In-situ observations: processes and methods

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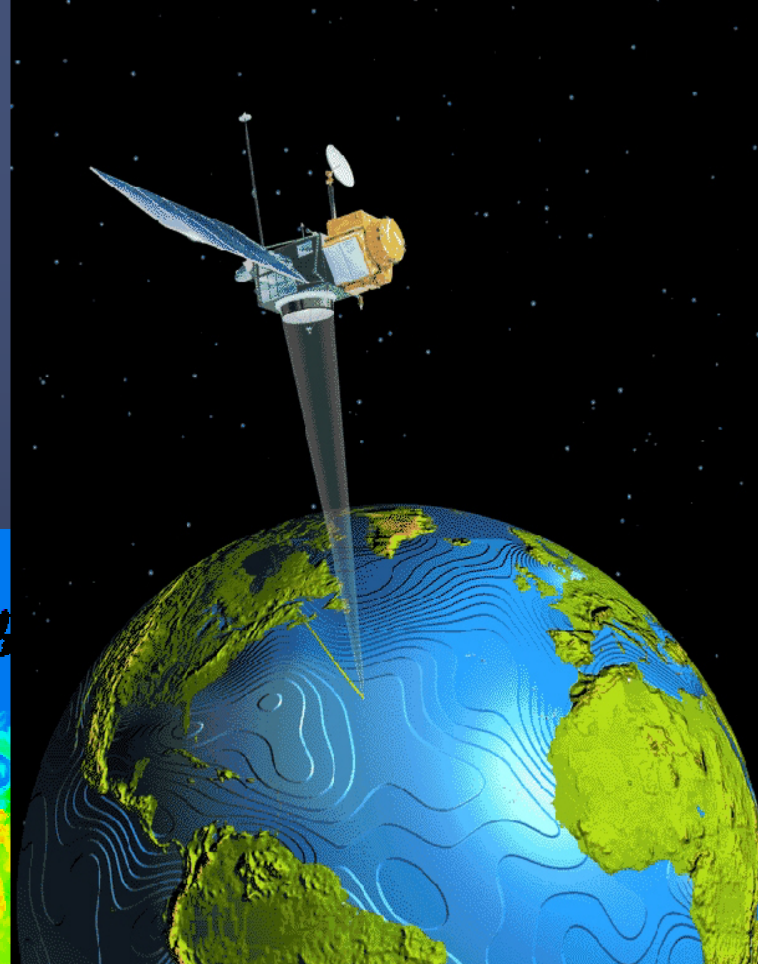
GODAE Summer School
La Londe, Sept. 2004

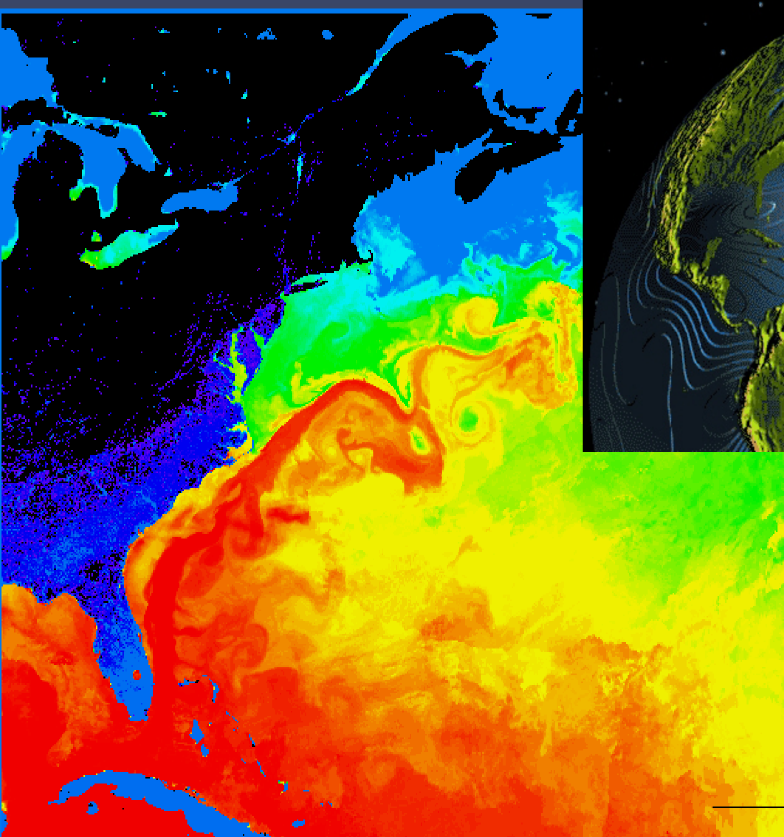
Objectives:

Provide an understanding for the need of in-situ observations, and of the options for obtaining sustained in-situ data.

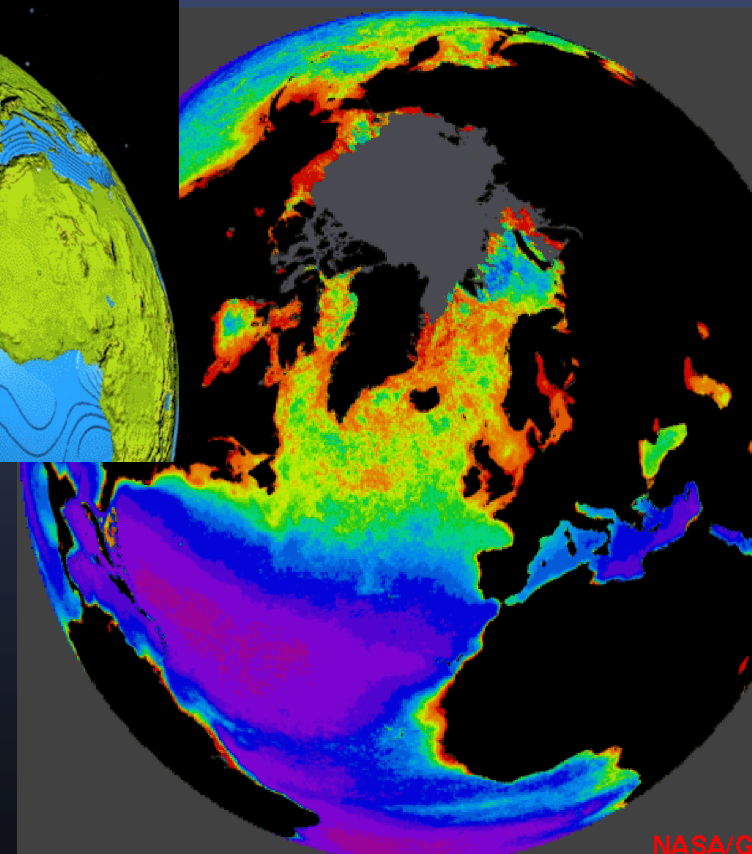
Strong complimentarity between remote sensing and in-situ data



Need an integrated approach to provide the data needed for ocean modelling and forecasting



Gulfstream temperature



spring plankton bloom

The lecture will present....

1) Examples where satellite observations depend on or are enhanced by in-situ data

2) Additional variables or processes that cannot be observed from space

Will naturally guide through some of the platforms and sensors...

Satellite Altimetry

Sea surface height (SSH) consists of

- the steric (dynamic height H_{dyn}) contribution of T and S
- a barotropic flow component (reference level pressure P_{ref})

Symbolically $\mathbf{SSH = P_{ref} + H_{dyn} = SSH' + \overline{SSH}}$

altimetry

Altimetry has good spatial and temporal coverage but cannot determine

- steric and non-steric components
- mean SSH field (relative to geoid)
- T and S contributions (spiciness)
- interior structure (vertical distribution) of H_{dyn}

Profiling float data can help resolve these issues

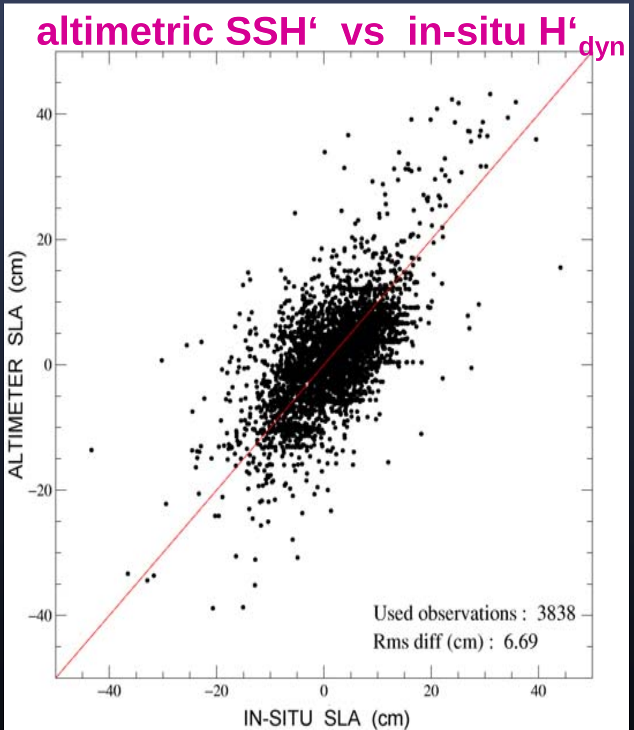
Symbolically $SSH = P_{ref} + H_{dyn} = SSH' + \overline{SSH}$

Float profiles (H_{dyn})

altimetry (SSH')

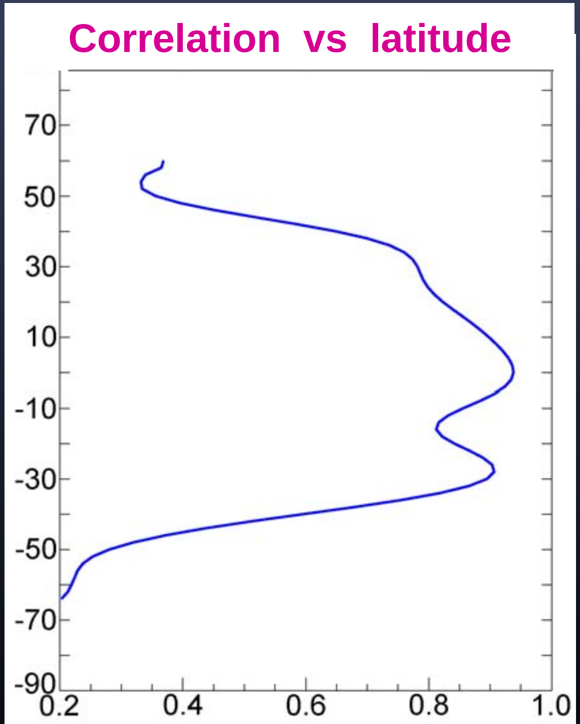
Compare SSH' and float H'_{dyn} :

(from P.-Y. Le Traon)



scatter is a measure for non-steric contributions (plus errors)

large barotropic contributions at high latitudes



Symbolically $$SSH = P_{ref} + H_{dyn} = SSH' + \overline{SSH}$$

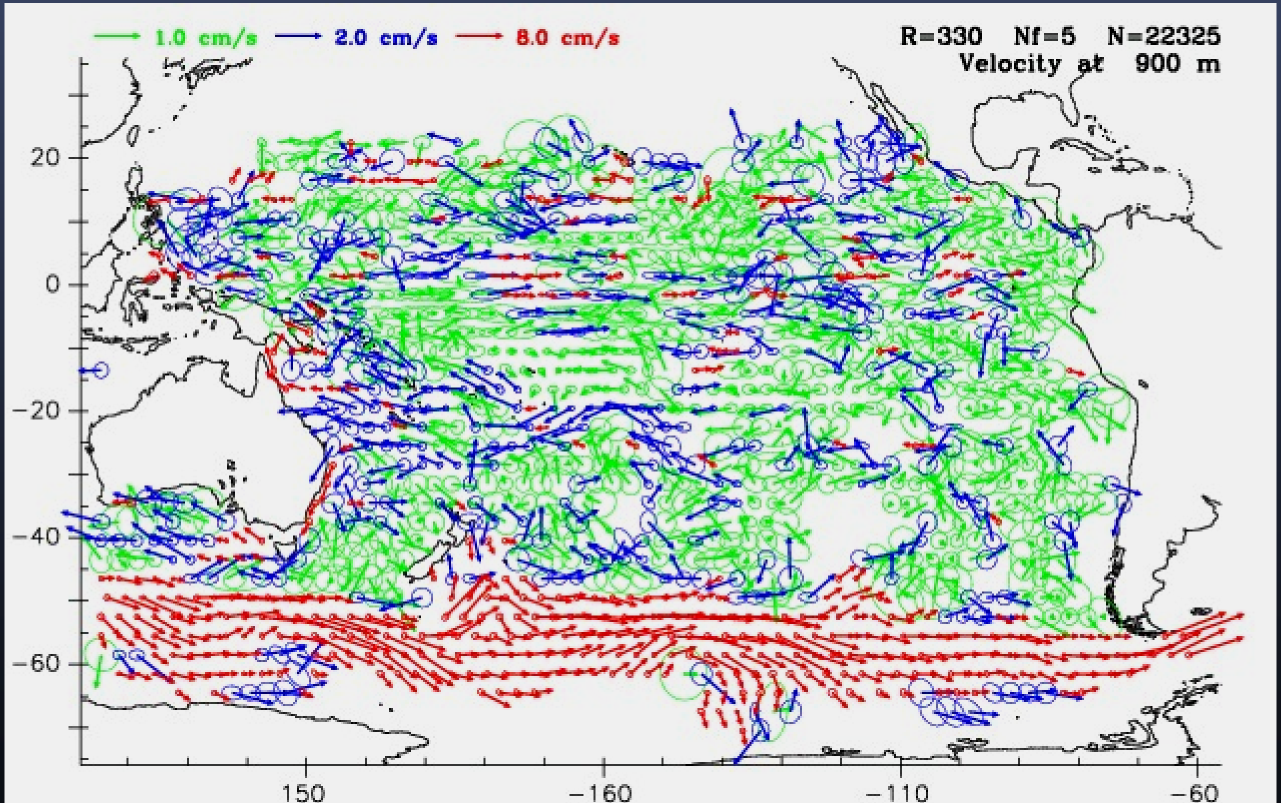
deep trajectories → P_{ref}

Float profiles → H_{dyn}

altimetry → SSH'

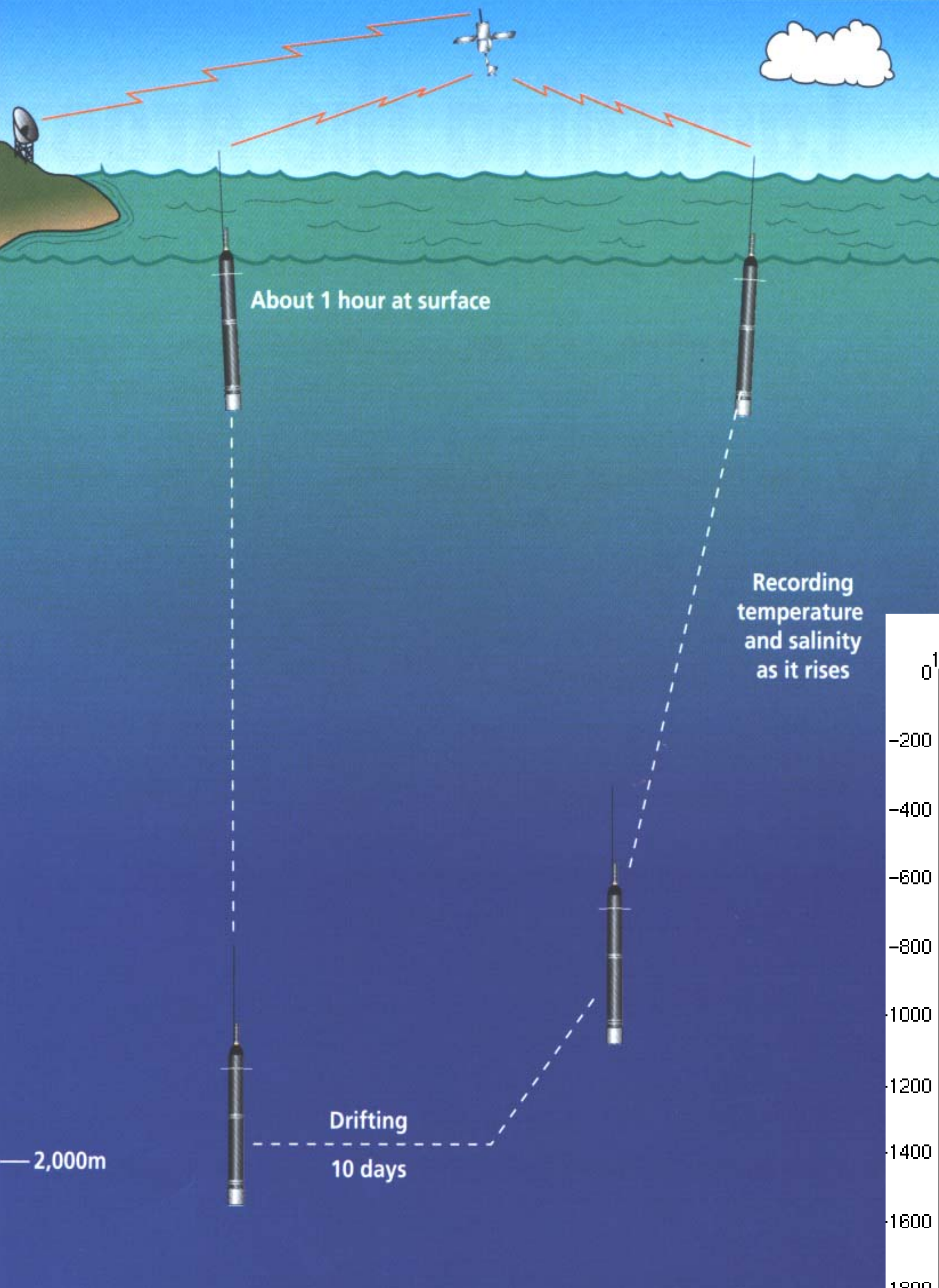
residual → $\overline{SSH}$

Deep mean flow (p_{ref}) from float trajectories :

