EPFL

Aerosol-cloud-climate interactions research

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FORTH C-STACC Center for the Study of Air Quality & Climate Change

CleanCloud

FORCeS

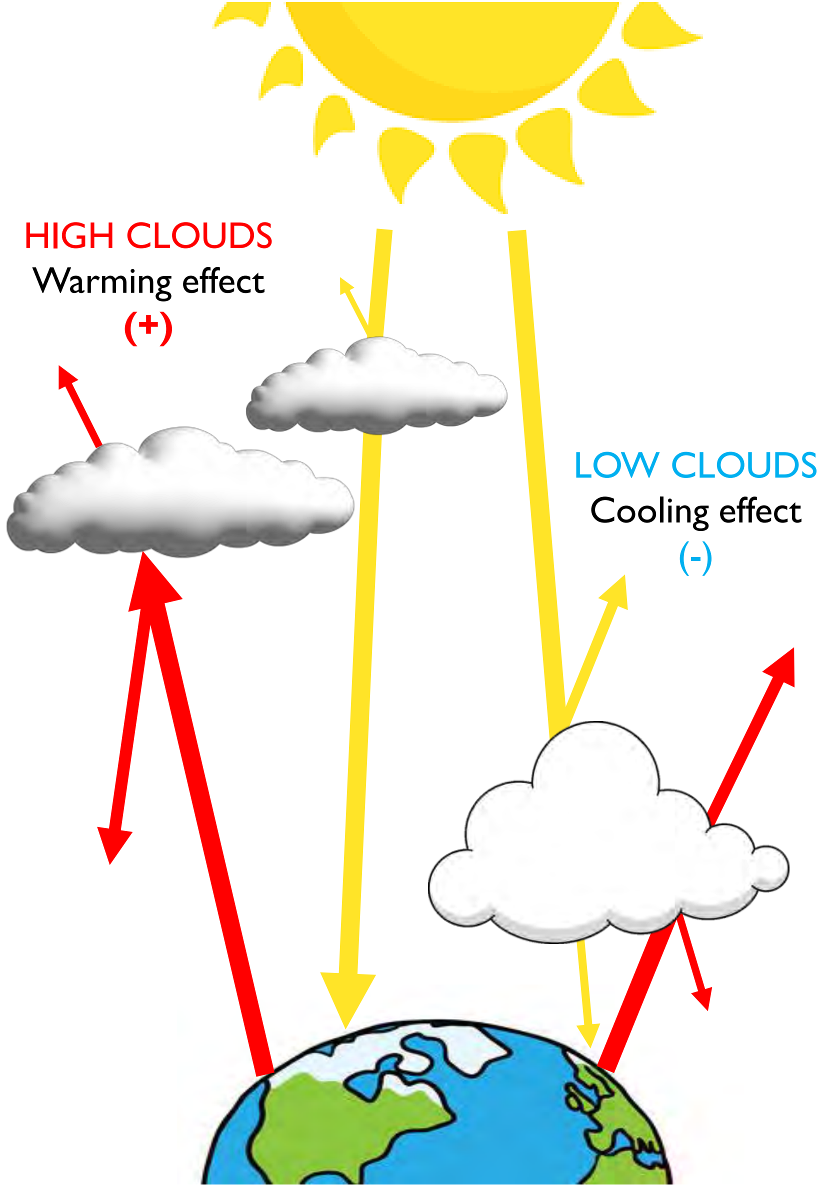
erc European Research Council Established by the European Commission

PyroTRACH

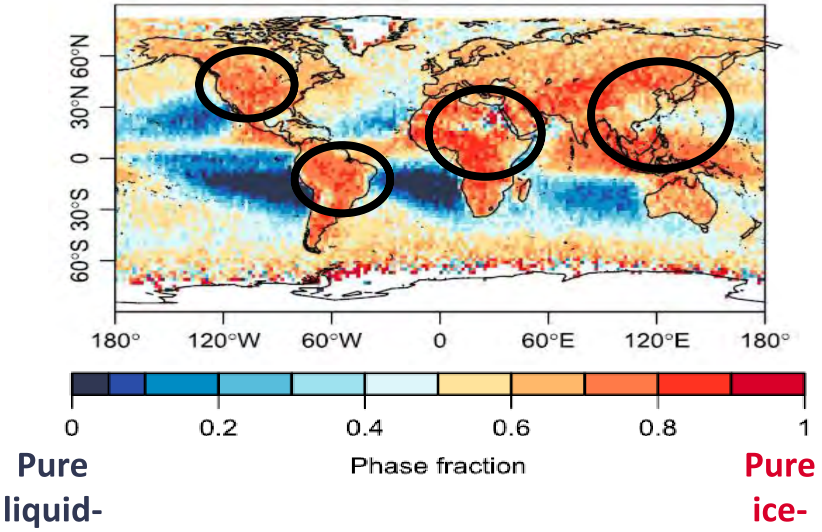
EPFL Symposium: Research and Sustainability

