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Hailstorm characterization with a synergistic active and passive, GEO and LEO observation strategy

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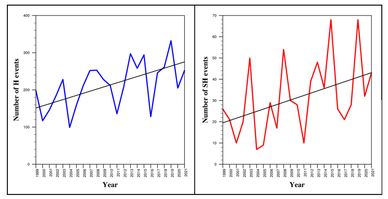
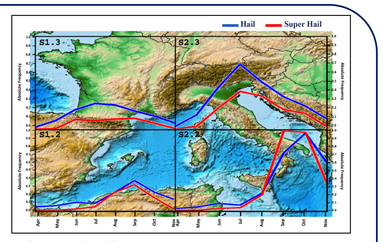
Motivation

Convection is a vital process which helps to redistribute energy in the atmosphere and is often conducive to severe weather events worldwide, including hailstorms highly impacting infrastructures and properties.
The Mediterranean Basin has an increasing trend in the number of occurrences of such events in the last decades, thus calling for an advancement in the observational capability and retrieval methodologies for the analysis of convective storm associated with hail production.



Annual hail (2-10 cm) and super hail (>10 cm) events for the Mediterranean Basin from combined NOAA 15, MetOp-A, and MetOp-C satellites observations (1999-2021). Laviola et al. (2023)



Seasonality of hail and super hail events across the Mediterranean regions.

Synergistic GEO and LEO observation strategy

EarthCARE Cloud Profiling Radar

The CPR is a 94 GHz (W-band) cloud radar with Doppler capability (horizontal resolution 750 m, vertical resolution 500m). Despite penetrating issues down to the warmer levels due to attenuation and multiple scattering (Battaglia et al., 2010, 2011) the CPR measurements provide the first insights on upper level vertical motions. Challenges are expected from aliasing and non uniform beam filling issues (Tanelli et al., 2002; Kollias et al., 2018).

EUMETSAT NWC SAF

The Rapidly Developing Thunderstorm - Convection Warning (RDT-CW) product has been developed by Meteo-France in the framework of the EUMETSAT SAF in support to Nowcasting. Using mainly geostationary satellite data, it provides information on clouds related to significant convective systems, from mesoscale (200 to 2000 km) down to smaller scales (tenth of km).
RDT-CW is generated with MSG RSS data.

Multi-sensor Approach for Satellite Hail Advection (MASHA)

Multi-instrument technique designed for tracking hail-bearing clouds, combining the strengths of the previously developed MicroWave Cloud Classification-Hail (MWCC-H, Laviola et al., 2020) method - which estimates hail probability using the GPM sensor constellation - with the high temporal resolution of infrared brightness temperatures from MSG Rapid Scan Service.

Category Description	Probability of Hail	Diameter Range (cm)	Potential Severity
Hail Potential (HP)	0.20 ÷ 0.36	~	Absent to low
Graupel/Hail Initiation (HI)	0.36 ÷ 0.45	<2	Low to moderate
Large Hail (H)	0.45 ÷ 0.60	2 ÷ 10	High to severe
Super Hail (SH)	> 0.60	>10	Severe to extreme

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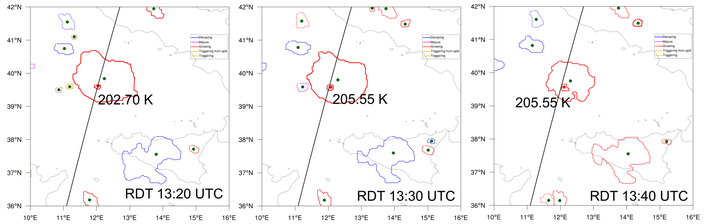
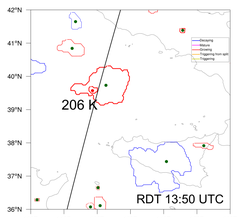
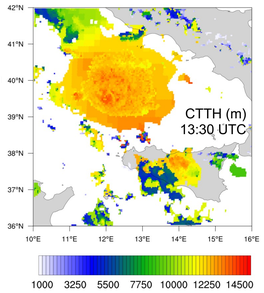
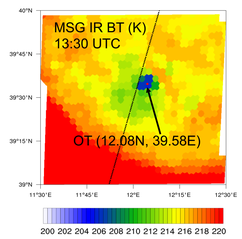
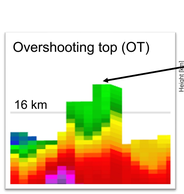


