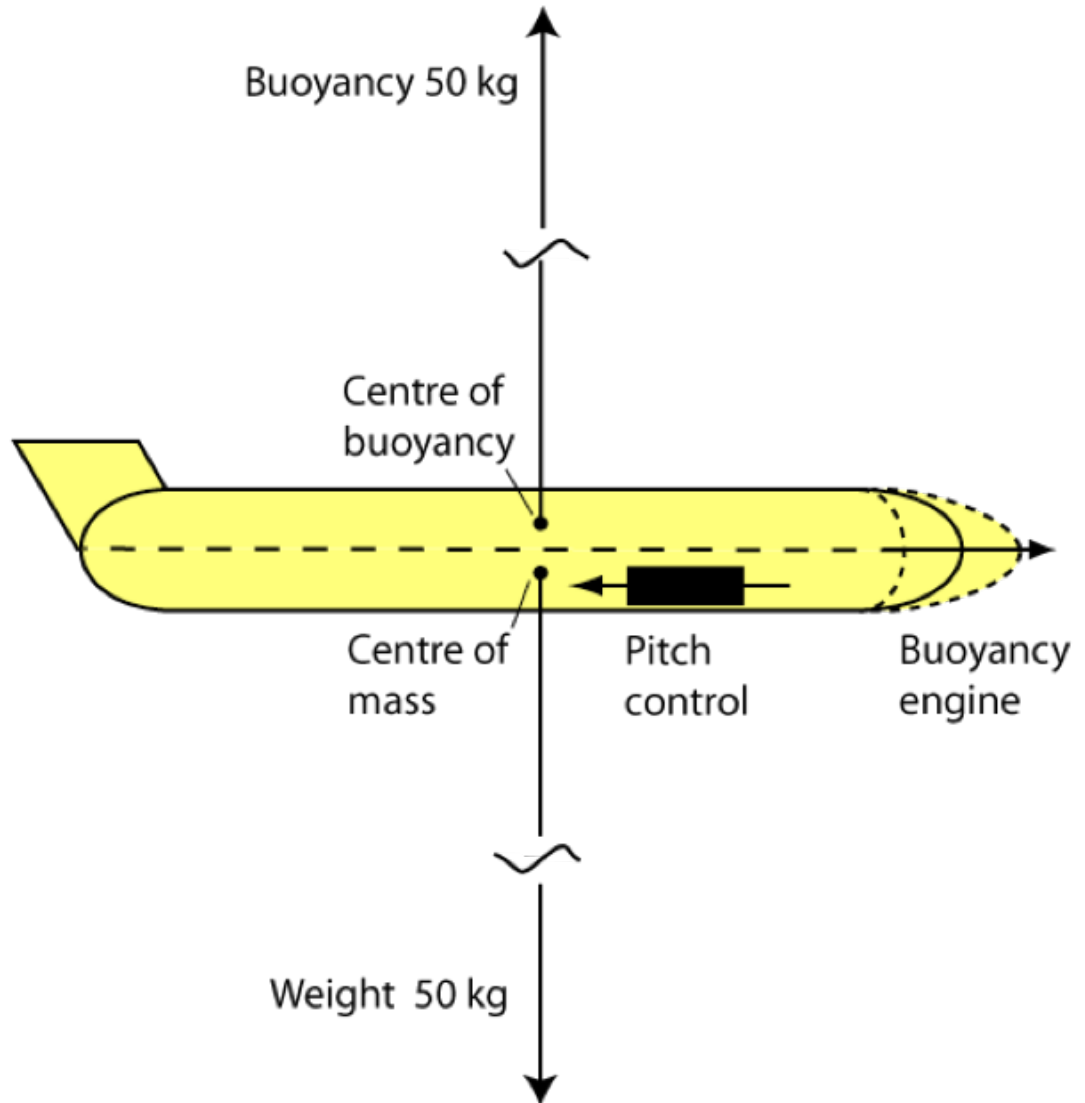


Maximum depth

To climb the volume is increased so that the buoyancy is greater than the weight.

