Measurement Techniques in Physical Oceanography

- Topics of lecture:

  Research Platforms

  Instrumentation

  Principles of Operation

- Literature:

  R.H. Stewart Introduction to Physical Oceanography. Texas A & M University (http://oceanworld.tamu.edu/home/course_book.htm)

  ! **L. D. Talley, G. L. Pickard, W. J. Emery and J. H. Swift** Descriptive Physical Oceanography. Academic Press. Chapter S16 Instruments and Methods (http://booksite.elsevier.com/DPO/suppchapters.php) !

  NOAA Ocean Explorer (http://oceanexplorer.noaa.gov/technology/technology.html)

  W. J. Emery and R. E. Thomson Data Analysis Methods in Physical Oceanography. Elsevier (http://www.sciencedirect.com/science/book/9780444507563)

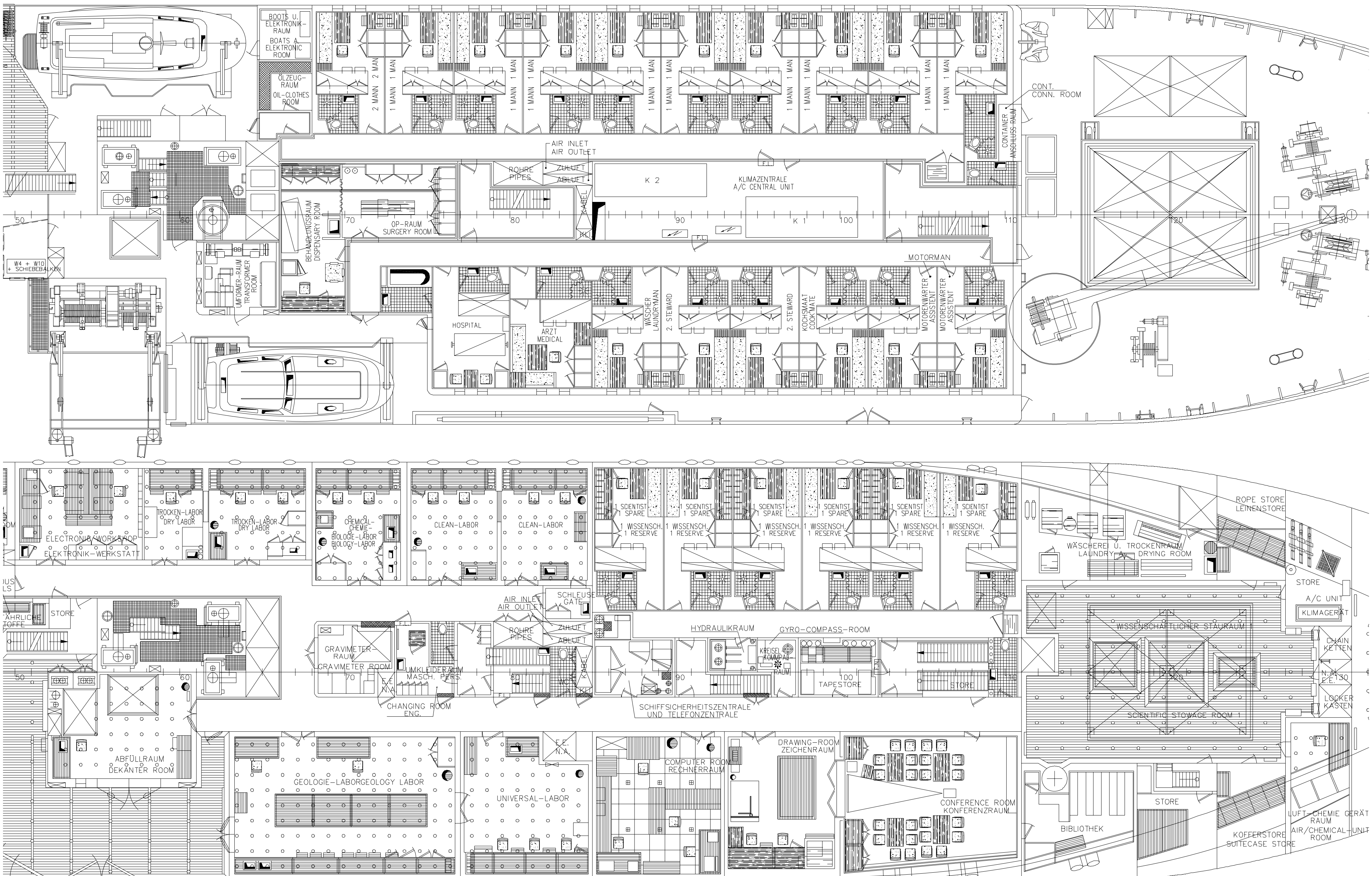
Research Platforms

- Research Vessels
- Moorings
- Floats and Drifters
- Autonomous Vehicles
- Remote Sensing (Satellites)

Research vessel

German research vessel *Meteor*

Research vessel *Meteor*



Length: 98 m, Speed: 12 kn, Range: 10000 nm, Scientists: 30

Research vessel

German polar research vessel *Polarstern*
(breaks through 1.5 m thick ice at a speed of about 5 knots)

Research vessel

Length: 118 m, Speed: 16 kn, Scientists: 55

Measurements from research vessels

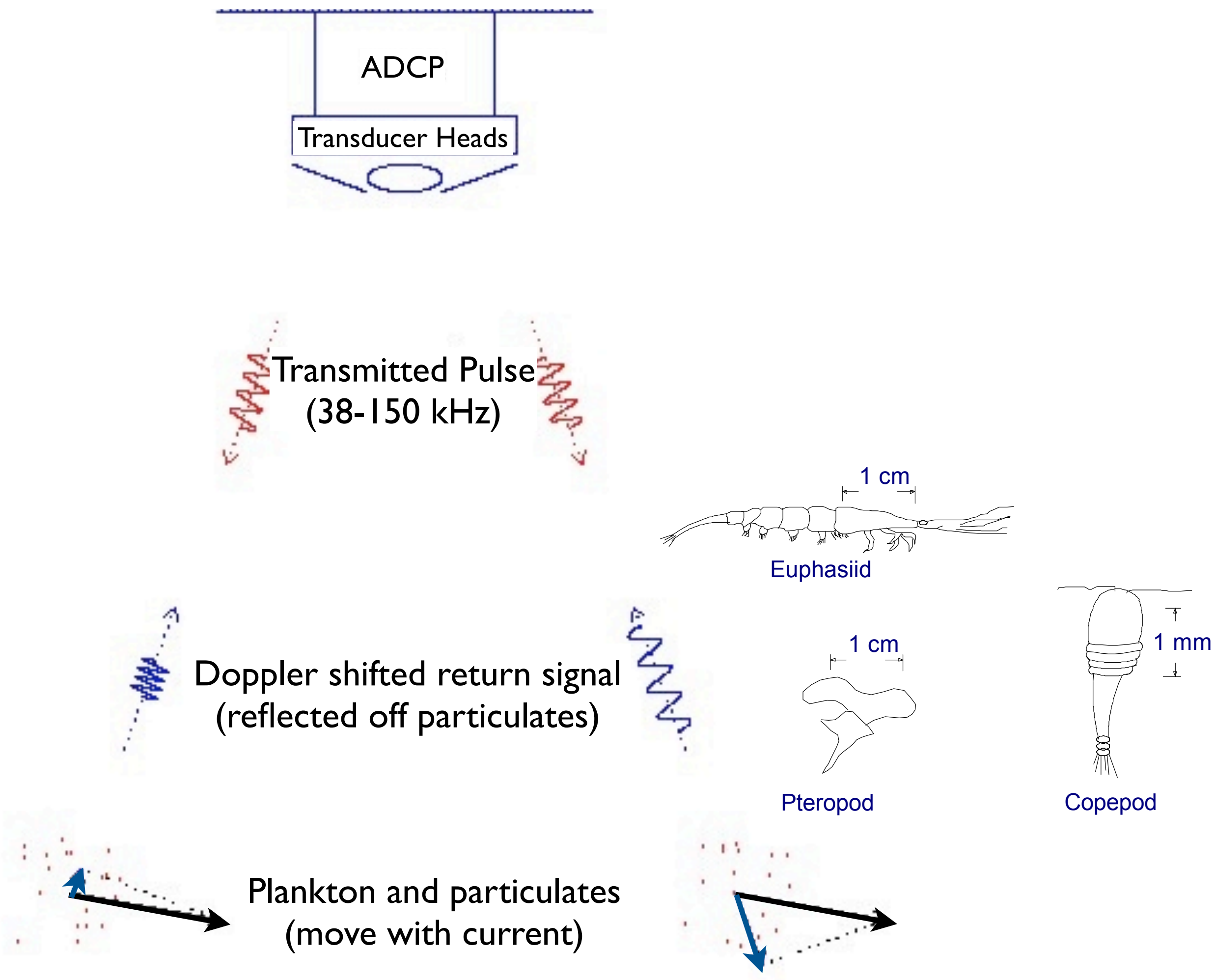
Underway measurements (moving ship)

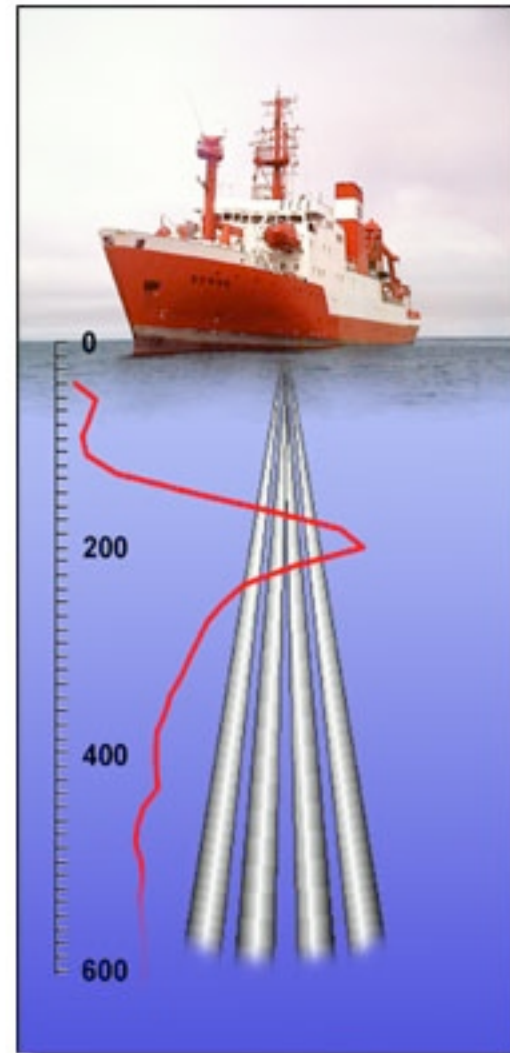
- navigation & echo sounding (latitude, longitude, bathymetry)
- meteorology (air temperature, dew point, wind, radiation)
- sea surface temperature & salinity
- vertical profiles of current velocity (range 150 to 1200 m)
- expendable probes (temperature, conductivity, currents)

Stations (ship stopped)

- CTD (conductivity/salinity, temperature, depth + oxygen, optical backscatter, pH, etc.)
- lowered current profiler (velocity)
- water samples (salinity, oxygen, nutrients, gases, tracers, etc.)
- free falling probes (velocity, microstructure)

Shipboard acoustic Doppler current profiler (ADCP)





(GEOMAR)

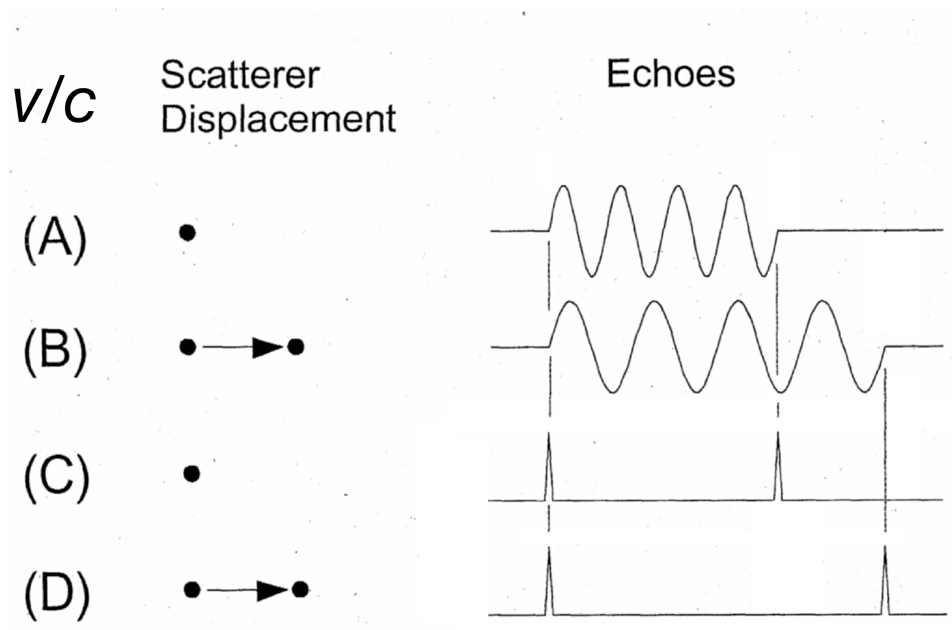
Depth cells:

- range-gating of received echos
- profile from each pulse

ADCP measurement principle

Narrowband (A+B)

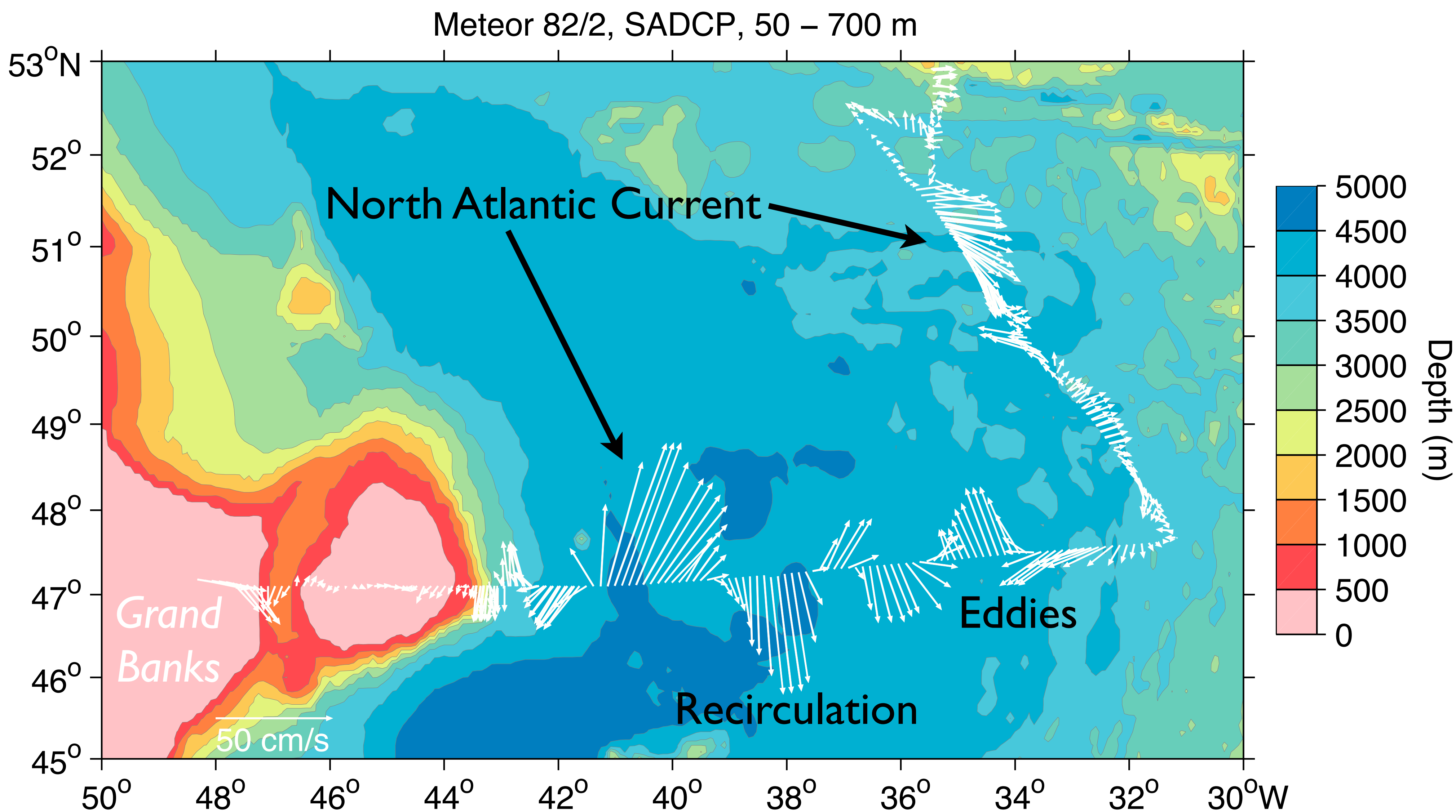
- send ping
- ping reflected by moving particle of size 1 mm to 1 cm (e.g. plankton)
- measure Doppler frequency shift
- obtain velocity from shift as $\Delta f = f\, v/c$



Broadband (C+D)

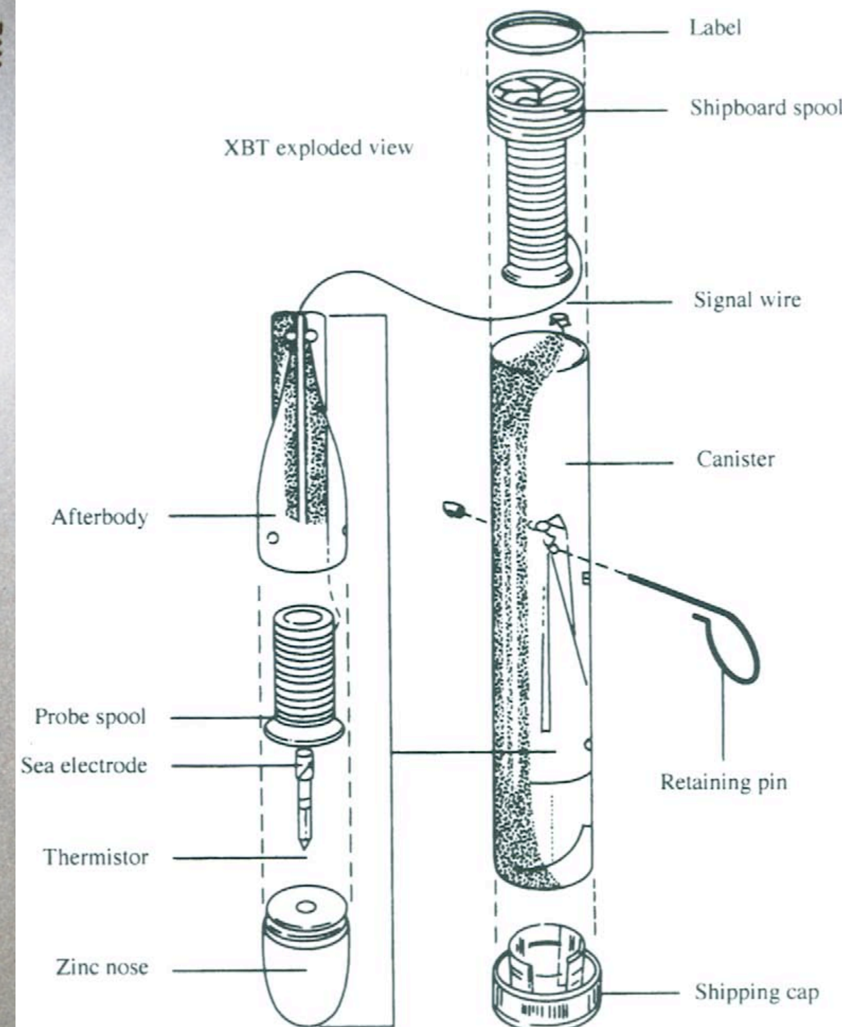
- longer modulated signal (pulse); code
- change in the length of the signal (determined by autocorrelation)
- time delay yields velocity
- higher accuracy but shorter range

