

How to remove clouds in a time series of SST images?

Application to the Canary Island – Madeira Region

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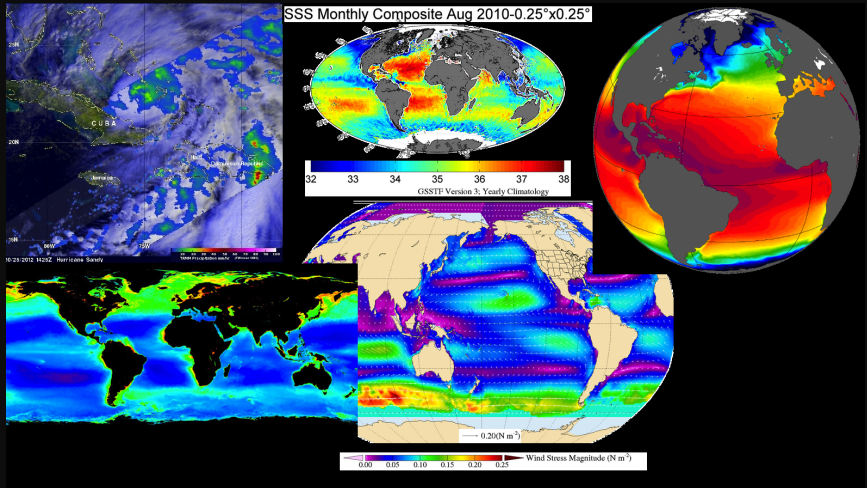
GeoHydrodynamics and Environment Research,
University of Liège, Belgium

<http://modb.oce.ulg.ac.be>

Madrid, November 14–16, 2012



Satellites measure a lot of parameters, but ...

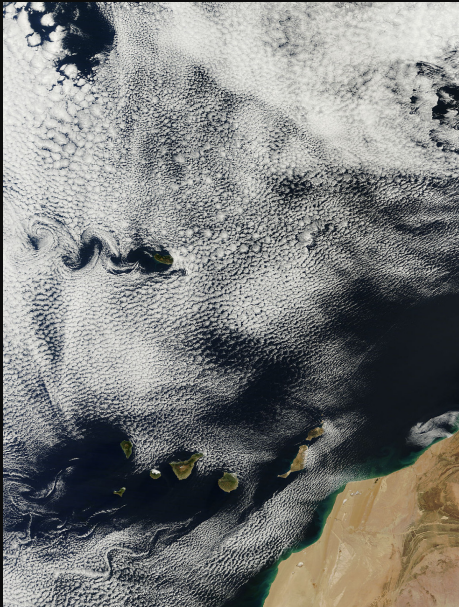


... they are limitations:

- 1 Spatial/temporal resolutions
- 2 Measurements limited to surface
- 3 Cannot view through clouds, dust, smoke, ...

