Exploiting data assimilation for model improvement

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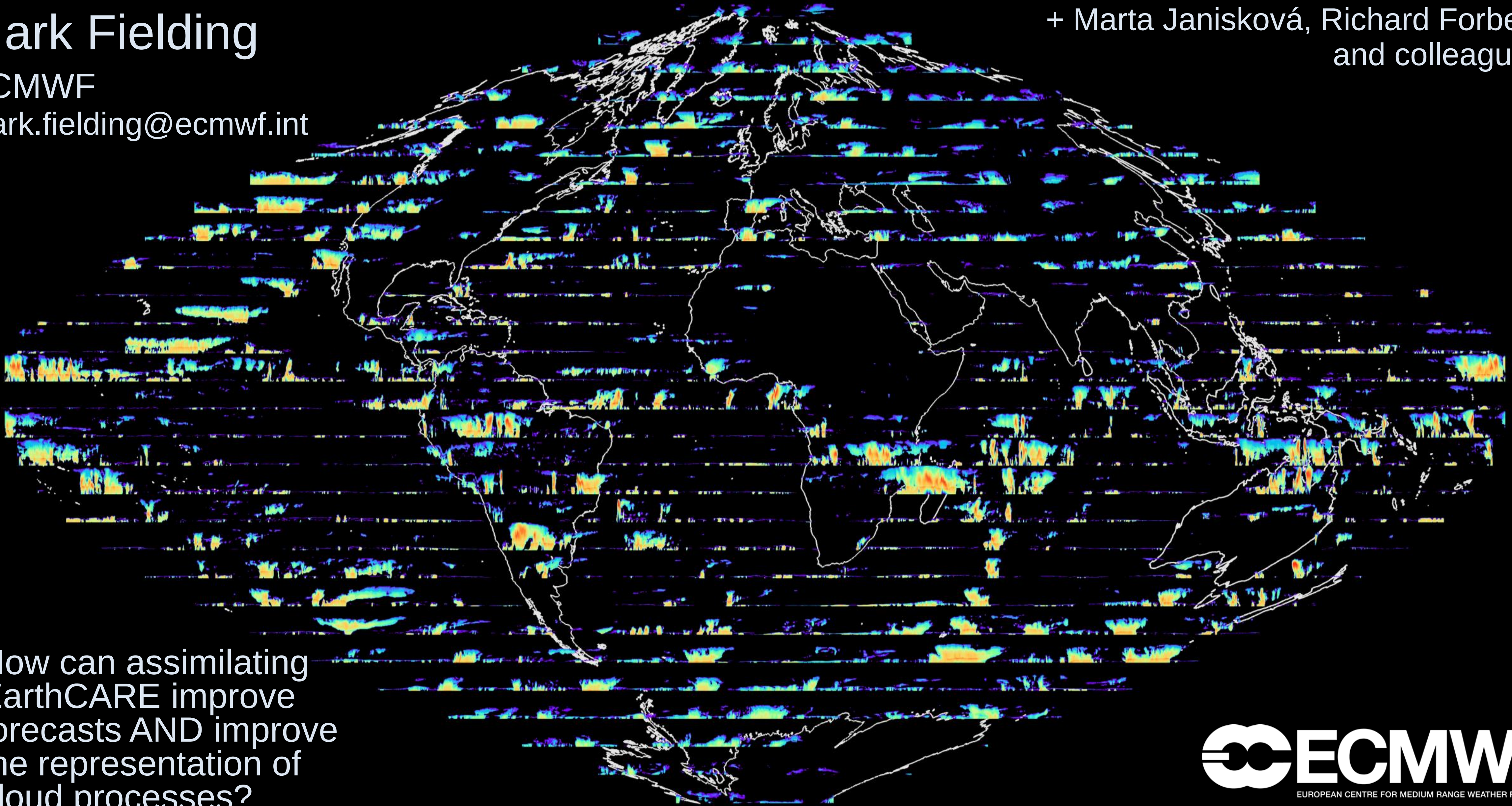
+ Marta Janisková, Richard Forbes, and colleagues



How can assimilating EarthCARE improve forecasts AND improve the representation of cloud processes?

