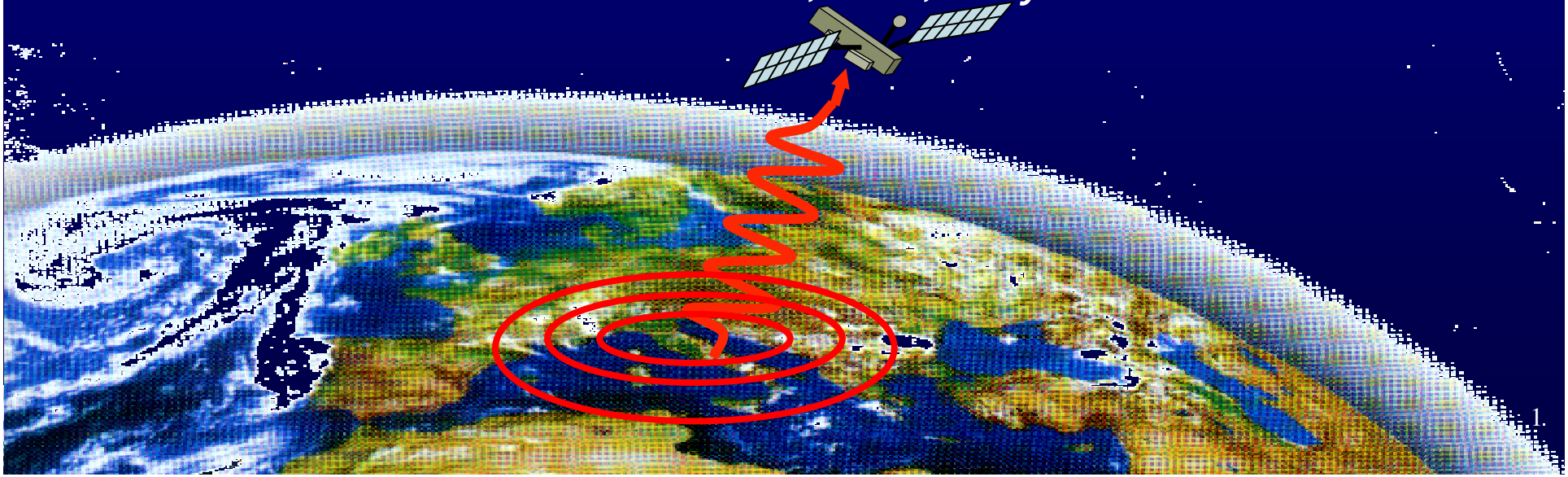
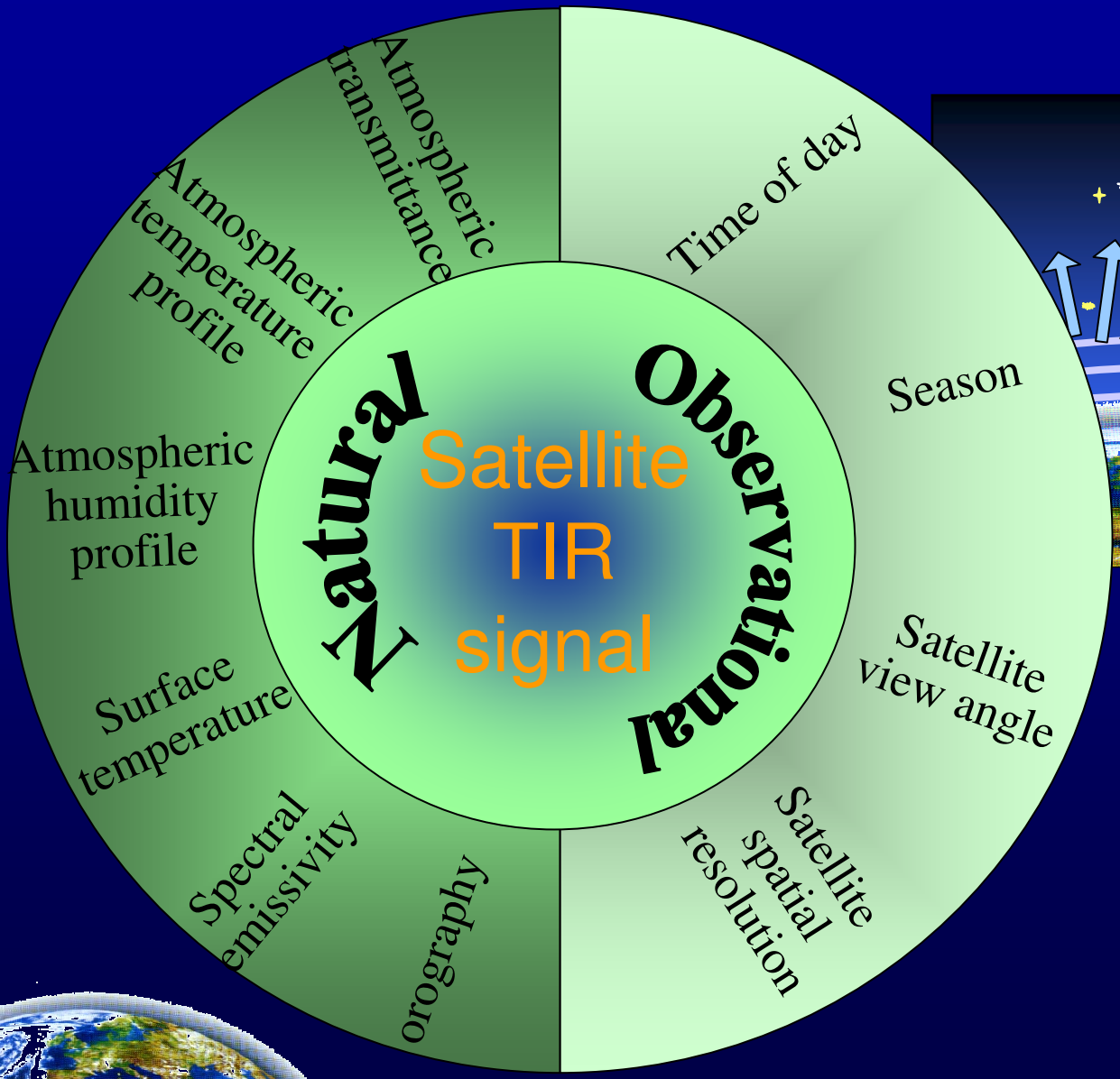
RST analysis of TIR radiances at the time of Abruzzo, 6 April 2009, earthquake: a study on 30 years of independent satellite observations

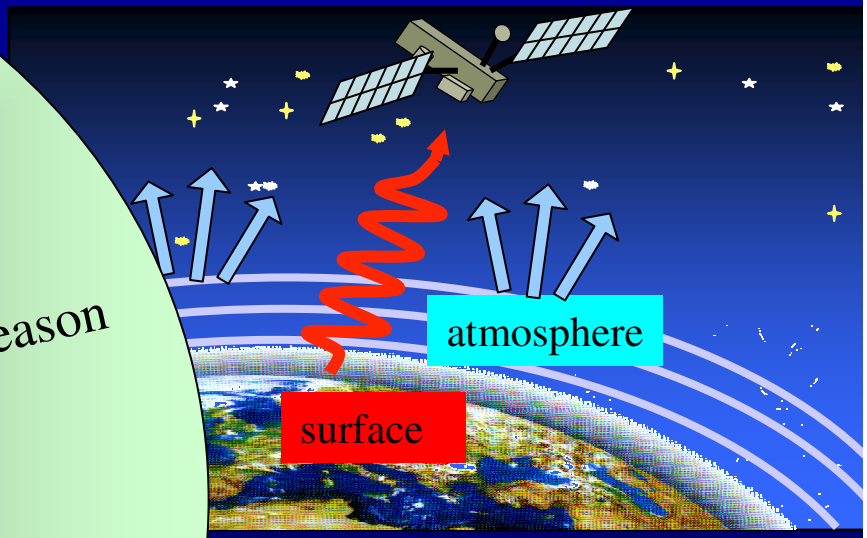
V. Tramutoli, R. Corrado, N. Genzano,, M. Lisi,G. Mazzeo
DIFA,University of Basilicata, Potenza, Italy
(valerio.tramutoli@unibas.it)

C. Filizzola, T. Lacava, F. Marchese, N. Pergola
IMAA-CNR, Tito, Italy



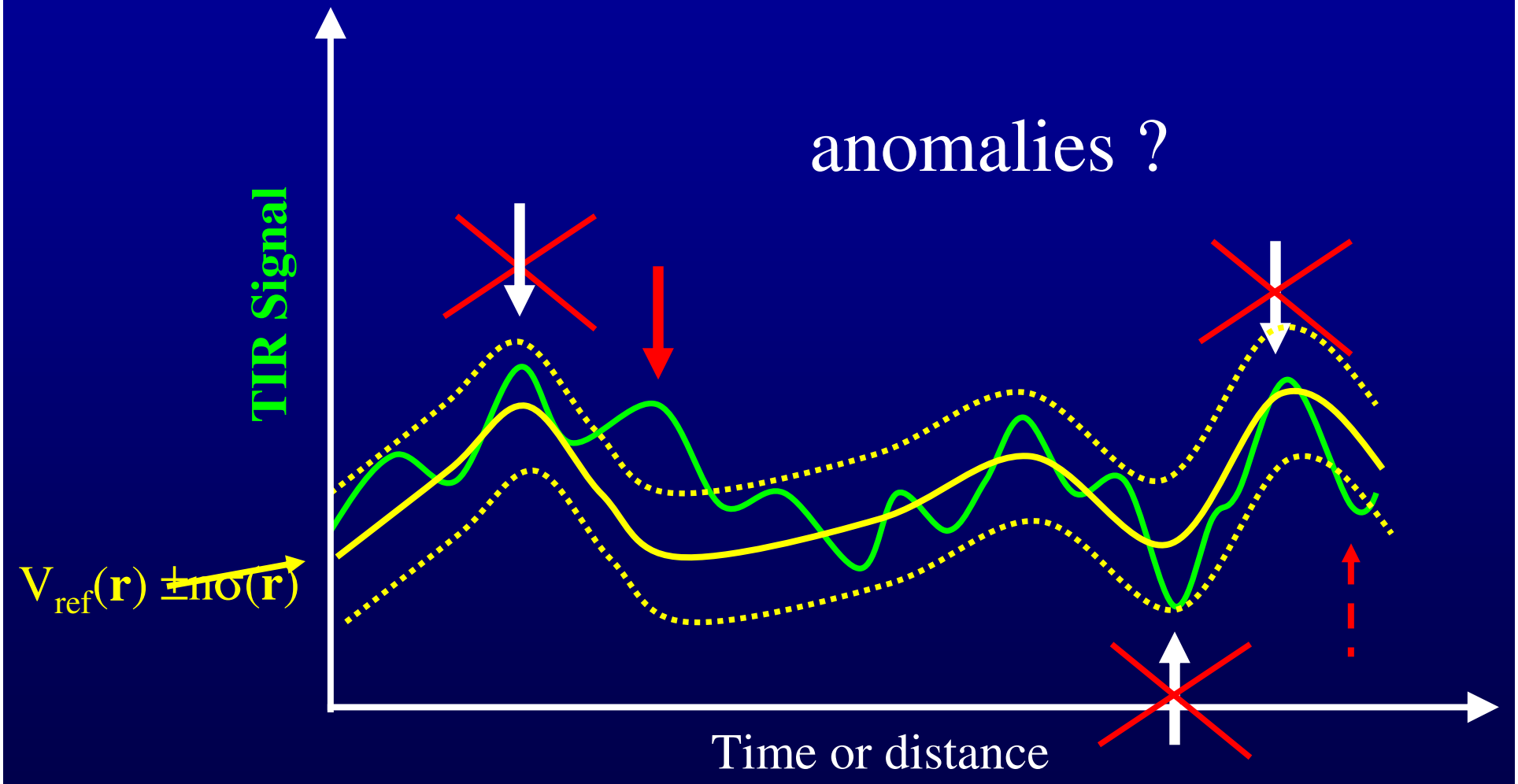
TIR signal and noise





TIR signal is strongly variable depending on the observation time *t* and place *r*.

What "anomaly" means ?



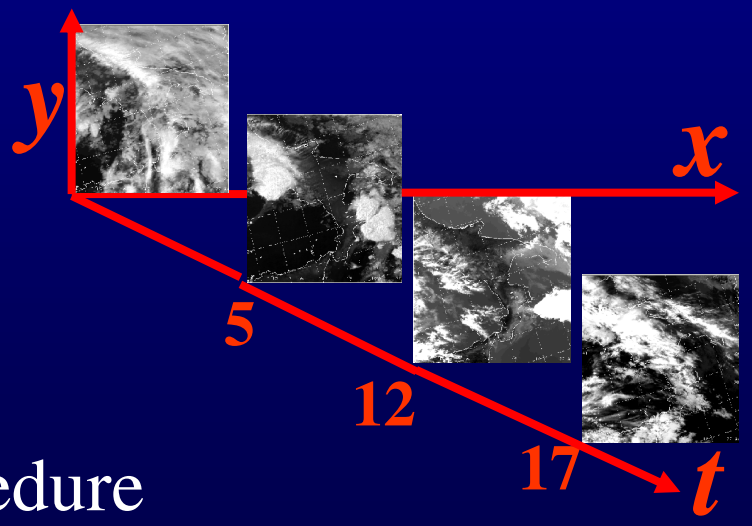
Robust Satellite Techniques (RST)

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

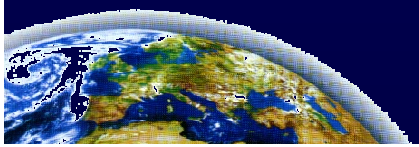
- **Robust definition of signal anomaly** based on the multi- temporal analysis of long-term historical satellite records

ALICE (Absolutely Llocal Index of Change of the Environment)

$$\otimes_V(\mathbf{r},\tau) \equiv \frac{[V(\mathbf{r},\tau) - V_{REF}(\mathbf{r})]}{\sigma_V(\mathbf{r})}$$



