EarthCARE 2026 Science and Validation workshop

8–12 June 2026 | Rhodes House | Oxford, UK

Vertical Structure and Zonal Evolution of Clouds across Madden-Julian Oscillation Phases over the Maritime Continent from EarthCARE Observation

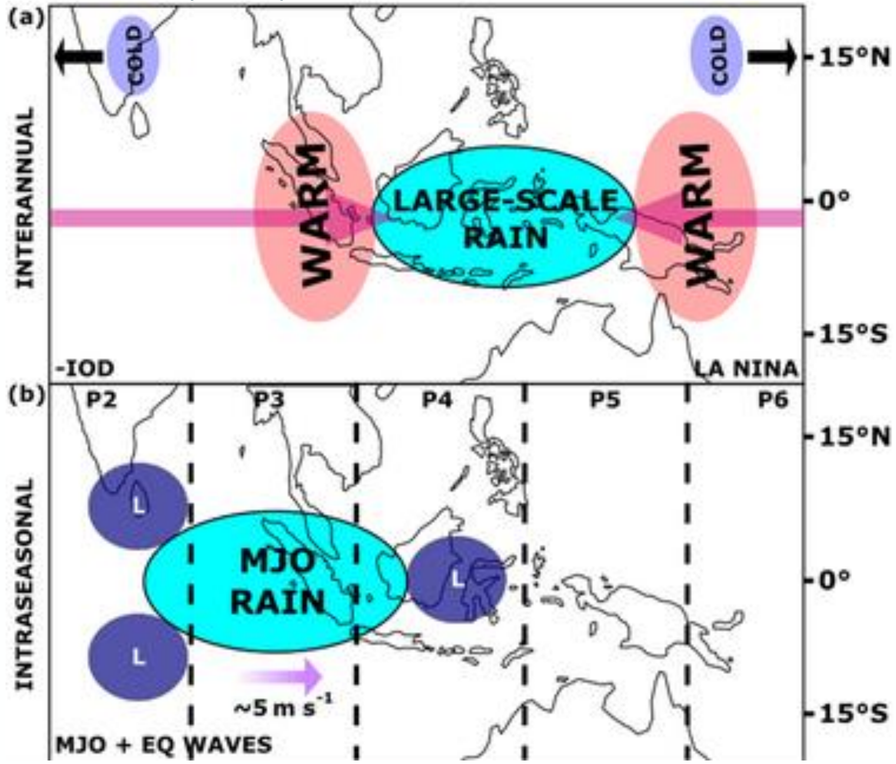
Sopia Lestari (National Research and Innovation Agency-BRIN, Indonesia)

Nobuhiro Takahashi (Nagoya University, Japan)

The influence of the Madden-Julian Oscillation on the rainfall over the Maritime Continent (MC)

- The MJO consists of a broad range of convective regions and precipitation moves eastward, from the Indian Ocean across the Maritime Continent (MC) to the Pacific, with its typical propagation is split into eight MJO phases (P1-P8) (Mustafa et al. 2025; Wheeler and Hendon, 2004)

Aslam (2025)



Jakarta Globe (2013)

BBC news (2013)

Detik.com (2021)

- MJO strongly influences rainfall over the MC and can increase extreme flooding events (Lestari et al. 2026; 2022, Lubis et al. 2022, Wu et al. 2013).
- Previous studies using radiosondes, TRMM, CloudSat, and CALIPSO show cloud evolution from shallow cumulus to deep convection and stratiform anvils during the MJO cycle (Kiladis et al., 2005; Del Genio et al., 2012).
- EarthCARE CPR can observe more detailed cloud dynamics and the physical processes behind cloud evolution during MJO, improving MJO representation in models and subseasonal prediction, as well as its rainfall impacts.

Method

- The EarthCARE's cloud profiling radar can simultaneously observe cloud reflectivity, cloud terminal velocity, air vertical velocity, and liquid water content.
- Together with JAXA auxiliary products, these measurements provide a comprehensive view of cloud development.

How do cloud depth and vertical motion speed evolve around MJO peak events?

