Evaluation of simulated Arctic cloud cover and PBL heights with satellite observations

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January 16, 2013
Arctic: Energy sink of the Earth

- Strong anthropogenic signal (Polar Amplification) and decadal variability
- Insufficient availability of measurements in polar regions
- Global Earth System Models (GESMs) show largest biases in polar regions
- Arctic regional climate model (RCM) as magnifier (higher resolution)
- Added value: Development of adapted/improved model physics
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### AWI as part of the Helmholtz Association

#### Programs in the research field “Earth and Environment”

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**Geosystem: The Changing Earth**

- **Atmosphere and Climate**
- **Marine, Coastal + Polar Systems**
- **Terrestrial Environment**

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### Helmholtz Association

- 8 German research centers in the research field "Earth and Environment"

- **AWI**  - Alfred Wegener Institute for Polar and Marine Research
- **FZJ**  - Research Center Jülich
- **GEOMAR**  - Helmholtz Center for Ocean Research Kiel
- **KIT**  - Karlsruhe Institute of Technology
- **GFZ**  - Helmholtz Center Potsdam, German Research Center for Geo-sciences
- **HZG**  - Helmholtz Center Geesthacht, Center for Materials and Coastal Research
- **HMGU**  - Helmholtz Center Munich, German Research Center for Environmental Health
- **UFZ**  - Helmholtz Center for Environmental Research (Leipzig)

- Networking to resolve highly complex environmental and climate problems
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- Networking to resolve highly complex environmental and climate problems
AWI research units

- Sylt
- Helgoland
- Bremerhaven Am Handelshafen
- Bremerhaven Columbusstraße
- Potsdam
AWI research unit Potsdam (Telegrafenberg)
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- ... started work in 1992
- ... accommodates two sections: Atmospheric Circulations and Periglacial Research
- ... employs 105 staff members
Goal: Integration of atmospheric observations/measurements and model simulations of climate processes into the coupled atmosphere-ocean-cryosphere (permafrost-soil, sea-ice) system
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AWI research platforms
AWI research platforms

- Tethered balloon, Lidar, ozone-/radiosonde, etc. measurements at land stations (e.g. AWIPEV, Svalbard) or drifting sea-ice stations (e.g. NP-35) to reduce polar data gap
AWI research platforms
Validation of CryoSat sea-ice thickness with EM-Bird on board of the Polar 5 aircraft
Polar components of the Earth system at AWI

- The "three poles" of the Earth in our atmospheric RCM simulations
- In this talk: Focus on the pan-Arctic integration domain
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Motivation
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HIRHAM5
Regional Climate Model of the Arctic atmosphere
Motivation

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Regional Climate Model of the Arctic atmosphere

HIRHAM5-SCM
Single-column Climate Model

reduce complexity (switch off dynamics)
**Motivation**

**HIRHAM5**
Regional Climate Model of the Arctic atmosphere

- **HIRHAM5-SCM**
  Single-column Climate Model

  - Parameterizations (Cloud Scheme)
    - reduce complexity (switch off dynamics)
    - understand subgrid-scale physical processes
Motivation

HIRHAM5
Regional Climate Model of the Arctic atmosphere

HIRHAM5-SCM
Single-column Climate Model

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understand subgrid-scale physical processes

Tuning Parameters Source Code

sensitivity studies or modification of physics
Motivation

HIRHAM5
Regional Climate Model
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HIRHAM5-SCM
Single-column Climate Model

Observations
(e.g. MODIS)

Parameterizations
(Cloud Scheme)

Tuning Parameters
Source Code

reduce complexity
(switch off dynamics)

understand subgrid-scale
physical processes

adjust parameters or
validate changed code

sensitivity studies or
modification of physics
**Motivation**

**HIRHAM5**
Regional Climate Model of the Arctic atmosphere

Reduce complexity (switch off dynamics)

**HIRHAM5-SCM**
Single-column Climate Model

Understand subgrid-scale physical processes

**Observations** (e.g. MODIS)

Improved cloud-radiation interaction

**Parameterizations** (Cloud Scheme)

Sensitivity studies or modification of physics

**Tuning Parameters Source Code**

Adjust parameters or validate changed code
**Motivation**

**HIRHAM5**
Regional Climate Model of the Arctic atmosphere

**HIRHAM5-SCM**
Single-column Climate Model

- implement improved model physics
- reduce complexity (switch off dynamics)

