The Thermohaline Circulation in Semi-enclosed Marginal Seas

Michael A. Spall
WHOI MS #21
360 Woods Hole Road
Woods Hole, MA 02543-1541
TELEPHONE: (508) 289-3342 FAX: (508) 457-2181 e-mail: mspall@whoi.edu
Grant Number N00014-03-1-0338

LONG TERM GOALS

The long-term goal of this project is to contribute to our understanding of the circulation within marginal seas and their exchange with the open ocean.

OBJECTIVES

The objective of this work is to better understand how the exchange between a marginal sea and the open ocean and the circulation within the marginal sea depend on buoyancy-forcing in the marginal sea. Areas of focus include: mass and heat flux through the straits; circulation pathways in the marginal sea; instabilities and eddy formation; regions of deep mixing and regions of downwelling in the marginal sea.

APPROACH

The approach is to develop analytic and numerical models that demonstrate how the exchange between the marginal sea and the open ocean, the circulation within the marginal sea, and the properties of the waters produced in the marginal sea depend on the buoyancy-forcing within the marginal sea. The basin configurations are necessarily idealized in order to permit simple representations of the important geometrical and physical parameters, and to determine their influences on the quantities of interest. The overall objective is to provide simple physical explanations for the dominant aspects of the observed circulations in the marginal seas and the properties of the waters produced within the marginal seas. Idealized numerical models and supporting theories have also been developed to explore how mean and low frequency variability interacts with porous western boundaries, both at mid-latitudes and in the equatorial Pacific Ocean.

WORK COMPLETED

Numerical and analytic models have been applied to the thermohaline circulation in a marginal sea subject to a basin-scale buoyancy loss in the interior. The marginal sea is connected to an open ocean through a narrow strait. Cases with a flat bottom, a region of sloping topography around the perimeter of the basin, and sloping topography throughout the interior have been studied. Comparisons between a series of model calculations and the theory have been carried out. Comparisons between the model, theory, and observations of the downwelling and mechanisms of meridional heat transport in the Labrador Sea have also been carried out.

RESULTS

Throughout these studies is has been shown that boundaries, and boundary currents, play key roles in the net vertical motion of buoyancy-driven circulations. Small-scale mixing of density and momentum and bottom topography play fundamental roles in determining the characteristics of this downwelling motion. It has been found that a region of sloping topography around the perimeter of marginal sea plays an important role in controlling both the circulation and the properties of the water masses formed by buoyancy-forcing within the marginal sea. The topography supports strong boundary currents, which transport heat into the basin and, through baroclinic instability, provide eventual restratification of regions of deep convection in the interior through the formation of eddies. A simple parameterization of this baroclinic instability over a sloping bottom permits a theoretical estimate of the density of waters formed in the interior of the marginal sea, of the waters that are exported to the open ocean, net downwelling within the marginal sea, and of the net exchange between the marginal sea and the open ocean (strength of the boundary currents).

Marginal seas that have topography extending from the open ocean through the region of cooling are subject to different contraints and dynamics. In these cases, the heat loss to the atmosphere is balanced by mean advection from the open ocean. Eddies, although they develop, play a much less important role than has been found previously in many deep convection problems. This is because the topography connects the cooling regions to the open ocean source region by the characteristics of the system. This drives a mean flow down the mean temperature gradient, something that is not possible in buoyancy-forced problems that are essentially two-dimensional (localized cooling, periodic channels). Scaling theory provides an estimate of the exchange rate with the open ocean and the properties of the waters formed within the marginal sea. A simple analytic two-layer model reproduces the essential characteristics of the full three dimensional nonlinear primitive equation calculations, and provides a means to understand the controlling dynamics of the circulation.

For the problem of westward propagating equatorial Rossby waves, it is shown that a majority of the energy carried in the waves is able to penetrate through a narrow gap near the equator into a western basin and that very little of the energy is reflected off the boundary as an eastward propagating Kelvin wave. This result differs from previous findings and suggests that the narrow passages near the equator in the western Pacific might provide an efficient means to communicate low-frequency variability into the Indian Ocean (and generate strong currents in the Indonesian Seas) and limit the role of reflected Kelvin waves in triggering El Nino events.

IMPACTS/APPLICATION

These results demonstrate how the exchange between marginal seas and the open ocean depends strongly on the physical processes with the marginal sea. This not only points to the importance of buoyancy-forcing and a proper representation of boundary currents, topography, and small-scale instabilities for basin-scale models, but also suggests that care must be taken in the specification of the strait transports for regional models of marginal seas.

