Evaluation of NWP Simulations of Cold-Season Mixed-Phase Clouds Using EarthCARE and ECALOT Observations

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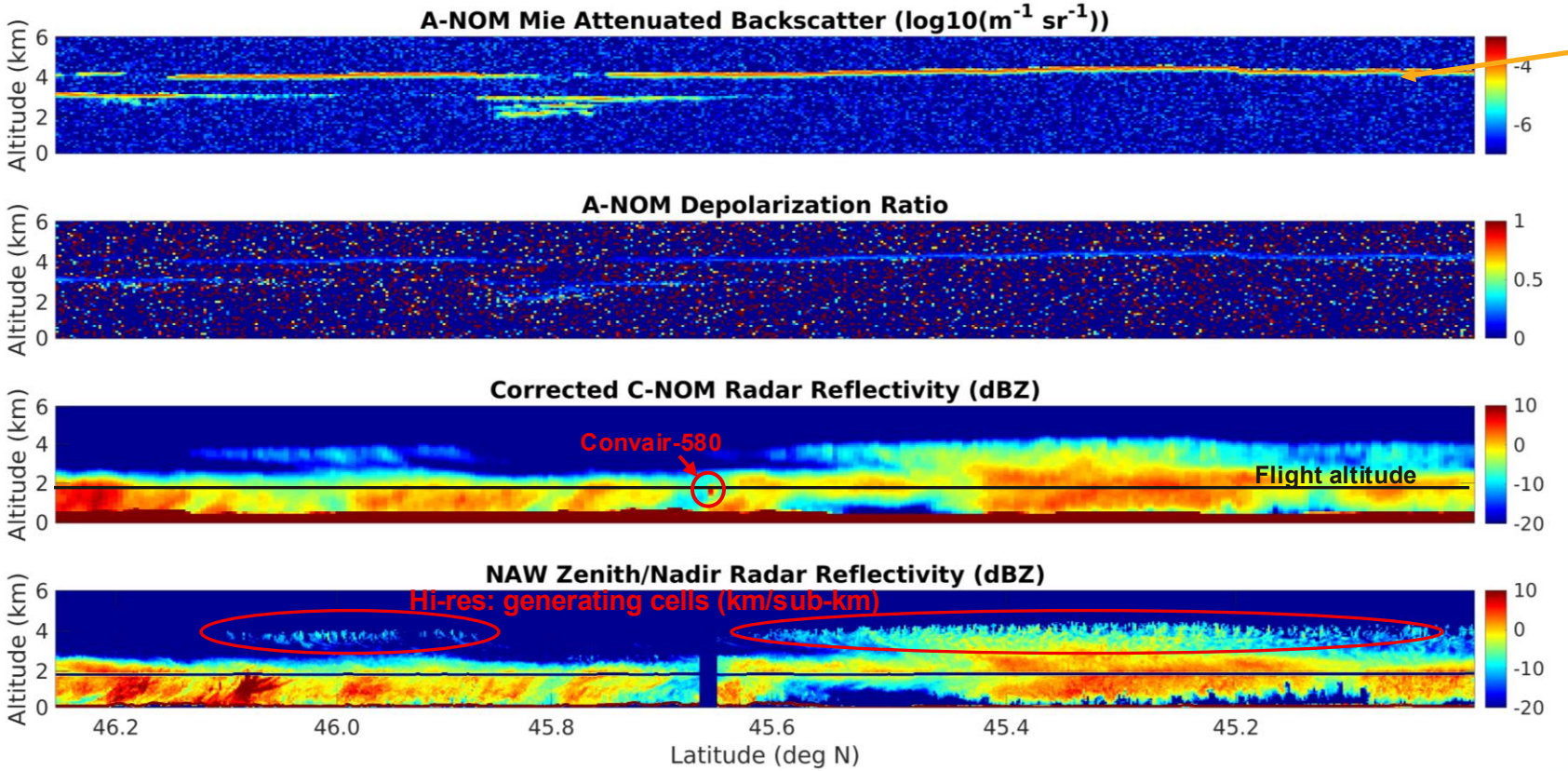
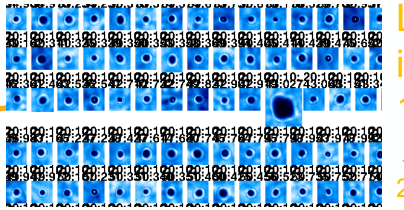
1. Background & Objectives

