UNIVERSITÀ DEGLI STUDI DELLA BASILICATA

STAC SPACE TECHNOLOGIES AND APPLICATIONS CENTRE

Robust Satellite Techniques for real-time monitoring of natural, environmental and man-made hazards

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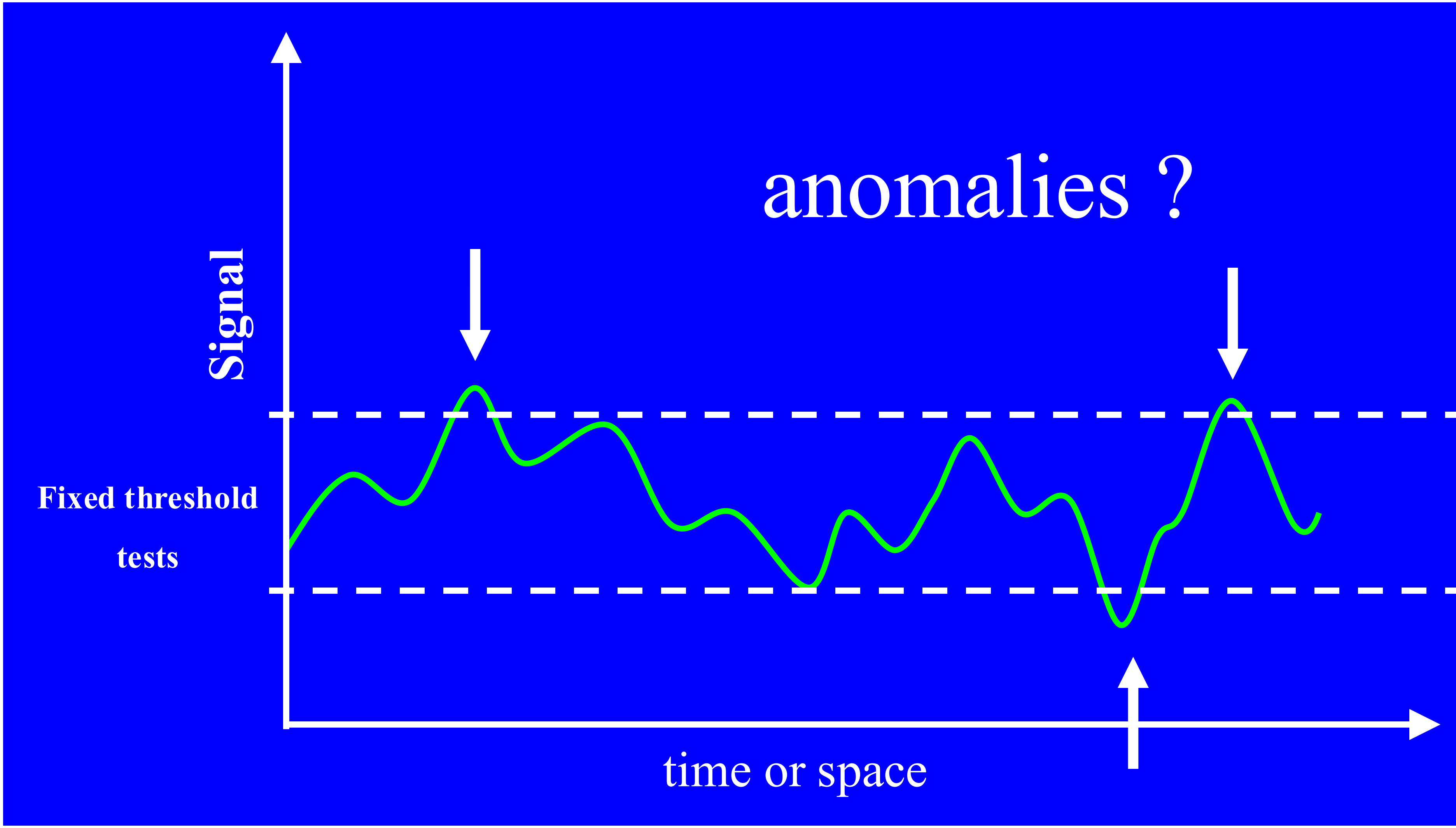
TECH4YOU The more you change, the less climate changes.
Finanziato dall'Unione europea NextGenerationEU
MUR Ministero dell'Università e della Ricerca
Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA

Change detection by traditional fixed-threshold approaches

Why they do not work ?



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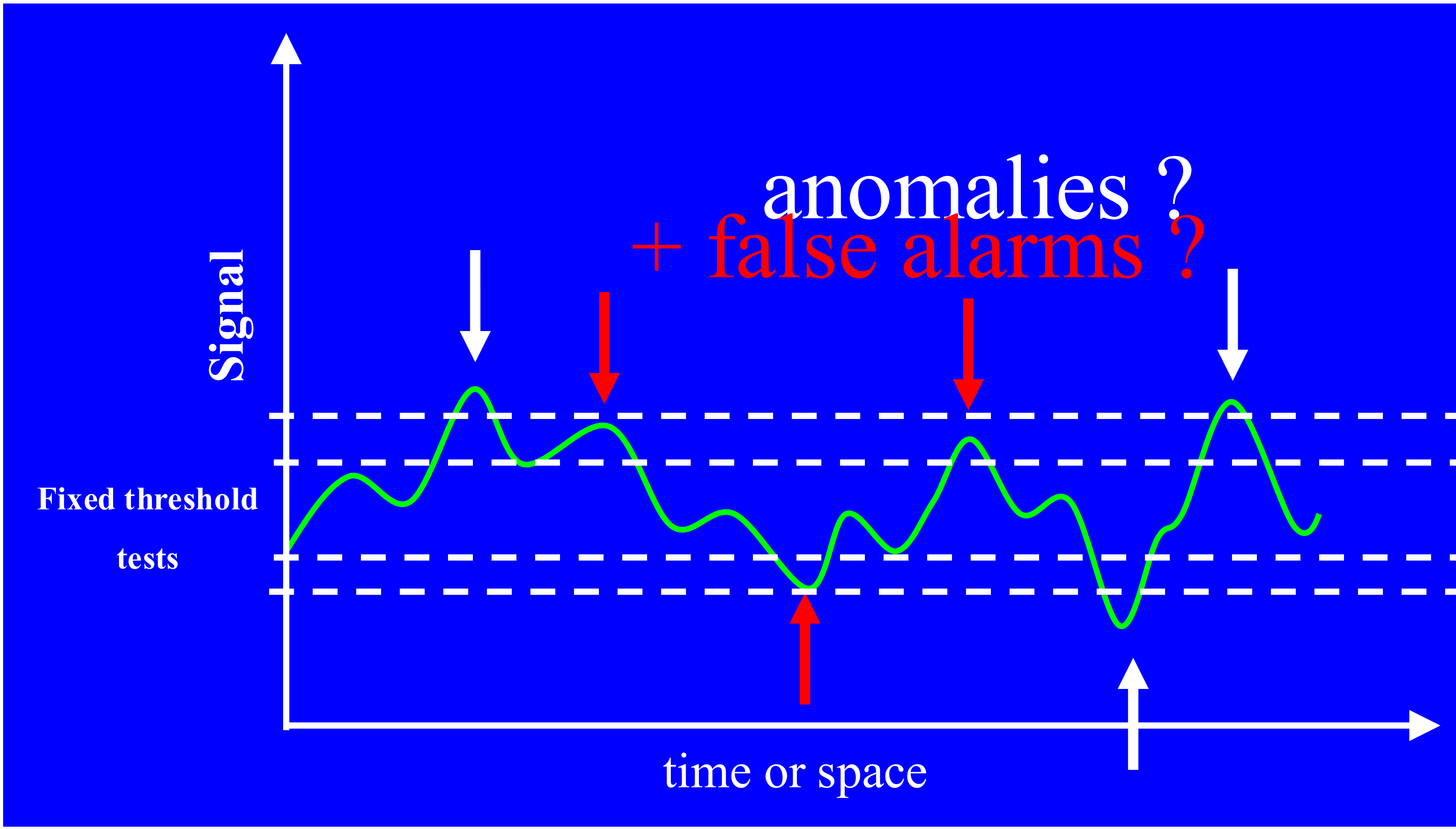

Change detection by traditional fixed-threshold approaches

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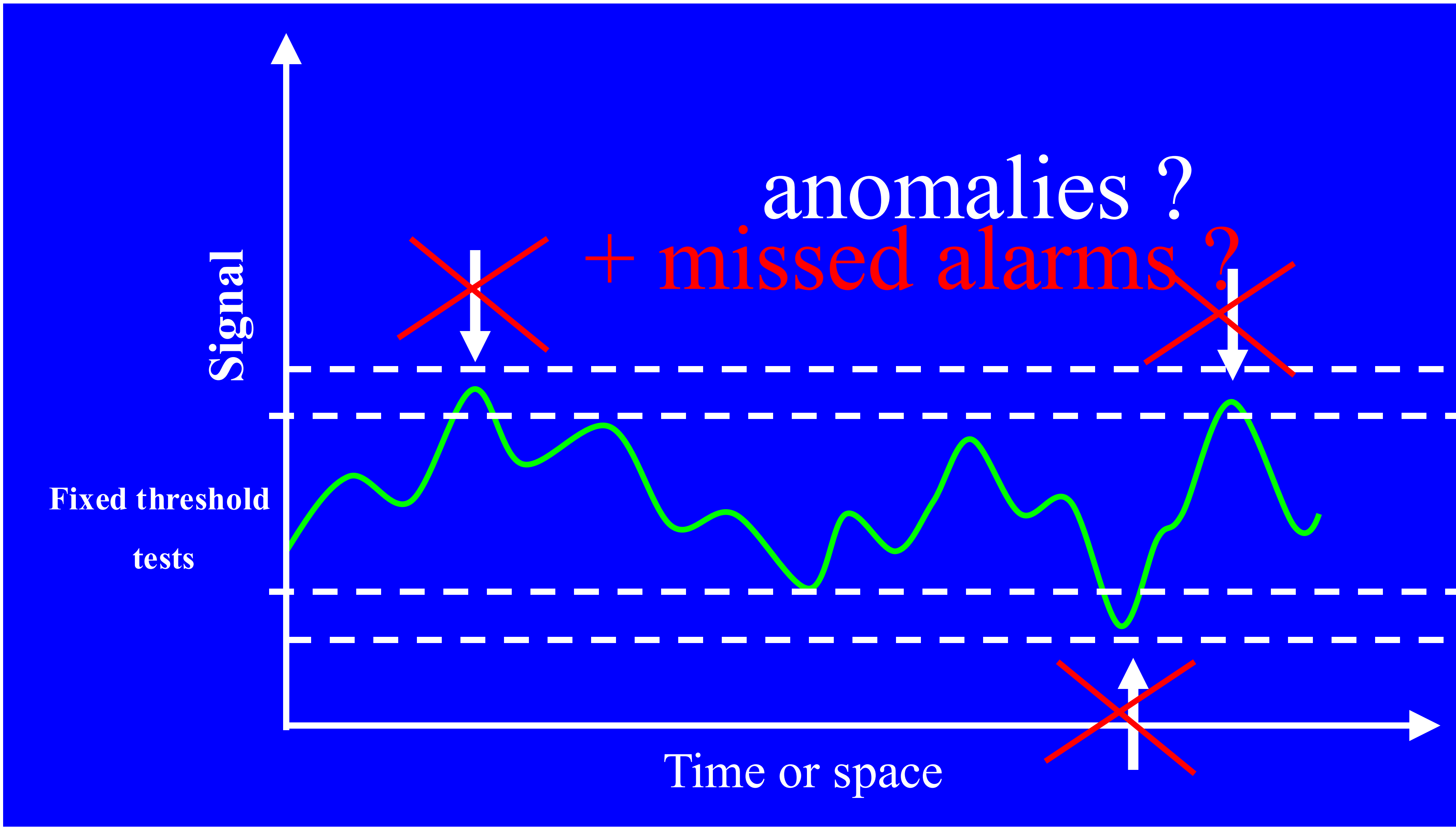
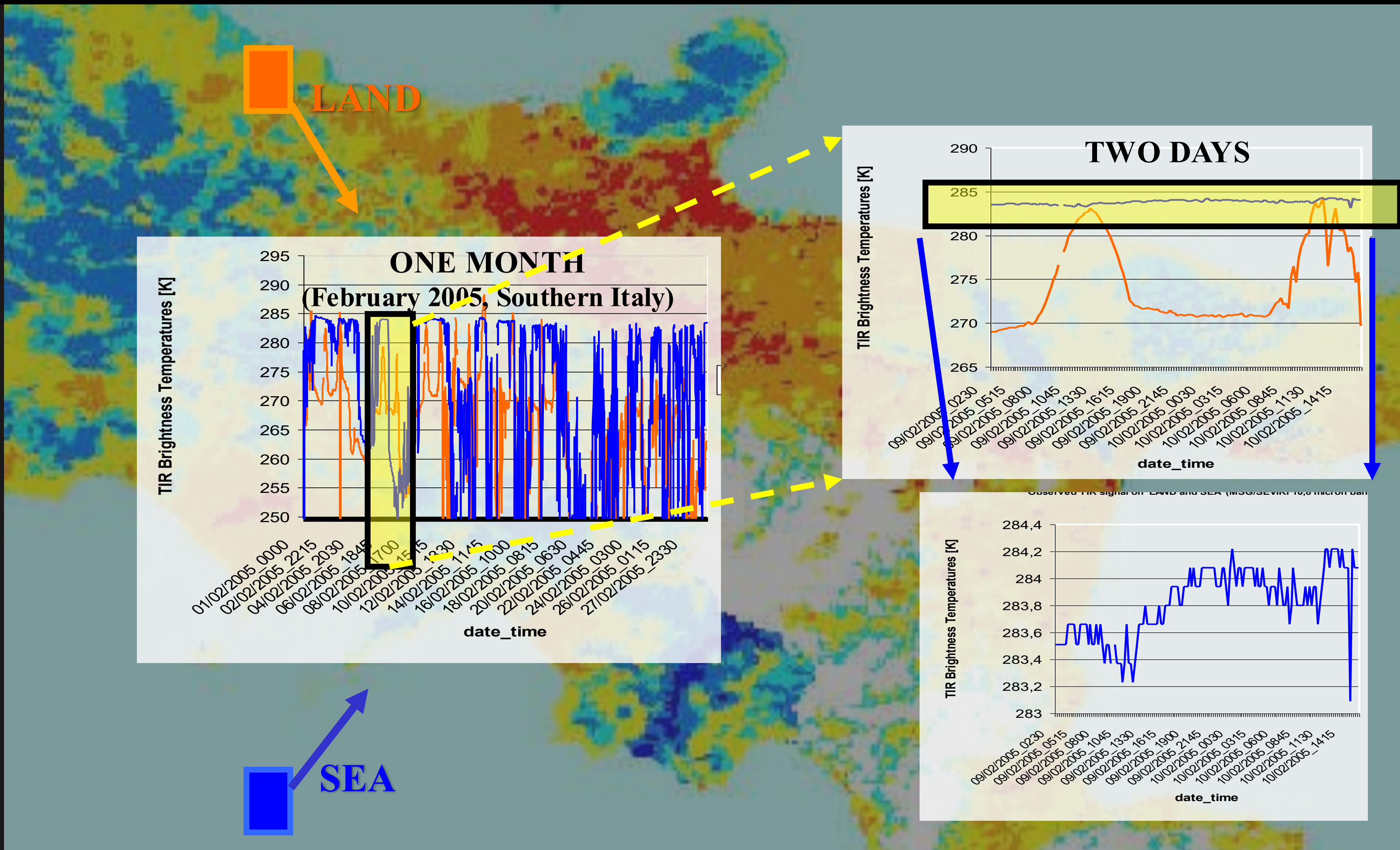


