Cloud microphysical parameterizations in global and regional numerical weather prediction models

Axel Seifert and Kristina Fröhlich
Deutscher Wetterdienst

Outline

- Overview of state-of-the-art microphysical parameterizations
- Diagnostic vs prognostic precipitation in GME
- One- vs two-moment microphysics in COSMO-DE
- A few conclusions and recommendations

Overview of state-of-the-art microphysical parameterizations

Diagnostic schemes with equilibrium mixed-phase assumption	QC+QI	IFS, global climate models
Diagnostic schemes with non-equilibrium cloud ice	QC, QI	GME, UM, few climate models (e.g. ECHAM5-HAM)
One-moment prognostic schemes	QC, QI, QR, QS	Operational LAMs, e.g. COSMO, WRF, etc.
Two-moment prognostic schemes	QC, QI, QR, QS, QG, QH NC, NI, NR, NS, NG, NH	Research versions of LAMs, e.g. COSMO, WRF, GEM, Meso-NH
Spectral bin microphysics schemes	Several hundred bins for particle size distributions	Pure research, even for the next decade

Diagnostic rain and snow

Simplification of the budget equation

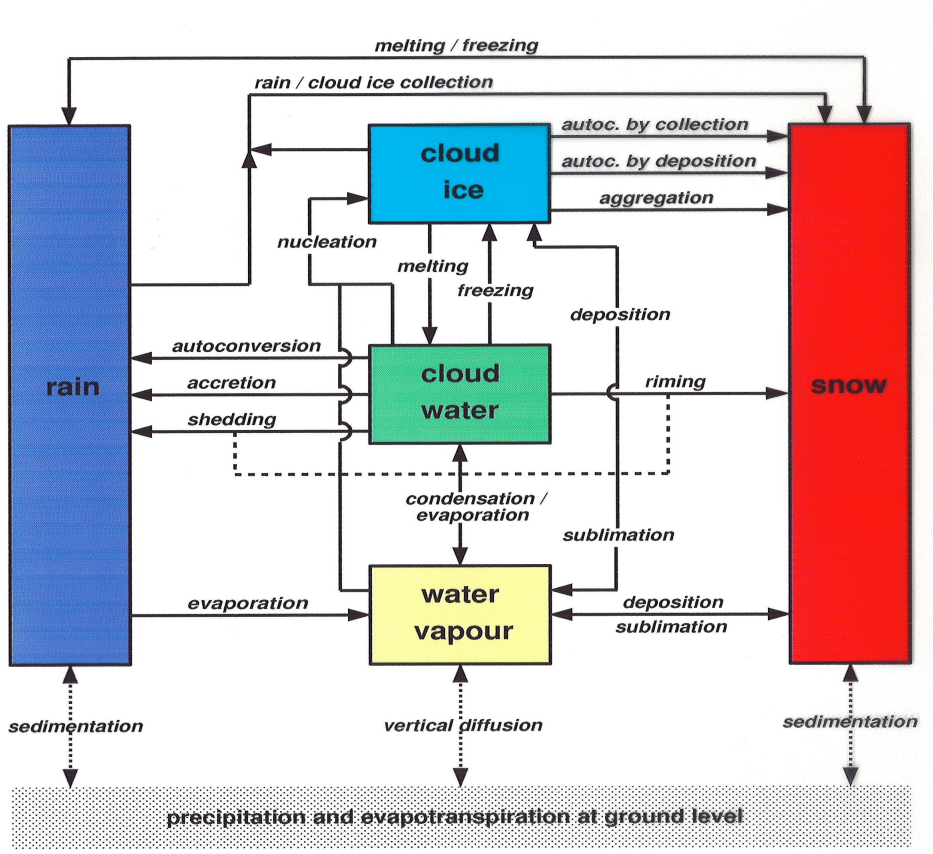
$$\cancel{\frac{\partial q^x}{\partial t}} + \cancel{\mathbf{v} \cdot \nabla q^x} - \frac{1}{\rho}\frac{\partial \rho q^x v_T^x}{\partial z} = S^x$$

with x in {cloud, rain, ice, snow}, but for rain and snow the time derivative and the advection term are neglected.

This approximation, often called column-equilibrium assumption, is used in almost all global NWP and climate models.

- ➔ No advection of precipitation
- ➔ No history or storage term for precipitation

New prognostic precipitation scheme

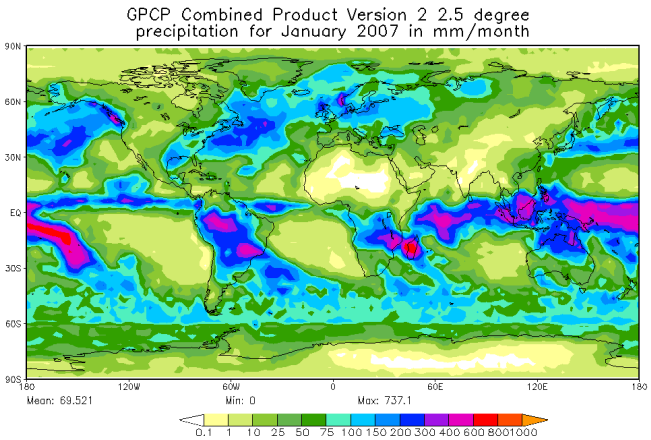


Full treatment of sedimentation and time evolution (storage) of snow and rain

Update of physical parameterizations, e.g., autoconversion and growth of ice and snow. New parameterization of snow size distribution.

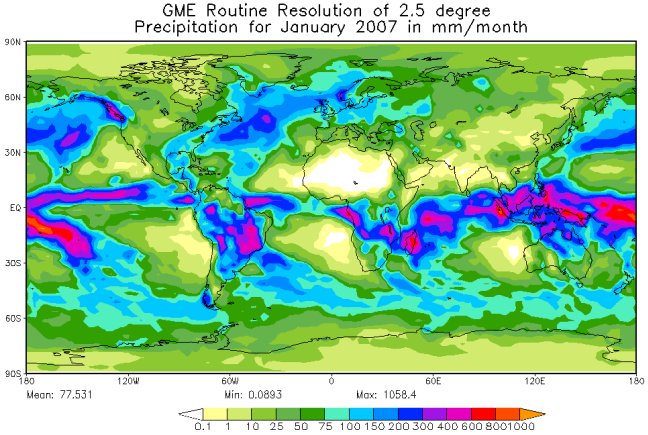
This scheme is operational in COSMO-EU and will probably become operational in GME in Summer/Fall 2009.

