Derivation of high resolution TSM data by merging geostationary and polar-orbiting satellite data in the North Sea.

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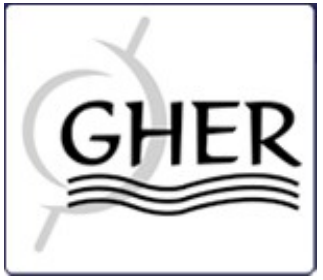

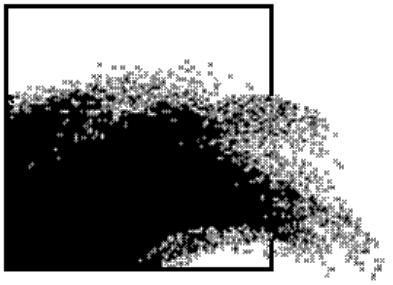

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Objectives

Context

- Need for high resolution ocean colour data
  - In space: complex coastlines, small-scale variability
  - In time: effect of tides and winds in shallow areas

- Polar satellites: high spatial resolution, low temporal resolution
- Geostationary satellites: low spatial resolution, high temporal resolution

Objective: to develop a methodology that allows to merge both sources of information

Most approaches use a parameterized error covariance matrix

Problem: error covariance matrix is very difficult to estimate (specially for colour-related variables)

To overcome this difficulty, the error covariance matrix is expressed using a truncated spatial EOF basis calculated by analysing MODIS data using DINEOF.

DINEOF (Data Interpolating Empirical Orthogonal Functions)

Technique to **fill in missing data** in geophysical data sets, based on a EOF decomposition

- Truncated EOF basis to calculate missing data (iterative method)
  - EOFs extract main patterns of variability
  - Reduced noise
- Optimal number of EOFs?: reconstruction error by cross-validation
- Uses EOF basis to infer missing data: **non-parametric**
- No need of a priori information (correlation length, covariance function...)
- Spatio-temporal coherence exploited to calculate missing values

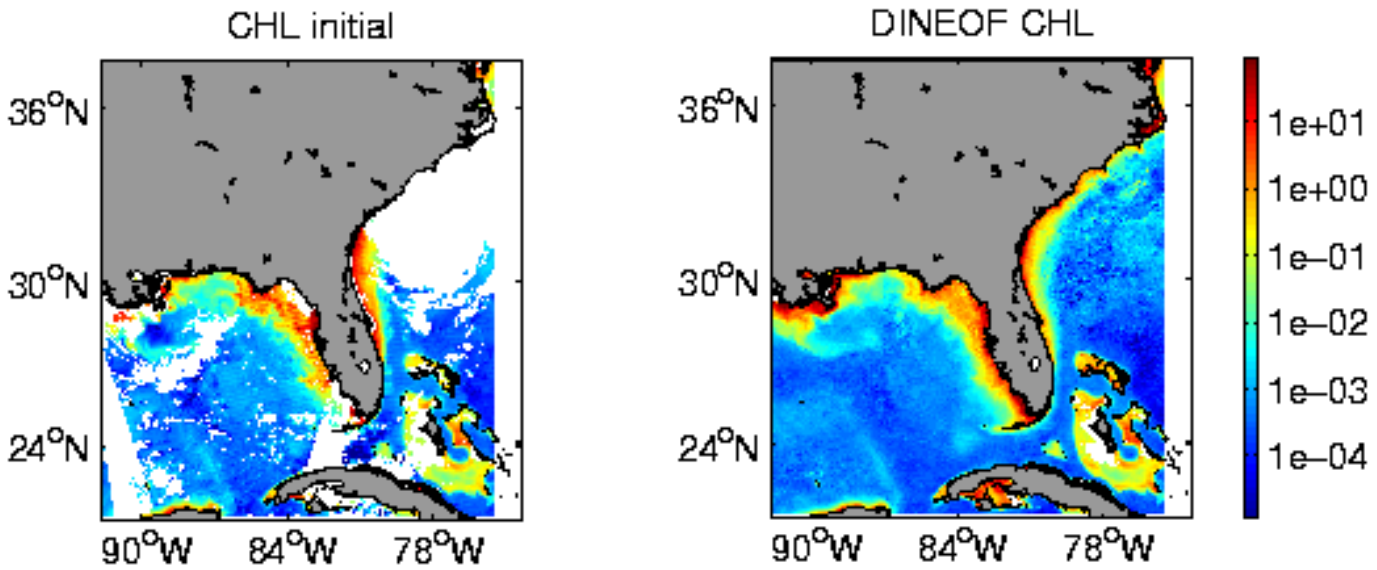
Additional features:

- **Multivariate analyses** using extended EOFs
- **Error maps:** based on an OI approach

  background covariance : EOF basis from DINEOF

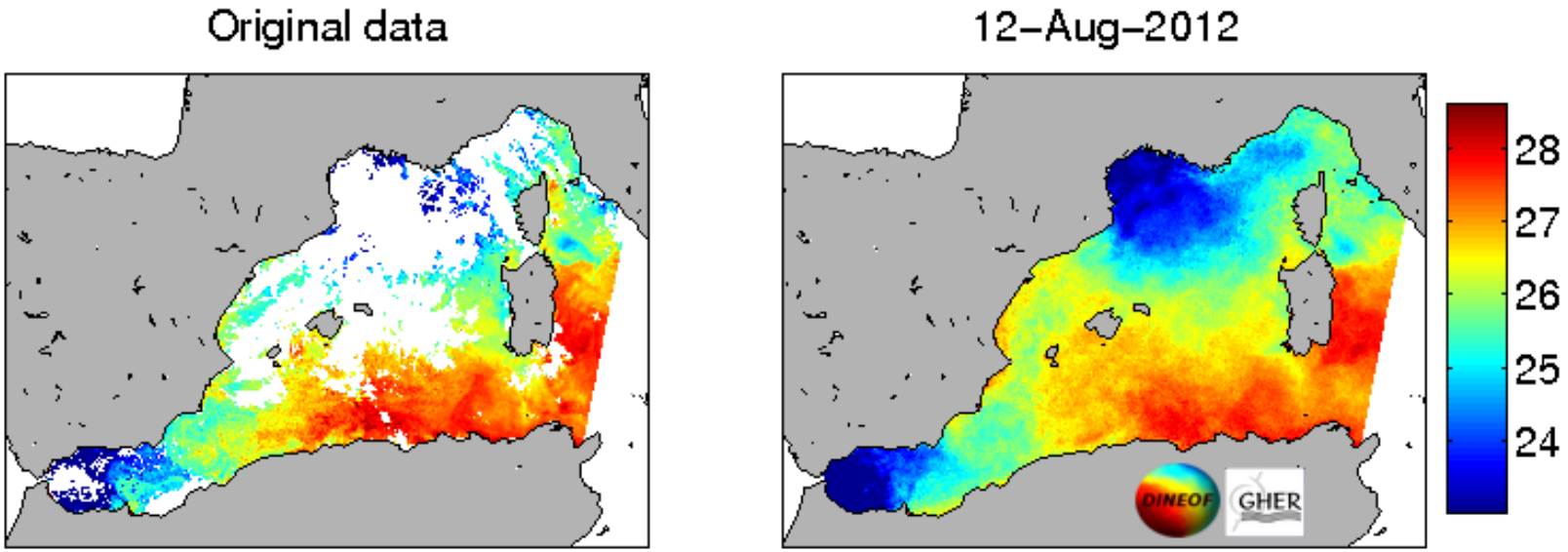
  observational error variance: rejected variance (truncated EOF series)
- **Temporal covariance matrix filter:** improves temporal coherence of reconstruction.
- **Outlier detection using spatial coherence**

