SPECIAL PROJECT PROGRESS REPORT

Progress Reports should be 2 to 10 pages in length, depending on importance of the project. All the following mandatory information needs to be provided.

Reporting year	2018
Project Title:	Stochastic Coastal/Regional Uncertainty Modelling: sensitivity, consistency and potential contribution to CMEMS ensemble data assimilation
Computer Project Account:	SPGRVERV
Principal Investigator(s):	Vassilios D. Vervatis (1), Pierre De Mey (2)
Affiliation:	(1) National Kapodistrian University of Athens (UoA) .. (2) Laboratoire d'Etudes en Géophysique et Océanographie Spatiales (LEGOS)
Name of ECMWF scientist(s) collaborating to the project (if applicable)	Sarantis Sofianos (1), Nadia Ayoub (2), Charles-Emmanuel Testut (Mercator Ocean, Ramonville St. Agne, France)
Start date of the project:	24 March, 2016
Expected end date:	31 December, 2018

Computer resources allocated/used for the current year and the previous one

(if applicable)

Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	4 MSBU	~ 3.4 MSBU	1.5 MSBU	~ 0.8 MSBU
Data storage capacity	(Gbytes)	8 TB	~ 6 TB	2 TB	~ 1 TB

Summary of project objectives

(10 lines max)

The ECMWF-SP resources are used in a joint project within the CMEMS Service Evolution open tender under Lot 3: links with coastal environment. The project aims at strengthening CMEMS in the areas of coastal/regional ocean uncertainty modelling, ensemble consistency verification and ensemble data assimilation. The work is based on stochastic modelling of ocean physics and biogeochemistry in the Bay of Biscay, on an identical sub-grid configuration of the IBI-MFC system in its latest CMEMS operational version.

Summary of problems encountered (if any)

(20 lines max)

The problems encountered during November-December of the previous year and in this year are mainly linked to the ECMWF changes performed in the default versions of the software packages and libraries, combined with an update on the default compiler environments on the HPCF. The compiler environment has been updated switching from "cdt/16.03" to "cdt/17.09" version. Following this update, we have encountered several compilation problems associated with the intel optimization options and the xios library. Due to this fact, we have used the 85% of the total resources requested in 2017 and we are at about 50% for the 2018 resources. We are currently in contact with the ECMWF admins trying to solve this issue.

Summary of results of the current year (from July of previous year to June of current year)

This section should comprise 1 to 8 pages and can be replaced by a short summary plus an existing scientific report on the project

In this section, we give a brief overview of SCRUM based on the final report of the joint CMEMS project.

Ensemble production

We investigate whether Ensemble-based cross-covariances are enriched (with the possibility to increase DA performance), by perturbing both components of the coupled ocean-biogeochemical model. In this regard, an increasing complexity of experiments to augment chlorophyll spread is designed as follows: initially perturbing only physics (Ens-1), then only biogeochemistry (Ens-2) and finally both models simultaneously (Ens-3). In the coupled Ens-3 simulation, the evolution of the biogeochemical tracers is described by the advection-diffusion equation:

$$\partial_t \mathrm{C} = \overbrace{\overbrace{-\underbrace{\nabla(\mathrm{u}\cdot\mathrm{C})}_{\text{advection}} - \underbrace{\mathrm{K_h}\,\nabla_h^2\mathrm{C}}_{\substack{\text{horizontal}\\ \text{diffusion}}} - \underbrace{\partial_z(\mathrm{K_z}\ \partial_z\mathrm{C})}_{\substack{\text{vertical}\\ \text{diffusion}}}}^{\text{Ens1}} + \overbrace{\underbrace{\mathrm{SMS(C)}}_{\text{biology}}}^{\text{Ens2}}}^{\text{Ens3}} \qquad (1)$$

where on the right hand of Eq. (1) the first term represents the advective transport of tracers along isopycnals, the second and third terms the 3D parametrized diffusion processes and the last term denotes all biological processes affecting the concentration of tracer C including the Sources Minus Sinks (SMS), such as for example respiration and death in phytoplankton growth and decay.

Fig. 1 shows the surface Chl Ensemble spread for all three Ensembles calculated in this project. In general, the spread is largest in Ens-3 (where both physical and bgc perturbations were applied). This is due to the fact that bgc uncertainties result from errors in physics and in bgc, in variable proportions depending on the location: compare e.g. the English Channel to the mesoscale field of the South Armorican slope current.

