Biogeochemical impacts of submesoscale processes in the Peruvian upwelling region

Regional, interannual submesoscale-permitting coupled physical-biogeochemical simulation to assess the impact of filaments and associated submesoscale frontal processes on the biogeochemistry of the oxygen minimum zone off Peru

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In Short

- We propose to quantify the effect of submesoscale eddy-fluxes associated with filaments and fronts on the ventilation of the oxygen minimum zone off Peru and the distribution of biogeochemical tracers in general
- We see potential for improving the representation of filaments in submesoscale-permitting model simulations by increasing the vertical resolution to improve near-surface stratification and vertical tracer gradients.
- Near-surface stratification and tracer gradients can be expected to significantly impact vertical and horizontal eddy-fluxes of biogeochemical tracers

Motivation

The eastern margins of the subtropical oceans are characterized by upwelling of cold and nutrient-rich subsurface waters, caused by persistent along-shore winds that drive an offshore Ekman transport. The nutrients supplied to the sunlit surface ocean subsequently fuel high phytoplankton growth which supports a rich ecosystem These Eastern Boundary Upwelling Systems (EBUS) are found in all major ocean basins and named after the Canary, Benguela, California, and Peru-Chile current systems. The Peru-Chile upwelling system (PCUS) is the most productive EBUS in the world ocean accounting for 10 % of the global fish catch while occupying only 0.1 % of the ocean surface [1]. The Peru upwelling ecosystem and the fisheries that depend on it thus have immense economical importance for the local population. Furthermore, the high productivity and export of organic matter from the euphotic zone and its subsequent remineralization at depth by oxygen-consuming organisms lead to - in conjunction with poor ventilation by sluggish currents - the presence of the shallowest and most intense oxygen minimum zone (OMZ) in the world ocean [2,3]. Because of the particularly shallow oxycline that varies between only 10 m - 80 m depth, submesoscale frontal processes are potentially important for its ventilation [4].

Mesoscale eddies, upwelling filaments and strong sea-surface temperature (SST) gradients at the upwelling front separating cold coastal from warm offshore waters are ubiquitous features in the PCUS [4,5]. When the upwelling front meanders and eventually becomes unstable, an ageostrophic secondary circulation develops in order to restore geostrophic balance [6,7]. This ageostrophic flow field can drive large vertical velocities and thus impact the physical-biogeochemical coupling by modifying vertical and lateral transports of nutrients and organic matter [8]. Furthermore, frontal processes may provide an effective conduit for vertical fluxes of heat and gas between the subsurface ocean and the atmosphere [9]. While the submesoscale comprises of filaments, fronts, mixed-layer instabilities and symmetric instabilities, we focus here on filaments and fronts which constitute the upper end of the submesoscale variability spectrum with length scales of $\mathcal{O}(1 - 10)$ km.

Eddies have in the past been assumed to generally enhance biological productivity by either exposing nutrient-rich subsurface water to the well-lit euphotic zone or by lateral advection of nutrients. They are considered a major source of nutrients to the oligotrophic subtropical gyres, although the magnitude of this supply and the processes involved have been discussed controversially [e.g. 10, 11, 12]. It has since become clear that the eddy-flux of any tracer strongly depends on the standing stock and its lateral and vertical gradients. In the highly productive EBUS, eddies and filaments have been shown to decrease productivity by exporting nutrients and organic matter offshore and downward below the euphotic zone [e.g. 13, 14].

So far these simulations are limited to mesoscale resolution of $\mathcal{O}(1/10\,°)$ and use rather simple biogeochemical models [14, 15]. Various purely physical model simulations [16,17] and idealized biogeochemical simulations [13] suggest that an increase in the horizontal resolution leads to further enhancement of horizontal and vertical fluxes. Effects of mesoscale eddies on oxygen minimum zones were the subject of several studies [18,19,20] but without sufficient horizontal resolution to include submesoscale processes. Moreover, previous studies also lack sufficient vertical resolution to reproduce the very sharp vertical gradients in density and biogeochemical tracers found in the Peruvian upwelling. A quantification of the net effect of filaments and fronts on the offshore and downward flux of biogeochemical tracers off Peru is missing so far.

Aim

We set out to quantify the impact of submesoscale processes on biogeochemical tracer distributions in the oxygen minimum zone off Peru using a coupled physical (ROMS) and biogeochemical (PISCES) model. To achieve this final goal, we want to (1) investigate the impact of the vertical model resolution on the representation of filaments, fronts and near-surface stratification and (2) optimize the simulations with respect to this based on high-resolution physical-biogeochemical measurements.

Method

We employ the well documented, coupled physical-biogeochemical ROMS [21] and PISCES [22] models. The submesoscale-permitting ROMS configuration consists of a 1/45° nest embedded in a 1/9° parent grid (Fig. 1). The simulations were compared with high-resolution observations, indicating good agreement of physical fields (Fig. 2). Biogeochemical fields showed good agreement in terms of nitrate, chlorophyll and oxygen. However, the relatively low vertical resolution was identified as a potential weakness of the model configuration with respect to the representation of filaments in the vicinity of strong near-surface stratification. In an attempt to overcome this issue and improve the representation of submesoscale frontal processes, we plan to increase the number of vertical levels in a suite of sensitivity experiments. We will then evaluate the sensitivity experiments by comparing them with high-resolution synoptic observations and use the cheapest well-performing configuration to quantify the net effect of submesoscale processes on biogeochemical tracer fluxes in the Peruvian upwelling region.

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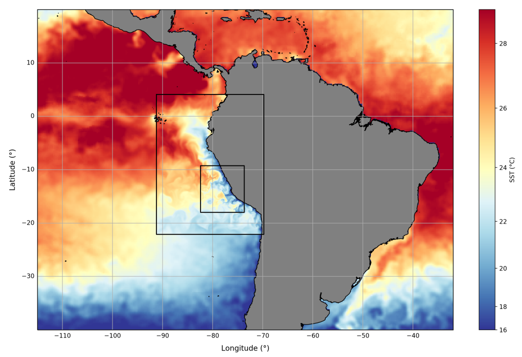

Figure 1: *Modeled sea-surface temperature (SST) on April 14, 2017 in the coarse- (1/9°) and high-resolution (1/45°) simulations superimposed on AVHRR satellite SST. Black rectangles indicate model domains of the coarse- and high-resolution nests.*

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Funding

DFG Sonderforschungsbereich 754

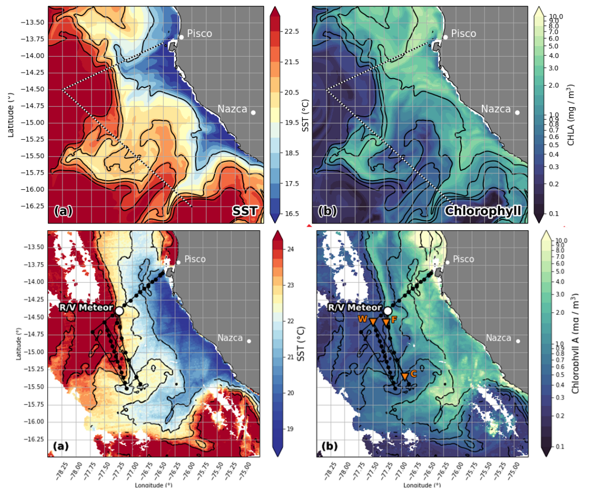

Figure 2: *Snapshots of SST and Chlorophyll in both model (top) and observations (bottom).*