Airborne Closure of Moisture Budget inside Arctic Atmospheric Rivers

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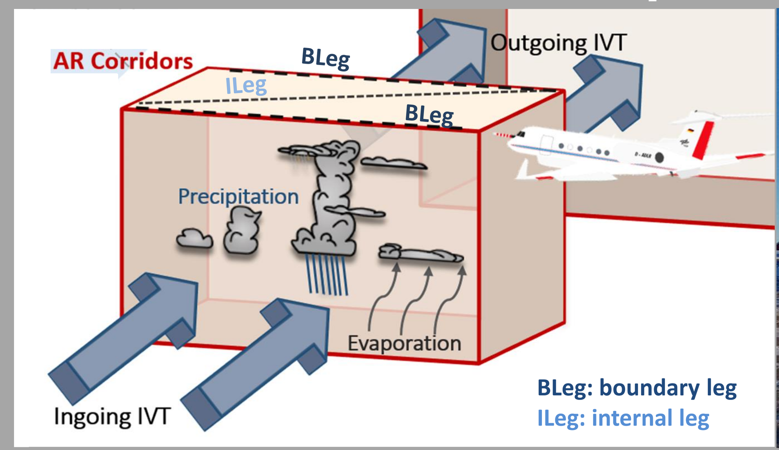
Motivation:

Analyzing the moisture budget in corridors of Atmospheric Rivers (ARs) along their pathway is key to understand the spatiotemporal AR evolution and precipitation efficiency and air mass transformation.

- Long-range aircraft allow calculating moisture budgets of AR corridors (Eq. 1) by zig-zag flight pattern.
- Different flight legs for specific components of moisture budget.

Can the research aircraft HALO and its measurement instrumentation close the moisture budget of Arctic ARs?

The airborne concept of moisture budget closure:



$$\frac{\delta IWV}{\delta t} = E - P - \nabla IVT \qquad (EQ.1)$$

Local change in integrated water vapour; Surface Evaporation; Surface Precipitation; Divergence of integrated water vapour transport (IVT)

General methods:

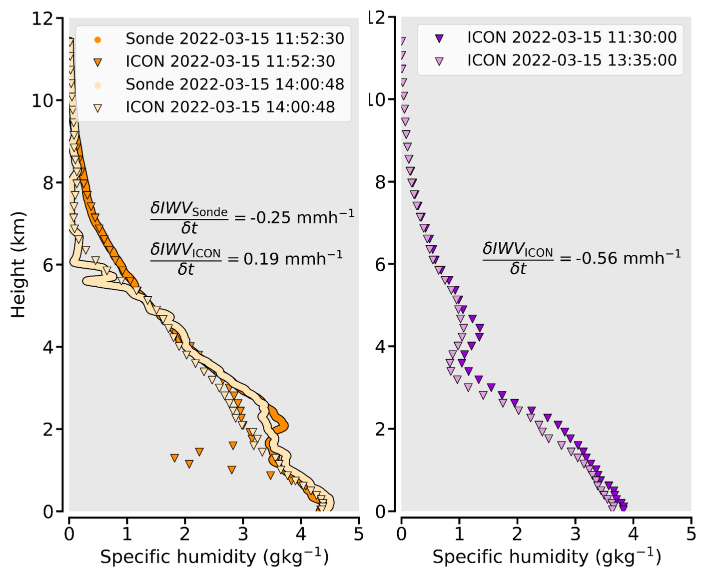
Different measurement devices suit for specific budget quantities. However, viewing perspective, resolution (e.g. Dorff et al., 2022) and sampling frequency deteriorate airborne representation of AR conditions (Dorff et al., 2023) → **multiple collocated observations are envisioned.**

Across the AR core front, ARs exhibit lateral gradients in thermo-dynamical conditions (Cobb et al., 2021), the budget closure needs to distinguish between pre-frontal and post-frontal sectors (Guan et al., 2020).

Comparison with ICON-2km simulations interpolated onto the flight track (model set-up aligned to Schemann et al., 2020).

