Comparisons between EarthCARE's Cloud Doppler Radar and A Global Convection-Resolving Simulation

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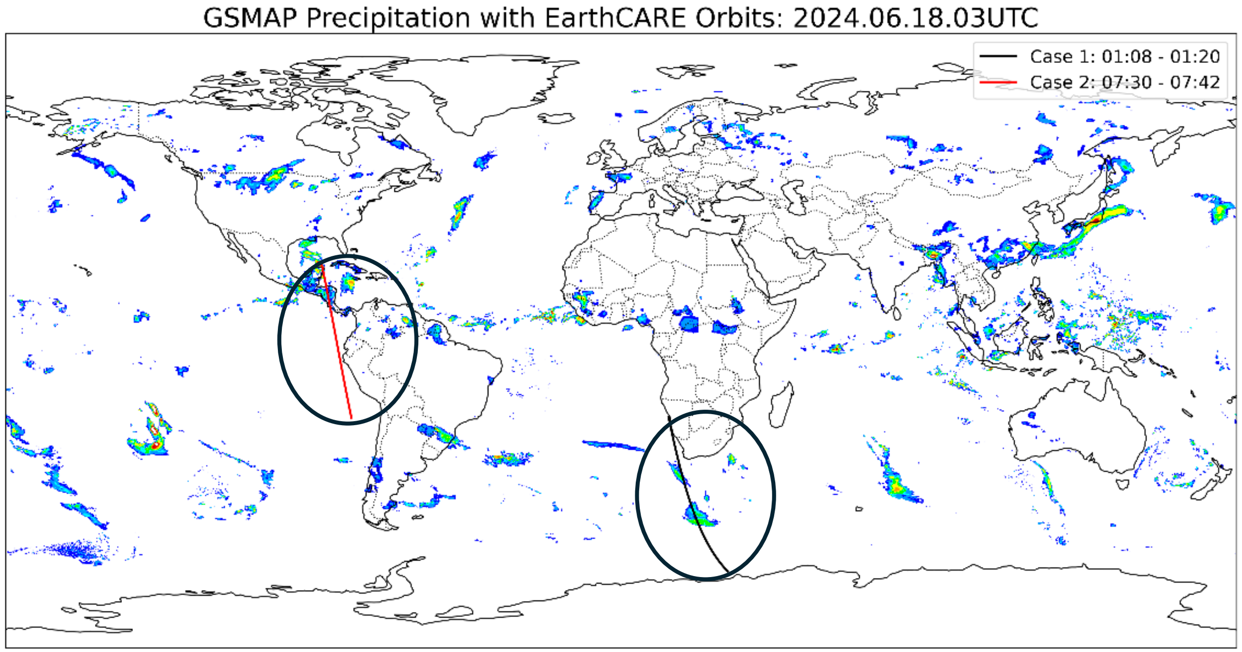
Introduction

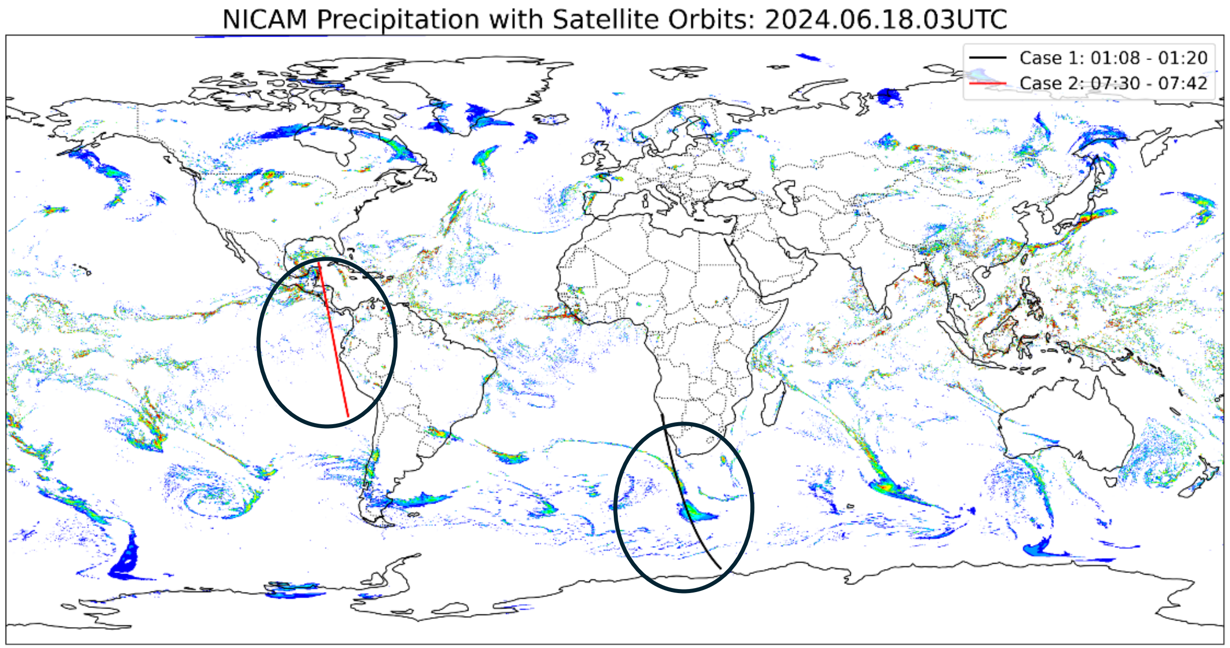
- Global storm-resolving models (GSRMs) have emerged as pivotal tools for climate and weather studies (Satoh et al. 2019; Stevens et al. 2019). With a mesh size of approximately a few km or less, these models provide a resolution capable of resolving mesoscale convective systems (MCSs) and their intricate dynamics.
- The EarthCARE satellite, equipped with a 94 GHz Cloud Profiling Radar (CPR) with Doppler capability, provides the first global observations of Doppler velocity from space.
- These observations offer valuable insights into cloud and precipitation dynamics by capturing both downward motions associated with hydrometeor terminal velocity and upward air motions linked to convective processes.
- Despite the significant potential of EarthCARE's Doppler velocity data, several challenges must be addressed.
- To understand these observations, comparisons with high-resolution numerical simulations are also essential.
- In this study, we compare and assess EarthCARE's CPR and NICAM with an 870 m horizontal resolution with the Joint Simulator.

