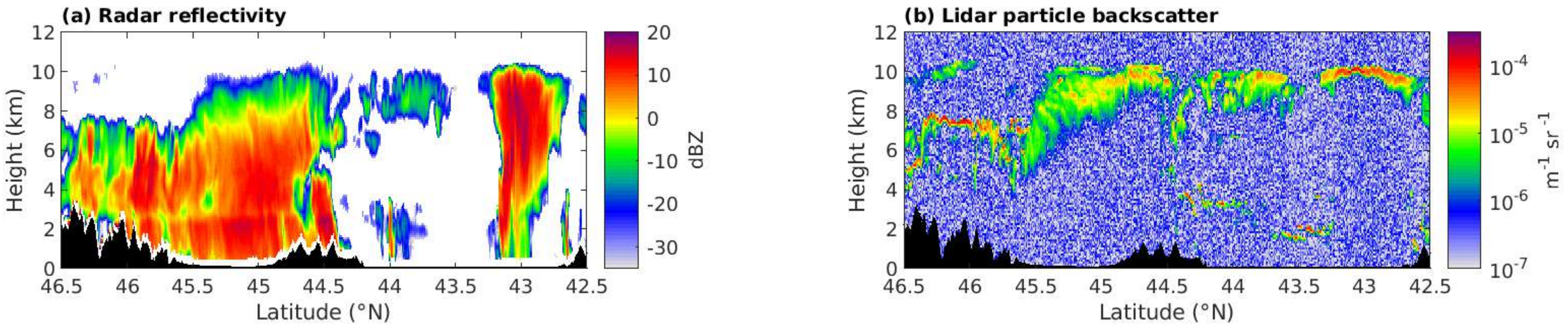
Using CPR & ATLID to characterize ice-cloud size distributions and improve ACM-CAP retrievals

Robin Hogan & Shannon Mason
ECMWF and University of Reading
David Donovan
KNMI

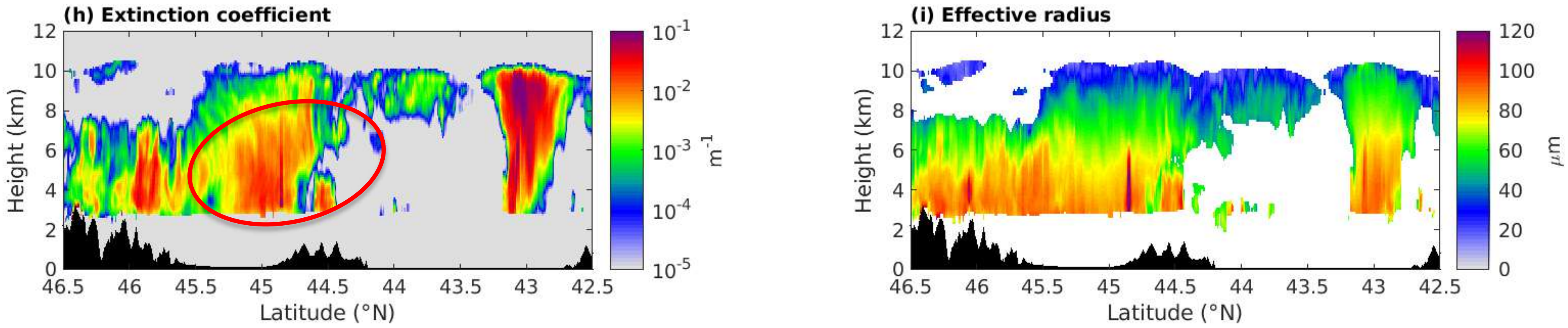
robin.hogan@ecmwf.int

Motivation

- Observations:



- ACM-CAP ice-cloud retrieval:



- How good are the synergistic retrievals where the lidar runs out of signal?
- What can we learn from the radar-lidar region that can be applied throughout the cloud?

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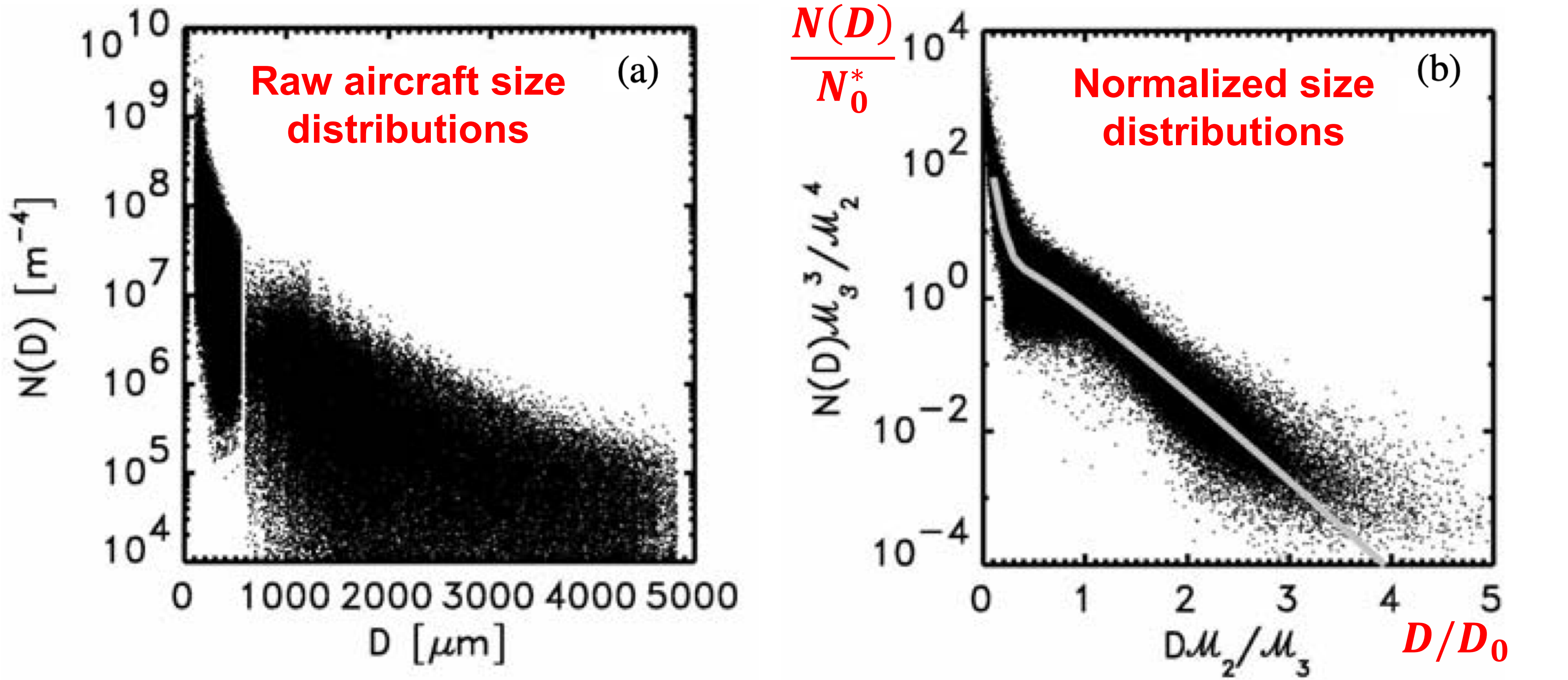
ACM-CAP (and DARDAR) retrieval of ice cloud properties

- We measure **two** moments of size distribution (radar reflectivity and lidar backscatter) and wish to retrieve others (e.g. ice water content): we describe unrimed size distributions by **two** independent variables, e.g.