DINEOF reconstruction: examples



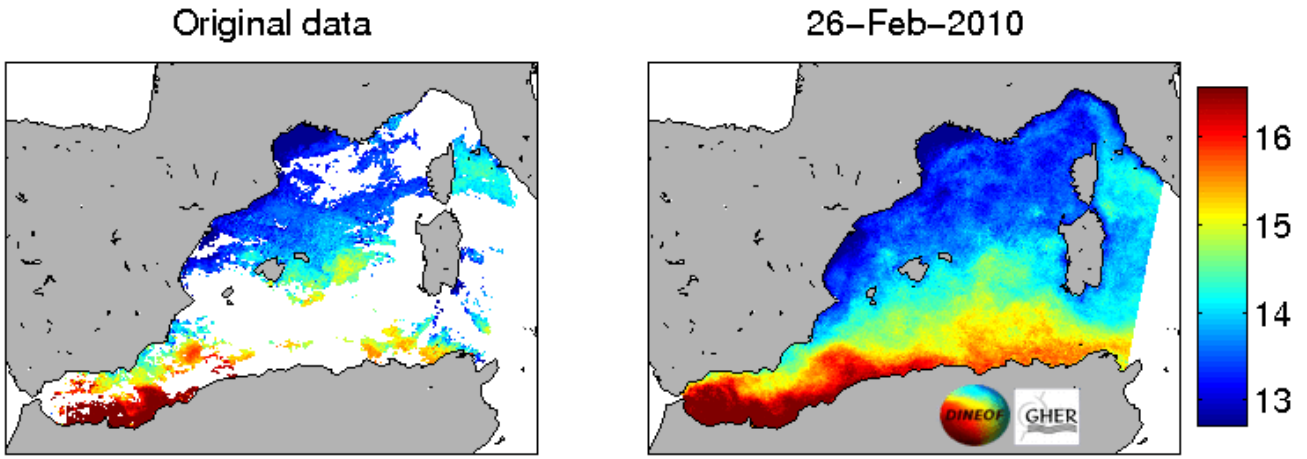
Mississippi river plume advected by Loop Current

