Three-dimensional analysis of oceanographic data with the software Diva

C. Troupin[1], M. Ouberdous[1], F. Machín[2], M. Rixen[3], D. Sirjacobs[1] & J.-M. Beckers[1]

[1] Université de Liège, GeoHydrodynamics and Environment Research (GHER), Sart-Tilman B5, Liège 1, Belgium
[2] Institut de Ciències del Mar (CSIC), Passeig Marítim de la Barceloneta, 37-49, 08003 Barcelona, SPAIN
[3] NURC - NATO Undersea Research Centre, Viale San Bartolomeo 400, 19126 La Spezia, Italy

1 Abstract

Diva (Data-Interpolating Variational Analysis) is a method designed to perform *data-gridding* (or *analysis*) tasks, with the assets of taking into account the intrinsic nature of oceanographic data, *i.e.* the uncertainty on the *in situ* measurements and the anisotropy due to advection and irregular coastlines and topography.
In the present work, three-dimensional reconstructions of temperature and salinity fields in the North Atlantic Ocean are achieved by stacking horizontal layers where independent analysis are performed. We also present a method to remove static instability between two or more consecutive layers.

2 Theory

2.1 Variational inverse method

The field φ reconstructed by Diva using N_d data d_j located at (x_j, y_j) is the solution of the variational principle

$$J[\varphi] = \sum_{j=1}^{Nd} \mu_j \left[d_j - \varphi(x_j, y_j)\right]^2 + \|\varphi\|^2 \qquad (1)$$

with

$$\|\varphi\| = \int_D (\alpha_2 \nabla\nabla\varphi : \nabla\nabla\varphi + \alpha_1 \nabla\varphi \cdot \nabla\varphi + \alpha_0 \varphi^2)\, dD \qquad (2)$$

where α_i and μ are determined from the data themselves, through their *correlation length* L and *signal-to-noise ration* λ.

2.2 Advection constraint

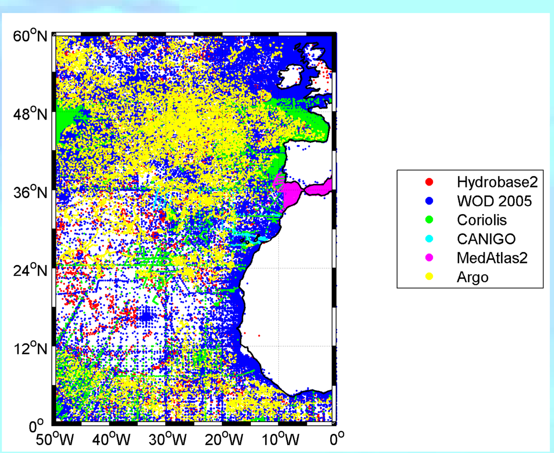
The advection constraint aims at modeling the effects of velocity on the reconstructed field. In theory, this constraint is activated by adding a term to the norm (2), leading to

