The exceptional hailstorm over the Gulf of Naples on 5 September 2015: observational analysis and role of the GPM Core Observatory

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Introduction

- On September 05, 2015 a violent hailstorm hit the Gulf and the city of Naples in Italy.
- The storm dropped 6-10 cm diameter hailstones along its path over the sea, and in Pozzuoli, near Naples.

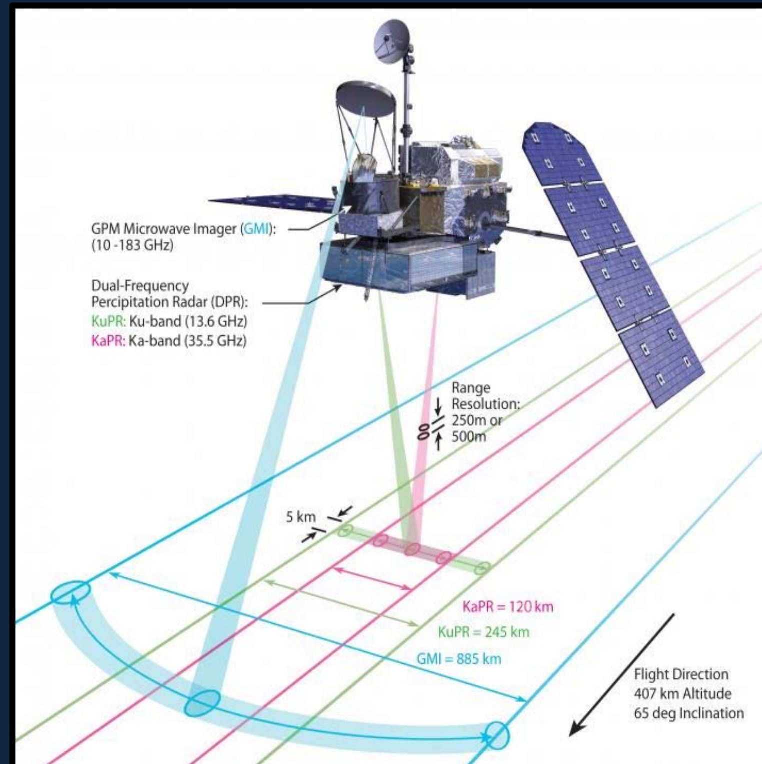
Massive hailstones found near Pozzuoli

GPM Core Observatory (GMI and DPR) overpass captured the storm in proximity of Naples at 8:47 UTC

https://www.youtube.com/watch?v=yarARzbkjI4)

THE GPM CORE OBSERVATORY

- **GPM Microwave Imager (GMI)**: The most advanced spaceborne microwave radiometer equipped with 13 precipitation sensing channels (10-183 GHz) with the highest spatial resolution available (5-30 km);
- The first spaceborne **Dual-frequency Precipitation Radar (DPR)** (Ku and Ka band)



Goal

Analyze the observations by GPM in conjunction with other satellite and ground-based measurements to assess the potentials of GMI and DPR to characterize such storm and its rarity over the Mediterranean area

Outline

Observational dataset

Analysis

- Temporal evolution of the storm by MSG, lightning and ground radar observations
- GPM observations of the hailstorm mature stage
  - PMW observations: GMI and MHS
  - DPR observations
  - Lightning activity and MW observations
  - Event characterization at global scale

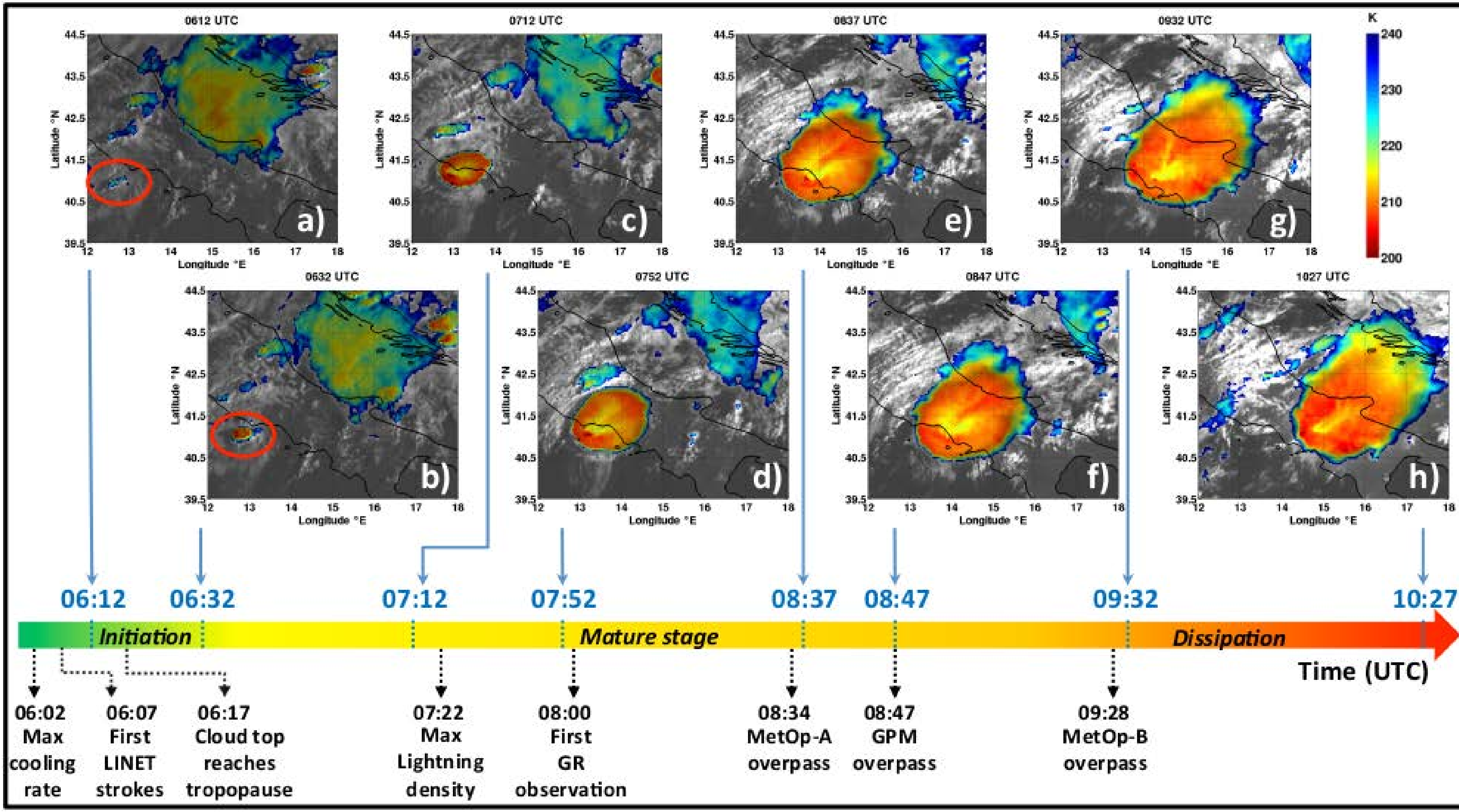
Summary

Marra et al., Observational analysis of an exceptionally intense hailstorm over the Mediterranean area: Role of the GPM Core Observatory, Atmospheric Research, 2017, in press.

Observational dataset:

- MSG SEVIRI IR and VIS images;
- Ground-based C-band polarimetric radar at Monte il Monte (41.94°N, 14.62°E, 710m ASL), 130 km away from the storm;
- LINET (LIghtning NETwork) ground-based data;
- Overpasses by MW sensors in GPM constellation:
  - GPM-CO (GMI and DPR) overpass (8:47 UTC at lat 40.79° N lon 13.86°E);
  - MetOp-A and MetOp-B (AMSU/MHS) overpasses (8:34 UTC at lat 40.99°N lon 13.64°E and 9:28 UTC at lat 40.84°N lon 14.35°E, respectively)

Hailstorm life cycle

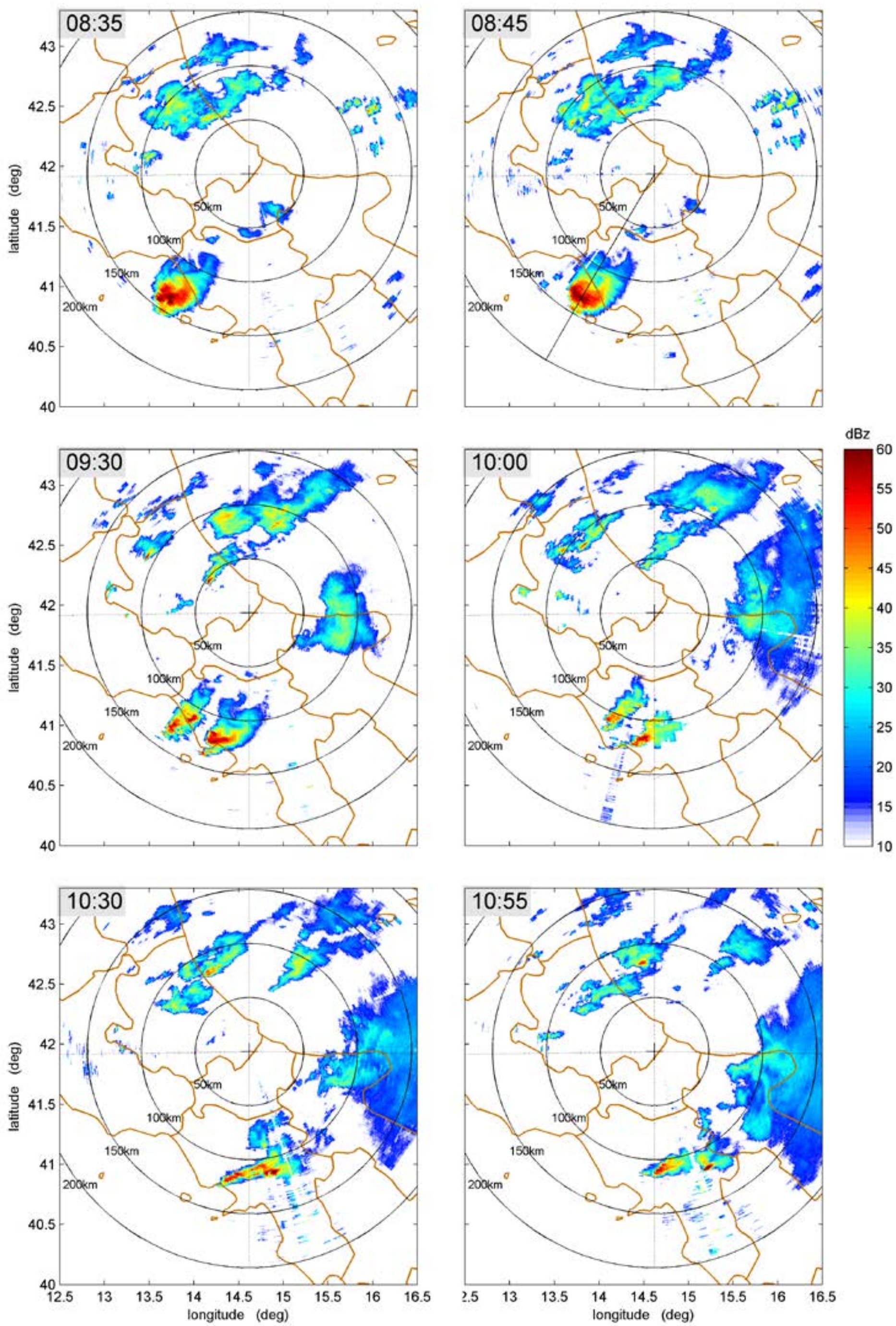


Lowest TB value at 10.8 µm: 198 K at 07:12 UTC;

