Analysing a convective event (09 June 2012) with satellite, radar and lightning data

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Data providers:

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Lightning data: **Bálint Varga**
Hungarian Meteorological Service

Croatian radar images: **Petra Mikus**
Croatian Meteorological and Hydrological Service

Outlines

- Applied remote sensing data
- About the case
  - What happened?
  - Synoptic situation
  - Environment
- How to characterise **the evolution of the structure** of the studied severe storm?
  - Features indicating possible severity
  - Temporal evolution of satellite, radar and lightning data
  - Temporal and spatial analyses in storm relative system
    - Area of low level downdraft
    - Area of updraft/mesocyclone
    - **Distribution of the lightning strokes**
- Conclusions

Complex case study of a severe storm
Main emphases on remote sensing data : satellite, radar, lightning

Technical information on the applied remote sensing data

<u>Satellite</u>

METEOSAT SEVIRI RSS

<u>Lightning</u> – data of LINET network - operationally used at OMSZ

European Lightning Detection NETwork (~130 sensors in Europe, 7 sensors in Hungary)

every stroke: time [ms], location, height, type (CC, CG), current amplitude estimation [+/-kA], location uncertainty

It detects at low frequency (very long wave)

It **discriminates CC from CG strokes according their heights** (software based on high precision time measurement)

(ratio of CC and CG in Hungary ~ 1:1)

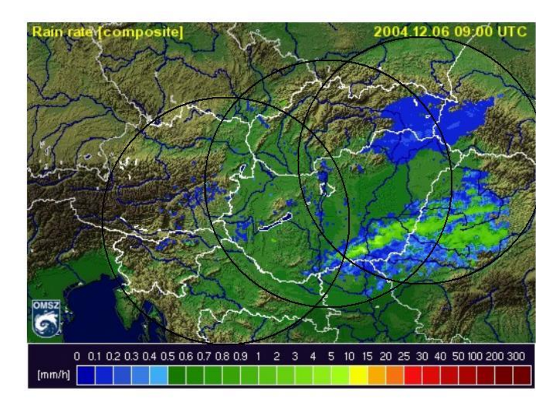
<u>Hungarian radar system (in 2012)</u>

Three Doppler dual-polarization DWSR radars working at 5,3 cm wavelength

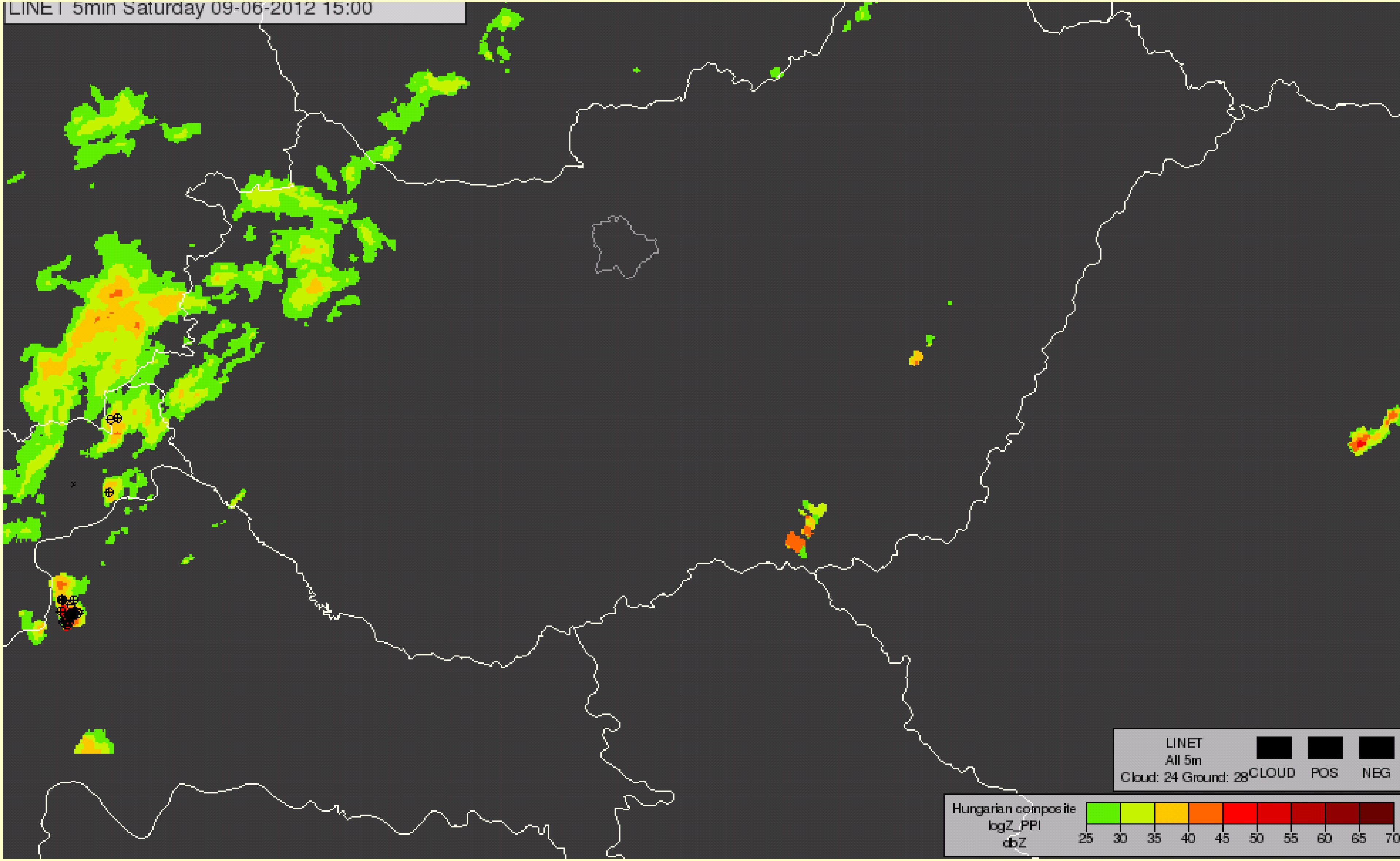
- **5 minute** reflectivity data at 10 elevation angles (0.0, 0.5 ,1.1, 1.9 ,3.0 ,4.7, 7.0, 10.0, 14.2, 20), in 240 km radius area
- **15 minute** wind measurement in 5 elevation angles (1.1, 1.9, 3.0 ,6.5 ,14.0), in120 km radius area (3 minute shift)

<u>Volume data</u>→ products with 1x1 km resolution

- For each radar: PPI, CAPPI, Cmax, VIL, ETOPS
  + Hungarian composite images (Cmax, VIL, ETOPS)
- Doppler wind measurements

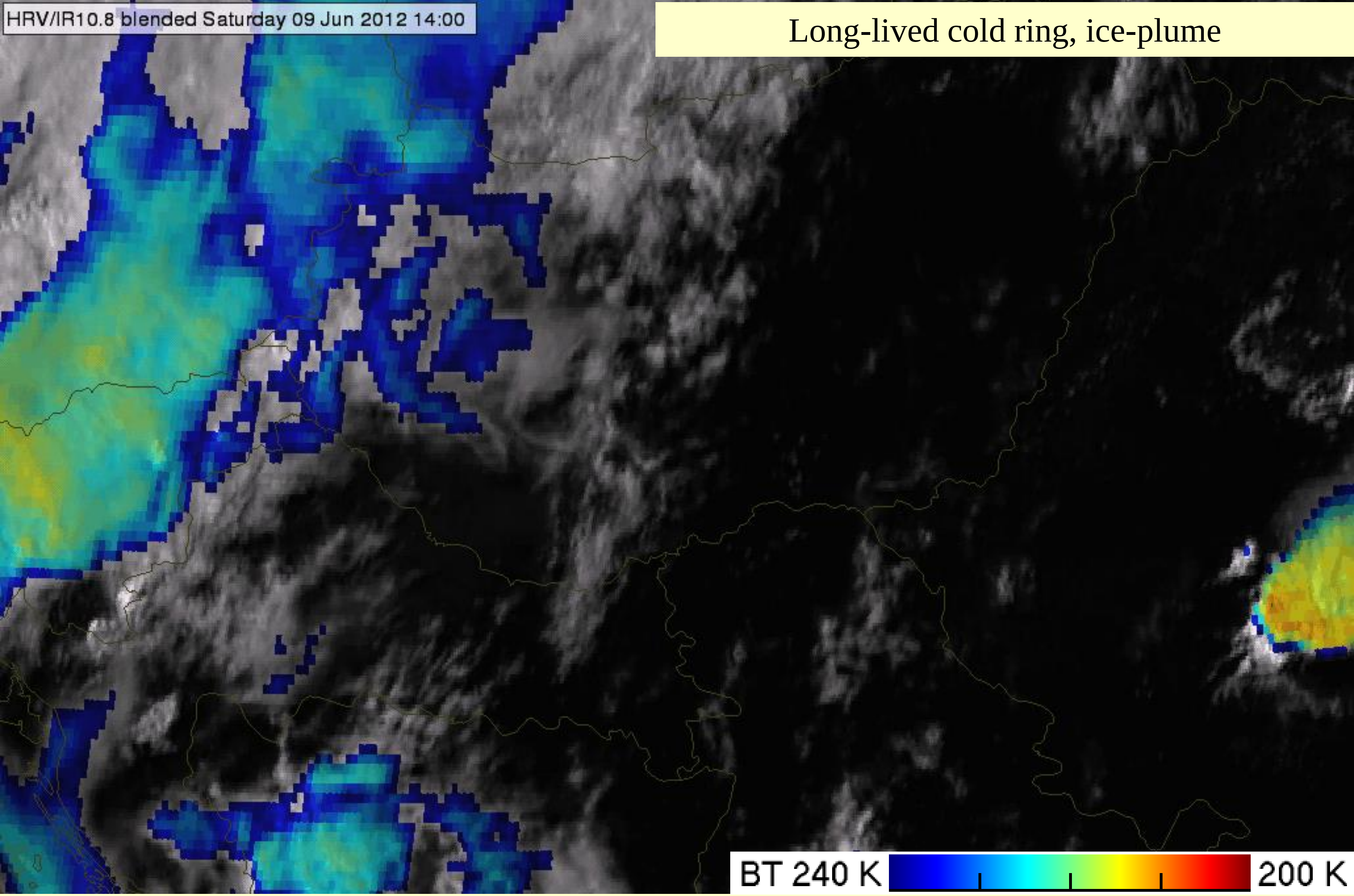


Convective system ~13-14 UTC - ~23:00 UTC It initiated over Croatia, propagated over Hungary
We studied the supercell, which initiated close to the Hungarian Croatian border until it interacted with a multicellular cictem at east of Hungary (15:50 - 21:50 UTC)



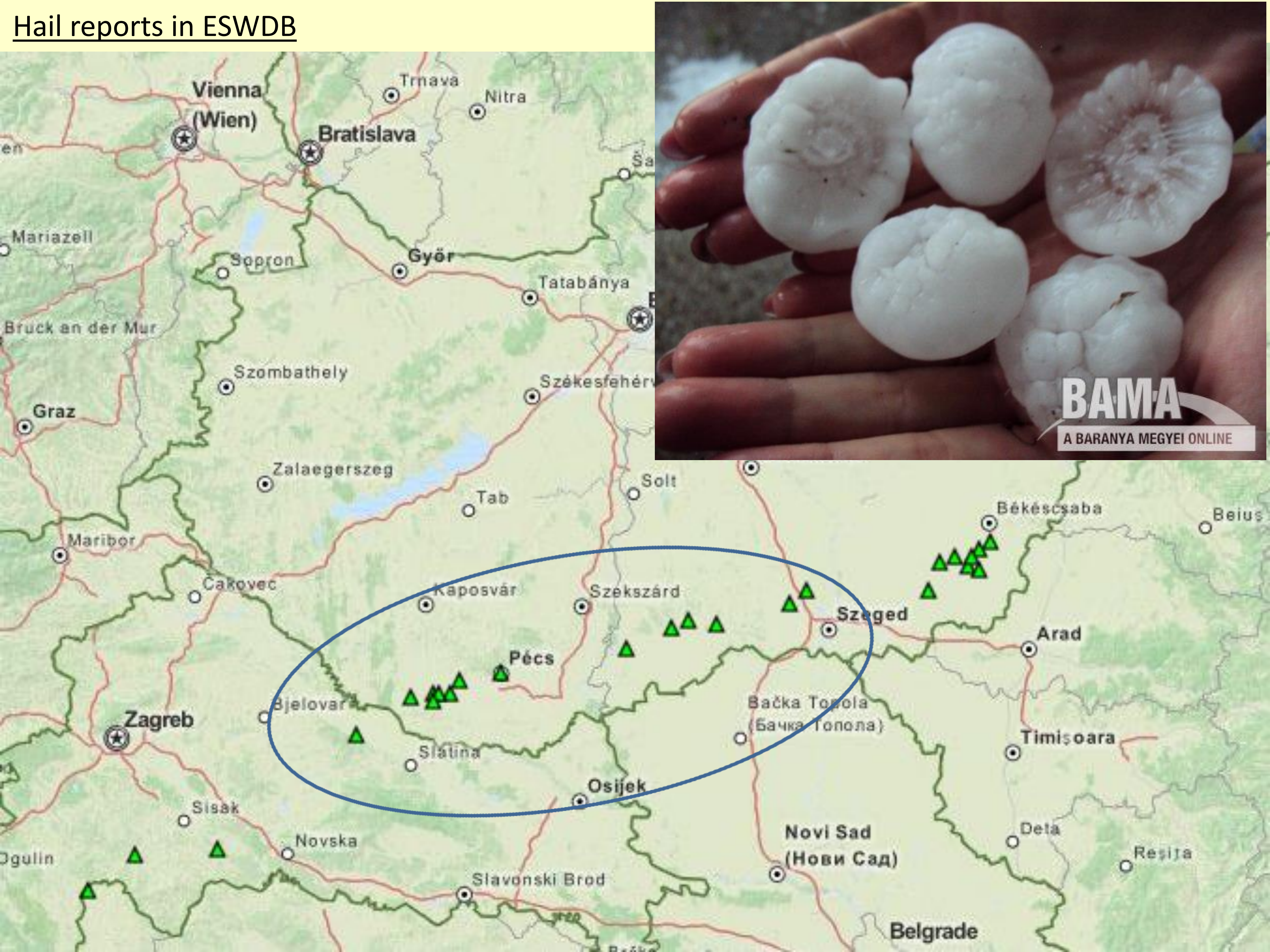
Animation created from Column maximum composite from 3 Hungarian radars overlaid with lightning strokes (09 June 2012, 15-23:55 UTC)

Long-lived cold ring, ice-plume

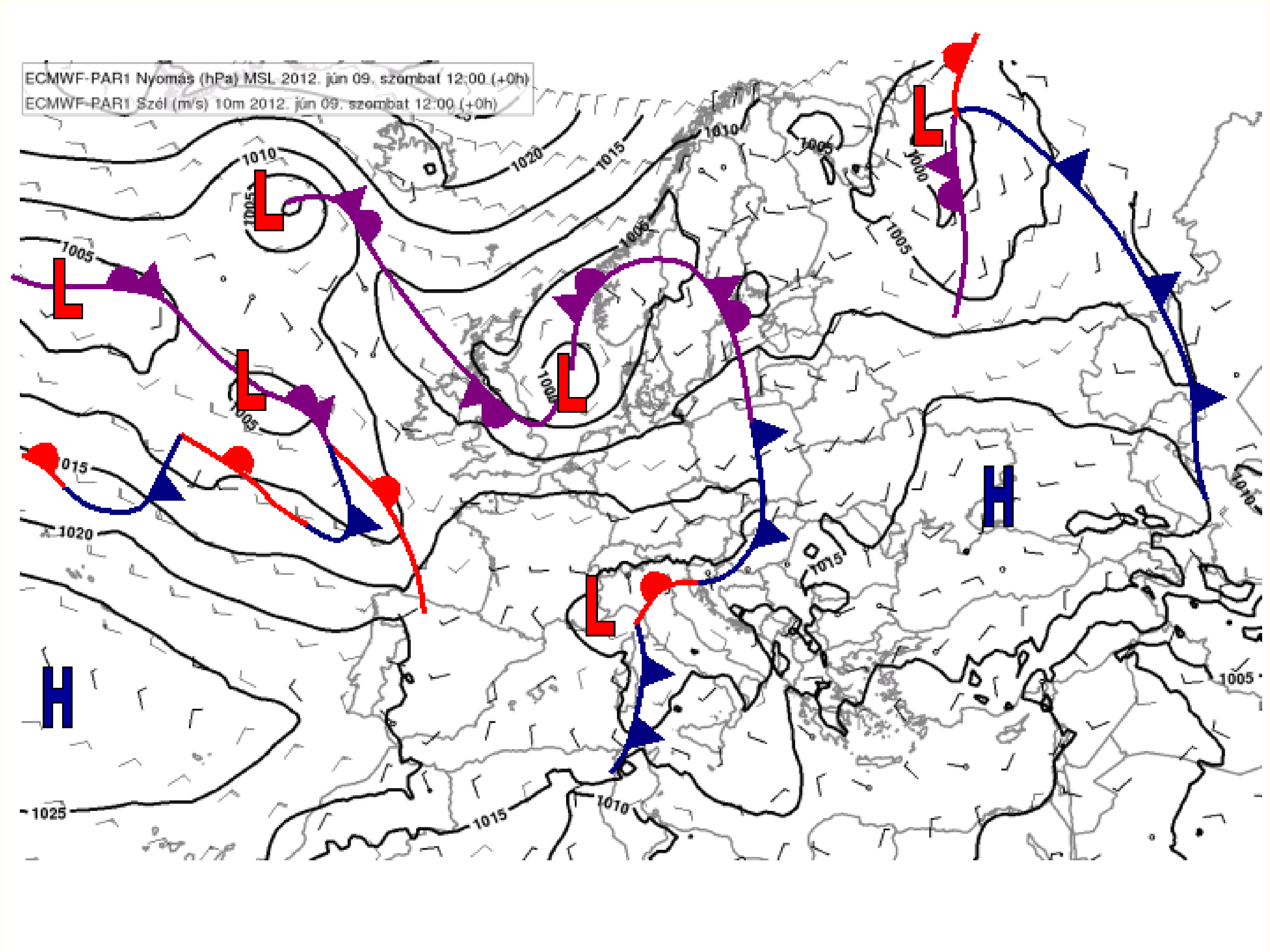


Animation created from HRV/IR10.8 blended (14:00 - 17:50 UTC) and IR10.8 (17:55-22:00 UTC) images

<u>Hail reports in ESWDB</u>

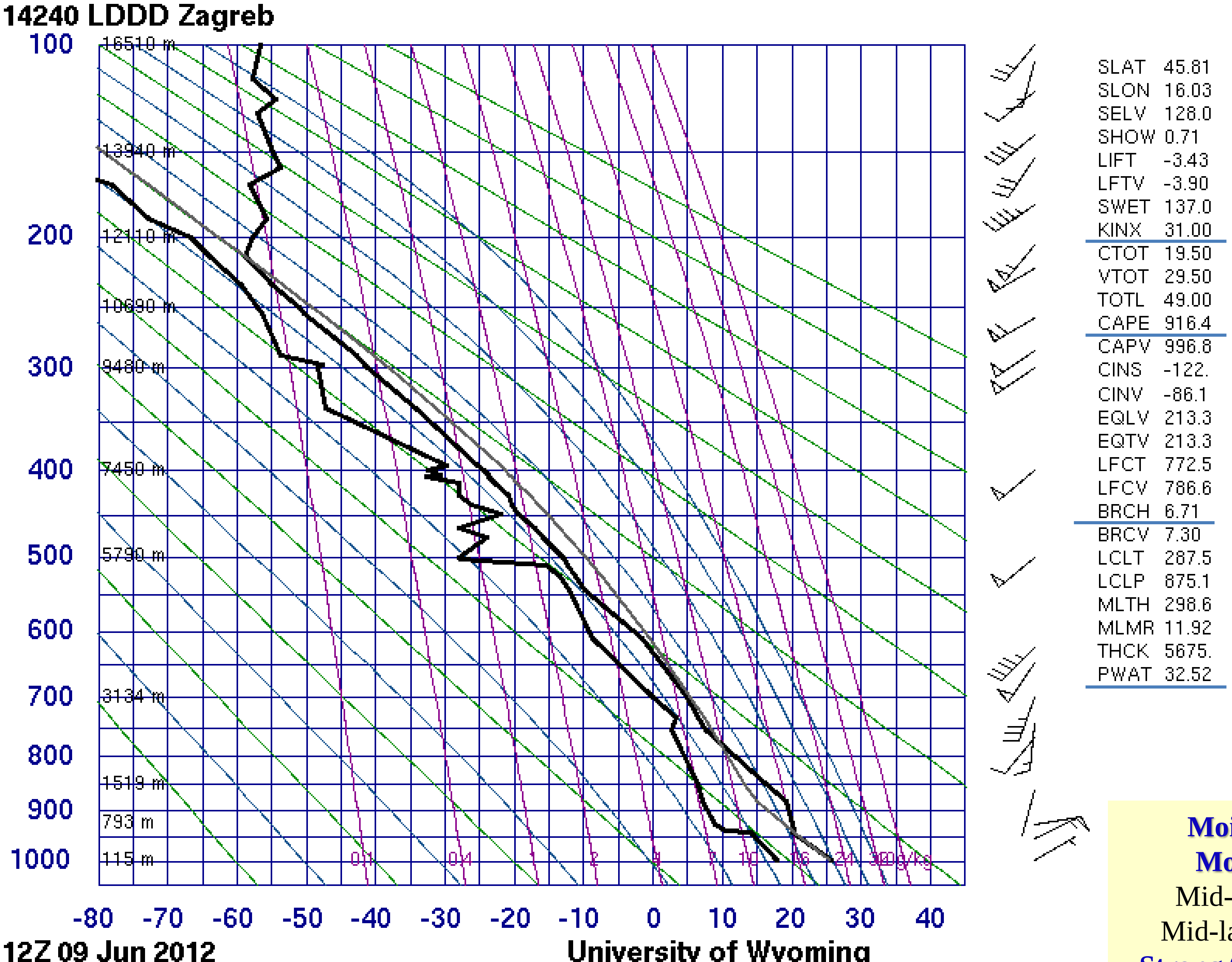


Synoptic situation - The studied convective system developed at a wavy front (or just ahead it).



