Linking lightning activity to radar signatures of EarthCARE satellite

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Do radar signatures (reflectivity, ice content, Doppler variability) correspond to where storms are electrically active?
Does lightning activity align with radar-inferred "turbulent / mixed phase" regime?

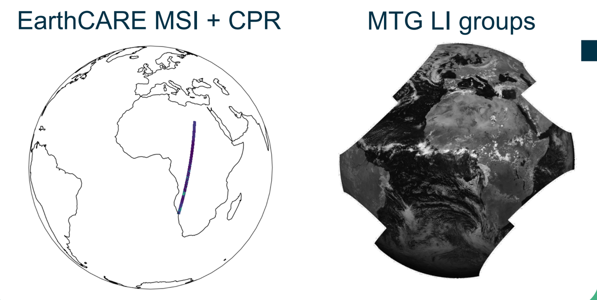
Background

- Lightning initiation is strongly linked to mixed-phase microphysics, graupel–ice collisions, and turbulent updrafts/downdrafts. But we rarely have observations that simultaneously resolve storm microphysics, dynamical signatures, and lightning activity in the same cloud volume.
- **New measurement synergy** of EarthCARE + MTG-LI + GOES-GLM allows such comparisons
- We build a storm catalogue from this synergy, which forms the basis for all subsequent analysis

Data & Methods

- **EarthCARE** → Polar orbiting satellite having onboard 94 GHz **Cloud Profiling Radar (CPR)** with **Doppler capability** + **high-spectral-resolution UV lidar** + passive **multi-spectral imager (MSI)**
- **MTG-LI** + **GOES-GLM** → continuous lightning optical detection from geostationary orbit
- **eLMA (Ebro Lightning Mapping Array)** → 3D ground-based measurements of lightning structure (Technical University of Catalonia)

Spatio-temporal matching

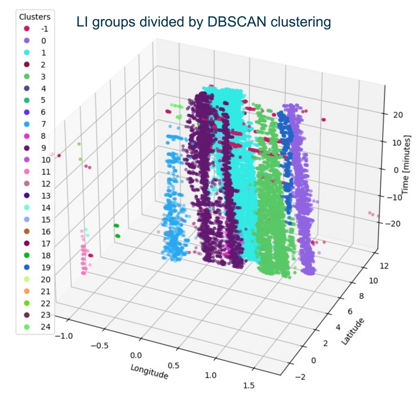


New dataset creation

Lightning data matched with EarthCARE frame
Time difference ± 60 min,
parallax corrected lat/lon, distance from CPR track

Storm detection

Clustering of lightning data using DBSCAN algorithm applied to space-time (lat, lon, time)



Storm catalogue creation

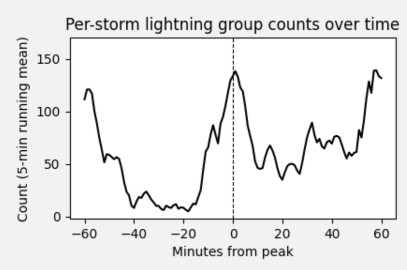
Storms crossed by EarthCARE CPR
Saved to storm catalogue with indication of lightning activity, flash rate evolution, storm trajectory

Joint Analysis
with EarthCARE vertical profiles and LMA

Examples from Storm Catalogue

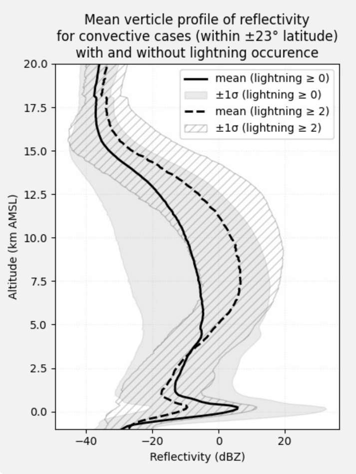
1 Lightning evolution

For each case, we keep lightning groups ±1 hour around the CPR overpass, and cluster them into storm objects. This lets us follow the same storm before/after the slice and see where in its life-cycle the overpass occurred.

