Investigating the response to doubling the CCN concentration in ICON LEM simulations

Fast cloud adjustments to aerosols (S1)

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ACPC - Bad Honnef - Physiczentrum, 4th April 2017

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

Motivation S1

Investigate key uncertainty in climate predictions:
cloud adjustments to anthropogenic aerosol emissions implying an effective radiative forcing from -1.3 to 0 Wm^{-2}

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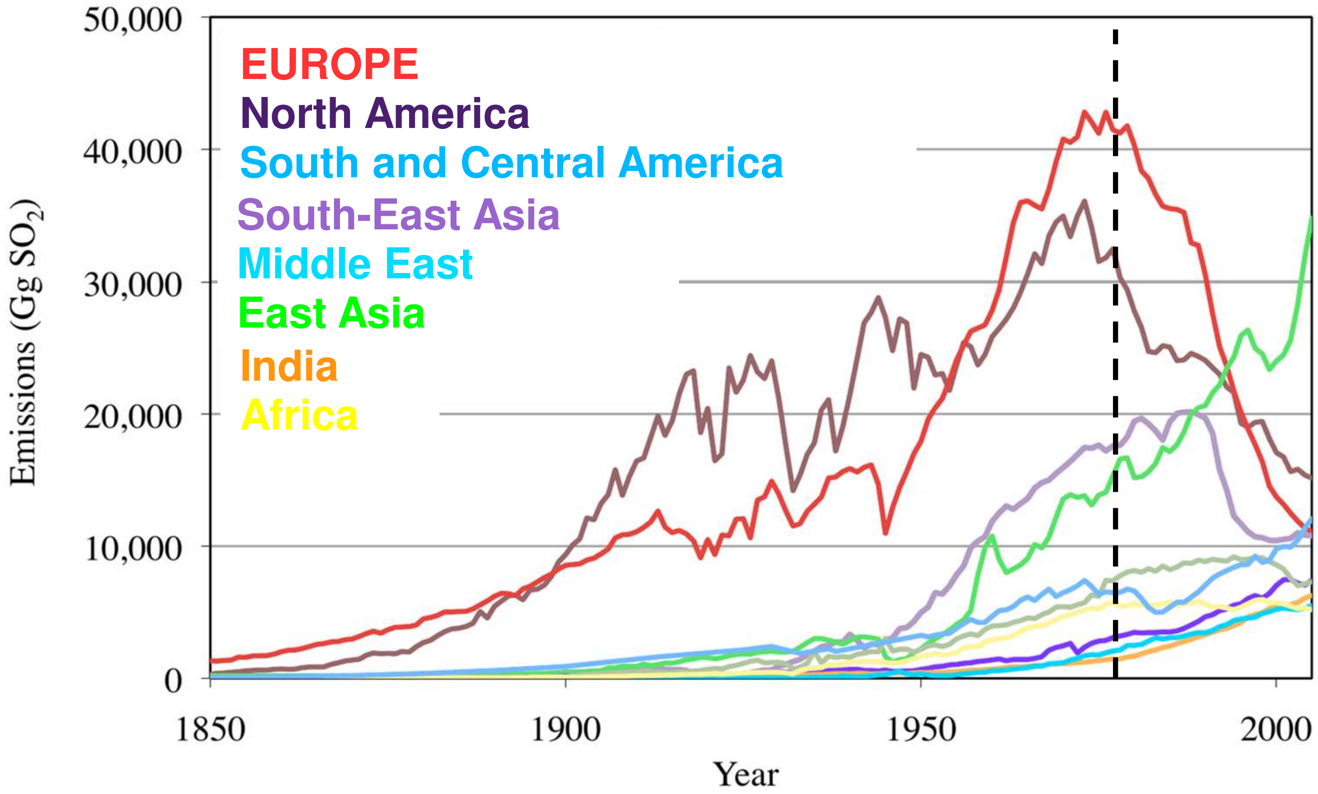
- Perform sensitivity studies with different aerosol concentrations using the high resolution cloud resolving model (ICON-LEM)
- Improve representation of relevant processes (activation, contrails) in ICON-LEM
- Evaluate simulations using supersite and satellite observations
- Detect and attribute the simulated cloud adjustments

Global Anthropogenic SO_2 Emissions

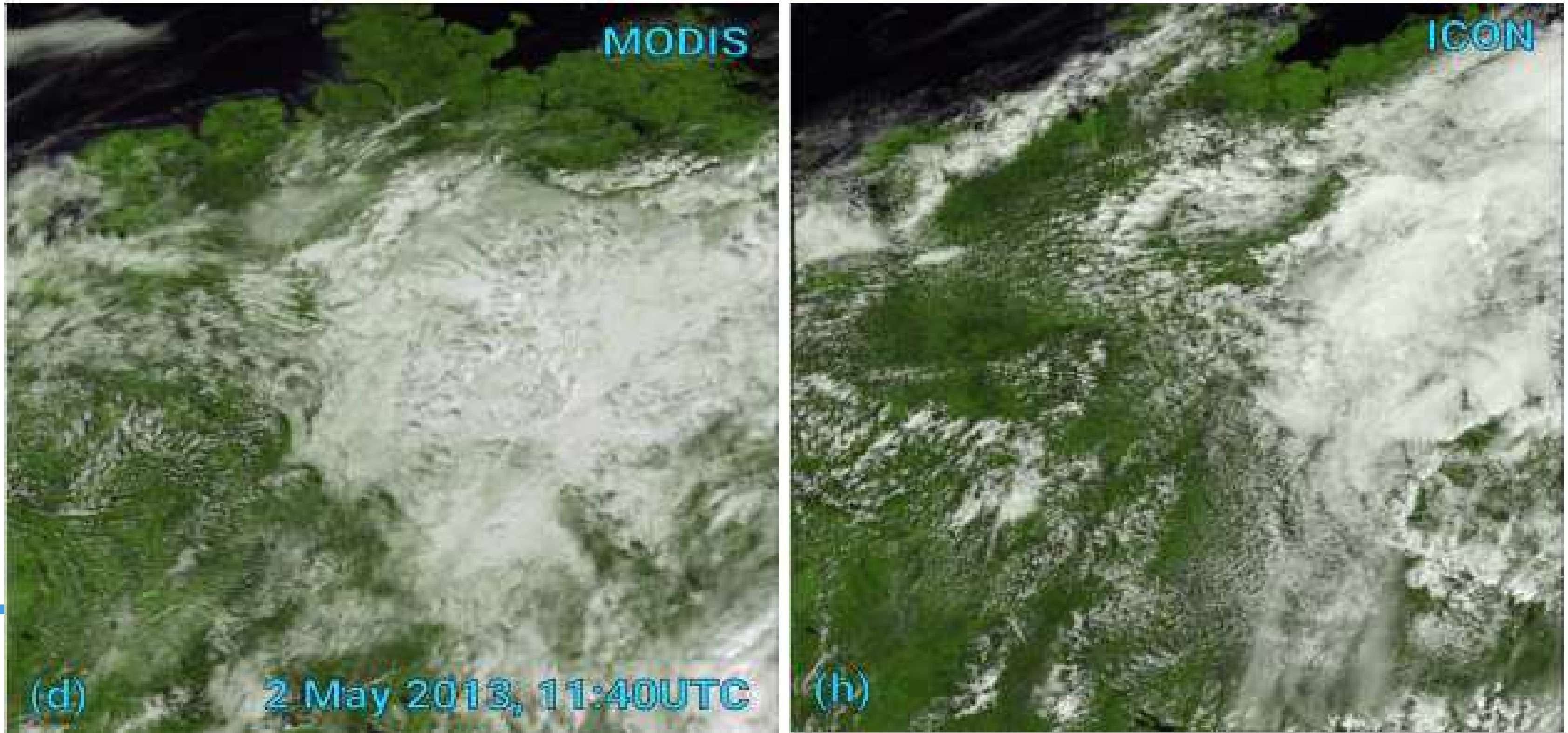


First test:
Assume 50% CCN reduction from 1980's compared to today

Smith et al. (2011), Atmos. Chem. Phys.

