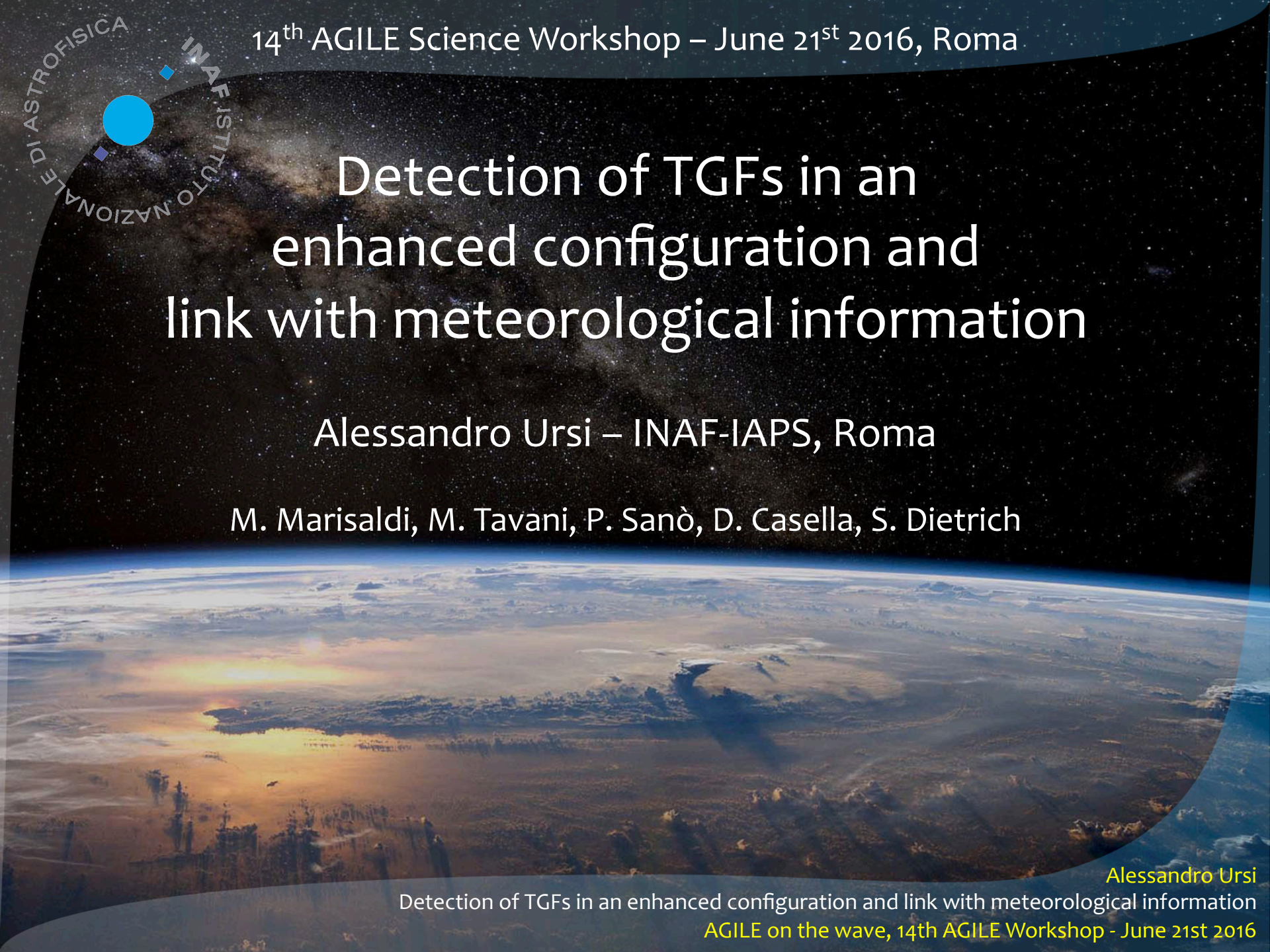
14th AGILE Science Workshop – June 21st 2016, Roma

Detection of TGFs in an enhanced configuration and link with meteorological information

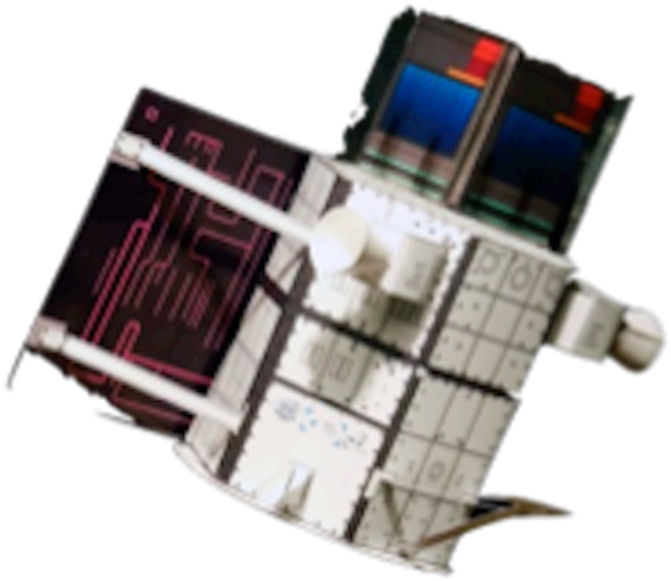
Alessandro Ursi – INAF-IAPS, Roma

M. Marisaldi, M. Tavani, P. Sanò, D. Casella, S. Dietrich



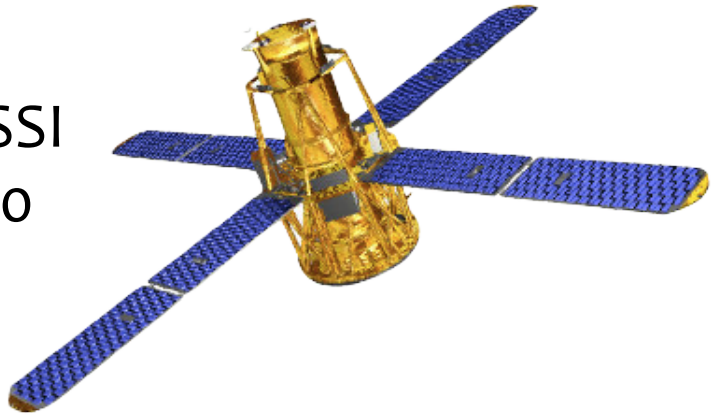
AGILE: the satellite

AGILE
2007

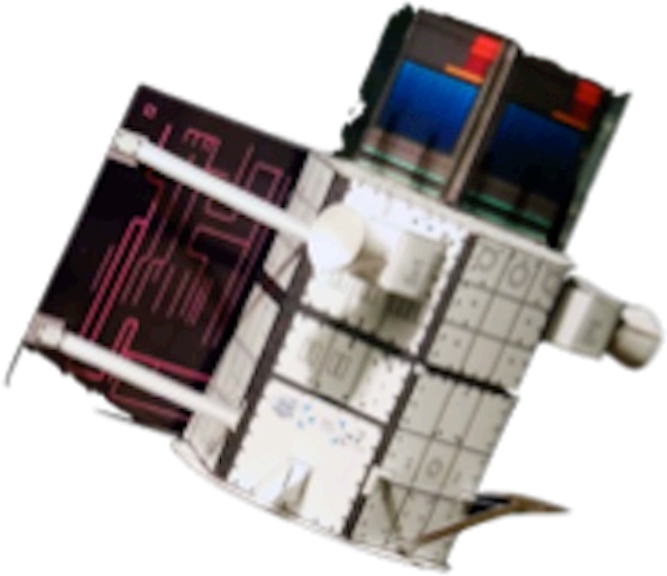


AGILE: the satellite

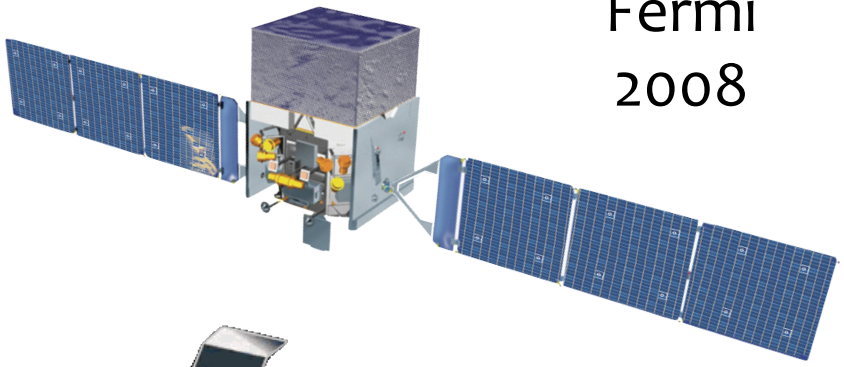
RHESSI
2000

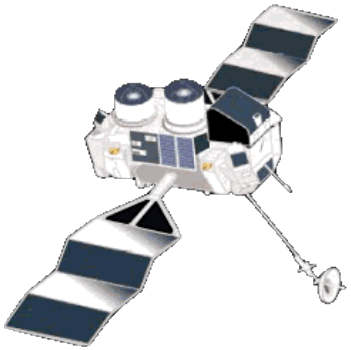


AGILE
2007



Fermi
2008

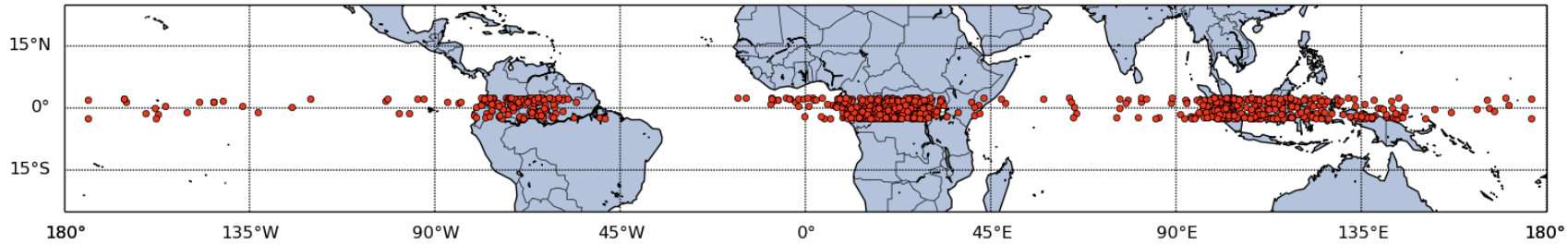


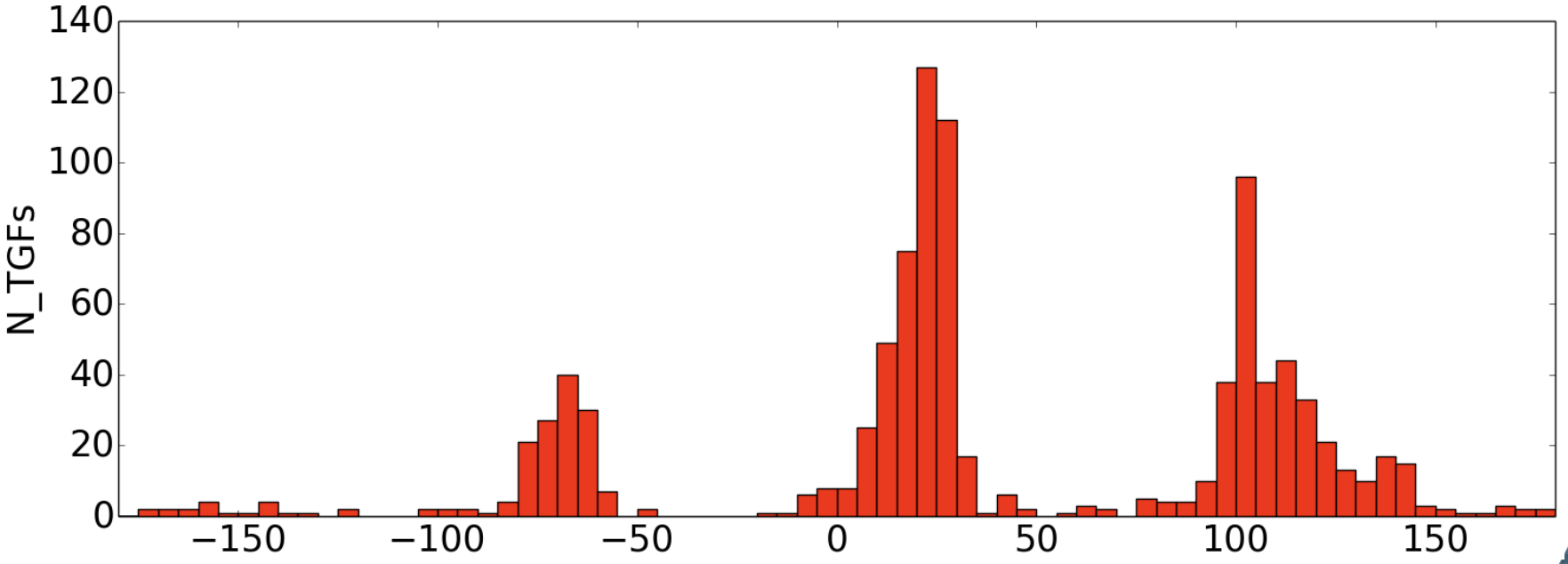


BATSE/CGRO
1990 – 2000
R.I.P.