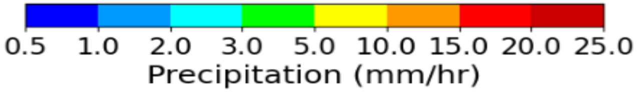
Horizontal distributions of precipitation between observation and NICAM

GSMAP



NICAM





EarthCARE data

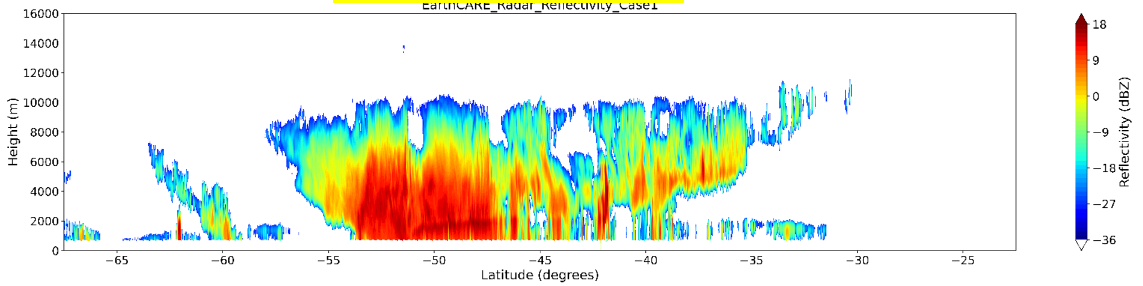
- The CPR Level 1b product (version vCa)
- Calibration: pointing error, mirror image, multiple scattering tail
- 10 km integrated data

NICAM simulation data

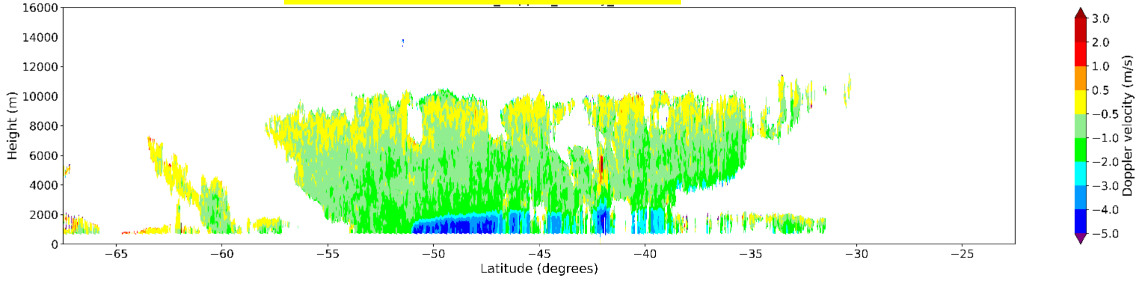
- Horizontal mesh: 870 m
- Vertical layers: 78
- Microphysics scheme: a single moment scheme (NSW6)
- Initial condition: 00 UTC on 17 June 2024 (ERA5)