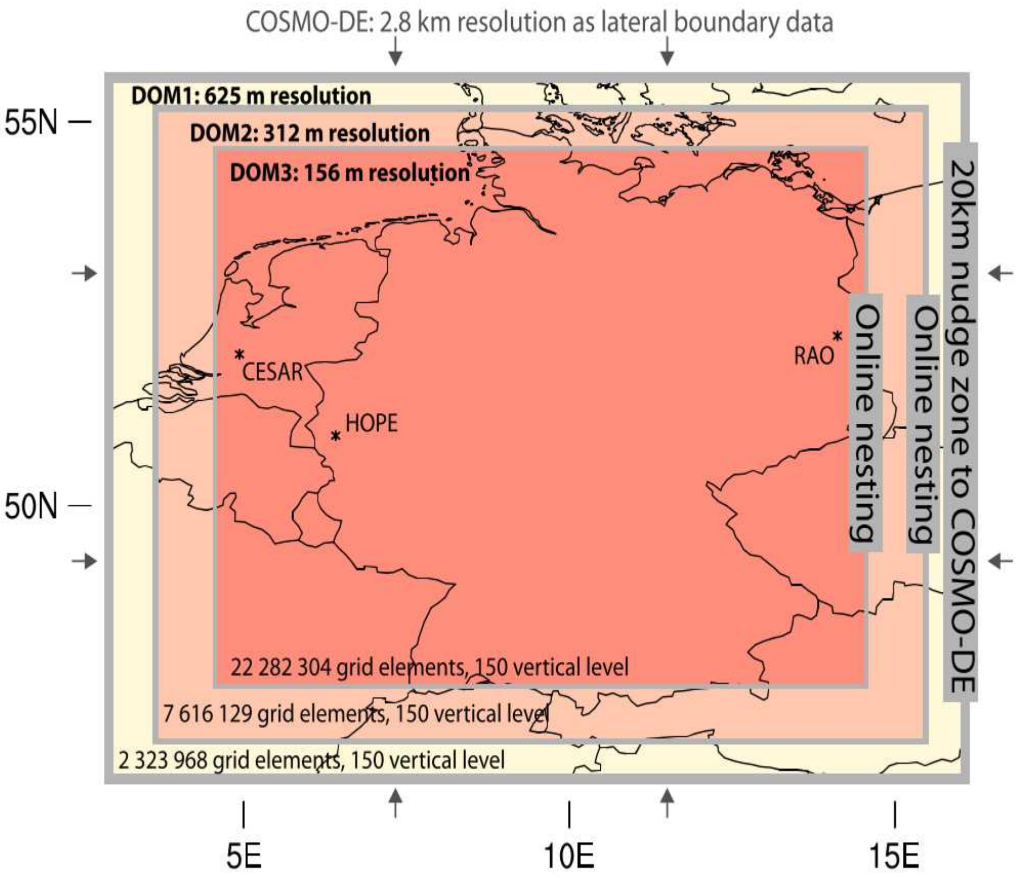
First assessment of cloud adjustments

- Use sensitivity runs with ICON-LEM for May 2, 2013 with current (control) and doubled CCN concentration (perturbed)
- Study the aerosol effects to clouds and precipitation



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

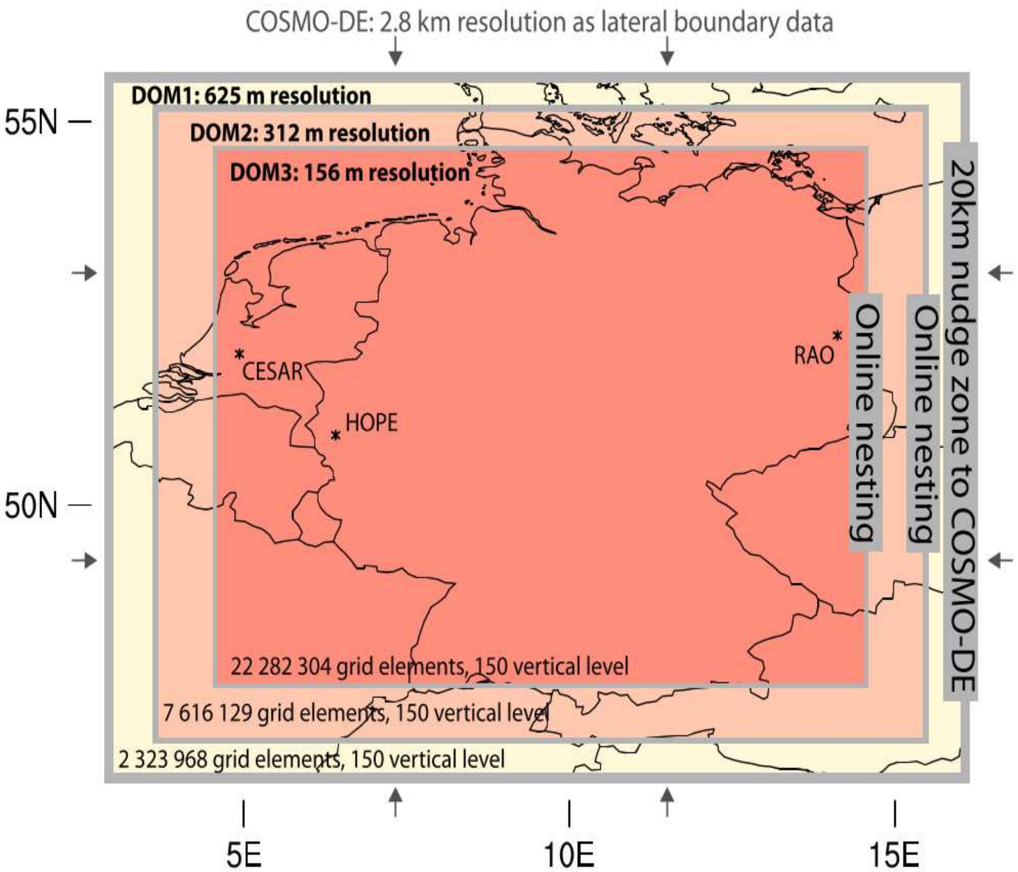
ICON-LEM simulations



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

- Horizontal resolution: 156m → less parametrized
- Two-moment mixed-phase bulk microphysical parametrization of Seifert and Beheng

