Project: **1430**
Project title: **Ice optical sensitivities of cloud-radiative heating in ICON**
Principal investigator: **Emma Järvinen**
Report period: **2024-07-01 to 2025-06-31**

Nhrs requested	***Nhrs used***	***Work storage***	***Archive***
13545 (granted)	11342	3 Gb	44 Tb

Project Overview

By interacting with radiation, ice clouds determine atmospheric temperature and circulation patterns. Ice clouds scatter shortwave (SW) radiation and absorb-emit longwave (LW) radiation, depending on the optical properties of in-cloud ice crystals. The assumed ice crystal complexity in numerical weather prediction (NWP) simulations impacts the computed radiative fluxes and ice cloud radiative heating rates (CRH). This project evaluated the impacts of increasing ice complexity on CRH profiles with a series of ICON-NWP simulations. Ice optical schemes, such as Yi et al. 2013 and Baran et al. 2016, parameterize ice cloud optical properties by including ensembles of ice crystal habits, surface roughness and hollowness. In contrast, the default Fu 1996-1998 schemes assume only smooth hexagonal crystals. Our analysis has recently expanded to understand the impacts of ice optical properties on simulated precipitation also.

Technical aspects

1. ICON-NWP simulations

An Asian monsoon domain was simulated using ICON v2.6.4 with an equivalent resolution of 2.5 km (Figure 1) over 4 days (5-9 Aug 2017). We performed a series of simulations, using the RRTM radiative transfer scheme for one- and two-moment microphysics. The Fu optical scheme was used as a reference point, relative to the Yi and Baran optical schemes. Relative to earlier simulations in ICON v2.6.1 for the same domain, considerable differences in outgoing longwave radiation (OLR) occurred (Figure 1). Similar differences were found when comparing with CERES satellite data product, specifically over sea. With help from Daniel Rieger and Mareike Burba from the Deutscher Wetterdienst (DWD), we were able to apply the corrected settings and operational setup used in ICON v2.6.4.

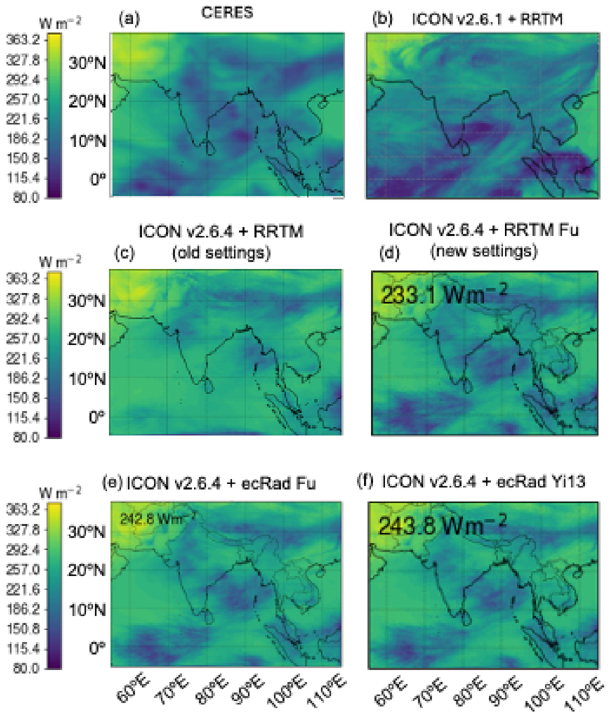

Figure 1. Outgoing longwave radiation (OLR) fields over the simulated domain. CERES SYN1deg-3Hour data product is compared against different model configuration.

From October to December 2024, we used the corrected namelists to run 8 simulations in which we compared the radiative fluxes and heating rates from RRTM to those from the ecRad radiative scheme and across three ice optical schemes (Fu, Yi13, and Baran16) for both one- and two-moment microphysics. Along with multi-day simulations, we again ran all 8 setups but for a shorter duration of 4 hours corresponding to Flight 7 of the StratoClim field campaign on 9 August 2017. We output 2D and 3D fields with 10-minute frequency to compare ice cloud and water vapor profiles with those measured.

Scientific Results

We are in the progress of analysing and writing up the results of our first set of ICON simulations (Sepulveda Araya et al, *in prep*). In general, schemes with greater ice complexity, such as Yi13 and Baran16, lead to weaker net CRH (Figure 2). However, this effect can be modulated by the microphysics: The Baran16 scheme produces the strongest heating in the one-moment setup and the weakest in the two-moment setup. The cause of this modulation is still under study but could be related to the scheme inputs. Both Fu and Yi13 schemes optical properties depend only on ice crystal effective radii, while properties in Baran16 depend on both ice mass mixing ratio and temperature. The ice mass mixing ratio is strongly dependent on the microphysics used. Moreover, Sepulveda Araya et al. 2025[7] show that weaker SW and LW absorption in the Yi13 scheme results in less in-cloud heating and cloud top cooling, as is shown in Figure 2. In contrast, a temperature-dependent scheme, such as Baran16, enhances ice cloud absorption and, hence, CRH (Figure 2a).

