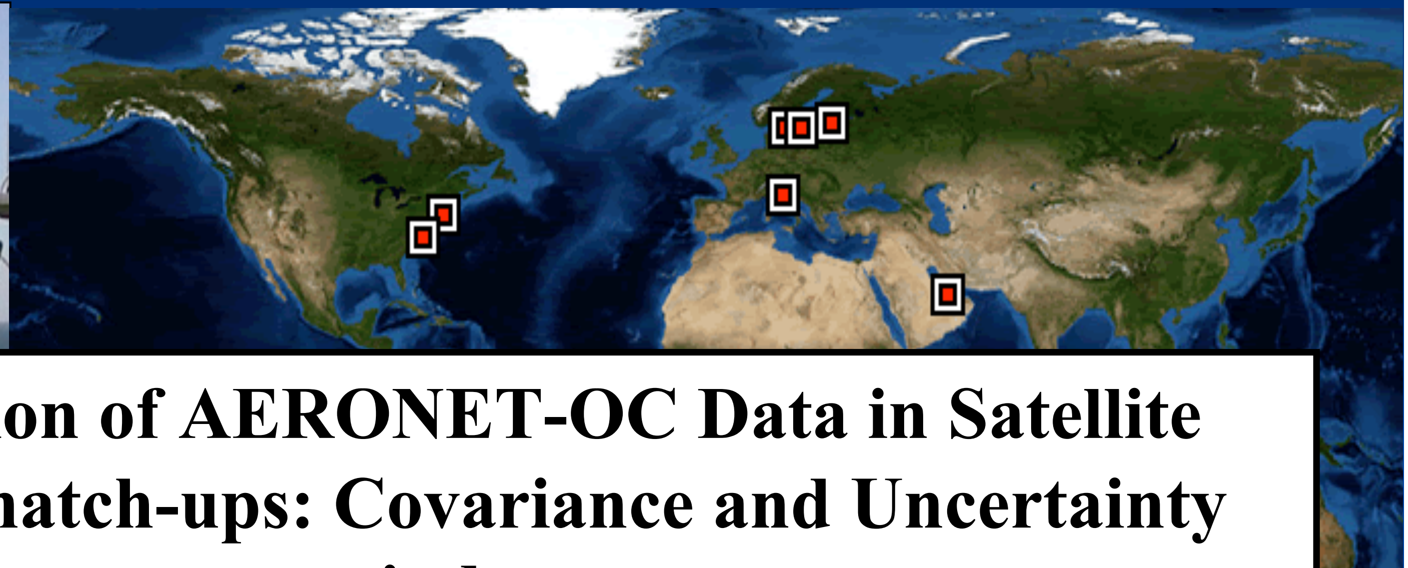
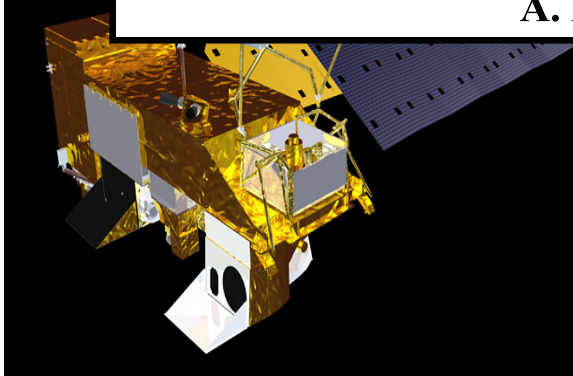
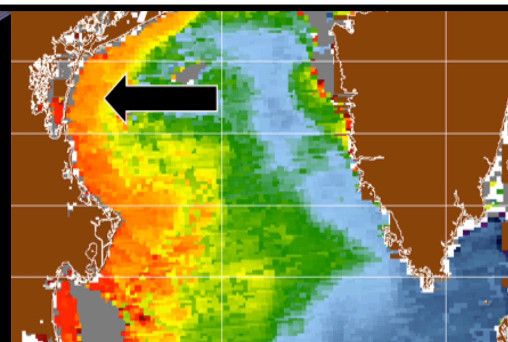



Application of AERONET-OC Data in Satellite Product match-ups: Covariance and Uncertainty index

A. Alvarez, G. Pennucci, C. Trees and G. Fargion


Goals:

Our main goals are to 1) merge remote sensing data with *in situ* measurements to increase the quality of satellite-derived products, and 2) estimate satellite derived product uncertainties based on the number of in situ measurements

- Develop techniques to evaluate the covariance in SST and ocean color images;
- Develop a methodology to merge satellite images with *in situ* data to improve the satellite product;
- Develop software to ingest single or time series images to compute covariance, to merge satellite and *in situ* data and to determine which is the best placement for *in situ* measurements
- Estimate product retrieval uncertainties to estimate optimal *in situ* sampling strategies (one basis for a defined Uncertainty Index-UI).

