Yesterday's cloud, tomorrow's rain

Quantifying cloud and precipitation re-evaporation with a Lagrangian diagnostic

Lena Fasnacht[1,2], Killian P. Brennan[1,2], Franziska Aemisegger[1,2]

[1] Institute of Geography, University of Bern, Switzerland, [2] Oeschger Centre of Climate Change Research, University of Bern, Switzerland

Motivation

Effect of internal moisture recycling on atmospheric water budget and downstream dynamics remains largely unknown

Evaporation of clouds and precipitation affects the atmospheric water cycle and can be understood as internal moisture recycling. Observations of stable water isotopes have shown that in the tropics, **20–50% of precipitation can re-evaporate** (Worden et al. 2007), and in the extratropics, this proportion can even rise to **60% during cold front passages** (Aemisegger et al. 2015). While these studies highlight the importance of precipitation evaporation, there is still **little information available on the role that cloud evaporation** plays in the atmospheric water cycle. Furthermore, there are currently **no tools available to systematically and efficiently investigate internal moisture recycling**. By extending an existing Lagrangian tool, we aim to contribute to a better understanding of internal moisture recycling and its effects on the atmospheric water budget.

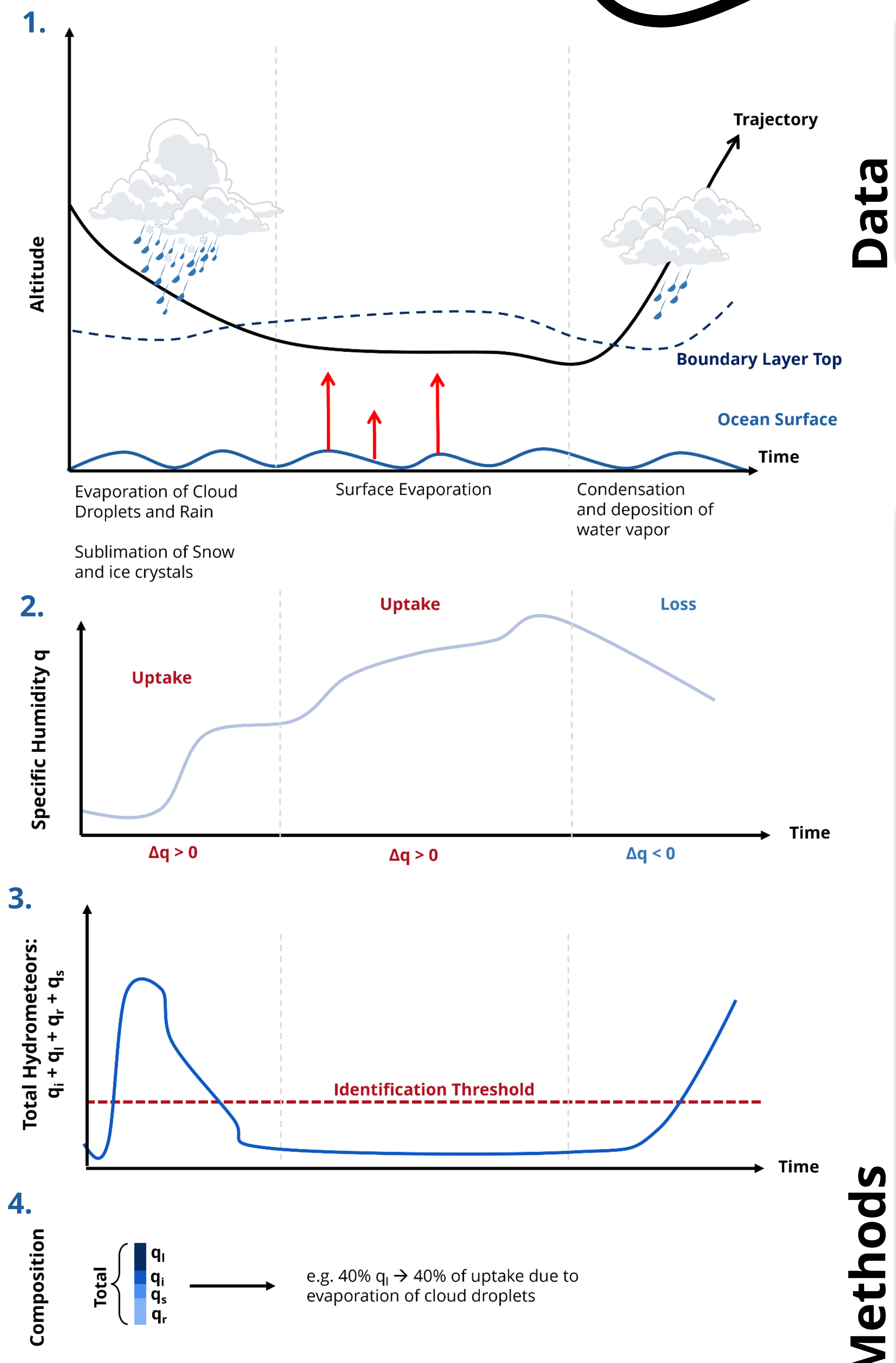

Fig. 1: Schematic description of the moisture source diagnostic (MSD; Sodemann et al. 2008) and the extended version of it to identify moisture uptake processes (MSPA).