  Normalized number concentration $N_0^* = M_2^4/M_3^3$, and **mean dimension** $D_0 = M_3/M_2$

- The *j*th moment of the distribution is $M_j = \int N(D) D^j dD$
- Delanoe et al. (2005) and Field et al. (2005) showed that this helps parameterize size distributions



Parameterize size distributions with these two variables:

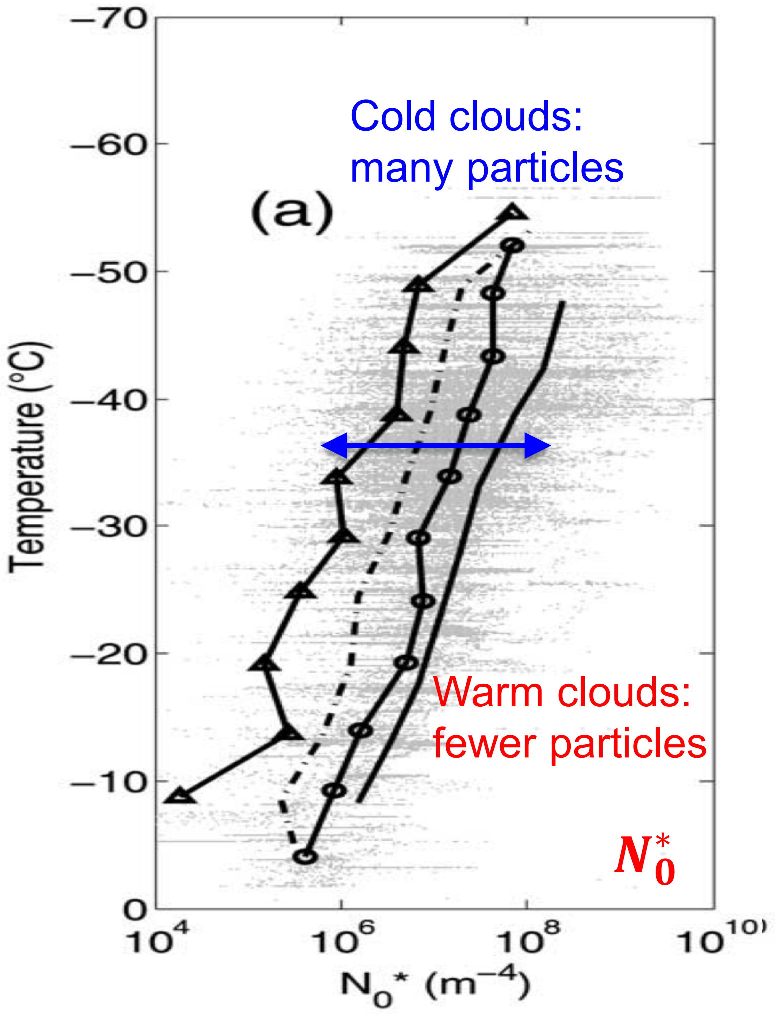
$$N(D) = N_0^* F\left(\frac{D}{D_0}\right)$$

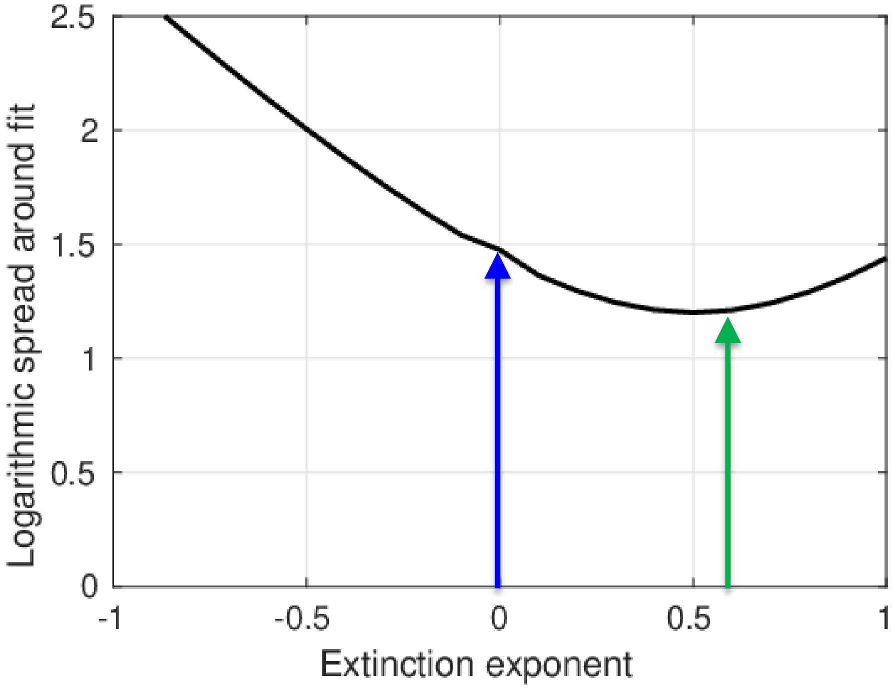
where the universal shape function $F(x)$ can be fitted to aircraft data

Any moment can then be computed

What if we have only one measurement?

- Deep in ice cloud lidar is extinguished: only measure radar reflectivity
- Need a temperature-dependent prior assumption for another variable