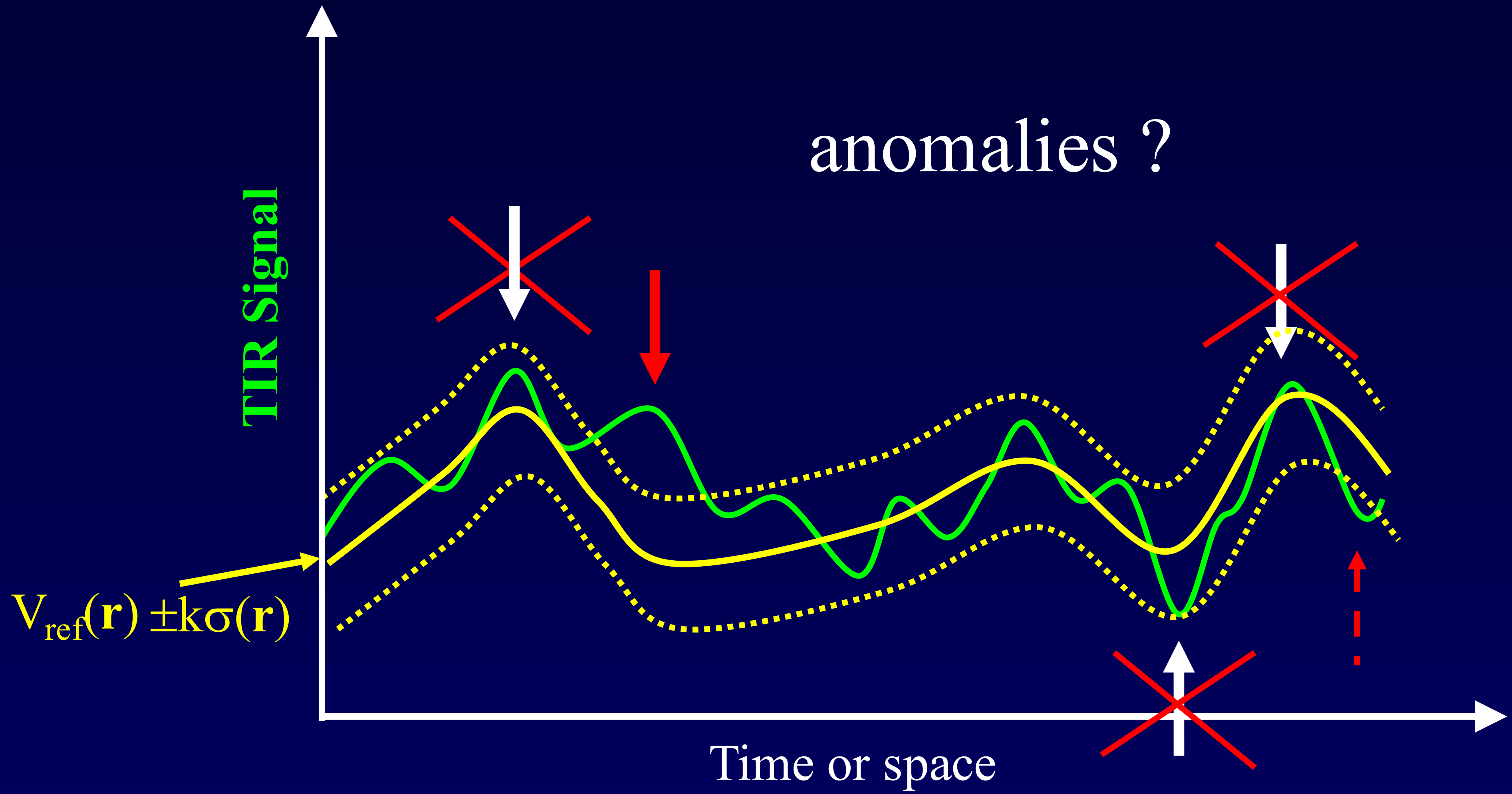
Signal temporal Dynamics

Example: TIR signal on LAND and SEA

(MSG/SEVIRI 10,8 micron band)



What "anomaly" means ?



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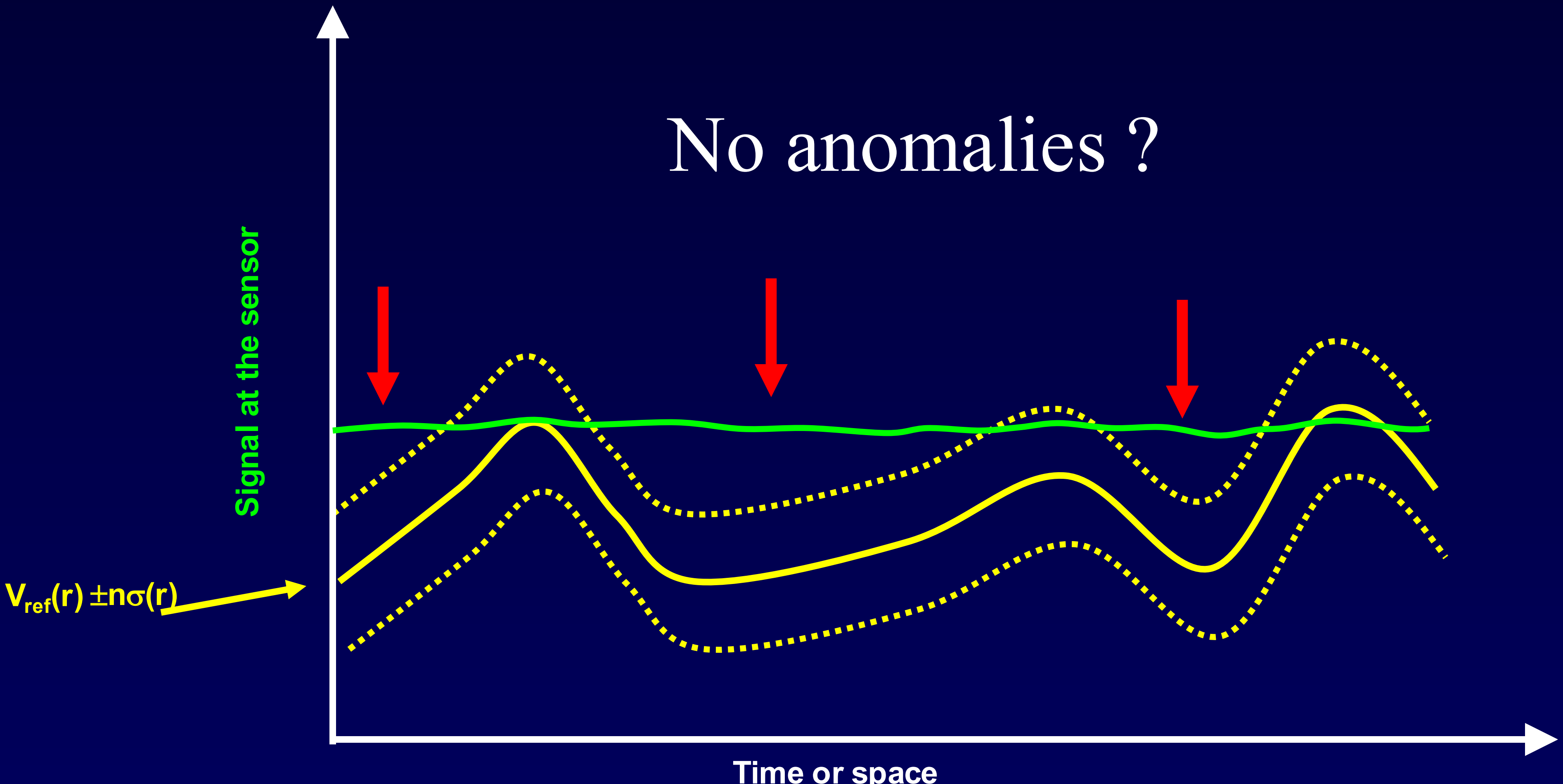
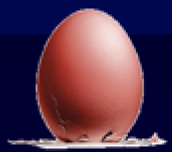
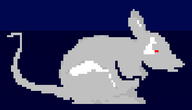
What "anomaly" means ?

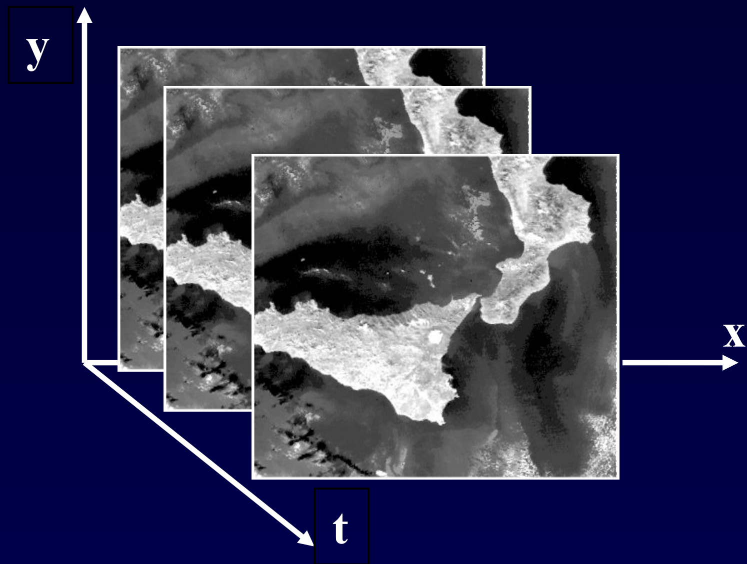




Robust Satellite Techniques (RST)



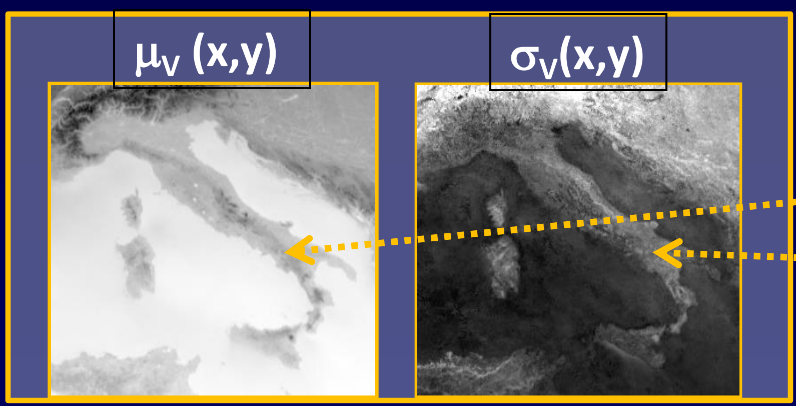
(formerly **RAT**: Robust AVHRR Techniques, *V.Tramutoli, 1998, 2005,2007*)



1. Selection of a database V(x,y,t) of cloud-free images homogeneous for selected observational conditions (same period of the year and satellite overpass time).

2. . Computing the unperturbed reference fields images $V_{REF}(x,y)$ and $\sigma_V(x,y)$ for $V(x,y,t)$

3. Computation of the ALICE (*Absolutely Llocal Index of Change of Environment*) index for detecting and qualifying anomalous variations of the signal.