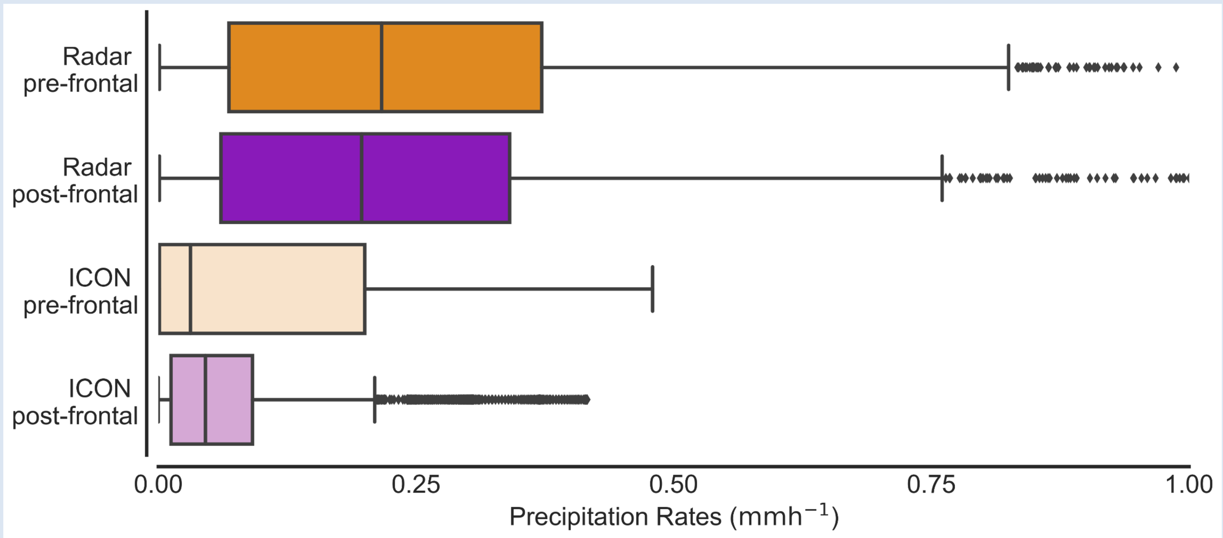
Temporal change in IWV:

- Temporal tendency from sondes in warm sector during internal leg with similar location
- Since we lack real dropsondes, we place synthetic sondes in ICON to mimic their feasibility
- Sondes indicate **moistening in the pre-frontal sector**, while ICON misrepresents the low-level moisture
- Signs of post-frontal drying



Surface precipitation:

- from Ka-Band cloud and precipitation radar → offset calibrated radar reflectivity (Ewald et al., 2019), melting layer detection for phase classification, average of multiple Z-R / Z-S relationships
- Radar precip. occurrence: 46% (pre-frontal), 22% (post-frontal) of flight time

