



# **Airborne lidar observations of mid-latitude upper-tropospheric water vapour variability**

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COST WaVaCS Workshop, Paris, 27.9.2011



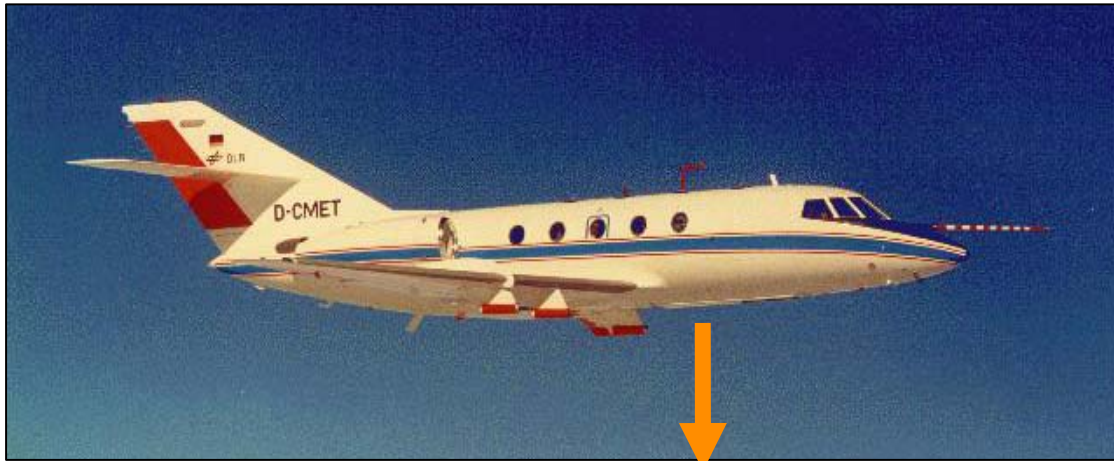
Deutsches Zentrum  
für Luft- und Raumfahrt e.V.  
in der Helmholtz-Gemeinschaft

Institut für Physik der Atmosphäre

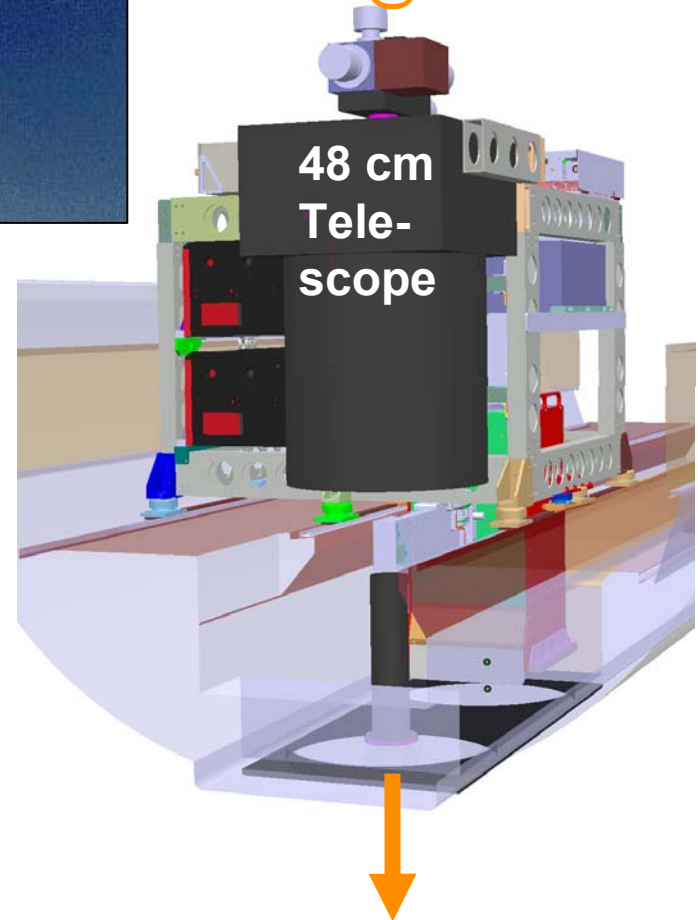


Meteorologisches Institut  
der Universität München

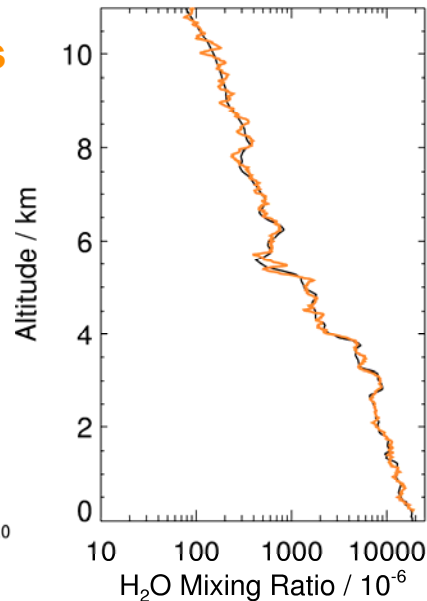
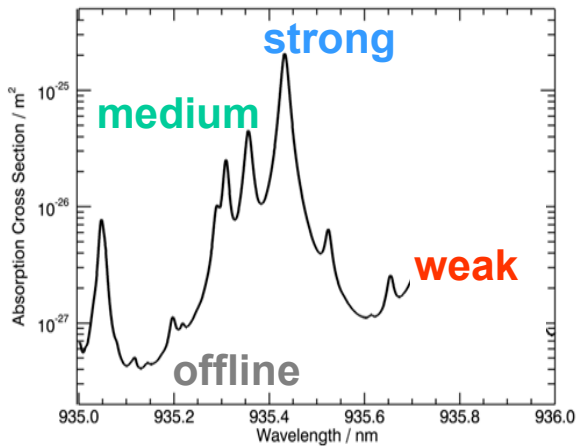
# Water Vapour Differential Absorption Lidar on Falcon