AGILE: the TGF sample

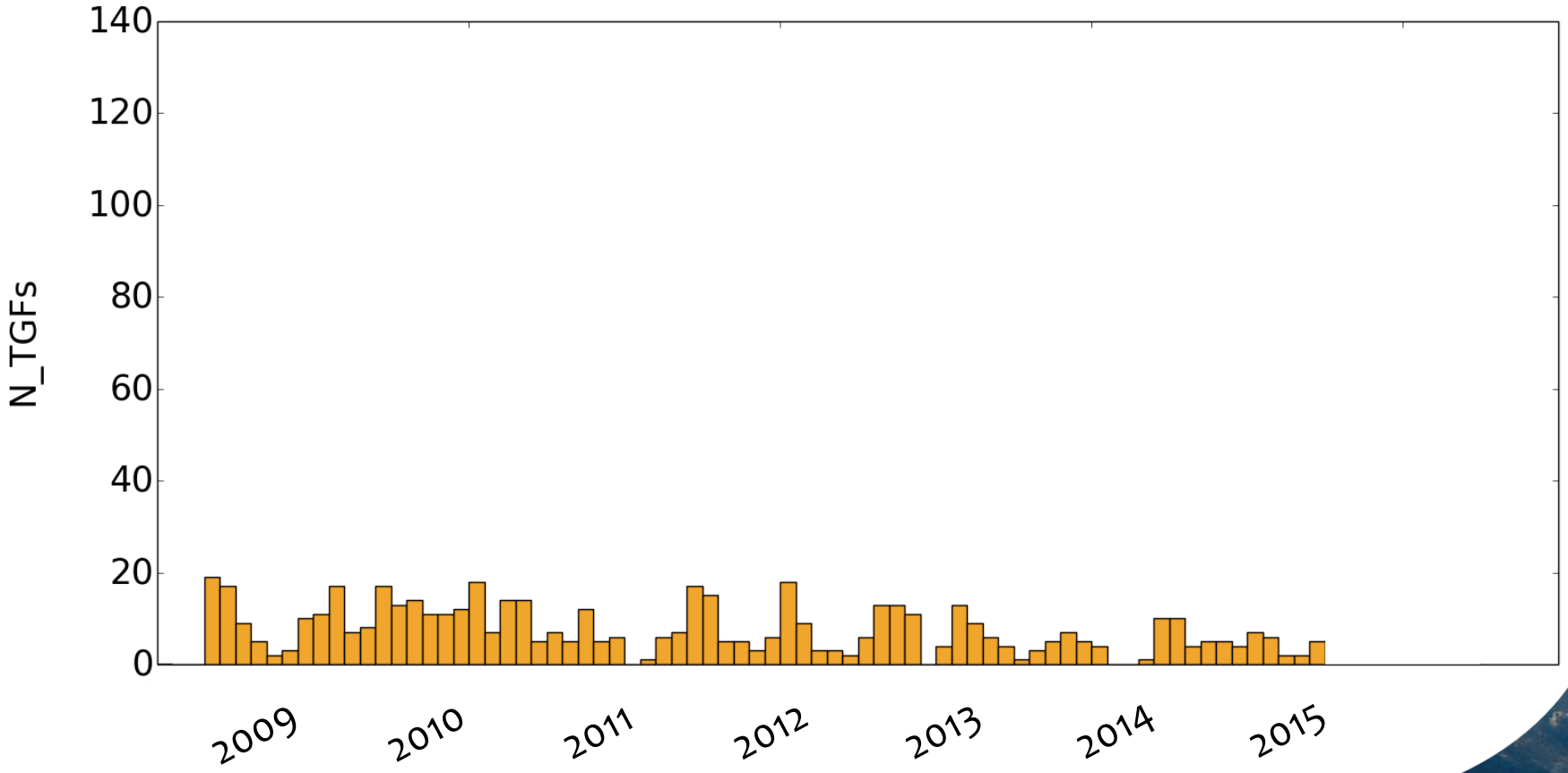
> 1000 TGFs





AGILE: the enhanced configuration

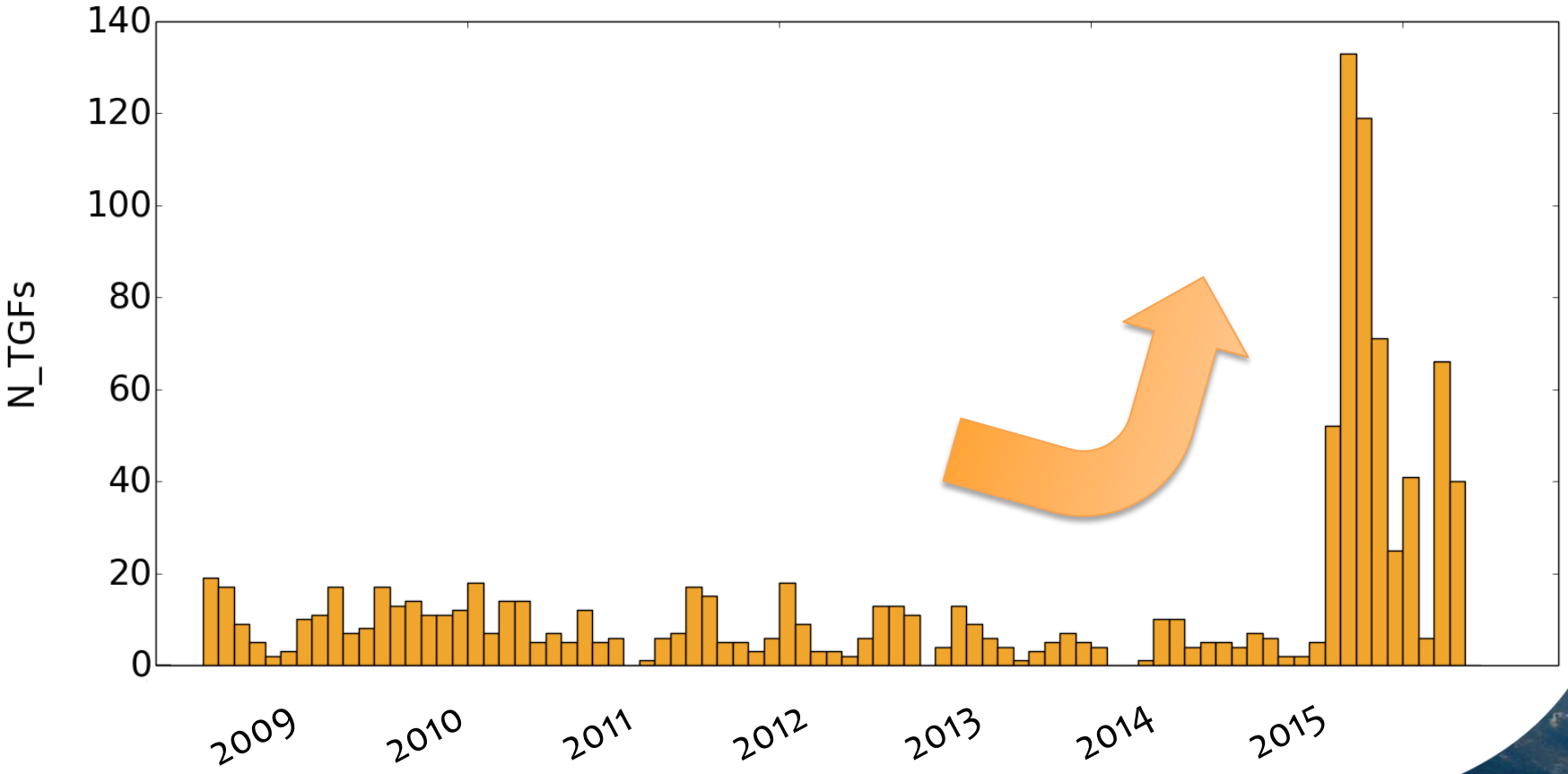
~ 10 TGFs / month



AGILE: the enhanced configuration

~~~ 10 TGFs / month

~ 100 TGFs / month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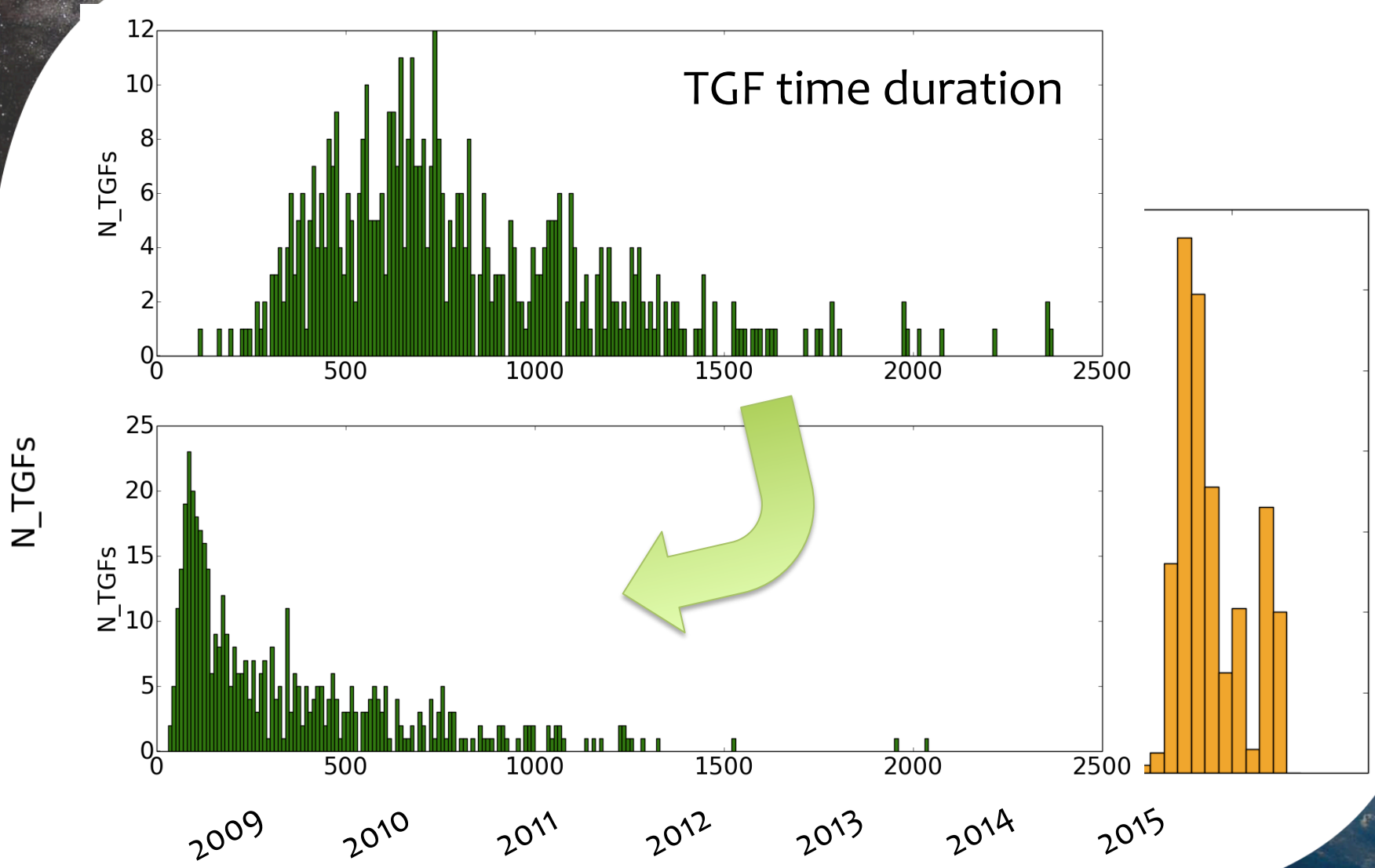
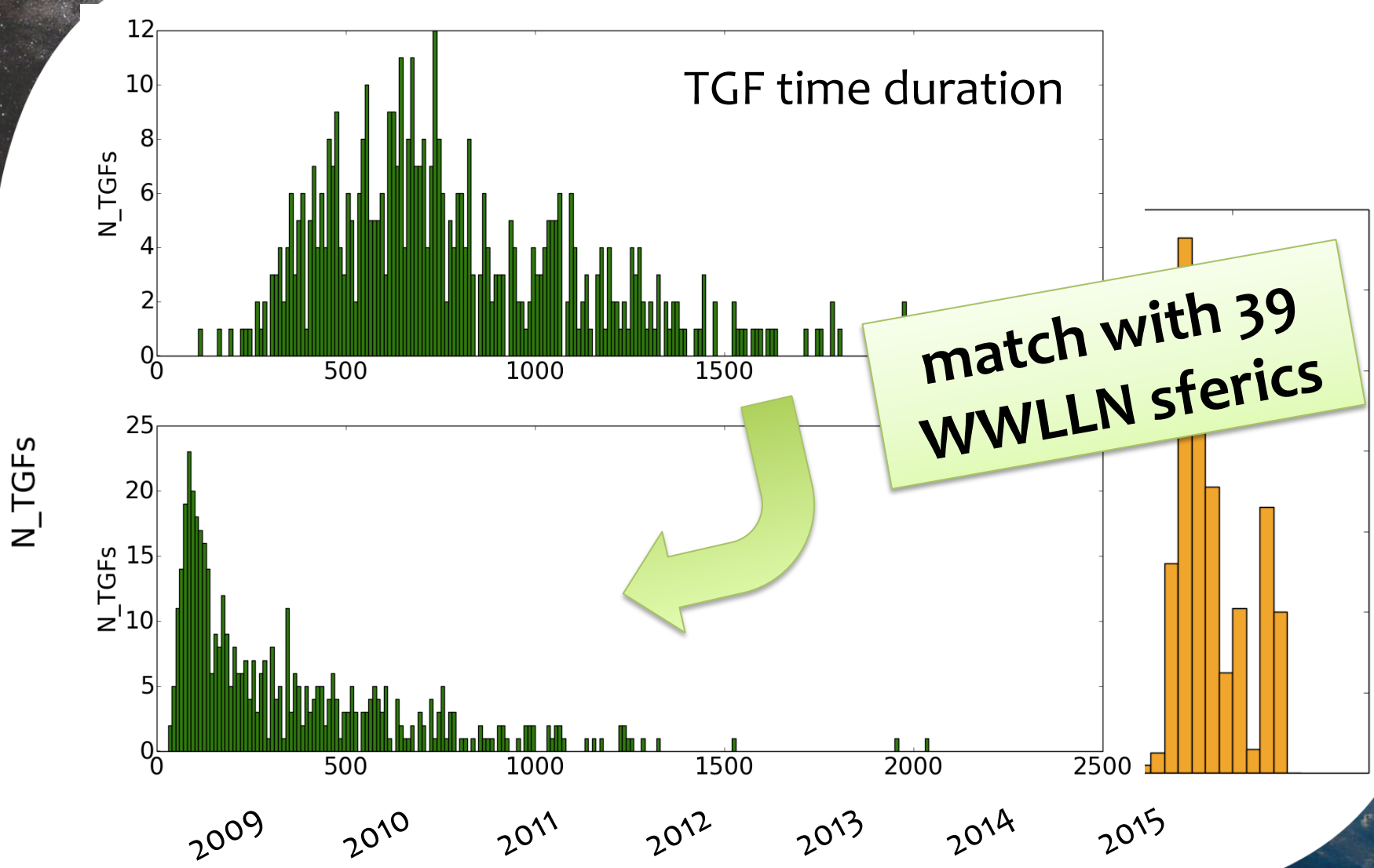
AGILE: the enhanced configuration



AGILE: the enhanced configuration



AGILE: the meteo pipeline

AGILE: the meteo pipeline

TGFs detected by AGILE

AGILE: the meteo pipeline

TGFs detected by AGILE

+

AGILE: the meteo pipeline

TGFs detected by AGILE

+

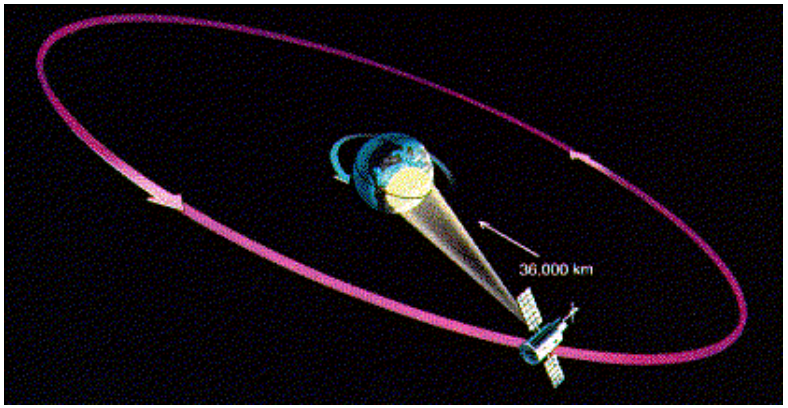
information by meteo satellites

AGILE: the meteo pipeline

TGFs detected by AGILE

+

information by meteo satellites



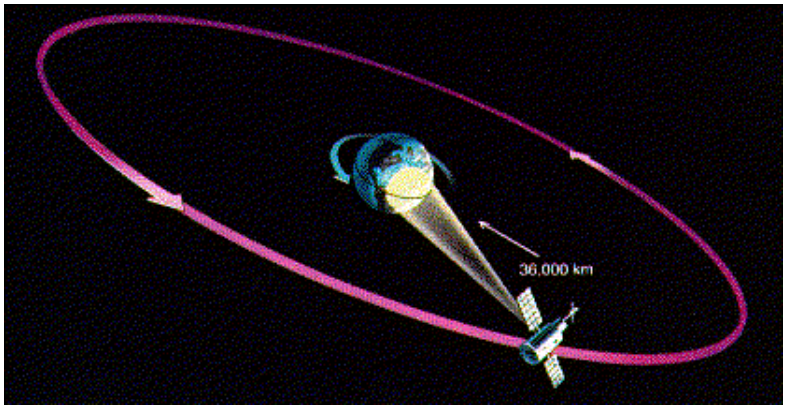
geostationary satellites

AGILE: the meteo pipeline

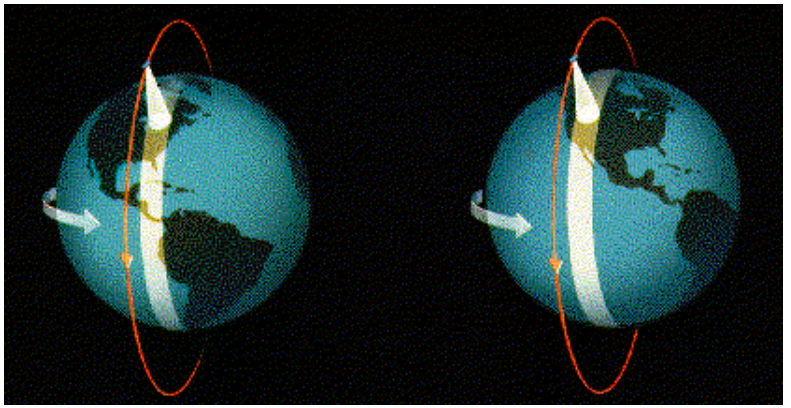
TGFs detected by AGILE

+

information by meteo satellites



geostationary satellites



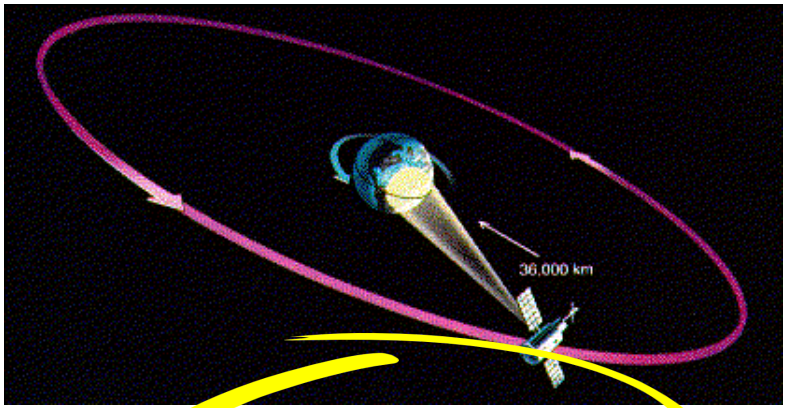
low earth orbit satellites

AGILE: the meteo pipeline

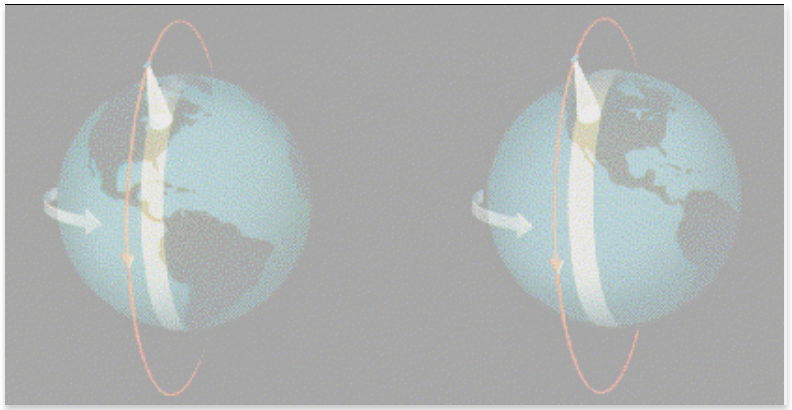
TGFs detected by AGILE

+

information by meteo satellites



geostationary satellites



low earth orbit satellites

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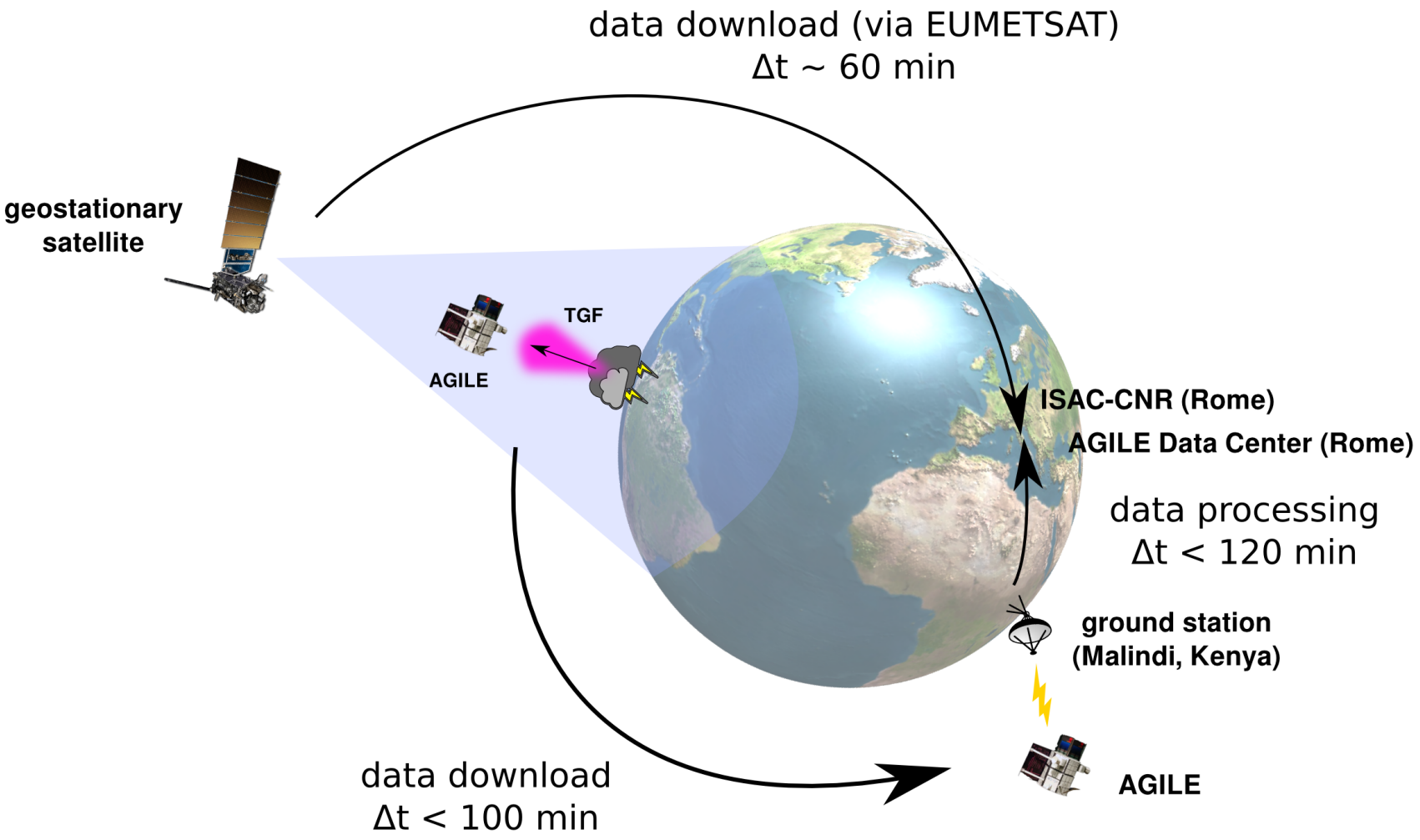
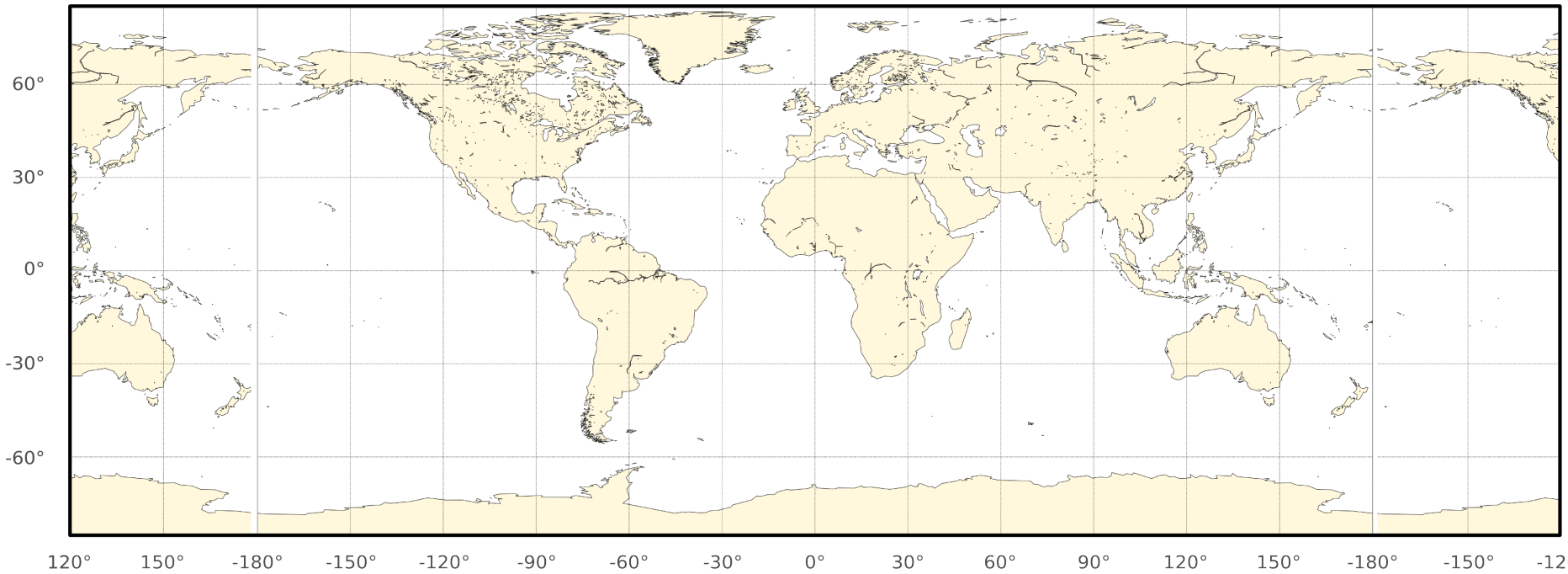


AGILE: the meteo pipeline



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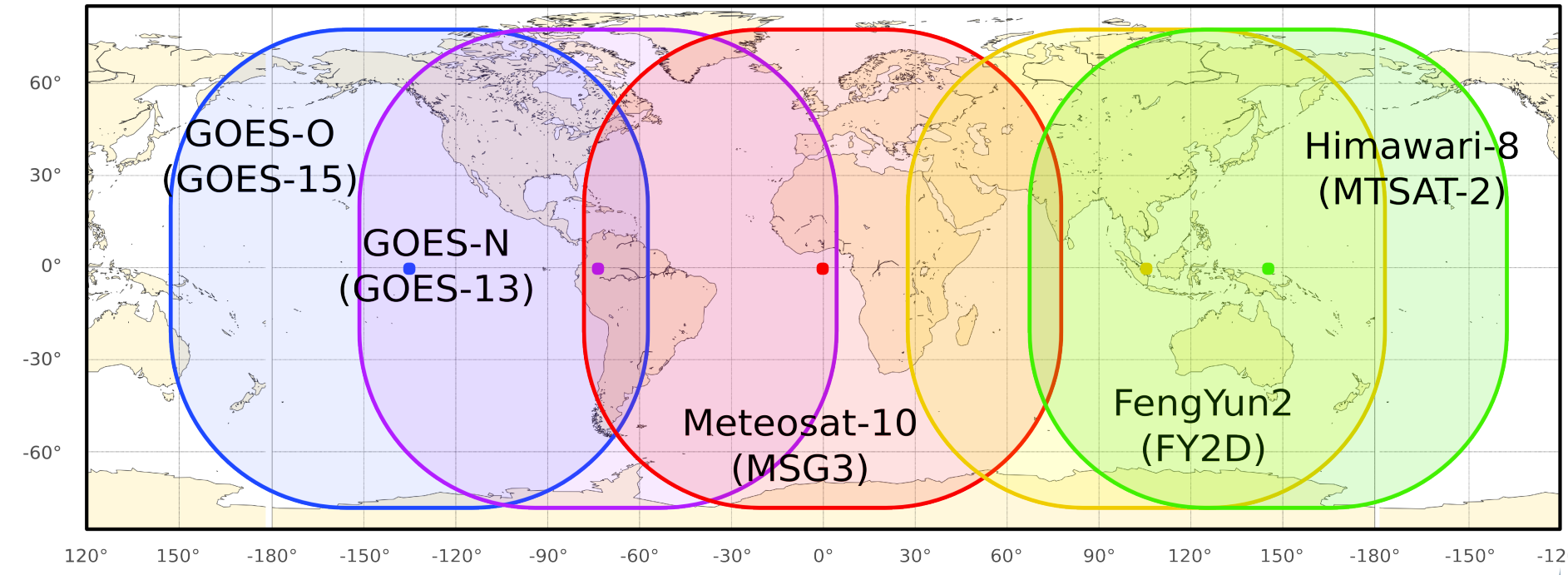

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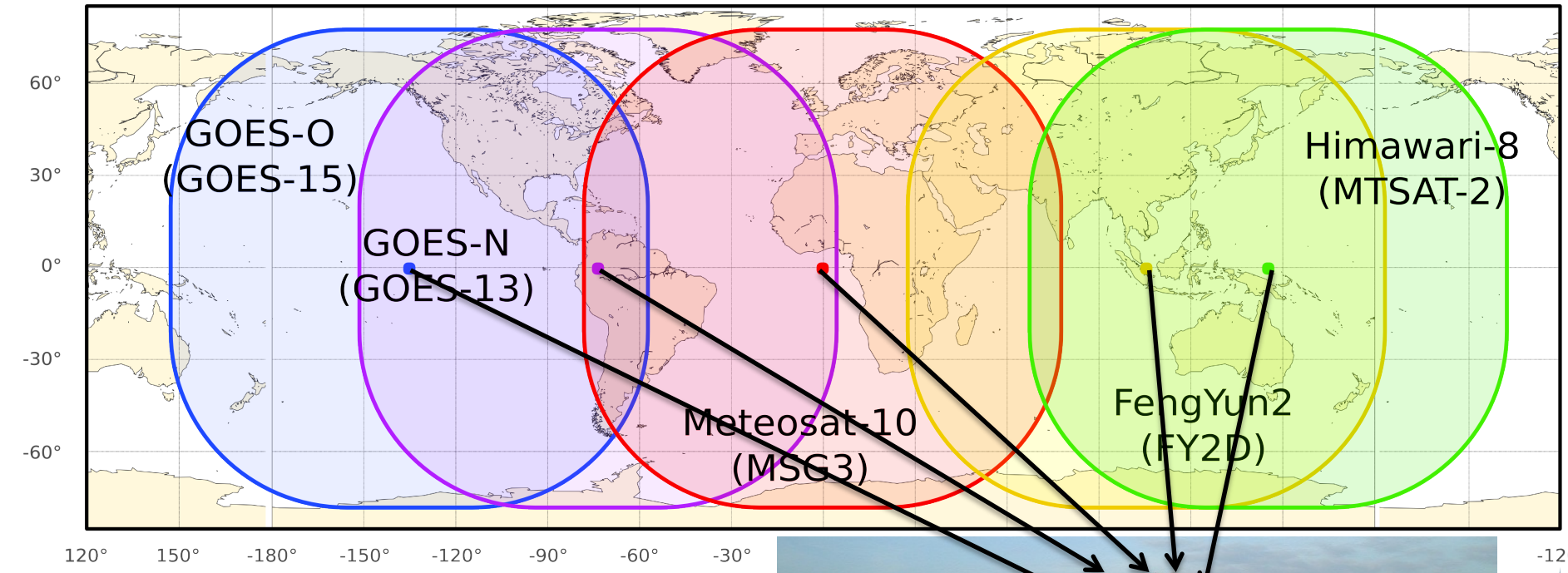

ISAC-CNR, Rome

1 week buffer

AGILE: the meteo pipeline

AGILE: the meteo pipeline

TGF ID

12/04/2015
12:11:44
(23.74°, -2.01°)
E_{max} = 6.70 MeV

AGILE: the meteo pipeline

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12/04/2015
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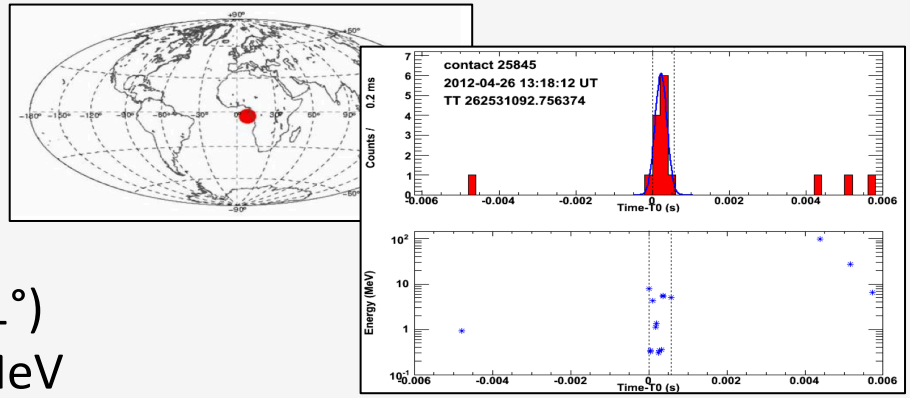

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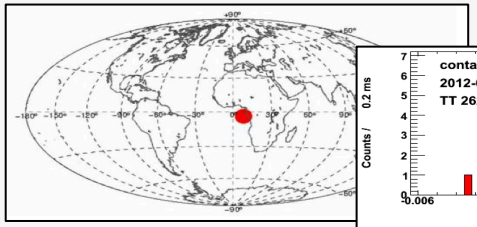

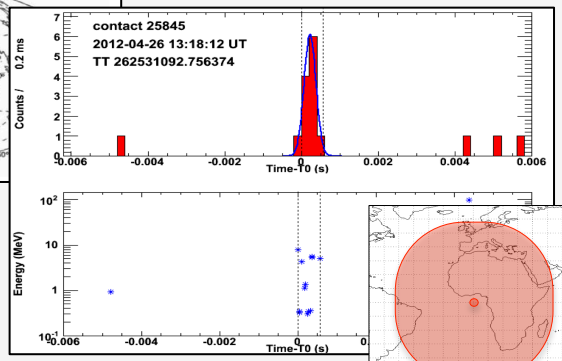

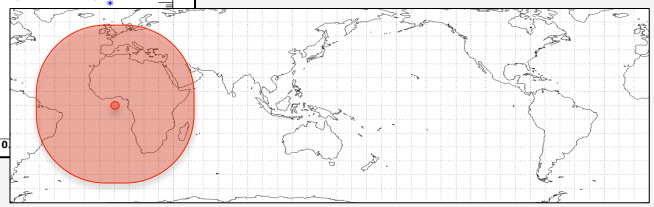

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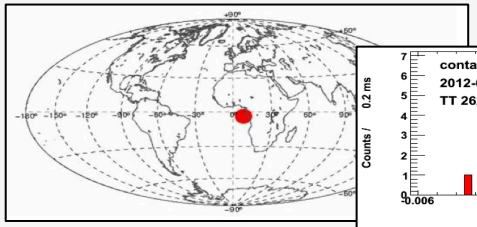

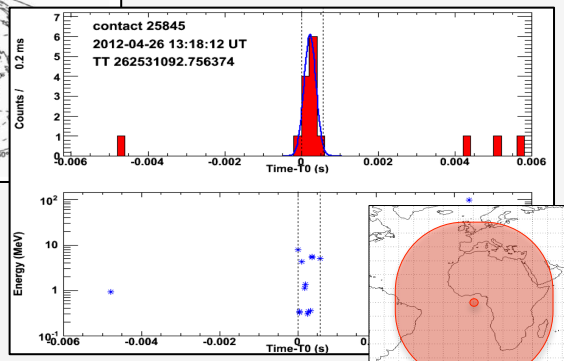

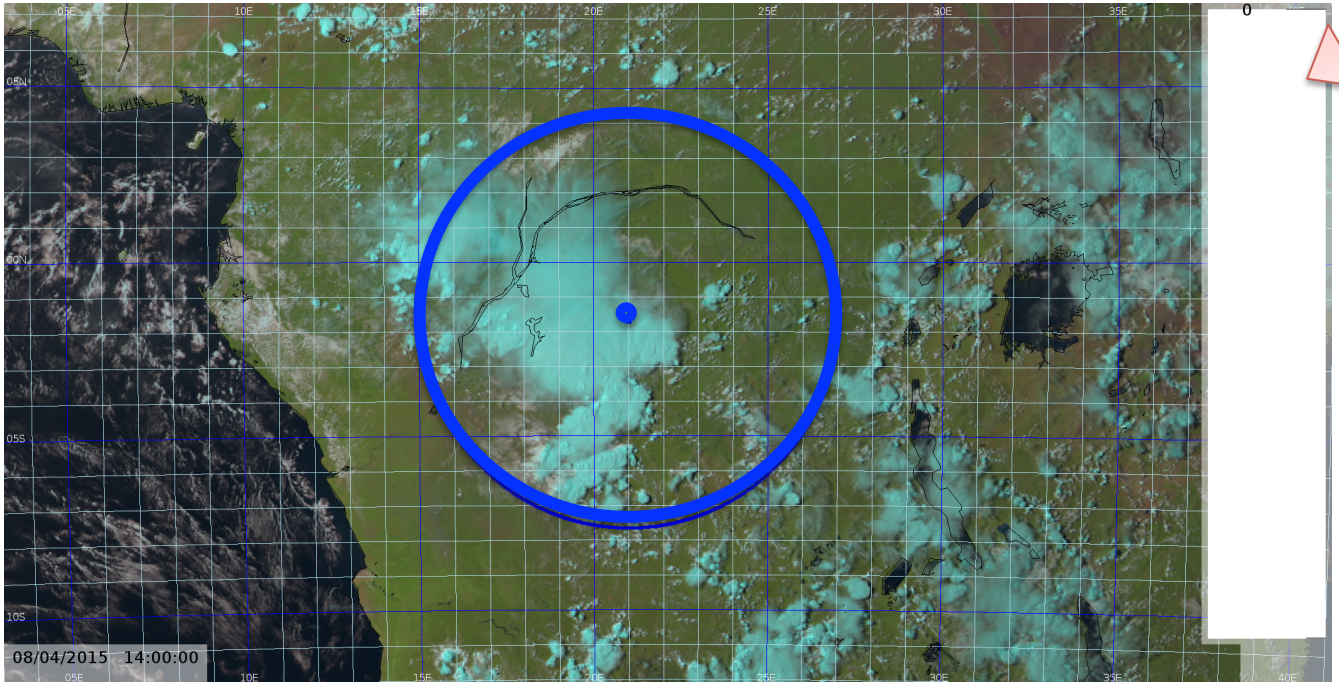

VIS channels

AGILE: the meteo pipeline

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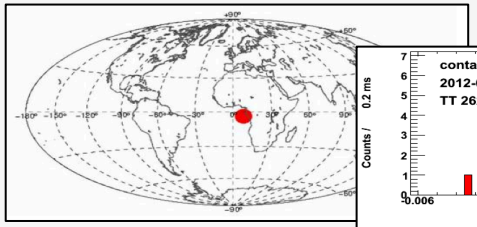

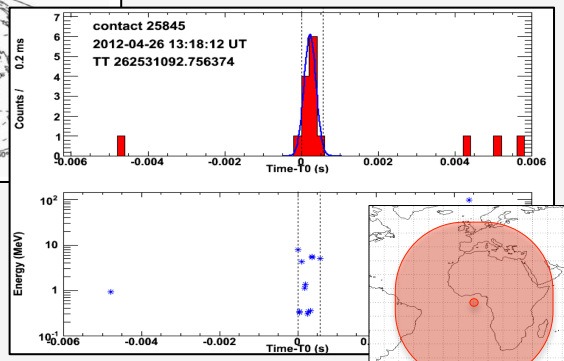

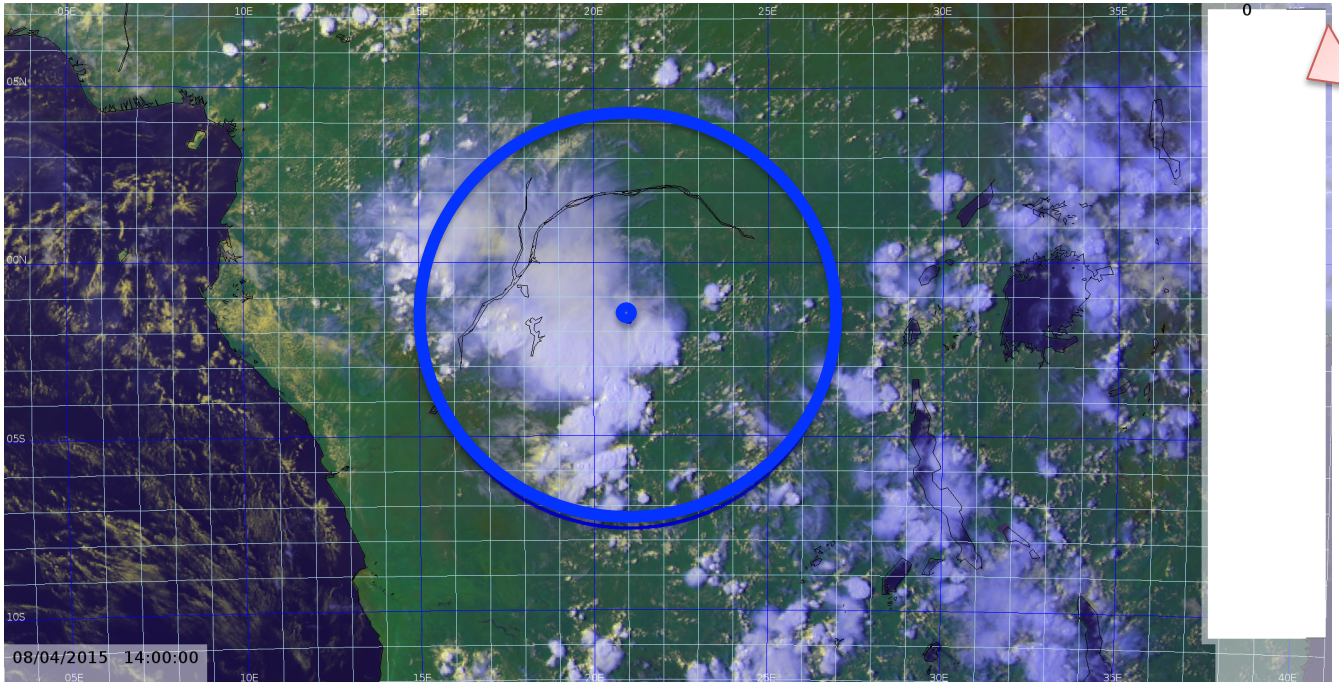

VIS channels

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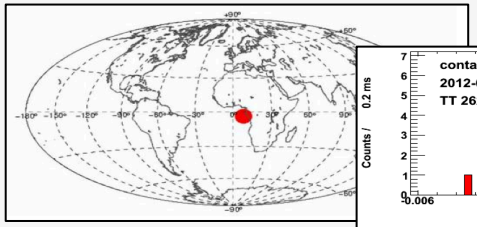

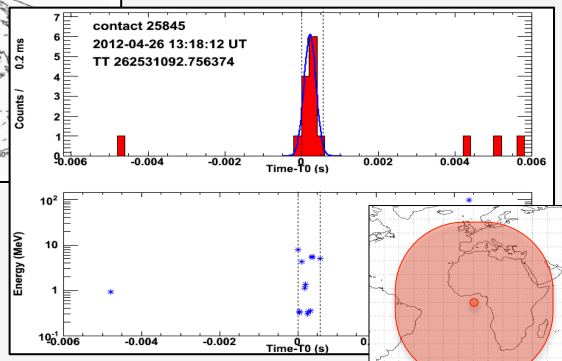

