Improving the realism of high ice clouds in the IFS using EarthCARE

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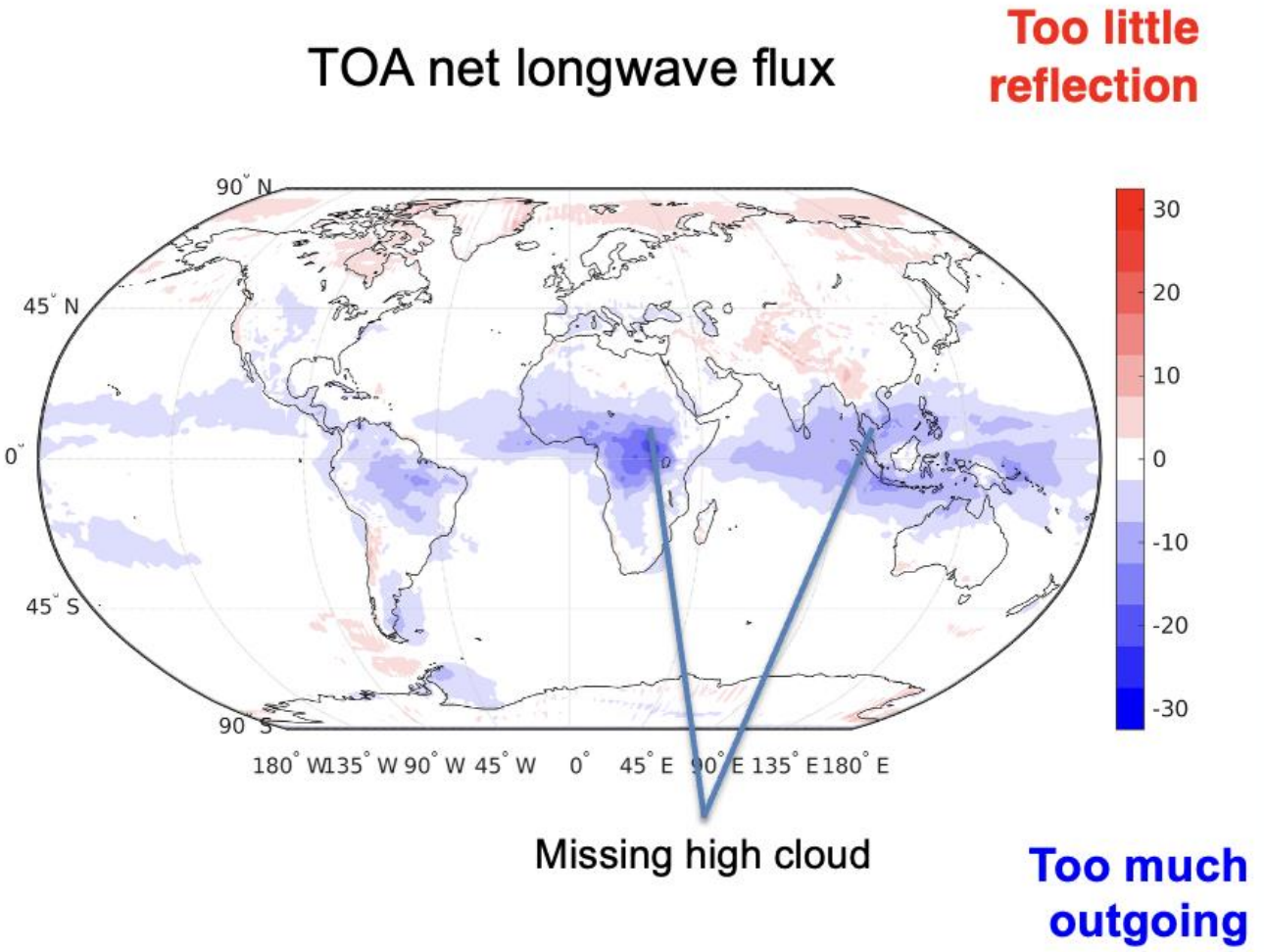
ECMWF

Why are ice clouds important for 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

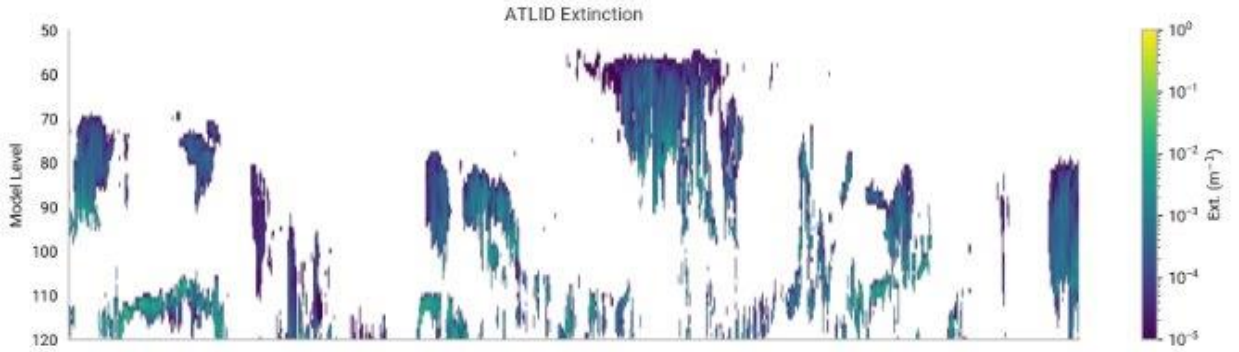
Using EarthCARE to find missing high ice clouds

- CERES shows too much LW escaping to space in the tropics – consistent with missing high cloud
- Why is the ice cloud missing?
  - Falling out too quickly?
  - Not forming enough in the first place?
- EarthCARE's provides the vertical cloud information needed to diagnose the problem



EarthCARE reveals the missing high cloud

- ATLID detects optically ice clouds – which are missing from the model
- Missing cloud occurs primarily at high altitudes and low temperatures
  - Relative humidity with respect to ice is often sufficient for cloud formation, suggesting a microphysical deficiency
- Clouds are radiatively important despite low water contents



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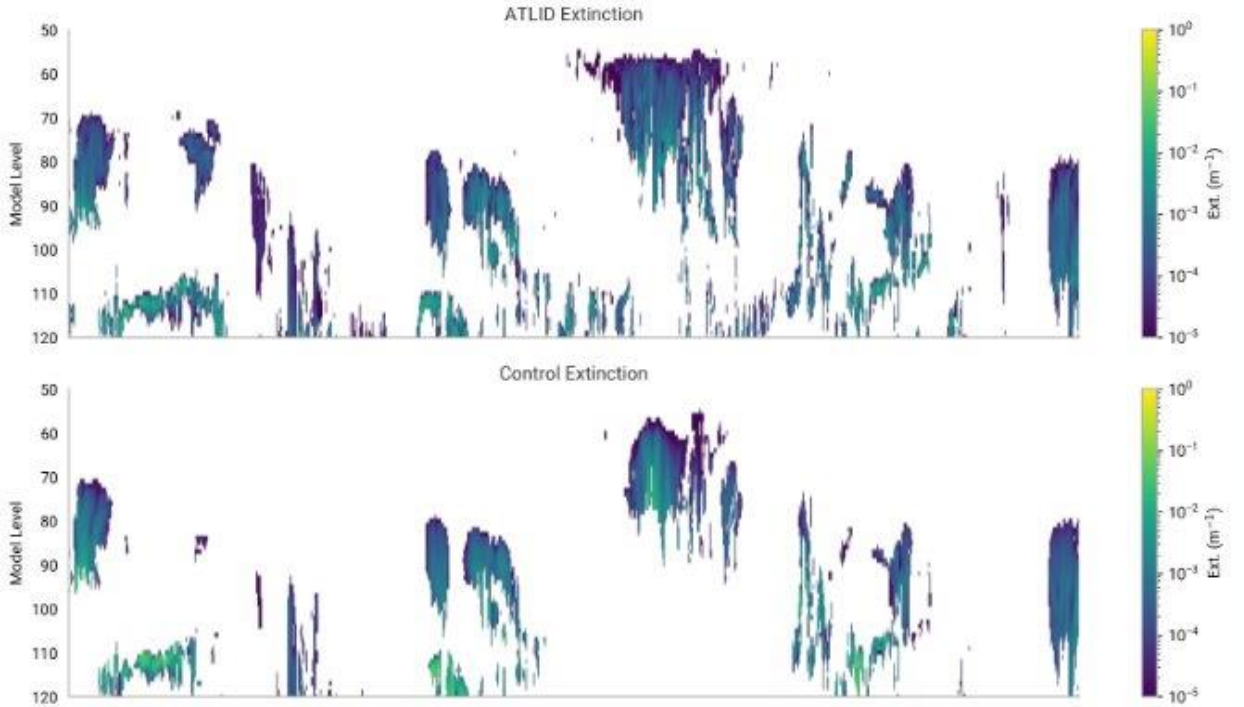

