EGU General Assembly 2023 | 23–28 April 2023 | AS1.10 Mixed-phase and ice cloud observations and modelling

Unraveling secondary ice production in winter orographic clouds through a synergy of in-situ observations, remote sensing and modeling

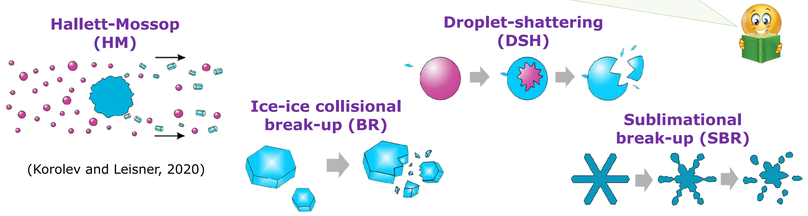
Paraskevi Georgakaki[1], Anne-Claire Billault-Roux[2], Romanos Foskinis[3,4,5], Kunfeng Gao[1], Eliot Perrin[1], Georgia Sotiropoulou[1,5], Franziska Vogel[6], Maria Gini[4], Konstantinos Eleftheriadis[4], Ottmar Moehler[6], Satoshi Takahama[1], Alexis Berne[2], and Athanasios Nenes[1,5]

1 Laboratory of Atmospheric Processes and their Impacts (LAPI), EPFL, Lausanne, Switzerland, 2 Environmental Remote Sensing Laboratory (LTE), EPFL, Lausanne, Switzerland, 3 Laser Remote Sensing Unit (LRSU), National Technical University of Athens, Zografou, Greece, 4 Center for Studies of Air Quality and Climate Change (C-STACC), FORTH, Patras, Greece, 5 ERL, Institute of Nuclear and Radiological Sciences and Technology, Energy and Safety, National Centre of Scientific Research "Demokritos", Ag. Paraskevi, Greece, 6 Institute of Meteorology and Climate Research, Karlsruhe Institute of Technology, Karlsruhe, Germany

paraskevi.georgakaki@epfl.ch, athanasios.nenes@epfl.ch

How can secondary ice production (SIP) affect orographic clouds

- ✓ SIP can be an important source of ice particles in orographic mixed-phase clouds (MPCs), resulting in ice crystal number concentrations (ICNCs) that exceed the number of ice nucleating particles (INPs) in the surrounding environment by several orders of magnitude
- ✓ Changes in the ice- and liquid-phase partitioning in MPCs can enhance or suppress orographic precipitation, which remains a challenge to accurately represent in models



(Korolev and Leisner, 2020)

Did you find an interesting event to study

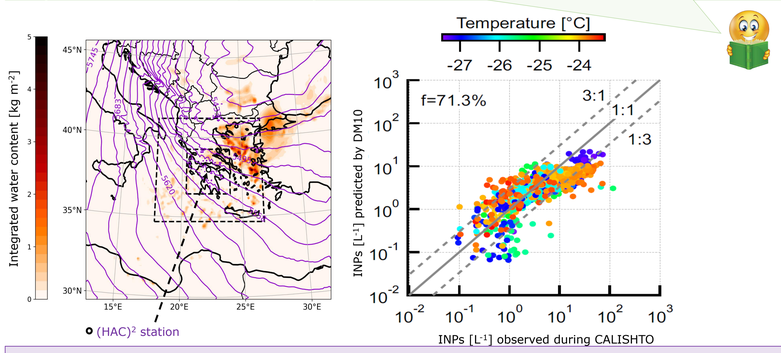
On December 18, 2021, a low-pressure system named "**Carmel**" caused an intense snowfall event at Mount Helmos in Peloponnese, Greece, which was recorded during the **CALISHTO** (Cloud-AerosoL InteractionS in the Helmos background TropOsphere) campaign. From Fall 2021 to Spring 2022, the campaign was conducted with the aim of studying aerosol-cloud interactions in warm and MPCs. In this study we used:

- ✓ Cloud in-situ and INP measurements performed by a **PVM100** cloud probe and the Portable Ice Nucleation Experiment (**PINE**) instrument, respectively, at the mountaintop Helmos Hellenic Atmospheric Aerosol and Climate Change **(HAC)²** station
- ✓ Radar equivalent reflectivity factor and mean Doppler velocity measured by **WProf** – a vertically-pointing W-band (94 GHz) Doppler cloud radar on the leeside of (HAC)²

Which tools did you use to study the storm Carmel

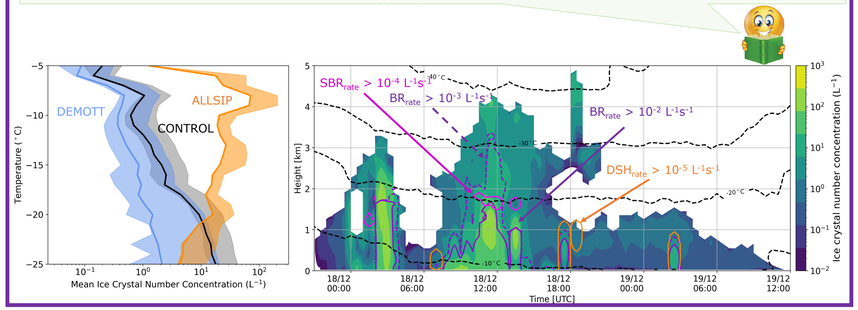
We use the mesoscale Weather Research and Forecasting (**WRF**) model, with three domains of horizontal resolutions of 12, 3, and 1 km, respectively. To quantify the effect of SIP we perform 3 sensitivity simulations:

- ✓ **CONTROL:** No SIP processes are accounted for, while primary ice production (PIP) follows the simplified temperature dependent relationships included in the default version of WRF
- ✓ **DEMOTT:** The PIP schemes are replaced by DeMott et al. (2010; DM10) constrained by temperature and the number concentration of particles > 0.5 μm aerodynamic diameter measured at (HAC)²
- ✓ **ALLSIP:** PIP follows DM10, with additional descriptions of SIP through HM, BR (Phillips et al., 2017; Sotiropoulou et al., 2021), DSH (Phillips et al., 2018; Georgakaki et al., 2022) and SBR (Deshmuch et al., 2022)



Did SIP contribute to the simulated ICNCs during this storm

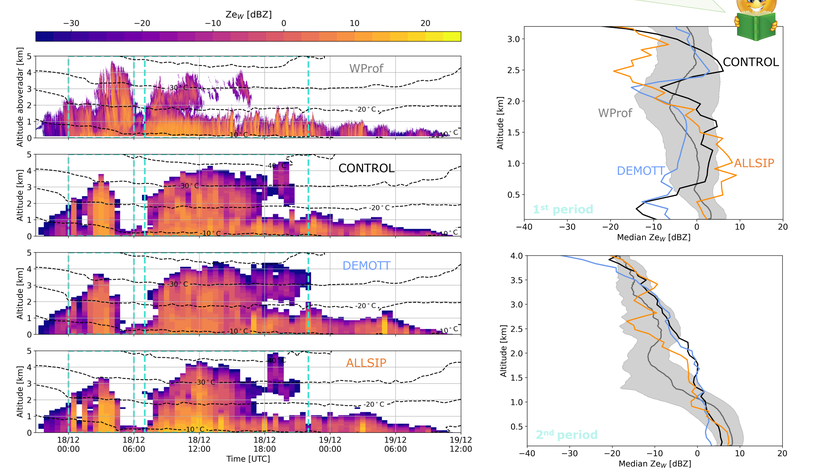
- ✓ The ALLSIP simulation predicts up to **2 orders of magnitude** enhanced ICNCs compared to CONTROL and DEMOTT, especially at temperatures **> -15˚C**
- ✓ SIP is most pronounced under the "**seeder-feeder**" configuration, where large precipitating ice particles from high-level synoptic clouds fall into low-level orographic clouds



Is there a way to compare your simulations against the radar observations

Sure! Coupling WRF with the Cloud Resolving Model Radar SIMulator (**CR-SIM**; Oue et al., 2020) allows us to emulate radar observables, such as the equivalent radar reflectivity (Ze_w), and compare them directly against the WProf measurements. Below we can see:

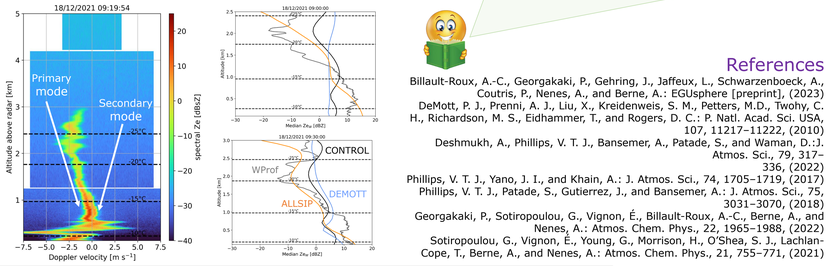
- ✓ Increased Ze_w produced by ALLSIP at heights below 1 km → enhanced orographic precipitation
- ✓ At higher altitudes ALLSIP predicts decreased Ze_w due to a shift in the size distribution of ice particles towards smaller sizes



Are there any SIP signatures in the radar dataset

- ✓ The radar signatures indicate SIP processes (Billault-Roux et al., 2023) when ALLSIP predicts it to happen → precipitation predictions are improved for the right reason

Vertical distribution of INCs is distinctly different between simulations with primary ice only and with SIP. This is a profoundly important reason to include SIP processes for improved orographic precipitation in models



References

Billault-Roux, A.-C., Georgakaki, P., Gehring, J., Jaffeux, L., Schwarzenboeck, A., Coutris, P., Nenes, A., and Berne, A.: EGUsphere [preprint], (2023)

DeMott, P. J., Prenni, A. J., Liu, X., Kreidenweis, S. M., Petters, M.D., Twohy, C. H., Richardson, M. S., Eidhammer, T., and Rogers, D. C.: P. Natl. Acad. Sci. USA, 107, 11217–11222, (2010)

Deshmukh, A., Phillips, V. T. J., Bansemer, A., Patade, S., and Waman, D. J. Atmos. Sci., 79, 317–336, (2022)

Phillips, V. T. J., Yano, J. I., and Khain, A.: J. Atmos. Sci., 74, 1705–1719, (2017)

Phillips, V. T. J., Patade, S., Gutierrez, J., and Bansemer, A.: J. Atmos. Sci., 75, 3031–3070, (2018)

Georgakaki, P., Sotiropoulou, G., Vignon, É., Billault-Roux, A.-C., Berne, A., and Nenes, A.: Atmos. Chem. Phys., 22, 1965–1988, (2022)

Sotiropoulou, G., Vignon, É., Young, G., Morrison, H., O'Shea, S. J., Lachlan-Cope, T., Berne, A., and Nenes, A.: Atmos. Chem. Phys., 21, 755–771, (2021)

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