Constraining a Global Storm-Resolving Model with EarthCARE Observations and a Satellite Simulator

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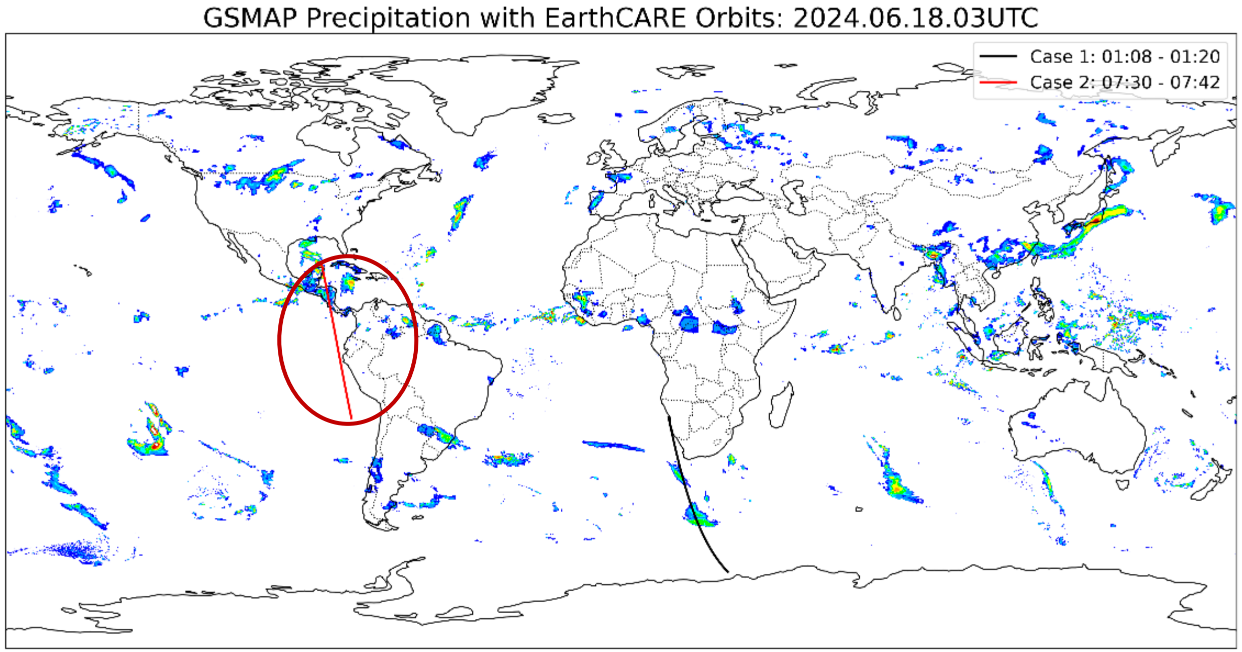
GSRMs + EarthCARE: A Powerful Combination

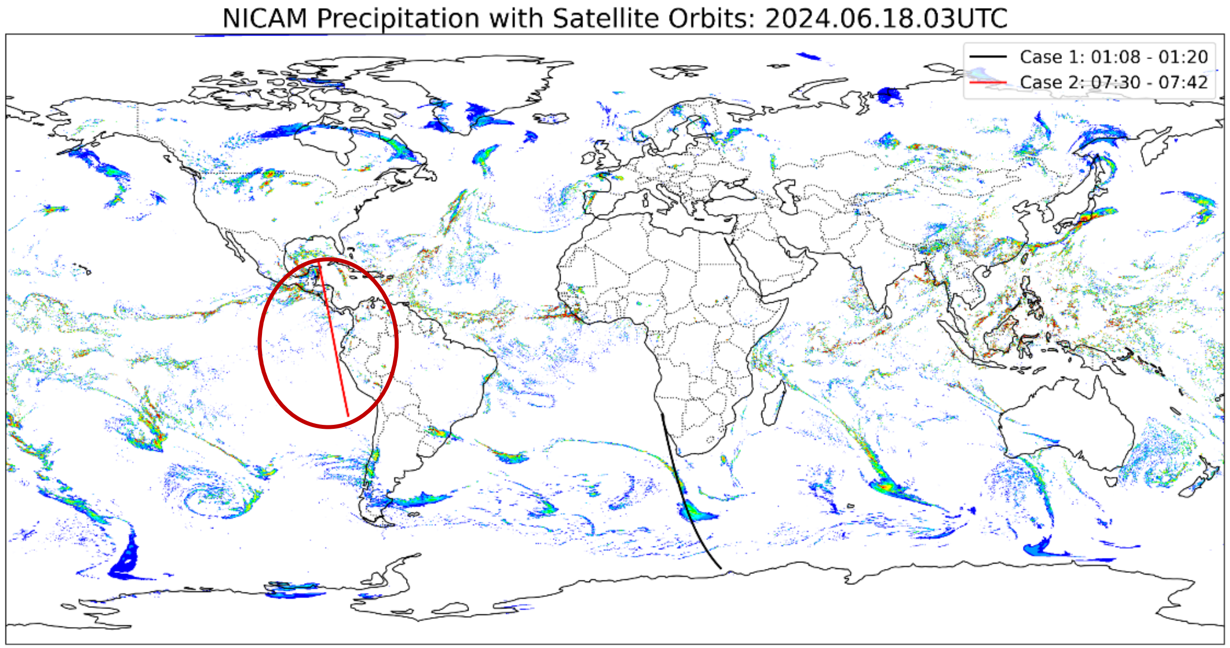
- EarthCARE provides a new insight into the vertical structure of clouds and precipitation.
- Global Storm-Resolving Models (GSRMs) explicitly resolve convection and represent cloud and precipitation structures in detail.
- We use EarthCARE CPR observations to explore ways to constrain GSRMs and to compare the vertical structure of convection.
- In this study, we focus on understanding shallow precipitation and convection by analyzing specific frames of EarthCARE observations and corresponding NICAM simulations.

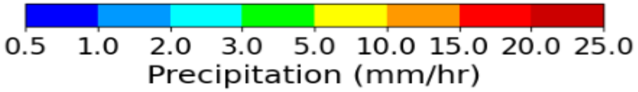
Horizontal distributions of precipitation between observation and NICAM

GSMAP



NICAM





EarthCARE data

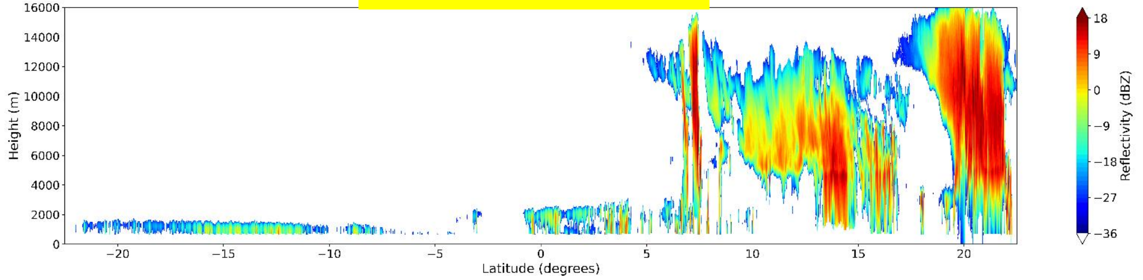
- The CPR Level 1b product (version vCa), 16 km observation window
- Calibration: pointing error, mirror image, multiple scattering tail
- 10 km integrated data

