Using EarthCARE to evaluate and constrain snow and ice fall speeds in the IFS

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ECMWF

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Motivation for improving cloud and precipitation for global NWP

1. Reducing regime-dependent systematic errors
   - Clouds affect radiation, dynamics, precipitation prediction
   - Need to increase the realism, detailed representation of physical processes

2. Movement towards higher-resolution models (km-scale)
   - Resolving smaller scale motions (km-scale, convective resolving)
   - Microphysics handles more – details are important

3. Assimilating cloud and precipitation-affected observations
   - Cloudy areas are often meteorologically sensitive areas (reduce error growth)
   - More accurate cloud microphysics means more data can be used in the assimilation
   - Better analyses, better forecasts, and training data for AI/ML

We need cloud and precipitation **observations** to constrain the model

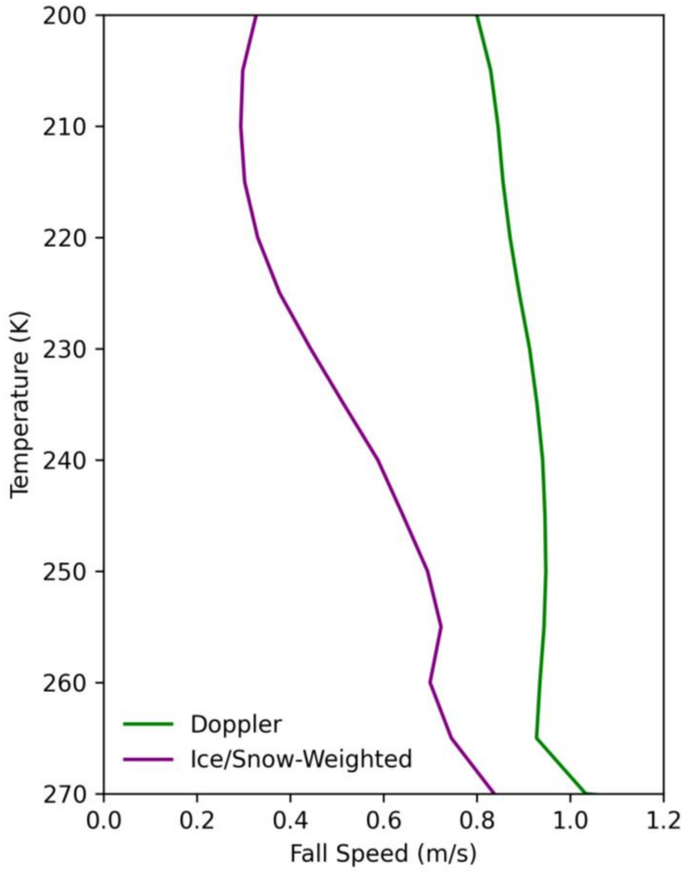
Improving the cold-phase hydrometeors in the IFS

- The IFS represents frozen hydrometeors with two single-moment (mass) categories ”**ice**” and “**snow**” (aggregates)
- No graupel or hail, there is a riming process, but represented with properties of snow
- Particle size distributions defined for certain processes (e.g. snow depositional growth)
- But historically (for numerical reasons), ice and snow sedimentation used constant fall speeds, currently **0.13 m/s** for ice and **1 m/s** for snow.
- Hydrometeor fall speeds affect vertical profiles of ice and snow water contents and other microphysical processes (e.g., through ventilation, riming, depth of sublimation), but are currently **very uncertain**
- **Desire to make this more realistic**
- EarthCARE Doppler radar provides unique data to **constrain fall speeds**

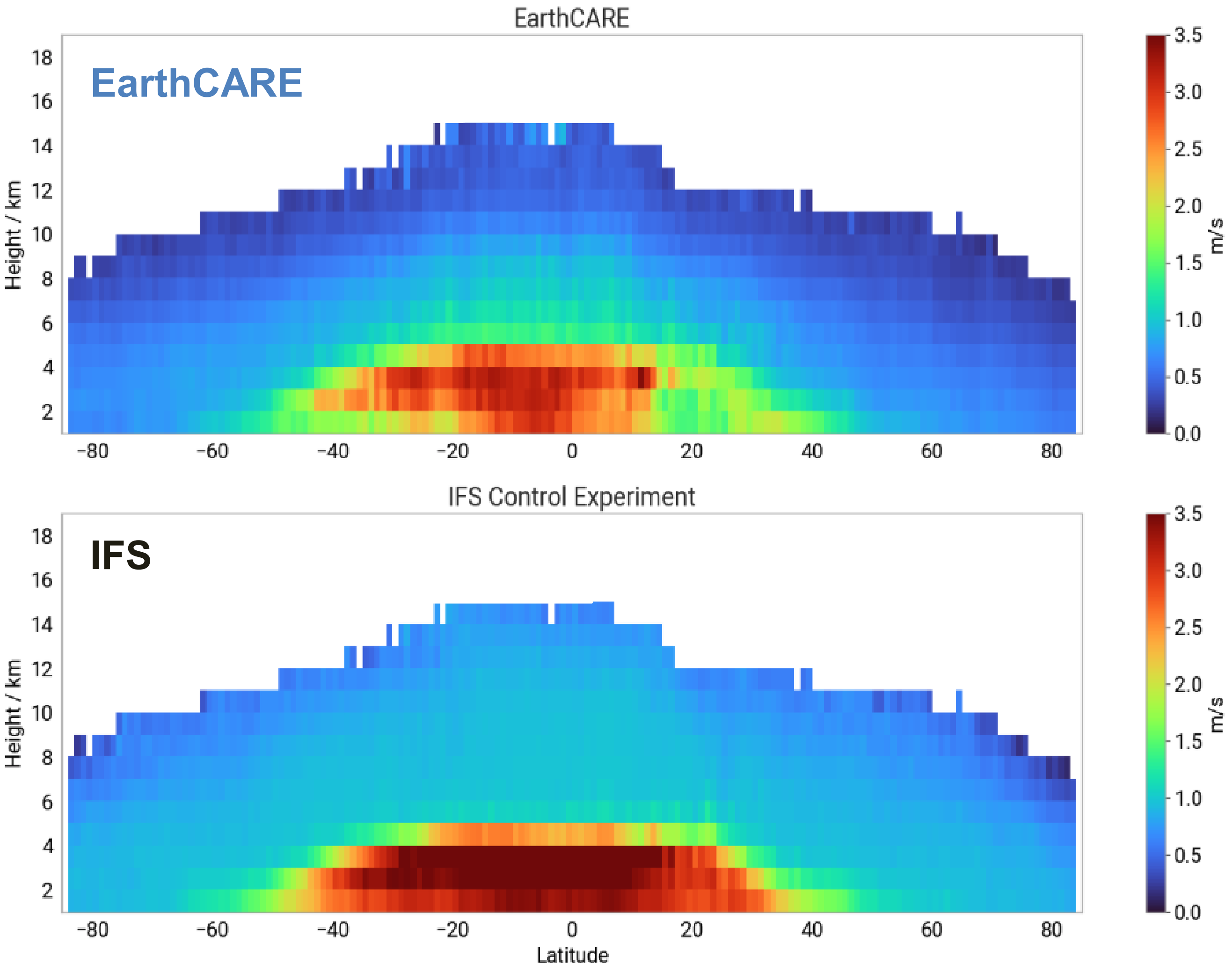
Comparing the IFS and EarthCARE Doppler ice phase fall speeds