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

ALICE

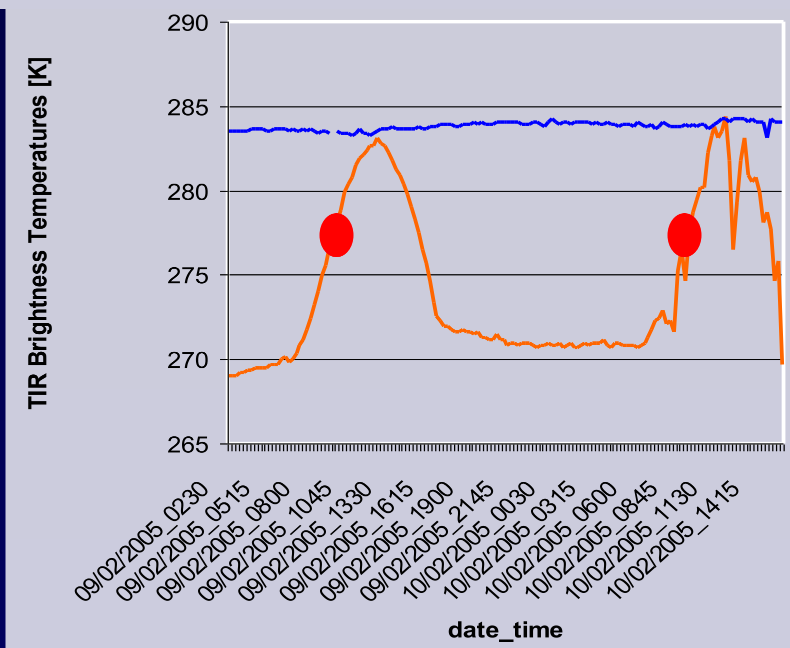
(*Absolutely Llocal Index of Change of Environment*)

RST Main advantages

1. Entirely based on satellite data at hands (non-parametric approach) it is **intrinsically exportable** at the global scale to whatever geographic area and existing/planned sensors

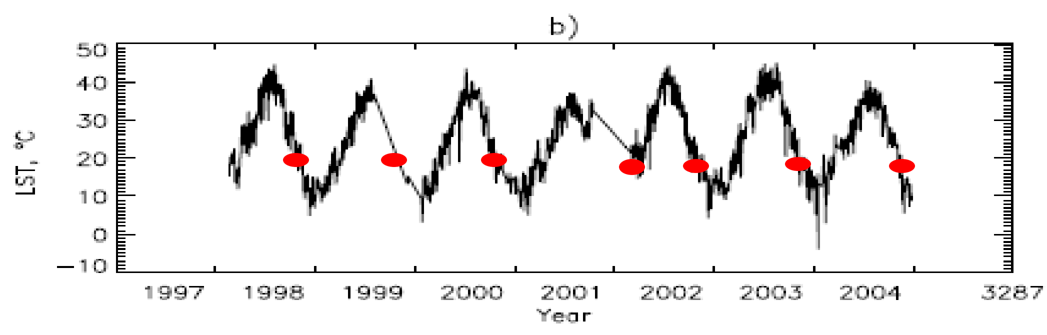
same time of the day

to reduce the variability of *V(x,y,t)* associated to the daily solar cycle



same period (e.g. month) of the year

to also reduce the variability of the signal due to the annual solar and vegetation (growing) cycles



2. No ancillary data required
3. Independent from site effects

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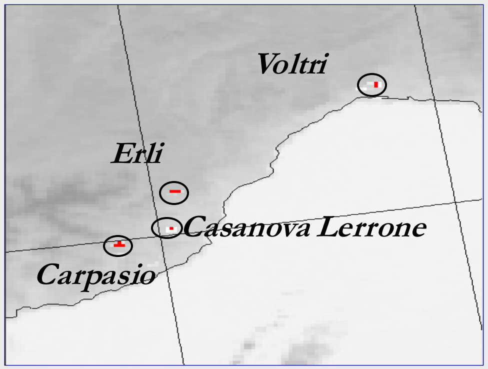
25 years of RST applications

to optical and microwaves sensors onboard polar and geostationary satellites

Forest fires

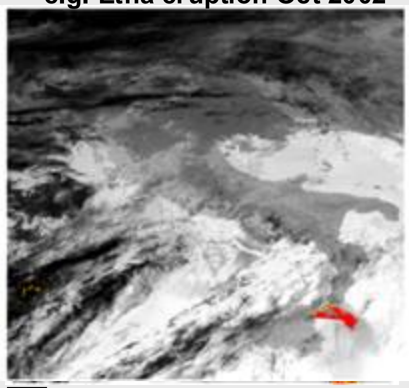
e.g. Fires in Italy, February 2005



fires

Volcanic Eruptions

e.g. Etna eruption Oct 2002



Ash Clouds

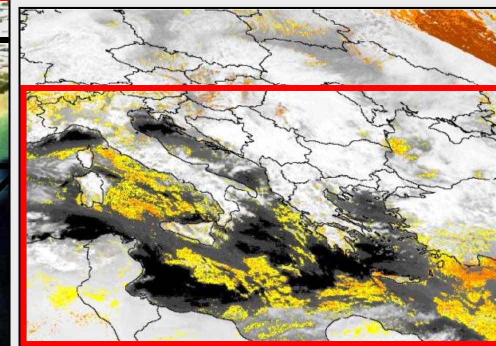
Floods

e.g. Basilicata flood, March 2011

Flooded areas

Dust storms

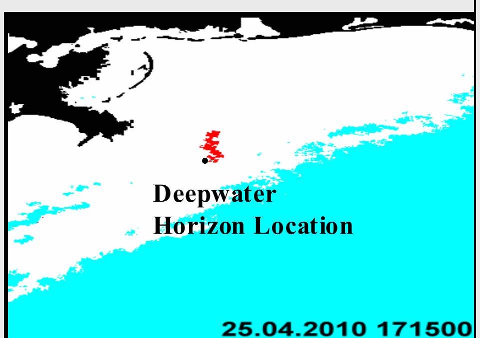
e.g.Libia 13 May 2004



Dust clouds

Oil spills

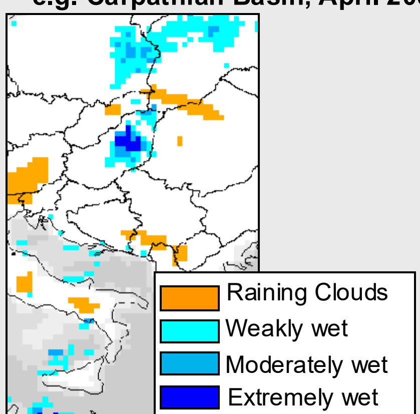
e.g. Oil spill in the Mexico Gulf, April 2010



Oil spill

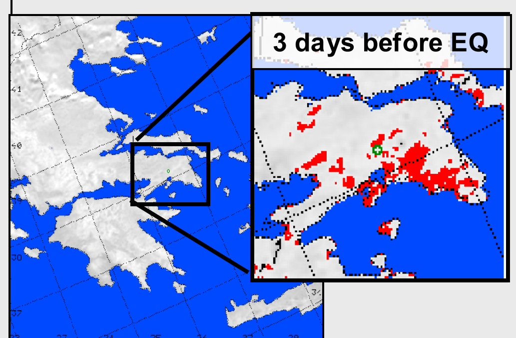
Soil wetness

e.g. Carpathian Basin, April 2000



Earthquakes

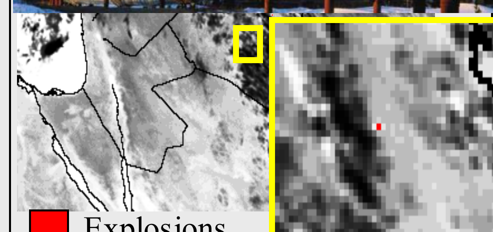
e.g. 7 September 1999 Athens Earthquake



Thermal anomalies

Infrastructures

e.g. 18 October 2005 IRAQ



Explosions

25 years of RST Applications

short scale changes (relatively confined in the space and/or in time) to be detected mainly for damages mitigation purposes

- Volcanic eruptions (*e.g. Remote Sens. of Env.*, 2004a, 2004b, 2007, 2011)
- Forest fires detection (e.g *Remote Sens. of Env.*, , 2016, *Int. J. of Rem. Sens*, 2001)
- Oil spill and water monitoring (*NHESS*, 2011, *Int. J. Rem. Sens.*, 2011, *AGU Books*, 2011)
- Landslides (e.g. *Remote sensing* 2023)
- Radio interference monitoring (*e.g. IEEE-TGRS 2012, IGARSS 2010*)
- Energy production and transport systems monitoring (*e.g. GNHR 2024, Rem. Sens. 2020*)
- Infrastructures monitoring (*e.g. Nat hazards* 2017, *Springer Verlag Book,* 2009)
- Cloud-detection (e.g. *Atmosph. Research.*, 2004)
- Rapid alert for security purposes (*Multitemp 2007., Springer Verlag Book,* 2009)

medium, long scale, changes (in space and/or time) to be analysed in terms of relative trends or as precursor of short scale events

- Saharan dust, air quality and pollution monitoring (e.g *Rem. Sens.*, 2017, *Acta Astronautica* 2014, *GIGS* 2014)
- Soil Wetness and flood risk monitoring (e.g., *Rem. Sens. Env., 2005,* 2010a, 2010b, *Phys. Chem. Earth*,. 2006)
- Flood monitoring and mapping (*Int. J. Rem.Sens.., 2010, Remote Sensing 2024)*
- Seismic hazard forecast (e.g. *JGR 2021,* Rem.Sens.Env.,2005, Tectonoph., 2007)
- Water quality and pollution monitoring (e.g. *Continental Shelf Research* 2018, Rem. Sens. 2018, 2021)

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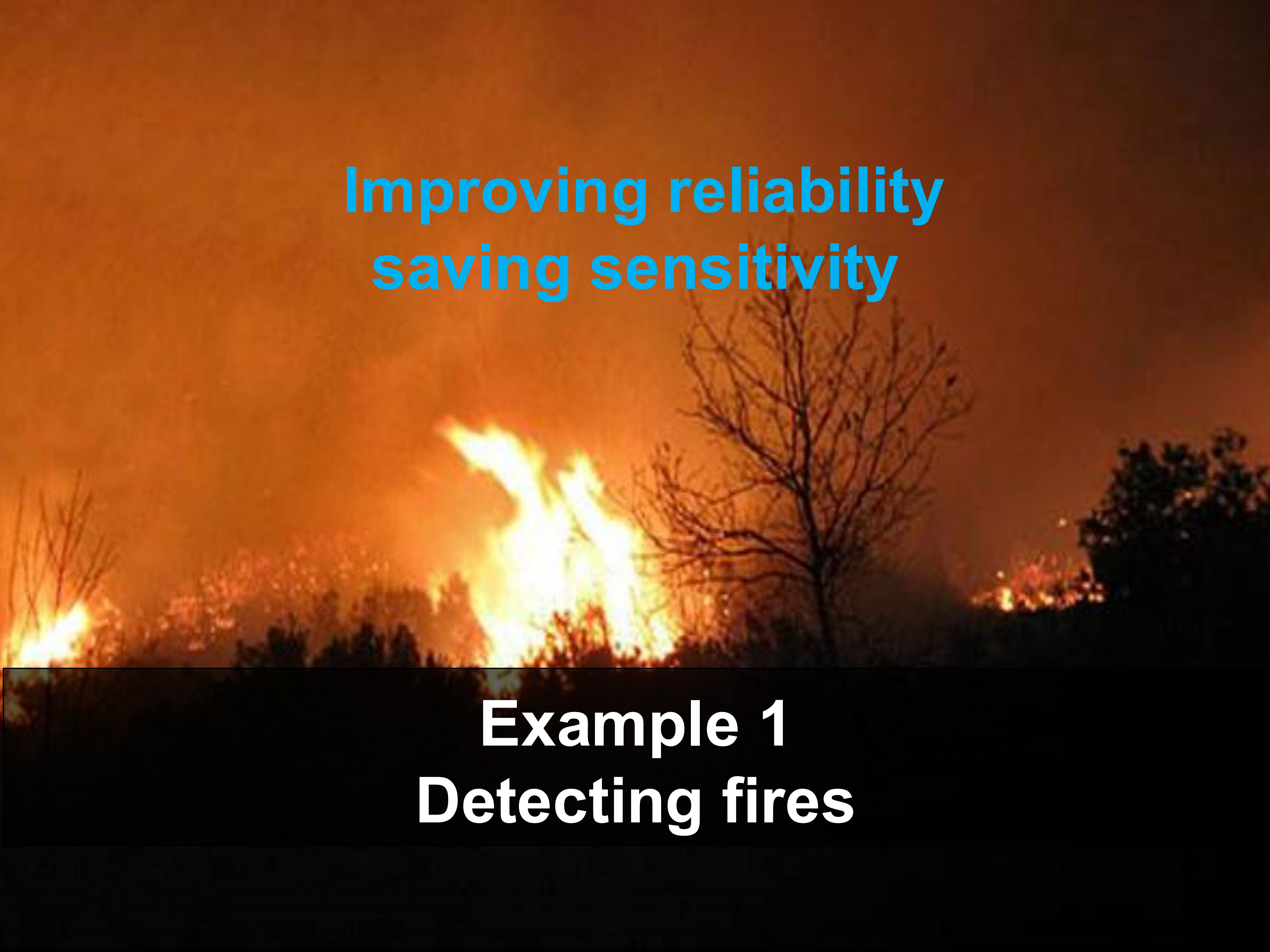
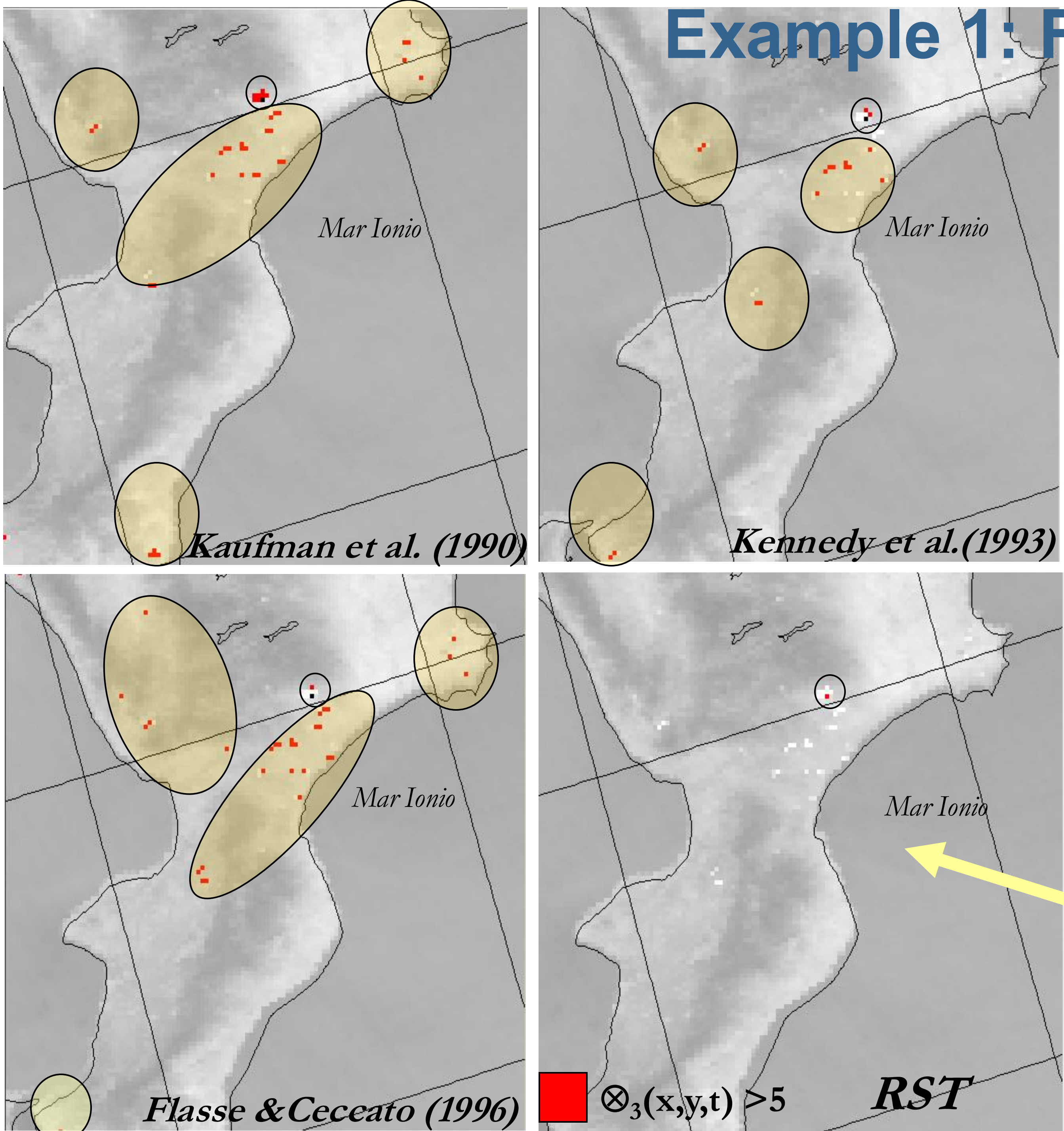