Comparison of EarthCARE CPR and NICAM for Case1

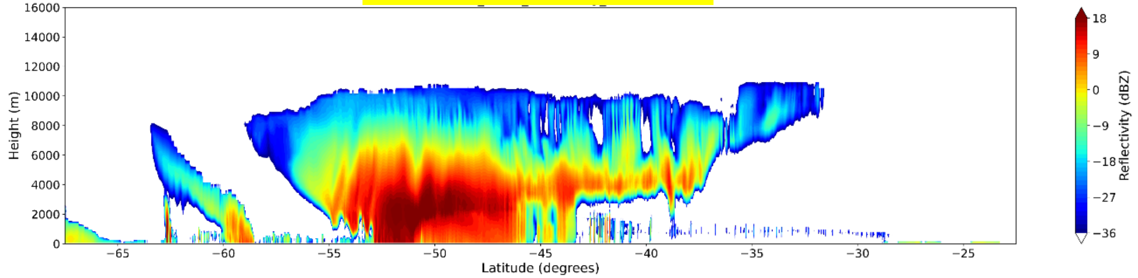
EC radar reflectivity



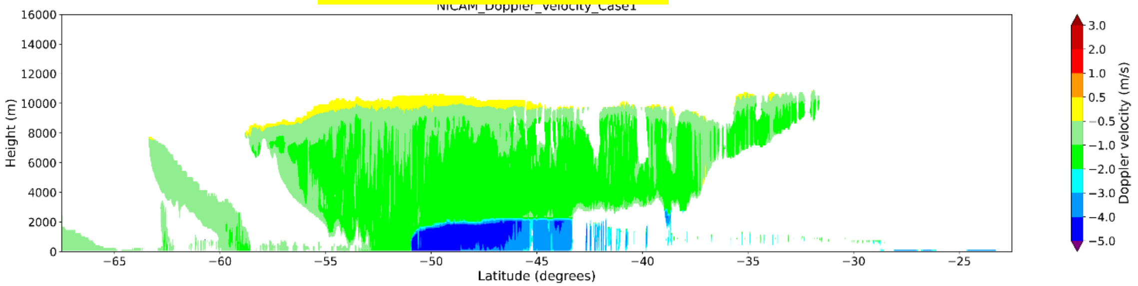
EC Doppler velocity 10km



NICAM radar reflectivity



NICAM Doppler velocity



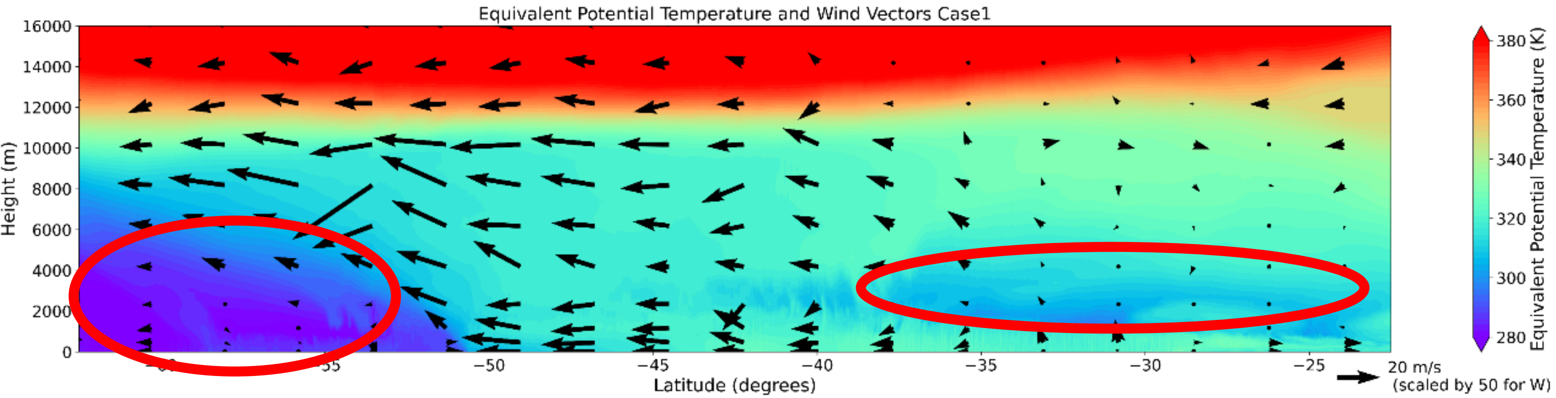
- EarthCARE CPR observations clearly depict the cold front associated with the extratropical cyclone, as well as the low clouds near the tail of this system.

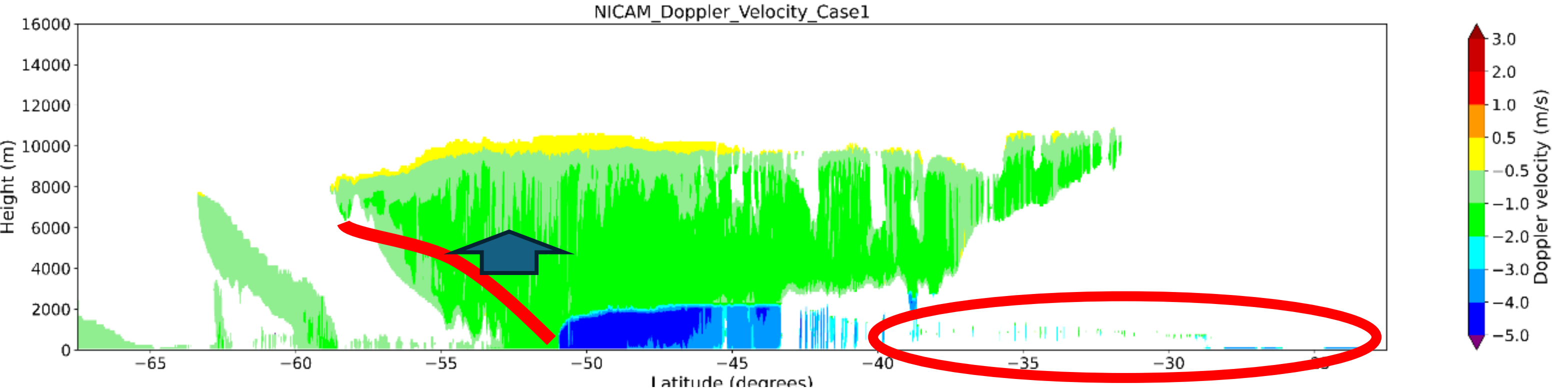
- Doppler velocity data effectively distinguishes between snow and rain within the observed system.

