Project Information	
Project full title	EuroSea: Improving and Integrating European Ocean Observing and Forecasting Systems for Sustainable use of the Oceans
Project acronym	**EuroSea**
Grant agreement number	862626
Project start date and duration	1 November 2019, 50 months
Project website	https://www.eurosea.eu

Deliverable information	
Deliverable number	D2.1
Deliverable title	**Design of the Observing System Simulation Experiments with multi-platform in situ data and impact on fine- scale structures**
Description	This report presents the work plan of the Task 2.3: Observing System Simulation Experiments: impact of multi-platform observations for the validation of satellite observations
Work Package number	2
Work Package title	Ocean Observing System Design
Lead beneficiary	CSIC
Lead authors	Bàrbara Barceló-Llull (CSIC)
Contributors	Ananda Pascual (CSIC); Eugenio Cutolo (CSIC); Ronan Fablet (IMT); Florent Gasparin (MOI); Stéphanie Guinehut (CLS); Jaime Hernández Lasheras (SOCIB); Stephanie Leroux (Ocean Next); Alexander Mignot (MOI); Baptiste Mourre (SOCIB); Sandrine Mulet (CLS); Elisabeth Rémy (MOI); Sabrina Speich (ENS); Nathalie Verbrugge (CLS)
Due date	31 October 2020
Submission date	23 October 2020
Comments	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 862626.

https://doi.org/10.3289/eurosea_d2.1

Table of contents

1. Introduction to EuroSea

Although the Ocean is a fundamental part of the global system providing a wealth of resources, there are fundamental gaps in ocean observing and forecasting systems, limiting our capacity in Europe to sustainably manage the ocean and its resources. Ocean observing is “big science” and cannot be solved by individual nations; it is necessary to ensure high-level integration for coordinated observations of the ocean that can be sustained in the long term. For Europe, EuroSea will point the way for the current and future cooperation between science and industry, politics and the public with the common goal of a sustainable blue economy and the responsible handling of the sensitive marine ecosystems. The project will make a significant contribution to not only generating, processing and linking information about our oceans, but also to make long-term and extensive use of this and the resulting knowledge in a wide variety of areas. As a link between sectors and disciplines, EuroSea faces a very big challenge.

2. Introduction to WP2

The overall objective of WP2 is to apply the systems design processes of the Framework for Ocean Observing (FOO) on the EuroSea observing system in support of connected and integrated European Ocean Observing systems for the broader Atlantic Ocean and Mediterranean Sea. It builds on the H2020 AtlantOS achievements and take on its legacy to further develop them within the Galway and Belém agreements objectives. Specific objectives are:

- To define the high-level requirements of EuroSea based on the societal benefits, providing a direct link to societal challenges related to the larger Atlantic and Mediterranean basins and the European Blue Growth strategy. These requirements will be translated into strategic recommendations about sustained monitoring of EOVs and linked with LR7 and LR8 societal relevant indicators.
- To identify the requirements in existing observing networks in support of specific demonstrators (WP5,6,7).
- To deliver guidance to improve existing elements and/or implement new ocean observing components to EuroSea using various techniques, including OSSEs and data assimilation to optimally merge in-situ and satellite observations with models to provide accurate estimates for indicators.

3. Observing System Simulation Experiments: impact of multi-platform observations for the validation of satellite observations (Task 2.3)

Space borne and in situ observations provide essential and complementary information on fine-scale ocean structures. Task 2.3 has the objective to improve the design of multi-platform experiments aimed to validate the Surface Water and Ocean Topography (SWOT) satellite observations with the goal to optimize the utility of these observing platforms. Considered the next big breakthrough in Earth observation, the SWOT satellite mission, with a resolution one order of magnitude higher than present altimeters, will be launched in 2022 by the National Aeronautics and Space Administration (NASA) and the Centre National d’Études Spatiales (CNES) with contributions of the UK and Canadian Space Agencies (Morrow et al., 2019). The SWOT mission will provide sea surface height (SSH) measurements in two dimensions along a wide-swath altimeter with an expected effective resolution in wavelength of 15-45 km (Fu and Ferrari, 2008; Fu and Ubelmann, 2013, Wang et al., 2019). After launch, the SWOT satellite will follow a fast-sampling orbit to provide observations of SSH on a daily basis in specific areas of the world ocean for instrumental calibration/validation. The SWOT fast-sampling phase is considered an ideal opportunity to coordinate in situ experiments with the objective to study fine-scale dynamics and their role in the Earth system (d'Ovidio et al., 2019).

To anticipate the daily high-resolution two-dimensional (2D) SSH fields that SWOT will provide, the PRE-SWOT multi-platform experiment was conducted in the southern region of the Balearic Islands (western Mediterranean Sea) in May 2018 (Barceló-Llull et al., 2018). In situ observations from gliders, drifters, a Conductivity Temperature Depth probe (CTD), and a hull-mounted Acoustic Doppler Current Profiler (ADCP), were collected to evaluate the horizontal and vertical velocities associated with the scales that SWOT will resolve (defined as fine-scales). This experiment highlighted the need to increase the spatial resolution of altimetric observations comparing present altimetric fields with in situ observations. It also revealed the need to study the impact of including some modification in the design of future experiments aimed to validate SWOT, like the depth of the CTD measurements and the impact of changing rosette CTD casts for an underway CTD. In addition, even if the southern region of the Balearic Islands will be sampled by a SWOT crossover during the fast-sampling phase, this study demonstrates that (i) this region has low variability and is characterized by low hydrographic gradients, and (2) there are limitations to stay in Spanish or international waters. Because of this, the authors suggest that the next cruise experiments to validate SWOT will be held in the north-western region of the Balearic Islands, a region with more dynamic activity and that will be crossed by a swath of SWOT during the fast-sampling phase.