Data

The ECMWF IFS cycle 43R1 was used to simulate a 13-day period in Jan-Feb. 2018, initialized on 24 January at 12 UTC, with 83 vertical tropospheric levels and 0.4° horizontal resolution. In addition to the standard IFS output, the dataset also includes tendency (TEND) outputs for specific humidity (q) and diabatic heating rates for the parameterized processes large-scale microphysics, convection and turbulence (Spreitzer et al. 2019).

Methods

Moisture Source Diagnostic (MSD) and Process Attribution (MSPA)

We identify moisture sources and attribute uptake processes in the following way (Fig. 1):

1. and **2.** Identify moisture uptake regions along backward trajectories computed with LAGRANTO and the moisture source diagnostic developed by Sodemann et al. (2008).

3. Moisture Source Process attribution

Given **uptake at t:**

$$\textbf{At t-1}: \underbrace{q_i + q_l + q_s + q_r}_{\text{Total hydrometeors}} > \text{threshold}$$

yes

Uptake assigned to:
- Microphysics
  (rain or cloud droplet evaporation, snow or ice crystal sublimation)

no

Uptake assigned to:
- Surface Evaporation (BL)
- Mixing/Convection (above BL)

4. Distribute moisture uptake based on hydrometeor content prior to the uptake

Evaluation with IFS q-TEND

Moisture sources identified with the Lagrangian moisture source process attribution (MSPA) are compared with IFS q-TEND output.

Results

Do MSPA and IFS q-TEND agree?