Shipboard ADCP measurements in the western subpolar North Atlantic

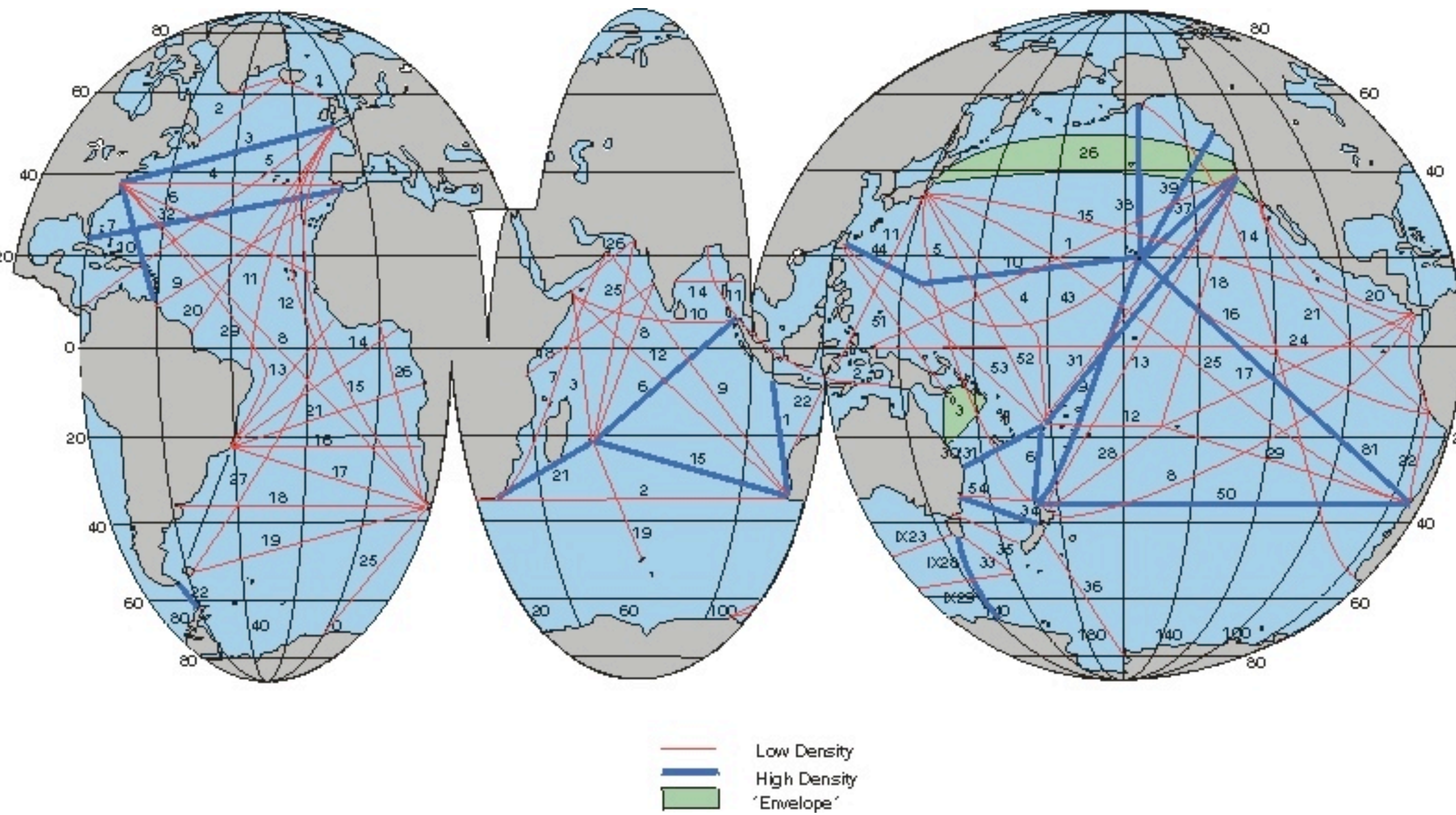


Mean velocity in averaged from 50 to 700 m

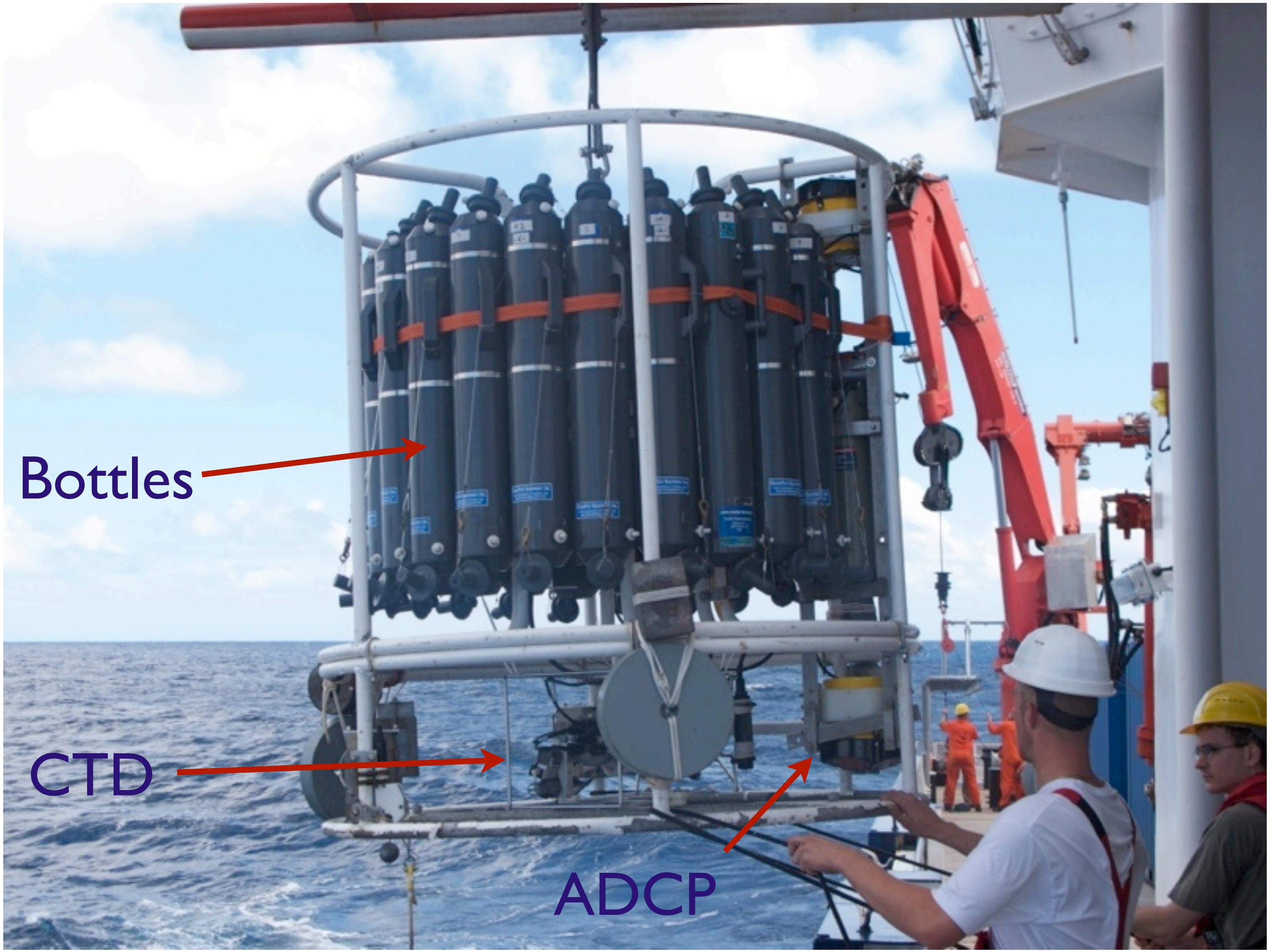
Expendable bathythermograph (XBT)



Volunteer observing ships

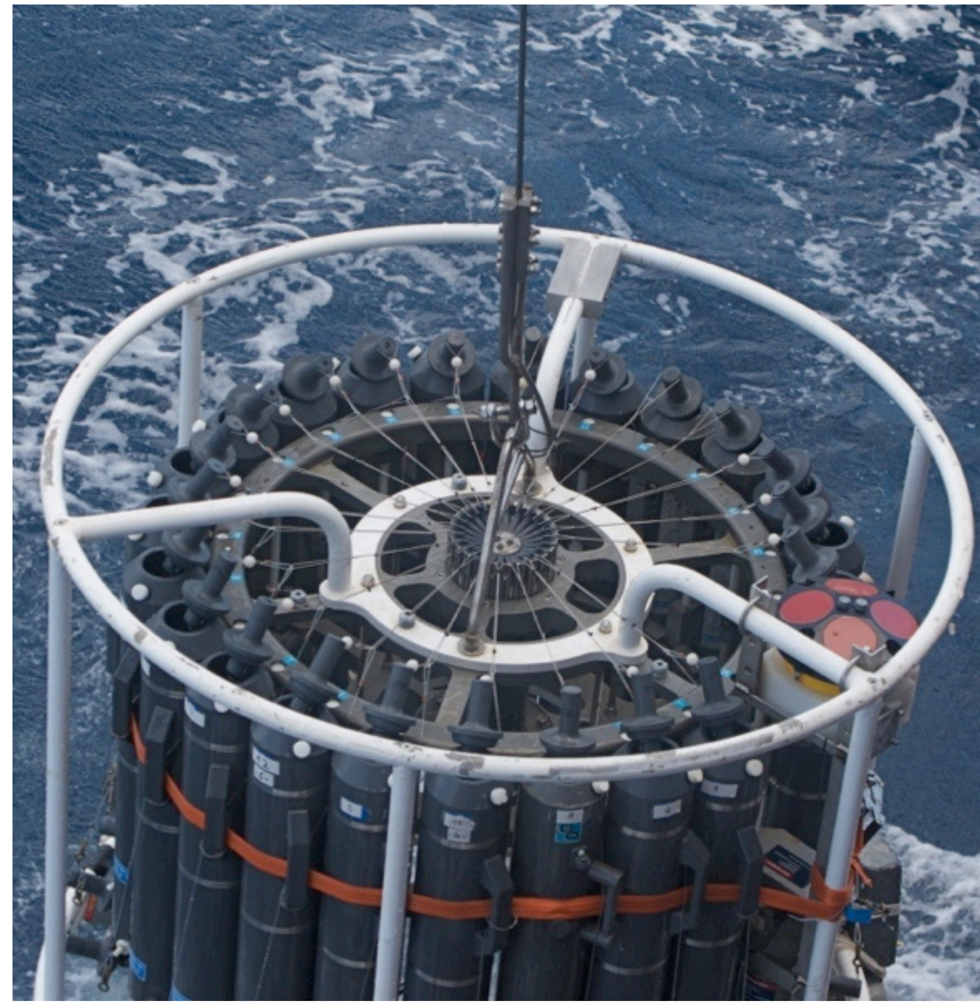


Stations: Water sampling carousel Niskin bottles, ADCPs and CTD

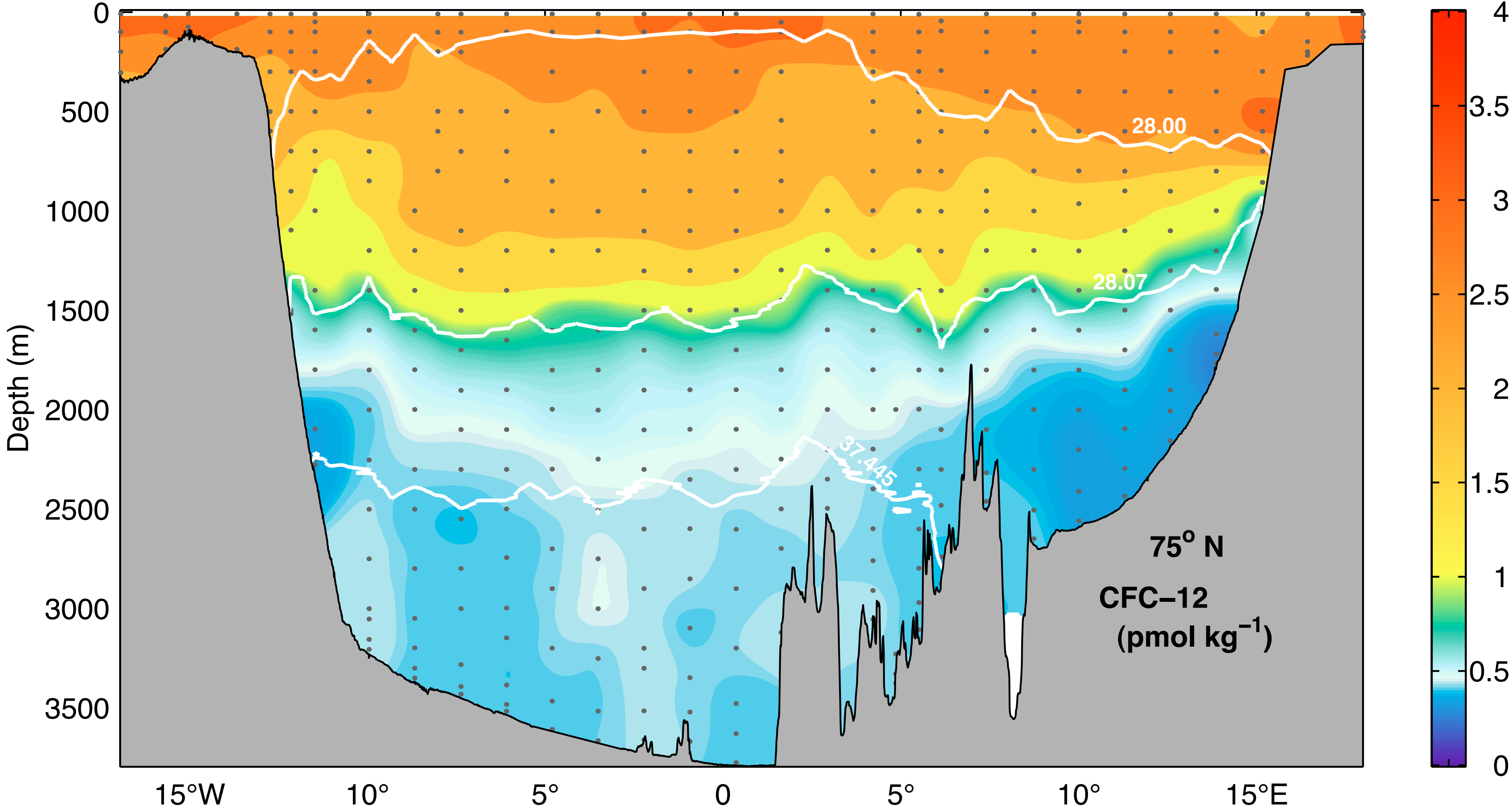


Water samples (lab analysis)

- chemical analysis (eg. oxygen, nutrients)
- electrochemical: salinity (Salinometer)
- chromatography (gases, eg. CH_4, CFCs)
- spectroscopy (noble gases, eg. ^3He, Ne)



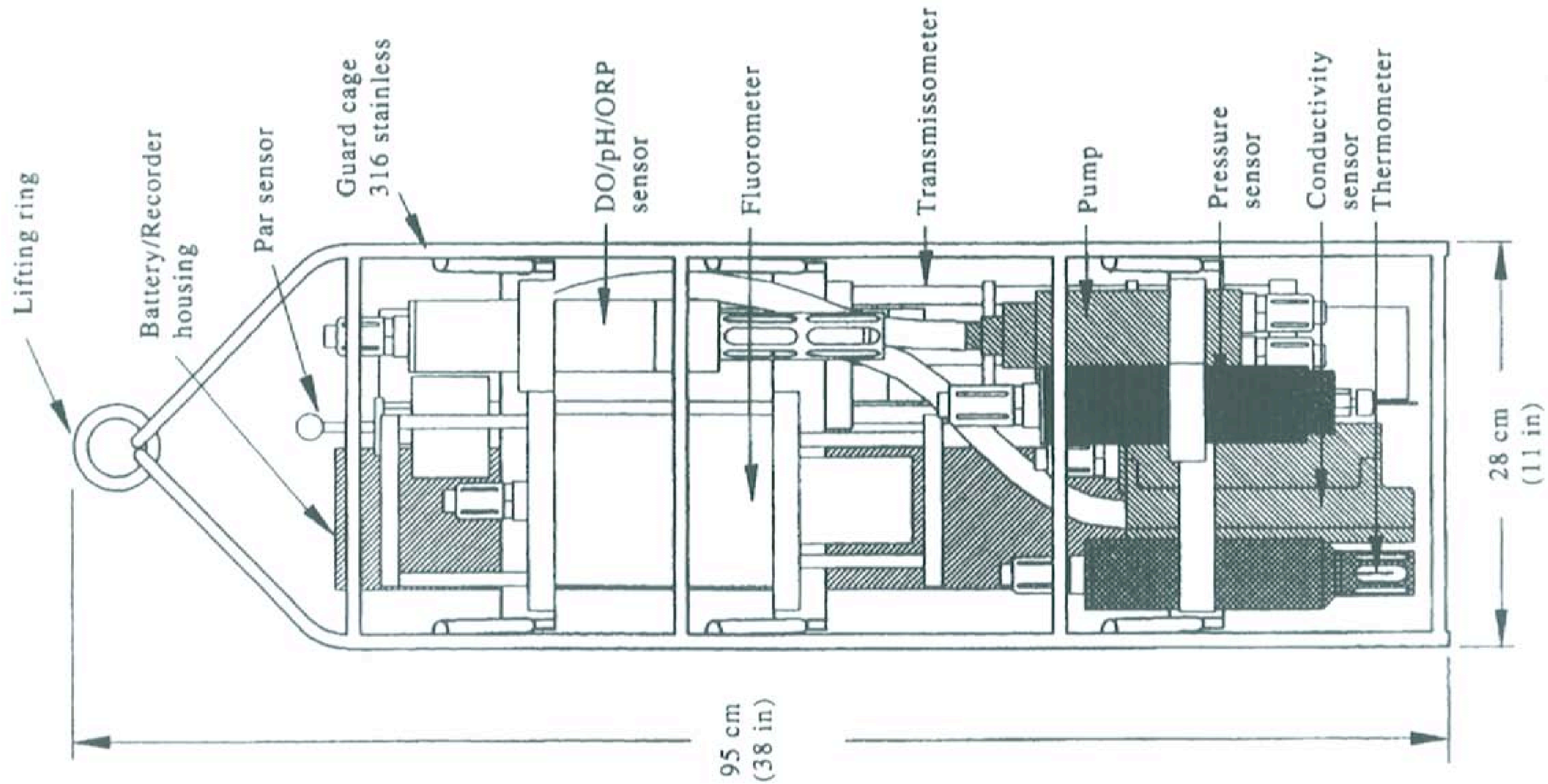
Trace Gases



CFC-12 (anthropogenic) section at 75°N across the Greenland and Norwegean Seas

Water sampling carousel with Niskin Bottles, CTD and downward looking ADCP

CTD: Conductivity, Temperature, Depth



(from Emery and Thomson, 2001)