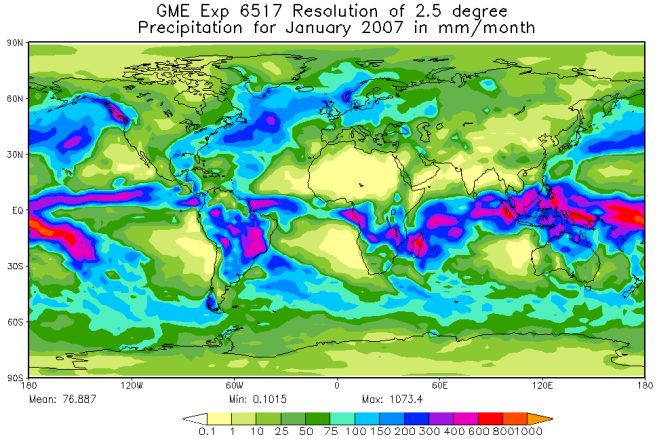
Precipitation for Jan 2007: Validation with monthly accumulation using GPCP data



Global Mean:

OBS	**69.5 mm**
GME	**77.5 mm**
EXP	**76.9 mm**



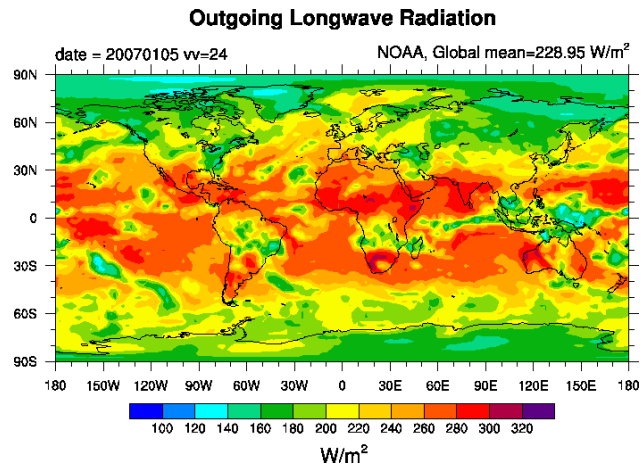


➔ **No significant difference on this scale.**

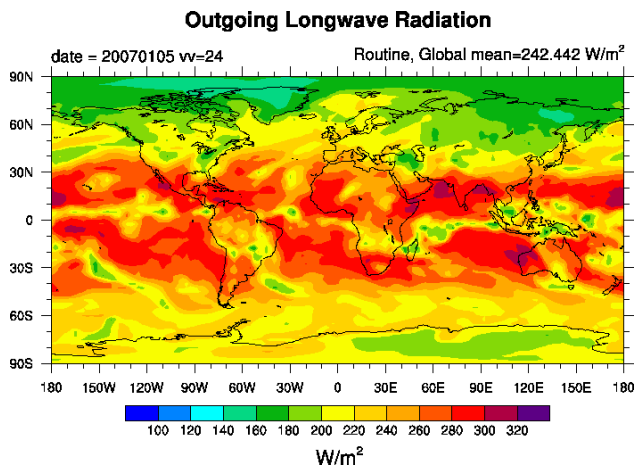
(Except for some rain in the Sahara desert when using the fully prognostic scheme)

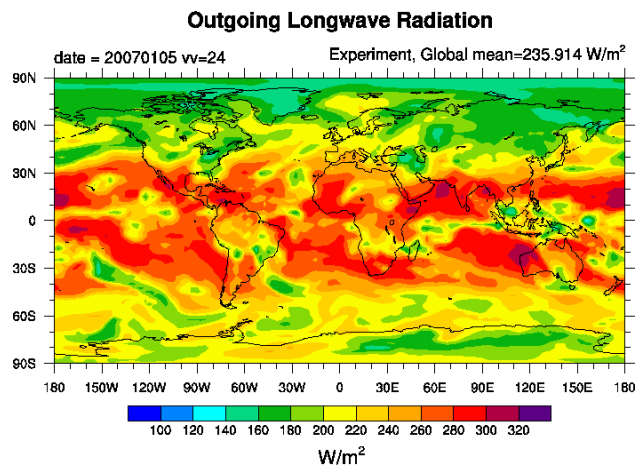
Outgoing Longwave Radiation (OLR)

05 Jan 2007
00 UTC + 24 h



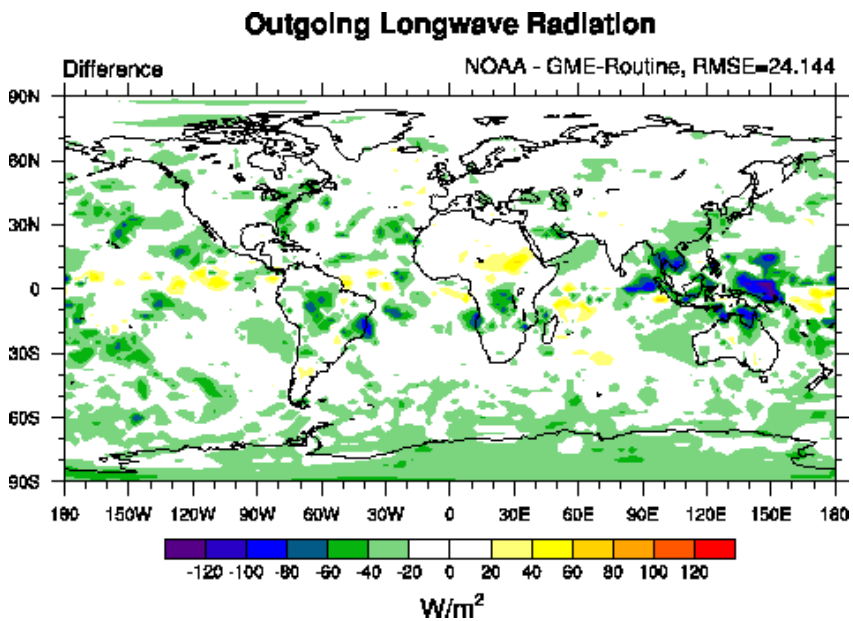
Global Mean:
OBS 229 W/m²
GME 243 W/m²
EXP 235 W/m²