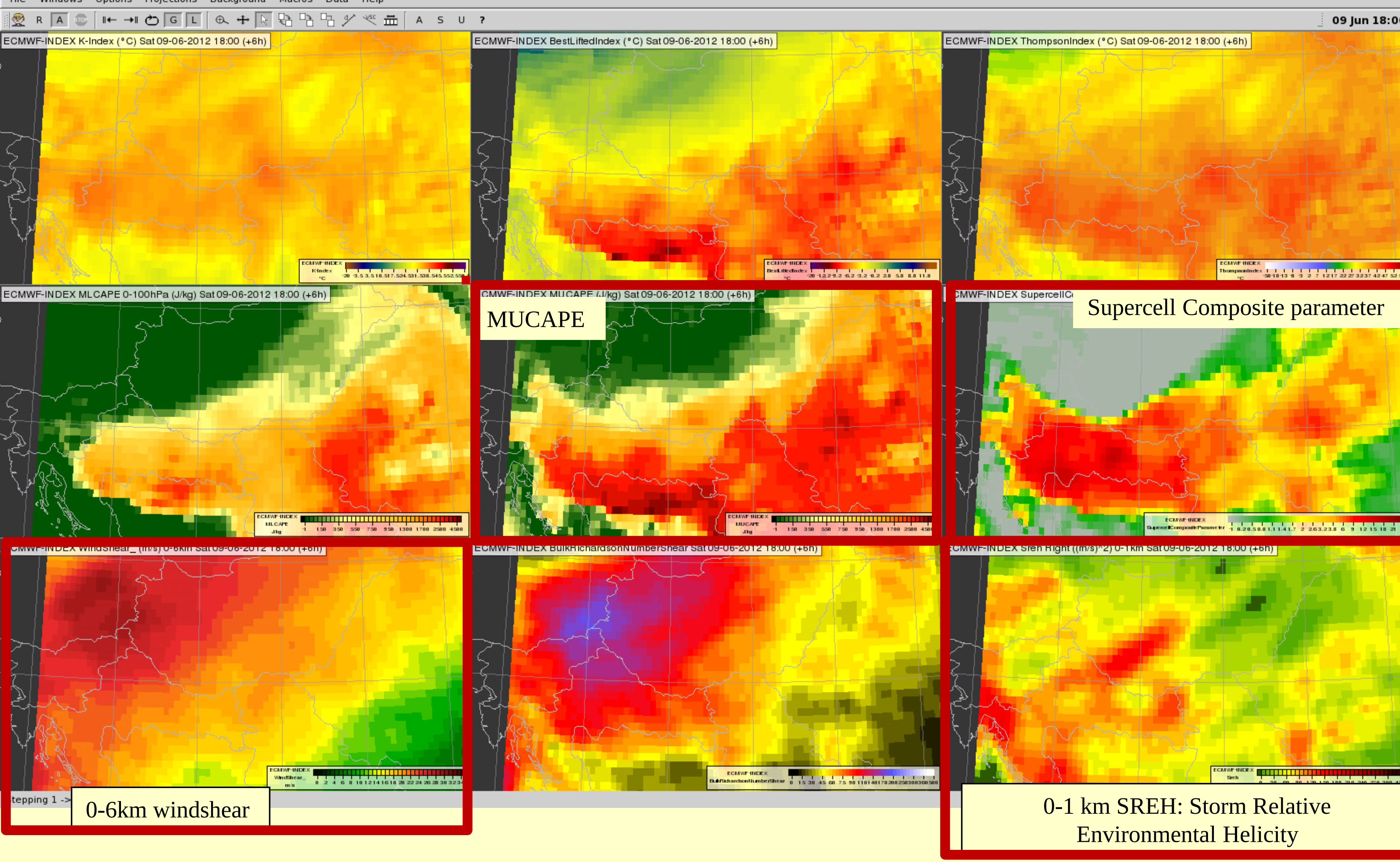
Environment

Radiosonde measurement at Zagreb, Croatia



Moist atmosphere
Moderate CAPE
Mid-layer is unstable
Mid-layer is not too dry
Strong 0-6 km wind shear

The 0-6 km wind shear is strong compared to CAPE → Bulk Richardson Number is 6.7



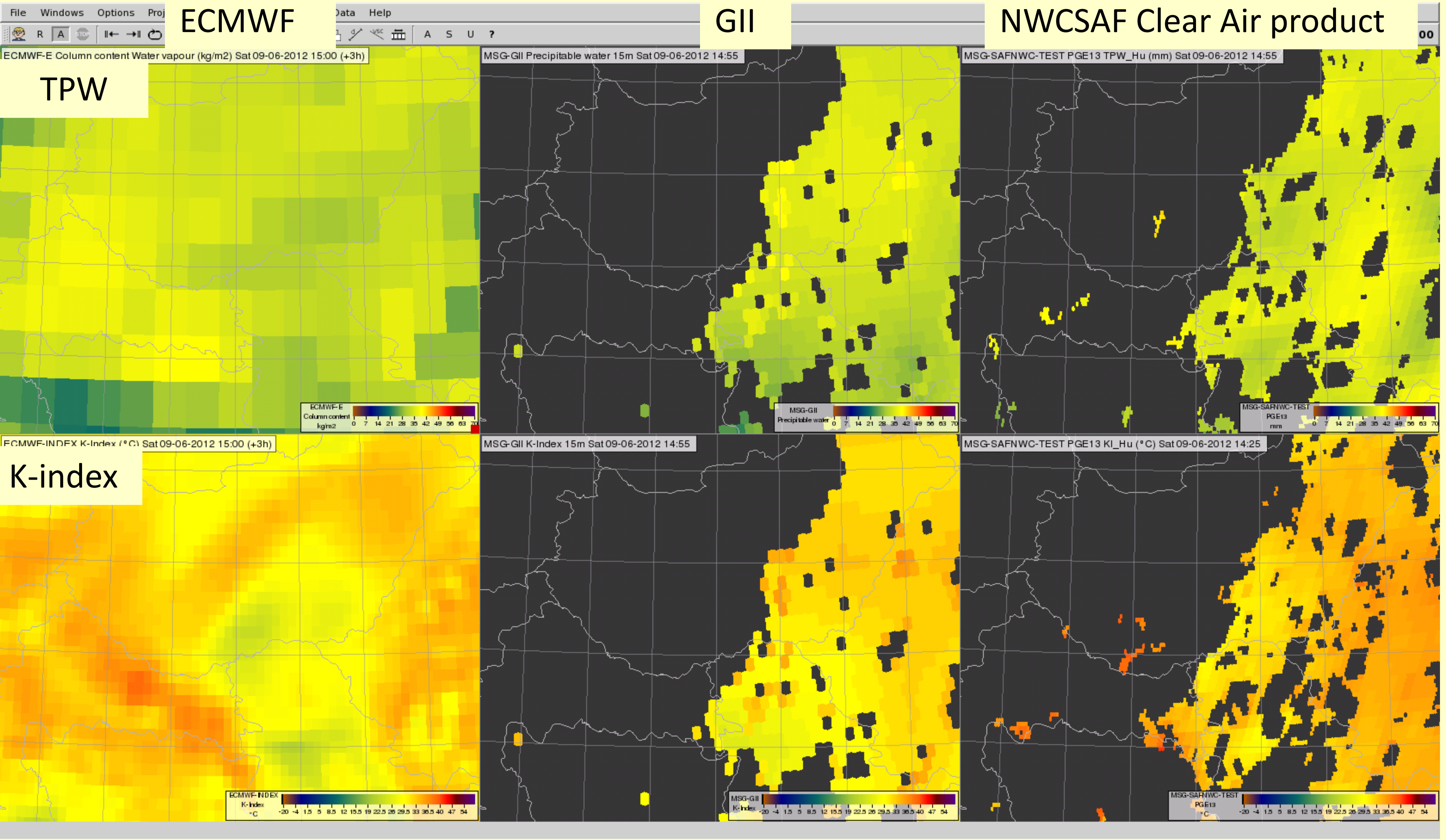
ECMWF analyses (12 UTC) and forecasts (for 15 and 18 UTC) - convective parameters

Moderate CAPE at the southern part of Hungary
Strong 0-6 km wind shear
High Supercell Composite Parameter

Favorable environment for severe storm development

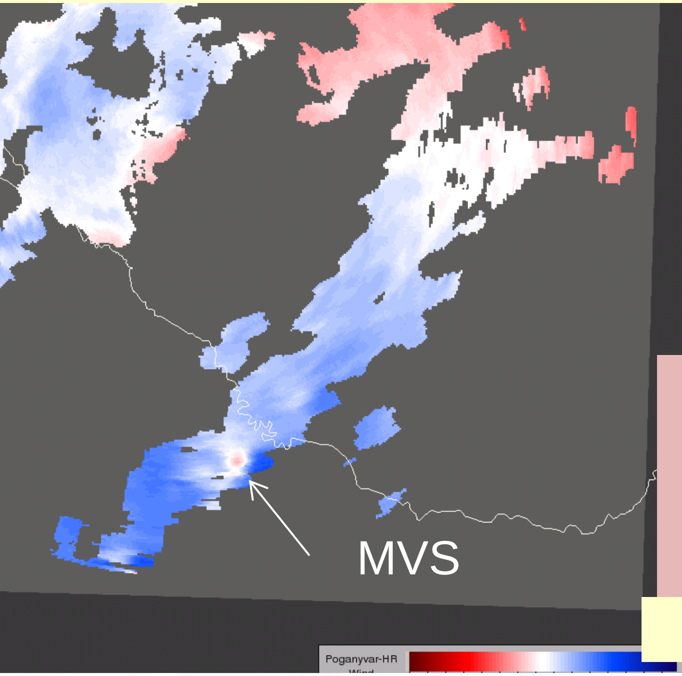
TPW ~36-40 mm

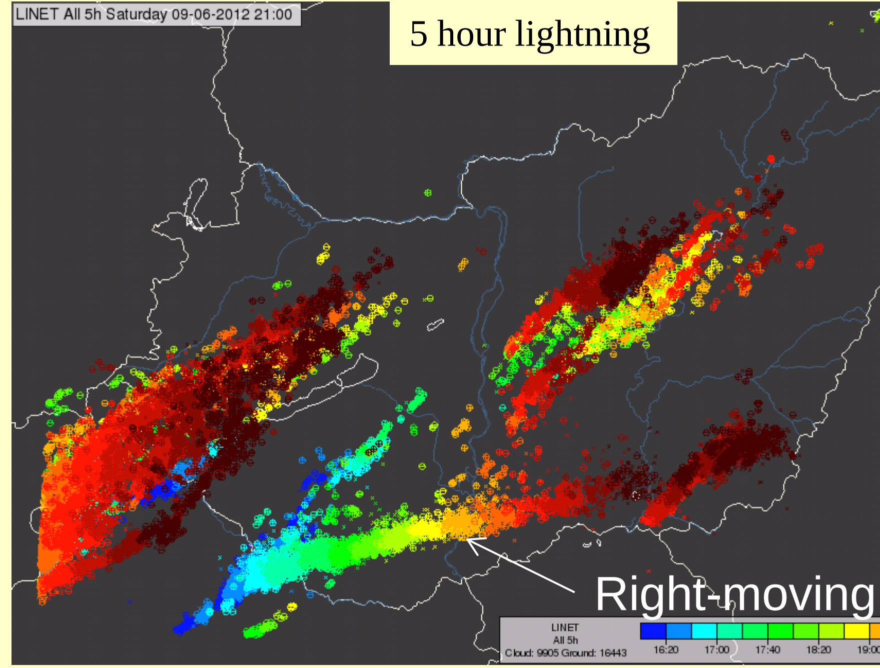
K-index ~30-40 C



The satellite derived TPW and K-index fields were slightly higher than the forecasted ones

Right mover
Long lifetime (> 8 hours)
Mesocyclone detected by Doppler radar
Photos, Hail reports
↓
Supercell





How can we characterize the temporal evolution of its structure based on remote sensing data?

MVS - Mesocyclonic vortex signature

Satellite data - Meteosat SEVIRI (RSS)

Features indicating possible severity of the storm

High cooling rate

(seen only when it overrun the anvil **–3,9 K/5** minute in the first 5 minute period)

Right mover – visually seen, NWCSAF HRW image

Extreme cold overshooting tops (OT) (down to -66.3 °C)

After ~16:20 UTC big elevated dome with complex structure – with long life time

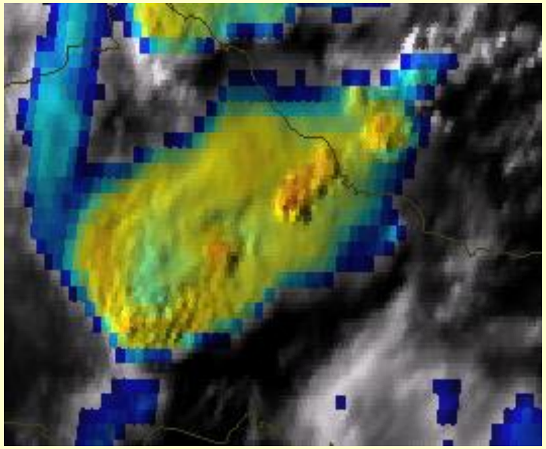
Long-lived Cold ring (more then 8 hours)

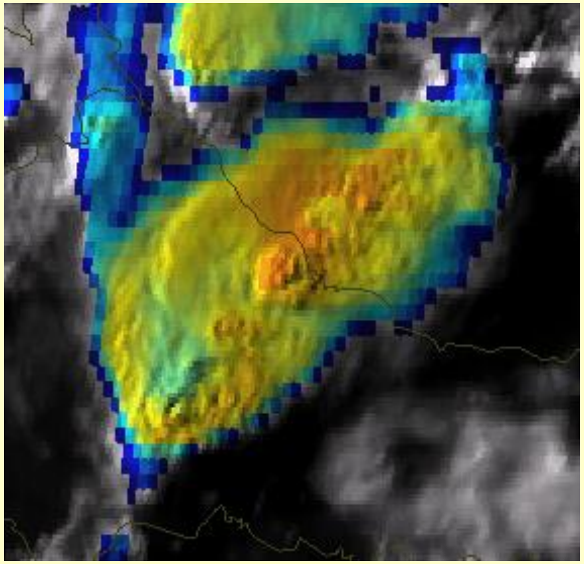
High difference between the coldest BT10.8 of the ring and the warmest BT10.8 of the warm spot

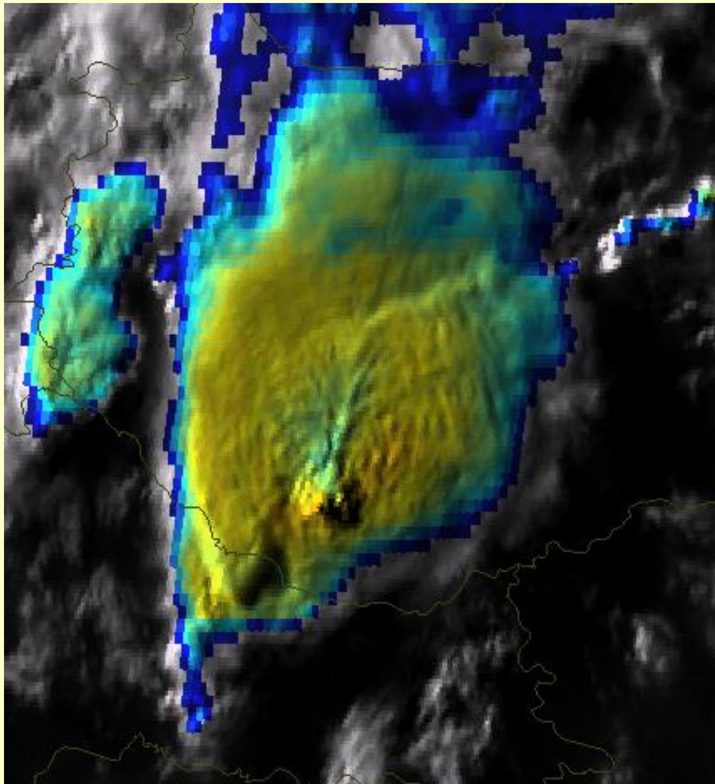
Over anvil **ice-plume**

Small ice crystals on the cloud top (Day Microphysics and Severe Storms RGBs, Re)

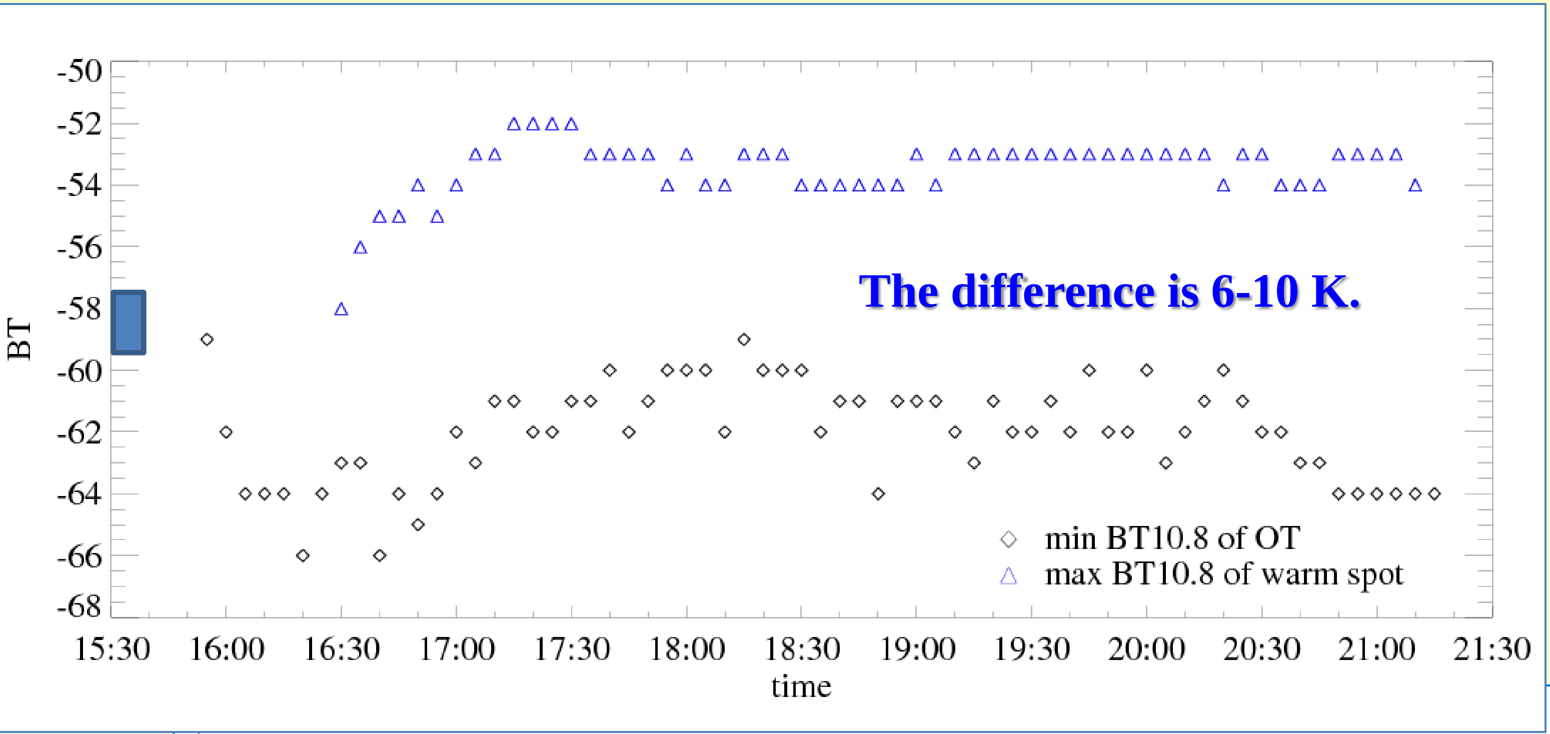
HRV/IR10.8 blended images 16:03,16:25, 17:33 UTC



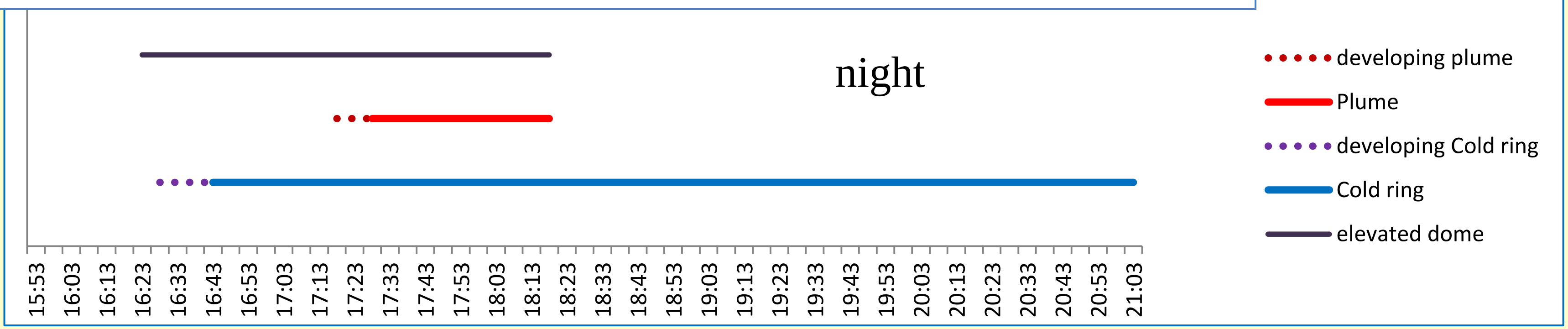




Temporal evolution: min BT10.8, max BT10.8 of warm spot (5 minute data)



Tropopuse temperature of the environment (based on radosonde measurement at Zagreb, Bukarest and Vienna: -57.3 -59.9 °C)



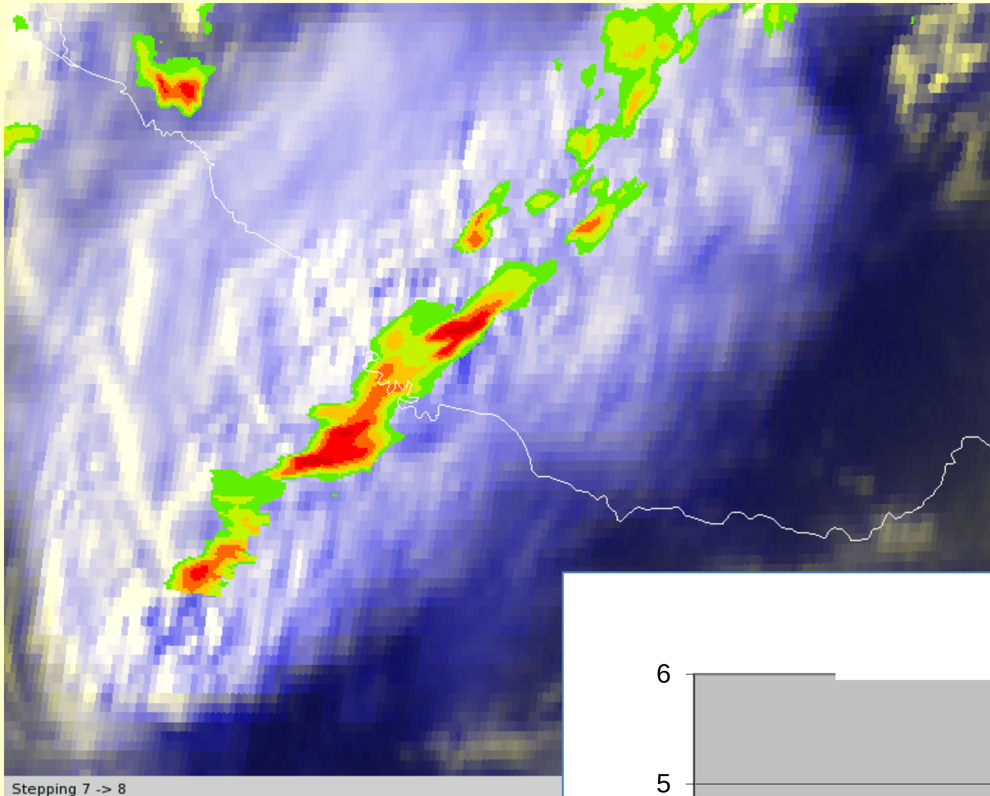
The minimum BT10.8 is jumping. The OTs might be in different phases.

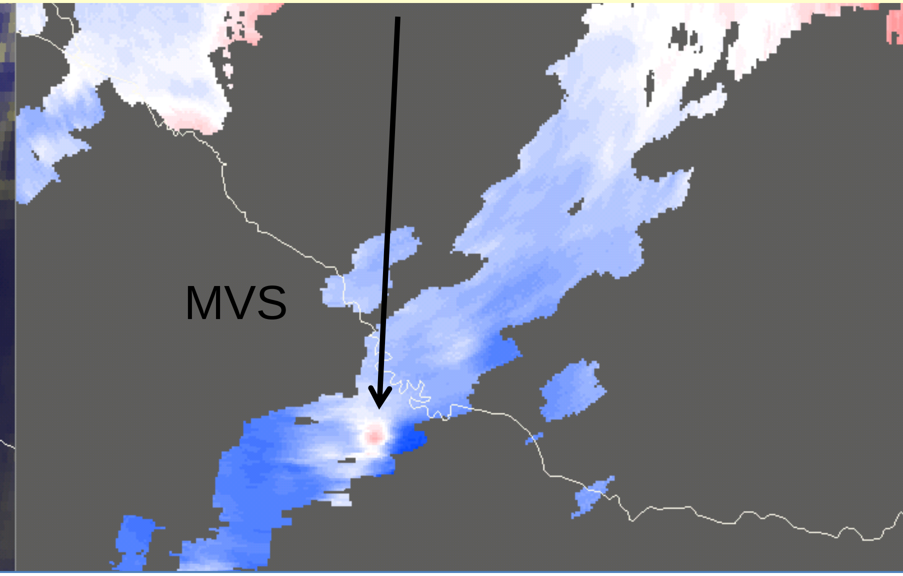
The max BT of the warm spot is more smooth.

