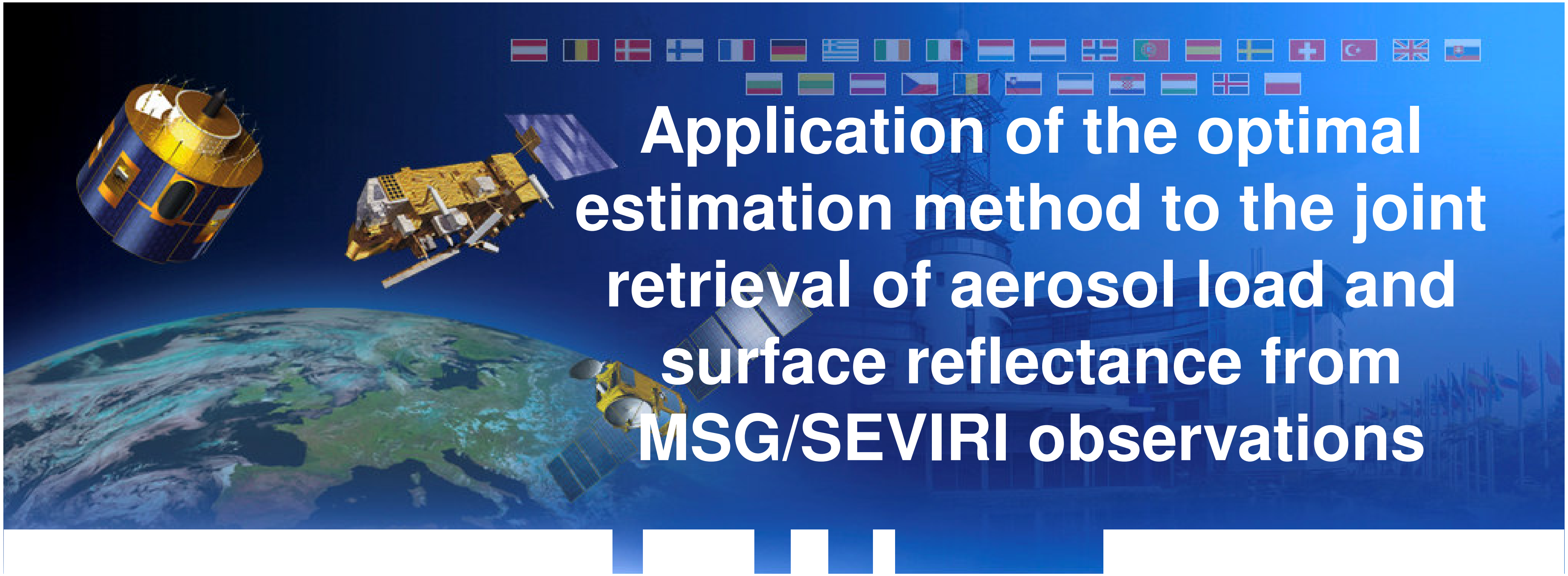


Application of the optimal estimation method to the joint retrieval of aerosol load and surface reflectance from MSG/SEVIRI observations

Yves Govaerts, EUMETSAT

Sebastien Wagner, Wagner Consulting

Phil Watts, EUMETSAT

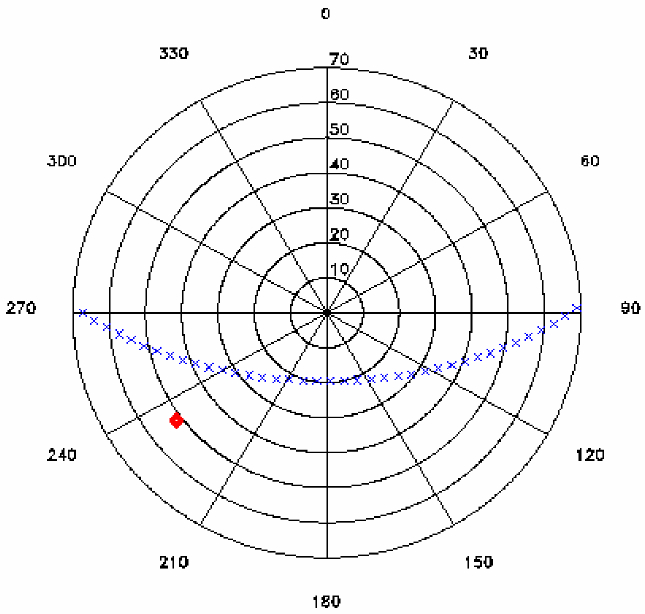
Alessio Lattanzio, Makalumedia

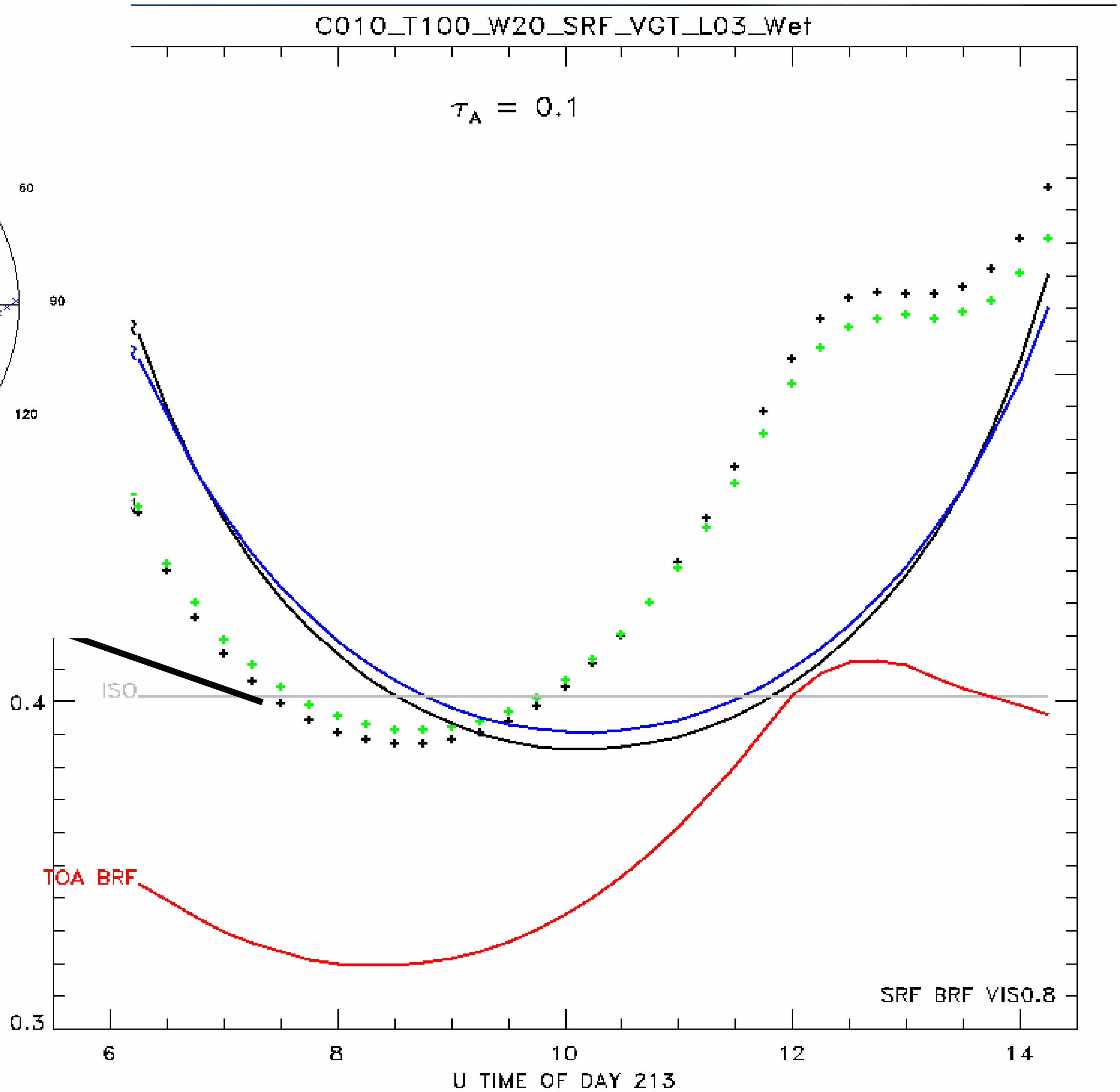
SURFACE/ATMOSPHERE RADIATIVE COUPLING

- **The anisotropy of the surface BRF is due to shadowing effects resulting from the "porosity" or "roughness" of the scene.**

- **The magnitude of this anisotropy is controlled by the ratio between the direct and diffuse downwelling radiation, and therefore by the amount of aerosol in the atmosphere.**

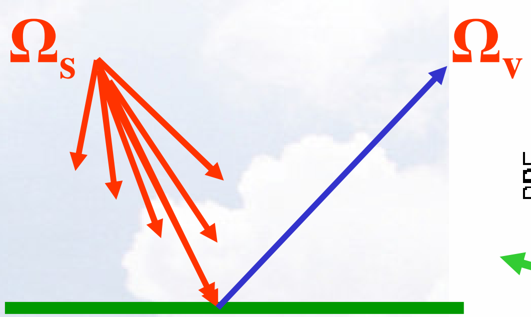
- **Diffuse downwelling radiation tends to reduce "sharpness" of the shadow and therefore the anisotropy magnitude.**



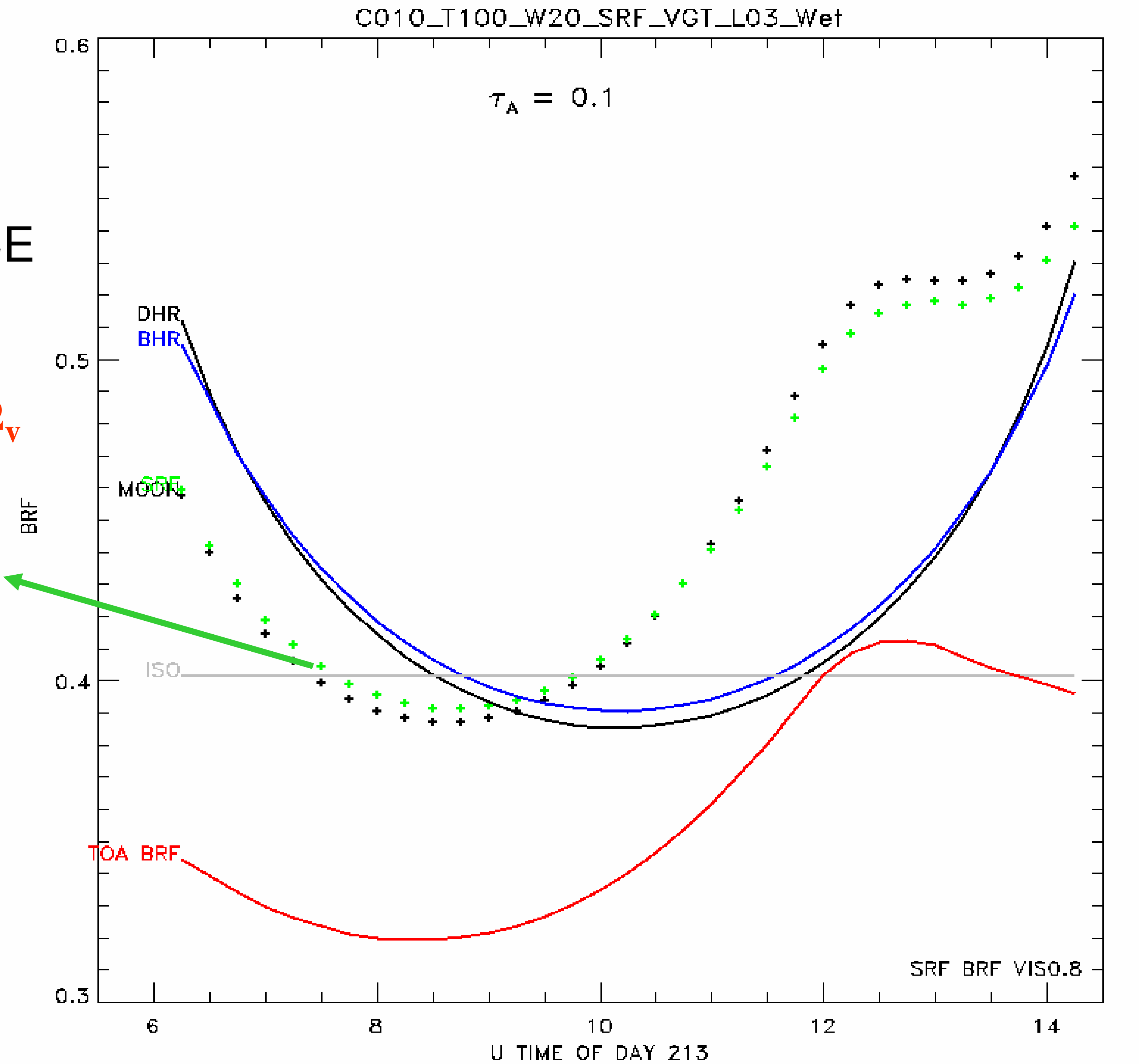


Surface reflectance
No atmosphere

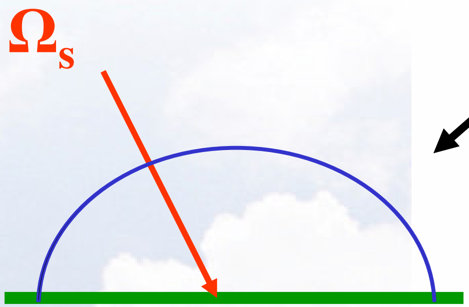
AT THE SURFACE

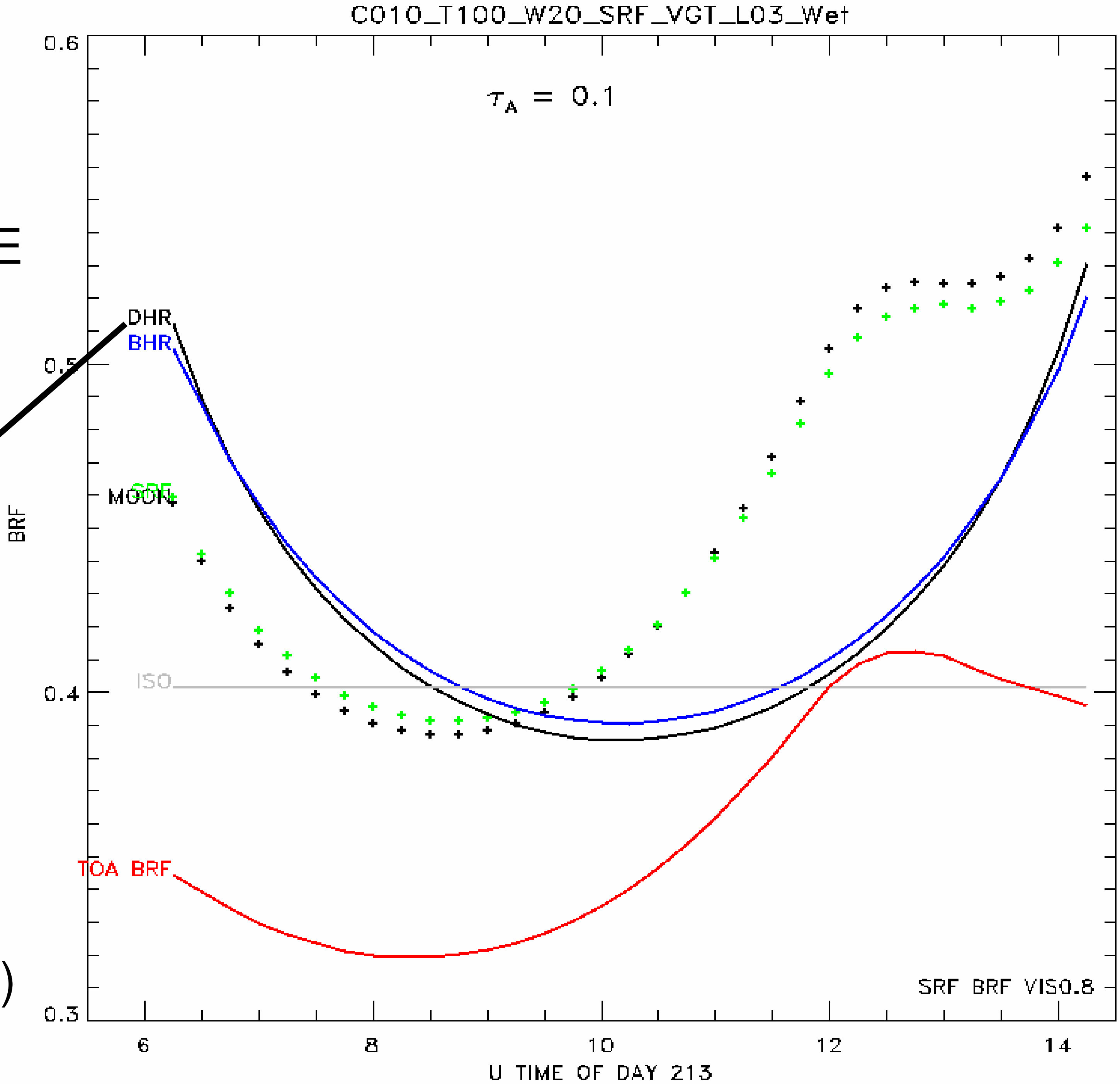


Apparent surface
Reflectance



AT THE SURFACE

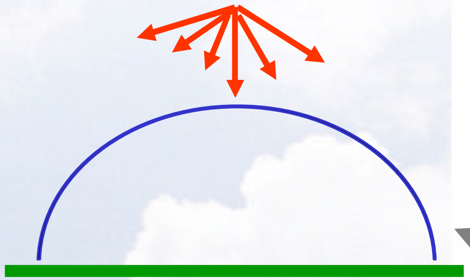


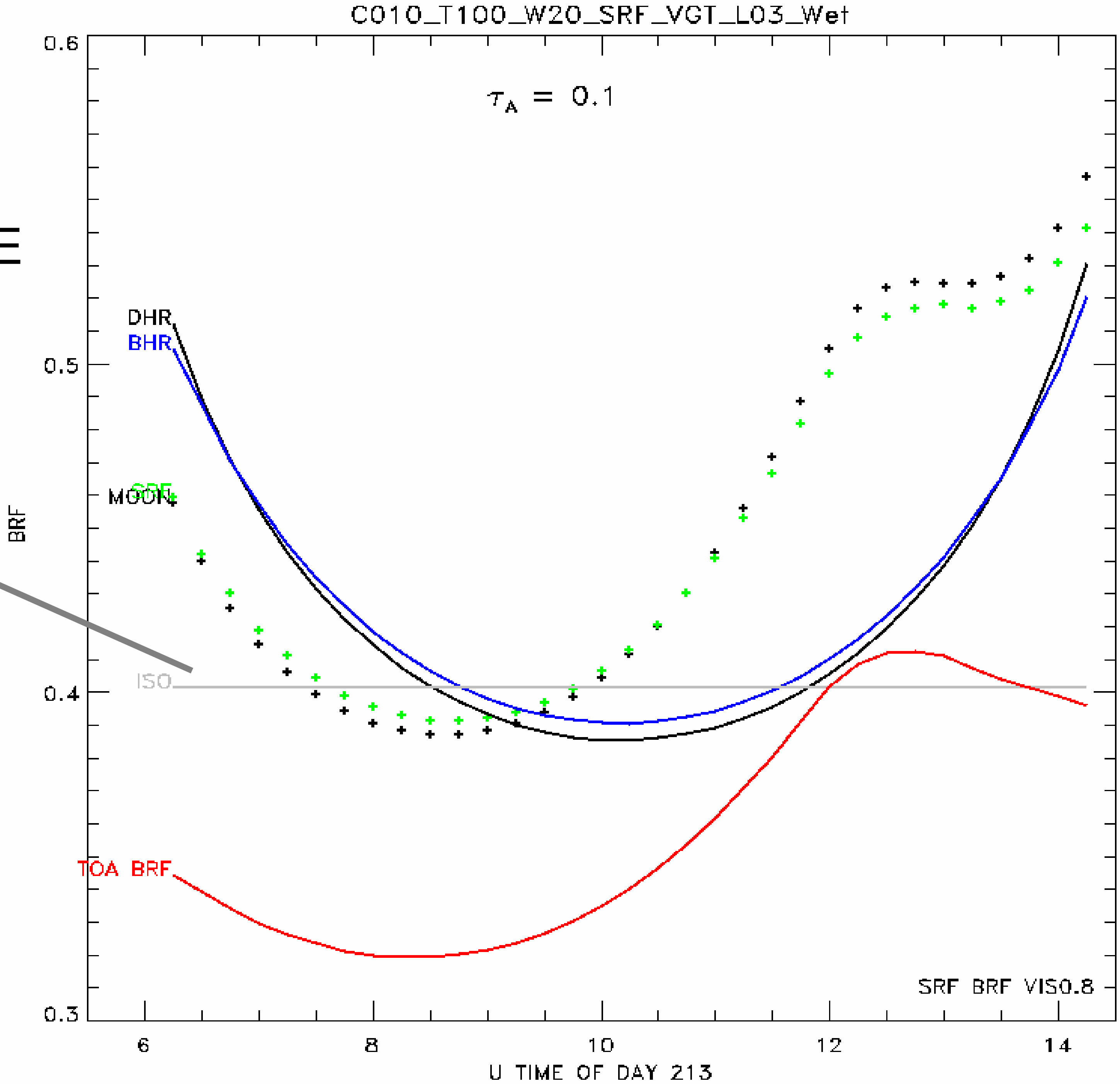


Black sky albedo

Directional
Hemispherical
Reflectance (DHR)