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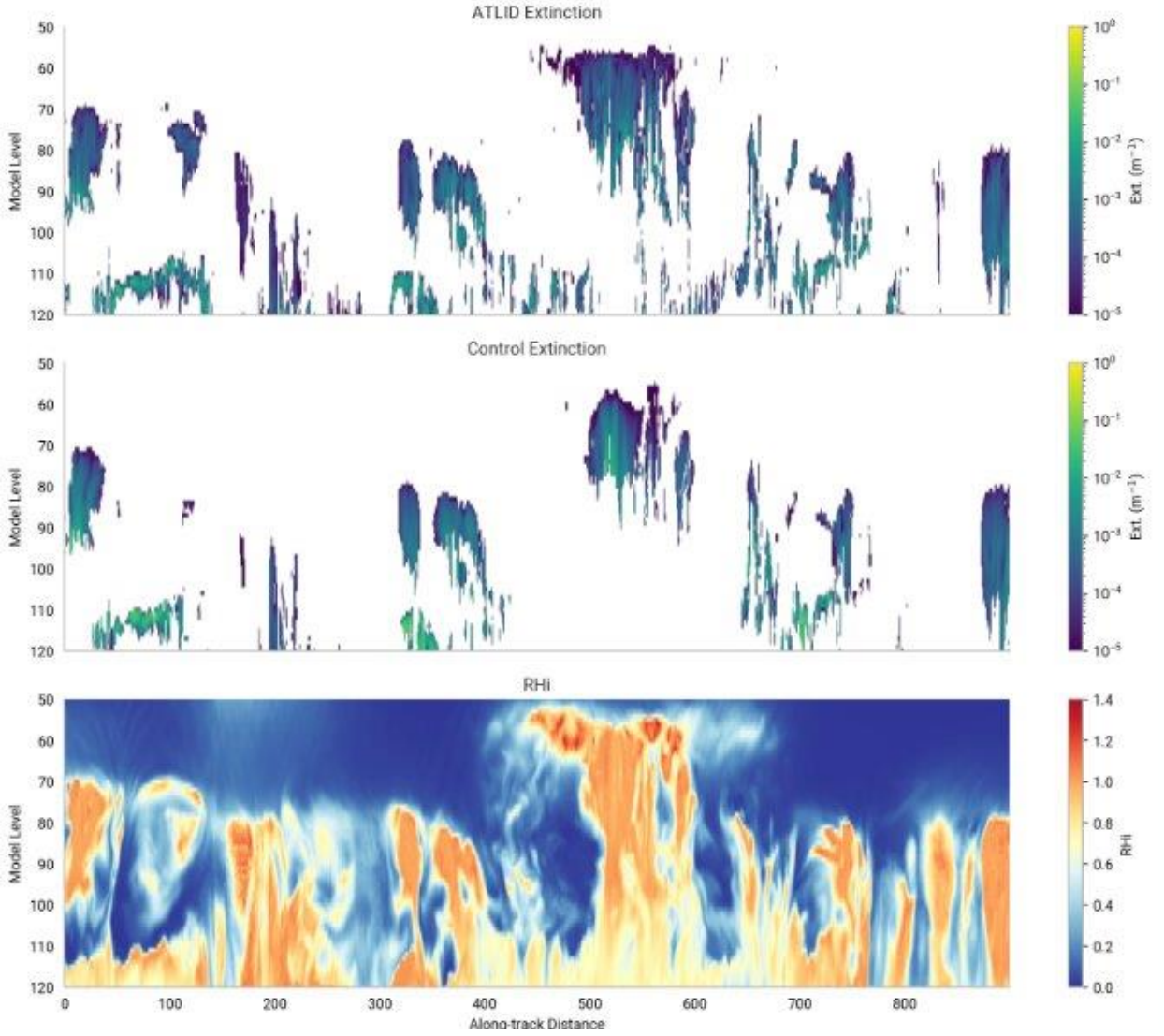
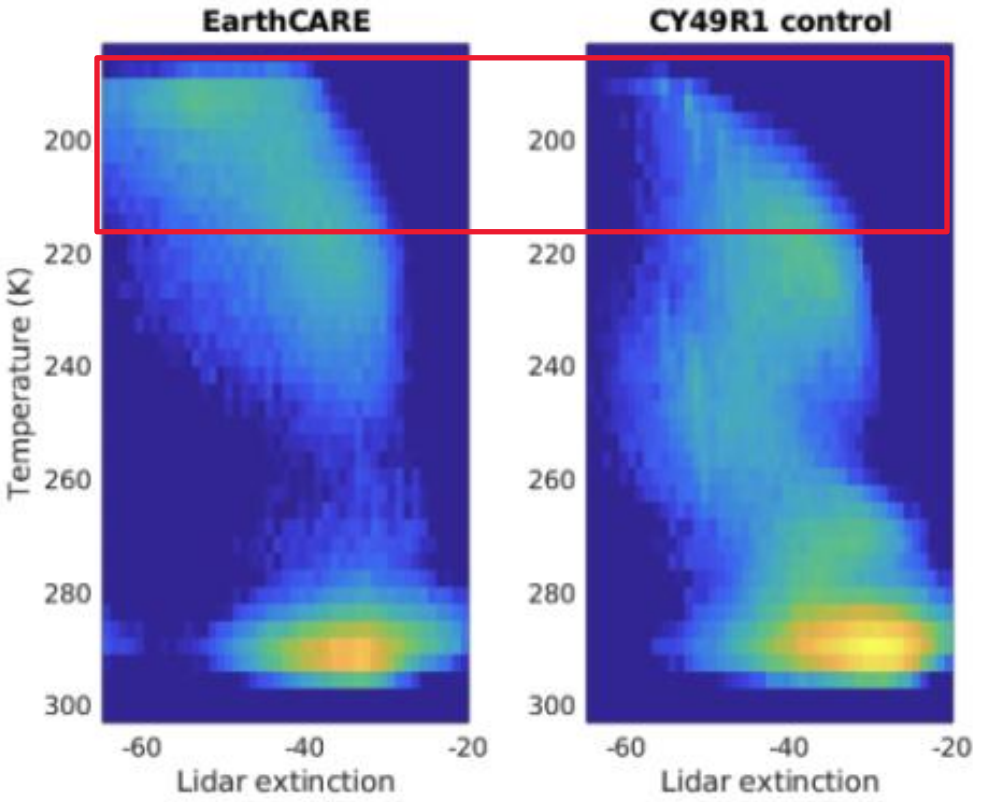
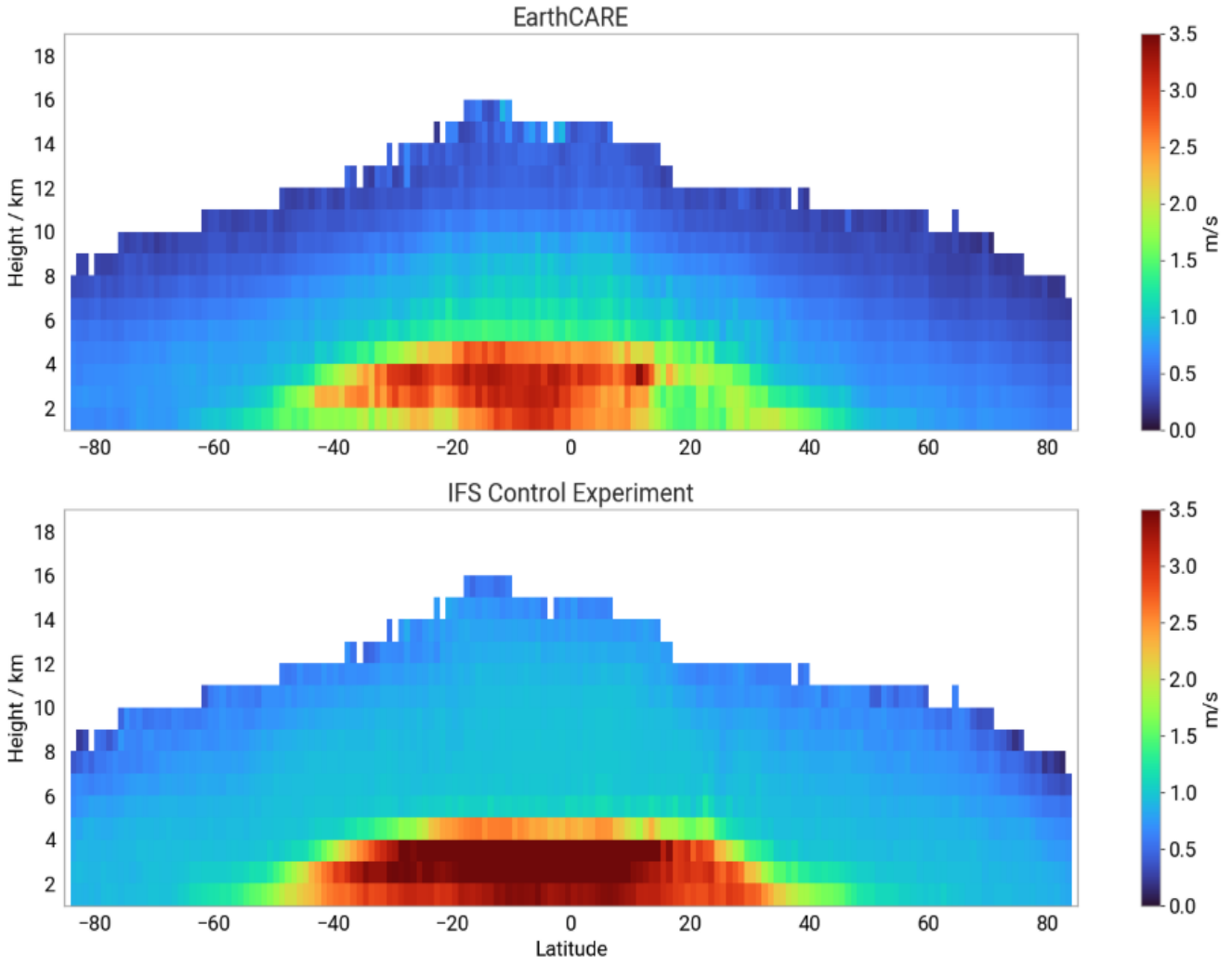


