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

## Fast cloud adjustments to aerosols (S1)

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High definition clouds and precipitation for advancing climate prediction

# Motivation S1

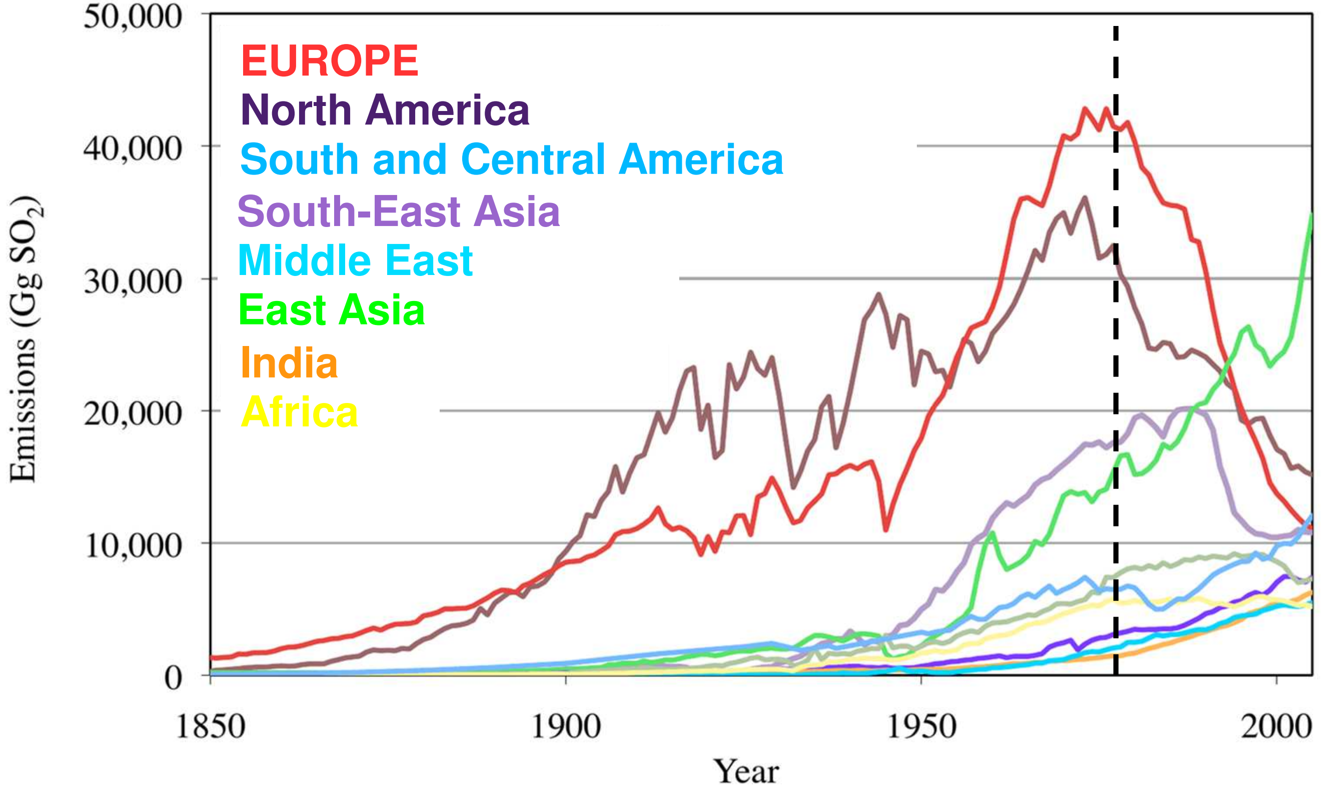
Investigate key uncertainty in climate predictions:
cloud adjustments to anthropogenic aerosol emissions implying an effective radiative forcing from -1.3 to 0 $Wm^{-2}$

- Perform sensitivity studies with different aerosol concentrations using the high resolution cloud resolving model (ICON-LEM)
  → **P1** on Cloud Condensation Nuclei (CCN) and Ice nucleating particles (INP)
- Improve representation of relevant processes (activation, contrails) in ICON-LEM → **P2**
- Evaluate simulations using supersite and satellite observations → **P3**
- Detect and attribute the simulated cloud adjustments

# S1 Poster presentations

- **P1**: “Improving the representation of aerosols and mixed-phase clouds in ICON-LEM” (Engler et al.)
- **P2**: “Cloud scheme and contrails cirrus” (Verma and Baumgartner)
- **P3**: “Statistical analyses of remote sensing data” (Baars et al.)