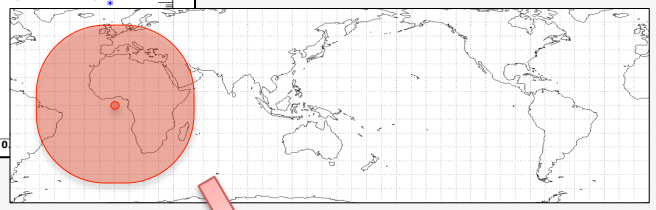

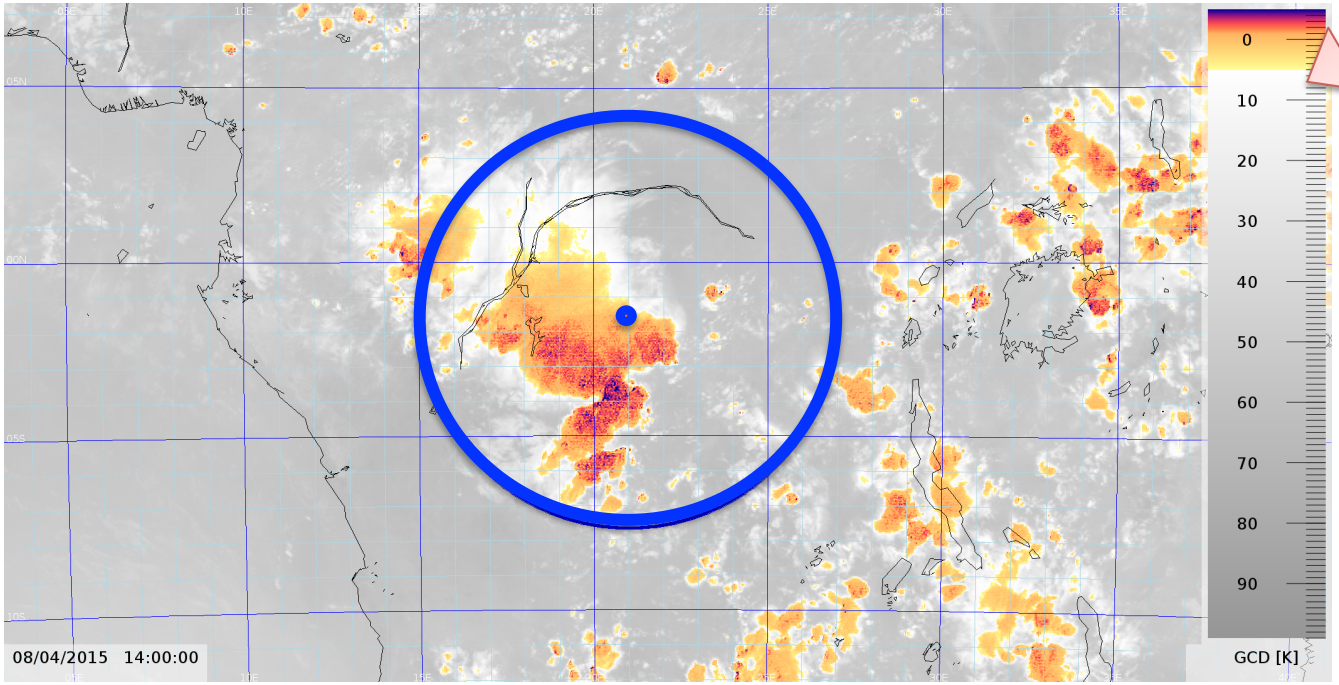

GCD algorithm

$T_{IR} - T_{WV}$

AGILE: the meteo pipeline

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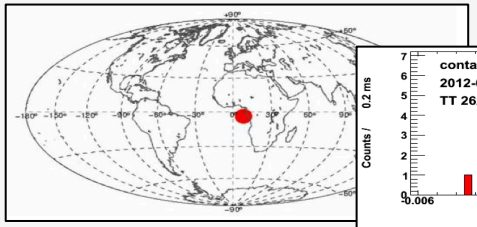

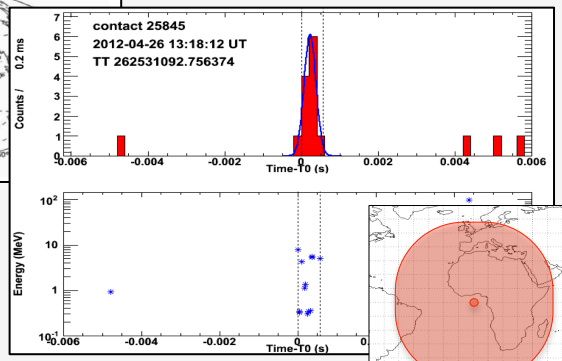

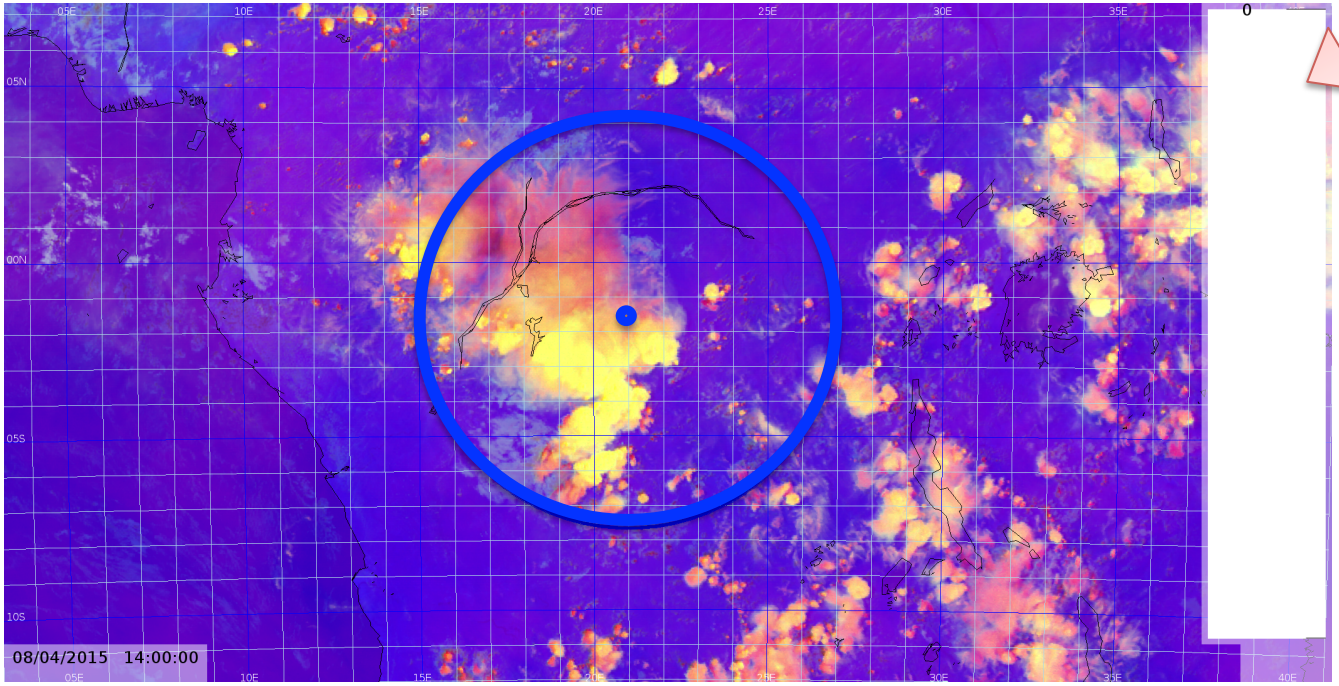

severe
storm
RGB

AGILE: the meteo pipeline

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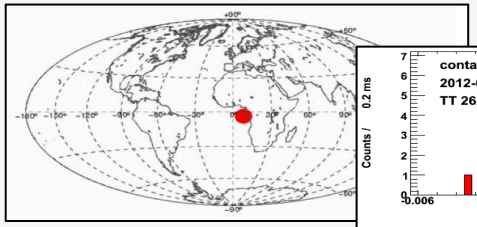

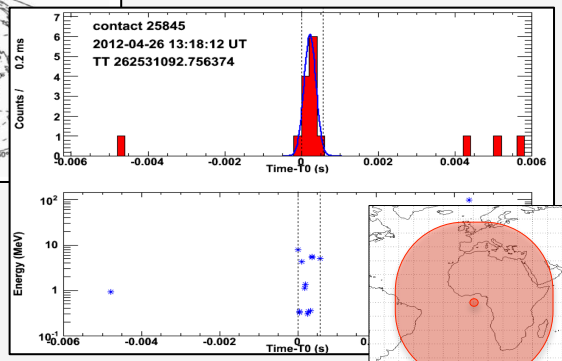

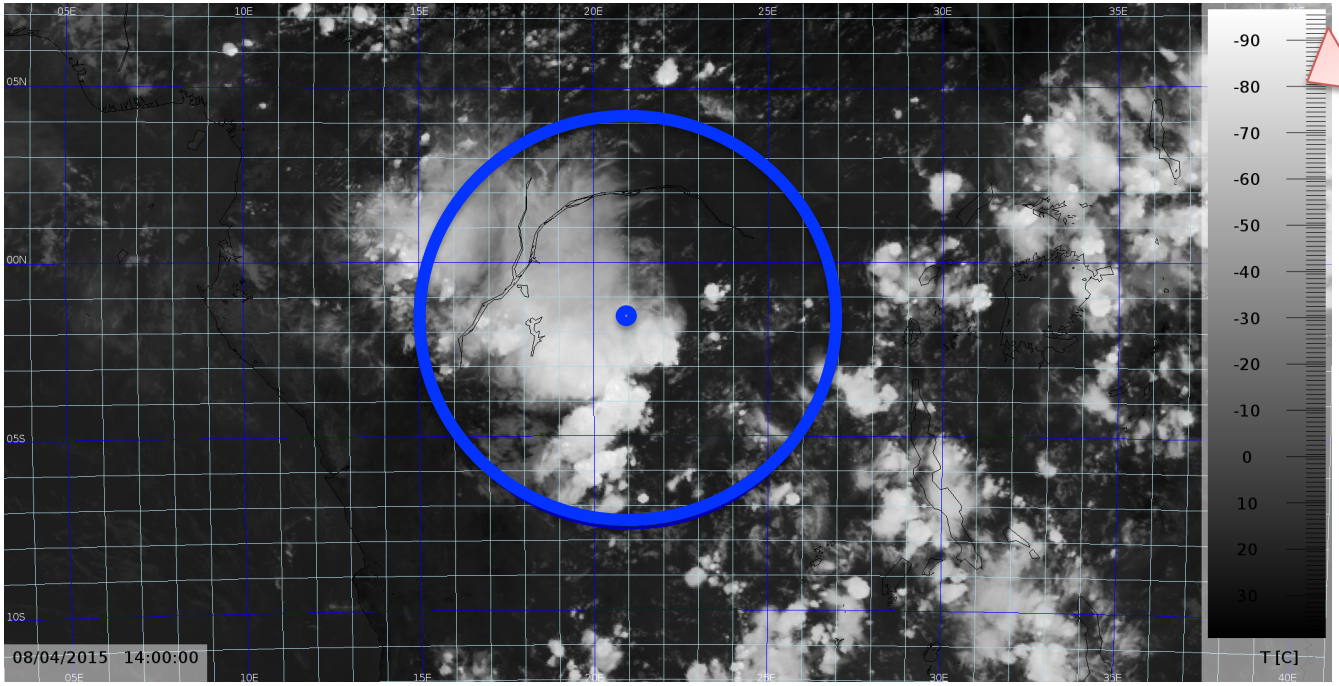

IR
10.8 μm

AGILE: the meteo pipeline

TGF ID

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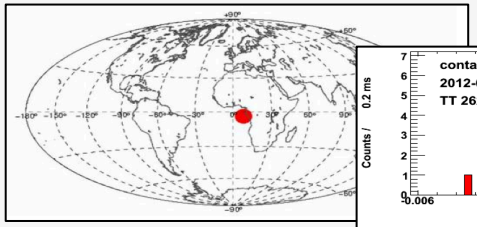
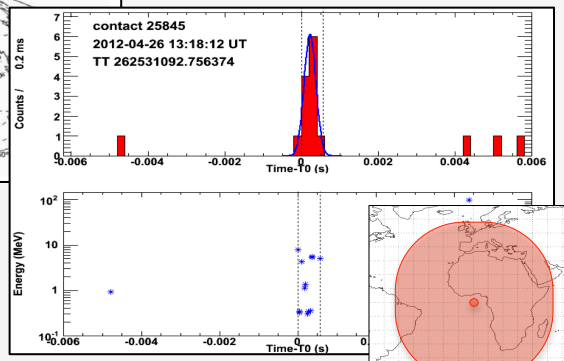
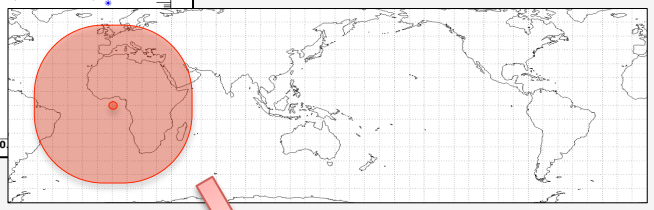
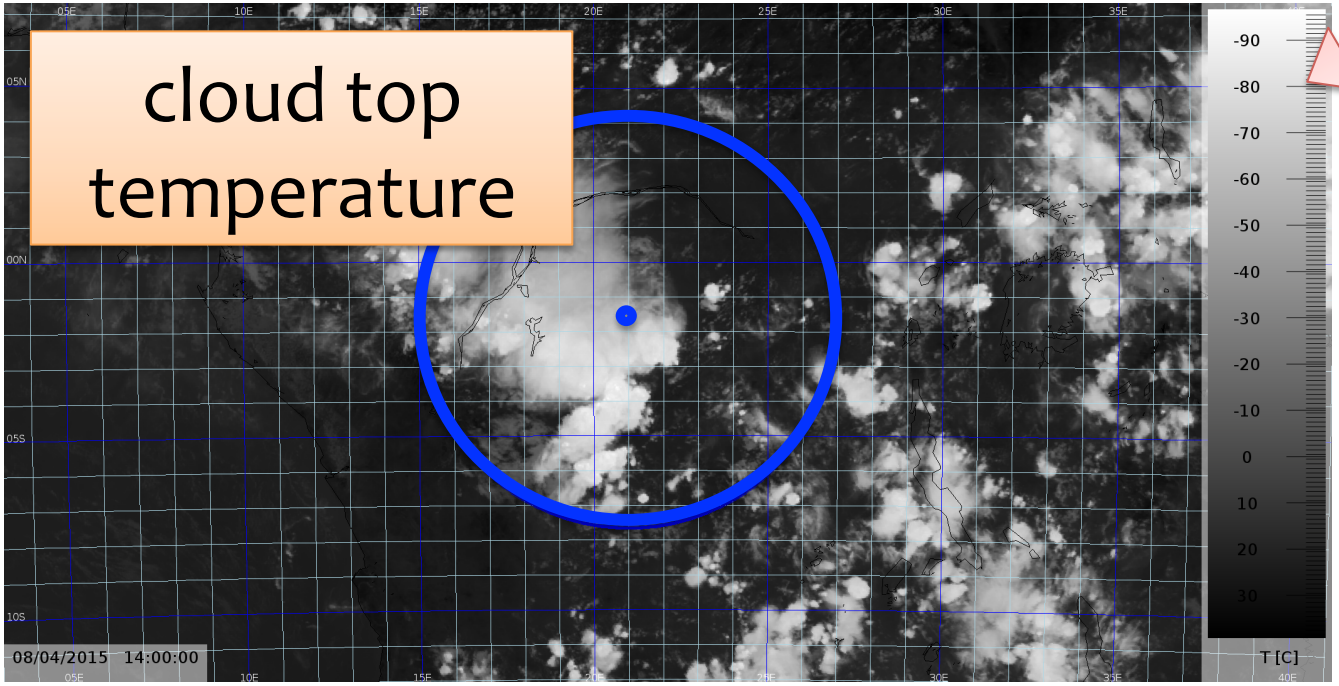






cloud top temperature



IR
10.8 μm

AGILE: the meteo pipeline

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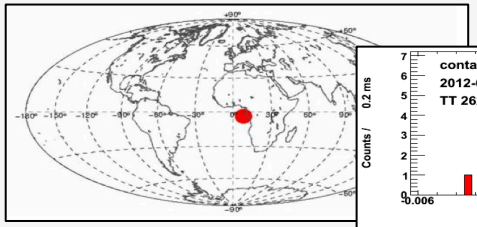
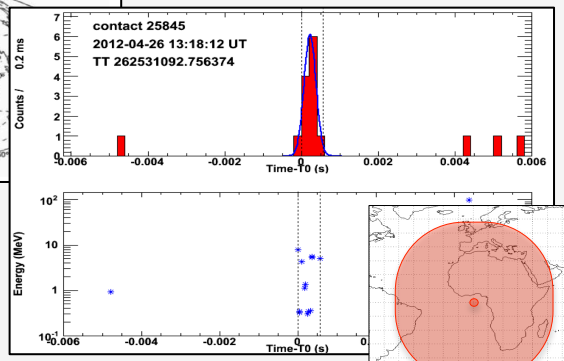
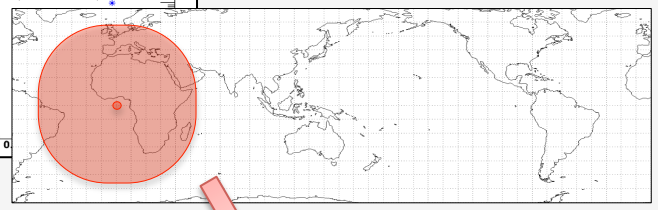


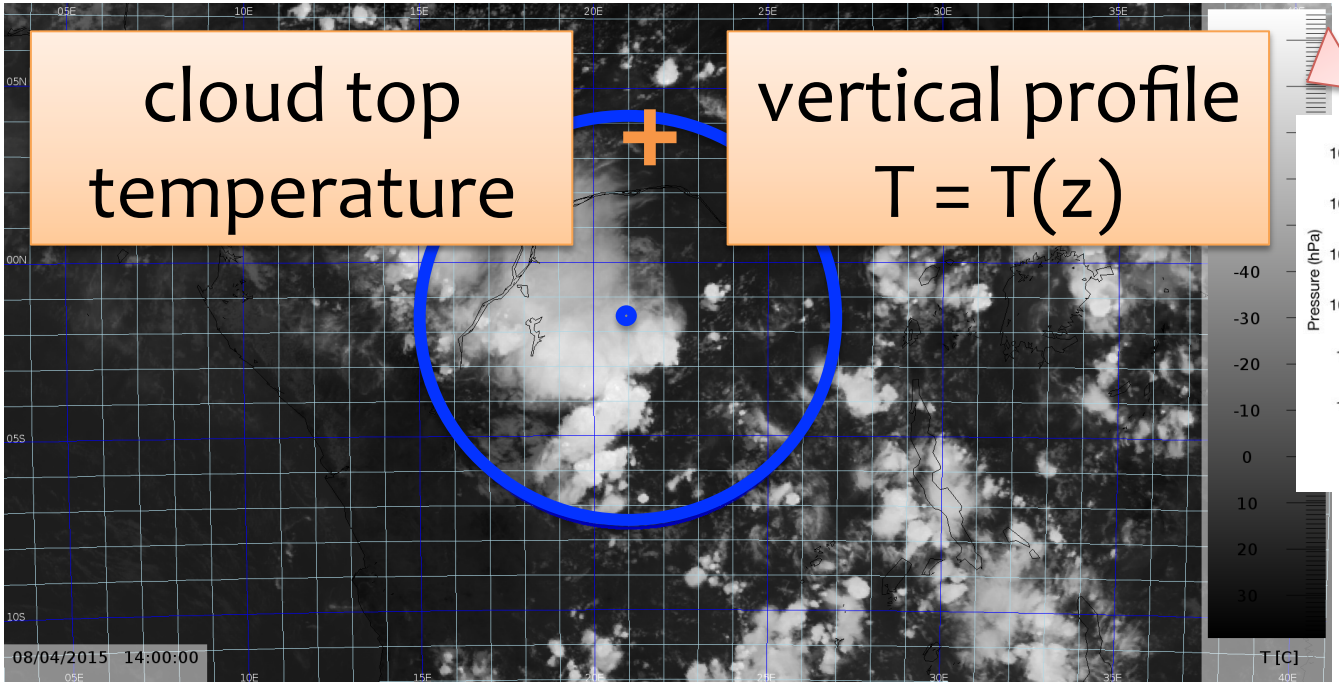


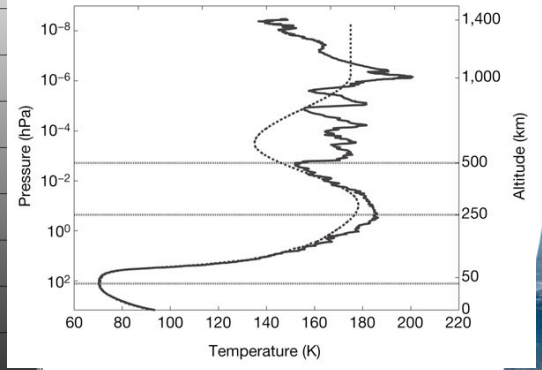


cloud top temperature

+

vertical profile
T = T(z)





AGILE: the meteo pipeline

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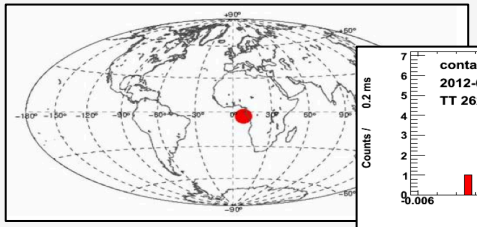
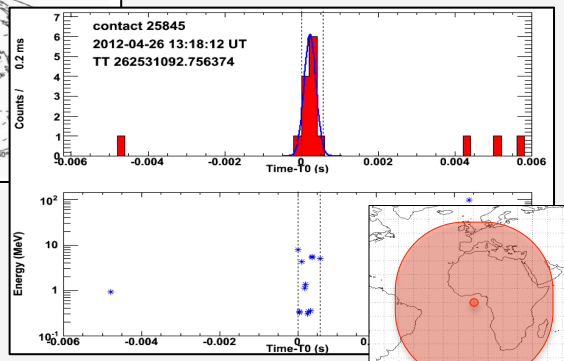
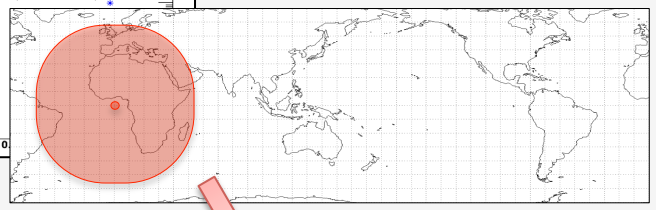






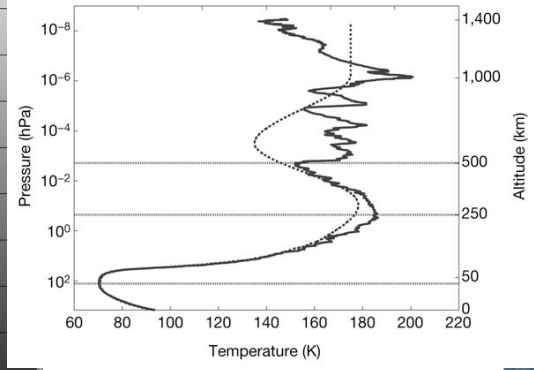
cloud top temperature

+

vertical profile T = T(z)

=

cloud top height



AGILE: the meteo pipeline

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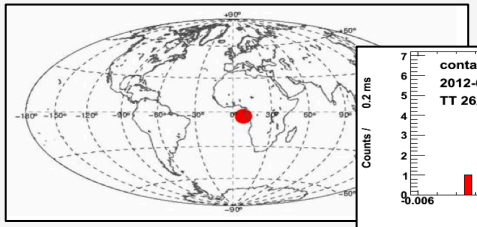
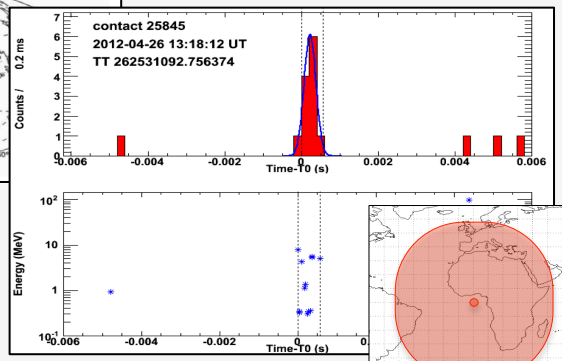
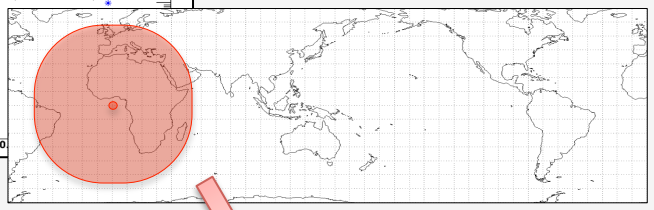
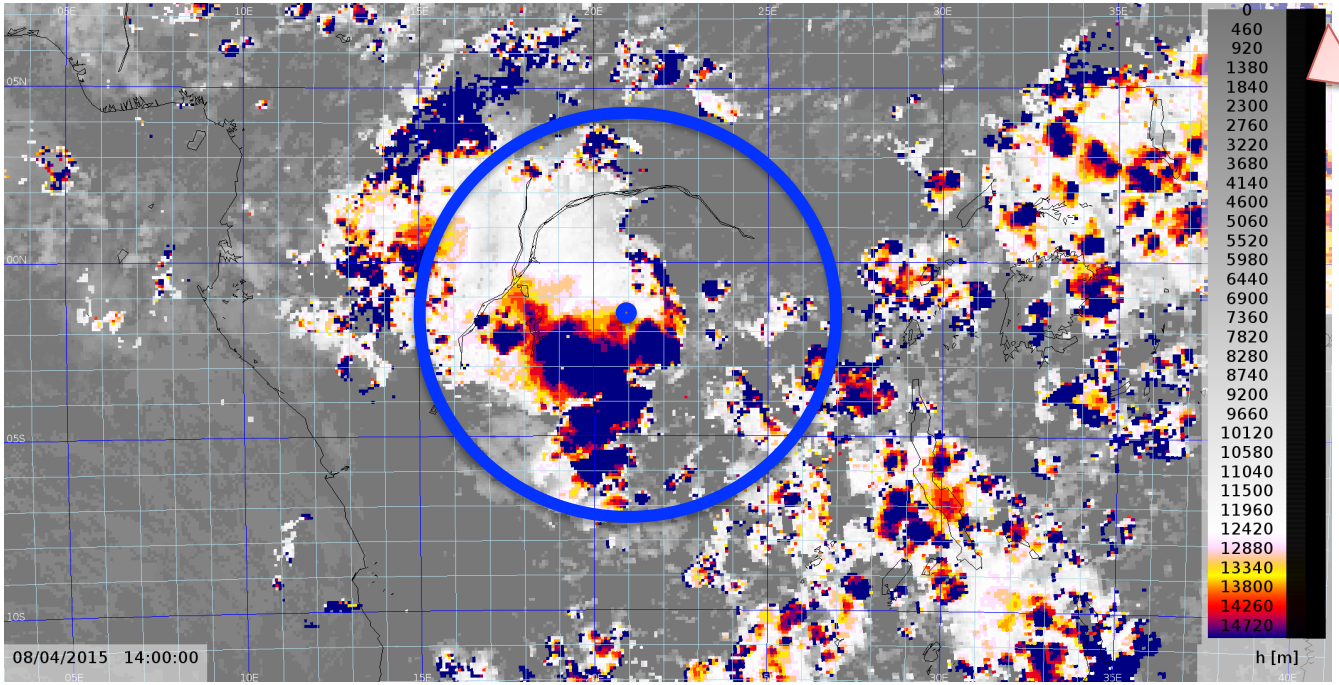
12:11:44
(23.74°, -2.01°)
E_{max} = 6.70 MeV



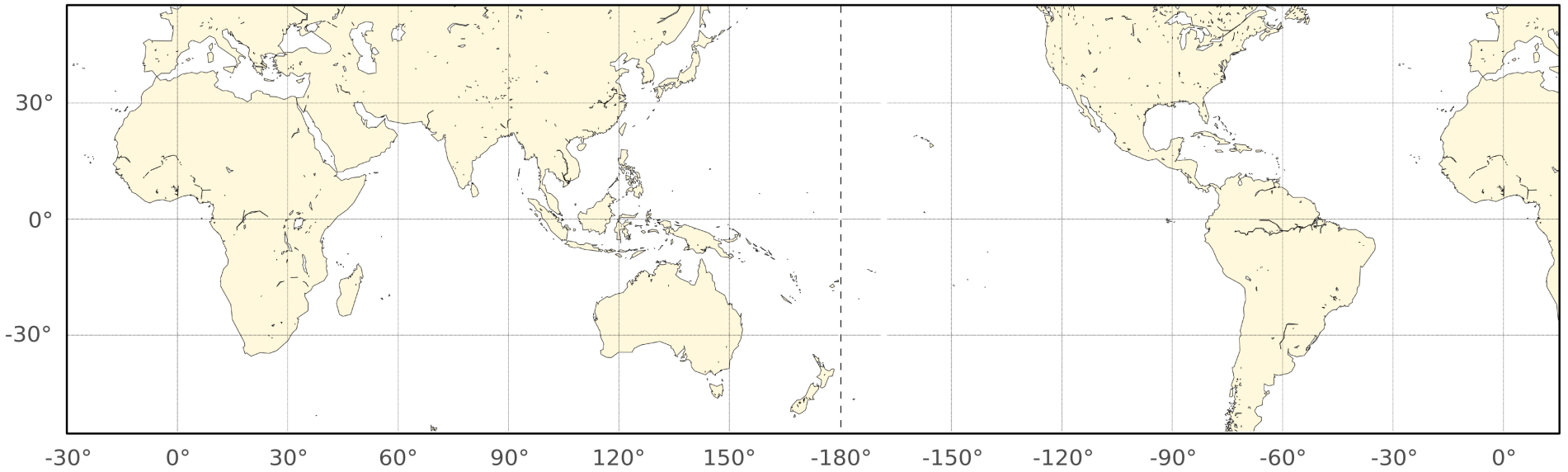






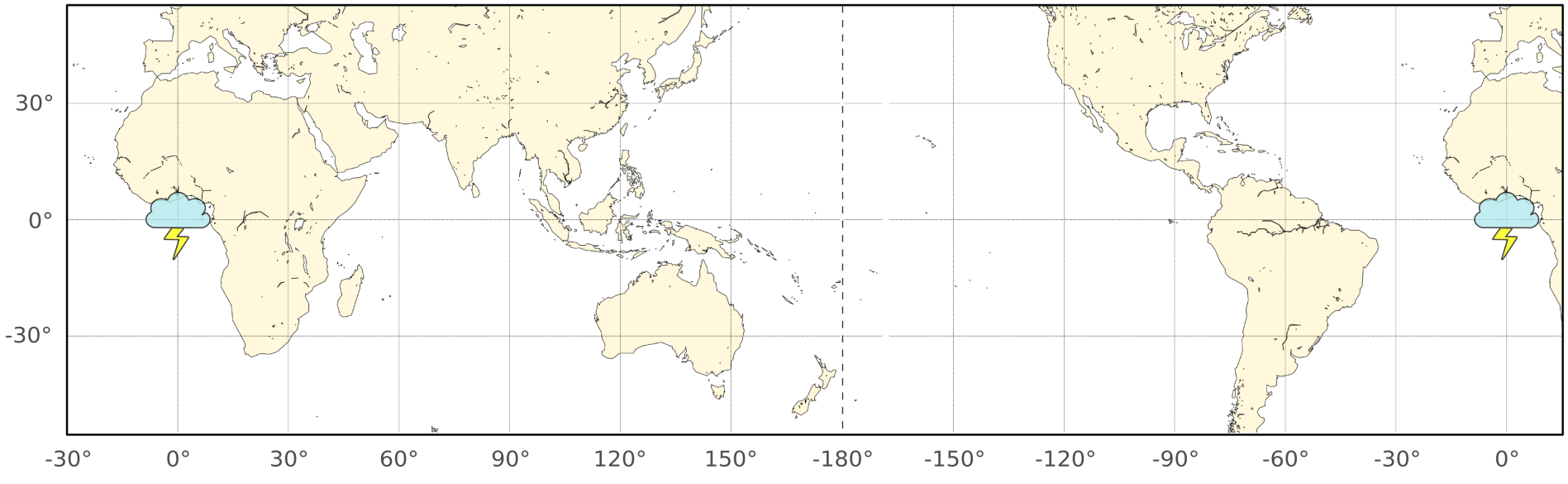
cloud top height (MSG3)

AGILE: the quasi-equatorial orbit

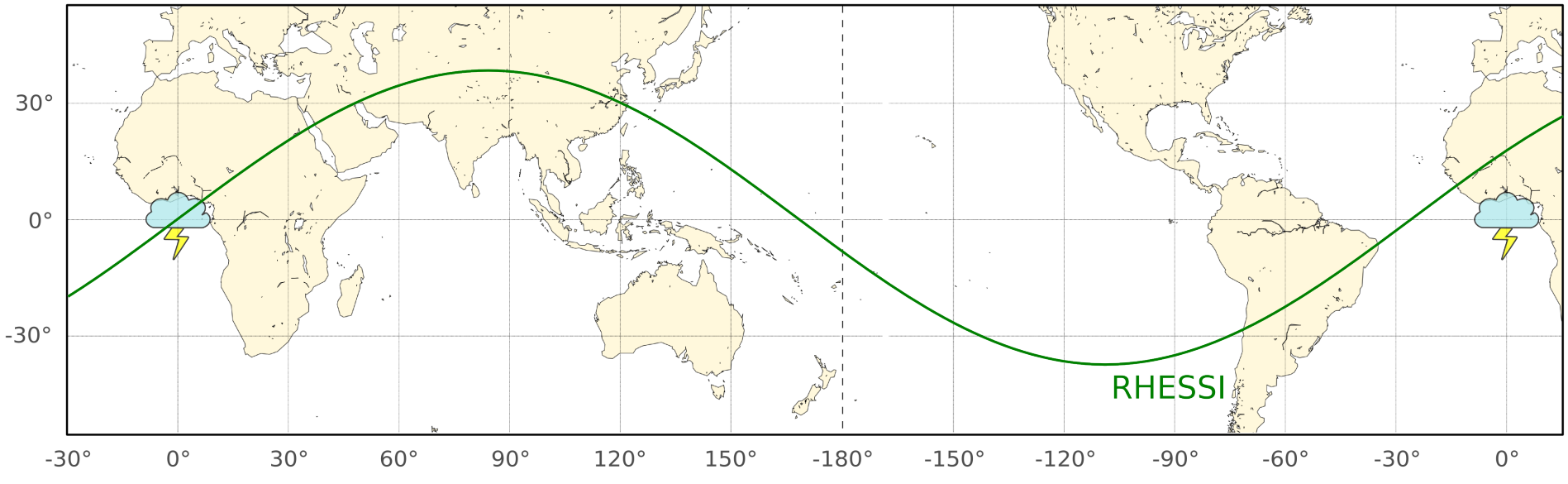


Alessandro Ursi
Detection of TGFs in an enhanced configuration and link with meteorological information
AGILE on the wave, 14th AGILE Workshop - June 21st 2016

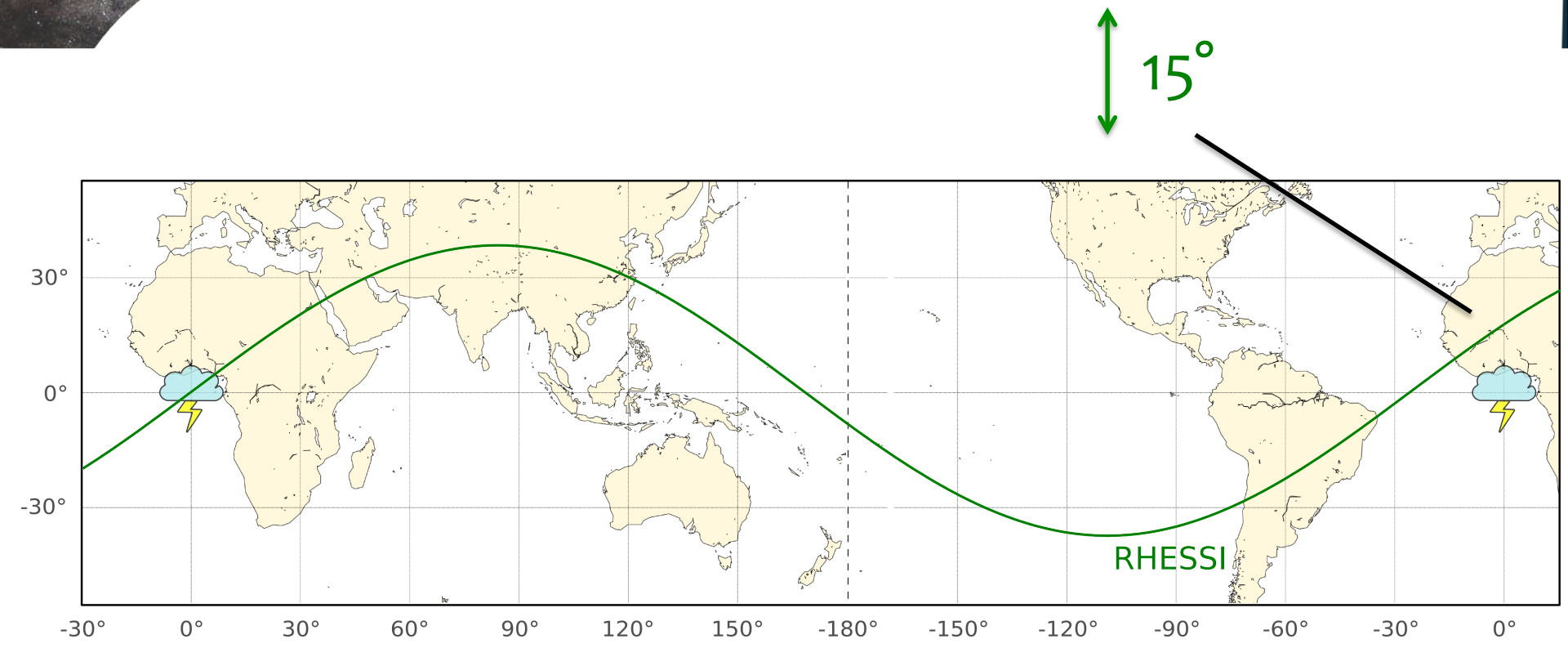
AGILE: the quasi-equatorial orbit



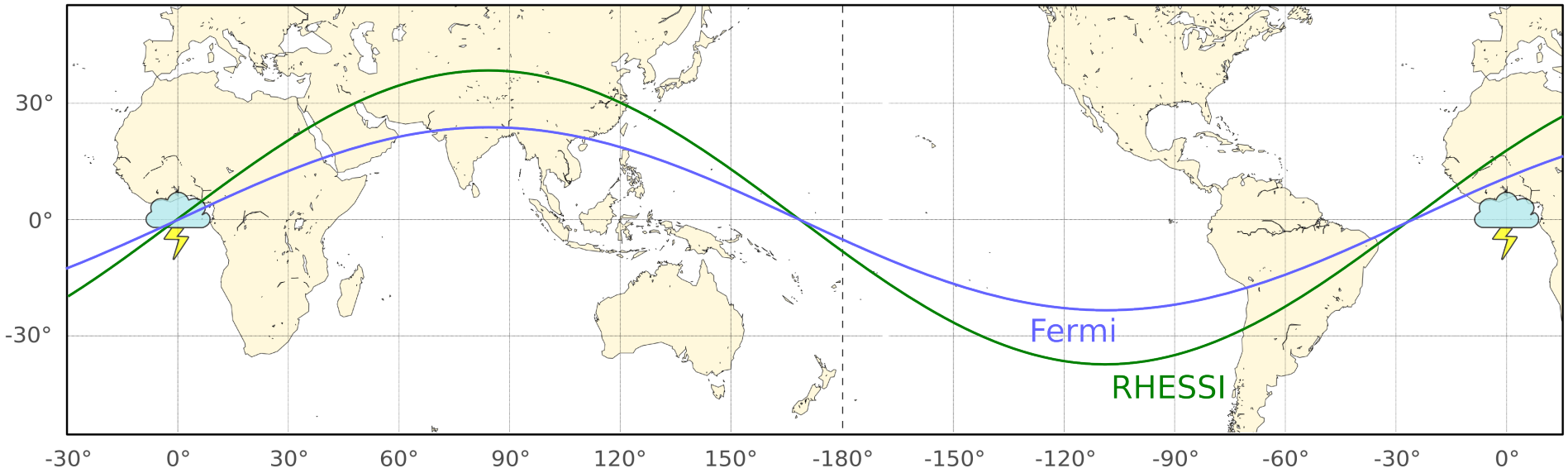
AGILE: the quasi-equatorial orbit



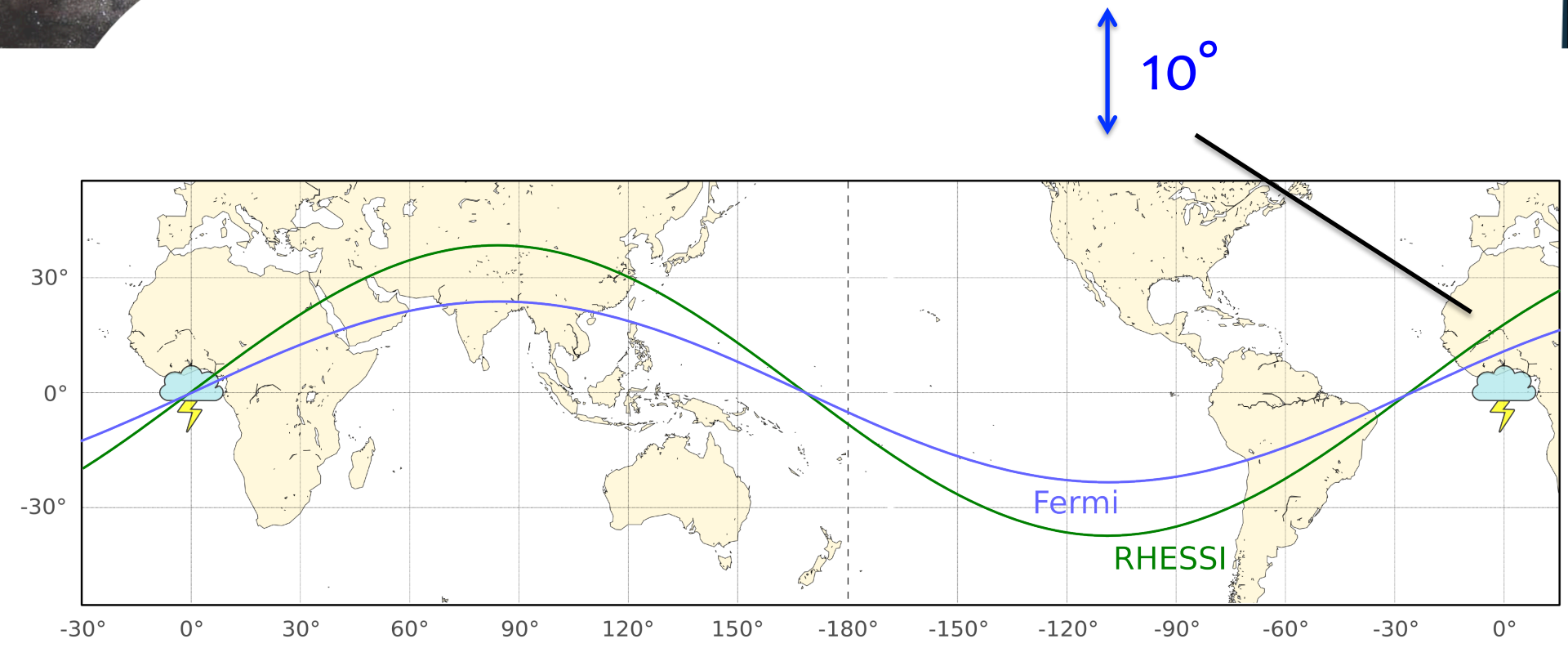
AGILE: the quasi-equatorial orbit



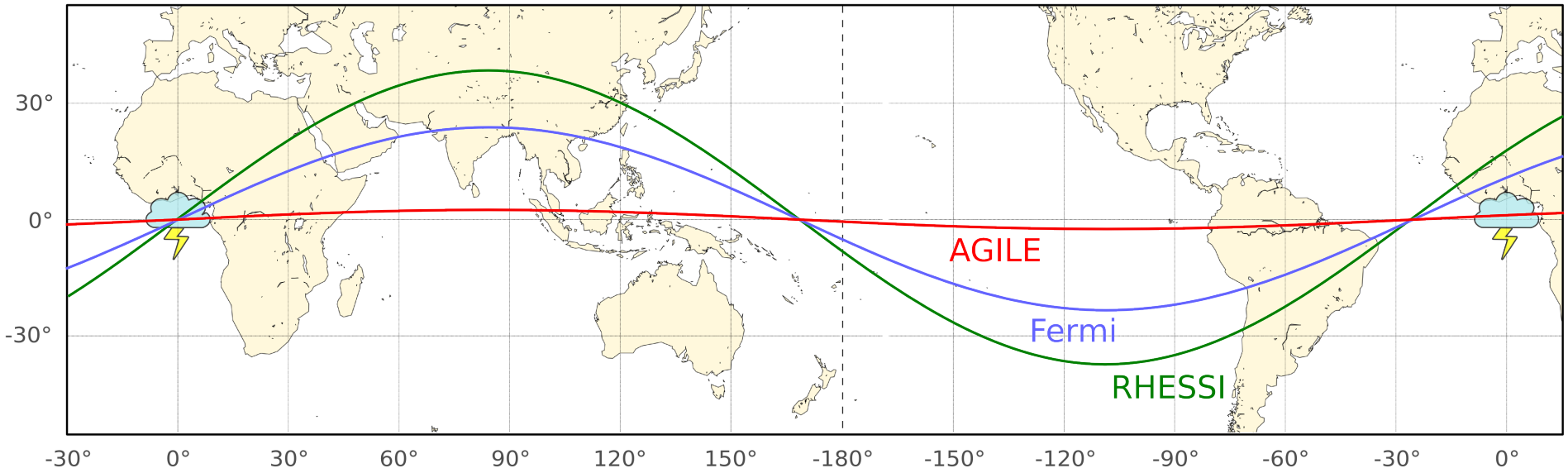
AGILE: the quasi-equatorial orbit



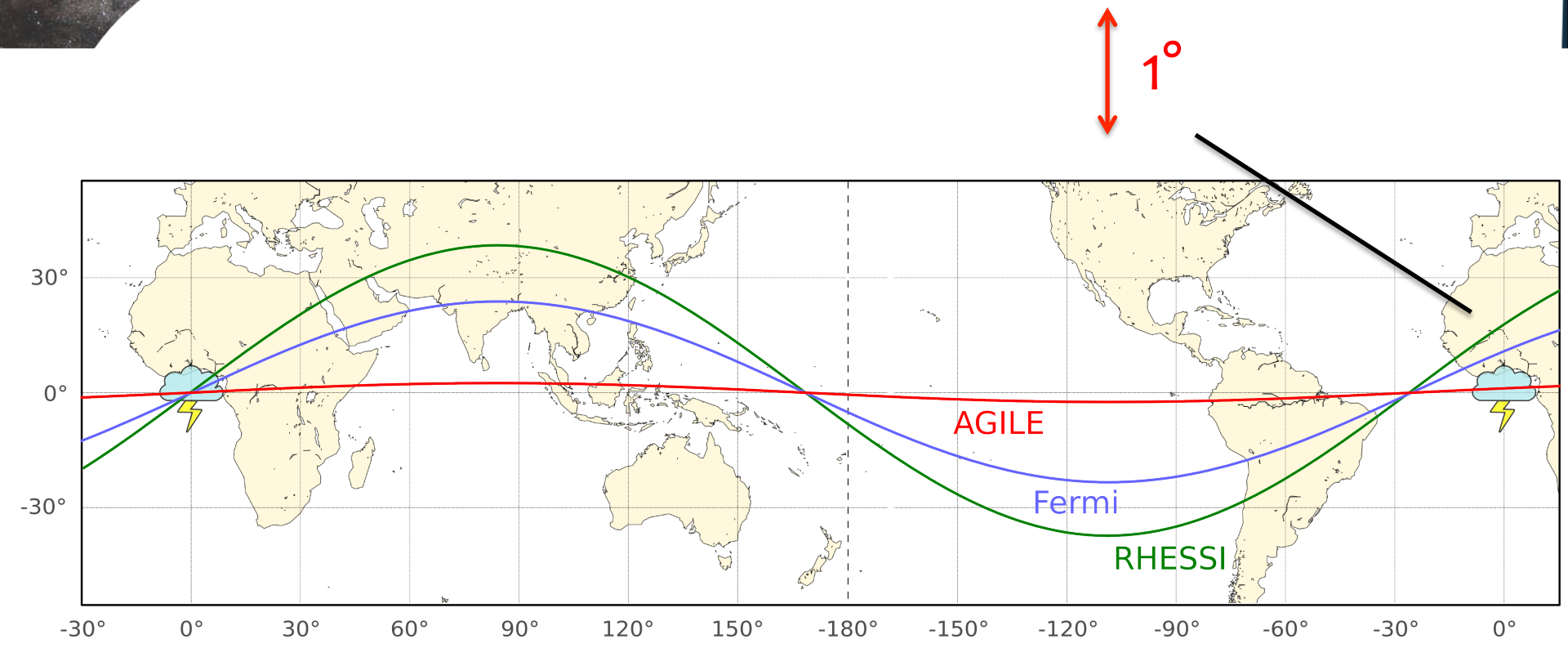
AGILE: the quasi-equatorial orbit



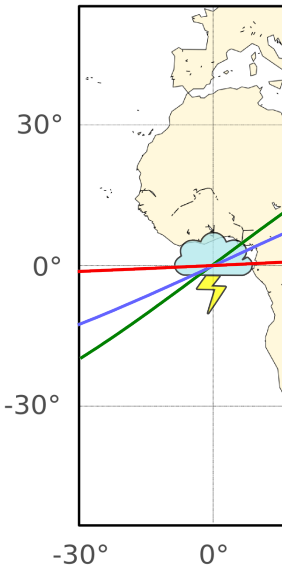
AGILE: the quasi-equatorial orbit

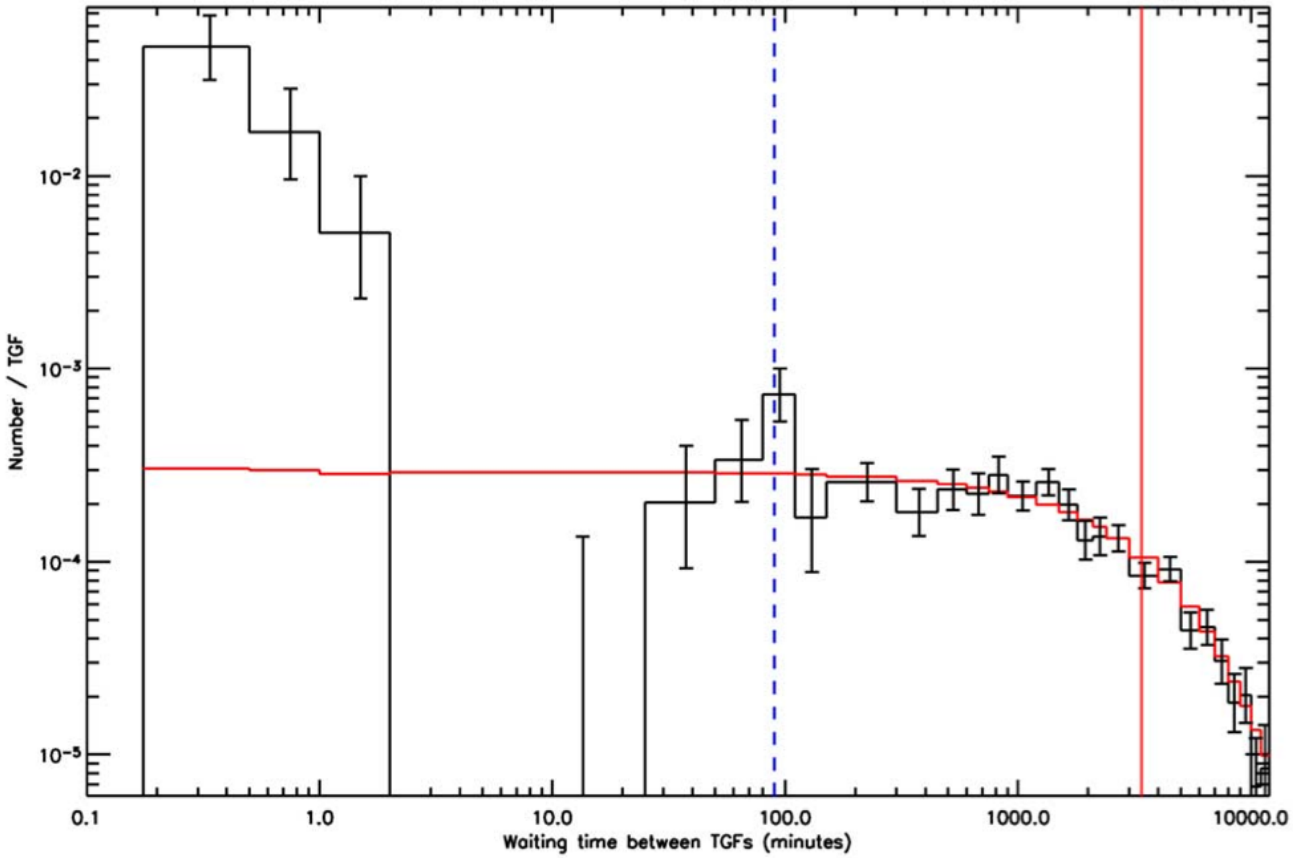