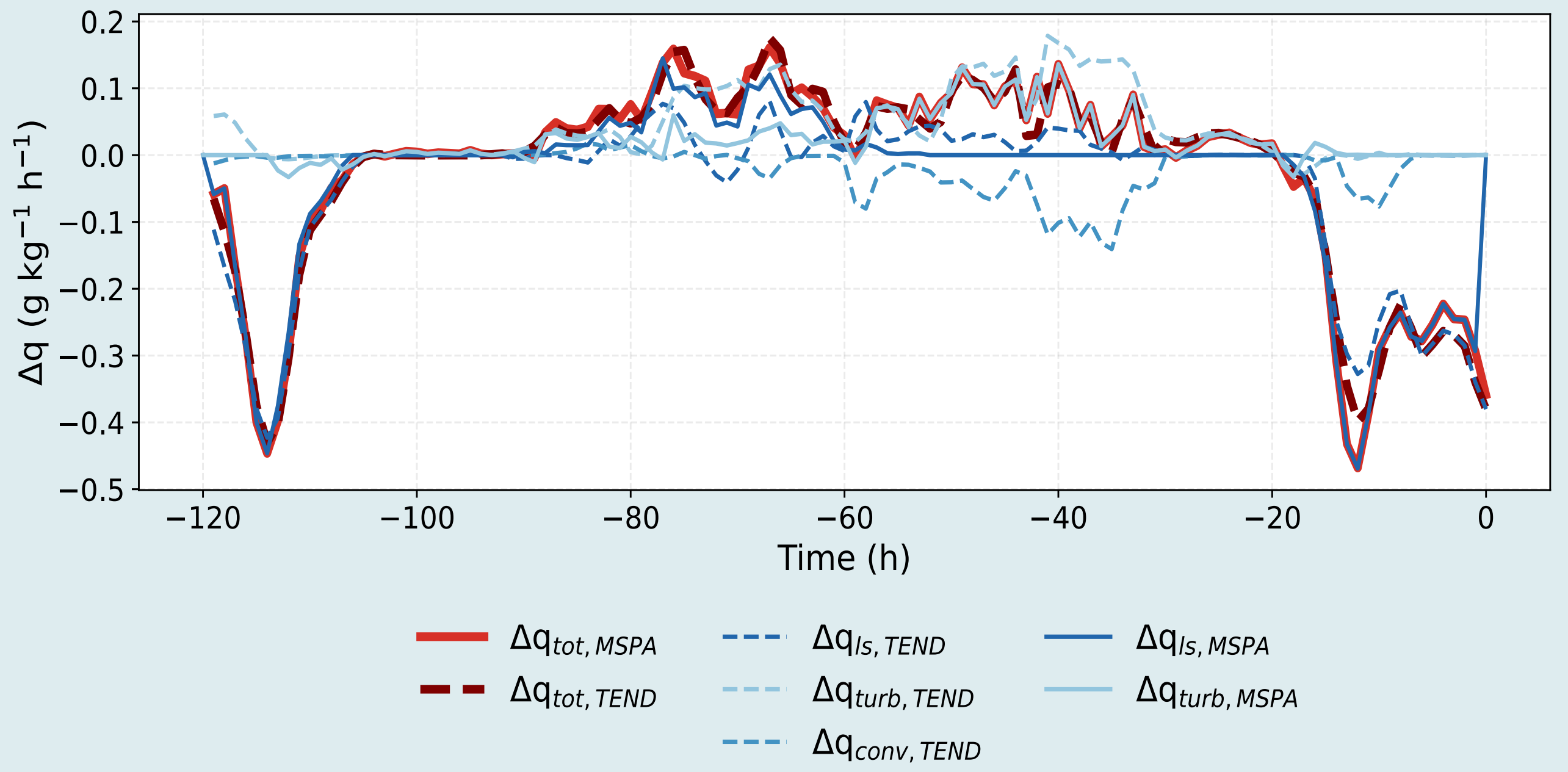

Fig. 4: Temporal evolution of hourly changes in q, averaged over all trajectories, for moisture uptakes identified and attributed using the Lagrangian diagnostic MSPA and the IFS q-TEND output. Shown components are TOT = total, LS = large-scale microphysics, turb = turbulent, and conv = convection. Pearson correlation coefficients between MSPA and TEND are 0.95 for TOT, 0.82 for LS, and 0.44 for turb.