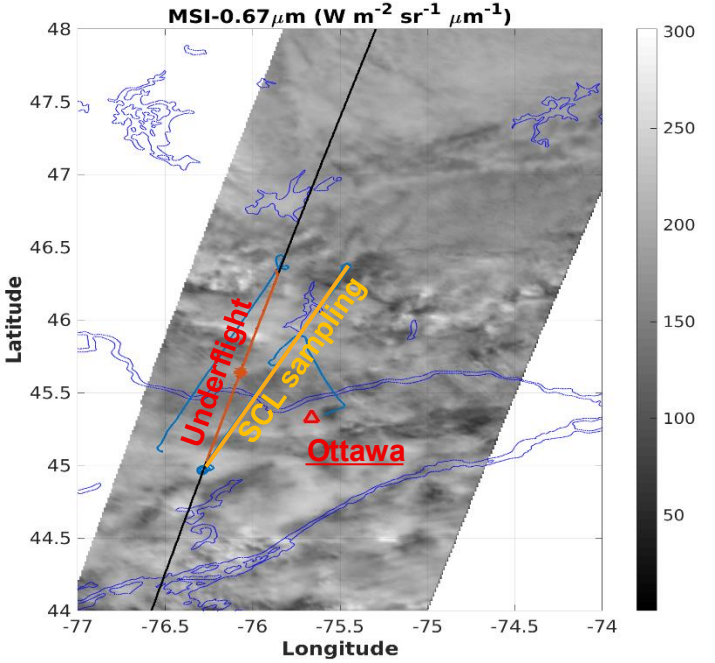
EarthCARE Frame 04681D (~19:30 UTC) & ECALOT Flight 7 (2025-03-25)





Liquid droplets in CPI image 19:20:11 UTC

200 µm



- 2025-03-25: supercooled liquid layer (SCL) near cloud top (good agreement between EarthCARE & Convair-580)
- Operational NWP at 2.5 km (climatology aerosols & lower ver. res): missing the SCL layer near cloud top
- Previous findings: formation of SCL influenced by ver. res. & ice nucleation → **Other factors? Any solutions?**

2. Model/Experiment Configuration

Global Environmental Multi-scale Model (GEM)

P3 microphysical scheme (Morrison, H. and Milbrandt, 2015)

- Triple-moment, free-ice categories (3), liquid fraction (Cholette et al., 2019, 2024)

Model resolution

- Vertical (alt ≈ 4 km): ~100 m/120 levels vs. ~50 m/174 levels (operational version: ~300 m)
- Horizontal: 2.5 km vs. 1.0 km

Aerosols (CCNs & INPs):

- Constant climatology value vs. prognostic aerosols: Cholette et al. (2026, in prep.)

Secondary ice production (SIP) (6+ known processes, still poorly understood today):

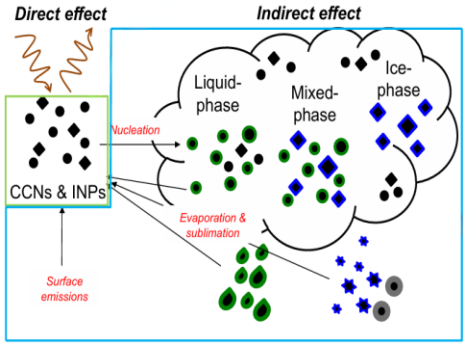
- Rime splintering/Hallett-Mossop (HM): Hallett and Mossop (1974)
- Fragmentation of freezing drops (FFD): Lawson et al. (2015) + Lachapelle et al. (2025)
- Ice collision breakup (CB): Phillips et al. (2017) + imposed V_{rel} threshold (1.5 m s^{-1})

Model setting & combinations:

Hor. Res	Ver. Res. (~ 4 km)	Aerosols	SIP
2.5 km	100 m	Climatology (Ac)	No SIP
1.0 km	50 m	Prognostic (Ap)	SIP

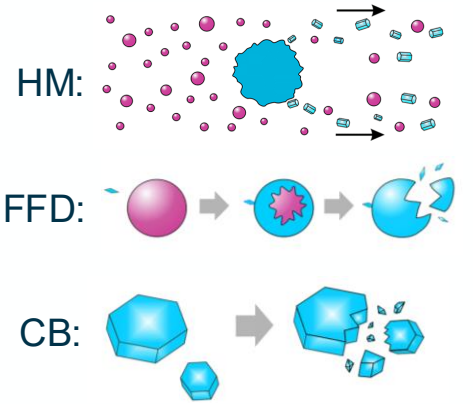
Experiment name example: Ap-SIP-1p0km-50m, etc.

