Supplement to D2.3: A European Strategy plan with regard to the Argo extension in WBC and other boundary regions

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EXECUTIVE SUMMARY

This document is a follow-up of the work done for deliverable 2.3 A “European Strategy plan with regard to the Argo extension in Western Boundary Currents and other boundary regions'', in which the partners summarised the historical Argo sampling in the boundary currents, setting a benchmark level for the evaluation of a new strategy. Here we present our recommendations for sampling those boundary currents based on simulations of virtual Argo floats trajectories done with the Virtual Fleet python library. These sampling strategies are given in terms of deployment positions and/or mission configurations (parking depth and cycle length). The numerical experiments performed are also briefly described. All the code used and results of the experiments are available in the Euroargodev Github https://github.com/euroargodev in dedicated public or private repositories.

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1 Introduction

This document is a supplement for D2.3 that includes recommendations for the boundary current of interest based on trajectories of virtual argo floats performed with the python library Virtual Fleet. At the moment, the OceanParcels library used by Virtual Fleet to compute float trajectories still exhibits errors which are difficult to reproduce and hence to fix. Therefore not all the simulations planned were run to completion. The software developers have been made aware of this issue and will attempt to fix this issue in the future.

The code used for running the simulations, internal report documents, results, figures and other material related to the activities leading to this document are stored in the Euro-Argo online collaborative framework https://github.com/euroargodev. Given that some of these materials may be used for peer-review publications, some of the repositories hosting them are not public. The nature of the repositories, public or private, is indicated next to the links throughout this document. To gain access to the private repositories, please contact contact@euro-argo.eu. Without granted access private repository links lead to a "not found" error.

2 Atlantic

2.1 Gulf Stream

Experiment design

For the Gulf Stream extension region (GSE) it was decided to explore the impact on the long term Argo array sampling if one chooses to temporarily modify float configuration parameters (with Iridium command) when they enter the study area. This was motivated by the fact that it would be quite difficult to significantly alter the North Atlantic deployment plan to accommodate for a better GSE sampling, and that using 2-ways communications to update the fleet configuration temporarily may be more acceptable to the network operators.

We simulated 10 years (2008-2018) of a realistic Argo fleet using (i) the historical deployment plan and (ii) an eddy resolving state of the art ocean re-analysis (assimilating sea level, SST, in-situ T/S profiles and Sea Ice concentration and/or thickness).

A control simulation was performed without modifying Argo float parameters and using typical values for cycling frequency (10 days) and drifting depth (1000 db). All floats profiling depth was set to 2000 db. The control simulation was deemed correct (see figures here and here) given the simulation limitations (eg: we used a similar life expectancy for all simulated floats, i.e. 159 cycles that was determined as an optimum to reproduce the same 175.000 amount of total profiles).

A series of experiments was then performed, where Argo float parameters are modified when they enter the study area (GSE box) and restored when they exit the area.

We finally compared the 10 years simulation difference in profile density computed on a 1x1 degree grid.

Results are shown here for experiments where the cycling frequency was increased to 5 days and drifting depths changed to: 500, 1000, and 1500 db.

We see that if floats drift at 500db, they are taken by the GS out of the box, downstream/eastward, too fast. The result is that the upstream region is now less sampled, to the benefit of the eastern part of the box and outside of it. This is not the expected outcome.

On the other hand, if floats drift at 1500db, they are taken by the southward flowing under-current. The result is a better sampling of the GS along the U.S. east coast but a rather in-homogeneous increase over the GSE box.

Keeping the drifting depth to 1000db seems the best solution in the case where the cycling frequency is increased to 5 days. This set-up leads to an homogeneous increase of the profiles density in the GSE box and a smaller impact on the downstream/eastward sampling decrease.

Many more experiments were conducted. All results are summarised on this webpage:

https://github.com/euroargodev/VirtualFleet_GulfStream/blob/main/RESULTS.md

And all the code used to run the simulation and experiment is publicly available here:

https://github.com/euroargodev/VirtualFleet_GulfStream

Recommendations

We found that 2-ways communication “online” changes of the cycling frequency to 5 days leads to a 40-to-50% increase in profile density in the high EKE region of the Gulf Stream, using a drifting depth of 1000db.