Near-real time SST in the Mediterranean Sea



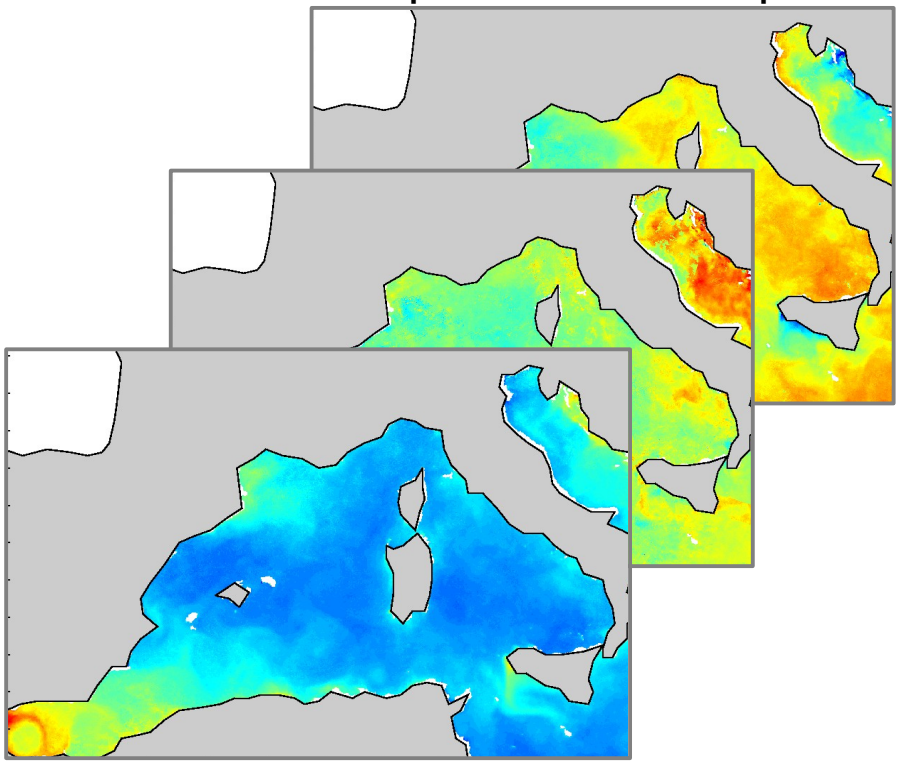
Merging data using DINEOF

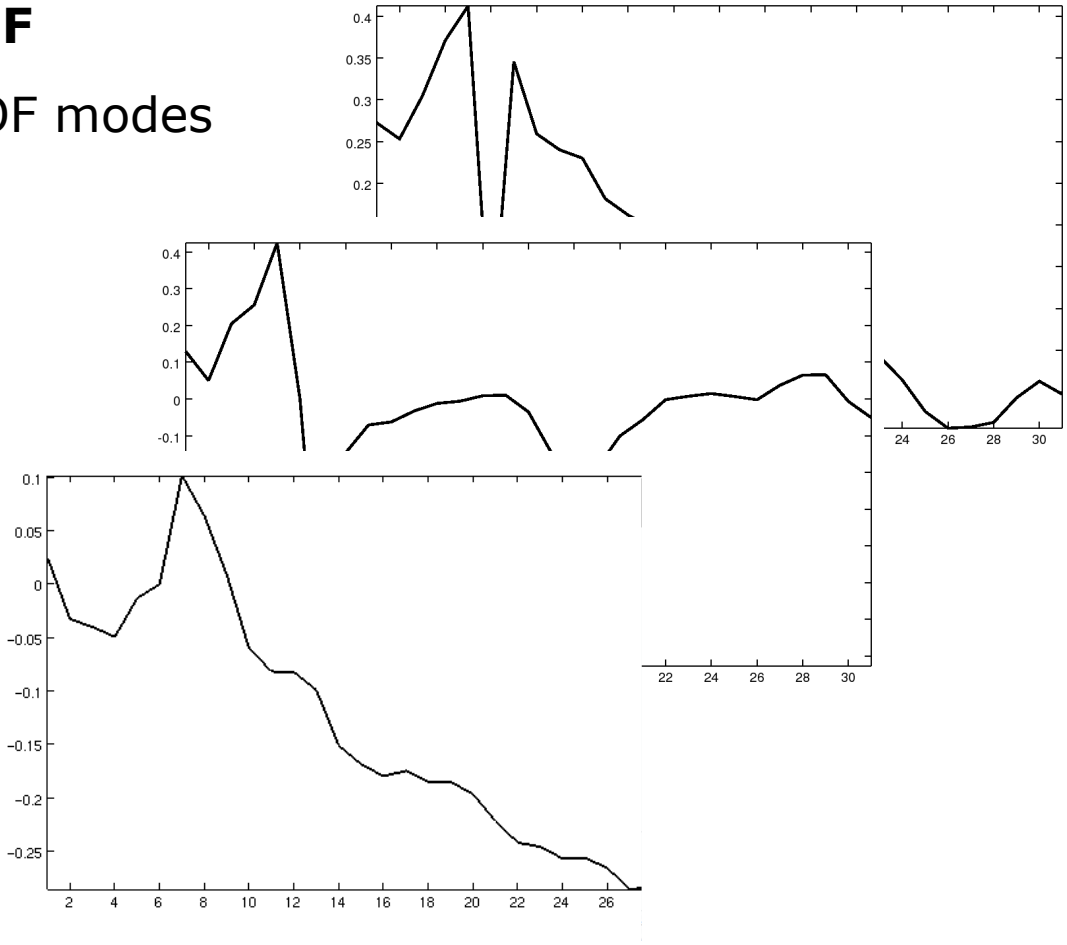
1) DINEOF applied to polar-orbiting data set



DINEOF

Spatial and temporal EOF modes

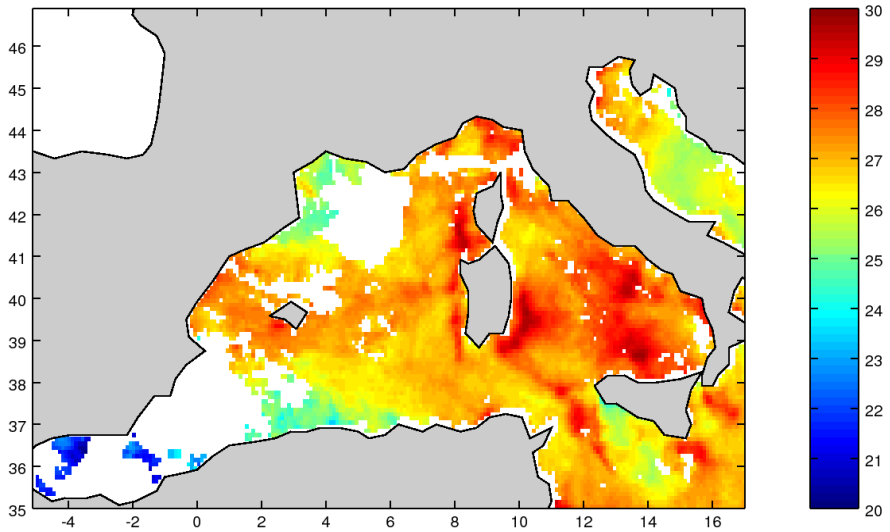




HiSea: DINEOF merging capabilities

2) EOF basis (at high spatial resolution) used to reconstruct geostationary data (using an OI approach)

Geostationary data



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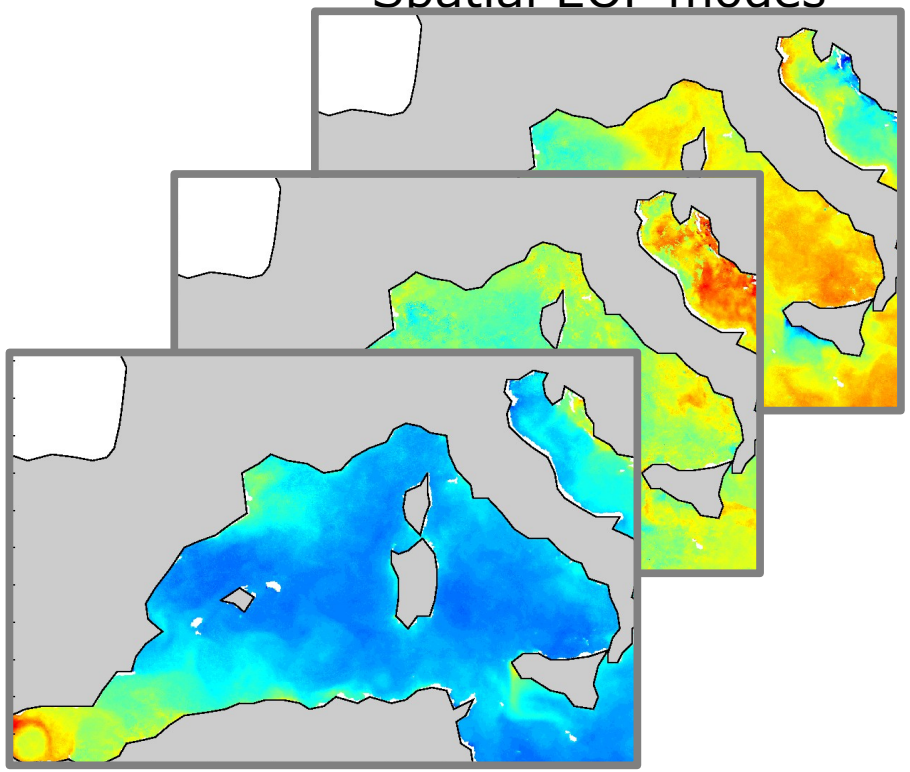
Spatial EOF modes



- Merged data set (polar + geostationary)
- Spatial resolution from polar data (~2km)
- Temporal resolution from geostationary data (~15 min)

The analysis is based on the formalism of optimal interpolation (OI) but the **crucial difference is that the error covariance is not parametrized a priori using an analytical expression, but expressed using the spatial EOFs.**

DINEOF + OI

Two-step process:

- DINEOF on polar satellite data (MODIS)
- Optimal Interpolation to merge polar and geostationary data (SEVIRI)

Truncated EOF basis given by DINEOF used as covariance matrix (**P**).