Prognostic aerosol in P3:



Thompson & Eidhammer, 2014
Cholette et al., 2026 (in prep.)

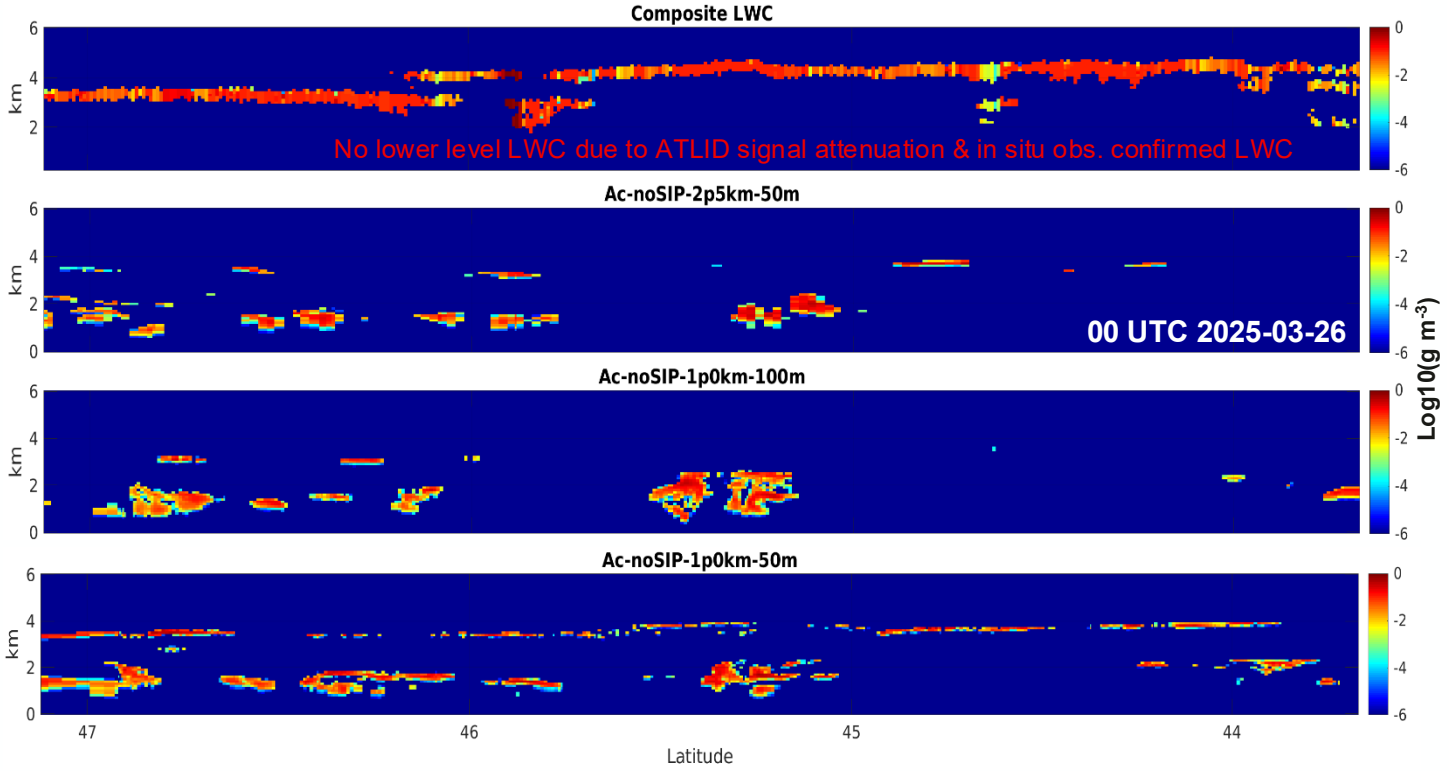
Implemented SIP processes:



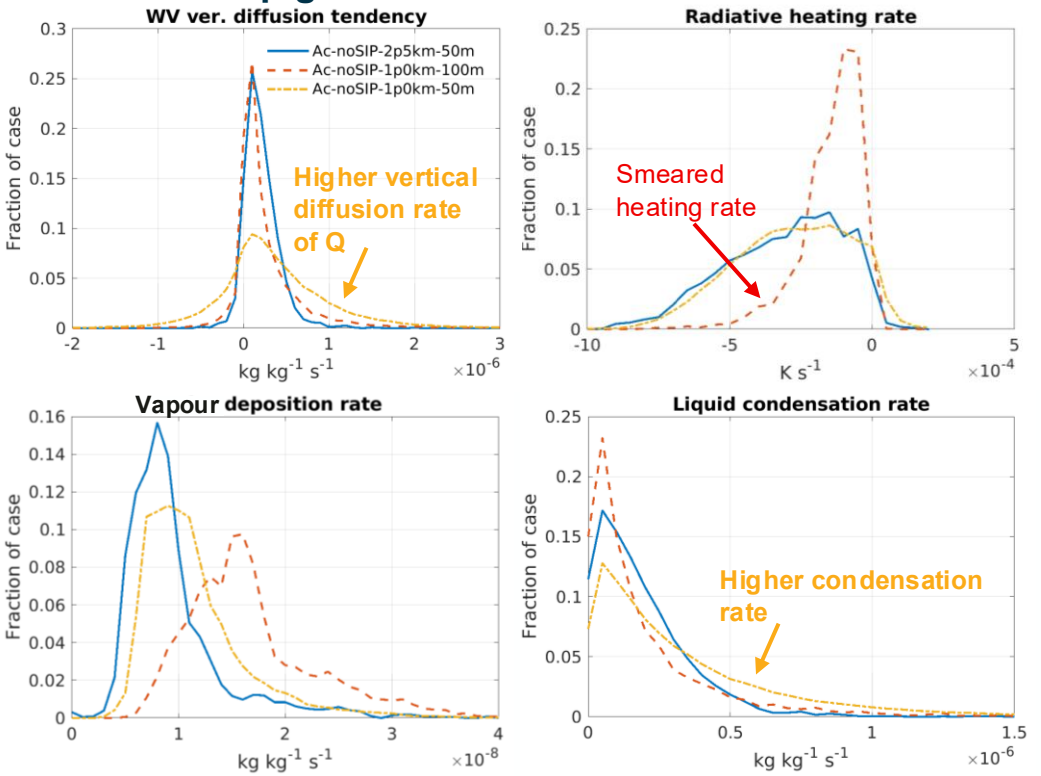
Korolev and Leisner (2020)

3. Model Resolutions

➢ Horizontal & Vertical Model Resolutions (no prognostic aerosols & no SIP)