If followed, this local change of Argo float mission parameters would have a “reasonable cost” of a smaller than 25% decrease in profile density up and downstream of the Gulf Stream Extension region, where sampling would remain above Argo nominal target (1 profile every 10 days on a 3x3 grid).

Therefore we recommend the following:

- Test with real floats the automatic change of mission parameters over the Gulf Stream area, in order to assess the technical feasibility of the procedure (changing parameters at DACs by operators would be impossible to manage, one need to make this changes automatically),
- Conduct an OSSE to assess the impact of local sampling changes to Ocean Climate Indicators such as heat content.

2.2 Gulf of Cadiz

Experiment design

The VirtualFleet software and a genetic algorithm were used to simulate and find the best Argo float configuration to maximise the resident time of each float deployed in the Gulf of Cadiz (GoC) region . The code used for this purpose can be found in https://github.com/euroargodev/VirtualFleet_Optimization (private repository). Current fields were downloaded from the Copernicus Monitoring Environment Marine Service and were provided from the Mediterranean Sea Physical Analysis and Forecast (Clementi et al., 2021). The spatial and temporal resolution of the ocean circulation model data was 0.042° × 0.042° and monthly. The validation of the VirtualFleet and ocean model data were done by the comparison with the trajectories of Argo float WMO6901914 deployed in the Lisboa canyon on March 26th, 2013 and that was active 4.96 years until March 12th, 2018, as well as by comparisons with other floats, namely the two deployed in the frame of this project. The comparisons obtain good results since the simulations agree well with the real float, staying the virtual float in the same area as the real one. After the model was validated a genetic algorithm to find the best parameters for the floats stay in the same area was used. For each simulation the algorithm assigns a score out of 100 based on the time the float spends in a defined area. This simulation starts with a first generation of floats with random configuration parameters, after each generation containing 12 floats and the algorithm selects the one with the highest score to become the parent float for the next generation. In the last generation we will obtain a score at least equal or better than the first generation. Thus, at the end of the simulation we have found the Argo mission configuration that maximises the time the float stays near the deployment location. The Gulf of Cadiz is divided in 3 zones, each one with three deployment locations at the same longitude (1 = -8.855; 2 = -8.146; 3 = -7.438). For all the three simulations it uses three floats named A, B and C, and each simulation takes one year. More details can be found in the internship report of Matthieu LeJeune (2021, in a private repository).

Recommendations

To optimise the monitoring of the GoC with Argo floats we recommend to reduce the drifting depth to values between 400 and 800 m.

3 Nordic Seas

The Virtual Fleet library was used to perform and analyse numerical simulations of virtual Argo floats in the Nordic Seas with the objective of explore which float configurations can be used to improve the sampling of the boundary currents in the Nordic Seas: West Spitzbergen Current (WSC) and East Greenland Current (EGC). A repository hosts all the code use to perform these simulations and the main results, including figures: https://github.com/euroargodev/VirtualFleet_NordicSeas/ (private repository)

Experiment design

Two different approaches were used:

Trajectory optimisation

The deployment positions and parameter configuration were optimised such that the Virtual Argo floats trajectories followed the boundary current. The optimisation algorithm used was based on the algorithm used for the Gulf of Cadiz simulations described above (https://github.com/euroargodev/VirtualFleet_Optimization, private repository) and was extended to incorporate both the deployment positions and the parameter configuration as unknown variables. The algorithm finds the combination of parameters and deployment positions that optimises a score that summarises how good the trajectory fits the purpose of following the boundary current. This score consists of a weighted sum of three components: trajectory length, residence time and covered latitude range. In this approach we used a simulation resolution of 30 minutes and the position of the floats was evaluated in 200 steps, equivalent to 100 hours (approx. 4 days). The cycle phase of the float is not considered. The initial runs were done using 10 floats using velocity fields for 2019 and 2020. The deployment positions evaluated correspond to the IO-PAN Arex (Poland) Cruises and IMR cruises (Norway). Since the northernmost region of the EGC is covered with ice almost year-round, the positions tested for deployment were outside of the region of interest.