NICAM simulation data

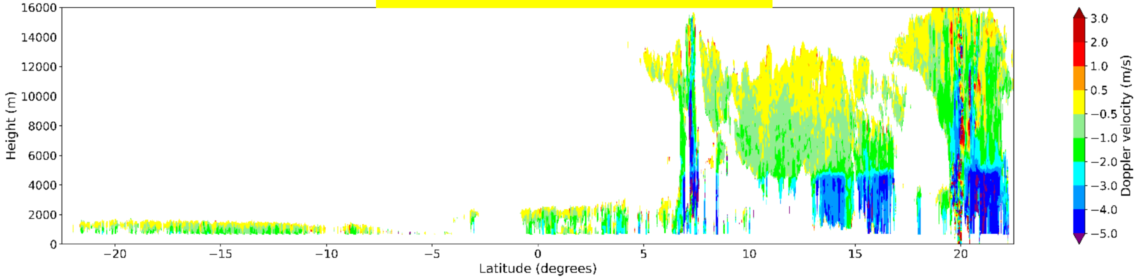
- Horizontal mesh: 870 m
- Vertical layers: 78
- Microphysics scheme: a single moment scheme (NSW6)
- Initial condition: 00 UTC on 17 June 2024 (ERA5)

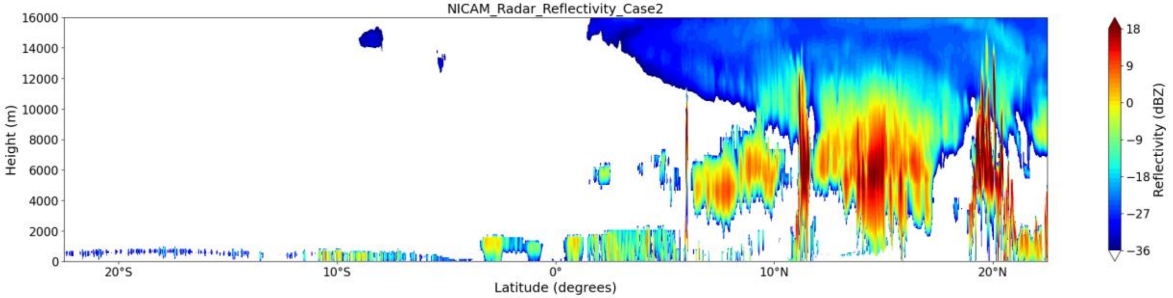
Comparison of EarthCARE CPR and NICAM

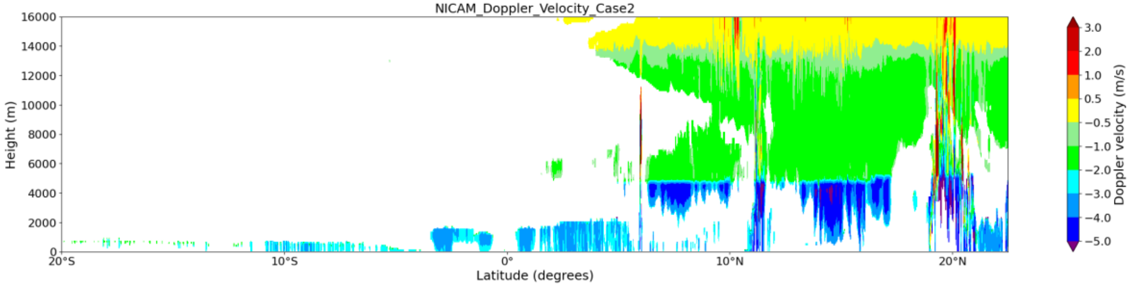
EC radar reflectivity



EC Doppler velocity 10km

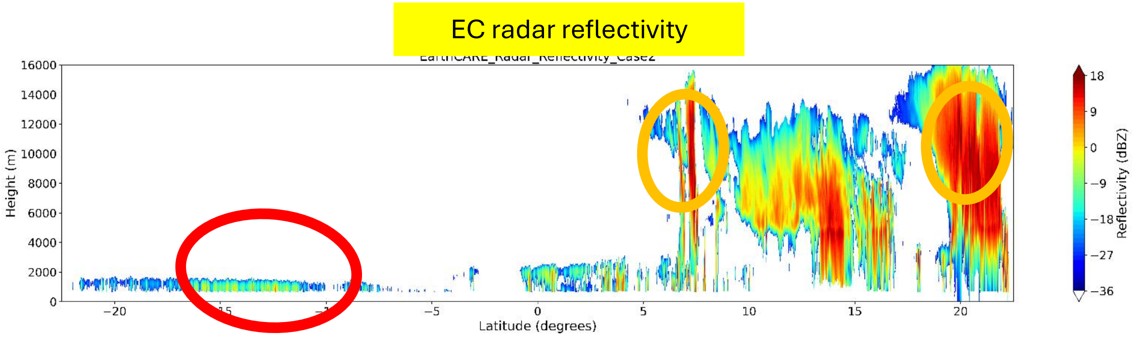


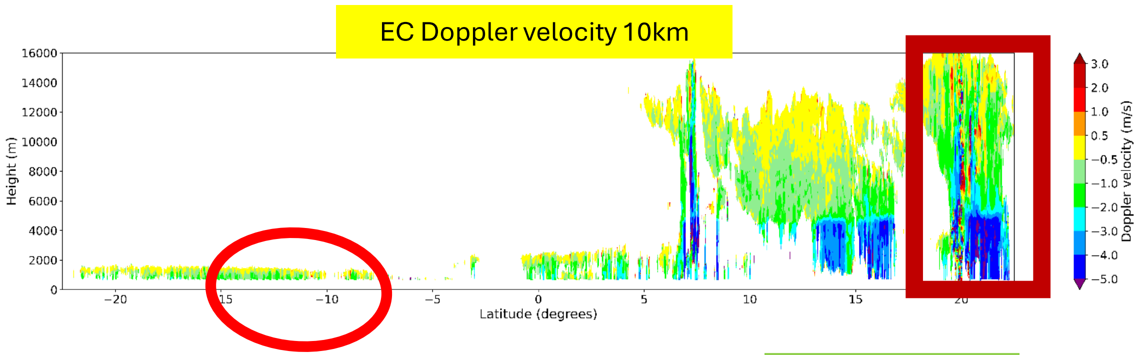


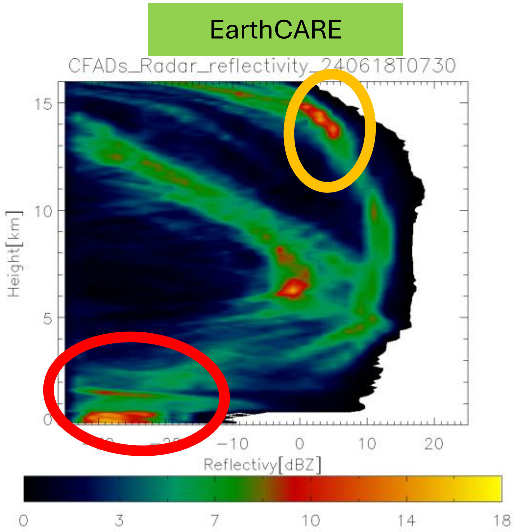


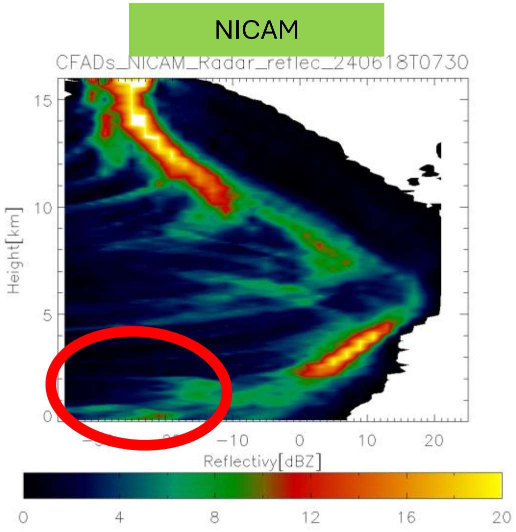
- EarthCARE observations clearly capture low-level clouds in the Southern Hemisphere and a tropical storm in the Northern Hemisphere, including distinct convective signals near 8°N and 20°N.
- NICAM successfully reproduces the observed systems, including low clouds and the tropical storm structure.
- NICAM simulations accurately capture the convective core near 20°N.
- However, NICAM slightly overestimates the downward Doppler velocity compared to EarthCARE observations.