Improving reliability
saving sensitivity
Example 1
Detecting fires

Example 1: Fire Detection



AVHRR – 5th july 2000 15:00 GMT (South Italy)

Fires detected

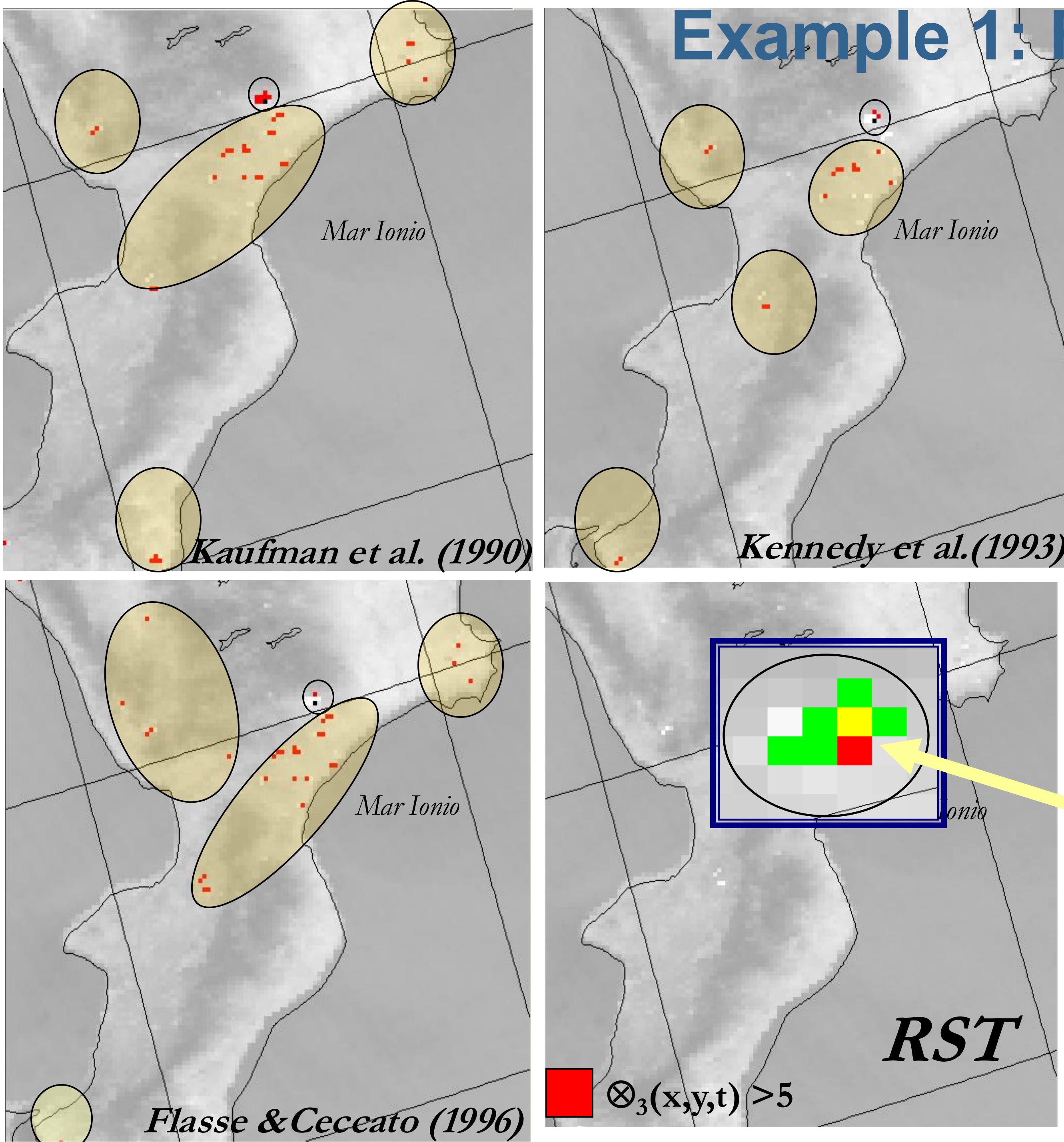
Actual fires

FALSE ALARMS

NO FALSE ALARMS

$$\otimes_{MIR}(x,y,t) \equiv \frac{T_{MIR}(x,y,t) - \mu_{MIR}(x,y)}{\sigma_{MIR}(x,y)}$$

Example 1: Fire Detection



AVHRR – 5th july 2000
15:00 GMT (South Italy)

Fires detected

Actual fires

FALSE ALARMS

RST tunability: Thermal structure description

- $\otimes_3(x,y,t) > 5$
- $\otimes_3(x,y,t) > 4$
- $\otimes_3(x,y,t) > 3$

Example 1: Fire Detection

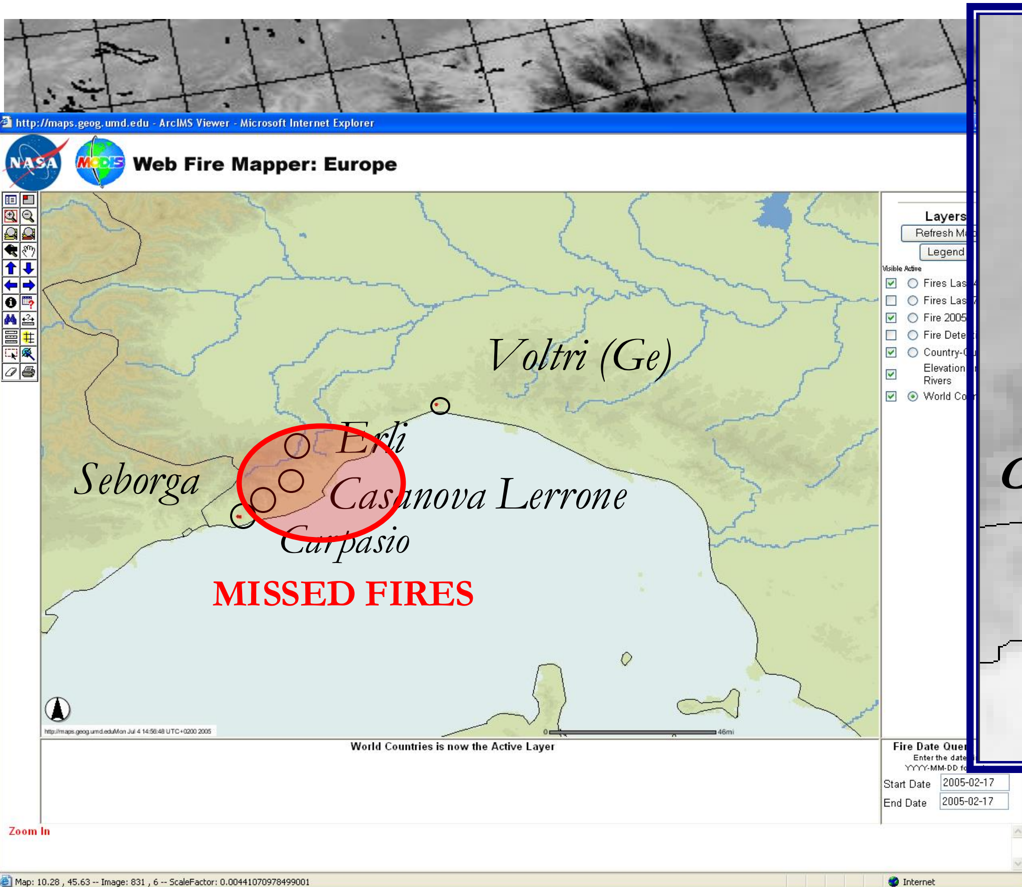
Thanks to its «fire-band» (at higher saturation level) EOS/MODIS facilitate reduction of the false positives rate BUT…

$$\otimes_{MIR}(x,y,t) \equiv \frac{T_{MIR}(x,y,t) - \mu_{MIR}(x,y)}{\sigma_{MIR}(x,y)}$$

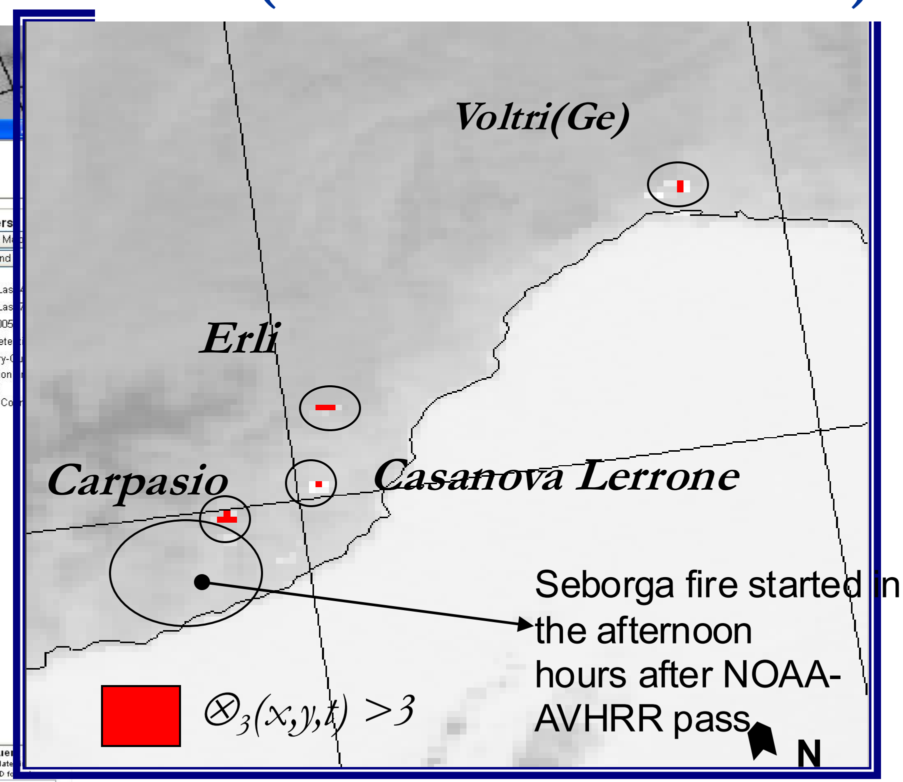
AVHRR – 17th February 2005 15:00 GMT (South Italy)

