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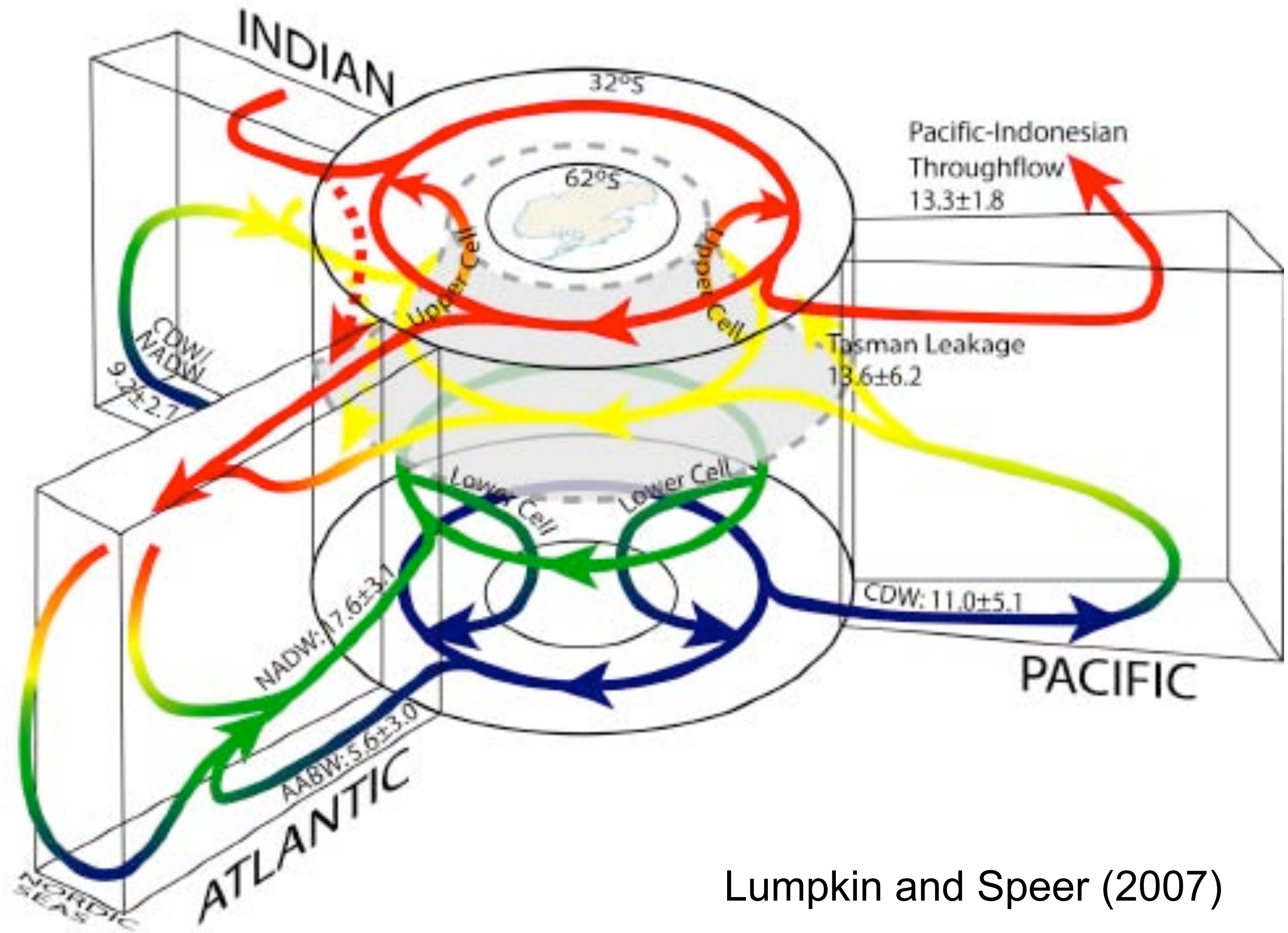
Deep circulation and meridional overturning

Presented by Steve Rintoul on behalf of the >100 co-authors on relevant Community White Papers.

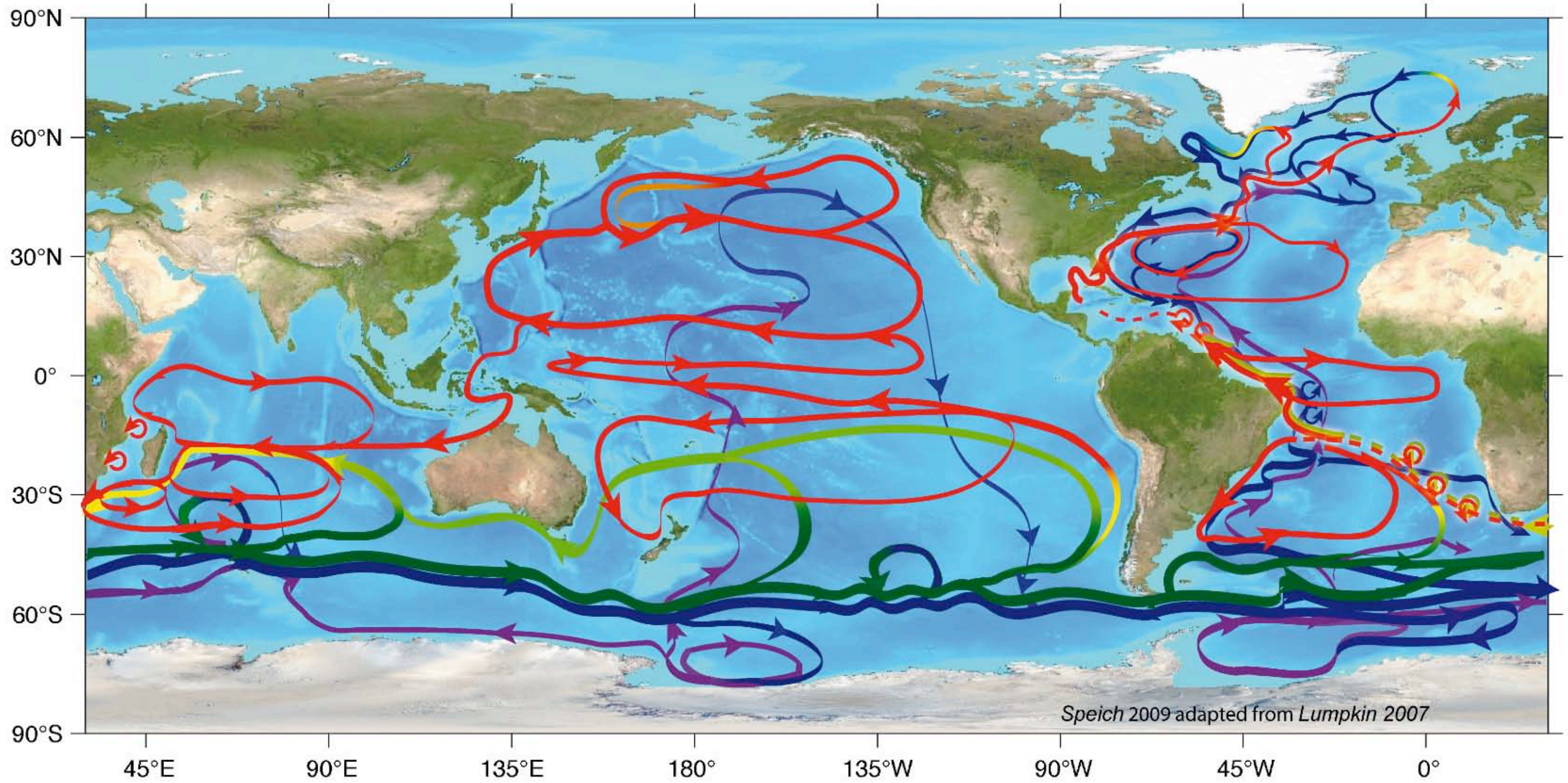
CSIRO

Global overturning circulation



Lumpkin and Speer (2007)

Global overturning circulation



Speich (2009) adapted from Lumpkin (2007)

Significance of the deep ocean and MOC

- Roughly half the ocean volume is below 2000 m and changes in the deep ocean make a significant contribution to budgets of carbon, freshwater and heat (and hence sea-level rise).
- The MOC is a dominant mechanism for transport and storage of heat, freshwater and carbon and the resupply of nutrients.
- The MOC is a three-dimensional circulation spanning the ***full-depth*** global oceans. Therefore our observations of the MOC must extend throughout the full-depth of the ocean.
- Variations in the MOC are linked to past climate variations and will likely have consequences for present and future climate.
- Decadal and longer time-scale variability is intimately linked to the deep circulation.
- Changes in the overturning circulation will impact on ecosystems by changing the nutrient content and carbon saturation state of surface waters.