May 14, 2024

Clouds in the climate system

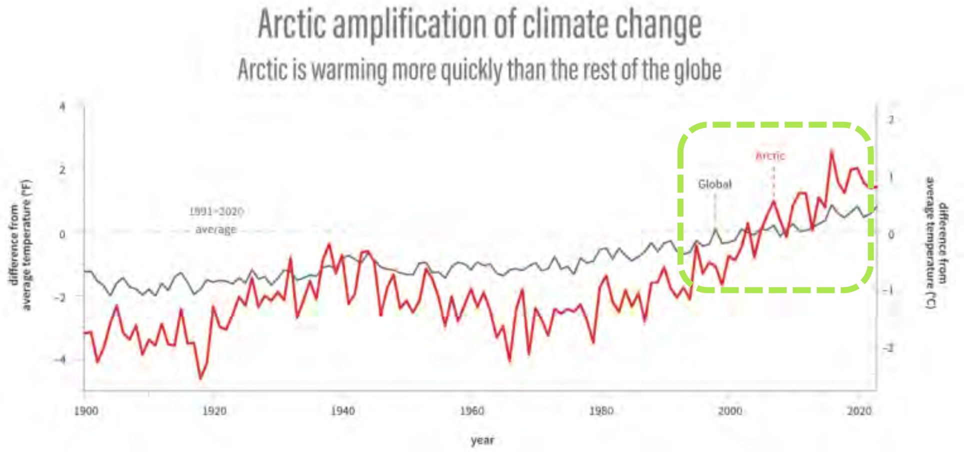


… and the importance of the liquid/ice phase



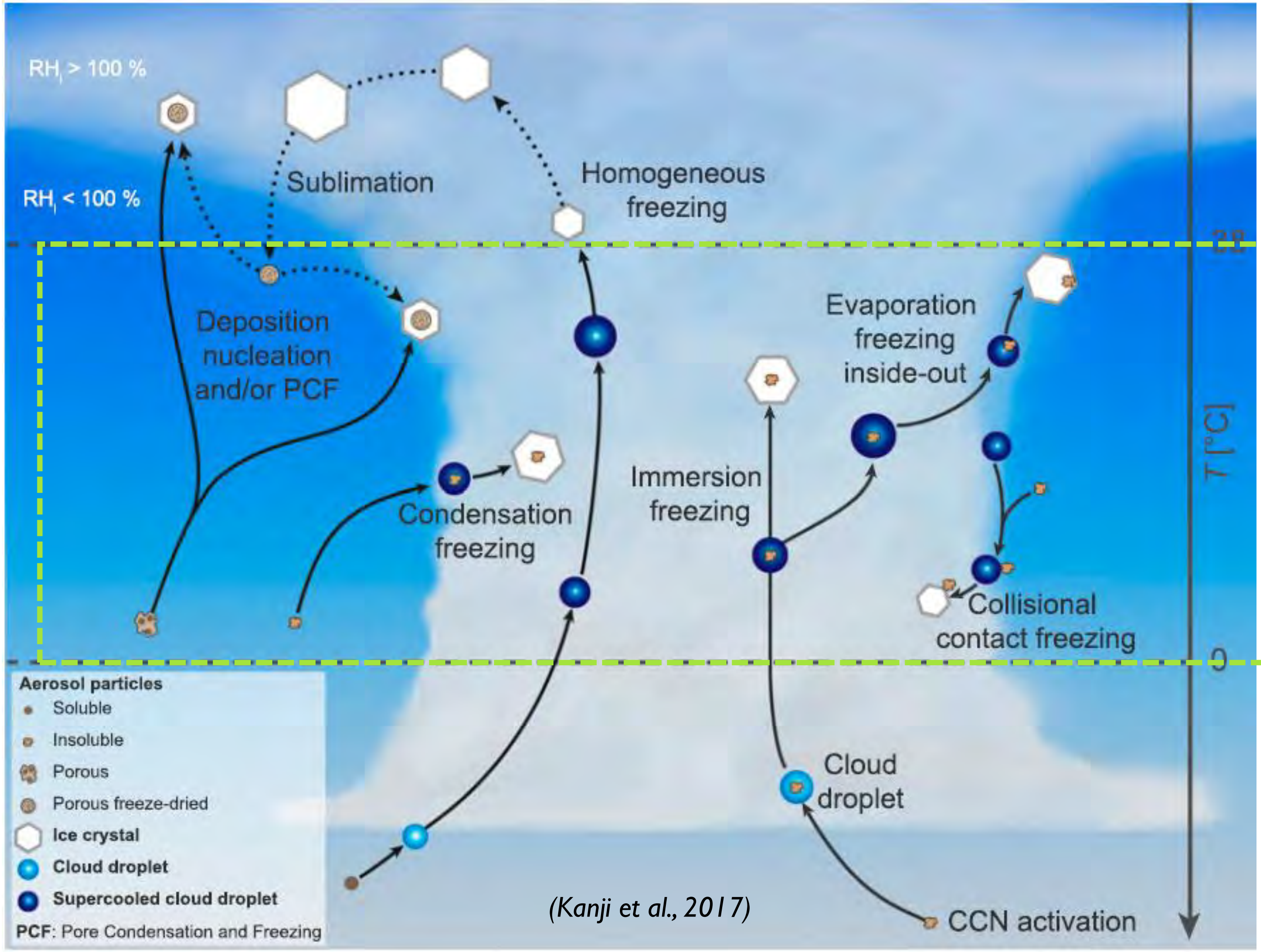
- ✓ 30-50% of precipitation in the mid-latitudes occurs from the ice phase

(Mülmenstädt et al., 2015)



Improved representation of clouds – especially those containing ice key for improved accuracy of precipitation and climate projections

Clouds in the atmosphere



(Kanji et al., 2017)

Pure ice clouds (glaciated)

Mixed-phase clouds

Liquid-phase clouds

Atmospheric Particles ("aerosol") are the seeds for cloud formation

Aerosol/Cloud/Climate interactions are a major source of uncertainty in climate projections

Ice formation mechanisms in global clouds

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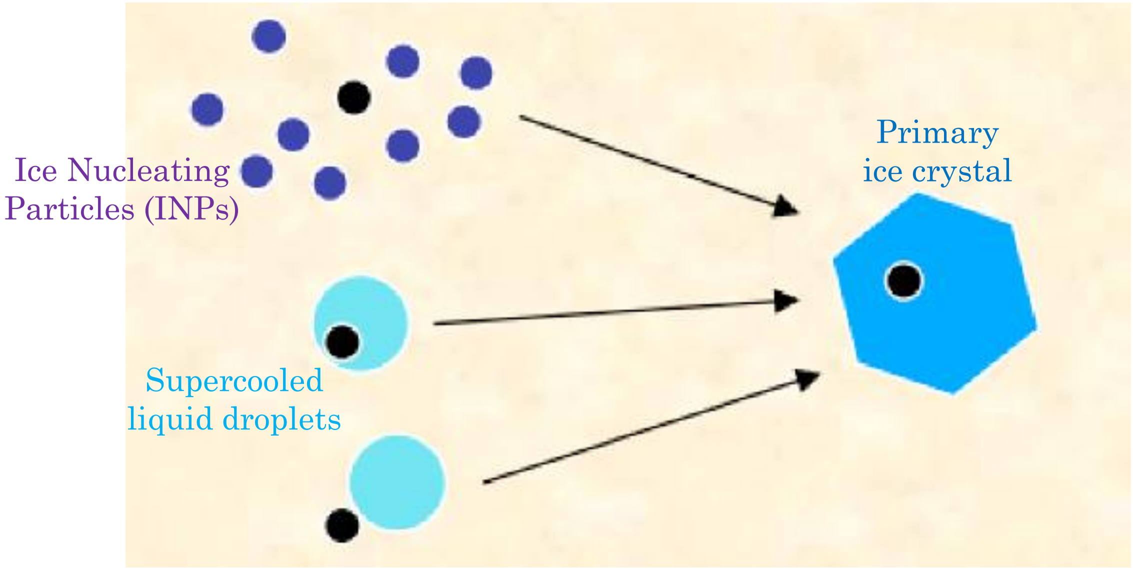
I. Primary Ice Production (PIP)

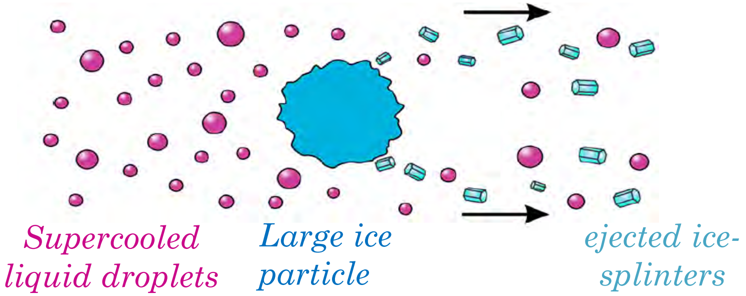


- ✓ Insoluble aerosols needed to facilitate freezing at T >-38 ˚C, by acting as Ice Nucleating particles (INPs)
- ✓ Secondary Ice Production (SIP) processes can multiply the few primary ice crystals mostly at T>-15 ˚C

