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Spatiotemporal variability of water vapor investigated using lidar and FTIR vertical soundings above the Zugspitze

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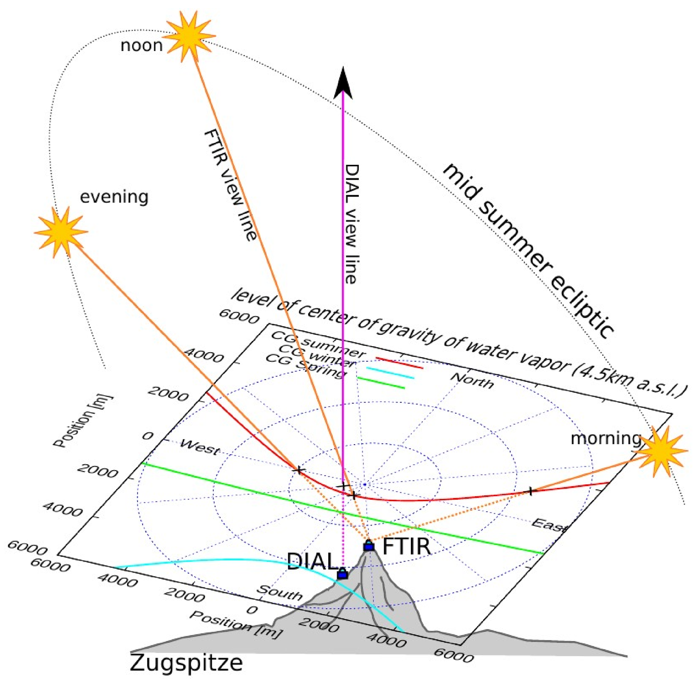
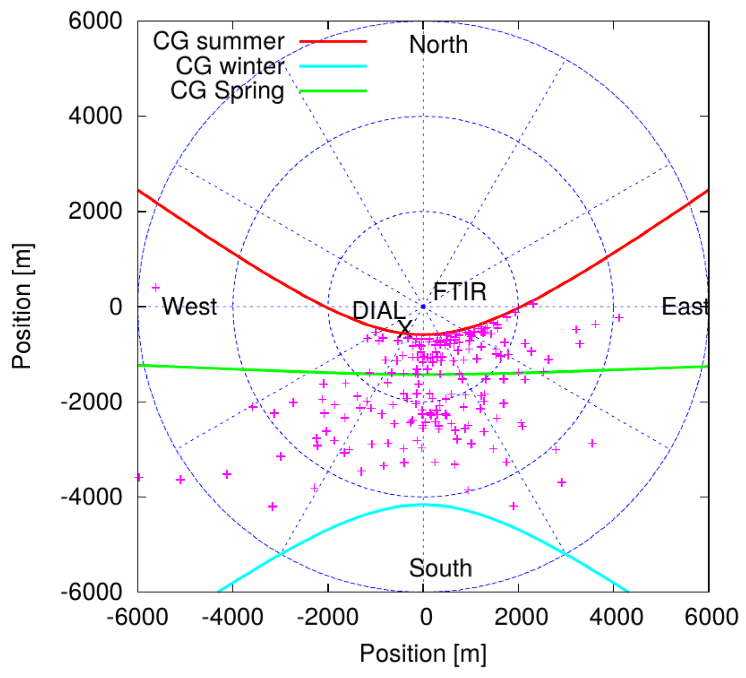
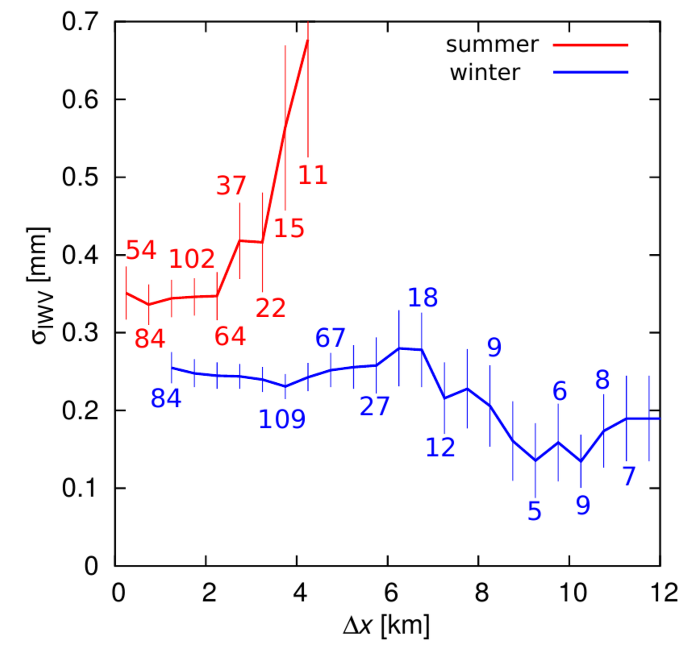
Water vapor is the most important greenhouse gas and its spatiotemporal variability strongly exceeds that of all other greenhouse gases. However, this variability has hardly been studied quantitatively so far. We present an analysis of a five-year period of water vapor measurements in the free troposphere above Mt. Zugspitze (2962m a.s.l., Germany). Our results are obtained from a combination of measurements of vertically integrated water vapor (IWV), recorded with a solar Fourier Transform InfraRed (FTIR) spectrometer on the summit of Mt. Zugspitze and of water vapor profiles recorded with the nearby differential absorption lidar (DIAL) at the Schneefernerhaus research station. The special geometrical arrangement of one zenith-viewing and one sun-pointing instrument and the temporal resolution of both instruments allow for an investigation of the spatiotemporal variability of IWV on a spatial scale of less than one kilometer and on a time scale of less than one hour.



