Using the Atmosphere-Ocean Single-Column Model (AOSCM) with HALO-AC3 and other observational campaigns to understand model representation of warm and moist air intrusions to the Arctic

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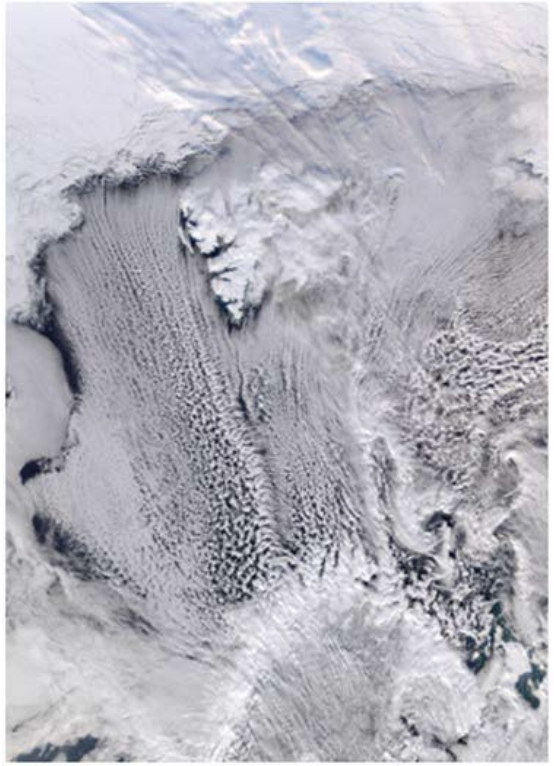
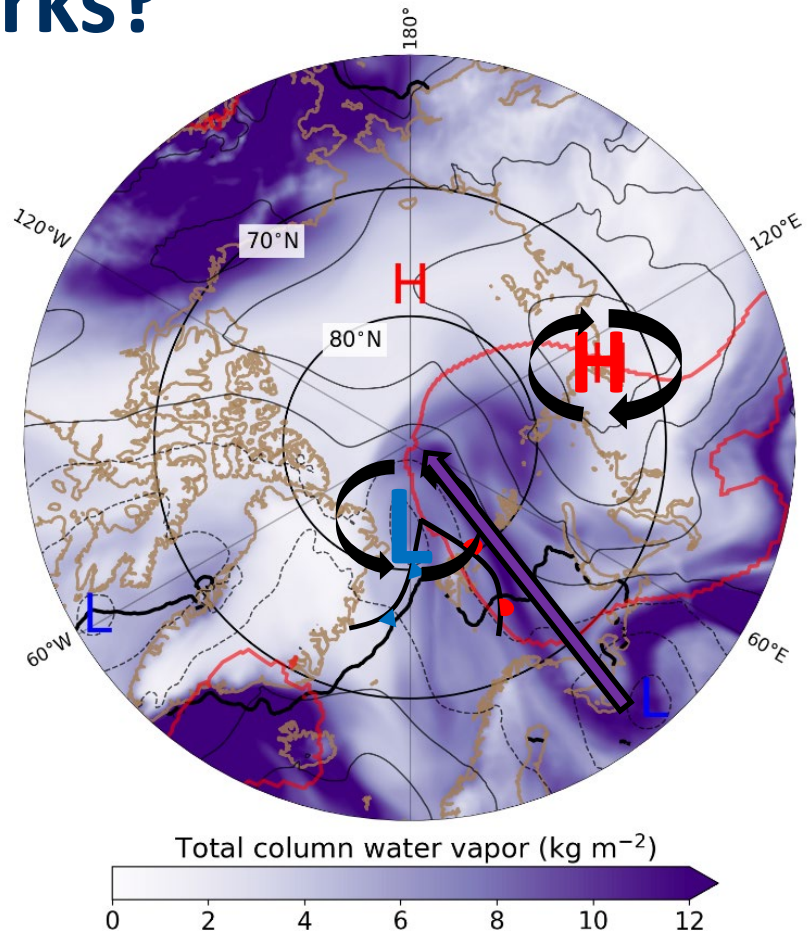
Why Lagrangian and Eulerian frameworks?

- Eulerian frameworks are useful to evaluate models at locations
- However, airmass transformation happens along the transport pathway
- Many studies of their importance for the climate are based on models or reanalysis (e.g. Woods et al. 2013, Murto et al. 2022; 2023)
- We know that models and reanalysis have problems representing processes such as turbulent mixing and cloud properties (e.g. Tjernström et al., 2021)

Warm air intrusions/ atmospheric rivers

Cold air outbreaks





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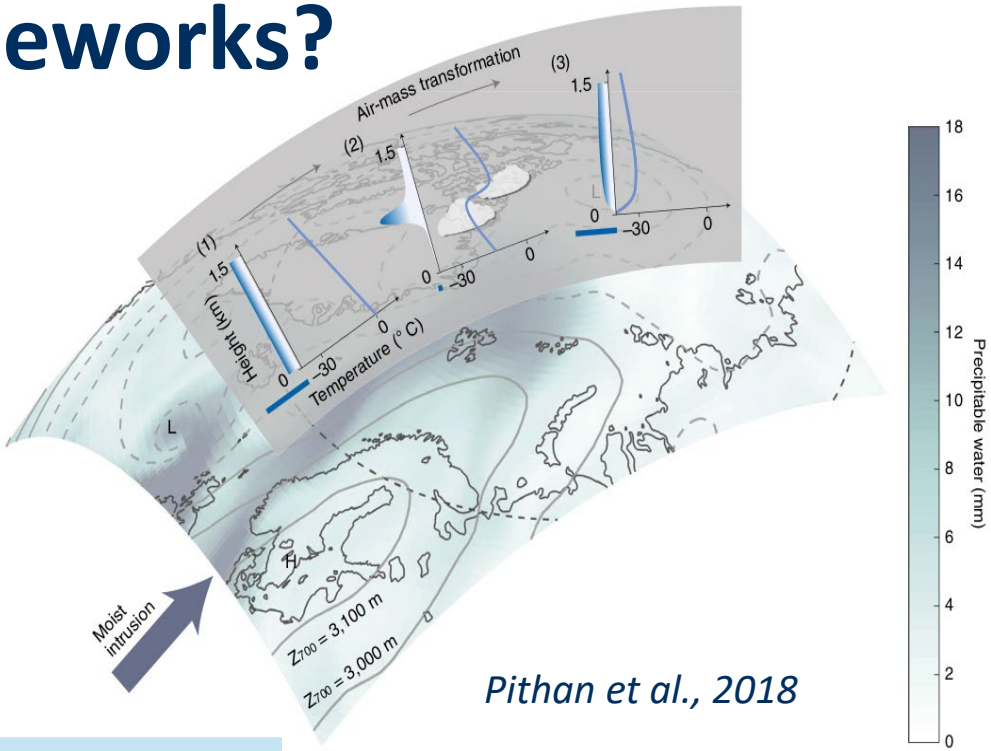
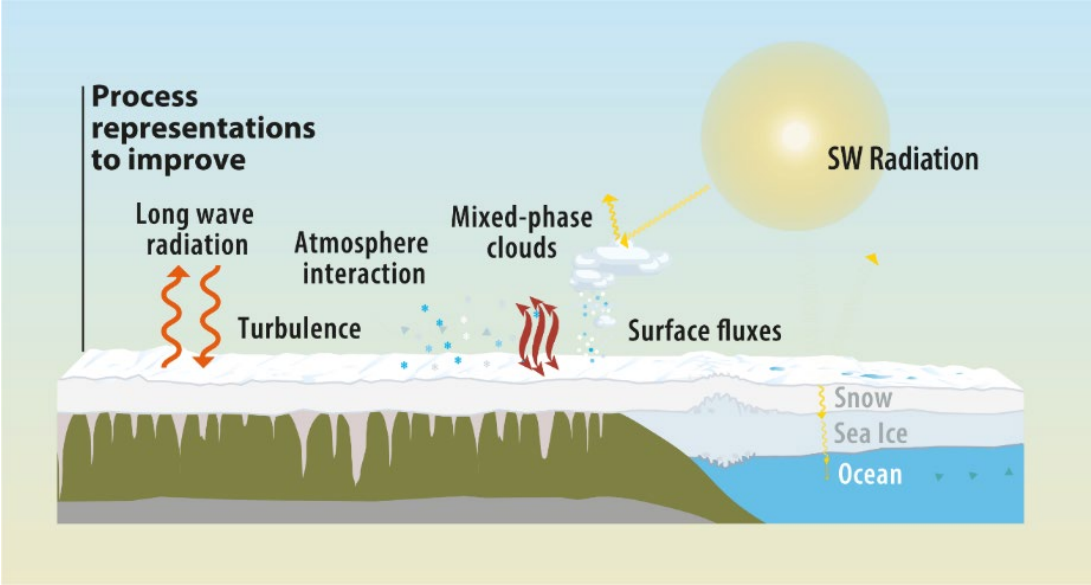
Why Lagrangian and Eulerian frameworks?