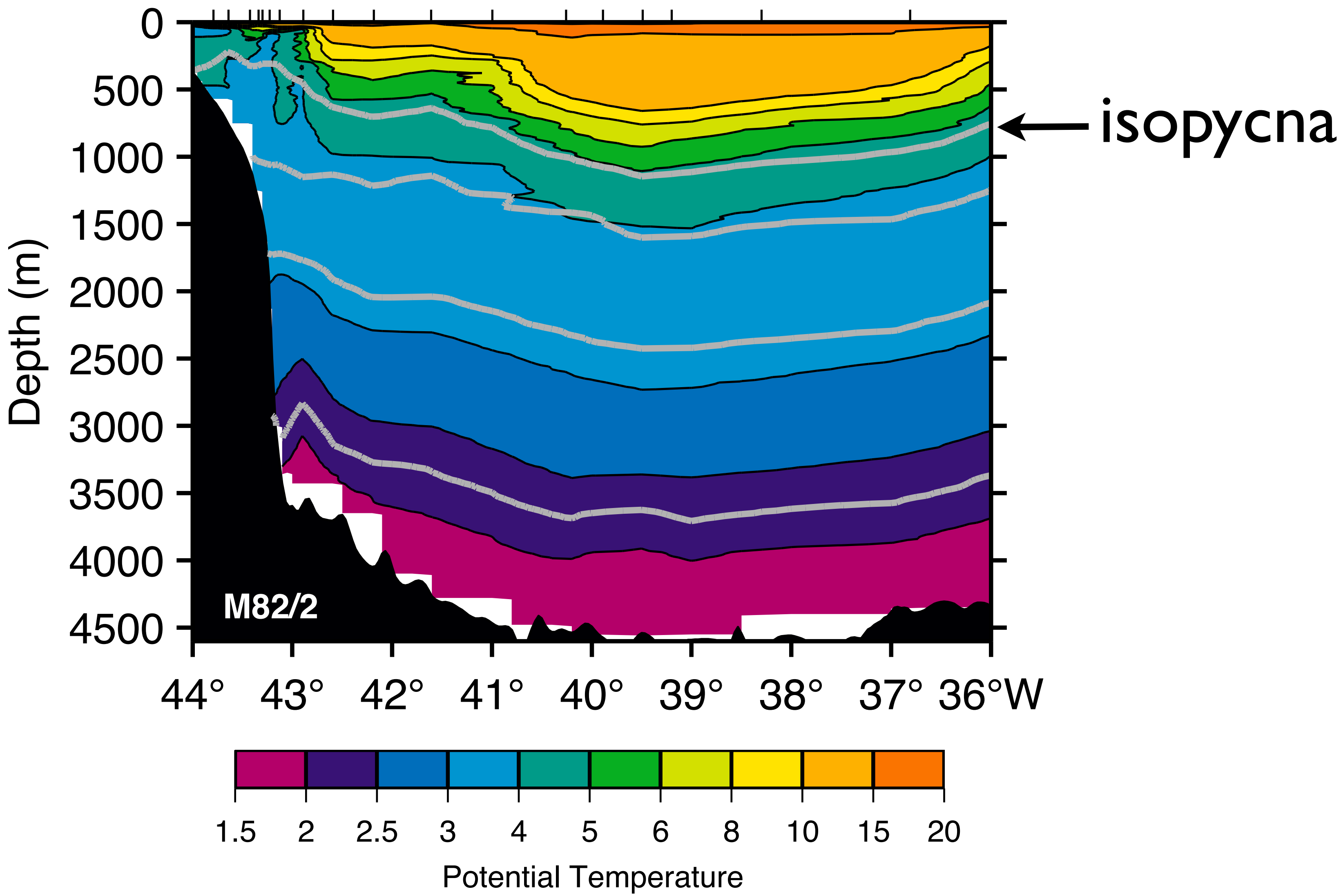
Temperature

- pressure-protected, high-speed thermistor
- initial accuracy: ± 0.001 °C

Depth

- Digiquarz pressure sensor: quartz crystal resonator whose frequency of oscillation varies with pressure induced stress
- accuracy: 0.01% of full range (e.g. 0.6 dbar for 6000 dbar range)

Pot. Temperature, Θ (°C)



Example from the North Atlantic (47°N)

Conductivity/Salinity

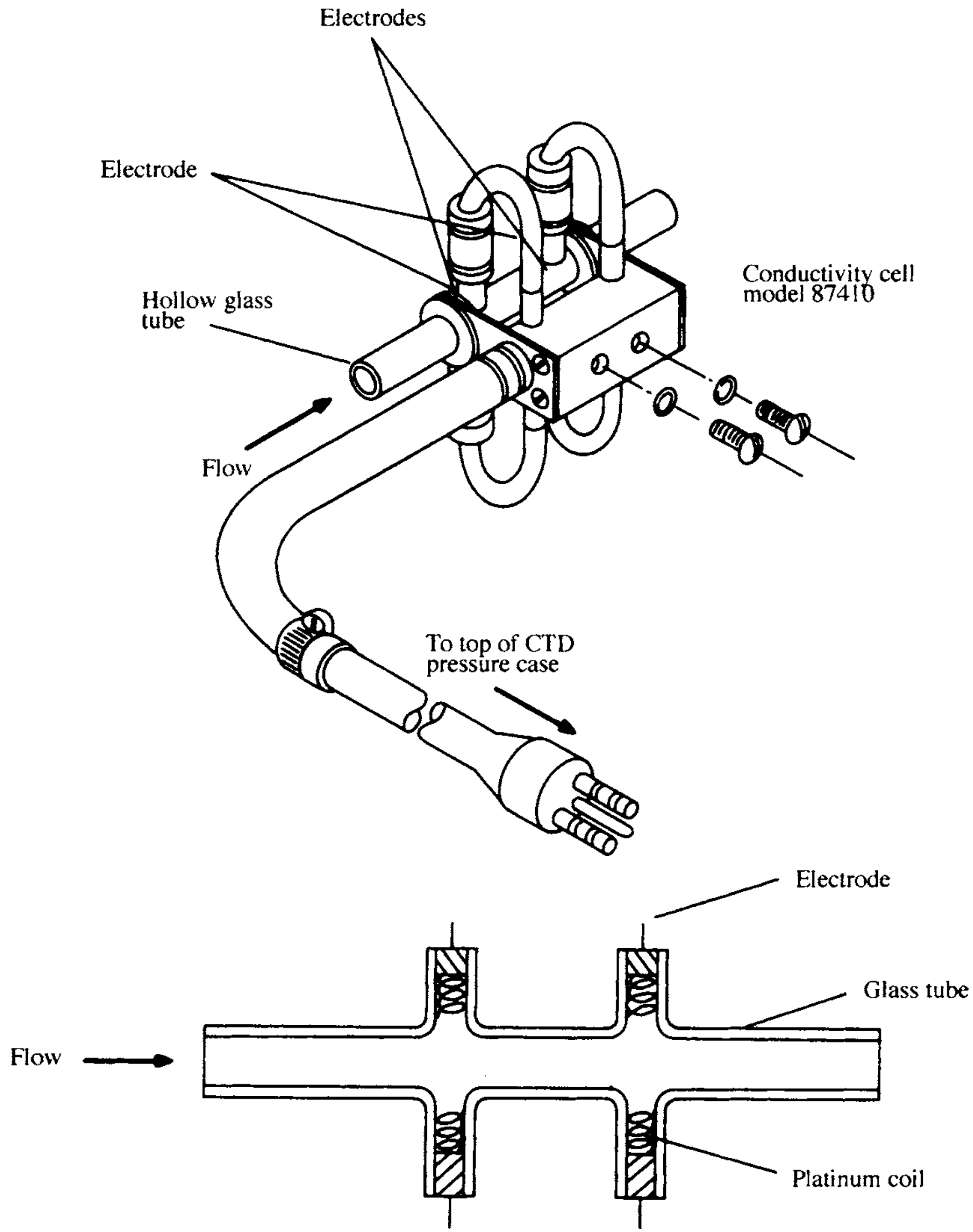
In situ:

- cylindrical, flow-through, borosilicate glass cell with three internal platinum electrodes
- initial accuracy: ± 0.0003 S/m (± 0.003 mS/cm)

Density

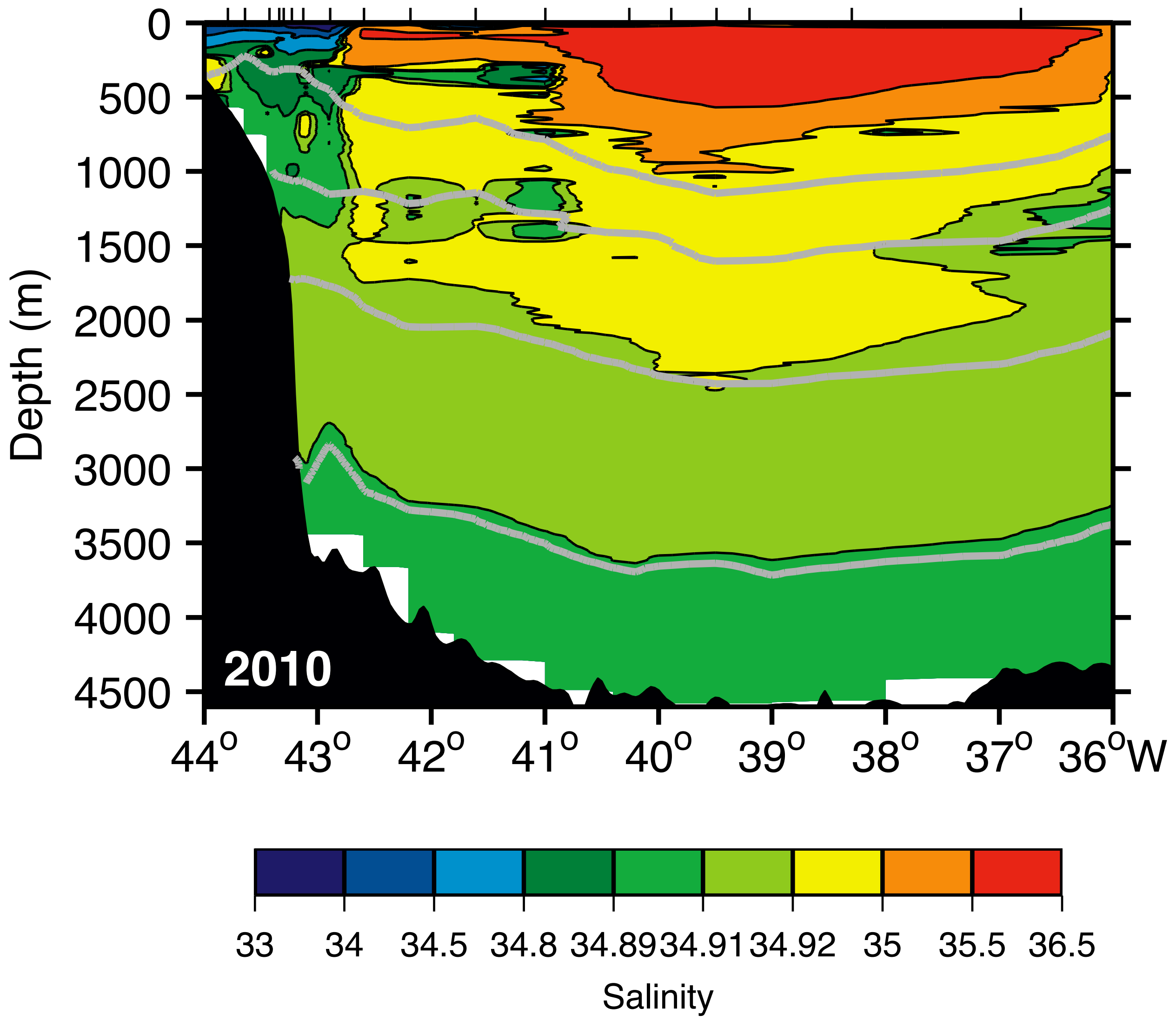
- via equation of state from T,S,p

Conductivity cell



(from Emery and Thomson, 2001)

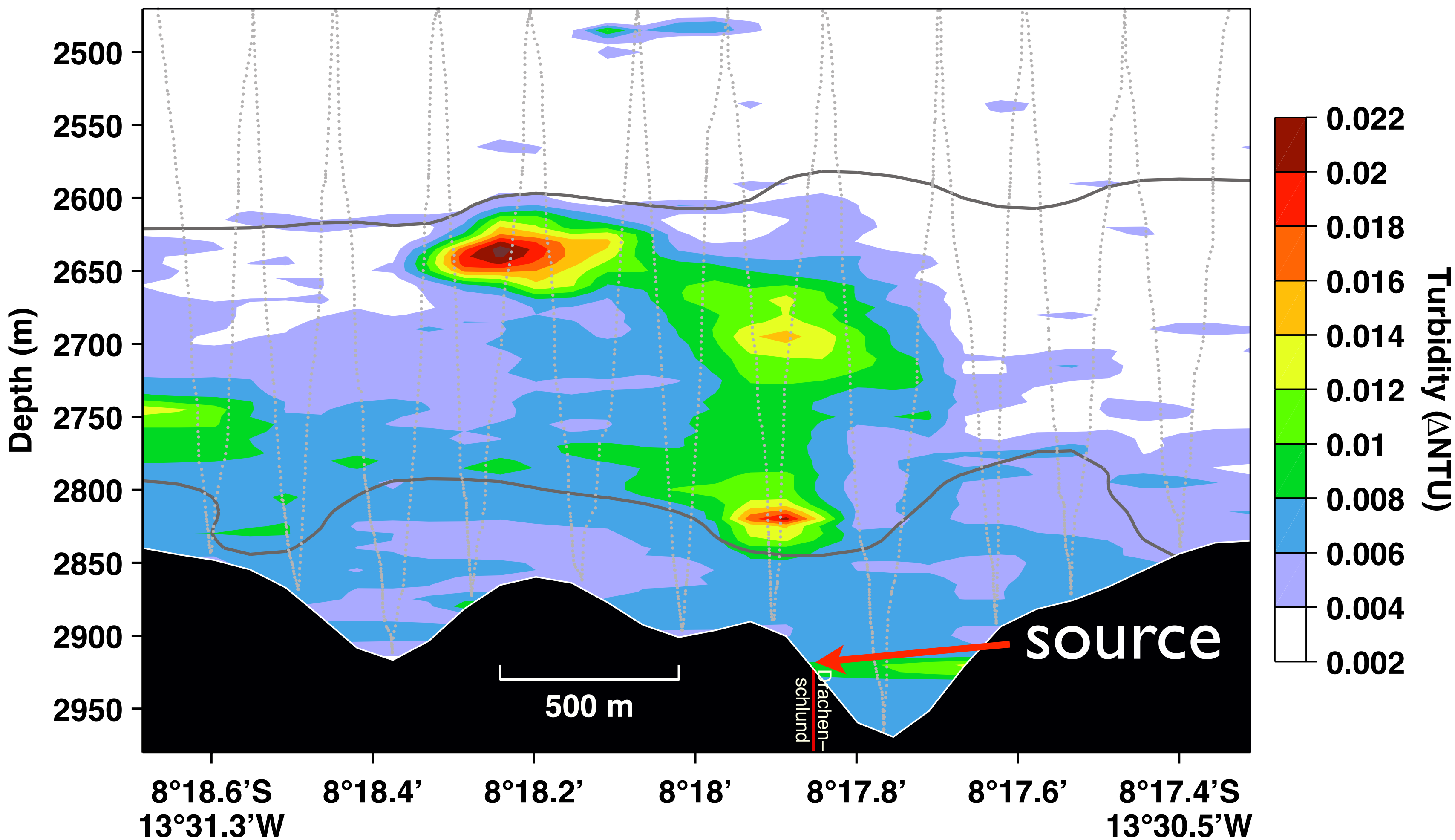
Salinity



Example from the North Atlantic (47°N)

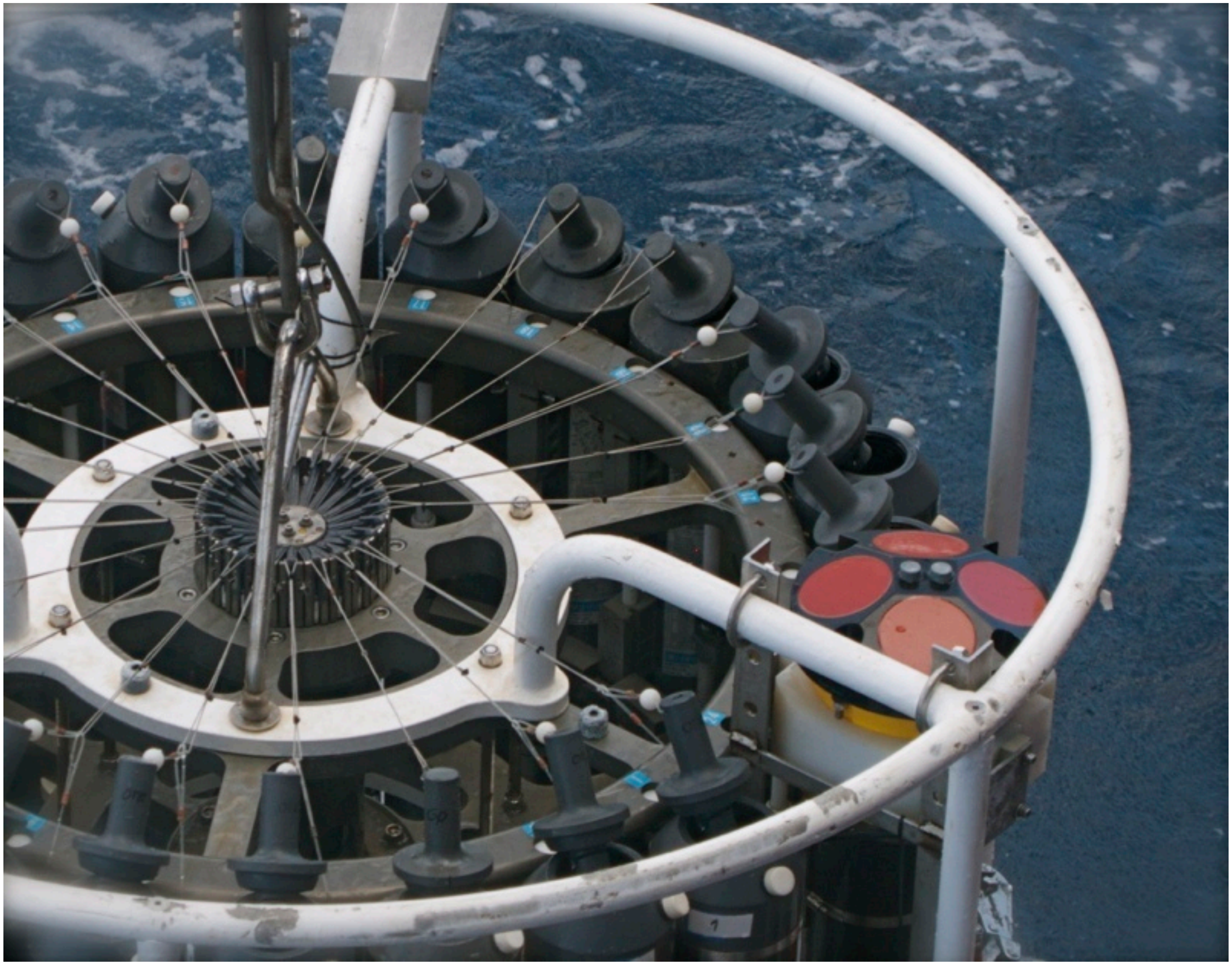
Optics/Turbidity

- light transmission or optical backscatter



Example at a hydrothermal vent site from towed CTD measurements

Lowered ADCP: Velocity profiling with ADCPs



LADCP Setup

upward looking ADCP

battery case

downward looking ADCP

300 kHz Workhorse ADCP

Lowered ADCP (LADCP)

Small profiles are joined to a single **surface-to-seafloor velocity profile**.

