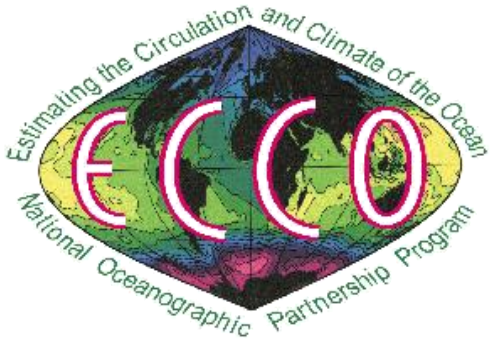
Why and How Did ECCO Originate?

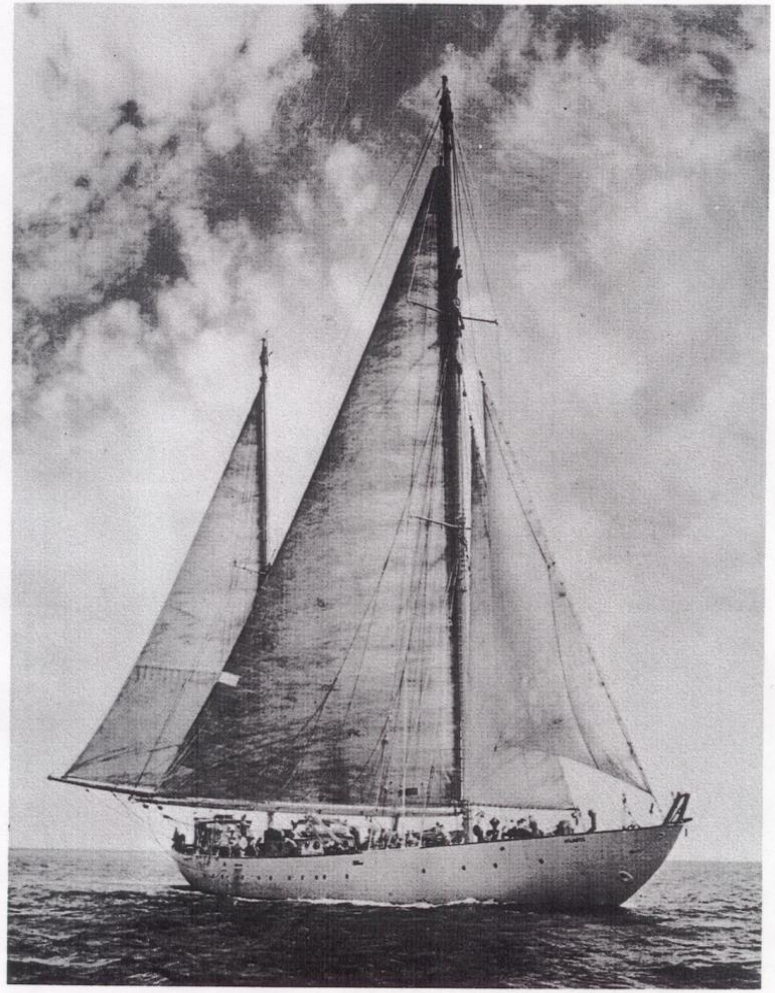
& A Small Subset of Interesting Results



Carl Wunsch
May 2025

Origins of ECCO lie in the World Ocean Circulation Experiment (WOCE, 1992-~1997). That in turn lies with the Mid-Ocean Dynamics Experiment (1973)---which led to an intellectual and technological revolution coinciding with the rise in urgency concerning climate change.

Hence a quick historical review:



R/V *Atlantis I*

A 142-foot steel ketch built in Copenhagen in 1931 for Woods Hole Oceanographic Institution. In 1964 *Atlantis* was sold to the Consejo Nacional de Investigaciones Cientificas y Technicas, Buenos Aires, Repulica de Argentina, where she was renamed *El Austral.*

R/V *Knorr* (AGOR 15)

Built in 1970 by Defoe Shipbuilding Company of Bay City, Michigan, the *Knorr,* a sister ship of the R/V *Melville* (AGOR 14), features the use of cycloidal propellers for propulsion, position keeping, and maneuverability. The Navy has assigned her to Woods Hole Oceanographic Institution.

Length: 245' Displacement: 2,075 tons

WHOI Data Library and Archives, Woods Hole, MA

Oceanography from about 1850-1993.
Ship-based. (Attracted me into the field!)

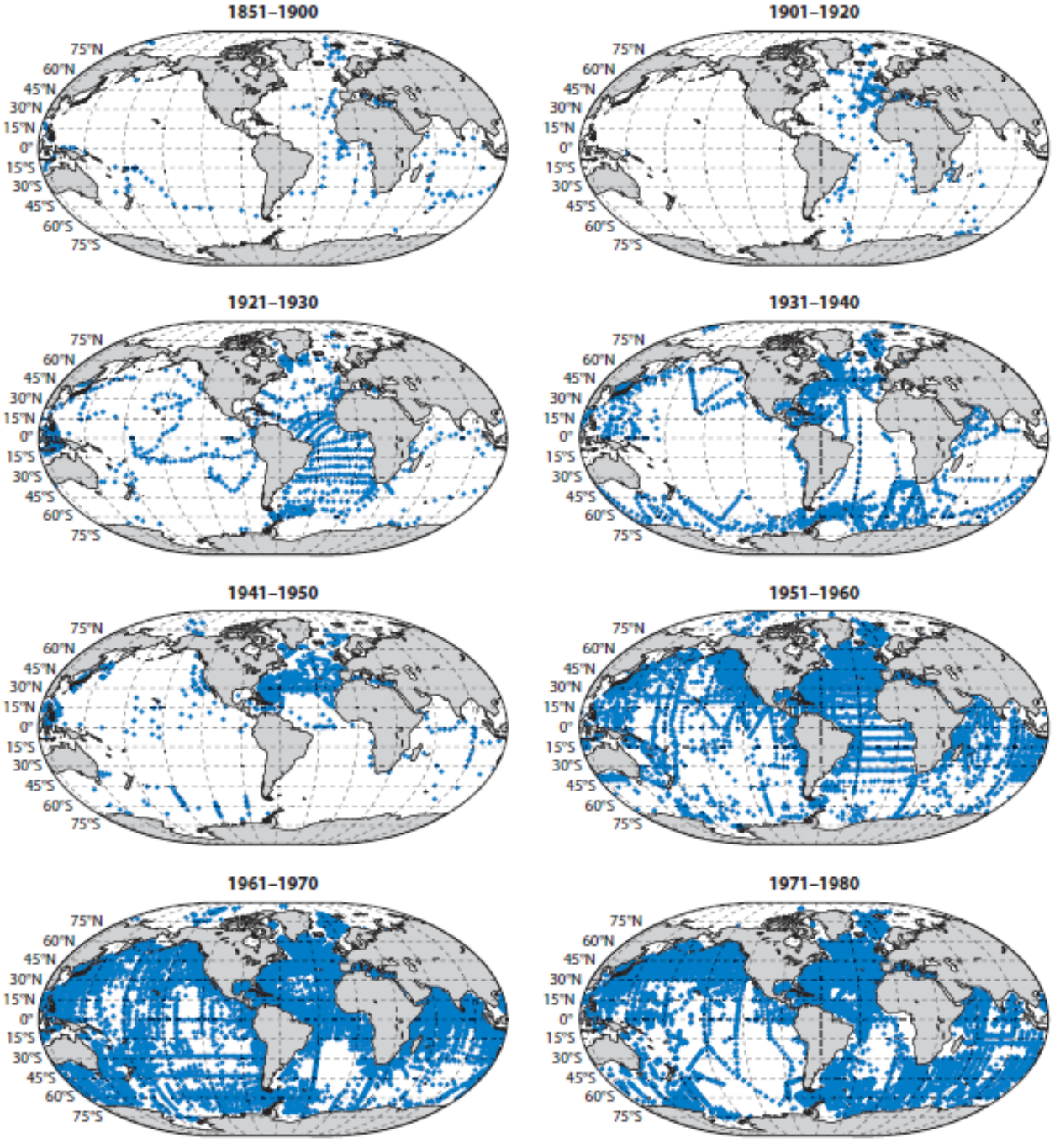
L. Valentine Worthington Woods Hole

Circa 1970 to about 2000m:

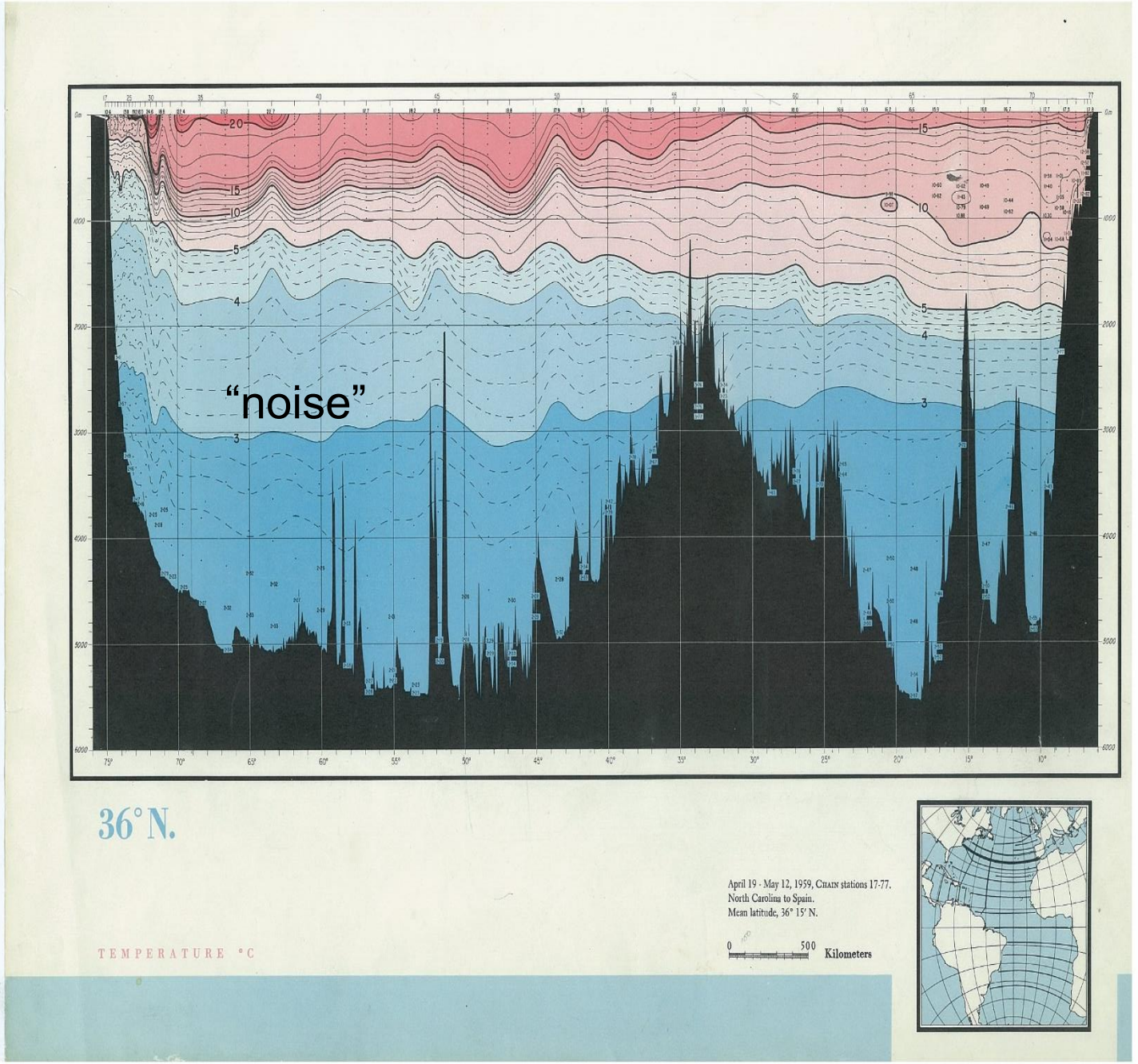
Main observational tool was still hydrography from ships. Coarse horizontal spacing.

Sporadic (space/time) Swallow float data, moored current meters running a few weeks.

Interpretation as a steady-state with a bit of “noise.” 100 years of record with little below 1000m.



The ocean is opaque to useful electromagnetic radiation, is corrosive, and involves pressures much exceeding 400 atmospheres. Until about 1975 the only useful observational tool was the ship, with purely mechanical instruments that could be lowered to depths.



From Fuglister (1960) Atlas. IGY survey was the first in the Atlantic since the Meteor measurements of the 1920s. In today's terms, takes a ship about 1 month, and 1 million dollars to do once. Took 100+ years to build up a global-scale picture.

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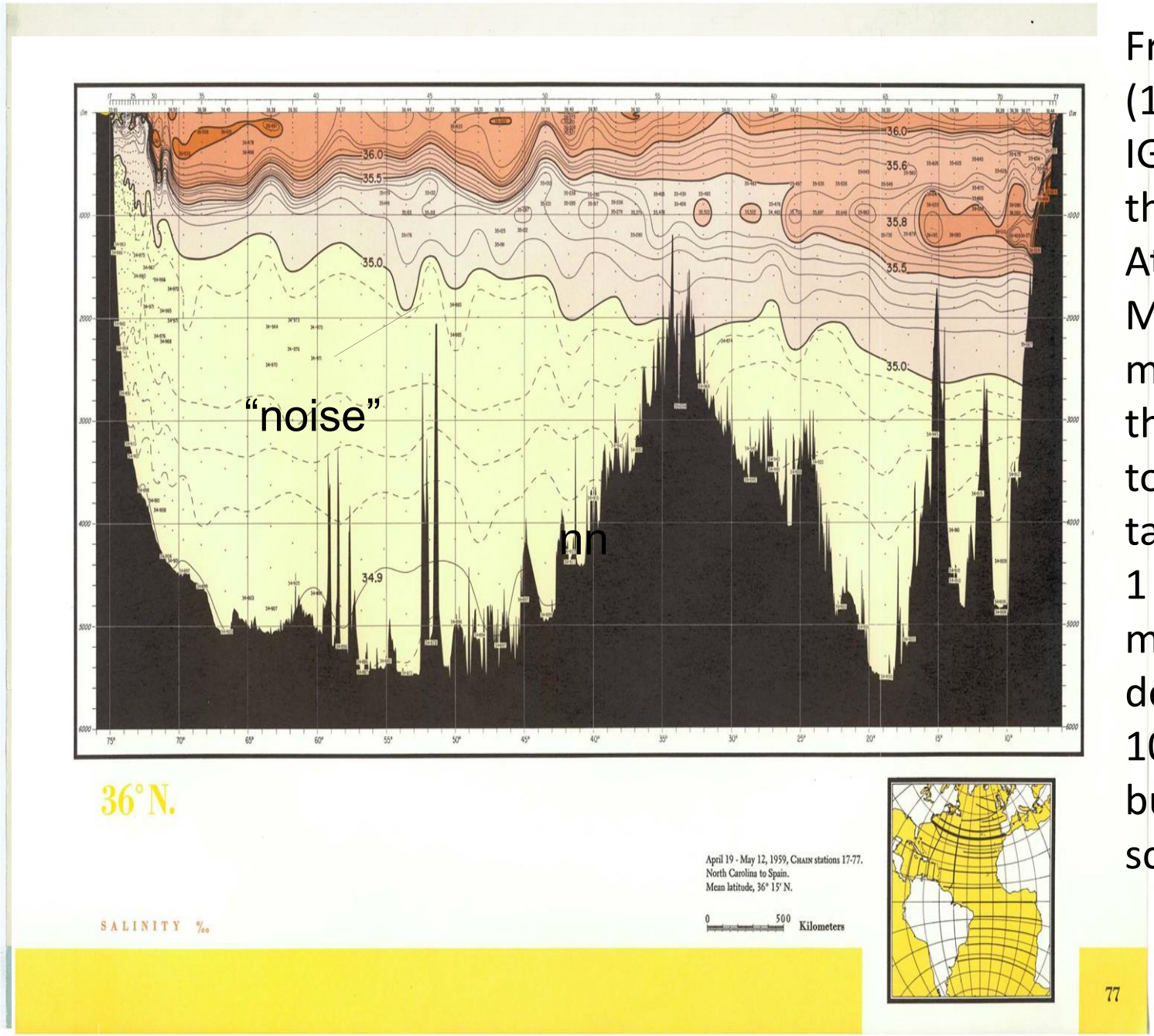