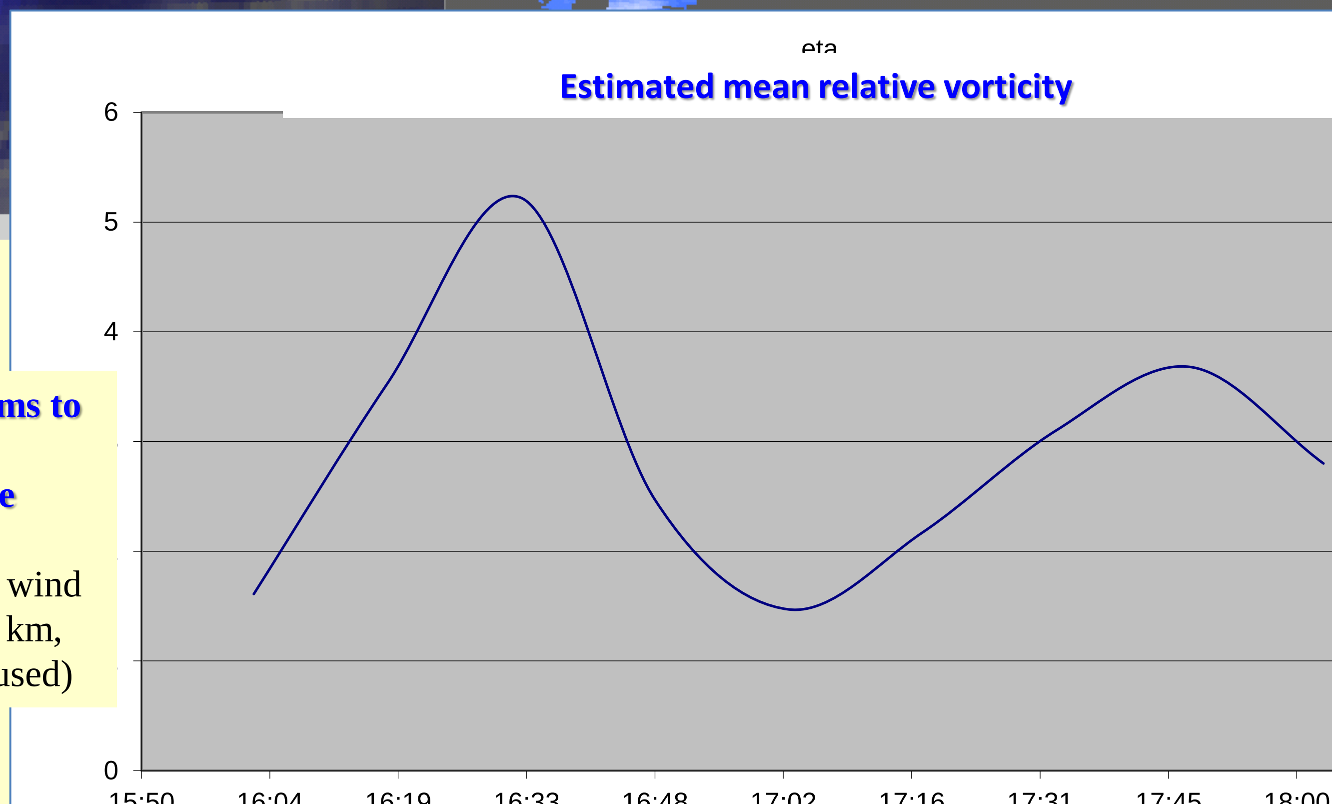
The difference is 6-10 K.

Their difference depend on the storm relative wind and the updraft strength, (and the phase of the OT oscillation).

Radar data – detection of radial Doppler velocity and estimation of the mean relative vorticity





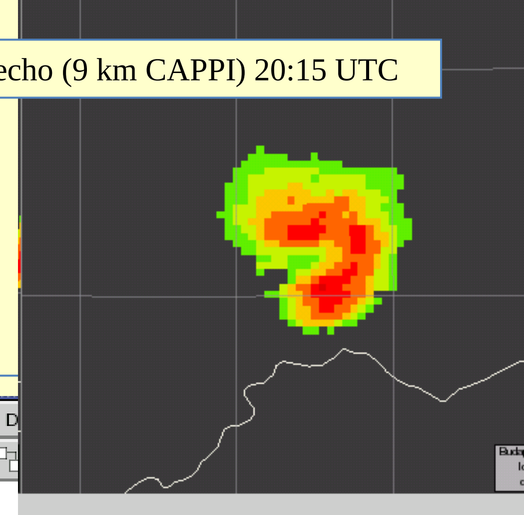


→ **The mid-level mesocyclone seems to have two phases**
It was higher in the first phase

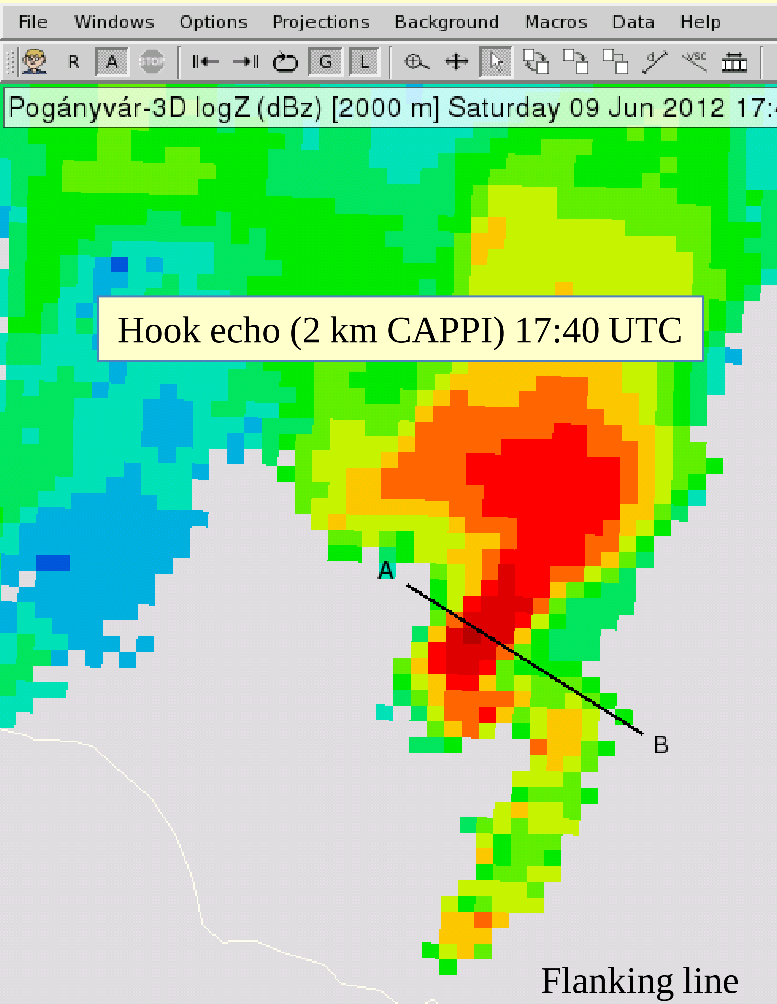
The detection height of the Doppler wind in the mesocyclone center was 2.5 km, later 3-3.5 km (PPI measurements used)

Radar features indicating possible severity of the storm

- Doppler wind feature - **MVS** – indicating **rotation**
- **Right mover**
- **Long-lived intense** radar cell (more than 8 hours)
  - **High reflectivity values (up to 61.5 dBz)**
  - **High VIL values (up to 76 kg/m^2)**
- **Hook, bow and WER/BWER echos**

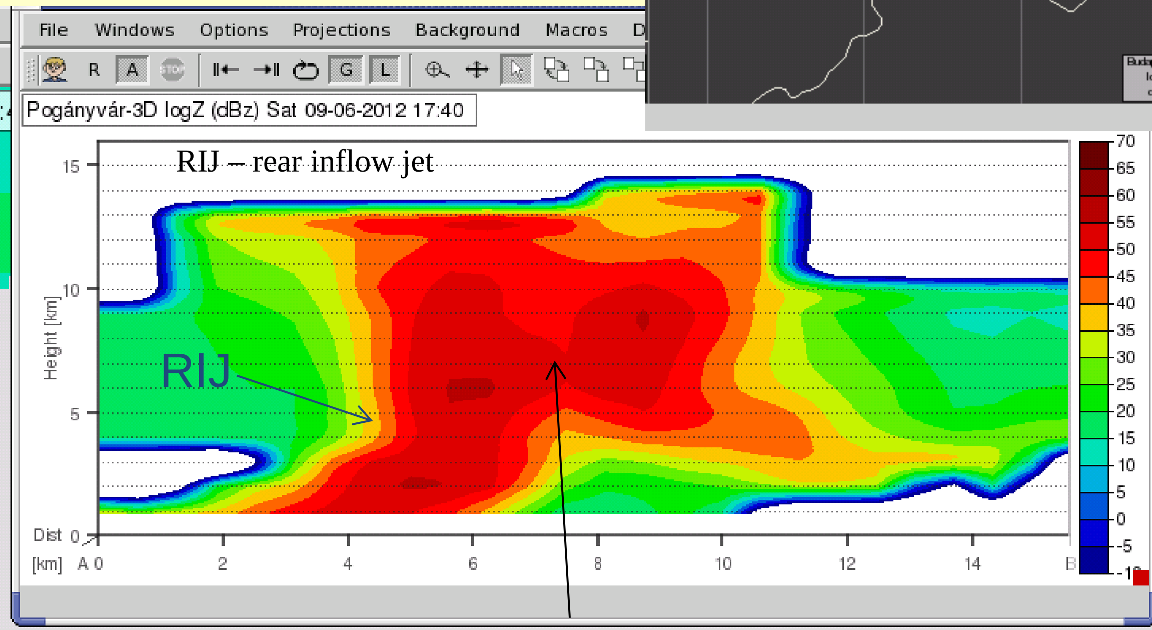


Bow echo (9 km CAPPI) 20:15 UTC

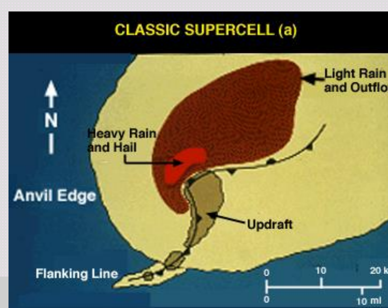


Hook echo (2 km CAPPI) 17:40 UTC

Flanking line

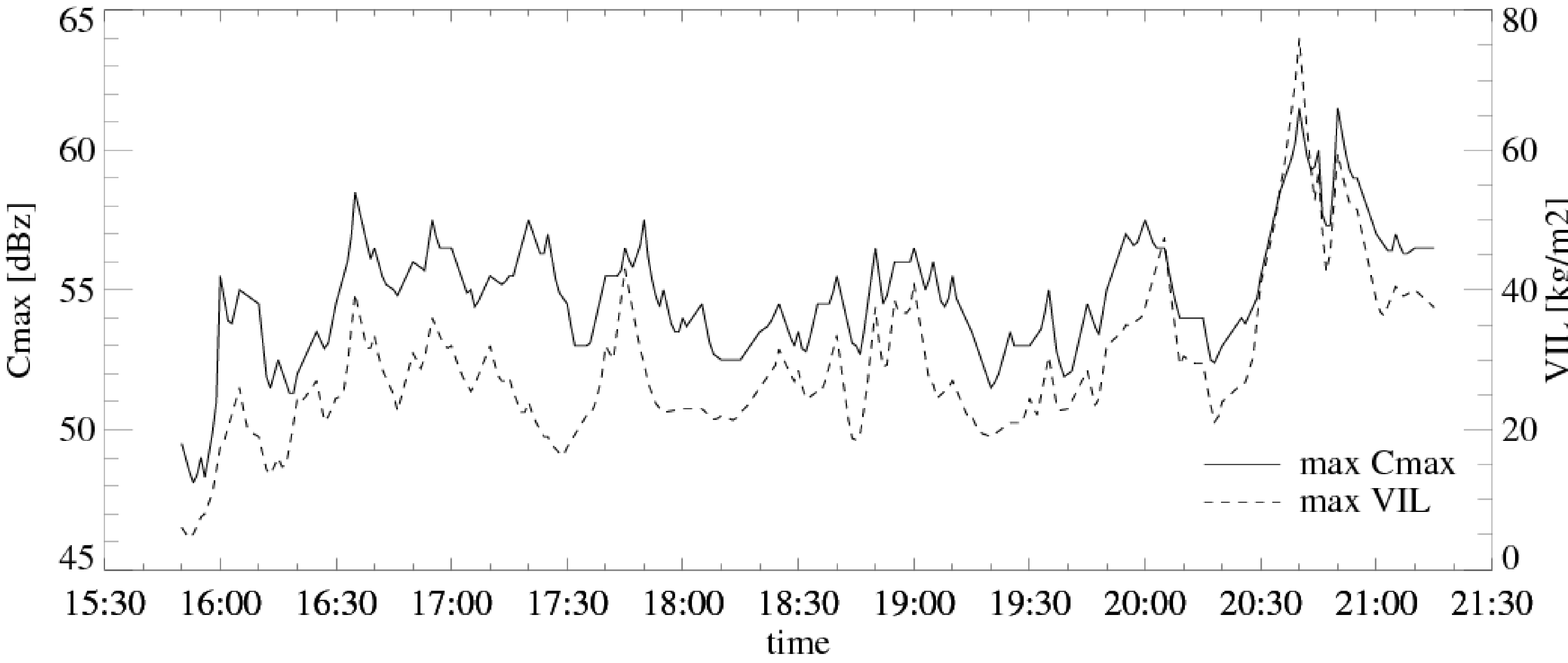


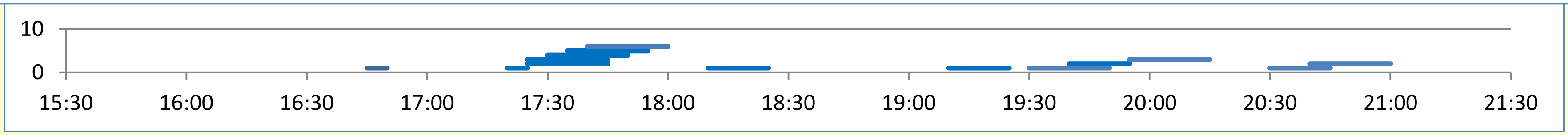
WER+BWER echo (vertical cross section) 17:40 UTC



The radar cell was **tracked** (visually) - 5-minute radar data were **interpolated to 1 minute data**

Temporal evolution of the maxima of Cmax and VIL values





Hail report (ESWDB)
time intervals based on VIL values

Lightning strokes (total, CC,CG+,CG-) belonging to the studied radar cell were separated

Lightning features indicating possible severity:

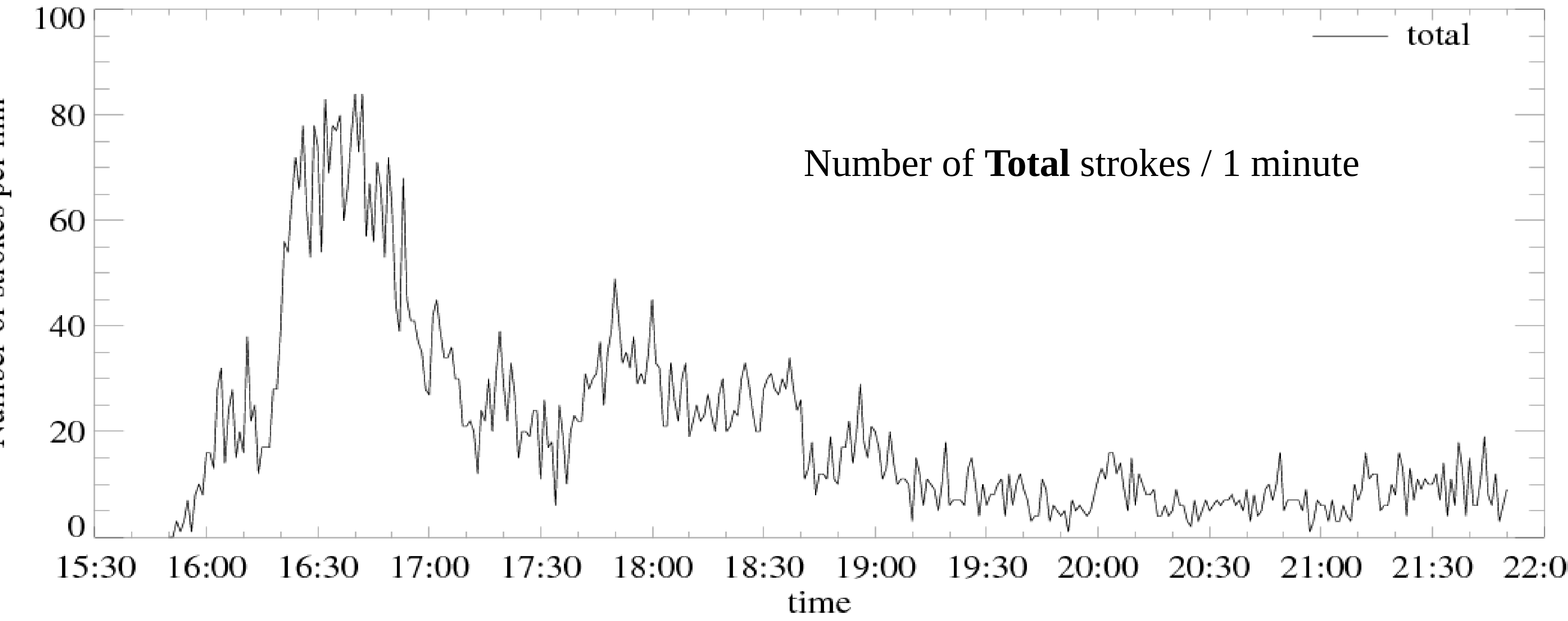
'Lightning jump' - sudden increase of the number of strokes

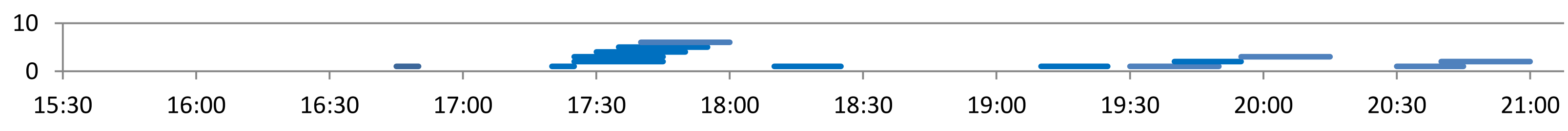
High stroke frequency (up to 80 strokes/minute)

Right mover

Two significant maxima, the first one is higher

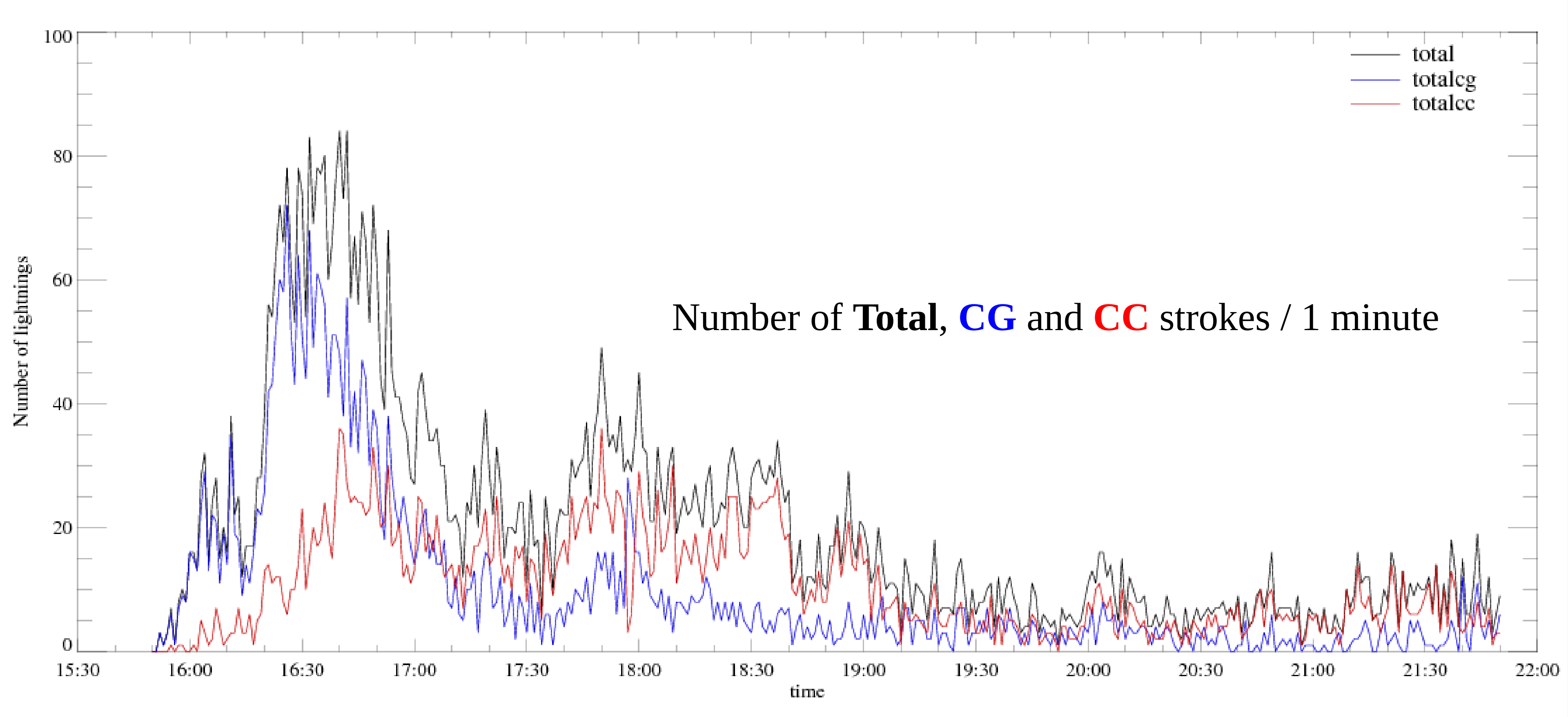
Lightning activity depends on
- microphysical properties,
- strength of updraft