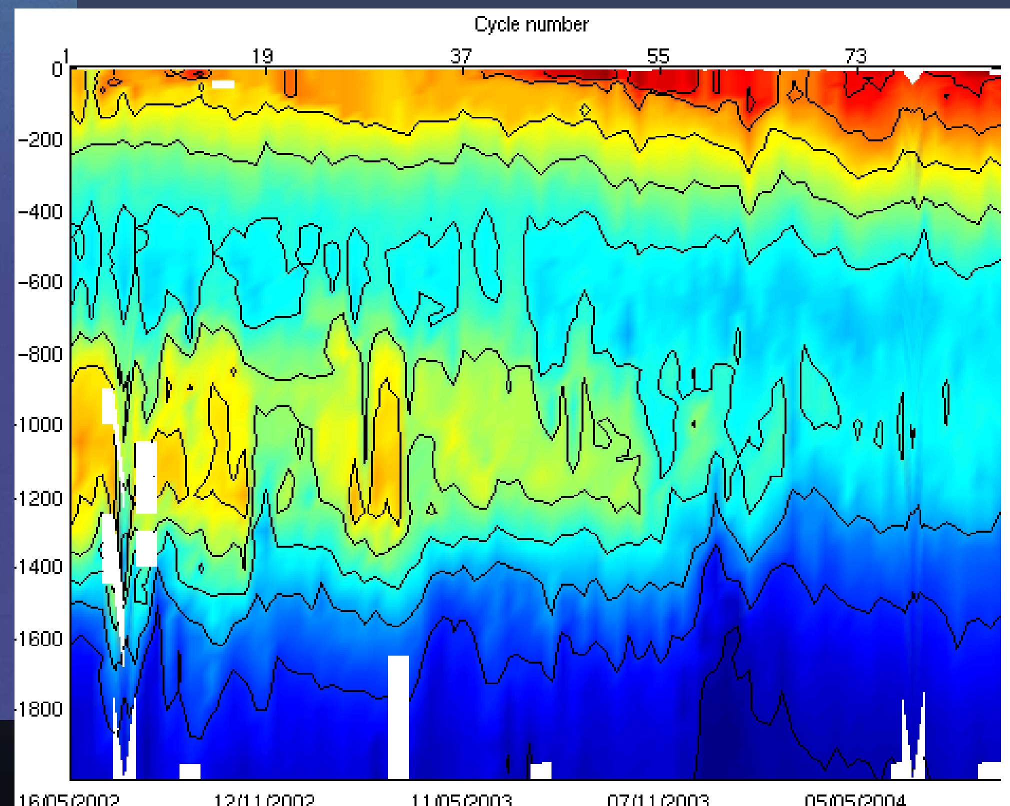


(from R.Davis)

Working principle of a profiling float

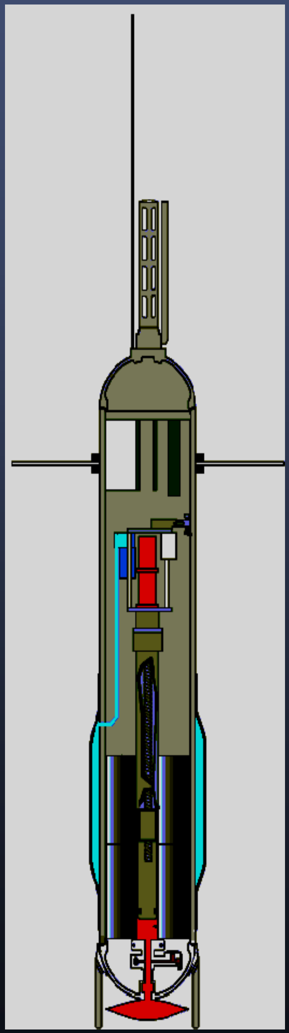


Example of float salinity timeseries (2 years) in Mediterranean outflow



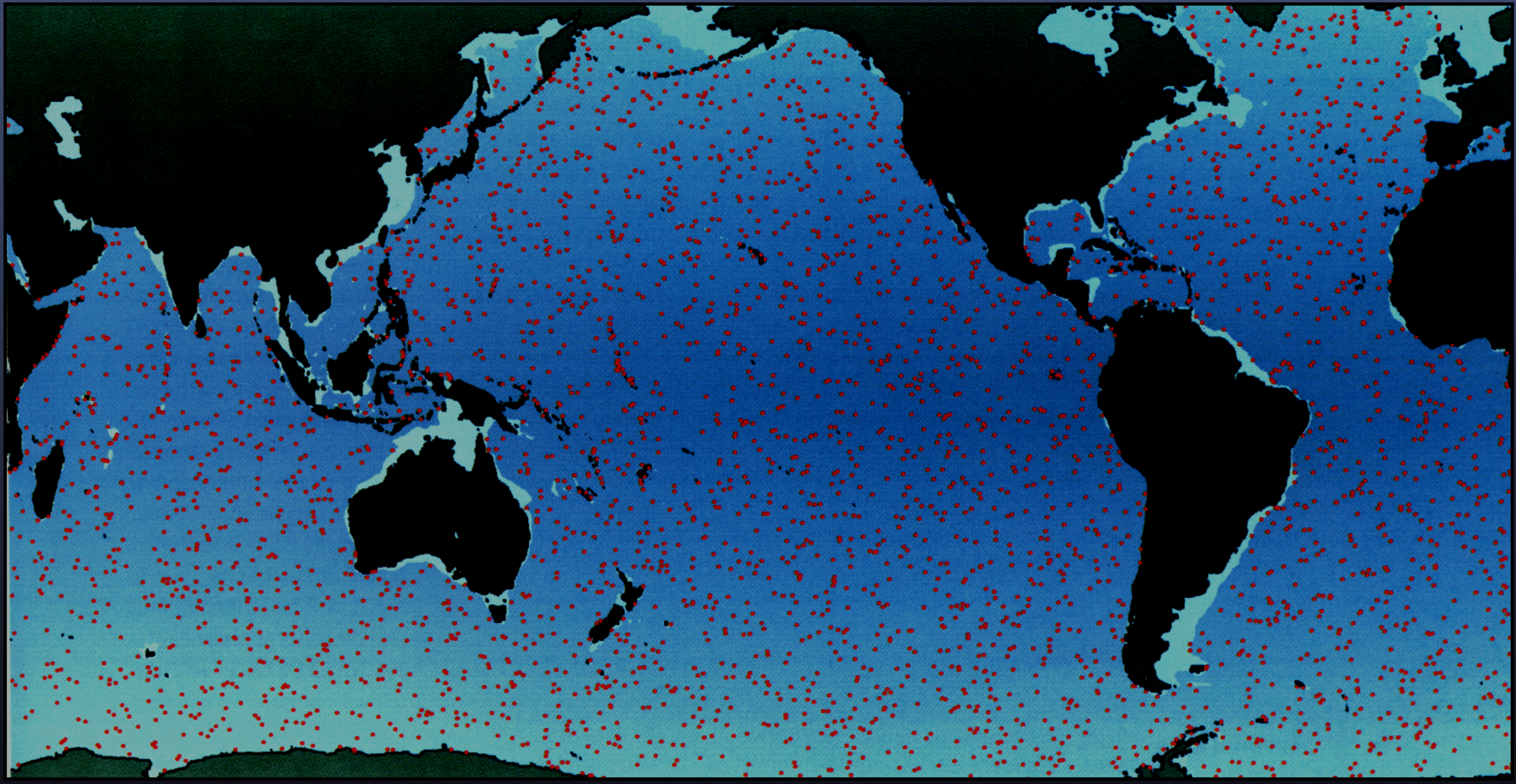
Various models of floats exist now:

- up to 4 years life
- up to 180 profiles
- profile depth currently up to 2000m



ARGO

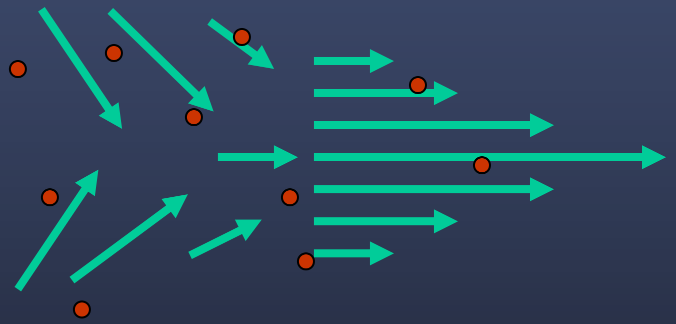
A global system of floats, on average one per 300x300km,
i.e. total of over 3000 floats.
Profiling every 10 days.... i.e. 3000 new profiles every 10 days !



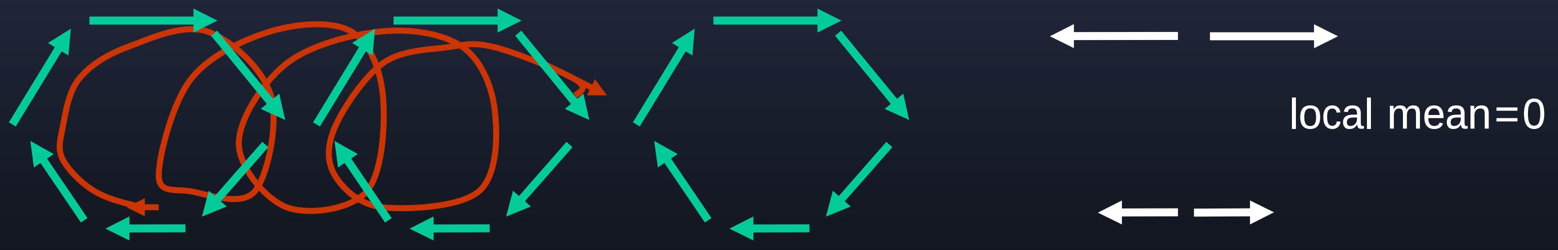
Sampling Issues:

1) Sensor stability:
no post-calibration possible, sensor-offsets/drifts need to be detected by comparison with other measurements in the region

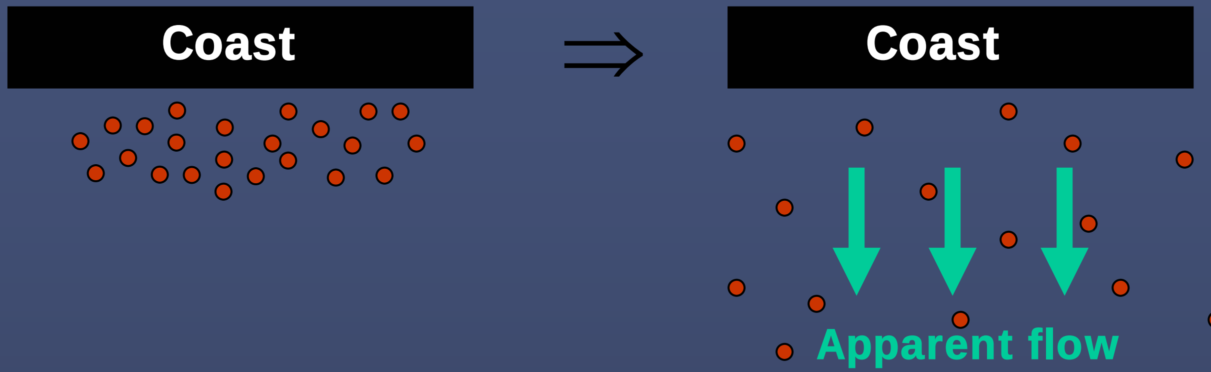
2) Bias due to preferred/more frequent observations in convergent regions



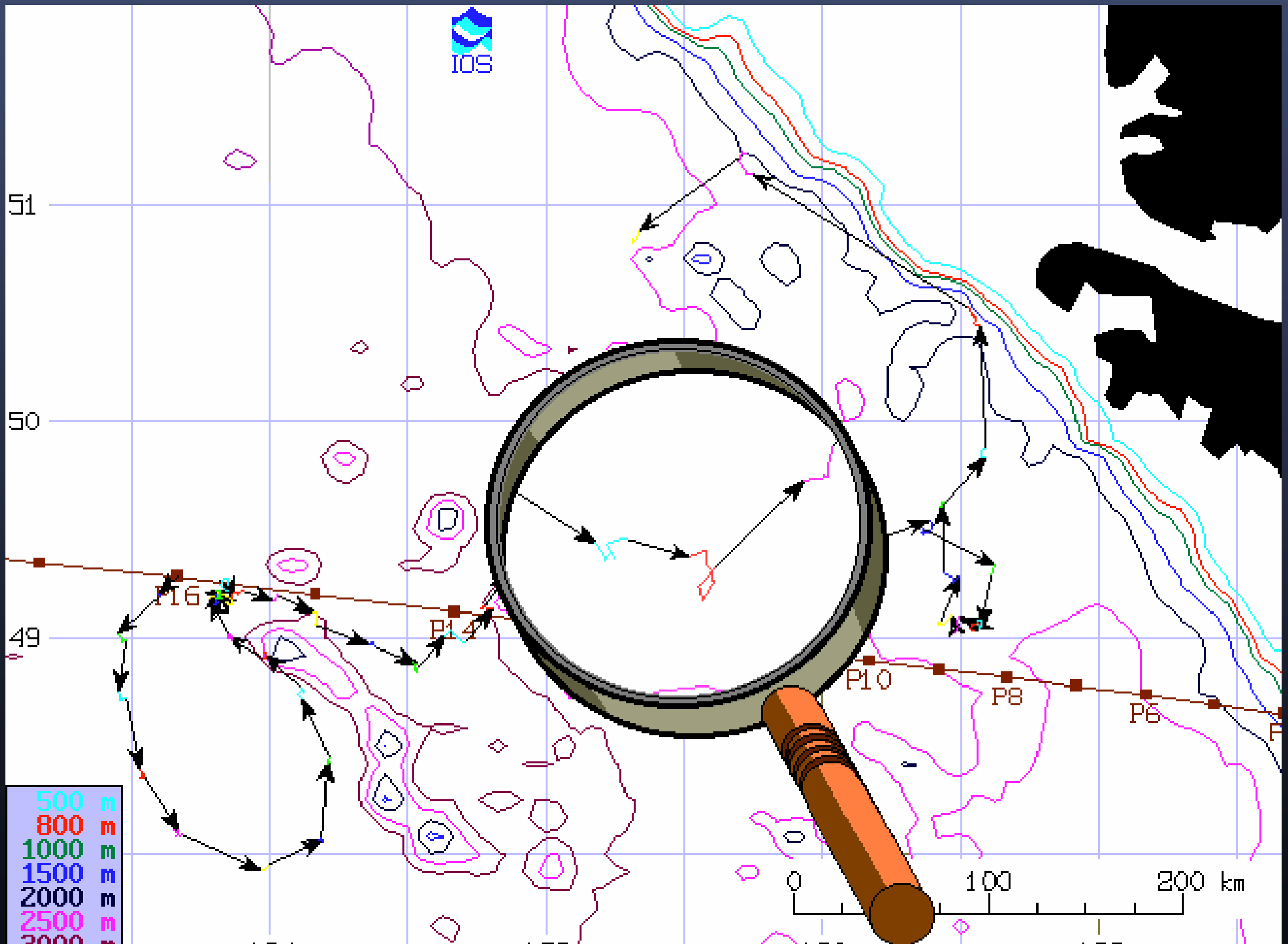
3) Stokes-drift due to spatial gradients in oscillating flow fields



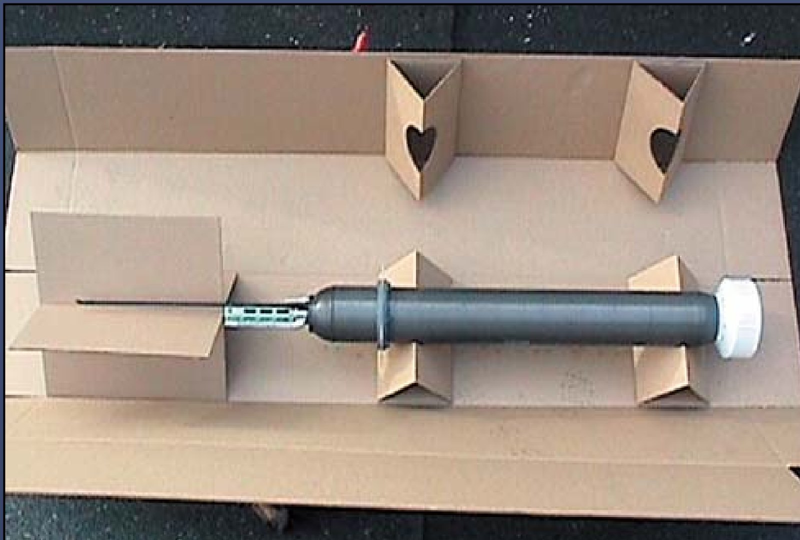
4) Diffusion-Bias:



5) Not true deep trajectories:

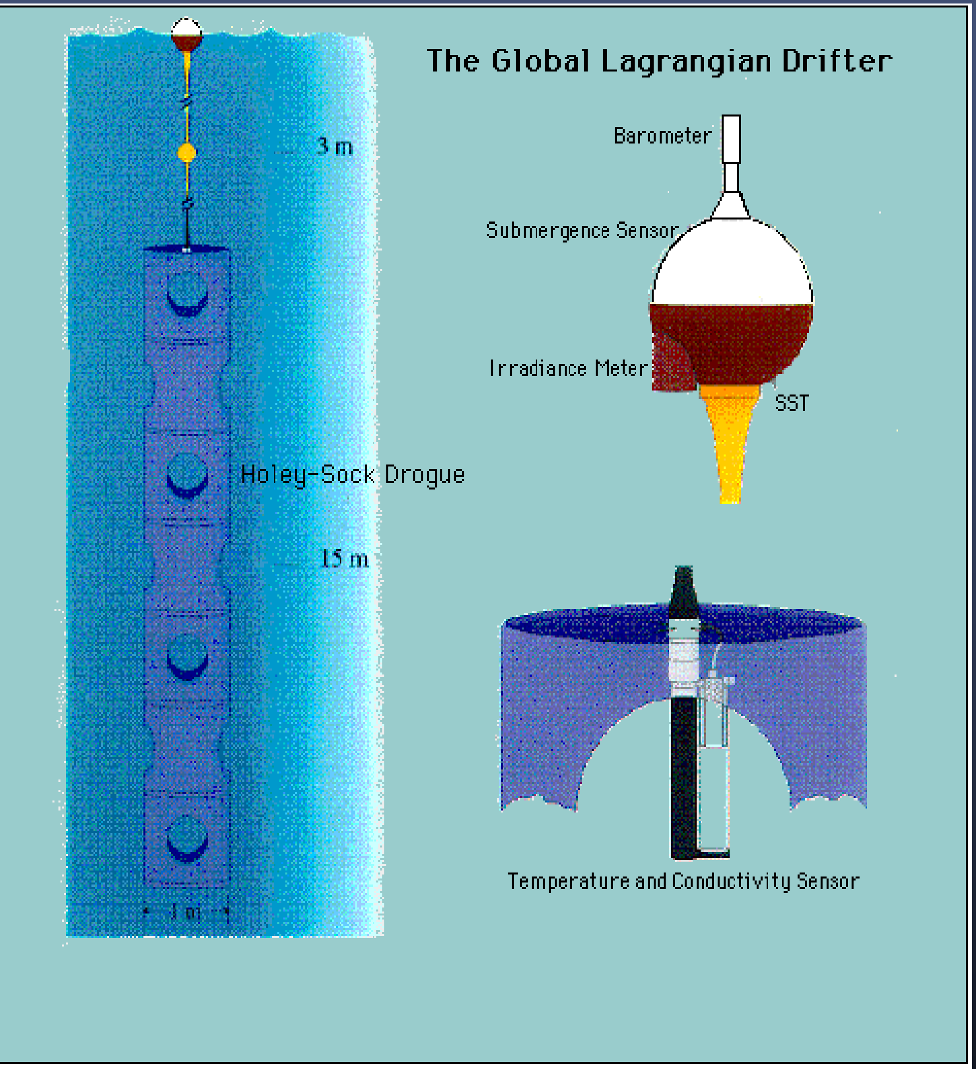


Deployment also from commercial vessels



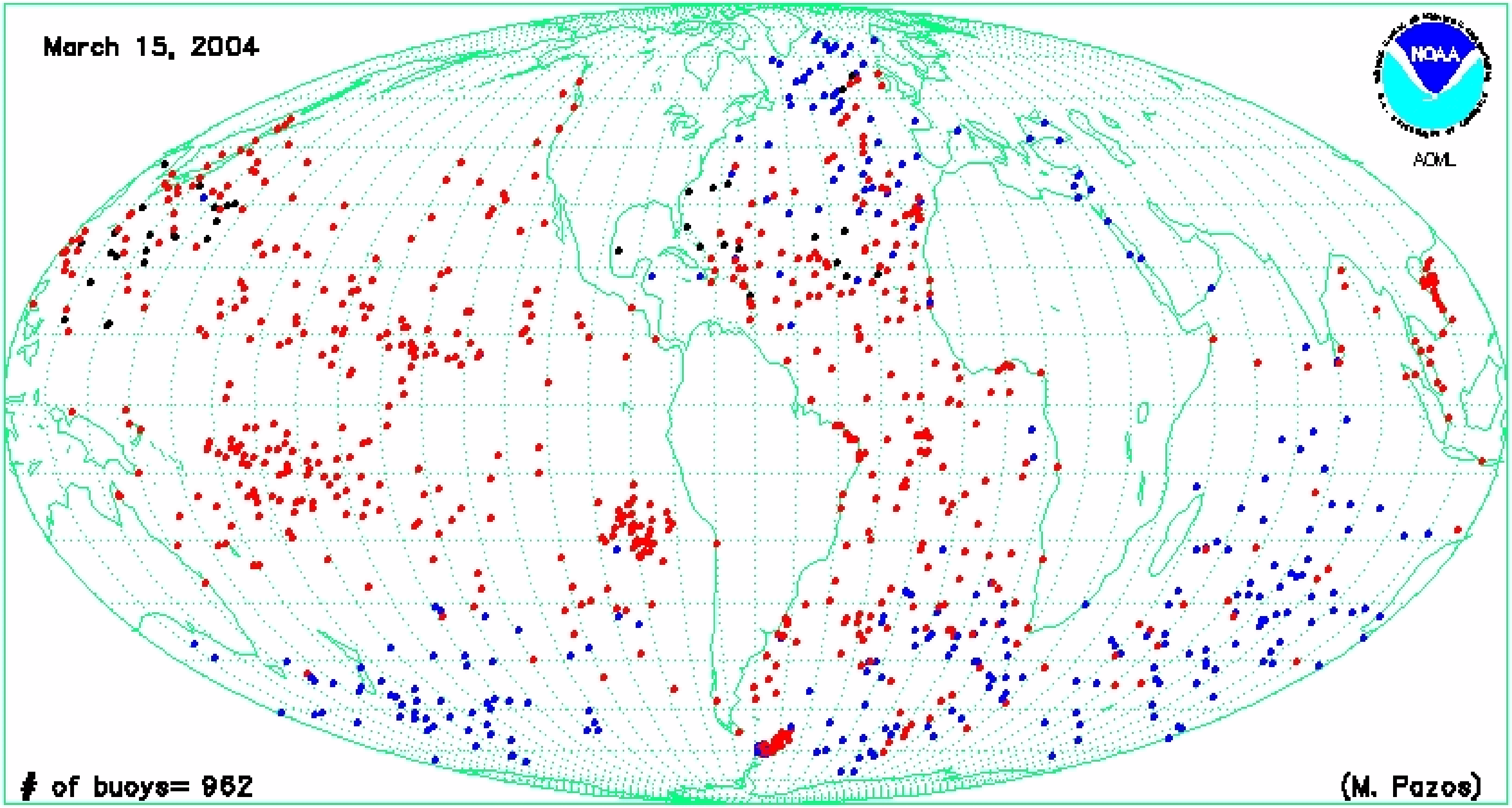
and from airplanes

Both global mean circulation and SST reference data are provided by the surface drifter program



www.aoml.noaa.gov/phod/dac/dac.html

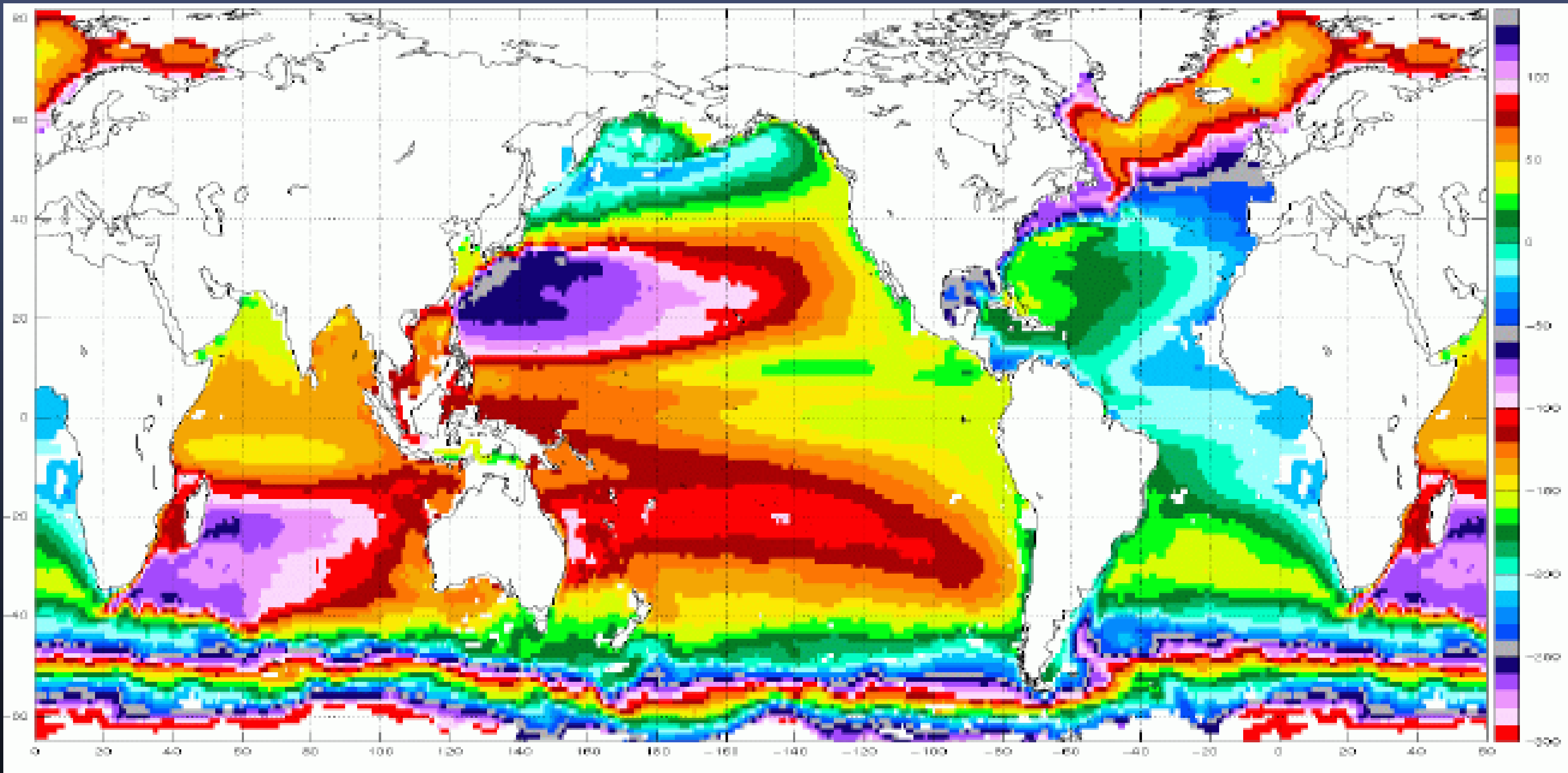
STATUS OF GLOBAL DRIFTER ARRAY



- SST ONLY
- SST/SLP
- SST/SLP/WIND

GLOBAL DRIFTER PROGRAM

Global mean geostrophic surface circulation from 10 years of surface float data:

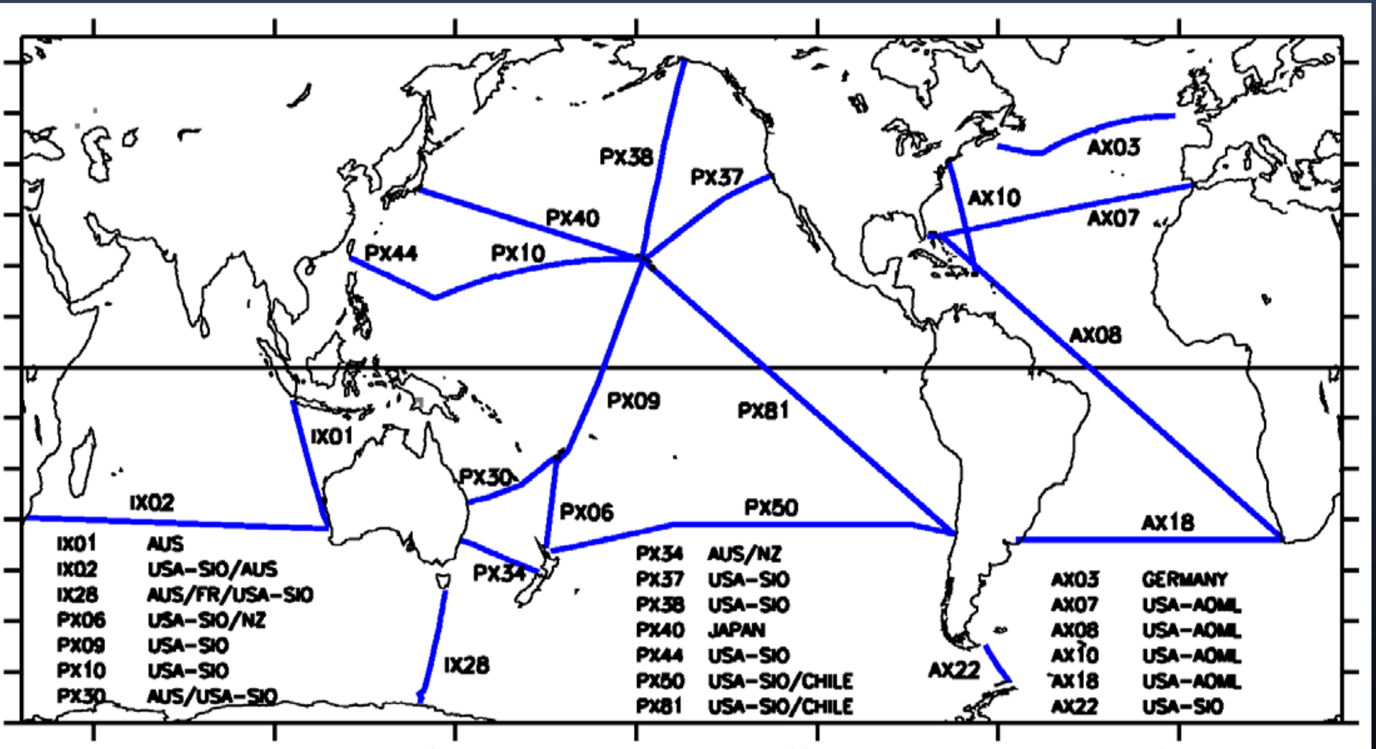


(P.Niiler)

The models also require subsurface temperatures (and densities).

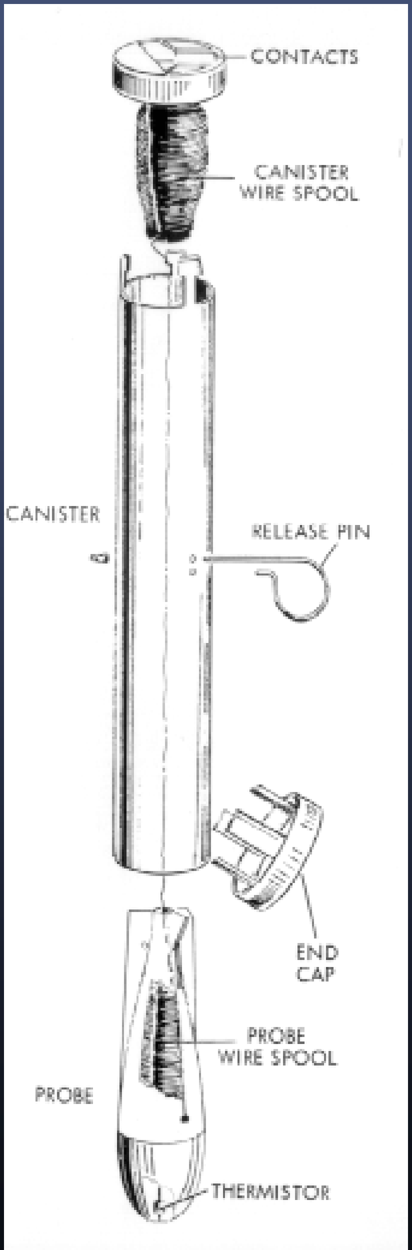
- ARGO provides some with coarse temporal (10days) and spatial (300km) resolution.

Better spatial sampling:
ship sections (research vessels or Volunteer Observing Ships)



High-resolution XBT network from VOS

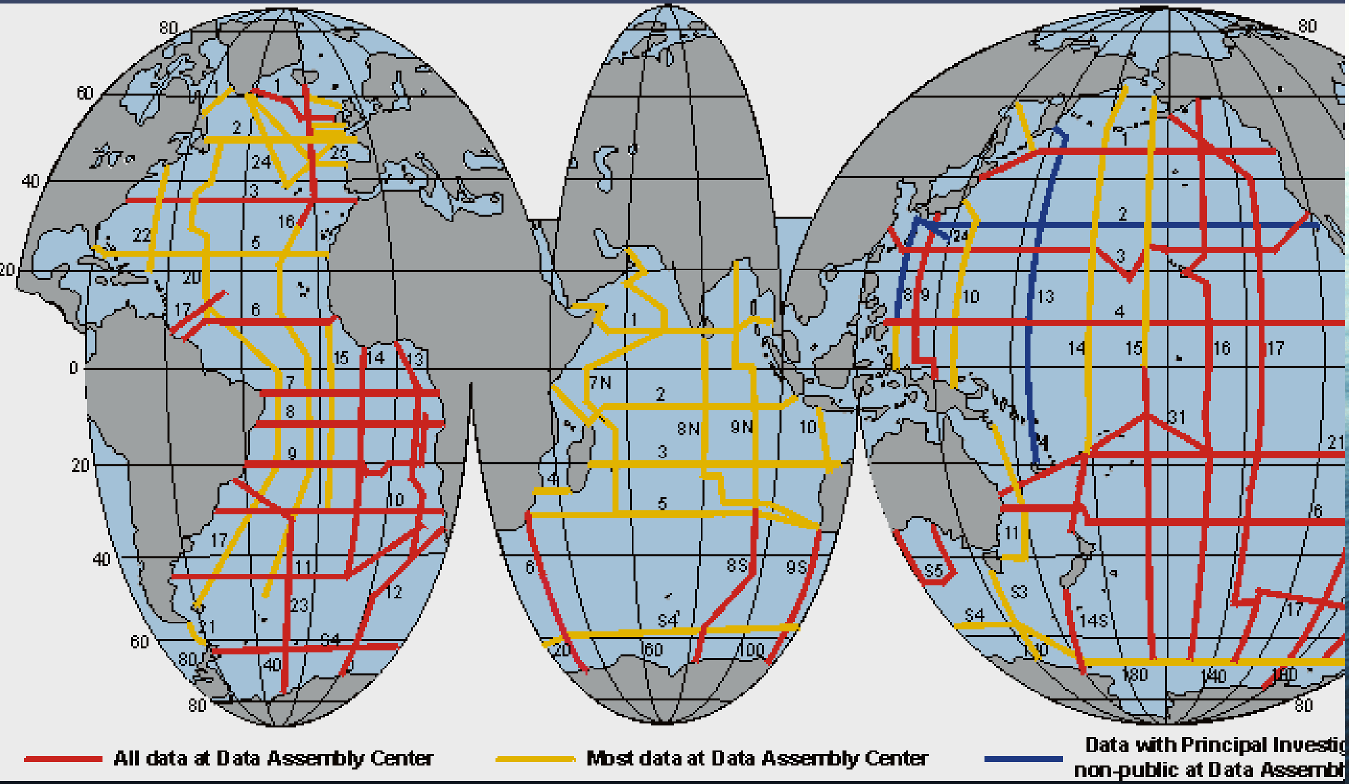
XBT: expendable profiling temperature sensor, profile depth normally 800m

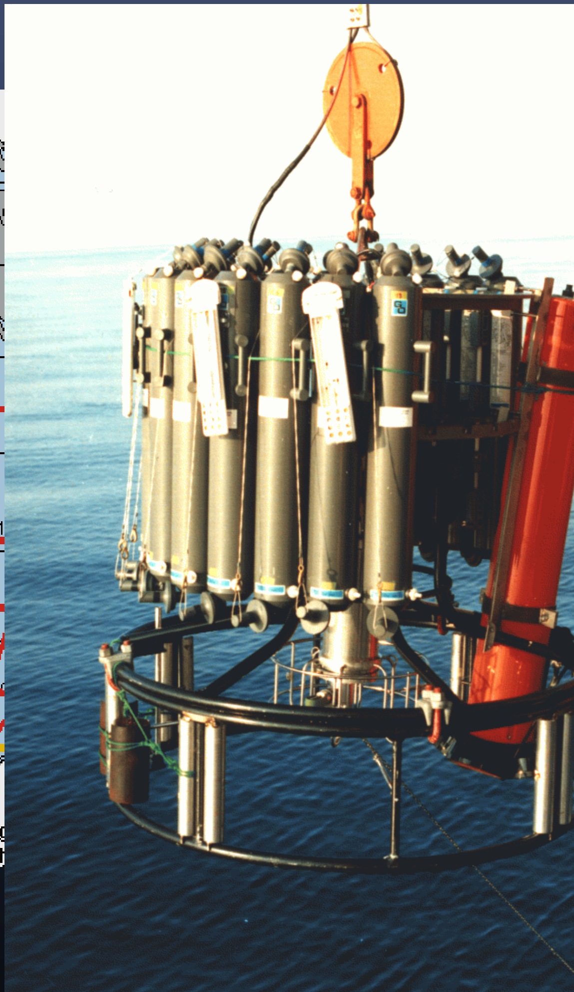


Surface measurements from VOS also available for many other variables (S, O2, CO2, plankton, etc) via pumped hull intake.