- Physical processes of importance are radiative cooling, cloud formation and turbulent mixing, surface exchange
- Aim here is to build a modeling framework that can be used to improve representation of the parameterized small-scale processes



Pithan et al., 2018



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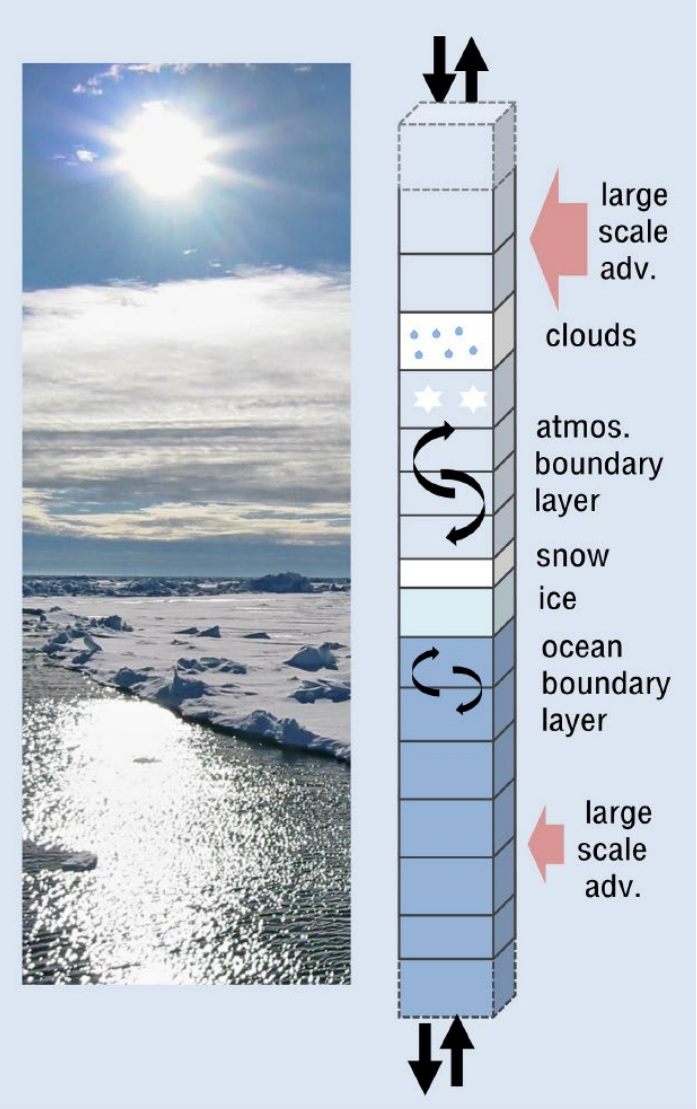
Can we utilize the single-column modeling framework?



Same model components as IFS/OpenIFS, EC Earth and ERA5/ERA6

Atmosphere-ocean single-column model (AOSCM) Hartung et al., 2018, 2022

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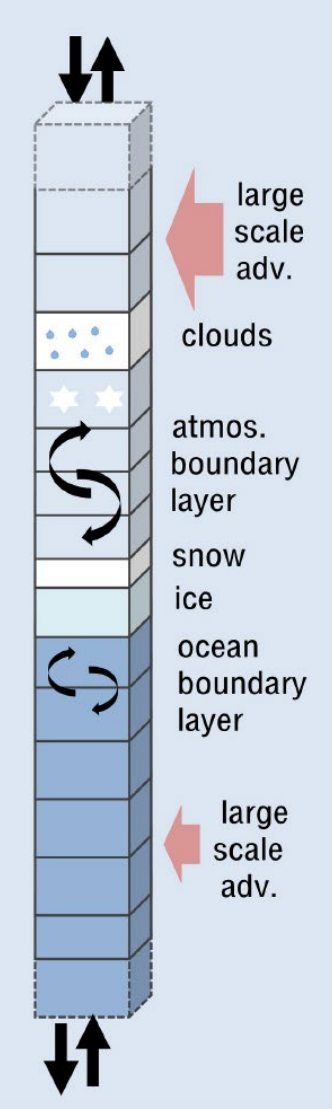
Can we utilize the single-column modeling framework?

Decoupling the large-scale circulation and the effect of the parameterized small-scale processes makes it possible to investigate process representation without changing the large-scale (resolved) flow



Eulerian view

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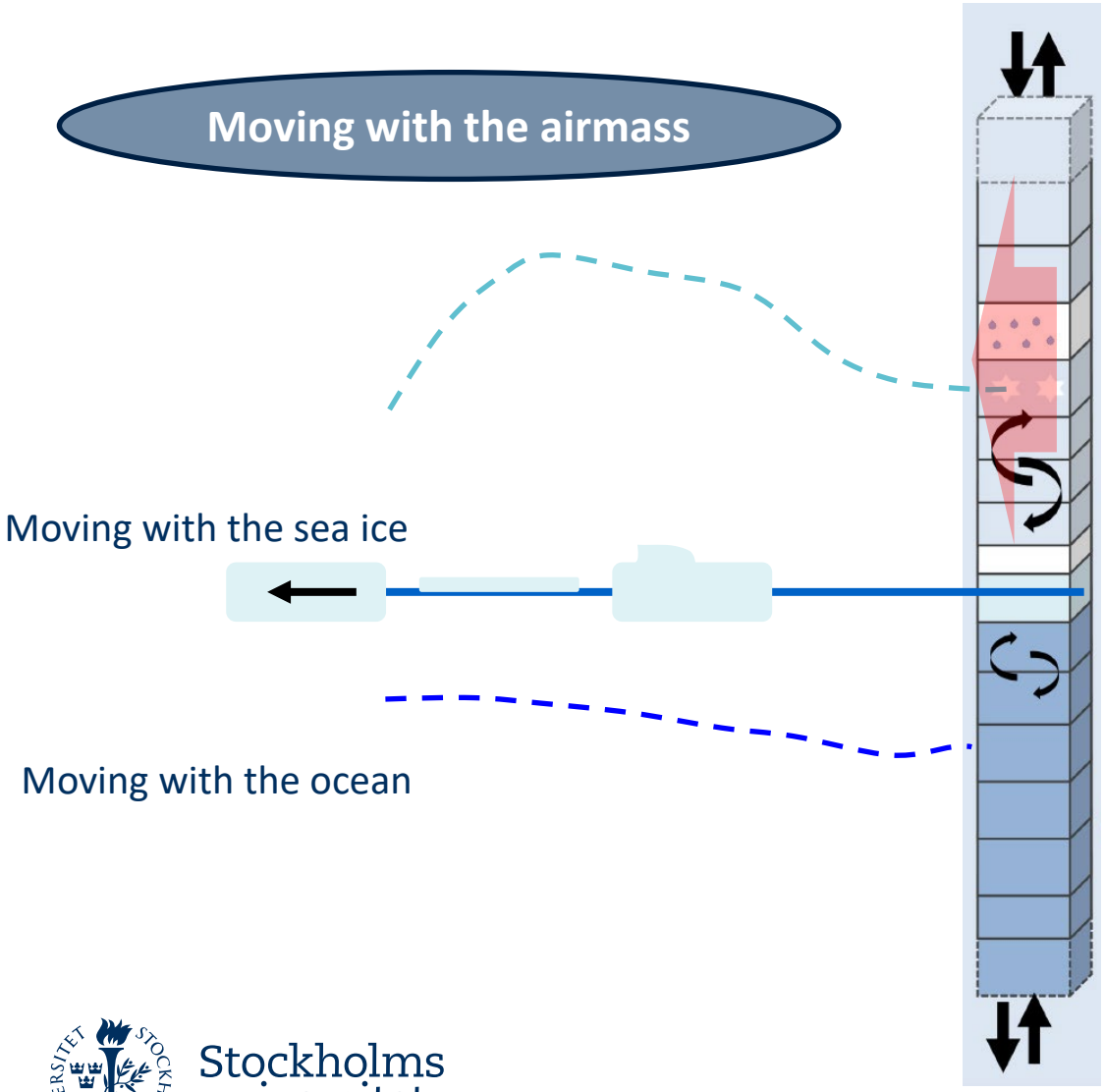
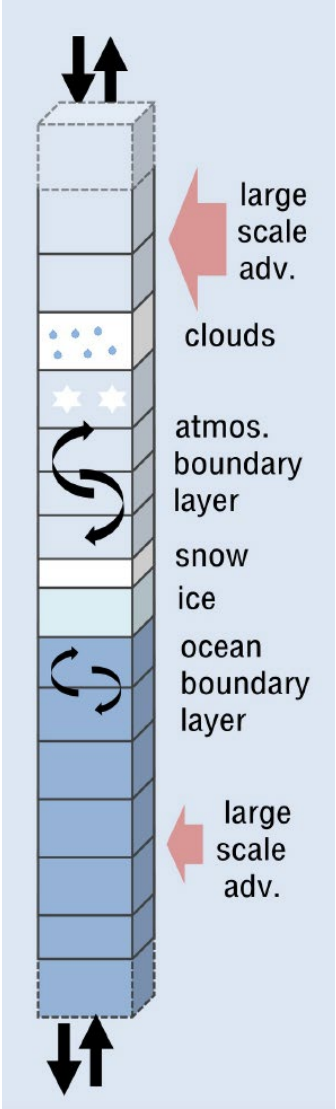
Can we utilize the single-column modeling framework?