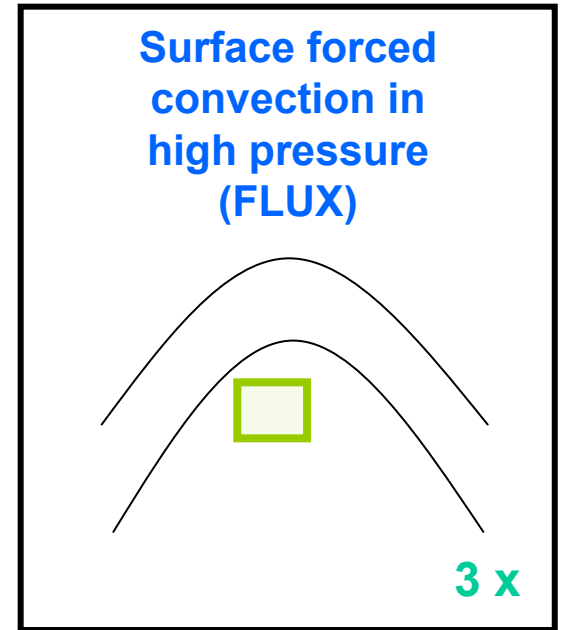
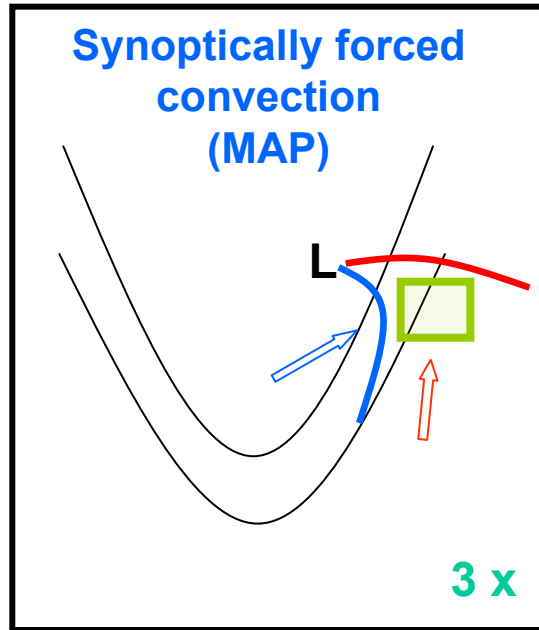
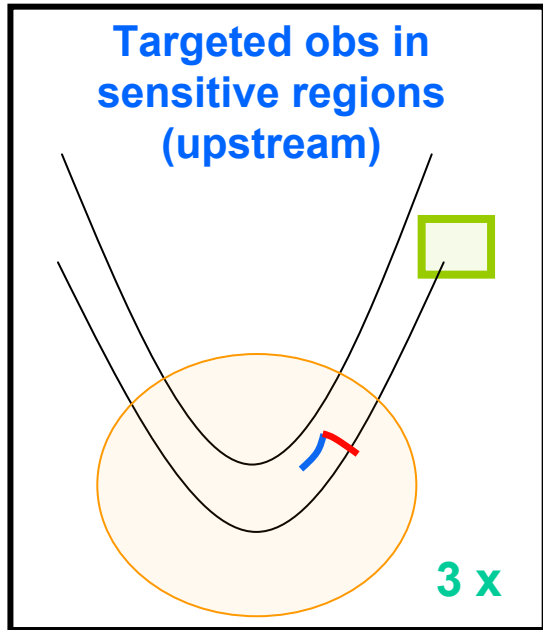
New System  
since 2007:  
4 wavelengths,  
8 W @ 935 nm



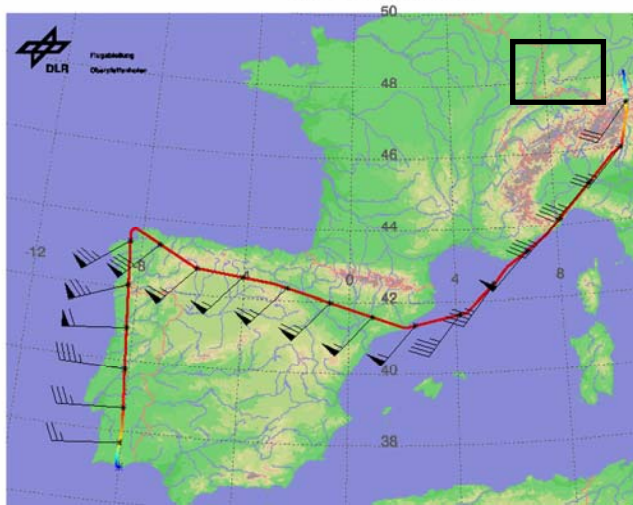
Full tropospheric profile  
by combining 3 abs. lines



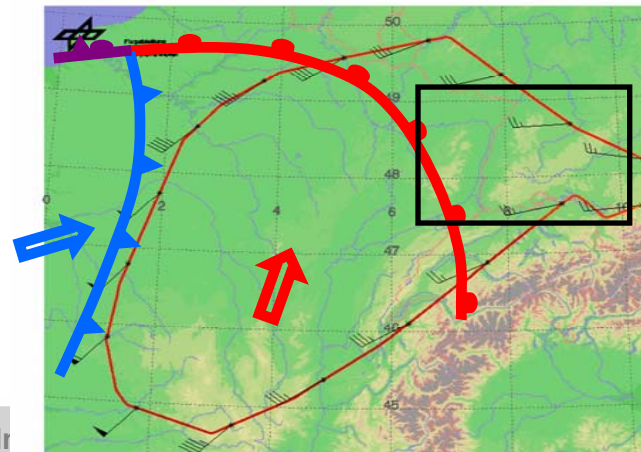
# Convective and Orographically-induced Precipitation Study, COPS 2007: Lidar Objectives