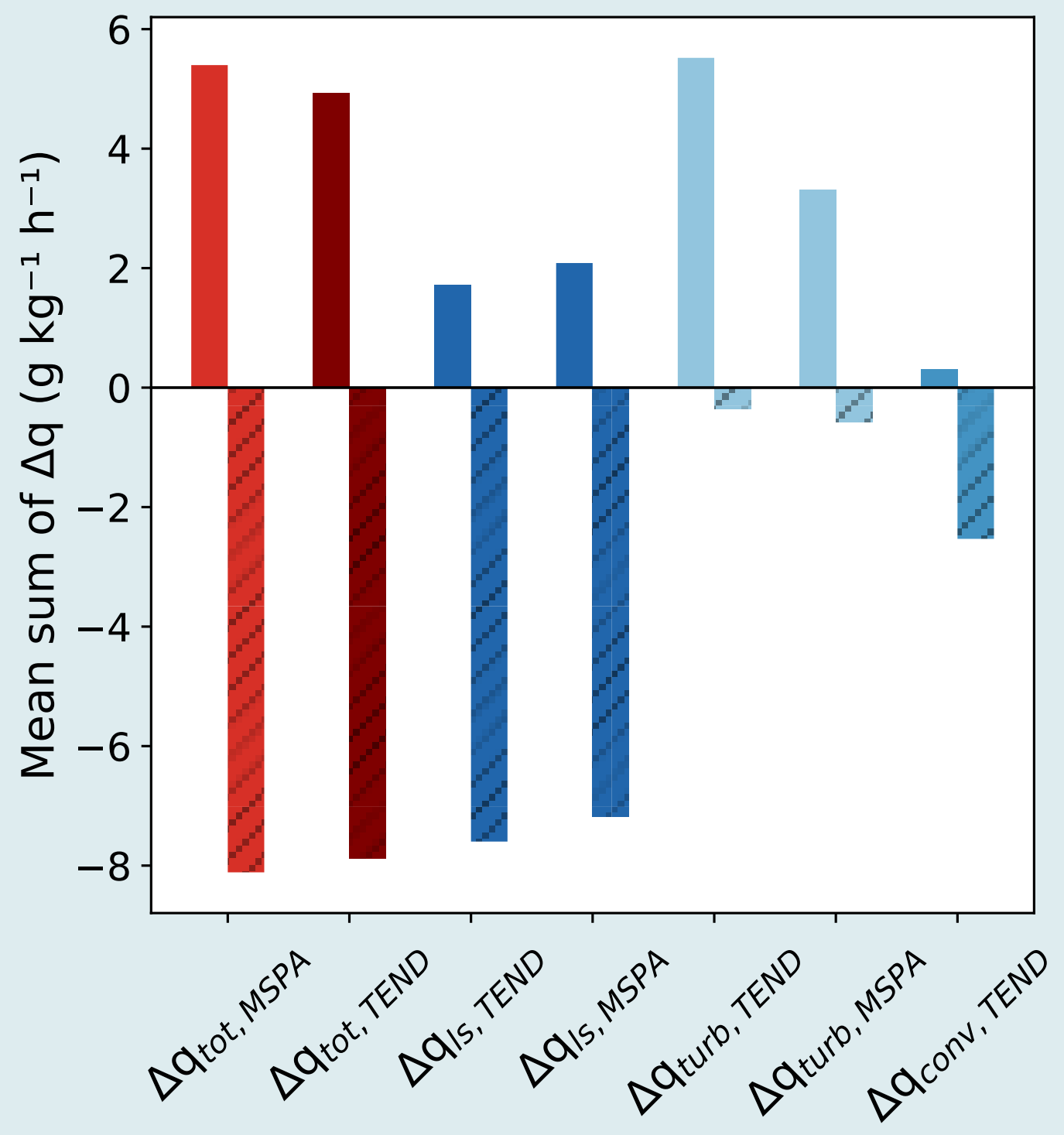

Fig. 5: Sum of positive and negative hourly changes in q averaged over all trajectories, for moisture uptakes identified and attributed using MSPA and the IFS q-TEND output. Shown components are TOT = total, LS = large-scale microphysics, turb = turbulent, and conv = convection.

- MSPA microphysical uptakes agree well with q-TEND (Fig. 4)
- Turbulent-process uptakes show weaker agreement (Fig. 4)
  → including surface fluxes as constraints could improve results
- Uncertainty of the convection parameterization
- Total uptakes and losses along trajectories are similar between MSPA and q-TEND (Fig. 5)

Methods

Trajectory Setup

Coherent airstream identified as a subset of 5-day backward trajectories initialized on 6 February 2018 at 12 UTC within a 200 km radius around Reykjavik, Iceland.