Delanoe & Hogan (2008) found that

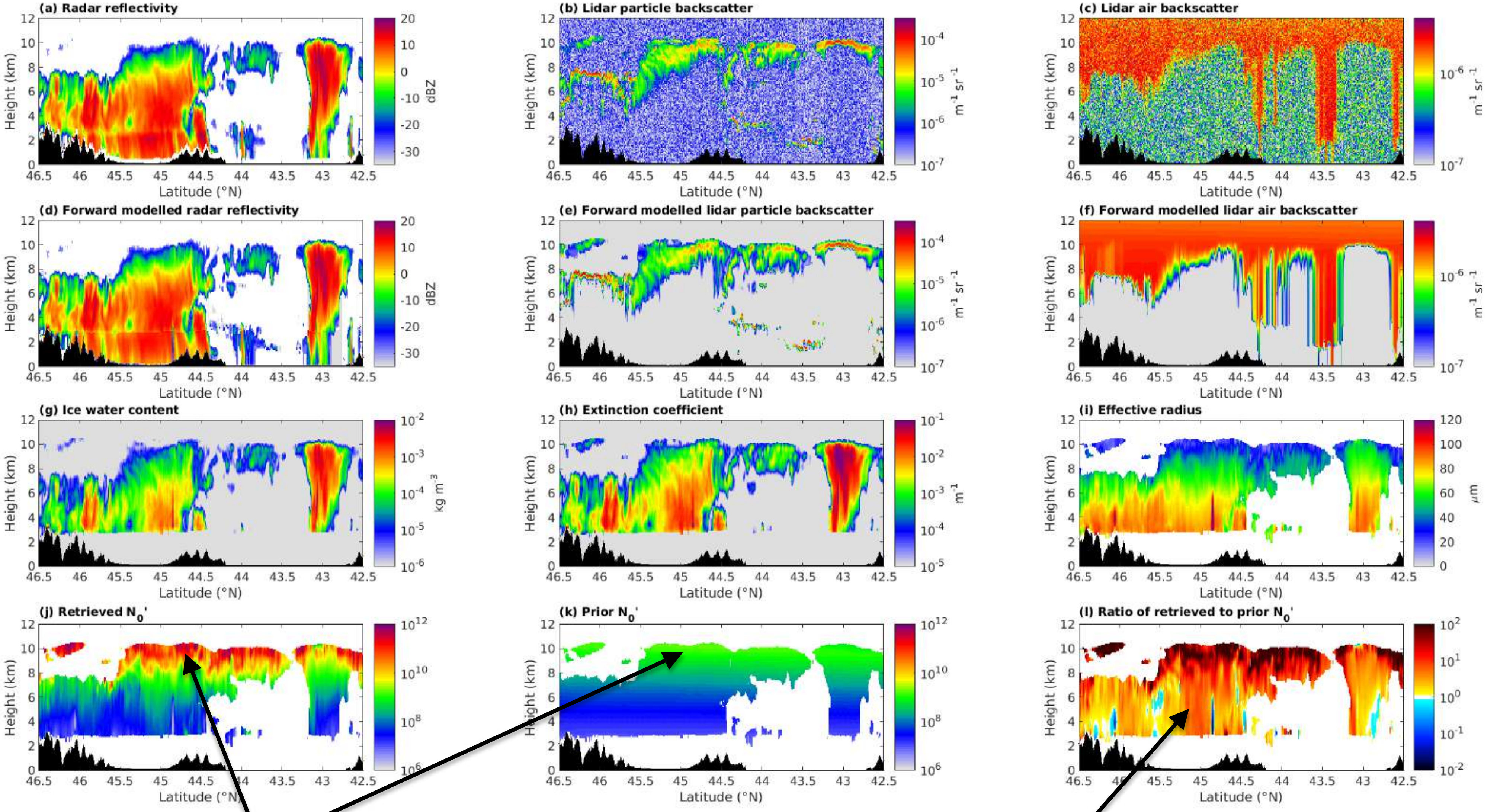
$$N_0' = N_0^*/\alpha^{0.6}$$

had least spread at given temperature

Use as temperature-dependent prior in ACM-CAP

Where do real EarthCARE observations pull the retrieved N_0'?

- Observations
- Forward model
- Retrievals
- "N_0 prime" retrievals

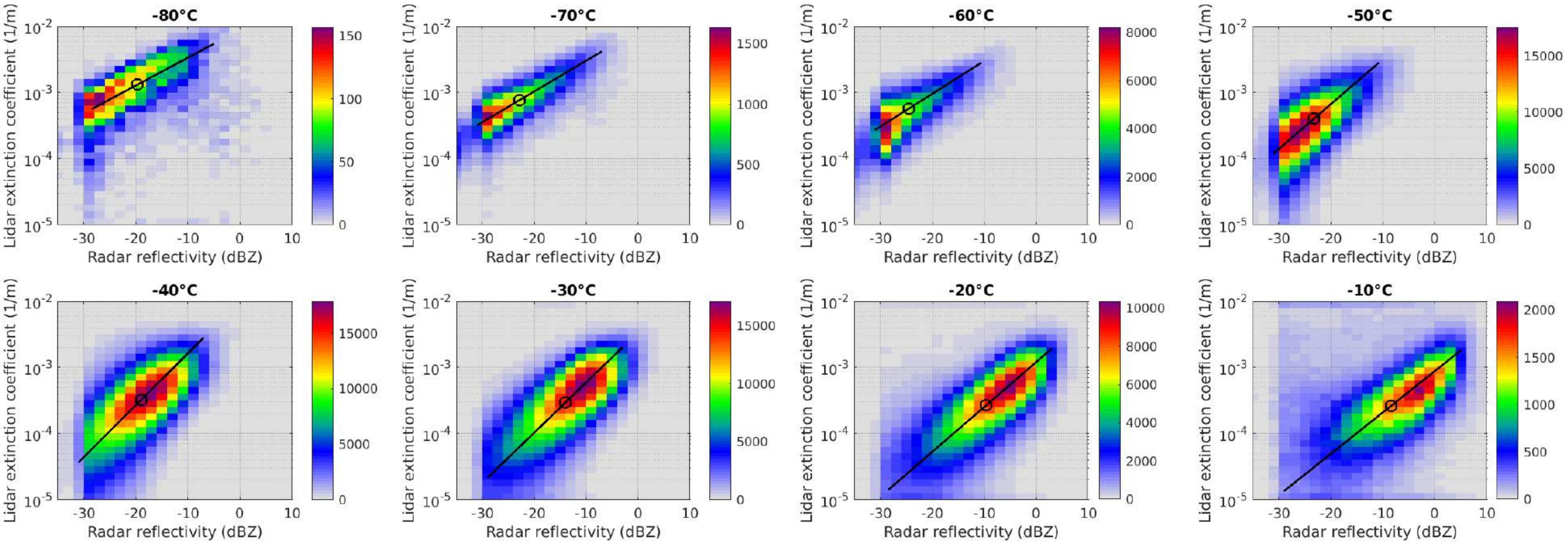


Radar & lidar observations at cloud top imply much larger N_0' than prior!

Also, solar radiances pull the entire column to higher N_0' (not available at night)

