Detection and attribution of cloud and precipitation adjustments to aerosol perturbations

Fast cloud adjustments to aerosols (S1)

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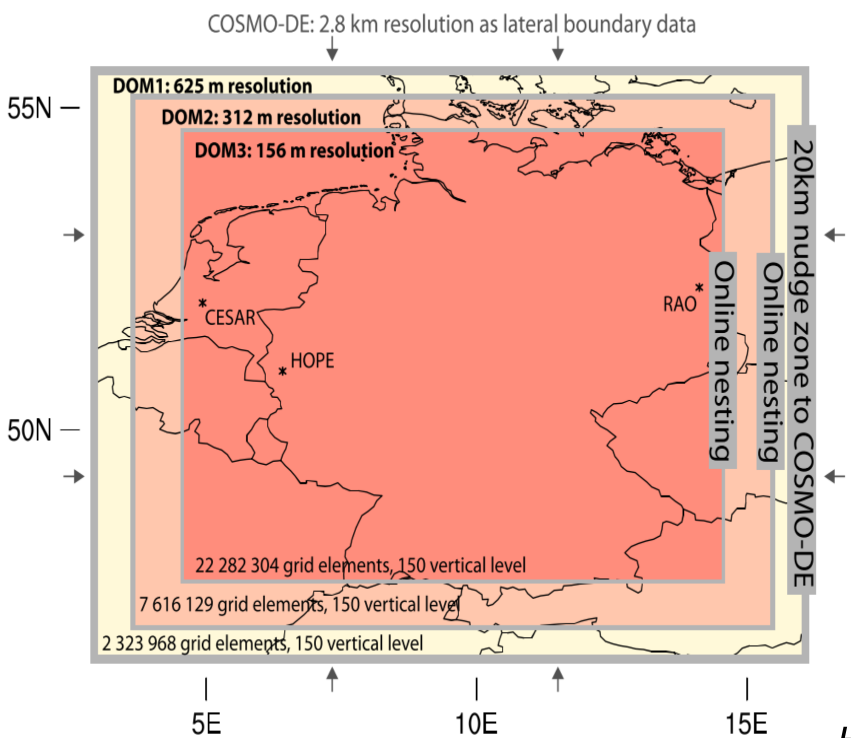
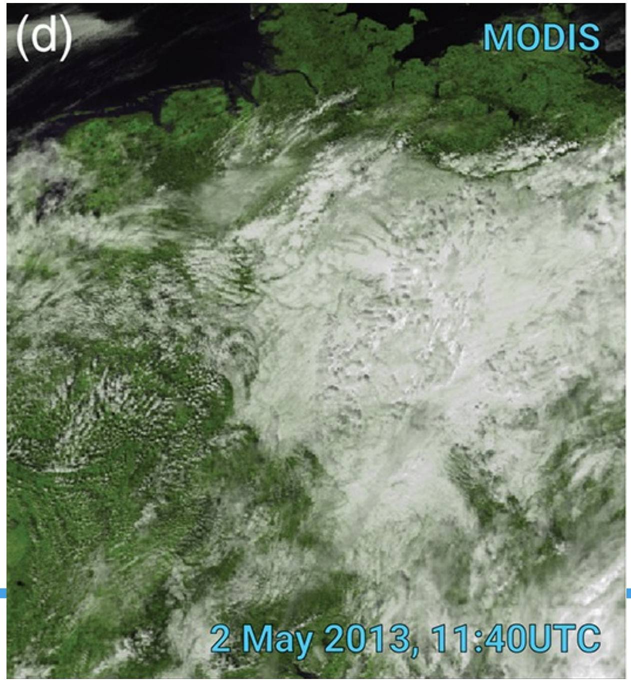
Motivation

Investigate key uncertainty in climate predictions: the response and adjustments of clouds and precipitation to anthropogenic aerosol emissions, by the detection and attribution of **aerosol-cloud interactions**.

How to investigate aerosol-cloud interactions?

- Improved ICON-LEM-DE high resolution (156 m) simulations on the 2 May **2013** with current cloud condensation nuclei (CCN) concentrations (as **control** run) and with those from **1985** (as **perturbed**).





Heinze et al. (2017), Q.J.R. Meteorol. Soc.

How to investigate aerosol-cloud interactions?