Small-scale processes in the studied region

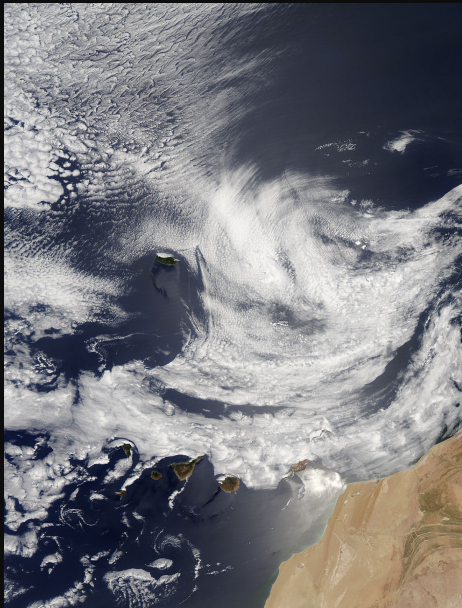
Eddies



MODIS-Terra
February 22, 2011

Small-scale processes in the studied region

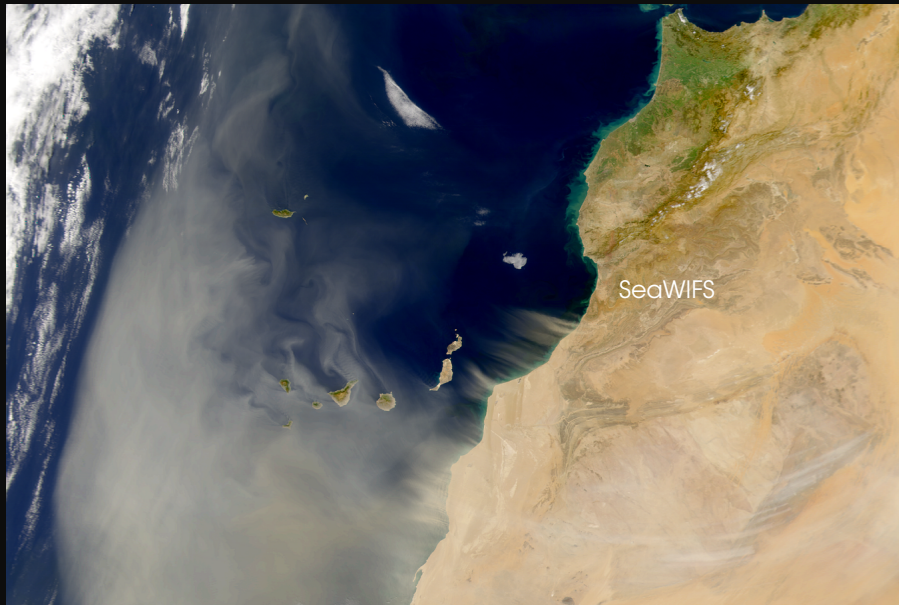
Island wakes



MODIS-Aqua
June 3, 2010

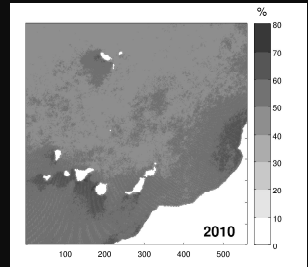
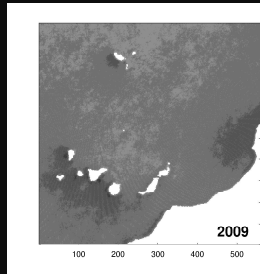
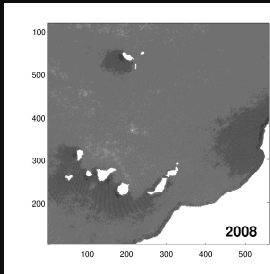
Small-scale processes in the studied region