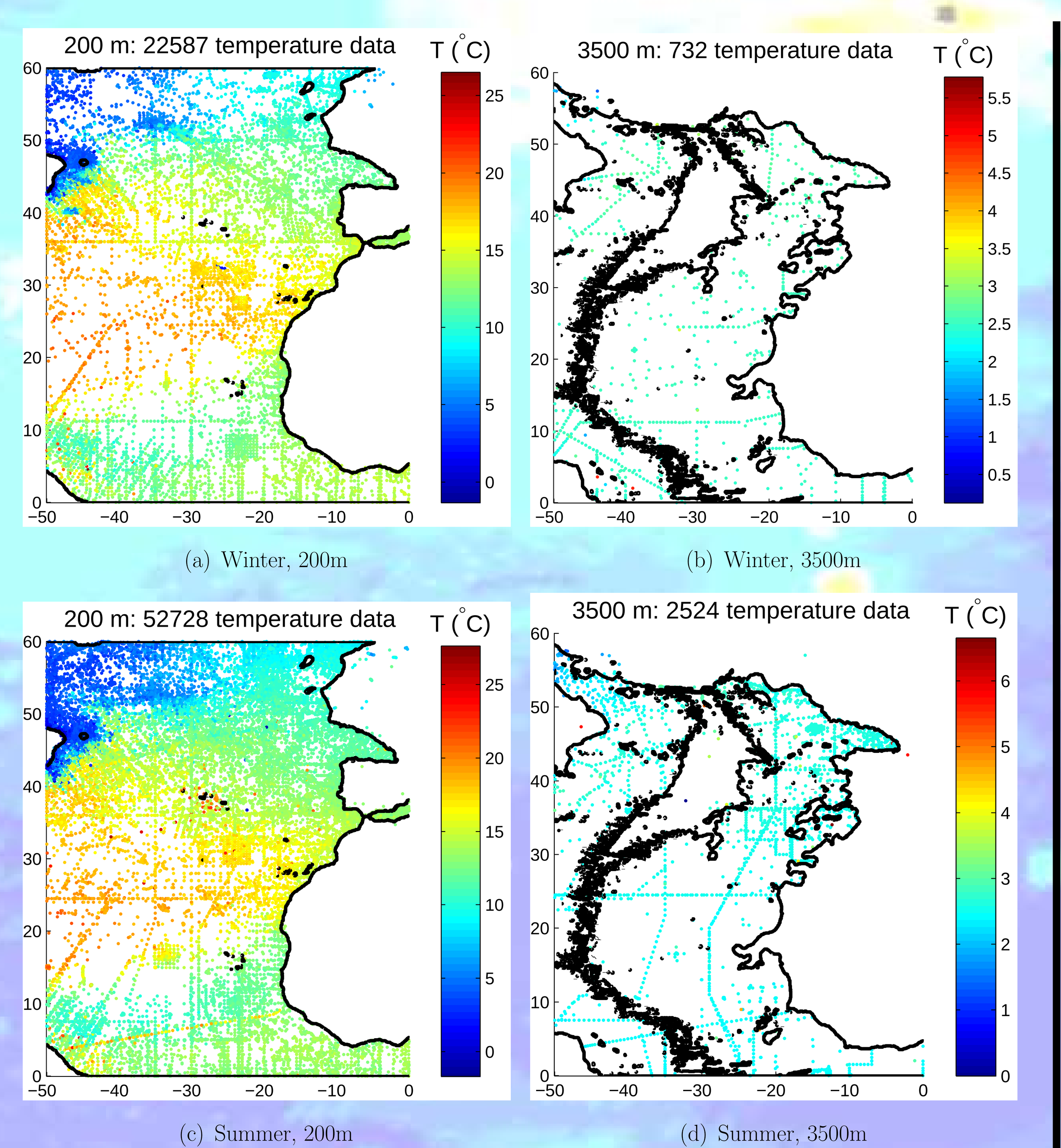
$$\tilde{J} = J(\varphi) + \frac{\theta}{U^2 L^2} \int_{\tilde{D}} \left[\vec{u} \cdot \tilde{\nabla}\varphi - \frac{\mathcal{A}}{L} \tilde{\nabla} \cdot \tilde{\nabla}\varphi\right]^2 d\tilde{D} \qquad (3)$$

where U is a velocity scale deduced from the provided (u, v) field;
L is a characteristic length;
θ is a parameter that controls the weight of the additional term;
$\mathcal{A}$ is a diffusion coefficient.

3 Data

Data were gathered from various databases in the region $0-60°$N $\times$ $0-50°$ W. We processed them to remove duplicates, detect outliers and perform vertical interpolation with *Weighted Parabolas* method [Reiniger and Ross (1968)].





(a) Winter, 200m (b) Winter, 3500m (c) Summer, 200m (d) Summer, 3500m

FIGURE 1: *Localisation of temperature observations at 200 m and 3500 m in winter and summer.*

4 Finite-element mesh

Resolution of Eq. (1) relies on a highly optimized finite-element technique, which permits computational efficiency independent on the data number and the consideration of real boundaries (coastlines and bottom).