Max cooling rate: 4.5 K min^{-1};

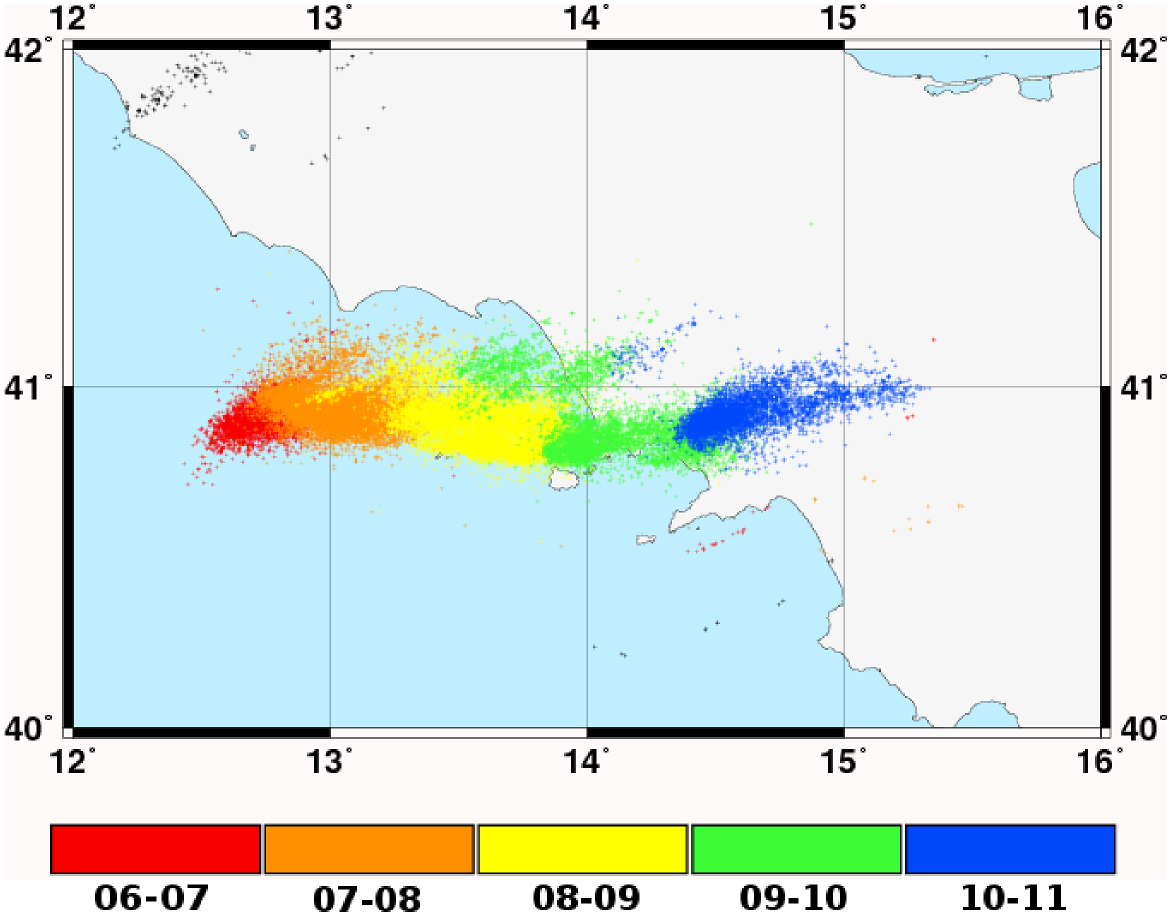
Estimated updraft strength compatible with hailsize 8-10 cm

Ground radar observations

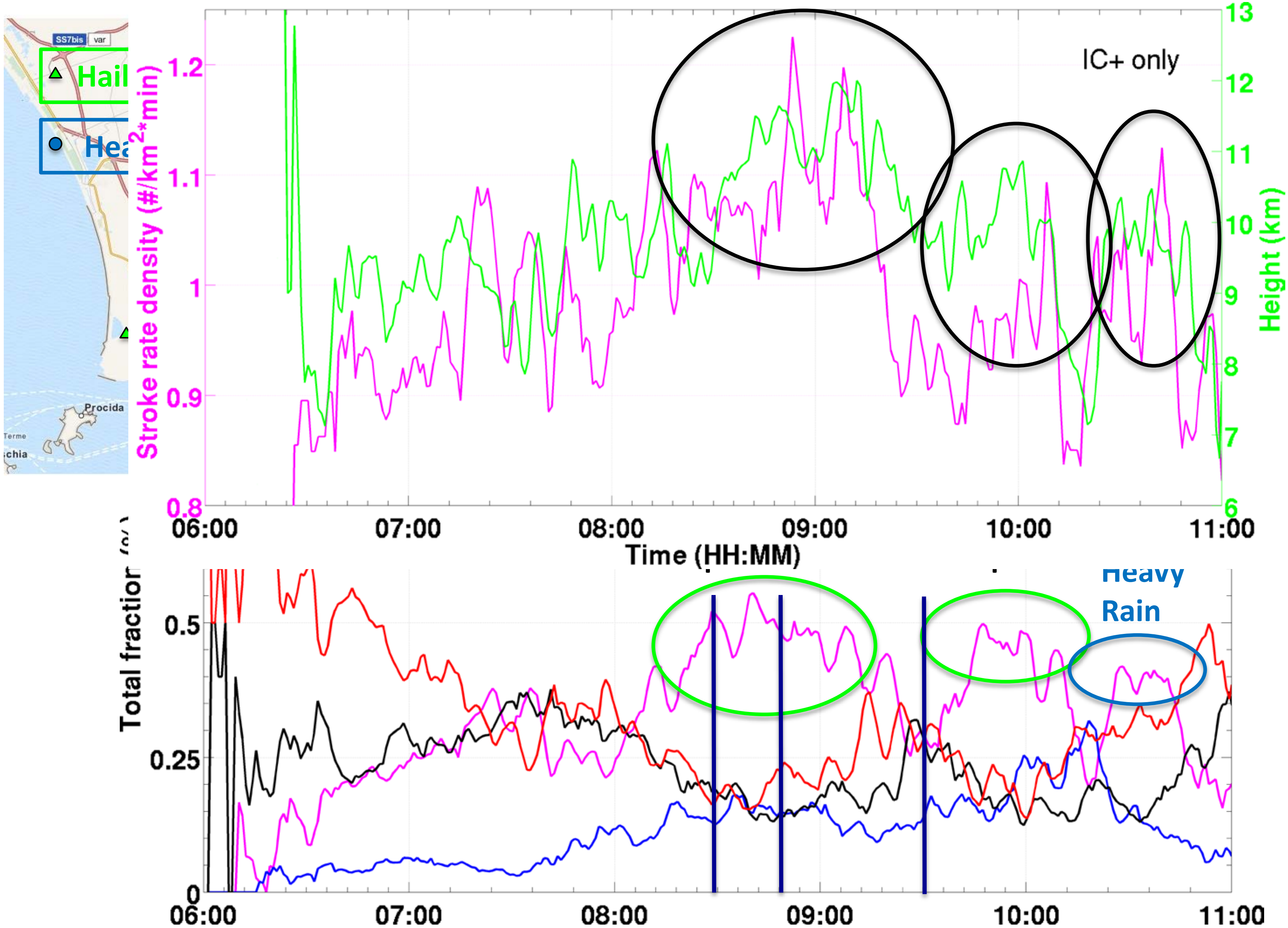


Sequence of reflectivity factor maps collected by the Monte il Monte radar from 08:30 UTC to 10:55 UTC highlighting the evolution of the hailstorm.

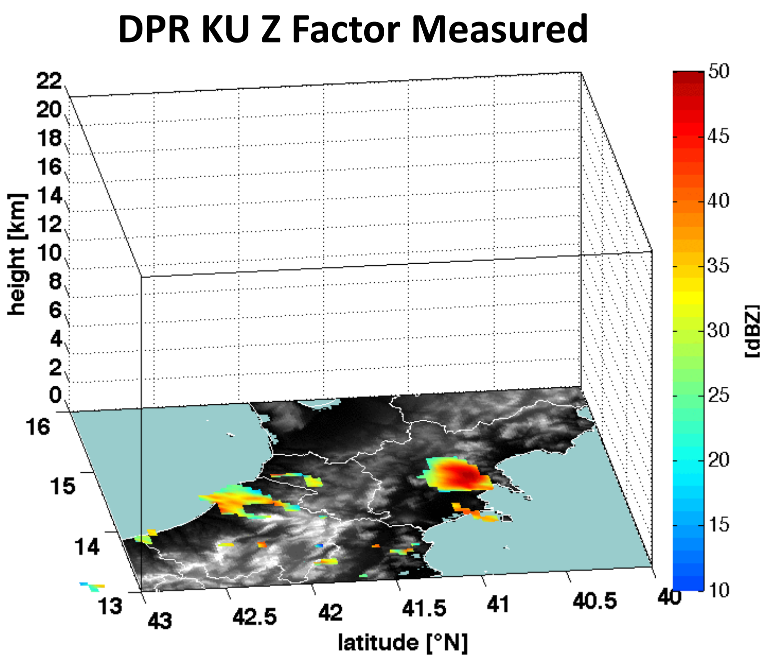
37220 strokes in the area swept by the storm between 06:12-11:00 UTC!



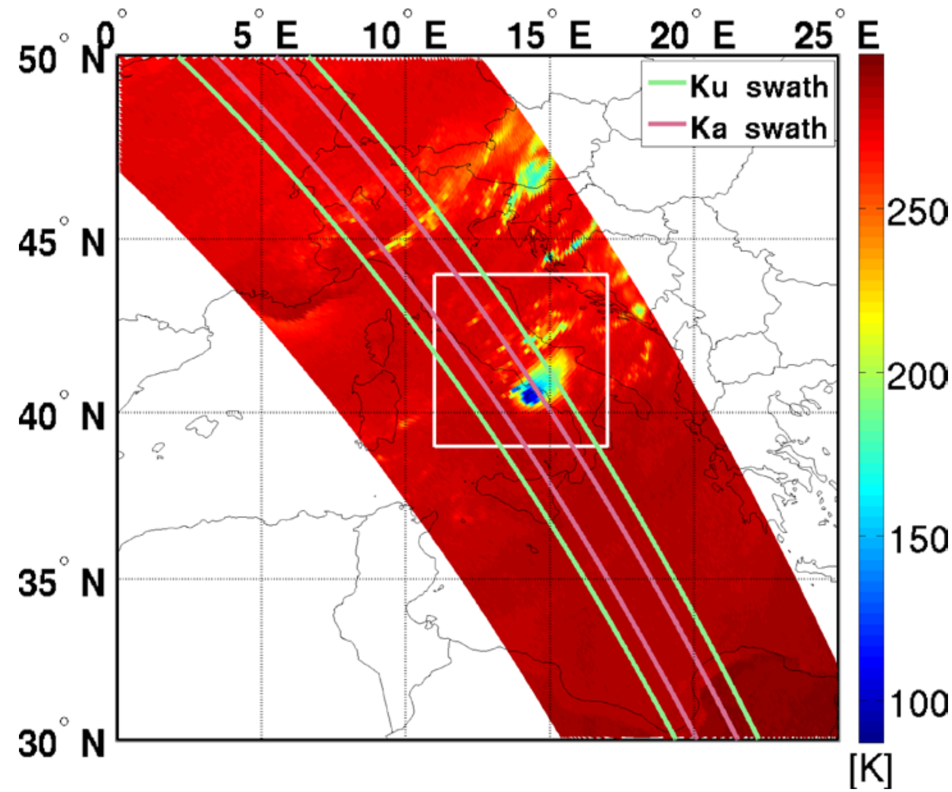
Time (UTC)	06:12-07:00	07:00-08:00	08:00-09:00	09:00-10:00	10:00-11:00
Number	3665	10581	10265	7331	5378
Rate (Strokes/min)	76	176	171	122	90