Lagrangian view

De-coupling the large-scale circulation and the effect of the parameterized small-scale processes makes it possible to investigate process representation without changing the large-scale (resolved) flow



Eulerian view

OpenIFS SCM cy43r3

OASIS cpl

NEMO3.6/LIM or NEMO4/ SI^3

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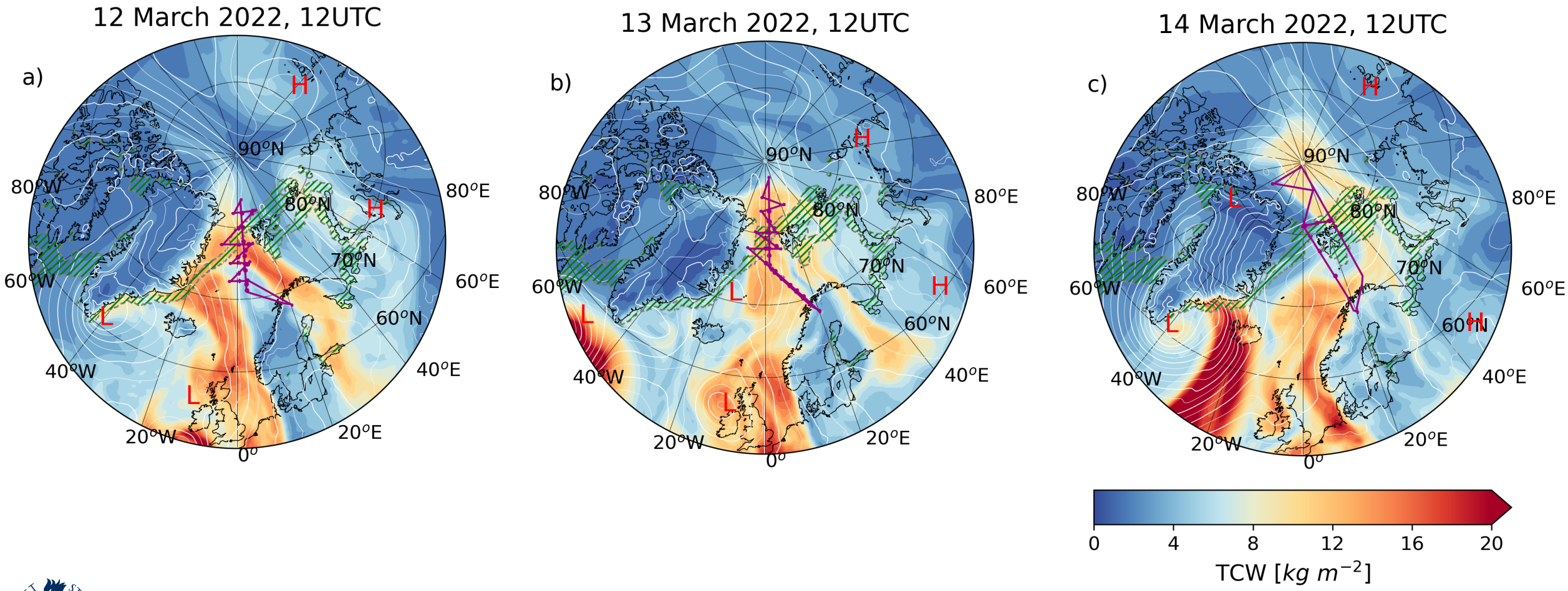
HALO-AC3 campaign provides observations to test the framework



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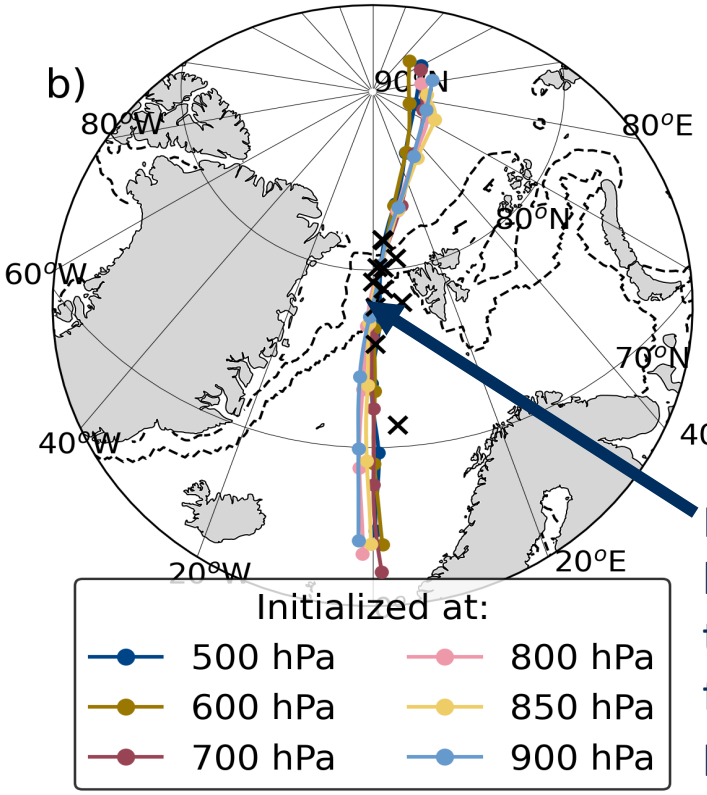
Karalis et al., 2025; Wendisch et al., 2024

Experimental setup for the Halo-AC3 warm air intrusion



x - dropsondes within 3 h and 250 km from trajectory

Forward and backward trajectories from central point

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Karalis et al., 2025

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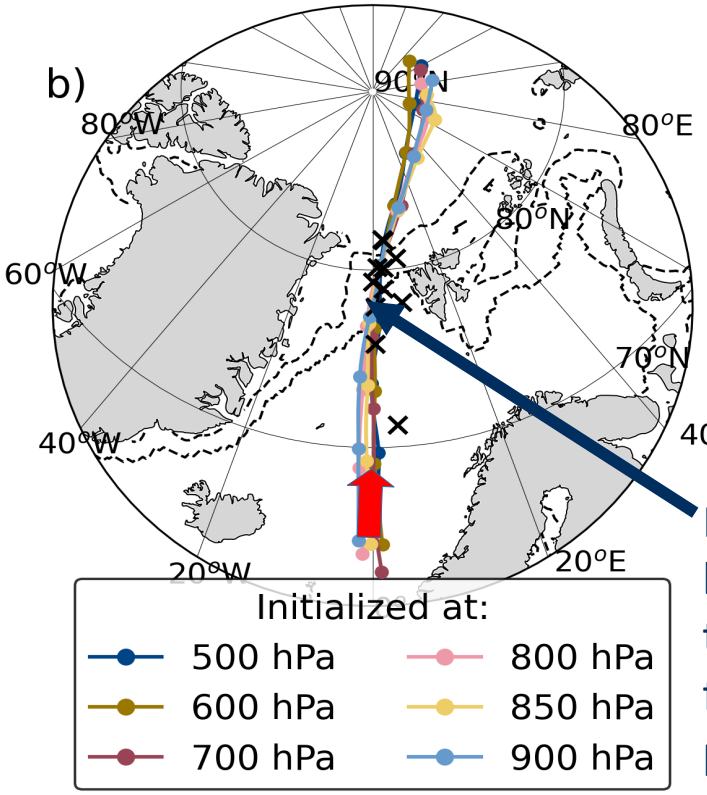