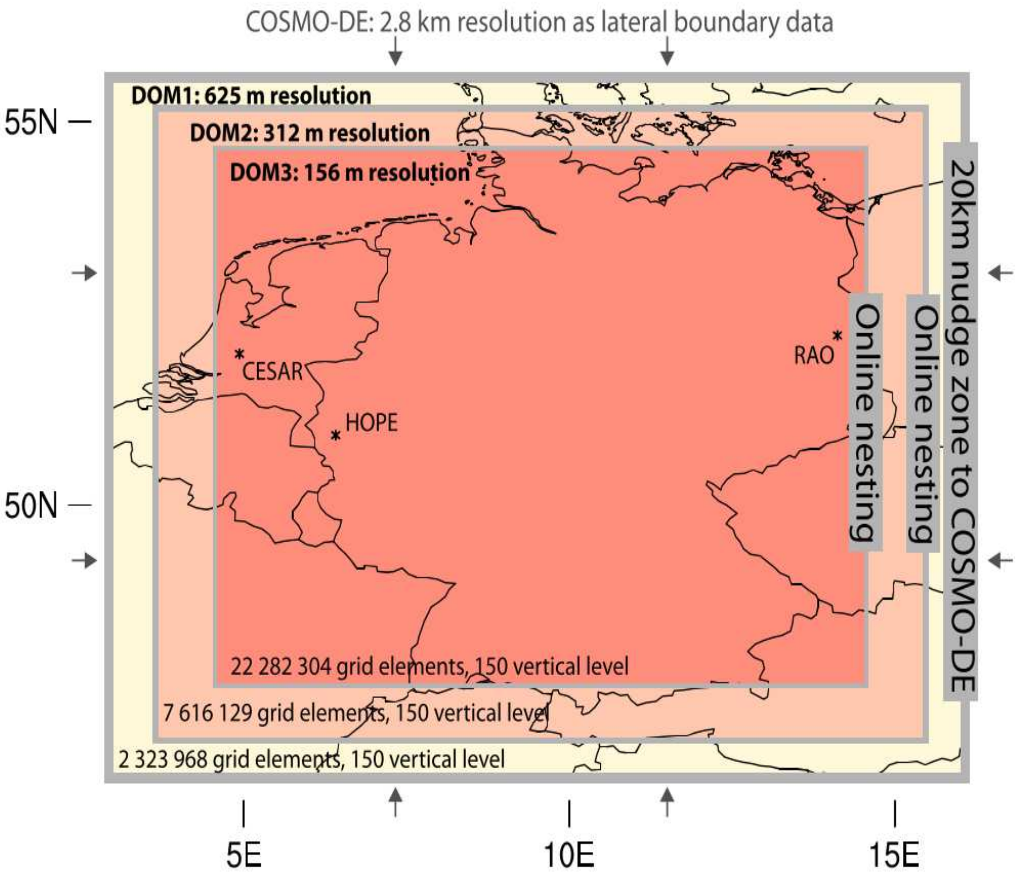
ICON-LEM simulations



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

- 1d variables (meteograms)
  - 36 stations
  - 9 seconds

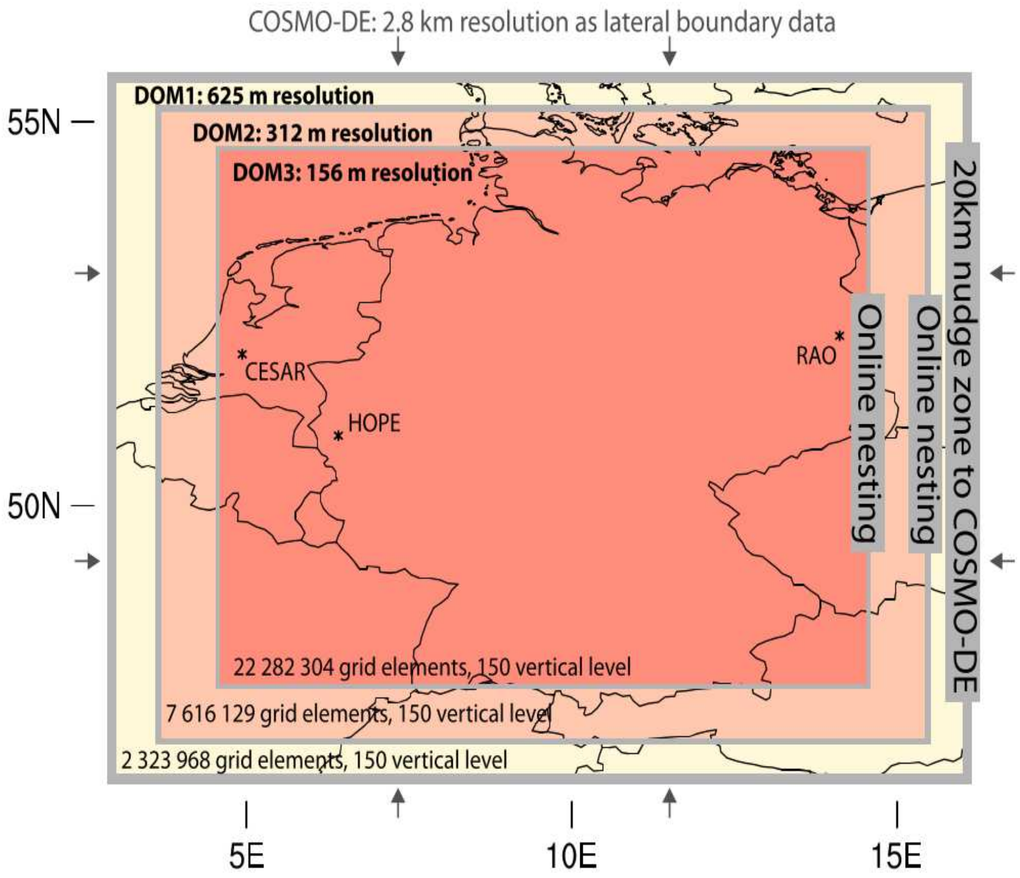
ICON-LEM simulations



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

- 2d variables: radiative fluxes, liquid water path (LWP), etc.
  - 10 min
  - Original spatial grid

ICON-LEM simulations



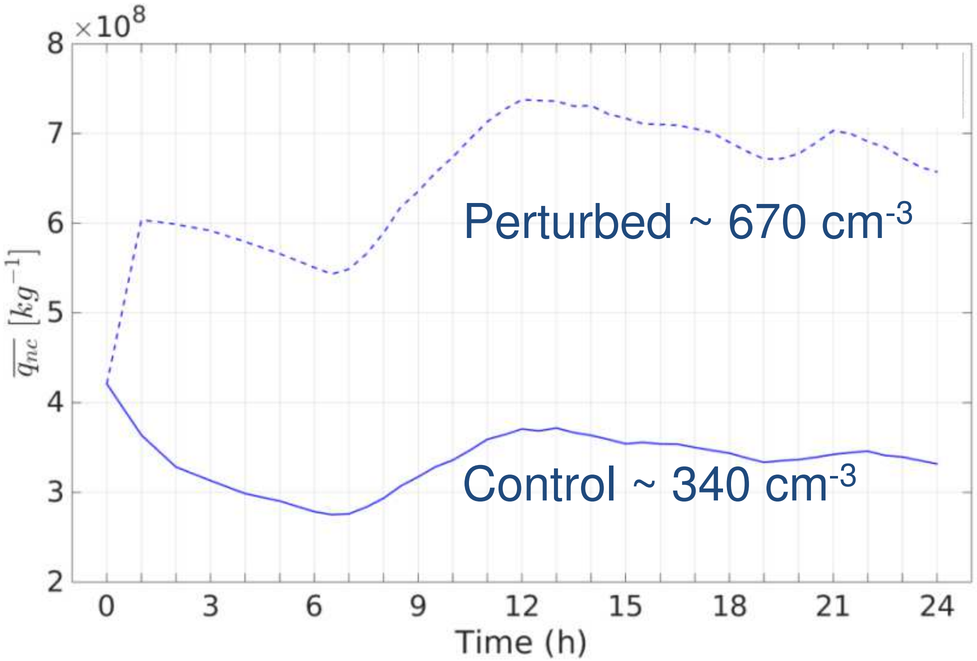
Heinze et al. (2017), Q.J.R. Meteorol. Soc

- 3d variables: temperature, specific hydrometeor contents, etc.
  - 30 min (daytime), 1 h (nightime)
  - Sampled every 4.8 km

CCN representation

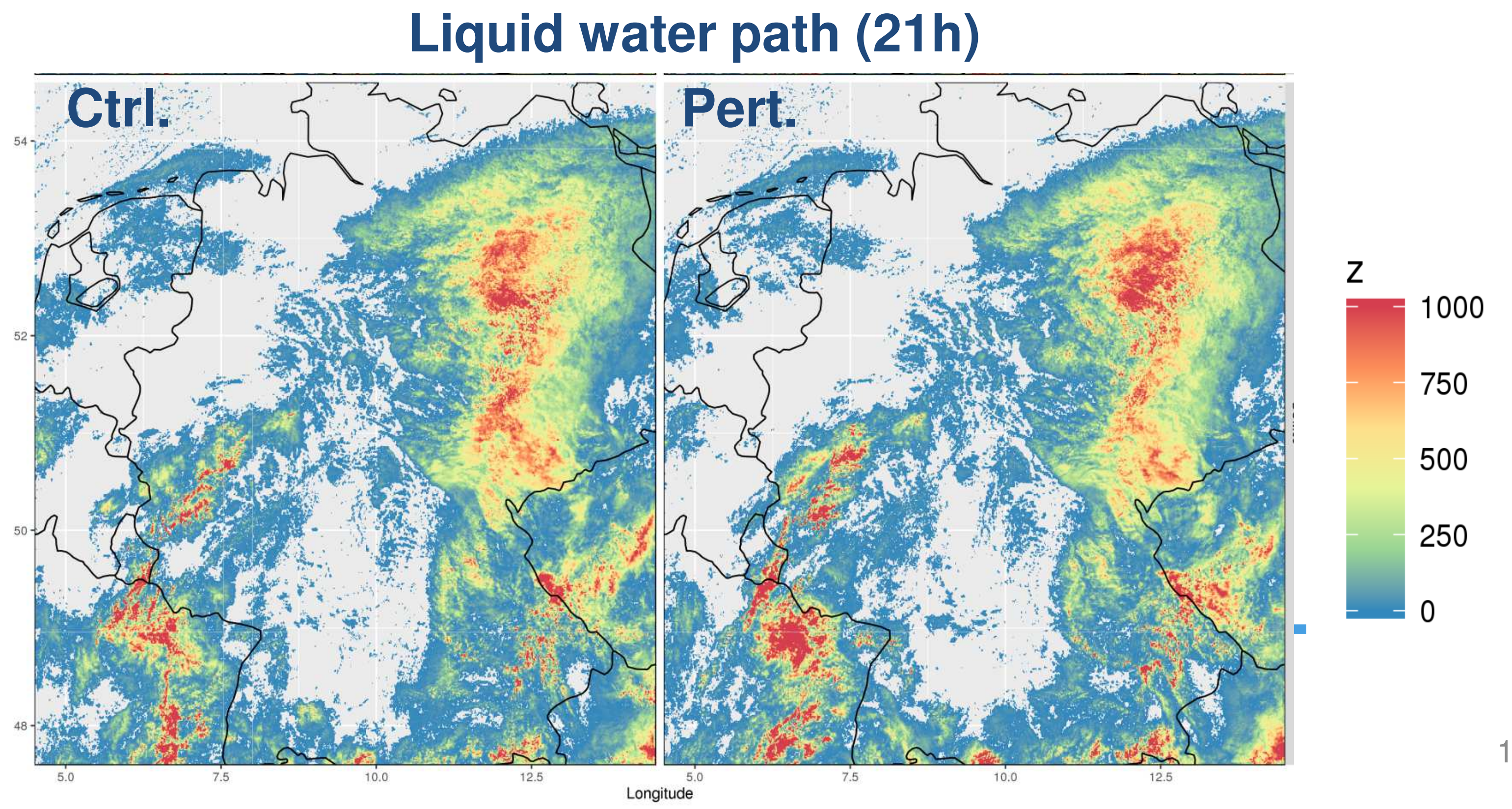
- Parametrization of CCN profile as function of pressure and vertical velocity derived in Phase I by Tegen & Hoose
- Assumed to be constant in time and space
- Perturbed run with doubled CCN compared to control run

Cloud droplet number concentration (QNC)