**Observations** (e.g. MODIS)

**Parameterizations** (Cloud Scheme)

- understand subgrid-scale physical processes
- sensitivity studies or modification of physics

**Tuning Parameters**
Source Code

- adjust parameters or validate changed code
- improved cloud-radiation interaction
- observations
Motivation

- Evaluation of HIRHAM5ctrl (with NP-35, SHEBA, MODIS, GPS-RO, CALIOP, ...)
- Compare HIRHAM5ctrl with HIRHAM5sens

HIRHAM5
Regional Climate Model of the Arctic atmosphere

HIRHAM5-SCM
Single-column Climate Model

Adapt model physics through:
- improved cloud-radiation interaction
- adjust parameters or validate changed code

Reduce complexity (switch off dynamics) through:
- sensitivity studies or modification of physics

Parameterizations
(Cloud Scheme)

Tuning Parameters
Source Code

Observations
(e.g. MODIS)

understand subgrid-scale physical processes

Implementation:
- implement improved model physics
Model description

- Regional climate model HIRHAM5
- Single-column climate model HIRHAM5-SCM

Results from HIRHAM5-SCM

- Modeled vs. observed total cloud cover
- Parameter sensitivity studies
- Modification of the PS-Scheme

Results from HIRHAM5

- Used observational PBL height datasets
- Calculation of PBL height in HIRHAM5
- Definition of PBL height in observational datasets
- General performance of HIRHAM5
- Shortcomings in satellite PBL heights over land
- Evaluation of simulated PBL heights I + II

Summary/Outlook
Outline

1. Model description
   - Regional climate model HIRHAM5
   - Single-column climate model HIRHAM5-SCM

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   - Modeled vs. observed total cloud cover
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4. Summary/Outlook
Regional climate model HIRHAM5

- Atmospheric RCM with pan-Arctic integration domain (> 53.5°N)
- Comprises dynamical core of the HIRLAM NWP model and physical parameterizations of the ECHAM5 GCM coupled by an interface

**HIRLAM (Undén et al., 2002)**

- Hydrostatic model solves 7 prognostic equations
  - Surface pressure ($p_s$)  
  - Temperature ($T$)  
  - Horizontal wind ($u,v$)  
  - Specific humidity ($q$)  
  - Cloud water content ($q_l$)  
  - Cloud ice content ($q_i$)  
- 0.25° horizontal resolution (~25 km)  
- 40 hybrid levels (≤ 10 hPa; 10 in PBL)  
- Semi-implicit Euler time scheme ($\Delta t = 2$ min)  
- ERA-Interim initialization/lateral boundary forcing

**ECHAM5 (Roeckner et al., 2003)**

Subgrid-scale parameterizations:

- SW and LW radiation transfer  
- Stratiform cloud scheme  
- Cumulus convection  
- Surface fluxes and vertical diffusion  
- Sea and sea-ice surface processes  
- Land surface processes  
- Gravity wave drag
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Single-column climate model HIRHAM5-SCM

**Model description**

- **Predefined geographic location**
- **60 hybrid levels (≤ 0.1 hPa; 10 in PBL)**
- **Euler forward time scheme (Δt = 10 min)**
- **Initialization with ERA-Interim data set**
- **Physical tendencies explicitly computed by ECHAM5 parameterizations**
- **ρ_s** and dynamical tendencies of T, q, u, and v are prescribed 3-hourly from ERA-Interim

**Cloud cover parameterization**

- Prognostic equations for vapor, liquid, and ice phase
- Bulk cloud microphysics according to Lohmann and Roeckner (1996)
- Relative humidity cloud scheme (RH-Scheme; Sundquist et al., 1989)
- Prognostic statistical cloud scheme (PS-Scheme; Tompkins, 2002)
Single-column climate model HIRHAM5-SCM

Model setup
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Modeled vs. observed total cloud cover

Monthly means of $C^{tot}$ at NP-35 start position (102.81°E; 81.40°N)

- MODIS features moderate (high) cloudiness during winter period (summer period)
- In general, HIRHAM5-SCM agrees qualitatively but systematically overestimates $C^{tot}$
- PS-Scheme shows reduced biases and good agreement from November 2007 to January 2008
- Transition seasons worst reproduced with largest biases in October 2007 and May 2008