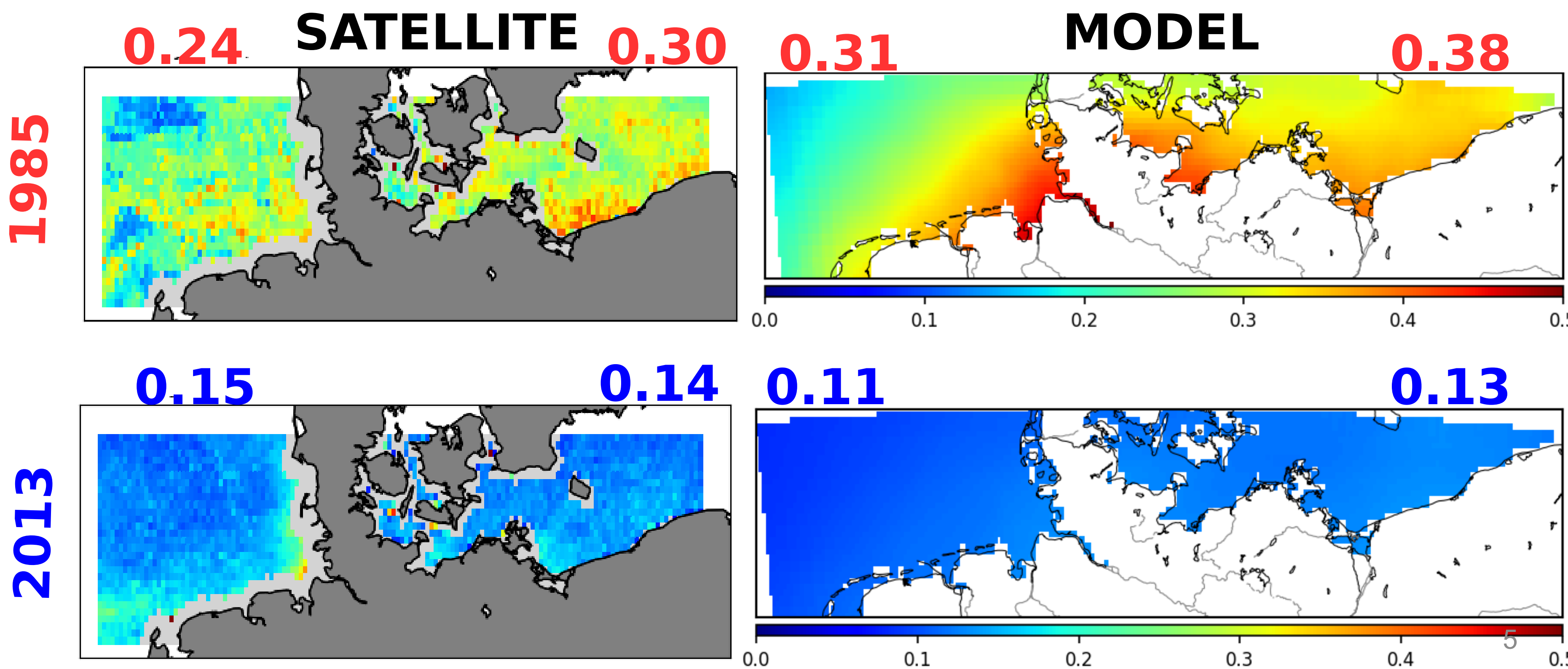
- Improved ICON-LEM-DE high resolution (156 m) simulations on the 2 May **2013** with current cloud condensation nuclei (CCN) concentrations (as **control** run) and with those from **1985** (as **perturbed**).
- A prerequisite for realistically simulating the cloud adjustments to aerosol cloud interactions (aci) is a realistic prescription of aerosol in the model.
- New time-varying 3D distributions of CCN concentration have been derived using the COSMO-MUSCAT model specifically for 02/05/2013 and for 1985 (i.e. peak of pollution in Europe) from comprehensive aerosol modelling.

How realistic 3D-CCN inputs are?