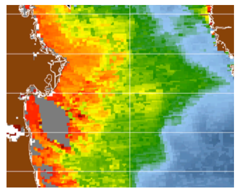
Summary:

- ✓ The general procedure;
- ✓ Covariance evaluation (spatial-temporal and spatial domains);
- ✓ Statistical model definition (spatial domain);
- ✓ Merging technique;
- ✓ Data ingestion criteria and cloud cover analysis;
- ✓ Example: covariance of MODIS time-series;
- ✓ Demo of the GUI (Version 2);
- ✓ Conclusion and work in progress.

Procedure Flow Diagram:

SPATIAL DOMAIN | **SPATIAL-TEMPORAL DOMAIN**

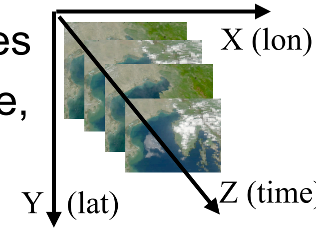
Ingestion of a satellite image (geotiff, tiff, hadf4, hadf5, grid or MATLAB format)



MODIS

STEP 1

Ingestion of a time-series (3D-cube with Longitude, Latitude and time info)

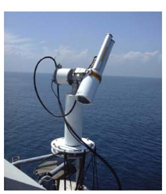


Selection of the desired geographic area **STEP 2** (with **low cloud percentage**)

Spatial Covariance Evaluation

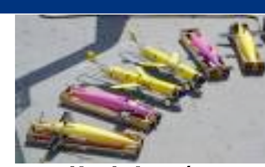
STEP 3

Spatial-temporal Covariance Evaluation



Merging with *in situ* data (such as AERONET, CTD, HyperPRO, and gliders), if they are available (~same time

STEP 4



Covariance Evaluation

SPATIAL-TEMPORAL DOMAIN

If a time-series is available ($\{\psi_i(\vec{x})\}_{i=1}^{N}$)

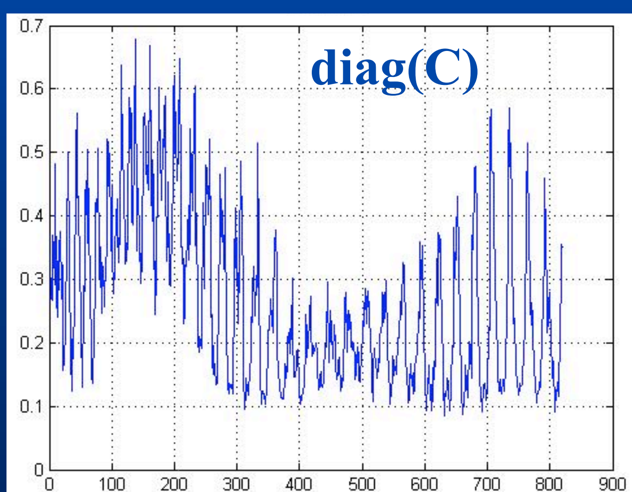
X

Y

Time

$$T_{mn} \Rightarrow C_{nn} = T' \cdot T$$

COVARIANCE

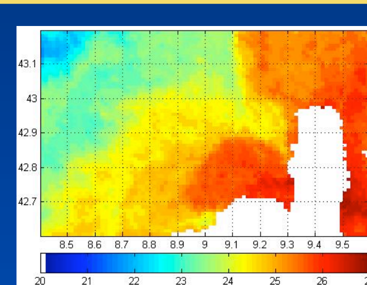


TIME SERIES

SPATIAL DOMAIN

Just an image is available: $\psi(\vec{x})$

X



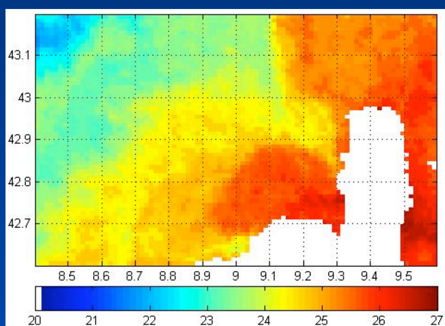
Y

How to make statistic without temporal variations… ?