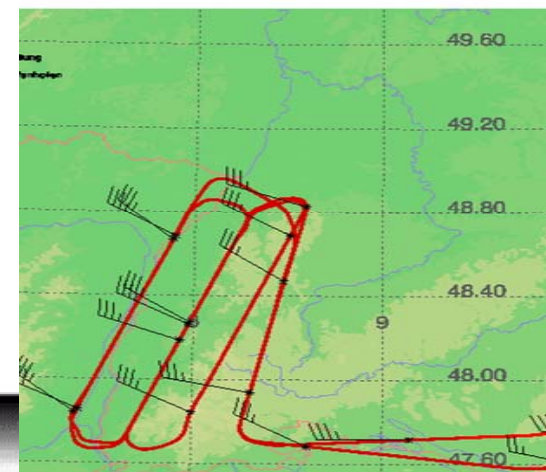
COPS Flug #6 19/07/2007



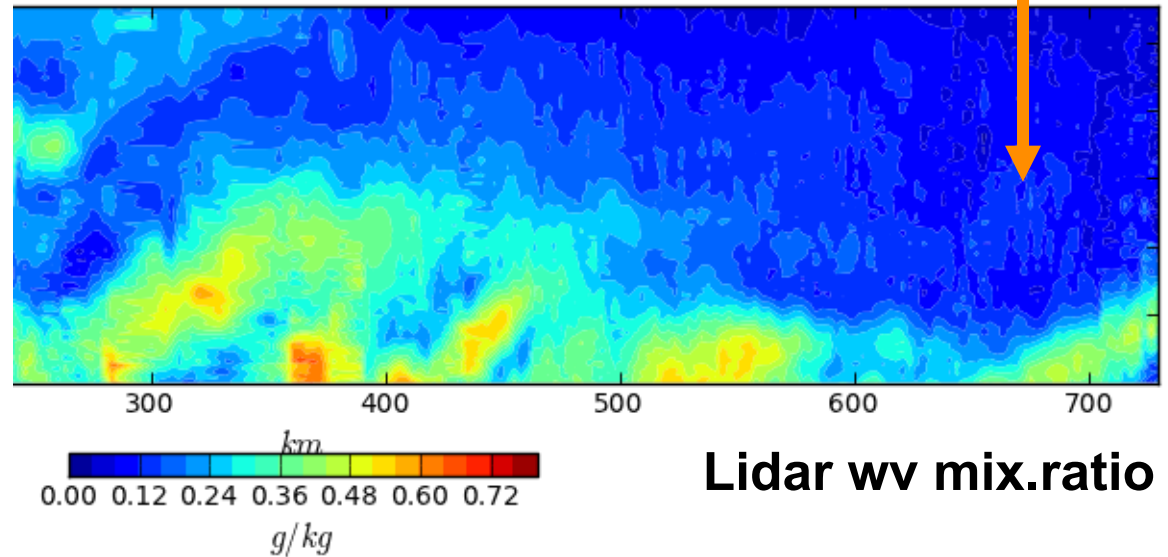
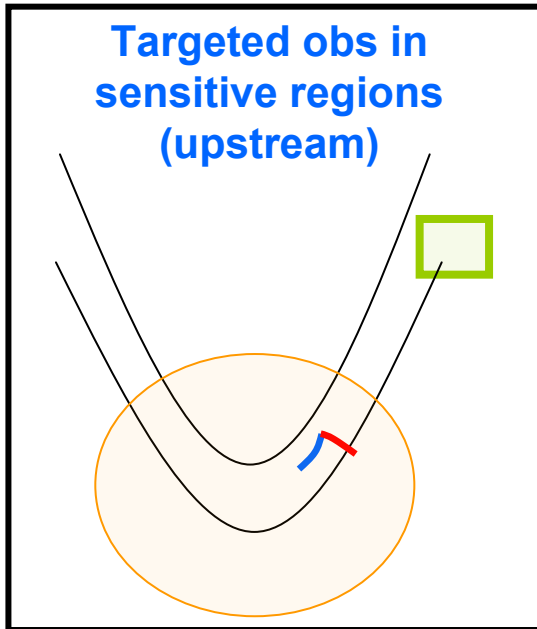
COPS Flug #14 01/08/2007