Causes of the missing ice cloud?

- **Two paths of exploration**
  - Ice and snow fall speeds are fixed – too-rapid sedimentation may remove ice before it accumulates
  - Insufficient ice formation at cold temperatures – change assumptions about humidity and introduce heterogeneous nucleation



Fix 1: Variable ice and snow fall speed



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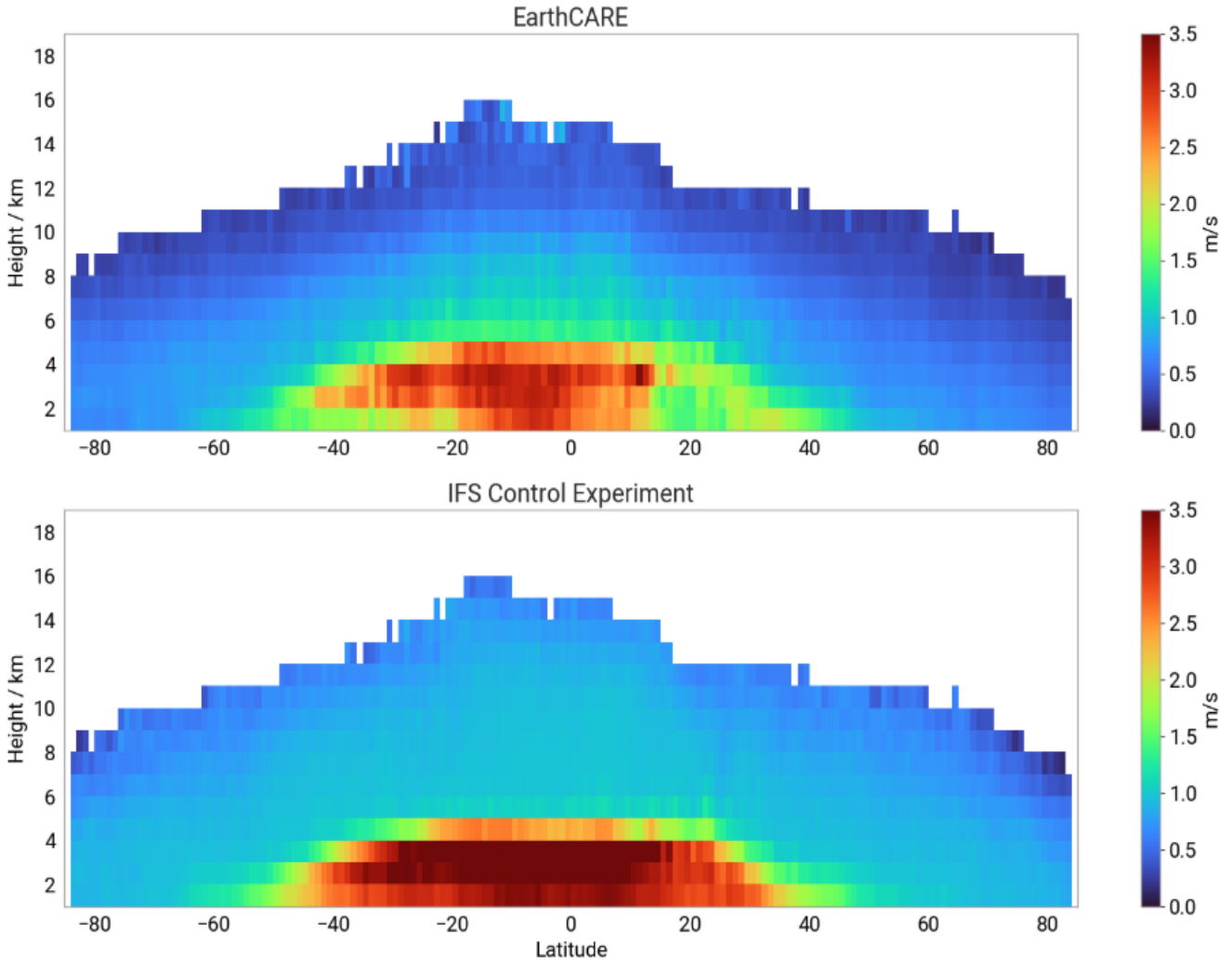
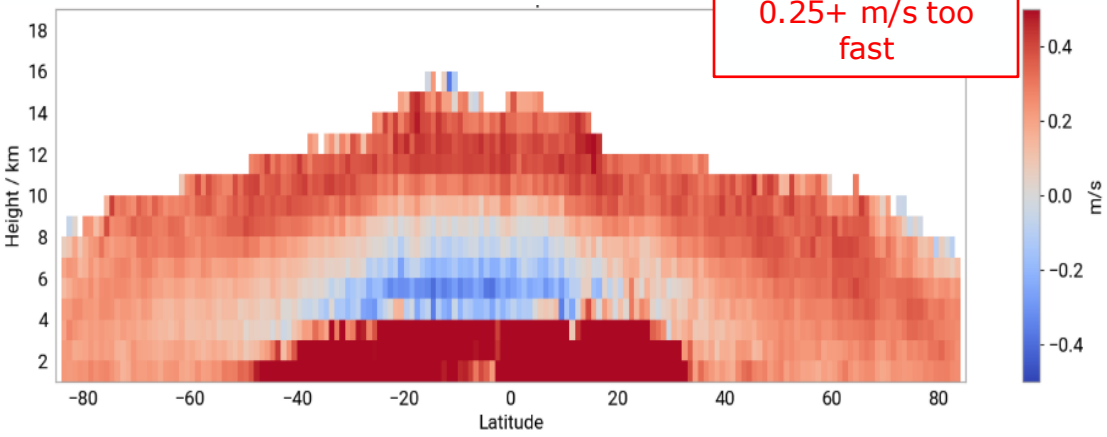