EarthCARE CPR (Aug 2024-Nov 2025)

↓

RMM Index

↓

OLR Minima

↓

Composite analysis

Background

To isolate robust MJO signals, only strong MJO events are selected based on Real-time Multivariate MJO (RMM) amplitude > 1 (Wheeler and Hendon, 2004)

Important Points

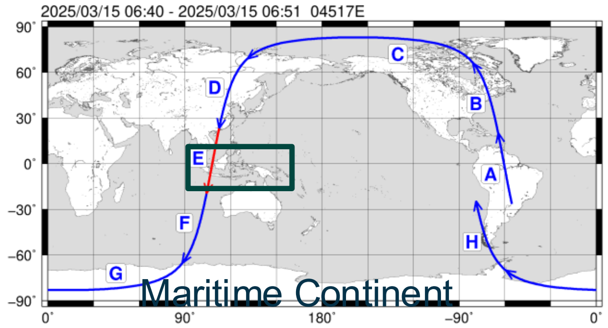
•MJO phases 2–6 are selected

•Peak defined using NOAA OLR minima (Genio et al. 2012)

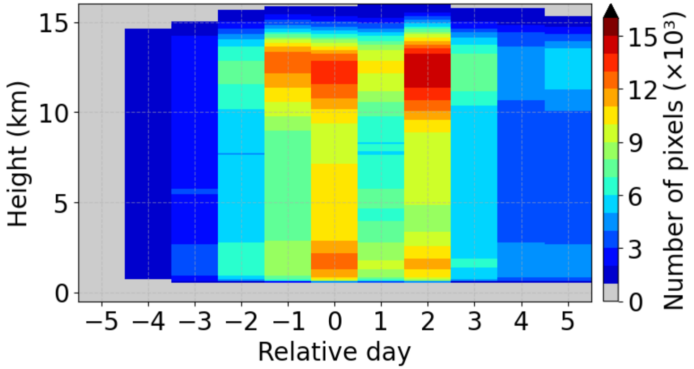
•652 hours of EarthCARE observations used

Results: Distribution of number of pixels of the reflectivity for different thresholds

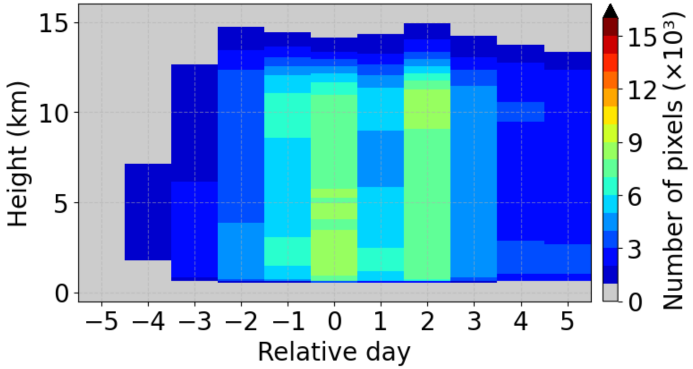
- Tracks E and A around the MC are selected
- Longitude between 90° and 150°, Latitude between -15° and 15°



