Bulk cloud model

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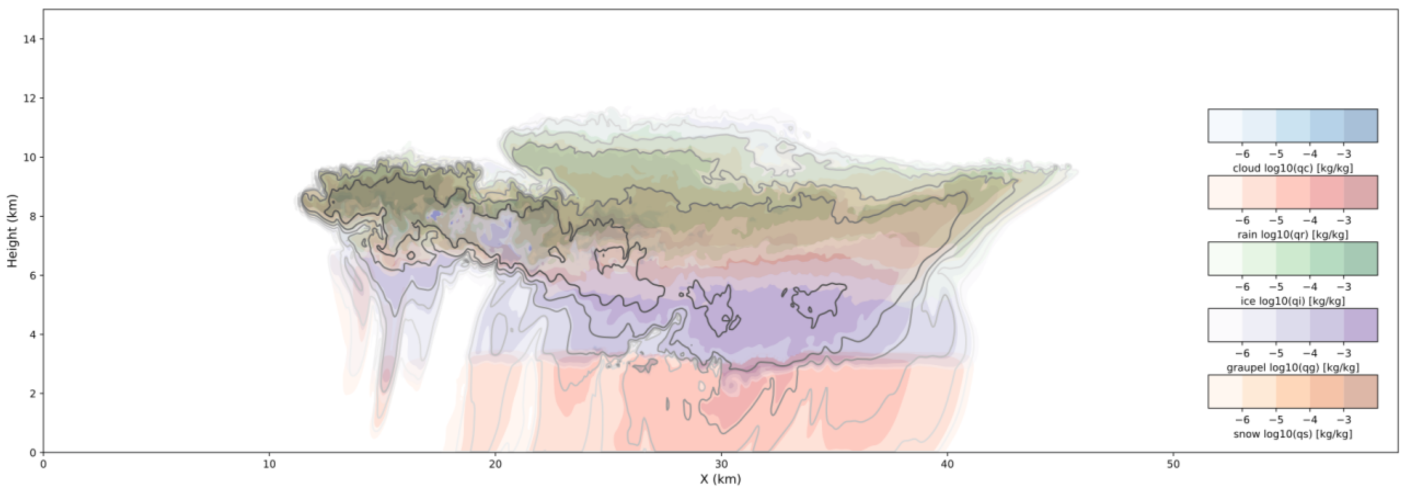
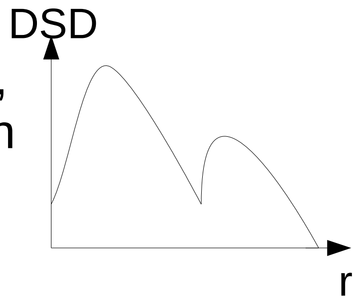
- The Bulk cloud model (BCM) is able to simulate clouds and their microphysics processes with different levels of detail