Best (worst) agreement between MODIS and HIRHAM5-SCM(PS) (ERA-Interim) but systematic overestimation of cloudiness regardless of whether model or reanalysis
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Parameter sensitivity studies

Monthly means of $C^{\text{tot}}$ at NP-35 start position

(a) Lower $\tilde{q}_0$ ($\tilde{q}_0^{\text{def}} = 2$)

(b) Higher $\text{CW}_{\text{min}}$ ($\text{CW}_{\text{min}}^{\text{def}} = 0.1 \text{ mg kg}^{-1}$)

(c) Higher $\gamma_1$ ($\gamma_1^{\text{def}} = 15$)

(d) Lower $\gamma_{\text{thr}}$ ($\gamma_{\text{thr}}^{\text{def}} = 0.5 \text{ mg kg}^{-1}$)

Suitable tuning parameters

$\tilde{q}_0$ – Shape parameter threshold
Controls the shape of the symmetric beta distribution acting as probability density function (PDF)

$\text{CW}_{\text{min}}$ – Cloud water threshold
Avoids negative cloud water/ice contents and controls the occurrence of clear-sky conditions in the PS-Scheme

$\gamma_1$ – Autoconversion rate
Controls the efficiency of rain drop formation by collision and coalescence

$\gamma_{\text{thr}}$ – Cloud ice threshold
Controls the efficiency of the Bergeron-Findeisen process

- Reduction of $C^{\text{tot}}$ through higher $\text{CW}_{\text{min}}$ or $\gamma_1$ as well as lower $\tilde{q}_0$ or $\gamma_{\text{thr}}$
- Most significant improvement through lower $\gamma_{\text{thr}}$ that also correct the ratio of liquid to solid water content
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- **(b) Higher CW_{\min} (CW_{\min}^{\text{def}} = 0.1 \text{ mg kg}^{-1})**
  - Suitable tuning parameters
- **(c) Higher $\gamma_1$ ($\gamma_1^{\text{def}} = 15$)**
  - Suitable tuning parameters
- **(d) Lower $\gamma_{\text{thr}}$ ($\gamma_{\text{thr}}^{\text{def}} = 0.5 \text{ mg kg}^{-1}$)**
  - Suitable tuning parameters

**Suitable tuning parameters**

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- CW_{\min} — **Cloud water threshold**
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**Klaus et al. (2012):** Evaluation of Two Cloud Parameterizations and Their Possible Adaptation to Arctic Climate Conditions, *Atmosphere* 2012, 3, 419–450.
Modification of the PS-Scheme

Default formulation
- Tompkins (2002)
- \( \bar{p} = \bar{q}_0 = 2 (\bar{q} \geq \bar{p}) \)
- positively skewed or symmetrical \( G(q_t) \)

Changed formulation
- Tompkins’ idea
- \( \bar{p} = F(\bar{q}) = \frac{\bar{q} + 1}{\bar{q} - 1} \)
- now negatively skewed \( G(q_t) \) permitted, too
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\[ G(q_t) \]

\[ \bar{p} \]

\[ \bar{q} \]

\[ q_t \]

\[ G(q_t) \]

\[ \bar{q} > \bar{p} \]

\[ \bar{q} < \bar{p} \]

Changed formulation
- Tompkins’ idea
- \( \bar{p} = F(\bar{q}) = \frac{\bar{q}+1}{\bar{q}-1} \)
- now negatively skewed
- \( G(q_t) \) permitted, too

Monthly means of \( C^{\text{tot}} \) at NP-35 start position

(e) Permit negative skewness, i.e. \( \bar{p} = F(\bar{q}) \)

- Reduction of clouds through the introduction of negatively skewed beta distributions is of the same order of magnitude as for lower \( \gamma_{\text{thr}} \)
Modification of the PS-Scheme

Default formulation
- Tompkins (2002)
- \( \tilde{p} = \bar{q}_0 = 2\) (\(\bar{q} \geq \tilde{p}\))
- positively skewed or symmetrical \(G(q_t)\)

Changed formulation
- Tompkins’ idea
- \(\tilde{p} = F(\bar{q}) = \frac{\bar{q}+1}{\bar{q}-1}\)
- now negatively skewed \(G(q_t)\) permitted, too