SS7bis
var
Hail
Hea
Procida
Terme
chia
Stroke rate density (#/km^2*min)
Height (km)
IC+ only
Time (HH:MM)
06:00
07:00
08:00
09:00
10:00
11:00
0.8
0.9
1
1.1
1.2
6
7
8
9
10
11
12
13
Total fraction
0
0.25
0.5
Heavy
Rain

GPM-CO overpass

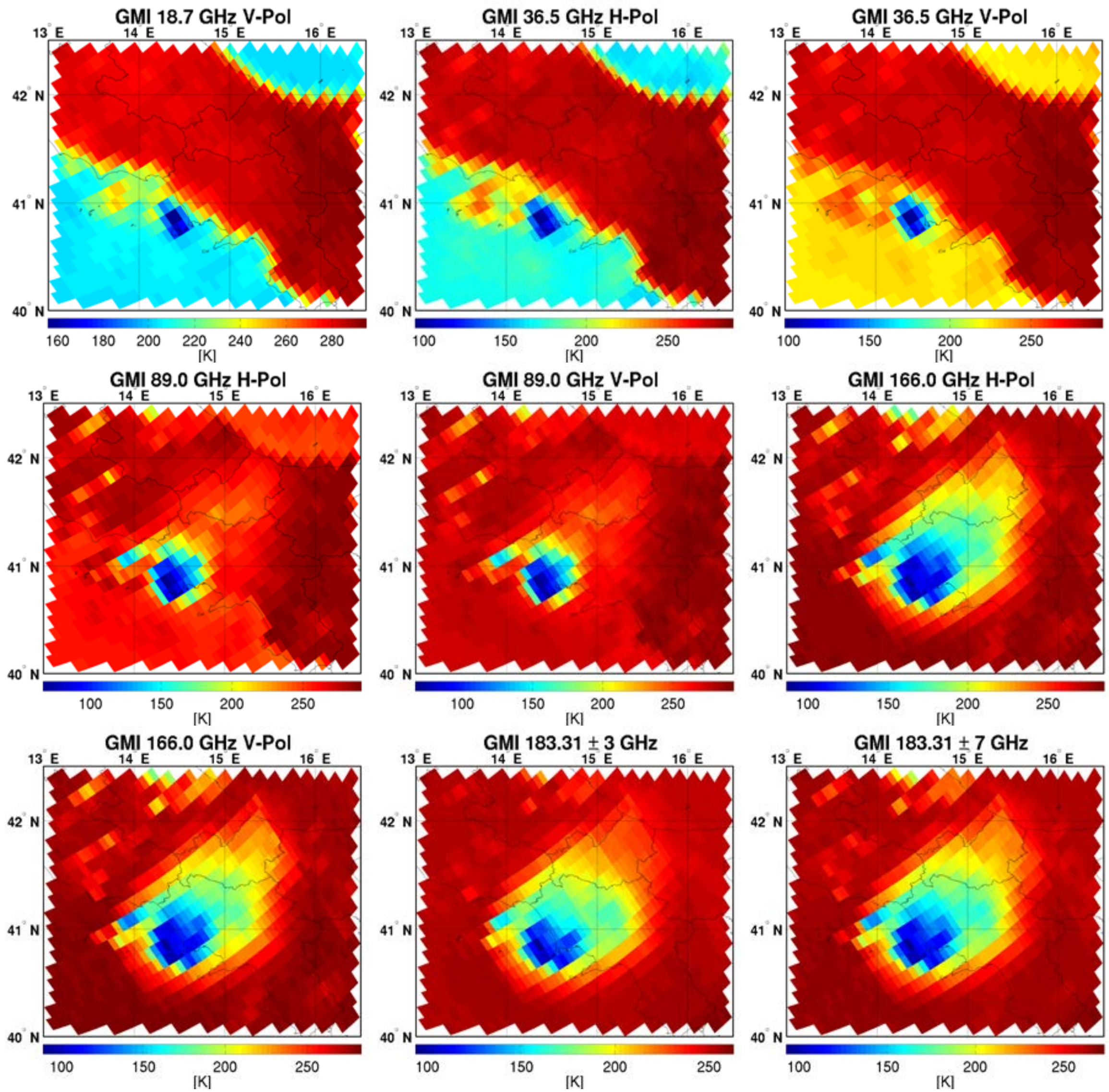


GPM Core Observatory (GPM-CO) captured the storm at its mature stage (descending orbit)



GMI, DPR-Ku and DPR-Ka swaths (904 km, 245 km and 120 km respectively) cover the deep convective core, while the anvil, fully covered by GMI, is partially covered by DPR (mostly Ku).

GPM-CO – GMI 8:47 UTC

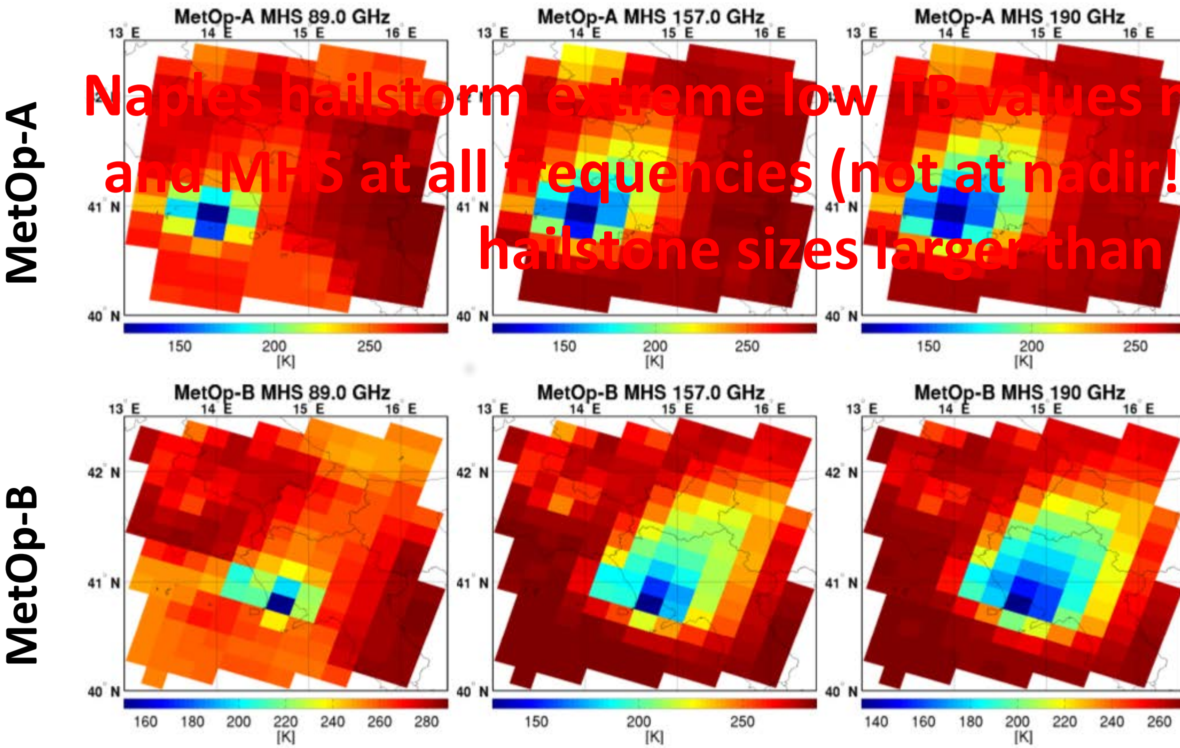


GMI channels	Min value (K)	IFOV (km^2)
18.7 GHz V	**158**	11x18
23.8 GHz	**138**	9.2x15
36.5 GHz PCT	**100**	8.6x14
89 GHz PCT	**68**	4.4x7.2
166 GHz H	**86**	4.4x7.2
166 GHz V	**87**	4.4x7.2
183±3 GHz	**94**	4.4x7.2
183±7 GHz	**92**	4.4x7.2

TB thresholds for hail detection based on 10 year TRMM TMI climatology are **70 K at 85 GHz, 180 K at 37 GHz, or 230 K at 19 GHz** (Cecil, 2009).

MetOp-A and MetOp-B MHS observations

89 GHz | **157 GHz** | **183+7 GHz**

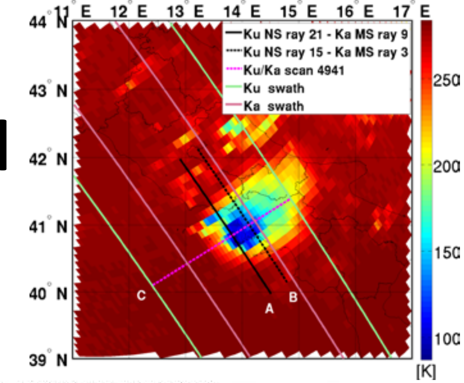


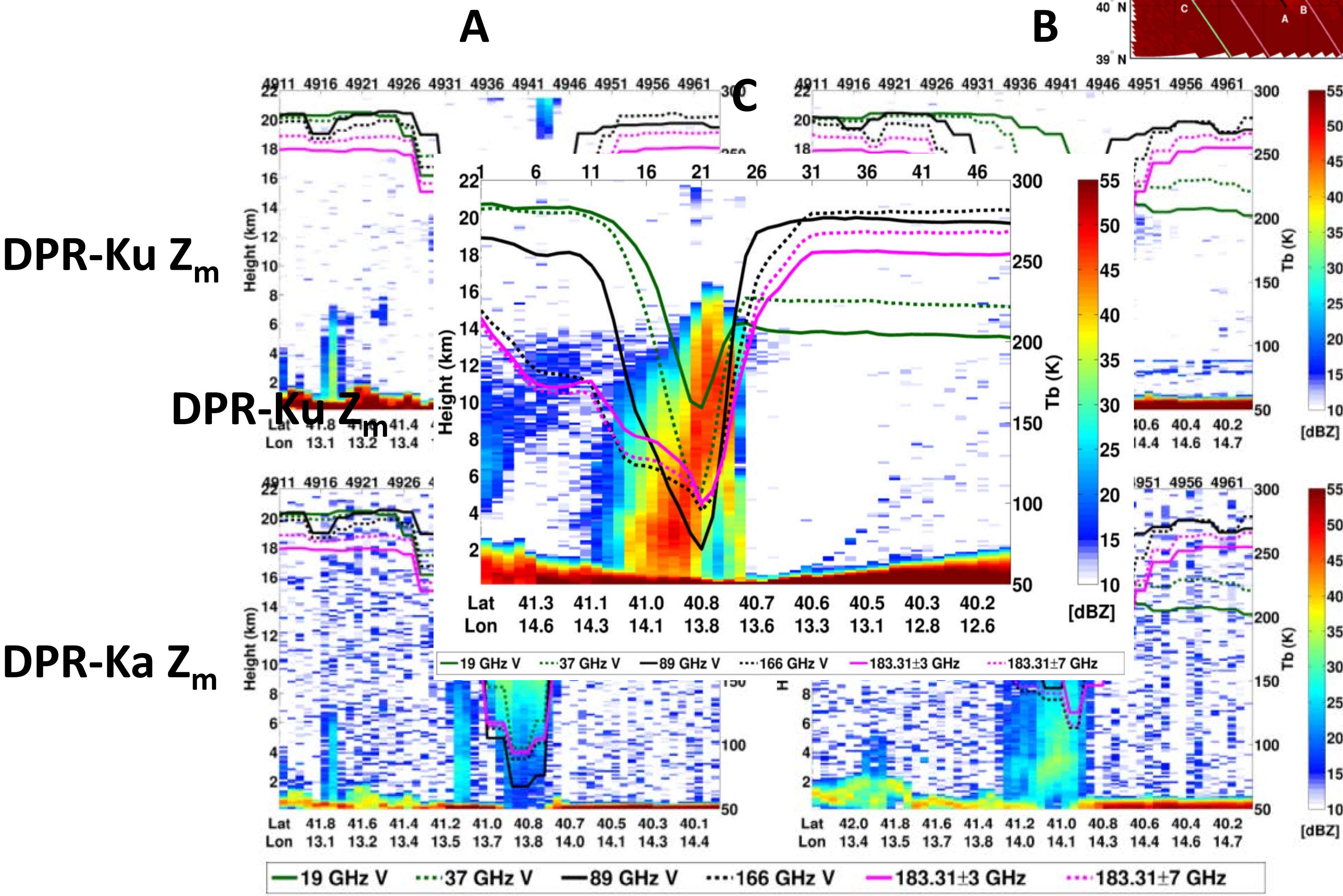
Naples hailstorm extreme low TB values measured by both GMI and MHS at all frequencies (not at nadir!) are compatible with hailstone sizes larger than 7.5 cm!