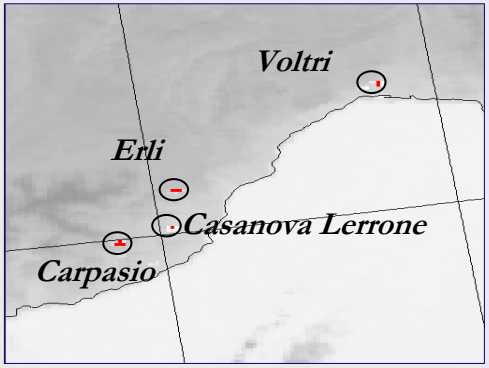
- **Validation/Confutation** procedure



Main Applications

Forest fires

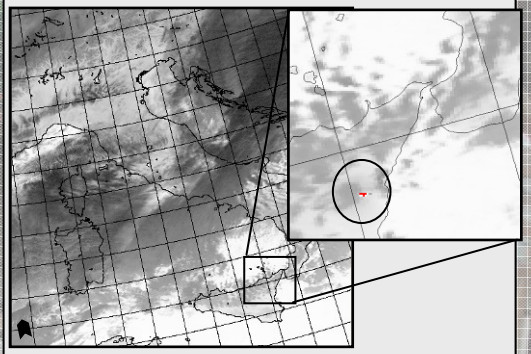
e.g. Fires in Italy, February 2005



fires

Volcanic eruptions

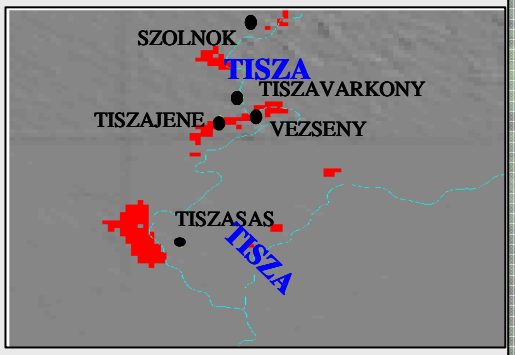
e.g. 2004-2005 Etna eruption (Italy)



Hot spot

Floods

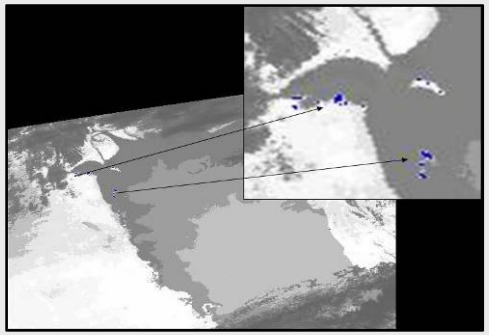
e.g. Ungary flood, April 2002



Flooded areas

Sea pollution

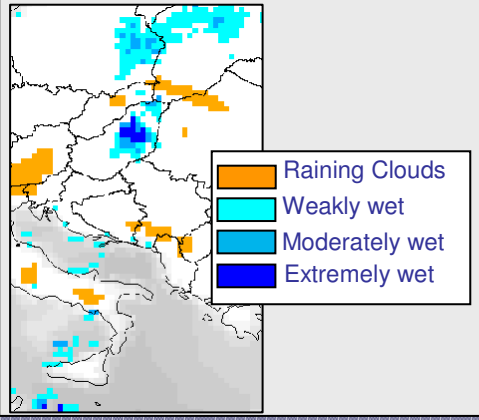
e.g. Oil spill in the Persic Gulf, January 1991



Oil spill

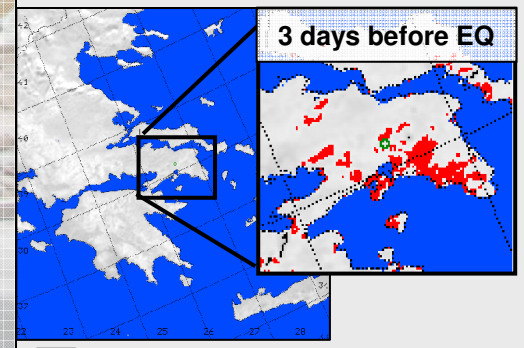
Soil wetness

e.g. Carpathian Basin, April 2000



Earthquakes

e.g. 7 September 1999 Athens Earthquake



Thermal anomalies

RST Applications

For two main classes of environmental processes:

short scale changes

- volcanic eruptions monitoring (e.g. Pergola, et al. *Remote Sensing of Enviroment*, 2004, Filizzola et al. *RSE, 2007*)
- forest fires detection and risk assessment (e.g. Cuomo et al. *International Journal of Remote Sensing* 2001)
- security issues (Tramutoli et al., Elsevier, 2007)
- oil spill monitoring (e.g. Casciello et al. *International Journal of Remote Sensing*, 2009), MULTITEMP, 2007)
- cloud-detection (e.g. Cuomo et al. *Atm. Research*, 2004)

medium, long scale, changes

- air and water quality and pollution monitoring (e.g. Tramutoli et al. *IRS 2000, Deepak, 2001*)
- flood risk evaluation and monitoring (e.g. Lacava et al., *Rem. Sens. Env, 2005, Int.J.Rem. Sens.2009)*
- seismic area monitoring (e.g. Tramutoli et al., *Rem. Sens. Env, 2005,* Genzano et al. *Tectonophysics, 2007)*
- desertification processes monitoring, etc……

Main Applications

Natural and Environmental hazards

- **Forest fires detection** and risk assessment
- **Volcanic eruption** detection, monitoring and prediction
- **Oil spill** detection and monitoring
- **Flood risk**
- **Seismic areas** monitoring
- **Desertification** process monitoring
- **Dust storms** detection and monitoring

Civil security

- **Pipeline** blasts
- **Bonefires** in refugee camps
- **Oil spill** due to pipeline sabotage
- **Terrorist attack** first warning
- Etc….

TIR Anomaly Monitoring by RST

Different TIR-based variable V(**r**,t) →→→ Different ALICE & RETIRA indexes

a) Simply TIR radiances at the sensor:

V(r,t) = TIR (r,t)

$$\otimes_{TIR}(\mathbf{r},t) \equiv \frac{[TIR(\mathbf{r},t) - < TIR(\mathbf{r}) >]}{\sigma_{TIR}(\mathbf{r})}$$

b) LST products taking into account of variable atmospheric conditions and satellite angles of view:

V(r,t) = LST (r,t)

$$\otimes_{LST}(\mathbf{r},t) \equiv \frac{[LST(\mathbf{r},t) - < LST(\mathbf{r}) >]}{\sigma_{LST}(\mathbf{r})}$$

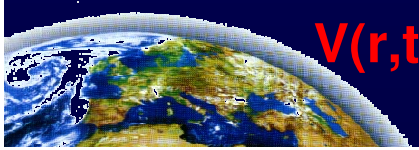
c) Spatial excesses (ΔLST and ΔTIR) computed *in place* as differences between the punctual value V(**r**,t) and spatial average in order to reduce year-to-year and seasonal drift effects:

V(r,t) = ΔLST= LST (r,t) - < LST (r) >

$$\otimes_{\Delta LST}(\mathbf{r},t) \equiv \frac{[\Delta LST(\mathbf{r},t) - < \Delta LST(\mathbf{r}) >]}{\sigma_{\Delta LST}(\mathbf{r})}$$

V(r,t) = ΔTIR=TIR (r,t) - < TIR (r) >

$$\otimes_{\Delta TIR}(\mathbf{r},t) \equiv \frac{[\Delta TIR(\mathbf{r},t) - < \Delta TIR(\mathbf{r}) >]}{\sigma_{\Delta TIR}(\mathbf{r})}$$



Data Analysis: learning
TIR Anomaly Monitoring by RST
HIGH (5.7 – 7.7) MAGNITUDE EQs

EVENT	TECHNIQUE
23 November 1980, Irpinia-Basilicata-Italy, M_s=6.9	AVHRR –ΔTIR (Tramutoli et al., Annals of Geophysics, 2001)
23 November 1980, Irpinia-Basilicata-Italy, M_s=6.9	AVHRR – ΔLST (Di Bello et al., Annals of Geophysics, 2004)
26 September 1997, Umbria, Italy M_s=5.9 to 6.4	METEOSAT – ΔTIR (Aliano et al., Annals of Geophysics,2008))
3-7-12-14 October 1997, Umbria, Italy M_s=5.7 max	METEOSAT – ΔTIR (Aliano et al., Annals of Geophysics, 2008))
17 August 1999, Kocaeli-Izmit, Turkey, M_s=7,4	METEOSAT – TIR (Aliano et al., Annals of Geophysics, 2008)
17 August 1999, Kocaeli-Izmit, Turkey, M_s=7,4	METEOSAT – ΔTIR (Tramutoli et al., Resmote Sensing of Env., 2005)
7 September 1999 Athens M_s=5.9	AVHRR – ΔLST (Filizzola et al., Phys. Chem. Earth, 2004)
7 September 1999 Athens M_s=5.9	METEOSAT – ΔTIR (Filizzola et al., Phys. Chem. Earth, 2004)
16 October 1999, Hector Mine, CA, M_s=7,4	GOES – ΔTIR (Aliano et al., Annals of Geophysics, 2008)
21 May 2003 Zemmouri, Algery M_s=6.9	METEOSAT – ΔTIR (Aliano et al., IEEE, Multi-Temp, 2007)
26 January 2001 Gujarat, India M_s=7.7	METEOSAT – ΔTIR (Genzano et al., Tectonophysics, 2006)
23 October 1992 Mestia Tianeti, Georgia M_s=6.3	METEOSAT – ΔTIR (Genzano et al., IEEE, Multi-Temp, 2009)
6 April 2009 Abruzzo, Italy M_l=5.8	MSG/SEVIRI, NOAA/AVHRR, EOS/MODIS – ΔTIR (Genzano et al 2009, Lisi et al 2010, Pergola et al 2010; NHESS)

TIR Anomaly Monitoring by RAT

LOW (4.0 – 5.2) MAGNITUDE EQs

*Corrado et al., Natural Hazards, **5**, 2005*

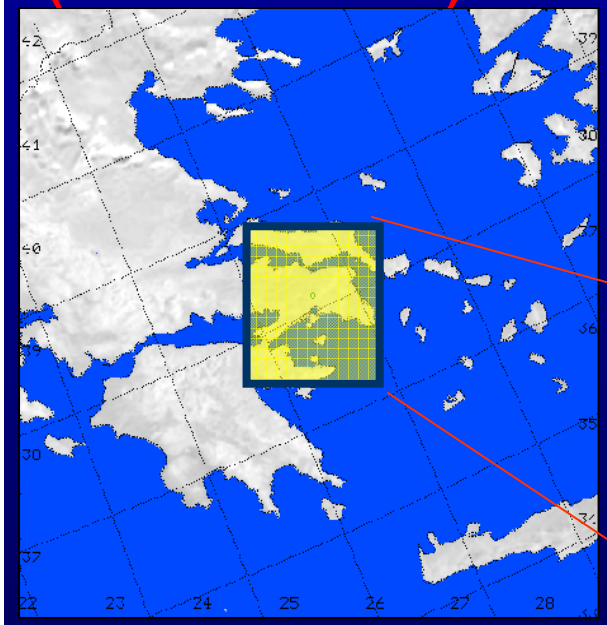
EVENT	TECHNIQUE
27 May 1995, Armenia-Azerbaijan-Iran, M_b 5.2	METEOSAT RAT–ΔTIR
29 May 1995, Cipro, M_b 5.3	METEOSAT RAT–ΔTIR
3 June 1995, Creta, M_b 4.2	METEOSAT RAT–ΔTIR
18 June 1995, Creta, M_b 4.9	METEOSAT RAT–ΔTIR
13 June 1996, Ionian Sea (Southern Greece), M_b 4.2	METEOSAT RAT–ΔTIR
16 June 1996, Patrasso (Greece), M_b 4.3	METEOSAT RAT–ΔTIR
17 June 1996, Creta, M_b 4.0	METEOSAT RAT–ΔTIR
29 June 1996, Isparta (Turkey), M_b 5.1	METEOSAT RAT–ΔTIR

7th September 1999 Athens EQ (Ms=5.9)

(Filizzola et al., *Phy. Chem.Earth, 2004*)

(AVHRR – ΔLST)

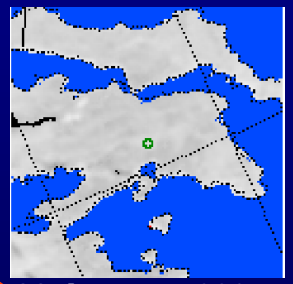
from polar data (NOAA-AVHRR)…



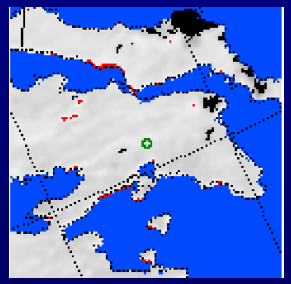
Pixels with S/N > 1.5

Epicentral area

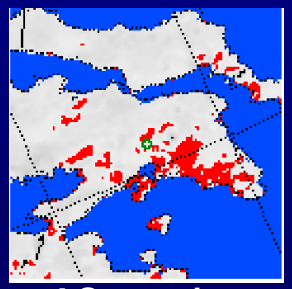
S/N>1.5



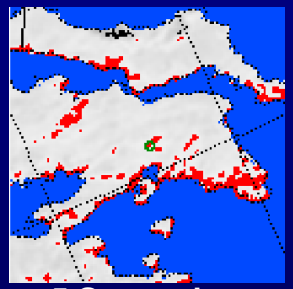
28 August 1999



2 September 1999



4 September

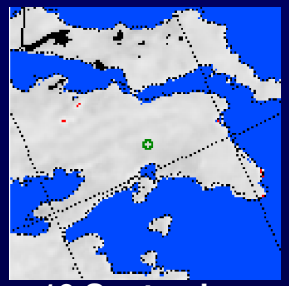


5 September

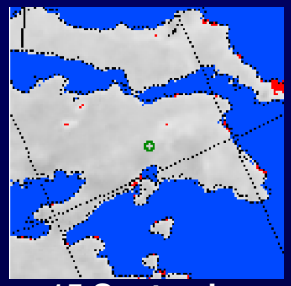
7th September 1999

Athens earthquake

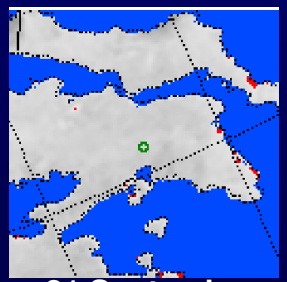
(overcast days)



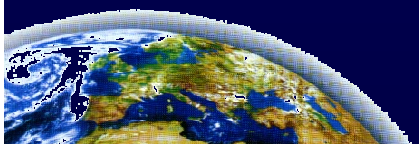
10 September



15 September



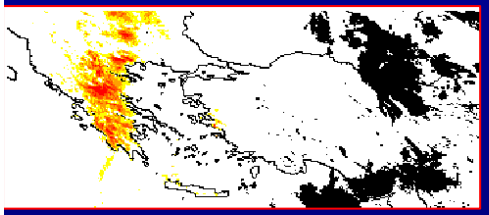
21 September



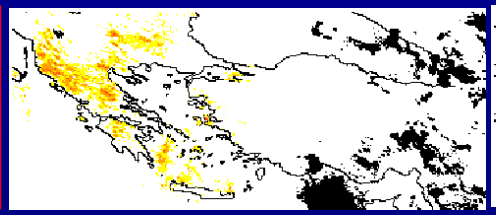
Kocaeli-Izmit (Turkey) 17 th August 1999 (Ms=7.4)

(Tramutoli et al., Remote Sensing of Environment, 2005)

