Reconstruction of Total Suspended Matter Data over the Southern North Sea and English Channel using Empirical Orthogonal Function Decomposition of Satellite Imagery and Hydrodynamical Modelling.

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MUMM - RBINS

1. INTRODUCTION

Although providing the best spatio-temporal coverage of all oceanographic surface observations, satellite data archives are still limited by clouds, satellite passage frequency or other retrieval problems. Various marine ecosystem studies requires more complete view of the dynamics and call for sound space-time filling of the gaps. This research is part of the RECOLOUR project (Reconstruction of Colour Scenes, Belgian Science Policy) exploiting the Data Interpolation with Empirical Orthogonal Functions methodology (DINEOF) for reconstruction of complete space-time information for the BELCOLOUR archive of surface chlorophyll A (CHL), total suspended matter (TSM) and Sea Surface Temperature (SST) images over the North Sea. Here, the DINEOF methodology is applied to the MODIS TSM images of the year 2005 and various main products are illustrated (dominants EOFs, filled images, associated error and outliers maps). Multivariate processings were realized including hydrodynamical fields from the C&SNS model and some subsequent improvements of the reconstruction quality are illustrated.

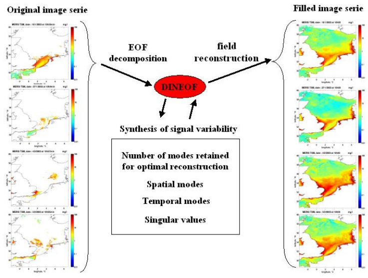


Fig 1 - Scheme of main DINEOF inputs and outputs (illustrated by MERIS TSM images of the North Sea).

More Information on DINEOF at :
http://groups.google.com/group/dineof

2. DINEOF

PRINCIPLE: **the information of a collection of cloud-free images can be efficiently synthetised by EOFs, each described by a spatial mode (2D map) and a corresponding temporal mode (1D time series, also called the EOF amplitudes).**

EOF Properties: **using 1 EOF = best possible approximation of all images using only one spatial mode multiplied by an amplitude for each image; using N EOF = best way to summarize the information content of all images if only N spatial patterns can be stored.**

Practical calculation of the EOFs: **DINEOF calculates the EOFs by an iterative method exploiting singular value decomposition of the data matrix, which sets a first guess of zero anomalies in the missing data points, while the number of retained EOFs is fixed by a cross-validation technique based on the minimisation of the root-mean-square (RMS) misfit between some data set aside and its reconstruction (Alvera-Azcárate et al.,2005; Beckers et al., 2003). Main inputs and outputs of the DINEOF analysis are summarized in Figure 1.**

Missing Data Reconstruction: **each image is replaced by a filtered version in which the basic spatial patterns are linearly combined with amplitudes corresponding to each image. If images are sequential in time: the amplitudes = time evolution of the spatial patterns amplitude or temporal mode.**

MULTIVARIATE EXPLOITATION : **DINEOF algorithm can take into account augmented state vector constituted of any complementary data added to the satellite image at each temporal step considered (Alvera-Azcarate et al., 2007). This allow to test for improvements of missing data reconstruction as to explore the common traits of the dynamics of several parameters. Prior to treatment, a normalisation of each parameter and a relative surface pixel weighting ponderation must be applied.**

GENERATION OF ERROR MAPS AND DETECTION OF OUTLIERS : **Based on the outputs of DINEOF analysis, Beckers et al. (2006) described a methodology allowing to produce error maps associated to every reconstruction, providing thus important complementary information for the practical interpretation or exploitation of the analysed scenes. Recently, a methodology was implemented to classify original pixels on a scale expressing their "outlying" character based on the overall statistics synthetised by DINEOF, a data beeing considered as outlier when the difference between the corresponding reconstructed (filtered) and original value is greater then 3 times the expected reconstruction error.**

3. DATA

Area of interest: English Channel and Southern North Sea [48.5°N-52.5°N, 4°W-5°E]

REMOTE SENSING DATA

MODIS Total Suspended Matter (TSM) : 313 images of the year 2005; Extracted from the BELCOLOUR database [Ruddick et al., 2000; http://www.mumm.ac.be/BELCOLOUR/EN/Products/index.php].
Spatial resolution : 1 km
Frequency: daily, occasionnaly two images per day
Proportion of missing data: 70 %
TSM data are provided to DINEOF as anomalies of the TSM natural logarithm around its background field (Figure 2).

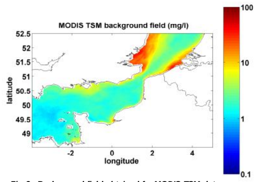


Fig 2 - Background field obtained for MODIS TSM data, year 2005.

C&SNS HYDRODYNAMIC MODEL DATA

A 3D hydrodynamical model based on the COHERENS code (Luyten et al., 1999) has been implemented for the English Channel and the Southern North Sea (C&SNS) (Lacroix et al., 2004).
Spatial resolution: about 5 km.
Temporal resolution : 15 minutes
Parameters were extracted during runs of the model to feed the DINEOF multivariate analysis, based on their potential influence on the TSM dynamics : 1) Wind-U [m/s]; 2) Wind-V [m/s]; 3) mean depth U-velocity [m/s]; 4) mean depth V-velocity [m/s]; 5) surface elevation [m]; 6) Bottom stress maximum [m²/s²], between 8hpm previous day-9am satellite image day.

4. RESULTS

For the DINEOF univariate treatment of MODIS TSM 2005 images, 6 EOFs were retained for an optimal reconstruction, synthetising 97.2 % of the variability of the input signal. The 3 dominant spatio-temporal modes are illustrated in Figure 3, together with the relative input data variability explained by each mode (parameter 'varex').