The spatial EOFs are scaled: $$\boldsymbol{U}_s = \frac{1}{\sqrt{(n)}} \boldsymbol{U}\,\boldsymbol{\Sigma}$$

Error covariance obtained from single sensor error statistics (SESS)

The formula used for the analysis step is equivalent to Optimal Interpolation:

$$\mathbf{x}_a = \mathbf{x}_b + \mathbf{P}\,\mathbf{H}^T (\mathbf{H}\,\mathbf{P}\,\mathbf{H}^T + \mathbf{R})^{-1} (\mathbf{y}_o - \mathbf{H}\,\mathbf{x}_b)$$

xa : analysis
xb : background field
yo are the data being analysed
H : an operator to extract the data at the observations location.
P: error covariance of background
R: error covariance of observations

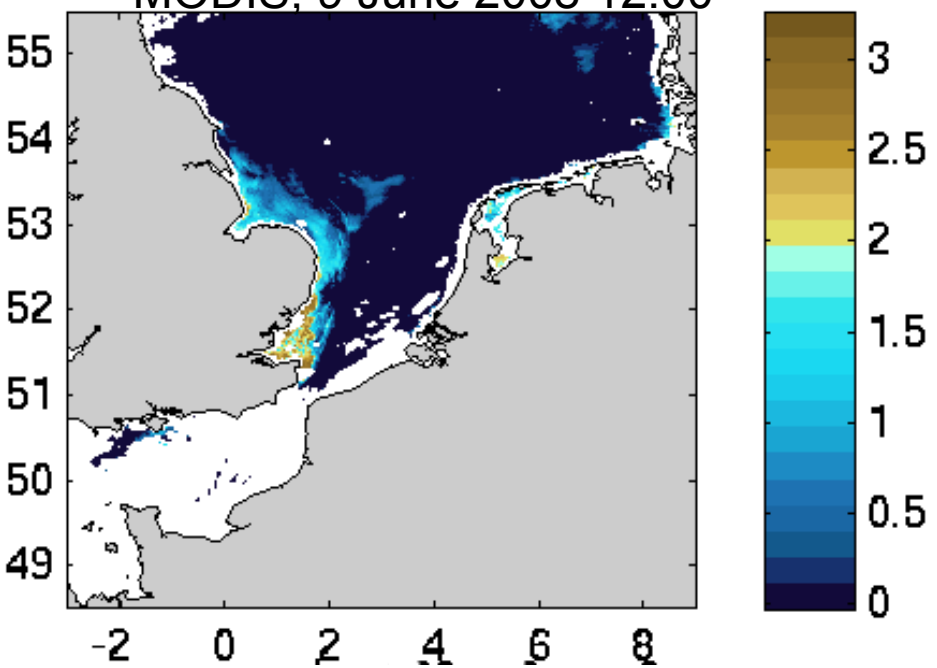
SEVIRI + MODIS data

Polar-orbiting data:
- MODIS
- ~ 2km spatial resolution
- 1 composite image per day

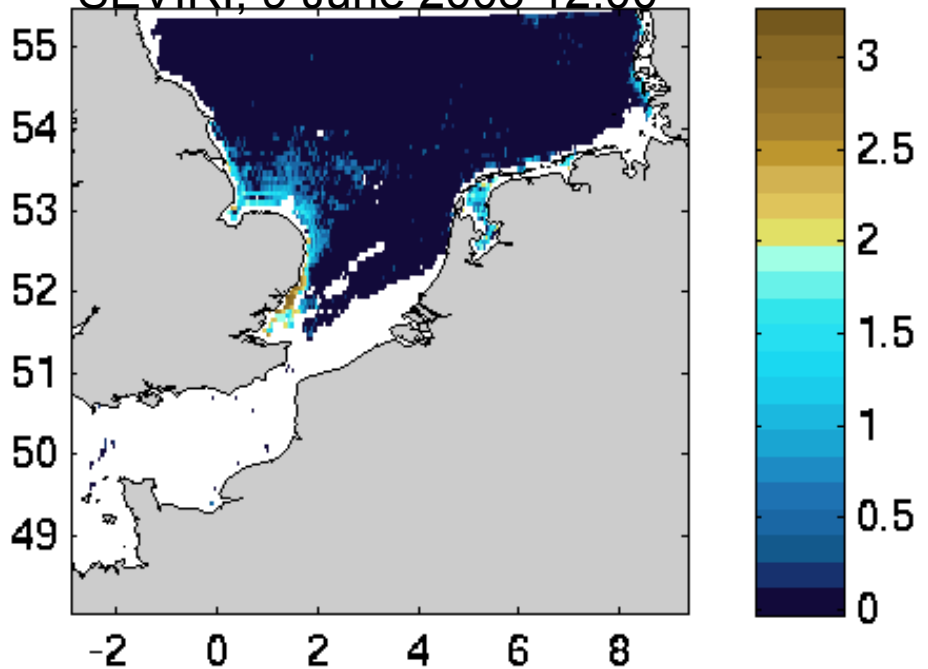
Geostationary data:
- SEVIRI
- ~ 6km spatial resolution
- 15 min temporal resolution