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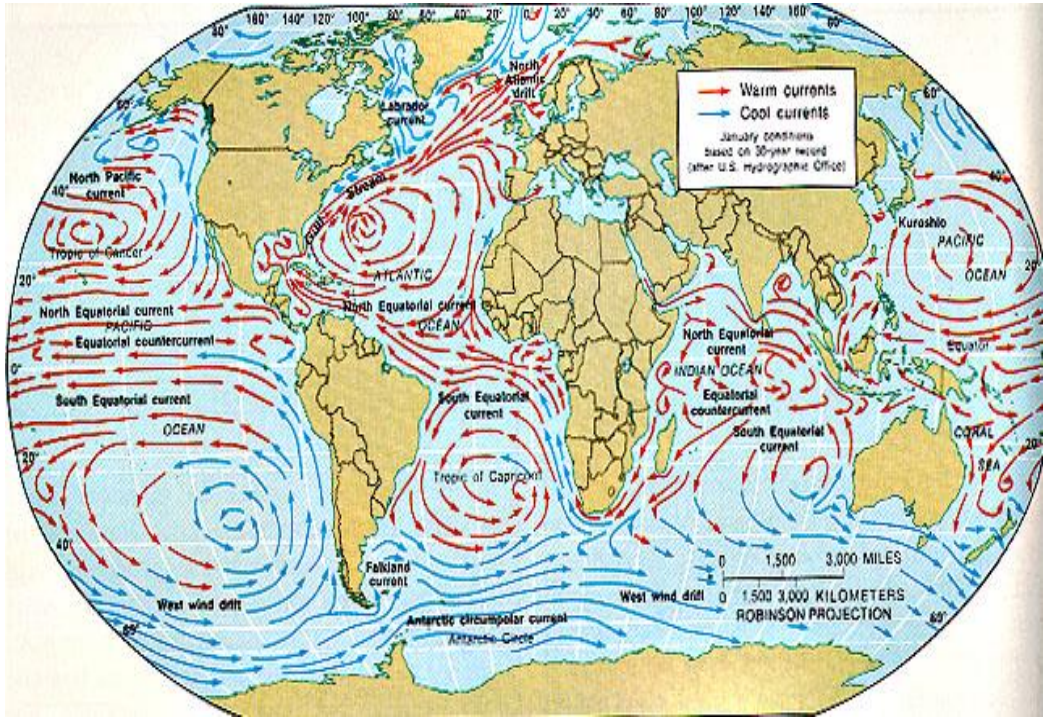
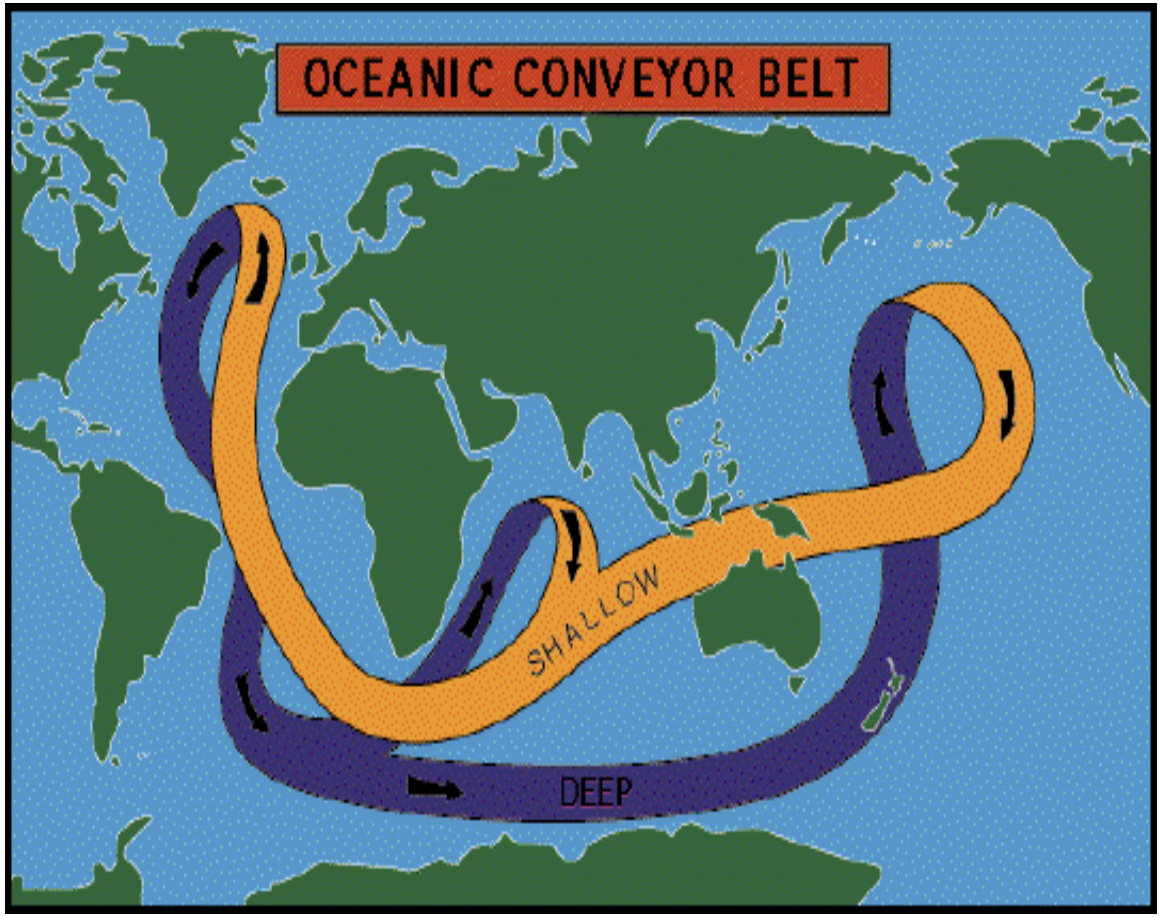


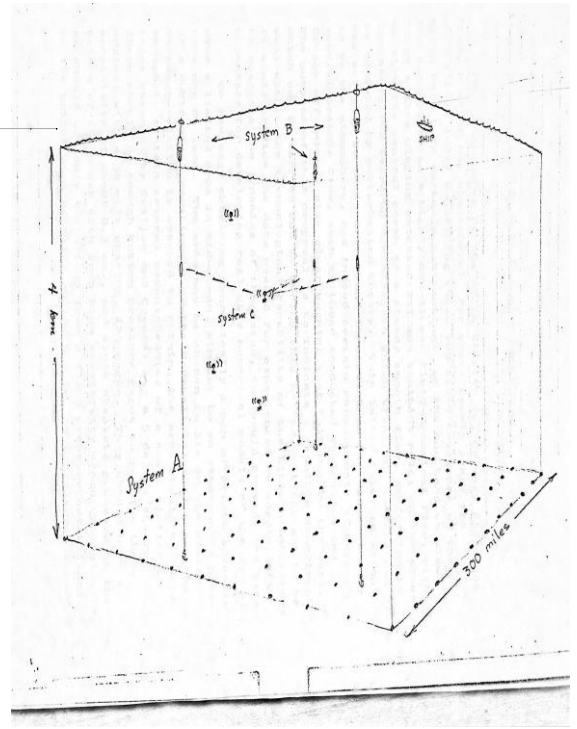


W. Broecker

(If these are accurate, a remarkable turbulence closure has been accomplished!)

A very partial Calendar:

1970 Henry Stommel proposes what became the Mid-Ocean Dynamics Experiment



1973 The Mid-Ocean Dynamics Experiment-1 (MODE-1)

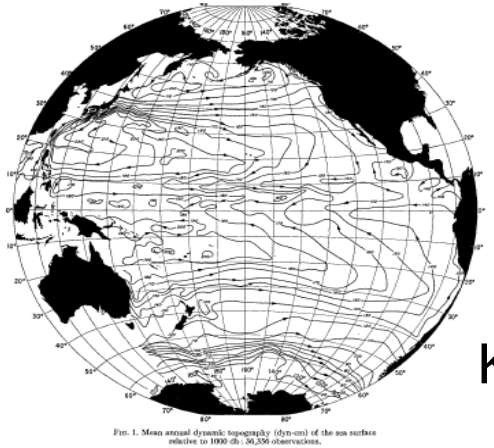
1973-1986 POLYMODE Arrays

Circa: 1975 The End of the “Classical Period” The laminar era
Start of the “Modern Period” The turbulent/time-dependent era.
(Both were 'global', but in very different ways!)