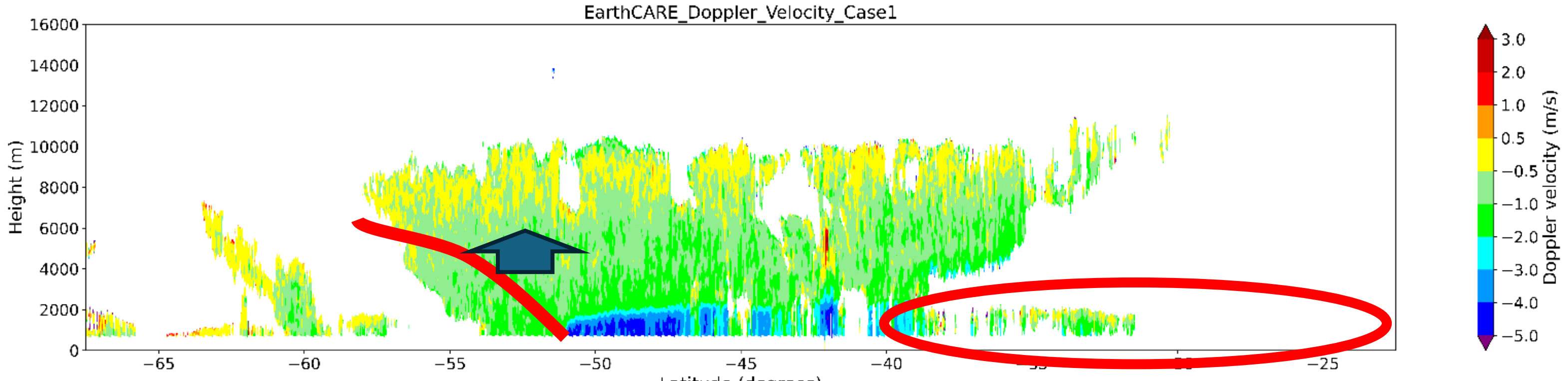
- NICAM successfully reproduces the observed cold front system and associated low clouds.

- NICAM simulations slightly overestimate the downward Doppler velocity compared to EarthCARE observations.

To understand the mechanism using simulations







- Cold front: Colder and drier air creates a sharply sloped boundary beneath warmer, moist air near the surface, forcing the warm air to rise.

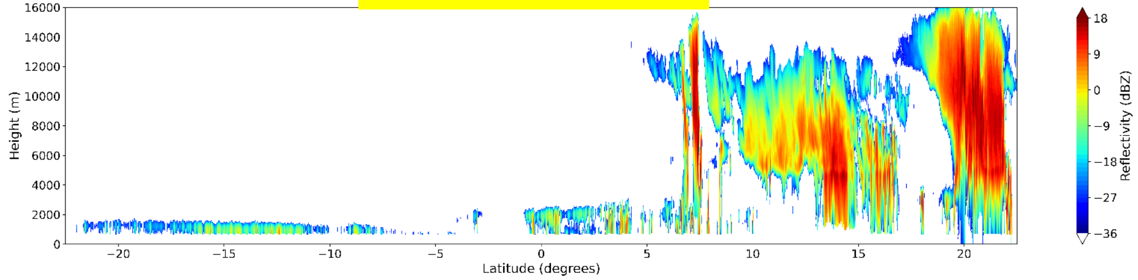
- Upward motion above the cold air is expected in this system.

- A layer of cold air is present between altitudes of 2 and 4 km, creating favorable conditions for forming low-level clouds.

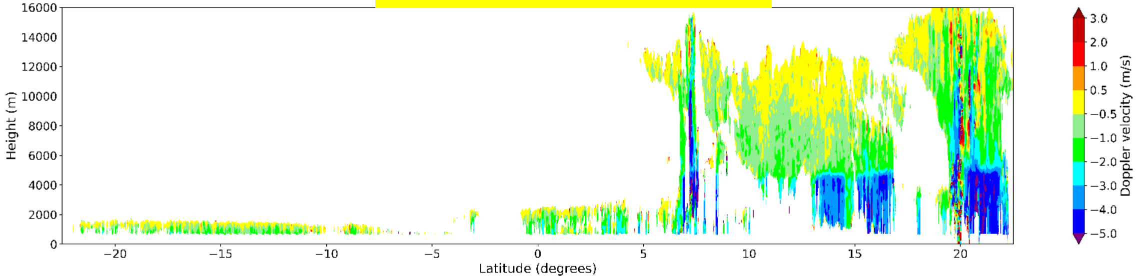
- Simulation results help clarify the mechanisms responsible for the observed vertical profiles of radar reflectivity and Doppler velocity.

Comparison of EarthCARE CPR and NICAM for Case2

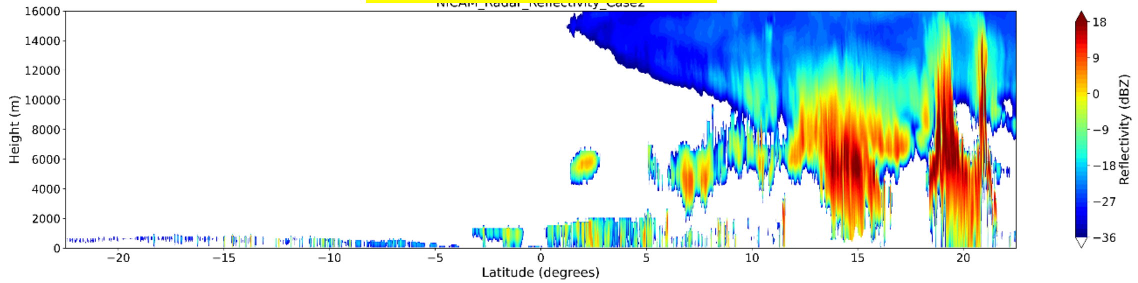
EC radar reflectivity



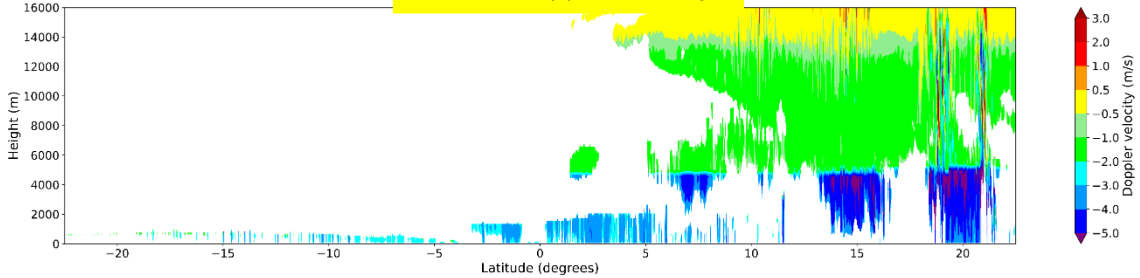
EC Doppler velocity 10km



NICAM radar reflectivity



NICAM Doppler velocity



- 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.