Cloud top grid boxes with condensation rate > 0

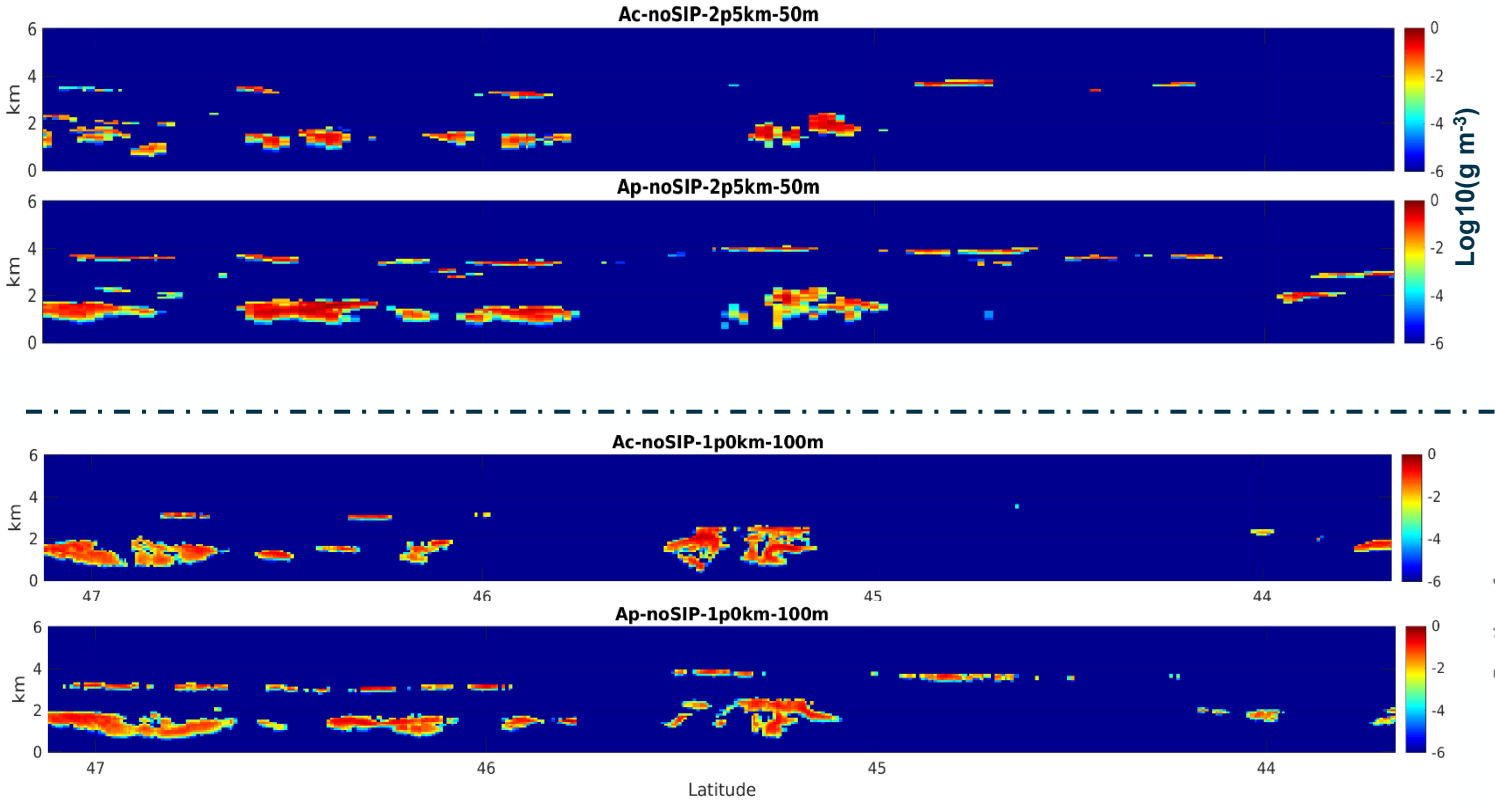


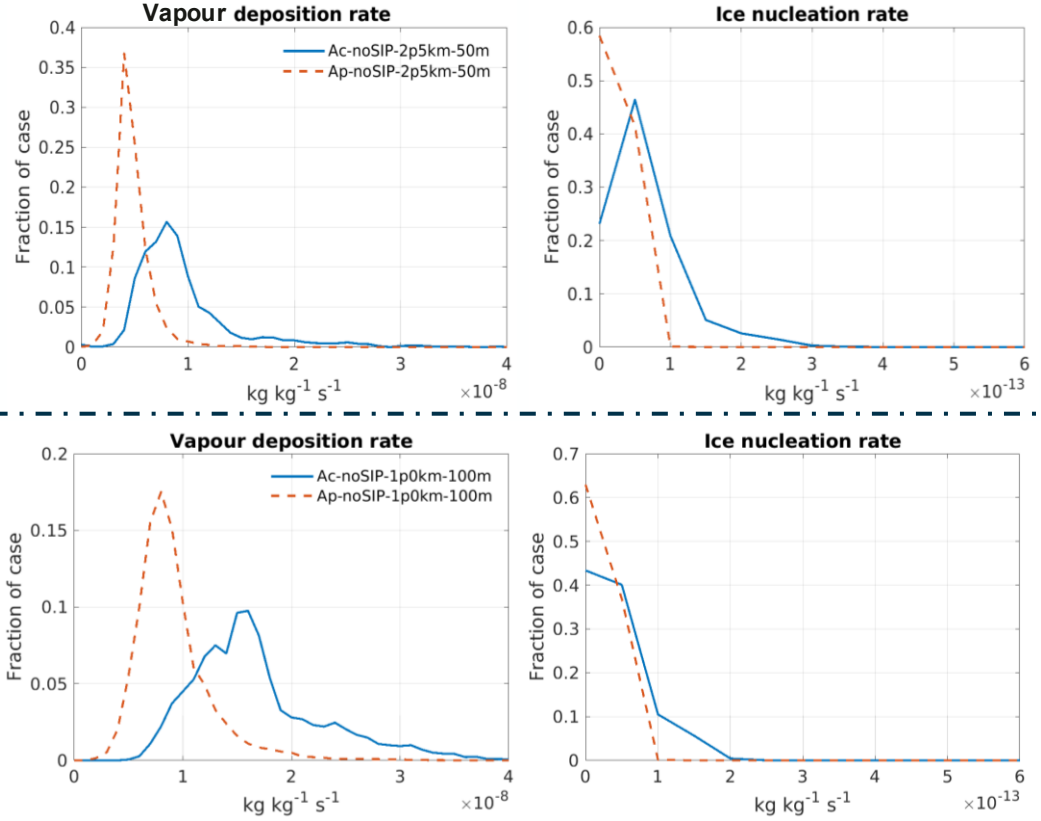
- 2.5km/50m → 1.0km/50m: vertical diffusion of Q↑ → reaching supersaturation/w → form liquid cloud & positive radiative cooling feed back!
  - **Vertical diffusion directly linked to cloud top generating cells which were better simulated with 1.0km/50m resolution**
- 1.0 km/100m → 1.0 km/50m: 'non-smeared' heating rate → T↓ & maintain supersaturation/w → persistent liquid layer

➢ Both horizontal & vertical resolutions are critical, optimal: 1 km / 50 m

3. Prognostic Aerosols (1)

➢ Impacting Heterogeneous Ice Nucleation & Vapour Deposition → Sink Terms for SCL