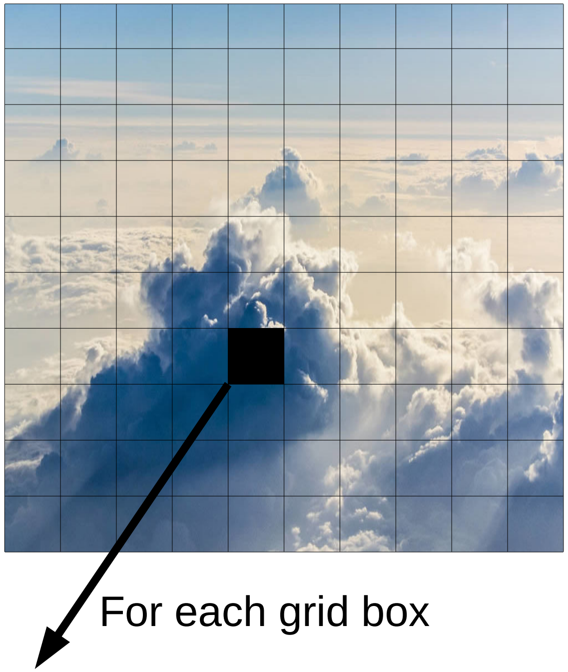


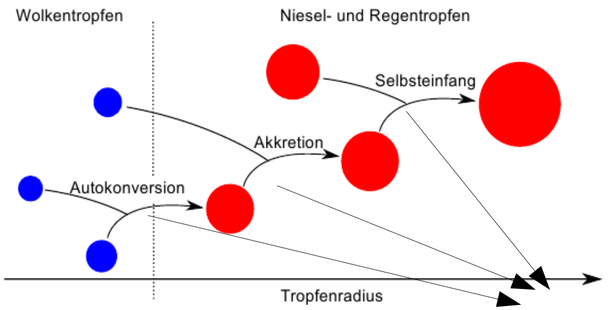
Bulk cloud model

Physics

- Assumption that cloud droplets, rain droplets or ice particles can be described by a **given distribution function**
- Different number of **moments** can be considered for different number of **species**
- Microphysical processes are **parameterized**







Assume rates

<u>Prognostic quantities</u>

- Mass mixing ratio
- Number concentration

Number of moments

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Physics II

- Evaporation and condensation of cloud droplets are parameterized by a saturation adjustment scheme.
- But as LES sometimes requires very small timesteps also an explicit condensation scheme is available
- Activation can be parameterized using sophisticated Twomey-parameterization schemes.
- Autoconversion is an artificial process introduced by the separation of cloud droplets and rain.
- Evaporation of raindrops can be very important in convective systems, since it determines the strength of the cold pool. However, to parameterize it is difficult, since evaporation is very size dependent.
- Conversion processes, like snow to graupel conversion by riming, are very difficult to parameterize but very important in convective clouds.
- Aggregation processes assume certain collision and sticking efficiencies, which are not well known.
- Ice multiplication (or Hallet-Mossop process) may be very important, but is still not well understood

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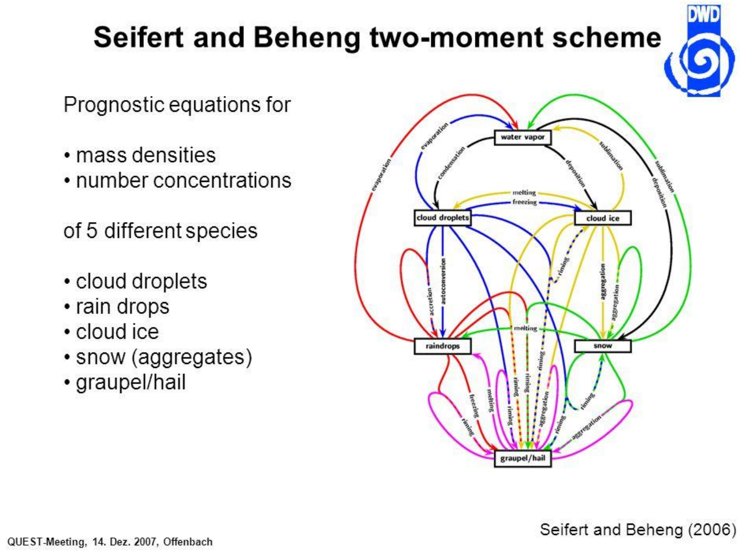
Physics III

- Based on the microphysics scheme of *Seifert and Beheng (2001,2006)*
- Implementation of liquid phase based on the code of *DALES & UCLA-LES* and ice phase on *ICON*
- Usage of mixing ratios
- Underlying prognostic equations of liquid water potential temperature (`pt`) and total water content (q) (e.g., *Emanuel, 1994*)