The airstream (Fig. 2) is characterized by segments of:
- Ascent and descent → formation or dissipation of clouds
- Positive CAO Index (Fig. 3) → strong surface evaporation and cloud formation (Fletcher et al. 2016; Papritz and Spengler 2017)

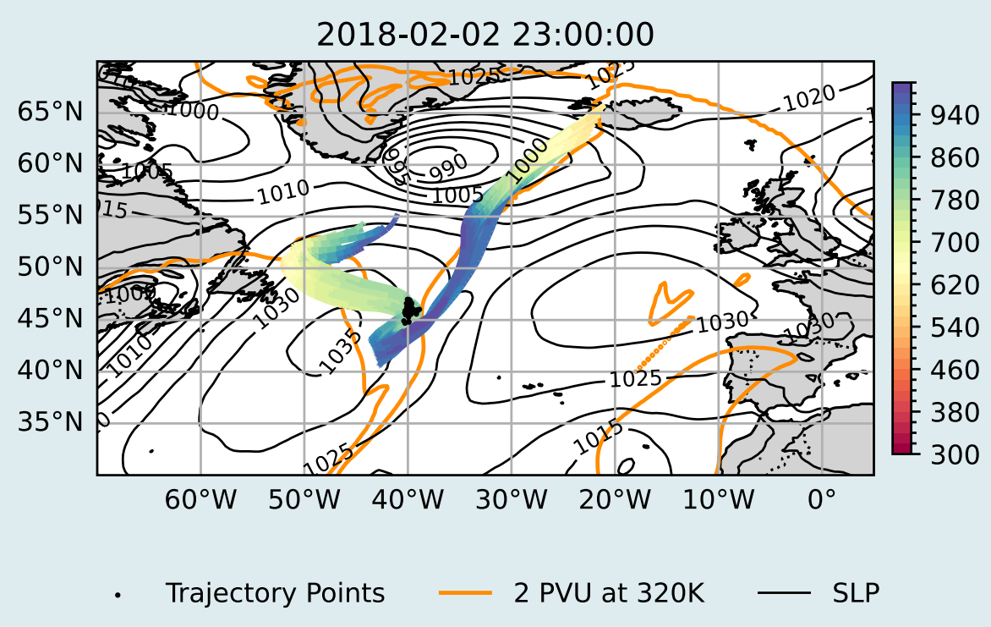

Fig. 2: Selected trajectories colored by pressure. Black dots show the location of the air parcel at indicated timestep.