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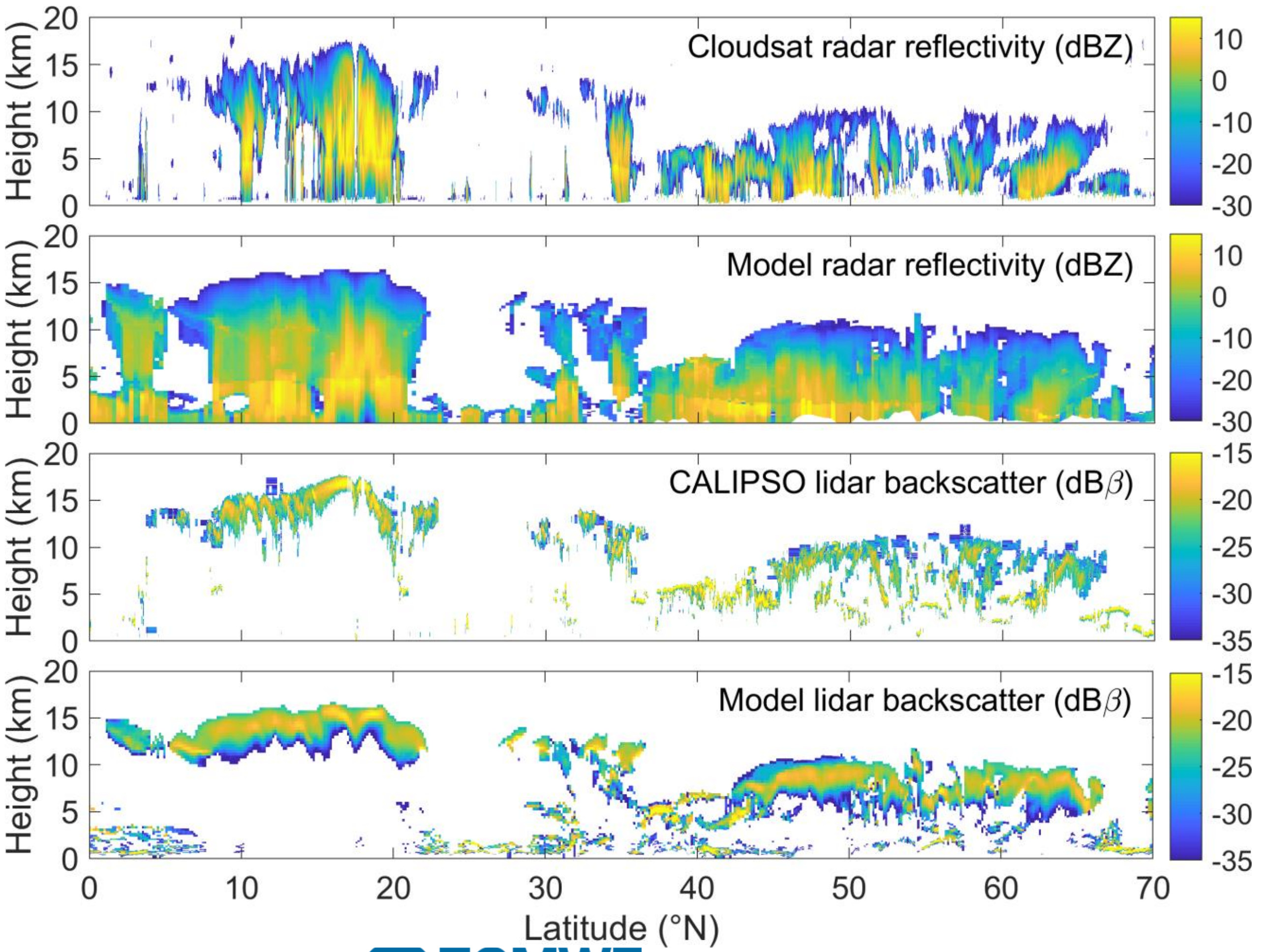
Background

• ECMWF and ESA have been developing the capability to monitor and assimilate EarthCARE radar and lidar observations since 2003.



Key outcomes

- Observation operators for space-borne radar and lidar (Di Michele 2012, Fielding and Janisková 2021, QJRMS)
- 1D+4DVAR feasibility studies (Janisková 2015, QJRMS)
- Flow dependent observation error characterization (Fielding and Stiller 2019, JGR)
- 4D-Var assimilation feasibility studies with CloudSat and CALIPSO (Janisková and Fielding 2021, QJRMS)

The ways developments for ***data assimilation*** can be exploited to improve model forecasts

Indirect

- Model validation using observation operators as instrument simulators
- Monitoring of instruments/products to detect instrument/model problems