COPS Flug #11 30/07/2007

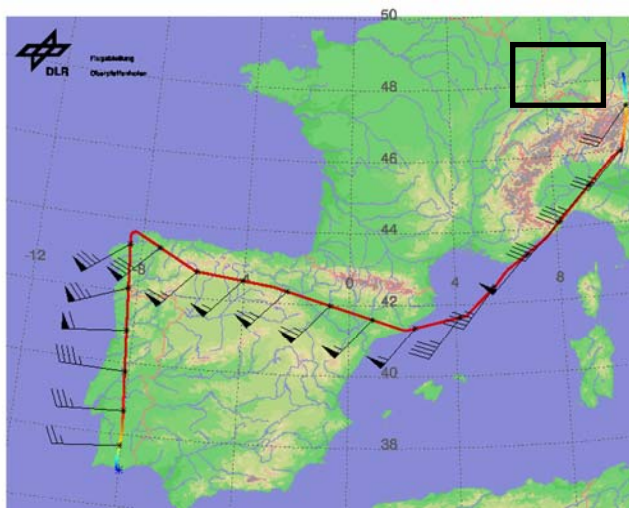


# European THORPEX Regional Campaign ETReC 2007

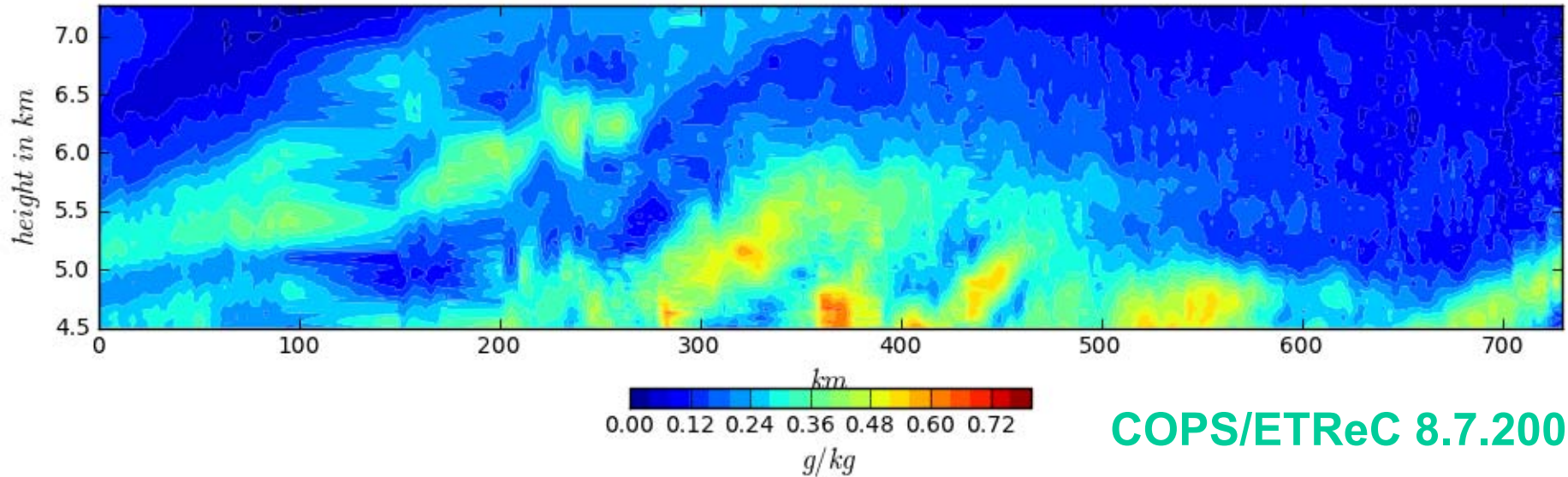


**Improved initializations for precipitation forecasts, coordinated with COPS.**

**Upstream water vapour and wind lidar measurements, plus dropsondes, to obtain additional data in advance of high impact weather events.**



# Humidity Variability in the Mid-lat. Free Troposphere

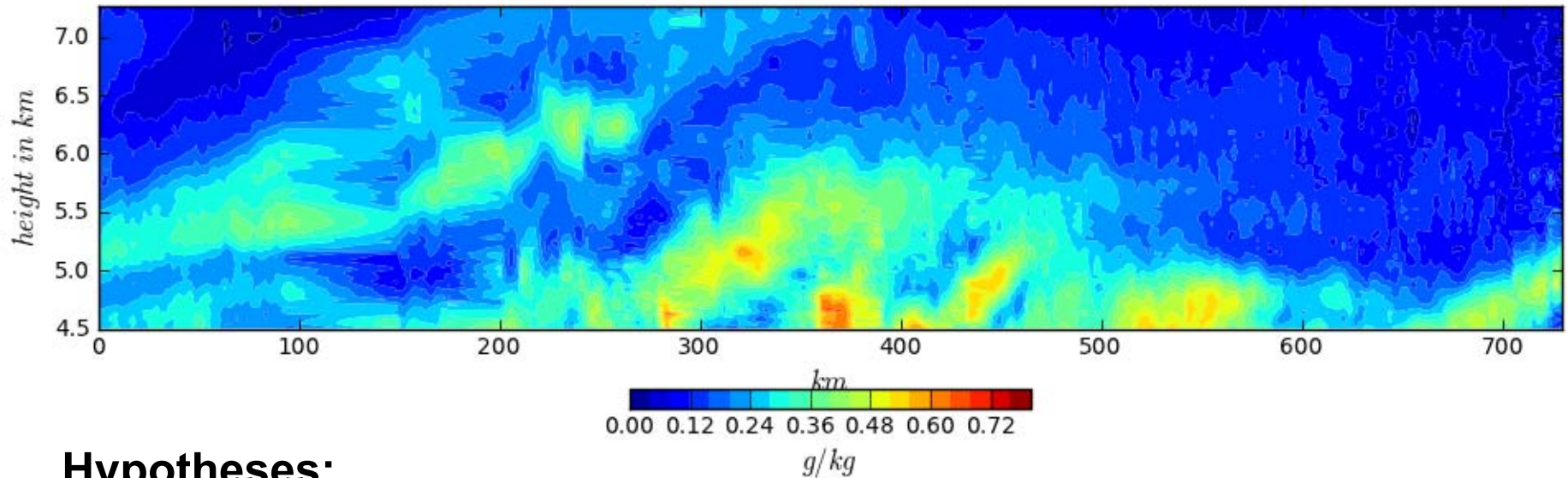


COPS/ETReC 8.7.2007

## Observations:

- Lidar wv mixing ratio, hor. res. 3 km, vert. res. ~ 300 m.
- Atm. dynamics dominated by large-scale processes.
- Humidity highly variable - implications for cloud variability.
- Distribution is non-stationary, non-Gaussian, intermittent.