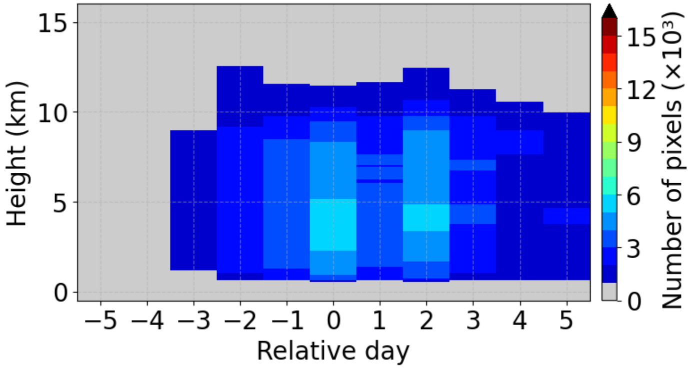
-35 to 20 dBZ



-15 to 20 dBZ

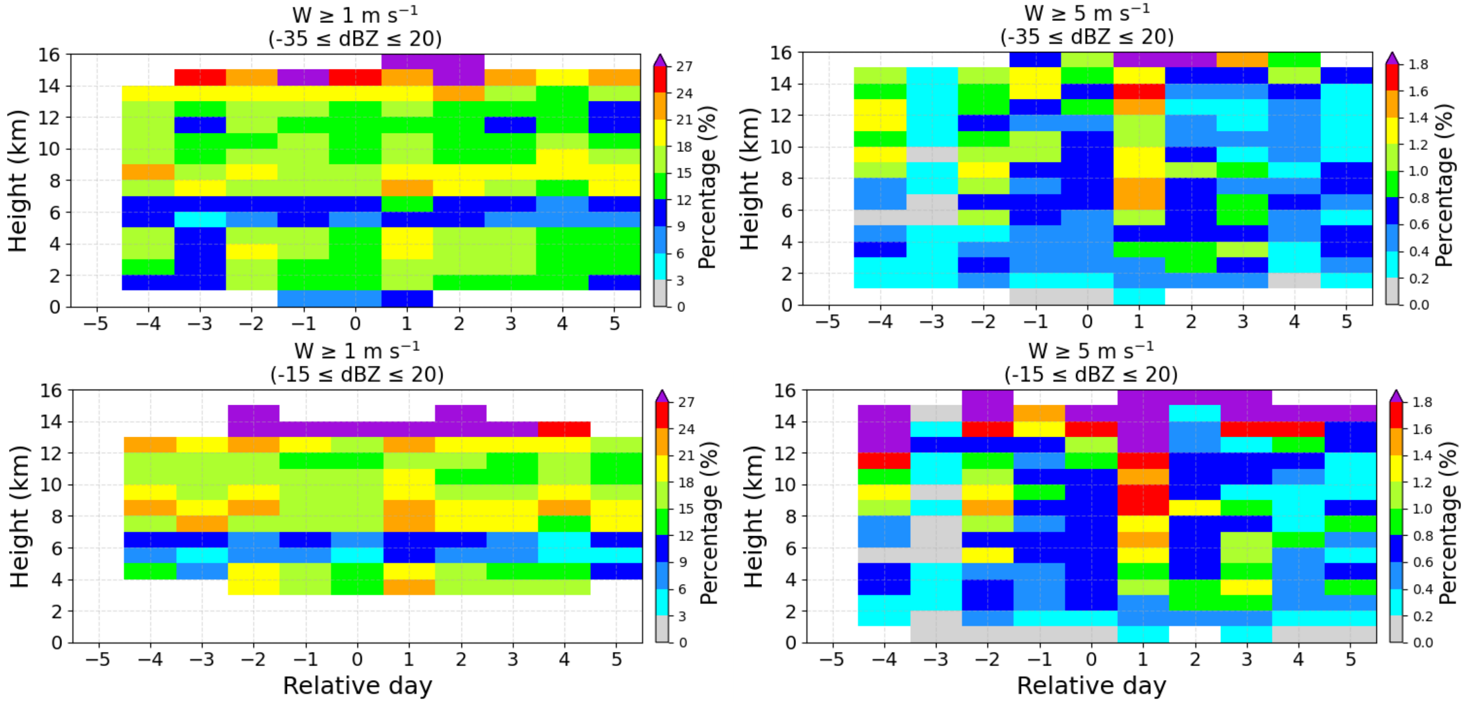


0 to 20 dBZ



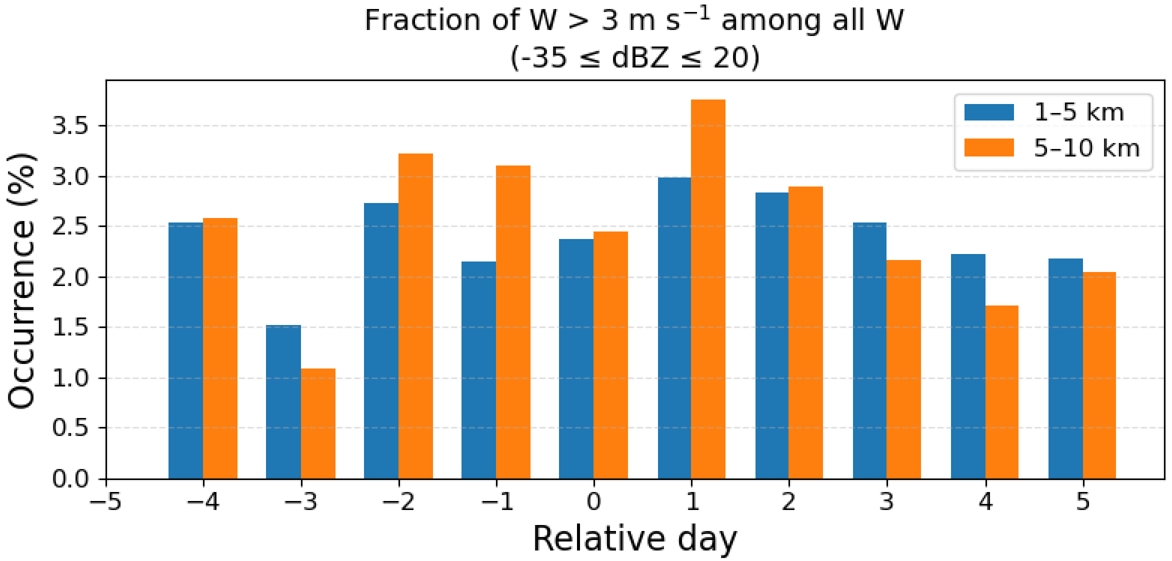
- Stronger echoes increase near the MJO peak.
- Occurrence of reflectivity peaks around days 0 and 2.
- A shallow-to-deep transition is observed.
- This behavior is consistent with the transition from shallow convection to deep convective systems over the MC (Kiladis et al. 2005).