EOS-MODIS (MOD14-algorithm)

North-Italy WINTER (*17 Feb 2005 24 h)*



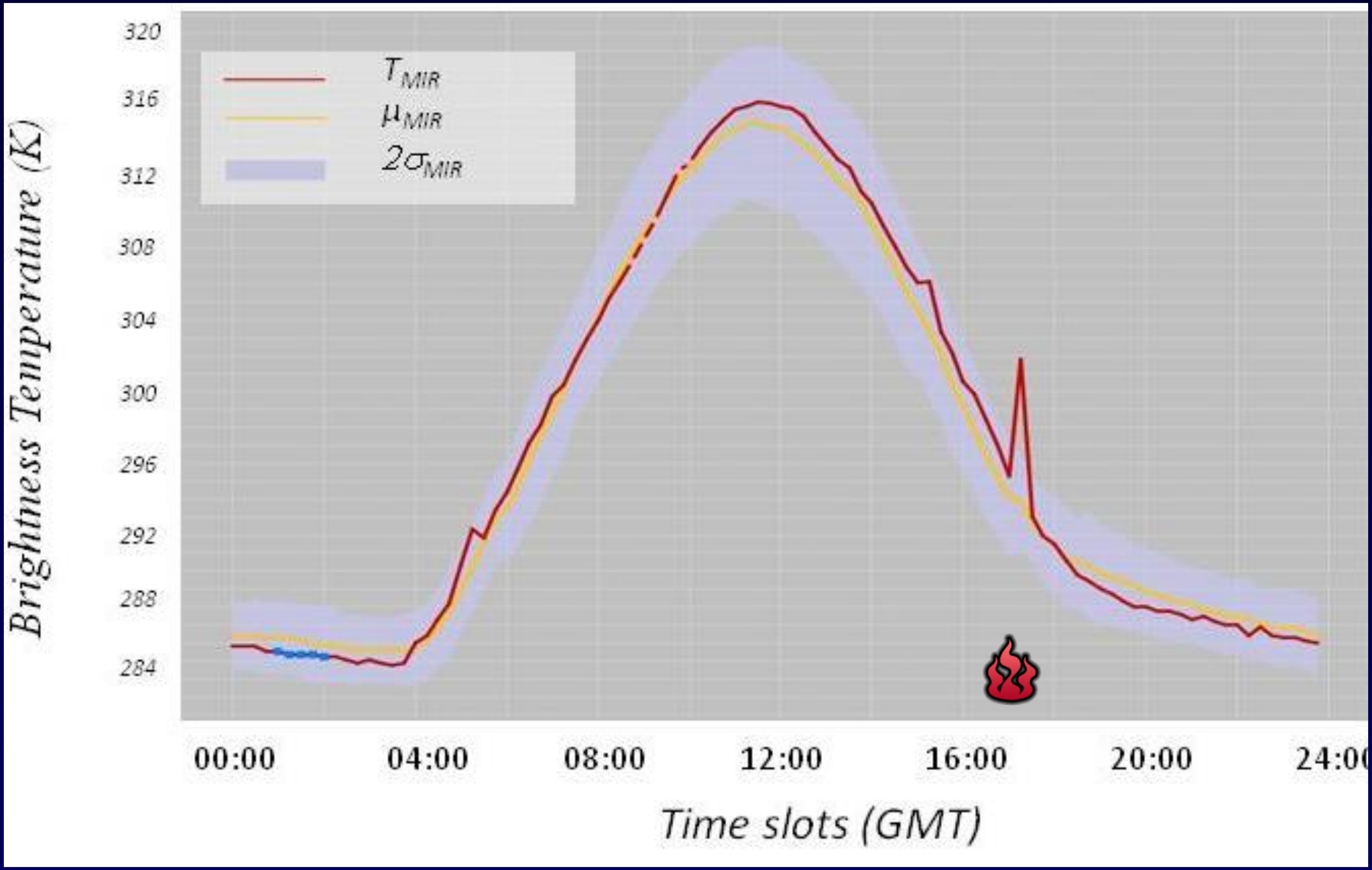
RST (AVHRR at 1:00 GMT)



NO MISSED NO FALSE FIRES

Example 1: Forest fires

(MSG/SEVIRI MIR band)



(Filizzola et al., Remote Sensing of Environment, 2017)

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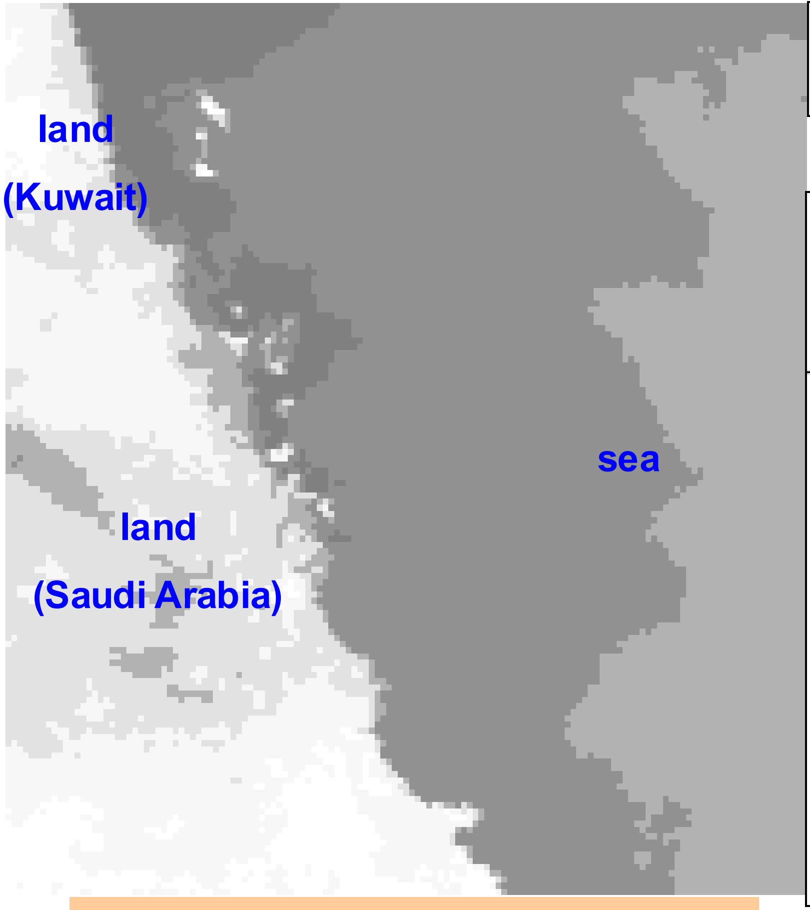
Automatic detection not just mapping

Example 2
Detecting oil spills

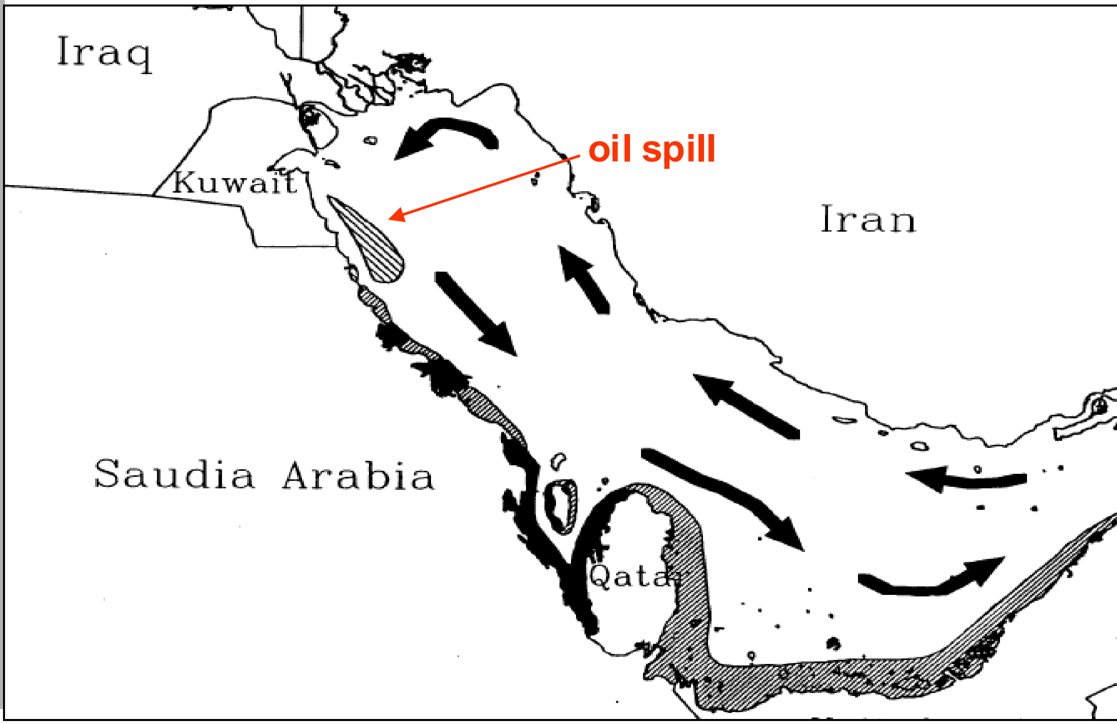
Example 2: Oil Spill Detection

Single image processing – Fixed threshold (Cross, 1991)



24th January 1991
(NOAA/AVHRR TIR channel 4 – 10:38 GMT)

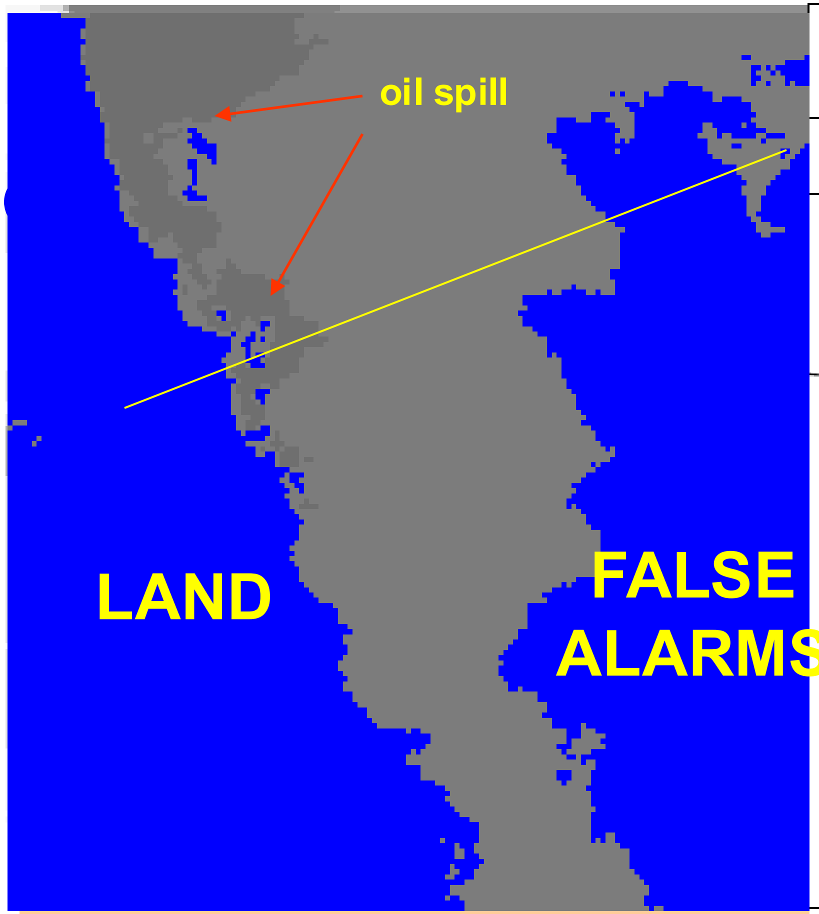
23 - 30 January 1991 (Gulf War): release of crude oil on Kuwait and Saudi Arabia coasts



Example 2: Oil Spill Detection

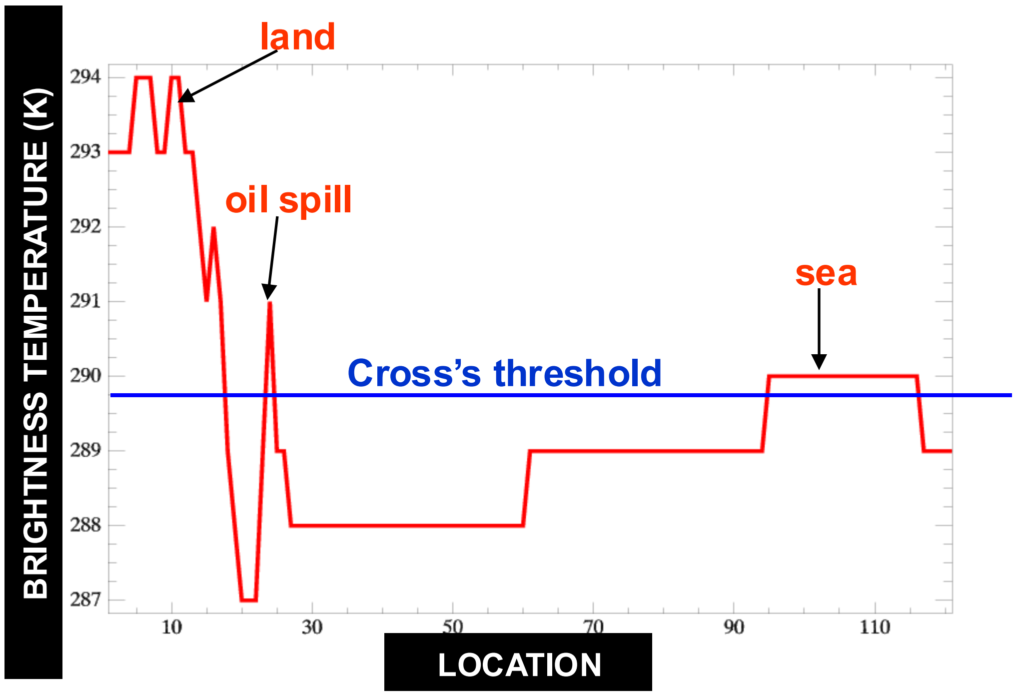
Single image processing – Fixed threshold (Cross, 1991)

oil spill if $T_4 > 289.8$ K



24th January 1991
(NOAA/AVHRR TIR channel 4 (11μ) – 10:38 GMT)