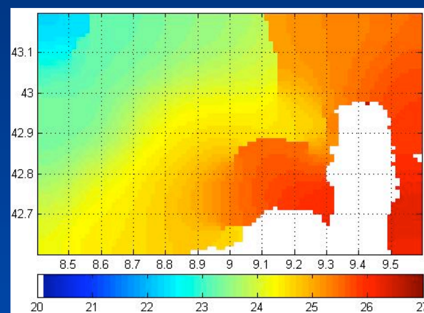
To properly evaluate the covariance (without the time domain) we have to define a statistical model.

Statistical model definition

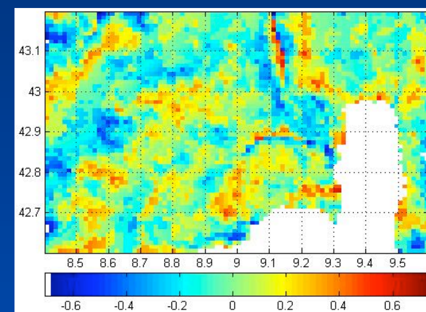
The image can be decomposed into: spatially varying mean + random Gaussian residual using an anisotropic diffusion operator that preserves front structures.



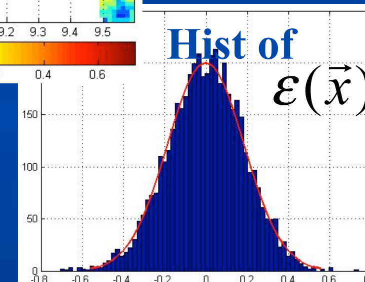
Oceanographic field $\psi(\vec{x})$
(SST original image)



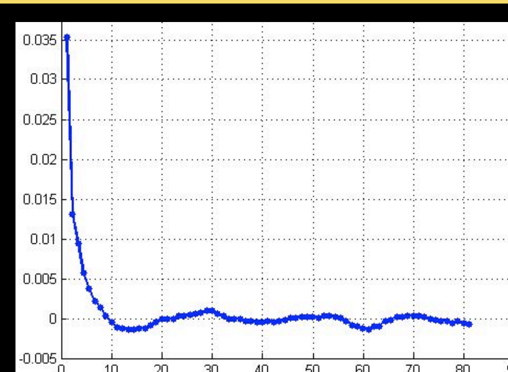
Mean field, $M\psi(\vec{x})$



Residual field
$\varepsilon(\vec{x})$

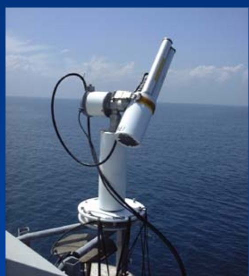


We assume that covariance (C) is a function of the relative distance between 2 points.
C is the covariogram of the residual field :



The merging technique:

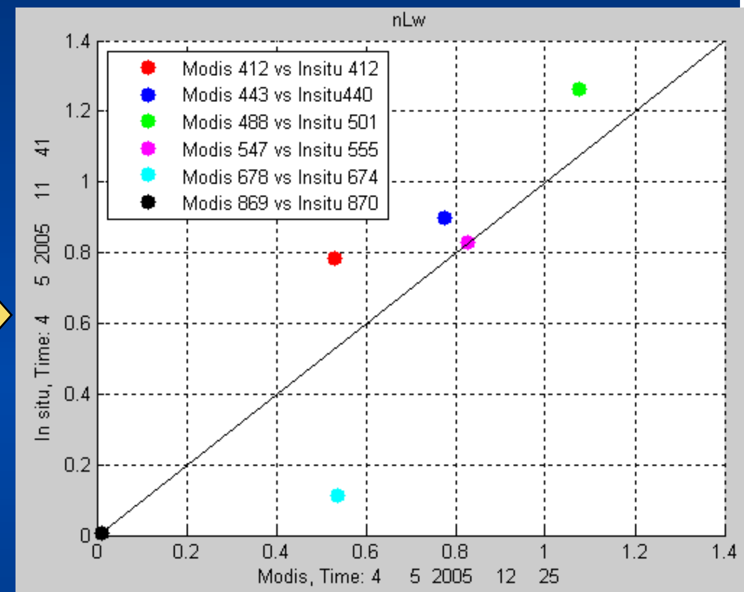
Assuming that *in situ* data are available:



AERONET data

User responsible for the QC & QA of in situ data

EXCLUSION CRITERIA:
Max Solar Zenith Angle: 70°
Wind speed <= 12 ms-1
Max time difference from
Satellite data = +- 1 hours



If the available *in situ* data are consistent, a new image merging AERONET and satellite data can be retrieved maximizing the probability distribution (that depends on the retrieved covariance).

