

C03 Improving process understanding and model representation of stratospheric water vapour and related climate feedbacks

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Motivation

- Water vapour in the UTLS needs **better observational constraints** (e.g. high accuracy, resolution, sampling)
- Climate models simulate **significant moist biases** in extratropical UTLS, as shown in Phase 1 for EMAC (Fig. 1), CMIP6 and CCMI-2022 models.
- UTLS moist bias **impacts dynamics and circulation** by inducing local cooling, related upward and poleward jet shifts, and strengthened BDC (Fig. 1).
- Many different processes affect the UTLS water vapour budget (e.g. BDC, monsoons, isentropic mixing, convection, ice microphysics), which implies **challenges for process understanding and model representation**

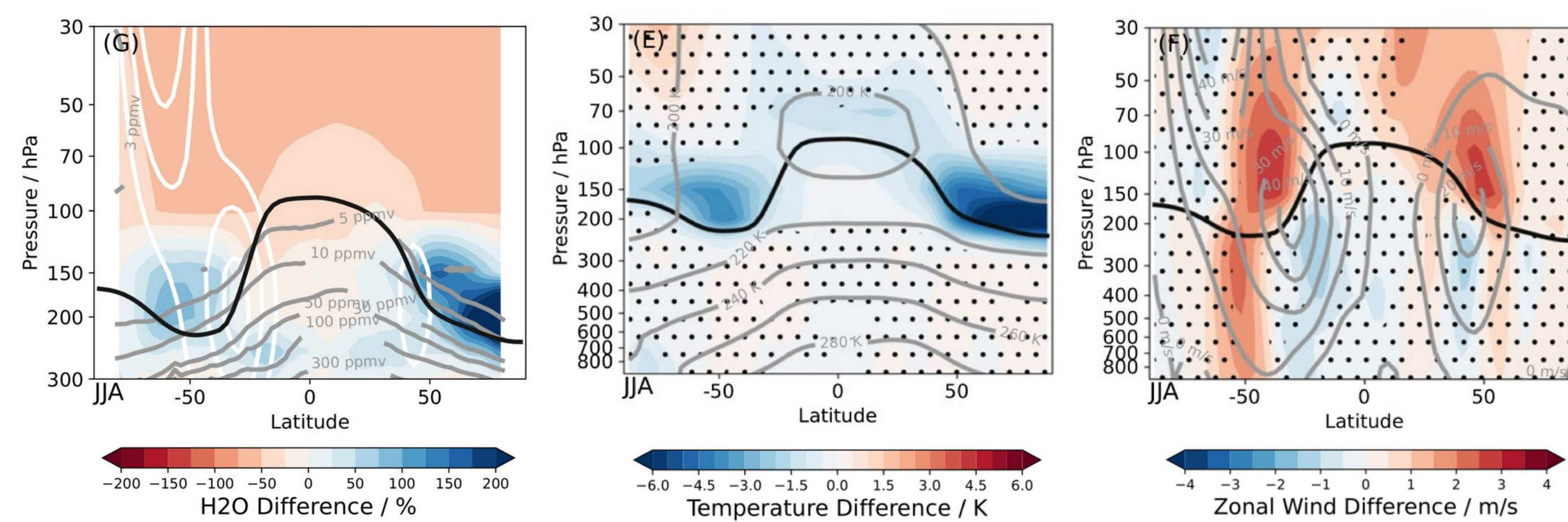


Figure 1. Circulation impact of stratospheric water vapour increase during JJA. (a) Water vapour bias of EMAC climate model simulation as difference to SWOOSH satellite observations, (b) temperature effect induced by that bias, and (c) the related circulation impact as change of zonal wind.

Charlesworth et al., 2023

Role within TPChange

Collaborations

A01, A04 **B01** **C01** TPEx II aircraft campaign for new measurements in the extratropical UTLS and case study on convection.

B01, B06, B07, B08 **C01, C05, C08** Analysis of control processes for UTLS water vapour budget; exchange of observational and model data and methods.

B09 **C02, C04, C07, C09** Investigation of impacts of water vapour changes (e.g. on circulation) based on hierarchy of models.