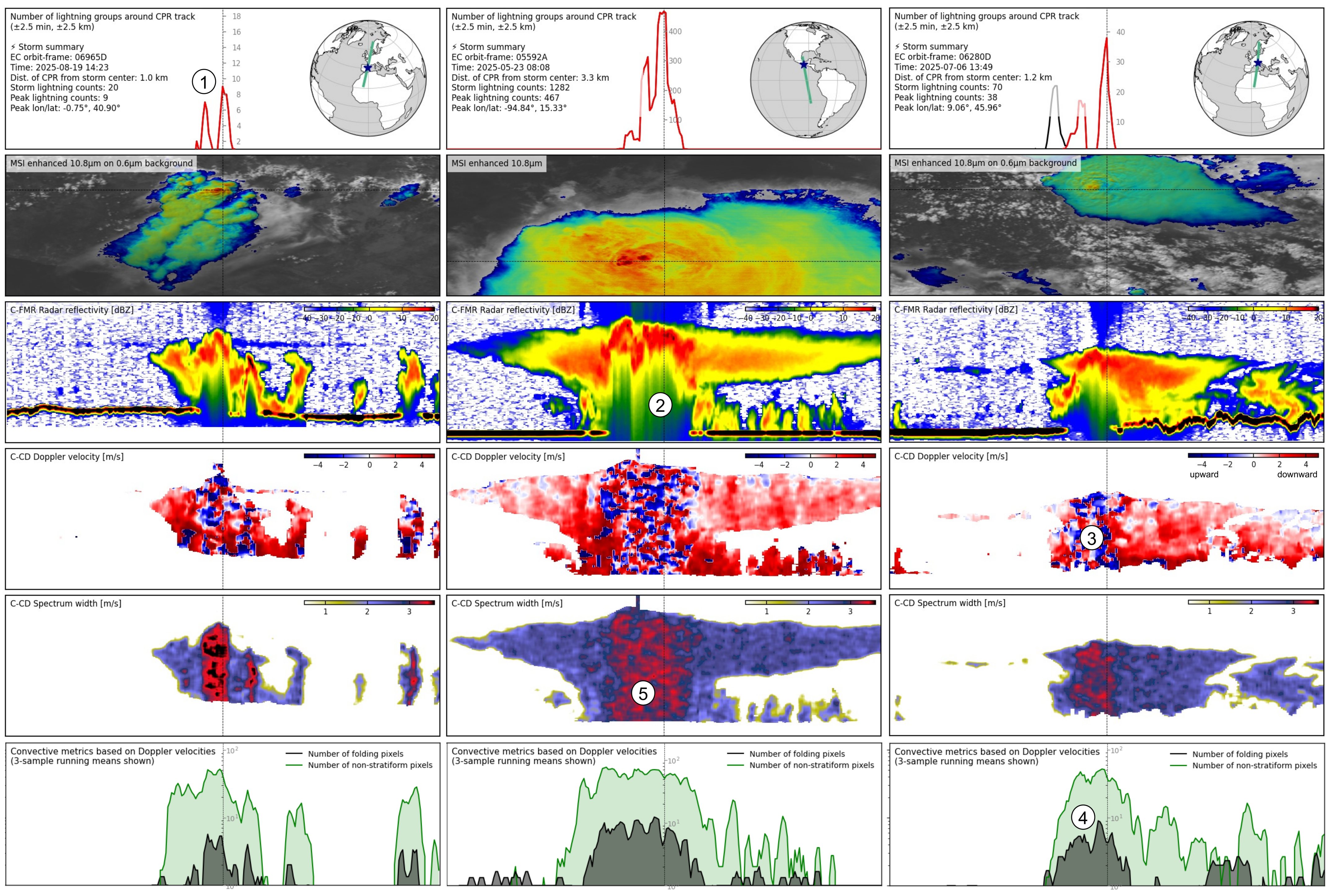


2 Attenuation & multiple scattering

In deep convective cores with large hydrometeors, the CPR signal collapses deeper down the curtain, and multiple scattering produces pulse-stretching artefacts (incl. apparent power returns below surface) [1]. These artefacts actually mark where very dense ice / mixed-phase volumes are — a useful constraint for testing microphysics schemes.



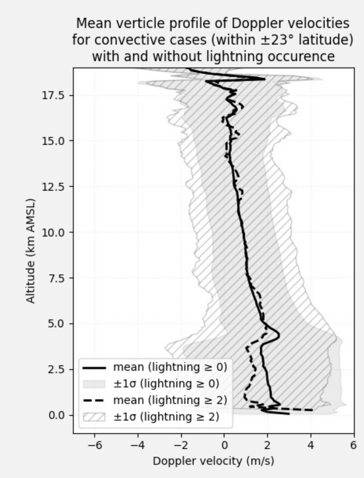
Mean reflectivity profiles show generally higher values for lightning-active convection, but there is a rapid drop below ~7 km with reduced surface returns consistent with stronger attenuation and multiple scattering effect.



