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WORLD OCEAN CIRCULATION EXPERIMENT

Report of the WOCE North Atlantic Workshop

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Remarks on meridional transports in ocean models

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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), ocean-atmosphere energy exchange, and climate. However, the community should extend its focus toward:

- Meridional freshwater transport, with its impact on high-latitude salinity, convection, and the large-scale circulation and energy transport. Although this has long been recognised as important, observational estimates of meridional freshwater transport are far less common than those for energy.
- Meridional transport of carbon, with its impact on ocean-atmosphere CO_2 exchange and the radiative forcing of climate.
- Meridional transports of nutrients, which influence the carbon cycle through the biological pump where nutrients are rate-limiting.

Notice that the ocean-atmosphere CO_2 exchange provides a climatically crucial ocean-atmosphere coupling that is NOT exclusively mediated through SST. Hence, there exists a parallel coupling strand, the dynamics of which have remained largely unexplored (see, however, Joos et al., 1999). In contrast to temperature, the maxima in carbon and nutrient concentrations typically occur far away from the sea surface, which immediately makes the deep circulation crucial for climate change. The area of research thus defined should lead to a convergence of interests that were previously either in oceanography or in climate.

Time-mean energy transport

Recent high-resolution (eddy-permitting) Atlantic and global model solutions (The DYNAMO Group, 1997; Parallel Ocean Climate Model, POCM, of B. Semtner and R. Tokmakian, see Jayne, 1999) show quite good agreement with estimates based on observations (e.g., A. Ganachaud, pers. comm., 1999). Major questions arise concerning the models' capability to simulate the mid-latitude convergence of energy transport and resulting loss to the atmosphere, and concerning the influence of the rest of the World Ocean on Atlantic energy transport (incorporated in regional models through southern boundary conditions).

Variability

Jayne (1999) has drawn on previous modelling work of Bryan (1982), Böning and Herrmann (1994), and Lee and Marotzke (1998); the theoretical work of Willebrand et al. (1980) on the ocean's response to wind fluctuations, Schopf's (1980) analogous analysis for low latitudes, Gill's (1980) theoretical model of (among others) equatorial wind fluctuations; and the observational angular momentum analyses of Rosen et al. (1990) and Ponte et al. (1998); to synthesise a reasonably complete theory of seasonal wind-induced heat transport variability. On seasonal and shorter timescales, heat transport variability is dominated by Ekman transport variability and barotropic compensation, as formulated by Bryan (1982) and confirmed in POCM.

Sensitivity and monitoring

In numerical modelling, very often the question arises how a central element of the model solution, such as the strength of the meridional overturning circulation (MOC) or maximum meridional heat transport, depends on the various independent parameters that enter the simulation, such as surface forcing, initial conditions, or diffusion parameters. Typical sensitivity calculations vary one parameter or one group of parameters at a time, which is not very efficient as the number of input parameters grows large. In contrast, the "adjoint" of a model calculates the sensitivity of one output variable, simultaneously to all input variables. Marotzke et al. (1999) have used R. Giering's "Tangent-Linear and Adjoint Model Compiler"