Societal relevance of deep ocean observations

Many of the most urgent challenges society is facing:

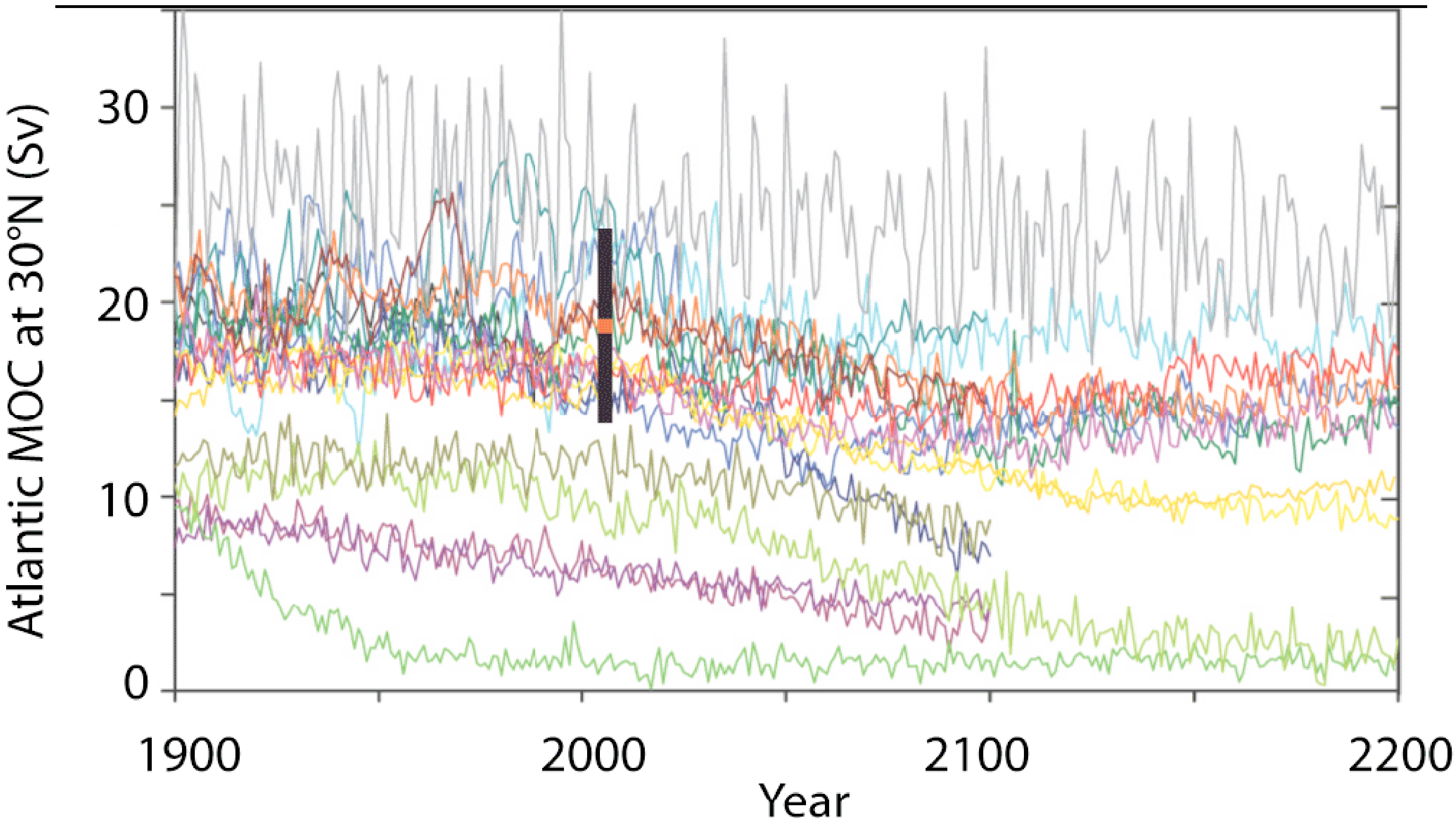
- climate change, including the risk of abrupt change;
- decadal variability driving cycles of floods and droughts;
- sea-level rise;
- the future of the carbon cycle; and
- food security

cannot be addressed without understanding (and therefore observing) the deep ocean.

Progress in the last decade

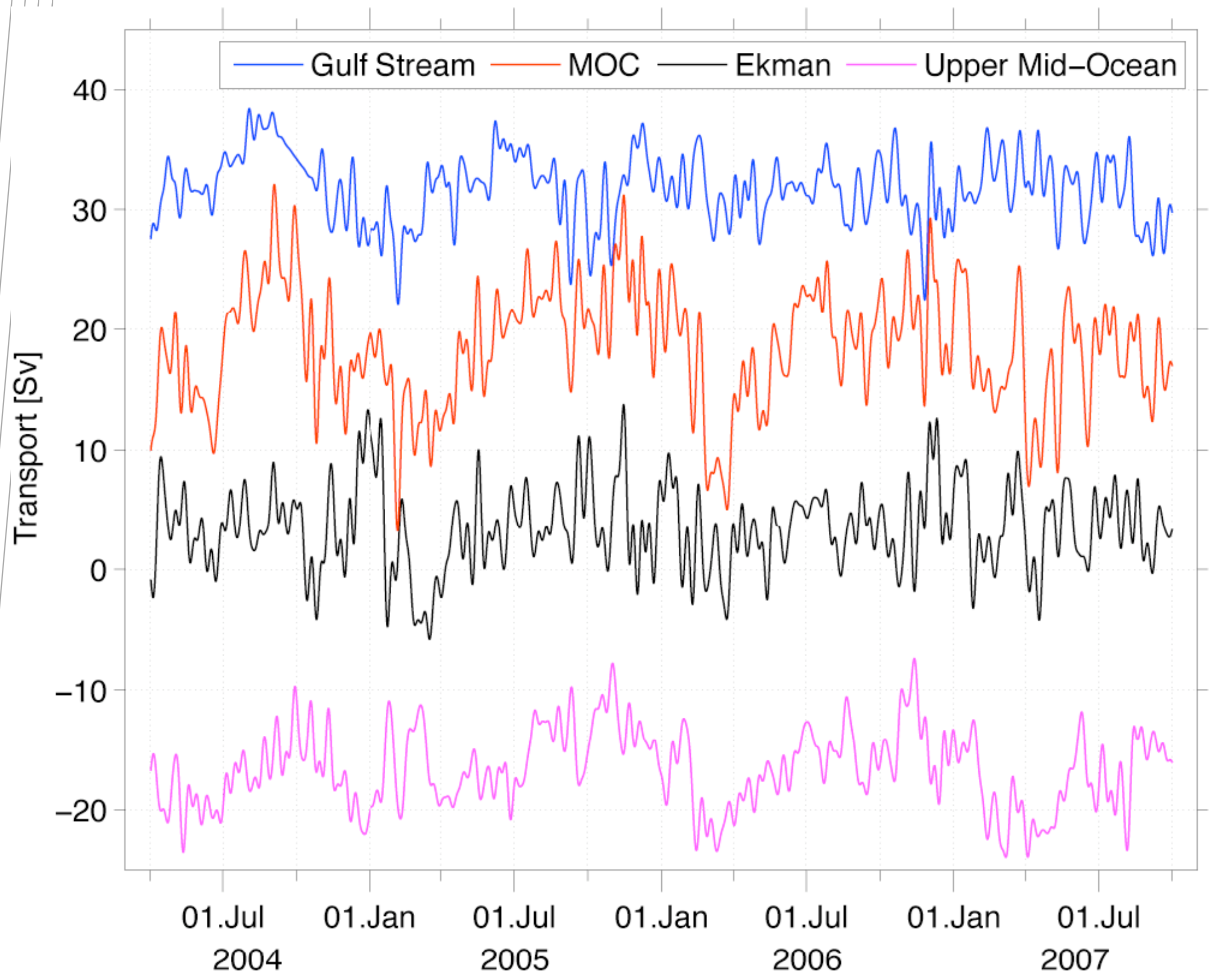
- Quantified the strength of the global overturning circulation.
- First time series measurements of the Atlantic overturning, finding unanticipated variability.
- Documented changes in the deep ocean: stronger climate link to deep ocean than anticipated.
- Deep ocean changes contribute significantly to changes in ocean heat content and sea-level rise.
- Deeper appreciation of role of the MOC and deep circulation in low-frequency climate variability.
- Deeper appreciation of role of the MOC in biogeochemical budgets.