- Mass-weighted fall velocity is the quantity used in the model
- EarthCARE sees the Doppler velocity – weighted by reflectivities, so presence of **larger particles dominate the radar retrieval**
- For a comparison need a forward model for Doppler velocity for the IFS, depends on particle size distribution (PSD), particle properties and fall speed assumptions
- Current fixed intercept exponential PSD for the snow gives large particles which dominate the Doppler-velocity
- Preliminary comparison performed here using all EarthCARE orbits for January 2025, model data matched with the observation orbits locations/times

Global average IFS (ice+snow) with constant fall speeds: mass-weighted and reflectivity-weighted (Doppler)



Comparing the IFS and EarthCARE Doppler ice phase fall speeds



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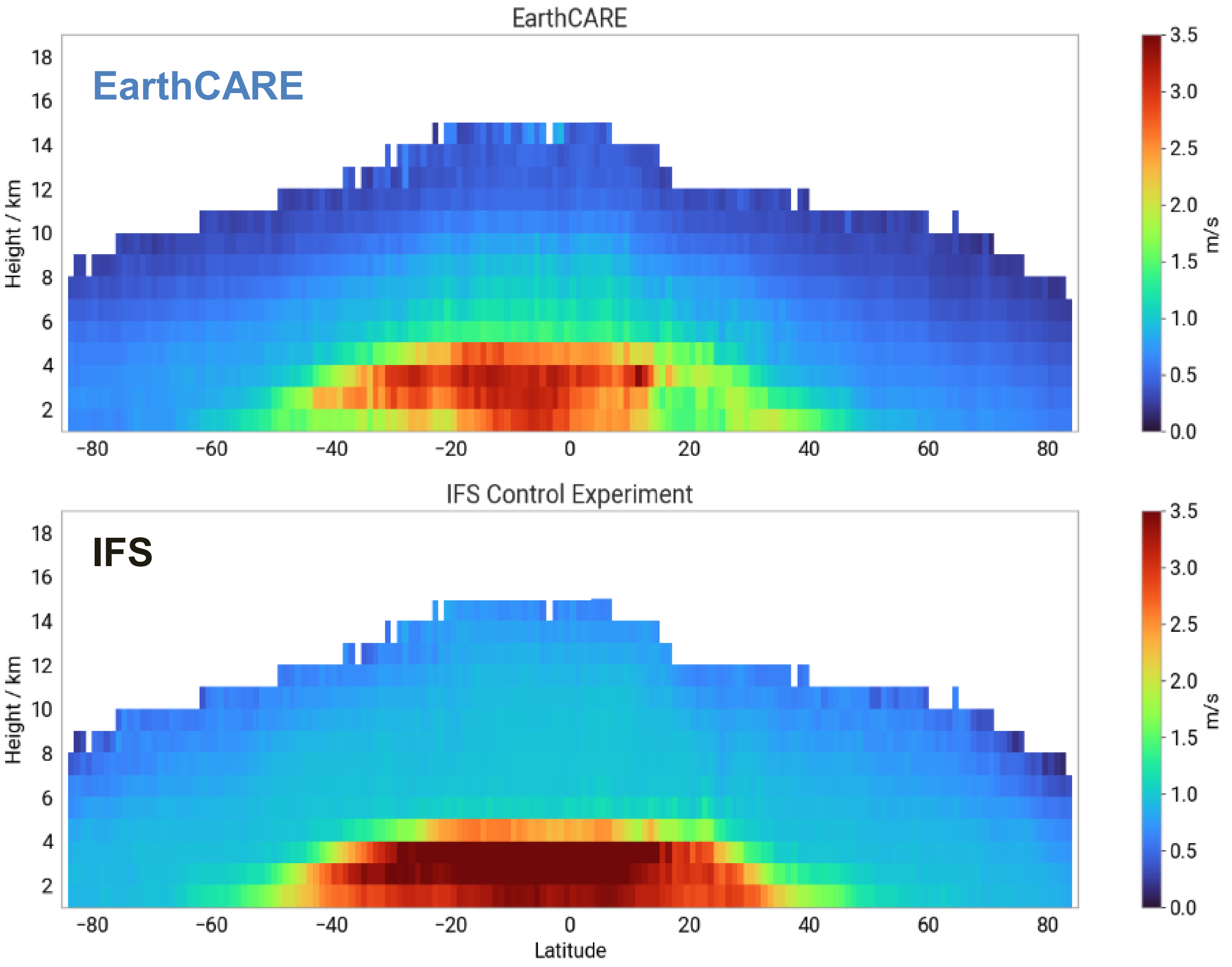
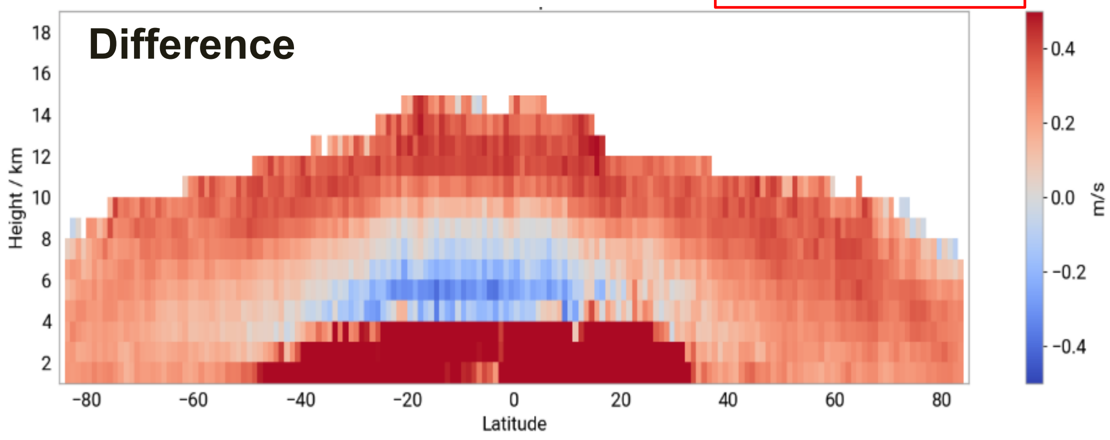
Comparing the IFS and EarthCARE Doppler ice phase fall speeds



