



Past, present and future of microphysical parameterizations

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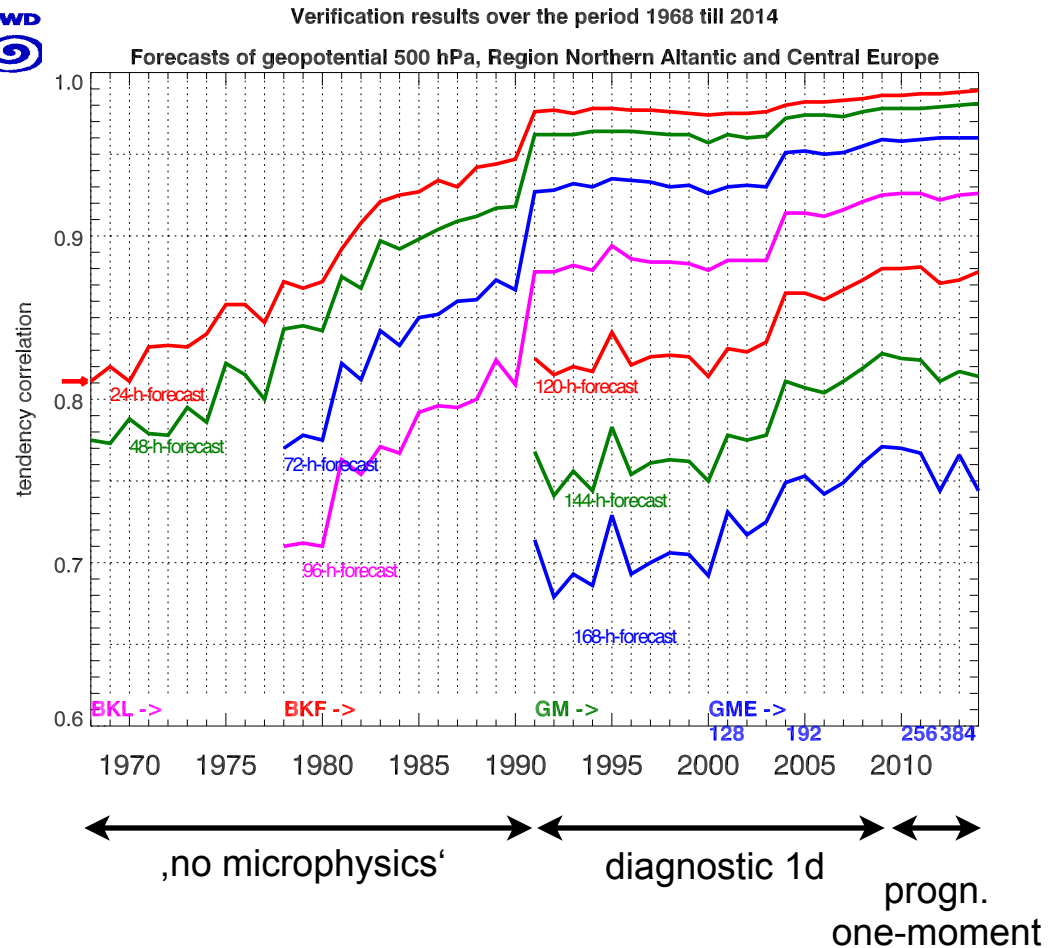
Operational Centers

Focus on improved skill scores.

Great improvement of the last decades, but very minor role of cloud microphysics.

Microphysics is important for:

- Amount of cloud ice and liquid matters for radiation.
- Below Δx of 20 km microphysics matters a lot for precipitation patterns, orographic precipitation amounts etc.



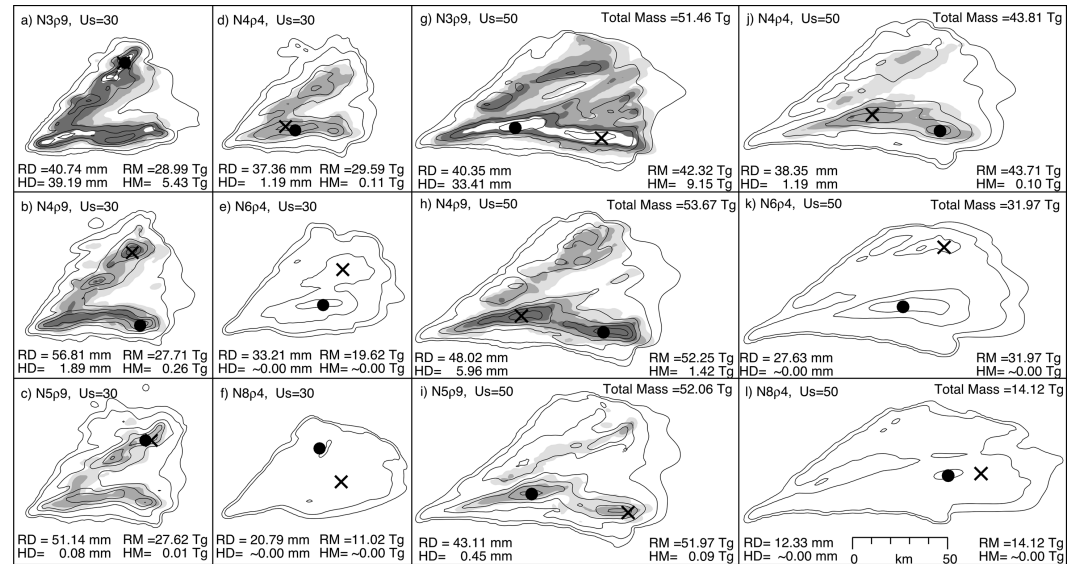
Research community

Focus on identifying and understanding sensitivities.

Since the late 70s focus on idealized isolated convective storms or squall lines.

Microphysics is important for:

- Precipitation efficiency.
- Intensity, structure and propagation speed of convective systems.



Sensitivity of supercell case to intercept parameter and graupel/hail density. Precipitation differs by a factor of 4 (Gilmore et al 2004).

R2O challenge

Two communities with quite different experience, tradition and goals:

- Researchers like to emphasize the sensitivities and pick special situations to prove their point. Focus on small scales and microphysics in isolation.
- Operational centers look at the bigger picture and customer needs. Each model component competes for the limited computational resources. Resolution usually wins over expensive physics.



Diagnostic vs prognostic schemes

Most global models have been using diagnostic scheme that apply column-equilibrium:

$$\frac{\partial q_x}{\partial t} + \vec{v} \cdot \nabla q_x - \frac{1}{\rho} \frac{\partial}{\partial z} (\rho v_x q_x) = S_x$$

This is appropriate in large-scale models with $\Delta x > 40$ km. For higher resolution one needs prognostic precipitation. First for snow, because it falls slowest, then for rain, graupel, hail, etc.