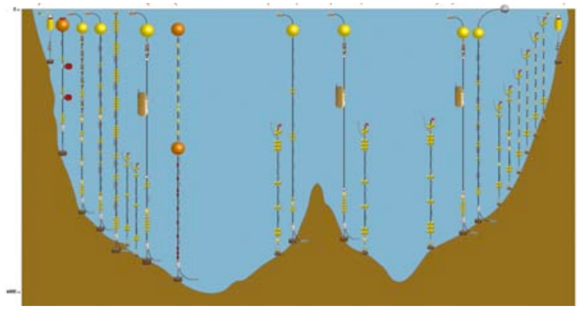
Projected slowing of Atlantic MOC



Cunningham et al., CWP

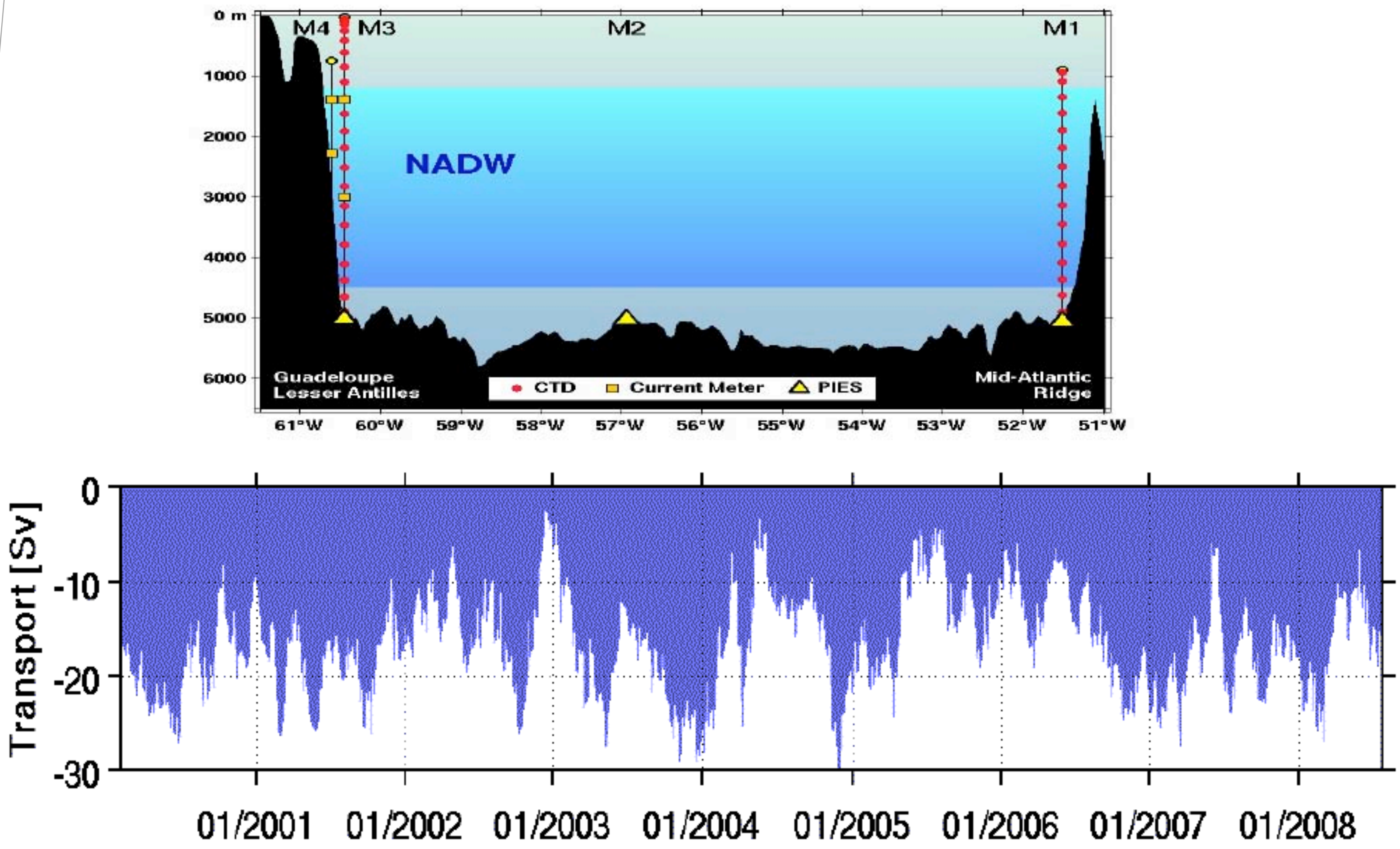
MOC variability at 26.5N





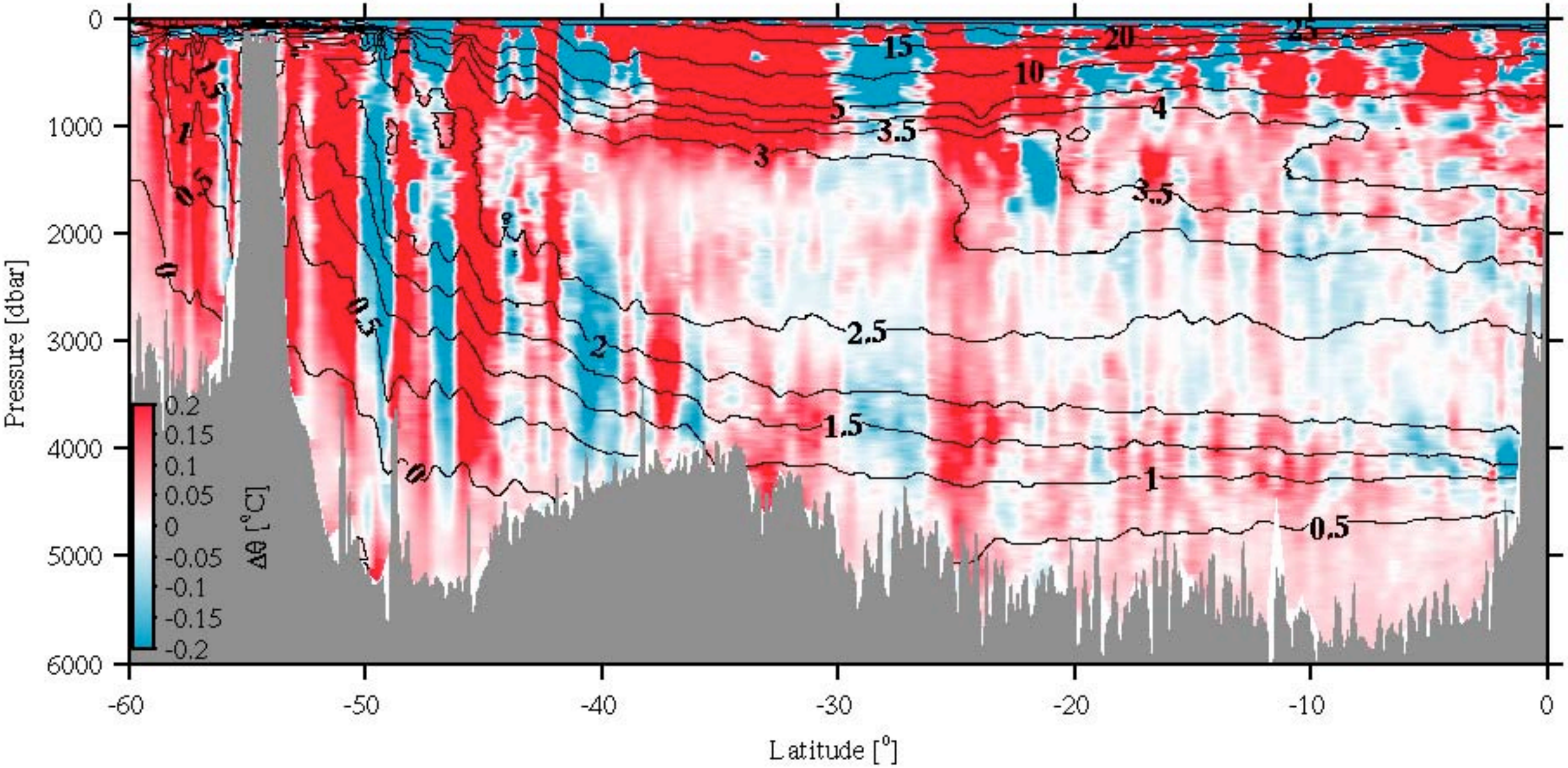
Cunningham et al., CWP

9 year record of NADW export at 16N



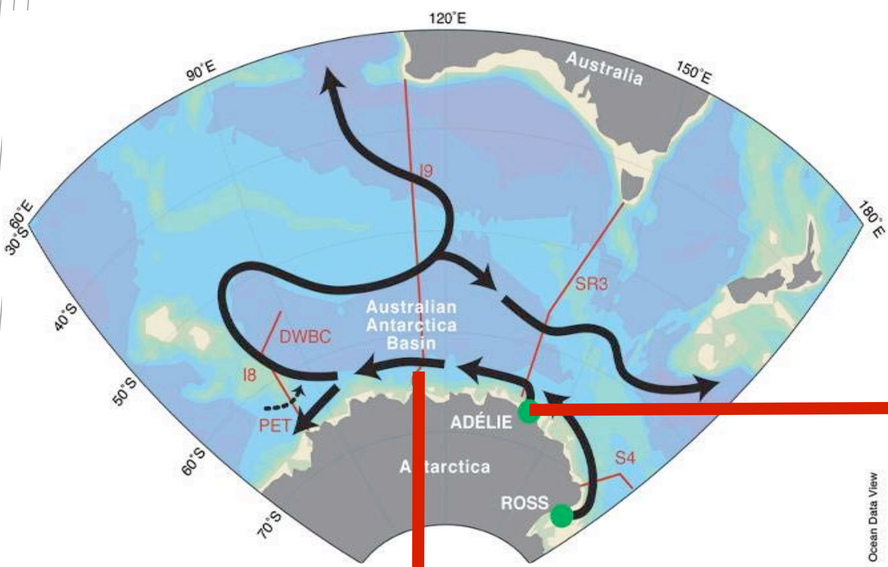
Send et al., CWP

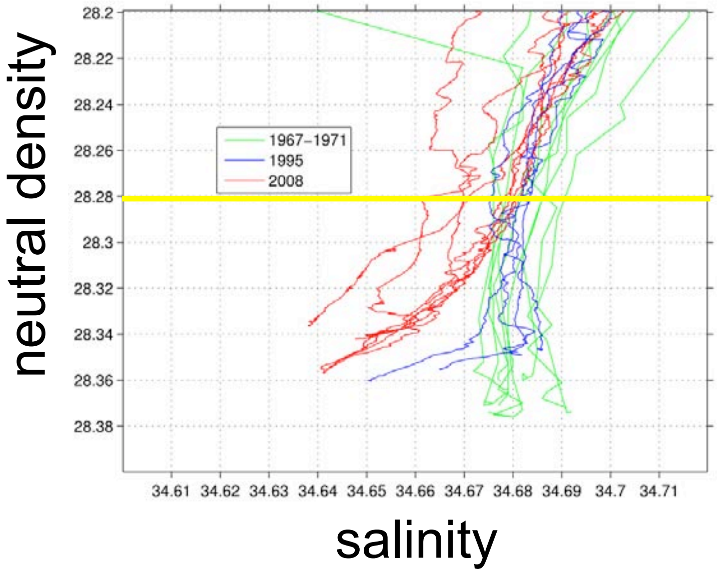