# Humidity Variability in the Mid-lat. Free Troposphere

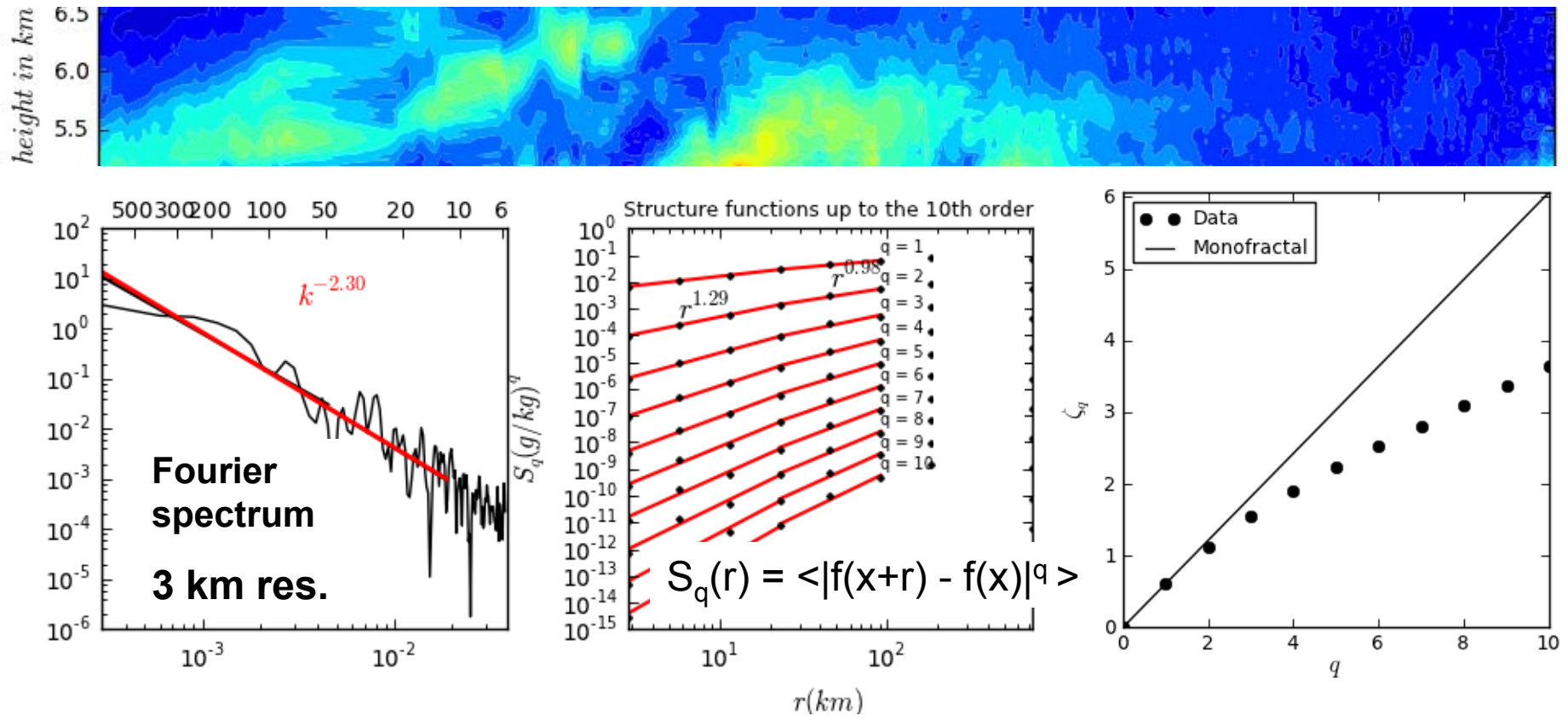


## Hypotheses:

- **Summertime:** humidity distribution results from transport and mixing of air initially lifted by scattered (deep) convection.
- Intermittency should decrease with height, smoothness increase.
- Fourier spectra are not adequate to characterize intermittency.
- Structure functions of higher order are needed (Davis et al, 1994).

# Humidity Variability in the Mid-lat. Free Troposphere

Power-law scaling  $S_q(r) \sim r^{\xi_q}$  observed for  $r \approx 10 \dots 100$  km



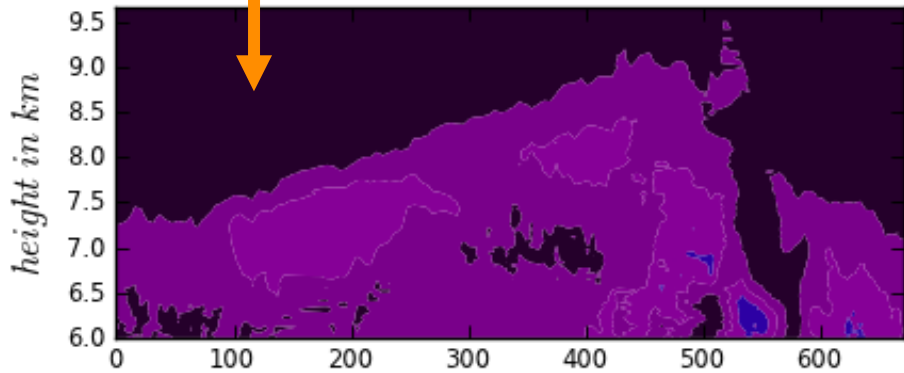
Intermittency and smoothness can be quantified by their deviation from the monofractal scaling behaviour (Pierrehumbert, 1996).



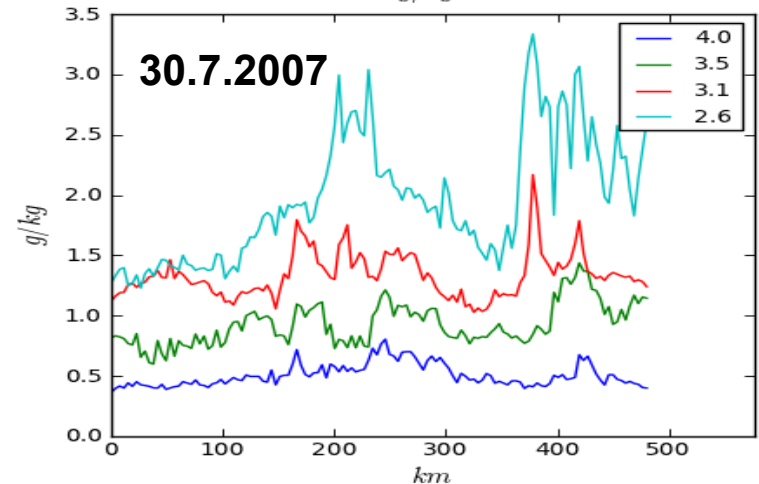
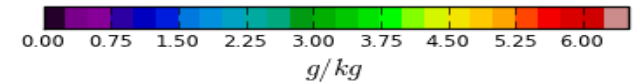
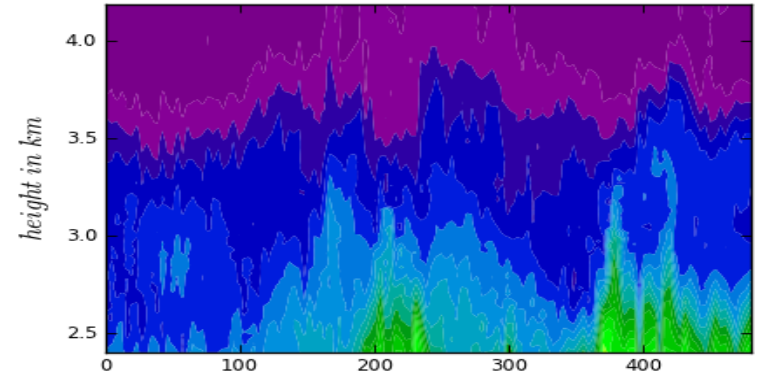
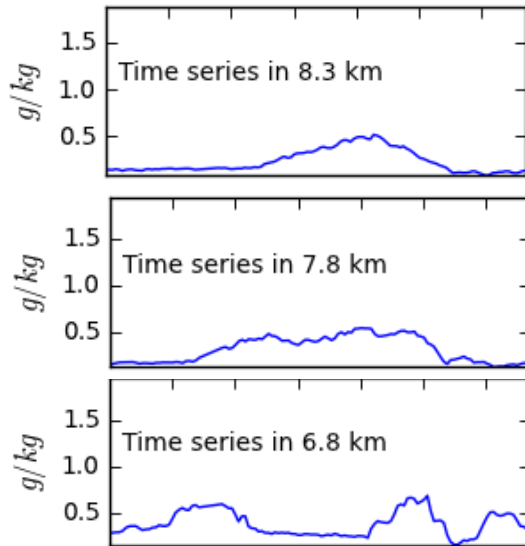
# WV variability: 2 different exemplary cases

