# Explicit aerosol-cloud interaction in DALES

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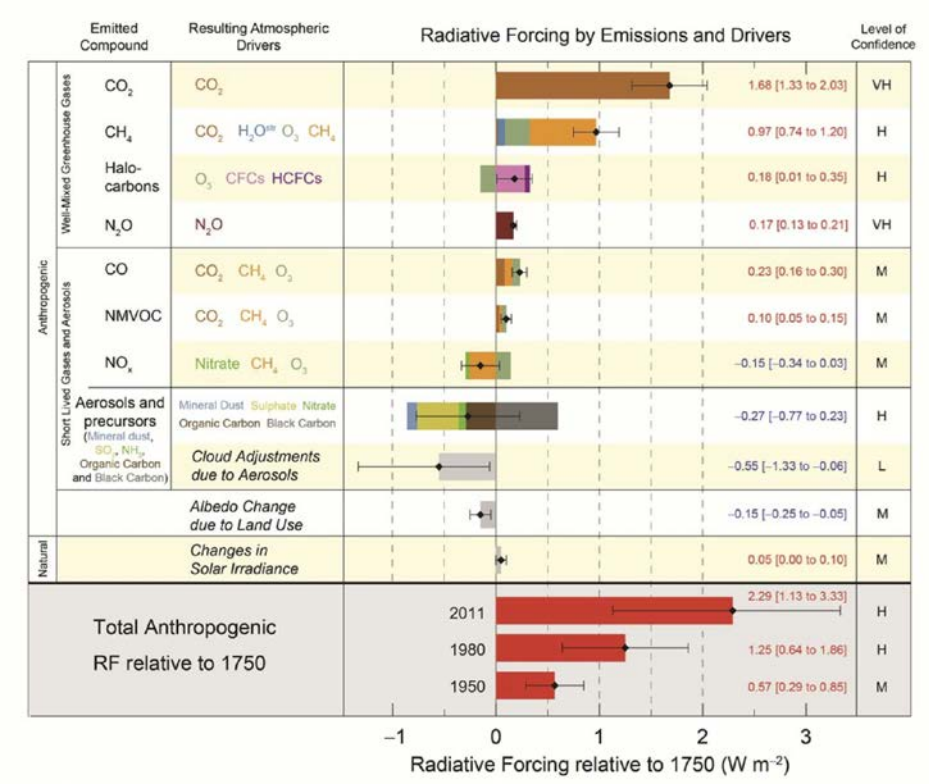
# Introduction

$CO_2$: 1.68 $Wm^{-2}$ [ 1.33 to 2.03]

ACI: -0.55 $Wm^{-2}$ [-1.33 to -0.06]

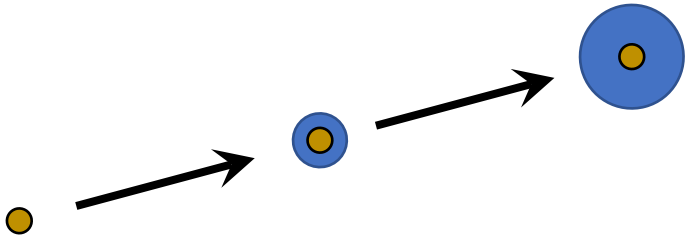


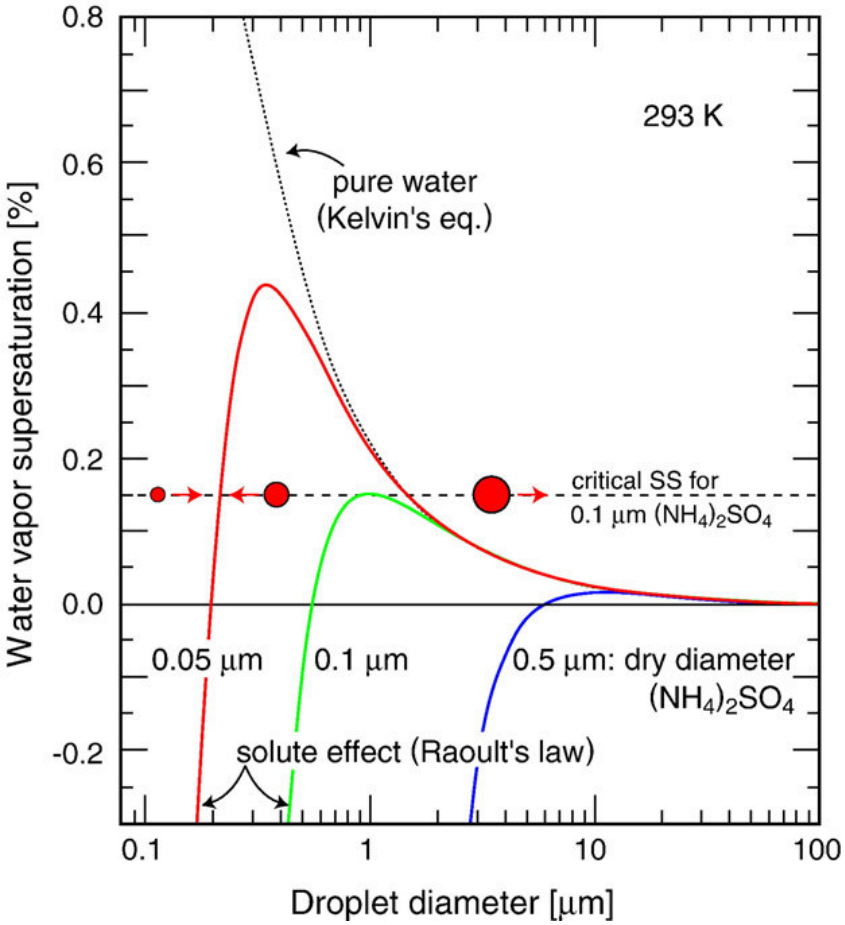
# Cloud droplet formation

*Air rises, cools down, water condenses*

Curvature prevents droplet formation

Aerosols provide surface for water to condense

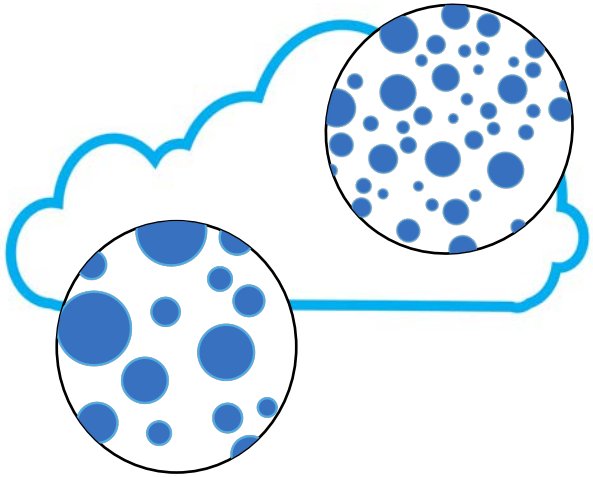


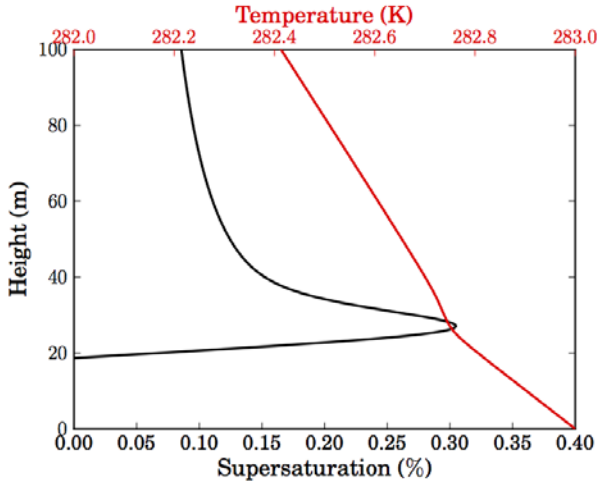


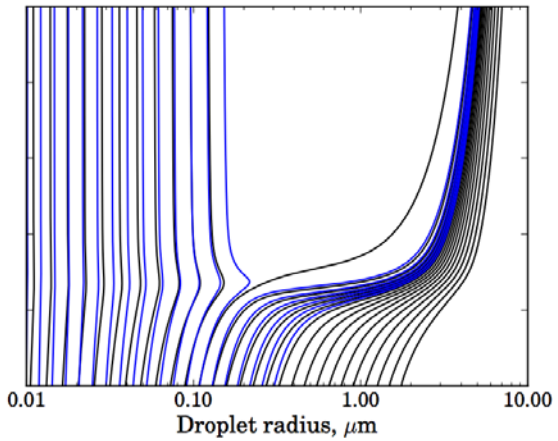
# Cloud droplet formation

Available moisture
vs.
Aerosol number, sizes and composition

How many droplets form?
How large will they grow?