Figure 4 illustrates two original images recorded at short interval on the 08/02/05, with their associated outlier coefficient maps, filled images and relative error maps. One can note areas of rather low values in the north of the first original image, also identified with high values (red) in the outlier map, and having been rather filtered in the reconstructed image.

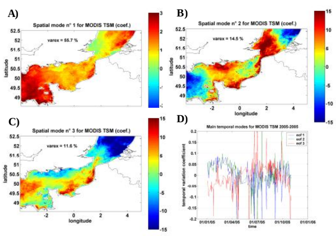


Fig 3 - 3 dominant modes (adimensional coef.) resulting from the univariate treatment of MODIS TSM 2005 images (spatial modes in A,B,C with related explained variability 'varex'; temporal modes in D).

Between the first and second images there is only 1h35 minutes interval, but changes of TSM concentrations can be observed in the western part of the Channel, both in original and reconstructed fields. This illustrates the interest of exploiting complementary hydrodynamical information to resolve better the smaller scale dynamics during reconstruction, as satellite acquisition frequency are low comparativelly to some driving physical phenomena, as tidal dynamics for instance.

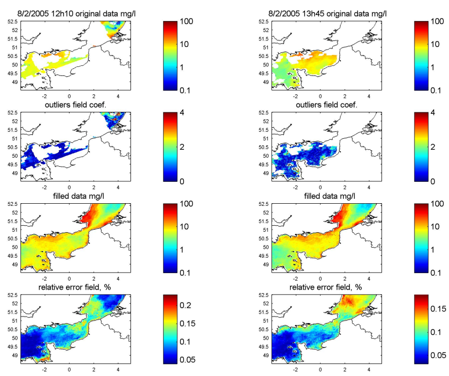
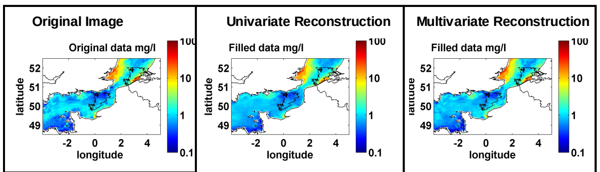


Fig 4 - Illustrations of original MODIS TSM image, associated outlier coefficient maps, filled image, and error map (top-down in a column). The 2 sets of images concerns the same day 08/02/05 at short interval: 12h10 (left) 13h45 (right).



run	parameters	Neof	Sumvarex	Cor. length.
			%	km
a	monovariate	6	97,22	17,12
b	wind U V	14	97,93	15,09
c	as in runs b and g	17	98,87	17,66
d	current U V	12	99,12	15,62
f	Wind and Current UV	17	98,88	15,82
g	surface elevation	6	97,15	19,23
h	shear stress max	6	97,15	19,23
i	as in run g and h	6	97,08	21,67
j	current U V and g	12	99,11	17,19
k	current U V and h	12	99,11	17,19
l	all param.	17	98,87	17,66

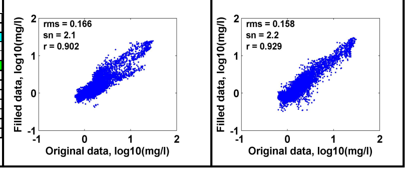


Fig 5 – Original MODIS TSM image on the 29/08/2005, top left. Synthesis table of multivariate analysis, down left. DINEOF univariate (top middle) and multivariate reconstructions with currents (top right). Reconstruction quality under false cloud identified by black edge on Belgian coastal area for univariate treatment and for multivariate treatment are down middle and right; (for data below cloud: rms=root mean square of the error, sn = signal to noise ratio for the reconstructed data sets, r = correlation coefficient).

To test the impact of multivariate treatment with different combinations of hydrodynamical model parameters, DINEOF runs were launched with an original set of images in which data were retrieved under 2 false clouds in 2 images of the serie. Forthe univariate treatment already, Figure 5 shows a rather encouraging reconstruction quality for data retrieved from the original image under the false clouds surrounded by black line over the Belgian coast. Fig 5 illustrates also the best improvement of the reconstruction obtained by the multivariate treatment considering mean depth U and V velocities (rigth column): raise of signal-to-noise ratio and correlation calculated under clouds, lower filtration of consistant small scale structures and a total variability synthetized (sumvarex) reaching 99,1 % against 97,2 % in monovariate run. Looking at quality of reconstruction under added clouds only, the multivariate exploitation of the wind components brought aslo some improvements, exploitation of surface elevation and/or shear stress had no impact, joint exploitation of wind with current components had negative impact, as it was also the case for the joint multivariate exploitation of all model parameters at once.

5. CONCLUSIONS

1) DINEOF methodology is efficient and allows production of :
- **reconstructed fields at image acquisition time, as at any other regular time steps (i.e. daily)**
- **less biaised multitemporal averages and climatologies**
- **continuous time serie at any reference station, or over particular subregions.**

2) Successfull applications where earlier shown on TSM, CHL and SST products from MERIS and MODIS over the North Sea (Sirjacobs et al., 2008).

3) Outliers maps are promising for furher improvements of original and filled data quality, as for easier identification of unusual events.

4) Monovariate treatment of MODIS TSM data for 2005 could be synthetized into 6 EOFs accounting 97,2 % of the total variability of the input signal.

5) Multivariate approach : best improvement obtained with mean depth current U and V components, (12 EOFs accounting for 99,1% of the total input signal variability), with less filtration of smaller structures (correlation length estimate reduced from 17,1 to 15,6 km).

Acknowledgments

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