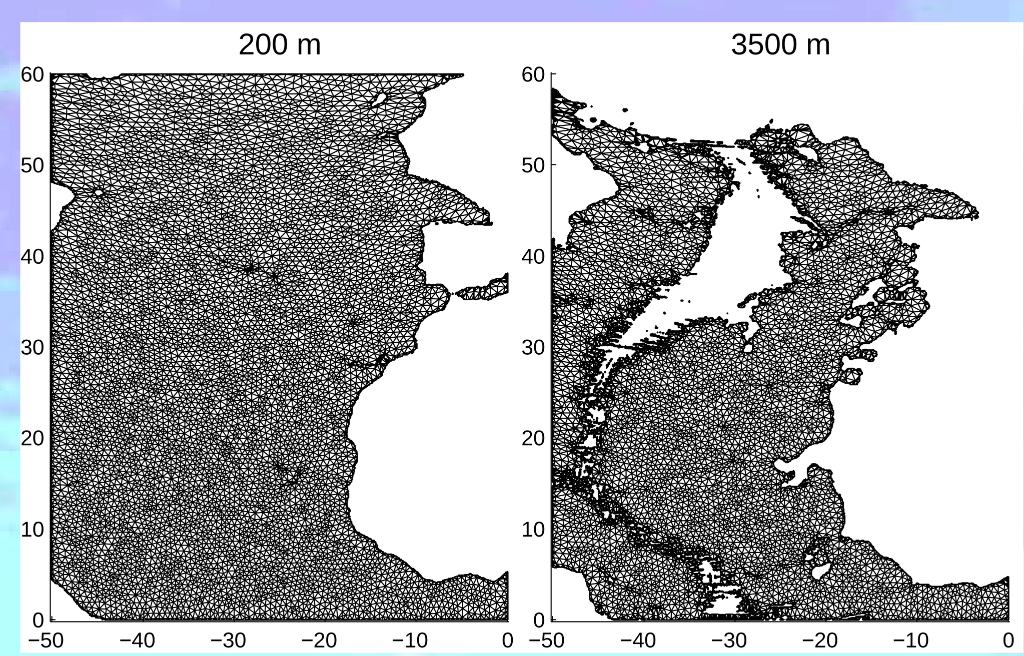
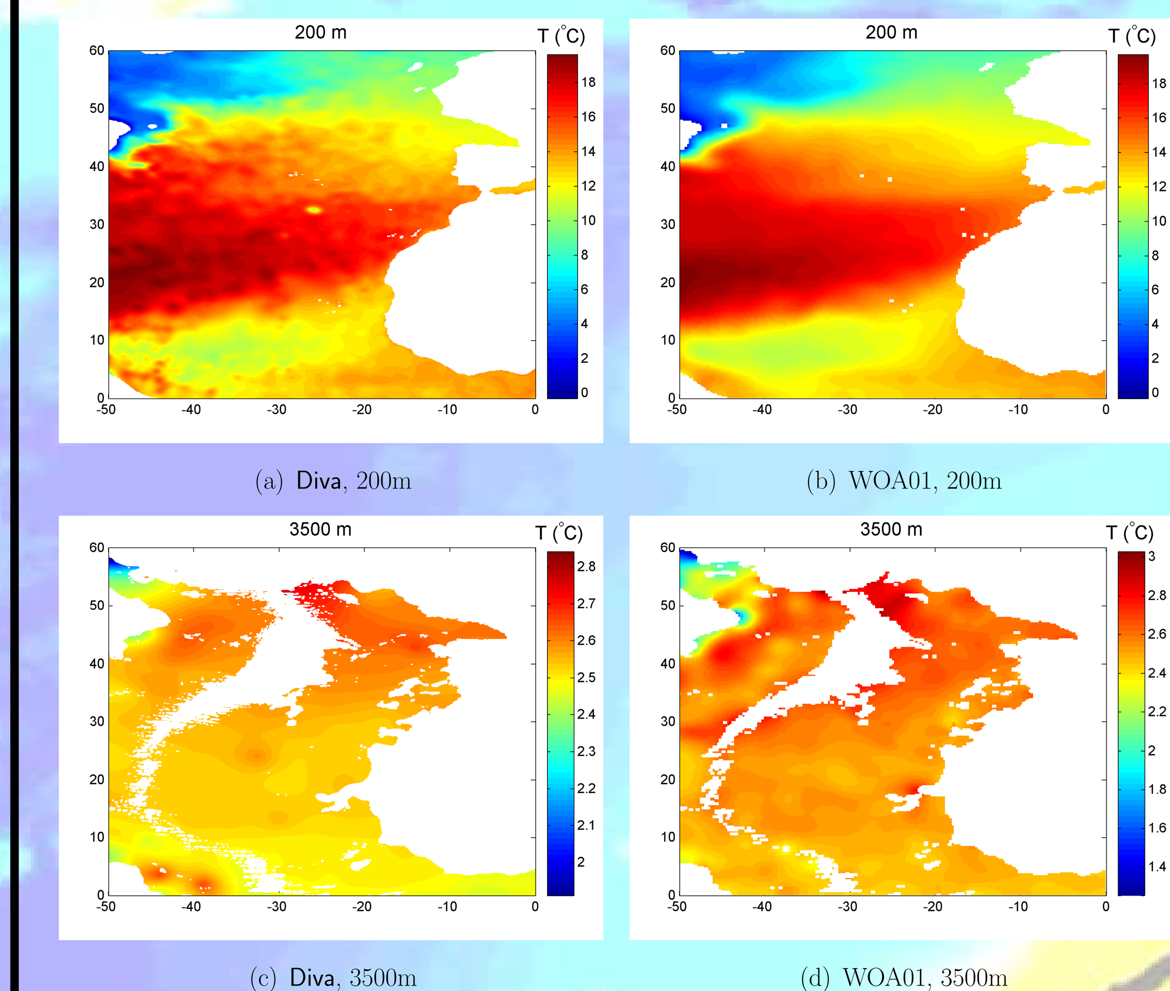


FIGURE 2: *Meshes generated at the 200 m (left) and 3500 m.*

5 Results

Our results are compared with 1/4° climatology from the World Ocean Atlas 2001 (WOA01 in the following, Boyer et al. (2005)).