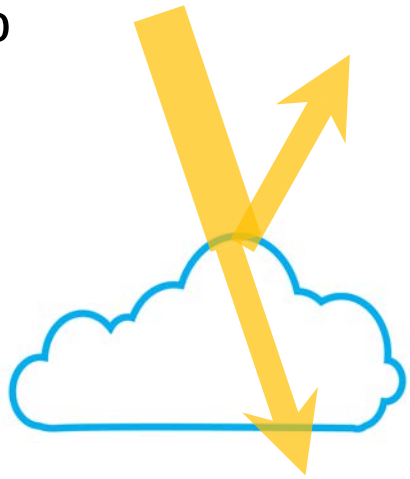




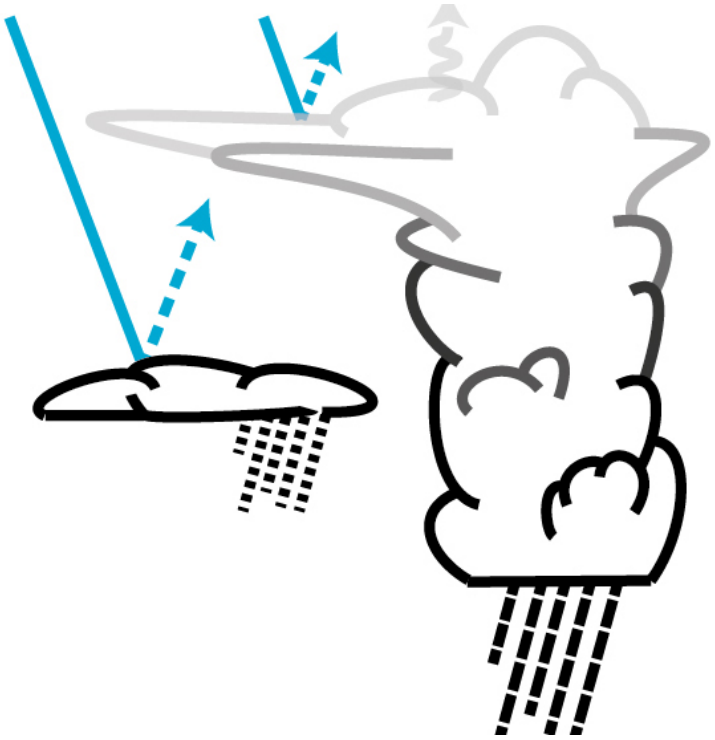
# Aerosol-cloud interaction

albedo

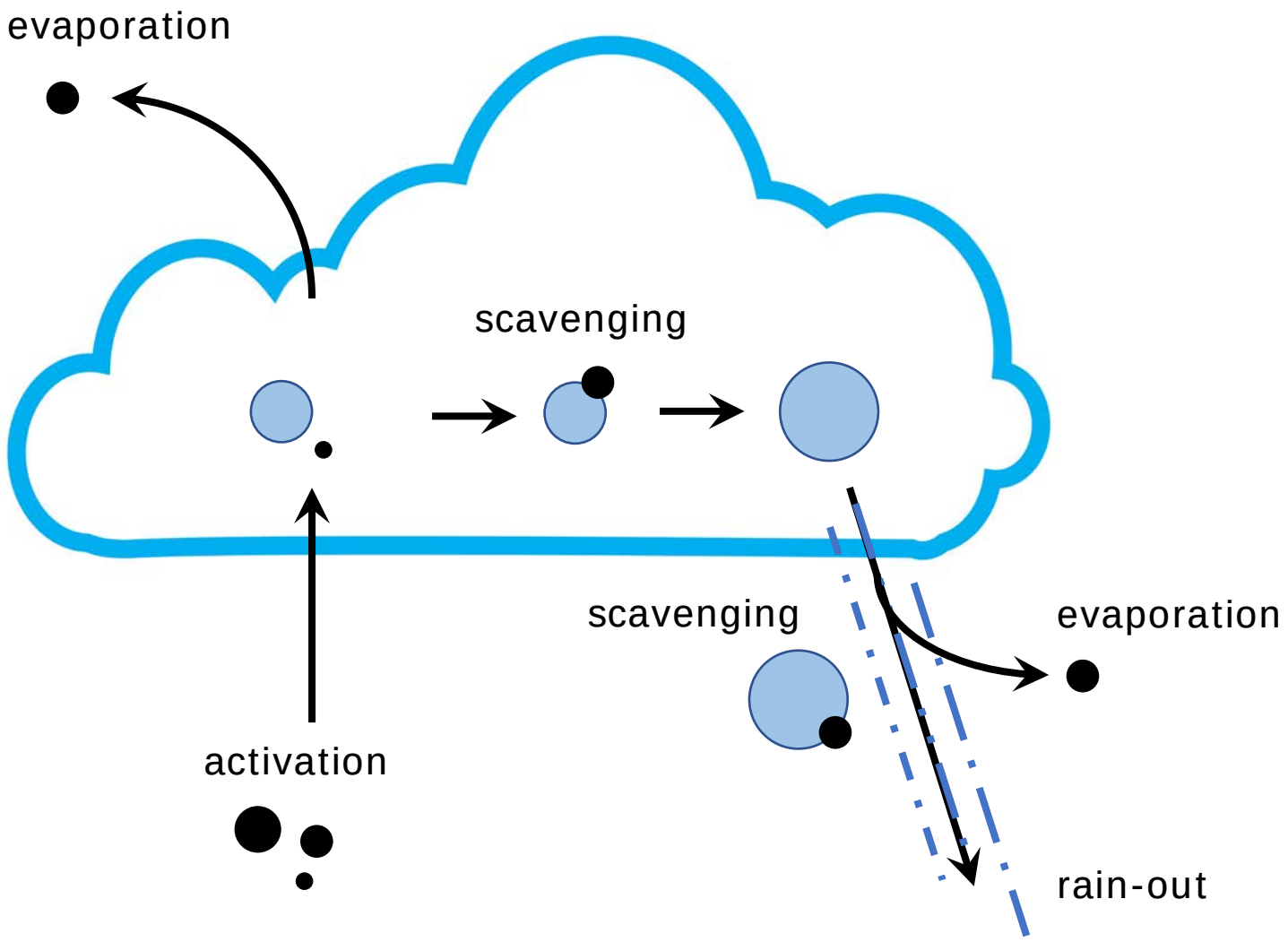


lifetime

thermodynamic

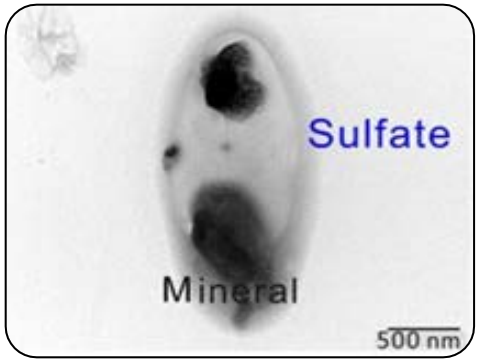


# Aerosol-cloud interaction



# Scaling problem

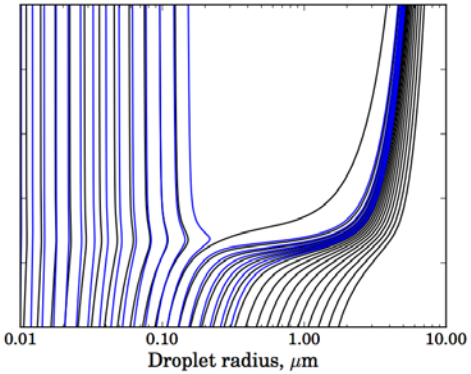
microphysics




macro dynamics

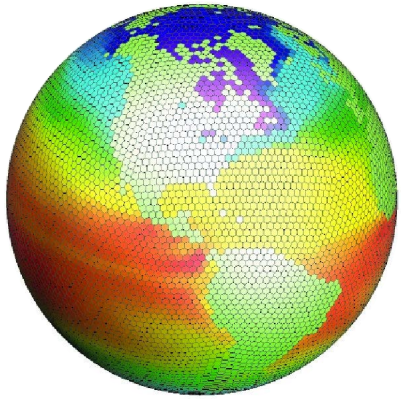
$10^{-6}$ m ⟷ $10^{6}$ m

12 orders of magnitude




0D parcel models

⟷

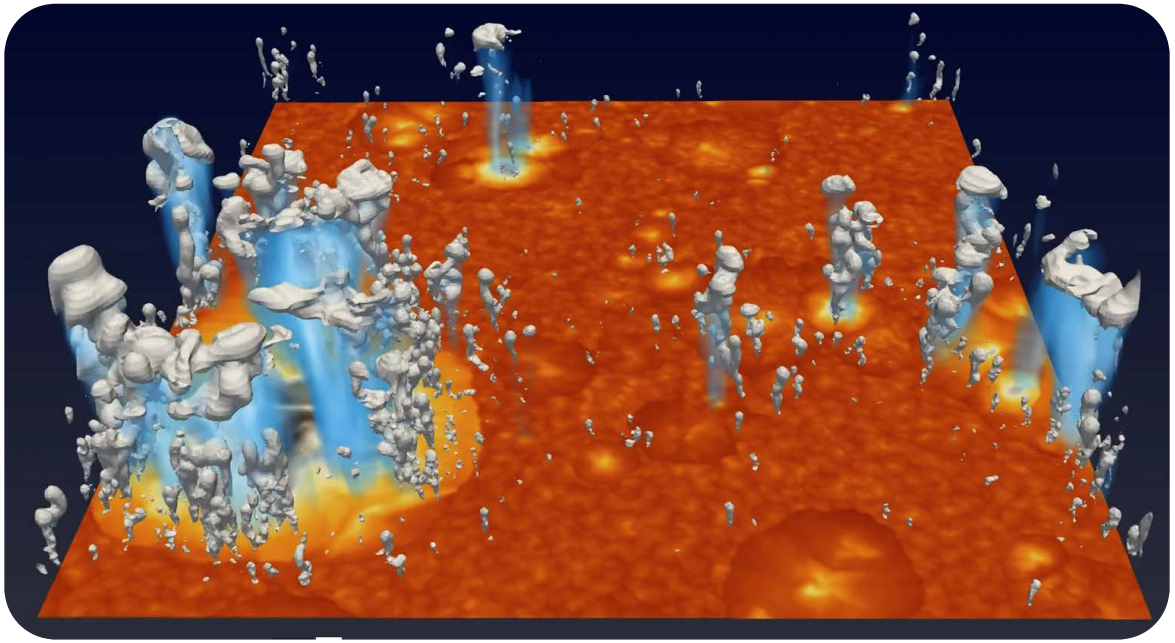


GCMs / ESMs

# LES – Large Eddy simulation

- Domain size ~25 x 25 $km^2$
- Resolution ~50 x 50 x 20 $m^3$
- Timestep ~1 s

Resolves cloud structure in a domain that allows macrodynamic feedbacks



Wouter Mol,
Chiel van Heerwaarden
microhh.org

# Numerical framework

2-moment cloud microphysics (Seifert & Beheng, 2006)
No aerosol --> Cloud droplet number prescribed and fixed