Warming of the deep ocean

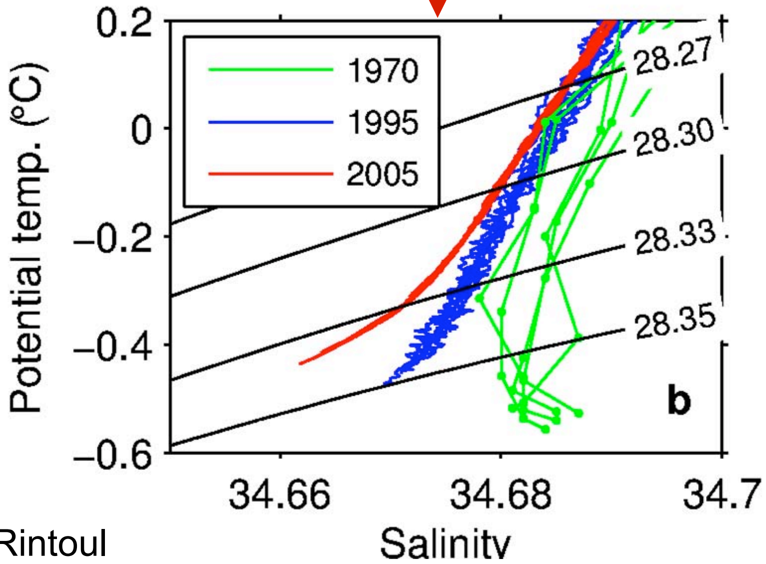


Johnson and Doney (2006)

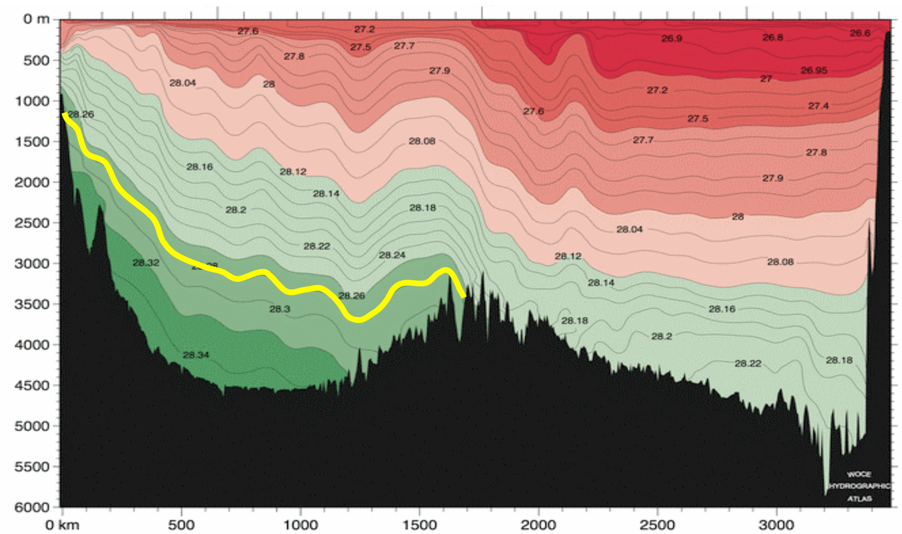
Changes in salinity of Antarctic Bottom Water



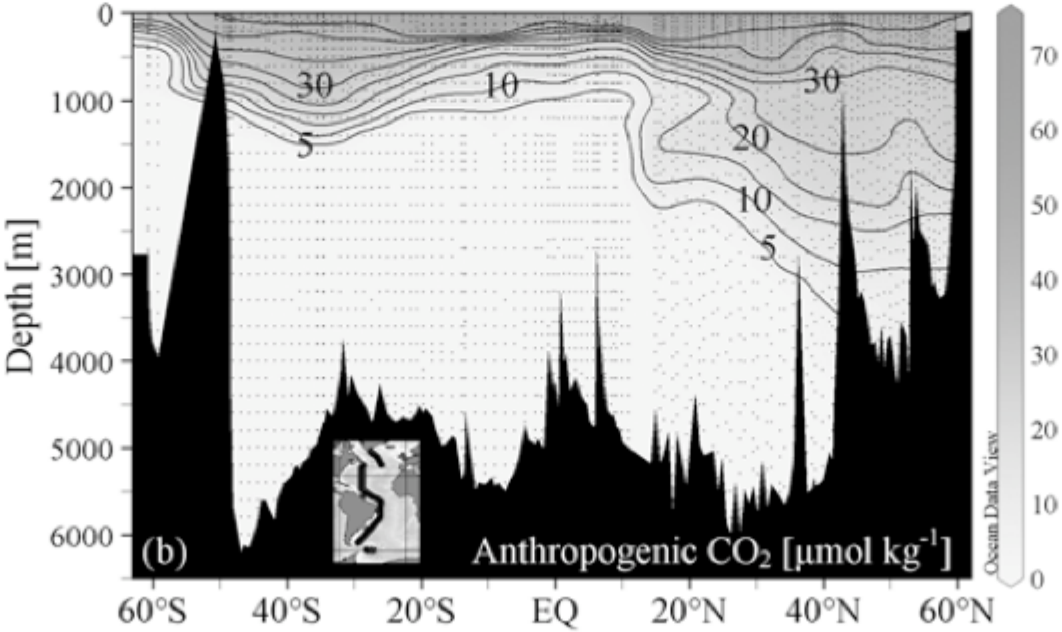




Rintoul

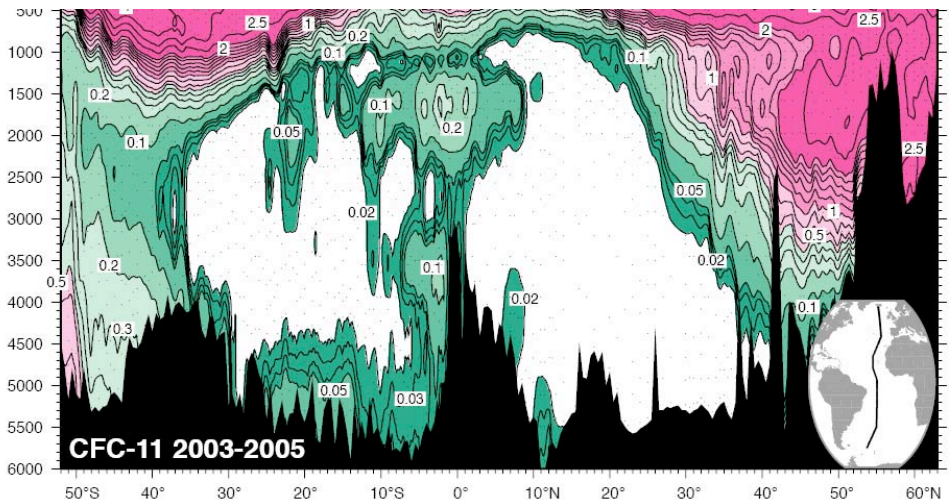


Evolving deep ocean



Anthropogenic CO_2

Wanninkhof et al. (2009)