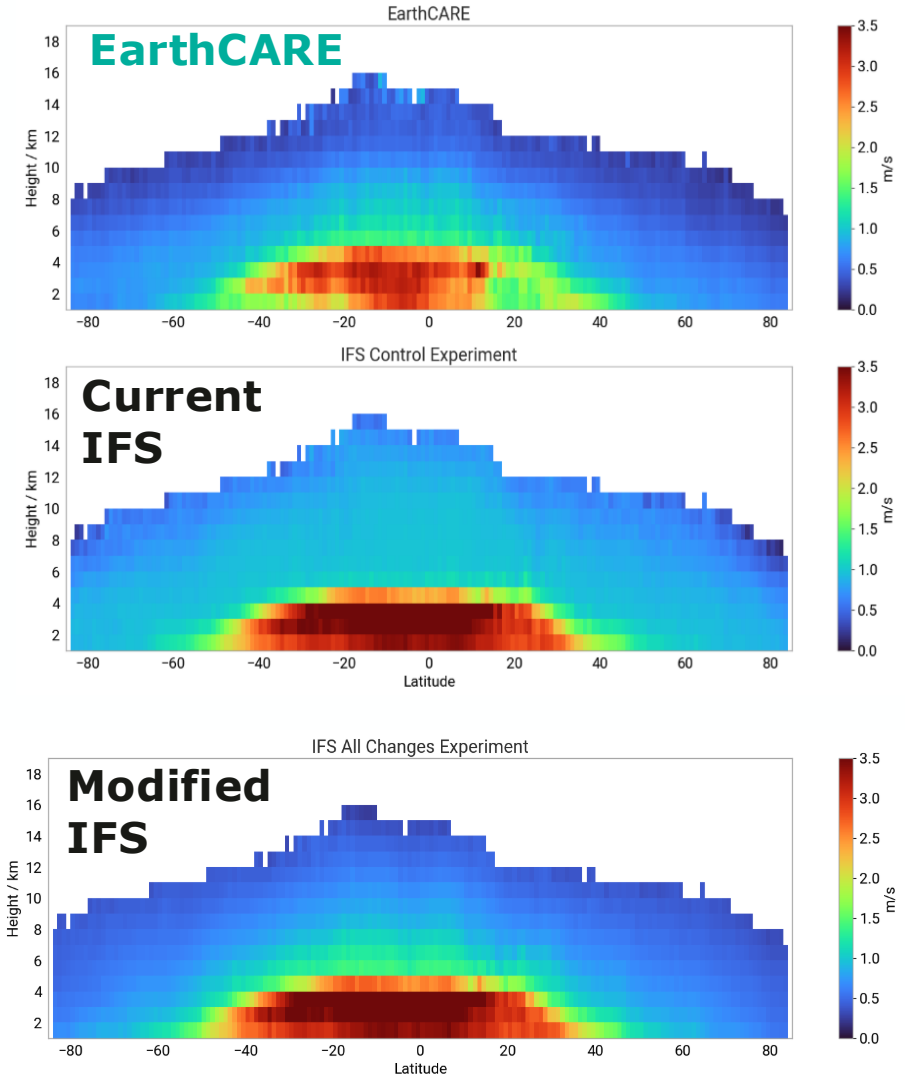


Upper troposphere ice/snow falls 0.25+ m/s too fast

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

Fix 1: Variable ice and snow fall speed

- Introduce mass-weighted snow and ice fall speeds
- Change PSD assumptions
- Introduce diagnostic riming fraction



