Evaluation and sensitivity of Arctic clouds simulated by the single-column climate model HIRHAM5-SCM

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1. Motivation

Single-column climate models (SCMs) are considered as a useful tool for developing and evaluating subgrid-scale physical parameterizations of climate models. The motivation to this study [1] was to evaluate and possibly adapt two selectable cloud cover schemes for inner-Arctic climate conditions. For this purpose, the newly designed SCM version of the most recent regional climate model version HIRHAM5 was exploited.

2. Model description

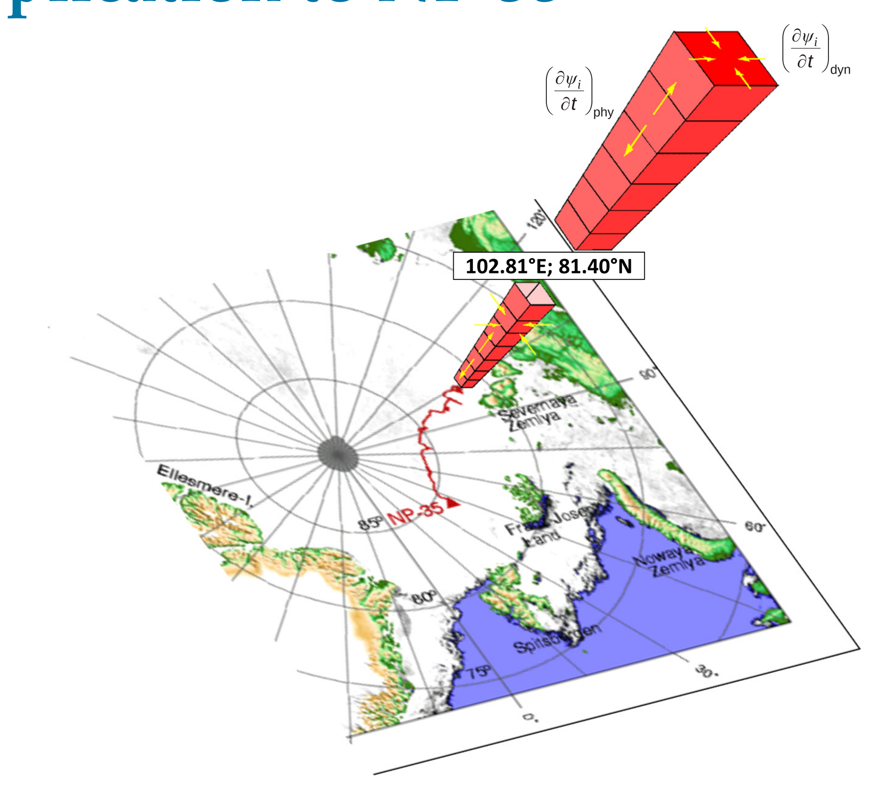
HIRHAM5-SCM is the one-grid-point formulation of HIRHAM5, where the latter comprises the dynamical core of the regional weather forecast model HIRLAM and the physical parameterization package of the atmospheric general circulation model ECHAM5.

Model setup

- 60 model levels (up to 0.1 hPa; 10 in ABL)
- Euler forward time scheme ($\Delta t = 10$ min)
- Initialization with ERA-Interim data set
- Physical tendencies explicitly computed by ECHAM5 parameterizations
- Surface pressure and dynamical tendencies of temperature, specific humidity and horizontal wind are prescribed 3-hourly from ERA-Interim

We employed this model to simulate the 35th Russian North Pole drifting station (NP-35).

