DE-FG02-01ER63252

**Final report for: The Role of Eddy-Tansport in the Thermohaline Circulation**

Several research themes were developed during the course of this project:

*Low-frequency oceanic variability:*

One theme of the project is the "natural modes of variability" of the upper ocean. We have demonstrated the existence of global basin modes. The consequence of these natural modes is that the response to forcing, localized in a sub-basin area such as the North Atlantic, occurs in conjunction with the adjustment of the rest of the global ocean, including remote sub-basins. This global "teleconnection" mediated by planetary waves is a mechanism by which mid-latitudes exert control over the tropics (e.g. changes in the North Atlantic can affect El Nino). Because this adjustment occurs on decadal time-scales, these modes are a prominent component of the decadal predictability of the climate system.

*The role of eddies in the Antarctic Circumpolar Current (ACC) region:*

Another theme of the project is the mechanism leading to the establishment of the stratification in the ACC region. We find that there is competition between the thermally indirect heat transport by the wind-driven Deacon Cell of the ACC region and the thermally direct heat transport by mesoscale eddies. These two competing mechanisms determine the stratification in the ACC region, which is then imprinted to the global ocean. Thus, the wind, the surface buoyancy forcing and the eddy-processes in the ACC region determine the intermediate, deep and abyssal stratification of the world ocean.

This project examines the wind and buoyancy driven dynamics of the ocean in the eddying regime, with a particular focus on the oceanic heat budget. The tools we use are a hierarchy of models in the eddying regime. We use the Massachusetts Institute general circulation model (MITgcm) configured in a reentrant channel, with flat bottom and forcings of simple shape; the same model configured in a semi-enclosed basin, i.e. a basin like the Atlantic, with a channel in the southern portion; and the Parallel Ocean Program (POP) in a global ocean configuration.

*Deep stratification and the overturning circulation:*

While the processes that maintain the flow and stratification of the water in and above the thermocline are well understood, the stratification and circulation of the intermediate and deep water are not. In this series of papers, we have made substantial progress at clarifying the mechanisms that determine the intermediate and deep stratifications of the world ocean and the pole-to-pole overturning circulation of the Atlantic ocean, which is responsible for the northward heat transport in the Atlantic. Its peculiar pole-to-pole heat transport determines the thermal asymmetry of the hemispheres, such as the position of the inter-tropical convergence zone, and the mild climate of northern Europe. Its stability and potential for abrupt change is a fundamental aspect of the climate uncertainty.

The approach is to use a hierarchy of models in large domains with a simplified geometry capturing the essential features of the Atlantic: a semi-enclosed basin with a circumpolar region (similar to the ACC region) in the southernmost portion of the domain. The hierarchy includes high-resolution computations which capture the eddy-scales in high latitudes and the narrow boundary currents, coarse resolution computations with parametrized eddy-fluxes, and a conceptual model of the longitudinally averaged flow.

The key finding are as follows:

1) The stratification below the main thermocline (at about 500m) is determined in the circumpolar region and then communicated to the enclosed portions of the oceans through the overturning circulation.

2) An Atlantic pole-to-pole overturning circulation can be maintained with very small interior mixing as long as surface buoyancy values are shared between the northern North Atlantic and the ACC region. This conceptual framework explains how we can have northward heat transport everywhere in the Atlantic, and a hefty overturning circulation with very weak mixing in the interior of the ocean. Our work also explains how the meridional circulation can be interrupted if the surface buoyancy in the North Atlantic increases above the values found in the surface region of the ACC. Equivalently, the meridional circulation can be interrupted if the surface buoyancy in the ACC region are decresed below the values found in the surface North Atlantic. This view represents a paradigm shift from the traditional concept of the Atlantic overturning relying on buoyancy difference between the North Atlantic and the ACC region. The strength of the overturning is instead determined by the wind suction in the ACC region, which "pulls" the overturning towards the surface, along *shared* buoyancy surfaces. This work provides a novel framework to predict shutdown or strenghtening of the Atlantic meridional overturning, which implicate the winds and the surface buoyancy in the ACC region as well as in the northern North Atlantic.

We have proven this scenario by several eddy-resolving computations in statistical equilibrium thanks to an INCITE allocation at Argonne Leadership Computing Facility in 2009, and allocations at NERSC in 2009, 2010 and 2011.

*Upwelling coastal dynamics and effective boundary conditions:*

"Effective boundary conditions" have been derived for use in coarse-resolution models, that parametrize the effect of tracers' transport in narrow up/downwelling layers near the coast. These "effective boundary conditions" conserve mass and total tracers, and can be used in climate models to remedy the systematic warm-bias in sea-surface temperature caused by poor resolution of upwelling layers.

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