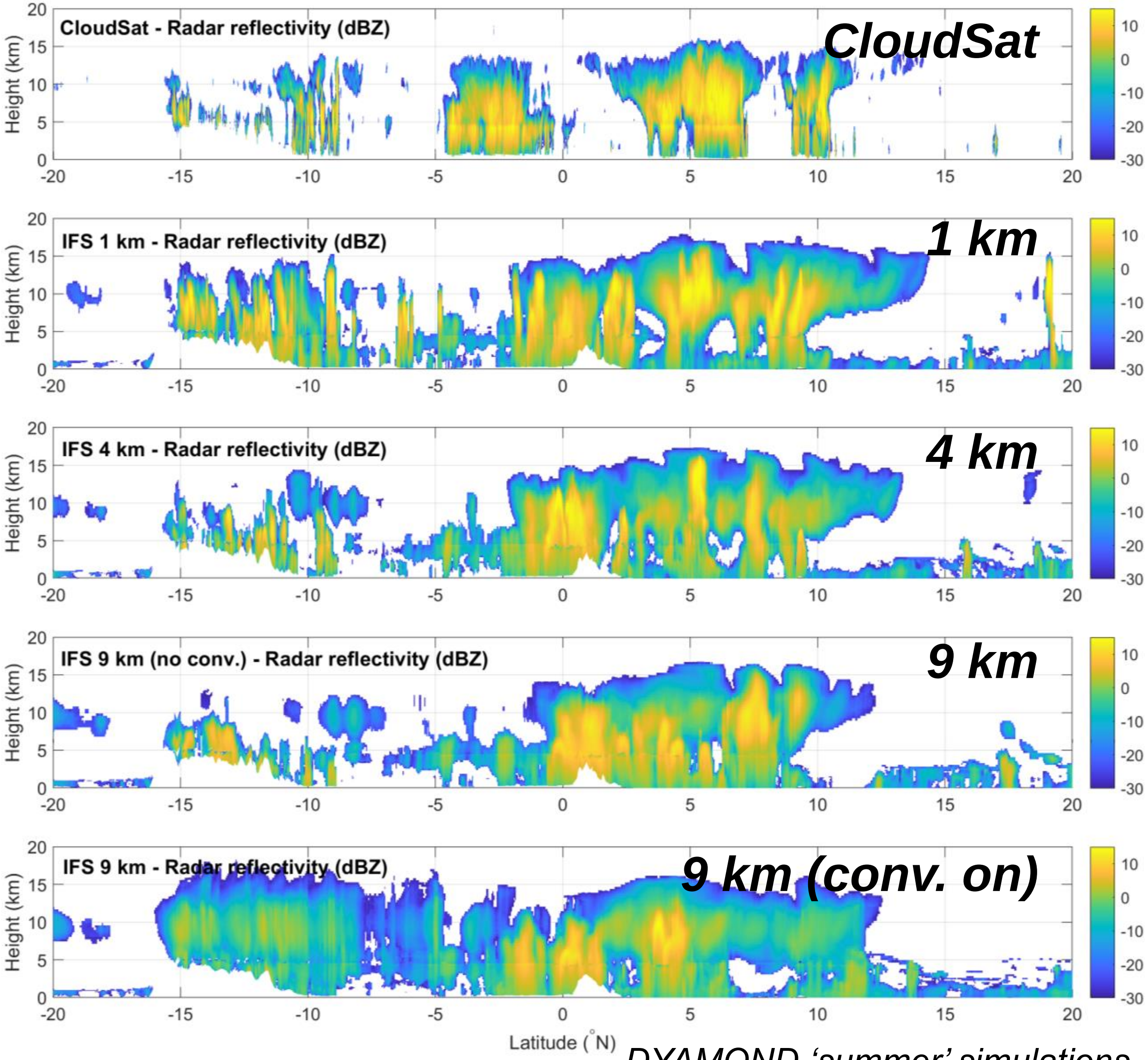
Direct

- Traditional DA – observations are combined with model to provide best estimate of initial state

Future research

- Reducing microphysical uncertainty via observation operator parameter estimation, exploiting synergies across observation spectrum
- Interactive state and parameter estimation data assimilation