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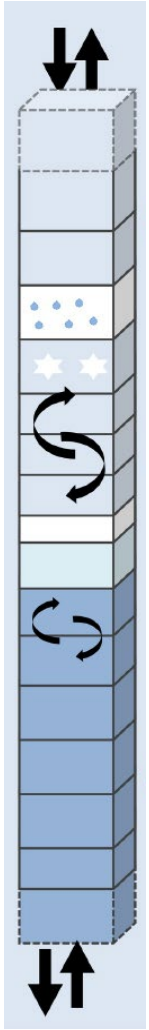
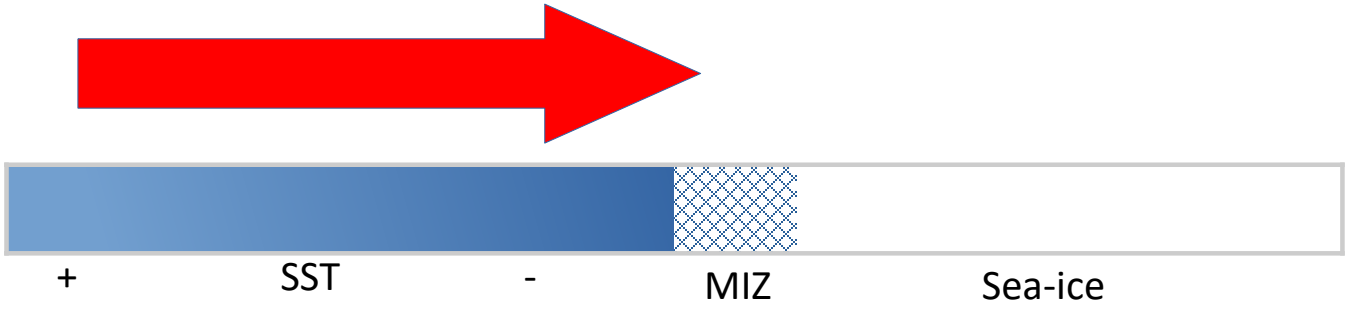


- Advective tendencies = **off**
- **Varying SST** over ocean,
- Coupled to sea-ice model over sea-ice
- Prescribed ERA5 vertical velocity **ω** and **nudged to ERA5 wind** throughout the column



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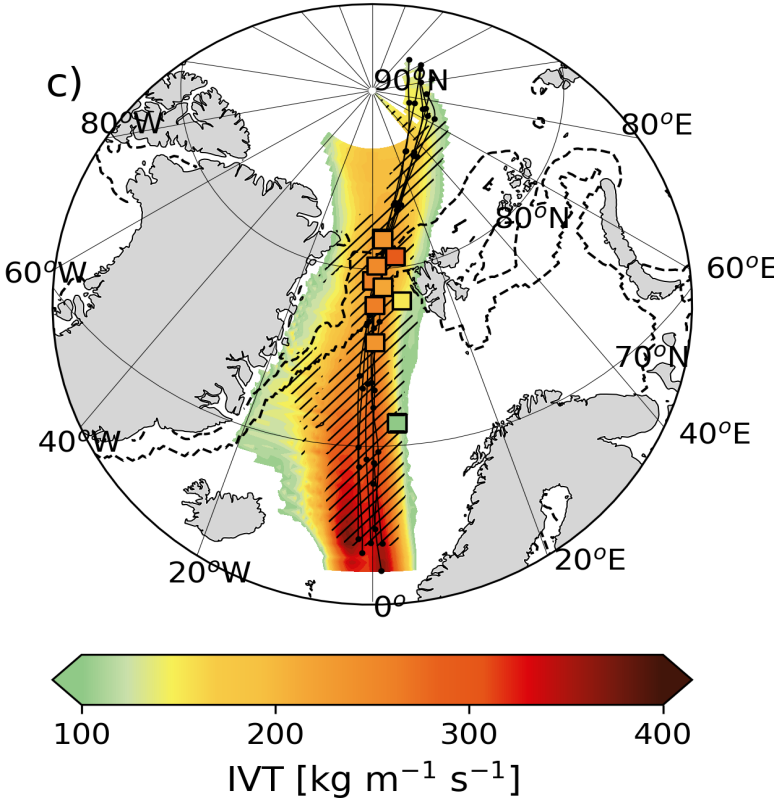
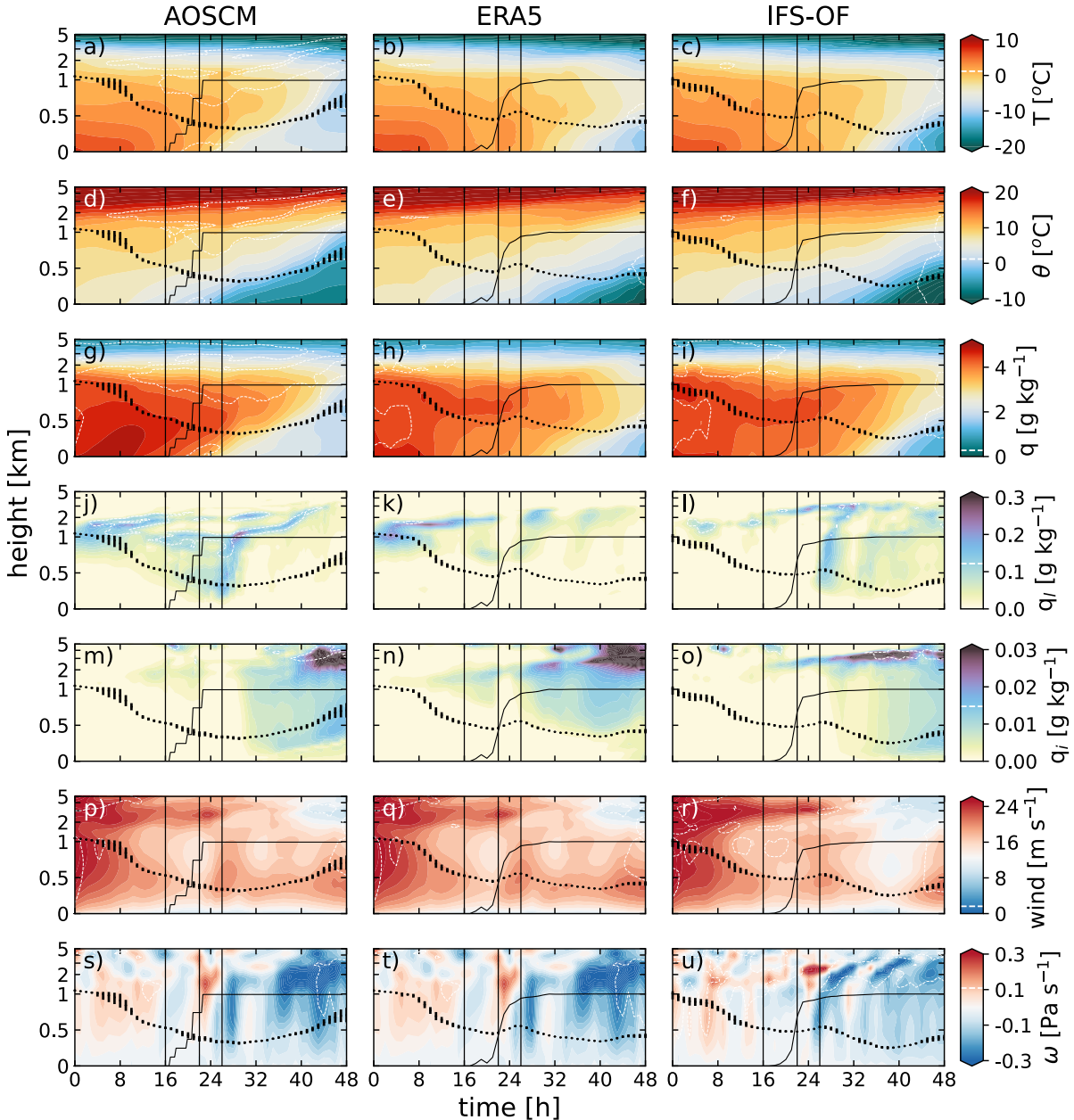
Karalis et al., 2025