Contribution to TPChange synthesis

- Z01** Contribution to compiled dataset & use for process study
- Z03** Improve model representation of UTLS water vapour

Results from phase I

Creation of IAGOS UTLS water vapour dataset

- 60000 flights aboard IAGOS passenger aircraft are compiled 1994-2020 (incl. adjustment method for LMS water vapour)

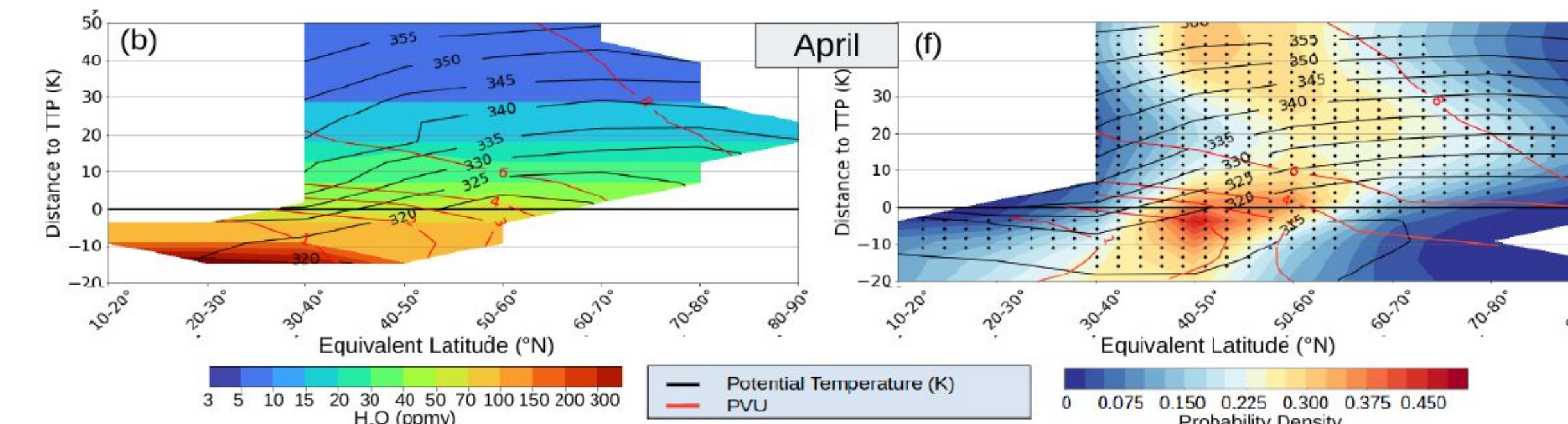


Figure 2. Multi annual representative IAGOS UTLS water vapor dataset. (left) Multi annual monthly mean for North Atlantic region for April, (right) Representativeness of observations compared to ERA5.

Konjari et al., 2025a

Observation of Overshooting convection during TPEx

- Overshooting convection and water vapour transport in a polar air mass outbreak
- Strong water vapour signature of up to 60 ppmv together with ozone of 600ppbv