Dust input

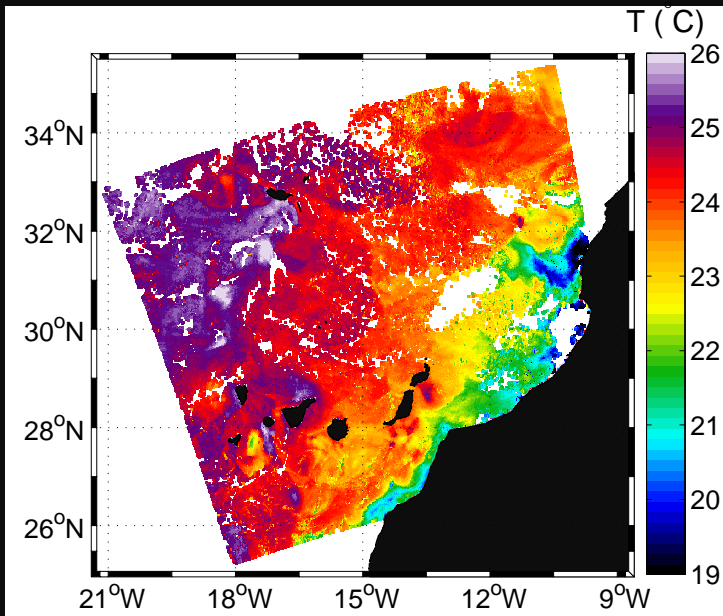


Application: SST

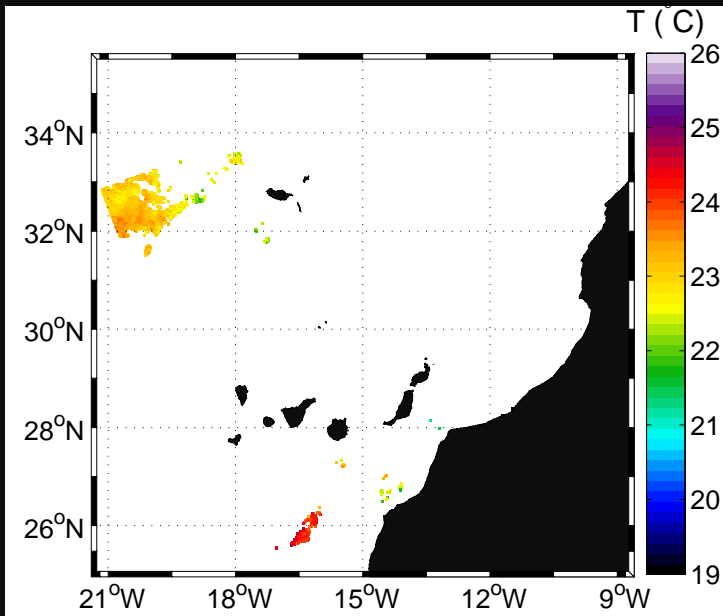
- Data (level 3): <http://www.medspiration.org>
- Night-time only
- Images with $> 5\%$ of valid pixels



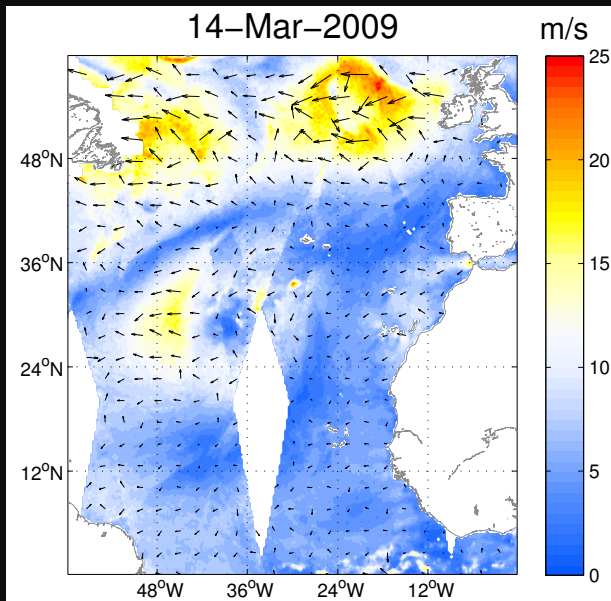
Examples



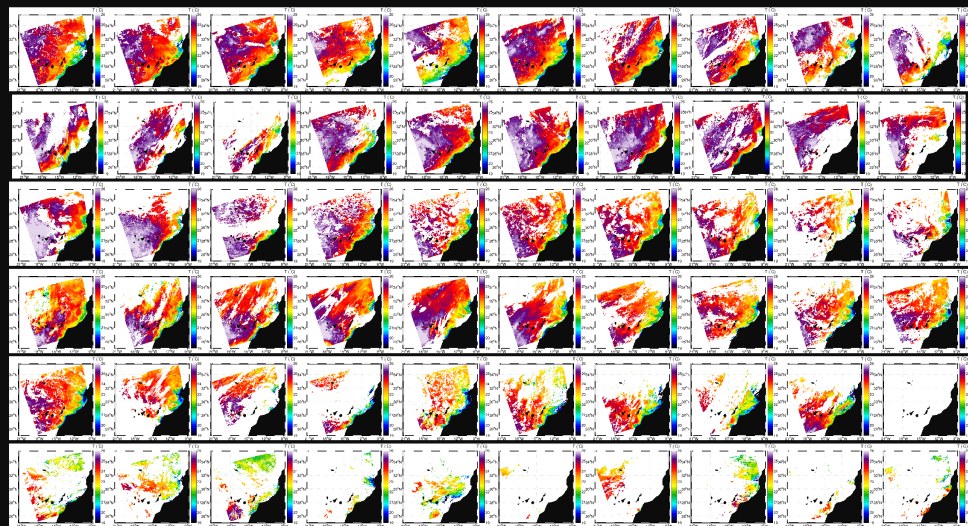
Examples



Examples



Solution: Use information from other images



A little bit of mathematics ...



