eo4geo

UNIVERSITÀ DEGLI STUDI DELLA BASILICATA

Airborne dust identification from space: a new, MSG/SEVIRI-based method for air quality assessment

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Particular matter PM_{10}

SOURCES

- **ANTHROPOGENIC**
- **NATURAL**

IMPACTS

HUMAN HEALTH

High PM_{10} concentrations…

…are responsible for 6% of total mortality

… cause damage to the cardiovascular and respiratory systems

CLIMATE

- **DIRECT**

…impact on reflection and absorption of solar and IR radiation in the atmosphere

- **INDIRECT**

…can alter cloud features by acting as condensation nuclei

DIRECTIVE 2008/50/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL (21/05/2008)
on ambient air quality and cleaner air for Europe

ANNEX XI - LIMIT VALUES FOR THE PROTECTION OF HUMAN HEALTH

PM10	Averaging Period	Limit value
	One day	50 µg/m^3, not to be exceeded more than 35 times a calendar year

Local authority actions (e.g. traffic restrictions)

Article 20 – CONTRIBUTIONS FROM NATURAL SOURCES*
Paragraph 2

Where the Commission has been informed of an exceedance attributable to natural sources in accordance with paragraph 1, that excedance shall not be considered as an exceedance for the purposes of this Directive.

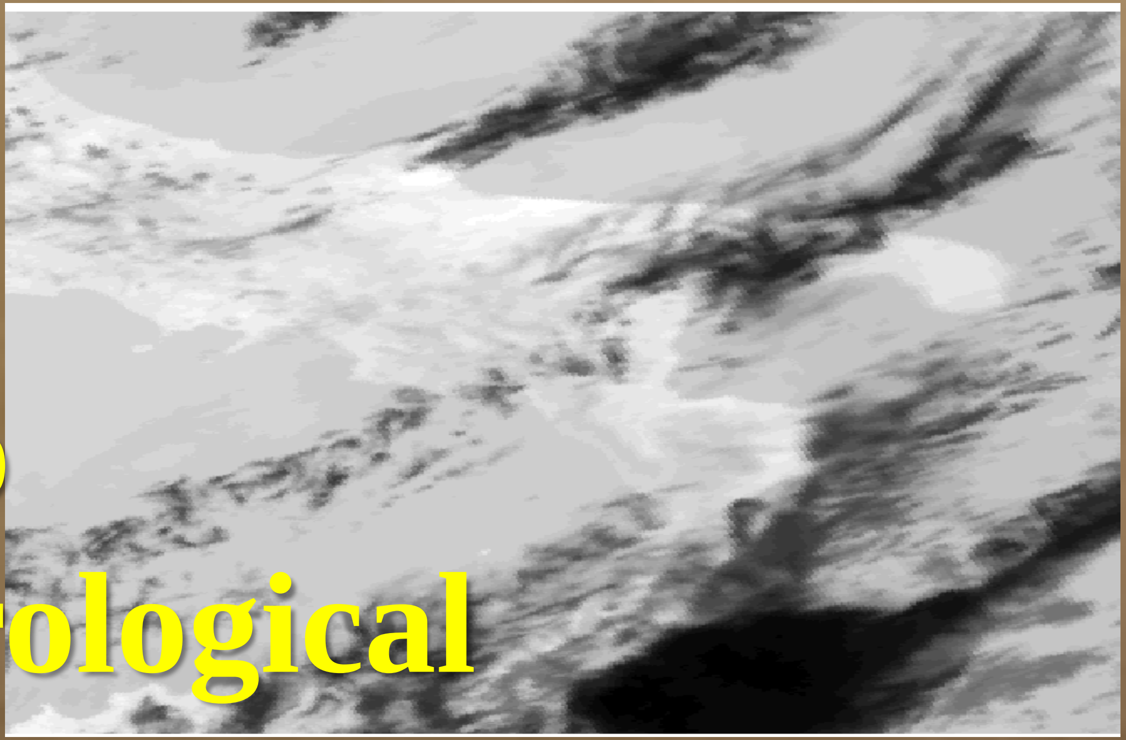
* Article 2 – Paragraph: 15 Contributions from natural sources' shall mean emissions of pollutants not caused directly or indirectly by human activities, including natural events such as volcanic eruptions, seismic activities, geothermal activities, wild-land fires, high-wind events, sea sprays or the atmospheric re-suspension or transport of natural particles from dry regions

Dust Storm Spectral Signatures

Highly reflecting
Solar radiation in the VISible
easier to detect over the sea than over land (low contrast)

Usually colder than background surfaces
(in the Thermal InfraRed .TIR)

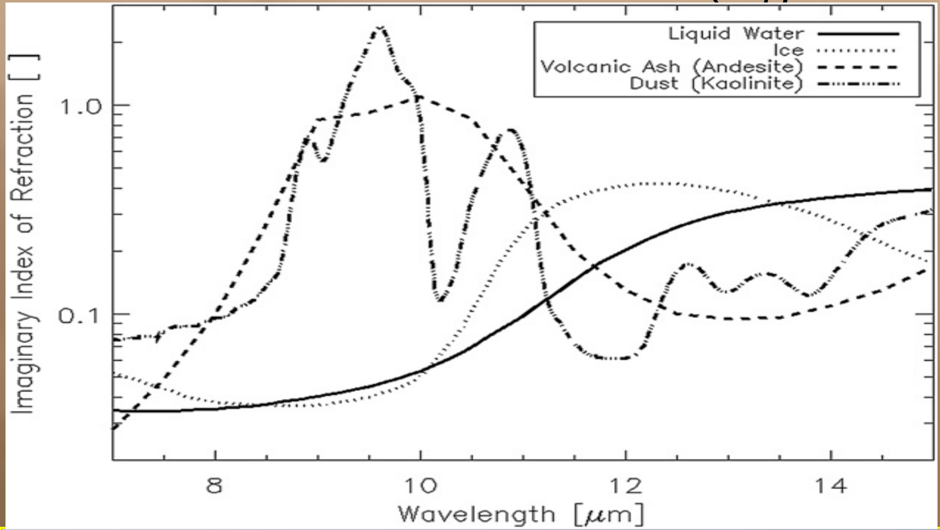
Like to meteorological clouds !



Discriminating meteo from dust clouds

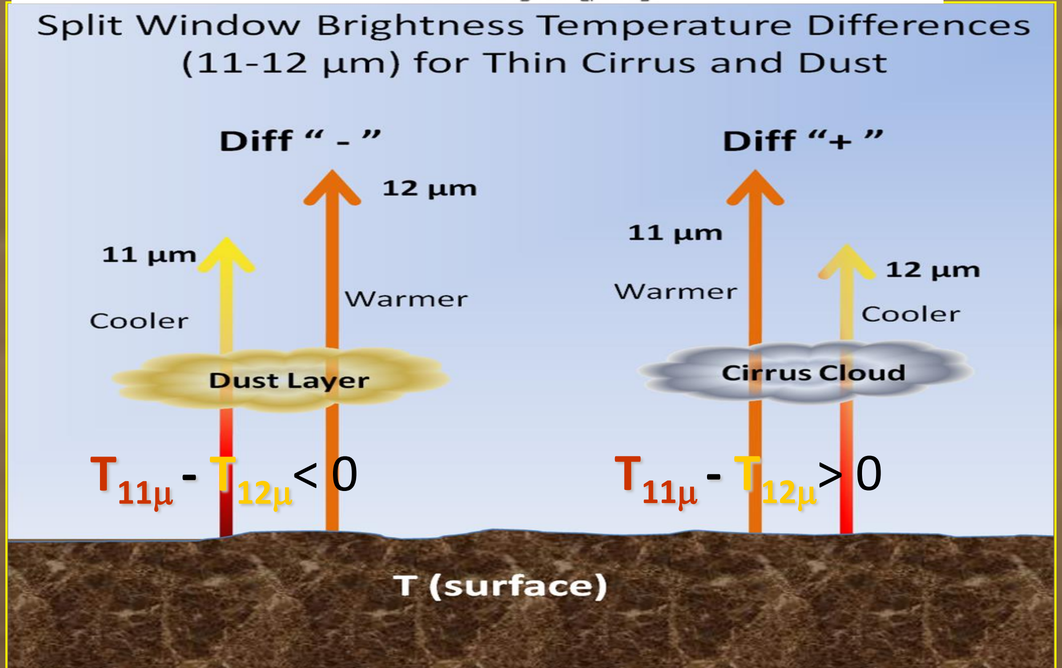
the Split Window BTD method

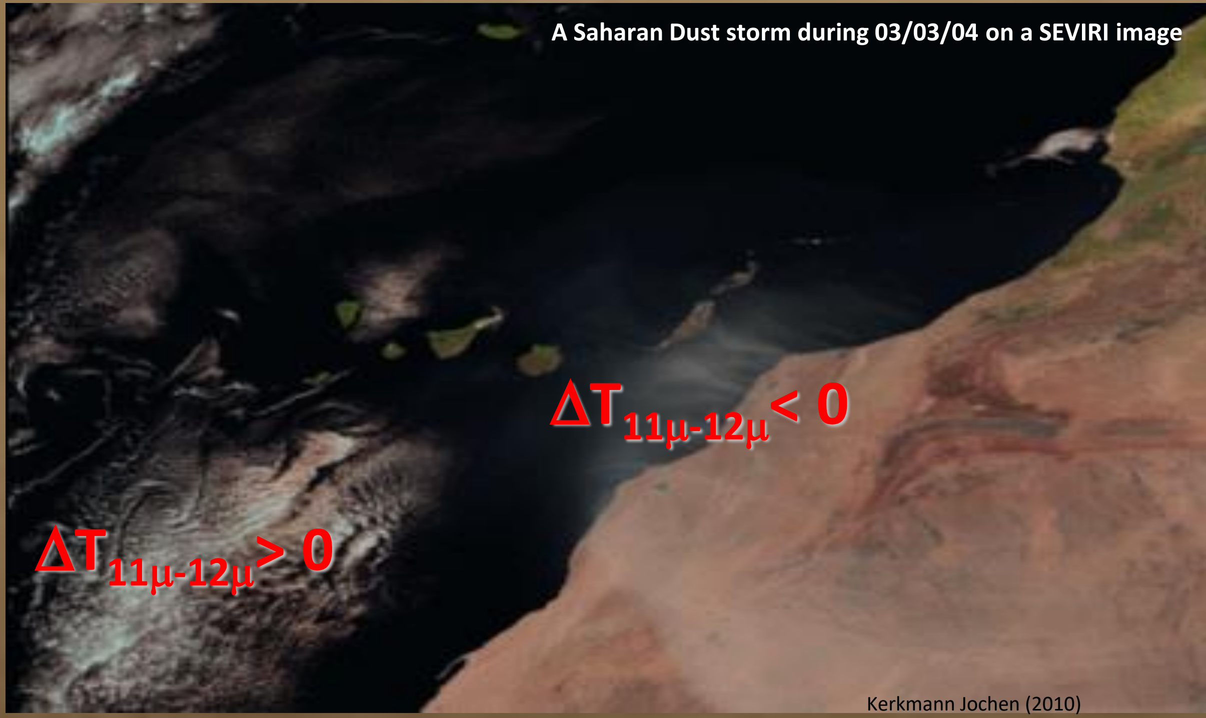
(e.g. Prata. 1989, Gu et al., 2003; Luo et al., 2003)



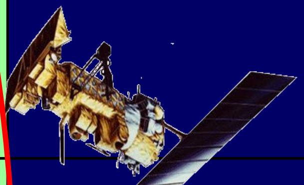
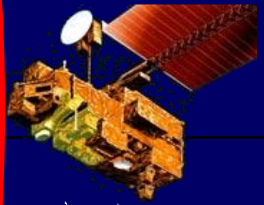
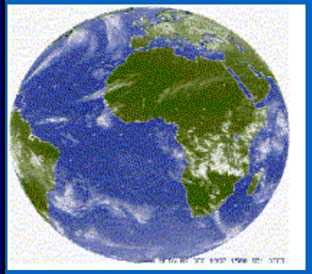
Dust → $T_{11\mu} - T_{12\mu} < 0$

Clouds → $T_{11\mu} - T_{12\mu} > 0$



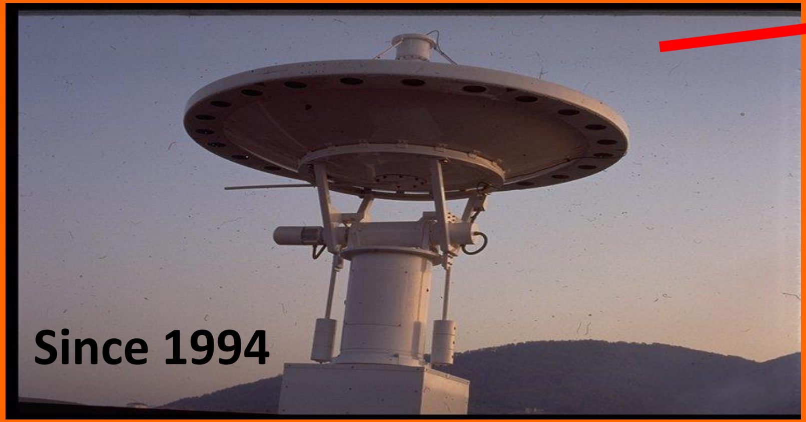


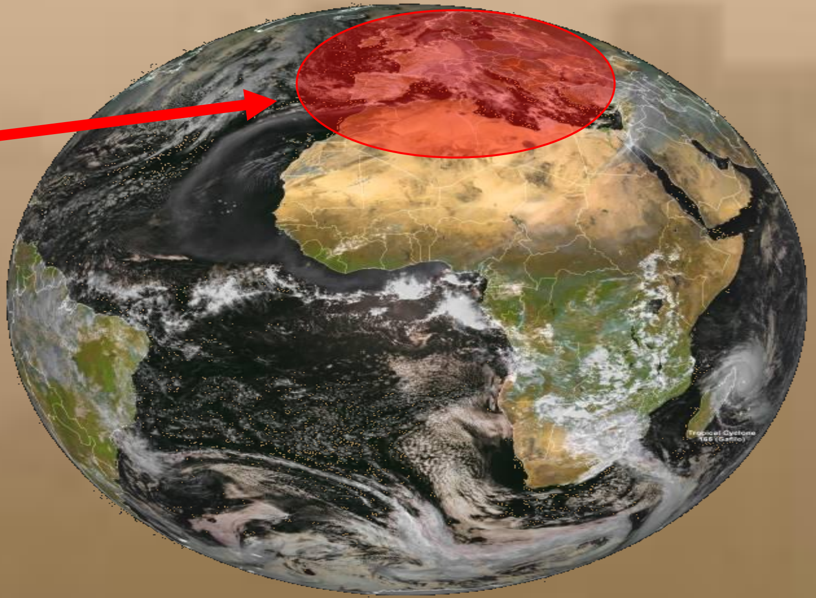
Main meteorological (high repetition) satellite sensors with split window capabilities

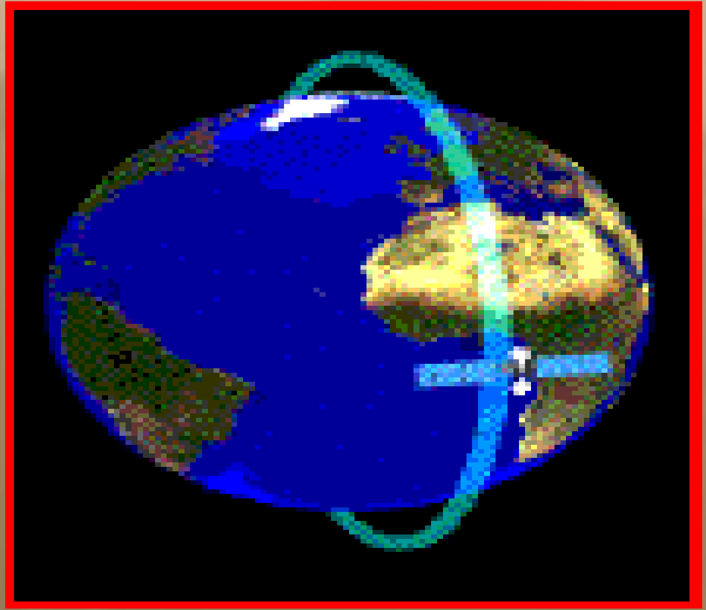
Sensor	Spatial Resolution	Temporal Resolution	Satellite	Available since
AVHRR (Global)	1,1 Km	6 h	 NOAA/ MetOp	 1978
MODIS (Global)	0,25 – 1 Km	12 h	 EOS	 1999
SEVIRI (Europe & Africa) Global by Geosttionary Constellation	1 - 3 Km	15 min.	 MSG	 2003