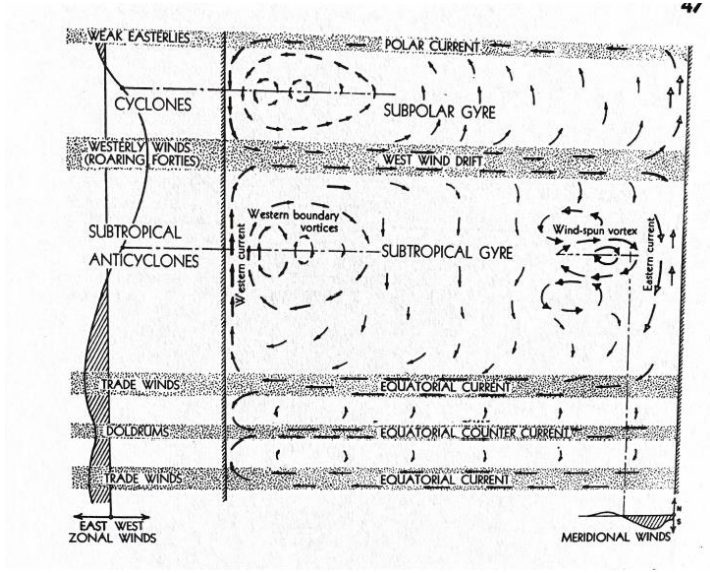
1979 Proposal for what became the World Ocean Circulation Experiment (WOCE)

1992-1997 WOCE in the field and with satellites
1992 Flight of TOPEX/POSEIDON

…



K. Wyrtki, 1973



Both observations and theory described a steady, laminar ocean

W. Munk, 1950

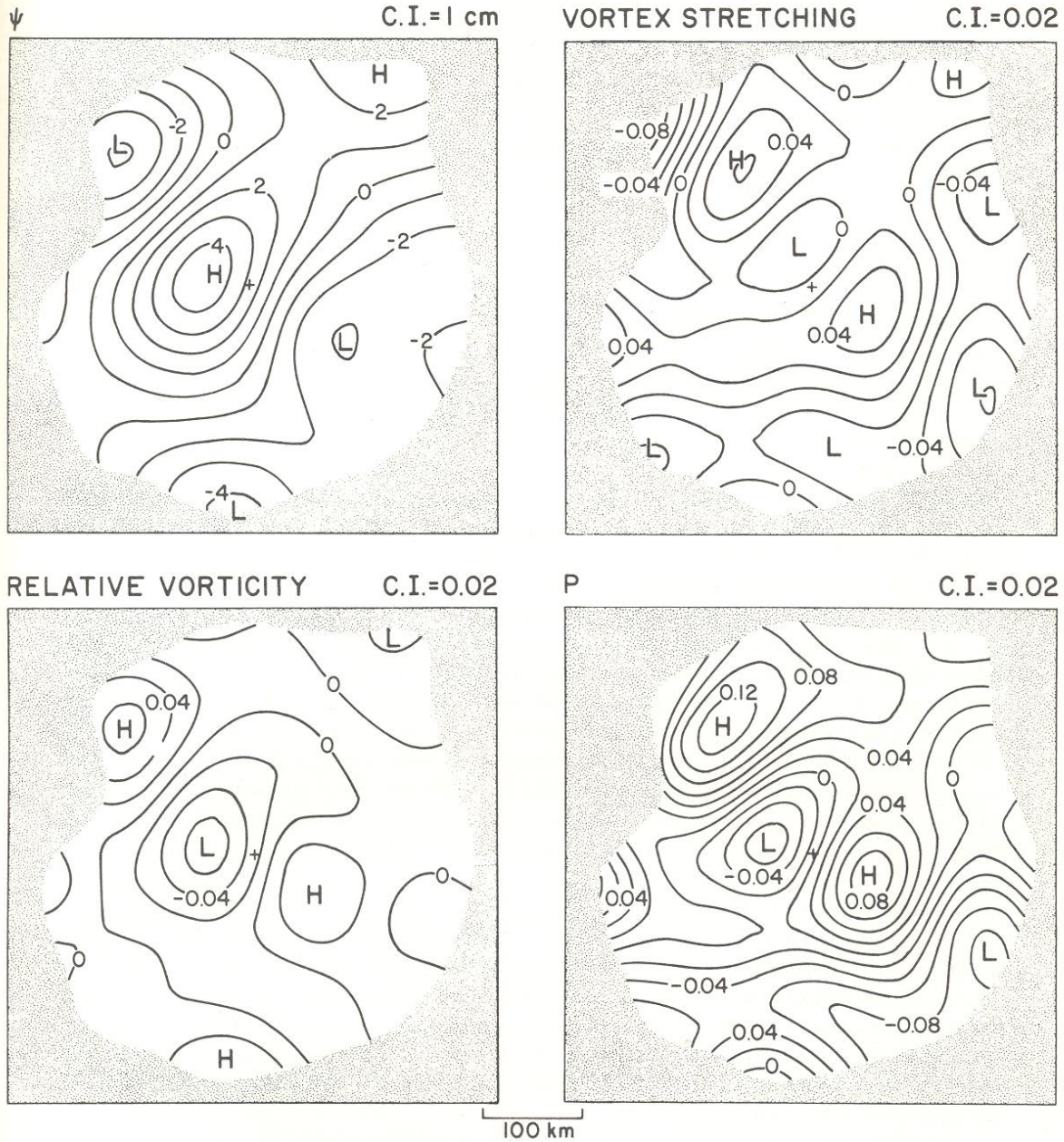


Fig. 16. Maps of stream function (ψ), vortex stretching, relative vorticity, and potential vorticity at 750 m on day 140 centered at MODE-center. C.I. means contour interval. [From McWilliams (1976b).]

McWilliams, 1976

Eddies did exist! (Earlier Soviet data wasn't taken seriously.)

Some effort, e.g. by Bill Schmitz, to deploy moorings around the world to last a year. Would be decades before global coverage could be obtained.

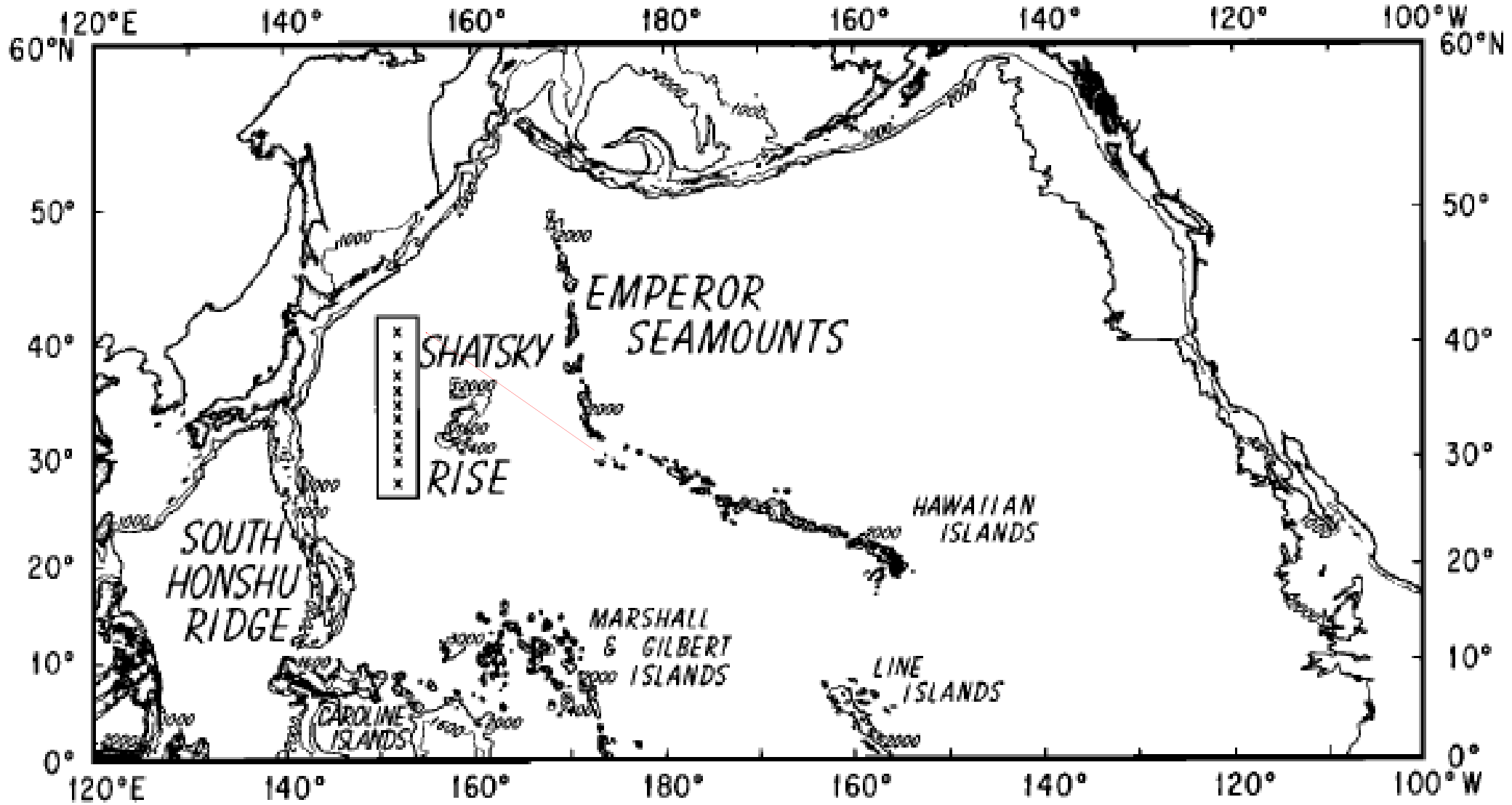


Fig. 1. Mooring locations along 152°E, denoted by crosses enclosed in a rectangular box. Depth contours in fathoms (1 fathom = 1.8 m) and feature names taken from *Chase et al.* [1977].