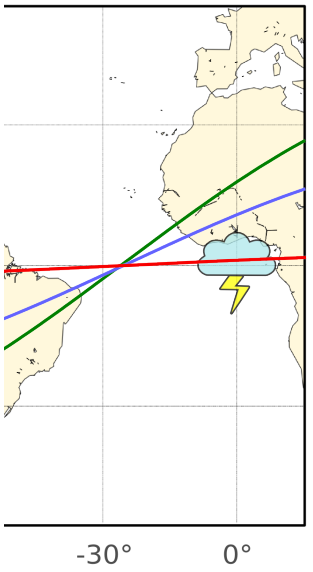
AGILE: the quasi-equatorial orbit



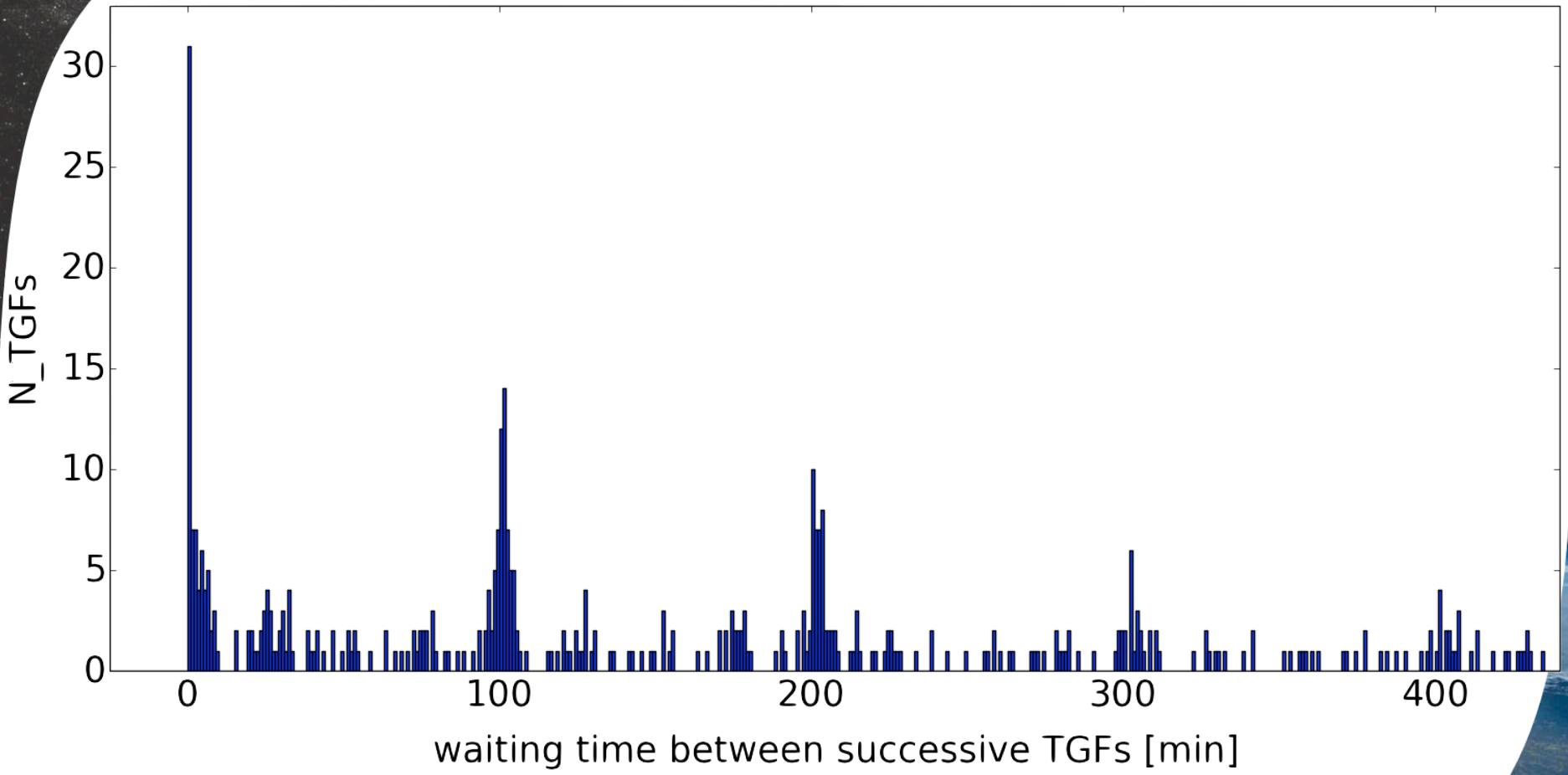
AGILE: the quasi-equatorial orbit



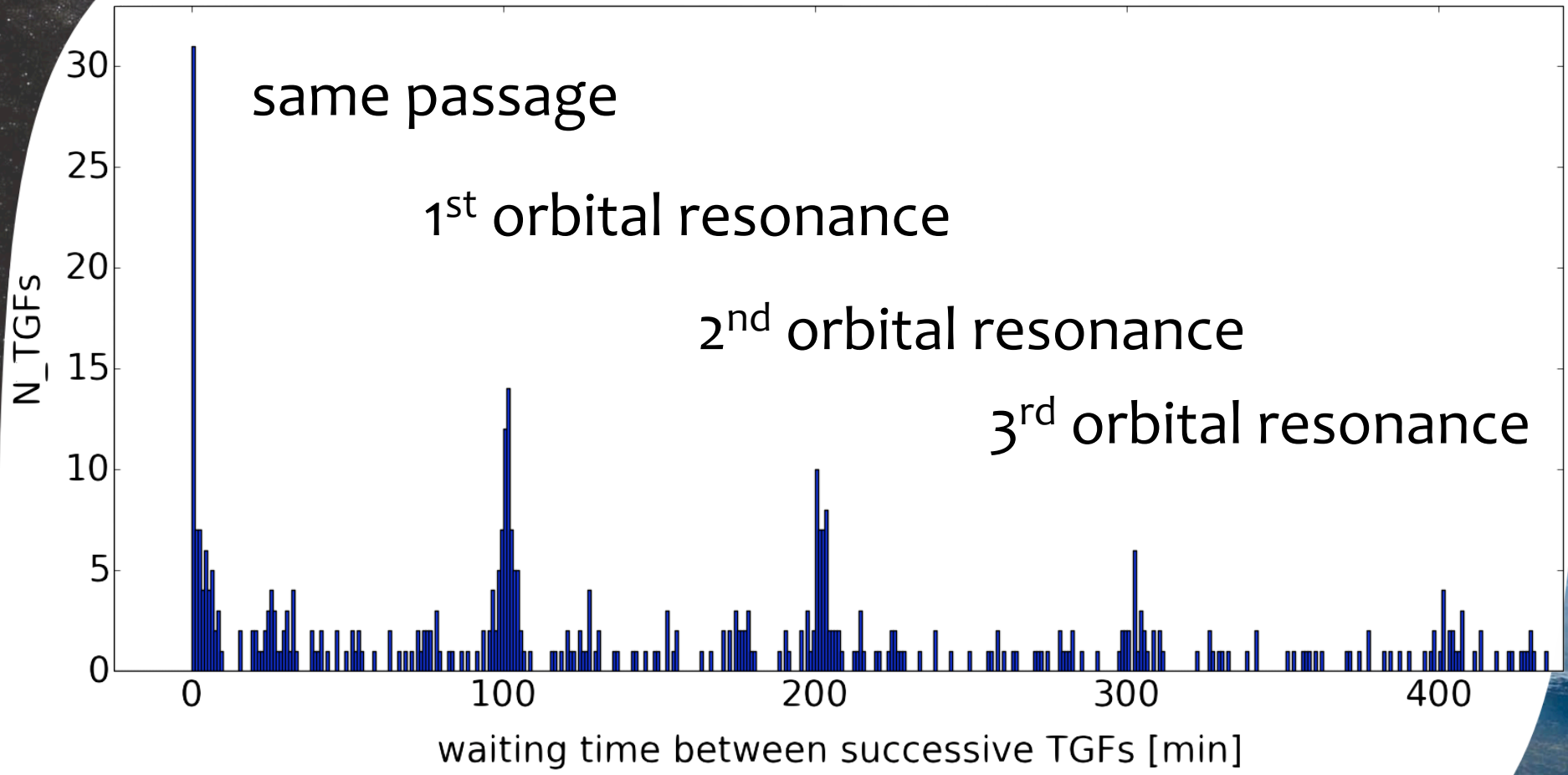




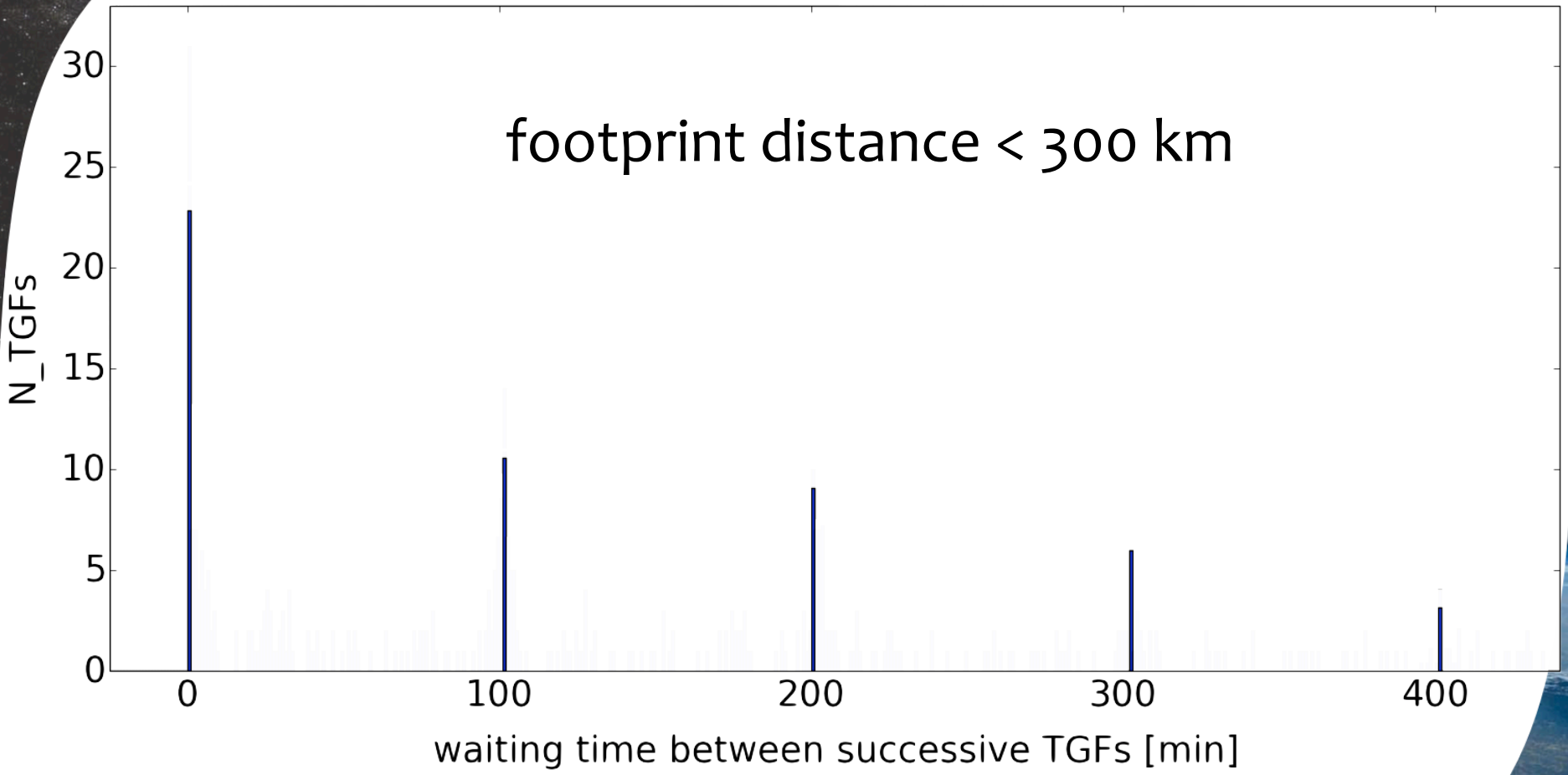
AGILE: the quasi-equatorial orbit



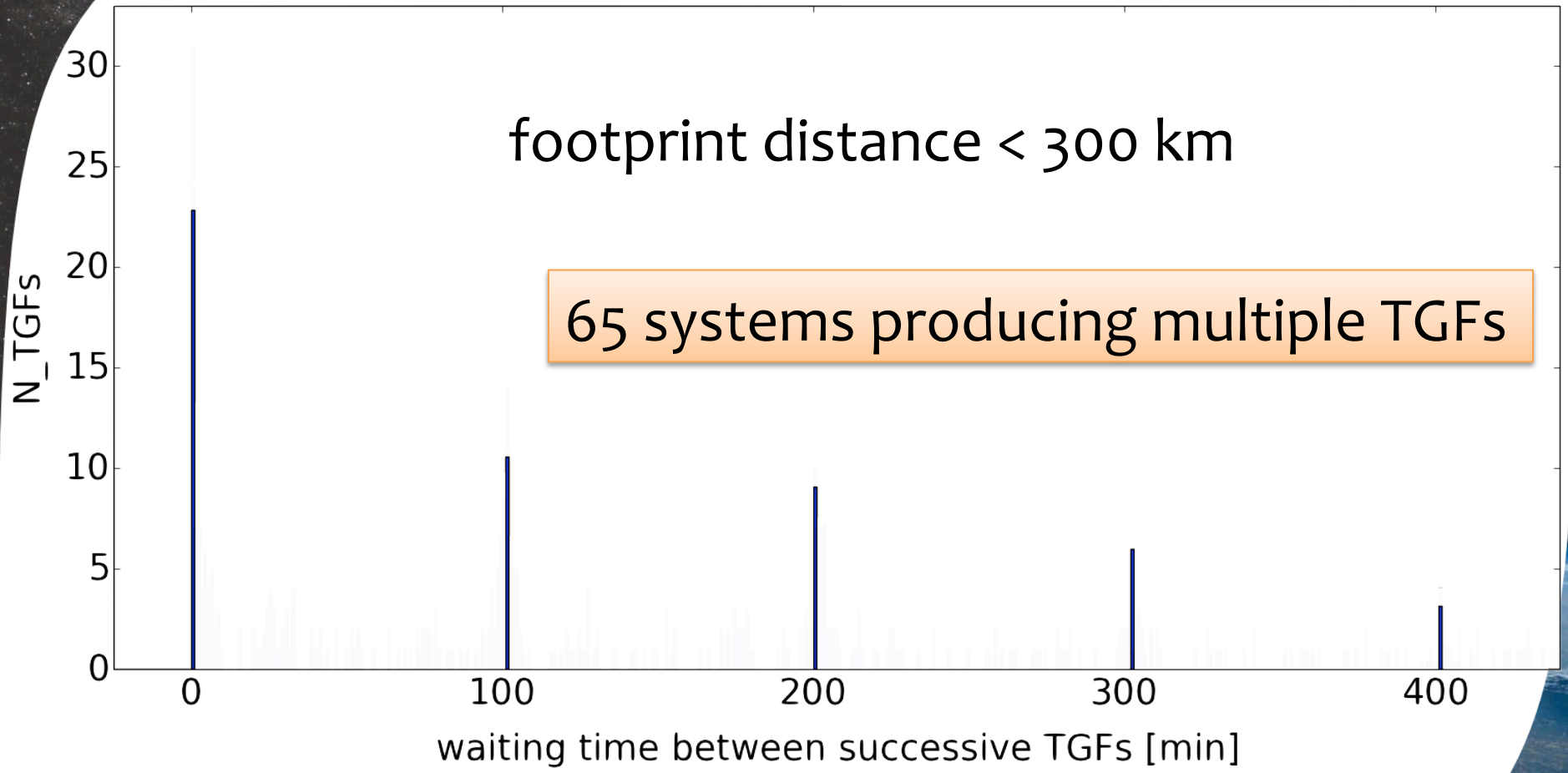
AGILE: the quasi-equatorial orbit



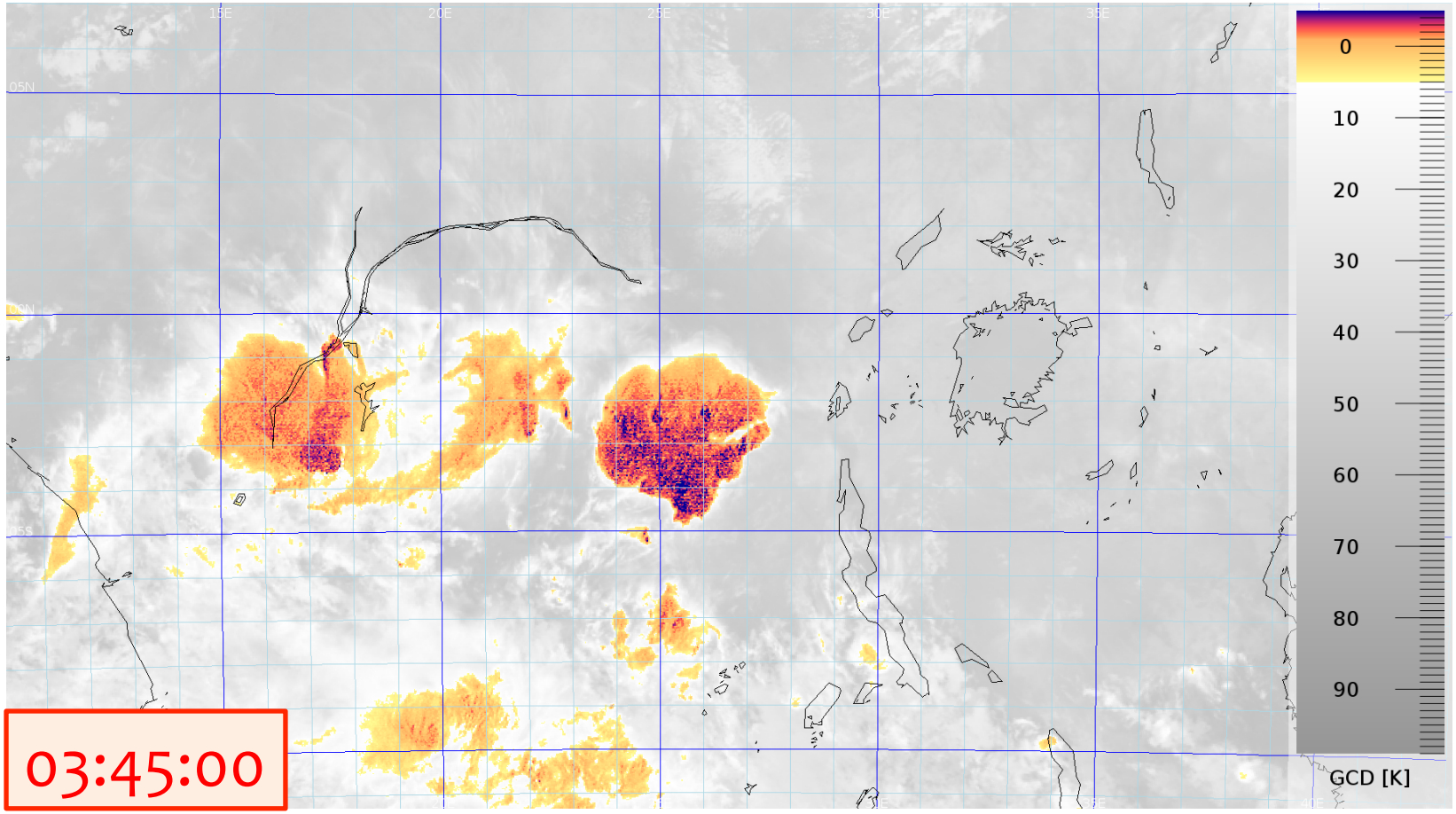
AGILE: the quasi-equatorial orbit



AGILE: the quasi-equatorial orbit

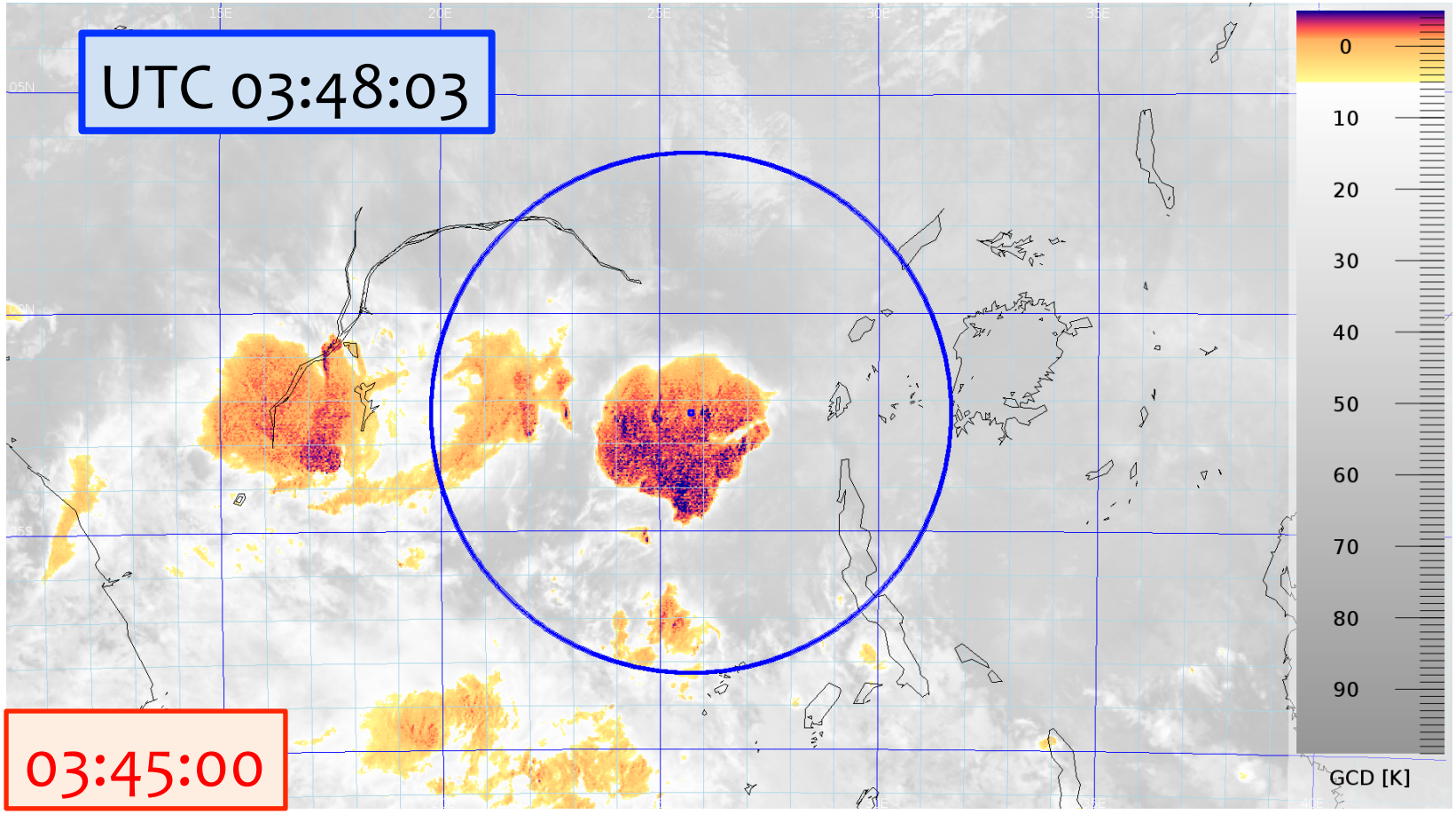


Successive TGFs



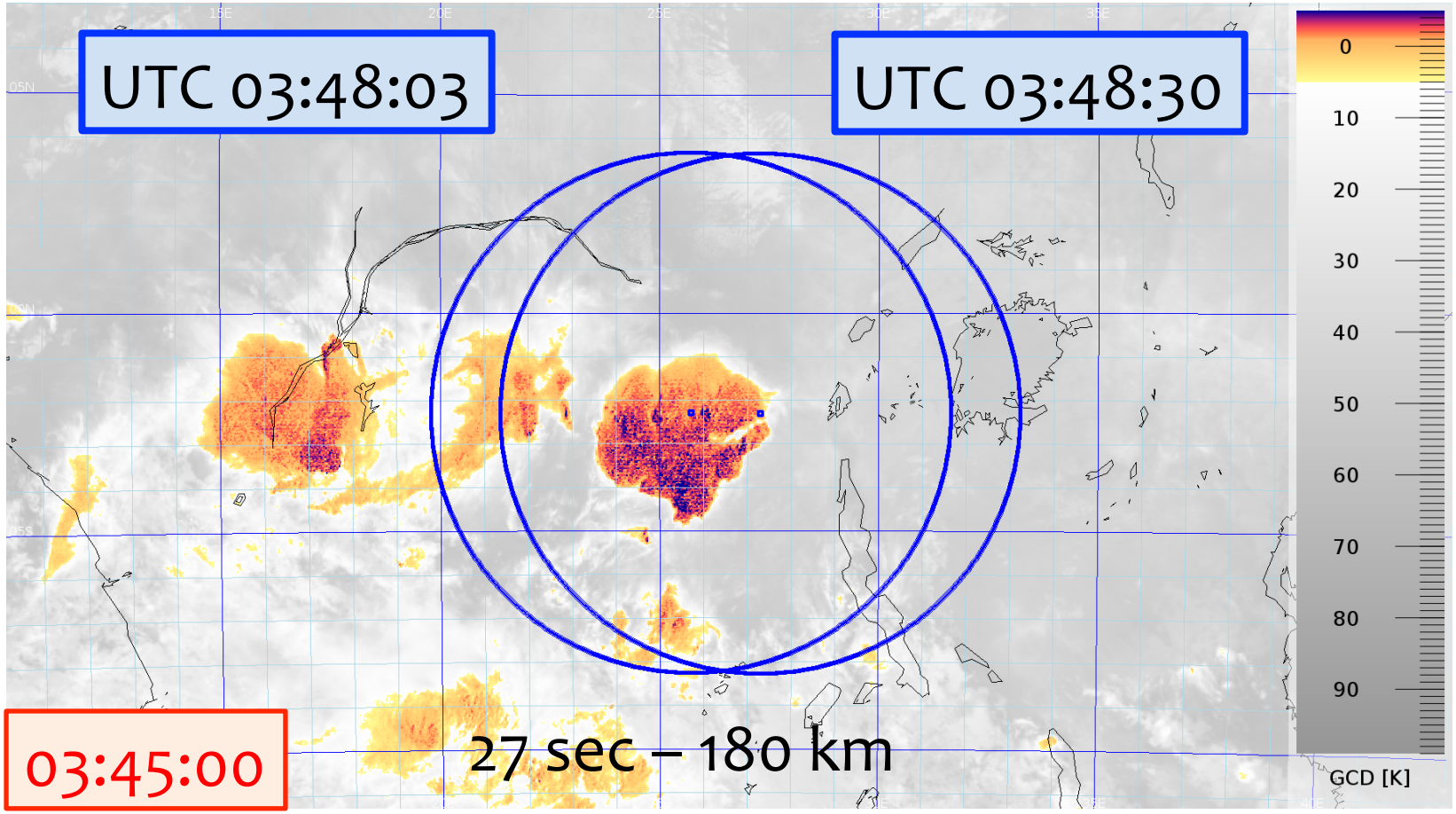
EXAMPLE 1: 26/02/2013

Successive TGFs



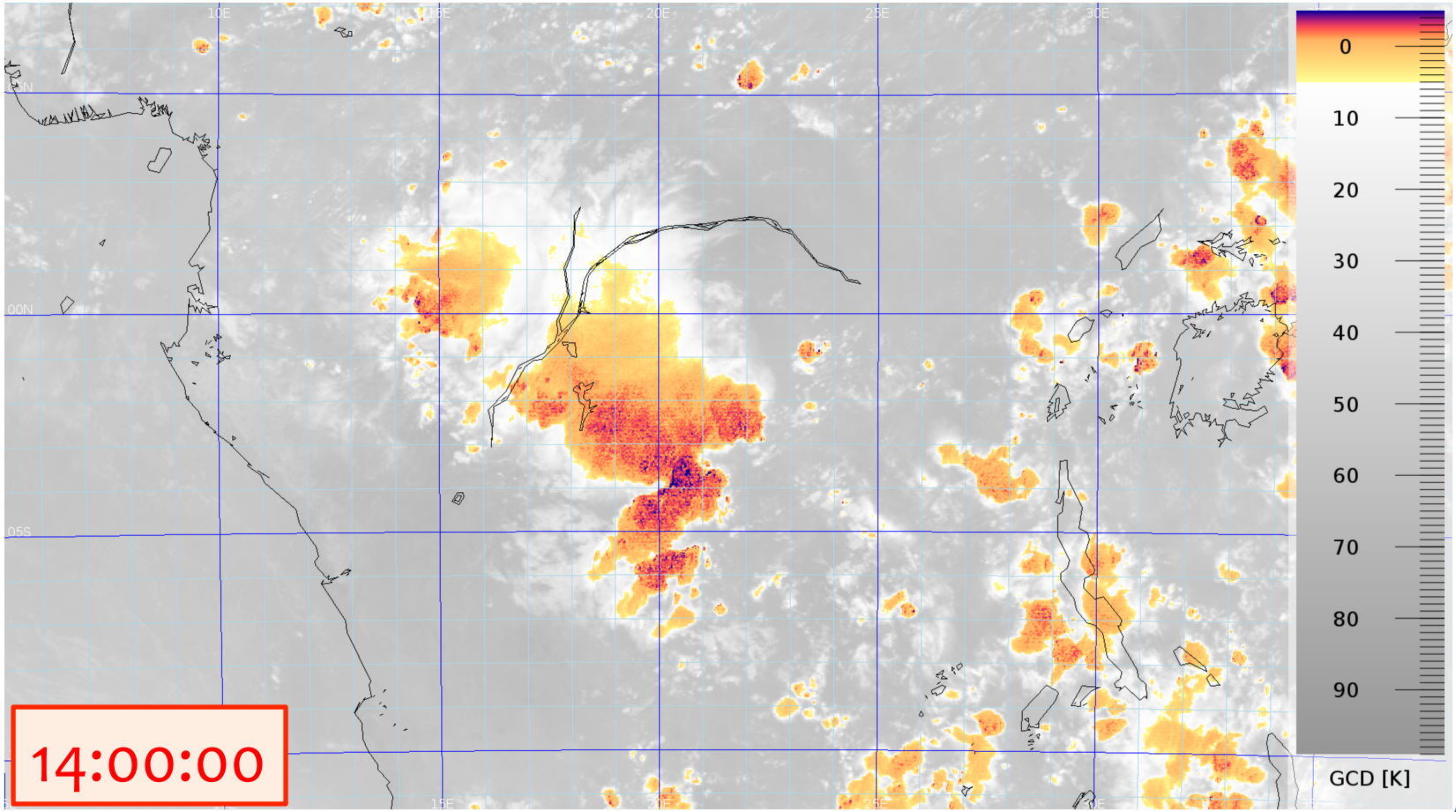
EXAMPLE 1: 26/02/2013

Successive TGFs



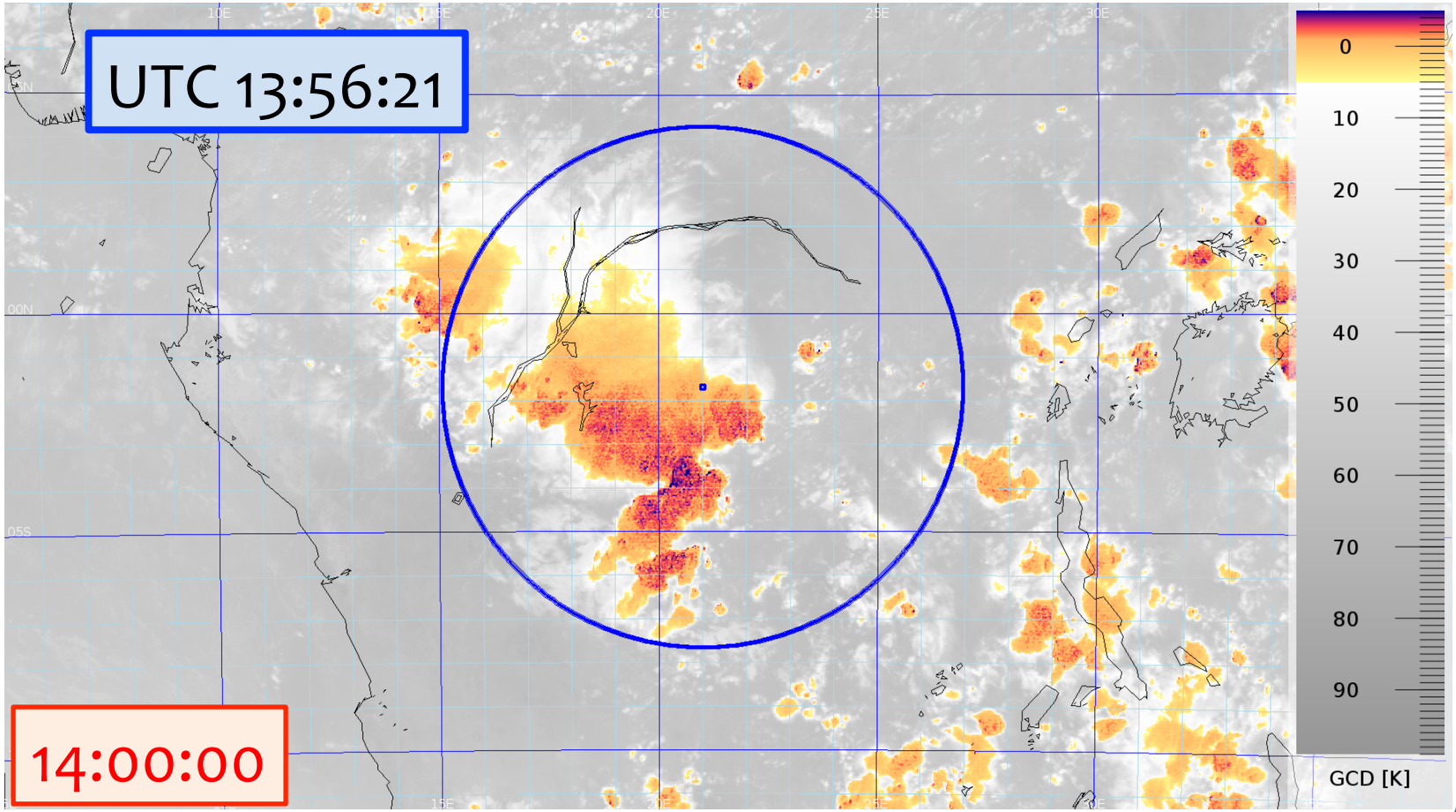
EXAMPLE 1: 26/02/2013

Successive TGFs



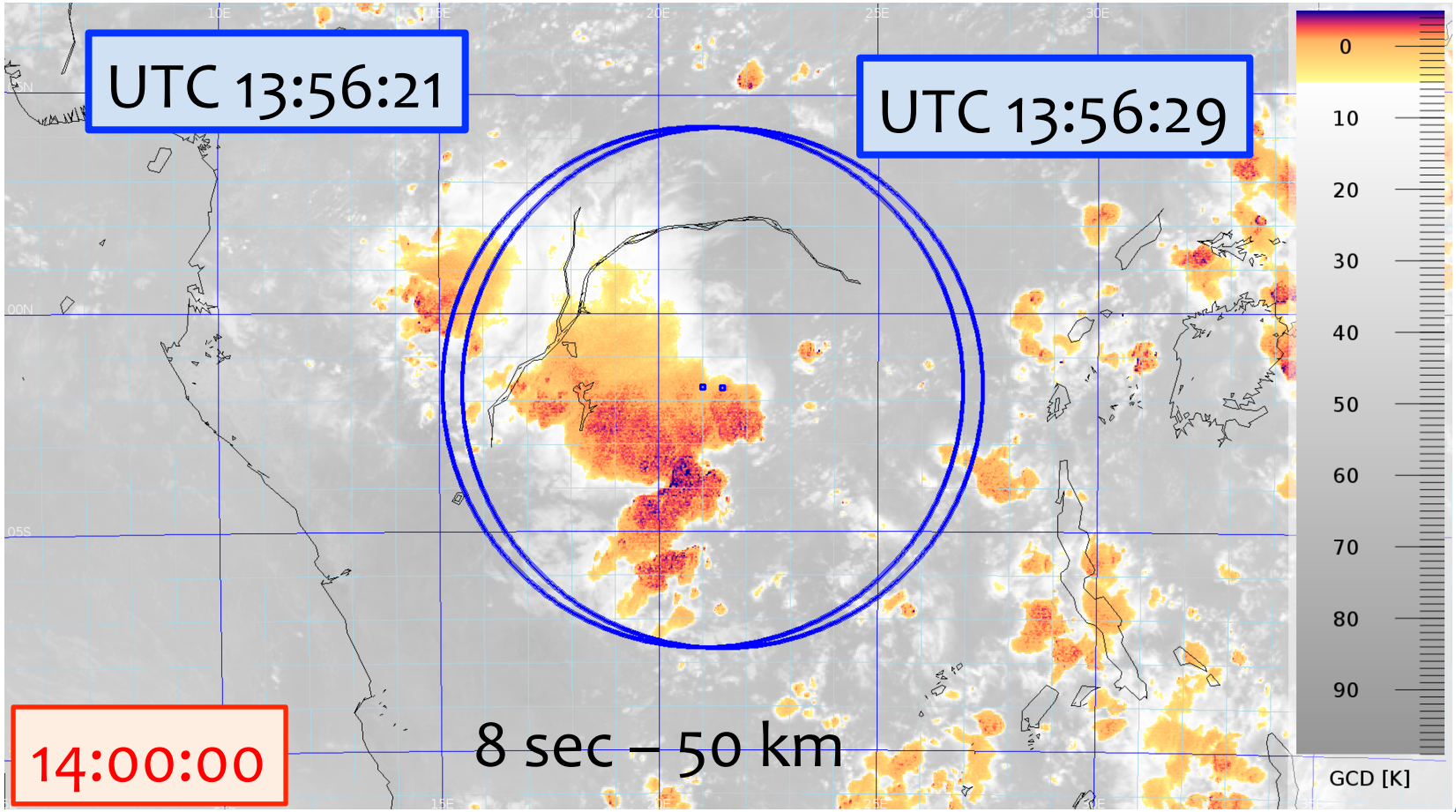
EXAMPLE 2: 08/04/2015

Successive TGFs



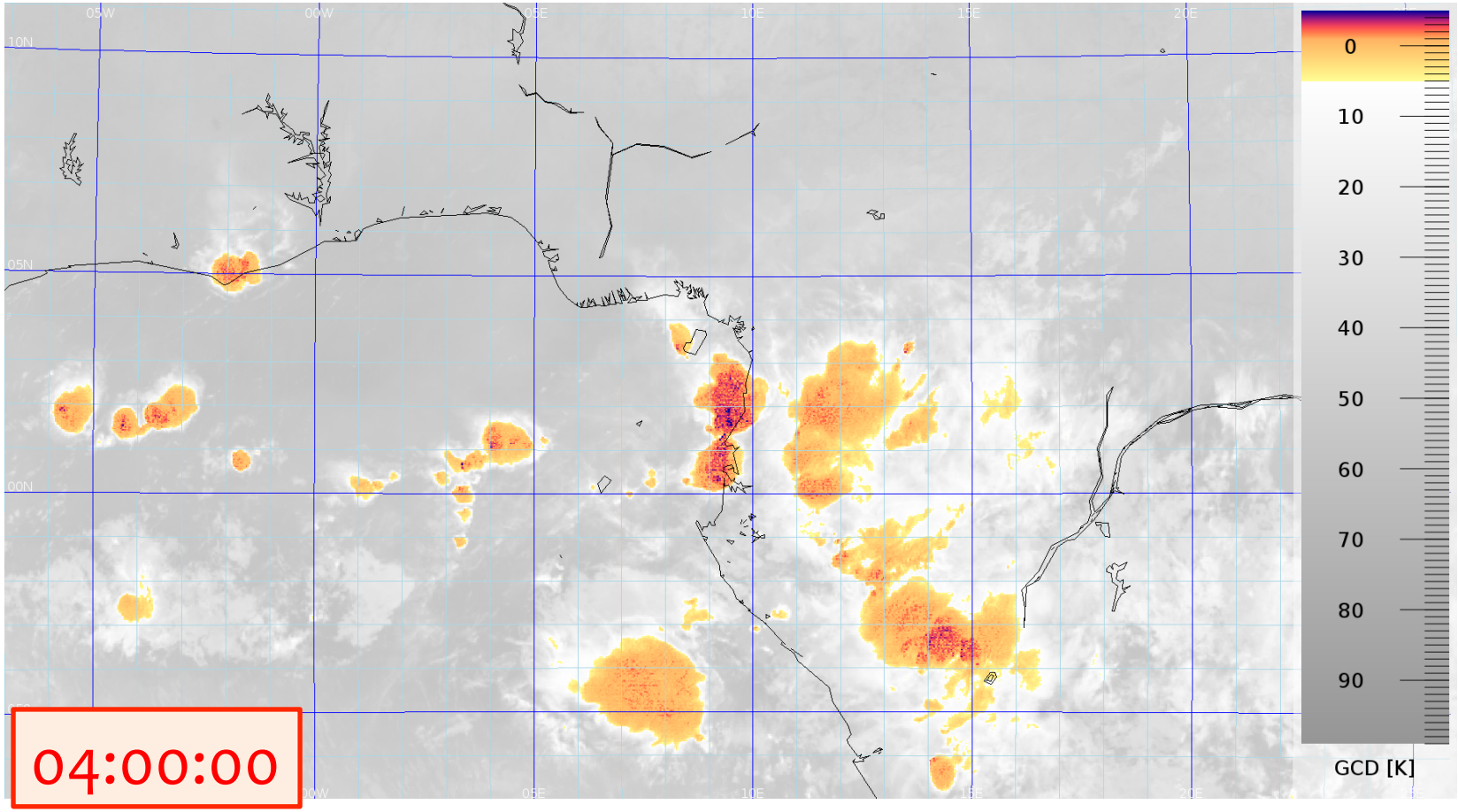
EXAMPLE 2: 08/04/2015

Successive TGFs



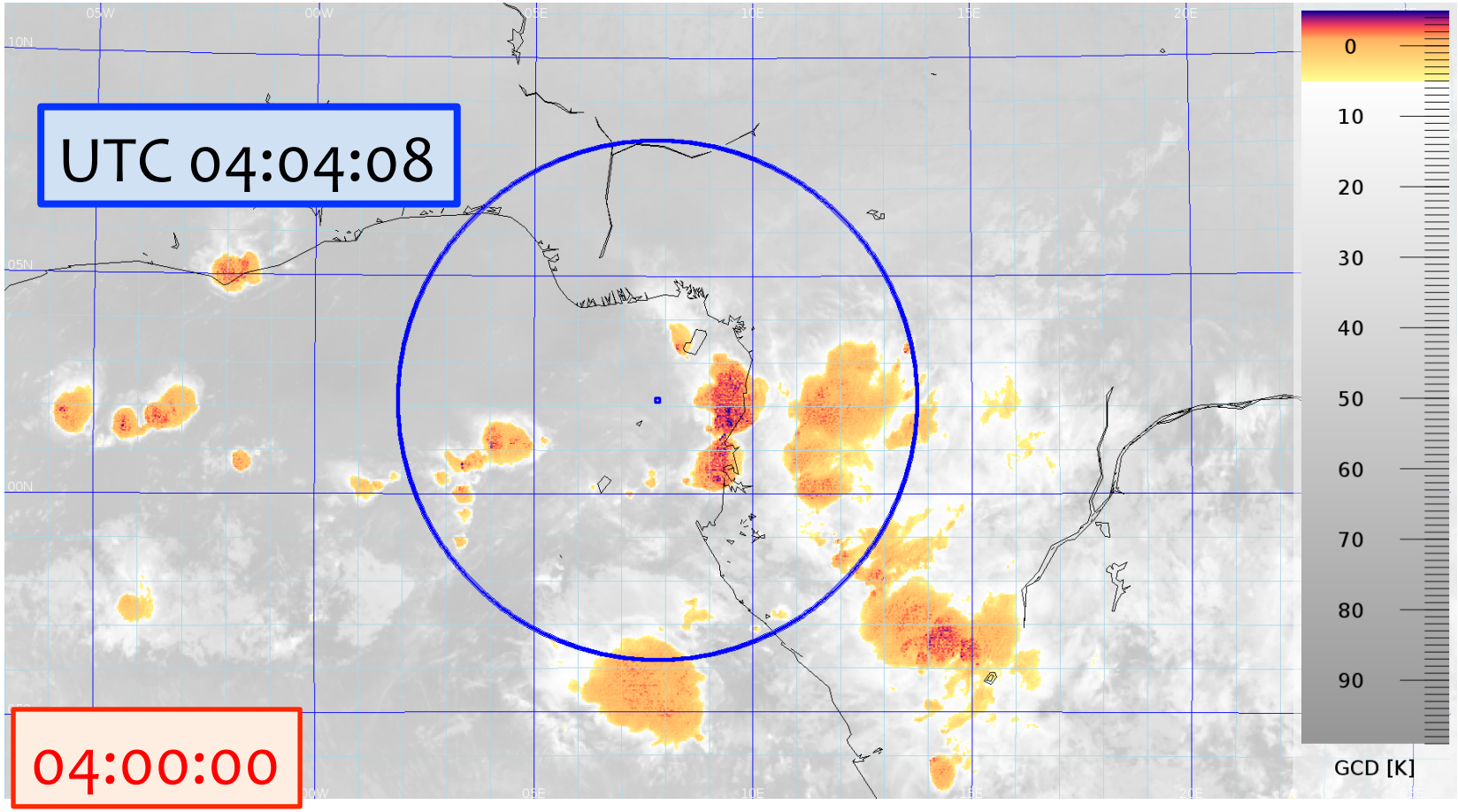
EXAMPLE 2: 08/04/2015

Successive TGFs



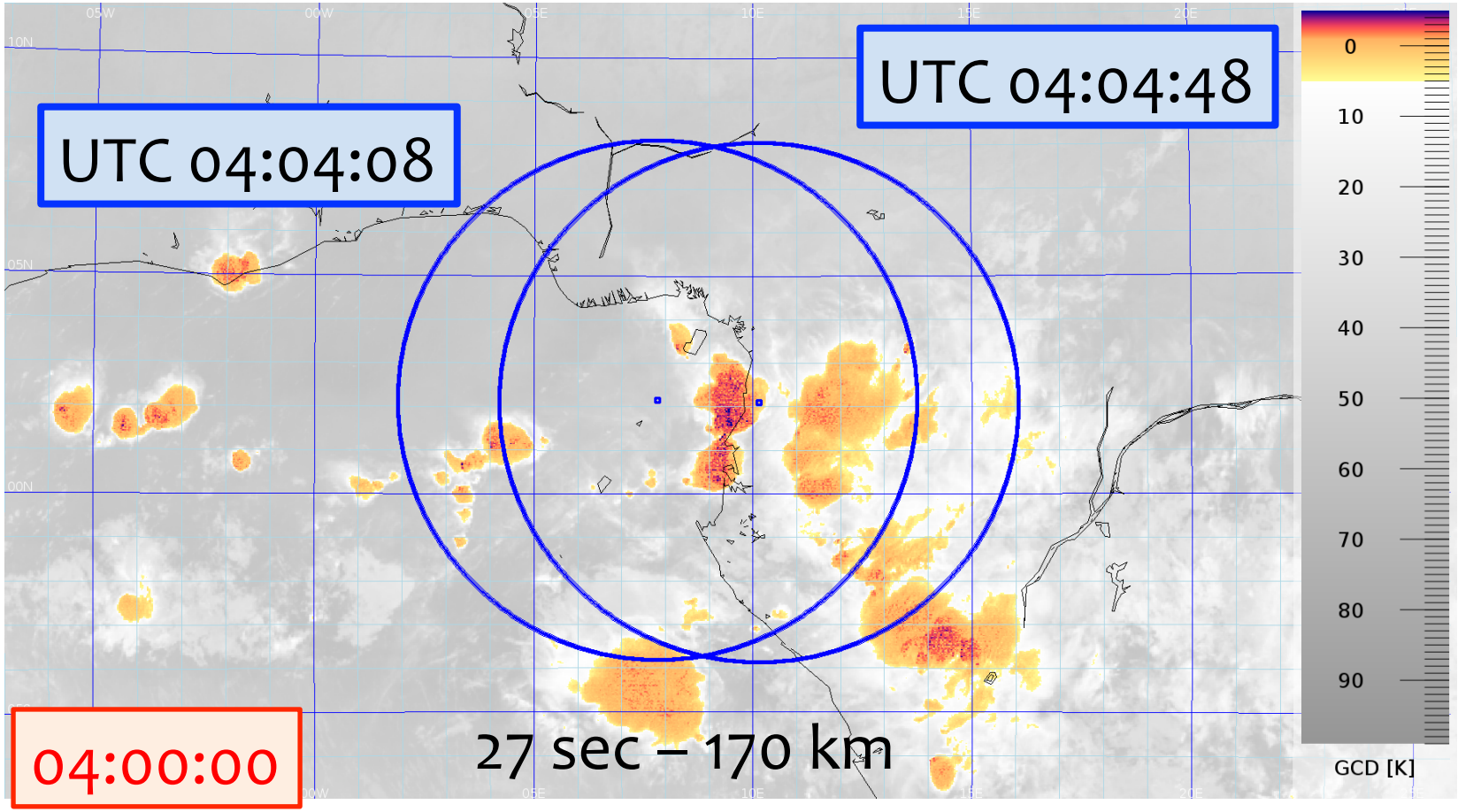
EXAMPLE 3: 15/04/2015

Successive TGFs



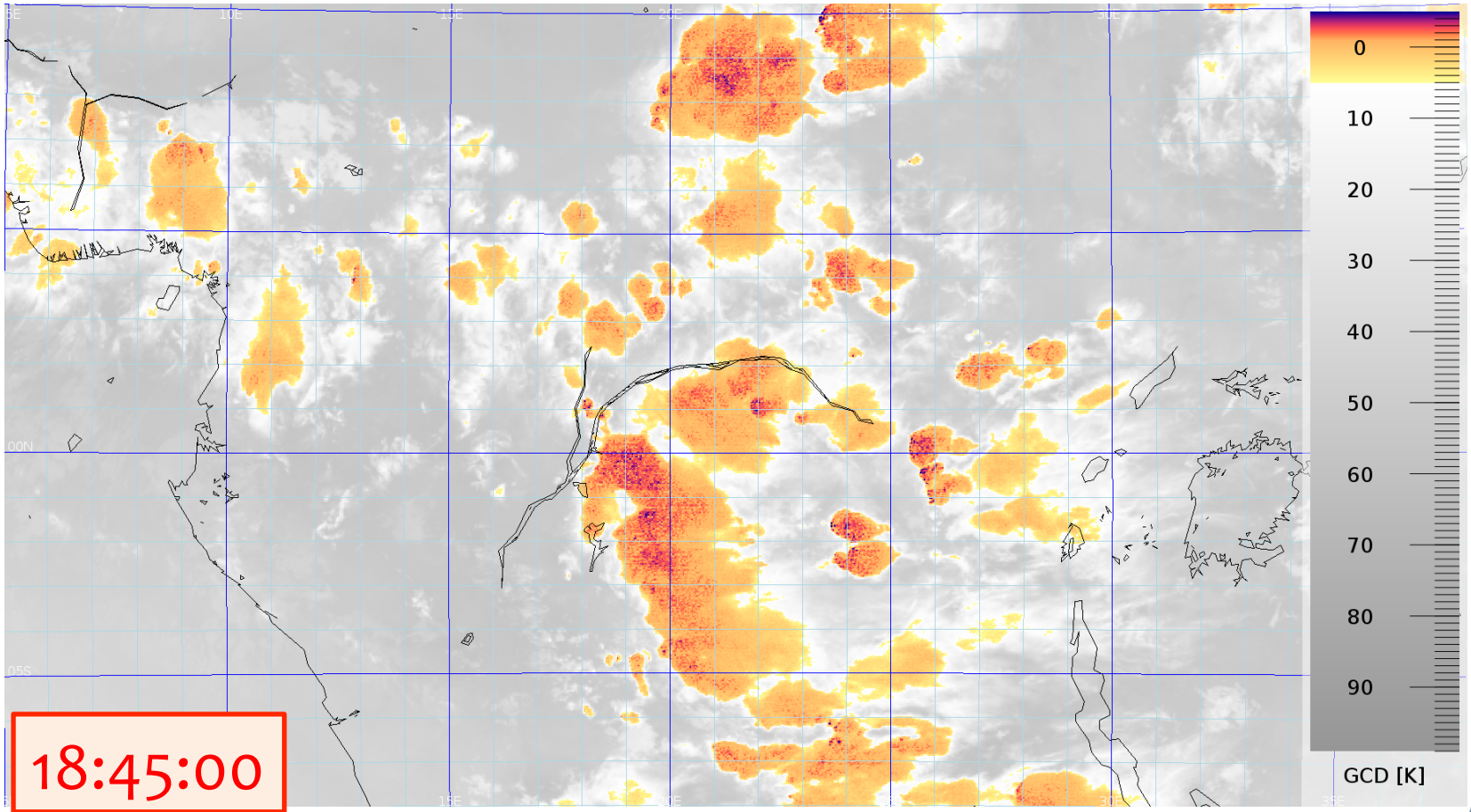
EXAMPLE 3: 15/04/2015

Successive TGFs



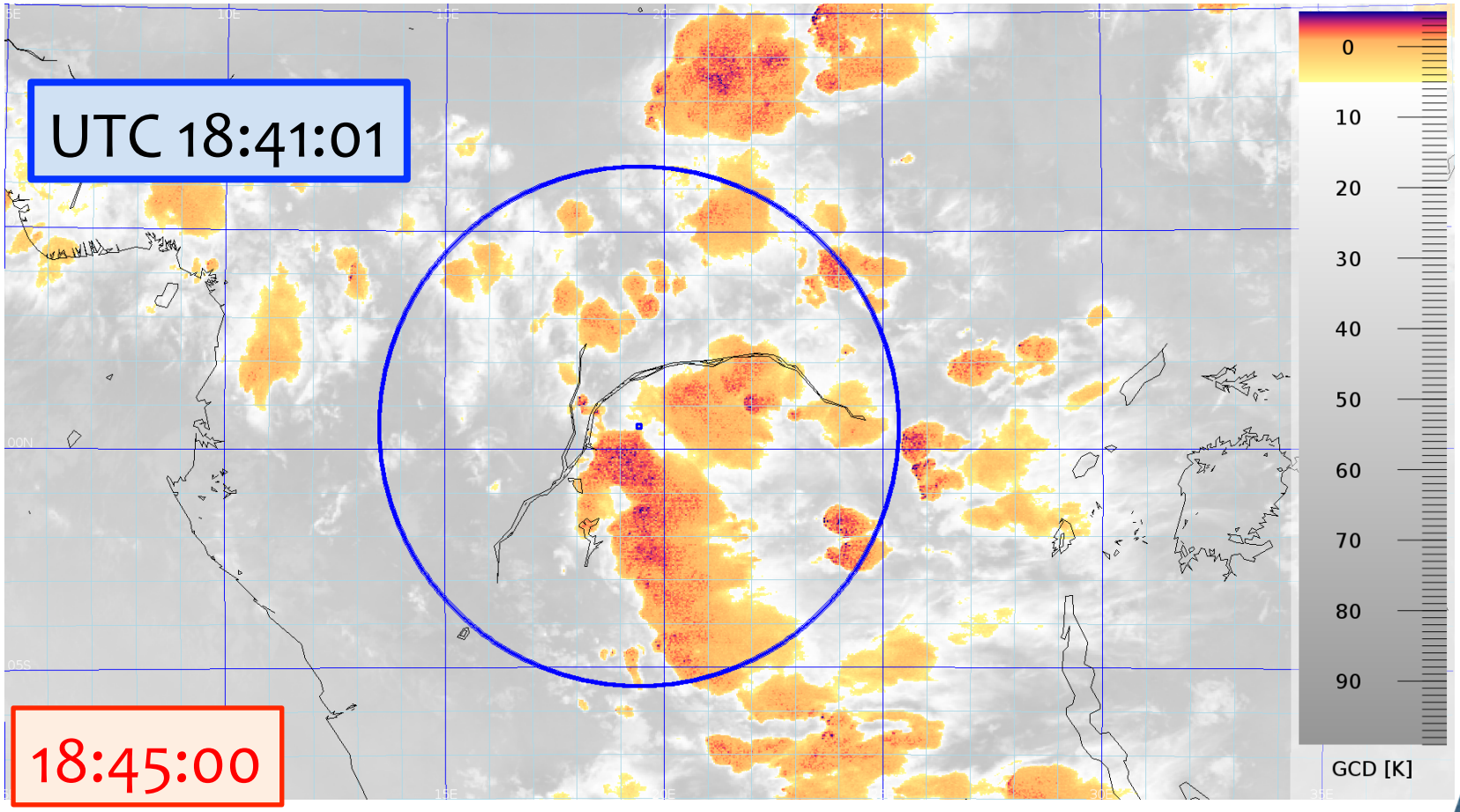
EXAMPLE 3: 15/04/2015

Successive TGFs



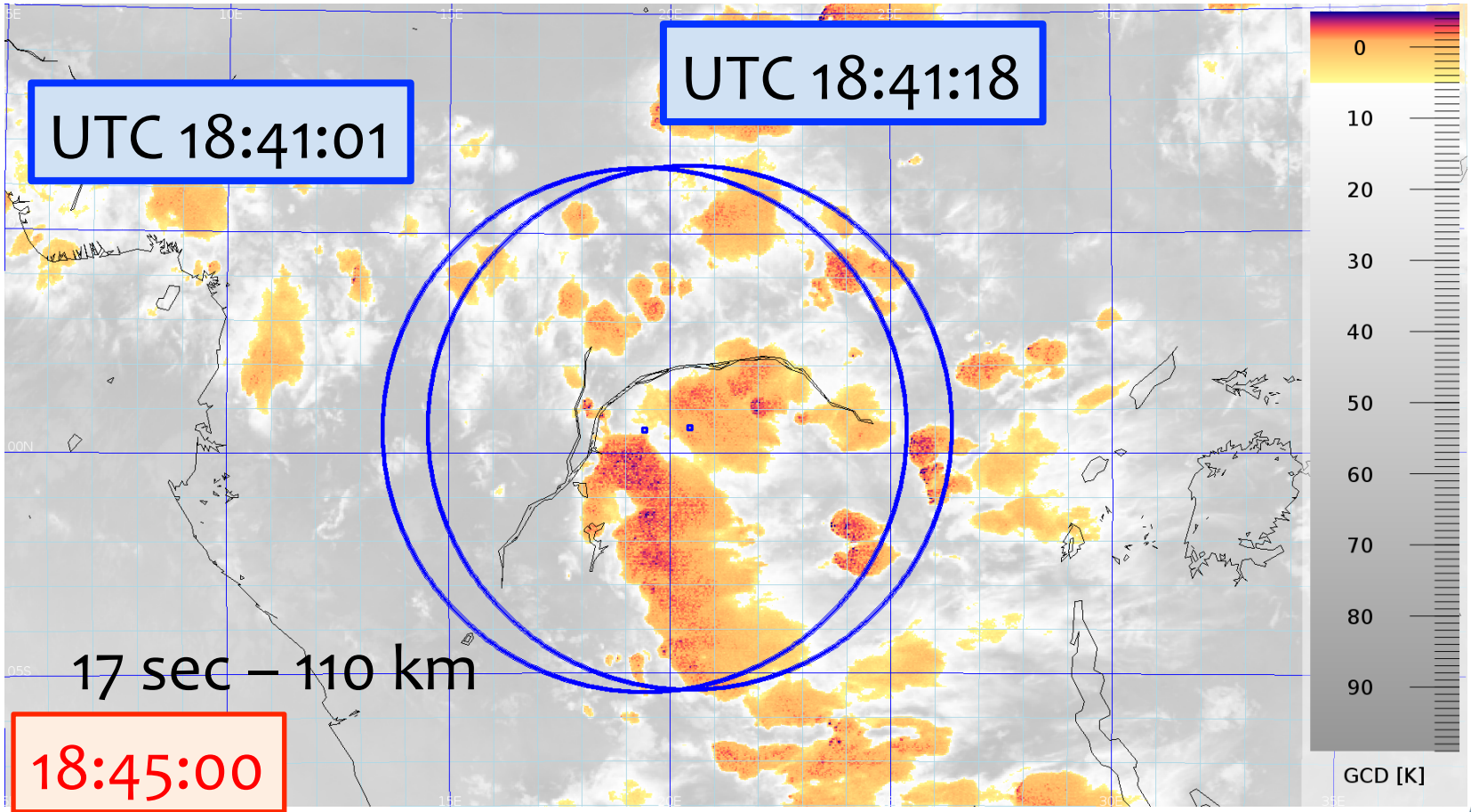
EXAMPLE 4: 29/09/2015

Successive TGFs



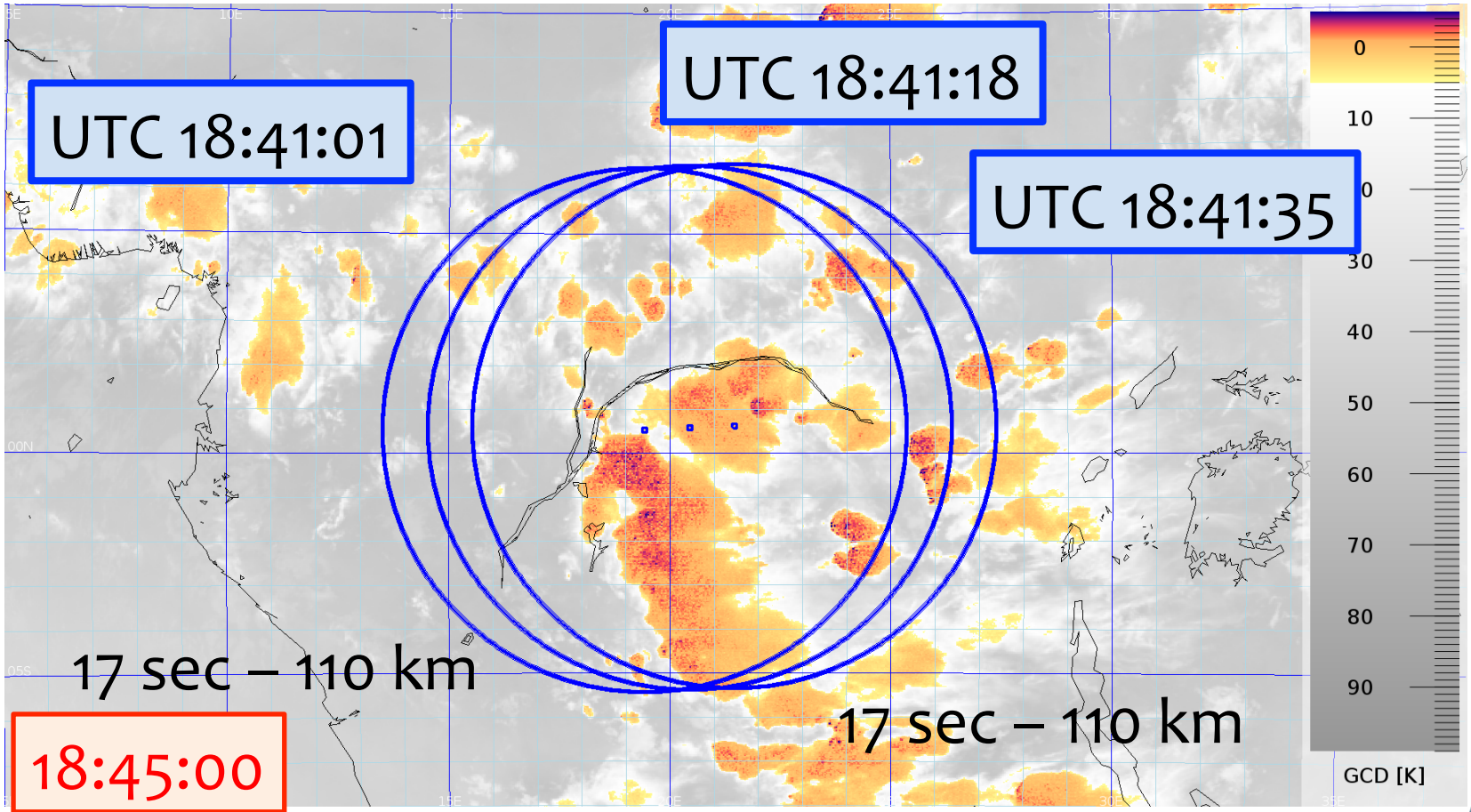
EXAMPLE 4: 29/09/2015

Successive TGFs



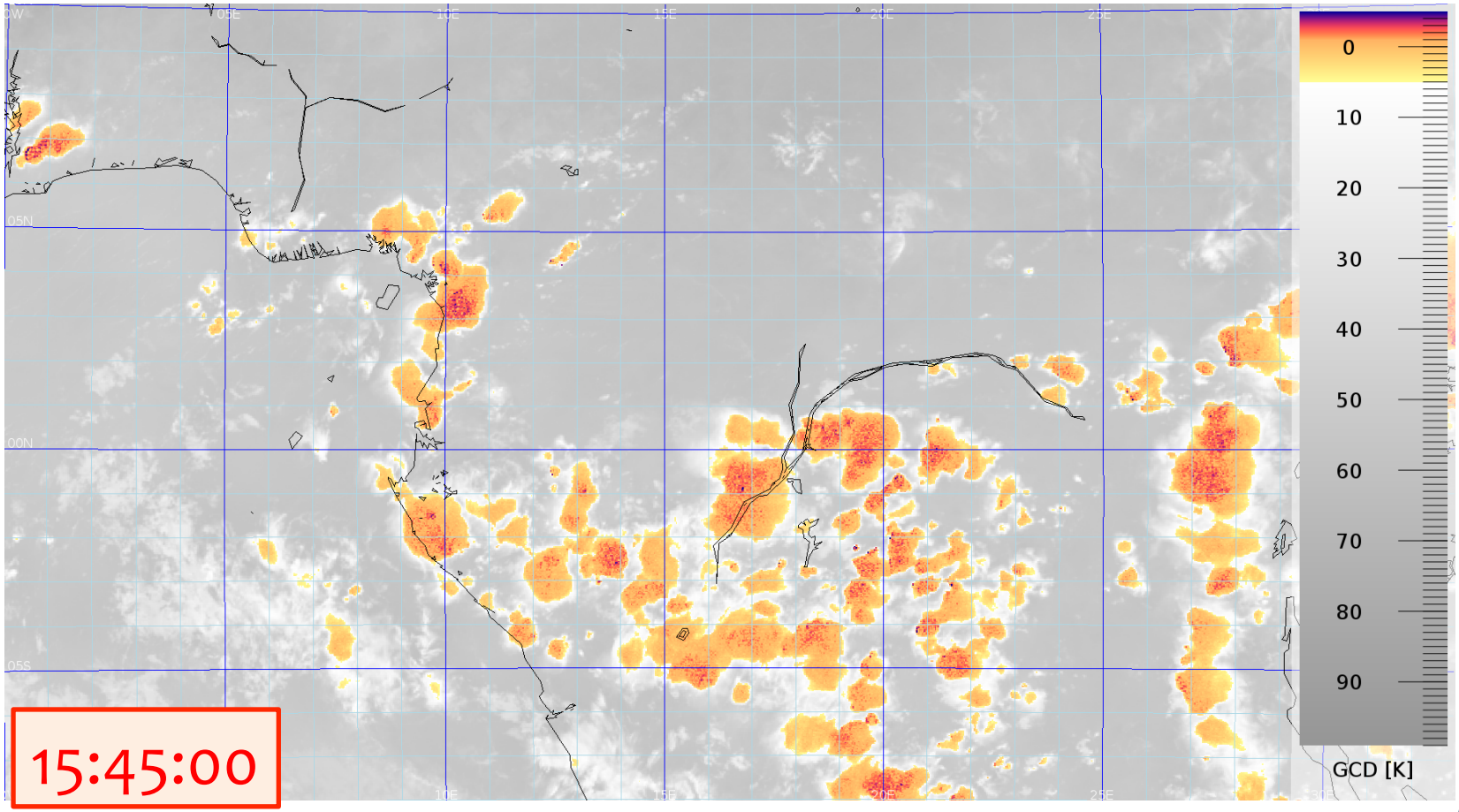
EXAMPLE 4: 29/09/2015

Successive TGFs



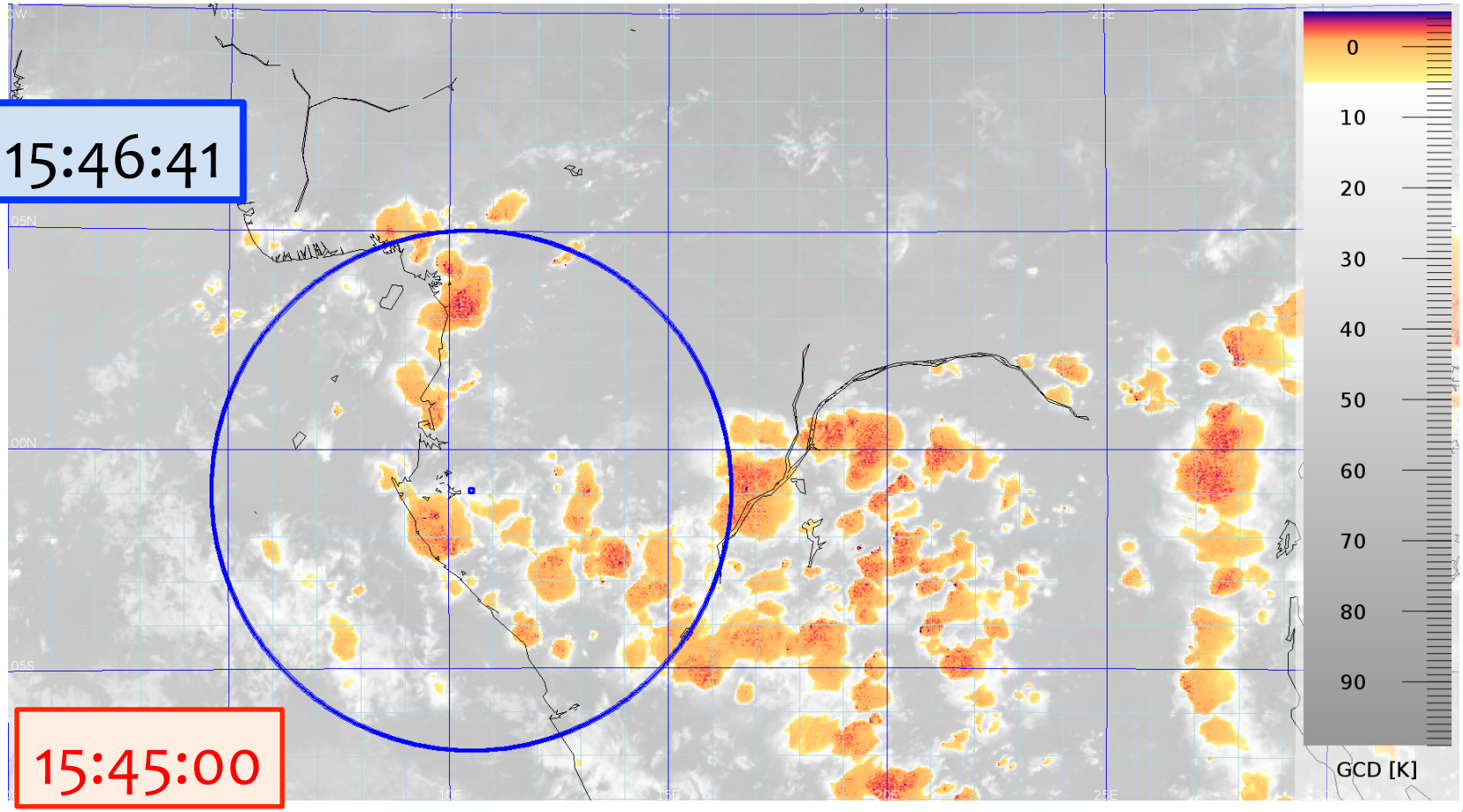
EXAMPLE 4: 29/09/2015

Successive TGFs



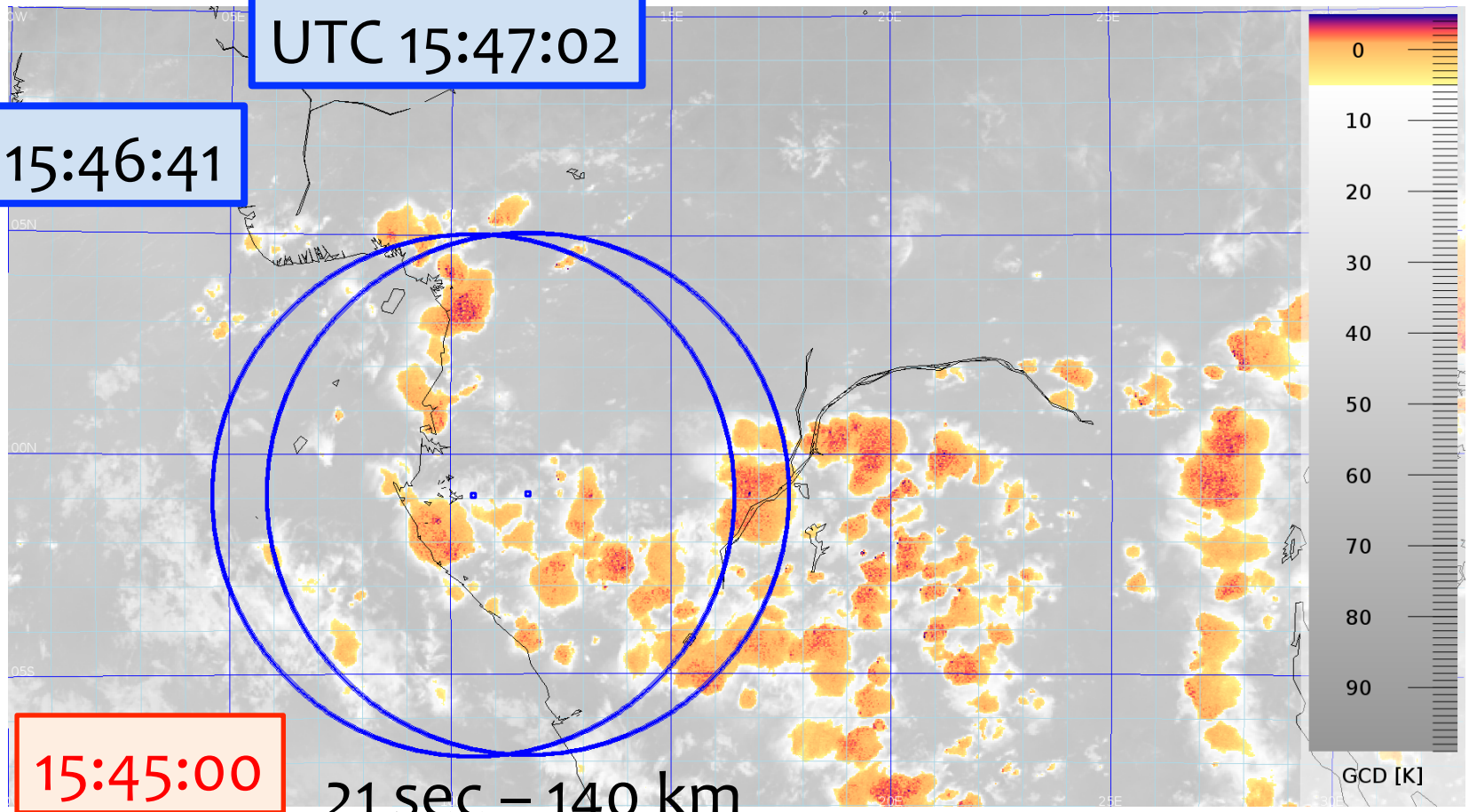
EXAMPLE 5: 19/04/2015

Successive TGFs



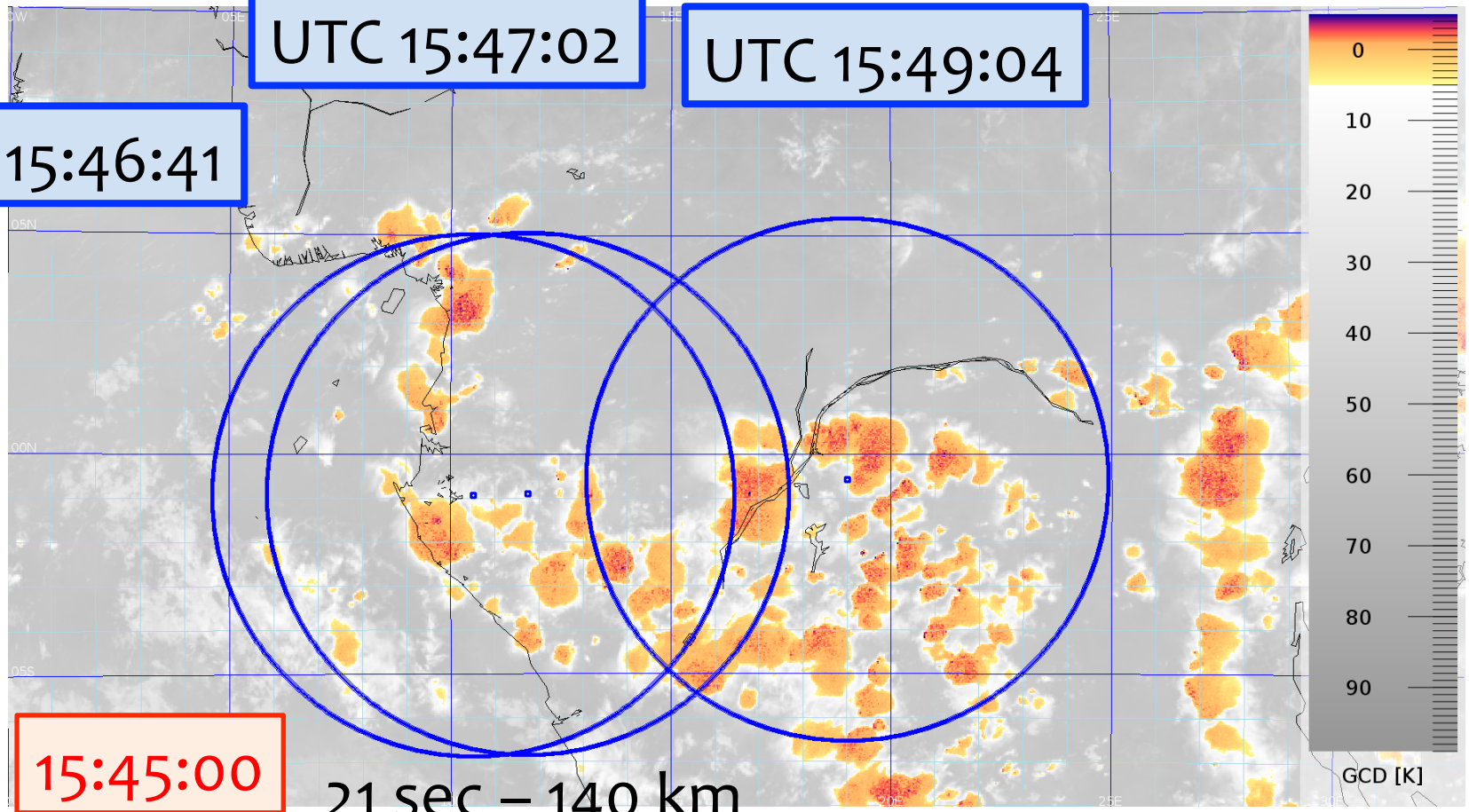
EXAMPLE 5: 19/04/2015

Successive TGFs



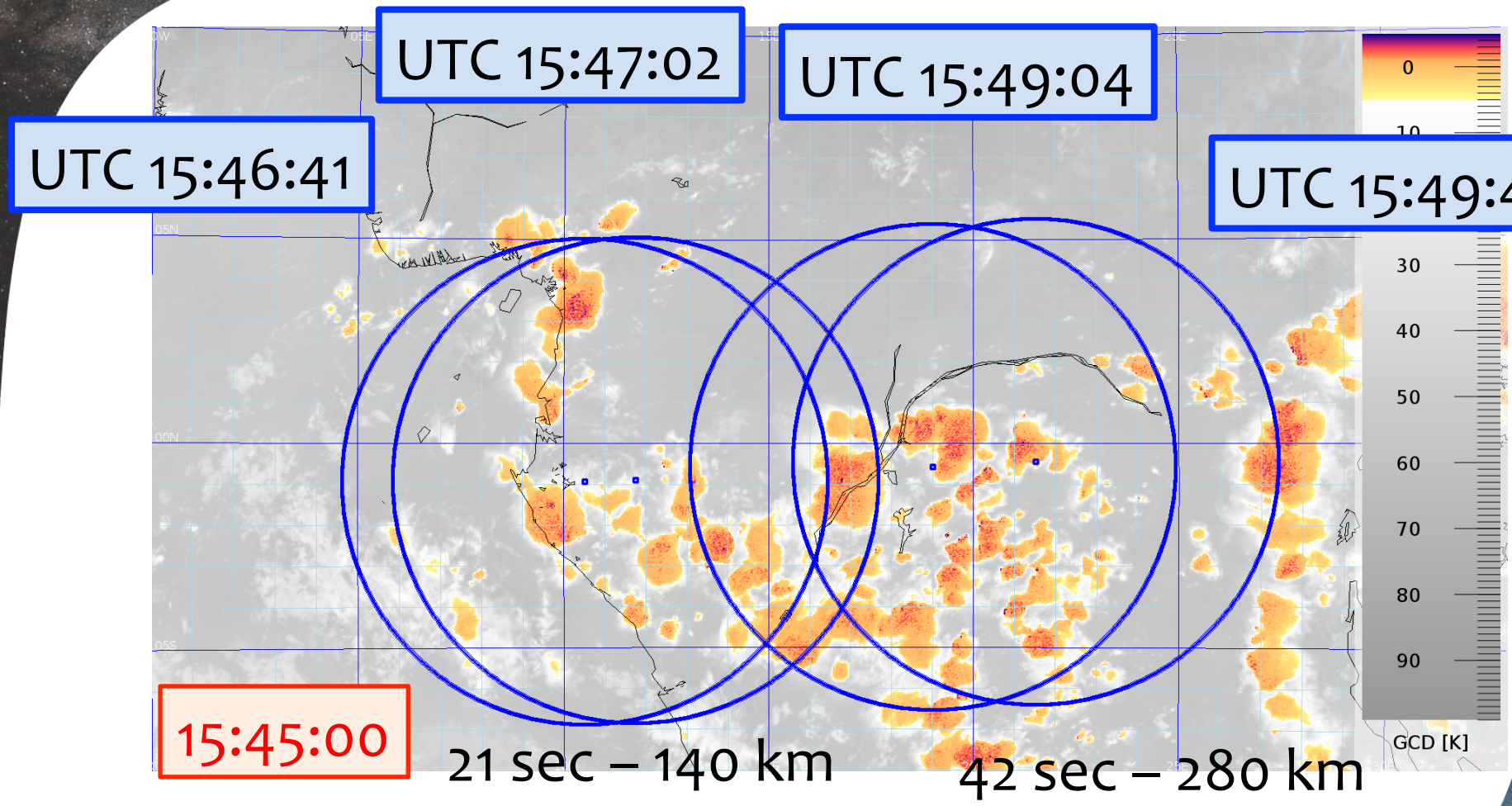
EXAMPLE 5: 19/04/2015

Successive TGFs



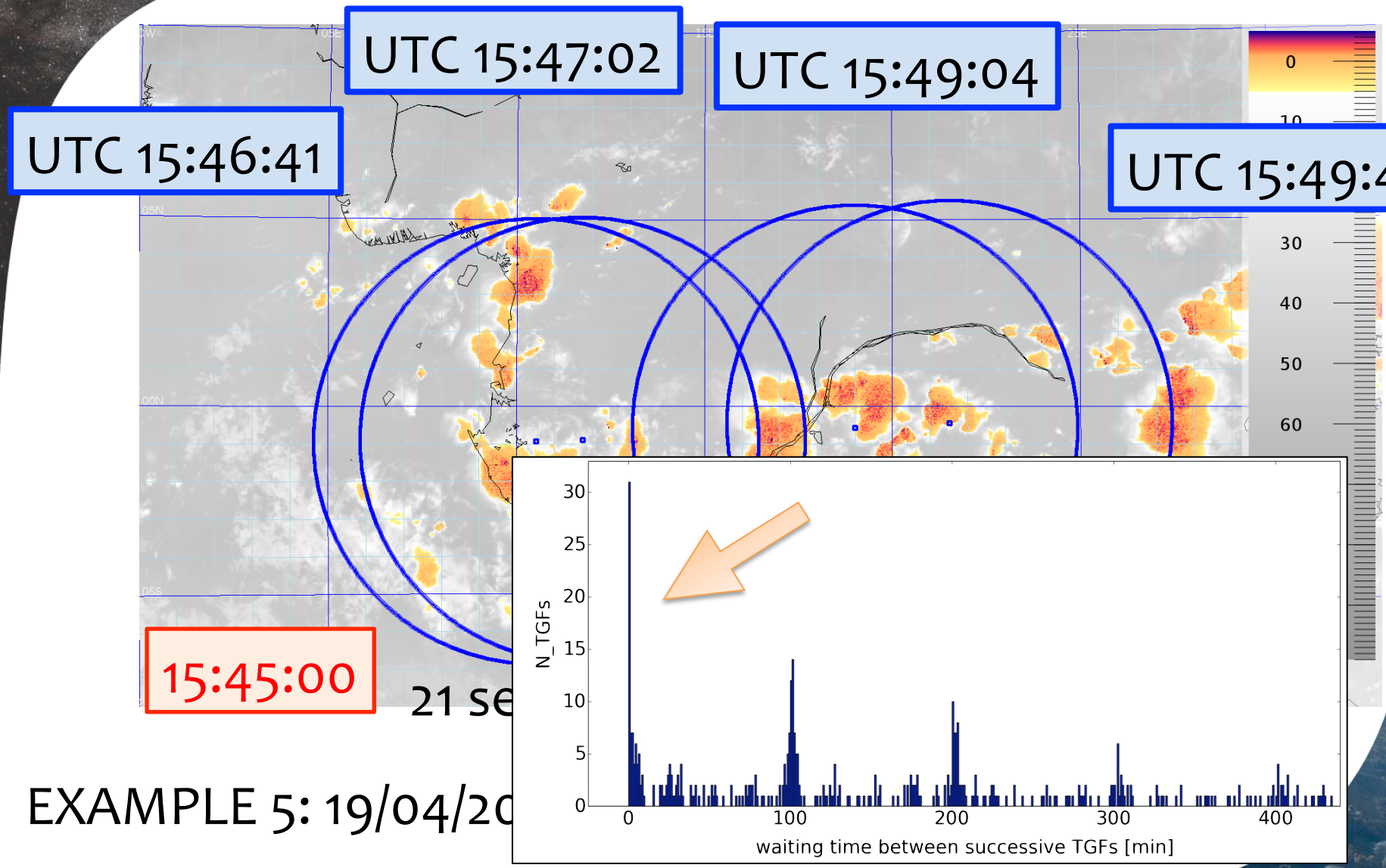
EXAMPLE 5: 19/04/2015

Successive TGFs



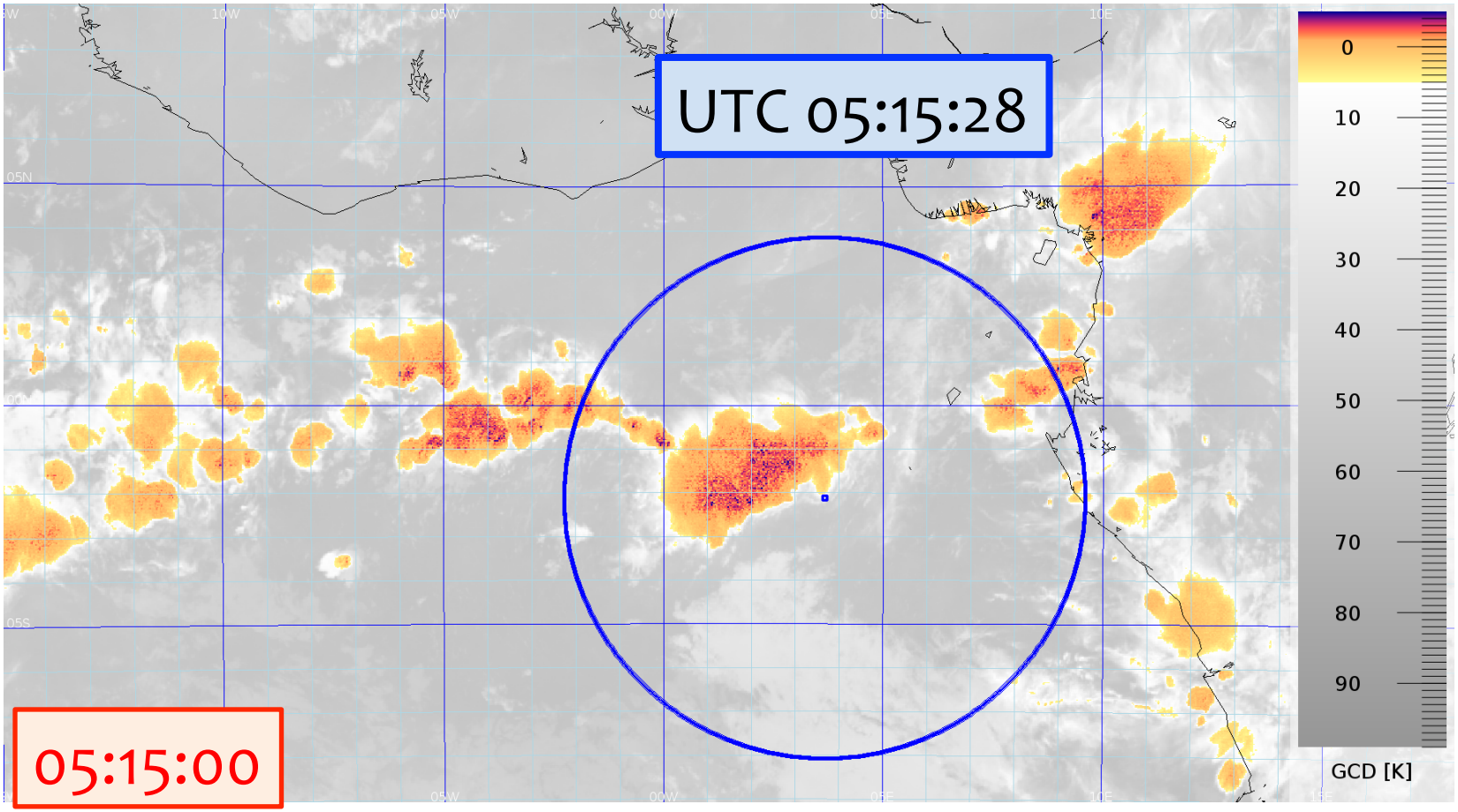
EXAMPLE 5: 19/04/2015

Successive TGFs



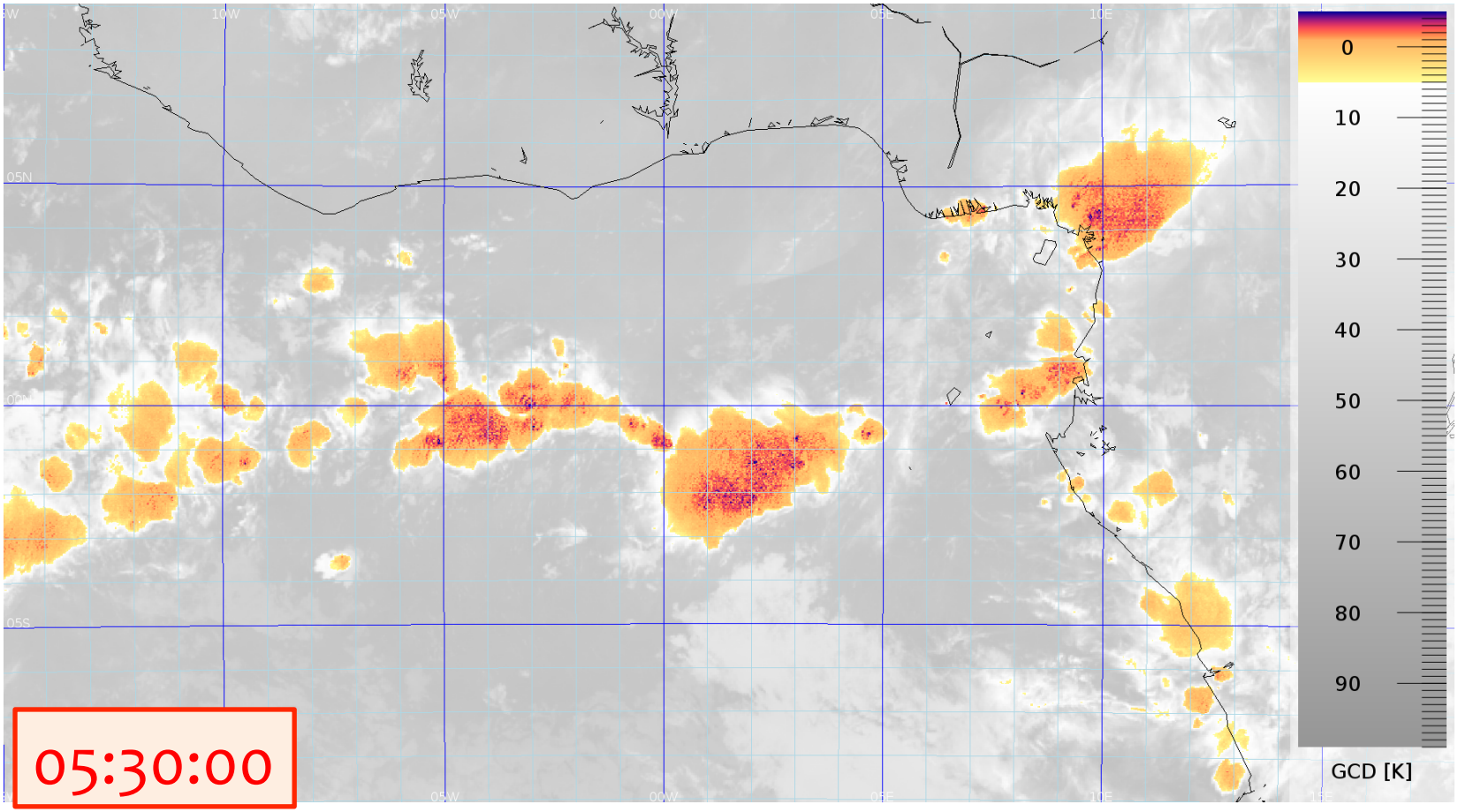
EXAMPLE 5: 19/04/20

Successive TGFs



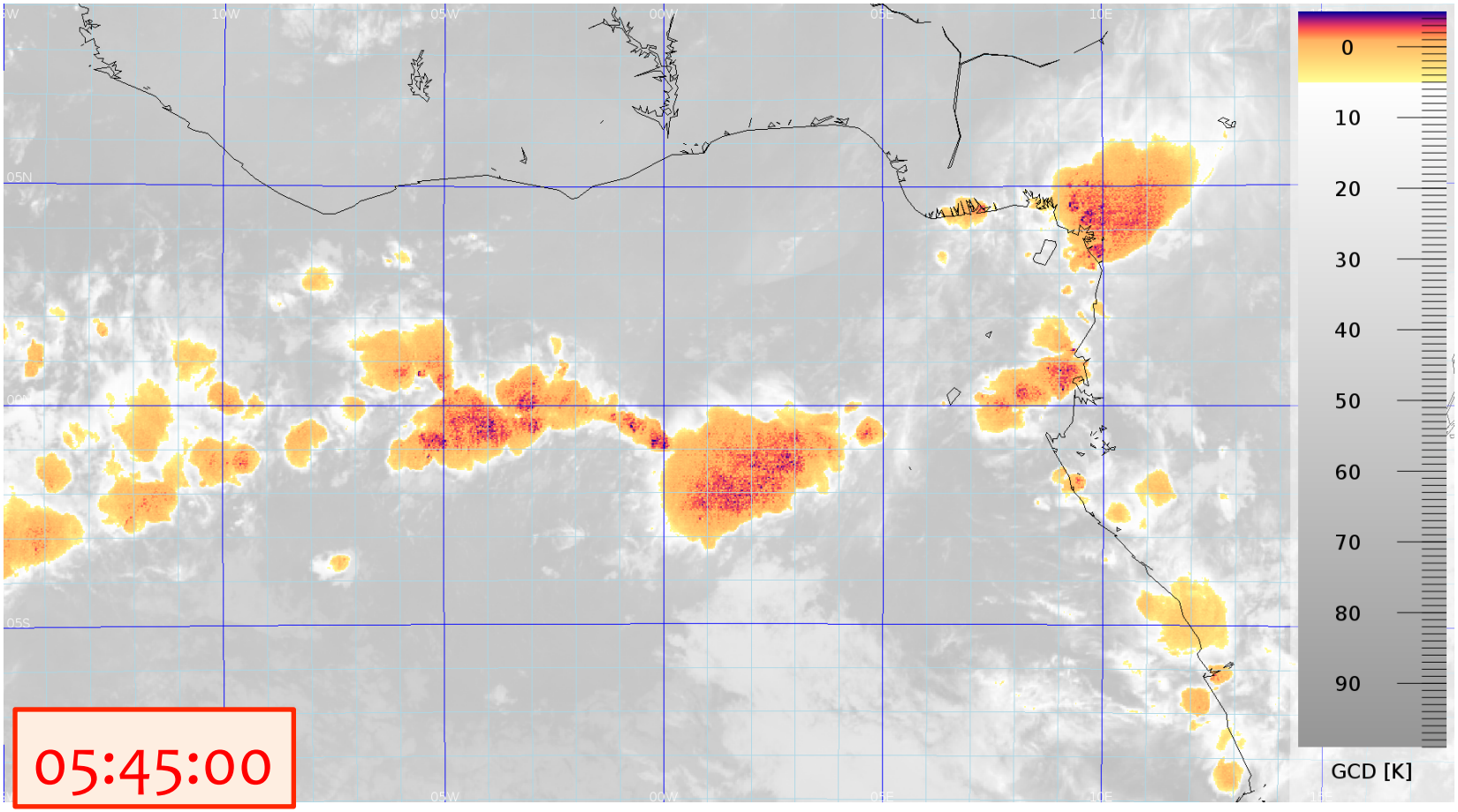
EXAMPLE 6: 24/03/2015

Successive TGFs



EXAMPLE 6: 24/03/2015

Successive TGFs



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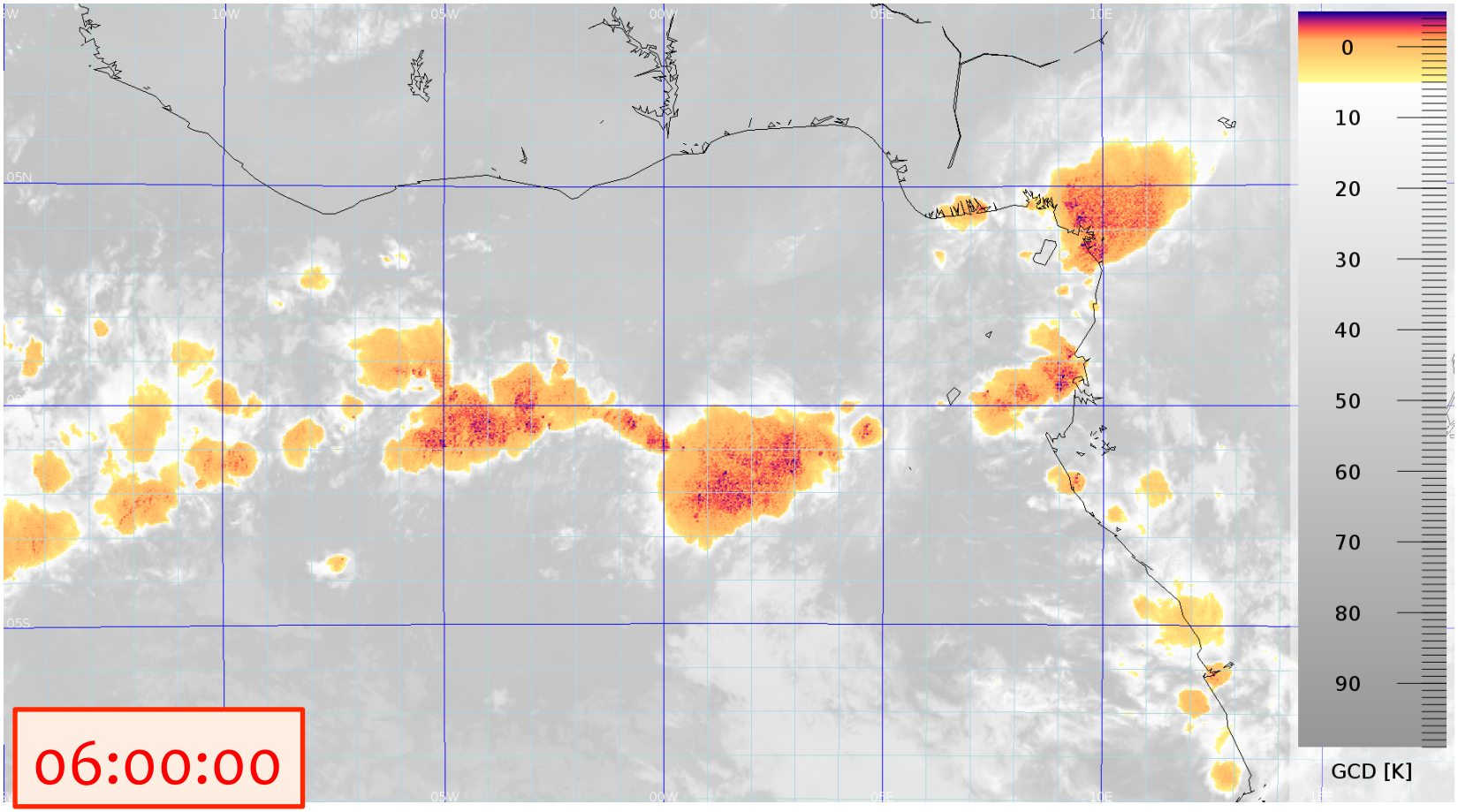

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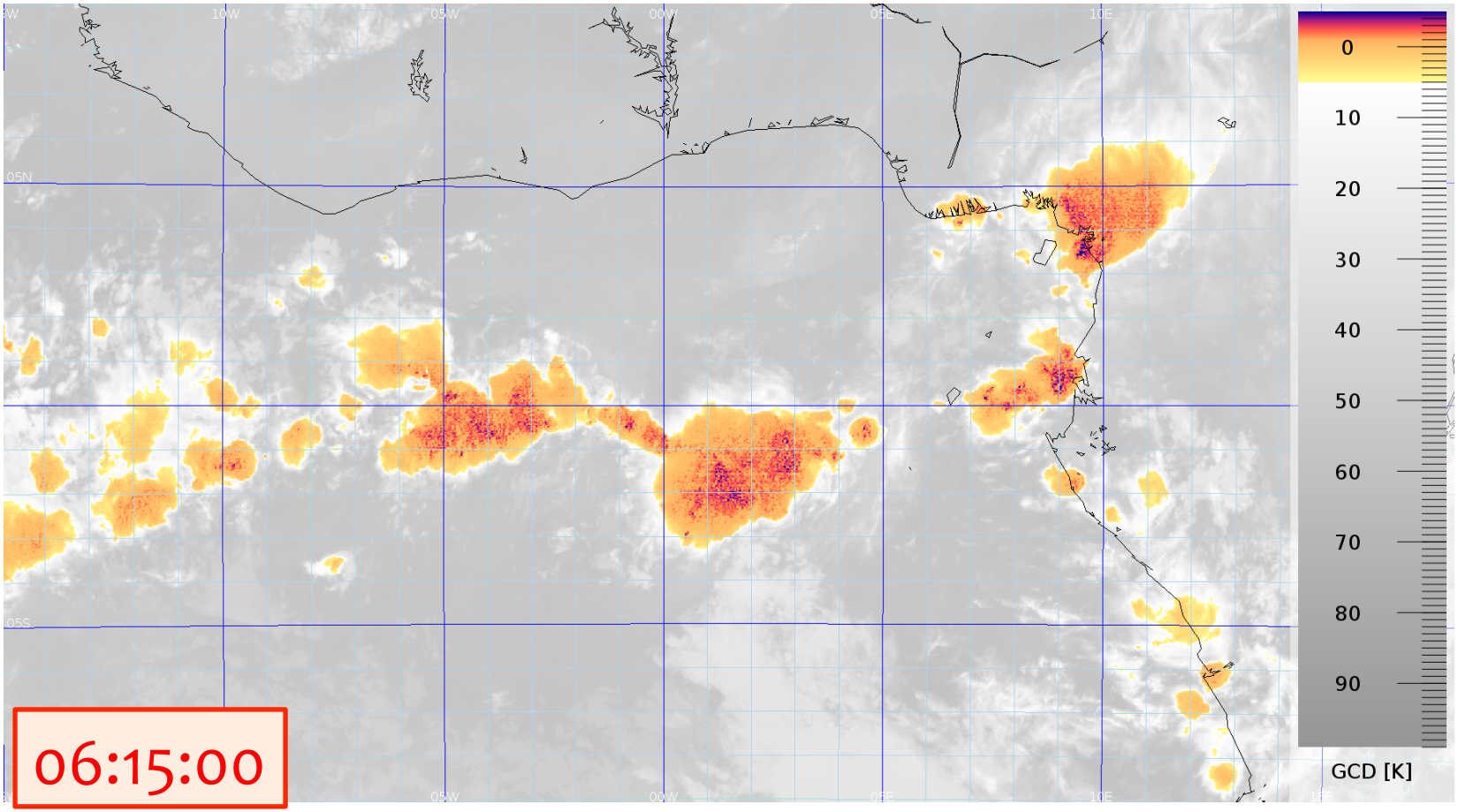

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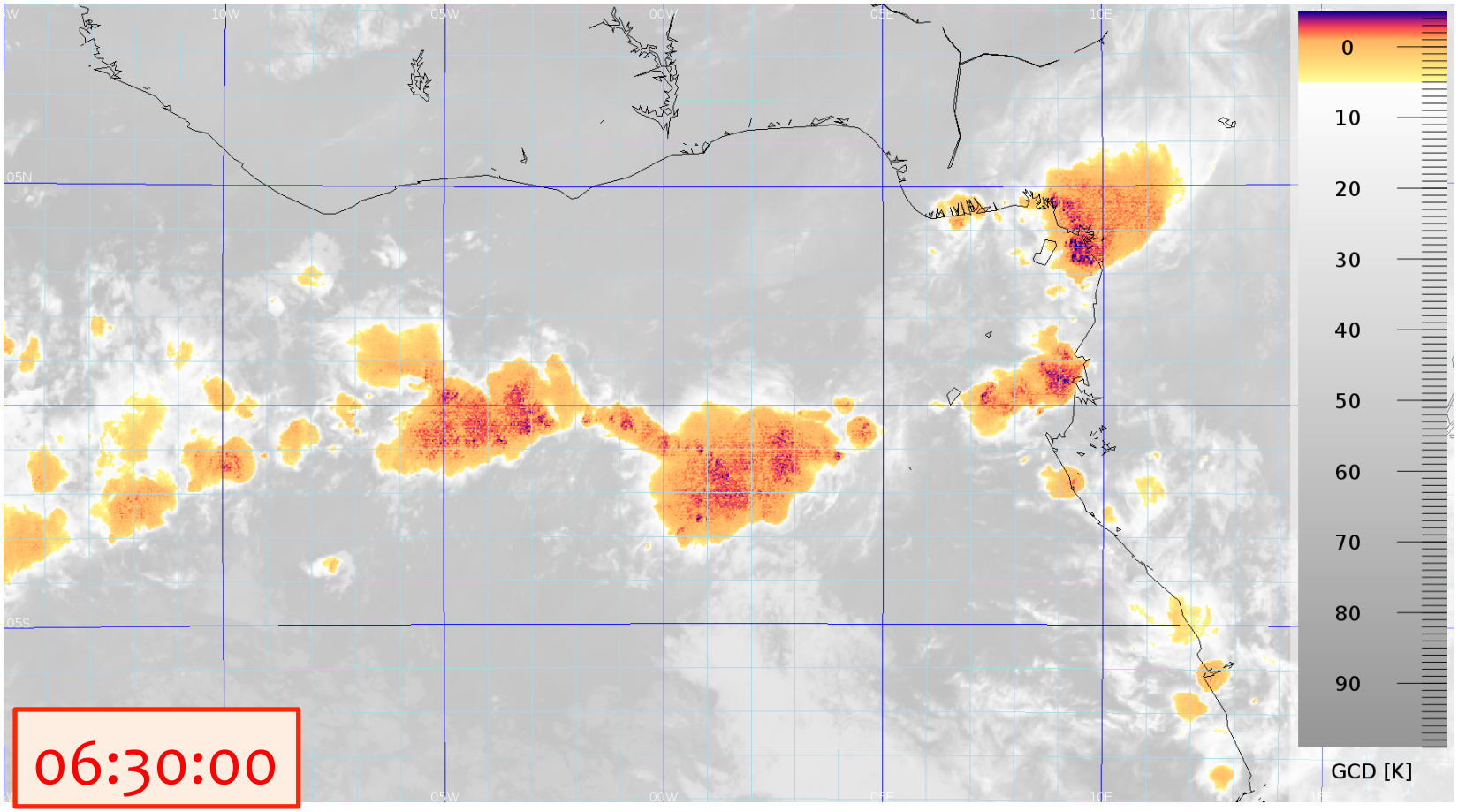

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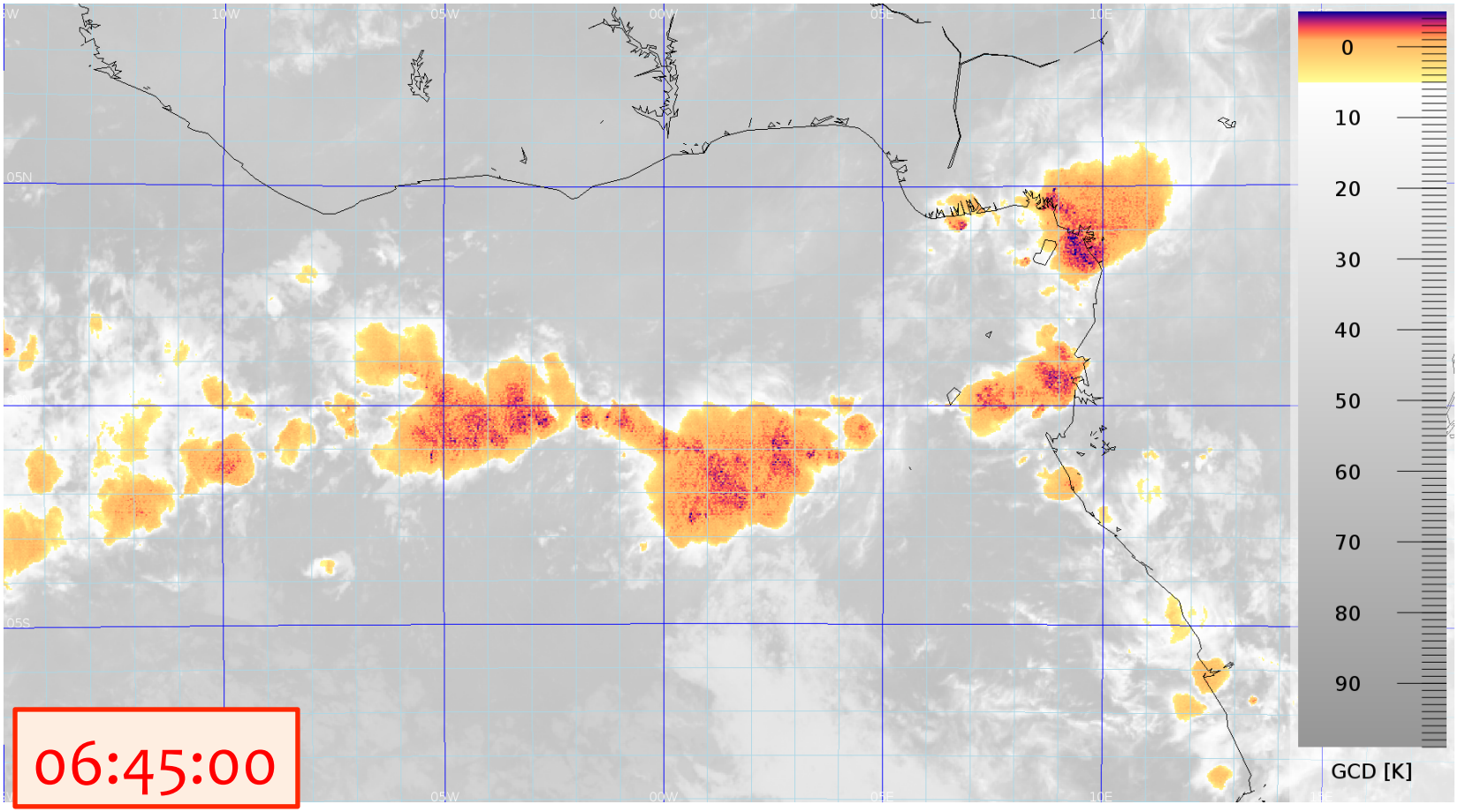
Successive TGFs



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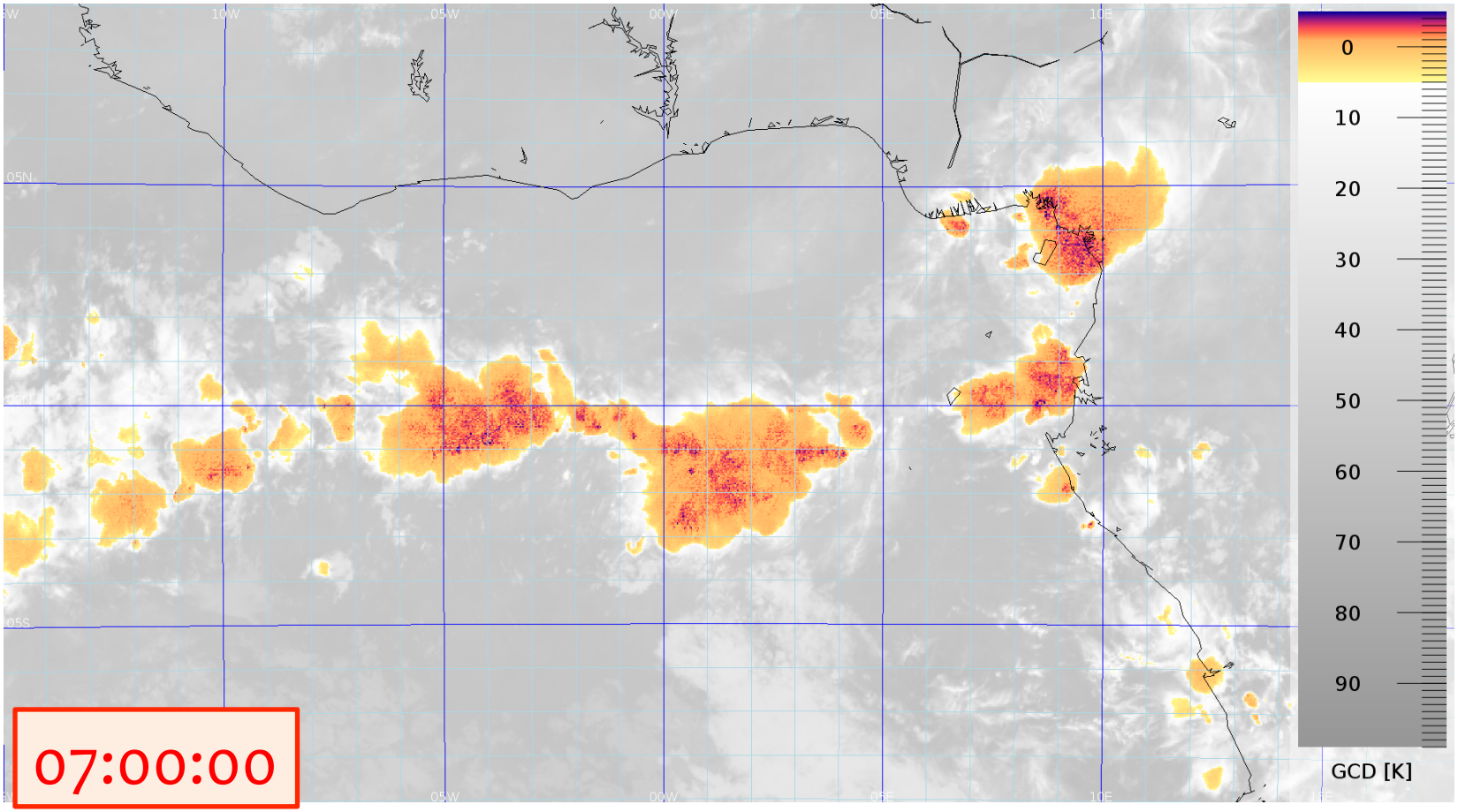

