EarthCARE:

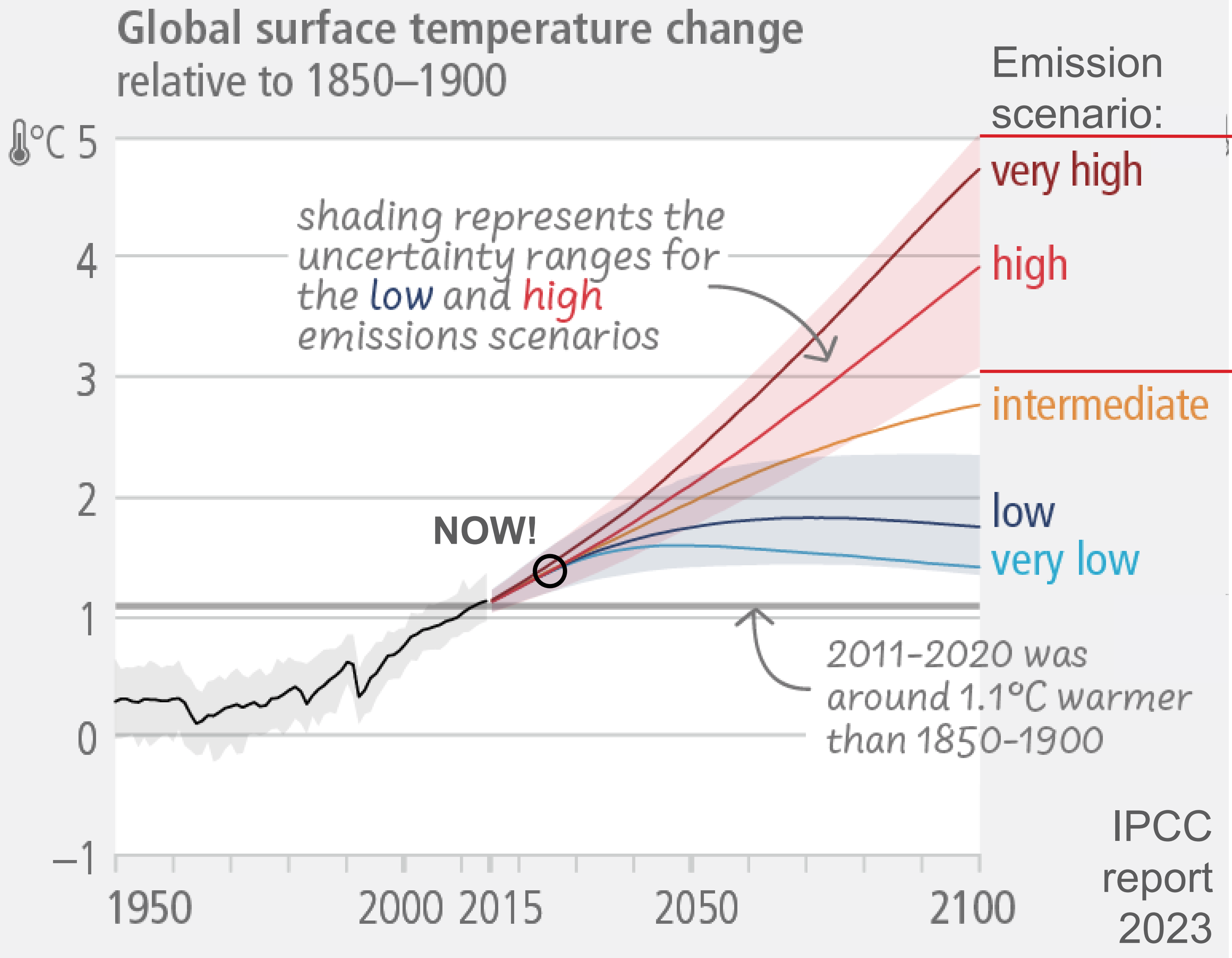
Unravelling the mysteries of clouds and aerosols

Robin J. Hogan and many others
ECMWF and University of Reading

Moving towards scientific exploitation of EarthCARE

- How can we use EarthCARE to answer key questions in climate science?
- *Just how cool is EarthCARE?!*

How much will the climate change this century?

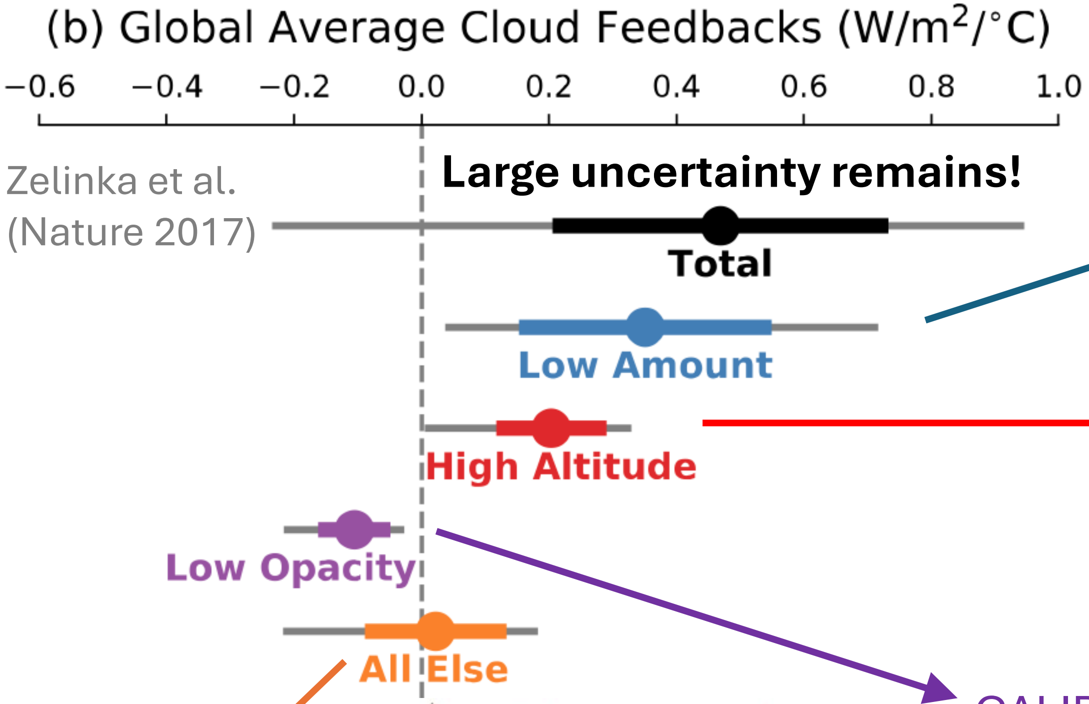


+5ºC if clouds amplify the warming, a *positive cloud feedback*

+3ºC if clouds stay about the same

How did CloudSat & CALIPSO improve our understanding, and how can EarthCARE make the next breakthrough?

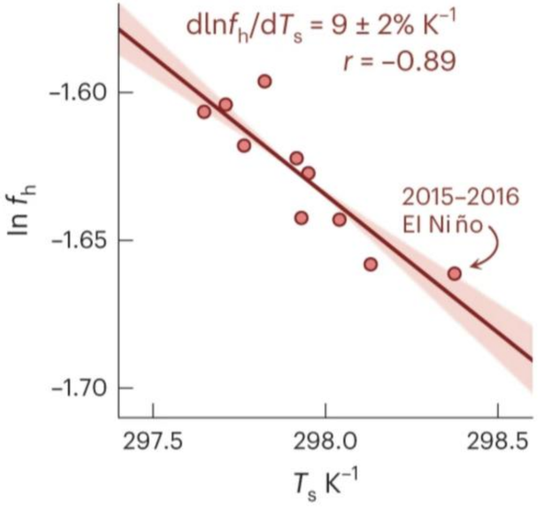
What did the A-Train tell us about cloud feedbacks?



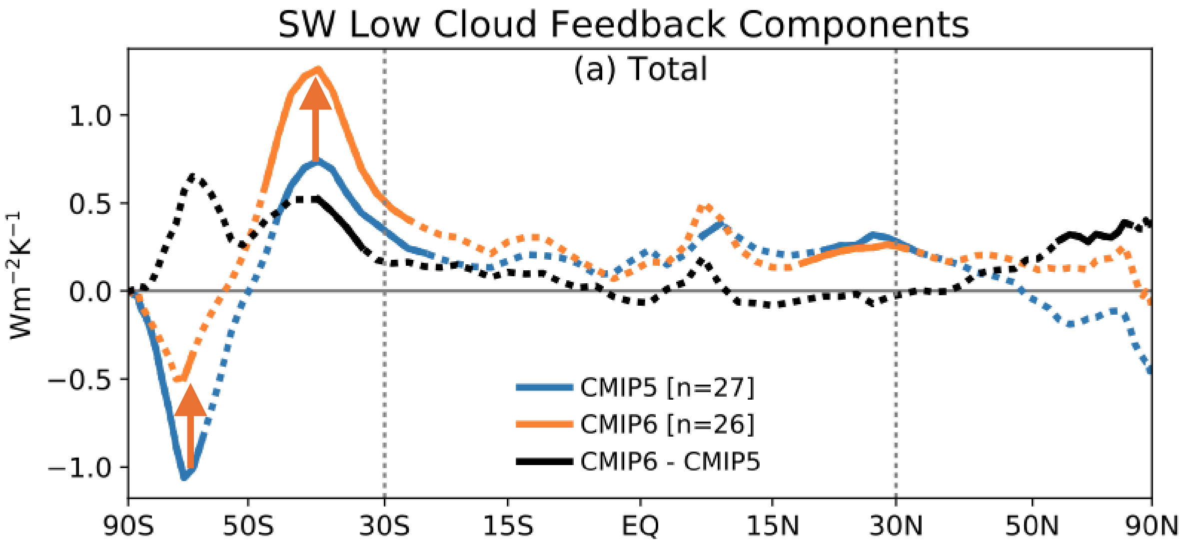
Most models suggest low cloud cover will decrease, amplifying climate change, but amplitude is very uncertain; CloudSat provided valuable information on precipitation from low clouds

High cloud tops rise and cool, now detectable in long time series from MODIS and CloudSat (Richardson et al)

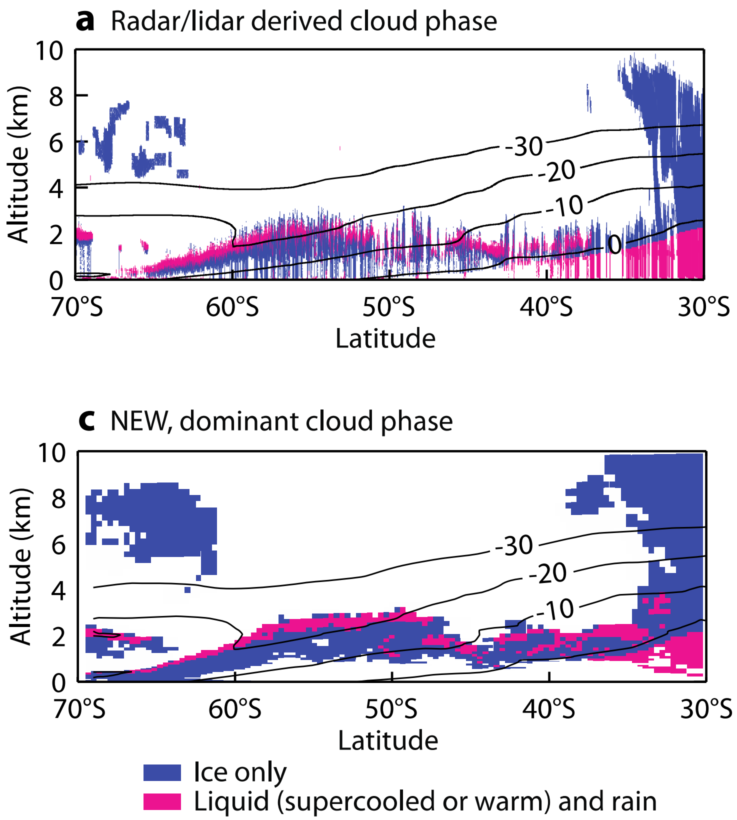
e.g. CALIPSO anvil cloud area weakly dependent on temperature (McKim et al. 2024)



