Air-Mass-Following Large-Eddy Simulations to Build Process-Level Understanding of Arctic Amplification

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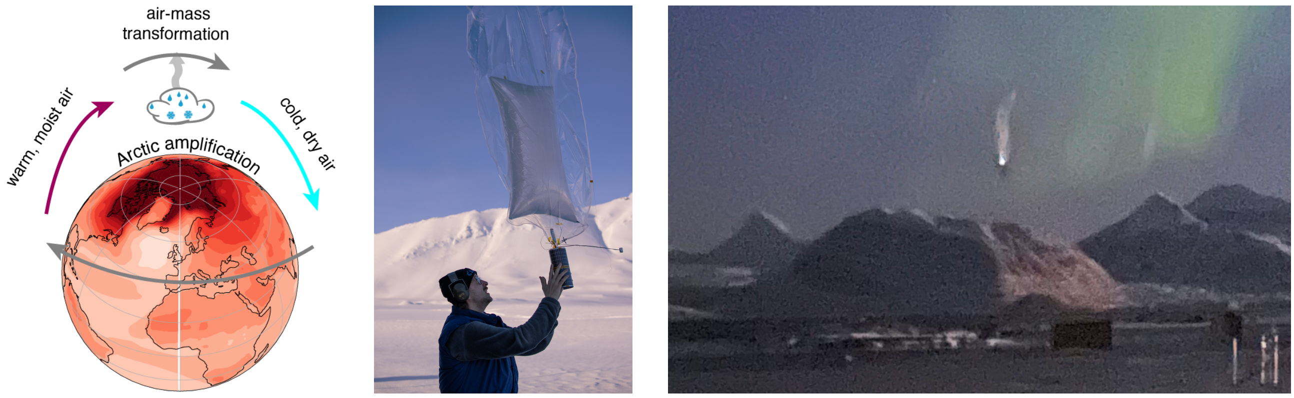
Probing Arctic amplification and its drivers requires process-level insight into how air masses entering the Arctic are transformed as they cool, mix, and exchange energy and moisture with surfaces and clouds. Within the ERC-funded research group A3M–Transform, we adopt an air-mass-centred framework that moves beyond the conventional steady-state box-model representation of the Arctic climate. This new perspective enables us to build a physically consistent link between Arctic amplification of large-scale temperature and precipitation changes and small-scale turbulent and microphysical processes that govern the local structure of the Arctic atmospheric boundary layer.



Arctic amplification beyond the box model: (Left) Conceptual sketch of how the Arctic couples to lower latitudes through transformation and exchange of air masses. (Mid/Right) Height-controlled meteorological balloon launched from Svalbard (Josua Schindewolf) to directly follow and observe a warm, moist air mass on its way into the Arctic.

Four air-mass transformation events have been successfully tracked using air-mass-following balloons launched from the Ny-Ålesund Research Station, Svalbard, during two field campaigns, providing unprecedented observational data. We will run a third campaign in early 2026, with twelve additional balloons to be launched from Station Nord, Greenland.

Our observational balloon data will be directly integrated into large-eddy simulations (LES) of the Arctic boundary layer through time-dependent forcings and boundary conditions. Our air-mass-following computer experiments will yield spatio-temporally resolved information on local thermo-fluid dynamic processes and mixed-phase cloud microphysics during the observed events.

For our air-mass-following computer study, we use the LES code DALES and employ a spatial resolution of 10 m in a computational domain that spans $(10 \times 10 \times 12)$ km and follows the recorded balloon tracks for two days. In addition to simulating the observed events, we will repeat selected runs under modified initial and boundary conditions following the SSP5-8.5 climate scenario. We will compute vertical fluxes of energy and moisture during transformations and analyse how the mean and final states of the air masses, as well as their energy and moisture budgets, change with varying climate parameters. We expect that our LES study will allow us to test the following hypotheses: (i) Liquid water path controls cloud persistence through cloud-top radiative cooling; and (ii) radiative cooling at cloud top (or in clear air) drives transformation during both the cloudy and clear states.