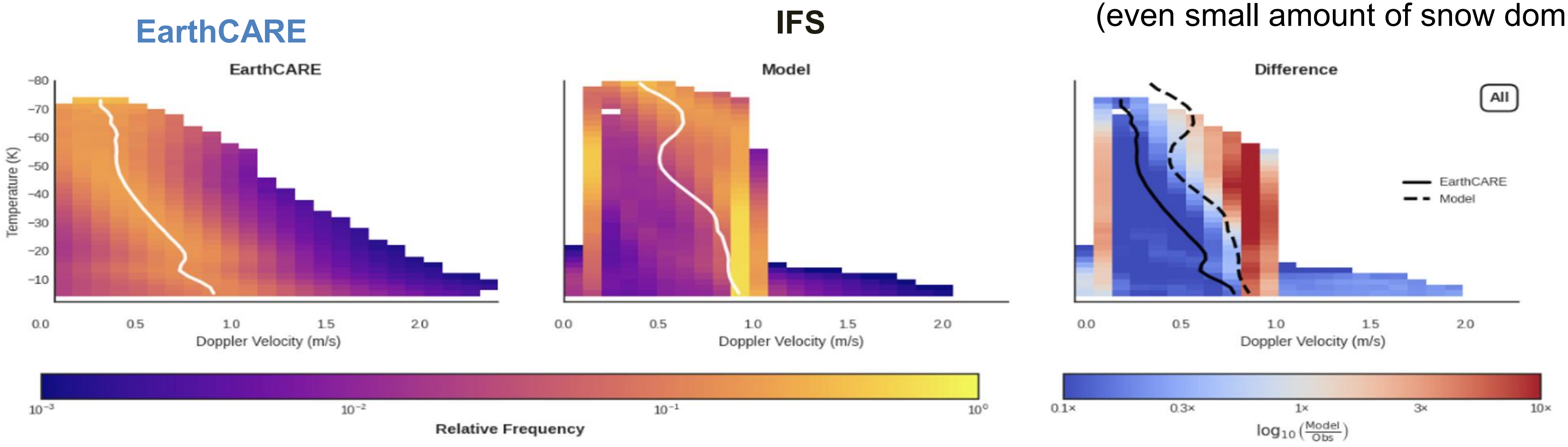
Upper troposphere ice/snow falls 0.25+ m/s too fast



Riming snow near the melting layer should fall 0.25 m/s faster

Comparing the IFS and EarthCARE Doppler ice phase fall speeds

Significant overestimation at colder temperatures (even small amount of snow dominates)



EarthCARE obs include air motion – so much wider variability than in the model hydrometeor fall speed (could include air motion from the model as well)

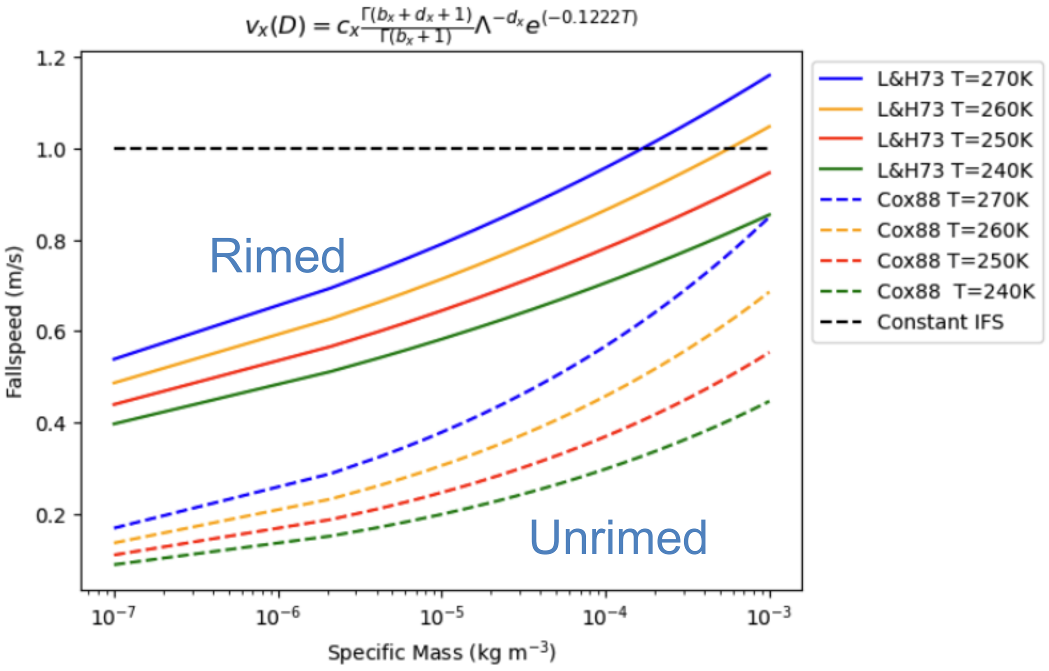
Modifications for more realistic ice and snow fall speed representation

Ice changes :

– Fall-speed dependent on particle size
– More realistic particle size distribution (PSD) with temperature factor (larger particles at warmer temperatures, as observed)
– No air density correction

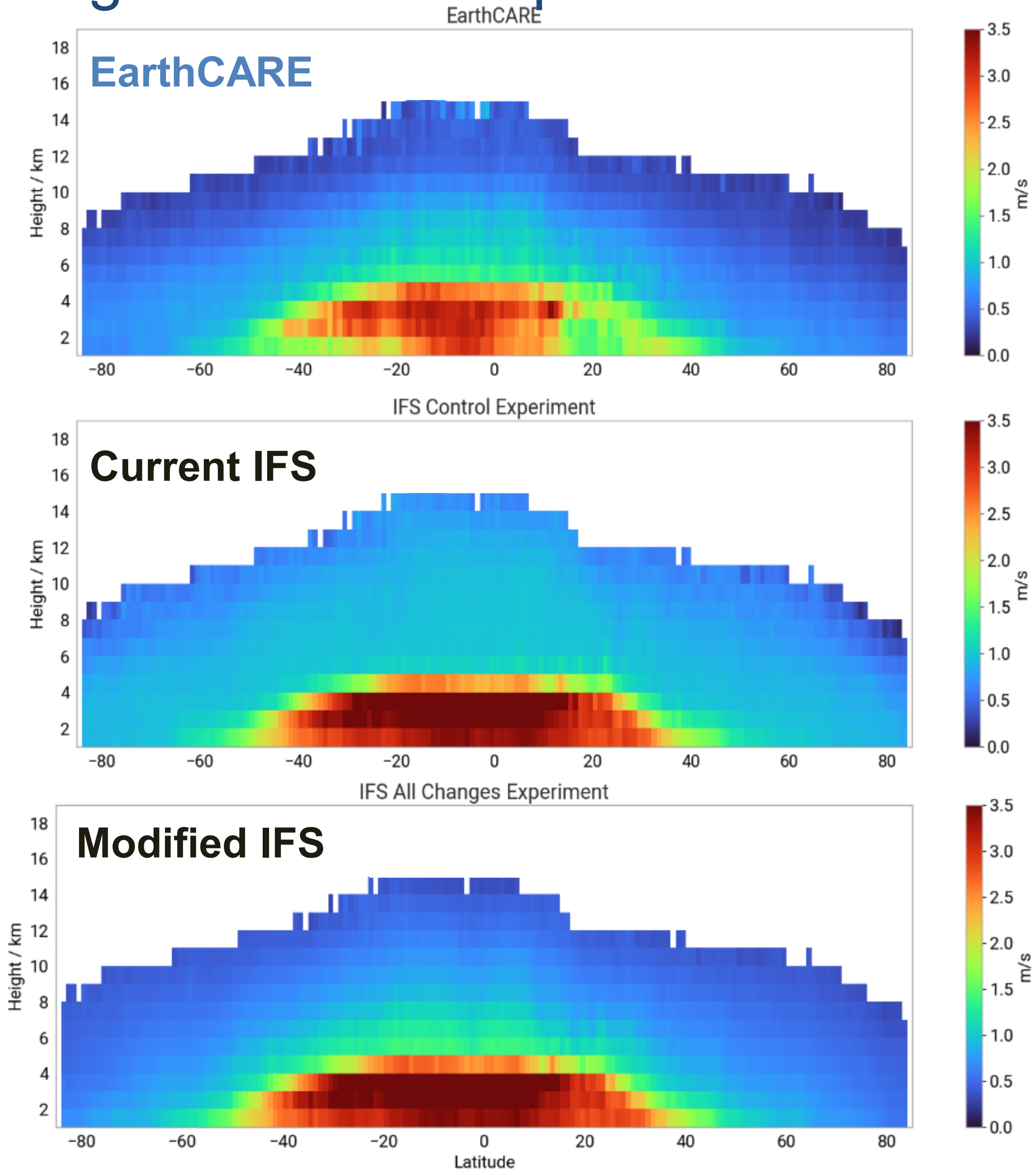
Snow changes:

– Fall-speed dependent on particle size
– More realistic particle size distribution (PSD) with temperature factor (larger particles at warmer temperatures, as observed)
– Air density correction
– New riming factor and riming increases the fall speed (denser particles)
– Snow sublimation uses new PSD and fall speeds



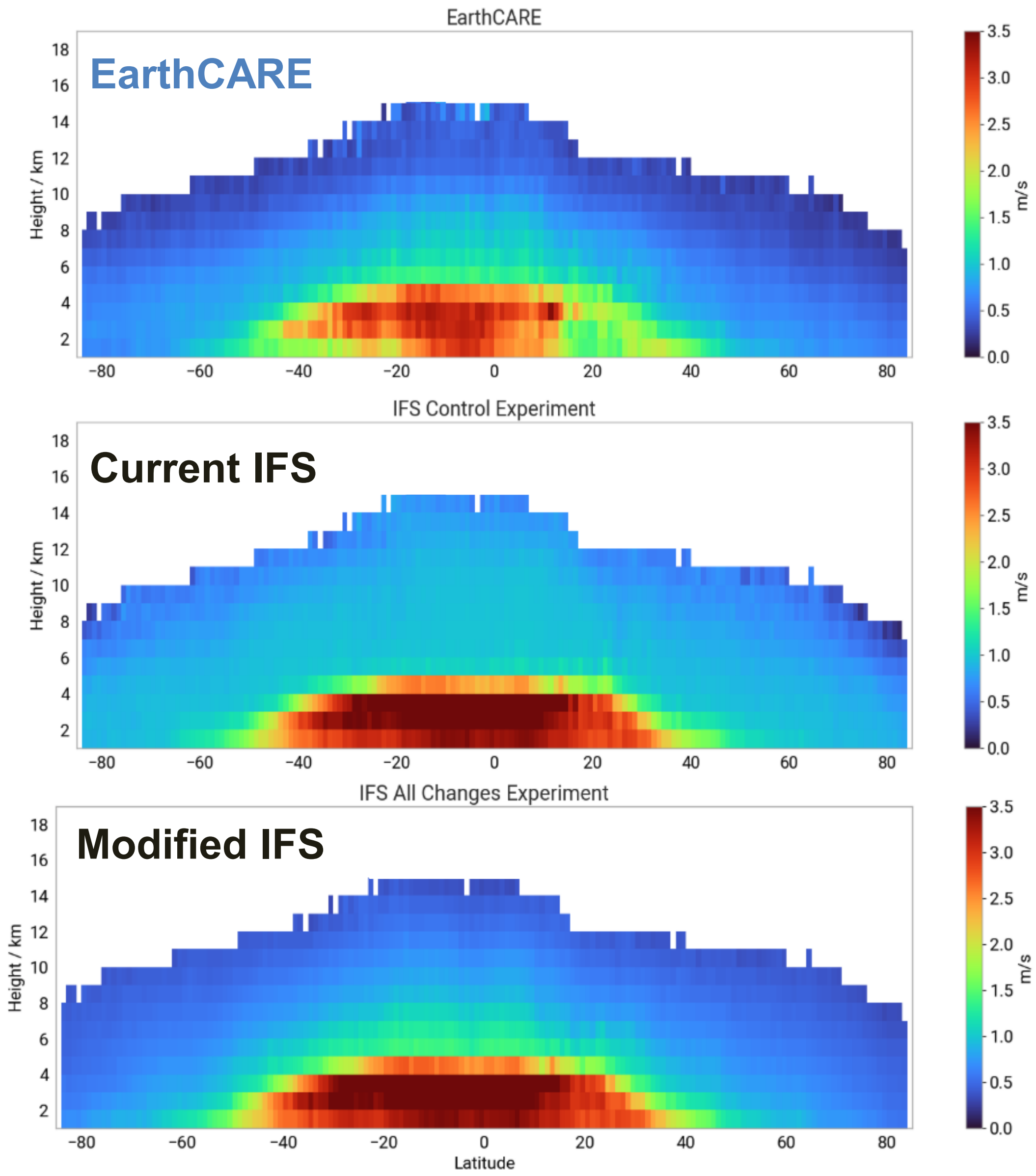
Fraction of snow mass from riming vs mass from deposition is used to determine the fall speed using relationships from Locatelli and Hobbs (1973) for rimed particles, Cox (1988) for unrimed

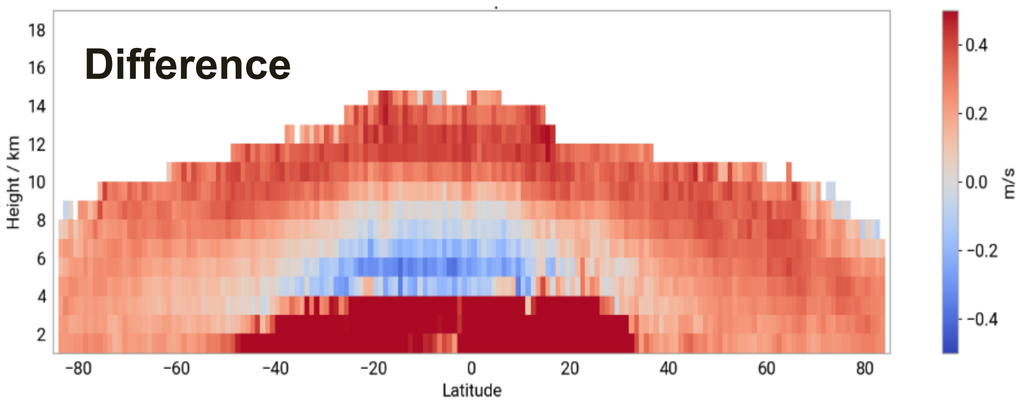
Improving ice/snow fall speed in the ECMWF model

