Deep Convection in the Labrador Sea: Moorings, Hydrography and Laboratory Simulations

Peter B. Rhines
School of Oceanography
Box 357940
University of Washington
Seattle, WA 98195
phone: 206-543-0593 fax:206-543-6073 email: rhines@ocean.washington.edu
Award # N000149401729
http://ocean.washington.edu/research/gfd/gfd.html

LONG-TERM GOALS

The intensive resources directed at numerical models of the ocean need to be balanced by direct observation, theory and laboratory simulation. By applying these methods to some of the most complex parts of the ocean system, we hope to improve understanding of the total system. The convection and wind-driven activity of the upper ocean provide such a challenge, and in addition are particularly significant to problems of air/sea interaction, upper-ocean dynamics and dynamics of coastal seas. At high latitudes, convection reaches great depth, and influences the global general circulation.

OBJECTIVES

The Deep Convection ARI (Accelerated Research Initiative) produced a wealth of data, spanning from the fine scales of turbulent mixing and convection to mesoscale eddies, boundary currents and 1000 km-scale basin circulation. The northwest Atlantic has, thanks to this program, received intense attention from many research groups in many countries. Our objective is to synthesize the mooring data with hydrographic observations from the 7 or so major US/Canadian cruises that entered the region between fall 1996 and summer 1998. In addition, so long as funding can be found to do so, we will pursue numerical and laboratory simulation of convective processes in the ocean, and more broadly, the interaction of eddies and general circulations.

APPROACH

We have data from our Bravo mooring (56.75N, 52.5W) from May 1994 to the present. During the intense phase of the ARI we were joined by moorings from Institut fuer Meereskunde (IFM), Germany, as well as the many other components of the ARI. With ONR support we deployed extra moorings in the boundary current, and have combined this data with that of the IFM group, who have the resources to continue observations well into the future. The combined data set is striking and has established the shape and size of the boundary currents on the southwest side of the Labrador Sea, and given the first reliable transport numbers. In other areas we are pursuing numerical and laboratory modelling, and have helped to provide major upgrades involving multi-processor computers and the geophysical fluid dynamics laboratory during this year.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
30 SEP 1999		**00-00-1999 to 00-00-1999**

4. TITLE AND SUBTITLE **Deep Convection in the Labrador Sea: Moorings, Hydrography and Laboratory Simulations**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Washington,School of Oceanography,Seattle,WA,98195**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a REPORT	b ABSTRACT	c THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**4**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

WORK COMPLETED

This past year our major paper on the convection process was published (Lilly *et al.* 1999). This analyzed the 3600m deep water column as recorded by the current meters, temperature/salinity sensors and acoustic Doppler current profilers on the Bravo mooring. A paper (Lilly, 1999) giving detailed analysis of sub-mesoscale eddies seen at the mooring is complete and will be submitted to the Labrador Sea special volume of *J. Physical Oceanography*. Lilly (a graduate student working with the P.I.) has continued to develop wavelet analysis of the time-series data, and has another paper in preparation on this far-reaching technique.

Collaborative work with the IFM group in Germany was aided by an extended visit that Lilly made in August, during the Woce-Atlantic meeting in Kiel. There is now a plan to apply wavelet analysis to the extensive observations that Kiel has obtained. In addition the eddy analysis has turned up patterns which stand in disagreement with most numerical models of ocean convection, and plans have developed to analyze these differences with Drs. Kaese and Send at IFM, Kiel.

Despite some hardware failure during the 1996-98 deployment period, the mooring data-sets provide us with 5 continuous years of Bravo data, and 20 months of boundary current data. This fortuitously has been a period of major climatic extremes, from the weakest wintertime cooling, to perhaps the most intense of the 20th Century. Eddy and mixed-layer dynamics has been recorded through this range of forcing. Continuation of this time-series into the future is uncertain.

In addition to the mooring work we have temperature/salinity/tracer sections carried out annually along the Bedford Institute of Oceanography's line from Hamilton Bank, Labrador to Cape Desolation, Greenland, each year since 1990. Our participation in this work has led to extensive study of the fine-structure generated by convection, and the complex mechanisms of 'relaxation' of the Labrador Sea when winter is over. Restratification processes are diagnosed using water-mass properties. We participated also in 3-dimensional hydrographic surveys of the Sea in late 1996, which give an unequalled opportunity to understand the mixing of boundary currents and interior. We have access to some float and surface drifter data (courtesy of S. Bacon and P.P.Niiler, respectively). Analysis of this data is proceeding. An AGU presentation on the work is scheduled for AGU Ocean Sciences, January 2000, by Jerome Cuny, a graduate student working with the PI.

