**Project:** ba1552

**Project title:** Air-Mass-Following Large-Eddy Simulations to Build Process-Level Understanding of Arctic Amplification

**Principal investigator:** Daniel Feldmann

**Reporting period:** 2026-01-01 to 2026-10-30

**Where do we stand?** The experimental phase of A3M–Transform concluded successfully in spring 2026. Ten additional CMET balloons were launched from Station Nord, including our longest flights (up to three days, reaching 89°N). Combined with our earlier campaigns, we now have in-situ data from 18 flights across two sites, most of which are suitable for informing and validating our air-mass-following LES.

In response to the reviewer's critique and the substantial reduction in allocated compute, we deliberately stepped back from the original production plan for the simulation phase. Instead, we used the resources to (i) conduct a proof-of-concept validation of our LES setup against observed balloon data, and (ii) perform a rigorous domain and resolution sensitivity study. These steps have confirmed the readiness of our approach and, importantly, have strengthened the scientific case for even finer grid resolution than we originally anticipated (Feldmann et al., 2026).

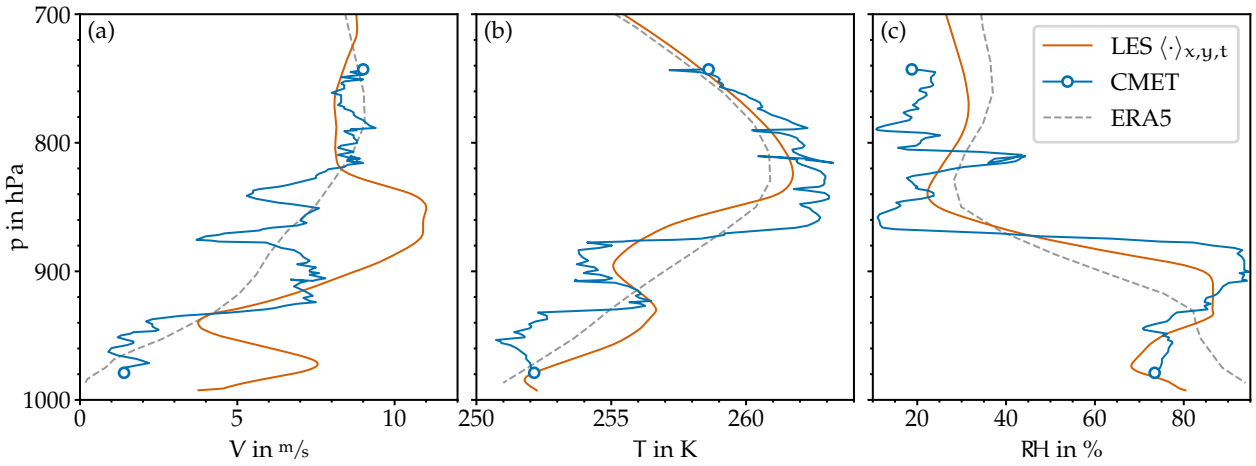



**Figure 1:** Validate simulation (LES) against in-situ measurements. Shown are vertical profiles (plotted against atmospheric pressure p) of different quantities that are representative for the launch time window of CMET balloon flight `20260318a3m04`. While the CMET sensor data represents highly localised data, the LES data represents a spatio-temporal mean, averaged over computational domain and 1800 s. Initial and boundary conditions of the LES are entirely informed from reanalysis data (ERA5) and independent of the CMET reference data the results are validated against. (a): Horizontal velocity magnitude $V = \sqrt{u^2 + v^2}$. (b): Atmospheric temperature T. (c): Relative humidity RH.

**Validation** We conducted one LES, deliberately keeping the simulation unaware of recorded CMET data. Instead, initial and boundary conditions were derived from reanalysis. The simulation was run with DALES, using the pseudo-Lagrangian, Arctic-adapted configuration of Schnierstein et al. (2024). Figure 1 compares vertical profiles of different mean quantities extracted from LES against highly localised CMET sensor data. Agreement is excellent above 820 hPa, where the flow field is essentially laminar. Below that level, the LES predicts the observed atmospheric structure reasonably well, with discrepancies consistent with the intrinsic variability of the turbulent boundary layer. Notably, the LES reproduces the observed moist layer and temperature inversion near the surface; features that are absent in the reanalysis forcing data. This demonstrates that the LES adds substantial spatio-temporal information beyond what reanalysis alone can provide,

even in simple mean profiles. The validation confirms that our setup is fit for purpose and that the planned production runs will yield physically meaningful results.