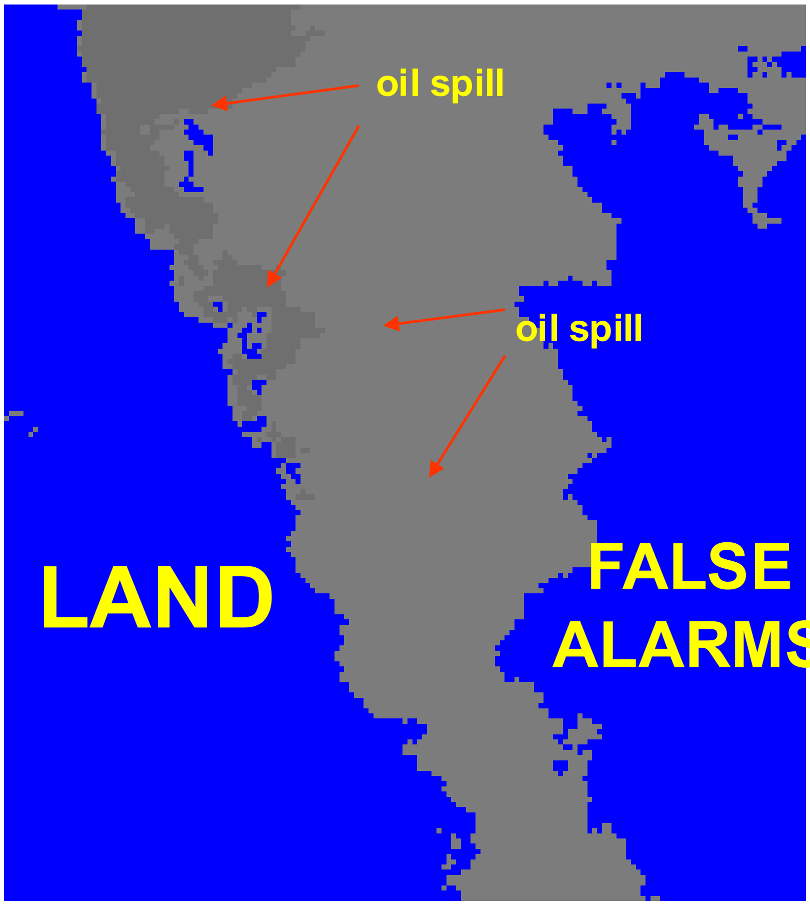
23 - 30 January 1991 (Gulf War): release of crude oil on Kuwait and Saudi Arabia coasts



Example 2: Oil Spill Detection

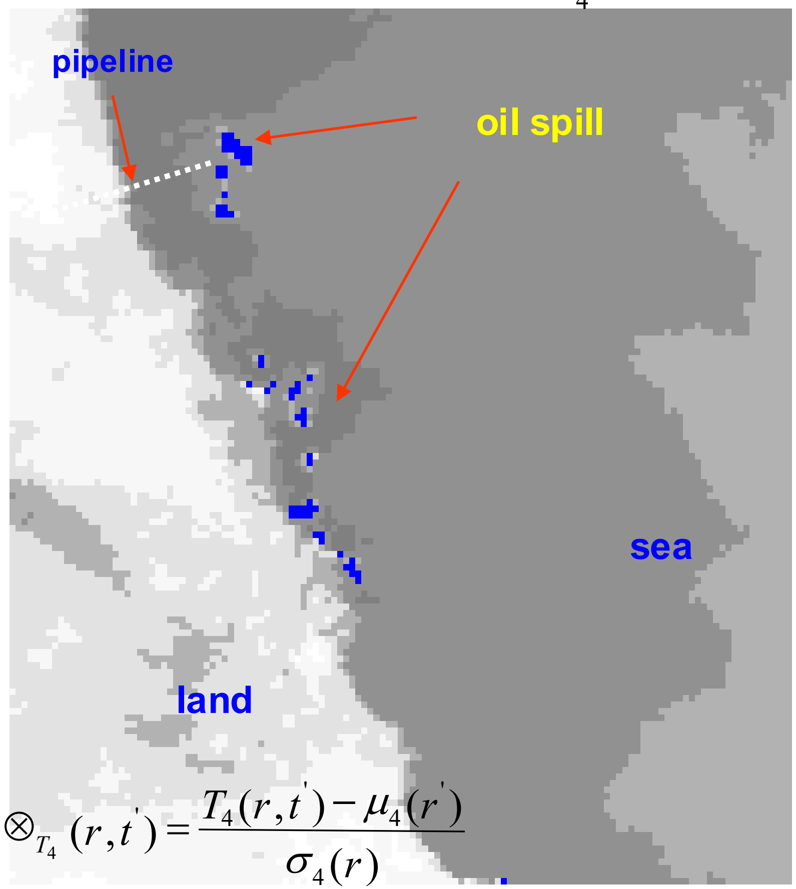
23 - 30 January 1991 (Gulf War): release of crude oil on Kuwait and Saudi Arabia coast)

Cross (1991) ■ $T_4 > 289.8$ K



1991- 01- 24
(channel 4 AVHRR - 10.38 GMT)

RST ■ $\otimes_{T_4} > 5$



$$\otimes_{T_4}(r,t') = \frac{T_4(r,t') - \mu_4(r')}{\sigma_4(r)}$$

1991- 01- 24
(channel 4 AVHRR - 10.38 GMT)

NO FALSE ALARMS

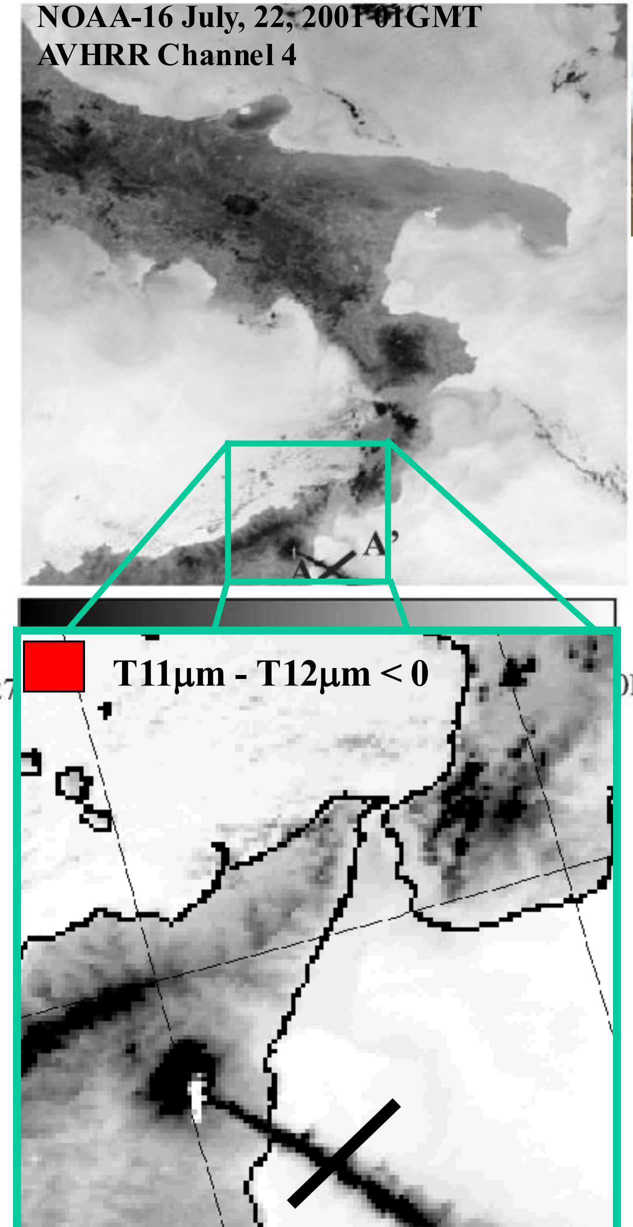
AUTOMATIC DETECTION (NOT JUST MAPPING)

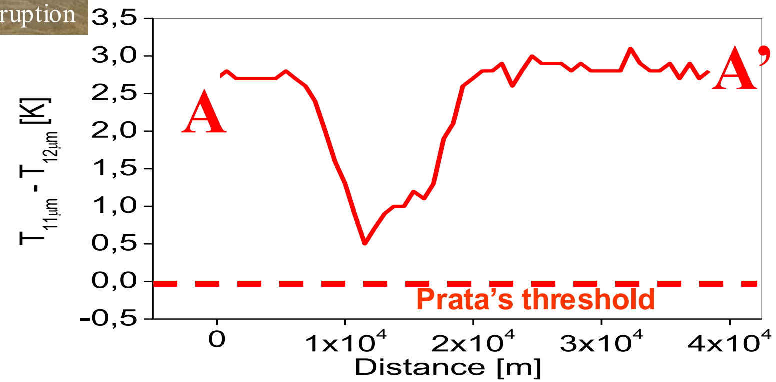
Again fixed threshod issues

Example 3: Detecting and monitoring volcanic ash clouds

A NASA satellite image taken on Saturday May 10 2010 shows the ash plume drifting from Iceland.

Example 3: Ash Cloud Detection
Traditional methods (Prata, 1989)





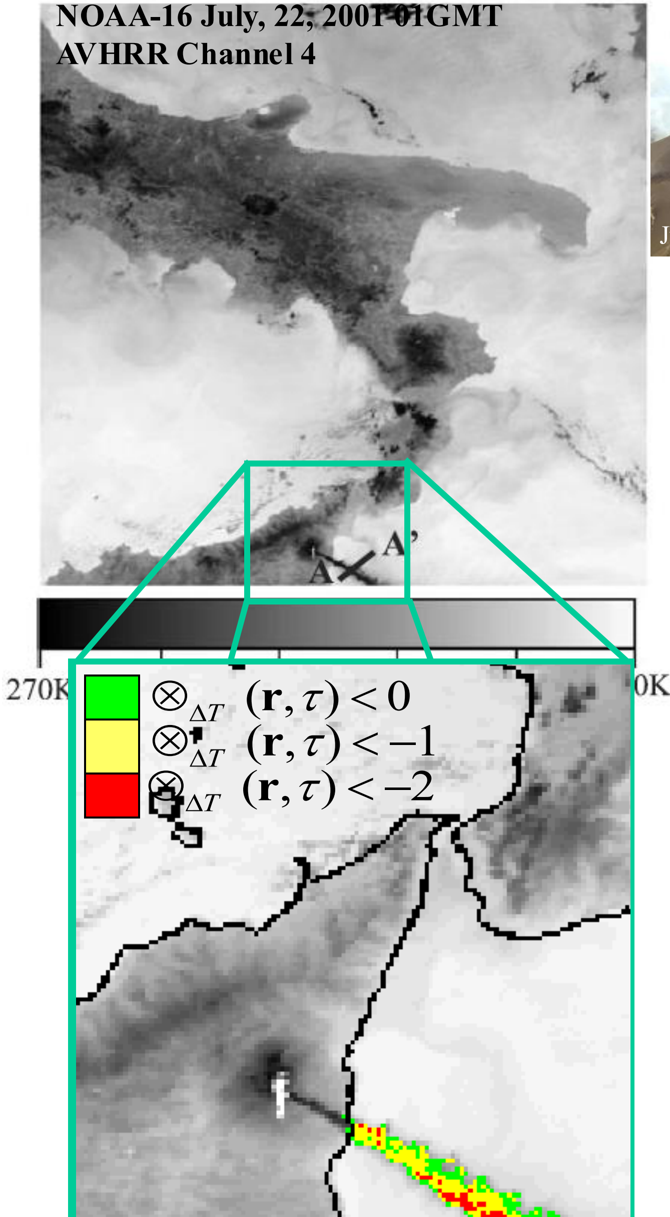
$$\Delta T = T_{11\mu m} - T_{12\mu m} < 0 \text{ K}$$

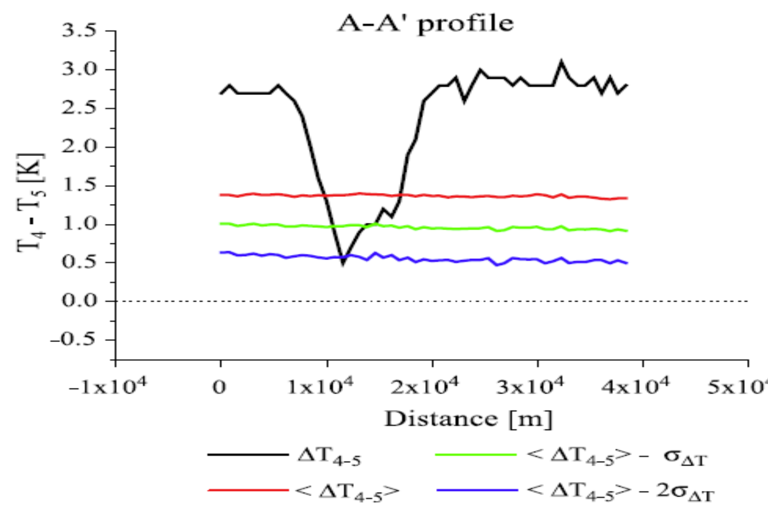
e.g. Prata, 1989

Traditional fixed threshold methods

NO DETECTION!!