This grant also supported laboratory experiments in convection. Here, Leif Thomas (a graduate student working with the PI) has carried out a program of numerical and laboratory simulations of a coastal region driven by windstress, with and without surface buoyancy flux. It is an abstract model of coastal upwelling, and Thomas will also present the work at AGU Ocean Sciences. William Wilcock and the PI will present a description of the use of the Geophysical Fluid Dynamics laboratory in teaching at this meeting. The late Dr. Boris Boubnov, before his untimely death during summer of 1999, had carried out three remarkable sets of experiments in our laboratory. One of these is described by LuAnne Thompson elsewhere in this volume. The others, involving convection in basins, are being completed by the PI. A paper (Boubnov and Rhines, 1999) was submitted to *J.Fluid Mechanics* in January 1999.

Finally, ONR has funded under this grant a separate activity in coastal and estuarine geophysical fluid dynamics led by Rhines: a 5-week workshop/graduate course at Friday Harbor Laboratories, San Juan Island, Washington in July/August 1999. The course involved a staff of 5 (Stephen Monismith, Craig Lee, Jody Klymak, Derek Fong and Rhines), 15 graduate students and 10 senior visitors. The course involved field work from two 22' boats, equipped with ctd and underway adcp. The students were able to exhaustively sample a tidal mixing site in San Juan Channel, and using the University of Washington's R/V Barnes, explored the Fraser River estuary. The course website, with down-loadable summer reports, may be found at

www.ocean.washington.edu/research/gfd/Ocean590.html

Two presentations of the summer research are scheduled for AGU Ocean Sciences, January 2000.

RESULTS

The major scientific results from the past year, stemming from ONR support are:

(i) a comprehensive observation, over nearly 2 years, of the transport and structure of the boundary currents of the Labrador Sea (e.g., presented by Fischer *et al.* at the Woce Atlantic Symposium, Kiel Germany, August 1999)

(ii) completion of 5 years' observation of convection and eddies at the Bravo mooring.

(iii) description of the mesoscale eddy field of the Labrador Sea using wavelet analysis (described in Lilly, 1999, and in several presentations at national and international meetings);

(iv) completion of two sets of laboratory experiments on convective eddies (the homogeneous-fluid studies being described in Boubnov and Rhines, 1999);

(v) discovery of a bifurcation of the boundary currents along the Greenland coast, into two favored paths, for the passage across the Labrador Sea to the Labrador coast.

(vi) identification of processes that determine the location of the upwelling front in an idealized theoretical/numerical/laboratory study of wind-driven circulation at a coast;

(vii) an observational portrait of the tidal mixing in the San Juan Islands, which is a key process in driving the overall estuary circulation of the Juan de Fuca Strait/Georgia Strait inland sea (the overturning circulation of the region has 10 to 20 times the volume flux of the river inflow, alone).

IMPACTS/APPLICATIONS

We would argue that understanding the processes of convection and wind-driven upwelling will unlock many new aspects of the ocean dynamics, and in addition the intense pressure to make better observations is leading to innovative new observational techniques. If we can find support to do so, we (C. Eriksen and the PI, in a proposal to ONR) will in the next two years have autonomous 'glider' platforms giving an order of magnitude better coverage of the Labrador Sea. We also (S. Monismith and the PI) will have the capability to rapidly scan an estuary with multiple small craft, and use it to teach graduate students the art and practice of coastal dynamics. We (W.Wilcock and the PI) will furthermore take the process of laboratory geophysical fluid dynamics to a new level of intensity in the teaching of both graduate and undergraduate students. We see these 'hands-on, brain-on' activities as antidotes to over-emphasis on computer modelling and 'distance' learning in our education system.

PUBLICATIONS

Boubnov, B.M. and P.B.Rhines, 1999: Regimes of convection in cooled rotating bowls, *J.Fluid Mech.*, submitted 1/99

Lilly, J.M., P.B.Rhines, M.Visbeck, R.Davis, J.R.N.Lazier, F.Schott, D.M.Farmer, 1999: Observign deep convection in the Labrador Sea during winter 1994-1995, *J.Phys.Oceanogr.* 29, 2065-2098.

Lilly, J.M. 1999: Coherent eddies in the Labrador Sea, *J.Phys.Oceanogr. special volume on the Labrador Sea*, to be submitted

LabSea group, 1998: The Labrador Sea deep convection experiment, *Bull. Amer. Met. Soc.* 79, 2033-2058.

Rhines, P.B., 1998: Circulation , convection and mixing in rotating, stratified basins with sloping topography. *In* Physical Processes in Lakes and Oceans, J.Imberger Ed., AGU Coastal and Estuarine Series 54, 435-451.