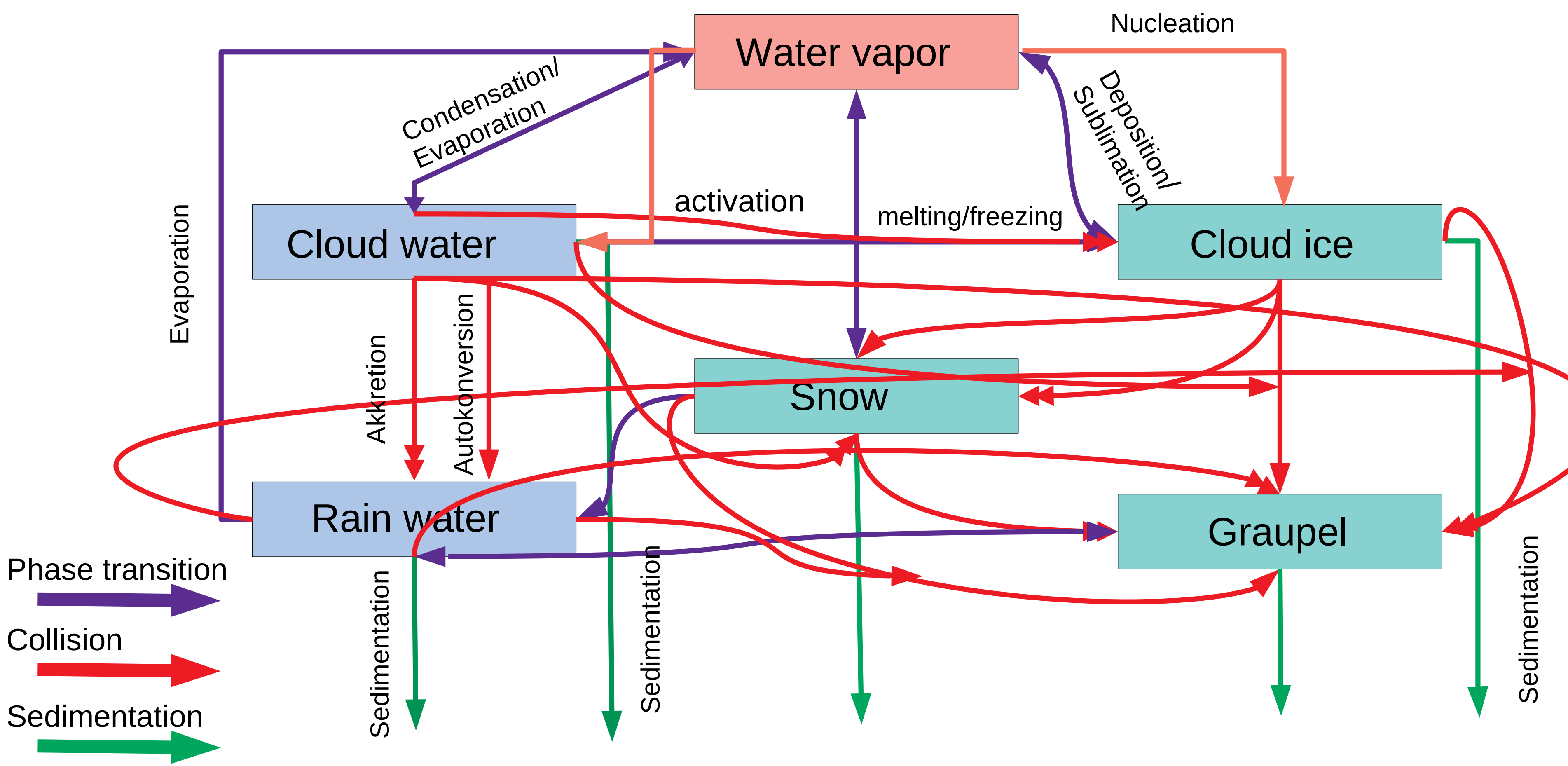
$$\theta_L \approx \theta - \left(\frac{\theta}{T}\right)\left(\frac{L_v}{c_{pd}}\right)(r_l),$$

Examples of not neglected cloud processes:

- effects of mixing / entrainment on the cloud droplet distribution
- effects of turbulence on coalescence
- Different coalescence efficiencies
- Collisional breakup
- Ice nucleation only roughly paramterized

Bulk cloud model

Physics parameterized



&bulk_cloud_parameters

General parameters

`cloud_scheme`	choose cloud scheme
`nc_const`	number of cloud droplets [m^{-3}]
`na_init`	number of aerosol [m^{-3}]
`cloud_water_sedimentation`	flag for sedimentation of clod droplets
`microphysics_ice_phase`	flag to turn on ice phase
`snow/graupel`	flag to additionally turn on snow and graupel species (only allowed together)