Note: it can be a reasonable choice to be prognostic, i.e. keep the time differential, but neglect advection. Especially for consistency between coarser- and finer-grid implementations. Reduces the need to maintain different codes for different resolution.

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One-moment, Two-moment, spectral (bin), ...

Spectral microphysics that predicts the size distribution (20-500 variables)

$$\frac{\partial f(x)}{\partial t} + \nabla \cdot [\mathbf{v} f(x)] + \frac{\partial}{\partial z} [v_T(x) f(x)] = \mathcal{F}(x)$$

Two-moment microphysics usually predicts number and mass densities (8-12 variables)

$$\begin{aligned} \frac{\partial N}{\partial t} + \nabla \cdot [\mathbf{v} N] + \frac{\partial}{\partial z} [v_N(\bar{x}) N] &= N \mathcal{G}(\bar{x}) \\ \frac{\partial L}{\partial t} + \nabla \cdot [\mathbf{v} L] + \frac{\partial}{\partial z} [v_L(\bar{x}) L] &= L \mathcal{H}(\bar{x}), \quad \bar{x} = L/N \end{aligned}$$

One-moment schemes predict only mass (3-5 variables)

$$\frac{\partial L}{\partial t} + \nabla \cdot [\mathbf{v} L] + \frac{\partial}{\partial z} [\tilde{v}_L(L) L] = \mathcal{S}(L)$$

There are more flavors like three-moment schemes, prognostic properties, and researchers are also starting to use Lagrangian particle methods.



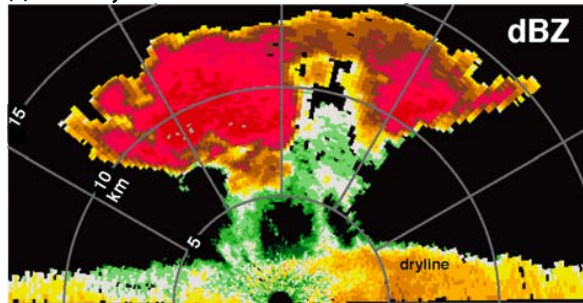
Sedimentation Issue (part 1)

A major problem of one-moment schemes is the sedimentation:

- No gravitational sorting, only one sedimentation velocity for each category
- Mixing ratio and mean particle size are correlated with a fixed relation. In the early development of a convective cell RWC is high, but raindrops are small.

Both lead to problems in the life cycles of individual convective storms

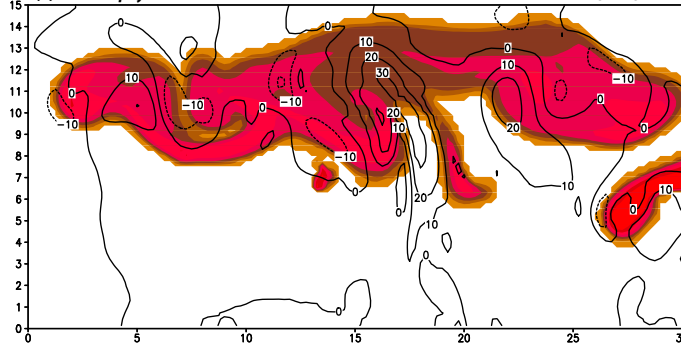
(a) reflectivity at 2142:21 UTC



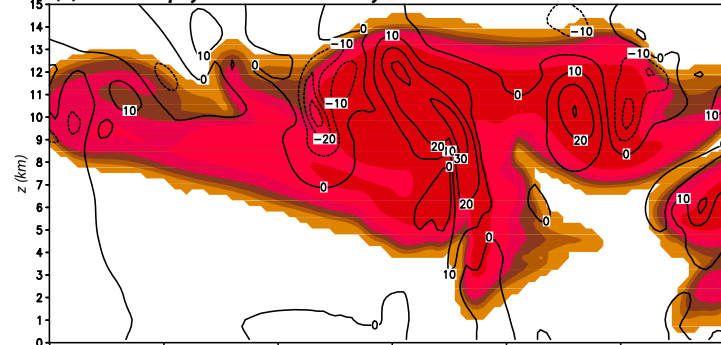
Cross section of radar reflectivity
Obs, SB two-moment, and LFO one-moment.

LFO overestimates fall speeds, and fails to produce a weak-echo region.

(b) SB microphysics $t = 28 \text{ min}$



(a) LFO microphysics -- LFO reflectivity

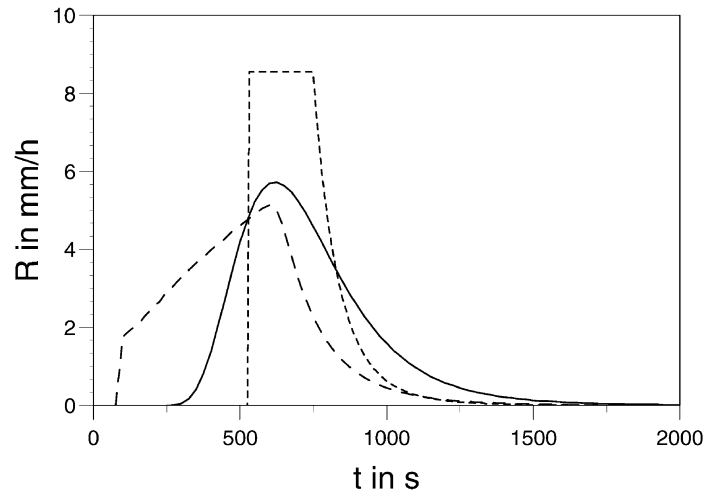


(Fovell and Seifert, 2005)

Sedimentation Issue (part 2)

One- and two-moment bulk schemes have issues with sedimentation:

(from Wacker and Seifert (2001), see also Milbrandt&Yau (2005), Milbrandt and McTaggart-Cowan (2010), etc.)



pure sedimentation of rain
spectral reference (solid line)
one-moment (short-dashed)
two-moment (long-dashed)

- Introducing a μ - λ - or μ - D -relation improves the behavior, but does not resolve the problem completely.
- The physical explanation is that the gravitational sorting leads to narrower size distribution, but in one- or two-moment schemes the width of the distribution is fixed.
- From a mathematical point of view, the elimination of the size variable transforms the simple linear PDE into a set of nonlinear PDEs, which leads to artifacts like shock waves and nonlinear wave propagation.

Microphysics and squall lines

One-moment schemes have difficulties to produce a trailing stratiform region.