Space-Time coverage

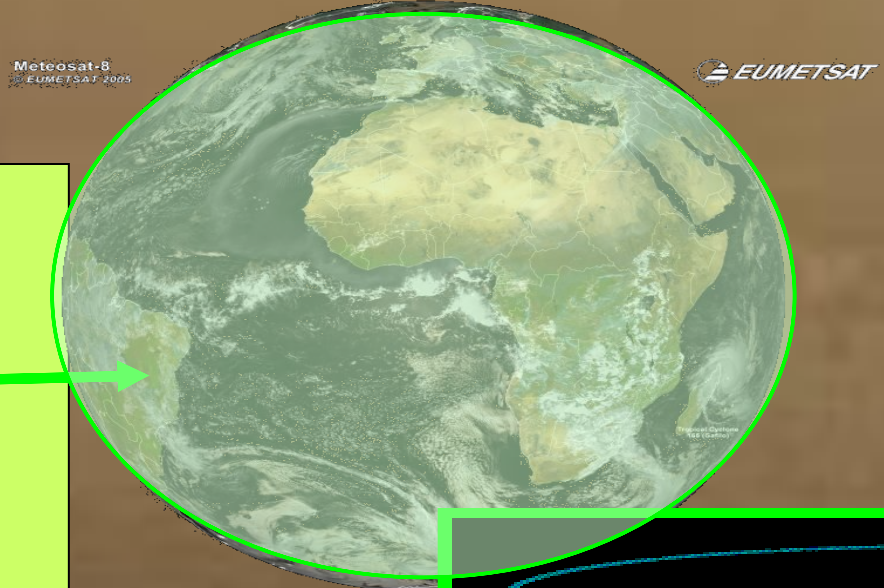
NOAA & EOS receiving station
at IMAA



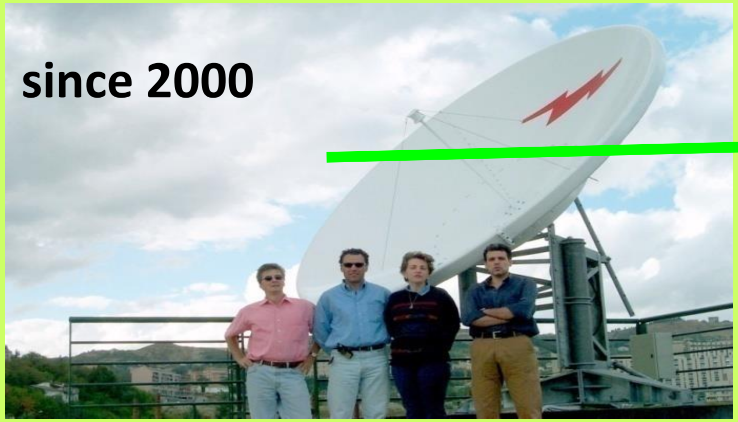




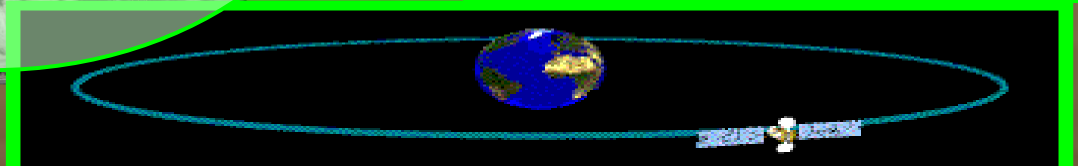
one image every
3-6 hours



Meteosat & MSG receiving station at UNIBAS



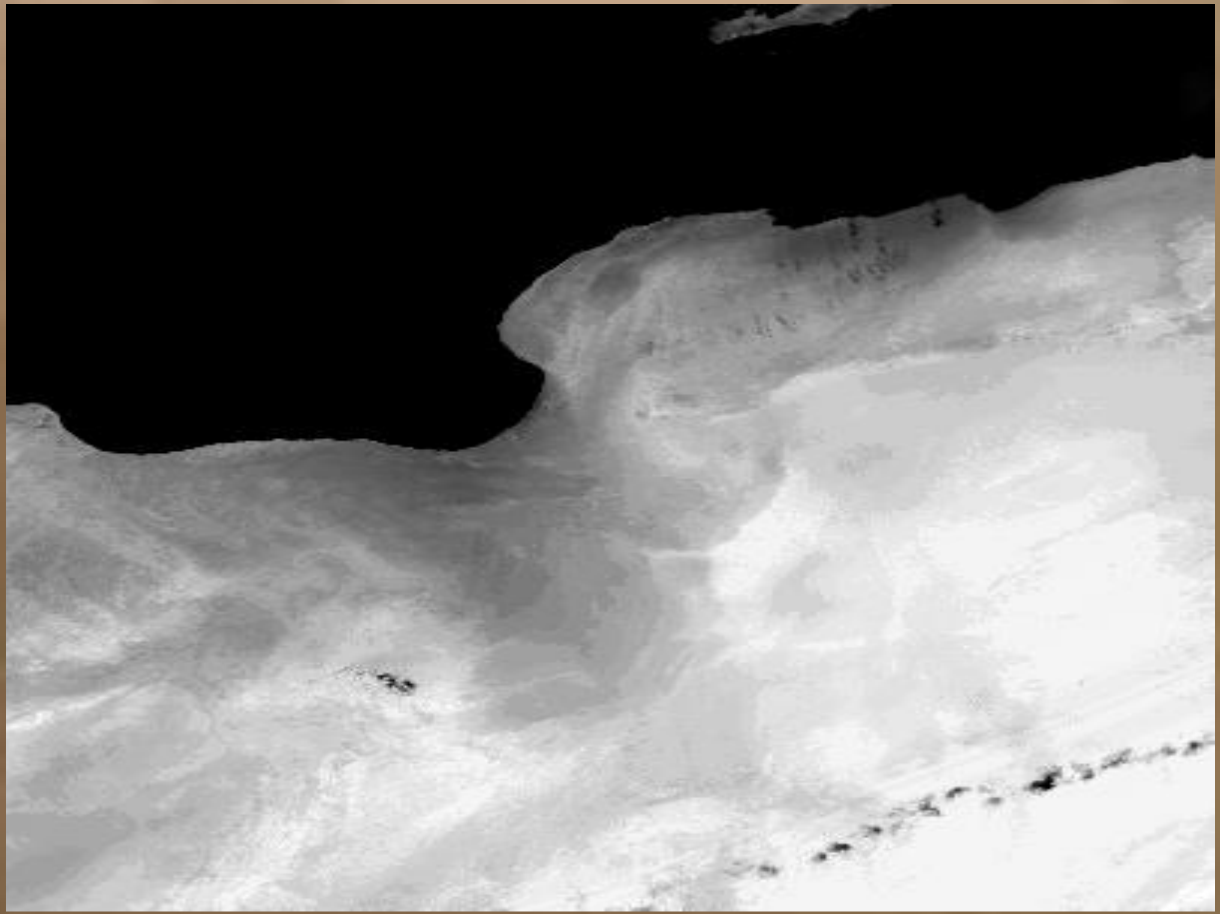
one image every
5-15 minutes



TRADITIONAL (FIXED THERSHOLD) METHODS FOR DUST-CLOUD DETECTION

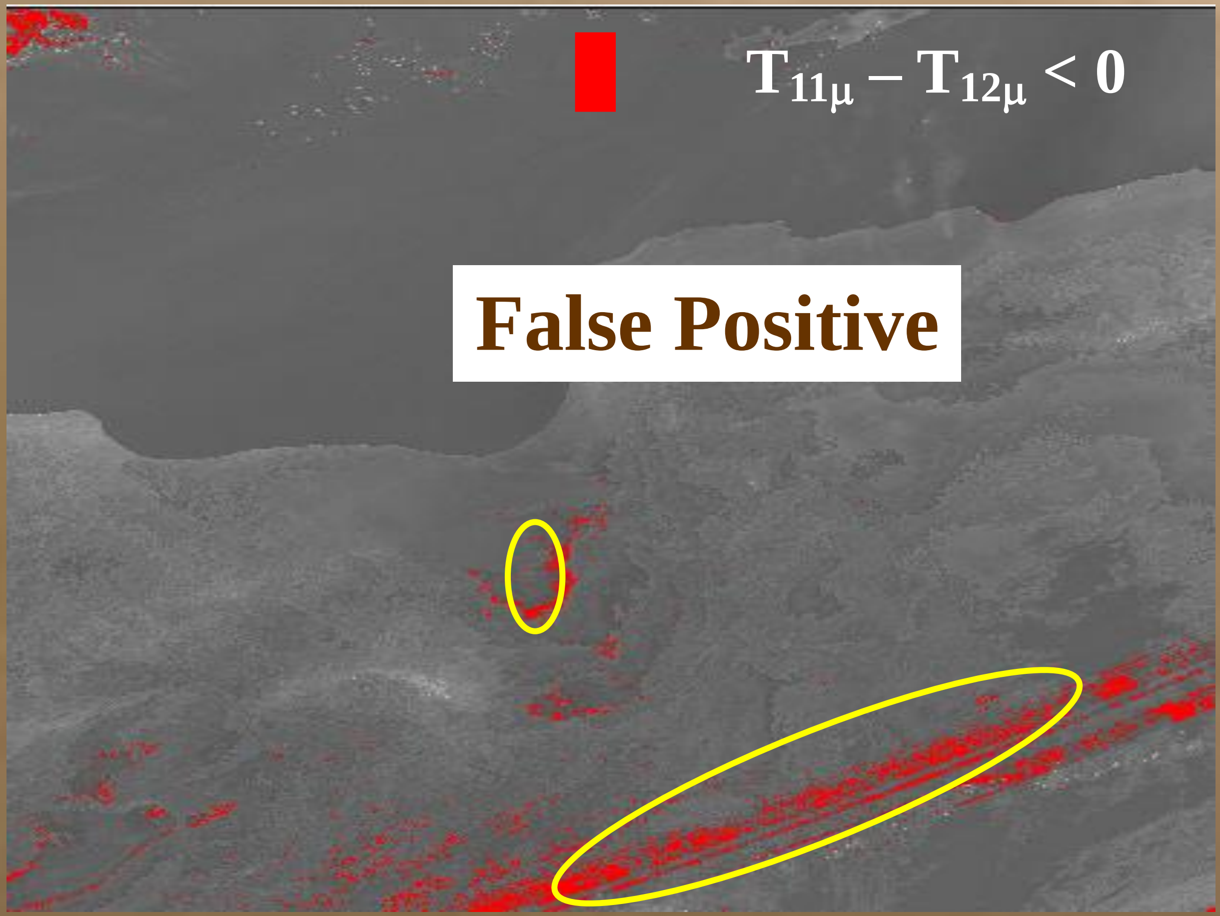
Split Window BTD method (e.g. Prata. 1989, Gu et al., 2003; Luo et al., 2003)

Main issues: false positives



14/05/1995: no dust storm present over the scene

Prata (1989)



Result of a traditional "split-window"-based method

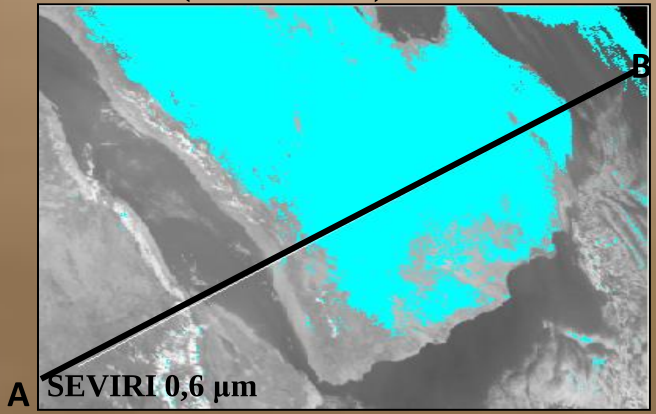
TRADITIONAL (FIXED THERSHOLD) METHODS FOR DUST-CLOUD DETECTION

Split Window BTD method (e.g. Prata. 1989, Gu et al., 2003; Luo et al., 2003)

Main issues: false positives

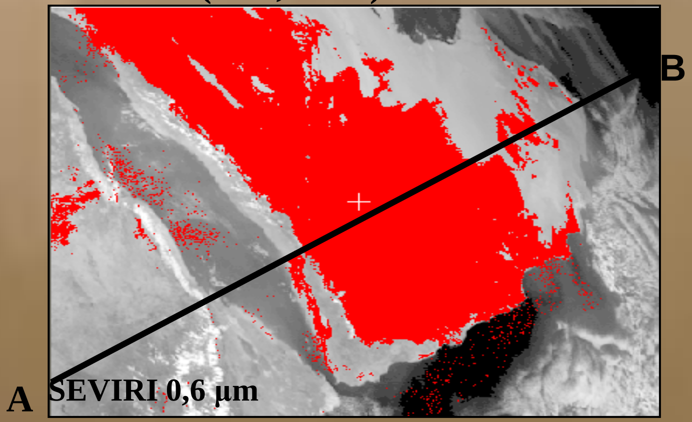
SEVIRI 06/02/2008_h 13 UTC

(Prata, 1989)

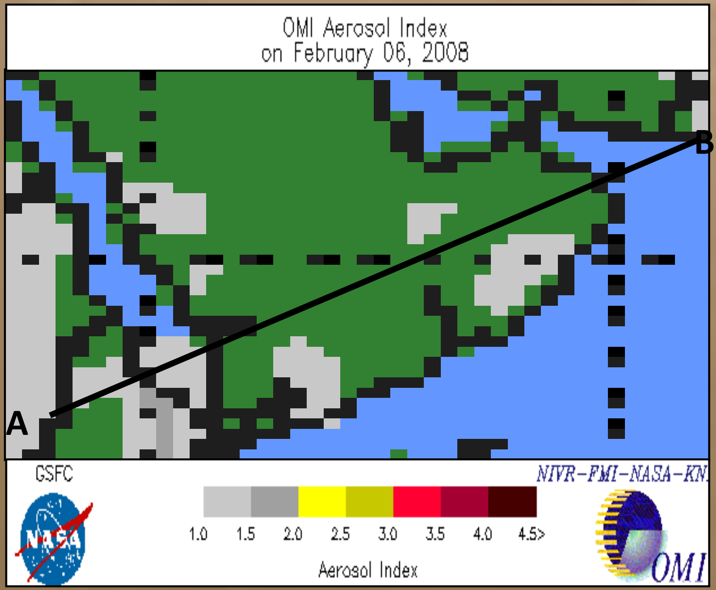


ΔT (11µm -12µm) < 0

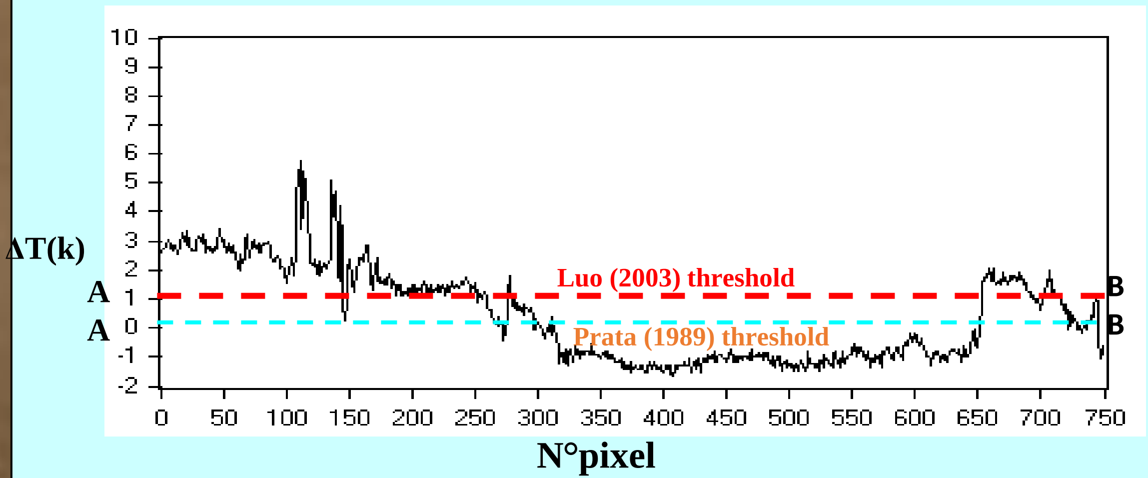
(Luo, 2003)



ΔT (11µm -12µm) <1



ftp://toms.gsfc.nasa.gov/pub/omi/images/aerosol/Y2008/



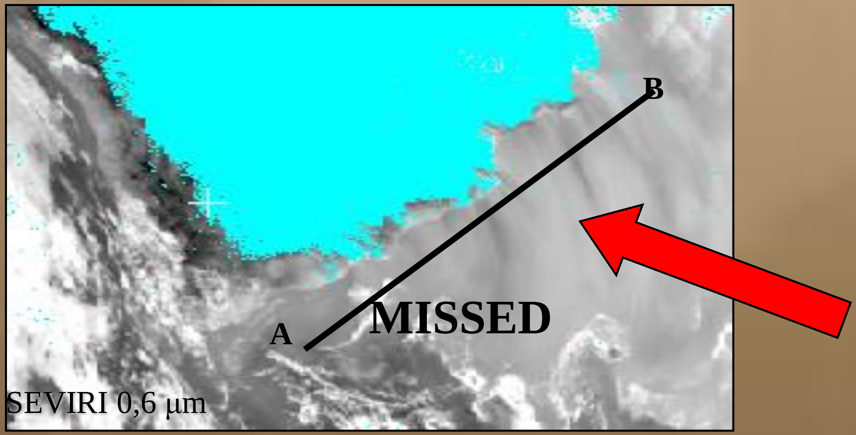
TRADITIONAL (FIXED THERSHOLD) METHODS FOR DUST-CLOUD DETECTION

Split Window BTD method (e.g. Prata. 1989, Gu et al., 2003; Luo et al., 2003)