Online observation operators provide direct comparison with observations

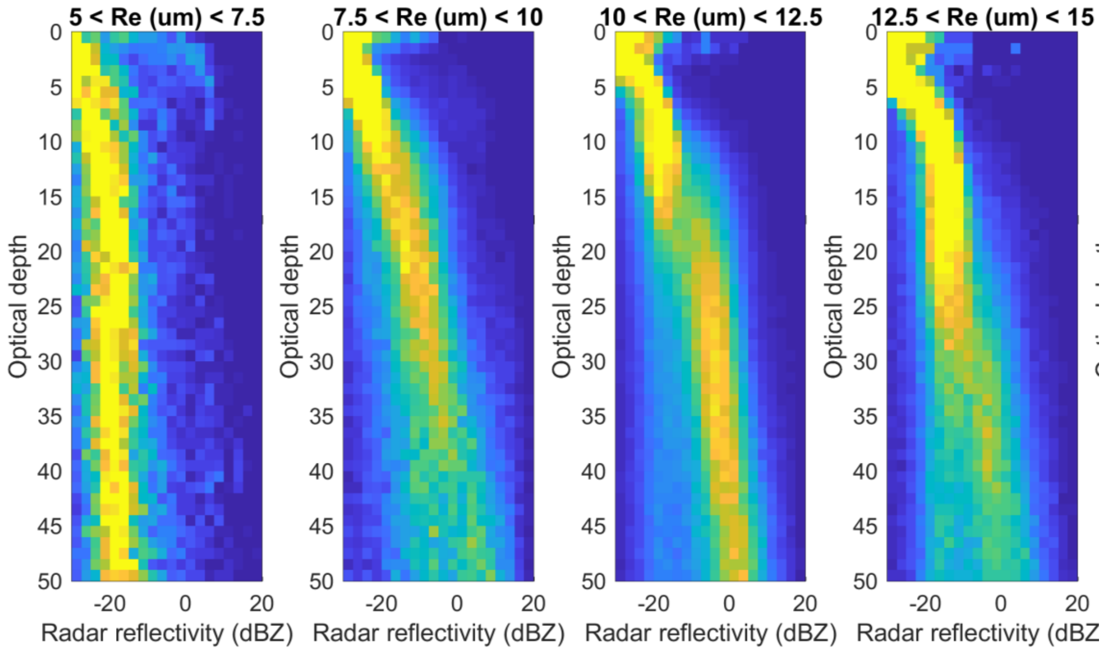


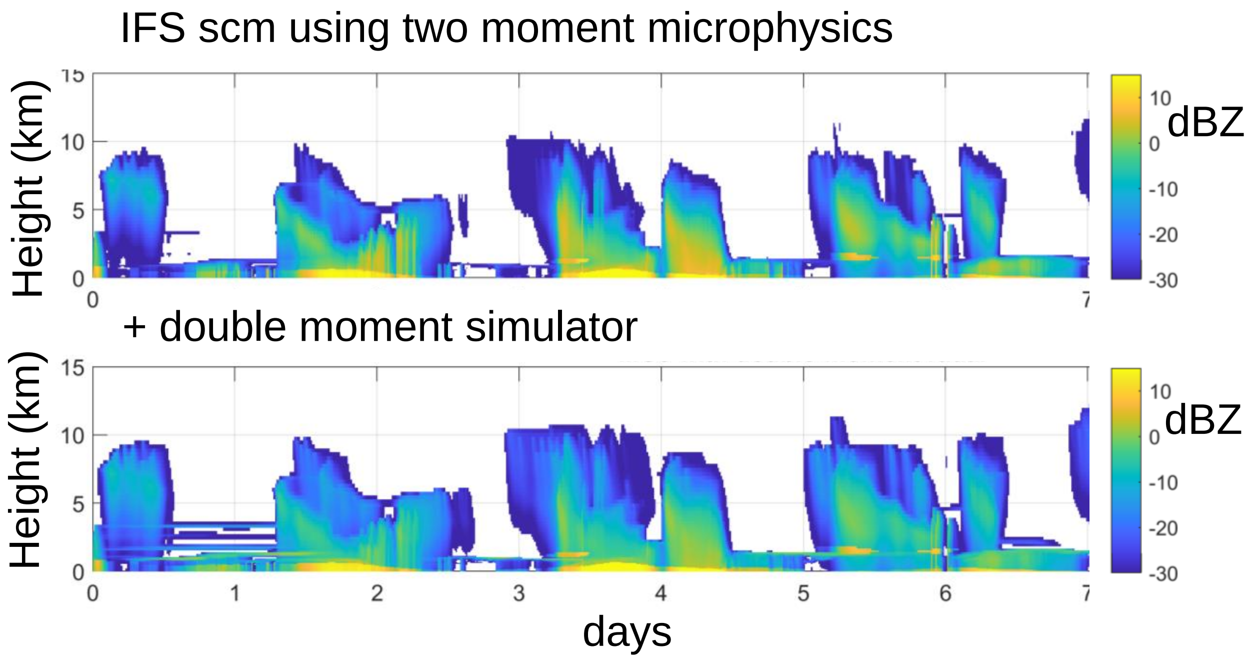
DYAMOND 'summer' simulations

- Instant qualitative check on cloud structure
- Useful for evaluating model analysis/reanalysis or forecast skill.
- Not necessary helpful for process understanding, but could be useful for evaluating 'rare events' – tropical cyclones, volcanic eruptions etc.
- Can be difficult to process data from higher resolution simulations -> online observation simulators could reduce computational demands

Synergistic approaches are key to process understanding

- Spatial matching of observations and model not always required.
- Interpretations still susceptible to assumptions in instrument simulators.

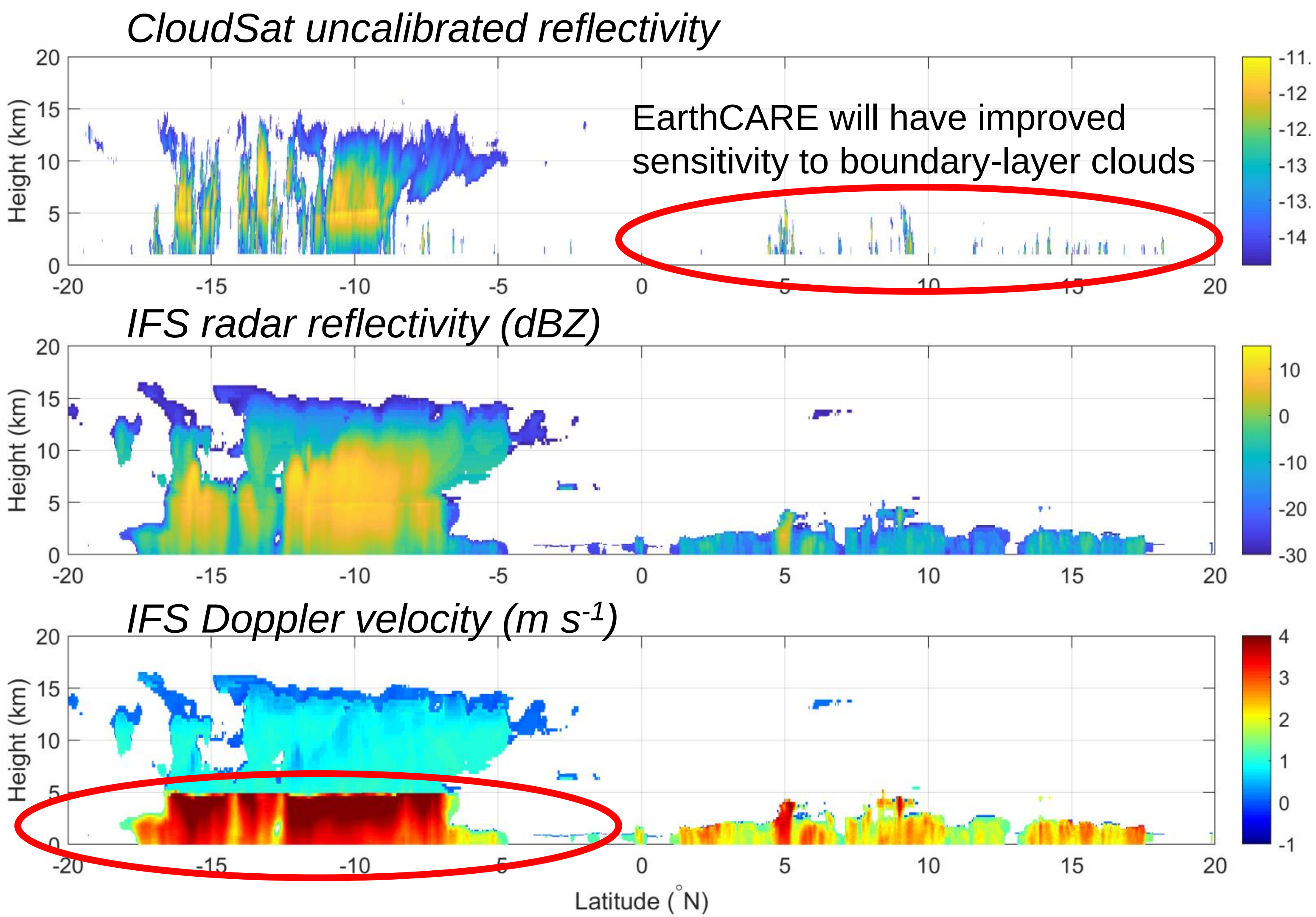




- Simulate CFODDs (see Suzuki et al., 2010) to compare with MODIS/CloudSat observations
- Two-moment version of observation operator to represent more complex microphysics schemes

➢ See Richard Forbes’s and Andrew Gettelman’s talks for more examples

How can we maximise EarthCARE's potential?