(a) Diva, 200m (b) WOA01, 200m (c) Diva, 3500m (d) WOA01, 3500m

FIGURE 3: *Comparison of analysed temperature field with Diva (left) and WOA01.*

6 Stabilisation procedure

Hydrostatic instabilities may arise from analysis performed on two or more consecutive levels, in zone where the data coverage is not dense enough. In order to remove these instabilities:

- we keep analysis in two dimensions, as vertical coupling is usually weak in ocean;
- we add data from a layer to the upper layer in order to restore stability.

6.1 Pseudo-observation location

Since analysis propagate the data over a distance comparable to the *correlation length* L, pseudo-data are first added in the location of the grid point with strongest instability; the surrounding points do not need any pseudo-data for this iteration.

6.2 Pseudo-observation values

The pseudo-data is characterised by a temperature $\tilde{T}_k$ and a salinity $\tilde{S}_k$ that have to satisfy the stability condition

$$\frac{g}{\Delta z}\left[\alpha(\tilde{T}_k - T_{k-1}) - \beta(\tilde{S}_k - S_{k-1})\right] = \tilde{N}^2. \qquad (4)$$

$\tilde{N}^2$ is a slightly positive value so as to ensure stability. In order to determinate $\tilde{T}_k$ and $\tilde{S}_k$, we need another equation:

1. *Mixing* approach: the new water mass is a mix of (T, S) at levels k and $k-1$:

$$(\tilde{T}_k, \tilde{S}_k) = (T_k, S_k) + \eta\left[(T_k, S_k) - (T_{k-1}, S_{k-1})\right]. \qquad (5)$$

2. *Minimal perturbation* approach: the combined effect of perturbations δT and δS on the density are minimised by considering the objective function:

$$J = w(n_T)\,\alpha^2 \delta T^2 + w(n_S)\,\beta^2 \delta S^2, \qquad (6)$$

where $w(n)$ is a decreasing function of n, n_T, n_S are the number of T and S data in layer k, respectively.

7 Conclusion

Diva is shown to be an efficient method for geophysical field reconstruction. Main assets over World Ocean climatologies are the better representation of coastline and the better resolution of small-scale processes.
Further work will include improved quality control of data (range specification not sufficient) and effect of advection through the definition of velocity fields.

Acknowledgments

Diva was developed by the GHER and improved in the frame of the SeaDataNet project, an Integrated Infrastructure Initiative of the EU Sixth Framework Programme. We thank all the users for their various contributions to the enhancement of the software.
We thank Eugenio Fraile Nuez (Instituto Espanol de Oceanografía) for his contribution during the data collection and Evan Mason (ULPGC) for his helpful suggestions in the data processing.
The support from the Fonds pour la Formation à la Recherche dans l'Industrie et dans l'Agriculture (FRIA) is greatly appreciated.

Some references

References

[1] Boyer, T., S. Levitus, H. Garcia, R. Locarnini, C. Stephens, and J. Antonov. Objective analyses of annual, seasonal, and monthly temperature and salinity for the world ocean on a 0.25° degree grid. *International Journal of Climatology*, **25**: 931-945; 2005.

[2] Brankart, J.-M., and P. Brasseur. Optimal Anlysis of In Situ Data in the Western Mediterranean Using Statistics and Cross-Validation. *Journal of Atmospheric and Oceanic Technology*, **13**:477-491, 1996.

[3] Brasseur, P., J.-M. Beckers, J.-M. Brankart, and R. Schoenauen. Seasonal temperature and salinity fields in the Mediterranean Sea: Climatological analyses of a historical data set. *Deep Sea Research*, **43**:159-192, 1996.

[4] Reiniger, R. and C. Ross. A method of interpolation with application to oceanographic data. *Deep-Sea Research*, **15**: 185-193, 1968.

[5] Rixen, M., J.-M. Beckers, J.-M. Brankart, and P. Brasseur. A numerically efficient data analysis method with error map generation. *Ocean Modelling*, **2**:45-60, 2000.

⋆ **Contact:** ctroupin@ulg.ac.be
http://modb.oce.ulg.ac.be/projects/1/diva