CCN perturbation

- Aerosol optical depth from AVHRR (sat.) and simulation

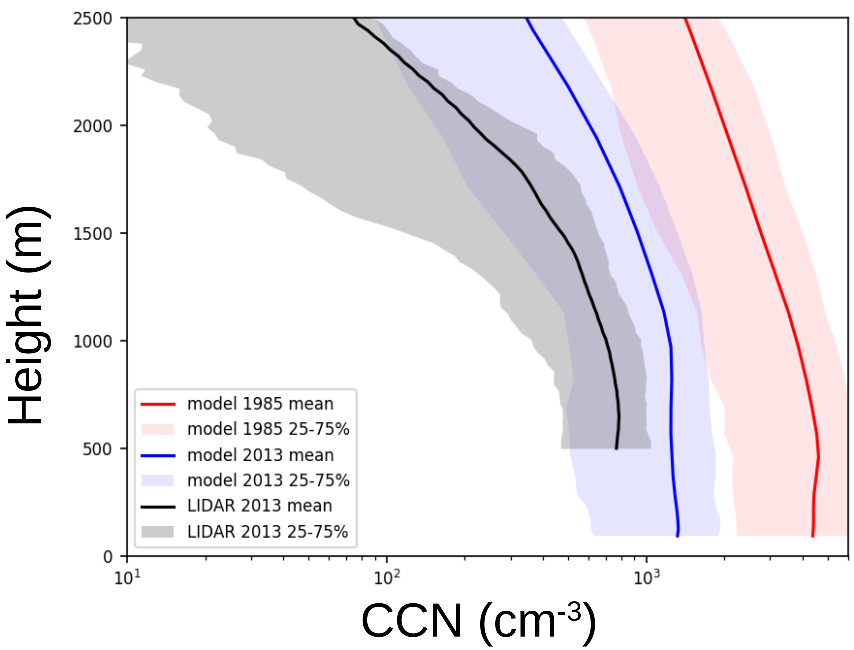
Mean AOD over North and Baltic Sea are realistic
~2x AOD



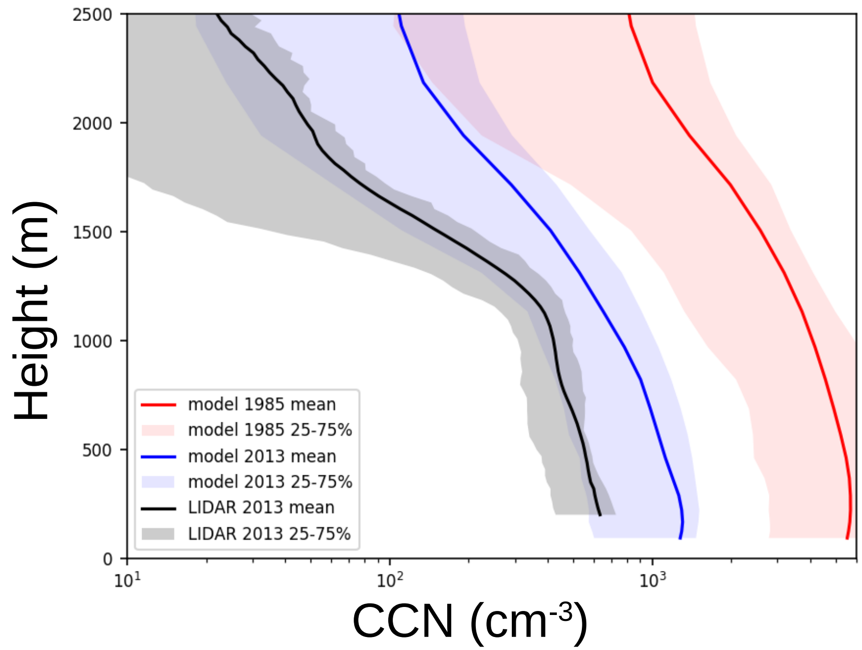
Costa-Surós, M. et al. (in preparation)
Source: König, M., Madrenach, N. and Schrödner, R.

CCN perturbation

- Lidar derived CCN profile vs model
  - Control run overestimates the obs. (~ 20 %), however, mostly within 25 / 75% percentile.
  - Perturbed CCN estimate is far above 2013 observations (2-4 factor than control).



Krauthausen , HOPE (May 2013)