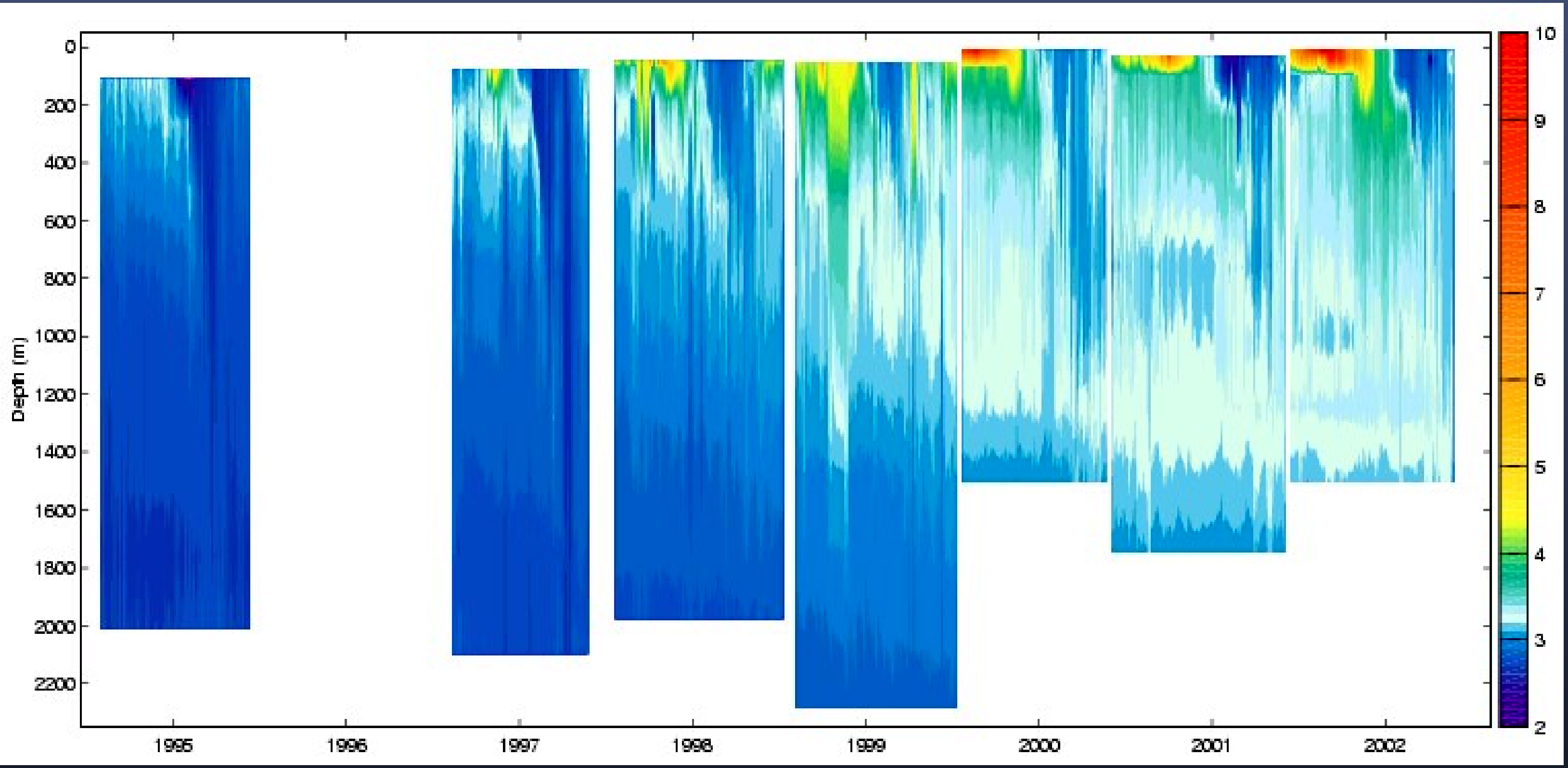
Research vessels can reach remote areas, stop, takes samples, handle heavy equipment, but are expensive and slow/not many
(the WOCE survey below took 10 years ....).

WOCE Experiment



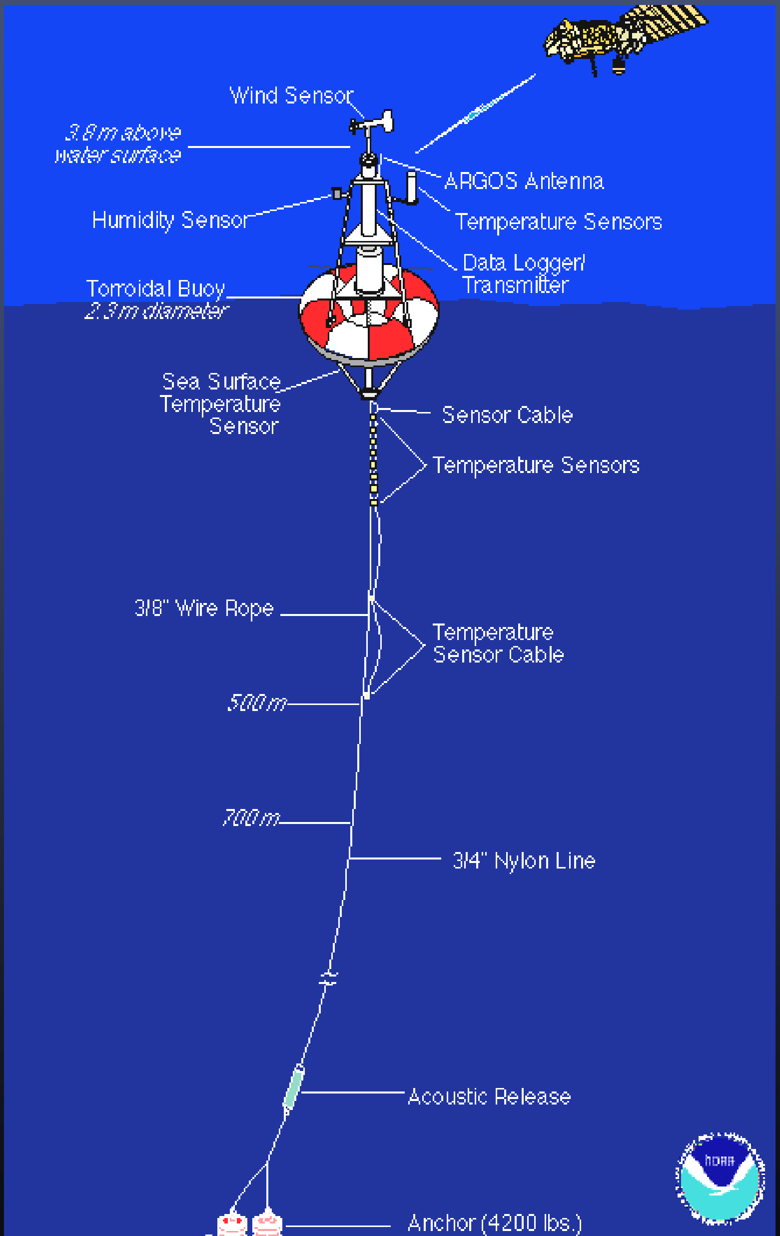


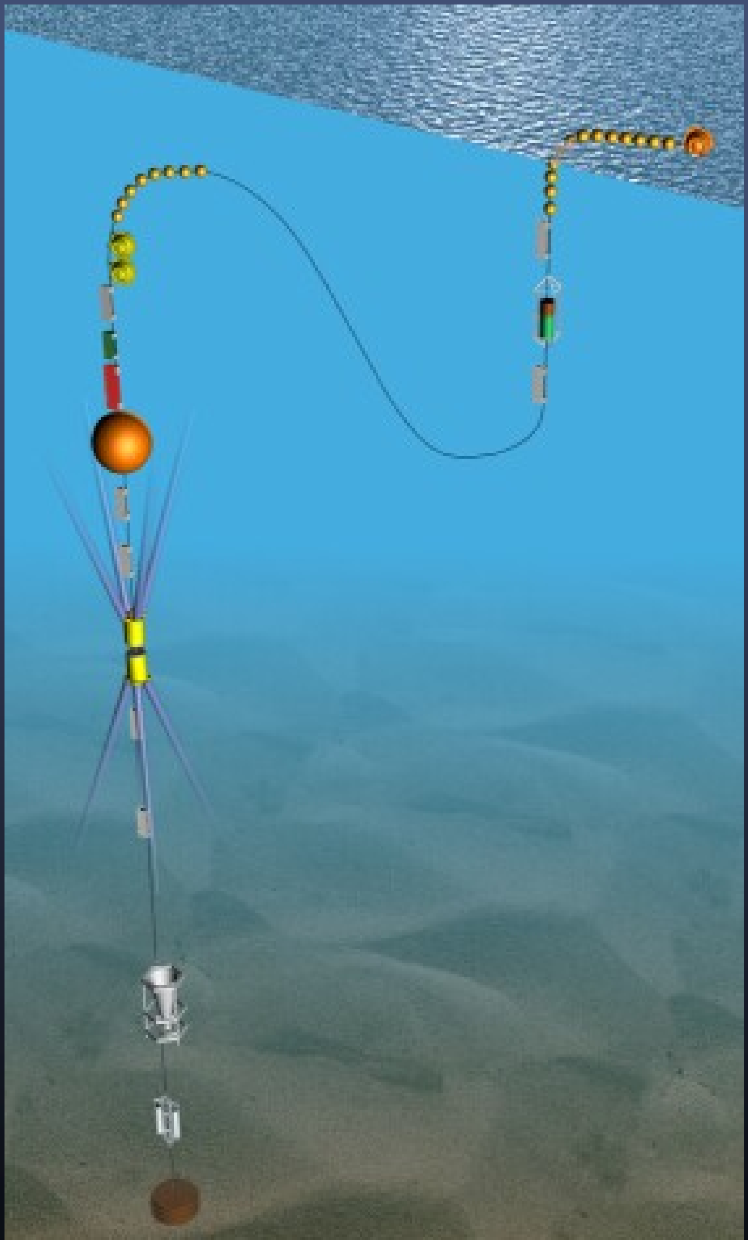
Better temporal sampling for subsurface temperatures: Moored instruments



Time-depth plot of temperature in central Labrador Sea over 7 years

Moorings can sample with high rate, from surface to bottom, and can carry heavy instruments

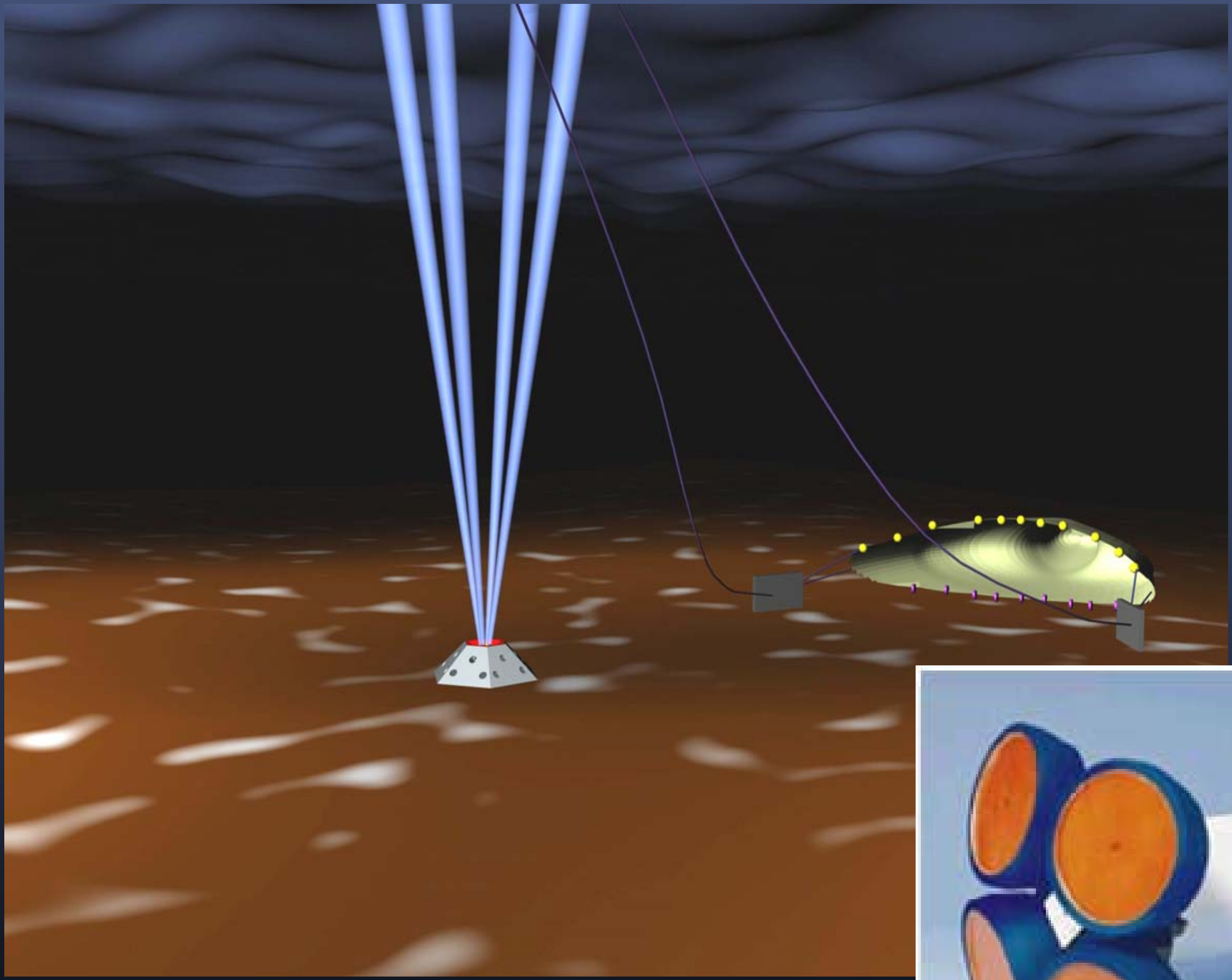


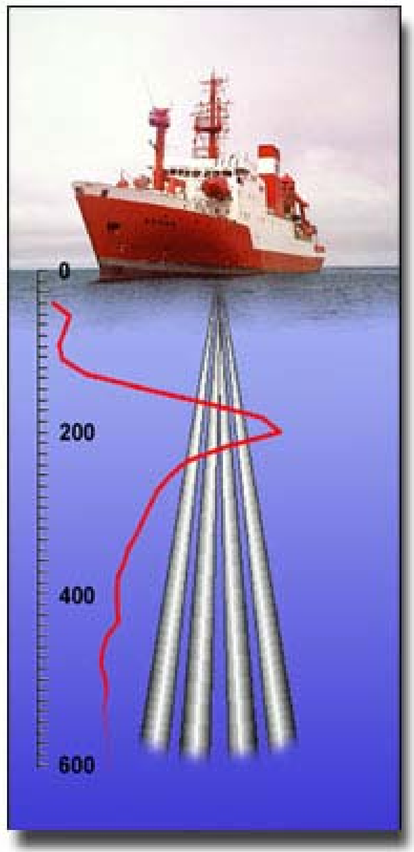


Computer animation of a subsurface mooring

Some larger moored instruments (sound sources)

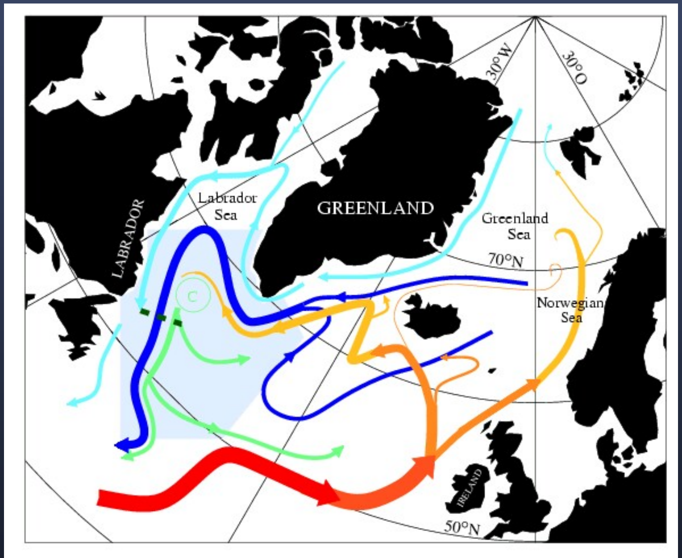
Fixed-location instruments may also be bottom-deployed

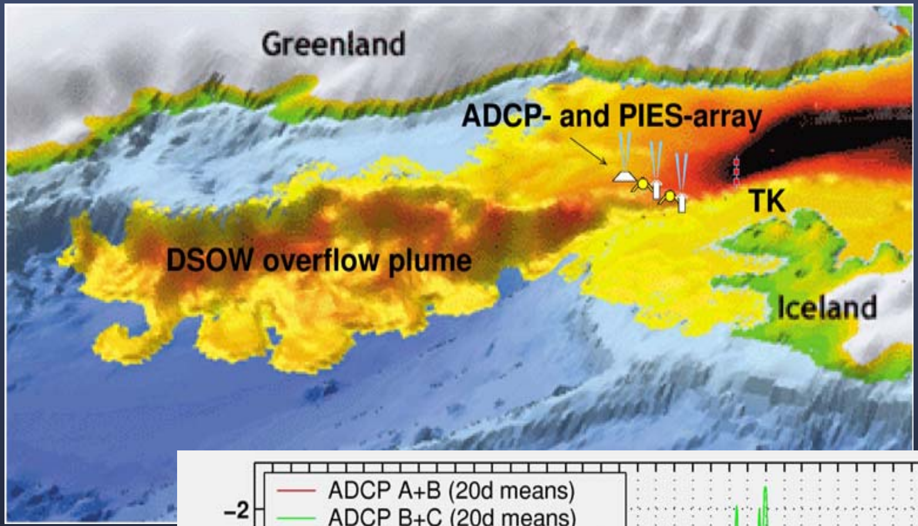


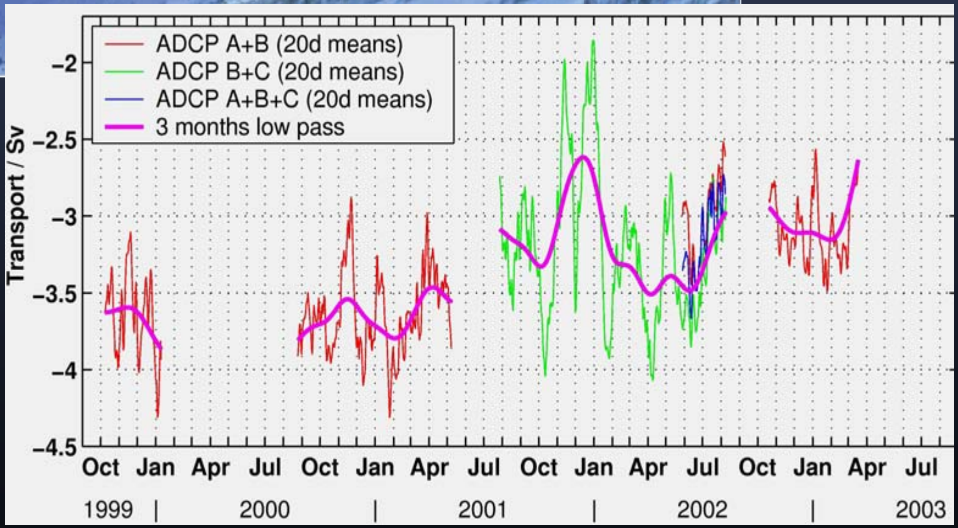


Since expensive to install and maintain, timeseries sites (or “ocean observatories“) are most useful for monitoring processes and changes in