Average TBs for hail greater than 7.5 cm detection based on 12 year MHS climatology are **224 K at 89 GHz, 198 K at 157 GHz, 197 K at 183±1 GHz, 191 K at 183±3 GHz** and **189 K at 183±7 GHz** (Ferraro et al., 2015).

Satellite	Time (UTC)	Lat	Lon	Min 89 GHz	Min 157 GHz	Min 183 ± 1 GHz	Min 183 ± 3 GHz	Min 183 ± 7 GHz	EFOV (km^2)
MetOp-A	08:34	40.99°N	13.64°E	121 K	111 K	146 K	123 K	118 K	34.4x21.4
MetOp-B	09:28	40.84°N	14.35°E	151 K	129 K	156 K	137 K	134 K	28.9x19.7

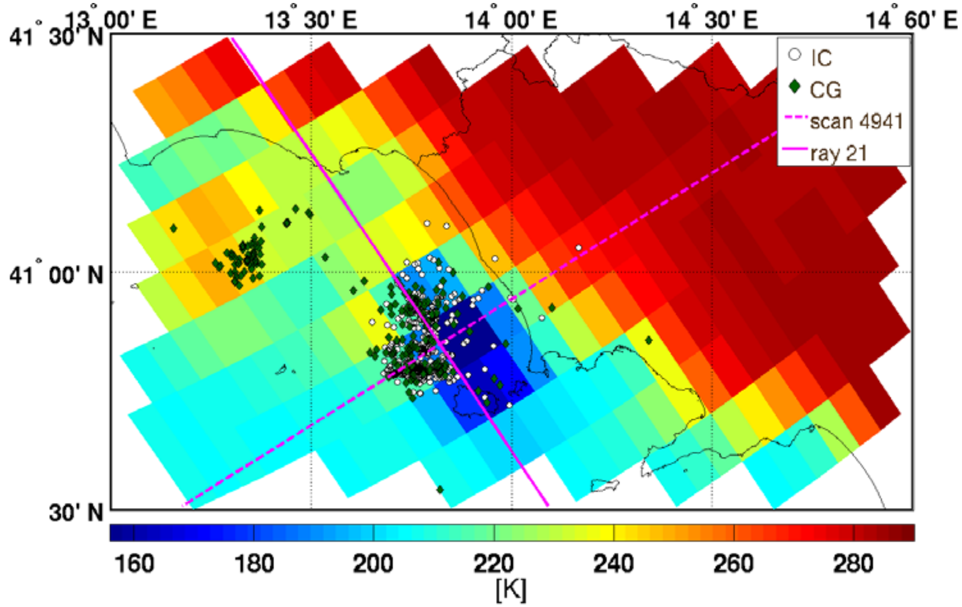
Cross-sections showing DPR measured reflectivity and corresponding GMI TBs