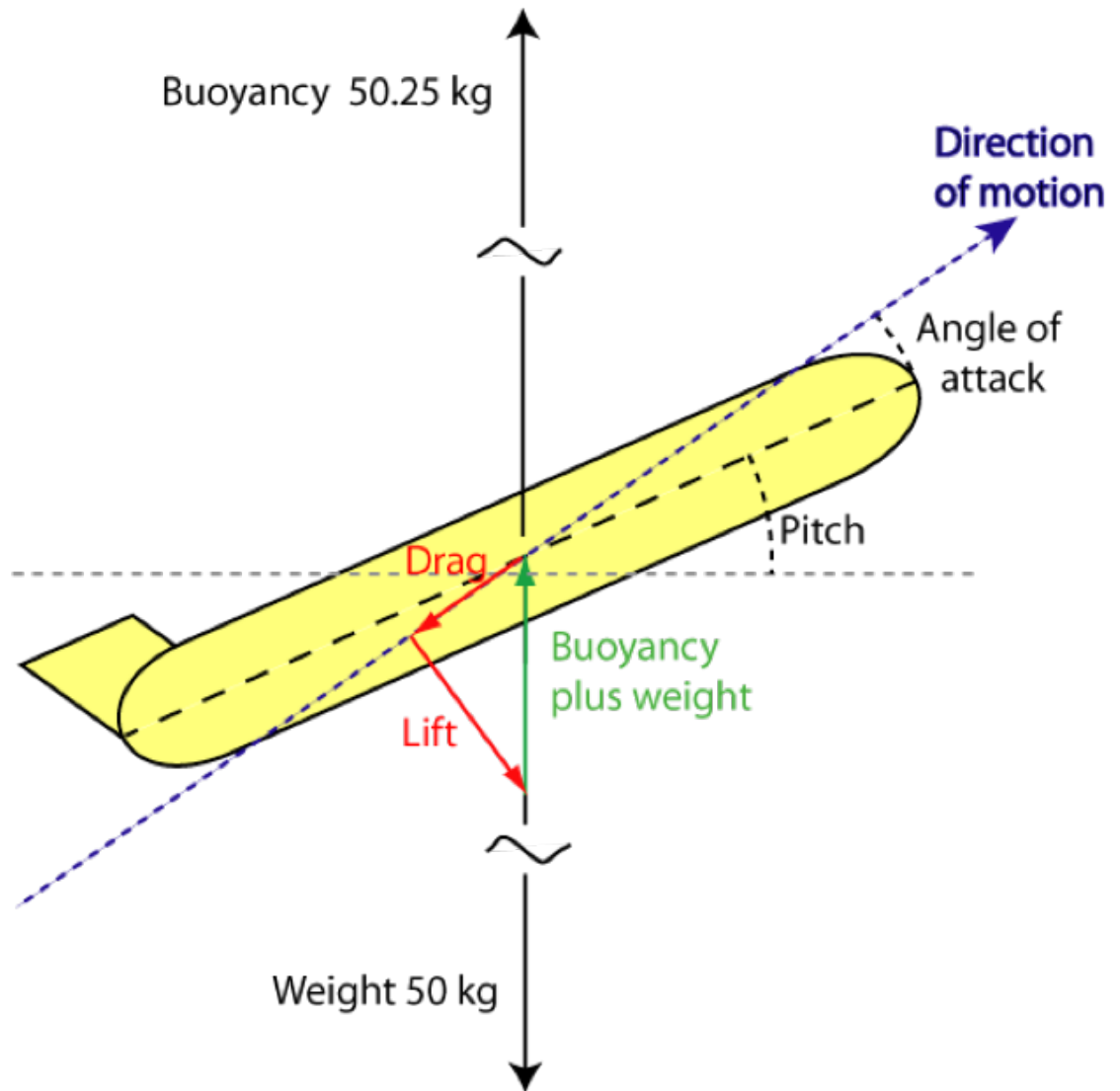
Increasing the volume uses energy
$$= (\text{change in volume}) \times (\text{pressure})$$

The pitch is changed by displacing the centre of mass towards the rear so that the nose points up.