- Not enough condensate in the stratiform region.
- Too localized and too strong evaporation and cold pool.

But having a hail category can also be important.

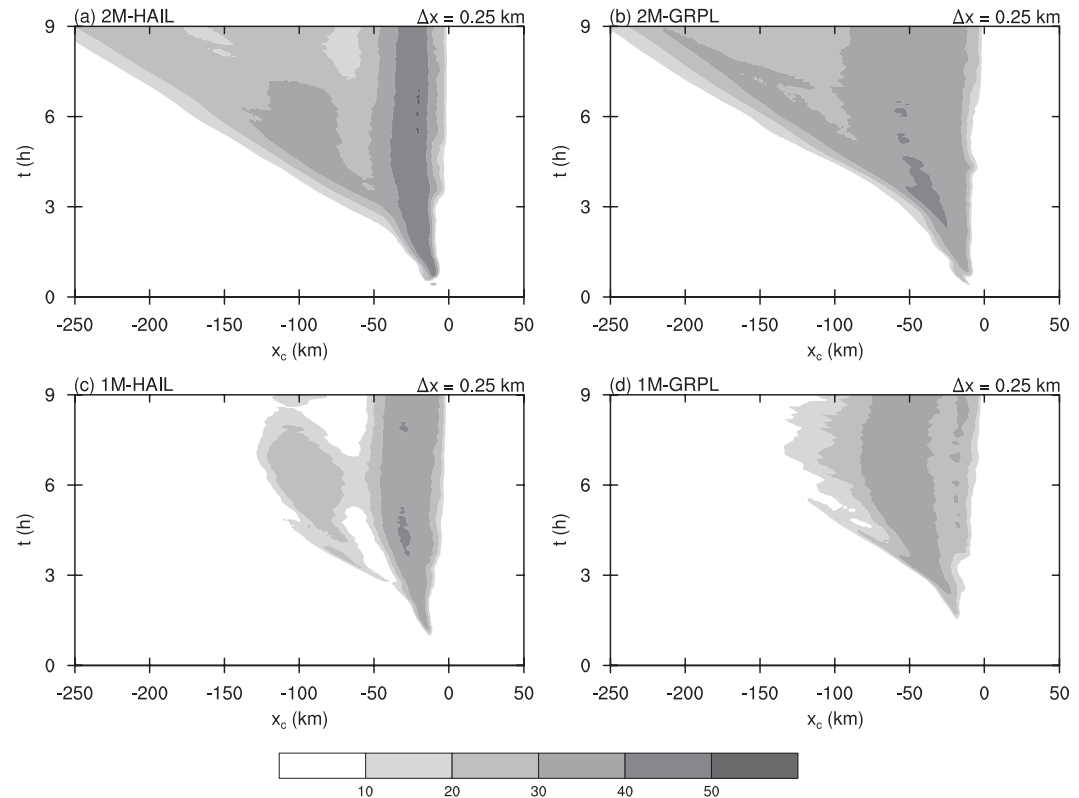


FIG. 6. Hovmöller diagrams of line-averaged reflectivity (dBZ) at the lowest model level using $\Delta x = 0.25$ km for (a) 2M-HAIL, (b) 2M-GRPL, (c) 1M-HAIL, and (d) 1M-GRPL.

(Bryan and Morrison 2012)

Microphysics and squall lines

A less idealized but European example:

- Squall line of 20 July 2007 with the passage of a cold front

- COSMO model at 2.8 km grid spacing with operational one-moment scheme underestimated 12 h precip accumulation and propagation speed.

- Two-moment scheme with high aerosol assumption performs better.

(Lack of high precip amounts in radar is mostly due to attenuation).

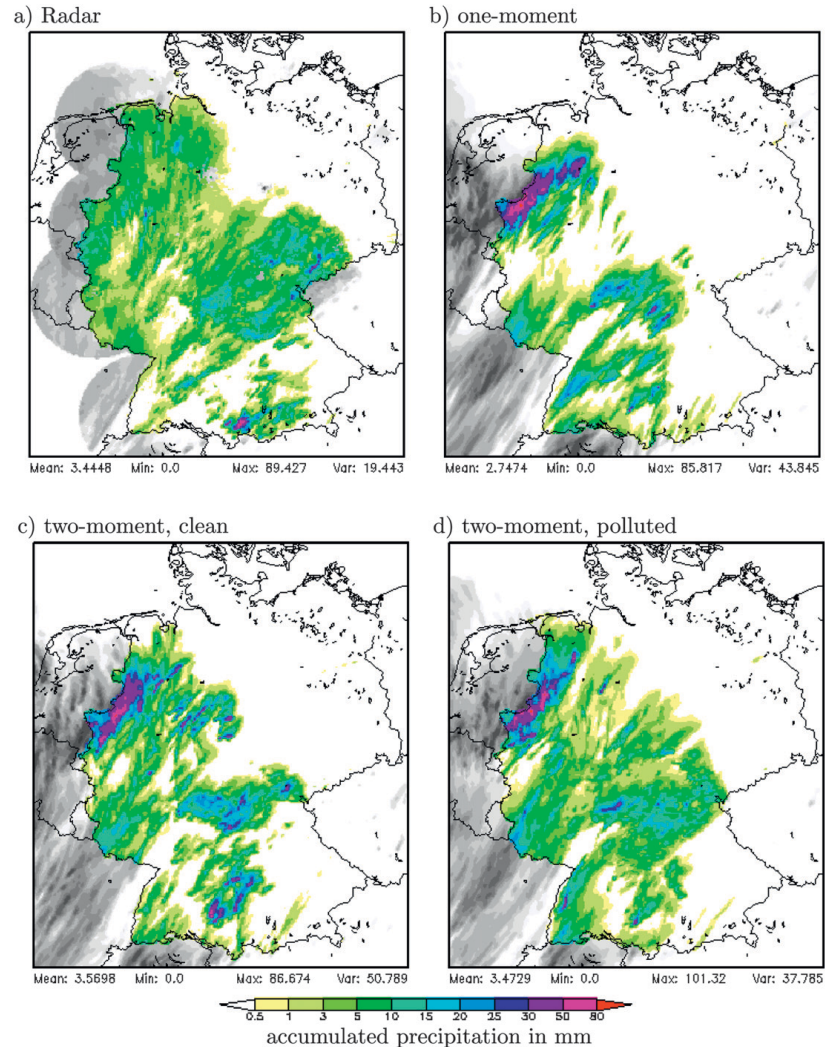


FIG. 14. Accumulated surface precipitation at 0600–1800 UTC on 20 Jul 2007. (a) German radar composite, (b) 0000 UTC + 18-h COSMO-DE forecasts using the one-moment scheme, (c) the two-moment scheme assuming clean CCN conditions, and (d) the two-moment scheme with polluted CCN conditions.