Find all parameters at latest changes:

https://docs.palm-model.org/23.04/Reference/LES_Model/Namelists/#bulk-cloud-parameters

https://palm.muk.uni-hannover.de/trac/wiki/doc/app/bcmequ

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Output quantities

Output for cloud quantities is steered via:

`&runtime_parameters`

`Timeseries (default)`	
▪ `Lwp`	liquid water path
▪ `cwp/rwp/iwp/gwp/swp`	cloud/rain/ice/graupel/snow water path
`2D/3D output`	
▪ `ql/qc/qr/qg/qi/qs`	Mixing ratios of: liquid water, cloud water, rain water, graupel, ice, and snow
▪ `nc/nr/ng/ni/ns`	Number concentration of: cloud droplets, rain droplets, graupel, ice, and snow
▪ `prr`	Total precipitation rate
▪ `prr_cloud, prr_rain, prr_ice, prr_graupel, prr_snow`	Prcipitation rates of: cloud, rain, ice, graupel, and snow
`Profiles`	
▪ `Same quantities as for 2D/3D output`	

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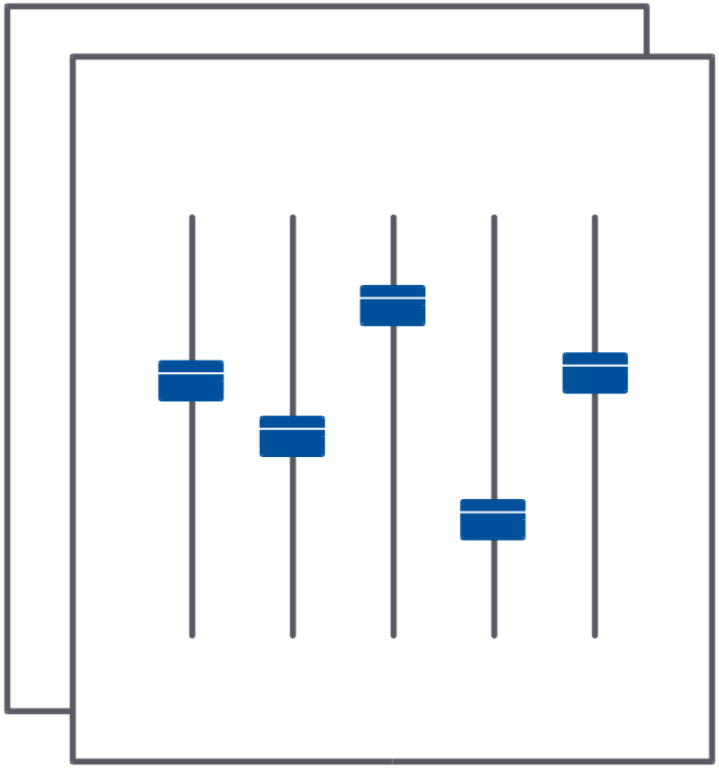
What must be considered for simulations with clouds?

- Turn on `&bulk_cloud_parameters`
- Set temperature and humidity profile in a way that air becomes supersaturated at some point
- Set a `cloud_scheme`
- Add output of cloud quantities
- Do you want to have radiation effects included? Yes: Turn on RRTMG



