MEDLEY : Mixed layer heterogeneity

Heat, energy and gas transfers through the oceanic mixed layer are extremely complex and spatially heterogeneous. The discontinuous, dynamic sea ice cover and the presence of oceanic eddies, fronts and filaments on a kilometer scale are major heterogeneities governing the thickness and properties of this layer. Current climate models used for IPCC's (Intergovernmental Panel on Climate Change) climate projections show major discrepancies in the simulation of the mixed layer depth, partly due to a poor representation of the integrated effect of these heterogeneities. This limits the usefulness of these models in assessing the impacts of future climate change in Europe and on marine ecosystems.

MEDLEY was a European project within the JPI Oceans & Climate that aimed to improve our understanding of the heterogeneity of the oceanic mixed layer in the northern North Atlantic, a hotspot for anthropogenic CO_2 storage, and in the rapidly warming Arctic Ocean. Its main objectives were (1) to assess the spatial heterogeneity of fluxes and processes controlling the oceanic mixed layer, and (2) to improve the representation of the transfers across this layer in climate models by taking this heterogeneity into account.

The project integrated state-of-the-art observational datasets and basin-scale ocean models resolving the kilometer scale, innovative sea ice models and the latest generation of global climate models that account for the eddying nature of the ocean. Relying on interdisciplinary collaborations between its partners (six institutions, including UCLouvain), MEDLEY took advantage of the most advanced data analysis methods. More specifically, the project aimed to improve the tuning and consistency of the mixed layer representation in the ocean component of global climate models through multi-scale modelling and validation against recent high-resolution observations. As part of this project, UClouvain's attention was focused on the ice-covered regions of the Arctic Ocean and its peripheral seas. Our efforts culminated in the publication of two key results in major scientific journals.

In a first study, we evaluated the ability of ocean–sea ice general circulation models participating in the CMIP6 Ocean Modelling Intercomparison Project (OMIP) to simulate the oceanic mixed layer depth and its seasonal cycle in the Arctic region. During summer months, all models systematically underestimate the depth of the mixed layer compared with observational data from the Monthly Isopycnal Mixed layer Ocean Climatology and Ice Tethered Profilers. In autumn and winter, differences of several tens of meters were observed between the models themselves and between the models and observational data. We then analyzed the origin of the model biases in autumn and winter in ice-covered regions, where the surface salinity and mixed layer depth are largely determined by the brine release associated with sea ice growth. Focusing first on the central Arctic Ocean, defined here as the region north of 80° N, we found that all models simulate similarly the sea ice mass balance and hence salt flux to the ocean during sea ice formation. In addition, all models show a strong relationship between the vertical stratification profile of the ocean in September and the depth of the mixed layer at the end of winter. We concluded that the discrepancies between models are therefore not so much related to the surface salt balance, but rather to the accuracy with which these models reproduce the vertical salinity profile. In short, a weakly stratified ocean tends to create a deep mixed layer, while strong stratification leads to a shallow mixed layer. To support this conclusion, we applied a simple

conceptual model, which computes the month-by-month evolution of the mixed layer depth using vertical salinity gradients and surface salt fluxes from ocean general circulation models as input data. Surprisingly, this simplified model captures the behaviour of the more complex ocean general circulation models very well, highlighting the role of the vertical stratification in governing the depth of the mixed layer during the ice growth season. Moreover, this link may also explain the large mixed layer biases noticed in other ice-covered regions of the pan-Arctic seas, even if sea ice–ocean interactions are not the only driver of the autumn and winter mixed layer variability in these regions.

In a second study, we assessed the performance of the vertical turbulent kinetic energy (TKE) mixing scheme of the NEMO-SI^3 (Nucleus for European Modelling of the Ocean – Sea Ice Modelling Integrated Initiative) global ocean–sea ice model at a 1° resolution in ice-covered regions of the Arctic Ocean. Specifically, we tested the model sensitivity to parameters involved in an ad hoc parameterization (referred to as TKE mixed layer penetration (MLP) parameterization) recently added to the default TKE mixing scheme to take into consideration the effect of small-scale processes such as near-inertial oscillations and ocean swells and waves. We evaluated this parameterization for the first time in three regions of the Arctic Ocean: the Makarov, Eurasian and Canadian Basins. We demonstrated the strong effect of the scaling parameter that accounts for the presence of sea ice. Our results confirm that the TKE MLP parameterization must be scaled down below sea ice to avoid unrealistic deep mixed layers. The other parameters considered were the percentage of energy penetrating below the mixed layer and the length scale of its decay with depth. All these parameters affect the simulation of the mixed layer depth and its seasonal cycle, the surface temperature and salinity as well as the underlying ocean vertical stratification. In particular, we observed significant impacts on sea ice thickness in the Arctic Ocean in two scenarios: when the scaling parameter due to the presence of sea ice is absent and when the TKE MLP parameterization is disabled. In the first case, we found an increase of several meters in the depth of the mixed layer as well as a reduction in sea ice thickness ranging between 5 and 30 cm, reflecting the impact of more mixing. Conversely, in the second case, we noticed that a lower mixed layer depth is accompanied by an increase in sea ice thickness, ranging from 5 to 20 cm, as expected from a weaker mixing. Furthermore, analysis of the interannual variability of the upper ocean and sea ice characteristics simulated by the model showed that experiments including a scaling parameter based on sea ice concentration display an increased mixed layer depth during periods of sea ice reduction, which is consistent with observed trends. These results highlight the importance of taking into account properly the influence of small-scale processes on oceanic vertical mixing in ice-covered oceans through the use of appropriate physically-based parameterizations in models.

Keywords: ocean mixed layer, spatial heterogeneity, climate models, North Atlantic, Arctic Ocean, sea ice, mesoscale eddies, sub-mesoscale fronts, observational datasets, high-resolution models.