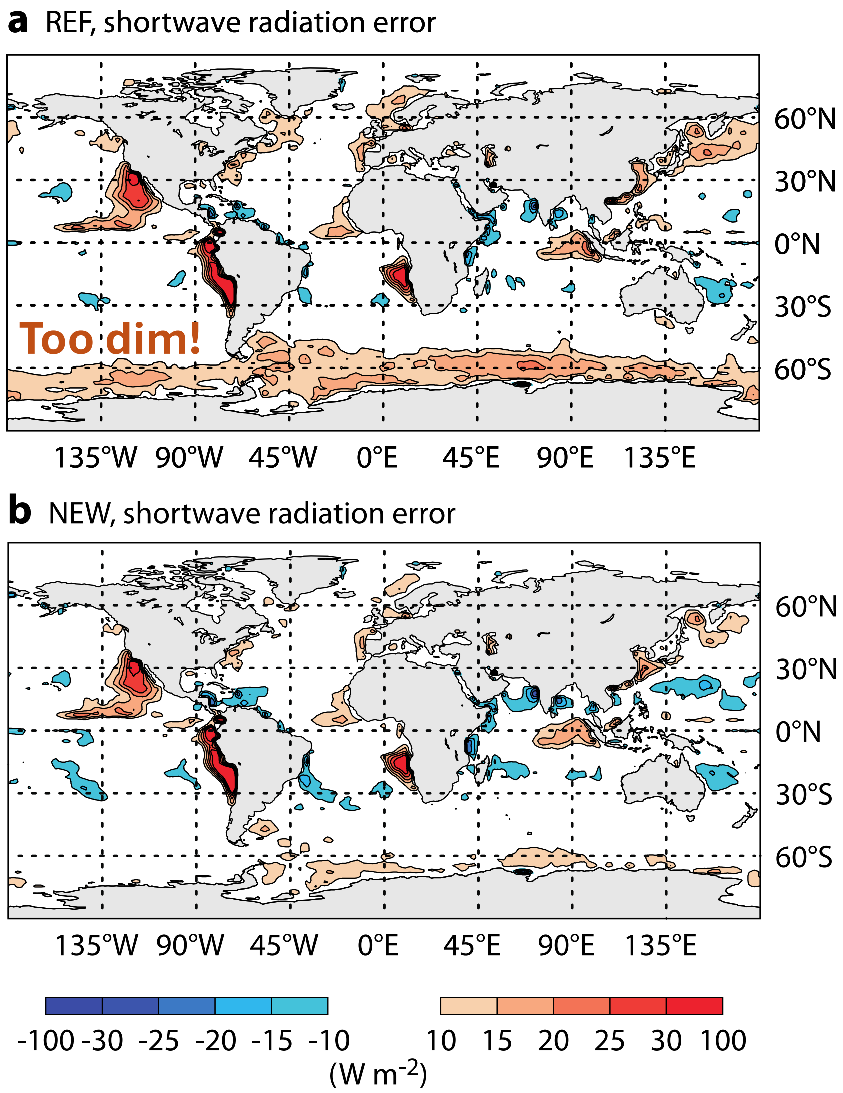
CALIPSO cloud phase observations improved models, reducing negative feedback & uncertainty (Zelinka et al. 2020)



How CALIPSO improved our understanding of a key cloud feedback (and improved the ECMWF weather model)



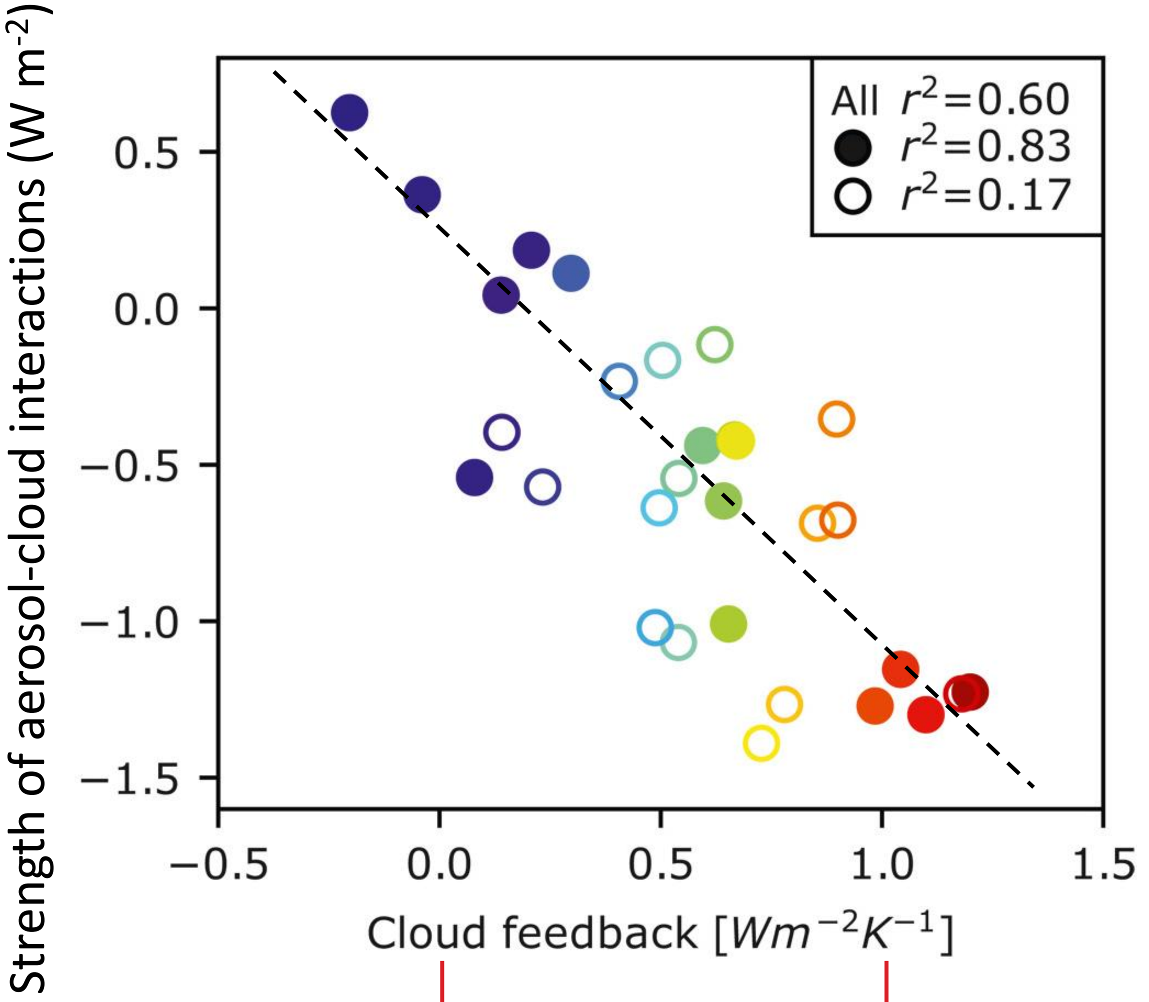
- **New mixed-phase cloud treatment** informed by CALIPSO cloud top phase (Forbes & Ahlgrimm 2014, Forbes et al. 2016)
- One of many model improvements inspired by CloudSat & CALIPSO



- Older climate models: warming up marine clouds converts ice to liquid, which is more reflective so a negative feedback, but CALIPSO showed that they already contain plenty of supercooled liquid, so effect overestimated

Improving the representation of processes in weather & climate models is one key way to reduce uncertainty in cloud feedbacks!

What about aerosol-cloud interactions?



Clouds stay about the same

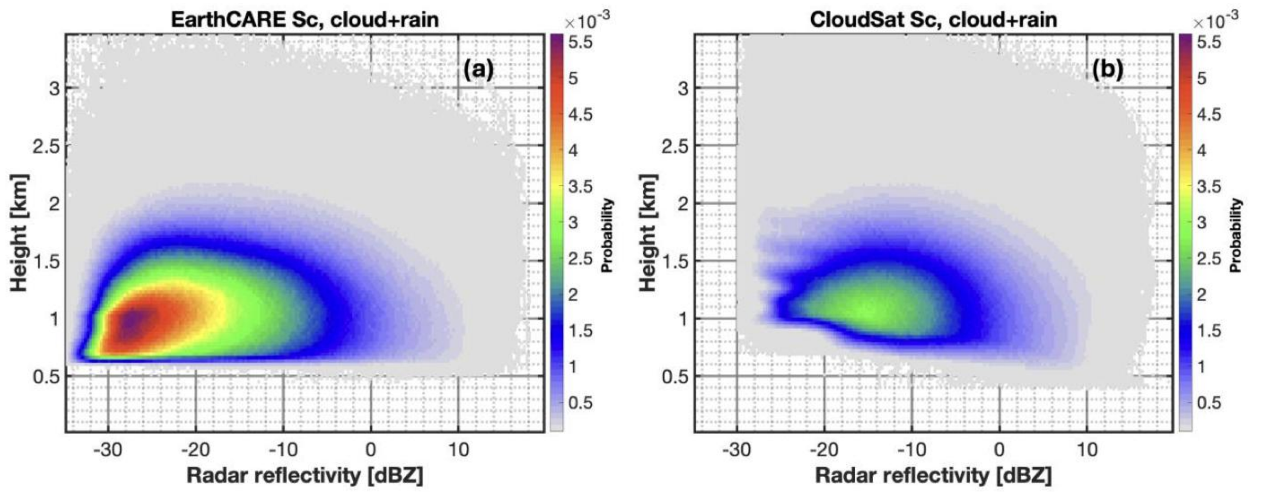
Clouds amplify the warming

- There is a huge compensation between the strength of the cloud feedback and the strength of aerosol-cloud interactions in CMIP6 climate models
- This allows models to fit the 20th-century temperature record for very different reasons, so their future projections diverge

It is crucial that we also try to use EarthCARE to pin down aerosol-cloud interactions!

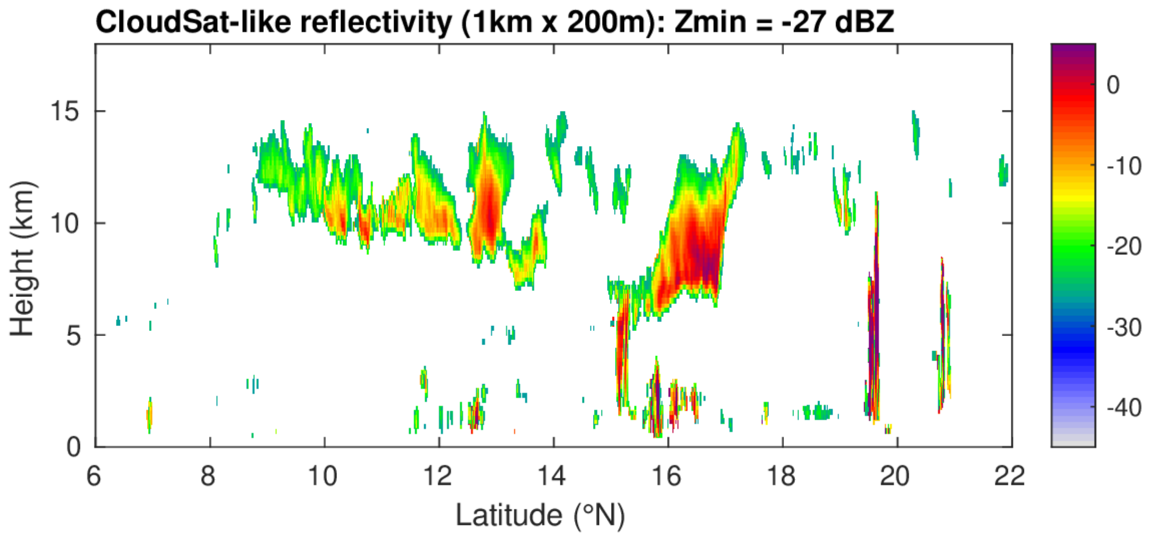
Wang et al. (GRL 2021)

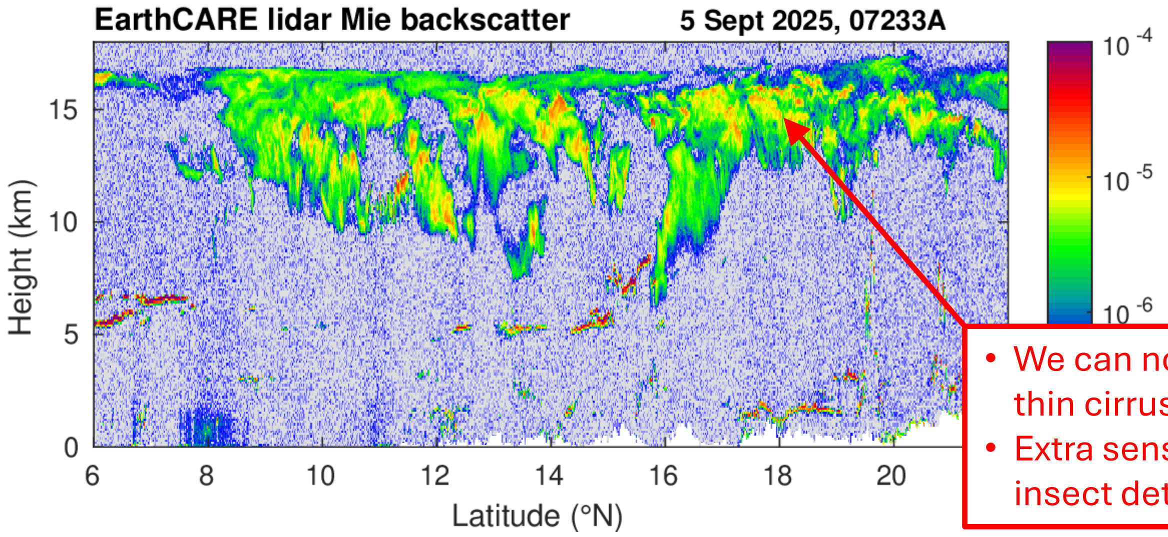
EarthCARE's CPR is incredibly sensitive!