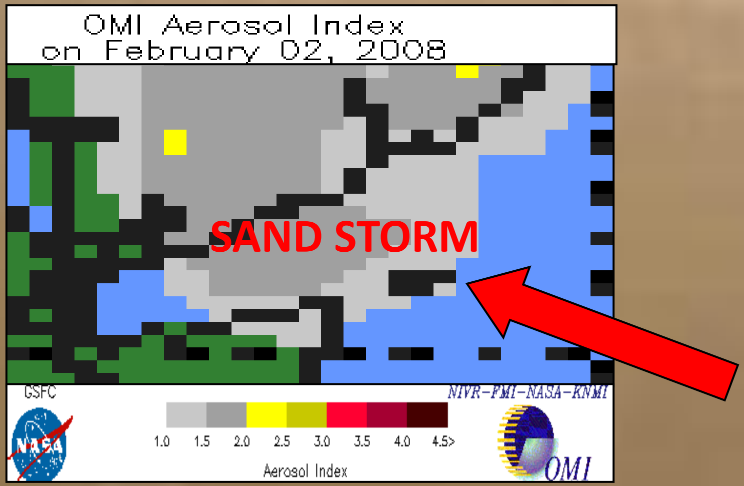
Main issues: missed detections

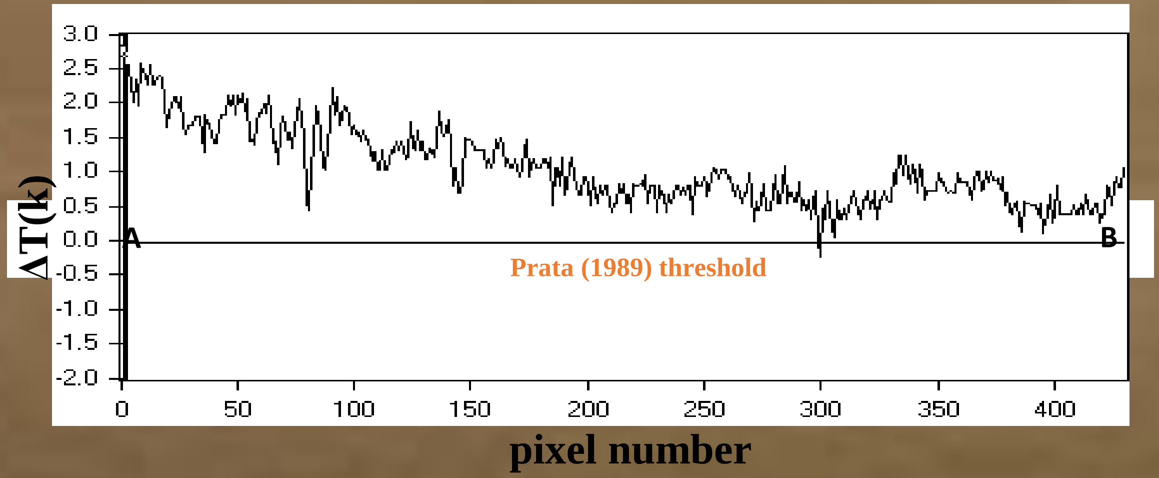
SEVIRI 02/02/2008_h 06 UTC

(Prata, 1989)



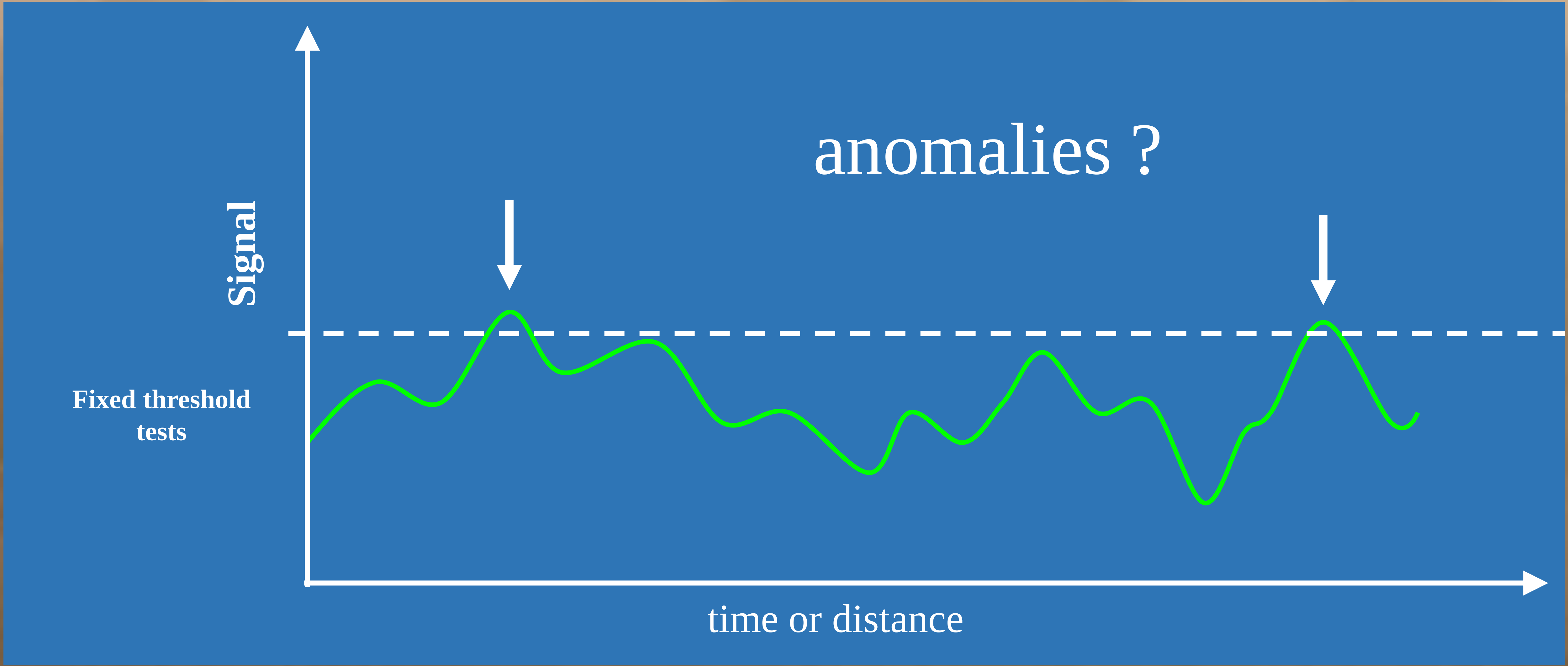
ΔT (11µm -12µm) < 0





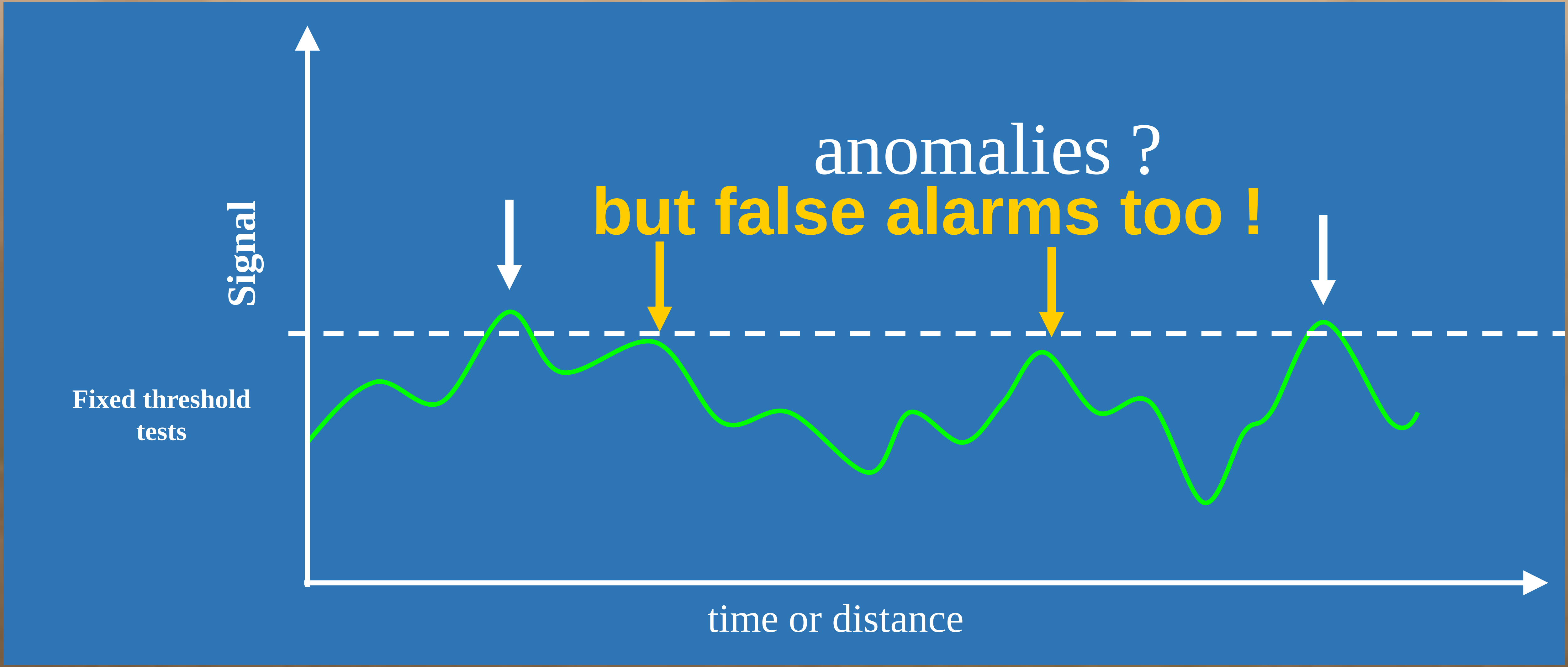
What does “anomaly” mean ?

TRADITIONAL (FIXED THERSHOLD) METHODS



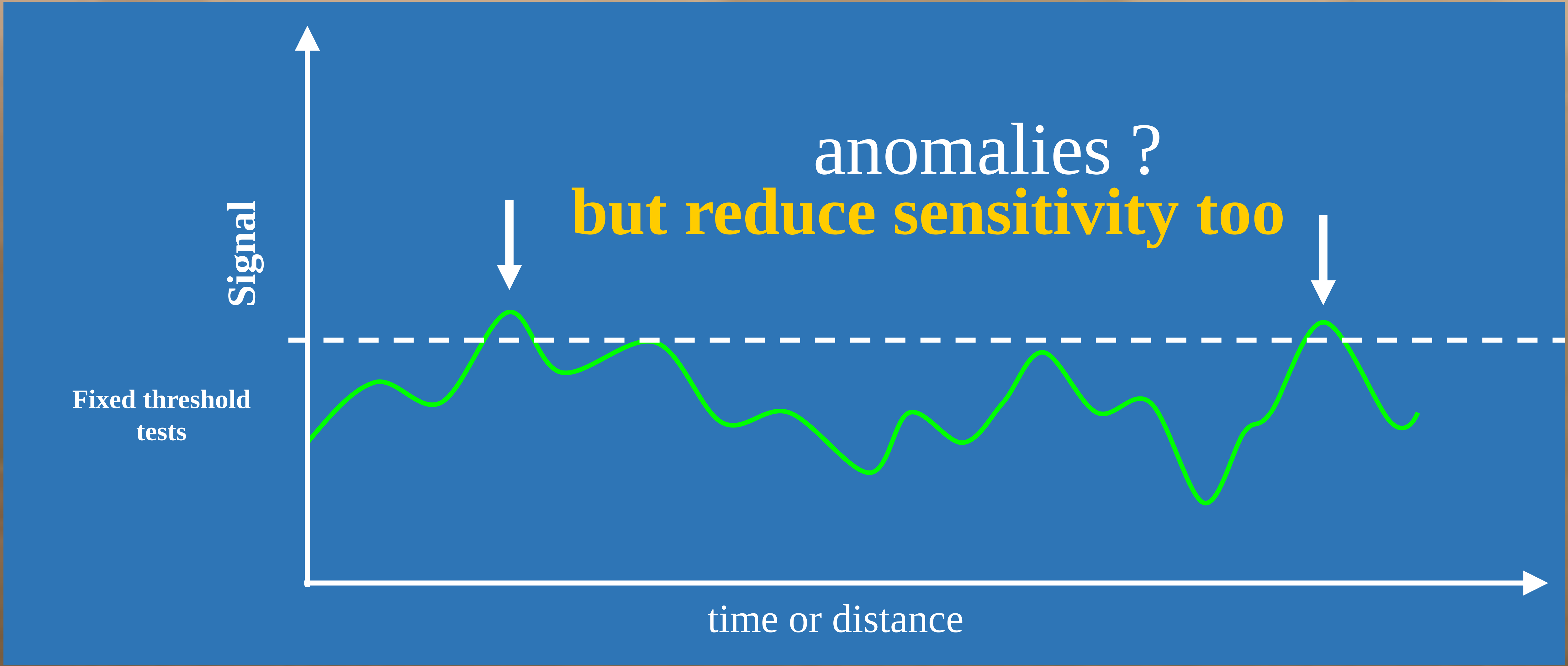
What does “anomaly” mean ?

lower thresholds increase sensitivity…

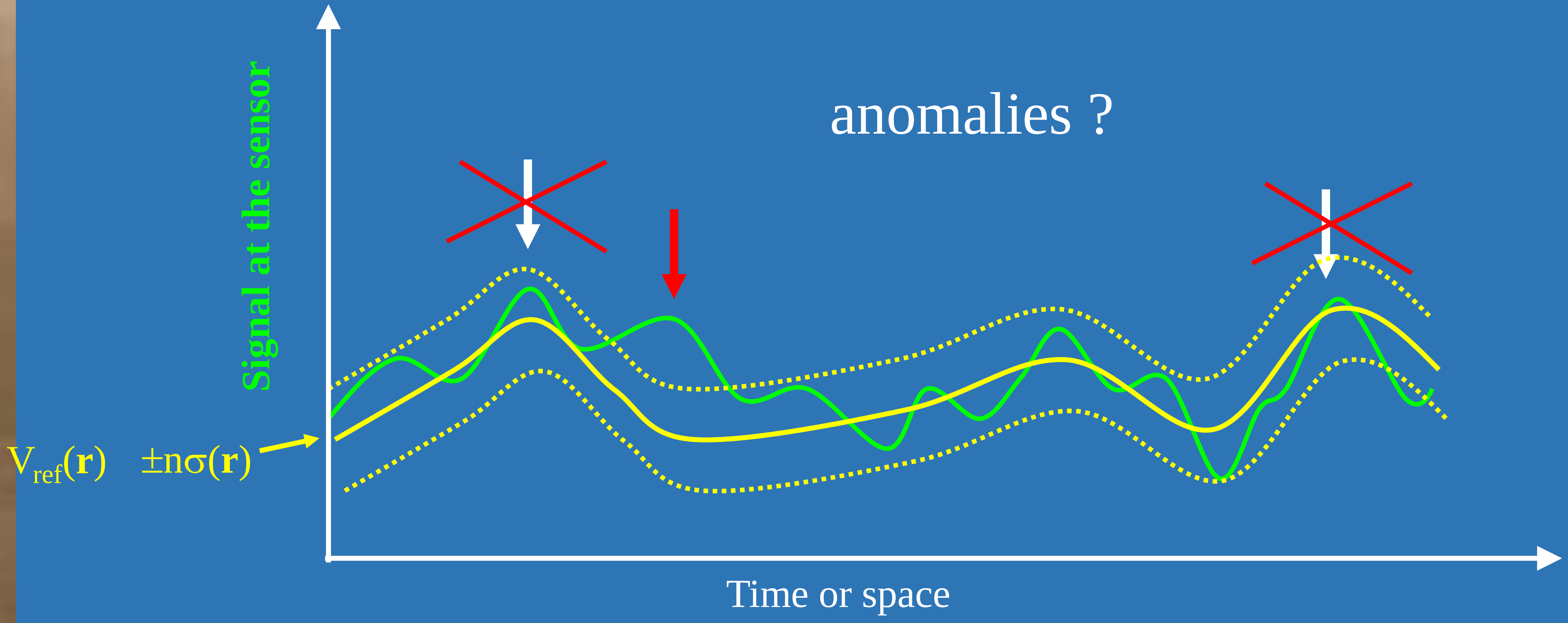


What does "anomaly" mean ?

higher thresholds increase reliability…



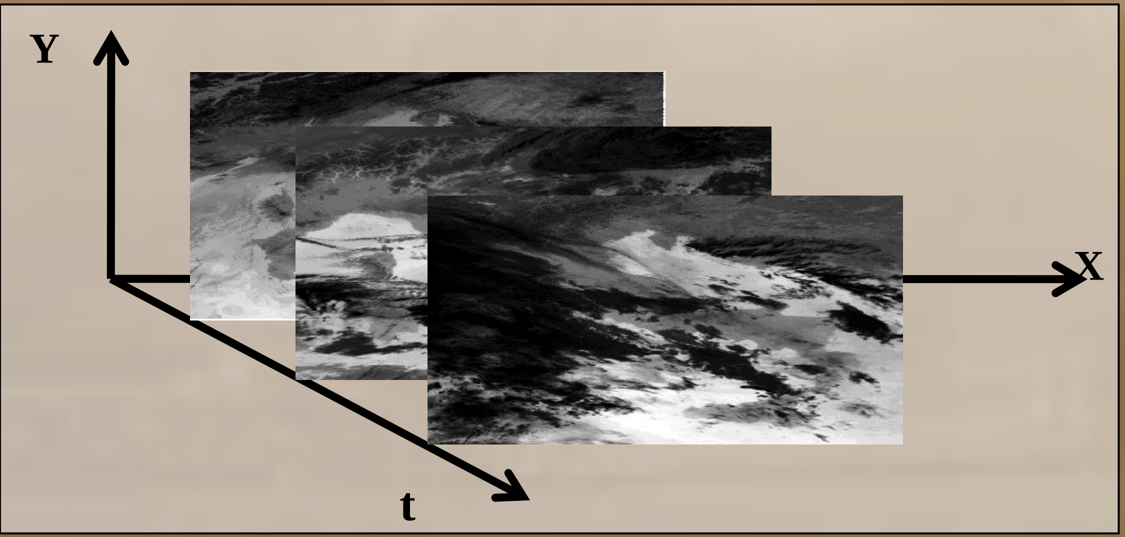
What does "anomaly" mean ?