Climb

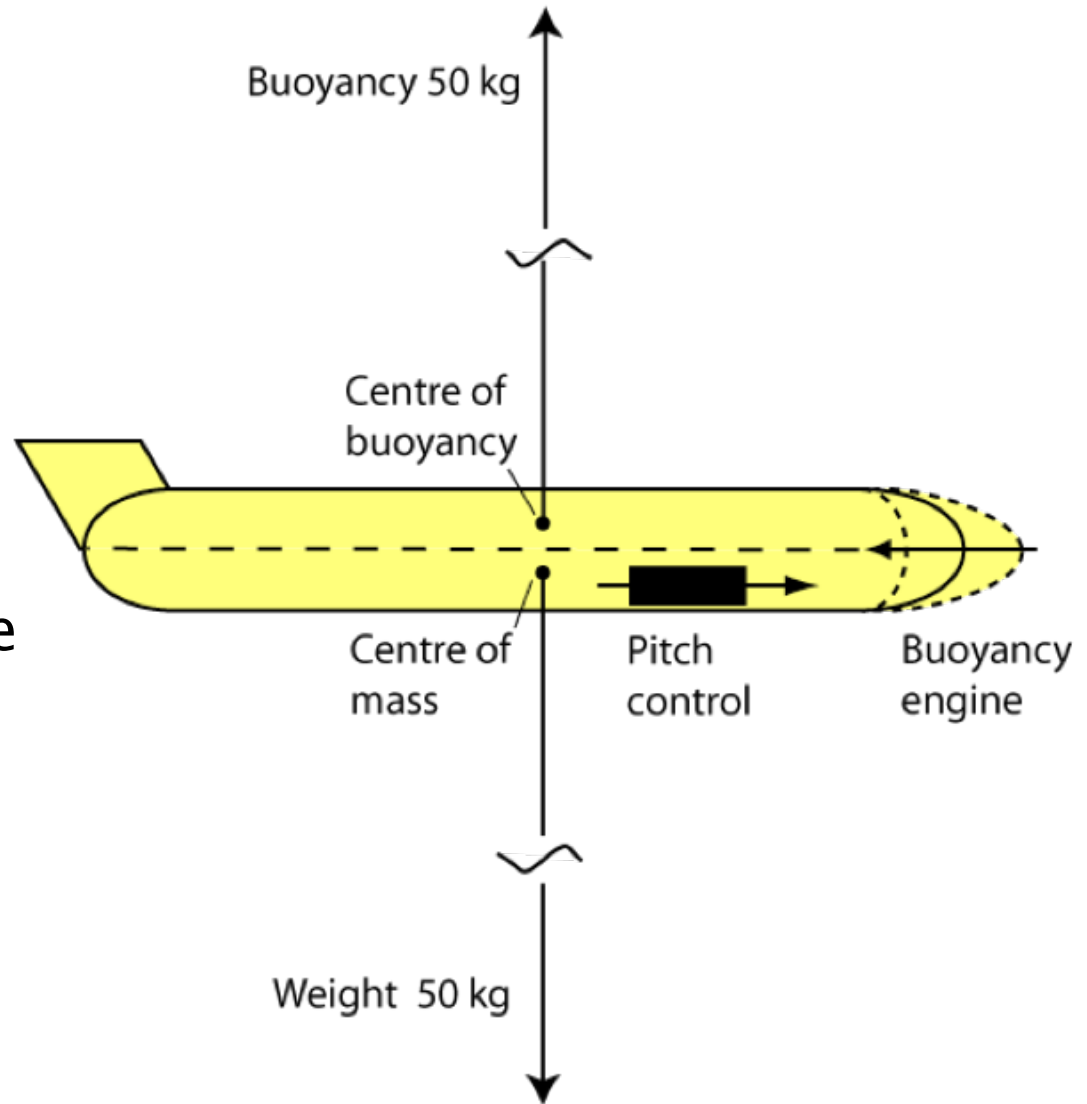
As the glider climbs
the sign of the angle
attack changes.



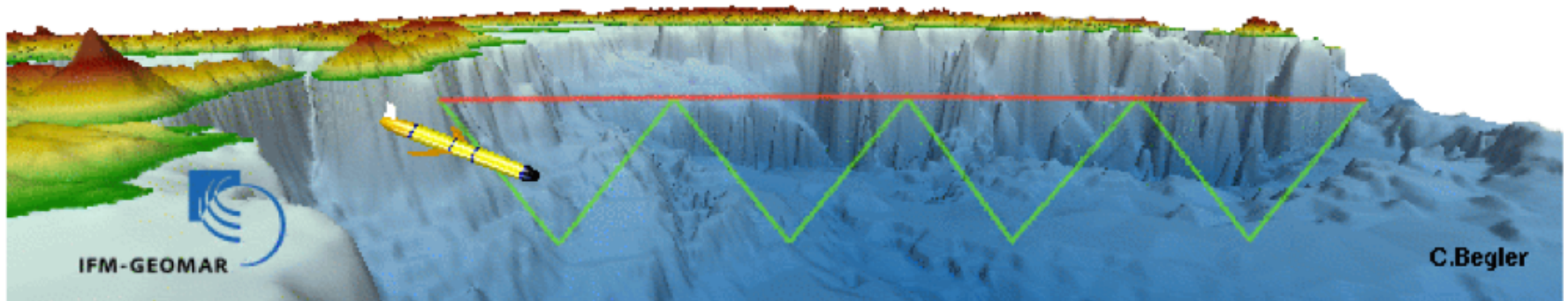
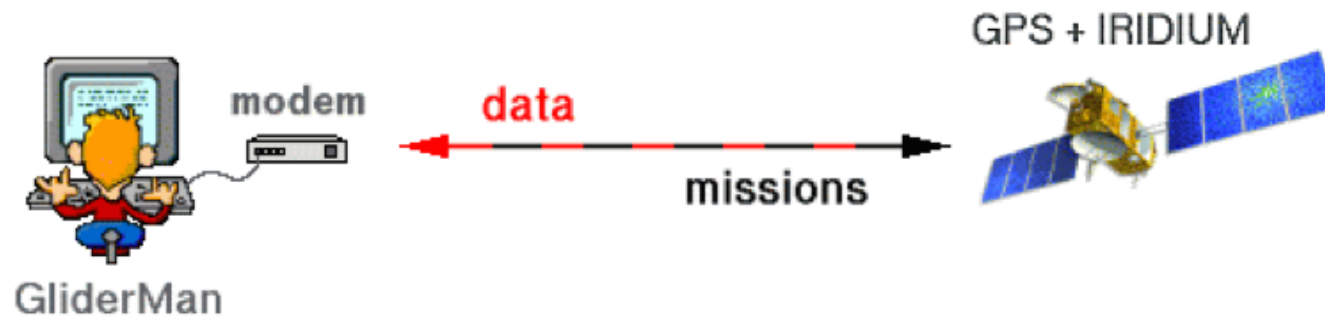
Surface