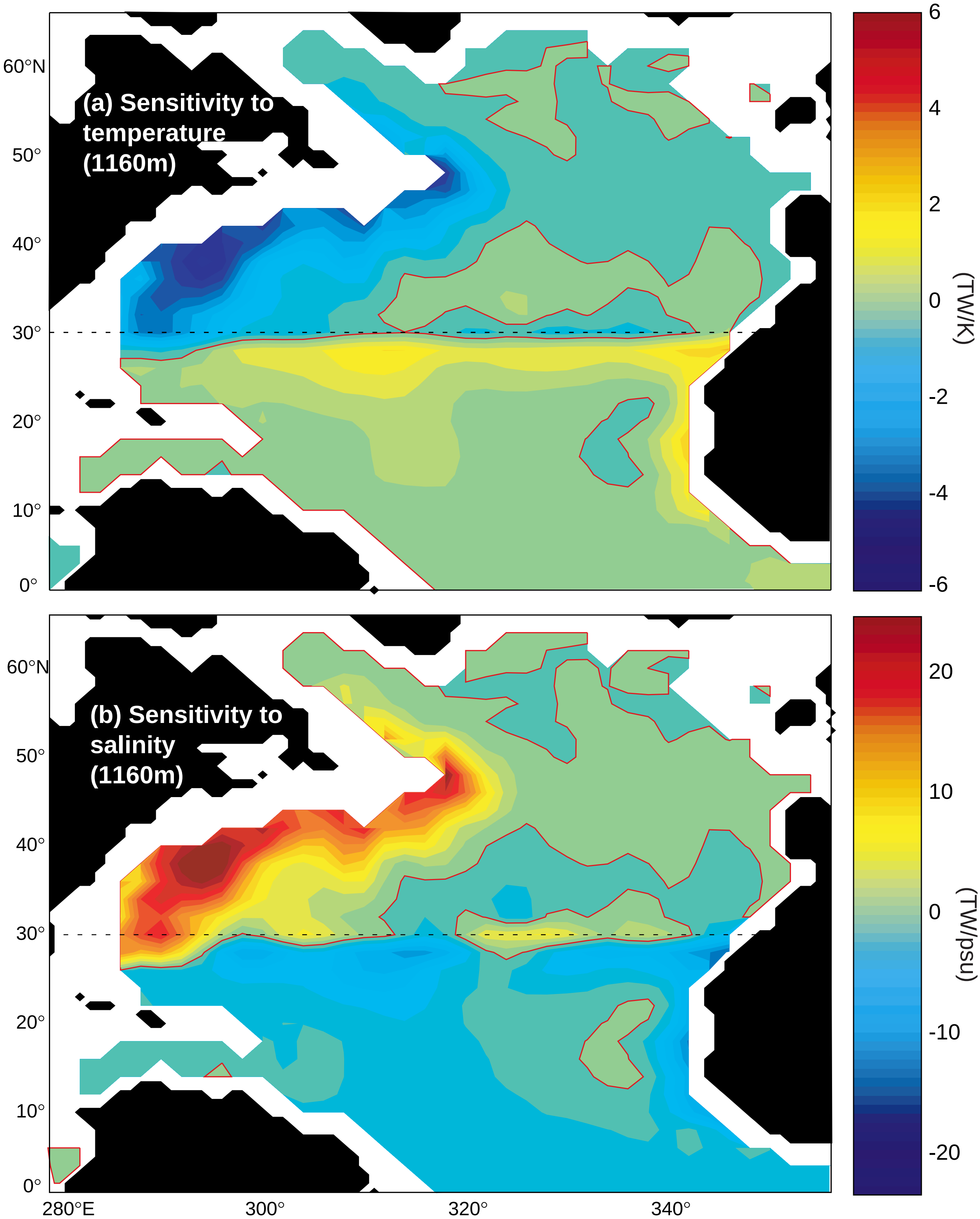

Figure 1. (a) Sensitivity of mean 1993 Atlantic heat transport across 29°N (dotted line), to temperature at 1160 m, on 1 January 1993. Contour interval is 0.5×10^{12} W / K, and the zero contour is drawn in red. (b) Sensitivity of mean 1993 Atlantic heat transport across 29°N (dotted line), to salinity at 1160 m, on 1 January 1993. Contour interval is 2×10^{12} W / psu, and the zero contour is drawn in red (from Marotzke et al., 1999).

(TAMC; Giering and Kaminski, 1998) to create the adjoint to the ocean general circulation model (GCM) of Marshall et al. (1997a,b). A particular application based on the global data assimilation solution of Stammer et al. (1997) for year 1993 is given in Fig. 1. It shows the sensitivity of mean 1993 Atlantic heat transport across 29°N, to temperature and salinity at 1160 m, on 1 January 1993. Most notable is the influence of density anomalies arising from as distant as the Labrador Sea, and its concentration on the zonal boundaries. This latter property is consistent with the concept that the MOC is in thermal-wind balance with the zonal density drop, and suggests that monitoring of the MOC by way of density observations near the boundaries should be a feasible strategy.

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