In this work, we discuss preliminary results during the second year of the CMEMS marine project SCRUM. In specific, we focus on the consistency analysis and data assimilation impact experiments incorporating Oceancolour data and ecosystem model variables.

Consistency analysis

The ArM ("Array Modes") toolbox propose criteria to characterize (1) array performance at detecting forecast errors, (2) consistency between forecast Ensemble statistics and innovation statistics. The tools work in space/time and across variables. The observational errors can be correlated.

The toolbox works in the space of Array Modes, which are in essence how the array views model error. They are the eigenmodes of the scaled Representer Matrix (although they are calculated in practice as the singular modes of the scaled matrix of Ensemble anomalies). They allow to implement pattern-dependent consistency analysis, and also scale-dependent consistency analysis since it is common that the dominant array modes capture the larger scales, with scales decreasing with increasing rank.

The ArM-CA consistency analysis tool projects the problem of statistical consistency between innovation and Ensemble statistics onto array-space along the basis of array modes, implements a systematic consistency criterion for each modal rank, and provides an overall consistency criterion involving a user-defined tolerance. The mathematical concepts are explained in Charria et al. (2016) and Lamouroux et al. (2016).

On **Fig. 2**, we show Hovmöller diagrams of variations in time of the ArM spectrum, including Chl innovation consistency check against Ens-1, Ens-2, and Ens-3, projected onto 39 array modes. The product ID is 009_093 (http://marine.copernicus.eu/). White areas depict inconsistent array modes. Values smaller than 1, i.e. dark blue, depict array modes below the observational noise Representer matrix (RM) spectra exhibit strong time variations, with peaks possibly corresponding to "differential blooms" across the Ensembles, associated with specific spatial patterns. The spectra also show a fairly long statistical bgc spin-up time, of the order of 3 months. Once past the bgc spin-up, e.g. in March/April, between 5 and 10 array modes show positive pattern consistency.

As for SST and SSH, consistency is verified for the larger-scale patterns (not shown). However, this time, we see that consistent patterns are not always large-scale, and that the scale of inconsistent patterns is not always so different from the scale of consistent ones. The scale dependency for statistical consistency is not always verified for Chlorophyll. In Ens-2, the physics are not perturbed, so bgc uncertainties are passively advected around. The patterns are of course more complex, and probably more realistic, in Ens-3: it seems difficult to attribute those error patterns to specific physical or biogeochemical processes.

Data assimilation impact experiments

In this step, we carry out the EnKF analysis step with SDAP, using multiple observations together. For this, we have developed a large part of the interface between SDAP and NEMO-PISCES: what is still missing for full EnKF is the model correction post-analysis. Considering this, we are getting closer to the perspective of a coupled Ensemble-based DA-ocean/biogeochemical system.

In this section, we illustrate the multivariate impact of both Temperature and Chl variables in the state vector, by assimilating two observational networks simultaneously, namely the OSTIA-SST and the Ocean Colour Chl (CMEMS Product IDs: SST_GLO_SST_L4_NRT_OBSERVATIONS _010_001;OCEANCOLOUR_GLO_CHL_L4_REP_OBSERVATIONS_009_093). In addition, we investigate the convergence of covariances and its impact on the increment analysis, incorporating different ensembles (i.e. Ens1 vs. Ens3) and ensemble sizes (10 vs. 40 members).

In **Figs. 3** and **4**, we compare the correction fields based on Ensemble covariances from 40-member Ens1 and 40-member Ens3 respectively, assimilating both SST and Chl. The most significant impact is observed in the area of the English Channel (EC) for the surface Chl. In all other variables the changes in the analyses are moderate while being locally large, with the most significant change for the SSH being in the shelves and the EC. If we use fewer Ensemble members (e.g. 10 members; not shown), the correction patterns are less smooth because covariances are calculated from partially converged statistics. Finally, if we assimilate both observational networks SST and Chl, instead of only SST (not shown), the changes in the analyses are mainly observed on the shelves and the EC. The latter confirms the capability of Chl assimilation to increase the increment values, mostly at small scales, for all variables.