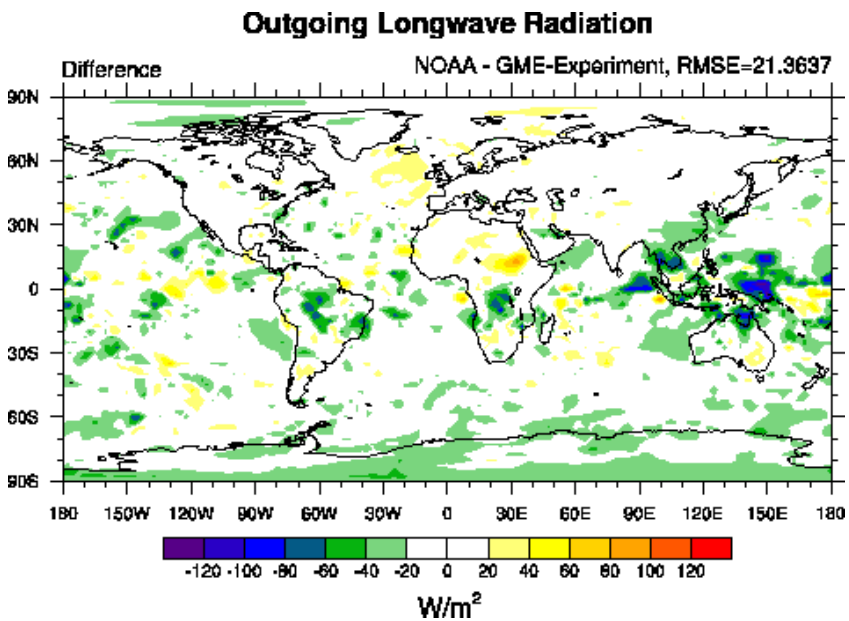




➔ **Slight improvement with new prognostic precipitation scheme**

Outgoing longwave radiation Jan 2007: NOAA- Model





RMSE: GME 24.1 W/m², EXP 21.4 W/m²

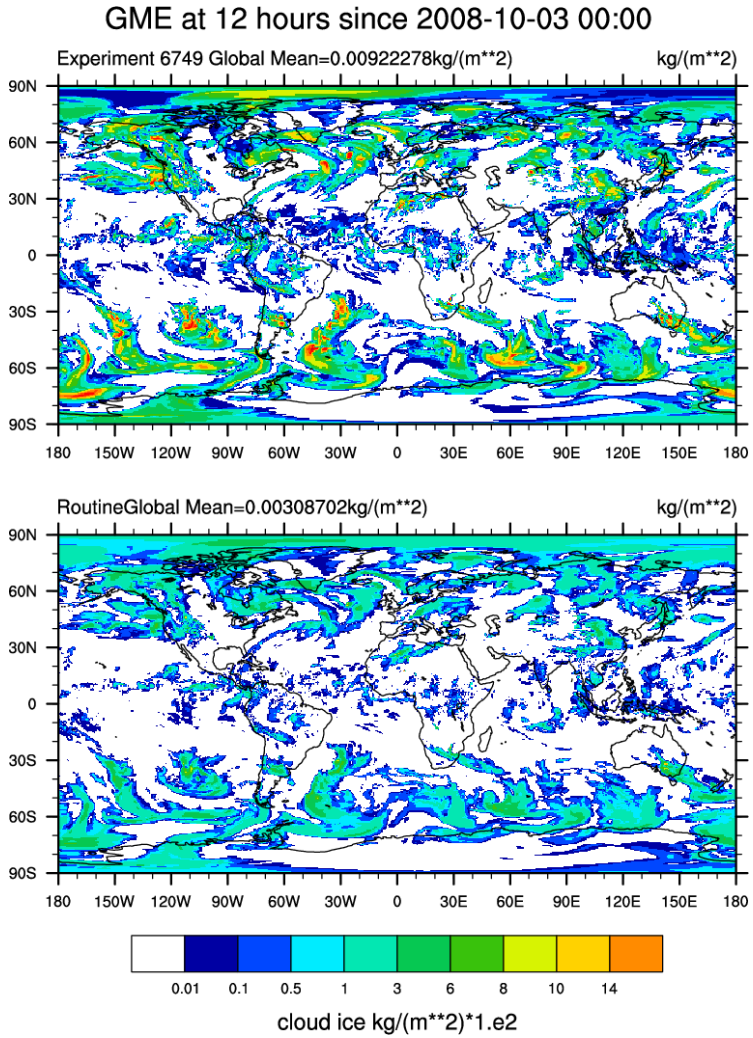
➔ **Slight improvement with new prognostic precipitation scheme**

Cloud Ice Water Path

03 Okt 2008 00 UTC + 12 h

Global Mean:
GME 3.09 g/m²
EXP 9.22 g/m²

Much higher IWP from clouds ice with the new scheme.
In addition the experiment has snow as explicit variable which adds even more mass to the total IWP.