How to interpret Doppler velocity?

- Doppler velocity (V_D)
- $V_D = V_T + W + E_R + E_p + E_{NUBF} + E_{MS}$
    - V_T: Radar reflectivity weighted terminal velocity from hydrometeors
    - W: Vertical air velocity including turbulences
    - E_R: Random error related to vibration of satellite and so on
    - E_p: Positioning error of satellite
    - E_{NUBF}: Nonuniform beam filling error
    - E_{MS}: Multiple scattering error

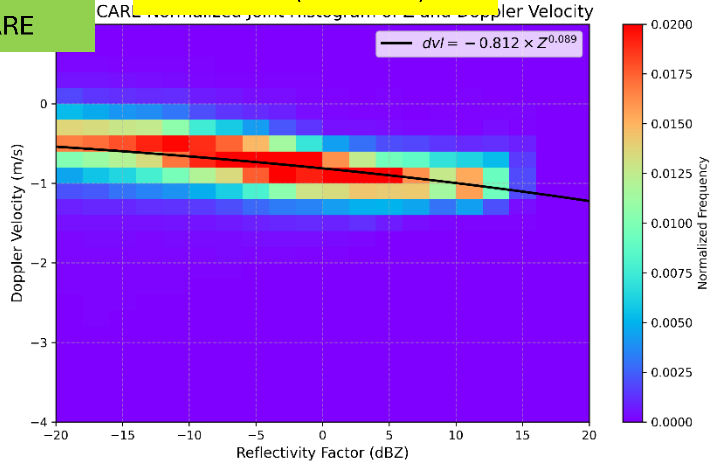
- There are several researches using ground observations about V_T from a power law relationship between V_D and radar reflectivity factor Z for ice clouds (Protat et al. 2003; Delanoe et al. 2007; Protat and Willams 2011; Kalesse et al. 2013)
    - $V_T \sim V_D = aZ^b$

Joint histograms between radar reflectivity and Doppler velocity

$V_D = aZ^b$

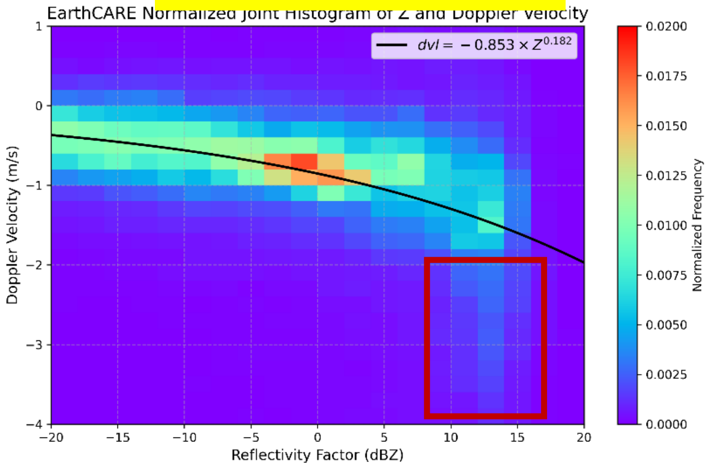
Case 1 (cold front)

EarthCARE



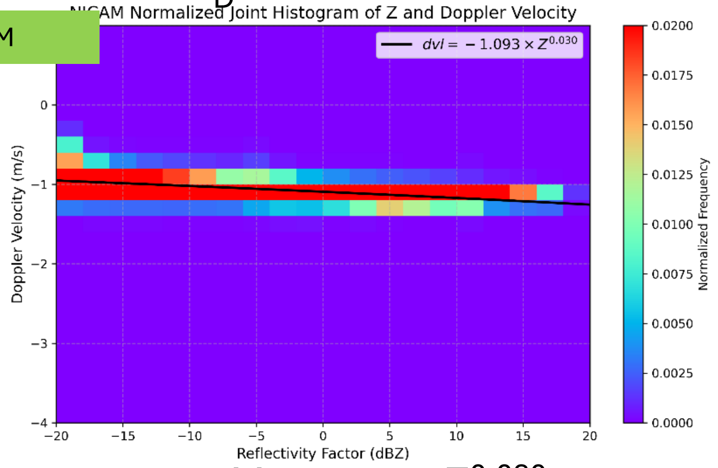
$V_D = 0.812Z^{0.0899}$

Case 2 (tropical storm)