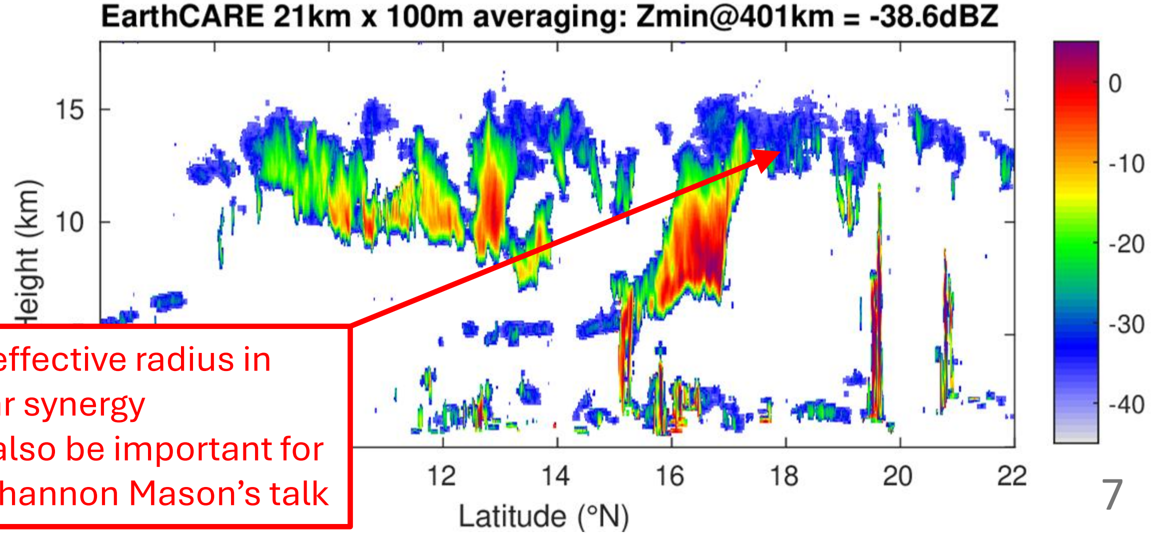


Zhuocan Xu et al. (2025): asymmetric pulse and 7-8 dB extra sensitivity means EarthCARE detects **twice** as much stratocumulus as CloudSat!

Can gain further sensitivity by averaging raw signal…





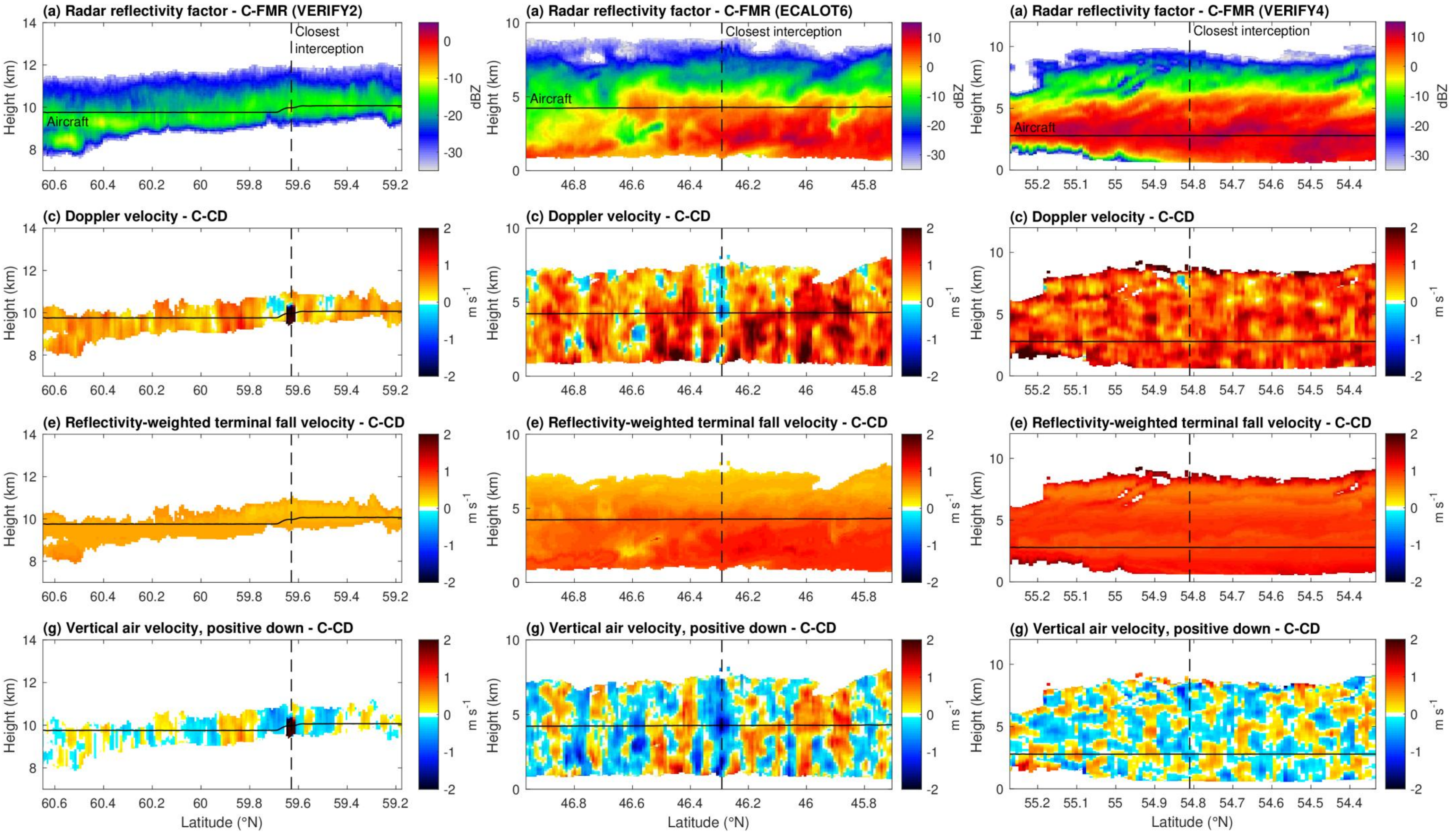


- We can now compute effective radius in thin cirrus by radar-lidar synergy
- Extra sensitivity could also be important for insect detection: see Shannon Mason's talk

How do we separate terminal velocity & vertical wind?

VERIFY2: 7 Nov 2024 | ECALOT6: 27 Jan 2025 | VERIFY4: 18 Nov 2024

- Radar reflectivity
- Doppler velocity
- Latest C-CD assumption: *all the small-scale variability is air motion*



With Bernat P-T, Shannon Mason, Zhipeng Qu, Kamil Mroz et al.

How do we separate terminal velocity & vertical wind?

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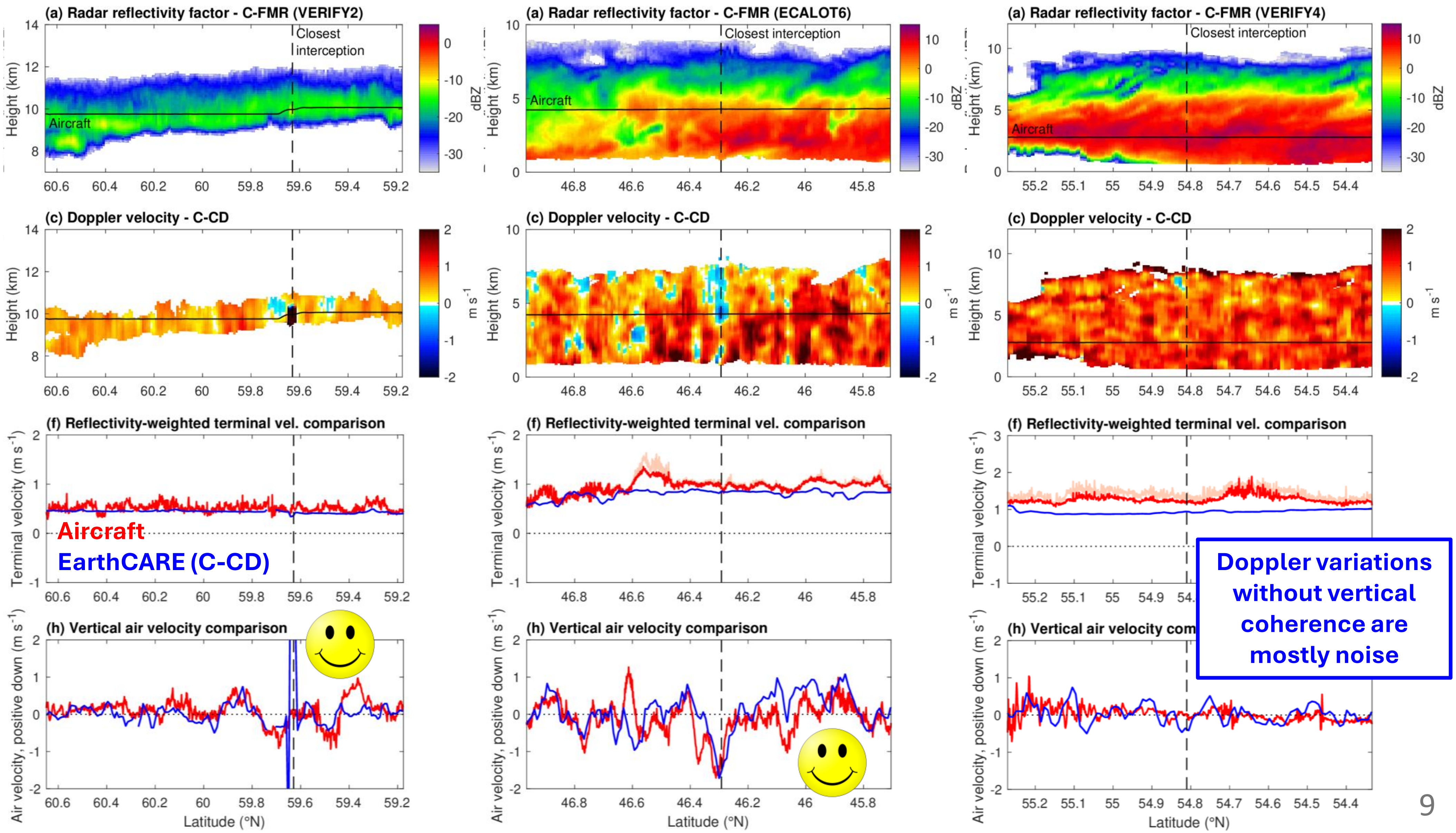
VERIFY2: 7 Nov 2024 **ECALOT6: 27 Jan 2025** **VERIFY4: 18 Nov 2024**