Figures

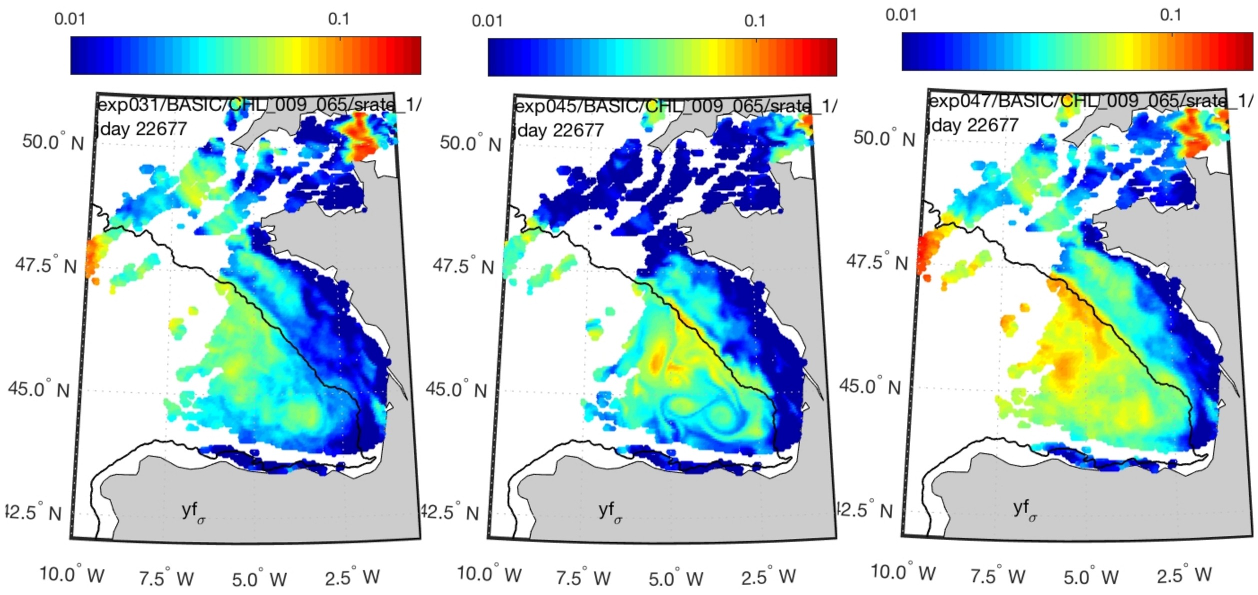

Fig. 1: Surface Chl 40-member ensemble spread (mg/m3) in data space (Product ID: 009_065). (left) Ens-1, (middle) Ens-2, (right) Ens-3. Date: 20120202.