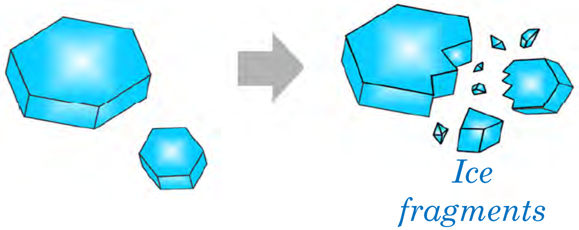
Primary Ice processes are always included in climate models, but most Secondary Ice processes are still missing

II. Secondary Ice Production (SIP)

Rime Splintering (RS) or the Hallett-Mossop process (HM)



Collisional break-up (BR)



Droplet Shattering (DS) during freezing

Secondary ice production mechanisms: our research points its always important!

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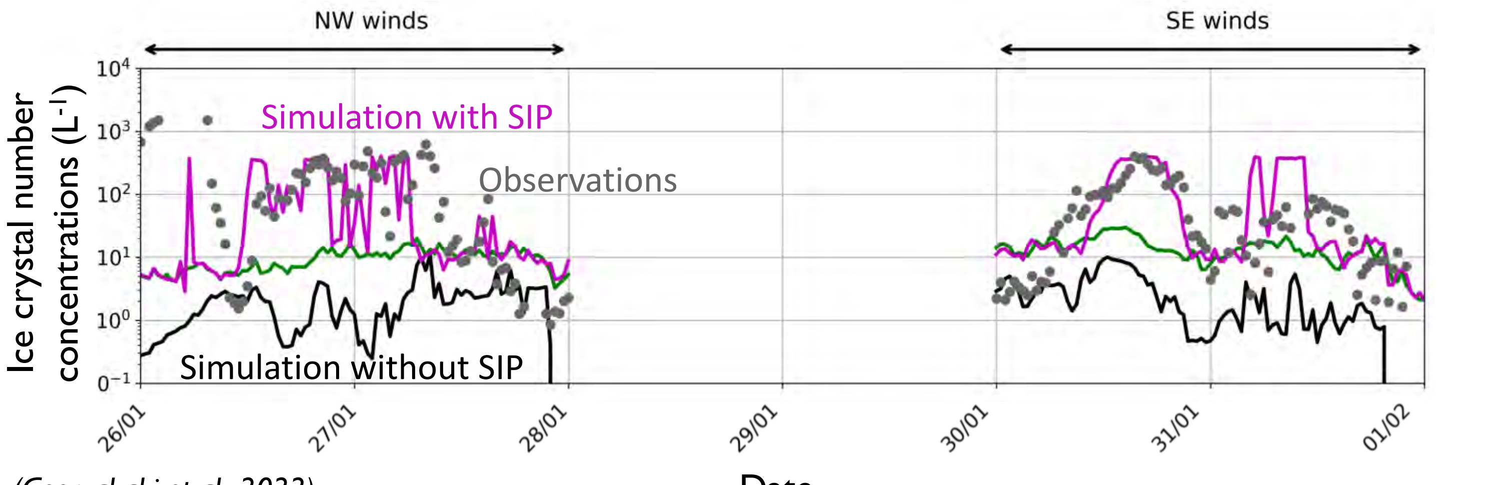
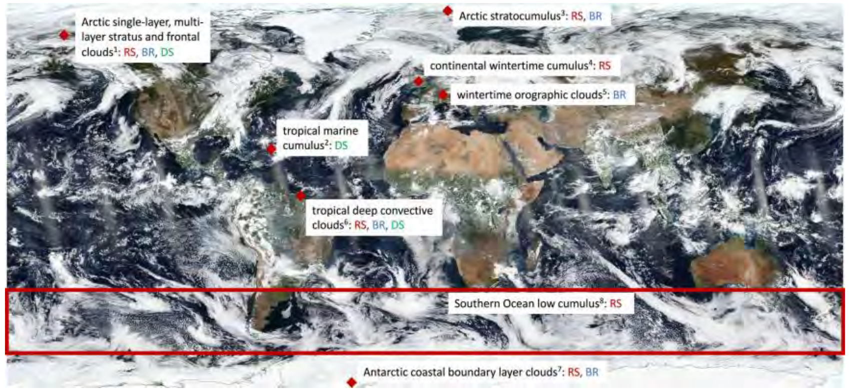
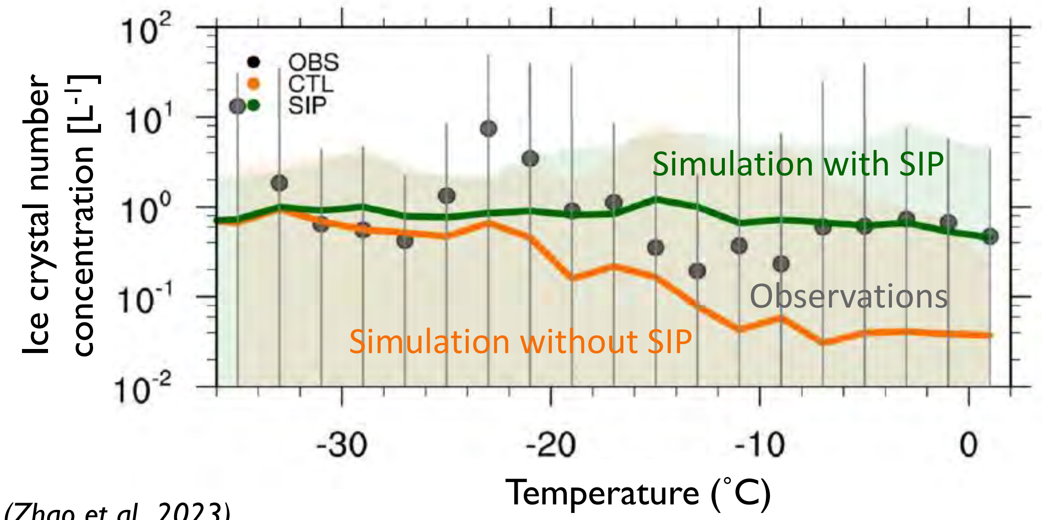
Orographic clouds



(Georgakaki et al., 2022)