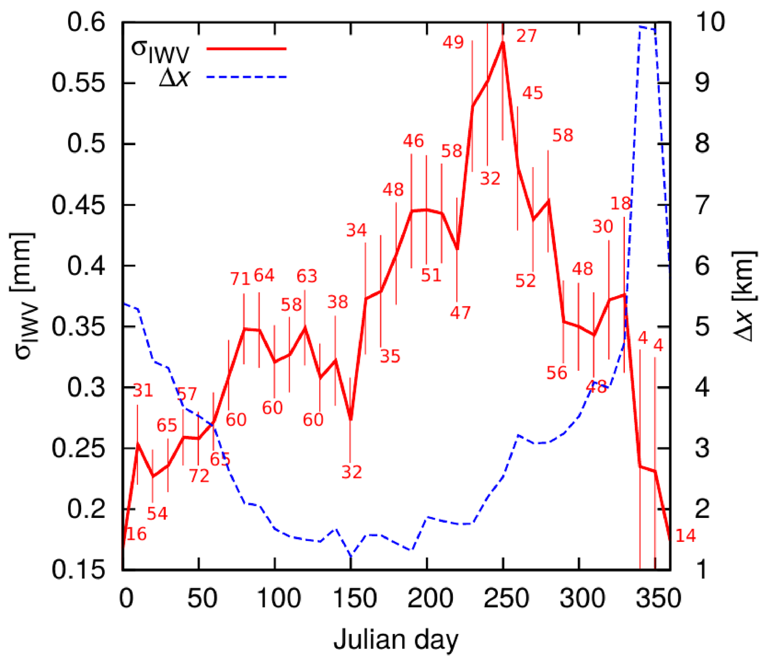


	FTIR	DIAL
Geographical	10°59′8.7″ E	10°58′46.8″ E
Coordinates	47°25′15.6″ N	47°25′0″ N
Altitude a.s.l.	2964 m	2675 m
Vertical range a.s.l.	above 2.96 km	2.95–12 km
Typ. integration time	13.3 min	17 min
Spectral range [cm^{-1}]	micro windows	ν_{on}
	839.5–840.5	12 236.560
	849.0–850.2	12 237.466
	852.0–853.1	12 243.537

