In situ observations of turbulent cross-tropopause mixing of cirrus particles at the jet stream over the North Sea

TP CHANGE

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MOTIVATION

- **Cross-tropopause exchange influences composition of the ExTL (extratropical transition layer)**
- **Water vapor in the ExTL has radiative impact on surface temperature**
- **Transport mechanism necessarily diabatic**
- **Cirrus particles not expected above the tropopause**
- **Limited research on cross-TP mixing of ice particles. Few in situ measurements of stratospheric cirrus (*)**

Case description and flight path

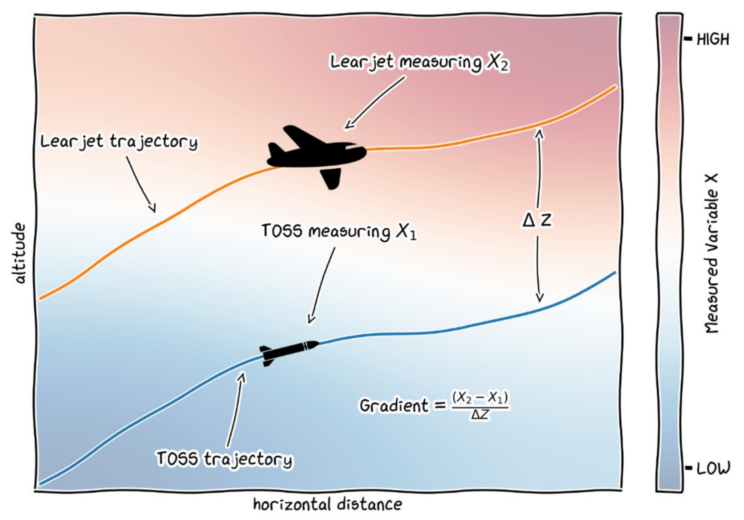


Fig. 1: Schematic representation of the two-platform measurement approach

- TPEx-campaign in summer 2024 over Northern Germany
- **Novel measurement setup: Two-platform measurements (TPC-TOSS) with redundant instrumentation**
- Here: Flight F10

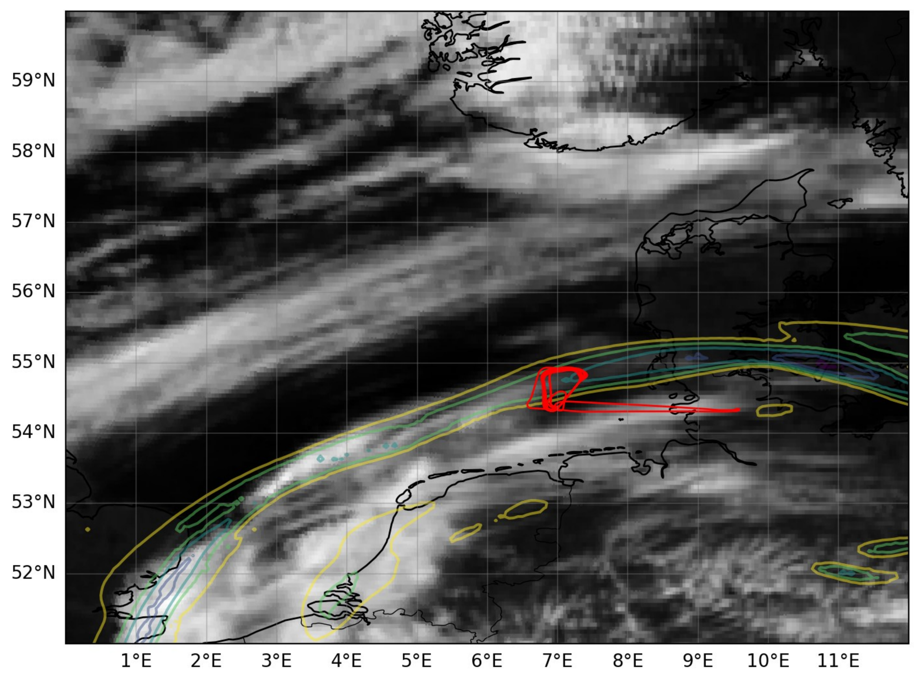


Fig. 2: Satellite image, flight path and shear (colors) for flight F10

- Location of the measurement flight over the North Sea
- Flight path crosses the northern edge of the jet stream on multiple flight levels
- High cirrus clouds at the southern side of the jet
- High vertical shear of horizontal wind above the jet