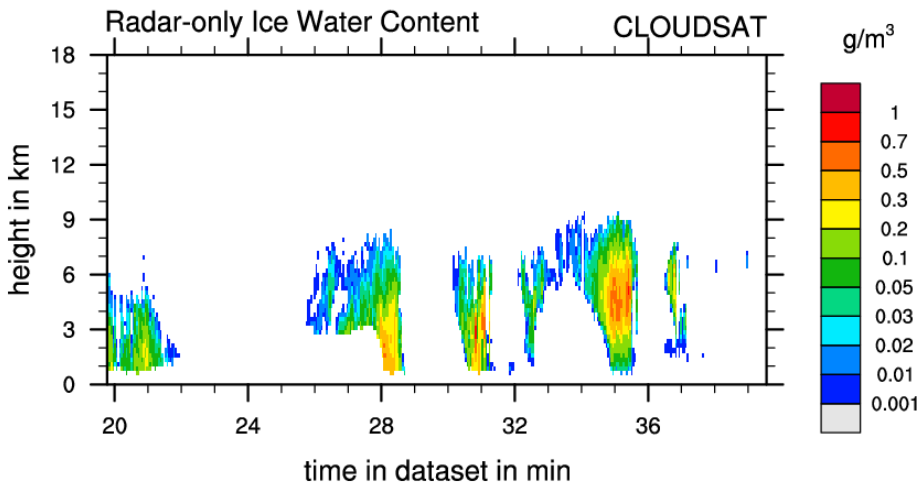


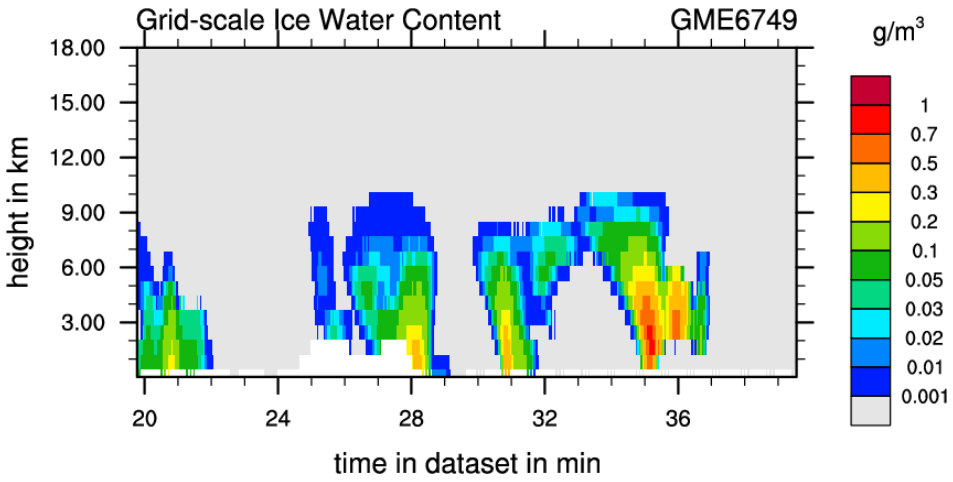
Ice Water Content

02 Okt 2008 00 UTC + 1 h

Validation with CLOUDSAT data.

High IWC values are realistic. The currently operational GME with the old diagnostic scheme underestimates IWC by an order of magnitude.

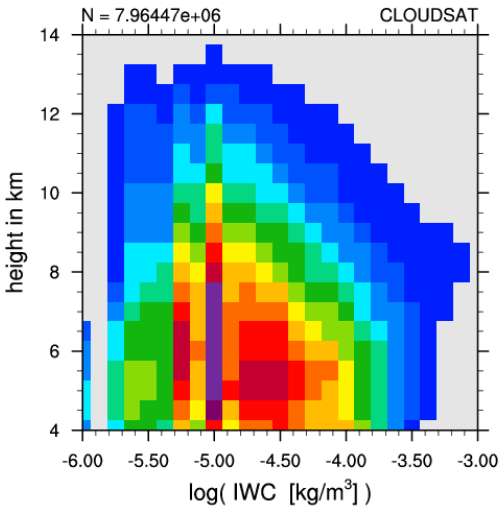




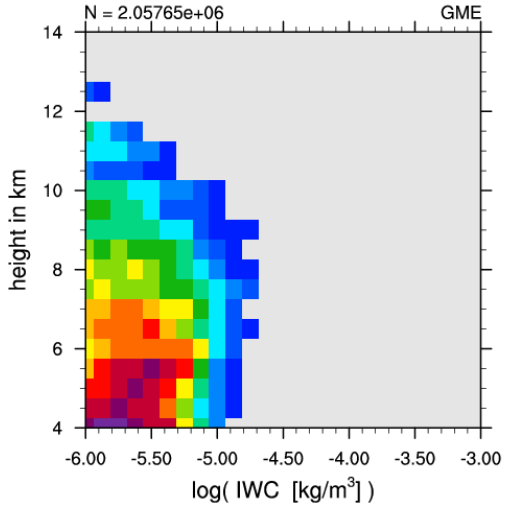
PDF of IWC: Validation with CLOUDSAT data

(preliminary results, only 1 week of data)

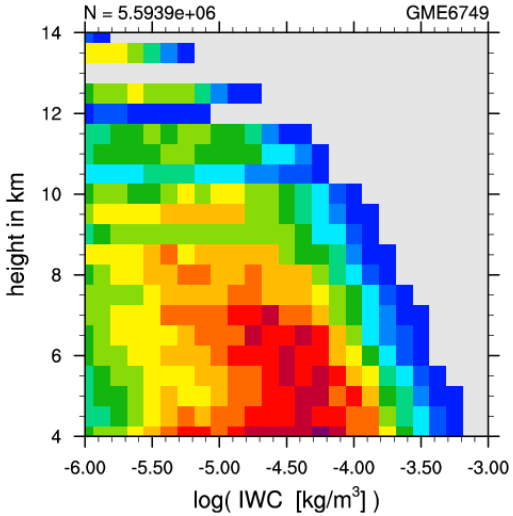
CLOUDSAT



DIAGNOSTIC



PROGNOSTIC



- ➔ **Diagnostic scheme underestimates IWC by roughly one order in magnitude.**
  (but here only grid-scale cloud ice, no snow, many observations show that 90% of IWC is snow)
- ➔ **Prognostic scheme can reproduce the observed PDF, at least qualitatively.**

Why is a validation of IWC so interesting?

Often the rain rate is quite robust to microphysical assumptions. Therefore the precipitation rate or amounts, which are often dominated by the dynamics, do not tell us much about the detailed cloud physics.

$$P = (v_s - w)\ IWC$$

Let's assume that the precipitation rate, P, is roughly correct. Then the amount of IWC is determined by $(v_s - w)$.

➔ IWC can be used to validate our microphysical assumptions about particle shape, size distribution etc. that determine the sedimentation velocity v_s

Validation of clouds in global NWP and climate models, diagnostic vs prognostic microphysical schemes

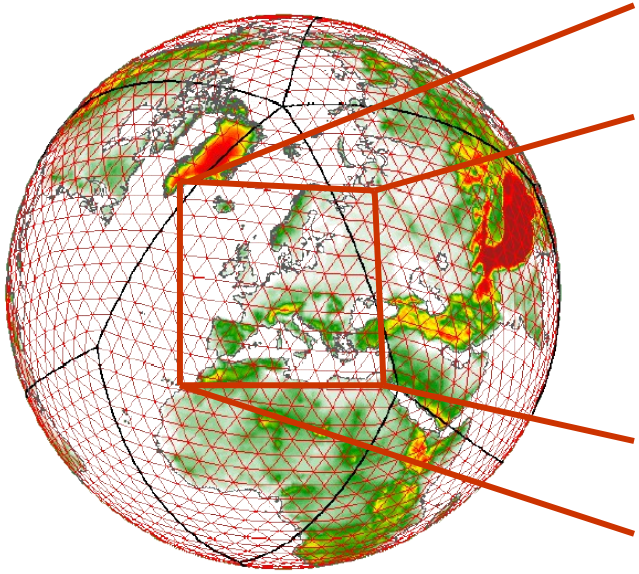
We have to be careful not to compare apples with oranges!