DINEOF =

Data INterpolating

Empirical Orthogonal Functions

(Beckers and Rixen, 2003, Alvera-Azcárate et al., 2005)

$$\mathbf{X} = \mathbf{U}\mathbf{S}\mathbf{V}^T \quad (1)$$

with

\mathbf{U} \rightarrow *spatial EOFs* $m \times N$

\mathbf{V} \rightarrow *temporal EOFs* $n \times N$

\mathbf{S} \rightarrow *singular values* $N \times N$

A little bit of mathematics ...

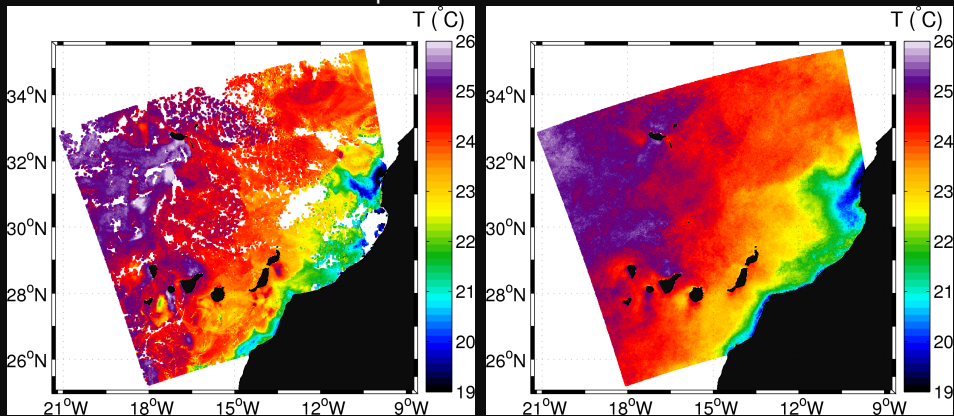


Iterative method

- 1 Start with $N = 1$
$$\mathbf{X}^1 = \mathbf{U}^1 \mathbf{S}^1 \mathbf{V}^{1T}$$
 - 1 Compute new values at missing pixels
 - 2 Repeat until **convergence**
 - 3 Estimate reconstruction error
- 2 $N = N + 1$ and repeat procedure
- 3 ...
- 4 Final reconstruction: find $N = N_{opt}$ that minimises error

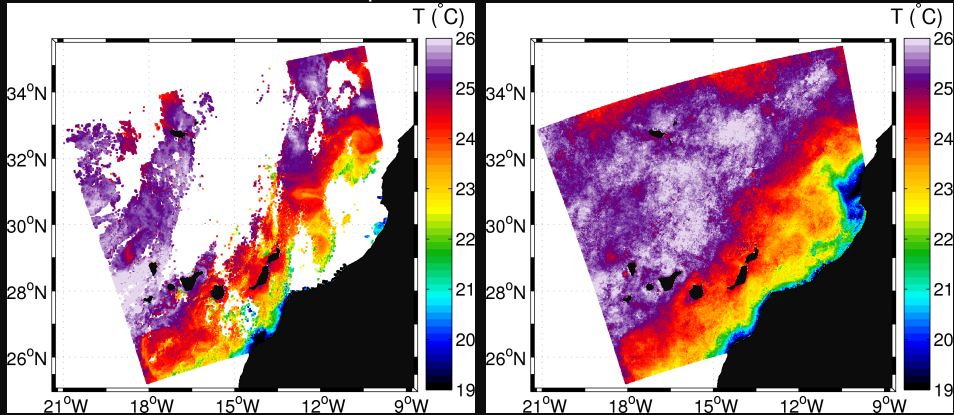
Results

September 5, 2012



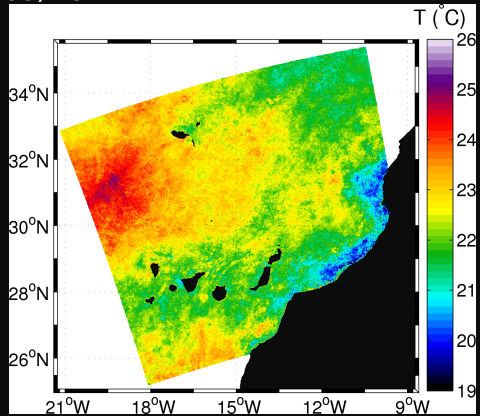
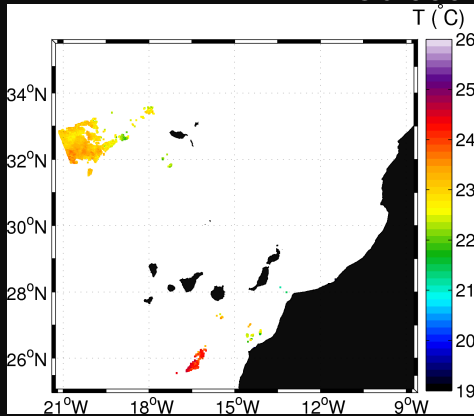
Results

