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Strongly coupled ocean/sea-ice surface data assimilation experiments

Andrea Cipollone[1], Doroteaciro Iovino[1], Cristina Gonzales Haro[2], Antonio Turiel[2], Manuel Arias[3], Evgeniia Makarova[2], Ferran Hernández Macia[2], Carolina Gabarró[2] , Jan-Erik Tesdal[1]

[1] CMCC Foundation, Euro-Mediterranean Center on Climate Change, Bologna, Italy [2] Institut de Ciències del Mar (CSIC), Barcelona, 08003, Spain

[3] Zenithal Blue Technologies, Barcelona, 08023, Spain

Introduction

Ocean and sea-ice play a fundamental role within the Earth system model at several timescales: the **ocean has a huge capacity** to store and triggers Earth system inertia, **while sea-ice influences surface heat**, moisture and freshwater flux, modulating the Earth's temperature. Present state-of-the-art global ocean/sea-ice **reanalyses** are generally **limited by the ingestion of few data types**, mostly **disentangling** the ocean and sea-ice sectors. In particular **SLA and SIC** are assimilated, **SST** is generally used during model integration, **SSS and SIT** are rarely used.

Objectives:

-) Exploring the benefit of assimilating diverse surface satellite datasets (SLA,SST,SSS,SIC,SIT) in a strongly coupled fashion, paving the way for future production

-) Analyze the model sensitivity to the observations, quantifying which dataset is more informative for the model point of view

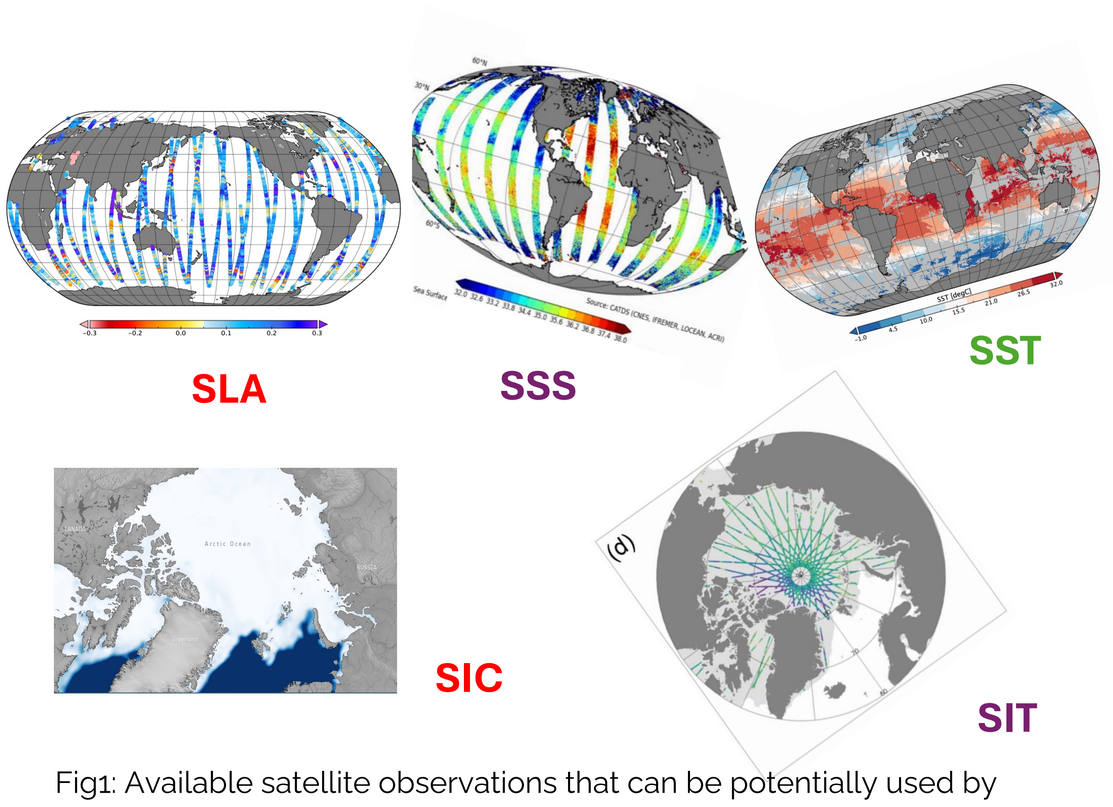

Fig1: Available satellite observations that can be potentially used by reanalysis system

C-GLORS development

The CMCC Reanalysis System (C-GLORS) has been used in the last decades to simulate realistic ocean and sea-ice conditions (Storto et al 2016;2019). The system has been presently enriched with a new sea-ice DA scheme (Cipollone et al, 2023). In COMET, we plan to further extend the C-GLORS system, **ensuring consistent corrections across different model components** (ocean and sea-ice) by proposing a strongly coupled approach and with the help of diverse observation operators.