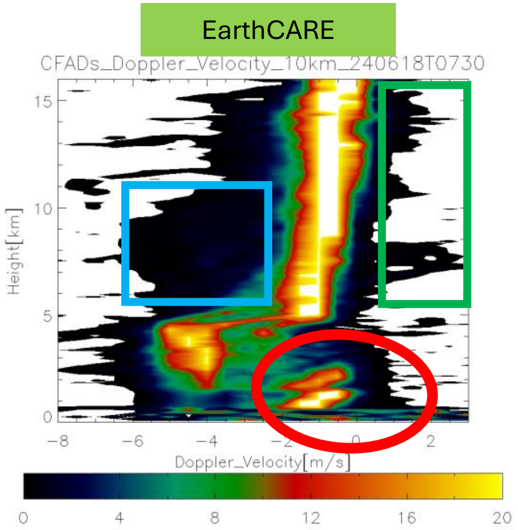
Interpretations of Contoured Frequency by Altitude Diagrams (CFADs)

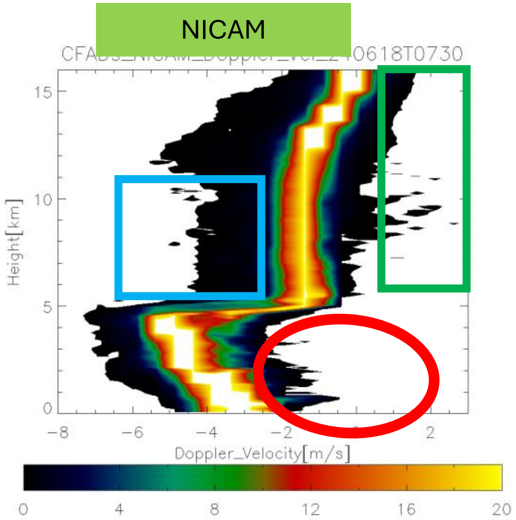












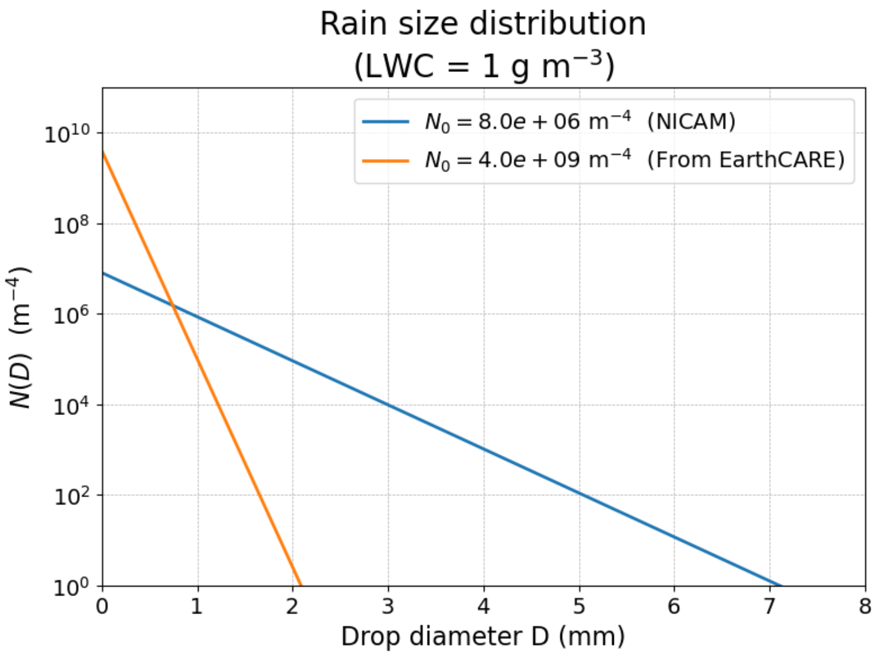
1. Shallow clouds or drizzle
2. Convective core and stratiform precipitation
3. Graupel or hail
4. Upward Doppler velocity

- **Drizzle (-25 dBZ, 1.5 m/s)**
- **Convective region**

Understanding of size distribution of Drizzle

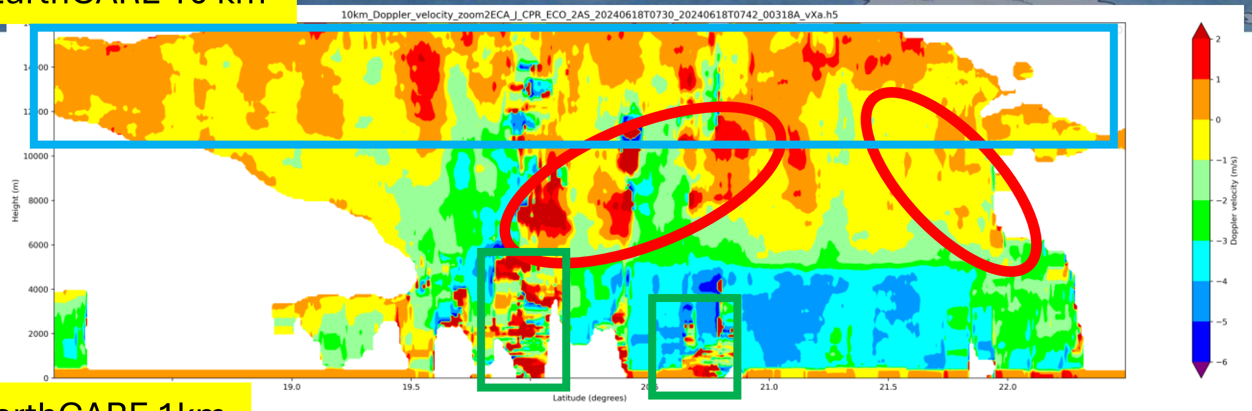
- Radar reflectivity (6th moment) and Doppler velocity (≈6.x th moment) provide complementary information that allows us to constrain the size distribution of shallow precipitation (drizzle).

