Mini-Proposal SFB754 (Subproject: B9 (Sören Thomsen), external collaborator Daniel Whitt (PostDoc at NCAR, https://danielwhitt.github.io/).

Diapycnal mixing and bio-geochemical coupling across submesoscale fronts off Mauritania

Abstract

Submesoscale fronts are omnipresent in upwelling regimes. They enhance the vertical advection of tracers and thus impact nutrient transport and biogeochemical cycles. Besides affecting the advective transport of tracers, submesoscale fronts also modulate diapycnal mixing rates in the surface boundary layer and upper thermocline. Numerical models and theory suggest that the alignment of wind vector relative to the frontal axis plays a key role in modulating the rate of diapycnal mixing. However, very few turbulence measurements of submesoscale fronts exist and it remains unclear how important the wind orientation is in comparison to the wind stress amplitude and/or buoyancy forcing. In this 6 month project, a student will analyze glider-based turbulence measurements collected off Mauritania in June 2014. This analysis shall clarify whether the turbulent mixing rates are modulated by the presence of submesoscale fronts under different surface forcing situations. The observations will further be used to motivate and validate large eddy simulations of submesoscale fronts carried out by collaborator Daniel Whitt.

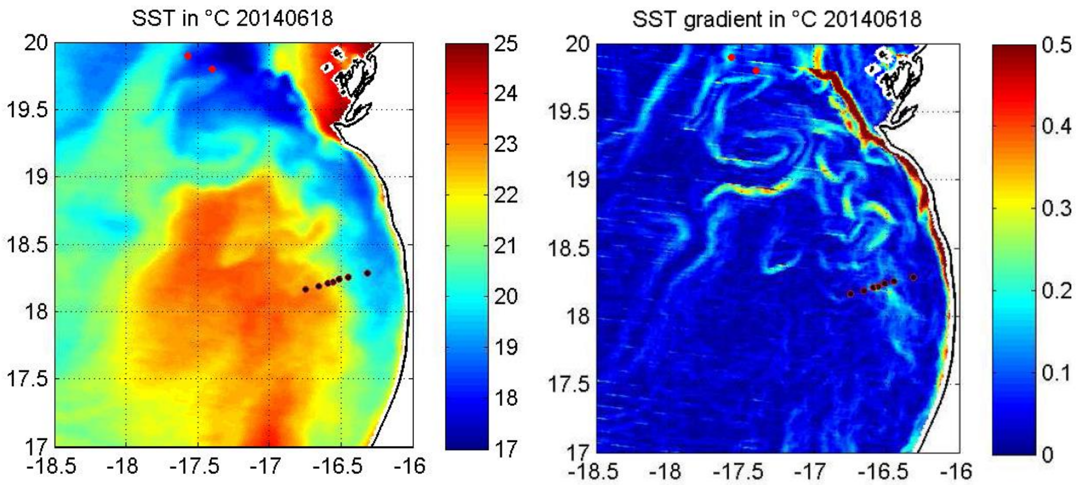

Figure 1: Sea surface temperature (left) and absolute horizontal sea surface temperature gradient off Mauritania on June 18 2014 during Meteor cruise 107. The black/red dots mark CTD station / mooring positions. Two glider turbulence deployments exist across several of these fronts. In total more than 2000 turbulence profiles are available at horizontal resolution O(100-500m) allowing the characterizing of turbulence rates across these fronts.

Scientific background, motivation and hypothesis:

Upwelling regimes are characterized by enhanced submesoscale variability such as sharp temperature (density) fronts in the surface layer with horizontal scales O(1km) (Fig. 1, Capet et al. 2008). Enhanced vertical velocities at these fronts promote a rapid exchange of tracers (e.g. oxygen and nutrients) between the surface and the thermocline and thus impact on biogeochemistry (Levy et al. 2012, Thomsen et al. 2016). In addition, diapycnal mixing rates may be significantly enhanced at fronts (D'Asaro et al. 2011, Thomas et al. 2016). However, the interaction of fronts with surface forcing (e.g. wind strength and directions, buoyancy fluxes) is rather complex and poorly understood. This is partly due to the fact that very few observations of diapycnal mixing rates across submesoscale fronts are available (e.g. D'Asaro et al. 2011, Thomas et al. 2016). Modeling and theoretical studies suggest that the down-frontal winds (i.e. winds blowing into the direction of the frontal jet) can lead to destabilization of the water column e.g. when the Ekman transport advects denser water over lighter (Thomas 2005). Contrary up-frontal wind can create stratification by advecting lighter water over denser and thus reduce diapycnal mixing rates. So far it is not clear how important this modulation is compared to other factors such as wind strength and/or buoyancy driven convective mixing. Given that submesoscale fronts are omnipresent in upwelling regimes (Fig. 1), these irreversible diapycnal fluxes might be important for the larger scale tracer fluxes.

During the meteor cruise 107 S. Thomsen carried out glider-based turbulence measurements in cooperation with M. Dengler within the upper ocean across multiple submesoscale fronts off Mauritania in June 2014. This unique data set consists of more than 2000 turbulence profiles and might shed some light into this largely unexplored topic.

This 6 months student project aims to answer the following research questions:

(1) Are the turbulence levels at the submesoscale fronts systematically different relative to the surrounding waters?

(2) Is it possible to link the turbulence levels to specific atmospheric forcing situations?

(3) Are the turbulence levels enhanced / reduced for down-/up-frontal wind forcing?