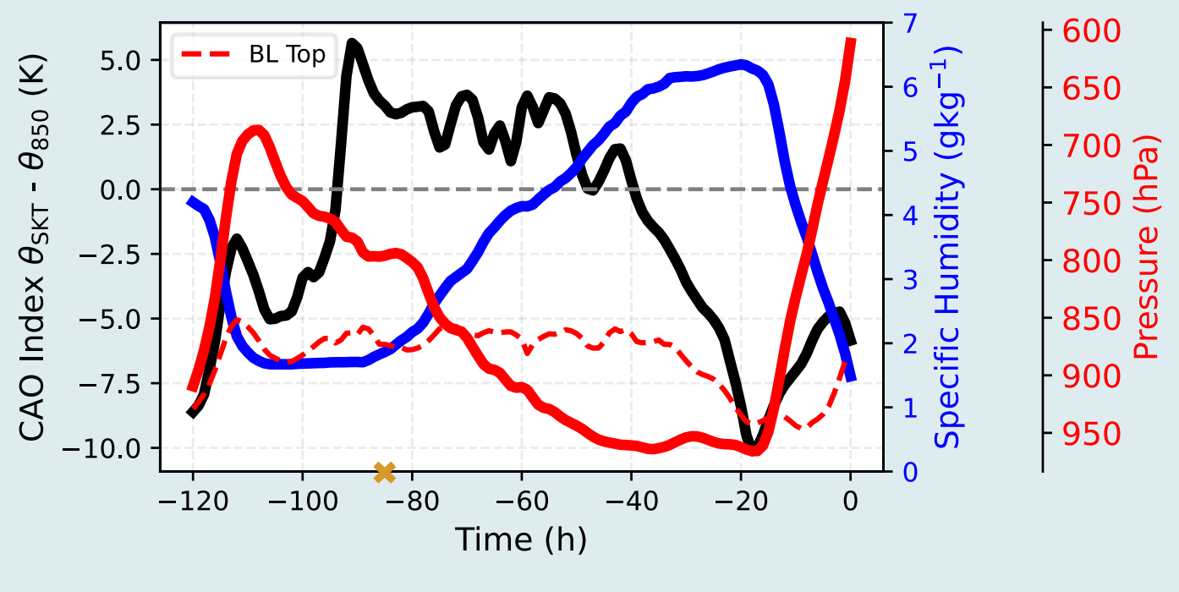

Fig. 3: Temporal evolution of pressure, CAO index, q and boundary layer top averaged over all trajectories. Orange cross marks the timestep of the air parcel location indicated in Fig.2.

Results

Are moisture uptakes from cloud and precipitation evaporation important?