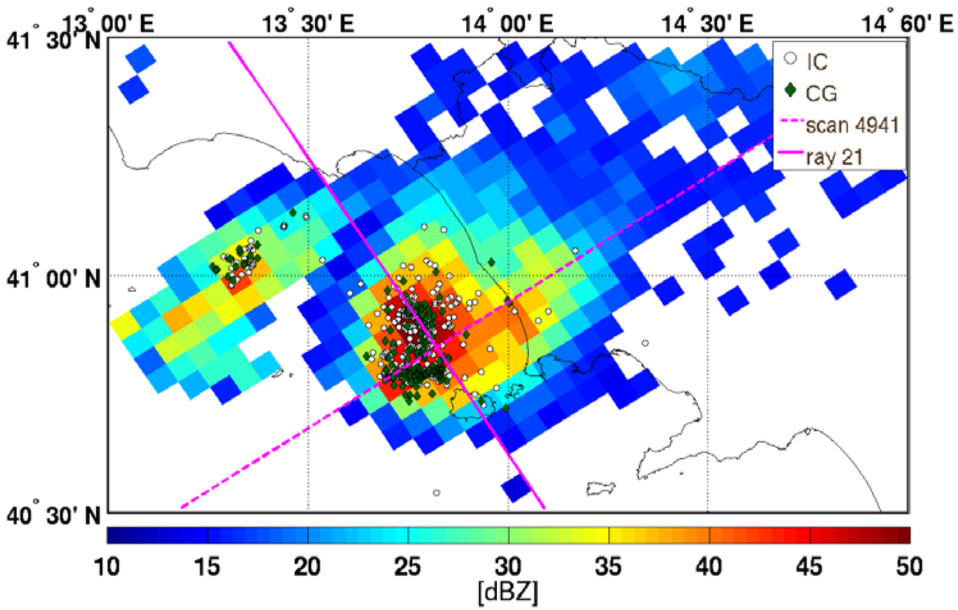


GMI-DPR, GR radar and lightning data

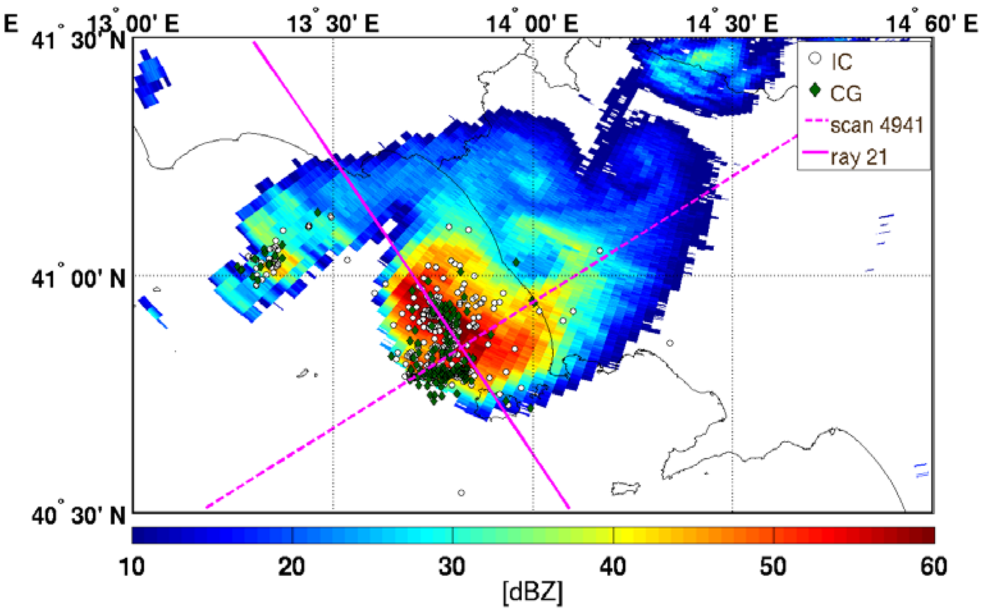
GMI TB 19 GHz V-Pol 08:47 UTC



DPR-Ku reflectivity 08:47 UTC



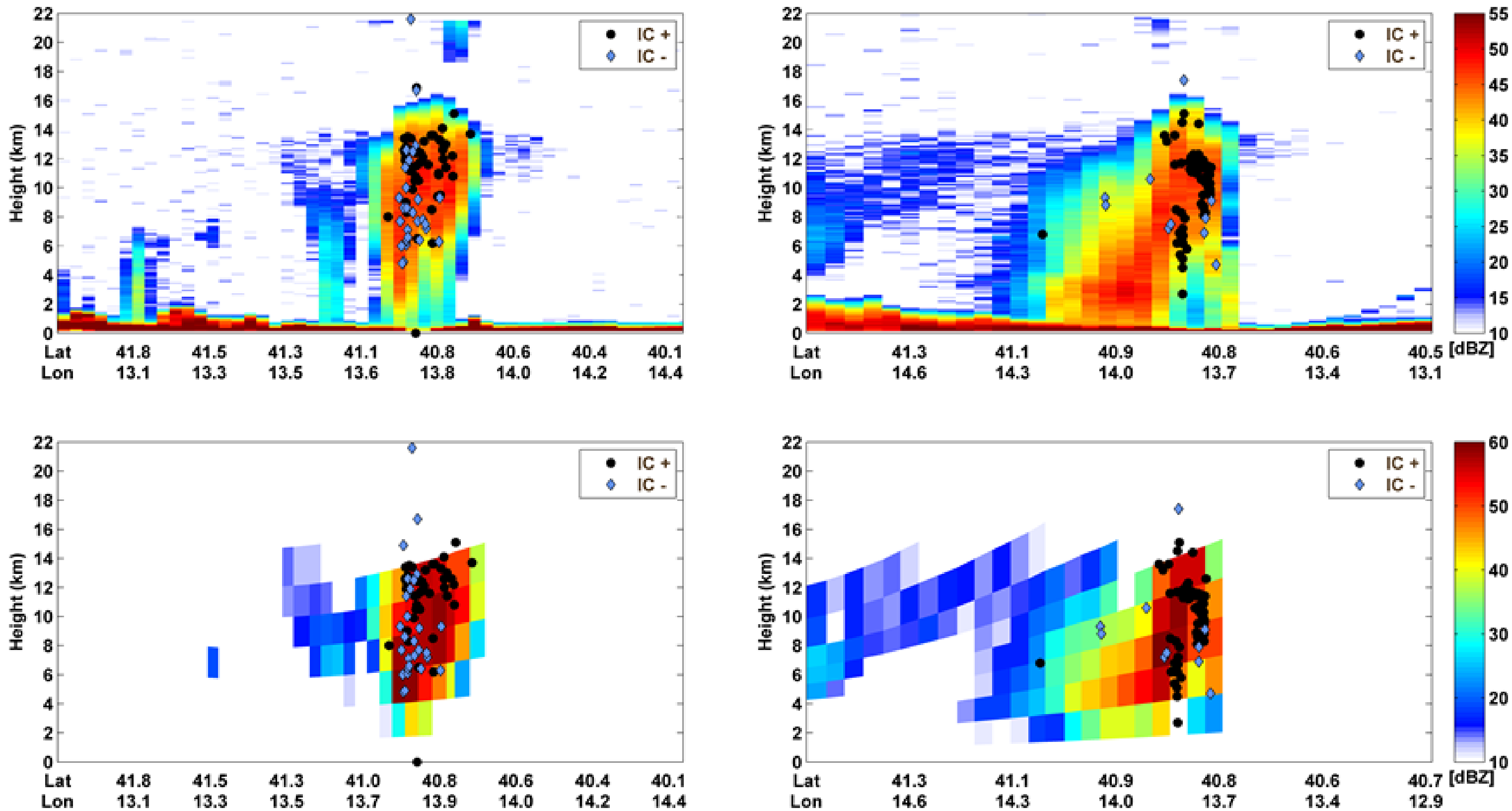
GR reflectivity 08:45 UTC



GMI-DPR, GR radar and lightning data

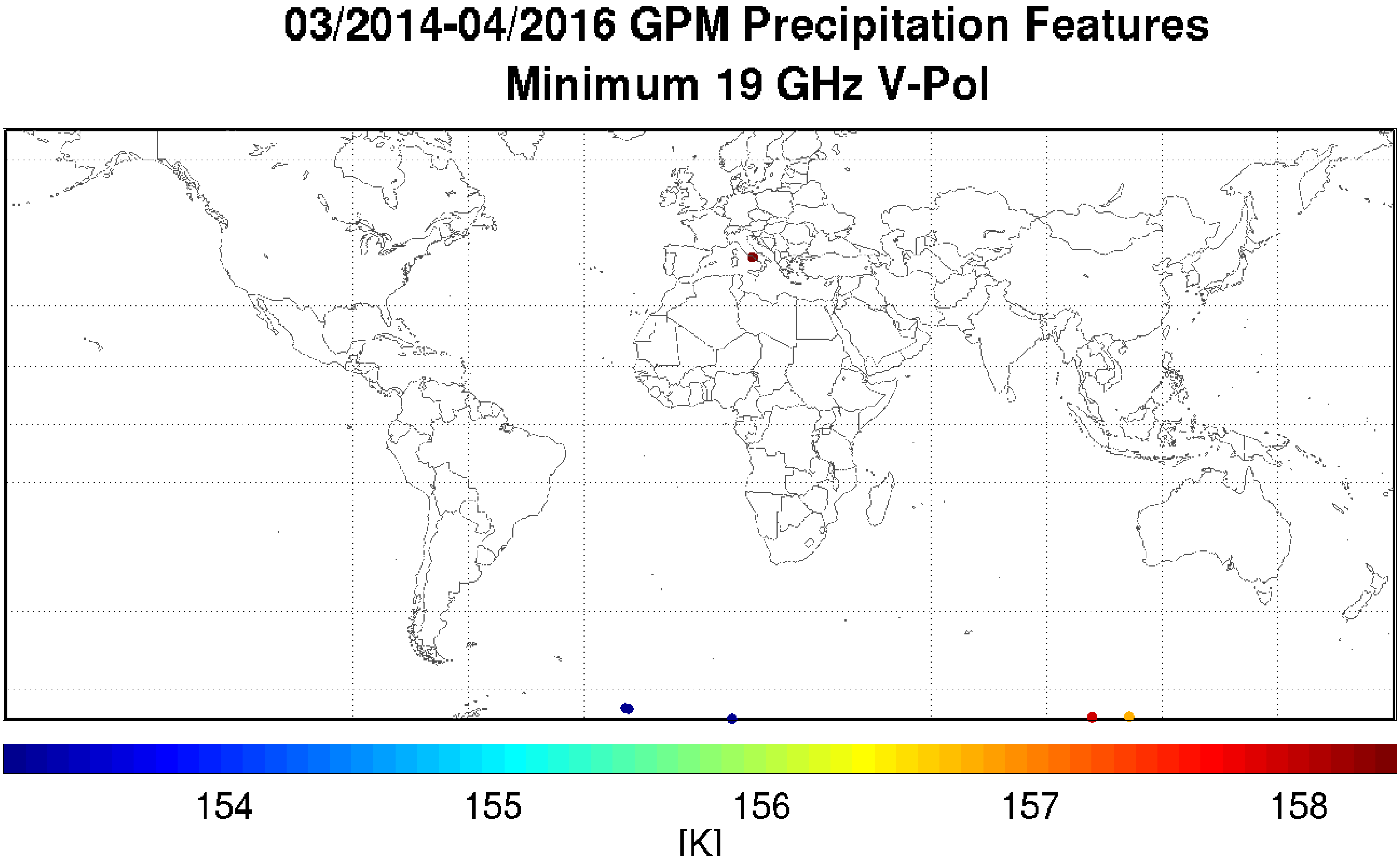
DPR-Ku Z_m

GR Z_h



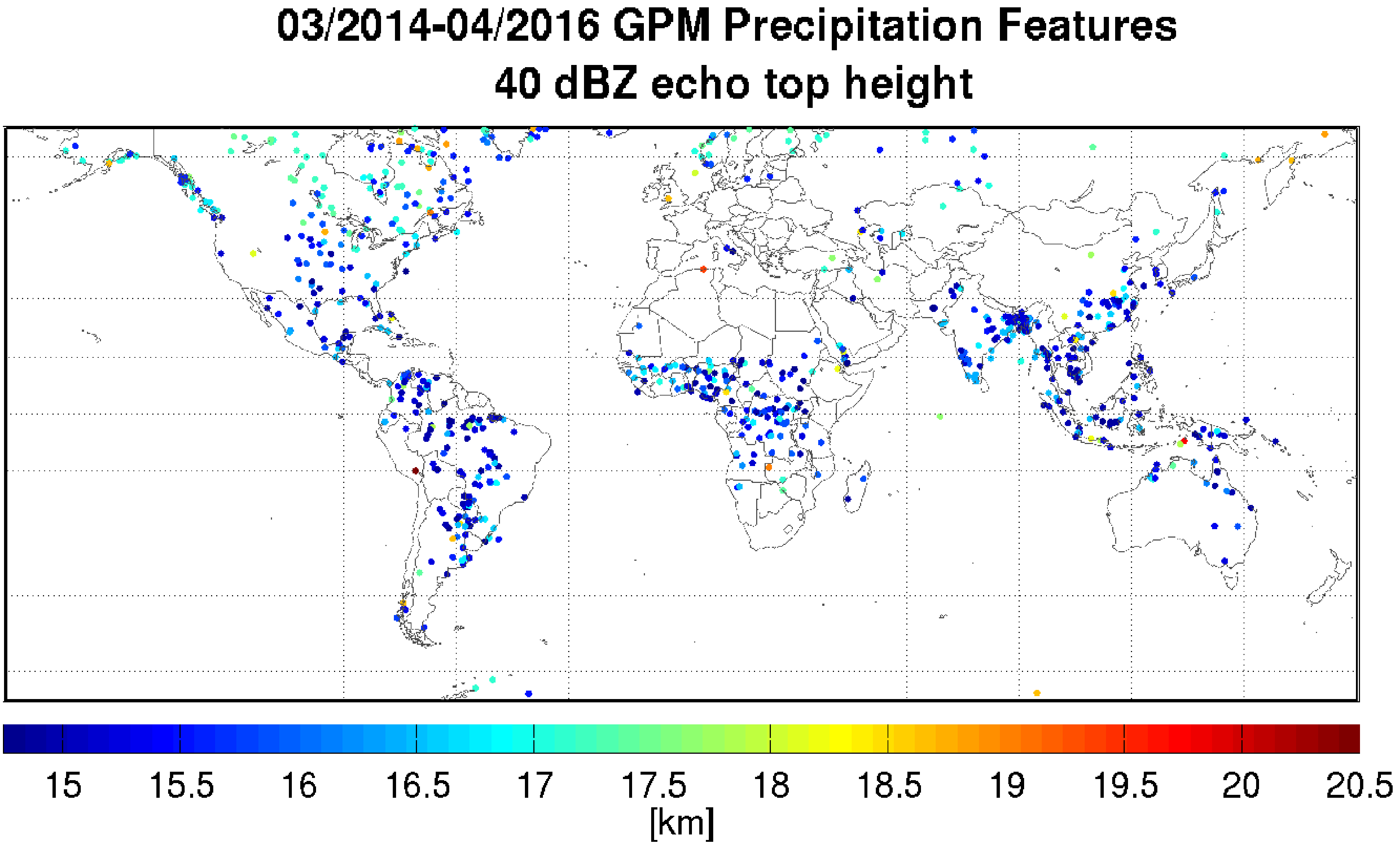
How rare is this type of storm in the Mediterranean area?

GPM PF with TB (or PCT) ≤ min. Naples hailstorm TB (or PCT)



GPM PF Database http://atmos.tamucc.edu/trmm/data/gpm/level_2/kurpf/
(Liu, C., and E. Zipser, 2015) - http://atmos.tamucc.edu/trmm/data/gpm

GPM PF with 40 dBZ e.t.h. ≥ Naples hailstorm 40 dBZ e.t.h.



GPM PF Database http://atmos.tamucc.edu/trmm/data/gpm/level_2/kurpf/
(Liu, C., and E. Zipser, 2015) - http://atmos.tamucc.edu/trmm/data/gpm

Global Ranking of Naples hailstorm based on GPM-CO measurements

GMI TB or PCT	Ranking	TRMM area (No CONUS)	Mediterranean Area	CONUS	Other regions
18.7 GHz V-Pol	1	-	1 (100%)	-	-
23.8 GHz	2	-	1 (50%)	1 (50%)	-
36.5 GHz PCT	4	-	1 (25%)	2 (50%)	1 (25%)
89 GHz PCT	98	80 (81.63%)	3 (3.06%)	12 (12.24%)	3 (3.06%)
166 GHz V-Pol	1798	1740 (96.77%)	6 (0.33%)	33 (1.83%)	19 (1.06%)
183±3 GHz	1745	1704 (97.65%)	4 (0.23%)	23 (1.32%)	14 (0.80%)
183±7 GHz	2219	2161 (97.39%)	6 (0.27%)	32 (1.44%)	20 (0,90 %)