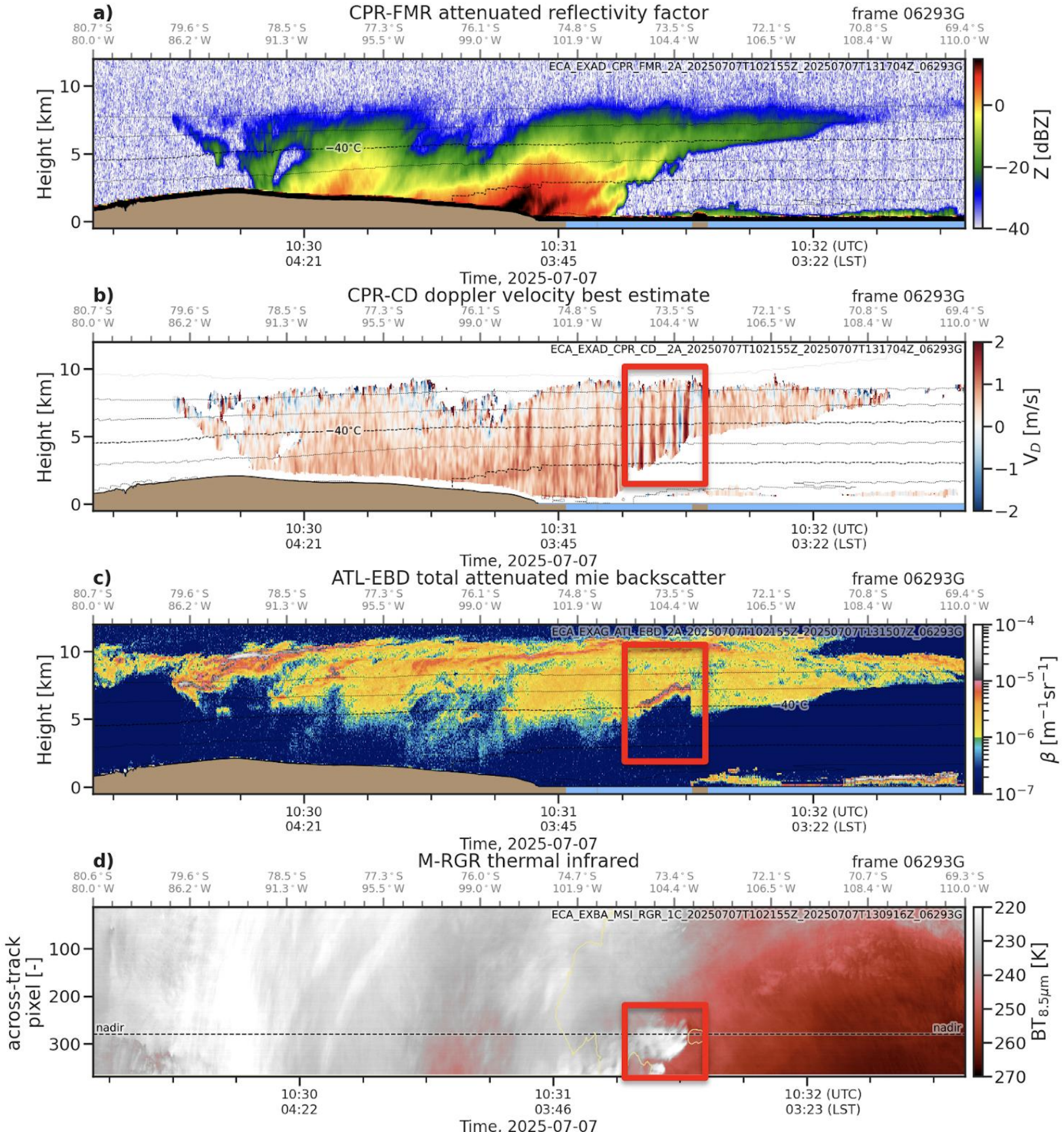
- Radar reflectivity
- Doppler velocity
- **Excellent agreement in phase and amplitude of gravity waves!**

See my poster tomorrow (Lobby10)

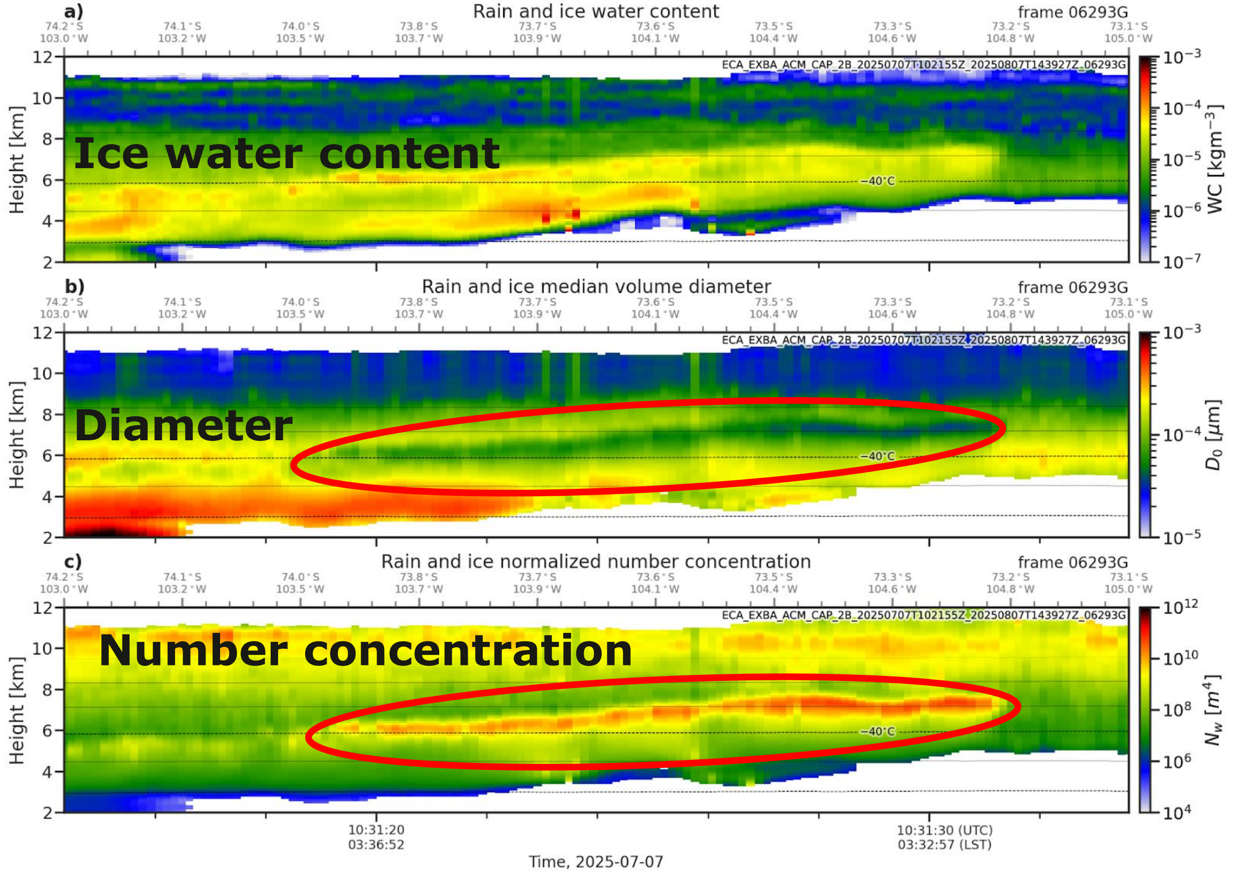


Influence of gravity waves on cloud physics

Shannon Mason
(ECMWF)



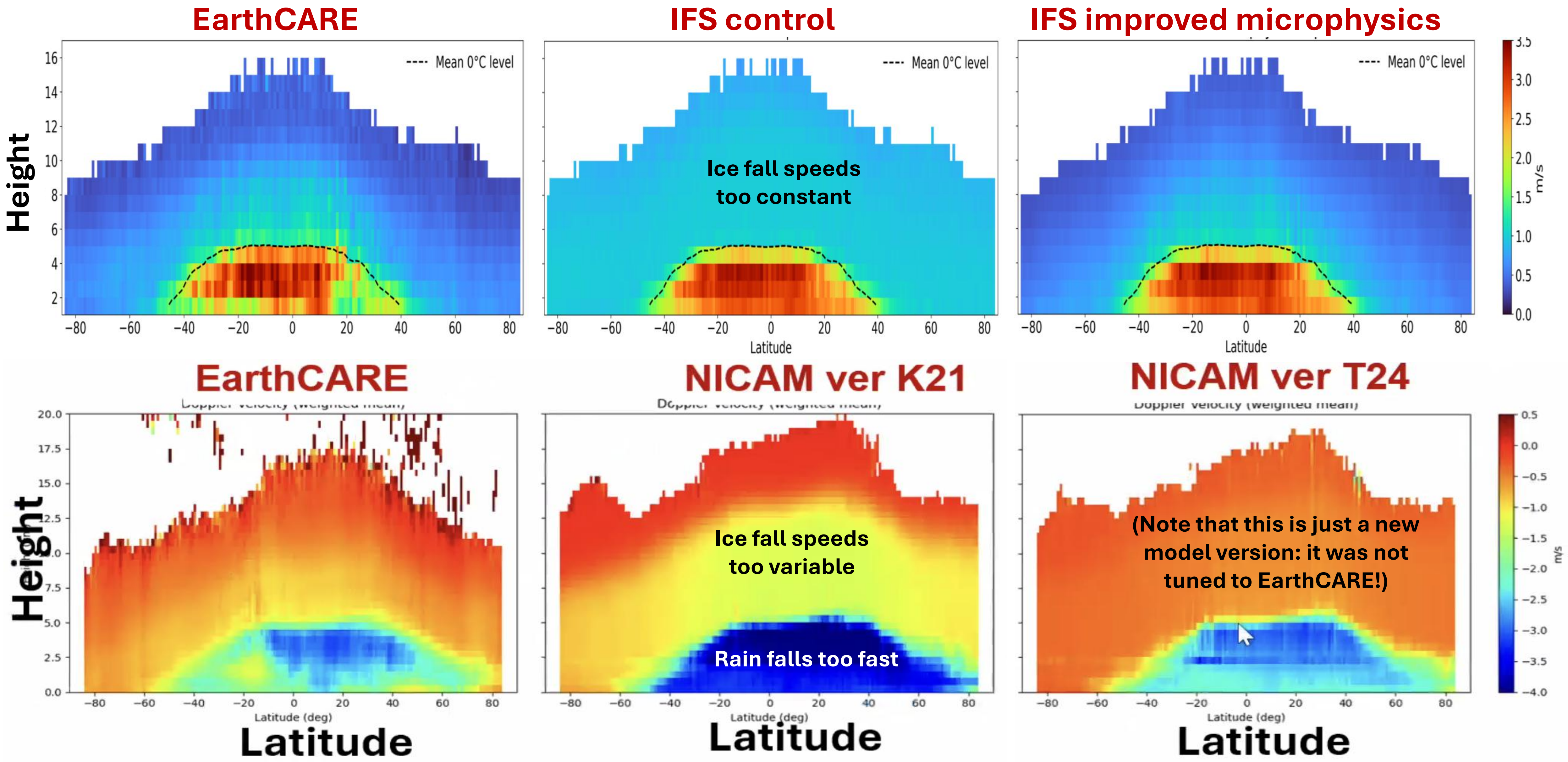
- Gravity waves coincide with strong lidar backscatter at -45°C (so due to ice) and sharp drop in thermal emission
- ACM-CAP: mean particle diameter drops from ~200 to ~40 μm while number concentration increases by over two orders of magnitude!



How common is this globally? What's its radiative impact? Is this process represented in models?

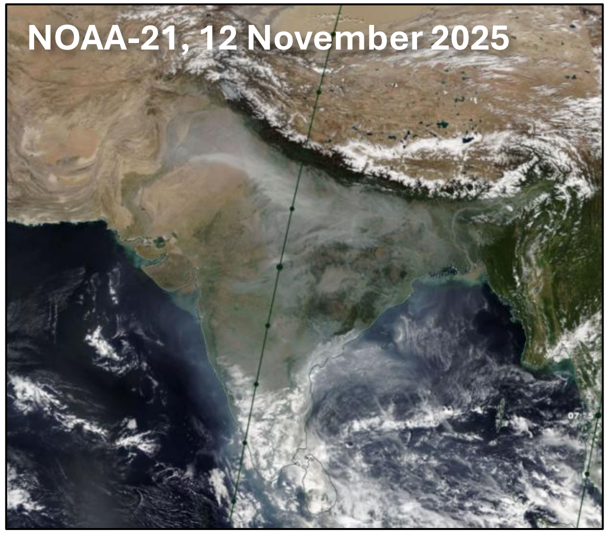
Doppler improves model fall speed

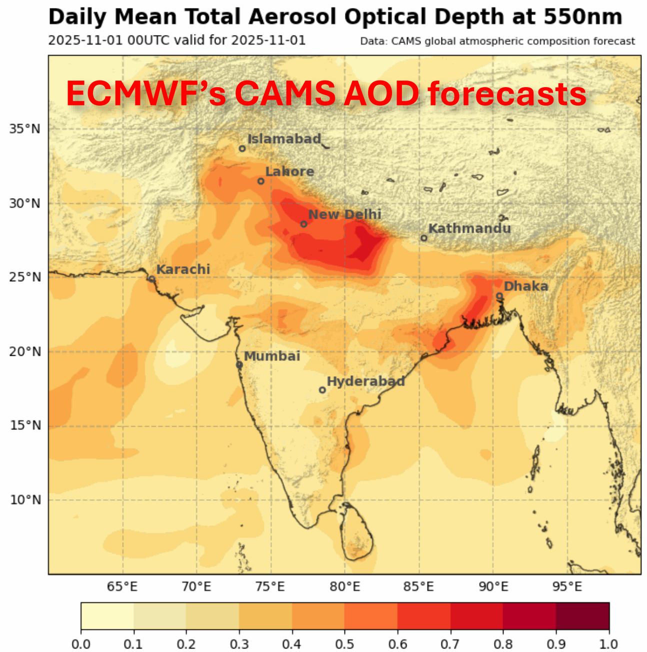
Rebecca Murray-Watson (ECMWF)
Shuhei Matsugishi (U. Tokyo)