Bulk cloud model

Example cases

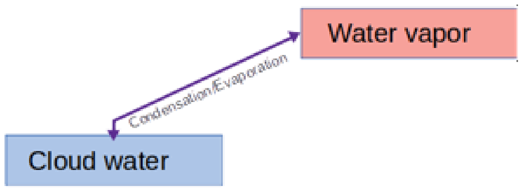
- Examples could be found in the test repository
- `../model/tests/cases/`
- `mixed-phase-stratus_with_rrtmg`

```
!--------------------------------------------------------------------------------
!-- BULK CLOUD PARAMETER NAMELIST
!   Documentation: https://palm.muk.uni-hannover.de/trac/wiki/doc/app/bcmpar
!--------------------------------------------------------------------------------
&bulk_cloud_parameters
!
!-- set microphyiscs scheme
!--------------------------------------------------------------------------------
    cloud_scheme           = 'seifert_beheng',      ! two-moment liquid water microphysics
                                                    ! including autoconversion,
                                                    ! accretion, sedimentation, precipitation
!
!-- steering of liquid phase
!--------------------------------------------------------------------------------
    collision_turbulence             = .TRUE.,       ! parametize turbulence effects for collision
    cloud_water_sedimentation  = .TRUE.,             ! enable cloud water sedimentation
    nc_const                         = 200.0E6,      ! cloud droplet concentration
    call_microphysics_at_all_substeps = .FALSE.,     ! microphysics every sub-timestep disabled

!
!-- steering of ice phase
!--------------------------------------------------------------------------------
    microphysics_ice_phase     = .TRUE.,       !  turn on ice microphysics
    in_init                    = 4000.0,       ! set ice nuclei concentration
    ice_crystal_sedimentation  = .TRUE.,       ! turn on ice sedimentation
    snow                       = .TRUE.,       ! turn on prog. quantities for snow
    graupel                    = .TRUE.,       ! turn on prog. quantities for graupel
    start_ice_microphysics     = 0.0,          ! start with ice microphysics at model start

/ ! end of bulk cloud parameter namelist
```