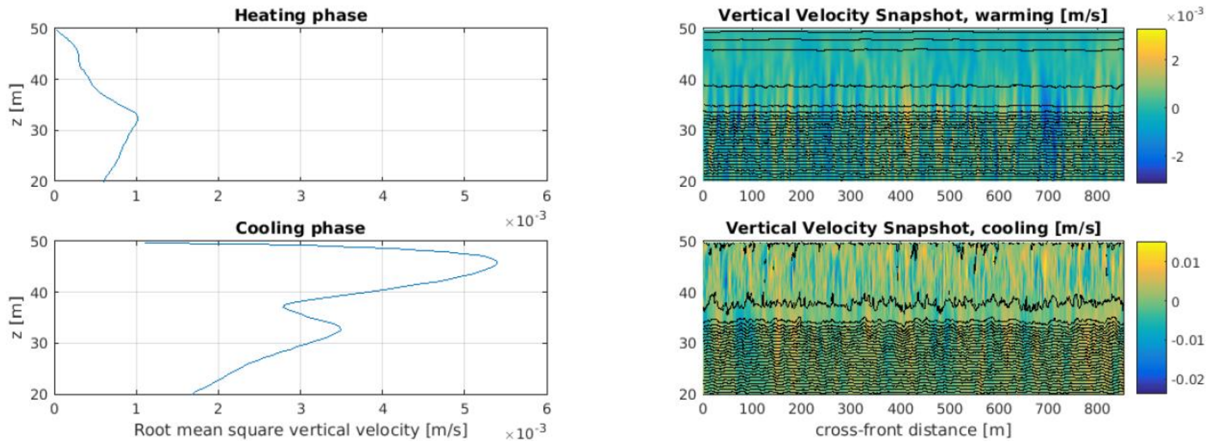

Figure 2: The glider data showed a clear diurnal cycle in the heat fluxes with cooling warming phases. The diurnal cycle is included in the LES model simulations as e.g. the cooling creates convective mixing and acts on similar timescales as the processes occurring at the submesoscale fronts. The model simulations and the analysis will be mainly done by collaborator Daniel Whitt but the employed student will give support in preparing figures for publication.

Student project outline

The student will focus on analyzing the glider-based turbulence measurements carried out by S. Thomsen off Mauritania 2014. The aim will be to relate these measurements to different surface buoyancy and wind forcing situations (e.g. down- / up-frontal wind, heating vs. cooling phases). This is a lot of work as the wind forcing and buoyancy forcing must be estimated at each point along the glider paths. In addition, discrete fronts must be identified and their orientations and properties must be quantified and matched with the corresponding forcing conditions. This work includes an analysis of remote sensing products of sea surface temperature and wind-stress. Also direct measurements carried out by the nearby research vessel will be used. This analysis is time consuming but does not require a priori knowledge and thus is ideal to be carried out by the employed master student. As the gliders crossed various fronts > 10 cases, this analysis will allow a systematic investigation of the turbulence levels at fronts in different atmospheric forcing situations. Extreme cases (high vs. low turbulence) will be identified in the observations and compared with the output of the LES simulations carried out by Daniel Whitt. The main model analysis will be done by Daniel Whitt. However, the student will also support Daniel Whitt by preparing simple plots and figures to support a faster preparation of a joint publication.

After the 6 months, we would encourage the student to write a Master thesis on a related topic, which we would support. However, this will depend on the student's interest.

Time schedule for student work

One glider-turbulence data set has already been processed and checked by S. Thomsen. Another deployment will be processed by S. Thomsen before July 2017.

July and Aug. 2017:

- analysis of remote sensing sea surface temperature measurements along the glider transects
- identification of surface fronts and estimation of the frontal orientation

Sept. and Oct 2017

- analyze the remote sensing wind measurements along the glider transects and compare them with the shipboard wind measurements
- calculate angle between the surface temperature fronts and the wind direction

Nov. and Dec. 2017

- categorize the different crossing of the glider into different wind forcing situations (e.g. up- / down-frontal
- categorize the different crossing of the glider into heating and cooling phases
- test whether the turbulence levels can be related to these different surface forcing situations

Allocation of tasks and future plans

The two glider deployments have been carried out by S. Thomsen during the meteor cruise M107 which included turbulence measurements. One turbulence dataset has already been processed and the second will be processed by S. Thomsen by July 2017 and will be analyzed by the employed student.

Preliminary analysis suggests that a clear diurnal cycle of turbulence exists associated with cooling and warming phases as already shown in other studies. This points to the importance of contextualizing the glider measurements relative to both the air-sea fluxes and the underlying ocean state. In order to define the context, the student will use remote sensing sea surface temperature and wind measurements. In addition, the student will analyze the ship-based wind stress and buoyancy fluxes (calculated using bulk algorithms).

Daniel Whitt already ran test LES simulations (e.g. Fig. 2) and will perform more expensive simulations (10km x 200 m, with dx=dy=dz O(1m)) based on the results of analysis of the student. The model will aid in the interpretation of the different diapycnal mixing rates observed in the glider-measurements by testing different forcing situations in frontal or non-frontal regions. Finally, Daniel Whitt and Soeren Thomsen aim to write a joint manuscript for publication.

<u>Funding request:</u>

- 3000€ to fund a student assistant for 6 months (37.5h per months contract)
- 200€ for an external 4TB hard-drive to store the LES simulation output in Kiel

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