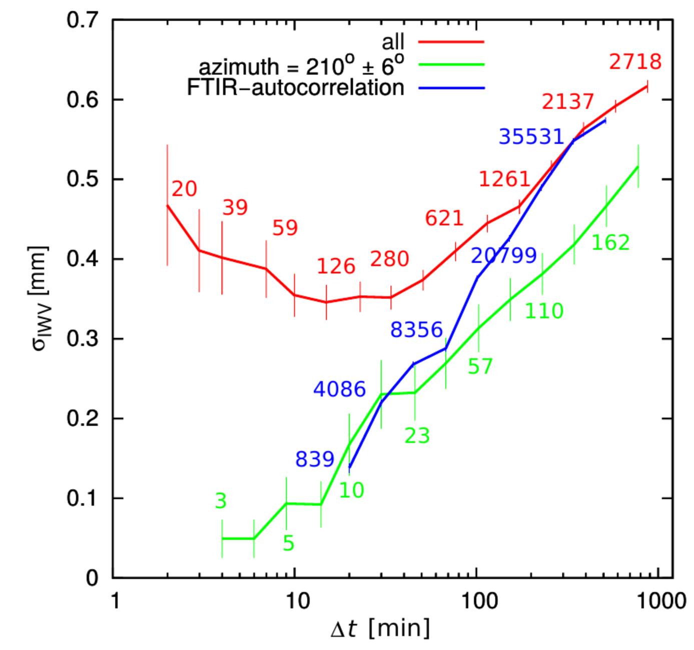
Variability of Integrated Water Vapor



- Within 20 minutes, the spatial variability becomes significant for horizontal distances above 2 km, but only in the warm season (σ_{IWV} = 0.35 mm). However, it is not sensitive to the horizontal distance during the winter season.

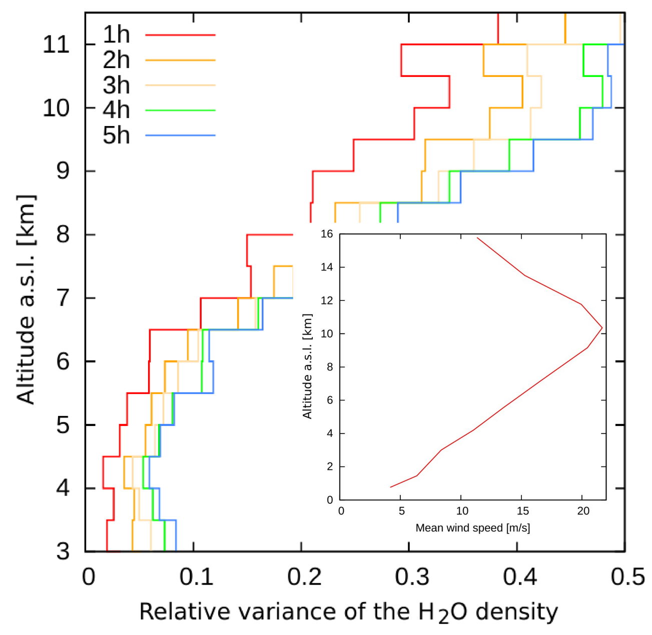


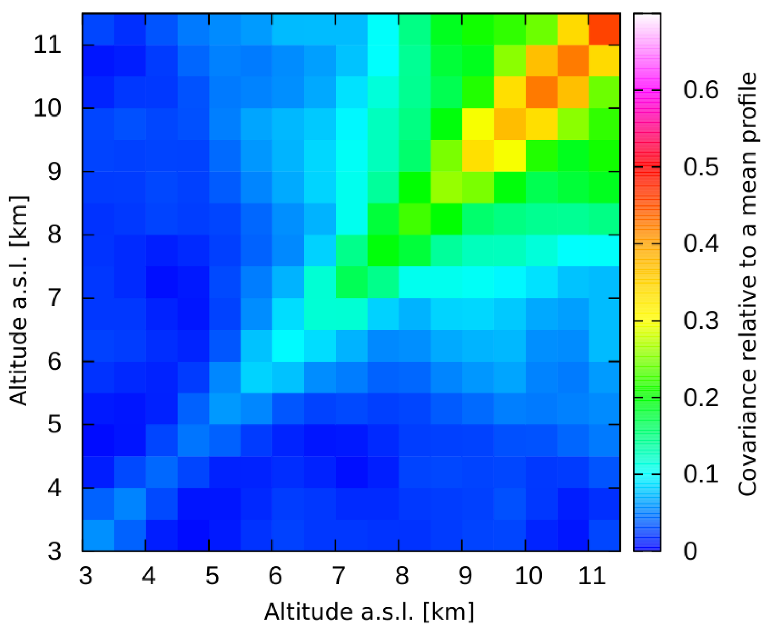
- The variability of IWV within a time interval of 30 minutes peaks in August (σ_{IWV} > 0.55 mm, mean horizontal distance = 2.5 km) and has its minimum around midwinter (σ_{IWV} < 0.2 mm, mean distance > 5 km).