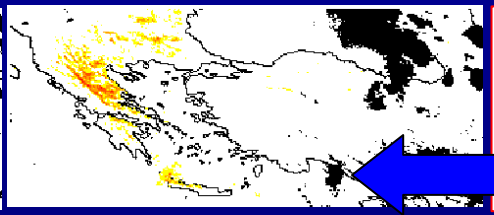
to geostationary data (Meteosat)…



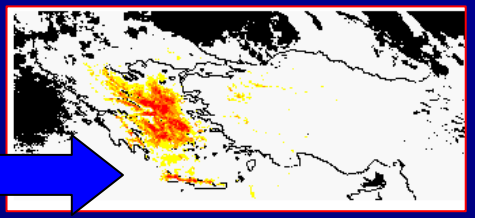
9 August 1999



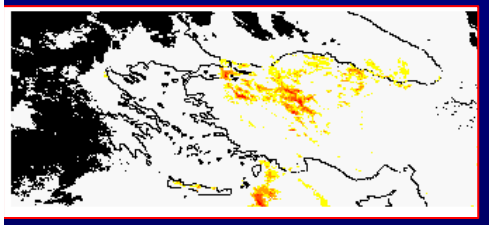
10 August 1999



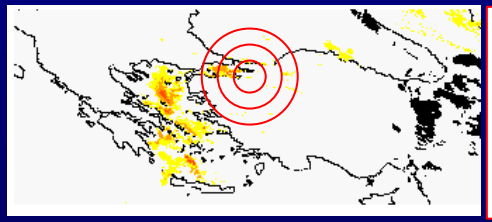
11 August 1999



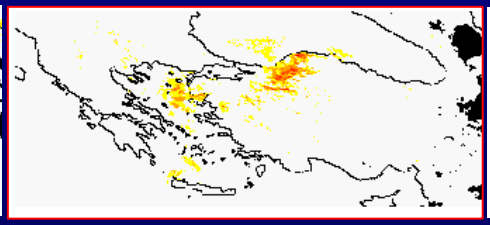
12 August 1999



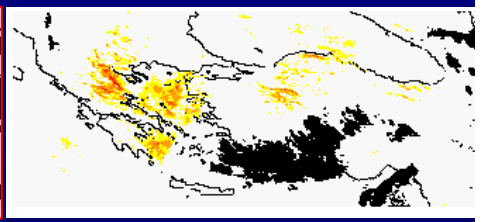
13 August 1999



17 August 1999



18 August 1999



19 August 1999

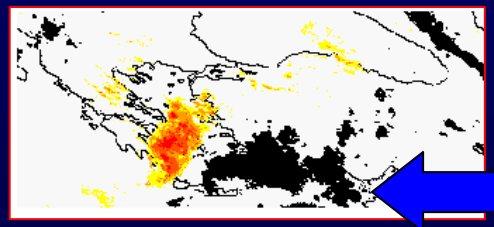
S/N> 2

S/N > 2.5

S/N > 3

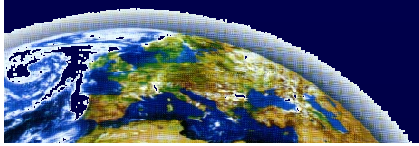
S/N > 3.5

S/N>3.5



20 August 1999

21 August 1999

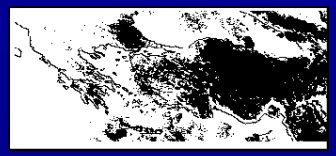


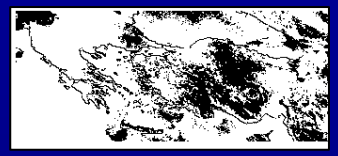
V.Tramutoli - L'Aquila, 27 Aprile 2010 - (valerio.tramutoli@unibas.it +39-3293178385)

Kocaeli-Izmit (Turkey) 17 th August 1999 (Ms=7.4)

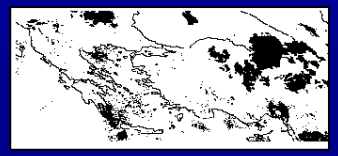
CONFUTATION-1: August 1992, No Eqs with M>5

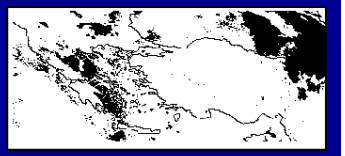
METEOSAT - ΔTIR

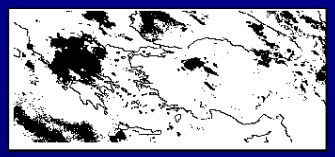

01-08-1992


02-08-1992


03-08-1992


04-08-1992


05-08-1992


06-08-1992


07-08-1992


08-08-1992


09-08-1992


10-08-1992


11-08-1992


12-08-1992


13-08-1992


14-08-1992


15-08-1992


16-08-1992


17-08-1992

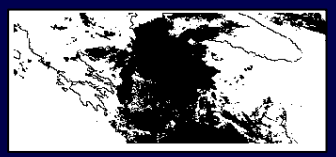

18-08-1992


19-08-1992

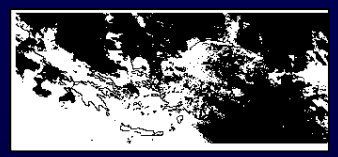

20-08-1992

No data (cloudy)

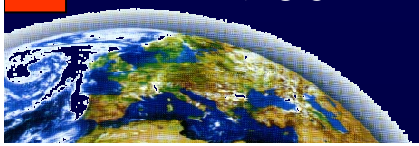
RETIRA > 3.5


21-08-1992


22-08-1992


23-08-1992


24-08-1992

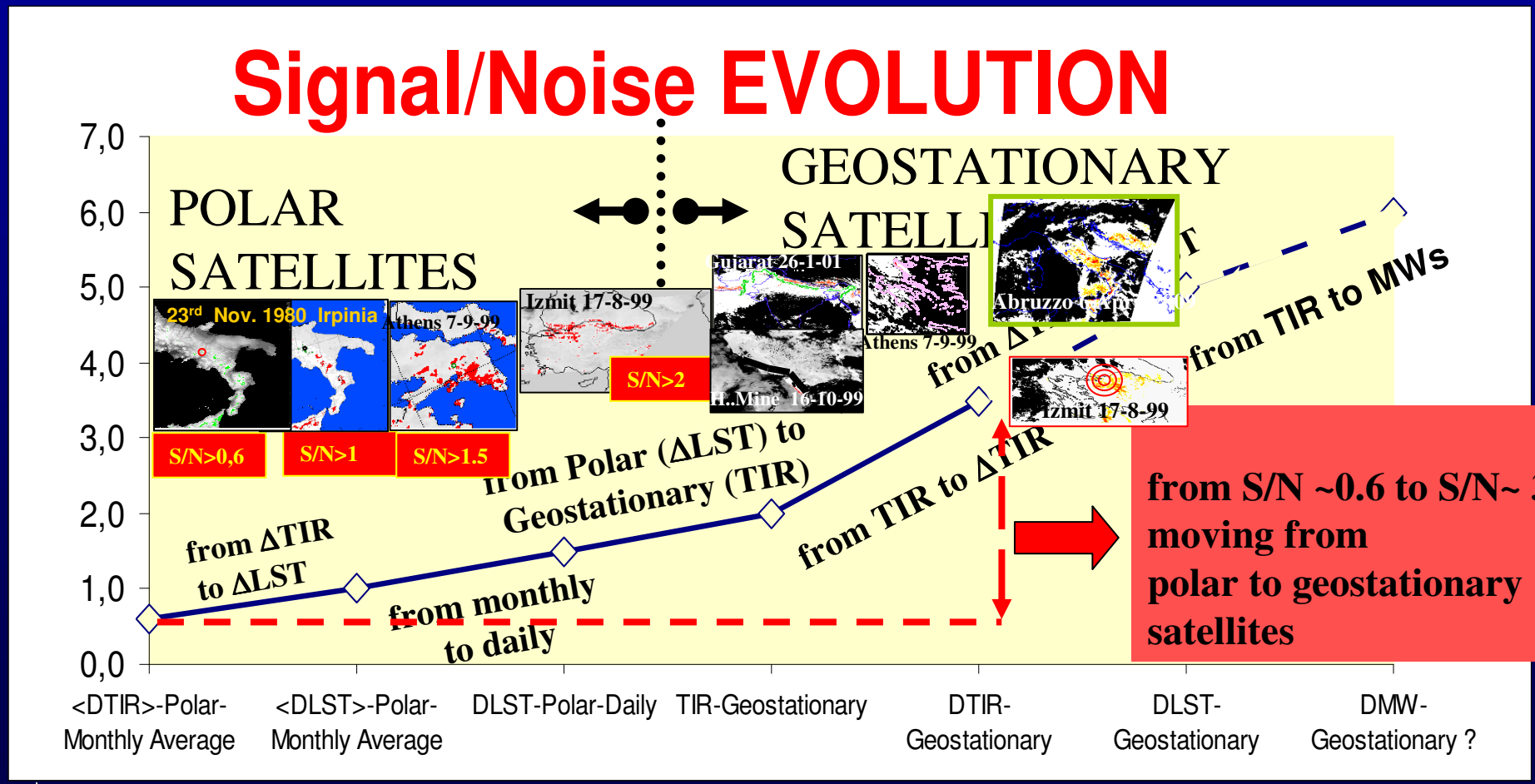


V.Tramutoli - L'Aquila, 27 Aprile 2010 - (valerio.tramutoli@unibas.it +39-3293178385)

Data Analysis

LESSON LEARNT

after RST application to GEOSTATIONARY SATELLITES

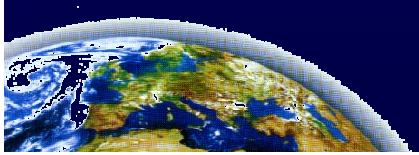


V.Tramutoli - L'Aquila, 27 Aprile 2010 - (valerio.tramutoli@unibas.it +39-3293178385)

RST analysis over Italy at the time of Abruzzo earthquakes (April 6th 2009, Ml~5.8)

Used satellite TIR data:

Satellite/Sensor	Channel Number (Wavelength-μm)	Used data-sets			Number images
		Years	*Months*	*Time*	
MSG/SEVIRI (Genzano et al., 2009 - NHESS)	9 (9.80-11.80)	2005-2009	March-April	24:00 GMT	232
EOS/MODIS (Pergola et al., 2010 - NHESS)	31 (10.78-11.28)	2000-2009	March-April	24:00-02:00 GMT	492
NOAA/AVHRR (Lisi et al., 2010 - NHESS)	4 (10.50-11.50)	1995-2009	March-April	24:00-02:00 GMT	408
	Historical data-set of 30 years				Total images 1132

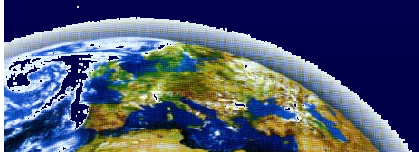


V.Tramutoli - L'Aquila, 27 Aprile 2010 - (valerio.tramutoli@unibas.it +39-3293178385)

RST analysis over Italy at the time of Abruzzo earthquakes (April 6th 2009, Ml~5.8)

VALIDATION
(March 15th – April 15th 2009)

CONFUTATION
(March 15th – April 15th 2008)



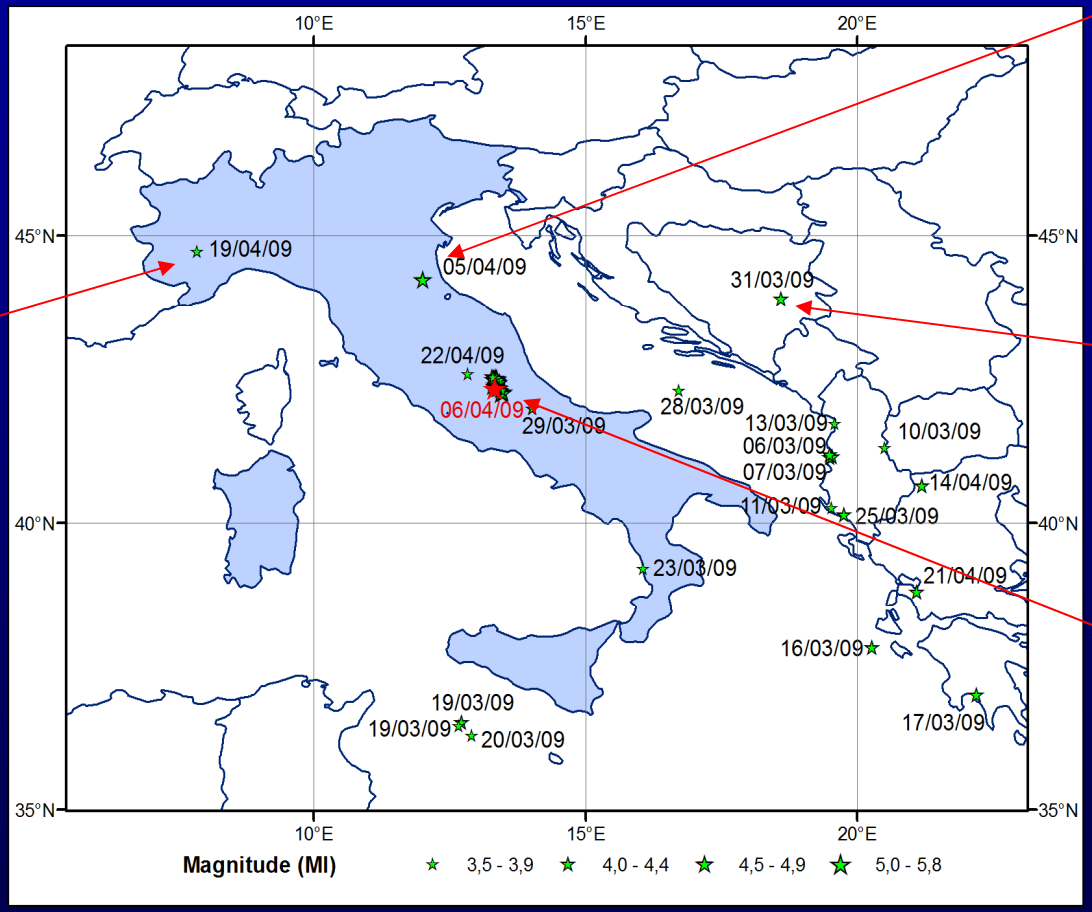
VALIDATION (March 15th – April 15th 2009)