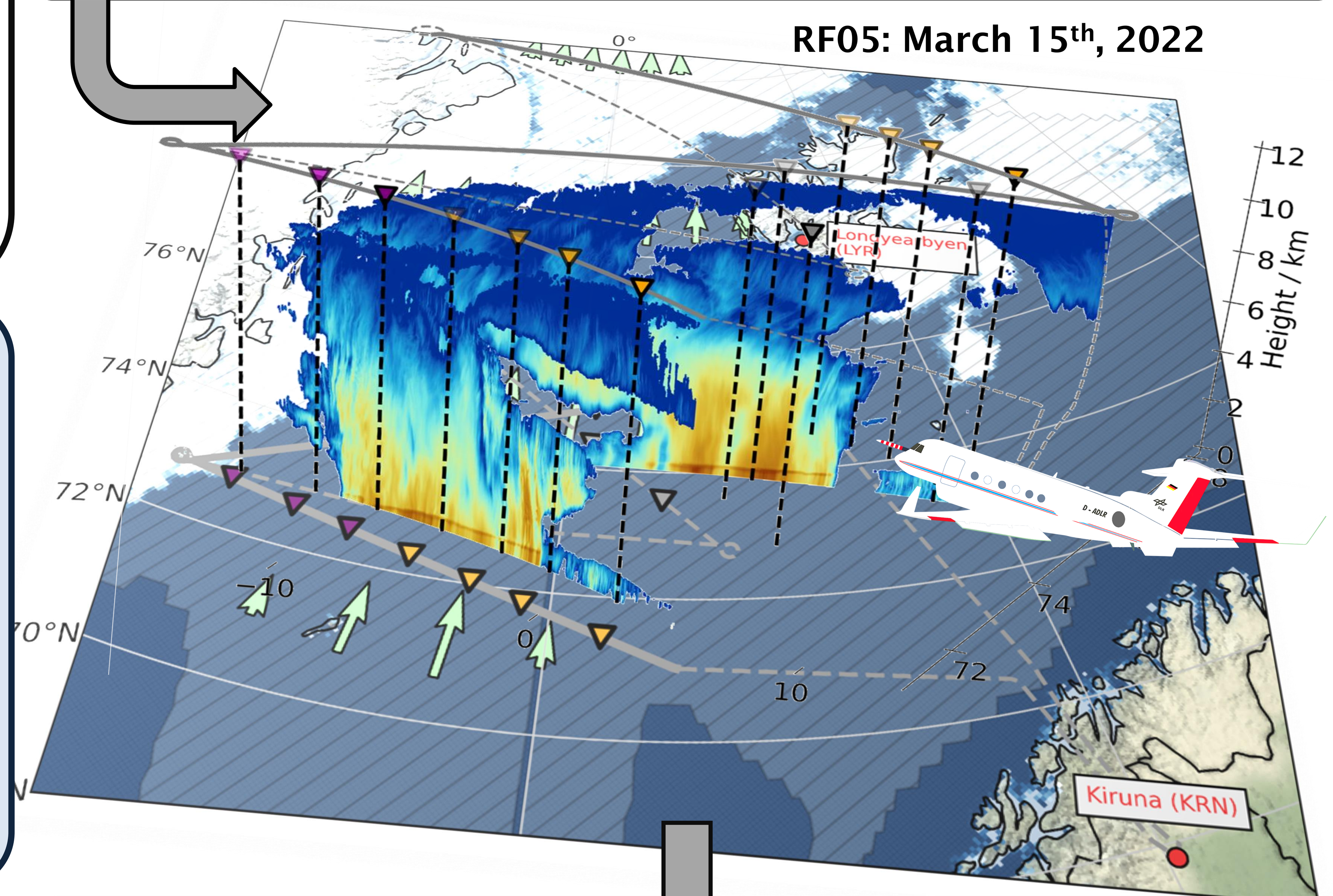


Evaporation:

- derivable from sonde-based SST temperature estimates (tbd.)
- ICON indicates minor role of evaporation; one order of magnitude smaller than other components

The realisation during HALO-(AC)³:

The first week of the HALO-(AC)³ flight campaign (Spring, 2022) was characterised by a 'family' of ARs heading sequentially into the Arctic ocean. The strongest AR observed during research flight RF05 (Walbröl et al., 2023)



Conclusions:

- ➢ Moisture advection dominates against mass convergence in contrast to mid-latitude ARs.
- ➢ HALO's instrumentation allows the derivation of all budget components that reflect the frontal gradient in a reasonable order of magnitude compared to ICON.
- ➢ HALO provides unique vertical resolution of budget components.
- ➢ Airborne measurements can represent the correlation between precipitation and convergence. The simplified airborne closure yields an error of roughly 1 mm/h.
- ➢ Major error sources are the flight duration, the sounding frequency (Dorff et. al, 2023) and the limited representativeness of the flight curtain (Dorff et al., 2022).
- ➢ Missing post-frontal dropsondes increase uncertainties.