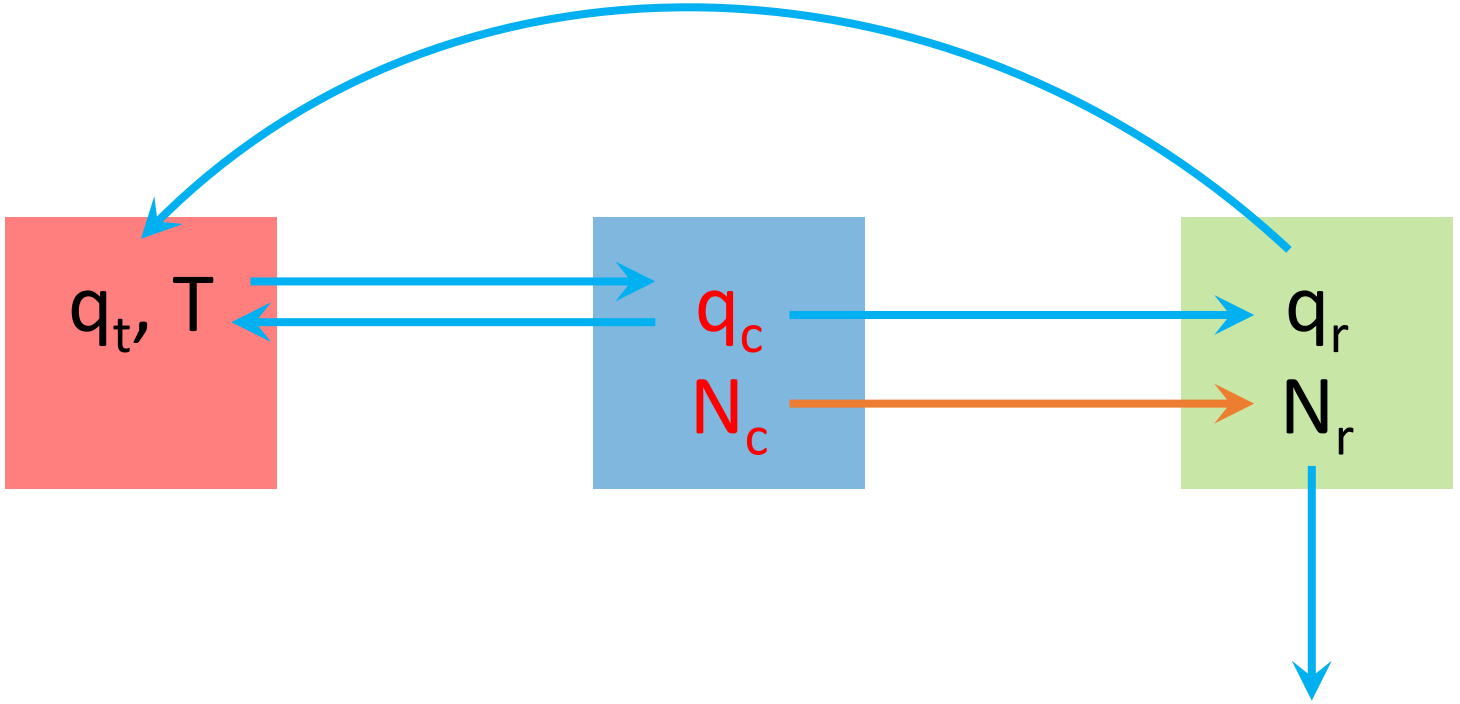



Fig. 3 (Heus et al., 2010)

# Numerical framework

Nc determined by aerosol
Explicit calculation of aerosol-cloud interaction

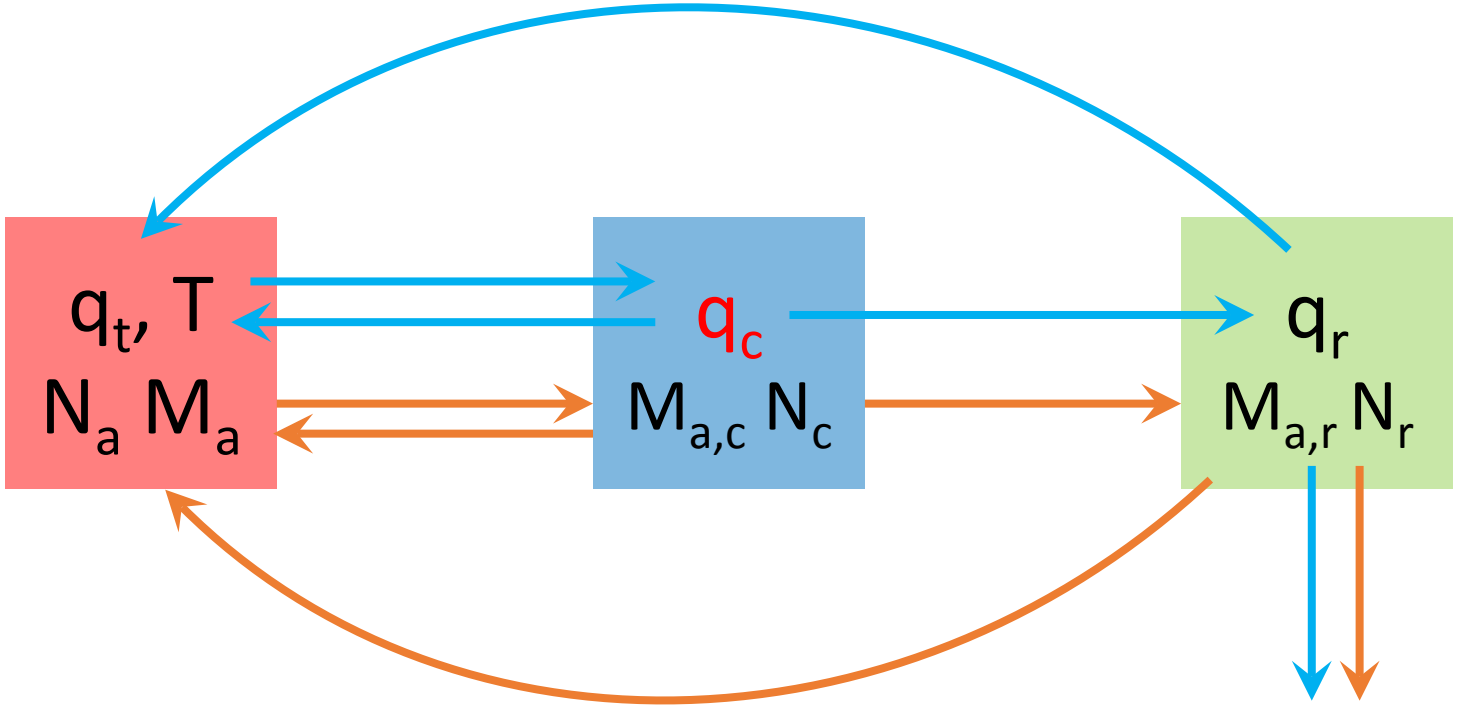
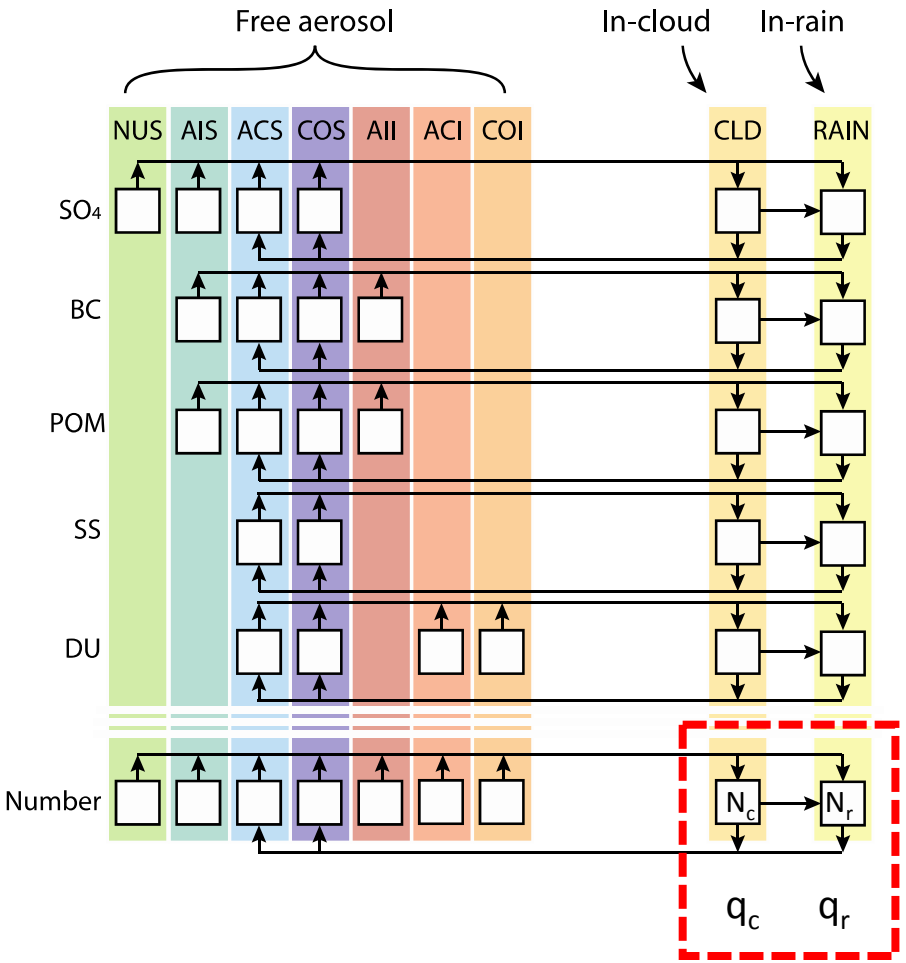



Fig. 3 (Heus et al., 2010)

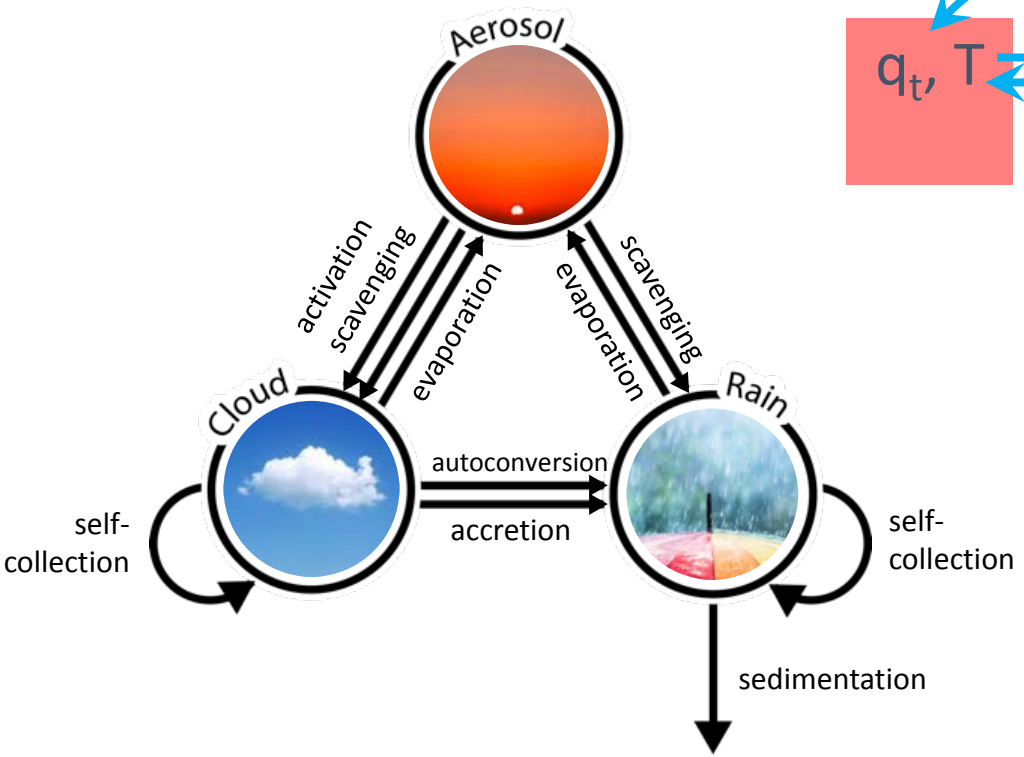
# Numerical framework

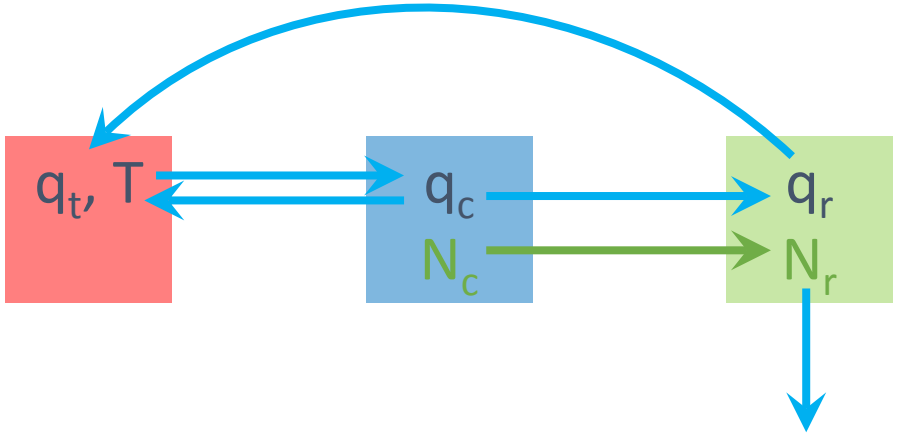
- M7 aerosol framework (Vignati et al., 2004) to describe aerosol population