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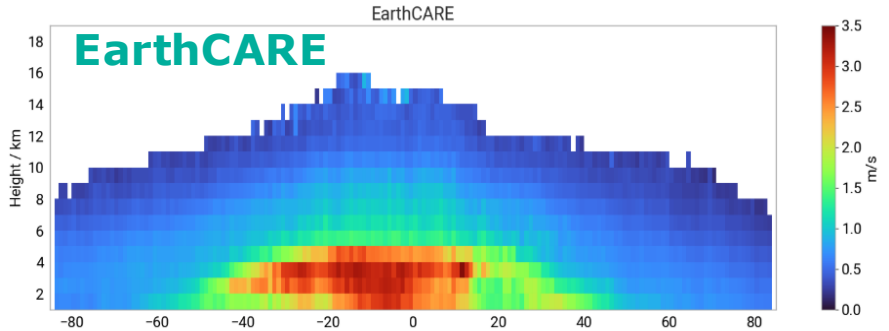
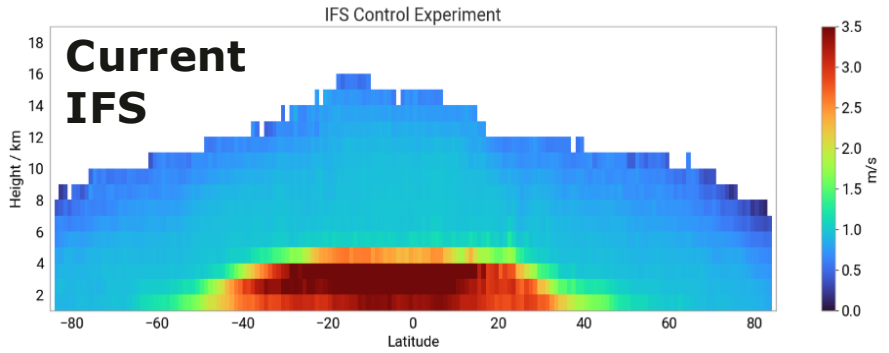
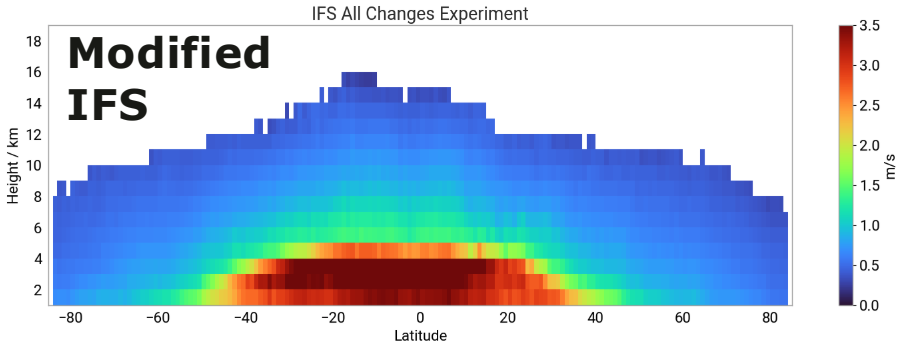
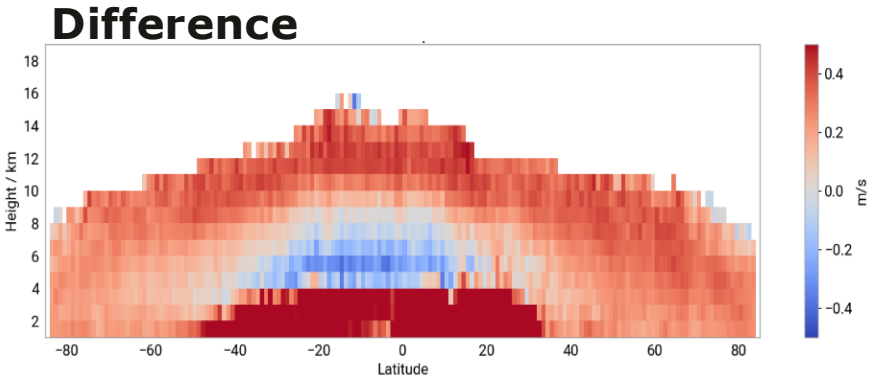
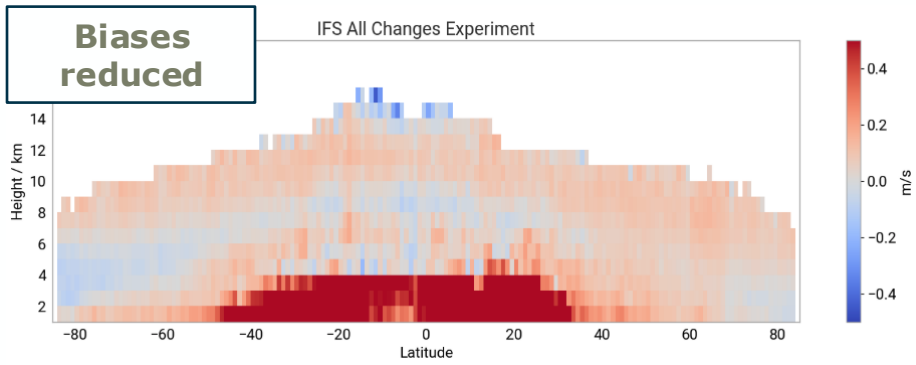