Years later: 2-year current meter records: Schmitz, Niiler, Koblinsky, 1987

First attempt,1979, by National Academy of Sciences to provide a coherent statement about climate change under CO2 increase:

Carbon Dioxide and Climate: A Scientific Assessment

Report of an Ad Hoc Study Group on Carbon Dioxide and Climate
Woods Hole, Massachusetts
July 23–27, 1979
to the
Climate Research Board
Assembly of Mathematical and Physical Sciences
National Research Council

NATIONAL ACADEMY OF SCIENCES
Washington, D.C. 1979

Steven Flajser, Committee on Commerce, Science and Transportation, U.S. Senate
Elbert W. Friday, Department of Defense
Lawrence R. Greenwood, National Aeronautics and Space Administration
Galen Hart, Department of Agriculture
Keith Howard, Department of the Interior
Gerald J. Kovach, Committee on Commerce, Science and Transportation, U.S. Senate
Ian Marceau, Subcommittee on Natural Resources and Environment, U.S. House of Representatives
Lloyd J. Money, Department of Transportation
Douglas H. Sargeant, National Oceanic and Atmospheric Administration
David Slade, Department of Energy
Herbert L. Wiser, Environmental Protection Agency

STAFF
John S. Perry, National Research Council, *Executive Secretary*
Robert S. Chen, National Academy of Sciences, *Resident Fellow*

Oceanographers on the Committee could say little more than that the ocean would likely take up some unknown fraction of the heat and carbon dioxide on an unknown time-scale.

Ocean was being treated as completely passive in the new coupled models: a swamp. (Sensible)

Ad Hoc Study Group on Carbon Dioxide and Climate

Jule G. Charney, Massachusetts Institute of Technology, *Chairman*
Akio Arakawa, University of California, Los Angeles
D. James Baker, University of Washington
Bert Bolin, University of Stockholm
Robert E. Dickinson, National Center for Atmospheric Research
Richard M. Goody, Harvard University
Cecil E. Leith, National Center for Atmospheric Research
Henry M. Stommel, Woods Hole Oceanographic Institution
Carl I. Wunsch, Massachusetts Institute of Technology

STAFF
John S. Perry
Robert S. Chen
Doris Bouadjemi
Theresa Fisher

WOCE: Selected Commentaries

"WOCE is a program entirely without intellectual content" (well-known theoretical physical oceanographer)

'WOCE stands for "Willful Oceanographers Current Entitlement"' (well-known sea-going physical oceanographer and government leader)

"All he [CW] wants is an enormous amount of terrible quality data." (Comment made following a meeting (circa 1982) at WHOI to explain idea of WOCE.)

"All these planning meetings are a sham. WOCE is being run by a small club that knows exactly what it wants to do, and which is just to find a way to ensure their own funding." (email comment on preliminary WOCE planning document).

"Why is Carl trying to ruin his career?" (asked of my wife by a prominent physical oceanographer, circa 1985)

(It did destroy a scientific way of life!)

"The WOCE organizers don't have any idea what the program should do." (email comment)

"So many people have been consulted in designing WOCE that no one is in charge." (email comment)

"Anyone who starts a big program should be removed from the steering committee after two years. They are only in it to feather their own nests." (NRC Committee Draft Report)

Some very early time-dependent models existed:

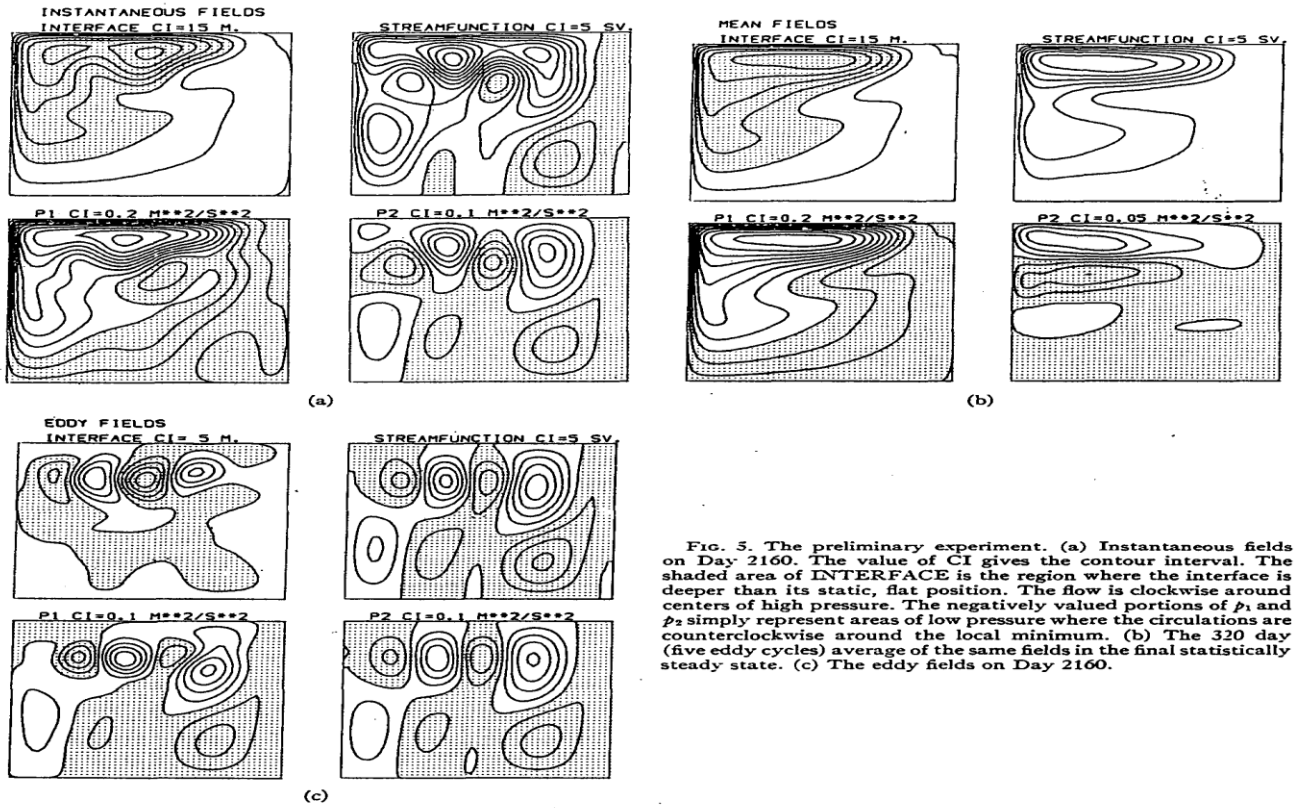


FIG. 5. The preliminary experiment. (a) Instantaneous fields on Day 2160. The value of CI gives the contour interval. The shaded area of INTERFACE is the region where the interface is deeper than its static, flat position. The flow is clockwise around centers of high pressure. The negatively valued portions of p_1 and p_2 simply represent areas of low pressure where the circulations are counterclockwise around the local minimum. (b) The 320 day (five eddy cycles) average of the same fields in the final statistically steady state. (c) The eddy fields on Day 2160.

Hints in data that strong transients existed, e.g. Swallow and Crease float measurements.

Theoretical description by Norman Phillips.