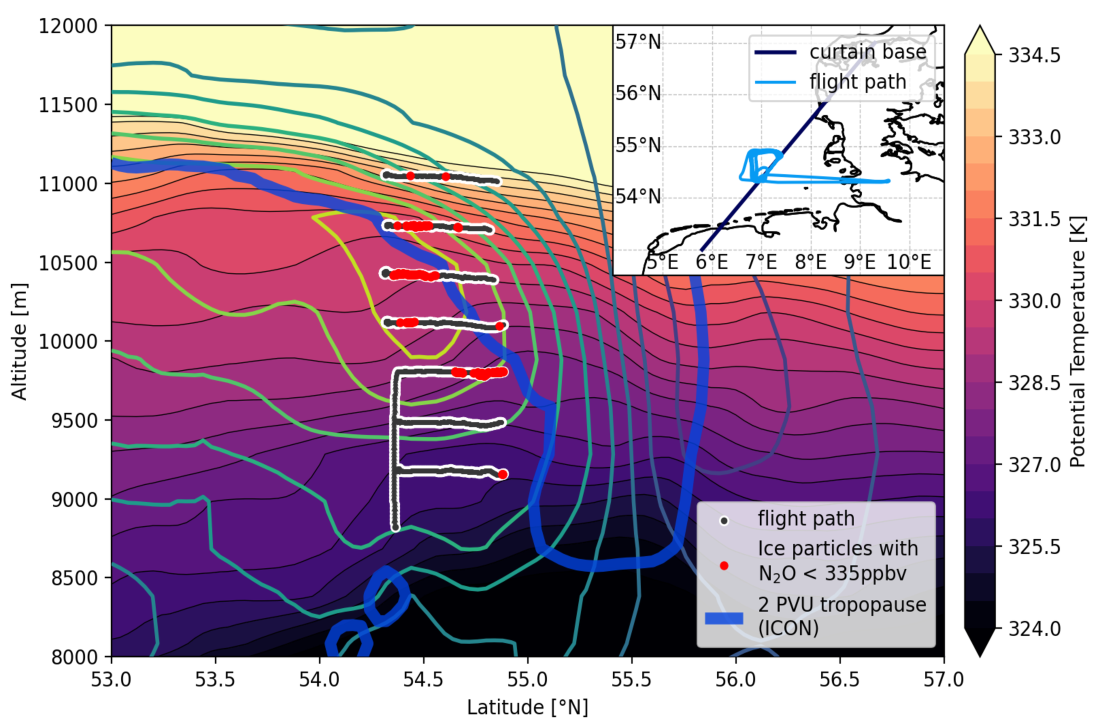


Fig. 3: Vertical cross-section, potential temperature, 2 pvu-tropopause, flight path

- **Simultaneous measurements of ice particles and chemically stratospheric signature of the probed air mass**
- FL350 entirely above 2 pvu, focus of this study