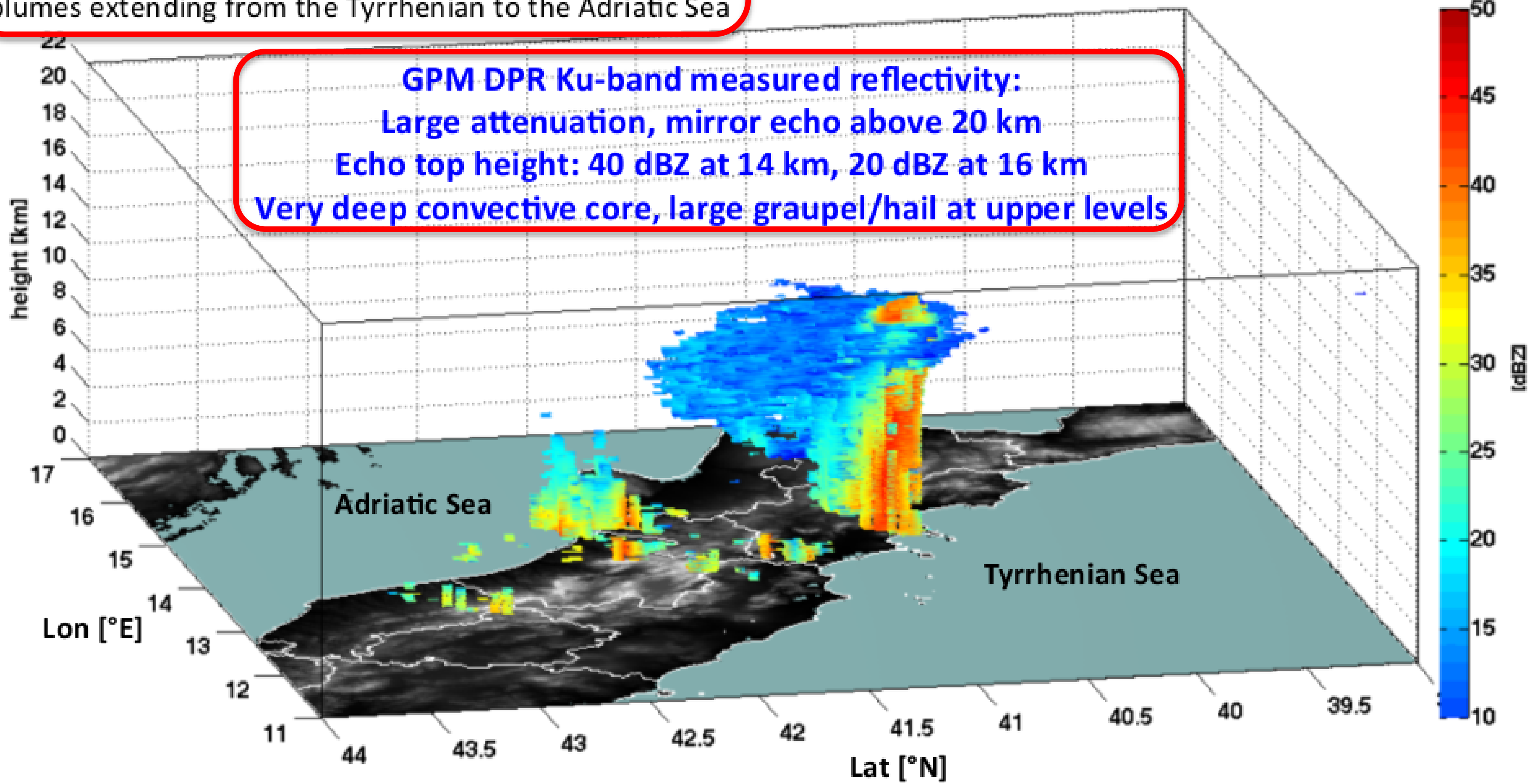
Analysis of PFs found in 26 months of global observations (03/2014-04/2016, http://atmos.tamucc.edu/trmm/data/gpm) based on minimum TB and PCT values. Second column shows the ranking of Naples hailstorm (for each TB or PCT) with respect to **over 15 millions (15,274,291)** global PFs. Third to sixth column show the geographical distribution (in terms of number and %) of the PFs with TB and PCT minimum values equal to or lower than those found for the Naples hailstorm.

Naples hailstorm – 5 September 2015

MSG VIS-IR:
Minimum cloud top temperature 198 K
Peak cooling rate 4.5 K min^{-1}
Outflow region with overshooting top, and cloud-top plumes extending from the Tyrrhenian to the Adriatic Sea

C-band polarimetric ground radar:
strong hook-echo
three-body scattering

GPM DPR Ku-band measured reflectivity:
Large attenuation, mirror echo above 20 km
Echo top height: 40 dBZ at 14 km, 20 dBZ at 16 km
Very deep convective core, large graupel/hail at upper levels



GPM GMI Brightness Temperatures:
Large convective core with record minimum at 19 GHz (globally) and ≤ 37 GHz (Mediterranean area)
20 K lower at 89 GHz than at 166 GHz
Complex upper level structure revealed by 166 GHz V-H signal

LINET:
21000 strokes in two hours
Peak rate 300 min^{-1}
IC+ fraction and heights correlated to updraft strength

Nisida and Gulf of Pozzuoli, Naples, Italy

Contacts

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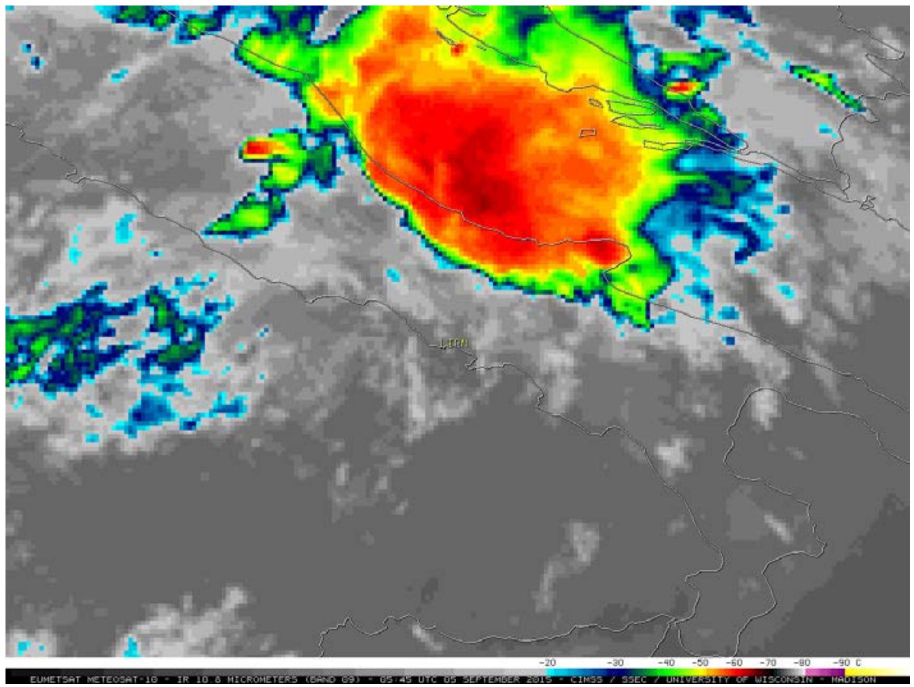
Back-up slides

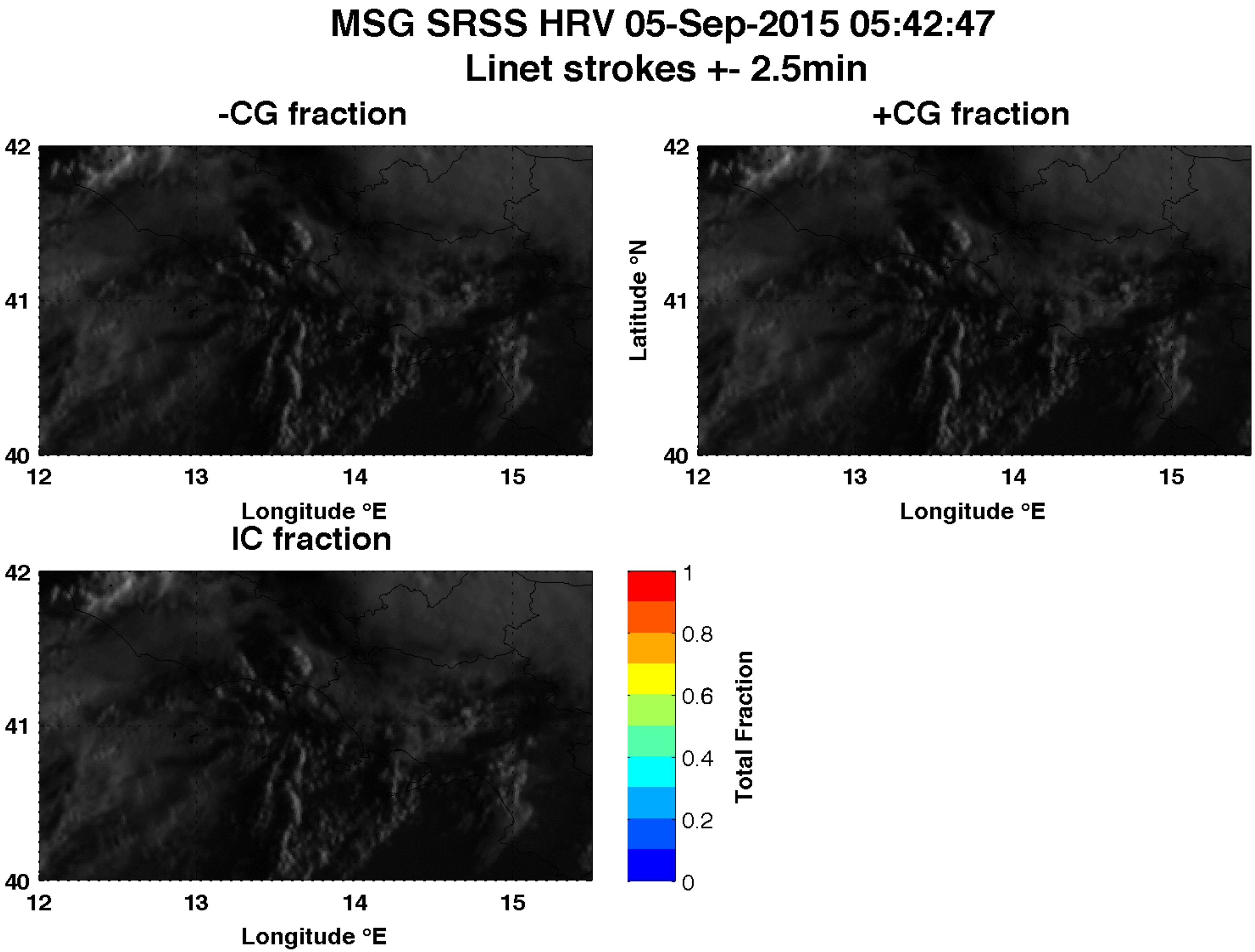
Evolution of the storm at 10.8 µm - SEVIRI IR channel

Extremely rapid development of the storm, with cloud-top temperatures at 10.8 µm dropping from 270 K at 0557 UTC to 225 K at 6:12 UTC (**45 K in 15 minutes!**) *(mean TB values on a 3x3 MSG pixel box);*

