Atlantic Meridional Overturning Circulation: Dynamical processes in idealized solutions forced by surface buoyancy flux and winds

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We explore the dynamics Atlantic Meridional Overturning Circulation (AMOC) in idealized solutions forced by a surface buoyancy flux Q(y), zonal wind stress τ(y), and an externally prescribed tropical-density structure with a thermocline depth H. Our overall goal is to understand the impact of wind forcing on overturning structure and strength. Solutions are obtained analytically for a variable-density, 2-layer ocean model (VLOM) and numerically for an ocean general circulation model (MITgcm). The model domain is a rectangular basin with a flat bottom, extending latitudinally from the equator to 60∞N and longitudinally from 0-40^o. For simplicity, density depends only on temperature, and the surface heat flux Q quickly relaxes near-surface temperature to a prescribed T*(y), which decreases linearly from 23^{o}C to T'=3^{o}C from 30^{o}N to y'=50^{o}N. In VLOM, where the deep-layer temperature remains constant at T', the upper layer vanishes at y>y', so that the model reduces to a one-layer system. Wind stress τ has a cosine shape with a maximum located at yw=35oN, so that the depth-integrated flow forms a subtropical and a subpolar gyre. A comparison of the model results reveals that VLOM qualitatively reproduces the main features of the MITgcm solutions, including the structure of the flow field and the strength of the AMOC. Deep water is formed in VLOM either by surface cooling, when the upper layer flow converges horizontally into the region to the north of y' (Wc), or via Wd, which represents mixing processes in MITgcm that tend to flatten the thermocline near y', at the bottom of the layer. The relative contributions of these two processes depend on H and the strength of the winds. The deep-water export from the subpolar ocean is given by M = Mn - Win - Ww, that is, a source due to formation rate of deep water, Mn, and losses due entrainment processes in the subpolar ocean, Win and Ww. When winds are sufficiently strong (or H small), the deep layer outcrops in the interior ocean, and divergent Ekman flow entrains water into a thin mixed layer to generate Win. Furthermore, dynamics sets a maximal northward upper-layer transport Vm, which depends on H and τ, and has a minimum near yw. Western boundary layer entrainment Ww reduces M to Vm, if the strength of the MOC to the north of yw exceeds that limit, Mn - Win > Vm, essentially decoupling M from Mn. These results provide a novel dynamical perspective on how wind forcing affects the formation and export of deep water from the subpolar ocean, and hence its role as a controlling factor of the AMOC.