Ice particle measurements and mixing

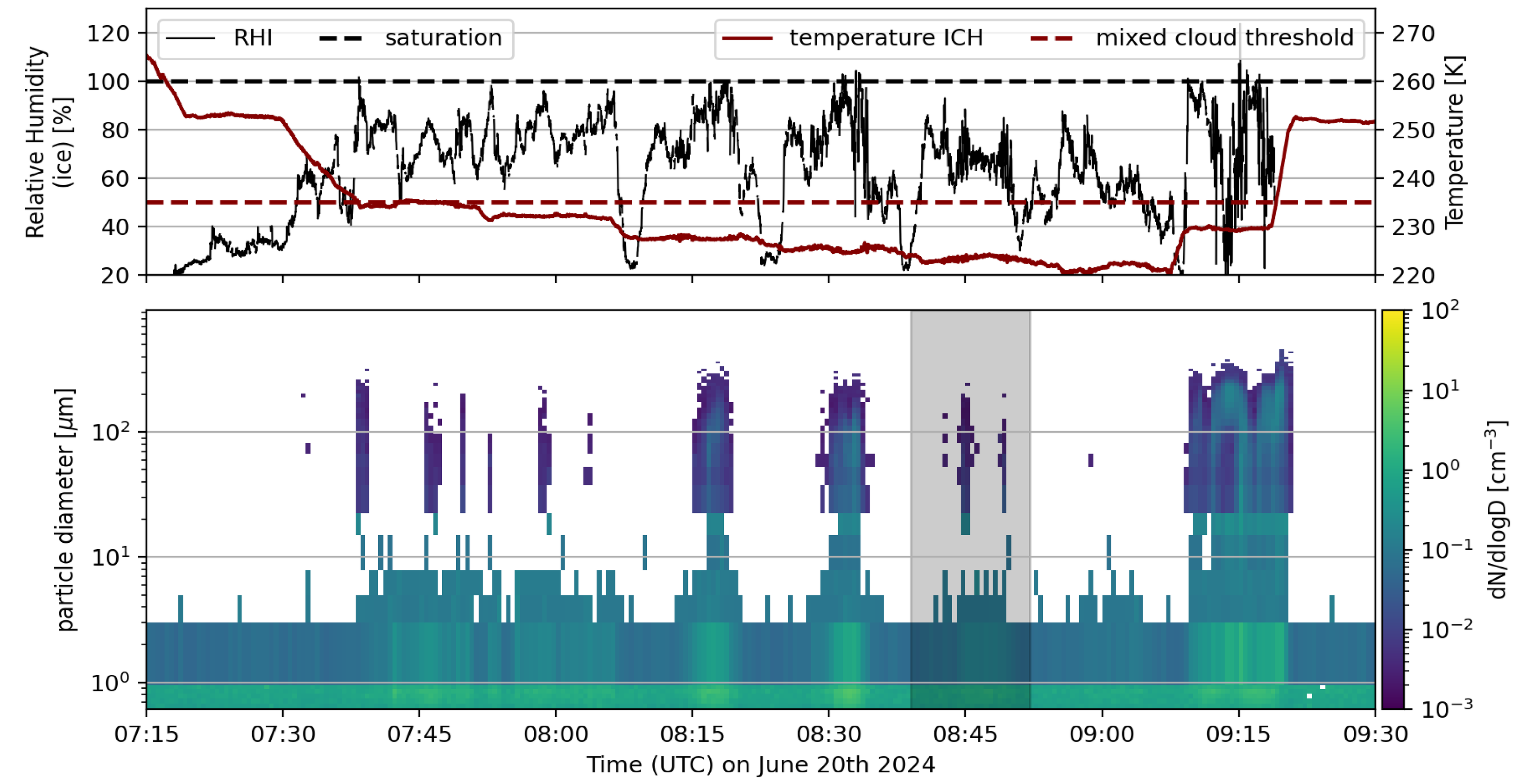


Fig. 4: Time series of relative humidities and Ice particle size distributions

- Particle size distribution consistent with evaporating thin cirrus
- **Relative humidity below 100% (subsaturation)**

