Project: **1542**

Project title: **ICE2DYN: From Ice Microphysics to Midlatitude Dynamics and Predictability**

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Report period: **2026-01-01 to 2026-10-31**

The ICE2DYN project aims to investigate the impact of ice microphysical processes and their uncertainties on the dynamics of extratropical cyclones with implications for the midlatitude predictability. In 2026, we focused on evaluating the model parameterization of secondary ice production (SIP) and its impact on the dynamics of extratropical cyclones (see our proposal for 2026). To this end, we performed ICON high-resolution simulations of two cyclones observed during the NAWDEX field campaign. Through two parallel subprojects (one of which was designed for a master's thesis), we investigated the impact of SIP on cloud microphysics and the dynamics of the cyclones. The project's progress to date is summarized below.

0- Summary of used resources until October 2026

- Node hours: 5058 out of 5740 (expired Node hours: 1147)
- Work: 70 TiB out of 84 Tib allocated
- Arch: 0 Tib out of 98 TiB allocated

We successfully used the allocated resources to achieve our goals this year. We plan to use the remaining resources, especially archival space, to store our simulations. Initially, we planned to run additional simulations to examine how uncertainties in the ice optical parameterization combined with SIP affect cyclones. However, we needed to use more of the allocated resources for additional test simulations to develop the model. Therefore, in addition to our planned simulations for the NAWDIC campaign next year, we plan to perform the aforementioned simulations in 2027 (see our proposal for 2027).

1- The impact of SIP on the microphysics of clouds during NAWDEX

We performed hindcast simulations of Cyclones Vladiana and Karl during NAWDEX IOPs 3 and 4, when the FAAM research aircraft equipped with the Cloud Imaging Probes (CIP) measured the number concentration of frozen hydrometeors within the cyclone clouds. Figure 1 shows that SIP increases the frozen number concentration by an order of magnitude, and that the ICON simulations with SIP better represent the observed frozen number concentration and frozen water content.

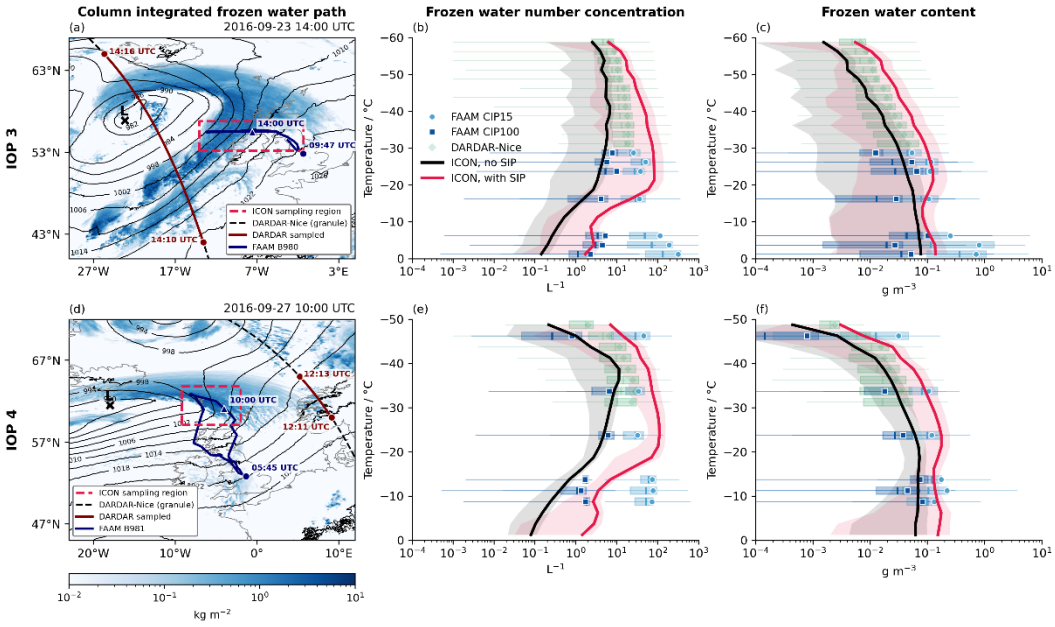


Figure1. Cyclone Vladiana (top) and Cyclone Karl (bottom). (a, d) Frozen water path (shading) and mean sea level pressure (contours) with the FAAM track (navy), the DARDAR-Nice granule (dark red) and the ICON sampling region (red box). (b, e) Number concentration of frozen hydrometeors larger than 100 µm and (c, f) frozen water content against temperature, from FAAM and DARDAR-Nice (box plots) and from ICON without SIP (black) and with SIP (red).

To evaluate the impact of SIP on the microphysics of clouds within cyclones, we examined changes in cloud condensate amount, microphysical process rates, and precipitation rates. Our results show that SIP produces ice at a rate that is three to four orders of magnitude faster than primary nucleation. Enhanced ice number particles result in about 30 percent increase in column condensate, primarily due to enhanced snow and

graupel formation. These microphysical changes can alter the latent heating within the ascending regions of the cyclone, which affects the dynamics of the cyclones. Although enhanced snow and graupel promote cold rain processes, the precipitation rate increases slightly. We are currently preparing a manuscript based on these results for submission.

