Filling data gaps through interpolation: innovative analysis tools for oceanography

DIVAnd = Data-interpolating variational analysis in n dimensions
DINEOF = Data-interpolating Empirical Orthogonal functions
DINCAE = Data-Interpolating Convolutional Auto-Encoder

1 The situation

Spatial interpolation of in situ and remote-sensing observations has been performed for decades in oceanography, with several applications:

- simple visualisation
- initialisation of numerical models
- quality control of observations

We will present 3 tools designed for the interpolation of oceanographic data.

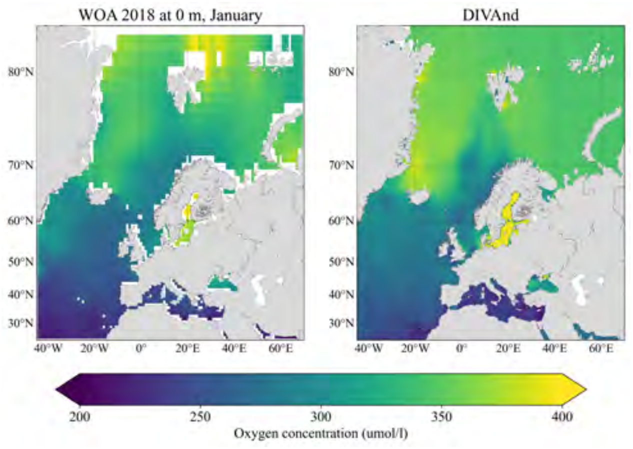

Figure 1: Gridded oxygen concentration from WOA and from EMODnet Chemistry.

2 The problems

Observing the ocean is complex:
variety of processes and spatial scales
always changing conditions
presence of clouds that prevents satellite observations

Oceanographic data interpolation is complex:

- Uneven data coverage
- Large amount of data to process
- Presence of physical boundaries (coastlines, land)

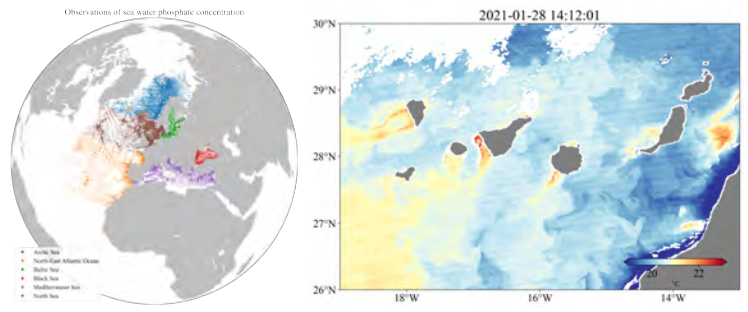

Figure 2: ↖ data locations for the phosphate concentration, taken from EMODnet Chemistry. ↗ sea surface temperature on January 28, 2021, as measured by SNPP/VIIRS.

3 Tool I: DINEOF

Method Empirical Orthogonal Function (EOF) based approach to fill in missing data from geophysical fields, typically because of the presence of clouds

Applications Sea surface temperature (SST), sea surface salinity (SSS), chlorophyll concentration or suspended particulate matter (SPM)

New developments Detection and removal of cloud shadows in high-resolution images.
Combination of data from sensors with different spatial and temporal resolutions, for instance Sentinel-2, Sentinel-3 and SEVIRI.

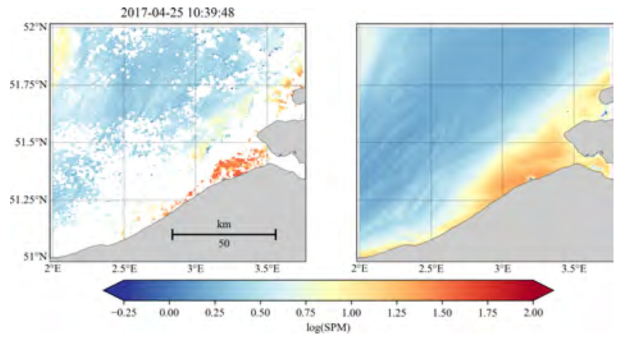

Figure 3: Reconstruction of Sentinel-3 suspended particular matter on April 25, 2017.