- For example, we can pick up -25 dBZ and 1.5 m/s from the EarthCARE observation.
- $V(D) = 130D^{0.5}$
- $N(D) = N_0 e^{-\lambda D}$ (NICAM $N_0 = 8.0 * 10^6$)
- $Z = \int N(D) D^6 \ dD$
- $V_{\text{Dopl.}} = \dfrac{\int N(D) D^6 V(D) \, dD}{\int N(D) D^6 \, dD} = \dfrac{\int N_0 D^6 (130 D^{0.5}) e^{-\lambda D} \, dD}{\int N_0 D^6 e^{-\lambda D} \, dD}$
- $N_0 \ \approx 4.0 * 10^9$

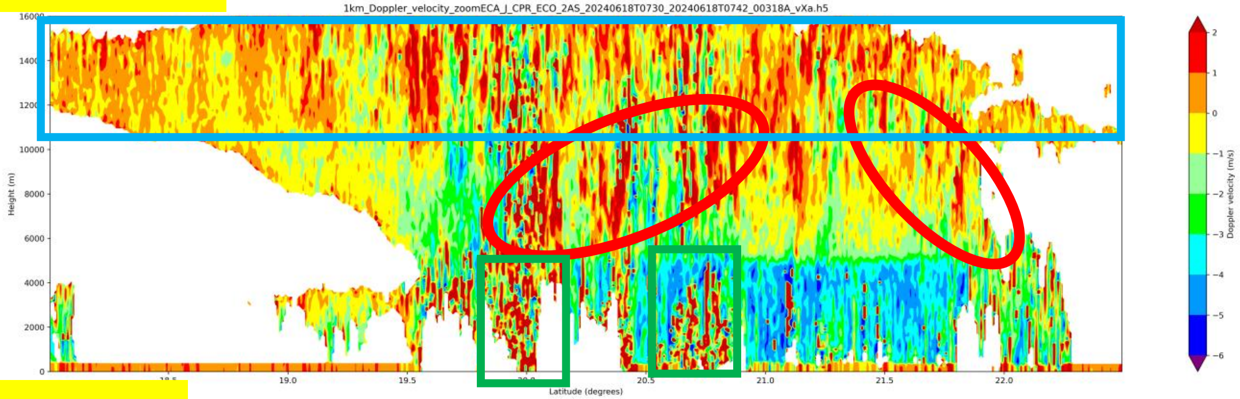


Convective region (zoomed In)

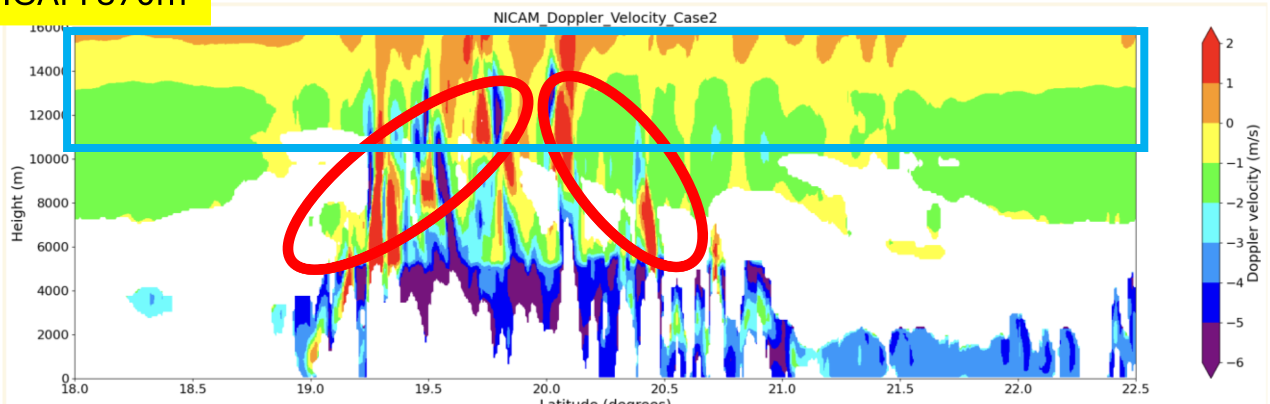
EarthCARE 10 km



EarthCARE 1km



NICAM 870m



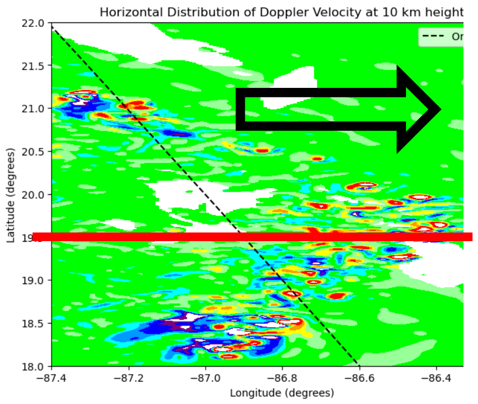
1. Convective signals (Between Melting Layer and ~12 km)
   - The EarthCARE data shows upward motion associated with convection.
   - Strong downward motion also appears near the convective updrafts, suggesting the presence of hail or graupel related to the riming process.

2. Gravity waves near cloud top regions
   - Clear fluctuations in upward motion are seen around 12–16 km height, corresponding to gravity wave activity.
   - The vertical oscillations occur over a scale of about 2 km.
   - These variations are captured more clearly in the 1 km EarthCARE data.

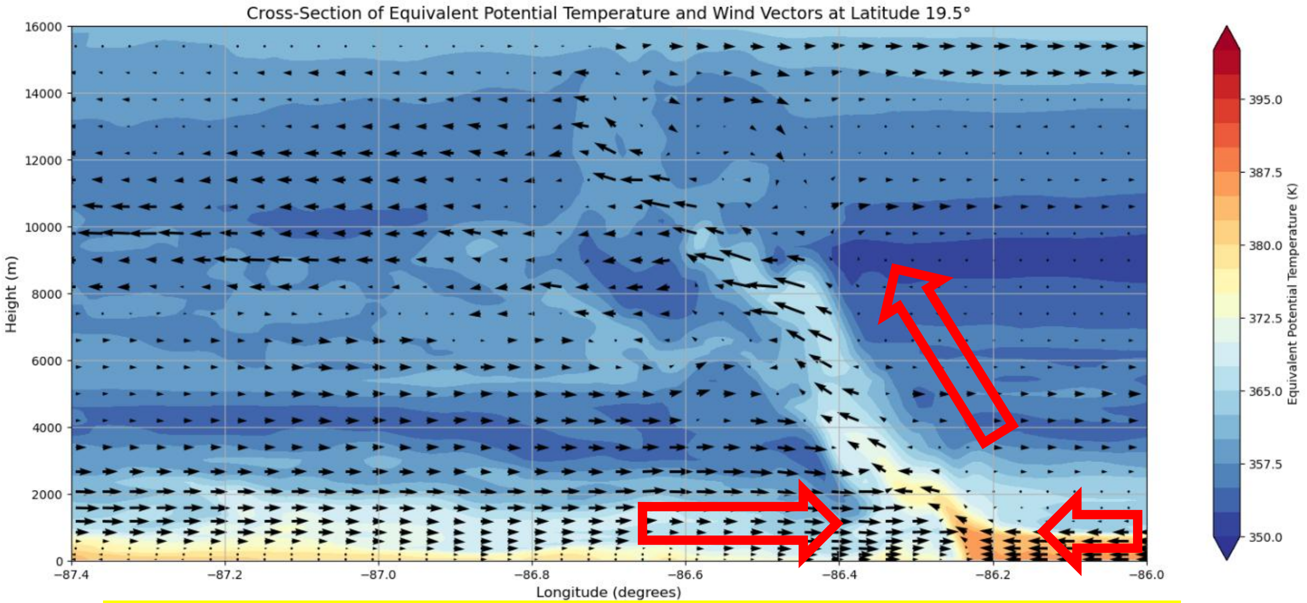
3. Multiple scattering impacts or folding effect
   - In regions with strong convection, signals below the melting layer show alternating positive and negative Doppler velocities.
   - These patterns likely result from multiple scattering effects or signal folding in intense convective areas.