- ➔ Diagnostic schemes have most IWC on the sub-grid and can therefore not directly be validated with observations. Maybe better validate cloud cover?
- ➔ Prognostic schemes can be validated directly against IWC retrievals. But maybe a model-to-observation approach is more suitable.

In general, the proper cloud validation method may differ depending on the model's microphysical parameterization.

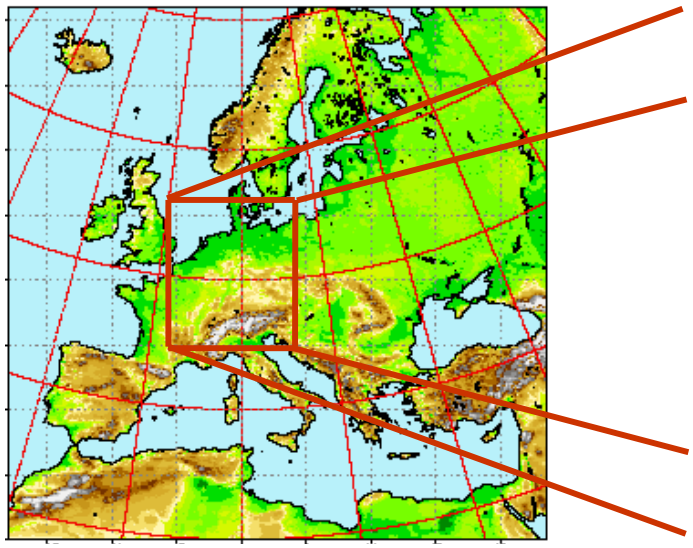
The operational NWP system at DWD

GME 40 km



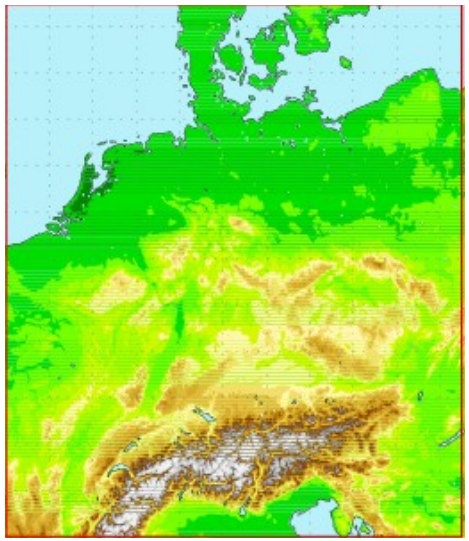
- hydrostatic equations
- parameterized convection

COSMO-EU 7 km



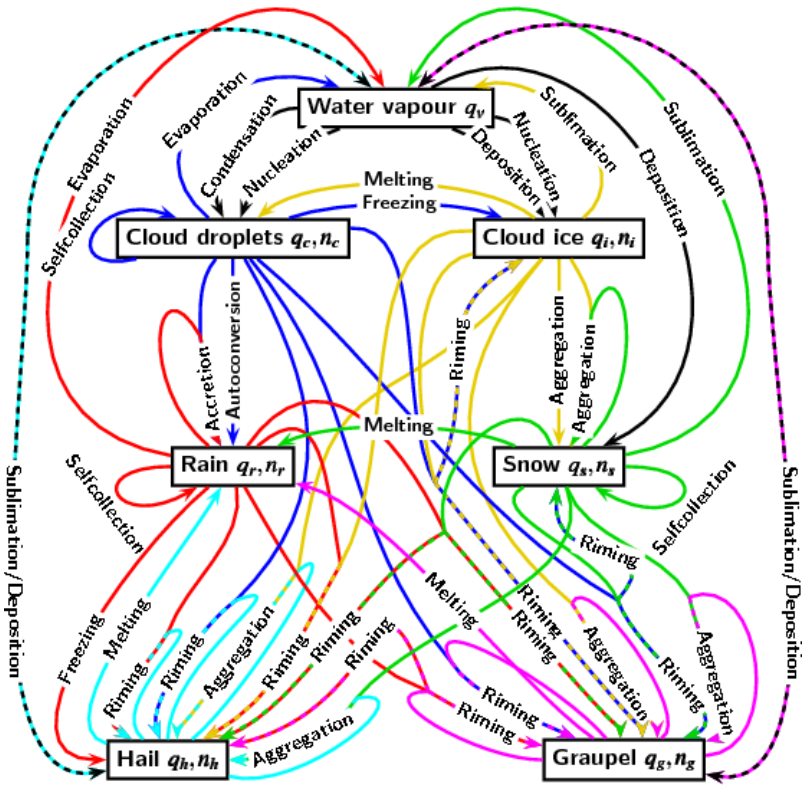
- compressible equations
- parameterized convection