HALO-AC3 campaign provide observations to test the framework





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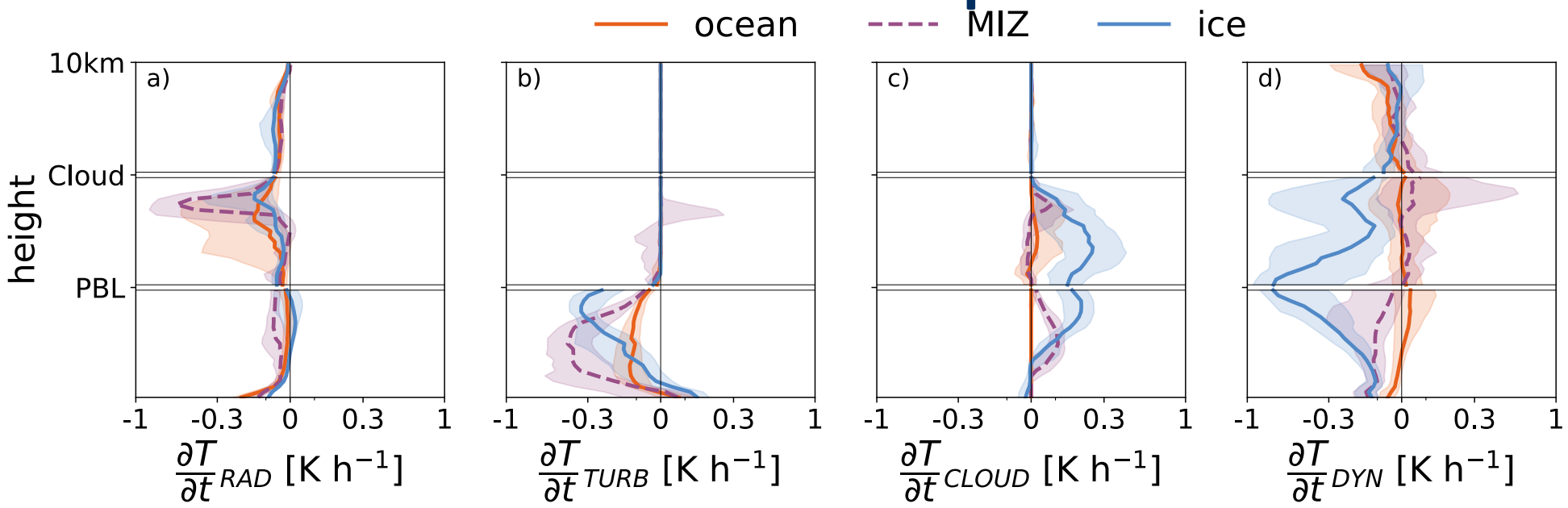
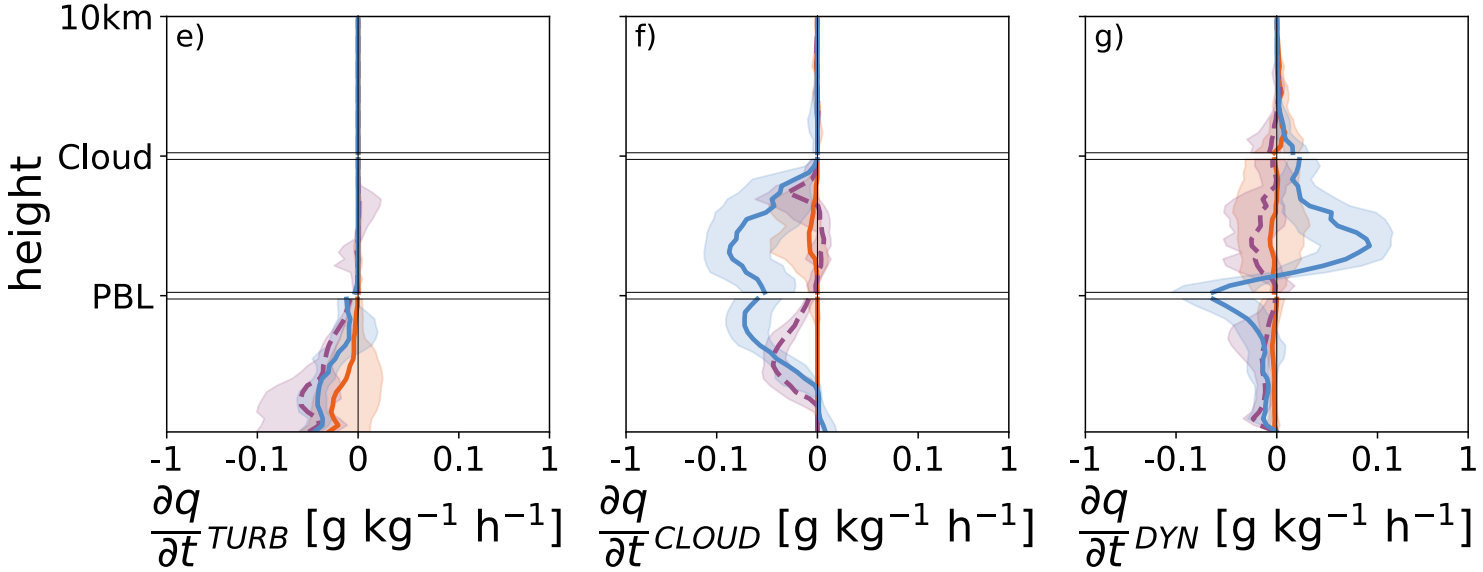
Karalis et al., 2025

AOSCM simulated tendencies for temperature and moisture



Temperature



Moisture

The tendency analysis shows when and where processes are important for the transformation

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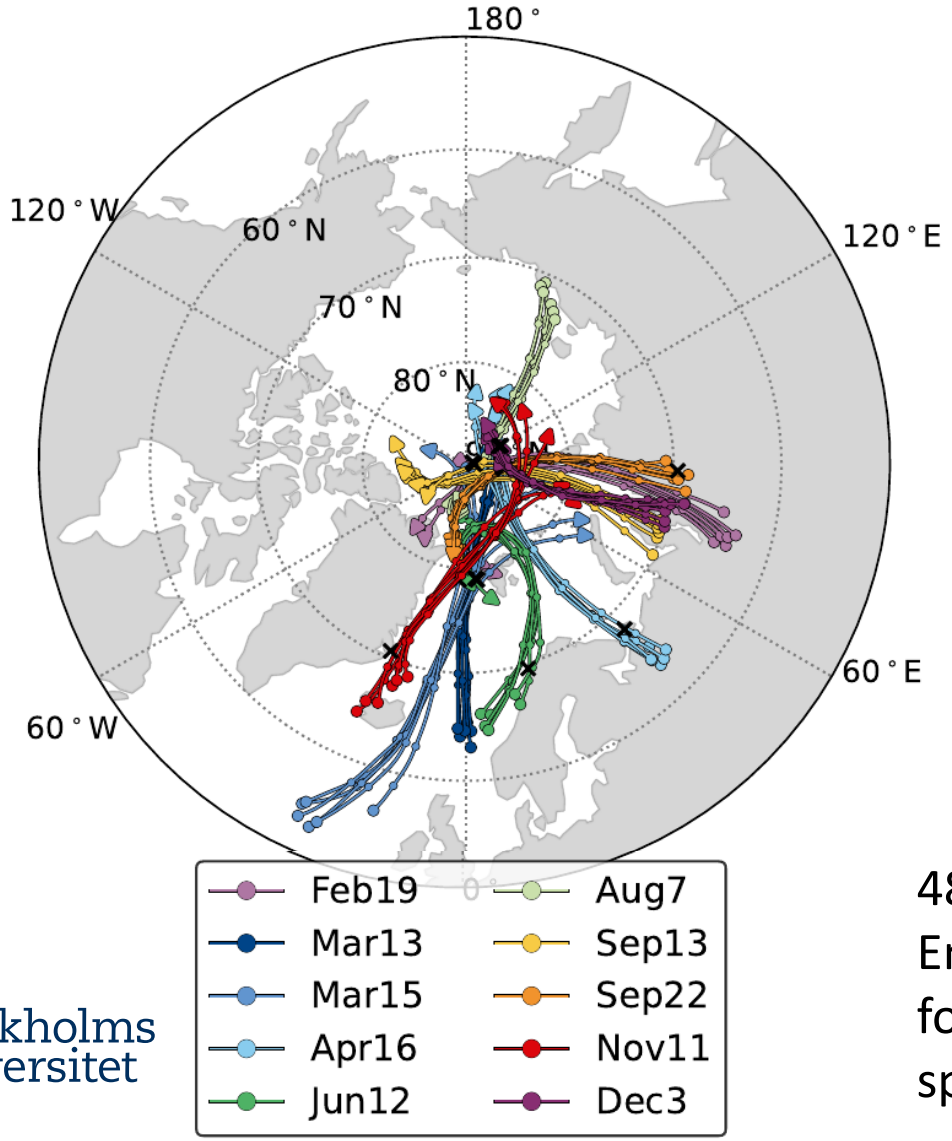
Karalis et al., 2025

Expanding to other warm air intrusions



MOSAiC, 19/02
HALO-AC3, 13/03
HALO-AC3, 15/03
MOSAiC, 16/04
AoM, 12/06
ACSE, 07/08
MOSAiC, 13/09
MOSAiC, 22/09
MOSAiC, 16/11
MOSAiC, 03/12

48 h trajectories
Ensemble simulations
for 6 pressure levels
spanning 500 – 900 hPa