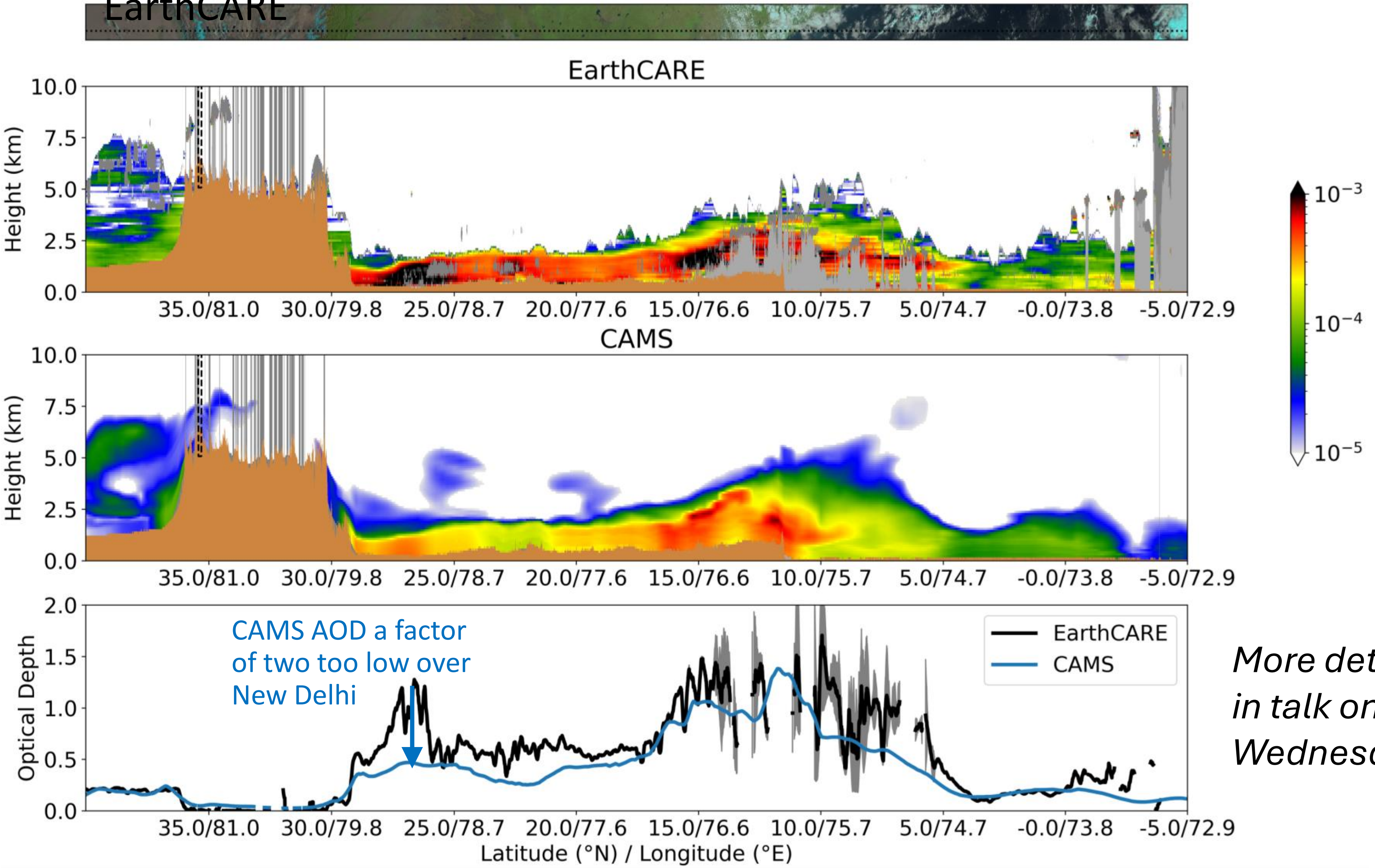
ATLID is a gamechanger for testing aerosols in models!

Peter Hill (ECMWF)





- Evaluation of CAMS aerosol 355-nm extinction profiles using EarthCARE

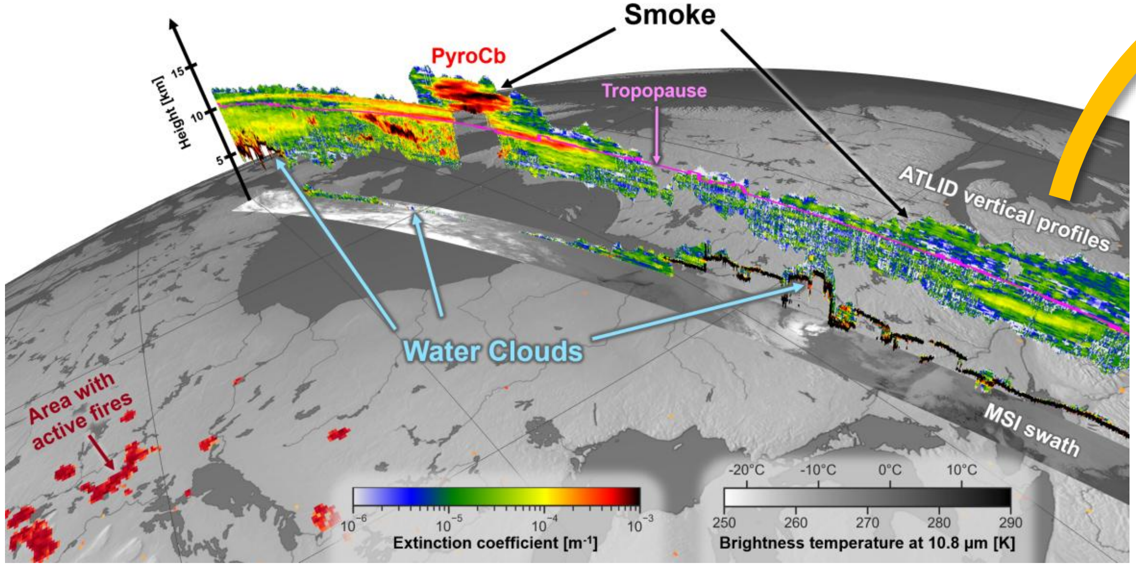


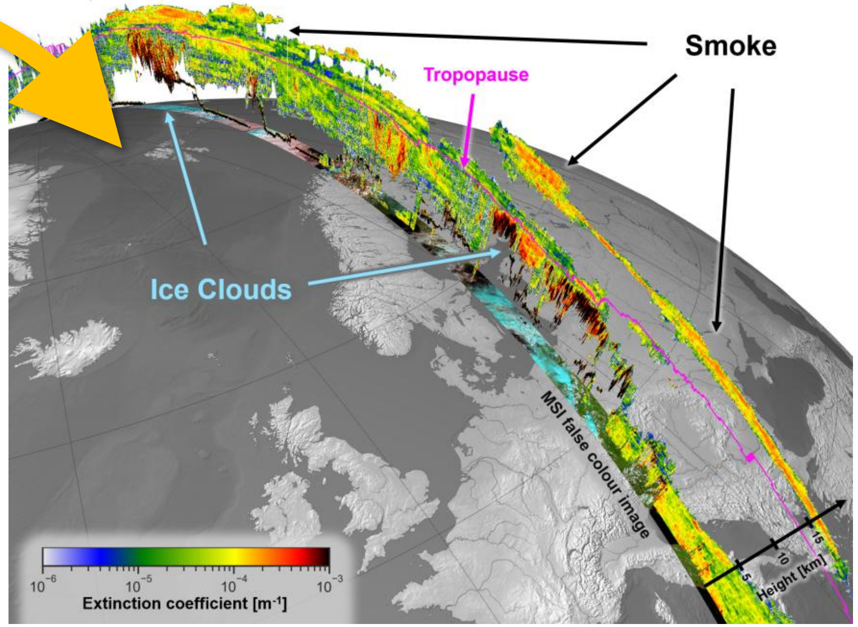
More detail in talk on Wednesday

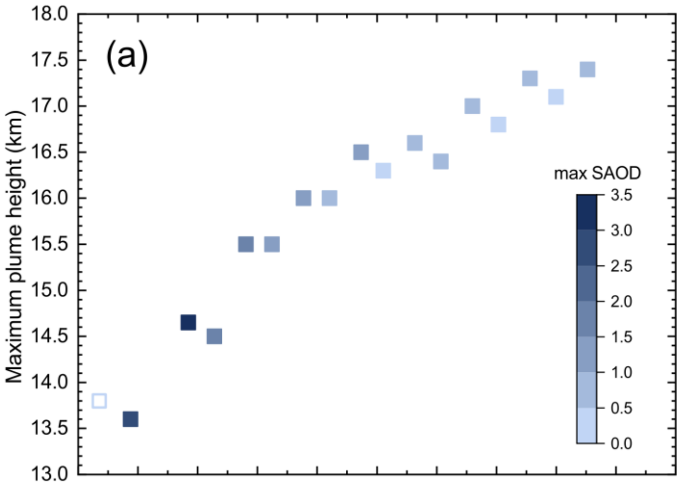
Tracking smoke from Canadian wildfires

Moritz Haarig
(TROPOS)

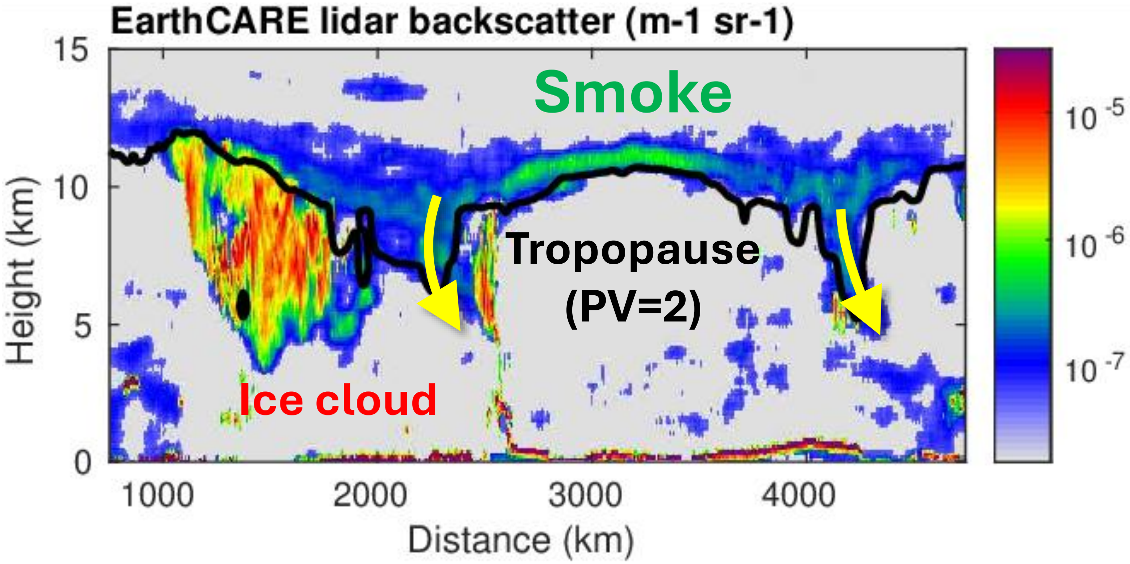
Aerosol carried from Canada (1 June) to Europe (6 June)







- ATLID revealed that the plume rose 3.6 km in 9 days: 400 m per day (Haarig et al. 2025)
- Smoke lingers above tropopause and mixes back into troposphere by tropopause folds



What is the climate impact of Canadian smoke?

