The Thermohaline Circulation in Semi-enclosed Marginal Seas

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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; boundary currents in the marginal sea; instabilities and eddy formation; regions of deep mixing and regions of downwelling in the marginal sea.

A second area of interest has also emerged, that being the transmission of low frequency variability from the open ocean into the marginal sea through the strait.

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 low frequency variability on the equator in the Pacific Ocean interacts with a porous western boundary and is transmitted into the Indonesian Seas. This work is being carried out in collaboration with Dr. Joseph Pedlosky.

WORK COMPLETED

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

Similar models have been applied to the restratification of the Labrador Sea, in which it is shown that instability of the Irminger Current along west Greenland, triggered by a region of very steep topography, produces a large number of strong, buoyant eddies that propagate into the interior regions of deep convection.

Numerical and analytic models have also been applied to the transmission of low-frequency equatorial Rossby waves through a narrow gap in the western boundary into an adjacent basin.

RESULTS

It has been found that the 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 (see Fig. 1). 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).

Calculations based on an idealized Labrador Sea basin show that the region of steep topography along west Greenland is responsible for intense eddy formations via a mixed instability, and that the heat transport carried into the interior of the Labrador Sea by these eddies is sufficient to close the heat budget and restratify the regions of deep mixing in the western Labrador Sea.

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 (see Fig. 2). This 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 Niño events.

TRANSITIONS

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.

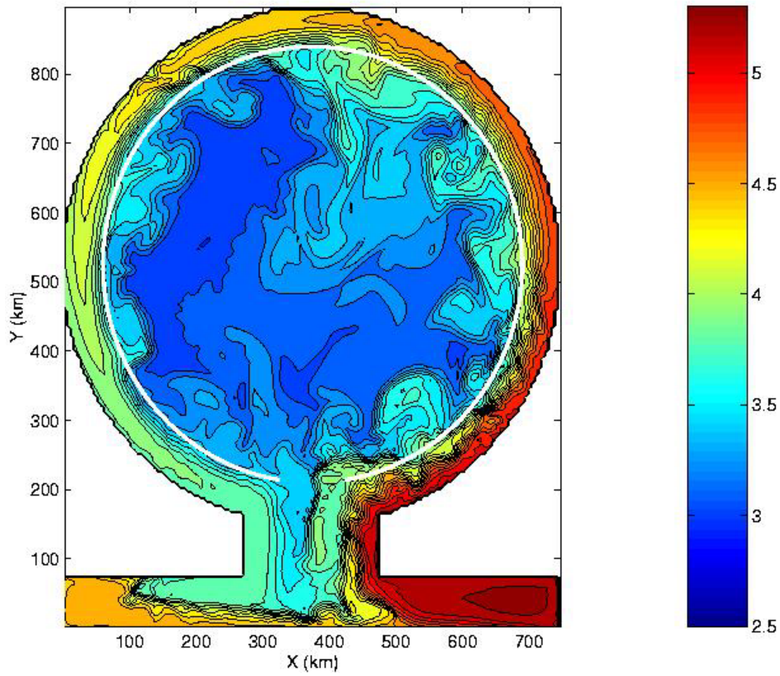

Figure 1: Spring sea surface temperature in a marginal sea that is connected to an "open ocean" and subject to uniform cooling. A region of sloping topography is found between the outer boundary and the bold white line. Warm water is transported into the marginal sea by a strong boundary current over the sloping bottom. The boundary current is baroclinically unstable and sheds eddies that restratify the interior and provide heat to balance the surface cooling. The boundary current is cooled as it encircles the basin due to both this eddy heat flux and direct cooling by the atmosphere.

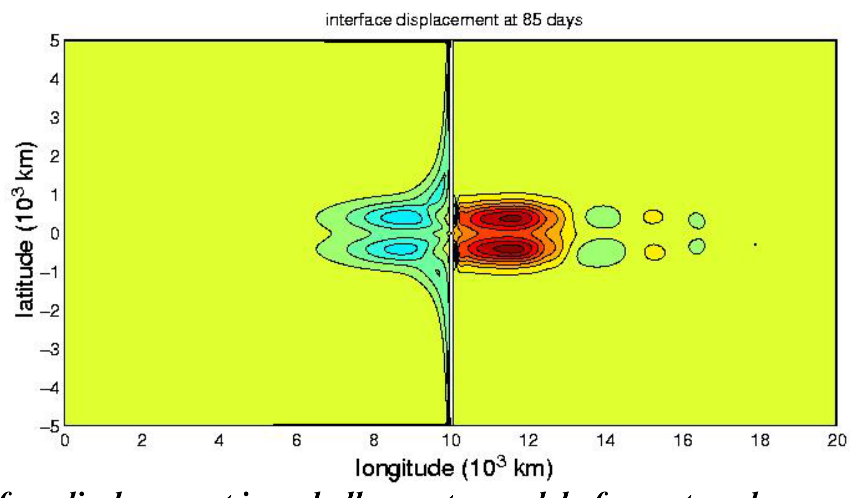

Figure 2: Interface displacement in a shallow water model of a westward propagating equatorial Rossby wave. The eastern and western basins are connected by a narrow gap on the equator (too small to be clearly visible in this figure). Most (70%) of the incident Rossby wave energy is transmitted through this narrow gap and into the western basin, generating strong currents within the gap in the process. This energy then takes the form of the mode 1 Rossby wave once again within the western basin and continues its westward propagation. After 85 days of integration, the low pressure signal has been transmitted into the western basin and the high pressure signal is just beginning to penetrate the gap.

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

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