# Global Anthropogenic $SO_2$ Emissions

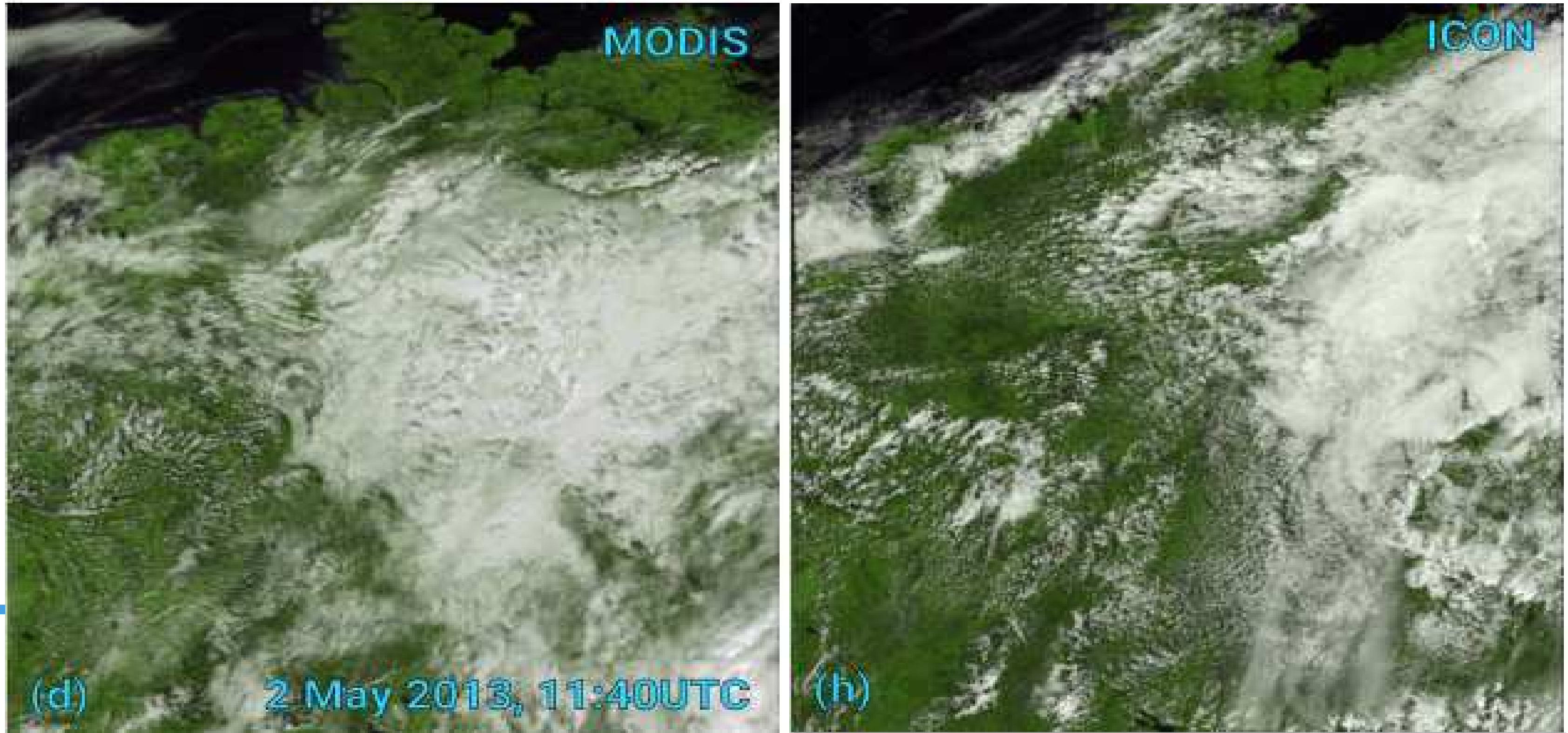



First test:
Assume 50% CCN reduction from 1980's compared to today

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

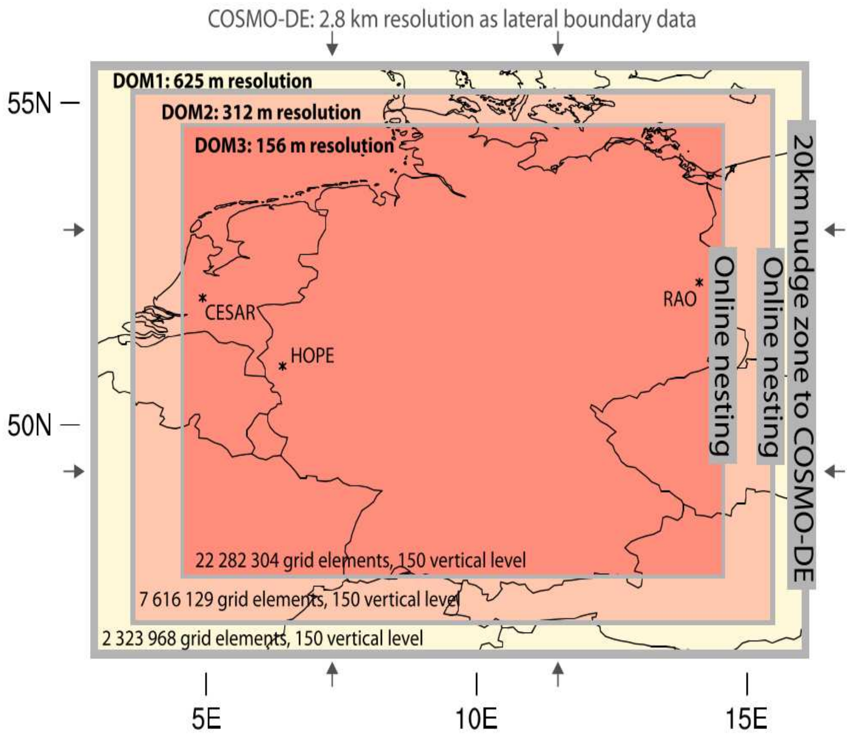
# First assessment of cloud adjustments

- 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



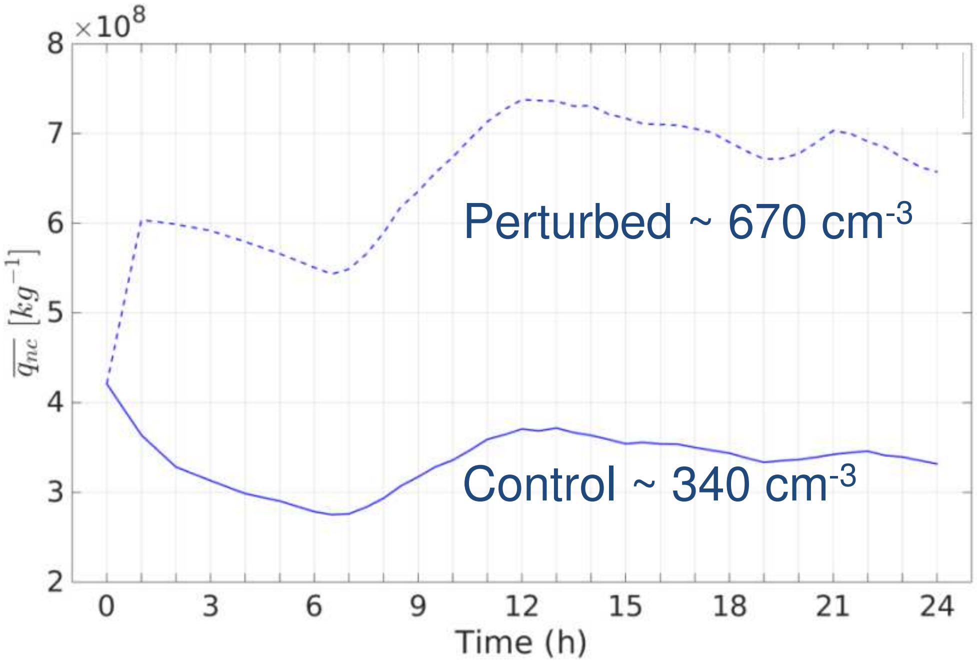

Heinze et al. (2017), Q.J.R. Meteorol. Soc

- Horizontal resolution: 156m
- Two-moment mixed-phase bulk microphysical parametrization of Seifert and Beheng
- 2d variables: radiative fluxes, liquid water path (LWP), etc.
  - 10 min
  - Original spatial grid
- 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

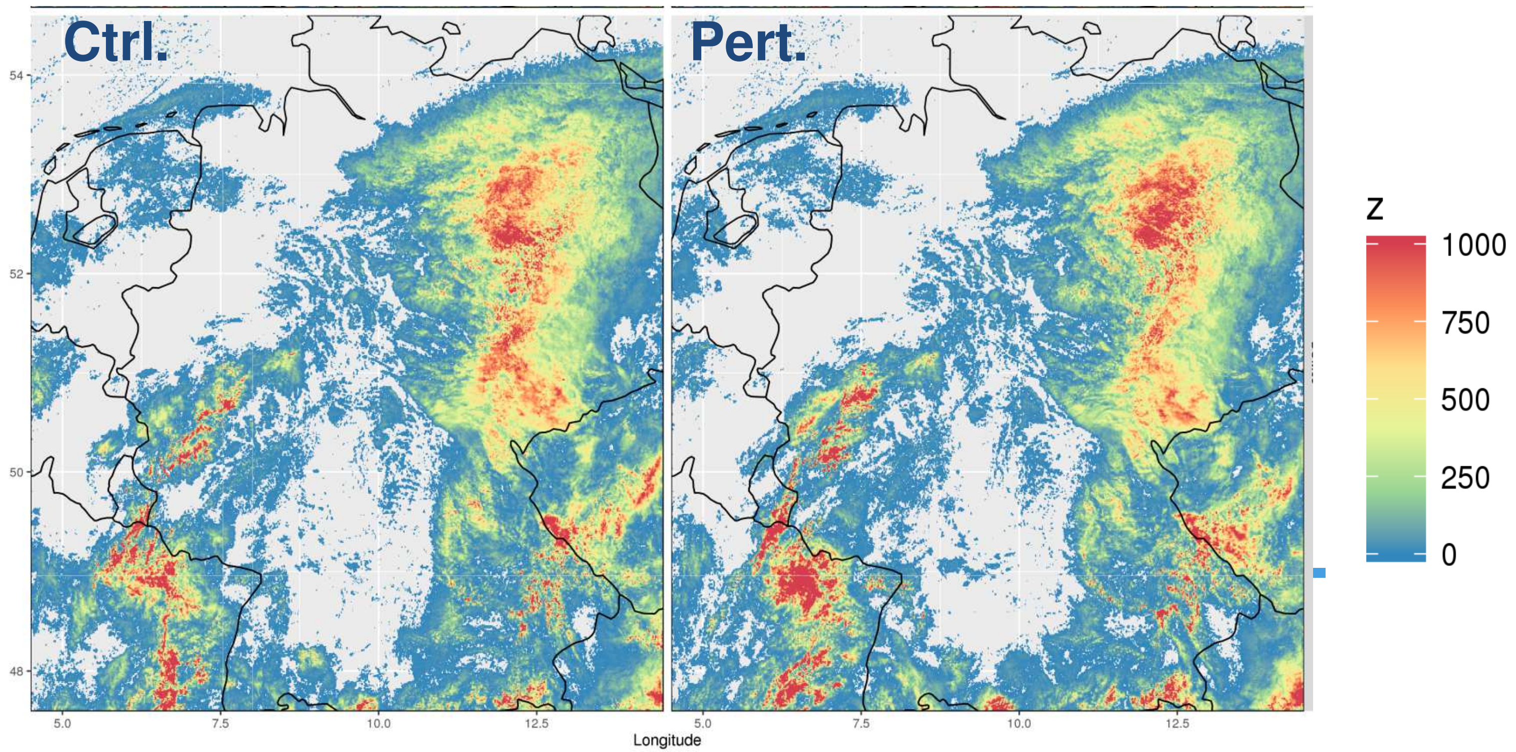
Cloud droplet number concentration (QNC)