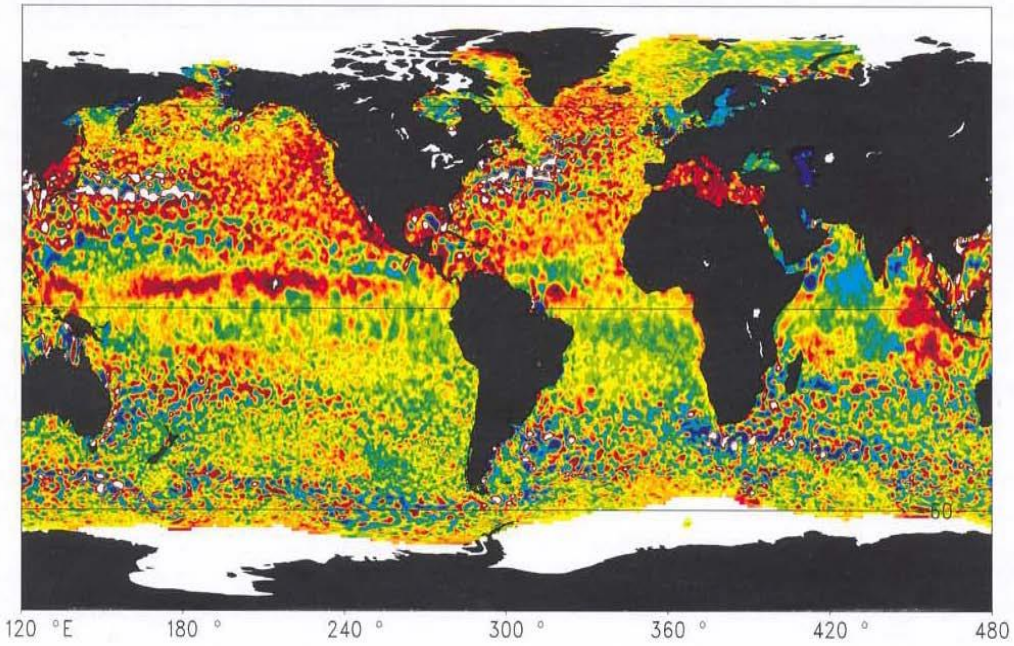
Holland and Lin, JPO, 1975.

Bryan and Manabe, 1975, had produced what might be the first coupled model.

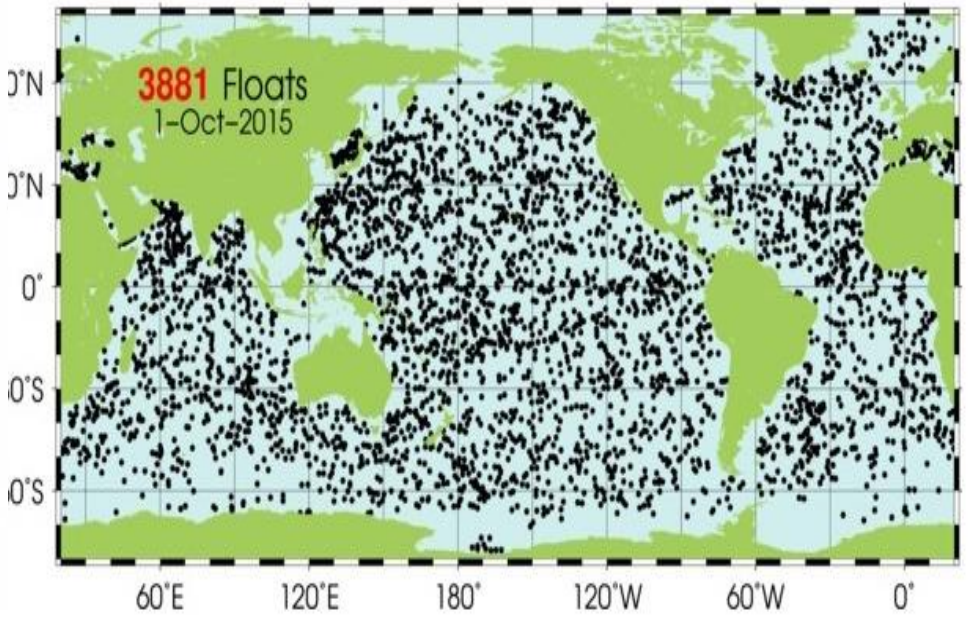
To some of us, circa 1979, appeared that in climate terms, physical (and chemical and biological) oceanography were in grave danger of becoming intellectually irrelevant, with the dominant meteorological/climate community treating it as a swamp.

What to do?

Beginning about 1979, numerous discussion meetings led ultimately to international agreements---scientific and logistical and financial---for the World Ocean Circulation Experiment (WOCE, circa1992+). That in turn led to the on-going global observing systems that continue today:



TOPEX/POSEIDON +



Argo
+

Issues remain for both these and other systems of aliasing in space and time.

Also GO-SHIP, gravity, winds,... et al.

By about 1992 was clear that a considerable part of WOCE was actually going to happen. (Notably little about high latitude oceans/ice.) Chemistry (particularly carbon measurements) were off-loaded to a different community.

Meteorologists were long experienced in using global scale data, particularly in on-going numerical weather prediction. They had a considerable governmental infrastructure to handle the data, develop and run models, interpret the results. Physical oceanographers had nothing like that.

NWP represented a false analogy: As early as 1942, Norbert Wiener had divided the goals of time-series analysis into 3-components (1) Prediction (extrapolation), (2) filtering (now-casting) (3) smoothing (state estimation). He and many others developed the distinct tools for the 3 goals.

For NWP, if some method yields useful short-range forecasts, one should use it, even though it may not be fully understood (a bridge can be built without full understanding of stress-strain, etc. physics). But *WOCE and subsequent programs were directed at understanding of a highly time-dependent, turbulent ocean*---with climate-scale prediction postponed.

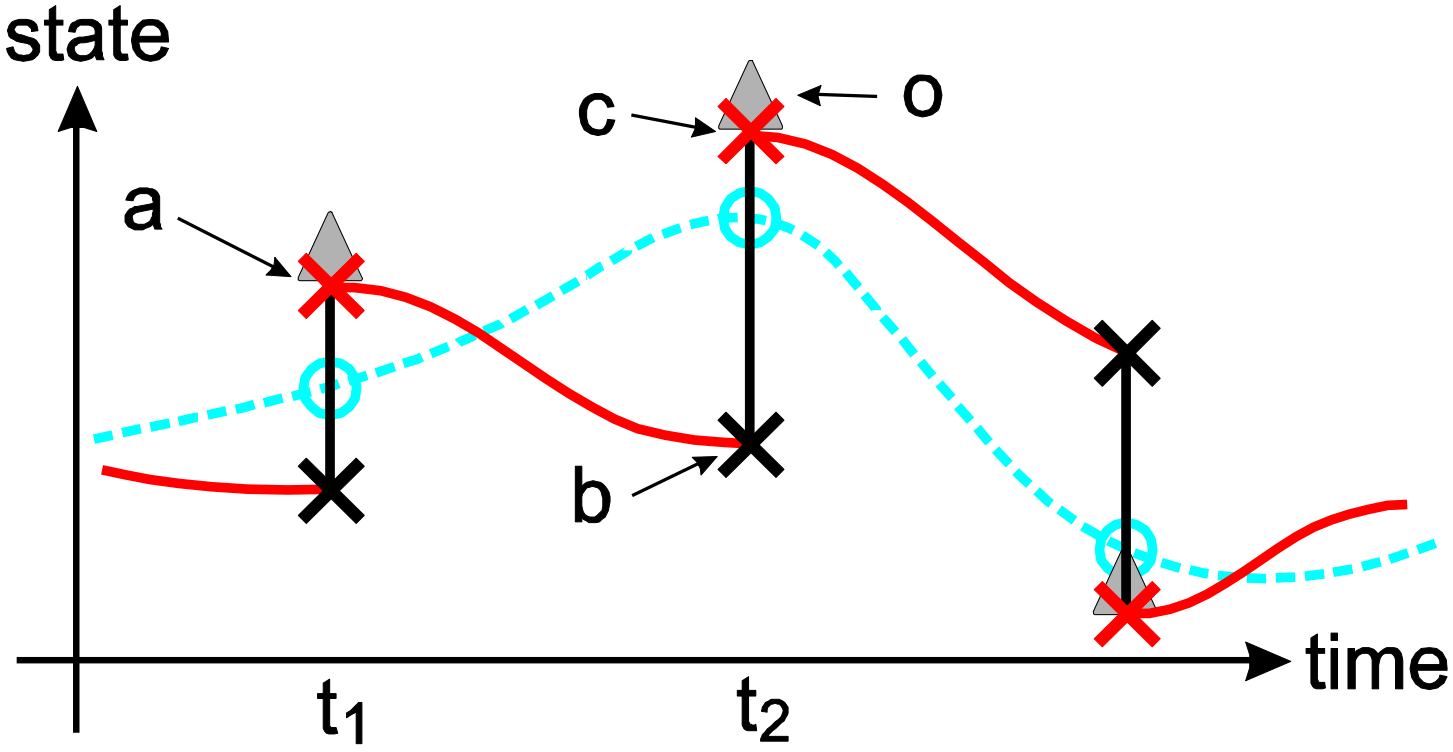
Getting funding for what eventually became ECCO was not so easy!