NICAM 870m

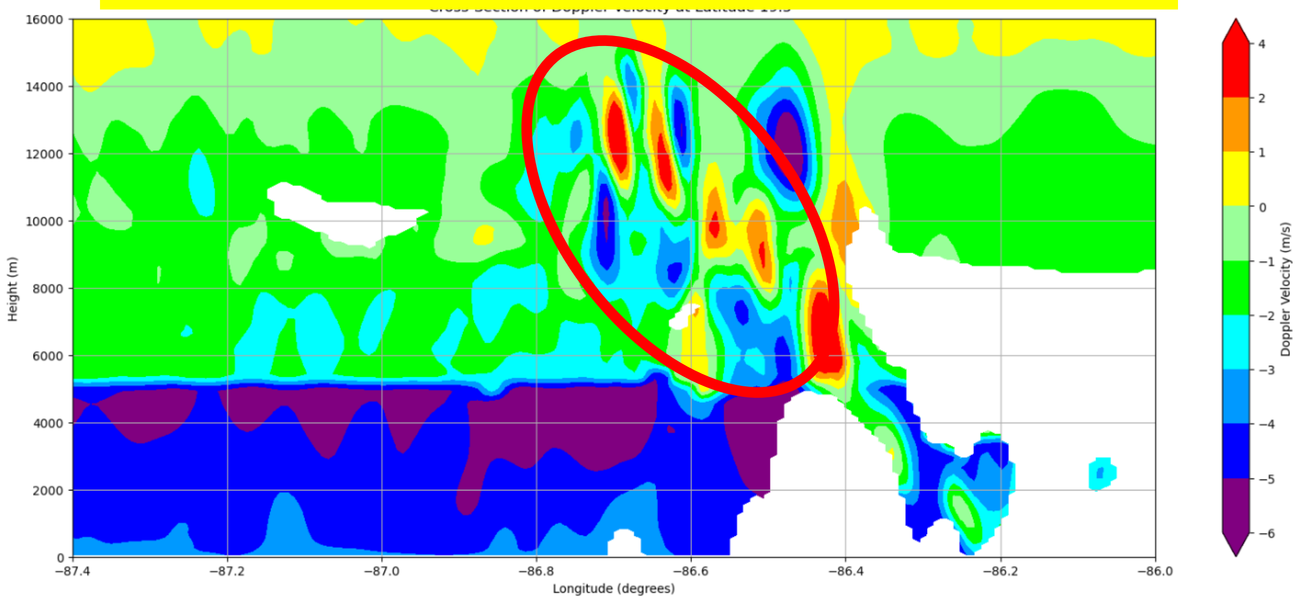
NICAM
The distribution of
Doppler velocity at 10km



Equivalent potential temperature and wind fields



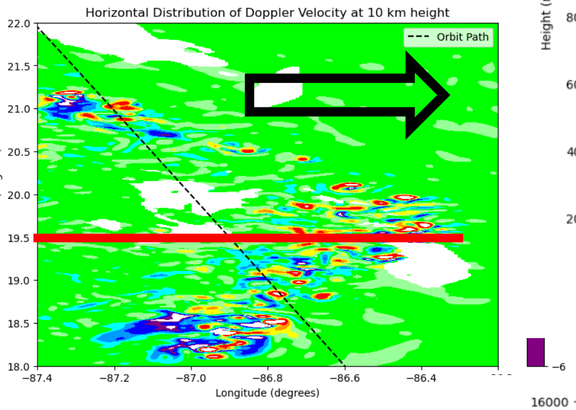
Doppler velocity

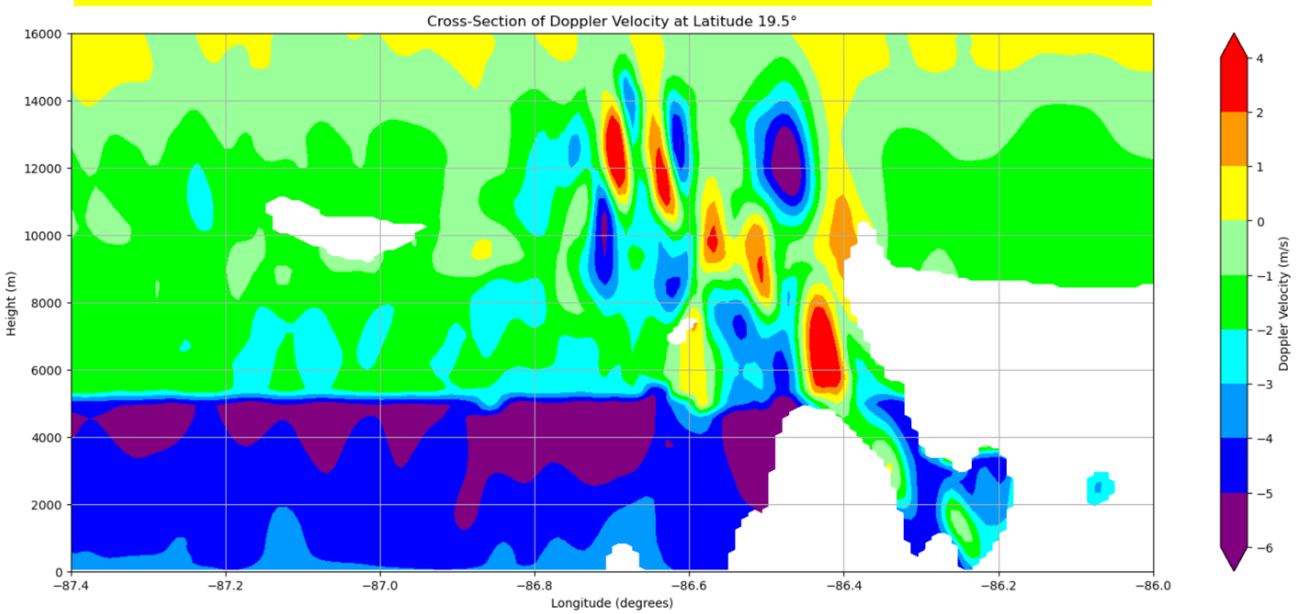


- The mesoscale convective system (MCS) is propagating westward.
- It interacts with warm, moist air flowing from the east, creating a zone of strong convergence.
- This convergence leads to the development of deep convection, which can be seen clearly in the model field.
- The simulated Doppler velocity also captures this process well, showing strong upward Doppler signals associated with the convective updrafts.

