Satellite and in situ sea surface temperature comparison and merging in the Mediterranean Sea

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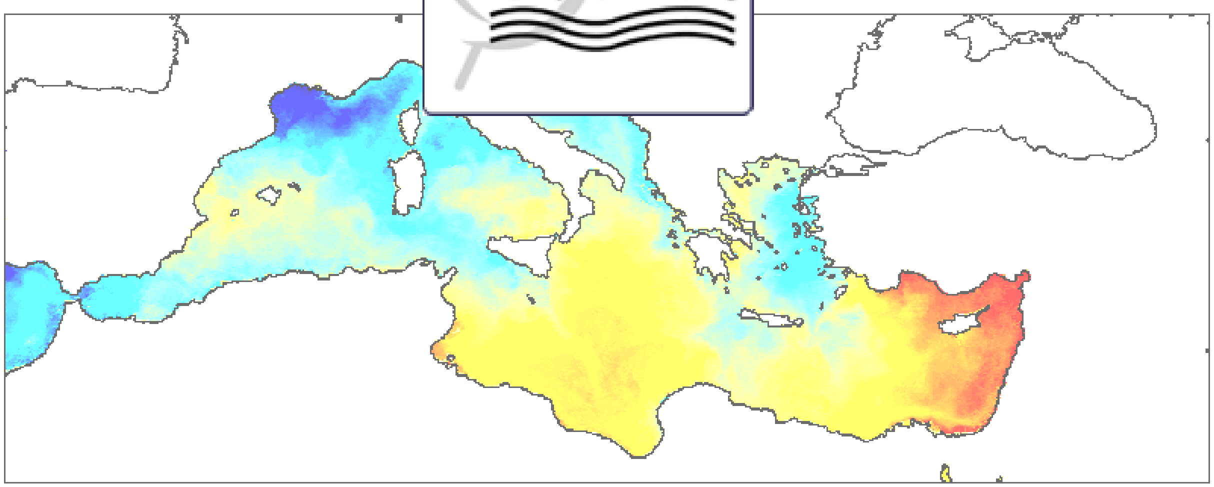


HiSea project (BELSPO SR/12/140, Research programme for earth observation STEREO II)

Motivation

High quality SST data sets needed for various applications, including numerical weather prediction, ocean forecasting and climate research.

Coverage, resolution and precision of individual SST observations not sufficient for these applications

Merging of complementary data sets is needed to increase the coverage and to reduce the final data set error.

Satellite data and in situ data: different characteristics, depth of measurement, spatial and temporal resolution...

A careful analysis of the differences between these two data sets is necessary

Objectives

- To develop a technique to merge SST data on different platforms into a unique field
- To assess the spatio-temporal differences between satellite data and in situ data

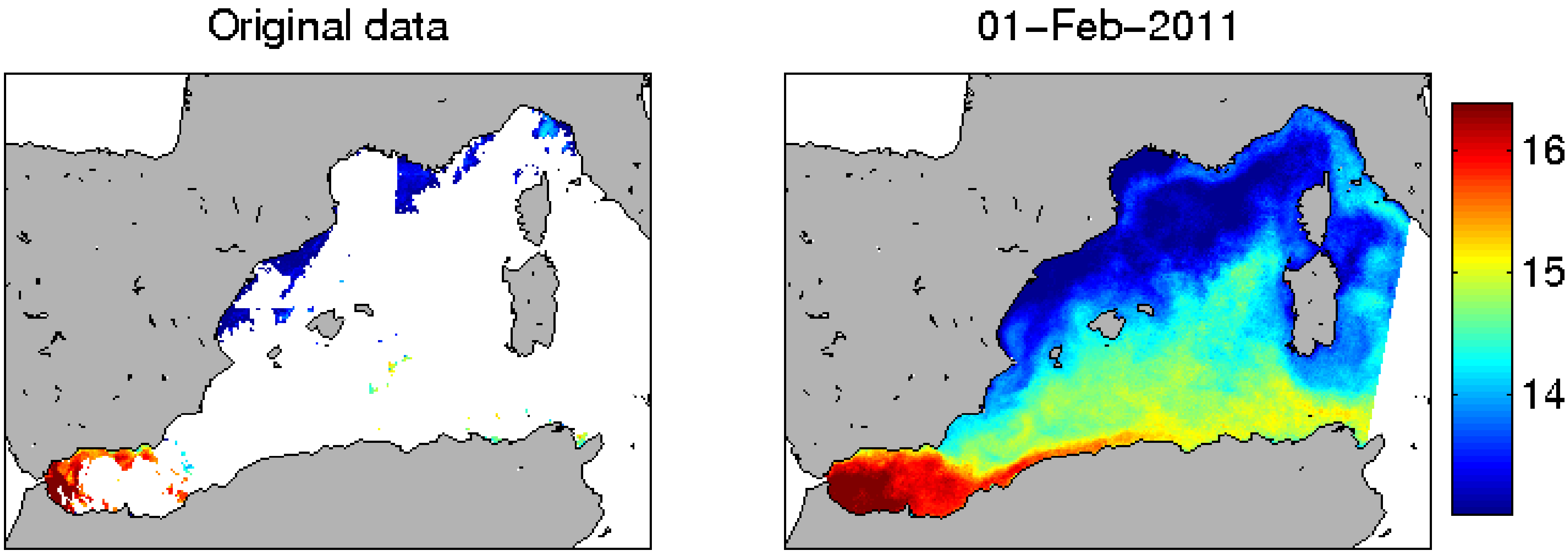
DINEOF
(Data Interpolating Empirical Orthogonal Functions)

• Reconstruction method for gappy data based on an EOF decomposition

• Parameter-free, no need of *a priori* information

• Truncated EOF basis: determines optimal number of EOFs by cross-validation. Reduced noise in reconstruction

Example: SST in the western Mediterranean Sea



http://gher-diva.phys.ulg.ac.be/DINEOF/

• Merging capability of DINEOF in development

• Combination of DINEOF + Optimal Interpolation using the EOF basis from DINEOF

Data used

Year: 1999 (higher number of in situ data)
Domain: western Mediterranean Sea

SATELLITE DATA

- AVHRR SST data (http://podaac.jpl.nasa.gov)
- ~5 km spatial resolution

IN SITU DATA

Databases used:

- World Ocean Database 2005 (WOD05, http://www.nodc.noaa.gov/)
- International Comprehensive Ocean-Atmosphere Data Set (ICOADS http://icoads.noaa.gov/).
- MEDAR/MedAtlas (MEDAR-Group (2002), http://www.ifremer.fr/medar/)
- Coriolis Data Center (http://www.coriolis.eu.org/)
- International Council for the Exploration of the Sea (ICES, http://www.ices.dk/).