Extinction (from A-EBD) versus radar reflectivity and temperature from 50 frames

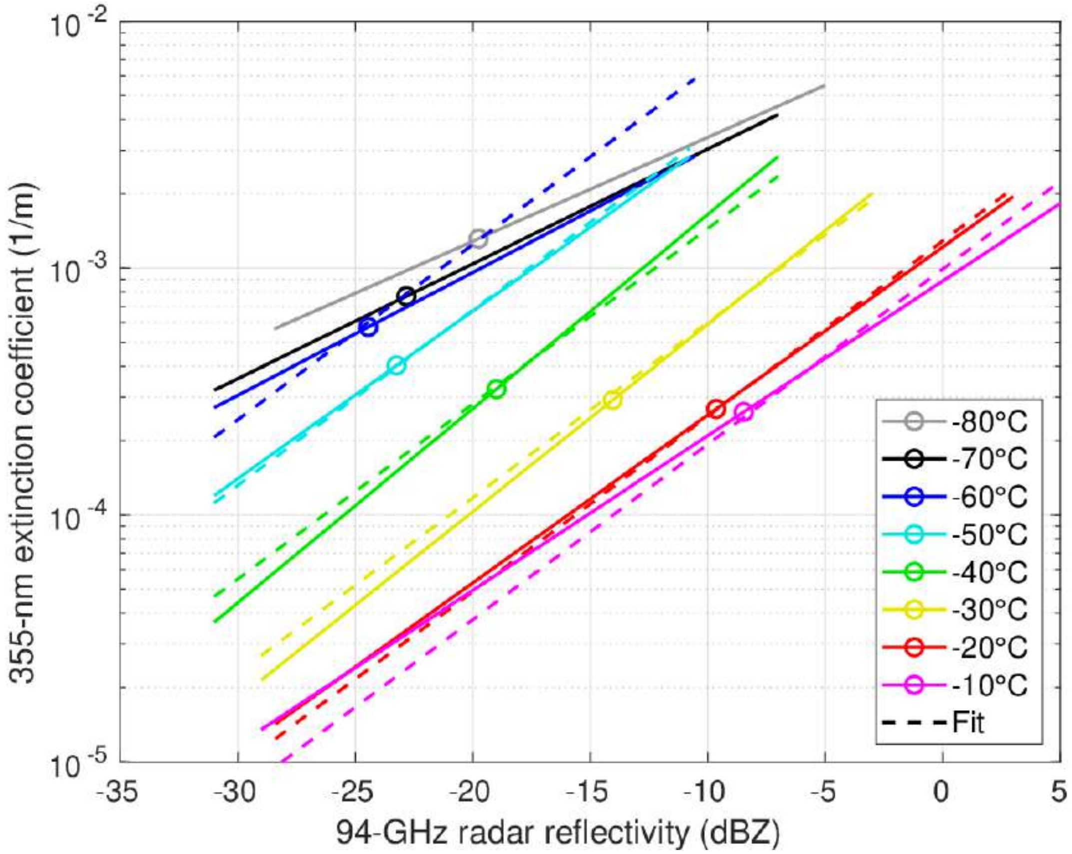
- Idea: use coincident radar and lidar observations to characterize temperature dependence of N_0'
- Use as new prior assumption to spread this information into clouds detected only by one instrument
- Only possible with EarthCARE via its HSRL-retrieved extinction!



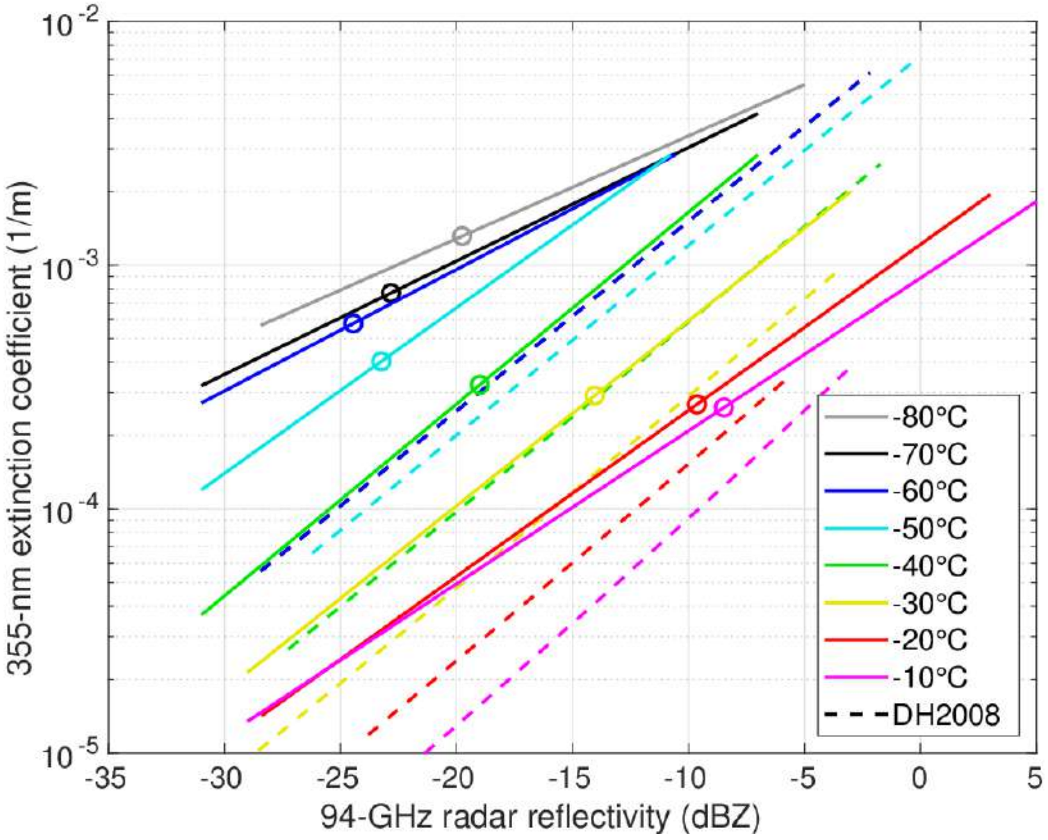
Black line shows the "SD line" whose slope is the ratio of the standard deviation of the two dimensions

Parametric fit

- Best fit: $\alpha = 10^{0.071Z[\mathrm{dBZ}]-0.038T[°\mathrm{C}]-3.65}$
- Limit T-dependence to $-57°\mathrm{C} < T < -17°\mathrm{C}$



*Existing ACM-CAP prior relationship from Delanoe & Hogan (2008) underpredicts extinction from Z & T by a **factor of three**!*