Monthly means of \(C^{\text{tot}}\) at NP-35 start position

(e) Permit negative skewness, i.e. \(\tilde{p} = F(\bar{q})\)

(f) Lower \(\gamma_{\text{thr}}\) and negative skewness

- Reduction of clouds through the introduction of negatively skewed beta distributions is of the same order of magnitude as for lower \(\gamma_{\text{thr}}\)
- Combined effect of lower \(\gamma_{\text{thr}}\) and permitted negatively skewed \(G(q_t)\) can be used to adapt the PS-Scheme to Arctic climate conditions
Used observational PBL height datasets

**HIRHAM5**
- Atmospheric RCM (control run → ctrl)
- pan-Arctic integration domain (> 53.5°N)
- 0.25° × 0.25° horizontal resolution
- 01/01/1979 – 12/31/2011 (33 yrs)

**ERA-Interim**
- Most recent ECMWF reanalysis
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Calculation of PBL height in HIRHAM5

a) **Dynamical height** (Ekman layer height)

\[ h_{\text{dyn}} = C \cdot \frac{u_*}{f} \]

- \( C = 0.3 \) \( \rightarrow \) Dimensionless parameter
- \( u_* = \sqrt{\frac{\tau_0}{\rho}} \) \( \rightarrow \) Friction velocity as defined by Charnock (1955), where \( \tau_0 \) = surface drag and \( \rho \) = density of air
- \( f \) \( \rightarrow \) Coriolis parameter

First model level above \( h_{\text{dyn}} \) defines level number of dynamical PBL height \( h_{\text{PBL,d}} \)

b) **Dry convective level** (Using dry static energy)

\[ s = c_{pd} (1 + (\delta - 1)q) \cdot T + g \cdot z = c_p \cdot T + \Phi \]

- \( \delta = \frac{c_{pv}}{c_{pd}} \) \( \rightarrow \) Ratio of specific heat capacities for water vapor and dry air
- \( q, T \) \( \rightarrow \) Specific humidity and air temperature
- \( \Phi = g \cdot z \) \( \rightarrow \) Geopotential

First model level where \( s \) exceeds value of the lowermost model level defines level number of convective PBL height \( h_{\text{PBL,c}} \)

PBL height is then calculated in 3 steps

\[ h_{\text{PBL}} = \text{MIN}(h_{\text{PBL,d}}, h_{\text{PBL,c}}) \]

\[ \Phi_{\text{PBL}} = \text{MIN}(50,000 \text{ m}^2\text{s}^{-2}, \Phi(h_{\text{PBL}})) \]

\[ H_{\text{PBL}} = \Phi_{\text{PBL}} / g_n \]

with standard gravity \( g_n = 9.80665 \text{ m s}^{-2} \)
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Definition of PBL height in observational datasets

**ERA-Interim**

- **Bulk Richardson number-based approach**

\[
R_{iB} = \frac{\text{buoyancy production/consumption}}{\text{shear production}} = \frac{g}{\theta_v} \frac{\Delta \bar{\theta}_v \Delta z}{[(\Delta u)^2 + (\Delta \bar{v})^2]}
\]

- turbulent flow if \( R_{iB} < 0 \), laminar flow if \( R_{iB} > 0.25 \)
- PBL height is defined as level where \( R_{iB} \) exceeds critical value of 0.25
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**GPS-RO**
- **Maximum refractivity gradient method**
  → described e.g. by Anthes et al. (2008)
- GPS receiver on a low Earth orbiting (LEO) satellite detects signal of GPS transmitter
- Vertical refractivity profile depends on temperature, pressure, water vapor pressure, and electron density: \(N = N(T, p, e, n_e)\)
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http://www.newscientist.com
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CALIOP

- **Maximum variance technique**
  → described e.g. by Jordan et al. (2010)
- Assumption that at the top of the PBL there exists a maximum in the vertical standard deviation of Lidar backscatter (Melfi et al., 1985)
- First level (lowest altitude) of maximum in standard deviation and backscatter defines PBL height
General performance of HIRHAM5

Mean sea level pressure (top = Jan2007 and bottom = Jul2007)

HIRHAM5 and ERA-Interim basically show the same large-scale circulation
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Shortcomings in satellite PBL heights over land

Arctic PBL heights during winter

- Unrealistic behavior over (high) orography
- Reason: Algorithm of Xie et al. (2012)
- Only RO profiles that penetrate 500 m (above mean sea level) have been used for computing PBL heights