These simulations were run in September 2021 while the float grounding management[1] was not yet included in the Virtual Fleet library, and therefore trajectories with parking depths deeper than the local bathymetry, resulted in unrealistic trajectories. Therefore, these initial simulations were restricted to parking depths shallower than the standard 1000 dbar. Details on these simulations can be found in the internship report by van Migerode (2021, in a private repository) and in deliverable D8.3.

Evaluation of profile positions in multi-year simulations

Simulations of a large number of virtual floats using velocity fields from different years (2010-2019) and different combinations of cycle length (3, 5, 7 and 10 days) and parking positions (250, 350, 500, 750, 1000 and 1250 db) were performed. In this way statistically significant conclusions can be drawn from the comparison between the simulations, while the interannual variability is also considered. The simulations consisted in the deployment of several virtual floats inside the currents (43 in the EGC and 121 in the WSC) each day during 14 consecutive days in 100 days simulations that started on 01.09 (EGC) and 01.06 (WSC). In the EGC the floats were deployed in the northernmost part of the current that is ice free during the ice minimum in September. In the WSC the floats were deployed in a small region slightly west from the optimal deployment positions found in the trajectory optimization experiments (van Migerode, 2021 in a private repository). Profiling depths of 2000 dbar were used in all simulations. Unfortunately, due to some erroneous behaviour of the python library Oceanparcels, on which the Virtual Fleet library is based, many simulations stalled and could not be completed for the entire simulation length. This problem was more frequently encountered in the WSC simulations. The stalled simulations were discarded. In this approach the profile positions were analysed and summarised as the fraction of the total number of profiles inside the current. For this we used the function simu2index to convert the Virtual fleet simulations into cycles, which will become available in the next release of the Virtual Fleet, and a polygon describing the current area.

Velocity field

Velocity fields from the Global Ocean Physical Multi Year CMEMS reanalysis product were used. The TOPAZ4 model was also considered, however the boundary currents of interest are not properly represented.

To ensure that the Global Ocean Physical Multi Year CMEMS reanalysis was appropriate for the use with the virtual fleet a control run was done, similar to that described in the Gulf Stream section, for the Nordic Seas. The real deployment plan (including floats already present in the region) for the 3000 days between 01.01.2008 and 2016.08.11 was used. A maximum life expectancy of 148 cycles was used to approximately reproduce the same number of total profiles observed (13895). The control simulation was deemed satisfactory (see this jupyter notebook in a private repository) since the spatial distribution of the observations exhibit similar patterns. The number of profiles inside the boundary currents also exhibit similar values.

[1] In the ocean, when a float hits the ground and cannot descend to the desired depth, it performs a so-called grounding management. When a float hits the seabed during the descent to parking depth, it will go up 50 dbar and try again to park at this depth. If the float hits the ground during the descent to profile depth, it starts the profile at the current position.

Recommendations

Based on the simulation results from the approaches described above and other initial tests we make the following recommendations. Of course, testing them with real floats it is still necessary to confirm their validity.

West Spitzbergen Current

- *Floats should be deployed inside the current as defined by the polygon and north of 70°N for them to follow the WSC.* Floats deployed outside are unlikely to enter it. Floats deployed inside the current but in the southernmost region (south of 70°) tend to remain there, trapped in the eddy field, and rarely travel along the current further north.
- The profile positions of floats parked at 250 db, independent of the cycle length, are poorly predictable (the fraction of cycles inside the current varies largely between the virtual floats simulated). Therefore, *a parking depth of 250 db (or above) is not recommended for sampling the WSC.*
- For floats parked at 350 db there is also large variability in the fraction of cycles inside the current, but the floats stay mostly inside the current and tend to rapidly cover large distances in the south-north direction. *This parking depth is recommended if the objective is to sample along the current with the same float and to reach the Nansin Basin in the same season.*
- Floats parked at 750 db and below are more predictable and stay inside the current, with the cycle length playing a secondary role. *Parking depths of 750 db and deeper seem to be appropriate to sample the WSC.*
- *If the objective is to increase the number of profiles available in the WSC*, shorter cycle lengths should be used to take maximum advantage of the floats that have been deployed in this region. Moreover, the potential negative effects of grounding in the float integrity should be considered if parking depths of 1250 db want to be used. Therefore, p*arking depths of 750 db or 1000 db and cycle lengths of 3, 5 or 7 days are recommended.*