The objective of Task 2.3 is to optimize the design of multi-platform experiments aimed to validate SWOT observations. Observing System Simulation Experiments (OSSEs) will be conducted to evaluate different configurations of the in situ observing system, including rosette and underway CTD, shipborne ADCP, velocities from surface drifters, and Argo vertical profiles, together with conventional satellite nadir altimetry. Simulations from high-resolution models will be used to simulate the observations and the ocean "truth" to represent fine-scale sea level and surface ocean velocities. Dedicated efforts will be devoted to error parameterization determination for each observing platform. Several methods of reconstructions will be tested; the first method is the optimal interpolation that will be used to reconstruct the simulated in situ observations in all the configurations to evaluate the best sampling strategy to validate SWOT. Secondly, new algorithms of reconstruction of in situ data using machine-learning techniques (neural networks, analogue methods) will be explored, implemented and benchmarked to be compared with high-resolution satellite observations of sea surface height and ocean currents that will be simulated using the SWOT simulator (https://swot-simulator.readthedocs.io/en/latest/api.html). Then, the 2-km resolution Western Mediterranean OPerational system (WMOP) model and data assimilation (Juza et al., 2016; Mourre et al. 2018) will be used to reconstruct multivariate three-dimensional (3D) fields from these virtual observations. Finally, the Multiscale Inversion for Ocean Surface Topography (MIOST) variational tool will be used to reconstruct sea surface height and ocean currents at the ocean surface. The capacity of the reconstructed fields to represent the sea level and surface current variability of the nature run models at the scales and with the expected accuracy of the future SWOT satellite mission will be evaluated considering different configurations of in situ observations.

The analysis will focus on two regions of interest for the Climate Demonstrator in WP7: (i) the western Mediterranean Sea and (ii) the Subpolar North West Atlantic. In the western Mediterranean Sea, the target area will be located within a swath of SWOT, while in the North West Atlantic the region of study will include a crossover of the SWOT mission during the fast-sampling phase. These OSSEs will contribute to the design of the in-situ observing systems to support the future calibration and validation of high-resolution SWOT satellite measurements.

3.1. Scientific goals and subtasks

Objective 1: Optimize the design of a multi-platform in-situ experiment to validate SWOT (Task 2.3.1)
Evaluate the impact of different sampling strategies in the reconstruction of fine-scale features comparing the simulated and reconstructed observations with the ocean "truth" from the model. Optimal interpolation (OI) will be used for this analysis, as this method has been widely used to reconstruct in situ observations (e.g. Bretherton, et al., 1976; Davis, 1985; Le Traon, 1990, Gomis et al., 2001; Pascual et al., 2004, 2017; Ruiz et al., 2019, Barceló-Llull et al., 2017). This analysis will be done in each region of study and using all models to provide robustness to the results.

Objective 2: Compare different methods of reconstruction to validate simulated observations of SWOT (Task 2.3.2)
Test different methods of reconstruction (OI, machine-learning techniques, and WMOP assimilation) to reconstruct the simulated observations in two common configurations: (1) the "reference" configuration and (2) the best configuration determined in Task 2.3.1. Compare the reconstructed fields with simulated observations of SWOT to anticipate the SWOT launch. Define assessment metrics. Evaluate the impact to include in the multi-platform in situ experiment observations of drifters and Argo buoys to validate SWOT. First, this comparison will be done in the Mediterranean and using one model as "nature run". The extension of this analysis to the Atlantic and using the other models will be discussed after having the first results.

Objective 3: Explore the capability of the existing observing system networks to validate SWOT (Task 2.3.3)
We aim to use surface drifters in addition to nadir altimetry to improve the accuracy and resolution of SLA maps, usually constructed only from nadir altimetry. We will (i) evaluate the performances of the reconstruction and (ii) analyze if this merging can be useful for the validation of SWOT. In this experiment we will also evaluate the impact of doubling the number of drifters and quantify the impact in terms of resolution. This study will be done in the same region(s) and using the same model(s) as in Task 2.3.2.

4. Design of the Observing System Simulation Experiments with multi-platform in situ data and impact on fine-scale structures

4.1. Regions of study

The analysis will focus on two regions of interest for the Climate Demonstrator in WP7: the subpolar northwest Atlantic and the western Mediterranean Sea.

In the subpolar northwest Atlantic, the region of study will include a crossover of SWOT during the fast-sampling phase. In the western Mediterranean Sea, the domain will be located within a swath of SWOT at the northern part of the Balearic Sea, a region with high dynamic activity and already studied by several authors using in situ and remote sensing observations (e.g. Pascual et al., 2002; Ruiz et al., 2009; Bouffard et al., 2010; Mason and Pascual, 2013).

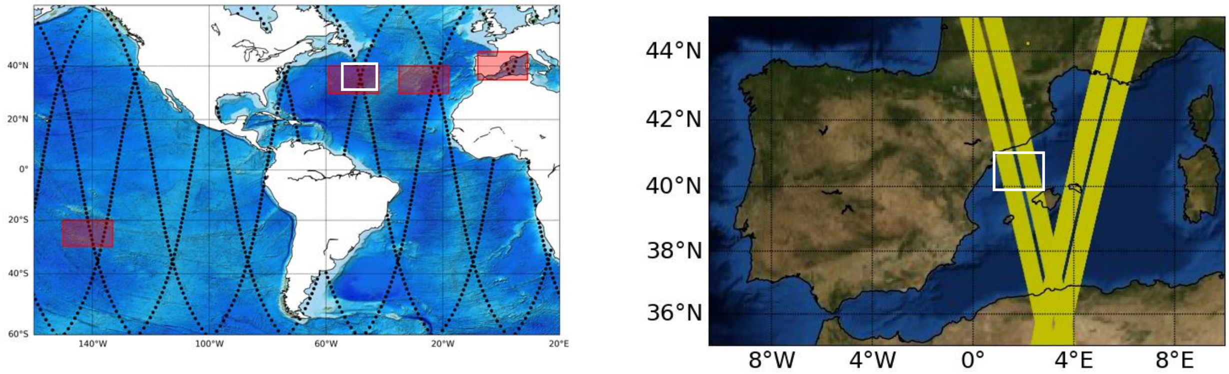

Figure 1: Regions of study: a SWOT crossover in the subpolar northwest Atlantic and a swath of SWOT at the northern part of the Balearic Sea in the western Mediterranean. Figures courtesy of Laura Gómez-Navarro.