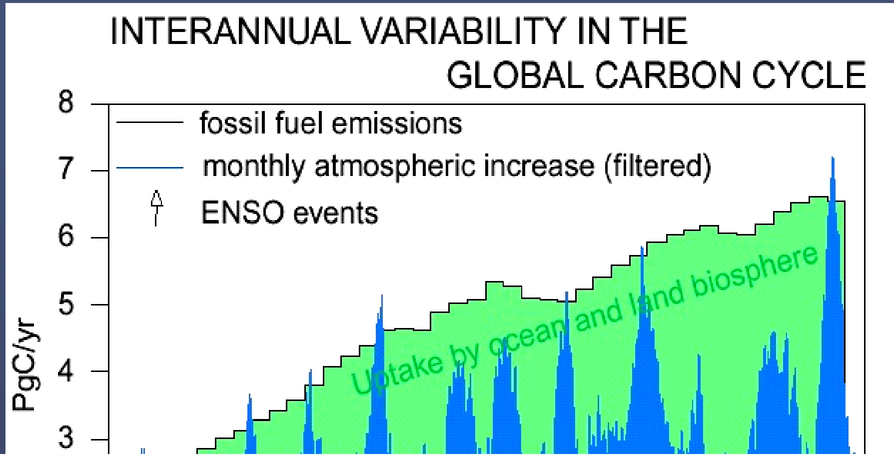
- important/critical locations, or
- places representative of ocean „provinces“



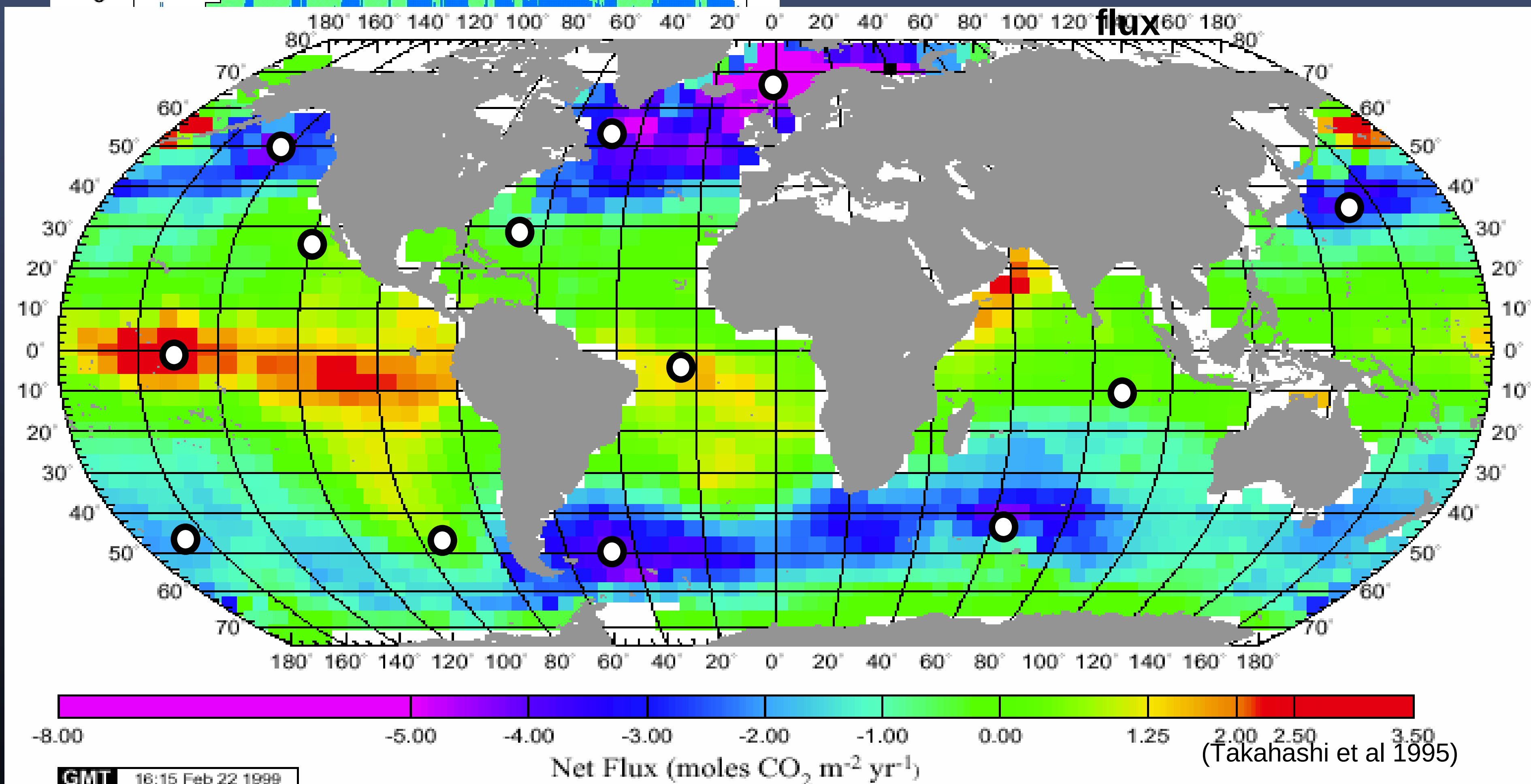




Example: variability in carbon uptake

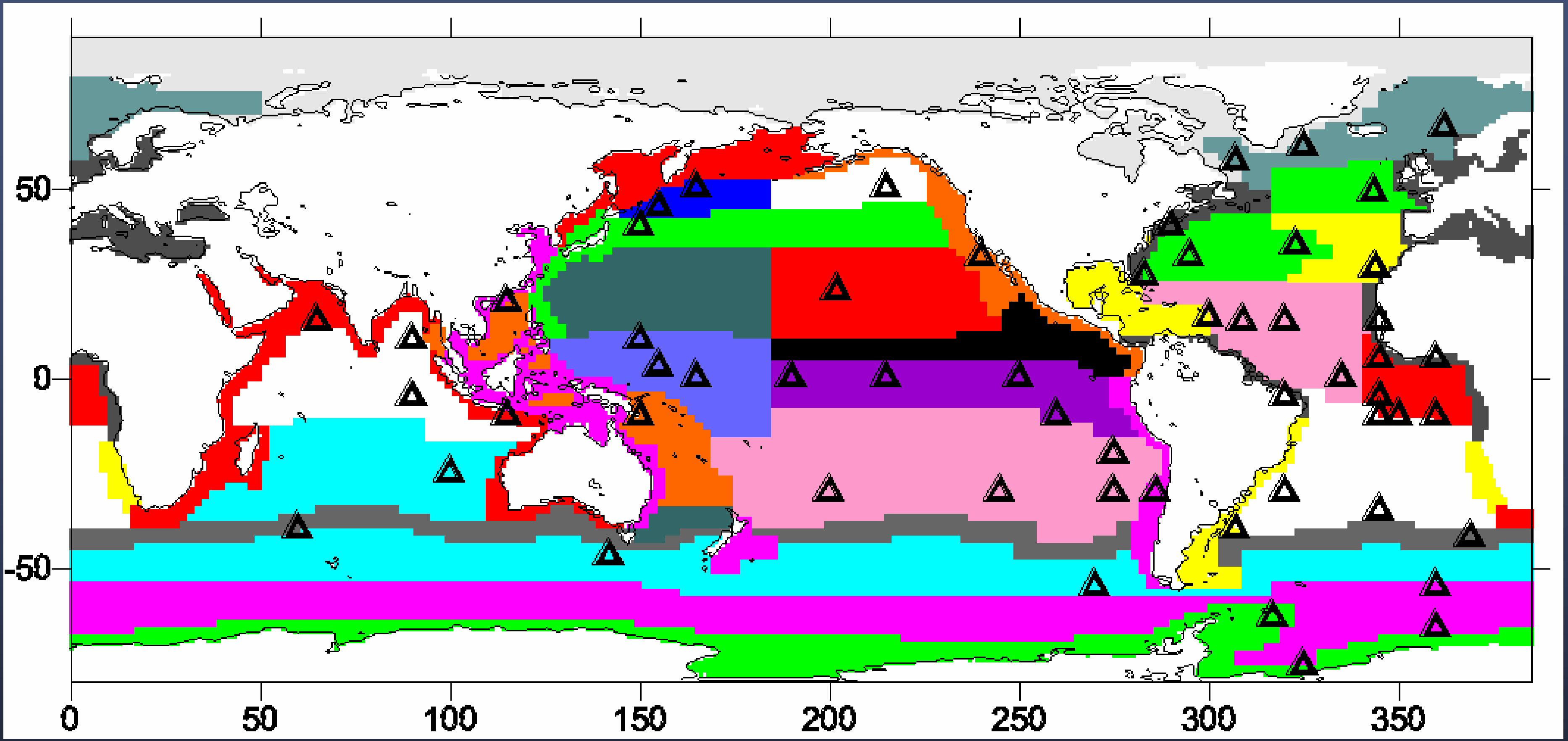


Net CO_2 flux



(Takahashi et al 1995)

Ecological Ocean Provinces



57 provinces on the basis of:

Surface chlorophyll from CZCS

Vertical distribution of Chl from 21,000 profiles

Mixed layer depth from NOAA-NODC archive

Surface nutrients

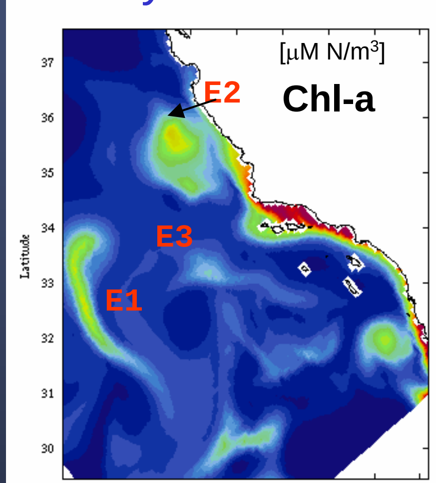
Brunt-Vaisala

Longhurst 1995

Third complementarity with remote sensing: chlorophyll

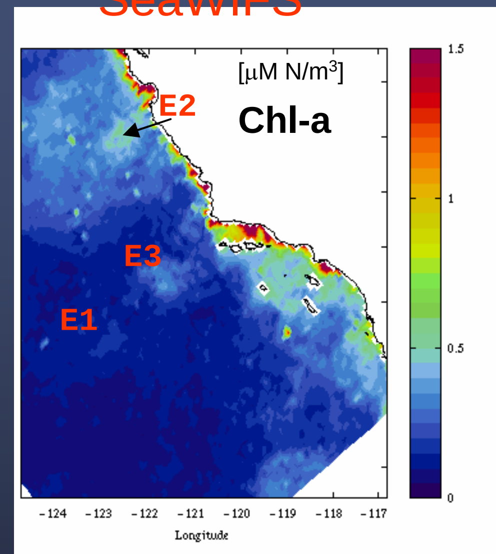
Ecosystem models clearly need observations on chlorophyll, nutrients, etc…

Ecosystem Model

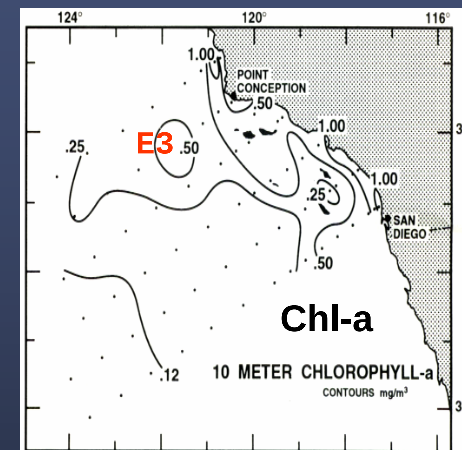


Independent verification

SeaWIFS



CalCOFI in Situ



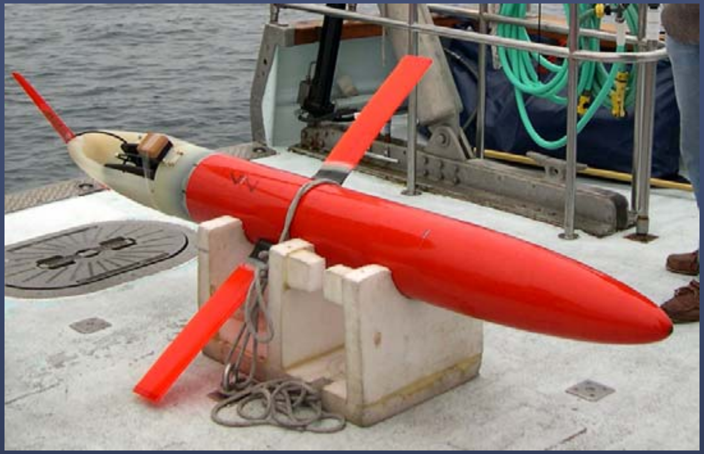
I.Robinson showed that satellite chlorophyll estimates need in-situ data

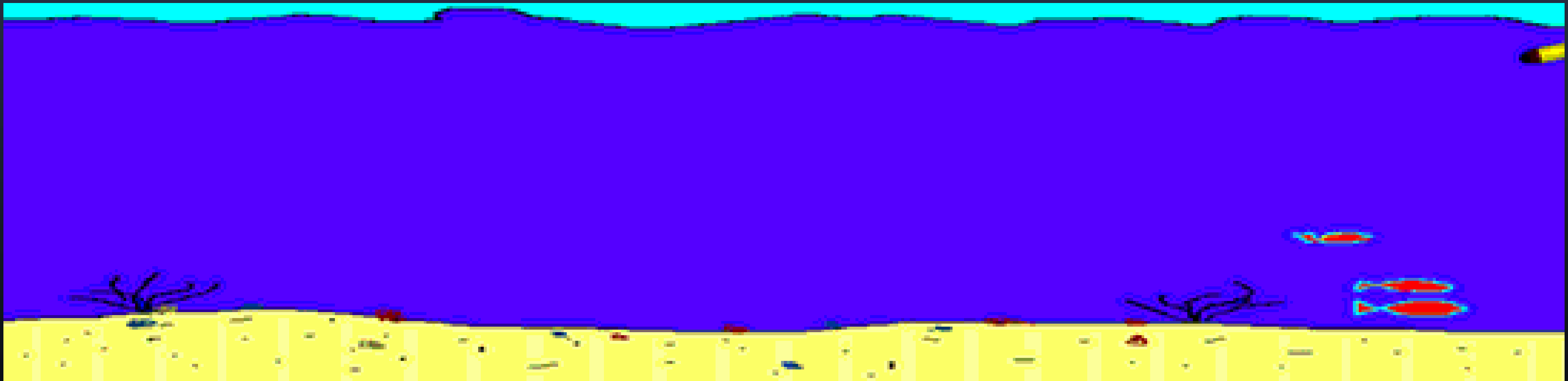
- **since large uncertainties (30% in best cases)**
- **no data in cloud-covered regions or such periods**
- **uncertain about vertical integration (light penetration, deep Chl maximum, etc)**

Can be provided by moorings or gliders....

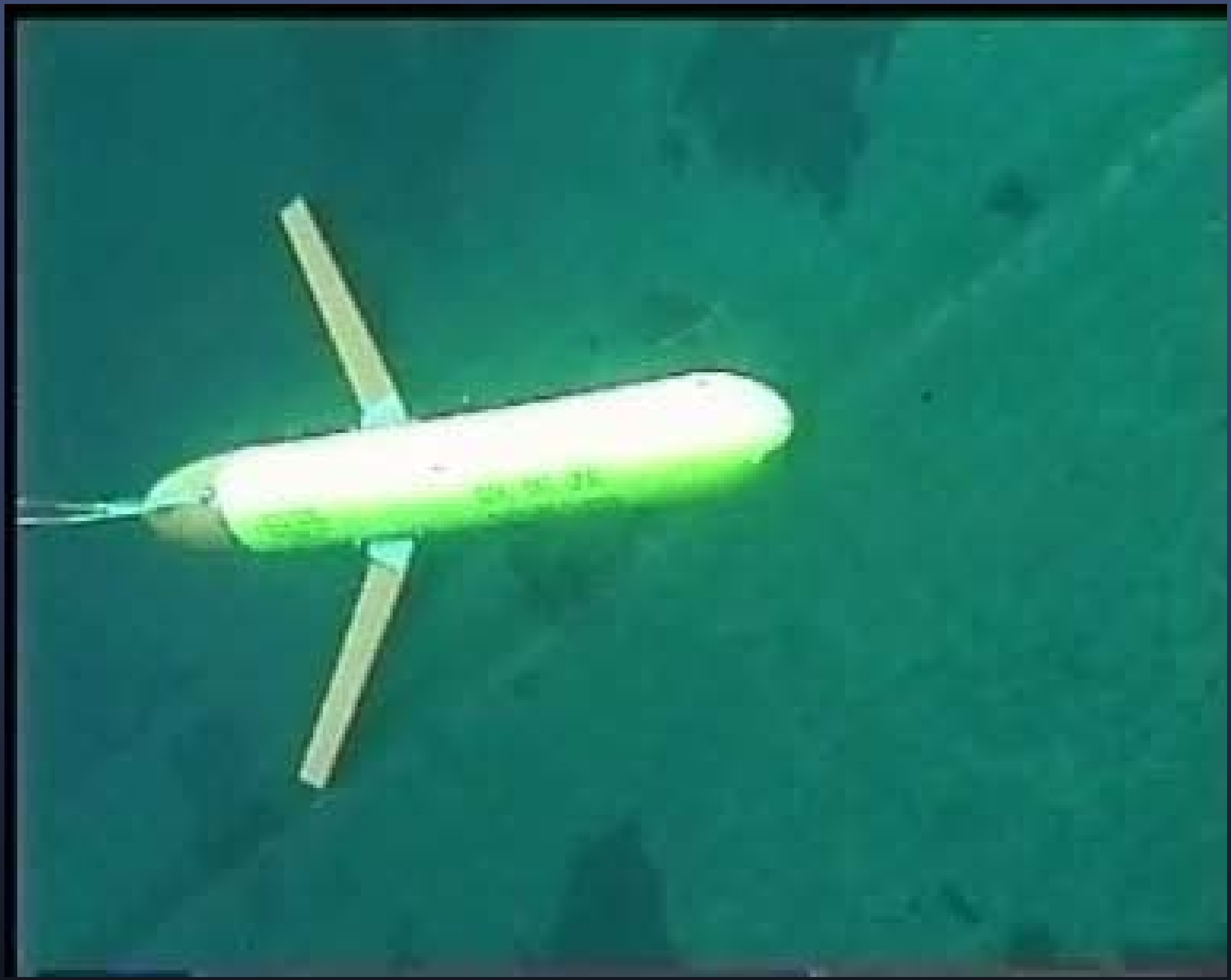
Underwater gliders:

for long repeat sections or profiling in fixed location, now in prototype stage.