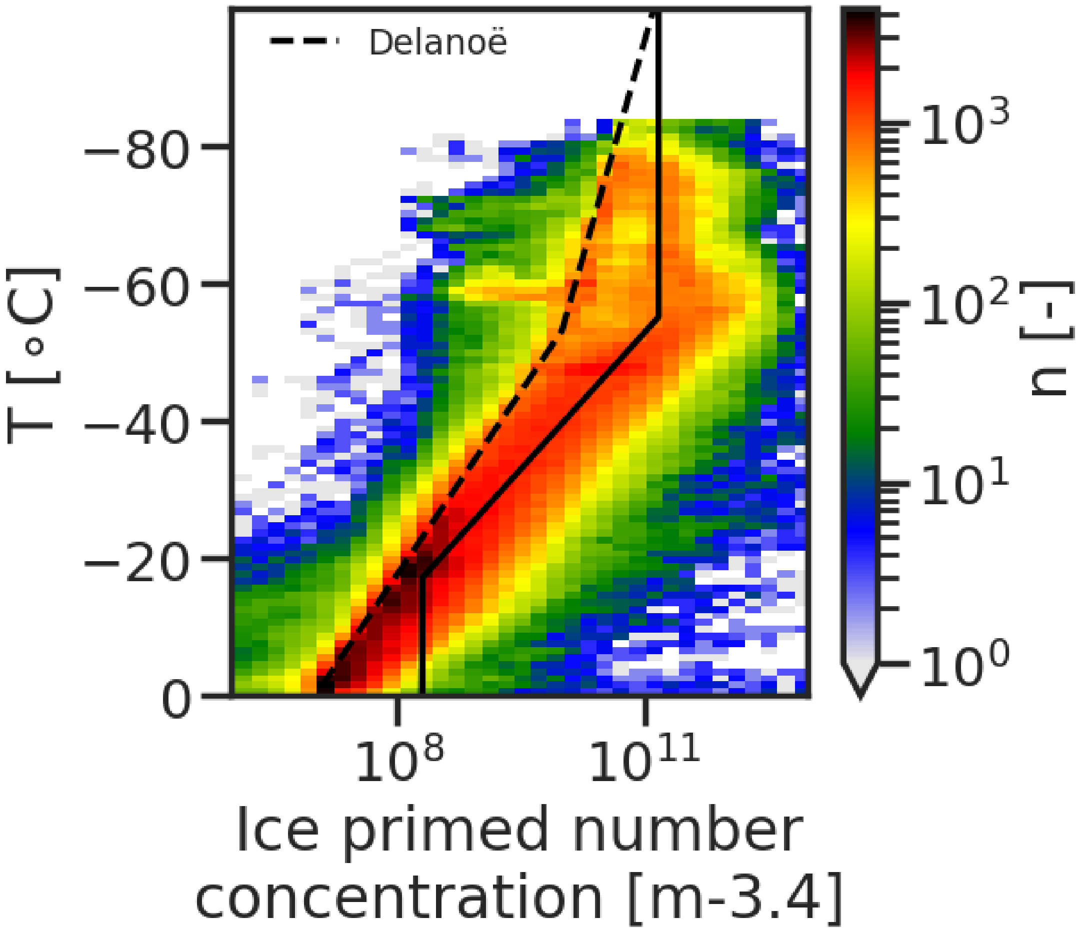


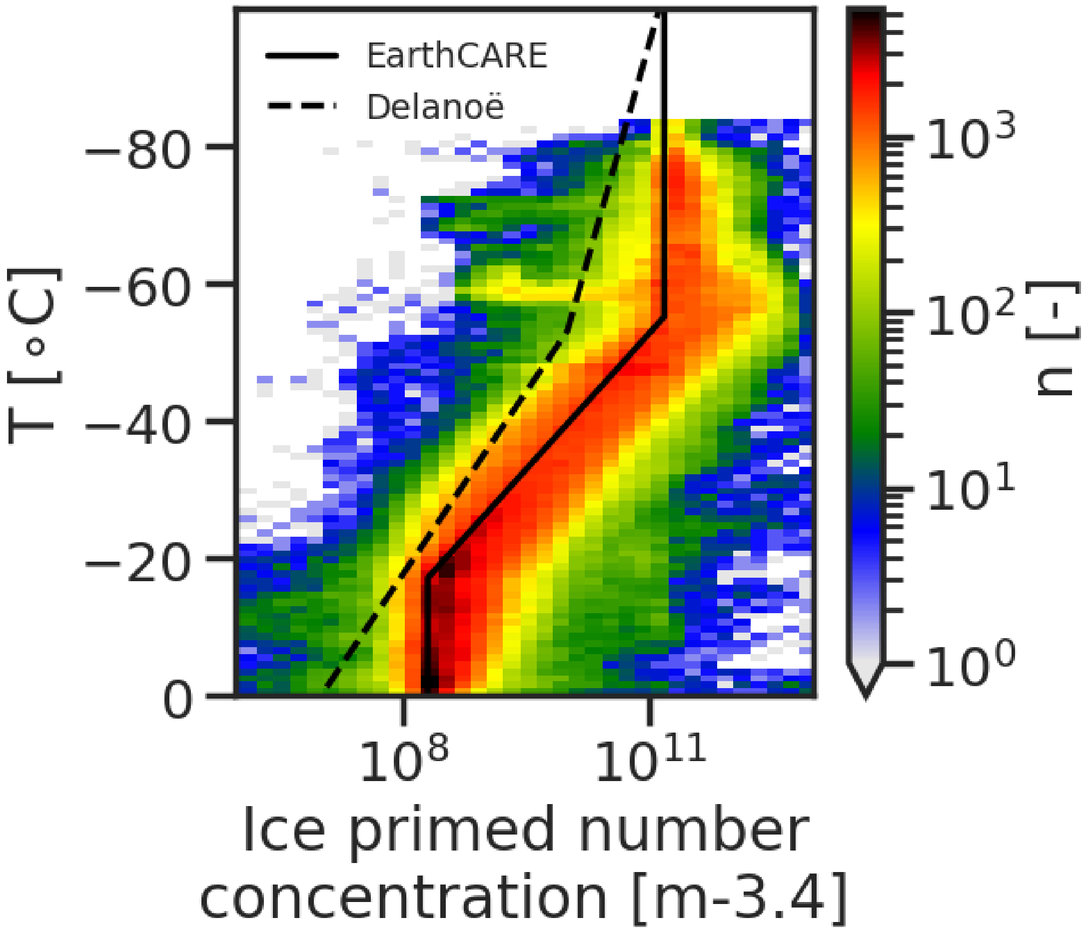
- Can calculate implied N_0' as a function of temperature, and use as new prior constraint in ACM-CAP
- This is also useful for radar-only retrievals

Distribution of N_0' retrievals from one orbit (01752)

- Original retrieval: pulls to higher N_0' than the Delanoe & Hogan prior (dashed line) except when only one instrument available