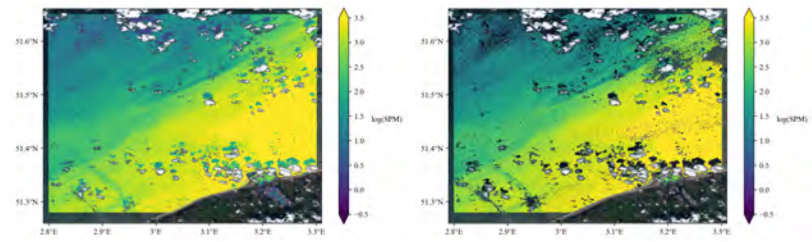

Figure 4: Sentinel-2 SPM before and after cloud shadow removal

4 Tool II: DIVAnd

Objective Generation of a gridded field using in situ measurements, in an arbitrary high dimensional space

Method Minimisation of a cost function that takes into account the proximity to the observations, the smoothness of the interpolated field and the presence of coastlines

Applications

EMODnet Chemistry interpolated maps

SeaDataCloud Climatologies

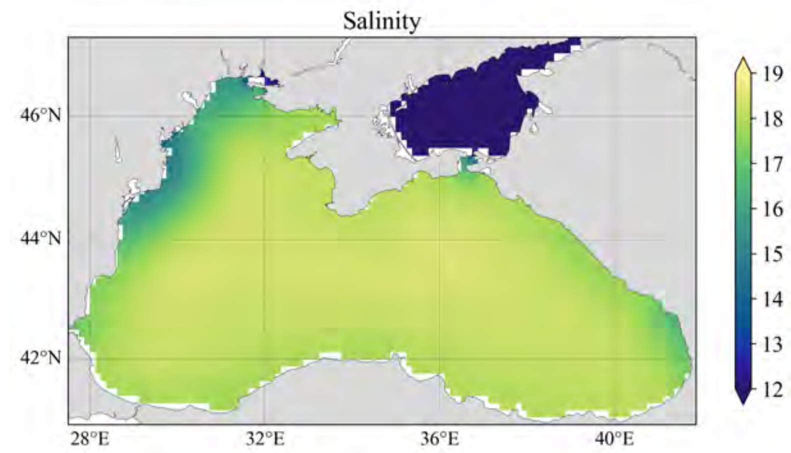

Figure 5: Winter salinity at 10 m depth in the Black Sea.

DIVAnd

New developments

EMODnet Biology: interpolation of presence/absence data with DIVAnd coupled with a neural network

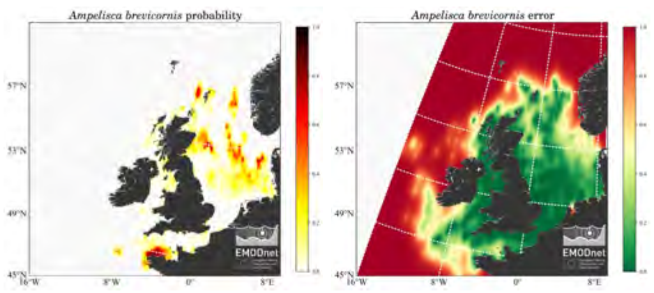

Figure 7: ← Map of probability of presence and → error field for "Ampelisca brevicornis".