Land points need to be masked out
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CALIOP
- Generally unrealistic behavior over land
- PBL heights always > 1500 m during MAM, JJA, and SON (not shown)
- No improvement through subtraction of topography → other reason ???
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Evaluation of simulated PBL heights I

Arctic PBL heights during winter

- ERAint shows systematically lower $H_{PBL}$ (especially over land)
- ERAint low bias already shown by von Engeln and Teixeira (2011)
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- Spatial patterns agree well
- HIRHAM5 **negative bias** over North Atlantic, Greenland and Barents Sea but **positive bias** otherwise

- Spatial patterns agree except for North Atlantic and along seashores
- Tendency to HIRHAM5 **positive bias** over North Atlantic, Greenland and Barents Sea but **negative bias** otherwise
Evaluation of simulated PBL heights II

Arctic PBL heights during summer

- ERAint shows mainly lower $H_{PBL}$
- More areas with equal or slightly higher $H_{PBL}$ compared with DJF
Evaluation of simulated PBL heights II

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- ERAint shows mainly lower $H_{PBL}$
- More areas with equal or slightly higher $H_{PBL}$ compared with DJF

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- GPS-RO shows much higher $H_{PBL}$
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Evaluation of simulated PBL heights II

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- More areas with equal or slightly higher $H_{\text{PBL}}$ compared with DJF

- Spatial patterns disagree
- GPS-RO shows much higher $H_{\text{PBL}}$
- GPS-RO seems to be biased
- Biases in SON, too (not shown)

- Spatial patterns agree well but large differences along seashores
- Tendency to HIRHAM5 negative bias over Greenland, Norwegian, Barents, and Kara Sea but positive bias otherwise
Summary

- PS-Scheme performs better than RH-Scheme but systematic overestimation of $C_{tot}$
- Combined effect of lower $\gamma_{thr}$ and permitted negative skewness of $G(q_t)$ significantly reduces biases relative to MODIS
- HIRHAM5, ERA-Interim, and CALIOP show same annual cycle of $H_{PBL}$ but GPS-RO seems to be biased in JJA and SON
- Found low bias of ERA-Interim $H_{PBL}$ consistent with e.g. von Engeln and Teixeira (2011) and Xie et al. (2012)
- In part contrary patterns of relative differences between HIRHAM5 and GPS-RO (CALIOP)

Outlook

- Comparison of HIRHAM5 model variables with (satellite) observations
  i) More detailed investigation of simulated Arctic PBL heights (Monthly means, Scatter plots)
  ii) Validation of cloud variables ($C$, $C_{tot}$, LWP, IWP, CRF)
      → Prepared gridded datasets are welcome

- Sensitivity run with HIRHAM5 (2006 – 2011)
  i) Use $\gamma_{thr} = 0.05$ mg/kg and permitting negative skewness of $G(q_t)$
  ii) Comparison of control (HIRHAM5ctrl) and sensitivity (HIRHAM5sens) simulations
      → Also improved performance in the 3D model version?
Summary

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A1: Polar Amplification

Snow/Ice Albedo Feedback

- temperature increase
- melting ice and snow
- reduced solar reflection
- open water forms
- water vapor – cloud feedback changes

Feedback +
**A2: Use of dynamical tendencies in HIRHAM5-SCM**

**Dynamical tendencies from ERA-Interim**

- Dynamical tendencies of $\psi_i = T, q, u, v$ as dynamical forcing

- ERA-Interim provides:
  1. 3-hourly total tendency of $\psi_i$
  2. 3-hourly physical tendency from forecast run

- Problem: accumulated data and 12-hourly reinitialization

Linear interpolation of 3-hourly dynamical tendencies available at every time step

[Equations and diagrams related to dynamical tendencies and linear interpolation]
A3: Parameterization of stratiform clouds

Fractional cloud cover $C$
- parameterization consists of three components:
  1. prognostic equations for the vapor ($q$), liquid ($q_l$), and ice ($q_i$) phase
  2. cloud microphysics according to Lohmann and Roeckner (1996), which considers water phase changes and precipitation processes
  3. selectable cloud cover scheme ...