COSMO-DE 2.8 km



- compressible equations
- explicit convection

The Seifert and Beheng two-moment scheme

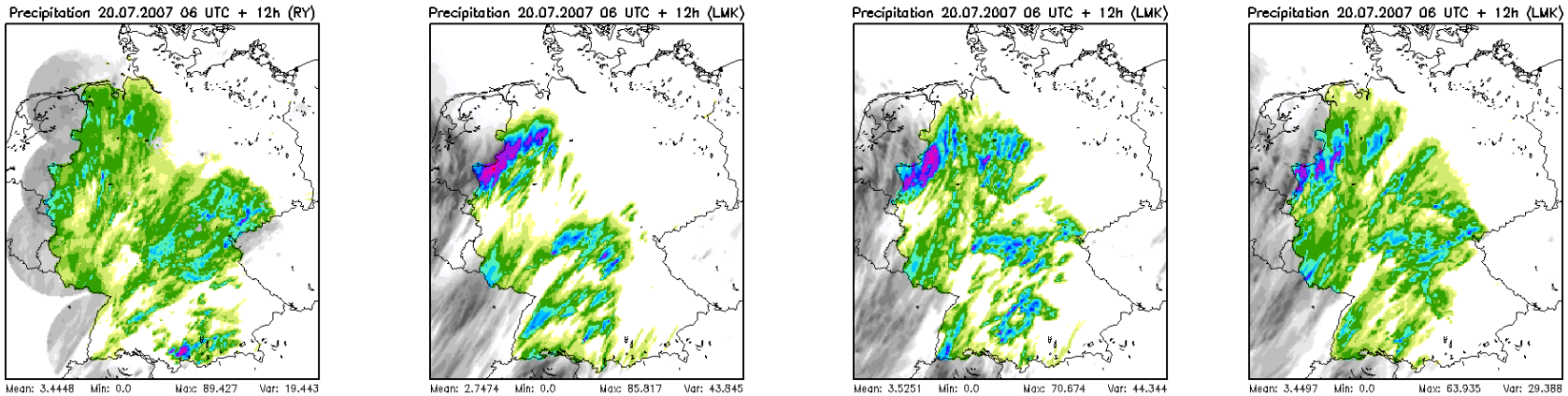


- Prognostic number and mass concentrations
- Six different particle species
  - cloud droplets
  - rain drops
  - cloud ice
  - snow
  - graupel
  - hail
- Activation/nucleation scheme Segal&Khain (2006) parameterization for activation of CCN.
- Advanced evaporation scheme (Seifert 2008)
- Hail formation by spectral partitioning of freezing processes (Blahak 2008) .

Case study 20 July 2007: Squall line over Germany

Validation with radar-derived 12-h accumulated precipitation

RADAR **ONE-MOMENT** **SB-CLEAN** **SB-POLLUTED**



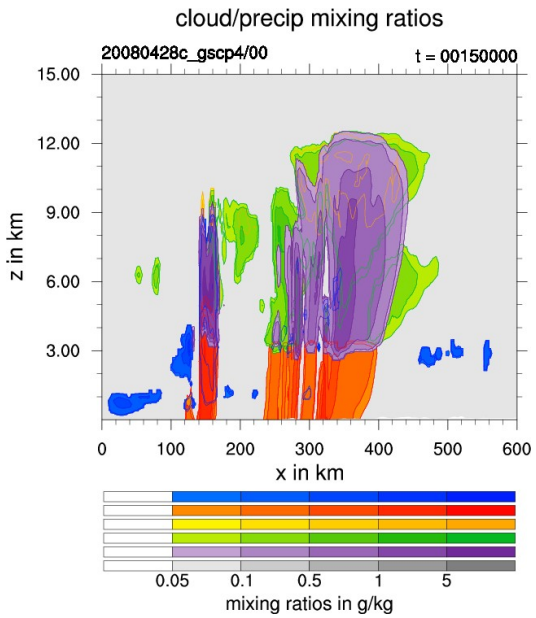
accumulated precip in mm

- ➔ **This squall line case shows a strong sensitivity to cloud microphysics.**
- ➔ **The two-moment scheme with 'polluted aerosol assumptions' would give the best precipitation pattern.**
- ➔ **But is SB-POLLUTED really the most realistic simulation overall?**

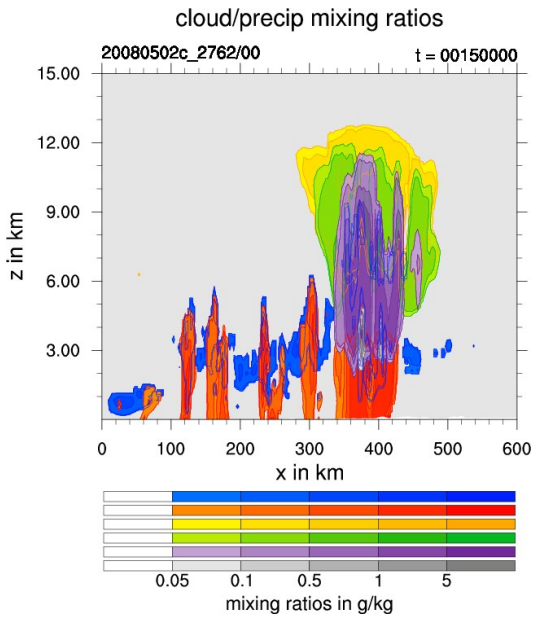
Case study 20 July 2007: Squall line over Germany

Vertical cross sections of cloud structure

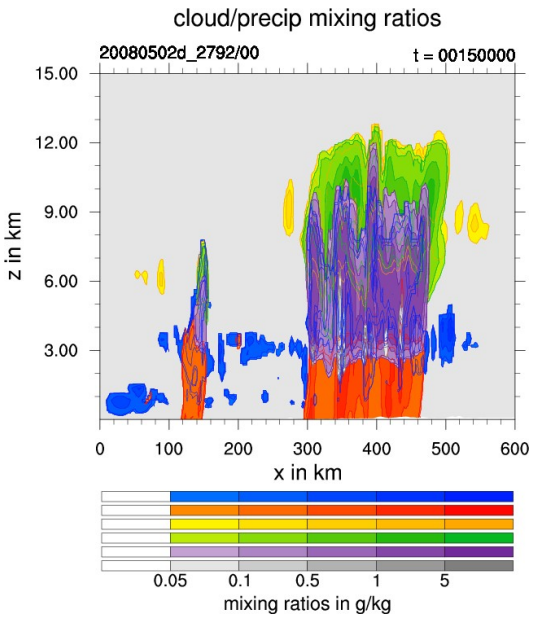
ONE-MOMENT



SB-CLEAN



SB-POLLUTED

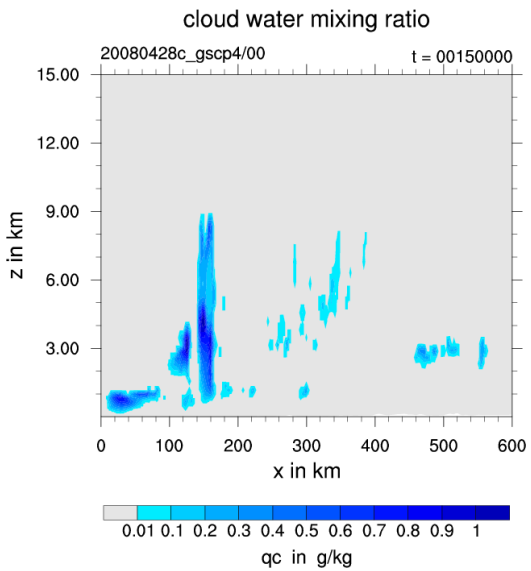


- ➔ **Squall line resulting from one-moment scheme is least vigorous**
- ➔ **SB-CLEAN produces a lot of small post-frontal cells**
- ➔ **SB-POLLUTED has the most intense multi-cellular squall line structure.**