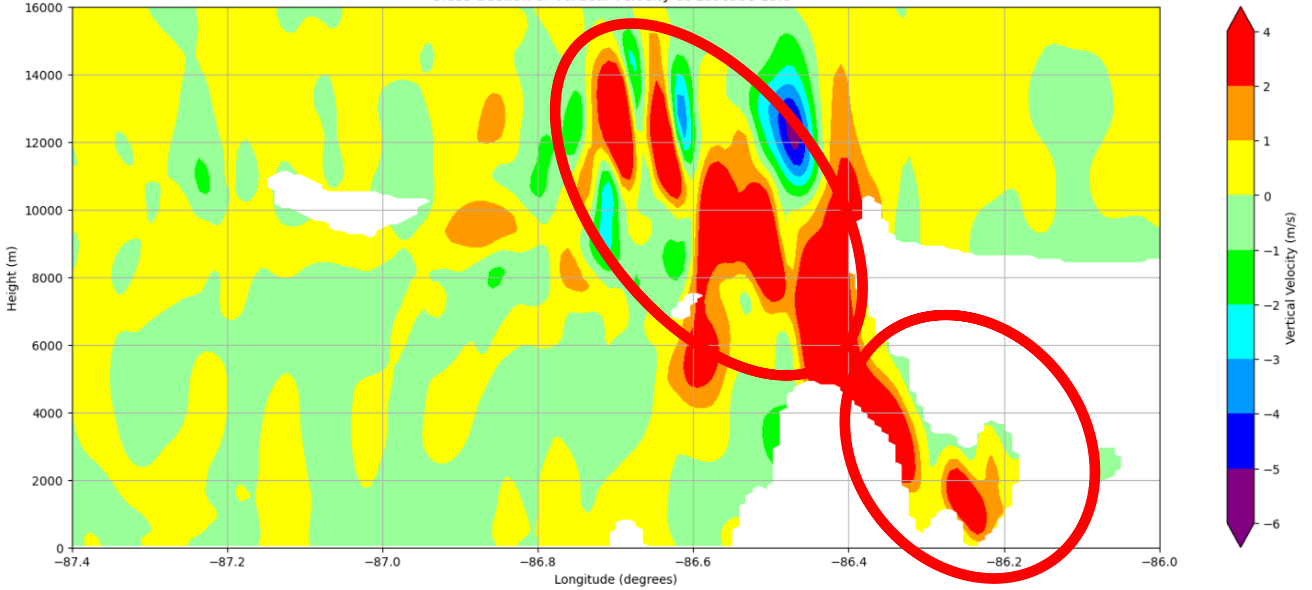
NICAM 870m

NICAM
The distribution of Doppler velocity at 10kr





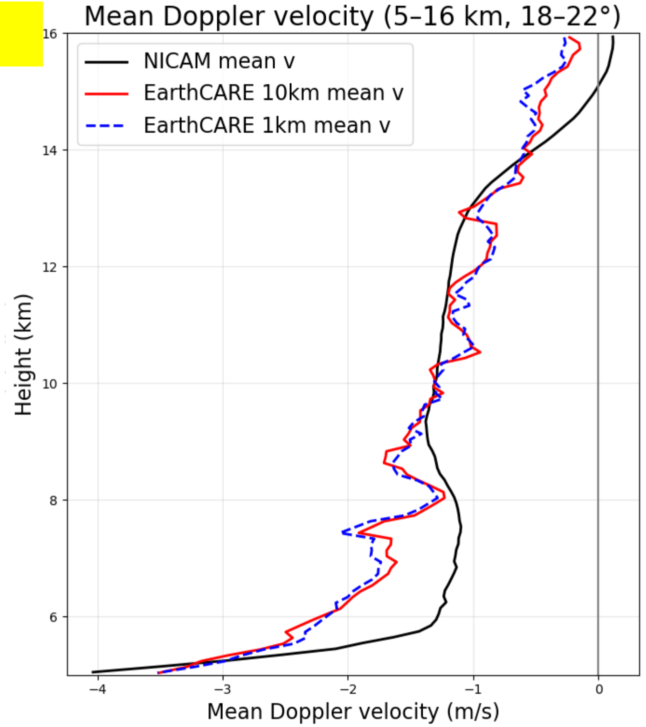
Vertical air velocity from Doppler velocity



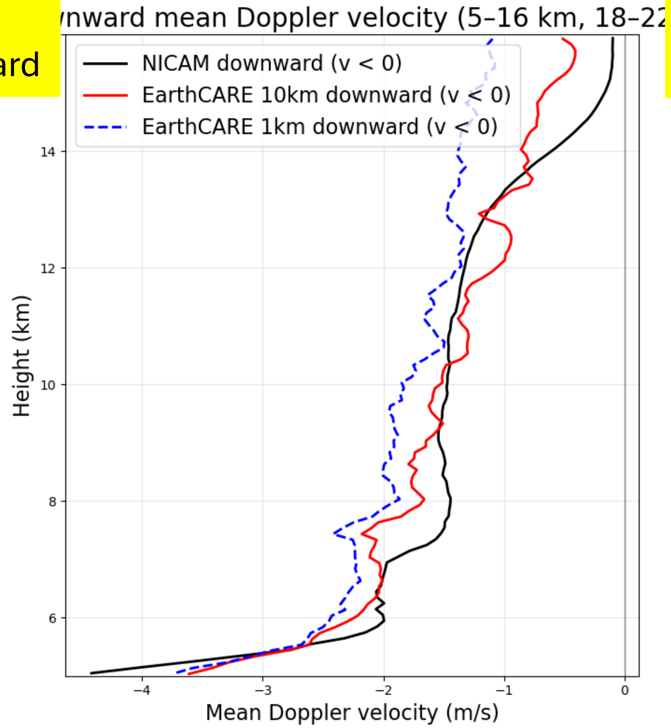
- Above the melting layer, upward Doppler velocities appear, but small-scale upward and downward cells can also be seen. These are caused by riming processes and the unfreezing of rain droplets.
- Below the melting layer, the terminal velocity of raindrops dominates, so upward Doppler signals are not visible.
- Such detailed information will be valuable for interpreting EarthCARE observations, especially in understanding how microphysical processes affect the Doppler velocity field.