Domain: North Sea
Period: January to March 2008

MODIS, 9 June 2008 12:00

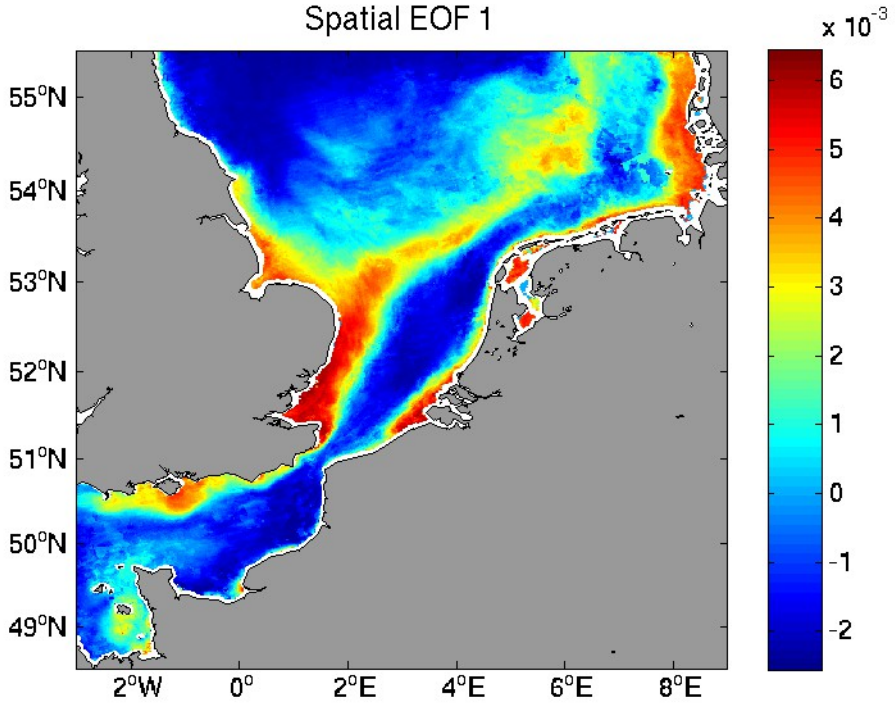


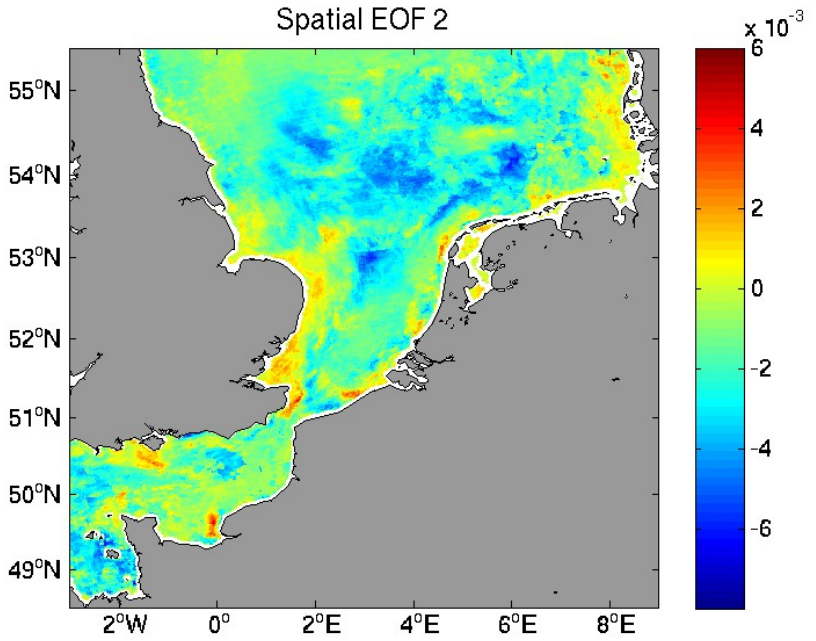
SEVIRI, 9 June 2008 12:00

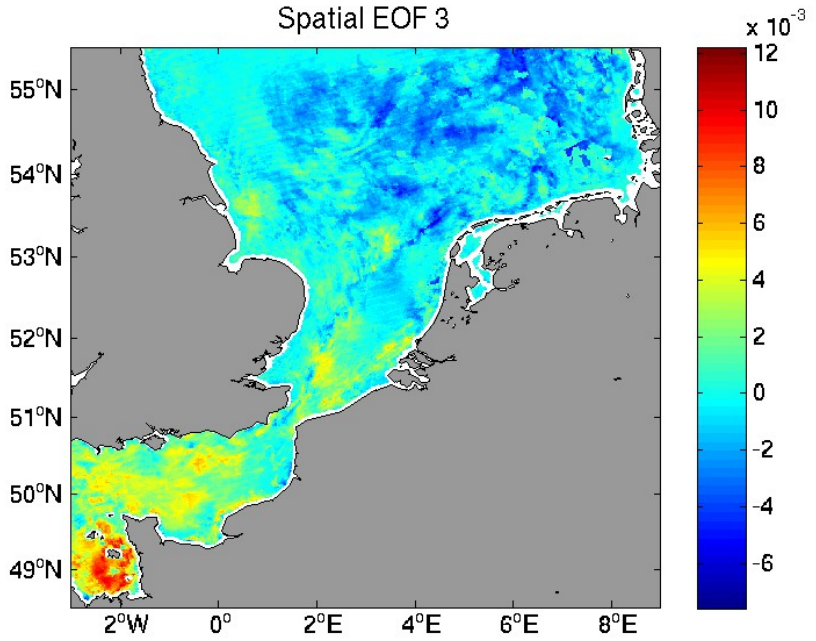


DINEOF analysis: EOF basis

37 EOFs retained, 99.8% of the total variance
Representative of January to March 2008







EOF 1: 85% of variability

EOF 2: 4.35% of variability

EOF 3: 2.61% of variability

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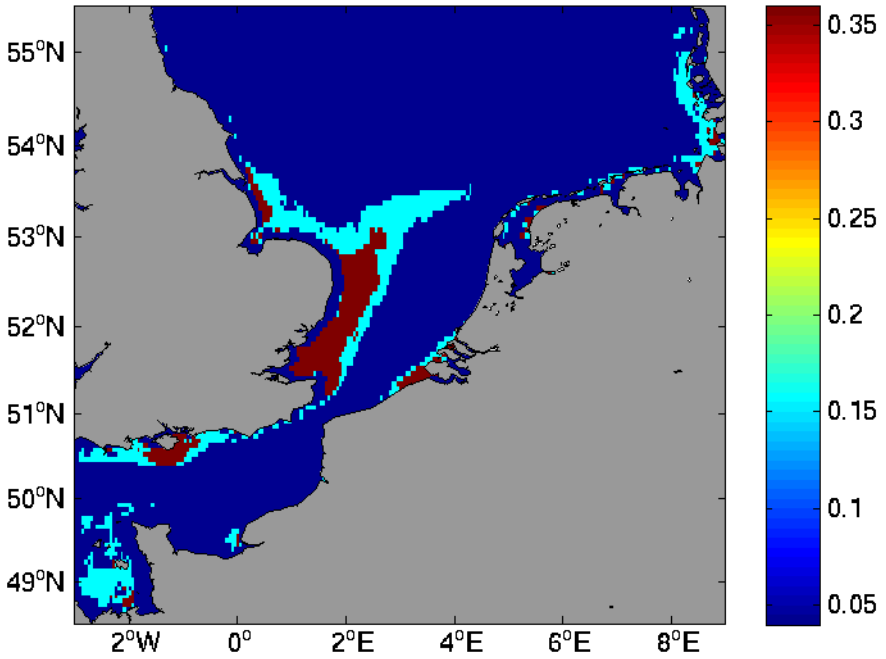
Error variance