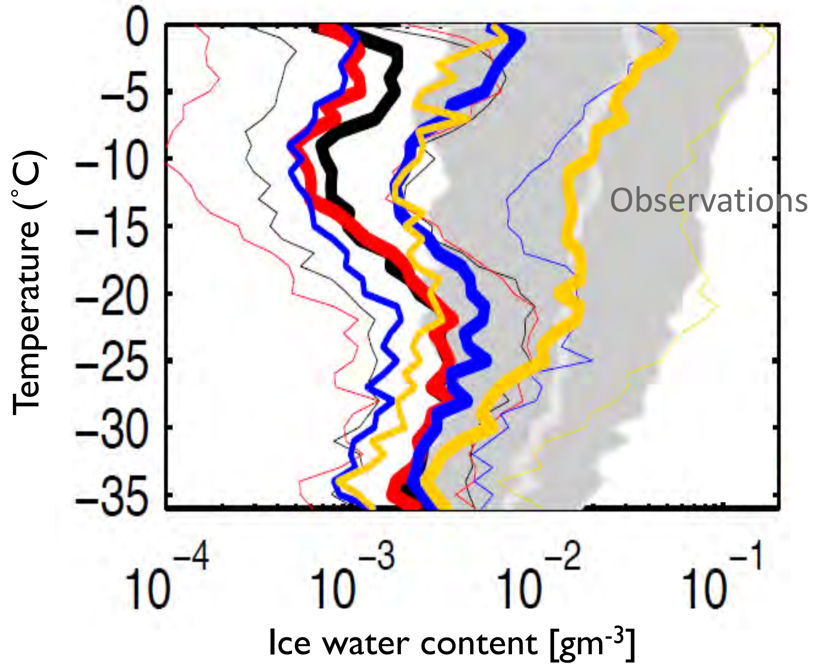
Southern Ocean



(Zhao et al., 2023)

All the sources of ice production (primary and secondary) needed in models to reproduce observations

Arctic



(Sotiropoulou et al., 2022)

Including secondary ice production in models

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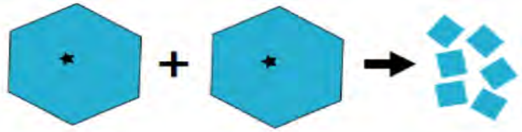
Collisional break-up *(Phillips et al., 2017)*



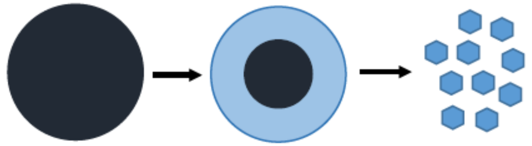
Number of fragments per collision

asperity–fragility coefficient | Collisional kinetic energy

$$F_{BR} = aA\left(1 - exp\left\{-\left[\frac{C\,Ko}{aA}\right]^{\gamma}\right\}\right), \quad a = \pi D^2$$

Surface area | number density of breakable asperities

Droplet shattering *(Phillips et al., 2018)*



Both tiny and big splinters generated

$$F_{DS} = \Xi(D)\Omega(T)\left[\frac{\zeta\eta^2}{(T - T0)^2} + \beta T\right]$$

Shattering probability | Freezing probability

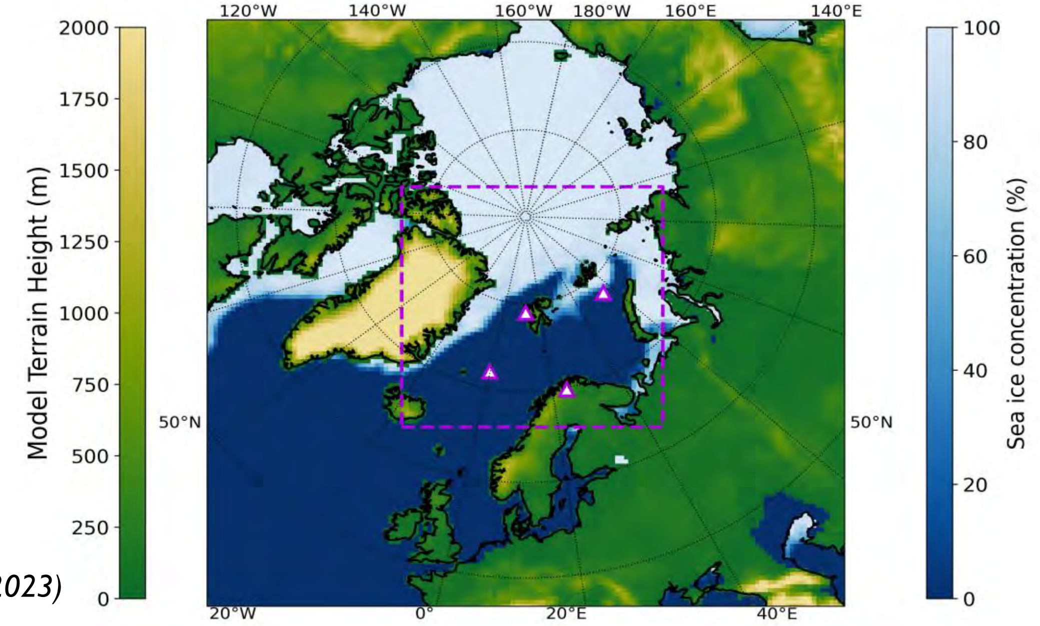
- ✓ Complex parameterizations
- ✓ Models need to consider multiple liquid/ice species and interactions among them

Training data → Machine learning model → Trained model

WRF Weather Research & Forecasting

Mesoscale model simulations

2-year (**2016-2017**) regional climate simulations over the **pan-Arctic region** with the updated version of WRF with detailed microphysics



(Georgakaki & Nenes, 2023)

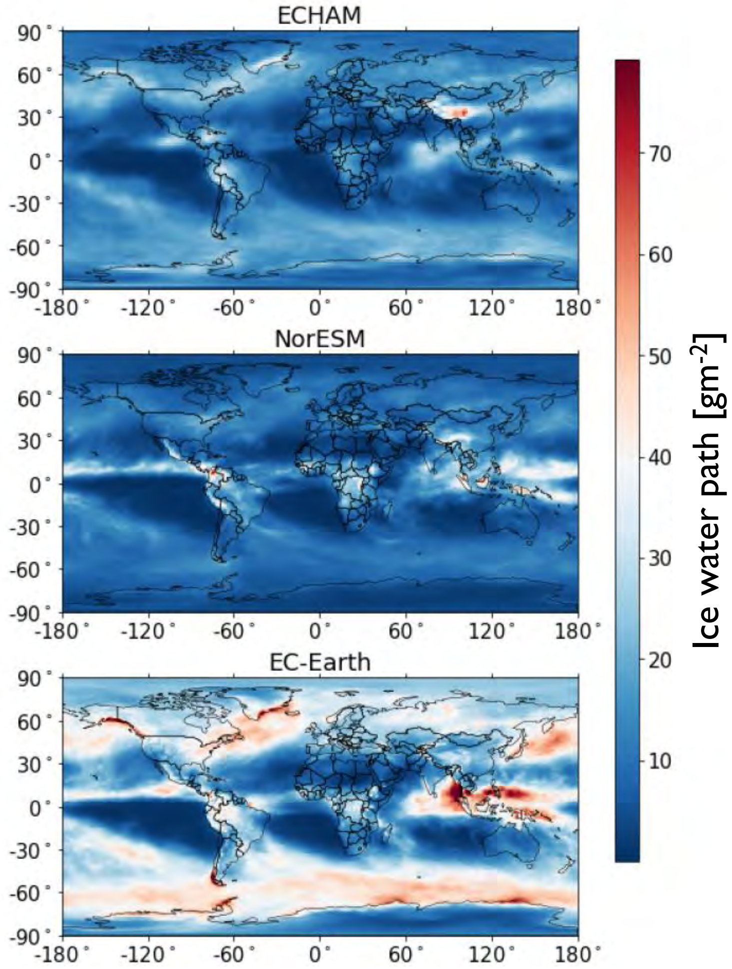
Simulations with the **full physics packages** → machine learning algorithms → parameterizations for **simpler models**