Percentages of profiles for different thresholds of air vertical velocity (w) by relative day



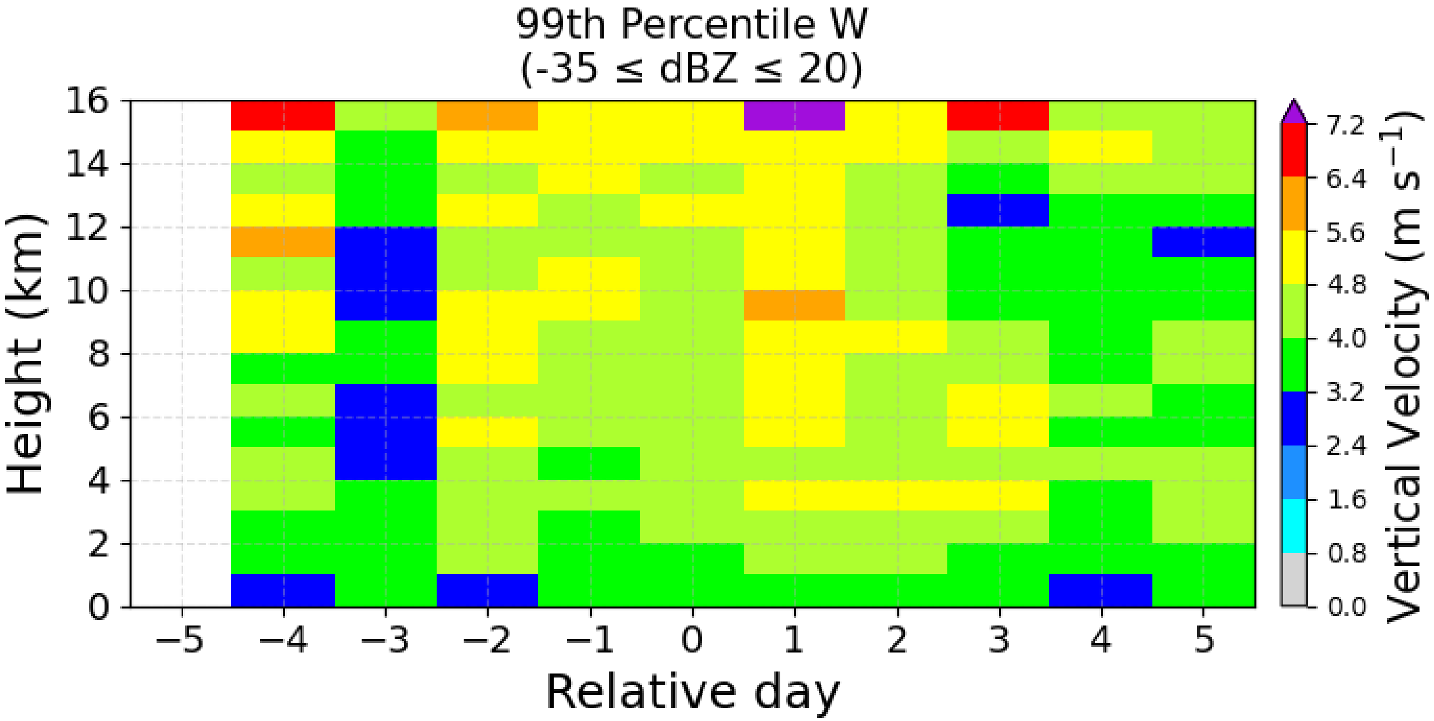
- Updrafts with w ≥ 1 m/s are observed throughout the MJO lifecycle, indicating that weak-to-moderate upward motions are continuously present during the MJO.
- In contrast, the frequency of strong updrafts (w ≥ 5 m/s) increases as the MJO approaches its peak phase.
- A relatively smaller frequency (w ≥ 1 m/s) is observed near the freezing height. It may be caused by the treatment of the melting layer in the retrieval algorithm or natural phenomena around the freezing level.
- Strong updrafts (w ≥ 5 m/s) occur for several days around the peak, suggesting sustained deep convective activity.
- As indicated by the reflectivity occurrence, deepening of shallow clouds is shown from day -3 to -1, but the w does not clearly show these characteristics.