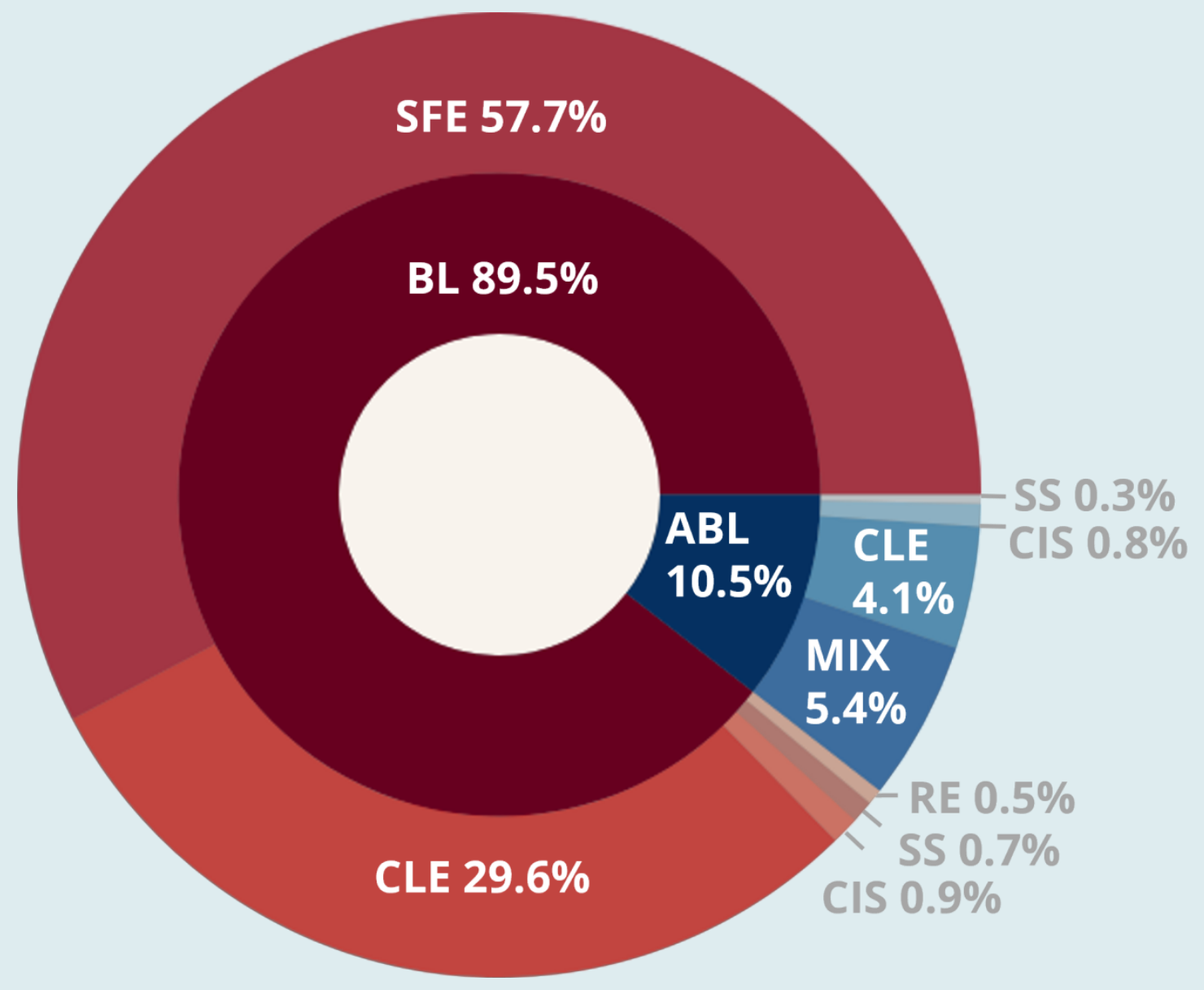

Fig. 6: Contribution of each uptake process to the moisture explained at trajectory arrival points (80% accounted for). Red shading indicates uptake within the boundary layer (BL), and blue shading indicates uptake above the boundary layer (ABL). The processes are: SFE (surface evaporation), CLE (cloud droplet evaporation), CIS (cloud ice sublimation), SS (snow sublimation), RE (rain evaporation), and mixing.

Where is the moisture taken up?