September 15, 2012



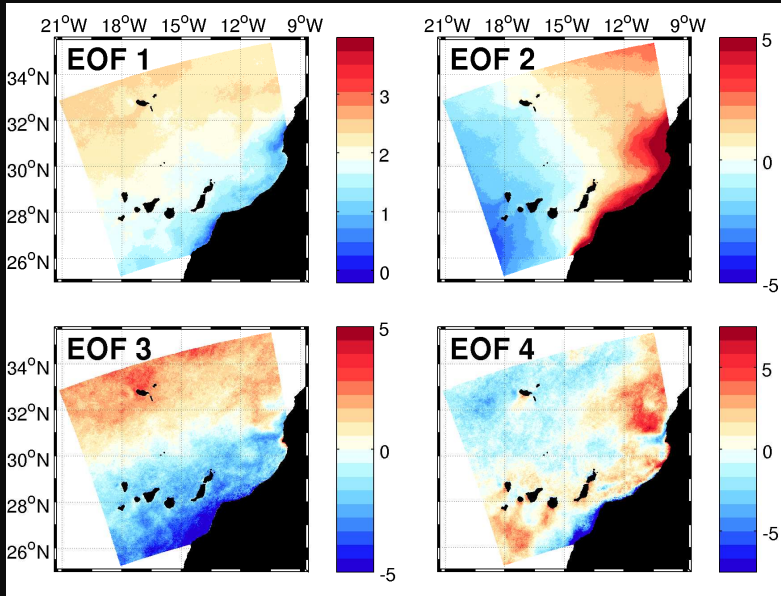
Results

October 30, 2012



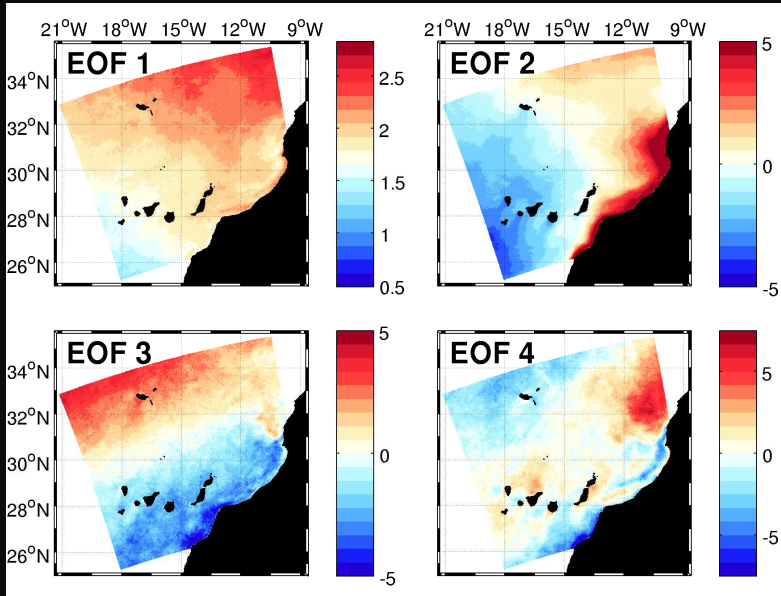
Spatial modes

2008



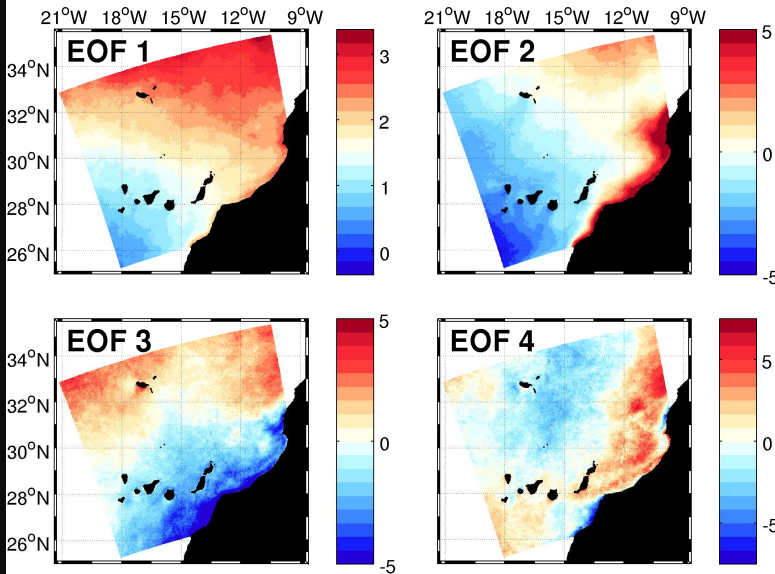
Spatial modes

2009

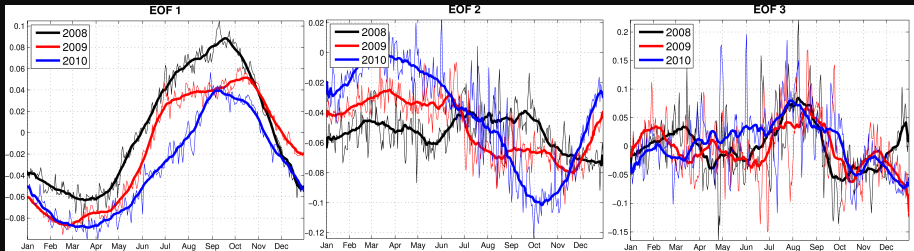


Spatial modes

2010



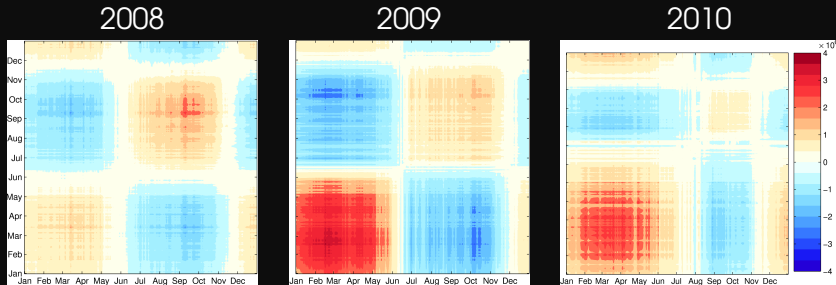
Temporal modes



Improvement: smoothing temporal covariance

- $\mathbf{X} = \mathbf{USV}^T$ decomposition
- $\mathbf{B} = \mathbf{X}^T \mathbf{X}$ time covariance
- $\mathbf{B} = \mathbf{F}^T \mathbf{B} \mathbf{F}$ filtering

→ Coherence in time between close images
(Alvera-Azcárate et al., 2009)



diagonal = variance with respect to mean

off-diagonal = covariance of one image with the others

Automatic processing

<http://gher-diva.phys.ulg.ac.be/DINEOF/dineof.html>



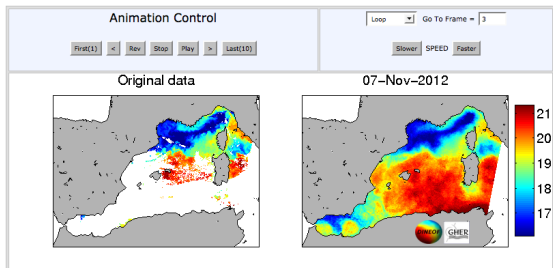
DINEOF daily cloud-free SST for the Western Mediterranean Sea

- [Reconstructed SST field](#)
- [Initial and Reconstructed SST fields](#)
- [Outliers field](#)
- [All fields](#)
- [DINEOF Wiki page](#)

See also:

- [Canary-Madeira SST](#)

DINEOF (Data Interpolating Empirical Orthogonal Functions) is an EOF-based technique to reconstruct missing data in satellite images. In this page the initial cloudy data set and the reconstruction for the last 10 days are shown. This product is updated daily with the latest SST data.