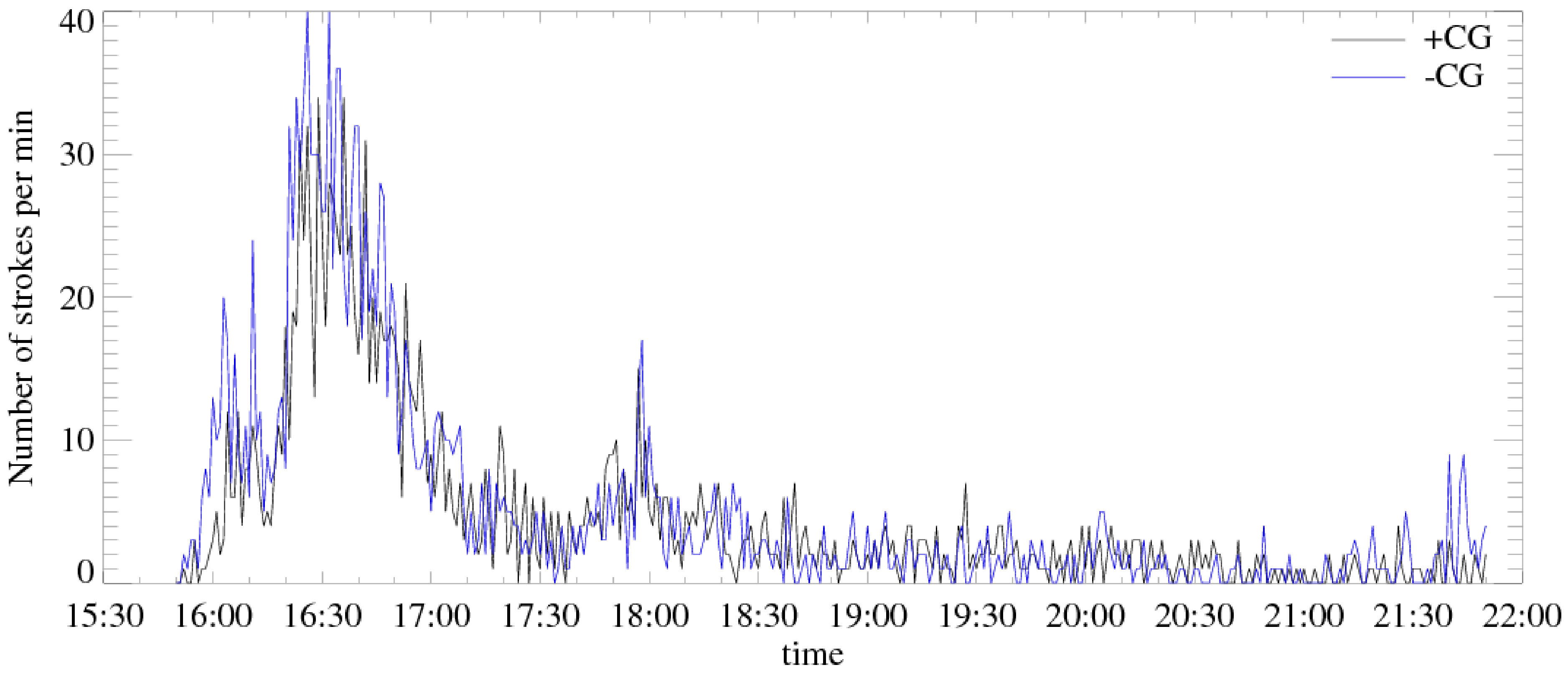


Hail reports

At the beginning more CG than CC, later more CC than CG

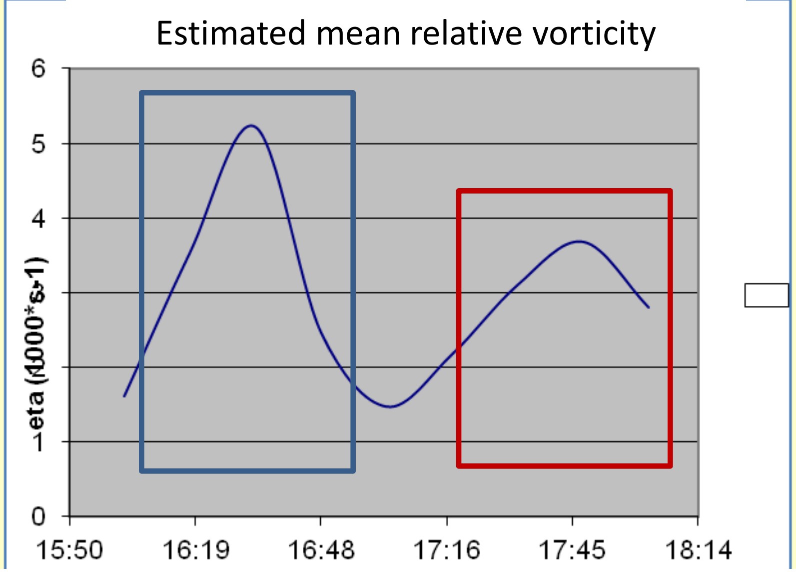


Number of **CG+** and **CG-** / 1 minute

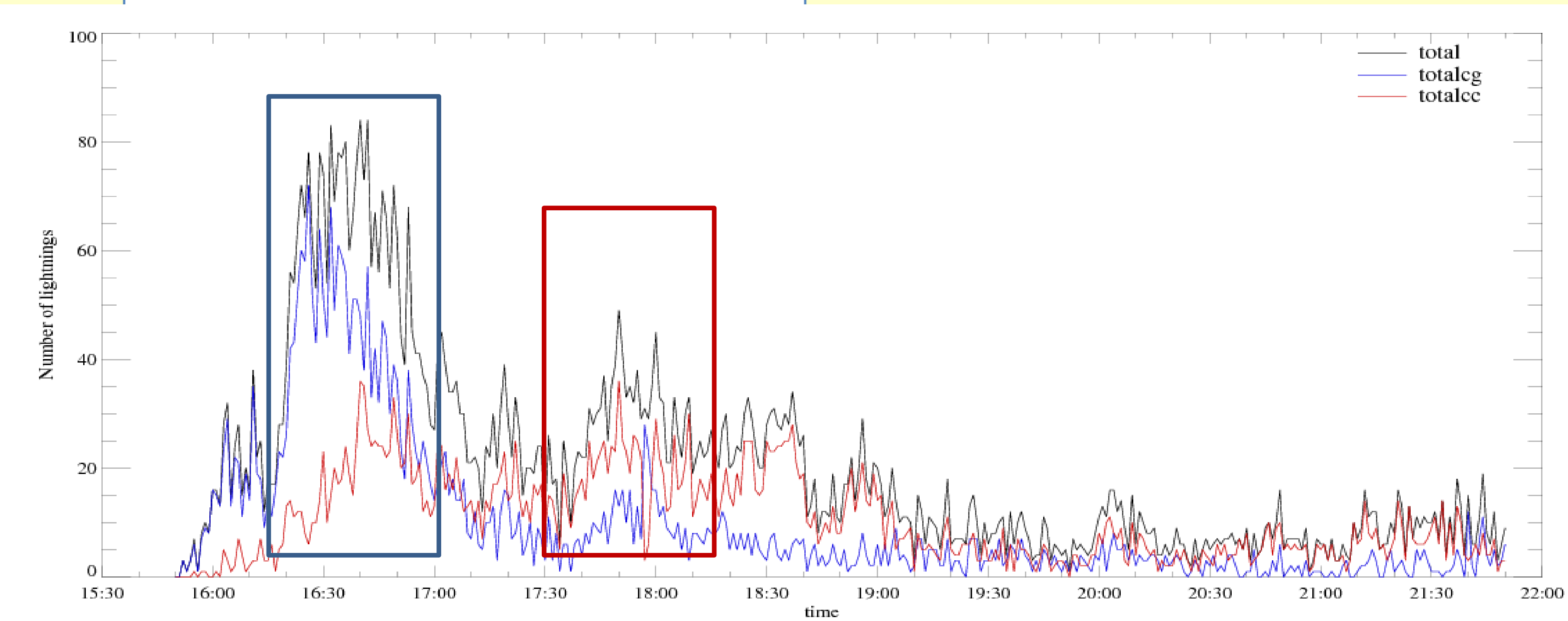


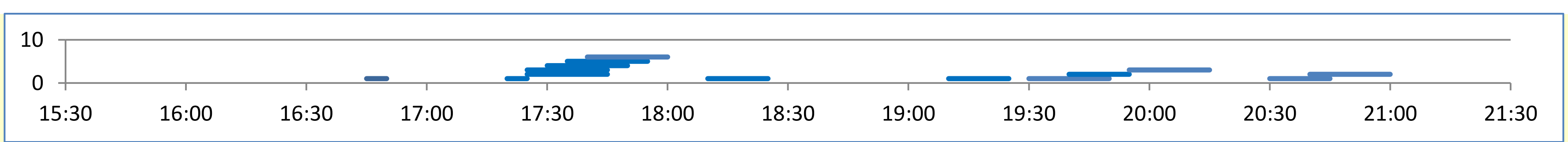
About the same number of CG+ and CG- (except the very beginning, around 16 UTC)
The second significant maximum of the total stroke curve is less significant here

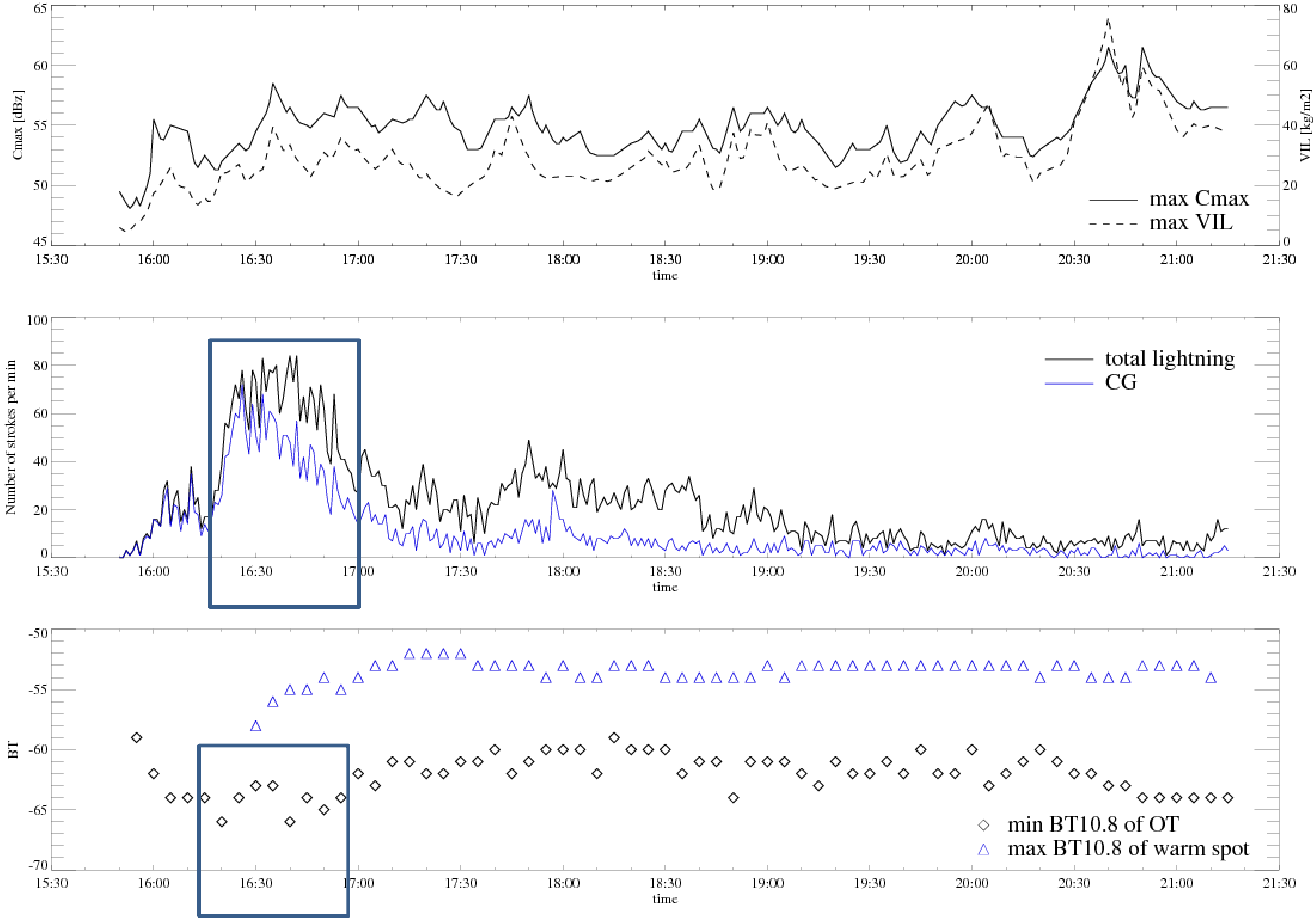
Very high CG+ rate – can be a signature of a severe storm (MacGorman, Burgess, 1994)



Both the estimated mean relative vorticity and the total lightning activity has two maxima – more or less in the same time periods



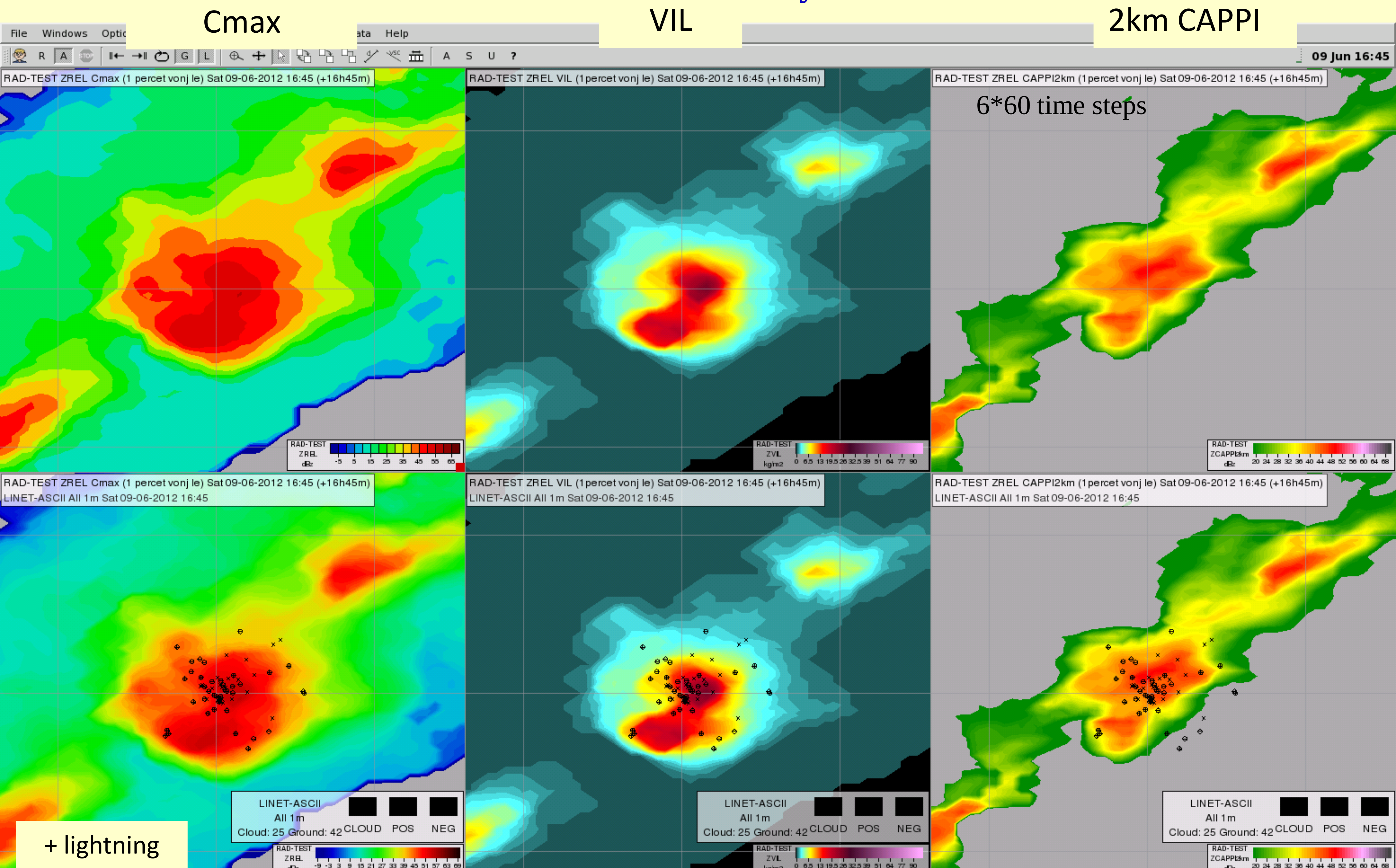




The coldest BT10.8 and the more intense lightning activity periods are almost the same

Analysing the storm structure , time- and spatial distribution of respective parameters

The 1-minute radar (Cmax, VIL, CAPPIs) + lightning data were visualised in storm-relative coordinate system

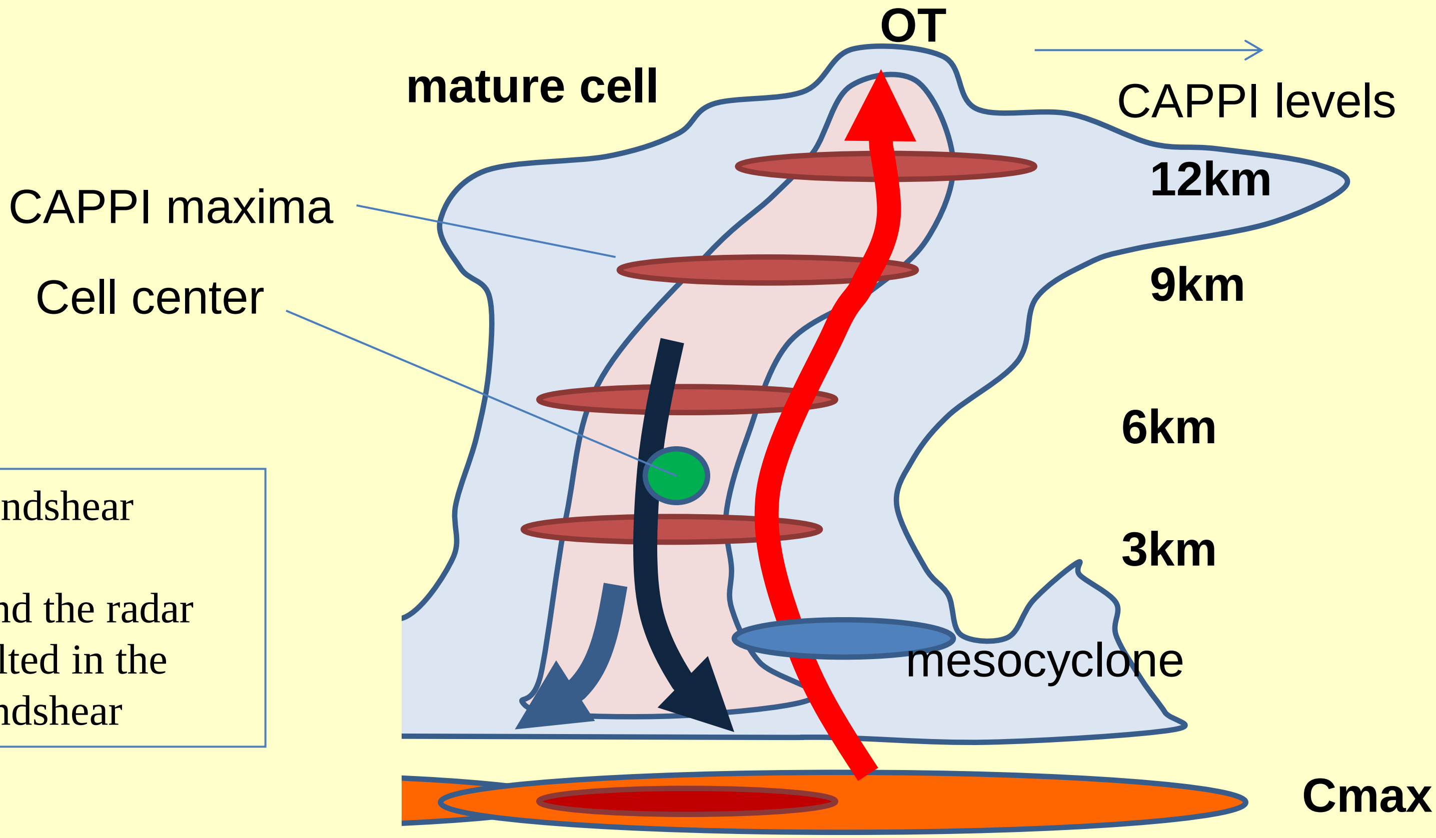


to map the area of **precipitation** / (low/mid level downdraft**)** and
the area of – **updraft/mesocyclone**

2km CAPPI – represents the area of precipitation

How to represent the likely area of **updraft/mesocyclone**?

- From satellite data –
    - OT – upper part of the updraft (at the cloud top level)
- From radar data –
    - 'Mesocyclonic Vortex Signature' in the Doppler velocity measurement (mid-level info, if any)
    - WER/BWER echo – likely location of mid-level updraft/mesocyclone



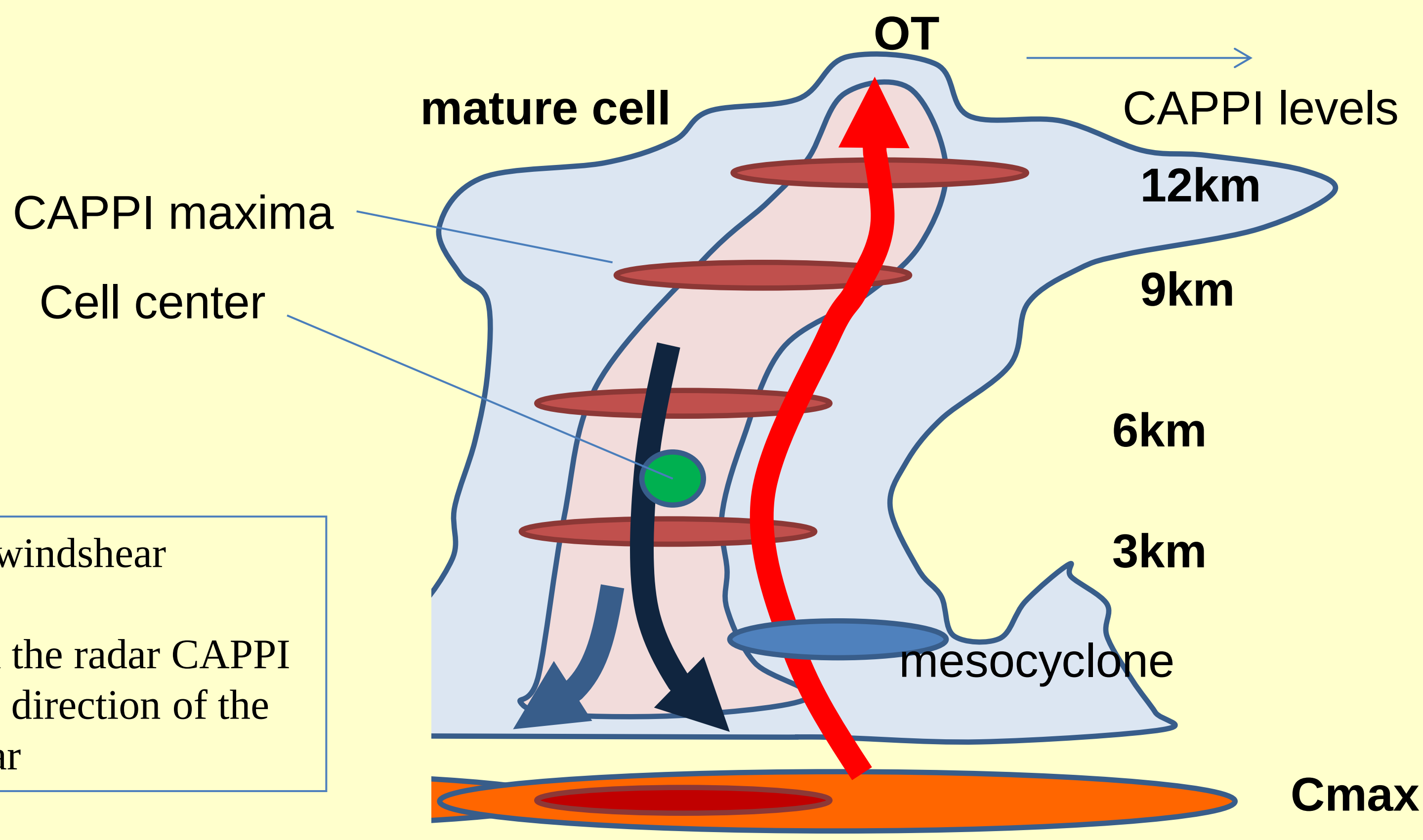
In case of strong windshear
↓
the storm, its updraft and the radar CAPPI maxima are tilted in the direction of the windshear

A parameter to highlight the areas where the radar reflectivity increases with height, which is typical for the updraft region

WER2 --- a parameter to find area of WER/BWER echos
definition:
WER2 = [max(C6,C7) – min(max(C2,20),max(C3,20))]*[ge(C2,0)*ge(C3,0)]
Where C2,C3,C6,C7 = CAPPI at 2,3,6,7 km

maximum of 6 and 7 km CAPPIs - minimum of 2 and 3 km CAPPIs

(but at least 20, because we do intend not emphasize the impact of very weak echos.
(if C2 and C3 are not negative). Many other variations of this parameter are possible.