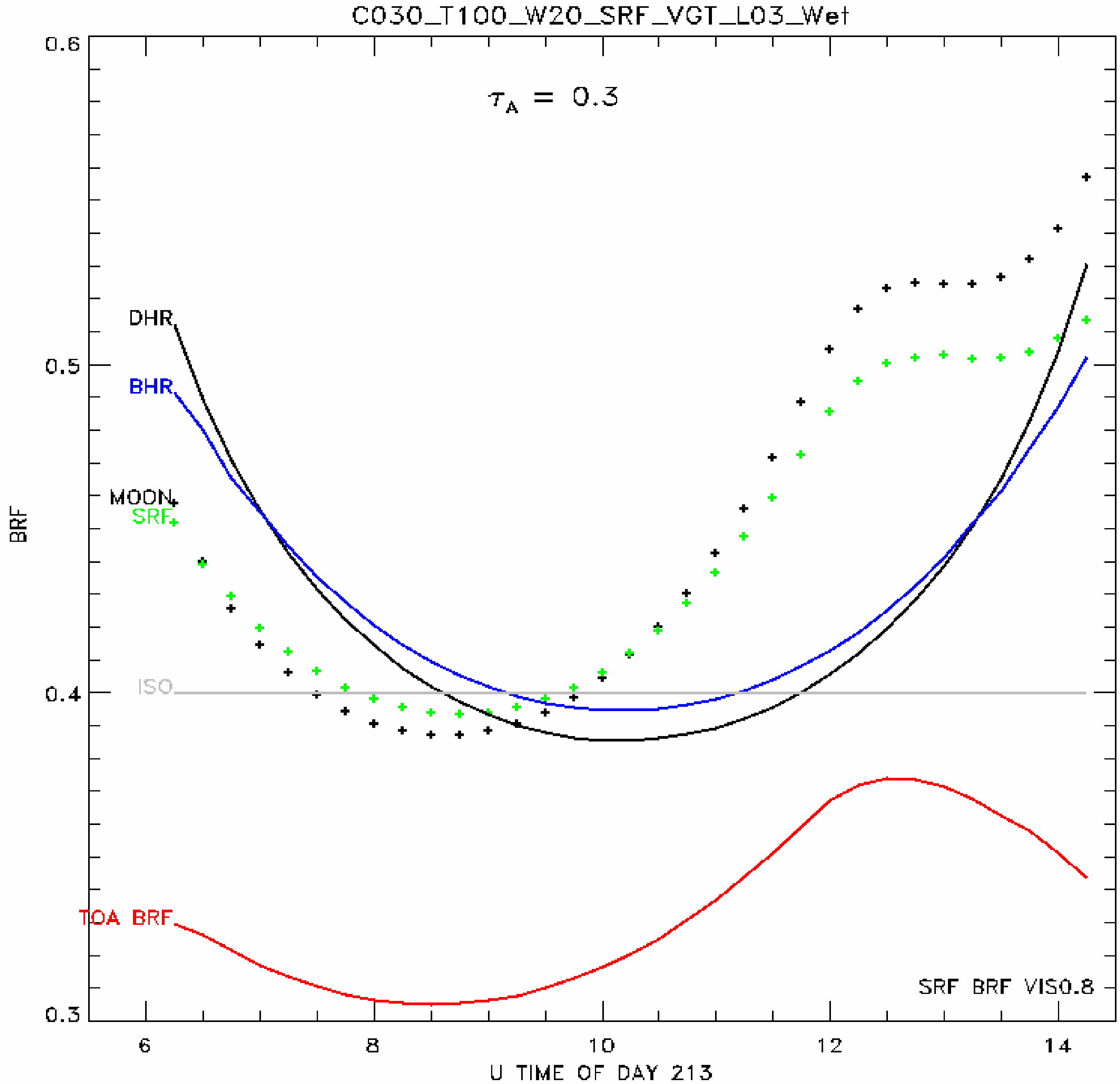
AT THE SURFACE





White sky albedo

Bi**H**emispherical **R**eflectance isotropic (BHR_{iso})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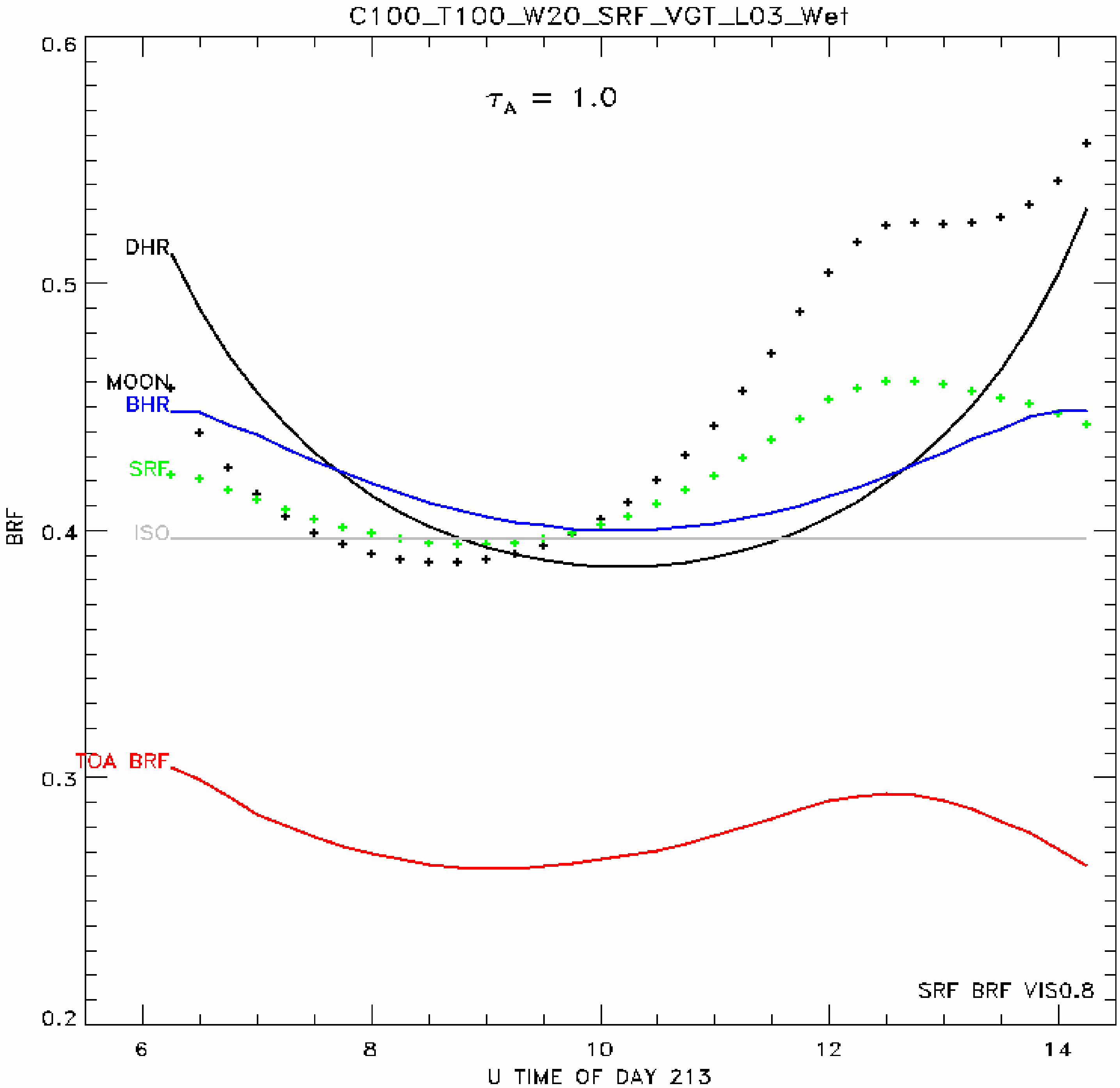
τ_A = 0.3
0.6
0.5
0.4
0.3
BRF
DHR
BHR
MOON
SRF
ISO
TOA BRF
SRF BRF VIS0.8
6
8
10
12
14
U TIME OF DAY 213


C100_T100_W20_SRF_VGT_L03_Wet
τ_A = 1.0
DHR
MOON
BHR
SRF
ISO
TOA BRF
SRF BRF VIS0.8
BRF
0.6
0.5
0.4
0.3
0.2
6
8
10
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14
U TIME OF DAY 213

OVERVIEW

- Objective
- Algorithm description
- Product evaluation
- Conclusions

OBJECTIVE

Objectives of the Land Daily Aerosol algorithm (LDA):

Derive a mean daily aerosol optical thickness at 0.55µm for various types of aerosol classes over land surfaces.

Aerosol above land…

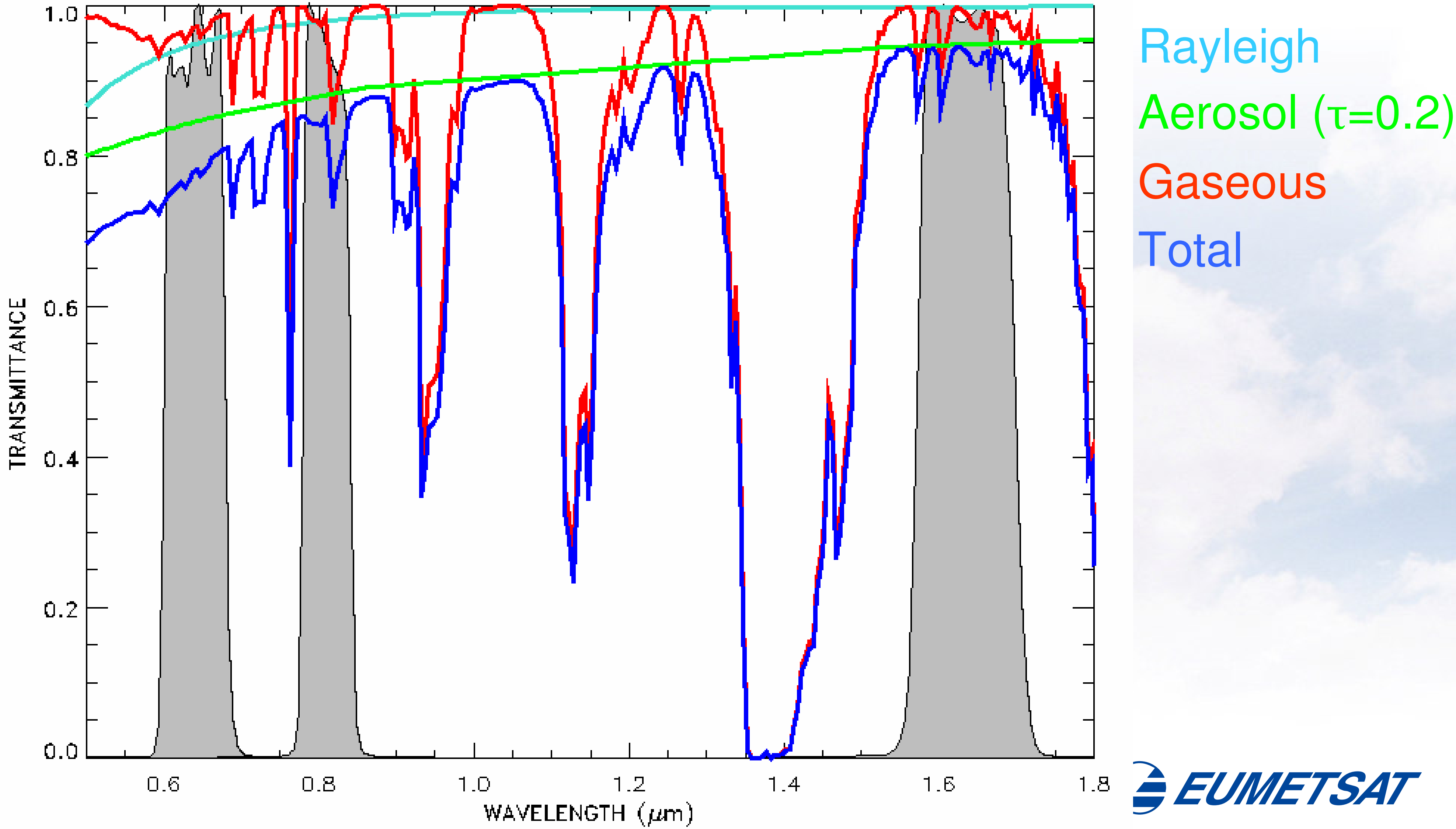
How to separate the aerosol contribution from the surface one?

(Simultaneous retrieval of aerosol load and the surface properties)

Retrieval strategy:

- Daily accumulation of METEOSAT/SEVIRI data in VIS06 / VIS08 / NIR16 (15 / 30 min resolution)
- SIMULTANEOUS retrieval over land of:
  - mean daily AOD (550 nm) [Phase 1]
  - Hourly (?) AOD (550 nm) [Phase 2]
  - surface reflectance
- Inversion based on Optimal Estimation
- Update of the surface prior information, using a “memory” mechanism

OBJECTIVE : SEVIRI TRANSMITTANCE

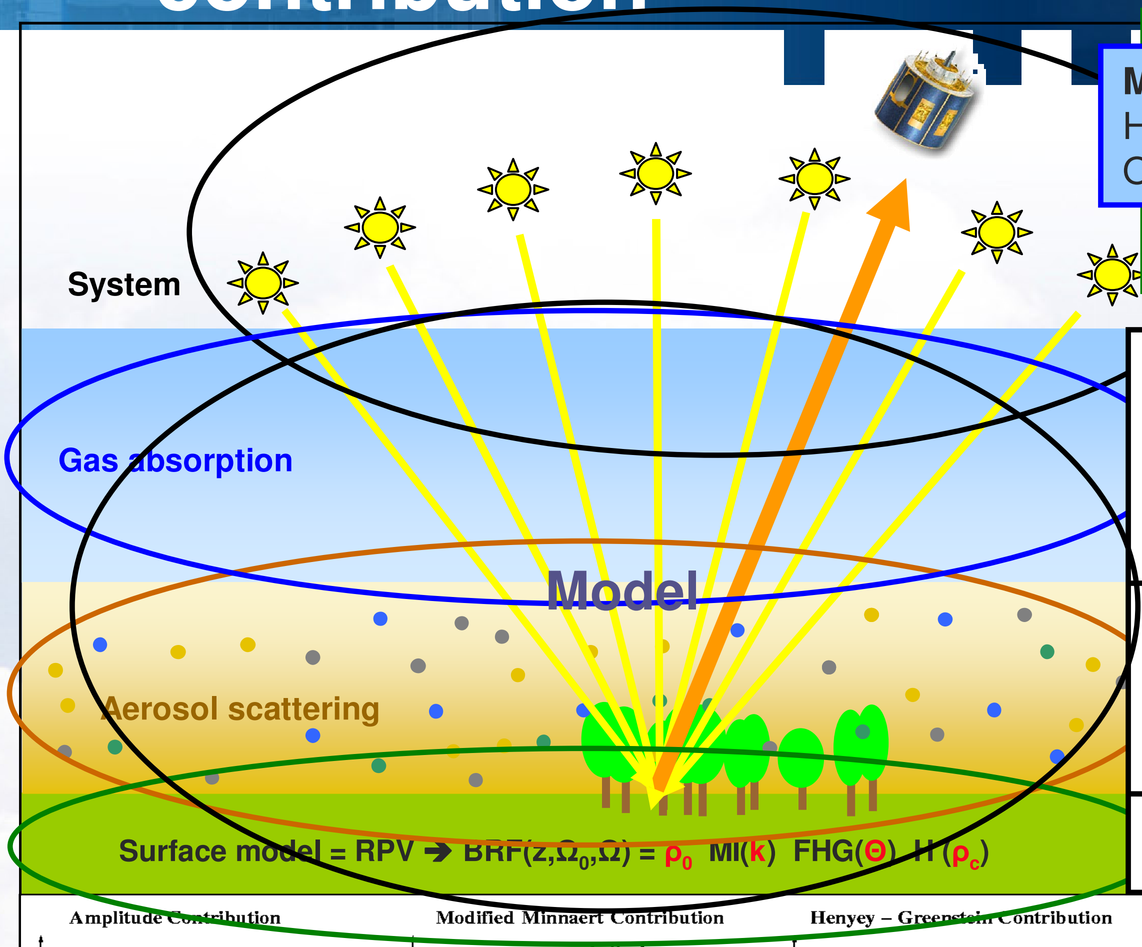


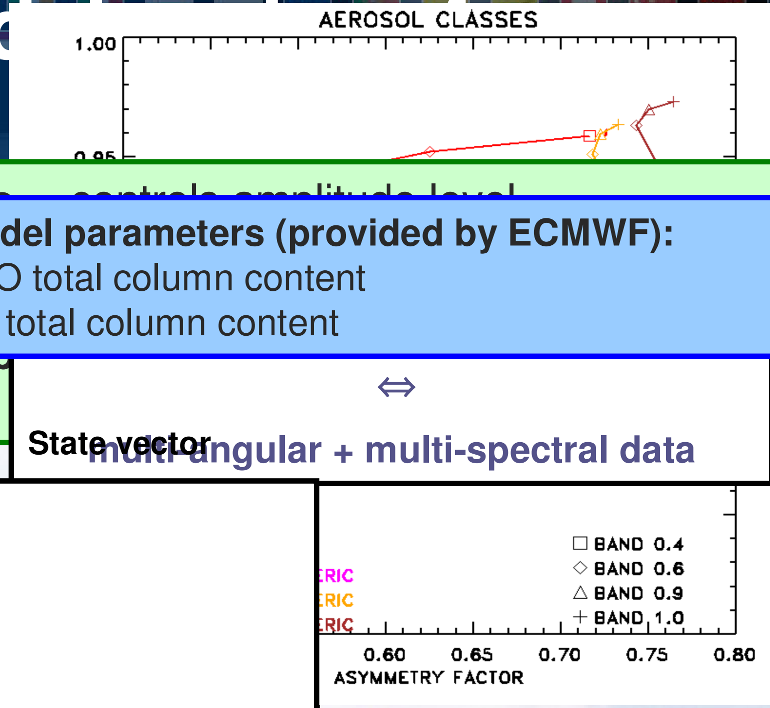
EUMETSAT

OE RETRIEVAL METHOD

- Measurement vector and error covariance matrix
- Forward model and state parameters
- Cost function
- Surface prior information update
- Quality indicator
- Aerosol class selection

LDA algorithm: forward model contribution





Model parameters (provided by ECMWF):
H2O total column content
O3 total column content

⇔

State vector

multi-angular + multi-spectral data

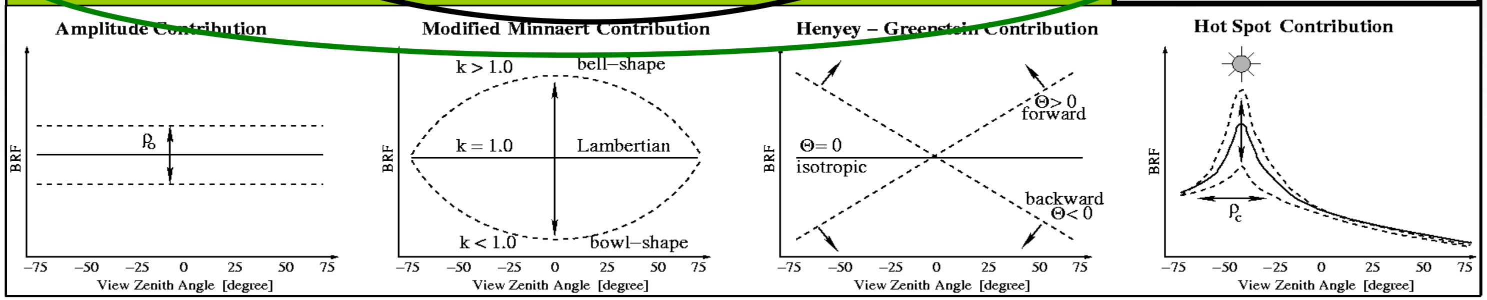
AOD = τ

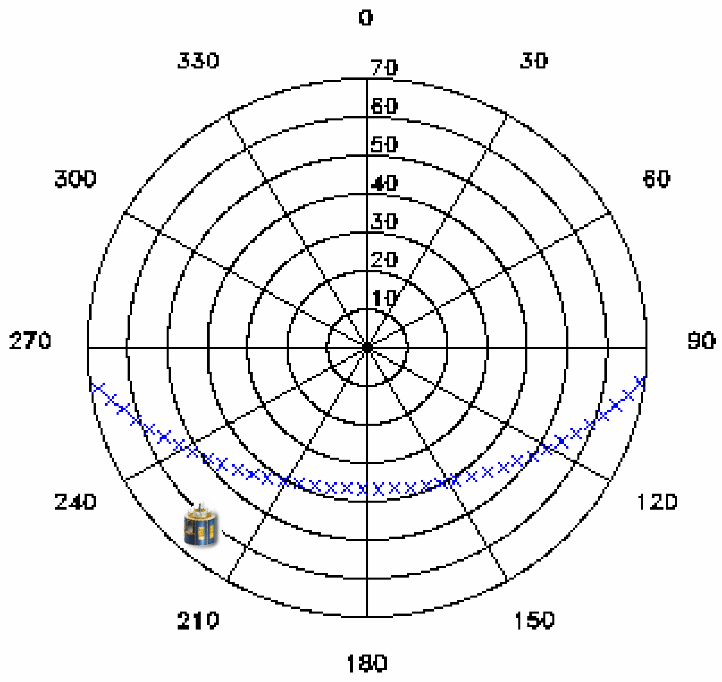
+ Aerosol class

ρ_0 / k / Θ / ρ_c
in VIS06 / VIS08 / NIR16

Optimal Estimation

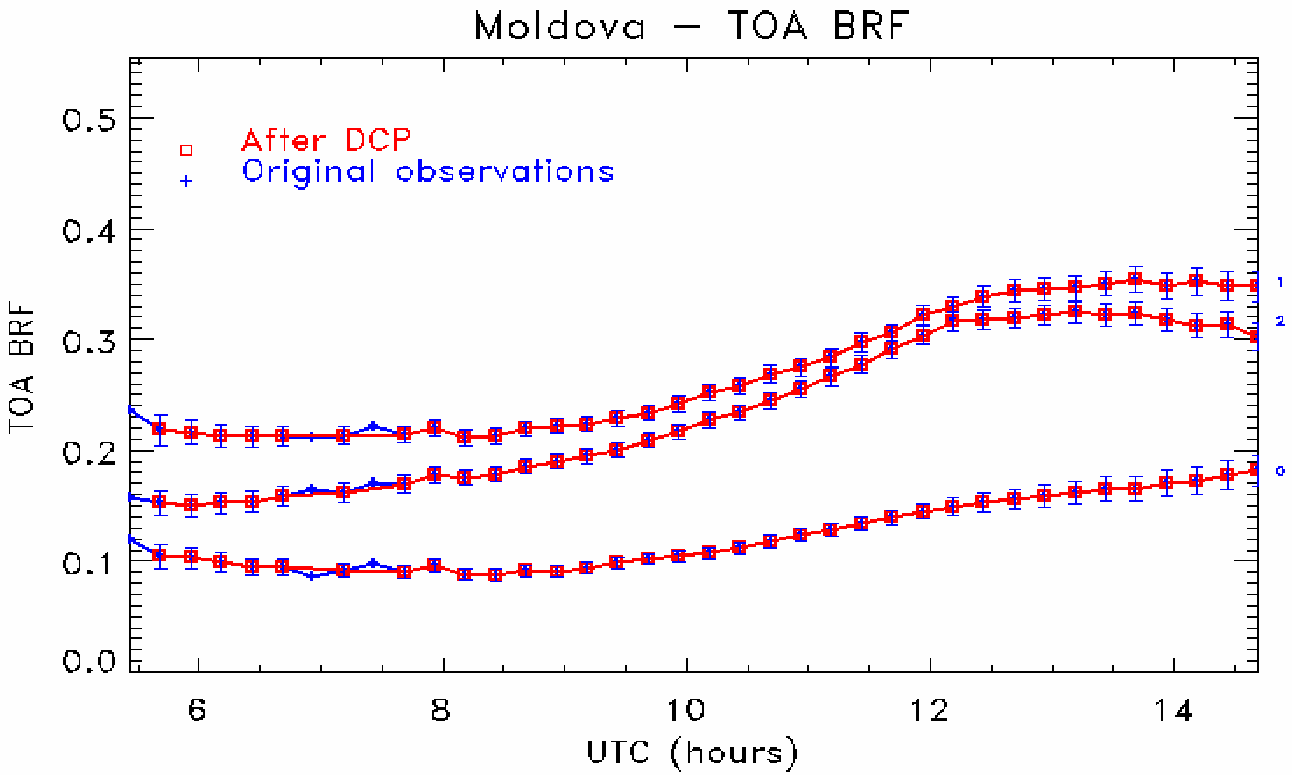
Link between observations, model, and prior knowledge on the system



