Evolution of Western Mediterranean Sea Surface Temperature between 1985 and 2005:

A complementary study in situ, satellite and modelling approaches

C. Troupin, F. Lenartz, D. Sirjacobs, A. Alvera-Azcárate, A. Barth, M. Ouberdous, and J.-M. Beckers

GeoHydrodynamics and Environment Research (GHER), University of Liège

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Outline

Objectives

- Evaluation of variability of SST in Western Mediterranean Sea,
- Application of different tools on common region
- Characterization of differences

Outputs

- Annual, seasonal and monthly fields $(1/16^\circ)$
- Interannual trend of SST

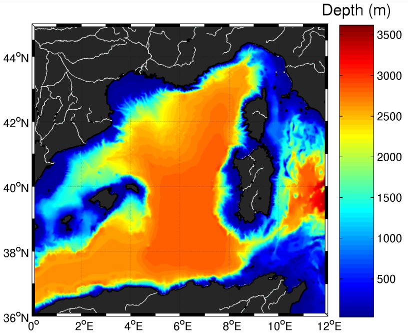


Figure: Bathymetry and rivers of the studied region.

Domain: $0 - 12^\circ E \times 36 - 45^\circ N$

Period: $1985 - 2005$

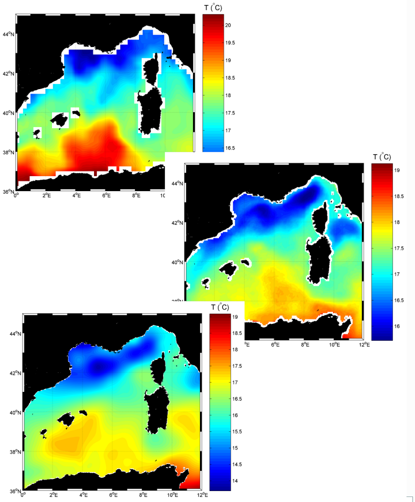
Tools

= Numerical model
+ satellite images
+ *in situ* data analysis

GHER : 3D model (Beckers, 1991, JMS)

DINEOF : Data Interpolation with Empirical Orthogonal Functions (Alvera-Azcárate et al., 2005, OM)

Diva : Data Interpolating Variationnal Analysis (Brasseur et al., 1996, DSR)



GHER model

General:

- Variables: T, S, SSE, u, v, $\mathtt{tke}$
- Boussinesq approximation, Cartesian coordinates, Arakawa C-grid, mode splitting
- k-turbulent kinetic energy closure scheme (Nihoul et al, 1989, ESR)
- algebraic equation for ϵ

Atmospheric forcing:

- Sources: ECMWF reanalysis + NCEP
- Bulk formula (Kondo et al., 1975)

Implementation: (Barth et al., 2006, OM)

Applications:

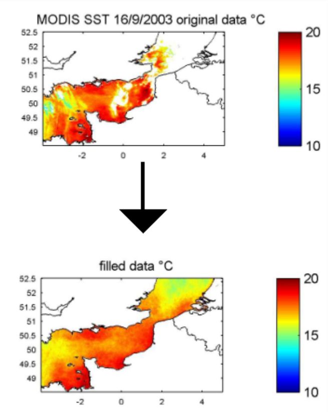
- Western Mediterranean Sea (Beckers, 1991, JMS ; Beckers et al., 1997, DSR),
- MEDMEX experiment (Beckers et al., 2002, JMS)

Objectives:

- identification of dominant spatio-temporal features
- full gridded data at regular time steps
- identification of suspect data

Principle (Alvera-Azcárate et al., 2005, OM ; 2006, JGR ; Beckers et al., 2006, OS)

1. Empirical Orthogonal Functions (EOF) decomposition (iterations)
2. General Cross Validation (GCV) $\rightarrow$ optimal number of EOF



Wednesday, 09:30-09:45, Room: 3

A. Alvera-Azcárate *et al.*

Reconstruction of missing data in satellite data sets using DINEOF with constraints to reduce spurious high-frequency variations in the temporal EOFs.