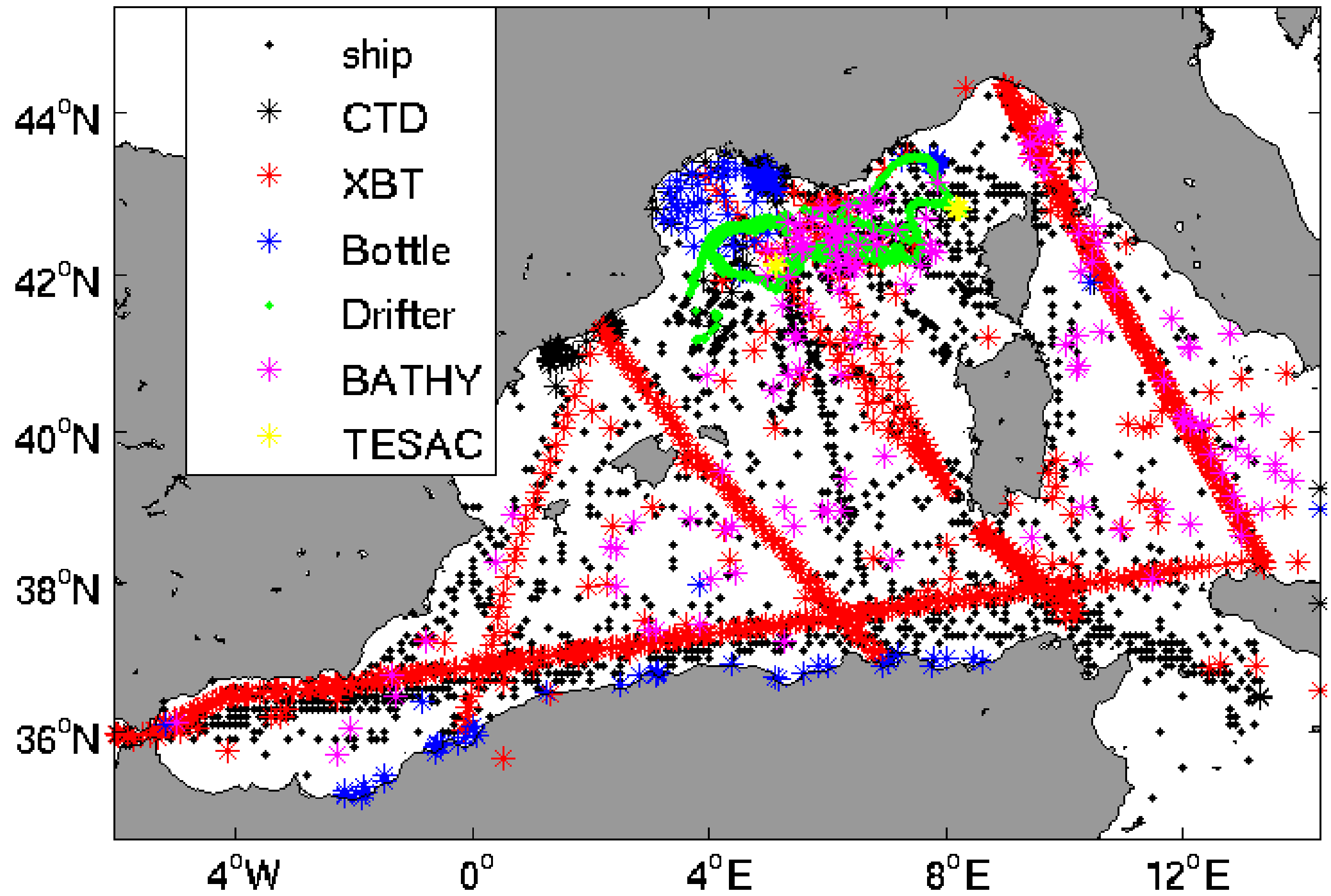
After check for doubles and depth ≤ 5 m, total number of data: 6636

From 6636 in situ data, 4522 satellite match-ups (~50% night-time, ~50% day-time)

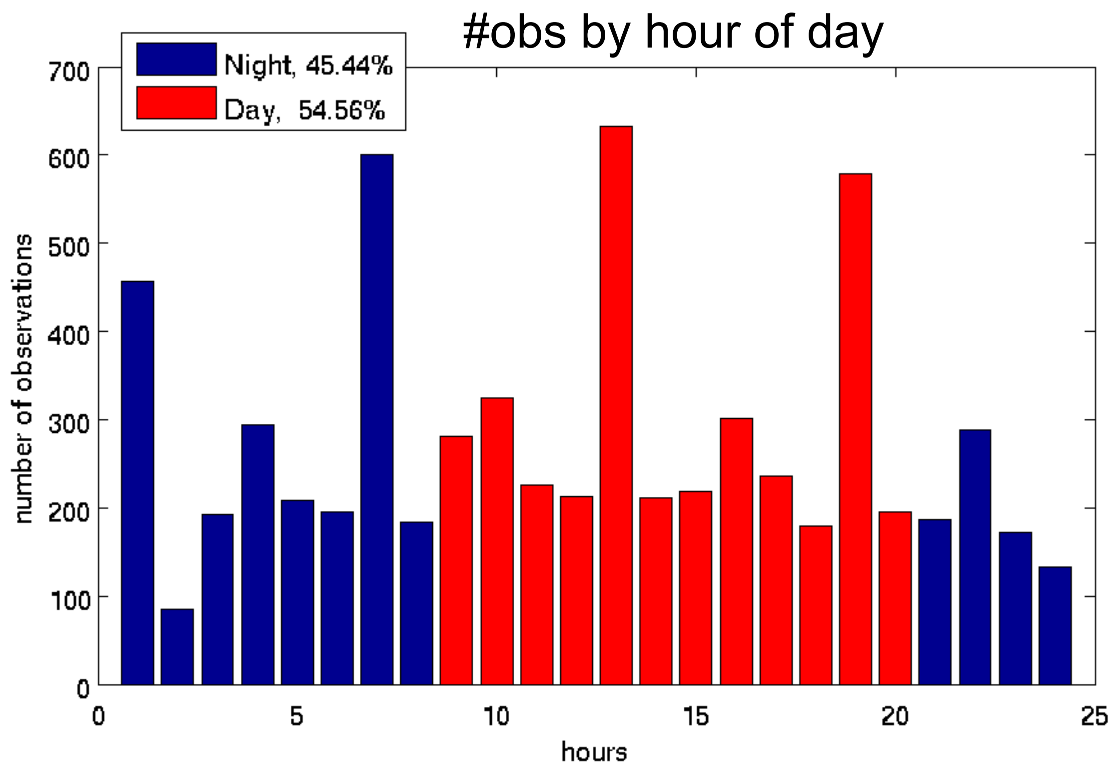
Satellite - in situ data comparison

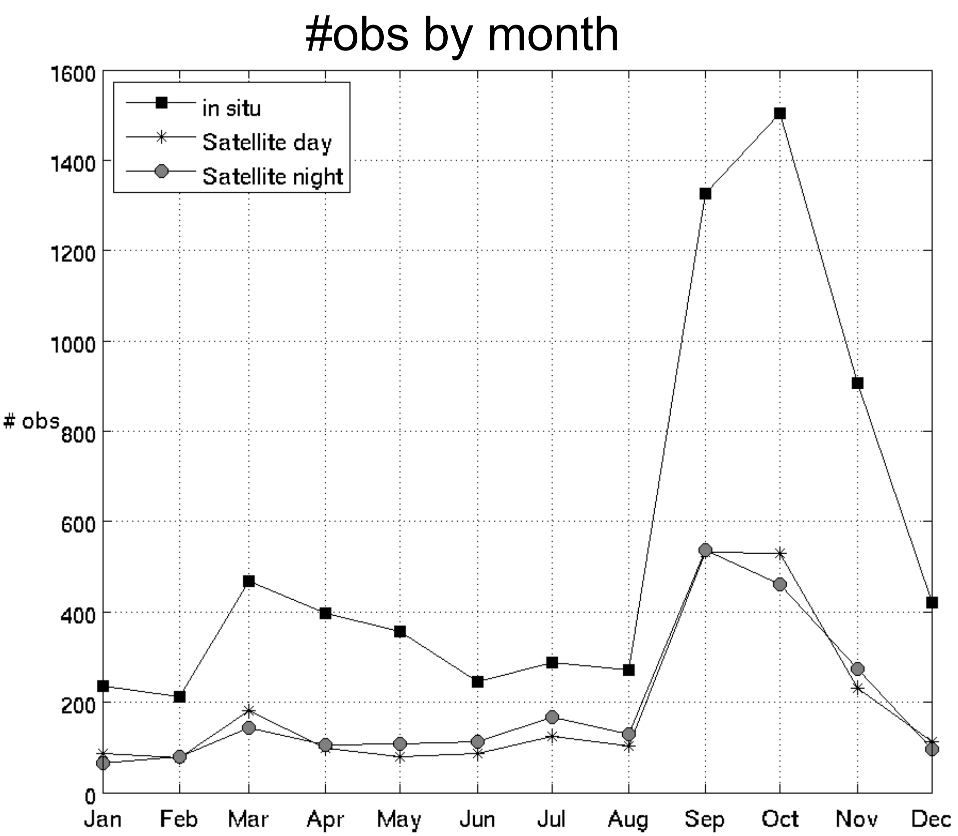
In situ data: location and type

Platform	# of data
CTD	320
XBT	1043
Bottle	260
Float	1994
BATHY	141
Tesac	13
Ship	2865