1) "The ocean has no physics, and so there is no need for observations. Oceanographers should be forced to stay home and run models." Statement in a climate meeting by a prominent meteorologist (and repeated 13 years later).

2) “We don't need observations, we have models.” Prominent ocean modeler.

3) "The ocean's role in climate change is very simple to determine. One just needs a few high latitude XBT measurements to determine the state of the upper branch of the `conveyor belt' and everything else can be calculated." Assertion by a different prominent meteorologist.

4) "Observations of the deep ocean aren't necessary. The flow is what Henry Stommel told us it was, in 1958." Assertion by yet another prominent meteorologist.



"Reanalyses", ocean and atmospheric, are based upon a "predictor-corrector" method in which the state jumps every 6 hours as the system is shoved towards the new observations. Do not conserve energy, water, enstrophy, …. Equations of motion are not satisfied at the jump times....

To understand any physical system, it has to satisfy conservation of energy, mass, vorticity, salt, … etc. We needed a system where that was guaranteed. Hence: ECCO

Classical era: laminar, global, slowly changing on large-scale, if at all. Ship sampling. Primarily analytic models.

Modern era: turbulent, global, fluctuating on all time scales from 1 sec to the age of the ocean. Argo floats, altimeters, scatterometers, gravity satellites, autonomous instruments of many sorts,..., ship sampling still. Dynamical models approaching true eddy and internal wave scales,...

Can climate trends be calculated from reanalysis data?

JGR 2004

Lennart Bengtsson[1]
Environmental Systems Science Centre, Reading, UK

Stefan Hagemann
Max-Planck-Institute for Meteorology, Hamburg, Germany

Kevin I. Hodges
Environmental Systems Science Centre, Reading, UK

Received 14 January 2004; revised 23 March 2004; accepted 14 April 2004; published 9 June 2004.

[1] Several global quantities are computed from the ERA40 reanalysis for the period 1958–2001 and explored for trends. These are discussed in the context of changes to the global observing system. Temperature, integrated water vapor (IWV), and kinetic energy are considered. The ERA40 global mean temperature in the lower troposphere has a trend of +0.11 K per decade over the period of 1979–2001, which is slightly higher than the MSU measurements, but within the estimated error limit. For the period 1958–2001 the warming trend is 0.14 K per decade but this is likely to be an artifact of changes in the observing system. When this is corrected for, the warming trend is reduced to 0.10 K per decade. The global trend in IWV for the period 1979–2001 is +0.36 mm per decade. This is about twice as high as the trend determined from the Clausius-Clapeyron relation assuming conservation of relative humidity. It is also larger than results from free climate model integrations driven by the same observed sea surface temperature as used in ERA40. It is suggested that the large trend in IWV does not represent a genuine climate trend but an artifact caused by changes in the global observing system such as the use of SSM/I and more satellite soundings in later years. Recent results are in good agreement with GPS measurements. The IWV trend for the period 1958–2001 is still higher but reduced to +0.16 mm per decade when corrected for changes in the observing systems. Total kinetic energy shows an increasing global trend. Results from data assimilation experiments strongly suggest that this trend is also incorrect and mainly caused by the huge changes in the global observing system in 1979. When this is corrected for, no significant change in global kinetic energy from 1958 onward can be found. *INDEX TERMS:* 1610 Global Change: Atmosphere (0315, 0325); 3309 Meteorology and Atmospheric Dynamics: Climatology (1620); 3337 Meteorology and Atmospheric Dynamics: Numerical modeling and data assimilation; *KEYWORDS:* trend, reanalysis, climate, water vapor

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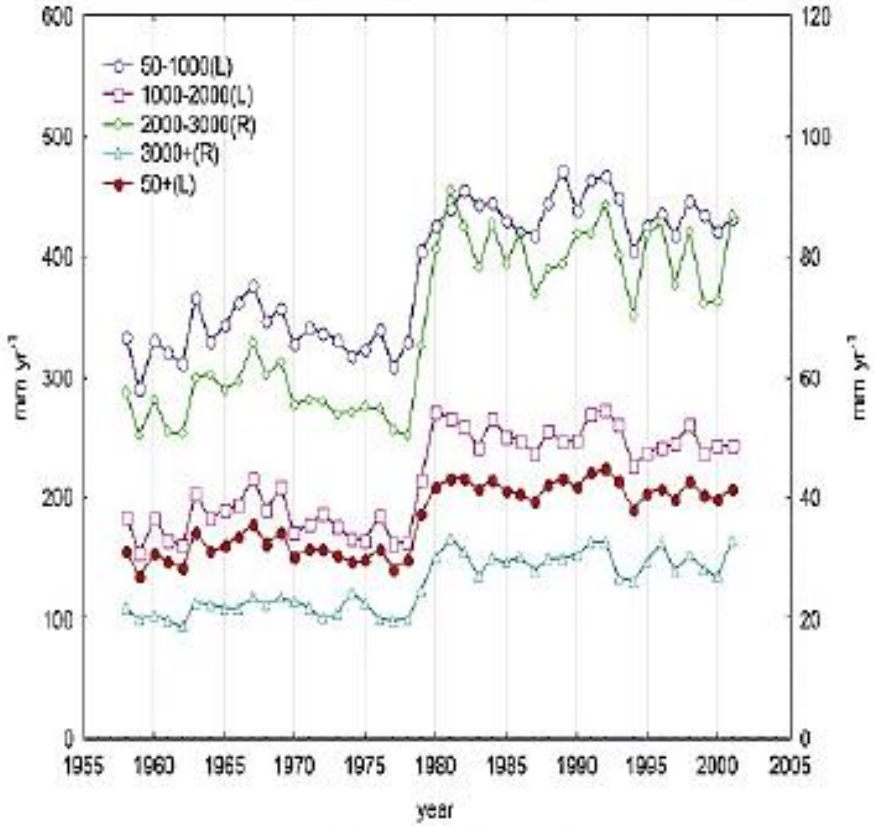
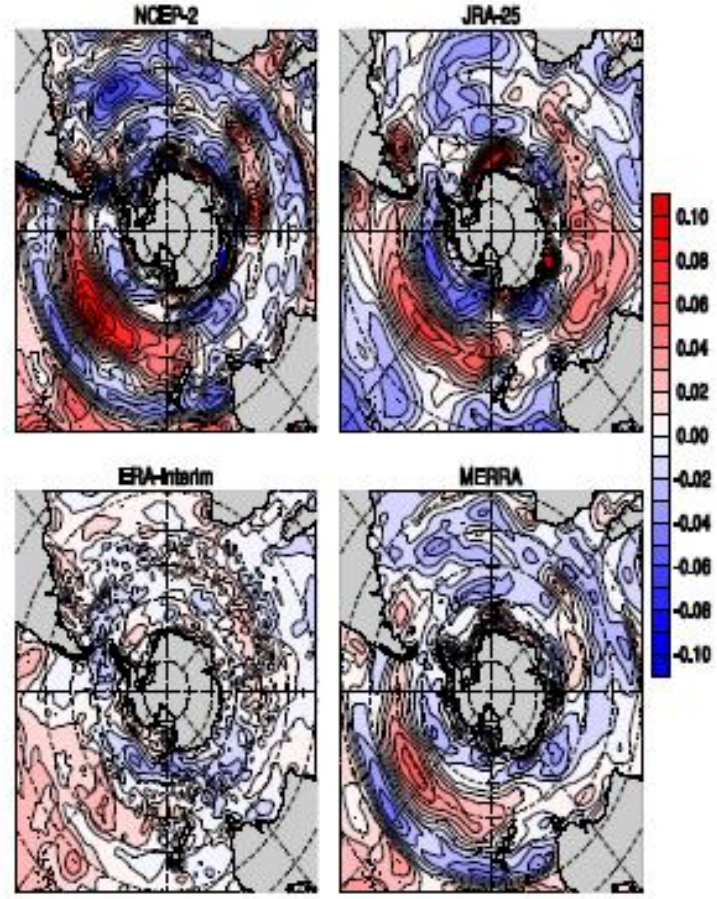
INDEX TERMS: 1610 Global Change: Atmosphere (0315, 0325); 3309 Meteorology and

Use of prediction schemes for physical estimation purposes can go badly wrong:



Change in SH atmospheric precipitation when the polar orbiters became operational. Water content not conserved.