Measured velocity is given by:

$$U_{meas}(t) = U_{ref} + U_{baroclinic}(z) - U_{instr}(t)$$

$U_{baroclinic}$ is calculated from measurements

$$U_{baroclinic}(z) = \int \frac{\Delta U_{meas}}{\Delta z_{bin}} dz$$

Reference velocity is calculated from ship's position, assuming that the ocean currents vary little during the station

$$U_{ref} = \frac{1}{T}\left(\int U_{meas}dt - \int U_{baroclinic}dt + \Delta X\right)$$

$$\Delta X = \int U_{ship}dt$$

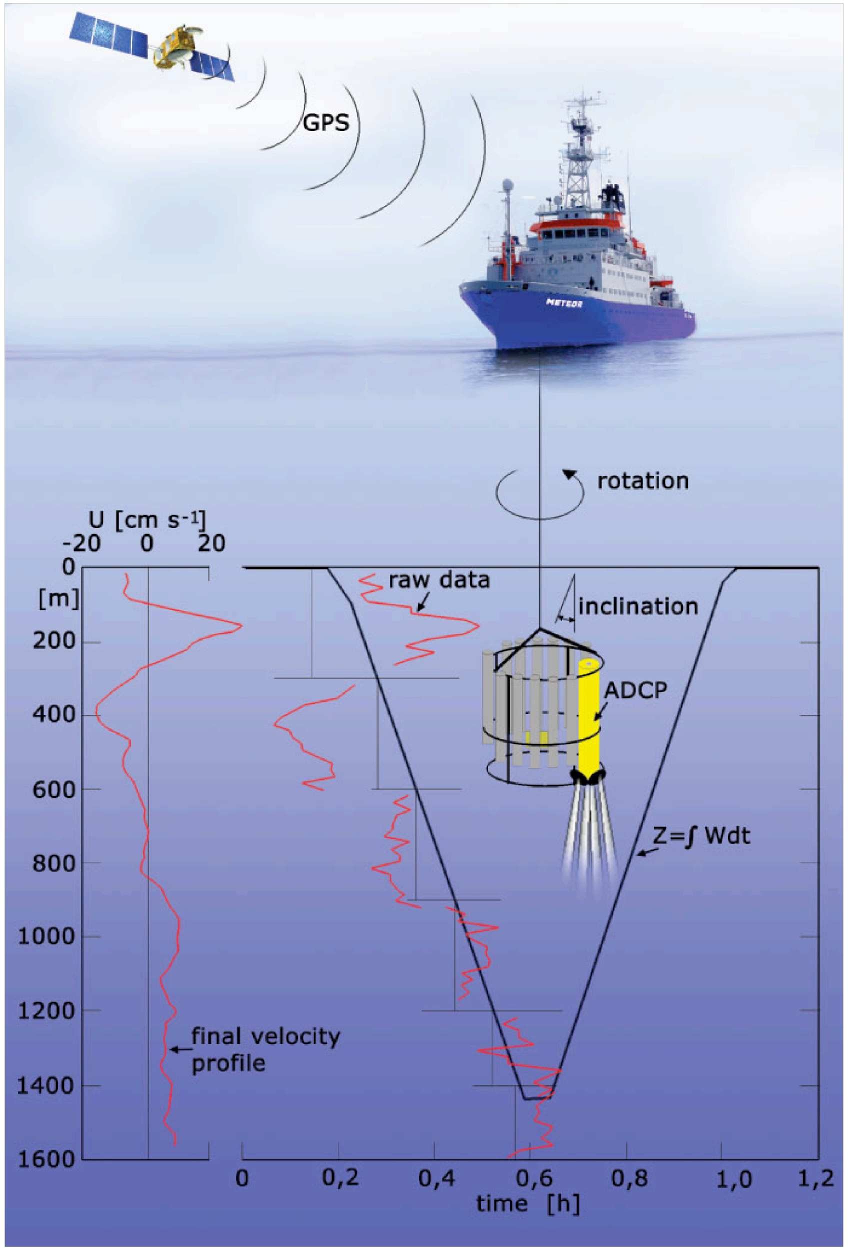
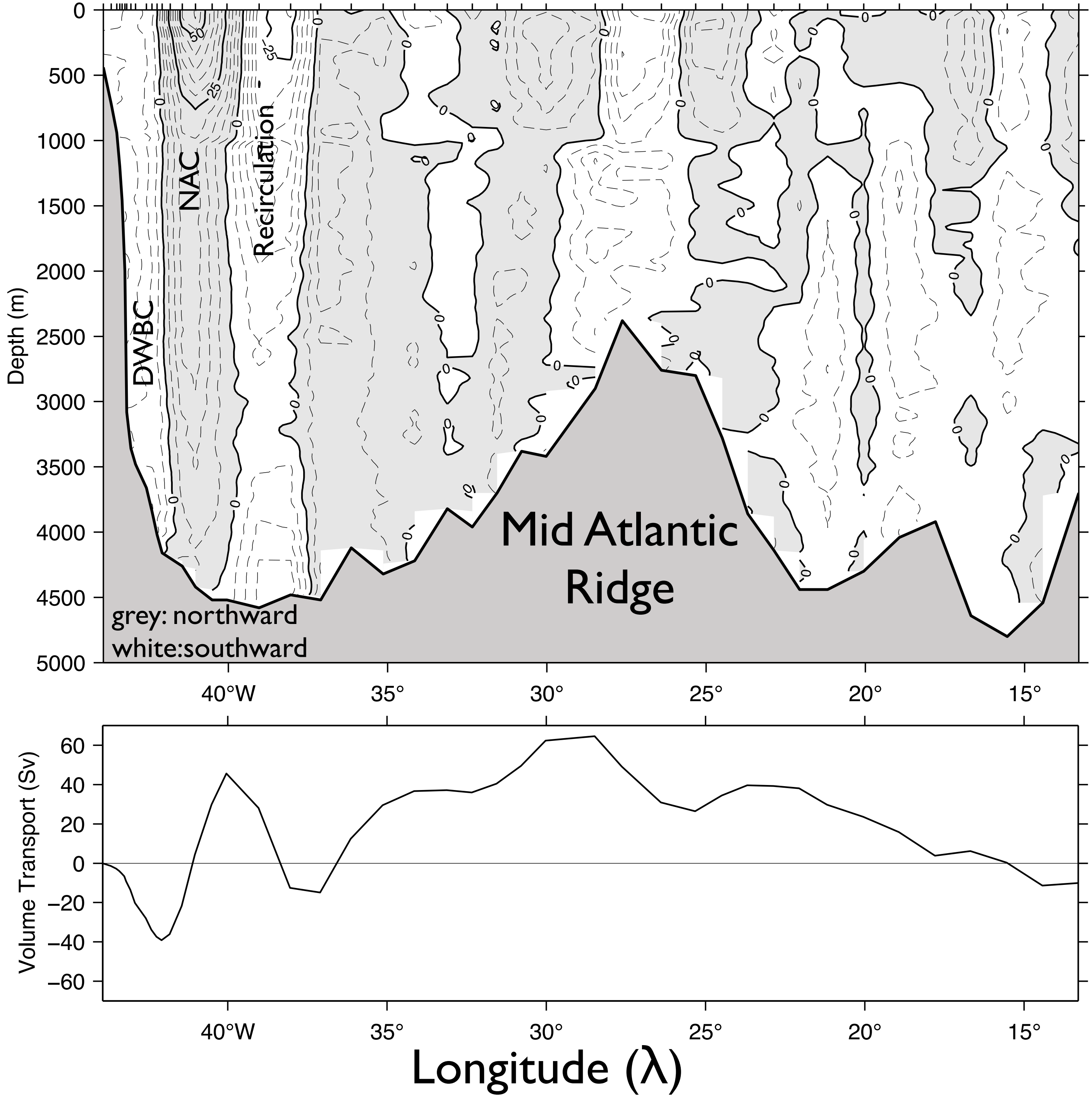
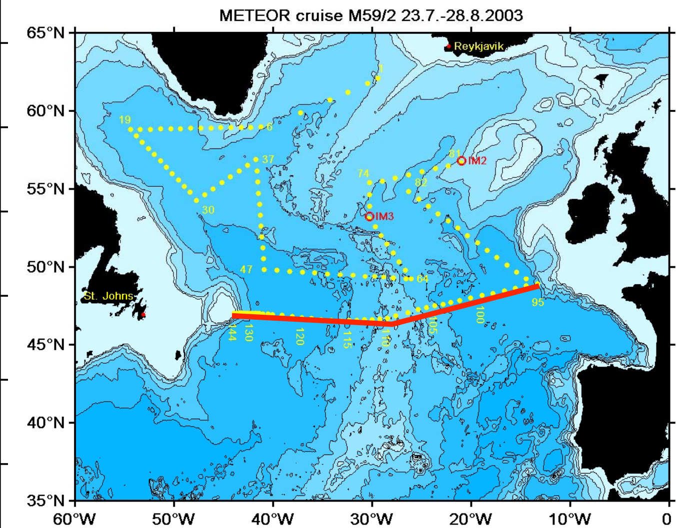


Figure after Fischer et al., 1993

LADCP section across the North Atlantic





North-south current & volume flux, ~48°N

Volume transport:

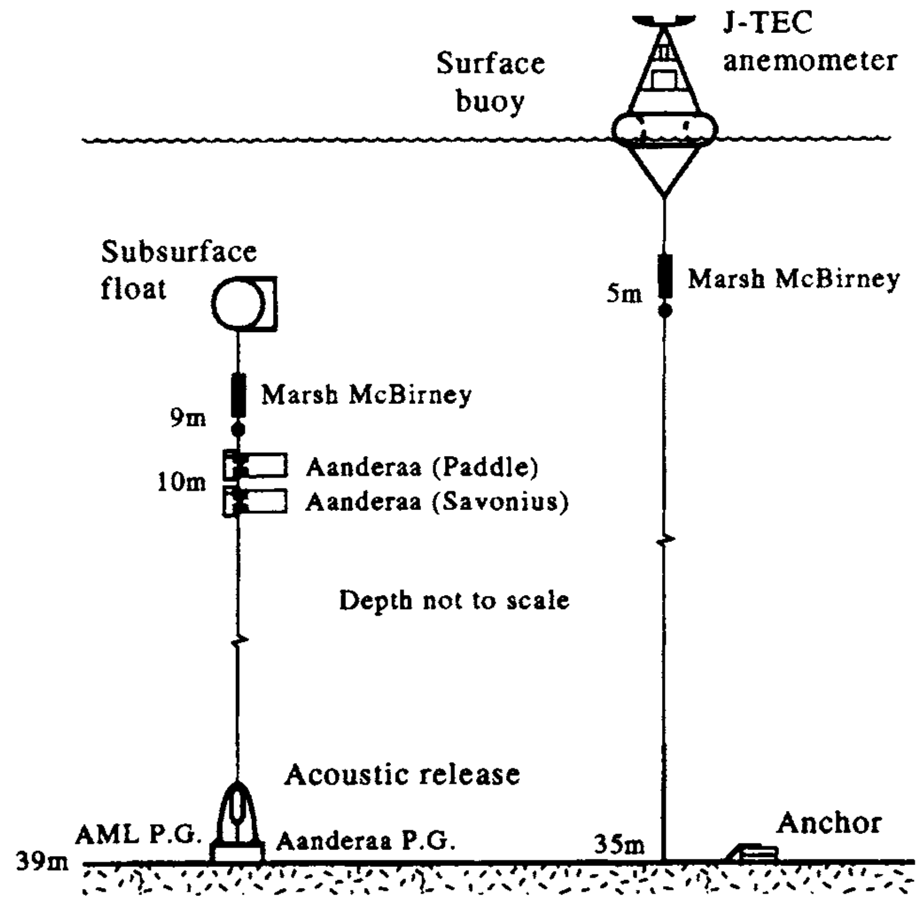
$$V = \frac{\pi a}{180^\circ} \cos\varphi \int_{west}^{\lambda_{east}} \int_{bottom}^{top} v\,dz\,d\lambda$$

a: Earth radius

φ: Latitude

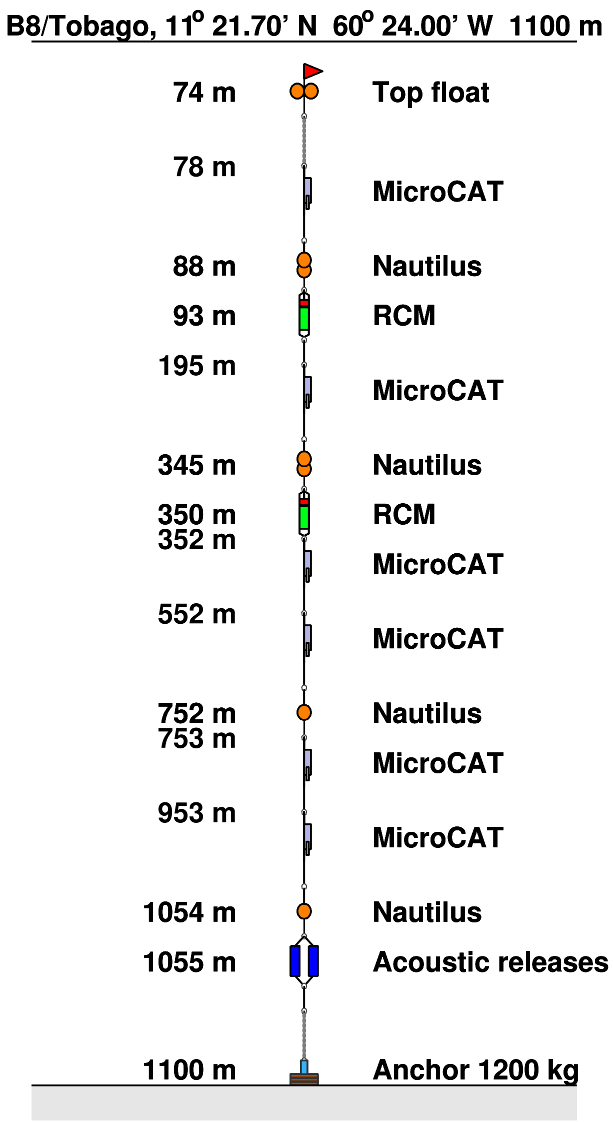
Moorings and bottom mounted equipment

- current meters & profilers
- temperature & conductivity recorders
- moored profilers
- upward looking sonars
- inverted echo sounders
- pressure gauges
- sound sources