In situ data: temporal distribution





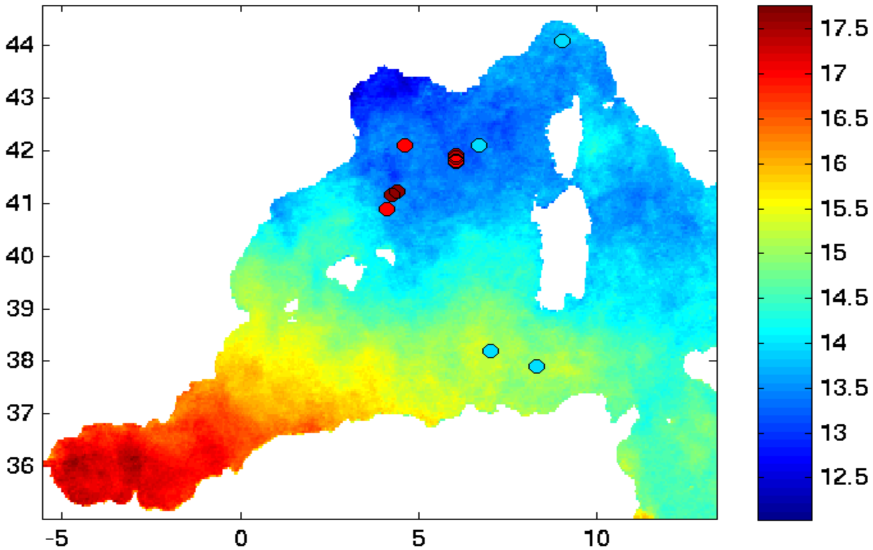
	Bias(ºC)	RMS(ºC)	Anom. Corr.
Day-time	0.16	1.12	0.7
Night-time	-0.12	1.23	0.7

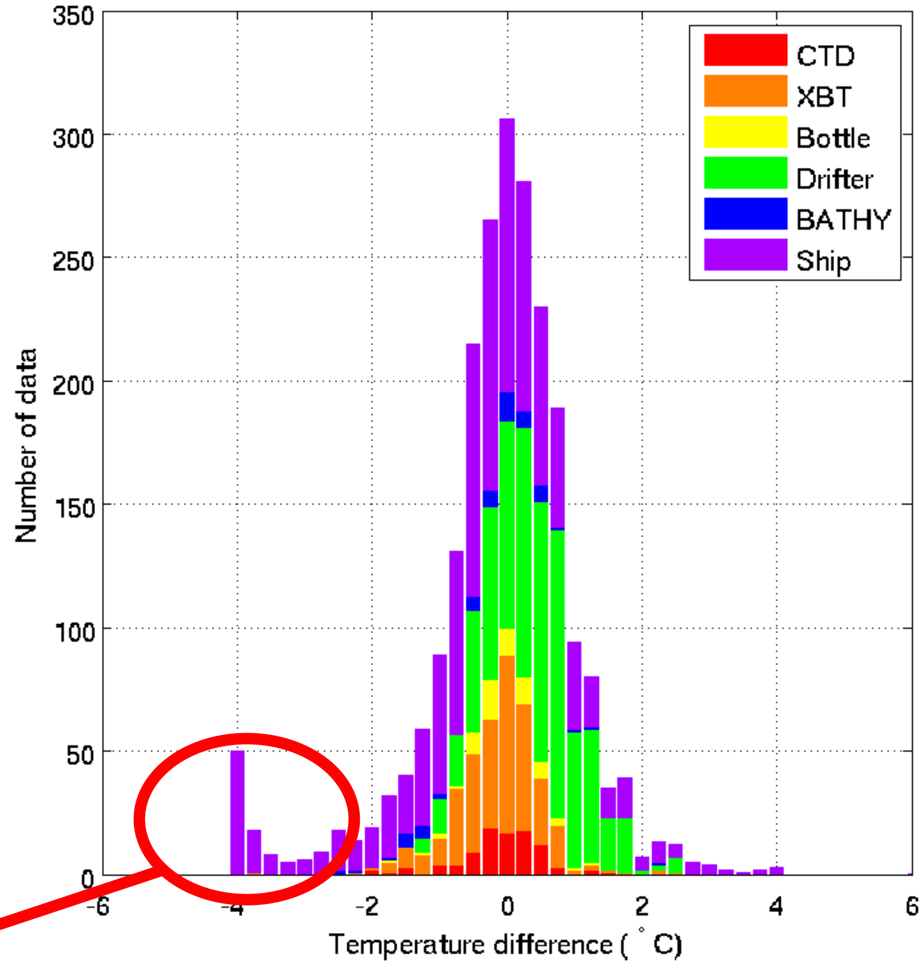
High number of data in fall mostly due to drifters and XBTs

Satellite – in situ difference

- Non-normal distributions (Anderson-Darling test)
- Outliers: ship data during March in Gulf of Lions