Vertical profiles of averaged Doppler velocity in the convective region

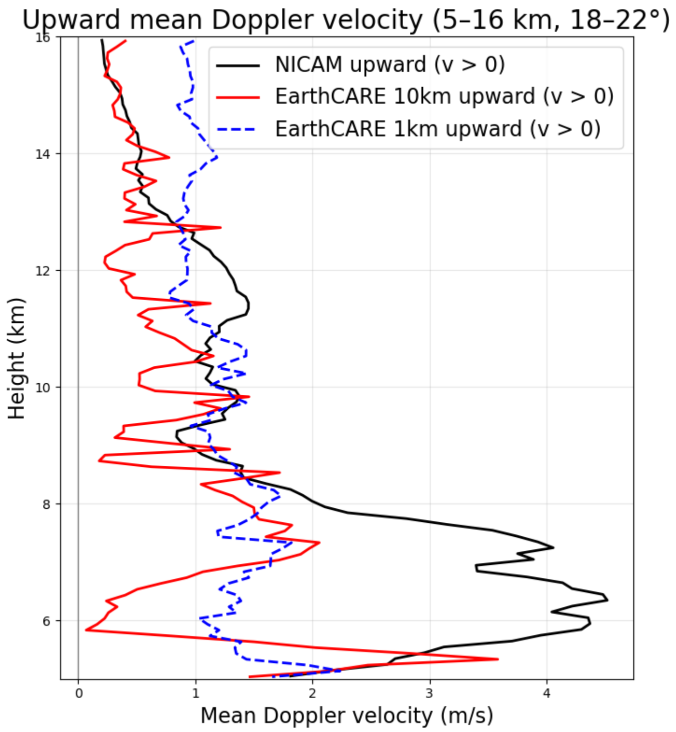
Total



Only Downward



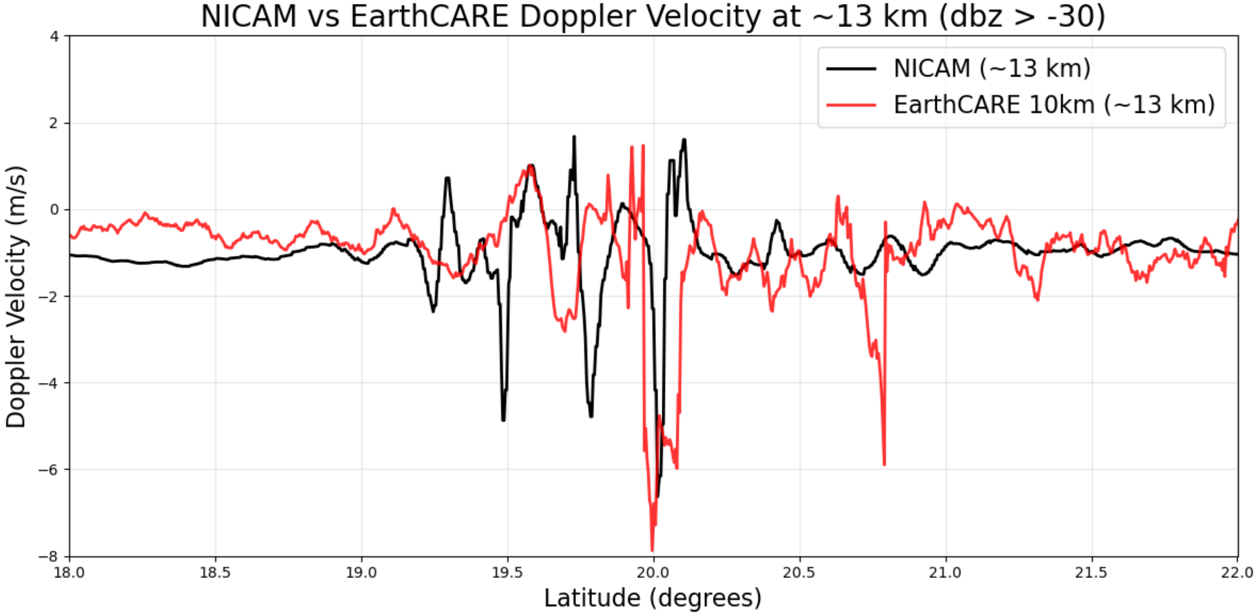
Only Upward



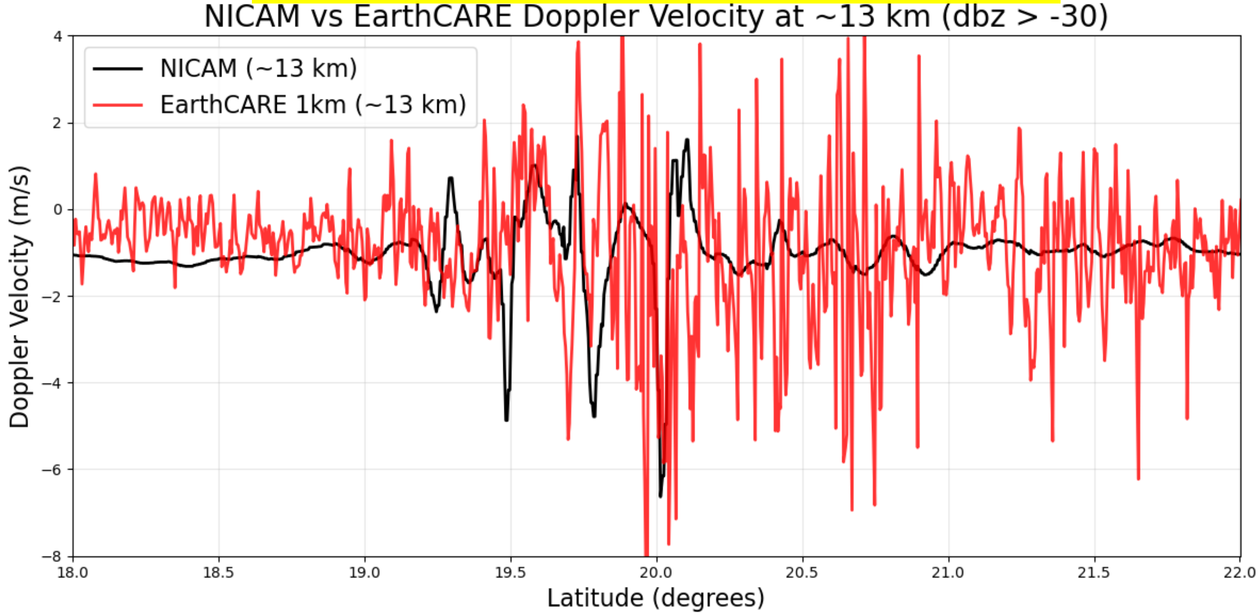
- NICAM agrees reasonably well with the EarthCARE 10 km mean profile, though it overestimates Doppler velocity below 8 km.
- Downward motion matches well, but NICAM underestimates upward motion, affecting the total mean.
- EarthCARE 1 km data show larger amplitudes compared to the 10 km product especially above 13 km altitude.

Doppler velocity at 13 km altitude

NICAM and EarthCARE 10km Doppler velocity



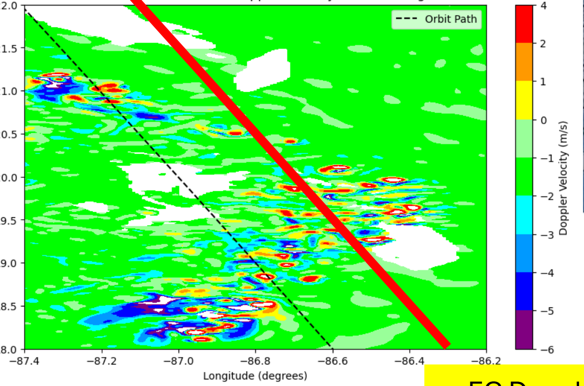
NICAM and EarthCARE 1km Doppler velocity



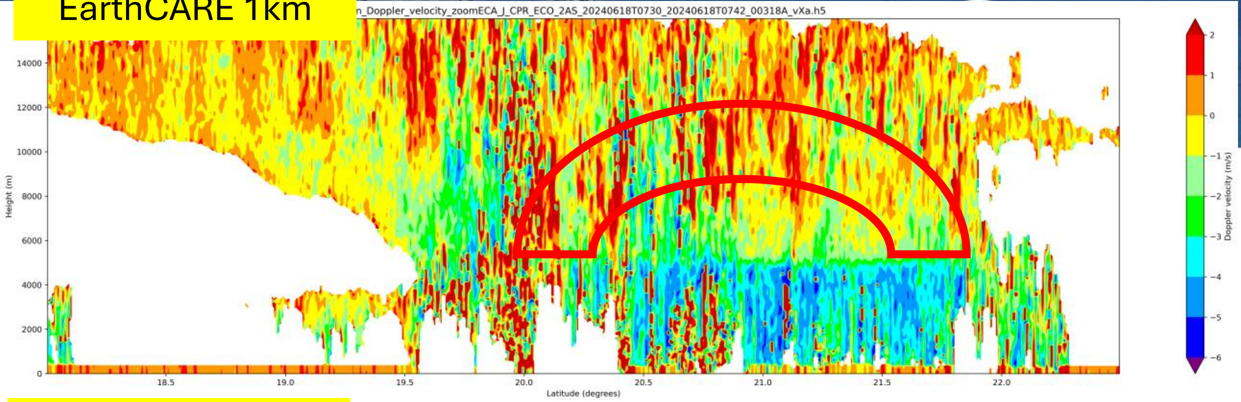
- Doppler velocity between EarthCARE 10km and NICAM at 13 km altitude data shows a convective core with north–south gravity wave propagation, consistent with EarthCARE, although the observed Doppler amplitudes are larger.
- EarthCARE 1 km data (right) display even stronger amplitudes and shorter-wavelength waves (represent real signals or Doppler observational errors?).