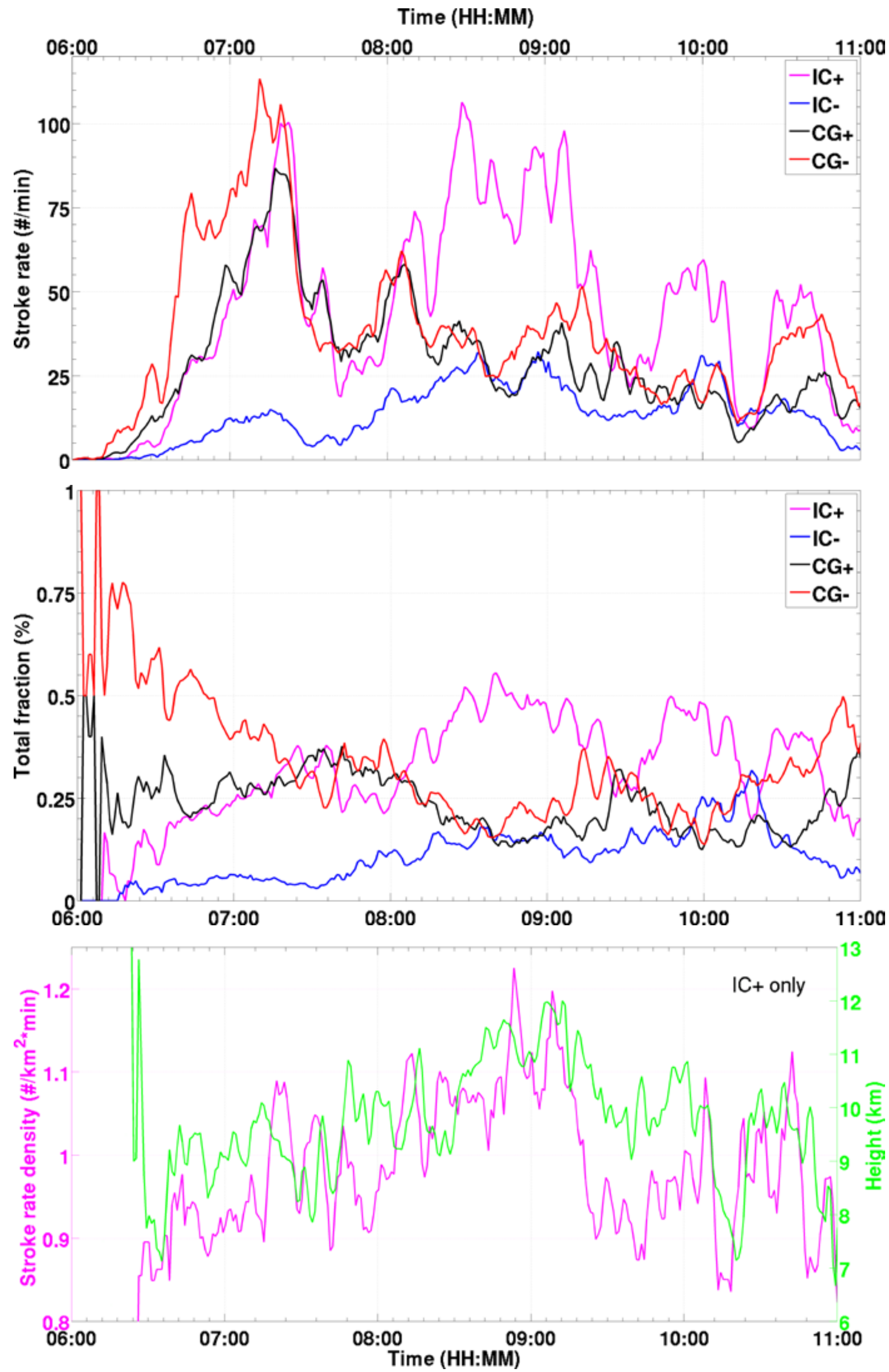
Lowest TB value 197.87 K found at 0900 UTC; Max cooling rate 4.5 K min^{-1}



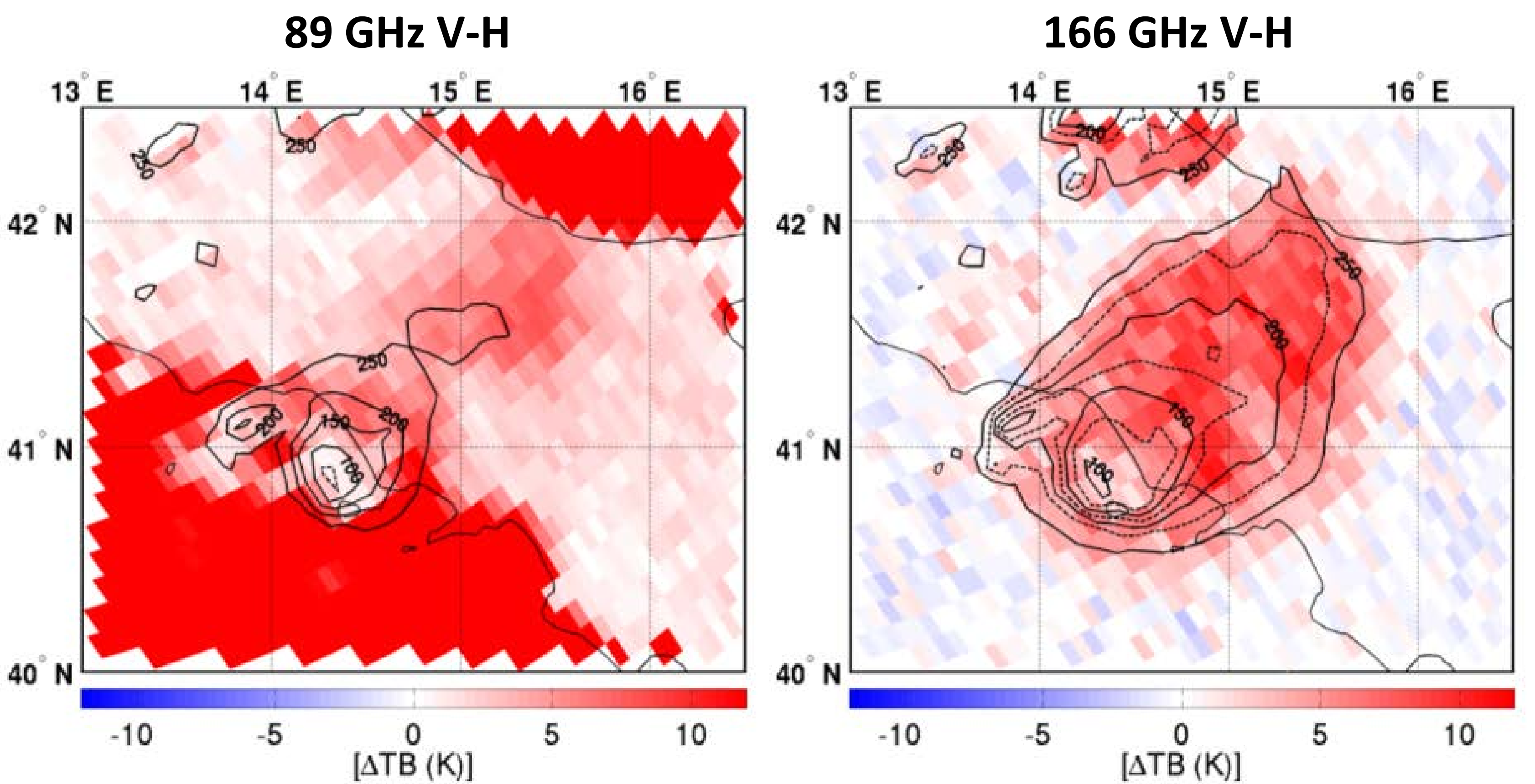
Cloud Top Divergence estimated from MSG IR images (early studies by Sidkar et al, 1970)
Est. Max Cloud Top Divergence at 6:12 UTC: $3.3 \times 10^{-3}\ s^{-1}$
Estimated updraft strength: 130 km/h! Value compatible with hailsize 8-10 cm
(according to theoretical models and experimental data)



MSG SRSS HRV 05-Sep-2015 05:42:47
Linet strokes +- 2.5min
-CG fraction
+CG fraction
IC fraction
42
41
40
12
13
14
15
Longitude °E
Latitude °N
1
0.8
0.6
0.4
0.2
0
Total Fraction

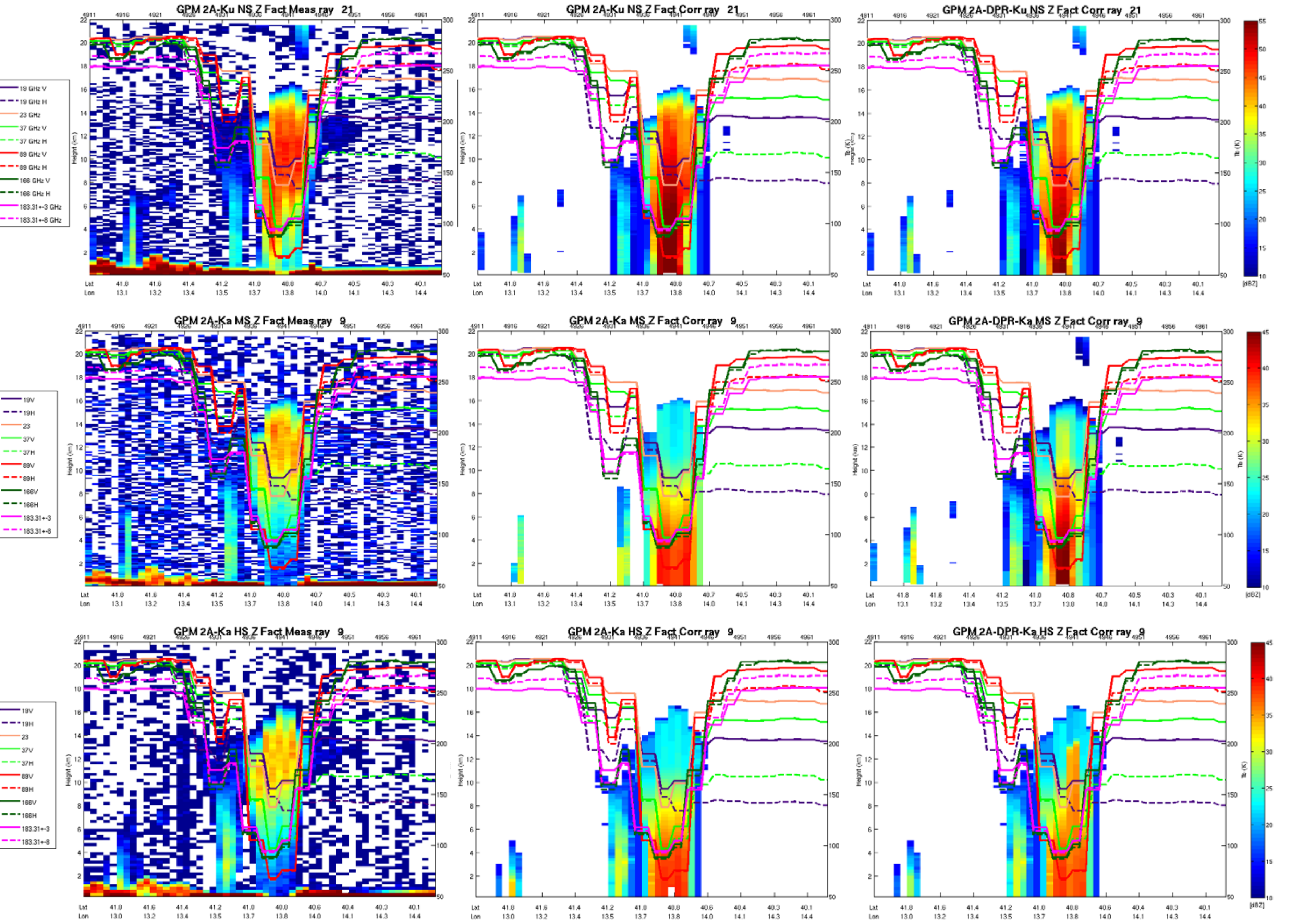

Time (HH:MM)
06:00
07:00
08:00
09:00
10:00
11:00
Stroke rate (#/min)
0
25
50
75
100
IC+
IC-
CG+
CG-
Total fraction (%)
0
0.25
0.5
0.75
1
IC+
IC-
CG+
CG-
Stroke rate density (#/km²*min)
0.8
0.9
1
1.1
1.2
Height (km)
6
7
8
9
10
11
12
13
IC+ only

GMI TB difference at 89 GHz and 166 GHz

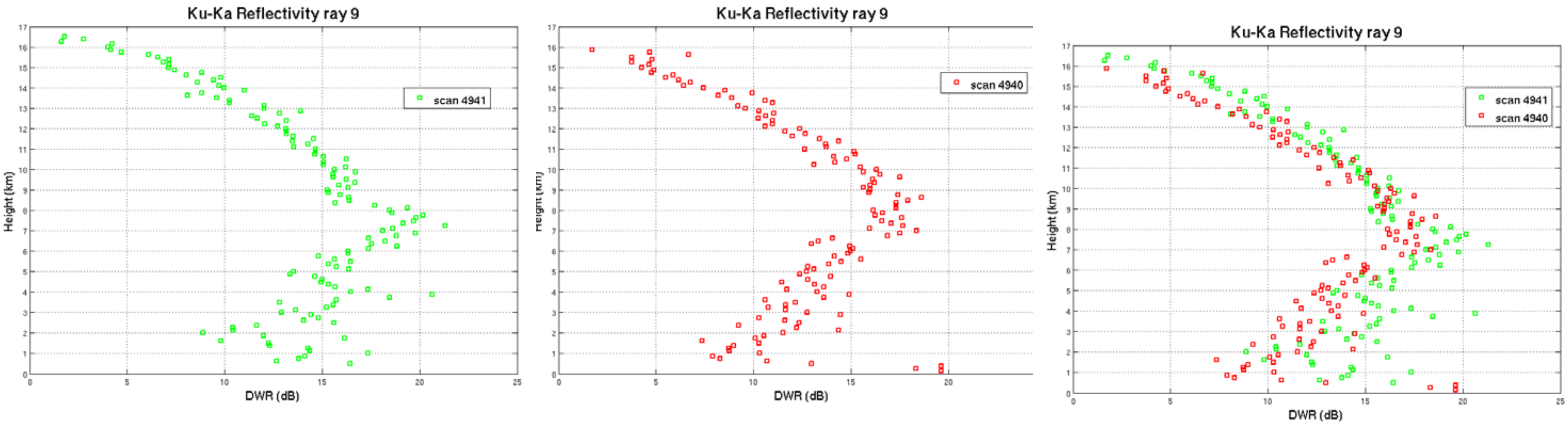


TB difference between vertical and horizontal polarization channels (V–H) at 89 GHz and 166 GHz from GMI overpass and contour lines of TB at 89 GHz and 166 GHz in the vertical polarization.

