SPECIAL PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	2020
Project Title:	Enhancing regional ocean data assimilation in high and mid latitude European seas
Computer Project Account:	spitstor
Principal Investigator(s):	Andrea Storto
Affiliation:	Centre for Maritime Research and Experimentation (CMRE)
Name of ECMWF scientist(s) collaborating to the project (if applicable)	N/A
Start date of the project:	01/JAN/2019
Expected end date:	31/DEC/2021

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

Please answer for all project resources

		Previous year		**Current year**	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	725k	725k	700k	545k
Data storage capacity	(Gbytes)	15 TB	15TB	20 TB	36 TB (ECFS)

Summary of project objectives (10 lines max)

The project has several objectives, corresponding to the following tasks, in order to improve the data assimilation systems for the oceanographic configurations in use at NATO/CMRE.

Task A. Test the feasibility of assimilating small-scale current data collected by HF radars, drifters and ADCP profilers mounted on vessels and buoys;

Task B. Include uni (aka "weakly coupled") and multi-variate (aka "strongly coupled") data assimilation of sea-ice parameters in the Arctic analysis system exploiting the synergy of different observing networks.

Task C. Experiment multi-scale data assimilation in order to simultaneously ingest both the large- and the small- scale information collected by gliders during the observational campaign;

Task D. Run ensemble variational experiments with stochastic physics in order to i) retune the background-error covariances for use in data assimilation and ii) provide an ensemble of realizations for forcing downstream acoustic models and characterize the uncertainty and the cross-covariances between physical and acoustic parameters;

Task E. Test optimal ways to assimilate SST observations (L2, also daytime) in the analysis systems, exploiting the synergy with in-situ profiles to verify the methodology, and in particular data from gliders piloted to follow the satellite tracks.

Summary of problems encountered (10 lines max)

None

Summary of plans for the continuation of the project (10 lines max)

During the third year of the project, we will focus on the following developments and the associated assessment:

- **Development of an advanced observation operator to assimilate underwater acoustic measurements into ocean models.** We have developed an observation operator based on canonical correlation analysis (CCA) applied to an ensemble of acoustic simulations to build an observation operator for use in ocean forecasts. We plan to develop two alternatives that will be compared to the CCA-based observation operator: i) a simplified tangent-linear version of the parabolic equation acoustic model as acoustic measurements observation operator; ii) developing a data-driven observation operator, based on the same datasets of the CCA, but using a deep neural network (DNN) to model the response of acoustic transmission loss as a function of seawater temperature. The DNN is implemented in the variational data assimilation scheme after its linearization through reverse-mode automatic differentiation.
- **Assessment of velocity balance operator to assimilate sea surface currents.** We have implemented several ways to assimilate sea surface current data (from drifter, High Frequency Radars and moored ADCP) through formulating the velocity balance operator in several fashions, especially with regards to its unbalanced component. Resources for the next year will be devoted to the assessment of such schemes in an operational context.
- **Testing the impact of weak-constraint 4DVAR.** The newly developed TL/AD model (see Results section) will be used to test the potential benefits of a weak-constraint formulation of the 4DVAR.

List of publications/reports from the project with complete references

- Storto, A., P. Oddo, E. Cozzani, and E. F. Coelho, 2019: Introducing Along-Track Error Correlations for Altimetry Data in a Regional Ocean Prediction System. J. Atmos. Oceanic Technol., 36, 1657–1674, https://doi.org/10.1175/JTECH-D-18-0213.1.
- Storto, A.; Oddo, P. Optimal Assimilation of Daytime SST Retrievals from SEVIRI in a Regional Ocean Prediction System. Remote Sens. 2019, 11, 2776, doi:10.3390/rs11232776
- Storto, A., Falchetti, S., Oddo, P., Jiang, Y.- M., & Tesei, A. (2020). Assessing the Impact of Different Ocean Analysis Schemes On Oceanic and Underwater Acoustic Predictions. Journal of Geophysical Research: Oceans, 125, e2019JC015636. https://doi.org/10.1029/2019JC015636

Summary of results

Ocean-acoustic coupled assimilation. Assimilation of transmission loss (Tl) data in an idealized context was achieved through implementing an observation operator that maps forward and backward increments of temperature onto increments of Tl. Such operator is based on the canonical correlation analysis (CCA) of physical and acoustic datasets coming from an ensemble of oceanic and acoustic simulations. The use of CCAs approximates to large extent the correlations between temperature and transmission loss data extracted from integrated NEMO ocean model and RAM acoustic model simulations, respectively. The assimilation leads also to improved acoustic predictions if the corrected temperature fields are used within the RAM simulations, with significant impact on the prediction accuracy of the mixed layer thickness.