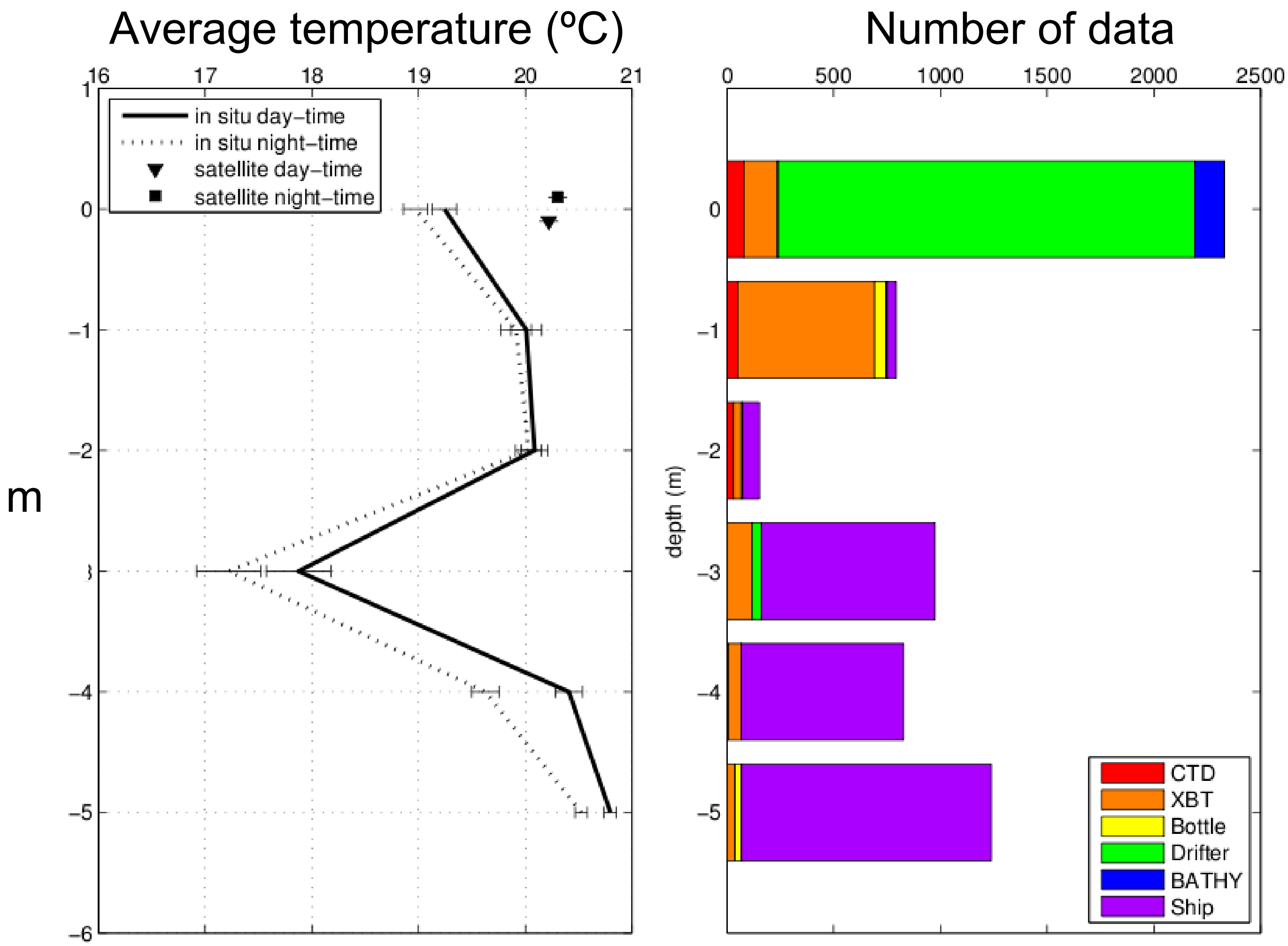
20 March 1999





Temperature difference between satellite and in situ data

In situ-satellite data comparison

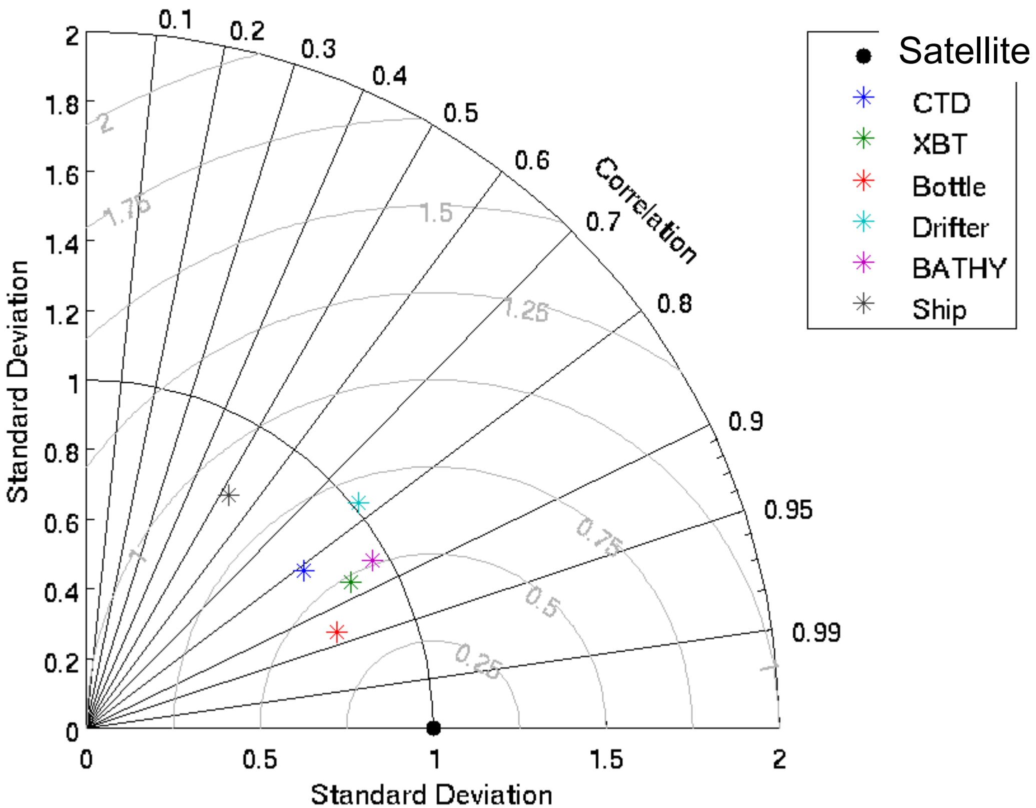


- In situ – satellite data differences larger than day-night differences
- Satellite data closest to 1-2 m depth in situ data
- Cold bias at 3 m (ship design?)

