Modelling mixed-phase clouds with large-eddy model UCLALES-SALSA

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Outline

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Motivation

- Better understanding of aerosol-cloud interactions and their impact on the climate
- Shallow clouds are hard to model with General Circulation Models but are important for the climate
  - Earth's albedo depends highly on shallow marine clouds

Model description: UCLALES-SALSA

- Large-eddy simulation (LES) model UCLALES [1,2] for atmospheric turbulence
- Bin microphysics description with SALSA [3]
- coupled UCLALES-SALSA first introduced in Tonttila et al., 2017 [4]

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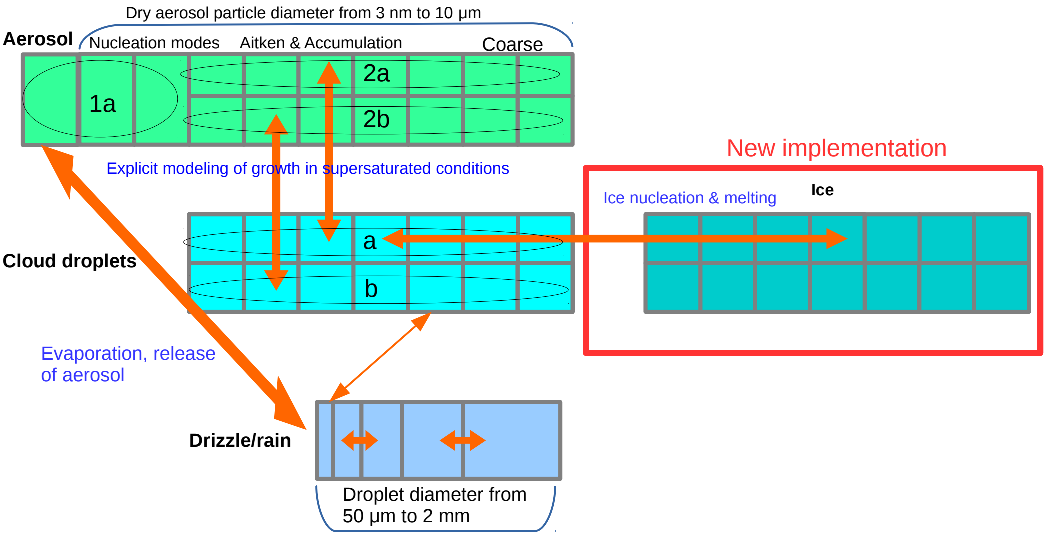
[1] Stevens, B., Moeng, C.-H., Ackerman, A. S., Bretherton, C. S., Chlond, A., de Roode, S., Edwards, J., Golaz, J.-C., Jiang, H. , Khairoutdinov, M., Kirkpatrick, M. P., Lewellen, D. C., Lock, A., Müller, F., Stevens, D. E., Whelan, E., Zhu, P.: Evaluation of large-eddy simulations via observations of nocturnal marine stratocumulus. Mon. Wea. Rev., 133, 1443–1462, doi:10.1175/MWR2930.1, 2005.

[2] Stevens, B., Moeng, C.-H., Sullivan, P. P.: Large-eddy simulations of radiatively driven convection: sensitivities to the representation of small scales. J. Atmos. Sci., 56, 3963–3984, doi:10.1175/1520-0469(1999)056¡3963:LESORD¿2.0.CO;2, 1999.

[3] Kokkola, H., Korhonen, H., Lehtinen, K. E. J., Makkonen, R., Asmi, A., Järvenoja, S., Anttila, T., Partanen, A.-I., Kulmala, M., Järvinen, H., Laaksonen, A., Kerminen, V.-M.: SALSA - a Sectional Aerosol module for Large Scale Applications. Atmos. Chem. Phys., 8, 2469-2483, doi:10.5194/acp-8-2469-2008, 2008.

[4] Tonttila, J., Maalick, Z., Raatikainen, T., Kokkola, H., Kühn, T., and Romakkaniemi, S.: UCLALES–SALSA v1.0: a large-eddy model with interactive sectional microphysics for aerosol, clouds and precipitation, Geosci. Model Dev., 10, 169-188, doi:10.5194/gmd-10-169-2017, 2017.

Bin microphysics description



Model verification base on the ISDAC campaign

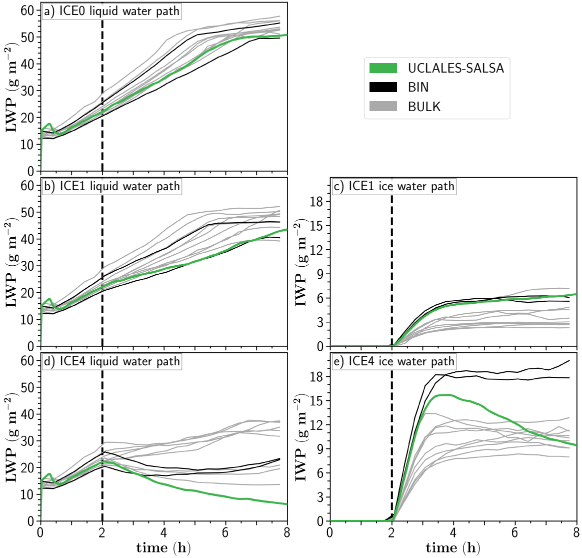
ISDAC Arctic case study (Ovchinnikov et al. 2014.[5])

- Comparisons between LES models of mixed phase cloud simulations
- 11 models
    - 2 models with bin microphysics, 9 models with bulk 2-moment microphysics

[5] Ovchinnikov, M., A.S. Ackerman, A. Avramov, A. Cheng, J. Fan, A.M. Fridlind, S. Ghan, J. Harrington, C. Hoose, A. Korolev, G.M. McFarquhar, H. Morrison, M. Paukert, J. Savre, B.J. Shipway, M.D. Shupe, A. Solomon, K. Sulia: Intercomparison of large-eddy simulations of Arctic mixed-phase clouds: Importance of ice size distribution assumptions. J. Adv. Model. Earth Syst., 6, no. 1, 223-248, doi:10.1002/2013MS000282, 2014.