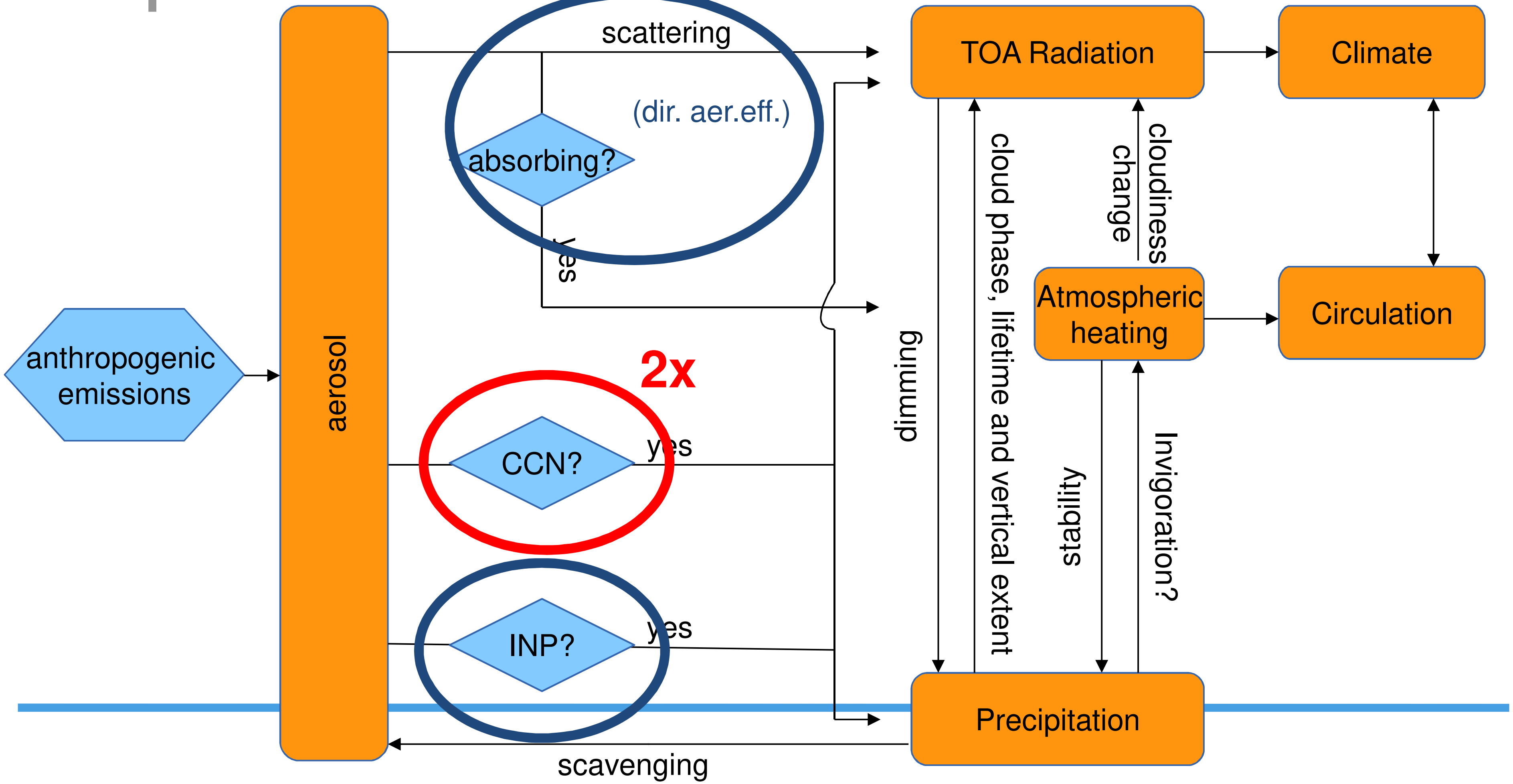


Challenge

- Detection of small signal imposed on complex cloud microphysics
- First description of differences in cloud related parameters



Expected aerosol effects



Rosenfeld et al. (2014), Rev. Geophy.

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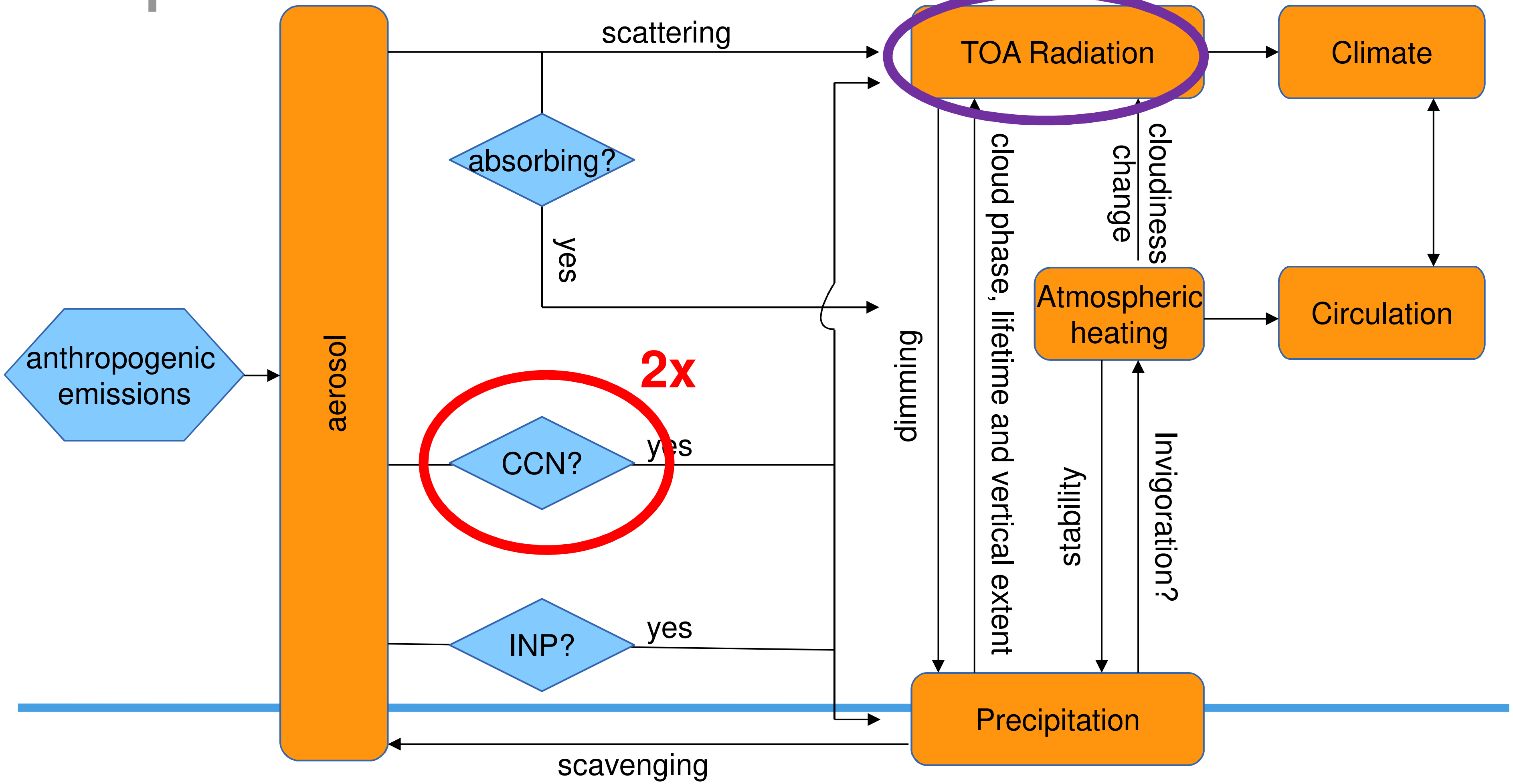
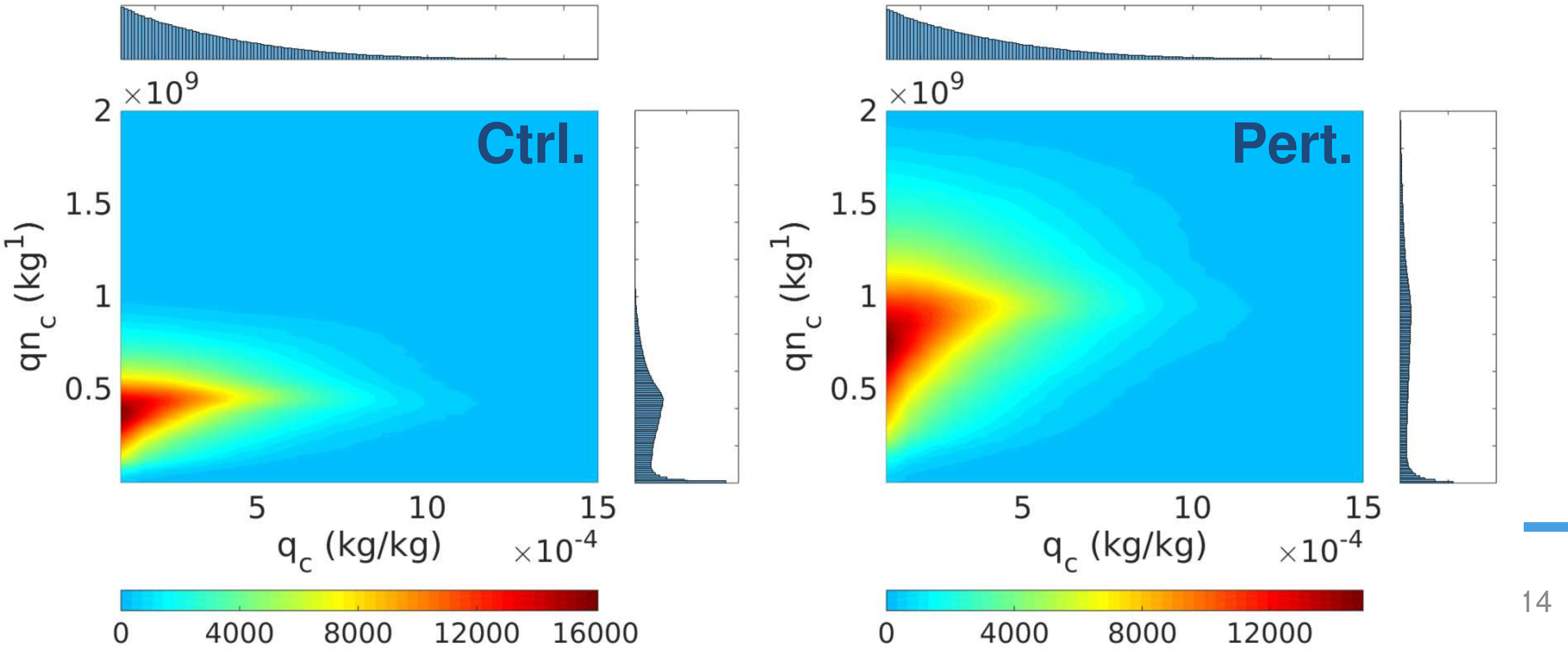


Rosenfeld et al. (2014), Rev. Geophy.