Within each region of study, a smaller sub-region will be defined to simulate the in situ multi-platform experiments.

The tentative coordinates of these regions are:

- Atlantic: region centered in the crossover (approx. 48.5ºW, 35.5ºN) with a size of 15º in longitude and 10º in latitude.
    - Sub-region: centered in the crossover and 1ºx1º
- Mediterranean: longitude [6ºW, 8ºE] and latitude [35ºN, 44ºN]
    - Sub-region: longitude [1.5ºE, 2.5ºE] and latitude [40ºN, 41ºN]

4.2. Nature run model simulations

In each region of study, different high-resolution models will be used as “nature run models” depending on the objective. These models will be assumed to represent the ocean “truth” and will be used to simulate the observations in different configurations. Model outputs will be extracted in a common temporal period between 1-july-2009 and 30-june-2010. However, the simulated observing systems will be representative of a recent period (see next section).

The model outputs used for each region and their characteristics are:

- Atlantic: CMEMS global reanalysis and NEMO (eNATL60 configuration)
- Mediterranean: CMEMS Mediterranean reanalysis, NEMO (eNATL60) and WMOP

Two CMEMS reanalyses

- The CMEMS (Copernicus Marine Environment Monitoring Service) global ocean physics reanalysis model that will be used in the Atlantic experiments has a spatial resolution of 1/12° and 50 vertical levels. The model component is the Nucleus for European Modelling of the Ocean (NEMO) platform driven at the surface by ECMWF ERA-Interim reanalysis. Along-track Sea Level Anomaly (SLA), satellite Sea Surface Temperature, Sea Ice Concentration and in situ temperature and salinity vertical profiles are jointly assimilated. This product includes daily and monthly mean files of temperature, salinity, currents, sea level, mixed layer depth and ice parameters from the top to the bottom, and covers the period between 1993 and 2018. The model outputs are available at https://resources.marine.copernicus.eu/?option=com_csw&view=details&product_id=GLOBAL_REANALYSIS_PHY_001_030.

- The CMEMS Mediterranean Sea physics reanalysis model (Simoncelli et al., 2019) that will be used in the Meditarranean experiments has a spatial resolution of 1/16º and 72 vertical levels. The Mediterranean physical reanalysis component is a hydrodynamic model, supplied by NEMO, with a variational data assimilation scheme for temperature and salinity vertical profiles and satellite SLA along-track data. The temporal coverage is from 1987 to 2018 with daily and monthly temporal resolutions. The model outputs are available at https://doi.org/10.25423/MEDSEA_REANALYSIS_PHYS_006_004.

eNATL60

eNATL60 corresponds to a pair of twin numerical ocean simulations performed in 2019 with the [NEMO](https://www.nemo-ocean.eu) ocean model over the North Atlantic at 1/60° grid resolution by [Ocean-Next](https://www.ocean-next.fr/) and the [MEOM group](http://meom-group.github.io) at [IGE](http://www.ige-grenoble.fr) on MareNostrum supercomputer at [BSC](https://www.bsc.es) within a [PRACE](http://prace-ri.eu/) project.

The model configuration has been defined in order to model as accurately as possible surface signature of oceanic motions of scales down to 15 km in line with the expected effective resolution of SWOT ocean data. The choice of the model horizontal and vertical resolution derives from this objective. A particular emphasis has also been put on the representation of high frequency motions associated with internal tides as several studies suggest that these signals will be prominent in SWOT data at scale <100km.

The eNATL60 simulations span the North Atlantic from about 6°N up to the polar circle and fully include the Gulf of Mexico, the Mediterranean Sea, and the Black Sea (Figure 2):

- Horizontal grid: 1/60°, 8354×4729 points
- 0.8 km < Δx < 1.6 km
- Vertical grid: 300 levels
- Lateral Boundary Conditions for U,V, T, S & sea-ice: daily, GLORYS12 v1 (1/12°, Mercator Ocean)
- Lateral Boundary Conditions for tides (SSH, u, v) : FES2014 (F. Lyard)
- Atmospheric forcing: 3-hourly, ERA-interim (ECMWF)

This model configuration has been implemented and run in two different "free" simulations (no data assimilation). The reference experiment eNATL60-BLB002 has been run without explicit tidal forcing from 1-july-2009 to 6-july-2010; the sensitivity experiment eNATL60-BLBT02 was run with explicit tidal forcing from 1-july-2009 to 29-october-2010.

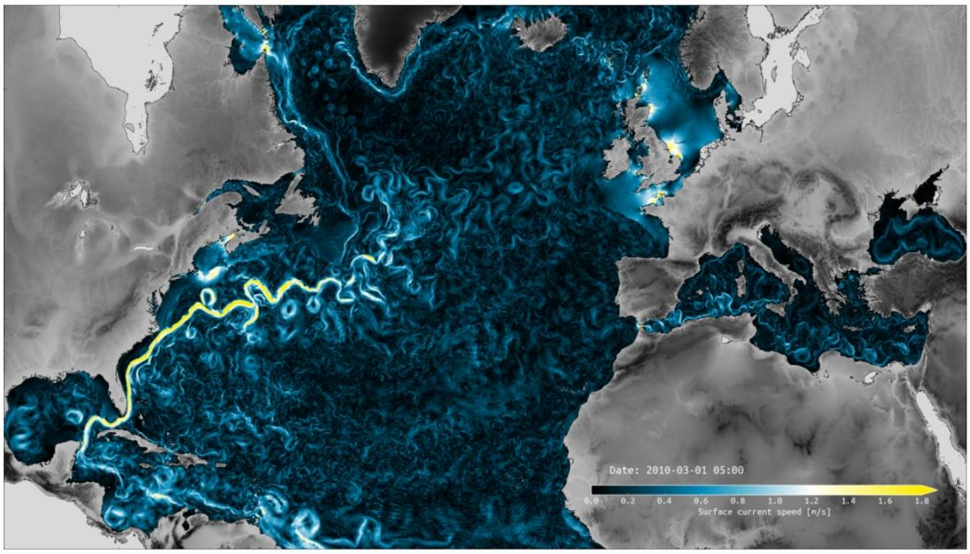

Figure 2: Horizontal extent of the eNATL60 domain illustrated by a snapshot of surface current speed.