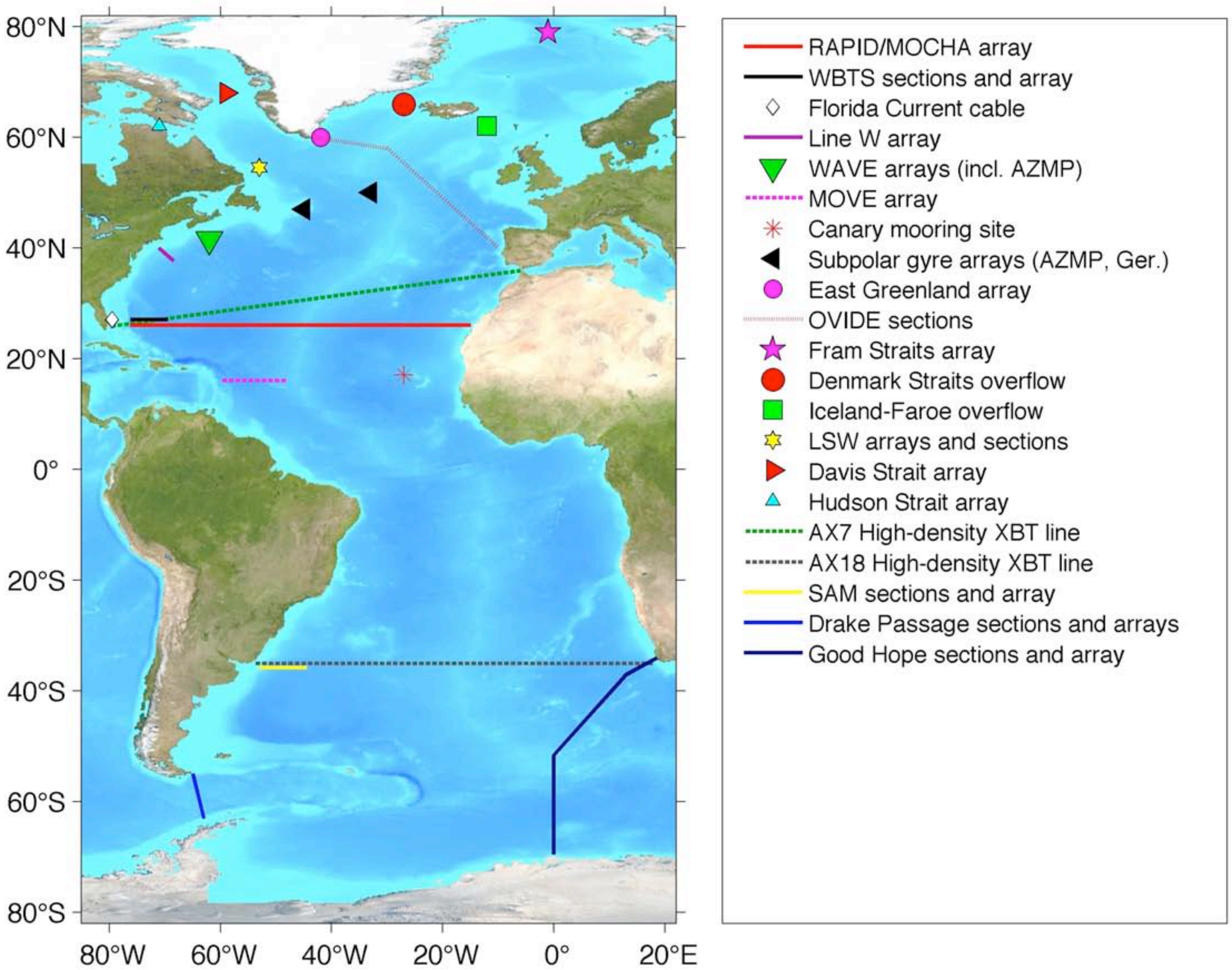


CFC-11 2003-05

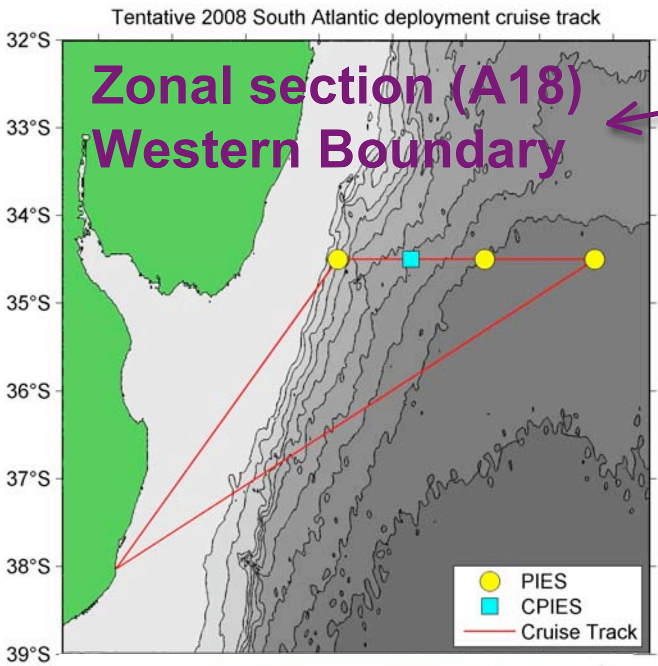
Observing the deep ocean and MOC

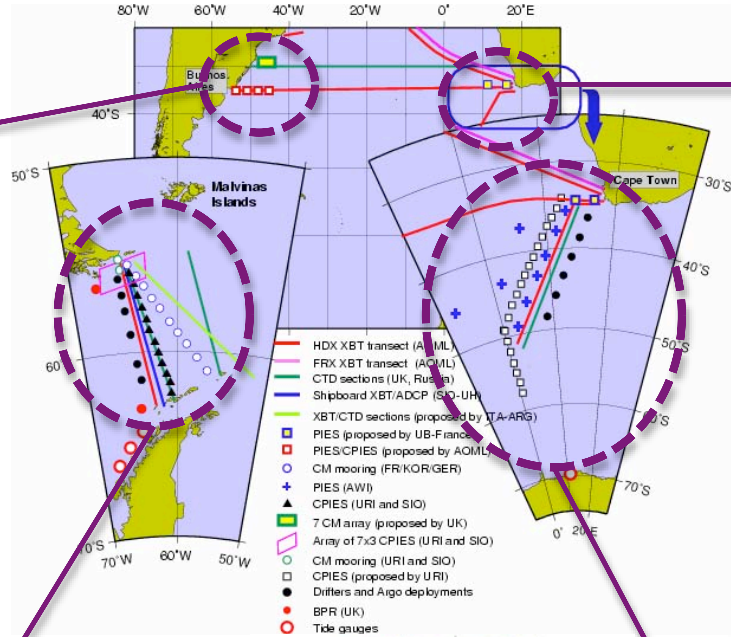
- Need to observe ***transport*** and ***inventory*** in the deep ocean.
- Transport strategy:
  - Direct velocity measurements in boundary current (current meters, PIES, cables, pressure gauges)
  - Deep hydrography and PIES in interior
  - Ekman contribution calculated from winds (eg QuikScat)
  - End-point monitoring of geostrophic flow
  - Altimetry and gravity measurements
- Inventory strategy:
  - Repeat deep hydrography (with tracers; ie GOSHIP)
  - More rapid repeat hydro in overflows and main deep flow paths
  - Broad-scale, long-duration deep moorings with data transfer
  - Altimetry and gravity measurements
  - Acoustic tomography/thermometry
  - Deep floats