Cloud albedo effect

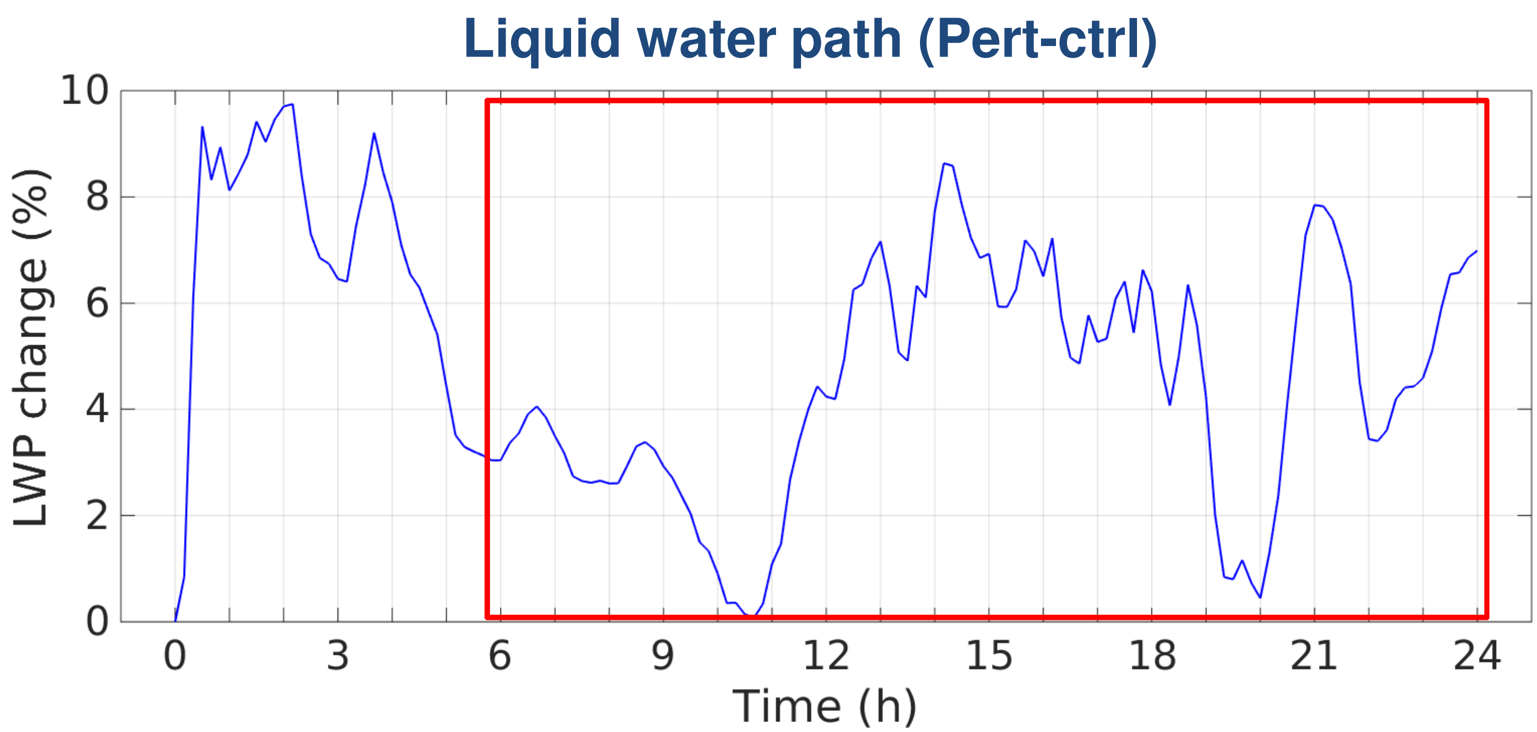
- More CCN should lead to more frequent but smaller cloud droplets (for a constant liquid water content).
- Findings:
  - Cloud number concentration (qnc) doubled
  - Specific cloud water content (qc) almost the same

  Smaller droplets



Cloud liquid path response

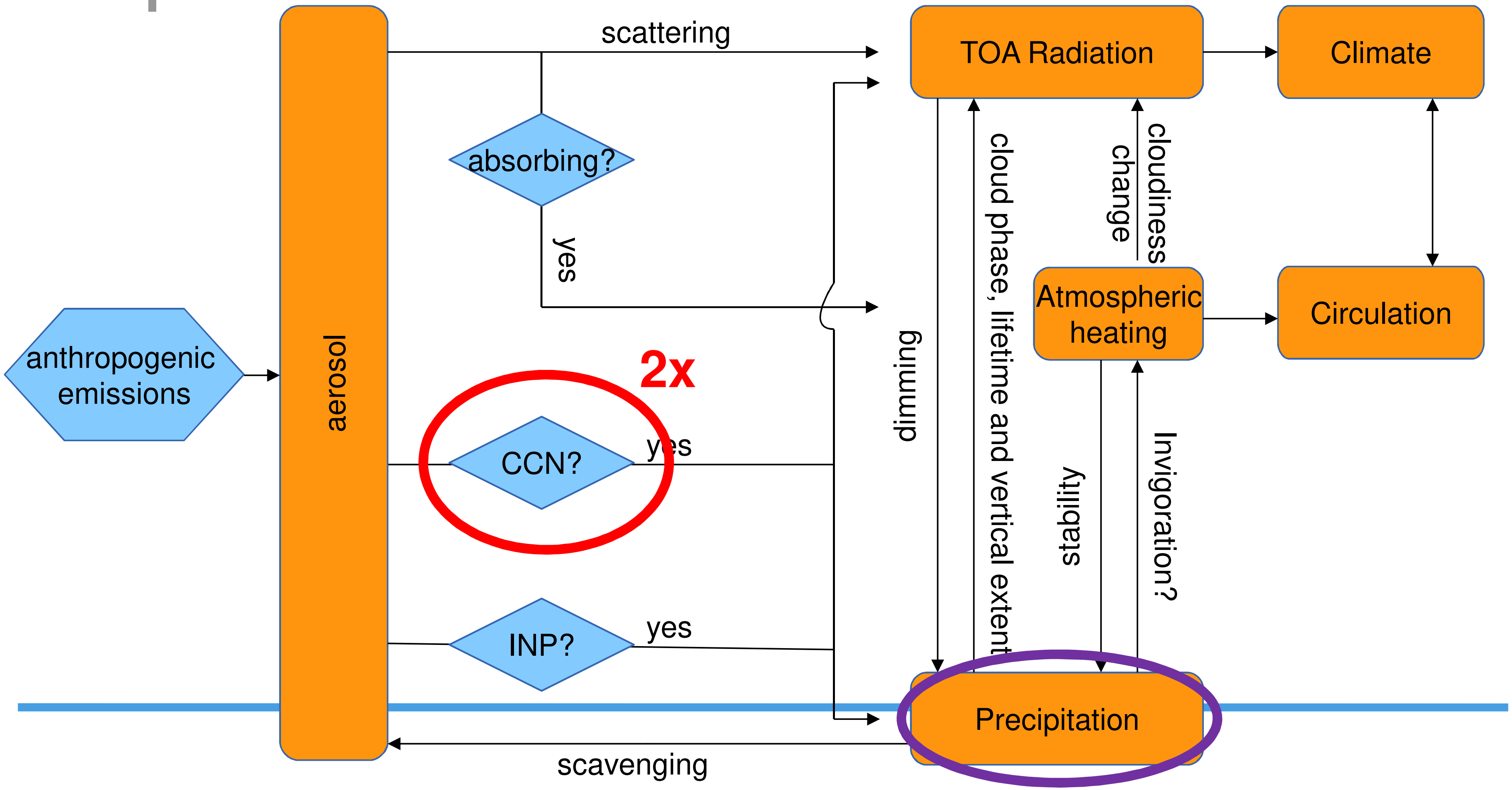
- How much the liquid water path change?
- Perturbed run shows LWP increase of about **5%**.



Cloud albedo effect

- More small droplets would produce more cloud reflection leading to a decrease in the net solar radiation at the top of the atmosphere.
- Number concentration was not coupled to radiation scheme (RRTMG) in these ICON runs (but is implemented now).
- Offline tests with RRTMG performed to estimate effect on radiation.

Expected aerosol effects



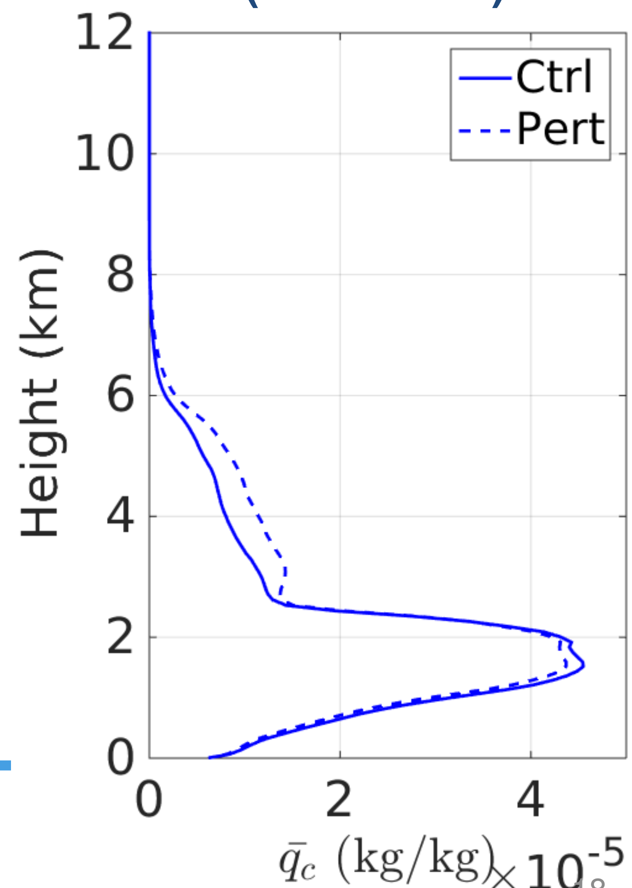
Rosenfeld et al. (2014), Rev. Geophy.