Application to NP-35



The parameterization of stratiform clouds, which diagnoses fractional cloud cover C, consists of three components (see [2]):

Cloud cover schemes

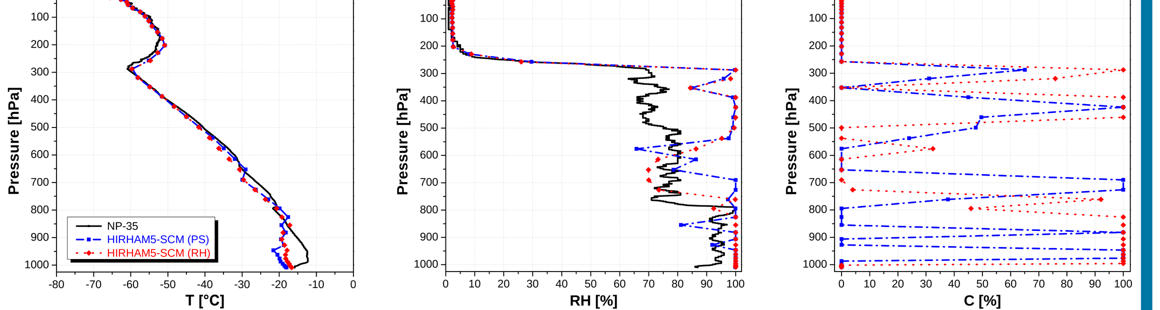
1. Prognostic equations for the vapor, liquid and ice phase
2. Bulk cloud microphysics according to [3]
3. Two selectable cloud cover schemes
   a) Relative humidity scheme (RH-Scheme) by [4]
   b) Prognostic statistical scheme (PS-Scheme) by [5]

Total cloud cover C^{tot} is calculated using a maximum-random overlap assumption.

3. Evaluation I: T and RH

For the model evaluation, we conducted 26 case studies and compared simulated vertical profiles of temperature T and relative humidity RH with ground-based measurements from NP-35. Modeled fractional cloud cover C is shown as well.

Vertical profiles of T, RH, and C



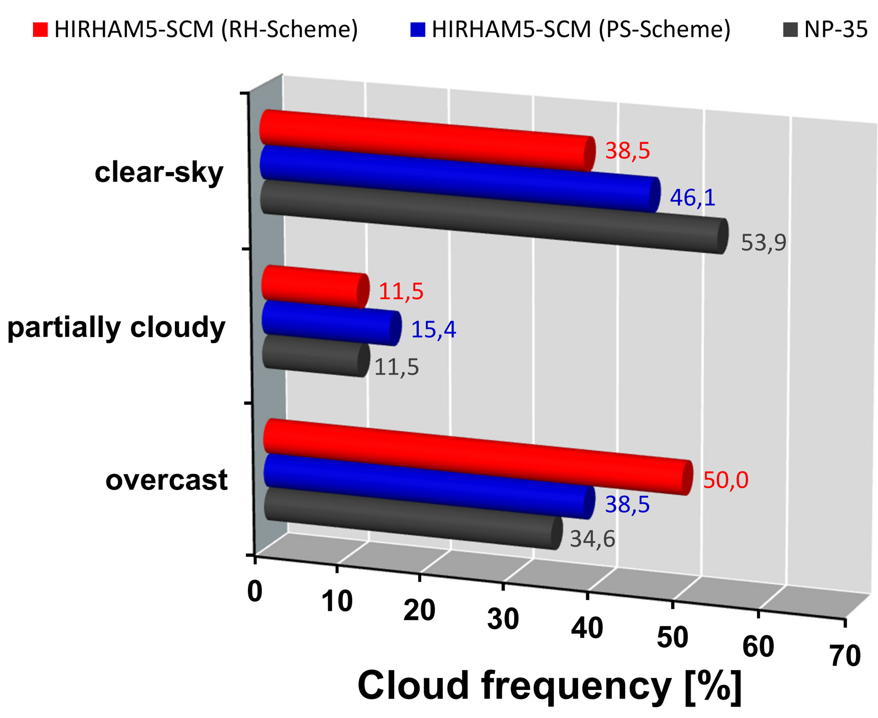
1 November 2007 (0 UTC)

