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Understanding Large-Scale Oceanic Transport Processes

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Of the various transports of properties by the ocean circulation, the focus has mostly been on the transport of energy, because of its direct influence on sea surface temperature (SST) and climate. However, the community should extend its focus toward

i) Meridional freshwater transport, with its impact on high-latitude salinity, convection, and thermohaline circulation (THC). Observational estimates of meridional freshwater transport are far less common than those for energy. ii) Meridional transport of carbon, with its impact on ocean-atmosphere CO_2 exchange and the radiative forcing of climate. iii) Meridional transports of nutrients, which influence the carbon cycle through the biological pump where nutrients are rate-limiting.

The CO_2 exchange provides a climatically crucial ocean-atmosphere coupling that is NOT exclusively mediated through SST. As maxima in carbon and nutrient concentrations typically occur far away from the sea surface, deep transports are crucial for climate change.

The main processes by which the ocean transports mass, energy, and properties meridionally, are the meridional overturning circulation (MOC), quasi-horizontal gyre circulation, and mesoscale eddies. I will review current empirical estimates of transport strengths and patterns in the major oceans.

Our dynamical understanding of the strength and structure of the MOC can be classified by the 2-by-2 matrix

	Steady state	High-frequency variability
THC	x	Weak?
Wind-forced	x (heat)	x

where a check indicates an emerging conceptual understanding. At high frequencies (seasonal and shorter timescales), MOC variability is dominated by variations in wind-induced Ekman transport and compensating depth- independent flow, as anticipated by Bryan (1982) and rigorously confirmed in model analyses of Lee and Marotzke (1998) and Jayne and Marotzke (2000) for the Indian and World Oceans, respectively. A theory for the steady-state THC has been formulated for idealised cases by Marotzke (1997) and Marotzke and Klinger (2000), covering the THC confined to a single hemisphere and a single, cross-hemispheric basin, respectively. Klinger and Marotzke (2000) have proposed a simple recipe for calculating heat transport of shallow, wind-driven overturning cells purely from wind and SST information.

Not understood are (1) the interactions of wind- and buoyancy forcing in setting MOC variability on timescales of years and longer; (2) the response of the THC to variability in convection; (3) the interactions between North Atlantic Deepwater and Antarctic Bottom Water transports, which are crucial for deep nutrient transports.

In simulating tracer concentrations, one often wants to know the relative influences of all surface regions on the distributions at depth. Typical sensitivity calculations vary one parameter at a time, which is not very efficient as their number grows large. In contrast, the "adjoint" of a model calculates the sensitivity of one output variable to all input variables simultaneously. Marotzke et al. (1999) have used a "compiler" (TAMC; Giering and Kaminski 1998) to create the adjoint to the MIT ocean general circulation model. Their first sensitivity calculation, that of Atlantic heat transport across 29N to various measurable quantities, suggests that monitoring of the MOC through density observations near the zonal boundaries should be a feasible strategy.

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