Measured Corrected (2A-Ku or 2A-Ka) Corrected (2A-DPR)



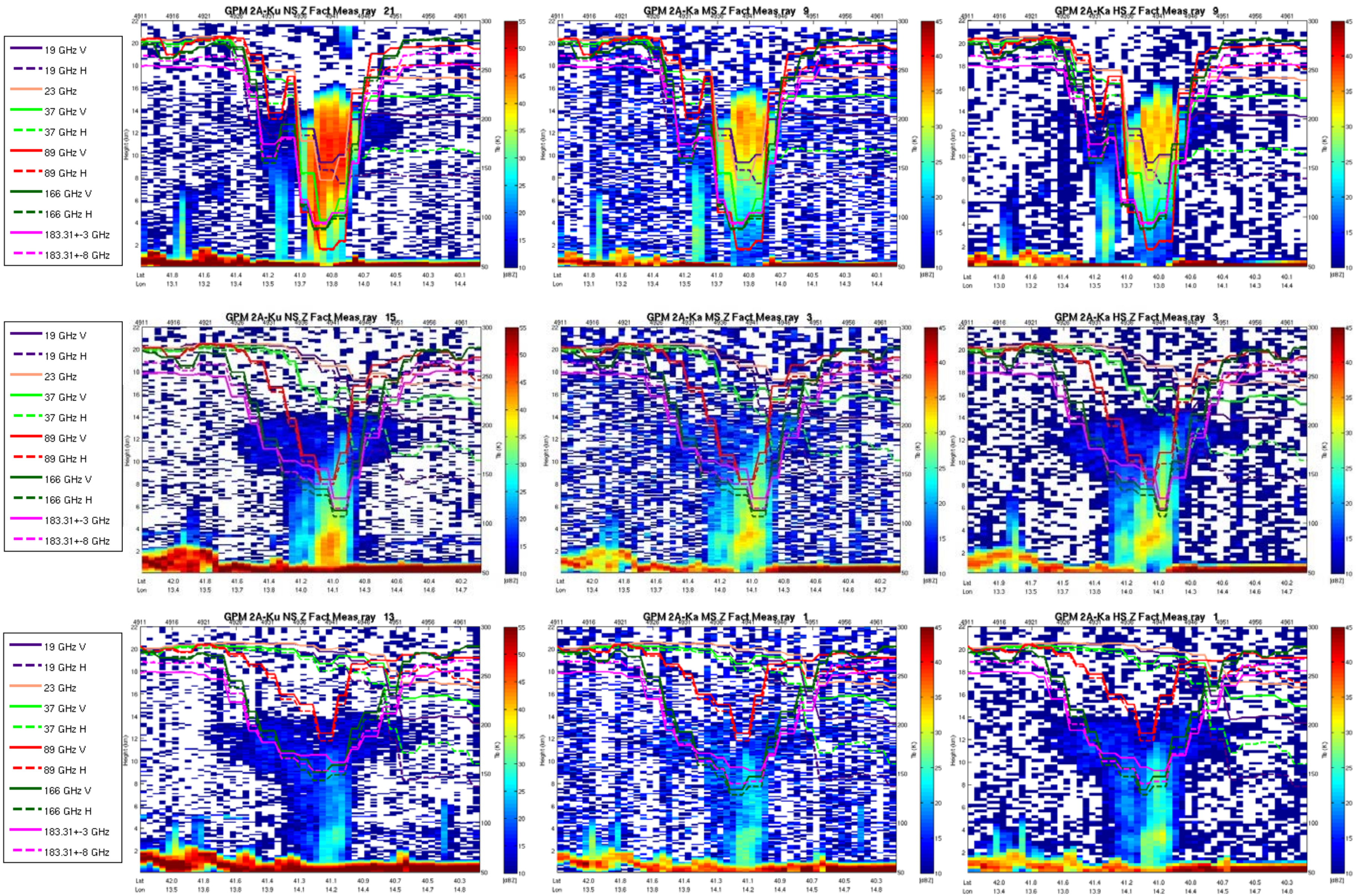
Multiple scattering (Battaglia et al, 2015)



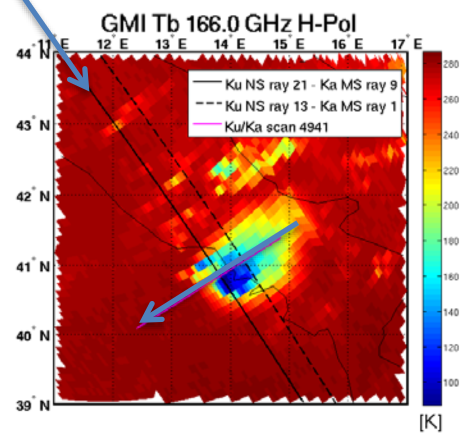
GPM – DPR cross section analysis

Along track (Ku-NS ray number 21, 15, and 13)

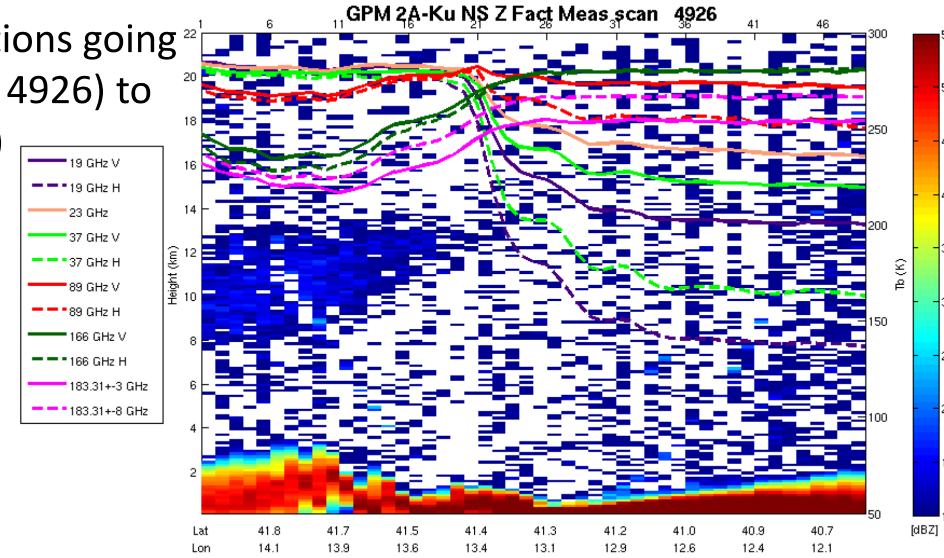
Ku-NS **Ka-MS** **Ka-HS**



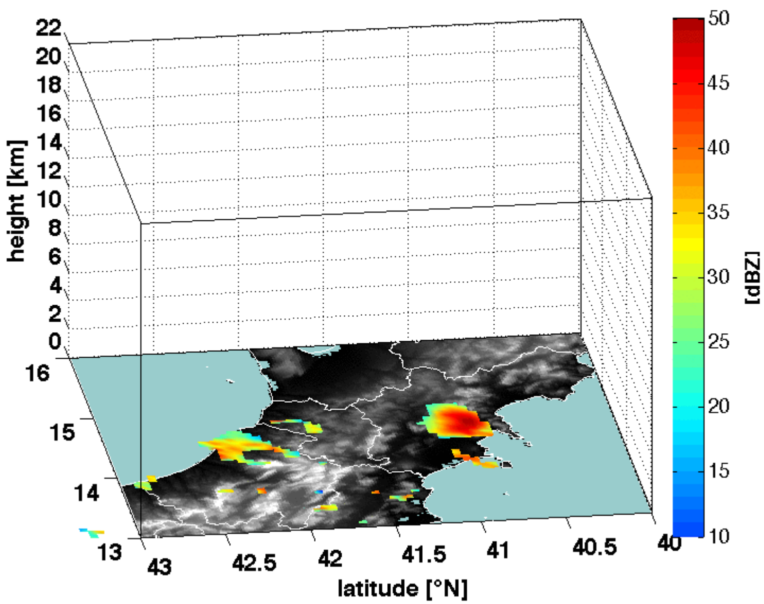
Overview of GPM 3-D cloud structure analysis capabilities

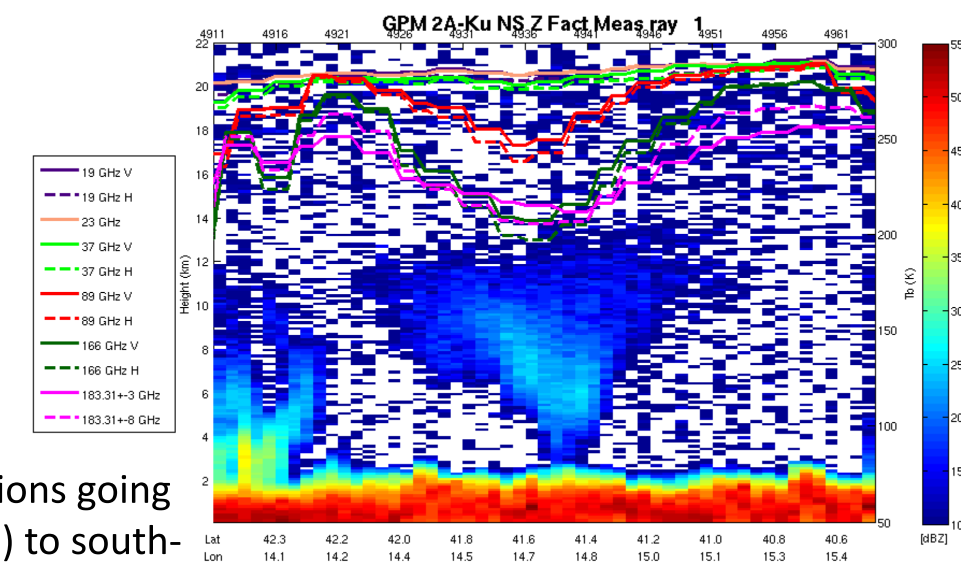


Across-track cross sections going from north-west (scan 4926) to south-east (scan 4948)



DPR KU Z Factor Measured





Along-track cross sections going from north-east (ray 1) to south-west (ray 34)