(Baldauf et al. 2011)

Microphysics and squall lines

Some 12-h precip scores from hindcasts over 3 summer seasons comparing one- and two-moment microphysics:

- Only marginal improvement.
- High CCN + high IN gives best results, which is reasonable.
- Unfortunately there are too few strong squall lines in Europe.

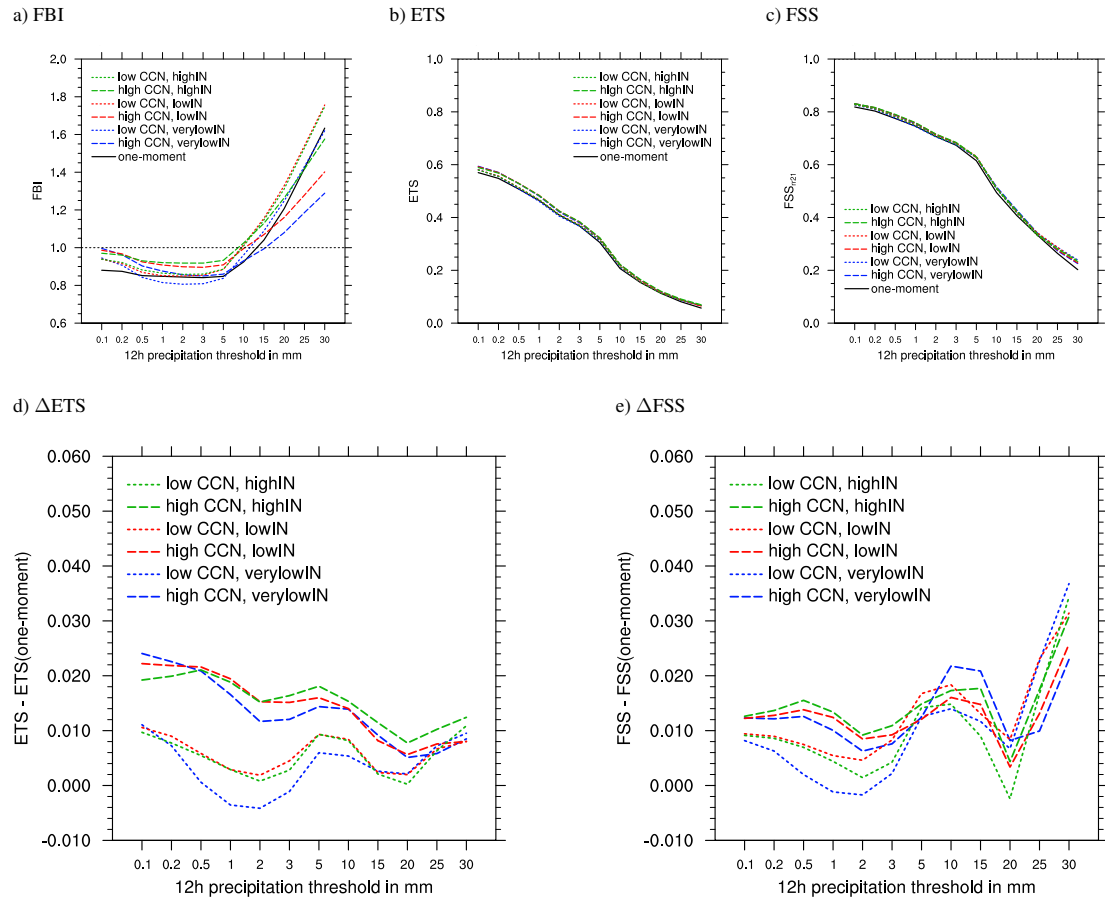


Fig. 6. Precipitation scores for 12-h accumulated precipitation with reference to radar observations. The absolute differences given in (d) and (e) are calculated w.r.t. the operational one-moment scheme (Exp. 7).

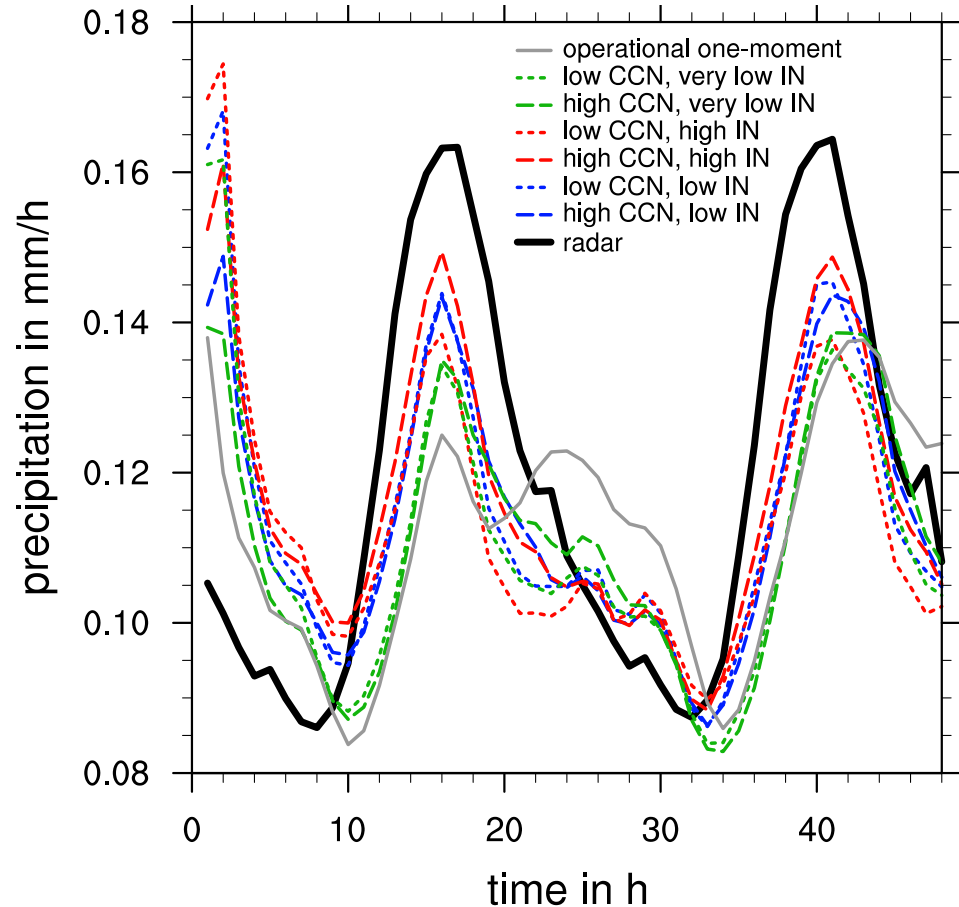
(Seifert et al. 2012, ACP, online supplement)

Microphysics and squall lines

Some 12-h precip scores from hindcasts over 3 summer seasons comparing one- and two-moment microphysics:

- Only marginal improvement.
- High CCN + high IN gives best results, which is reasonable.
- Unfortunately there are too few strong squall lines in Europe.
- Only the diurnal cycle shows a nice improvement.

