Data-Interpolating Variational Analysis (DIVA) software: recent development and application

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1. Context

The Data-Interpolating Variational Analysis (DIVA) software is a tool designed to reconstruct a continuous field from discrete measurements. This method is based on the numerical implementation of the Variational Inverse Model (VIM), which consists of a minimization of a cost function, allowing the choice of the analyzed field fitting at best the data sets. The problem is solved efficiently using a finite-element method. This statistical method is particularly suited to deal with irregularly-spaced observations, producing outputs on a regular grid.

Initially created to work in a two-dimensional way, the software is now able to handle 3D or even 4D analysis, in order to easily produce ocean climatologies. These analyses can be improved by taking advantage of the DIVA's ability to take topographic and dynamic constraints into account (coastal relief, prevailing wind impacting the advection,...).

2. Method

2.1 Variational inverse method

We are looking for the field φ which minimizes the variational principle over our domain of interest D:

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

with

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

where the α_i and the μ_j are determined from the data d_j themselves, through their correlation length L and signal-to-noise ratio λ.

2.2 Finite-element mesh

In order to solve the problem, a triangular-element mesh is computed by DIVA. The characteristic length of each element is directly linked to the correlation length of the analyzed variable (see Fig. 1).

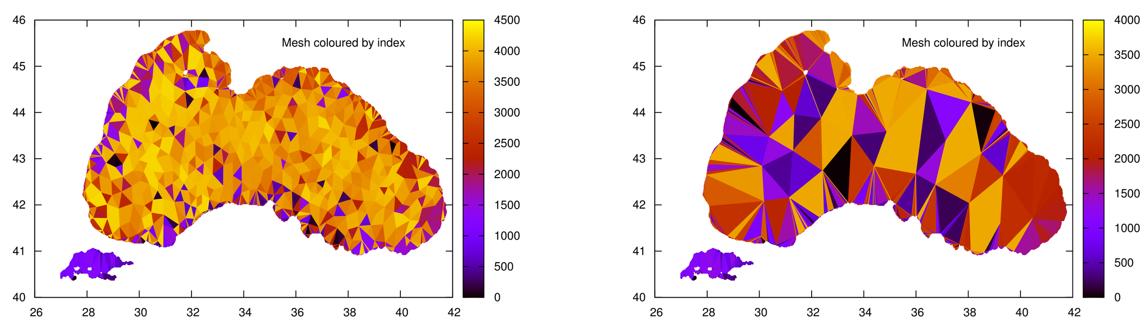

Figure 1: The mesh computed by DIVA for the Black Sea at 30 m depth, using a correlation length of 1.5 degrees (left) and 5 degrees (right). The resolution is higher near the coast, allowing the analyses of coastal phenomenons such as upwellings.

3. Data weighting

3.1 The problem

Since DIVA works with a diagonal observation error covariance matrix, it is assumed that the observation errors are uncorrelated in space and time. In practice, this assumption is not always valid especially when dealing e.g. with cruise measurements (same instrument) or with time series at a fixed geographic point (representativity error).

3.2 The solution

The data weighting option proposes to decrease the weight of such observations in the analysis. These weights are based on an exponential function using a 3D (x,y,t) distance between several observations:

$$W_i = \frac{1}{\sum_{j=1}^{N_{box}} \exp(-((\frac{\triangle x_{ij}}{L_X})^2 + (\frac{\triangle y_{ij}}{L_Y})^2 + (\frac{\triangle t_{ij}}{L_T})^2))} \quad (3)$$

where N_{box} is the number of data in a box defined by the characteristic length scales $(3L_X, 3L_Y, 3L_T)$ surrounding each data. $\triangle x_{ij}, \triangle y_{ij} and \triangle t_{ij}$ are the distances between 2 data in this box. A simple example is presented in Fig. 2.