Example 3: Ash Cloud Detection RST





$$\otimes_{\Delta T}(\mathbf{r},t) = \frac{[\Delta T(\mathbf{r},t) - \mu_{\Delta T}(\mathbf{r})]}{\sigma_{\Delta T}(\mathbf{r})}$$

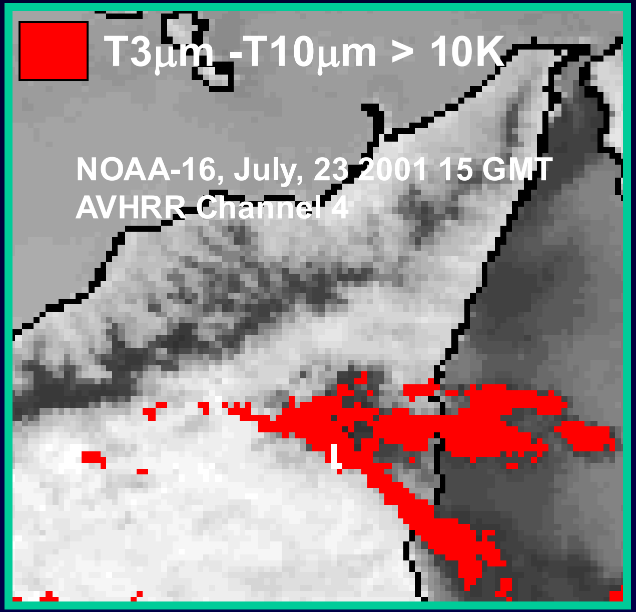
RST

$$\Delta T(\mathbf{r},t) = T_{11\mu}(\mathbf{r},t) - T_{12\mu}(\mathbf{r},t)$$

DETECTION AND TUNABILITY!


Improving reliability
saving sensitivity
Example 4
Monitoring lava flows

Example 4: Monitoring lava flows

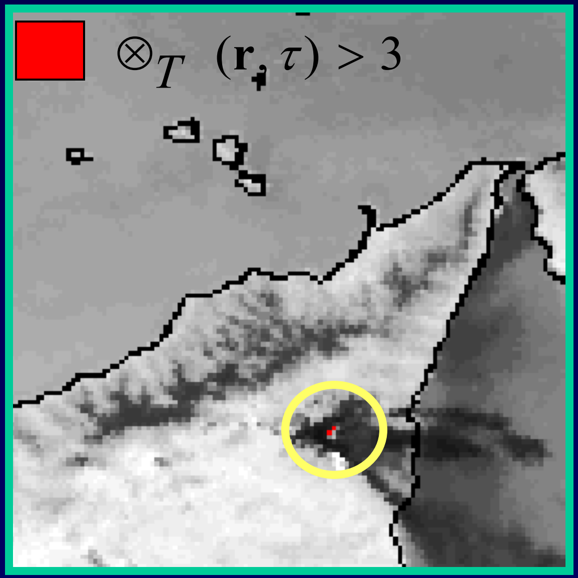


Tradictional Methods

(Harris et al. , 1995)

$$\Delta T = T_{3\mu m} - T_{11\mu m} > 10K$$

FALSE DETECTIONS



$$\otimes_{T_{3\mu m}}(\mathbf{r},\tau) = \frac{\left[T_{3\mu m}(\mathbf{r},\tau) - \mu_{T_{3\mu m}}(\mathbf{r})\right]}{\sigma_{T_{3\mu m}}(\mathbf{r})}$$

RST

NO FALSE DETECTIONS!

Example 4: Monitoring lava flows

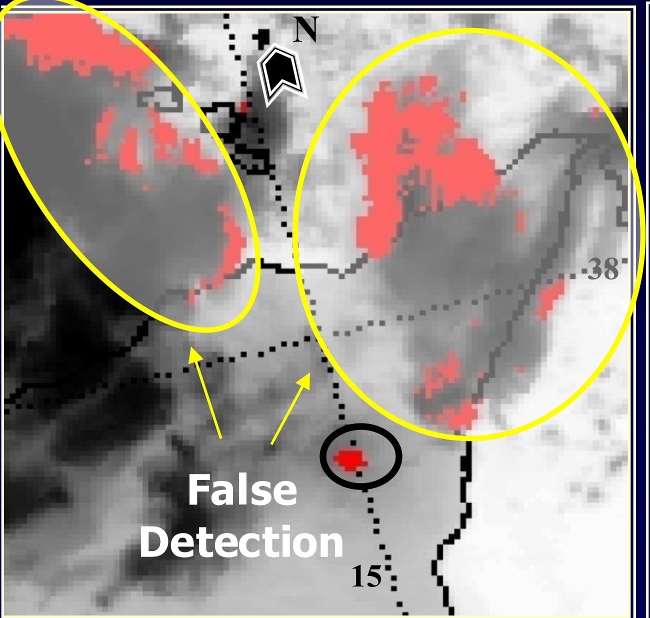
$\mu_{MIR\text{-}TIR}$
$\sigma_{MIR\text{-}TIR}$ spatial averages

$$\otimes_{T_{3\mu m}}(\mathbf{r},\tau) = \frac{\left[T_{3\mu m}(\mathbf{r},\tau) - \mu_{T_{3\mu m}}(\mathbf{r})\right]}{\sigma_{T_{3\mu m}}(\mathbf{r})}$$

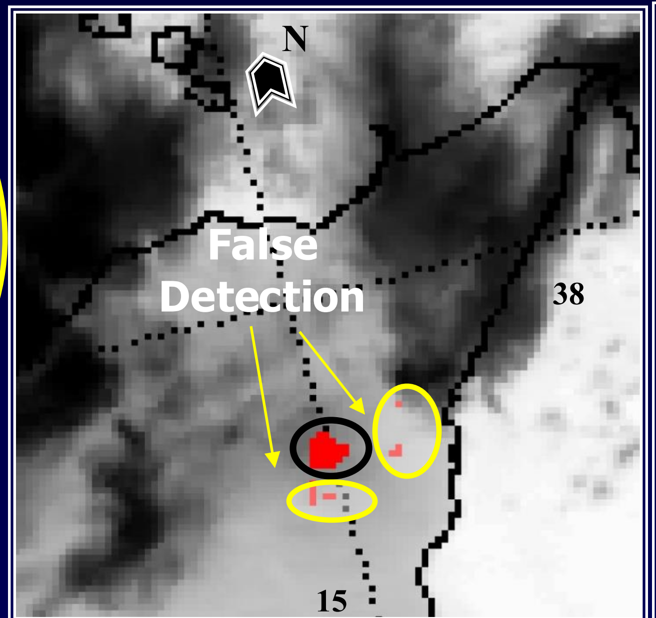
■ $T_{MIR} - T_{TIR} > 10\ K$

■ $\dfrac{[(T_{MIR} - T_{TIR}) - \mu_{MIR\text{-}TIR}]}{\sigma_{MIR\text{-}TIR}} > 3$

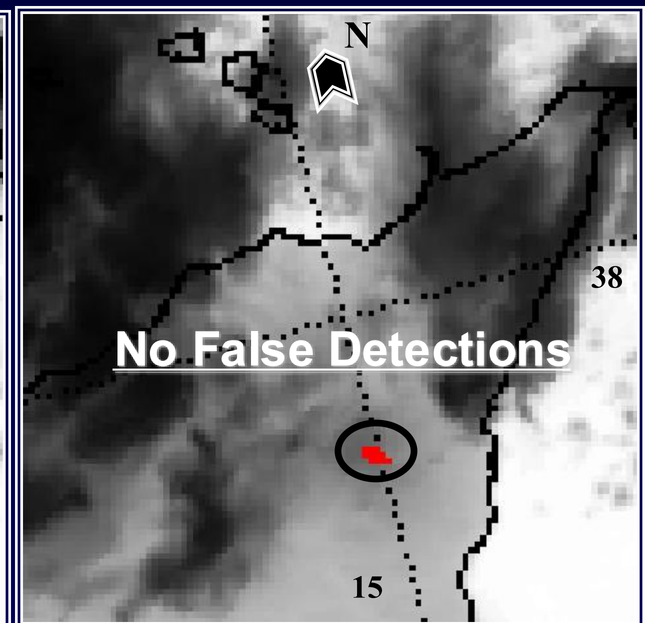
■ $\otimes_3(x,y,t) > 3$



Multichannel fixed threshold Techniques (e.g. Harris et al. 1995)



Contextual algorithms (Kaneko, 2002)



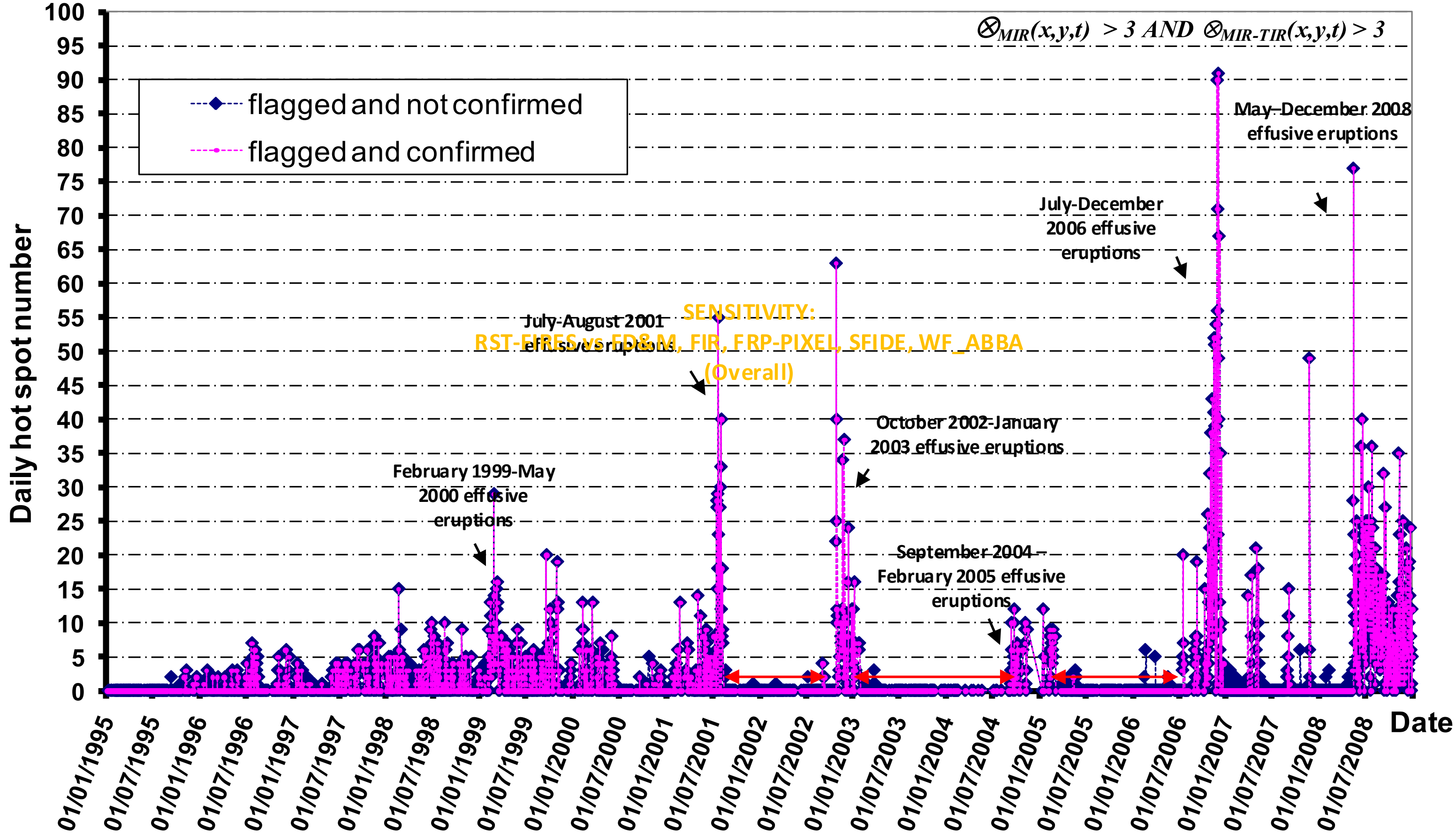
RST

(12 February 1999 around h01 GMT)

Reliability

RST_{VOLC} vs volcanological bulletins at Mt. Etna (1995-2008)