Forlì
05/04/2009 Ml 4.6

Bra (Cuneo)
19/04/2009
Ml 3.9

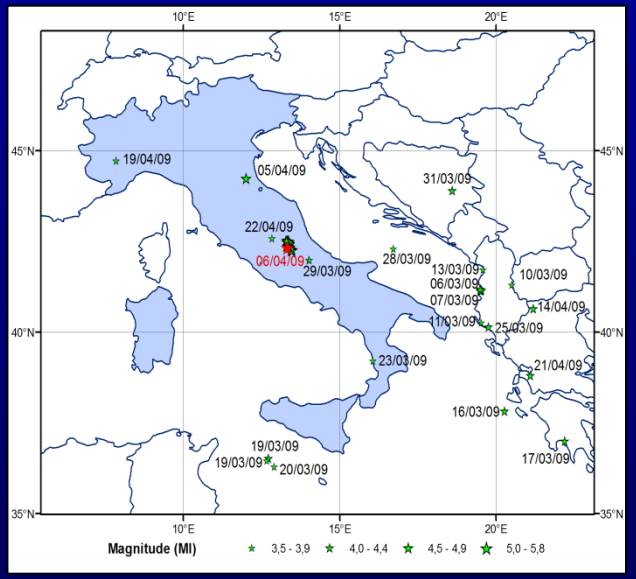
Bosnia
31/03/2009 Ml 4.2

L'Aquila
06/04/2009 Ml 5.8
07/04/2009 Ml 5.3
09/04/2009 Ml 5.1

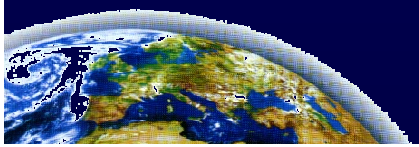


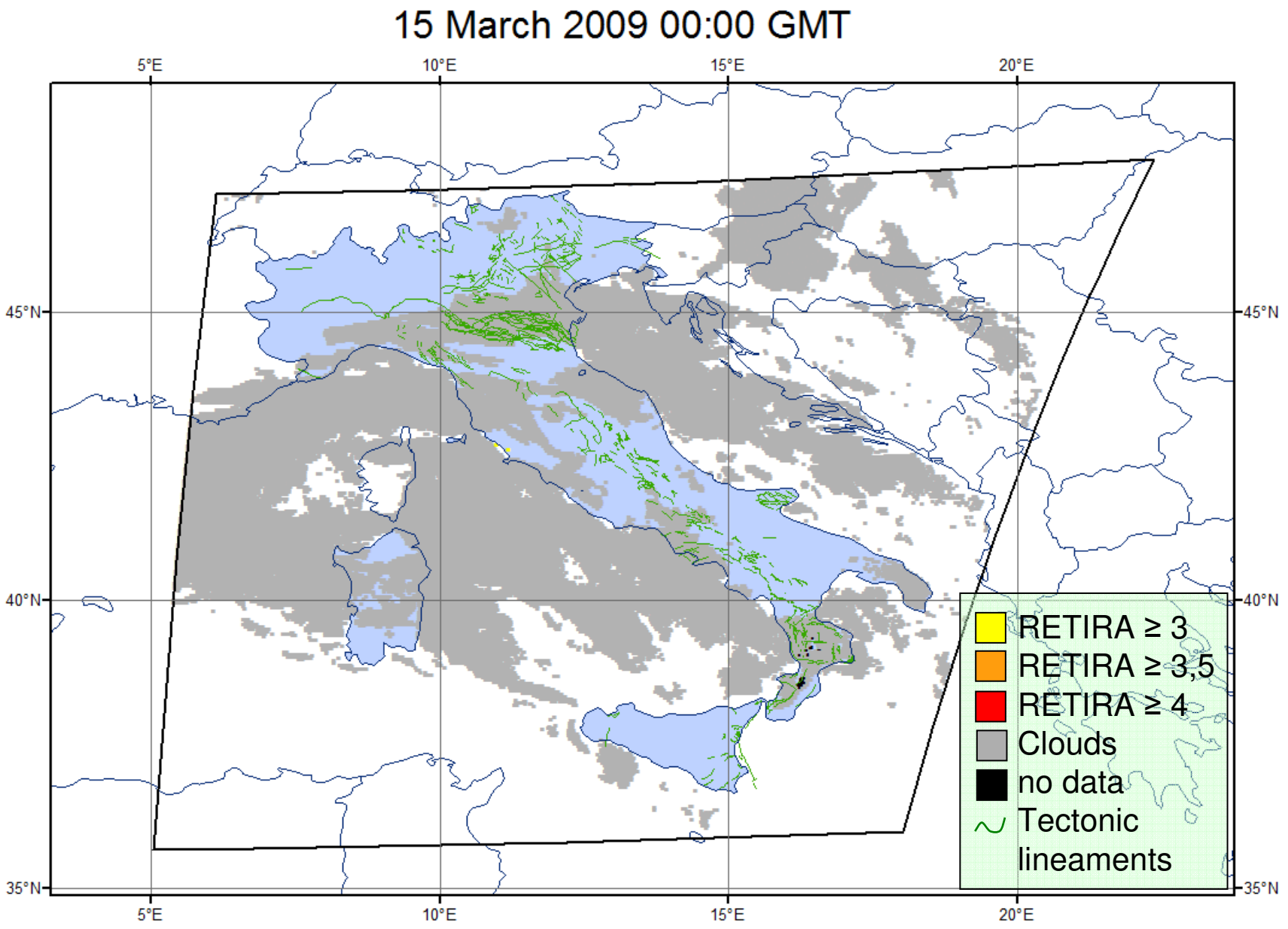
Seismic events (Ml≥3.5) occurred during March-April 2009 (INGV, 2009)

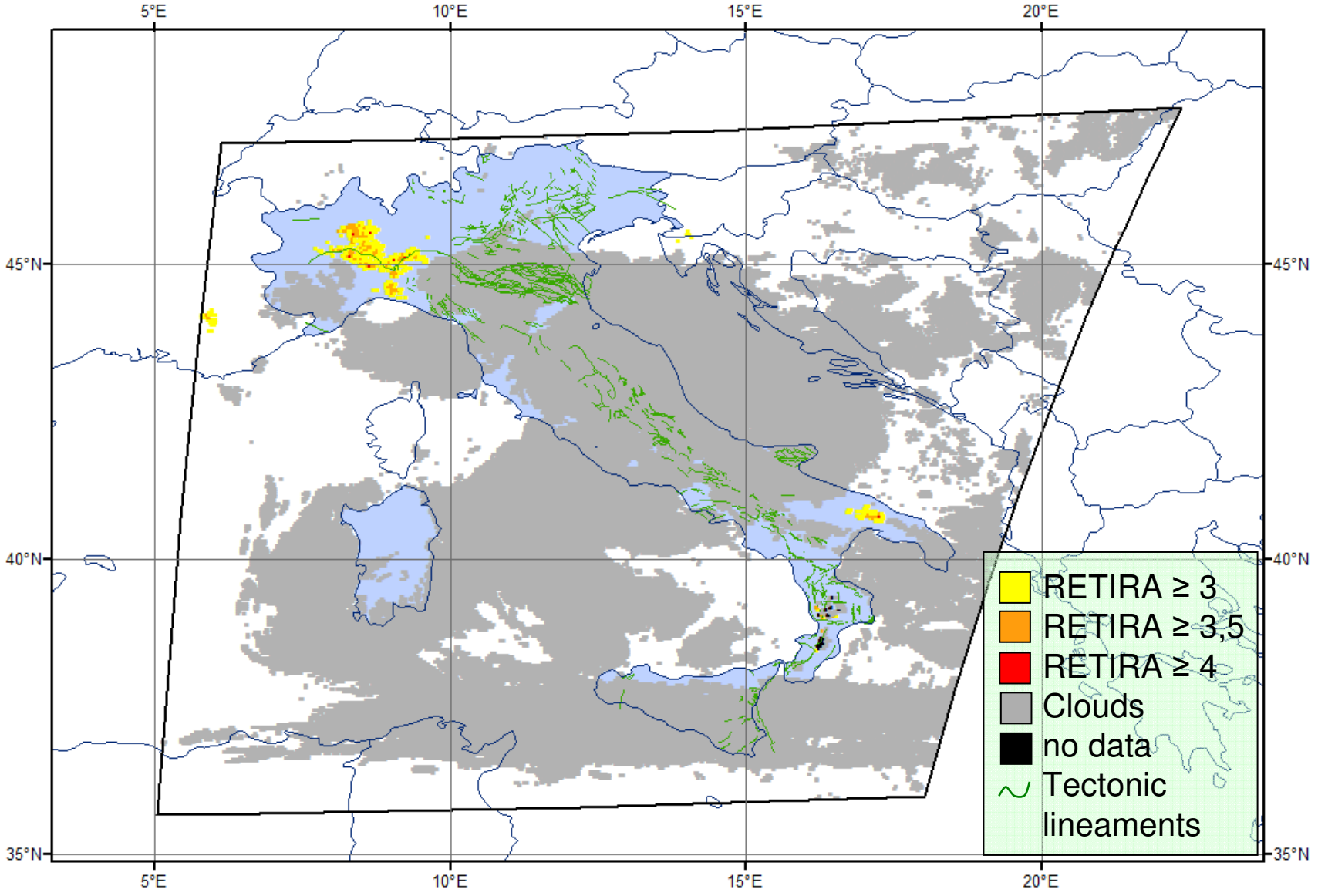
VALIDATION (March 15th – April 15th 2009)

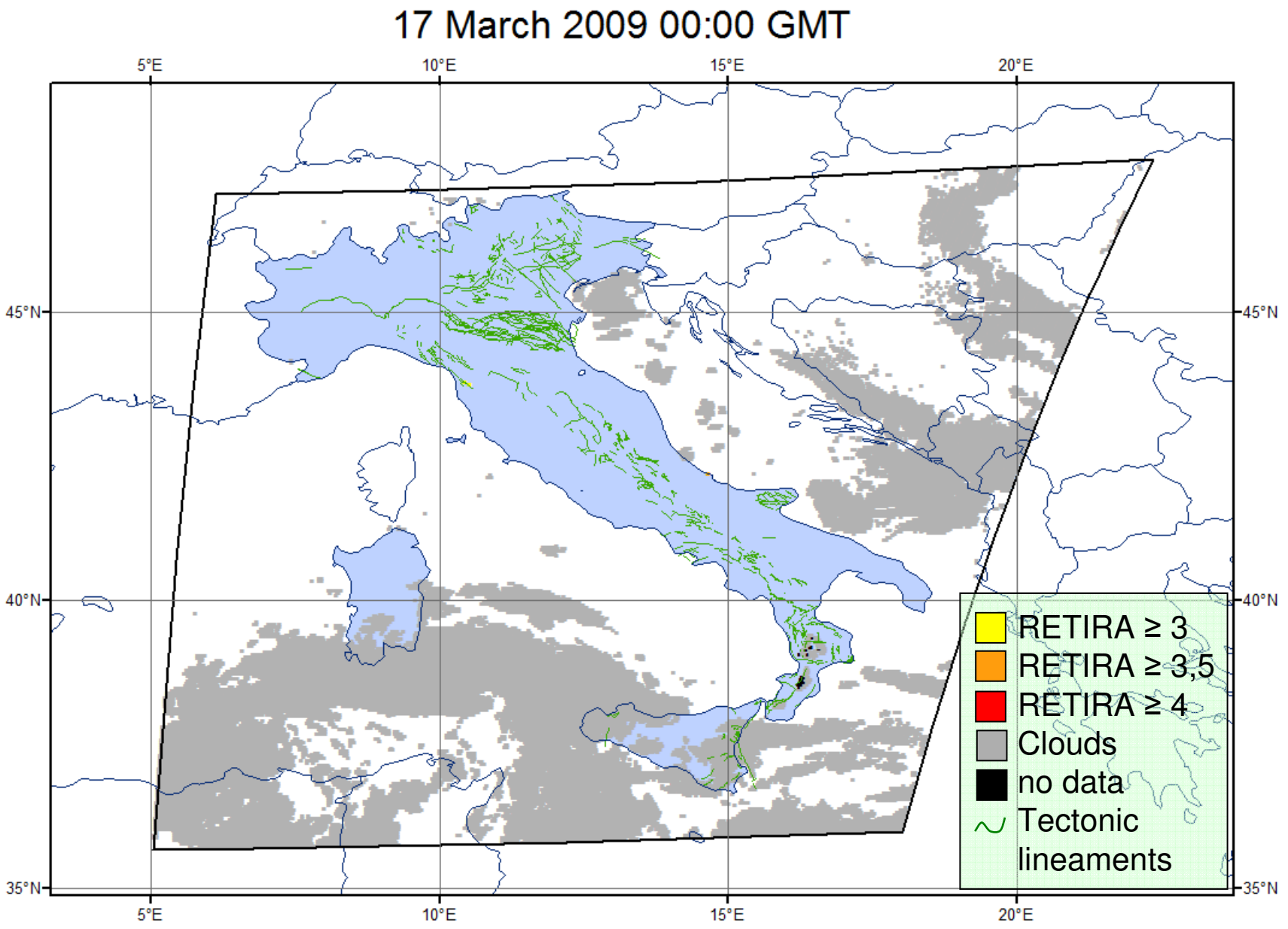


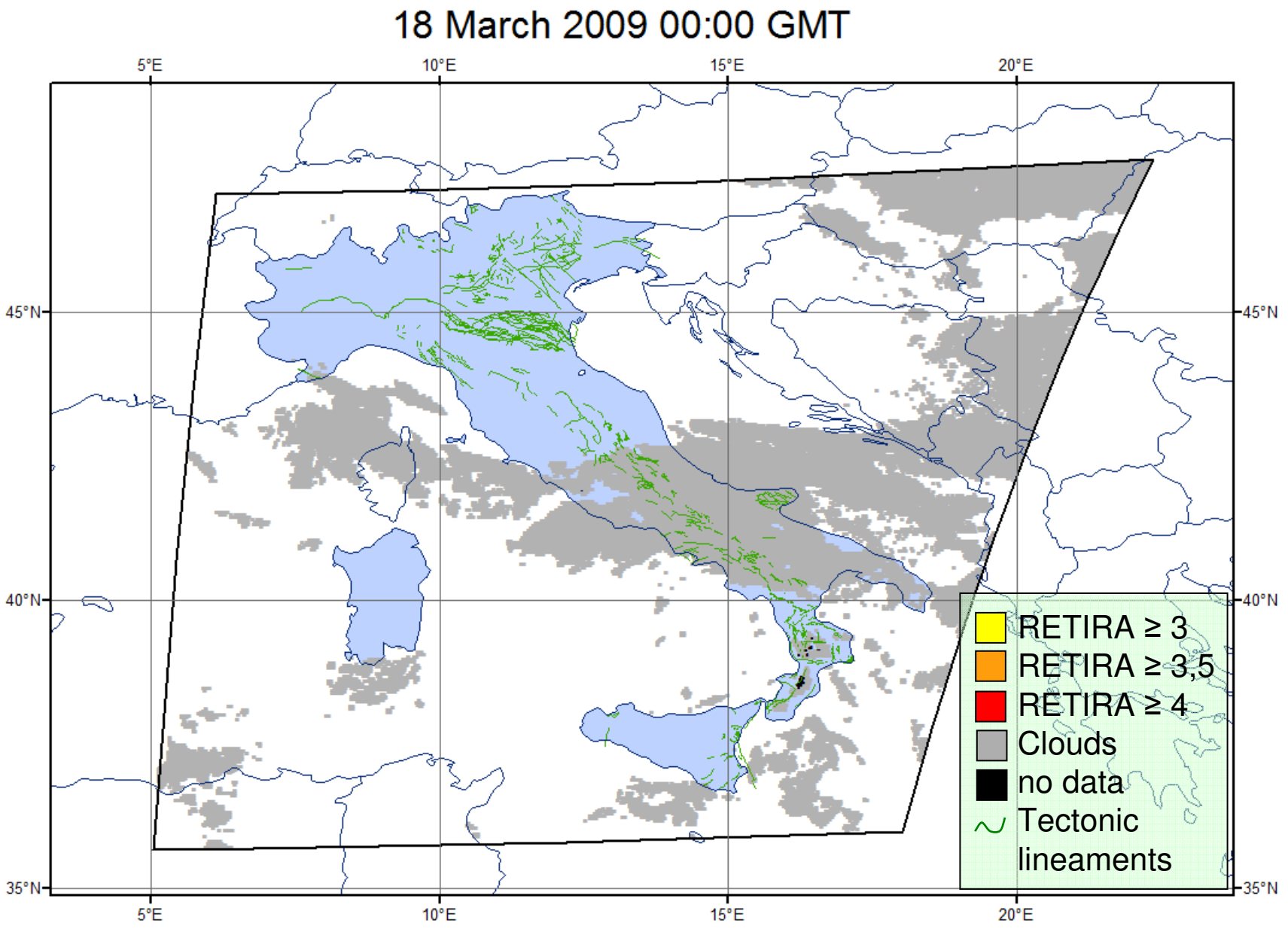
RETIRA ≥ 3
RETIRA ≥ 3,5
RETIRA ≥ 4
clouds
no data
Tectonic lineaments