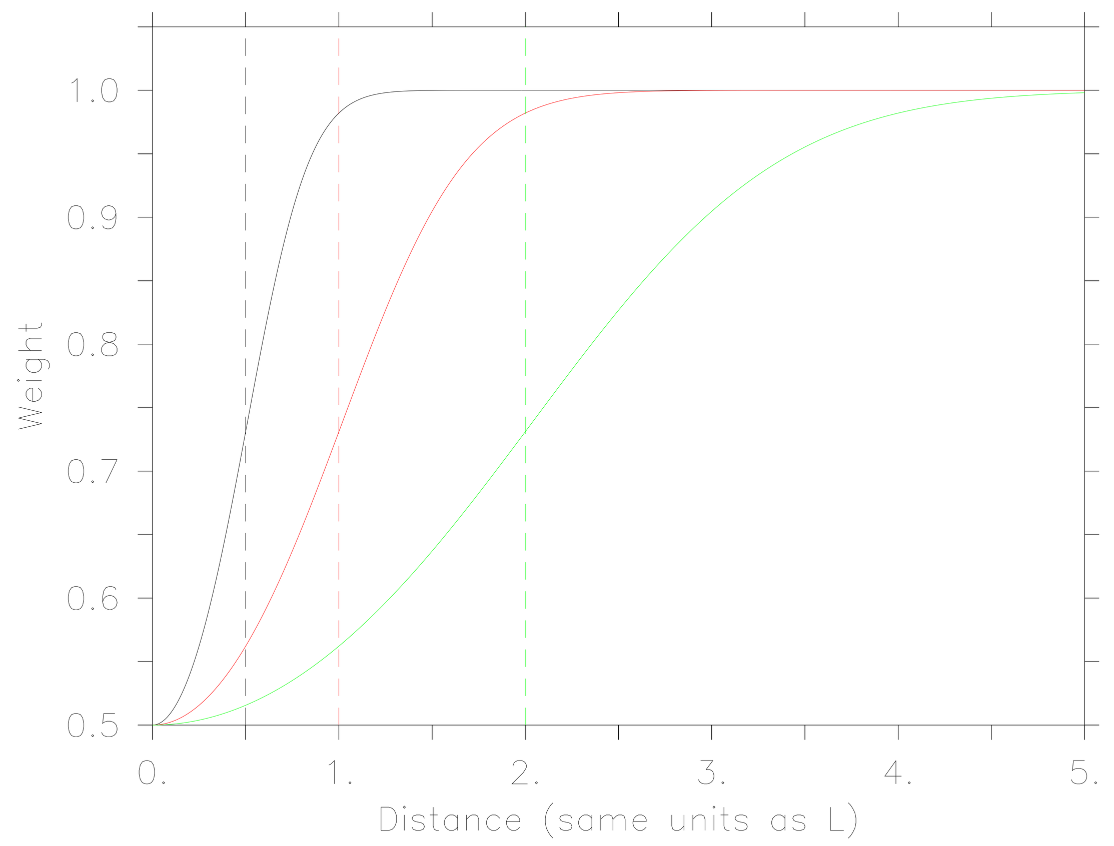

Figure 2: 1D example of data weighting for 2 points. Each curve represent the weight of each data in the analysis as a function of the distance between them, using the L_x of the corresponding dashed line. The maximum weight of 1 correspond to an isolated point without redundance of information.

3.3 Application

A comparison between not-weighted and weighted analyses is shown in Fig. 3. The following approach is used:

- DIVA analysis over the Baltic;
- Sea Surface Temperature (SST);
- July 1900–2012.

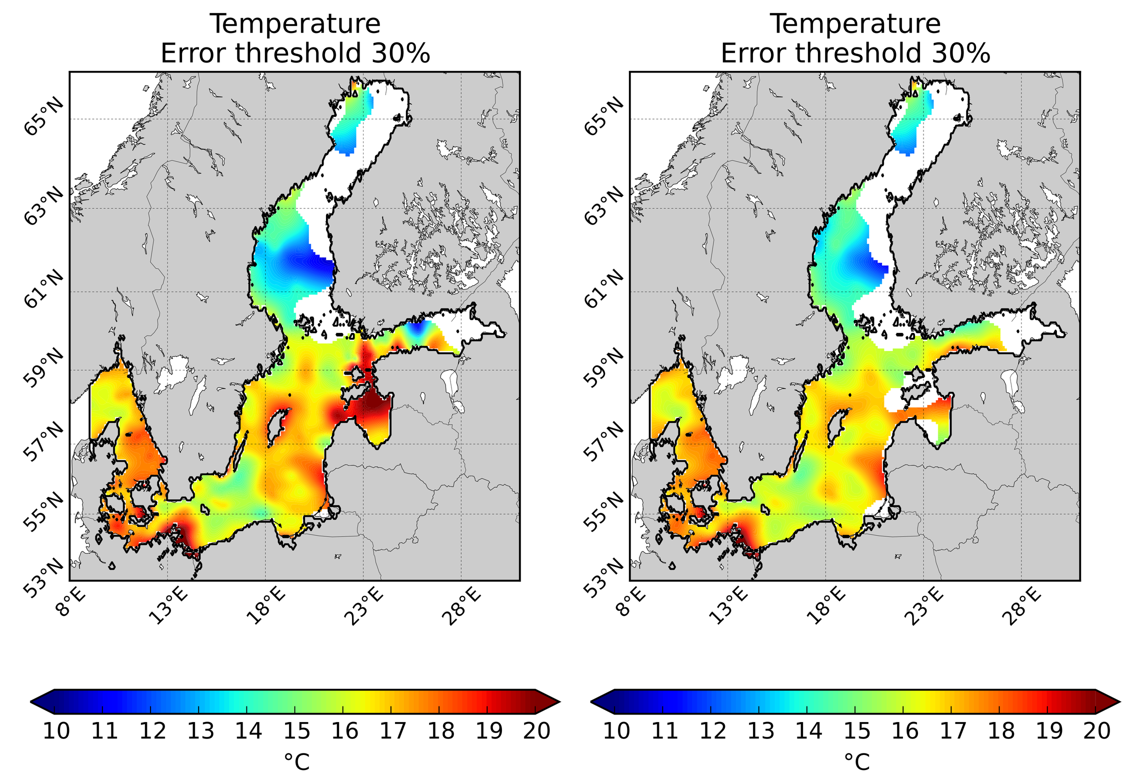

Figure 3: SST analyses over the Baltic Sea with (right) and without (left) data weighting. These analyses use in situ data over July 1900–2012.

