Insights into the Dynamics of the Gulf Stream and Other Strong Fronts under Wintertime Forcing: A Legacy from the CLIMODE Field Campaign

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CLIMODE (CLIvar MOde water Dynamics Experiment) was a project to study the dynamics of 'Eighteen Degree Water' (EDW), the subtropical mode water of the North Atlantic. Mode waters are voluminous water masses characterized by anomalously weak stratification. They are thought to play an important role in climate variability because of their capacity to store and release heat on interannual to decadal timescales, their influence on the circulation, and their ability to temporarily sequester carbon. EDW is but one example of a pervasive tendency for mode waters to form equatorward of strong fronts such as those associated with the Antarctic Circumpolar Current, Kuroshio, and Gulf Stream. The correspondence of mode water with these current systems suggests that there is a causal relation between their formation and processes that occur at these fronts under strong atmospheric forcing. The 2006/2007 wintertime cruises of the CLIMODE field campaign presented a unique opportunity to study the submesoscale and mesoscale frontal dynamics of the Gulf Stream under extreme air-sea fluxes and investigate their role in EDW formation. In this presentation I will summarize the main findings from our observational analyses of the CLIMODE frontal surveys interpreted in the context of recent theoretical studies and high-resolution numerical simulations.

The analyses indicate that a substantial portion of new EDW entering the Sargasso Sea is likely generated within the Gulf Stream, possibly exceeding the fraction formed locally by the traditional one-dimensional formation mechanism of cooling-driven convection. This nonlocal EDW formation mechanism involves mixing by upper-ocean turbulence that is strongly constrained by the slanted isopycnals and vertical shear of the Gulf Stream. Closer analysis of the frontal surveys and comparison with large-eddy simulations configured with idealized representations of the observed forcing and Gulf Stream flow field, indicate that the turbulence is likely associated with wind-forced symmetric instability (SI). SI is a shear instability that draws its energy from geostrophic flows. A parameterization for the rate of kinetic energy extraction by SI applied to the observations suggests that this mechanism could result in a net dissipation of 1-10 mW m^{-2}. The surveys also show signs of baroclinic instability (BCI). The rate of release of available potential energy (APE) by BCI is estimated to be comparable in magnitude to the net dissipation associated with SI. This result points to an energy pathway where the Gulf Stream’s reservoir of APE is drained by BCI, converted to kinetic energy, and then dissipated by SI. Similar dynamics are likely to be found at other strong fronts forced by winds and/or cooling and could play an important role in the energy balance of the ocean circulation.