RST (Robust Satellite Technique)

(formerly **RAT: Robust AVHRR Techniques**, V. Tramutoli, 1998, 2005)

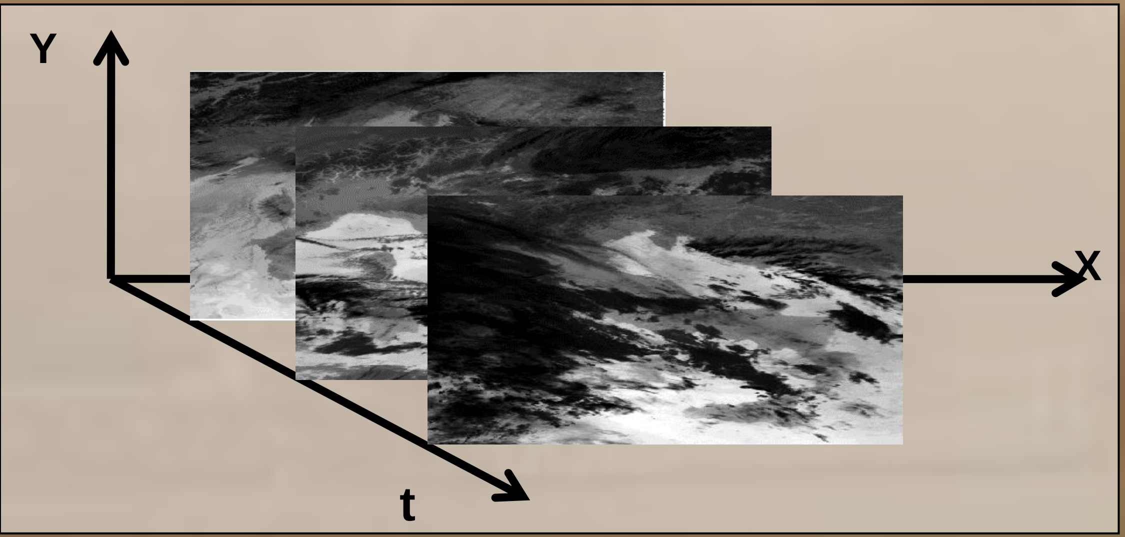
1. Select an **historical data-set** *V(**r**,t)* as homogeneous as possible: same time of the day and period of the year (*T*-domain) in order to reduce natural/observational noise

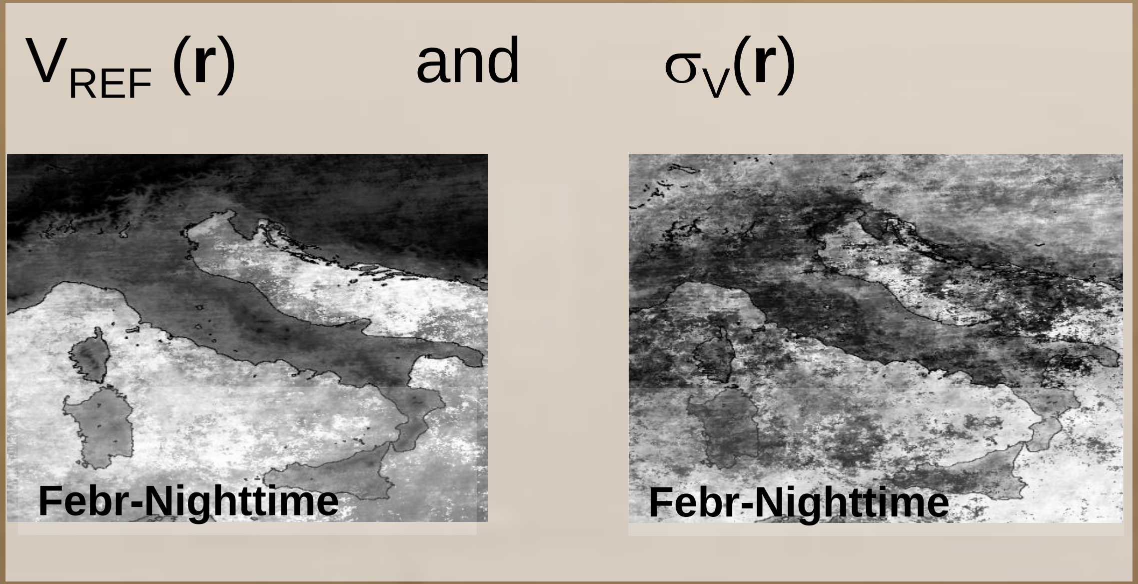


RST (Robust Satellite Technique)

1. Select an **historical data-set** *V(r,t)* as homogeneous as possible: same time of the day and period of the year (*T*-domain) in order to reduce natural/observational noise

2. Compute the ***unperturbed* reference fields** for the observable *V(**r**,t)*



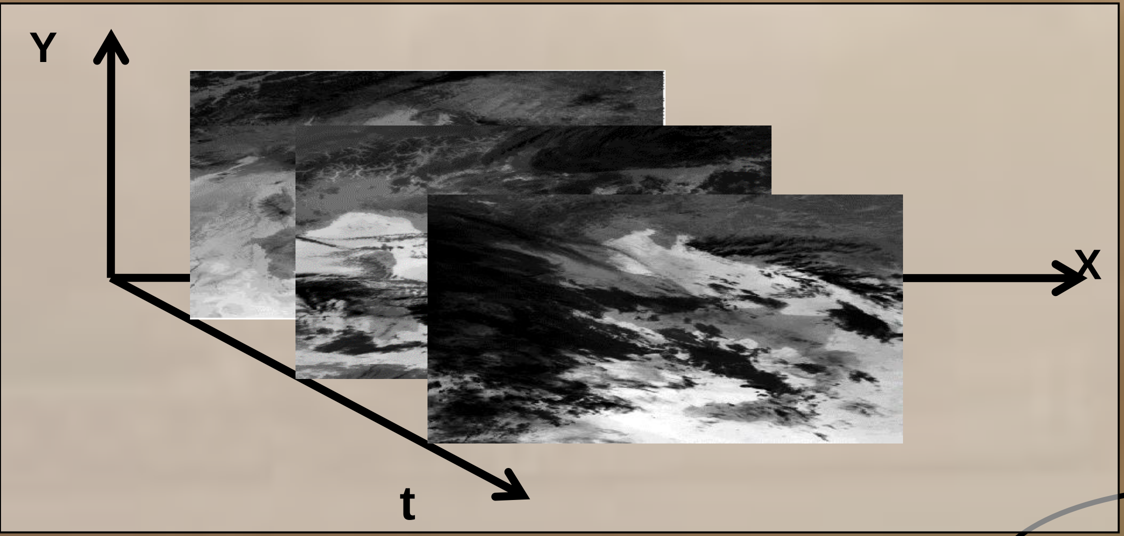


RST (Robust Satellite Technique)

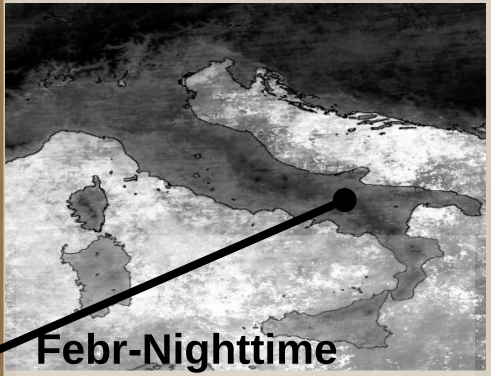
1. Select an **historical data-set *V(r,t)*** as homogeneous as possible: same time of the day and period of the year (*T*-domain) in order to reduce natural/observational noise

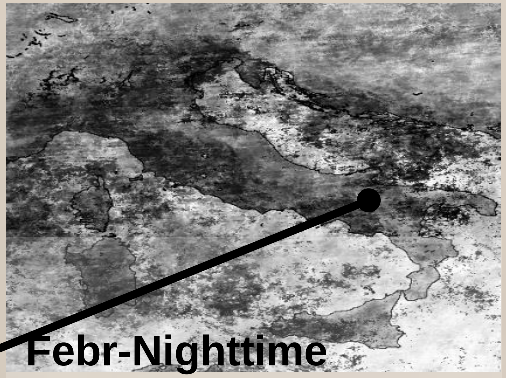
2. Computing the ***unperturbed reference fields*** for the observable *V(**r**,t)*

3. Change - Detection at the time *t* by



V_{REF} (**r**) and σ_V(**r**)





$$\otimes_V(x,y,t) = \frac{V(x,y,t) - V_{REF}(x,y)}{\sigma_V(x,y)}$$

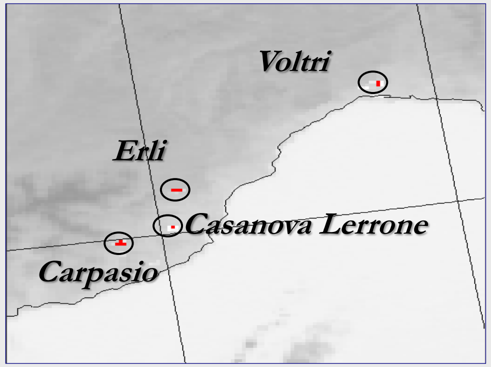
A.L.I.C.E.

(Absolutely Llocal Index of Change of the Environment)

20 years of RST Applications

Forest fires

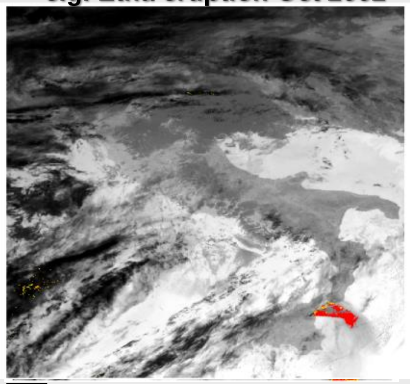
e.g. Fires in Italy, February 2005



fires

Volcanic Eruptions

e.g. Etna eruption Oct 2002



Ash Clouds

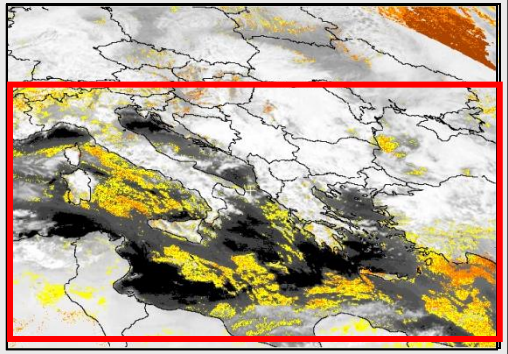
Floods

e.g. Basilicata flood, March 2011

Flooded areas

Dust storms

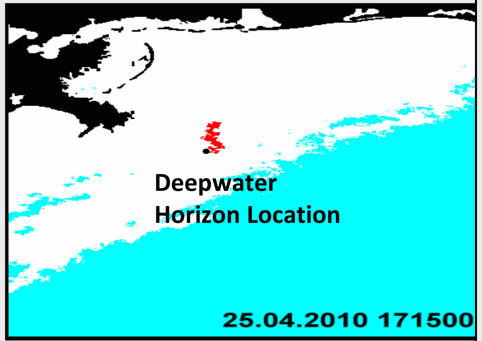
e.g.Libia 13 May 2004



Dust clouds

Oil spills

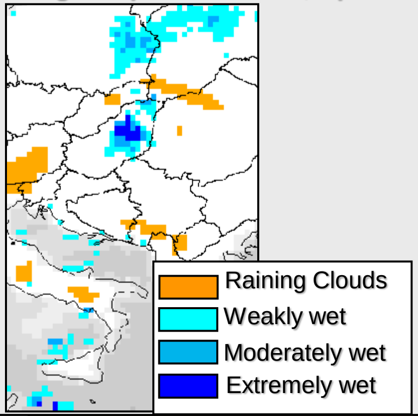
e.g. Oil spill in the Mexico Gulf, April 2010



Oil spill

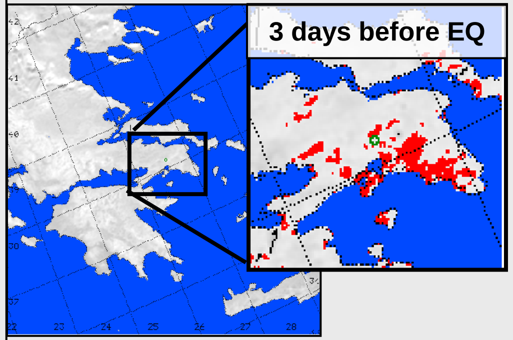
Soil wetness

e.g. Carpathian Basin, April 2000



Earthquakes

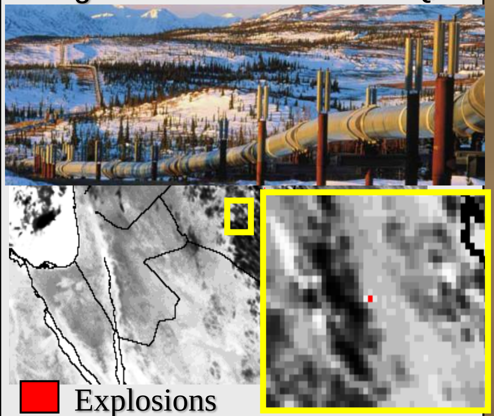
e.g. 7 September 1999 Athens Earthquake



Thermal anomalies

Infrastructures

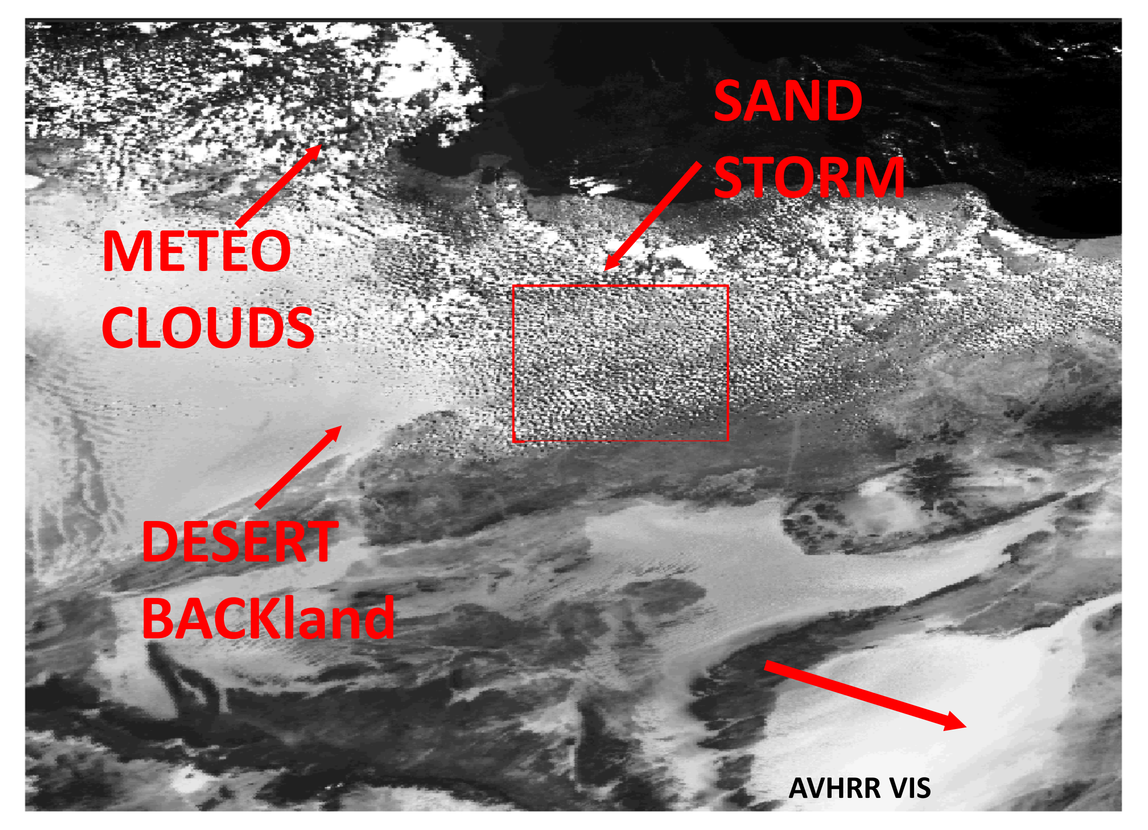
e.g. 18 October 2005 IRAQ



Explosions

Dust Storm Detection by RST

Compared with the background in (normal) clear-sky conditions both meteorological and dust clouds are characterized by:

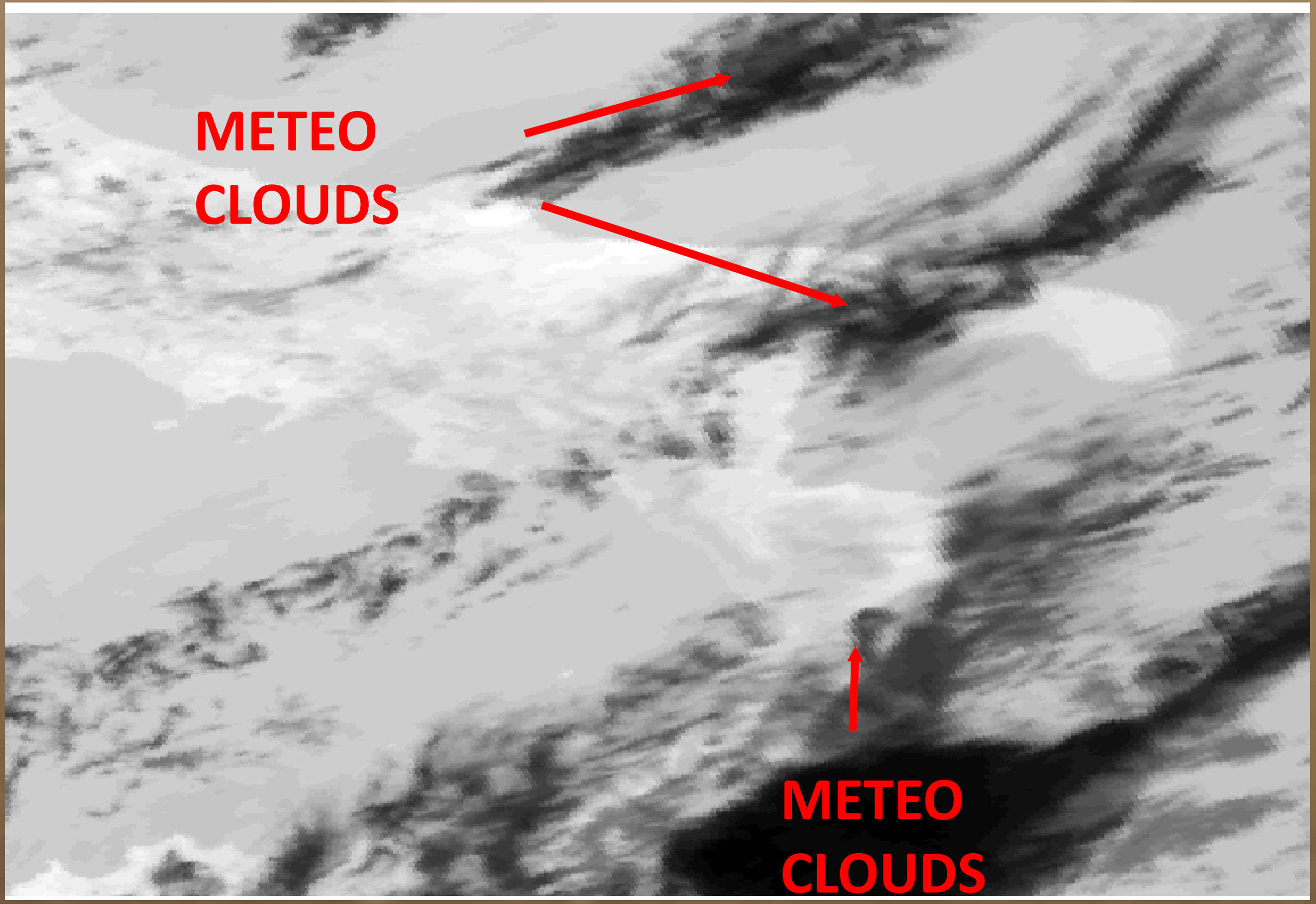


higher VIS reflectance

$$\otimes_V(x,y,t) = \frac{VIS(x,y,t) - VIS_{REF}(x,y)}{\sigma_{VIS}(x,y)}$$

Dust Storm Detection by RST

Compared with the background in (normal) clear-sky conditions both meteorological and dust clouds are characterized by:



higher VIS reflectance

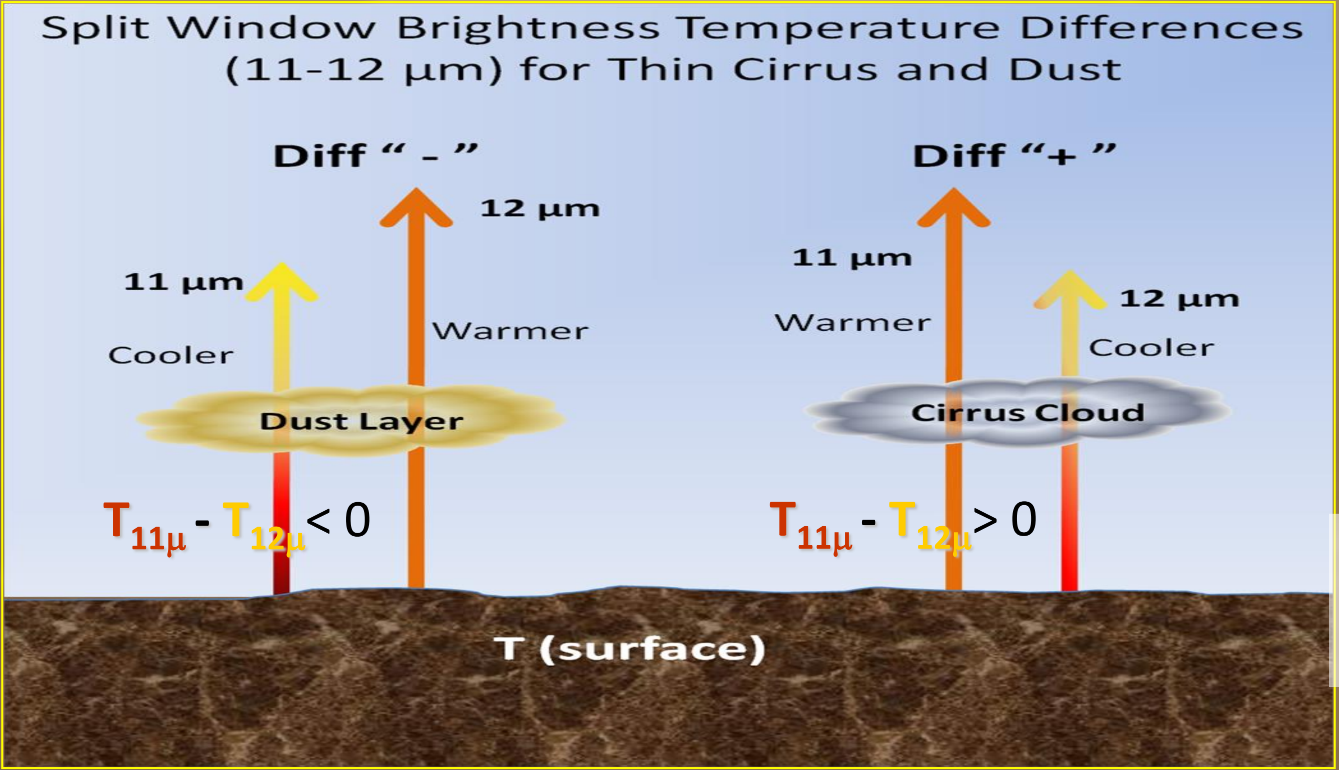
$$\otimes_V\ (x,y,t) = \frac{VIS(x,y,t) - VIS_{REF}(x,y)}{\sigma_{VIS}(x,y)}$$

lower brightness temperatures

$$\otimes_{TIR}\ (x,y,t) = \frac{TIR(x,y,t) - \mu_{TIR}(x,y)}{\sigma_{TIR}(x,y)}$$

Dust Storm Detection by RST

Compared with the background in (normal) clear-sky conditions both meteorological and dust clouds are characterized by:



higher VIS reflectance

$$\otimes_V (x,y,t) = \frac{VIS(x,y,t) - VIS_{REF}(x,y)}{\sigma_{VIS}(x,y)}$$

lower brightness temperatures

$$\otimes_{TIR} (x,y,t) = \frac{TIR(x,y,t) - \mu_{TIR}(x,y)}{\sigma_{TIR}(x,y)}$$

$$\otimes_{\Delta T} (x,y,t) = \frac{\Delta T(x,y,t) - \mu_{\Delta T}(x,y)}{\sigma_{\Delta T}(x,y)}$$

but they can be discriminated
by using the BTD signature $\Delta T = T_{11\mu} - T_{12\mu}$

Dust Storm Detection by RST

(RST$_{DUST}$ Sannazzaro et al., Acta Astronautica93(2014) 64–70)

$$\otimes_{VIS}(\mathbf{r},t') \equiv \frac{\lfloor VIS(\mathbf{r},t') - \mu_{VIS}(\mathbf{r}) \rfloor}{\sigma_{VIS}(\mathbf{r})}$$

&

$$\otimes_{TIR}(\mathbf{r},t') \equiv \frac{\lfloor TIR(\mathbf{r},t') - \mu_{TIR}(\mathbf{r}) \rfloor}{\sigma_{TIR}(\mathbf{r})}$$

&

$$\otimes_{\Delta T}(\mathbf{r},t') \equiv \frac{\lfloor \Delta T(\mathbf{r},t') - \mu_{\Delta T}(\mathbf{r}) \rfloor}{\sigma_{\Delta T}(\mathbf{r})}$$

Detecting Clouds (VIS and TIR)

Discriminating dust-clouds from meteorological clouds (ΔT)

RST_{DUST} application to the event of May 2008:

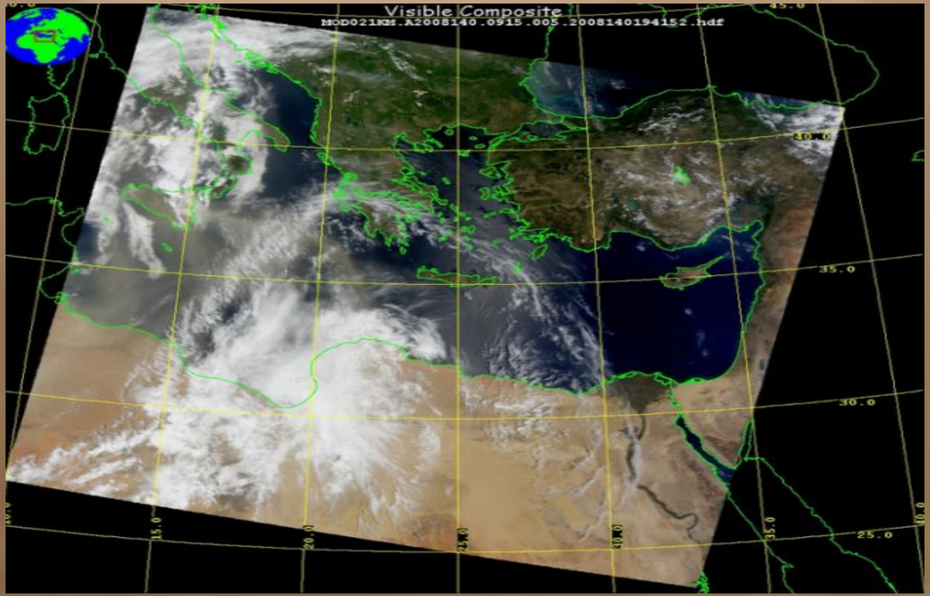
comparison with fixed threshold methods

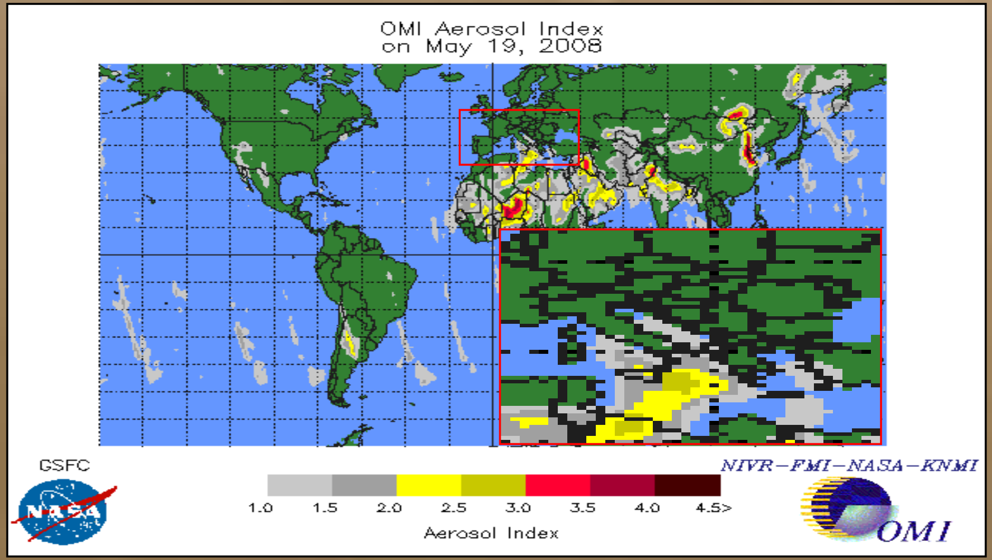
and

with independent aerosol products (validation)

Saharan dust event of 18-23 May 2008

During 18-23 May 2008 a massive Saharan dust load coming from Algeria and Tunisia moved towards Europe diffusing over Greece.





- On 18 May, Italy and Central Europe were the regions more affected by dust.

- From 19 May also the Eastern Europe was involved by dust.

- On 20 May the Saharan dust event was more intense over Greece, where it reached a value of dust loading estimated at around 0.75 g/m^2 (Amiridis, et al., 2009).

SEVIRI satellite data

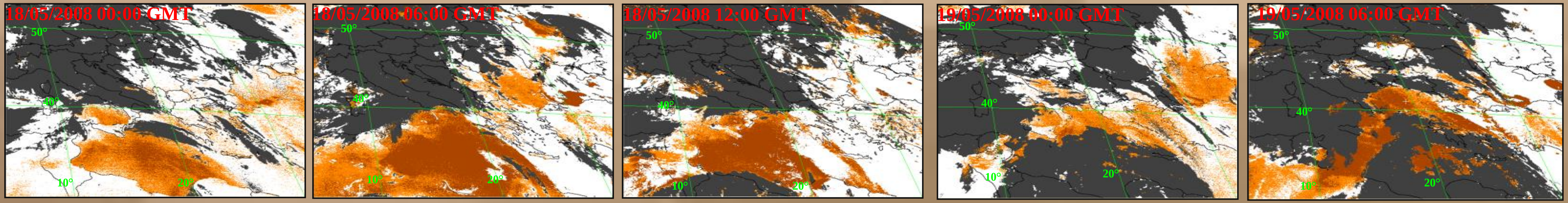
Spinning Enhanced Visible and InfraRed Imager (**SEVIRI**) is on board the Meteosat Second Generation (**MSG**) platform

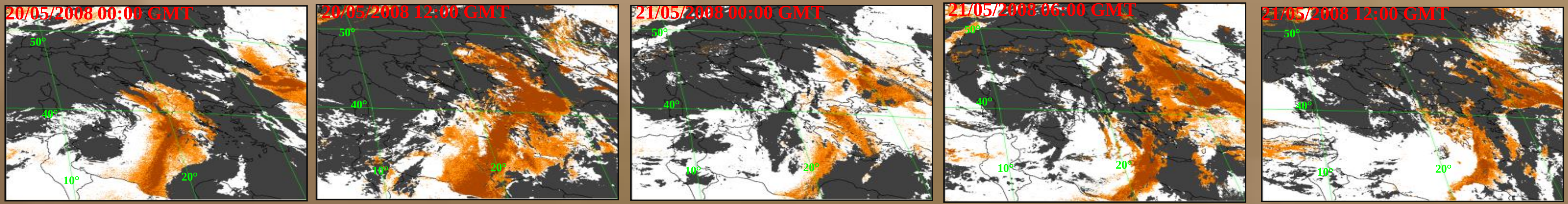
Channel no.		Characteristics of spectral band (μm)			Main gaseous absorber or window
		λ_{cen}	λ_{min}	λ_{max}	
1	VIS0.6	0.635	0.56	0.71	Window
2	VIS0.8	0.81	0.74	0.88	Window
3	NIR1.6	1.64	1.50	1.78	Window
4	IR3.9	3.90	3.48	4.36	Window
5	WV6.2	6.25	5.35	7.15	Water vapor
6	WV7.3	7.35	6.85	7.85	Water vapor
7	IR8.7	8.70	8.30	9.10	Window
8	IR9.7	9.66	9.38	9.94	Ozone
9	IR10.8	10.80	9.80	11.80	Window
10	IR12.0	12.00	11.00	13.00	Window
11	IR13.4	13.40	12.40	14.40	Carbon dioxide
12	HRV	Broadband (about 0.4 – 1.1)			Window/water vapor

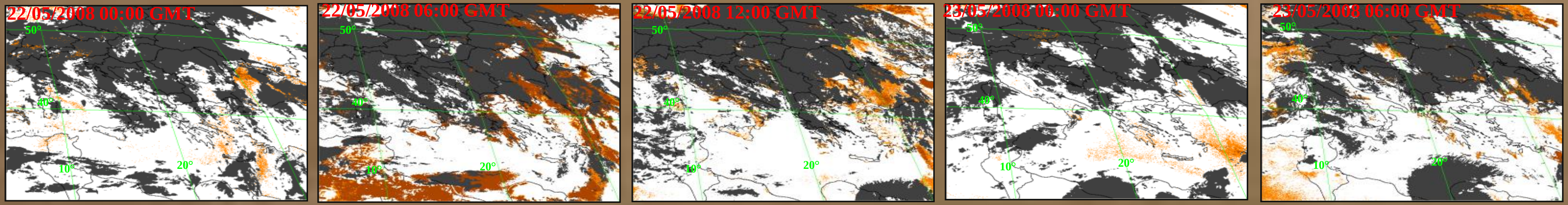
Repeat cycle: *15 min*

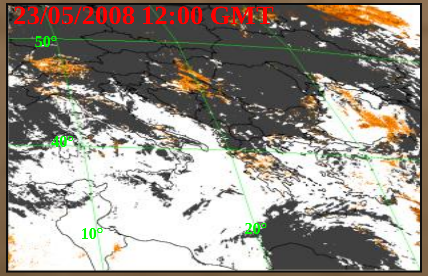
Spatial resolution (sub-satellite point): *3×3 Km^2 (1×1 Km^2 HRV)*

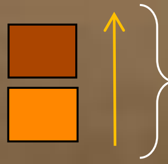
Space-time evolution of dust outbreak of 18-23 May 2008 detected by RST_{DUST} on SEVIRI data