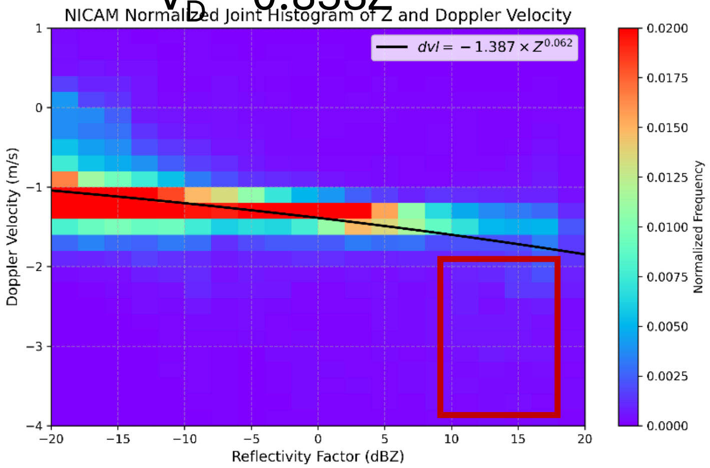


$V_D = 0.853Z^{0.182}$

NICAM



$V_D = 1.093Z^{0.030}$



$V_D = 1.387Z^{0.062}$

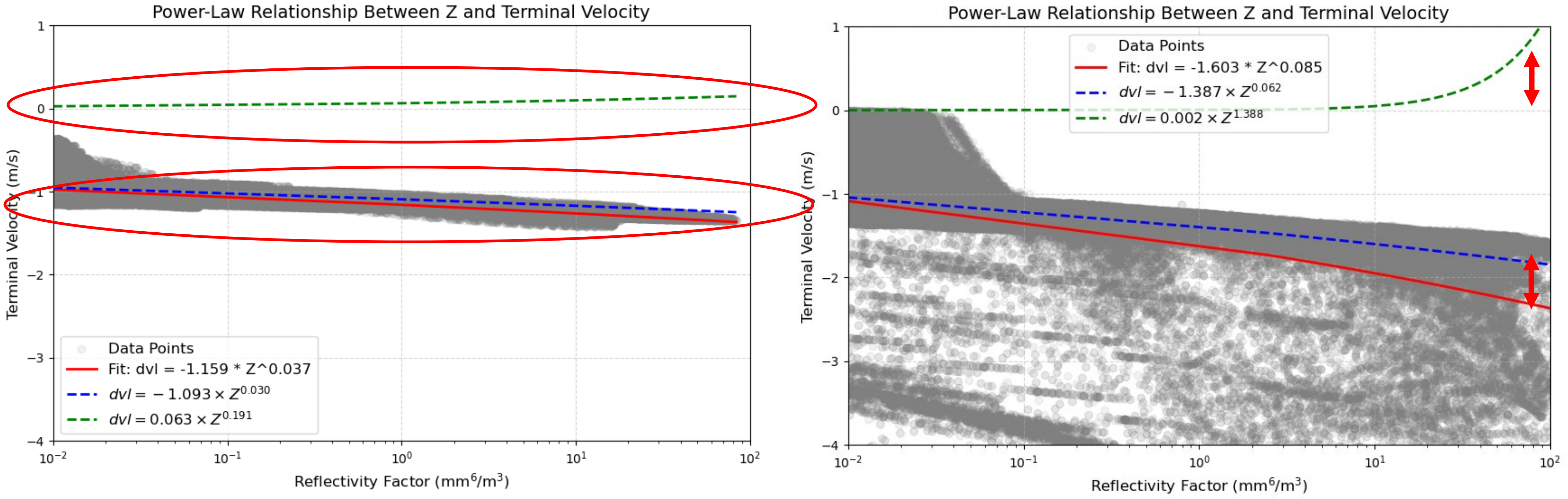
In Case 1, dry ice particles, such as snow and cloud ice, are dominant, resulting in fewer rapidly falling ice particles.
In Case 2, radar reflectivity values greater than 5 dBZ and Doppler velocities lower than -2 m/s indicate the presence of graupel and hail. Both observations and model simulations successfully capture this trend.

How to retrieve vertical air velocity from Doppler velocity in clouds?

- $V_D = V_t + W$
- $V_T = aZ^b$
- $W = V_D - V_t$
- Assumptions:
  - The attenuation of radar reflectivity is small for ice particles.
  - Averaged W is small.
  - V_T is a function of a radar reflectivity factor Z.
  - We can check these assumptions using the simulation data (NICAM).

- This study only focuses on the vertical air velocity in ice clouds.

