



TGFs and Meteorology

An overview on satellite methods to characterize the cloud type during a TGF event

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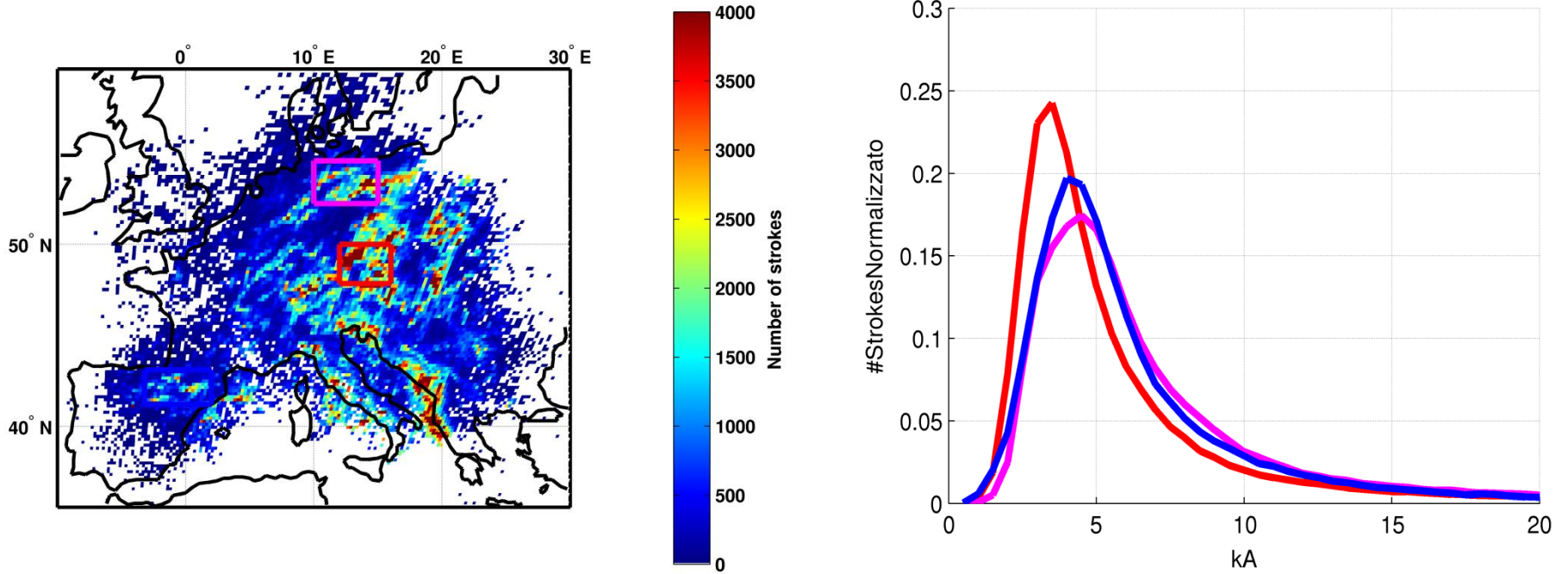
Mathias Möhrlein, Silvia Riso, Hans Dieter Betz (Nowcast GmbH)

Kristopher Bedka (Science Systems and Applications, Inc. NASA Langley Research Center)

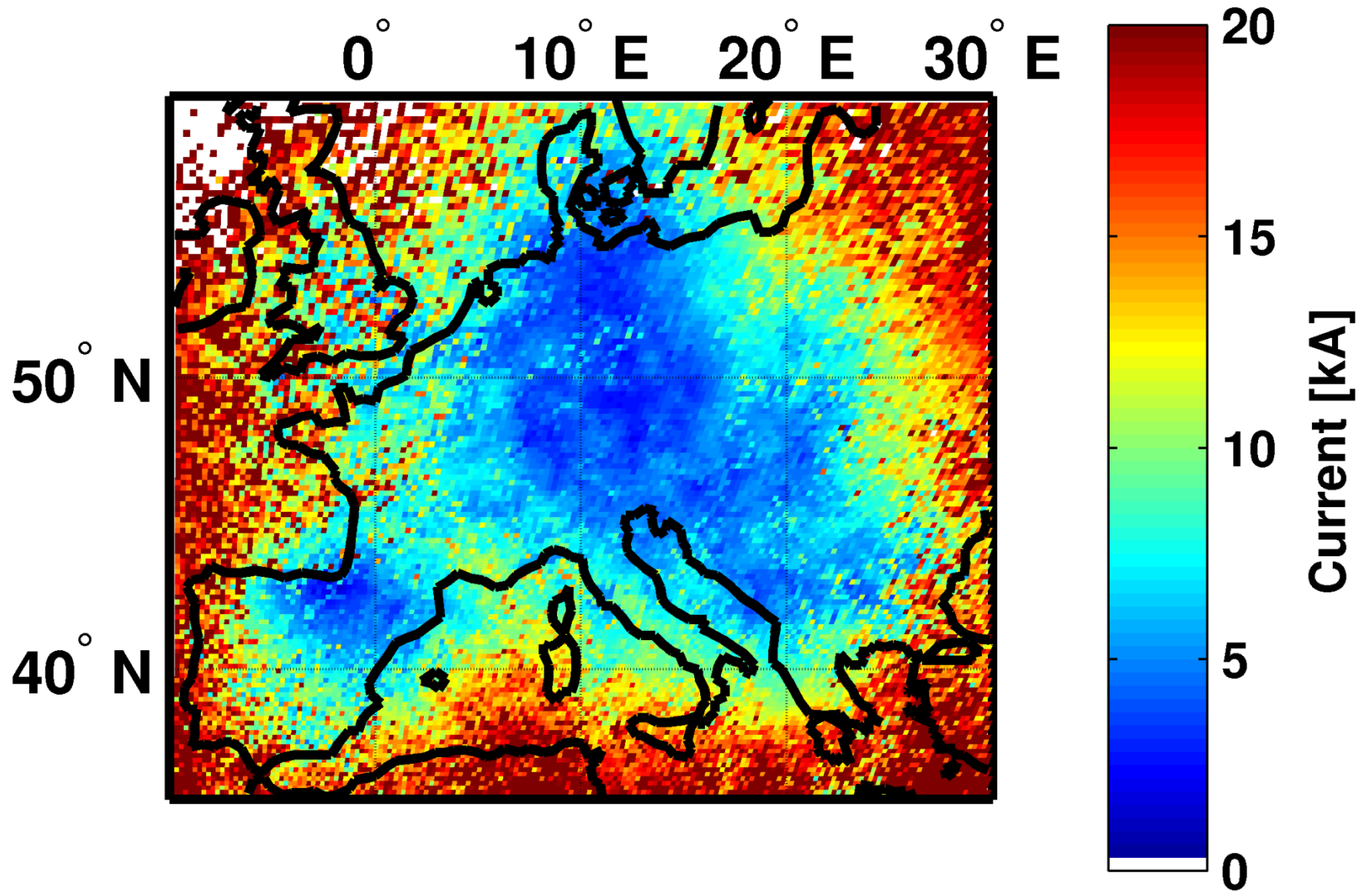
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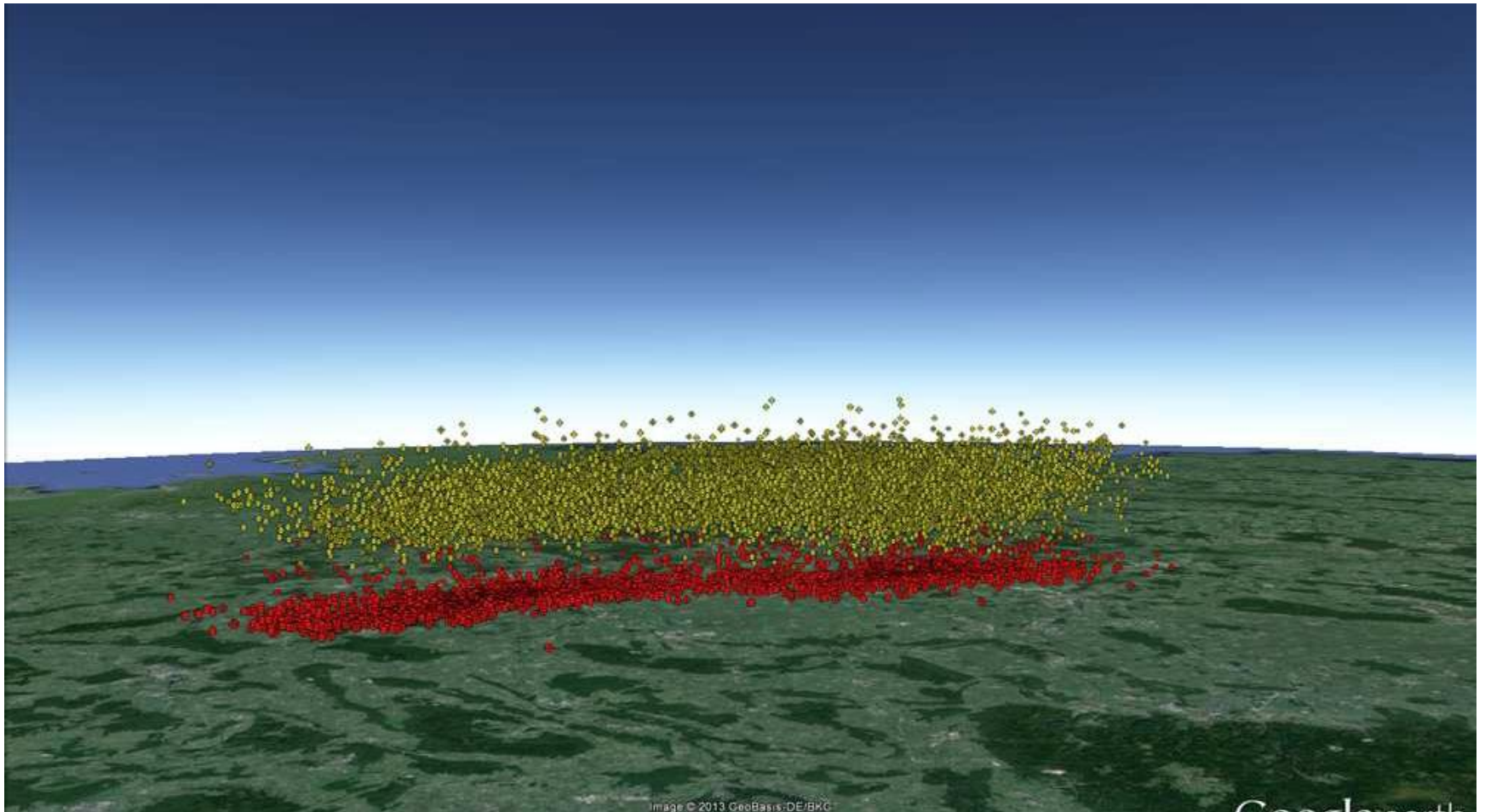


Lightning peak current distribution



LINET - Estimated Detection Efficiency





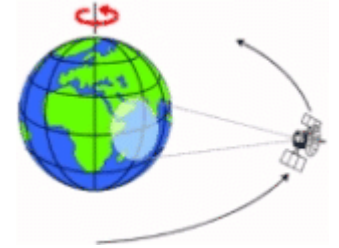
LINET 3D-visualization of a severe storm. Dominating occurrence of IC strokes is evident.

Preliminary Considerations

- Most of (weak current ones) lightning strokes are not detected even by very dense lightning networks like LINET
- Global lightning networks detect only a small portion of CG strokes
- This makes more difficult to find matches between TGF and lightning strokes over tropics.
- Satellite meteorology can help (!?)

Summary

1. An overview on GEO and LEO satellites
2. Overshooting tops
 1. The numerical model in supporting to the satellite investigation
 2. TGFs during two Mediterranean storms
1. Final considerations ... to be continued!



Geosynchronous Earth Orbit (GEO)

A geostationary (GEO=geosynchronous) orbit is one in which the satellite is always in the same position with respect to the rotating Earth. The satellite orbits at an elevation of approximately **35,790 km** because that produces an orbital period (time for one orbit) equal to the period of rotation of the Earth (23 hrs, 56 mins, 4.09 secs). By orbiting at the same rate, in the same direction as Earth, the satellite appears stationary (synchronous with respect to the rotation of the Earth).

Geostationary satellites provide a "big picture" view, enabling coverage of weather events. This is especially useful for monitoring severe local storms and tropical cyclones.