Merging technique (details)

Once the covariance (C) has been obtained, a new field merging *in situ* and satellite data is obtained maximizing the probability distribution:

$$P(\psi_k) \propto \exp(\psi_{obs} - H\psi_k)^T \Sigma_{obs}^{-1} (\psi_{obs} - H\psi_k) - (\psi_k - \overline{\psi})^T C_\varepsilon^{-1} (\psi_k - \overline{\psi})$$

Observation vector

Observation matrix

Estimated pixel values

Observation error matrix

The solution of the following equation:

$$\psi_{MERGED} = \arg\min(\psi_{obs} - H\psi_k)^T \Sigma_{obs}^{-1} (\psi_{obs} - H\psi_k) - (\psi_k - \overline{\psi})^T C_\varepsilon^{-1} (\psi_k - \overline{\psi})$$

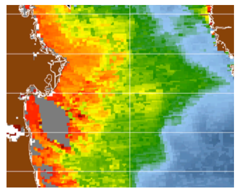
represents the **merged image**: the best estimation compatible with the available information.

The procedure:

SPATIAL DOMAIN

SPATIAL-TEMPORAL DOMAIN

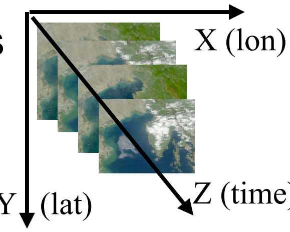
Ingestion of a satellite image (geotiff, tiff, hadf4, hadf5, grid or MATLAB format)



MODIS

STEP 1

Ingestion of a time-series (3D-cube with Longitude, Latitude and time info)



Data ingestion criteria (user required)

Selection of the desired geographic area

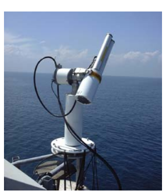
STEP 2

(with **low cloud percentage**)

STEP 3

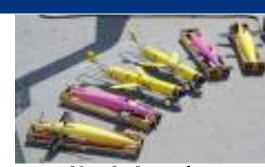
Spatial Covariance Evaluation

Spatial-temporal Covariance Evaluation



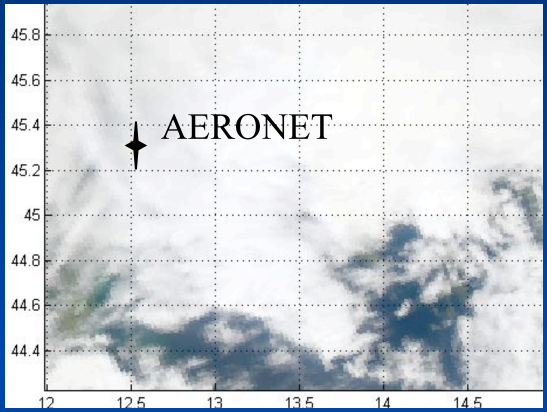
Merging with *in situ* data (such as AERONET, CTD, HyperPRO, and gliders), if they are available (~same time

STEP 4



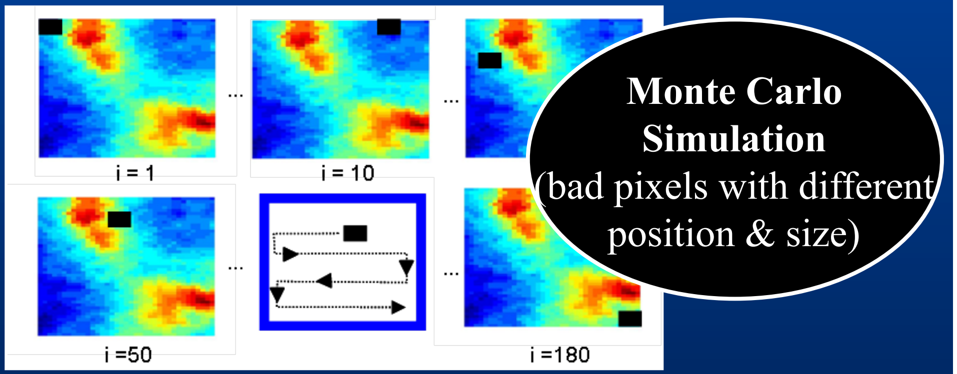
Data ingestion criteria

It's important to note that our study is directly related to the quality of satellite data: results are directly related to the amount of information.