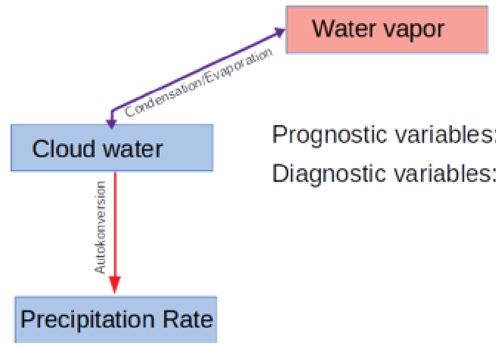
Saturation Adjustment



Prognostic variables: q

Diagnostic variables: qc

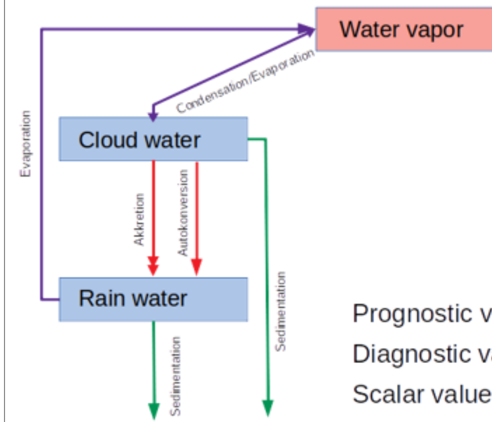
Kessler



Prognostic variables: q

Diagnostic variables: qc

Seifert and Beheng

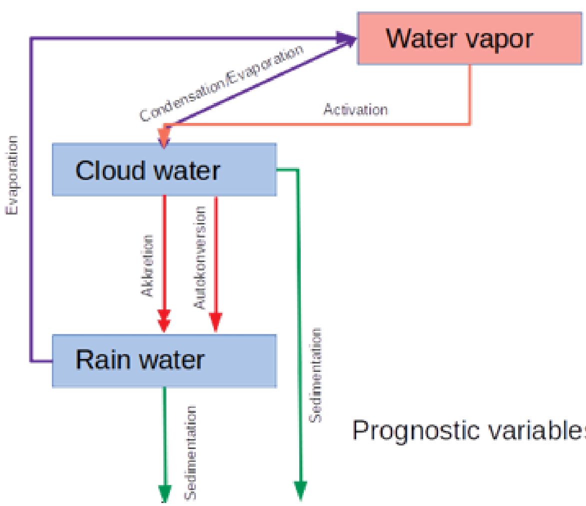


Prognostic variables: q, qr, nr

Diagnostic variables: qc

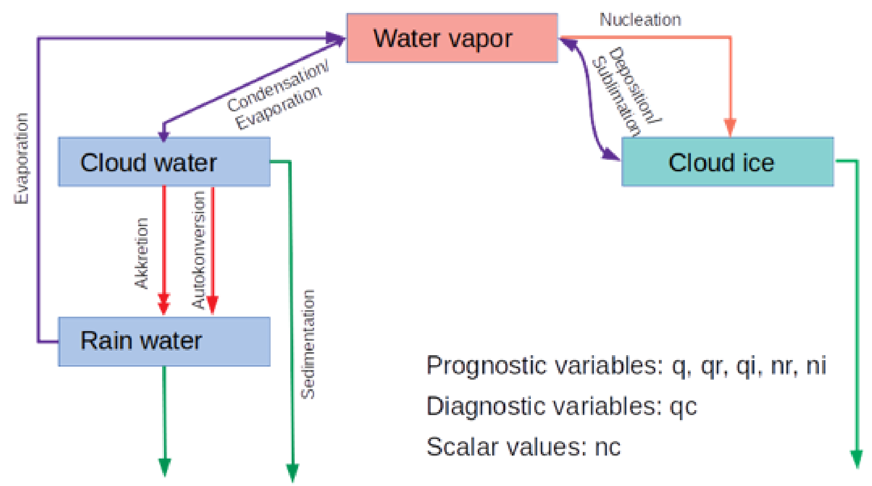
Scalar value: nc

Morrison



Prognostic variables: q, qr, nr, qc, nc

Seifert and Beheng + Microphysics ice phase

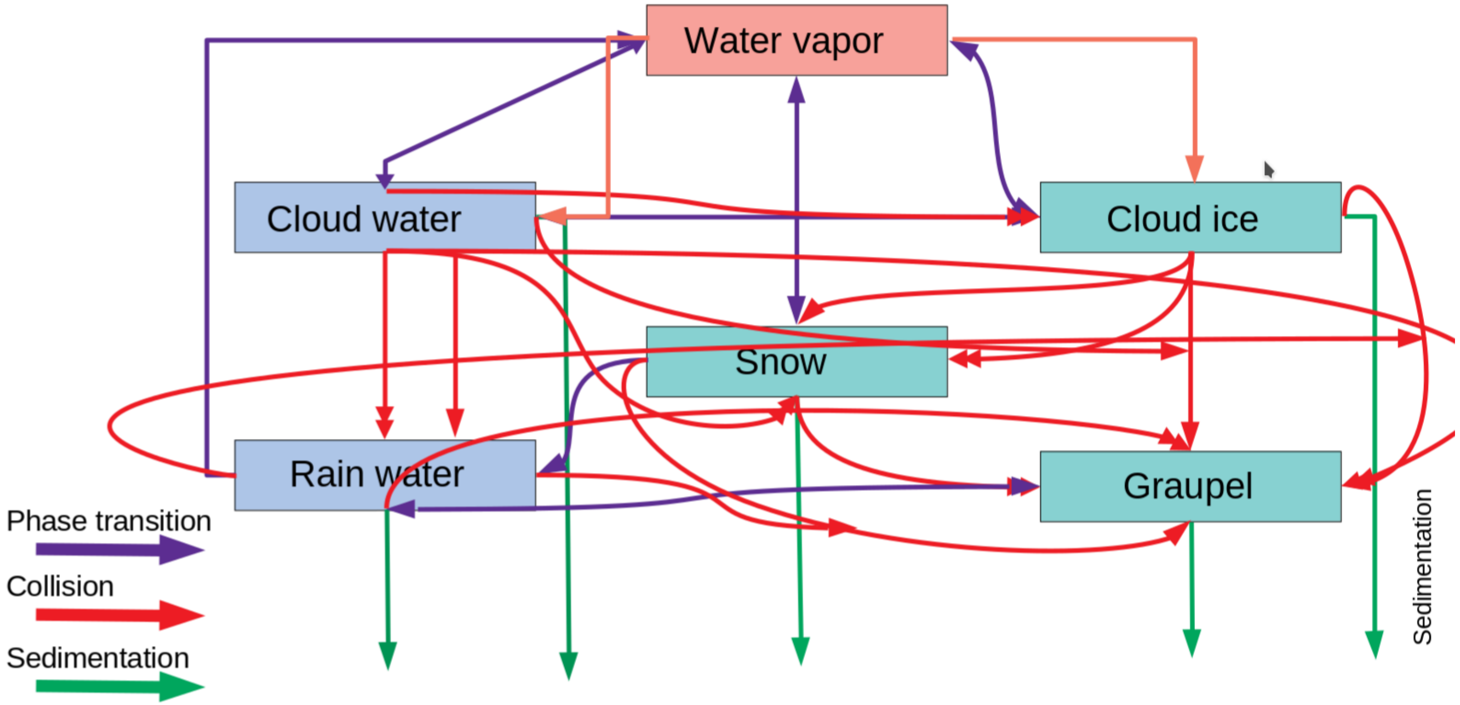


Prognostic variables: q, qr, qi, nr, ni

Diagnostic variables: qc

Scalar values: nc

Seifert and Beheng/Morrison + microphysics_ice + snow and graupel



Prog. Quantities: qc, nc, qr, nr, qi, ni, qs, ns, qg, ng

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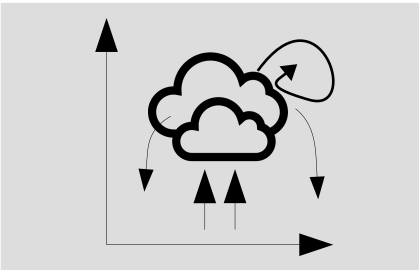
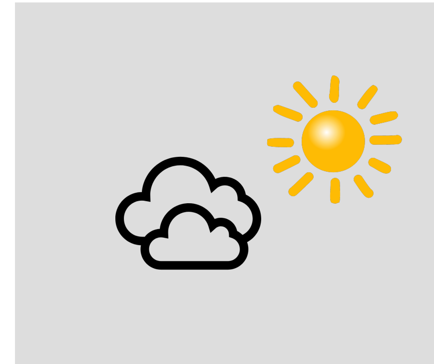