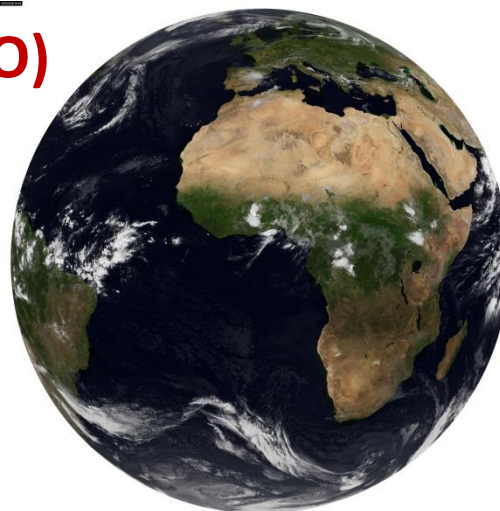
Because a geostationary orbit must be in the same plane as the Earth's rotation, that is the equatorial plane, it provides distorted images of the polar regions with poor spatial resolution.

Geosynchronous Earth Orbit (GEO)

Cloud products (VIS-IR)

- Altitude and top temperature
- Cloud phase (ice, water, mixed)
- Cloud microphysics (opt. thick)
- Precipitating and convective clouds

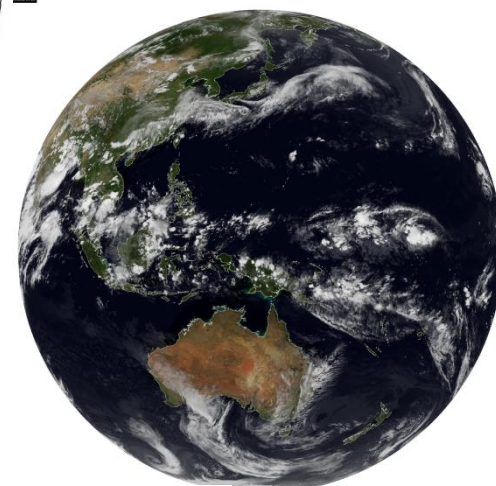
Wide spatial coverage



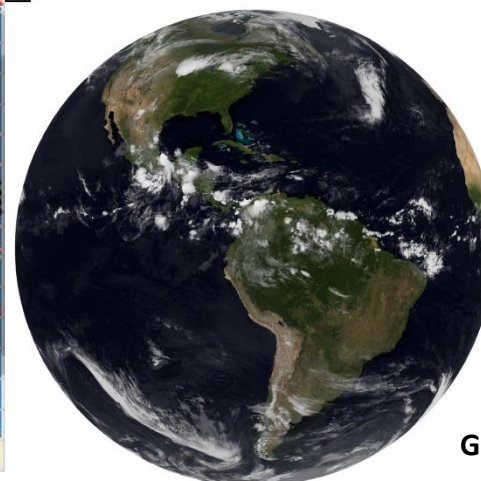
MSG

Spatial resolution ≈ 4 Km

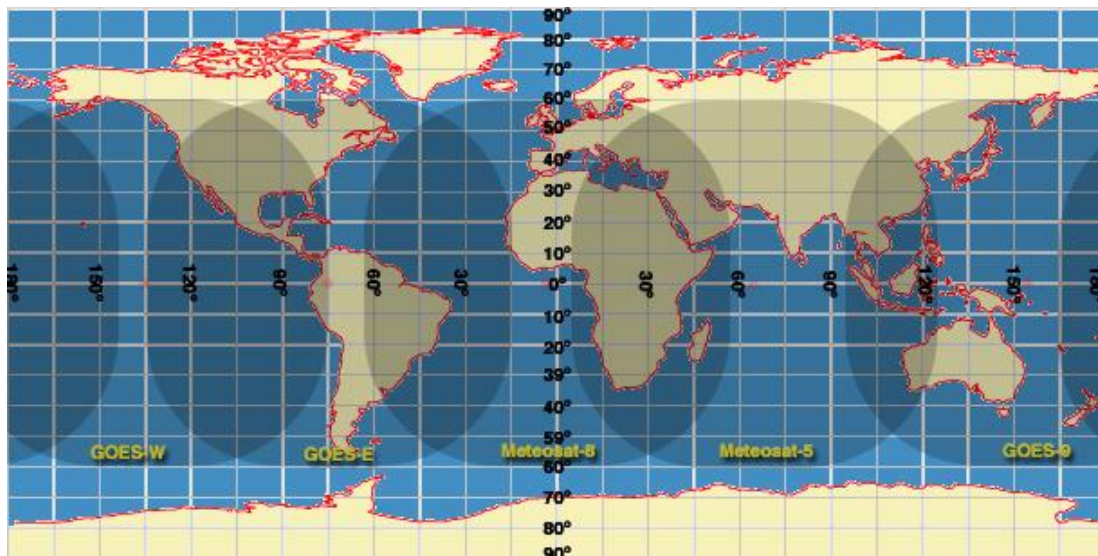
Time image: 15 min

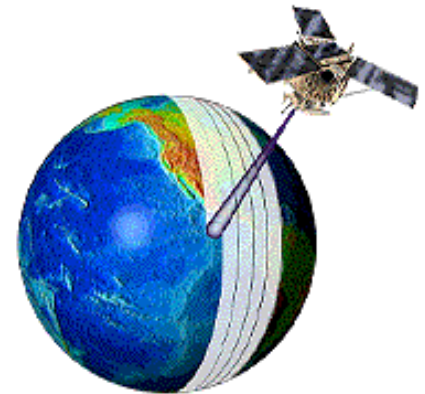


MTSAT



GOES





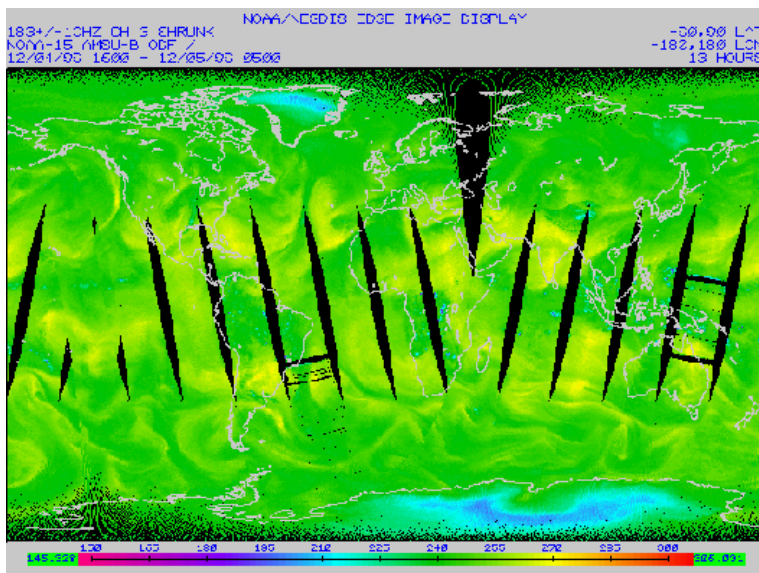
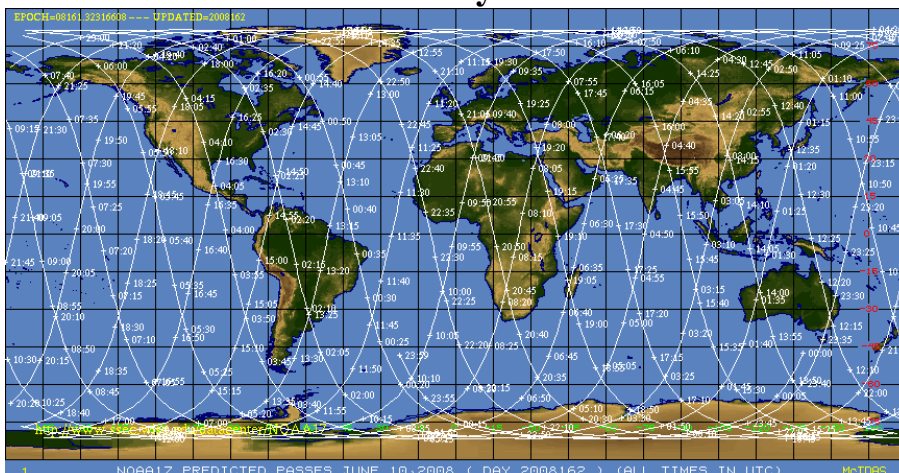
Low Earth Orbit (LEO)

Polar-orbiting satellites provide a more global view of Earth, circling at near-polar inclination (the angle between the equatorial plane and the satellite orbital plane -- a true polar orbit has an inclination of 90 degrees). Orbiting at an altitude of 700 to 800 km, these satellites cover best the parts of the world most difficult to cover in situ (on site). For example, McMurdo, Antarctica, can be seen on 11-12 of the 14 daily NOAA polar-orbiter passes.

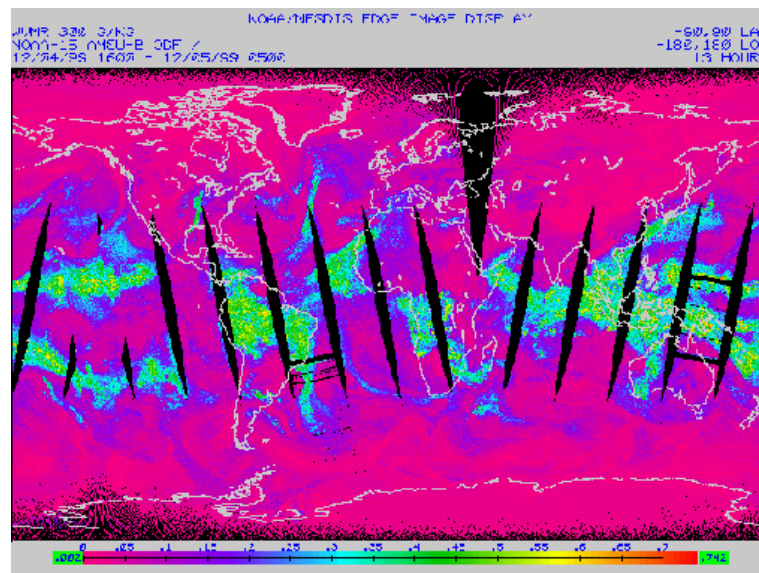
These satellites operate in a sun-synchronous orbit. The satellite passes the equator and each latitude at the same local solar time each day, meaning the satellite passes overhead at essentially the same solar time throughout all seasons of the year. This feature enables regular data collection at consistent times as well as long-term comparisons. The orbital plane of a sun-synchronous orbit must also rotate approximately one degree per day to keep pace with the Earth's surface.

Low Earth Orbit (LEO)

Noaa-17 daily orbit

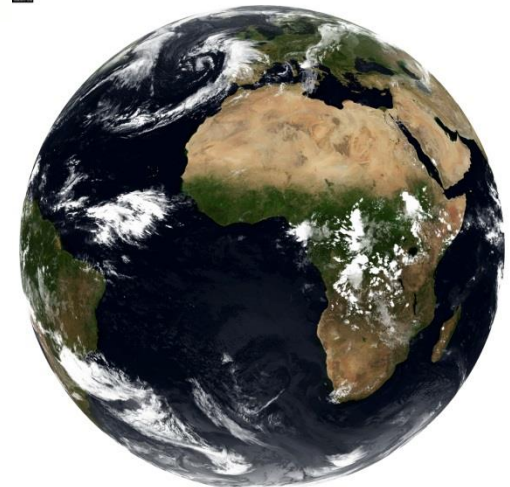
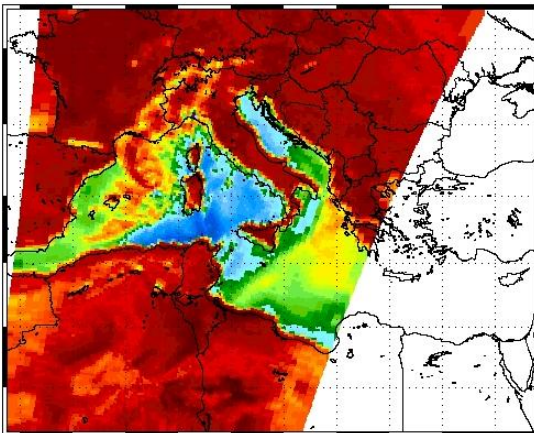
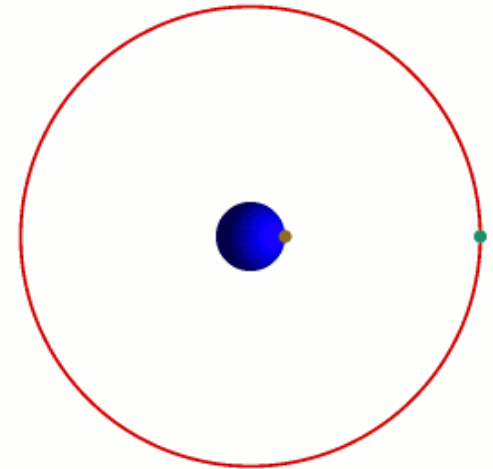
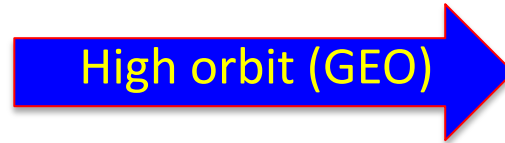