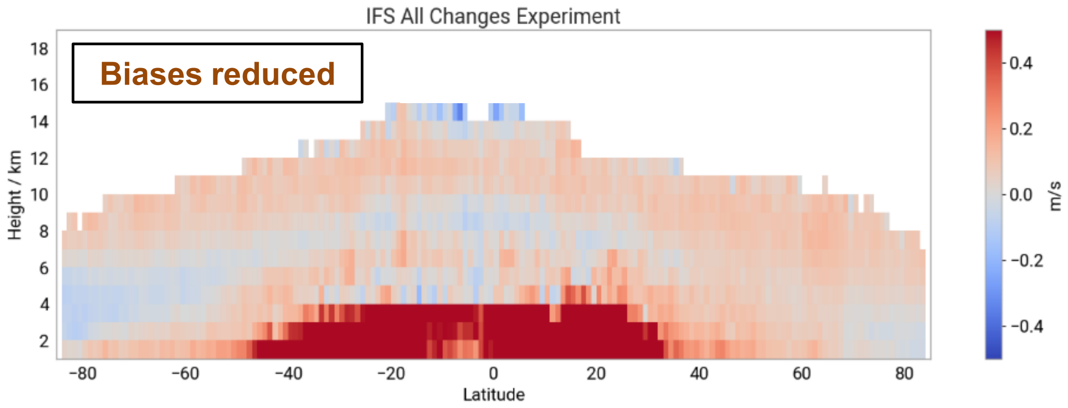


ECMWF

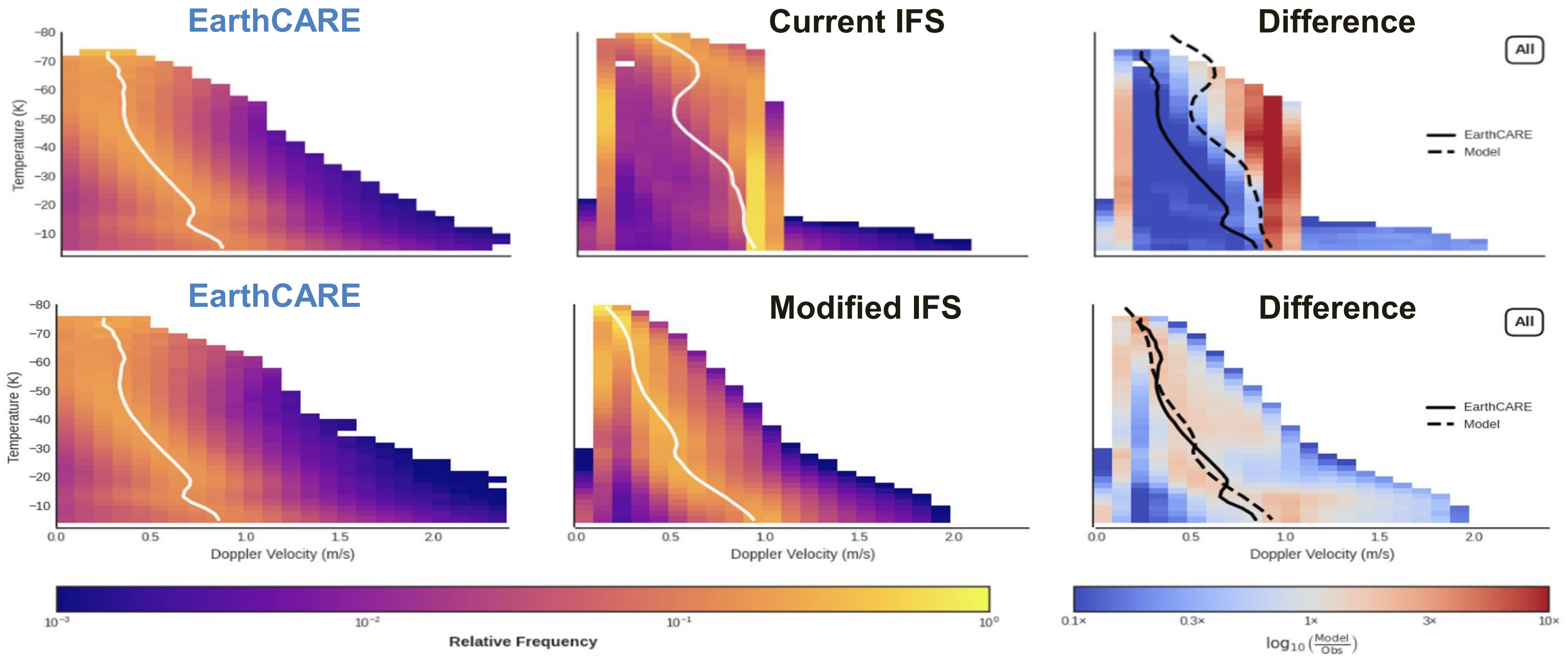
Improving ice/snow fall speed in the ECMWF model