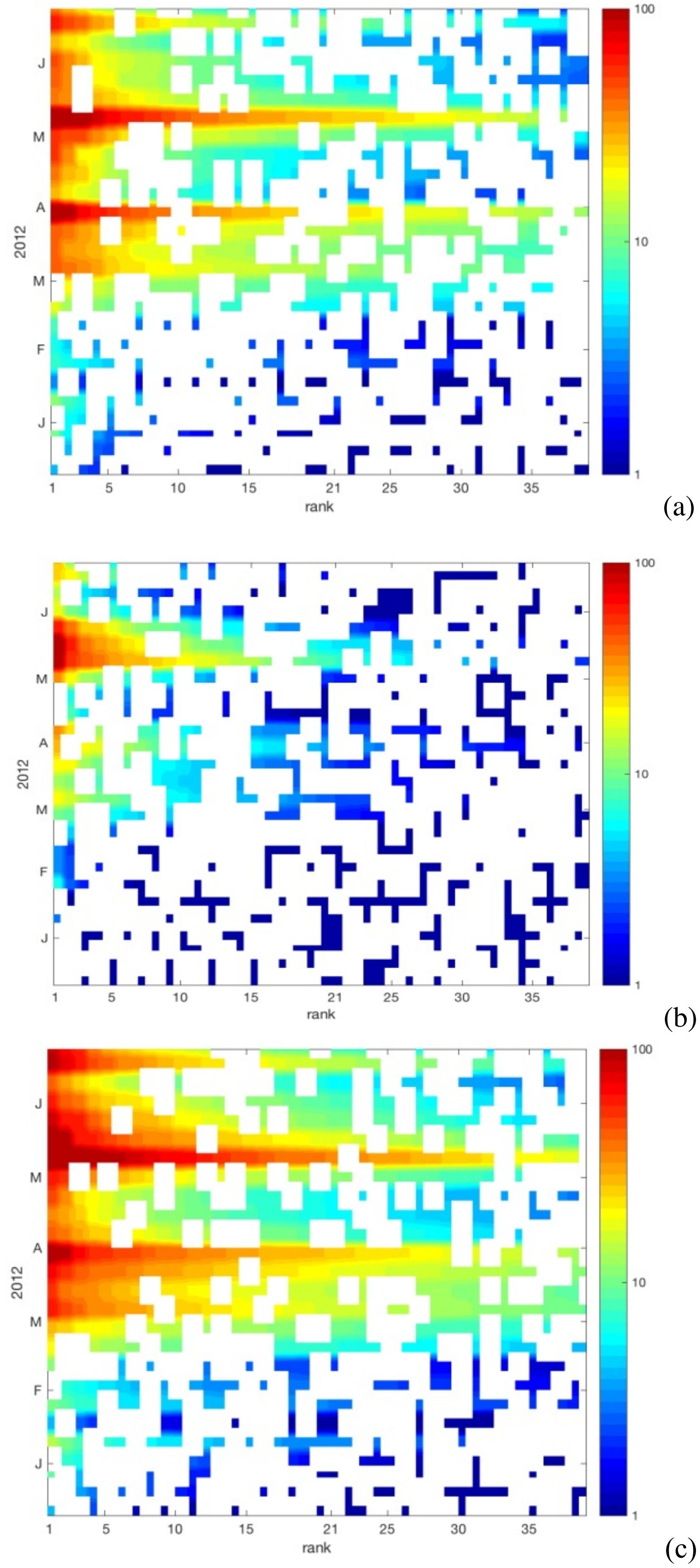

Fig. 2: (a) Hovmöller diagram of variations in time of the ArM spectrum, including a CHL gridded data innovation consistency check against Ens-1, projected onto 39 array modes. Product ID: 009_093. White areas depict inconsistent array modes. Colorbar: RM spectrum (values smaller than 1, i.e. dark blue, depict array modes below the observational noise), (b & c) same for Ensembles Ens-2 & Ens-3, respectively.