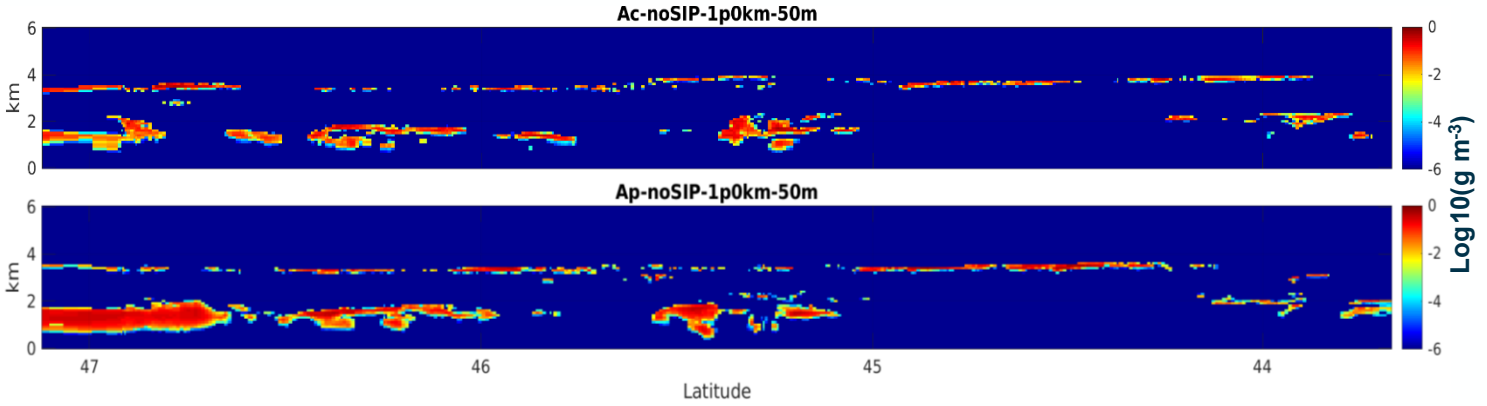


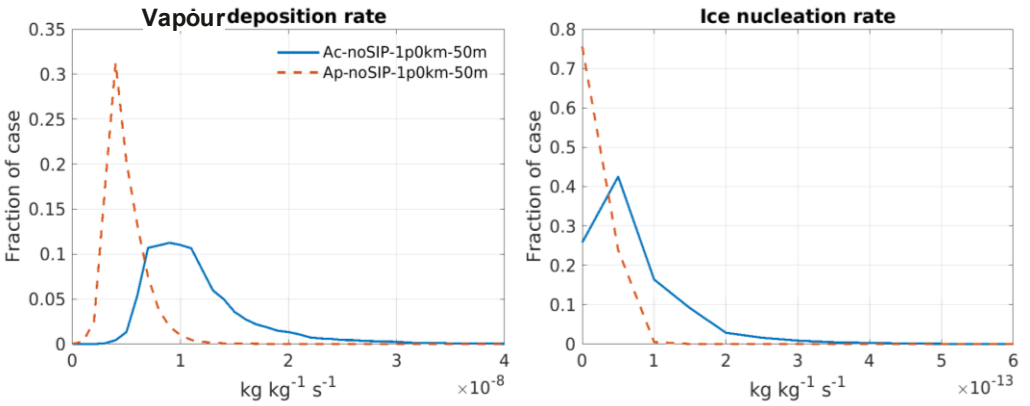


- Prognostic aerosols in P3 → lower (ice-friendly) aerosol amount due to removal → INPs↓ & ice nucleation↓ & N_i↓ & vapour deposition rate↓
- Significant impacts on both 2.5km/50m (× 2.5 in a 400 × 400 km² area) & 1.0km/100m (× 3.6) cases

3. Prognostic Aerosols (2)

➢ Impacting Heterogeneous Ice Nucleation & Vapour Deposition → Sink Terms for SCL