AMSU Channel 18 data, taken at December 4/5, 1999. The image shows measured radiances in units of brightness temperature [K]

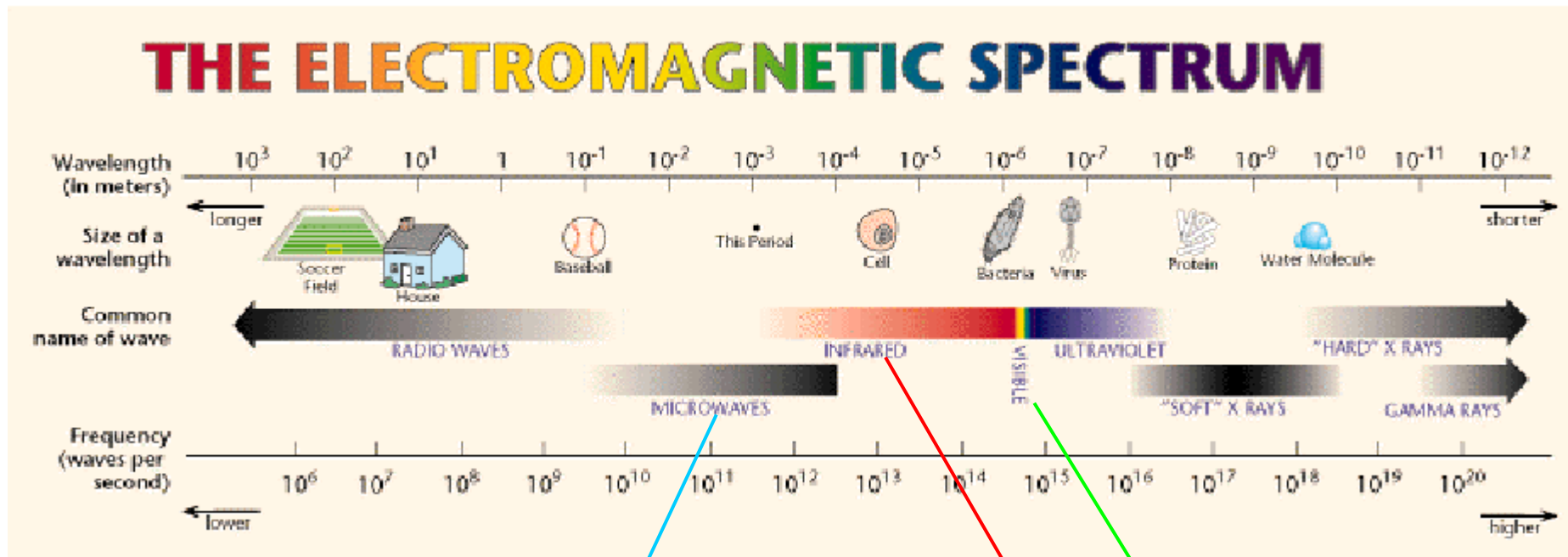


Upper tropospheric humidity [g/kg] at 300 hPa, derived from the data displayed on the left

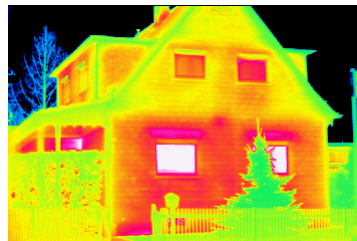
Meteorological satellites



Frequencies onboard meteorological satellites



- 300 MHz – 30 GHz
- 30 GHz – 300 GHz (Millimeter wave))
- > 300 GHz (Centimeter waves)



Tools for studying the meteorology of the TGF events

MSG-SEVIRI and NOAA-AMSU-B satellites

MSG-SEVIRI

	λ_{cen}	λ_{min}	λ_{max}	
VIS0.6	0.635	0.56	0.71	Surface, clouds, wind fields
VIS0.8	0.81	0.74	0.88	Surface, clouds, wind fields
NIR1.6	1.64	1.50	1.78	Surface, cloud phase
IR3.9	3.90	3.48	4.36	Surface, clouds, wind fields
WV6.2	6.25	5.35	7.15	Water vapor, high level clouds, atmospheric instability
WV7.3	7.35	6.85	7.85	Water vapor, atmospheric instability
IR8.7	8.70	8.30	9.1	Surface, clouds, atmospheric instability
IR9.7	9.66	9.38	9.94	Ozone
IR10.8	10.80	9.80	11.80	Surface, clouds, wind fields, atmospheric instability
IR12.0	12.00	11.00	13.00	Surface, clouds, atmospheric instability
IR13.4	13.40	12.40	14.40	Cirrus cloud height, atmospheric instability

HRV	Broadband (about 0.4 – 1.1 μm)	Surface, clouds
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NOAA-AMSU-B

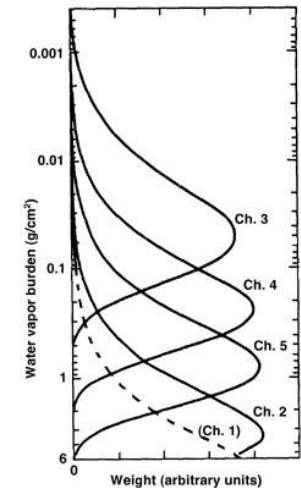
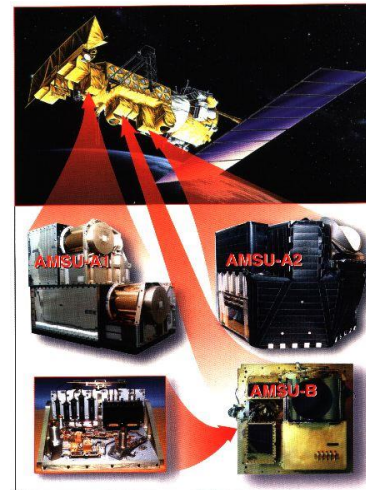


TABLE II
AMSU-B CHANNELS AND SOUNDING CHARACTERISTICS

Ch. Num.	ν [GHz]	Opacity	Sensitivity
1	89.0 ± 0.9	Window	BL water vapor, cloud liquid water, surface, precipitation
2	150.0 ± 0.9	Window	BL water vapor, cloud ice particles, surface, precipitation
3	183.31 ± 1.0	Opaque	Upper troposphere water vapor
4	183.31 ± 3.0	Opaque	Mid-troposphere water vapor
5	183.31 ± 7.0	Opaque	Lower troposphere water vapor

Investigation methodology

By using the SEVIRI_MSG channels at $10.8\ \mu\text{m}$ and $6.2\ \mu\text{m}$ it is possible to monitor if the horizontal and the vertical development of storms. To study the TGF clouds we have used the thermal channel at $10.8\ \mu\text{m}$ to evaluate the temperature of the cloud tops and the horizontal lapse rate while the water vapor channel at $6.2\ \mu\text{m}$ has been exploited to assess the possible intrusion of convection into the Stratosphere.

A second step was consisting in the evaluation of cloud type with the MicroWave Cloud Classification (MWCC) algorithm developed at ISAC-CNR. Based on the microwave signal at $183.31\ \text{GHz}$ the method classify the observed clouds into two categories (stratiform and convective) estimating the altitude of the tops. For TGF study only the convective clouds have been considered.

A third step was the application of the Weather Research and Forecasting (WRF) model. The new parameterization scheme for convective clouds improves reconstruction of the cloud microphysics supporting the satellite evaluation. The numerical results of the WRF model help us to better characterize the convection both in terms of vertical development of convective tower and in terms of cloud particle distribution, concentration and phases.

International Space Station Photograph Of A Thunderstorm With An
Overshooting Top Over The Ivory Coast, 5 February 2008

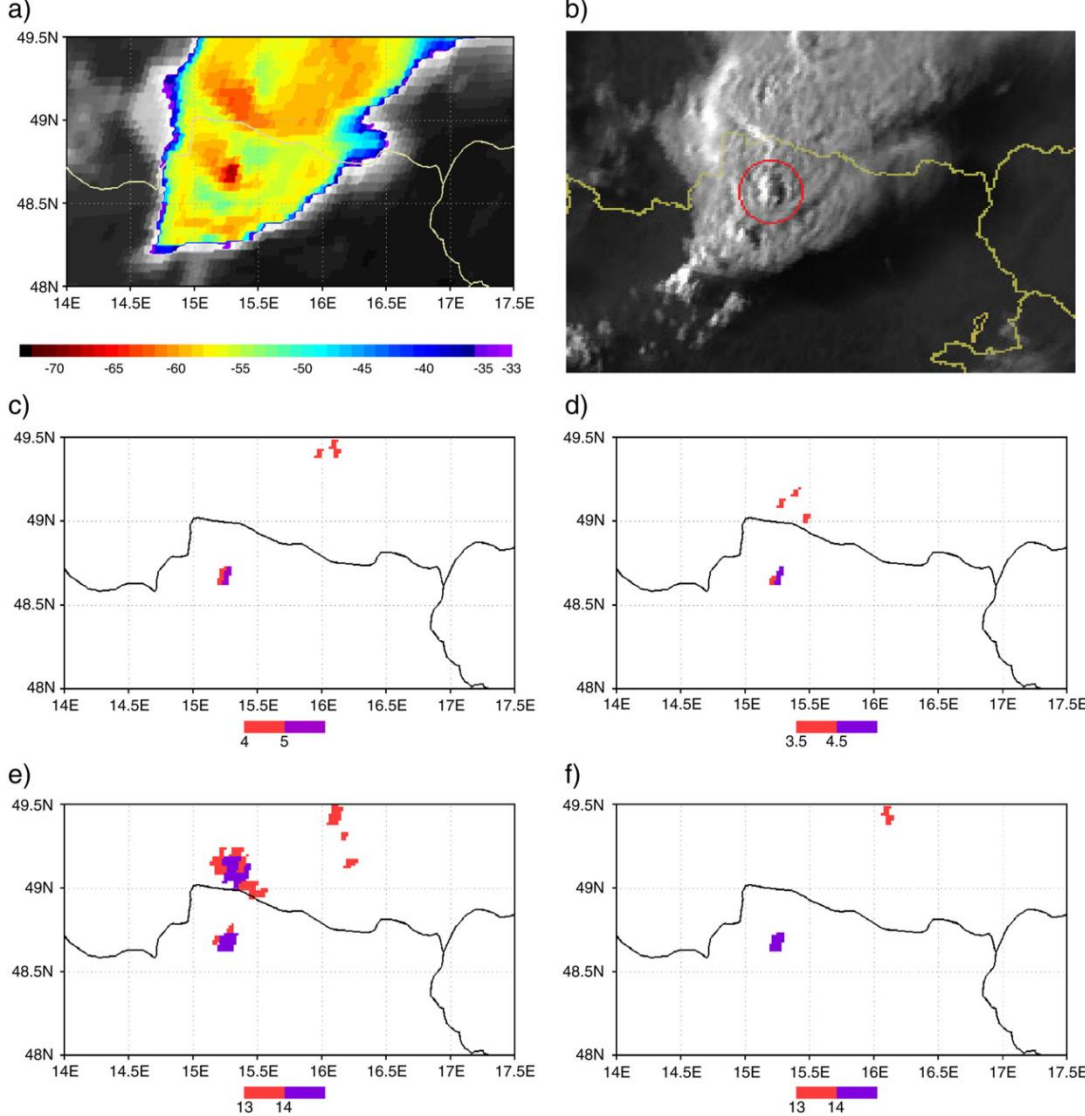
Overshooting Top



BASICS

- Localized IR brightness temperature (BT) minima correspond to convective updraft cores and are associated with:
 - 1) Heavy rainfall
 - 2) Frequent lightning, both cloud-to-ground and in-cloud
 - 3) Severe weather
 - 4) Water vapor and ice injection into the stratosphere

(from Kristopher Bedka)



a) Color-enhanced Meteosat 9 10.8 (IRW) μm image at 16:45 UTC, 23 July 2009. Color scale from $-33\text{ }^{\circ}\text{C}$ (purple) to $-72\text{ }^{\circ}\text{C}$ (dark red).
 b) Meteosat 9 HRV channel image. Location of observed OT is marked with the red circle.