3 Doppler velocity limitations

The CPR PRF (~6–7 kHz) at W-band (λ≈3 mm) gives a Nyquist of only ±5–6 m/s. Deep convection frequently exceeds this → velocities fold/alias in the cores [2]. Interestingly, CPR still reports Doppler values even inside multiple-scattering "white noise" — to what extent this aliased signal still contains usable dynamical information is an open question.

Mean Doppler profiles for convection with vs. without lightning look similar, but the standard-deviation show a larger spread in the lightning cases — indicating greater velocity variability (including foldings)



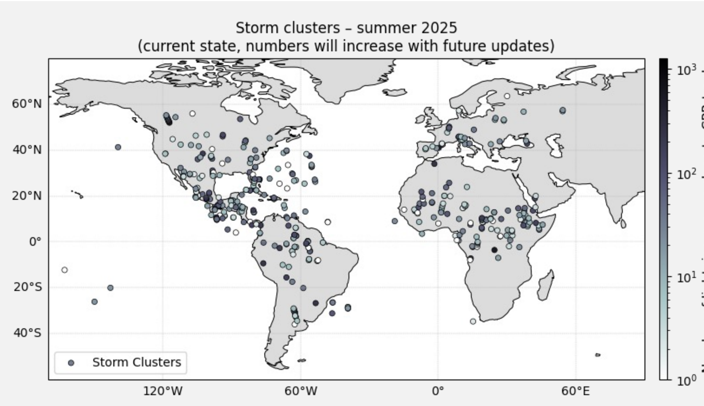
4 Velocity variability as a dynamic proxy

Even if we cannot trust the absolute Doppler velocity in the convective core because of aliasing, the texture is informative. Two simple dynamic criteria are tested to flag strong convection and compare it directly with lightning activity:
(i) counts of Doppler velocity foldings in ice
(ii) counts of Doppler velocity pixels outside [-2, +3] m/s in ice

Storm catalogue status (as of now):

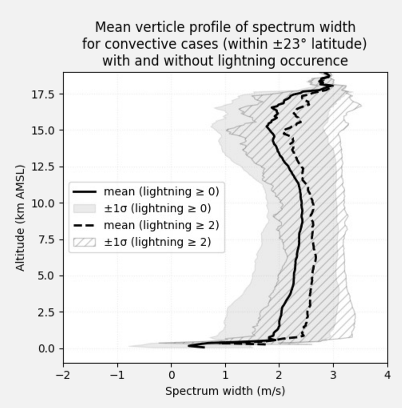
~30 days of data processed → **~400 storms**
170 storms from **MTG-LI**, **230** from **GOES-GLM**
20 storms observed by **both** instruments
Catalogue will ultimately cover **Aug 2024** → **present**

Each storm record stores:
lightning counts, CPR-track distance from cluster centroid, lightning activity evolution (±1 hour), centroid trajectory



5 Spectrum width

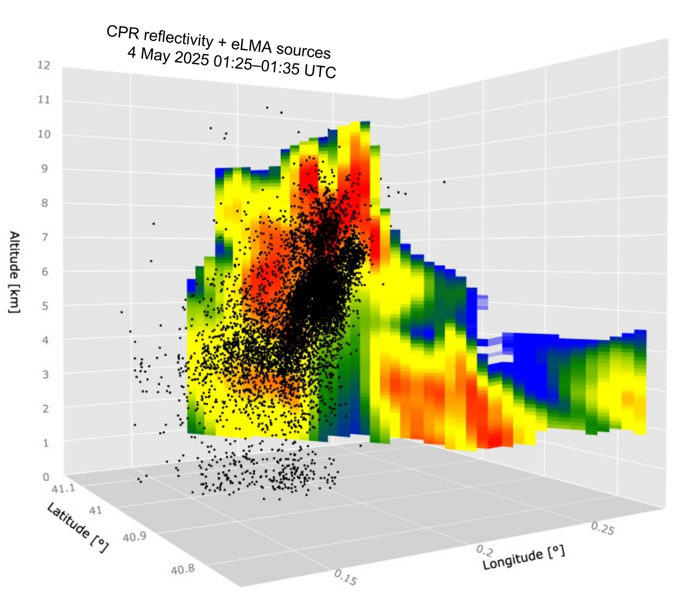
Spectrum width describes the spread of Doppler velocities. In spaceborne Doppler this is hard to recover because the spacecraft speed (~7.2 km/s) induces velocity fading (leakage), which broadens the Doppler spectrum and makes the measured widths larger than their true atmospheric values [3]. Absolute values are therefore uncertain, but we do observe systematically larger widths in convective cores — and we are now assessing whether this contains usable information e.g. on cloud turbulence.