- Biased simulation of the (stable) ABL
- Biased simulation of vertical moisture variability
- Cloud top radiative cooling likely overestimated
- Statistics over all cases showed that PS-Scheme correlates better with observed profiles of T and RH

4. Evaluation II: total cloud cover (C^{tot})

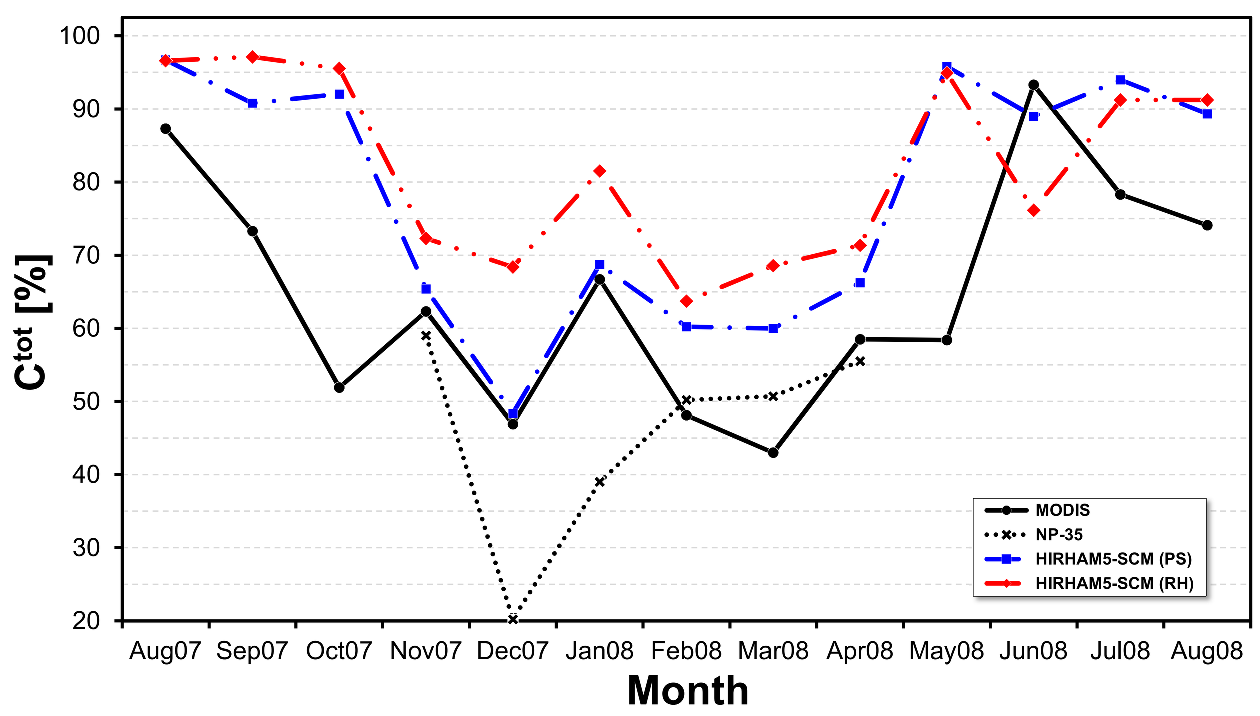
Based on the 26 case studies, conducted during the winter period (WP), we compared relative frequencies of simulated clear-sky, partially cloudy, and (totally) overcast conditions with NP-35 cloud observations. To further analyze the performance of the RH-Scheme and the PS-Scheme, we evaluated modeled C^{tot} with satellite-based Moderate Resolution Imaging SpectroRadiometer (MODIS; [6]) cloud amount at the start position of NP-35.