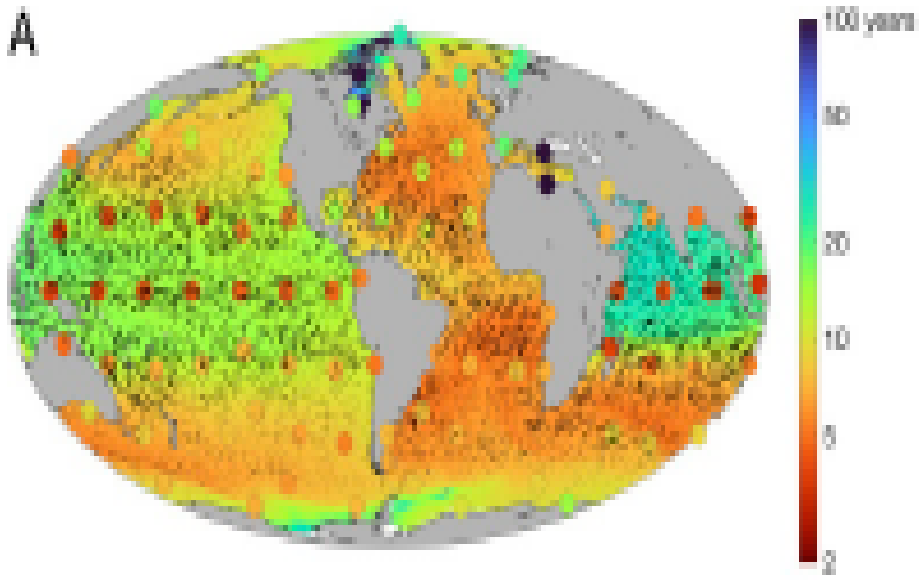
Apparent trends in Southern Ocean winds in 4 different atmospheric “reanalyses” (a data-poor area).

David Bromwich, Ohio State U.

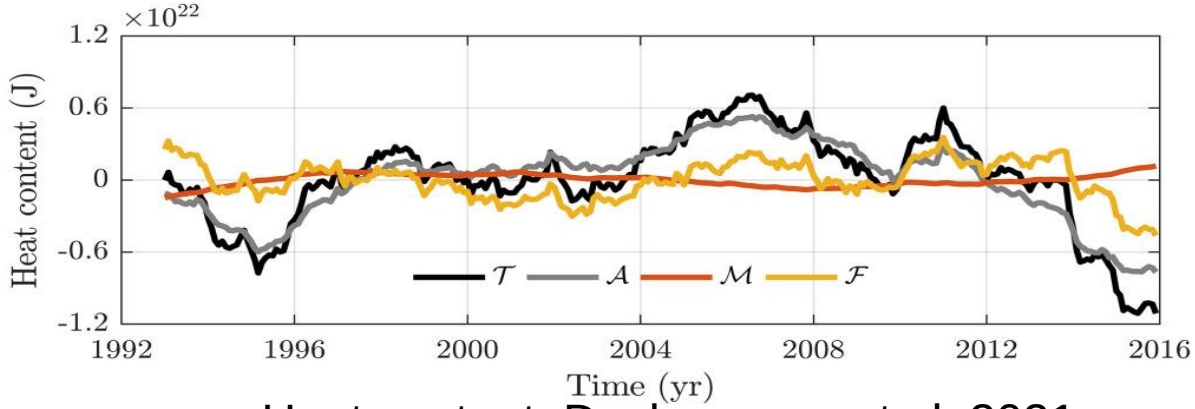
Putting ECCO together required expertise in: All the different observational types; theory; numerical models; optimization methods; computer architectures; adjoint compilers;...

People with all this expertise came together for a few years beginning in the mid-1990s on one floor of the Green Building at MIT. Some of the important individuals present at least parts of that time included Jochem Marotzke, Detlef Stammer; Patrick Heimbach; Dimitris Menemenlis; Alistair Adcroft; Jean-Michel Campin; Ralf Giering, Rui Ponte,... (and I'm forgetting some important people—apologies...), students, post-docs,....

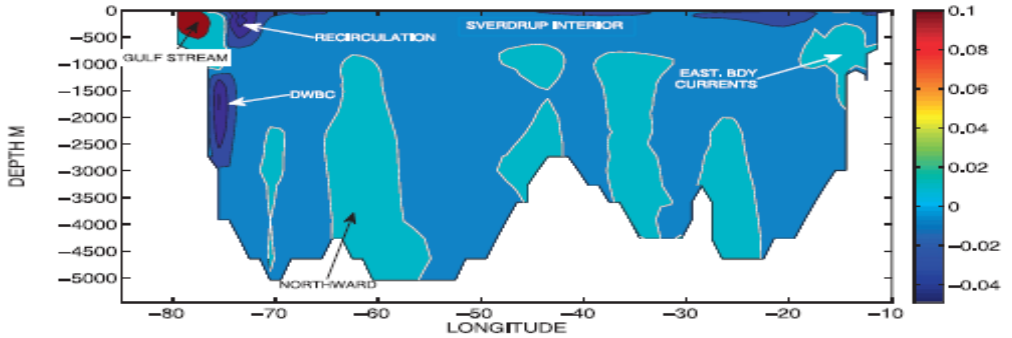
Lots of applications. Hundreds of papers



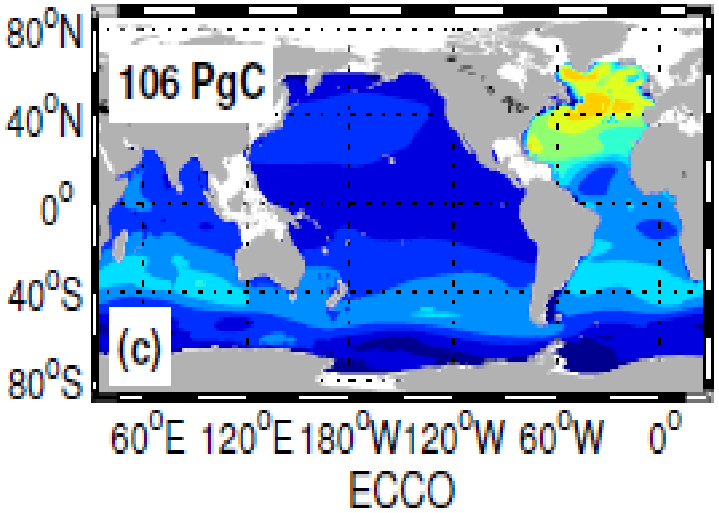
Plankton movements. Ward et al. PNAS 2021

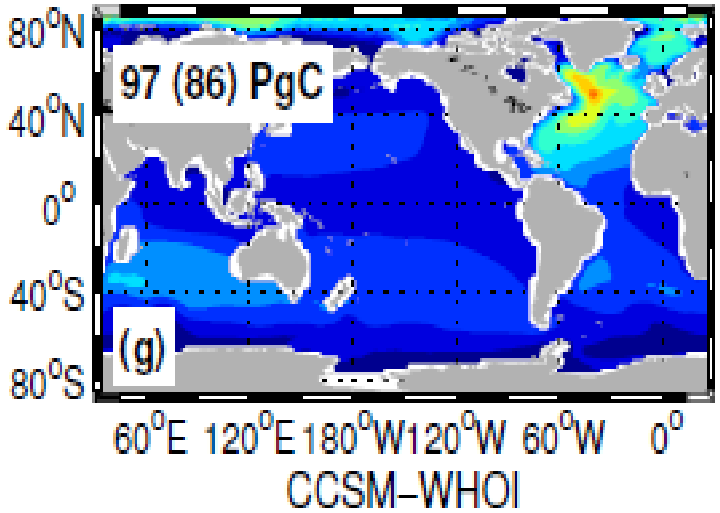


Heat content. Desbruyeres et al. 2021



Flows, Wunsch & Heimbach 2013





arbon uptake,
hatiwala et al. 2013

Also, ocean dynamics, earth rotation, sea level, ecology, annual cycle, means, trends,...