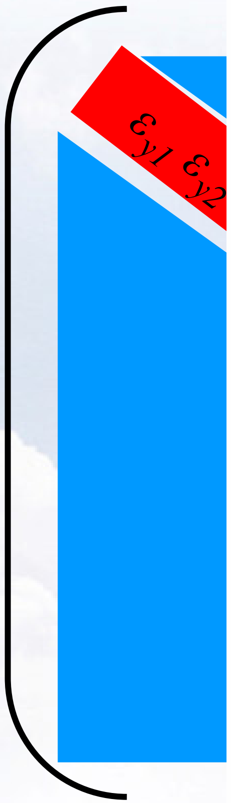


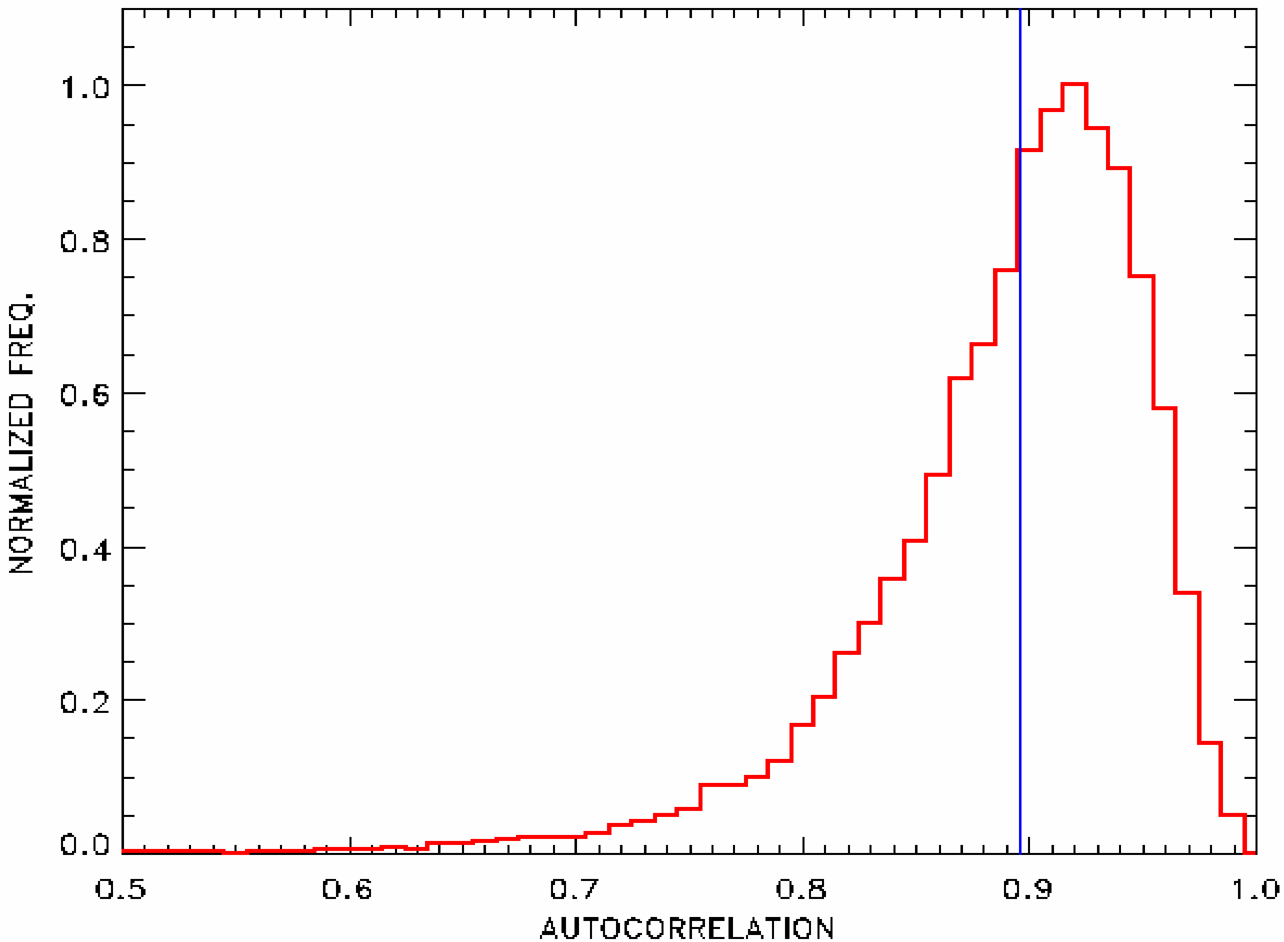
MEASUREMENT ERROR

- radiometric noise
- rectification inaccuracy
- inter-band calibration error
- Forward model
- Model parameters
- Aerosol autocorrelation



OE : MEASUREMENT VECTOR





tion : 1 - 10%

ror : 1.5%

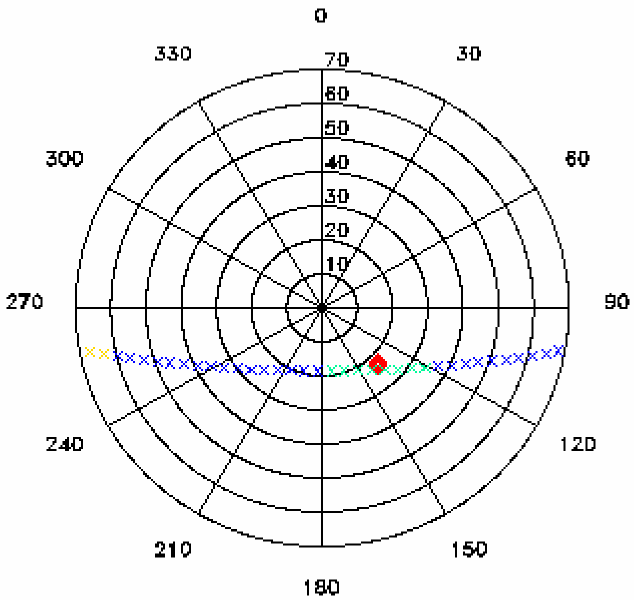
variation : 1-10%

error : 1%

r : 2 - 5%

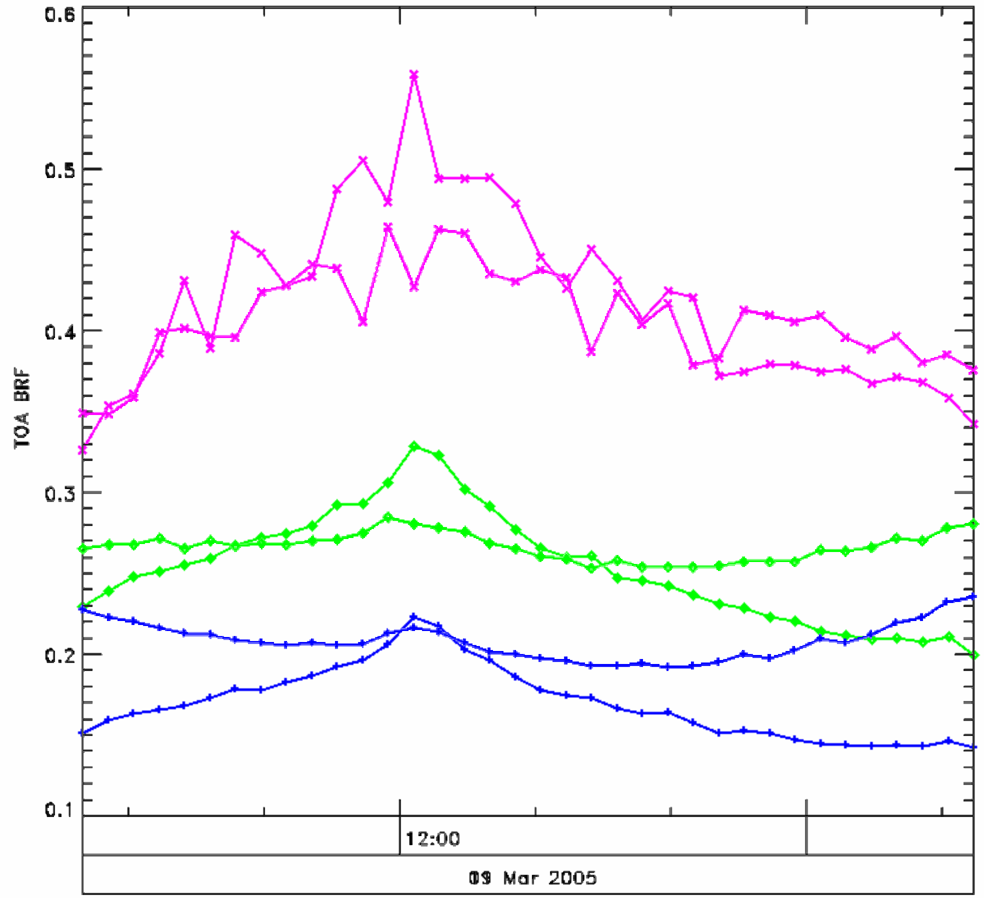
OE : MEASUREMENT VECTOR

Example over Dakar



AOD = 0.06

AOD = 1.18



OE : Bayesian approach

Forward model

Bayes theorem:

$$\boxed{P(\vec{x}|y_m) = \frac{P(y|\vec{x}) \cdot P(\vec{x}_a)}{P(y_m)}}$$

A priori information on $\vec{x}$

A priori information on y_m (constant = $P(x, y)$

$P(x|y)$ Posterior PDF of the state vector *x*, given the measurements

$P(y|x)$ PDF describing the knowledge of *y* if the state would be *x* (model + measurement errors)

$P(x)$ Prior PDF to the state *x*

$P(y)$ Prior PDF of the measurement (constant)

Assumption: PDFs = Gaussian distributions

OE : What now?

Goal: maximising $P\left(\vec{x}\,\middle|\,y_m\right)$

$$P\left(\vec{x}\,\middle|\,y_m\right) = \frac{P\left(y\,\middle|\,\vec{x}\right)\cdot P\left(\vec{x}\right)}{P\left(y_m\right)}$$

Problem equivalent to minimising a cost funtion $J\left(\vec{x}\right)$

Under the Gaussian assumption, and after development of the PDFs...

$$J\left(\vec{x}\right) = \left(\vec{y}_m - \vec{y}\right)^T \cdot S_y^{-1} \cdot \left(\vec{y}_m - \vec{y}\right) + \left(\vec{x} - \vec{x}_a\right)^T \cdot S_x^{-1} \cdot \left(\vec{x} - \vec{x}_a\right)$$

Where:

S_y : matrix representing the “errors” related to the observations and to the modelling

S_x : matrix representing the “errors” related to the a priori information on the state vector

Method for minimising the cost function depends on the problem to solve (possible presence of local minima)

Ex: Monte-Carlo, steepest descent, Marquardt-Levenberg, Newton, etc.

OE : quality control and error analysis

Error: $$S_{\varepsilon} = \left(\frac{\partial^2 J}{\partial \vec{x}^2}\right)^{-1} = \left(K_{\vec{x}}^T \cdot S_y^{-1} \cdot K_{\vec{x}} + S_x^{-1}\right)^{-1}$$

Measurement and numerical errors

Error on the prior information

$$K_{\vec{x}} = \frac{\partial F}{\partial \vec{x}}$$ = Jacobian matrix (also called kernel, tangent linear model, adjoint model)

Necessity to define diagnostic tools / parameters to quantify the quality of the retrieval: **eigenvalues of the error matrix, probability based on the number of degrees of freedom of the system, the cost function values, etc.**

WARNING: Careful analysis as the state variables can represent various physical quantities!

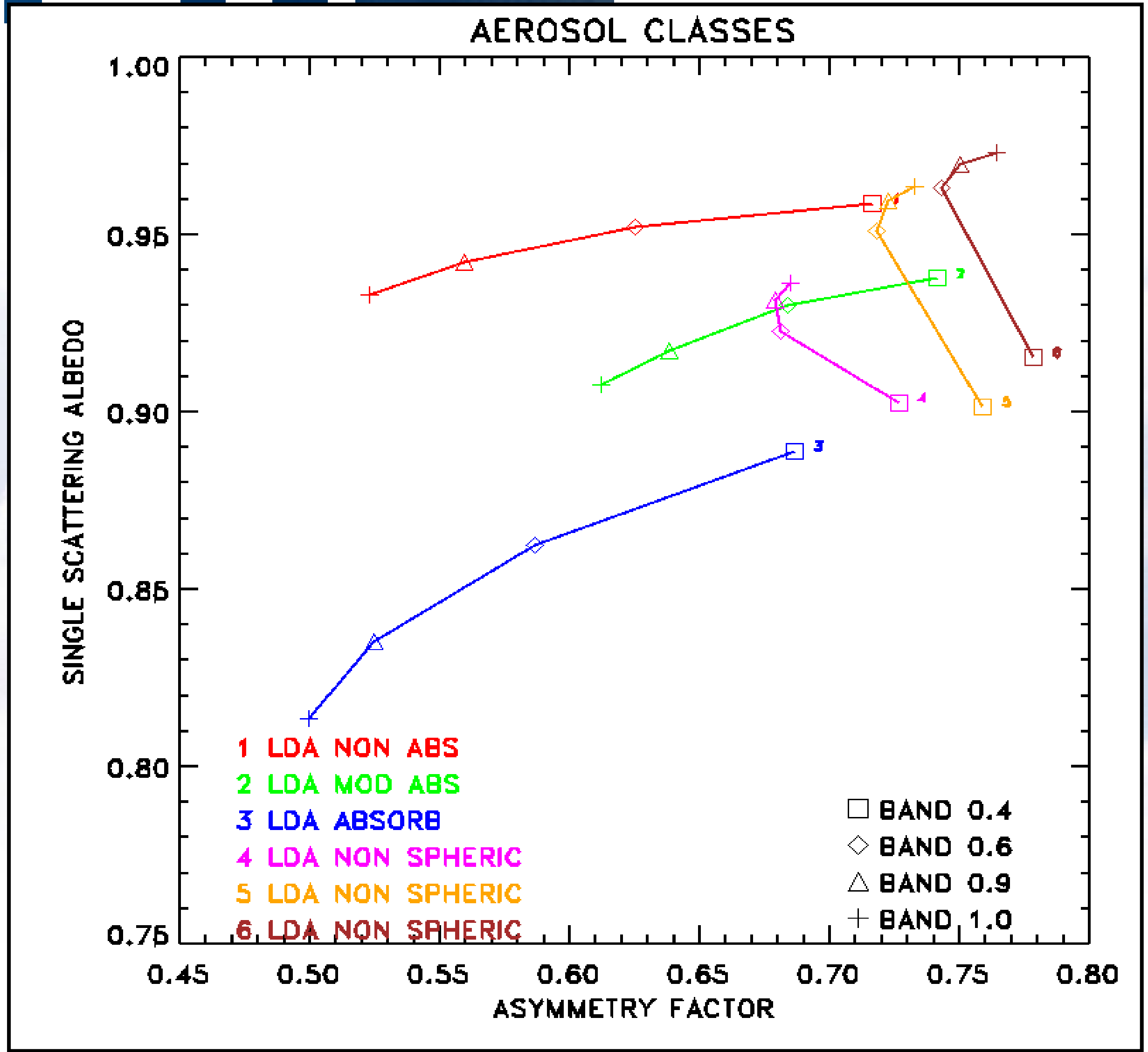
AEROSOL CLASSES

Non-spherical classes: organised according to the asymmetry parameter

➔ determined by the ratio between large and small particles

Spherical classes: organised according to the single scattering albedo

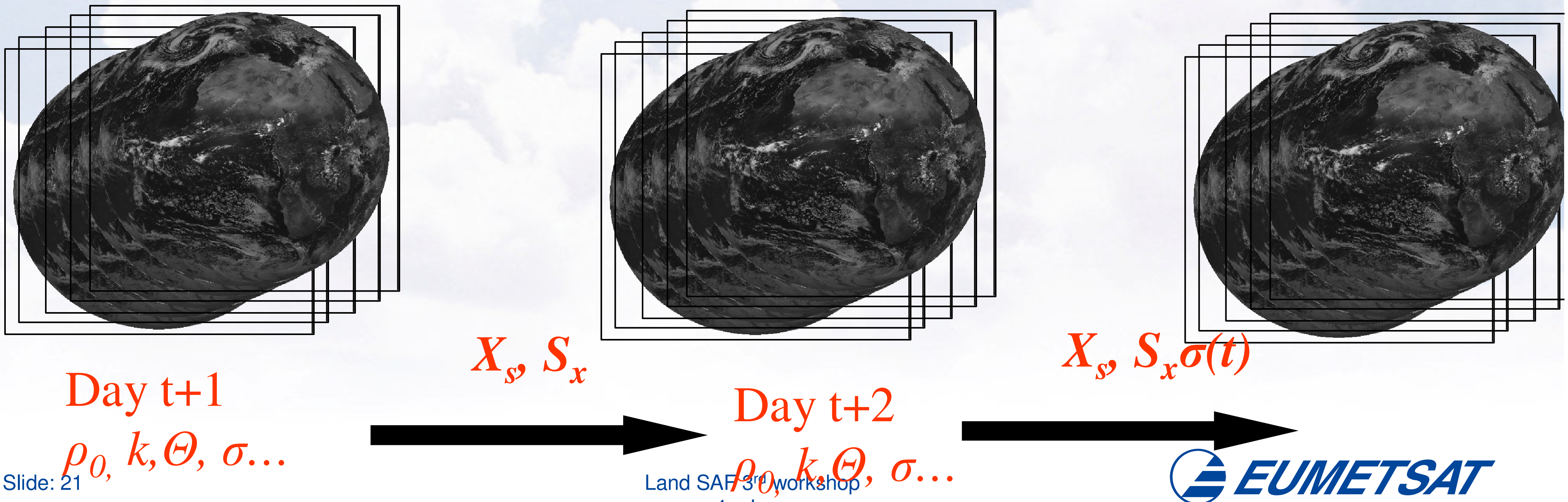
➔ determined by the imaginary part of refractive index