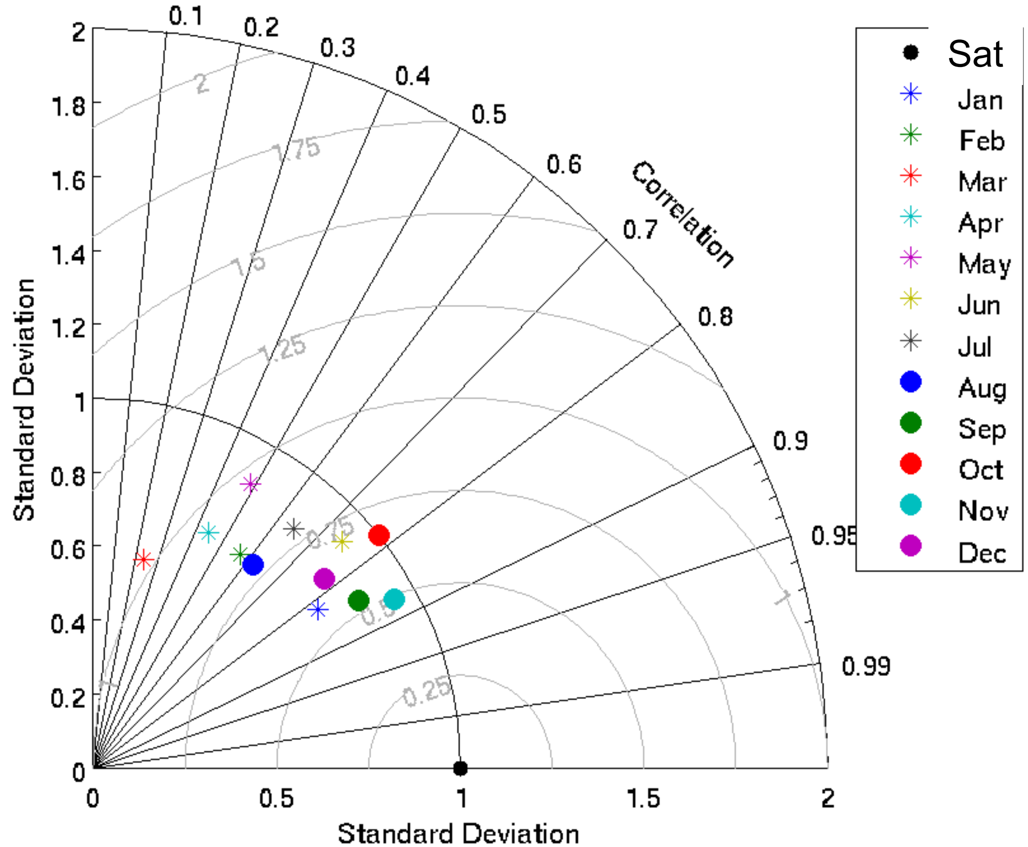
In situ-satellite data comparison

Night-time satellite data vs. in situ data

Taylor diagram by platform type



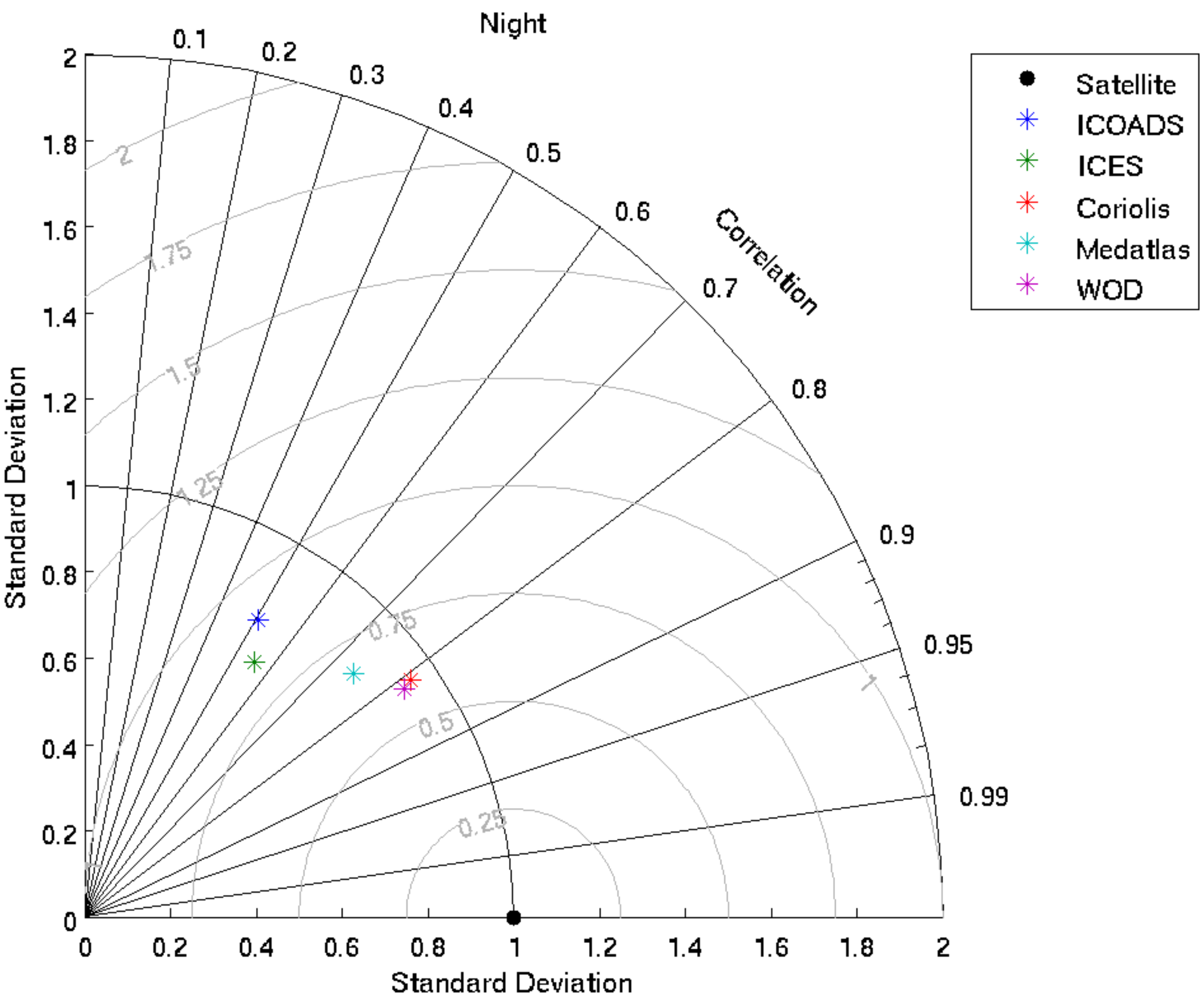
Taylor diagram by month



- Spring and summer months present the highest errors
- Ship data are the most heterogeneous

In situ-satellite data comparison

Taylor diagram by data set



Platform	RMS error
CTD	0.61 ºC
XBT	0.66 ºC
Bottle	0.51 ºC
Float	0.68 ºC
Bathy	0.89 ºC
Ship	1.5 ºC

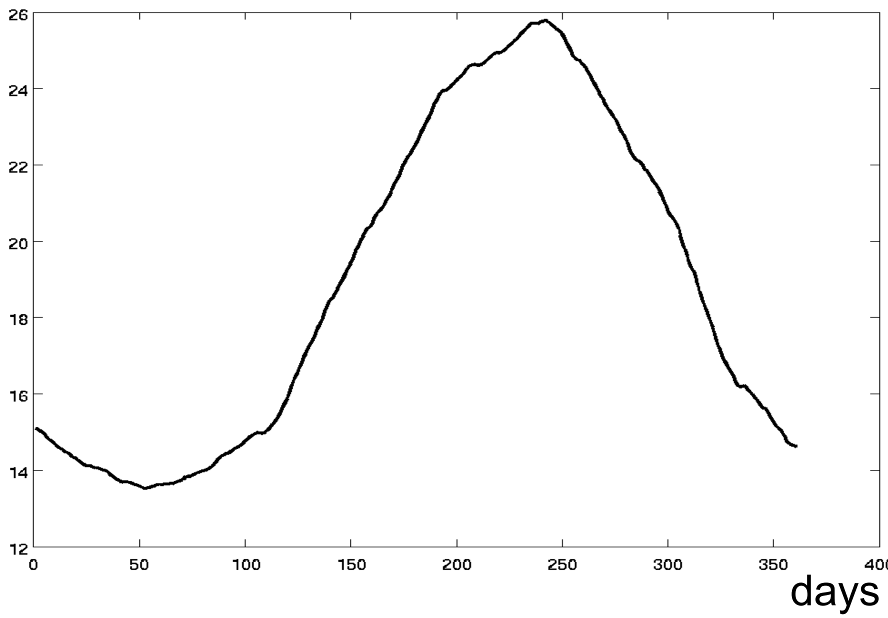
Detailed comparison in Alvera-Azcárate et al, Oc. Dyn. 2011

Satellite - in situ data merging

Night-time satellite data reconstruction

- 1 year satellite data, 64 % missing data
- 3% of cross-validation data (valid satellite data), in the form of clouds
- 14 EOFs retained
- 95.62 % total variance explained
- 0.4 ºC cross-validation error

Seasonal cycle, 20-days low-pass filtered



DINEOF + OI

Two-step process:

DINEOF on satellite data

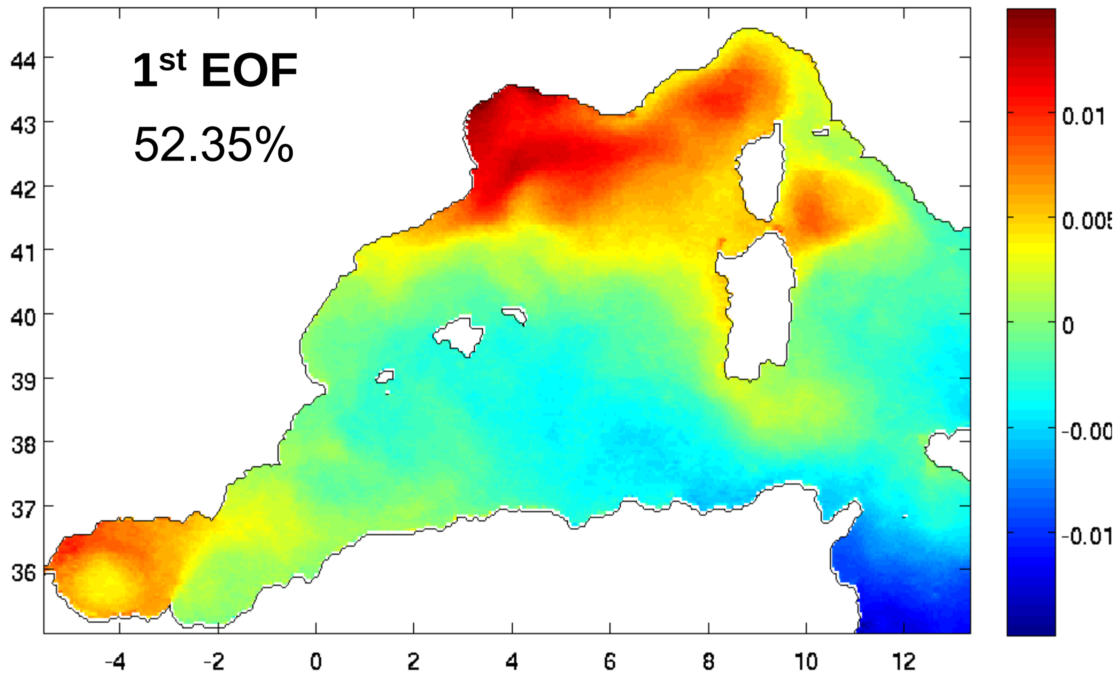
Optimal Interpolation to merge in situ and satellite data