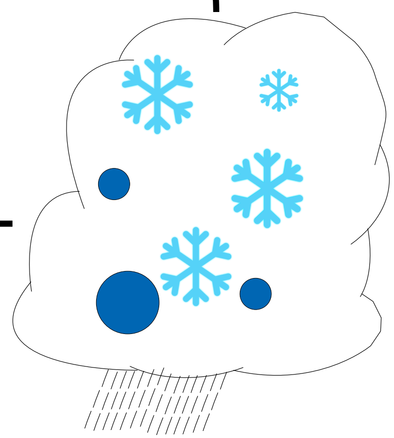
Coupling & Limitations



- Complete coupling with dynamics

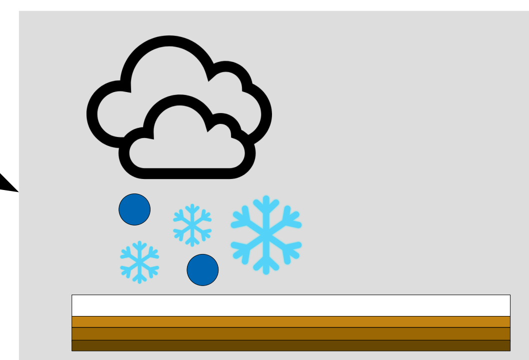
- Coupled with radiation model (RRTMG)
- but only within one column, i.e., solely perpendicular shading is considered





- Under development: Coupling with mesoscale models

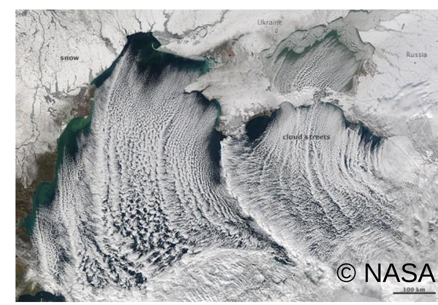
- Precipitation is coupled to land surface model (adds on vegetation or water reservoir)
- Ice surface scheme is under development



Bulk cloud model

Applications

- Simulations of fog (*e.g., Maronga and Bosveld, 2017, Schwenkel and Maronga 2019*)
- Simulations of trade wind cumuli (*e.g., Riechelmann et al., 2012*)
- Simulations of arctic mixed-phased stratocumulus clouds
- Simulations of cloud streets during cold air outbreaks (*e.g., Gryschka et al., 2014*)
- Simulation of an idealized thunderstorm