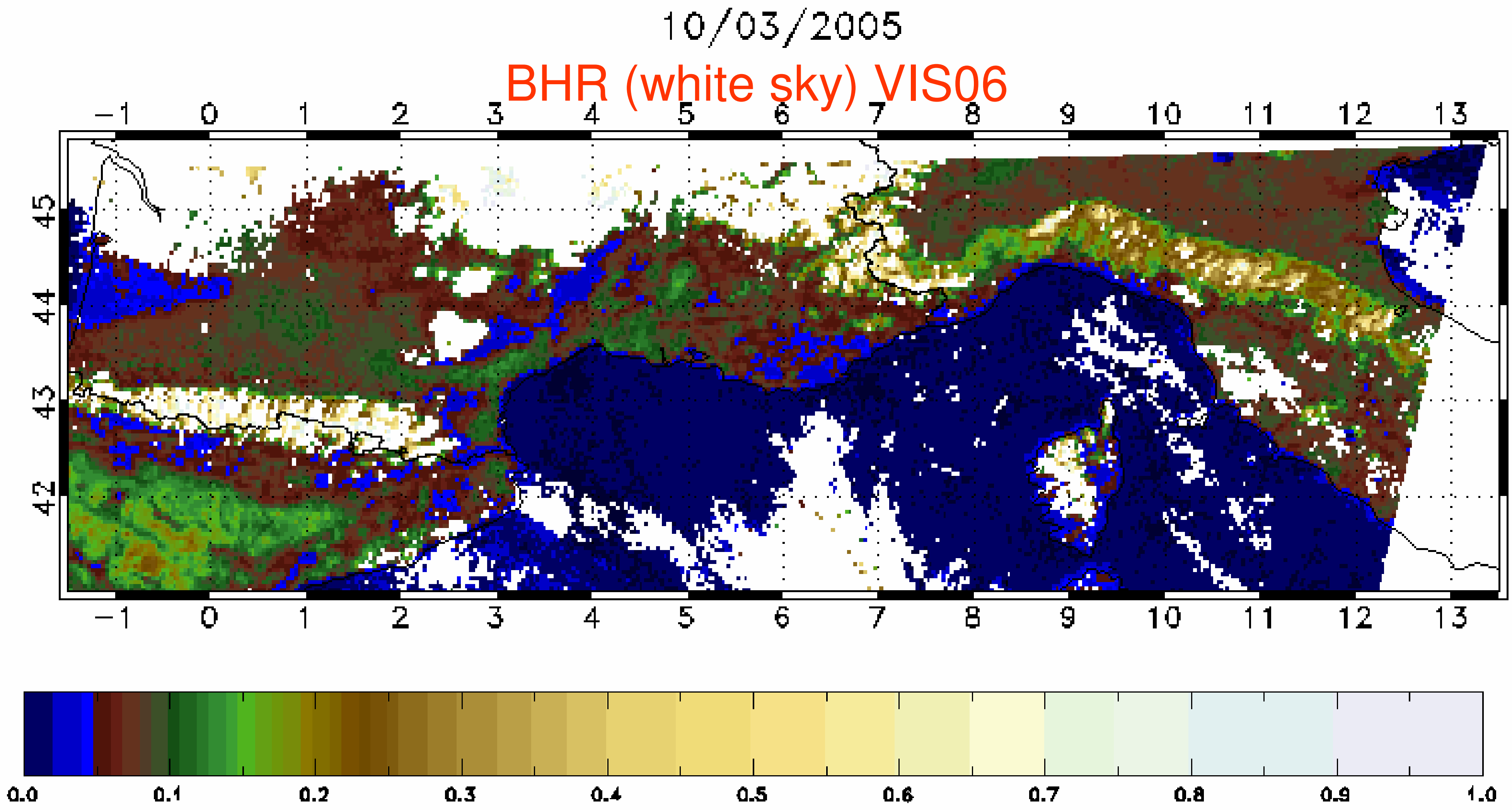
OE: PRIOR INFORMATION

- **Aerosol classes** *$\{(\omega_0(\lambda_1), g(\lambda_1)), (\omega_0(\lambda_2), g(\lambda_2)), \ldots\}$* **imposed to the retrieval system** **without associated error in S_x.**
- **No a priori information on AOD**
- **AOD "almost" constant during the day**

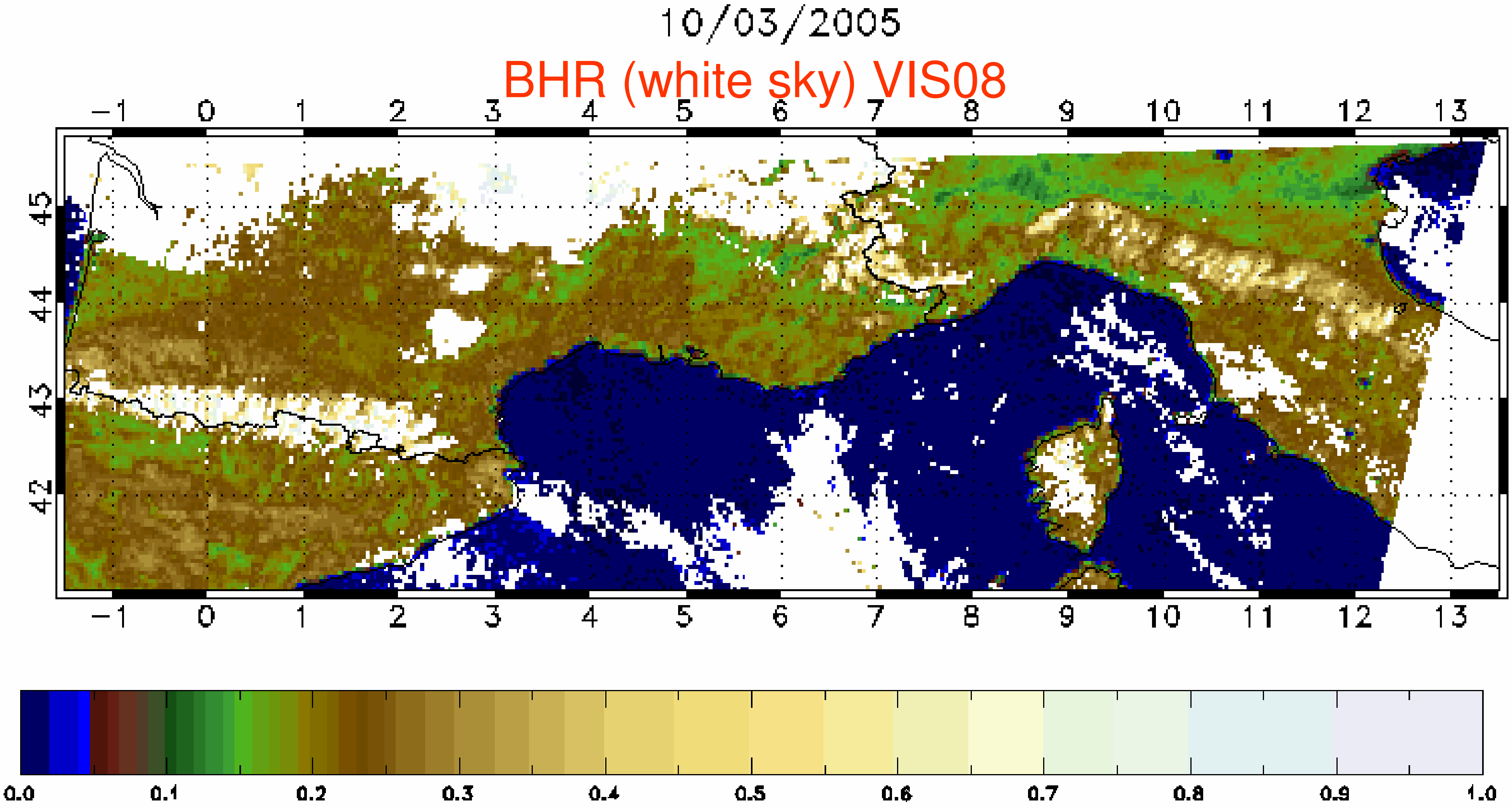
- **Surface temporal stability**



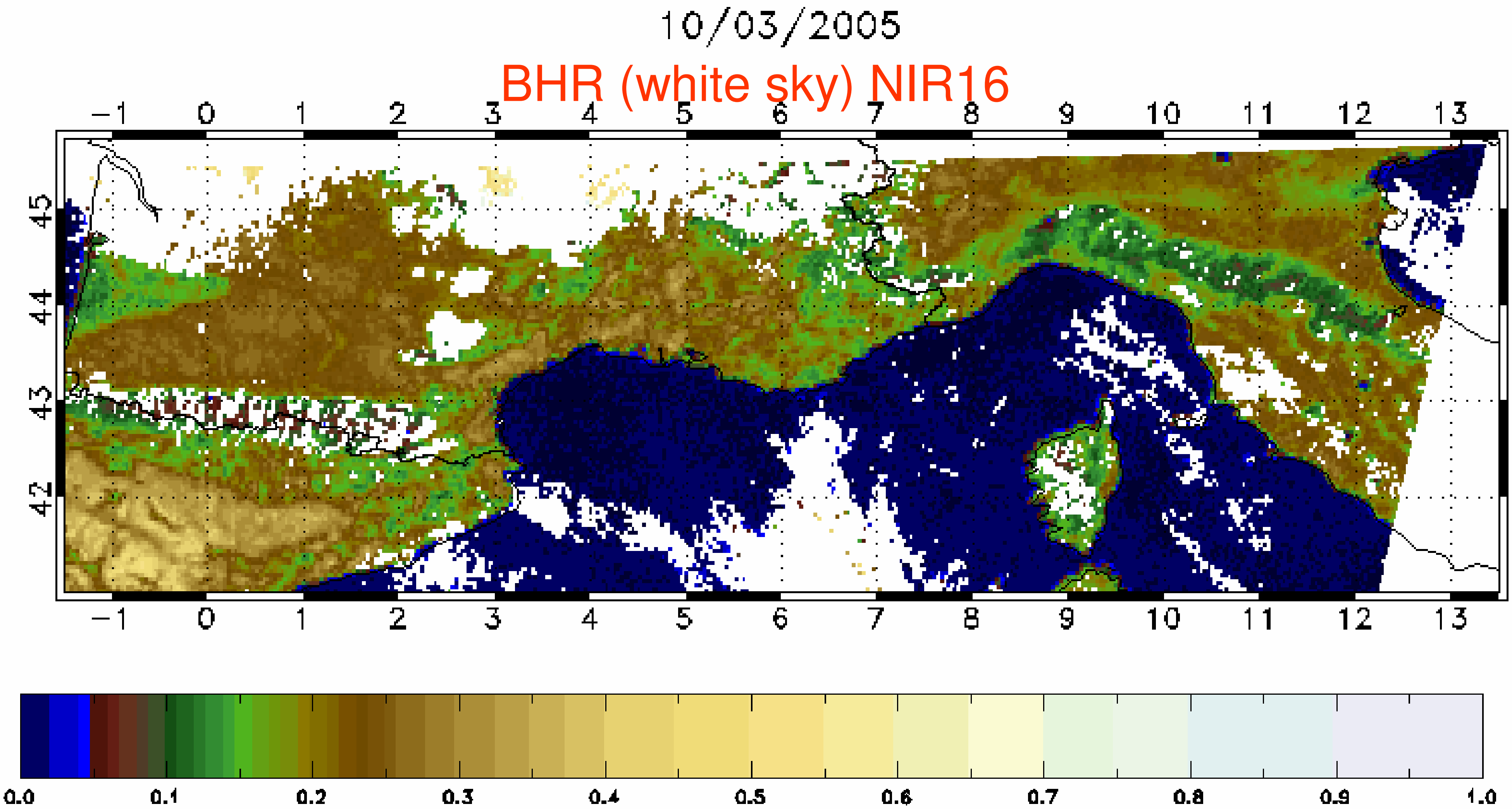
OE: OUTPUT EXAMPLE



OE: OUTPUT EXAMPLE



OE: OUTPUT EXAMPLE

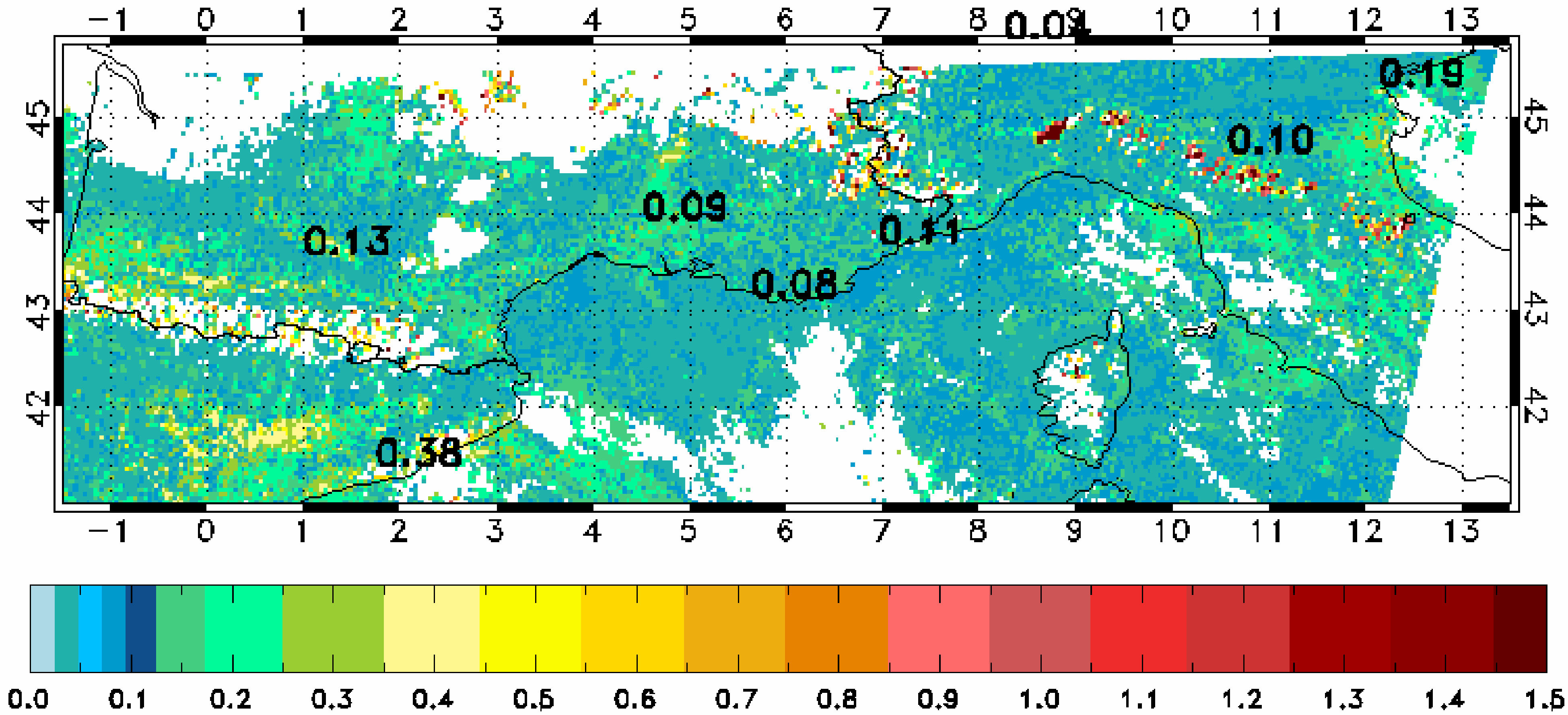


EUMETSAT

OE: OUTPUT EXAMPLE

10/03/2005

‹AOD› at 0.55µm



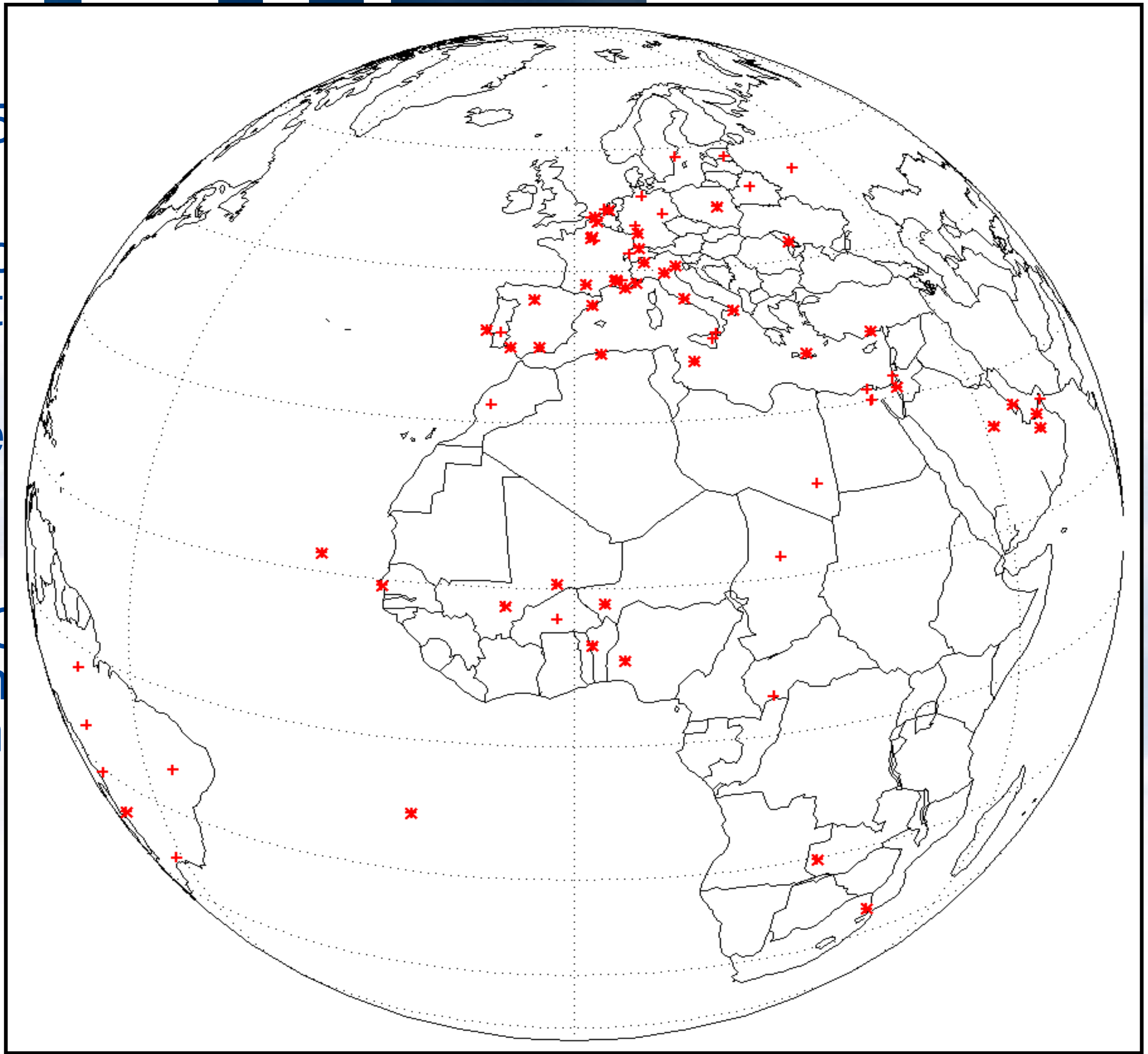
EVALUATION

Comparisons with AERON
period 15/02/2005 - 15

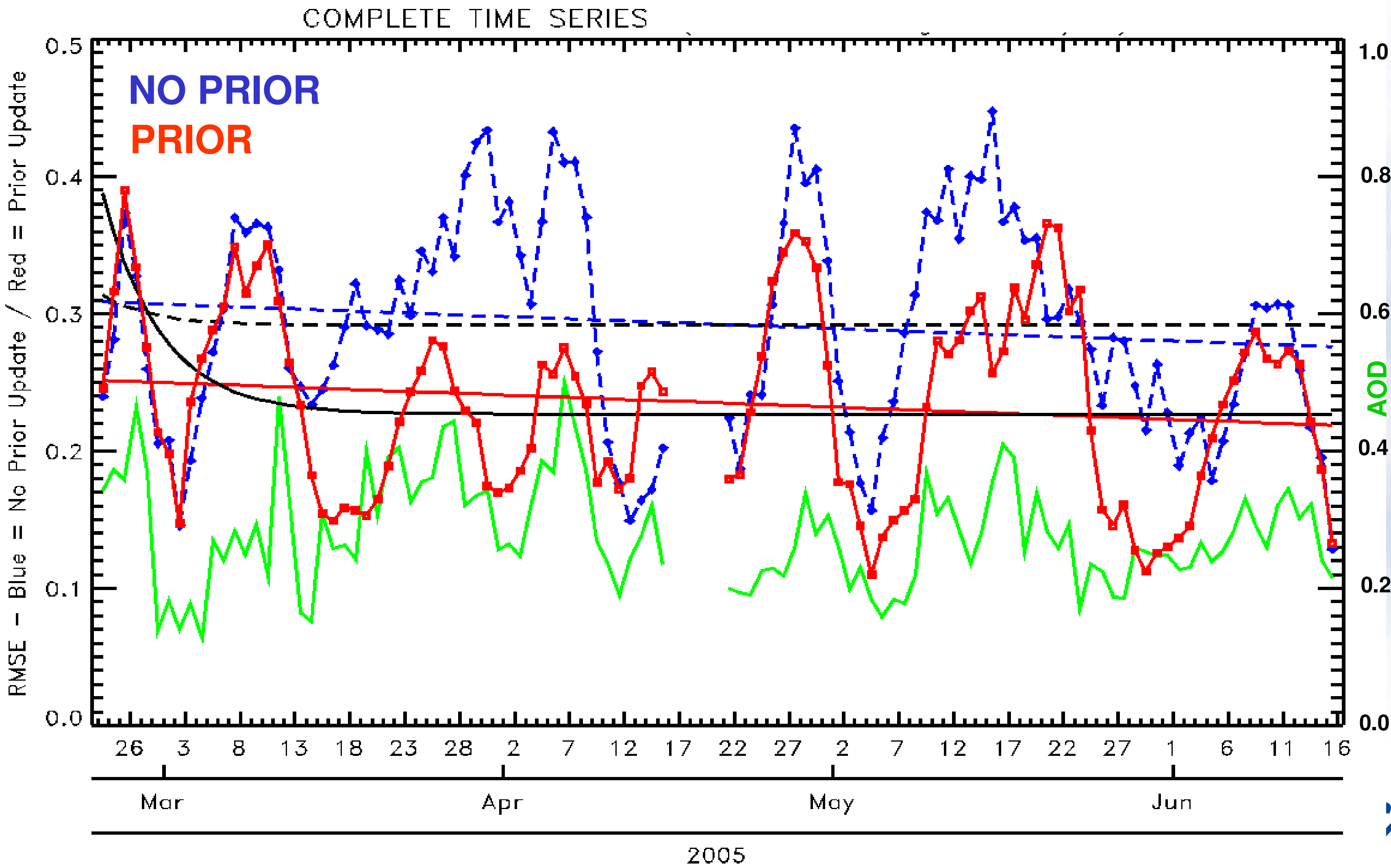
No prior update = referenc
analysis ⇒ update of t