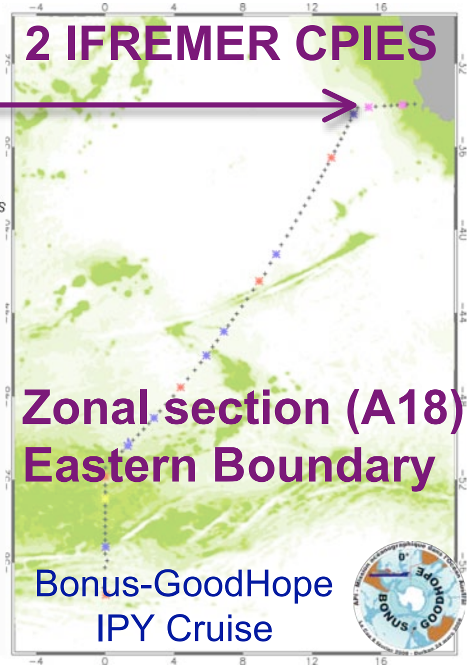
Measuring the Atlantic MOC

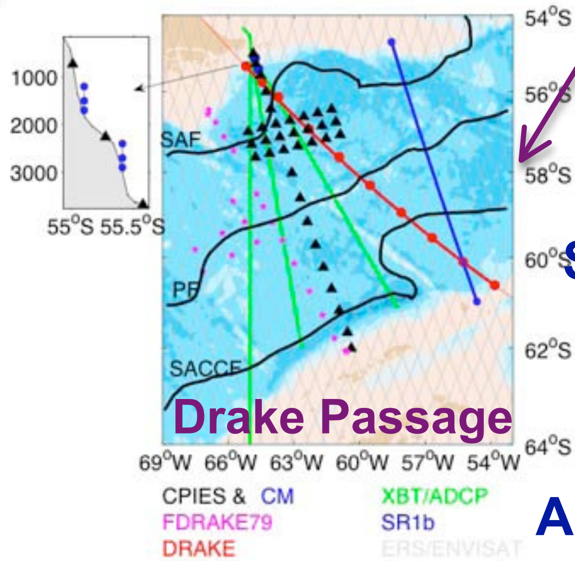


SAMOC development since 2007









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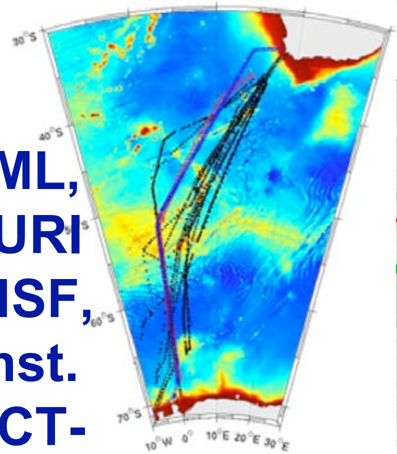
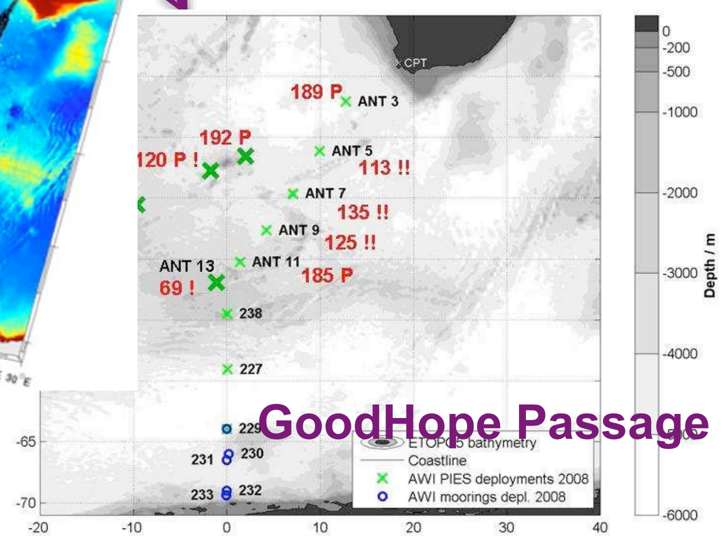
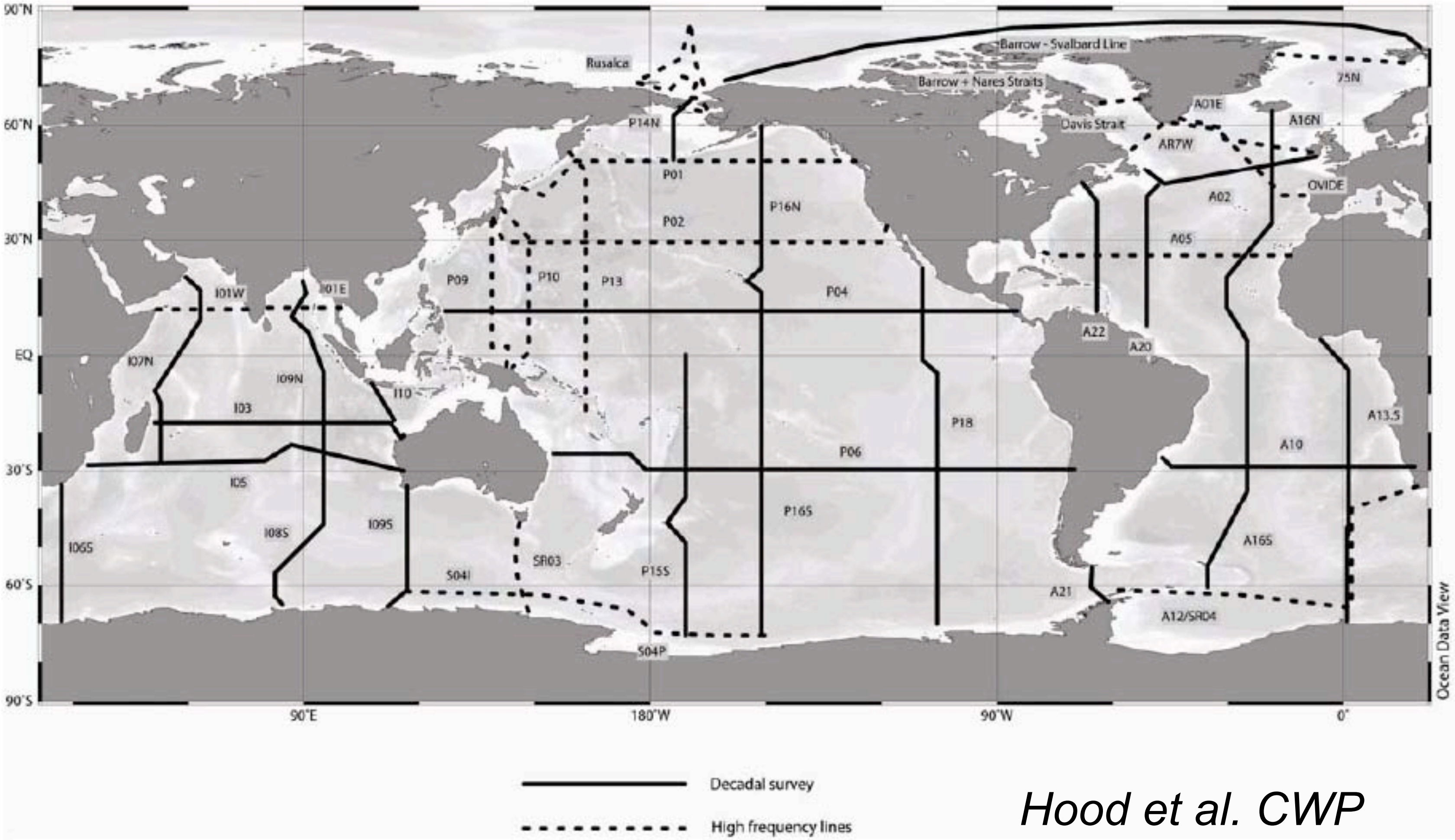