(But first we have to solve the spin-down problem with better data assimilation, waiting for storm-scale EnKF)

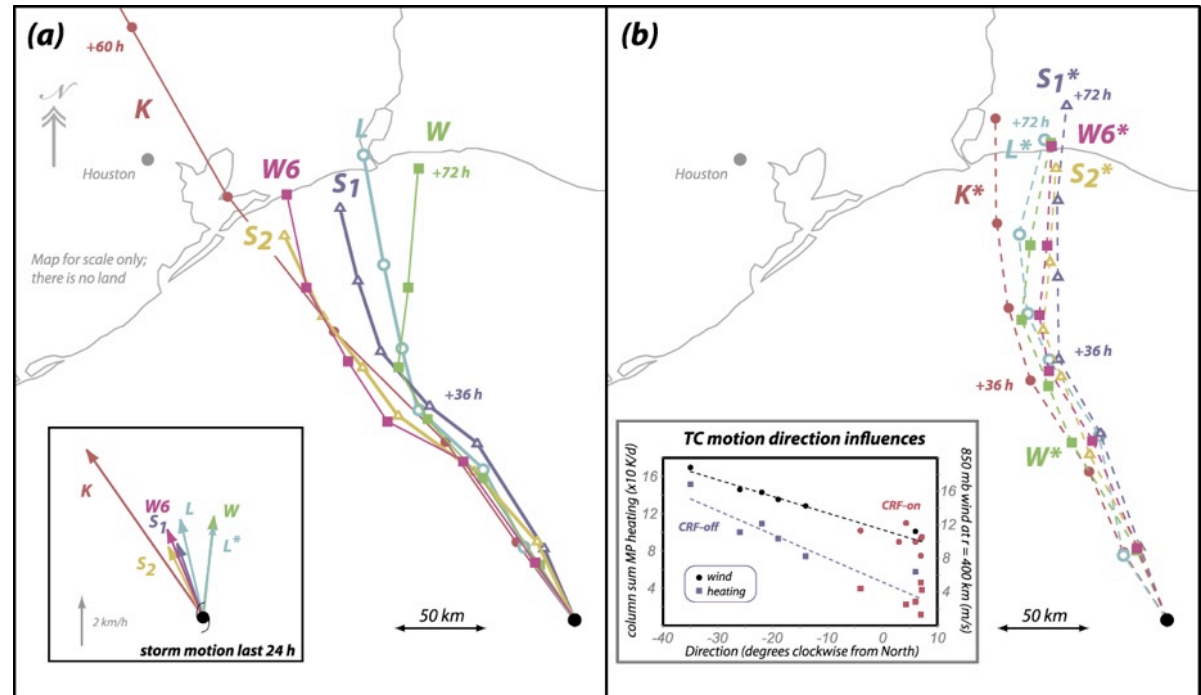


(Seifert et al. 2012, ACP)

Microphysics and hurricanes

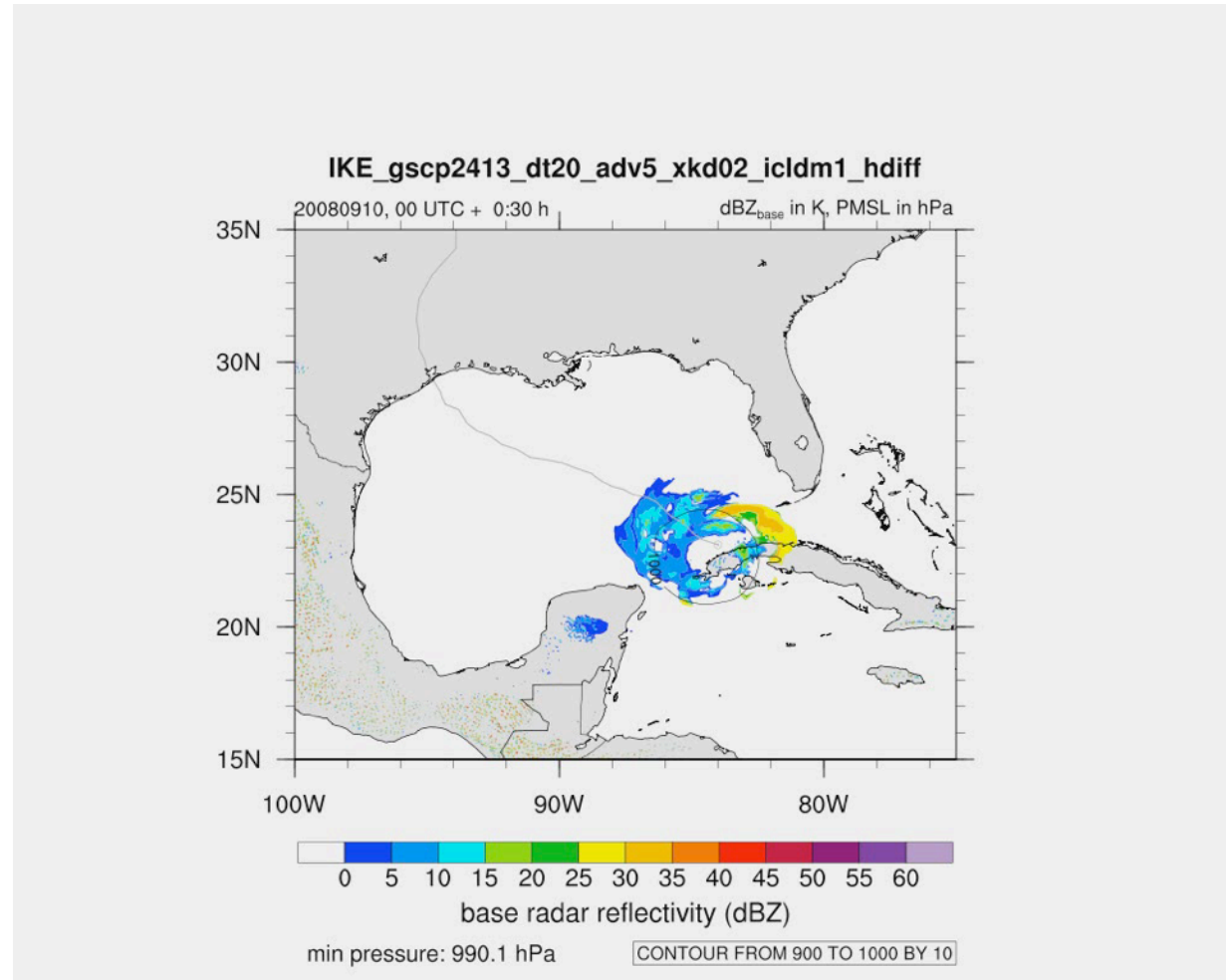
Fovell and Su (2007), Fovell et al. (2009,2010) and others have shown that the choice of the microphysics scheme can have a considerable impact on the track of a hurricane.