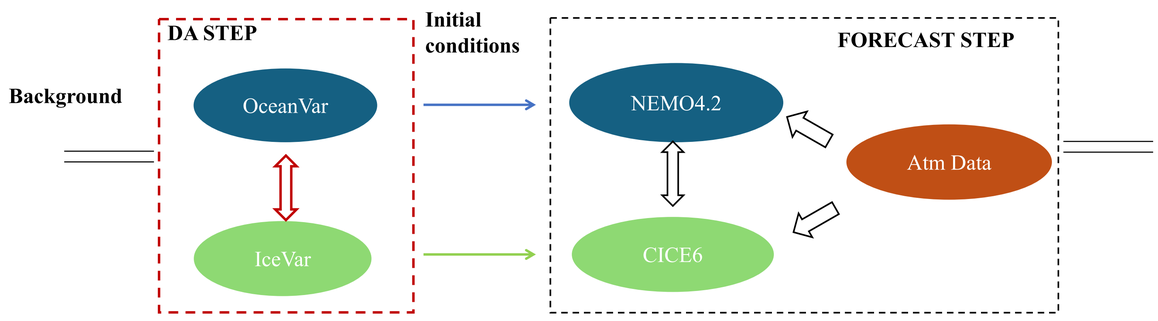

Fig2: Structure of the c-glors new system with cross covariances between ocean and sea-ice (new algorithm in **RED**)

ML SST observation operators

SST is the **most monitored** ocean feature within the satellite era, however a **variety** of SST datasets have been produced in recent years, each one with almost unique characteristics (with/without diurnal cycle, dust/cloud influence, etc) and differing from the model SST variable roughly at 0.5m. We use a ML scheme to project the satellite sst retrievals onto the first model level.

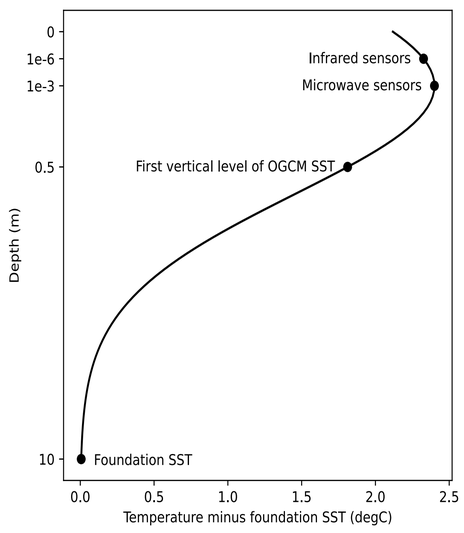

Fig2: Cartoon explaining the different observation types

A pix2pix scheme (conditional generative adversarial network) is used to **unbias the subskin temperature** and assimilate it in a reanalysis-like simulation (Broccoli et al 2025). Results shown an improvement in the subsurface temperature when unbiased SST are assimilated w.r.t. subskin SST especially in the Tropics (Figure 3). Validation is performed against independent insitu temperature observations from EN4 dataset (Good et al 2013)