At the surface the volume is decreased, the centre of mass is moved forward and the next dive commences.

Very little energy is required for this volume change



Gliders always follow a saw-tooth trajectory

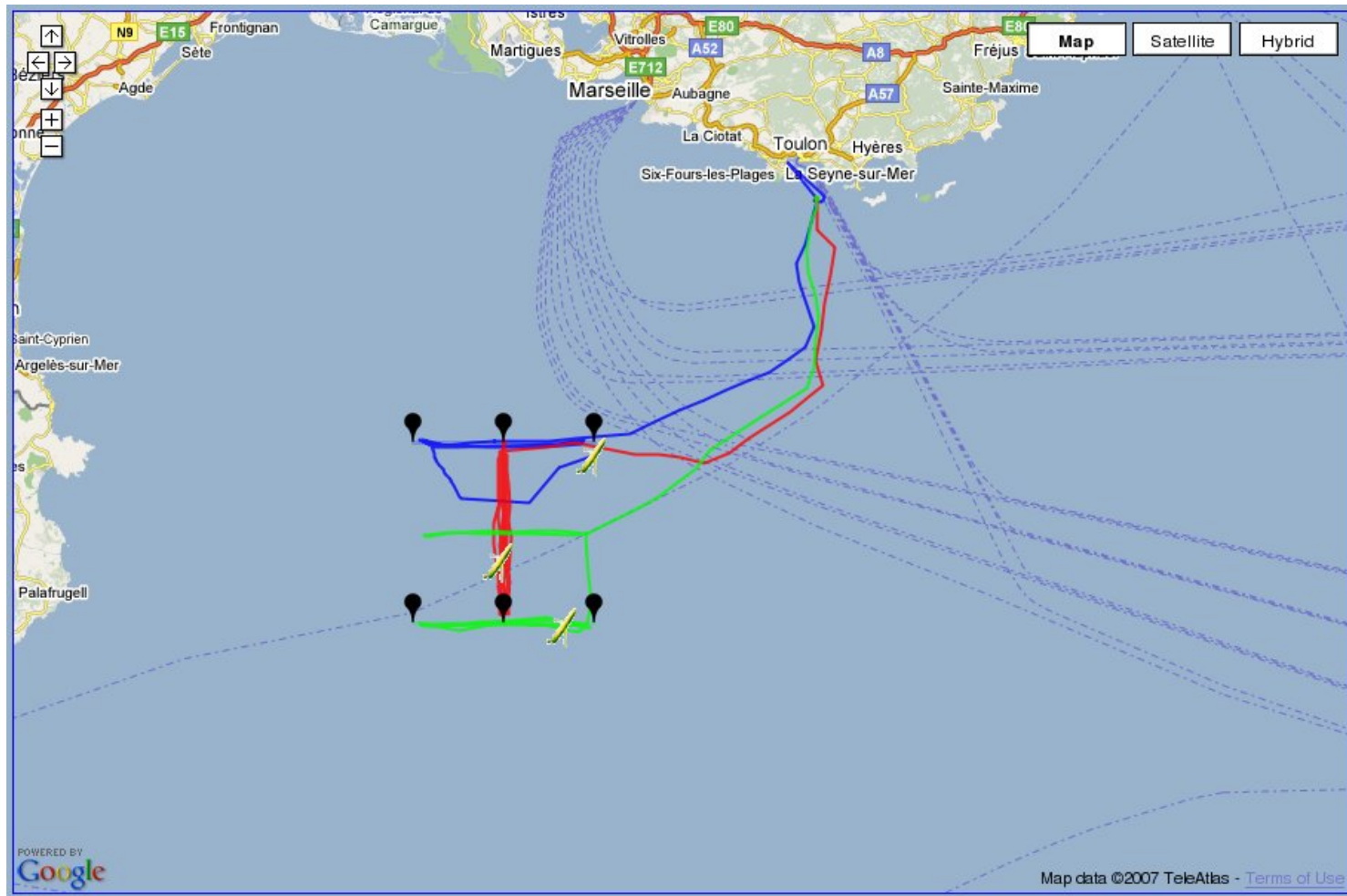


When at the surface a glider is not able to navigate

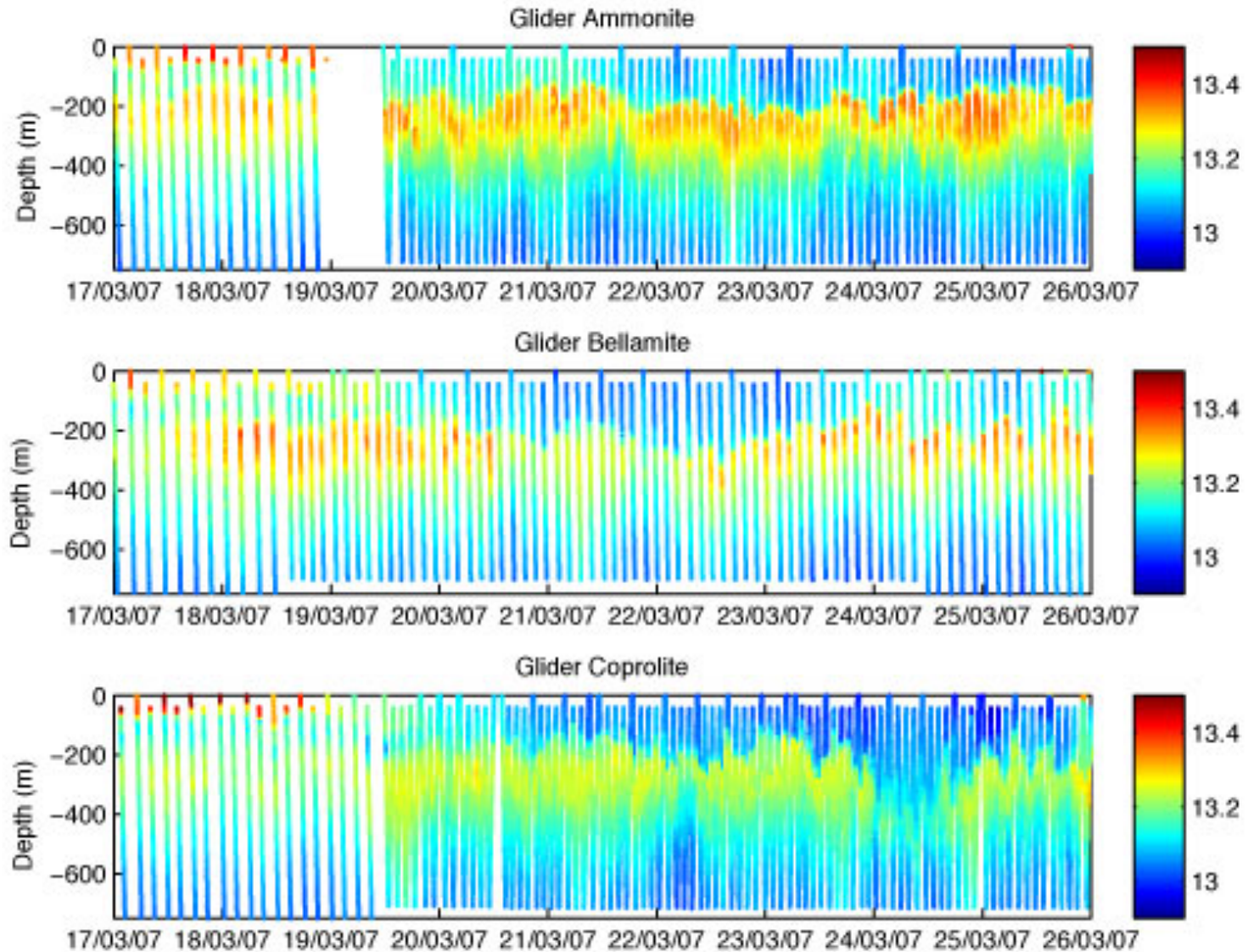
Gliders - key features

- Speed $\sim 0.3 \text{ ms}^{-1}$