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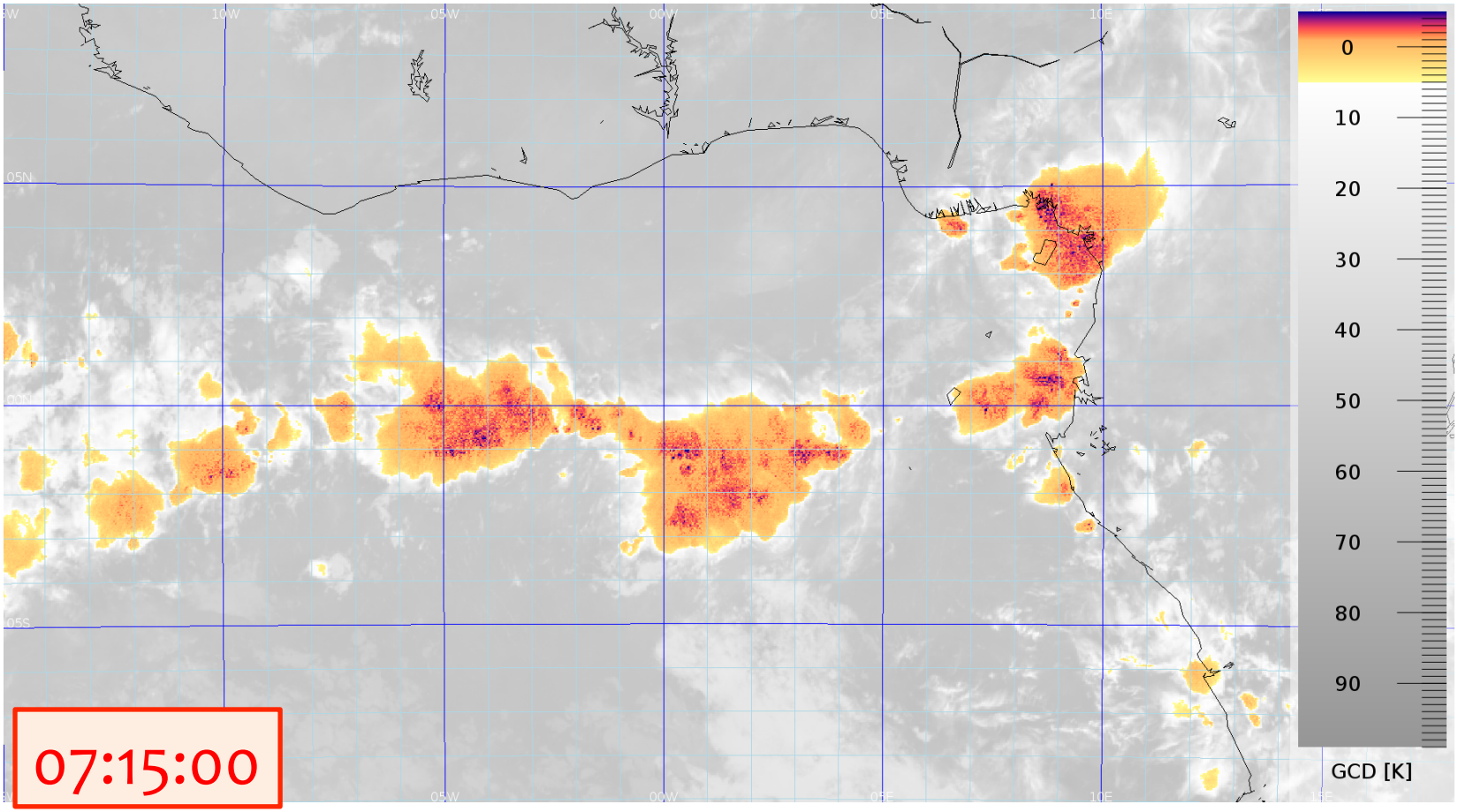
Successive TGFs



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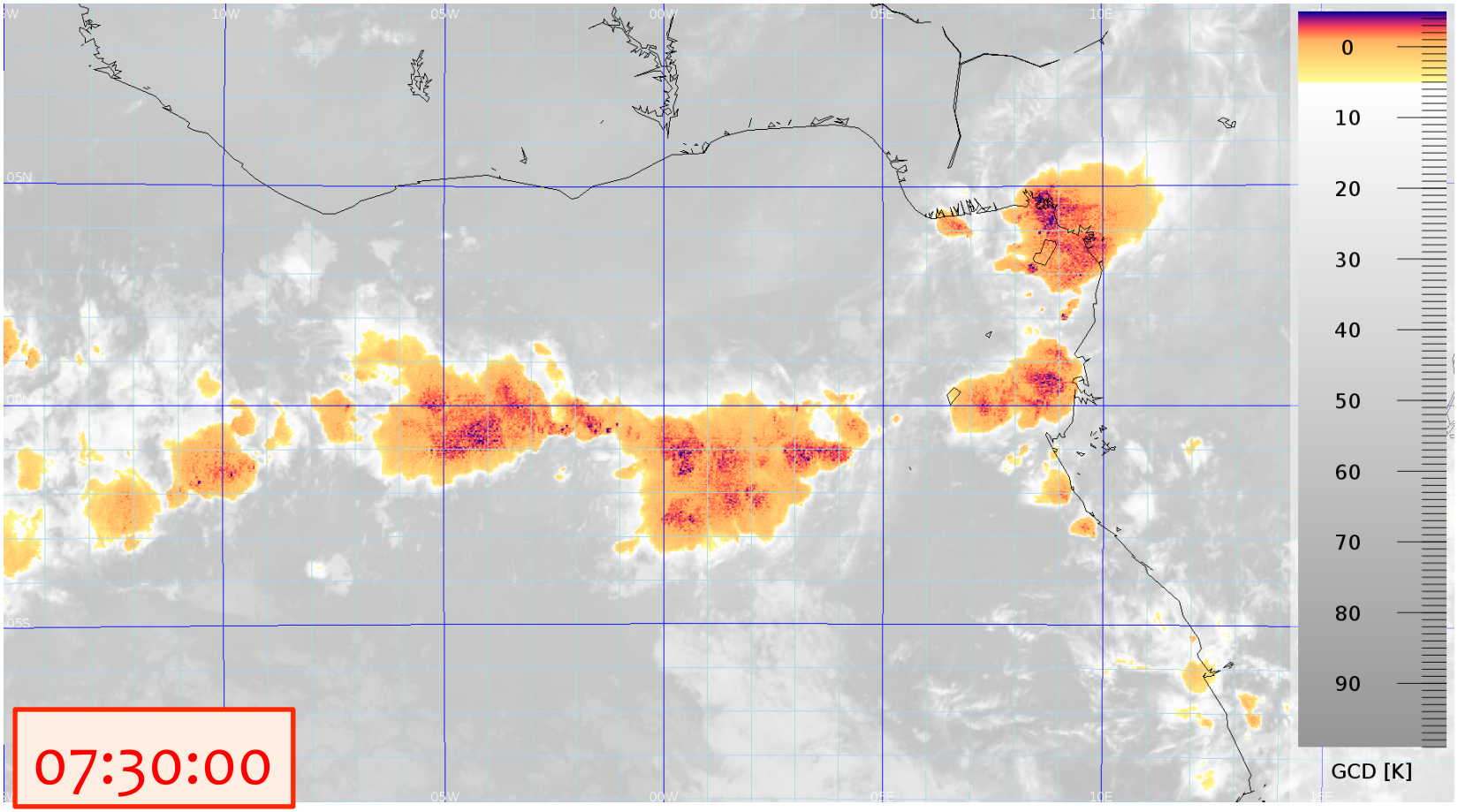

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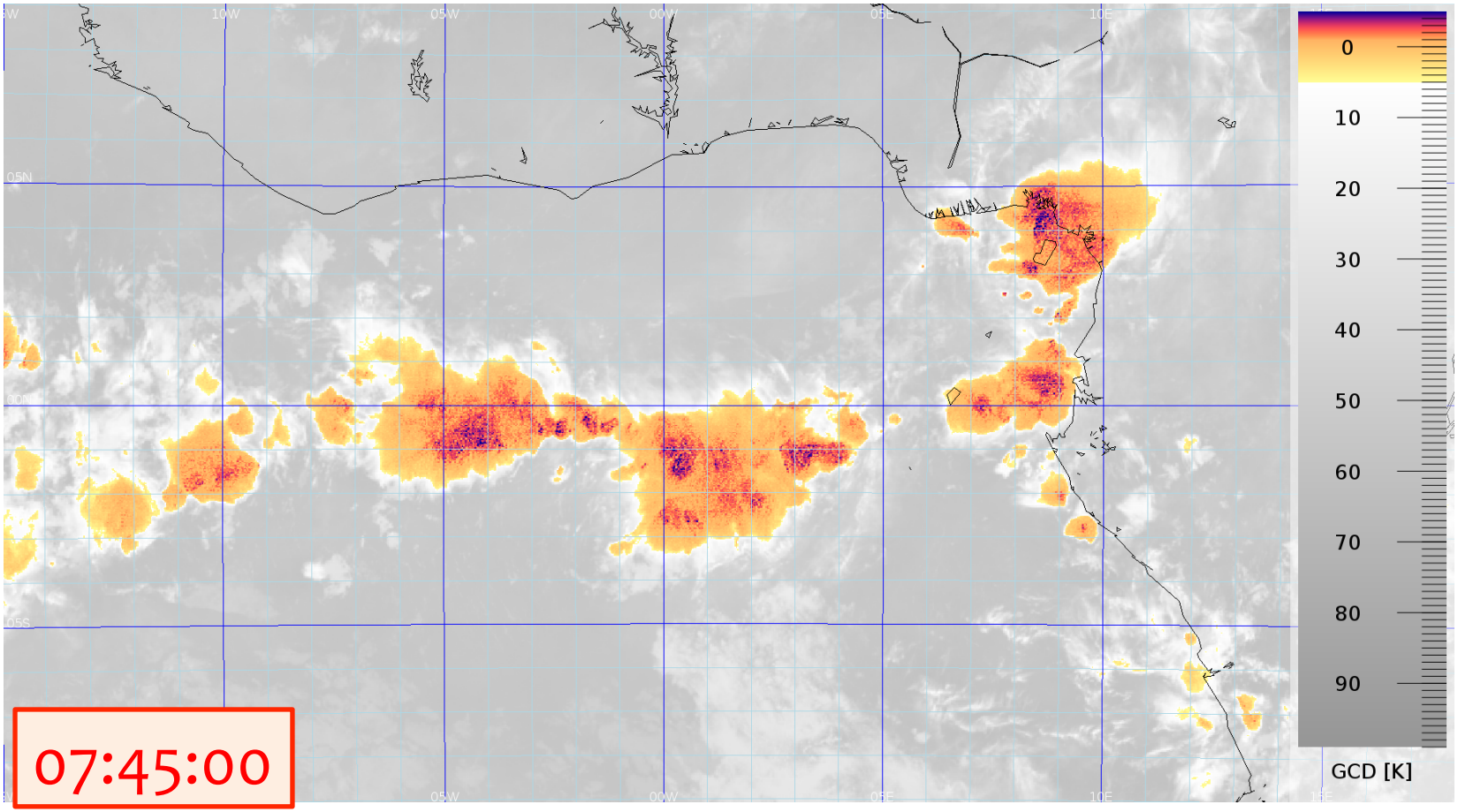

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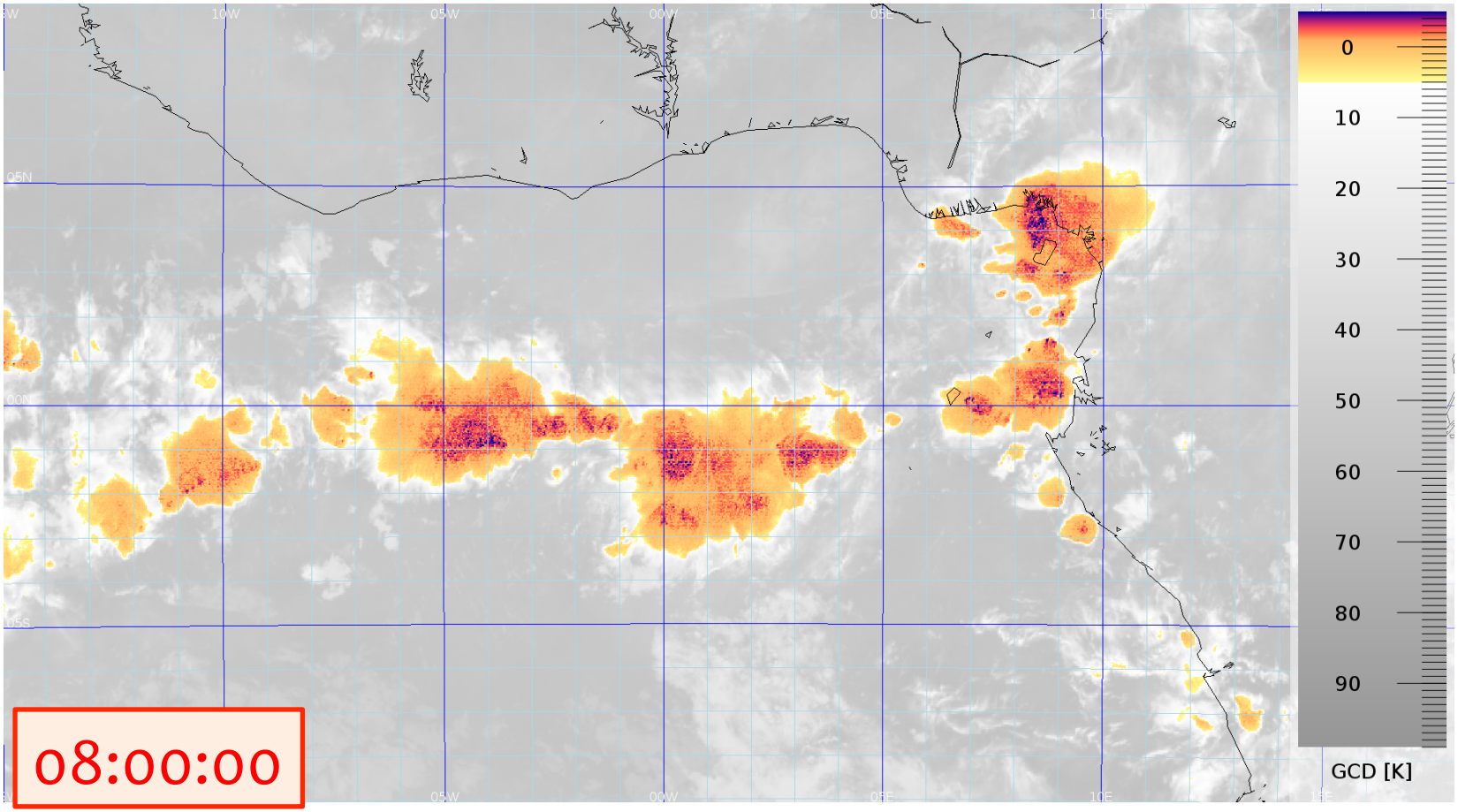

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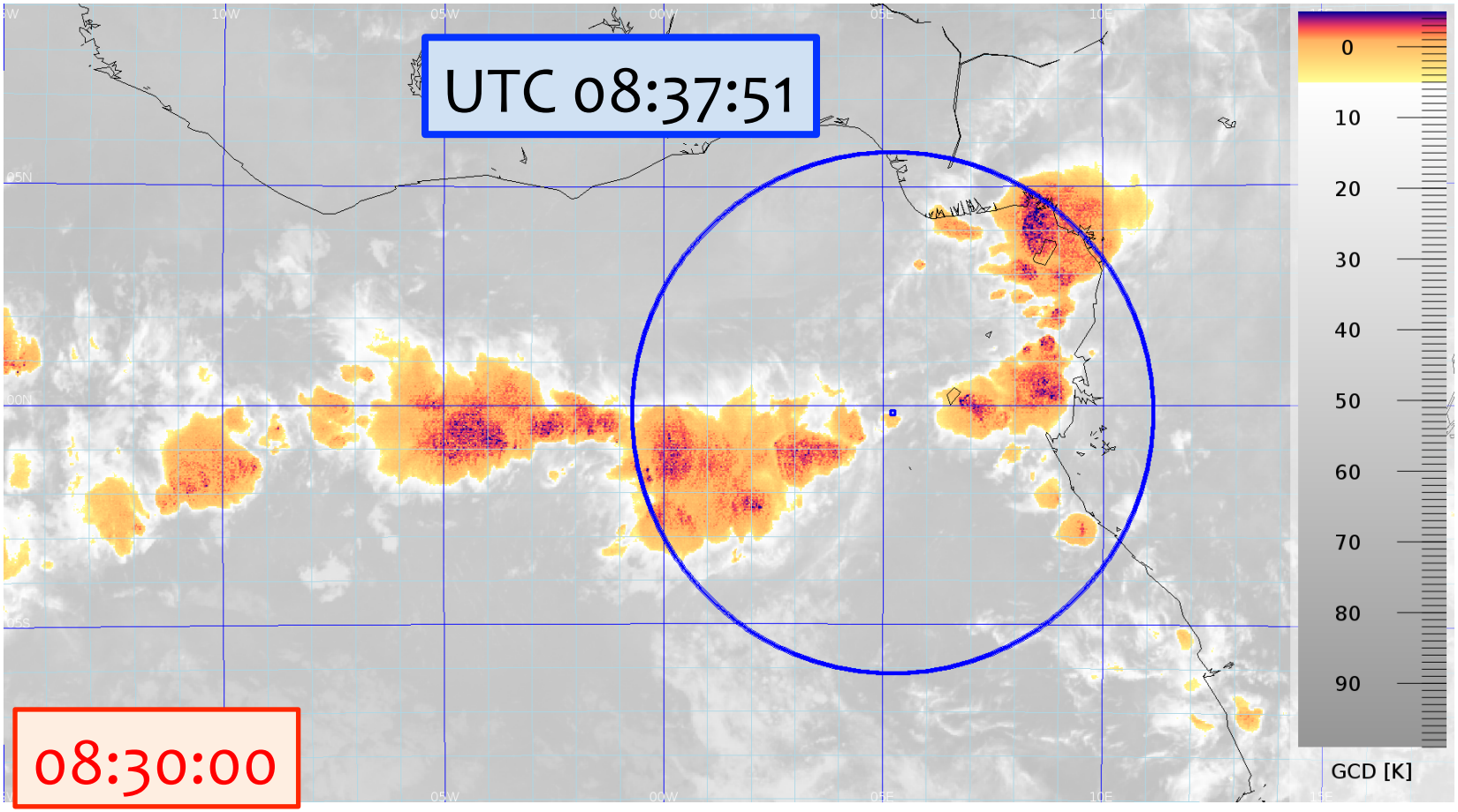
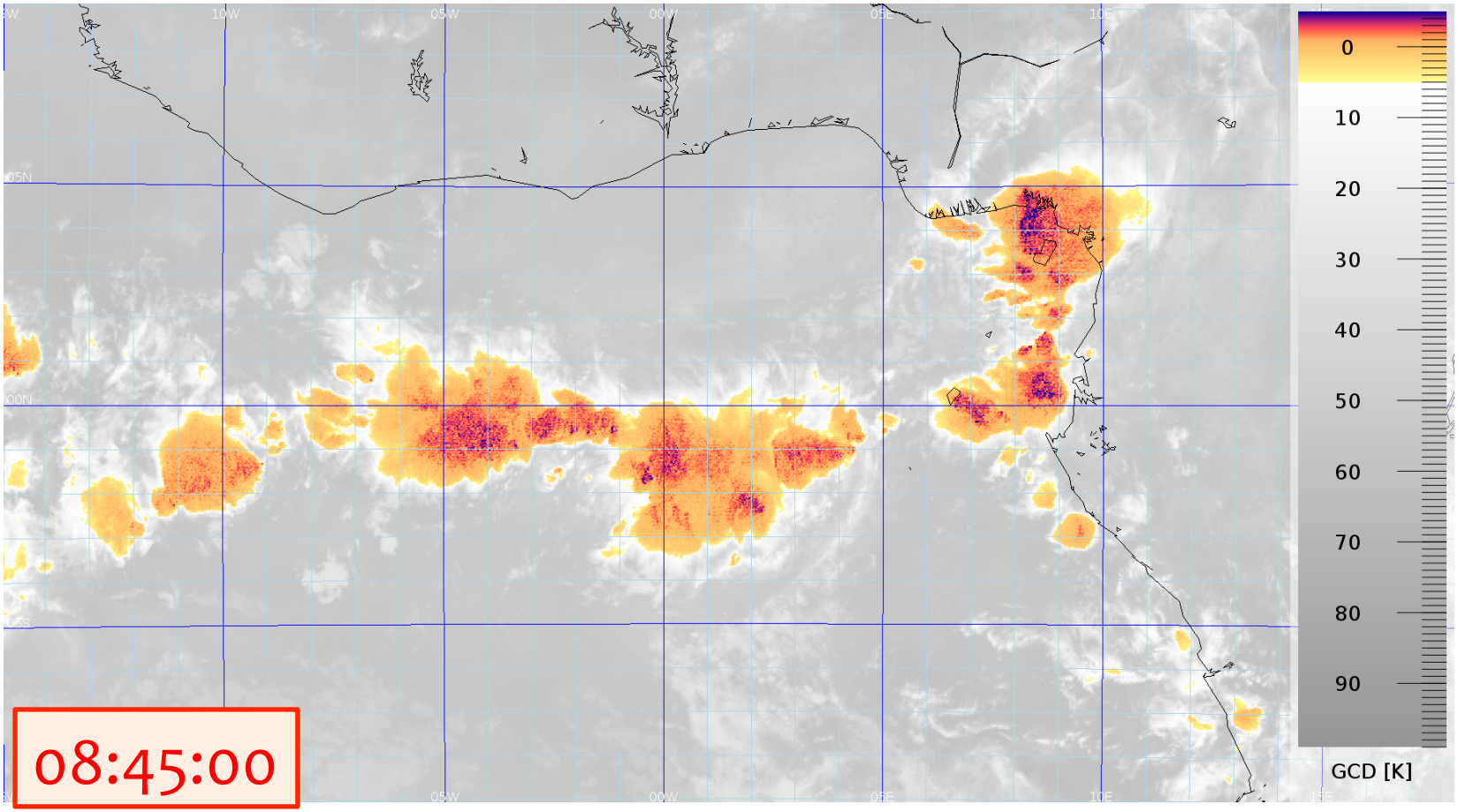
Successive TGFs



EXAMPLE 6: 24/03/2015

Successive TGFs



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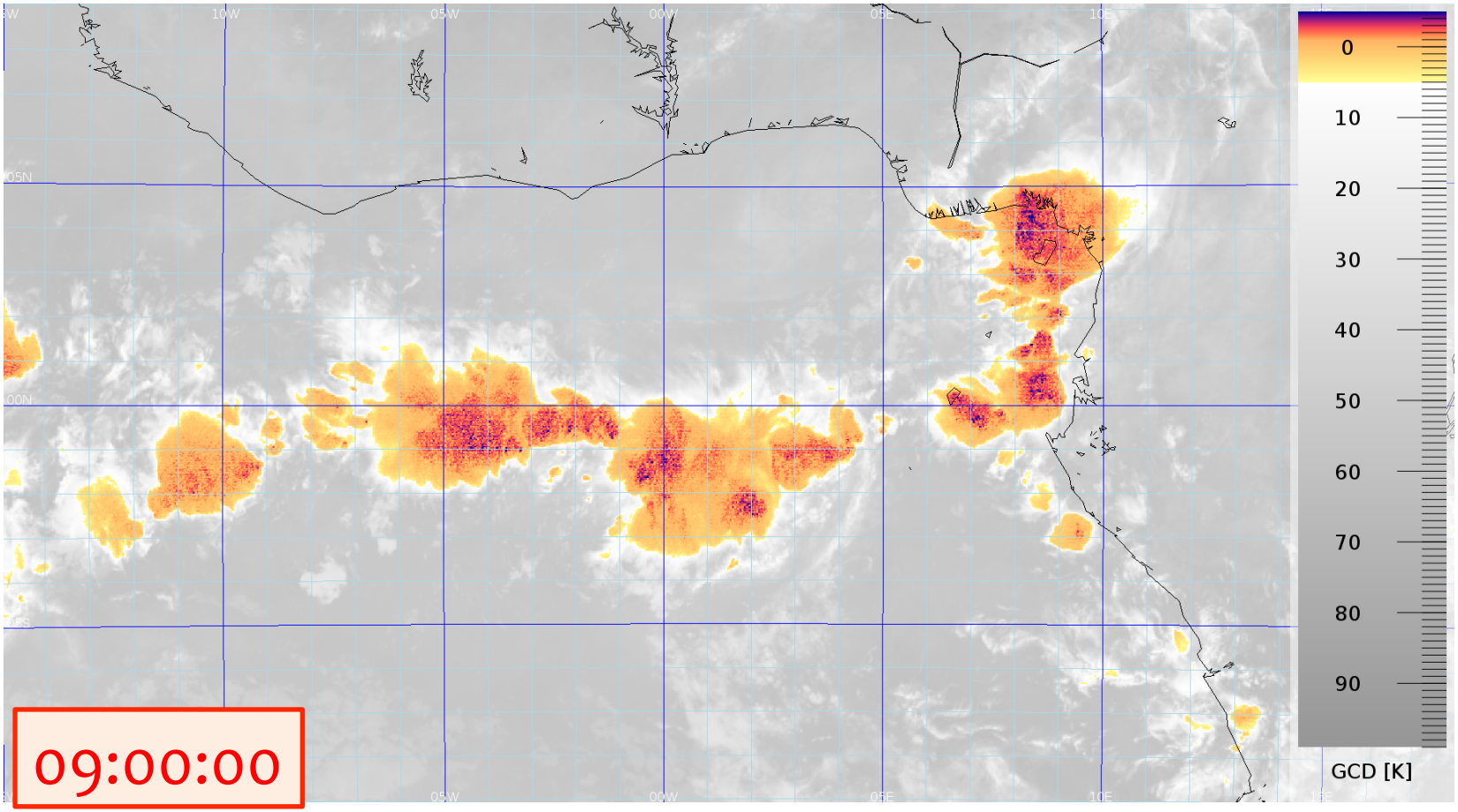
Successive TGFs



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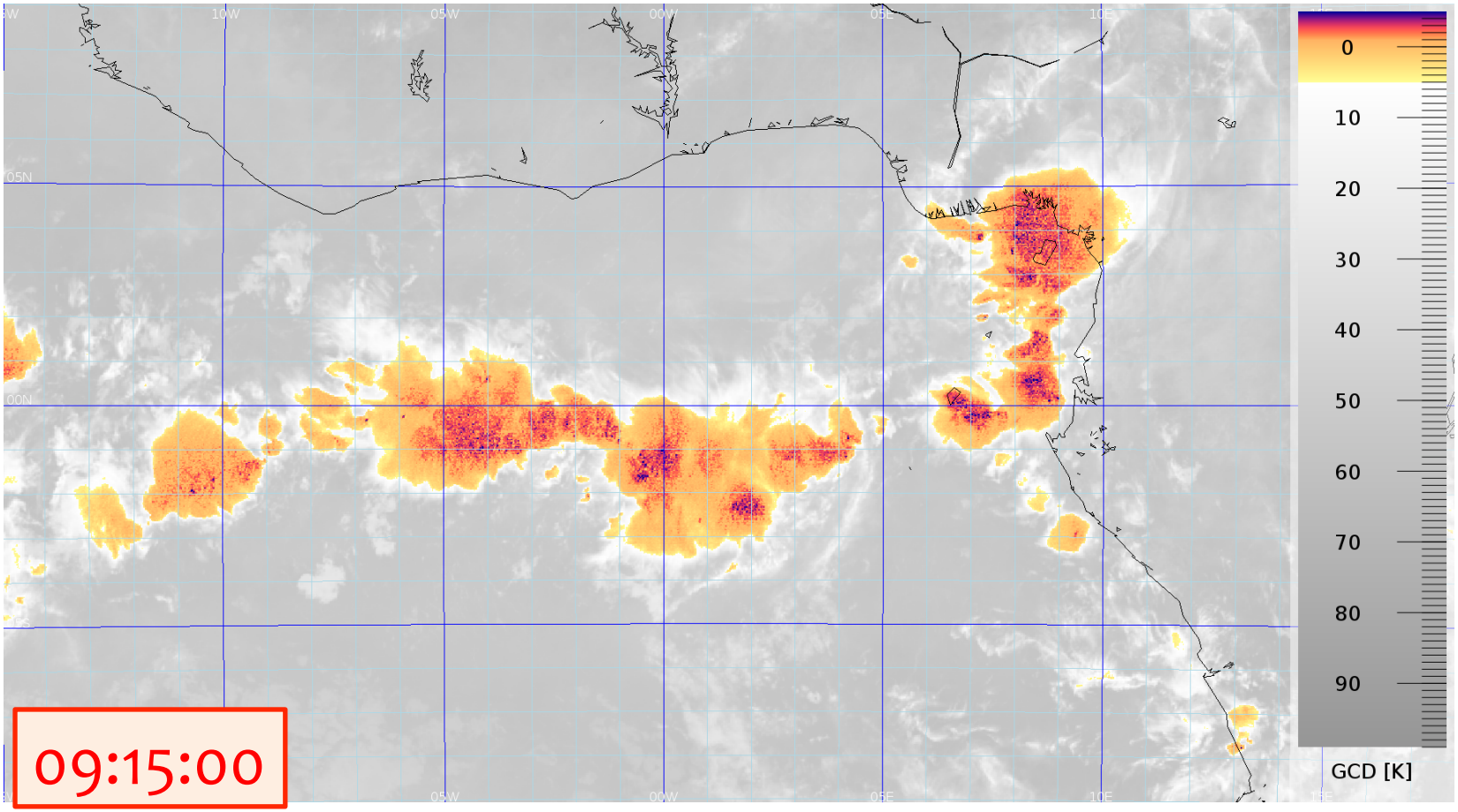
Successive TGFs



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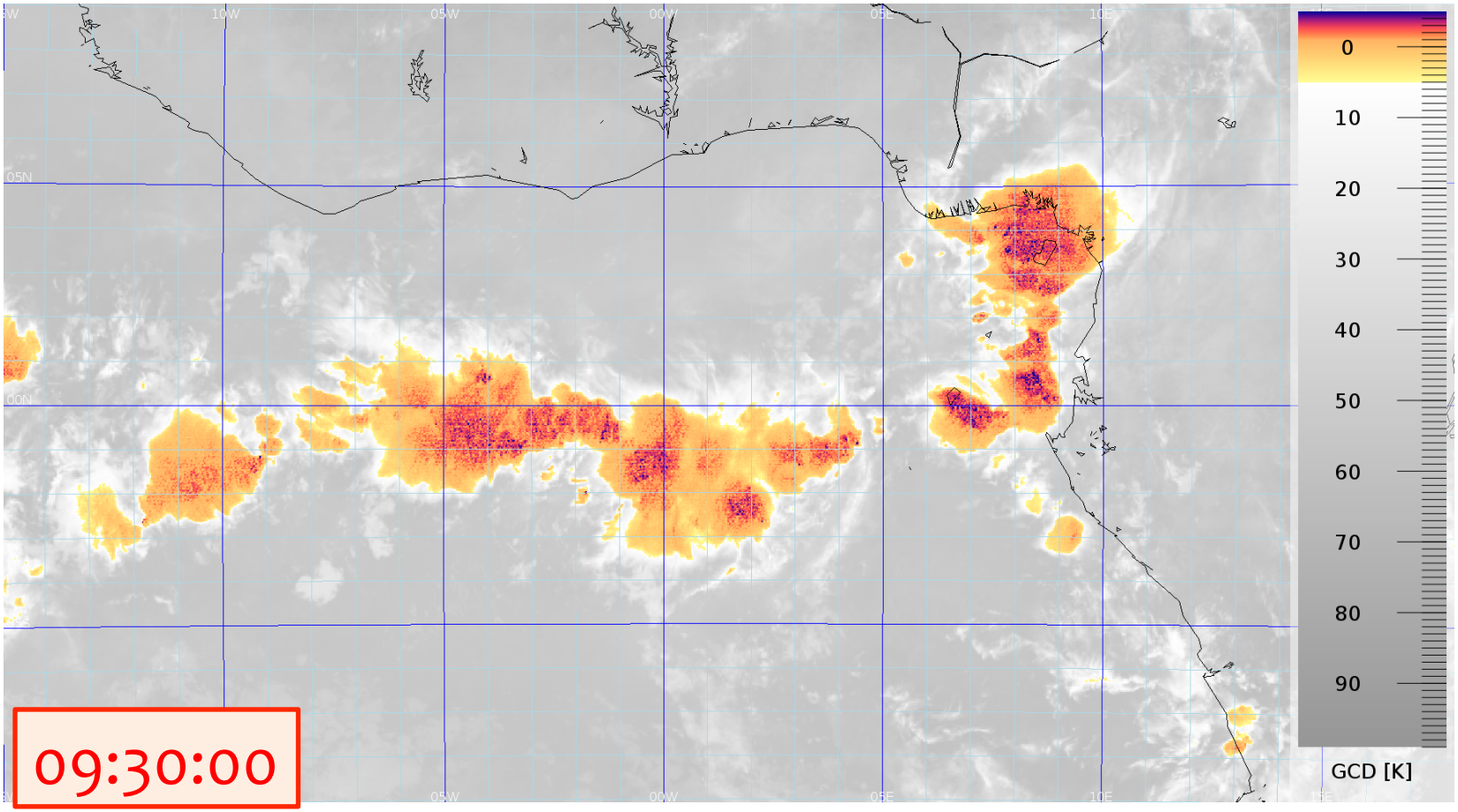

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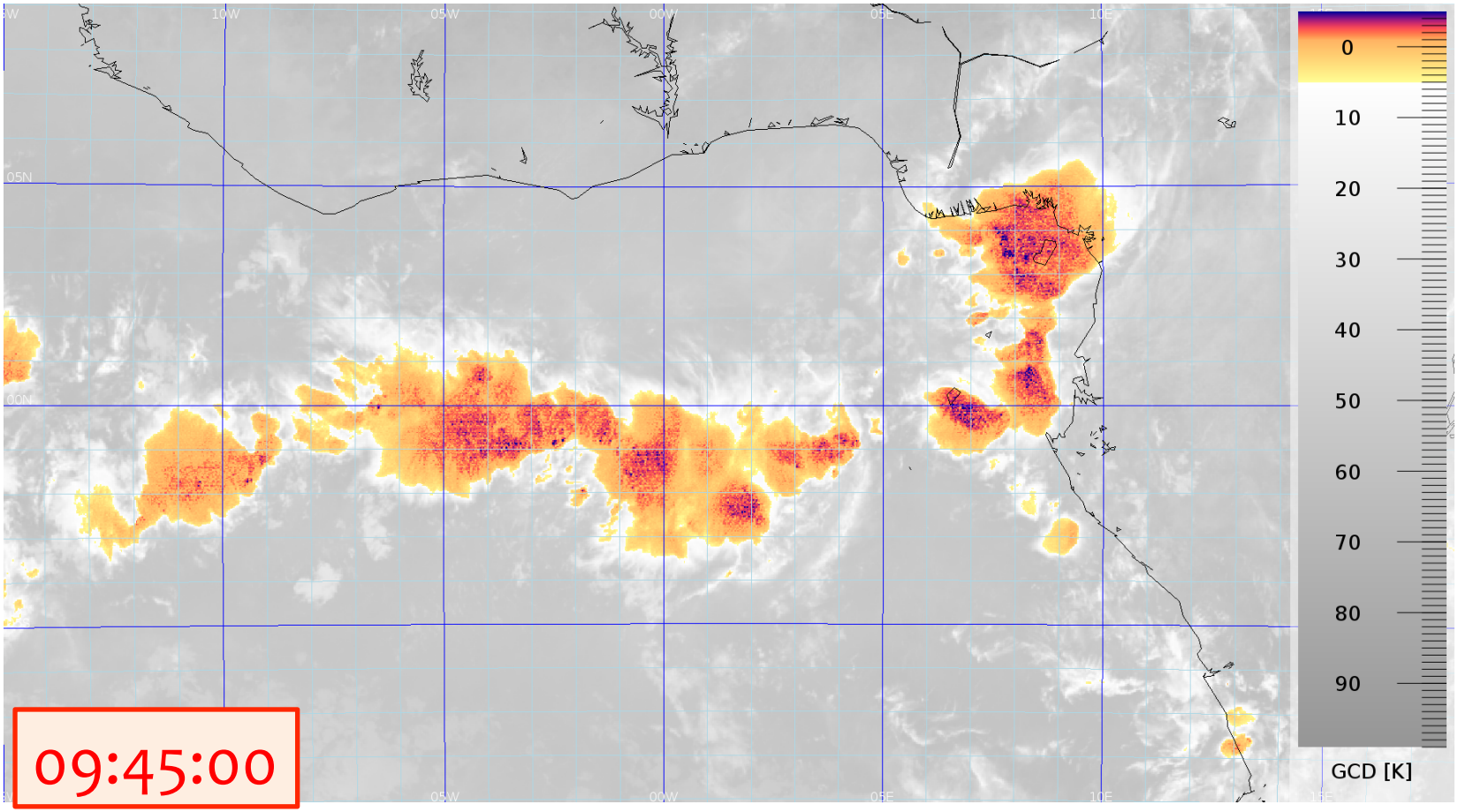
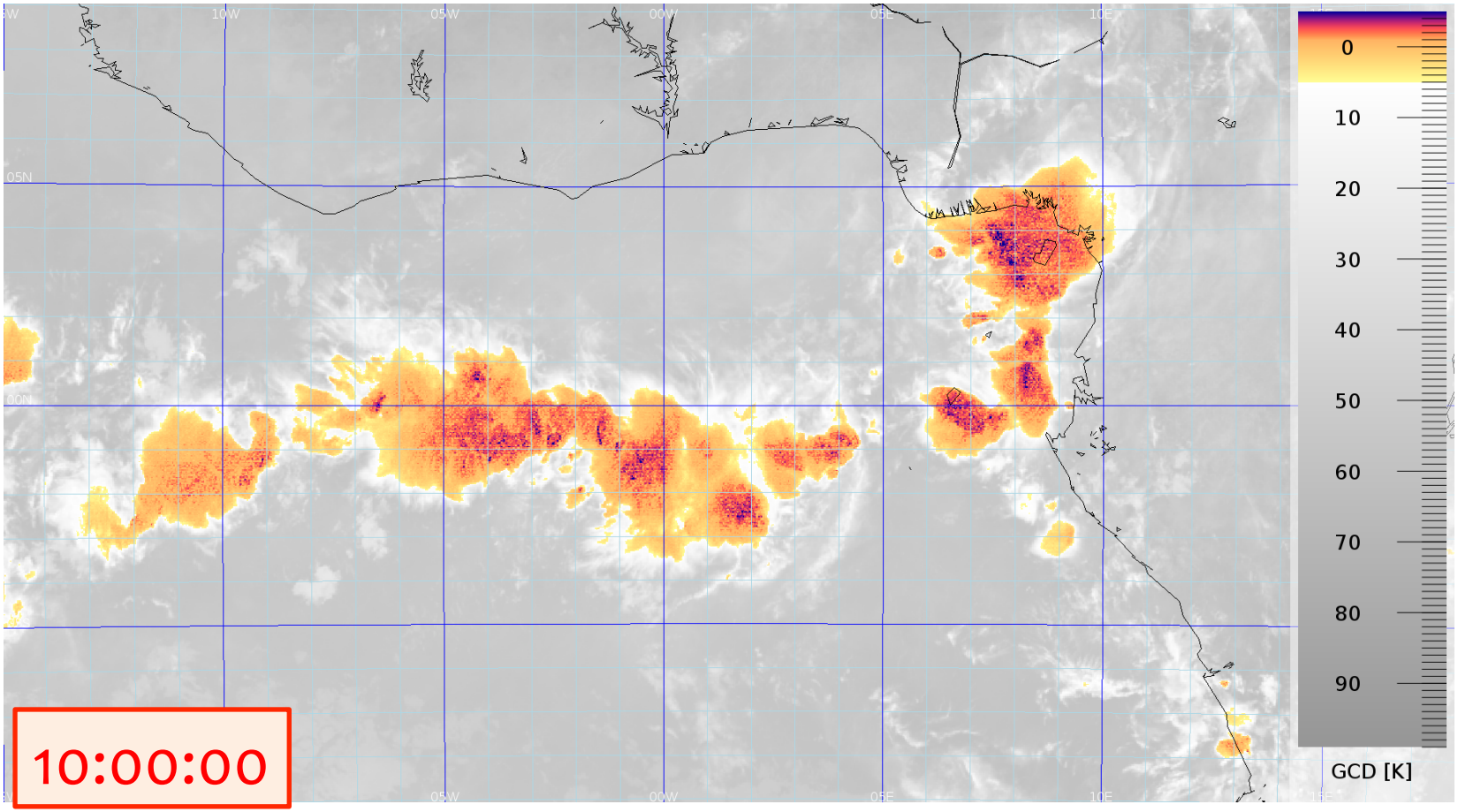
Successive TGFs



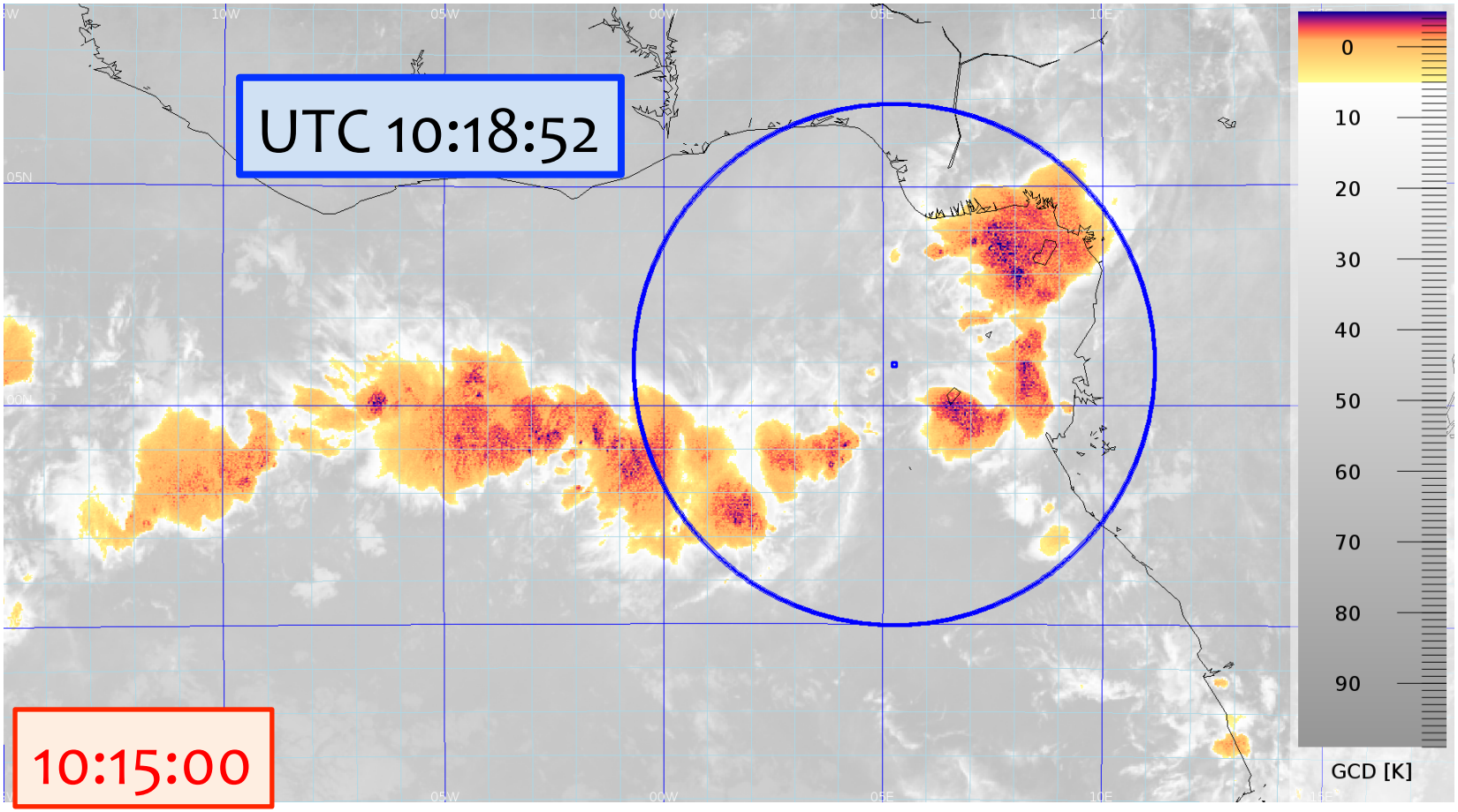
EXAMPLE 6: 24/03/2015

Successive TGFs



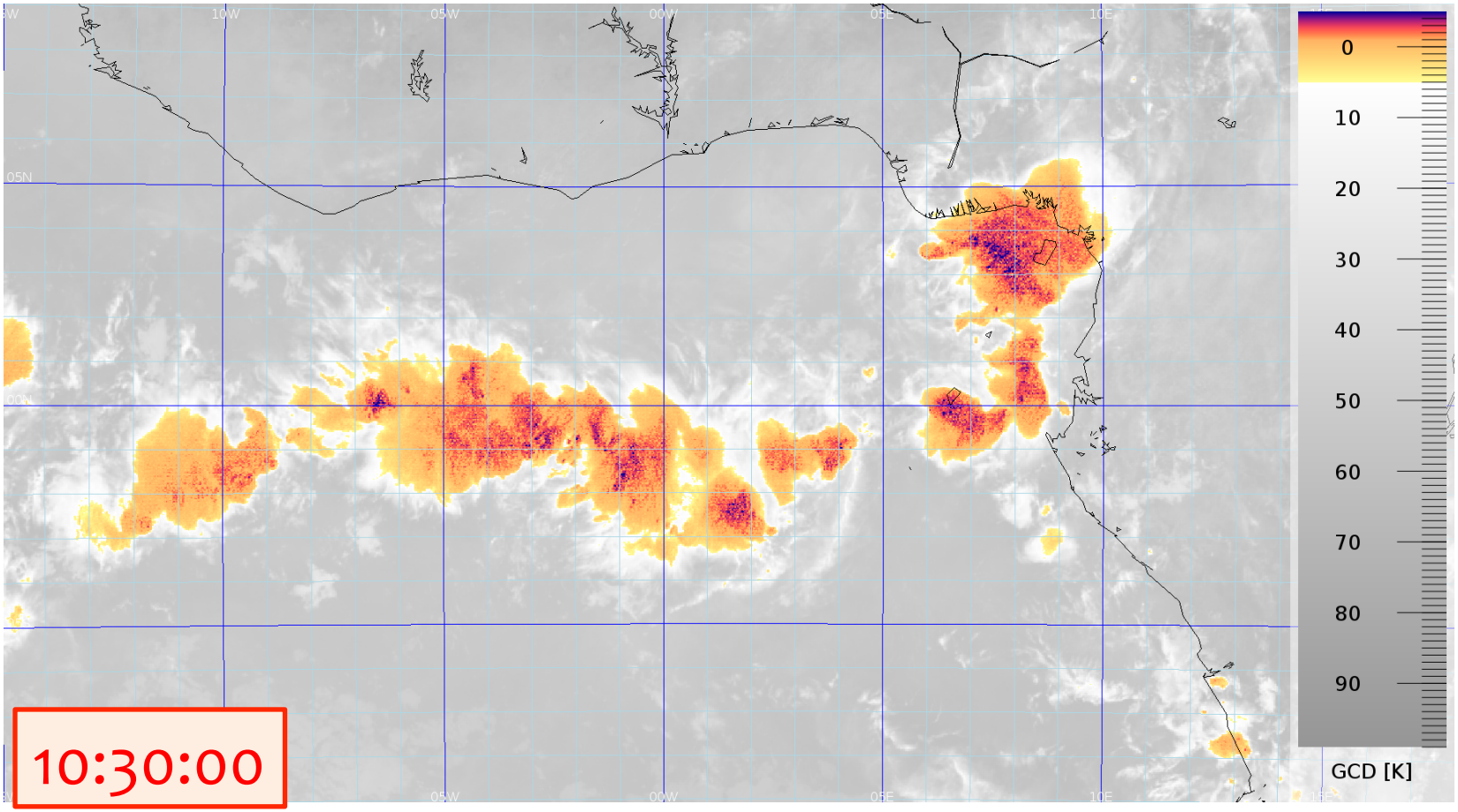
EXAMPLE 6: 24/03/2015

Successive TGFs



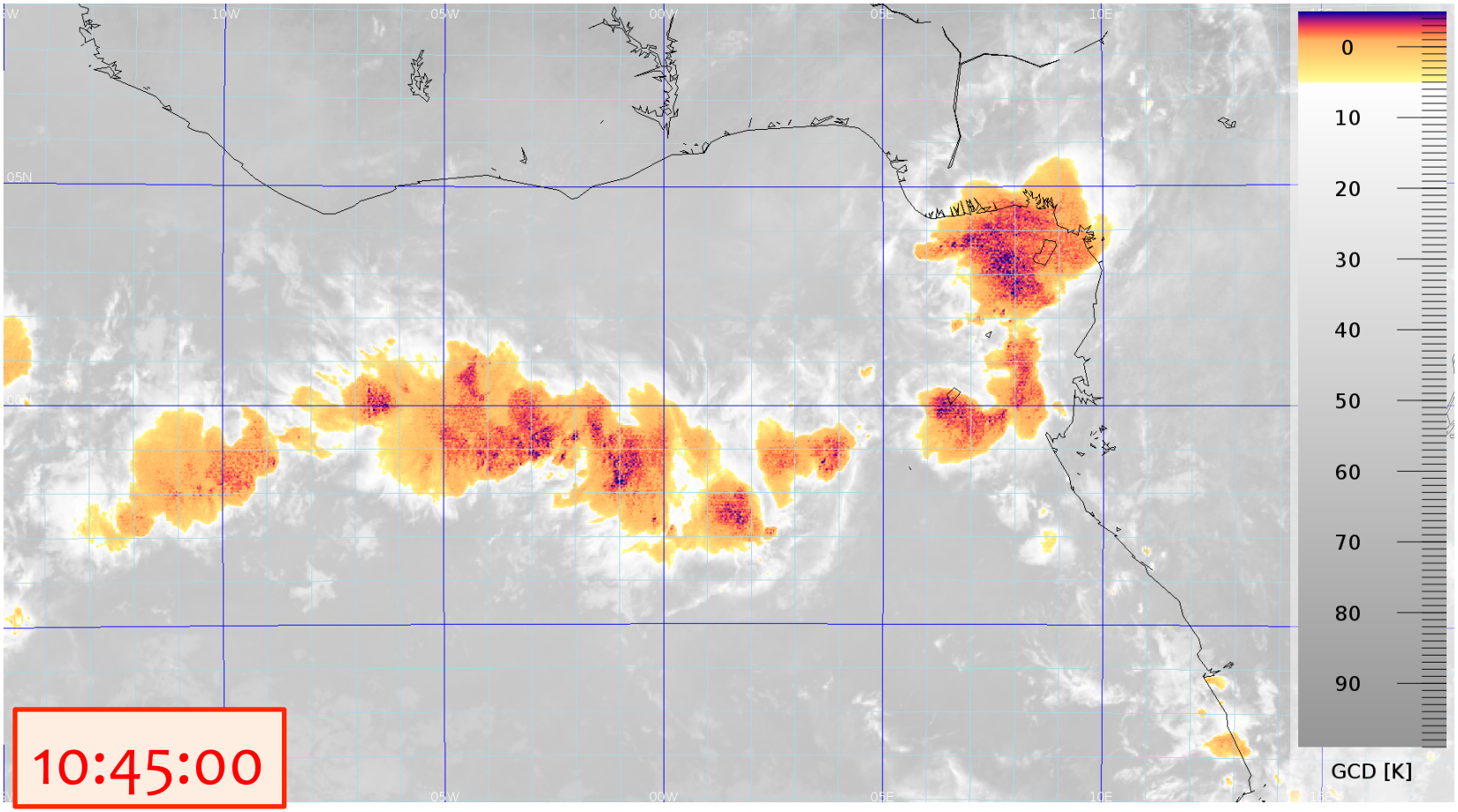
EXAMPLE 6: 24/03/2015

Successive TGFs



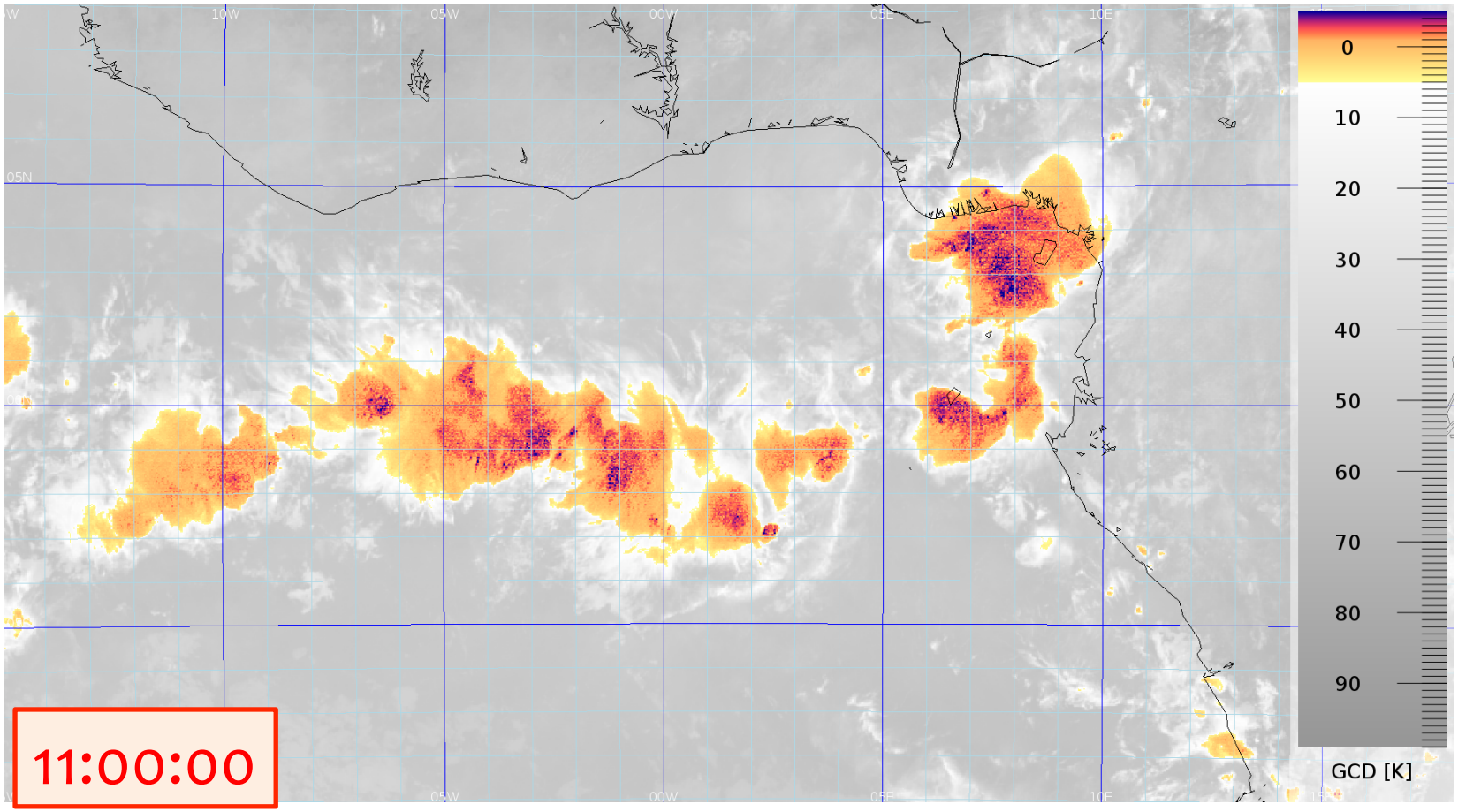
EXAMPLE 6: 24/03/2015

Successive TGFs



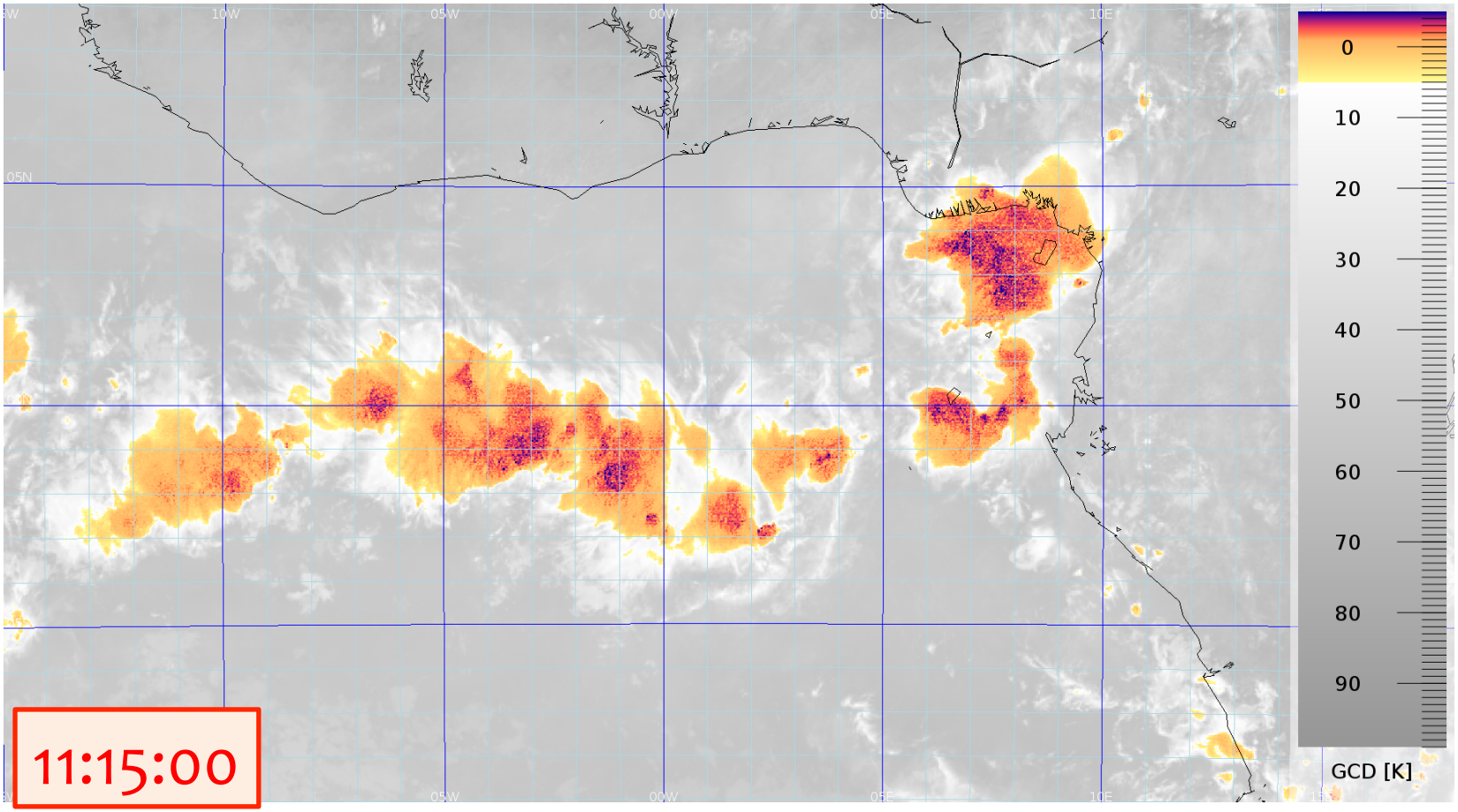
EXAMPLE 6: 24/03/2015

Successive TGFs



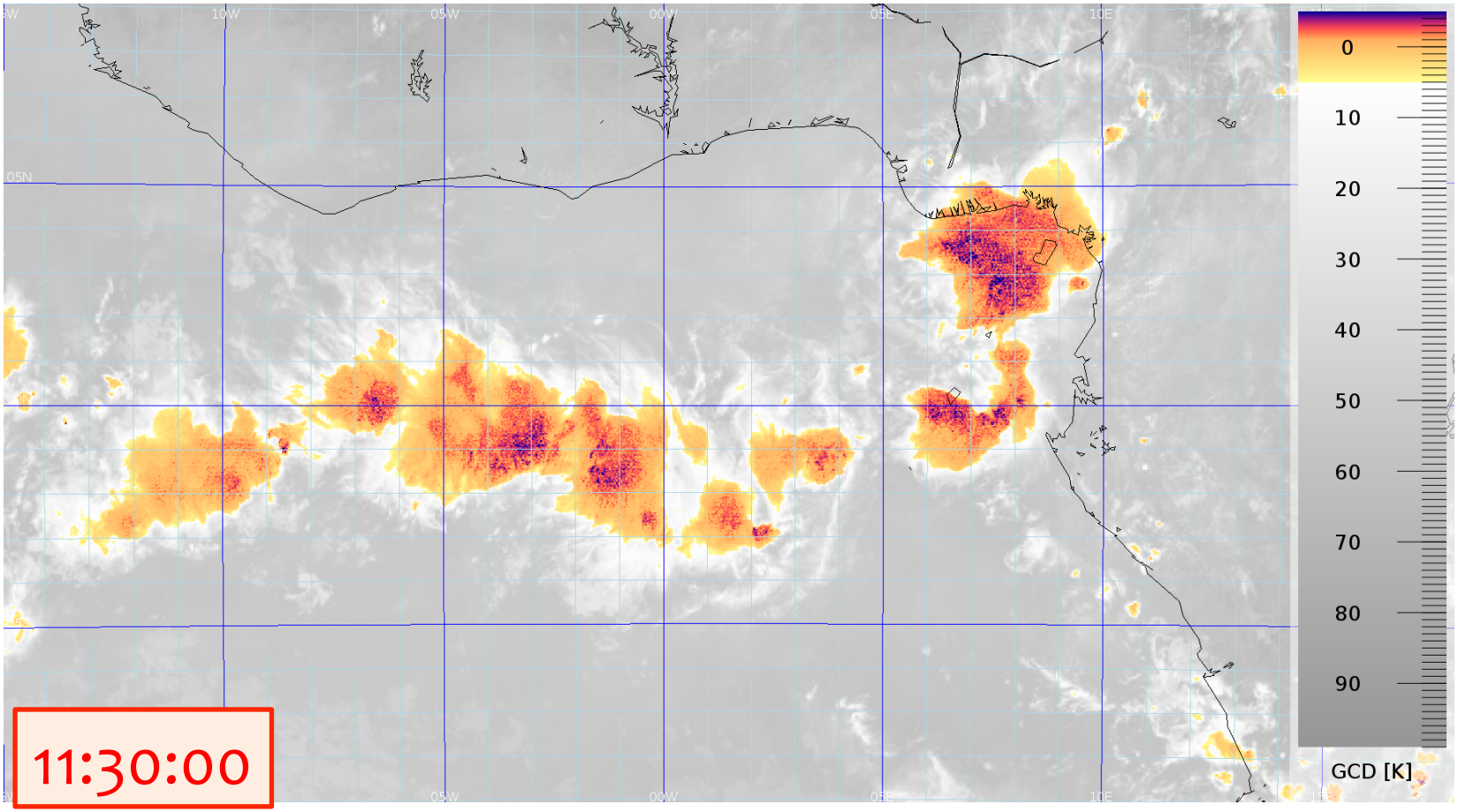
EXAMPLE 6: 24/03/2015

Successive TGFs



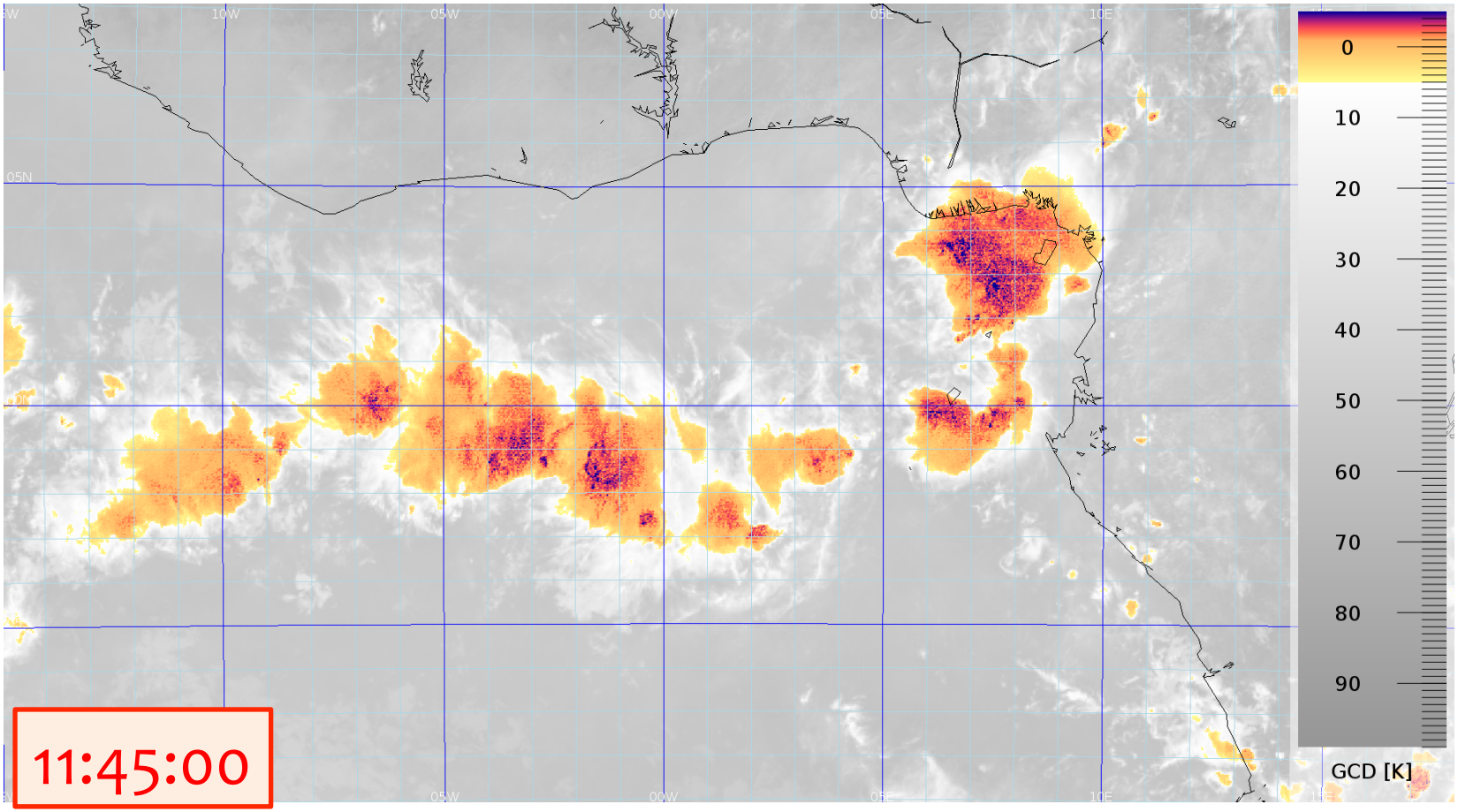
EXAMPLE 6: 24/03/2015

Successive TGFs



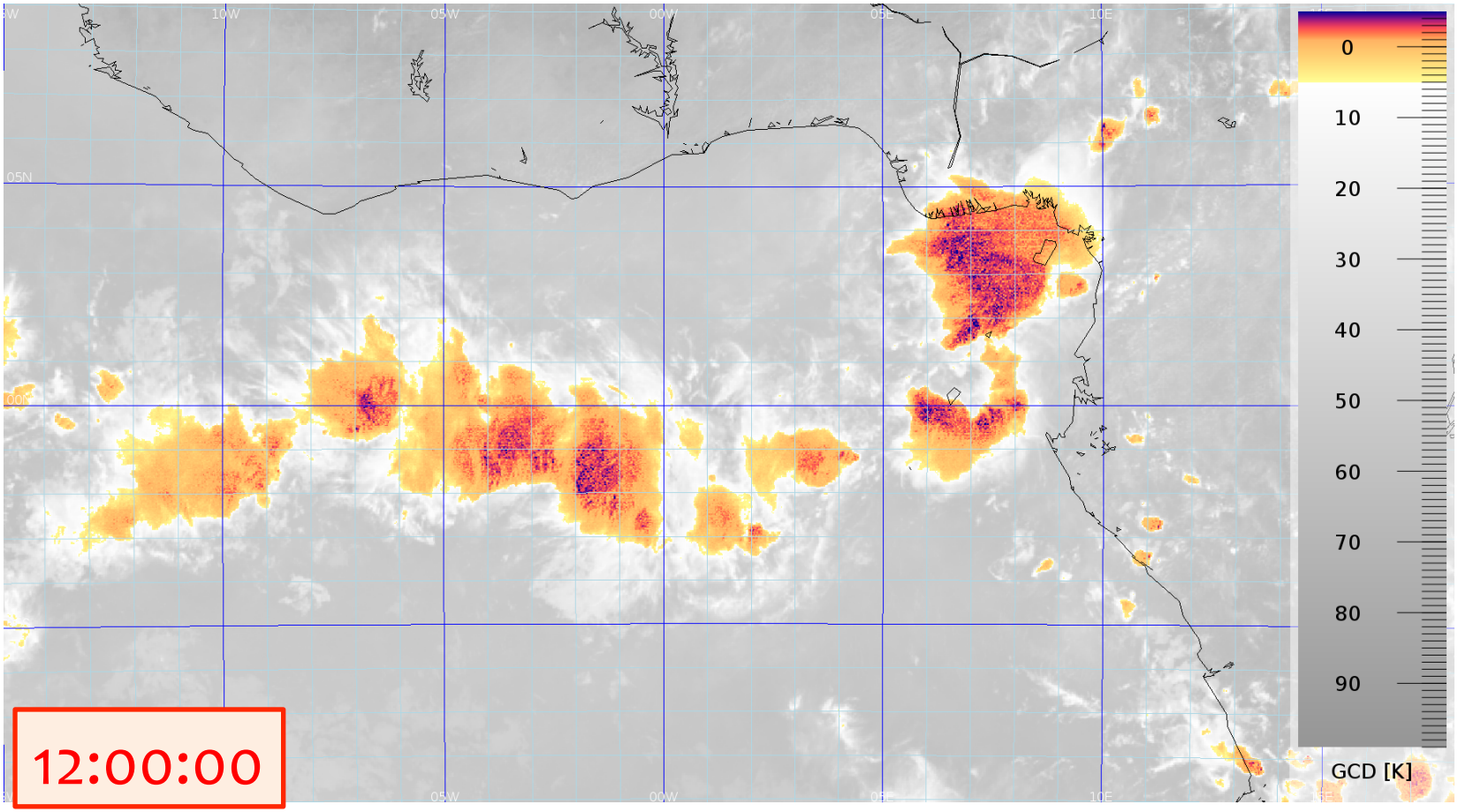
EXAMPLE 6: 24/03/2015

Successive TGFs



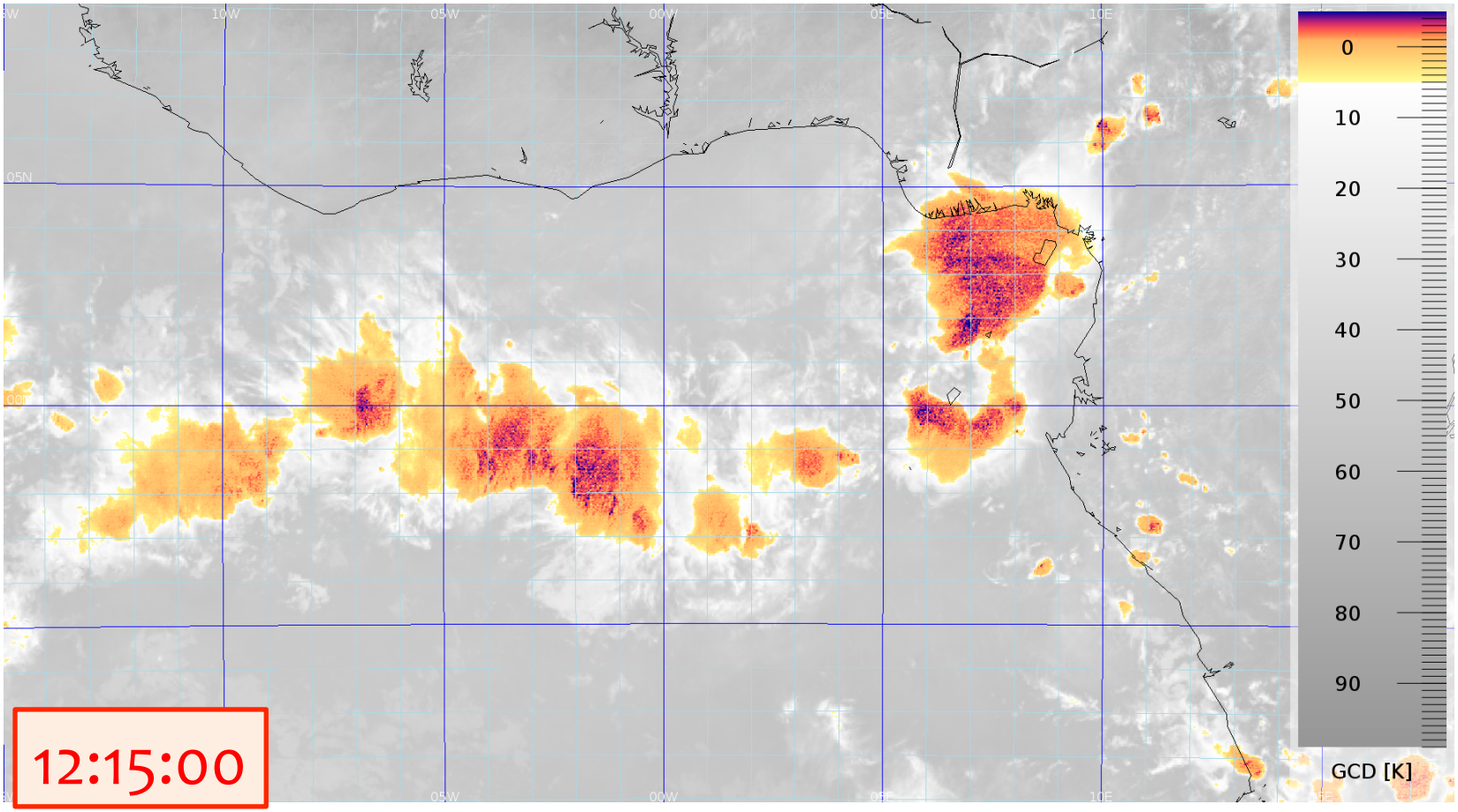
EXAMPLE 6: 24/03/2015

Successive TGFs



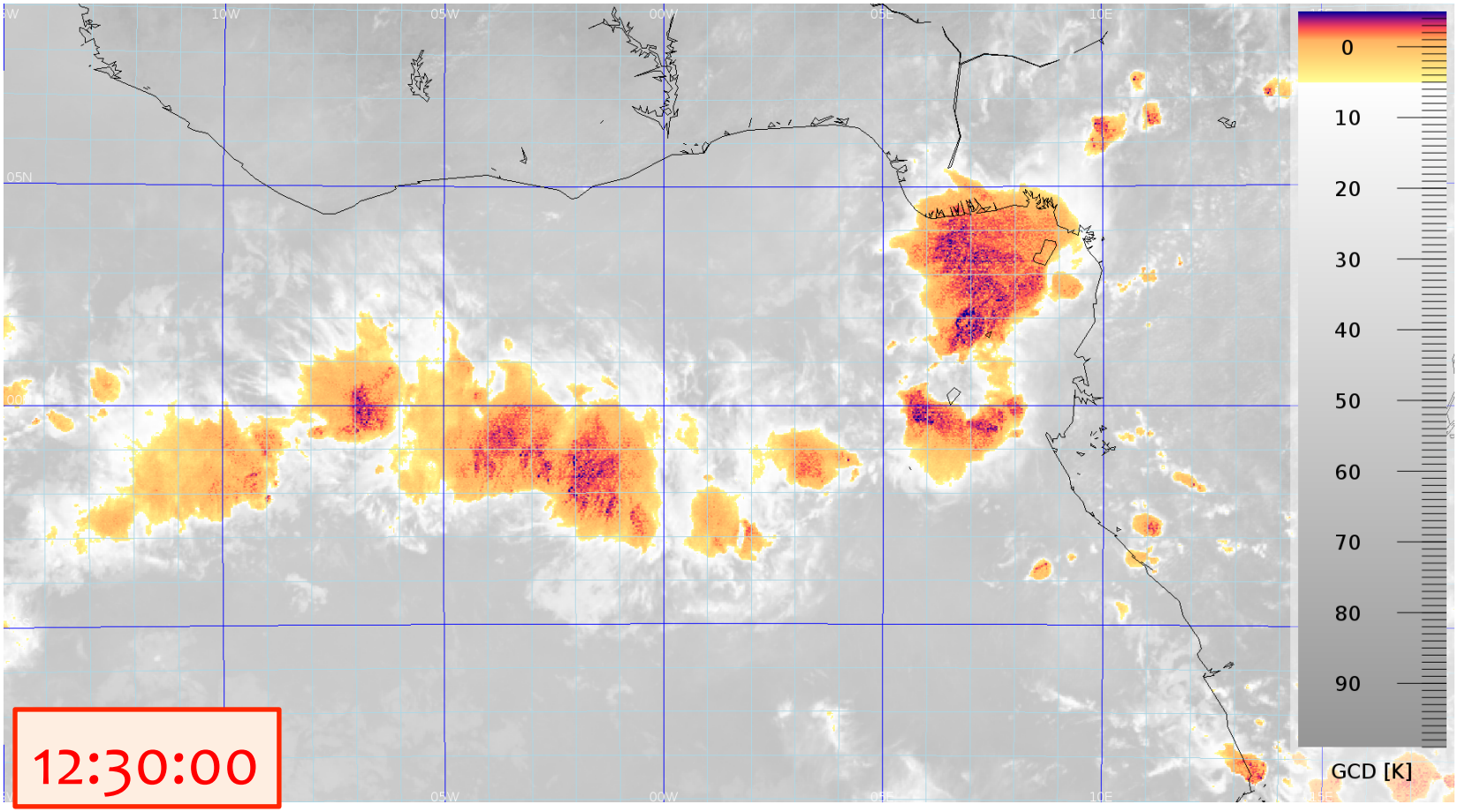
EXAMPLE 6: 24/03/2015

Successive TGFs



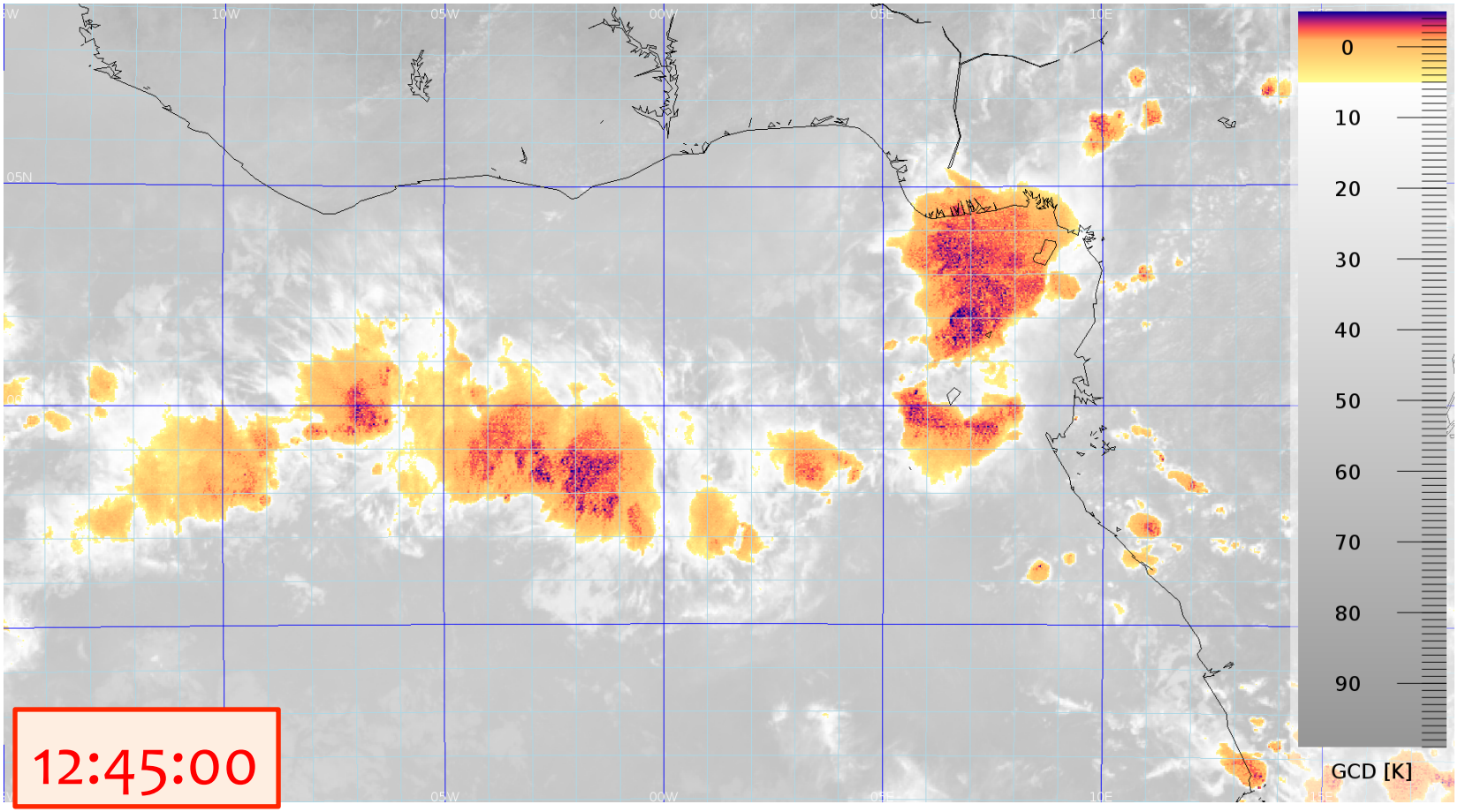
EXAMPLE 6: 24/03/2015

Successive TGFs



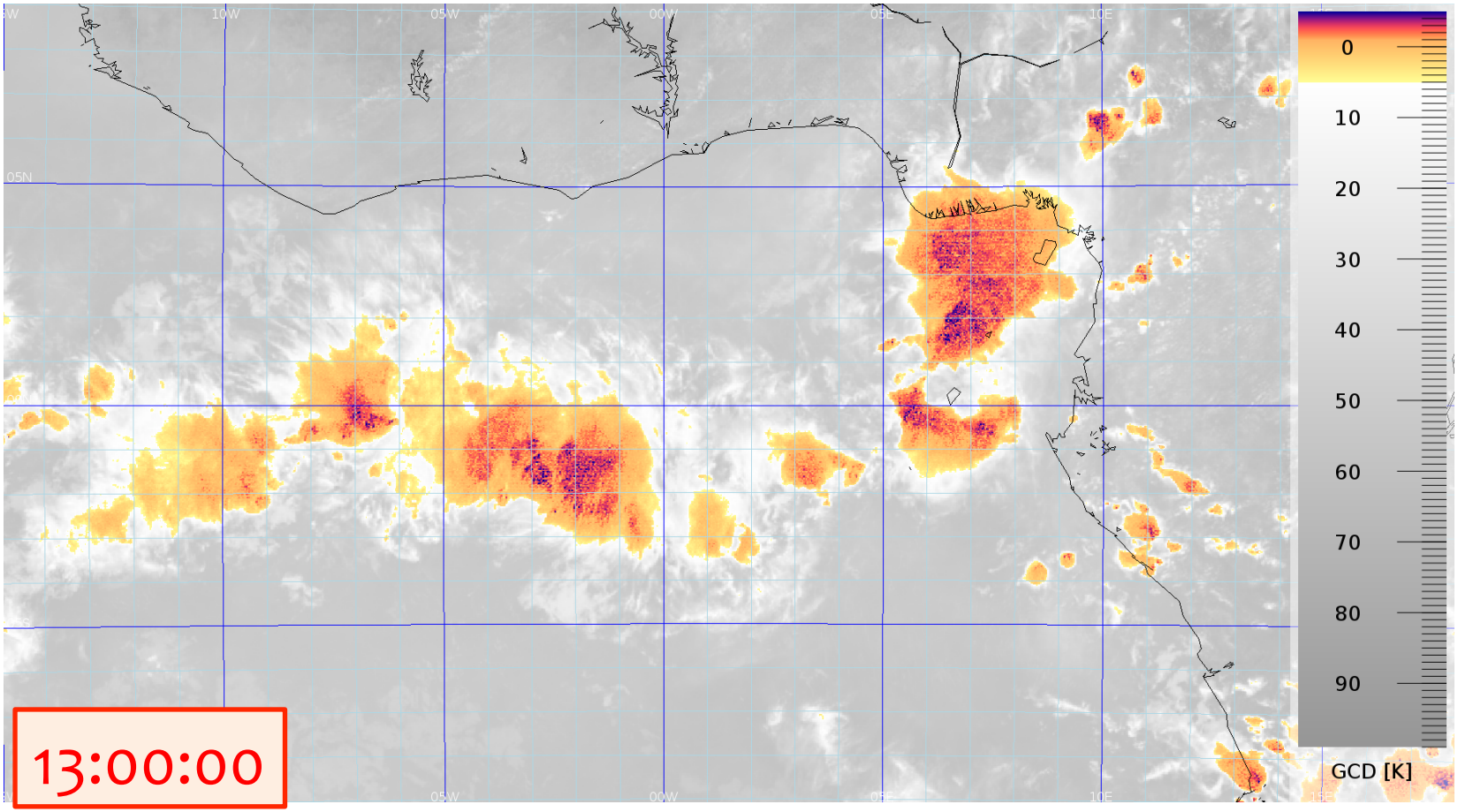
EXAMPLE 6: 24/03/2015

Successive TGFs



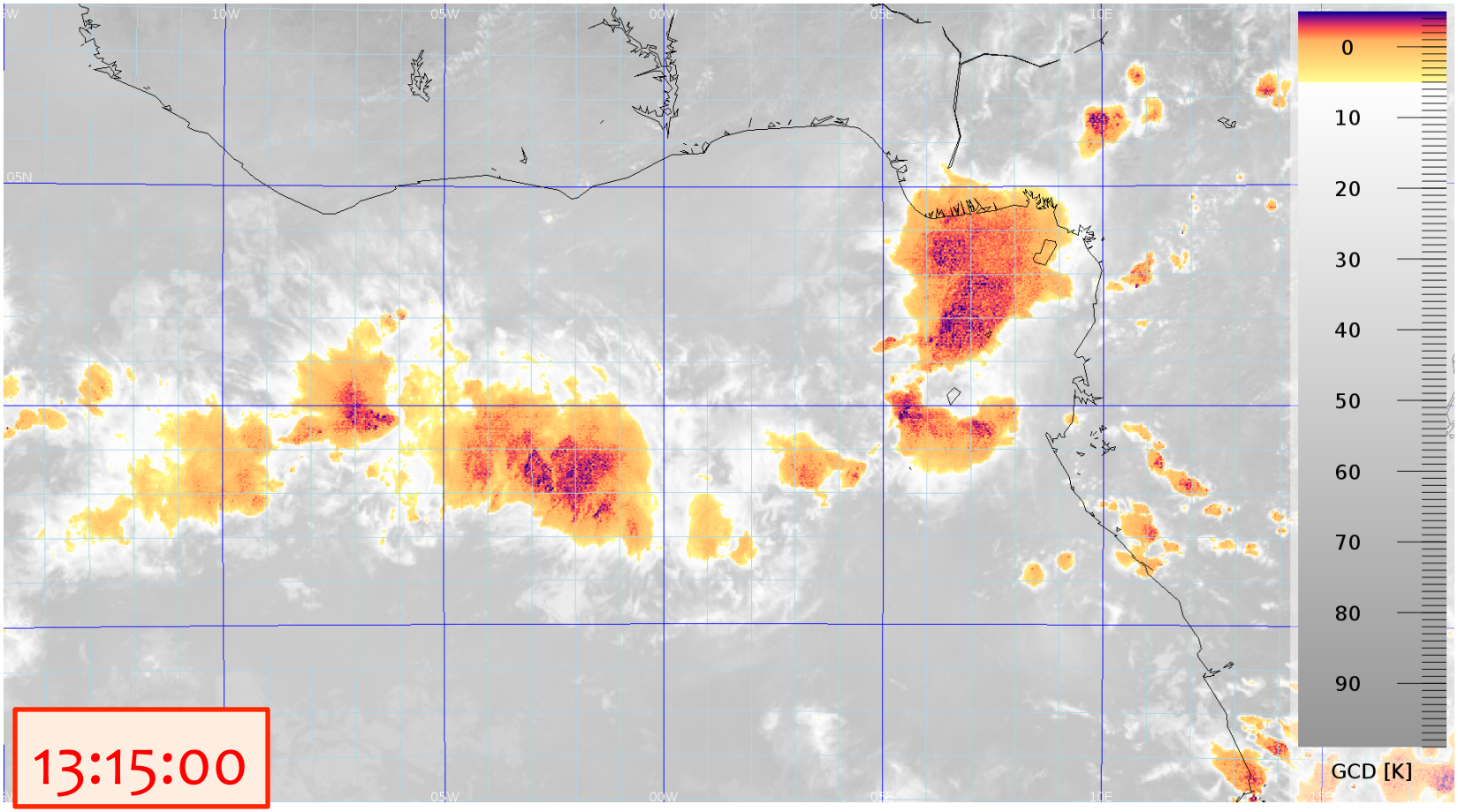
EXAMPLE 6: 24/03/2015

Successive TGFs



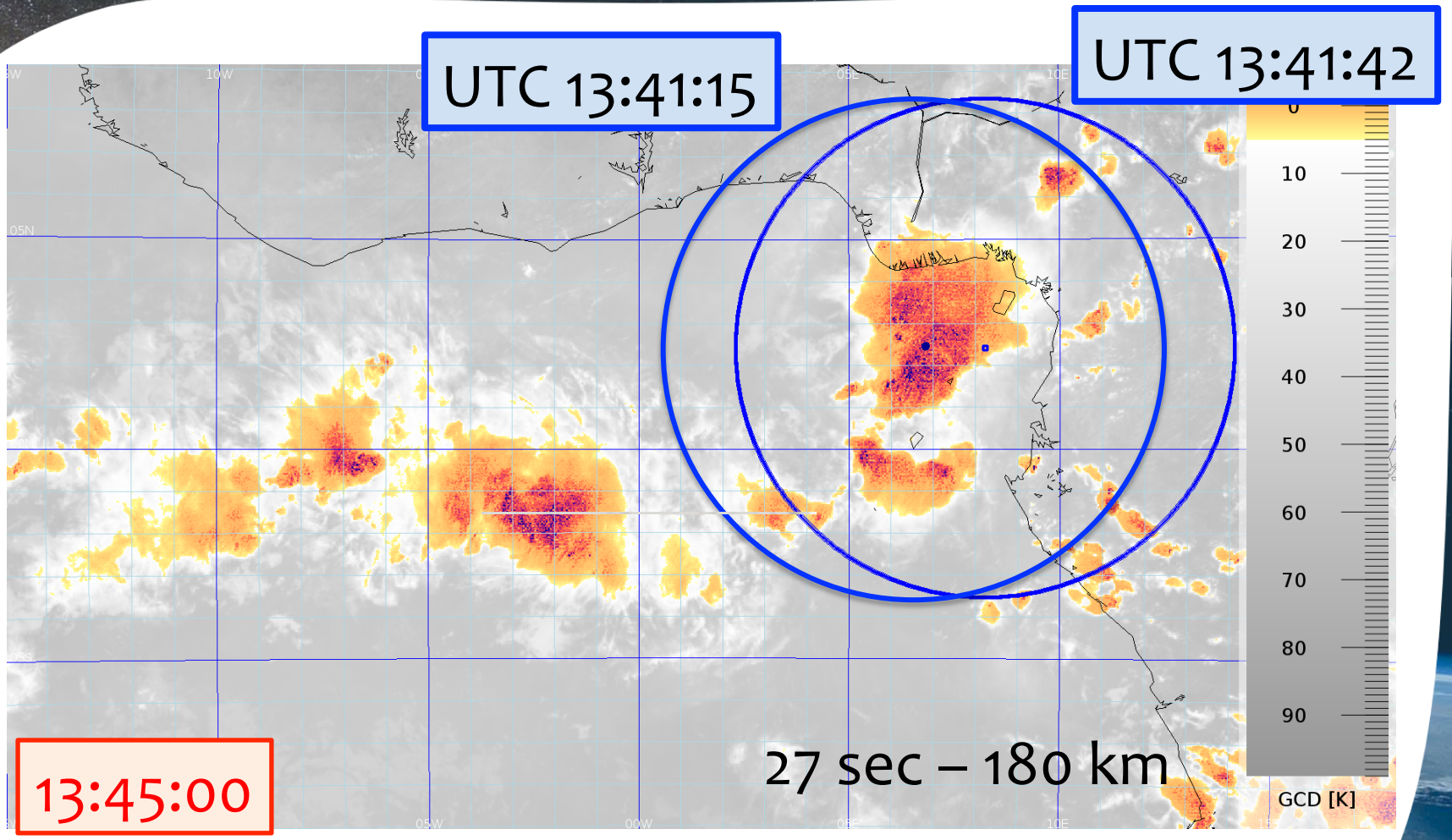
EXAMPLE 6: 24/03/2015

Successive TGFs



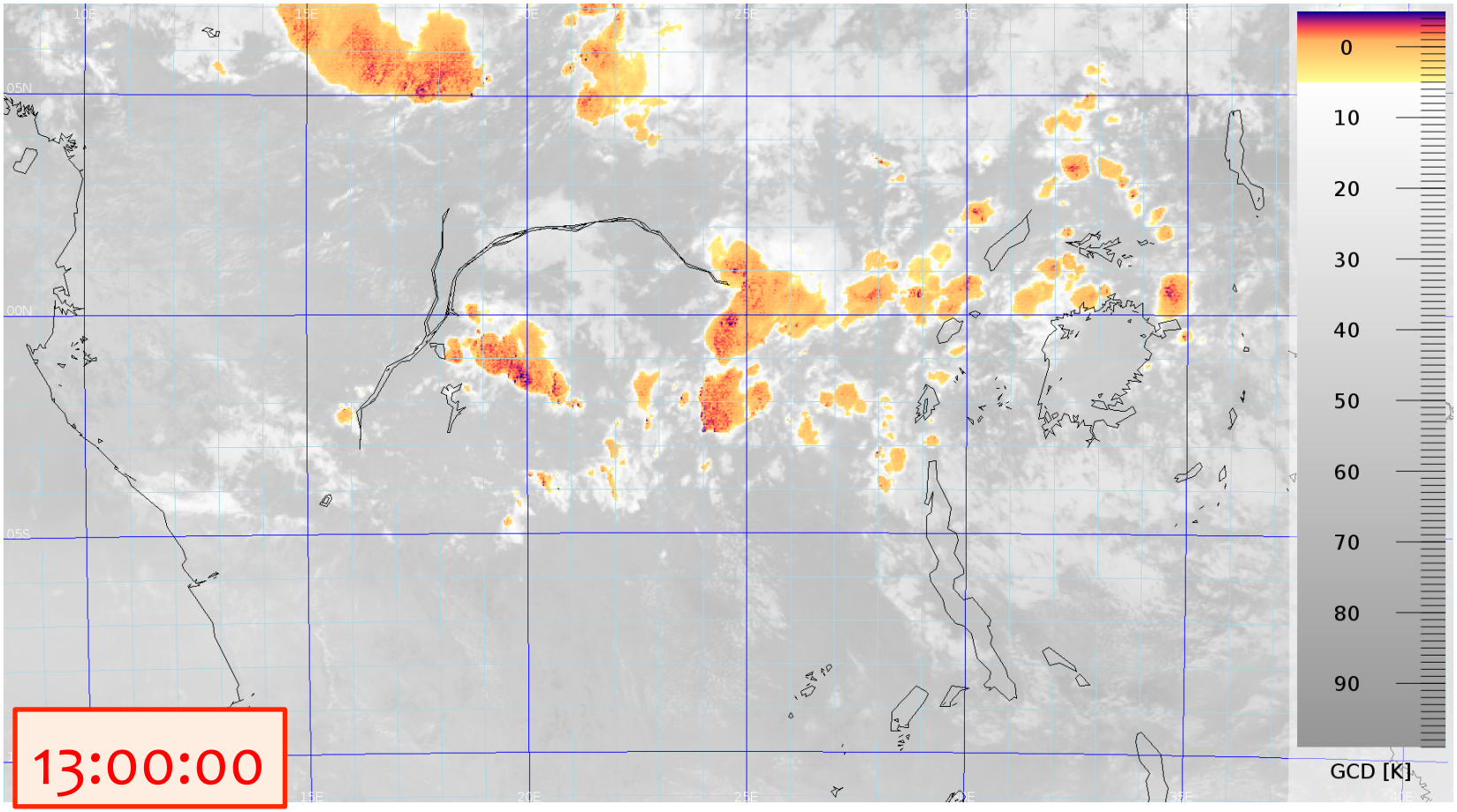
EXAMPLE 6: 24/03/2015

Successive TGFs



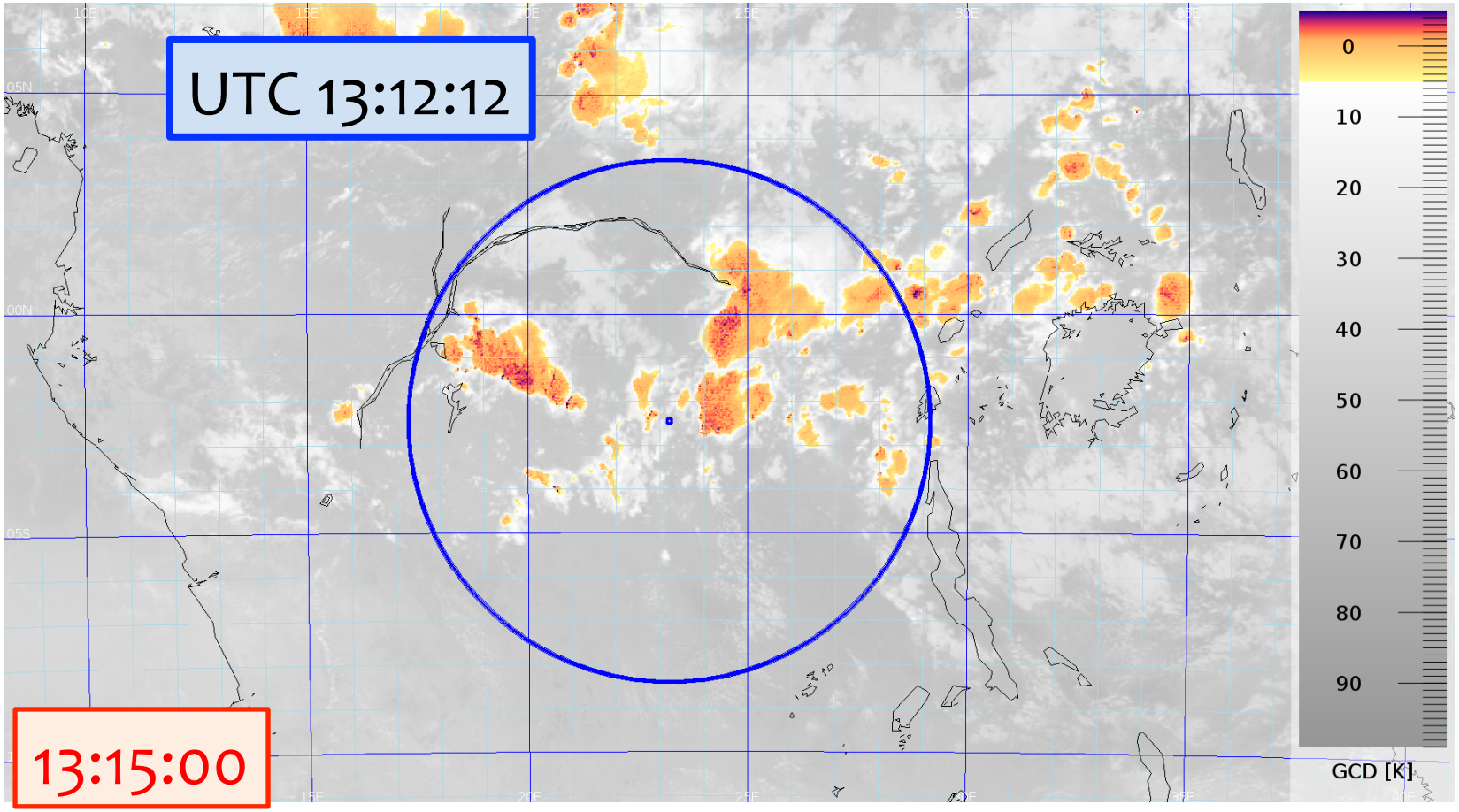
EXAMPLE 6: 24/03/2015

Successive TGFs



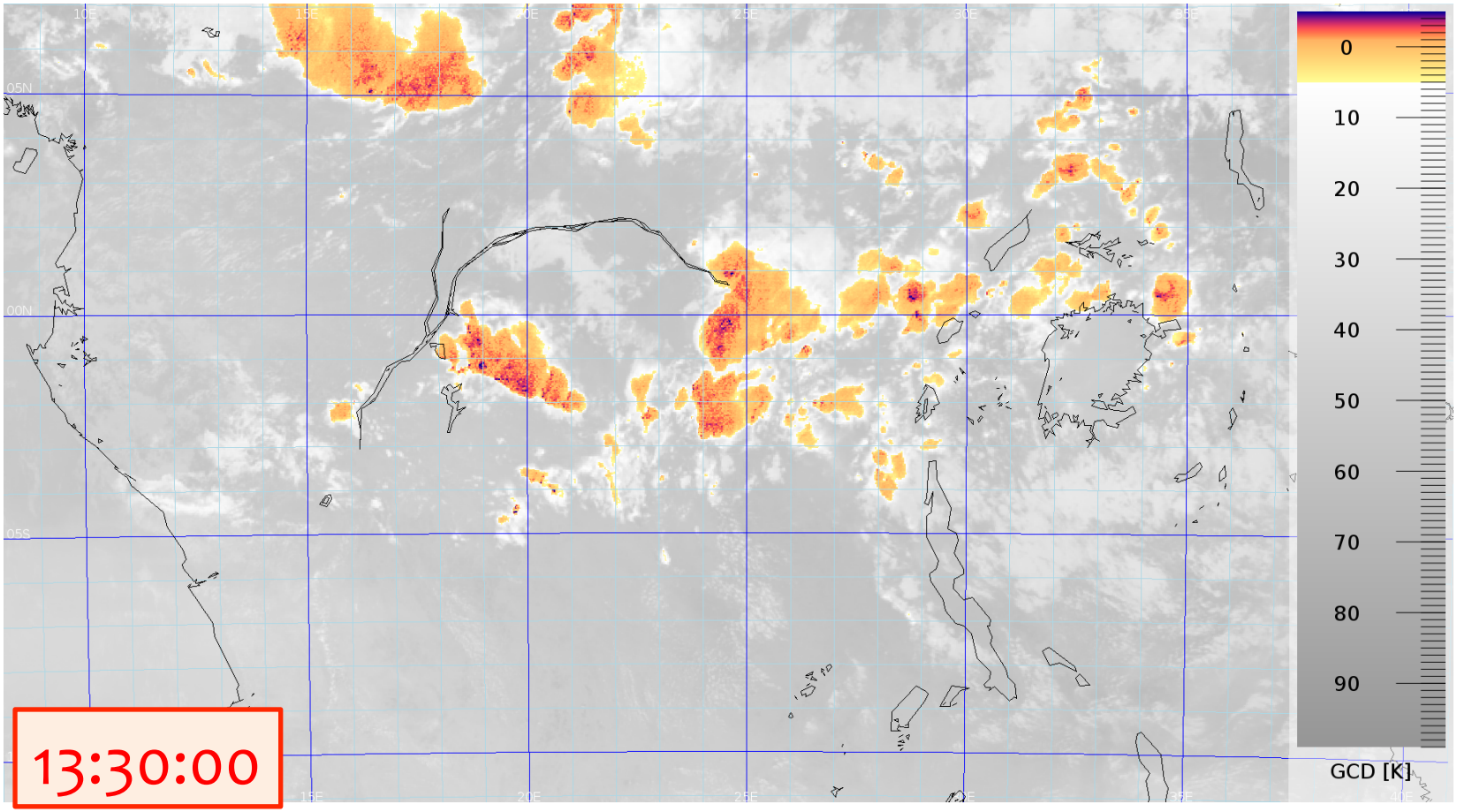
EXAMPLE 8: 25/05/2015

Successive TGFs



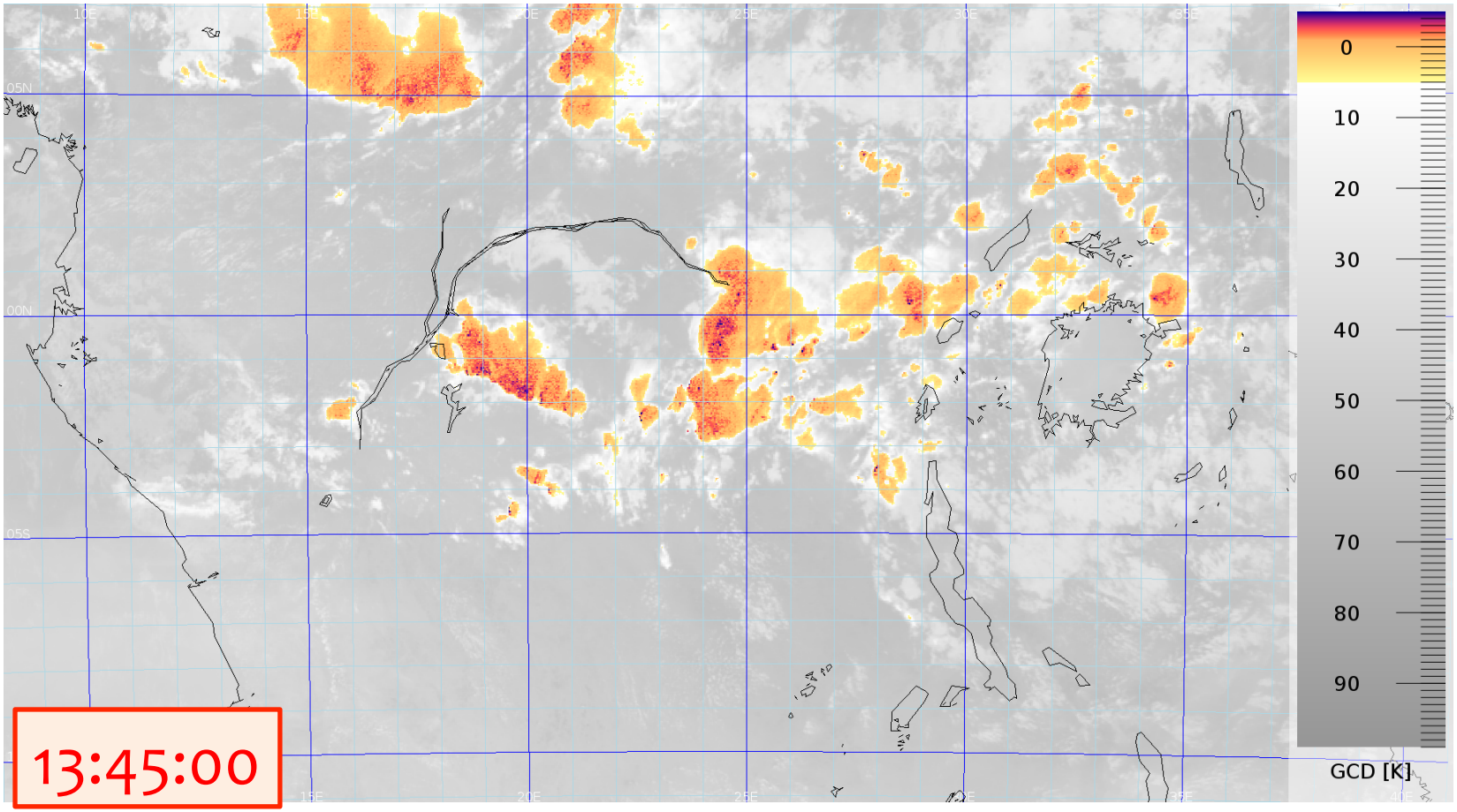
EXAMPLE 8: 25/05/2015

Successive TGFs



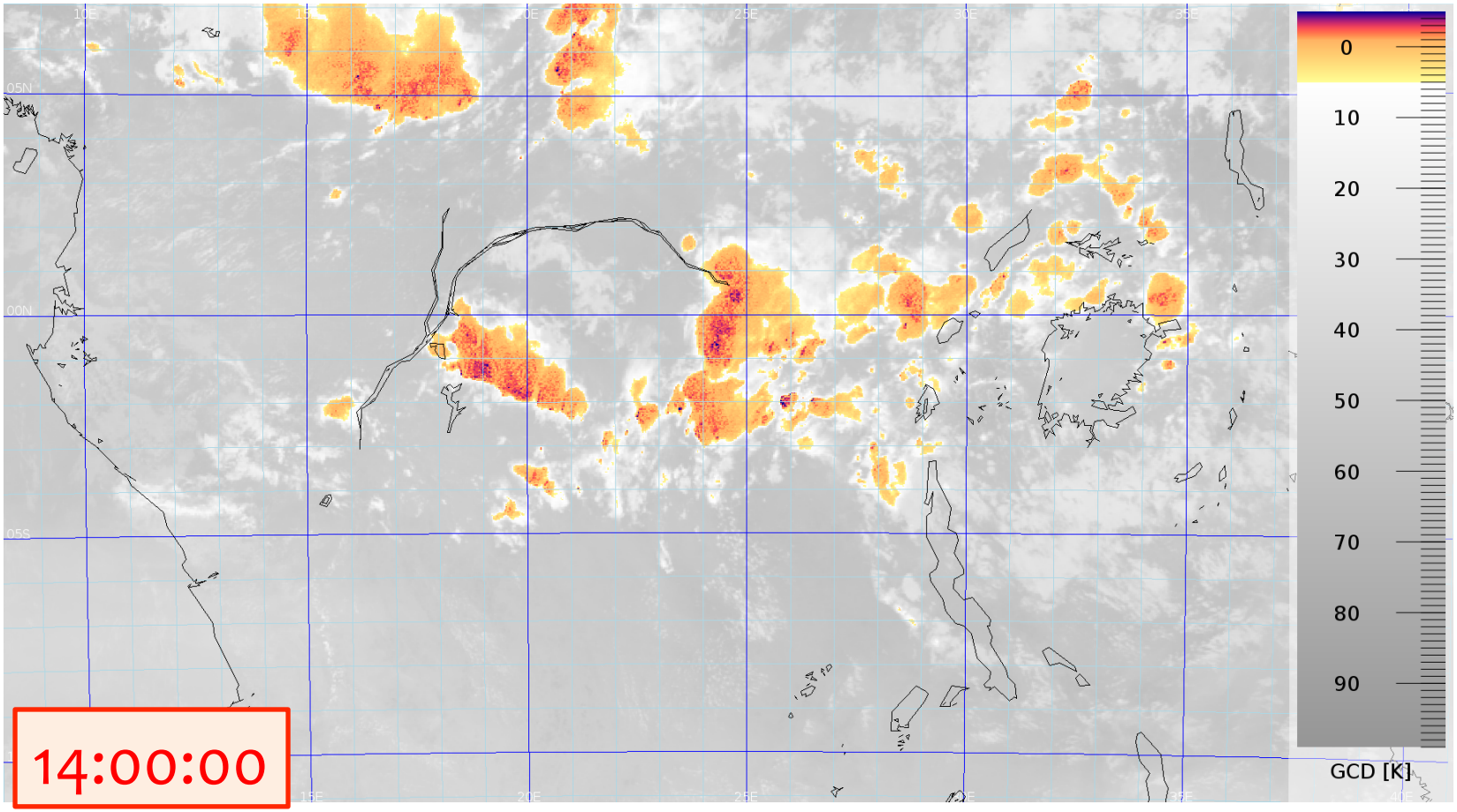
EXAMPLE 8: 25/05/2015

Successive TGFs