The physical understanding provided by these simple models focuses attention on the key processes that must be properly represented in predictive models of these regions. This should allow for better predictions of the ocean currents in such marginal seas and their sensitivity to air-sea exchange.

RELATED PROJECTS

This study is closely related to the ONR-funded Japan / East Sea program (JES) and the ONR LINKS (Dynamical Linkage of the Asian Marginal Seas) program, which use a combined observational and modeling approach to study the circulation and exchange between the Asian marginal seas and the open ocean. The ONR ASIAEX (Asia Seas International Acoustics Experiment) volume interactions program in the South China Sea also addresses some common issues of marginal sea/open ocean exchange, as does the Circulation Research on the East Asian Marginal Seas (CREAMS) program being jointly supported by Korea, Japan, and Russia. These results are also closely related to the circulation in the Adriatic Sea, the subject of both ONR Adriatic Mesoscale Experiment and the NRL Adriatic Circulation Experiment.

PUBLICATIONS

Spall, M. A., 2003. Thermohaline circulation in marginal seas. J. Marine Res., 61, 1-25 [published, refereed]

Spall, M. A., 2003. Islands in zonal flow. J. Phys. Oceanogr., 33, 2689-2701 [published, refereed]

Pratt, L. J. and M. A. Spall, 2003. A porous medium theory for barotropic flow through ridges and archipelagoes. J. Phys. Oceanogr., 33, 2702-2718 [published, refereed]

Spall, M. A., 2004. Boundary currents and water mass transformation in marginal seas. J. Phys. Oceanogr., 34, 1197-1213. [published, refereed]

Katsman, C, M. A. Spall, and R. S. Pickart, 2004. Boundary current eddies and their role in restratification of the Labrador Sea. J. Phys. Oceanogr., 34, 1967-1983. [published, refereed]

Spall, M. A., and J. Pedlosky, 2005. Reflection and transmission of equatorial Rossby waves. J. Phys. Oceanogr., 35, 363-373 [published, refereed]

Spall, M. A., 2005. Buoyancy-forced circulation in shallow marginal seas. submitted: J. Mar. Res. [in press, refereed]

Pedlosky, J., and M. A. Spall, 2005. Boundary intensification of vertical velocity in a beta-plane basin. J. Phys. Oceanogr. [submitted, refereed]

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)* 18-05-2005	**2. REPORT TYPE** FINAL - UNCLASSIFIED	**3. DATES COVERED** *(From - To)* JANUARY 2003- DECEMBER 2004

4. TITLE AND SUBTITLE The Thermohaline Circulation in Semi-Enclosed Seas	**5a. CONTRACT NUMBER**
	5b. GRANT NUMBER N00014-03-1-0338
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Michael Spall	**5d. PROJECT NUMBER** WHOI - 13033800
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Woods Hole Oceanographic Institution, 360 Woods Hole Road, Woods Hole, MA 02536	**8. PERFORMING ORGANIZATION REPORT NUMBER** FINAL
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Office of Naval Research, Ballston Centre Tower One 800 N. Quincy St. Arlington, VA 22217-5660	**10. SPONSOR/MONITOR'S ACRONYM(S)**
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

DISTRIBUTION UNLIMITED, UNCLASSIFIED

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The principles governing the buoyancy-forced circulation within marginal seas, and their exchange with the open ocean, are addressed using a series of idealized numerical models and theory. It is found that small scale mixing of density and momentum near the boundaries plays a central role in the net downwelling within the marginal sea and, at times, in the basin-scale stratification. Bottom topography is also found to be very important for both the circulation within the marginal sea and the exchange of mass and heat with the open ocean. Distinct dynamical regimes are found for open and closed topographic contours. The interaction of mean and low-frequency motions with a porous western boundary at both mid-latitudes and near the equator are also addressed.

15. SUBJECT TERMS

Ocean Circulation, Marginal Seas, Air-Sea Exchange

16. SECURITY CLASSIFICATION OF: UNCLASSIFIED			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** MICHAEL SPALL
a. REPORT UNCLASSIFIED	**b. ABSTRACT** UNCLASSIFIED	**c. THIS PAGE** UNCLASSIFIED	UNLIMITED	4	**19b. TELEPHONE NUMBER** *(include area code)* 508-289-3342

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