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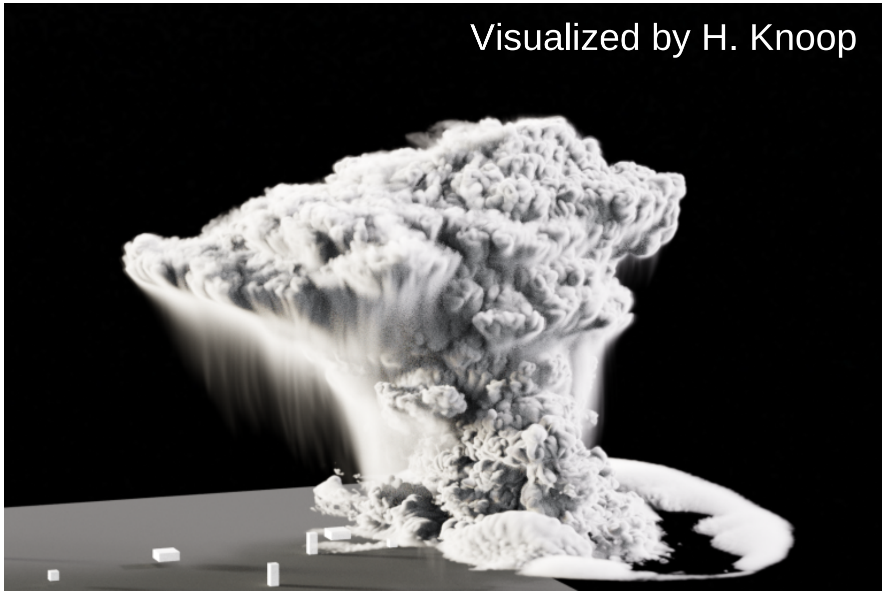
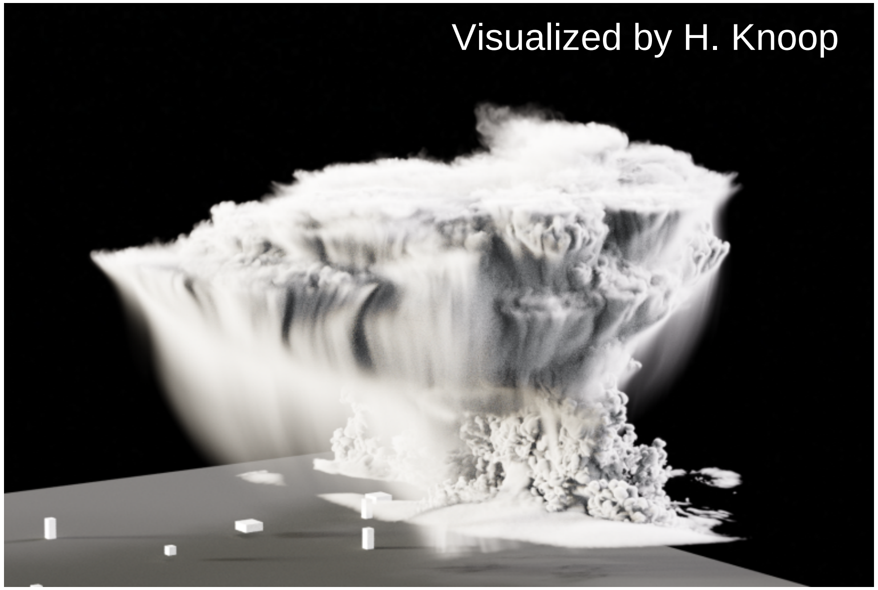
Summary

- Computational efficient module to consider clouds with different level of detail
- Two-moment scheme allows representation of complex cloud processes (parameterized)
- A more sophisticated cloud microphysical representation can achieved with the LCM
- Coupling to other modules allows simulating more complex cases (quasi-realistic cases)





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https://palm.muk.uni-hannover.de

Our YouTube channel:
youtube.com/user/palmhannover