- Extension to include aerosol mass in cloud and rain water
  → 37 prognostic variables



# Aerosol ‘states’



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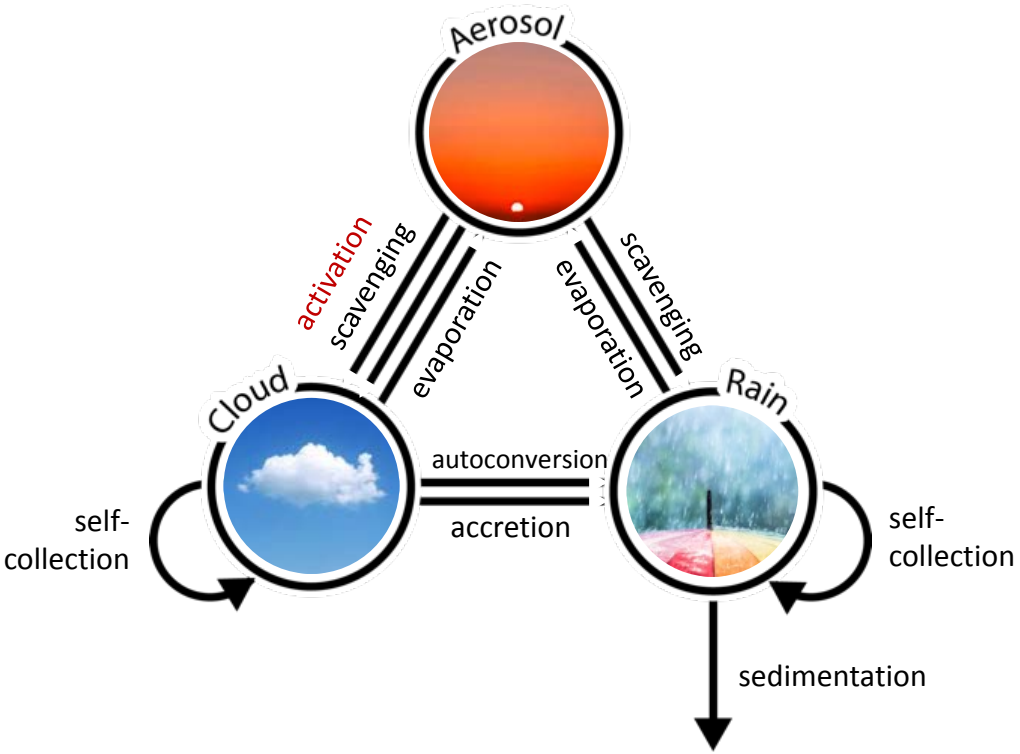


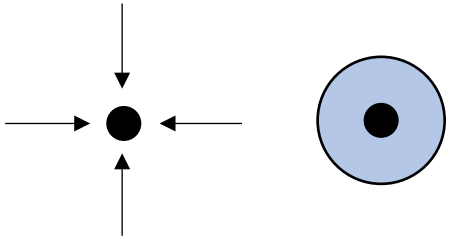

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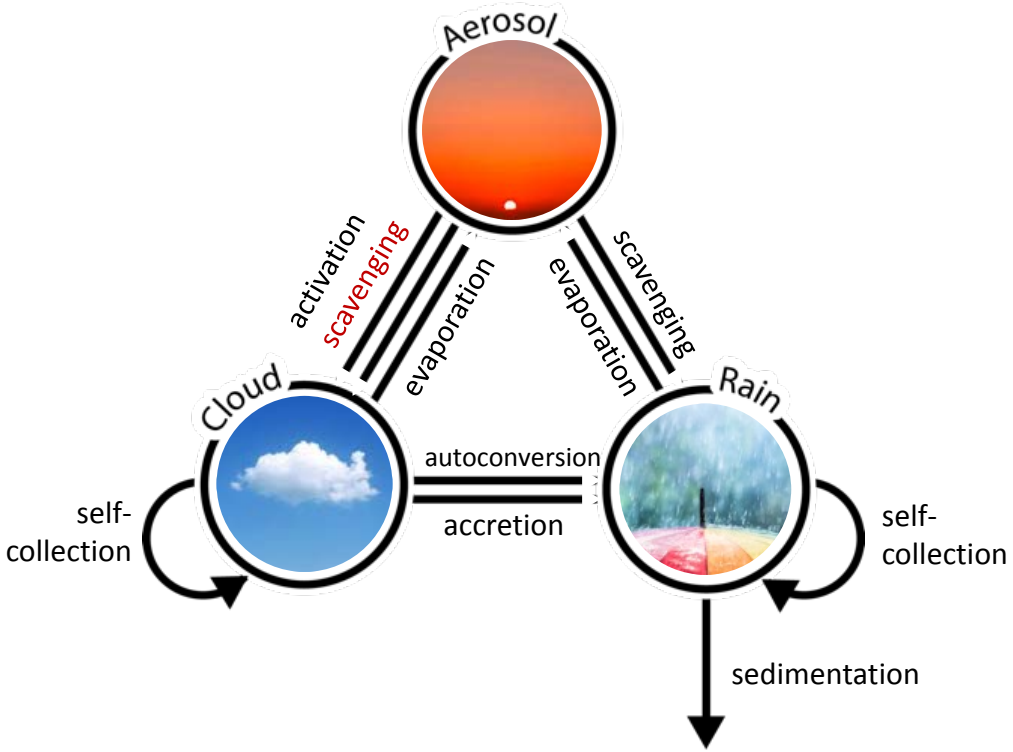


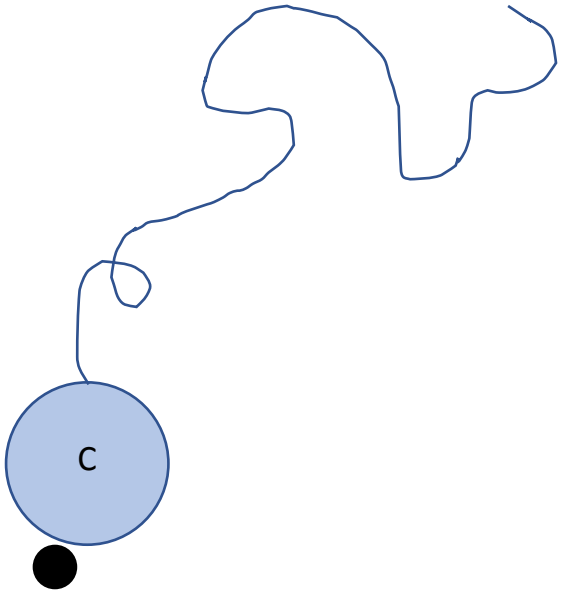

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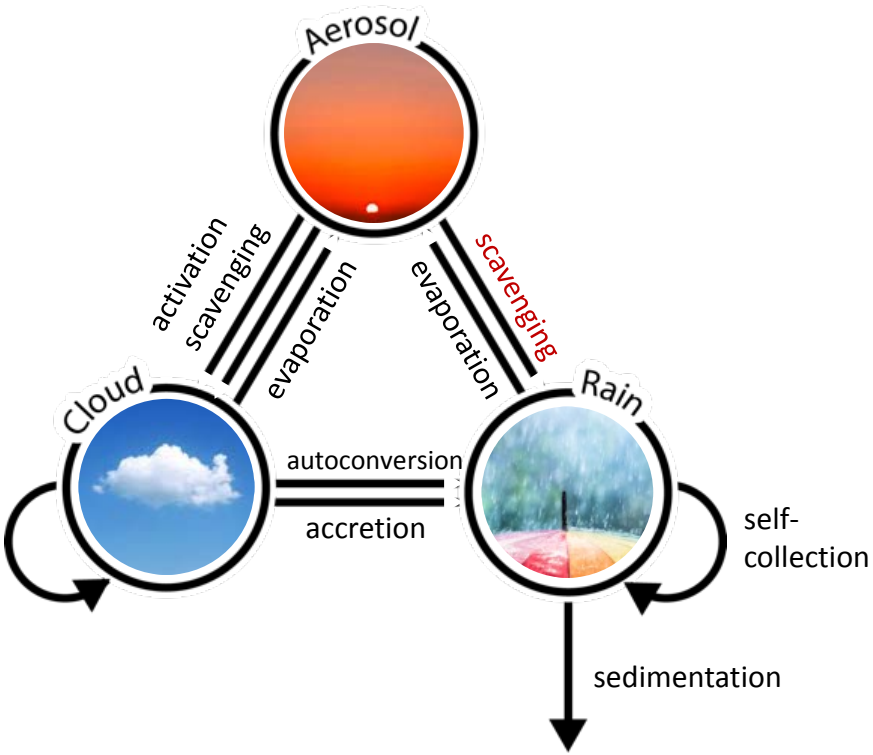