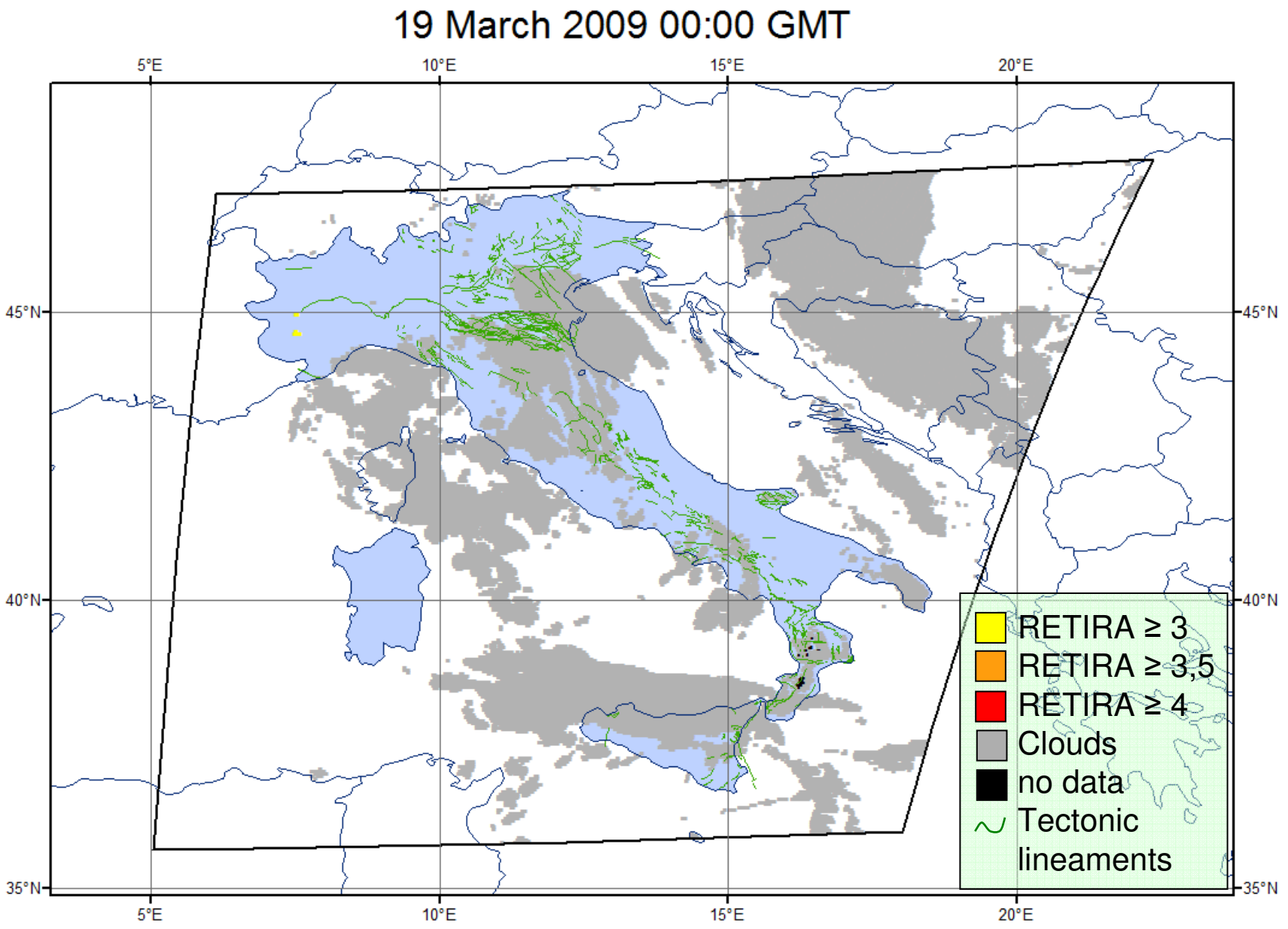


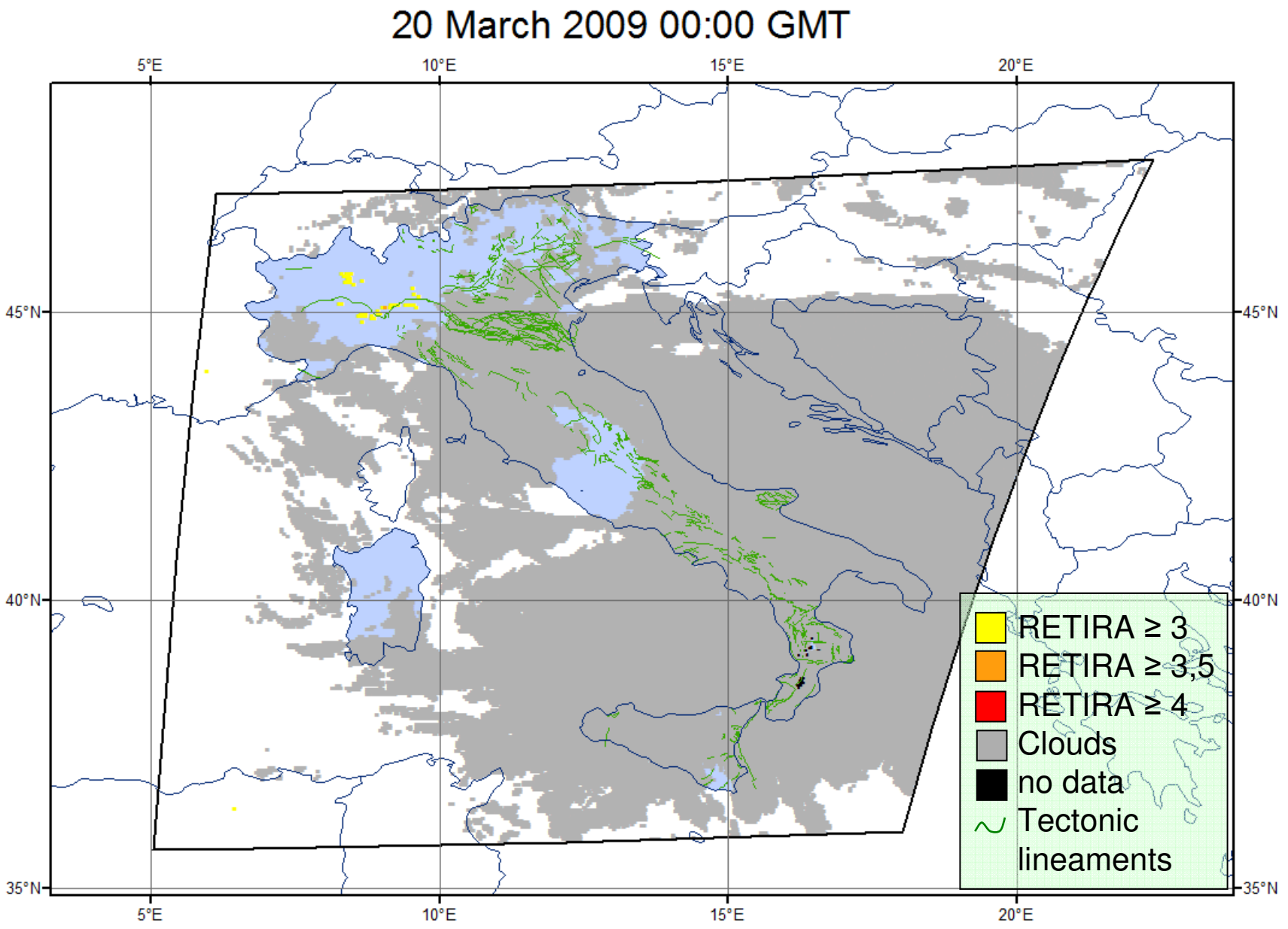

15 March 2009 00:00 GMT
5°E
10°E
15°E
20°E
45°N
40°N
35°N
RETIRA ≥ 3
RETIRA ≥ 3,5
RETIRA ≥ 4
Clouds
no data
Tectonic lineaments

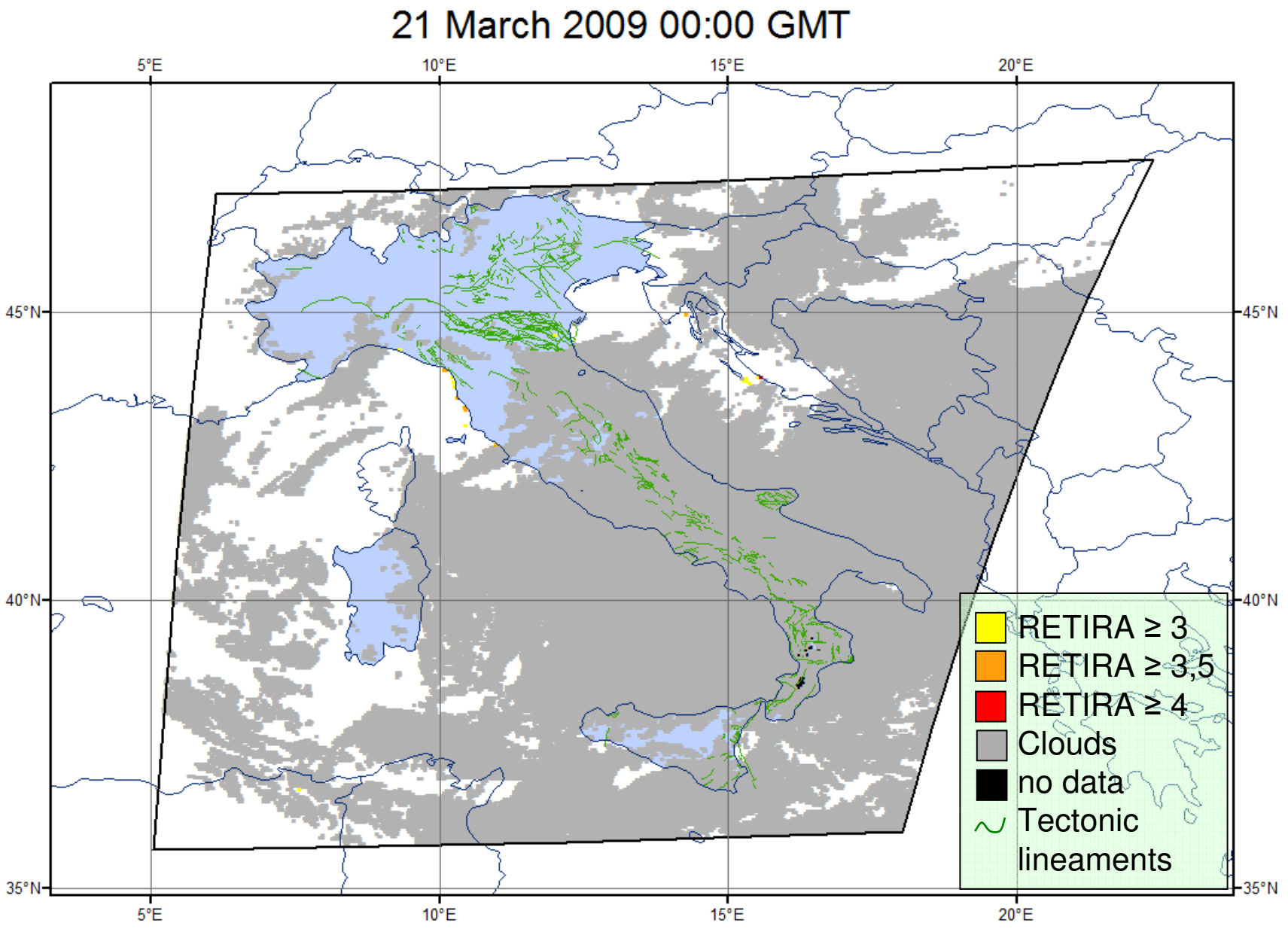

16 March 2009 00:00 GMT
5°E
10°E
15°E
20°E
45°N
40°N
35°N
RETIRA ≥ 3
RETIRA ≥ 3,5
RETIRA ≥ 4
Clouds
no data
Tectonic lineaments