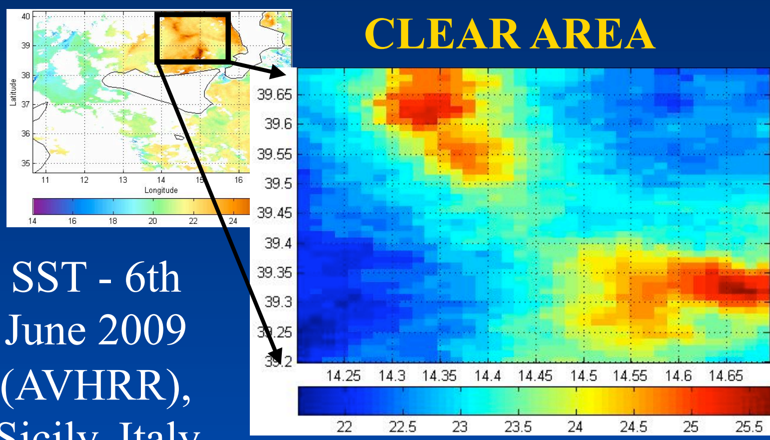
EVALUATION OF THE METHOD TO RESPECT CLOUDS/NOISE/BAD PIXELS

The covariance field was evaluated as a function cloud cover (bad pixels) to define a minimum amount of information for implementation of the model.



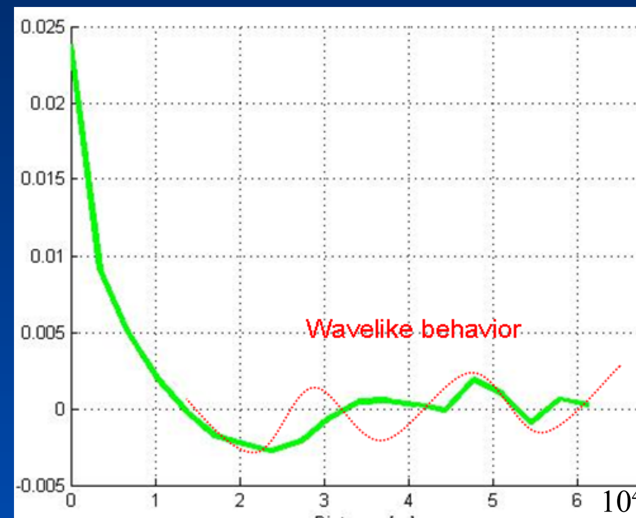
Covariance as function of clouds (1/2)

CLEAR AREA



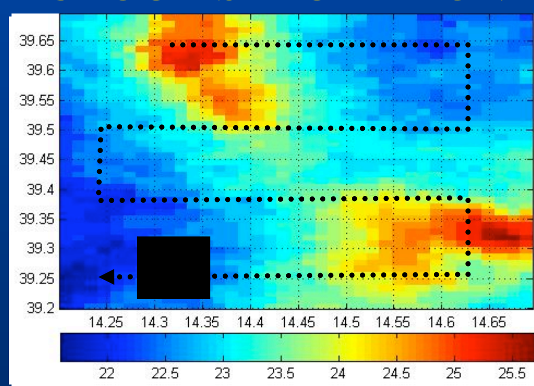
SST - 6th June 2009 (AVHRR), Sicily, Italy.

COVARIANCE

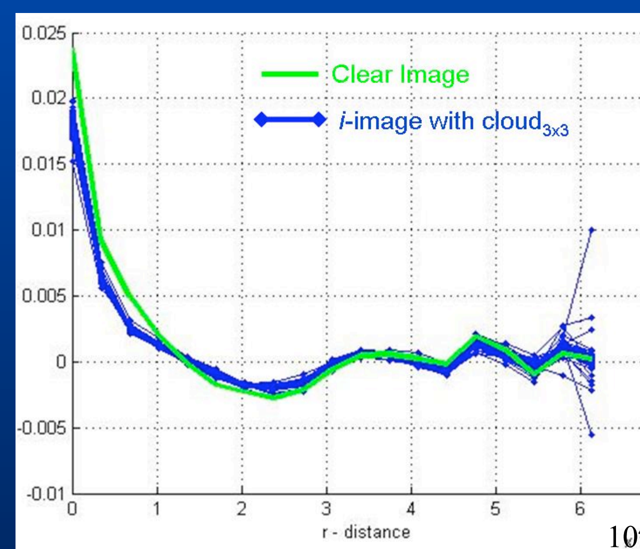


DISTANCE [m]