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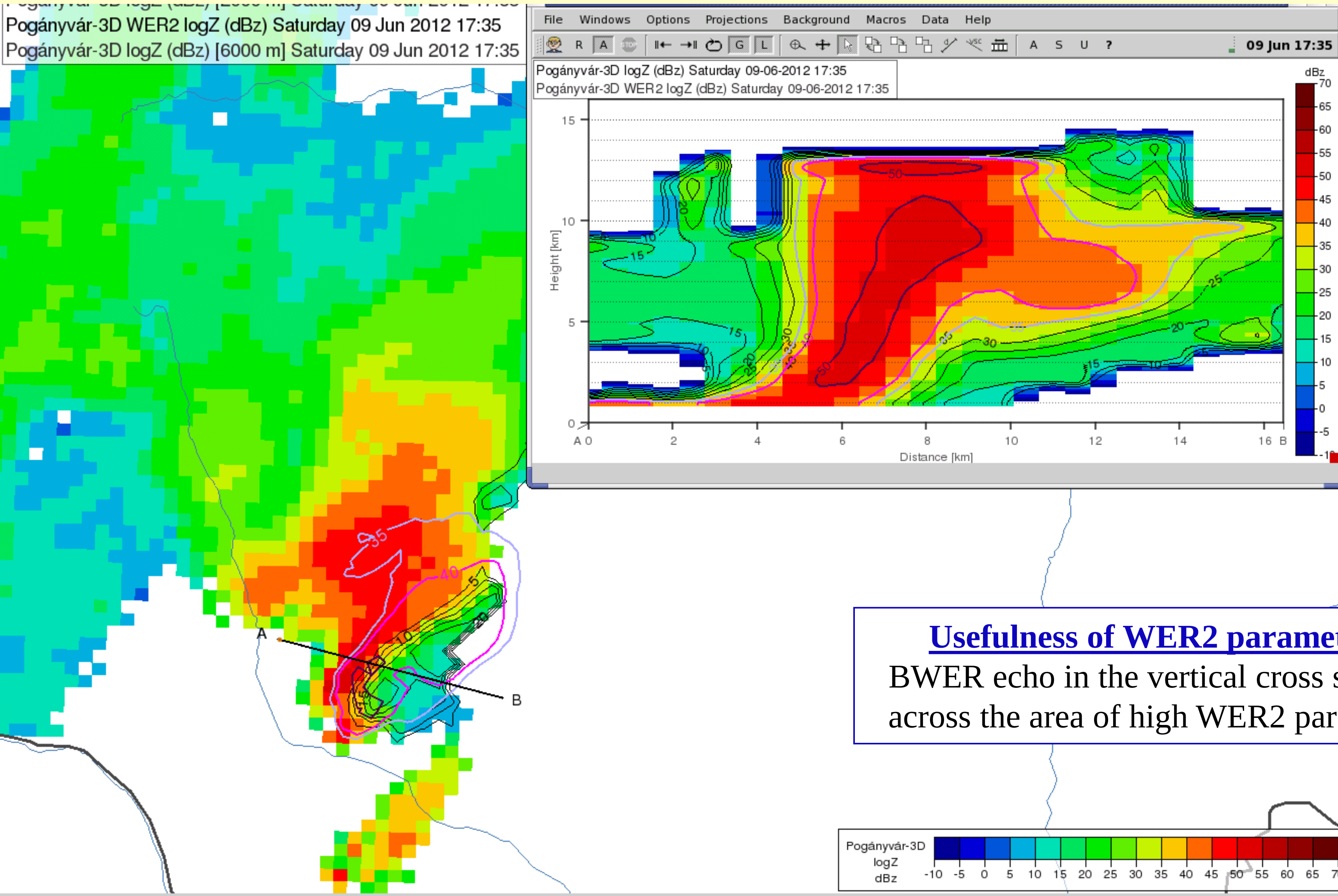
the storm, its updraft and the radar CAPPI maxima are tilted in the direction of the windshear

WER2 --- parameter helps to find WER/BWER echos

- 2 km CAPPI image - colour shades
- 6 km CAPPI isolines – coloured isolines
- **WER2 parameter – grey isolines**

Vertical cross-section along the AB solid black line



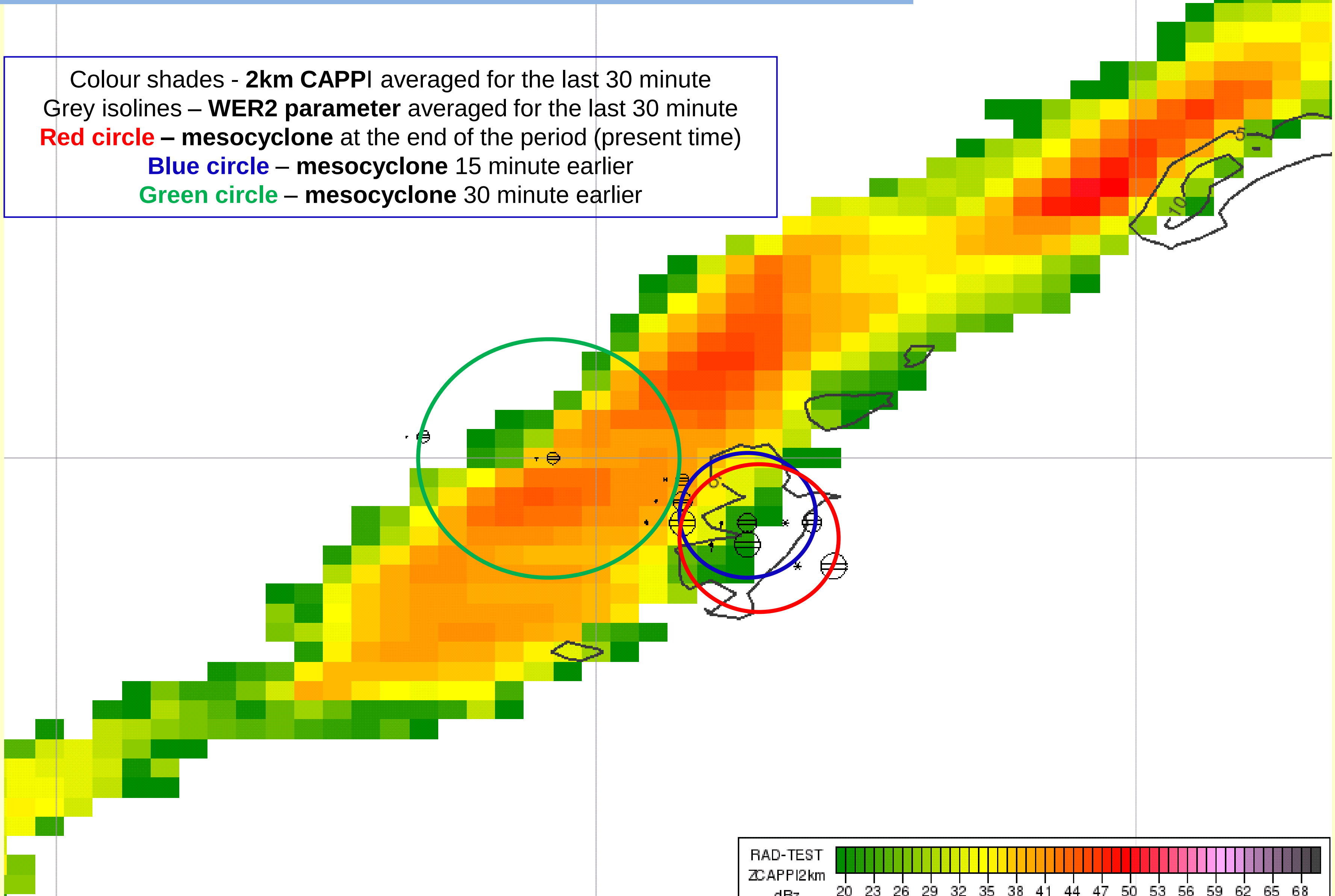
Usefulness of WER2 parameter:

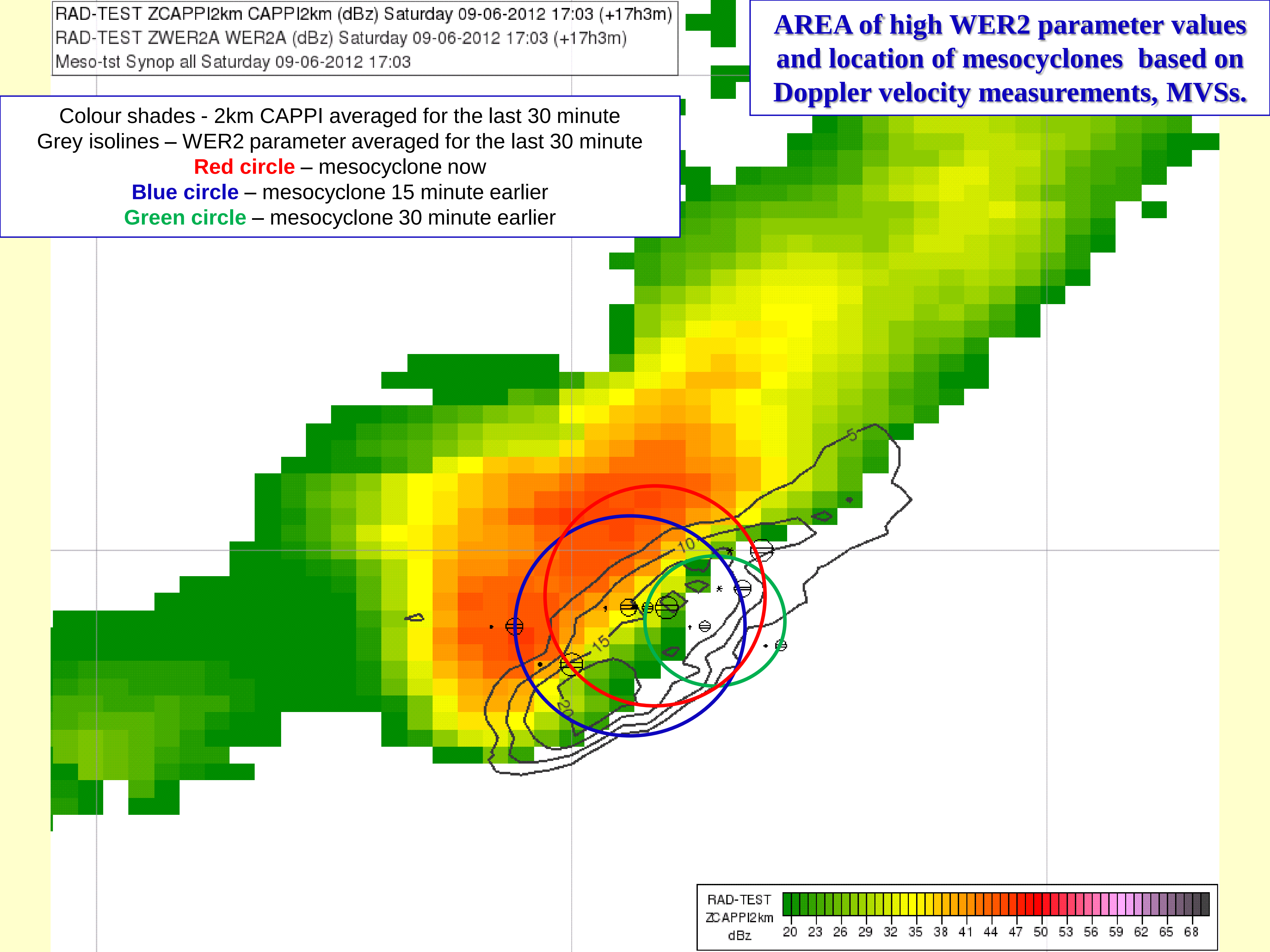
BWER echo in the vertical cross section across the area of high WER2 parameter

Demonstrate the usefulness of WER2 parameter:

Are the detected **mesocyclones** (by Doppler velocity measurements) close to or within the area of **high WER2** parameter?

Colour shades - **2km CAPPI** averaged for the last 30 minute
Grey isolines – **WER2 parameter** averaged for the last 30 minute
Red circle **– mesocyclone** at the end of the period (present time)
Blue circle – **mesocyclone** 15 minute earlier
Green circle – **mesocyclone** 30 minute earlier




AREA of high WER2 parameter values and location of mesocyclones based on Doppler velocity measurements, MVSs.
RAD-TEST ZCAPPI2km CAPPI2km (dBz) Saturday 09-06-2012 17:03 (+17h3m)
RAD-TEST ZWER2A WER2A (dBz) Saturday 09-06-2012 17:03 (+17h3m)
Meso-tst Synop all Saturday 09-06-2012 17:03
Colour shades - 2km CAPPI averaged for the last 30 minute
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Red circle – mesocyclone now
Blue circle – mesocyclone 15 minute earlier
Green circle – mesocyclone 30 minute earlier
5
10
15
20
RAD-TEST
ZCAPPI2km
dBz
20 23 26 29 32 35 38 41 44 47 50 53 56 59 62 65 68

AREA of high WER2 parameter values and location of mesocyclones based on Doppler velocity measurements, MVSs.

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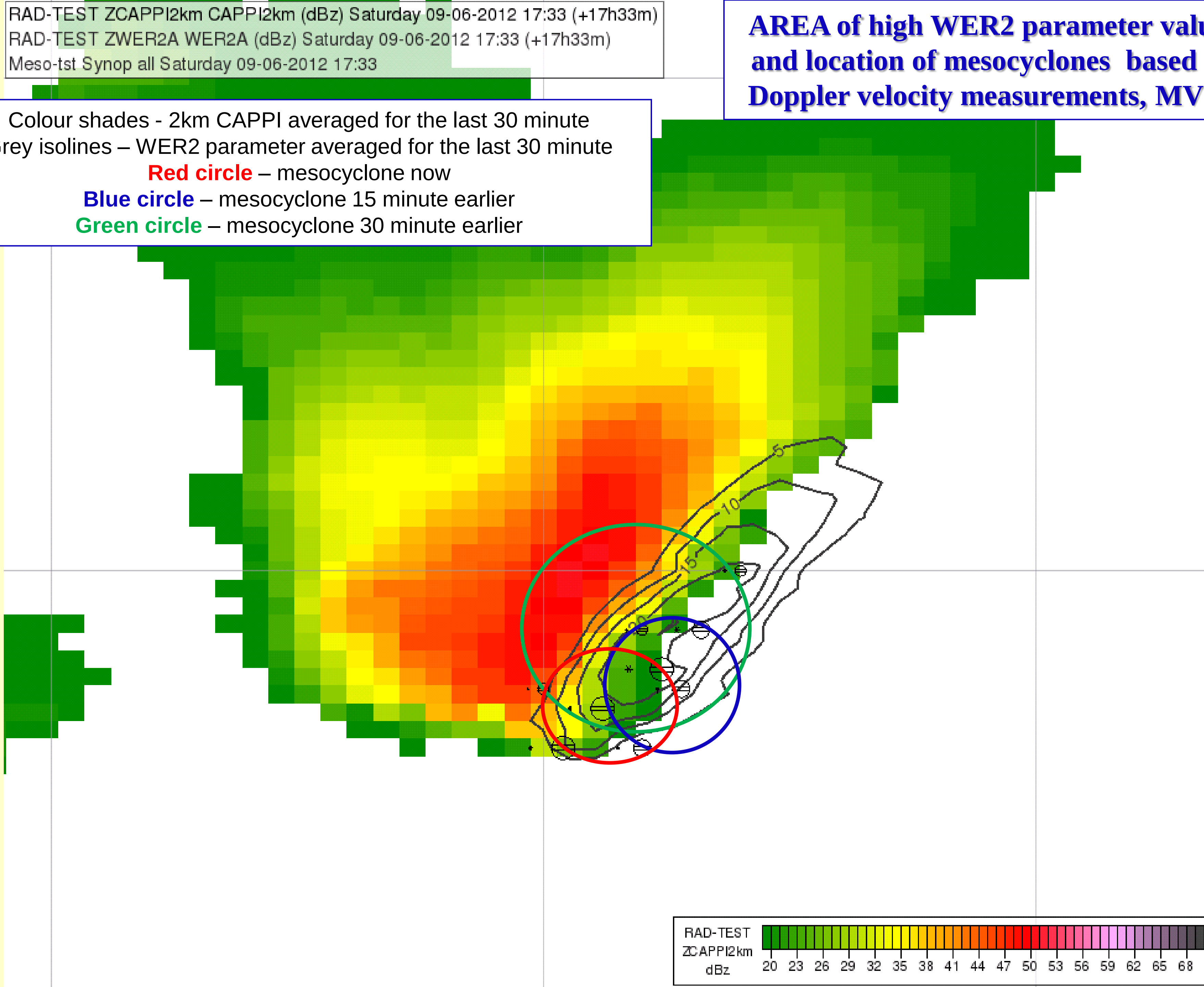

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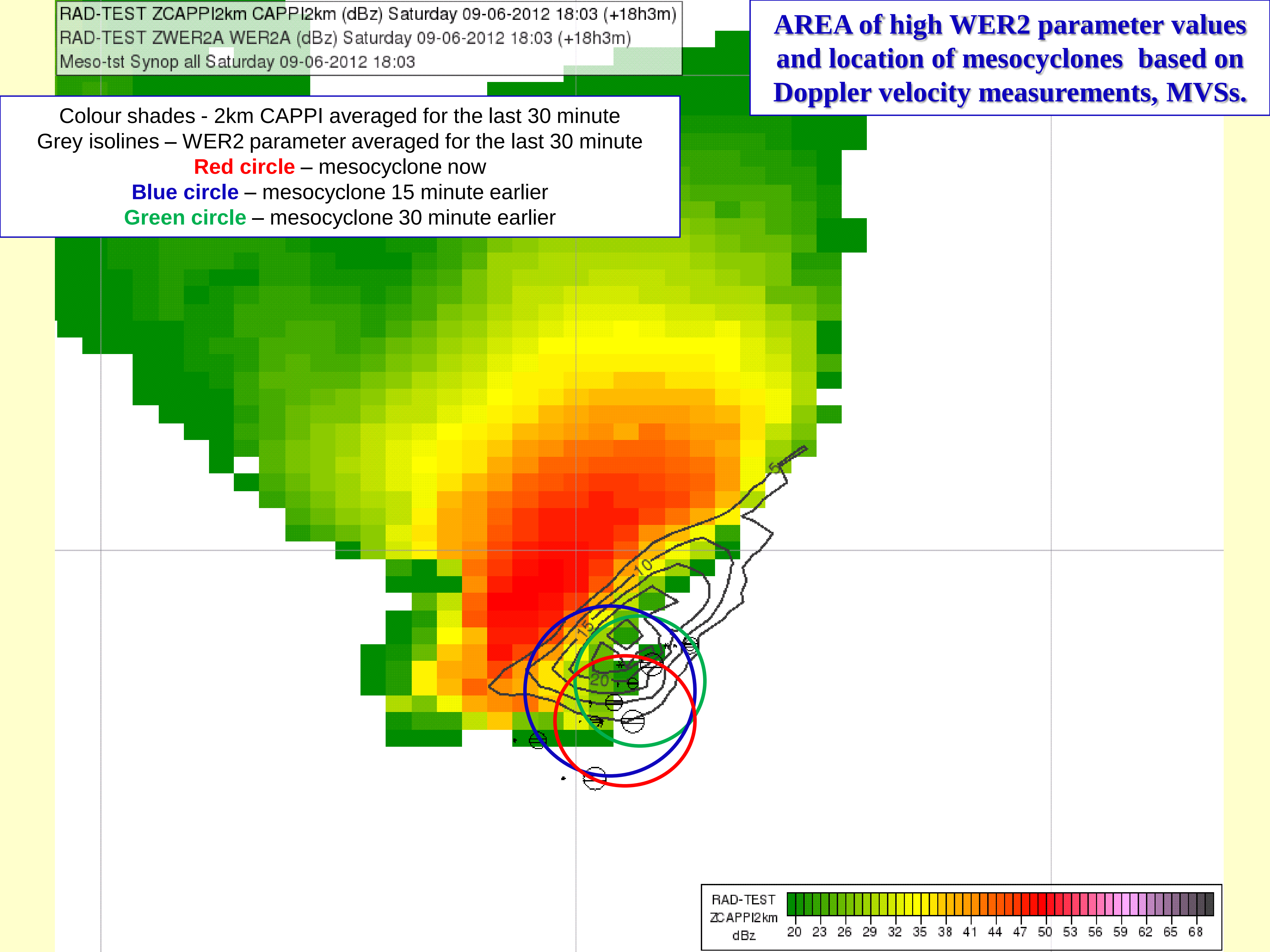


Further information about location of the **updraft**

Overshooting top (OT) – upper part of the updraft (at the cloud top level)

Locations of **OT**s and **ice-plume** were

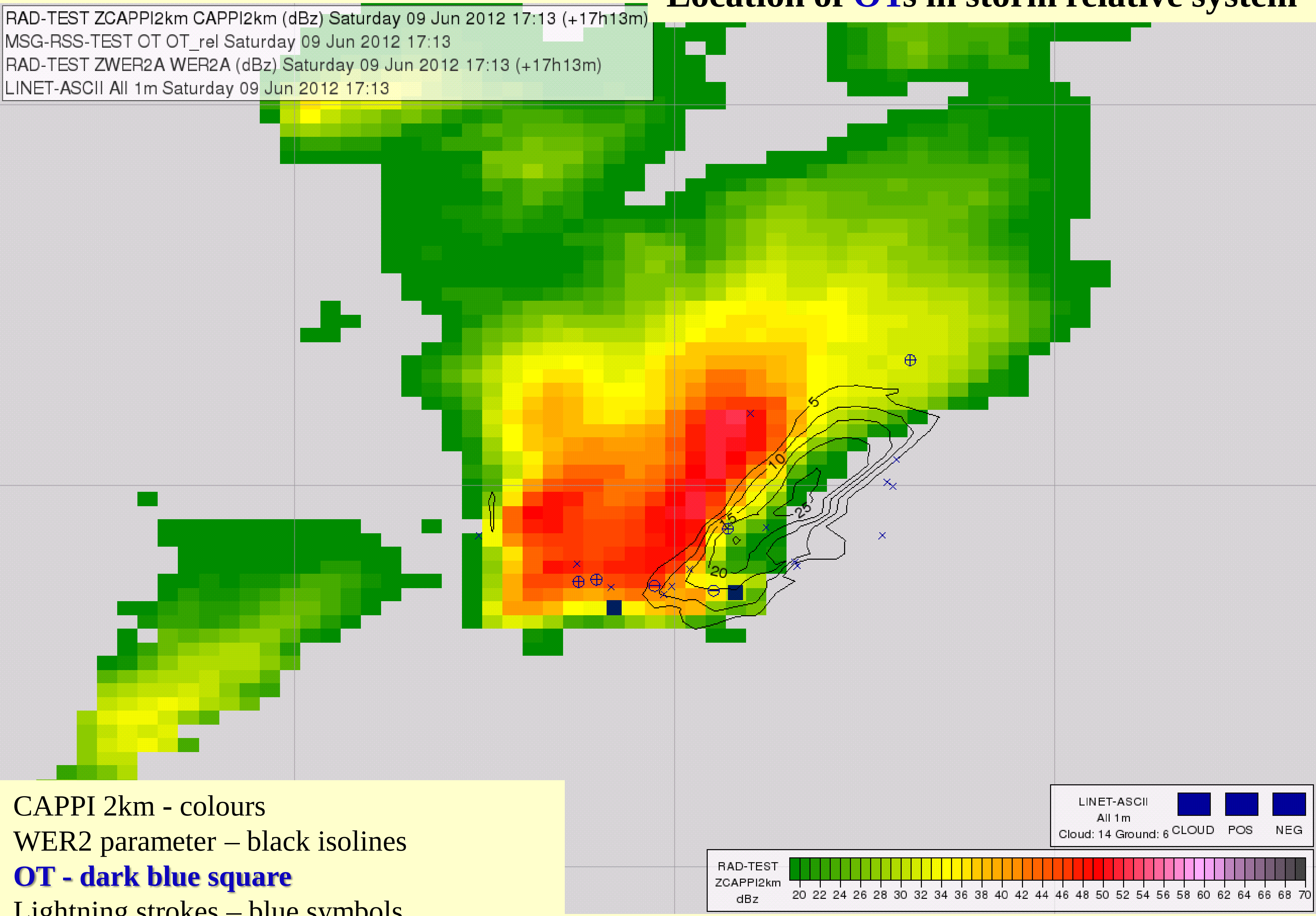
- detected visually on 5-minute HRV images (daytime)
- visualised in storm relative system - after parallax correction (cloud height was taken from radar ETOPS data)