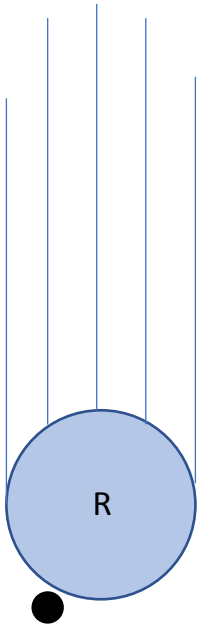

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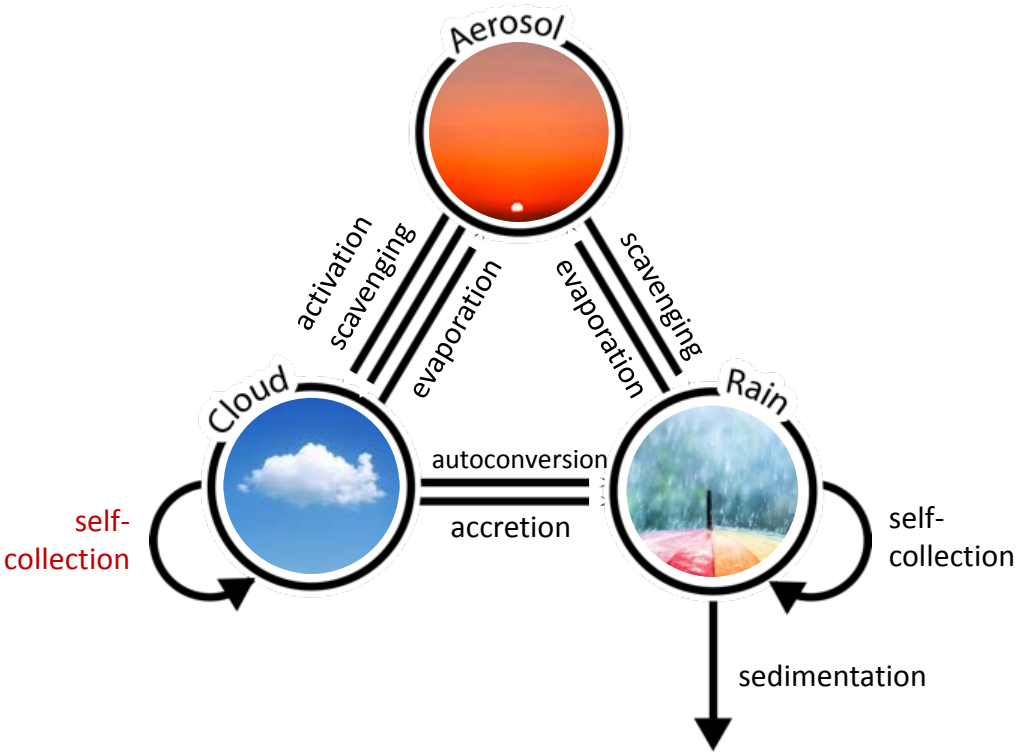


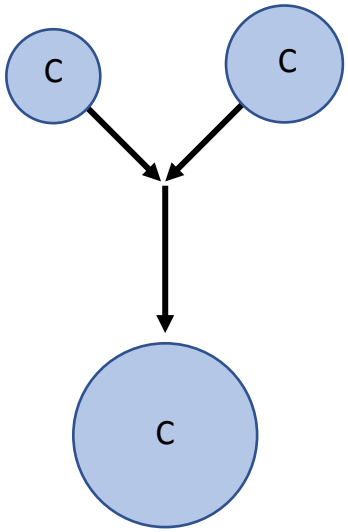

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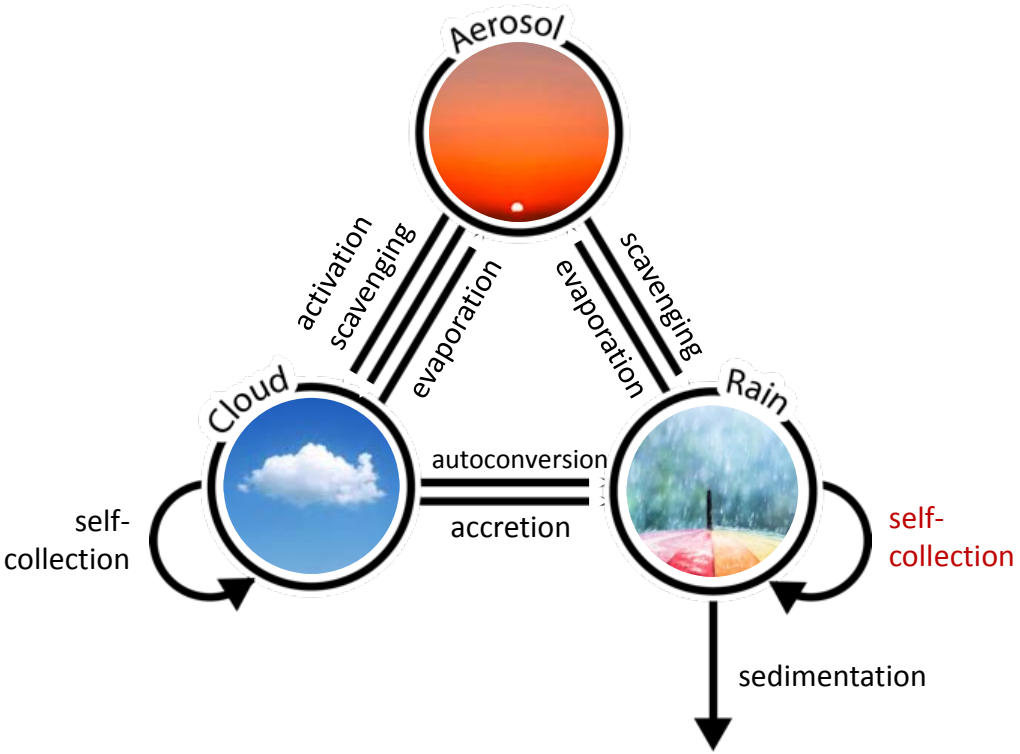


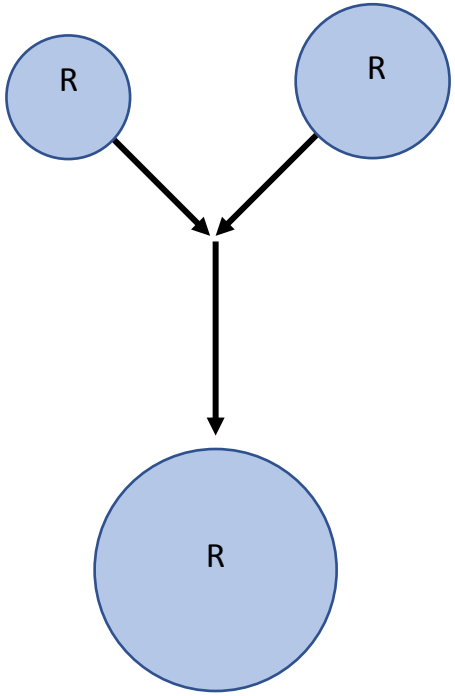

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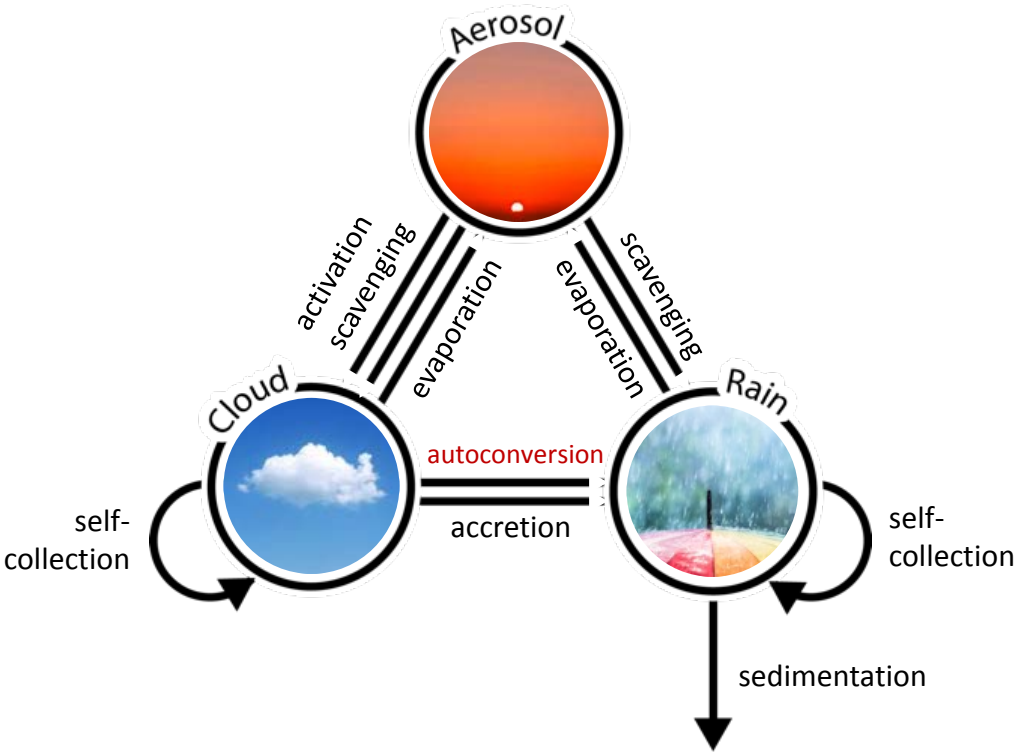