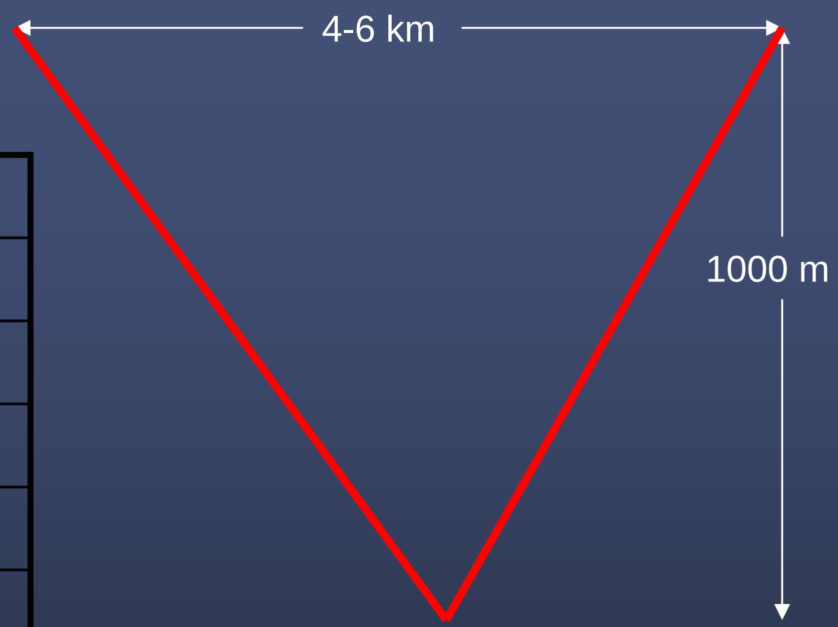


Test of a glider in a lake



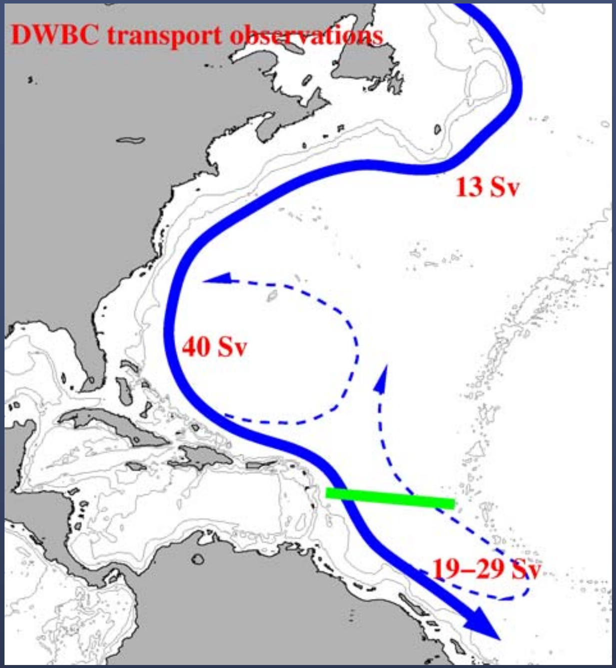
Spray Characteristics

Length	200 cm	
Wing Span	90 cm	
Mass	52 kg	
52 Lithium DD Cells	13 MJ, 12 kg	
GPS Navigation	± 100 m	
Iridium Data Relay	1 kbyte in 2 minutes	
Buoyancy	150 gm	50 gm
Glide Angle	25°	18°
Horizontal Velocity	39 cm/s	20 cm/s
Cycles in Life(1)	865	1300
Range(1)	2900 km	6000 km

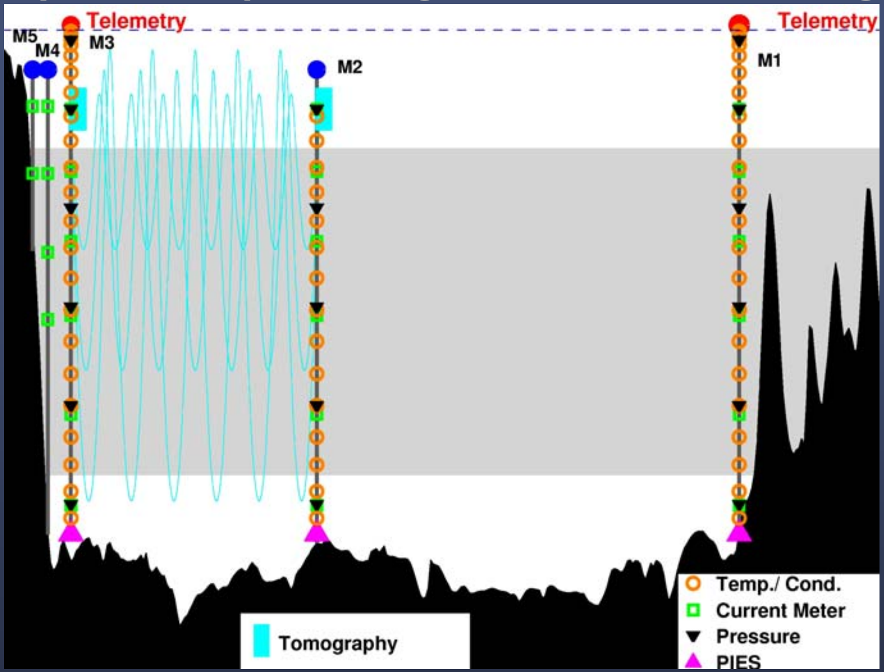


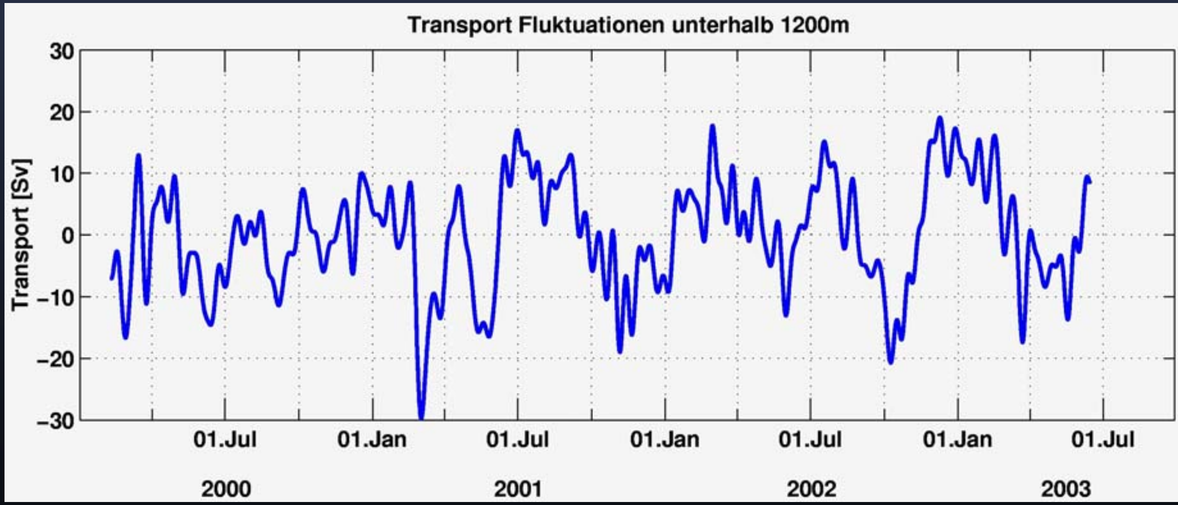
In a typical 1-km dive cycle a glider advances 4 to 6 km.

Integrating techniques:



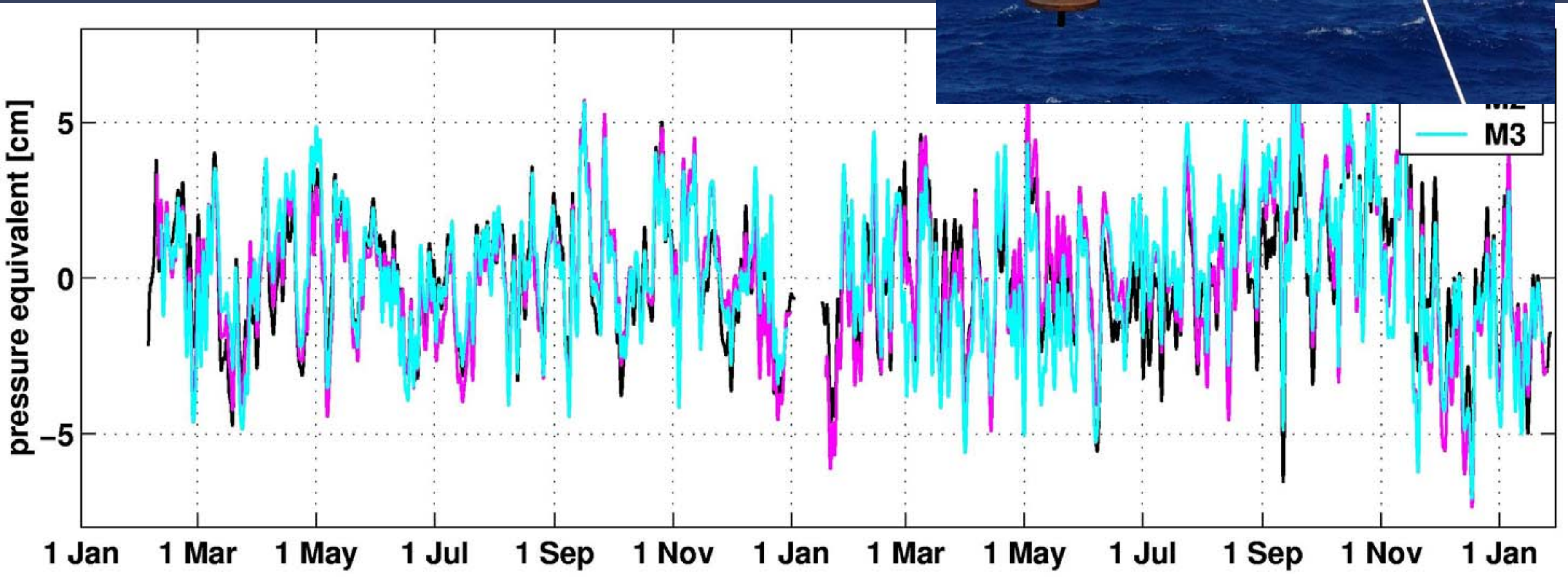
Geostrophic transport integrals between moorings



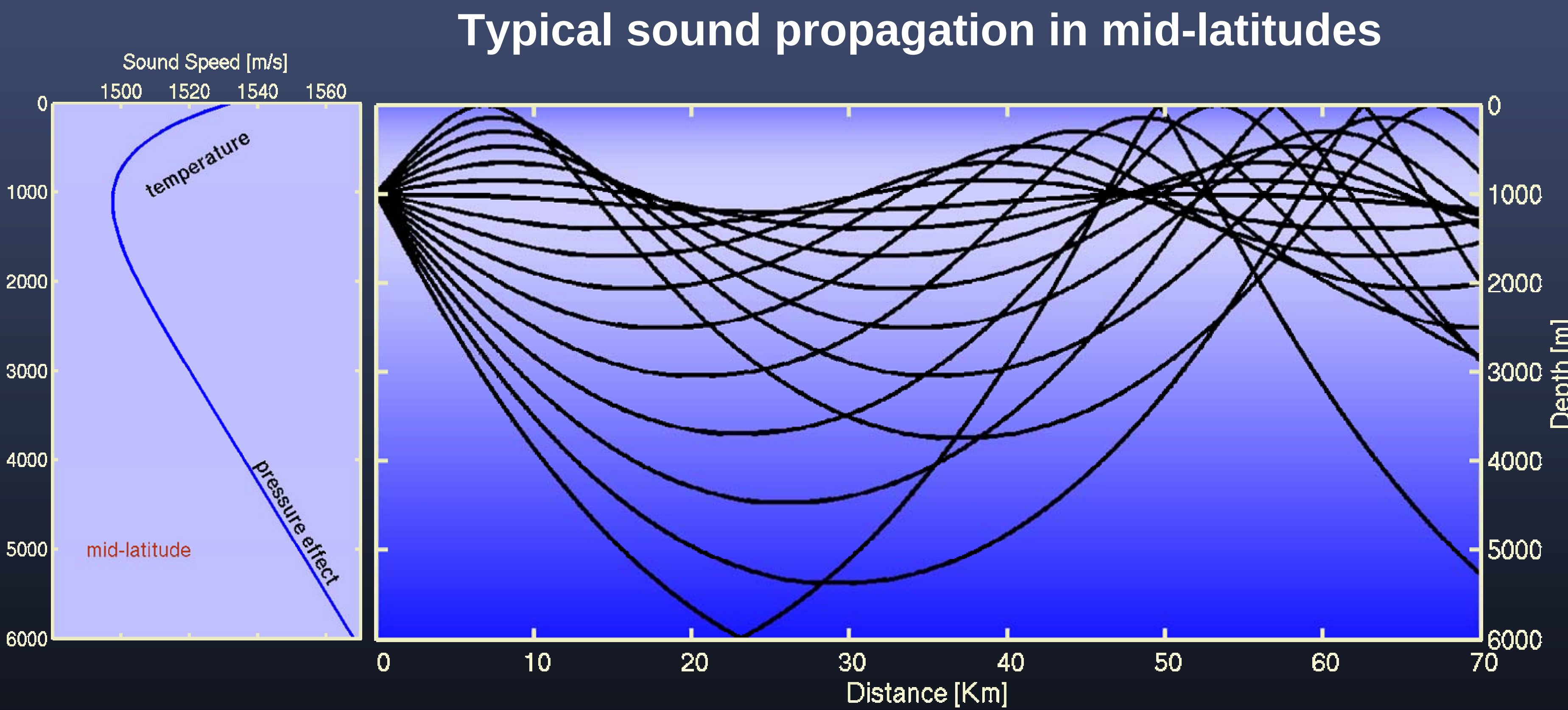


Bottom Pressures from 3 sensors 2000-2001:

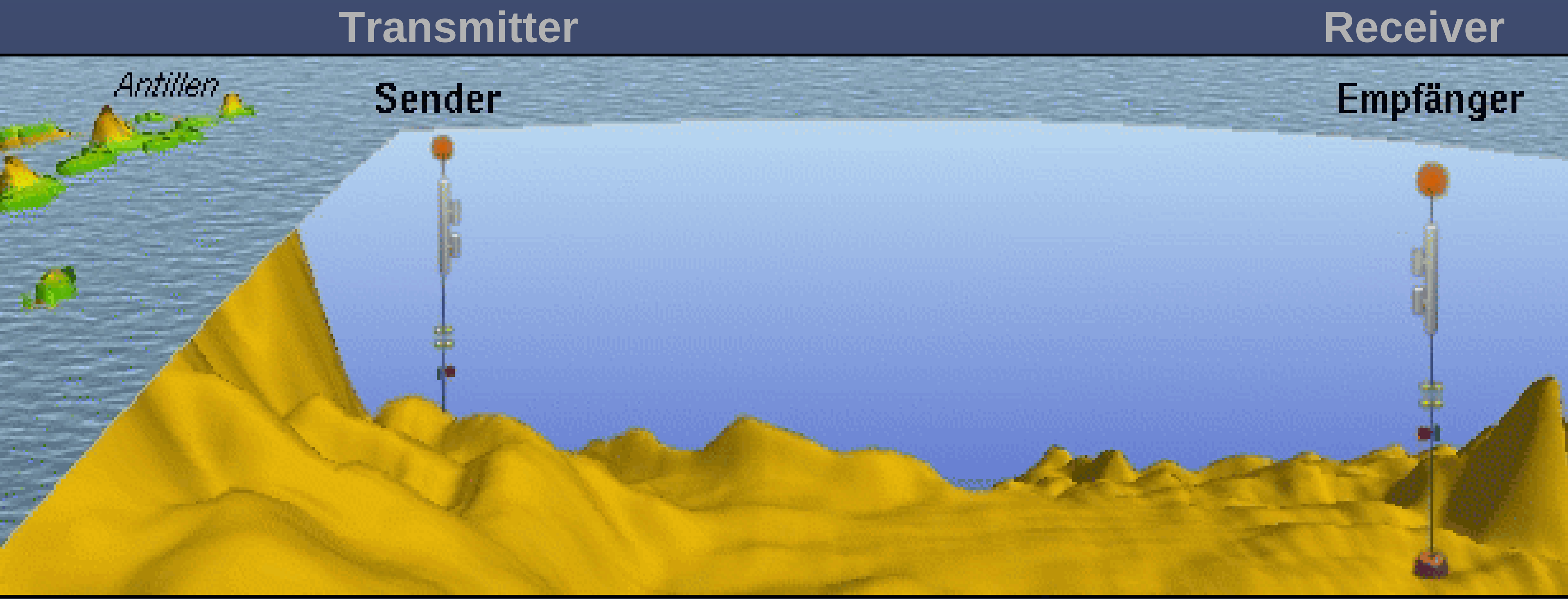
agreement to a few mm over 5000m = 5×10^{-7}