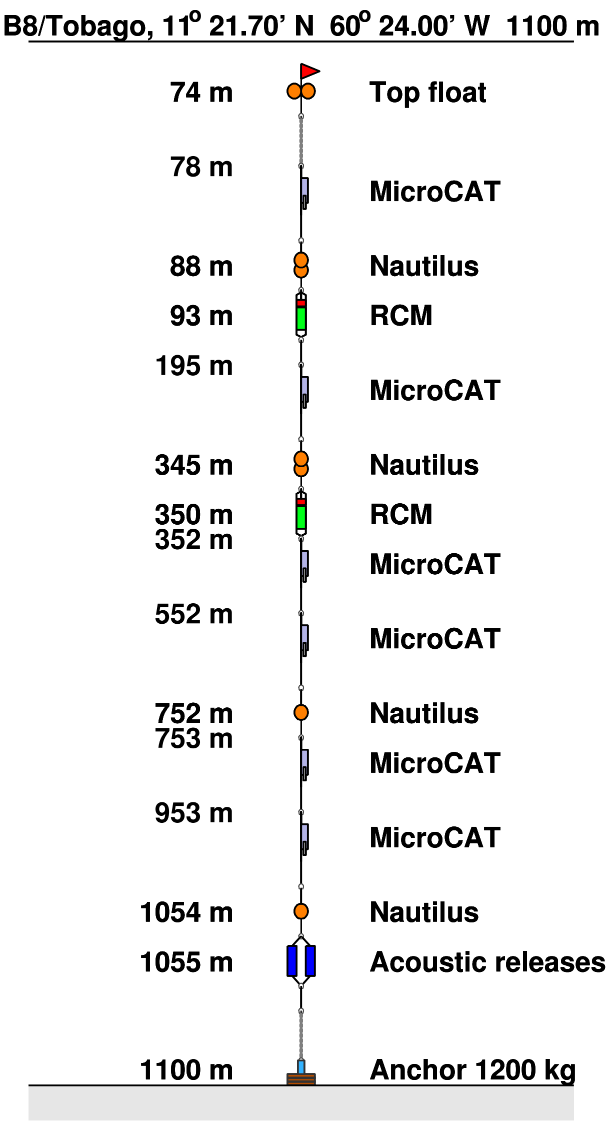


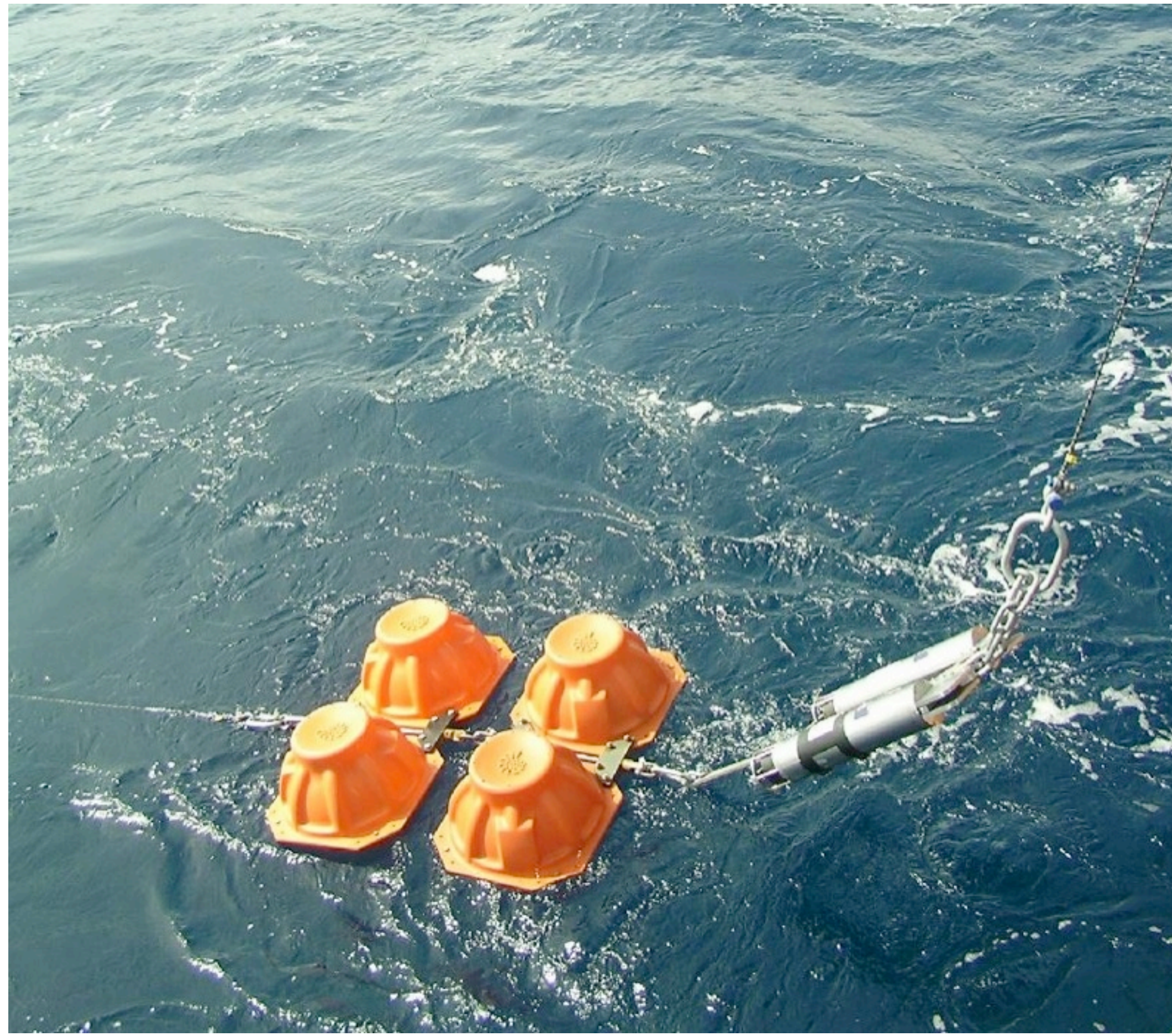
from Emery and Thomson, 2001

Moorings: Anchor

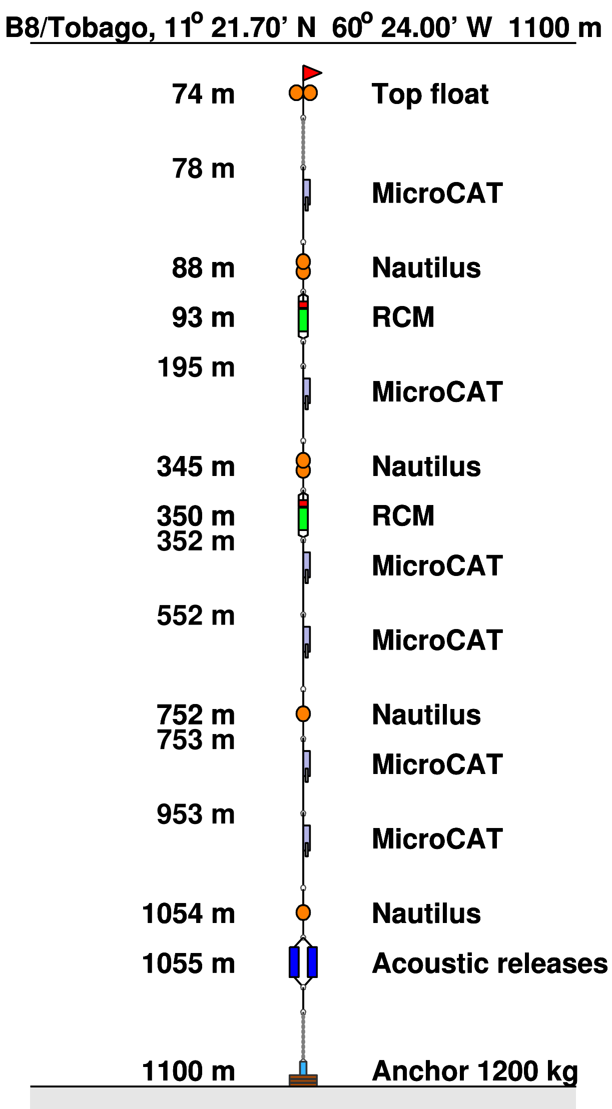


Moorings: Acoustic release and buoyancy

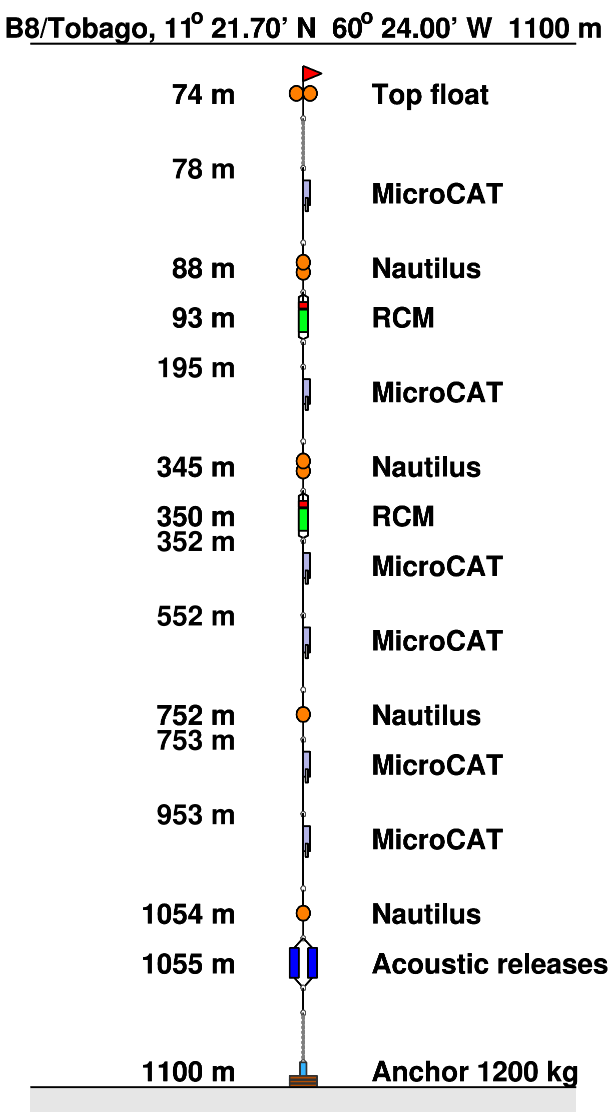


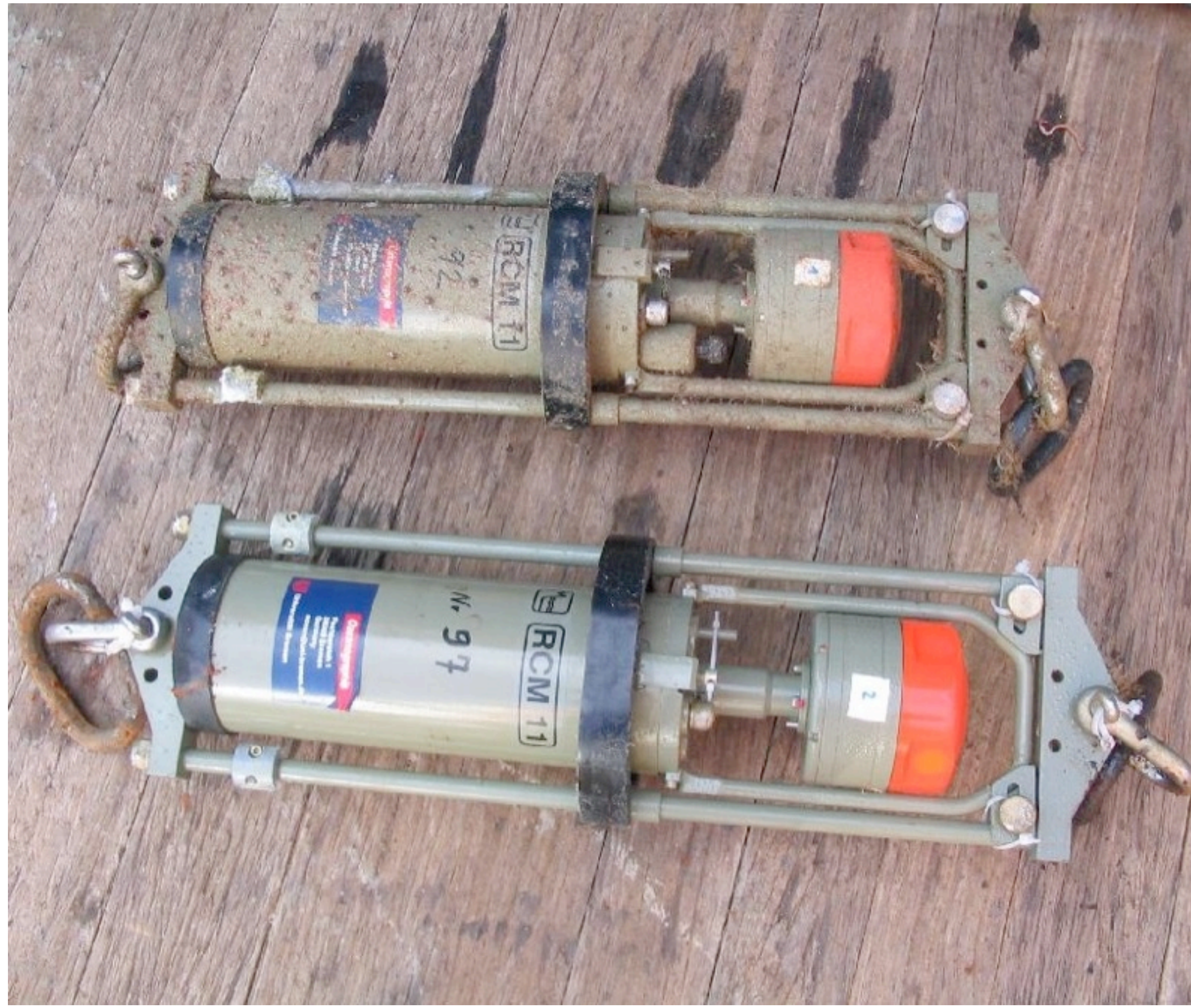


Moorings: Temperature/conductivity recorder (MicroCAT)

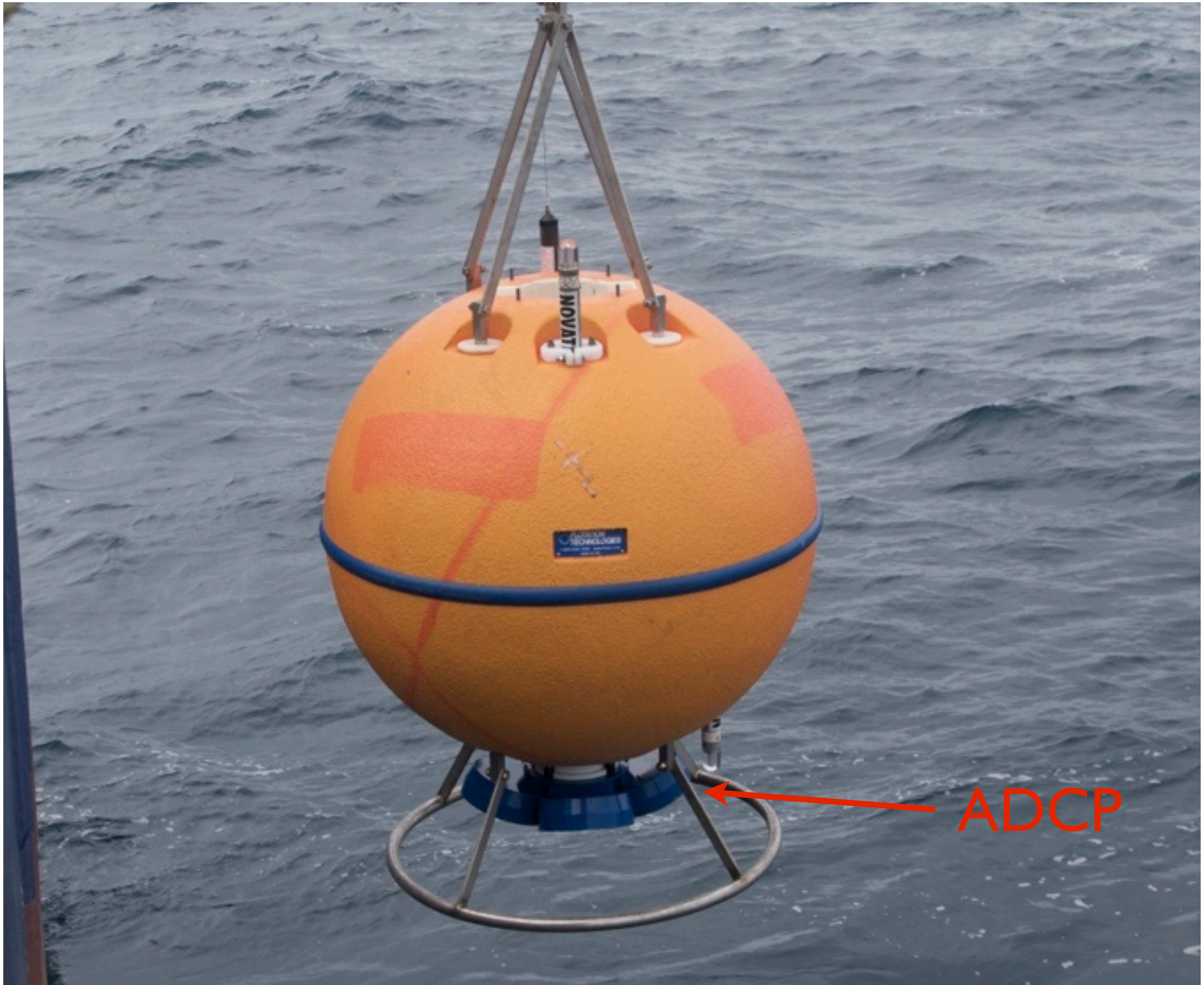


Moorings: Acoustic current meter (RCM)