Relative frequencies for WP



- Underestimation of clear-sky but overestimation of overcast conditions
- Both biases significantly larger when using RH-Scheme
- Frequency of partially cloudy conditions agrees well for RH-Scheme
- Overestimation of cloudy conditions reduced by PS-Scheme

Annual cycle of monthly averaged C^{tot}



- MODIS features moderate/high cloudiness during winter/summer period (WP/SP)
- In general, model 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

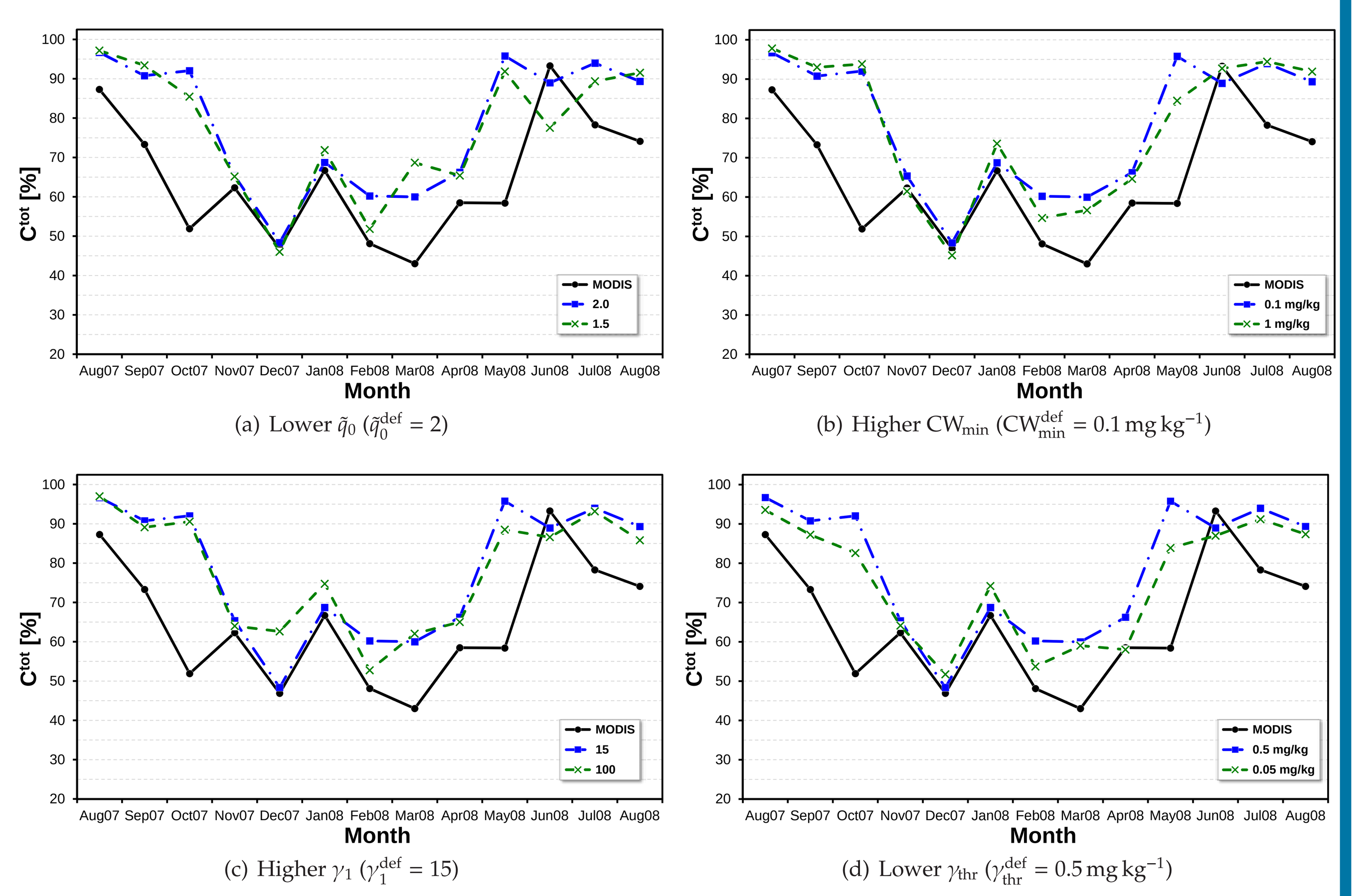
5. Parameter sensitivity studies

Conducted sensitivity studies revealed that the PS-Scheme adjustment parameter $\tilde{q}_0$ (controls the shape of the symmetric beta distribution acting as PDF), the cloud water threshold $\mathrm{CW_{min}}$ (avoids negative cloud water and ice contents and additionally controls the occurrence of clear-sky conditions in the PS-Scheme), the autoconversion rate γ_1 (controls efficiency of rain drop formation by collision and coalescence), and the cloud ice threshold γ_{thr} (controls efficiency of the Bergeron-Findeisen process) are eligible 'tuning' parameters enabling the adaptation of the cloud parameterization to Arctic climate conditions. The overall effect (↑/↓ = in-/decrease; +/— = improvement/deterioration) due to a parameter modification and the best-fit parameters concerning C^{tot} are summarized in the following.

Overall effects on cloud-related model variables

Model parameter	Changes due to *lower* value	Changes due to *higher* value
$\tilde{q}_0$	+ C & C^{tot} ↓ + q_i (IWP) ↑ — q_l (LWP) ↑ — P_{lasc} & P_{conv} ↑	+ q_i (IWP) ↑ but q_l (LWP) ↓; effect small (large) for q_l (q_i) — C, C^{tot}, P_{lasc}, and P_{conv} ↑