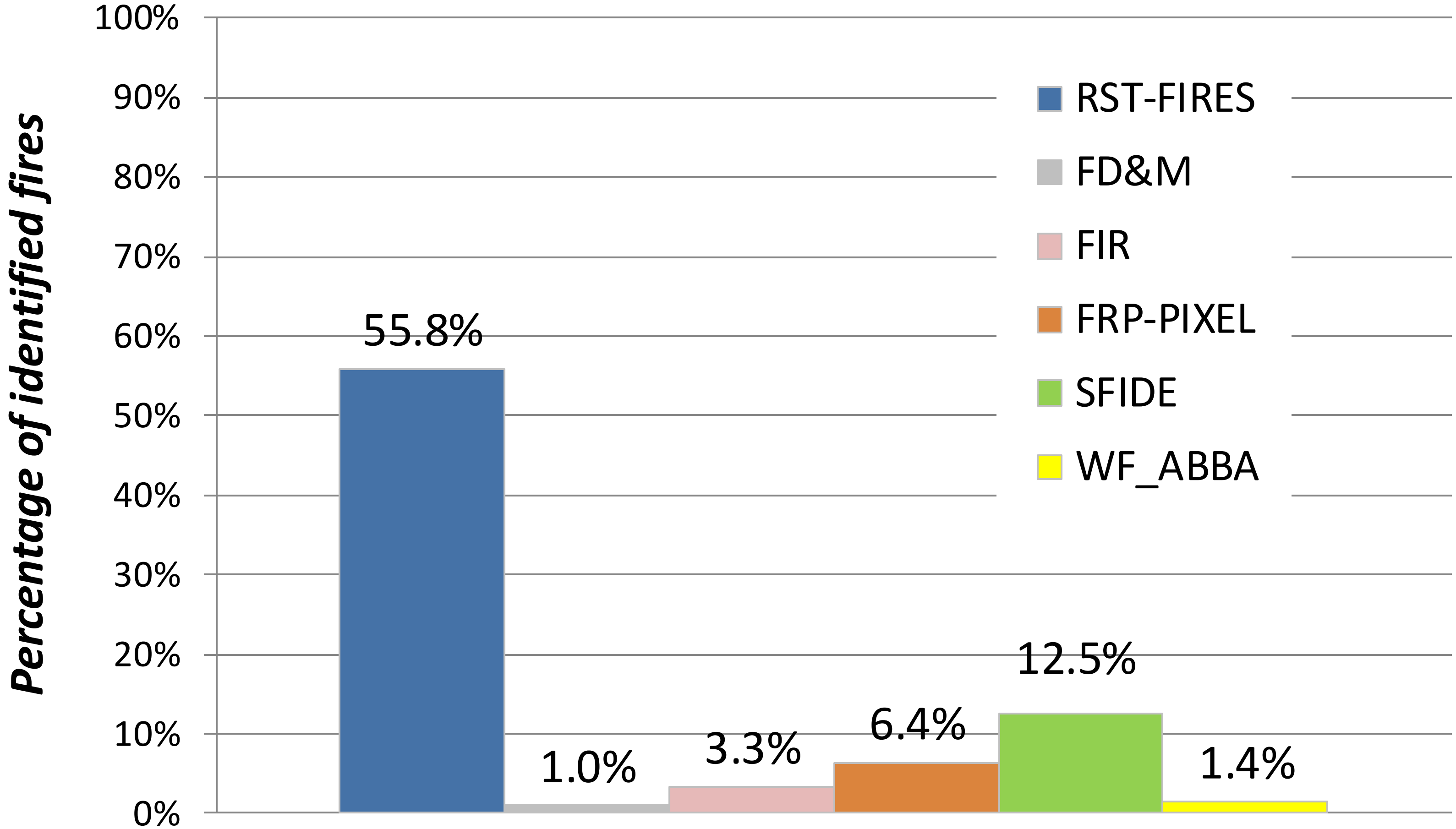
High trade-off between reliability/sensitivity of detection



False positive rate < 1 %

Sensitivity

RST_{FIRES} vs FD&M, FIR, FRP-PIXEL, SFIDE, WF_ABBA after aerial and ground surveys in Lombardy Basilicata and Sicily



Filizzola et al., 2016 *Remote Sensing of Environment*

RST-FIRES operational implementation in Italian Regions (Sicily 2008, MSG-SEVIRI)

S. Giuseppe Jato, 10 september 2008, pyromaniacs catch

CRONACA DI PALERMO

PROVINCIA. È in attività
di Corleone, Roccapalu

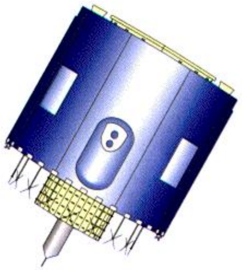
Primi risultat
Subito blocca

Un satellite preserverà i nostri boschi. Li sorveglia, li controlla, li scruta, si accorge del più piccolo principio di incendio, lo comunica a una sala operativa che immediatamente attiva le procedure di intervento. Non è fantascienza, è realtà. Che ha già dato i primi, significativi, risultati, evitando che sei focolai si sviluppassero in alcune zone del Palermitano, distruggendolo.

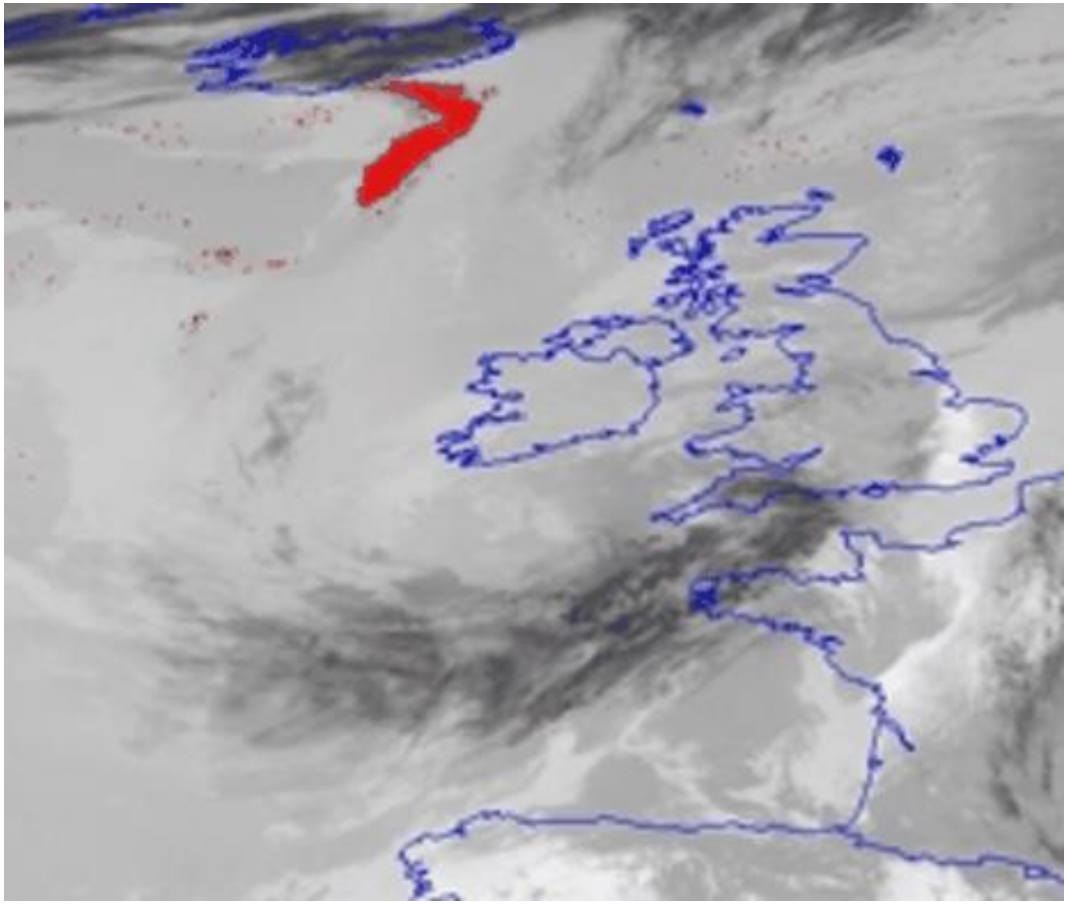
Il bilancio del primo mese di attività sperimentale di monitoraggio in collegamento con i satelliti Eumetsat, avviato dalla Provincia con il Cnr di Potenza e l'università della Basilicata, è positivo. A fornire i dati è l'assessore alla Protezione civile Gigi Tomasino. «Il 4 settembre diverse segnalazioni, la prima nella zona tra Valledolmo e Vallelunga e la seconda tra Corleone e Camporeale ha allertato le squadre di intervento, ma il sistema

Exportability

RST_{ASH} implementation on MSG-SEVIRI



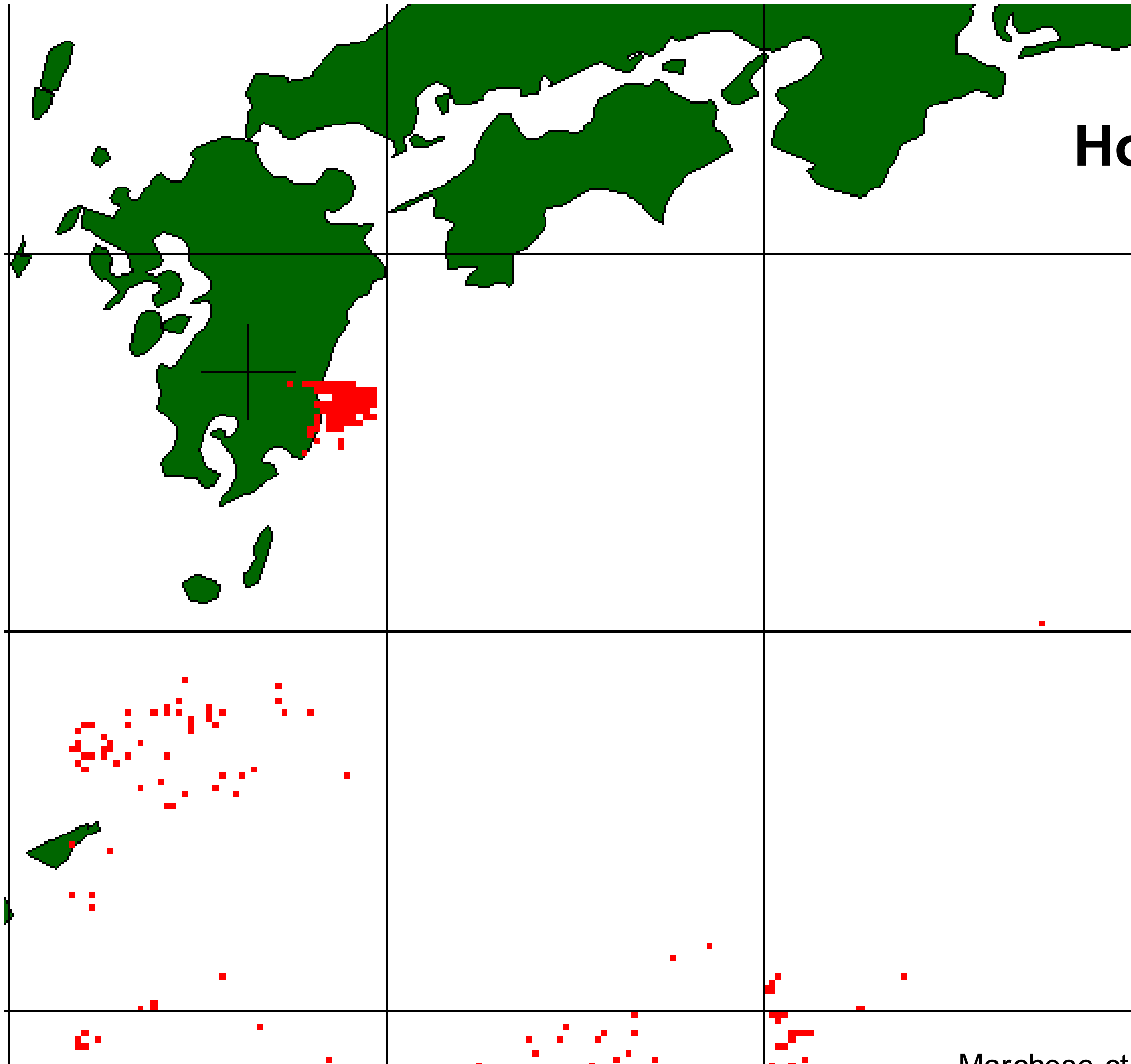
Eyjafjallajökull eruption - II phase



From 06/05/2010 to 16/05/2010 (@ synoptic hours)

Exportability
RST_{ASH} implementation on MTSAT

Shinmoedake (Japan) eruption of 26-27 January 2011



Hourly MTSAT data

Marchese et al, 2013, JVGR

CONCLUSIONi

Risultato chiave: Satelliti meteorologici (in particolare geostazionari) per il monitoraggio continuo di eventi rapidi

Lesson learnt / best practice: L'utilizzo di tecniche RST efficace nel migliorare contemporaneamente sensibilità e affidabilità delle tecniche di change-detection (intrinsecamente esportabile su aree geografiche e sensori diversi e facilmente implementabile per l'on-board processing)

Idea progettuale o tema di R&D che si propone per future iniziative: Sviluppo di un sistema integrato per il monitoraggio continuo e a grande scala dei territori per il riconoscimento tempestivo dei cambiamenti a breve (anche con integrazione Geostazionari con costellazione di 50+ VHR microsatelliti) e medio termine

Requisito utente o necessità di downstream non ancora soddisfatte: Controllo sistematico del territorio (reati ambientali, sovvenzioni in agricoltura, incidenti industriali, incendi, eruzioni vulcaniche, inondazioni, oil spills, inquinamento dell'aria, etc.)

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THANKS