Percentage of occurrence of w > 3 m/s by relative day



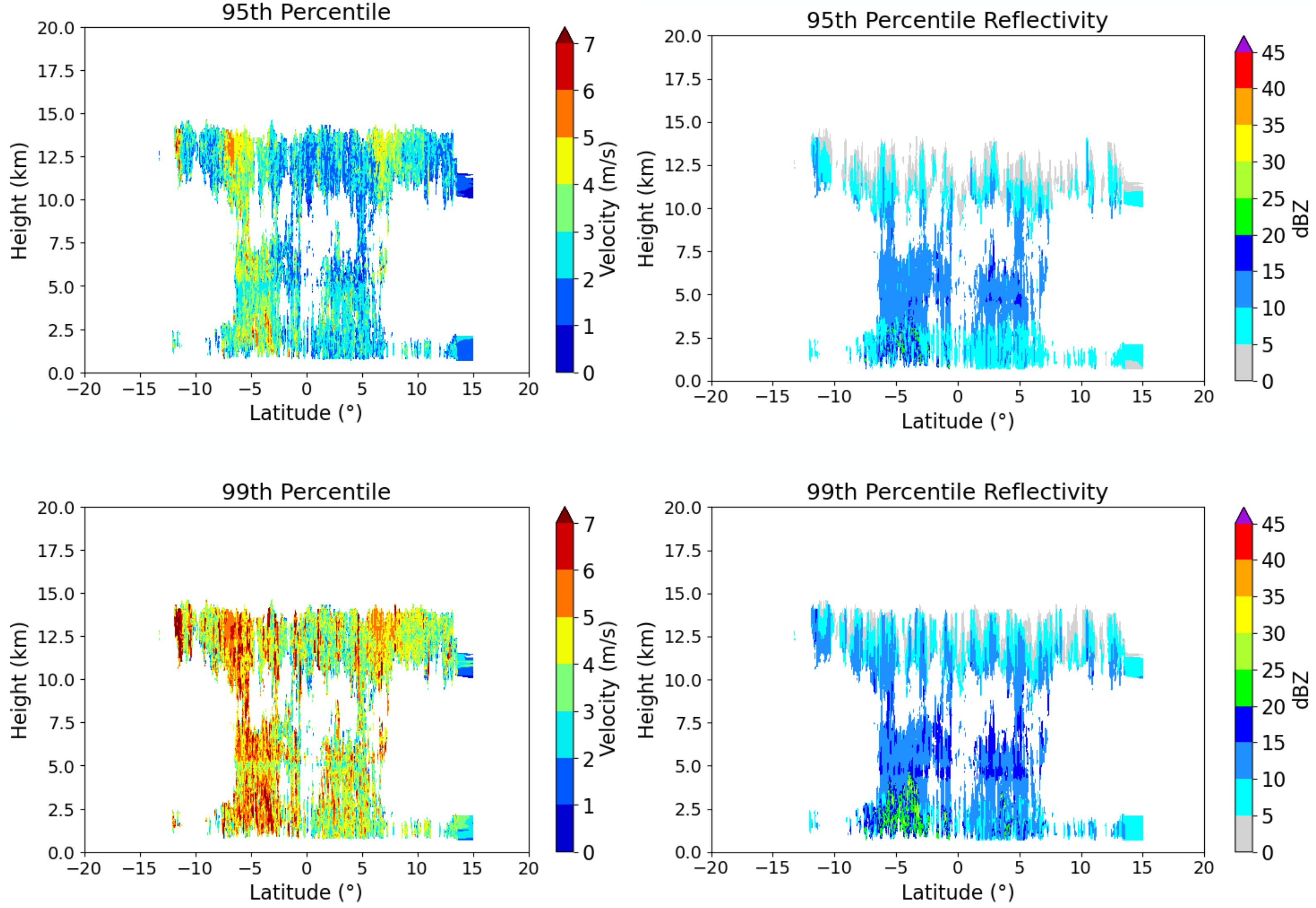
- Strong updrafts become more frequent near the MJO peak (between -2 and 2 days).
- Strong updraft occurrence increases near the active MJO phase, particularly between 5–10 km.
- At day 0, the reflectivity occurrence becomes much larger, causing the fraction of strong-updraft pixels to decrease slightly even though the absolute number of strong-updraft pixels remains high.
- This behavior is consistent with the convective-to-stratiform evolution of tropical mesoscale convective systems. Day 0 might be dominated by stratiform precipitation areas, which are characterized by small vertical velocities ($<|\pm 1\ m\ s^{-1}|$), low rain rates ($<5\ mm\ h^{-1}$), and widespread (~100-km horizontal dimension) (Schumacher and Houze, 2003).