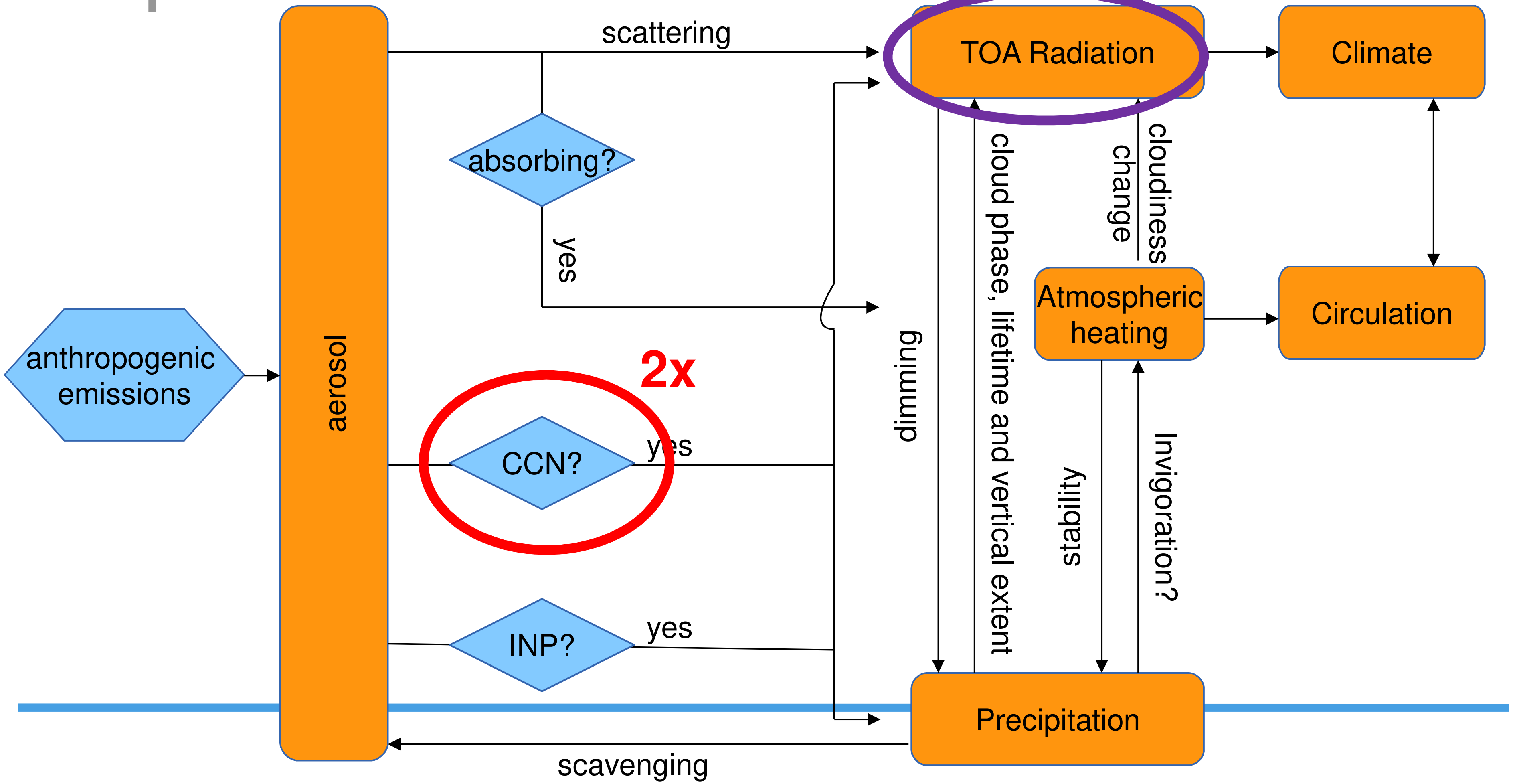
# Challenge

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

**Liquid water path**



# Expected aerosol effects

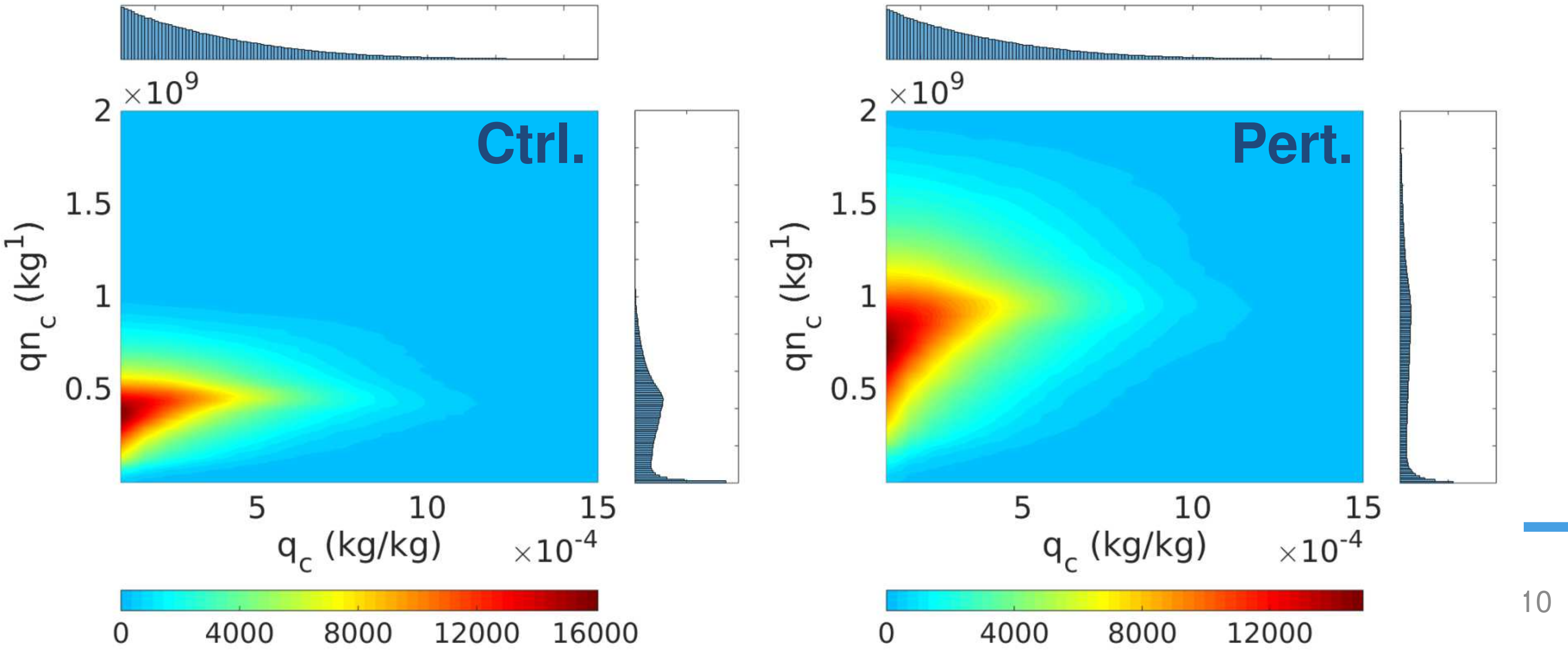



Rosenfeld et al. (2014), Rev. Geophy.