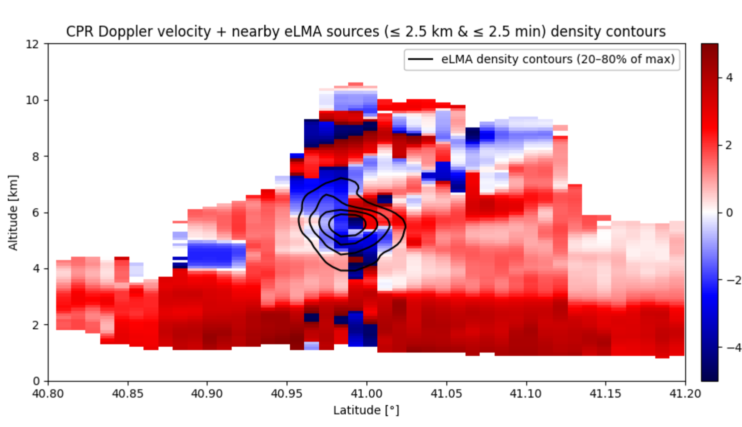


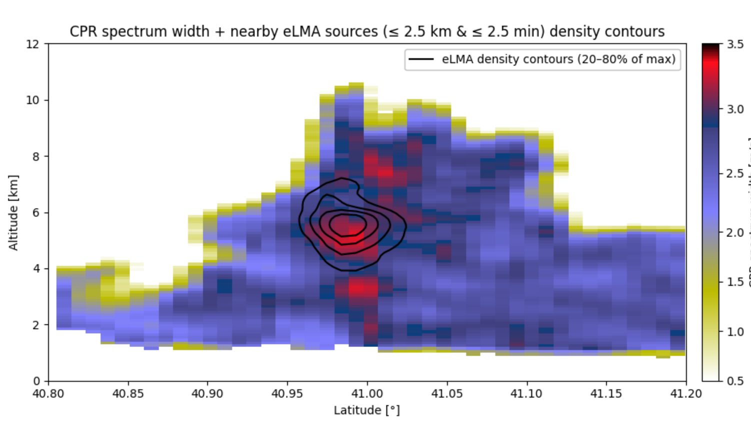
Mean spectrum width profiles show generally higher values for convection with lightning throughout the vertical column.

Comparison with eLMA

- We combine 3D lightning measurements with EarthCARE observations to directly compare the height of lightning sources with radar-derived dynamical signatures. Initial results show promising spatial agreement, and additional cases will be added to further investigate these relationships.







Conclusions & Outlook

- A storm catalogue is being developed from MTG-LI / GOES-GLM / EarthCARE synergy, linking storm lightning activity with vertical cloud and aerosol profiles; this catalogue will be expanded as EarthCARE sampling grows
- Despite CPR limitations (attenuation, multiple scattering, Doppler velocity folding), velocity variability + spectrum width consistently highlight deep convective cores and appear to be promising dynamical indicators for lightning activity
- First checks with 3D eLMA show that EarthCARE dynamical signatures coincide with increased lightning activity
- Future work will focus on:
  1. moving from individual cases to statistics across many storms
  2. formalising dynamic proxy thresholds (foldings + high absolute values of Doppler velocities) and comparing them against lightning rates
  3. investigating whether spectrum width contains physical information about convective dynamics
  4. exploring retrieved microphysics to test the linkage to electrification

References:

[1] Battaglia, A., Augustynek, T., Tanelli, S. & Kollias, P., 2011. Multiple scattering identification in spaceborne W-band radar measurements of deep convective cores. Journal of Geophysical Research: Atmospheres, 116. doi:10.1029/2011JD016142.

[2] Galfione, A., Battaglia, A., Puigdomènech Treserras, B. & Kollias, P., 2025. First insights into deep convection by the Doppler velocity measurements of the EarthCARE's Cloud Profiling Radar. EGUsphere [preprint]. https://doi.org/10.5194/egusphere-2025-1914.

[3] Sy, O.O. & Tanelli, S., 2023. Recovering the Elusive Spectral Width From Spaceborne Doppler Profiling Radar Measurements: The "ExpliSyT" Approach. IEEE Transactions on Geoscience and Remote Sensing, 61. doi:10.1109/TGRS.2023.3279767.