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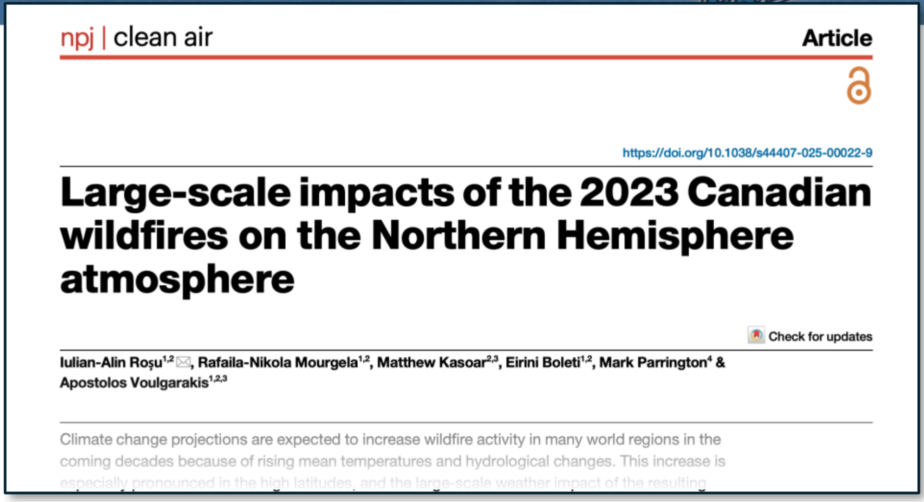

npj | clean air

Article

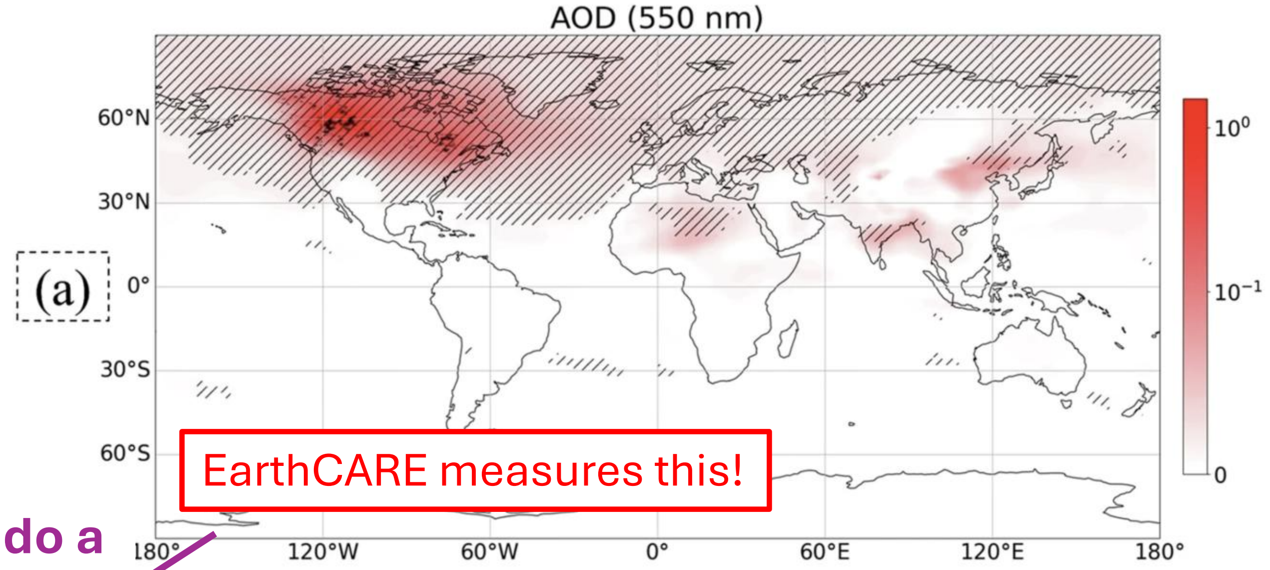
https://doi.org/10.1038/s44407-025-00022-9

Large-scale impacts of the 2023 Canadian wildfires on the Northern Hemisphere atmosphere

Check for updates

Iulian-Alin Roșu[1,2], Rafaila-Nikola Mourgela[1,2], Matthew Kasoar[2,3], Eirini Boleti[1,2], Mark Parrington[4] & Apostolos Voulgarakis[1,2,3]

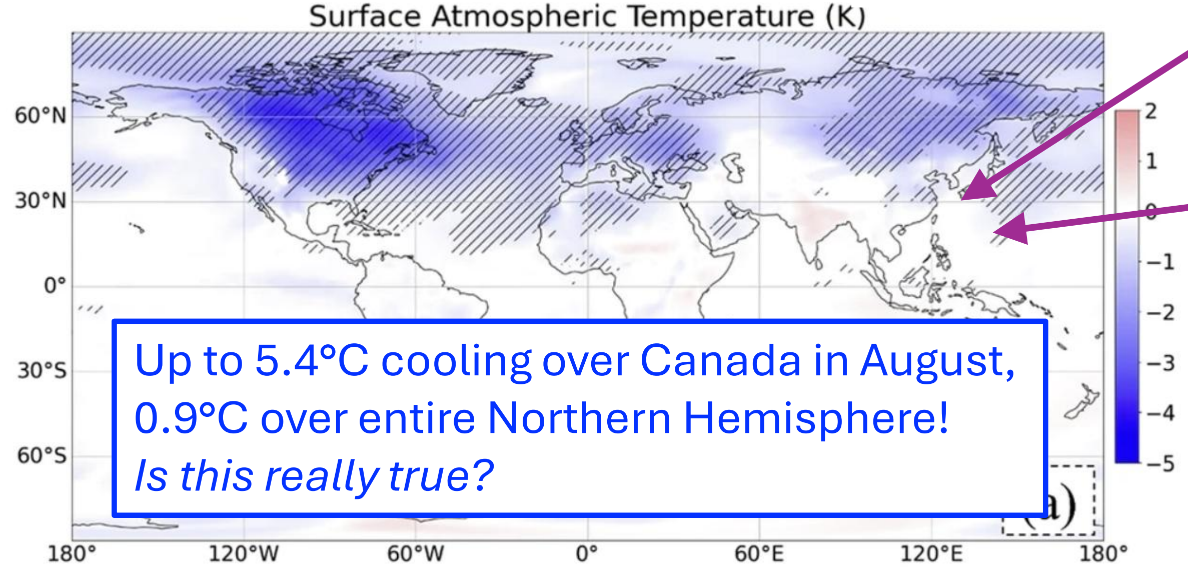
Climate change projections are expected to increase wildfire activity in many world regions in the coming decades because of rising mean temperatures and hydrological changes. This increase is



EarthCARE measures this!

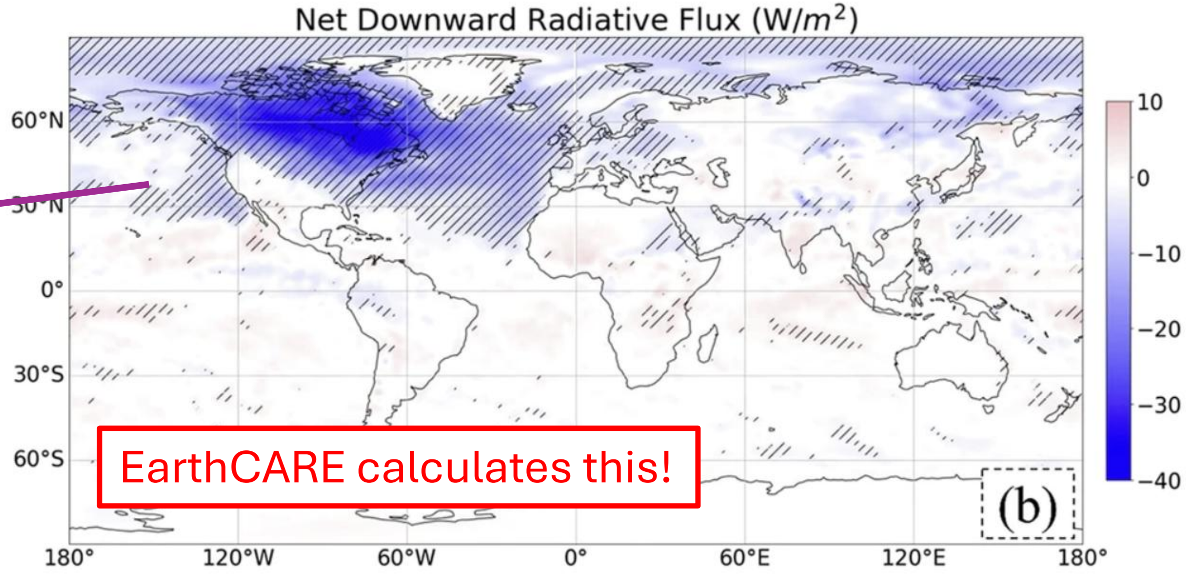
- Uses MODIS fires, GFAS emissions, EC-Earth simulations

Surely we can do a better job of this!



Up to 5.4°C cooling over Canada in August, 0.9°C over entire Northern Hemisphere!

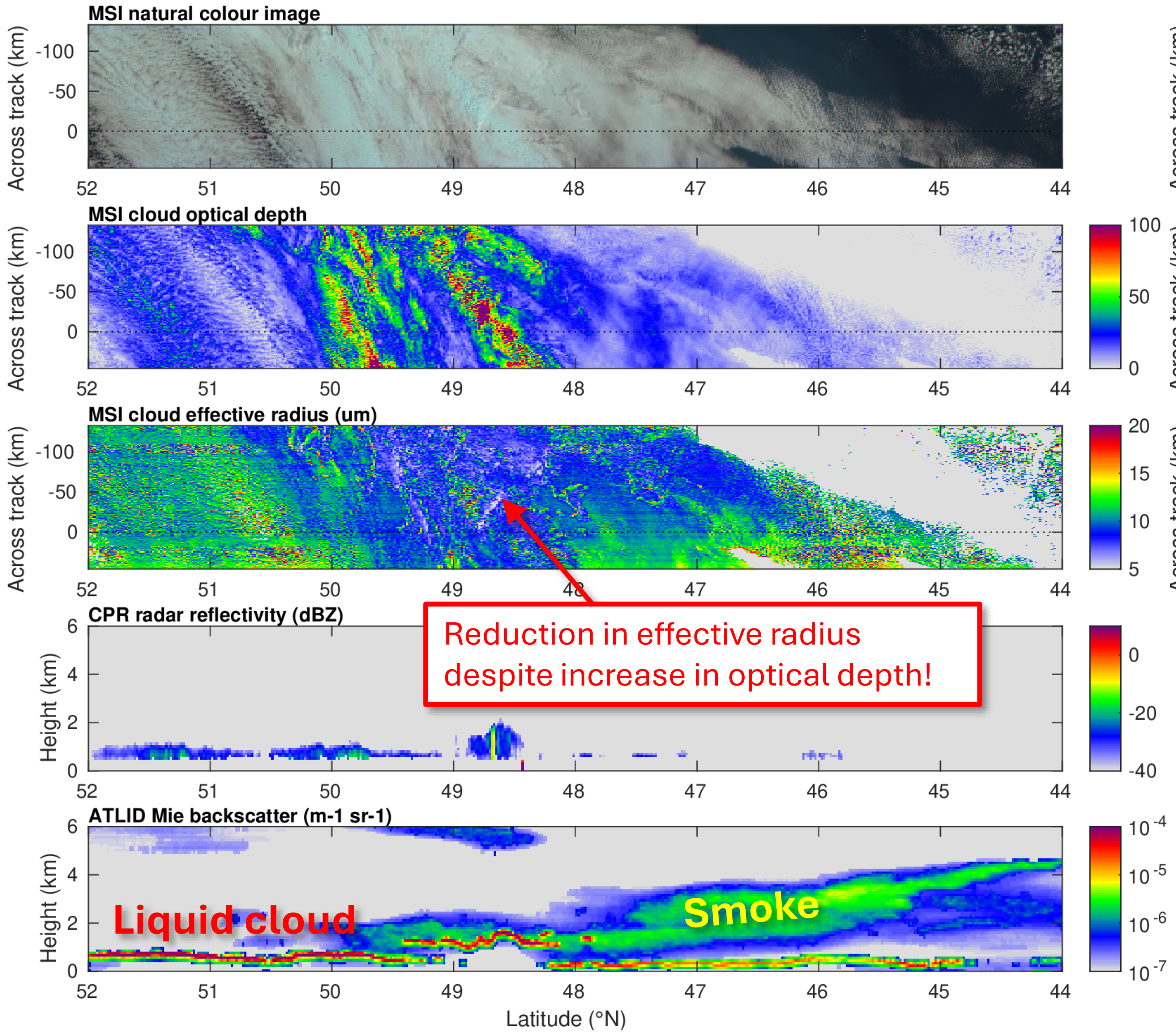
Is this really true?