# Cloud albedo effect

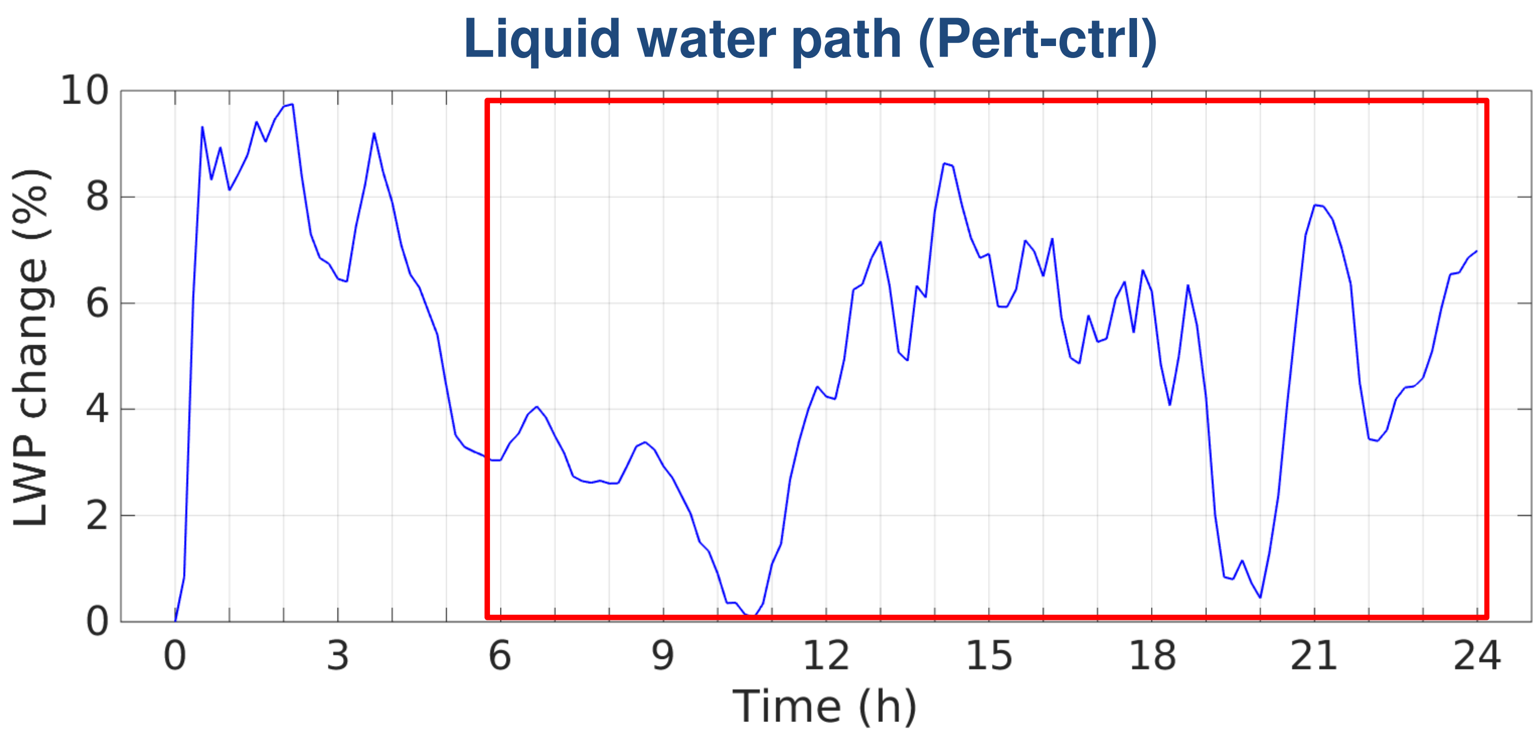
- More CCN should lead to more frequent but smaller cloud droplets (for a constant liquid water content).
- Findings:
  - Cloud number concentration (qnc) doubled
  - Specific cloud water content (qc) almost the same

  } Smaller droplets



# Cloud liquid path response

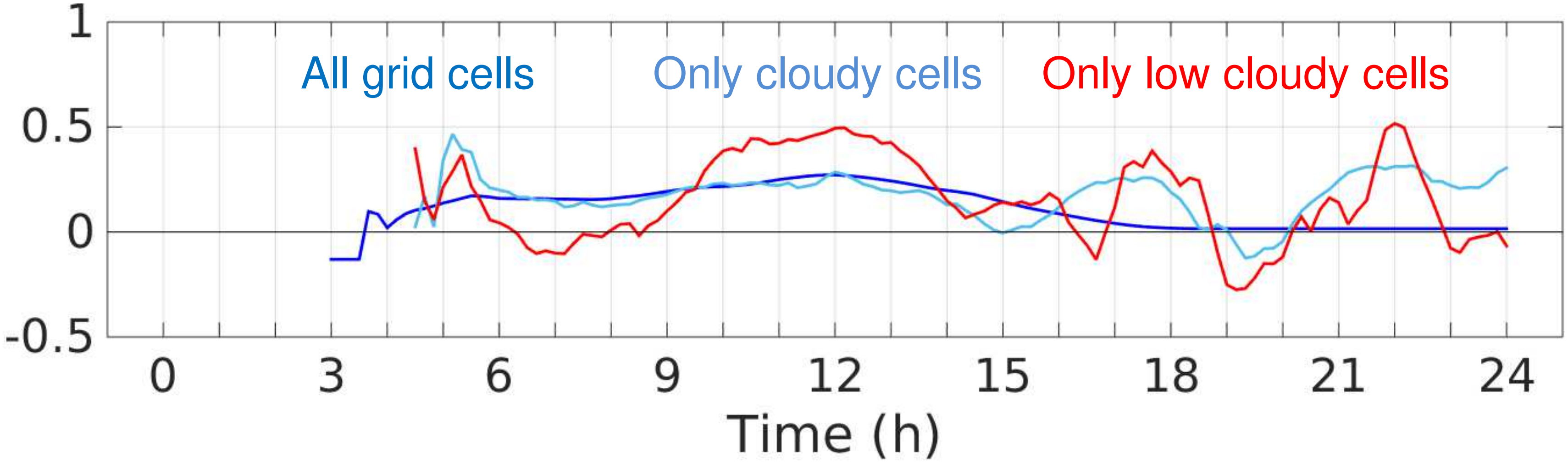
- How much the liquid water path change?
- Perturbed run shows LWP increase of about **5%**.