- Idealized simulations using WRF show a pronounced sensitivity to choice of the microphysics scheme
- Turning off the cloud-radiative feedback reveals that CRF is the link between microphysics and dynamics
- Amount of ice vs snow matters for track



Microphysics and hurricanes

A less idealized simulation of hurricane Ike with the COSMO model at 2.8 km grid spacing using the SB two-moment scheme.

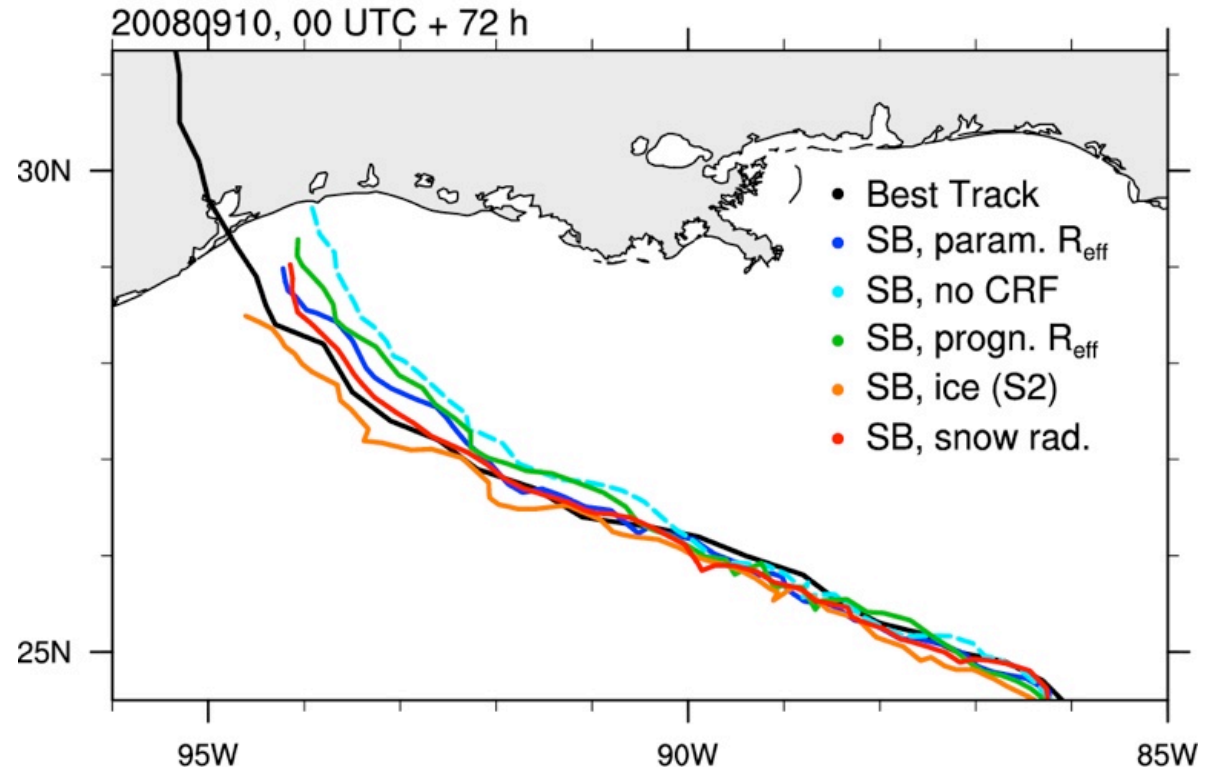


Microphysics and hurricanes

A less idealized simulation of hurricane Ike with the COSMO model at 2.8 km grid spacing using the SB two-moment scheme.

This confirms Rob's results:

- Cloud radiative feedback matters for track
- Sensitivity in microphysics and cloud-radiation coupling
- But not all hurricanes show this sensitivity.



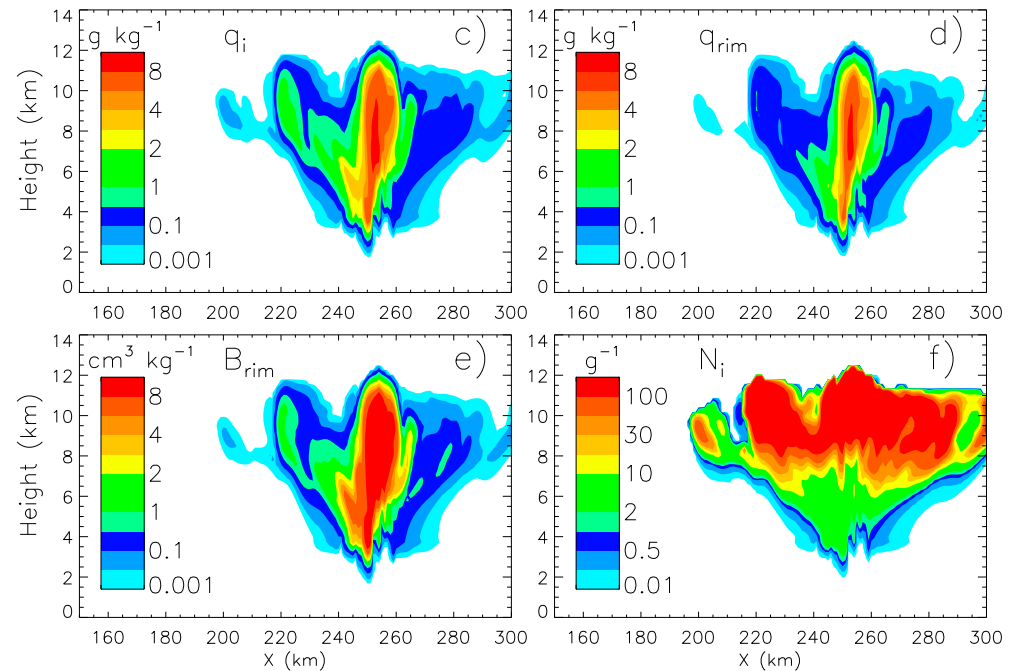
Predicted particle properties

Two-moment schemes (and bin schemes as well) do not address a basic problem of microphysics schemes: The conversion from one category to another. Especially the conversion from ice or snow to graupel is as problematic as it is important.