WMOP

The WMOP (Western Mediterranean OPerational system) model (Juza et al., 2016; Mourre et al. 2018) is a regional configuration of the ROMS model in the Western Mediterranean Sea, covering from Gibraltar strait to Corsica and Sardinia (Figure 3). It is a downscaling of the CMEMS-MED-MFC with a 2 km horizontal resolution and 32 vertical sigma levels. The model is forced with high-resolution atmospheric fields from AEMET (Spanish meteorological agency), with 1-hour and 5-km resolution for the operational model and does not include tides. The operational system assimilates SST, along-track SLA, Argo temperature and salinity profiles, mooring data and surface current observations from HF-radar using a sequential EnOi method every 3 days (method described in Hernandez-Lasheras and Mourre, 2018). It runs every day, producing a 3-day forecast of ocean temperature, salinity, sea level and currents, which is validated and publicly distributed at www.socib.es and http://thredds.socib.es/. The model represents the ocean variability from the (sub-)meso- to the basin- scale. The Balearic Islands Coastal Observing and Forecasting System (SOCIB) has also run a series of hindcast simulations spanning from 2009-2018, using different parent models, initial and boundary conditions and momentum and diffusion parameters (Mourre et al. 2018, Aguiar et al. 2020). For this study two different simulations will be used: the first one as nature run to generate pseudo-observations, and the second one to assimilate these pseudo-observations.

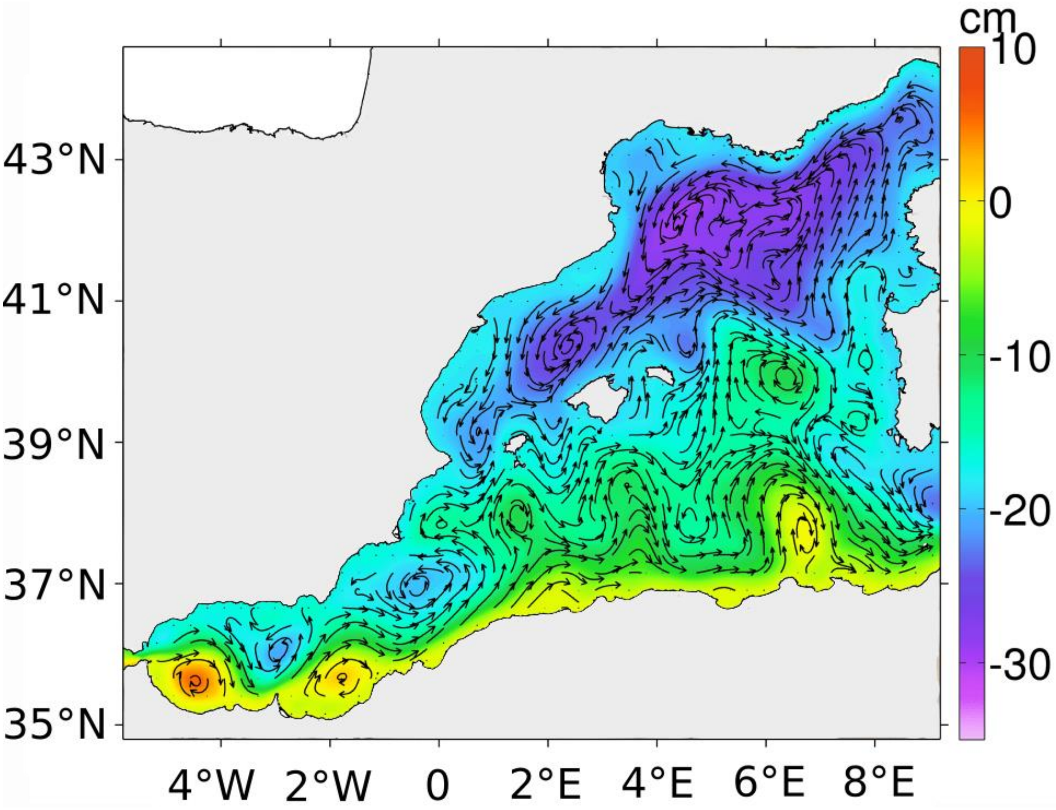

Figure 3: Sea surface height annual mean for 2014 and corresponding surface geostrophic currents from WMOP model.

4.3. Simulation of the observations

Remote sensing and in situ observations will be simulated from the models described in the previous section. The observing network will be representative of the recent years with some modifications to evaluate improvements in the design of multi-platform experiments. The observing platforms that will be simulated and the corresponding variables are presented below, together with the partner that will simulate each observation:

- Rosette CTD and underway CTD: vertical profiles of temperature and salinity (CSIC)
- ADCP: vertical profiles of total (geostrophic and ageostrophic) horizontal velocity (CSIC)
- Nadir altimetry: along-track SSH and associated errors (Ocean Next)
- Drifters: horizontal velocities along the trajectories at 0 and 15 m depth (Ocean Next)
- Argo: vertical profiles of temperature and salinity and dynamic height (Ocean Next)
- SWOT: SSH and associated errors (https://swot-simulator.readthedocs.io/en/latest/api.html) (Ocean Next)
- Glider vertical profiles of temperature and salinity (CSIC)

Due to the big size of the high-resolution model outputs, two different datasets will be shared between partners for each region and model:

- One dataset will include 3D fields of temperature, salinity and horizontal velocity from the surface to 1000 m depth in the sub-regions described in Section 4.1. These fields will be used to simulate CTD and ADCP observations. With temperature and salinity observations we will infer the dynamic height and the geostrophic velocity at the ocean surface, following the same procedure that will be applied to validate SWOT with real observations from multi-platform experiments during the fast-sampling phase after launch in 2022.