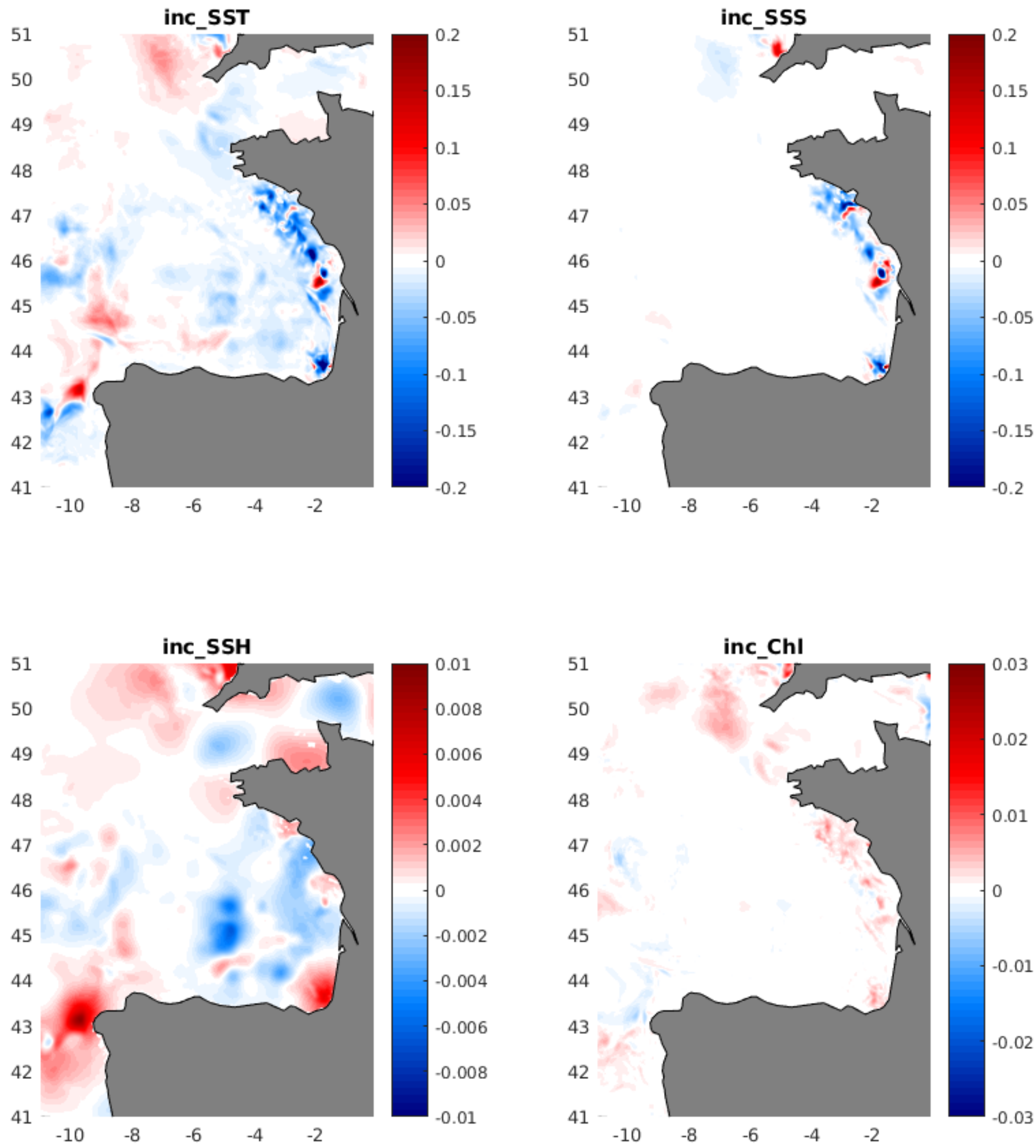

Fig. 3: Incremental analysis of the first member assimilating OSTIA-SST and Ocean Colour Chlorophyll on February 1, 2012. Ensemble covariances are calculated from Ens1 40 members. Correction fields on SST, SSH, SSS, Chl (cf. subplot titles “Inc_”).

