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The role of the Southern Ocean in the global conveyor: Eulerian and Lagrangian analysis of an ice-ocean model

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Experimental and numerical efforts have recently proposed that the Southern Ocean partially controls the rate of global meridional overturning. In spite of the renewed interest, there are yet many unknowns due to the scarcity of measurements and the complexity of the thermohaline circulation in the region, that includes ice-ocean interactions and slope gravity currents. Here we present the analysis of the thermohaline circulation of the Southern Ocean of a steady state simulation of a coupled ice-ocean model in order to clarify the relative role of the surface fluxes with respect to the internal mixing and describe the mechanisms of the deep water upwelling and of the freshwater export. The recent availability of data of passive tracers related to the oceanic ventilation, CFCs and 14C, for the upper and deep circulation, respectively, prompted to a model validation via comparisons with corresponding tracers off-line simulations. Volume transports are compared with the results of inversion of in situ data. Both analyses show a good correspondence with previous estimates including a weak but clear Antarctic Bottom Water formation. Using a new methodology a quantitative dynamical analysis of the water masses transformation is presented. Surface dianeutral fluxes, including the effect of the penetrative solar radiation, produce almost 40 Sv of Subantarctic Mode Water and while brine rejection forms 5 Sv on the shelves of Antarctica and in the Weddell Sea. Mixing transforms half of the SAMW into Intermediate Water and Upper Circumpolar Water while Bottom Water is produced by Lower Circumpolar Water and North Atlantic Deep Water mixing in the interior with the shelf water. The main pathways and transformation have been identified via the extensive

use of a Lagrangian quantitative diagnostics. The Southern Ocean is characterized by a shallow overturning transforming 20 Sv of thermocline waters into mode waters and a deep overturning related to the formation of Antarctic Bottom Water. Eventually, a definitive upwelling of 11.5 Sv of Circumpolar Deep Waters was observed. In particular about 40% of the North Atlantic Deep Water was found to definitively upwell while a similar amount is transformed into Antarctic Deep Water. The geographical distribution is also presented. The freshwater gain via vertical diffusion into the interior is found to be crucial for the wind-driven thermohaline transformation. The heat gain was instead found to dominate the final transformation into sub-surface and mode waters associated to the upwelling of the NADW. Eventually, the fate of the large freshwater excess was thus investigated. The large production of mode water associated to the shallow overturning in fact dominates the export. Regarding the thermodynamics of the transformations, the Lagrangian results were combined with the outputs of the new quantitative diagnostics of the dianeutral transformations.