The resulting analyses shows a better accuracy when the data weighting option is enabled, especially in the eastern part of the domain. In particular, the cold point (60° N, 25.5° E) due to the overabundance of data in cold years almost disappeared in the upgraded analysis.

4. Bottom variables...

4.1 Motivation

It has been a recurrent request from the DIVA users to improve the way the analyses near the ocean bottom are produced. Up to now, the analyses were performed at several depths counted from the ocean surface, meaning that horizontal layers were used for the analyses, and then combined in a "deepest variable" field using for each grid point the deepest result available.

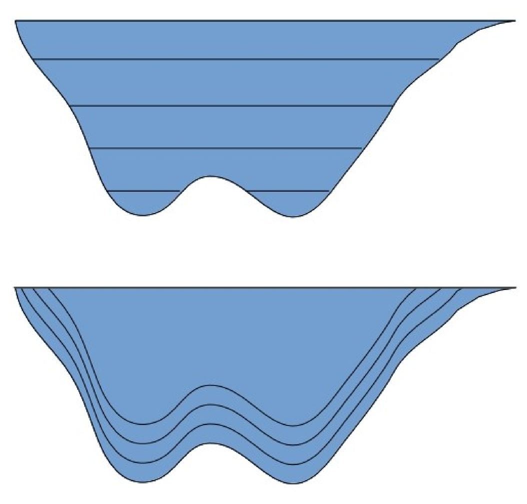

Figure 4: Illustration of both possibilities to analyze data on 2D layers: at a specific distance from the surface (top) and from the ocean bottom (bottom).

Although simple, this former method had two significant drawbacks:

- some layers close to the bottom become divided in many patches, leading to an underestimated propagation of the information;
- many applications require a fixed distance from the ocean bottom.

In the last DIVA version, a new feature allows the computation of the layers from several user-defined distances from the bottom surface (see Fig. 4).

5. ...using a very high resolution bathymetry!

This new method aims to minimize the error on the value of the bottom depth by using the new bathymetry of EMODnet at very high resolution (see Fig. 5).

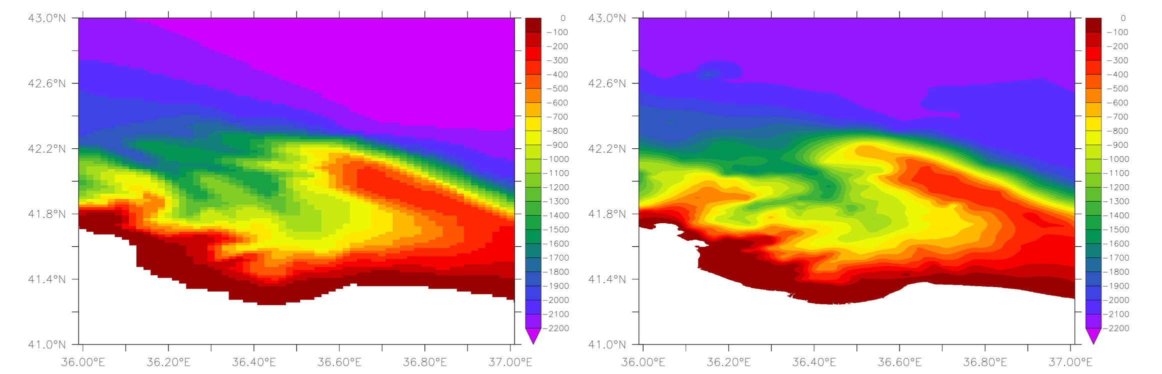

Figure 5: Improvement of the bathymetry used in DIVA for the extraction of the bottom depth, comparison over the Black Sea. Left: GEBCO bathymetry (30 s). Right: EMODnet bathymetry (7.5 s).

Take-home message

- **The data redundancy is mitigated via a weighting prior to the data analysis**
- This method gives **promising results** on the Baltic Sea
- **Ocean bottom variables can now be handled by DIVA**
- This feature is made robust thanks to a **new bathymetry at high resolution**
- DIVA users continue to play a key role in development

Acknowledgments

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Reference

Troupin et al. (2012). *Generation of analysis and consistent error fields using the Data Interpolating Variationnal Analysis (Diva).* Ocean Modelling, 52-53, 90-101.

How to get the code ?

Diva is available at `http://modb.oce.ulg.ac.be/mediawiki/index.php/DIVA`, as well as documentation (user guide, tutorials,...) and binaries for various O.S.