Horizontal integration by sound transmission

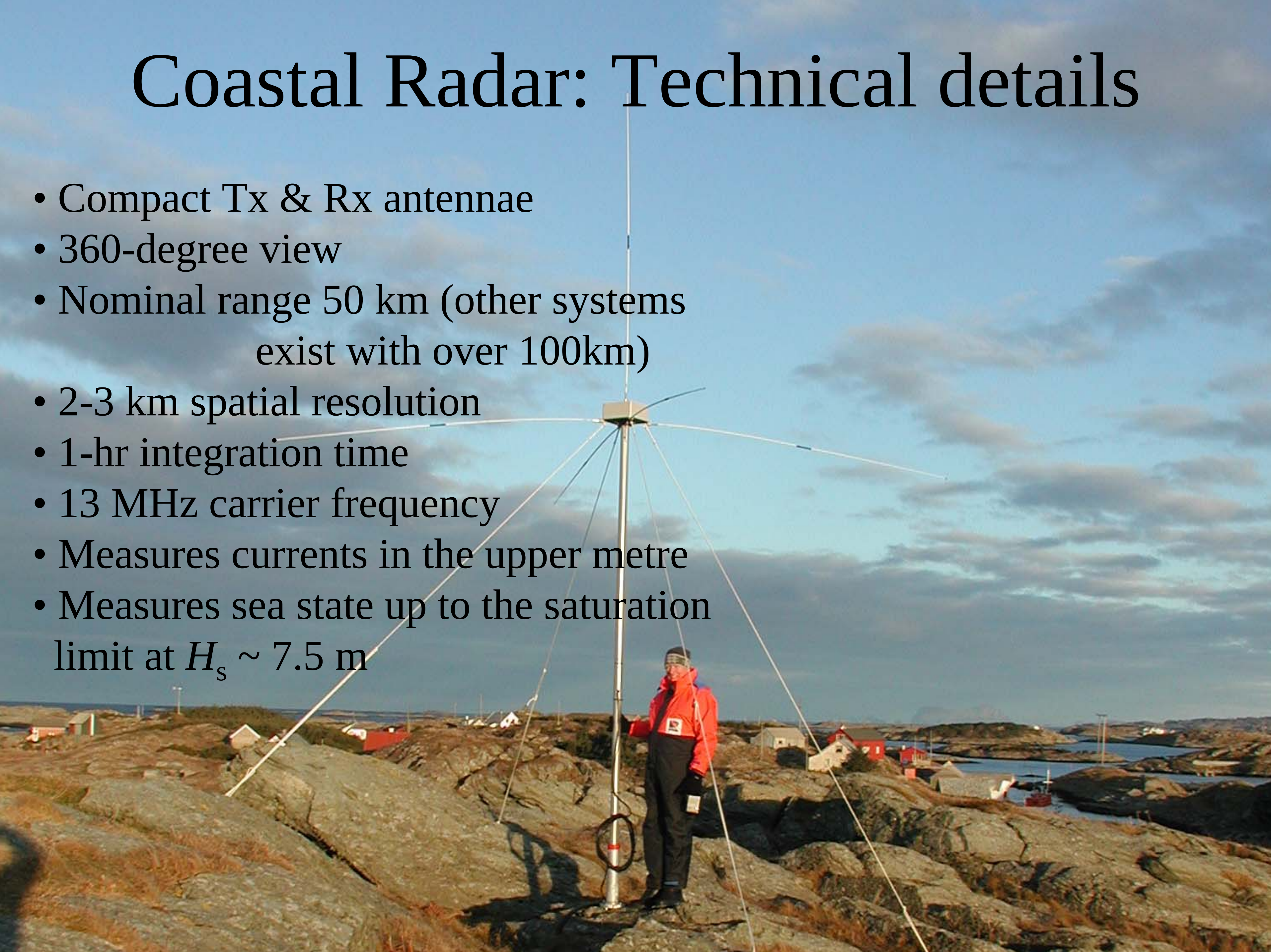


Acoustic tomography principle

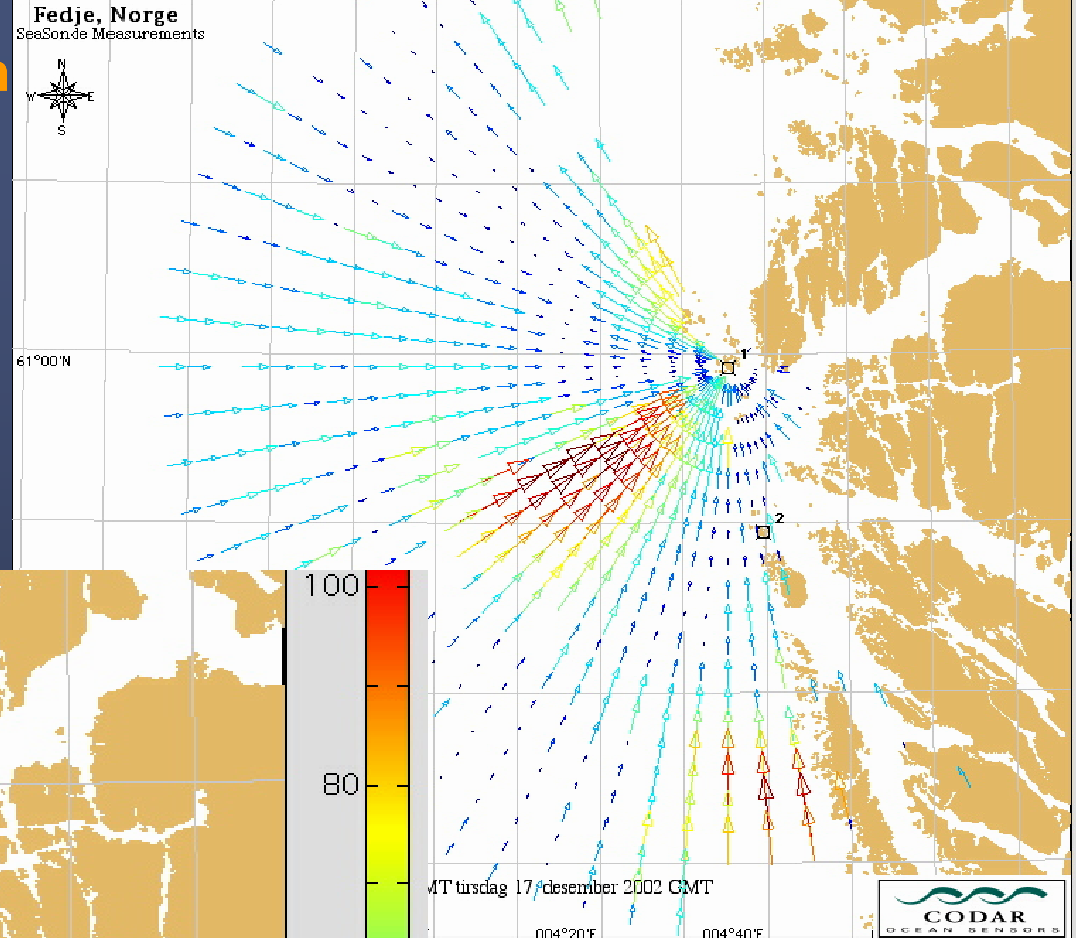


Coastal Radar: Technical details

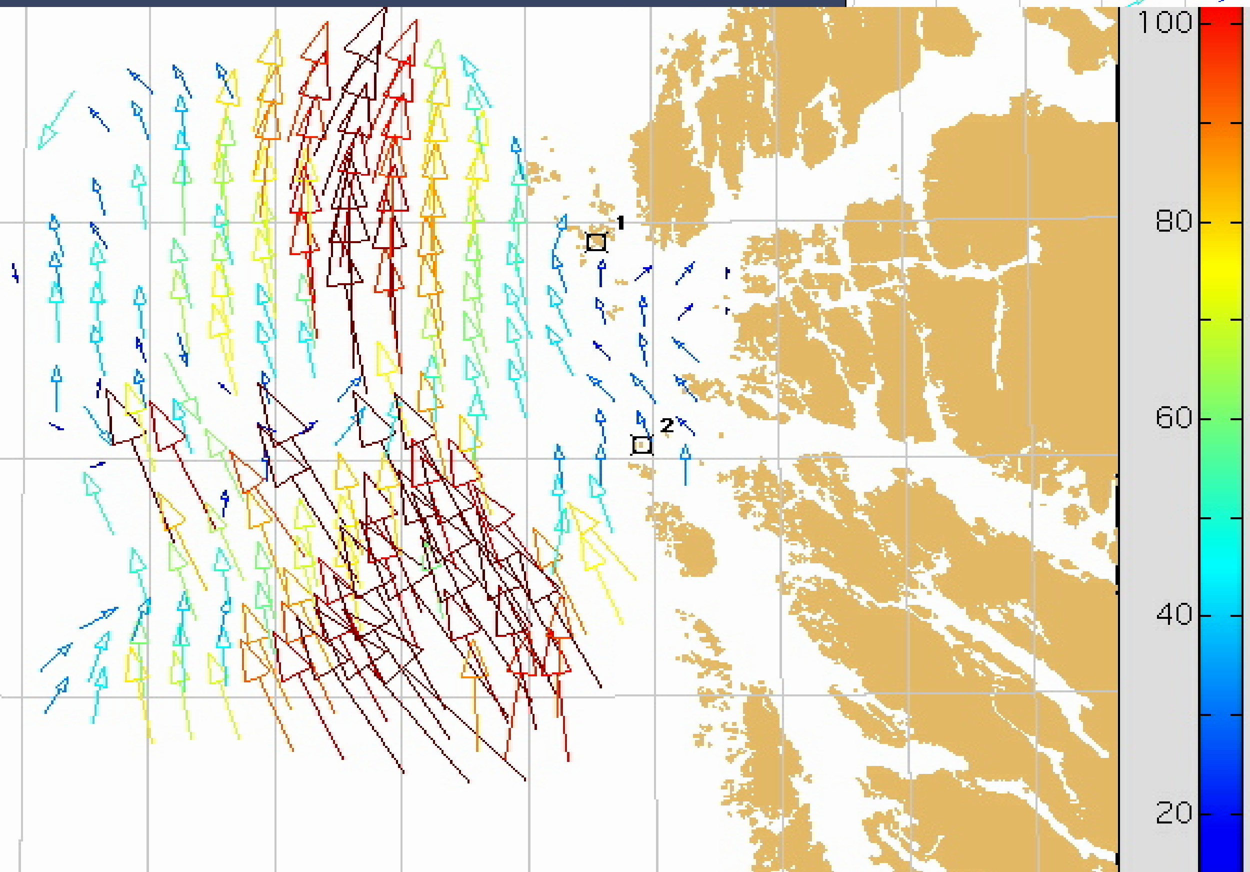
- Compact Tx & Rx antennae
- 360-degree view
- Nominal range 50 km (other systems exist with over 100km)
- 2-3 km spatial resolution
- 1-hr integration time
- 13 MHz carrier frequency
- Measures currents in the upper metre
- Measures sea state up to the saturation limit at H_s ~ 7.5 m



Radial vectors from one station

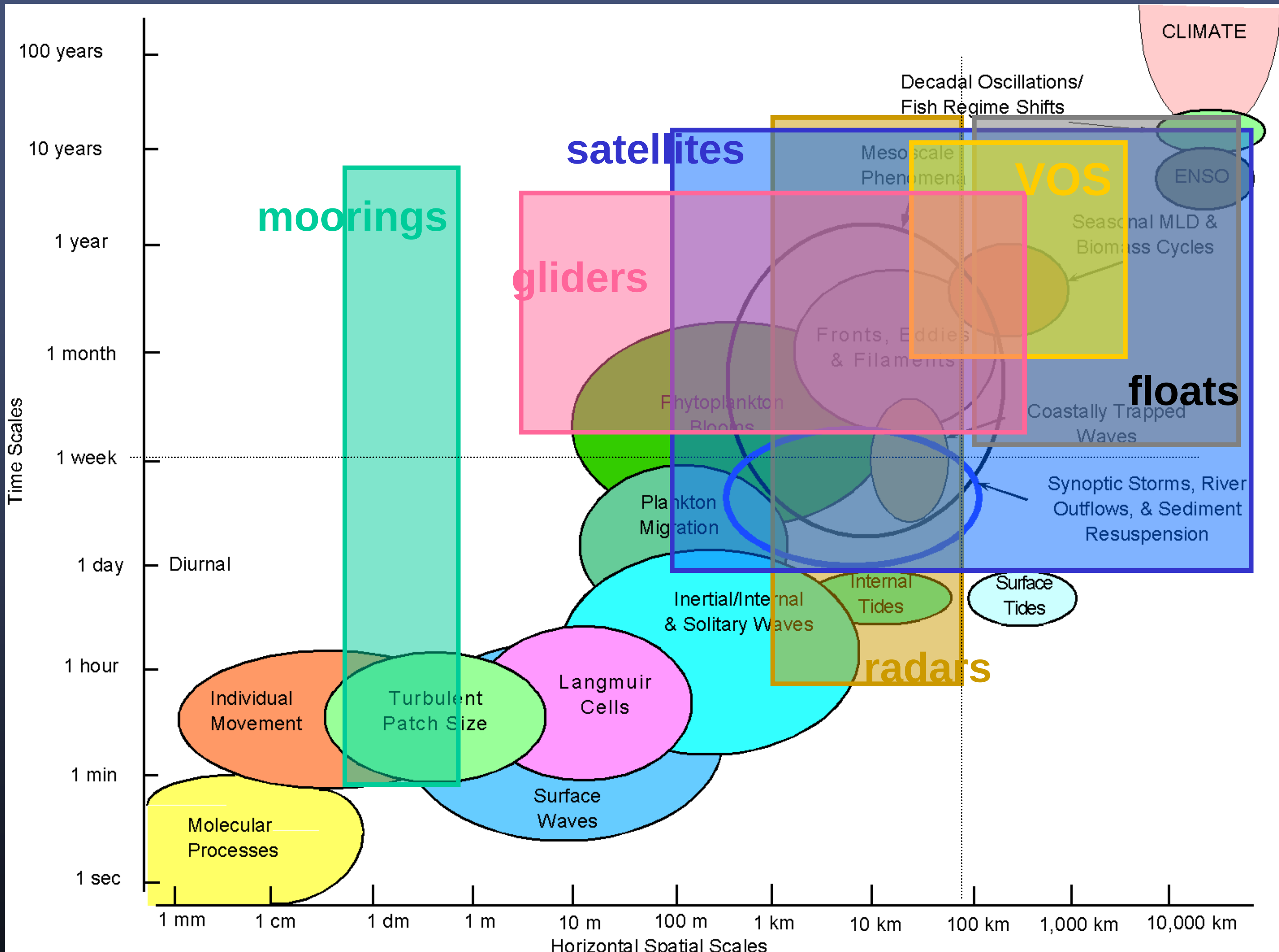


Full vectors from 2 stations



Sampling characteristics of the platforms

Platform	strengths	weaknesses
Research vessels ($25000/day)	- can take samples - handle/deploy heavy equipment - reach remote areas (use like VOS)	- very sparse sampling - expensive (too much for operationa obs, but needed for servicing)
VOS (free)	- high resolution along repeat tracks - for surface reading many variables	- tracks not always where wanted - tracks may change, they don‘t stop - no subsurface except T (800m)
Surface drifters ($2000 ?)	- global coverage - rapid sampling in time - low-cost, robust technology	- sparse spatial sampling - only surface obs - limited variables (T, air p, S)
Floats ($15000+5000)	- global coverage - vertical profiling to mid-depth - “cheap“ so large numbers feasible	- coarse x,y,t resolution - limited weight/power for sensors - avoid or quickly leave certain region
Moorings ($250000)	- high time resolution, surface to bottom - many variables possible - can monitor adverse/difficult locations - re-calibrations, so can be reference	- no x,y resolution - expensive, incl. ships needed - large technical effort/few groups
Gliders ($70000)	- good sampling along tracks - free choice of track, can be steered - small sensor suite feasible	- very slow (20-25cm/s) - limited depth range and variables
Integrals	- integrate over long distances - good time resolution	- expensive - limited variables and places possibl
Coastal radars	- good x,y,t resolution - land based	- limited coverage - only surface, only currents and wav


CLIMATE
Decadal Oscillations/
Fish Regime Shifts
satellites
Mesoscale
Phenomena
VOS
ENSO
moorings
Seasonal MLD &
Biomass Cycles
gliders
Fronts, Eddies
& Filaments
floats
Phytoplankton
Blooms
Coastally Trapped
Waves
Plankton
Migration
Synoptic Storms, River
Outflows, & Sediment
Resuspension
Diurnal
Internal
Tides
Surface
Tides
Inertial/Internal
& Solitary Waves
radars
Langmuir
Cells
Individual
Movement
Turbulent
Patch Size
Surface
Waves
Molecular
Processes
100 years
10 years
1 year
1 month
1 week
1 day
1 hour
1 min
1 sec
Time Scales
1 mm
1 cm
1 dm
1 m
10 m
100 m
1 km
10 km
100 km
1,000 km
10,000 km
Horizontal Spatial Scales

Example tasks:

Assume the goals are to

1) Monitor water mass formation

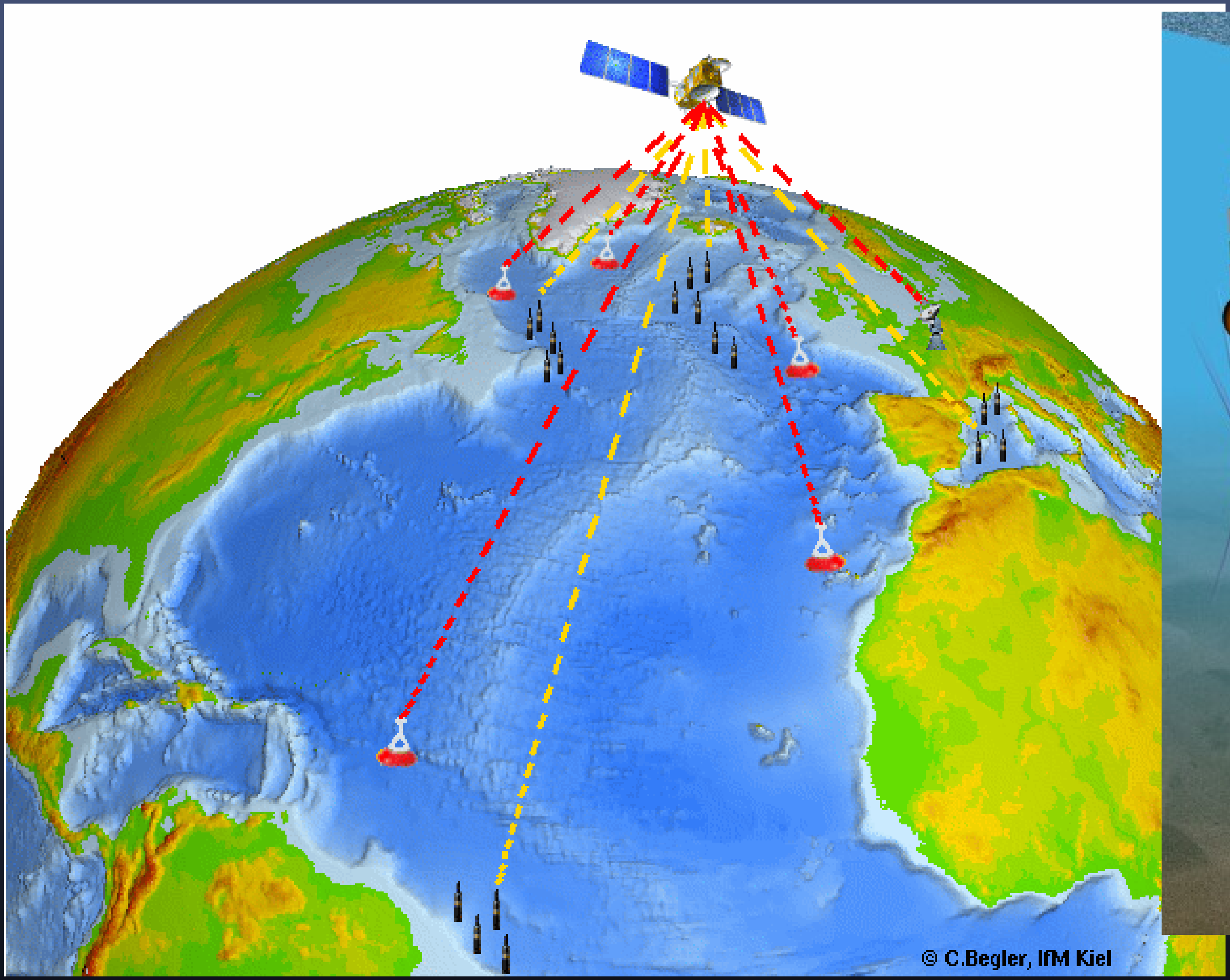
2) Detect coastal eddies and their impact on the ecosystem