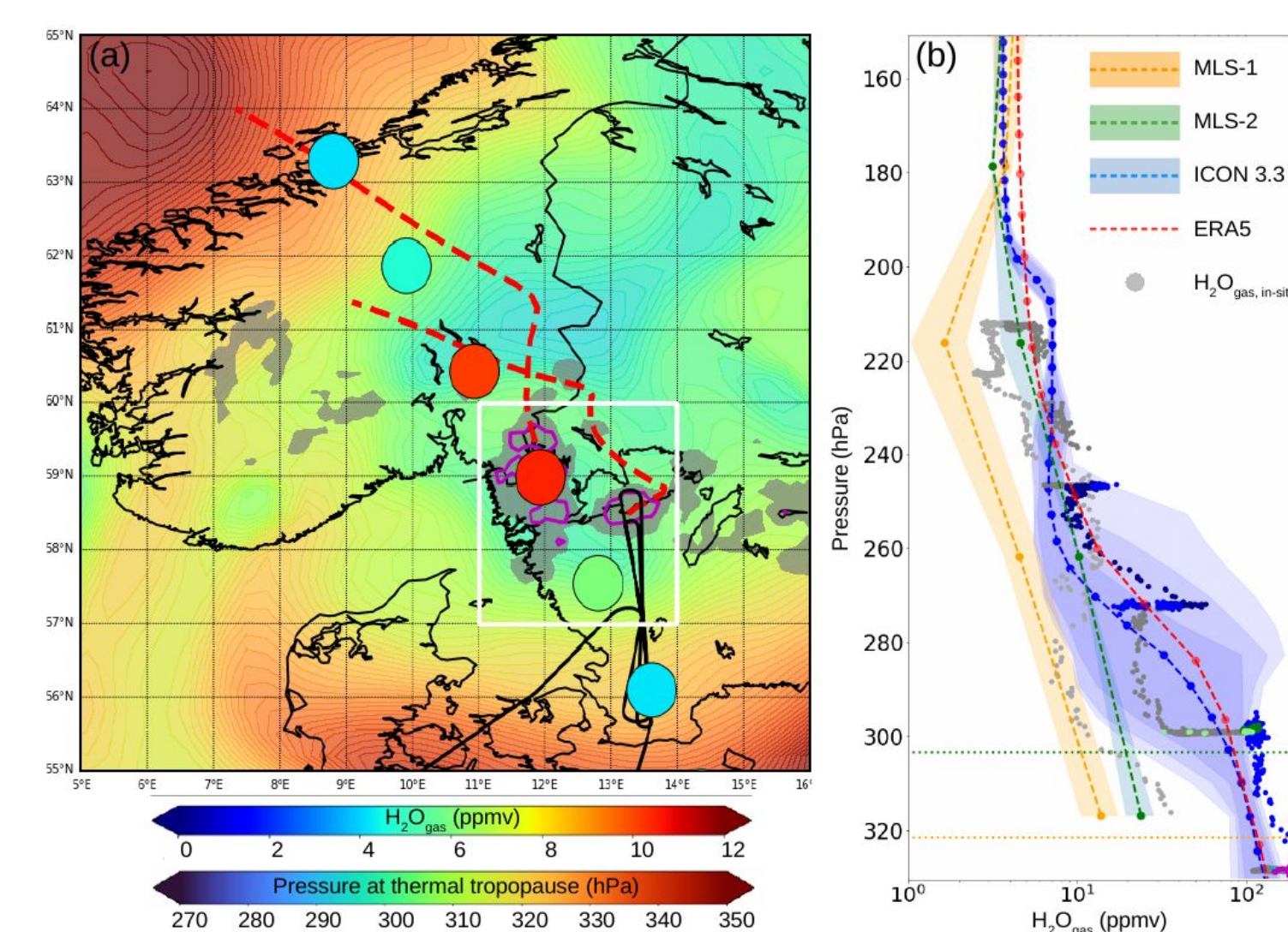


Figure 3. Observation of overshooting convection in UTLS polar air masses. (left) MLS water vapour observations (circles) and tropopause pressures, (right) Water vapour profiles from in-situ, MLS satellite and ICON / ERA5 model output.

Konjari et al., 2025b

Changes in UTLS structure and composition:

- Tropical upper troposphere narrows (above 340K) in addition to tropical widening below
- Related changes in composition show reduction of young air