Type of OTs

At the beginning there were ‘single OTs’

After ~16:20 UTC a long-lived huge elevated dome with complex structure formed with single OTs in some slots

Location of OTs in storm relative system



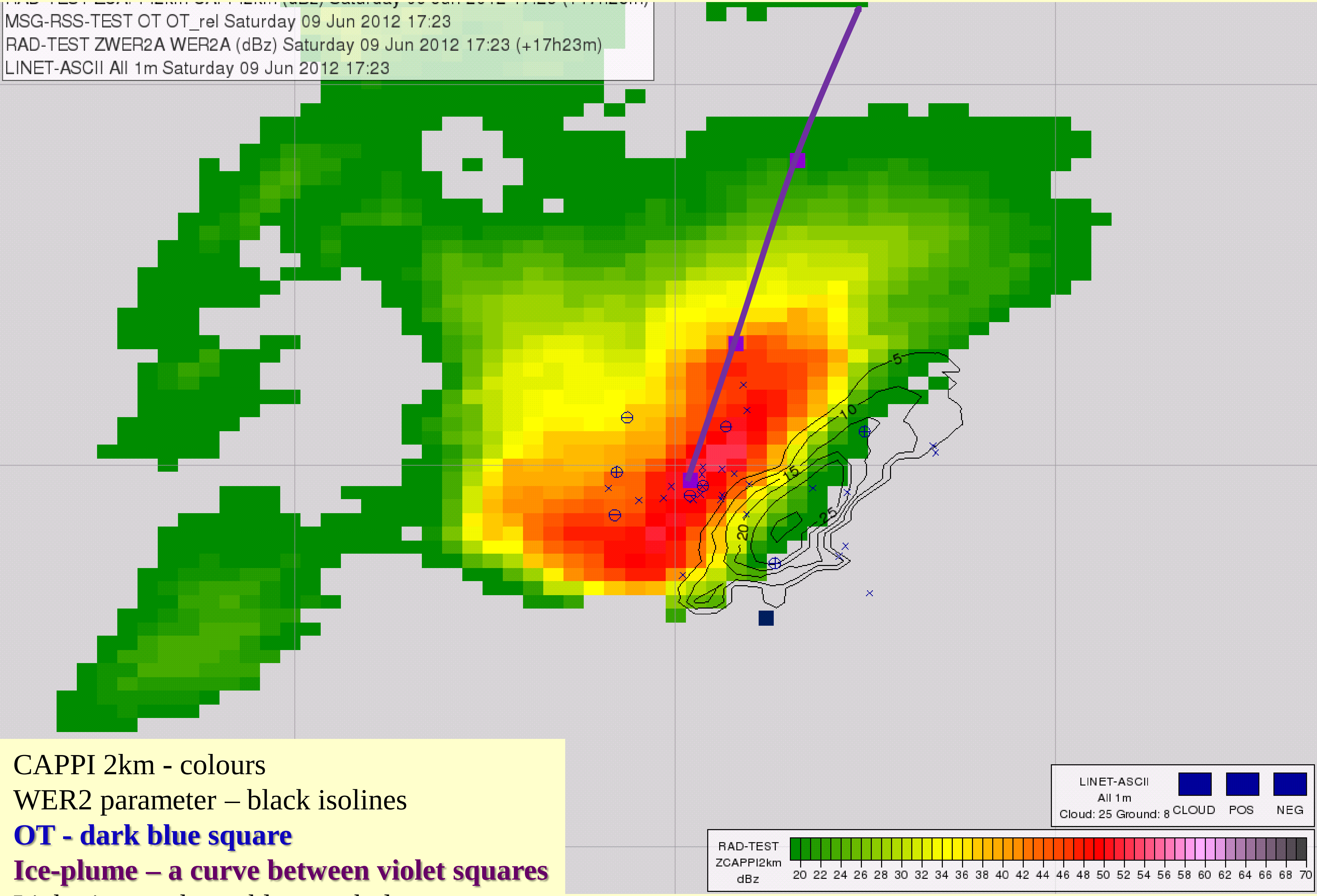
CAPPI 2km - colours

WER2 parameter – black isolines

OT - dark blue square

Lightning strokes – blue symbols

Location of OTs and ice-plume in storm relative system



CAPPI 2km - colours

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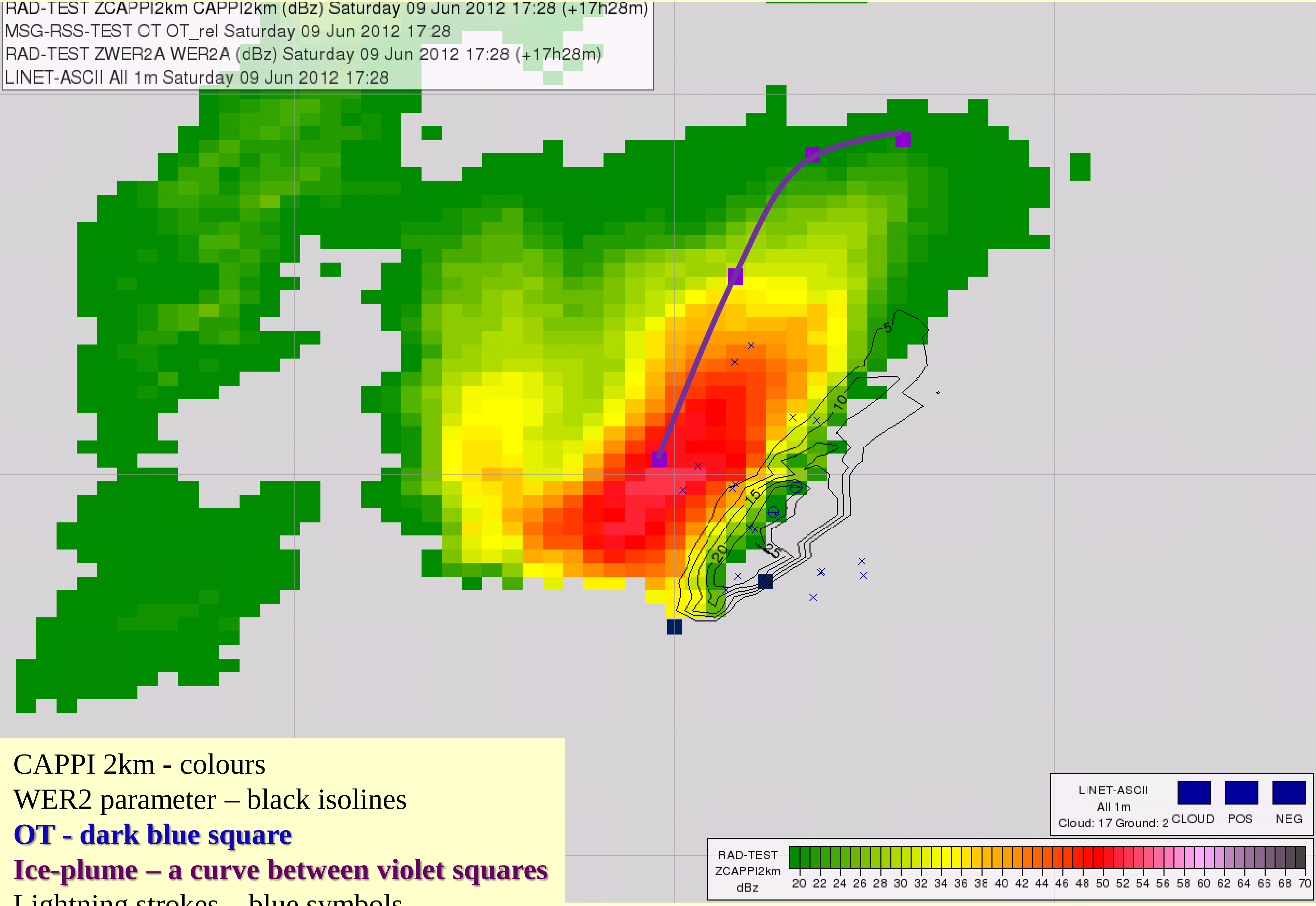
Ice-plume – a curve between violet squares

Lightning strokes – blue symbols

Location of OTs and ice-plume in storm relative system



CAPPI 2km - colours
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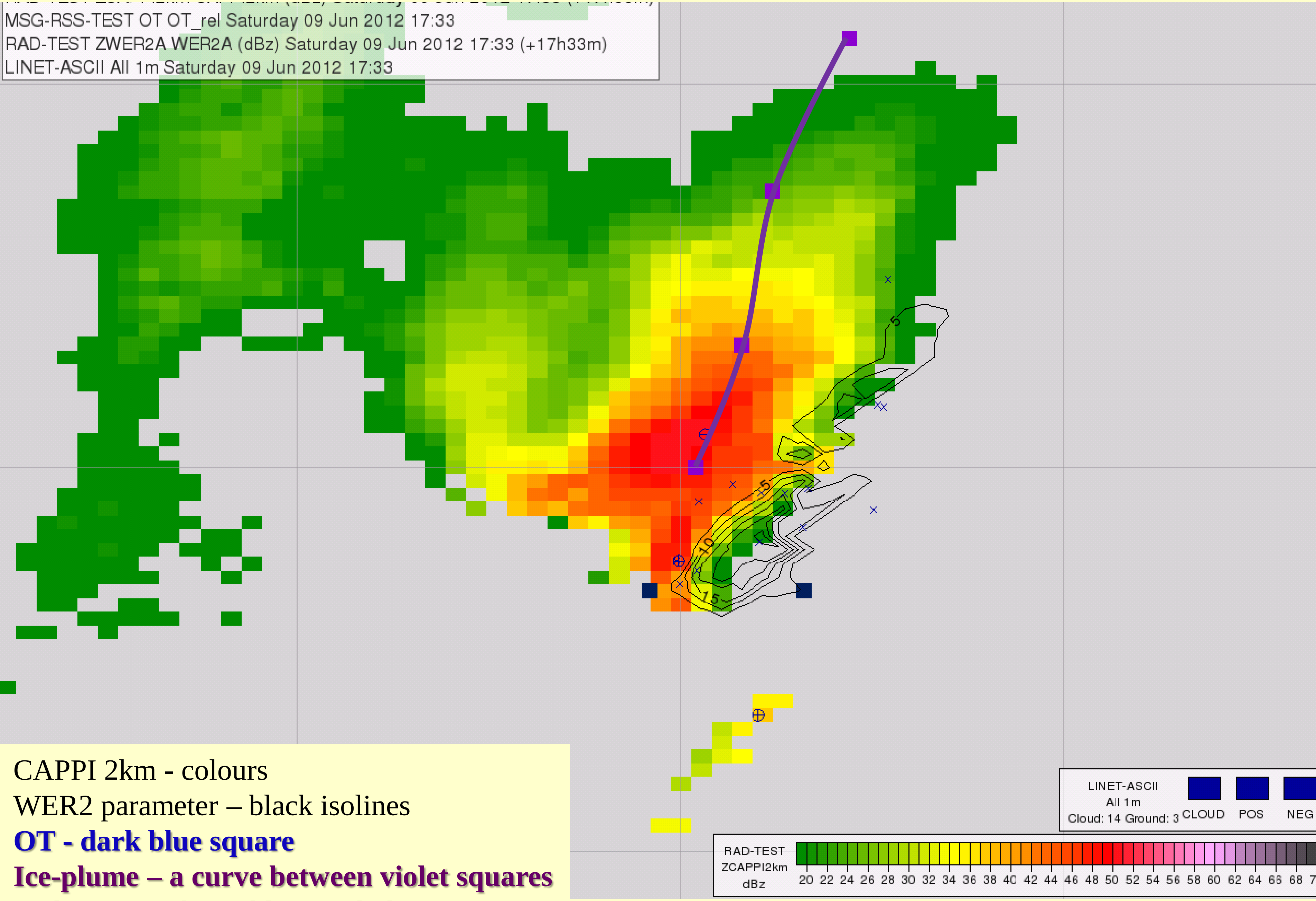
Location of OTs and ice-plume in storm relative system



CAPPI 2km - colours

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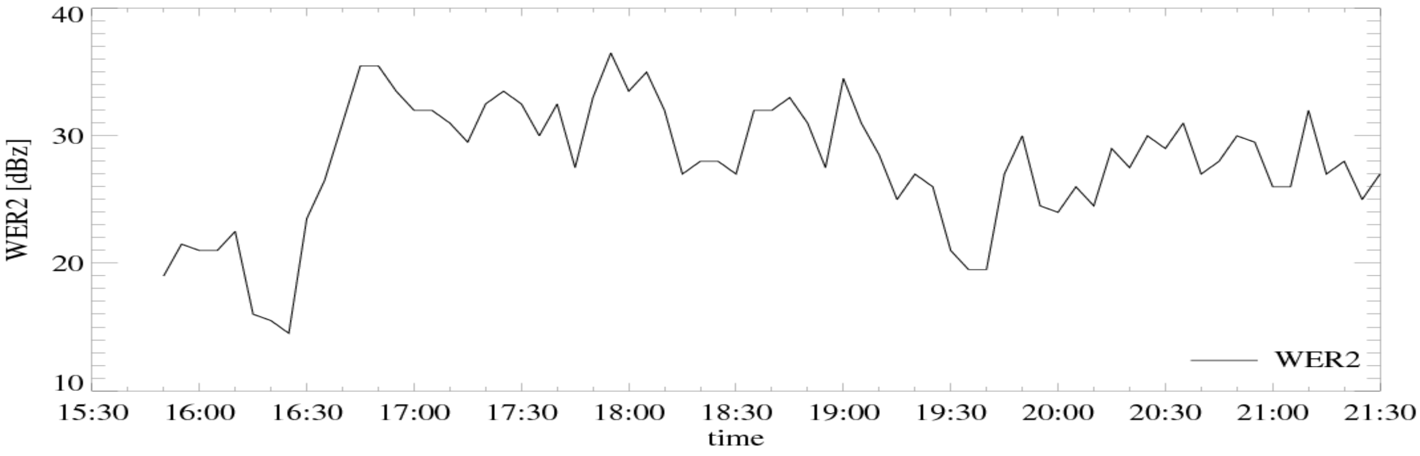
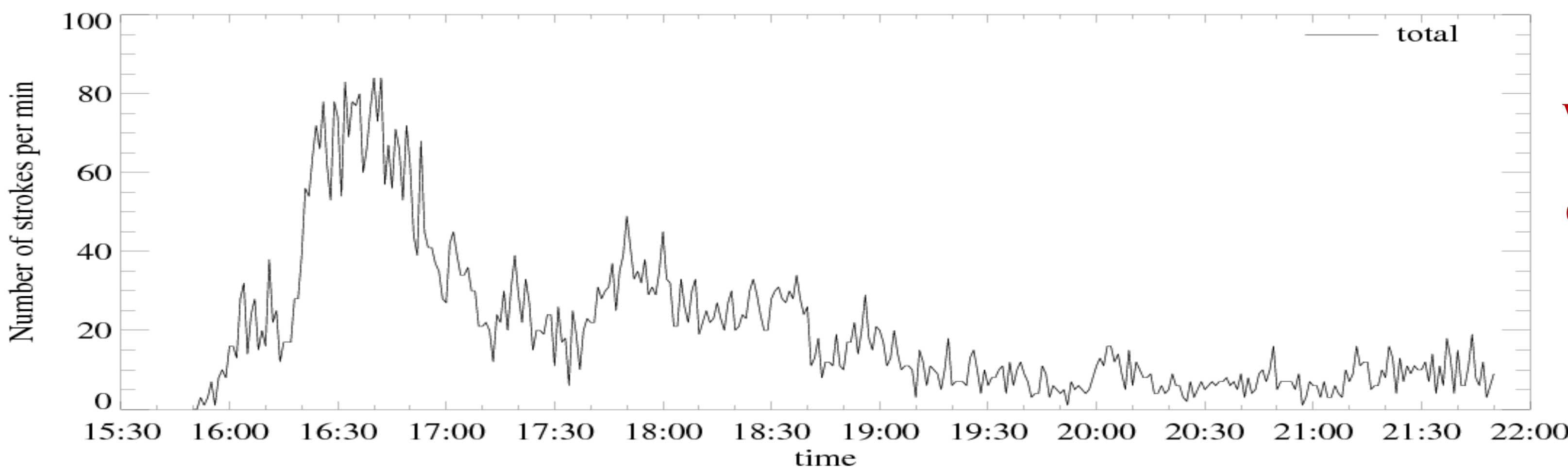
Temporal evolution of maximum of the WER2 parameter (5-minute time step)



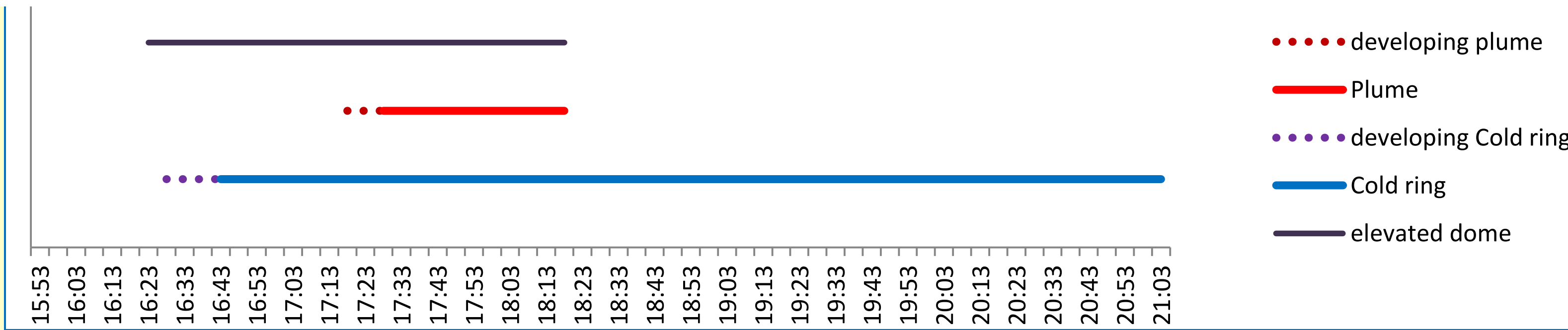
There is a jump – shifted compared to the lightning jump