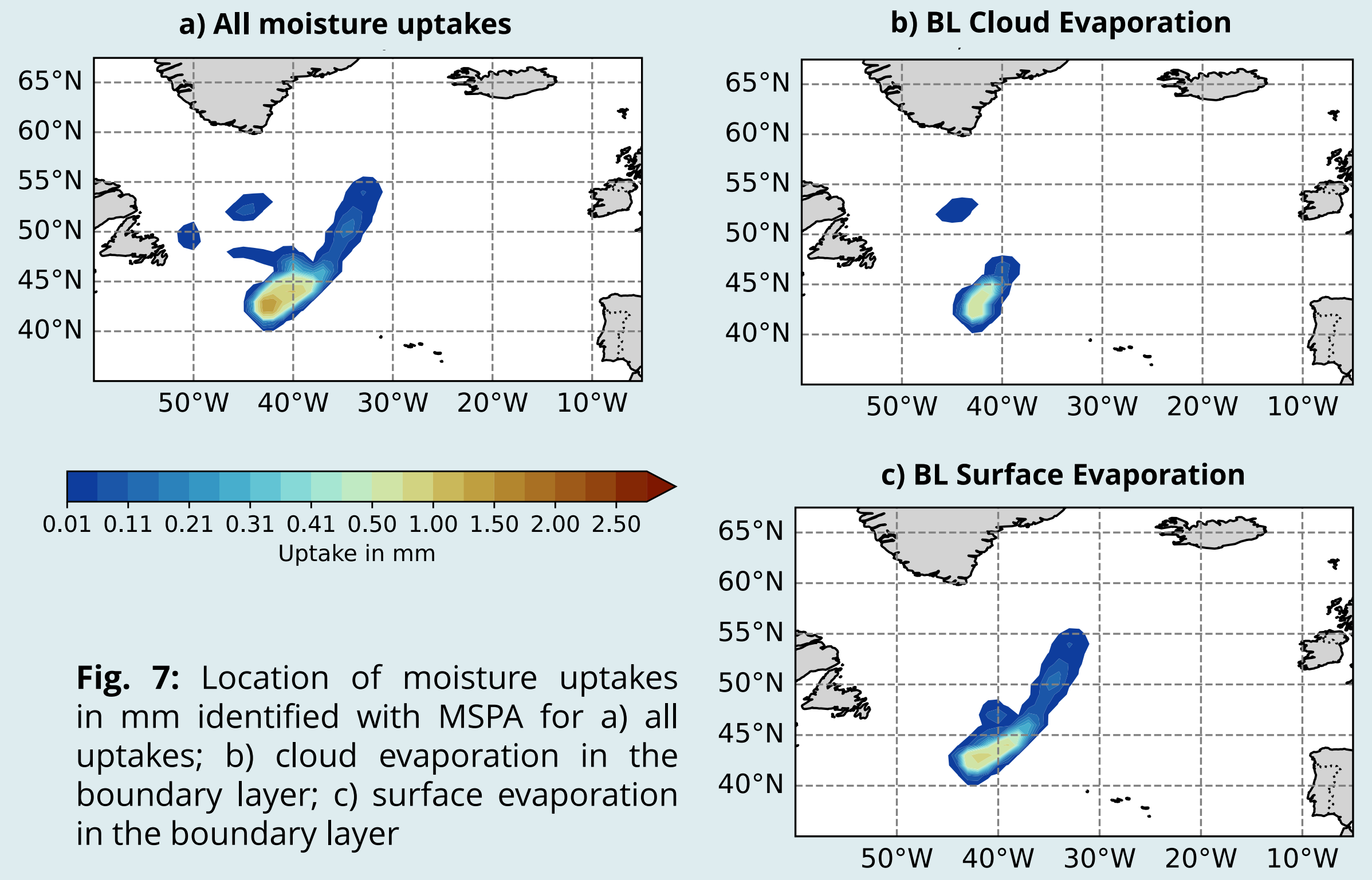

Fig. 7: Location of moisture uptakes in mm identified with MSPA for a) all uptakes; b) cloud evaporation in the boundary layer; c) surface evaporation in the boundary layer

- Cloud evaporation is an important moisture source (Fig. 6), especially in BL entrance region, with shallow cumulus clouds due to CAO (Fig. 7)
- Surface evaporation hotspot where air parcels are within the CAO and/or close to the ocean surface (Fig. 7)

Conclusions

Internal moisture recycling can be quantified by adapting an existing moisture source diagnostic tool

- MSPA agrees well with IFS q-TEND
- Cloud droplet evaporation is an important moisture source

Outlook:
- Inclusion of surface fluxes
- Investigate different atmospheric features (DI, extreme precipitation events in dry regions)
- Process-based evaluation with stable water isotope observations (NAWDIC)

Want to know more?

Abstract

Contact:
lena.fasnacht@unibe.ch

References
Aemisegger, F., Spiegel, J. K., Pfahl, S., Sodemann, H., Eugster, W., and Wernli, H.: Isotope meteorology of cold front passages: A case study combining observations and modeling, Geophys. Res. Lett., 42, 5652–5660, https://doi.org/10.1002/2015GL063988, 2015. **Fletcher, J. K.,** S. Mason, and C. Jakob, 2016: A Climatology of Clouds in Marine Cold Air Outbreaks in Both Hemispheres. *J. Climate*, **29**, 6677–6692, https://doi.org/10.1175/JCLI-D-15-0783.1. **Papritz, L.,** and T. Spengler, 2017: A Lagrangian Climatology of Wintertime Cold Air Outbreaks in the Irminger and Nordic Seas and Their Role in Shaping Air–Sea Heat Fluxes. *J. Climate*, **30**, 2717–2737, https://doi.org/10.1175/JCLI-D-16-0605.1. **Sodemann, H**., C.Schwierz, and H.Wernli (2008), Interannual variability of Greenland winter precipitation sources: Lagrangian moisture diagnostic and North Atlantic Oscillation influence, J. Geophys. Res., 113, D03107, doi:10.1029/2007JD008503. **Spreitzer, E**., R. Attinger, M. Boettcher, R. Forbes, H. Wernli, and H. Joos, 2019: Modification of Potential Vorticity near the Tropopause by Nonconservative Processes in the ECMWF Model. *J. Atmos. Sci.*, **76**, 1709–1726, https://doi.org/10.1175/JAS-D-18-0295.1. **Worden J,** Noone D, Bowman K; Tropospheric Emission Spectrometer Science Team and Data contributors. Importance of rain evaporation and continental convection in the tropical water cycle. Nature. 2007 Feb 1;445(7127):528-32. doi: 10.1038/nature05508. PMID: 17268467.