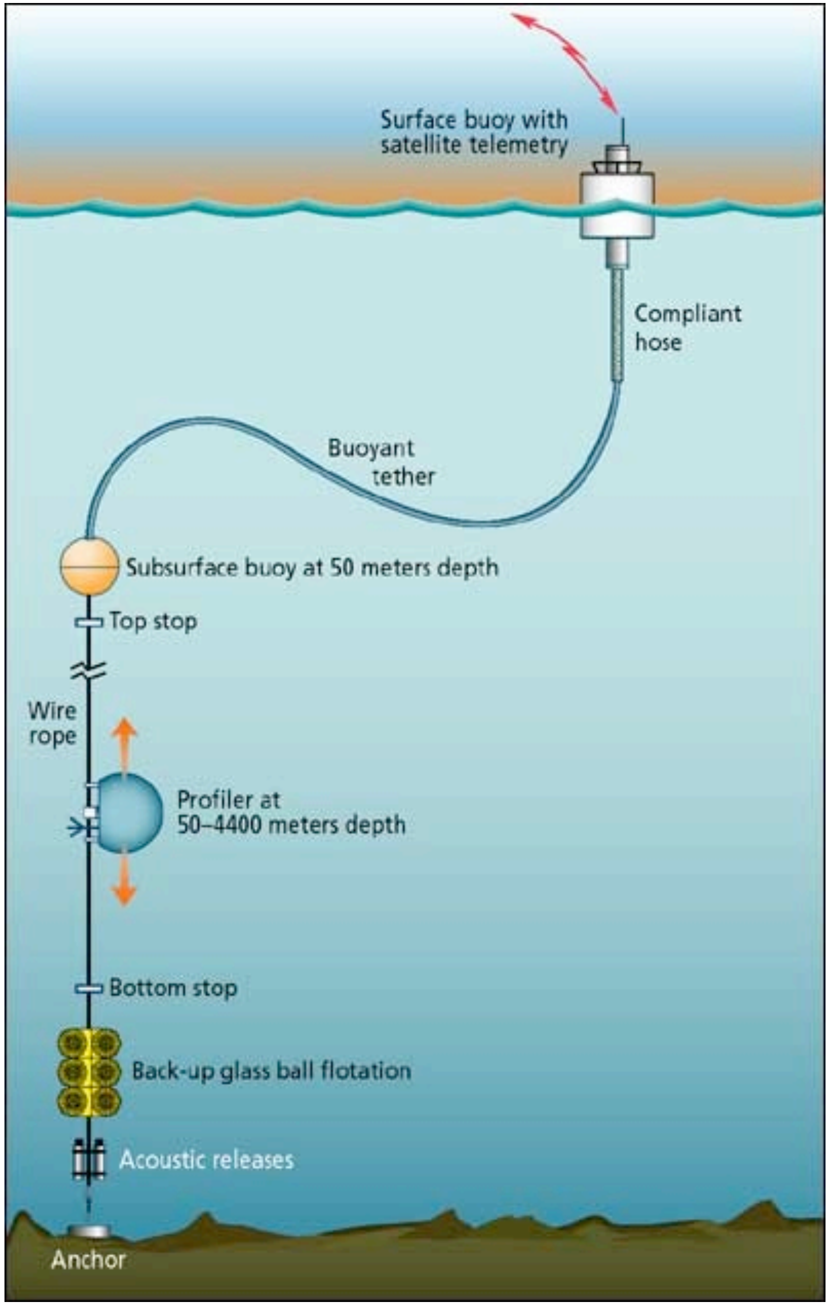


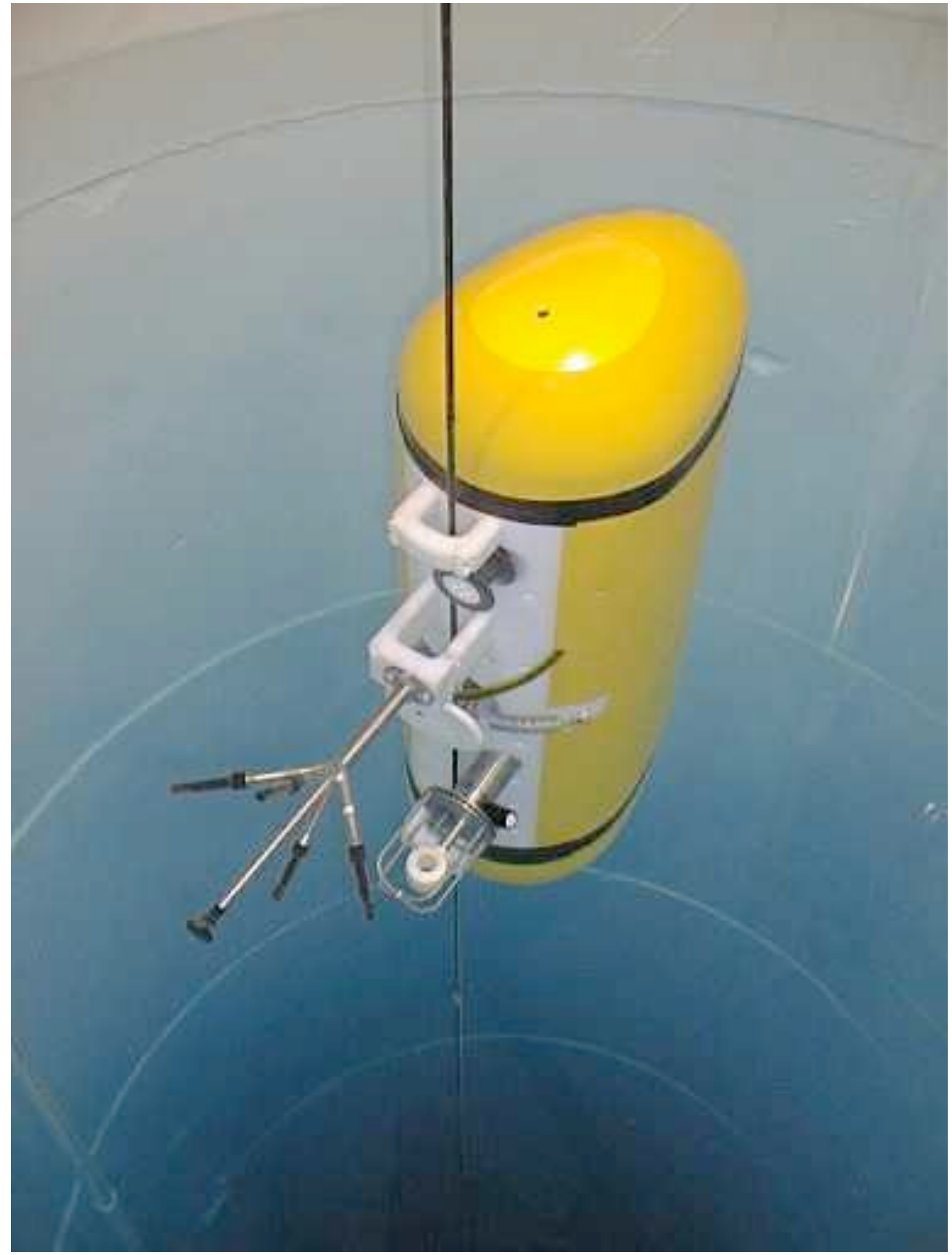


Moorings: Moored ADCP

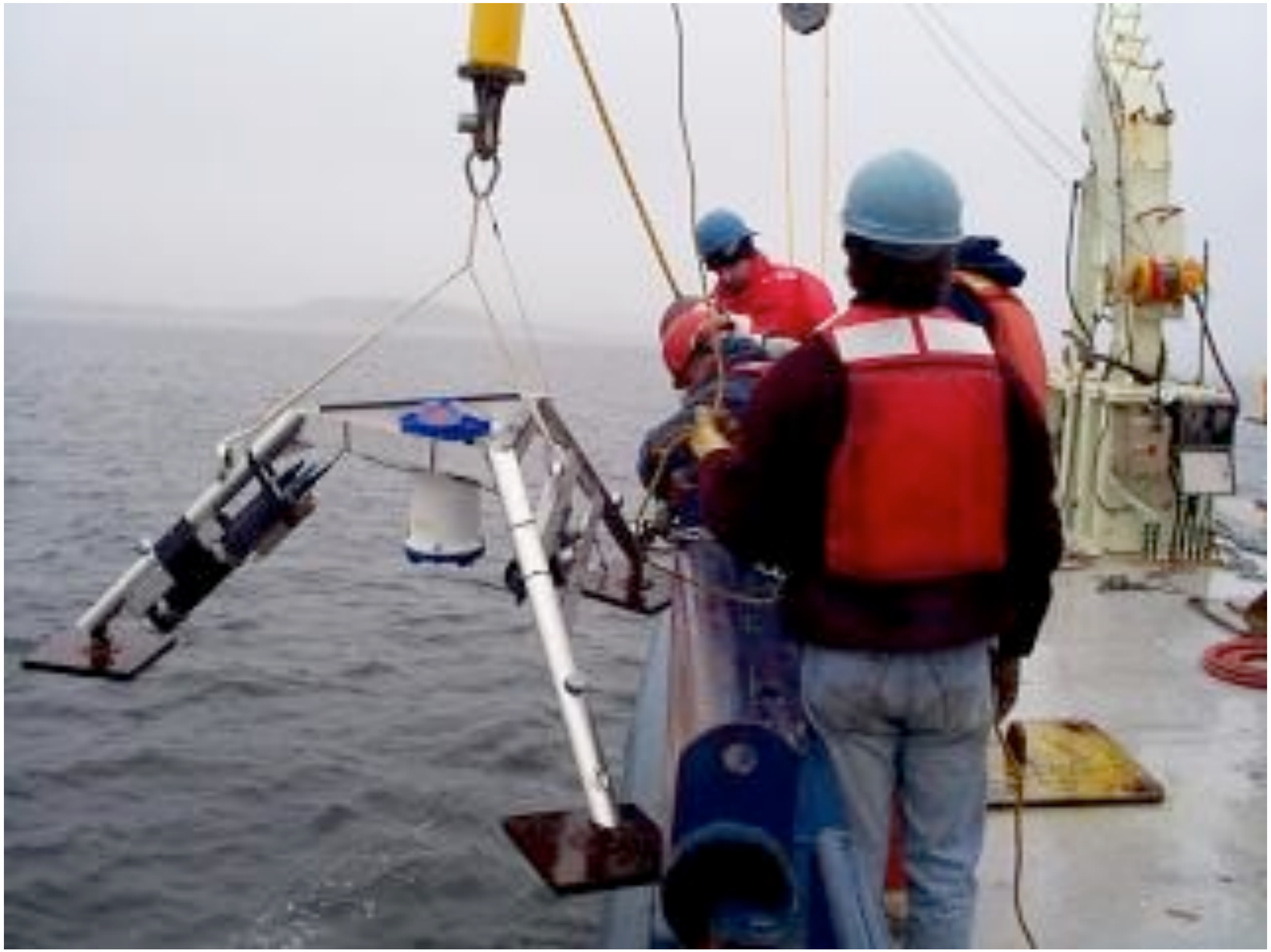


Moored profiler

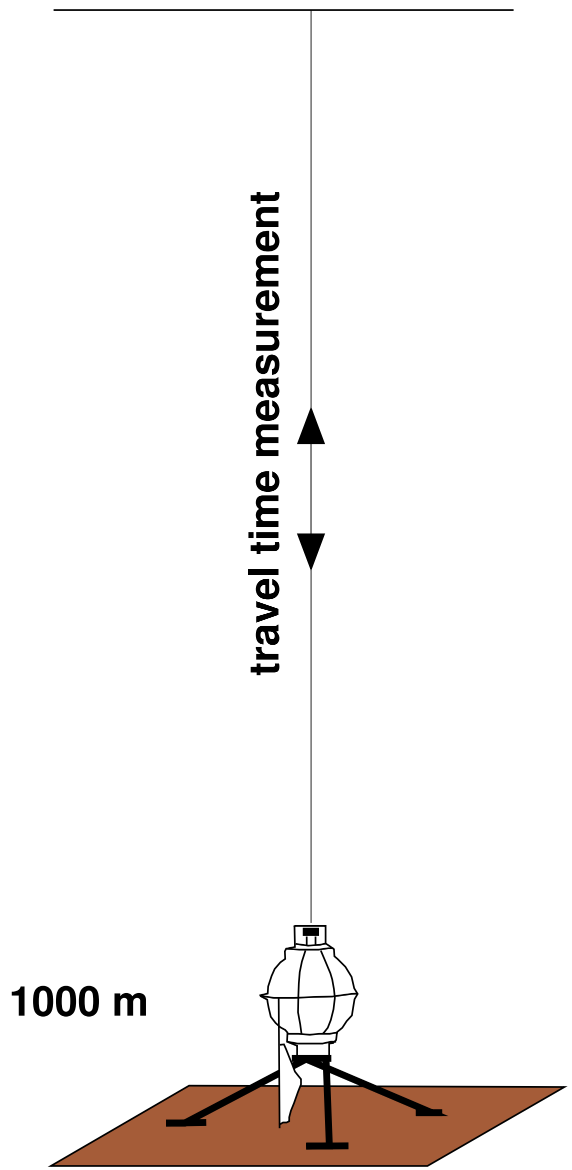




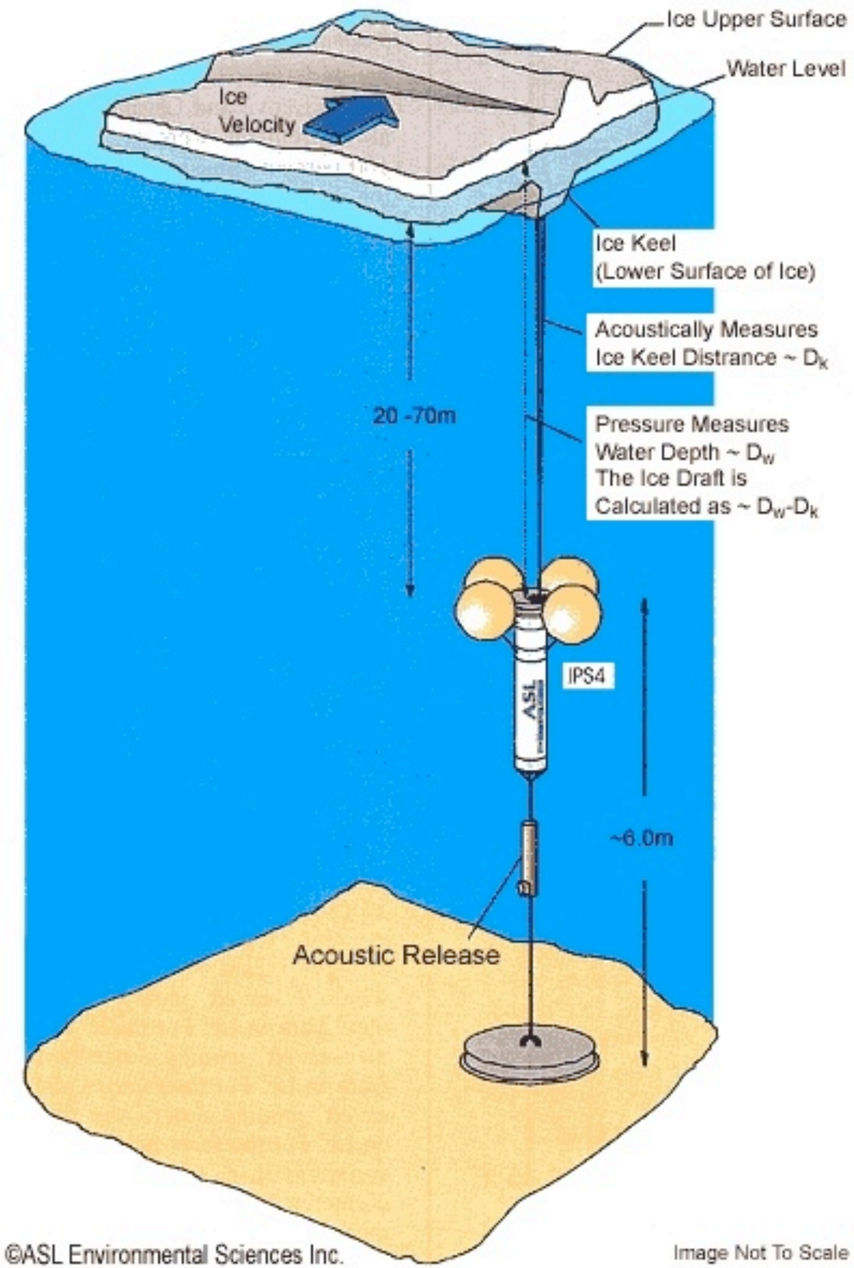
Bottom mounted ADCP



Inverted echo sounder (PIES)



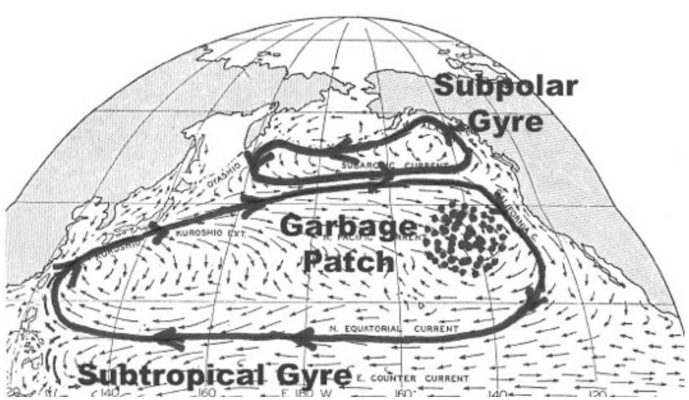
Upward looking sonar (ULS)

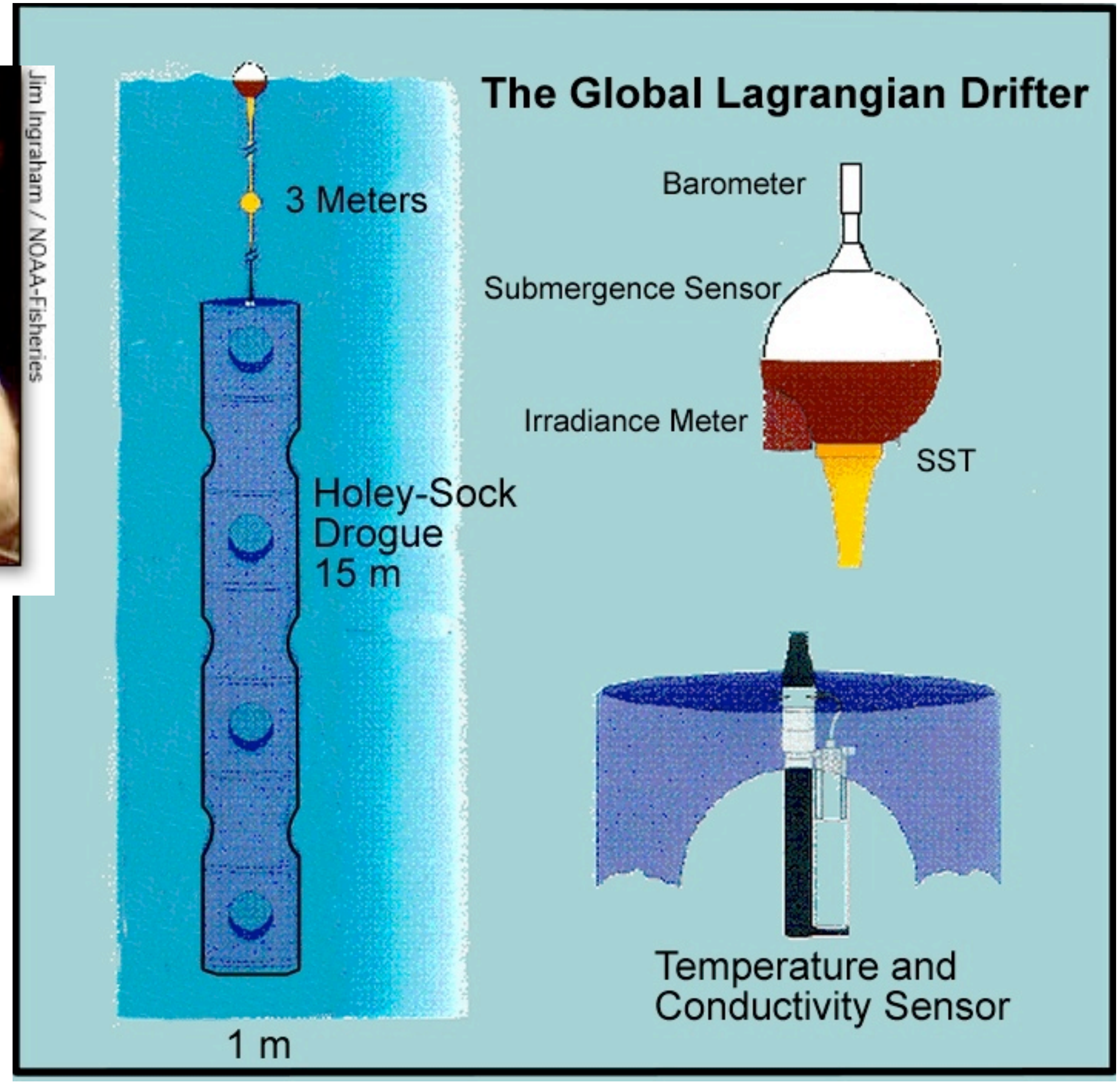


Autonomous vehicles

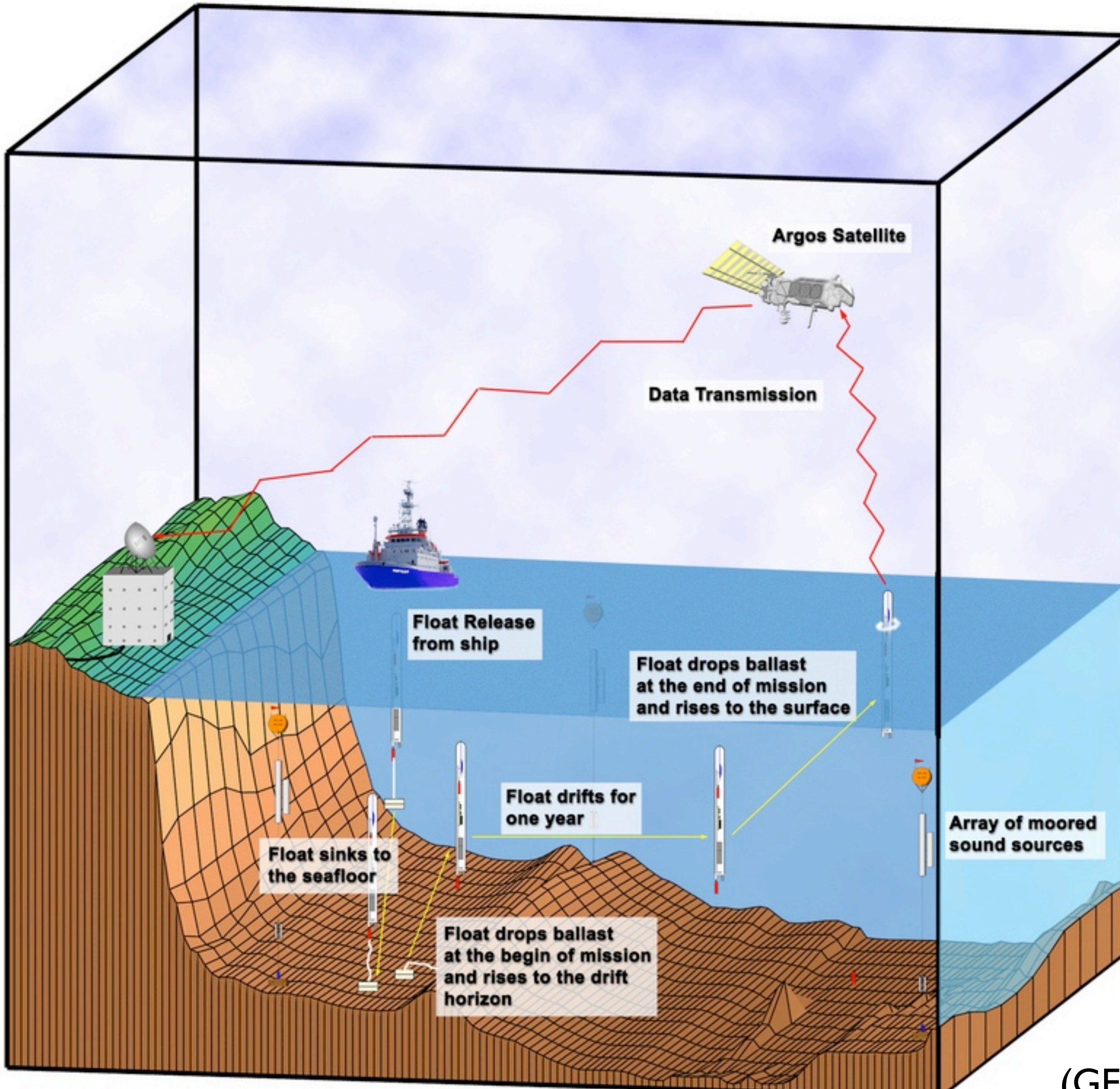
- drifters (surface currents)
- floats (subsurface currents)
- profiling floats (mean currents, temperature, salinity)
- gliders
- autonomous underwater vehicles (AUVs)

Surface floats



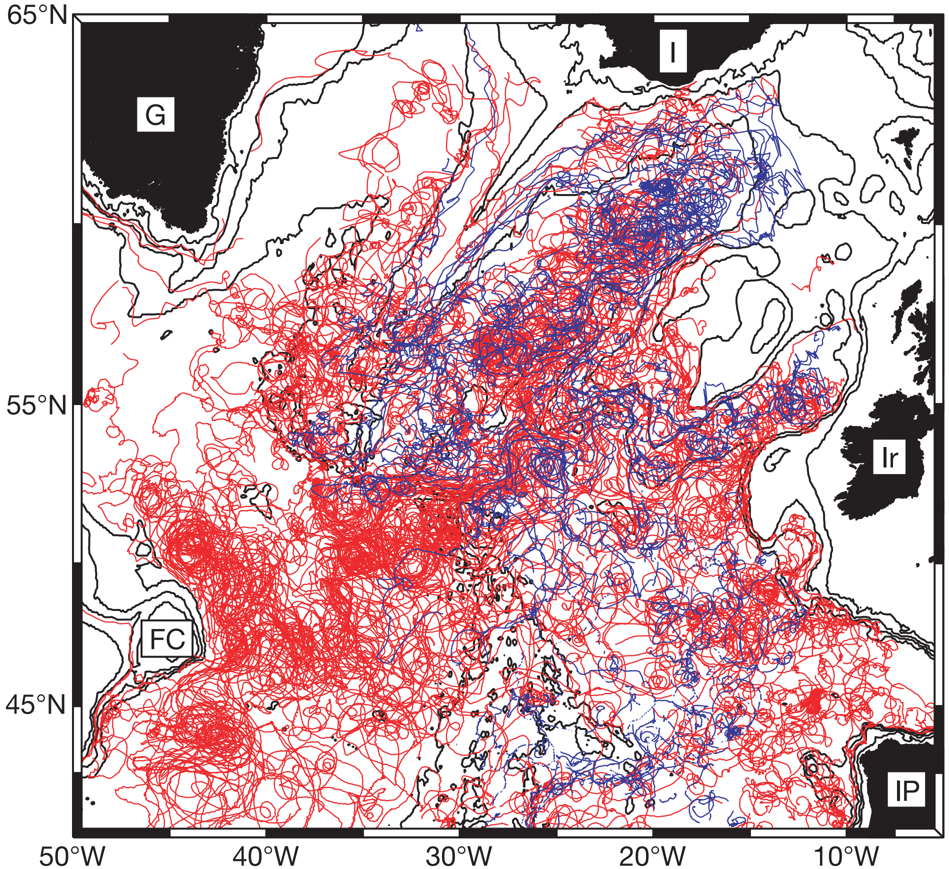


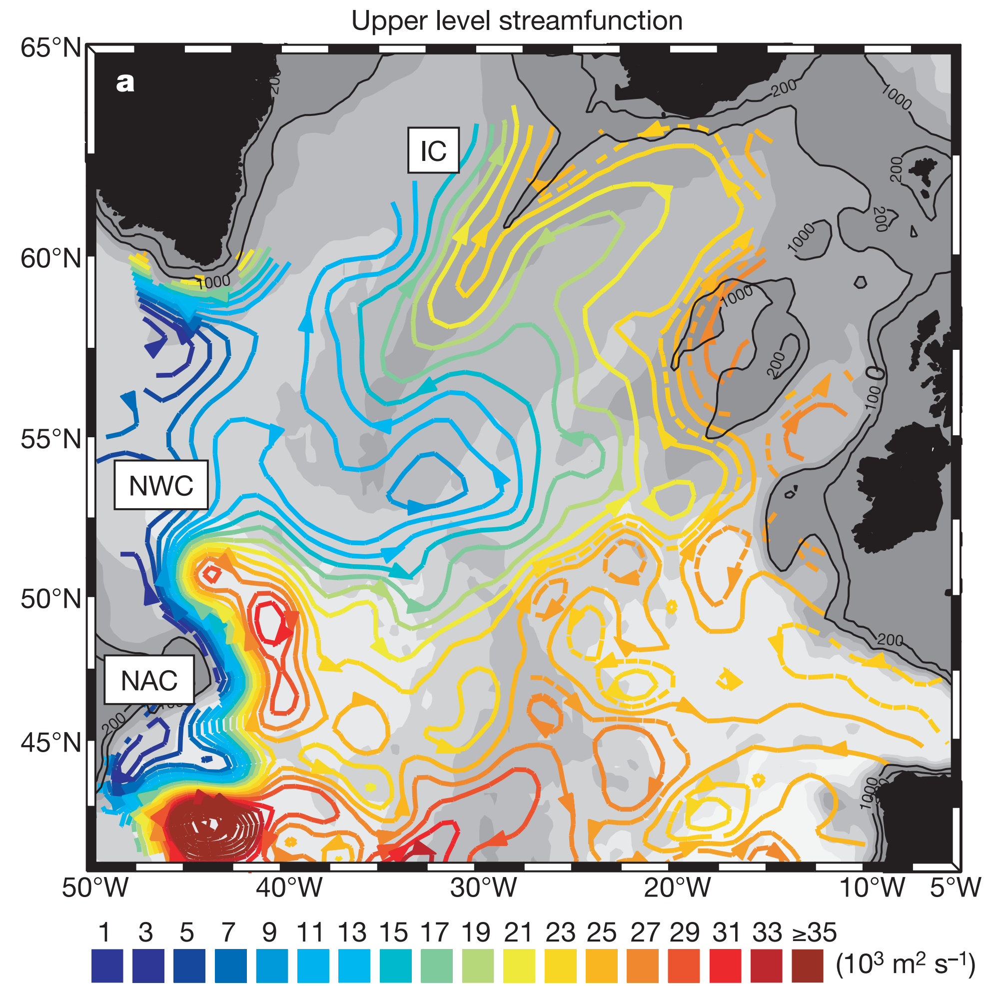
Subsurface floats



(GEOMAR)