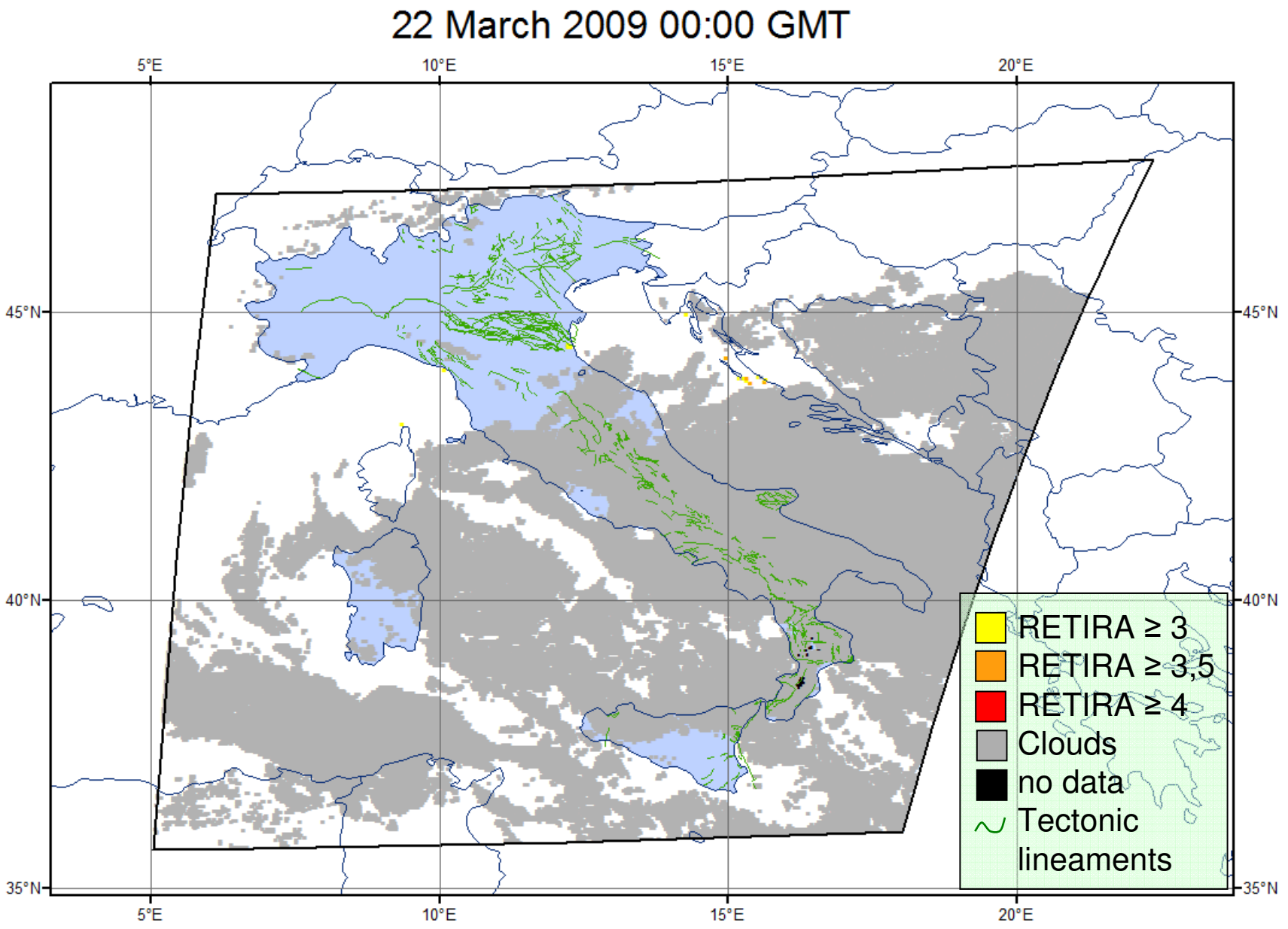

17 March 2009 00:00 GMT
5°E
10°E
15°E
20°E
45°N
40°N
35°N
RETIRA ≥ 3
RETIRA ≥ 3,5
RETIRA ≥ 4
Clouds
no data
Tectonic lineaments

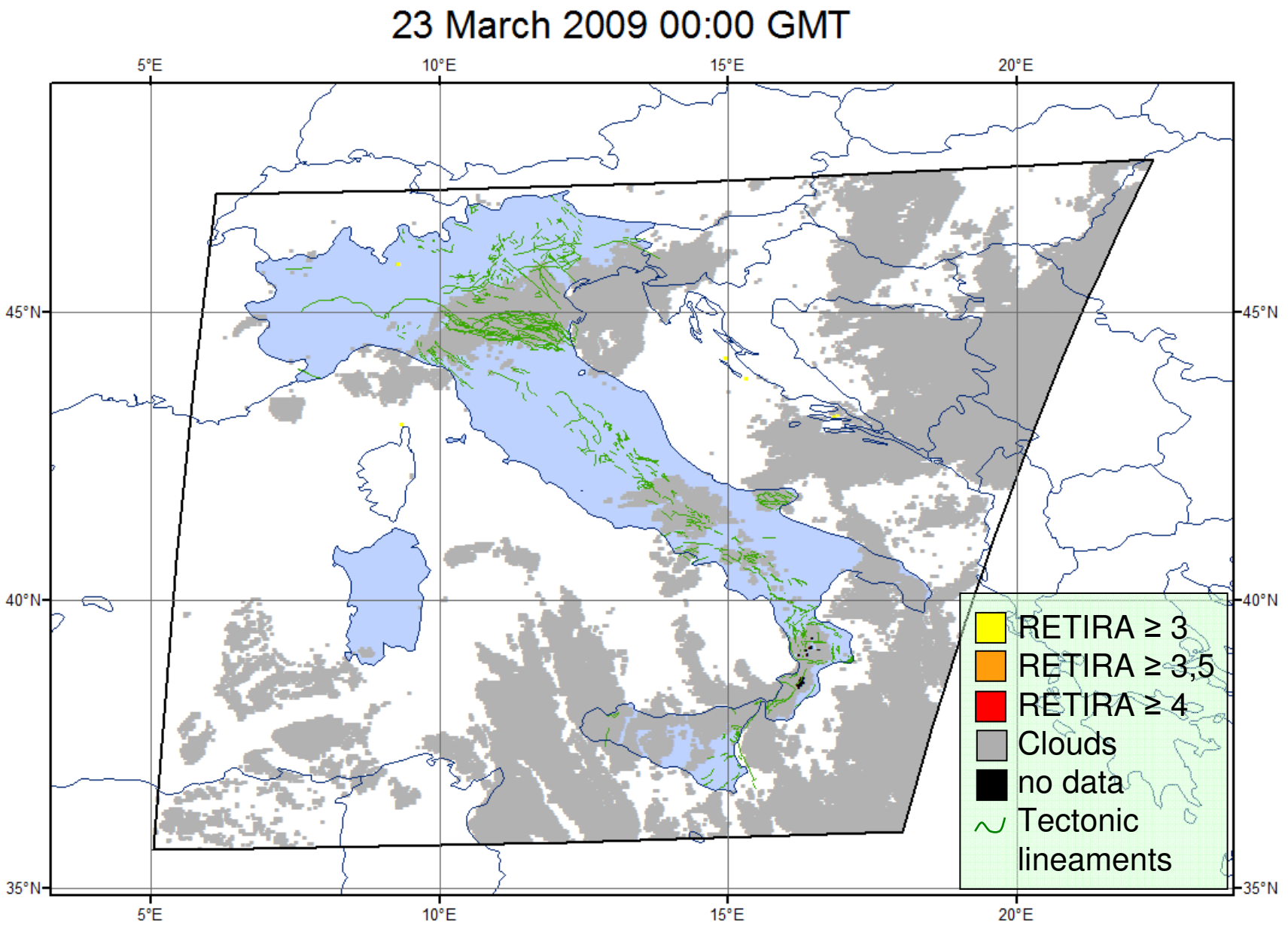

18 March 2009 00:00 GMT
5°E
10°E
15°E
20°E
45°N
40°N
35°N
RETIRA ≥ 3
RETIRA ≥ 3,5
RETIRA ≥ 4
Clouds
no data
Tectonic lineaments

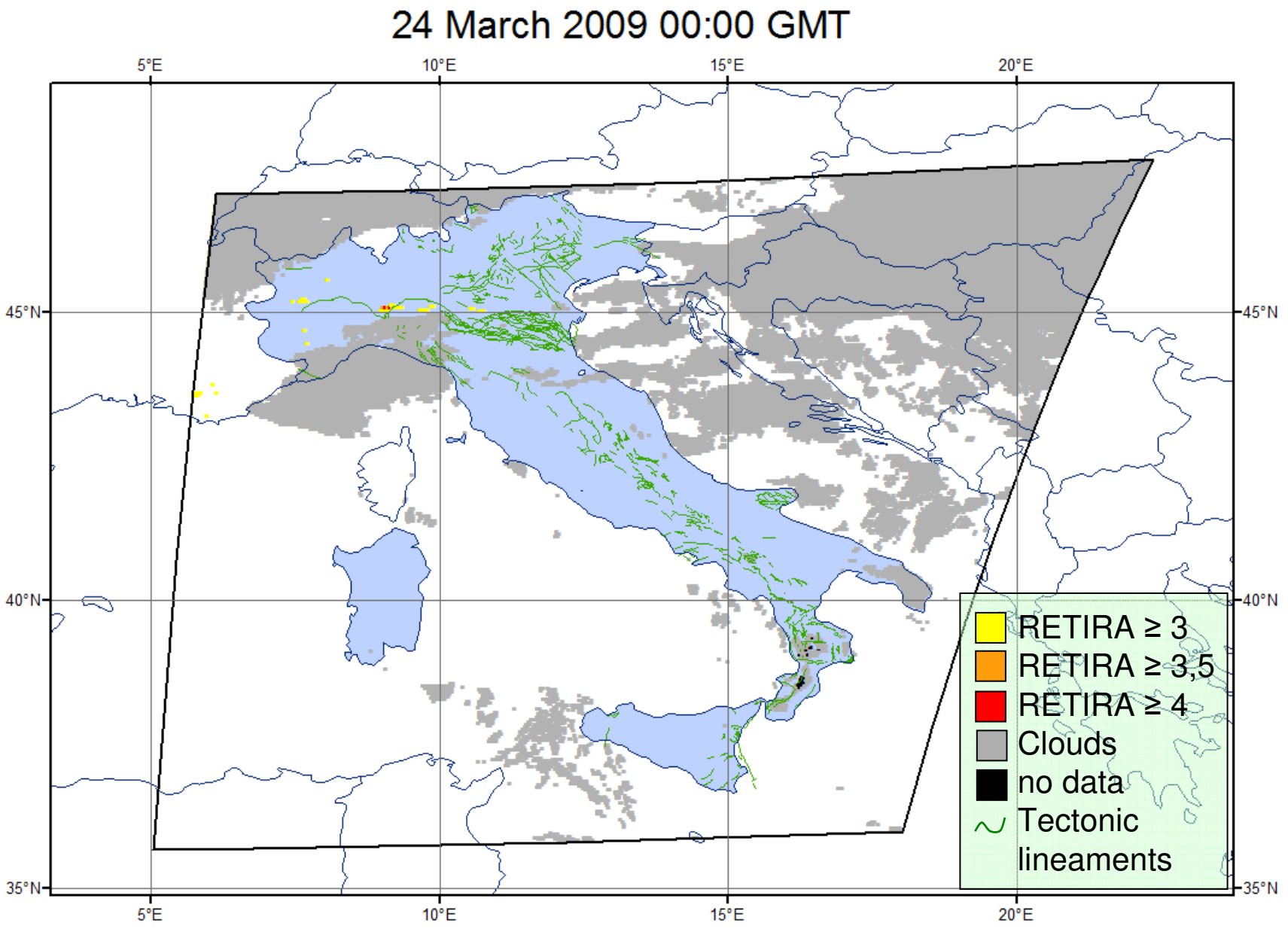

19 March 2009 00:00 GMT
5°E
10°E
15°E
20°E
45°N
40°N
35°N
RETIRA ≥ 3
RETIRA ≥ 3,5
RETIRA ≥ 4
Clouds
no data
Tectonic lineaments

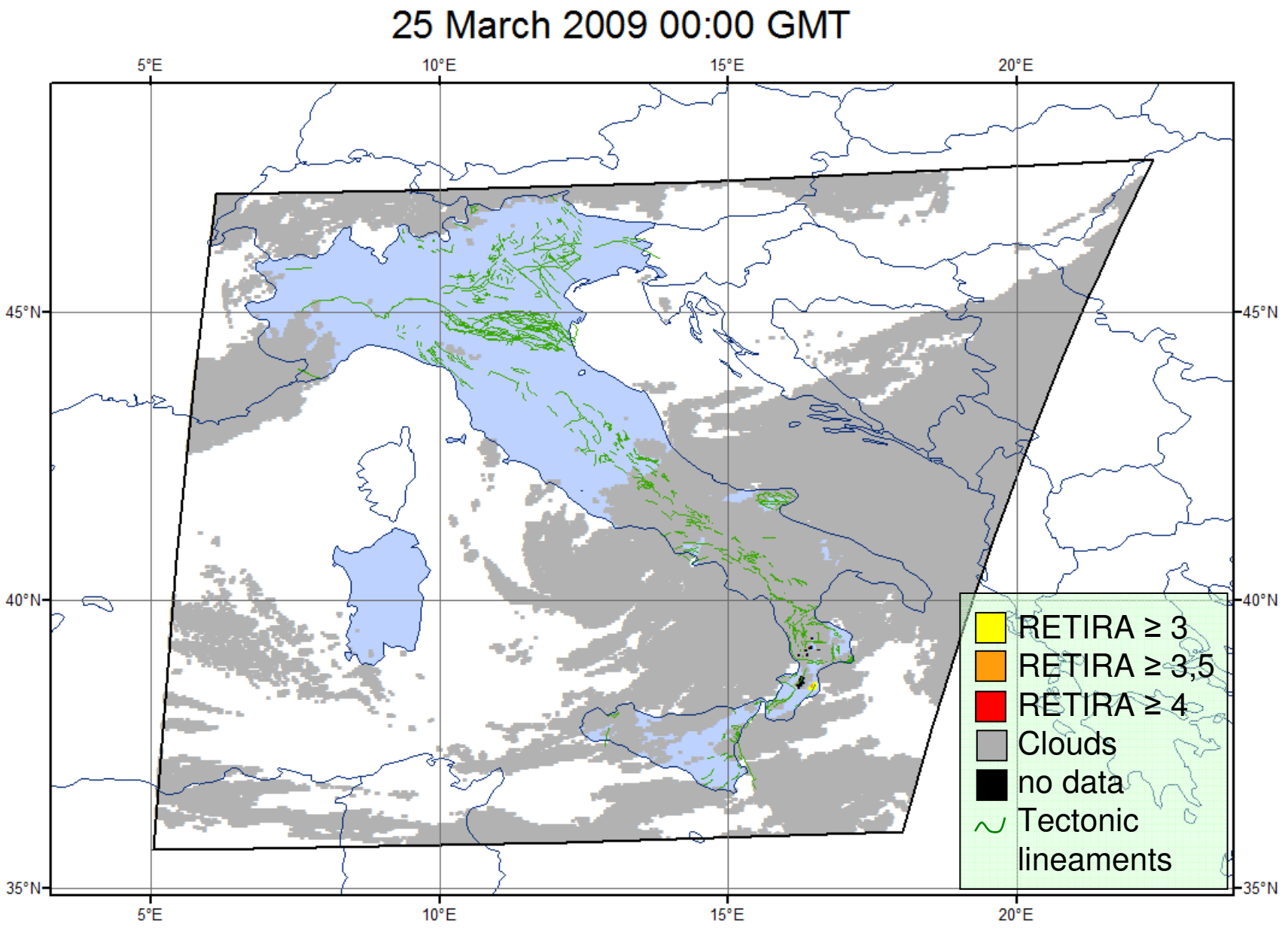

20 March 2009 00:00 GMT
5°E
10°E
15°E
20°E
45°N
40°N
35°N
RETIRA ≥ 3
RETIRA ≥ 3,5
RETIRA ≥ 4
Clouds
no data
Tectonic lineaments