2- Lagrangian analysis of SIP impact on the dynamics of two extratropical cyclones

To better understand the impact of SIP on the dynamics of cyclones and circulation near the tropopause, we examined changes in the warm conveyor belts (WCBs) of cyclones. Using LAGRANTO, we identified WCBs as air parcels that ascended by at least 600 hPa within 48 hours from the warm sector of the cyclones. Then, we traced various meteorological parameters, as well as diabatic heating and microphysical process rates, along the WCB trajectories.

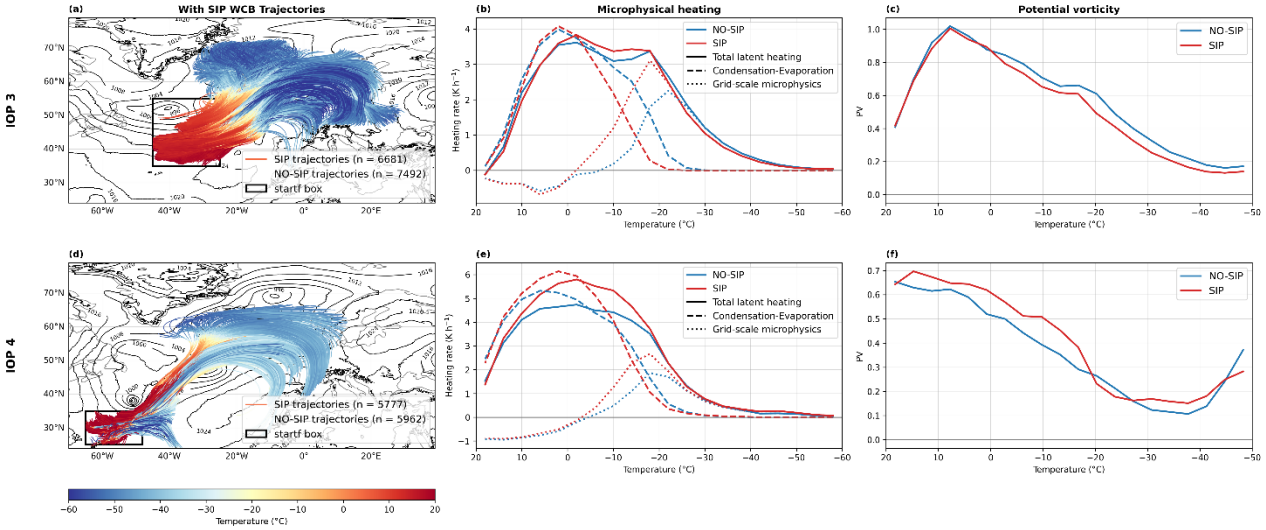


Figure 2. *Warm conveyor belt (WCB) analysis for Cyclone Vladiana (IOP 3, top row) and Cyclone Karl (IOP 4, bottom row). (a, d) WCB trajectories from the SIP simulation, colored by temperature. The black box marks the starting region of the trajectories, and black contours show mean sea level pressure at the starting time. (b, e) Mean latent heating rates along the WCB trajectories as a function of temperature. (c, f) Mean potential vorticity along the WCB trajectories as a function of temperature. Red and blue lines show simulations with and without SIP, respectively.*

Figure 2 a and d shows that SIP weakens the WCBs of both cyclones, as the number of WCB trajectories decreases by about 11 percent for Vladiana and 3 percent for Karl. This is consistent with the weaker intensity of both cyclones in terms of cyclone central pressure (not shown).

Despite the weaker WCBs, latent heating along the trajectories is higher with SIP in the mixed-phase regime for both cyclones, but for different reasons (Fig. 2b, e). For Vladiana, SIP shifts heating from condensation to ice processes: condensation decreases below about −5 °C, while grid-scale microphysical heating starts at warmer temperatures and peaks at 3.1 K h^{-1} compared with 2.3 K h^{-1} without SIP. This suggests a more efficient Wegener–Bergeron–Findeisen process, in which the additional ice particles produced by SIP grow by vapor deposition at the expense of liquid water, reducing condensation. For Karl, the increase is larger (up to about 1 K h^{-1}) and comes mainly from stronger condensation above about −10 °C, which may be related to its tropical origin. To understand why the latent heating increases while the cyclones become weaker, we are currently analyzing all diabatic and microphysical process rates along the WCB trajectories.

Finally, PV along the WCB trajectories (Fig. 2c, f) is lower with SIP above the freezing level for Vladiana, while for Karl it is higher with SIP between 15 and −20 °C, consistent with its stronger low-level heating. Since PV changes in the lower troposphere reflect changes in low-level cyclonic vorticity, and those in the upper troposphere affect the WCB outflow near the tropopause, these results suggest that SIP mainly modifies the upper-level outflow of Vladiana and the low-level vorticity of Karl.

3- The impact of SIP on cloud radiative effects

To evaluate the impact of SIP on cloud radiative effects (CREs), we performed offline radiative transfer calculations using ICON simulation output. Our goal was to assess the impact of SIP-induced changes in the number concentration of cloud hydrometeors by including them in the calculation of effective radii. These radii are typically calculated based solely on mass content. Our results show that considering number concentration substantially enhances CRE at the top of the atmosphere and cloud radiative heating for WCBs of cyclones. These radiative changes can affect cloud microphysics and, ultimately, the dynamics of the cyclones. We are continuing our analysis to compare our offline calculations with observations.