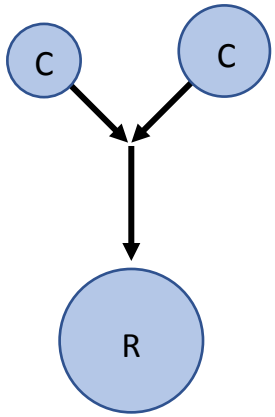

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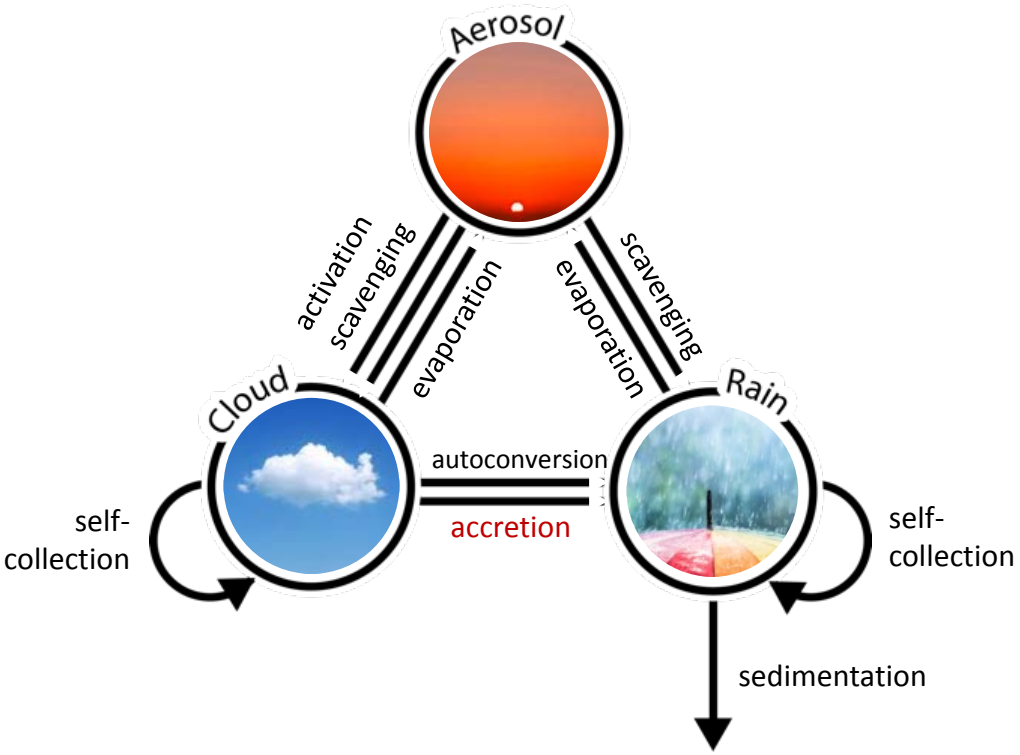
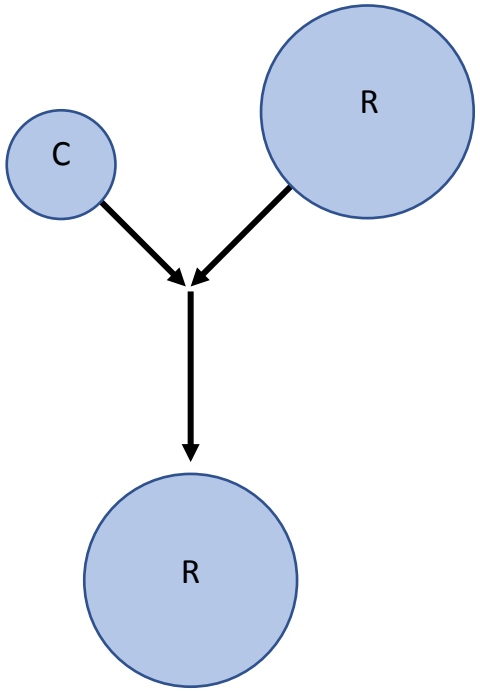
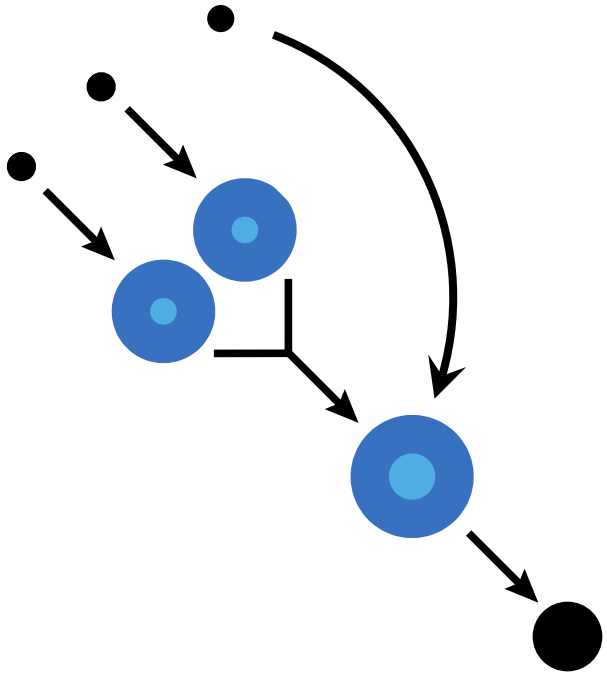


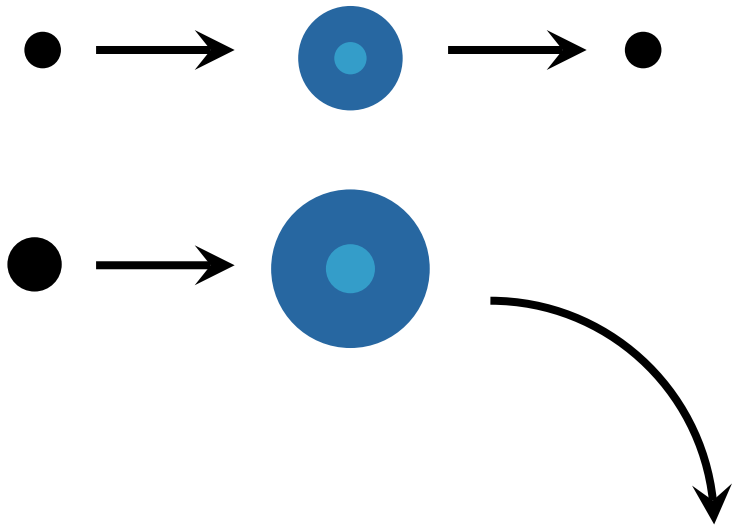
# Feedback to aerosol

Processing



aerosol size increases

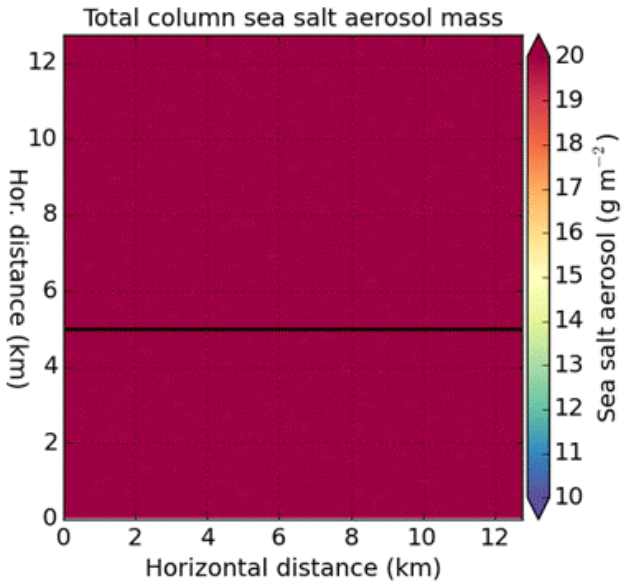
Removal

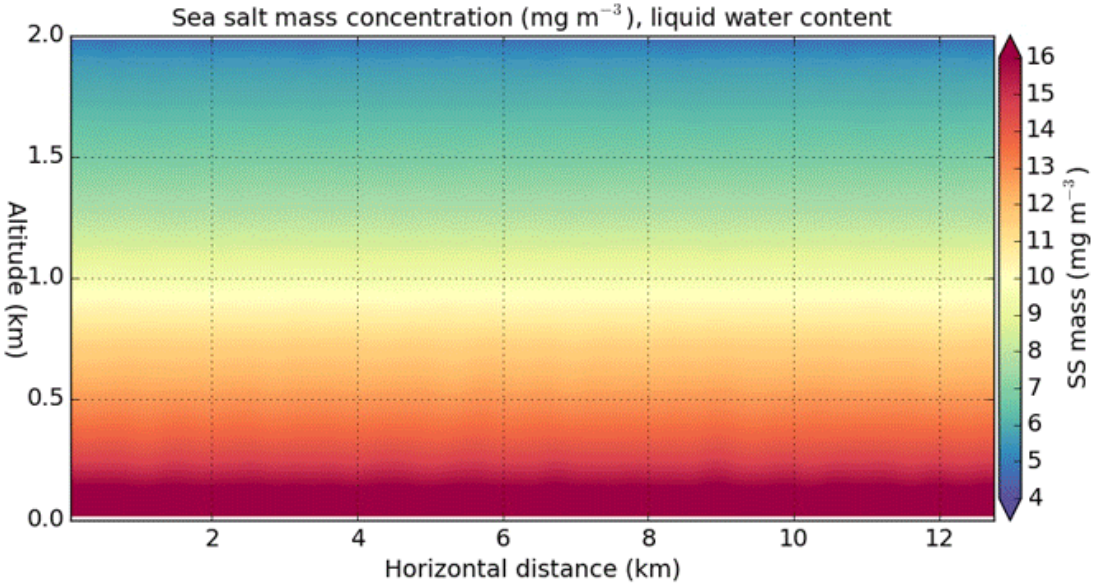


aerosol size decreases

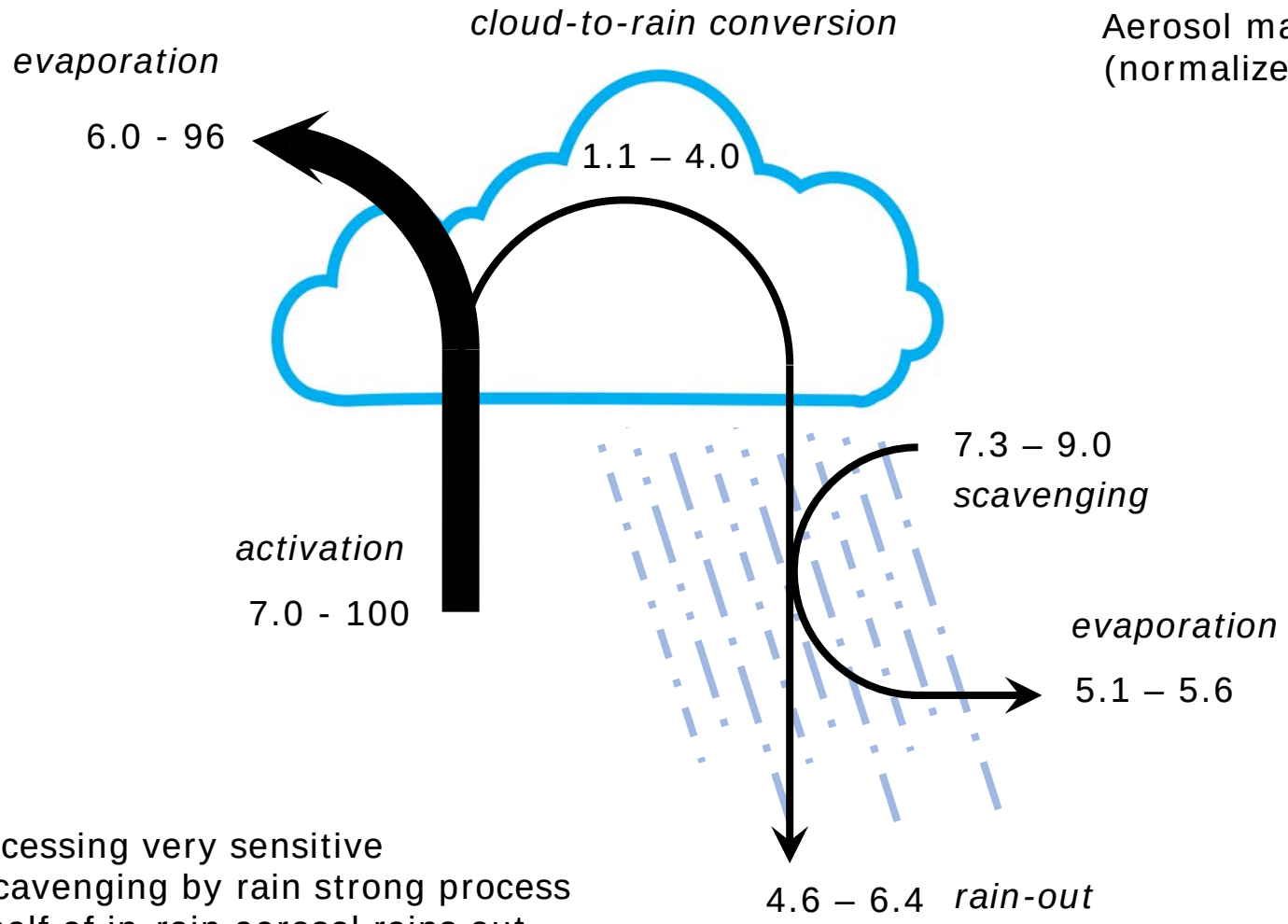
RICO (Rain in Cumulus over the Ocean;  Rauber et al., 2007)