Magnitude based on comparisons with in situ data

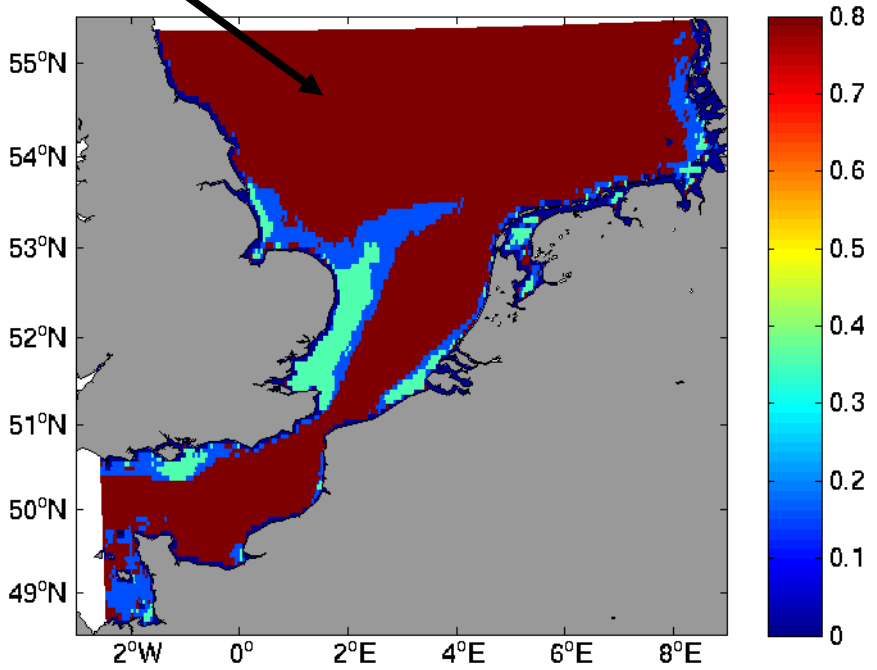
Spatial distribution based on average fields

SEVIRI low concentration waters penalized

MODIS



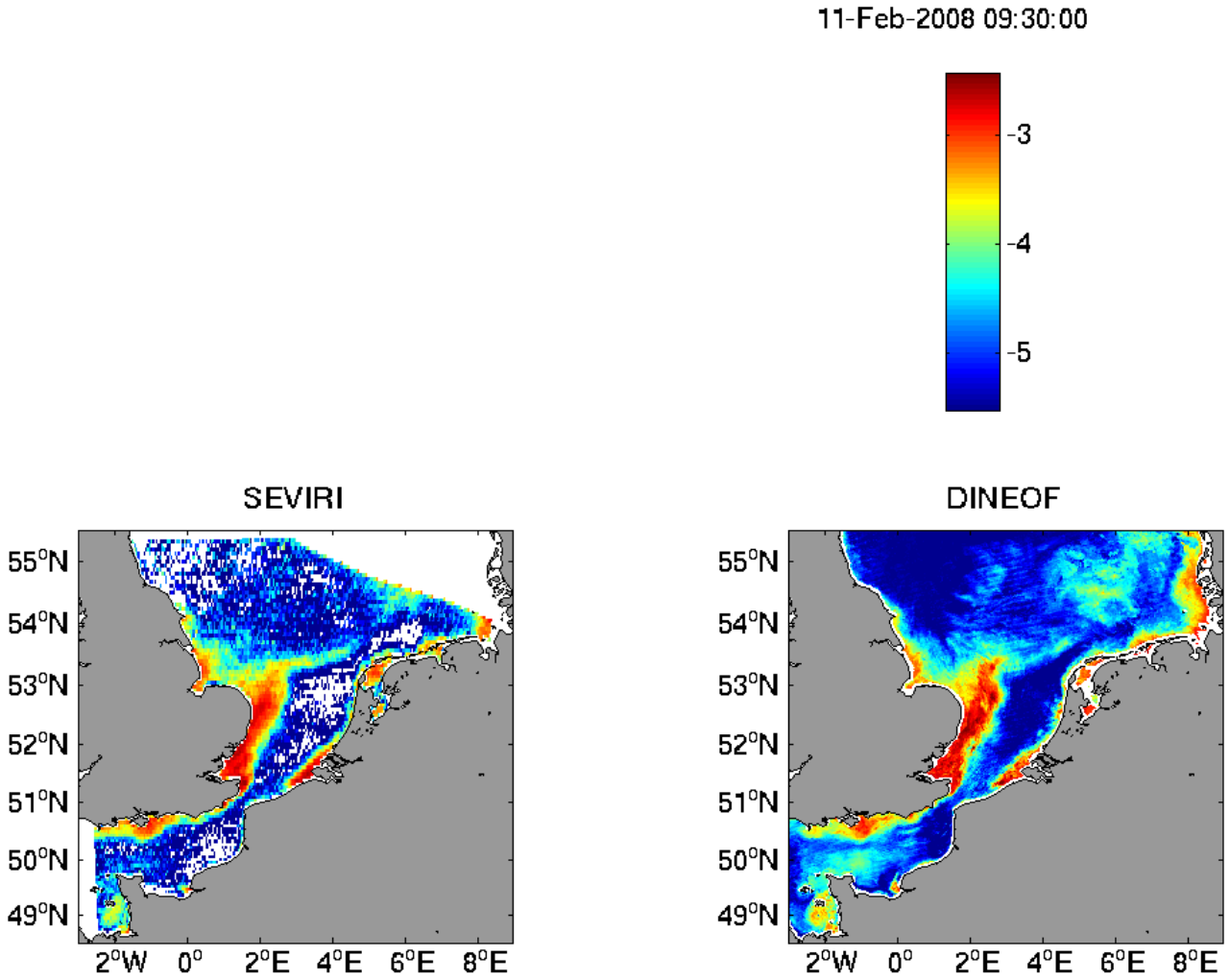
SEVIRI



Units : log(radiance)