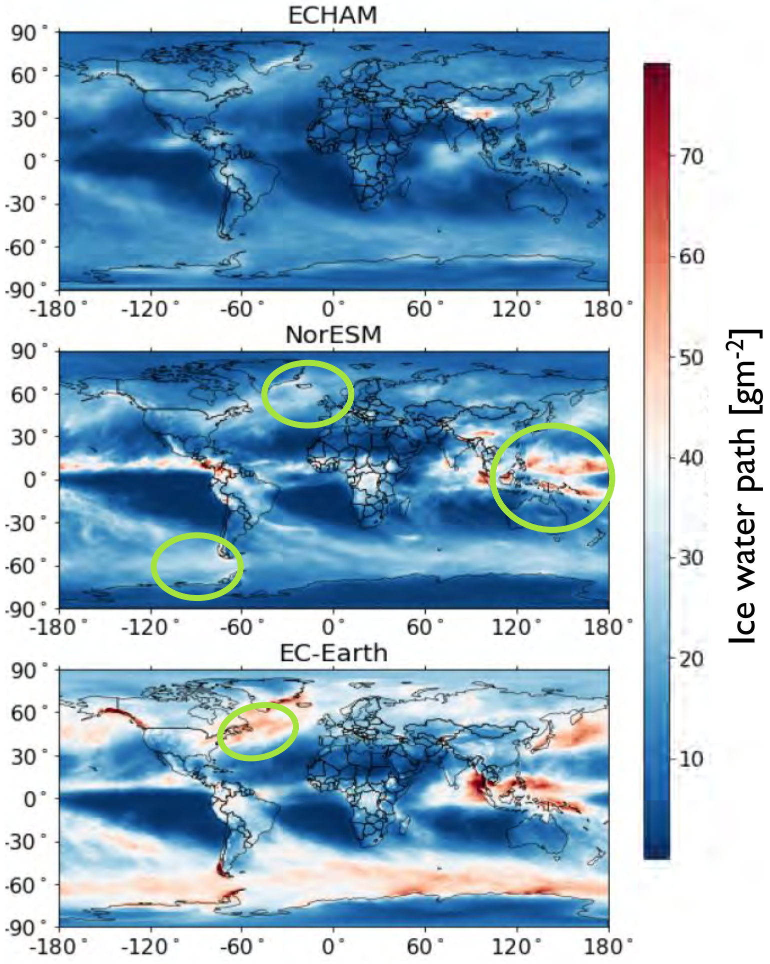
Current status of the RaFSIP parameterization

- ✓ RaFSIP available as **open-source** software (https://doi.org/10.5281/zenodo.10569644)
- ✓ Implemented in 3 models: NorESM, EC-Earth, ECHAM-HAM (participate in the Coupled Model Intercomparison Project CMIP7 - IPCC)
- ✓ Model intercomparison study within FORCeS (https://forces-project.eu/)

1-year simulation period starting from January **2018**

SIP OFF





Models coupled with RaFSIP

SIP ON

(Frostenberg et al., in prep)

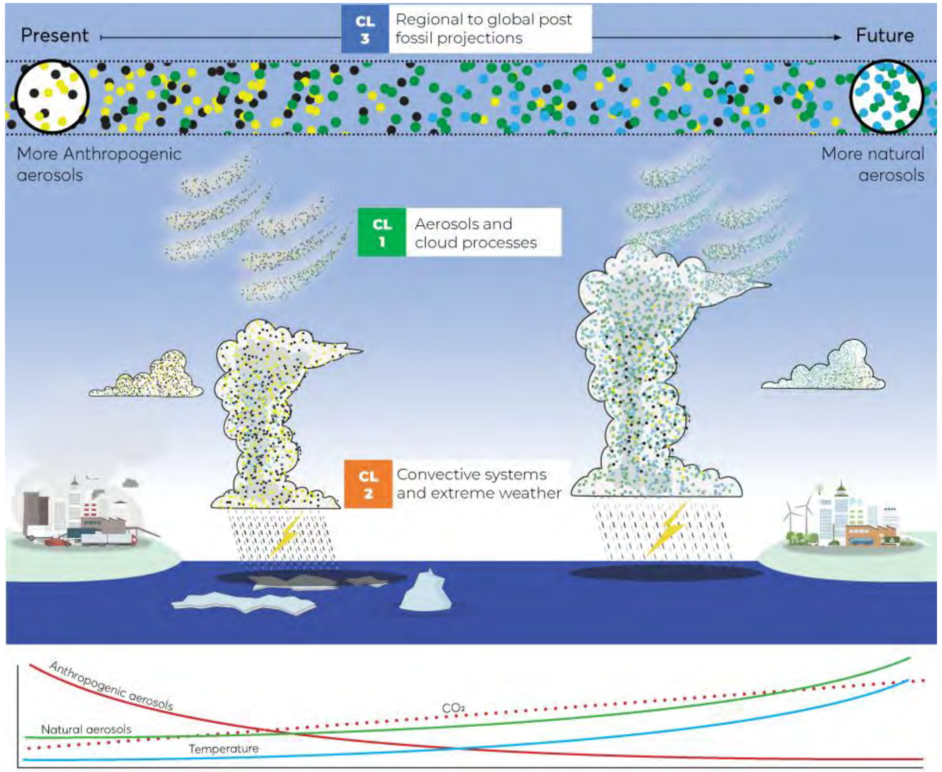
Horizon Europe Cluster 5 project

Clouds and climate transitioning to post-fossil aerosol regime

Funded by the European Union

Aims to:

- Holistically assess the role of aerosols in the life cycle of convective systems and extreme events
- improve and constrain kilometer- and large-scale climate models (**EC-Earth 4**, ICON) using machine learning, data assimilation & model calibration.