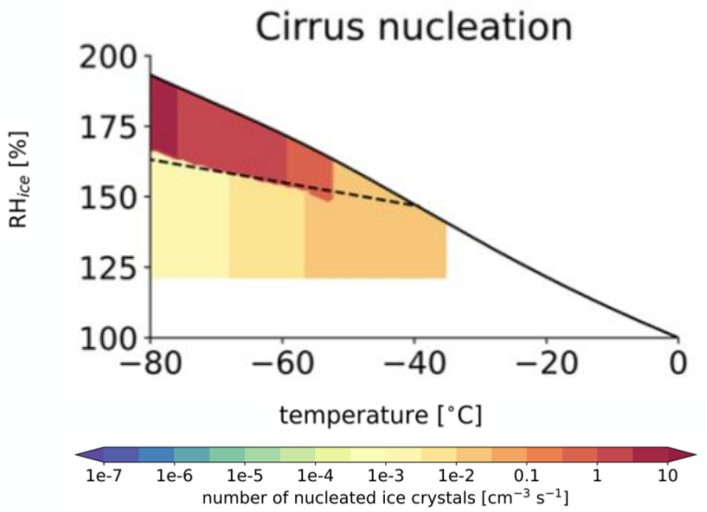




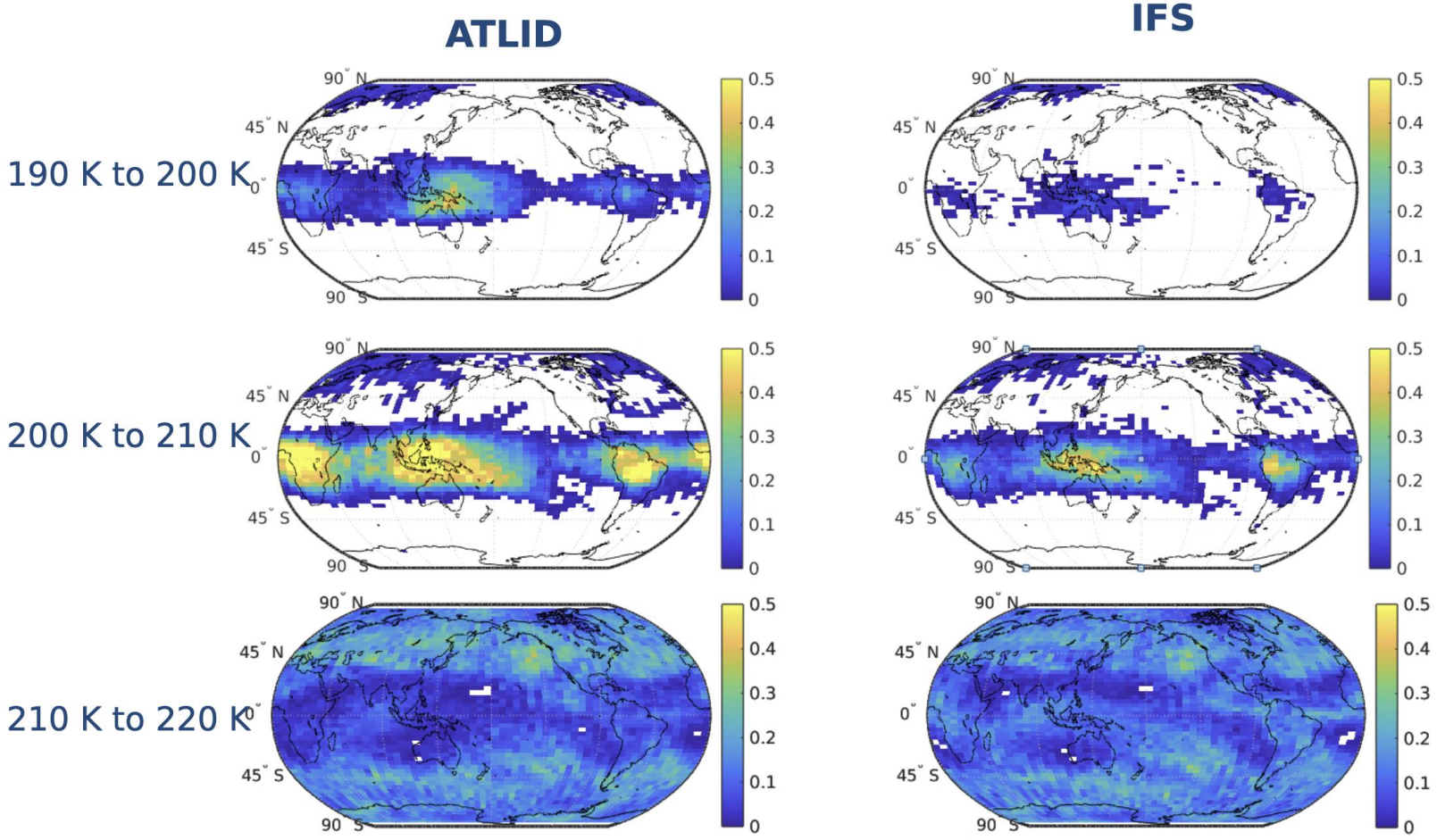


Fix 2: Change ice formation/destruction mechanisms

- Introduce a simple heterogeneous nucleation mechanism based on Gasparini et al 2025, simple dust parameterisation
- Change subgrid humidity assumptions - growth/decay of cloud is governed by ice deposition and sublimation

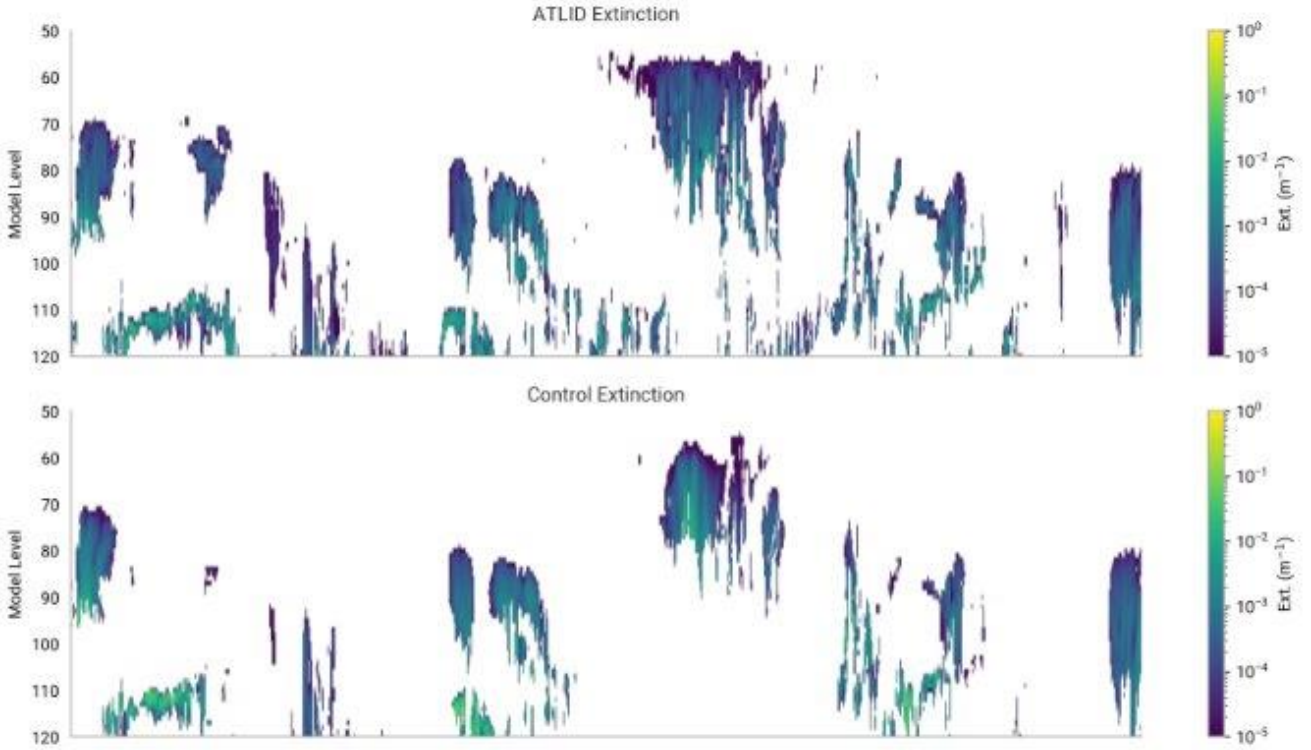


Probability of cirrus CTT (January 2025 – April 2025)



Evaluating the improvements against EarthCARE

- **EarthCARE** can provide valuable information on cloud vertical profiles which can be used to identify model deficiencies
- ATLID highlights the lack of high altitude, low temperature, thin clouds – can also be seen in radiation biases
- EarthCARE allows for evaluation of new parameterisations – such as **snow and ice fall speeds**, which has never been observed globally from space before



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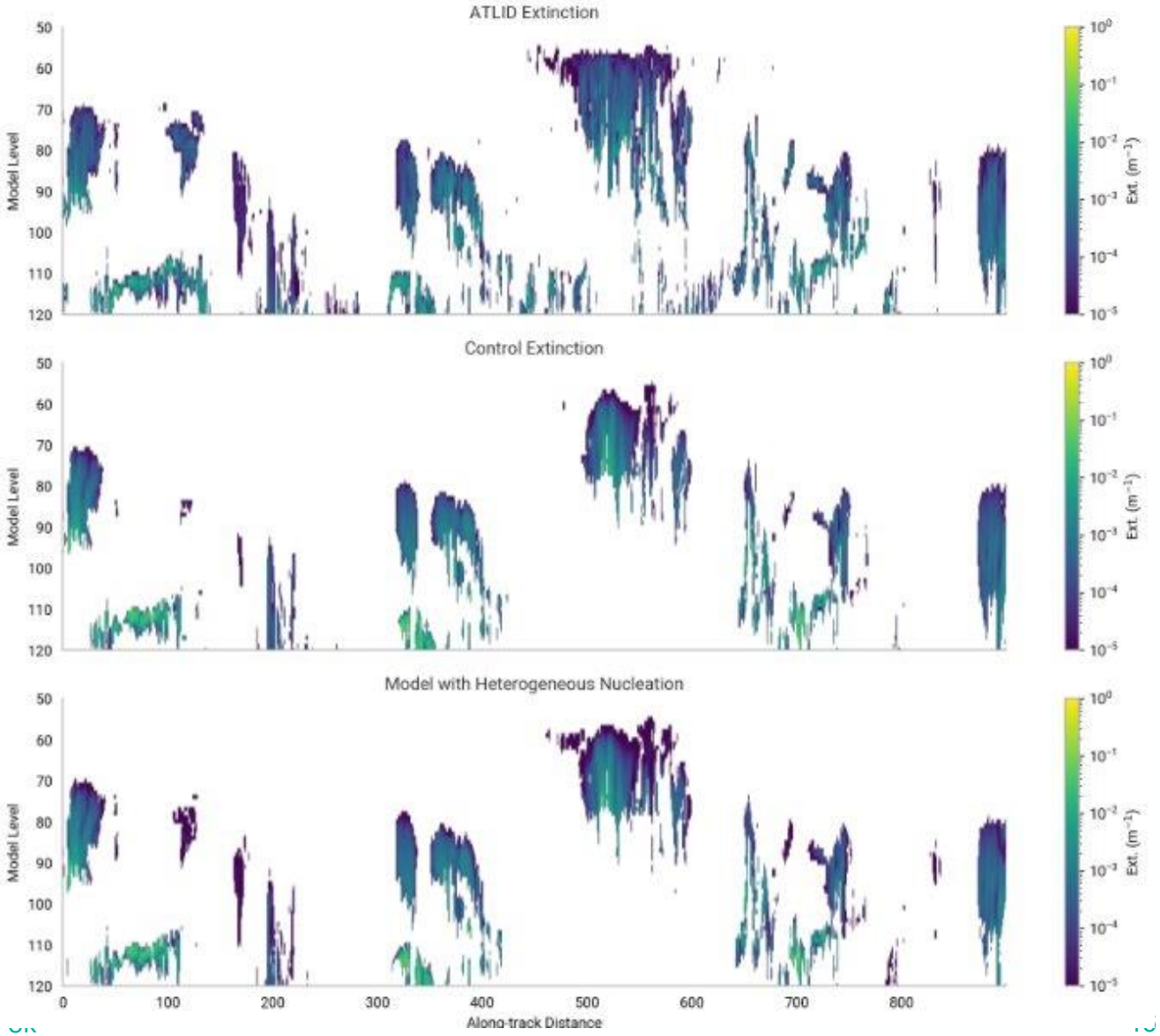