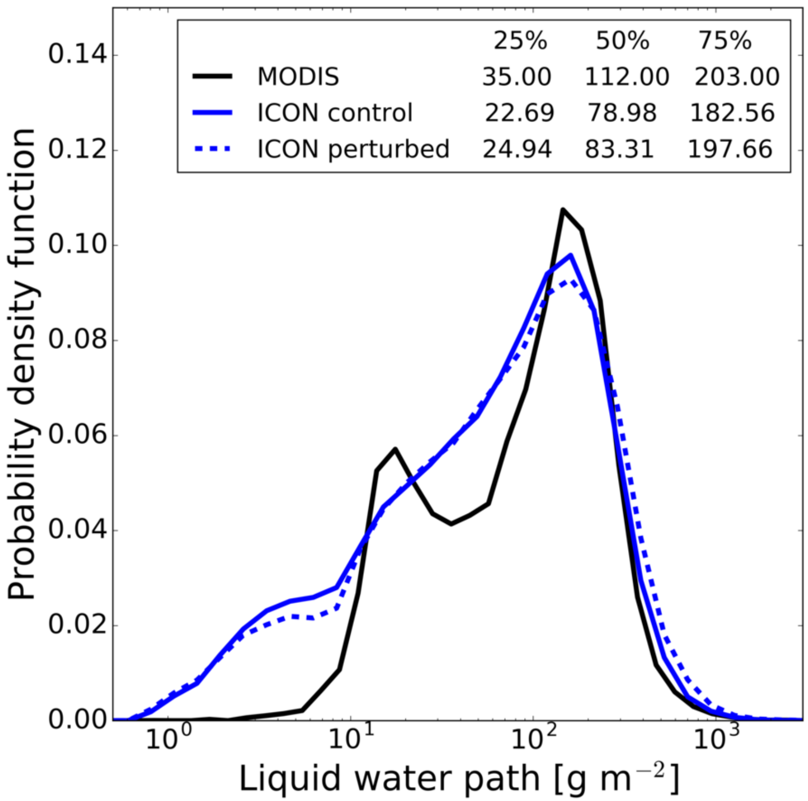


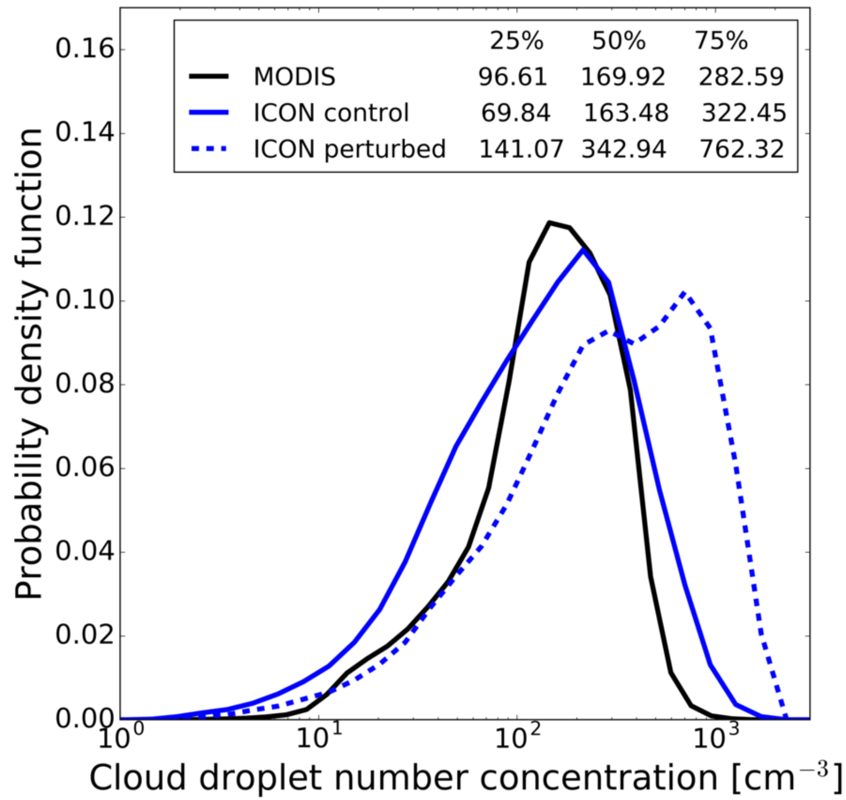
Melpitz (September 2013)

Costa-Surós, M. et al. (in preparation)
Source: Baars, H., Engler, C. and Schrödner, R. (TROPOS)
CCN from lidar as in *Mamouri and Ansmann (ACP 2016)*

Detectability in observations (LWP and Nd)

- From satellite: MODIS vs COSP (sat. simulator) applied to ICON-LEM output





Costa-Surós, M. et al. (in preparation)
Source: Carbajal-Henken, C. and Sourdeval, O.