Coordination:

AU (Ulas Im), FORTH/EPFL (Athanasios Nenes)

20 partners,12 countries (14 EU/2 CH/4 UK), 10 MEuros

Website: http://Projects.au.dk/cleancloud

Follow us on Twitter @CleanCloud_HE **& LinekdIn:** @CleanCloud ACI

Videos: https://mediaspace.epfl.ch/channel/CleanCloud

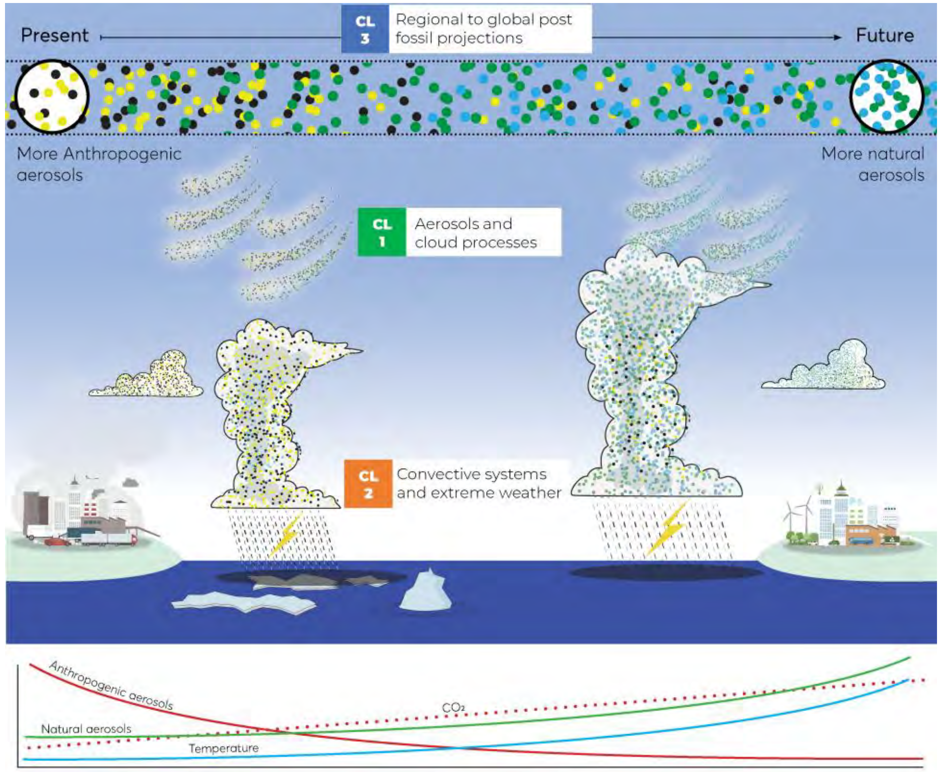
Horizon Europe Cluster 5 project

Clouds and climate transitioning to post-fossil aerosol regime

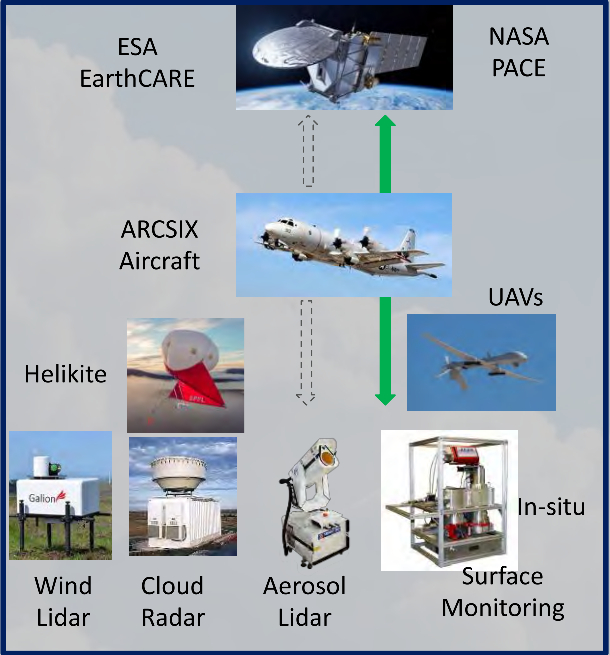
Funded by the European Union

OBJECTIVES

- carry out **targeted field experiments** in European climate hotspots
- develop **state-of-the-art retrieval algorithms** to obtain new proxies and diagnostics for key ACI-related processes
- contribute to the **calibration and validation** of upcoming satellite missions
- improve and **better constrain** kilometer- and large-scale climate models using advanced machine learning, data assimilation and model calibration
- assess the role of aerosols in the life cycle of convective systems and extreme events



CL1: AEROSOLS & CLOUD PROCESSES



- **Arctic (Villum: Spring & Summer 2024)**

- **Mediterranean: Mt. Helmos (Autumn 2024)**

Chamber Experiments

- **AU-Chem: AURA**
  - **Marine aerosols**
  - **Lab & in-situ**

- **FORTH/EPFL: FORTH dual MSC**
  - **Marine & Aged dust**
  - **Lab & in-situ**

CleanCloud team at Villum (24/25 March, 2024, -35ºC)

Funded by
the European Union

Villum Instruments: Spring campaign

In-situ aerosol (size distribution, composition, absorption, CCN)

Radar (W-band) and lidar (multi-wavelength)

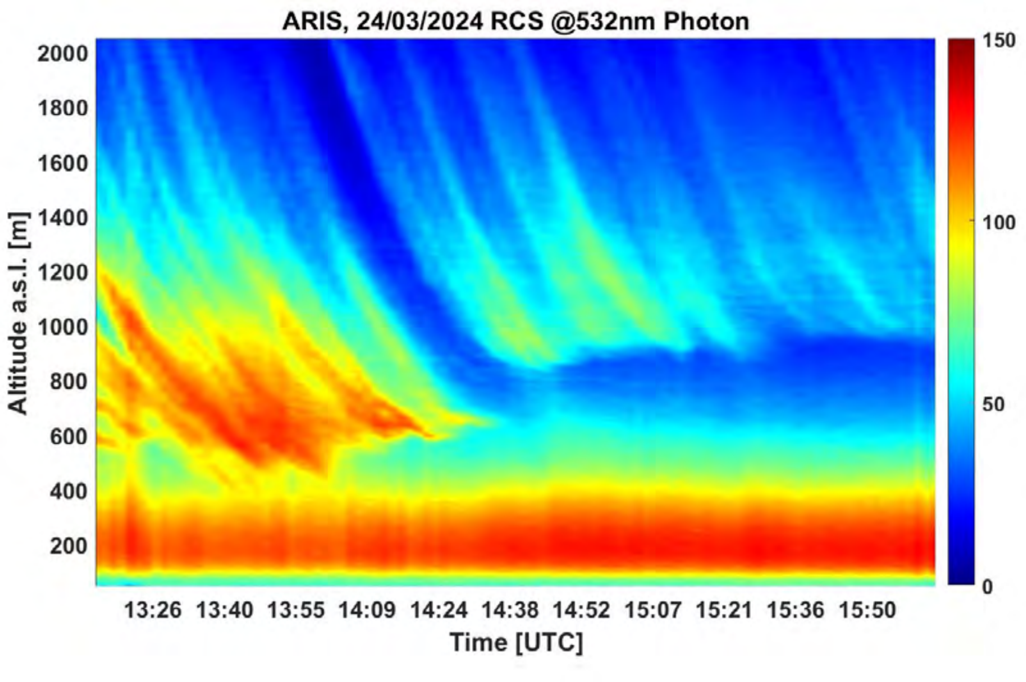
Tethered balloons with fully equipped in-situ instruments