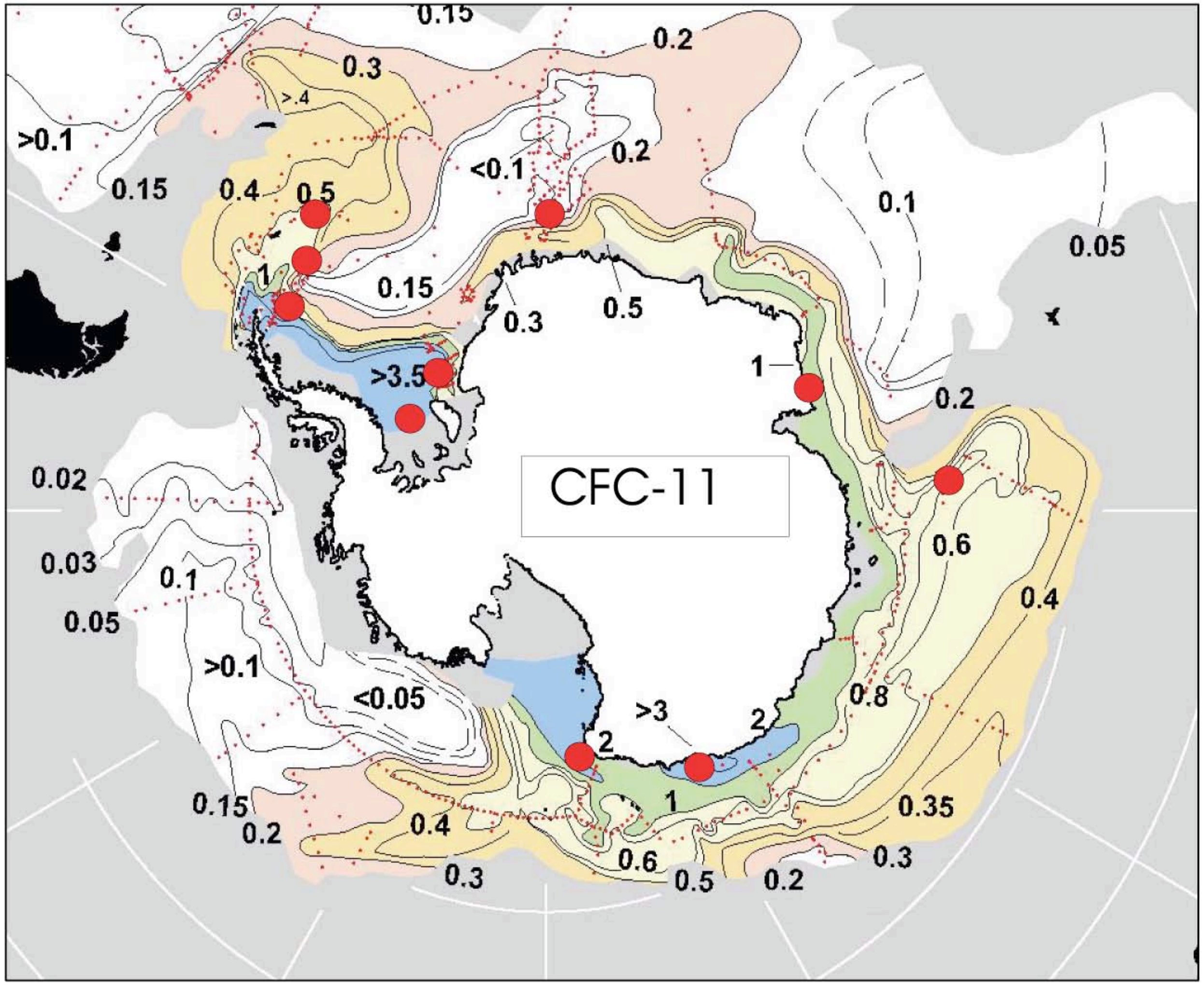


Repeat hydrography



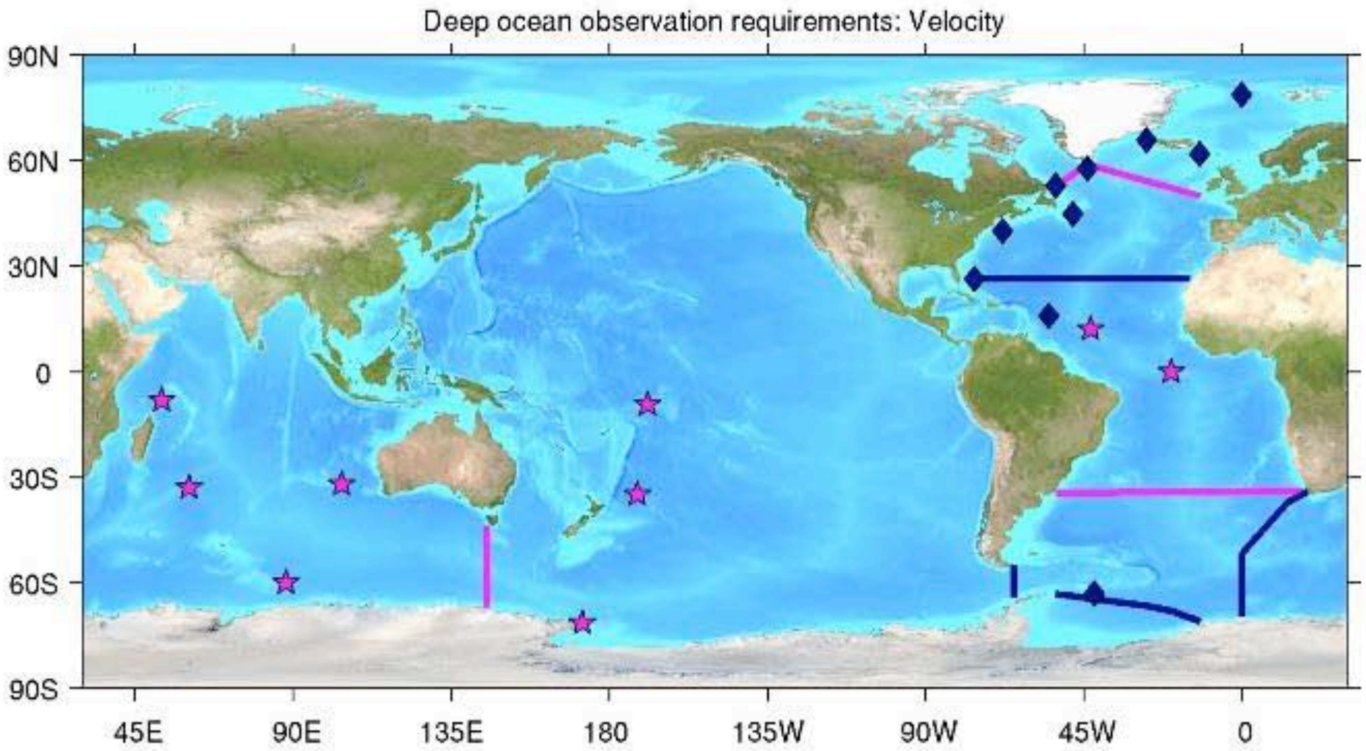
Hood et al. CWP

Measuring southern limb of the deep overturning



Rintoul et al., CWP

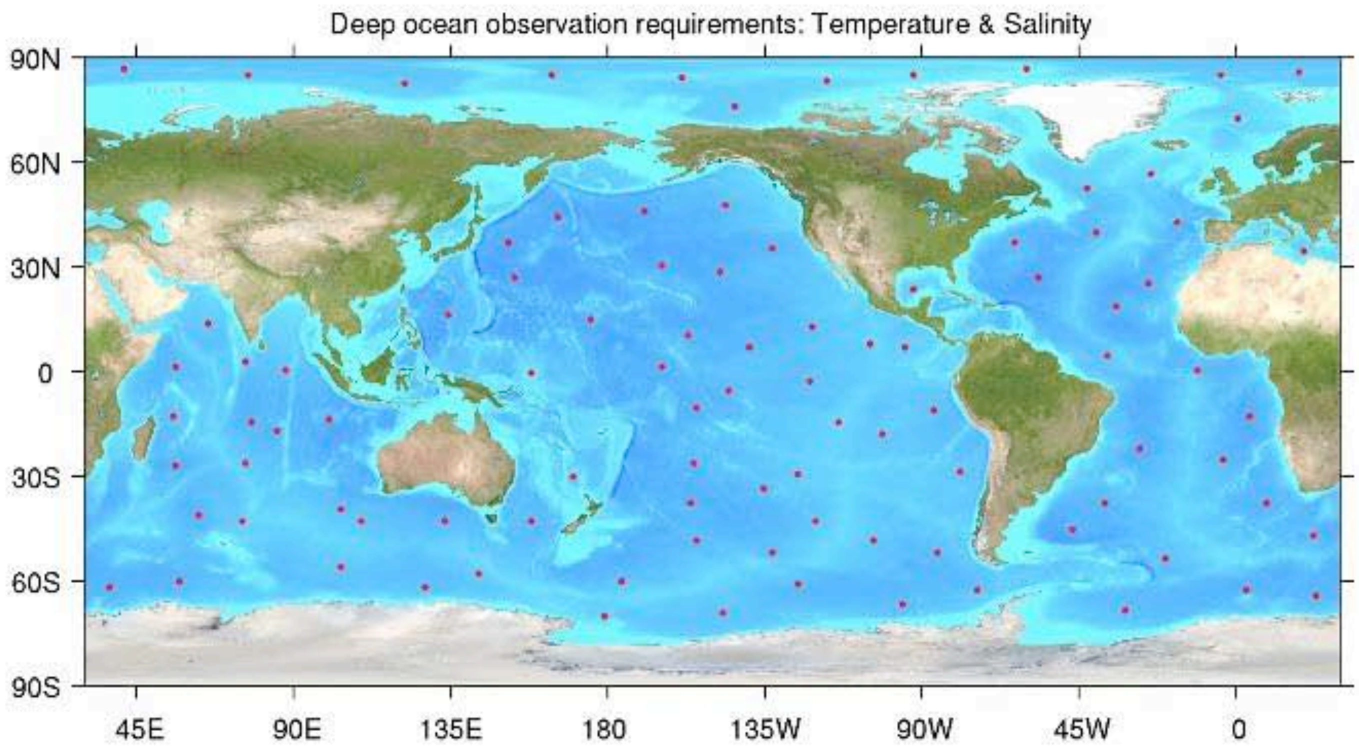
Global-scale deep observations: velocity



Recommended deep ocean observations that should be maintained (Blue) or improved/completed or initiated (Magenta). Technologies include - current meters, ADCP, PIES/CPIES, floats, gliders, HEFR, etc.

Garzoli et al., CWP

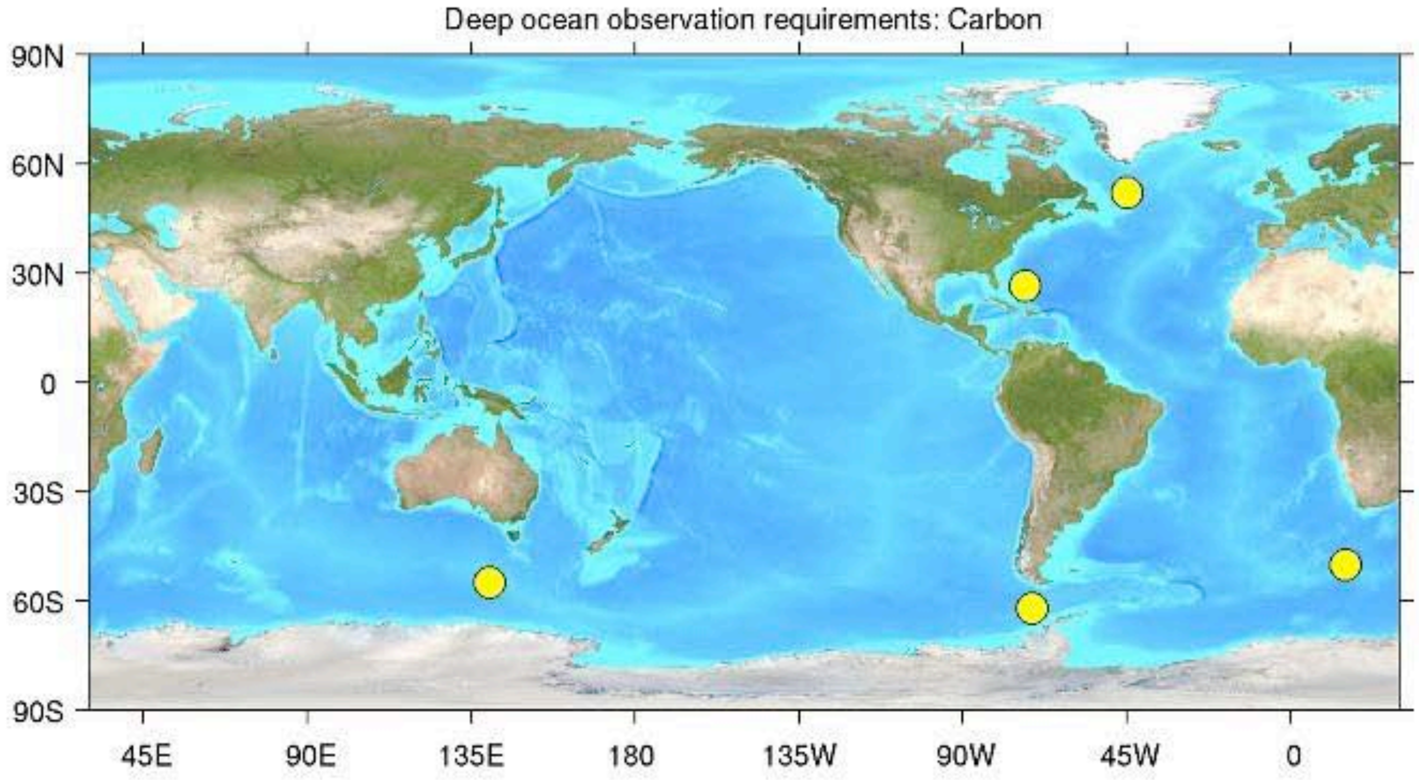
Global-scale deep observations: water properties



