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.

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

https://www.youtube.com/watch?v=yarARzbkjl4)
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.

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)
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 (LiLightning 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
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!

<table>
<thead>
<tr>
<th>Time (UTC)</th>
<th>06:12-07:00</th>
<th>07:00-08:00</th>
<th>08:00-09:00</th>
<th>09:00-10:00</th>
<th>10:00-11:00</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number</strong></td>
<td>3665</td>
<td>10581</td>
<td>10265</td>
<td>7331</td>
<td>5378</td>
</tr>
<tr>
<td><strong>Rate</strong></td>
<td>76</td>
<td>176</td>
<td>171</td>
<td>122</td>
<td>90</td>
</tr>
</tbody>
</table>
Lightning activity analysis

- Hail
- Heavy Rain

European Severe Weather Database
(http://www.eswd.eu/)

GPM-CO
MetOp-A
MetOp-B

Chart showing stroke rate density and total fraction over time.
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).
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

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).

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Time (UTC)</th>
<th>Lat</th>
<th>Lon</th>
<th>Min 89 GHz</th>
<th>Min 157 GHz</th>
<th>Min 183+1 GHz</th>
<th>Min 183+3 GHz</th>
<th>Min 183+7 GHz</th>
<th>EFOV (km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MetOp-A</td>
<td>08:34</td>
<td>40.99°N</td>
<td>13.64°E</td>
<td>121 K</td>
<td>111 K</td>
<td>146 K</td>
<td>123 K</td>
<td>118 K</td>
<td>34.4x21.4</td>
</tr>
<tr>
<td>MetOp-B</td>
<td>09:28</td>
<td>40.84°N</td>
<td>14.35°E</td>
<td>151 K</td>
<td>129 K</td>
<td>156 K</td>
<td>137 K</td>
<td>134 K</td>
<td>28.9x19.7</td>
</tr>
</tbody>
</table>
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)

03/2014-04/2016 GPM Precipitation Features
Minimum 19 GHz V-Pol

(Liu, C., and E. Zipser, 2015) - [http://atmos.tamucc.edu/trmm/data/gpm](http://atmos.tamucc.edu/trmm/data/gpm)
GPM PF with 40 dBZ e.t.h. ≥ Naples hailstorm 40 dBZ e.t.h.

03/2014-04/2016 GPM Precipitation Features
40 dBZ echo top height

(Liu, C., and E. Zipser, 2015) - [http://atmos.tamucc.edu/trmm/data/gpm](http://atmos.tamucc.edu/trmm/data/gpm)
Global Ranking of Naples hailstorm based on GPM-CO measurements

<table>
<thead>
<tr>
<th>GMI TB or PCT</th>
<th>Ranking</th>
<th>TRMM area (No CONUS)</th>
<th>Mediterranean Area</th>
<th>CONUS</th>
<th>Other regions</th>
</tr>
</thead>
<tbody>
<tr>
<td>18.7 GHz V-Pol</td>
<td>1</td>
<td>-</td>
<td>1 (100%)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>23.8 GHz</td>
<td>2</td>
<td>-</td>
<td>1 (50%)</td>
<td>1 (50%)</td>
<td>-</td>
</tr>
<tr>
<td>36.5 GHz PCT</td>
<td>4</td>
<td>-</td>
<td>1 (25%)</td>
<td>2 (50%)</td>
<td>1 (25%)</td>
</tr>
<tr>
<td>89 GHz PCT</td>
<td>98</td>
<td>80 (81.63%)</td>
<td>3 (3.06%)</td>
<td>12 (12.24%)</td>
<td>3 (3.06%)</td>
</tr>
<tr>
<td>166 GHz V-Pol</td>
<td>1798</td>
<td>1740 (96.77%)</td>
<td>6 (0.33%)</td>
<td>33 (1.83%)</td>
<td>19 (1.06%)</td>
</tr>
<tr>
<td>183±3 GHz</td>
<td>1745</td>
<td>1704 (97.65%)</td>
<td>4 (0.23%)</td>
<td>23 (1.32%)</td>
<td>14 (0.80%)</td>
</tr>
<tr>
<td>183±7 GHz</td>
<td>2219</td>
<td>2161 (97.39%)</td>
<td>6 (0.27%)</td>
<td>32 (1.44%)</td>
<td>20 (0.90%)</td>
</tr>
</tbody>
</table>

Analysis of PFs found in 26 months of global observations (03/2014-04/2016, [http://atmos.tamu.edu/trmm/data/gpm](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.
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 \(\leq 37\) 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:
21,000 strokes in two hours
Peak rate 300 min\(^{-1}\)
IC+ fraction and heights correlated to updraft strength
Acknowledgements

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Nisida and Gulf of Pozzuoli, Naples, Italy
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: 3.3x10⁻³ s⁻¹

Estimated updraft strength: 130 km/h! Value compatible with hailsize 8-10 cm (according to theoretical models and experimental data)
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.
Multiple scattering (Battaglia et al, 2015)
GPM – DPR cross section analysis
Along track (Ku-NS ray number 21, 15, and 13)
Overview of GPM 3-D cloud structure analysis capabilities

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

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