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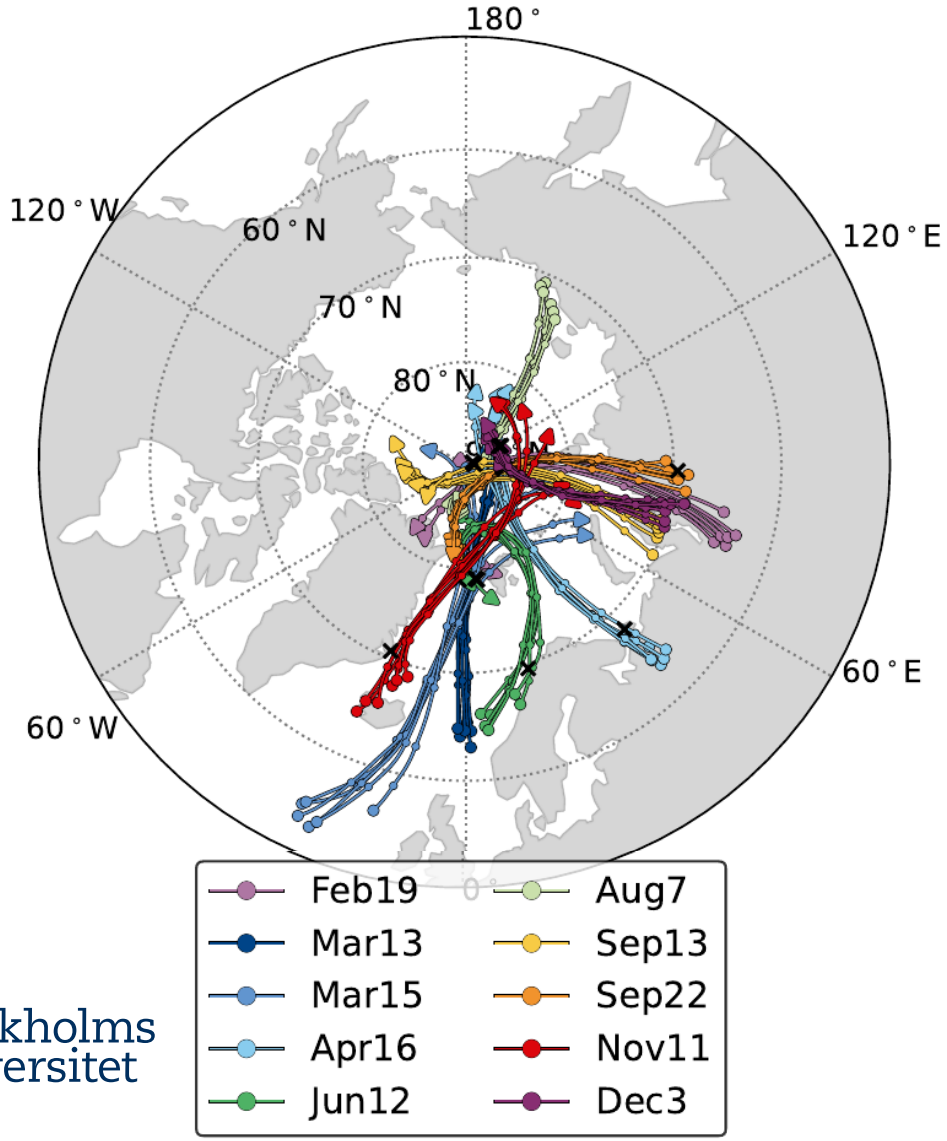
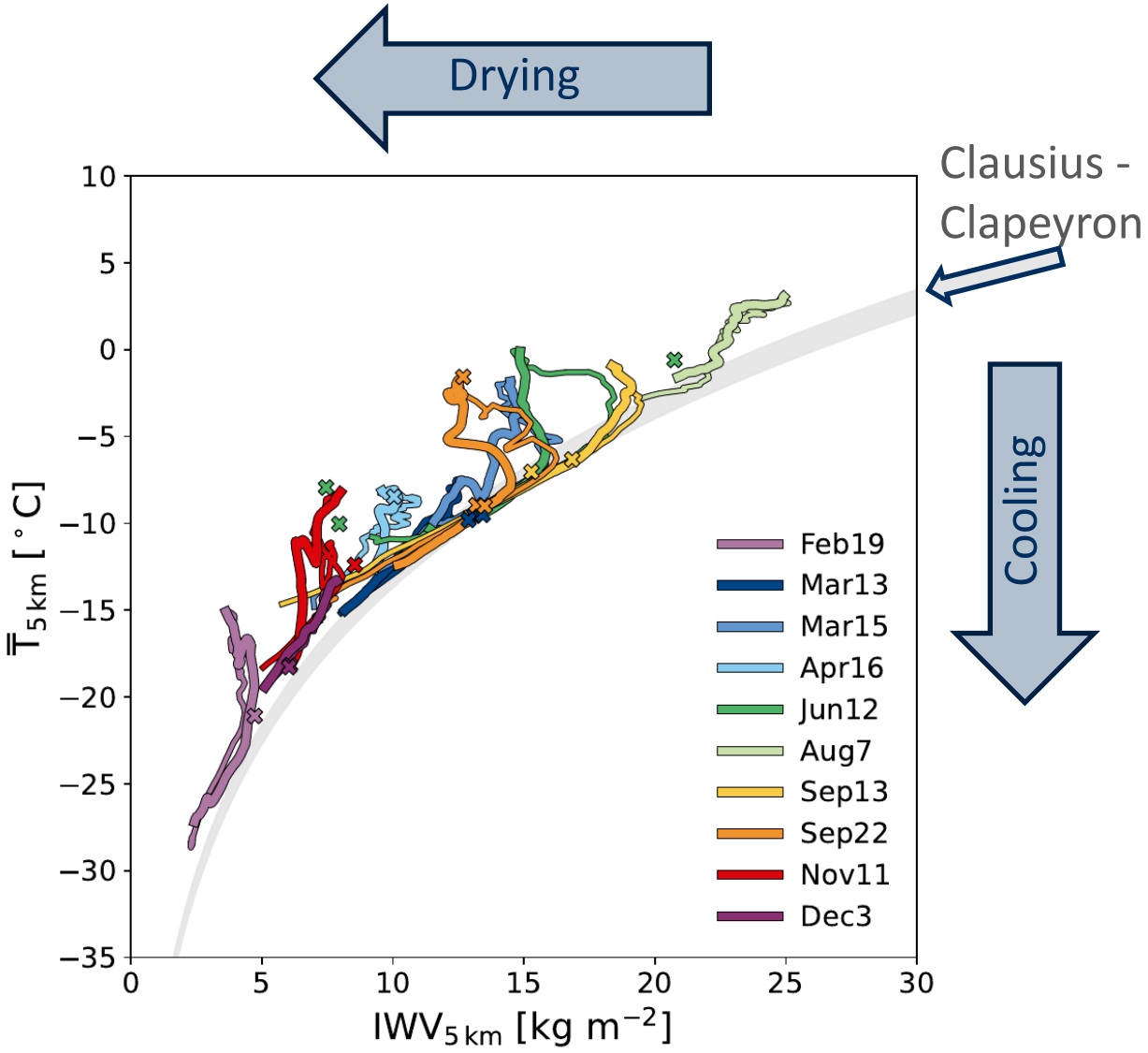
Karalis et al., 2026, submitted

Expanding to other warm air intrusions





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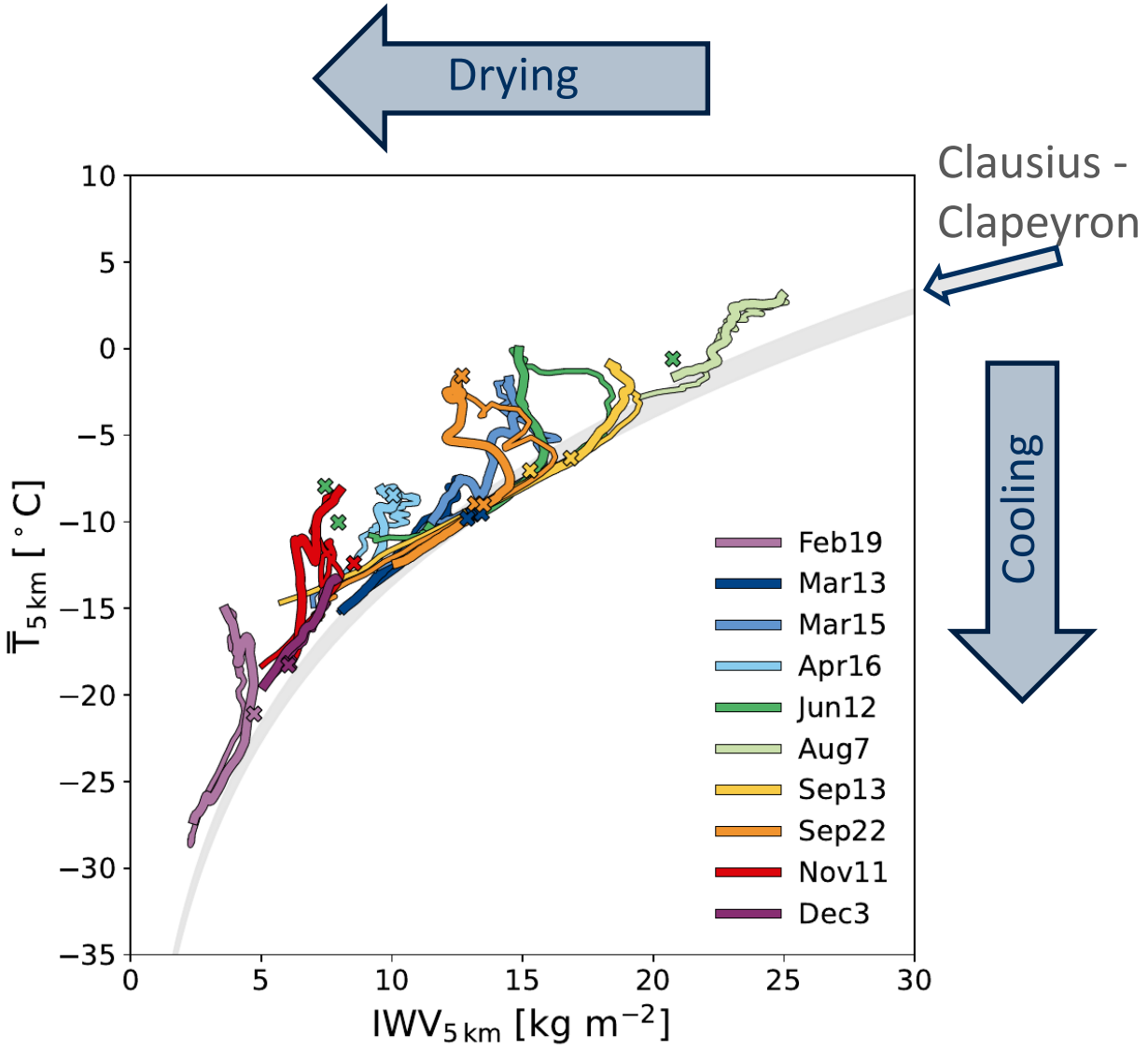
Karalis et al., 2026, submitted