# Qualitative impression of output



# Feedback to aerosol




- Cloud processing very sensitive
- Aerosol scavenging by rain strong process
- Roughly half of in-rain aerosol rains out

# Wrap-up

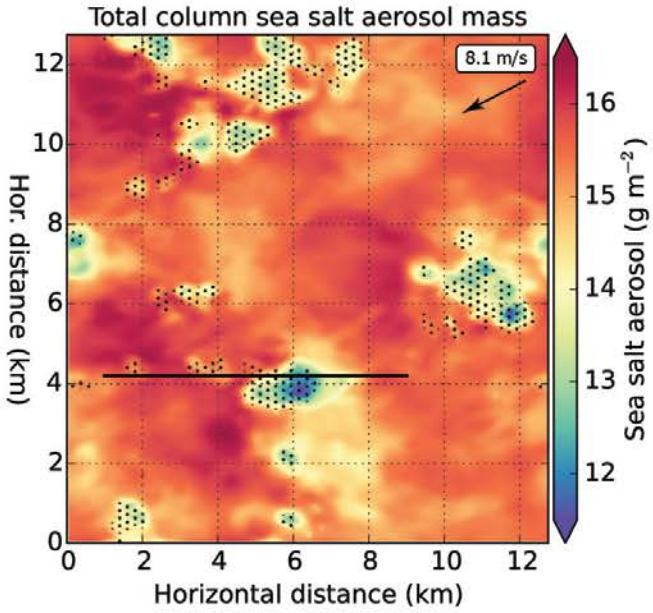
- LES: high resolution with sufficient domain size

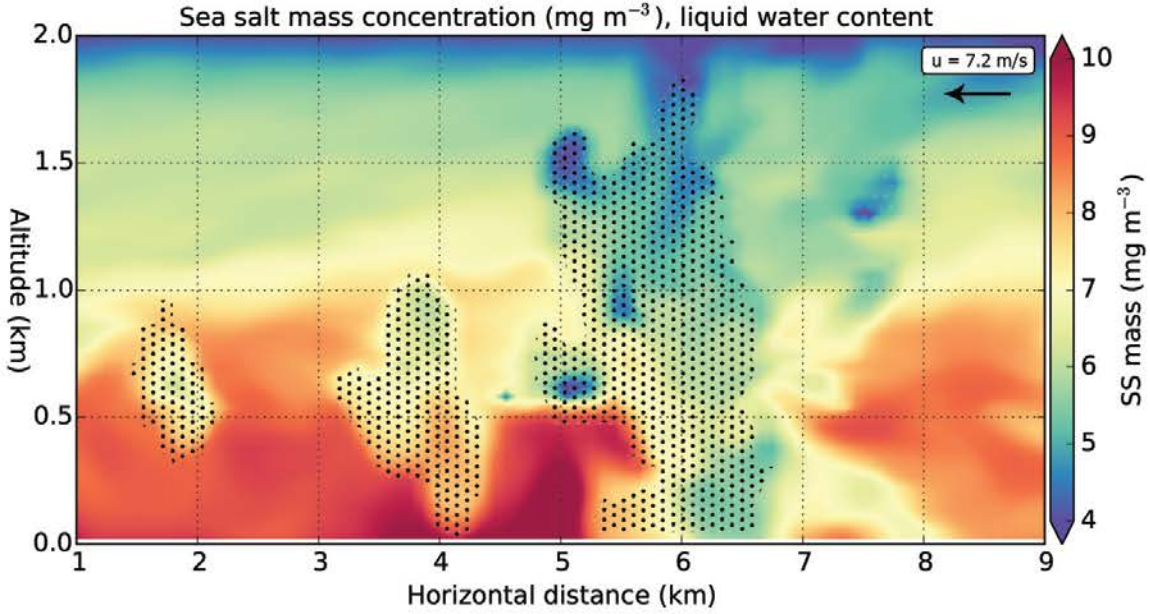
- Implementation of aerosol scheme M7
- Interactive calculation of cloud droplet number

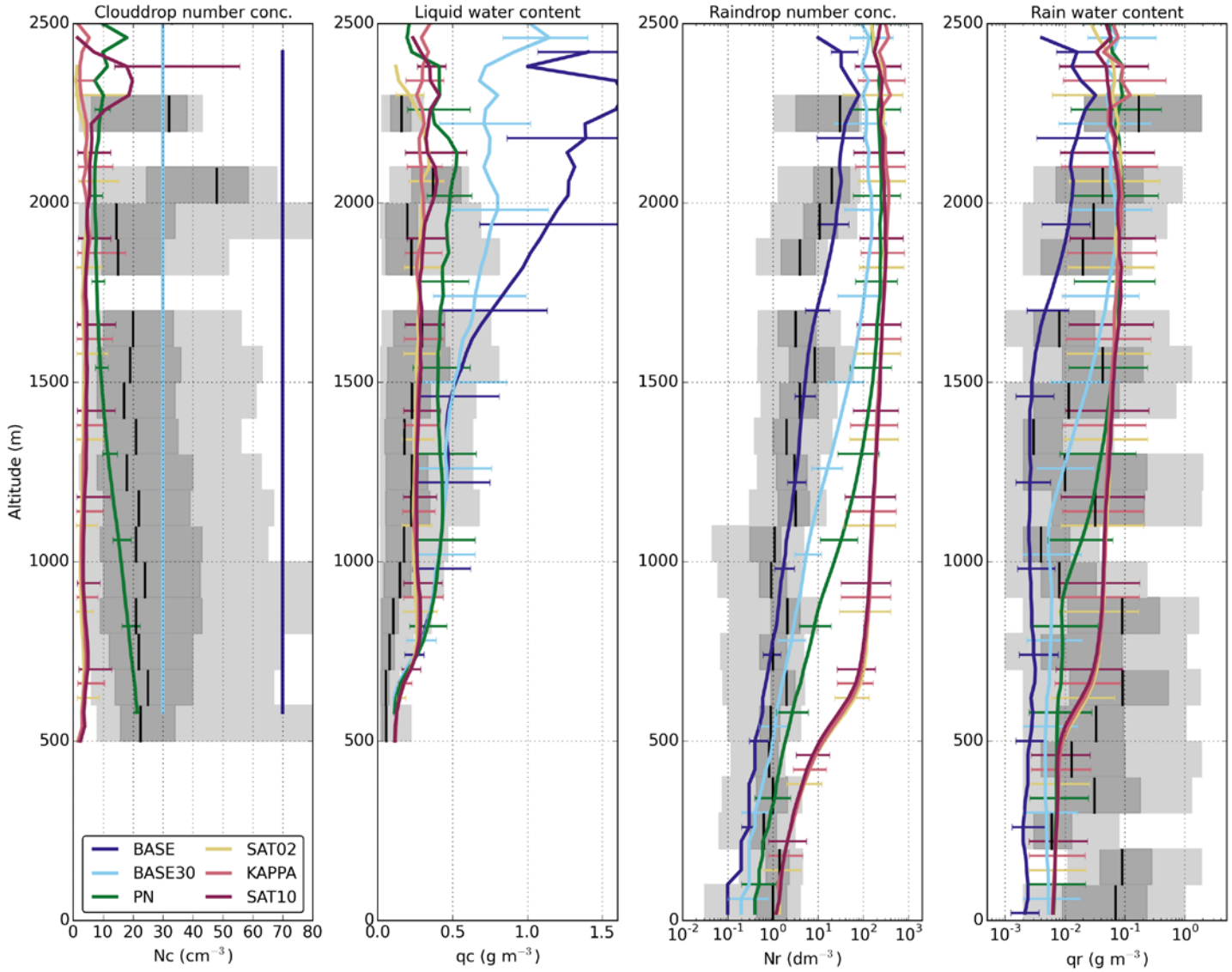
- Framework to study aerosol-cloud interaction
- Possible integration with (gaseous) chemistry using e.g. TM5/M7 code

# Additional slides

# Qualitative impression of output




Clouddrop number conc.
Liquid water content
Raindrop number conc.
Rain water content
Altitude (m)
Nc (cm$^{-3}$)
qc (g m$^{-3}$)
Nr (dm$^{-3}$)
qr (g m$^{-3}$)
BASE
BASE30
PN
SAT02
KAPPA
SAT10