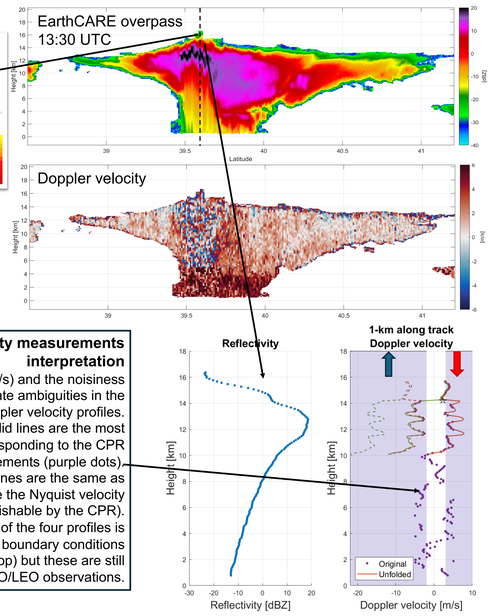


- Convective system tracked by the RDT product from 08:30 UTC, persisting for over 9 hours.
- Presence of overshooting top in various phases of the convective system life cycle.
- At 13:30 UTC, EarthCARE detected an updraft with negative vertical velocities, corresponding an overshooting top reaching a height of 16 km.
- The spatial resolution of MSG RSS (3-4 km) is insufficient to fully resolve the fine structure of the cloud top.
- The cloud top height (CTTH) retrieved by GEO sensor is underestimated with respect to CPR (13.55 km at OT).



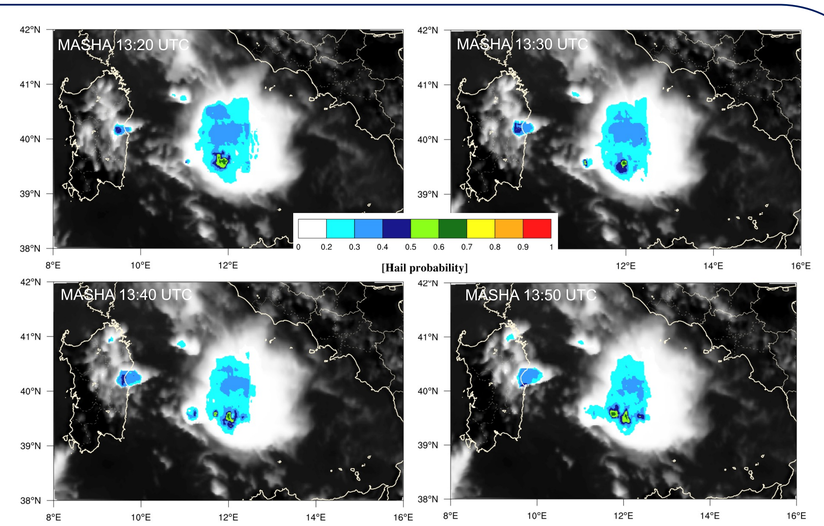






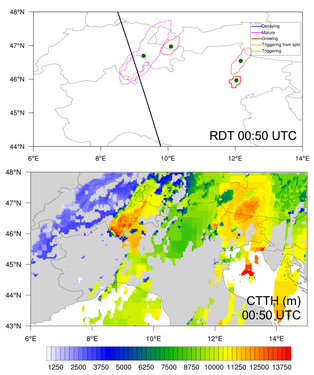
Challenges in Doppler velocity measurements interpretation

- The narrow Nyquist velocity (±5.5 m/s) and the noisiness of the measurements create ambiguities in the reconstruction of the Doppler velocity profiles.
- The two profiles plotted with solid lines are the most plausible solutions corresponding to the CPR measurements (purple dots).
- The two profiles plotted with dashed lines are the same as the solid lines but shifted by twice the Nyquist velocity (indistinguishable by the CPR).
- The final downselection out of the four profiles is challenging; it could be driven by the boundary conditions (e.g., updraft or downdraft at cloud top) but these are still missing from auxiliary GEO/LEO observations.