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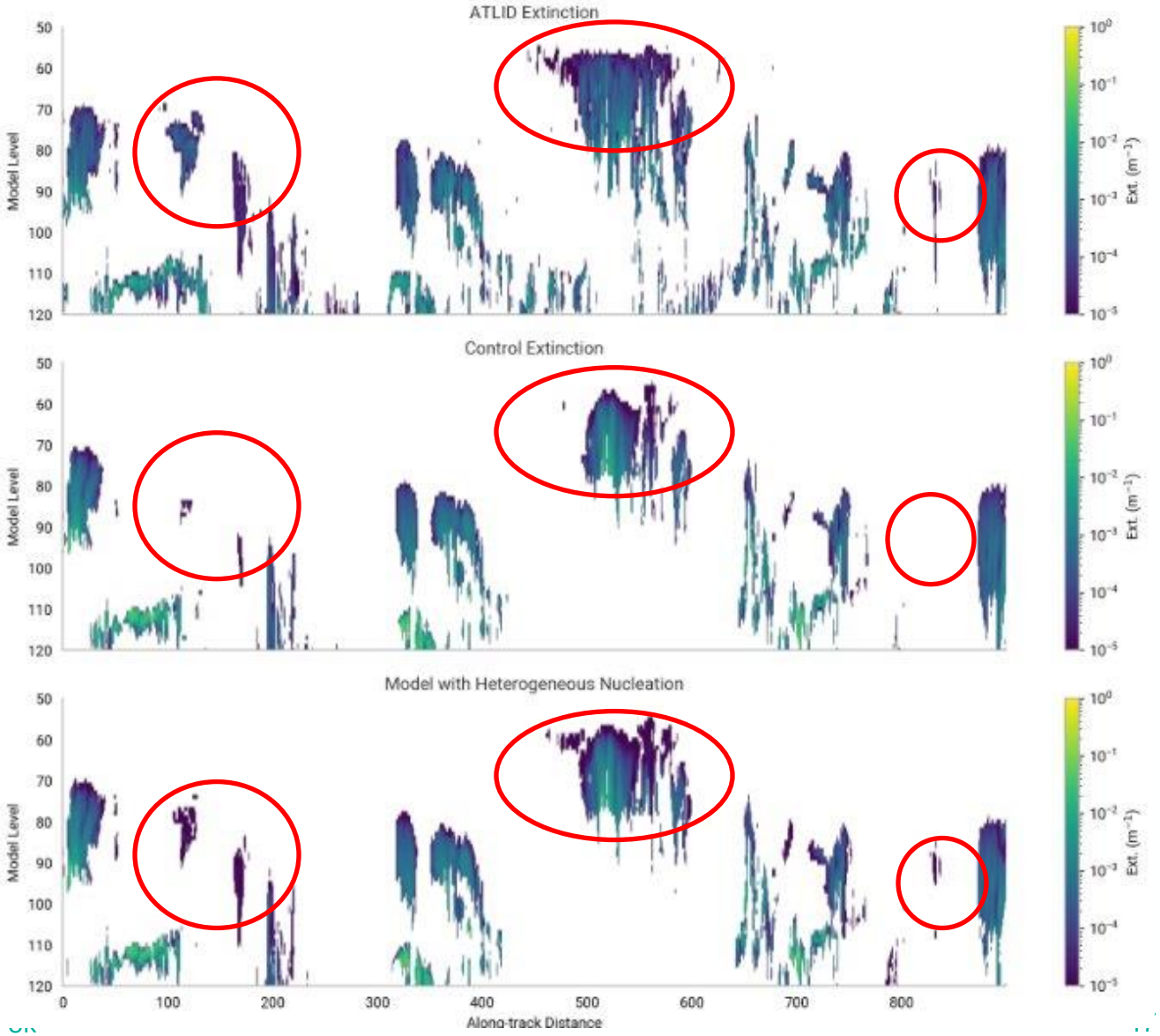
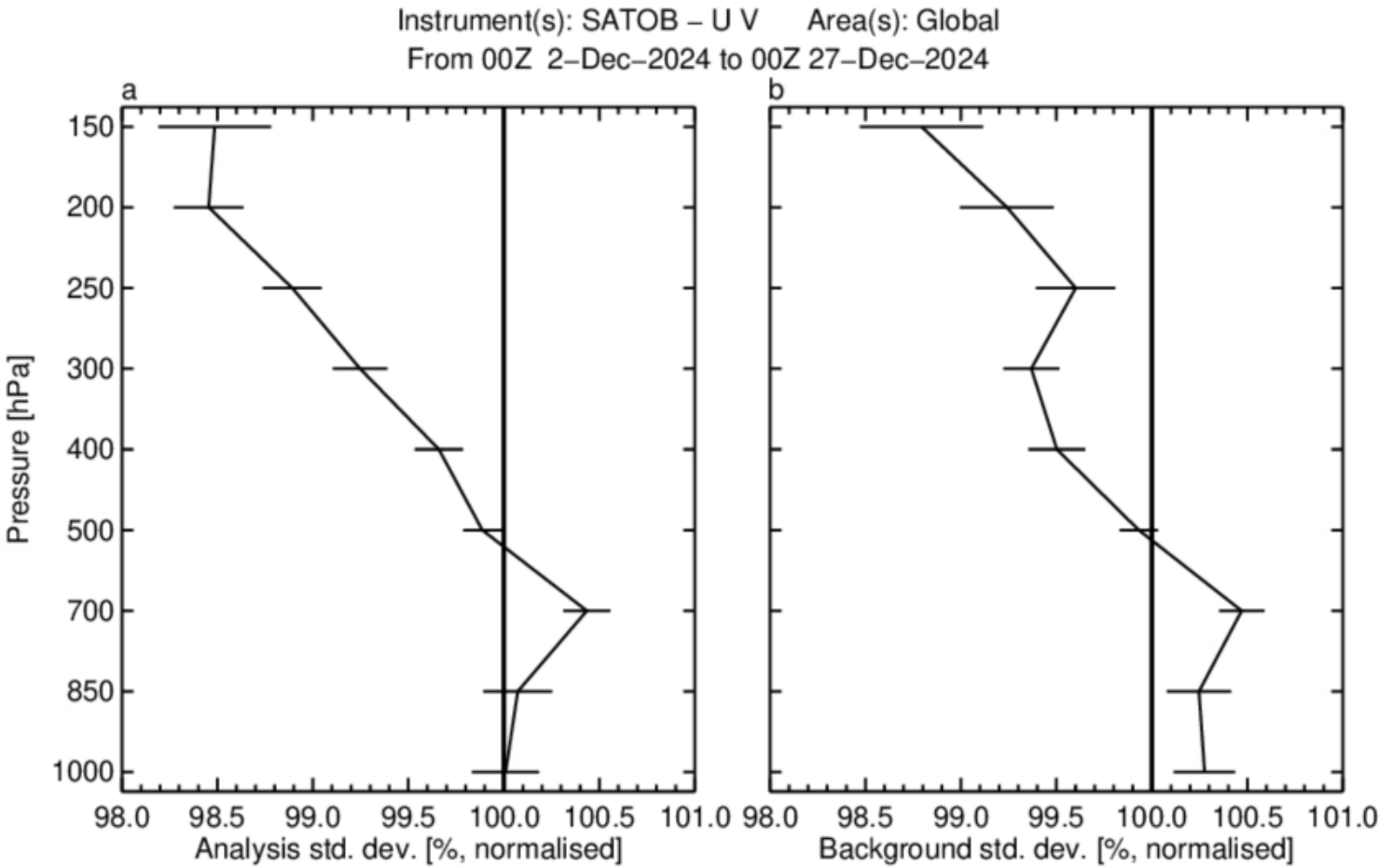