Morrison and Milbrandt (2015) suggest a scheme that predicts

- number and mass mixing ratios of a general ice category
- mass and volume of rime within this ice category

Predicted ice variables



Predicted particle properties

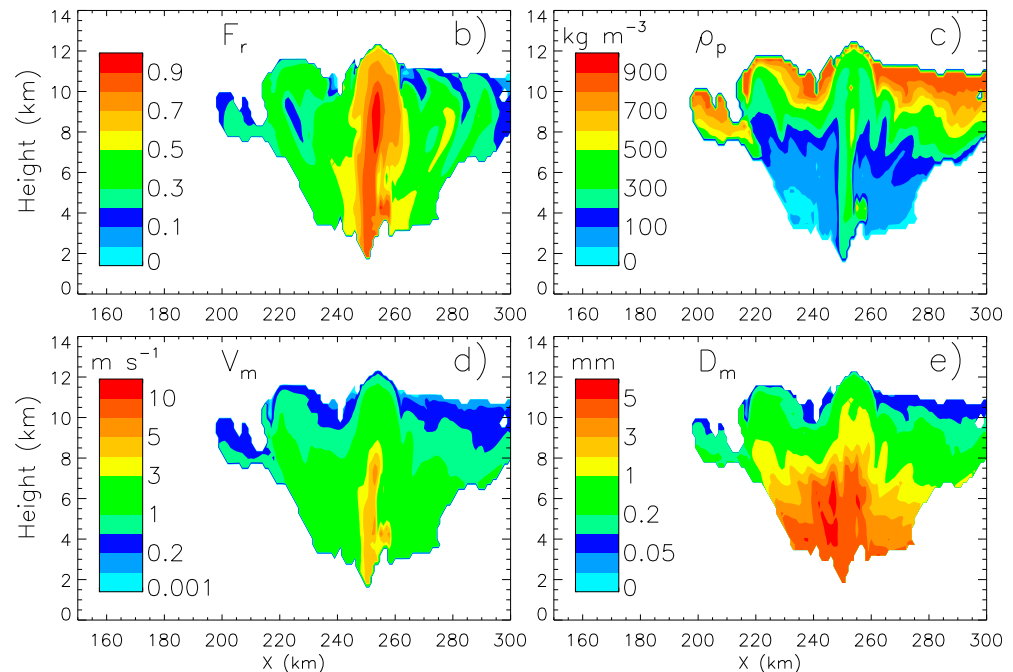
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By predicting these 4 quantities they can diagnose particle density, rime fraction, terminal fall velocity and mean-mass diameter.

Predicted ice properties



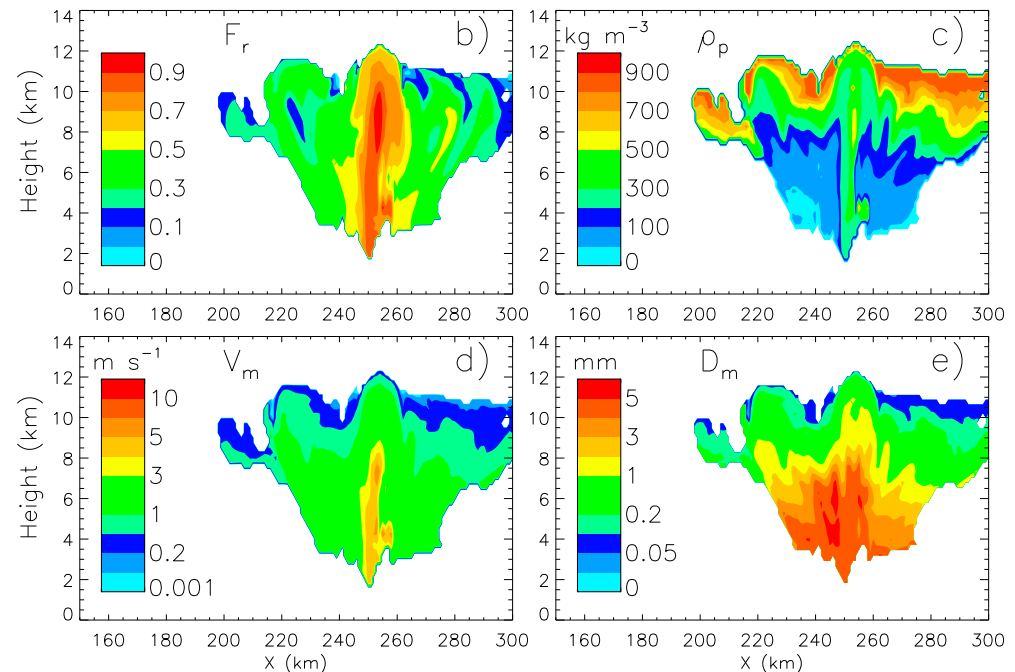
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Two-moment schemes (and bin schemes as well) do not address a basic problem of microphysics schemes: The conversion from one category to another. Especially the conversion from ice or snow to graupel is as problematic as it is important.

Morrison and Milbrandt (2015) suggest a scheme that predicts

- number and mass mixing ratios of a general ice category
 - mass and volume of rime within this ice category
- ▶ Great work!
 - ▶ Fewer variables, more efficient that multiple categories
 - ▶ But no co-existing particles types, e.g., ice multiplication or other bimodal ice distributions.
 - ▶ Mass and volume of rime are difficult to measure/validate.