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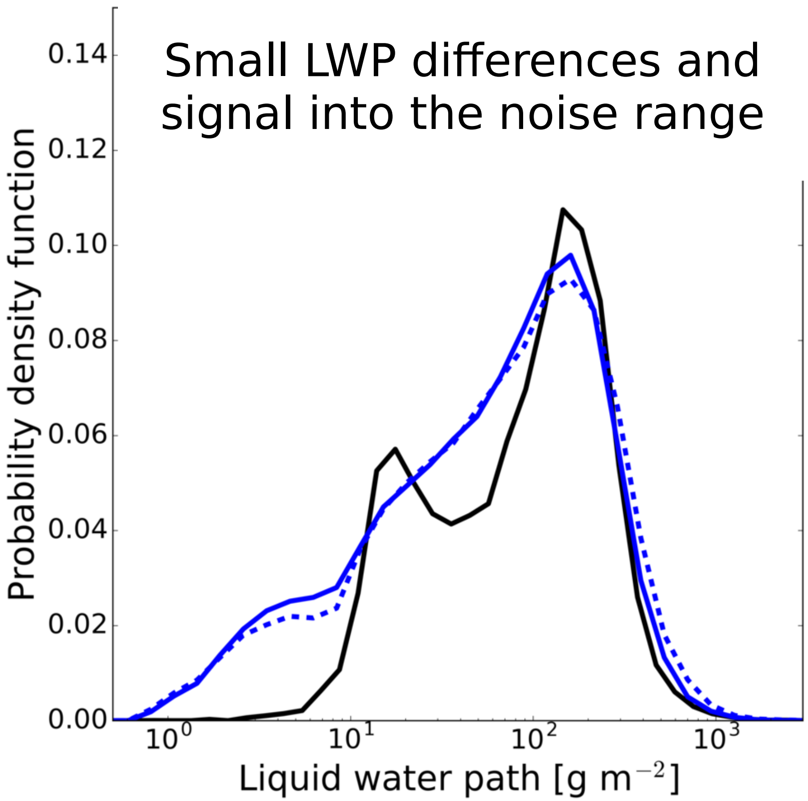
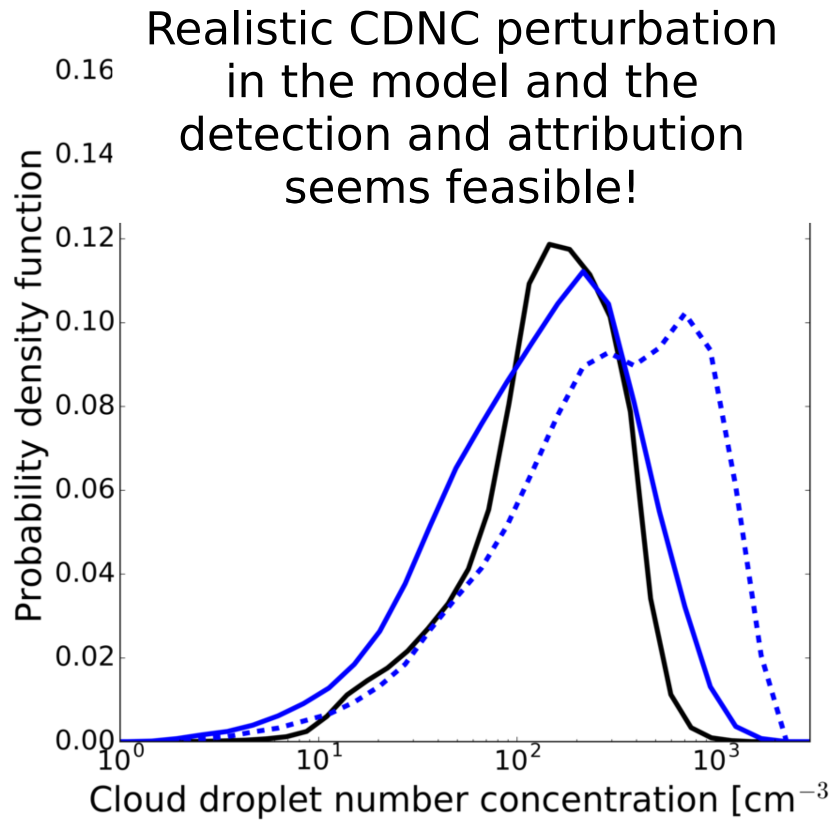