East Greenland Current

- If floats must be deployed when the northernmost region is covered with ice, they may be deployed in the Fram Strait, from where they are likely to follow the cyclonic circulation and end up entering in the Nordic Seas. Parking depths around 300 m and cycle duration of 7 or 10 days were found appropriate for this purpose.
- Floats deployed in the core of the current (northern part - 76 to 78N - in September, when it is ice free) tend to stay more in the current than those deployed in its margins.
- As in the WSC floats parked at 750 db and below are more predictable and stay inside the current, with the cycle length playing a secondary role. *Parking depths of 750 db and deeper seem to be appropriate to sample the EGC.*
- *If the objective is to increase the number of profiles available in the EGC*, and following the same considerations as in the WSC (specificity of the deployment position and potential negative effects of frequent float grounding) *parking depths of 750 db or 1000 db and cycle lengths of 5 or 7 days are recommended.*

4 Western Mediterranean and Ligurian Sea

Experiment design

For the Western Mediterranean and Ligurian Sea, it was decided to explore the Argo float's capacity to sample the Boundary Currents (Algerian, Northern and Balearic Currents) and the Ligurian Sea region, depending on the deployment points and the configuration float.

To carry on the experiment, VirtualFleet software was used to simulate the float trajectories. The current fields downloaded from the Copernicus Monitoring Environment Marine Service are the Mediterranean Sea Physical Analysis and Forecast (Clementi et al., 2021). The data field has a daily temporal resolution and the spatial resolution of 0.042° × 0.042°.

We used a homogeneous grid (1° × 1°) to deploy a total of 63 floats every 5 days and recorded positions every 30 mins. We simulated 1 year (2020-2021) of trajectories for each float. All floats' profiling depth was set to 2000 db, but the cycling frequency (2, 5, 10 days) and drifting depth (350, 500, 1000, 1500 db) were all tested. 2-D Histograms were used to visualise and analyse the results.

We differentiated deployments inside or close (< 0.15°) versus outside the BCs, and we compared both types of simulation to analyse their ability to sample the areas of interest (density maps code, here in a private repository). Regardless of the configuration, the results show that the sampling density is higher in the BCs, when the floats are deployed inside. When floats are deployed outside these areas, the sampling density in BCs is low. This is, possibly, because mesoscale activity in the Western Mediterranean causes them to become trapped in eddies.

Different configurations were compared subtracting 2-D histograms (code here in a private repository).

hf = h0-h1,

where h0 is the 2-D histogram with a specific configuration and h1 is the 2-D histogram with another configuration. Positive values represent that we have more points density for h0 than h1, and negative values show more points density for h1 than h0.

Keeping the parking depth to 1000 db seems the best solution to sample a more extensive BC area. However, 1500 db is better to sample along the coast, regardless of cycle length. On the other hand, in the Ligurian Sea the parking depth 1000 and 1500 db, sample the BC. The BC area closer to the coast is sampled when we use 1000 db and BC far away from the coast is sampled using 1500 db.

Recommendations

Following the experiment results, we found that to best sample the BCs, floats should be deployed directly inside the BC area.

To optimise the Northern and Balearic Currents sampling, it is recommended using a parking depth of 1000 db.

In the Ligurian Sea and Algerian Current, it is recommended to use floats with parking depths of 1000 and 1500 db, to sample the all BC in the area. Each parking depth samples a BC area.

These results should be carried on with real floats in order to assess the feasibility of the experiment.

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