High and persistent reflectivity aloft means large/many precipitating particles

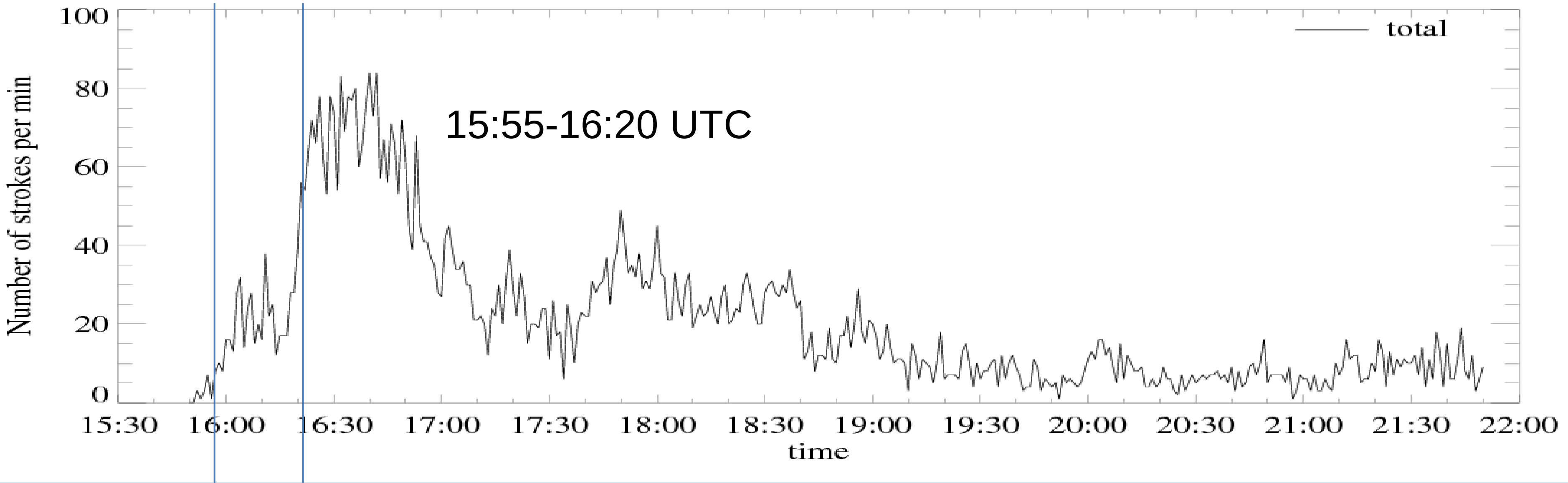


Maybe this is the period when the storm is rapidly evolving into a supercell

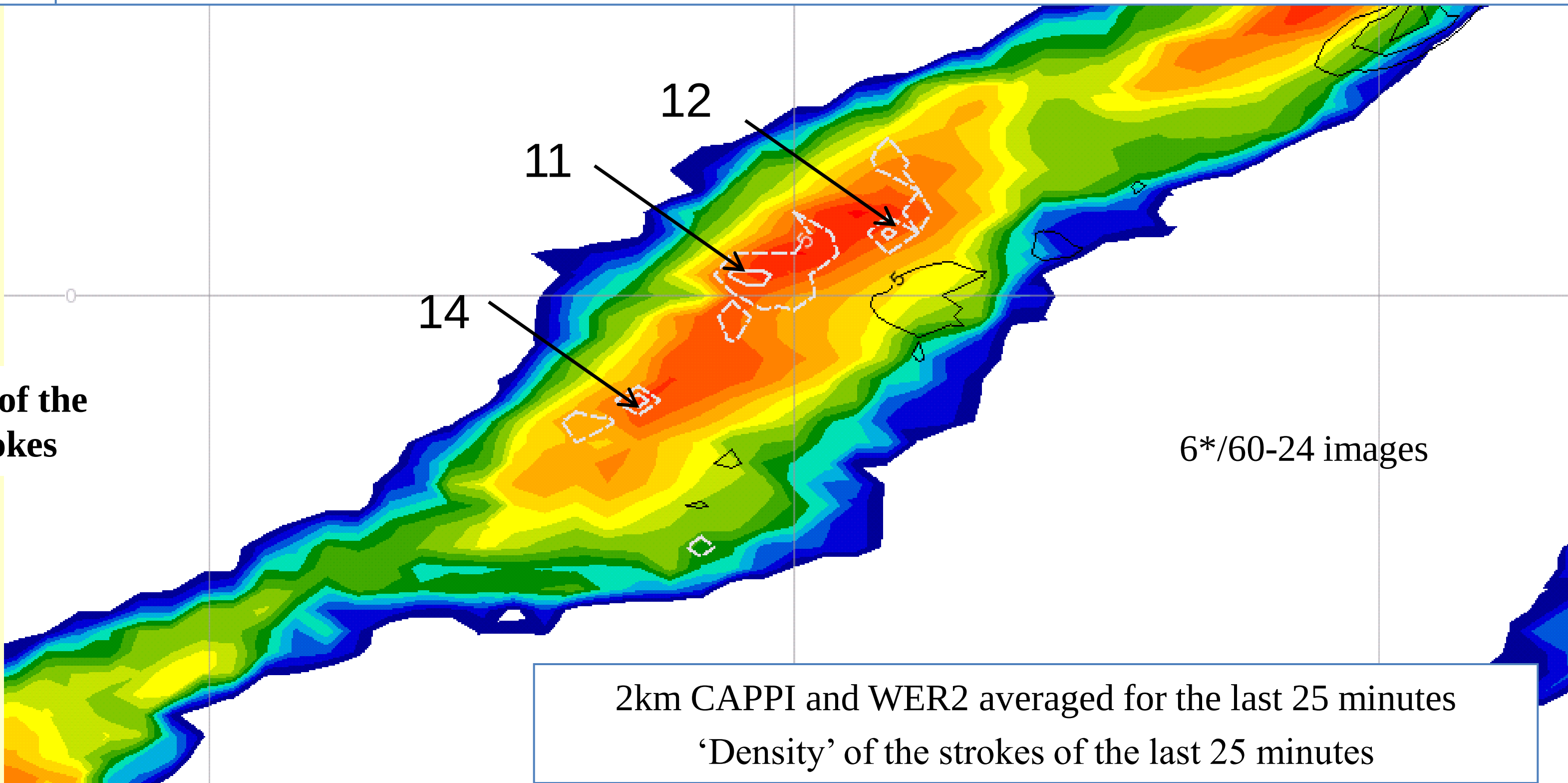
Topic for further study



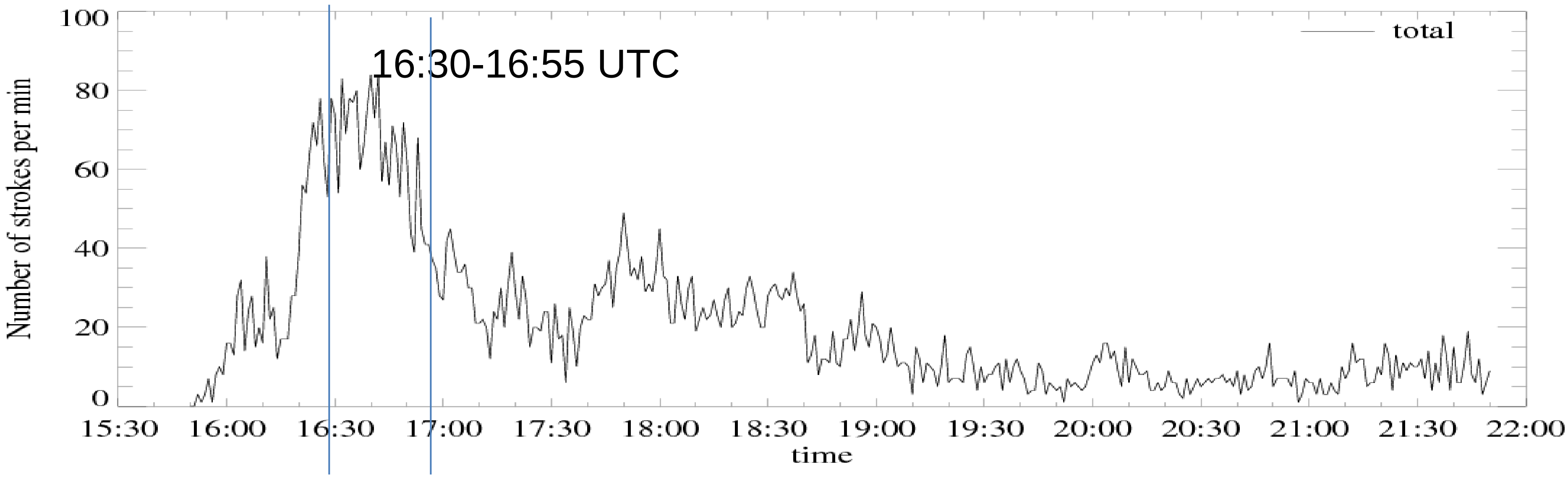
Our aim is to study spatial distribution of the stroke types within the supercell structure.



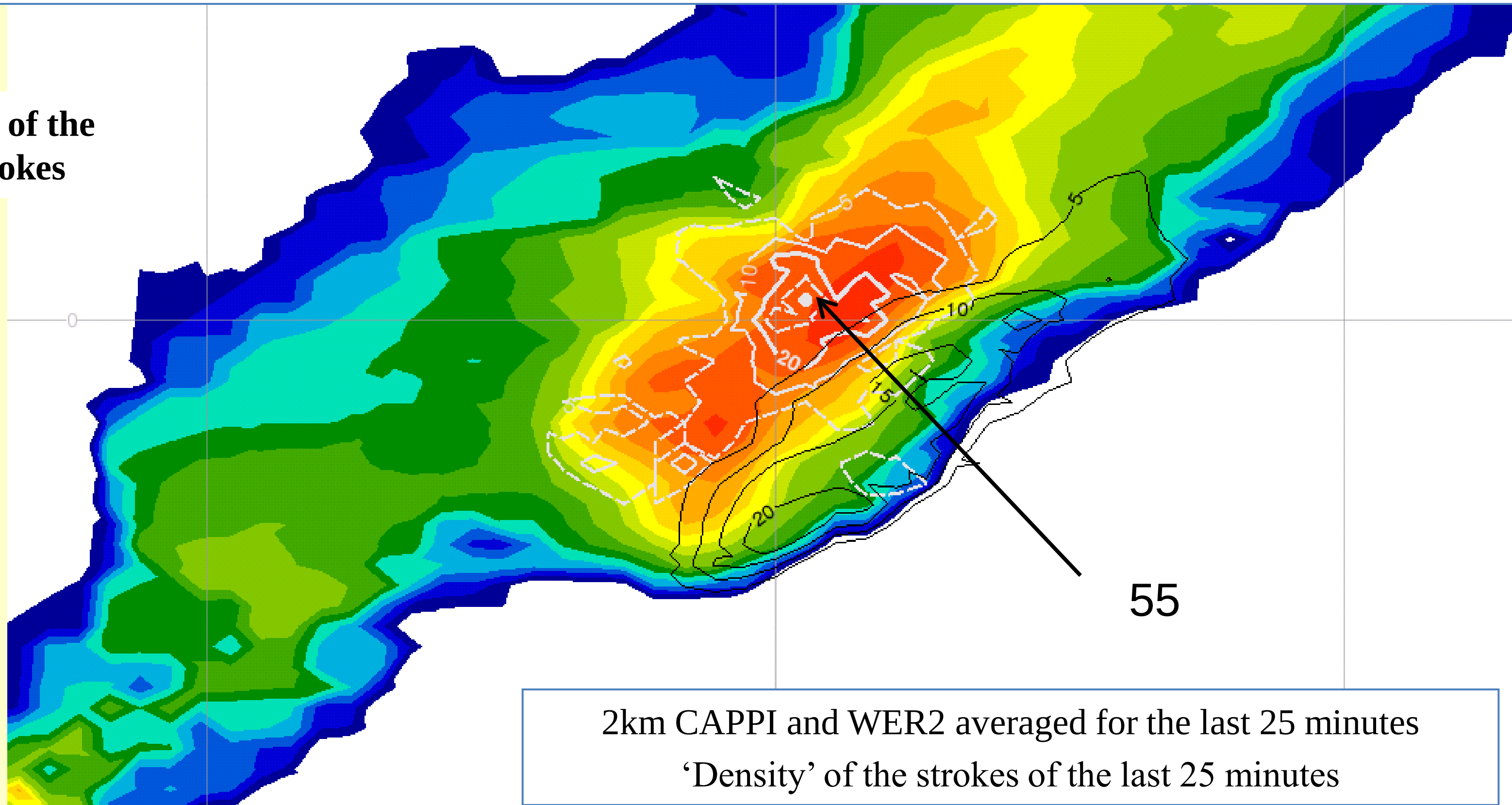
Spatial distribution of the number of the strokes



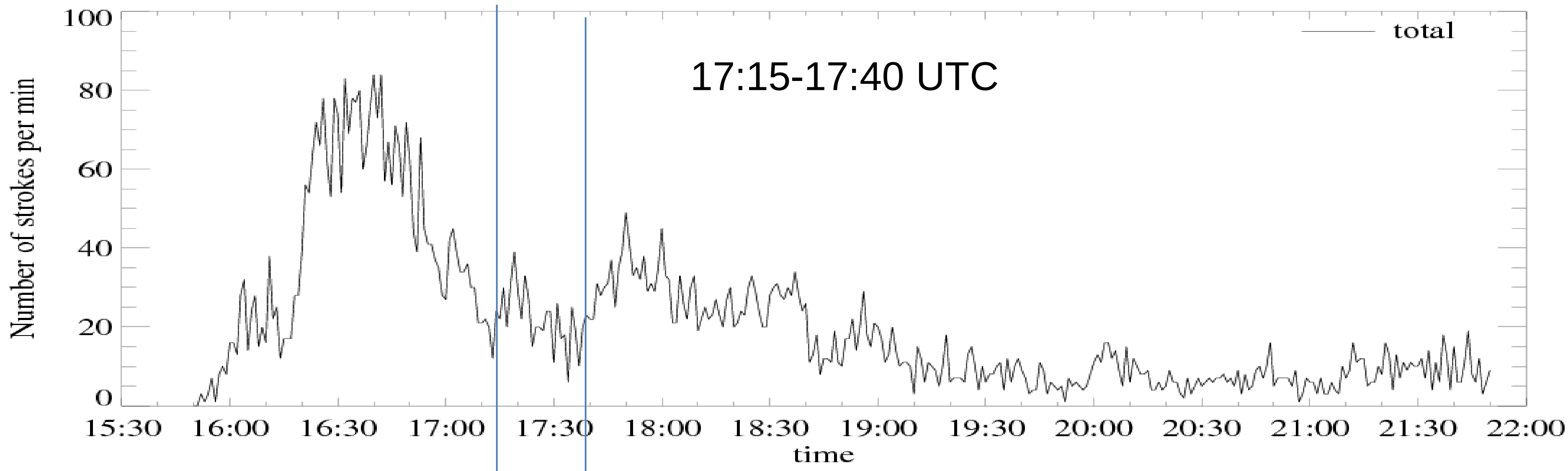
2km CAPPI and WER2 averaged for the last 25 minutes
'Density' of the strokes of the last 25 minutes



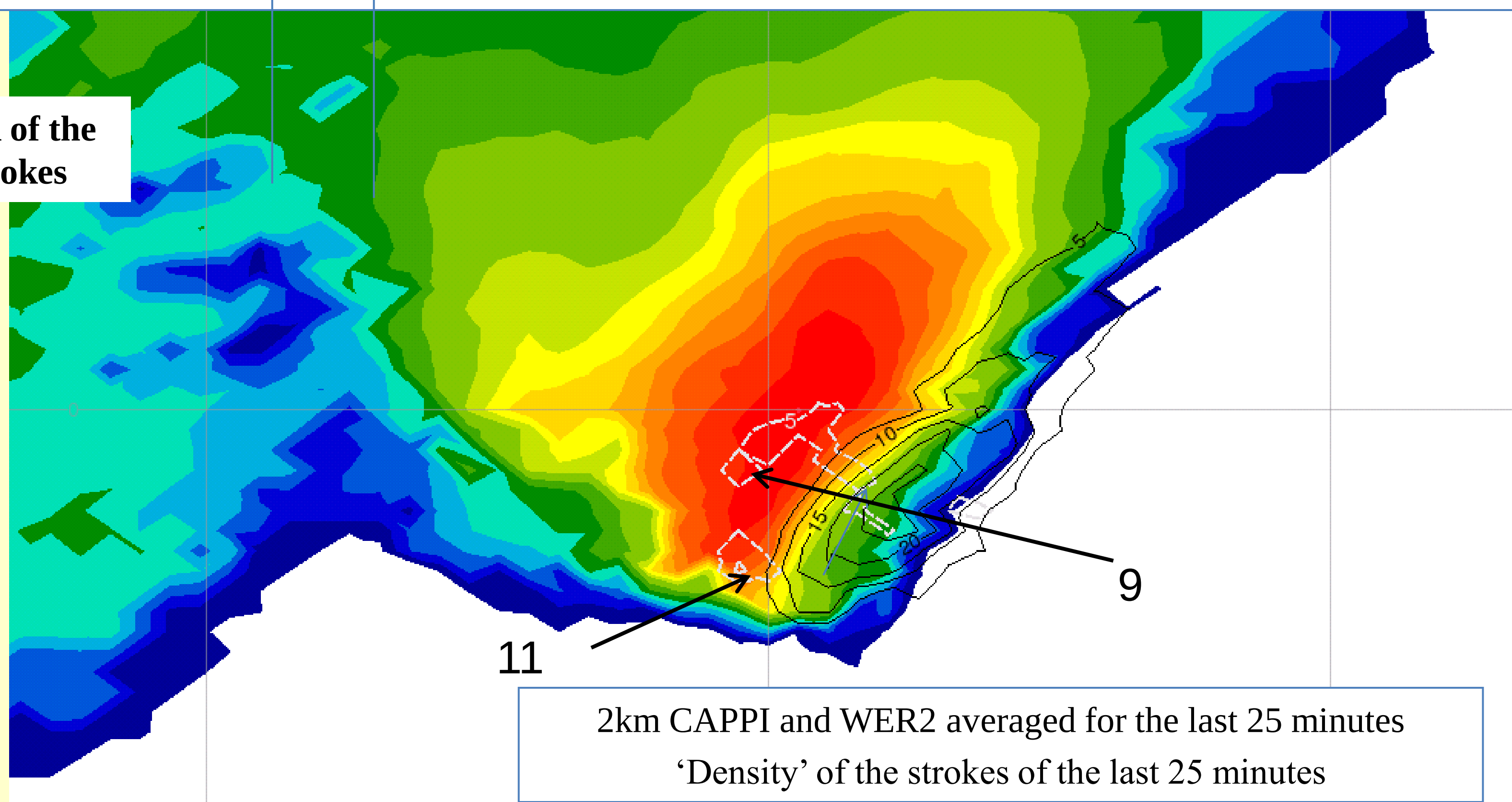
Spatial distribution of the number of the strokes



2km CAPPI and WER2 averaged for the last 25 minutes
‘Density’ of the strokes of the last 25 minutes

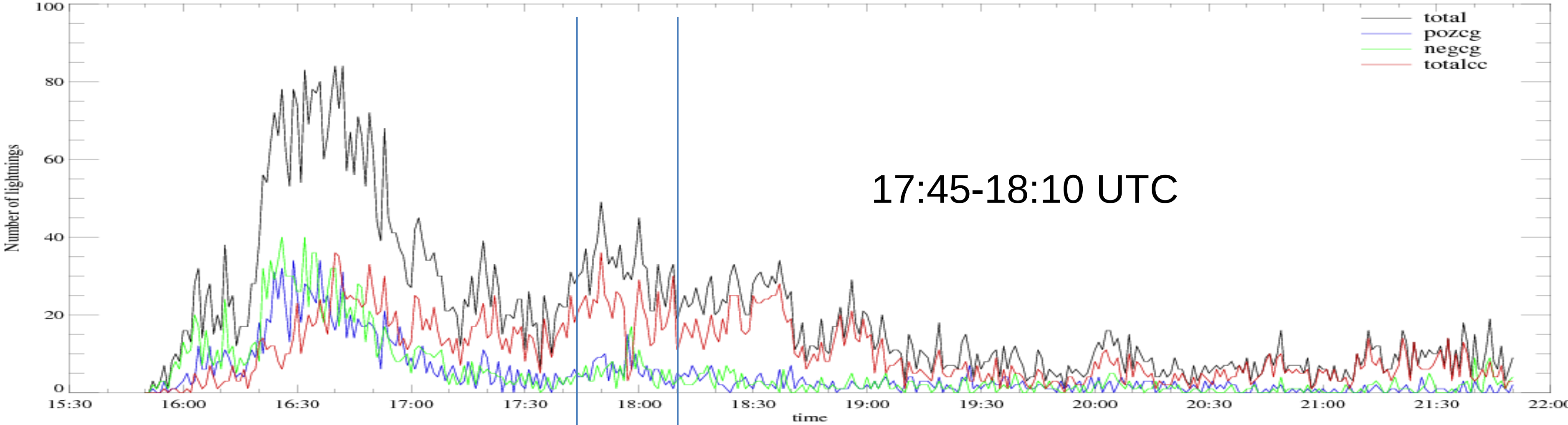


Spatial distribution of the number of the strokes



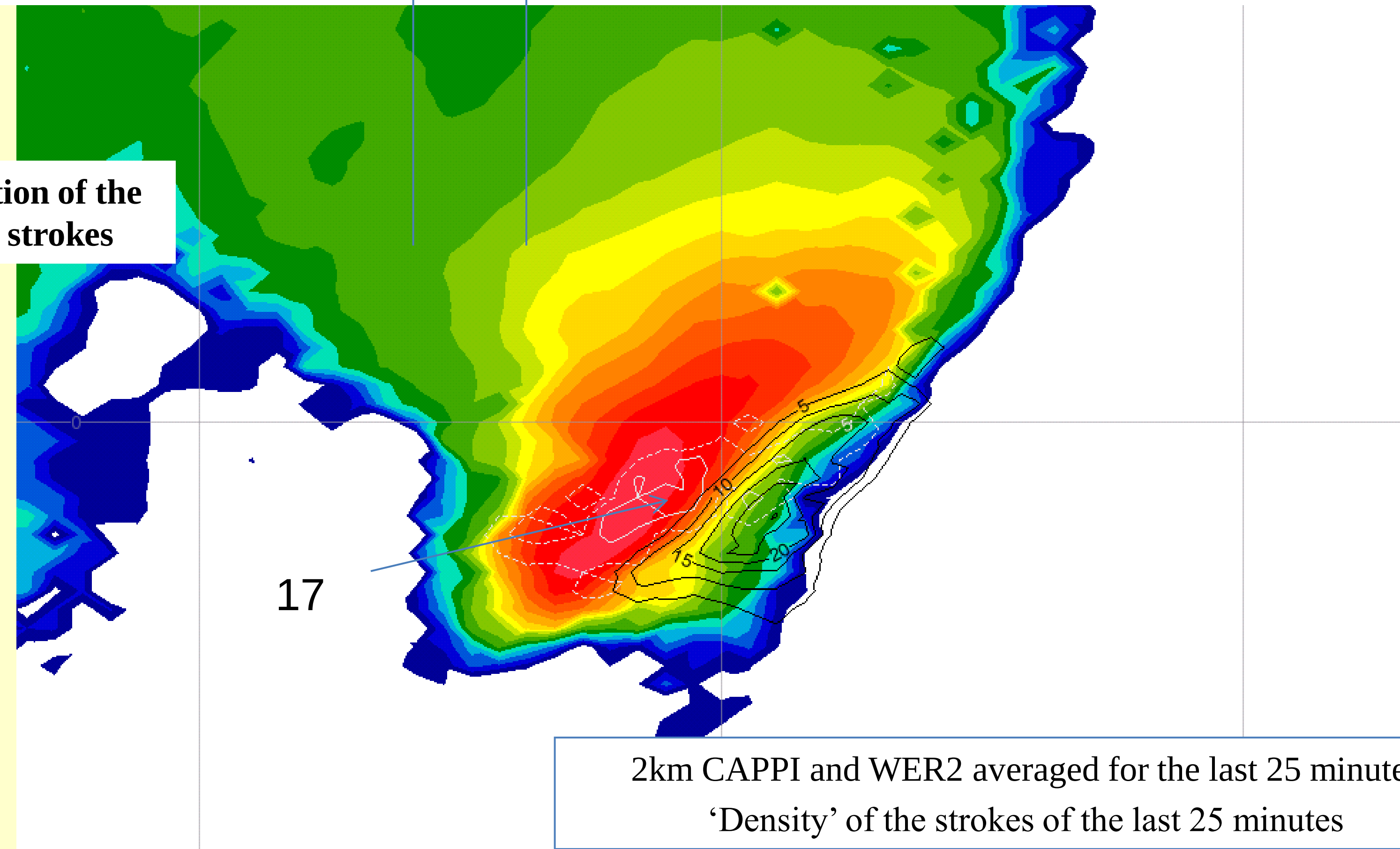
2km CAPPI and WER2 averaged for the last 25 minutes

'Density' of the strokes of the last 25 minutes



17:45-18:10 UTC

Spatial distribution of the number of the strokes



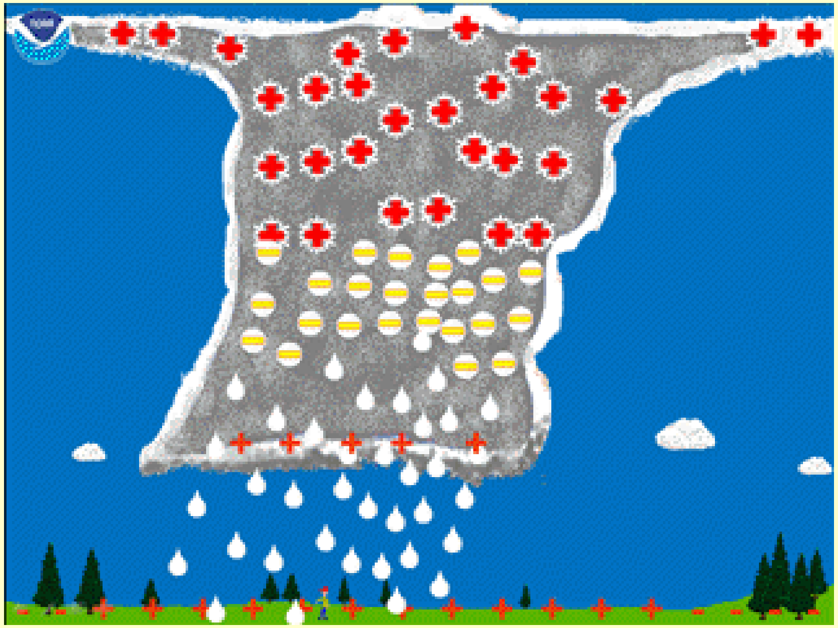
17

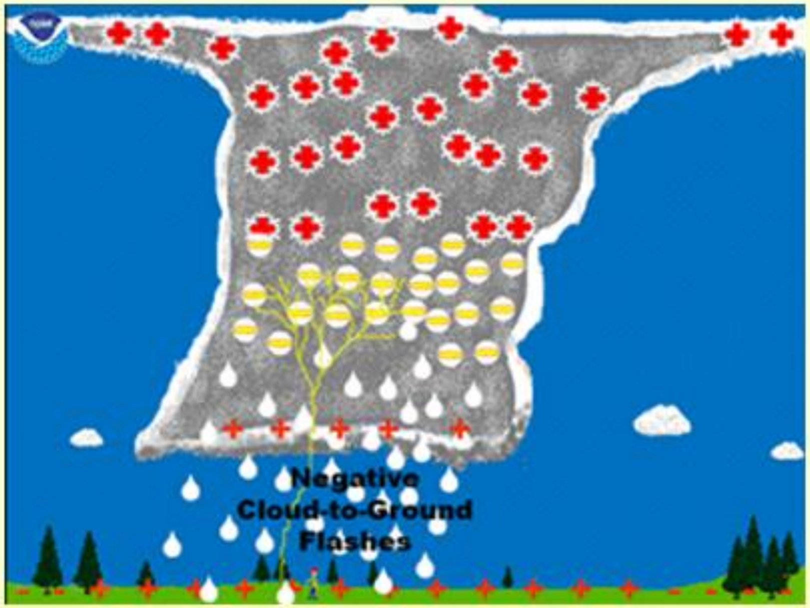
2km CAPPI and WER2 averaged for the last 25 minutes