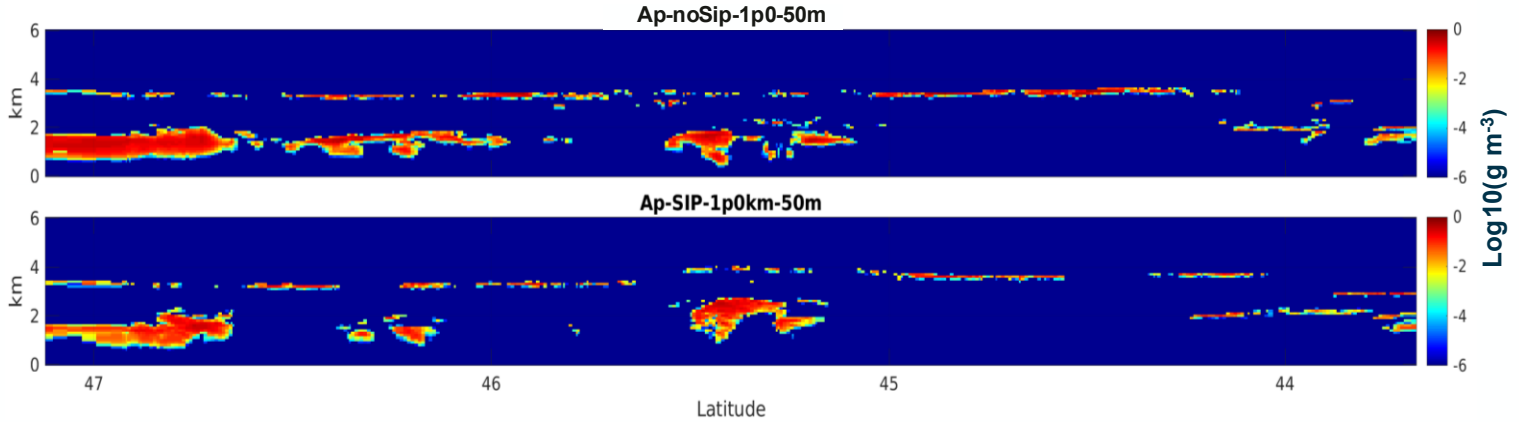


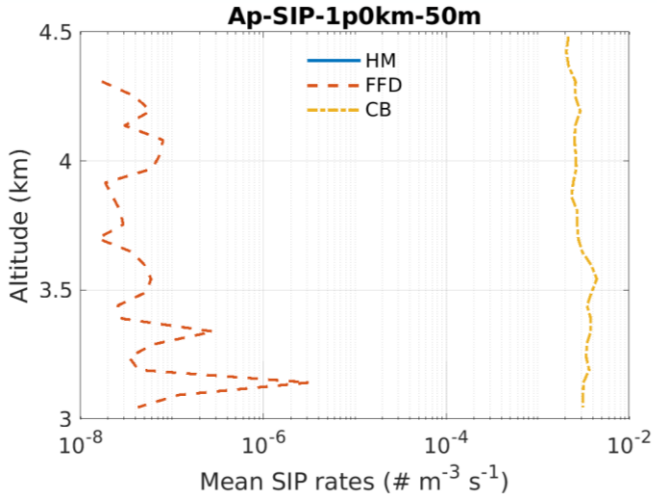


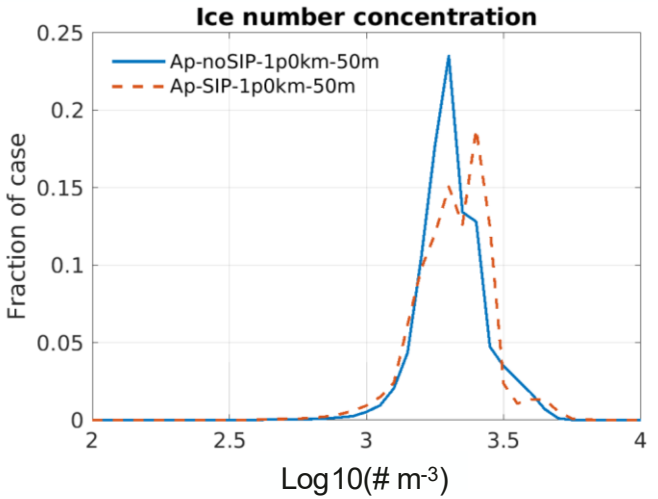
- Prognostic aerosols in P3 → lower (ice-friendly) aerosol amount due to removal → INPs↓ & ice nucleation↓ & N_i↓ & vapour deposition rate↓
- Significant impacts on 2.5km/50m & 1.0km/100m cases
- **The impacts on 1.0km/50m is positive but moderate (+23%)**
- For 2.5km/50m & 1.0km/100m: prognostic aerosols might compensate for the lack of physical accuracy due to coarser h/v model resolution

5. Secondary Ice Production

➢ SIP enhances N_i → WBF↑ & Collection Rate of SCL by Ice↑ → Sink terms for SCL







- Adding SIP processes slightly depletes SCL
- N_i↑ → more SCL collected by ice
- CB dominant, FFD slow (no large liquid drops), no HM (out of T range, -3 to -8 ° C)
- Similar for 2.5km/50m & 1.0km/100m cases (moderate depletion)
- Results are very sensitive to how CB is parameterized. Currently following Phillips et al., 2017 with a threshold of V_{rel} > 1.5 m s^{-1}
- Delicate test case for SIP parameterizations!

7. Conclusion and Perspectives

- EarthCARE and ECALOT obs. provided complementary constrains for characterizing *Ns* clouds with SCL
- Higher horizontal resolution (1 km) better simulates cloud top structure → better simulation of SCL
- Higher vertical resolution (50 m) better simulates radiative heating rate profile → better simulation of SCL
- Prognostic aerosols implementation → lower ice-friendly aerosols → less ice nucleation → protecting SCL
- SIP (CB) enhances N_i → enhances collection of SCL by ice → depletion of SCL

- Future work:
  - Radiative closure using GEM simulated clouds:
    - Comparing with BMA-FLX & ACM-RT results (TOA level)
    - Comparing airborne FIRR-2 (Far-Infrared Radiometer) measurements for infrared bands (preliminary results: Raphaël Peroni, Zen Mariani, et al., P077) (aircraft level)
  - Further investigations on SIP parameterizations (largely uncertain and need lab works!) & unrecognized SIP processes (discovered during ARCSIX & PONEX), and their impacts on SCL & radiation