Subsurface floats

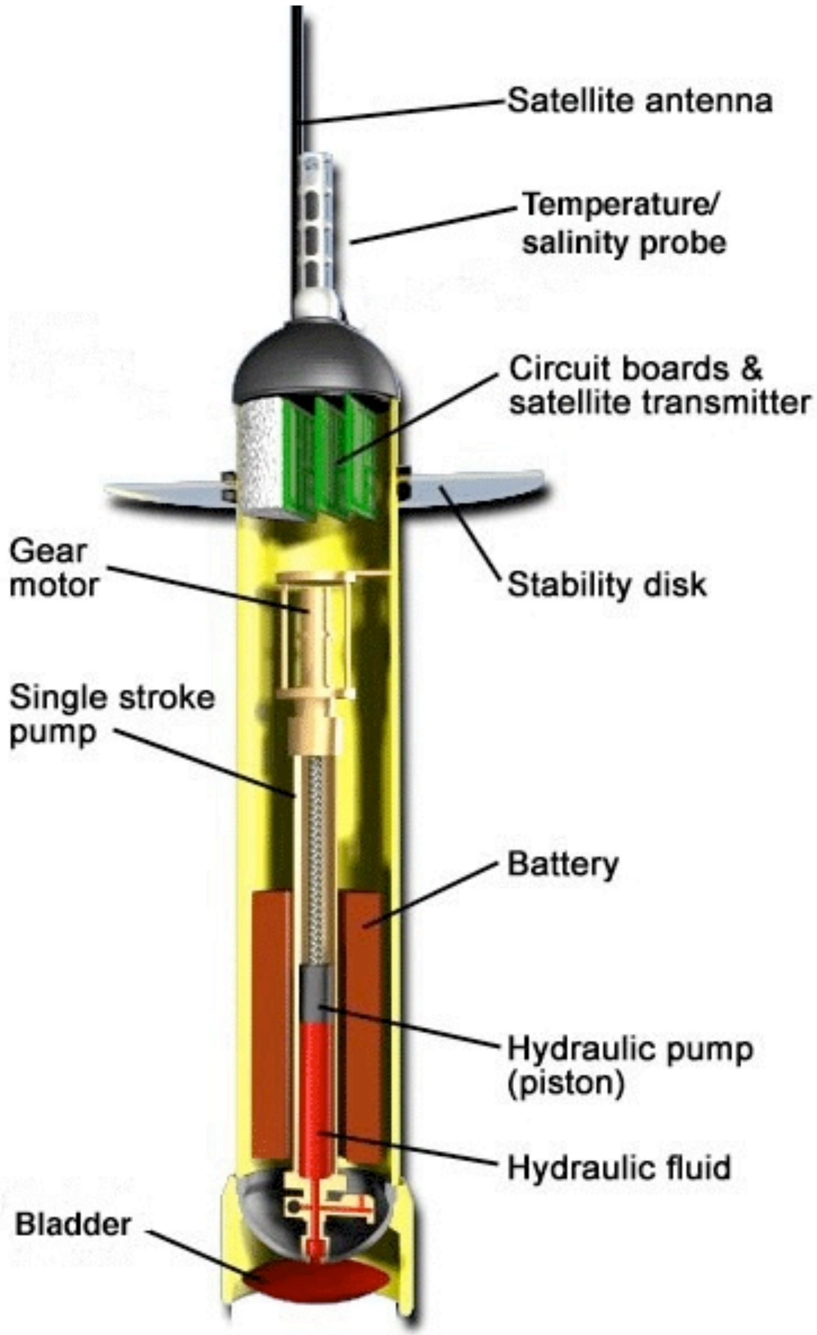


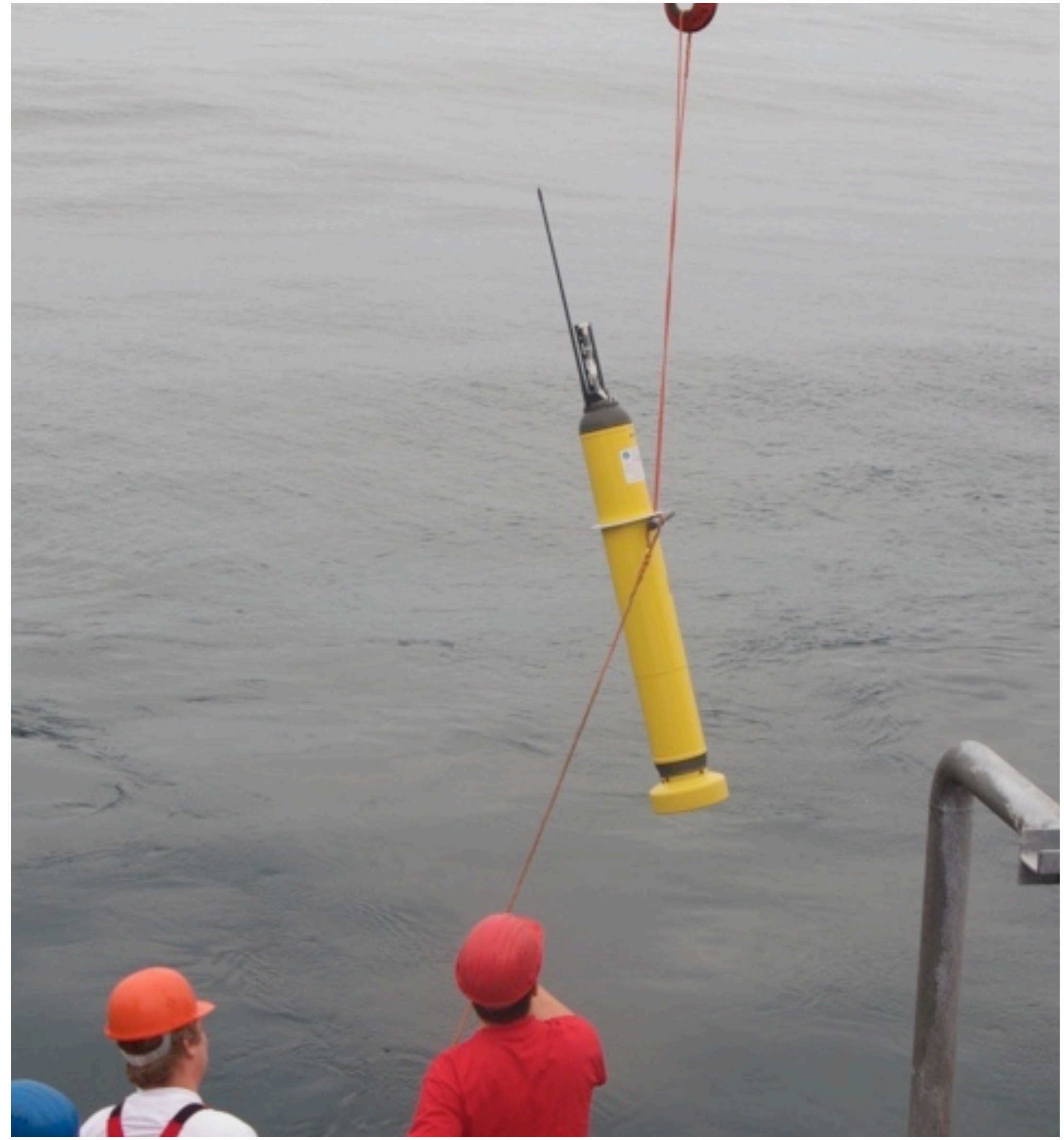


(Bower et al., Nature, 2002)

Example from the subpolar North Atlantic: *Spaghetti diagram* from 223 acoustically tracked subsurface drifting floats (left) and mean streamfunction at upper level (~1000 m) derived from red tracks (right). Blue tracks from floats at Labrador Sea Water level (1500 - 1750 m).

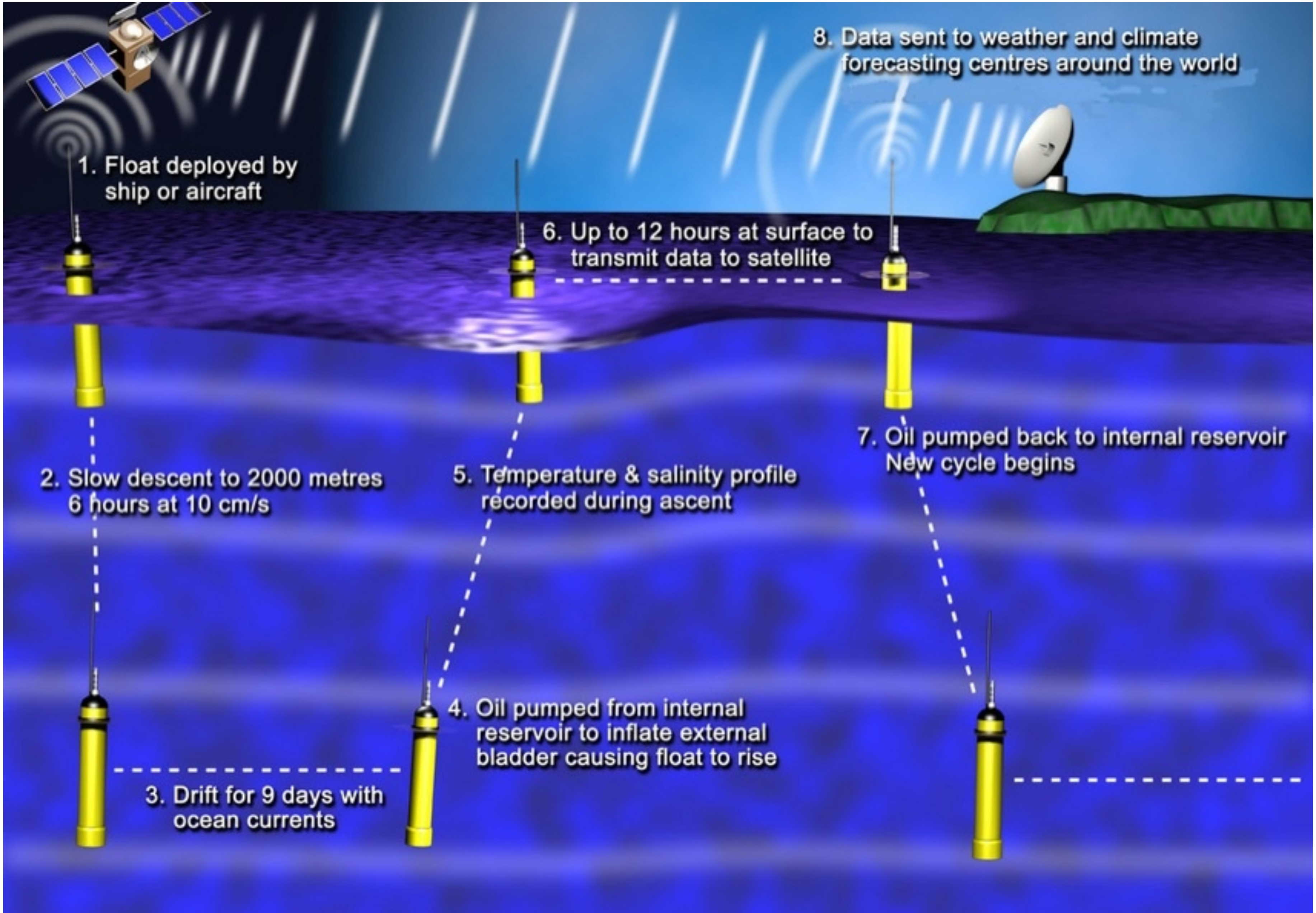
Profiling floats



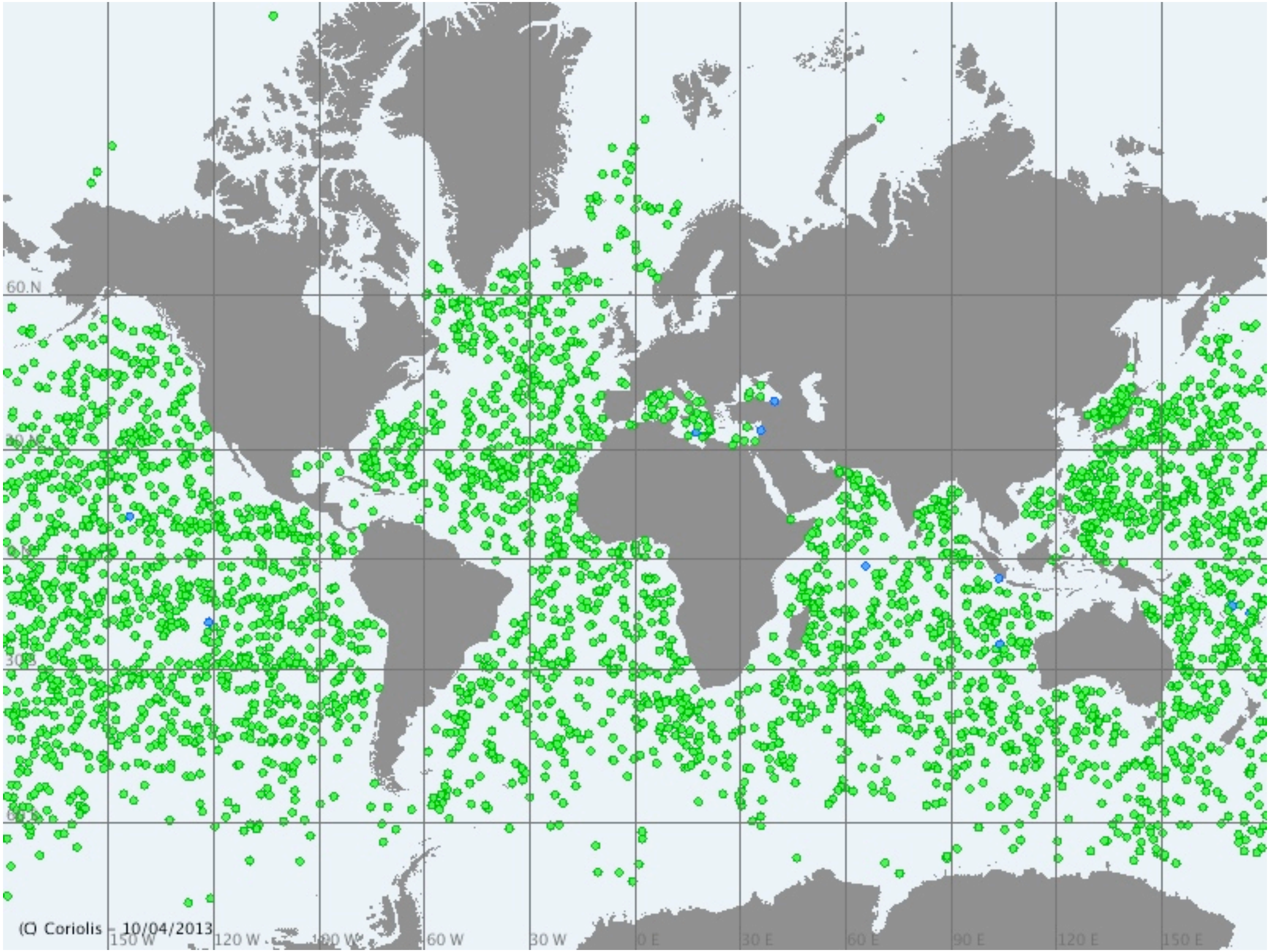


APEX (Autonomous Profiling Explorer)