- The other dataset will include surface 2D fields of SSH and horizontal currents in the whole domain of the regions of study. These fields will represent the ocean "truth" and will be used to simulate SWOT, nadir altimetry, and drifter trajectories.

Even if the model simulations are run in a common temporal period between 1-july-2009 and 30-june-2010, the simulated observing network will represent the observing system of recent years. The specific period of the simulated observing system will be defined after evaluating the real observations available in both areas of study. Ocean Next has already done an inventory of the available Argo and nadir altimetry data per year in the Mediterranean Sea that will be extended to the Atlantic. This information will be evaluated to select the configuration of Argo and nadir altimetry we are interested in simulating. Regarding the ship-based in situ observations (CTD and ADCP), we will use as reference configuration a sampling strategy similar to PRE-SWOT (Barceló-Llull et al., 2018). Regarding Argo, Ocean Next will provide the simulated Argo vertical profiles of temperature and salinity within the two regions of study by colocating them in eNATL60. Drifters will be released within the sub-regions in a configuration that will allow the study of convergence and divergence; the trajectories will be simulated using the Python package Ocean Parcels (https://oceanparcels.org).

Errors will be included in all observations following the procedure explained by Gasparin et al. (2019). In summary, two types of errors will be considered: (i) a representative error, vertically and horizontally correlated, and related to the unresolved variability, and (ii) a random instrumental error (uncertainty of the measurement). Uncorrelated instrumental errors will be added to each observation following a Gaussian distribution with the standard deviation given by the instrumental uncertainty (Table 3 in Gasparin et al., 2019).

4.4. Configurations (scenarios)

Task 2.3.1

Several configurations of the multi-platform in situ experiment will be simulated to evaluate the best sampling strategy to validate SWOT during the fast-sampling phase after launch in 2022.

The reference configuration of the ship-based in-situ observations (CTD and ADCP) will be similar to the PRE-SWOT cruise experiment sampling strategy (Figure 4) in both regions of study within the selected sub-regions. Then, additional configurations will be analyzed modifying this "reference" setting to evaluate improvements in the sampling strategy. Drifters will be released in triangles with a separation between drifters of 5 km within both sub-regions. The default Argo and nadir altimetry configurations will represent the observing system in recent years and will be the same in all the configurations analyzed.

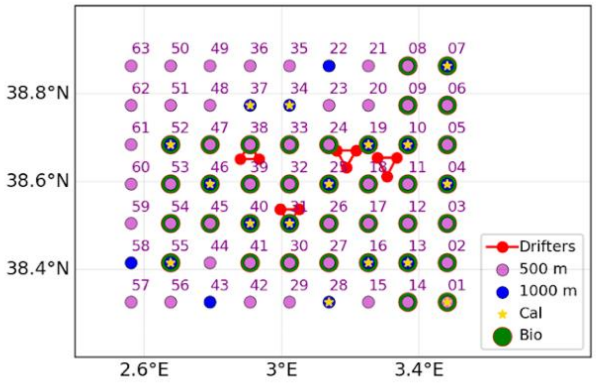

Figure 4:PRE-SWOT multi-platform experiment sampling strategy including rosette CTD, ADCP, 12 drifters, and gliders (Barceló-Llull et al., 2018).

Reference configuration:

- Rosette CTD casts separated by 10 km and forming a regular grid of 70 km x 90 km, from 5 to 1000 m depth with a vertical resolution of 0.5 m. Consider the time needed to do each cast and the transit time between stations.
- Current velocities continuously recorded using a hull-mounted ADCP at a transit speed of ~8 knots. The raw data are usually averaged in ensembles of 5 minutes that we will consider as their temporal resolution. Good quality data are usually located between 20 and 700 m depth (considering bin sizes of 8 m) in the transit between stations; during the CTD casts the ADCP data are disregarded.
- 51 drifters
- Argo
- Nadir altimetry
- Cruise experiment starting in September 1st (approximated expected date for the fast-sampling phase of SWOT).

Configurations to be tested in each sub-region:

1) Rosette CTD casts at 500 m depth:
   a) Check the time needed to cover all the sampled domain and evaluate the synopticity of the fields.
   b) Check the impact of having temperature and salinity observations between 500 and 1000 m depth on the inference of dynamic height and geostrophic velocity at the upper layer.
2) Rosette CTD casts at different spatial resolutions (5-15 km):
   a) Check the time needed to cover the sampled region with each spatial resolution and the impact in the synopticity of the reconstructed fields.
   b) Check the suitability of each spatial resolution to capture fine-scales.
3) Substitute rosette CTD for an underway CTD:
   a) Impact on synopticity (an underway CTD is expected to sample faster than sampling with rosette CTD casts).
   b) Impact on the reconstructed fine-scales (higher resolution of CTD measurements along the ship track).
4) Same reference configuration but in January (winter):
   a) Impact of season on the inference of dh and surface geostrophic currents.

5) Replace CTD casts with 8 gliders sampling the region in a radiator grid (strategy followed in Calypso; Mahadevan et al., 2020)

Additional configurations may be tested to further refine the sampling strategy depending on the results obtained from the reconstruction of these configurations.

Files with the simulated observations in each configuration and region will be shared with all the interested parts. The variables that will be studied in each scenario are SSH (and dynamic height), surface horizontal velocities (geostrophic and total) and vertical relative vorticity.