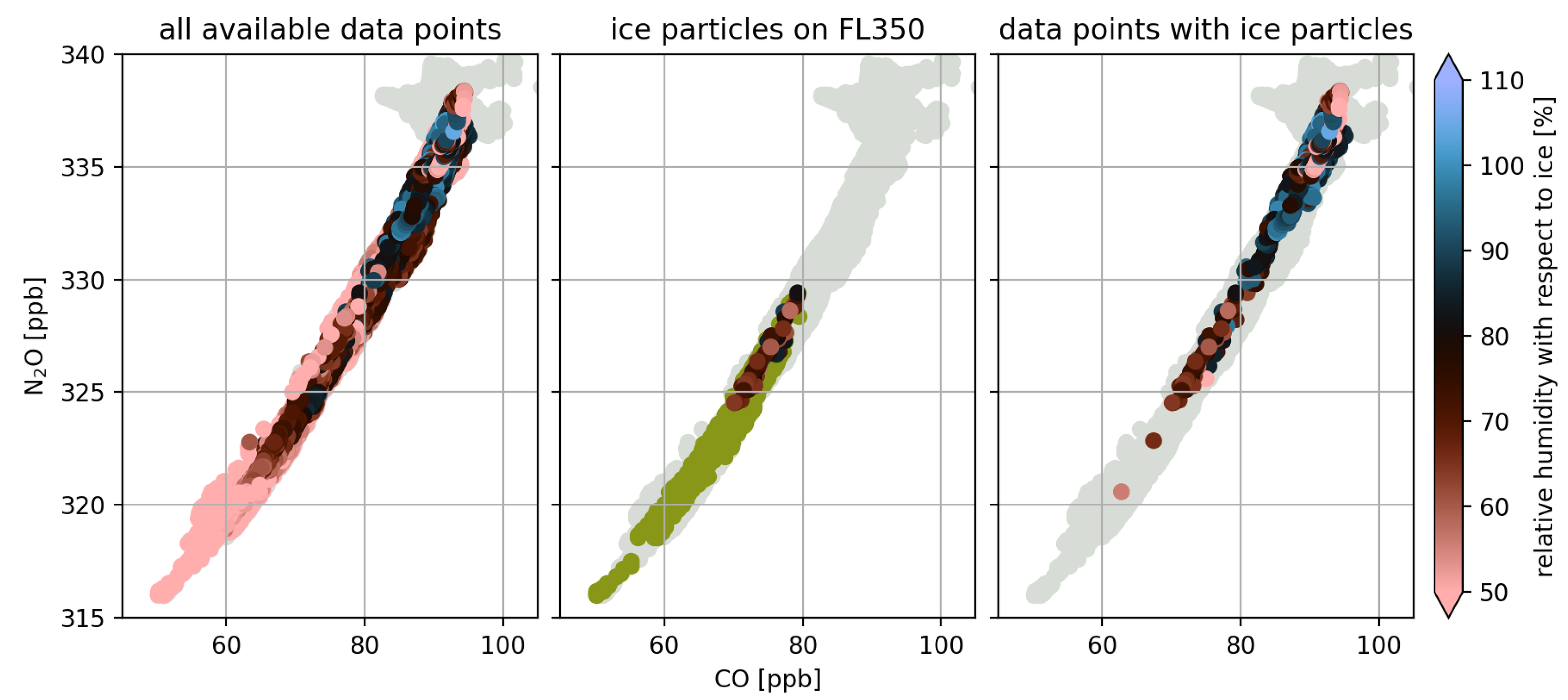
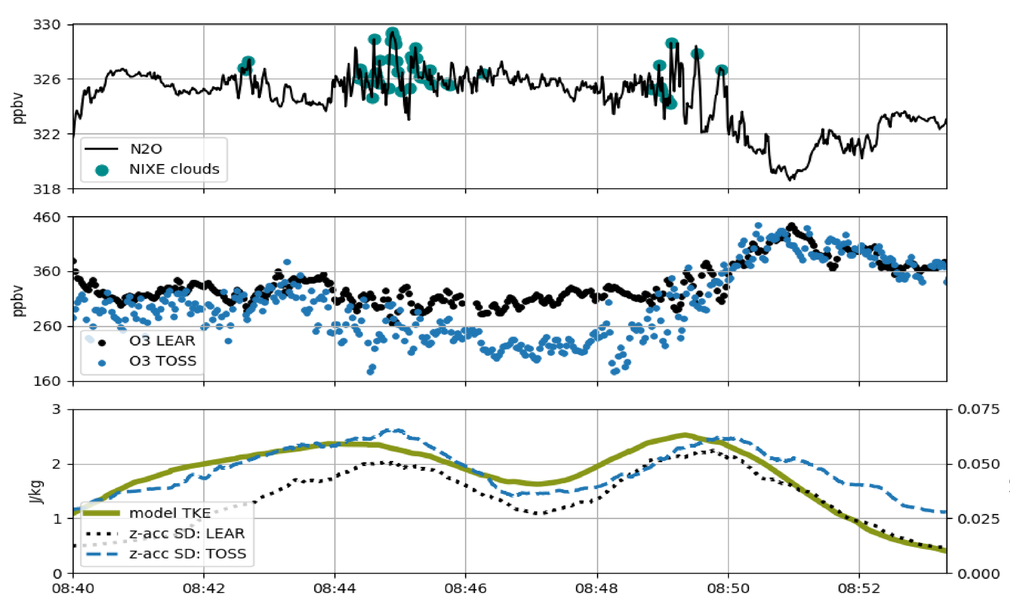


Fig. 5: N_2O – CO correlations colored by relative humidity with respect to ice

- The correlation shows mixing line characteristic for the ExTL
- High range of relative humidities (20 – 105 %)
- Subsaturation for substantial fraction of ice particles
- **Measurement before evaporation: Recent mixing event!**