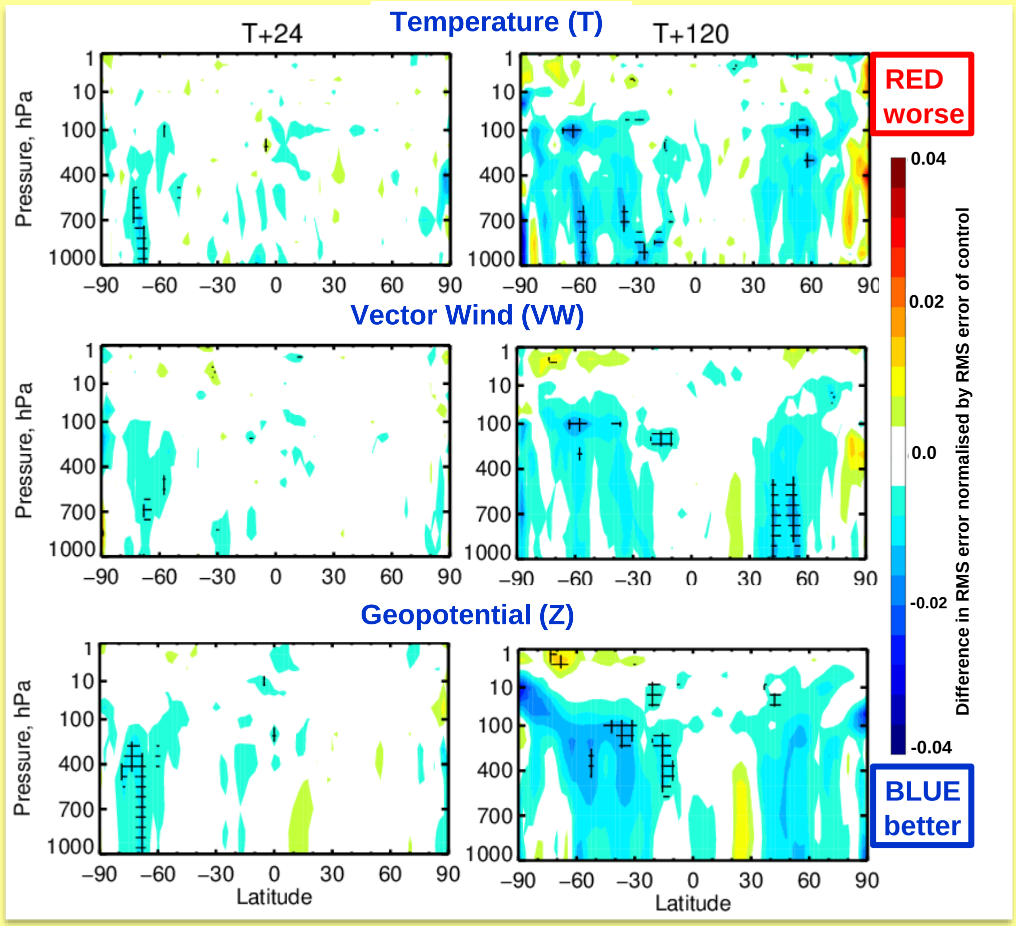
DYAMOND 4 km global simulations from 20 January 2020

Doppler velocity will allow investigation of precipitation processes

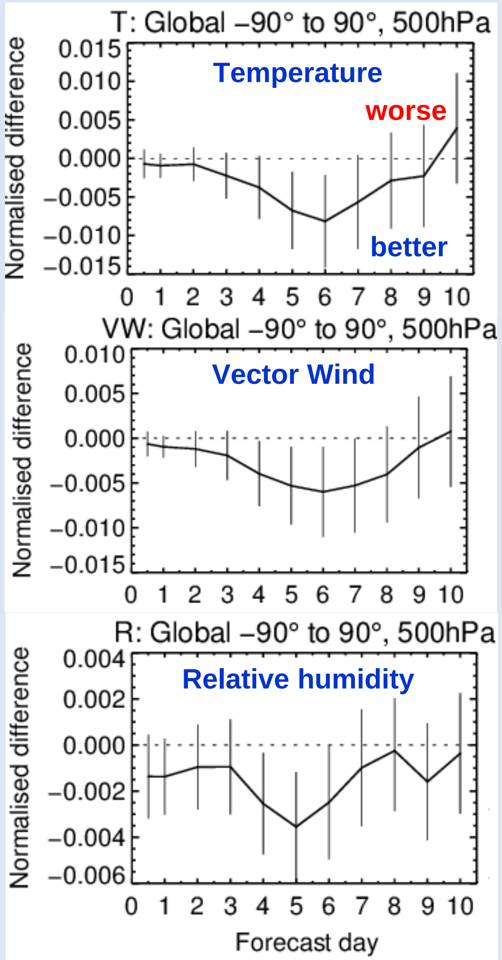
- Observation operator updated to include Doppler velocity and HSRL channels
- Use model simulations to help with quality control and provide stepping stone from CloudSat to EarthCARE
- Make observation operator publicly available (perhaps through RTTOV?)