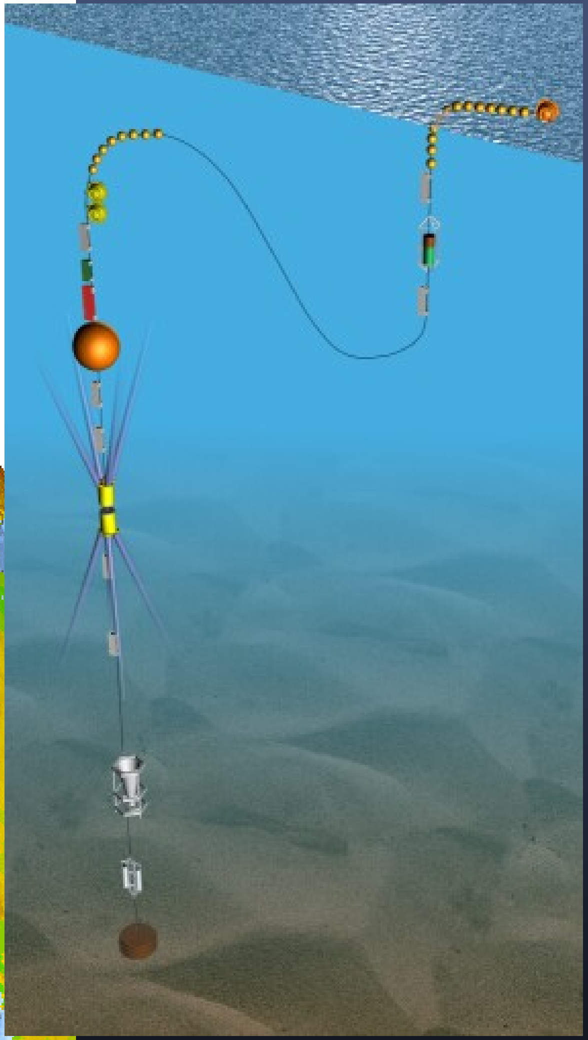
3) Observe the outflow through the strait of Gibraltar

4) Collect observations under the ice

Some technological aspects to remember:

- **data telemetry**



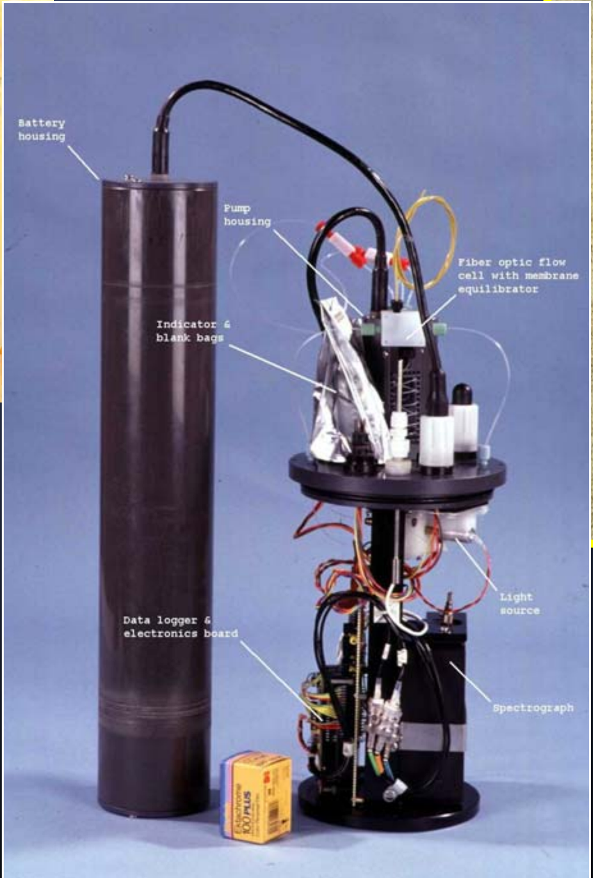


Now feasible for most platforms

Advanced sensors

^{14}C Primary Production Measurements(C. Taylor)

CO_2 sensor
(M. DeGrandpre)

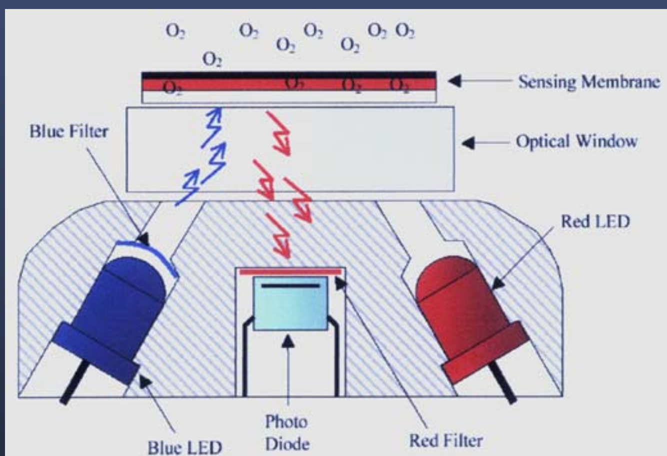


Optical (Dickey) and
O_2 sensors (Wanninkhof)

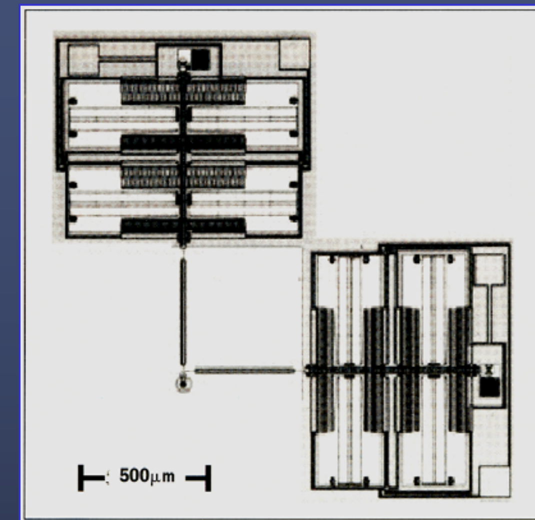
Essential for further developments:

Minituarization of sensors

- Biogeochemical sensors that are small, low-power, "dry" (optical, acoustic, chips)



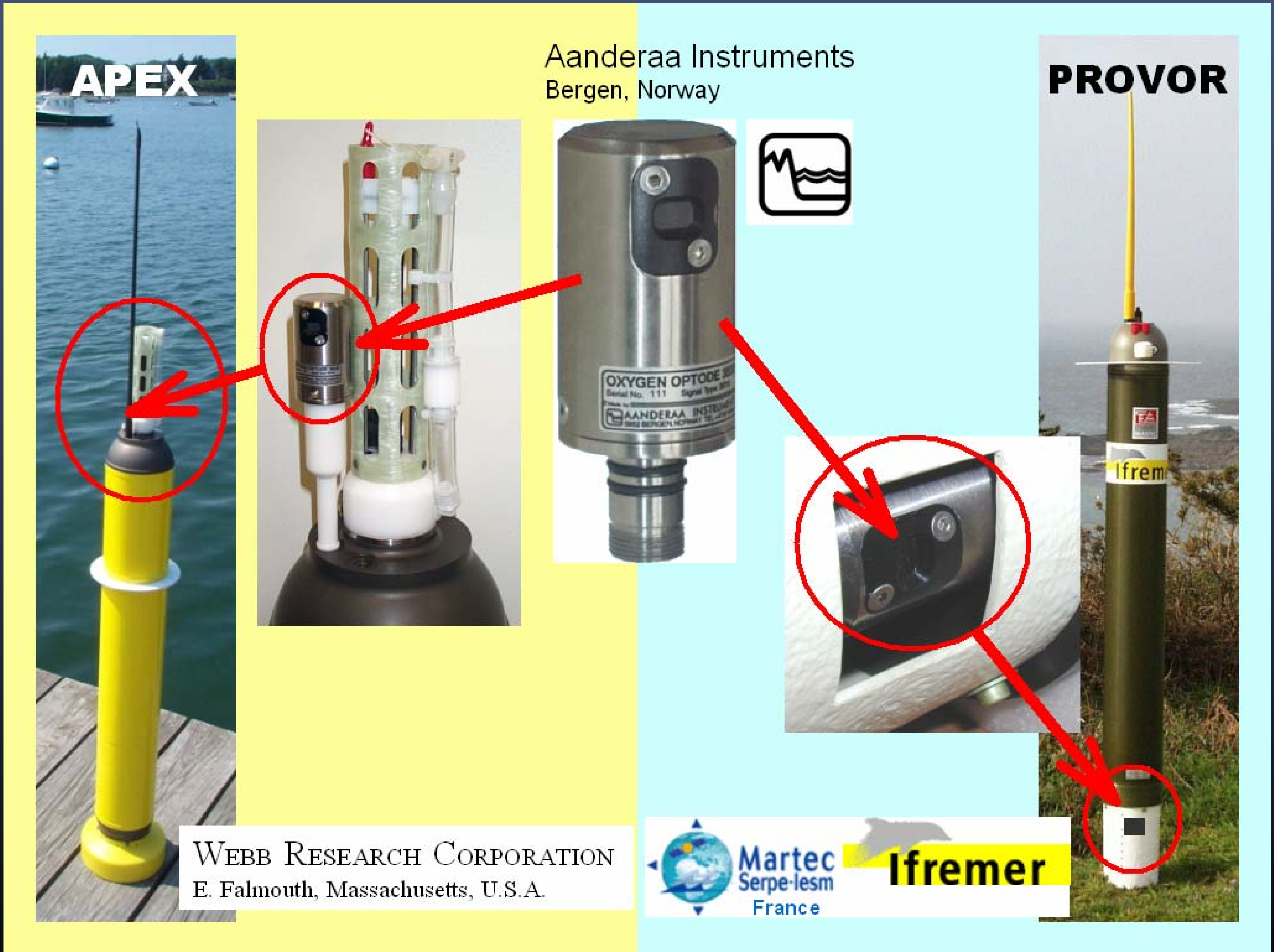
Optical O_2 sensor

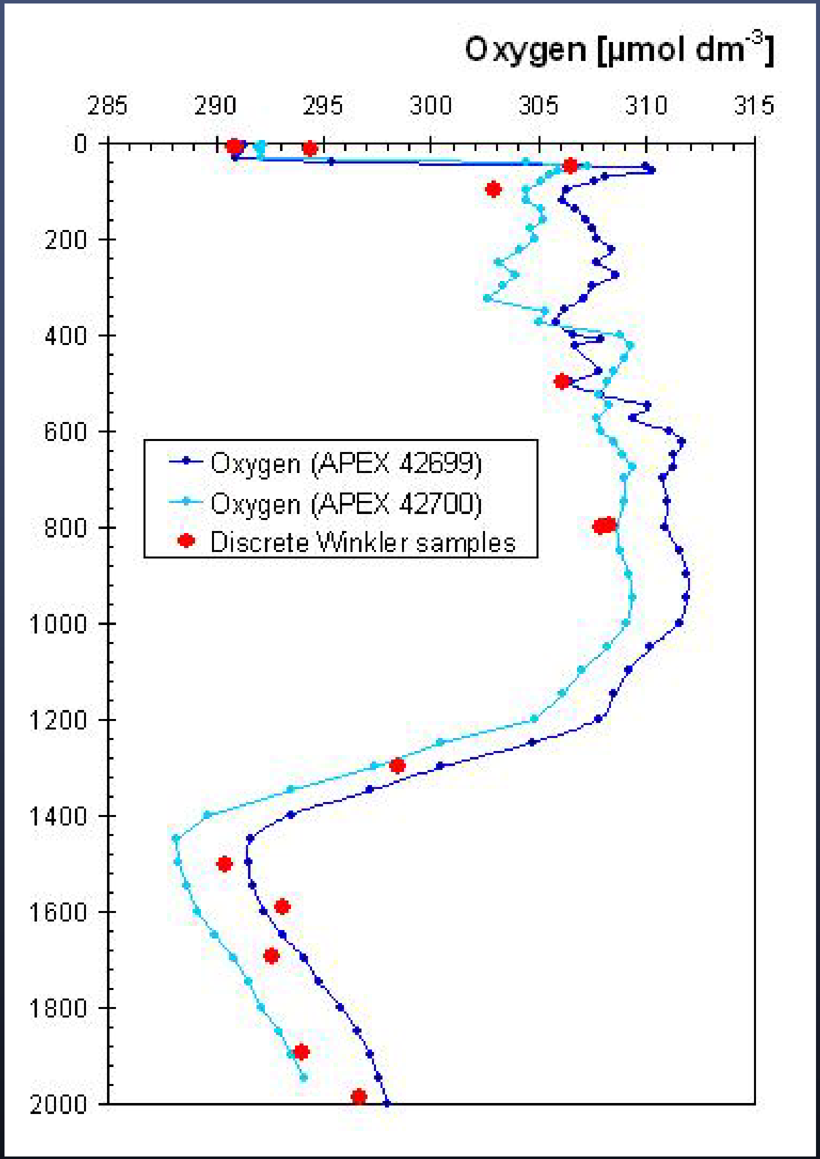


MEMS chip

Micro-humidity sensor (JPL)

Some sensors can now be installed on floats (and gliders)

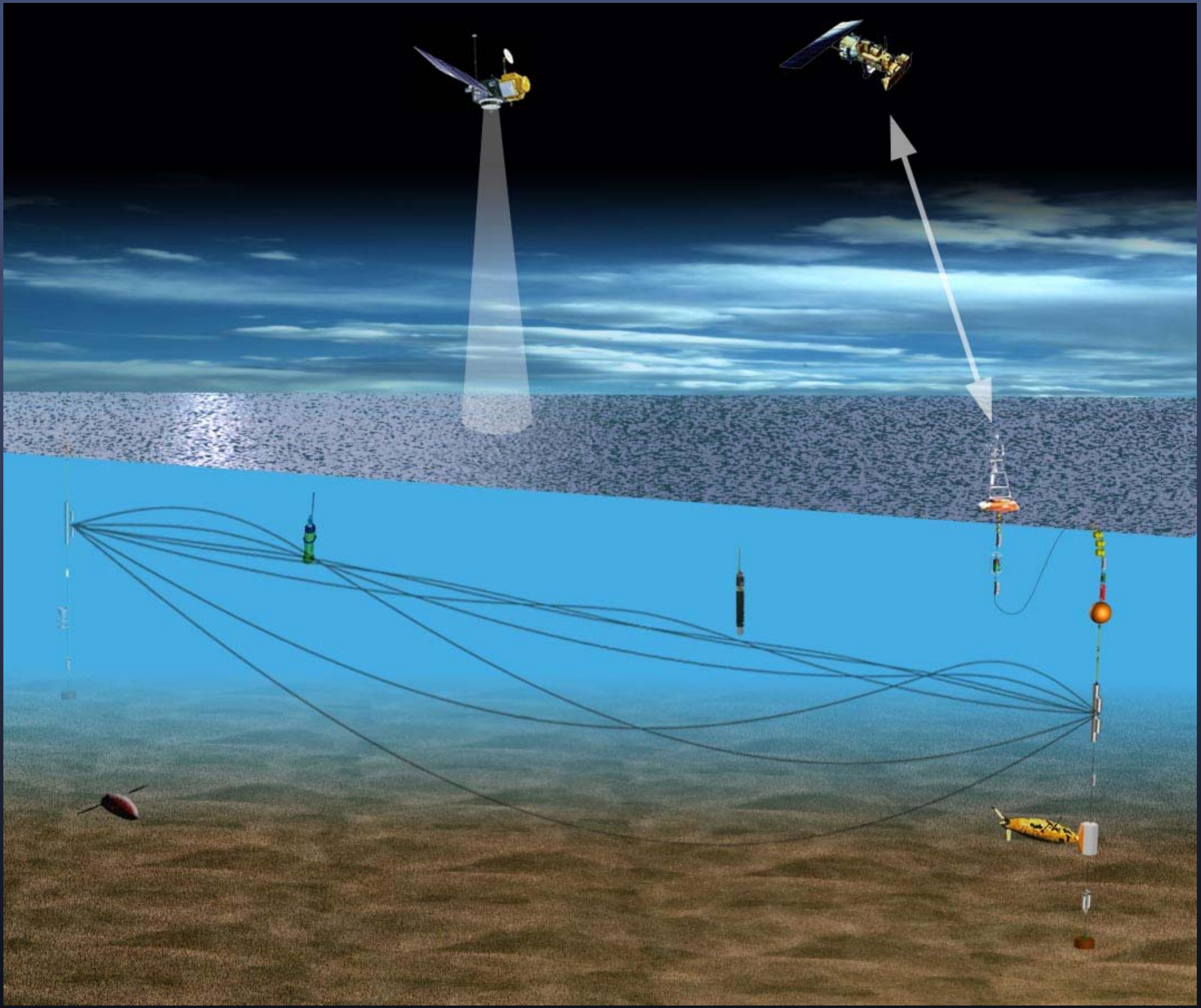




First O_2 optode profiles from floats (Labrador Sea).

(A.Koertzinger, J.Schimanski)

The challenge ahead is the integration of the various components



Sampling characteristics of the platforms

Platform	strengths	weaknesses
Research vessels ($25000/day)	- can take samples - handle/deploy heavy equipment - reach remote areas (use like VOS)	- very sparse sampling - expensive (too much for operationa obs, but needed for servicing)
VOS (free)	- high resolution along repeat tracks - for surface reading many variables	- tracks not always where wanted - tracks may change, they don‘t stop - no subsurface except T (800m)
Surface drifters ($2000 ?)	- global coverage - rapid sampling in time - low-cost, robust technology	- sparse spatial sampling - only surface obs - limited variables (T, air p, S)
Floats ($15000+5000)	- global coverage - vertical profiling to mid-depth - “cheap“ so large numbers feasible	- coarse x,y,t resolution - limited weight/power for sensors - avoid or quickly leave certain regior
Moorings ($250000)	- high time resolution, surface to bottom - many variables possible - can monitor adverse/difficult locations - re-calibrations, so can be reference	- no x,y resolution - expensive, incl. ships needed - large technical effort/few groups
Gliders ($70000)	- good sampling along tracks - free choice of track, can be steered - small sensor suite feasible	- very slow (20-25cm/s) - limited depth range and variables
Integrals	- integrate over long distances - good time resolution	- expensive - limited variables and places possibl
Coastal radars	- good x,y,t resolution - land based	- limited coverage - only surface, only currents and wav