Large-scale upper-trop. advective mixing ↔

Convection



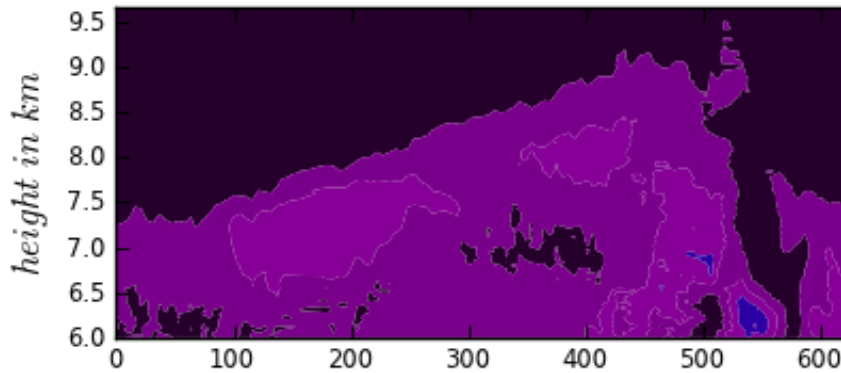
8.7.2007



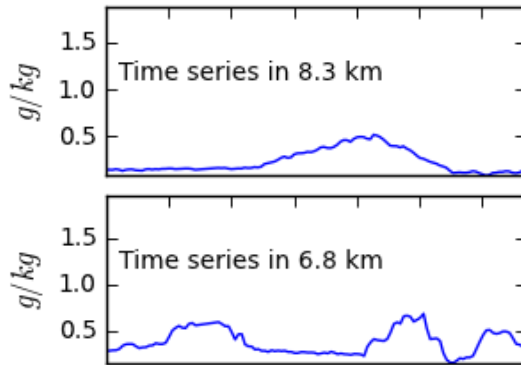


# 8.7.07: Moderate Intermittency in Mid-Troposphere

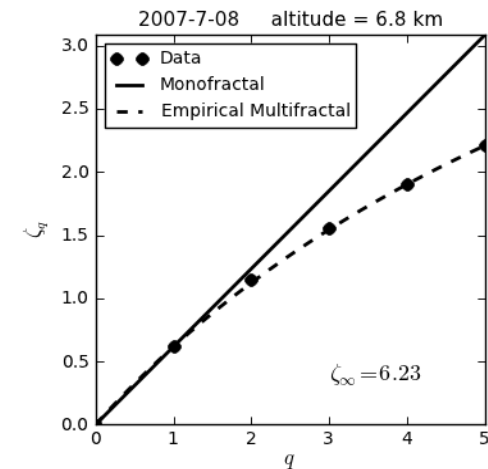
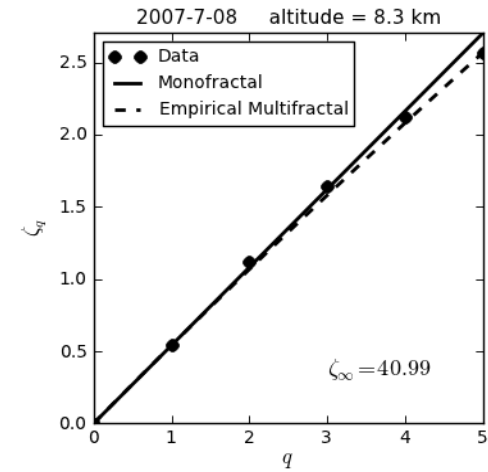
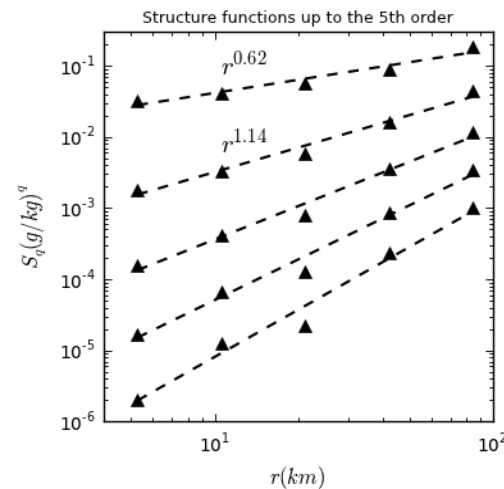
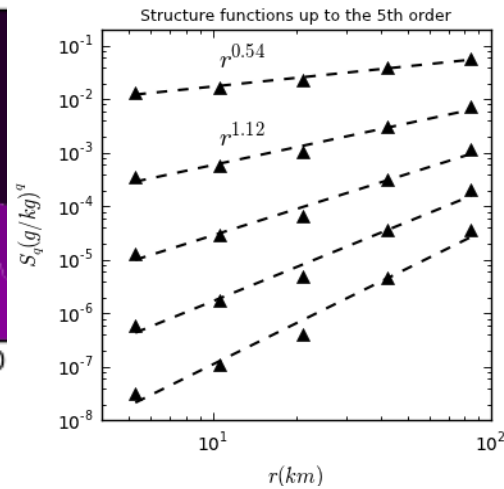
## Large-scale upper-trop. advective mixing