$\mathrm{CW_{min}}$	+ q_i (IWP) ↑ but q_l (LWP) ↓; effect more pronounced than for higher $\tilde{q}_0$ and more significant for q_i — C, C^{tot}, P_{lasc}, and P_{conv} ↑	+ C & C^{tot} ↓ + P_{conv} ↓ — q_i (IWP) ↓ but q_l (LWP) & P_{lasc} ↑
γ_1	+ q_i (IWP) ↑ but P_{conv} ↓ — all other regarded model variables ↑	+ q_i (IWP) ↑ but q_l (LWP) ↓; effect large (small) for q_l (q_i) + C & C^{tot} ↓ — P_{lasc} & P_{conv} ↑
γ_{thr}	+ q_i (IWP) ↑ but q_l (LWP) ↓; effect significant for q_l & q_i + C & C^{tot} ↓ — P_{lasc} & P_{conv} ↑	+ q_i (IWP) ↑ — all remaining model variables ↑

Reduction of C^{tot} due to parameter modification



(a) Lower $\tilde{q}_0$ ($\tilde{q}_0^{def} = 2$)
(b) Higher $\mathrm{CW_{min}}$ ($\mathrm{CW_{min}^{def}} = 0.1\,\mathrm{mg\,kg^{-1}}$)
(c) Higher γ_1 ($\gamma_1^{def} = 15$)
(d) Lower γ_{thr} ($\gamma_{thr}^{def} = 0.5\,\mathrm{mg\,kg^{-1}}$)

Model variables:
C - fractional cloud cover; C^{tot} - total cloud cover; q_l - cloud liquid water content
q_i - cloud ice water content; LWP - cloud liquid water path; IWP - cloud ice water path
P_{lasc} - large-scale precipitation; P_{conv} - convective precipitation; P_{snow} - snow fall

6. Conclusions

Evaluation

- PS-Scheme enables an improved simulation of Arctic clouds as compared to RH-Scheme
- Model systematically overestimates C^{tot} although cloudy conditions are reduced by PS-Scheme
- Overestimated cloud top radiative cooling and biased simulation of stable ABLs likely amplify cloud formation

Sensitivity studies

- Reduction of C^{tot} through *higher* $\mathrm{CW_{min}}$ or γ_1
- Reduction of C^{tot} through *lower* $\tilde{q}_0$ or γ_{thr}
- Most significant improvement through lower γ_{thr}

References

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