The 99th percentiles of w by relative day



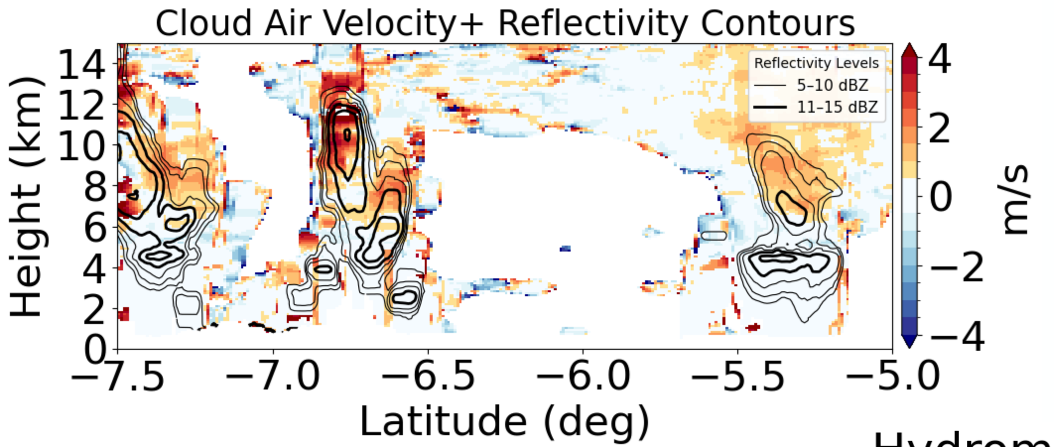
- Extreme updraft intensity (99th percentile w) reaches values exceeding 4.8 m s^{-1} around the MJO peak period, consistent with the increased occurrence of strong vertical velocities (w ≥ 1 and 5 m s^{-1}).
- Strong vertical motions are observed during both the pre-peak (e.g., Day −2) and post-peak (e.g., Day +1) stages of the MJO, suggesting active vertical transport throughout the transition from suppressed to active conditions (Peatman et al., 2014).

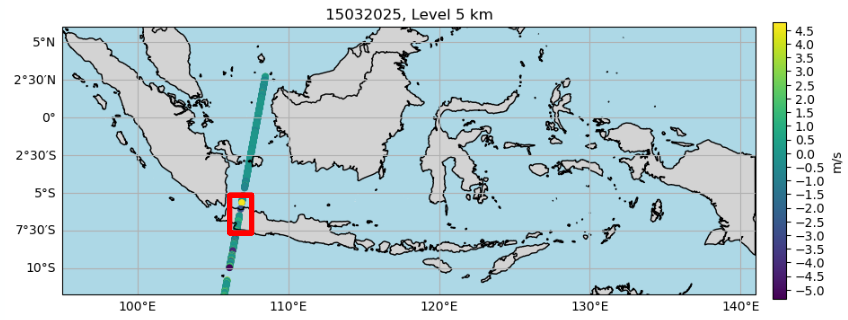
The 95th and 99th percentiles of w and reflectivity by latitude