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

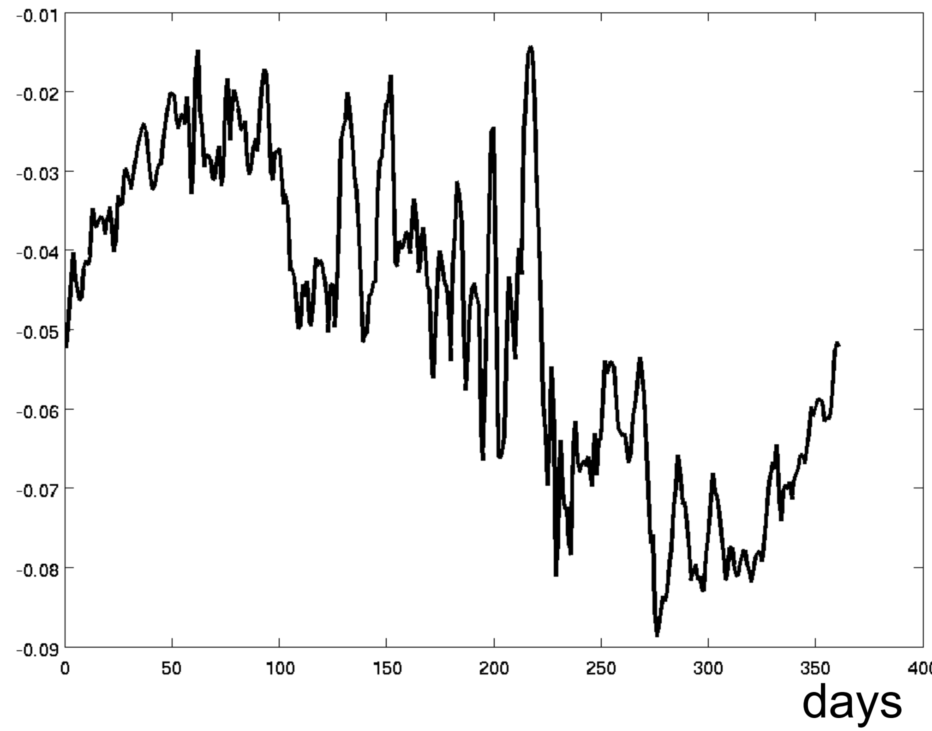
Error variance (**R**) fixed for in situ data (by platform type) and satellite data

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

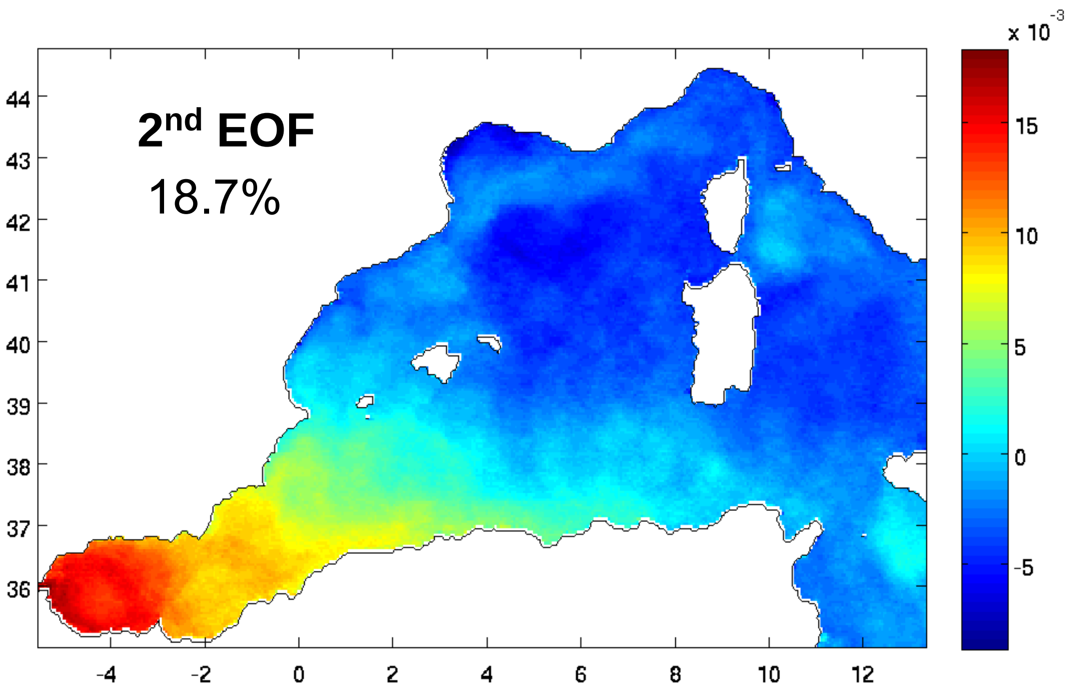
EOFs



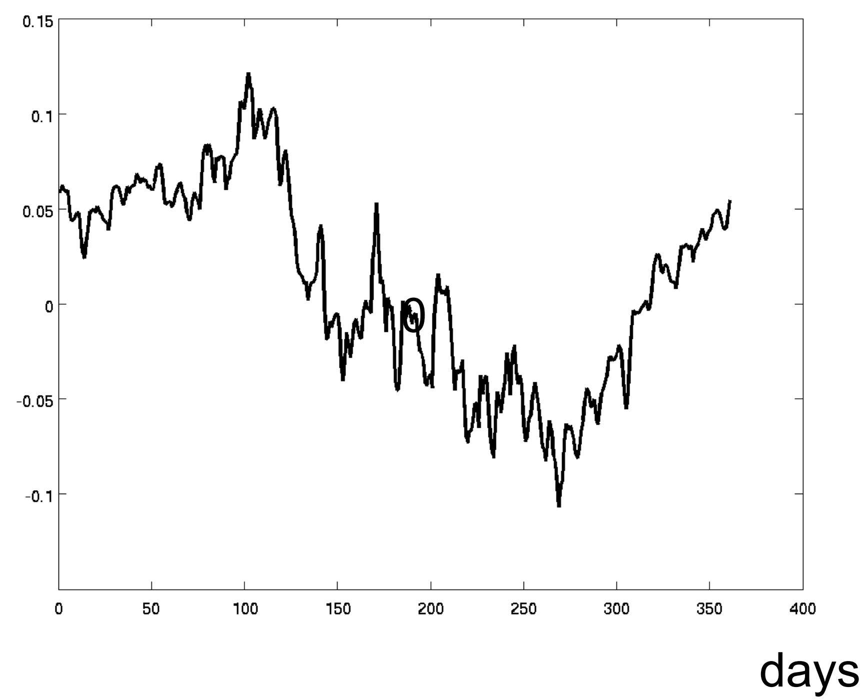
1st EOF
52.35%
0.01
0.005
0
-0.00
-0.01
44
43
42
41
40
39
38
37
36
-4
-2
0
2
4
6
8
10
12



-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-0.09
0
50
100
150
200
250
300
350
400
days

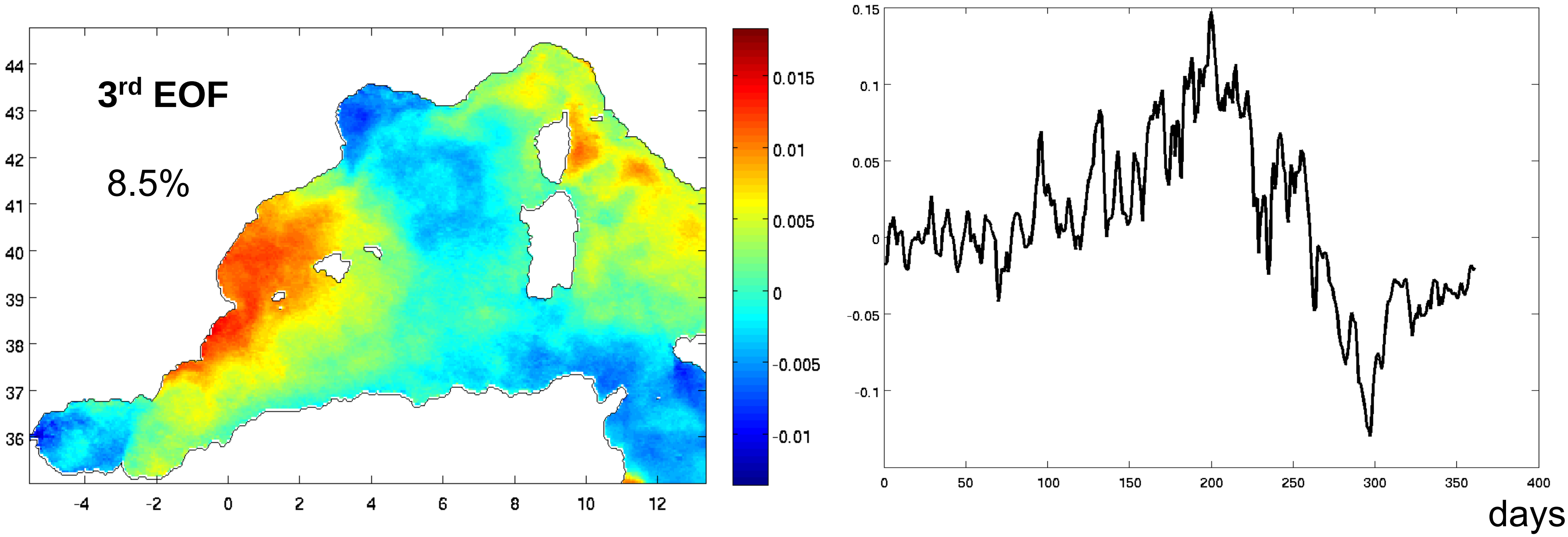


2nd EOF
18.7%
x 10^-3
15
10
5
0
-5
44
43
42
41
40
39
38
37
36
-4
-2
0
2
4
6
8
10
12