EXAMPLE 8: 25/05/2015

Successive TGFs



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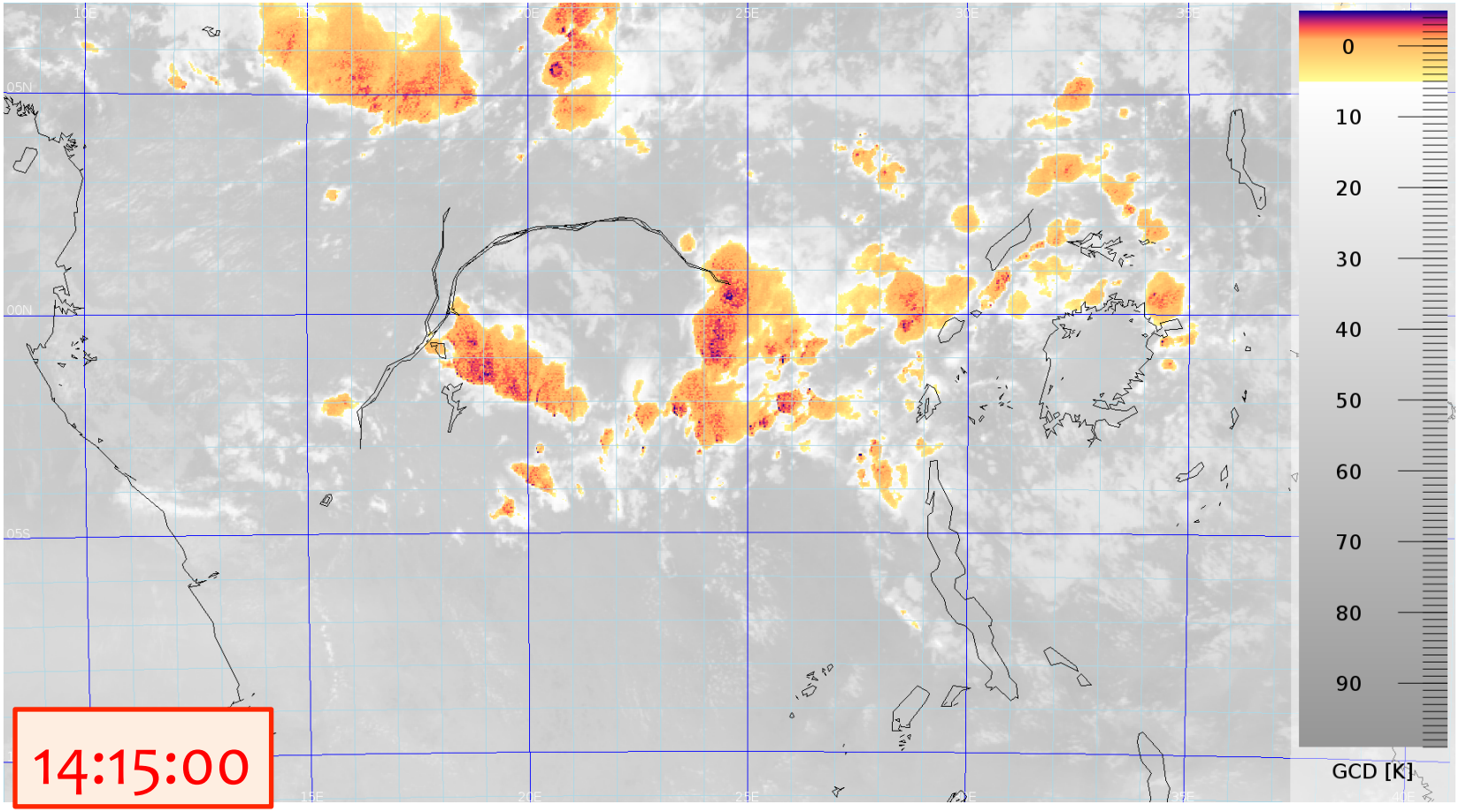
Successive TGFs



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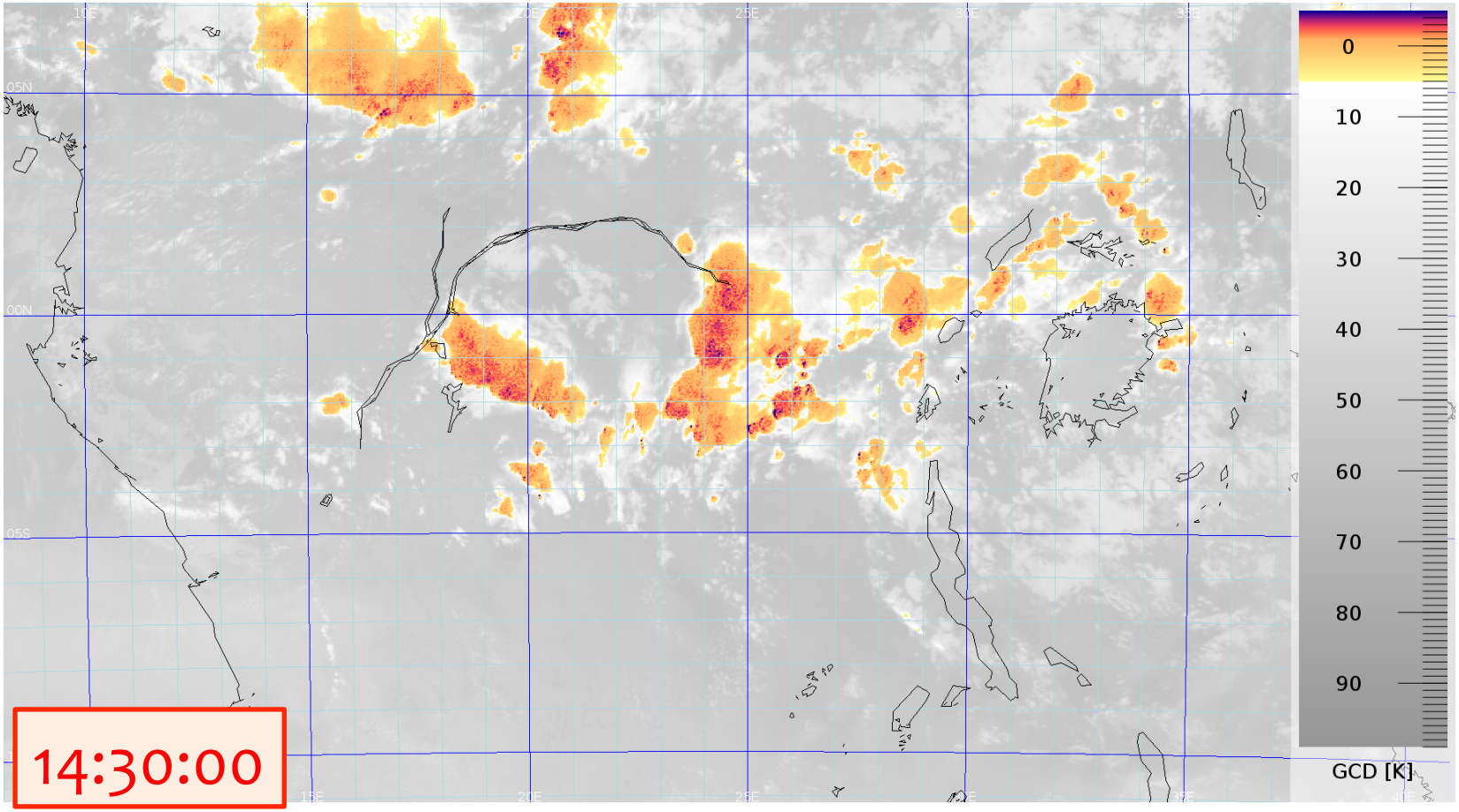
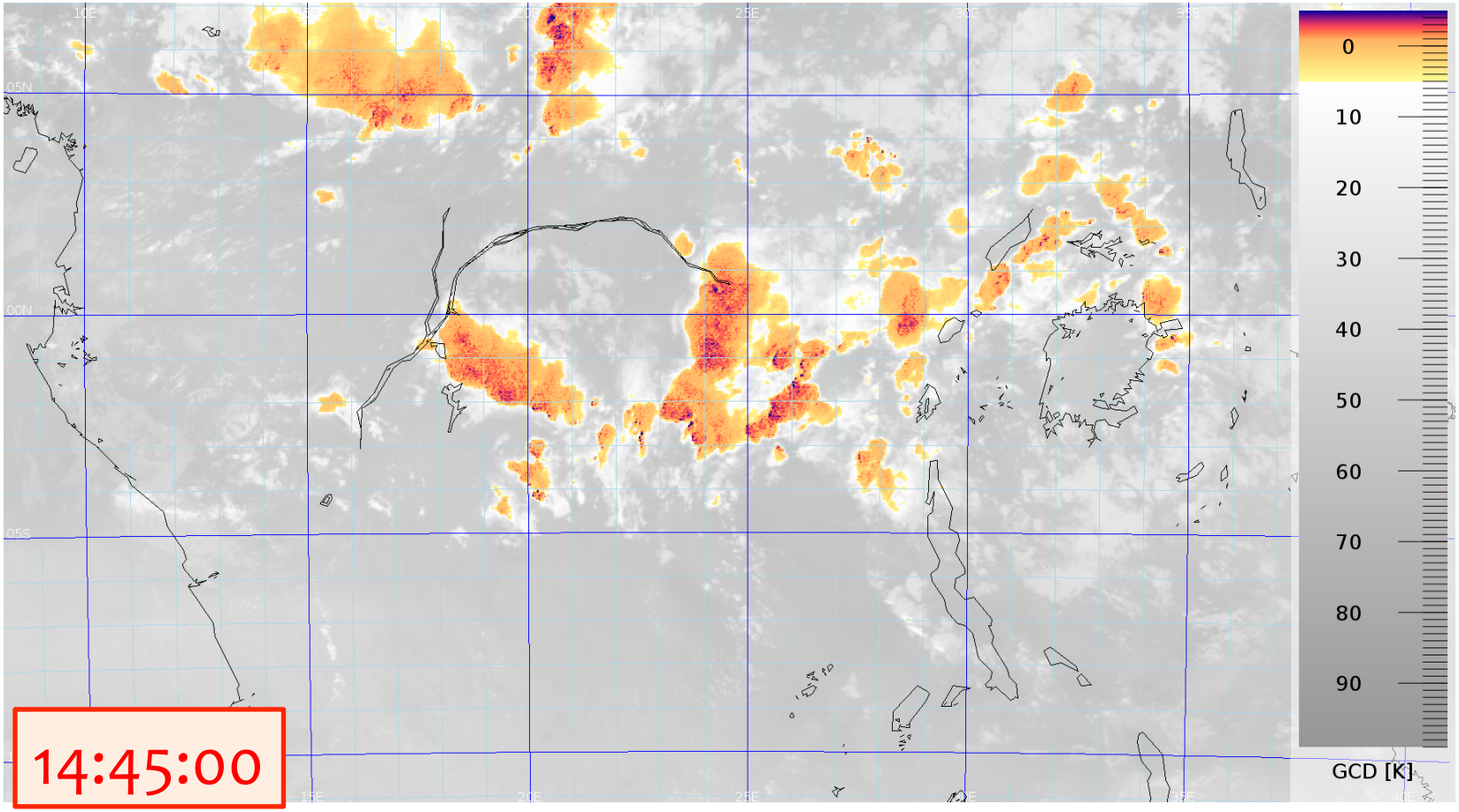
Successive TGFs



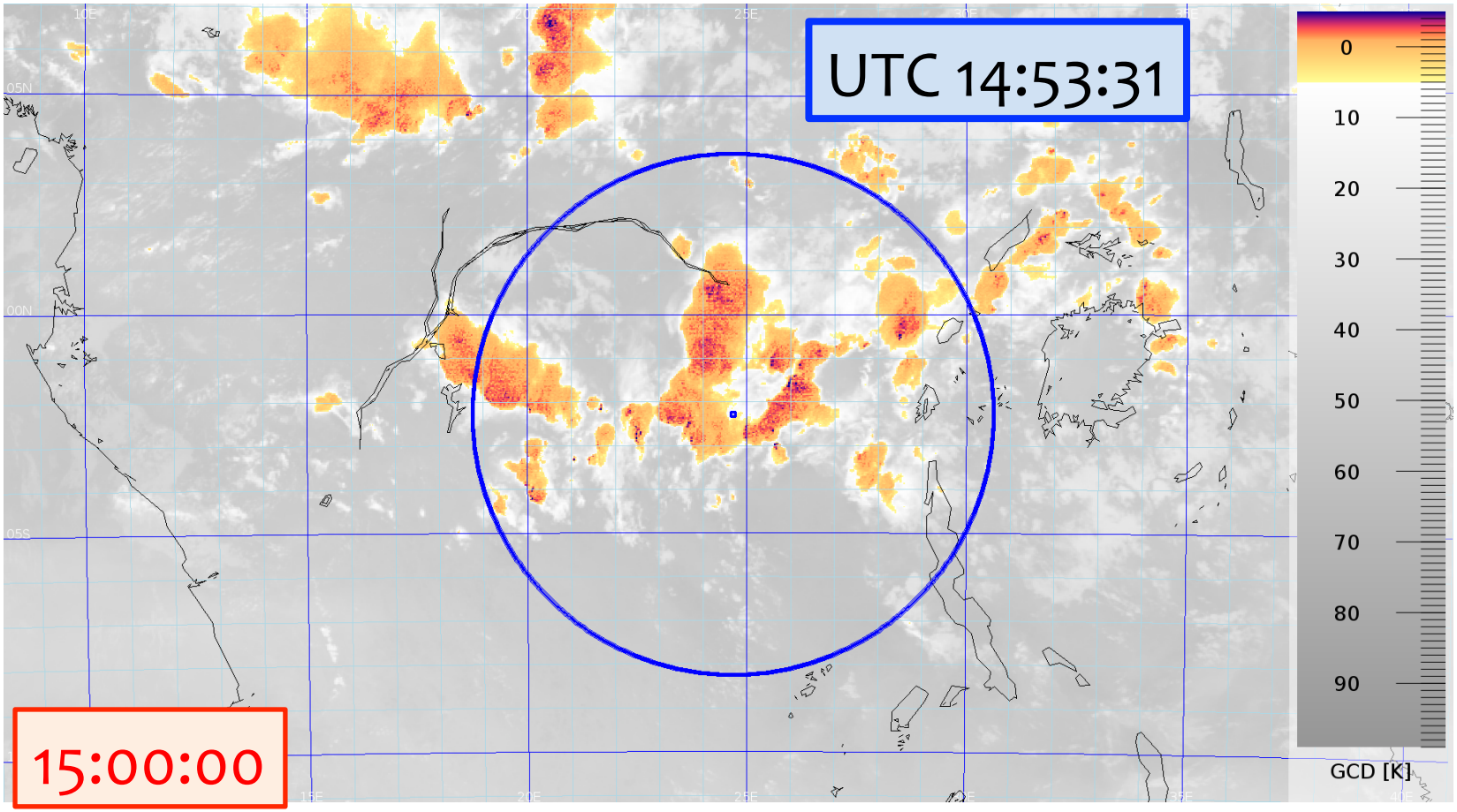
EXAMPLE 8: 25/05/2015

Successive TGFs



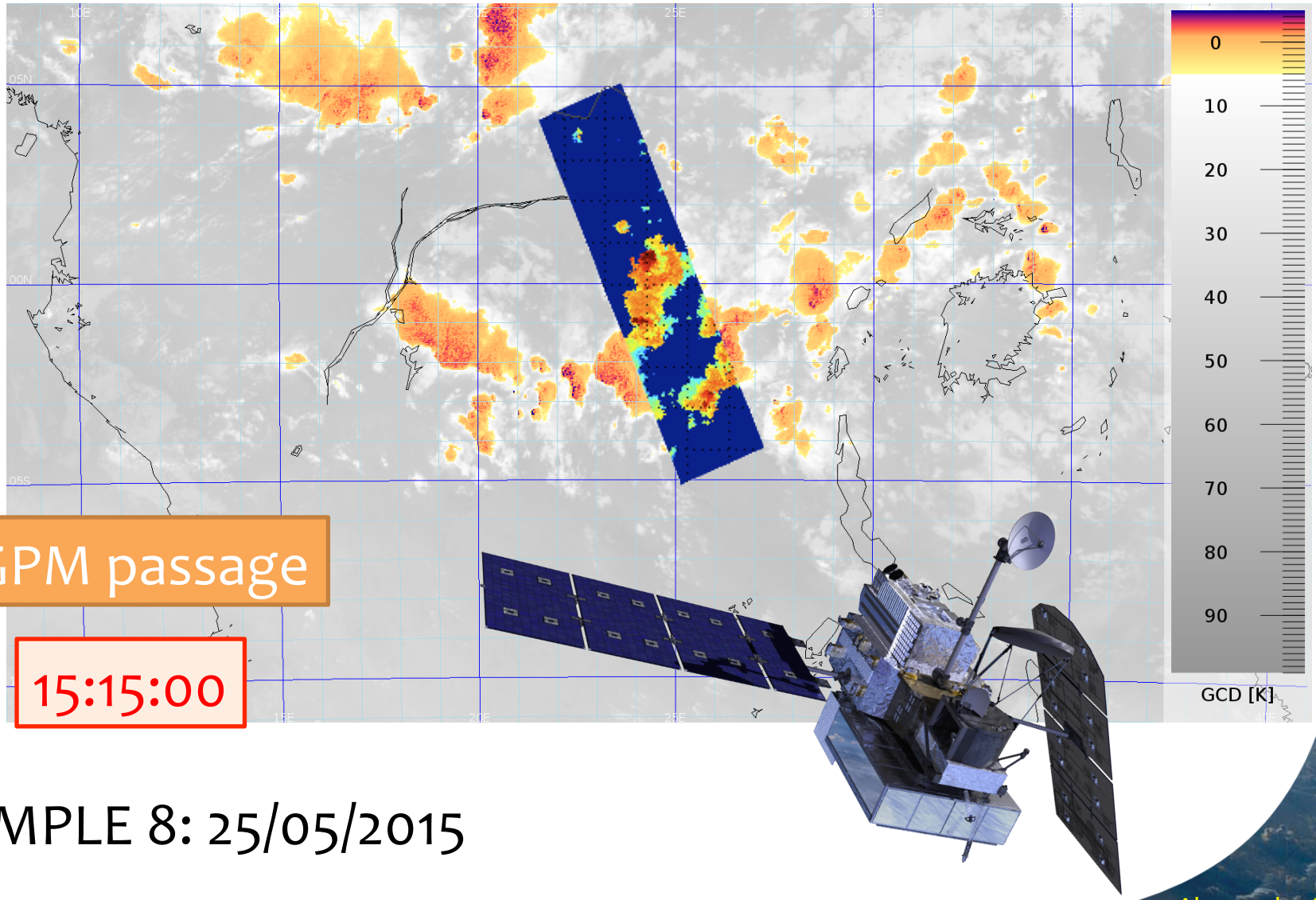
EXAMPLE 8: 25/05/2015

Successive TGFs



EXAMPLE 8: 25/05/2015

Successive TGFs

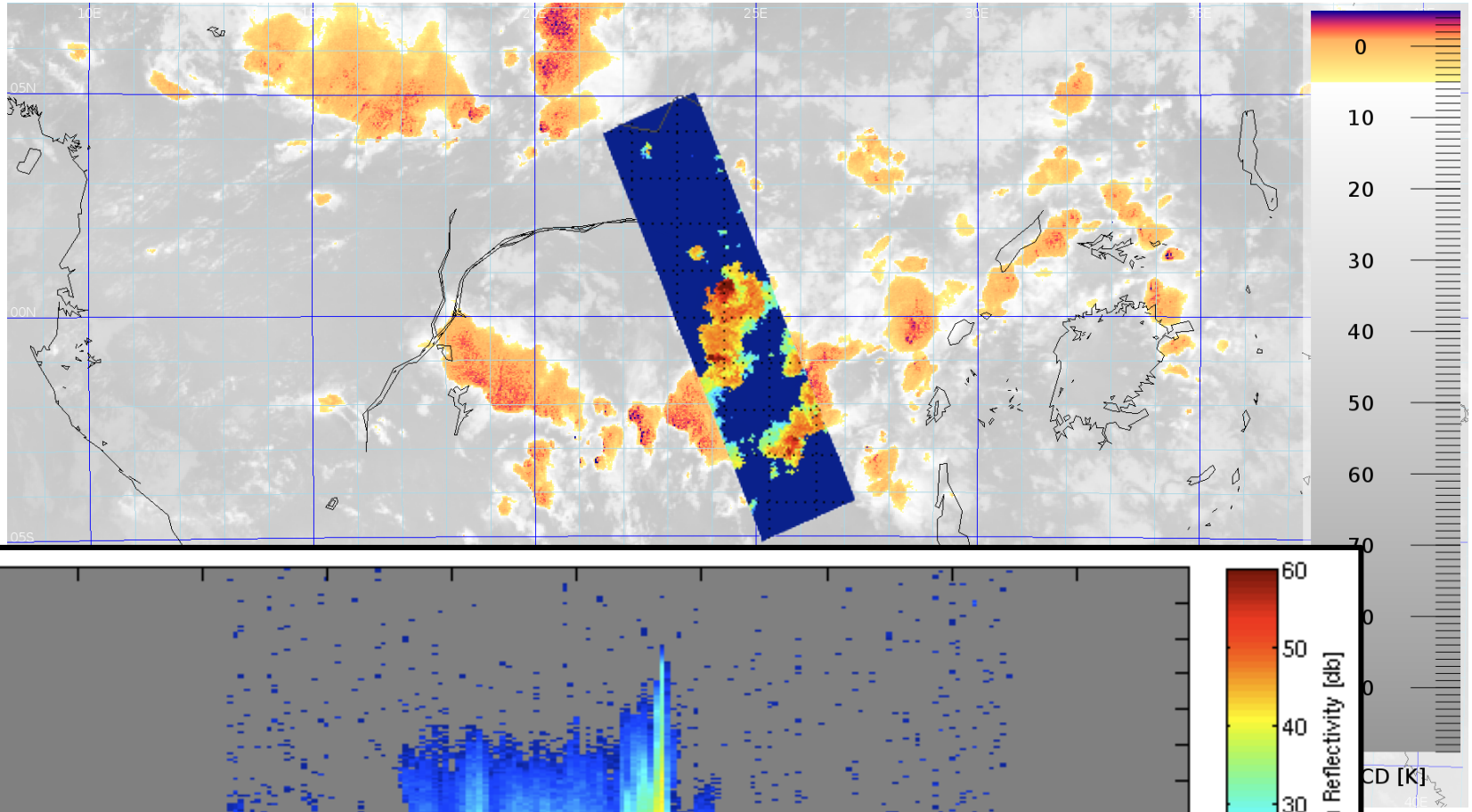


GPM passage

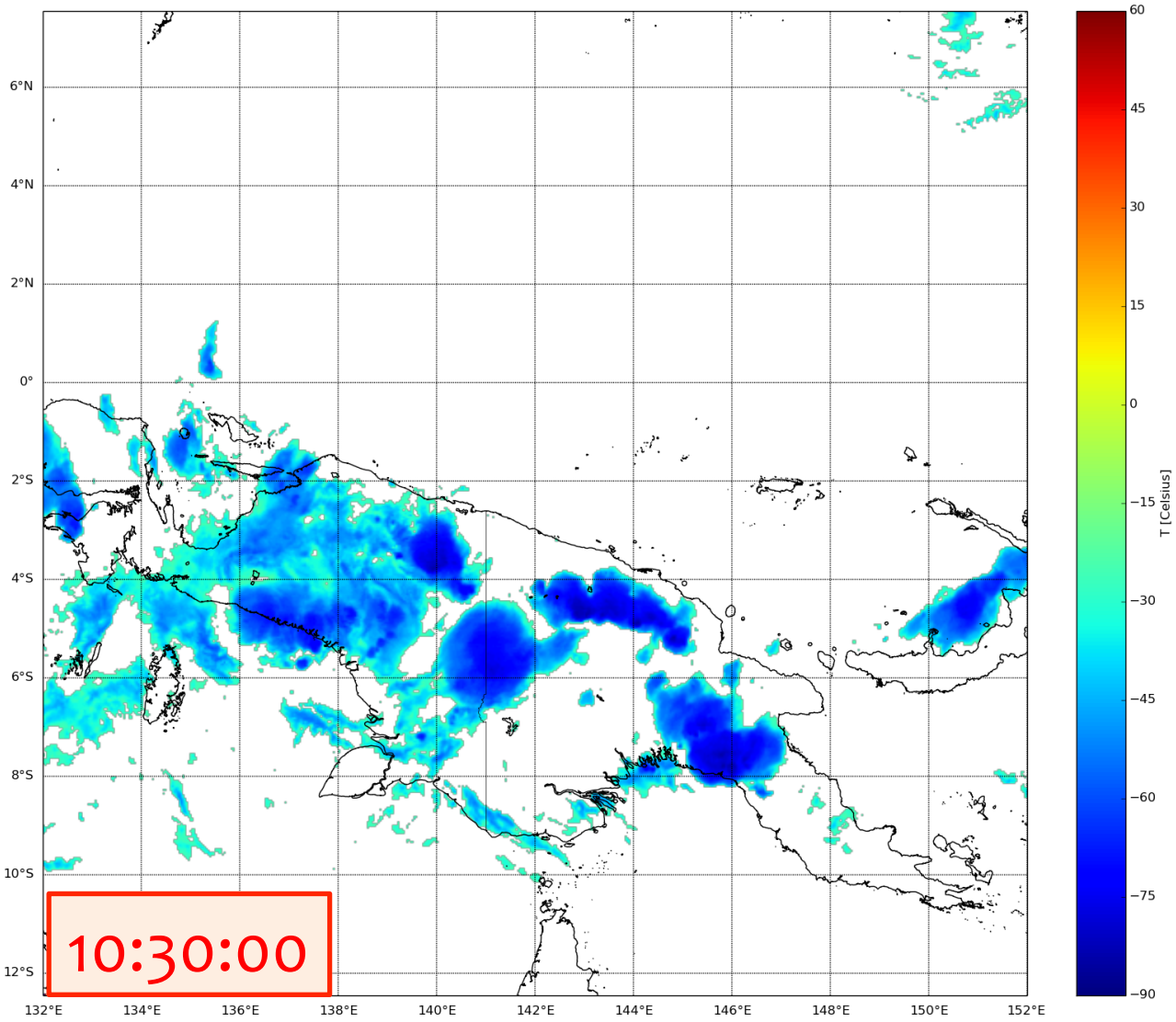
15:15:00

EXAMPLE 8: 25/05/2015

Successive TGFs

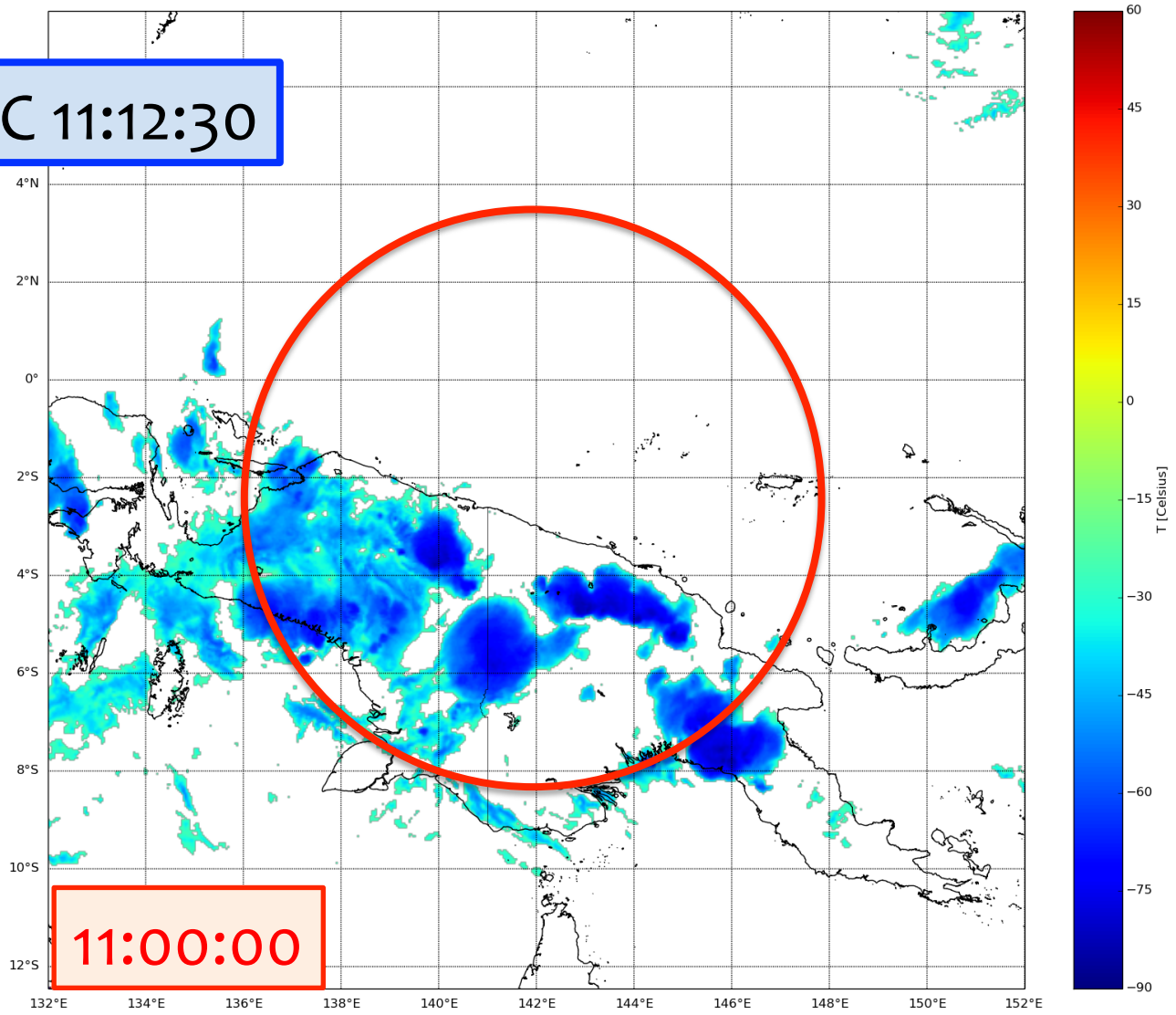


Successive TGFs



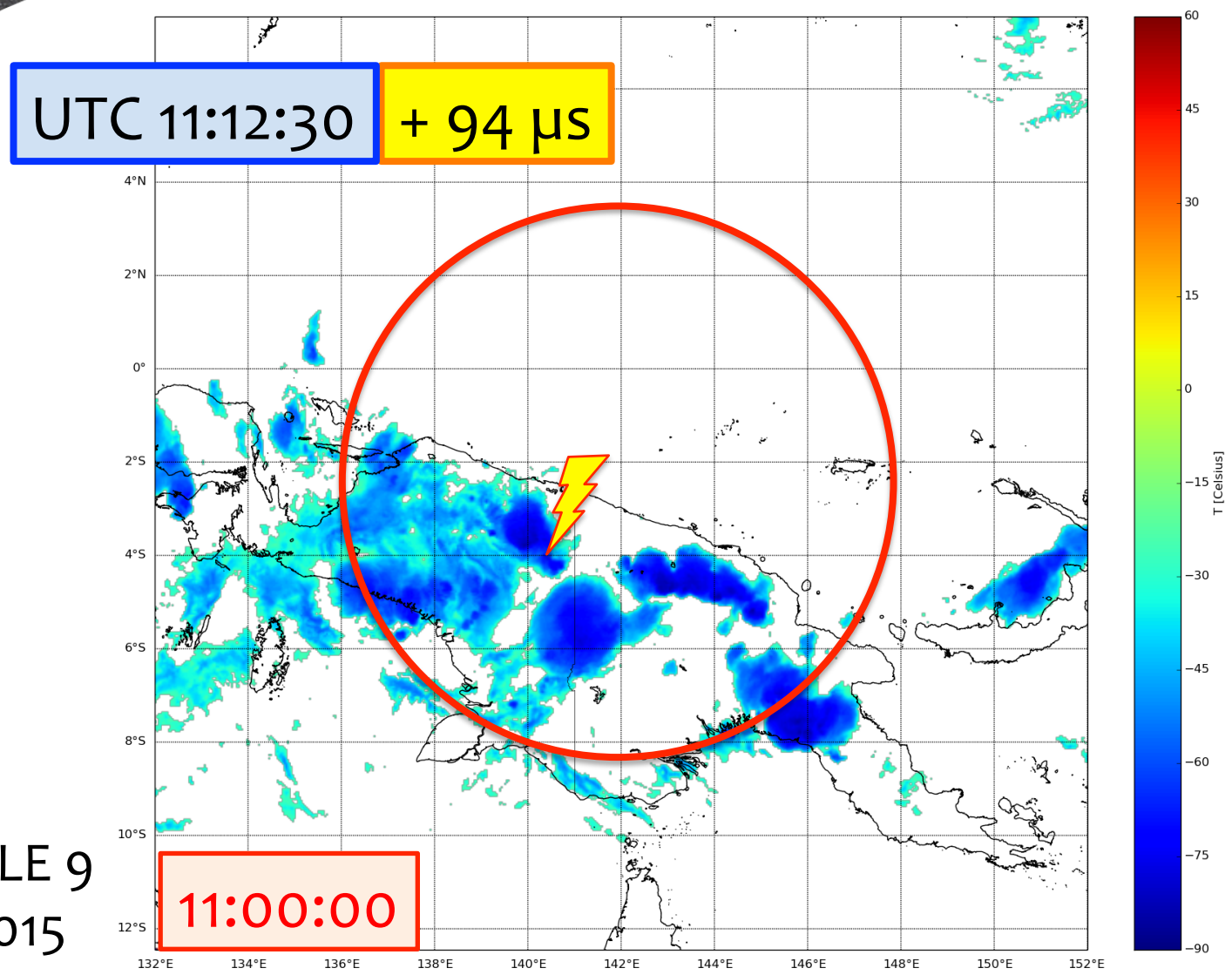
EXAMPLE 9
25/05/2015

Successive TGFs



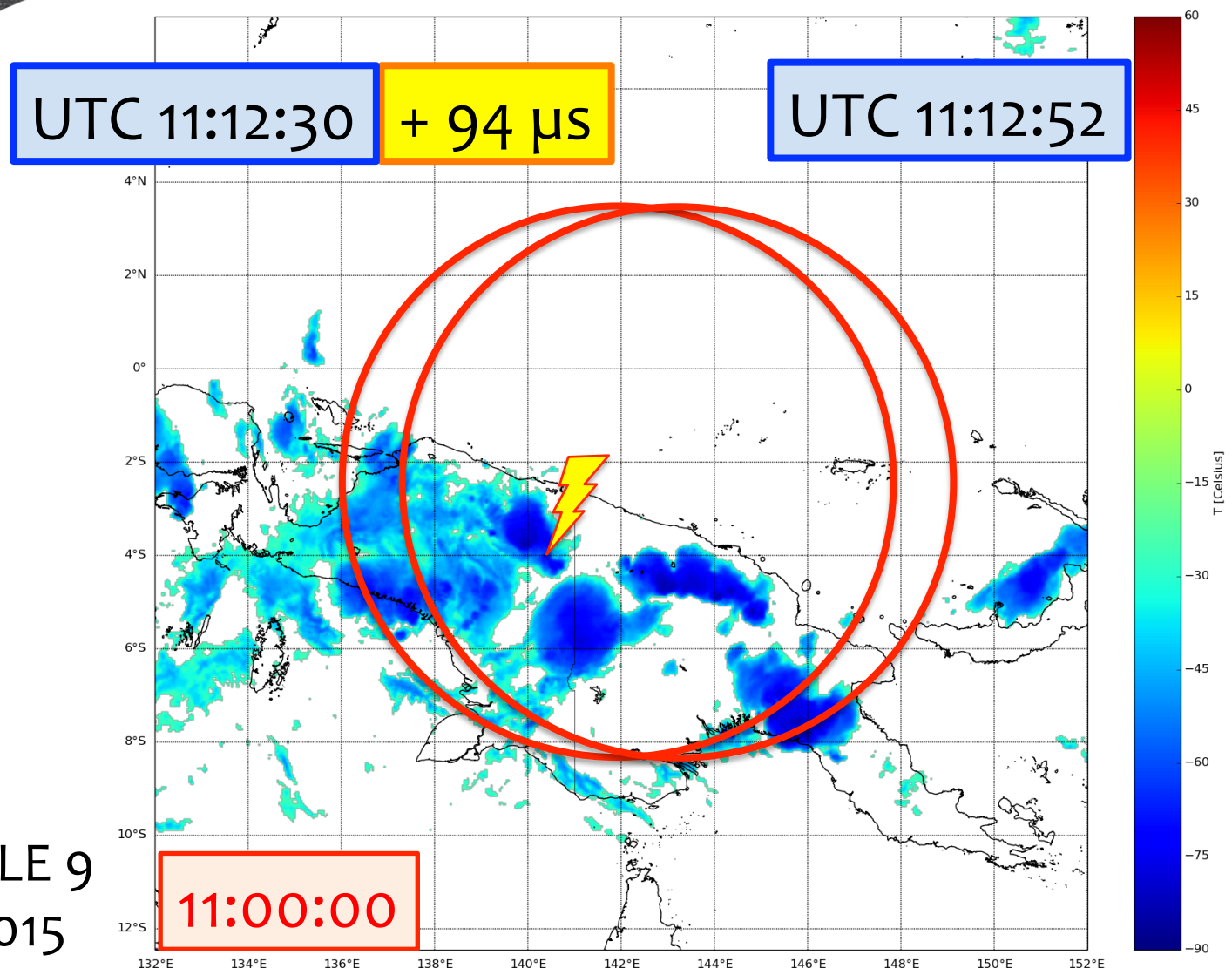
EXAMPLE 9
25/05/2015

Successive TGFs



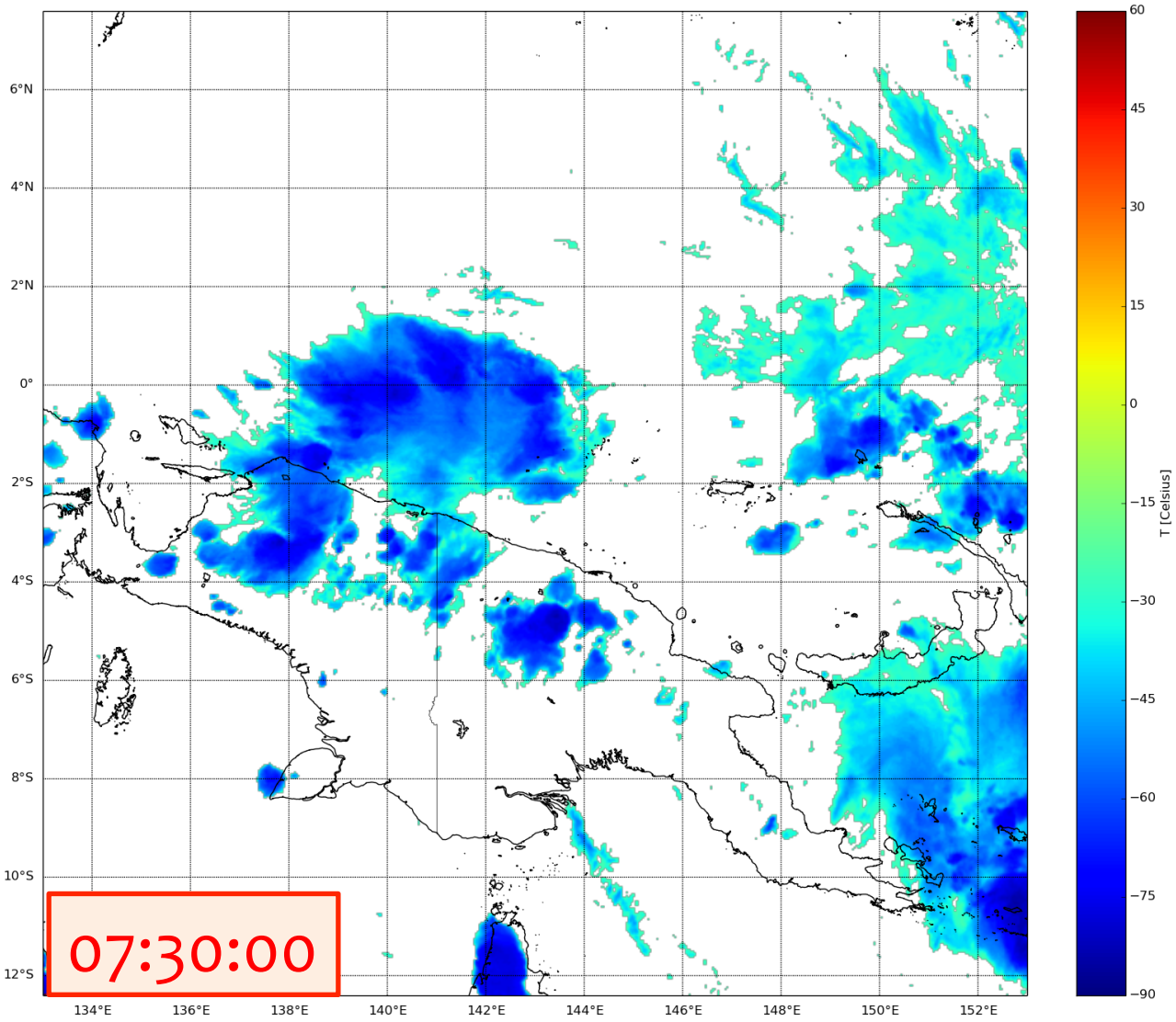
EXAMPLE 9
25/05/2015

Successive TGFs



EXAMPLE 9
25/05/2015

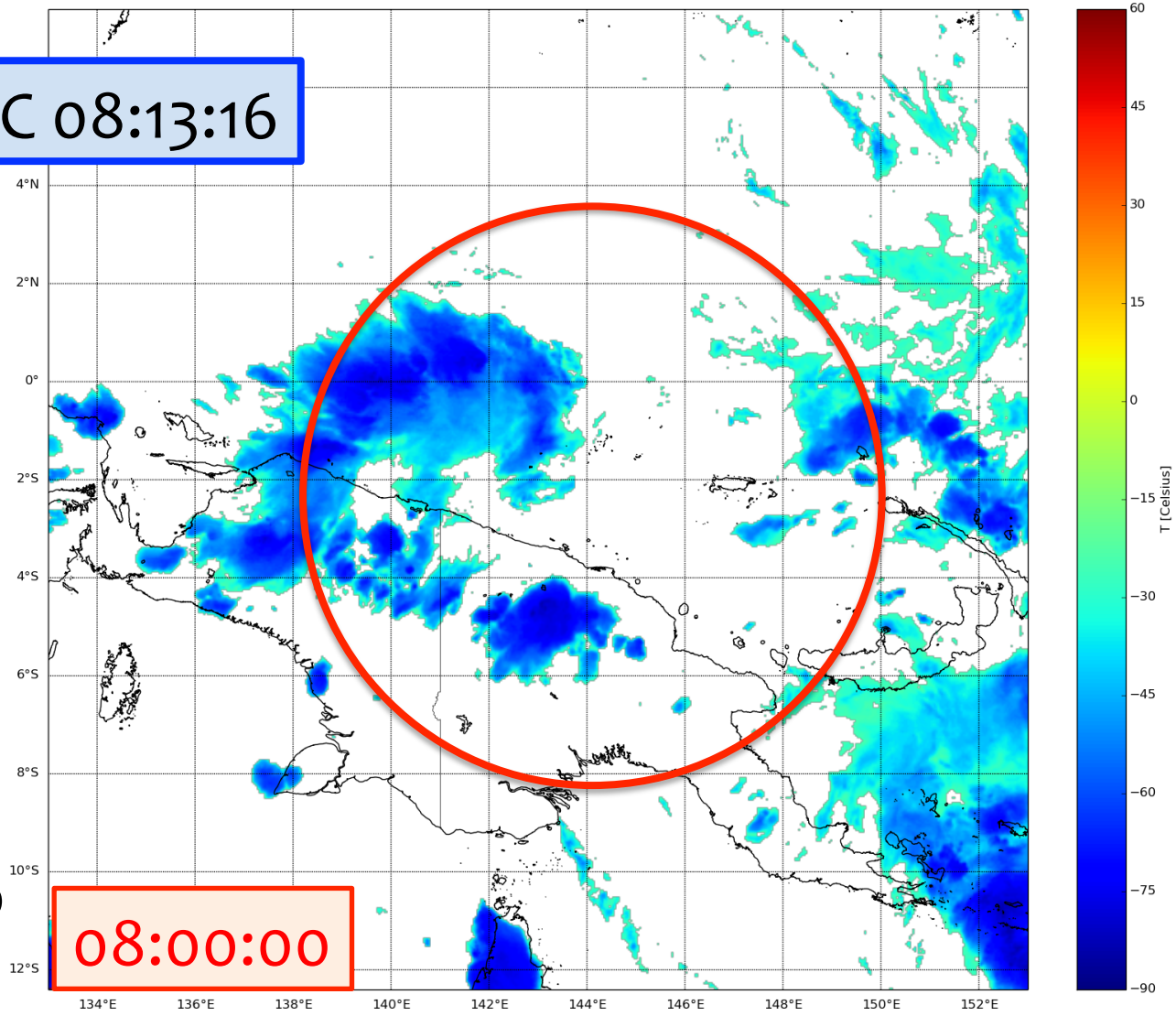
Successive TGFs



EXAMPLE 10
07/04/2015

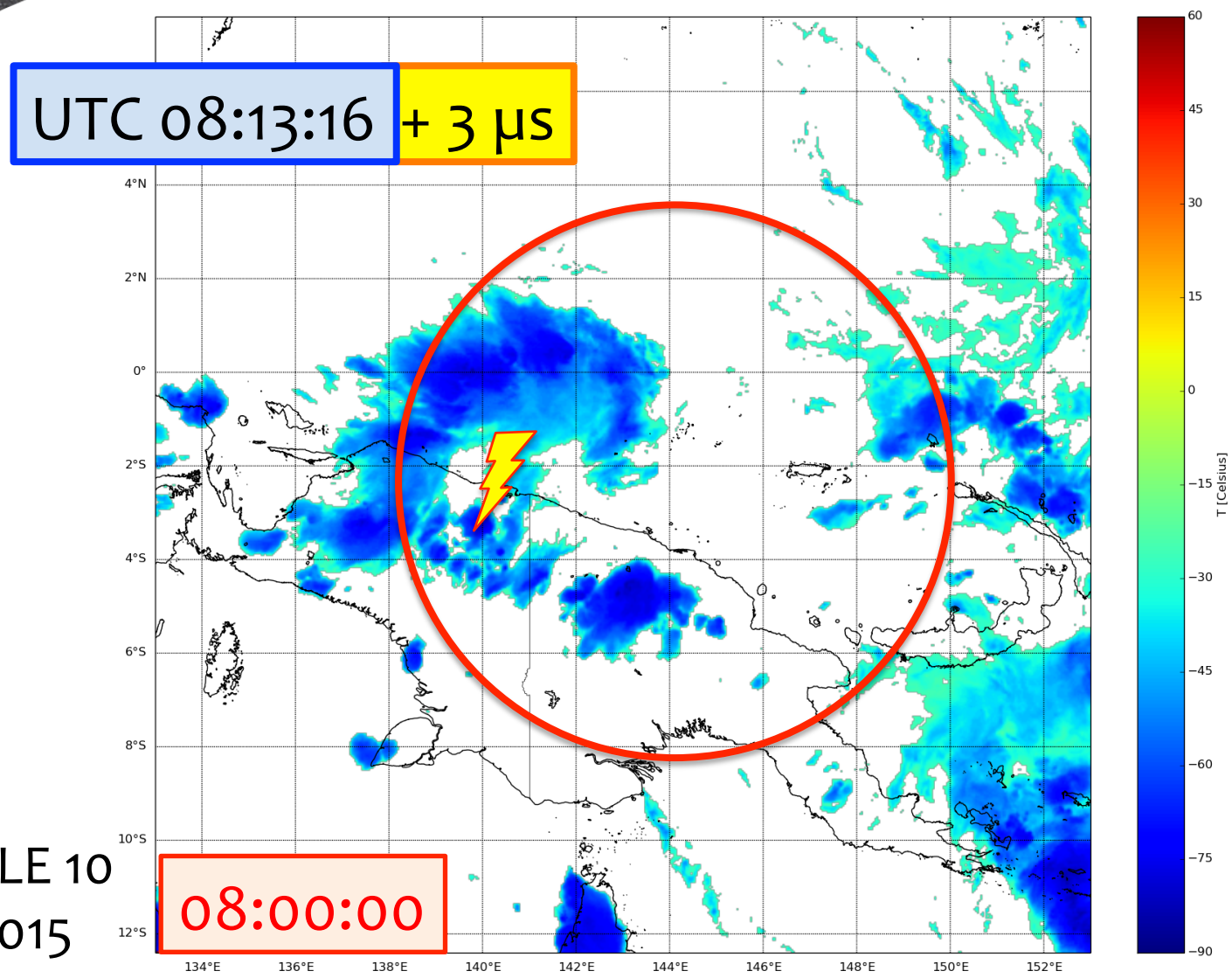
Successive TGFs

Successive TGFs



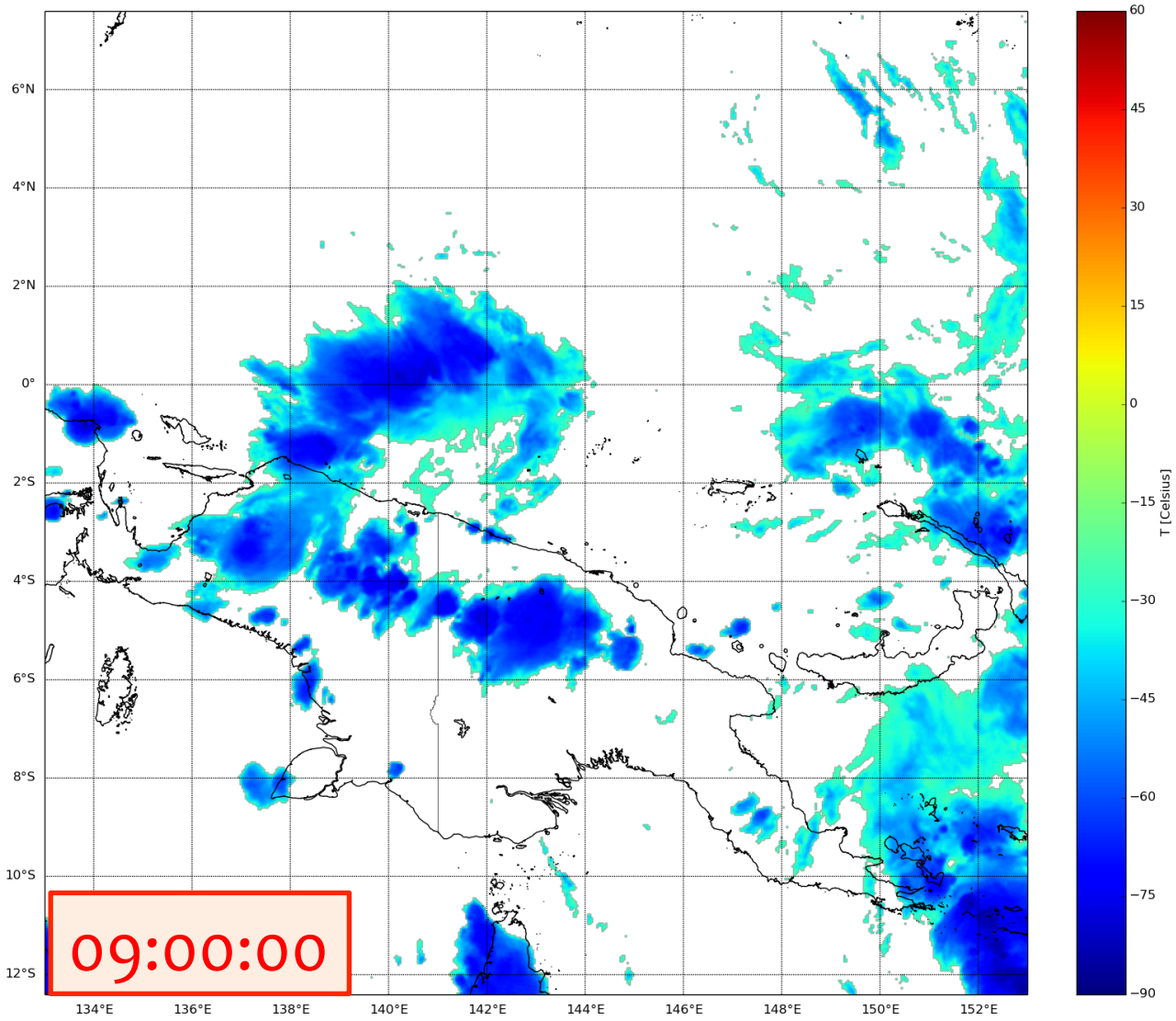
EXAMPLE 10
07/04/2015

Successive TGFs



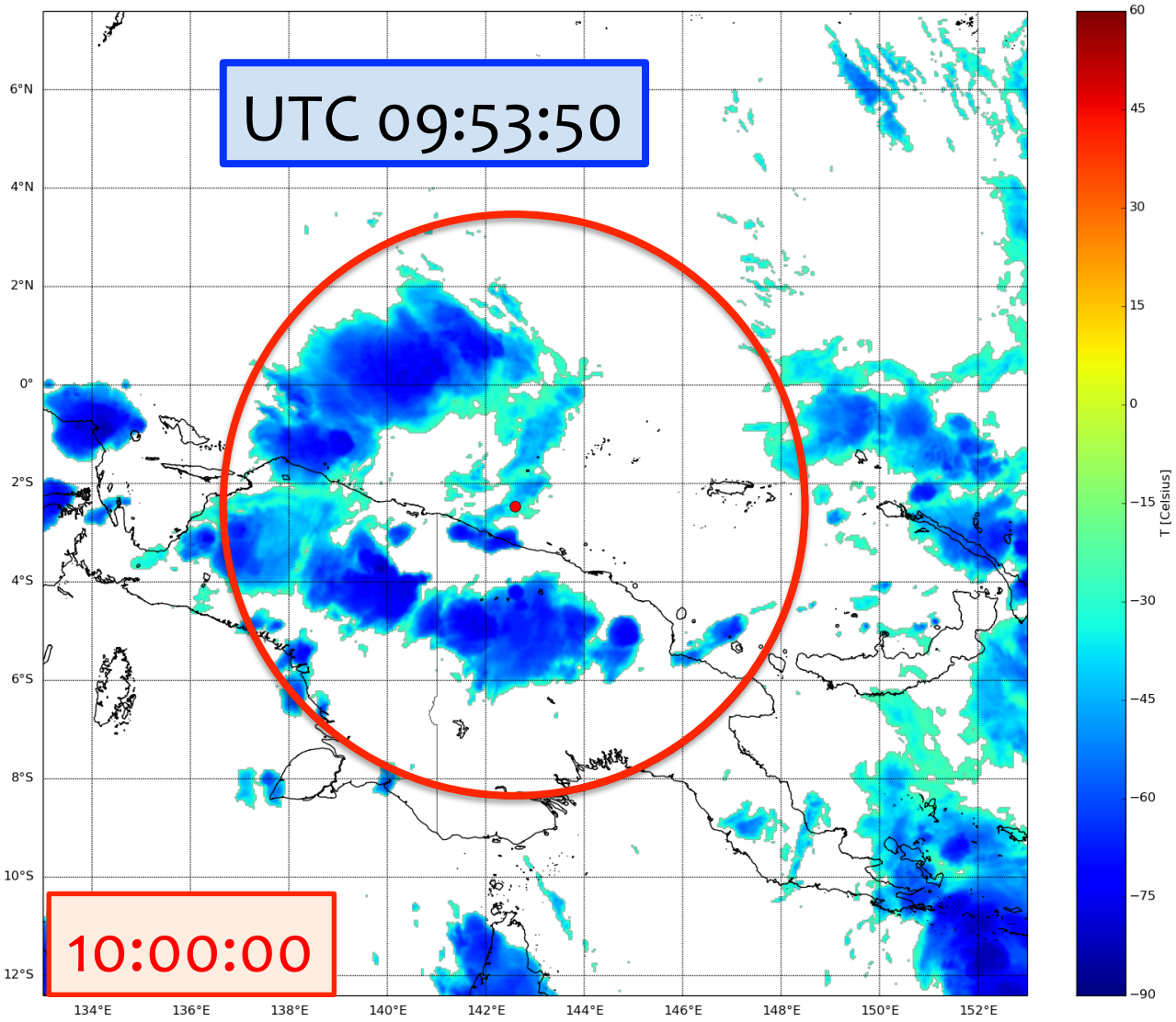
EXAMPLE 10
07/04/2015

Successive TGFs



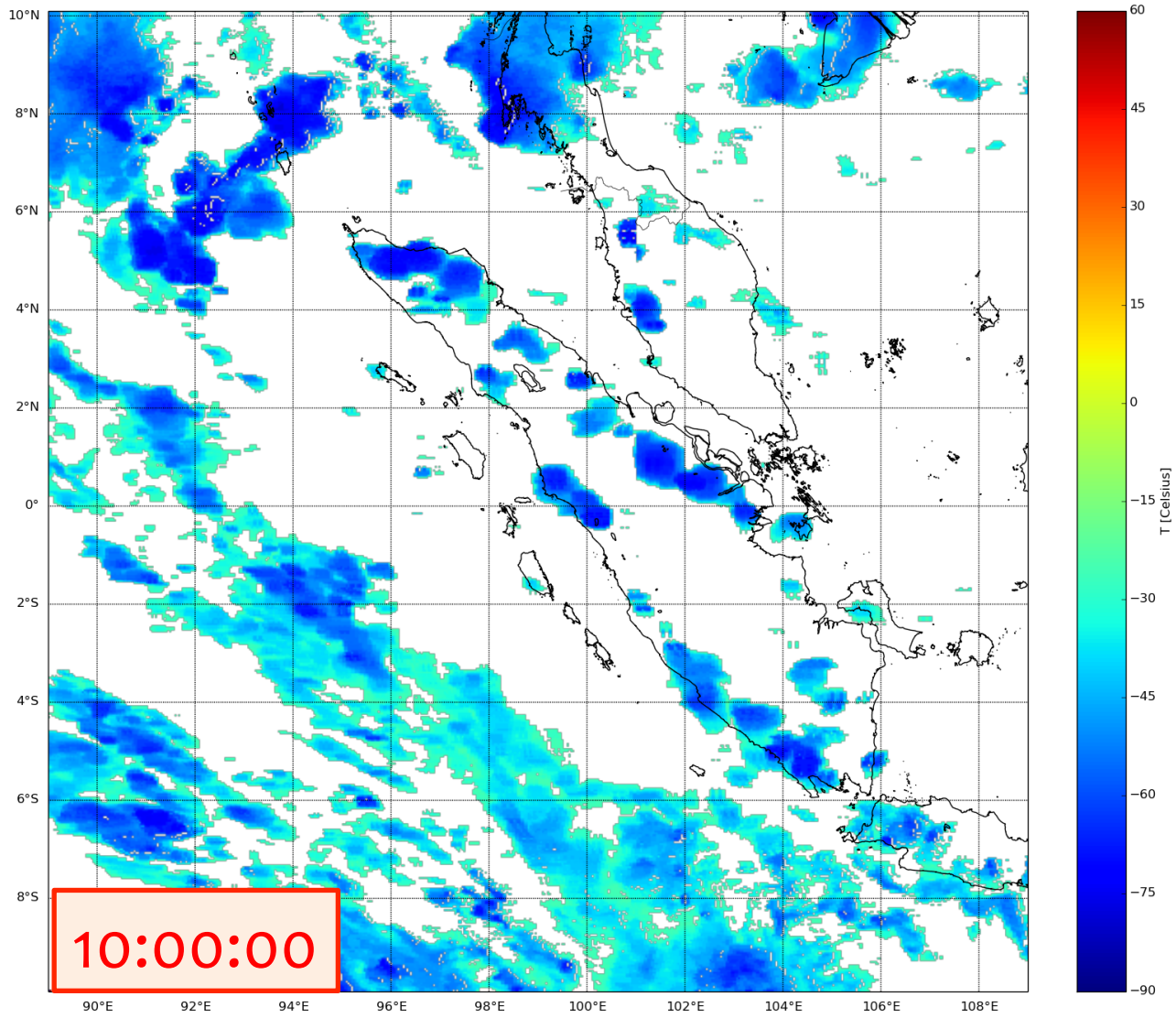
EXAMPLE 10
07/04/2015

Successive TGFs



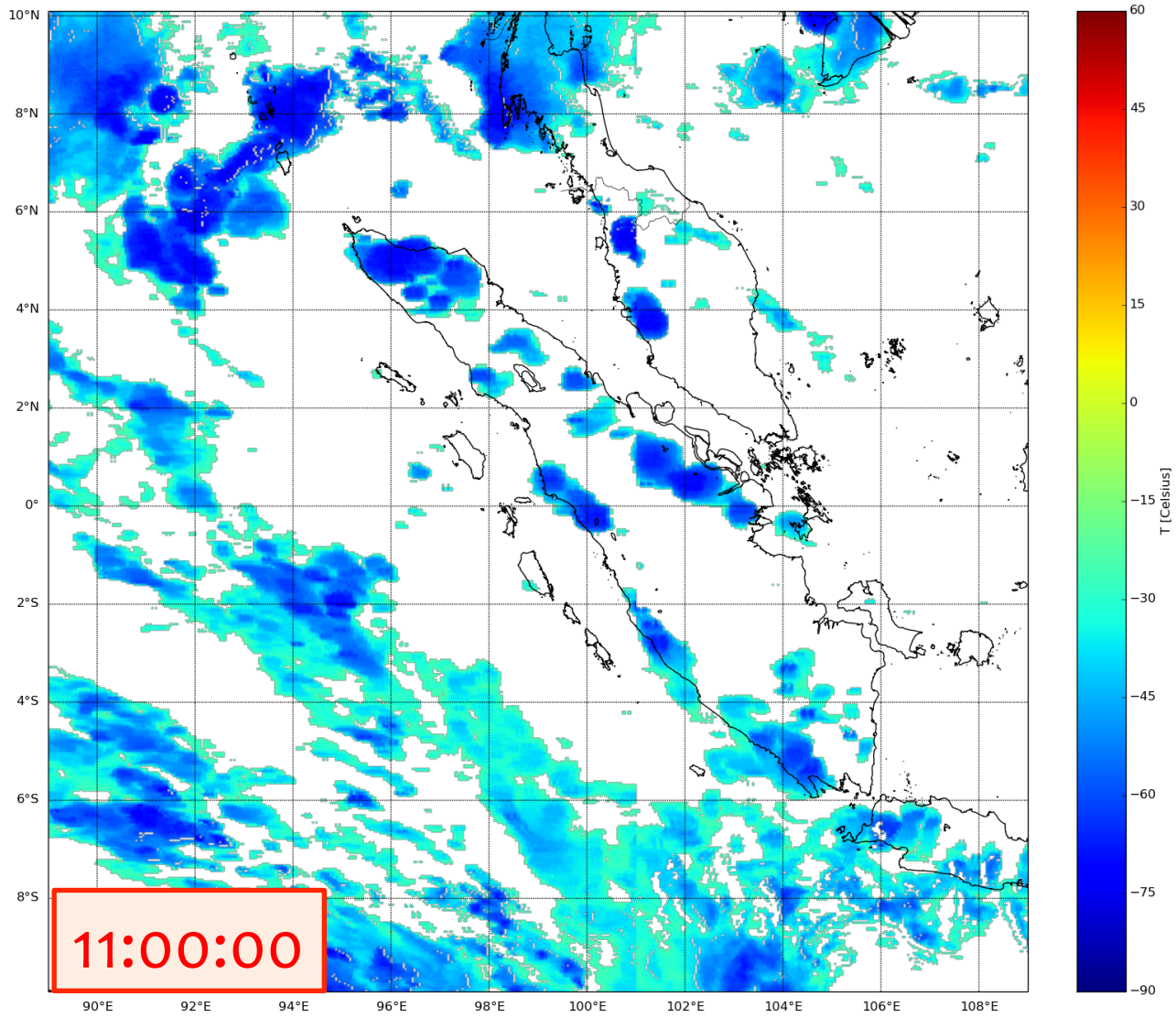
EXAMPLE 10
07/04/2015

Successive TGFs



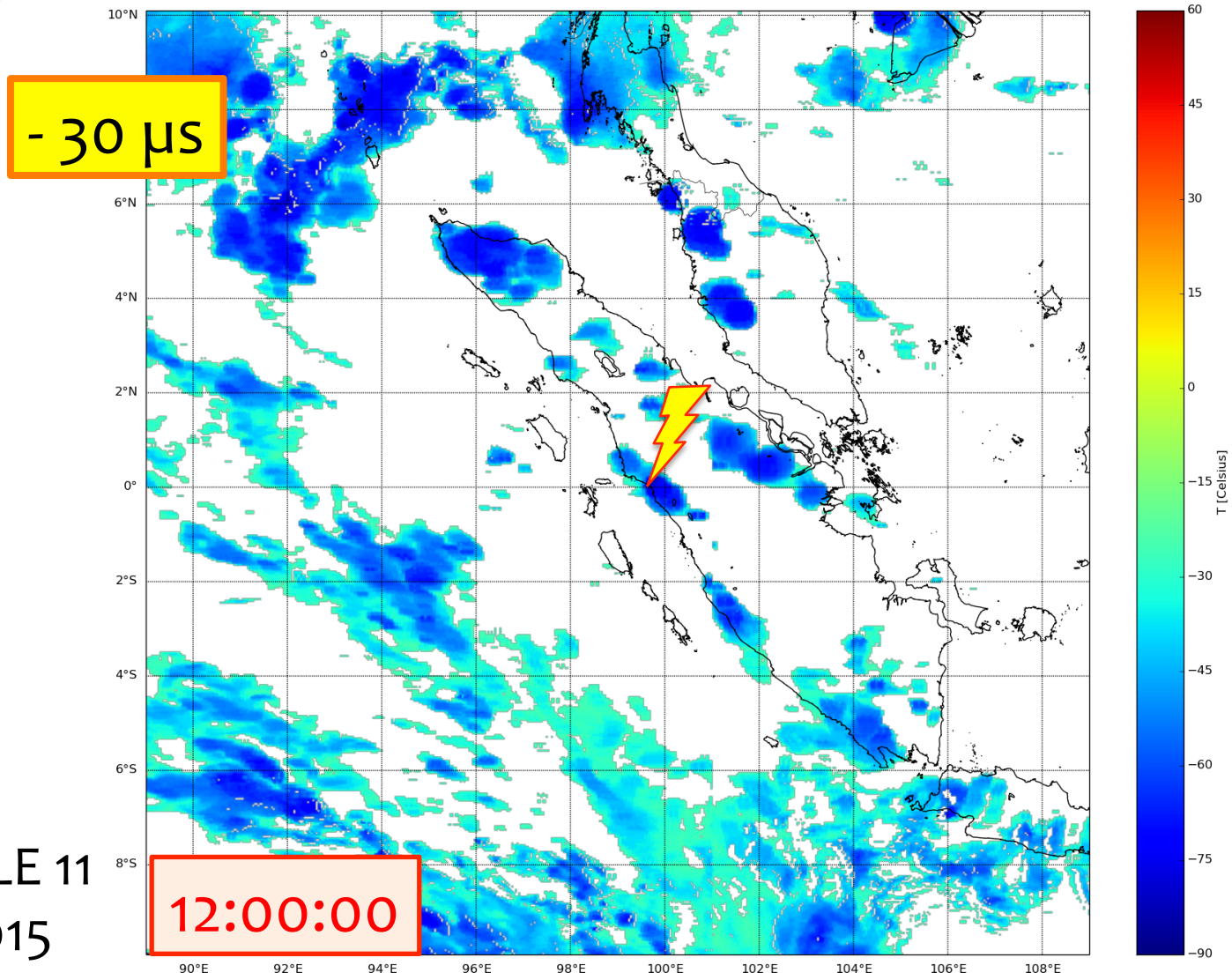
EXAMPLE 11
13/04/2015

Successive TGFs



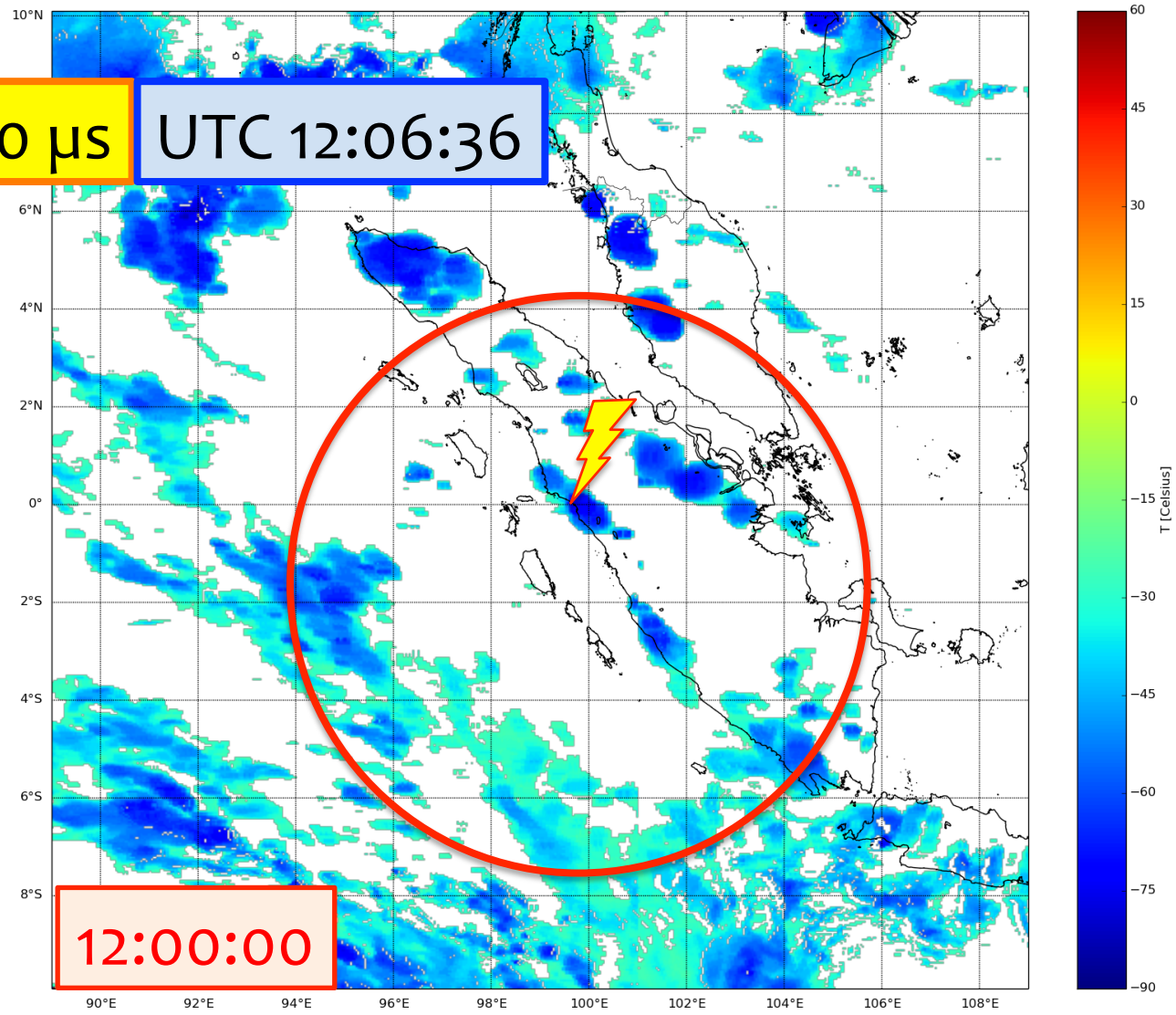
EXAMPLE 11
13/04/2015

Successive TGFs



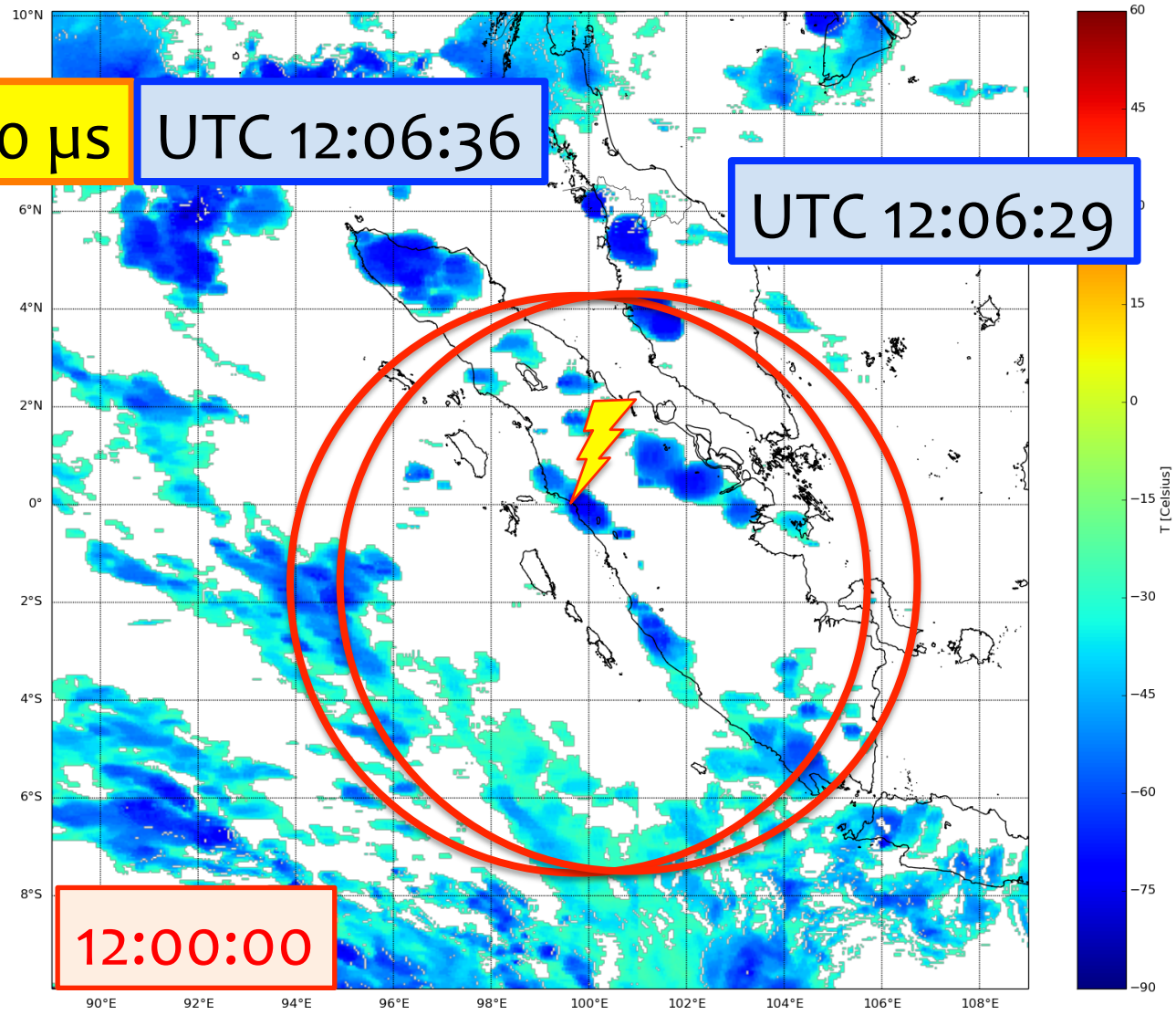
EXAMPLE 11
13/04/2015

Successive TGFs



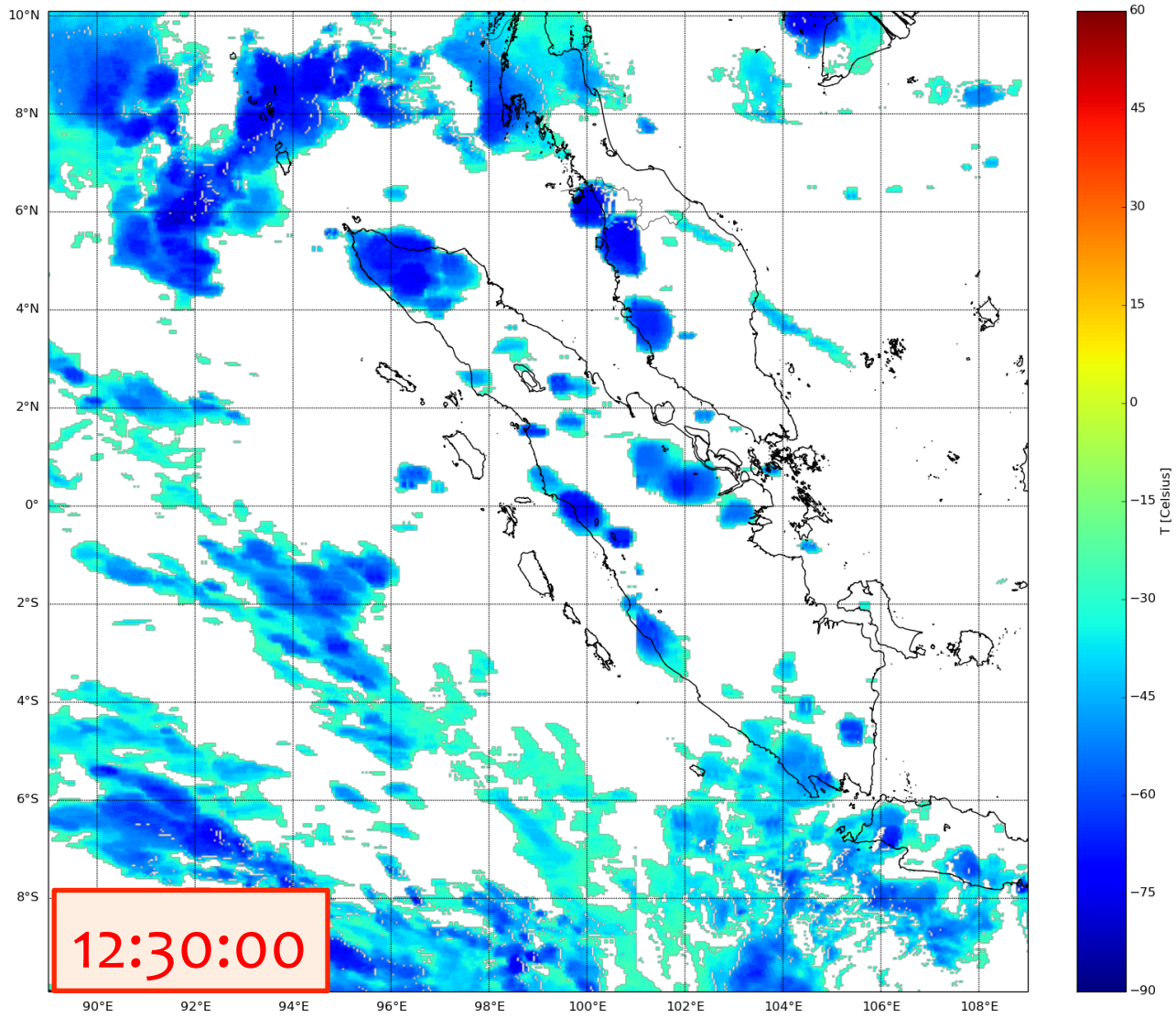
EXAMPLE 11
13/04/2015

Successive TGFs



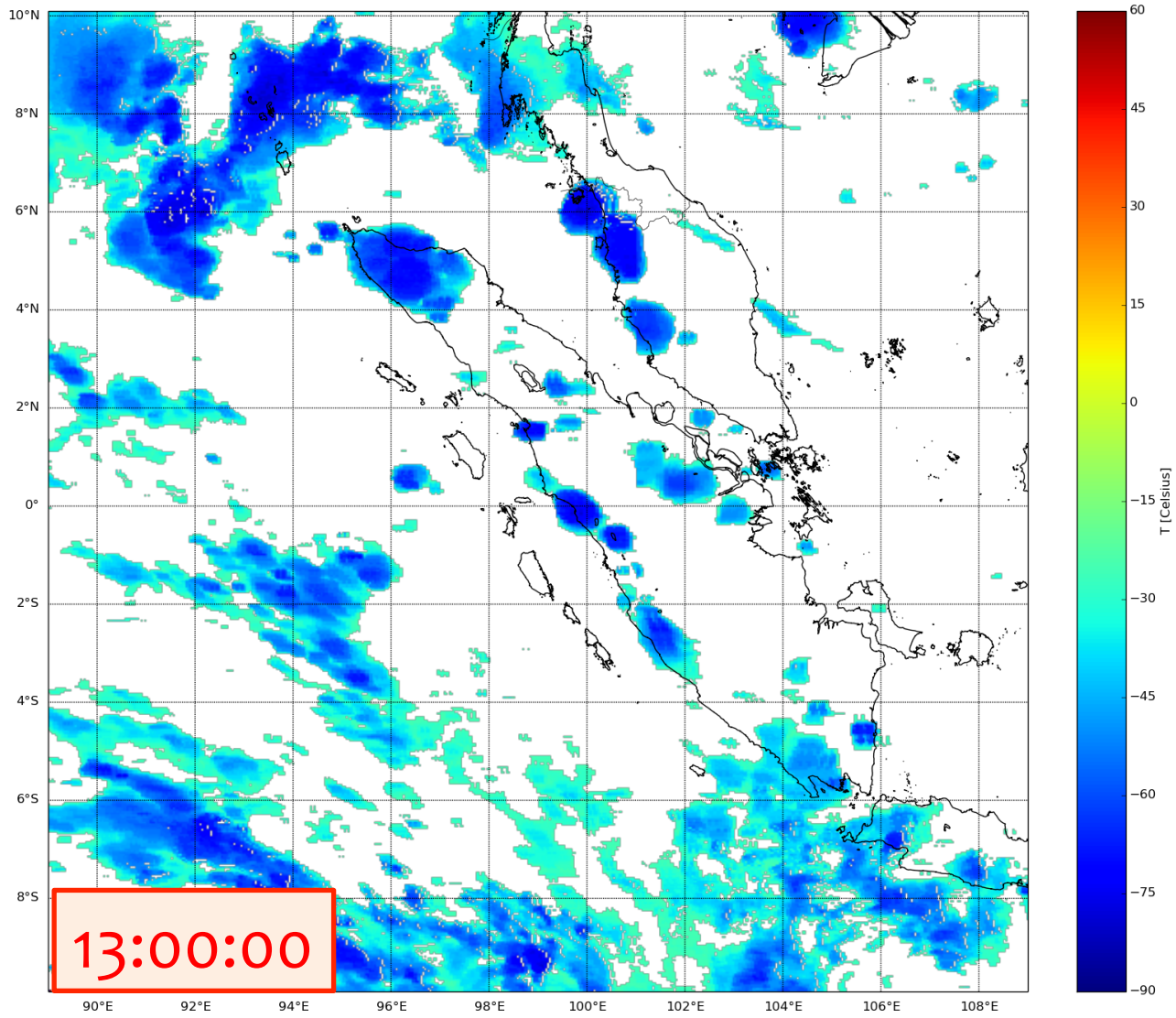
EXAMPLE 11
13/04/2015

Successive TGFs



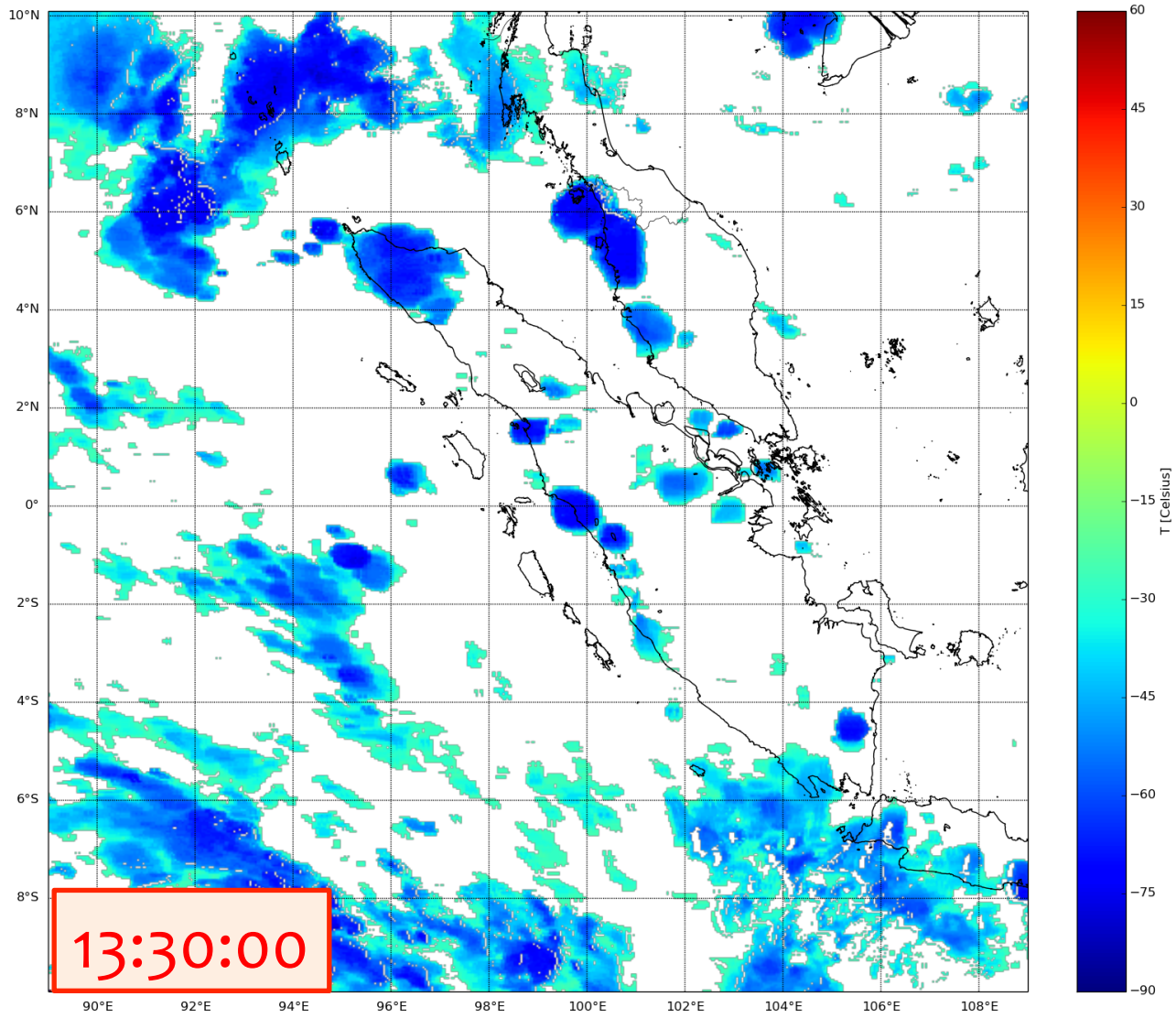
EXAMPLE 11
13/04/2015

Successive TGFs



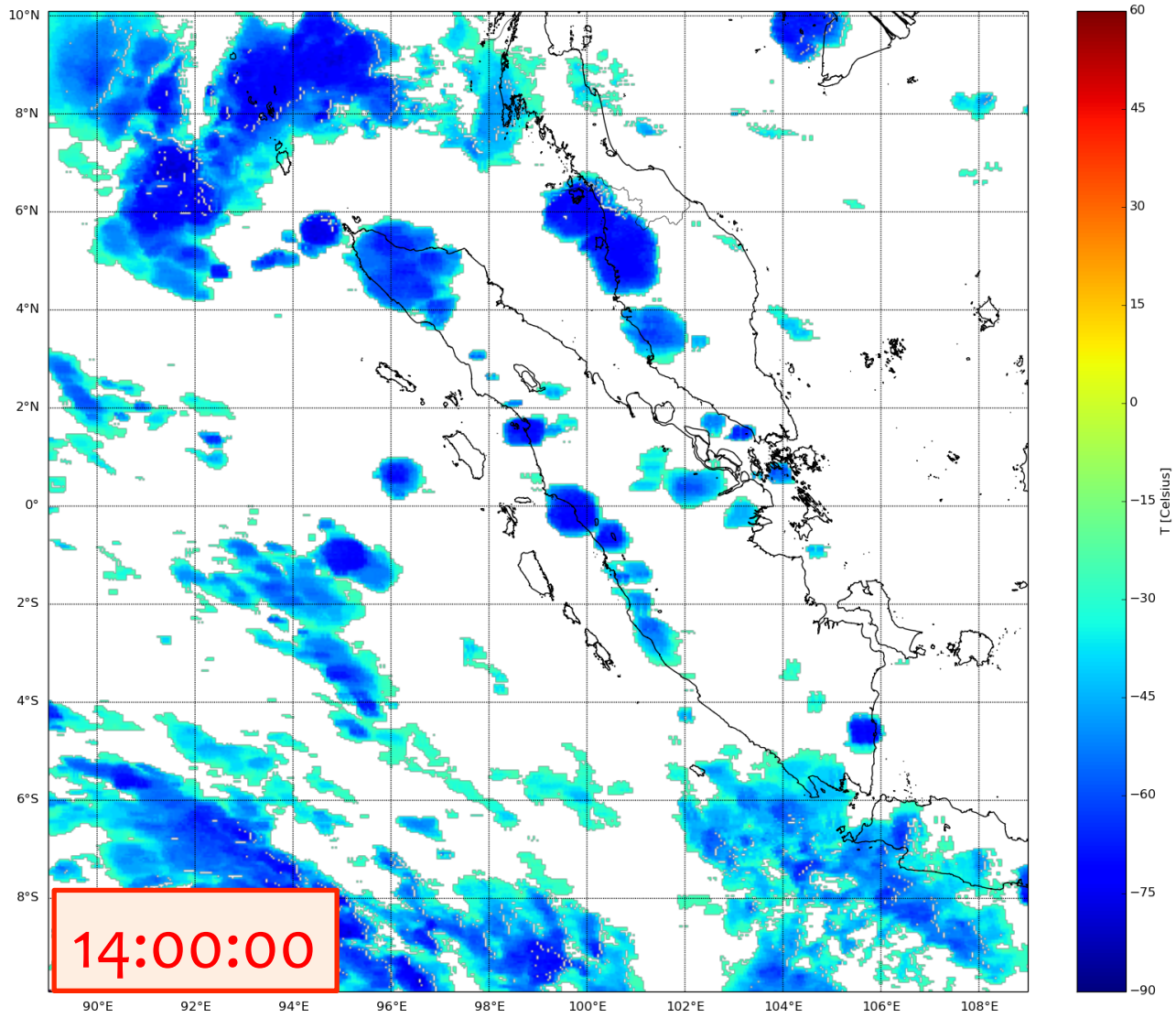
EXAMPLE 11
13/04/2015

Successive TGFs



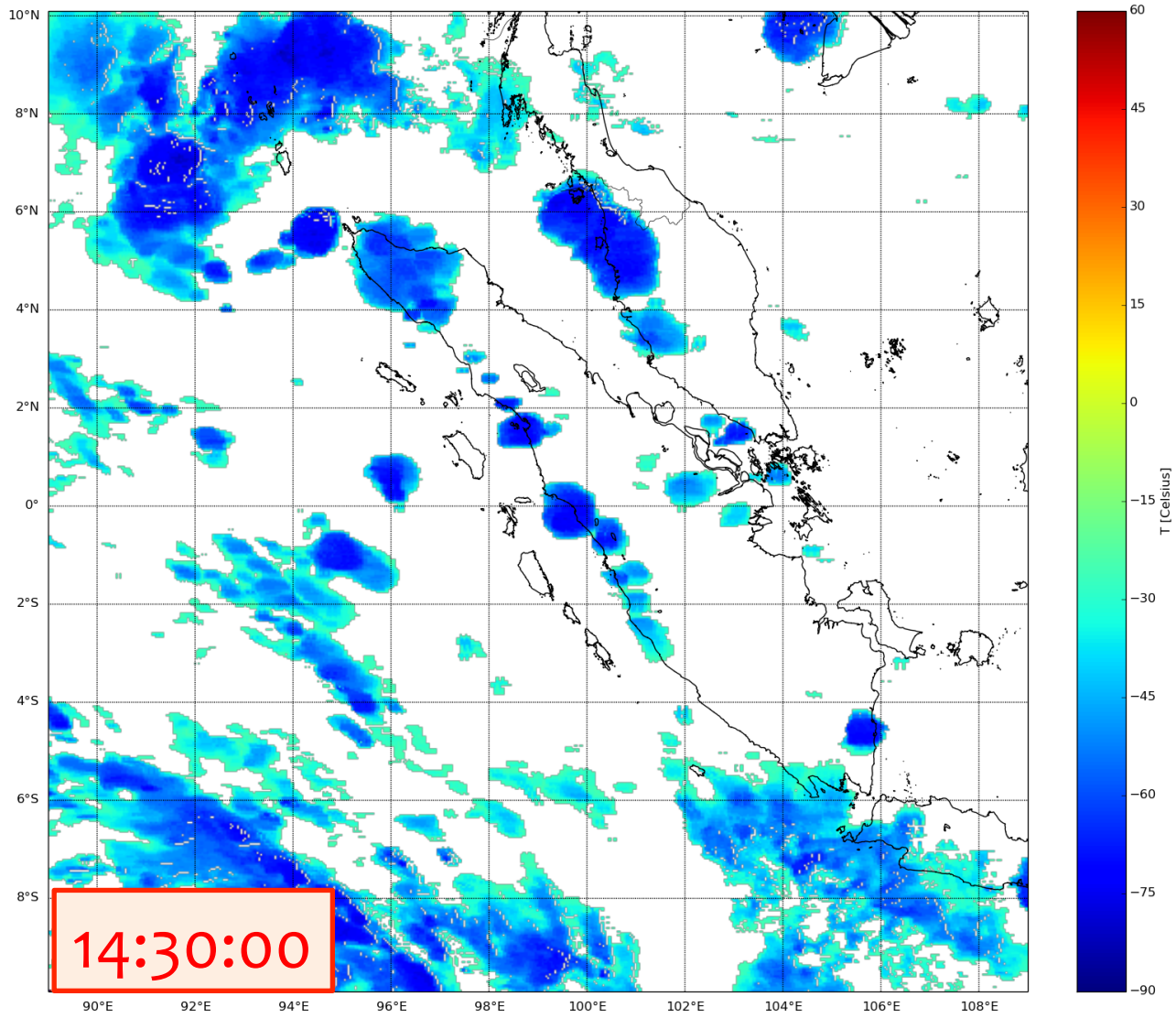
EXAMPLE 11
13/04/2015

Successive TGFs



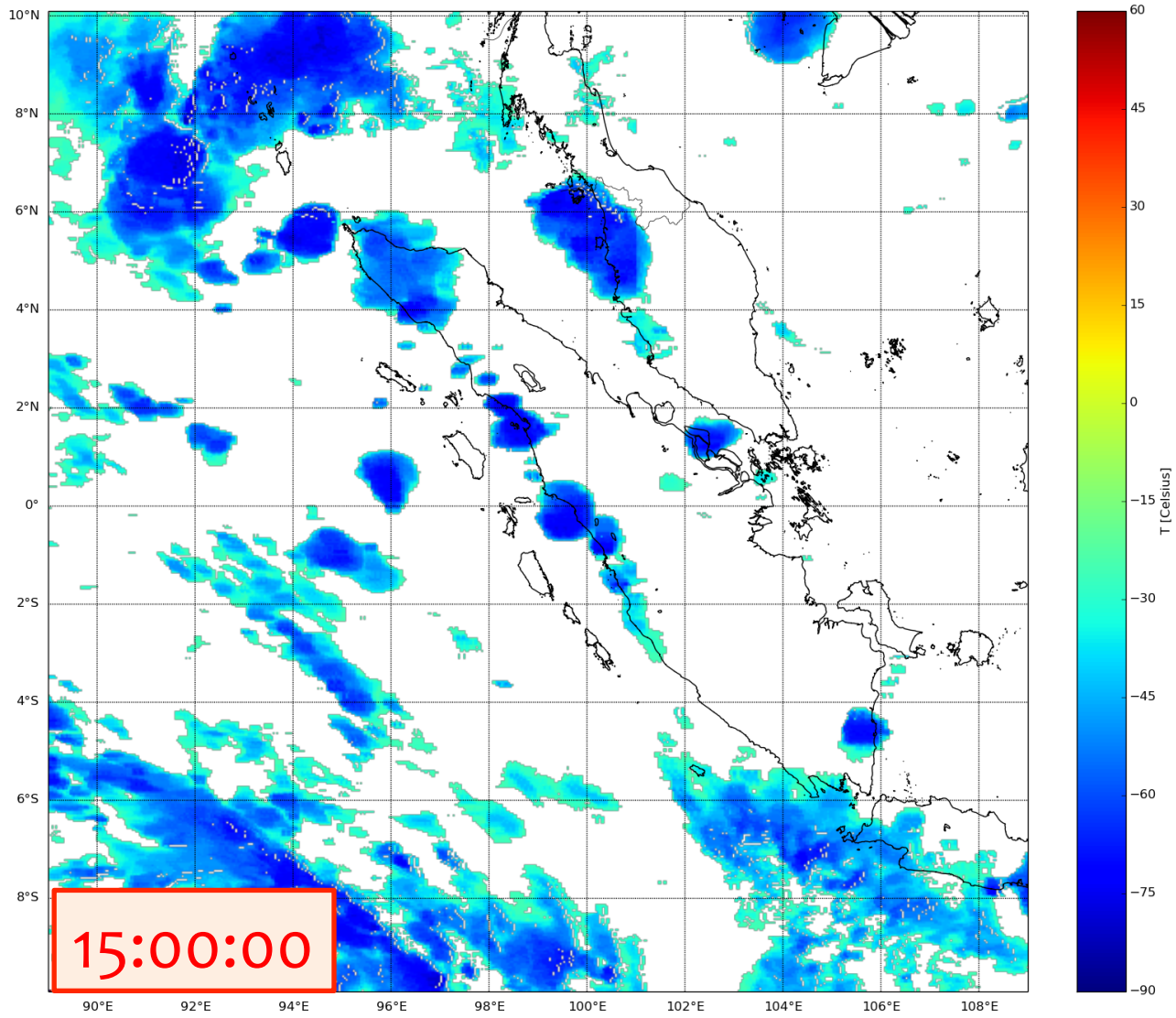
EXAMPLE 11
13/04/2015

Successive TGFs



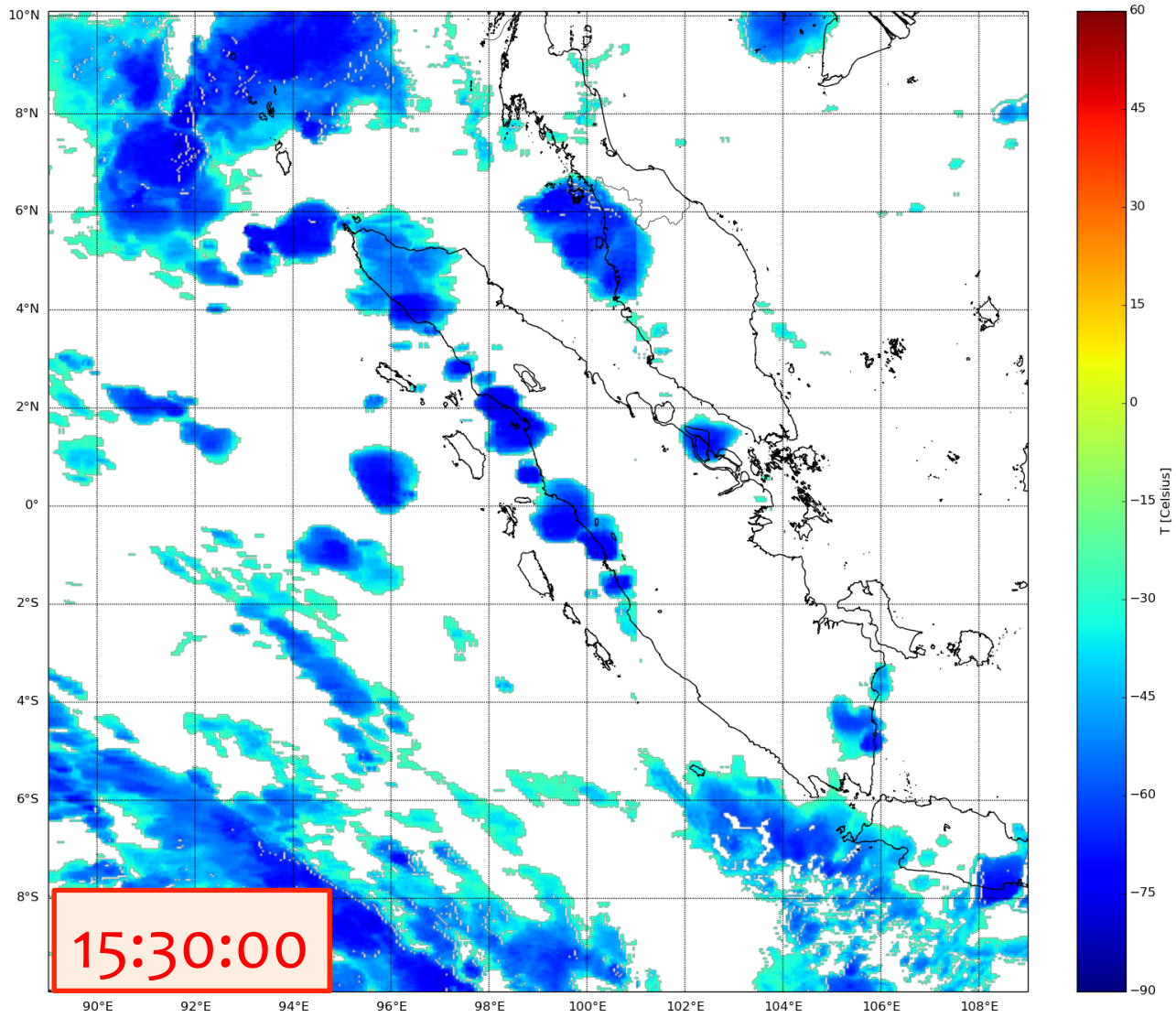
EXAMPLE 11
13/04/2015

Successive TGFs



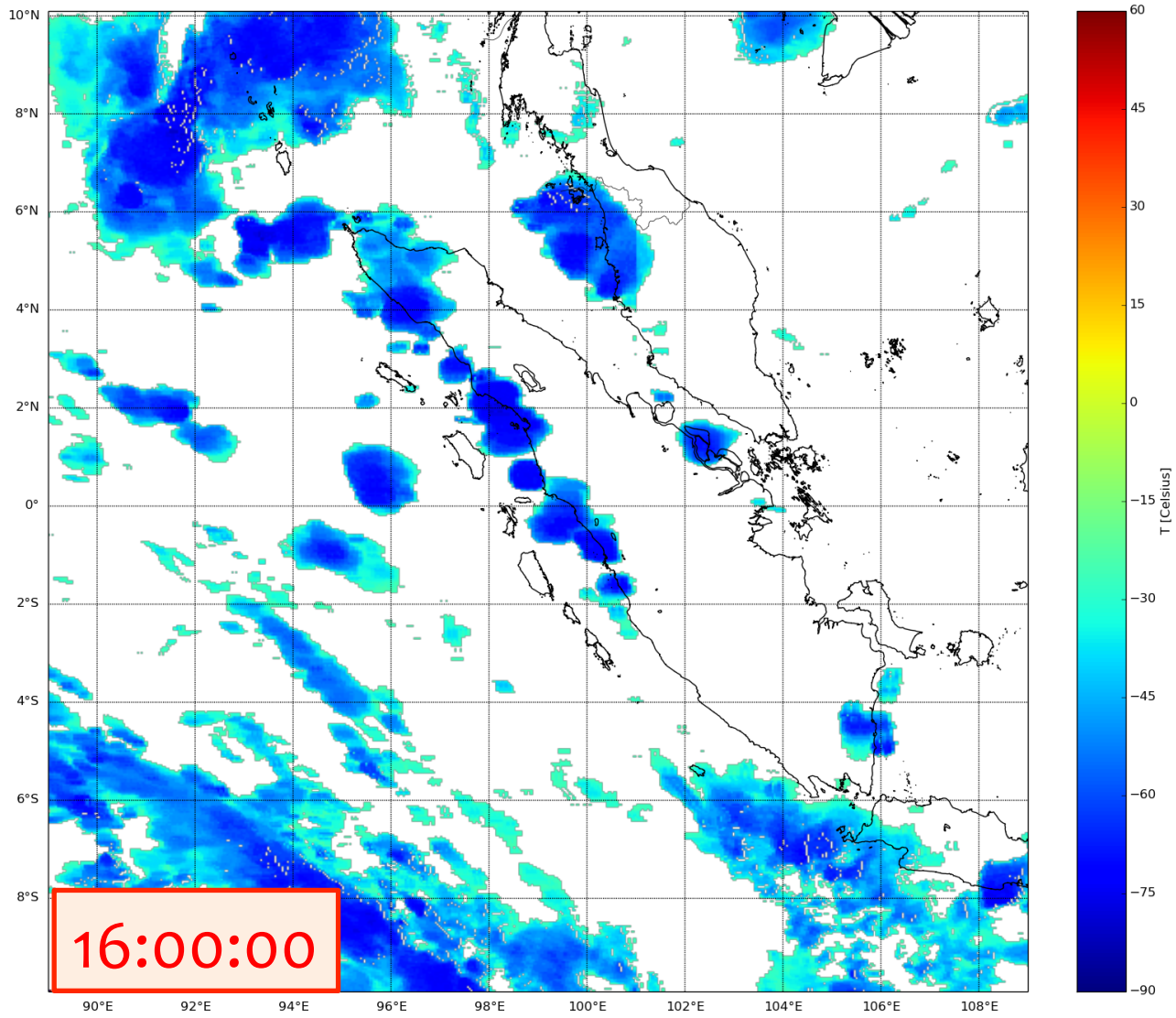
EXAMPLE 11
13/04/2015

Successive TGFs



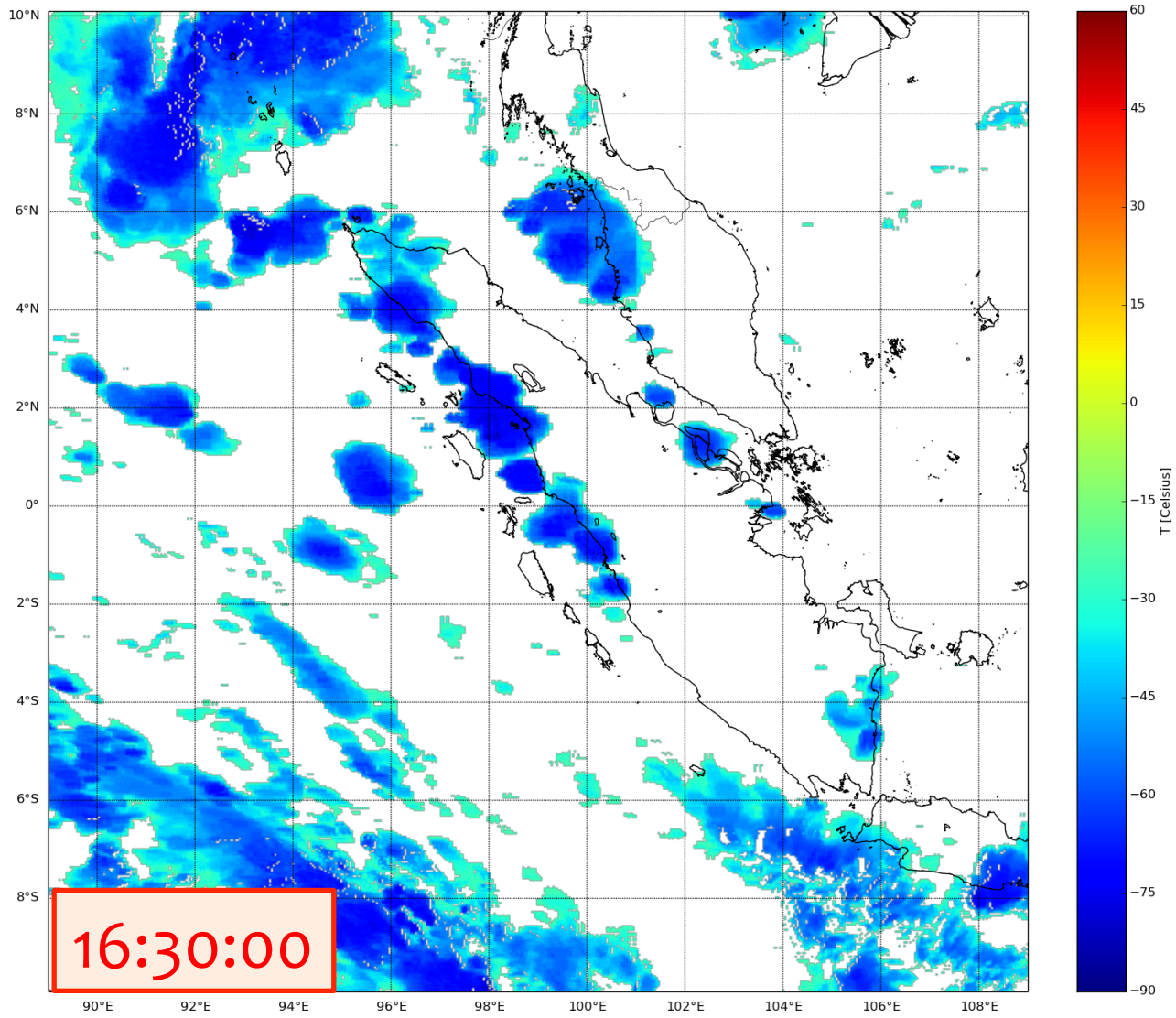
EXAMPLE 11
13/04/2015

Successive TGFs



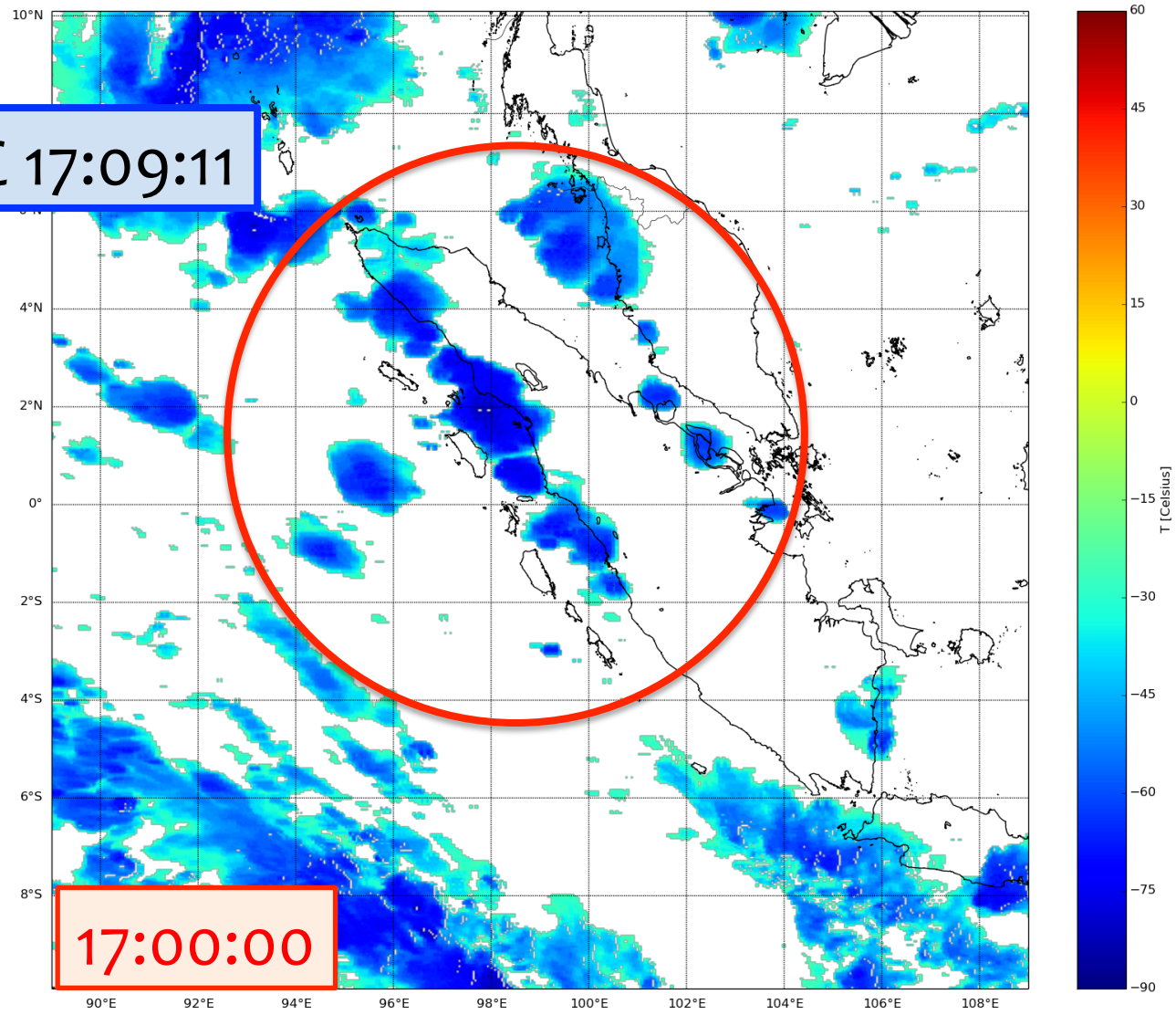
EXAMPLE 11
13/04/2015

Successive TGFs



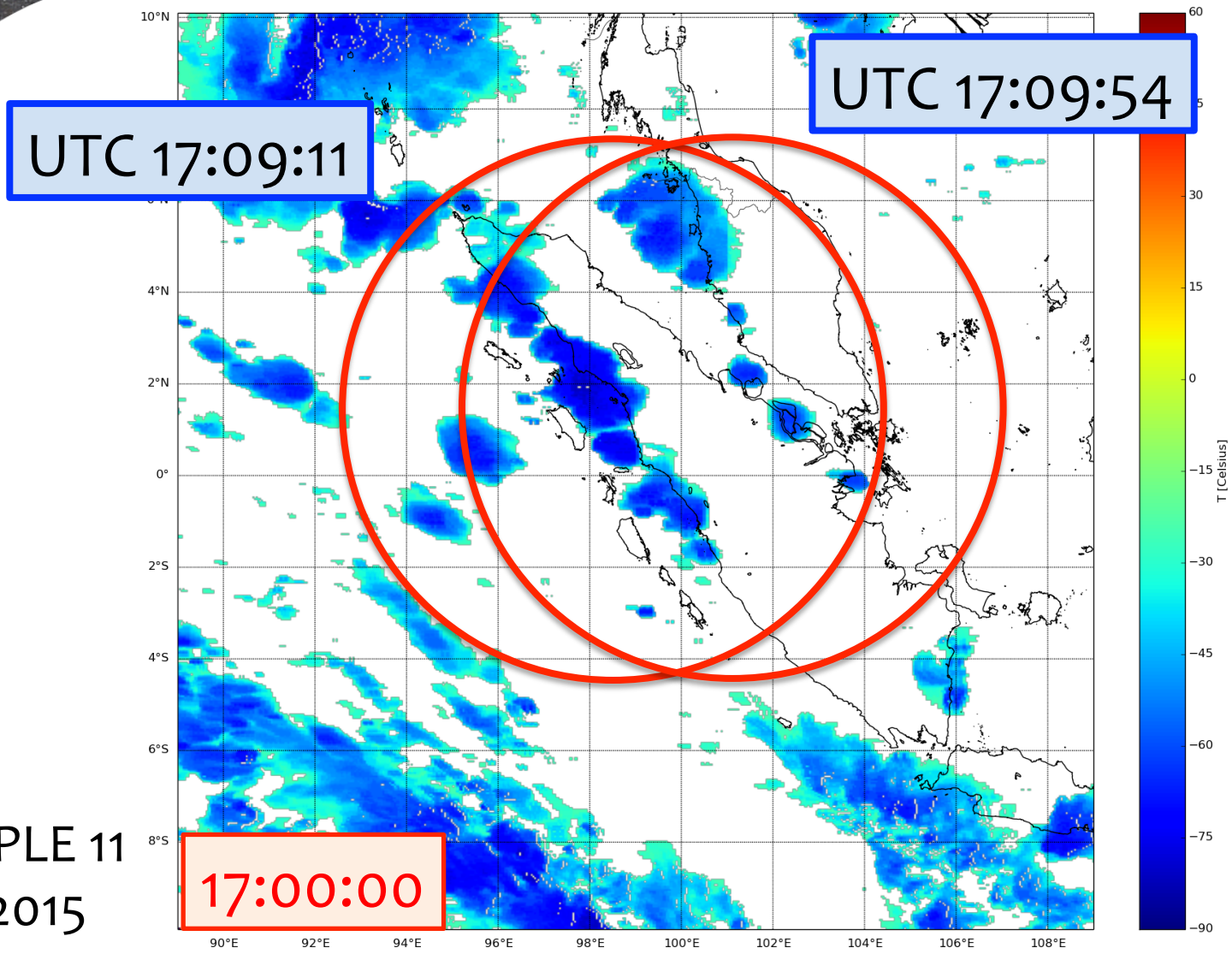
EXAMPLE 11
13/04/2015

Successive TGFs



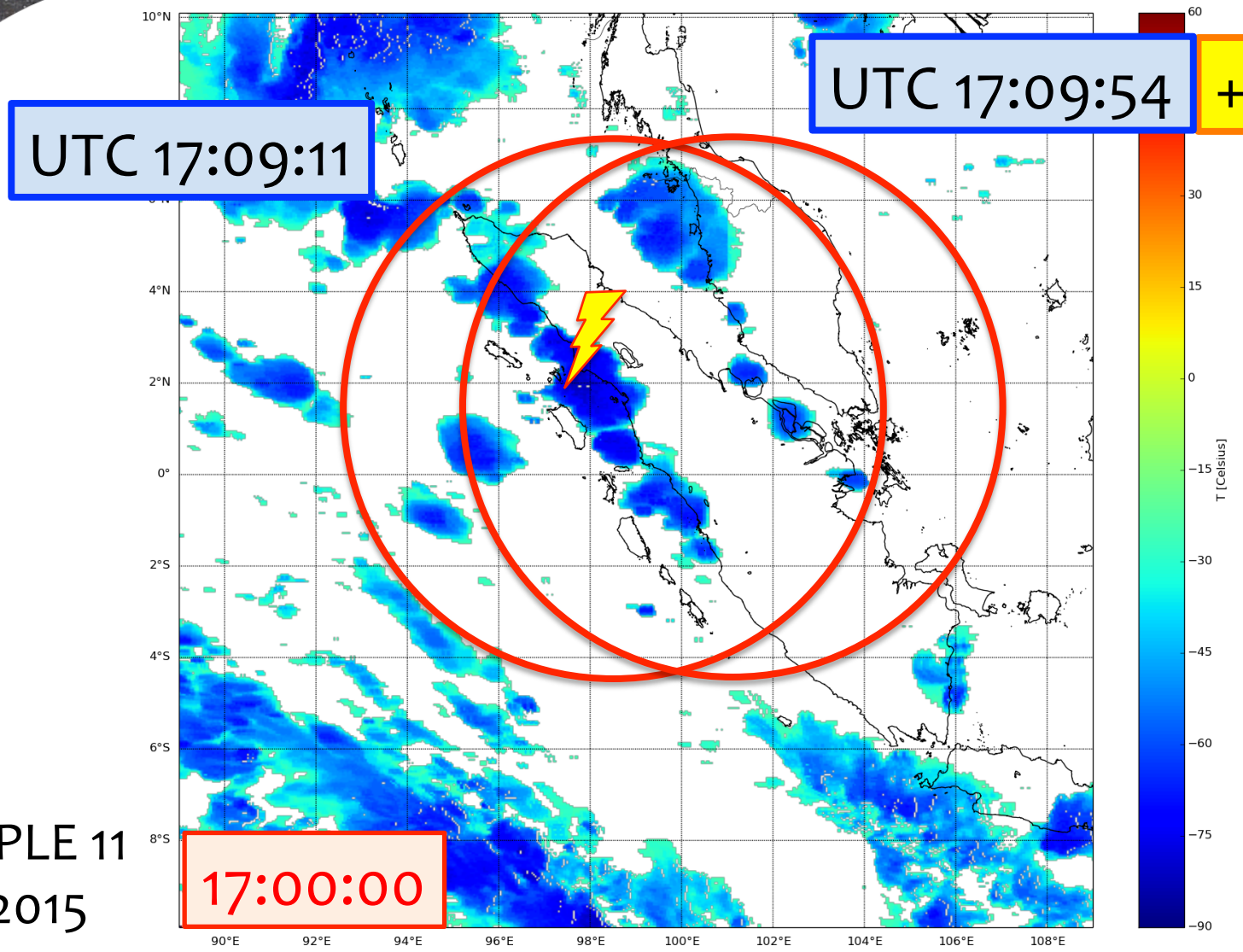
EXAMPLE 11