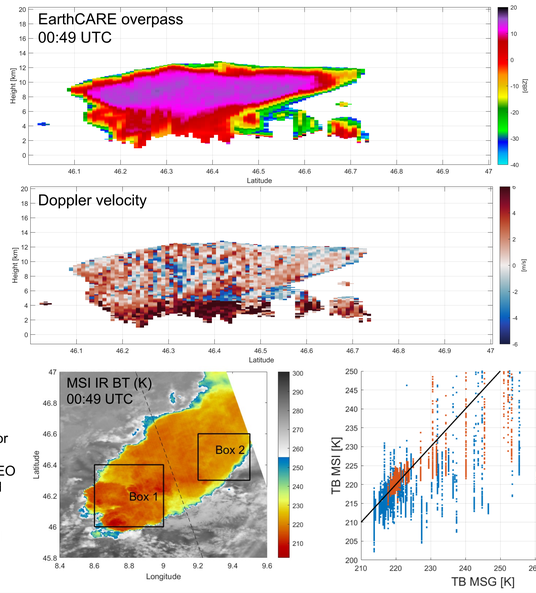


- At 13:30 UTC, the highest probability of hail coincides with the area of the overshooting top, as identified by CPR and GEO observations.
- The maximum hail probability (HP max = 0.63) falls within the Super Hail category, indicating the potential for hailstones exceeding 10 cm in diameter.
- After 13:30 UTC, a second area with hail probability greater than 0.60 becomes apparent.

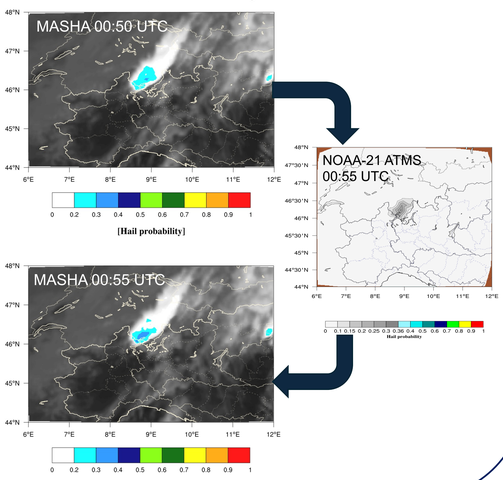
26 August 2024



- No updraft or overshooting top is evident in the CPR reflectivity or Doppler velocity data.
- A better agreement between the cloud top height retrieved by GEO CTTH product and CPR is observed due to the absence of cloud top structures.
- Sensor spatial resolution impacts cloud top height retrieval, as seen in the IR BT comparison between MSG-SEVIRI (4 km) and EarthCARE-MSI (500 m): more variable BTs in Box1 w.r.t. Box2 correspond to a greater range of variability of MSI BTs.



- Multiple hail events were recorded throughout the day in Italy (i.e., Toscana, Veneto, Emilia Romagna, Liguria, Puglia).
- The more recent GPM constellation overpass used for MASHA calibration occurred at 00:55 UTC, providing an update to the hail probability field.
- The HP values retrieved by MASHA are indicative of "hail potential", i.e., only presence of ice on cloud top, no hail on the ground.



Conclusion

- We combined the high-temporal-resolution measurements from MSG Rapid Scan Service, offering spatial and temporal context, with the detailed, range-resolved snapshots from EarthCARE CPR in LEO orbit, which reveal cloud vertical structure, to analyse the evolution of convective events.
- The EUMETSAT NWC SAF RDT-CW product enables the identification and tracking of convective systems, providing insights into their development phase, severity, cooling rate, and the presence of overshooting tops.
- The EarthCARE CPR is the first satellite cloud radar with Doppler capability to measure the vertical velocity of cloud particles in convection. It allows for convection identification based on dynamic criteria.
- GEO observations from MSG RSS also serve as input for the MASHA algorithm used to retrieve hail probability.
- The September 4th case study represents a key example demonstrating the effectiveness of the proposed observation strategy. All utilized tools contribute to characterizing the convective system, including the identification of the overshooting top, its vertical velocity profile, and the associated increase in hail probability reaching the Super Hail category.
- The quantification of vertical convective motions from CPR measurements is challenging due to CPR design drawbacks (noise and aliasing). Multiple plausible solutions are found for the same measured Doppler velocity profile. Auxiliary GEO measurements could help to disentangle these ambiguities, but they have key limitations, including their spatial/temporal resolution, which may be insufficient to resolve fine rapidly-evolving cloud-top structures.

Acknowledgements
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