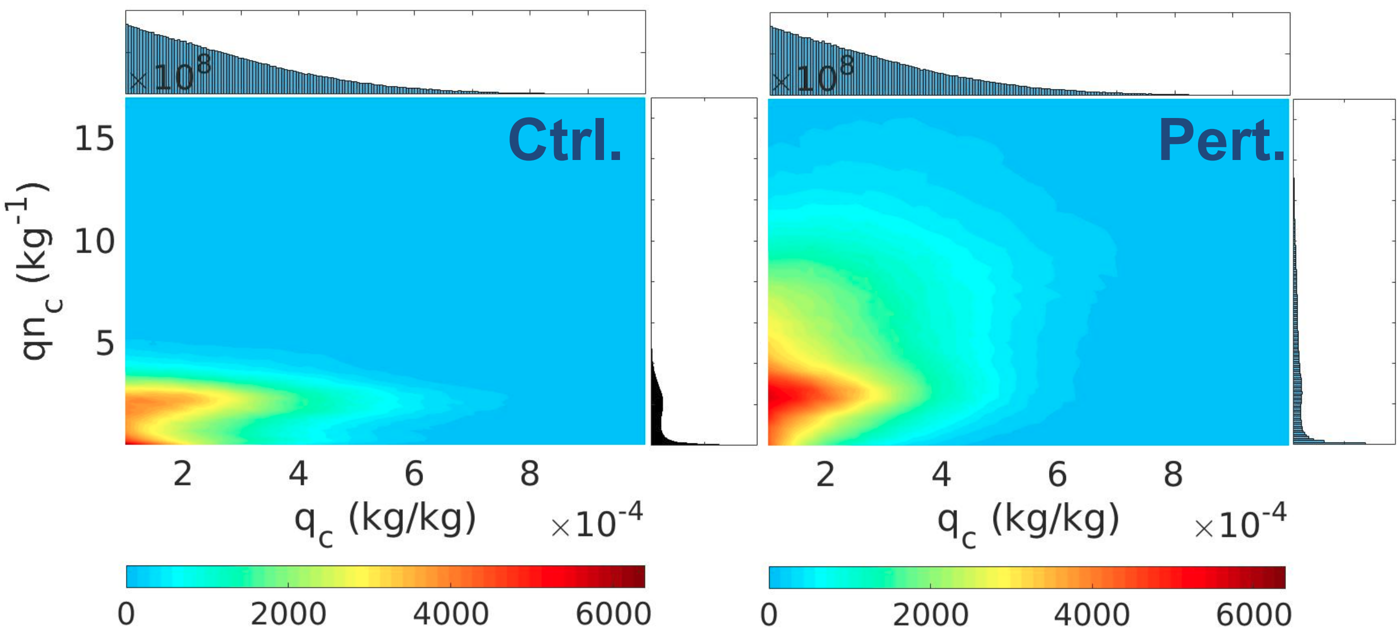


Costa-Surós, M. et al. (in preparation)
Source: Carbajal-Henken, C. and Sourdeval, O.

Cloud albedo effect

- More CCN should lead to more frequent but smaller cloud droplets (for a constant liquid water content)
- Findings (snapshot at 8 h):
  - Cloud number concentration (qnc) increased
  - Specific cloud water content (qc) almost the same

  } Smaller cloud droplets



Costa-Surós, M. et al. (in preparation)

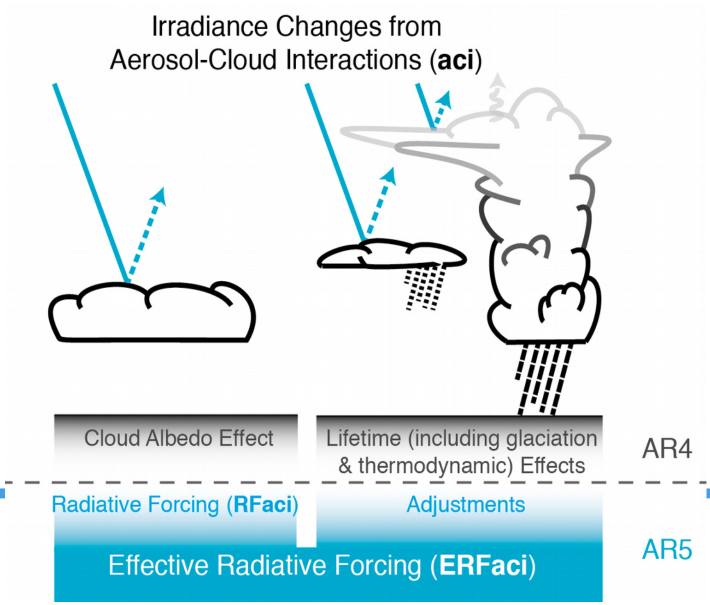
Cloud albedo effect

- Smaller cloud droplets increase the cloud albedo effect: more solar radiation is reflected back to the space ⟶ **ERFaci: -2.62 Wm^{-2}**

But, how we know that these changes are mainly due to **cloud albedo** effect?