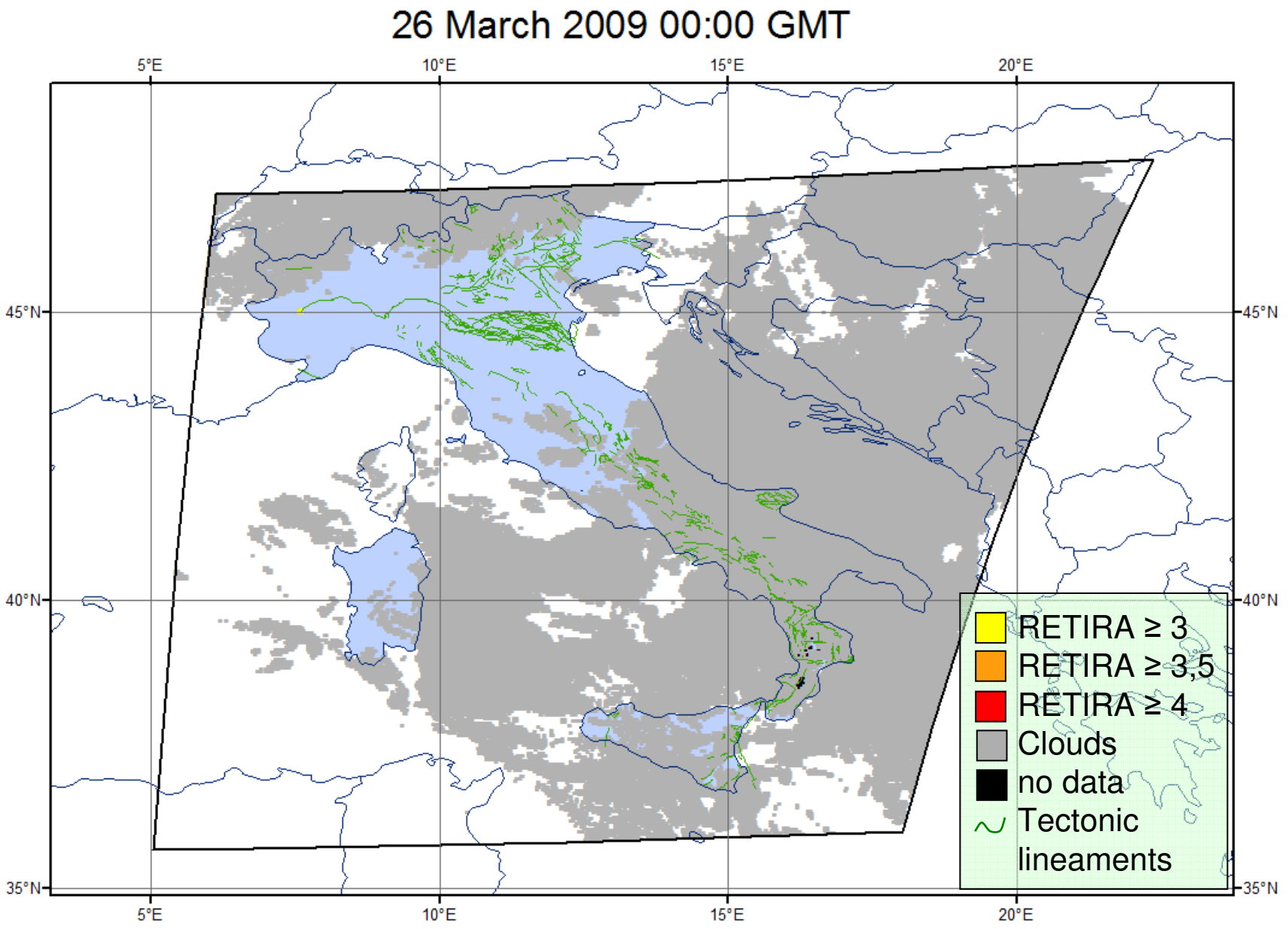

21 March 2009 00:00 GMT
5°E
10°E
15°E
20°E
45°N
40°N
35°N
RETIRA ≥ 3
RETIRA ≥ 3,5
RETIRA ≥ 4
Clouds
no data
Tectonic lineaments

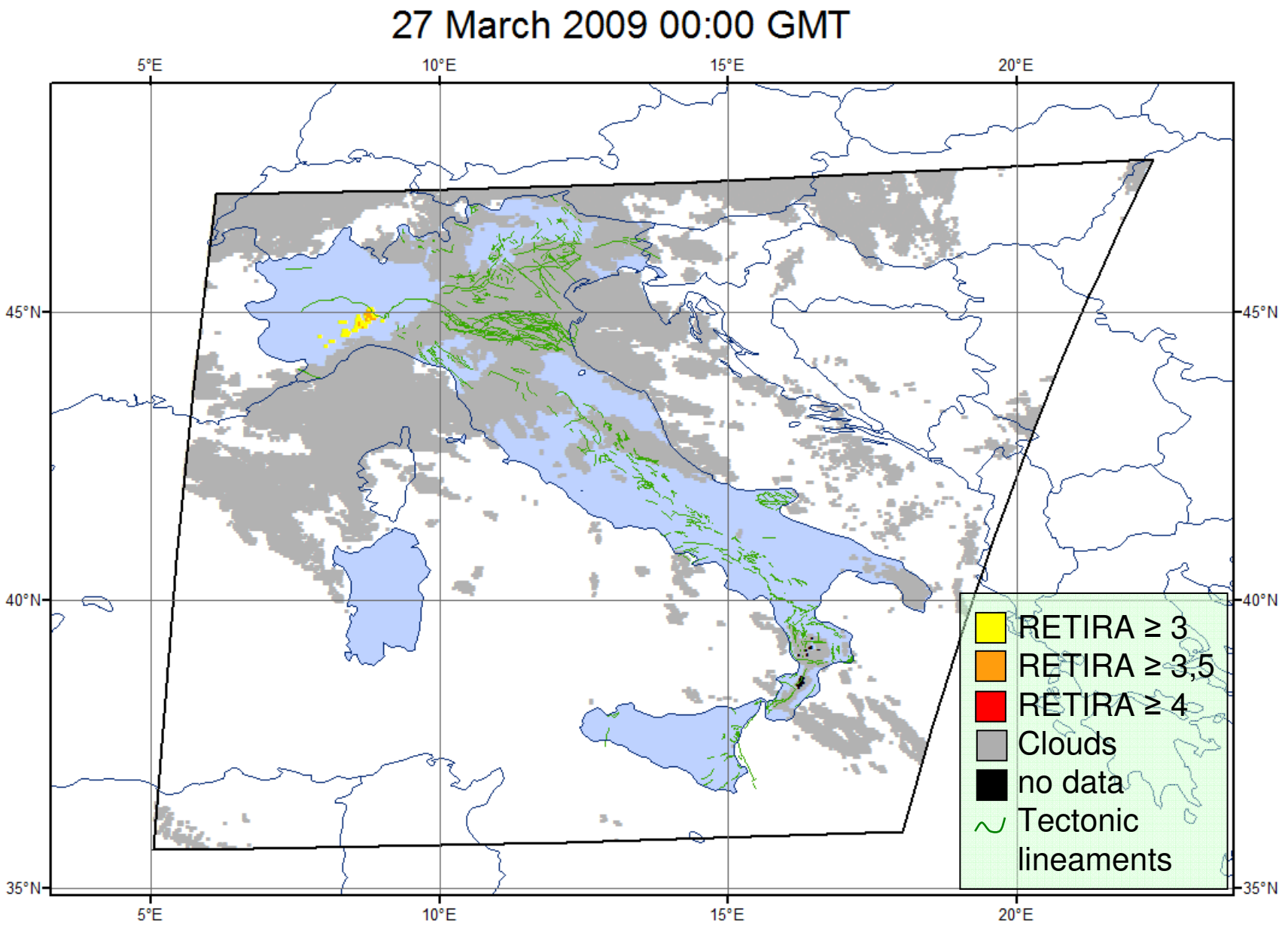

22 March 2009 00:00 GMT
5°E
10°E
15°E
20°E
45°N
40°N
35°N
RETIRA ≥ 3
RETIRA ≥ 3,5
RETIRA ≥ 4
Clouds
no data
Tectonic lineaments

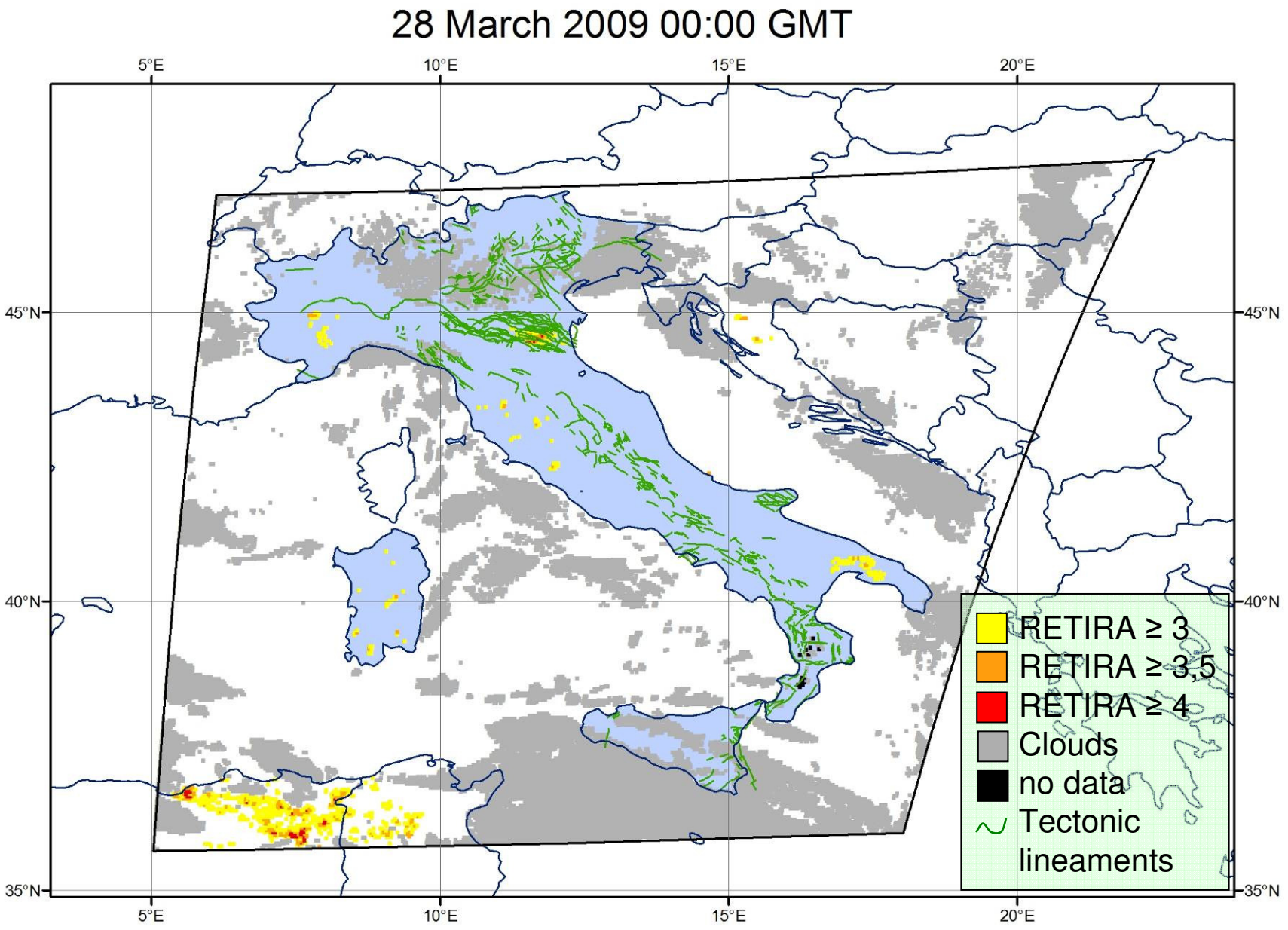

23 March 2009 00:00 GMT
5°E
10°E
15°E
20°E
45°N
40°N
35°N
RETIRA ≥ 3
RETIRA ≥ 3,5
RETIRA ≥ 4
Clouds
no data
Tectonic lineaments


24 March 2009 00:00 GMT
5°E
10°E
15°E
20°E
45°N
40°N
35°N
RETIRA ≥ 3
RETIRA ≥ 3,5
RETIRA ≥ 4
Clouds
no data
Tectonic lineaments


25 March 2009 00:00 GMT
5°E
10°E
15°E
20°E
45°N
40°N
35°N
RETIRA ≥ 3
RETIRA ≥ 3,5
RETIRA ≥ 4
Clouds
no data
Tectonic lineaments


26 March 2009 00:00 GMT
5°E
10°E
15°E
20°E
45°N
40°N
35°N
RETIRA ≥ 3
RETIRA ≥ 3,5
RETIRA ≥ 4
Clouds
no data
Tectonic lineaments


27 March 2009 00:00 GMT
5°E
10°E
15°E
20°E
45°N
40°N
35°N
RETIRA ≥ 3
RETIRA ≥ 3,5
RETIRA ≥ 4
Clouds
no data
Tectonic lineaments