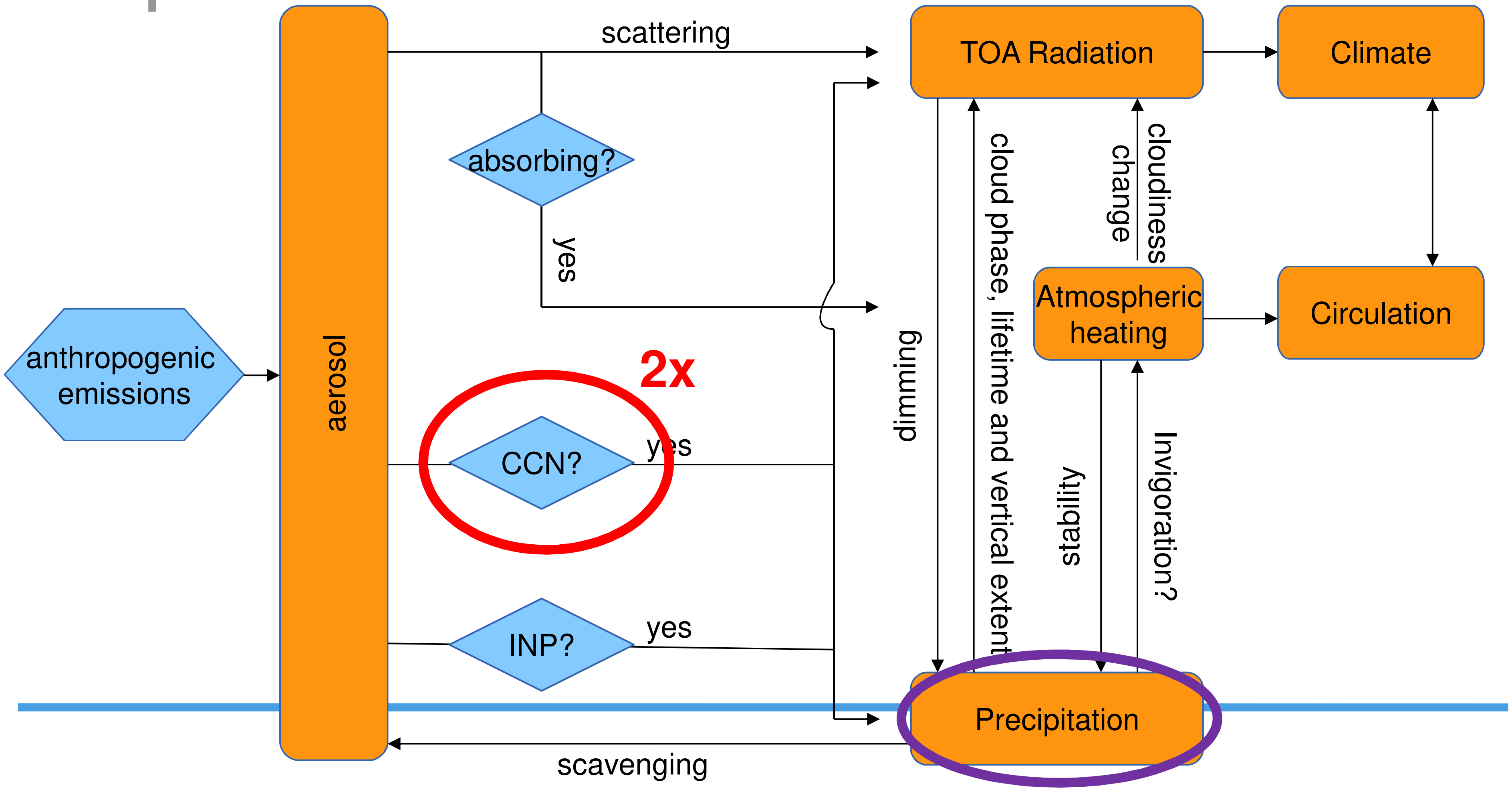
# Cloud albedo effect

- More small droplets would produce more cloud reflection leading to a decrease in the net solar radiation at the top of the atmosphere.
- Only very minor changes in net solar radiation at TOA are found:
  - All grid points: +0.04 $Wm^{-2}$
  - Only grid points with low level clouds: -0.15 $Wm^{-2}$

**Accumulated net solar radiation at TOA change (%) (Pert - Ctrl)**



# Expected aerosol effects



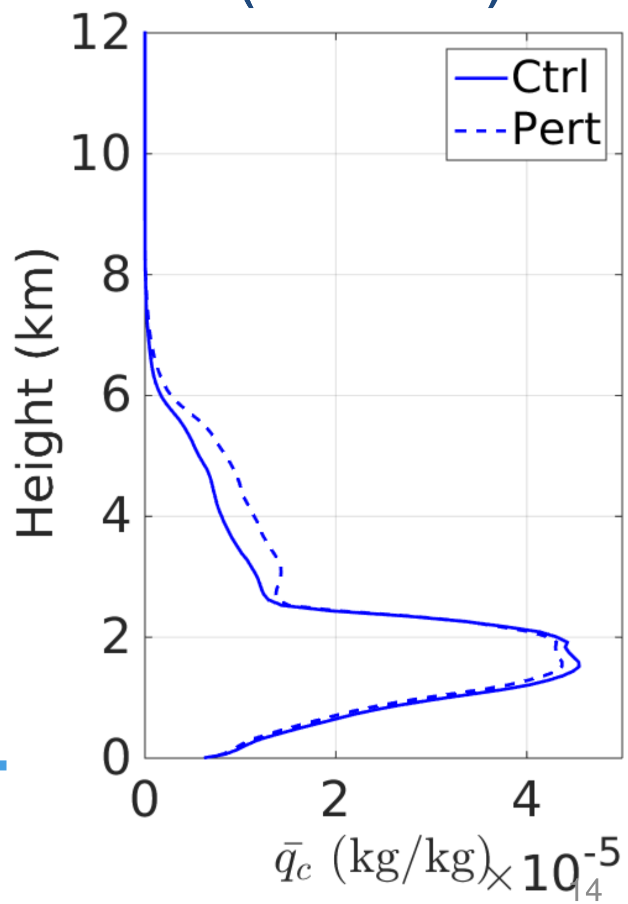

Rosenfeld et al. (2014), Rev. Geophy.