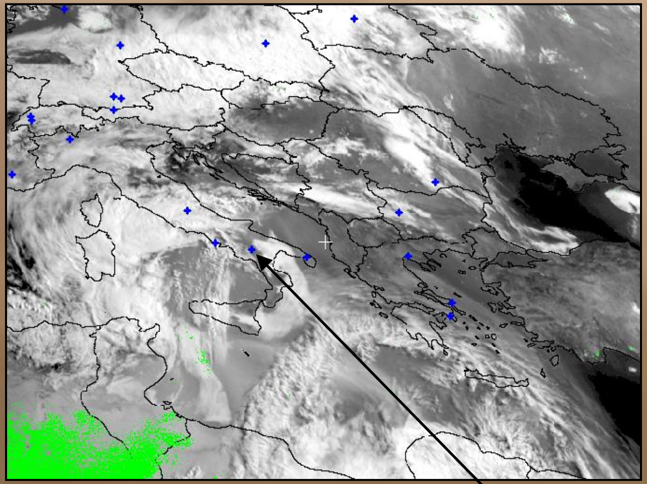
probability of dust presence in the atmosphere

RST-DUST maps reporting dynamic evolution (at six hours) of dust event which affected Mediterranean basin in May 2008

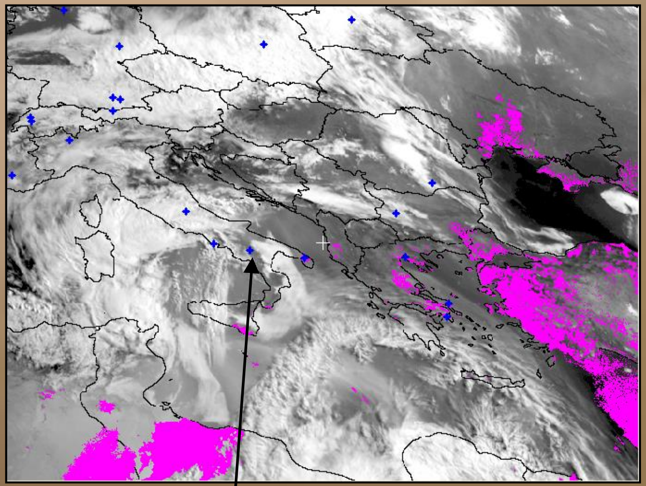
Comparison with fixed-threshold methods

19/05/2008 06:00 UTC

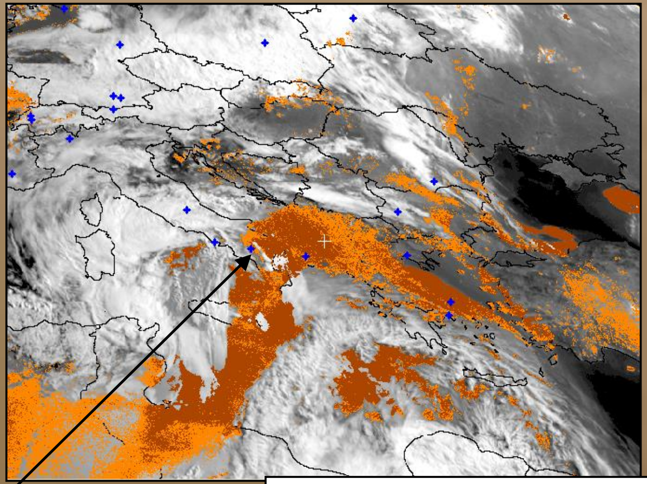
Gu et al. (2003)



Luo et al. (2003)

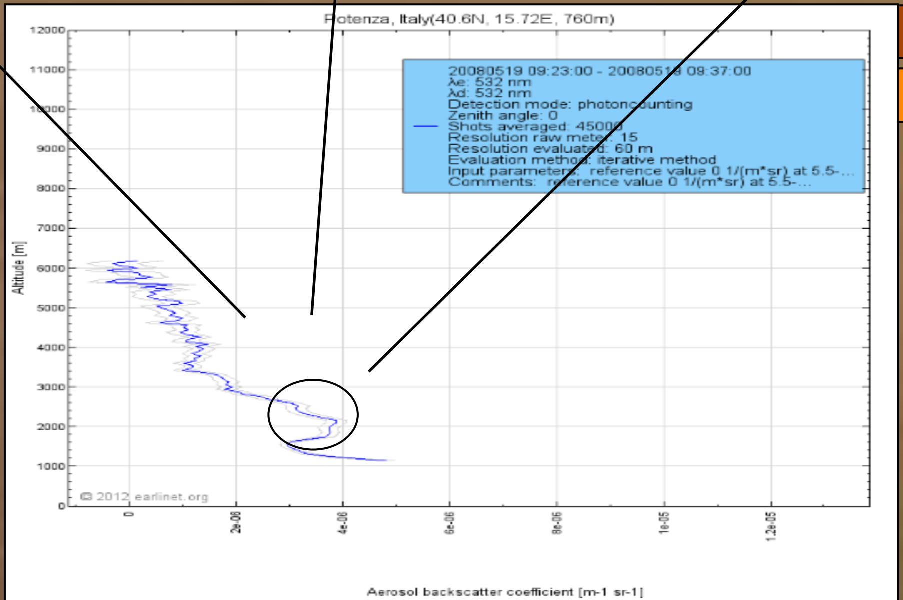


RST_{DUST}

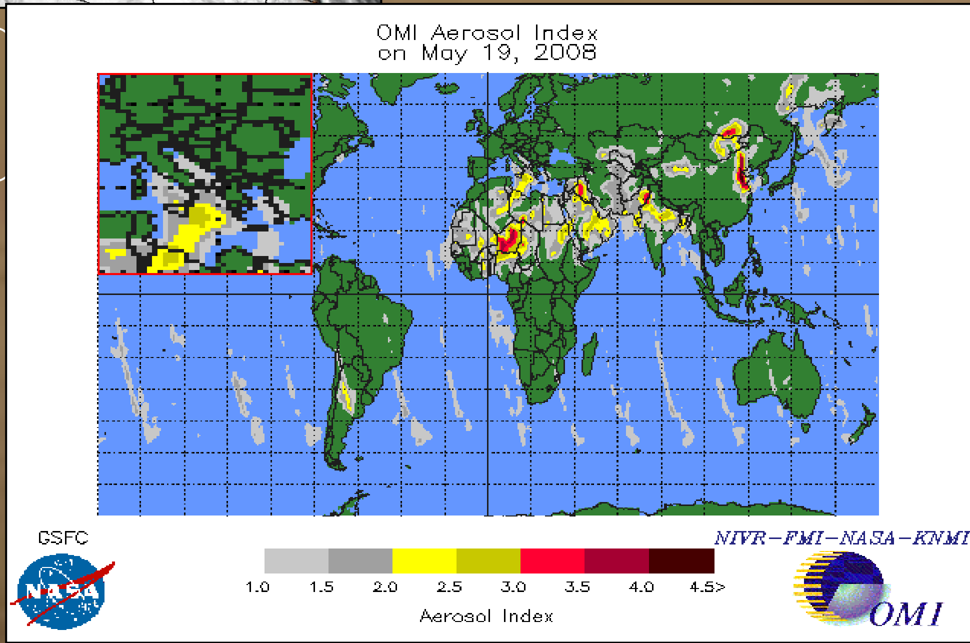


ΔT < -0.5k

OMI Aerosol index indicates the presence of dust



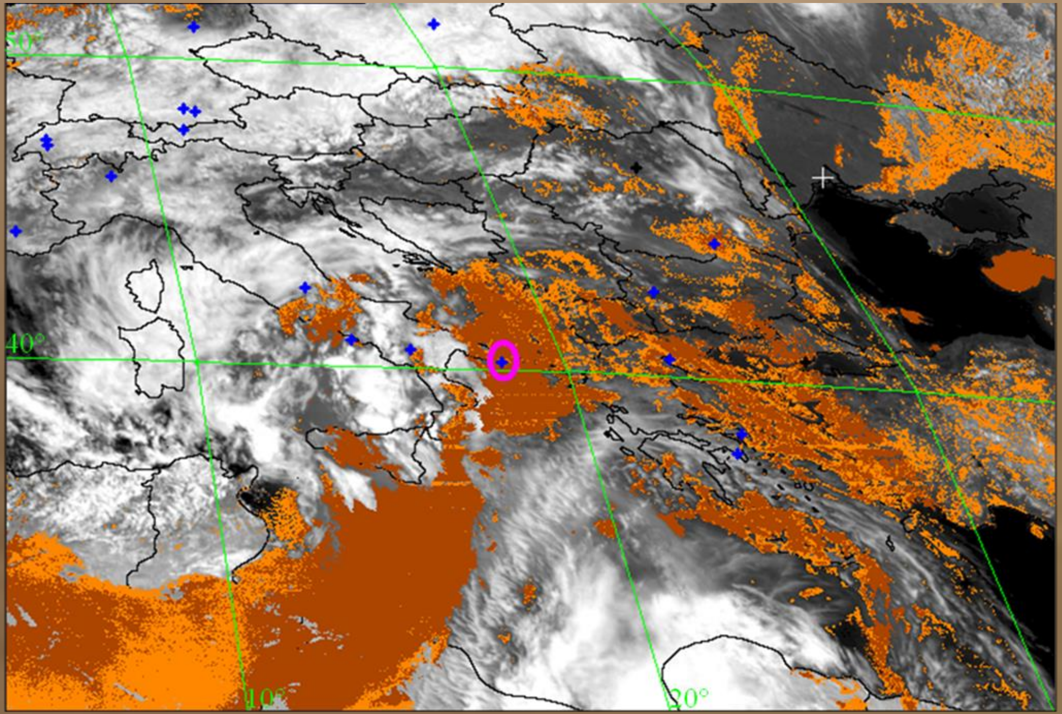
POTENZA EARLINET station indicates the presence of dust



Comparison with independent satellite-based aerosol products

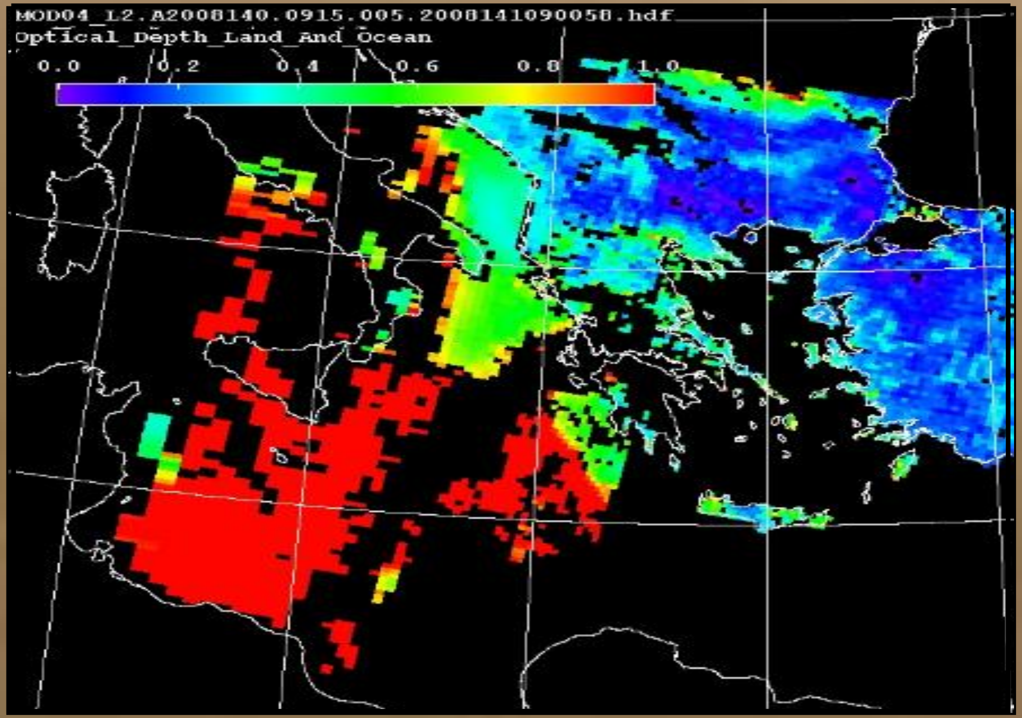
19/05/2008 at 09:15 UTC

RST_{DUST}



probability of dust presence in the atmosphere

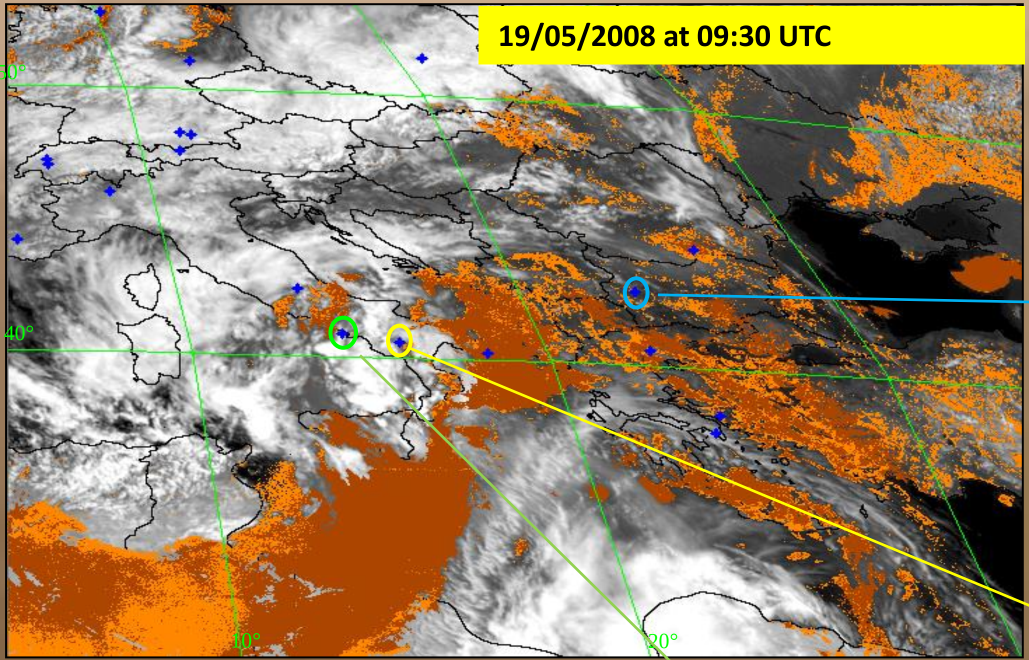
Terra-MODIS AOD product

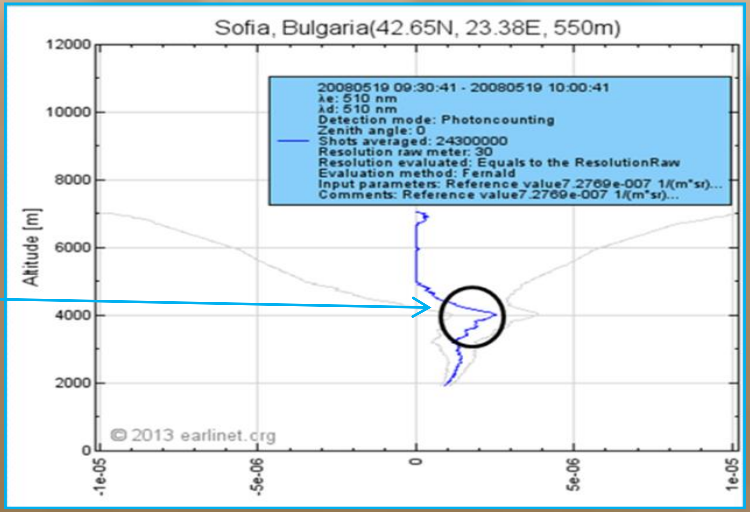


(10 km spatial resolution)

http://ladsweb.nascom.nasa.gov/data/search.html

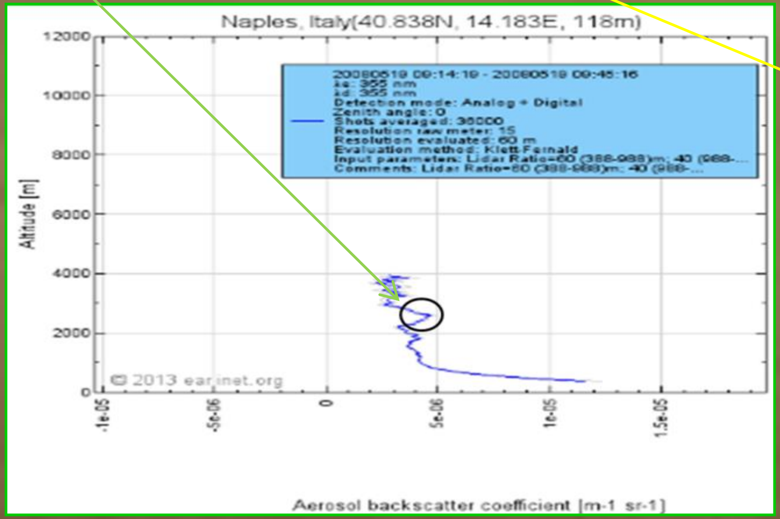
Assessment of RST_{DUST} products by means of ground-based lidar profiles (EARLINET data)