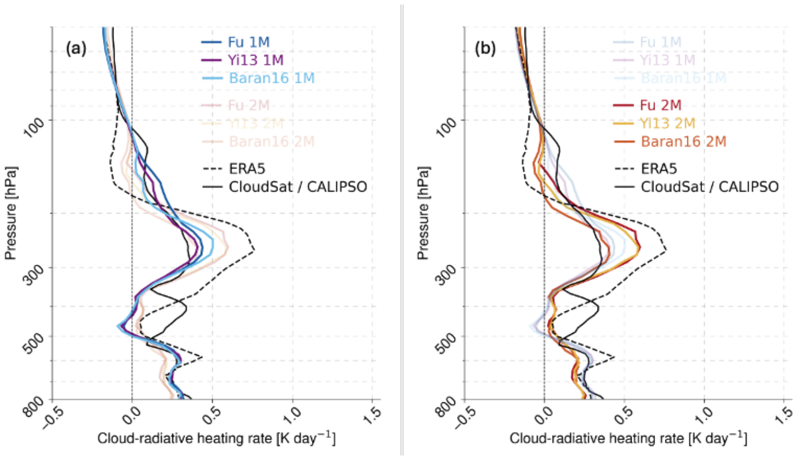

Figure 2. Domain- and daily-averaged net CRH for six of eight simulation. Left and right panel show 1-moment and 2-moment CRH calculations respectively. While Yi13 CRH profile is always slightly weaker than Fu, Baran16 CRH is strongly dependent on microphysical assumptions.

Diurnal cycles of CRH also exhibit interesting dependence on optics (Figure 3). Baran16 shows the biggest difference in CRH relative to Fu. For 2-moment microphysics, Baran16 reduces CRH by ~0.5 K d^{-1} throughout the daily cycle, but for 1-moment microphysics, the opposite is found with stronger heating in Baran16 (Figure 3c). Finally, we are currently studying differences in accumulated precipitation. In the tropics, radiative cooling and condensational heating must balance; as a result, previous climatological studies show that decreasing CRH can enhance precipitation (Haslehnner et al 2024[8], Pendergrass and Hartmann 2014[9]). Baran16 with the weakest CRH values follows this trend: for most ice water path values, this scheme also predicts larger accumulated precipitation. However, the analysis and test of previous hypothesis is work in progress and corresponding result must be analysed carefully.

Most of the preliminary results shown here, were presented and discussed in the Second Symposium on Cloud Physics of the 105th AMS Annual Meeting in January 2025[10] and the 26th ICON/COSMO/CLM/ART User Seminar ICCARUS in March 2025, including the ICCARUS WG meeting on "Radiation, Clouds, Aerosols and Chemistry". They will also be disseminated in an oral presentation at the Ice at the Microscale conference in July 2025. A first idealized study using the various optical schemes in ecRad has recently been accepted in *Atmospheric Chemistry & Physics* (Sepúlveda Araya et al., 2025[7]).

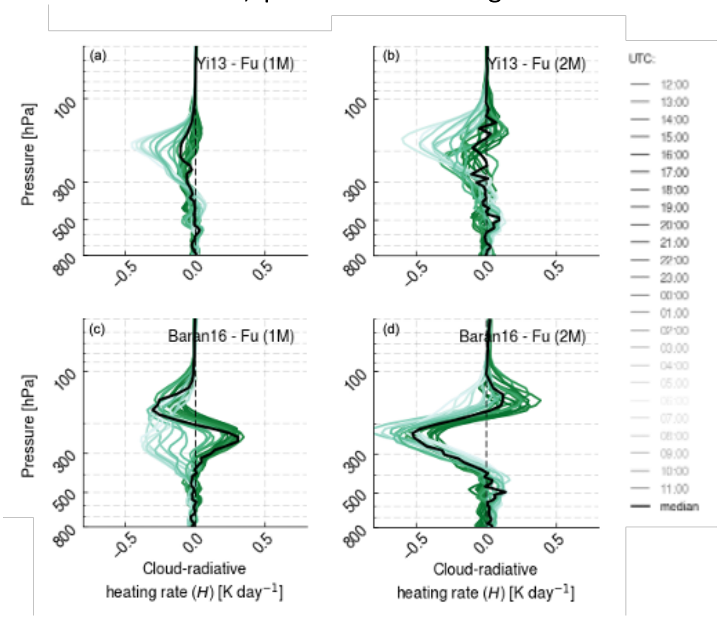

Figure 3. Diurnal cycle of interscheme differences in CRH, Yi13-Fu (top) and Baran16-Fu (bottom). Left and right columns show 1- and 2-moment output, respectively. Solid line transparency is proportional to time of day with darker colours for nighttime.

References

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