Cloud albedo effect

- Two more simulations have been run for the same dates and CCN profiles but switching off the interactive microphysics radiation module.
- The radiation changes between control and perturbed simulations will be only due to the adjustments. Therefore we can calculate the RFaci (Cloud albedo effect):



Changes in net solar radiation at TOA (domain mean values):

ERFaci = RFaci + adjustments

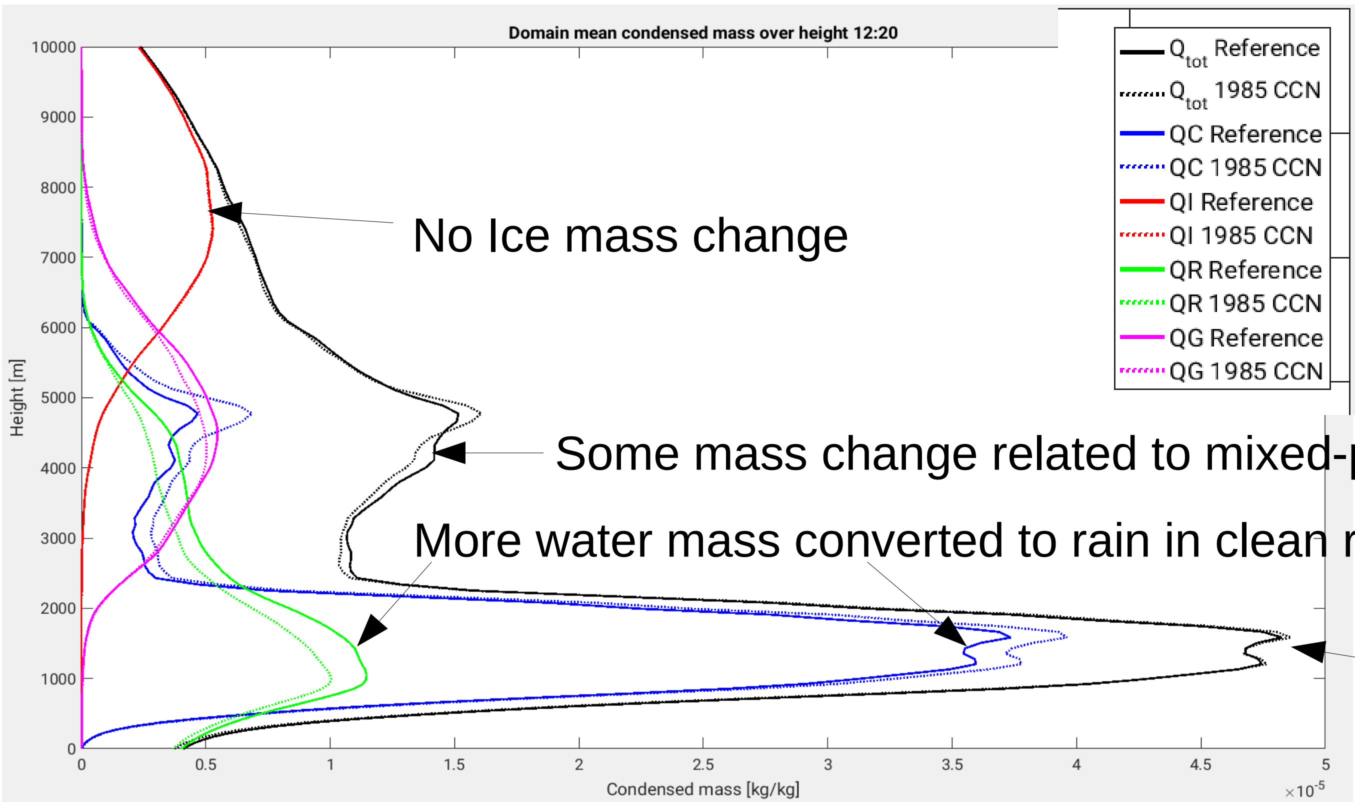
RFaci: $-2.62\ Wm^{-2}$

adjustments: $+\ 0.23\ Wm^{-2}$

ERFaci: $-2.85\ Wm^{-2}$

Boucher et al. (2013), 5th report IPCC

Mass vertical profiles



No Ice mass change

Some mass change related to mixed-phase

More water mass converted to rain in clean reference case

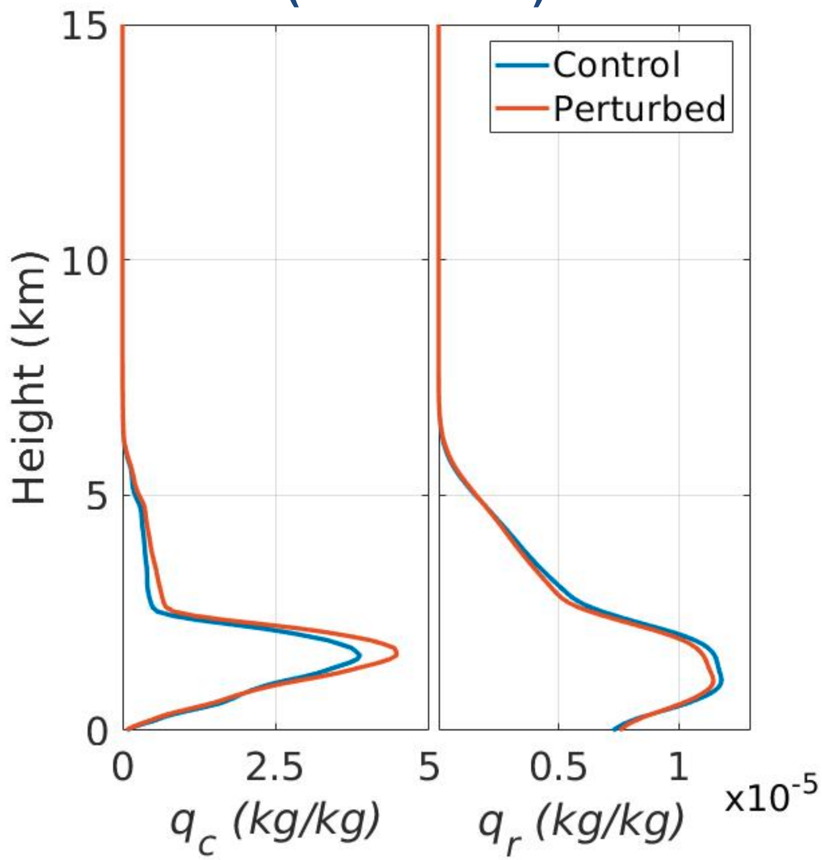
Almost no mass change

Costa-Surós, M. et al. (in preparation)
Source: Hesemann, J. and Hoose, C.

Effects on precipitation

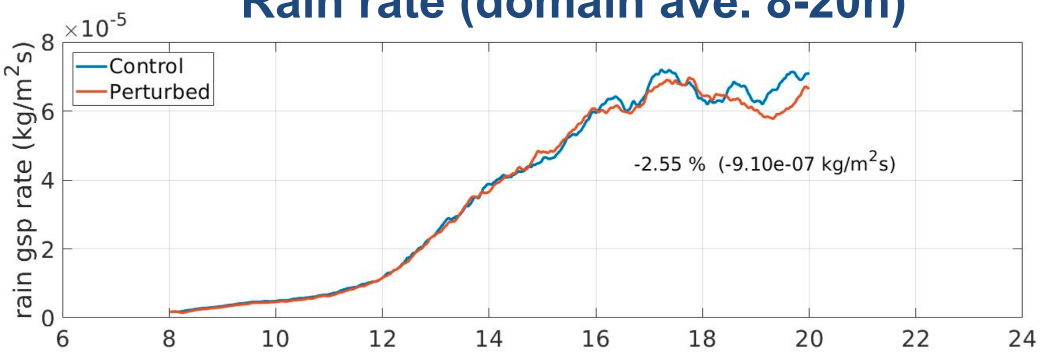
- With smaller cloud particles collision-coalescence should be reduced
  - Increased cloud water content
  - Rainfall suppression **-2.55 %**

Cloud water and specific rain content (ave. 8-20h)



Costa-Surós, M. et al. (in preparation)