- Endurance 6 weeks - 6 months
- Maximum depth 1000m
- GPS navigation at surface
- 2-way satellite communications (Iridium)
- Measurements
 - Conductivity, temperature and pressure
 - Average current velocities from navigation
 - Payload for additional sensors

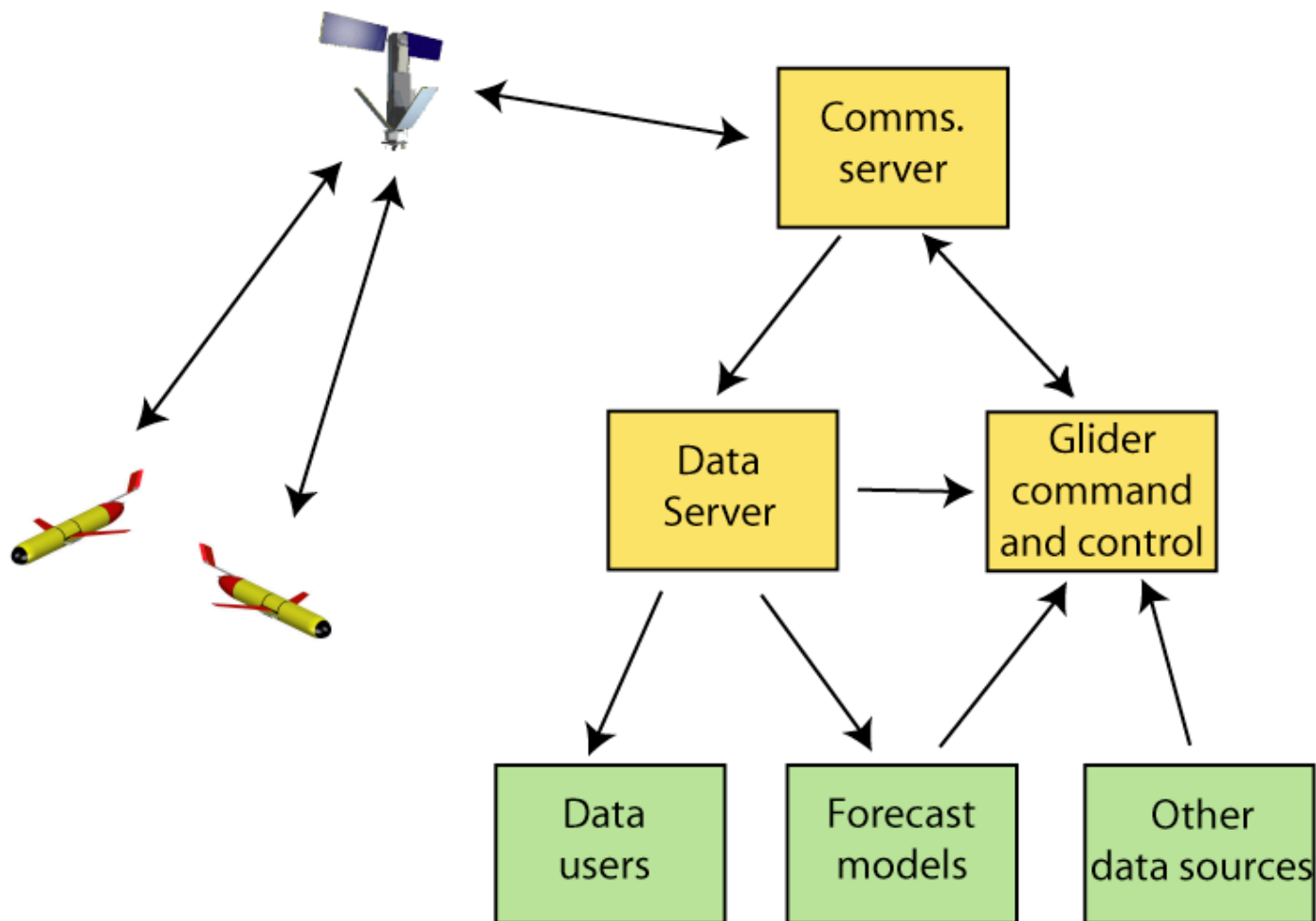
Real-time data displayed on the web



Temperature measurements



Operations: Adaptive sampling



Summary

- Gliders are buoyancy driven vehicles that follow saw-tooth profiles.
- Gliders obtain data with a high spatial resolution and can remain in the field for months at a time.
- Gliders can be used to observe infrequent events.
- Two-way communication enables adaptive sampling strategies to be used.
- Trials have been made using advanced programming architecture for gliders to enable *onboard* decision making