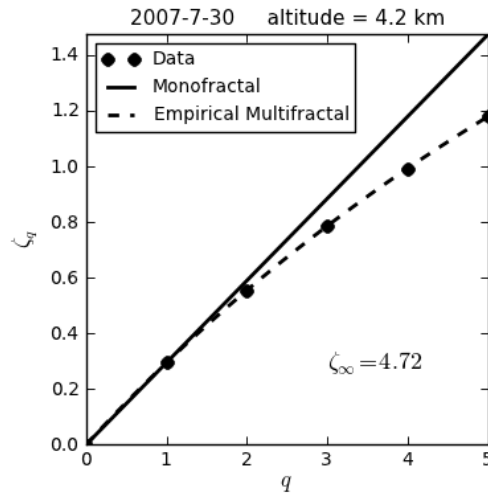
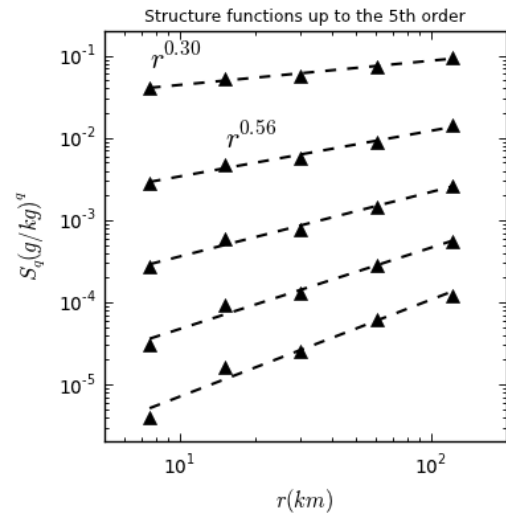
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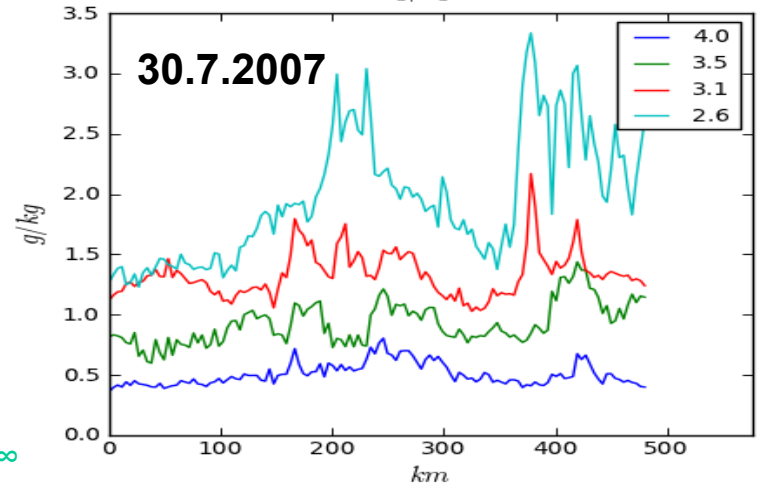
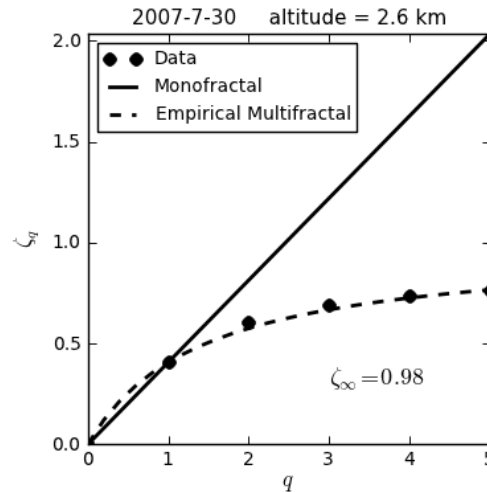
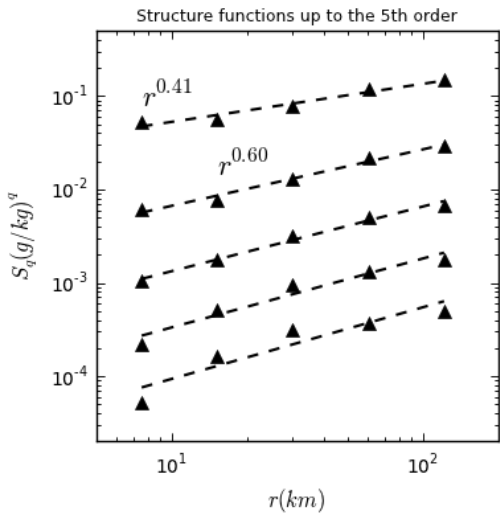
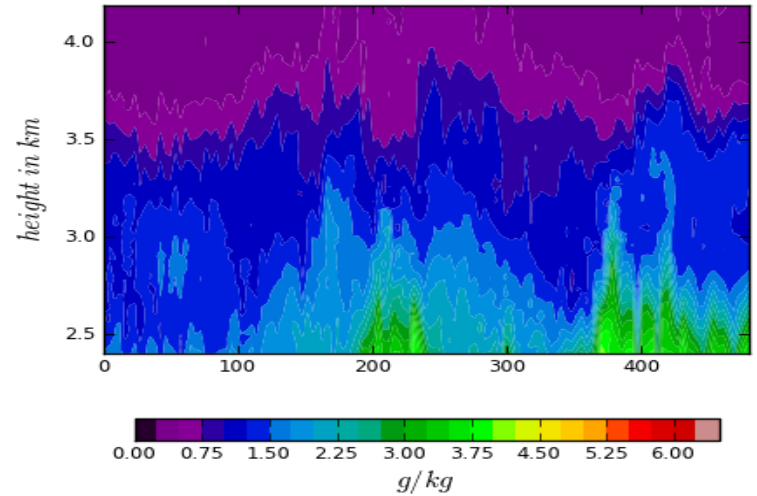
smoothness  $\sim \xi_1$   
intermittency  $\sim 1/\xi_\infty$