**Resolution** We tested horizontal grid spacings down to $\Delta_{x,y} = 5\,\mathrm{m}$ while keeping all other parameters unchanged. Figure 2a demonstrates a monotonically converging trend of the relative humidity profile. However, only the finest grid spacing reproduces the steep vertical humidity gradient inside the low-level moist layer we observed in our CMET measurements (Fig. 1c). Likewise, the vertical turbulent fluxes that are key to sustain this layer are only represented using the finest grid (Fig. 2b,c).

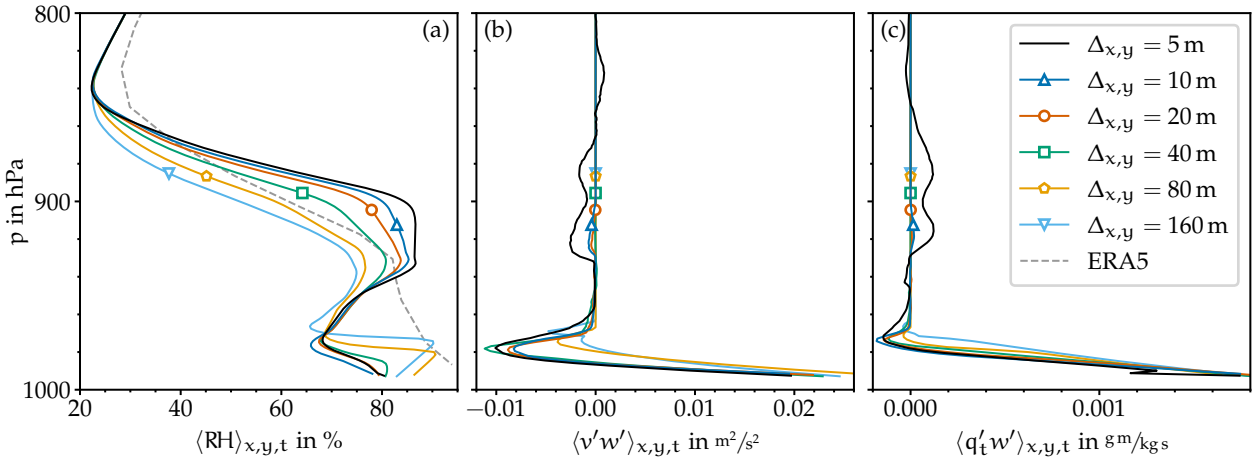



**Figure 2:** Effect of horizontal resolution ($\Delta_{x,y}$) on LES results. Shown are vertical profiles (plotted against atmospheric pressure p) of different quantities that are representative for the same flight/time as shown in figure 1. (a): Relative humidity RH. (b): Reynolds stresses $\langle v'w' \rangle$. (c): Moisture-velocity covariance $\langle q_t' w' \rangle$.

**Domain size** We varied the horizontal domain from 1 to 10 km. Small domains ($\leqslant 1\,\mathrm{km}$) artificially suppress large-scale structures and lead to qualitatively different turbulence dynamics and transport statistics. Convergence towards domain-independent behaviour is only approached at 10 km, particularly for near-surface fluxes (Feldmann et al., 2026).

**Implications** The combination of 5 m resolution and 10 km domain size makes full-trajectory simulations of multi-day flights prohibitively expensive. To address this, we have substantially reworked the pseudo-parallel I/O and restart infrastructure of DALES. Our new implementation supports true parallel I/O and allows flexible regridding and re-decomposition between restarts. This enables a nesting-like strategy: a coarse-resolution LES covering the full flight trajectory, with successive restarts onto finer grids at stations of interest. This approach delivers the required resolution where it matters, while keeping the overall computational cost within reach. With this, we are ready to commence the originally proposed production suite in the upcoming funding period.

## References


D. Feldmann, L. Graßmel, and F. Pithan. Combining air-mass-following balloon observations and large-eddy simulations to build process-level understanding of arctic amplification. Copernicus GmbH, Mar. 2026. doi: 10.5194/egusphere-egu26-20220.

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