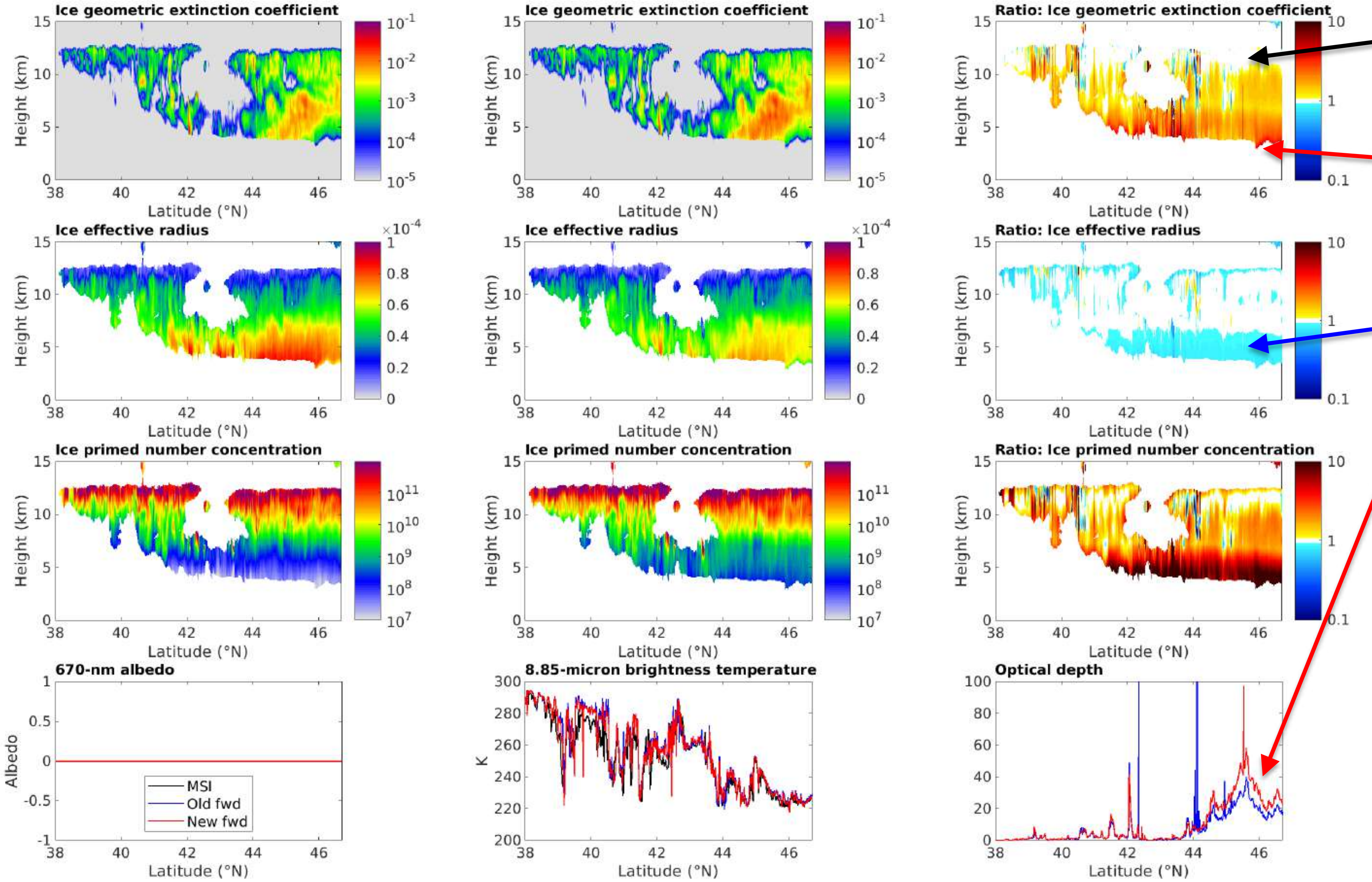
- New retrieval: **new N_0' prior** from EarthCARE's extinction(Z,T) sits close to middle of retrievals
- *Can we use a similar approach with other a priori constraints for other cloud types?*





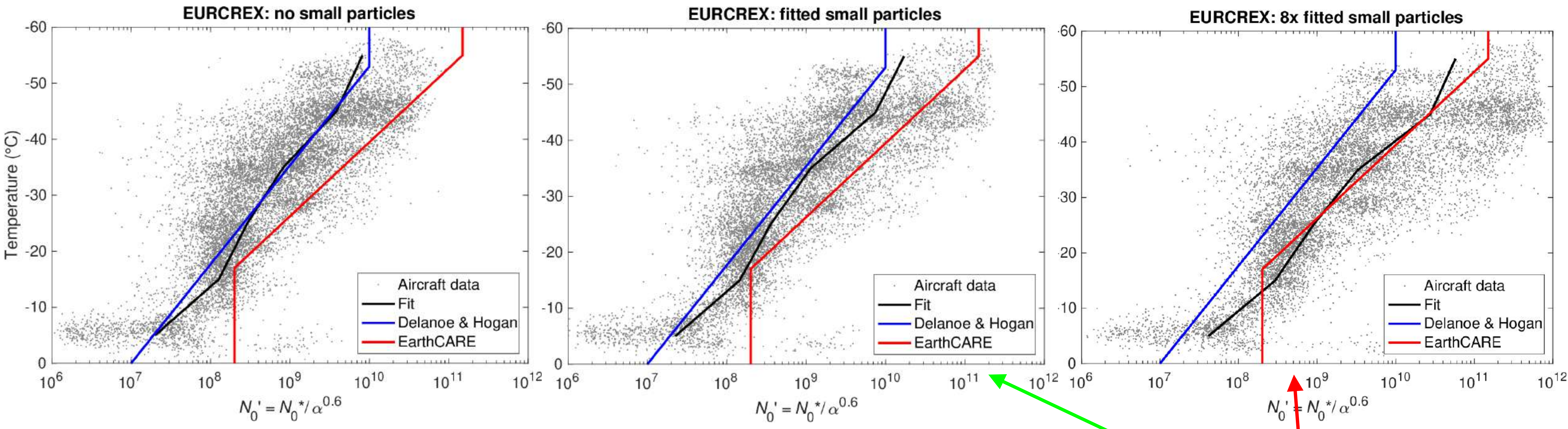
Impact of new N_0' prior on nighttime retrievals: 01752B

Old retrieval | **New retrieval** | **Ratio**

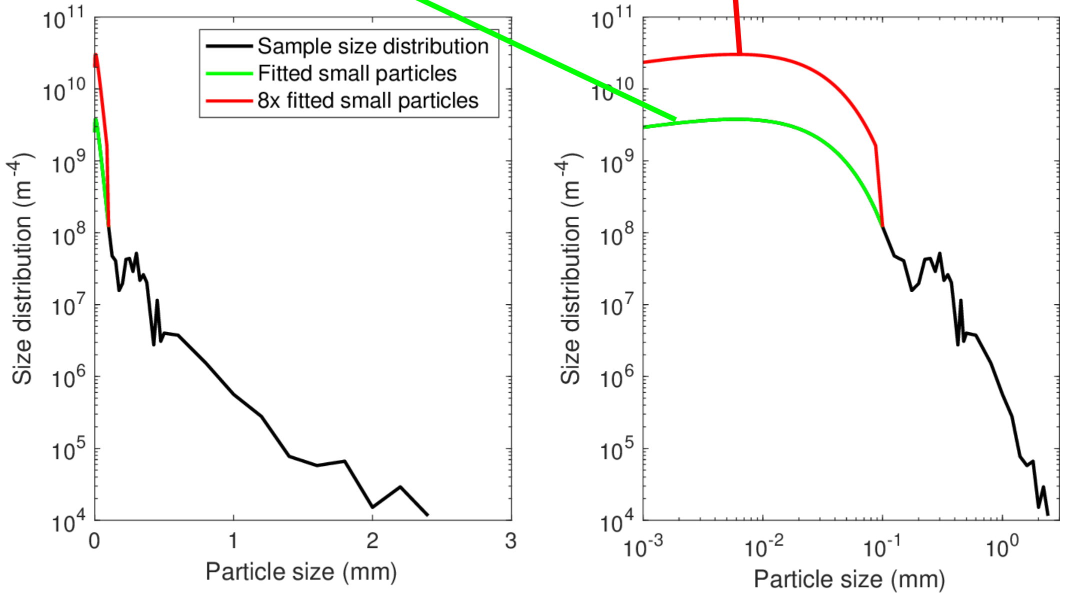


- Extinction near cloud top **unchanged**: well sampled by radar and lidar
- **Larger extinction** deeper in the cloud where we have only radar, because N_0' reverts to new prior implying **smaller** more numerous particles
- **Higher optical depth!**
- *Urgently need in-situ verification with latest cloud probes sampling < 100 microns! Use VERIFY/ECALOT?*
- *Cloud-top info from lidar may not be representative of whole cloud!*

New N_0' parameterization: does EarthCARE imply many more small ice particles?