Diva

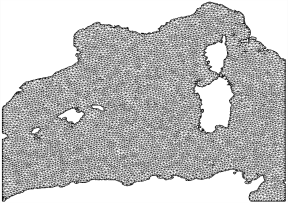
Principle: sparse data $\longrightarrow$ gridded field
Theory:

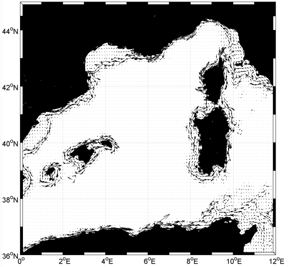
$$\min J\left[\varphi\right] = \sum_{j=1}^{Nd} \mu_j \left[d_j - \varphi(x_j, y_j)\right]^2 + \|\varphi\|^2$$

- + finite-element mesh solver
- + error maps
- + advection influence:

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

$\longrightarrow$ Reinforced correlation along isobaths





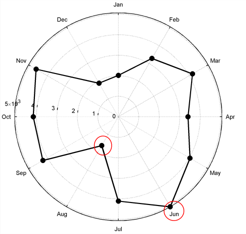
In situ measurements

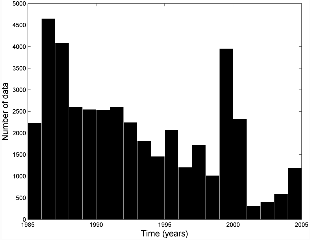
Sources : WOD05 + MedAtlas2 + Hydrobase2 + Coriolis

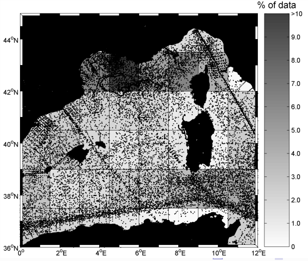
Pre-processing : duplicate detection + QC → 42305 profiles

Statistics

- 1986: 3267 measurements, 2002: < 400
- June: > 5000, August: 1600
- mean: $18.54°C$, standard deviation: $3.92°C$







Satellite images

Sources:

Sensor: AVHRR Pathfinder SST, http://podaac.jpl.nasa.gov

Period: 1985-2005

Resolution: remapped daily at $1/16°$ [Marullo et al. (2006)]

Quality:
- Space: $>5\%$ of valid data / image
- Time: $>5\%$ of data presence/ pixel

$\rightarrow$ Analysis with 3452 images

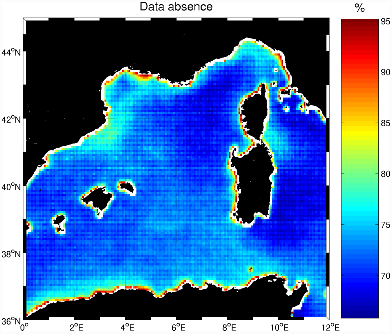


Figure: Percentage of non valid data per pixel.

Data analysis

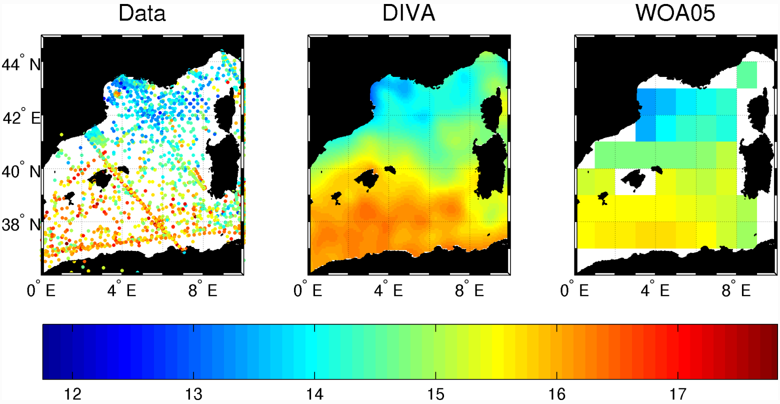


Figure: Data (left), analyzed fields (center) and WOA 2005 climatology for February.