EMODnet Physics: interpolation of sea surface velocity as measured by high-frequency radar

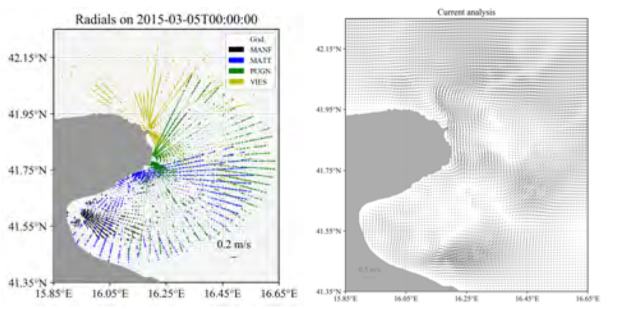

Figure 8: Radial velocities and interpolated field obtained combining 4 sites on March 5, 2015

Blue-Cloud: interpolation of abundance data for different species

5 Tool III: DINCAE

Objective Reconstruction of the missing data based on the available cloud-free pixels in satellite images.

Method Neural network with the structure of a convolutional auto-encoder
Requires a method to handle missing data (or data with variable accuracy) in the training phase.
The neural network is trained by maximizing the likelihood of the observed value.

Application reconstruction of 25-year time-series of Advanced Very High Resolution Radiometer (AVHRR) SST data

Results The reconstruction error of both approaches is computed using cross-validation and in situ observations from the World Ocean Database. DINCAE results have lower error, while showing higher variability than the DINEOF reconstruction.

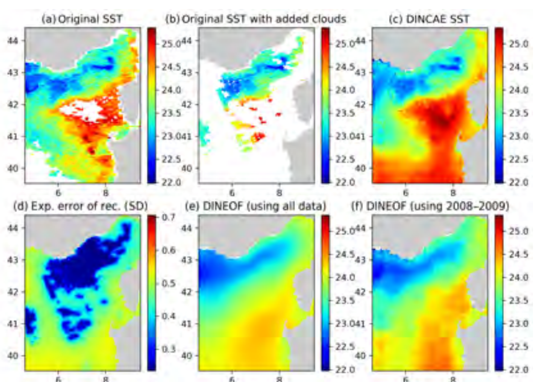

Figure 6: Original SST and reconstructions with DINCAE and DINEOF.

6 Code and publications

All the software tools are open source and the codes available on GitHub

https://github.com/gher-ulg/DIVAnd.jl (Julia)
https://github.com/aida-alvera/DINEOF (Fortran)
https://github.com/gher-ulg/DINCAE (Python, Julia)

Publications

Alvera-Azcárate, A.; Van der Zande, D.; Barth, A.; Cardoso dos Santos, J. F.; Troupin, C. & Beckers, J.-M. Detection of shadows in high spatial resolution ocean satellite data using DINEOF. *Remote Sensing of Environment*, 2021, **253**: 112229. 10.1016/j.rse.2020.112229

Barth, A.; Troupin, C.; Reyes, E.; Alvera-Azcárate, A.; Beckers, J.-M. & Tintoré, J. Variational interpolation of high-frequency radar surface currents using DIVAnd. *Ocean Dynamics*, 2021, **71**: 293--308. 10.1007/s10236-020-01432-x

Barth, A.; Alvera-Azcárate, A.; Licer, M. & Beckers, J.-M. DINCAE 1.0: a convolutional neural network with error estimates to reconstruct sea surface temperature satellite observations. *Geoscientific Model Development*, 2020, **13**: 1609--1622. 10.5194/gmd-13-1609-2020

Barth, A.; Beckers, J.-M.; Troupin, C.; Alvera-Azcárate, A. & Vandenbulcke, L. divand-1.0: n-dimensional variational data analysis for ocean observations. *Geoscientific Model Development*, 2014, **7**: 225--241. 10.5194/gmd-7-225-2014

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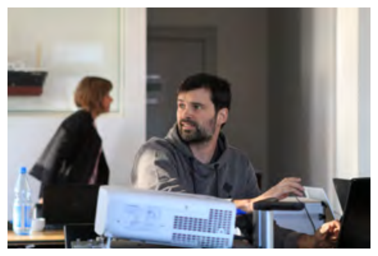

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