28 March 2009 00:00 GMT
5°E
10°E
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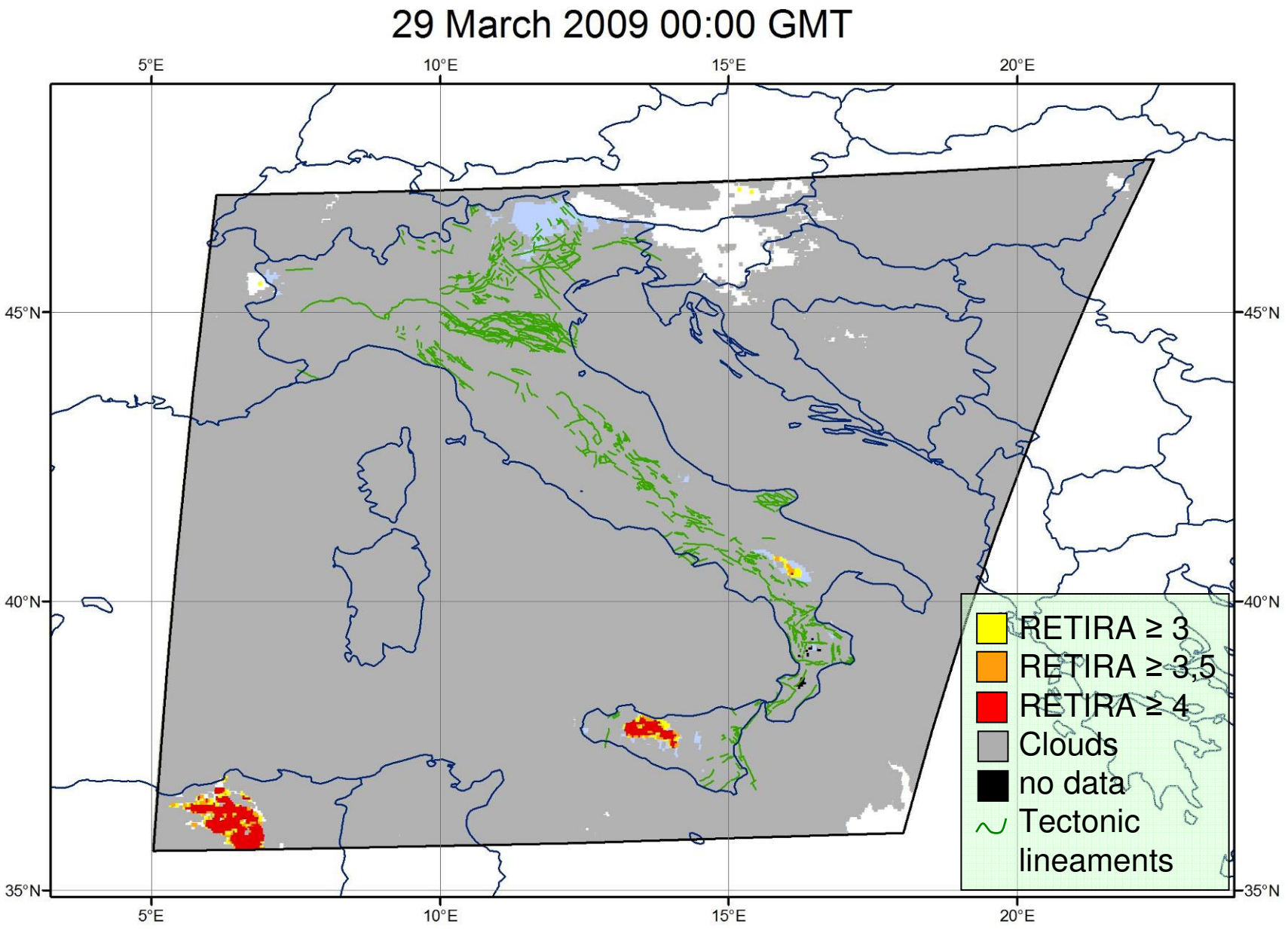
45°N
40°N
35°N
RETIRA ≥ 3
RETIRA ≥ 3,5
RETIRA ≥ 4
Clouds
no data
Tectonic lineaments


29 March 2009 00:00 GMT
5°E
10°E
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20°E
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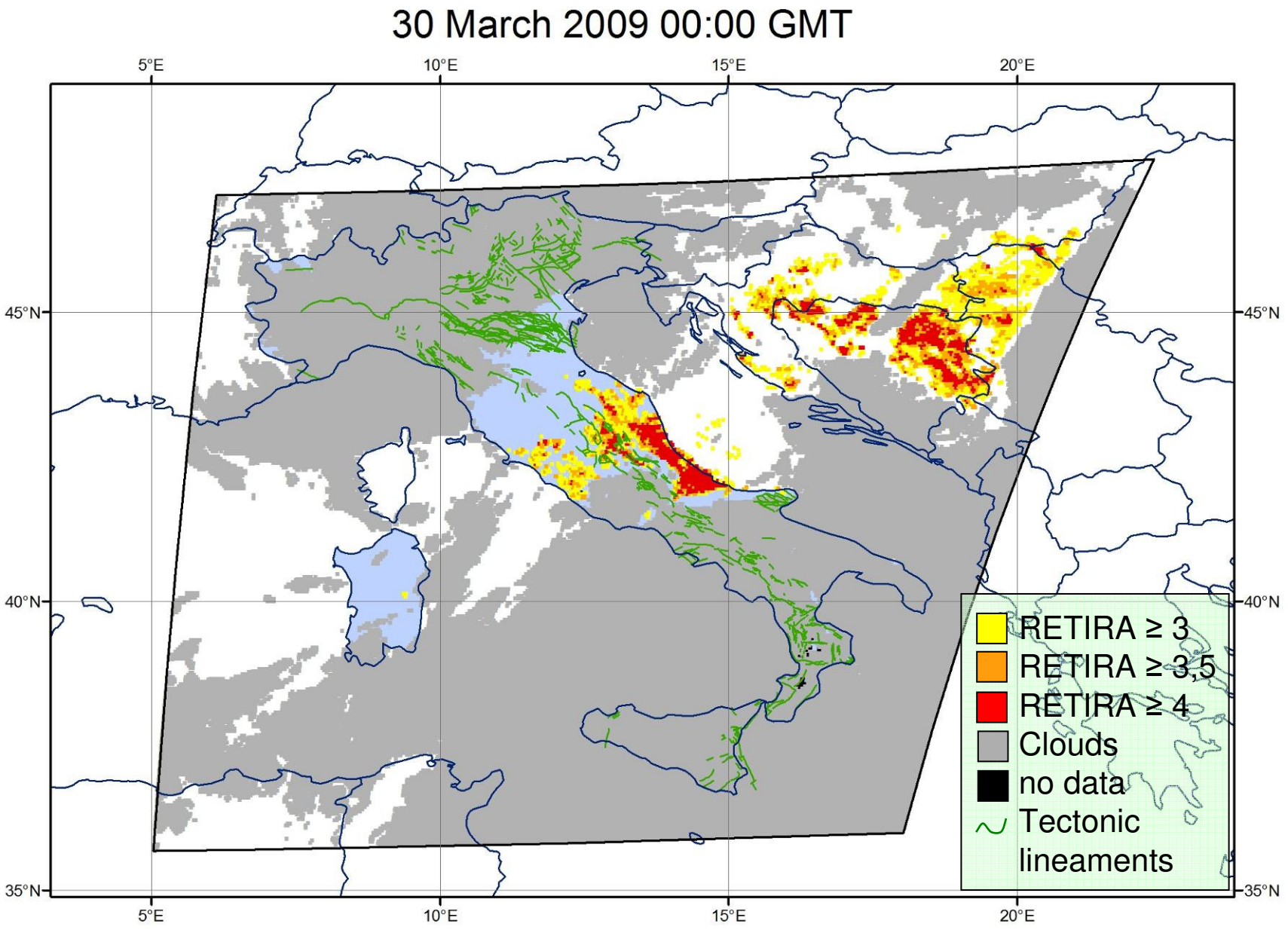
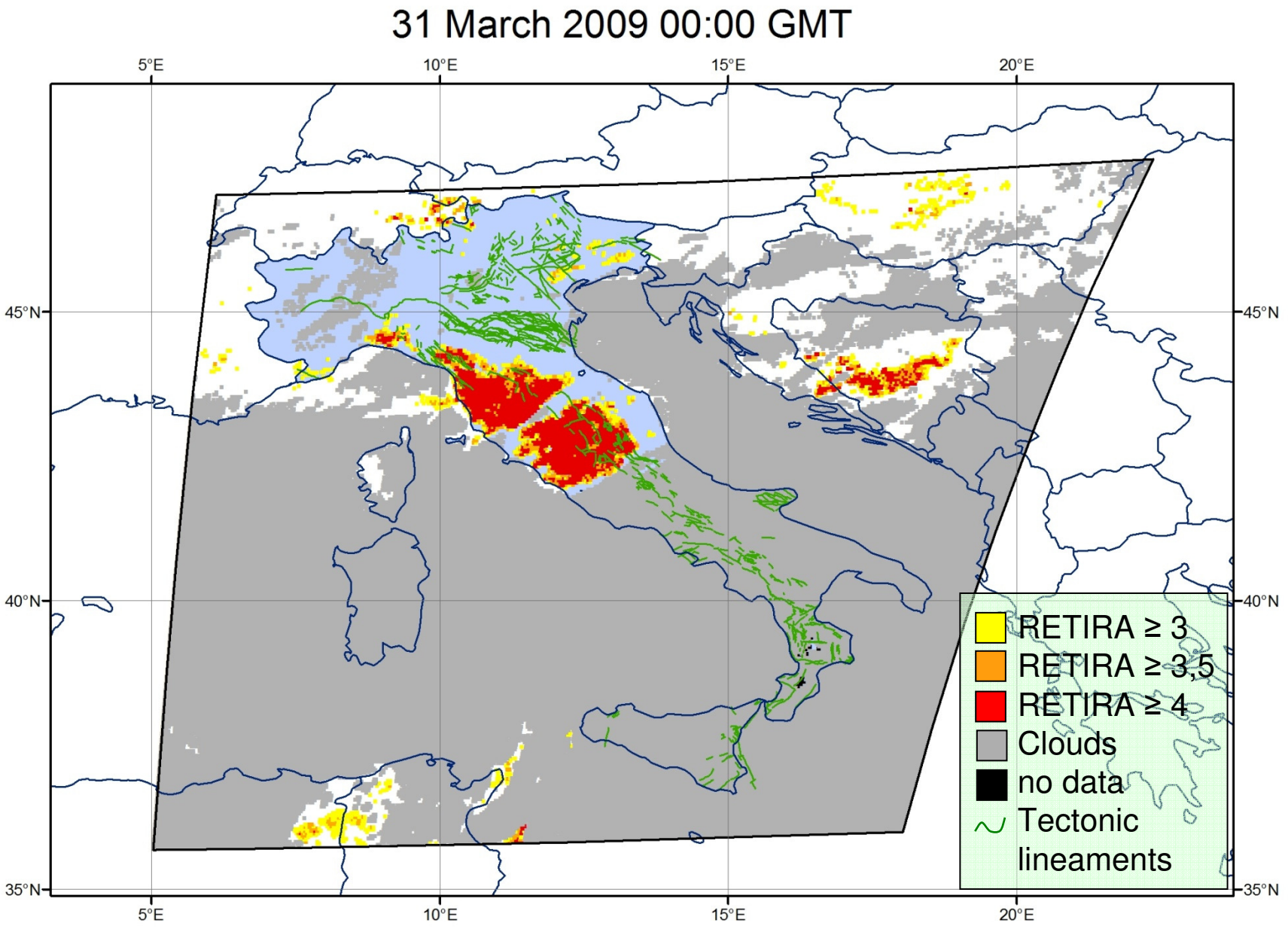
40°N
35°N
RETIRA ≥ 3
RETIRA ≥ 3,5
RETIRA ≥ 4
Clouds
no data
Tectonic lineaments


30 March 2009 00:00 GMT
5°E
10°E
15°E
20°E
45°N
40°N
35°N
RETIRA ≥ 3
RETIRA ≥ 3,5
RETIRA ≥ 4
Clouds
no data
Tectonic lineaments


31 March 2009 00:00 GMT
5°E
10°E
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20°E
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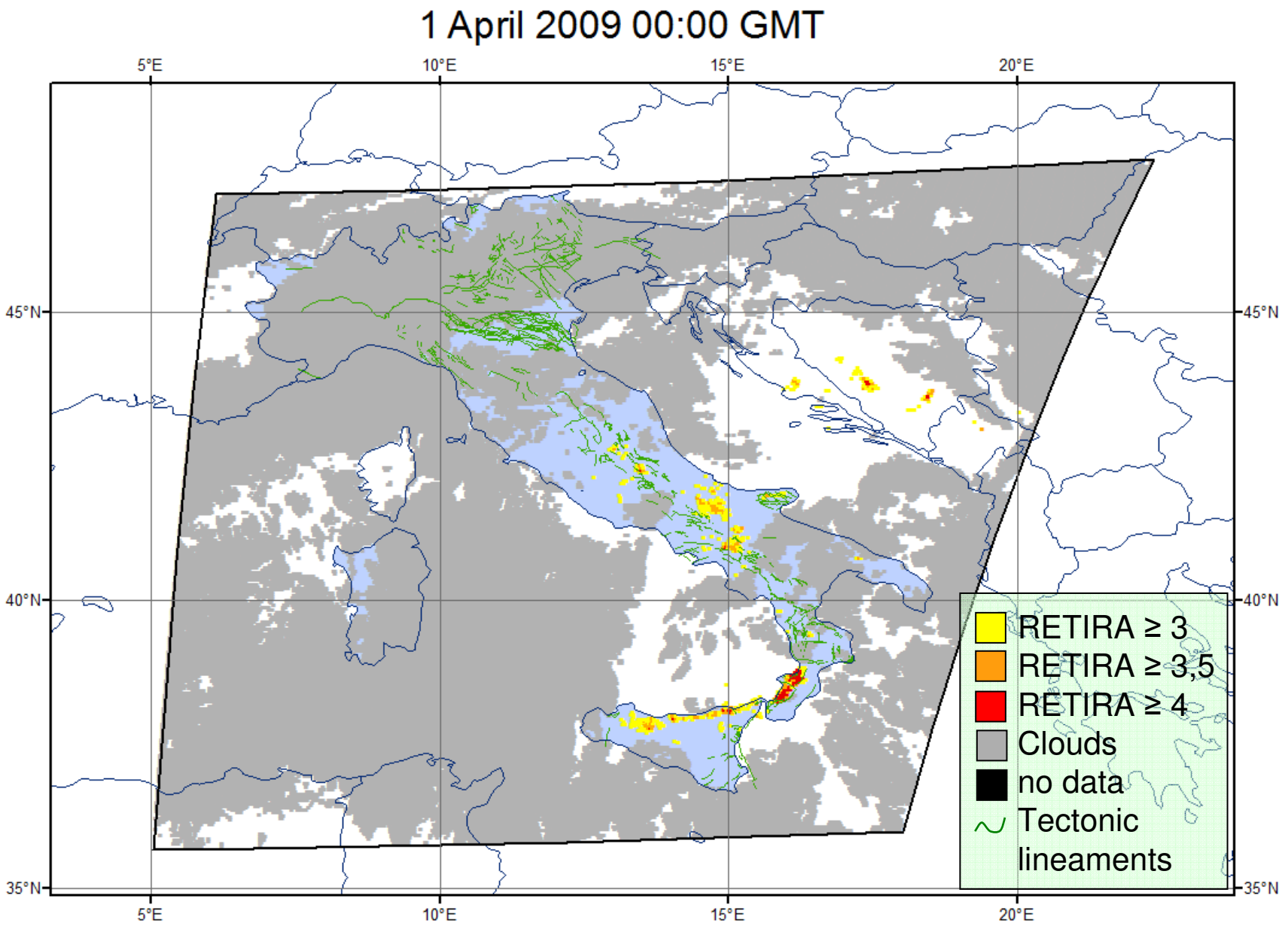
40°N
35°N
RETIRA ≥ 3
RETIRA ≥ 3,5
RETIRA ≥ 4
Clouds
no data
Tectonic lineaments


1 April 2009 00:00 GMT
5°E
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15°E
20°E
45°N
40°N
35°N
RETIRA ≥ 3
RETIRA ≥ 3,5
RETIRA ≥ 4
Clouds
no data
Tectonic lineaments