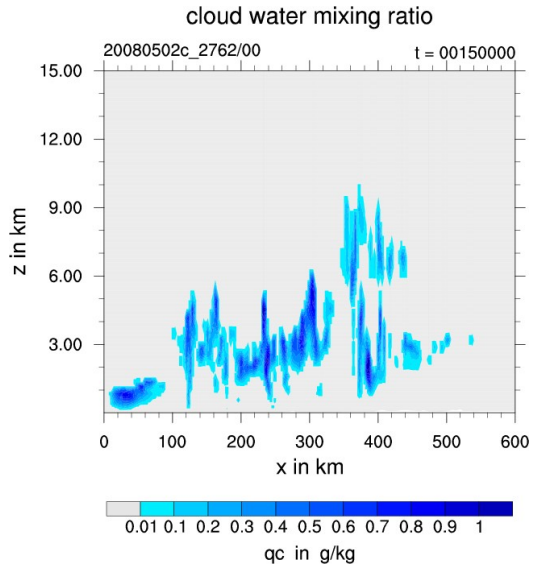
Case study 20 July 2007: Squall line over Germany

Liquid cloud water content with convective cells

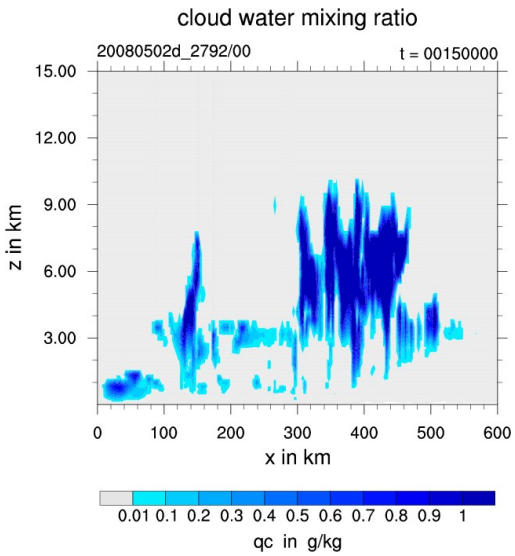
ONE-MOMENT



SB-CLEAN



SB-POLLUTED



- ➔ **One-moment scheme and SB-CLEAN produces moderate CWC in the cells.**
- ➔ **SB-POLLUTED produces large amounts of cloud water up to 10 km height.**
- ➔ **Can this be validated/falsified by satellite data? Maybe by using CLOUDSAT forward operators?**

Input data and validation of convective-scale NWP, one- vs two-moment microphysical schemes

- State-of-the-art microphysical parameterizations would in principle need information about the tropospheric aerosol as initial conditions.
- For model validation on the convective scale detailed information about the in-cloud structure would be necessary: LWC, IWC, effective radius and information about particle shape.
- In general, the high vertical resolution of active remote sensing, like CLOUDSAT/CALIPSO, seems to be more appropriate for process oriented validation.

Thanks for your attention!

Acknowledgements:

- ☺ OLR data provided by NOAA.
- ☺ CLOUDSAT data provided by CSU.
- ☺ Thanks to Thomas Hanisch, Helmut Frank, Reinhold Hess, Jochen Förstner and Detlev Majewski for their work on GME and the NWP system at DWD.
- ☺ The validation of GME with CLOUDSAT is an ongoing project with University Cologne (Sonja Eikenberg, Mario Mech, Susanne Crewell)
- ☺ The two-moment microphysics scheme is developed by DWD and KIT (Klaus Beheng, Uli Blahak, Heike Noppel)
- ☺ Most plots have been produced using NCL, the terrific software package from NCAR.

Additional slides…..

Non-equilibrium cloud ice scheme

1. Initiation of ice by various nucleation processes
   - Heterogenous freezing of rain water
   - Homogenous freezing of cloud water
   - Empirical parameterization of ice particle concentrations e.g. based Hobbs and Rangno (1985)

$$N_i(T) = N_0^i \exp\{0.2\,(T_0 - T)\}\,, \qquad N_0^i = 1.0 \cdot 10^2 m^{-3}$$

This includes all other nucleation mechanisms.

Prognostic non-equilibrium cloud ice

➔ Non-equilibrium growth of cloud ice

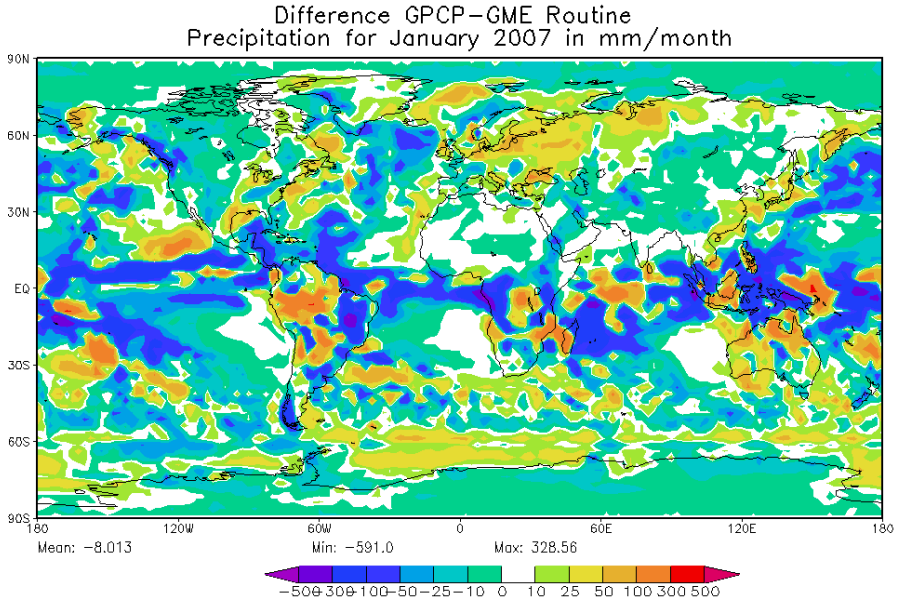
$$\left.\frac{\partial q_i}{\partial t}\right|_{\mathrm{dep}} = \frac{4D_v}{1+H}\left(\frac{m_i}{a_m}\right)^{1/3} N_i\left(q_v - q_{i,sat}\right)$$