# 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.

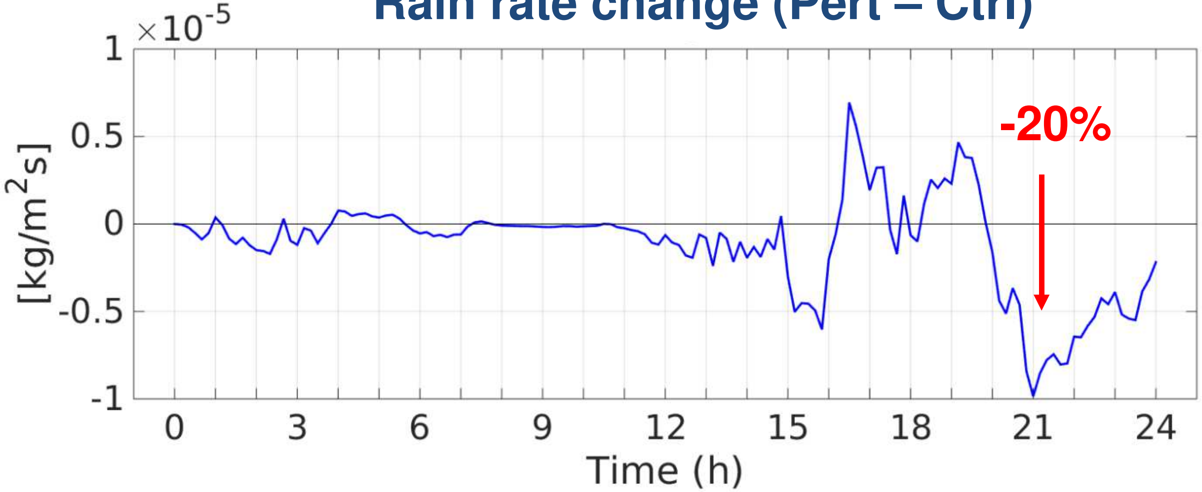
**Cloud water content (ave. 6-24h)**



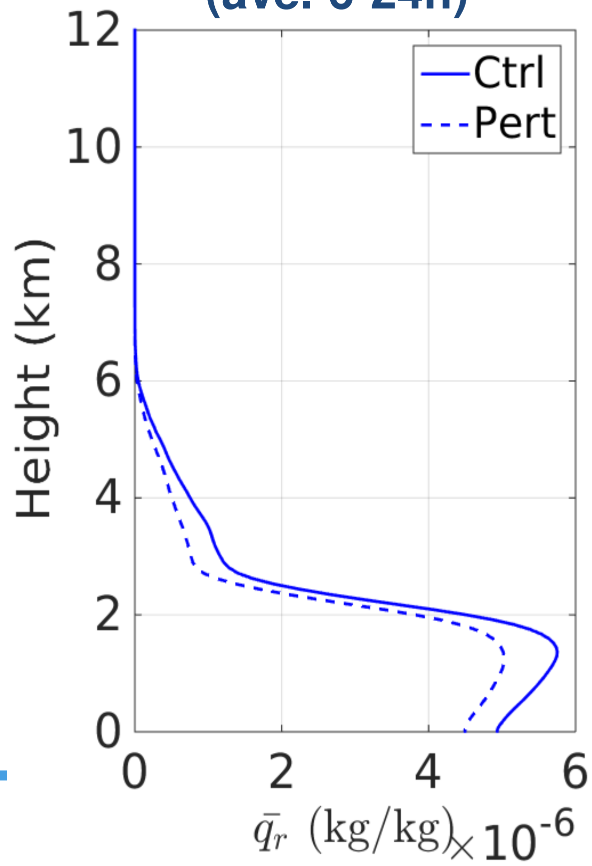
# Effects to precipitation

- 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%

**Rain rate change (Pert – Ctrl)**



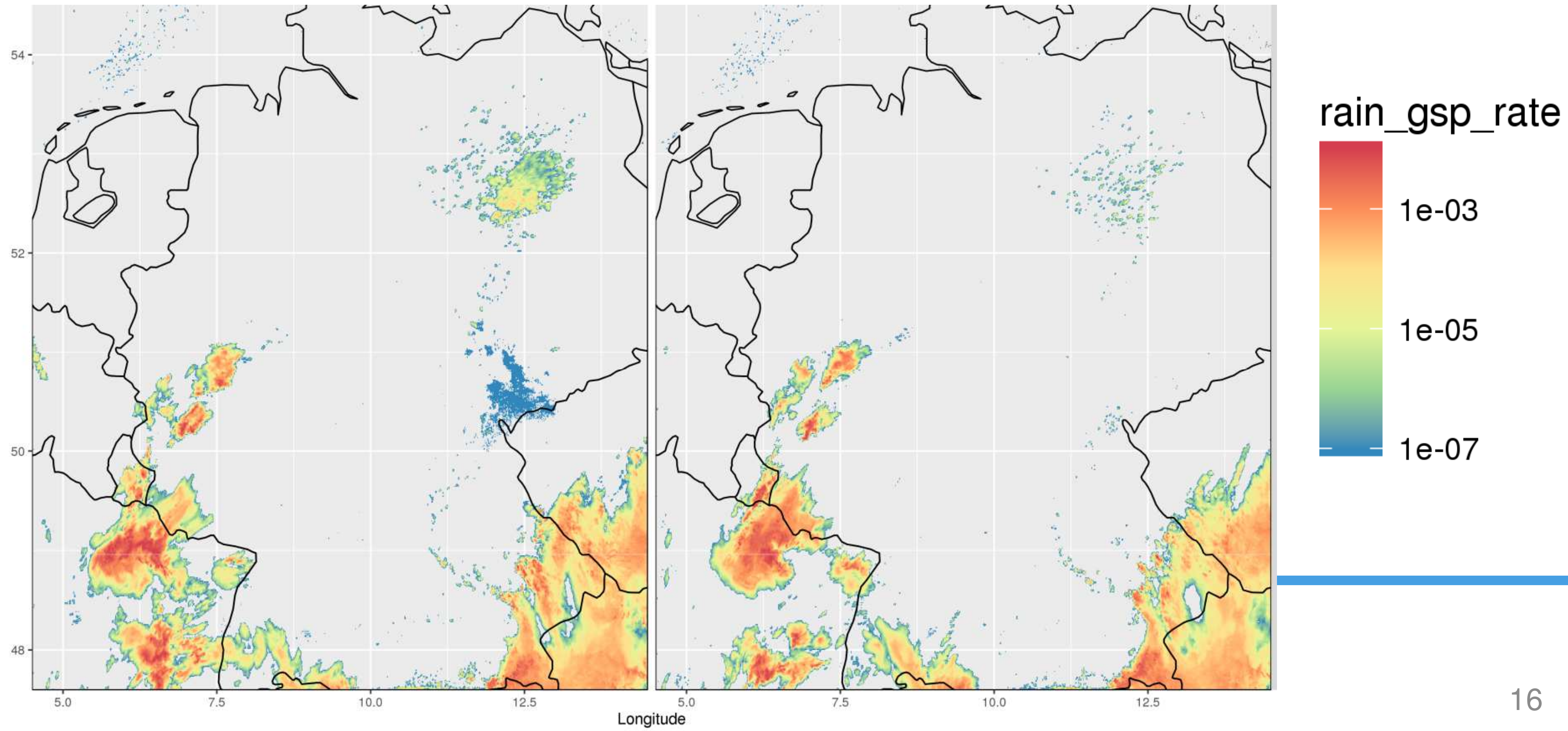

**Specific rain content (ave. 6-24h)**



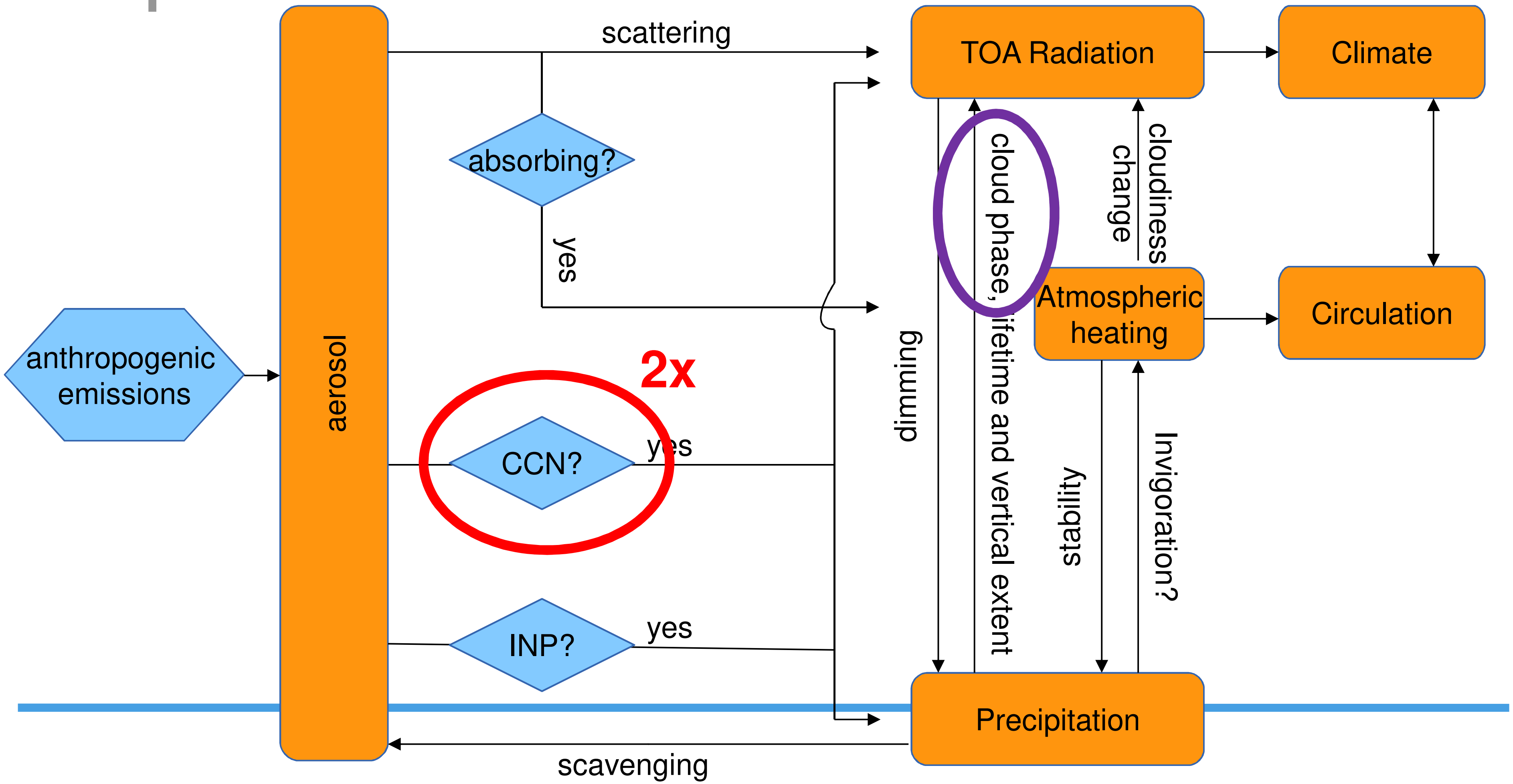