'Density' of the strokes of the last 25 minutes

Spatial distribution CG+ and CG- stroke densities

We expected to find **significant dislocation between the CG- and CG+ regions**

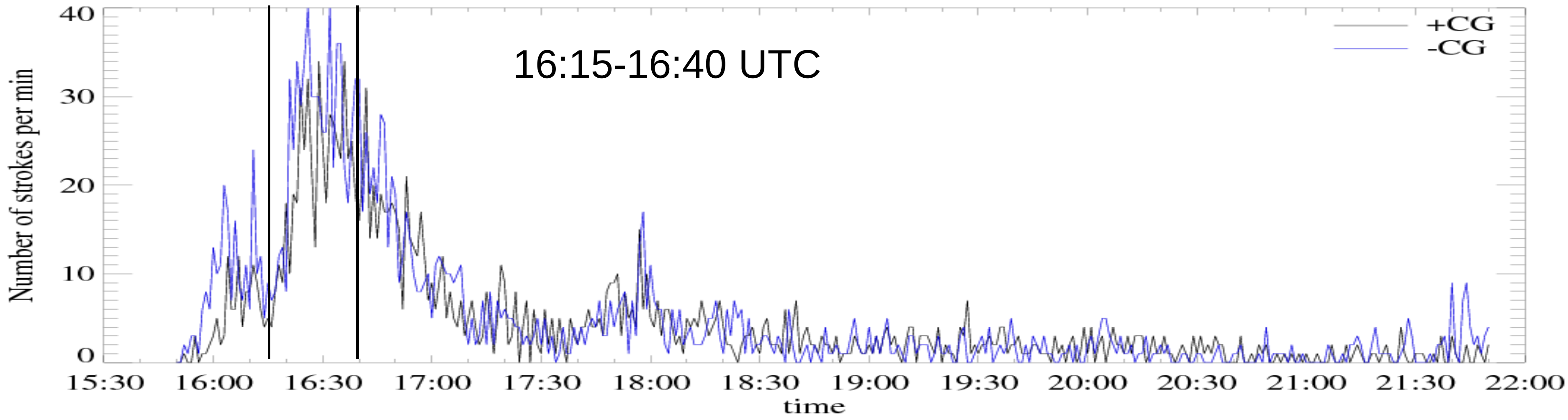


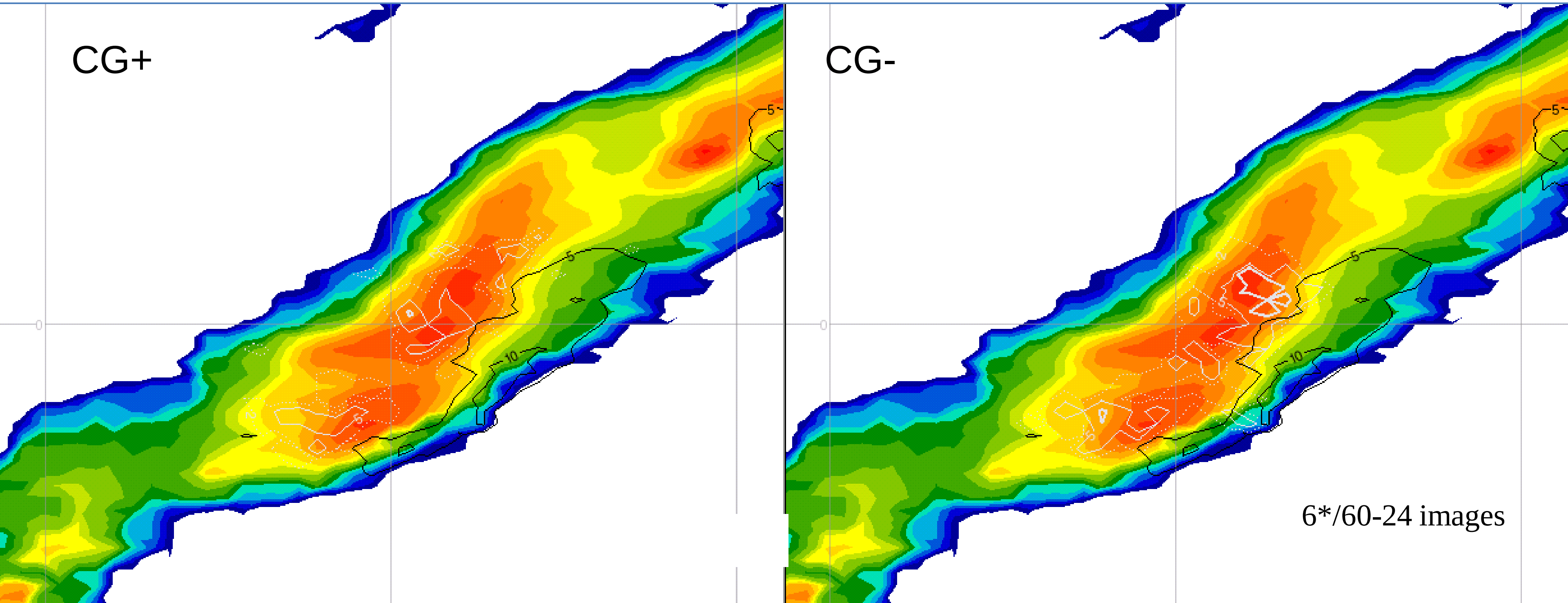


“Classic” tripole model

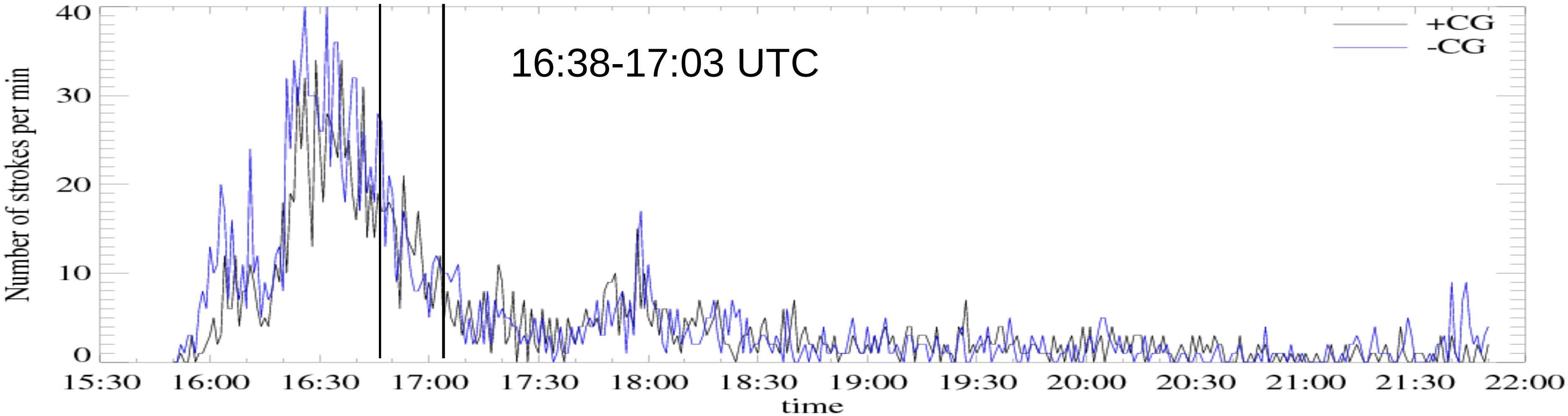
However, we did not found significant dislocation

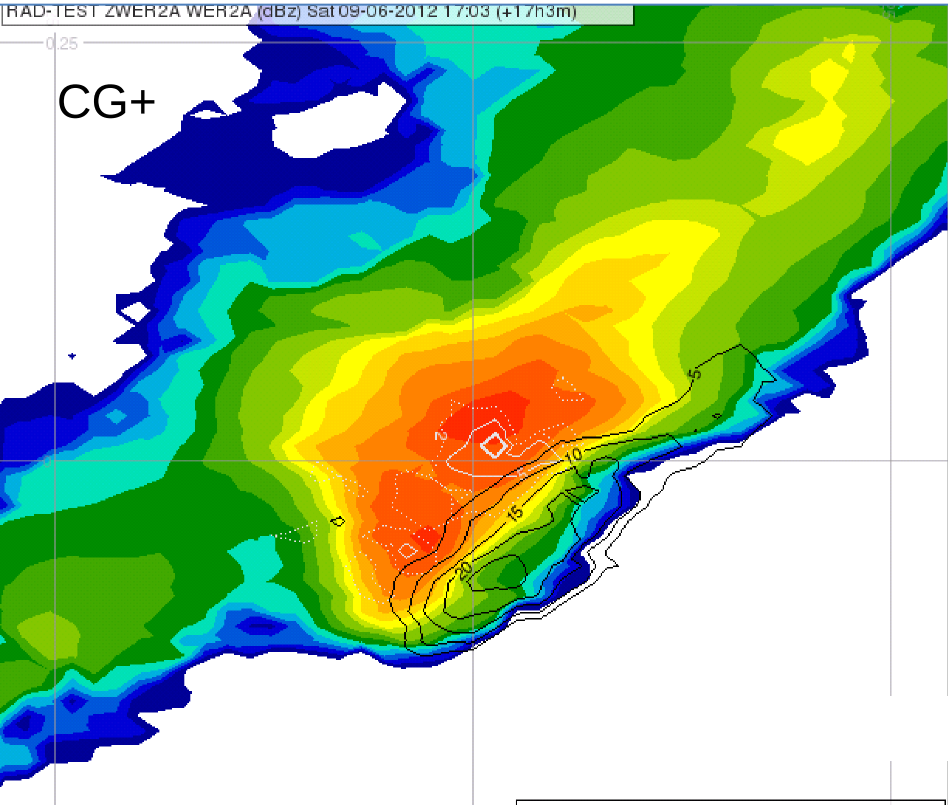
Spatial distribution of the number of the CG+ and CG- strokes

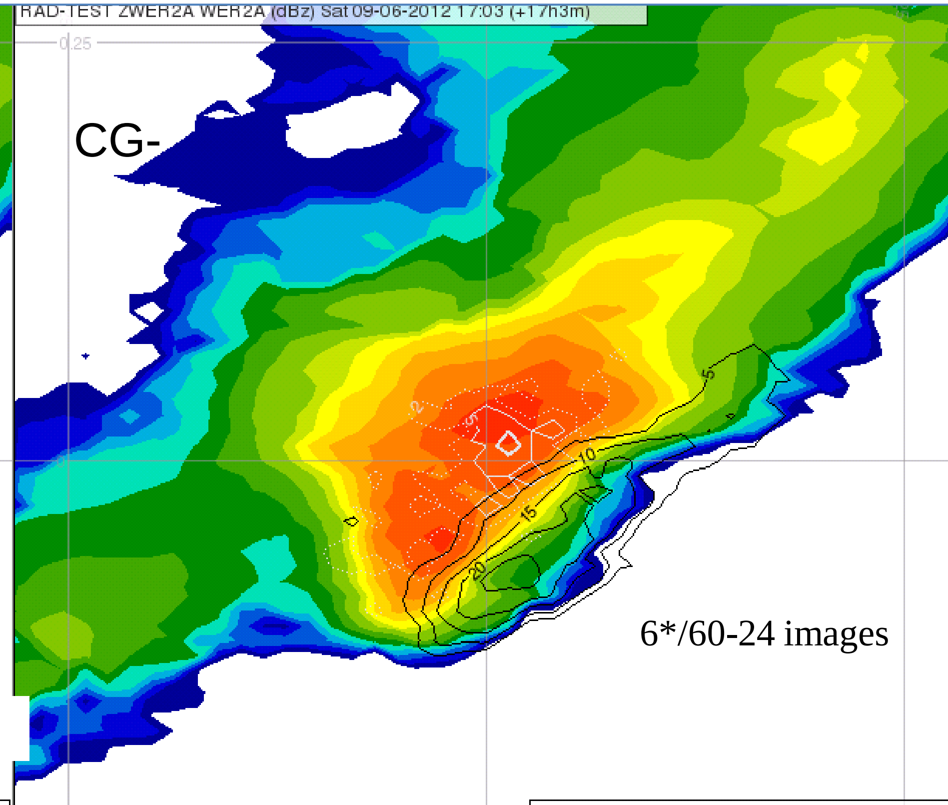


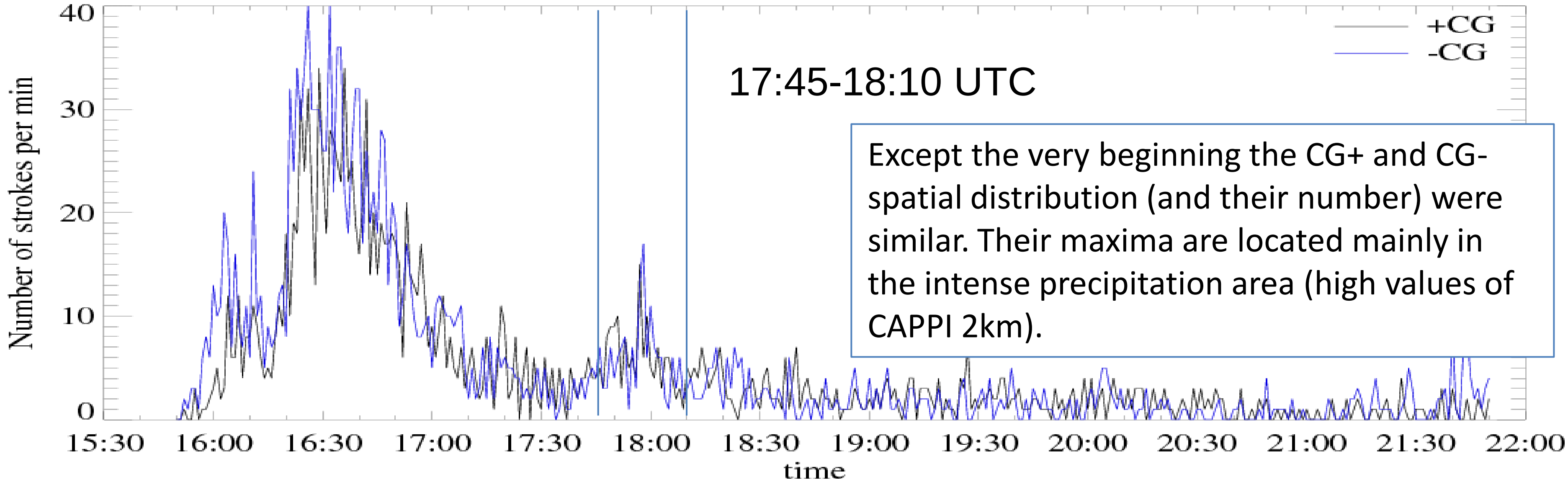


Spatial distribution of the number of the CG+ and CG- strokes



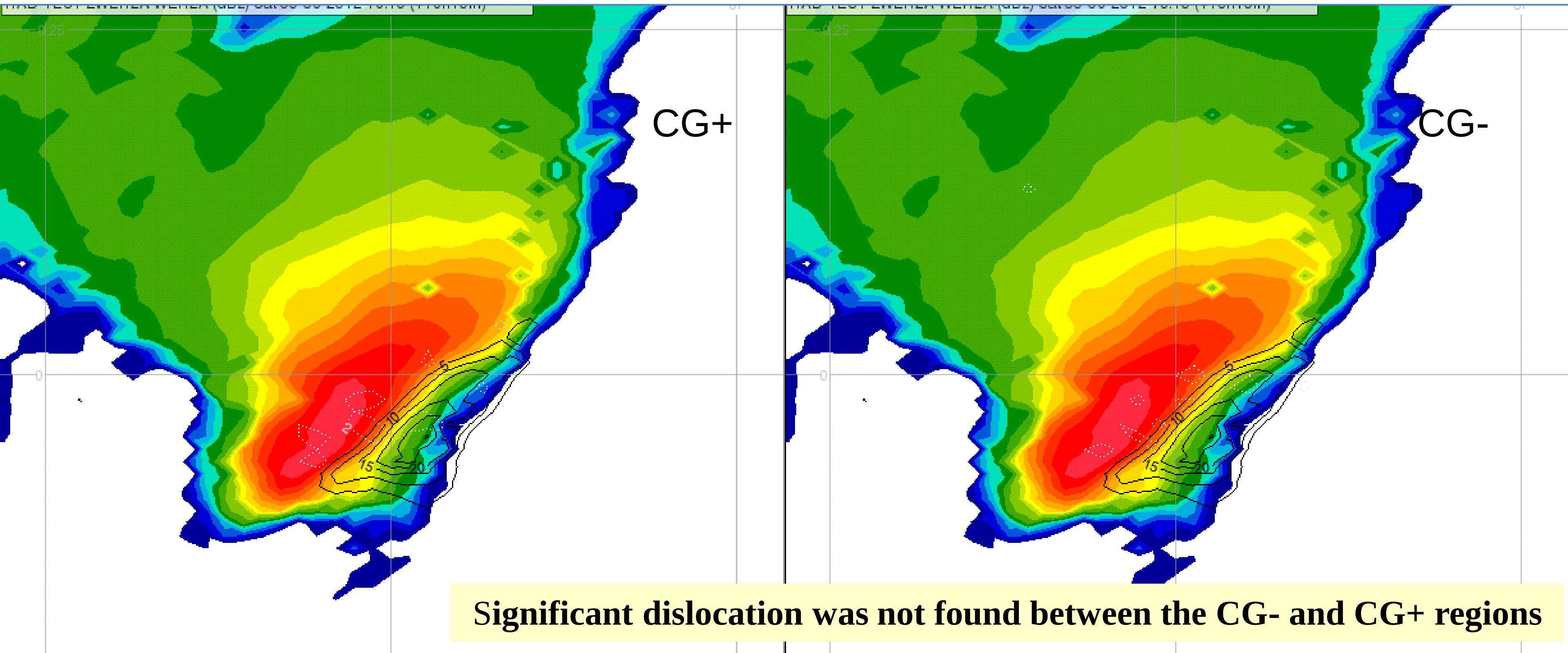






17:45-18:10 UTC

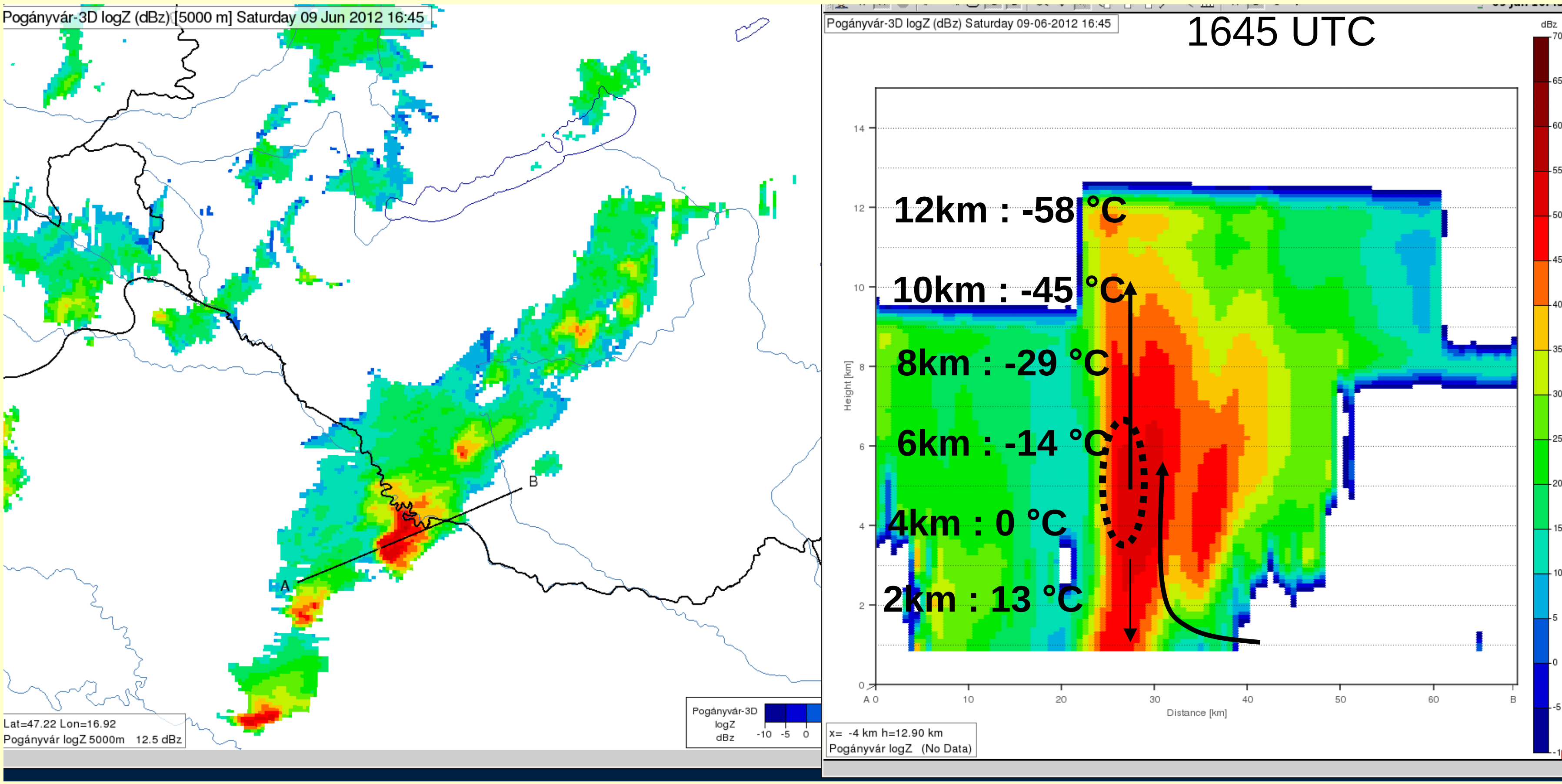
Except the very beginning the CG+ and CG- spatial distribution (and their number) were similar. Their maxima are located mainly in the intense precipitation area (high values of CAPPI 2km).



Significant dislocation was not found between the CG- and CG+ regions

Topic of further study

The polarity of the charge by graupel-ice mechanism depends on temperature.
MacGorman and Burgess (1994) expected generation of positive charge in areas with weak updraft and hail at temperatures between –15 and 0 °C. In our case we find high reflectivity at these levels..



Different structure, very strong updrafts (which can produce and keep large amount of hydrometeors at high levels for a long time), can be the reasons of different electrification of ordinary and severe storms.

Conclusions

-**Many characteristics of a severe storm**: (plume, OT-s, Cold ring, MVS, WER …)

-**Significant jump** in the **total number of lightnings**, already in the early phase of the storm. This jump correlates with the course of vorticity estimated from radial Doppler velocity measurements and the minimum of the cloud-top temperature from BT10.8

- CAPPI2km/WER2 parameters help to separate the heavy precipitation/potentially strong updraft areas

- Very high CG+ rate – this can be a signature of a severe storm (refer to MacGorman, Burgess, 1994)

-The **majority of the lightning strokes occur in heavy precipitation region**, close to the center of the storm (the **ice-plume** also propagates from this area)

- There is **no significant dislocation between the CG- and CG+ regions** (microphysics might play bigger role in the polarity of the lightning than eventual dislocation of the charges due to flow in the storm)

Future plans

- Find appropriate environmental parameters characterizing similar storms (high potential for severe weather, concerning hail and lightning production)
- Evaluating the **mid-tropospheric humidity conditions** (with use of both NWP and satellite data), which could eventually play important role in both storm dynamics and microphysics
- Evaluate impact of **temperature distribution** (e.g. height of the 0° or other isotherms) on hail production, find out, how to combine this information with satellite data and characteristics
- Evaluation of found characteristics (e.g. „flash rate jump”) on **other cases,** also with multicellular thunderstorms

Thank you for the attention!

Thanks for the Croatian colleagues for radar images