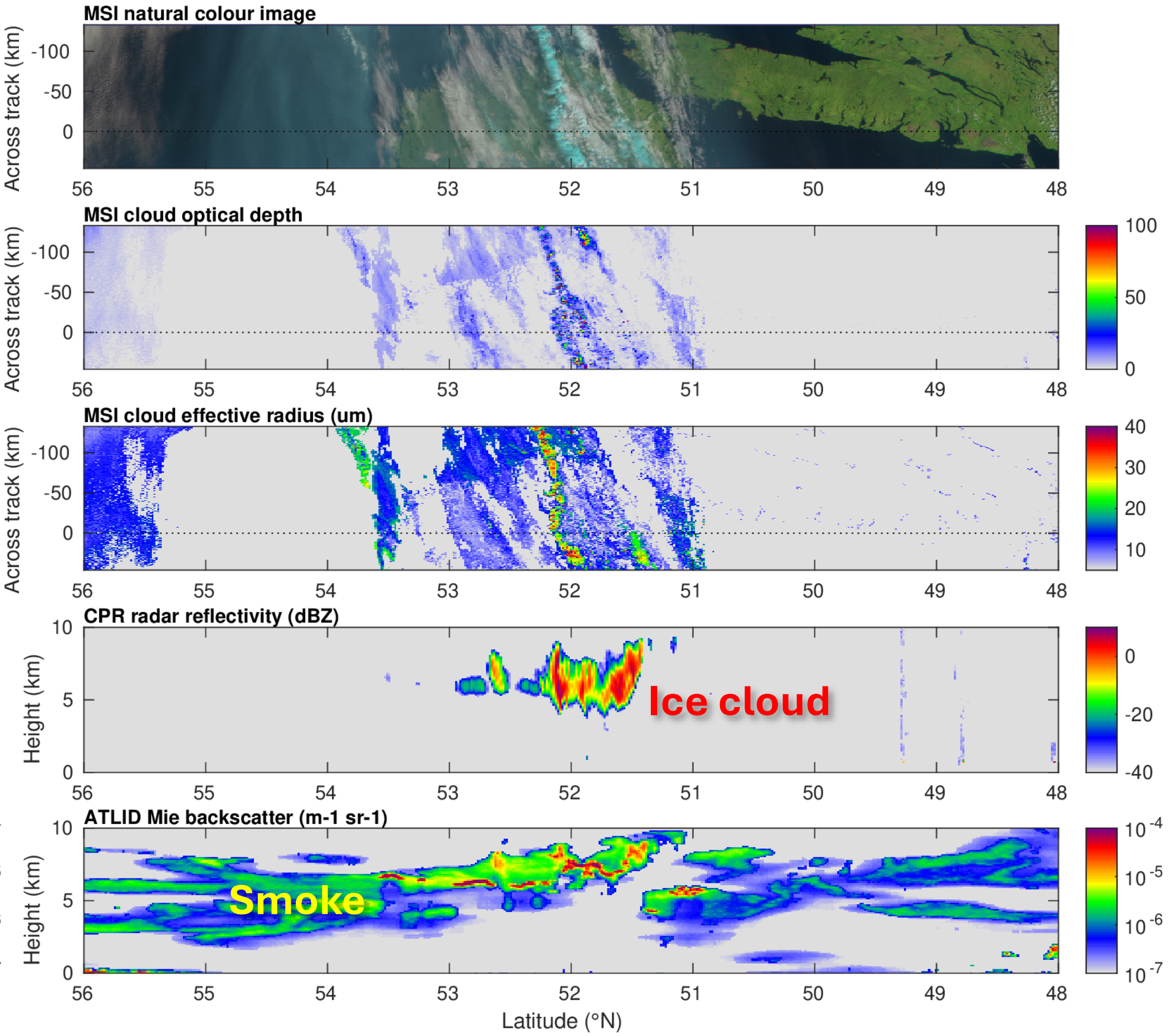
EarthCARE calculates this!

What can EarthCARE tell us about aerosol-cloud interactions, e.g. Canadian smoke August 2024?

01272D: Clear impact of smoke on liquid clouds!



01226D: Is there an impact on ice clouds?



Towards radiative closure

Jonathan Flunger, Alex Hoffmann
and the ESA visualization team

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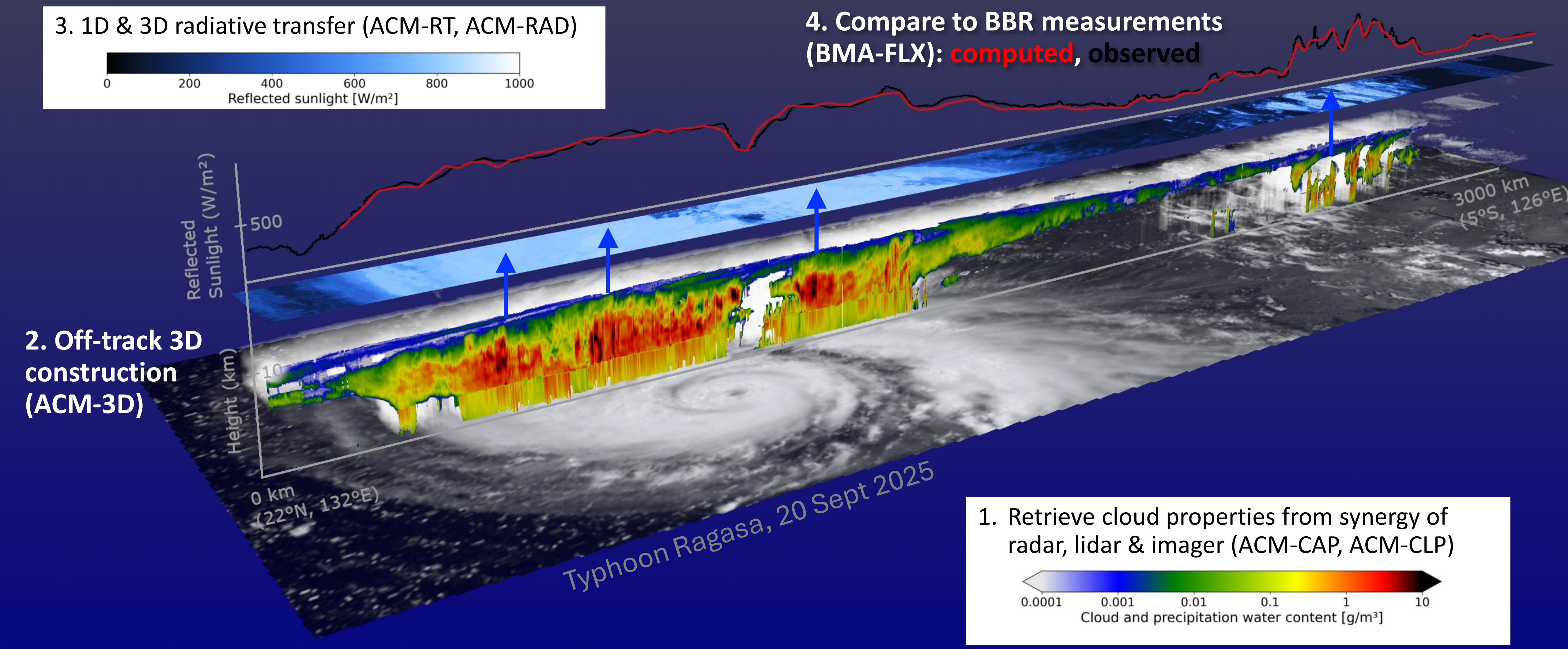
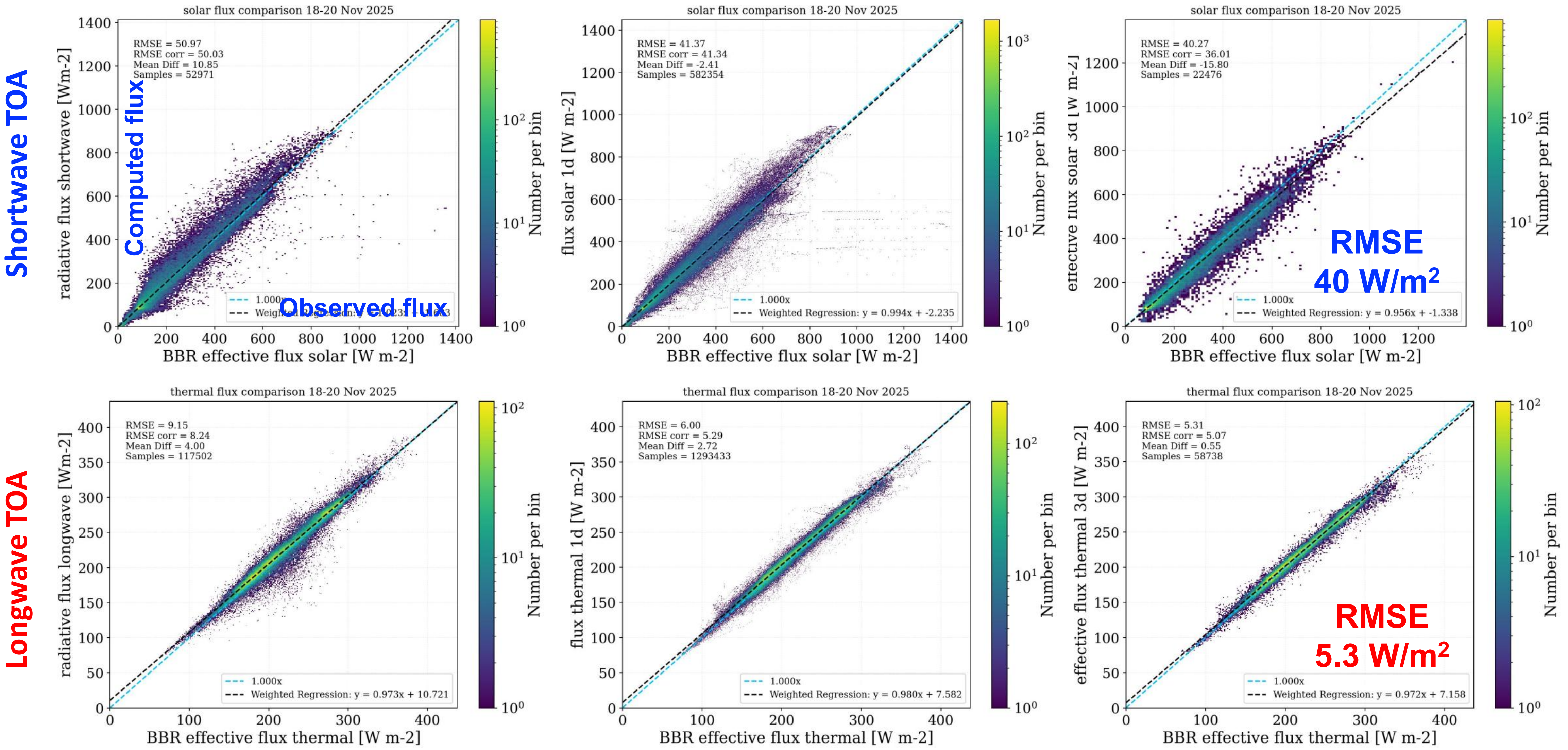


Latest radiative closure results

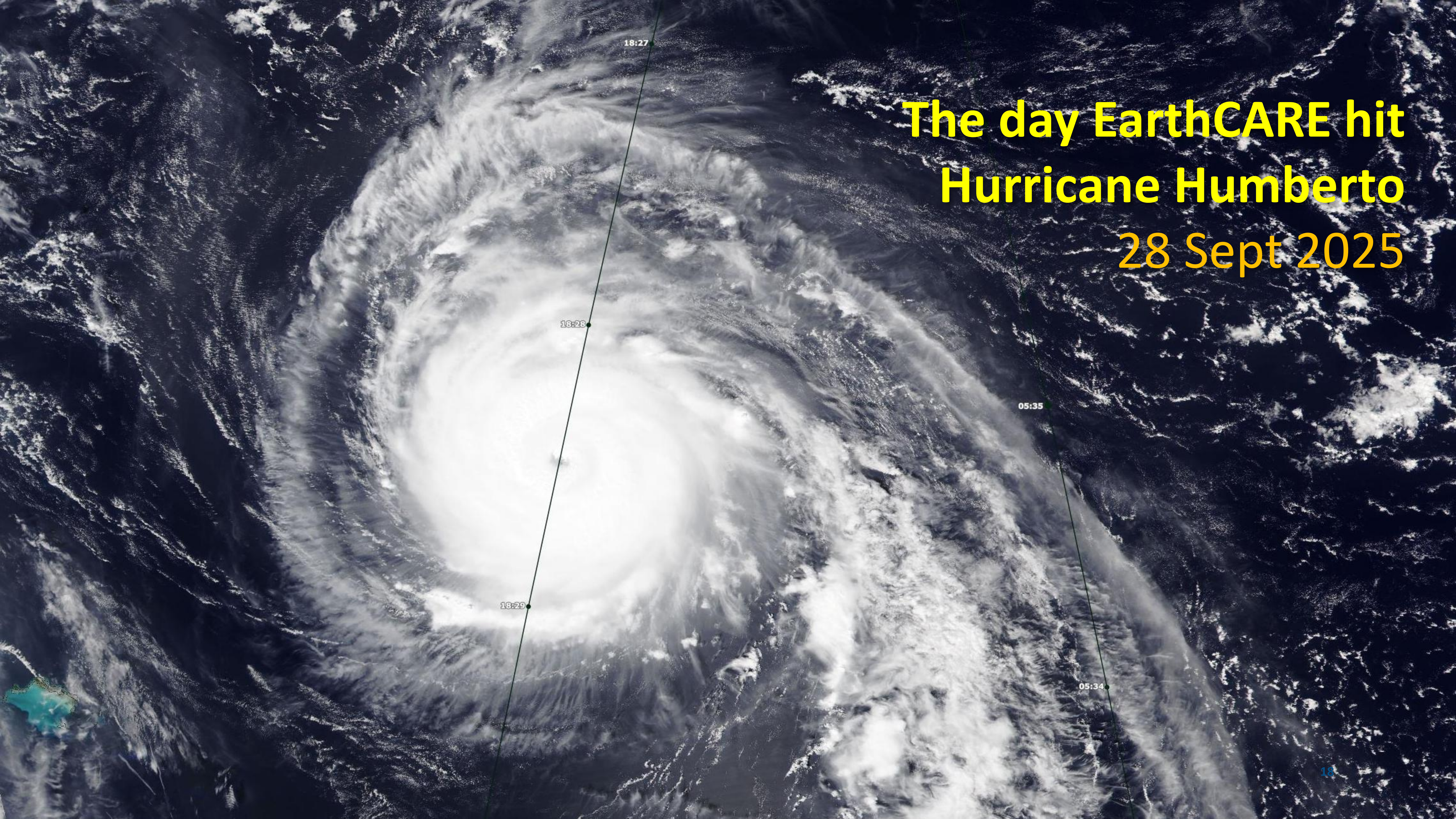
Jason Cole, Carla Salas, Kentaroh Suzuki,
Takashi Nagao, Zhipeng Qu et al.