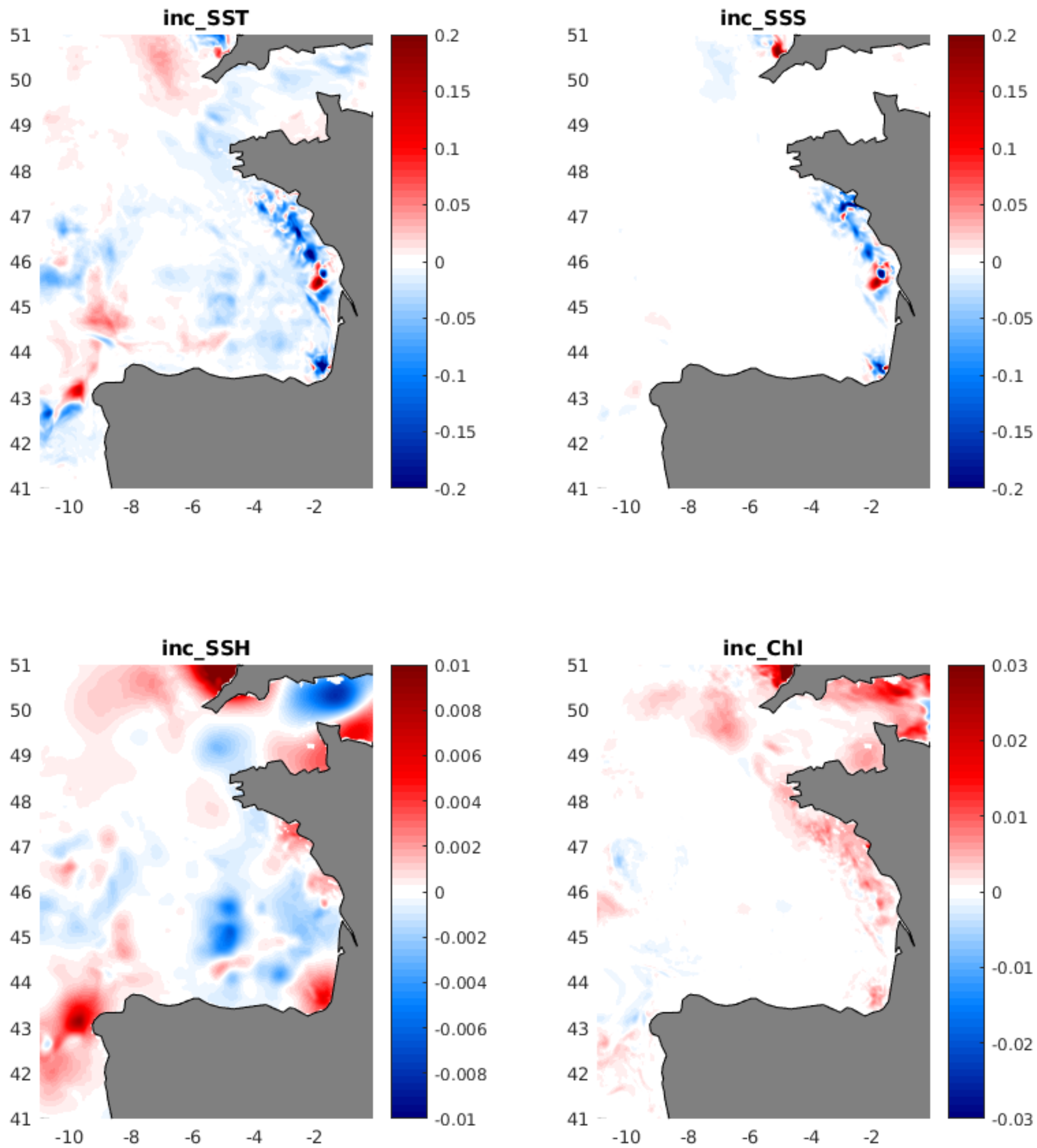

Fig. 4: Same as **Fig. 3**, for Ens3 40 members

References

Charria, G., Lamouroux, J. and P. De Mey, 2016: Optimizing observational networks combining gliders, moored buoys and FerryBox in the Bay of Biscay and English Channel. Journal of Marine Systems, http://dx.doi.org/10.1016/j.jmarsys.2016.04.003 .

Lamouroux, J., G. Charria, P. De Mey, S. Raynaud, C. Heyraud, P. Craneguy, F. Dumas and M. Le Hénaff, 2016: Objective assessment of the contribution of the RECOPESCA network to the monitoring of 3D coastal ocean variables in the Bay of Biscay and the English Channel. Ocean Dynam.,66(4):567-588, http://dx.doi.org/10.1007/s10236-016-0938-y .

List of publications/reports from the project with complete references

Results using computational resources from this ECMWF-SP has been presented in the following workshop/conferences:

De Mey, P., V. Vervatis, N. Ayoub, M. Kailas, G. Charria, J. Lamouroux, Ch. Skandrani, M. Iskandarani, M. Le Hénaff, and S. Sofianos (2017), Array design and Ensemble consistency analysis, GODAE OceanView Joint DA-TT & OSEval-TT Meeting, CMRE, La Spezia, 11-13 October 2017.

Vervatis, V., P. De Mey, M. Kailas, N. Ayoub and S. Sofianos (2018), Model uncertainties stemming from ocean-biogeochemical autoregressive processes: a high-resolution application for the Bay of Biscay, Abstract, Ocean Sciences Meeting, Portland, OR, 12-16 February 2018.

Vervatis, V., P. De Mey, S. Sofianos, N. Ayoub and M. Kailas (2017-2018) Stochastic Coastal/Regional Uncertainty Modelling (SCRUM & SCRUM2): Sensitivity, Consistency and potential contribution to CMEMS Ensemble Data Assimilation:

- CMEMS Service Evolution 2nd call - Kick off Meeting, teleconference, 03 April, 2018.
- CMEMS Service Evolution 1st call - 2nd coordination & Final-term Meeting, Mercator Ocean, Toulouse, FR, February 06-08, 2018.
- CMEMS Service Evolution R&D Copernicus Marine Week, Brussels, Belgium, September 25-29, 2017.

Summary of plans for the continuation of the project

(10 lines max)

This is the third and last year of the current project. A second Special Project named SCUM2 has been recently accepted at ECMWF, as a continuation of the current project SCRUM, linked also with a new awarded Copernicus marine project for the next two years in 2018-2020.