0.15
0.1
0.05
0
-0.05
-0.1
0
50
100
150
200
250
300
350
400
days

EOFs

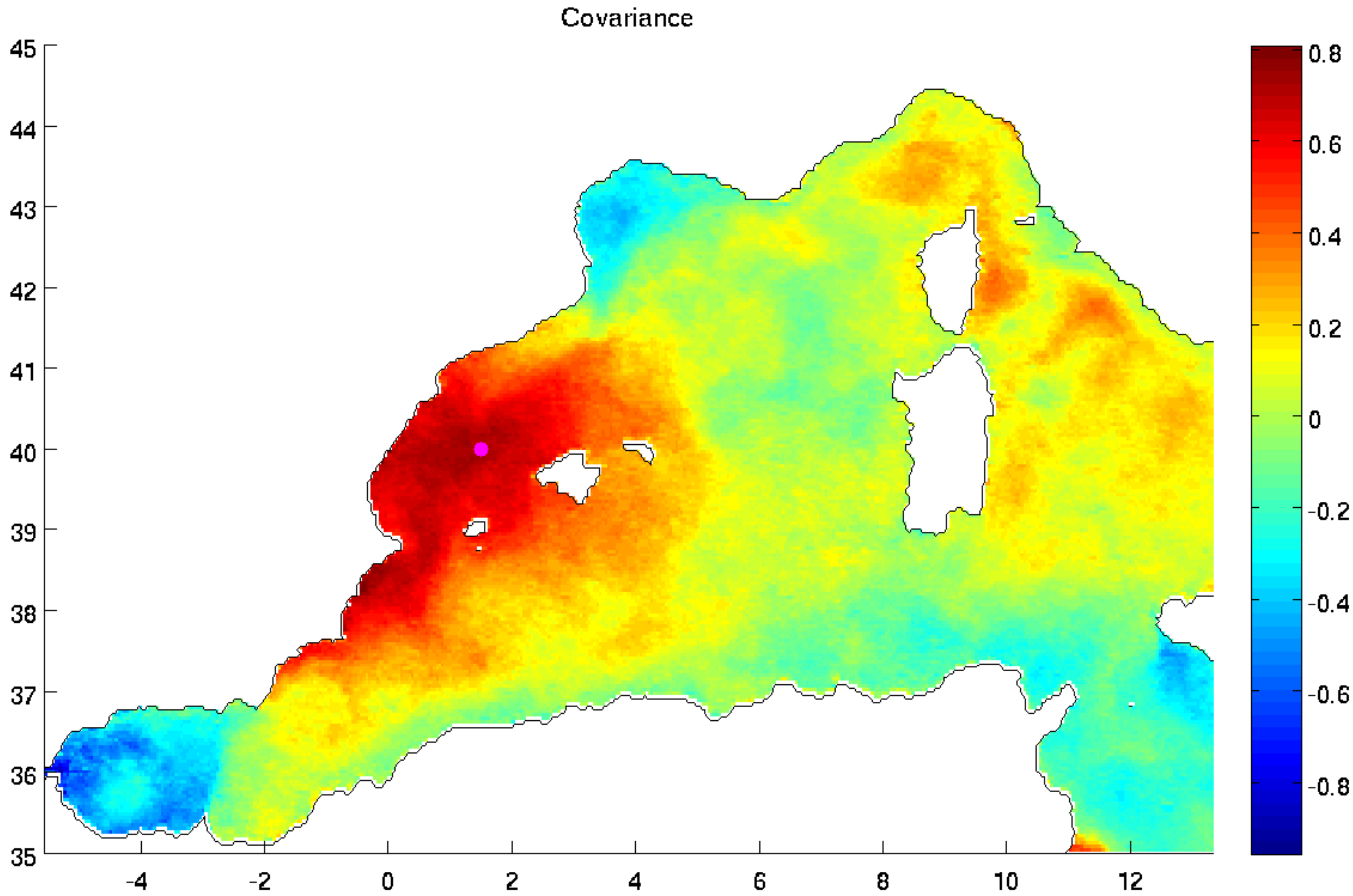


EOFs of the SST variability relative to the seasonal cycle

Alboran Sea: high variability, not strongly correlated with the rest of the western Mediterranean Sea