Expanding to other warm air intrusions

- Similar evolution in AOSCM and ERA5
- Air masses reach saturation over deep (5 km) layers
- Vertical ascent is a key driver for the transformation
- How sensitive is the transformation to parameterized processes?



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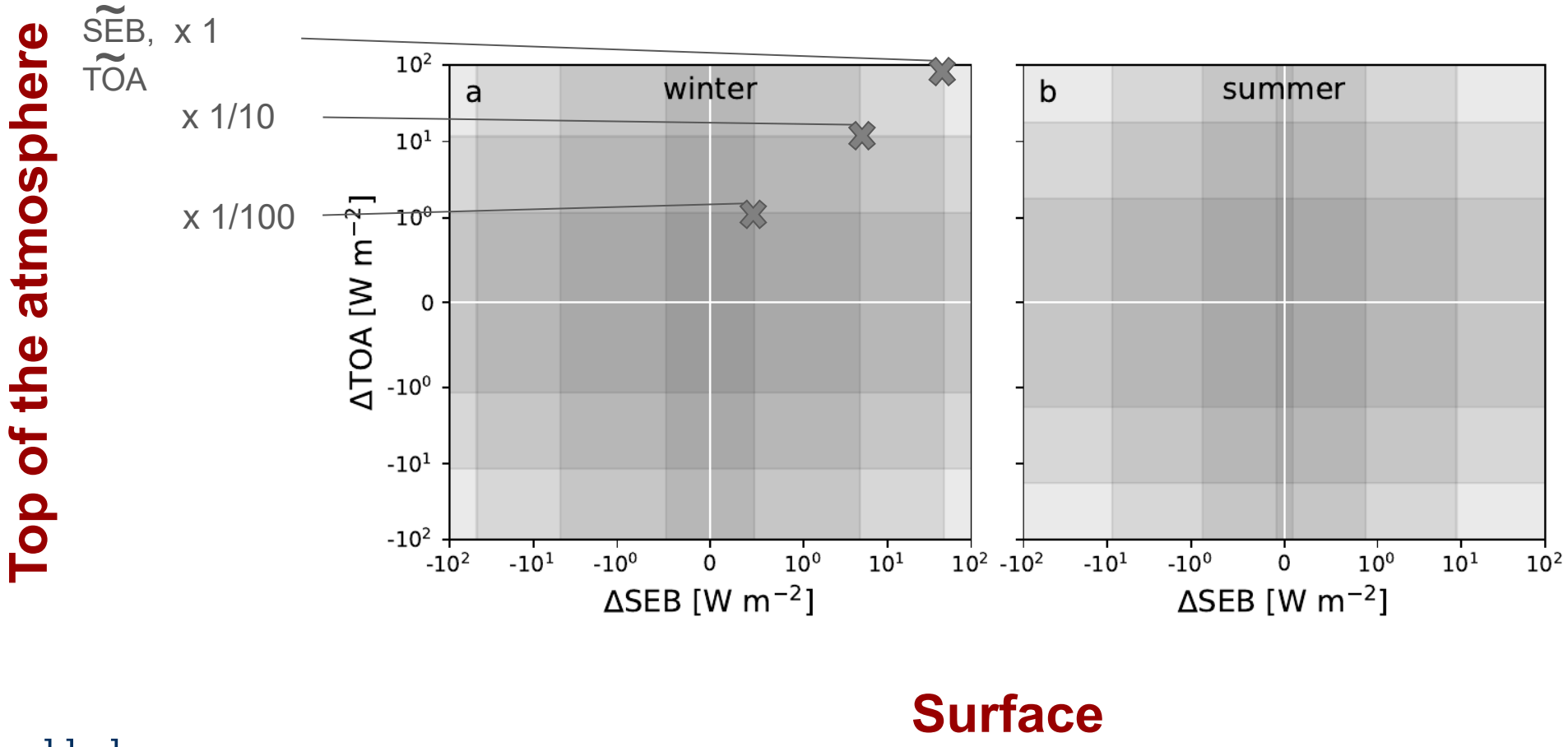
Karalis et al., 2026, submitted

Perturbations are evaluated on their effect on the energy balance at the top of the atmosphere (TOA) and the surface (SEB)



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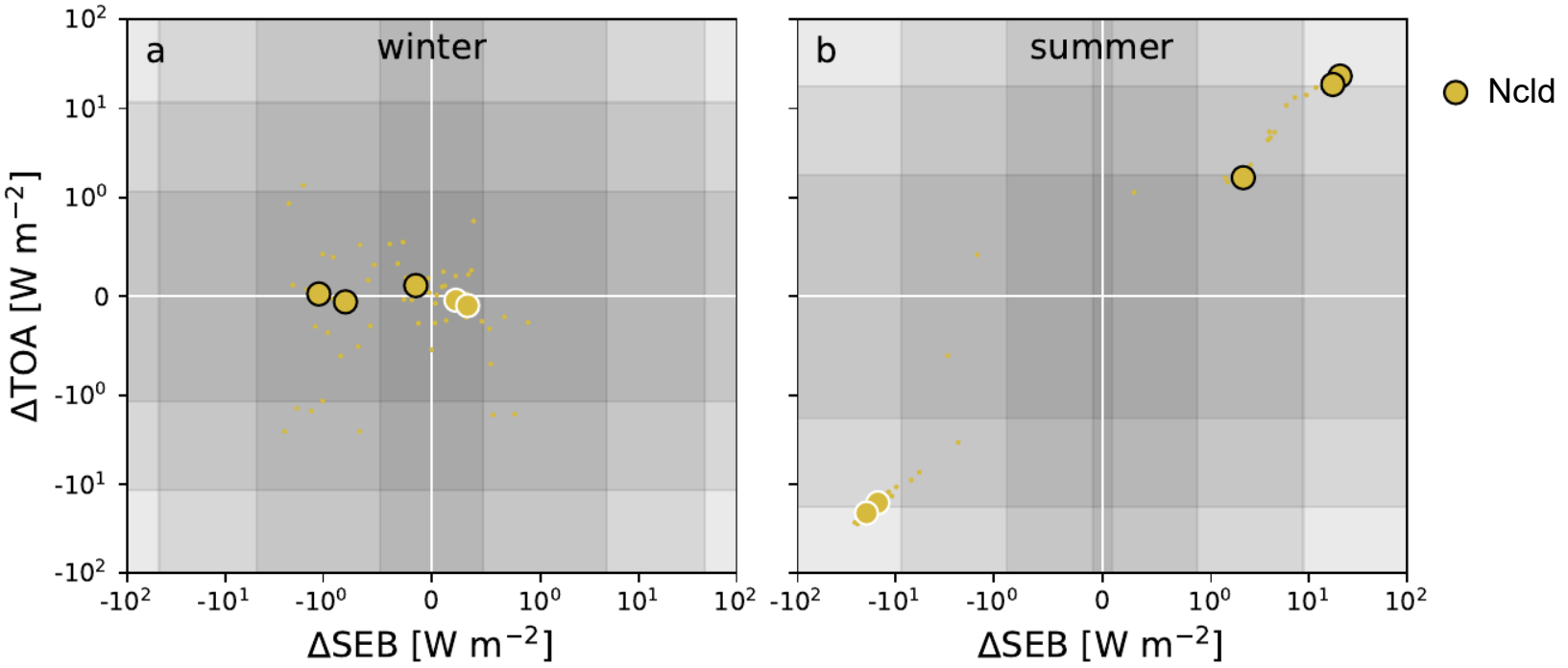
Karalis et al., 2026, manuscript