What impact can we expect from assimilating EarthCARE radar and lidar?

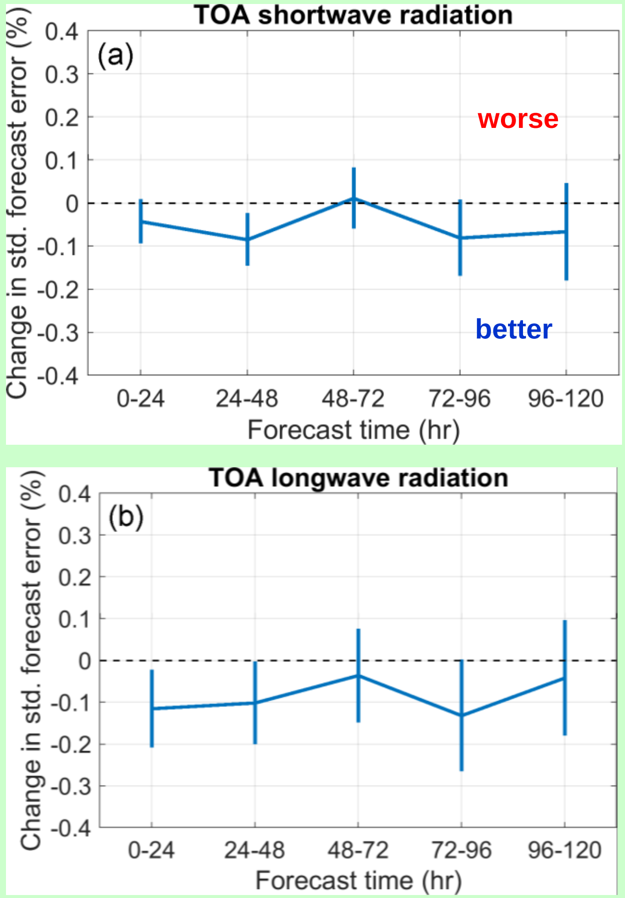
- 4D-Var experiments using CloudSat & CALIPSO show improvements to medium range forecast skill!



11-month combined period: 1 August 2007 – 31 August 2008



Forecast error reduction grows with forecast lead time



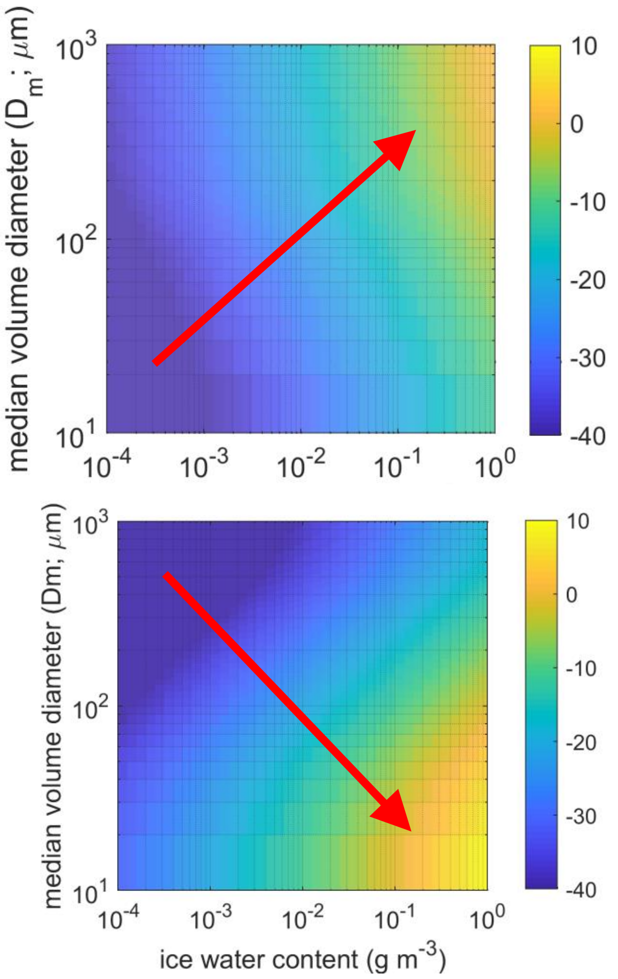
Improvements to forecast of TOA radiation based on verification against independent CERES observations

Outlook for direct assimilation of EarthCARE observations

- Assimilation of radar reflectivity and lidar backscatter has a measurable impact on global forecasts (e.g., ~0.5-1 % reduction in forecast error of upper-tropospheric winds at days 4-6).
- Observing system has grown over the past 15 years: will impact be the same?
- As global NWP models resolve increasingly finer scales, expect data assimilation of high-resolution observations to become more important, particularly for prediction at shorter time scales.
- What additional benefit would assimilating other EarthCARE observations bring, e.g., Doppler velocity, cloud extinction, MSI radiances?
- How do radar/lidar observations interact with other routinely assimilated observations?