- Recall that Delanoe & Hogan (2008) fitted to ice size distributions with no particles smaller 100 microns
- EarthCARE extinction/reflectivity/temperature relationship can be reconciled with aircraft data only if we use Hogan & Illingworth's (2003) **fit of small particles by extrapolation, then multiply by eight!**
- *Need underflights with FAAM aircraft!*



Ice-cloud effective particle size parameterization based on combined lidar, radar reflectivity, and mean Doppler velocity measurements

D. P. Donovan
Royal Netherlands Meteorological Institute, De Bilt, Netherlands

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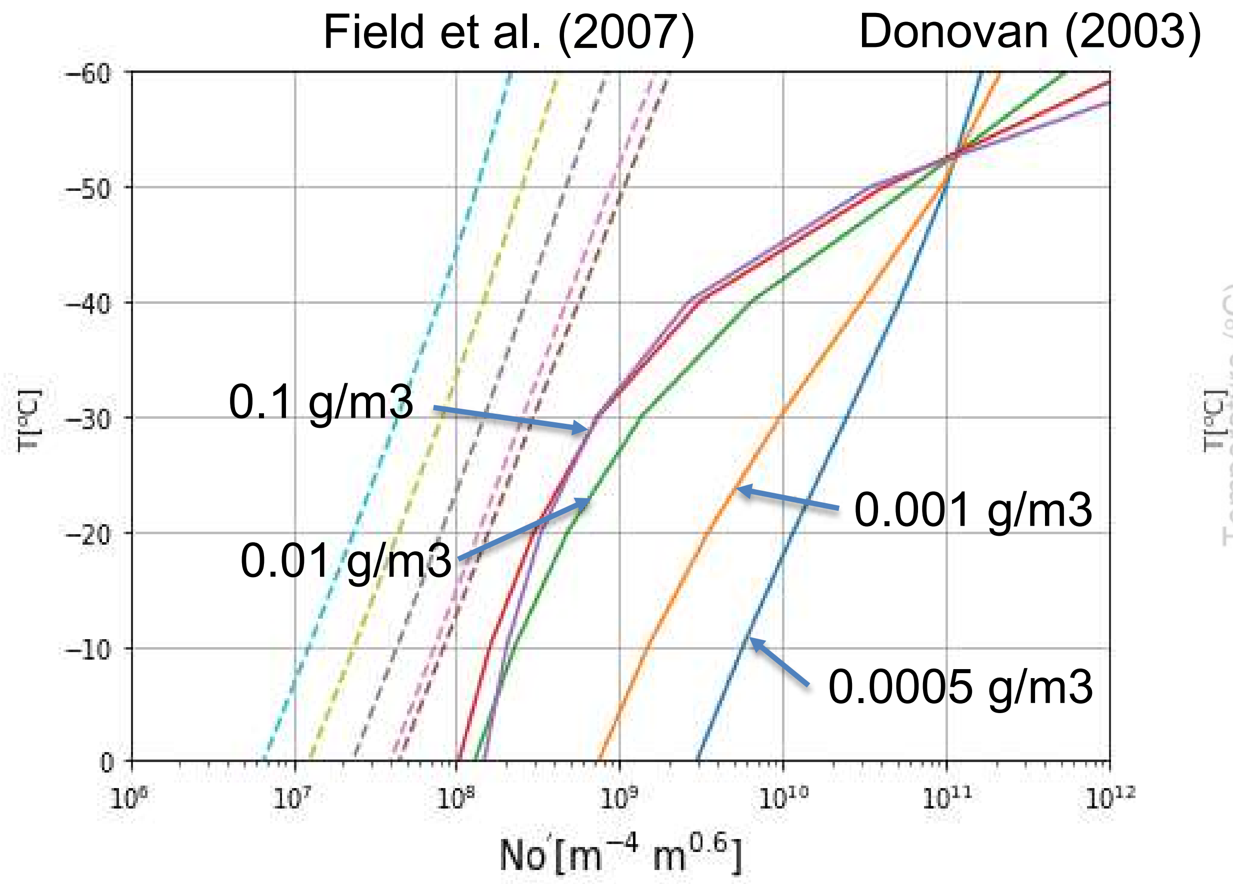
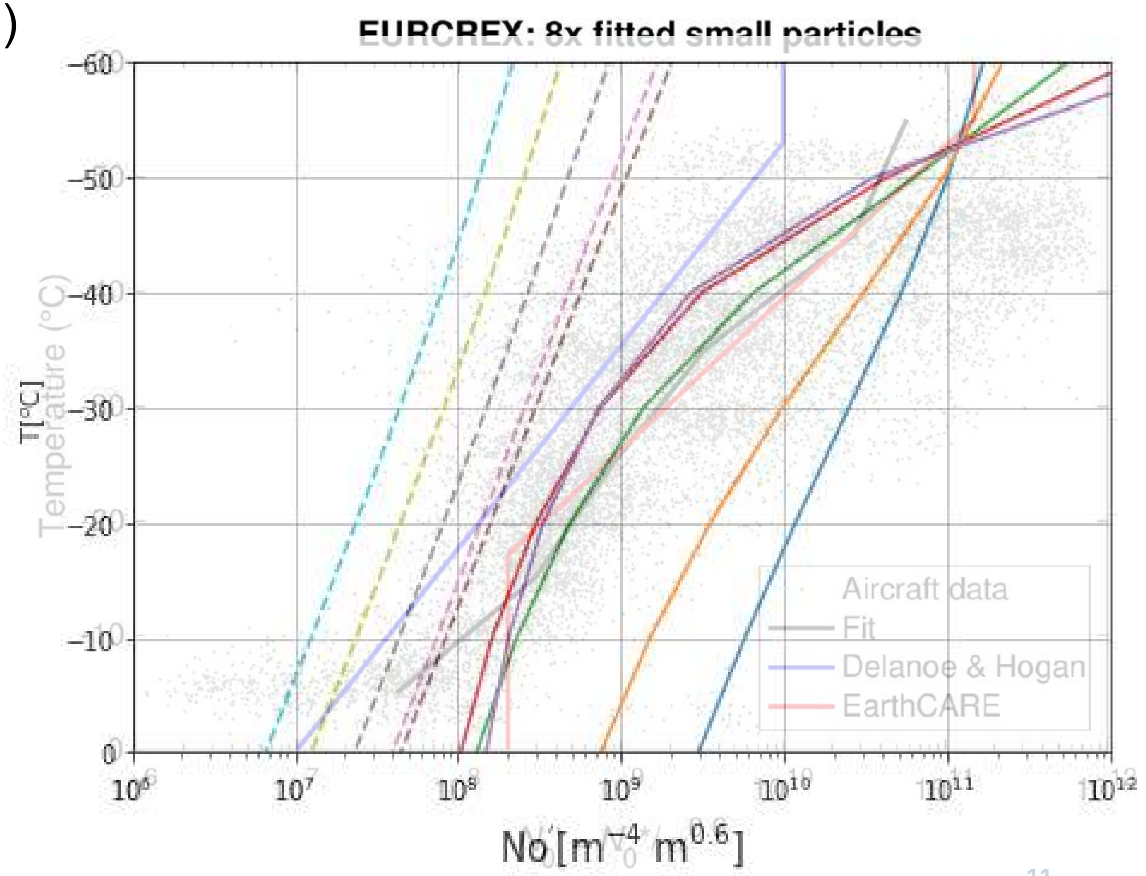
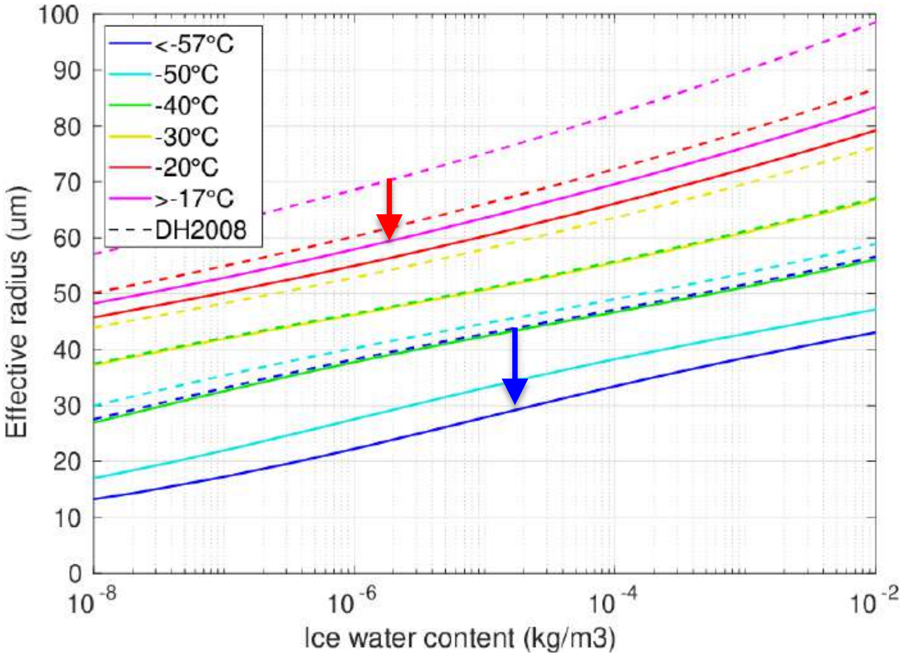
Very similar behaviour to inferences from ground-based radar and lidar retrievals!