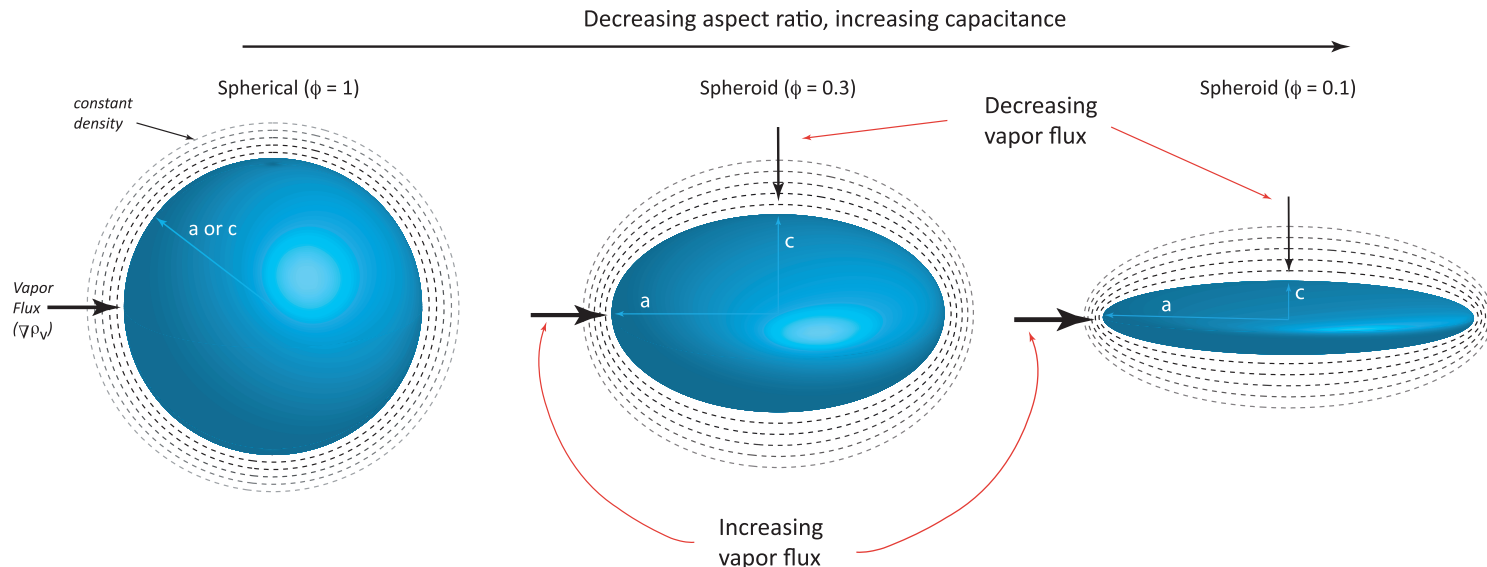
Predicted ice properties



Ice habit prediction

To improve the representation of the changing particle properties schemes have been developed to predict the axis ratio of crystals (Chen and Lamb 1994; Hashino and Tripoli 2007, 2011; Harrington et al. 2013, Sulia et al. 2013, 2014)

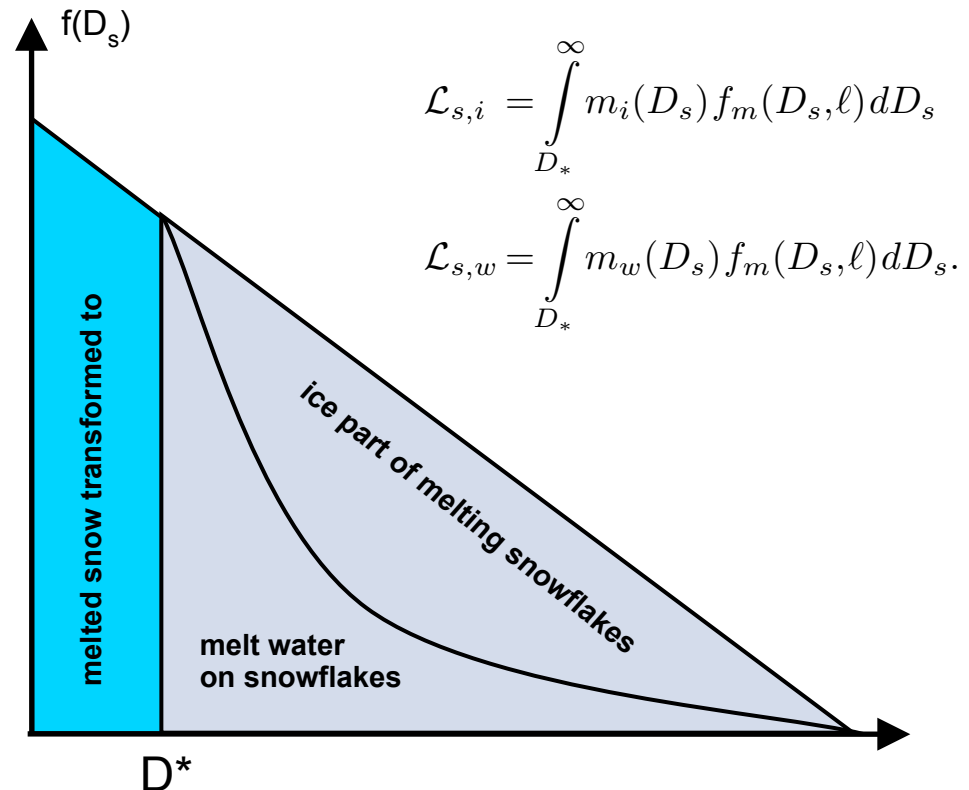
- More general than spherical assumption or fixed mass-size-relations.
- Based on lab data, but details are crystal growth are still not fully understood.
- Could be important, especially for arctic clouds



Prognostic melt water on ice particles

Another development that adds more information to the categories is to predict the meltwater on melting ice particles (Szyrmer and Zawadzki 1999, Frick et al. 2013)

- Predict snow mixing ratio, rain mixing ratio, and in addition meltwater mixing ratio (or alternatively D^*)
- Improved representation of the melting layer (bright band)
- Improved prediction of precipitation type at the surface



Not overly expensive, because new variable is quasi-2d, but benefit for snow only marginal and needs high vertical resolution (because snow has quite thin melting layers).

Frick et al. (2013) is a one-moment snow scheme, but we are currently working on the two-moment graupel and hail version.

Summary and Outlook

Recommendations (zero to 3 years):

- Global NWP: One-moment LFO-type prognostic scheme is probably good enough for the next years. Coupling with cloud cover scheme and convection might be more important than details of microphysics itself.
- Convective-scale NWP: Two-moment schemes are expensive, but should be the better choice for high resolution. Difficult to prove with skill scores due to double-penalty and predictability.
- Data assimilation: Assimilation of cloudy pixels or convective-scale DA might be a reason to introduce more detailed microphysics schemes, like two-moment.

Recommendations (3 - 10 years)

- Prognostic particle properties and habit prediction are much more attractive than adding more moments or using bin microphysics. Mostly because prognostic properties can make the scheme cheaper instead of more expensive.
- Research community will probably focus on ‚prognostic properties‘ and habit prediction in combination with Lagrangian particle methods as reference model.
- Need to develop ideas for stochastic microphysics.