# 30.7.07: Strong Intermittency in Lower-Troposphere



## Convection

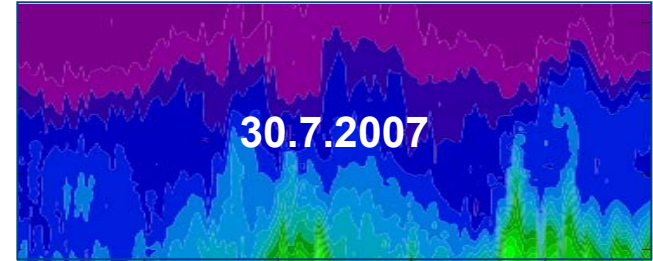


smoothness  $\sim \xi_1$

intermittency  $\sim 1/\xi_\infty$

# Comparison of Both Exemplary COPS Cases

## Water vapour Lidar cross sections



### ALTITUDE

6.3 km – 9.7 km

2.0 km – 4.4 km

### 1st-order SF EXPONENT $\xi_1$

0.51 – 0.87  
smooth time series

0.18 – 0.51  
very rough time series

### 2nd-order SF EXPONENT $\xi_2$

0.87 – 1.58  
very steep → little small scale influence

0.34 – 0.82  
flat → lots of small scale fluctuations flatten the spectra

### INTERMITTENCY

Small: mean  $\xi_\infty = 8.55$

Large: mean  $\xi_\infty = 2.77$

### SITUATION

Atmospheric dynamics in the middle and upper troposphere dominated by large-scale processes

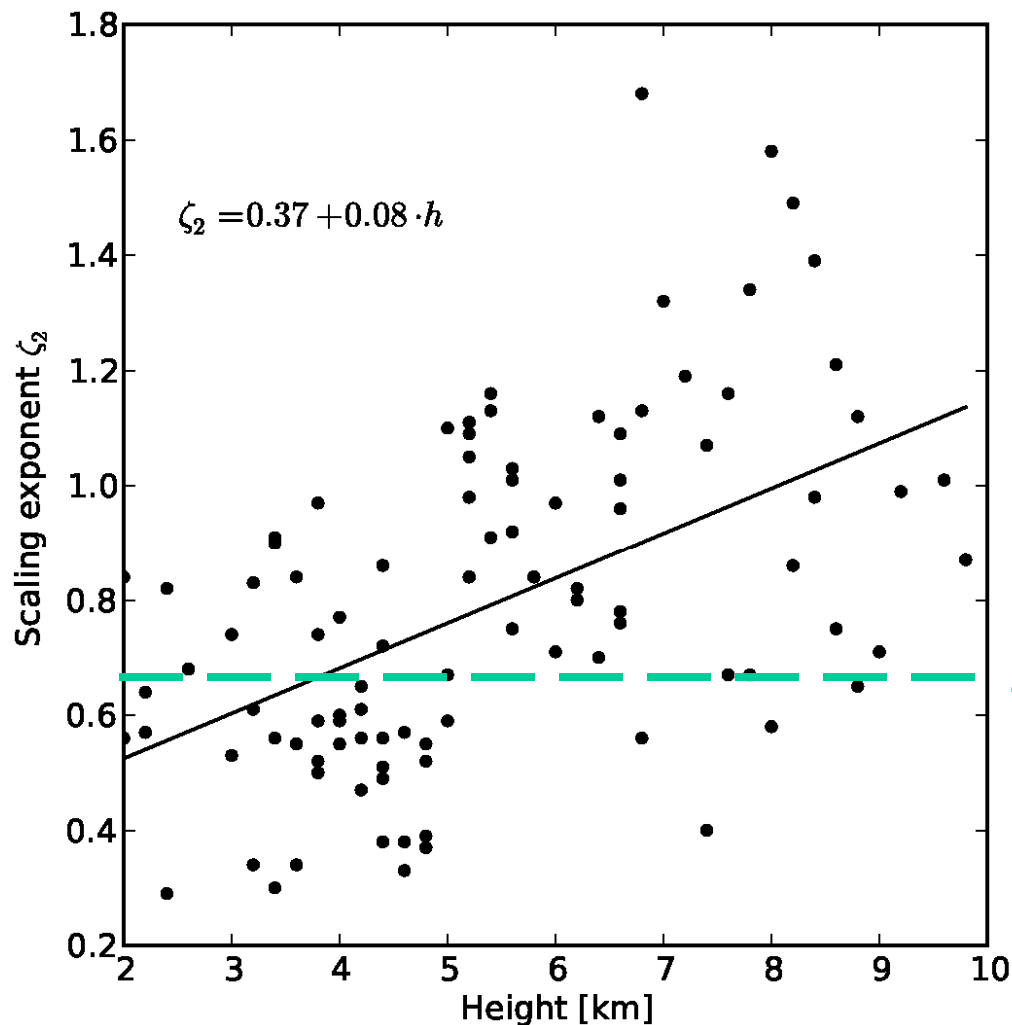
Atmospheric dynamics in the lower and middle troposphere controlled by convective moistening

smoothness  $\sim \xi_1$       intermittency  $\sim 1/\xi_\infty$

enables quantifying and separating different situations



# Scaling Exponent $\xi_2$ for all COPS Lidar Humidity Data



Total of 98 timeseries  
from 8 flights

Increase with height:  
physical meaning =  
loss of small-scale  
turbulent fluctuations

Passive scalar turbulent  
fluctuations:  $\xi_2 = 2/3$   
(Obukhov-Kolmogorov, 1941)

**Result:**  
Statistics can be  
related to physics.

# Conclusions

- ❖ **First application of structure functions to airborne water vapour lidar data, to quantify intermittency and smoothness.**
- ❖ **Power-law scaling exponents behave like expected: intermittency parameter decreases with height, smoothness increases.**
- ❖ **Structure functions appear to be superior to the Fourier spectrum and show potential to distinguish underlying physical processes responsible for water vapour variability.**
- ❖ **Useful tool for verification of humidity distributions in climate & weather models.**