13/04/2015

Successive TGFs



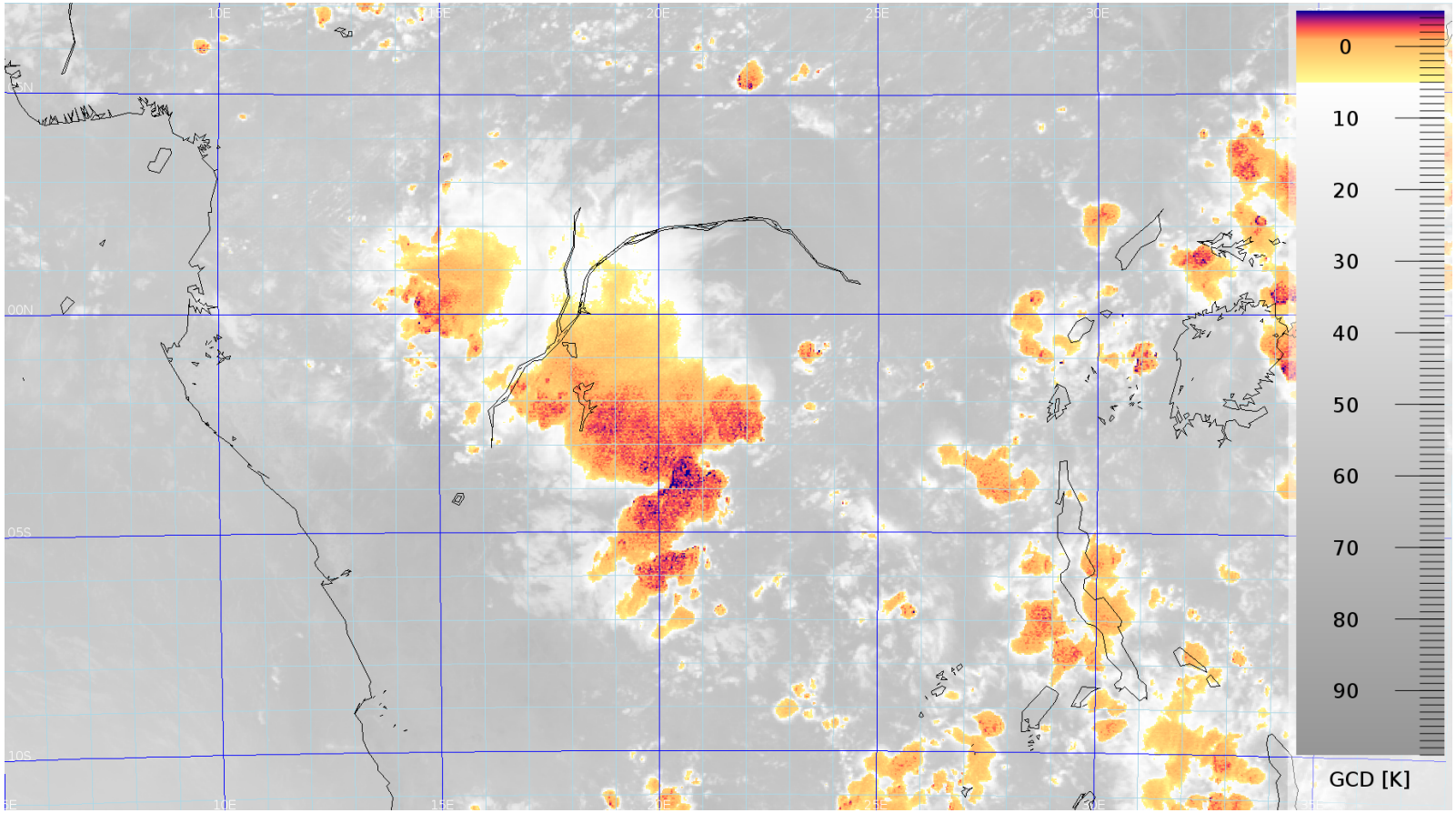
EXAMPLE 11
13/04/2015

Successive TGFs

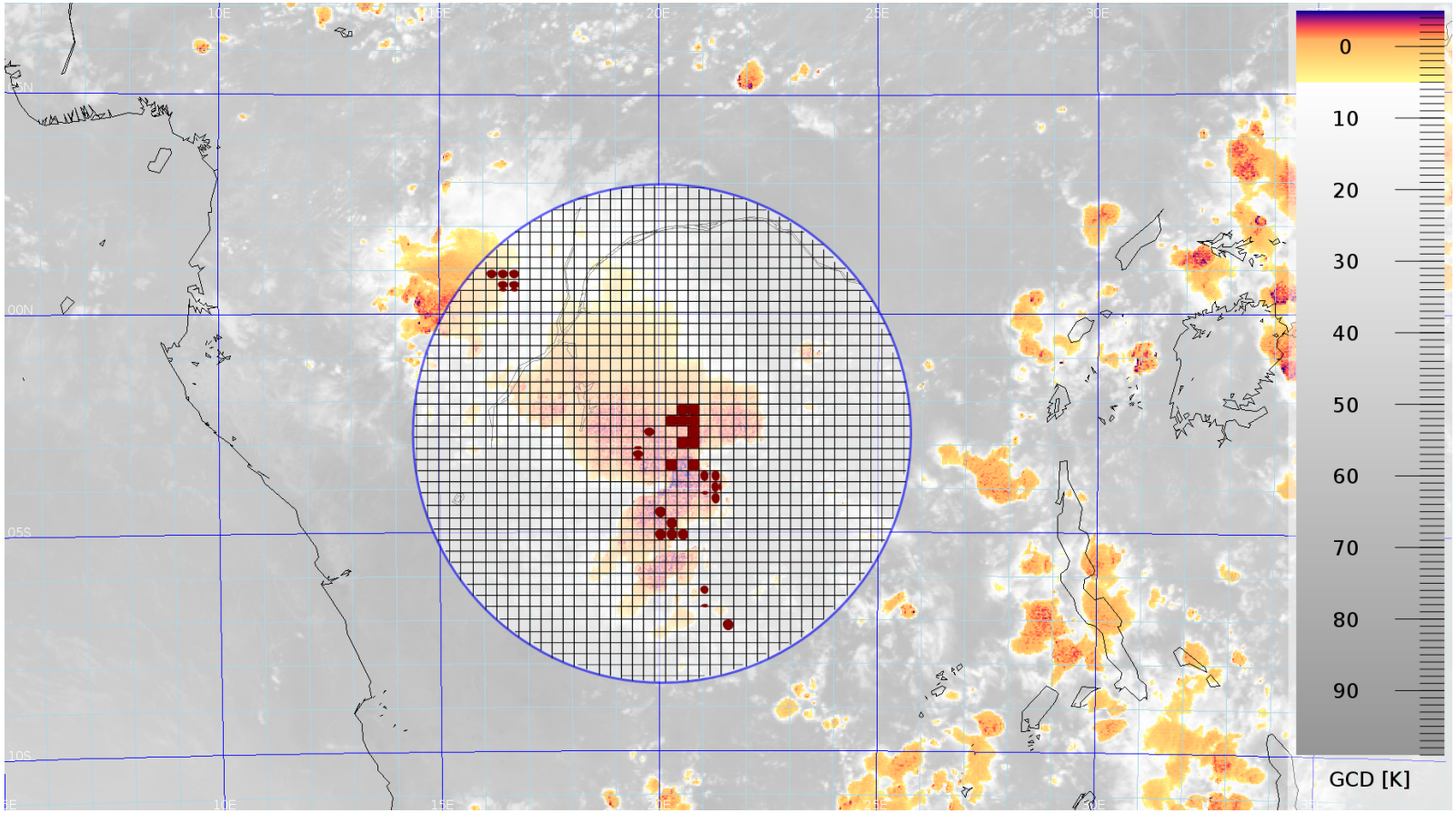


EXAMPLE 11
13/04/2015

Successive TGFs

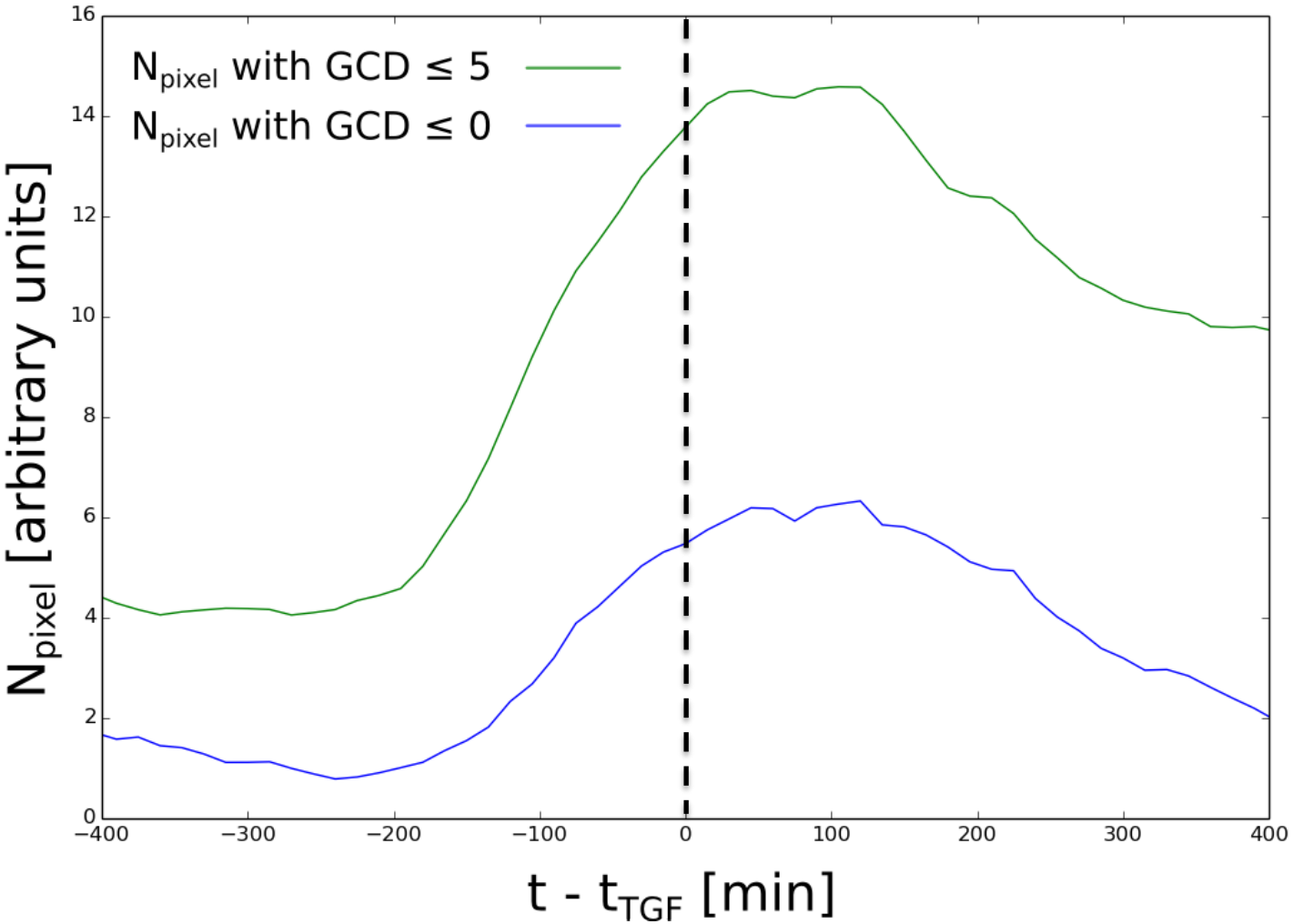


Successive TGFs



N_{pixels} satisfying the GCD

Successive TGFs

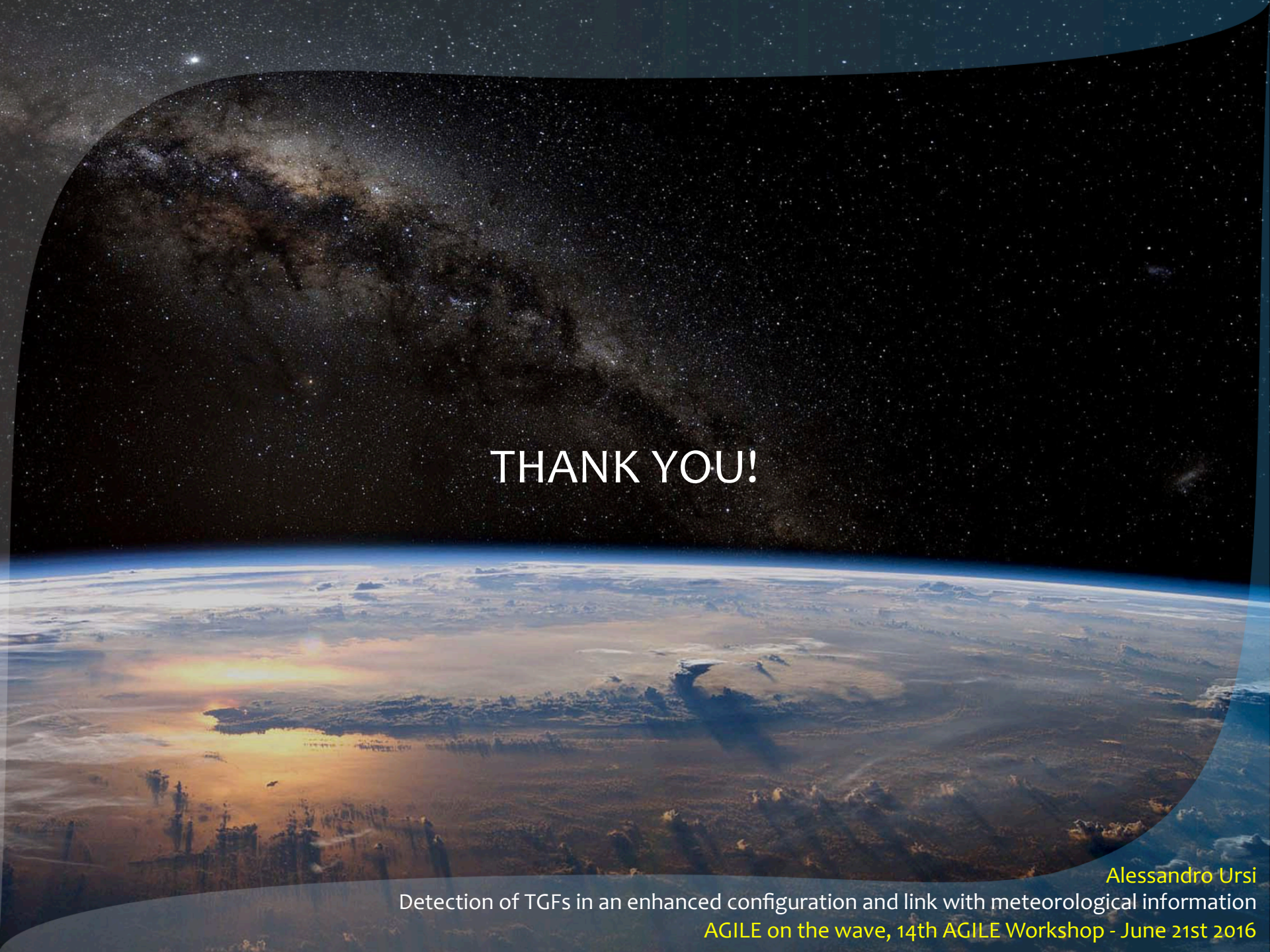


Conclusions

AGILE still goes on…

- MORE EVENTS
  - MORE SFERICS
    - MORE STATISTICS

- *Detection of multiple TGFs from thunderstorms* [Ursi et al., 2016, in preparation]
- *A real-time pipeline to link meteorological information to AGILE TGFs* [Ursi et al., 2016, in preparation]

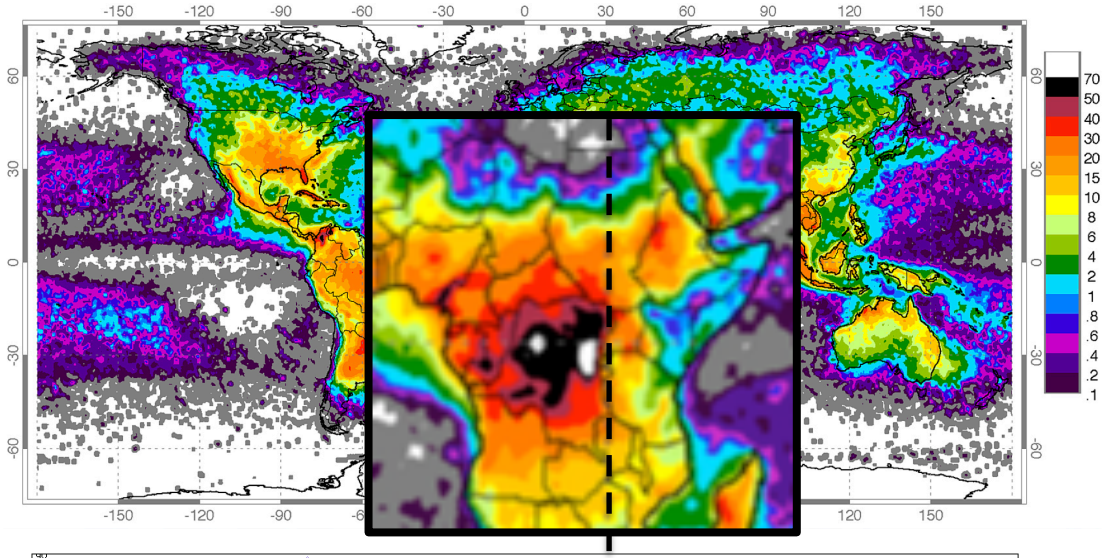

THANK YOU!


Backup slides

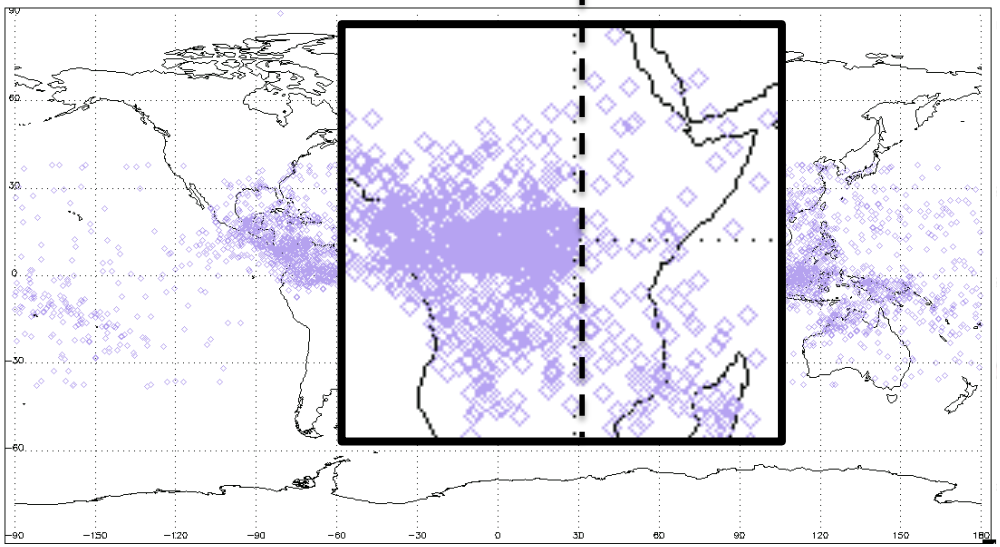
Terrestrial events – Terrestrial Gamma-ray Flashes (TGFs)

Association with lightning (1)

Geographical distribution of lightning strokes



All TGFs



Terrestrial events – Terrestrial Gamma-ray Flashes (TGFs)

Association with lightning (2)

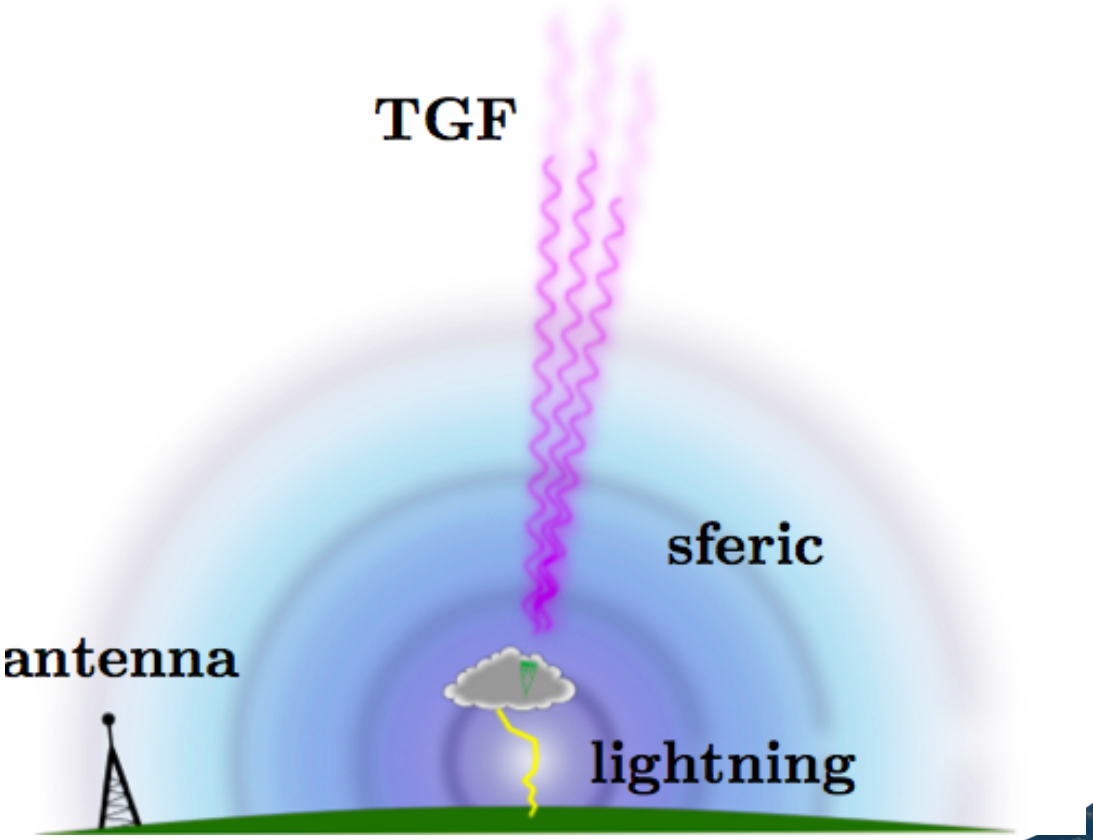
Radio atmospherics (sferics)

Hz ÷ 10 kHz

many matches for
RHESSI/Fermi TGFs

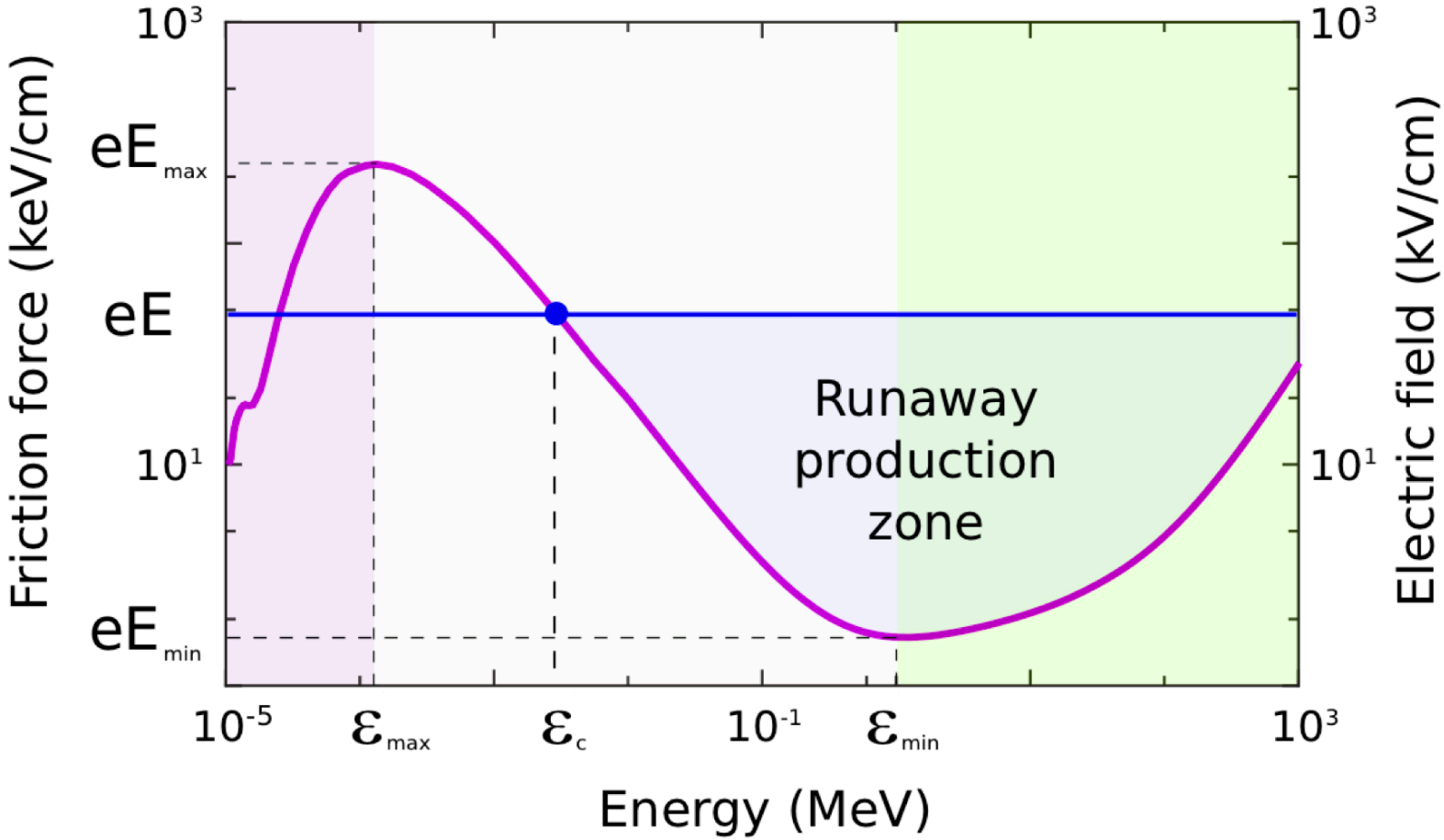
congiunzione

detector



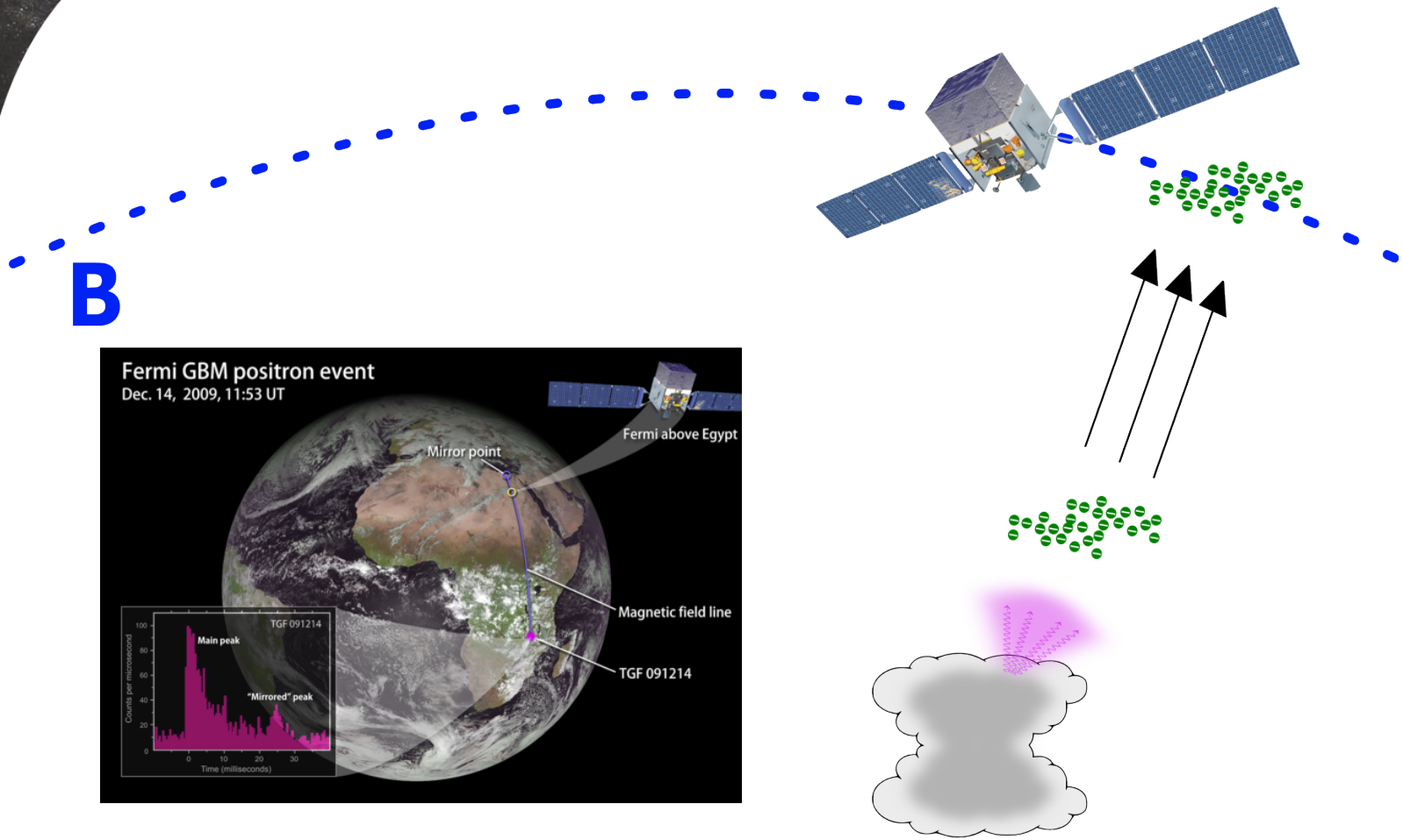
Terrestrial events – Terrestrial Gamma-ray Flashes (TGFs)

How does RREA work?



Terrestrial events – Terrestrial Gamma-ray Flashes (TGFs)

Electron TGFs or Terrestrial Electron Beams (TEBs)



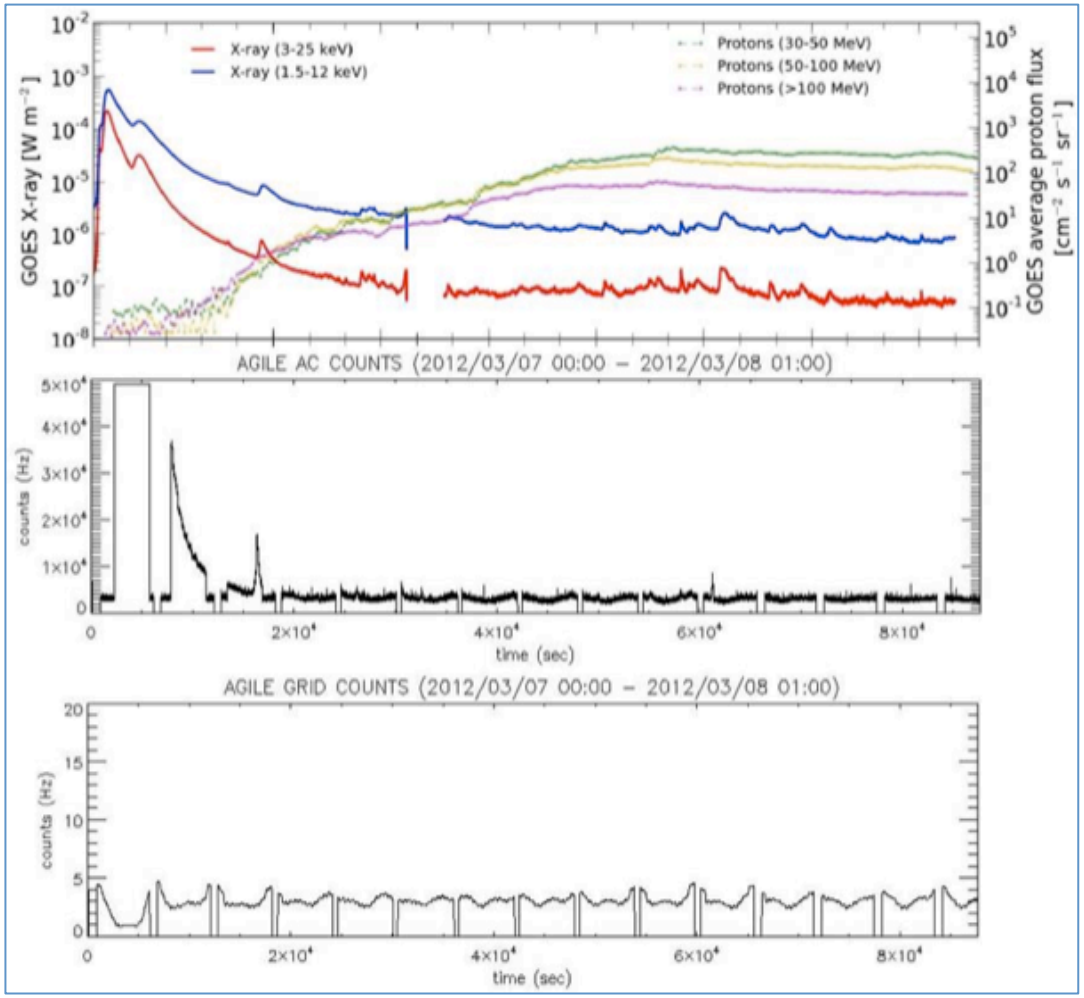
Terrestrial events – Terrestrial Gamma-ray Flashes (TGFs)

Solar flare March 7th 2012

X-rays and particles by GOES

X-rays by AGILE AC

Particles by AGILE GRID



Terrestrial events – Terrestrial Gamma-ray Flashes (TGFs)

Radiation doses

TGF radiation dose ~ 0.1 Sv/ms

N_{part} (1 ms, few km^2)
~
$10^3 \cdot N_{CR}$ (1 ms, whole Earth)

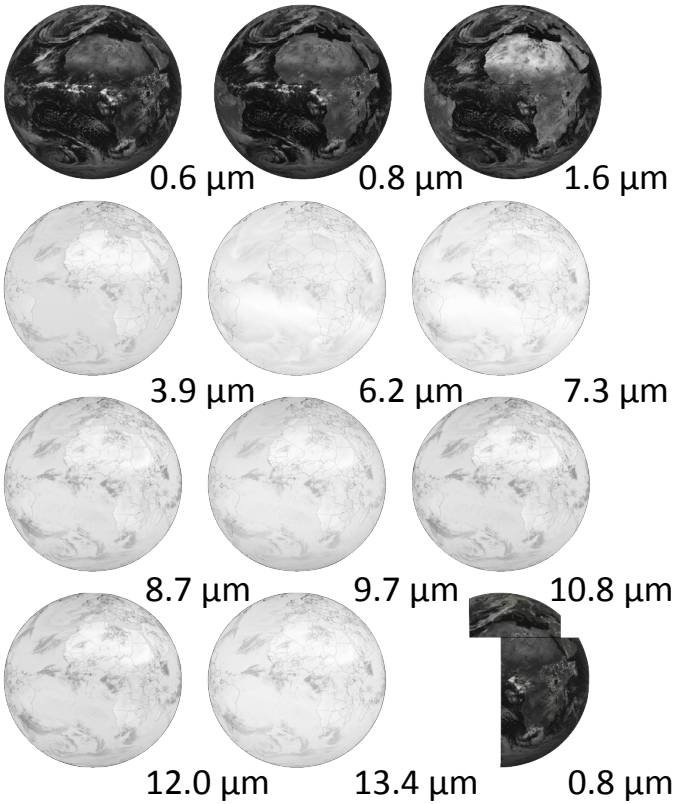
Radiation doses:

- nature ~ 2 mSv/year
- RX < 1 mSv
- TAC < 8 mSv
- PET < 20 mSv
- radiotherapy ~ Sv

→ injuries on aircraft passengers [*Dwyer, 2013*]
→ damages on on-board electronics [*Tavani et al., 2013*]

Terrestrial events – Terrestrial Gamma-ray Flashes (TGFs)

A real time pipeline to link meteorological data to TGFs detected by the AGILE satellite



- Meteosat Second Generation (MSG)
- geostationary satellites
- 12 energy channels:
  3 VIS ch. + 8 IR ch. with 3 km res.
  1 VIS ch. with 1 km res.
- Earth full-disc scan every 15'

Global Convective Diagnostics (GCD) algorithm is used to identify convective cells:

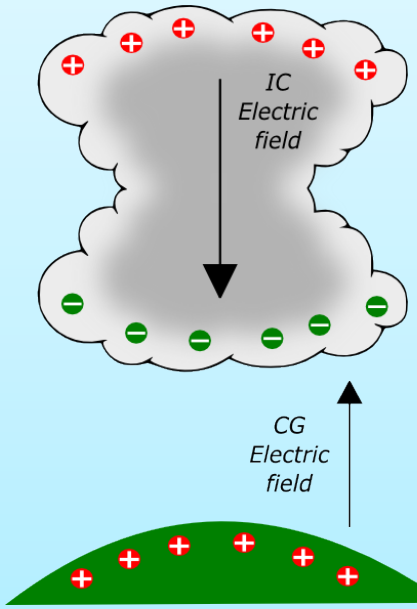
deep convection is present

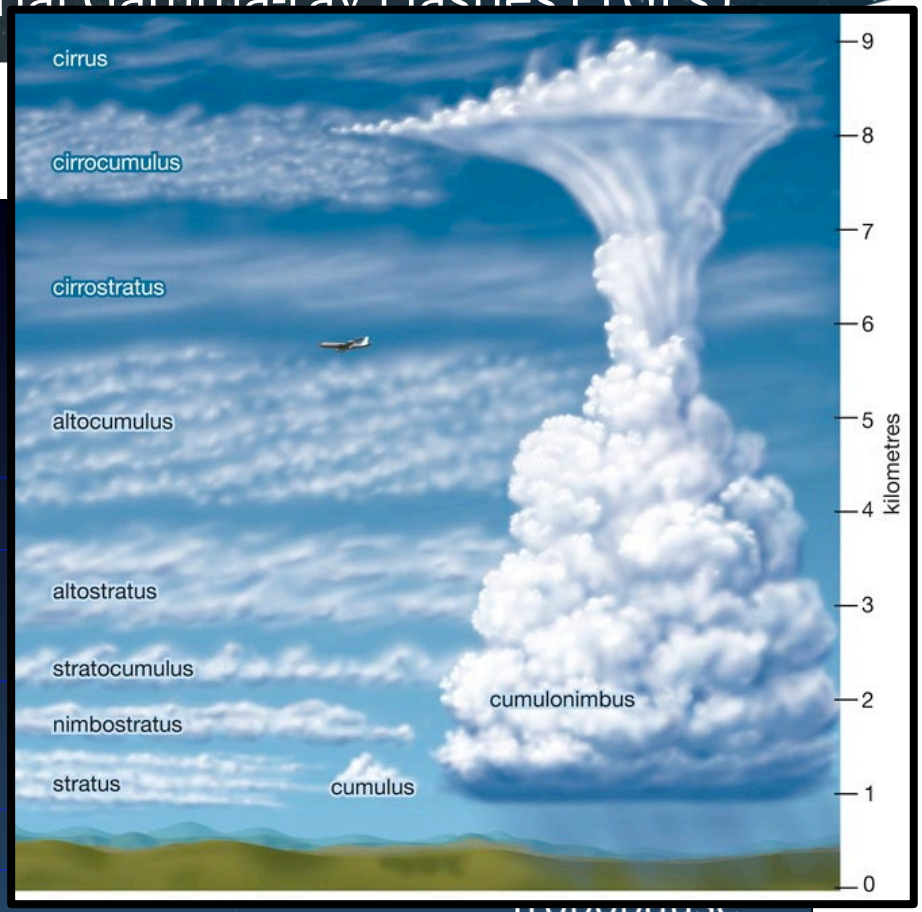
if GCD = T_b^{IR}-T_b^{WV} ≤ 1 K

Terrestrial events – Terrestrial Gamma-ray Flashes (TGFs)

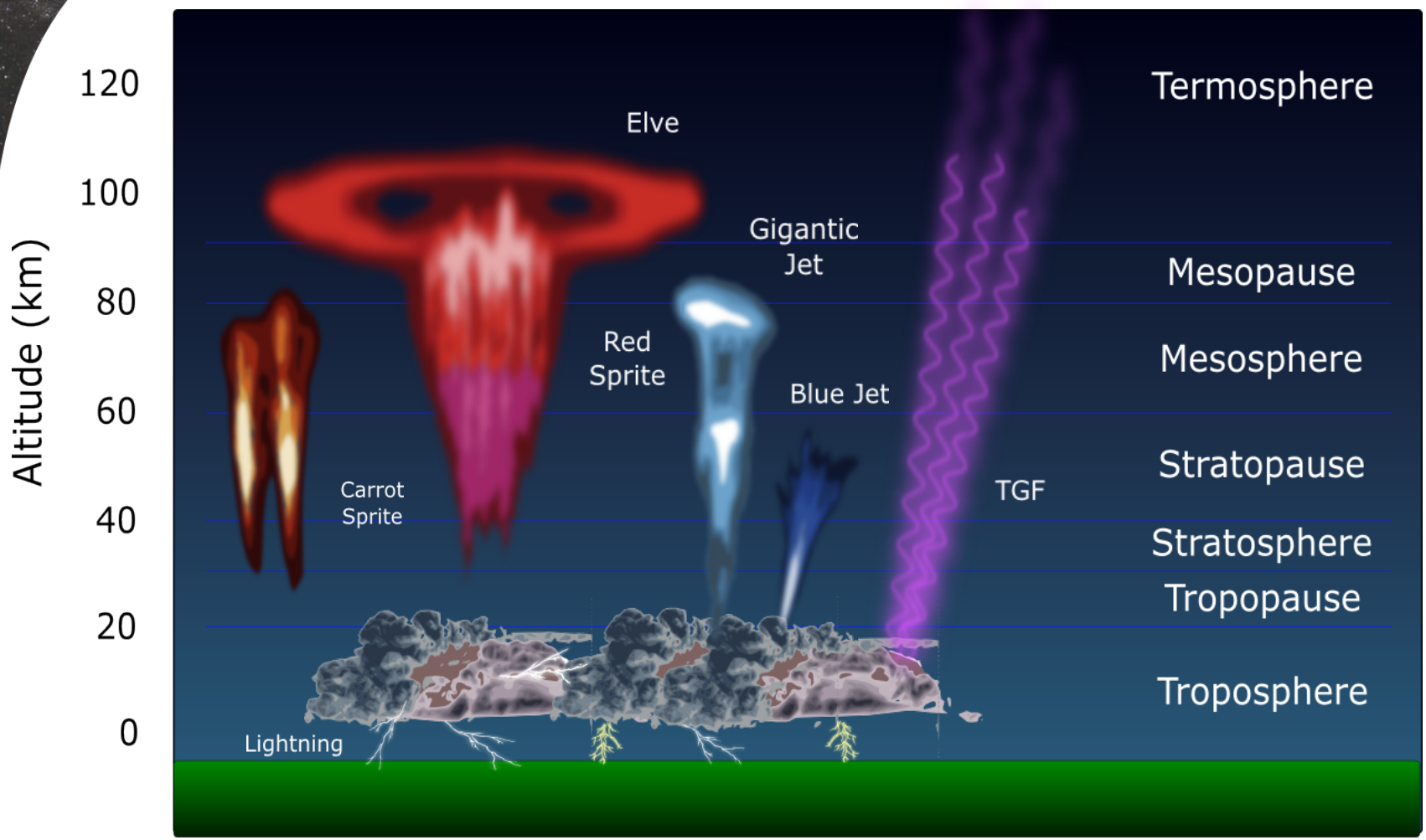