- 3 colors show different volume matching criteria.
  Green: Temporal variability of IWV is derived by selecting subsets of data from both instruments with optimal volume matching. For a short time interval of 5 minutes, the variability is 0.05 mm and increases to more than 0.5 mm for a time interval of 1000 min.
  Blue: Auto-correlation of the FTIR instrument.
  Red: No explicit volume matching criteria

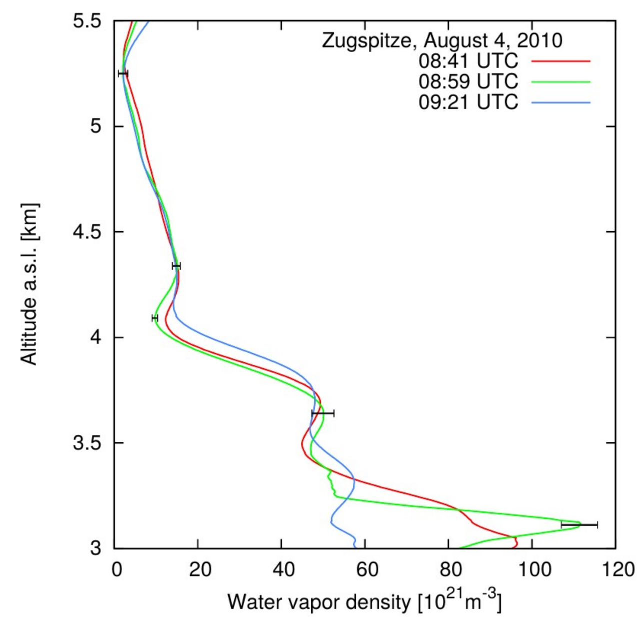
Profile Variability

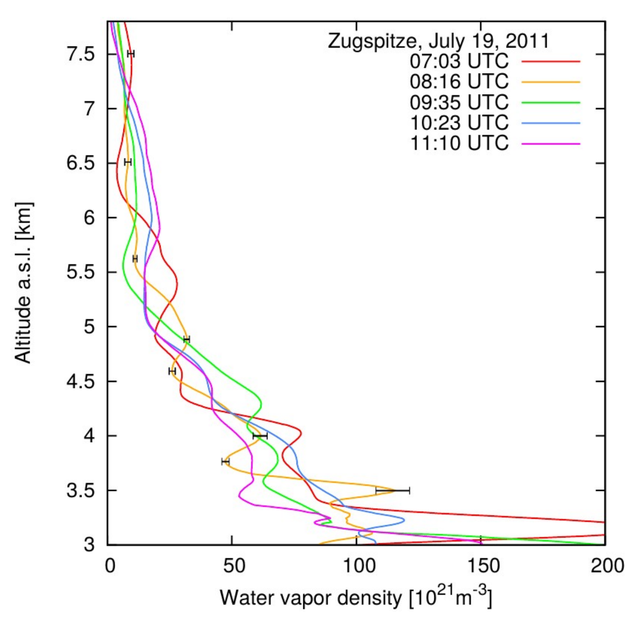


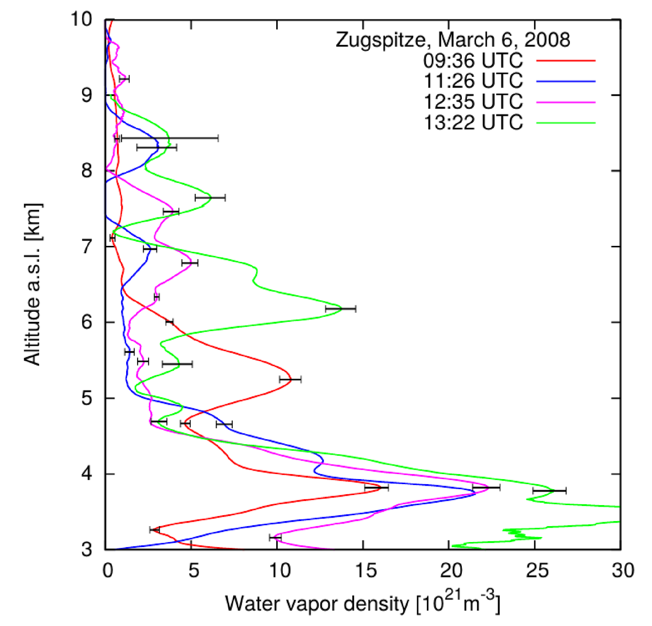


- The lowest relative variability is observed in the lower free troposphere around an altitude of 4.5 km.
- The variability increases with the time interval at all altitudes.
- Above 5 km, the relative variability increases continuously up to the tropopause by about a factor of 3.
- The altitude dependent increase is in agreement with the increasing wind velocity (small figure).