Task 2.3.2

To achieve the second objective, we will select two common configurations in the Mediterranean to apply the reconstruction methods:

(i) the reference configuration
(ii) the best configuration identified in Task 2.3.1

Task 2.3.3

To accomplish Objective 3, we will merge with the MIOST tool (see next section) the velocity estimated from simulated drifters with simulated observations of the conventional nadir altimetry. The first step consists in the processing of the drifters in order to have a signal consistent with altimetry (geostrophic current only). The drifters will be processed as done by Mulet et al. (2020). Then, using MIOST, we will compute daily maps of SLA and associated geostrophic current anomalies at 1/16° of grid resolution. To do this we will use the following simulated observations:

1) Along-track altimetric data, nadir and SWOT:
   - SSH from model
   - MDT from model (mean of SSH over the time period of the full run: 1-july-2009 to 1-july-2010) or observed MDT like MDT CNES-CLS18 (Mulet et al., 2020) to compute SLA from SSH – MDT
   - Errors
2) Drifter velocities at 15 meter depth (for simulated droggued drifters):
   - ‘Total velocity’ of particles advected by the total current of the model at 15 meter depth
   - ‘Geostrophic current’: geostrophic current from the model (derived from SSH) interpolated at the location of the drifters
   - Wind stress from ERA-interim (same forcing than eNATL60) interpolated at the location of the drifters
   - MDT from model or from observations interpolated at the location of the drifters
   - Errors
3) Eventually dynamic height:
   - Dynamic height estimated from T/S profiles from Argo and CTD
   - Mean of dynamic height over 1-july-2009 to 1-july-2010
   - Error

In a first experiment we will only use nadir altimetry. Then we will add the drifters and finally we will double the number of drifters used. Eventually we will also test to include dynamic height.

All the experiments will be compared to each other to quantify the impact of each observation system. We will also make comparisons with the nature run and simulated SWOT to estimate how much the merging of altimetry and drifters can be used for SWOT validation.

4.5. Methods of reconstruction

To accomplish each objective, different methods of reconstruction will be used to reconstruct the simulated observations.

Task 2.3.1: Optimal interpolation will be used to interpolate CTD and ADCP simulated observations onto a regular grid with a horizontal resolution of 2 km. This reconstruction will be applied to each configuration in order to evaluate the optimal sampling strategy to validate SWOT in each region. This analysis will be done with all the models described in Section 4.2.

Task 2.3.2: Optimal interpolation, WMOP assimilation and machine-learning techniques will be used to reconstruct the simulated observations in the reference configuration and also in the best configuration identified in Task 2.3.1. This analysis will be done in the Mediterranean and using the simulated observations from one nature run model. After the analysis of the first results, we will discuss the extension of this study to the Atlantic and using the other models.

Task 2.3.3: The MIOST tool will be used to merge the horizontal velocity estimated from simulated drifters with conventional nadir altimetry simulated observations.

The four methods of reconstruction are described below:

Optimal interpolation

Optimal Interpolation is a powerful method of data analysis that has been widely used by oceanographers and meteorologists to estimate values of geophysical variables on a regular grid from irregularly sampled observations (e.g. Bretherton, et al., 1976; Davis, 1985; Le Traon, 1990, Gomis et al., 2001; Pascual et al., 2004, 2017; Melnichenko et al., 2014, Barceló-Llull et al., 2017; Ruiz et al., 2019). This technique determines a point-wise estimate of the interpolated field with minimum ensemble mean-square error, considering information about the variances and correlation functions of the estimated field and the observational data. This method has the advantage to consider error information for each observational platform.

Machine learning

Recent advances in machine learning and variational deep learning for the space-time interpolation of sea surface dynamics (Lopez-Radcenco et al., 2018; Fablet et al., 2019; Beauchamp et al., 2020) provide additional means to explore observation datasets and jointly identify a representation of the underlying dynamics and an interpolation method. They have been shown to potentially lead to significant improvements in terms of the spatial scales resolved by the interpolation compared with OI and other data-driven schemes (e.g. dinEOF). For the proposed case-studies, we will first review the relevance of these approaches and select at least one learning-based scheme to be implemented within the considered benchmarking framework.

WMOP data assimilation

The WMOP Data Assimilation system employs a Multimodel Local Ensemble Optimal Interpolation (EnOI) scheme. It is a widely used method, which represents a good alternative to more complex and computationally expensive methods as EnKF or 4Dvar. It consists in a sequence of analyses (model updates given a set of observations) and model forward simulations.

The Background error covariances are computed from an ensemble of realizations, which are generated from randomly sampling a set of different hindcast simulations within a 90-day time-window centered on the analysis date and removing the seasonal cycle. They reflect the mesoscale variability, representing dynamically consistent covariances between different model variables and depths.

The configuration to be used in this work has been previously employed in several studies in different places of the Western Mediterranean Sea (e.g. Pascual et al., 2017; Barceló-Llull et al., 2018; Hernández-Lasheras and Mourre, 2018) and in the operational system. More details of the data assimilation procedure can be found in Hernández-Lasheras and Mourre (2018).

MIOST tool

MIOST (Multi-scale Inversion for Ocean Surface Topography) is a tool which allows multivariate and multiscale sea level and surface current mapping (Ubelman et al. 2020). It was designed to ingest a large volume of observations at a lower cost. While the traditional mapping algorithms used in DUACS use a matrix inversion in the observation space, which makes the problem numerically heavy, especially in the case of swaths, MIOST uses a variational resolution, covariance functions are expressed through wavelet modes and inversion is performed in this space.

4.6. Analysis of the results

The reconstructed fields of SSH and surface currents will be compared with the nature run model to estimate the errors associated with each reconstruction method. Then, the reconstructed fields will be compared with simulated observations of SWOT to anticipate the SWOT launch and define assessment metrics. A detailed description of the analysis of the results will be presented in the Deliverable 2.3: *Analysis of the OSSEs with multi-platform in situ data and impact on fine-scale structures*.