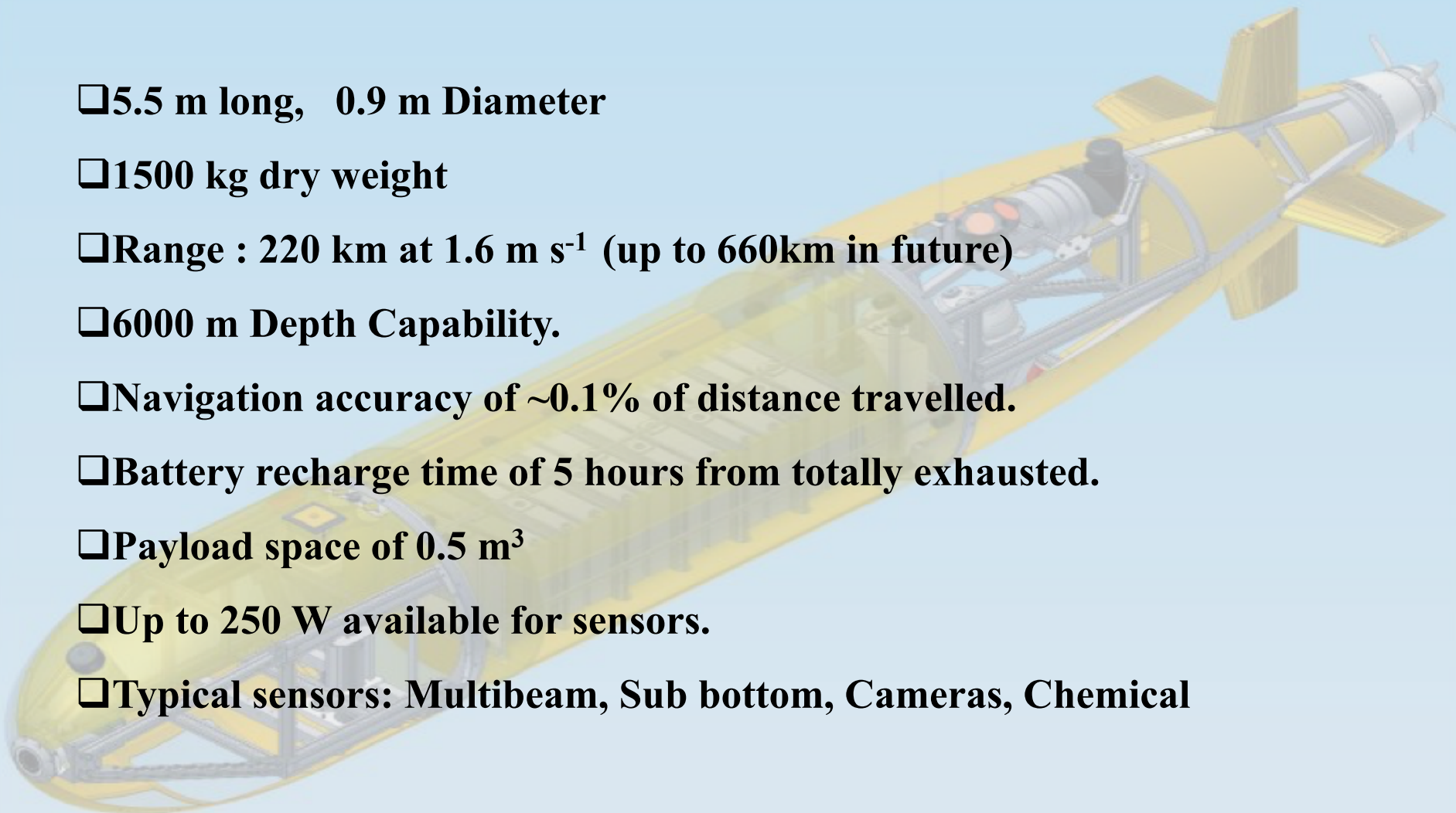
e) Autonomous Underwater Vehicles

The Autosub6000 AUV

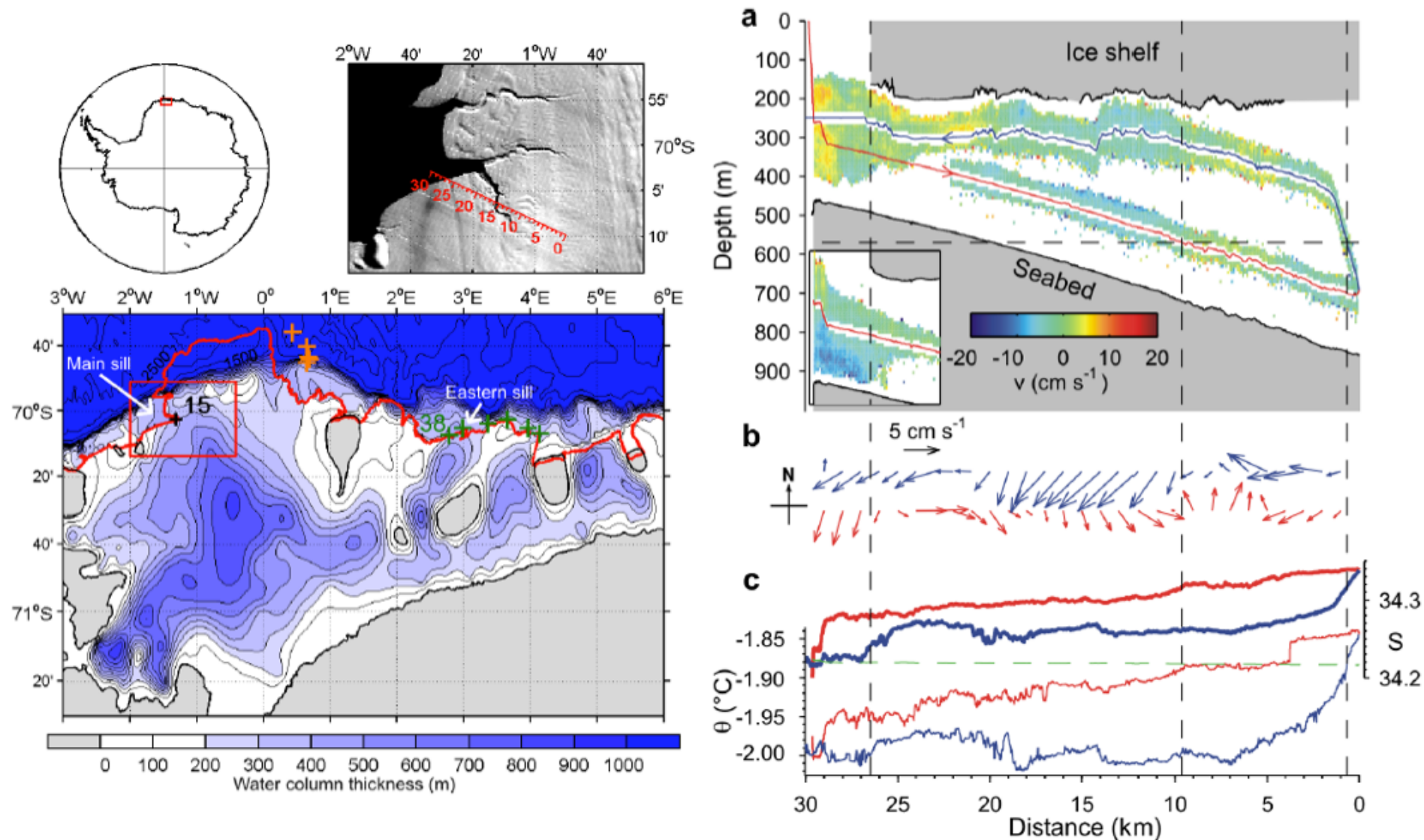


SPECIFICATIONS of Autosub6000

- ❑ 5.5 m long, 0.9 m Diameter**
- ❑ 1500 kg dry weight**
- ❑ Range : 220 km at 1.6 m s^{-1} (up to 660km in future)**
- ❑ 6000 m Depth Capability.**
- ❑ Navigation accuracy of $\sim 0.1\%$ of distance travelled.**
- ❑ Battery recharge time of 5 hours from totally exhausted.**
- ❑ Payload space of 0.5 m^3**
- ❑ Up to 250 W available for sensors.**
- ❑ Typical sensors: Multibeam, Sub bottom, Cameras, Chemical**



A first look under an ice shelf – Autosub I



Example Possible Missions