Wind lidar (vertical velocities)
Cloud Radar, Celiometer

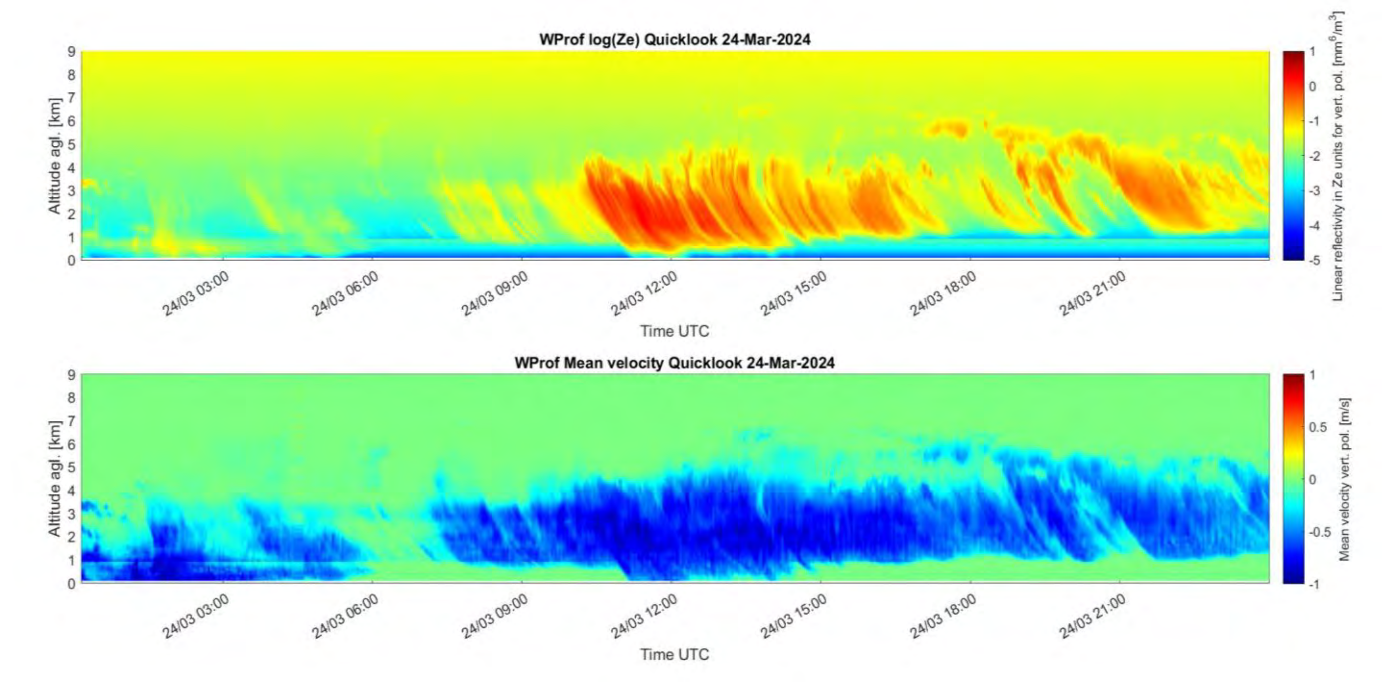
Ground-based instruments

Some data from Villum Spring campaign

Lidar backscatter



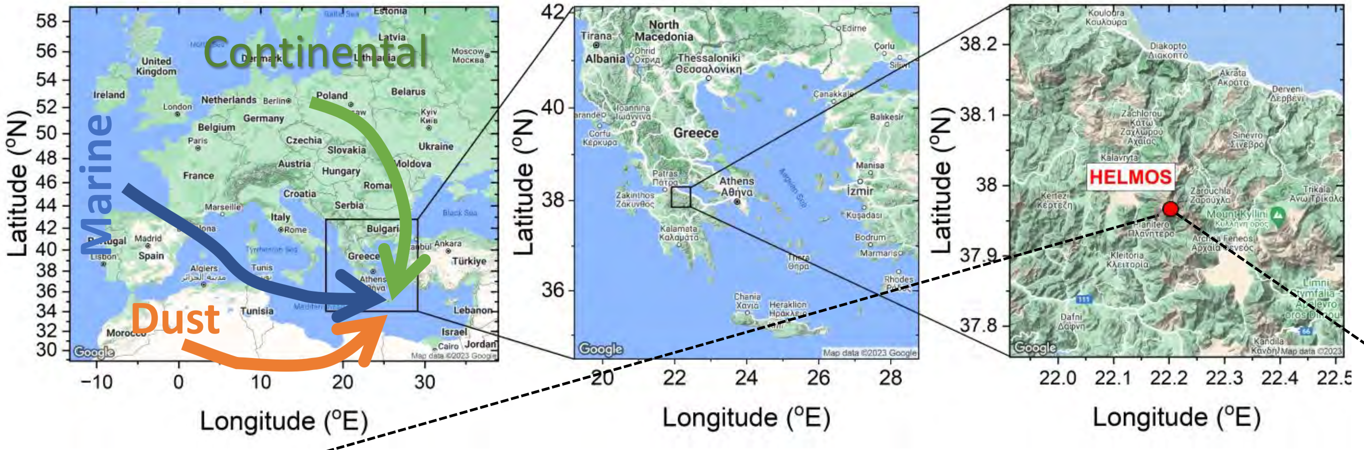
Radar reflectivity and (mean) vertical velocity



We see clearly the presence of a haze layer and precipitating (ice) clouds
Lots of great analysis to carry out (so stay tuned!)