72 AERONET stations ove

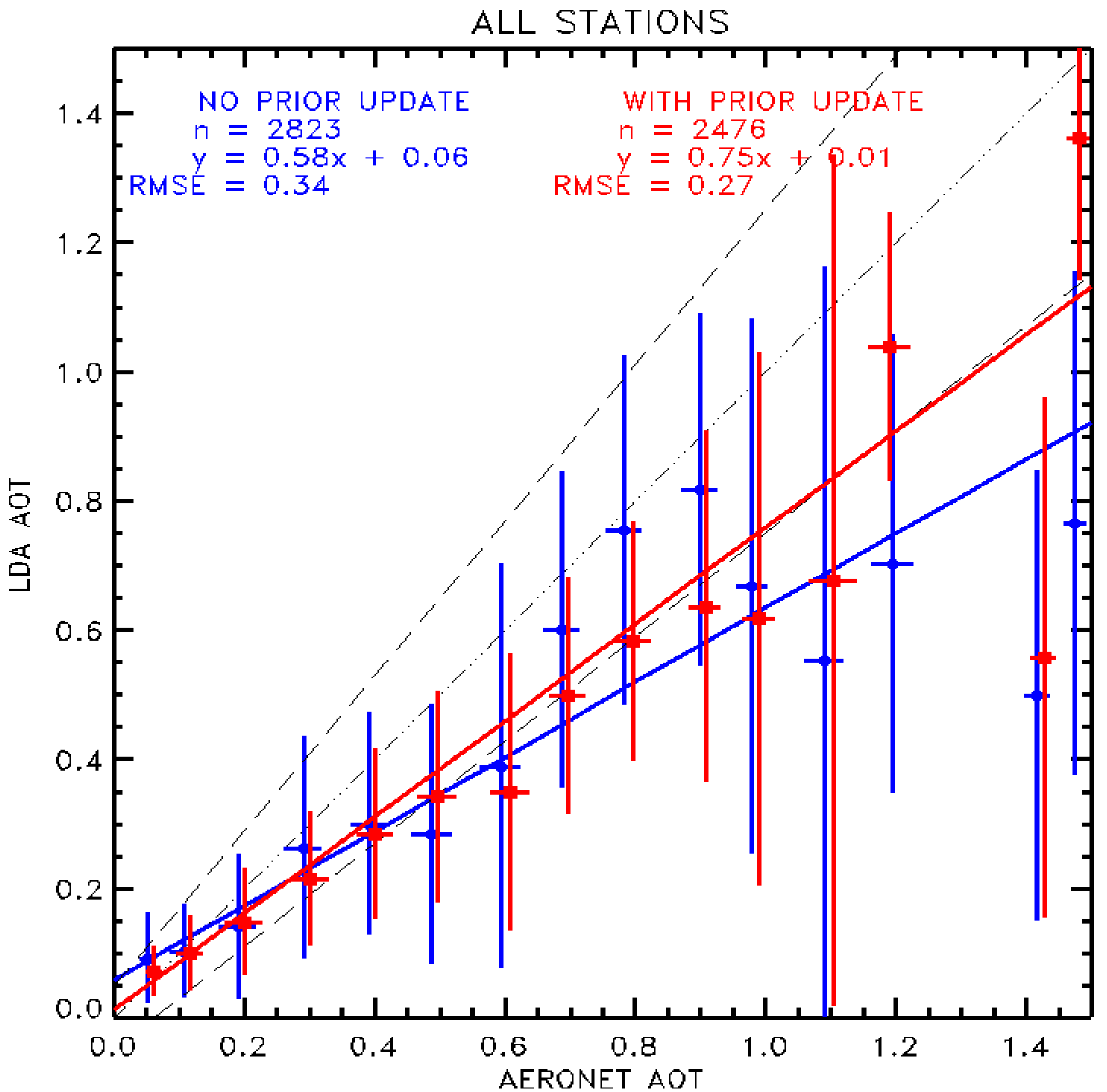
Comparison with the AERO
aerosol sphericity (con
retrievals derived from



Quantitative effects of updating the prior information



Quantitative effects of updating the prior information

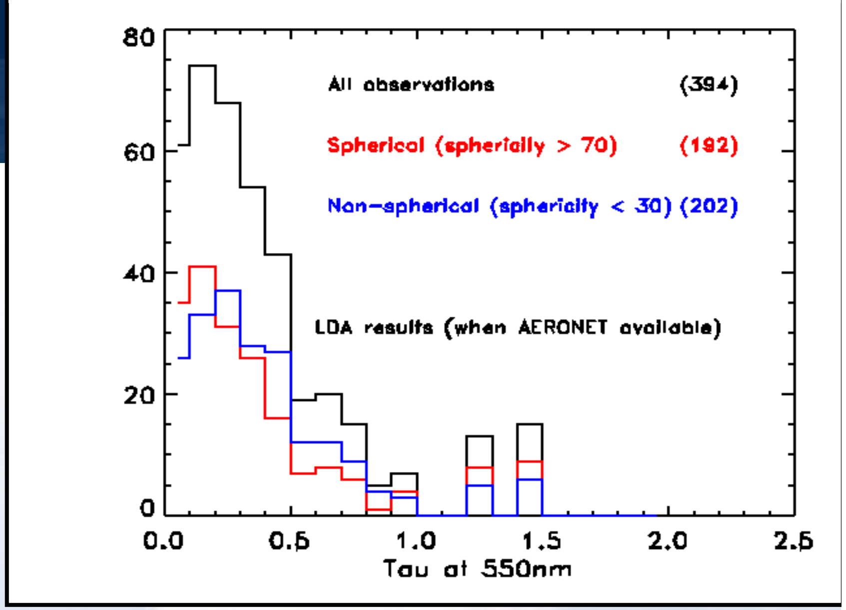


On average ➔ reduction of the RMSE and increase of the correlation when improving the prior information

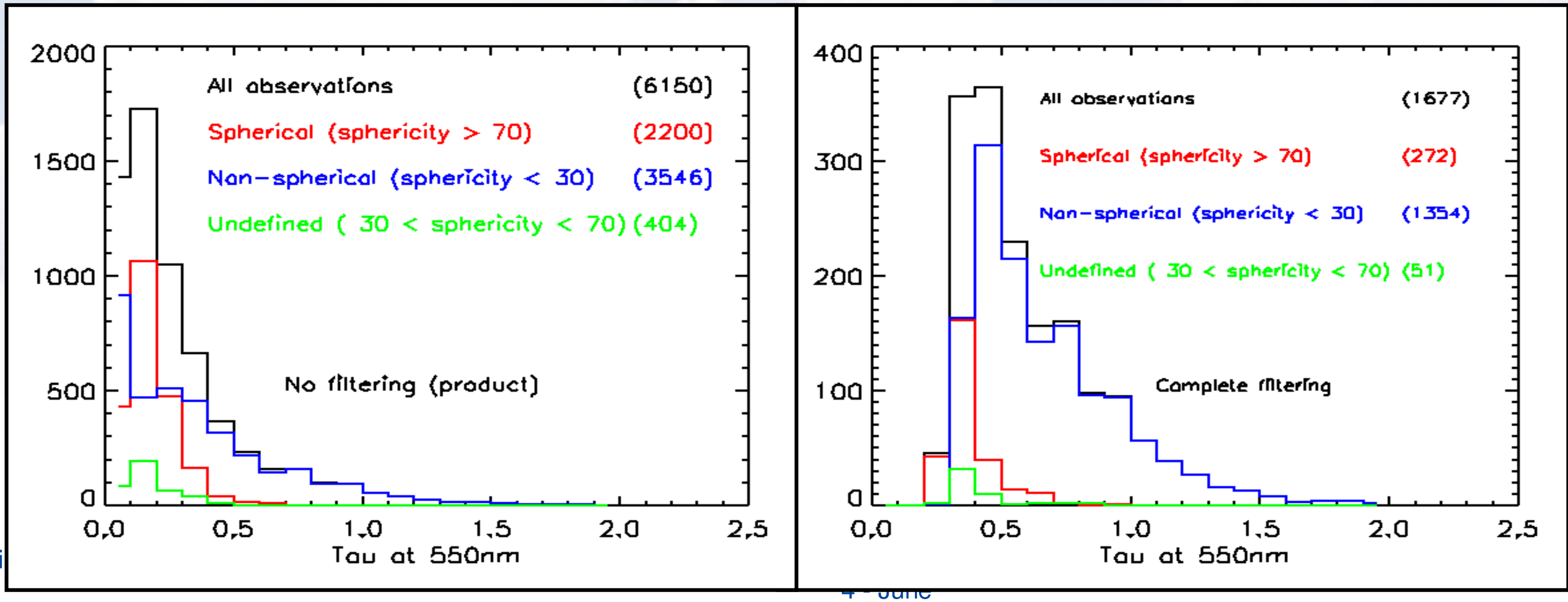
Aerosol sphericity: some comparisons…

AERONET \ LDA	SPHERICAL	NON-SPHERICAL
SPHERICAL	11.16%	34.05%
NON-SPHERICAL	5.16%	49.63%

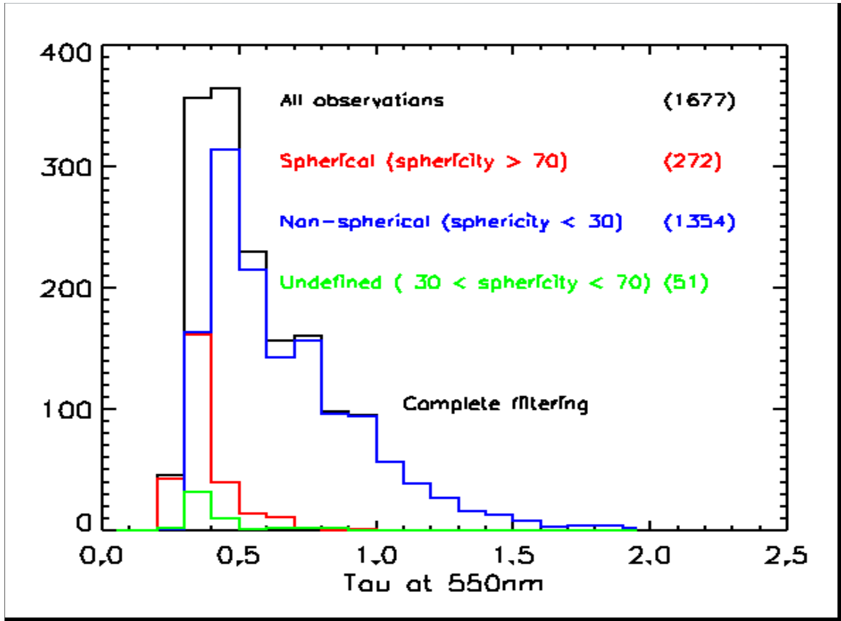
LDA

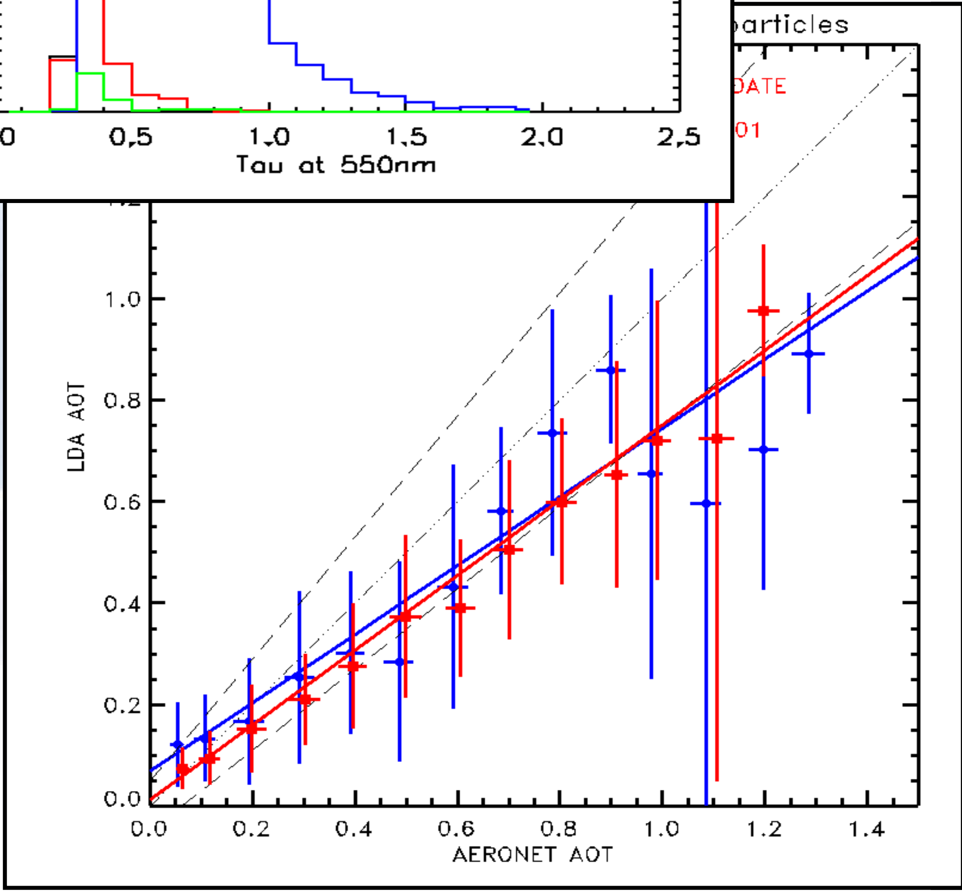


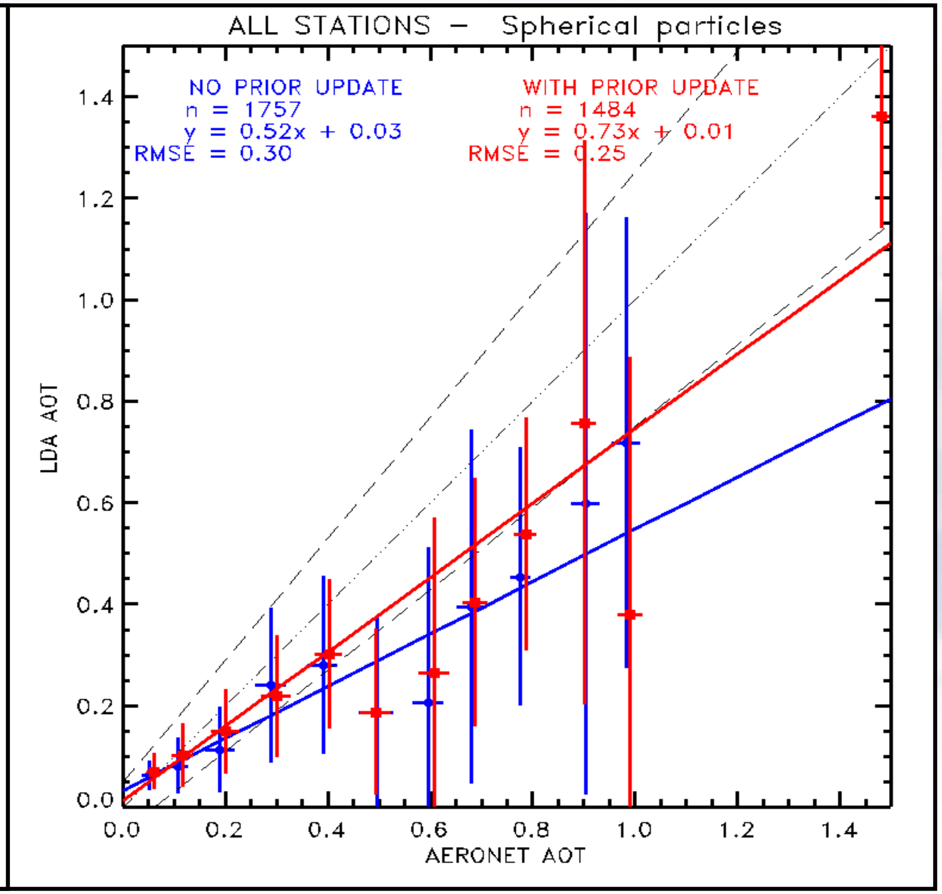
AERONET



ome comparisons...