Impact on effective radius



- An $N_0'(T)$ fit can be converted to an $r_e(\mathrm{IWC}, T)$ parameterization
- New N_0' implies effective radius ~10 microns lower than old
- This would have a substantial effect (~10%) on the radiative effect of ice clouds

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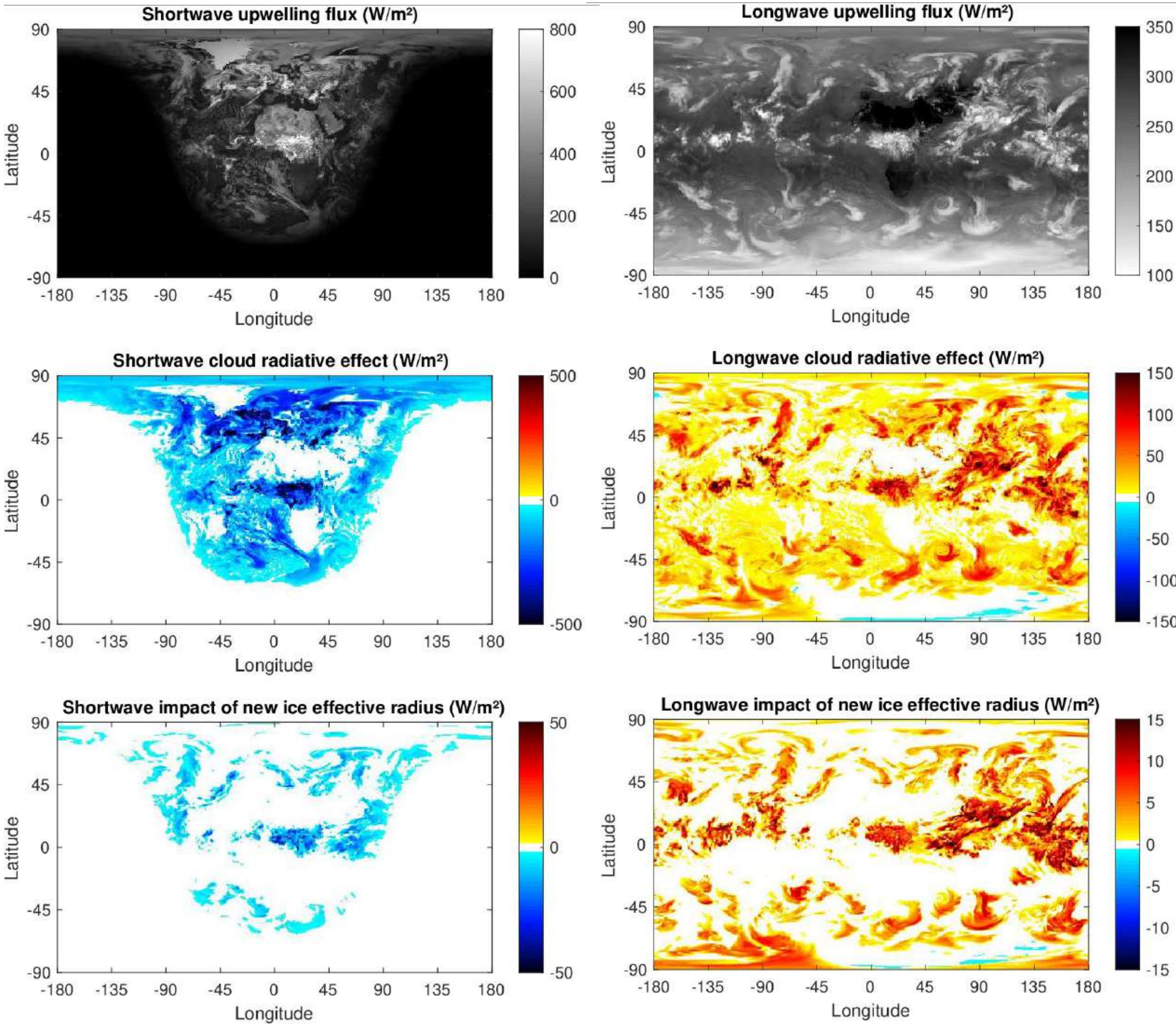

Summary

- ATLID extinction (*only possible with high spectral resolution lidar!*) finds ice clouds are three times more optically thick, at least at cloud top, than implied by analysis of aircraft data ignoring $D < 100\mu m$ particles
- We can modify the prior assumption of the N_0' parameter in ACM-CAP to improve retrievals, especially at night
- Could lead to improved ice effective radius assumptions in models

But…

- Can aircraft really be missing the implied number of small ice particles?
- Could it be because ATLID samples preferentially at cloud top?
  Donovan (2003) found the same thing from ground-based radar and lidar
- Need to:
  - test sensitivity to assumed mass-size and area-size relationships
  - additional campaign data to verify (or disprove) this finding!