Airborne Water Vapour and Wind Lidars to Estimate Latent Heat Fluxes over Complex Terrain

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Water Vapour and Wind Lidar on board the Falcon

**New system:**
- 2 high-power DIAL lasers
- 9 W @ 935 nm

- 48 cm Telescope
- 2 µm wind lidar
- two 50 cm aircraft windows
Water Vapour and Wind Lidar on board: Falcon full!

Displays for system control and quicklooks
Targeted obs. in sensitive regions (upstream)

Synoptically forced convection (MAP)

Surface forced convection in high pressure (FLUX)

### COPS Mission

<table>
<thead>
<tr>
<th>COPS Mission</th>
<th>flight days in 2007</th>
<th>flight time</th>
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</thead>
<tbody>
<tr>
<td>UPSTREAM</td>
<td>2 · 8.7., 2 · 19.7., 2 · 1.8.</td>
<td>21.7 h</td>
</tr>
<tr>
<td>MAP</td>
<td>18.7., 2 · 20.7., 1.8.</td>
<td>12.9 h</td>
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<tr>
<td>FLUX</td>
<td>15.7., 25.7., 26.7., 30.7.</td>
<td>14.8 h</td>
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<tr>
<td>Total</td>
<td>14 flights</td>
<td>49.4 h</td>
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**FLUX Mission Objectives**

1. Characterise initiation of convection with high resolution wind and water vapour lidar profiles.
2. Investigate the spatial variability of humidity, wind and latent heat fluxes.
3. Verify model skills in complex terrain.

2 examples:
15.7. + 30.7.07
IOP 8b: Ridge, no clouds in morning, S-wind

VT: Sun, 15 Jul 07, 12 UT (+00 h)

850 hPa Geopot. + wind (m/s); RS FZK 8 UT: 9 m/s at 2 - 4 km
15.7. 7 UT: Falcon Lidar Observations

- 9 m/s wind generates lee waves
- stationary waves above H
- BL hum. lifted 500m in 36min = 0.23 m/s
IOP 12: Trough rear side: adv. of cold, clean, dry air

VT: Mon, 30 Jul 07, 12 UT (+00 h)

850 hPa Geopot. + wind (m/s)
$w'q'$ is turbulent flux, $q' = q - q_{10km}$ and $w' \approx w$
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Rhine valley:
flat-terrain reference for statistics and fluxes.

High spatial res.: 180 m hor. (1 s), 200 m vert.
Fourier spectra in mid-CBL:

Kiemle et al., JTECH 2007
30.7.07: Eddy-correlation and Latent Heat Flux Profile

**Kinematic turb. flux:**
\[ F = w'q' \ [g/kg m/s] \]
\[ F = \text{integral (cospec.)} \]
\[ F = \text{CCF}_0 (w', q') \]

**Latent heat flux:**
\[ W = \rho_{\text{air}} L_v F \ [W/m^2] \]
\( L_v \) is latent heat of vaporisation
\( \rho \cdot L_v \approx 2.8 \text{ MJ/m}^3 \) (±4%)

**CBL flux divergence**
\[ \frac{\partial w'q' \partial z}{\partial z} \approx -0.09 \text{ g/kg m/s km}^{-1} \approx -0.3 \text{ g/kg h}^{-1} \]

Accuracy: ±30% due to instrument noise and sampling uncertainty.
30.7.07: Mid-CBL water vapour budget at 11-12 UT

Simplified q-budget eq.:
\[
\frac{\partial q}{\partial t} + \overline{u} \frac{\partial q}{\partial x} + \overline{v} \frac{\partial q}{\partial y} + \frac{\partial w' q'}{\partial z} = 0
\]

terms: local change advection flux divergence

+ 0.03 - 0.3 g/kg h\(^{-1}\)

obs. method: ECMWF (q), sonde (u,v), 2 airborne lidars.

conditions: stationarity, no q sinks (clouds), no hor. flux div.

Result: Rear-trough dry air in CBL humidifies by \(\sim 0.3\) g/kg h\(^{-1}\).

Likely reason: Surface evaporation due to previous days' rain.
30.7.07: Latent Heat Fluxes above Black Forest

Pos. flux div.: 0.5 g/kg h⁻¹

Drying of CBL likely due to entrainment of dry air that dominates surface evaporation to the East.
Conclusions and Outlook

- Successful operation of wind and water vapour lidars on aircraft with high spatial resolution (200 m);
- unique instrumentation to characterise BL variability and fluxes over complex terrain, essential to CI;
- 4 flux missions currently under investigation.

Next steps:

- explore methods other than eddy-correlation for latent heat fluxes in mountains and valleys: conditional sampling, ...
- compare with insitu fluxes from D-IBUF and Hornisgrinde lidars, for validation and more comprehensive case studies.