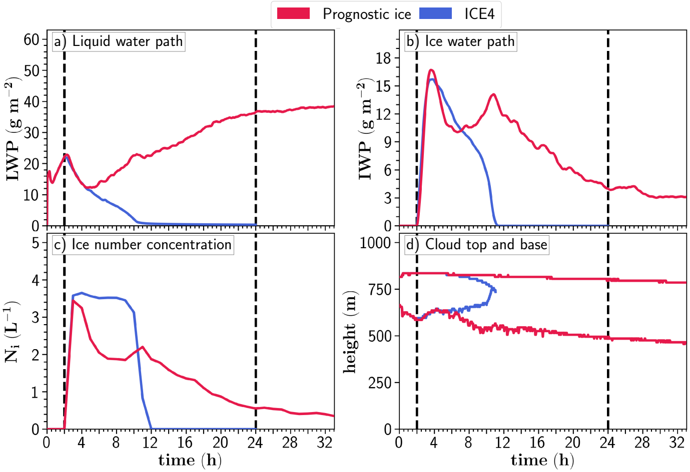
Model intercomparison

We confirmed the accuracy of newly implemented ice microphysics with a comparison to the ISDAC mixed-phase cloud model intercomparison study.



Prognostic ice simulation

To see the difference between fixed and prognostic droplet freezing, we made a prognostic ice simulation that was targeted to have similar IWP during the first 8 hours as in the simulation with ice number concentration of $4\ (L^{-1})$ (ICE4). This ICE4 simulation was selected for comparison because it is close to the tipping point where cloud either stabilises or glaciates.



The simulation demonstrated how larger droplets froze first.

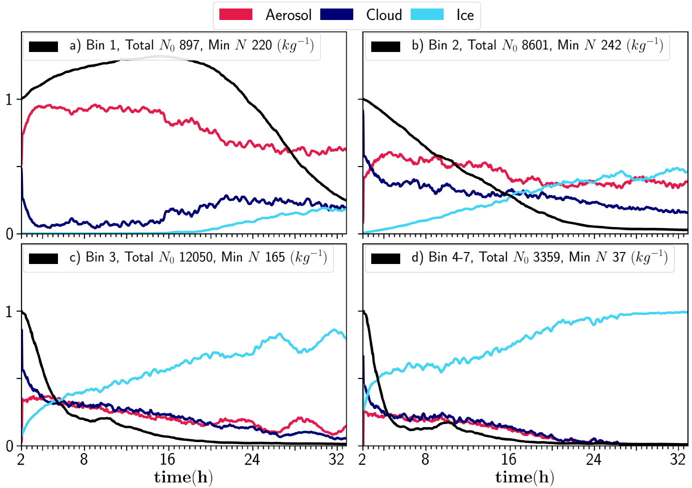


Figure: Relative portions of hydrometeors at each time step in the cloud layer. Cloud layer is defined when both cloud liquid water and ice mixing ratios are over 0.001 $(g\ kg^{-1})$. Black line represents relative change of the total number concentration in each bin.

The model captured the typical layered structure of Arctic mixed-phase clouds: a liquid layer near cloud top and ice within and below the liquid layer. Moreover, the simulation showed realistic freezing rates of droplets within the vertical cloud structure.

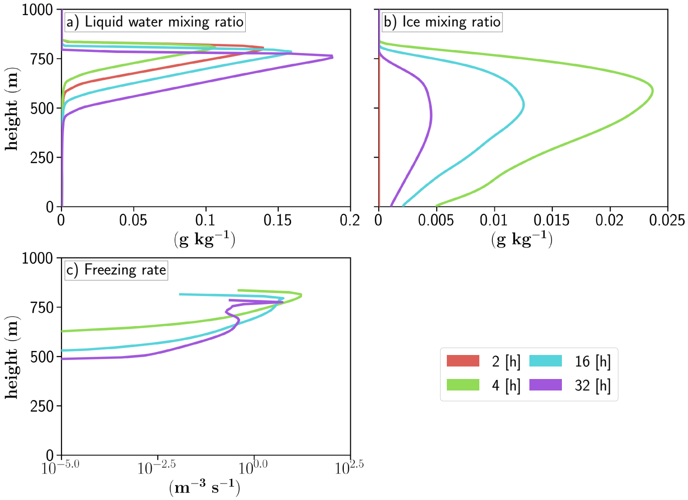


Figure: Vertical profiles of liquid water and ice and freezing rate of droplets (nucleation rate) UCLALES-SALSA simulation with prog-nostic droplet freezing

Conclusions

- New cloud model with explicit ice description (warm cloud microphysics implemented 2017)
- Matches well with other models
- The implemented detailed sectional ice microphysics with prognostic aerosols is essential in reproducing the characteristics of mixed-phase clouds.
- The prognostic simulation showed the importance of the self-adjustment of ice nucleation active particles.
- The manuscript describing this study is under review.[6]

[6] Ahola, J., Korhonen, H., Tonttila, J., Romakkaniemi, S., Kokkola, H., and Raatikainen, T.: Modelling mixed-phase clouds with large-eddy model UCLALES-SALSA, Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2019-1182, in review, 2020.

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