CLOUD SIMULATION



COVARIANCE



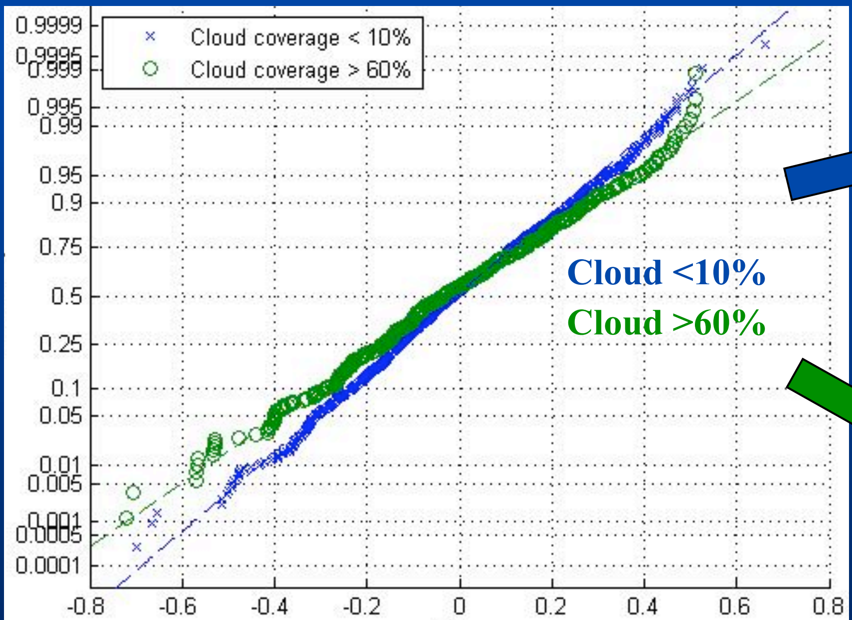
DISTANCE [m]

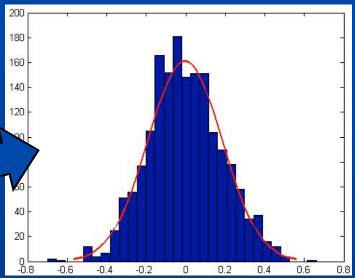
Covariance as function of clouds (2/2)

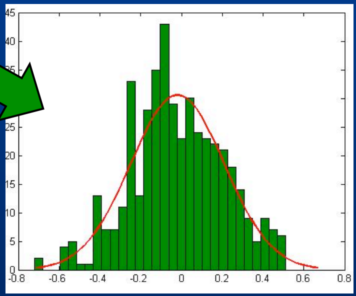
The results show that the covariance analysis is directly dependent on cloud size/position. Clouds cause a loss of information, which means:

1. Decreased correlation length;
2. Decreased goodness of the realization (Normal distribution)

PROBABILITY PLOT FOR NORMAL DISTRIBUTION (data vs prob)





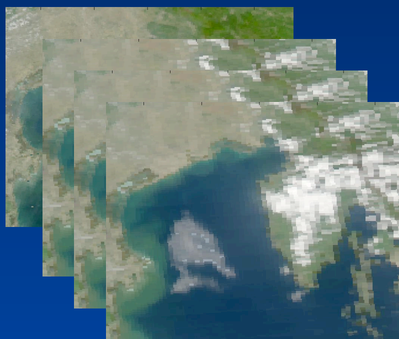


QUALITY INDICES DEFINITION:

Index 1 takes into account of the # of structures (~amount of information);

Index 2 takes into account Of the goodness of the residual field realization.

An example of MODIS time series (1/2)



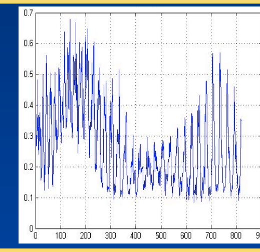
MODIS time-series images.
Month : May
Years : from 2005 to 2009