- The covariance of the vertical variability suggests a more coherent flow of heterogeneous air masses in the upper troposphere above 6 km, while the variability at lower altitudes is also driven by local atmospheric dynamics.
- The contribution of long-range transport and the advection of heterogeneous layer structures may exceed the impact of local convection by one order of magnitude even in the altitude range between 3 km and 5 km.

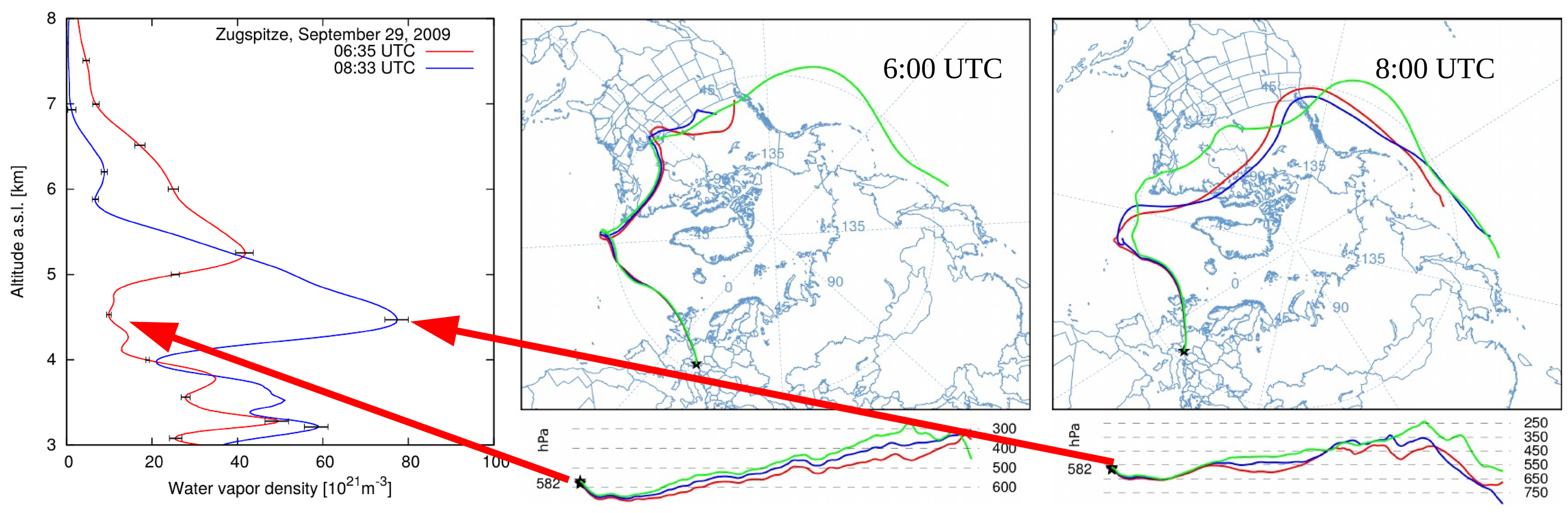
Case Studies







- Vertically limited convection, stable conditions
- High reaching convection, unstable conditions
- Deep stratospheric intrusion



- Quick change of the source-region from the upper troposphere (6:00) to a warm conveyor belt (8:00) suggested by backward trajectory calculations

References
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Vogelmann, H., Sussmann, R., Trickl, T., and Reichert, A.: Spatiotemporal variability of water vapor investigated using lidar and FTIR vertical soundings above the Zugspitze, Atmos. Chem. Phys., 3135–3148 2015.