Summary

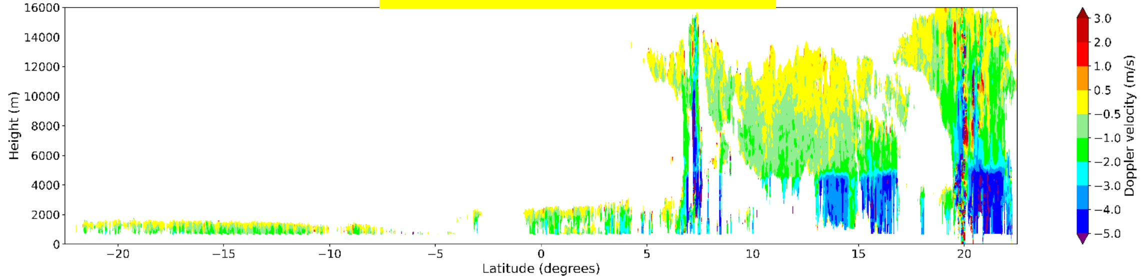
- We compared the 870 m NICAM simulation with EarthCARE CPR observations.
- EarthCARE CPR provides valuable constraints for understanding shallow precipitation, riming processes, and convection.
- NICAM appears to overestimate rain particle sizes in shallow precipitation.
- For convection, NICAM offers advantages for analyzing the underlying dynamical and microphysical mechanisms.
- The mean Doppler velocity patterns of EarthCARE 10 km data agree reasonably well with NICAM, whereas the 1 km data show larger amplitudes and shorter-wavelength gravity waves, which are not fully reproduced by NICAM.



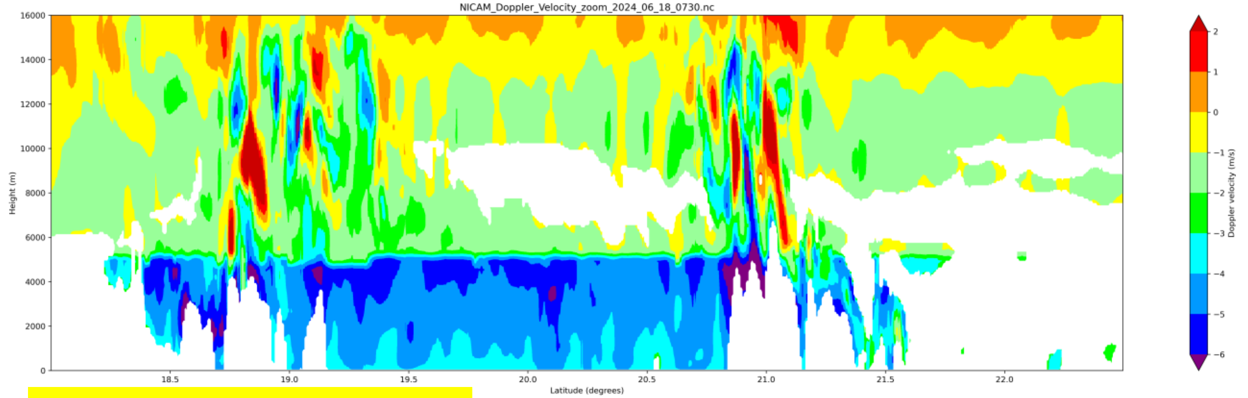
EarthCARE 1km



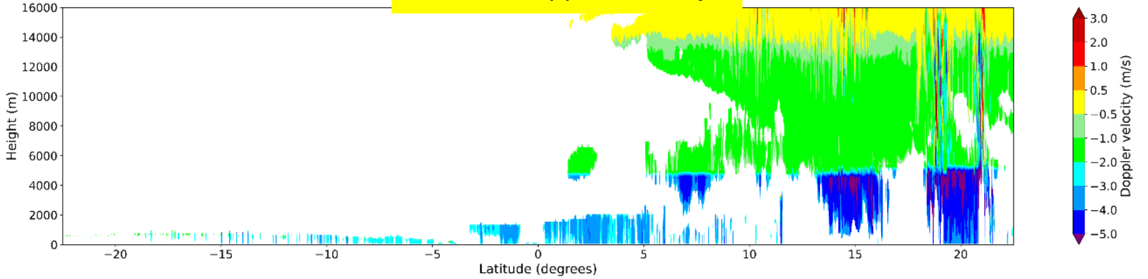
EC Doppler velocity 10km



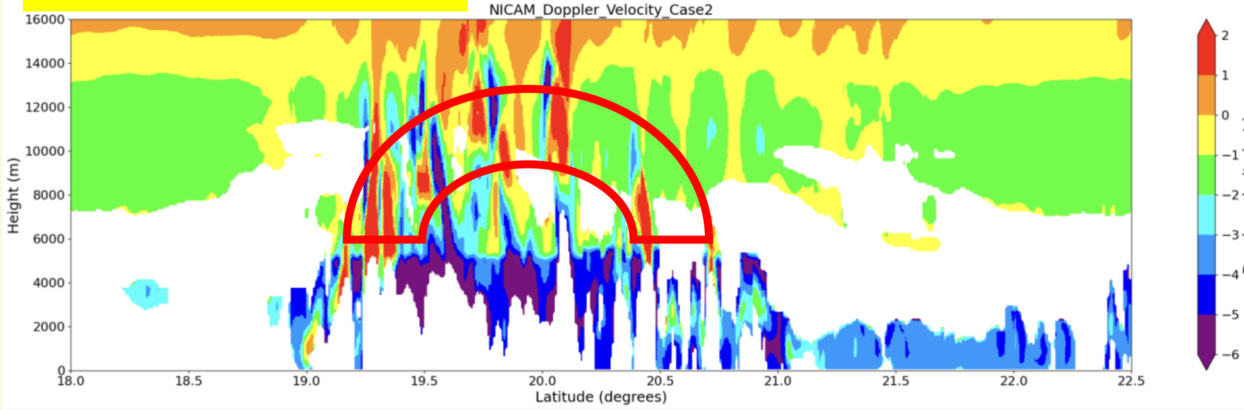
NICAM



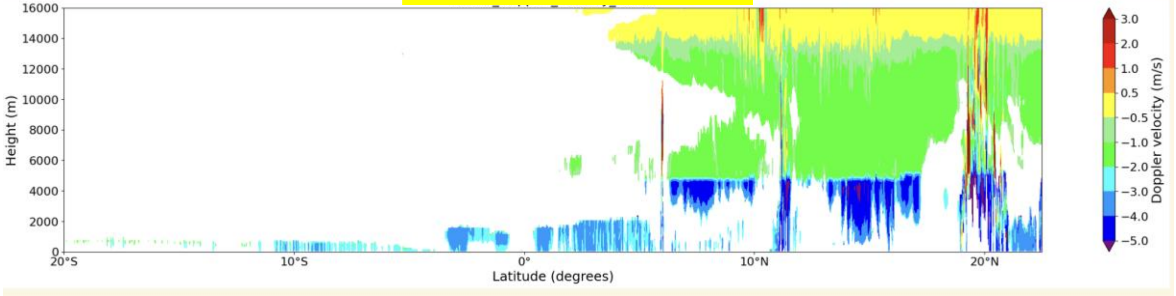
NICAM Doppler velocity



NICAM shifted orbit



NICAM Shifted orbit



Impact of rain size distribution?

- Smaller drizzle drop sizes imply:
  - Stronger evaporation for the same liquid water content
  - Longer residence time
- These effects suggest that shallow precipitation can generate more water vapor and enhance local evaporative cooling, influencing boundary-layer thermodynamics.