Microphysical parameter estimation via radar/lidar/passive synergy

- Significant proportion of uncertainty in observation operator is due to microphysical uncertainties
- Radar and lidar are sensitive to different moments of cloud/ice particle size distributions

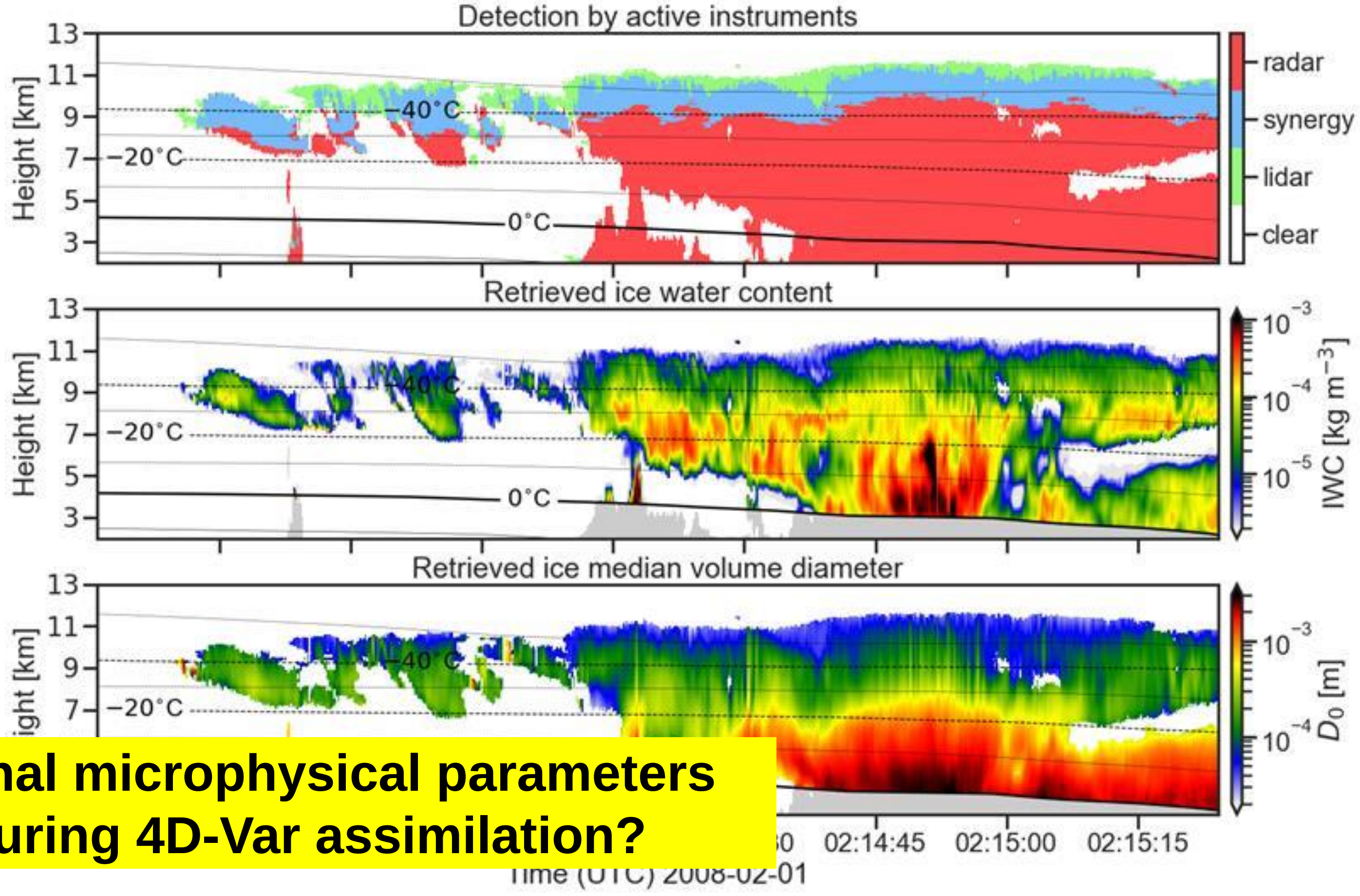


For a given iwc: radar reflectivity increases with particle size

dBZ

For a given iwc: Lidar backscatter decreases with particle size

dBβ



- **Could additional microphysical parameters be retrieved during 4D-Var assimilation?**

CAPTIVATE retrievals and plotting courtesy of Shannon Mason

Proof of principle: off-line parameter estimation of observation operator microphysical assumptions