Large seasonal differences in the TOA and SEB response of microphysical parameters such as the cloud droplet number concentration

Top of the atmosphere



Surface

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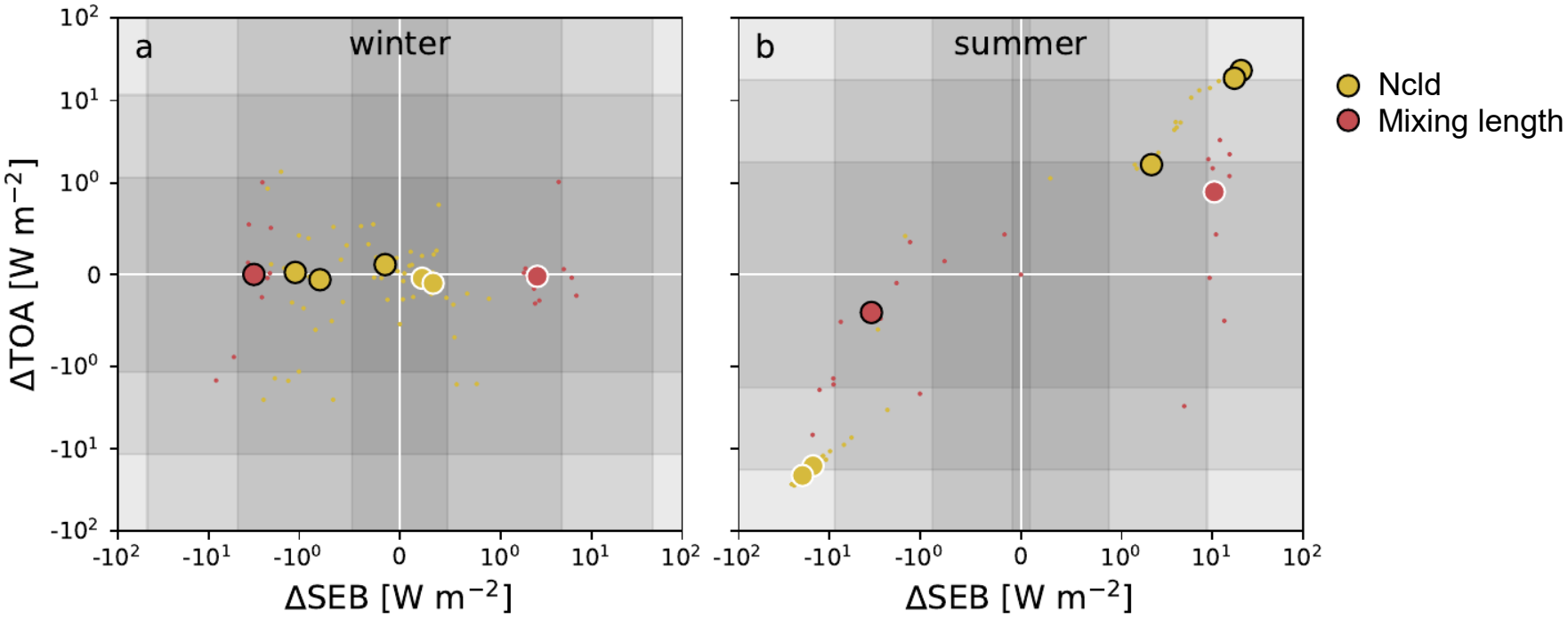
Karalis et al., 2026, manuscript

Perturbations in the boundary layer mixing properties drive considerable changes in the SEB in all seasons

Top of the atmosphere



Surface

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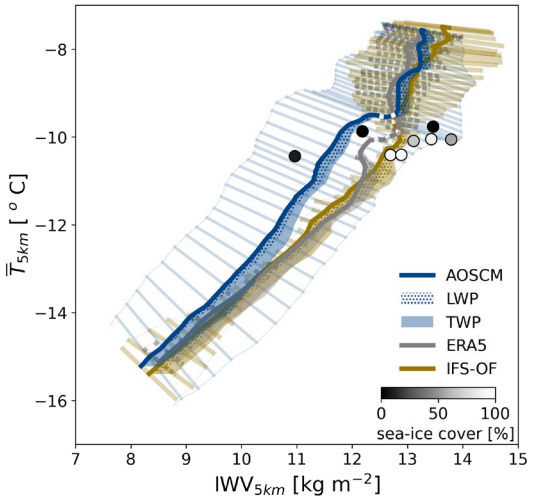
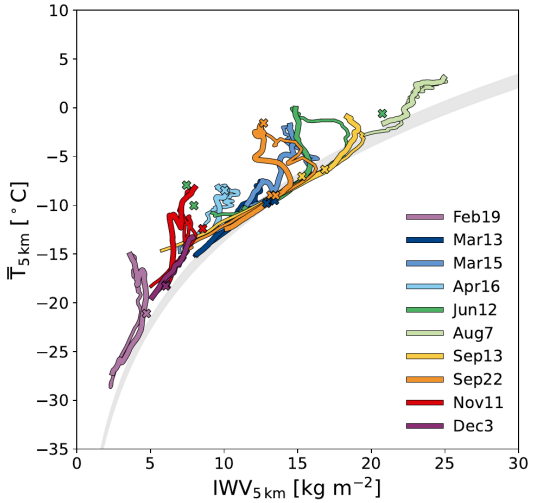
Karalis et al., 2026, manuscript

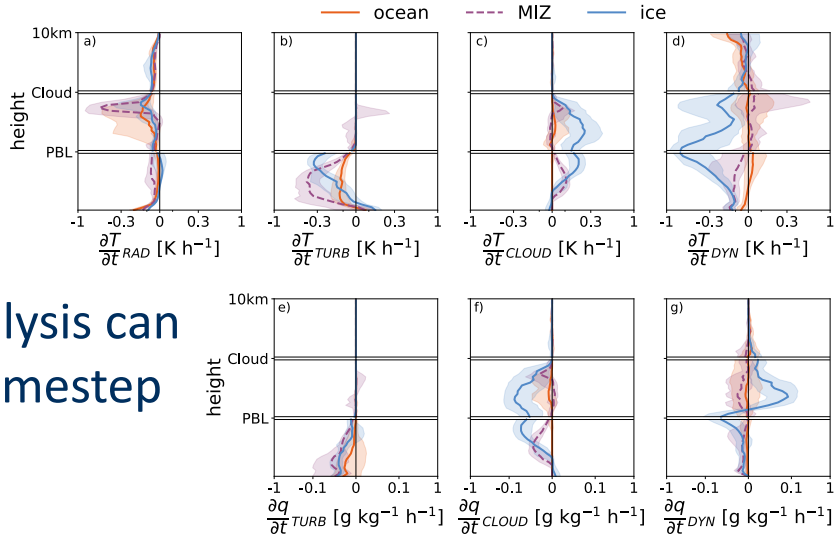
Framework summary



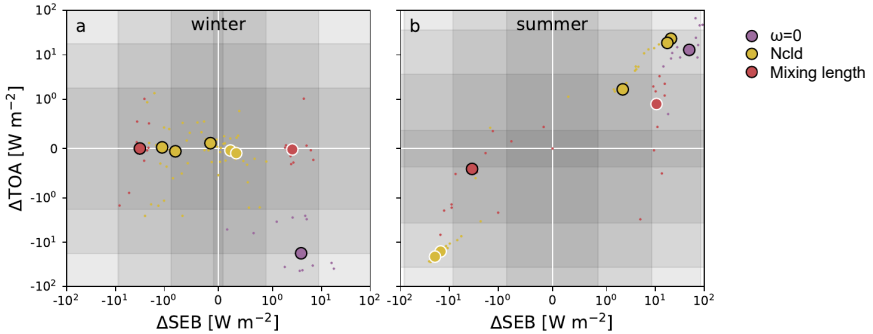
A Lagrangian single-column modeling framework can realistically simulate the Arctic air mass transformation



Large-scale ascent is the dominant driver of the transformation in ten WAIs across the seasonal cycle



The tendency analysis can be analyzed per timestep and process



The energy impact of Arctic air mass transformation is sensitive to perturbations in cloud and boundary layer processes

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Some final thoughts…

- AOSCM simulations are similar enough to the full model to be useful for examining the processes and their representation
- Interaction with the sea ice important for the evolution
- Vertical velocity is very important for the transformation, at least in the model
- HALO-AC3 observations revisited the same airmass, but only a limited part of the transformation was covered
- Framework has the potential to be used to design observational campaigns – upcoming CONIDA + IB Oden?
- Can be used, in combination with the full global model, to test and develop parameterizations

Thanks for listening! Questions?