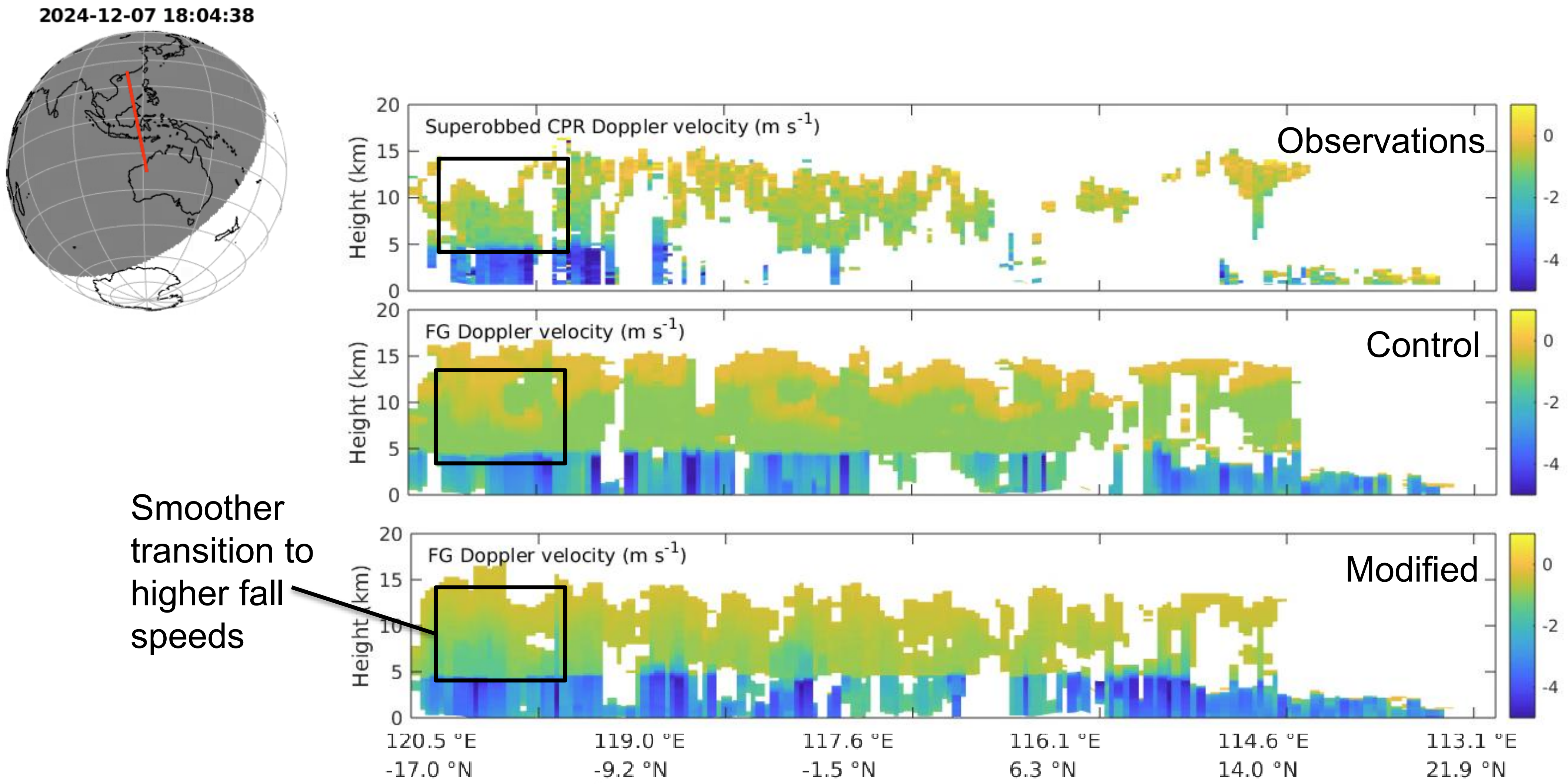


Improving ice/snow fall speed in the ECMWF model



Much improved agreement!

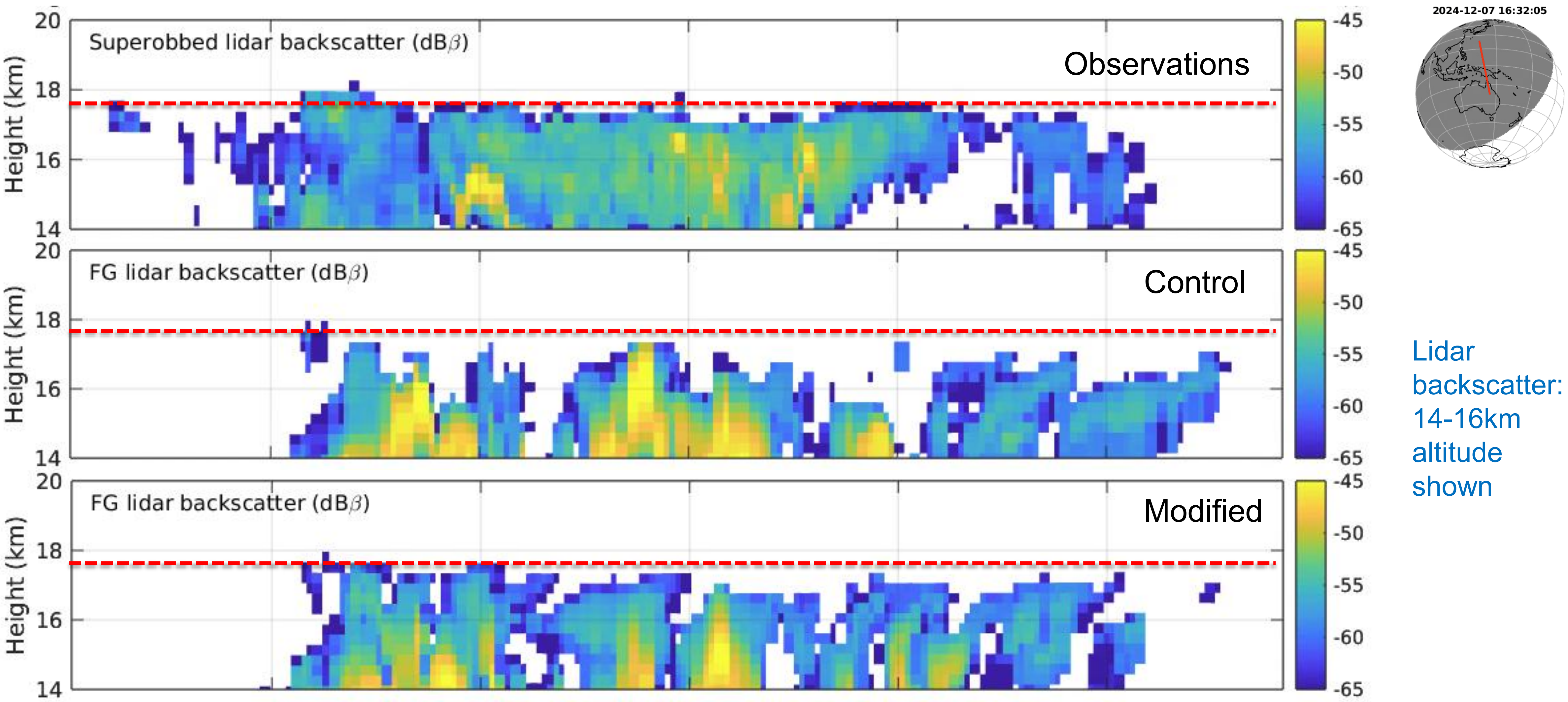
Improved representation of Doppler velocities – example orbit



Smoother transition to higher fall speeds

No min. sensitivity threshold used for the IFS here

Improved representation of convection-driven cirrus cloud top height – example orbit