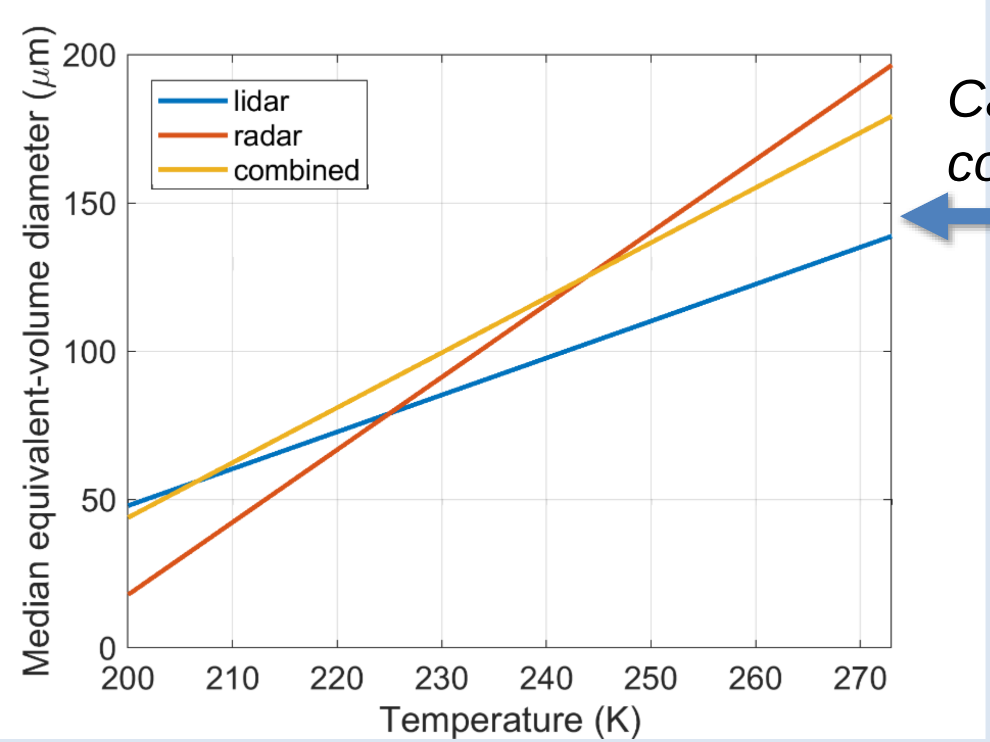
Radar and lidar

- Minimize cost function, *J*, assuming model analysis ice water content, w_a is truth:

$$J([D_{\min}, D_k]) = \left(y - h(w_a, D_m)\right)^2$$

where $$D_m = \max(D_{\min} + (T-200)D_k, D_{\min})$$

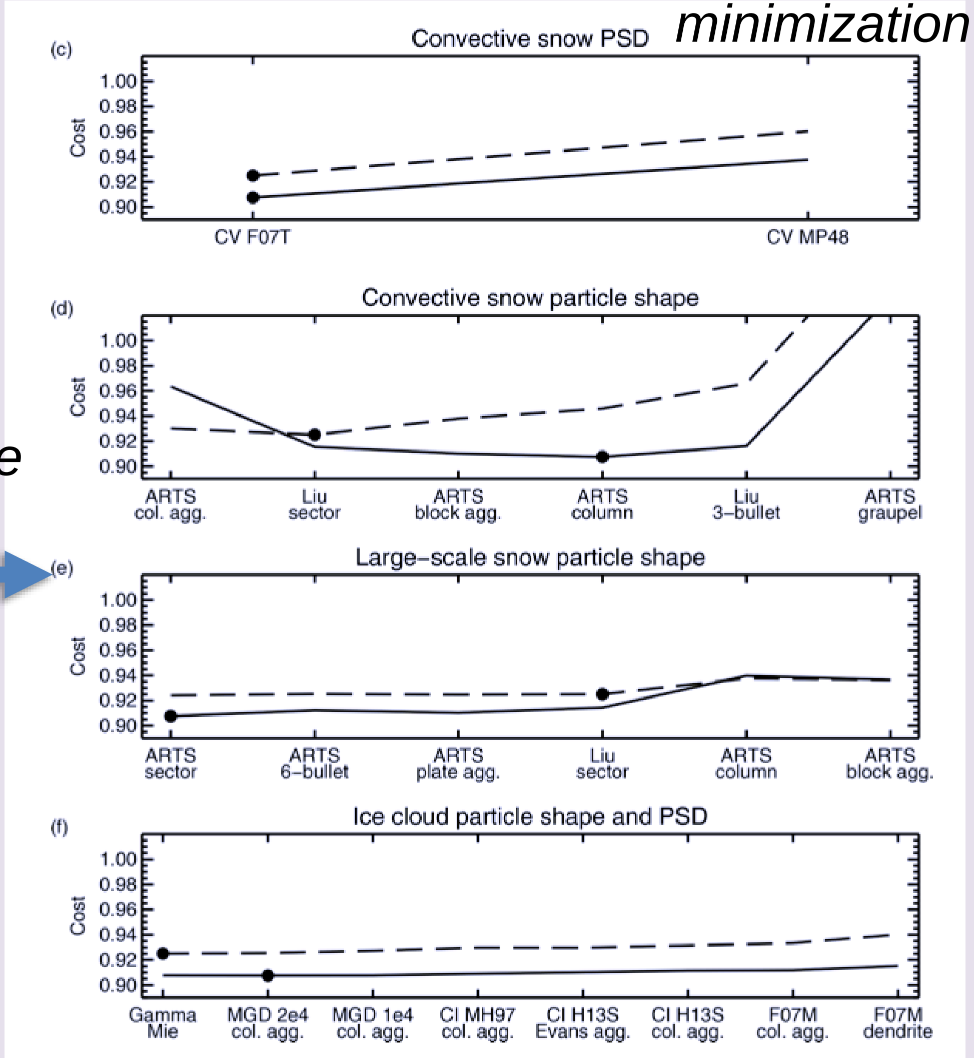
D_m



Can these be combined?

Microwave radiances

➢ *Multi-parameter minimization*



Geer 2021, AMT

Could data assimilation be used for state and parameter estimation?

- Physical parameterization schemes all require assumptions that are potential constrained by observations (e.g., cloud particle sizes, fall speeds, updrafts…)
- Theoretically possible to simultaneously estimate large-scale atmospheric state and model parameters (e.g., Solar constant estimation at ECMWF, Lopez 2013)
- Radar and lidar provide unique constraints on microphysics, but are more observations required?
- Practically, a huge challenge!
  - E.g., need to estimate all uncertain parameters at once, need to avoid unphysical parameters, potential correlations between parameters, requires same model in DA as full non-linear model…

Summary

- Preparations for the data assimilation of EarthCARE provide a framework for exploiting its observations for model improvement.
- Instrument simulators should be combined synergistically to have greatest impact.
- Being aware of microphysical uncertainties in simulators is critical to avoid mis-interpretation of results.
- Combined state and parameter estimation DA could create a step-change in the representation of physical processes in NWP models.