Input from WP3 will refine the work plan, but also when defining the assessment metrics, in coordination with the demonstrator activities (WP5,6,7) and T4.5 on validation of satellite products with multi-platform observations.

4.7. Work plan

Year	**2020**		**2021**												**2022**				
Year month	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5
Project month	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
	Pseudo-observations				*Reconstructions and analysis*								*Final adjustments*				*Writing*		
Extract and share model outputs (Ocean-Next, SOCIB, CSIC)	X																		
Generate pseudo-observations in different scenarios:																			
- CTD, ADCP, gliders (CSIC)	X	X	X	X															
- SWOT (Ocean-Next, CLS)	X	X																	

- Nadir Altimeters (Ocean-Next: SARAL-Altika and Sentinel-3)	X	X																	
- Drifters (Ocean-Next)			X	X															
- Argo (Ocean-Next)	X	X																	
add errors (CSIC, Ocea-Next)	X	X	X	X															
- Additional OSSEs													X	X					
Reconstruct all configurations with OI (CSIC)					X	X							X	X					
Analysis Task 2.3.1 (CSIC)					X	X	X[1]								X	X[3]			
Reconstruct common configurations:																			
- Machine-learning (IMT)					X	X	X	X	X	X			X	X					
- WMOP assimilation (SOCIB)					X	X	X	X	X	X			X	X					
Analysis Task 2.3.2 (all partners)								X	X	X	X	X[2]			X	X[3]			
Analysis Task 2.3.3 (CLS)					X	X	X	X	X	X	X	X[2]	X	X	X	X[3]			
Write publication(s)											X	X	X	X	X	X	X	X	X
Write Deliverable 2.3																X	X	X	

[1] *evaluation of the results from Task 2.3.1 in May 2021*

[2] *evaluation of the results from Tasks 2.3.2 and 2.3.3 in October 2021: implement adjustments/improvements to the reconstruction methods, test additional configurations, etc. in parallel to the writing of the publications*

[3] *evaluation of the final results to be included in the Deliverable 2.3 in February 2022*

5. References

Aguiar, E., Mourre, B., Juza, M., Reyes, E., Hernández-Lasheras, J., Cutolo, E., Mason, E., Tintoré, J., 2019. Multi-platform model as- sessment in the Western Mediterranean Sea : impact of downscaling on the surface circulation and mesoscale activity. Ocean Dynamics doi:https://doi.org/10.1007/s10236-019-01317-8 Multi-platform.

Barceló-Llull, B., Sangrà, P., Pallàs-Sanz, E., Barton, E. D., Estrada-Allis, S. N., Martínez-Marrero, A., Aguiar-González, B., Grisolía, D., Gordo, C., Rodríguez- Santana, A., Marrero-Díaz, A. & Arístegui, J. (2017). Anatomy of a subtropical intrathermocline eddy. Deep-Sea Res., 124, 126-139, DOI: http://dx.doi.org/ 10.1016/j.dsr.2017.03.012

Barceló-Llull, B., Pascual, A., et al., (2018). PRE-SWOT Cruise Report. Mesoscale and sub-mesoscale vertical exchanges from multi-platform experiments and supporting modeling simulations: anticipating SWOT launch (CTM2016-78607-P). 138 pp. http://dx.doi.org/10.20350/digitalCSIC/8584

Beauchamp, M., Ronan Fablet, Clément Ubelmann, Maxime Ballarotta, Bertrand Chapron. Intercomparison of data-driven and learning-based interpolations of along-track Nadir and wide-swath Swot altimetry observations. In press. ⟨hal-02931892v2⟩ https://hal-imt-atlantique.archives-ouvertes.fr/hal-02931892/

Bouffard, J., A. Pascual, S. Ruiz, Y. Faugère, and J. Tintoré (2010), Coastal and mesoscale dynamics characterization using altimetry and gliders: A case study in the Balearic Sea, J. Geophys. Res., 115, C10029, doi:10.1029/2009JC006087.

Bretherton, F. P., R. E. Davis, and C. B. Fandry, 1976: A technique for objective analysis and design of oceanographic experi- ments applied to MODE-73. Deep-Sea Res. Oceanogr. Abstr., 23, 559–582, doi:10.1016/0011-7471(76)90001-2.

Brodeau, L., J. Le Sommer, and A. Albert 2020 : ocean-next/eNATL60: Material describing the set-up and the assessment of NEMO-eNATL60 simulations (Version v1). Zenodo. http://doi.org/10.5281/zenodo.4032732

Davis, R. E., Objective mapping by least square fitting, J. Geophys. Res., 90(C3), 4773-4777, 1985.

d'Ovidio F, Pascual A, Wang J, Doglioli AM, Jing Z, Moreau S, Grégori G, Swart S, Speich S, Cyr F, Legresy B, Chao Y, Fu L and Morrow RA (2019) Frontiers in Fine-Scale in situ Studies: Opportunities During the SWOT Fast Sampling Phase. Front. Mar. Sci. 6:168. doi: 10.3389/fmars.2019.00168

Fablet, R., J. Le Sommer, J. M. Molines, L. Drumetz, F. Rousseau and B. Chapron, Learning Differential Transport Operators for the Joint Super-Resolution of Sea Surface Tracers and Prediction of Subgrid-Scale Features, IGARSS 2019 - 2019 IEEE International Geoscience and Remote Sensing Symposium, Yokohama, Japan, 2019, pp. 7916-7919, doi: 10.1109/IGARSS.2019.8900571.

Gasparin F, Guinehut S, Mao C, Mirouze I, Rémy E, King RR, Hamon M, Reid R, Storto A, Le Traon P-Y, Martin MJ and Masina S (2019) Requirements for an Integrated in situ Atlantic Ocean Observing System From Coordinated Observing System Simulation Experiments. Front. Mar. Sci. 6:83. doi: 10.3389/fmars.2019.00083

Gomis, D., Ruiz, S., Pedder, M., 2001. Diagnostic analysis of the 3D a geostrophic circulation from a multivariate spatial interpolation of CTD and ADCP data. Deep- Sea Res. 48, 269–295.