# Effects to precipitation

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

**Ctrl** **21 UTC** **Pert**



# Expected aerosol effects

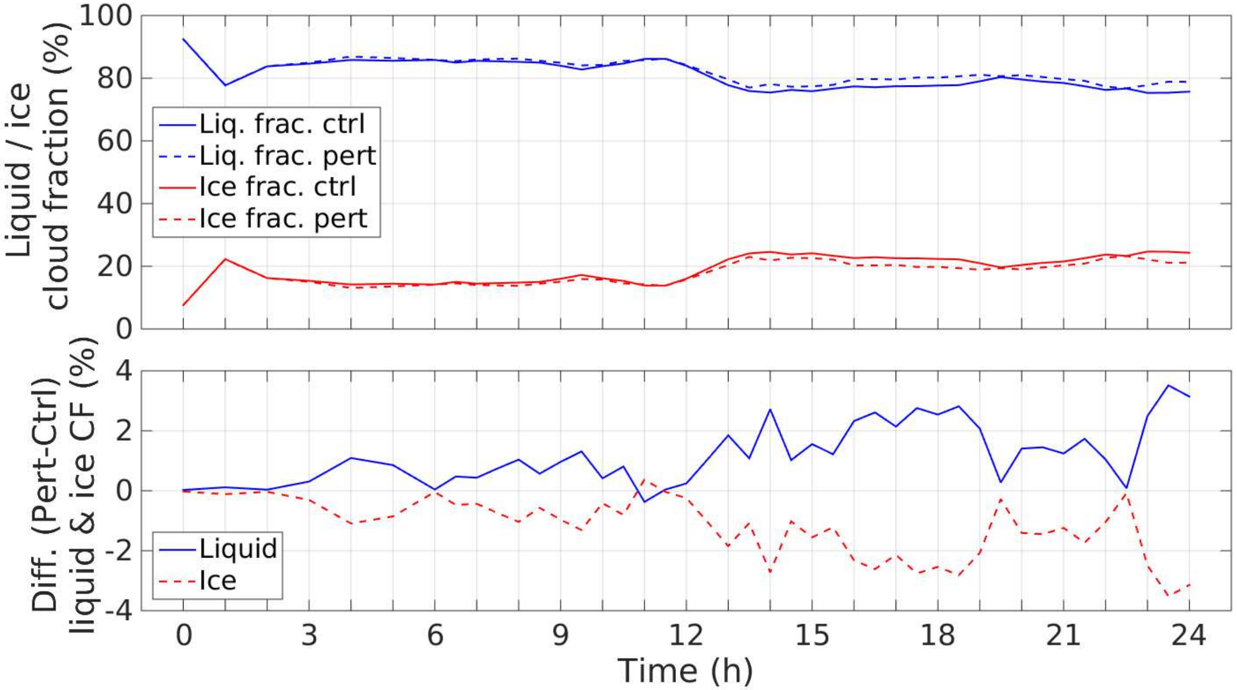



Rosenfeld et al. (2014), Rev. Geophy.

# Cloud phase

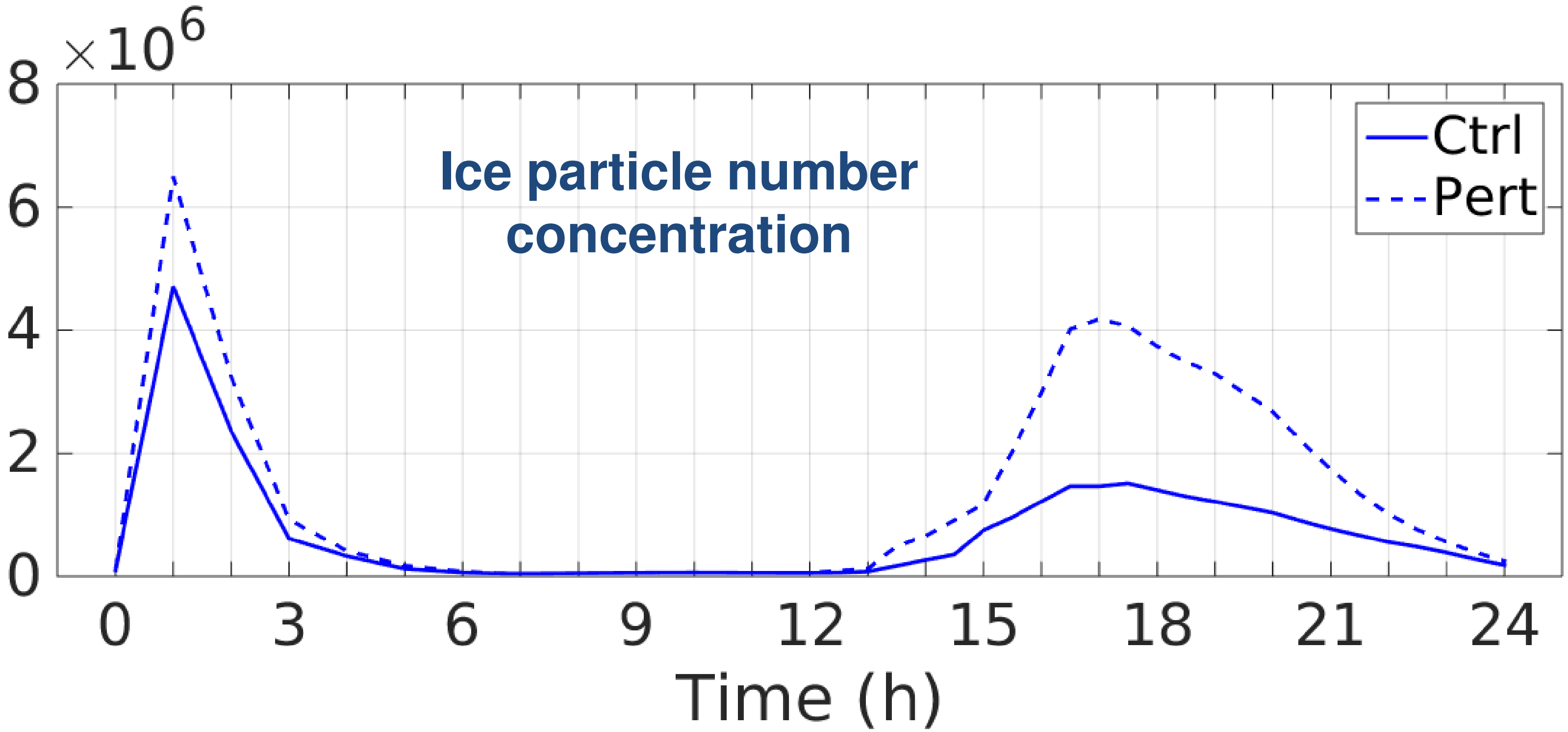
- Smaller cloud droplets can delay the onset of freezing.
- With the onset of convection around noon, 10% (8%) of liquid phase is converted to ice phase in the control (perturbed) run.