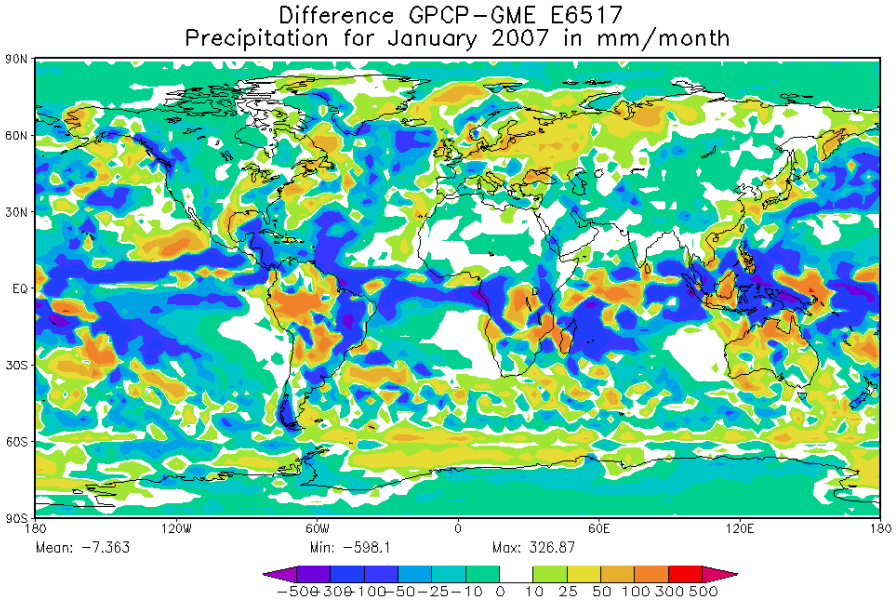
with $H_i = \dfrac{d_v L_S^2}{l_h R_v T^2}\rho q_{si}^v$ and

$$N_i(T) = N_0^i \exp\{0.2\,(T_0 - T)\}\,, \qquad N_0^i = 1.0 \cdot 10^2 m^{-3}$$

assuming a monodisperse size distribution.

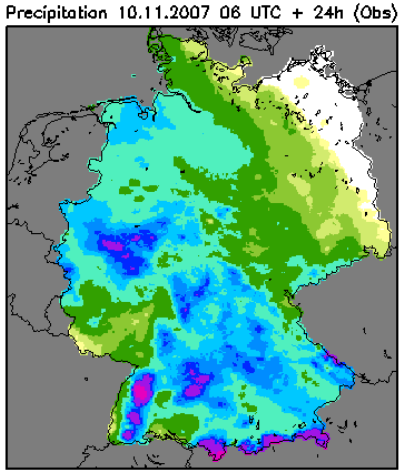
Accumulated precipitation for Jan 2007: GPCP - Model





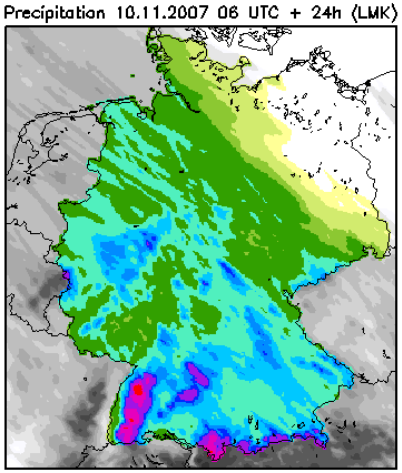
Case study 11 Nov 2007: Winter-time frontal system

Gauges



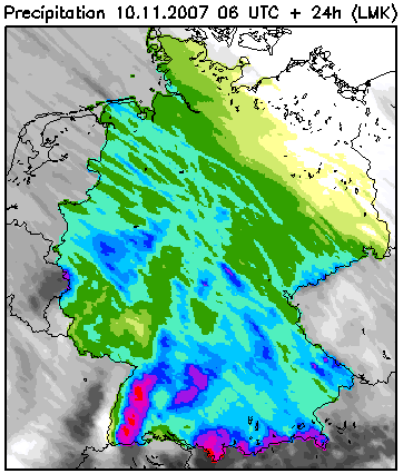
AVG: 11.7 mm

ONE-MOMENT



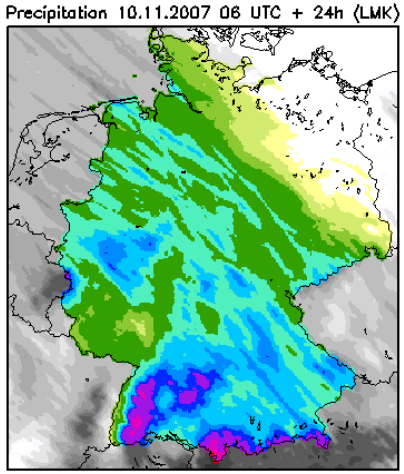
AVG: 10.7 mm

SB-CLEAN

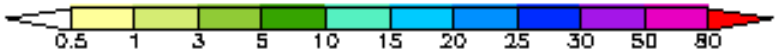


AVG: 11.4 mm

SB-POLLUTED



AVG: 11.0 mm



accumulated precip in mm

- Wintertime stratiform precipitation structures are quite robust to the chosen microphysics scheme. The operational one-moment scheme gives very similar results as the two-moment scheme assuming a low CCN number
- The local maximum values, e.g. at mountain tops, show some sensitivity to CCN assumptions.

Zusammenfassung

- GME beinhaltet bereits ein Wolkenmikrophysikschema, dass das Wachstum von Eiskristallen explizit berechnet und damit Eisübersättigungen zuläßt.
- Derzeit wird allerdings das homogene Gefrieren von Aerosolen nicht berücksichtigt. Es wird angenommen, dass die heterogene Nukleation dominiert.
- Im Laufe des Jahres soll ein neues Mikrophysikschema eingeführt werden. Dies hat Auswirkungen auf IWC, IWP, OLR etc., diese Felder werden dadurch realistischer. Auswirkung auf UFO-Felder müssen aber noch untersucht werden.