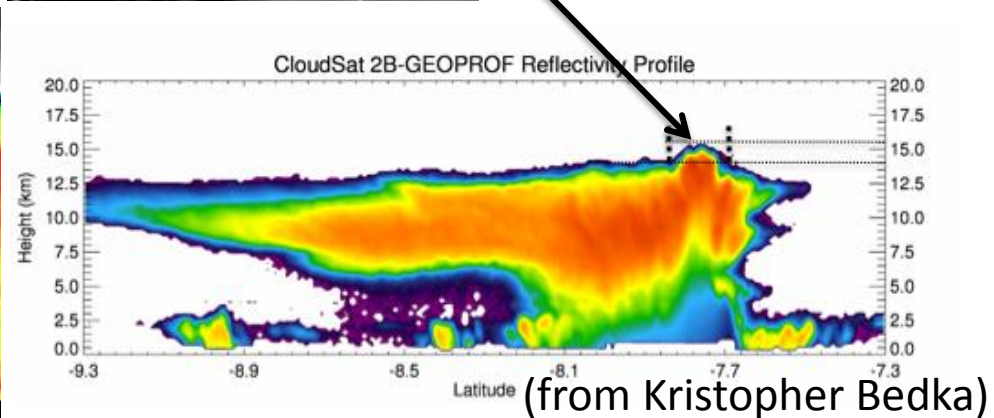
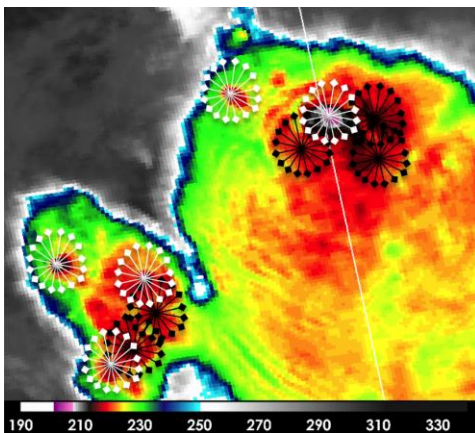
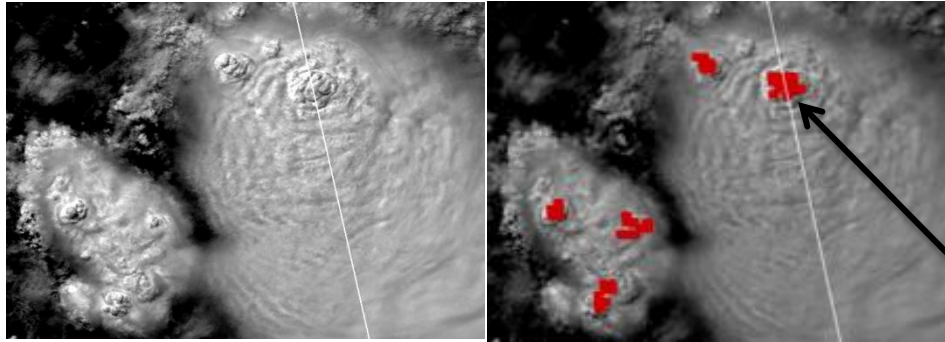
Location of pixels meeting the criteria for the brightness temperature and brightness temperature difference, detected using
 c) WV-IRW,
 d) CO₂-IRW,
 e) O₃-IRW,
 f) COMB BTM method for the region outlined by the red box in panel a.

Different objective satellite-based OT detection methods using multi-spectral satellite data are presented in several studies, such as Berendes et al. (2008), Lindsey and Grasso (2008), Rosenfeld et al. (2008), Schmetz et al. (1997) and Setvák et al. (2007). The most frequently used OT detection method is brightness temperature difference (BTD) between the water vapor absorption and the infrared window band (WV-IRW BTD) (Fritz and Laszlo, 1993; Ackerman, 1996; Schmetz et al., 1997).

Objective Overshooting Convective Cloud Top Detection

- A method to objectively detect overshooting convective cloud tops and the enhanced-V/cold-ring signature has been recently developed within the GOES-R Aviation Algorithm Working Group. The stated goal of these products is to improve aviation safety but they are also useful for recognition of severe storms and heavy rainfall
- Overshooting convective cloud tops represent deep convective updrafts that have penetrated through the local equilibrium level and into the upper troposphere – lower stratosphere region
- Adiabatic cooling induced by strong vertical ascent causes overshooting tops (OTs) to appear as a small regions (< 15 km diameter) of anomalously cold IR brightness temperatures surrounded by a warmer cirrus anvil cloud
- This objective OT detection algorithm utilizes IR brightness temperature (BT) and spatial gradient thresholding with NWP tropopause temperature information to identify OTs at their characteristic spatial scale

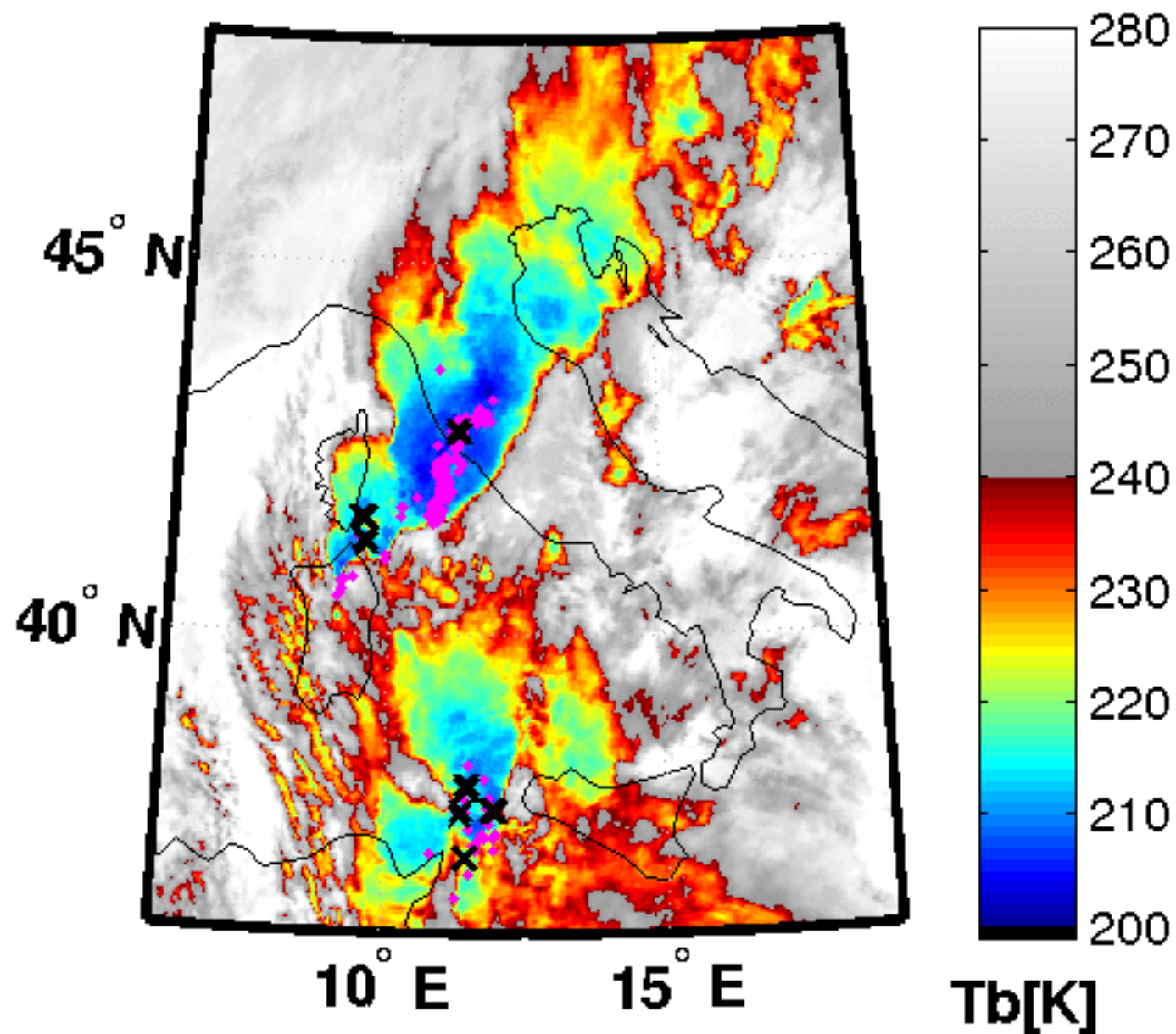
MODIS 250 m Visible and 1 km IR Window With Overshooting Top Detections



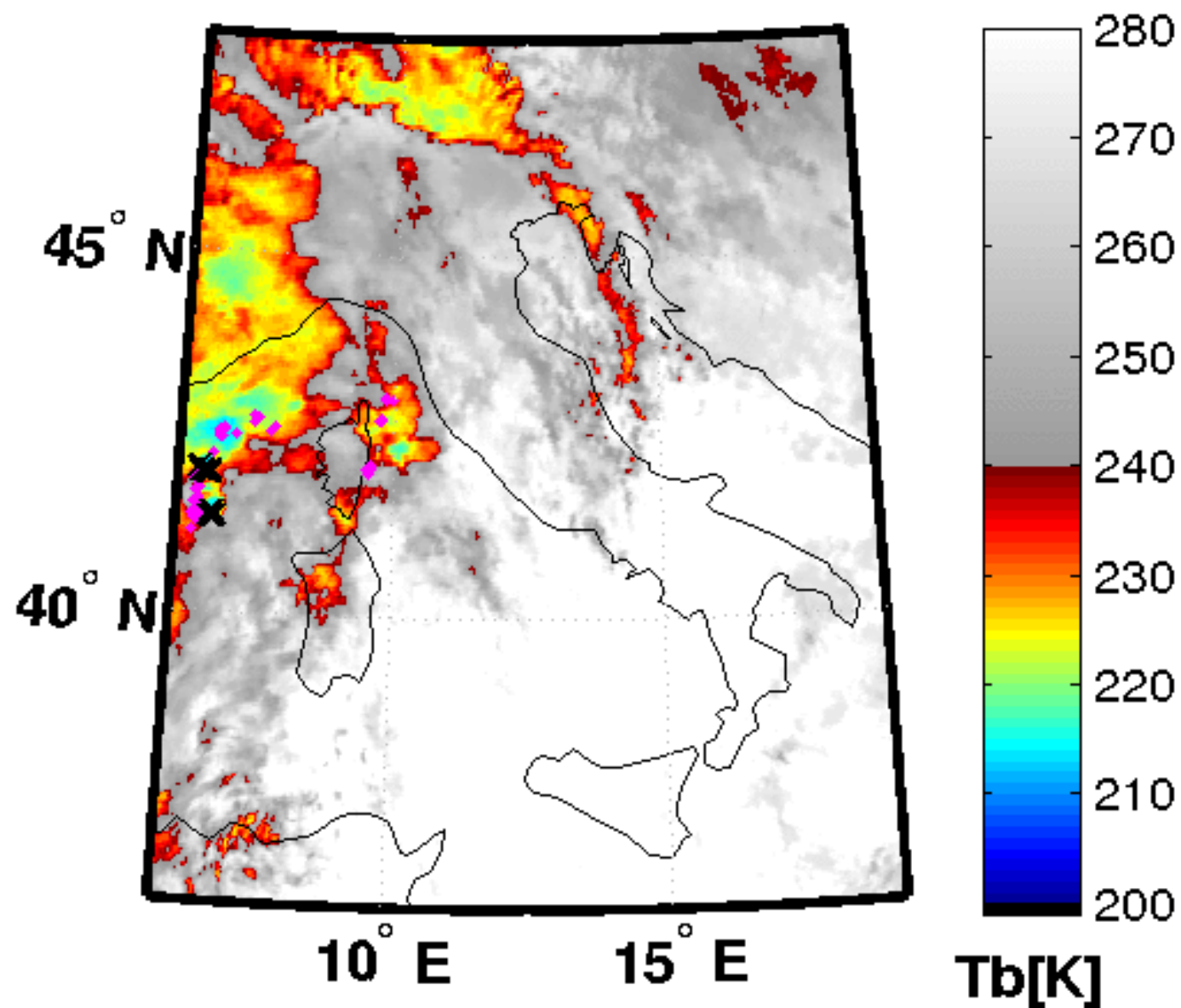
White: Region meets OT detection criteria

Black: Region not cold enough relative to surrounding anvil

12-Nov-2012 00:15:00 UTC
MSG IR 10.8 + Overshooting Tops +
LINET 12-Nov-2012 00:25:53 +/- 7 min.



25-Oct-2011 07:15:00 UTC
MSG IR 10.8 + Overshooting Tops +
LINET 25-Oct-2011 07:25:56 +/- 7 min.