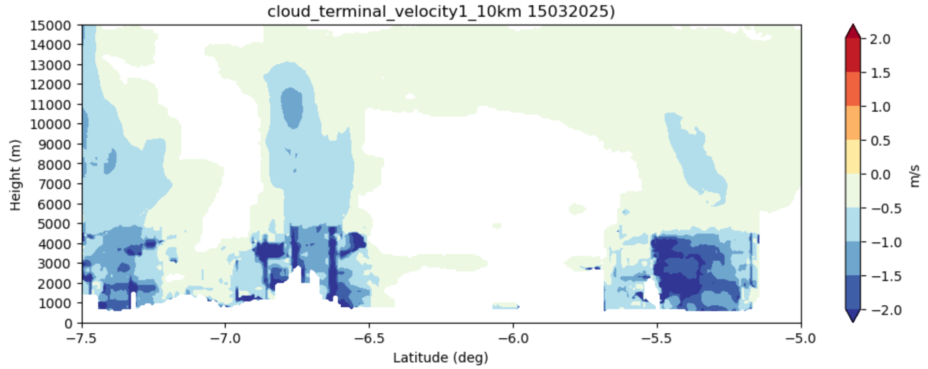


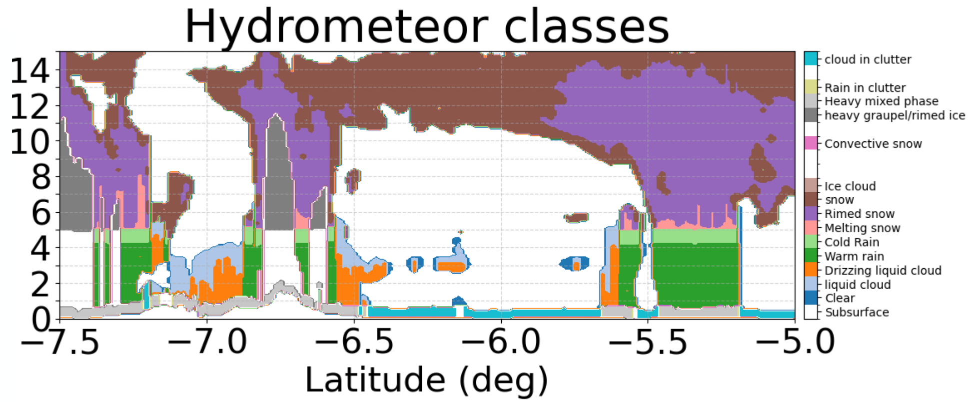
- Maximum cloud activity is concentrated near the equatorial MC, where both strong updrafts and high reflectivity values occur.
- The latitudinal distribution of intense vertical motions closely follows the distribution of strong radar echoes, suggesting a strong coupling between cloud dynamics and precipitation processes.
- Most observations consist of weak reflectivity. That means: the MJO affects not only deep convection but also extensive weak cloud systems.

Case study over the Jakarta megacity during a strong MJO Phase 7 (when the MJO convective envelope is located over the western Pacific Ocean)









- EarthCARE captured complex vertical cloud structures associated with convective activity over western Java during the strong MJO phase 7 event.

Conclusion

1. The MJO peak phase is associated with deeper clouds and stronger upward motions.

2. Cloud occurrence increases substantially above 10 km during active MJO periods.

3. EarthCARE can capture convective-to-stratiform evolution of tropical mesoscale convective systems. The strong updraft does not necessarily occur at the same time as the higher occurrence of reflectivity. Such a higher occurrence might be related to the weak reflectivity associated with the stratiform precipitation.

4. The magnitude of the mean vertical motion is considerably reduced in the stratiform region and is downward in the lower troposphere and upward in the upper troposphere (Abhilash et al. 2010). Strong convective updrafts occur first, producing deep clouds and lofting ice to upper levels. As the system matures, hydrometeors generated by those updrafts spread into extensive stratiform and anvil regions, increasing overall reflectivity occurrence even though the strongest updrafts have weakened.

5. EarthCARE provides a unique view of the vertical cloud structure associated with MJO convection over the MC. Ground-based radar observations show complementary information on the local cloud environment near Jakarta.

Caveat:

The analysis is based on approximately 652 hours of EarthCARE observations collected from April 2024 to November 2025. Although the dataset captures multiple MJO events, the sampling remains limited relative to the 30-60-day MJO timescale and may not fully represent the full spectrum of cloud variability during the MJO.