Advanced data assimilation methods. We continued developing a simplified tangent-linear and adjoint model (TL/AD) for use in ocean data assimilation experiments. The package is conceived to be a standalone library, more flexible than software relying on full ocean model infrastructure. Initial tests were performed to compare 1) the possibility of coarsening the grid through halving the horizontal resolution of the TL/AD computational domain; ii) the impact of selected tendencies on the resulting linear propagation performed by the TL/AD code.

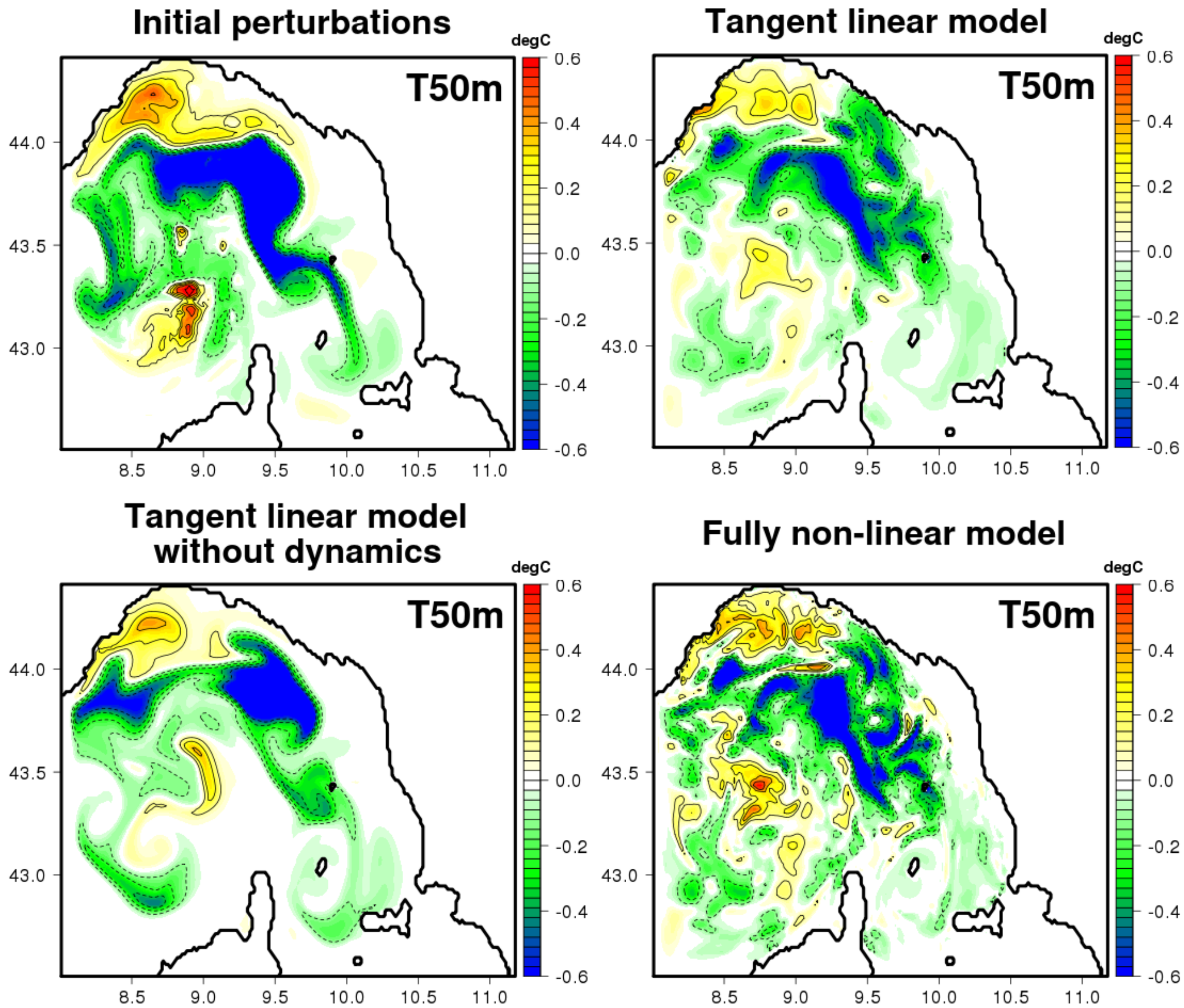

Figure 1. Linear and non-linear model evolutions (temperature at 50m of depth).

Figure 1 shows the 3-day propagation of initial increments (top left panel) through the new TL/AD model (top right panel), in comparison with the non-linear model evolution (differences between perturbed and unperturbed ocean model run, bottom right panel) and with the use of simplified

TL/AD model without propagation of the momentum (bottom left panel). The comparison between the fully non-linear model and the full TL model indicates the ability of the new TL/AD to follow the 3-day evolution of the temperature fields, except very small scale features that are not present in the linear propagation. This applies to temperature fields near the surface (not shown) and at 50 m of depth. However, when the dynamics in the TL/AD is neglected, patterns at 50 m resemble too closely those at 10 m (not shown) and vary significantly from the fully non-linear model, suggesting the importance of the momentum-induced processes on temperature linear propagation below the mixed layer.