What about the forecast?

- More realistic high ice clouds leads to
  - Better use of **AMVs** at high altitudes
  - Reduction in biases in **longwave radiation** around the tropics



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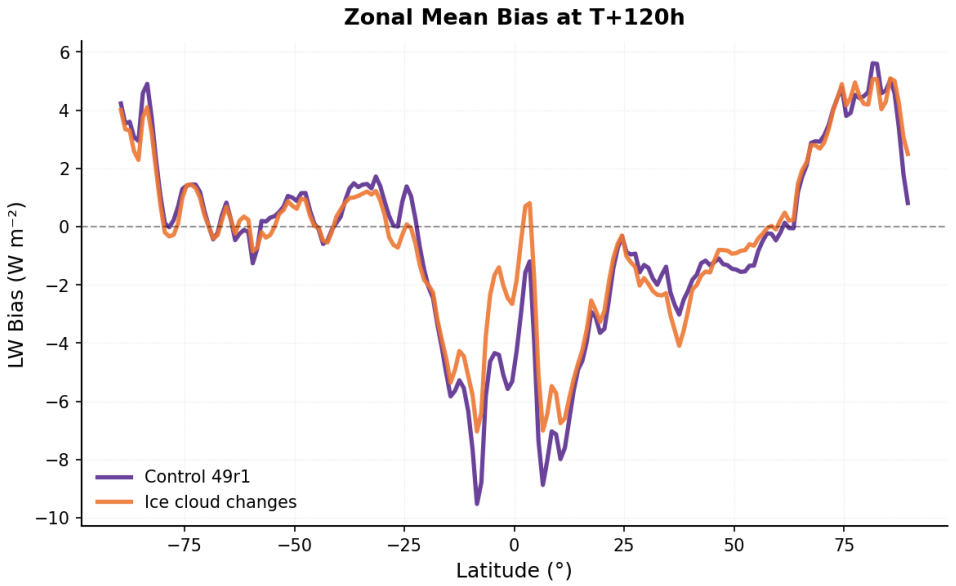

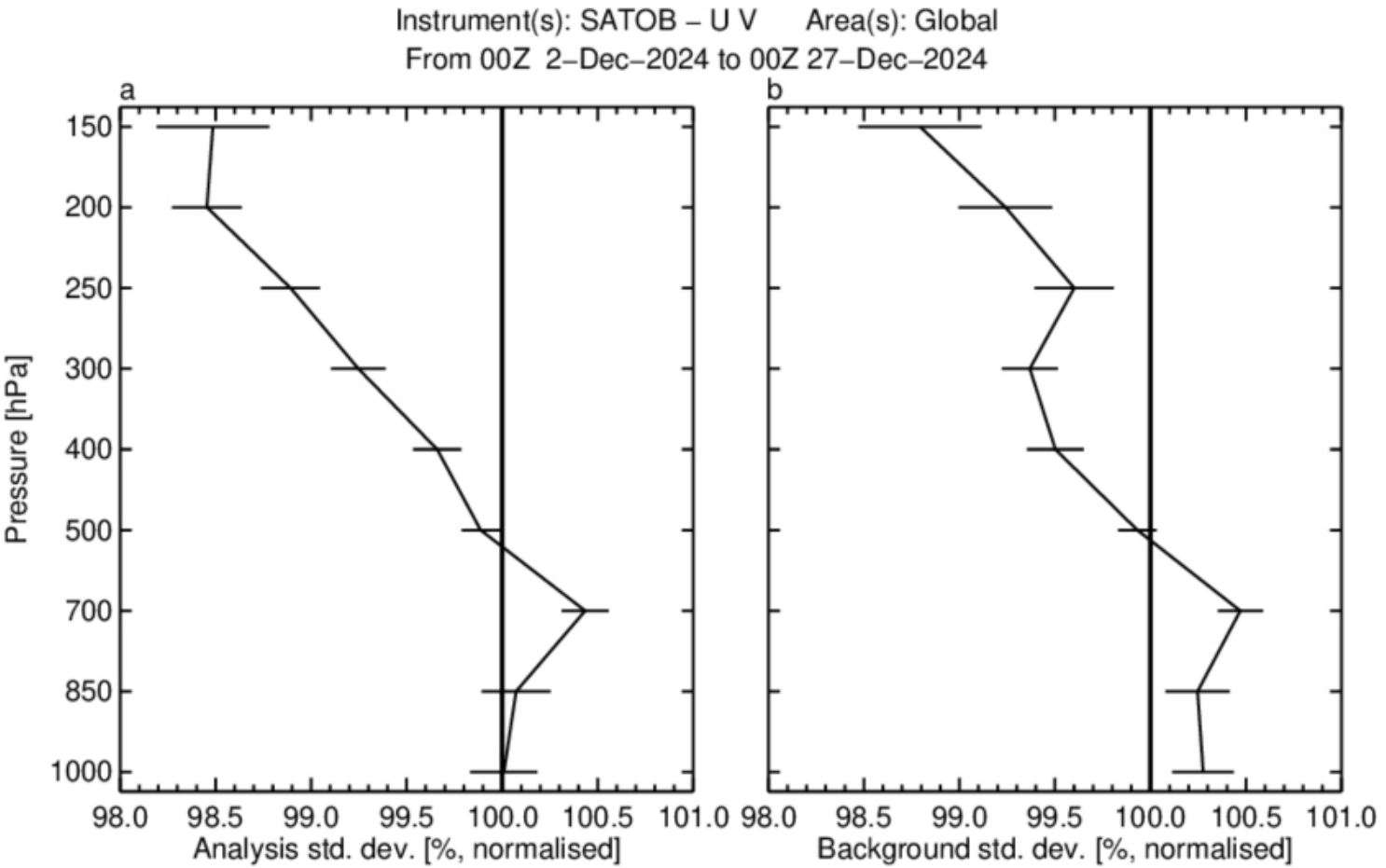

Conclusions

EarthCARE reveals a missing population of high, cold, optically thin ice cloud in the IFS

- Ice and snow sediment too rapidly in the upper troposphere
- Insufficient heterogeneous nucleation limits ice cloud formation
- Subgrid humidity assumptions destroy cloud too rapidly
- EarthCARE allows us to constrain and test the parameterisation and improve agreement with observations

Future paths of exploration

- Cloud lifetime – tracking!
- Mixed-phase clouds and phase partitioning
- Aerosols and INP parameterisations
- Cloud organisation and MSCs
- Representation of rimed particles