Effects on precipitation

- With smaller cloud particles collision-coalescence should be reduced
  → Rainfall suppression
  → Increased cloud water content

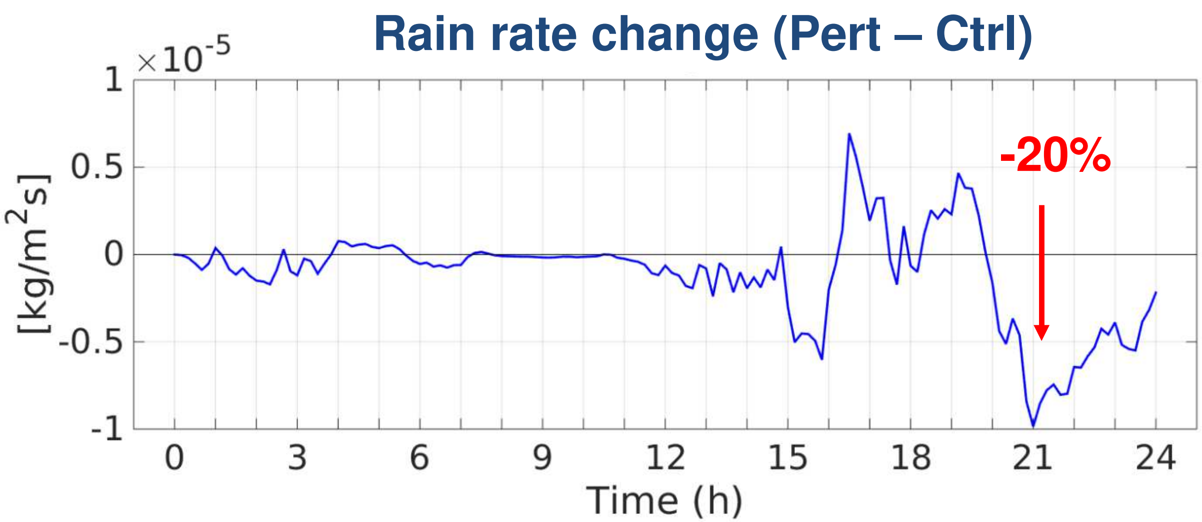
- Findings:
  - More (supercooled) liquid water at higher altitudes.
  - Less liquid water present in lower levels.

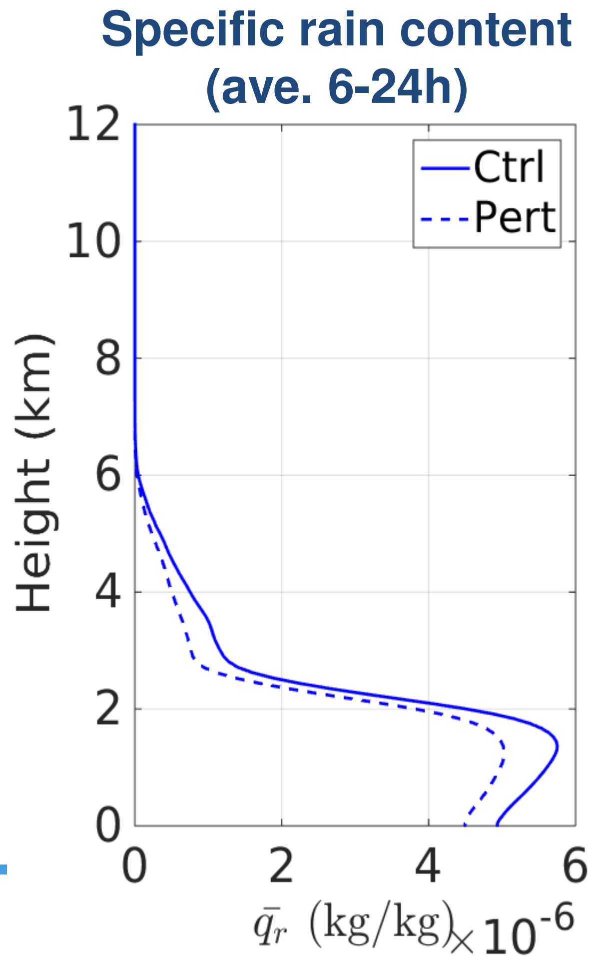
Cloud water content (ave. 6-24h)



Effects to precipitation

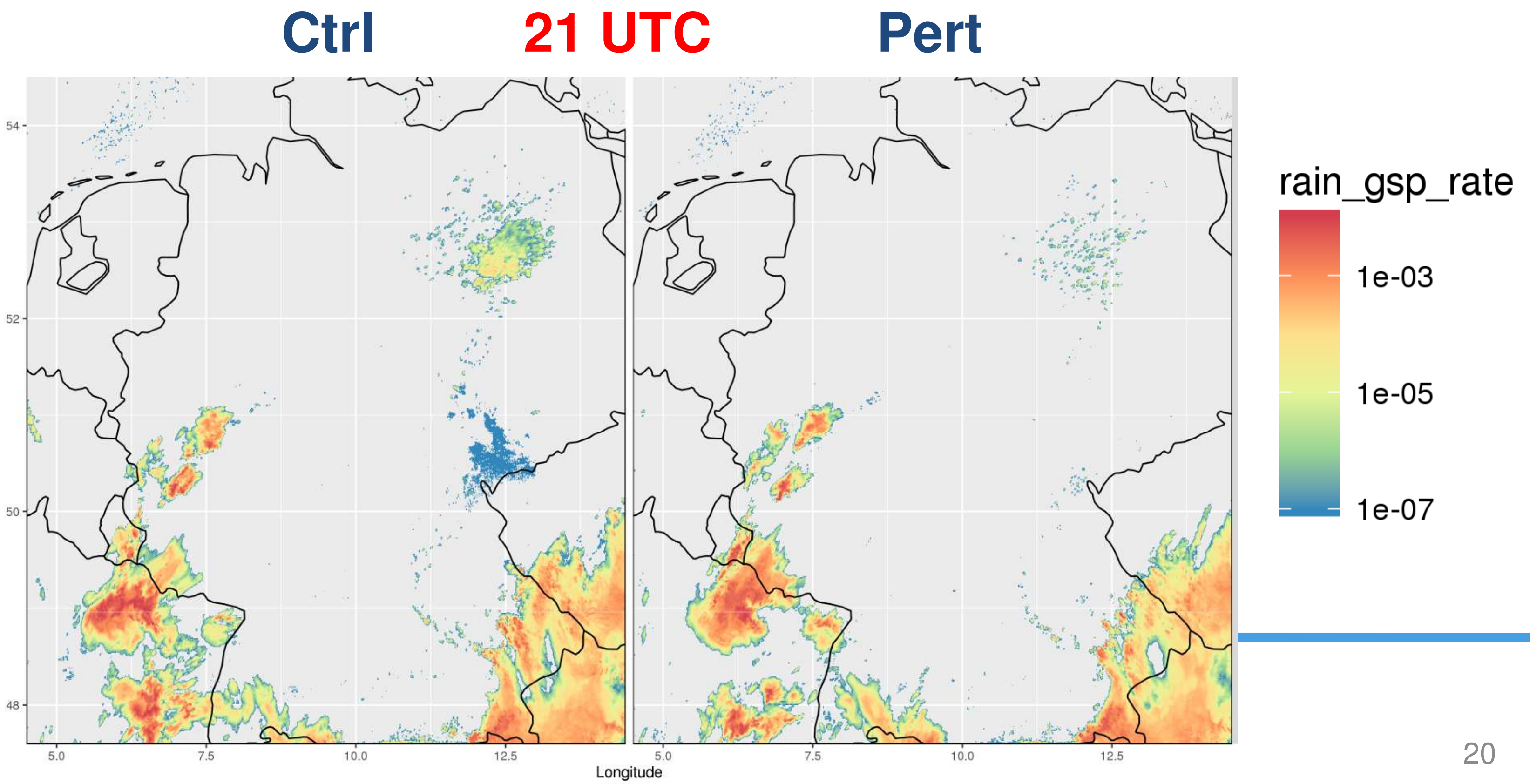
- Surface precipitation started to occur around noon, peaking at 17 UTC
- Findings:
  - Overall reduction of vertical rain profile
  - Accumulated rain rate reduced by 4.4%