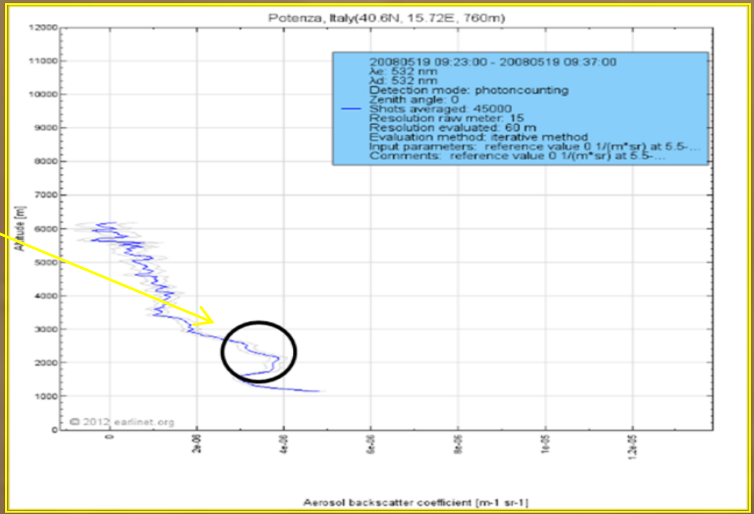




Sofia: 43.65 N, 23.38 E

probability of dust presence in the atmosphere



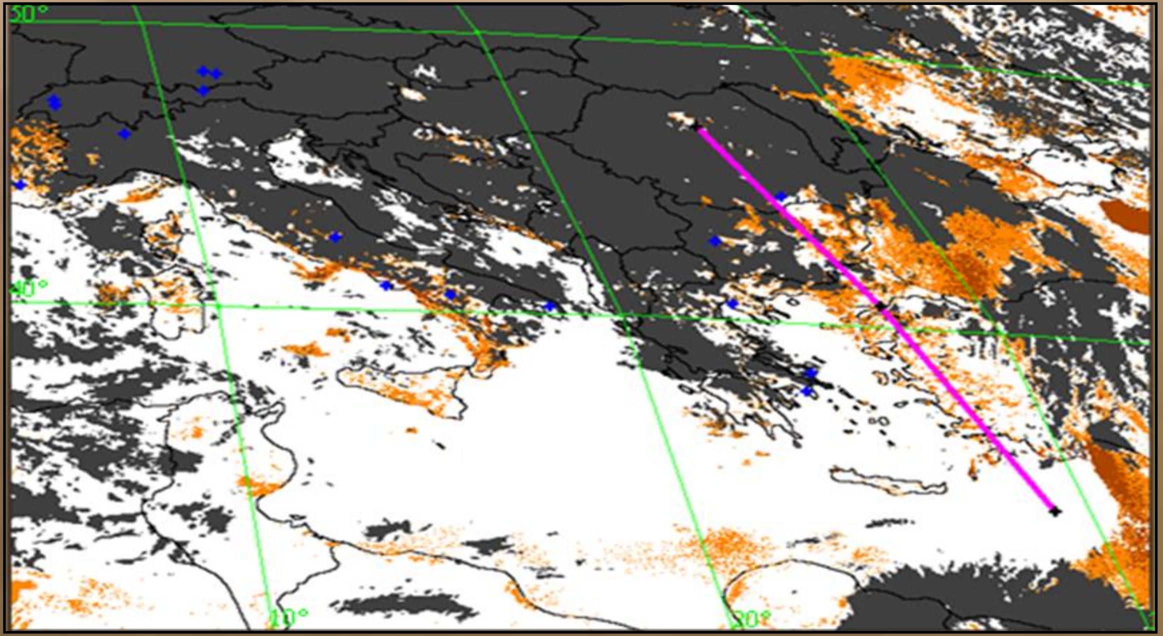


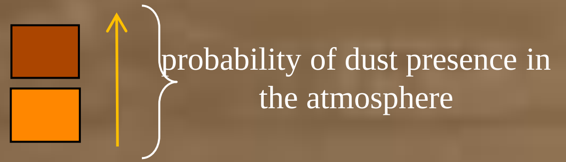
Potenza: 40.6 N, 15.72 E

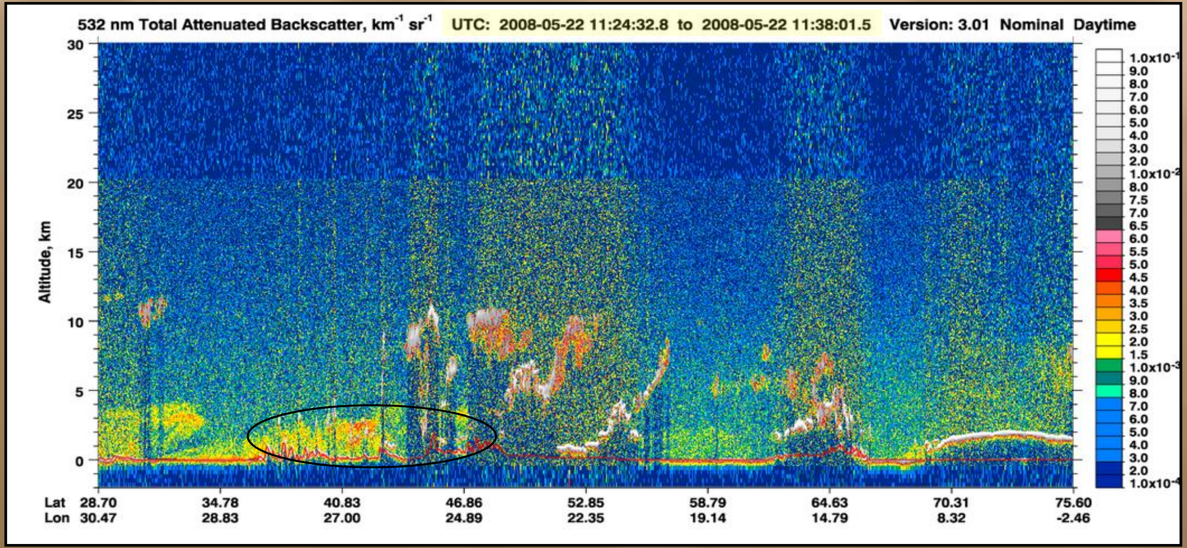
Naples: 40.83 N, 14.18 E

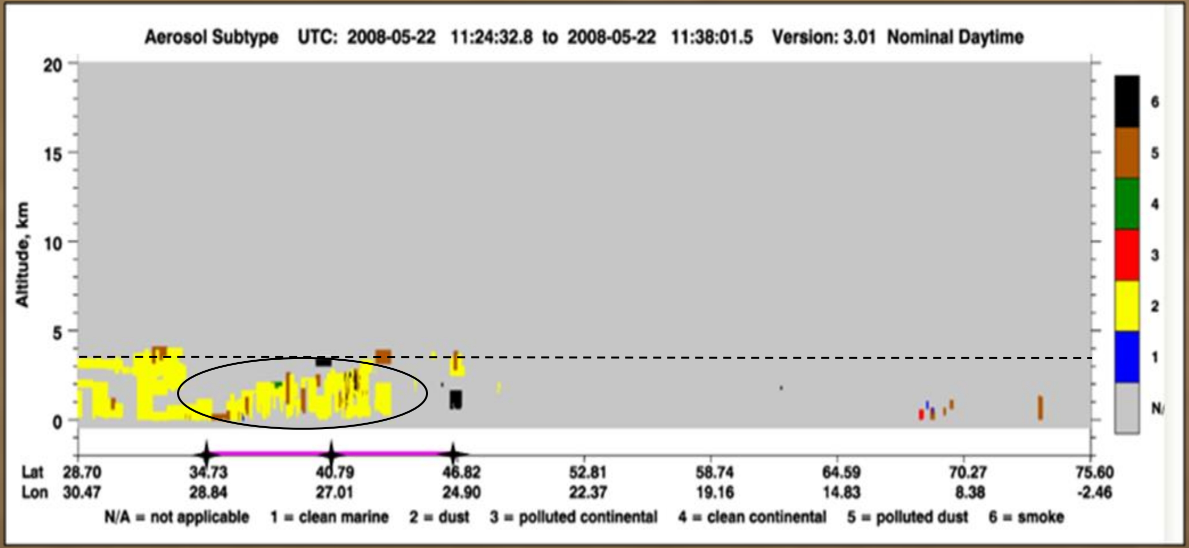
Assessment of RST_{DUST} products by means of CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarization) data

RST-DUST 22/05/2008 at 11:30 UTC





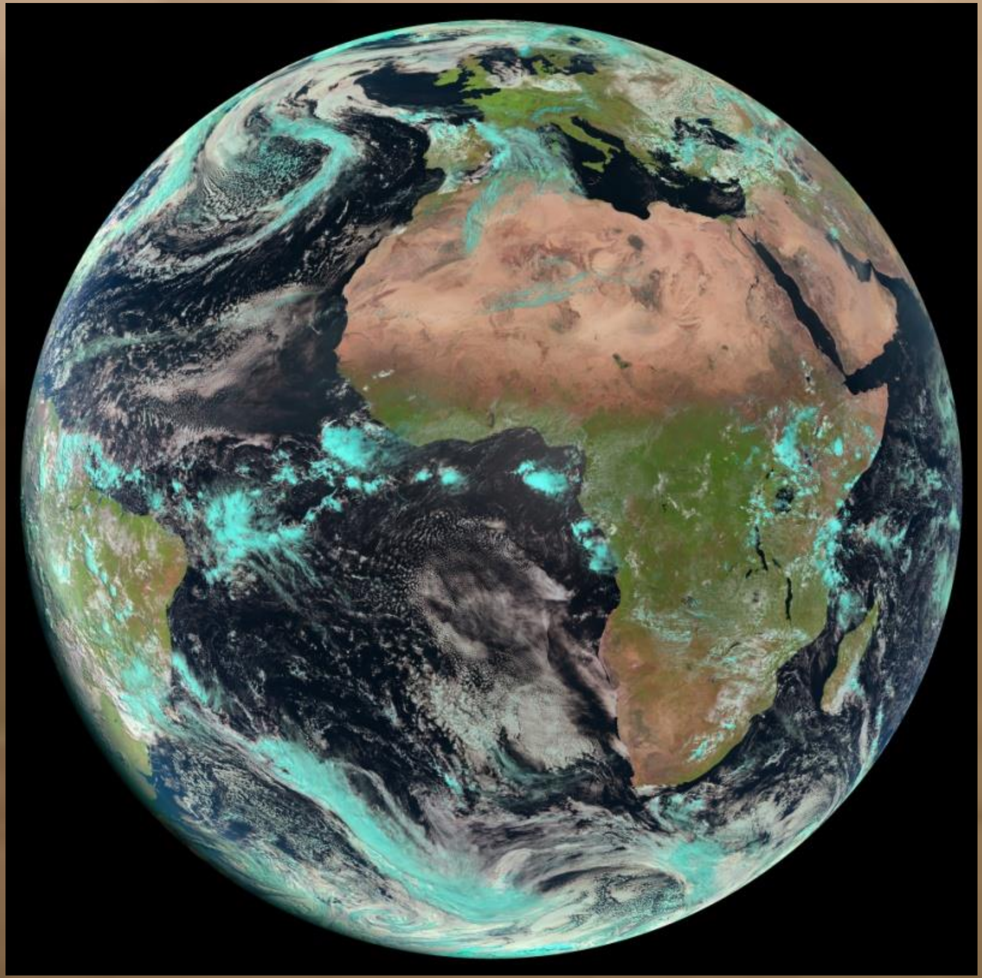




http://www-calipso.larc.nasa.gov/products/lidar/browse_images/production/

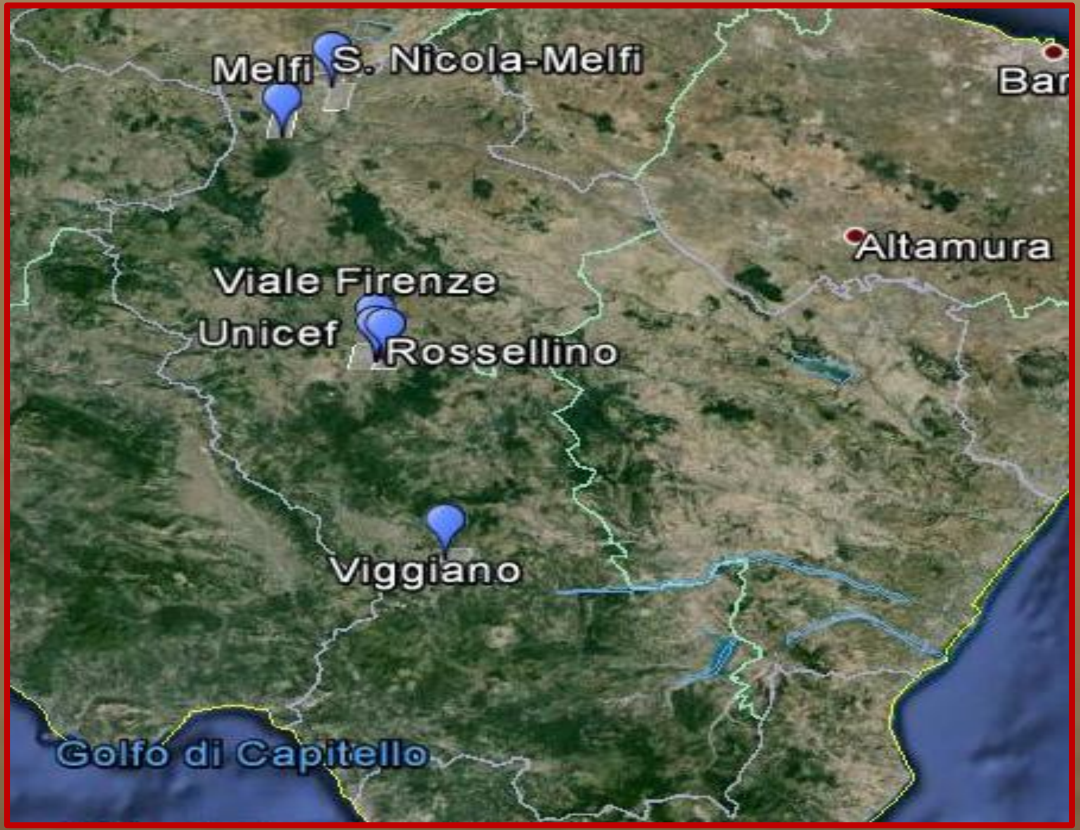
Integration of the RST_{DUST} satellite products and PM_{10} ground measurements

Satellite and ground data used



MSG-SEVIRI

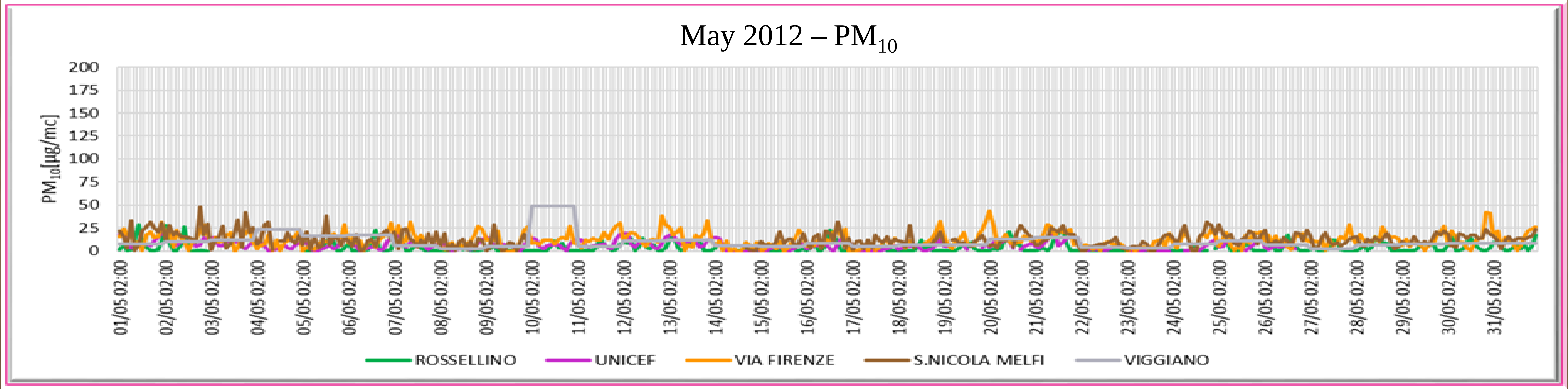
PM_{10} concentrations from ARPAB (Regional Environment Protection Agency of Basilicata) air quality monitoring ground stations



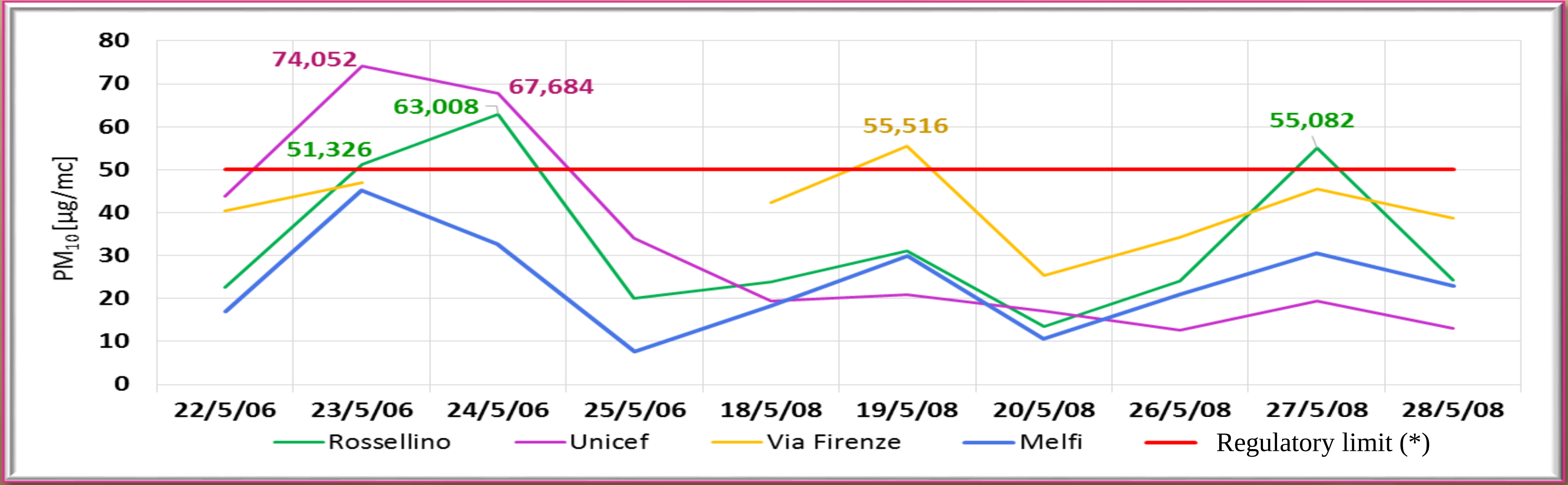
Time series of ARPAB ground PM_{10} concentrations