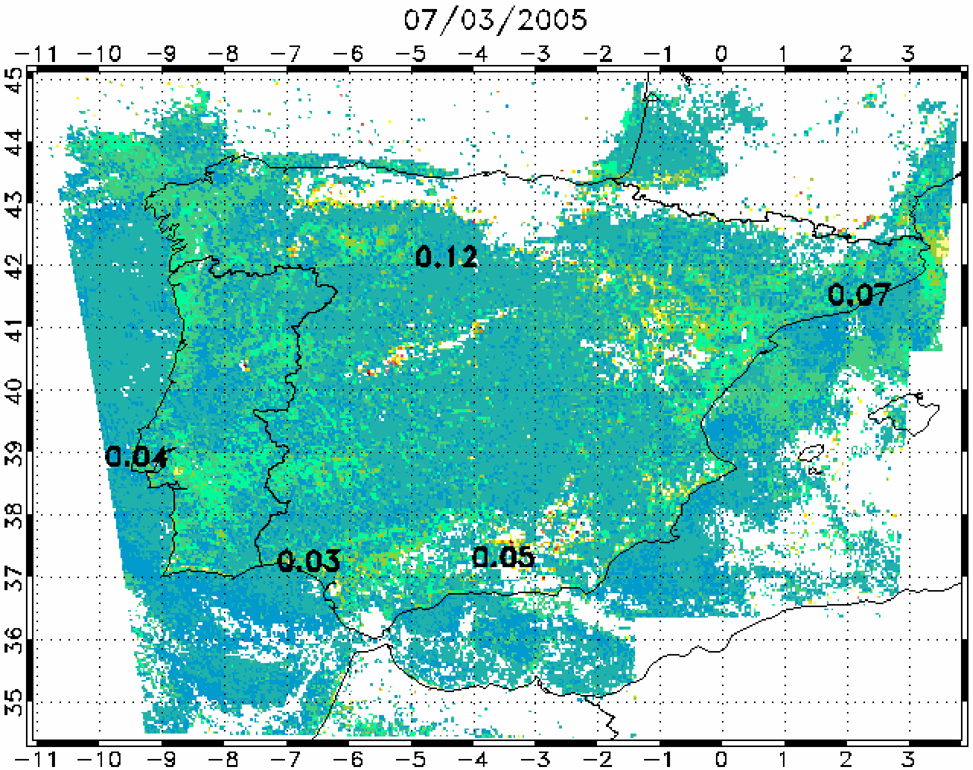




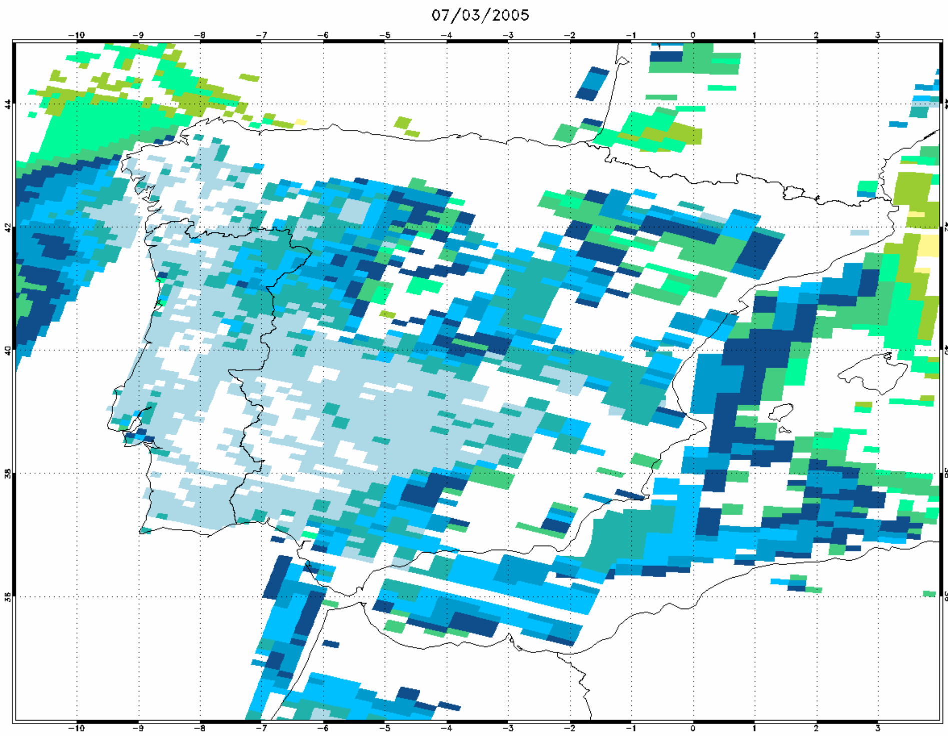


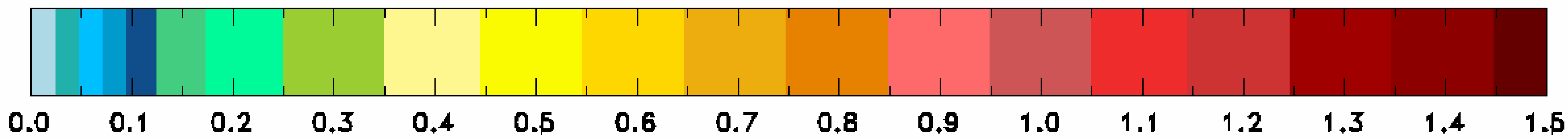
COMPARISONS WITH MODIS

SEVIRI



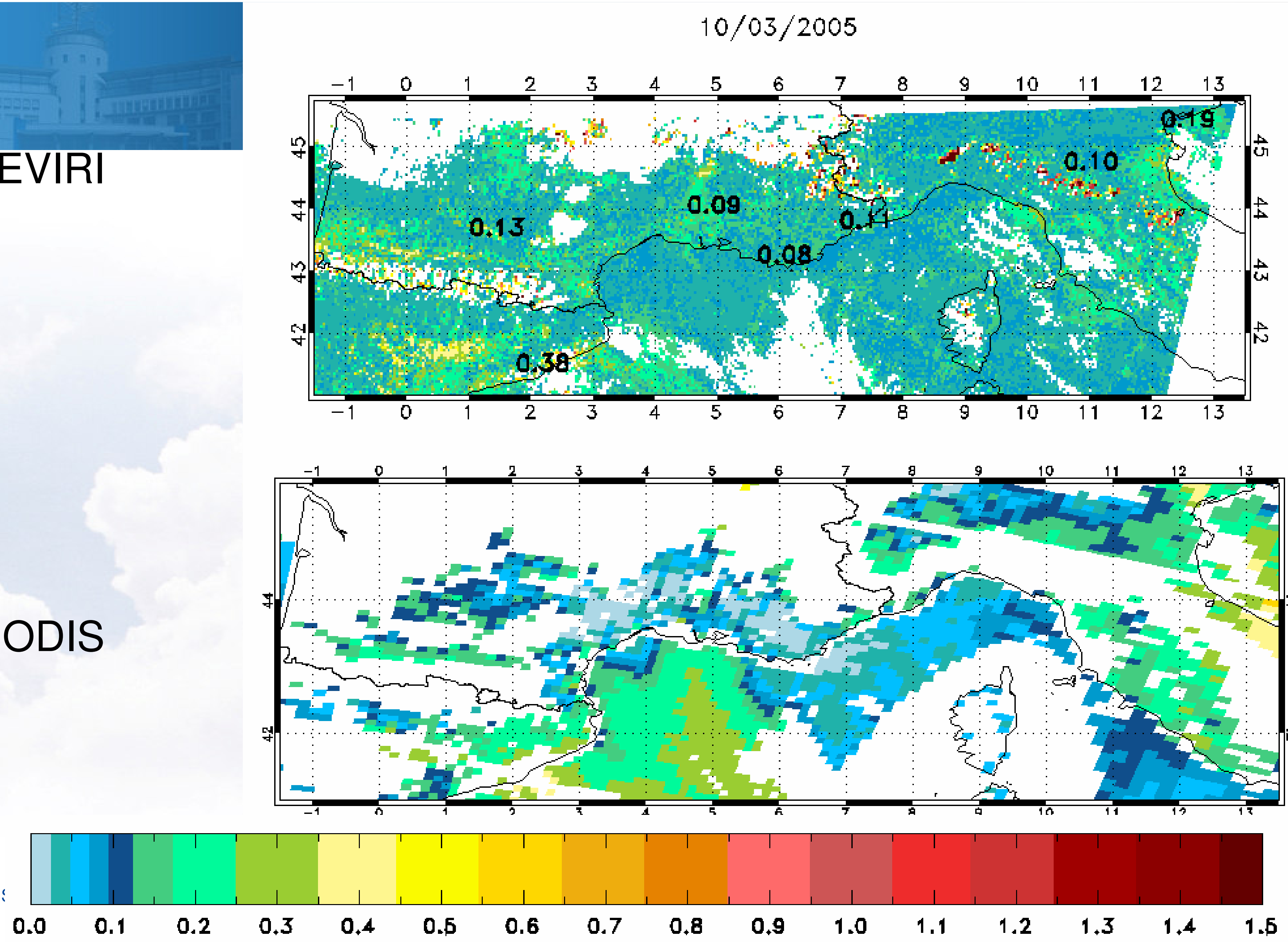
MODIS





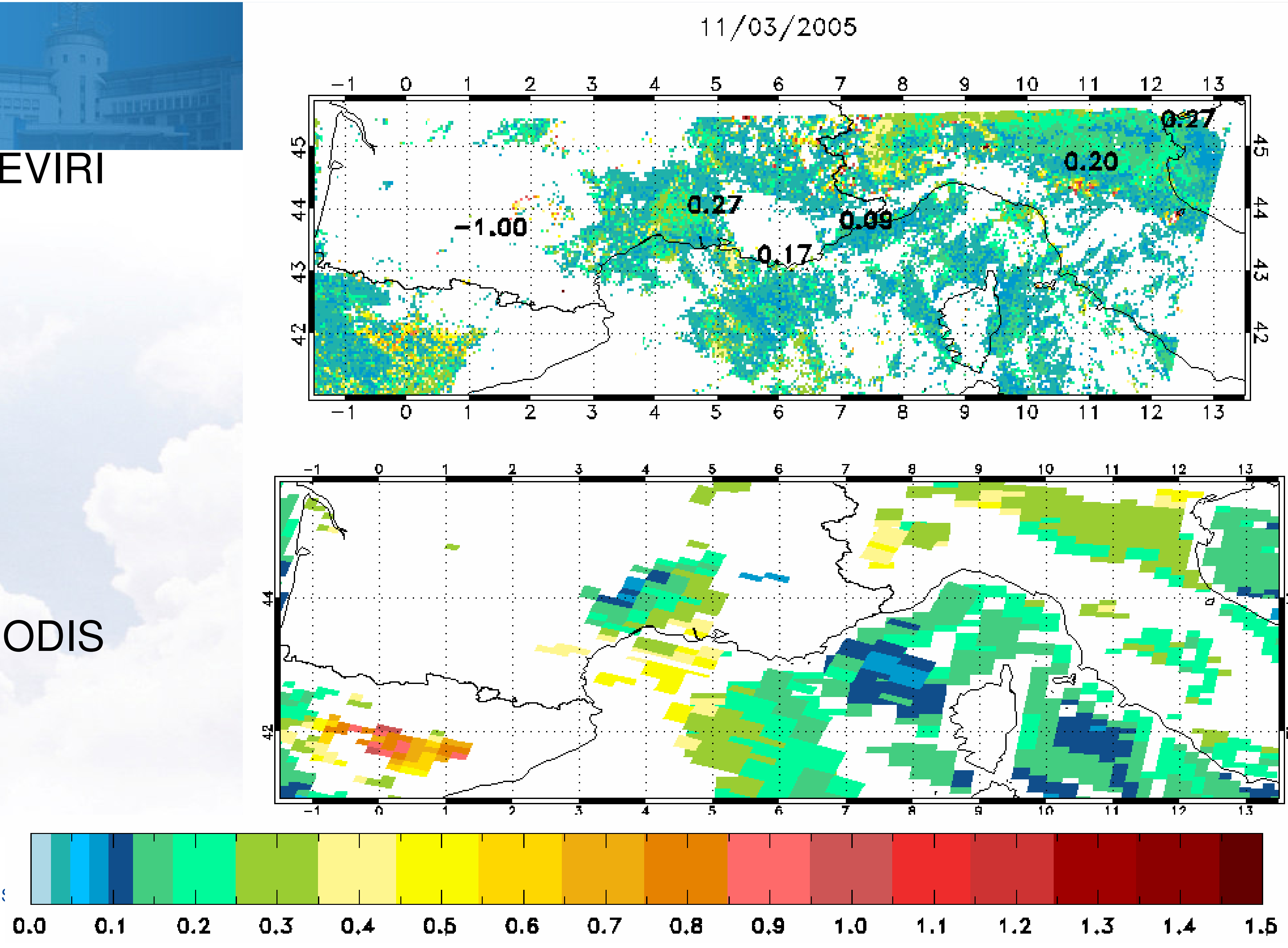
SEVIRI

MODIS



SEVIRI

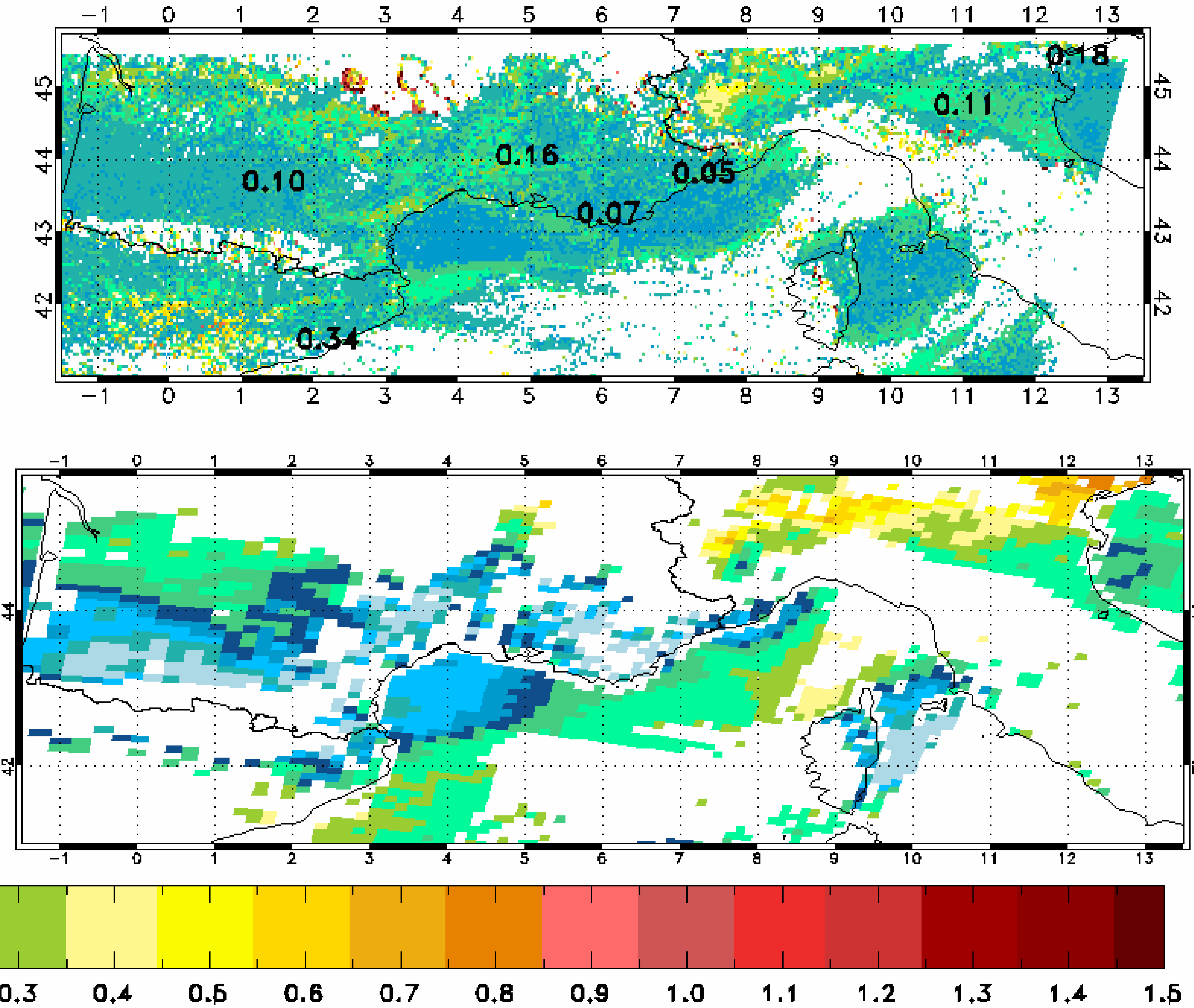
MODIS



12/03/2005

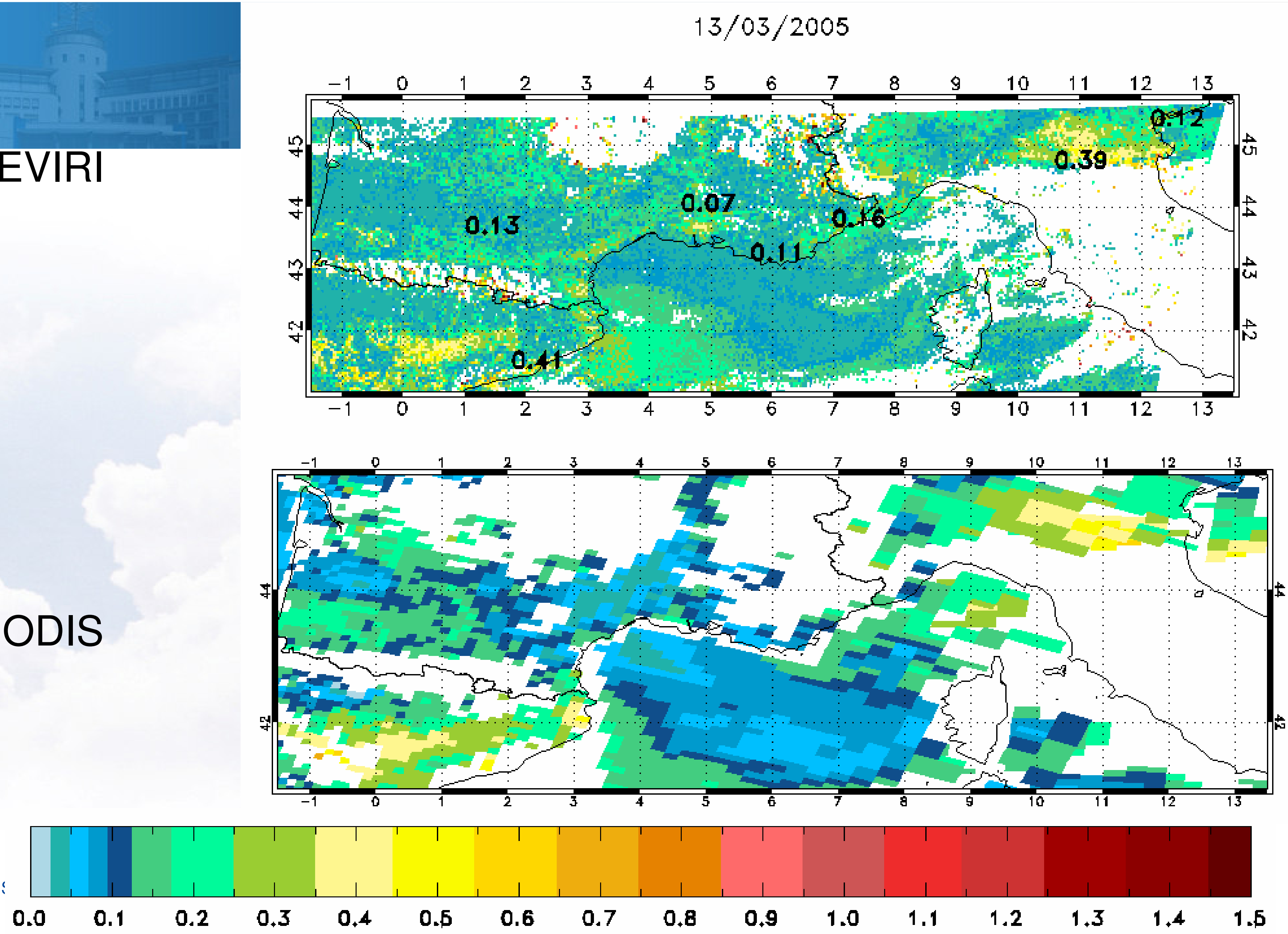
SEVIRI

MODIS



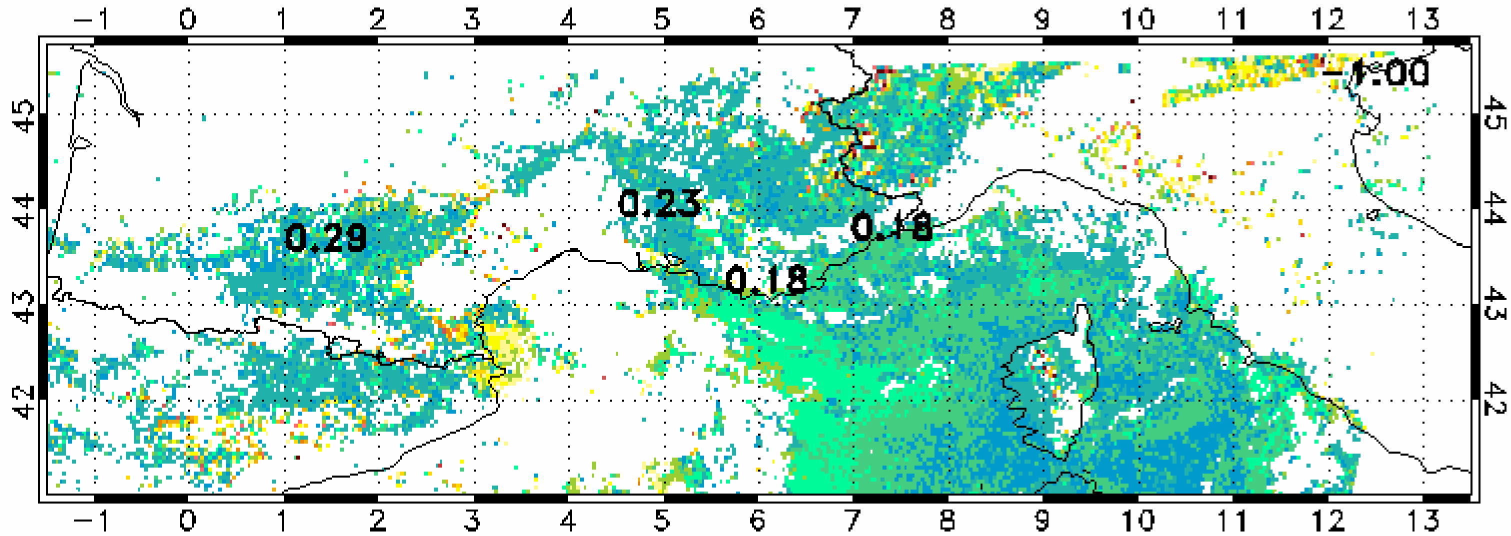
SEVIRI

MODIS

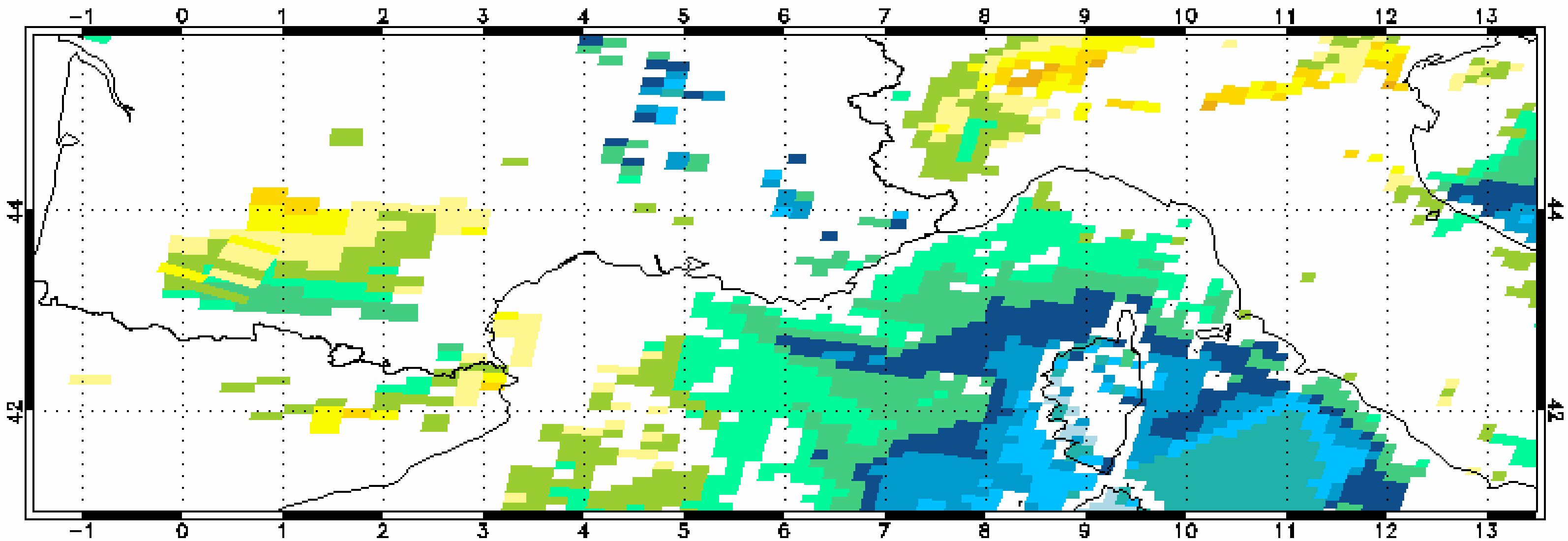


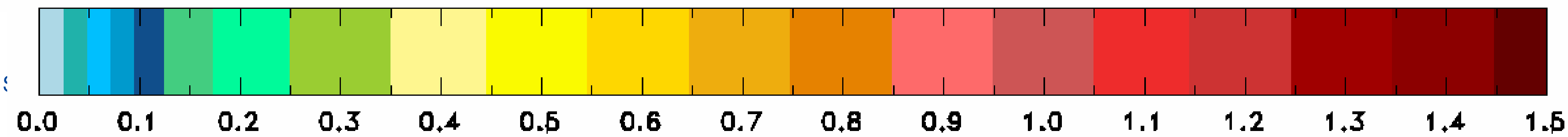
14/03/2005

SEVIRI



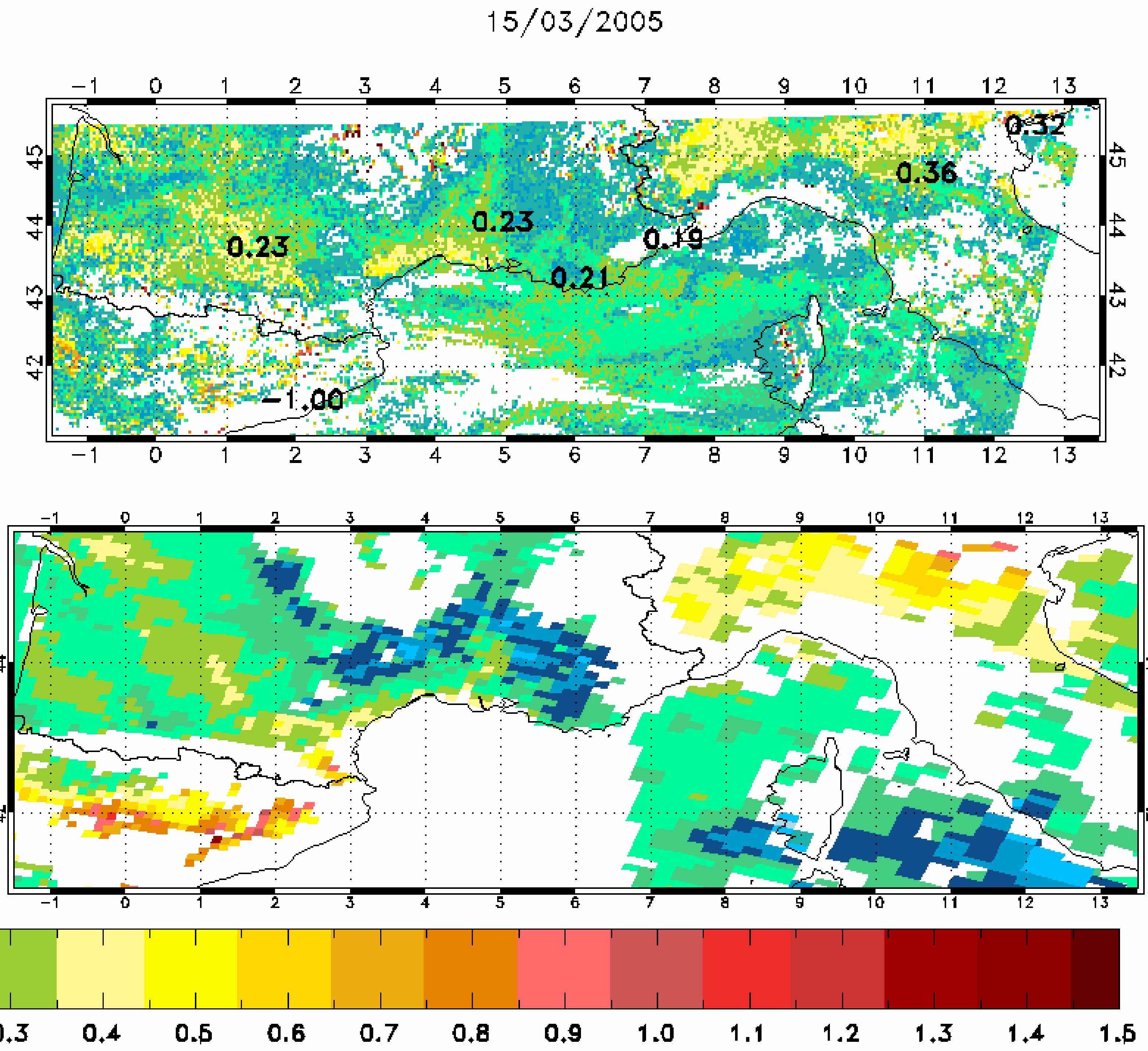
MODIS





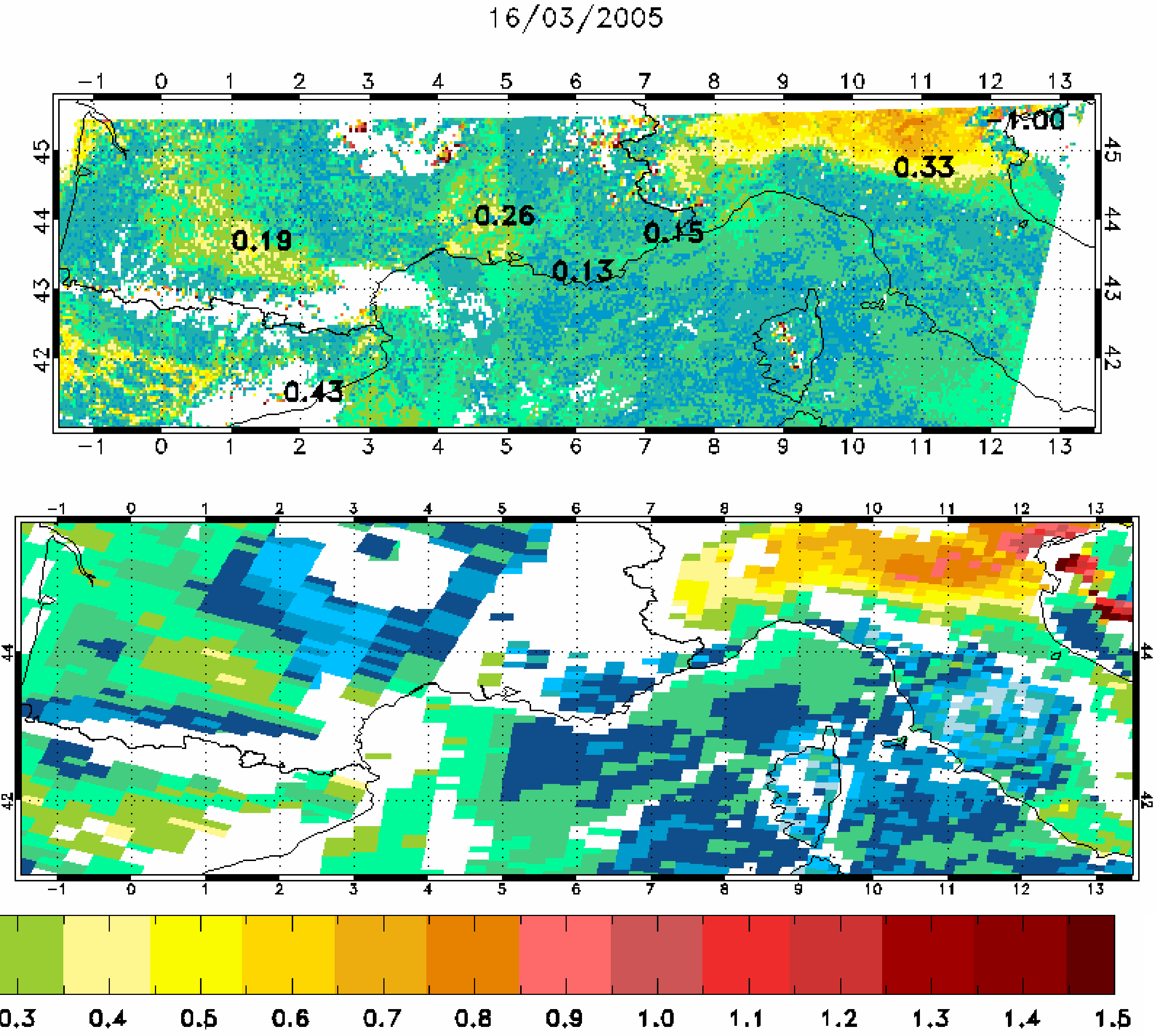
SEVIRI

MODIS

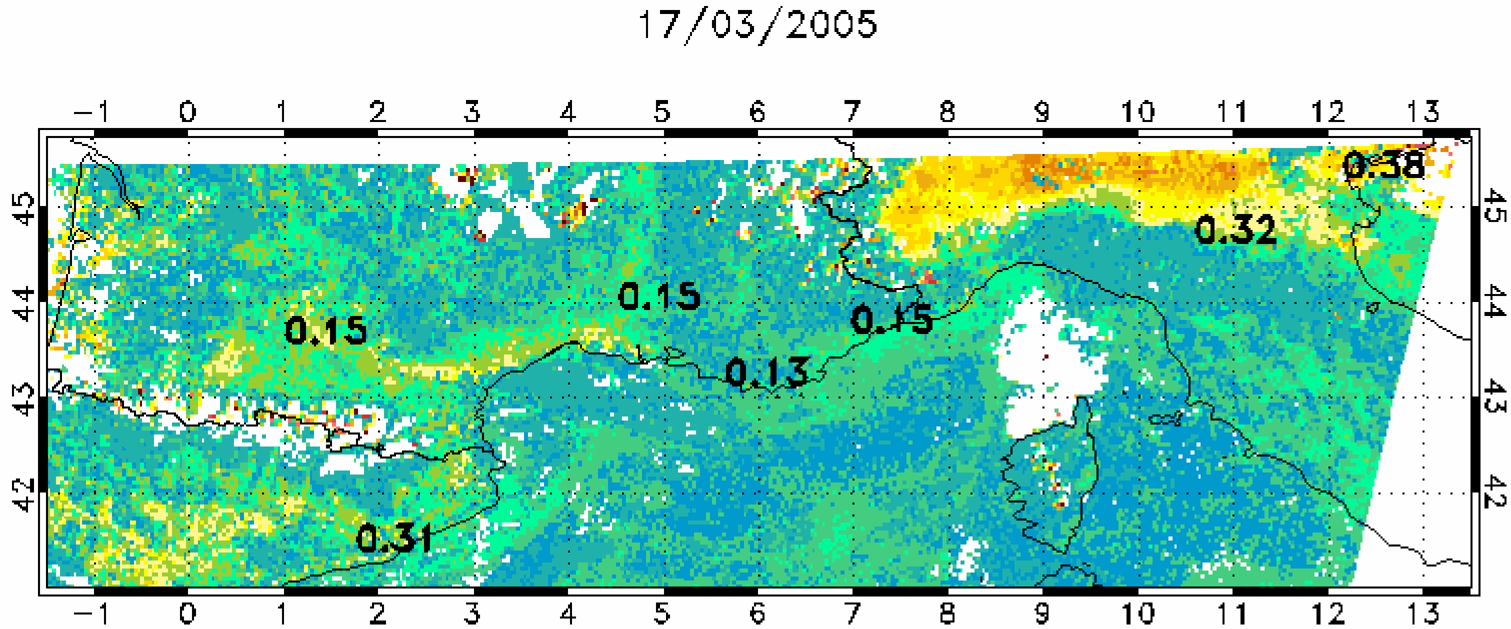