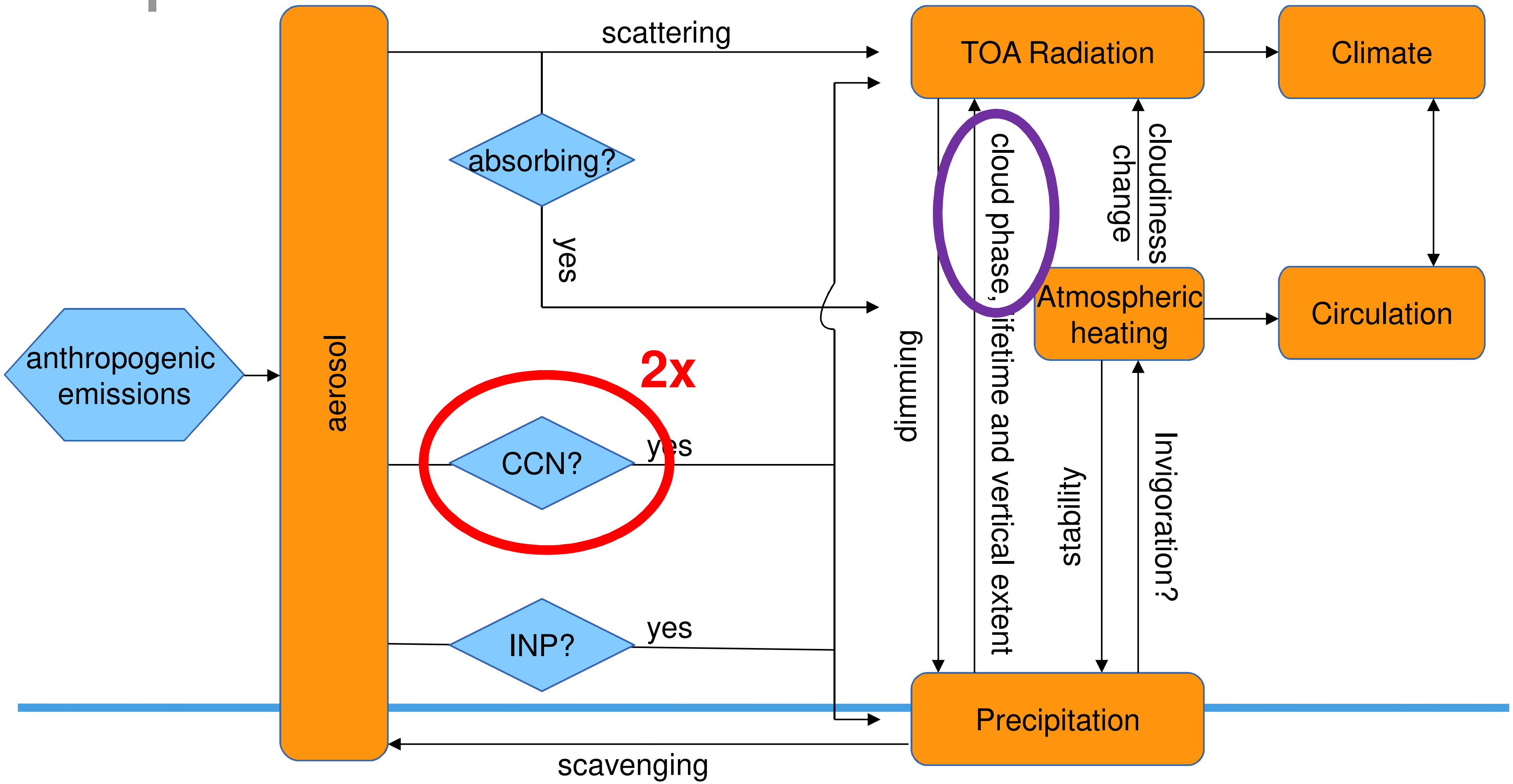


Effects to precipitation

- Little change in precipitation pattern
- Overall reduction in rainfall rate



Expected aerosol effects

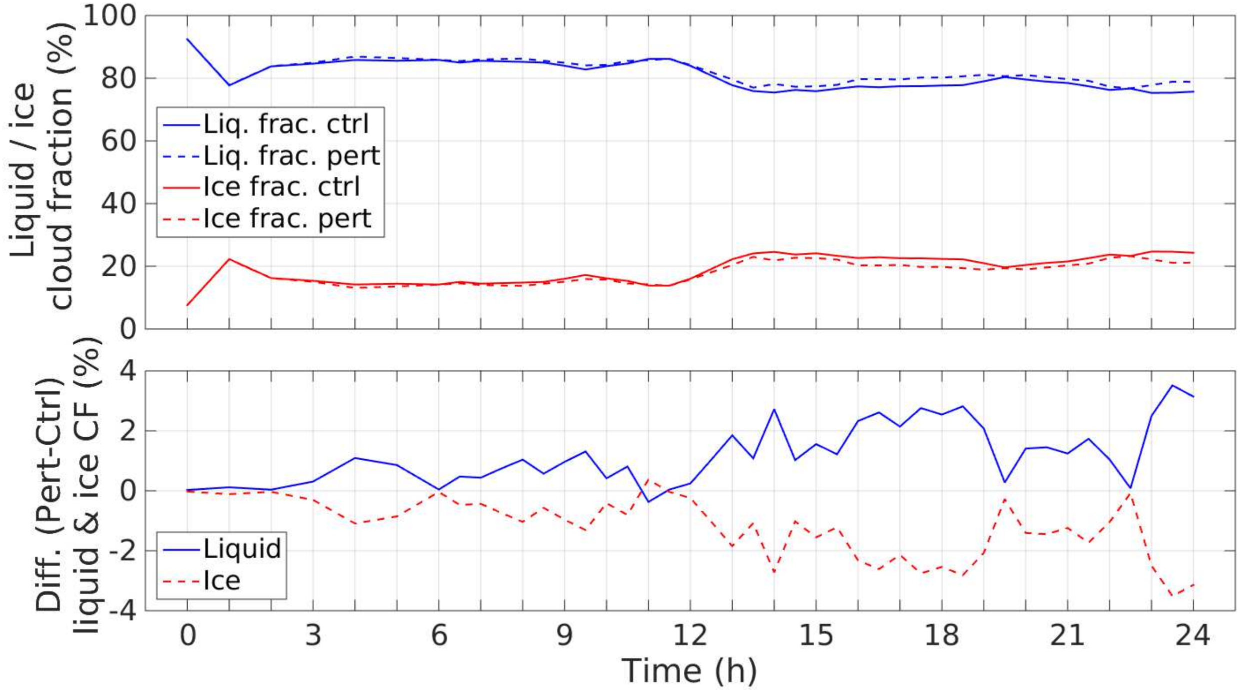


Rosenfeld et al. (2014), Rev. Geophy.

Cloud phase

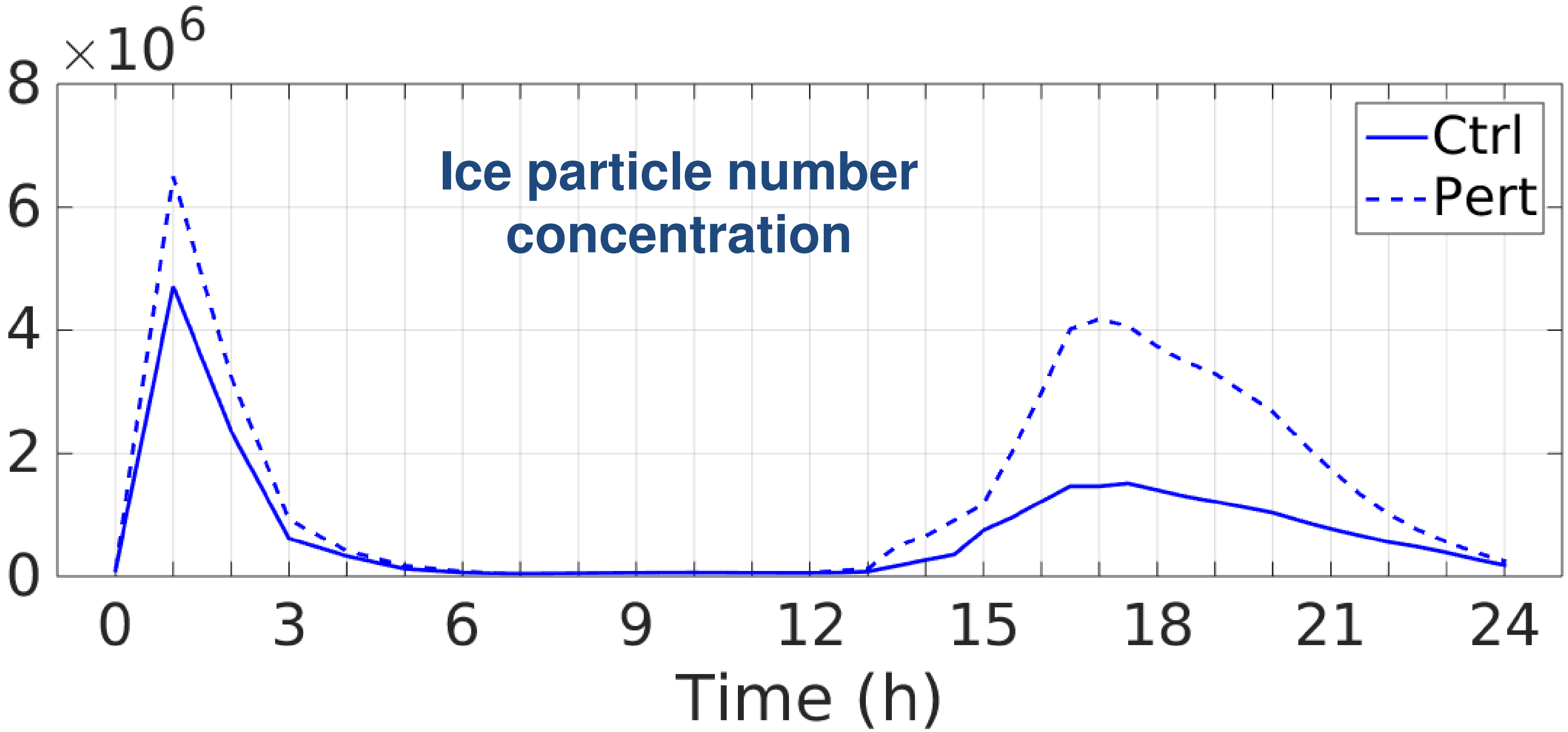
- Smaller cloud droplets can delay the onset of freezing.
- With the onset of convection around noon, 10% (8%) of liquid phase is converted to ice phase in the control (perturbed) run.