Stochastic physics. The assessment of different stochastic physics package in the context of short-term regional analyses and forecasts. These schemes (developed also with funding from the C3S_521b project) have been extensively tested in the regional configuration in use at CMRE over the Ligurian Sea.

The package includes three schemes applied simultaneously: stochastically perturbed parameterization tendencies (SPPT), stochastically perturbed parameters (SPP) and stochastic kinetic energy backscatter (SKEB) schemes. The three schemes allow for different temporal and spatial de-correlation scales. In our regional configuration, ensemble free-running simulations were performed to assess the impact and reliability of the schemes. The three schemes prove complementary in increasing the ensemble spread at different scales and for different diagnostics. The total ensemble spread appears reliable, e.g. in comparison with the differences of ocean simulations with respect to higher resolution (sub-mesoscale) simulations that here represent the "truth" (with unresolved physics). Interestingly, both the SPPT and the SKEB schemes lead to an increase of eddy kinetic energy at small spatial scales (2-10 km), and contribute to modify the ensemble mean state, mitigating warm biases near the thermocline thanks to the enhancement of the upper ocean vertical mixing.

Figure 2 shows the rank histogram computed from observed and modelled mixed layer depth data (the observed ones are derived from glider profiles). The all perturbation experiment improves the diagnostics compared to any of the individual stochastic schemes applied alone.

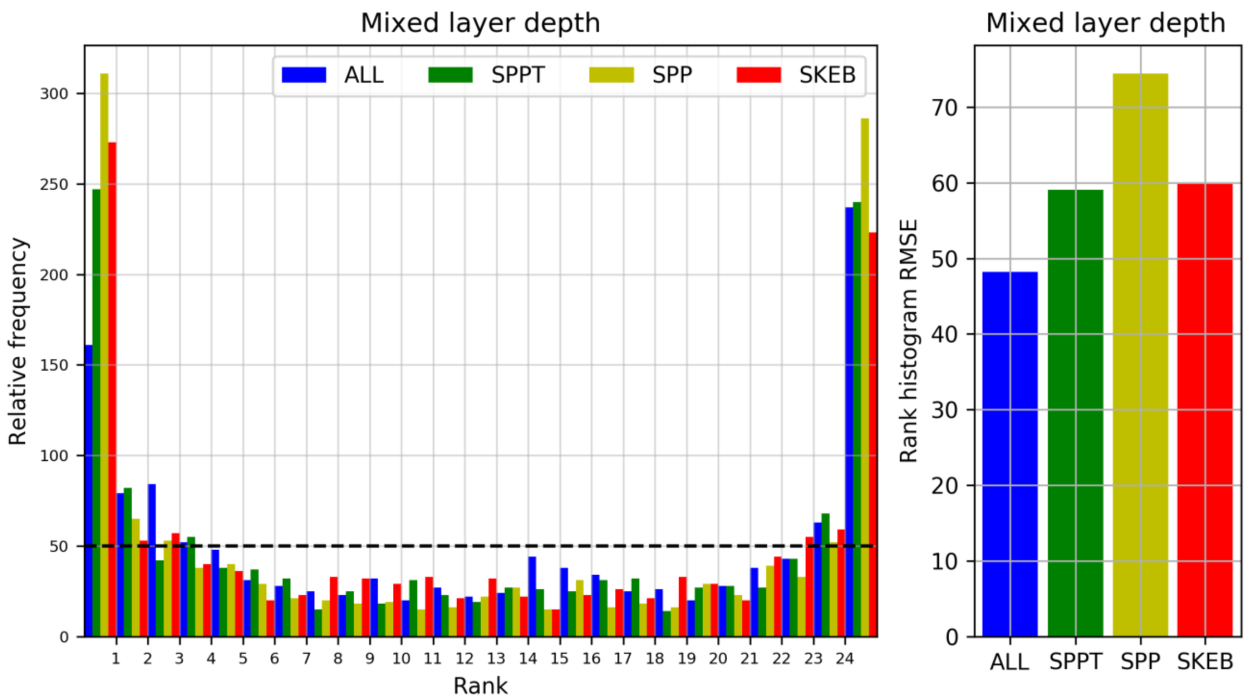

Figure 2. Rank histogram and associated root mean square difference compared to the flat p.d.f., for mixed layer depth data from stochastic physics experiments and glider profile observations. Four experiments are compared, either with all perturbation schemes applied simultaneously, or individually.