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%.



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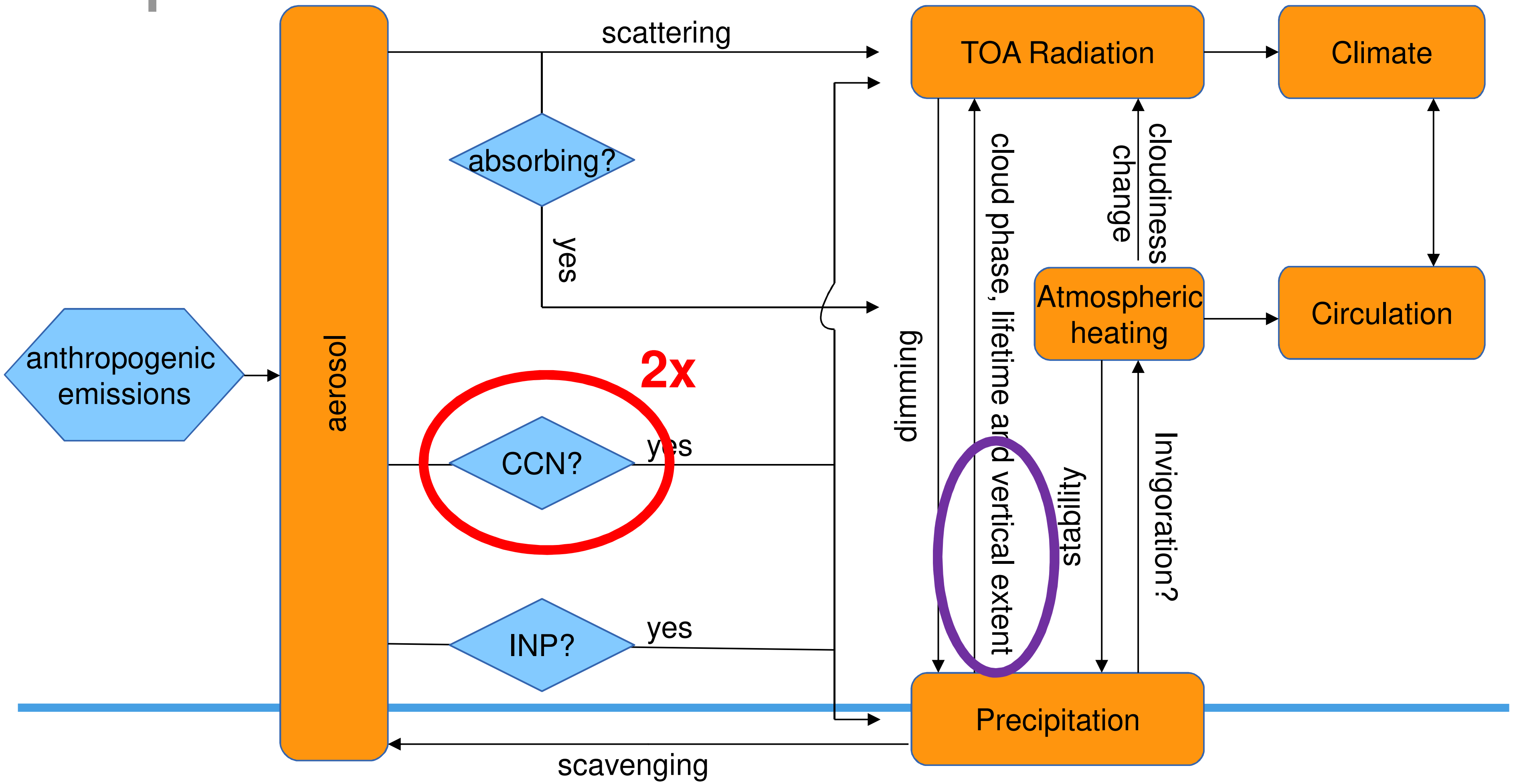
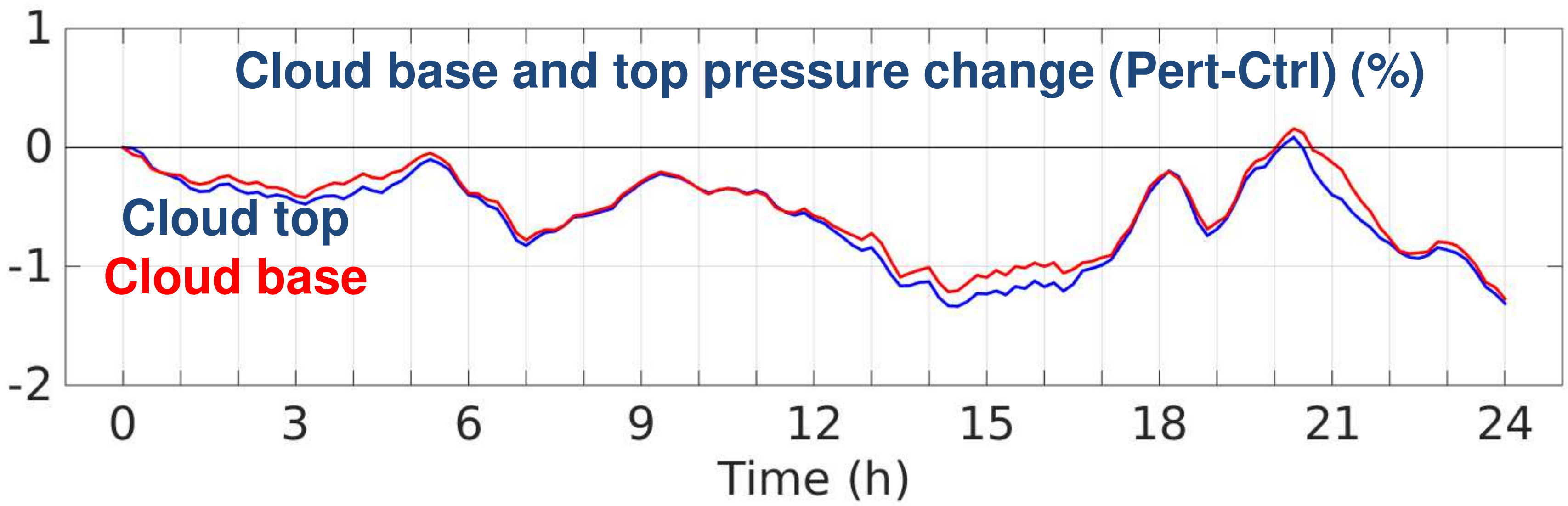



Rosenfeld et al. (2014), Rev. Geophy.

# 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.



# Summary

| Variable | Control | Perturbed | Change (%) |
|---|---|---|---|
| **Mean cloud cover (%)** | 84.8 | 85.2 | **+ 0.4** |
| **Cloud droplet no. concentration [$kg^{-1}$]** | $3.4 \times 10^8$ | $6.7 \times 10^8$ | **+ 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 [$kg\ m^{-2}$]** | $3.5 \times 10^{-3}$ | $3.3 \times 10^{-3}$ | **- 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 but negligible 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. Decreased ice fraction at the expense of liquid fraction in mixed-phase clouds.
  - Vertical extent: slightly higher cloud tops and bases.

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  - Vertical extent: slightly higher cloud tops and bases.

Preliminary results
Significance need to be investigated

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# 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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# On behalf of S1 team: Thank you for your attention!