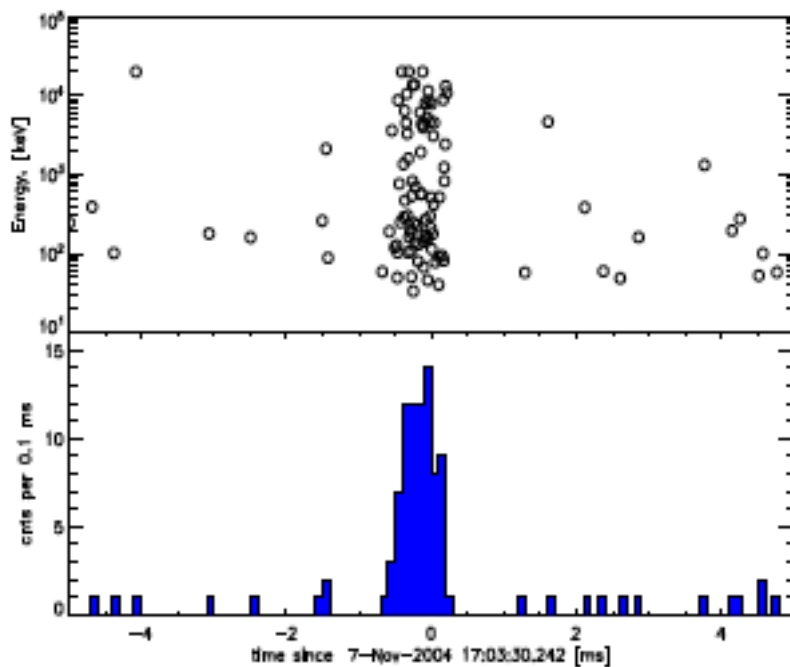


One or more of the OT detection scheme available in literature can be used to investigate the correlation between IR signatures (GEO) and TGF ... but this could be not enough.

A couple of contrasting examples will explain better

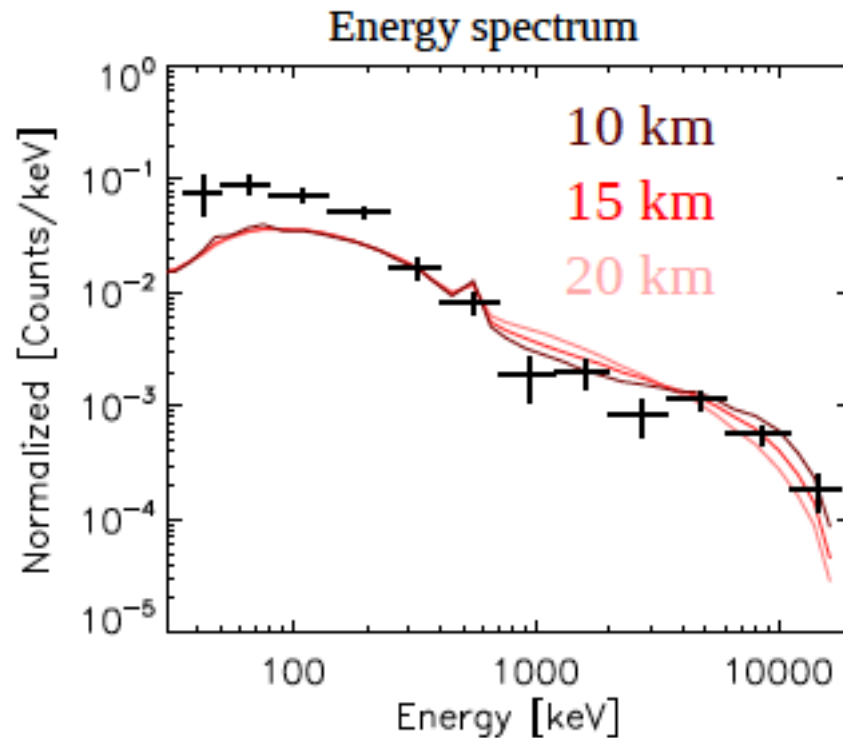
TGF over Mediterranean Sea on November 7th 2004

(Gjesteland *et al.*, EGU-2013 poster session)



Energy spectrum

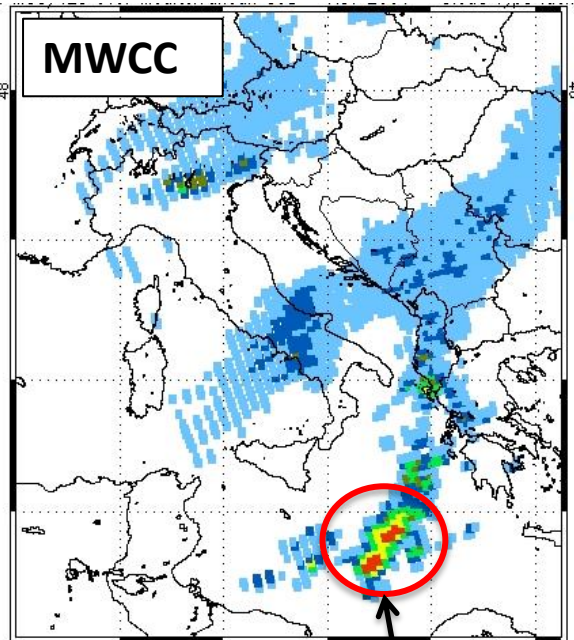
This TGF is unusually bright and it among the 1% brightest RHESSI TGF ever measured



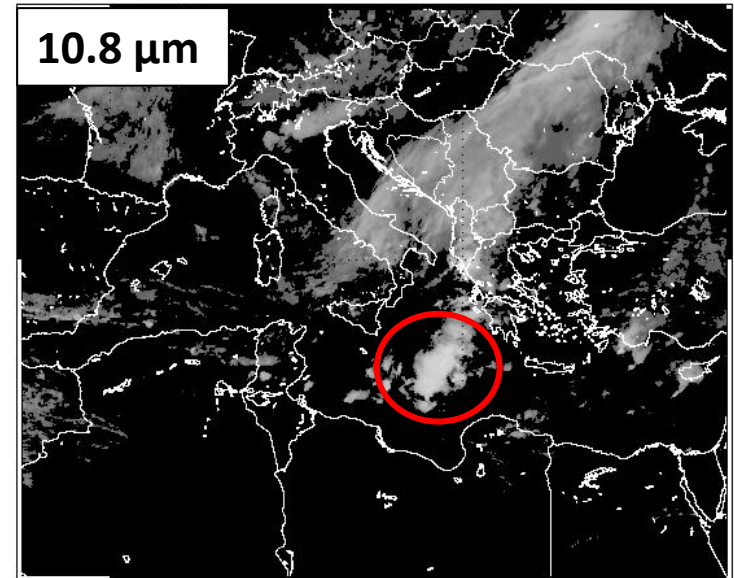
Curves show the simulated TGFs from 10, 15, and 20 Km of altitude folded through the RHESSI detector response matrix. For higher energies the 10 km production altitude gives best fit to the measurements (black crosses)

TGF over Mediterranean Sea on November 7th 2004

(The satellite analysis has been achieved by Sante Laviola – ISAC-CNR, Bologna)

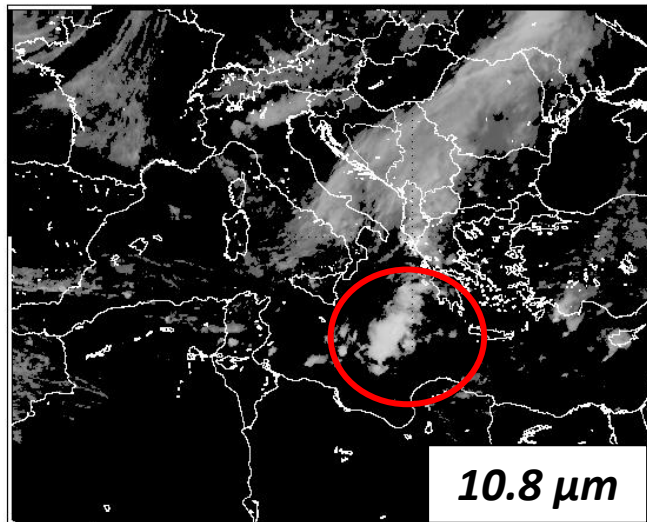
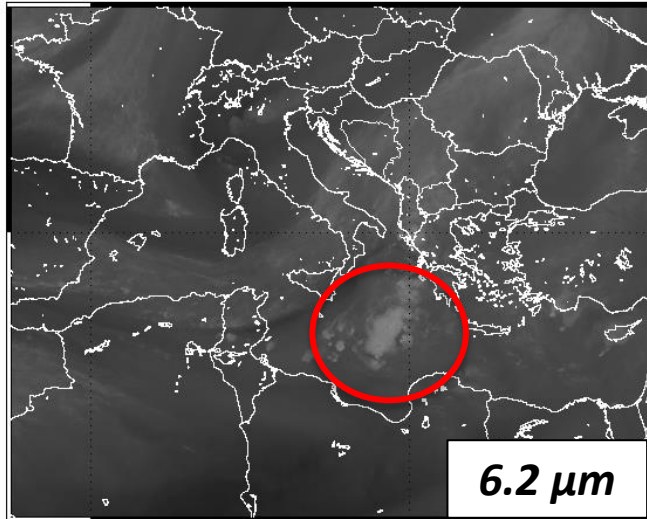


Convective cores (**red spots**) with altitude greater than 8-10 km calculated on the basis of the MicroWave Cloud Classification method. The maximum altitude of the cloud top is not well defined in this stage!

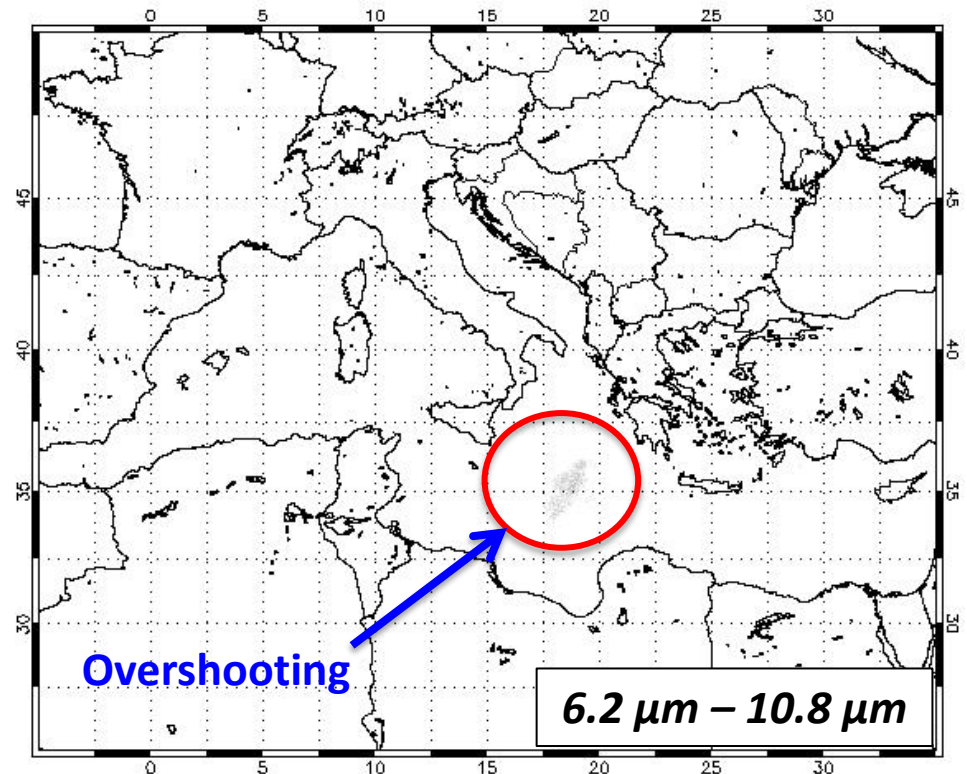


The MSG image at 10.8 μm (BT11) with a cloud threshold (BT11 < 260 K) reveals a cold cloud (red circle) which can be reasonably associated to convective rain cloud. The altitude cannot be accurately estimated in this stage!

The application of a commonly used threshold based on the difference between the MSG brightness temperature at $6.2 \mu\text{m}$ (water vapour channel) and that at $10.8 \mu\text{m}$ could be useful to highlight the possible intrusion of convection into the lower Stratosphere.