Data analysis

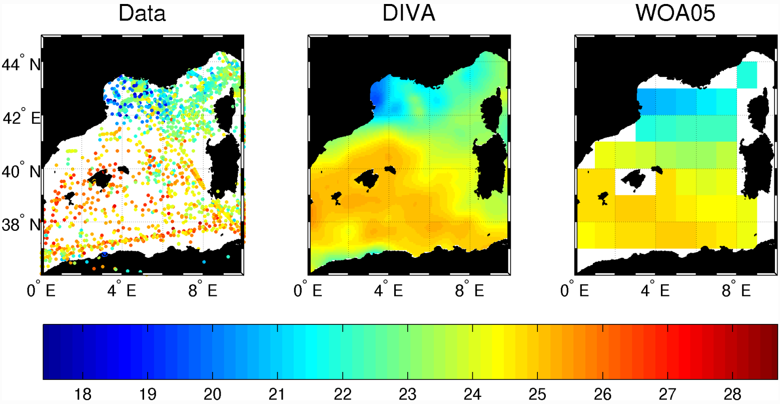


Figure: Data (left), analyzed fields (center) and WOA 2005 climatology for September.

Error fields

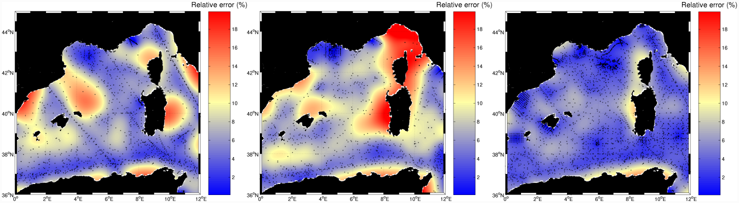
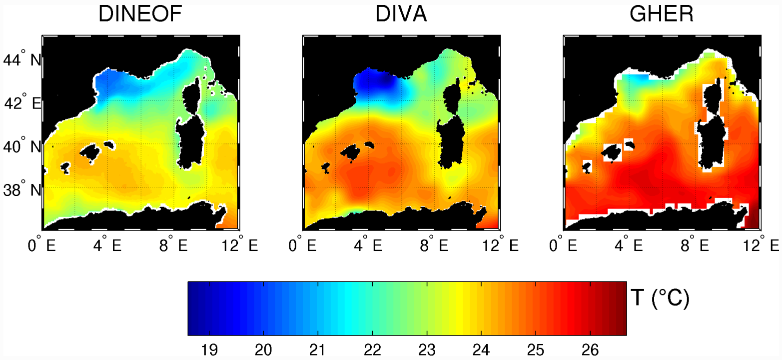


Figure: Relative error fields for January, August and November. Data locations are indicated by black dots.

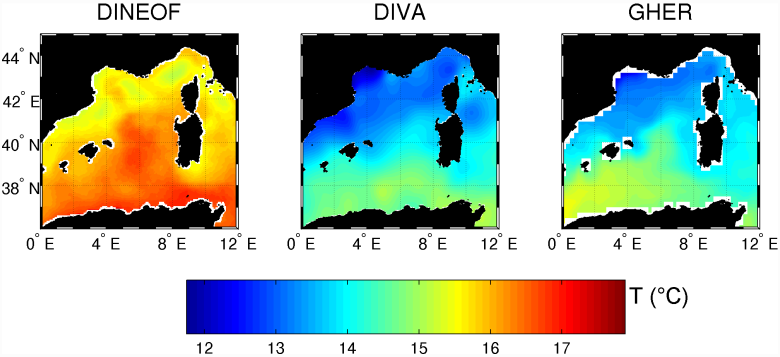
- Reflects *confidence* in the results
- Depend on two factors
  1. Data coverage
  2. Noise on data

examples:
All: African coast
August: least sampled month (see Slide data)
November: homogeneous sampling

Comparison: September



Comparison: February



Origins:

1. Irregular data distribution (Slide data)
2. Unequal repartition of cloud coverage
3. Surface effects (skin vs. *in situ* temperature)
4. Forcing accuracy
5. Small-scale process parameterization
6. Open boundary conditions

1. Need for good *a priori* quality control
2. Analysis dependent quality control

$$\|d_i - \tilde{d}_i\| > 3\Delta$$

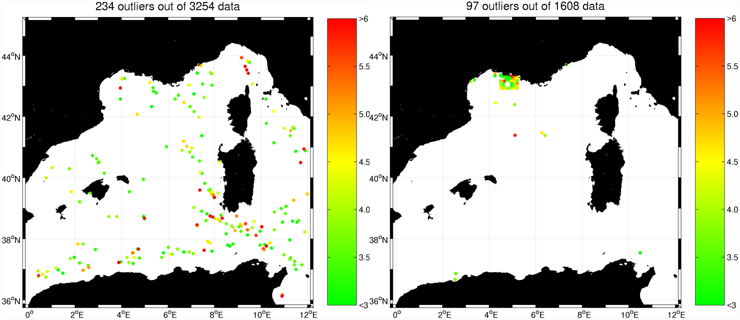


Figure: Outlier locations. Colorbars indicate ratio between data-analysis misfit and expected misfit.