THUNDERCLOUD

- high cloud (cumulonimbus)
  → **charge separation**



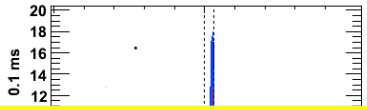


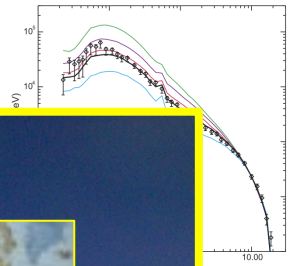
Terrestrial events – Terrestrial Gamma-ray Flashes (TGFs)



Terrestrial events – Terrestrial Gamma-ray Flashes (TGFs)

Main characteristics





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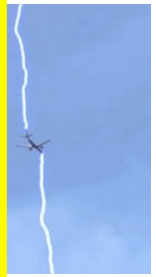
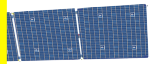
- rad. do
- detect
  - BAT
  - RHE
  - AGI
  - Ferr

Bep





Terrestrial events – Terrestrial Gamma-ray Flashes (TGFs)

AGILE as a TGF detector

2009: from pointing to spinning mode → observation of the Earth

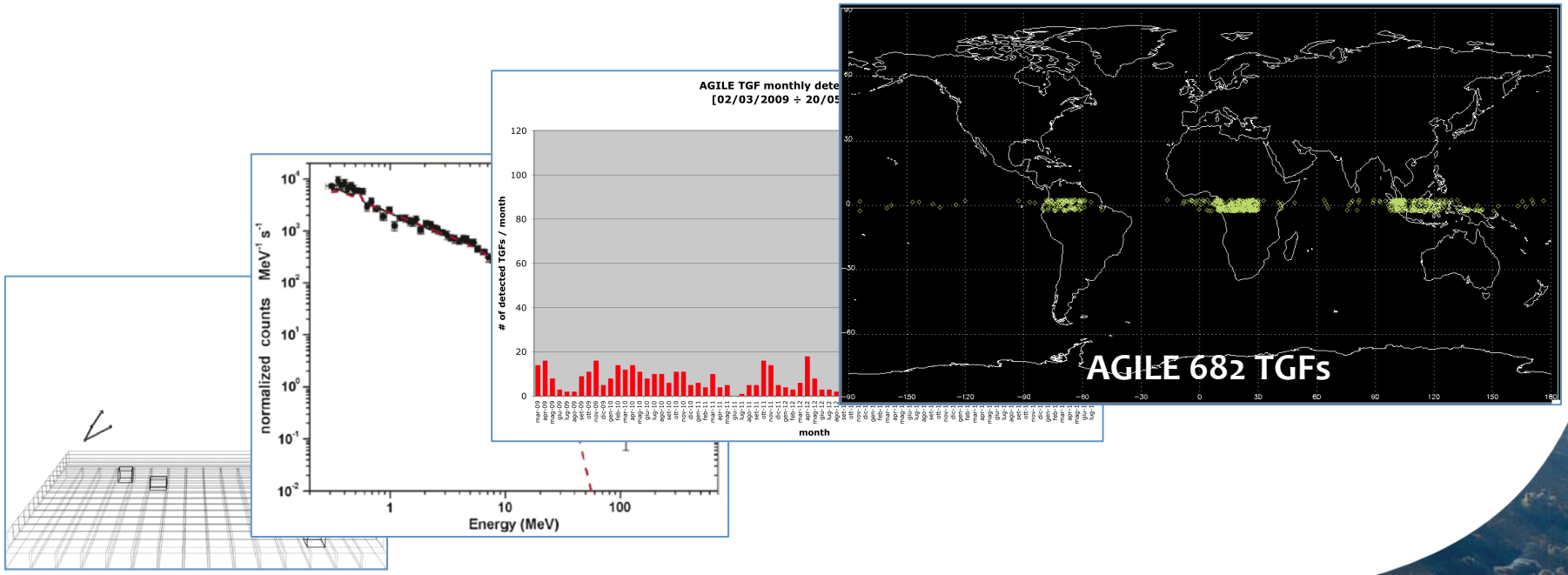
2010: detection of TGFs up to 40 MeV [*Marisaldi et al., 2010a*]

2011: TGF first imaging (accuracy ~ 5° ÷ 10°) with the ST [*Marisaldi et al., 2010b*]

2011: detection of TGFs up to 100 MeV [*Tavani et al., 2011*]

2014: AGILE MCAL on line catalog (**http://www.asdc.asi.it/mcaltgfcat/**)

2015: AC disabled → improvement in TGF detection (multiple TGFs)



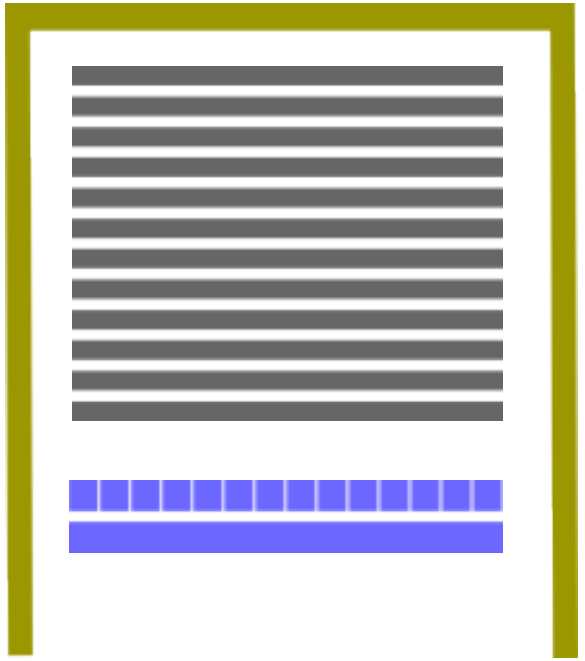
AGILE: the detector

- **Gamma-Ray Imaging Detector (GRID)**

- MiniCALorimeter (MCAL):
  - 350 keV ÷ 100 MeV
  - 30 CsI(Tl) bars + photodiode readout
  - time resol. = 2 μs (γ-by-γ)
    ≤ 300 μs (trigger)

- Silicon Tracker (ST):
  - 30 MeV ÷ 50 GeV
  - 10 W foils + 12 Si trays
  - imaging capabilities

- AntiCoincidence (AC):
  - plastic scintillators + PMT
  - preliminary direction



- **Super AGILE (SA)**

AGILE: the meteo pipeline

A real time pipeline to link meteorological data to TGFs detected by the AGILE satellite

General idea

TGFs detected by AGILE

+

information by meteo satellites

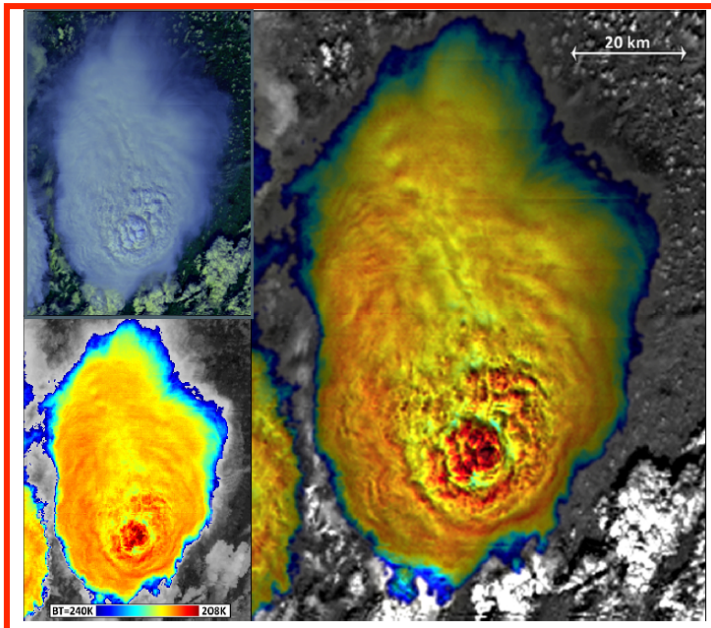


Figure 6: 2012-07-05, 12:07 UTC, Suomi NPP VIIRS, central-east Germany. Top left: RGB color composite of bands I1 (0.6 μm), I2 (0.9 μm) and I5 (11.5 μm). Bottom left: color-enhanced I5 (11.45 μm band) BT 208-240 K image. Right: sandwich product of I1 and color-enhanced I5 BT 208-240 K image.

Global Convective Diagnostics (GCD) algorithm is used to identify convective cells:

deep convection is present

if GCD = T_b^{IR}-T_b^{WV} ≤ 1 K

AGILE: the meteo pipeline

A real time pipeline to link meteorological data to TGFs detected by the AGILE satellite

General idea

TGFs detected by AGILE + information by meteo satellites

Why?

1) check whether convection is really present within the TGF production region

2) perform for the first time a follow-up of the TGF-producing thundercloud

3) understand whether just a specific class of thunderstorms produce TGFs

4) provide a real time (= fast-as-possible) service to alert aircraft networks