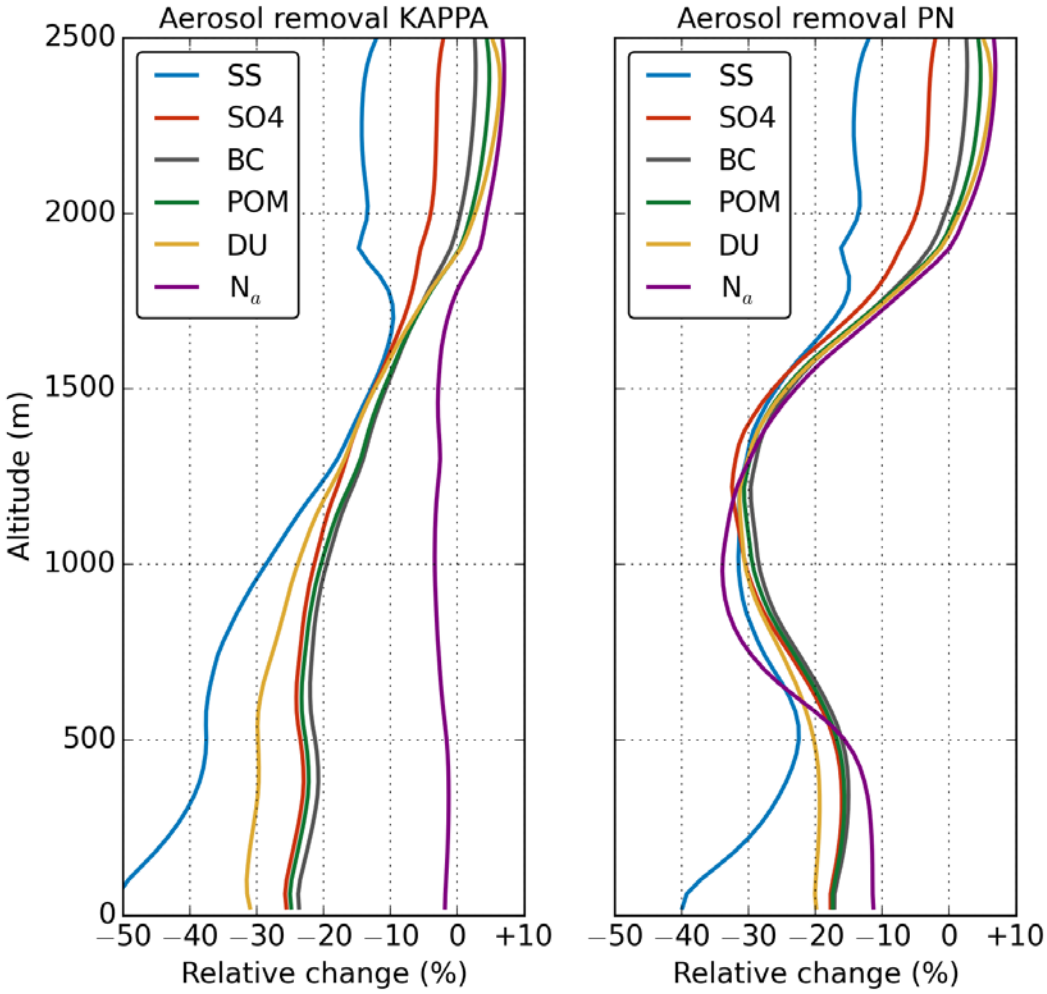

Aerosol removal KAPPA
Aerosol removal PN
SS
SO4
BC
POM
DU
$N_a$
Altitude (m)
2500
2000
1500
1000
500
0
−50 −40 −30 −20 −10 0 +10
Relative change (%)

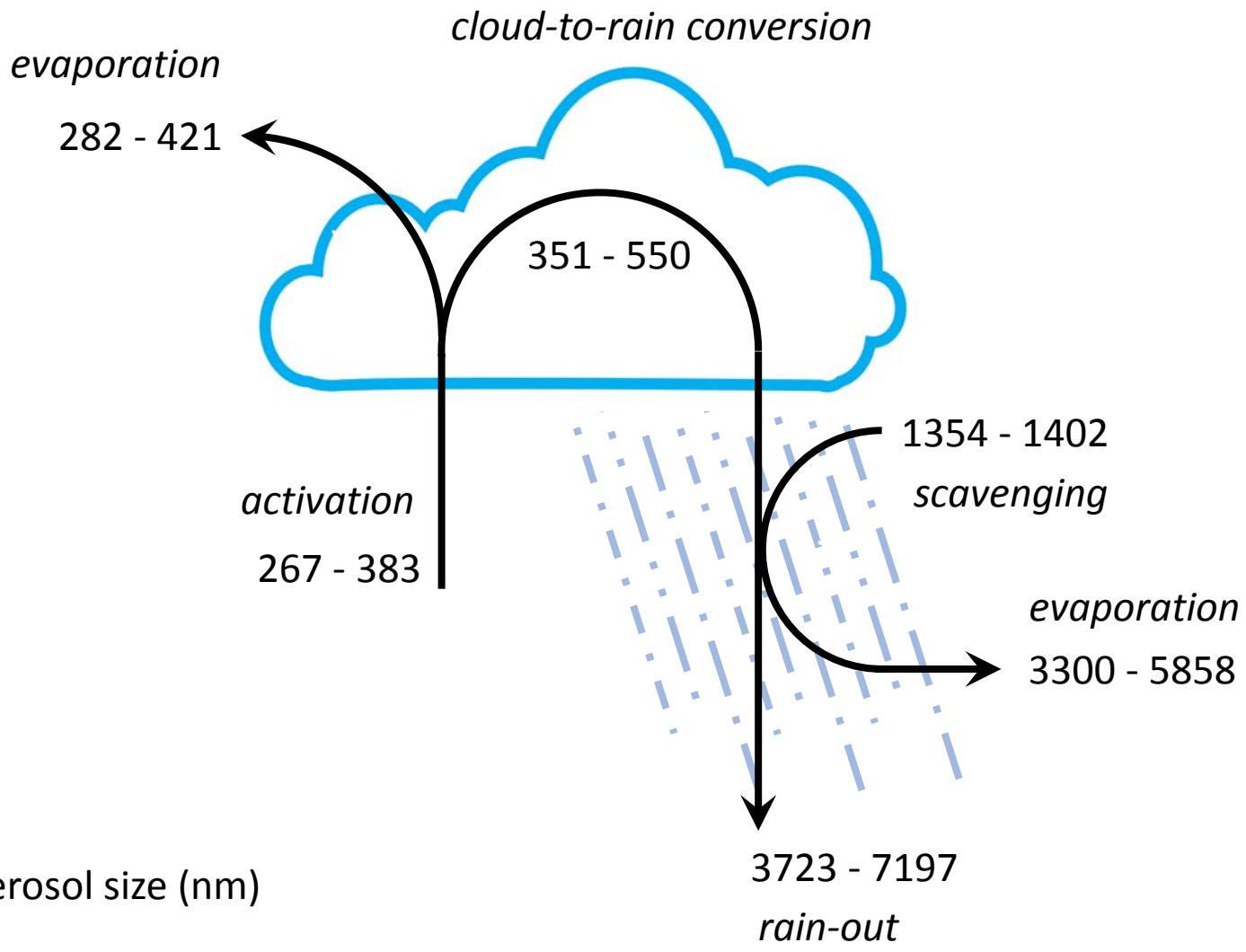
**Table 3.** Domain-average total column microphysical process strengths in the KAPPA simulation for the different aerosol species. All values are scaled to the species total column aerosol mass and can be interpreted as timescales (day $^{-1}$). For example, activation processes 1.37 times the total column sea salt aerosol mass per day.

| | activation | in-cloud scavenging | cloud evaporation | cloud-to-rain conversion | rain scavenging | rain evaporation | rain sedimentation |
|---|---|---|---|---|---|---|---|
| Sea salt | 1.37 | $1.09\times10^{-2}$ | 1.19 | 0.21 | 2.35 | 1.30 | 1.30 |
| Sulphate | 0.70 | $3.41\times10^{-3}$ | 0.60 | 0.11 | 0.90 | 0.56 | 0.46 |
| Organic matter | 0.44 | $2.16\times10^{-3}$ | 0.38 | 0.07 | 0.56 | 0.35 | 0.28 |
| Black carbon | 0.52 | $2.61\times10^{-3}$ | 0.45 | 0.08 | 0.62 | 0.39 | 0.32 |
| Mineral dust | 0.37 | $2.80\times10^{-3}$ | 0.32 | 0.06 | 0.61 | 0.37 | 0.30 |
| Water | | | | | | $3.51\times10^{-2}$ | $2.52\times10^{-3}$ |

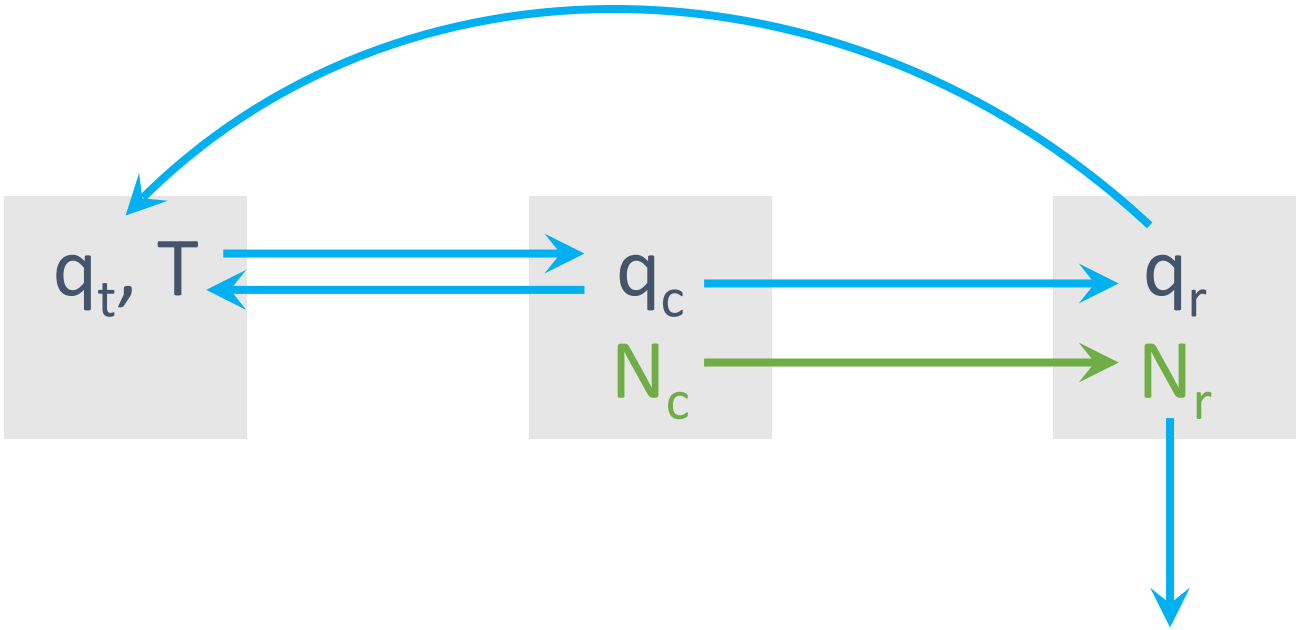
**Table 4.** Same as Table 3, but for the PN simulation.

| | activation | in-cloud scavenging | cloud evaporation | cloud-to-rain conversion | rain scavenging | rain evaporation | rain sedimentation |
|---|---|---|---|---|---|---|---|
| Sea salt | 18.62 | $2.33\times10^{-4}$ | 17.89 | 0.70 | 1.65 | 0.96 | 1.44 |
| Sulphate | 10.00 | $1.22\times10^{-4}$ | 9.59 | 0.40 | 0.73 | 0.51 | 0.64 |
| Organic matter | 6.25 | $1.45\times10^{-4}$ | 6.00 | 0.25 | 0.45 | 0.32 | 0.40 |
| Black carbon | 7.11 | $3.82\times10^{-4}$ | 6.82 | 0.28 | 0.52 | 0.36 | 0.45 |
| Mineral dust | 5.24 | $1.48\times10^{-3}$ | 5.03 | 0.21 | 0.50 | 0.33 | 0.39 |
| Water | | | | | | $1.94\times10^{-2}$ | $2.51\times10^{-3}$ |

# Feedback to aerosol




Typical aerosol size (nm)


$q_t$, T
$q_c$
$N_c$
$q_r$
$N_r$