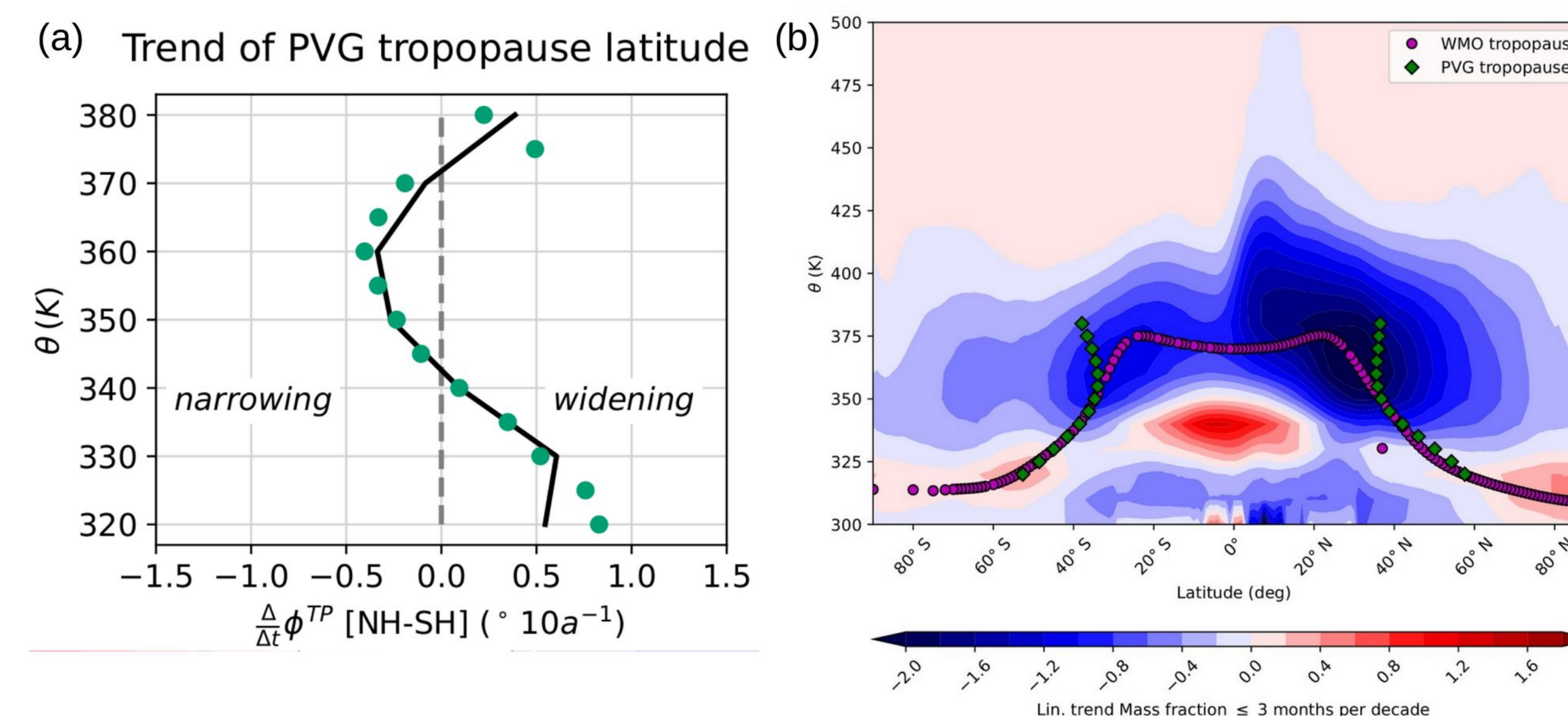


Figure 4. Trends in the structure of the UTLS over 1979-2017 diagnosed from (a) dynamical tropopause (PV gradient-based, ERA5) and (b) young air mass fraction (< 3 months) from CLAMS model age spectrum (in %/decade).

Turhal et al., 2024

Research plan phase II

Main goal: Enhance process understanding and model representation of UTLS water vapour to improve future climate projections.

Research questions:

- Which are the **control processes** for the water vapour budget of the extratropical UTLS (e.g. convection, isentropic & turbulent mixing, large-scale advection, cloud microphysics)?
- How reliable is the **process representation** in weather and climate models, what are model deficits?
- How does UTLS **water vapour change in a future climate** and what processes are involved in these changes?
- Which **climate and circulation feedbacks** are induced by UTLS water vapour changes and how well are these represented in models?

Work plan:

- WP 1:** Evaluation of in-situ aircraft and satellite observations and conduction of model simulations (present & future climate; EMAC and Lagrangian EMAC-CLaMS).
- WP 2:** Process investigation regarding overshooting convection and isentropic transport using aircraft observations; and model assessment regarding representation of UTLS water vapour.
- WP 3:** Investigation of future UTLS water vapour changes, involved processes, induced climate feedback, and improvements from Lagrangian model transport.
- WP 4:** Analysis of circulation effects (e.g. jets, storm tracks) and dynamical mechanisms induced by UTLS water vapour changes, based on dedicated mechanistic model simulations.