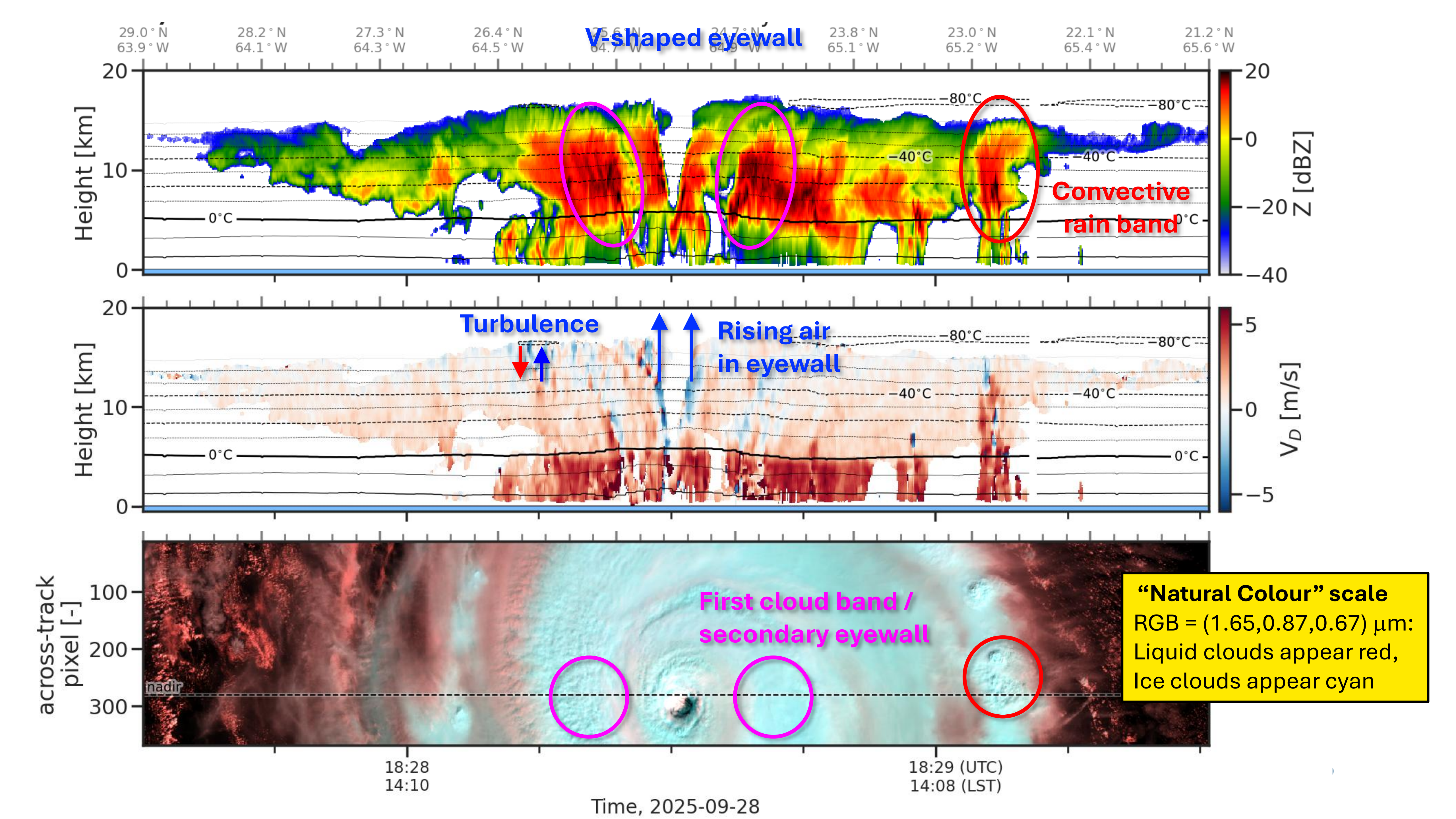
Japanese 1D comparison (AD) | **European 1D comparison (BC)** | **European 3D comparison (BC)**



The day EarthCARE hit Hurricane Humberto

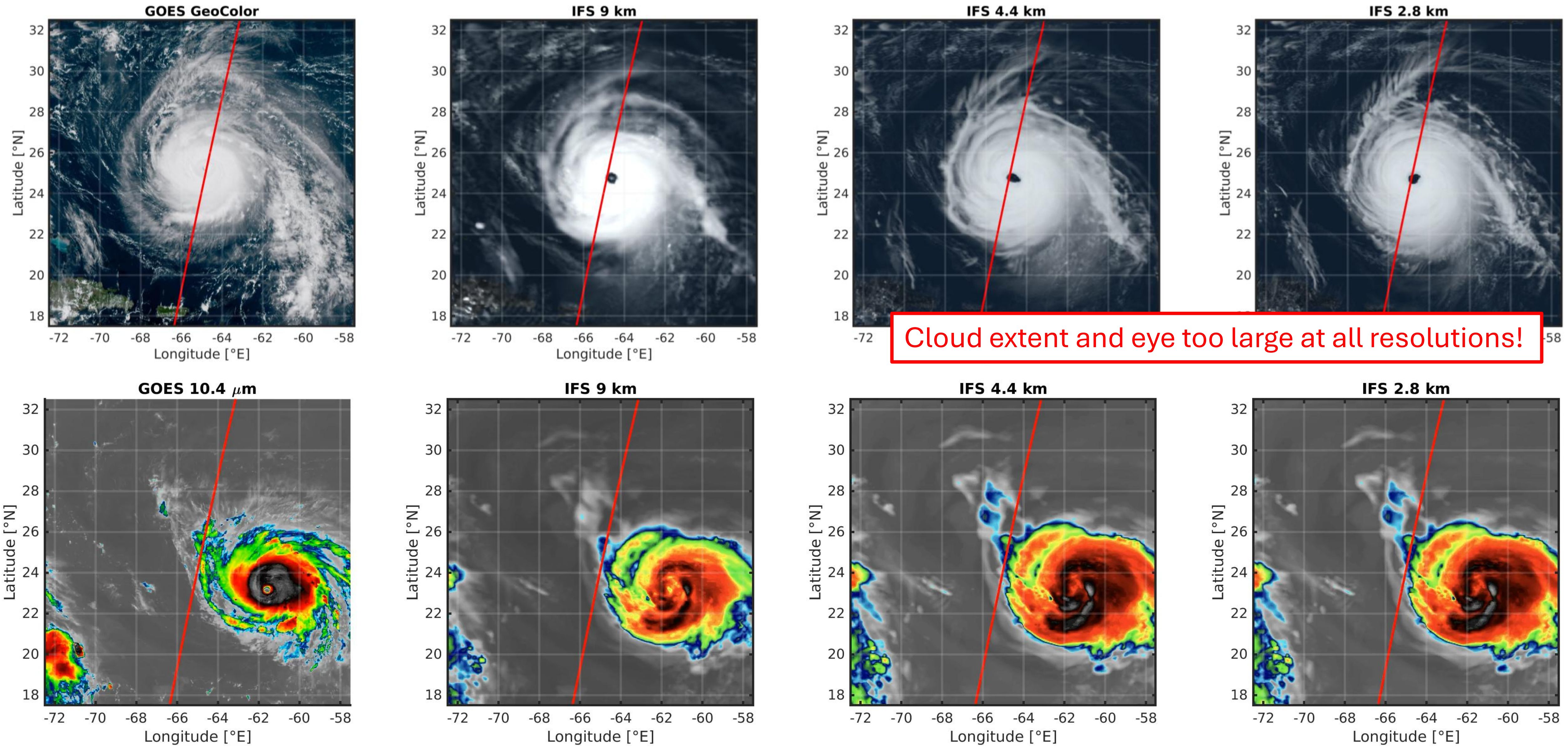
28 Sept 2025




V-shaped eyewall
29.0°N 63.9°W
28.2°N 64.1°W
27.3°N 64.3°W
26.4°N 64.5°W
23.8°N 65.1°W
23.0°N 65.2°W
22.1°N 65.4°W
21.2°N 65.6°W
Height [km]
-80°C
-40°C
0°C
Convective rain band
Z [dBZ]
Turbulence
Rising air in eyewall
V_D [m/s]
across-track pixel [-]
nadir
First cloud band / secondary eyewall
18:28
14:10
18:29 (UTC)
14:08 (LST)
Time, 2025-09-28
"Natural Colour" scale
RGB = (1.65,0.87,0.67) μm:
Liquid clouds appear red,
Ice clouds appear cyan

How does IFS perform in 5-day forecasts?

Mark Fielding (ECMWF)



Evaluation of IFS and NICAM using CPR

Mark Fielding
Jin-de Huang, Masaki Satoh

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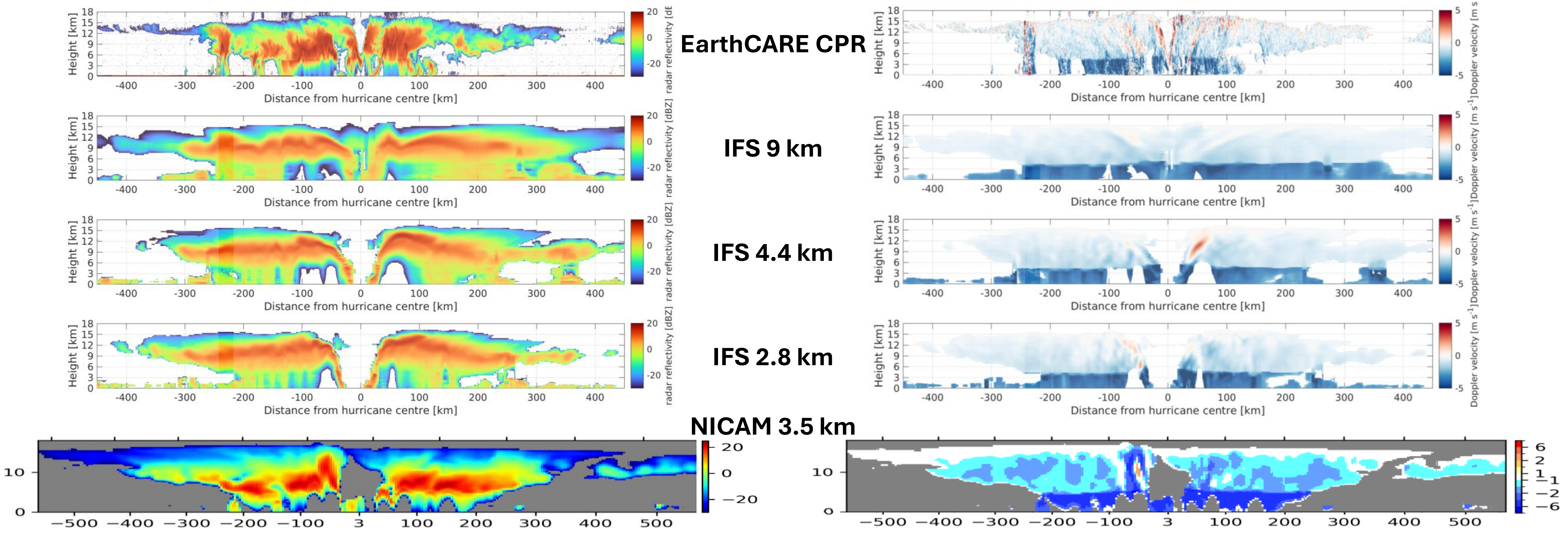
Radar reflectivity (dBZ)

Doppler velocity (m/s)



- Significant differences between models and EarthCARE, even with such high resolution
- In the ECOMIP project we are exploring how to best use these observations to improve models

Outlook

- EarthCARE can address so many aspects of the atmosphere that are poorly understood and represented crudely in both low- & high-resolution models
  - **Clouds & precipitation:** ice effective radius & size distribution, difference between ice and snow, snow evaporation rates, rain/drizzle fallspeeds and drop sizes, process rates in mixed-phase clouds e.g. riming, width and updraft strength of convective cores, marine cloud morphology, blah blah blah
  - **Aerosols:** Global distribution of different aerosol types, single-scattering albedo, scavenging & deposition rates, stratosphere-troposphere exchange, aerosol-cloud interactions in both liquid and ice clouds, radiative impact, blah blah blah

- We have an incredible satellite: it’s time to think big: how can EarthCARE contribute to solving the grand challenges of climate science?
  - The complete expertise to do this does not lie in this room: seek collaborations!
  - EarthCARE alone cannot do this: combine with other satellites, models and datasets!