Schematic of idealized recommendations for T & S measurements - particular focus should be near injection sites and choke points. Technologies include - CTD, floats, bottom moored microcats, PIES/CPIES, etc.

Garzoli et al., CWP

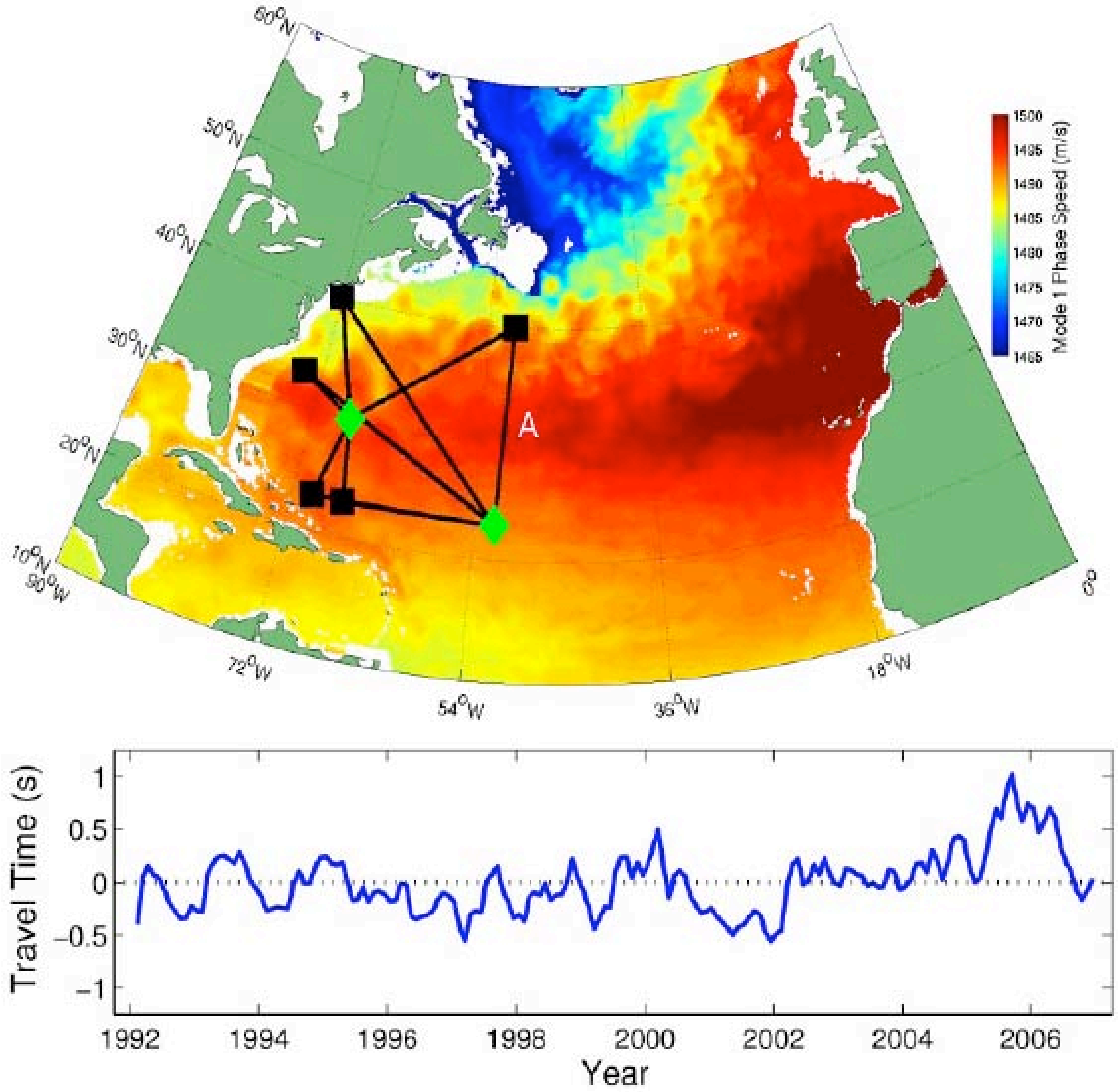
Global-scale deep observations: carbon



Technology to do bottom-moored carbon sensing is in its infancy - initially observations at these sites (Yellow) would be via hydrography, while later new technology may allow moorings.

Garzoli et al., CWP

Acoustic tomography



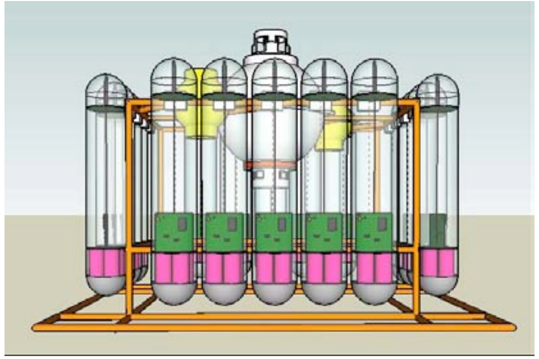
Sampling basin-wide integrals of heat content over 500-3200 m depth range, including the deep western boundary current (from ECCO state estimate).

Dushaw et al., CWP

Developing new technologies

In addition to the importance of maintaining the presently existent observing systems of deep ocean velocity, heat, salt, and carbon there is a critical need to develop new, cost-effective, technologies for retrieving data from instruments in the deep ocean. Examples include:

- Deeper-reaching Argo floats
- Moored instruments with expendable data capsules
- Carbon sensors capable of bottom mooring



Garzoli et al., CWP

Summary: deep ocean observations needed to:

- determine the MOC, its variability and influence on climate
- close the planetary energy budget
- determine rate and mechanisms of sea-level rise
- determine the global budgets of carbon and nutrients and their sensitivity to change
- constrain ocean state estimates (including errors)
- Initialise decadal climate forecasts
- understand the dynamics and nature of the global-scale ocean circulation, including response to forcing and modes of variability
- test and develop models, proxies and satellite data (eg gravity)

Summary: a strategy for deep ocean observations

- Maintain and build on established sites and technologies
- Moored arrays in deep boundary currents and passages
- End-point monitoring for cost-effective measurements of basin-scale, full-depth flows.
- Heat and FW flux generally require observations in interior (eg from PIES or repeat hydrography)
- Repeat full-depth hydrography with tracers (with more frequent measurements near dense water outflows)
- Broad-scale, inexpensive moorings for water properties
- Acoustic tomography/thermometry
- Satellite observations (altimeter, gravity)
- Assimilation in ocean state estimates
- More observing system evaluation studies needed

Contributors (>100 co-authors on CWPs)

The present and future system for measuring the Atlantic meridional overturning circulation and heat transport Cunningham et al.

Progressing towards global sustained deep ocean observations Garzoli et al.

Southern Ocean Observing System (SOOS): Rationale and strategy for sustained observations of the Southern Ocean Rintoul et al.

Ship-based Repeat Hydrography: A Strategy for a Sustained Global Program Hood et al.

Ocean Variability evaluated from an Ensemble of Ocean Syntheses Stammer et al.

Geodetic Observations of Ocean Surface Topography, Ocean Currents, Ocean Mass, and Ocean Volume Changes Shum et al.

A global ocean acoustic observing network Dushaw et al.

Initialization for seasonal and decadal forecasts Balmeseda et al.

Interocean Exchange of thermocline water: Indonesian Throughflow; "Tassie" Leakage; Agulhas Leakage Gordon et al.

Dynamics of decadal-scale variabilty and implications for its prediction Latif et al.

A global boundary current circulation observing network Send et al.