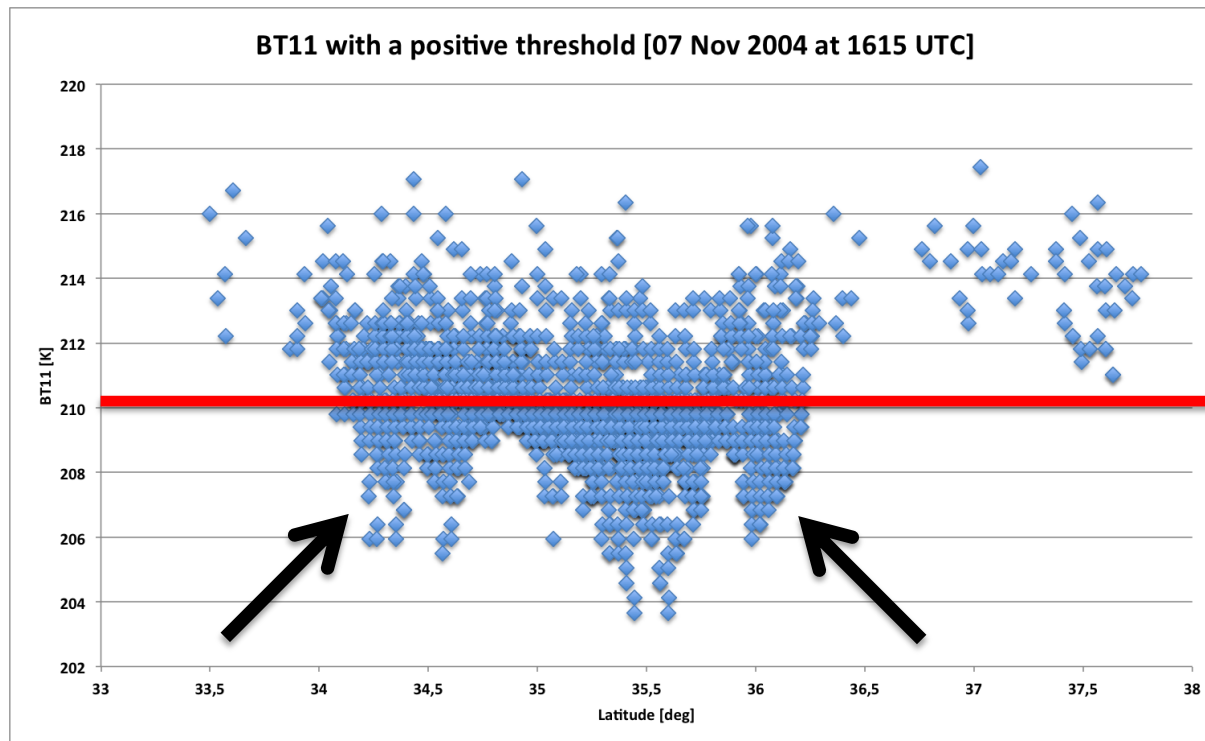
Although this threshold was originally developed over Tropics, the results of this analysis can be considered valid also for the Mediterranean basin.



Evaluation of the overshooting temperature!

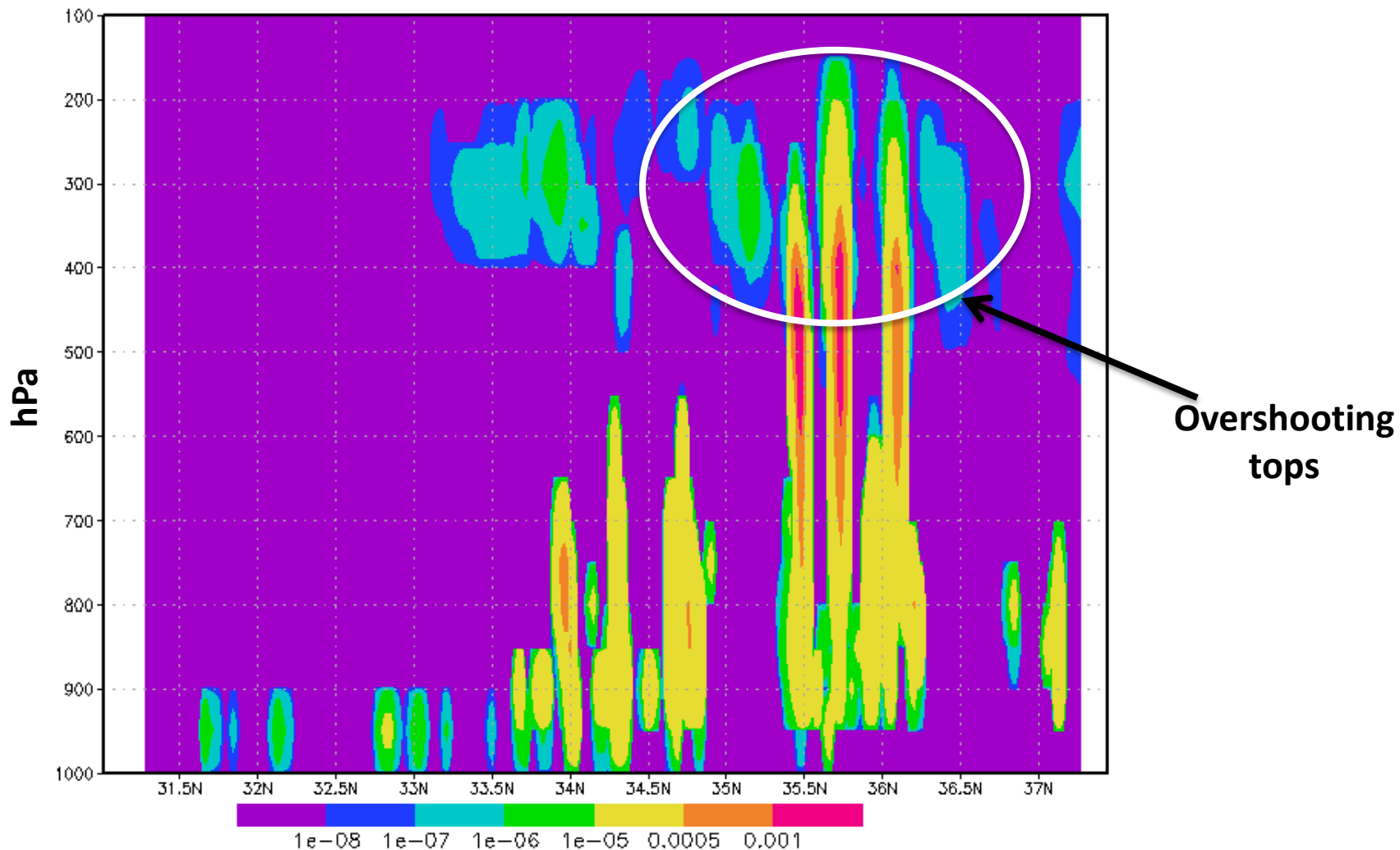
Horizontal distribution
of the brightness temperatures at $10.8 \mu\text{m}$.

Cold pixels under the red line correspond to the overshooting tops.

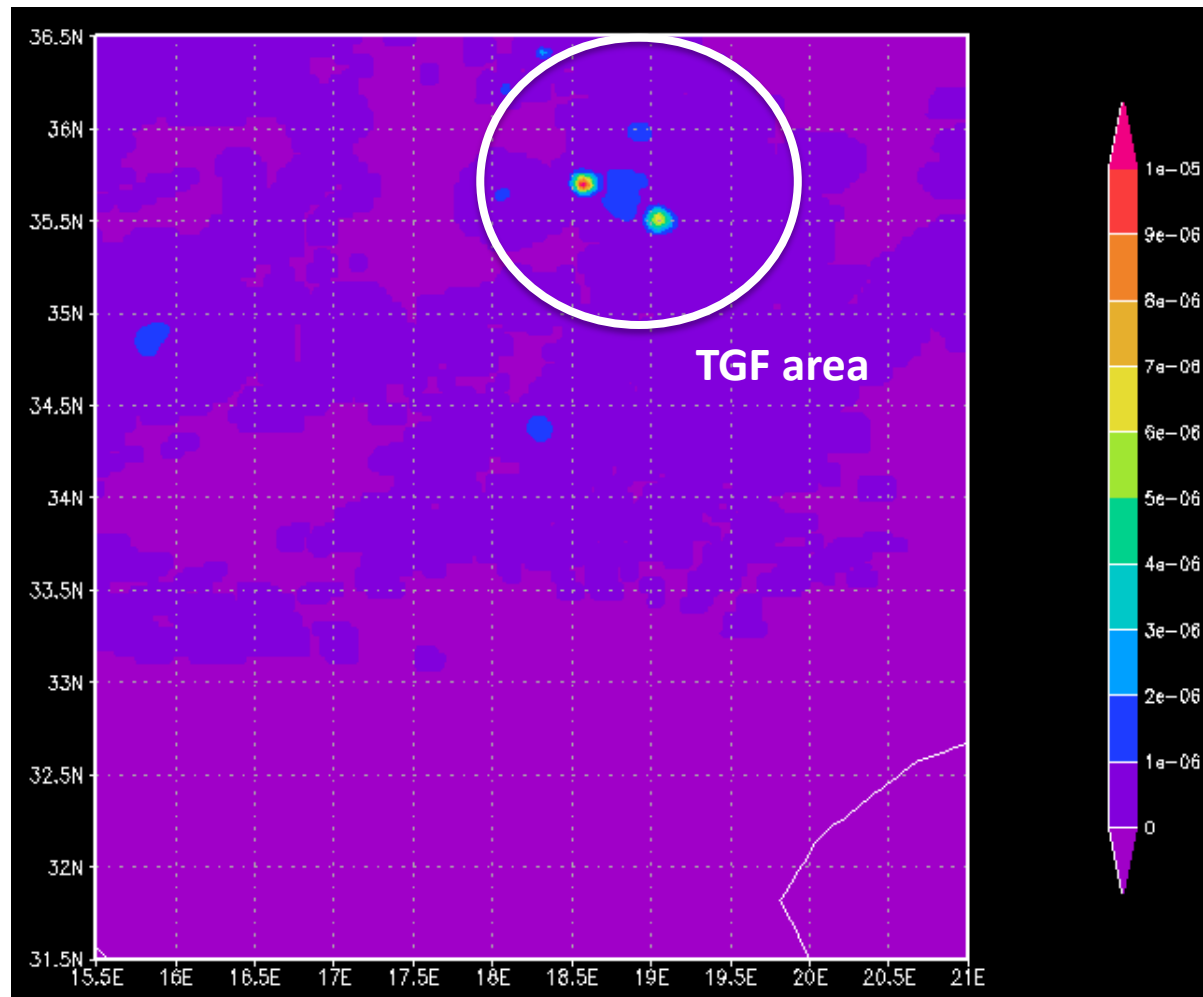


Cloud analysis with WRF model: vertical development of convection

(The WRF analysis has been achieved by Marcello Miglietta – ISAC-CNR, Padova)

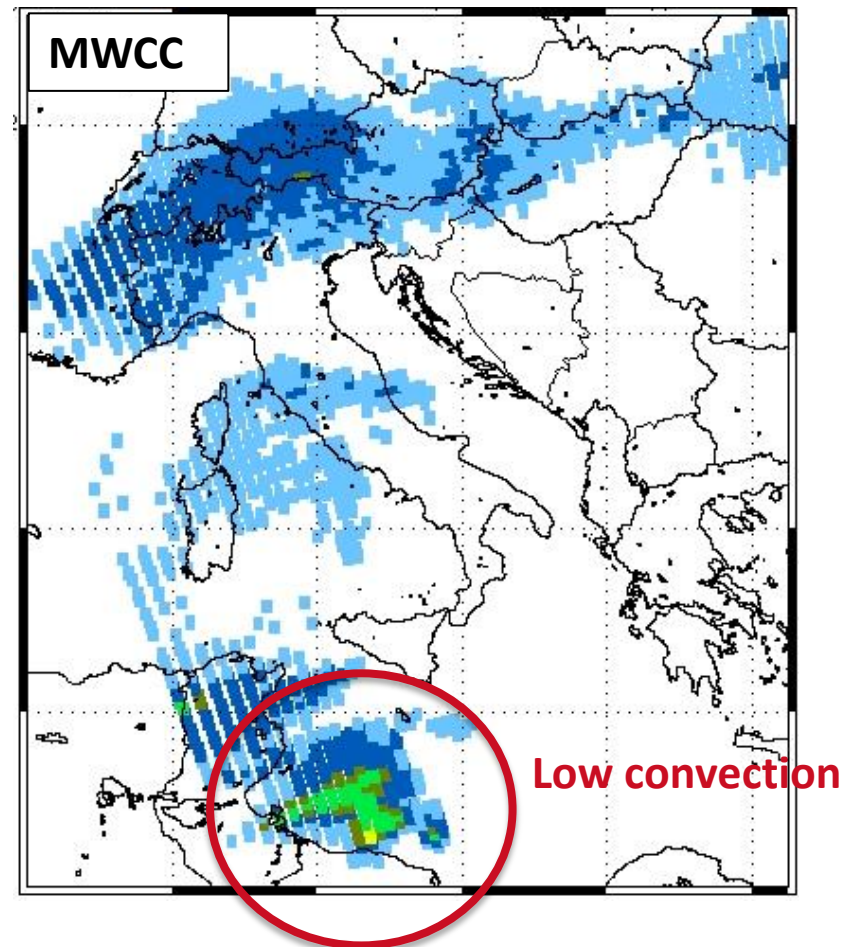
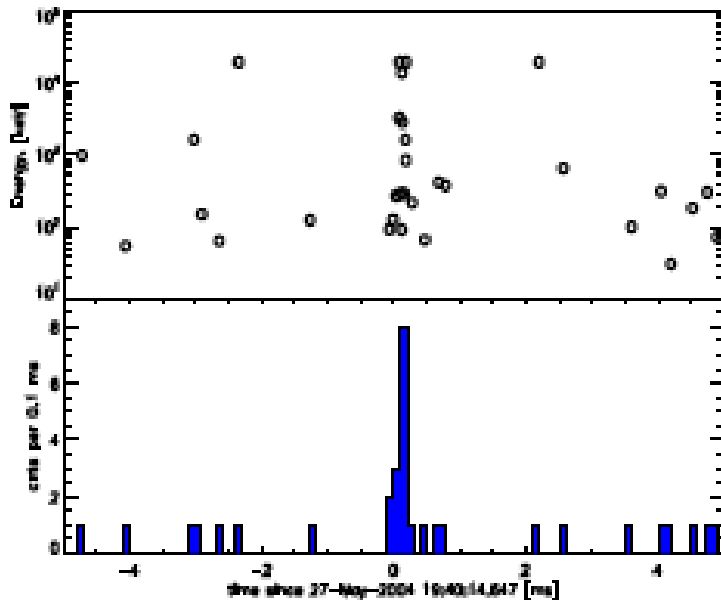