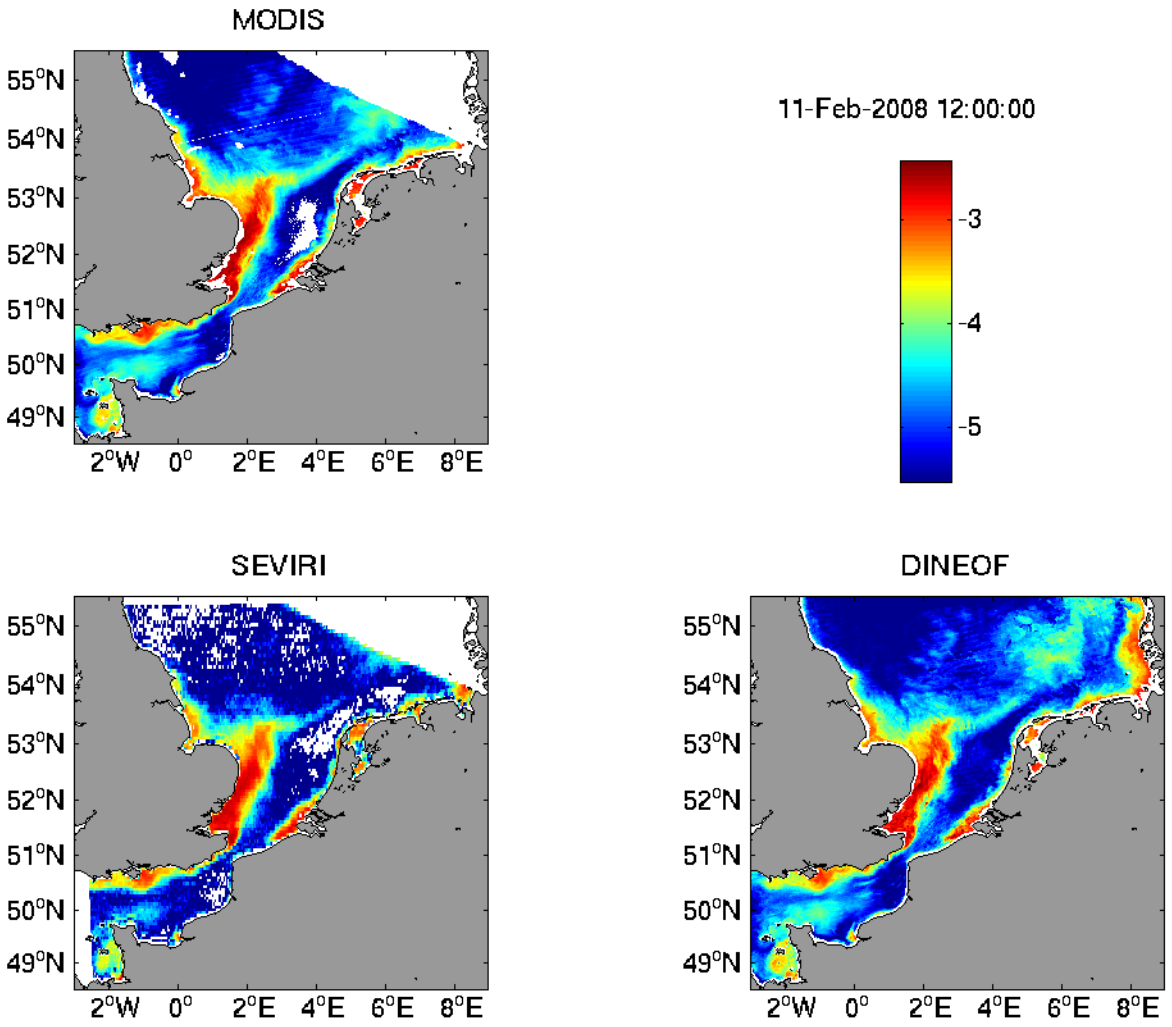
Results

Example for 11 February 2008



Units : log(radiance)

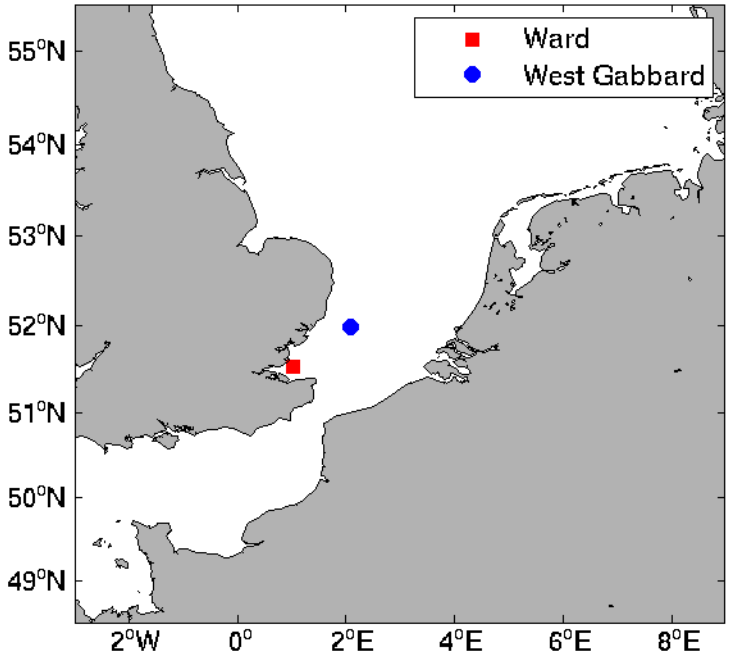
Results: snapshot



Noise removed
High temporal resolution from SEVIRI retained
Small scale features from MODIS

Units : log(radiance)

Validation with in situ data



From Cefas (Centre for Environment, Fisheries & Aquaculture Science, UK)

Located in shallow water (<35m)