205 images

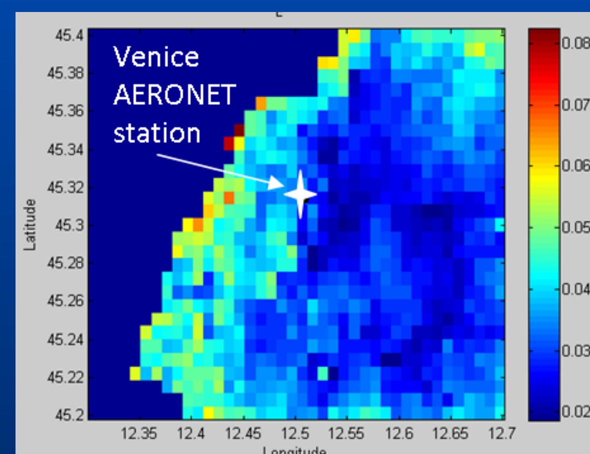
Automatic + user required procedures to select "clear" images (data quality)

15 images

Covariance evaluation

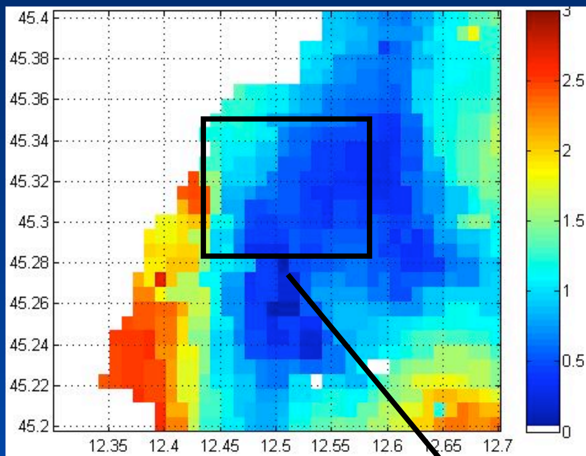


AERONET data Integration (water leaving radiance)



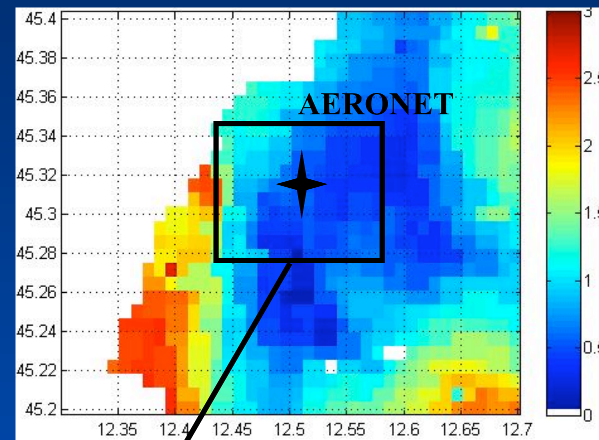
Satellite Error Estimation (uncertainty)

An example of MODIS time series (2/2)

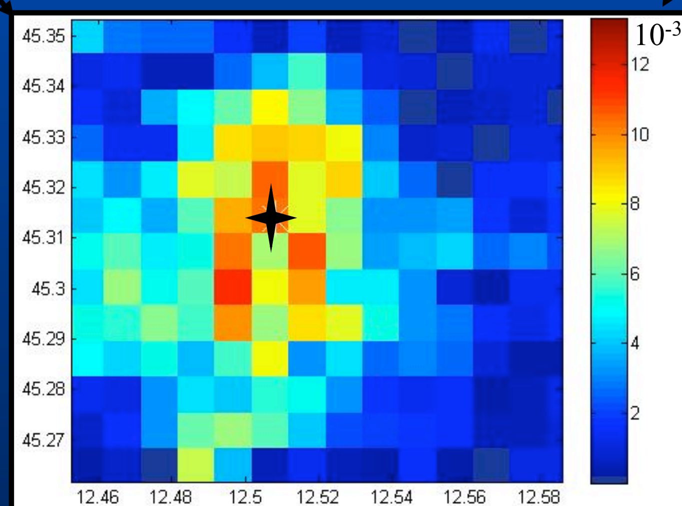


Water Leaving radiance (547 nm) from MODIS (4 May 05, h 12.25)

MERGING
Using C and AERONET measurement:
Lat = 45.3139;
Lon = 12.5083
Time = 4 May 2005, h12.21