Cloud analysis with WRF model: high clouds at 200 hPa



TGF over Mediterranean Sea on May 27th 2004

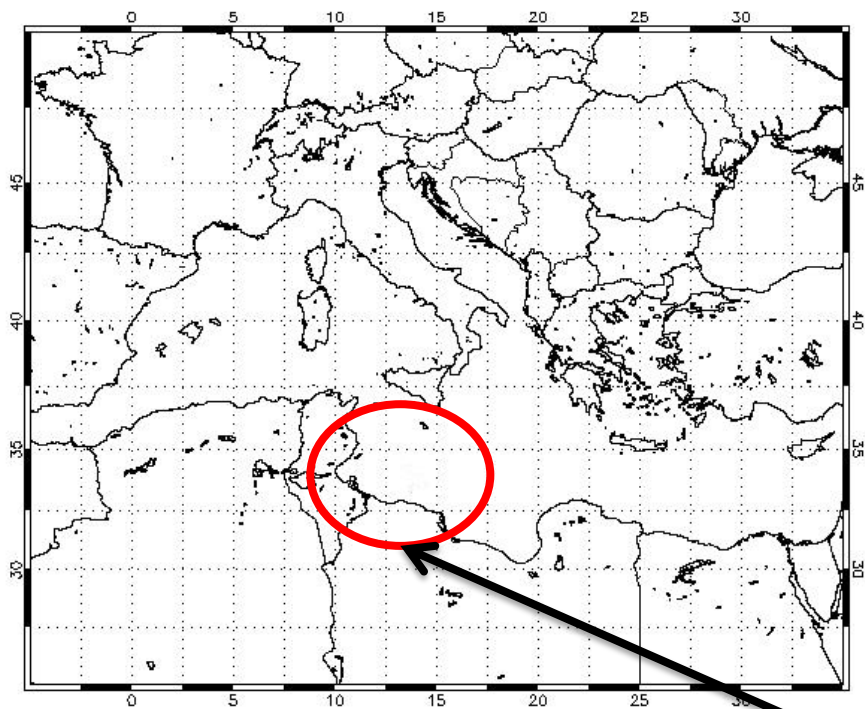
(Gjesteland *et al.*, EGU-2013 poster session)



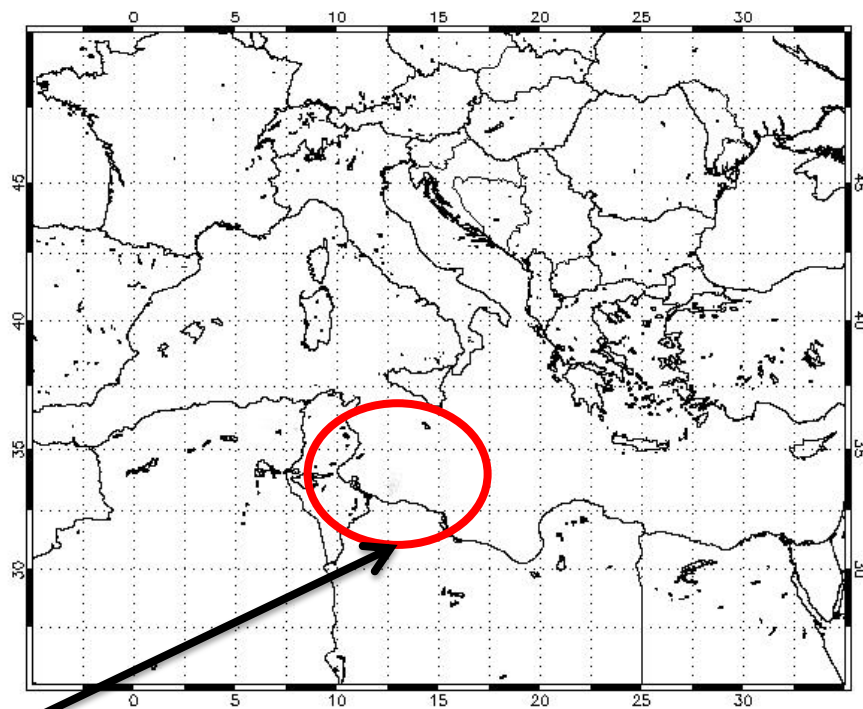
The MWCC provides information about the vertical development of a cloud. In this case, the algorithm classifies the analysed system as low convection (red colour), it means that the cloud top is lower than 8 km!

Investigation of the convection intrusion into the Stratosphere

May 27th 2004, at 1930 UTC

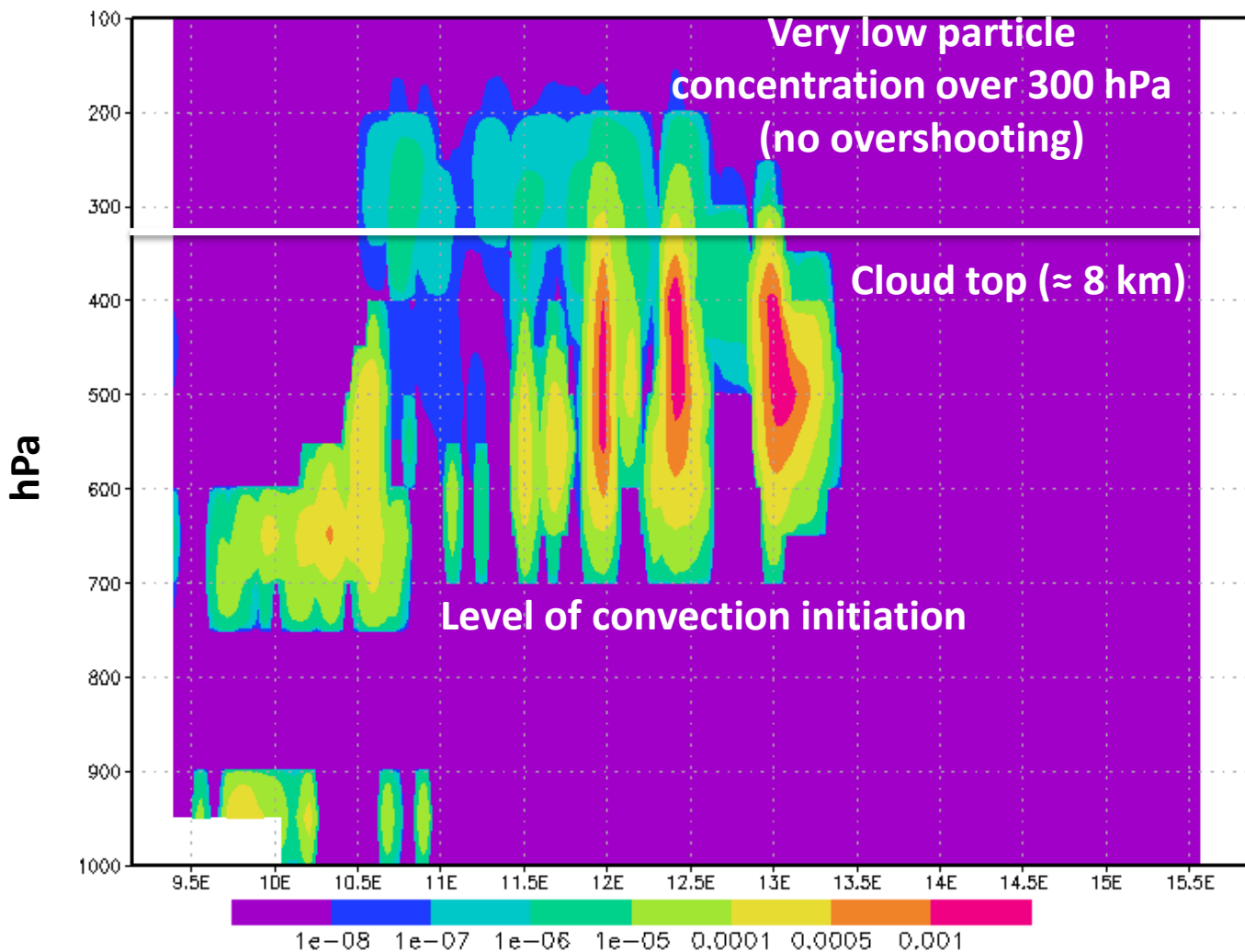


May 27th 2004, at 2030 UTC

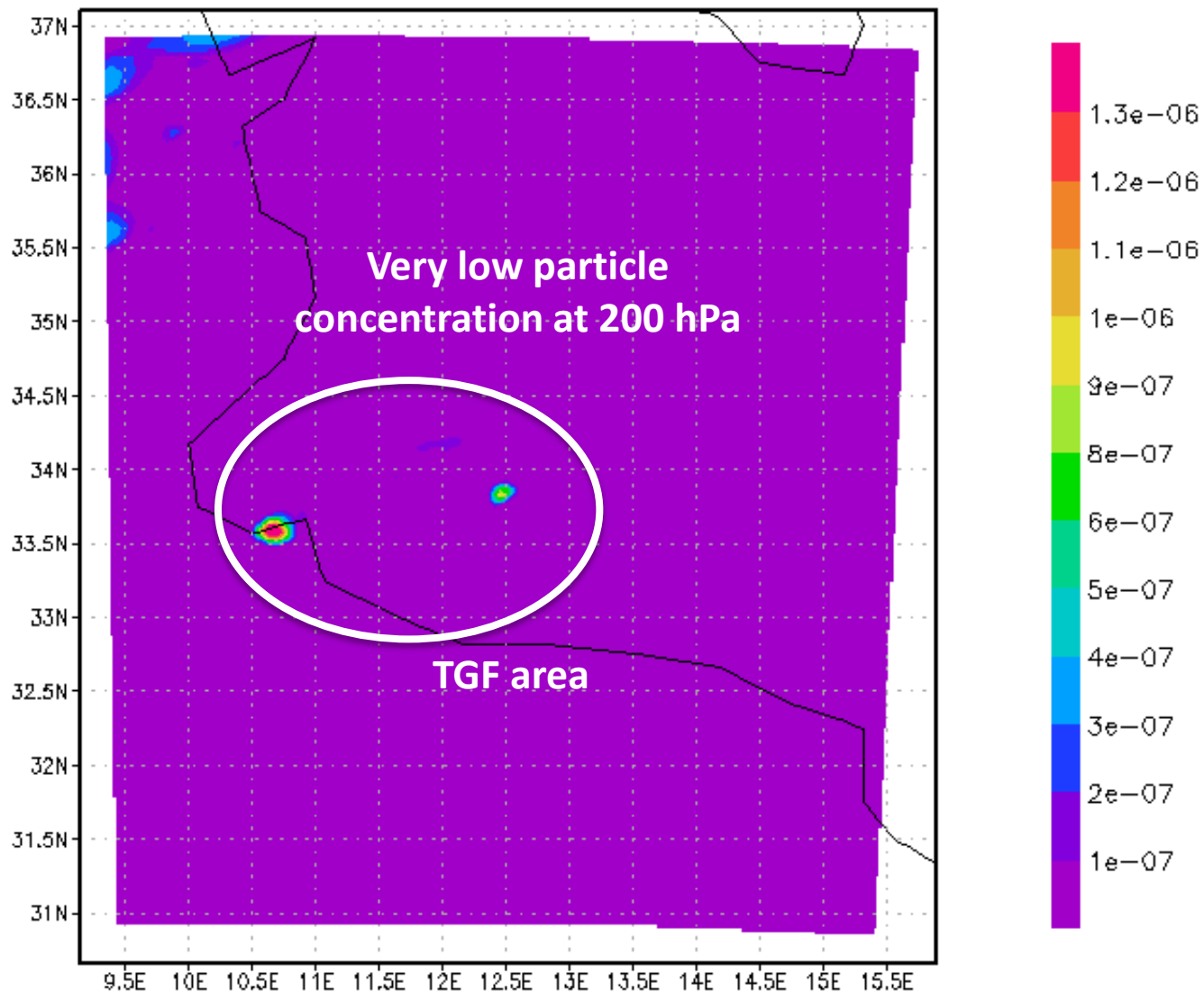


**No overshooting has been
retrieved**

Cloud analysis with WRF model: vertical development of convection



Cloud analysis with WRF model: high clouds at 200 hPa



Final considerations ... to be continued!