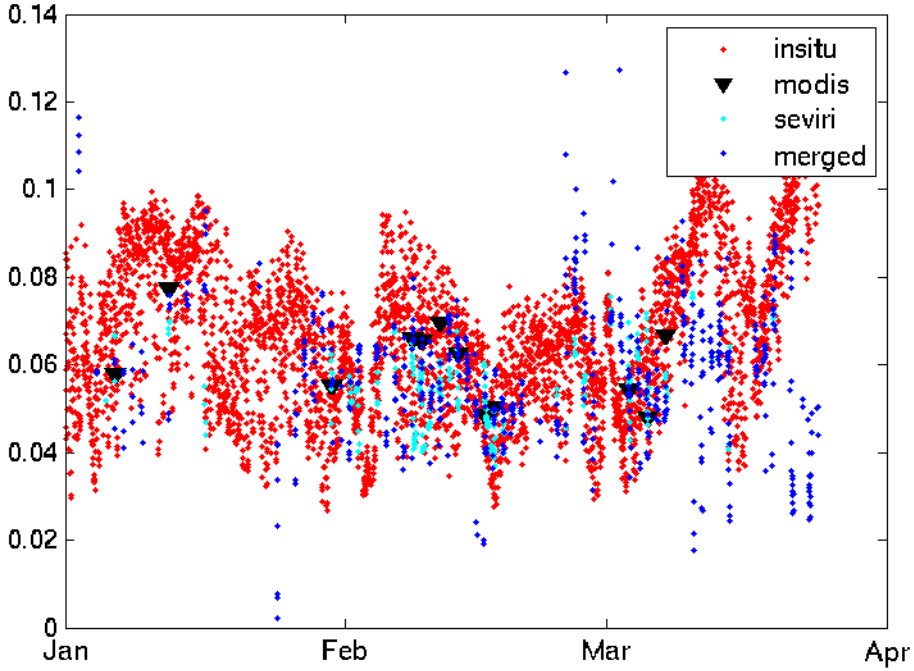
Highly turbid waters

	Ward	West Gabbard
	RMS	RMS
MODIS	0.27	0.32
SEVIRI	0.25	0.3
DINEOF-OI	**0.35**	**0.77**
DINEOF-OI at MODIS time step	0.23	0.5

Units : log(radiance)

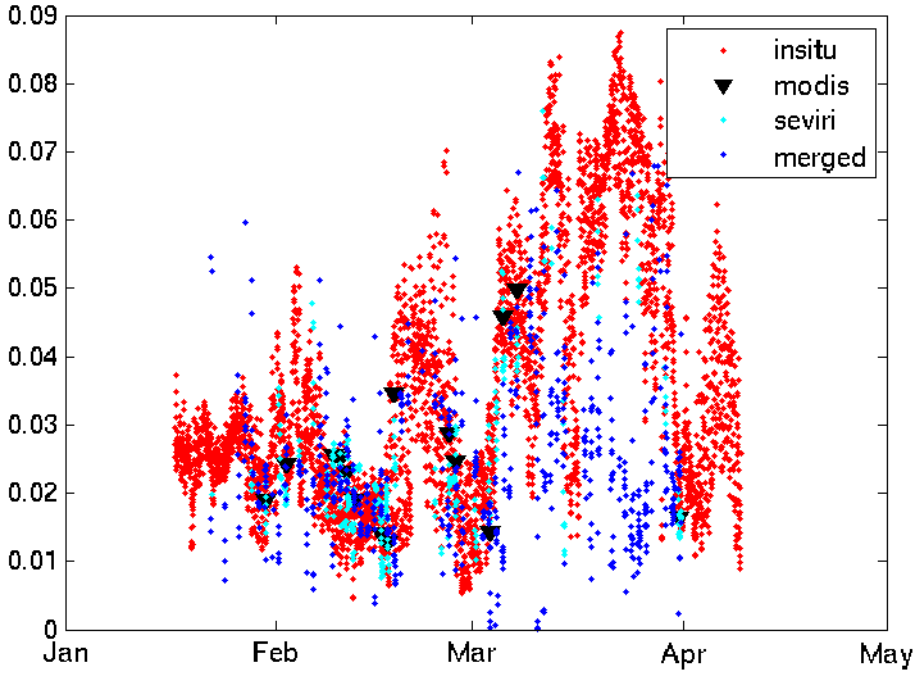
Time series

Warp



Units : log(radiance)

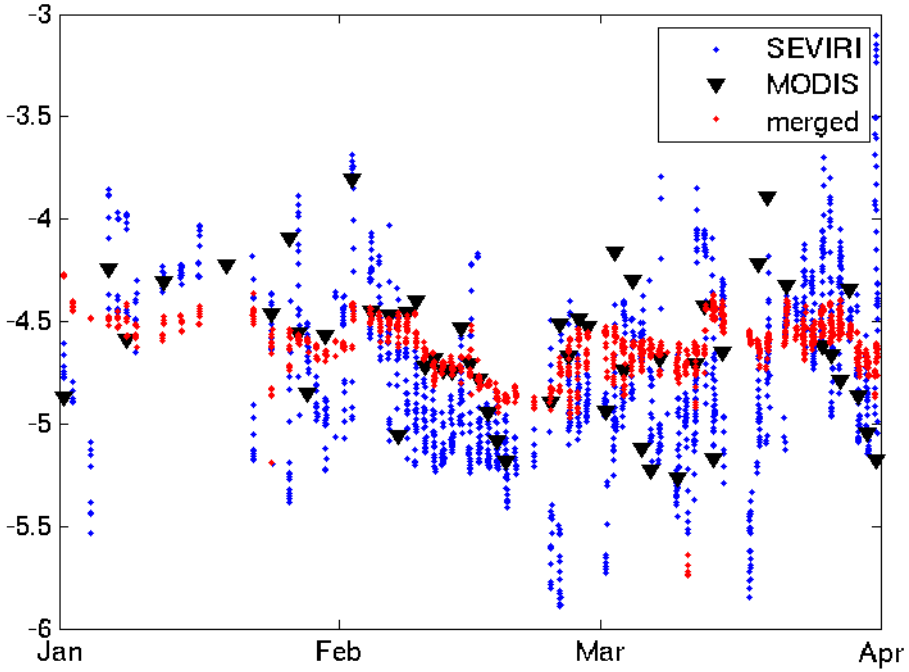
West Gabbard



In situ variability much higher

Decrease in performance in March, presumably from source data

Average time series



Variability of merged product needs to be increased: satellite data error variance too high?

Agreement of all records in March: difference with in situ data?

Conclusions

A technique to merge satellite data from different sources has been developed

- Realistic covariance matrix from truncated EOF basis
- Error variance estimated by comparing satellite data with in situ data
- Merging step based on OI formalism
- Merged data retain high temporal and spatial resolution

Application to colour data in the North Sea: January to March 2008

Results show that small scale features are retained in the reconstruction

However, merged result shows lower variability than satellite or in situ data: error variance might be too high

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DINEOF code available at http://modb.oce.ulg.ac.be/DINEOF