Meteorologisches Institut der Universität München

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Height-resolved Scaling Properties of Tropospheric Water Vapour based on Airborne Lidar Observations

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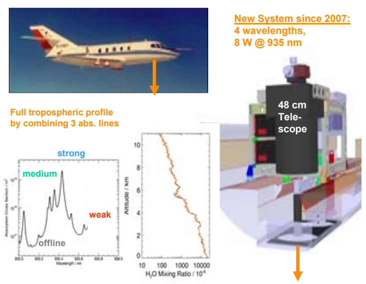
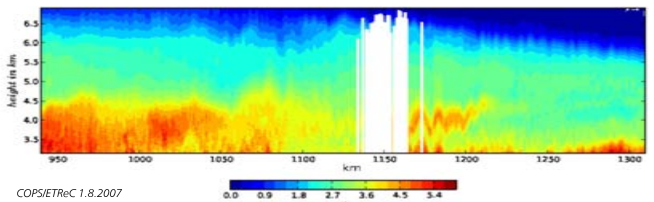
Abstract

- Two-dimensional vertical water vapour cross sections of the free troposphere between altitudes of 2 and 10 km, measured by nadir-viewing airborne differential-absorption lidar with high spatial resolution, were analyzed using structure functions up to the fifth order.
- In contrast to one-dimensional in situ measurements, the two-dimensional water vapor lidar observations allow height-resolved analyses of power-law scaling exponents at a vertical resolution of 200 m.
- We found scale invariance, i.e. a power-law dependency of structure function on length scale, for scales between 5 and 100 km, for the horizontal time series of water vapour mixing ratio.
- The power-law scaling exponents of the structure functions do not show significant latitudinal, seasonal or land/sea dependency, but they do differ between air masses influenced by moist convection and air masses aloft, not influenced.

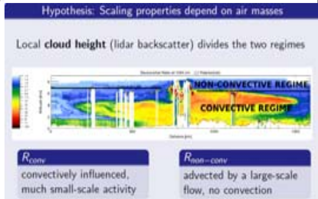
Differential Absorption Lidar on Falcon



Mesoscale moisture variability in long-distance Lidar cross section



COPS/ETReC 1.8.2007
vertical water vapour mixing ratio cross section
hor. res. 1 km, vert. res. 200 m, 3 % uncertainty

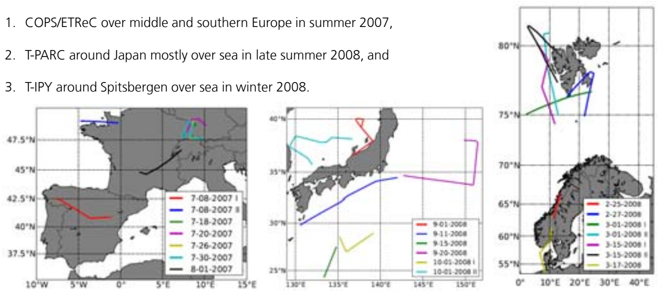


Observations:

- Humidity distribution results from transport and mixing of air initially lifted by scattered (deep) convection.
- Distribution is non-stationary, non-Gaussian, intermittent.
- Fourier spectra are hence inadequate for description.
- Instead, higher-order structure functions are needed.

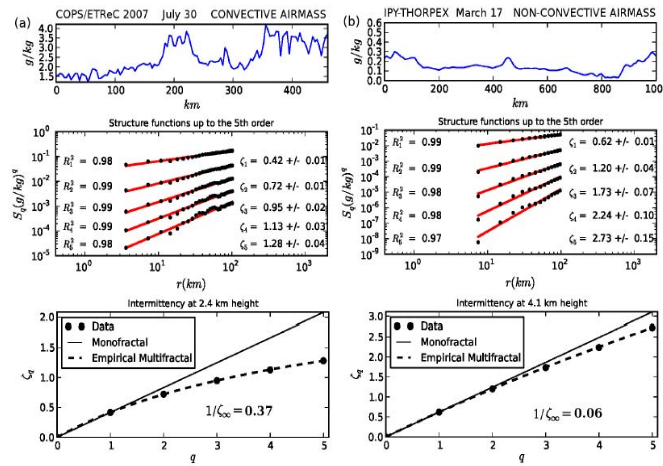
The lidar data stem from three very dissimilar aircraft campaigns:

1. COPS/ETReC over middle and southern Europe in summer 2007,
2. T-PARC around Japan mostly over sea in late summer 2008, and
3. T-IPY around Spitsbergen over sea in winter 2008.



After discarding flight segments with low lidar signals or large data gaps, and after averaging horizontally to a resolution of between 1 and 5 km to obtain a high signal to noise ratio, structure functions were computed for 20 flights at various heights, adding up to a length of more than 300,000 km.

Humidity injection by convection in the LT, versus advective mixing in the UT



- $S_q(r) = \langle |f(x+r) - f(x)|^q \rangle$
- Power-law scaling between about 5 - 100 km ()
- Scaling exponents: $S_q(r) \sim r^{\zeta_q}$
- ζ_1: Hurst exponent
- $\zeta_2 + 1$: Spectral slope
- $\frac{1}{\zeta_\infty}$: Intermittency

smoothness ~ ξ_1

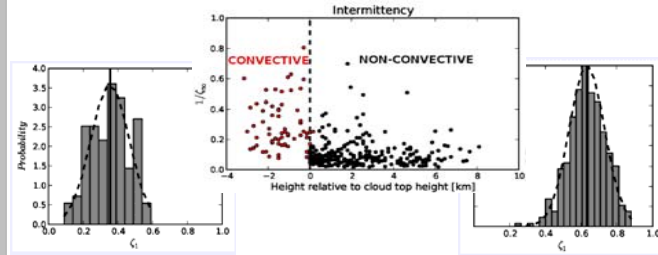
fractal dimension D = 2 - ξ_1

Convective air masses

- Rough: $\zeta_1 \approx 0.33$
- Highly intermittent

Non-convective air masses

- Smooth: $\zeta_1 \approx 0.6$
- Low intermittency



Humidity intermittency and smoothness depend on whether air masses are dominated by convection or advection

- The results strongly suggest that convection provides a source of moisture variability on small scales.
- The high horizontal and vertical lidar resolution allows characterising the scale dependency of the water vapour field at scales close to and smaller than the smallest resolved scales in modern weather and climate models.
- This provides both a reference for validation of high resolution models and a basis for the design of stochastic or pdf-based parameterisations of clouds and convection.

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Reference: Fischer, Kiemle, and Craig (2012), Geophys. Res. Lett., 39, L06803

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