Covariances

Non-parametric, based on satellite data

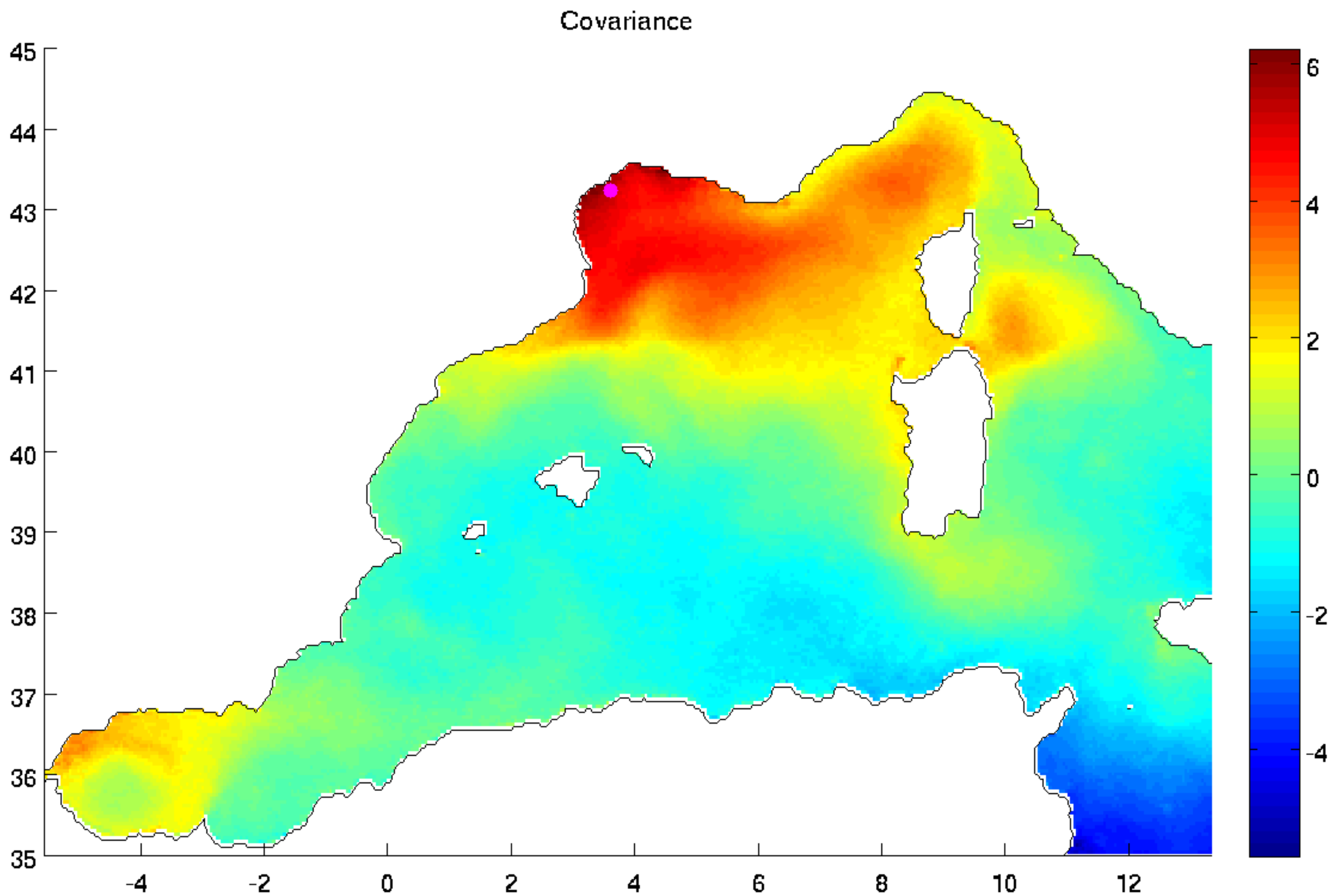


Balearic Sea

Northern current signature along Spanish coast

Spurious long-distance correlations due to truncated EOF basis

Covariances



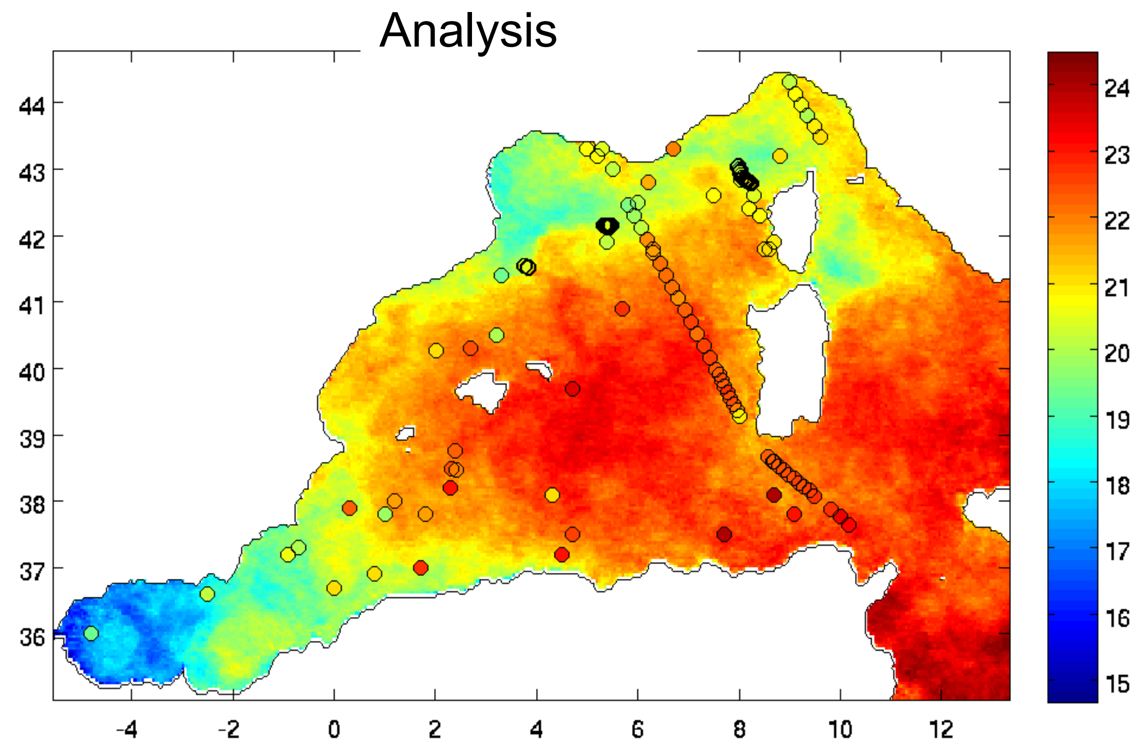
Gulf of Lions

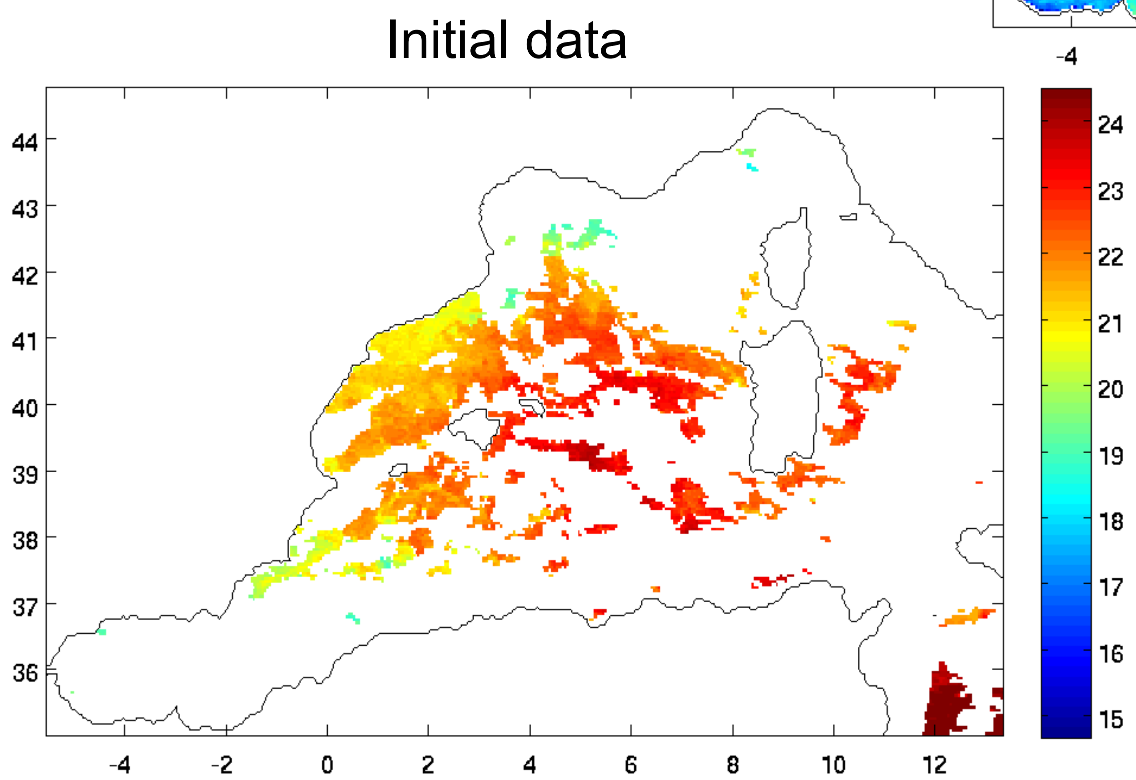
Strong correlation over the entire Gulf of Lions/Ligurian Sea domain

Signature of the Northern Current

Small correlation with Alboran Sea, probably only specific for the time period considered

Example of DINEOF-OI analysis, 16 October 1999





Cross-validation test

- 10% of in situ data set aside for cross-validation (CV) of DINEOF-OI method
- Random locations

	all	CV data
DINEOF	1.12	1.07
DINEOF-OI with all insitu data	1.08	1.04
DINEOF-OI without CV insitu data	1.08	1.06

- DINEOF-OI improves over DINEOF alone (only satellite data)

Conclusions

- Satellite – in situ data comparison shows relative good agreement, some outliers
- In situ – satellite data differences larger than day-night differences. Ship at 3 m depth cold bias
- Spring and summer months present the highest errors
- Ship data presents high errors (highly heterogeneous data set)

- DINEOF + OI step (EOF basis is covariance matrix) to merge satellite with in situ data
- Cross-validation shows improvement of DINEOF-OI over DINEOF alone
- Few EOFs retained: small scales may not be well represented
- Covariances realistic, although spurious correlations at long distances appear
- Future work

    Longer time series
    Embedding OI step into DINEOF analysis might improve small scales

Also: satellite + satellite data merging using EOFs