May 2006-2012

- ✓**Bihourly measurement**: air monitoring stations in **Rossellino**, **V. Unicef**, **V. Firenze**, **Melfi**, **S. Nicola-Melfi**
- ✓**Daily measurement:** air monitoring station in **Viggiano**



PM_{10} exceedances (May 2006, May 2008)



Exceedance day	Monitoring station	PM_{10} concentrations [µg/m^3]
23 May 2006	Rossellino	51,326
23 May 2006	V. Unicef	74,052
24 May 2006	Rossellino	63,008
24 May 2006	V. Unicef	67,684
19 May 2008	V. Firenze	55,516
27 May 2008	Rossellino	55,082

*Daily limit 50 µg/m^3 (Dir 2008/50/CE)

Quantifying natural contribution in PM_{10} (EC, 2011)

Methodology for the determination of re-suspended and transported Saharan dust

1. Identifying Saharan dust outbreak episodes (EC, 2011, suggests consultation of products such as dust-forecast models)

The use of **RST_{DUST} product** instead of forecast maps is expected to increase reliability of dust events detection

Exceedance day	Monitoring station	PM_{10} concentrations [μg/m^3]
23 May 2006	Rossellino	51,326
23 May 2006	V. Unicef	74,052
24 May 2006	Rossellino	63,008
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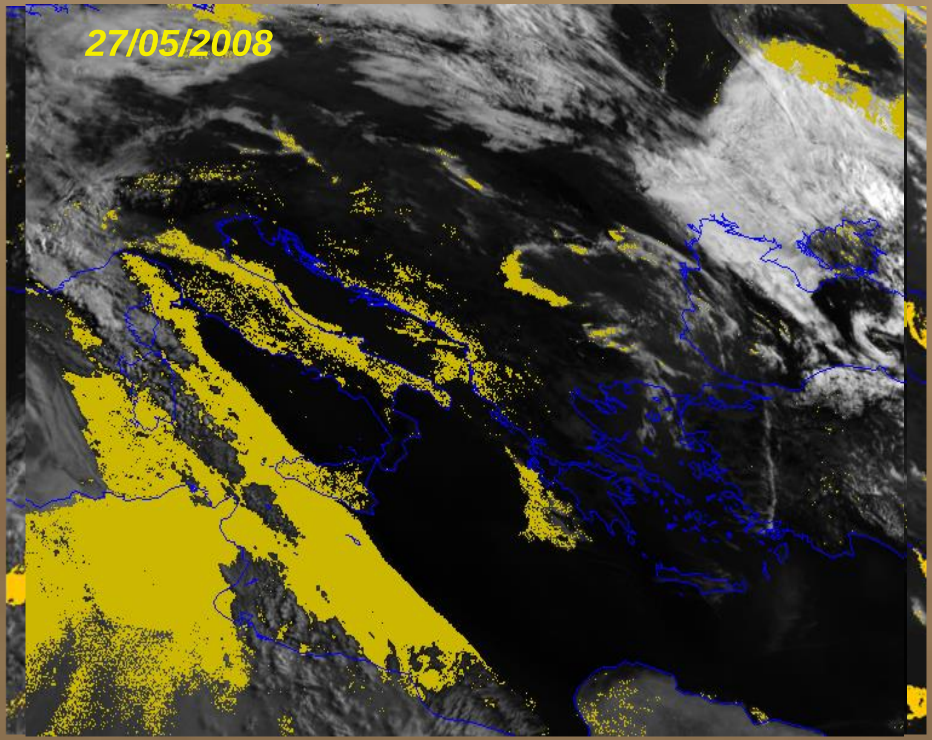
27 May 2008	Rossellino	55,082



EC (2011) - COMMISSION STAFF WORKING PAPER establishing guidelines for demonstration and subtraction of exceedances attributable to natural sources under the Directive 2008/50/EC on ambient air quality and cleaner air for Europe

Quantifying natural contribution in PM_{10} (EC, 2011)

Methodology for the determination of re-suspended and transported Saharan dust

1. Identifying Saharan dust outbreak episodes

2. Quantifying Saharan dust outbreak episodes

*Identification of the **regional background station***

Monitoring station in Melfi

Quantifying natural contribution in PM_{10} (EC, 2011)

Methodology for the determination of re-suspended and transported Saharan dust

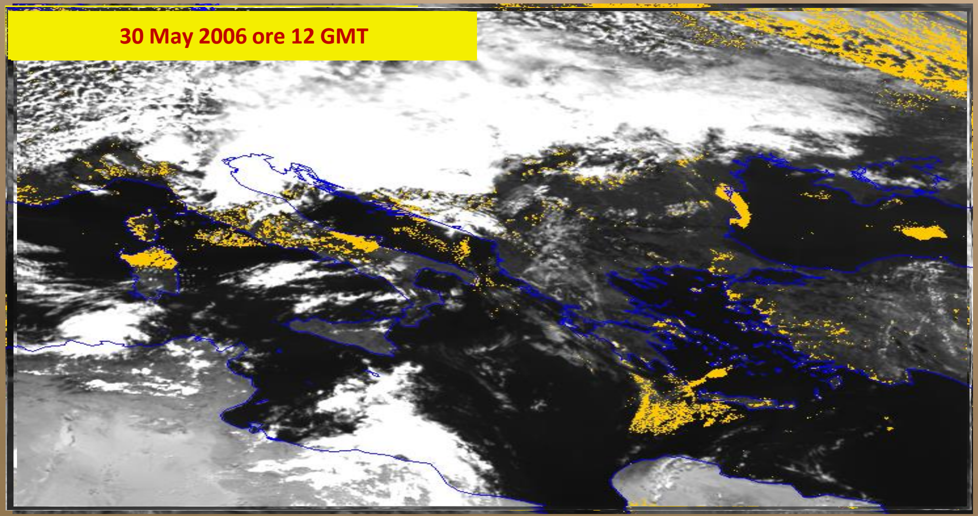
1. Identifying Saharan dust outbreak episodes

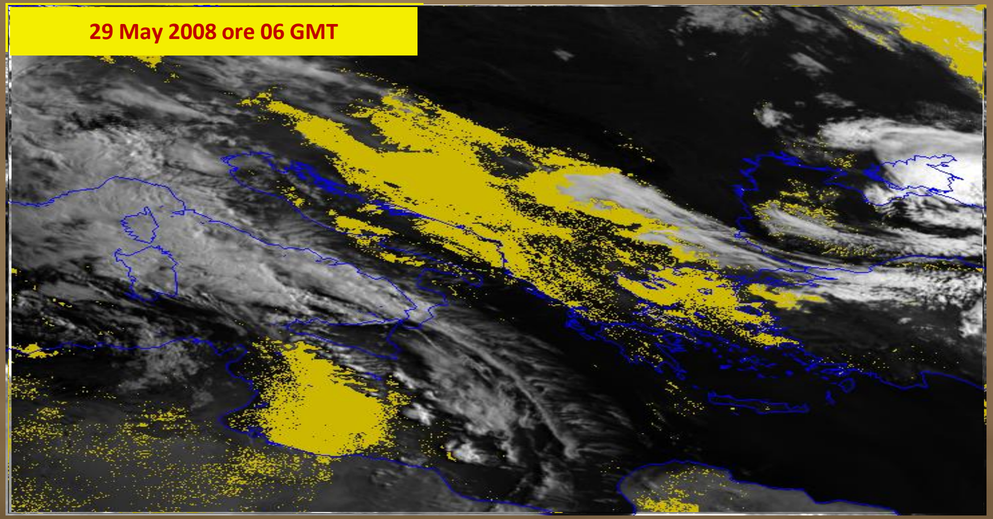
2. Quantifying Saharan dust outbreak episodes

*Computation of the **regional background level:***
in each time series of the regional background station, the monthly moving percentile 40 is determined for each day, excluding days with identified African influence.

Dust events in background station (identified by means of RST_{DUST})

02/05/2006
06/05/2006
07/05/2006
08/05/2006
12/05/2006
25/05/2006
30/05/2006
02/05/2008
11/05/2008
19/05/2008
22/05/2008
23/05/2008
26/05/2008
27/05/2008
28/05/2008
29/05/2008





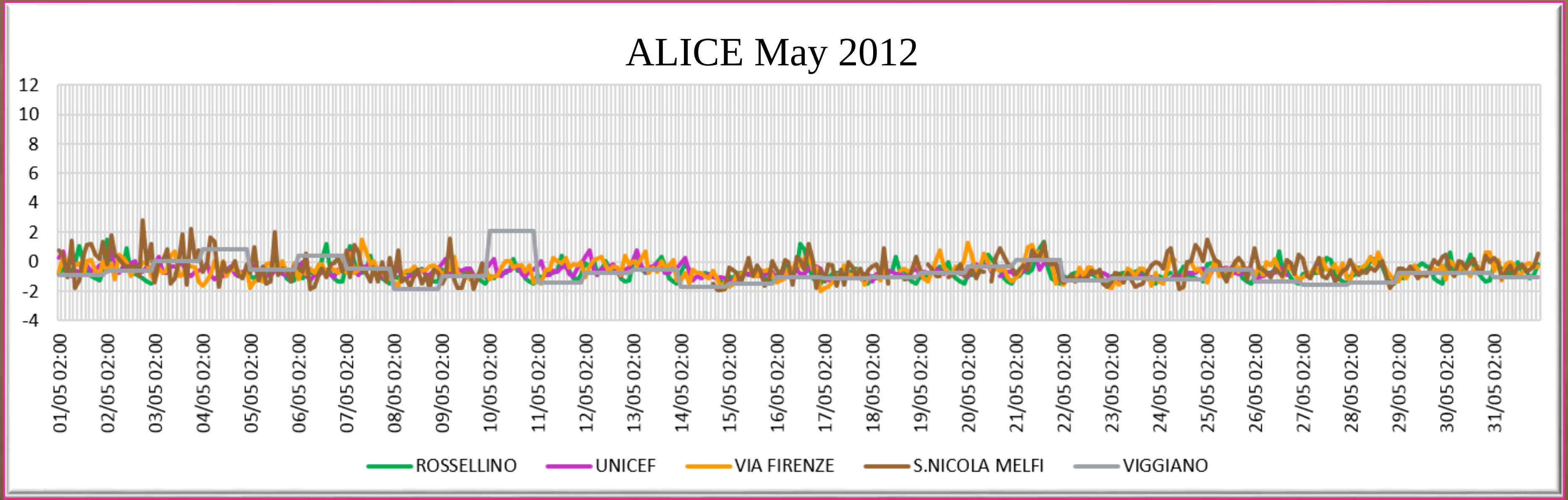
PM_{10} anomalies under exceedance limit

No PM_{10} threshold value has been identified below which there is NO observed damage to health

Importance of anomalous PM_{10} concentrations even if regulatory daily limit is not exceeded

RST approach to identify anomalous PM_{10} values

$$\otimes_{PM_{10}}(x,y,t) = \frac{\left[PM_{10}(x,y,t) - \mu_{PM_{10}}(x,y)\right]}{\sigma_{PM_{10}}(x,y)}$$



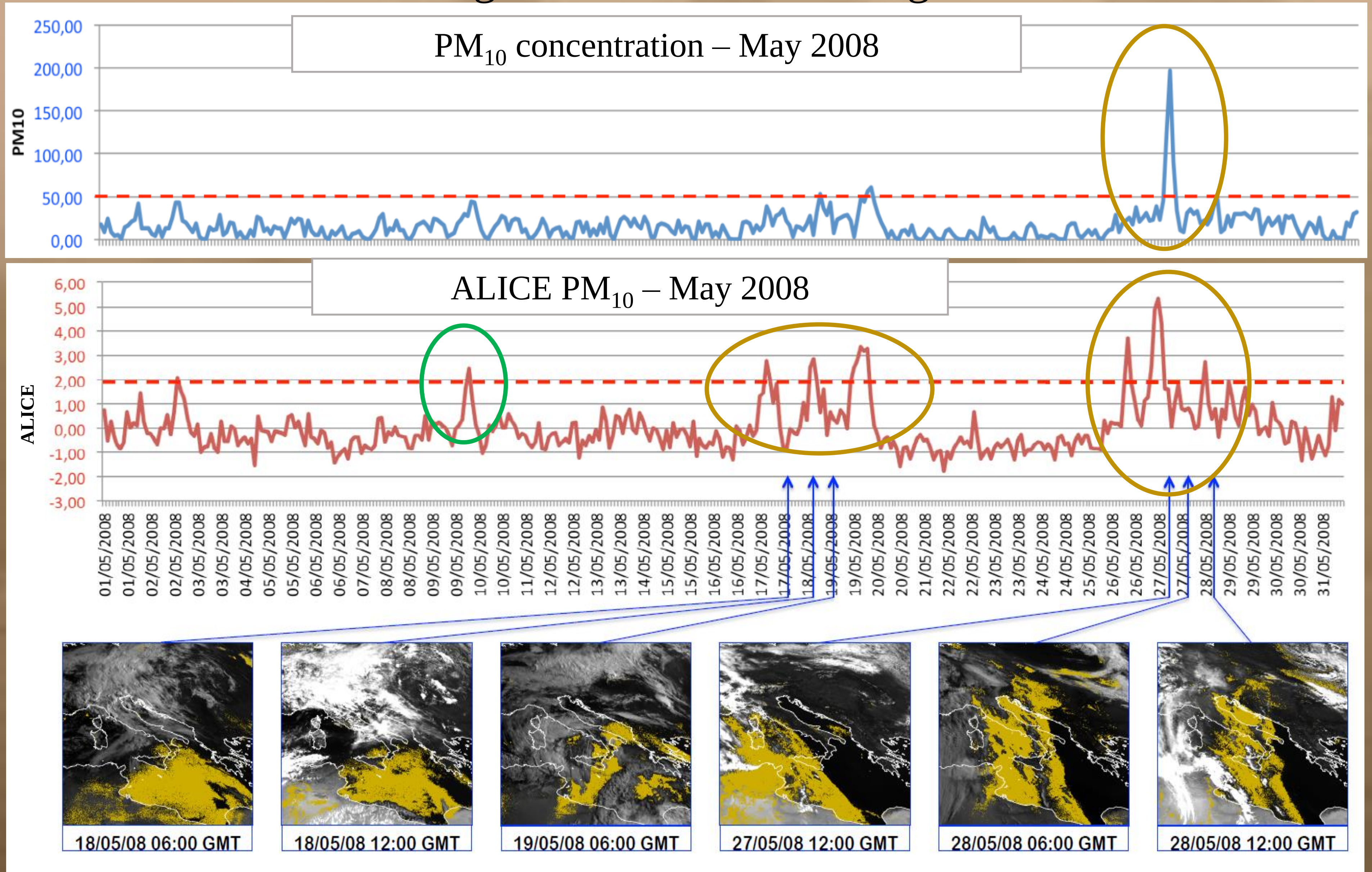
PM_{10} anomalies under exceedance limit

Over-threshold ($>50\mu g/m^3$) PM_{10} concentrations (due to dust contribution)

Under-threshold ($<50\mu g/m^3$) PM_{10} concentrations (due to dust contribution)

Under-threshold ($<50\mu g/m^3$) PM_{10} concentrations (probably due to anthropogenic contribution)

E.g. Rossellino monitoring station



Conclusions

The **RST_{DUST} algorithm** guarantees, in comparison with fixed threshold methodologies, **improved** performances both in terms of **reliability** (very low rate of false positives) and **sensitivity** (lower rate of missed identifications);

Being based only on satellite data at hand, RST_{DUST} is **intrinsically exportable** on whatever satellite sensor having VISible and TIR split-window capabilities

To quantify dust contribution, **RST_{DUST} maps were used instead of forecast maps**, as suggested by EC. This permitted us to recognize dust outbreaks with greater reliability

The **RST application to ground PM_{10} time-series permits us to identify anomalous PM_{10} concentrations under exceedance limit**. The comparison with RST_{DUST} products allows to **evaluate the source of such under-threshold anomalies (natural or anthropogenic source**).

1. **Airborne dust identification from space: a new, MSG/SEVIRI-based method for air quality assessment (valerio.tramutoli@unibas.it)**

Main References:

Marchese, F., F. Sannazzaro, A. Falconieri, C. Filizzola, N. Pergola, and V. Tramutoli (2017), An enhanced satellite-based algorithm for detecting and tracking dust outbreaks by means of SEVIRI data, Remote Sens., 9(6), 1–24, doi:10.3390/rs9060537.

Sannazzaro F, Pergola N, Corrado R, Filizzola C, Marchese F, Mazzeo G, Paciello R, Tramutoli V (2014). A New Approach for Detecting and Monitoring Saharan Dusts from Space. Geoinformatics & Geostatistics: An Overview S1. doi:10.4172/2327-4581.S1-019

Sannazzaro F, Filizzola C, Marchese F, Corrado R, Paciello R, Mazzeo G, Pergola N, Tramutoli V, (2013). Identification of dust outbreaks on infrared msg-seviri data by using a Robust Satellite Technique (RST). Acta Astronautica (ISSN:0094-5765). 93, pp. 64- 70.

Thank you