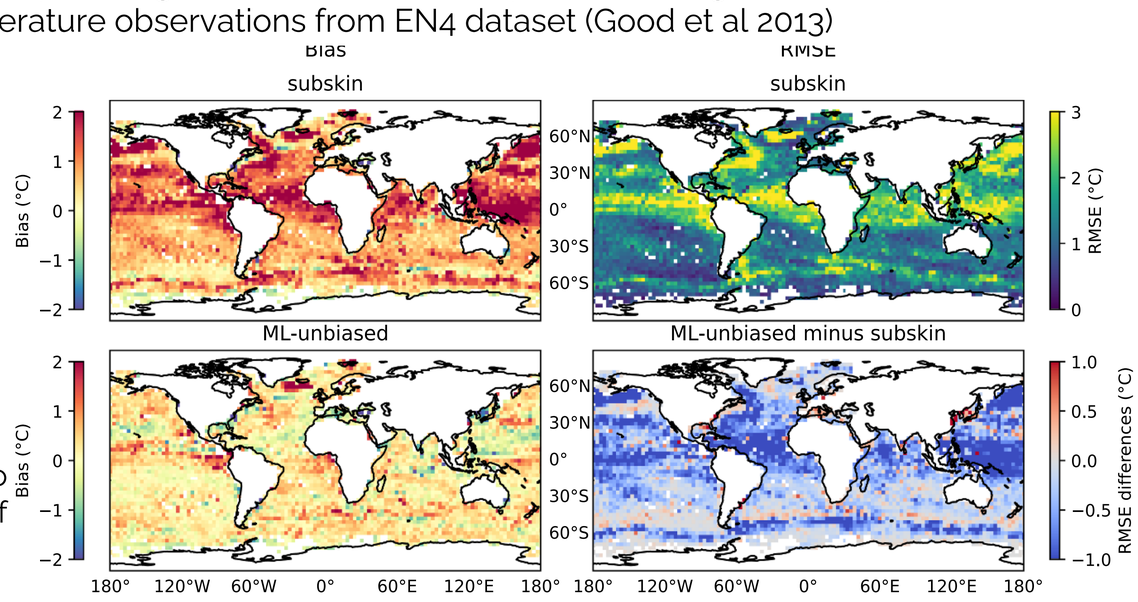

Fig3: Insitu Bias and RMSE, integrated between 0-100m, for the two experiments: 1) assimilation of original subskin SST. 2) assimilation of unbiased SST via ML . Statistics over the whole 2018 are considered.

Strongly coupled approach

The **synchronous** ingestion of corrections in a coupled model, is essential for generating realistic and balanced initial conditions and avoiding initial shocks. In COMET, SIC, SIT, SST, SSS and SLA will be assimilated at once, coupling gaussian-like sea-ice variables (through anamorphism) and ocean ones via covariance matrix (see Figure 4) thus generating increments that are consistent within themselves. Figure 5 shows increments for all the variables obtained by assimilating only SIC data for one day.

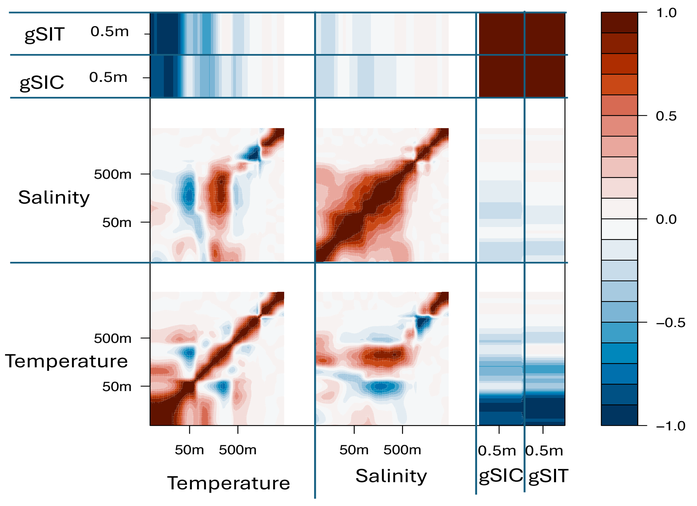

Fig4: Example of the vertical correlation between ocean and sea-ice variables for summertime

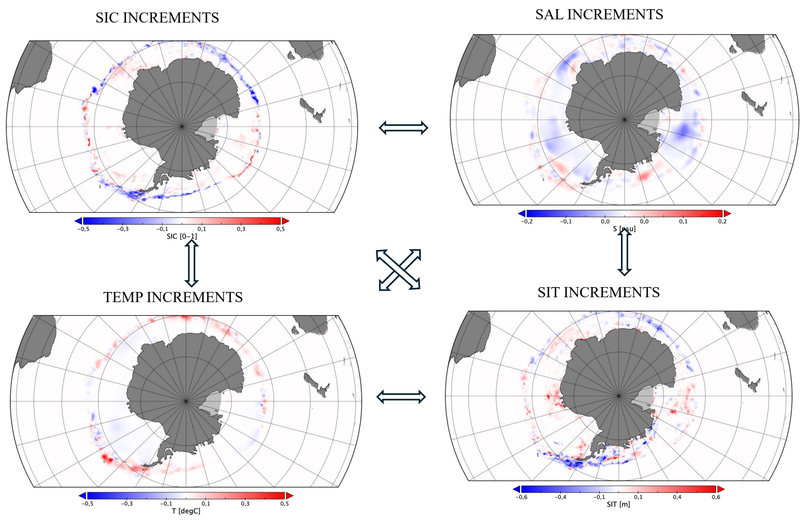

Fig5: Example of the balance increments obtaiined when assimilating SIC only

References:
Storto et al 2016, doi: 10.5194/essd-8-679-2016: Storto et al 2019; doi: 10.1007/s00382-018-4585-5; Cipollone et al 2023, doi: 10.5194/os-19-1375-2023; Broccoli et al 2025, doi 10.1088/3049-4753/adfb7e; Good et al 2013, doi: 10.1002/2013JC009067