SEVIRI

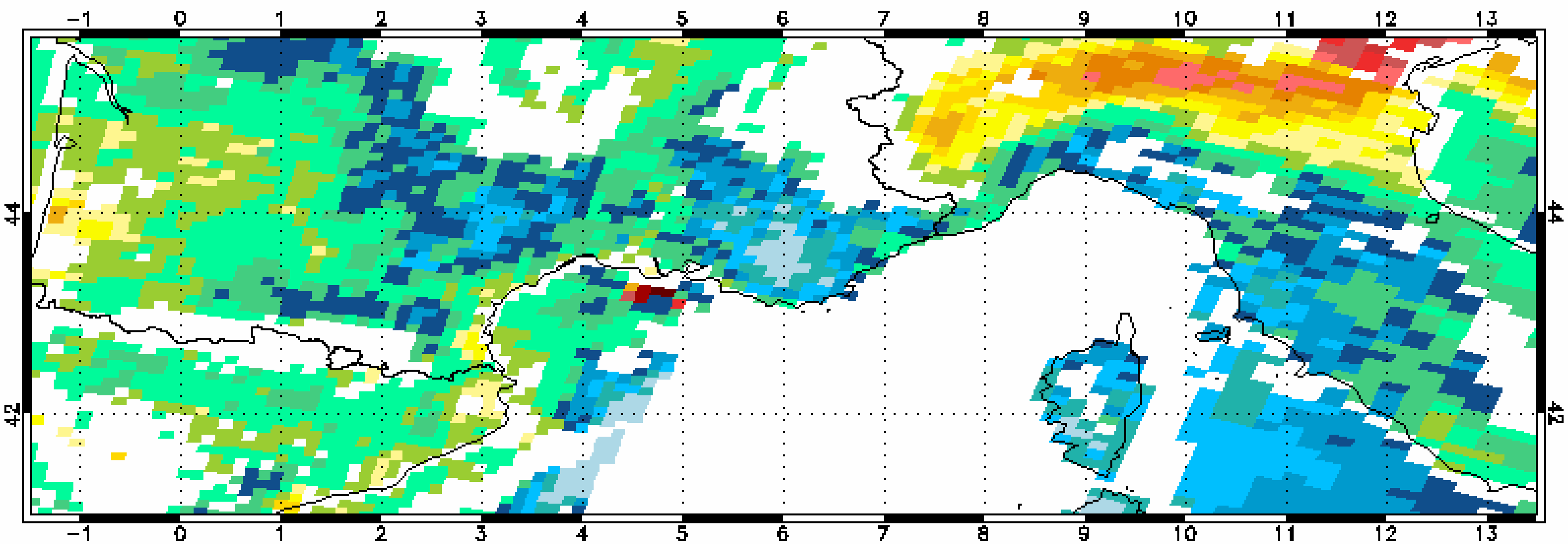
MODIS

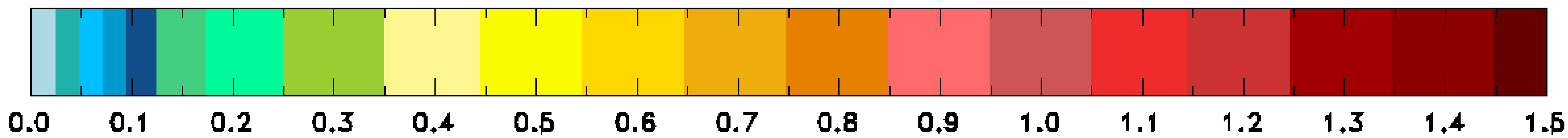


SEVIRI



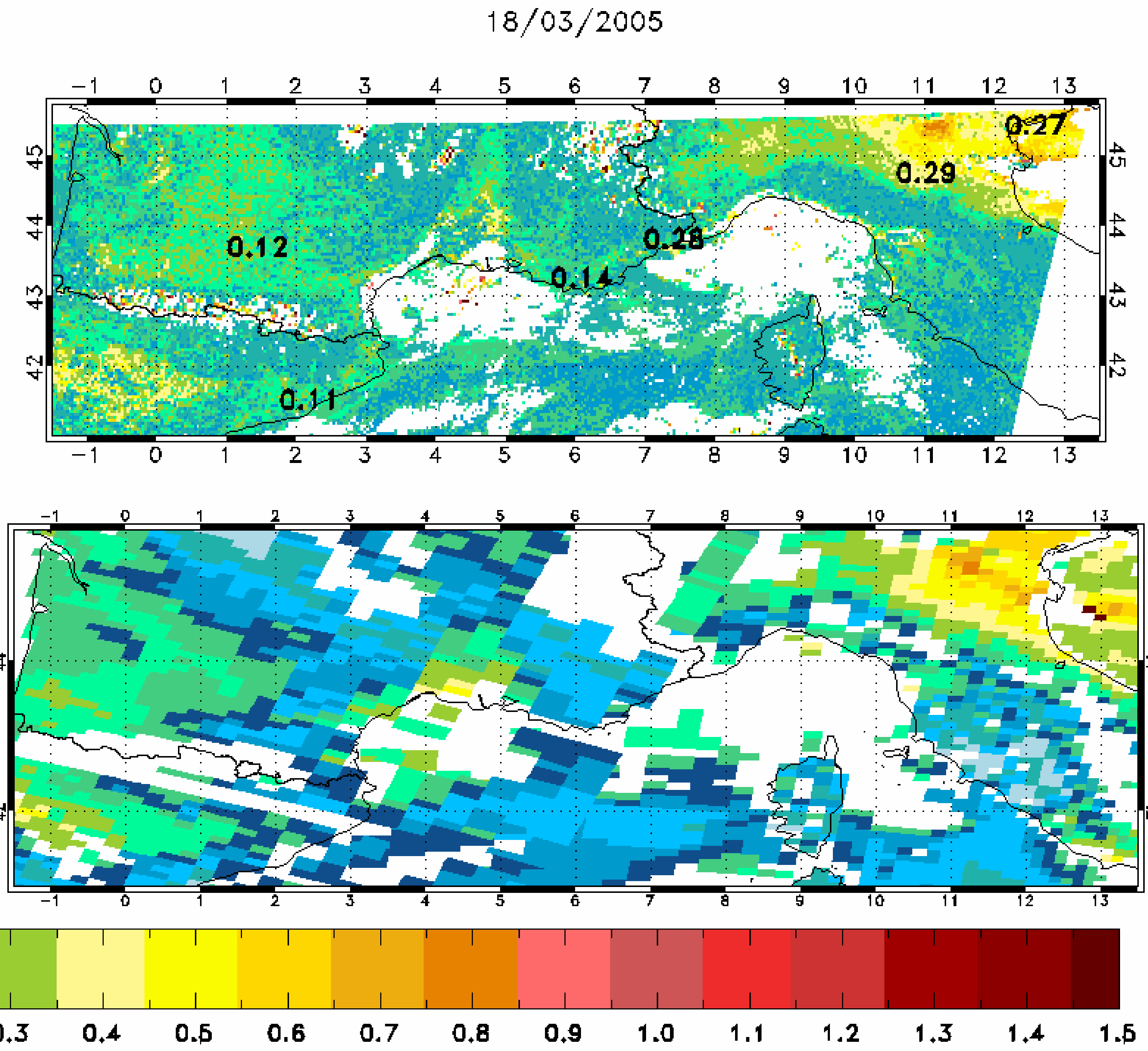
MODIS





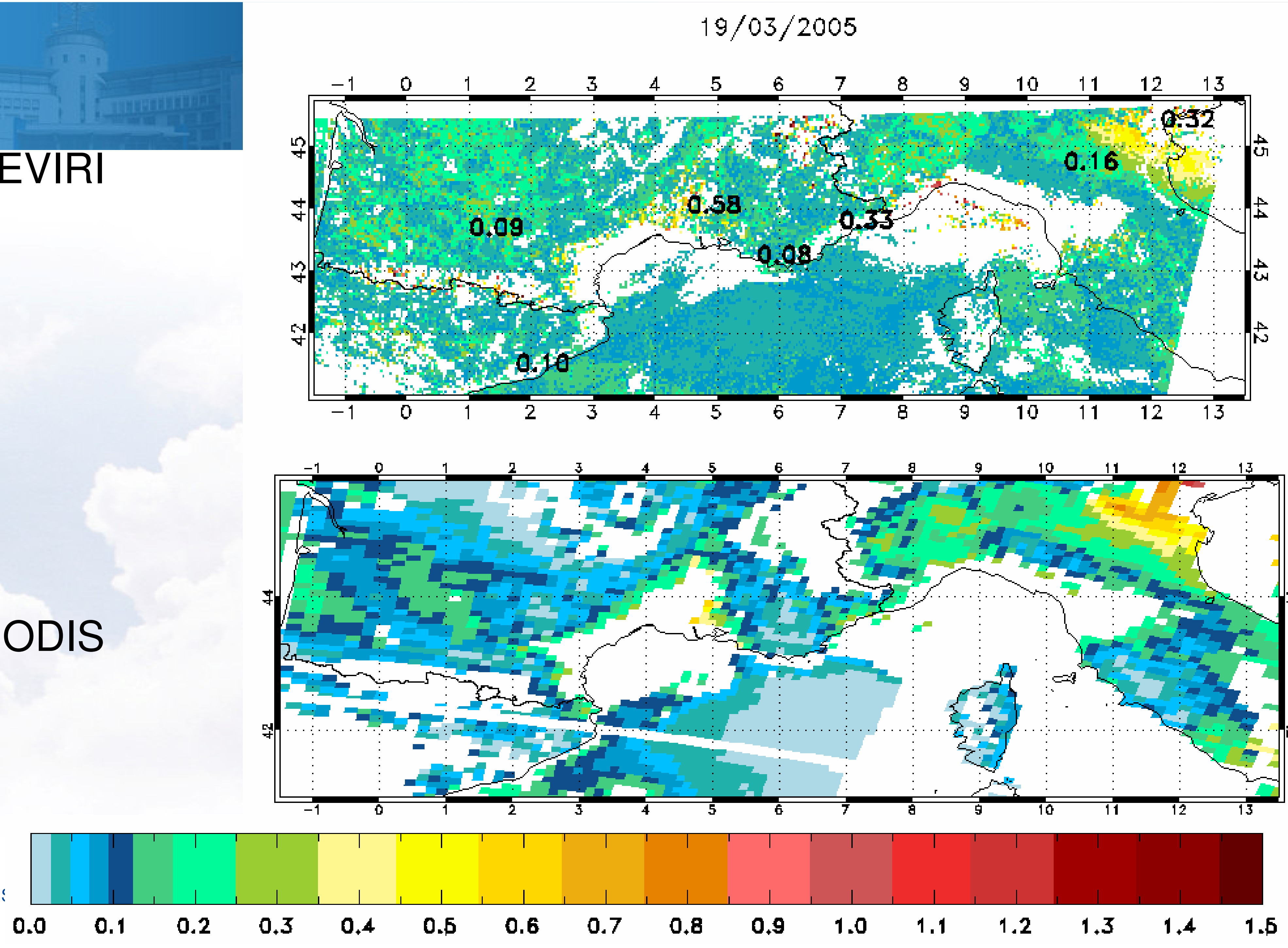
SEVIRI

MODIS

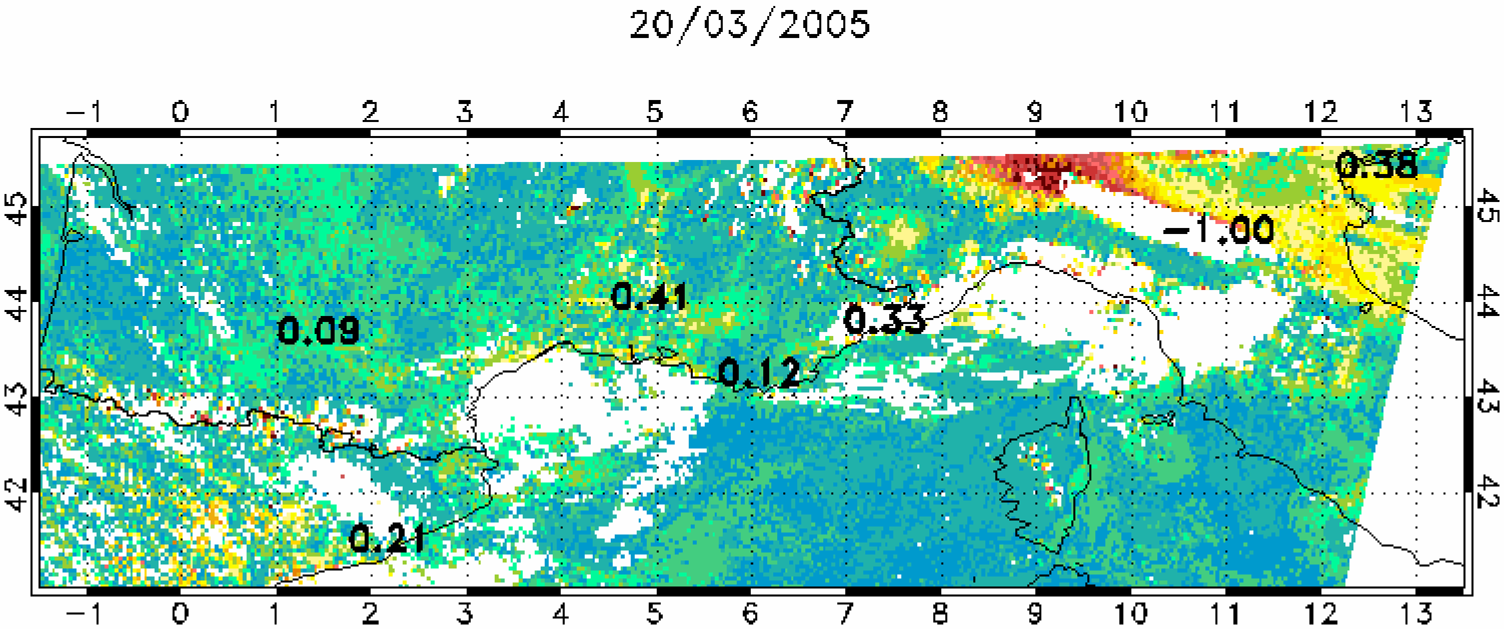


SEVIRI

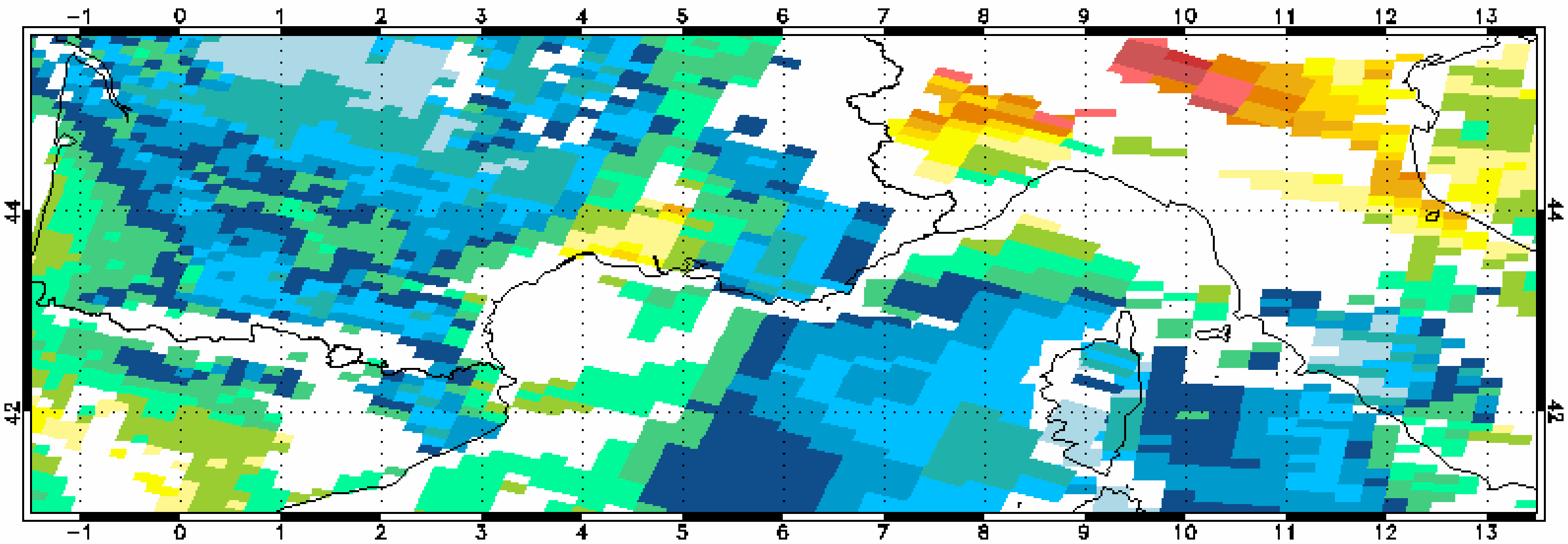
MODIS

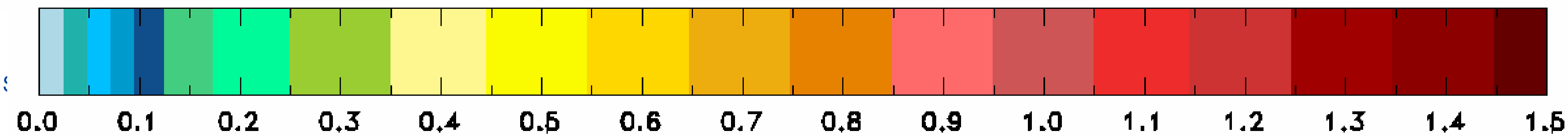


SEVIRI

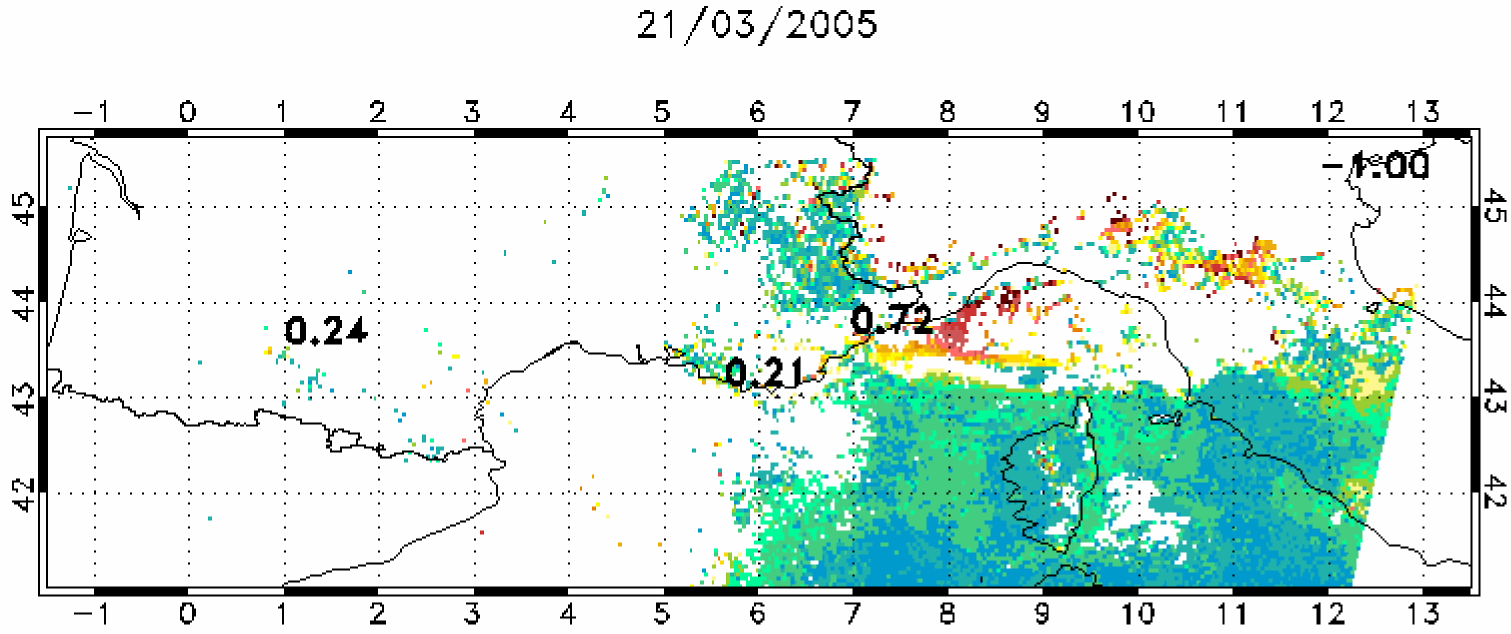


MODIS

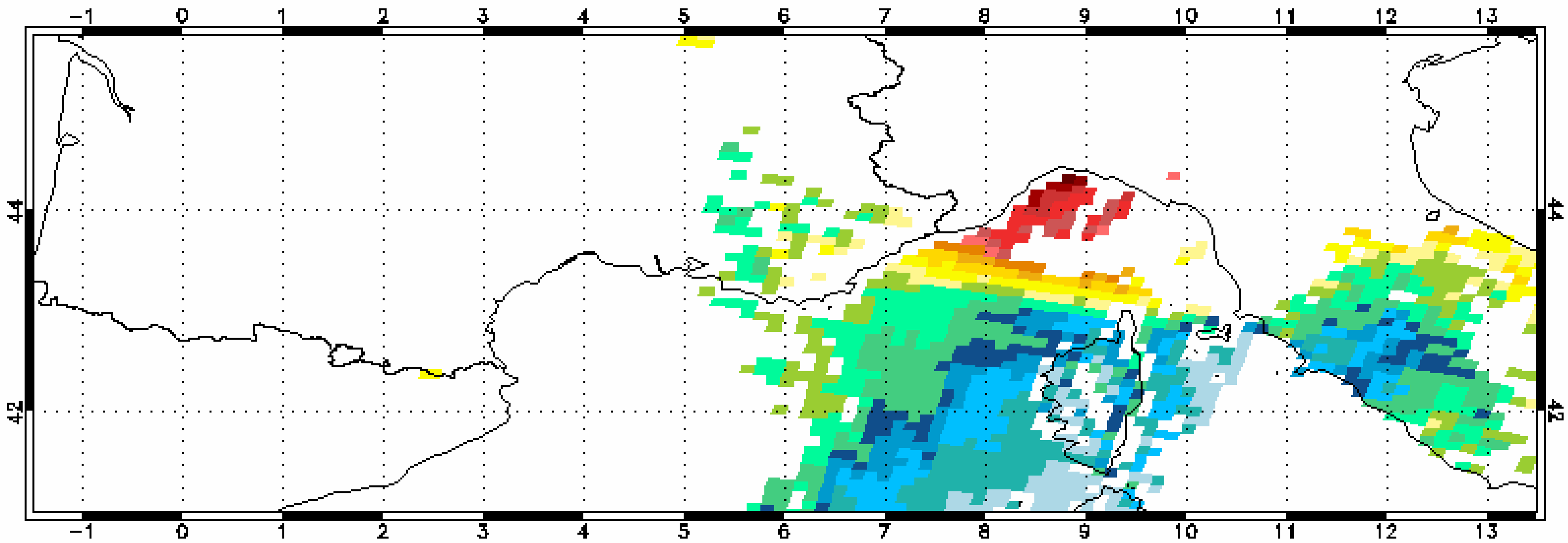


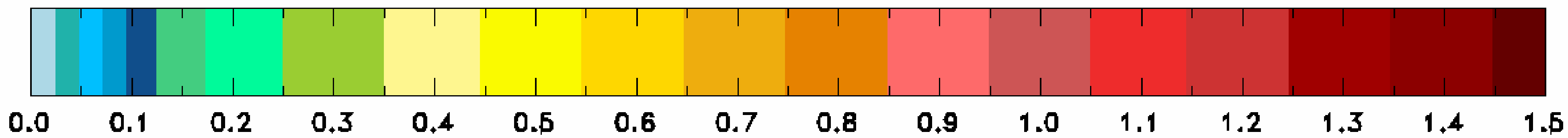


SEVIRI



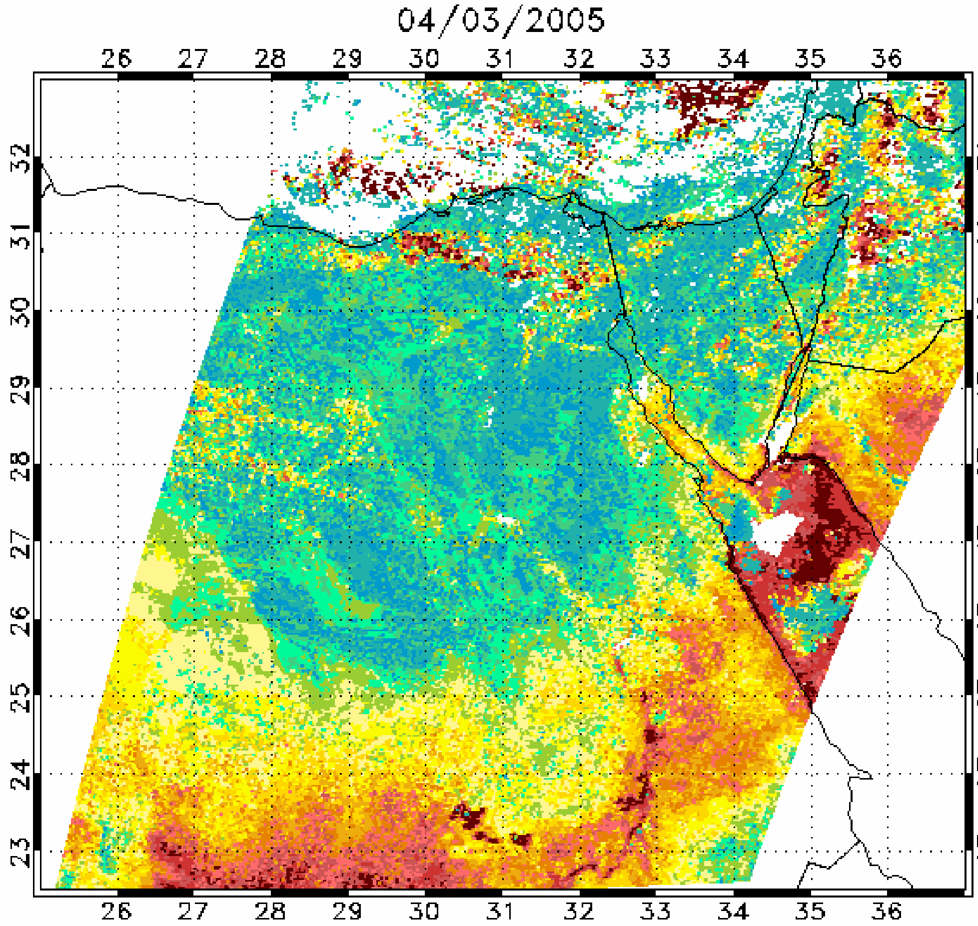
MODIS



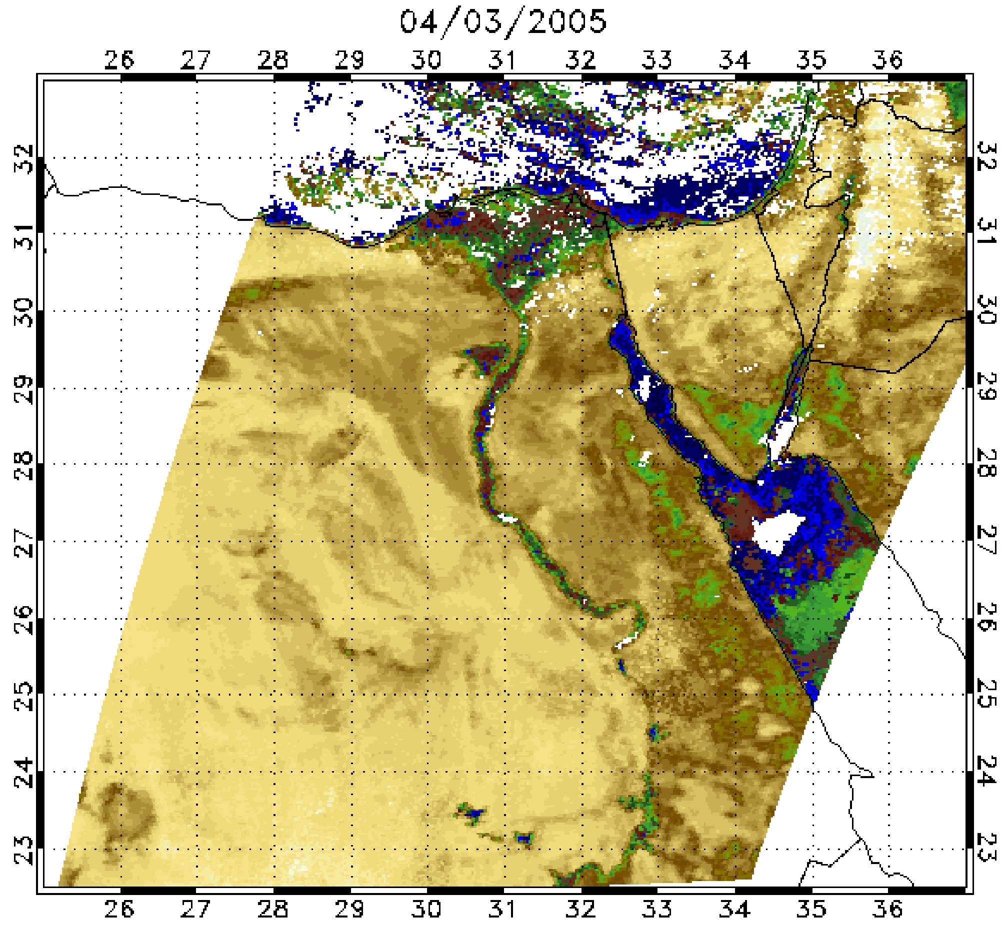


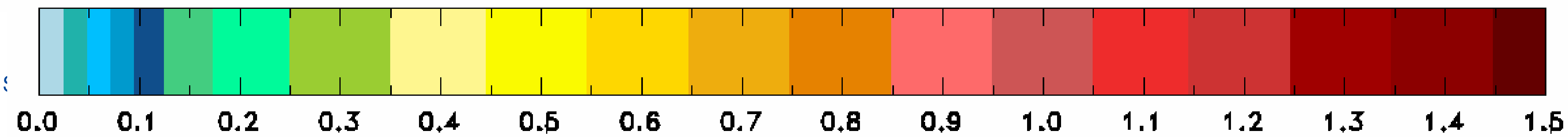
COMPARIONS WITH MODIS

SEVIRI



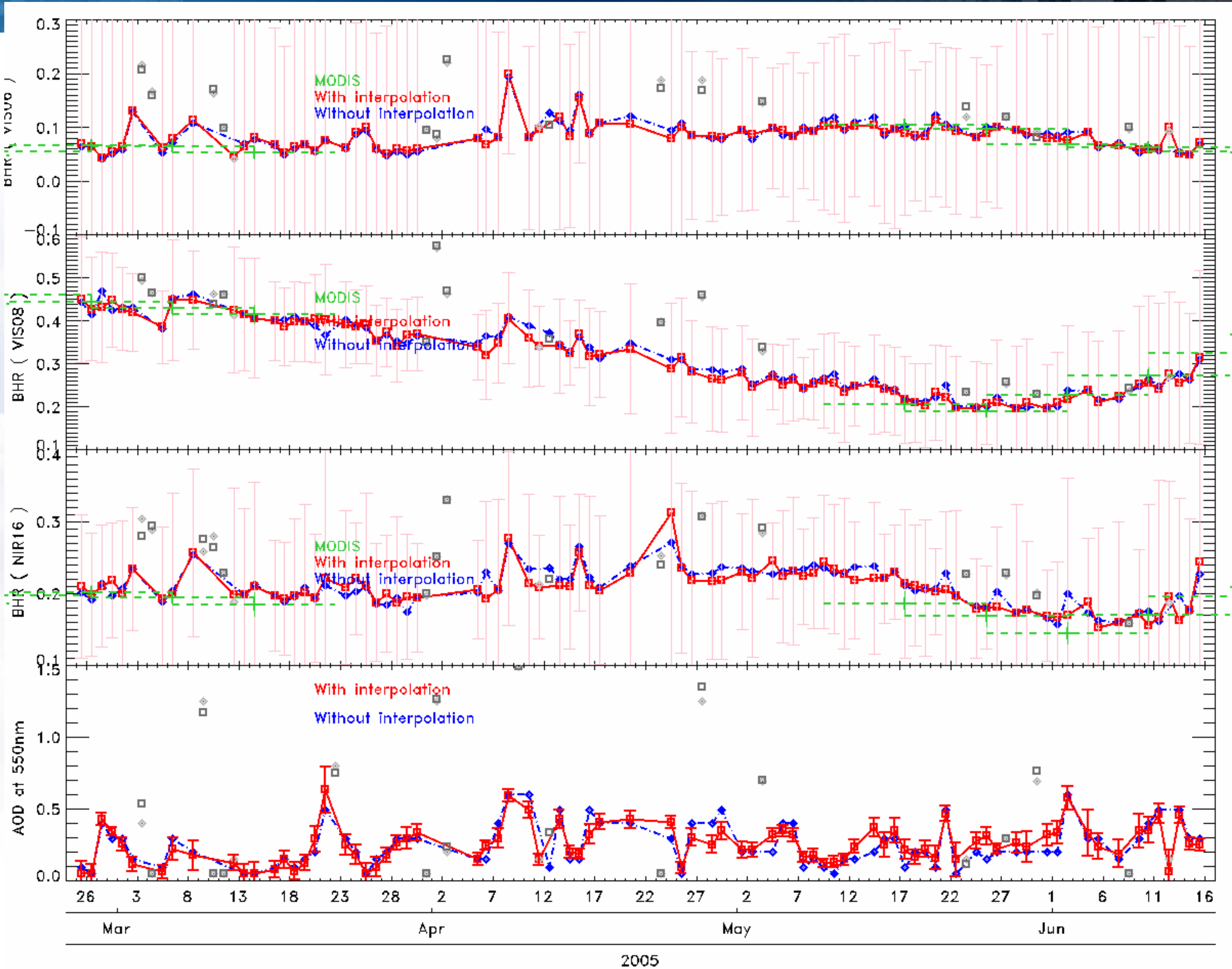
MODIS





COMPARISON WITH MODIS SRF ALBEDO

Nile Delta



SAT

Conclusions

Optimal Estimation :

- powerful (but expensive) tool to inverse satellite data to retrieve AODs and surface properties and document the radiative (de)coupling between the surface and the aerosols.

Comparison against AERONET :

- Importance to get the surface anisotropy accurately retrieved
- Importance of updating the prior information in order to stabilize the surface and reduce the errors (err = 0.05+20%τ)
- Separation between spherical and non-spherical particles. But more analysis needed…

Comparison with MODIS :

- LDA as a good spatial coverage
- Mean daily value might be a limiting assumption in case of dust storm.