Improvements: *detrending*

Definition of groups: one data $\in$ one class of the group
Example: group = years, classes = 1985, 1986, ...

Minimization:

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

$$\rightarrow \sum_{j \in C_1} \mu_j \left[d_j - d_{C_1} - \varphi(x_j, y_j)\right]^2 + \sum_{j \in C_2} \mu_j \left[d_j - d_{C_2} - \varphi(x_j, y_j)\right]^2 + \dots$$

$\rightarrow$ new unknows d_{C_ℓ}

$$d_{C_\ell} = \frac{\sum_{j \in C_1} \mu_j \left[d_j - \varphi(x_j, y_j)\right]}{\sum_{j \in C_1} \mu_j}$$

Resolution: iterative process, first guess: $d_{C_\ell} = 0$

Outputs: *detrended* fields + trend for each group

Detrending: application

Group 1: months
Classes: 1, 2, 3 . . . , 12

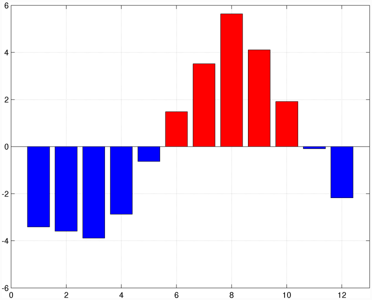


Figure: Monthly trend extracted during the analysis.

Group 2: years
Classes: 1985, 1986, . . . , 2005

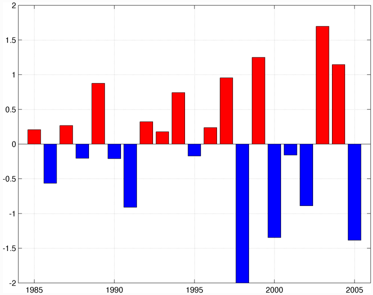


Figure: Annual trend extracted during the analysis.

Detrending: application

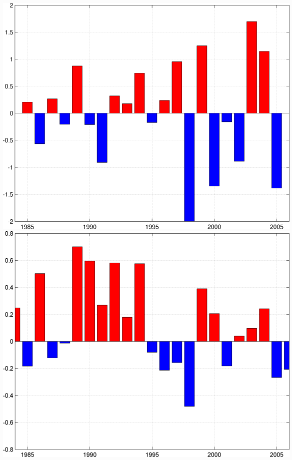


Figure: Trend extracted from data (top) and NAO index.

NAO index: from Li and Wang, 2003, Adv. Atmos. Sci.

Positive temperature anomalies: 1989, 1994, 1997, 1999, 2003, 2004
Strongest NAO indices: 1989, 1990, 1992, 1994, 1999

Negative temperature anomalies: 1986, 1991, 1998, 2000, 2002, 2005
Lowest NAO indices: 1985, 1996, 1998, 2005

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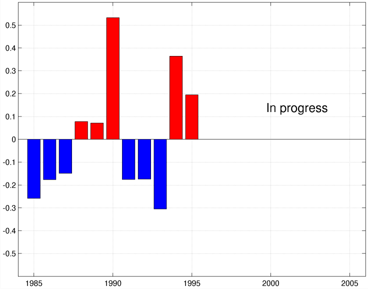
Satellite images



From satellite trend: $0.096^\circ C/$year (in progress)
From data only (no analysis): $-0.036774^\circ C/$year
From numerical model: $^\circ C/$year
Marullo et al., EGU 2007: $19.4^\circ C$ in the mid 1980's to $19.8 - 20.0^\circ C$ in early 2000's

Summary and perspective

- Original combined approach to study Western Mediterranean SST
- Aggregated *in situ* dataset
- Estimation of trends through various methods

Future work

1. Initialisation of numerical model with proper climatology
2. "Diva-EOF": use EOF's to link two distant points (A. Barth)
3. Extension to deeper levels