Geophysical Research Abstracts
Vol. 15, EGU2013-5076, 2013
EGU General Assembly 2013

The nonlinear equation of state and the global water mass distribution

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A vertical section through the South Atlantic shows a characteristic structure in the deep ocean, with a salinity maximum at mid-depth consisting of North Atlantic Deep Water (NADW), and fresher water both below (Antarctic Bottom Water, AABW) and above (Antarctic Intermediate Water, AAIW). What causes this structure? In particular, why does the fresher water from Antarctica split into an upper and an lower branch, while the saltier Atlantic water occupies the center? It is here shown that the nonlinear eqution of state (EOS), and in particular the thermobaric and cabbeling nonlinearities, are essential for this.

Simulations are done with NEMO, a general ocean circulation model, with a horizontal resolution of one degree. Several different versions of the EOS are used, and in each case the simulation is done for many centuries, to allow the water-mass distrubution to adjust to the new EOS.

First, a simple but nonlinear EOS is used, with only two nonlinear terms: the thermobaric term and the cabbeling term. The coefficients are adjusted so that the water mass distribution remains approximately the same as when the exact EOS is used. Next, the sign of the thermobaric term is switched. The layering between NADW and AABW is then switched, so that the warmer and saltier Atlantic water lies below the fresher and colder Antarctic water. (They should now perhaps be called NABW and AADW, respectively.) Above these two water masses, the AAIW remains as before. The explanation is straightforward: when the thermobaricity switches sign, the thermal expansion coefficient decreases with incresing depth, instead of increasing, as is normally the case. Therefore, at depth the warmer but saltier Atlantic water becomes denser than the Antarctic water.

Finally, the cabbeling term in the EOS is deleted. As a result, the AAIW alomost vanishes. Apperently, cabbeling is crucial for the formation of AAIW. To explain why cabbeling is particularly strong in this region, we note that the neutral surfaces slope steeply in the Antarctic Circumpolar Current, causing baroclinic instability and strong mixing along the neutral surfaces. At the same time, this is where water masses with different salinities meet, and the salinity gradient along the neutral surfaces is therefore strong. The result is strong cabelling.

In summary, the thermobaric nonlinearity is responsible for the layering of AABW and NADW, while the cabbeling nonlinearity is crucial for the formation of AAIW.