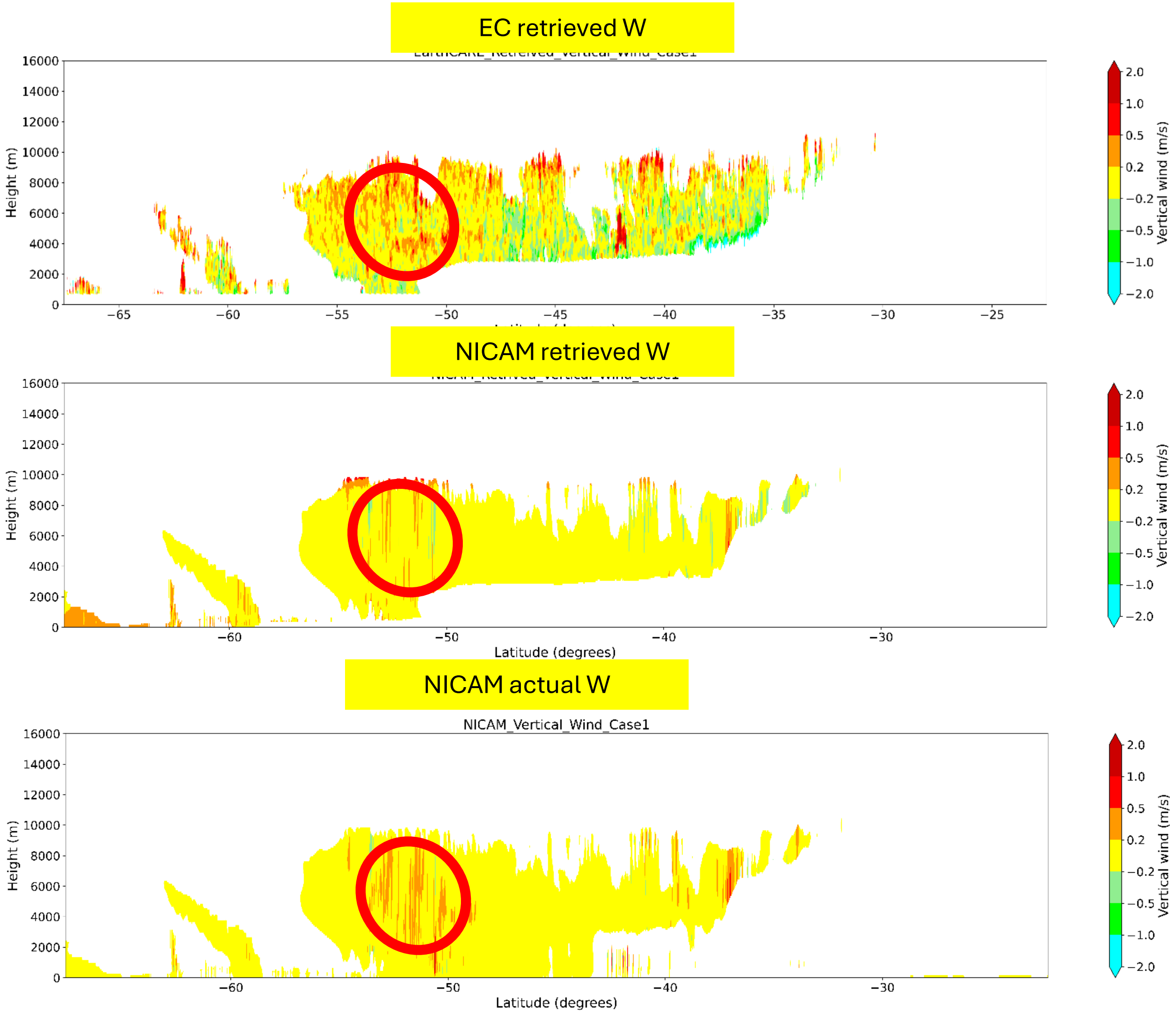
Scatterplots between terminal velocity and radar reflectivity factor in NICAM



Red line: The fitted line of a power law relationship between terminal velocity and radar reflectivity factor
Blue dotted: The fitted line of a power law relationship between Doppler velocity and radar reflectivity velocity
Green dotted: The fitted line of a power law relationship between vertical air velocity and radar reflectivity velocity

In Case 1, the assumption is well satisfied. The doppler velocity is almost same to the terminal velocity and vertical wind is relatively weak.
In Case 2, the assumption is not satisfied comparing to Case 1. We can expect the bias of of terminal velocity and vertical velocity related to riming particles and larger radar reflectivity area.

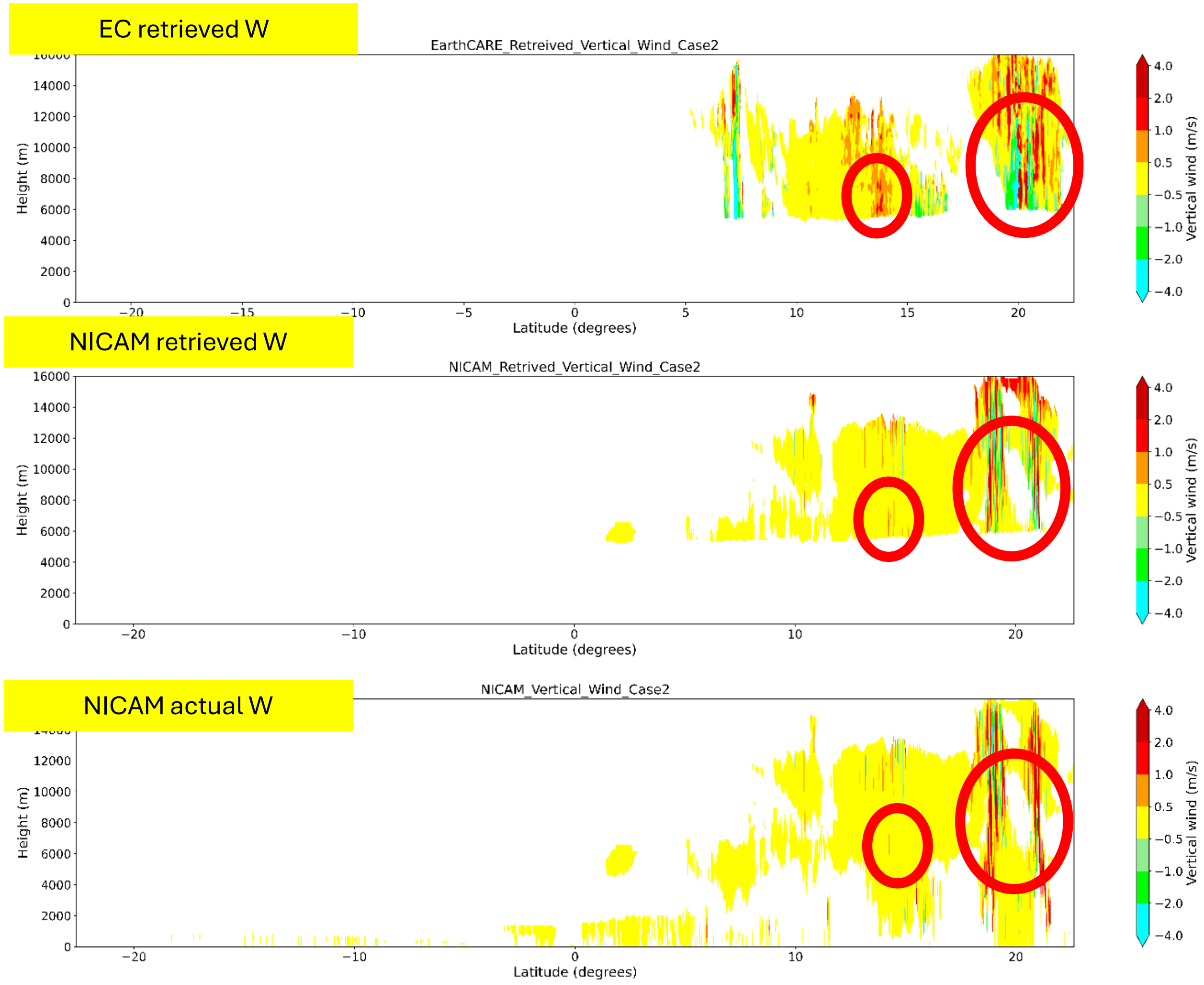
Comparisons of vertical winds for a cold front case