Note: Units are degrees Celsius

Here DINEOF is applied daily to NAR SST level 3 from the Ifremer Medspiration [ftp site](#).

Automatic processing

http:

//gher-diva.phys.ulg.ac.be/DINEOF/dineof_allCAN.htm



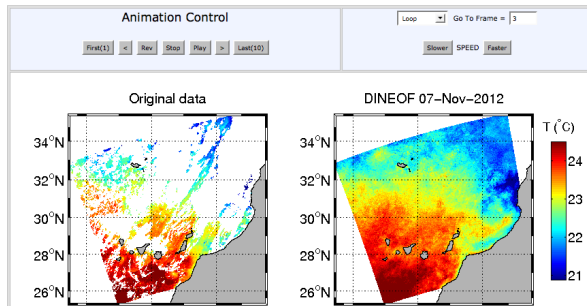
DINEOF daily cloud-free SST for the Canary-Madeira region

- [DINEOF Wiki page](#)
- [DINEOF google group](#)
- [GHER group](#)

See also:

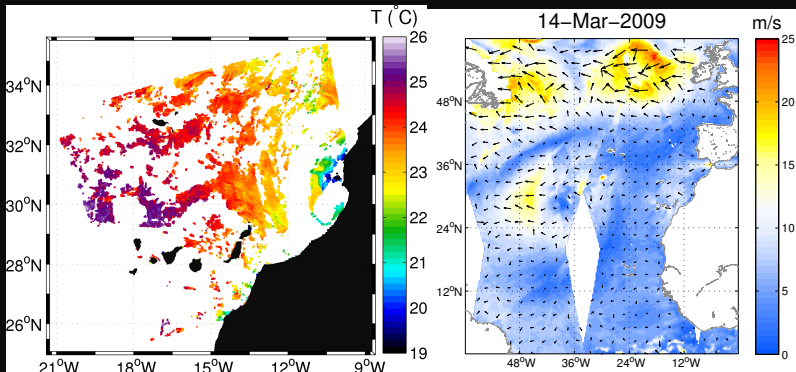
- [Mediterranean SST](#)

DINEOF (Data INterpolating Empirical Orthogonal Functions) is an EOF-based technique to reconstruct missing data in satellite images. Initial cloudy data, reconstruction, outliers and error field (all calculated by DINEOF) for the last 10 days are shown. This product is updated daily with the latest SST data. The different steps used to produce the filled images are described [here](#)



What's more?

Multivariate analysis



SST + wind

What's more?

Merging

data sets

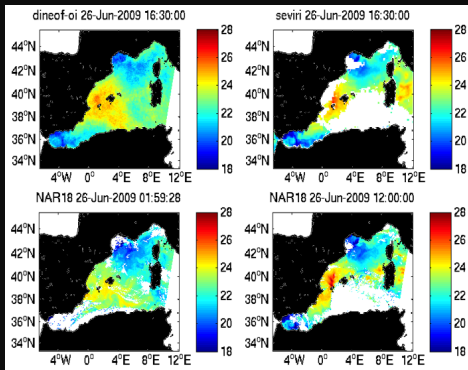
polar-orbiting + geostationary



Spatial resolution
Temporal resolution

2 km
12 hours

10 km
3 hours



What's more?

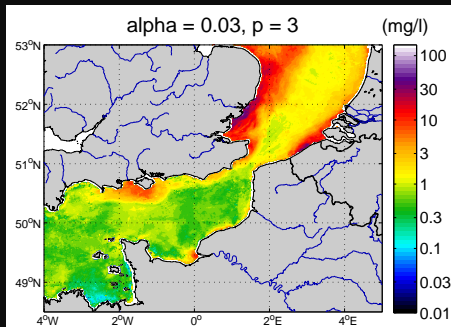
DINEOF: remote-sensing measurements + model variables



no explicit
parameterization

forecasts

"Forecast" of
Total Suspended
Matter



Conclusions

How to remove clouds in satellite images?

- Use the recurrence of information
- Combine relevant parameters
- Merge different satellites
- Exploit numerical model

A satellite image of the Mediterranean Sea region. The sea is a deep blue, with a lighter blue area in the northwest. The landmasses are shown in shades of brown and tan. The text "Thanks for you attention" is overlaid in white.

Thanks for you attention