IVT divergence:

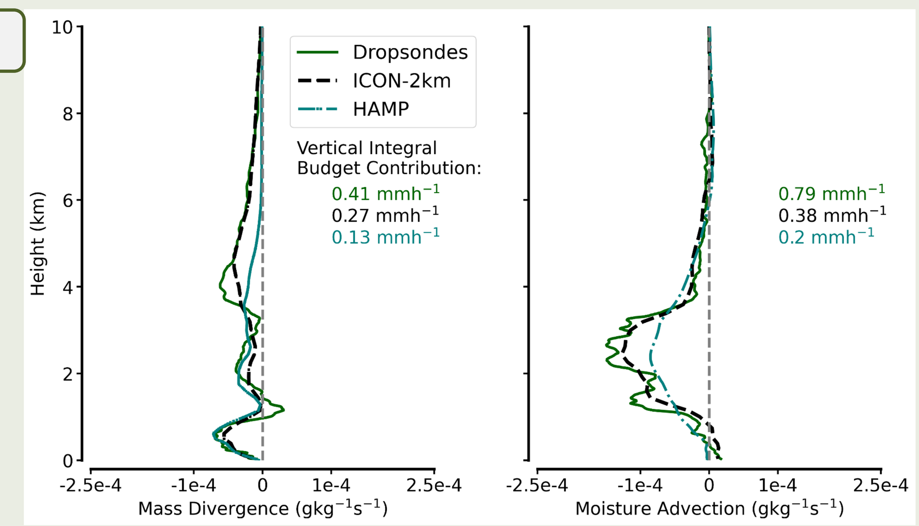
has two impacts (change in amount of moisture and precipitation) that can be attributed to two components:

$$\nabla IVT = -\frac{1}{g}\int_{p_{sfc}}^{p_{top}} \nabla (q\,\vec{v})\,dp = -\frac{1}{g}\Big(\underbrace{\int_{p_{sfc}}^{p_{top}} v\,\nabla q\,dp}_{\text{Moisture advection}} + \underbrace{\int_{p_{sfc}}^{p_{top}} q\,\nabla v\,dp}_{\text{Mass divergence}}\Big) \quad \text{(EQ. 2)}$$

- Dropsondes measure wind and moisture but restricted to sporadic profiles.
- A regression retrieval using brightness temperatures from the HALO microwave package (HAMP) & PAMTRA (Mech et al., 2014 & 2020) complements vertical moisture profiles
- Divergence derived via regression methods (Bony & Stevens, 2019)

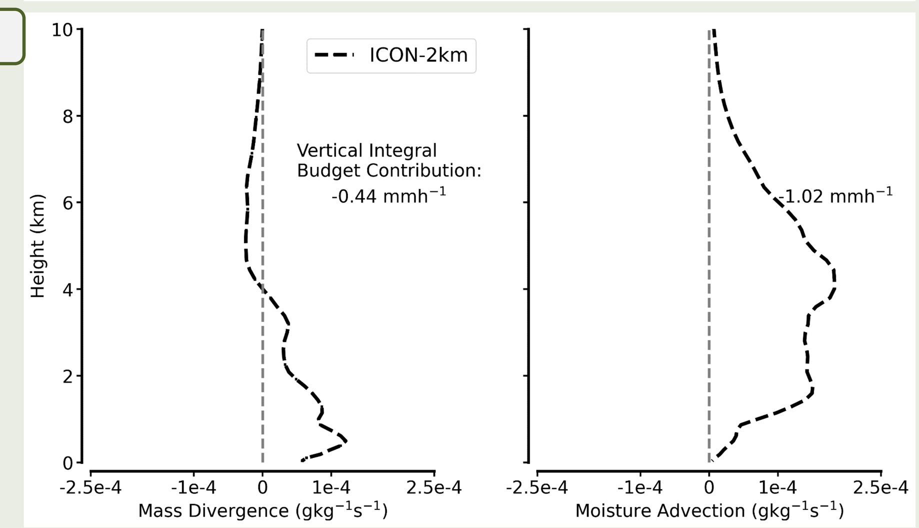
Pre-frontal:

- **Similar vertical profiles in moisture transport divergence for all datasets.**
- **Pre-frontal sectors supply moisture**



Post-frontal:

- **Post-frontal moisture transport acts as a sink for the budget.**
- Divergence calculations not feasible for sondes (missing releases) and HAMP due to sea-ice.



➢ **Moisture advection dominates IVT divergence (convergence) throughout the entire AR cross-section.**

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