Only mixed phase clouds

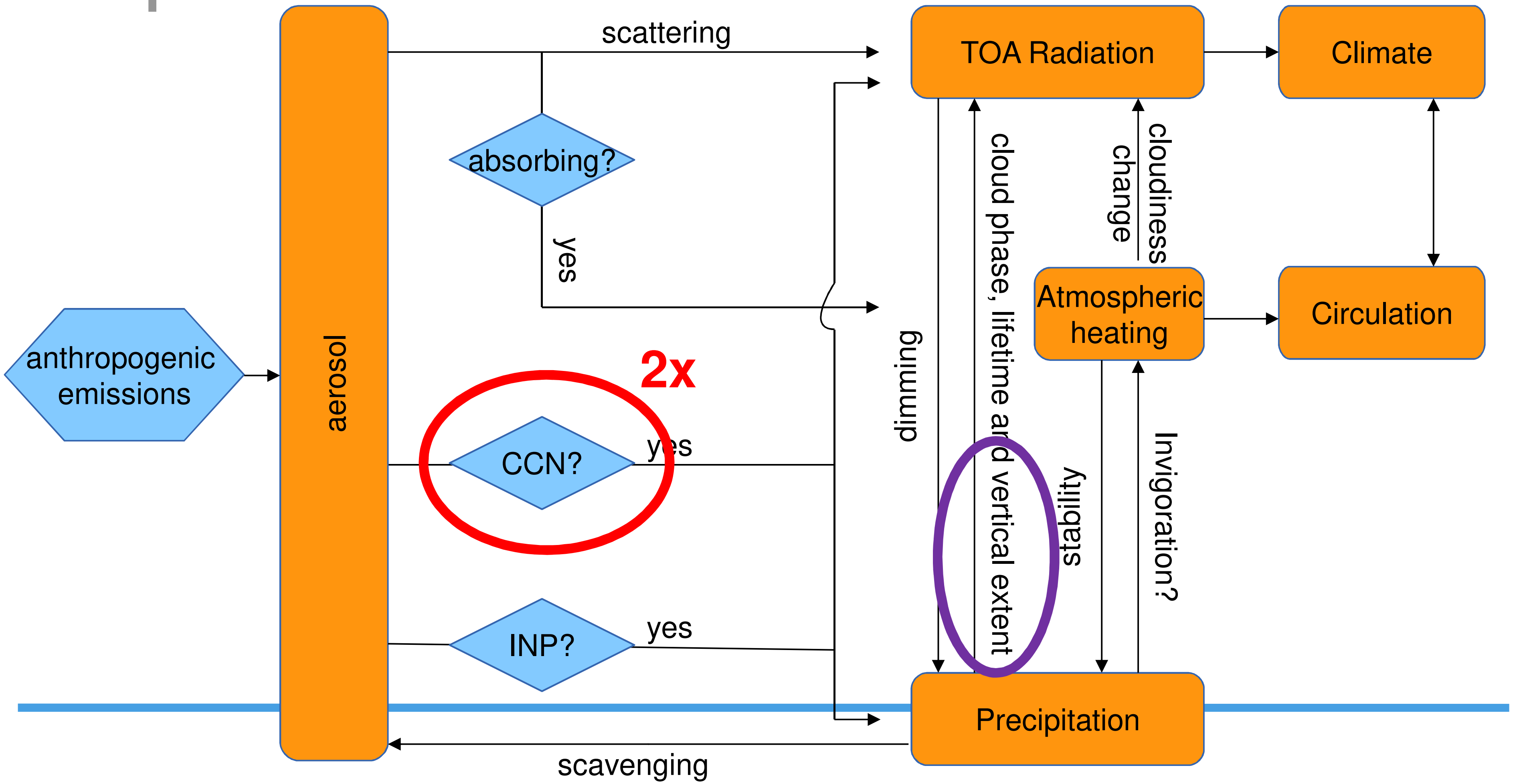


Cloud phase

- Increase in ice particle number concentration can be explained by homogeneous freezing.
- Ice water path is increased by 11.8%.



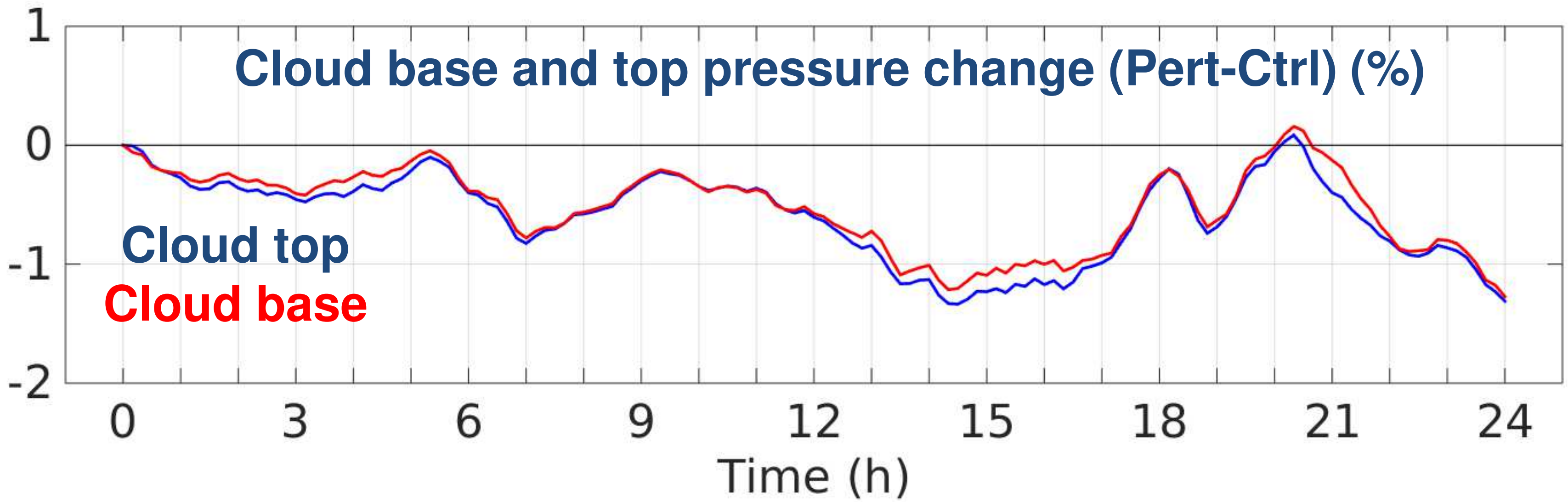
Expected aerosol effects



Rosenfeld et al. (2014), Rev. Geophy.

Vertical extent

- With the suppression of precipitation clouds might rise higher
- Findings:
  - Cloud base (top) pressure decreased by 0.6% (0.7%). Equivalent to approx. 65 m higher cloud top and base.
  - During strongest period of convection development (13-17h) clouds have slightly largest thickness.
  - Next step: comparing with ceilometer network and SEVIRI.



Summary

Variable	Control	Perturbed	Change (%)
Mean cloud cover (%)	84.8	85.2	**+ 0.4**
Cloud droplet no. concentration [kg^{-1}]	3.4×10^8	6.7×10^8	**+ 97**
Water vapor path [$kg\ m^{-2}$]	18.40	18.42	**+ 0.16**
Liquid water path [$kg\ m^{-2}$]	0.15	0.16	**+ 4.8**
Ice water path [$kg\ m^{-2}$]	0.03	0.04	**+ 11.8**
Acc. mean rain rate [$kg\ m^{-2}$]	3.5×10^{-3}	3.3×10^{-3}	**- 4.4**
Cloud base pressure [hPa]	782,4	777,5	**- 0.62**
Cloud top pressure [hPa]	739.4	734.3	**- 0.69**

Conclusions

- ICON model simulations provide useful tool for detecting and studying aerosol effects in clouds and precipitation.
- First indication of aerosol effects due to doubled CCN:
  - Cloud-albedo effect: more cloud droplets, slightly increased LWP and presumably changes in solar radiation
  - Effects on precipitation: reduced rain water and suppressed rain specifically at onset and towards the end of convection.
  - Cloud phase: increased ice particles and ice water path. Increased ice fraction at the expense of liquid fraction in mixed-phase clouds.
  - Vertical extent: slightly higher cloud tops and bases.

Conclusions

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Preliminary results
Significance need to be investigated

Outlook

- Investigate more dates to increase the robustness of the results.
- Perform more ICON-LEM runs using realistic spatio-temporal variations in CCN/INP.
- Use general circulation models for estimation of global effects.
- Use improved metrics to investigate aerosol effects and further variables, e.g. cloud lifetime using clouds tracking, stability, extreme values.
- Define/identify candidate observables and observing strategies sensitive to cloud aerosol effects.

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Thank you for your attention!

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