Lidar backscatter: 14-16km altitude shown

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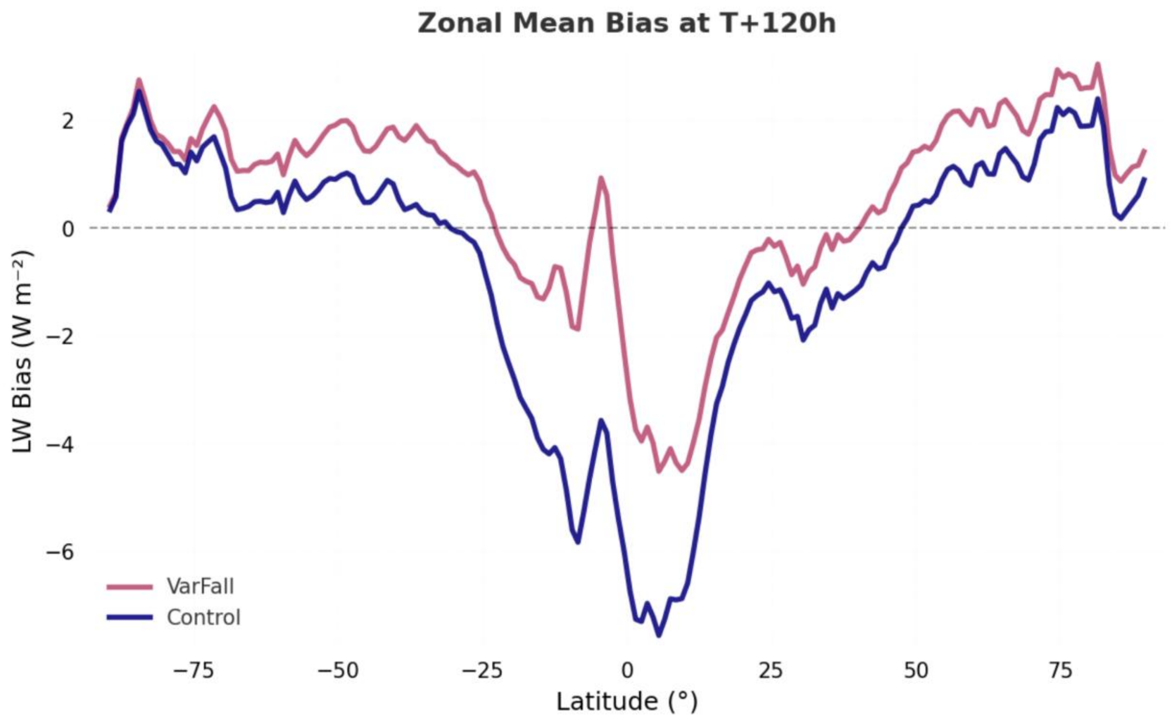
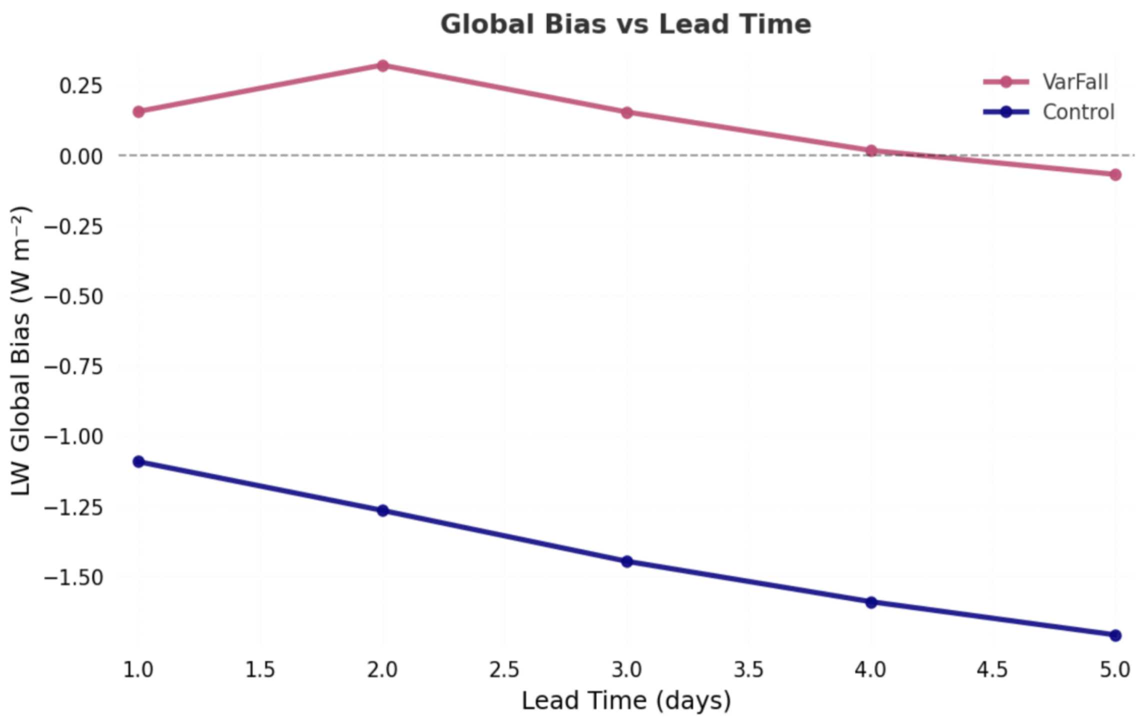
Radiation biases – globally improved, regionally varied





Much improved agreement in the tropics – better representation of high-level high clouds

Degradation in the extratropics – EarthCARE is **good constraint**, but need fine-tuning of other processes to balance

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Conclusions

- EarthCARE offers an **unprecedented opportunity** to evaluate hydrometeor fall speeds, and provides observational constraints on fall speeds and **cloud vertical structure**
- Ice & snow fall speeds affect model climate and forecast skill: this is **first time** we have been able to evaluate it globally
- With improved assumptions for the ice and snow hydrometeor particle size distributions and fall speeds, we are able to significantly improve the fit to the EarthCARE Doppler, with benefits for other aspects of the ice phase hydrometeor profile

Future work

- Use **regime analysis** to understand fall speed biases in particular cloud types
- Further work on representing **rimed particles** and effects on fall speed
- Wider use of EarthCARE data to improve the representation of clouds and precip in the IFS
- Evaluate the downstream effects on radiation biases, dynamics, etc…