- Focus on the two sections at 8:45 and 8:49
- High variability in N_2O, O_3 and z-acceleration
- Simultaneous detection of cirrus particles
- **Simulated TKE (ICON) matches maxima in turbulence-proxy**

Fig. 6: Time series of N_2O, O_3, model TKE and turbulence proxy

Turbulence and Lagrangian analysis

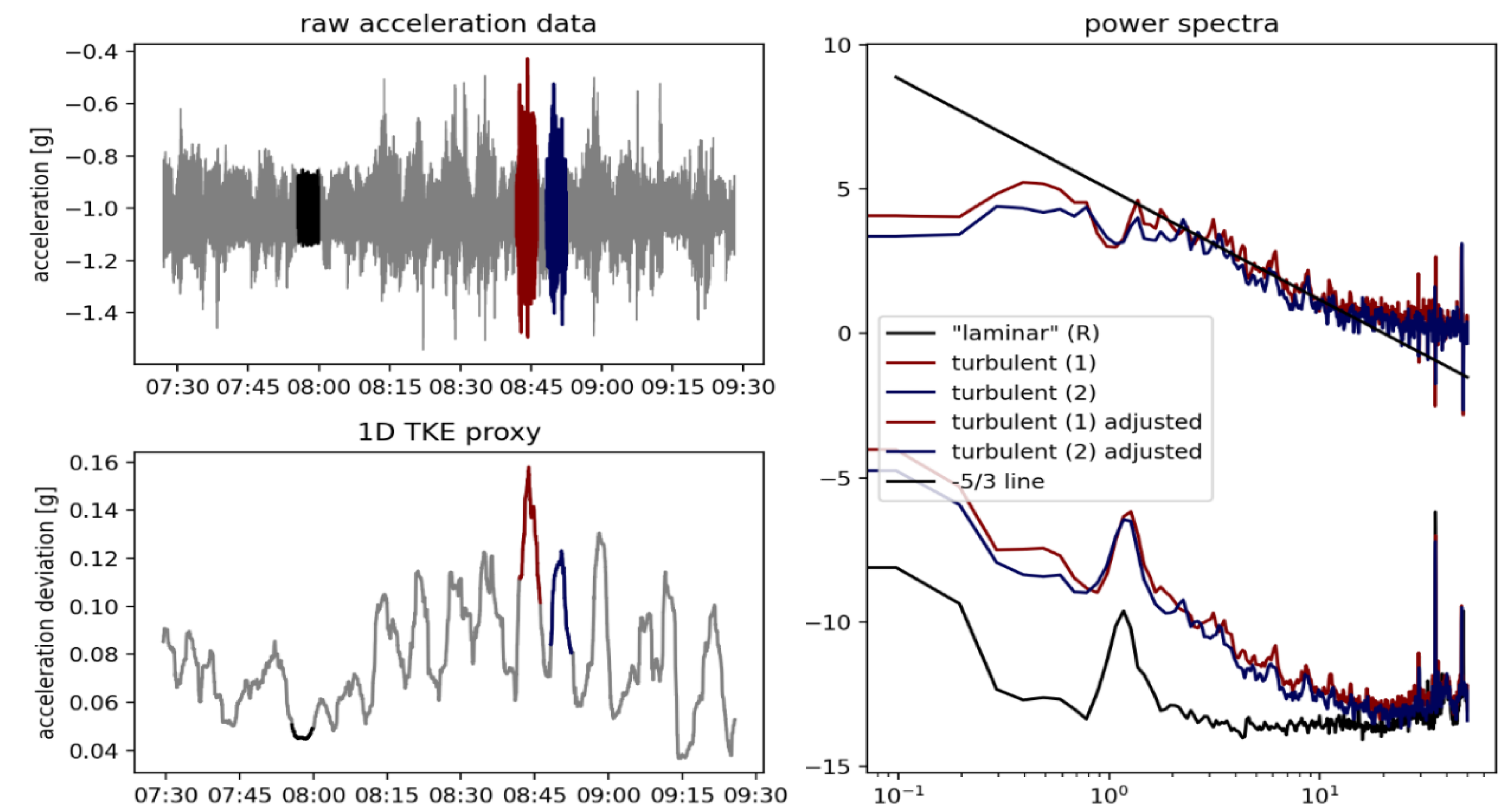


Fig. 7: Spectral analysis of z-acceleration measurements at the TOSS-platform

- Spectral analysis of z-acceleration measurements on the TOSS
- **Increased activity in all frequencies compard to reference spectrum**