Rain rate (domain ave. 8-20h)



University of Cologne

HD(CP)²
High definition clouds and precipitation for advancing climate prediction

Summary

Variable	Change (%)
TOA net solar radiation RFaci	- 0.58 % (- 2.62 Wm^{-2}) -2.85 Wm^{-2}
TOA net thermal radiation	-0.09 % (+ 0.21 Wm^{-2})
Mean cloud cover	+ 0.20
Cloud droplet no. concentration	+ 148
Water vapor path	- 0.02
Liquid water path	+ 11.1
Ice water path	+ 0.04
Rain rate	- 2.55
Cloud base pressure	- 0.17
Cloud top pressure	- 0.35

Conclusions

- High resolution ICON-LEM runs with realistic CCN perturbation:
  - Good agreement of AOD (satellite) and CCN (ground-based).
  - 2/5/2013 intensively validated.
- Response of model to CCN changes:
  - Nd perturbation realistic in model: detection and attribution feasible.
  - Small changes in LWP - signal in the noise range.
  - Implications to radiation budget: ERFaci and RFaci clearly negative.
  - Effects on precipitation: increased cloud water and suppressed rain.
- ICON model simulations provide useful tool for detecting and studying aerosol effects in clouds and precipitation.
- OUTLOOK:
  - Investigate mixed and frozen phase clouds
  - Study the resolution dependency