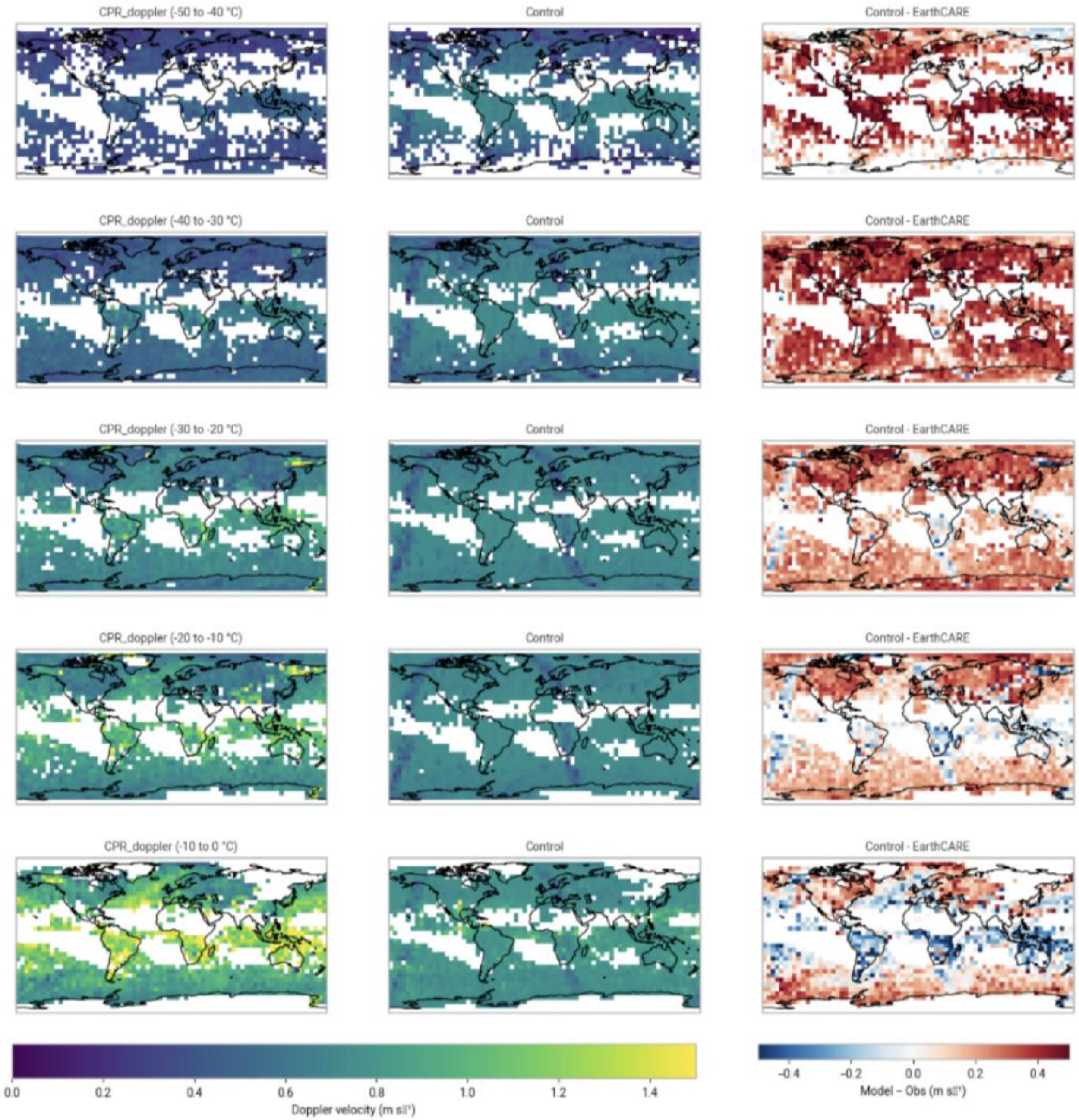
-50 to -40 C

-40 to -30 C

-30 to -20 C

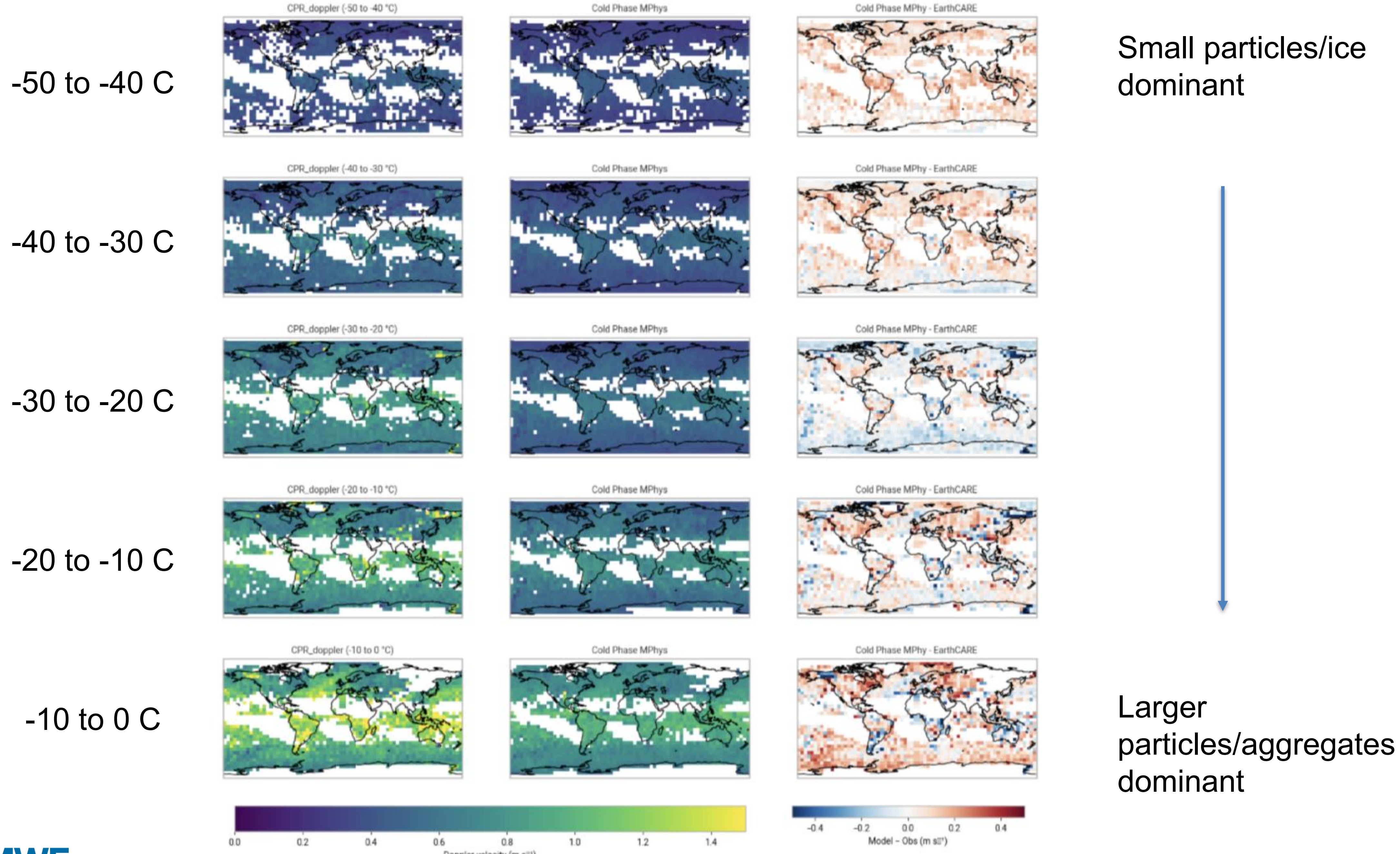
-20 to -10 C

-10 to 0 C



Small particles/ice dominant

Larger particles/aggregates dominant



-50 to -40 C
-40 to -30 C
-30 to -20 C
-20 to -10 C
-10 to 0 C
CPR_doppler (-50 to -40 °C)
CPR_doppler (-40 to -30 °C)
CPR_doppler (-30 to -20 °C)
CPR_doppler (-20 to -10 °C)
CPR_doppler (-10 to 0 °C)
Cold Phase MPhys
Cold Phase MPhy - EarthCARE
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
-0.4
-0.2
0.0
0.2
0.4
Model – Obs (m s⁻¹)
Small particles/ice dominant
Larger particles/aggregates dominant

Microphysics changes versus 50r1 physics branch, June 2022

Scorecards:

Blue – good!
Red – bad!

Mixed picture but can see some strong improvements in Z