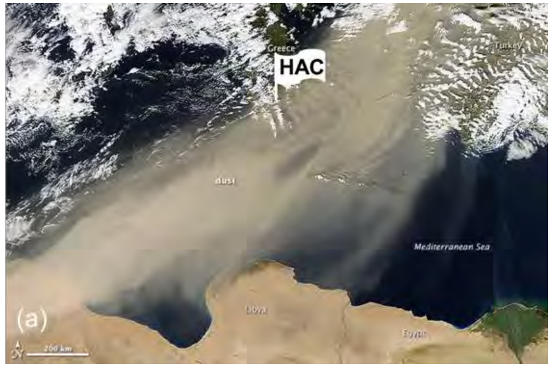
Funded by the European Union

Mt. Helmos: Where mythology, aerosols & clouds meet

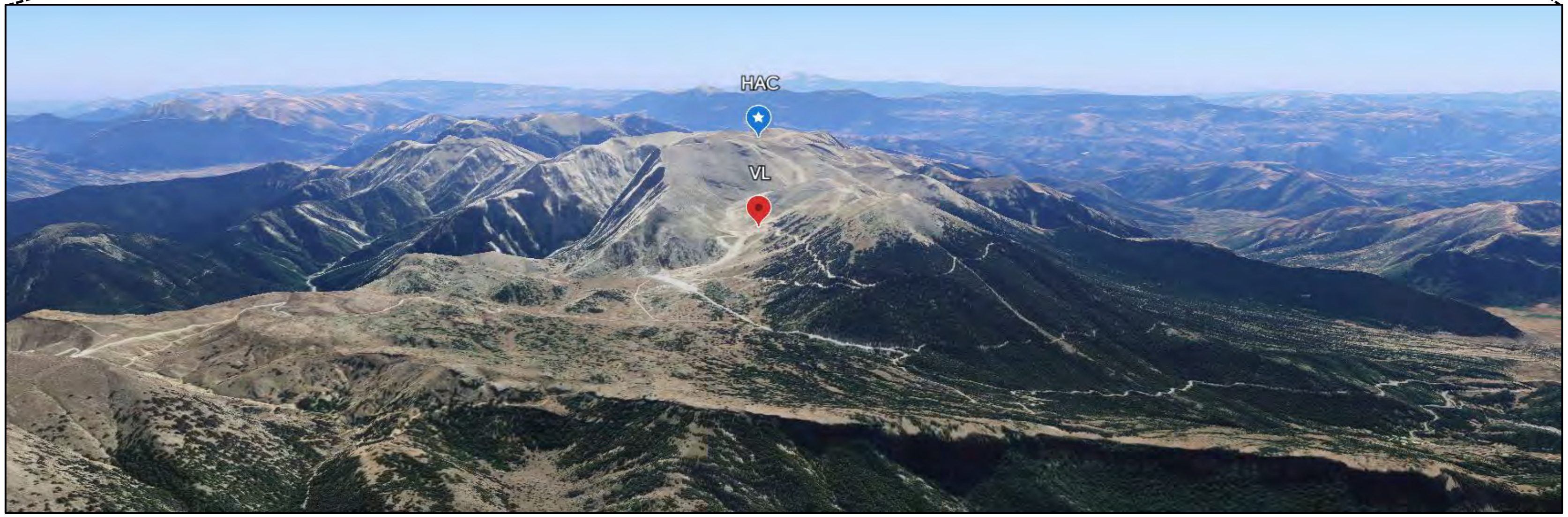


Some facts:

- River Styx, back entrance to Hades
- Hermes born there
- Achilles was bathed by the fairy Thetis there and… almost became immortal.



Dust transportation over Peloponnese (Feb 1, 2015)



Images: Google Earth; NASA (https://earthobservatory.nasa.gov)

Wildfire smoke over Peloponnese (Aug 8, 2021)

CleanCloud Mt. Helmos Experiment (upcoming)

Some facts:

- *Period*: Oct.2024 – Dec (Jan) 2025
- *Coordination*: Logistics by NCSR Demokritos (K.Eleftheriadis, M.Gini) with scientific coordination from EPFL (A.Nenes, A.Papayannis)
- Initial planning meetings regarding flight permissions (drones and Helikite) and in-situ measurements

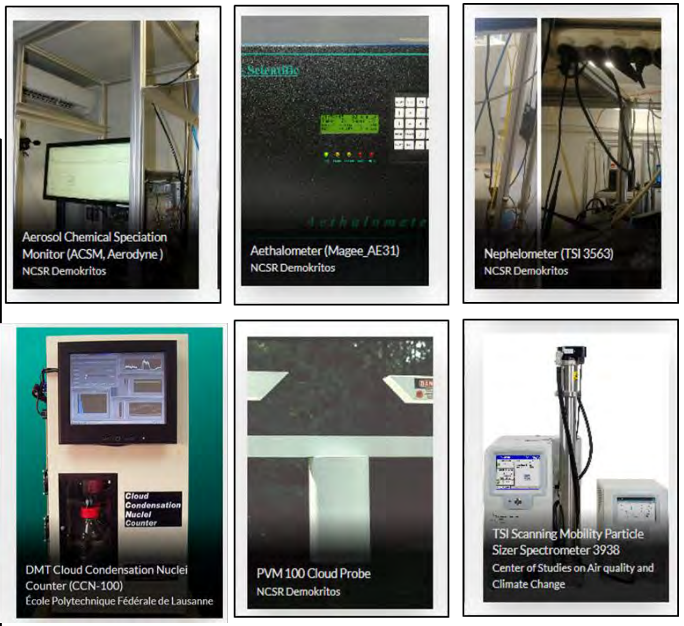
AARHUS UNIVERSITY · FORTH C-STACC Center for the Study of Air Quality & Climate Change · TROPOS Leibniz Institute for Tropospheric Research · Stockholm University · Finnish Meteorological Institute · KIT Karlsruher Institut für Technologie · °CICERO · The Cyprus Institute Research·Technology·Innovation · EPFL

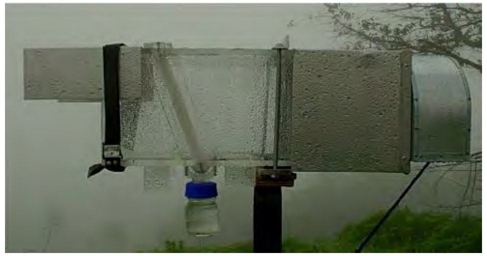
- Multiple labs from EPFL (LAPI, LTE, EERL) participating and playing a major/leading role.

Key goals of the experiment:

1. Understand processes and drivers of droplet/ice formation in clouds.
2. Quantify cloud effects on aerosols, develop parameterizations for models.
3. **Evaluate, improve and develop remote sensing algorithms for aerosols and clouds**

CleanCloud campaign instruments so far





Cloudwater collectors

Bioaerosol collectors

CyI Drones

Stay tuned for all the exciting media coverage on this campaign!

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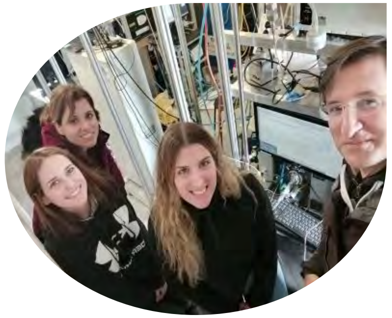
CALISTHO-HELMOS 2021
01 OCTOBER - 30 NOVEMBER

Clean Cloud



THANK YOU!

FORCeS

Please go to **http://lapi.epfl.ch** & follow us on X/Twitter **(@LAPI_epfl)**