Hernández-Lasheras, J., Mourre, B., 2018. Dense ctd survey versus glider fleet sampling: comparing data assimilation performance in a regional ocean model west of sardinia. Ocean Science 14. doi:10.5194//os-14-1069- 2018.

Juza M., B. Mourre, L. Renault, S. Gómara, K. Sebastián, S. Lora, J.P. Beltran, B. Frontera, B. Garau, C. Troupin, M. Torner, E. Heslop, B. Casas, R. Escudier, G. Vizoso,, and J. Tintoré (2016). SOCIB operational ocean forecasting system and multi-platform validation in the western Mediterranean Sea, J. Oper. Oceanogr., 9 :sup1, s155-s166, doi :10.1080/1755876X.2015.1117764

Le Traon, P.-Y., 1990: A method for optimal analysis of fields with spatially-variable mean. J. Geophys. Res., 95, 13 543–13 547, doi:10.1029/JC095iC08p13543.

Lopez-Radcenco, M., A. Pascual, L. Gomez-Navarro, A. Aissa-El-Bey and R. Fablet, Analog Data Assimilation for Along-Track Nadir and Swot Altimetry Data in the Western Mediterranean Sea, IGARSS 2018 - 2018 IEEE International Geoscience and Remote Sensing Symposium, Valencia, 2018, pp. 7684-7687, doi: 10.1109/IGARSS.2018.8519089.

Mahadevan, A., A. Pascual, D. L. Rudnick, S. Ruiz, J. Tintoré, and E. D'Asaro, Coherent pathways for vertical transport from the surface ocean to interior. Bull. Amer. Meteor. Soc., doi: https://doi.org/10.1175/BAMS-D-19-0305.1.

Mason, E., and Pascual, A. (2013), Multiscale variability in the Balearic Sea: An altimetric perspective, J. Geophys. Res. Oceans, 118, 3007– 3025, doi:10.1002/jgrc.20234.

Melnichenko, O., P. Hacker, N. Maximenko, G. Lagerloef, and J. Potemra, 2014: Spatial Optimal Interpolation of Aquarius Sea Surface Salinity: Algorithms and Implementation in the North Atlantic. J. Atmos. Oceanic Technol., 31, 1583–1600, https://doi.org/10.1175/JTECH-D-13-00241.1.

Morrow R, Fu L-L, Ardhuin F, Benkiran M, Chapron B, Cosme E, d'Ovidio F, Farrar JT, Gille ST, Lapeyre G, Le Traon P-Y, Pascual A, Ponte A, Qiu B, Rascle N, Ubelmann C, Wang J and Zaron ED (2019) Global Observations of Fine-Scale Ocean Surface Topography With the Surface Water and Ocean Topography (SWOT) Mission. Front. Mar. Sci. 6:232. doi: 10.3389/fmars.2019.00232

Mourre, B., Aguiar, E., Juza, M., Hernandez-Lasheras, J., Reyes, E., Heslop, E., Escudier, R., Cutolo, E., Ruiz, S., Mason, E., Pascual, A., Tintoré, J., 2018. Assessment of High-Resolution Regional Ocean Prediction Systems Using Multi-Platform Observations: Illustrations in the Western Mediterranean Sea. New Frontiers in Operational Oceanography,663– 694, doi:10.17125/gov2018.ch24.

Pascual, A., Buongiorno-Nardelli, B., Larnicol, G., Emelianov, M., Gomis, D., 2002. A case of an intense anticyclonic eddy in the Balearic Sea (western Mediterranean). J. Geophys. Res. 107 (C11), 3183. doi:10.1029/2001JC000913.

Pascual, A., Gomis, D., Haney, R. L., and Ruiz, S. (2004). A quasigeostrophic analysis of a meander in the palamós canyon: vertical velocity, geopotential tendency, and a relocation technique. J. Phys. Oceanogr. 34, 2274–2287. doi: 10.1175/1520-0485(2004)034<2274:AQAOAM>2.0.CO;2

Pascual A, Ruiz S, Olita A, Troupin C, Claret M, Casas B, Mourre B, Poulain P-M, Tovar-Sanchez A, Capet A, Mason E, Allen JT, Mahadevan A and Tintoré J (2017) A Multiplatform Experiment to Unravel Meso- and Submesoscale Processes in an Intense Front (AlborEx). Front. Mar. Sci. 4:39. doi: 10.3389/fmars.2017.00039

Ruiz, S., A. Pascual, B. Garau, Y. Faugère, A. Alvarez, and J.Tintoré (2009), Mesoscale dynamics of the Balearic Front, integrating glider, ship and satellite data, J. Mar. Syst., 78(suppl.), S3–S16, doi:10.1016/ j.jmarsys.2009.01.007.

Ruiz, S., Claret, M., Pascual, A., Olita, A., Troupin, C., Capet, A. et al. (2019). Effects of oceanic mesoscale and submesoscale frontal processes on the vertical transport of phytoplankton. Journal of Geophysical Research: Oceans, 124, 5999–6014. https://doi.org/10.1029/2019JC015034

Simoncelli, S., Fratianni, C., Pinardi, N., Grandi, A., Drudi, M., Oddo, P., & Dobricic, S. (2019). Mediterranean Sea Physical Reanalysis (CMEMS MED-Physics) [Data set]. Copernicus Monitoring Environment Marine Service (CMEMS). https://doi.org/10.25423/MEDSEA_REANALYSIS_PHYS_006_004

Ubelmann C., Dibarboure G., Gaultier L, Ponte P., Ardhuin F., Ballarotta M and Faugère Y. Reconstructing Ocean Surface Current Combining Altimetry and Future Spaceborne Doppler Data. JGR. Under review. 2020