Relative Humidity Scheme
(RH-Scheme; Sundquist et al., 1989)
- diagnostic relation to the grid box mean of relative humidity ($RH$)
  \[ C = 1 - \sqrt{\frac{1 - RH}{1 - RH_{\text{crit}}}} \]
- $RH_{\text{crit}}$ is the critical threshold according to Lohmann et al. (1999), controlling the onset of cloud formation

Prognostic Statistical Scheme
(PS-Scheme; Tompkins, 2002)
- subgrid-scale variability of total water content $q_t = q + q_l + q_i$ is explicitly specified by the beta distribution $G(q_t)$ acting as PDF
- Integral over the supersaturation range ($q_t > q_s$) below $G(q_t)$ yields
  \[ C = \int_{q_s}^{b} G(q_t) dq_t \]

Total cloud cover $C^{\text{tot}}$
- computed by use of the Maximum-Random Overlap Assumption
### Table 1: Notation, default value, regarded parameter range (co-domain), and description of parameter (Meaning)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Default</th>
<th>Co-domain</th>
<th>Description (Meaning)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tilde{q}_0$</td>
<td>2</td>
<td>$1.00001 \leq \tilde{q}_0 \leq 20$</td>
<td>determines the shape of the symmetric beta distribution, which is used as PDF in the PS-Scheme</td>
</tr>
<tr>
<td>$CW_{\text{min}}$</td>
<td>0.1 mg kg$^{-1}$</td>
<td>$(0 \leq CW_{\text{min}} \leq 750) \text{ mg kg}^{-1}$</td>
<td>avoids negative cloud water and ice contents and additionally controls the occurrence of clear-sky conditions in the PS-Scheme</td>
</tr>
<tr>
<td>$\gamma_1$</td>
<td>15</td>
<td>$0 \leq \gamma_1 \leq 500$</td>
<td>determines the efficiency of rain drop formation by collision and coalescence of cloud drops (autoconversion rate)</td>
</tr>
<tr>
<td>$\gamma_{\text{thr}}$</td>
<td>0.5 mg kg$^{-1}$</td>
<td>$(0 \leq \gamma_{\text{thr}} \leq 5) \text{ mg kg}^{-1}$</td>
<td>cloud ice threshold, which determines the efficiency of the Bergeron-Findeisen process</td>
</tr>
</tbody>
</table>

where $C_s$ is a tunable constant. Since the mixing will also reduce the skewness of the distribution, tending toward a symmetric one, the same relaxation is applied to the skewness parameter $q$

\[
\left(\frac{\partial q}{\partial t}\right)_{\text{diss}} = (q_0 - q) \left(\tau_v^{-1} + \tau_h^{-1}\right) \tag{10.22}
\]

where $q_0$ defines the shape of the final distribution.
A5: Modified tuning parameters II

\[ CW_{\text{min}} \]

This parameter is not mentioned by Roeckner et al. (2003).

\[ \gamma_1 \]

\[ Q_{\text{aut}} = C \gamma_1 \left[ a_2 n^{-b_2} (10^{-6} N_i)^{-b_3} (10^{-3} \rho r_i)^{b_4} \right] / \rho \]  

(10.45)

where \( a_2 = 6 \cdot 10^{28} \), \( n = 10 \) is the width parameter of the initial droplet spectrum described by a gamma distribution, \( b_2 = 1.7 \), \( b_3 = 3.3 \), \( b_4 = 4.7 \), and \( \gamma_1 \) is a tunable parameter which determines the efficiency of the autoconversion process and, hence, cloud lifetime.

\[ \gamma_{\text{thr}} \]

models and cannot be applied to large-scale models without adjustment. The parameter \( \gamma_{\text{thr}} \) is a cloud ice threshold which decides on either condensational growth of supercooled cloud droplets or depositional growth of ice crystals (see (10.34) and (10.35)). The following values are used in ECHAM5: \( \gamma_1 = 15 \); \( 0 \leq \gamma_2 \leq 0.5 \) depending on model resolution; \( \gamma_3 = 95 \); \( \gamma_4 = 0.1 \); \( \gamma_{\text{thr}} = 5 \cdot 10^{-7} \) kgkg\(^{-1} \).
Spatial patterns of the geopotential agree well between HIRHAM5 and ERA-Interim.
A7: General performance of HIRHAM5 III

2m air temperature (top = Jan2007 and bottom = Jul2007)

HIRHAM5 and ERA-Interim 2m temperatures differ in part significantly.