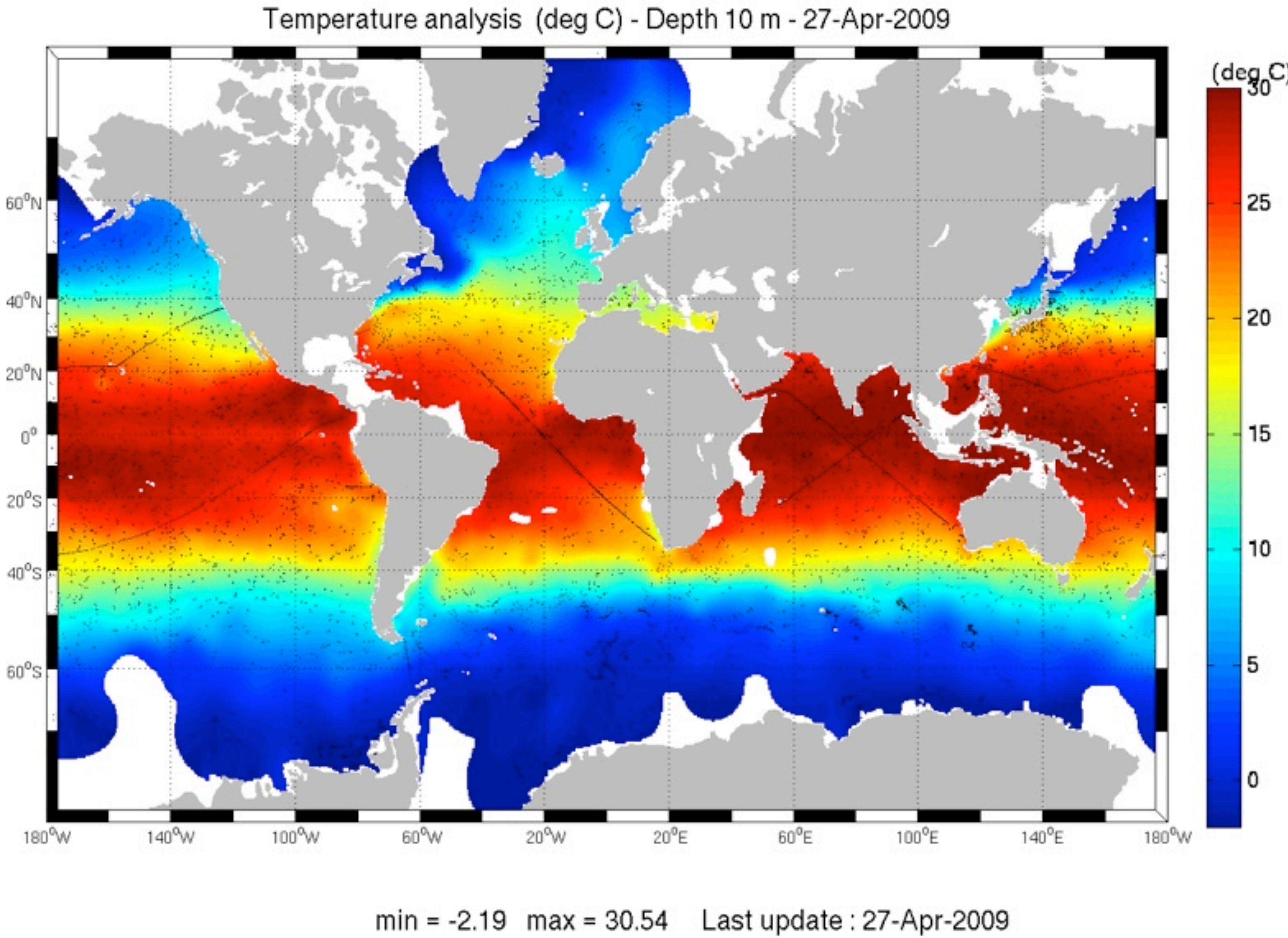
Profiling floats



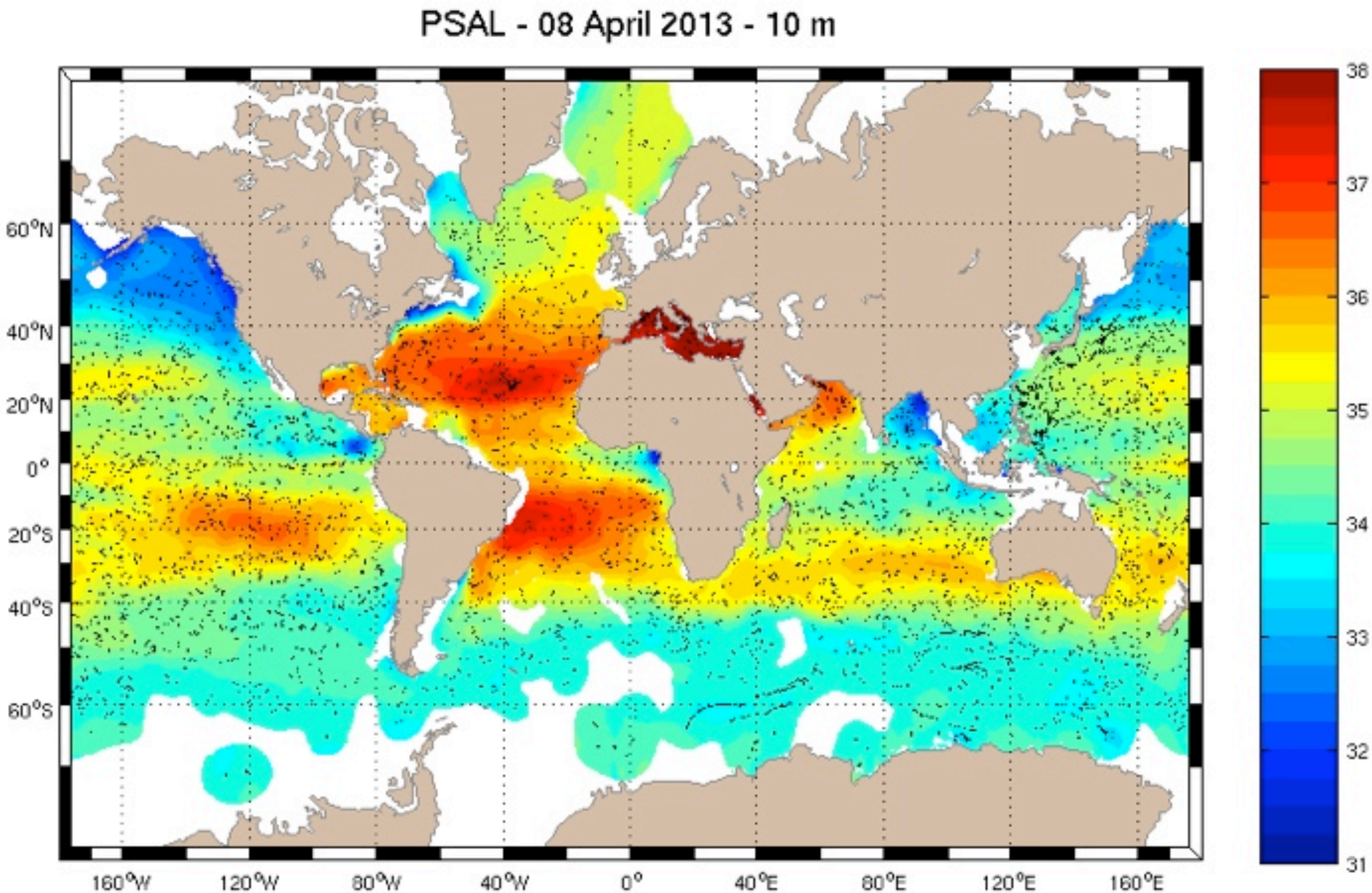
30 days profile data from Argo network



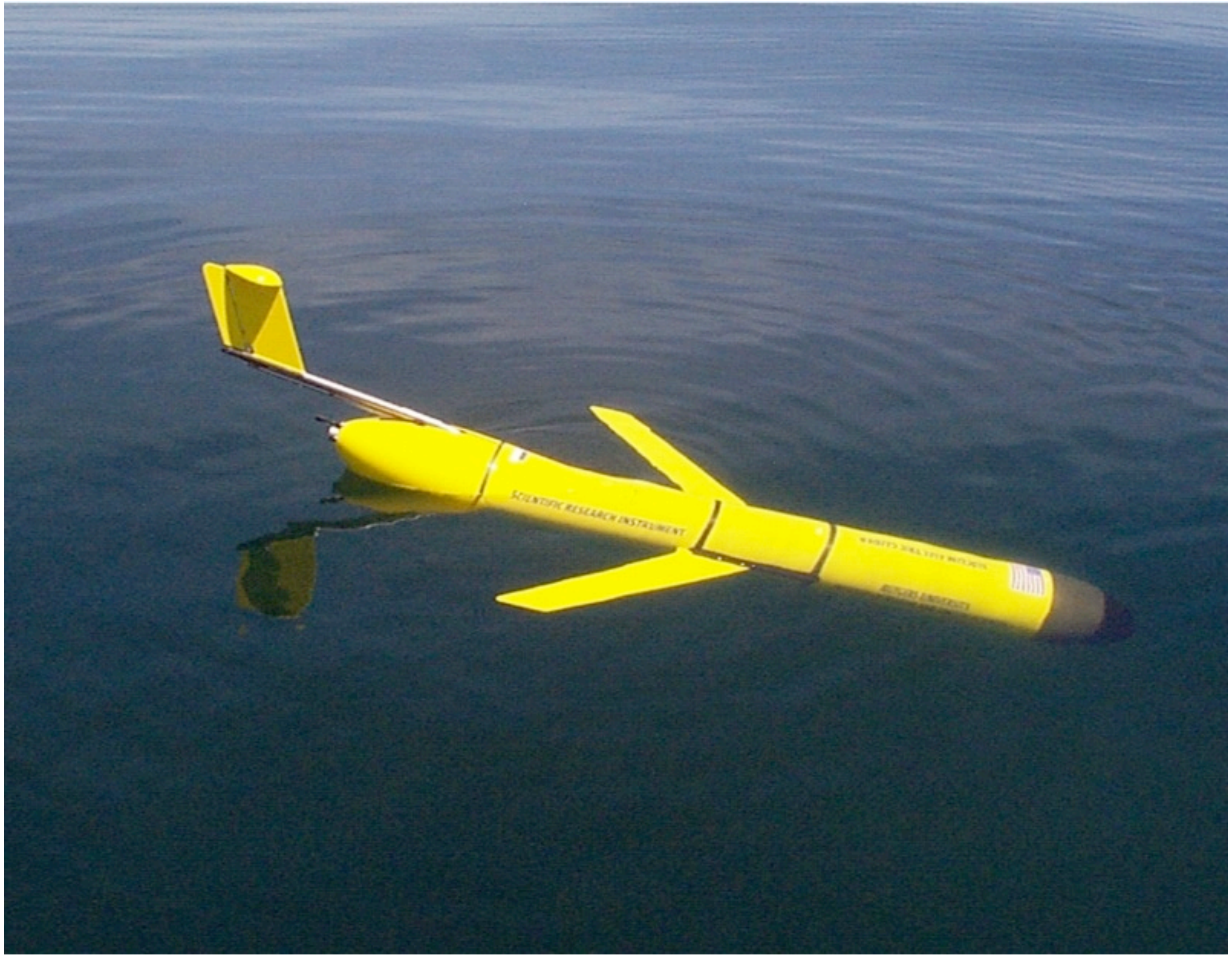
Temperature at 10 m from profiling floats



Salinity at 10 m from profiling floats

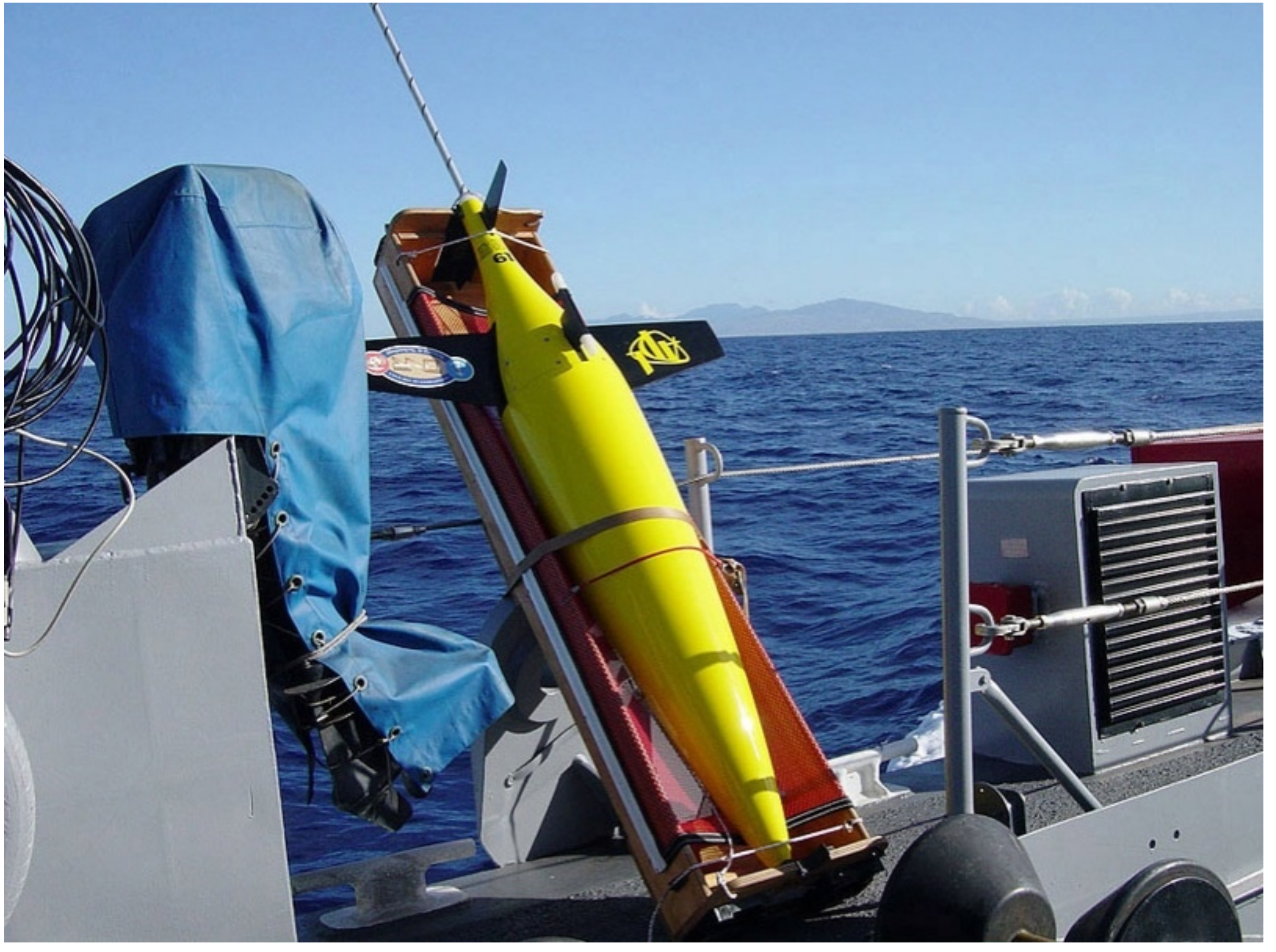


Glider



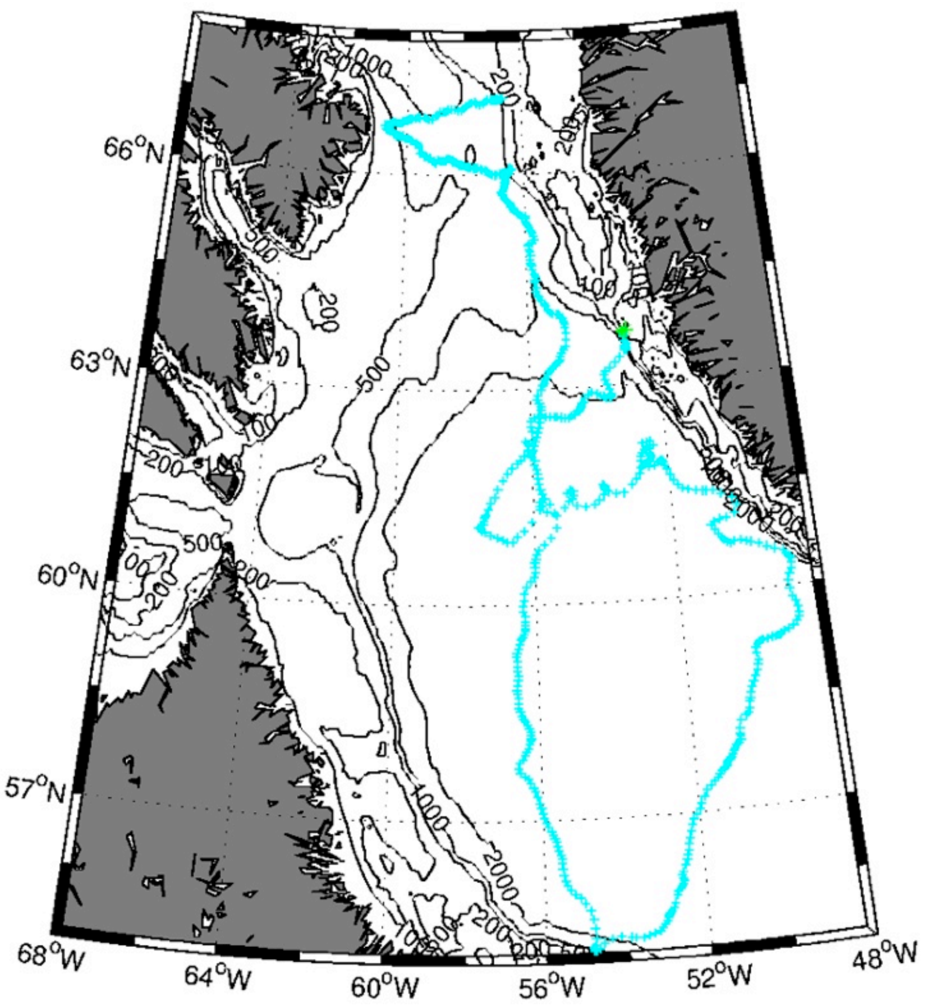
Slocum glider (Teledyne Webb Research)

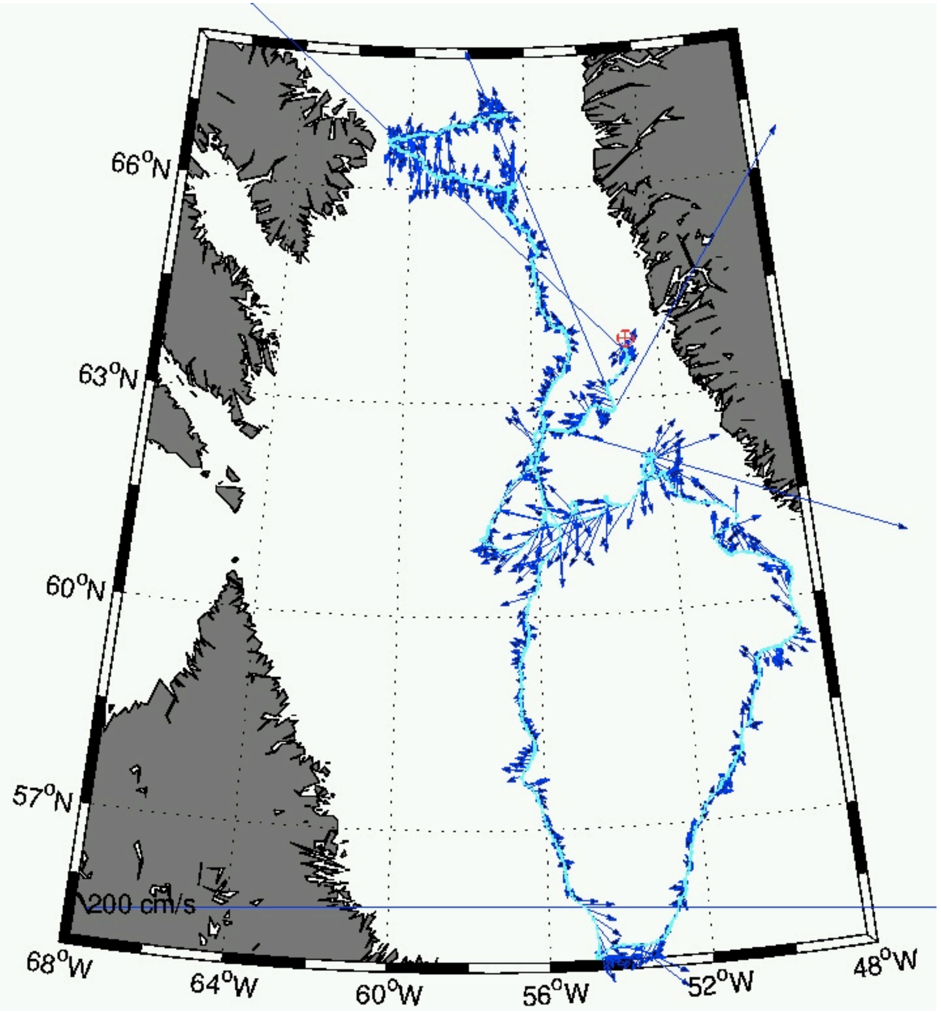
Glider



Seaglider (Univ. Washington)

Glider





Glider mission in the Labrador Sea, 24/6/06 - 29/4/05

Autonomous underwater vehicle

WHOI‘s Autonomous Benthic Explorer (ABE)

Remotely operated vehicles

ROV Quest 4000, MARUM, Univ. Bremen

Remote Sensing

- surface temperature
- ocean color
- surface elevation (altimetry)
- surface roughness/wind speed & direction
- wave height
- sea ice