By considering that these study are still in progress and just few cases over the Mediterranean Sea have been analyzed, we can conclude as follow:

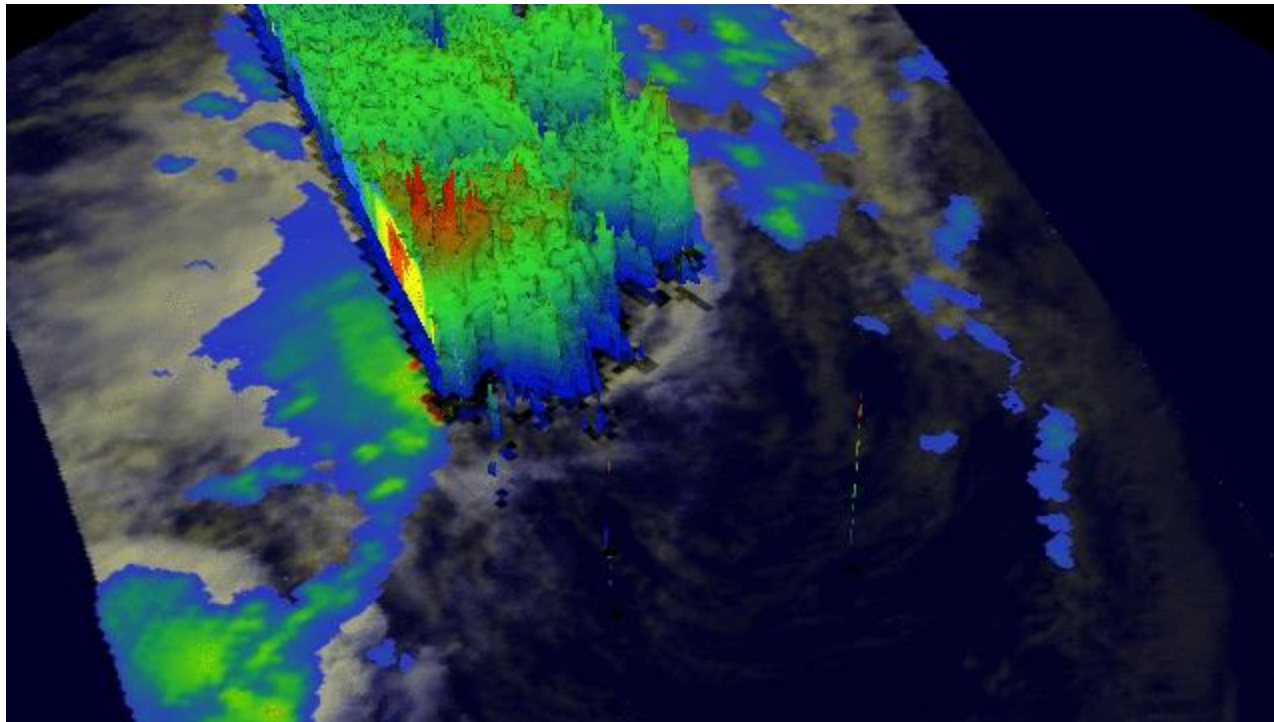
1. The methodology and methods applied in this study appears to be robust for the investigation of the cloud characteristics. Thus, this first results are reasonably accurate!
1. For the case of 7 November 2014, the convection is surely of tower type. This means that compact clouds vertically develop up to the limit of the Troposphere and possibly generate an anvil structure. The latter structure can be reasonably correlated to the retrieved overshooting tops. These results sustained by the MWCC method are also corroborated by the WRF outcomes which defines a deep cloud field over 300 hPa.
1. For the case of 27 May 2014 the situation is completely different. The algorithm MWCC retrieves a “low convection” localized in the TGF domain. This means that the altitude of convective tops are around 6-7 km corresponding the more intense towers calculated by WRF. Furthermore, the sensitivity test for the detection of the overshooting reveals no intrusion into the Stratosphere. This event with respect to November storm seems to demonstrate that TGF could be also produced by low convective clouds!!!
1. Further studies can undoubtedly improve these results. The application of other sensors, such as TRMM and GOES as proposed in the E-Earth project submitted in the framework of Horizon 2020, combined with these methods allow us to better define the cloud scenario out of the Mediterranean basin.

What about TGF studies over the Tropics?

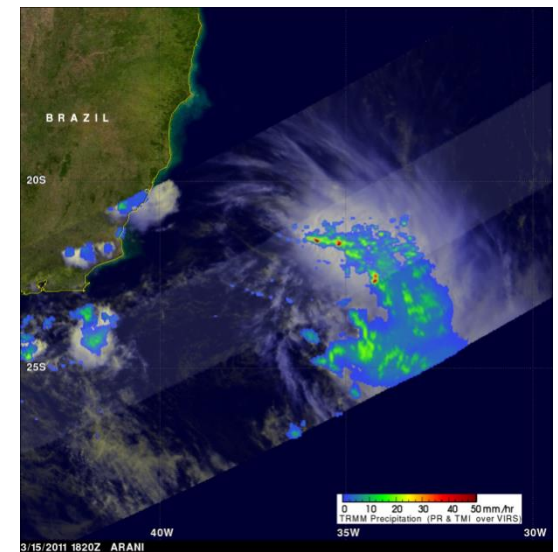
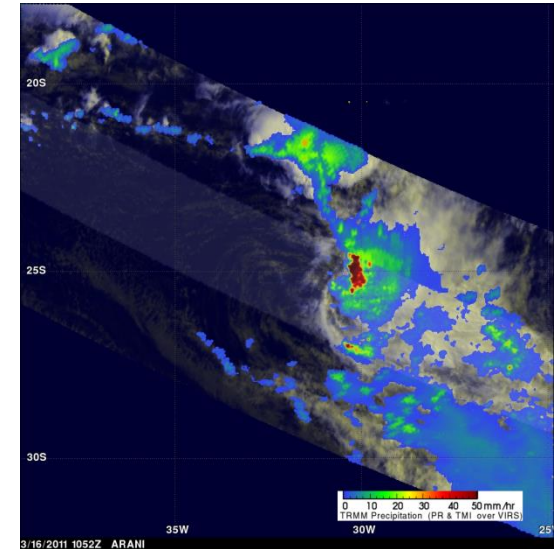
By using also the Precipitation Radar (PR) on board to the TRMM mission and soon (August 2014) the Dual-Frequency Precipitation Radar (DPR) on board the GPM the inner part of the convective clouds can be observed!

A Radar over Tropics: The TRMM-Precipitation Radar

Sub-tropical cyclone ARANI – March 16th 2011 at 1052 UTC

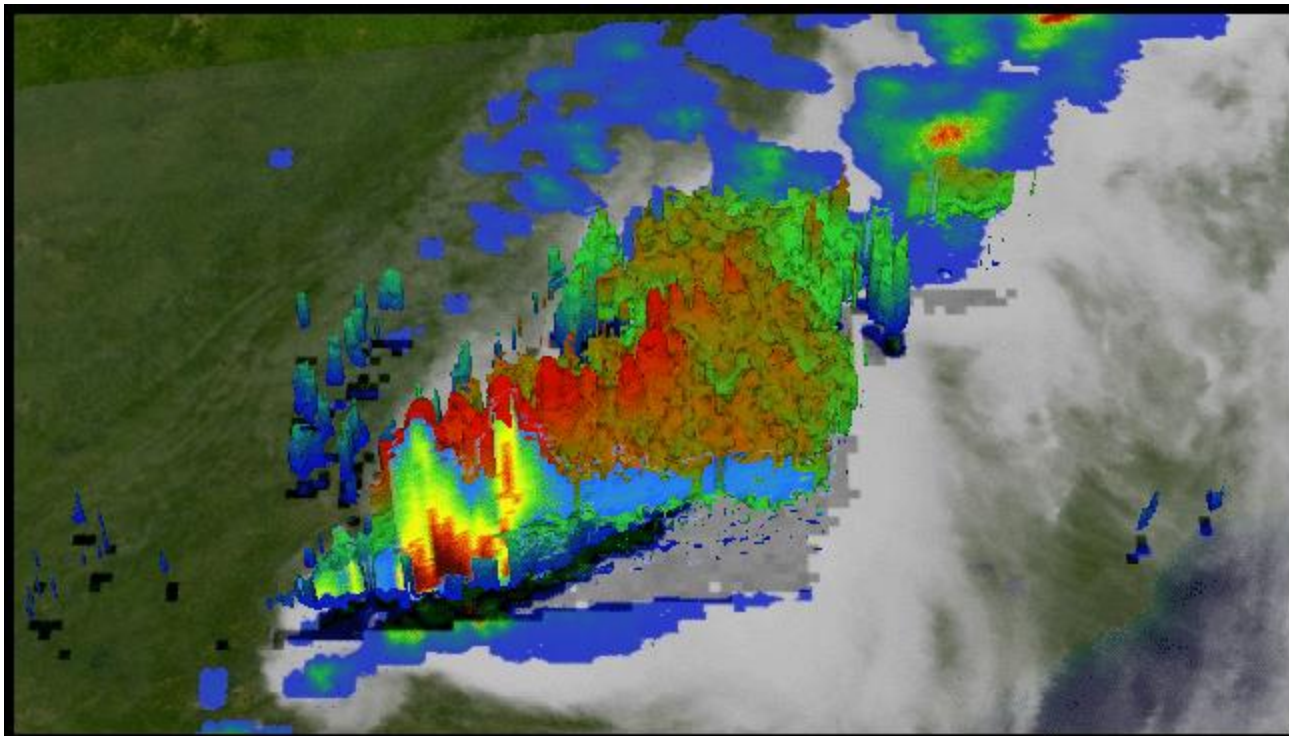


Flyby simulation of the PR

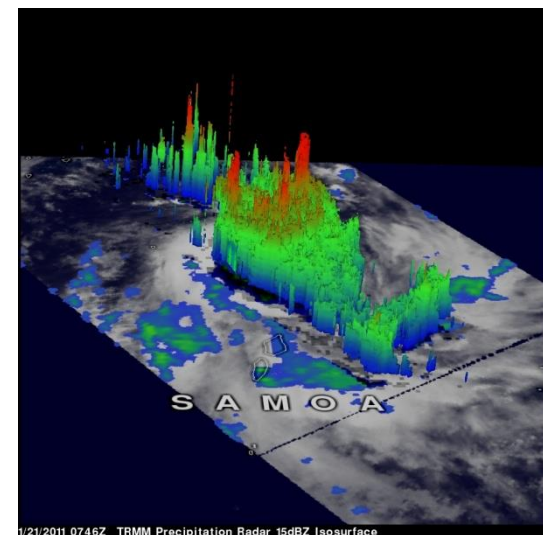
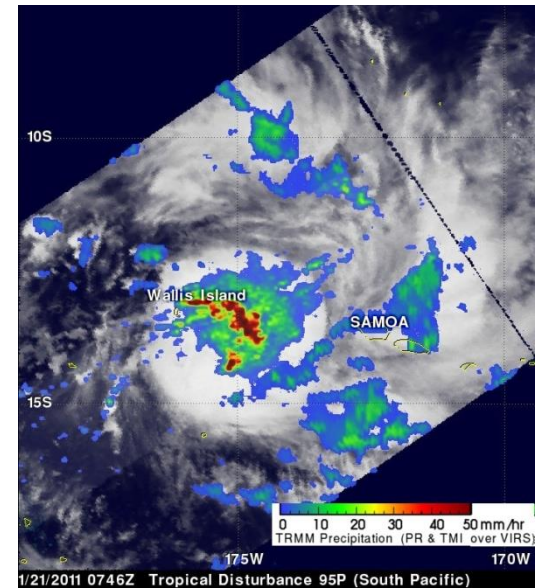


A Radar over Tropics: The TRMM-Precipitation Radar

Tornado over Alabama and Georgia – April 28th 2011 at 0652 UTC



Flyby simulation of the PR



Thanks for your attention!