- The retrieved vertical velocity shows upward motion above the cold air in both EarthCARE observations and NICAM simulations.

- However, the cloud top region near 10 km in the retrieved vertical velocity exhibits an upward motion, which may be related to biases in the retrieval methodology.

Comparisons of vertical winds for a tropical storm case

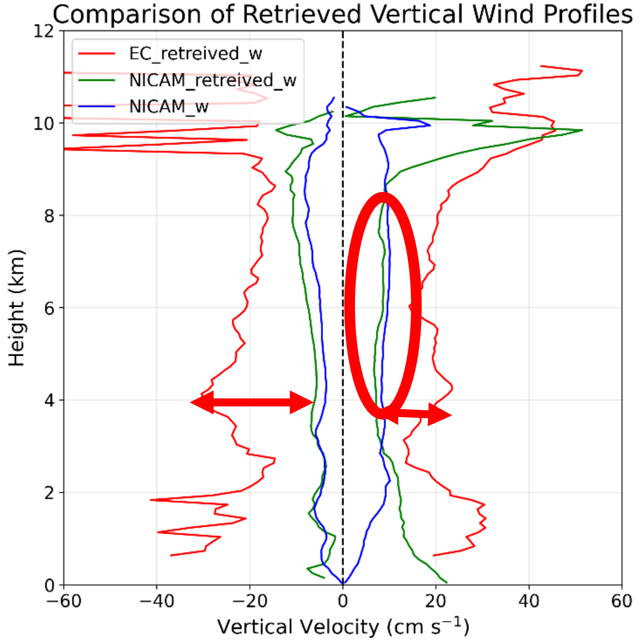


- Stronger convection is observed compared to Case 1.
- The simulated and observed convection show good agreement around 15°N, and 20°N.
- However, the retrieved vertical velocity exhibits a stronger downward than the actual vertical air velocity in NICAM, particularly in the convective systems near 20°N.

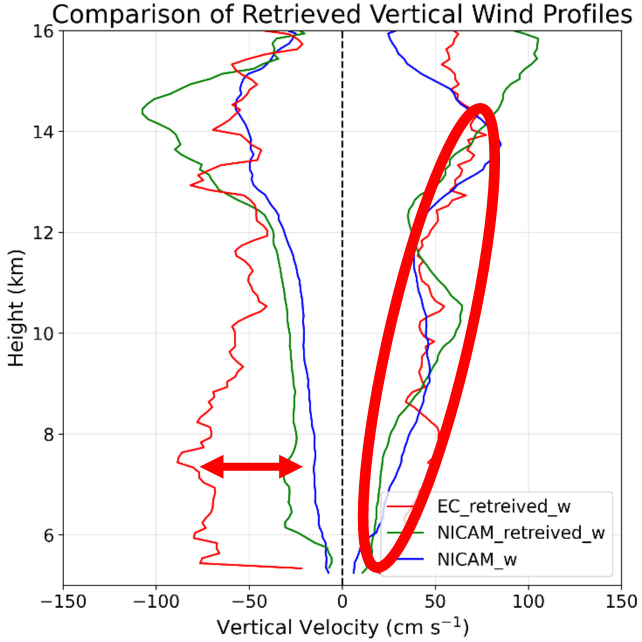
The averaged upward velocity and downward velocity for each frame

b)

Case 1 (cold front)



Case 2 (tropical convection)



- Case 1: Simulated and retrieved vertical velocities agree well between 2–9 km, consistent with observed patterns. NICAM slightly underestimates vertical velocities. Possible reasons for observed variance include unresolved turbulence in simulations and Doppler errors.

- Case 2: Vertical motions (both upward and downward) are stronger than in Case 1. Simulations and retrievals align well, but differences increase above 14 km. Observations show stronger downward motion than simulations.

Summary

- We compared the EarthCARE CPR and a global storm-resolving model (GSRM) for two frames.
- The EarthCARE CPR gives information about terminal velocities of hydrometeors and vertical air velocities in clouds, and a GCRM reproduced similar vertical structures.
- We can understand the performance of GSRMs using the EarthCARE CPR.
- GSRMs are also helpful in understanding the EarthCARE data.
- EarthCARE is opening a new era for exploring convection and microphysics with GSRMs.
- JAXA/ESA L2 data were released. We will evaluate GCRMs using L2 data.