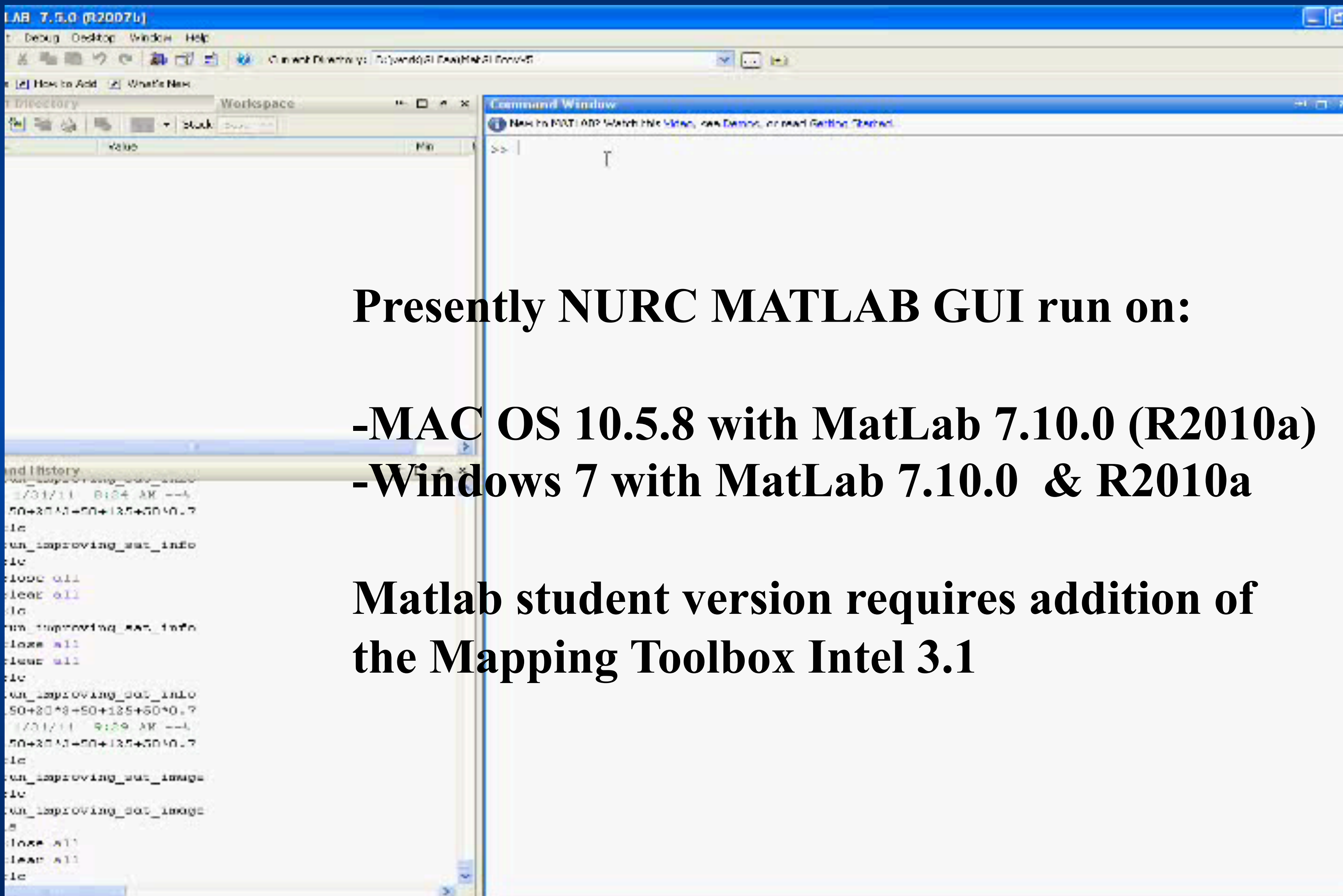


Merged Image



Difference between original and merged

GUI demo



Presently NURC MATLAB GUI run on:

-MAC OS 10.5.8 with MatLab 7.10.0 (R2010a)
-Windows 7 with MatLab 7.10.0 & R2010a

Matlab student version requires addition of the Mapping Toolbox Intel 3.1

Conclusion:

The procedure developed for the project Calibration/Validation (cal/val) Plan for Oceans Environmental Data Records (ERDS) for the Visible Infrared Spectrometer (VIIRS) have been described.

In particular:

- ✓ Covariance computation procedures;
- ✓ Evaluation of the covariance dependence on clouds size/position;
- ✓ Description of the merging procedure;
- ✓ Demo of the software developed (GUI version 3 – Jan 2011).

Work in progress:

- ➢ Integration of the spatial-temporal procedure in the GUI (Version 4 – April 2011);
- ➢ Utilization of VIIRS proxy data to estimate optimal *in situ* sampling strategies (one basis for a defined Uncertainty Index-UI).