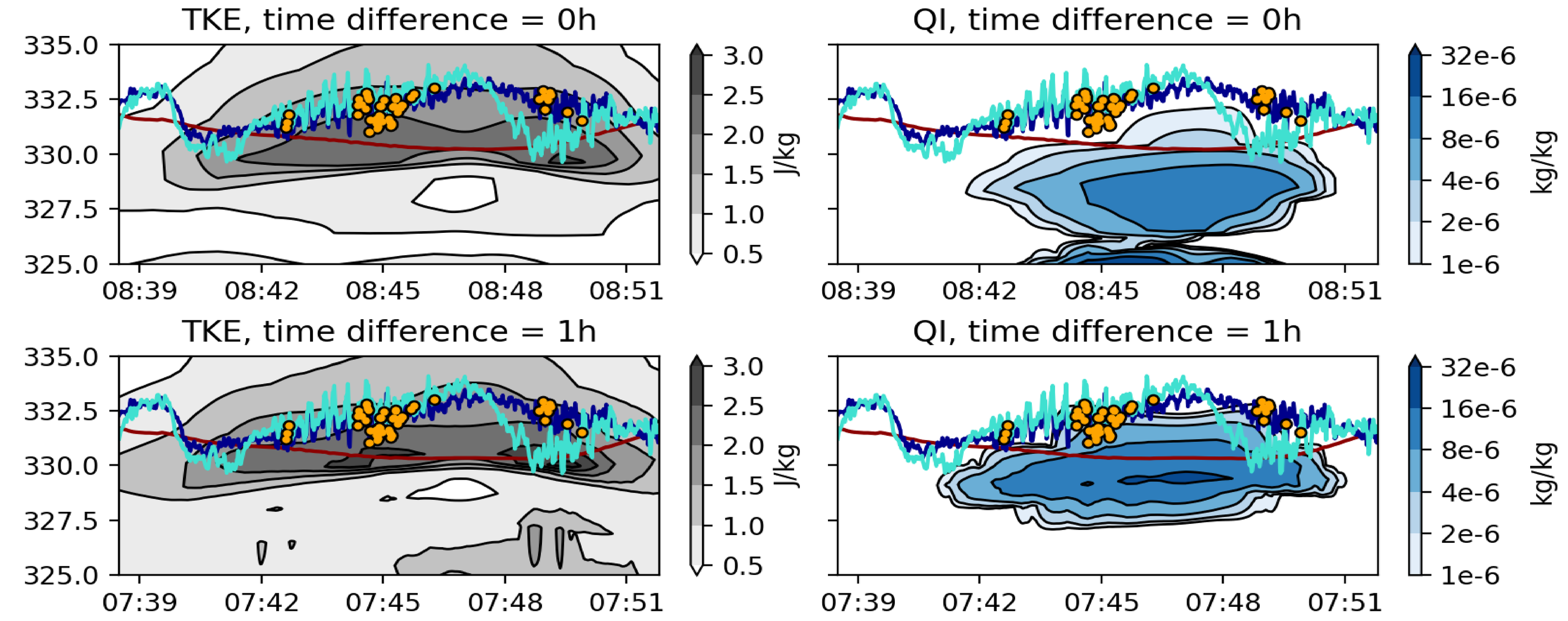


Fig. 8: Lagrangian model analysis (ICON) of TKE and ice water content; curtains at time of measurement and 1 hour prior to the measurements

- Negligible ice water content at time of measurement
- **Simultaneous occurrence of high TKE and ice water content** at the trajectory positions one hour before measurement
- Plausible conditions for turbulent transport of ice particles

RESULTS

- **Cirrus particles found in extratropical stratospheric air**
- **Turbulent mixing at the jet stream identified as the relevant diabatic transport mechanism**
- **Possible source of ExTL water vapor despite temperature minimum at the tropopause (cold trap)**
- **Frequency and statistical impact of such events currently unknown – motivation for further research**

* Emig et al. 2025: Impact of cirrus on extratropical tropopause structure