Environmental response functions - relating eddy-covariance flux measurements to ecosystem drivers

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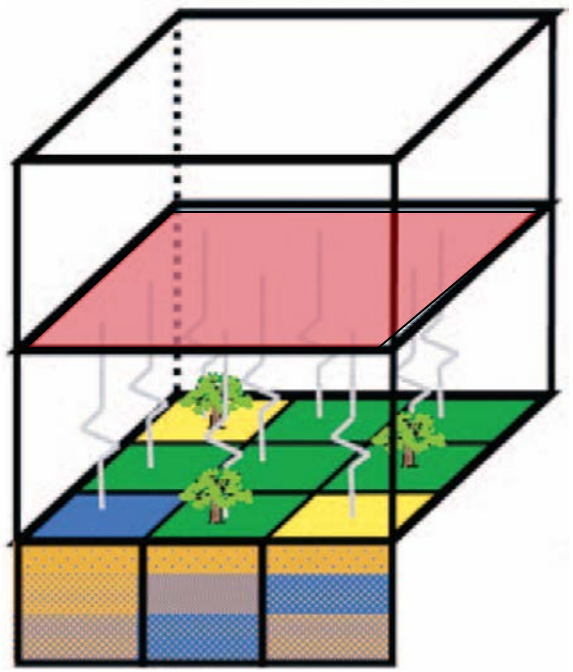
Motivation

- Bridging scales: Regional measurements
- Fixed wing aircraft: Wide range, but expensive
- Unmanned aircraft: Flexible, but limited payload
- Alternative?



Mengelkamp et al. (2006)

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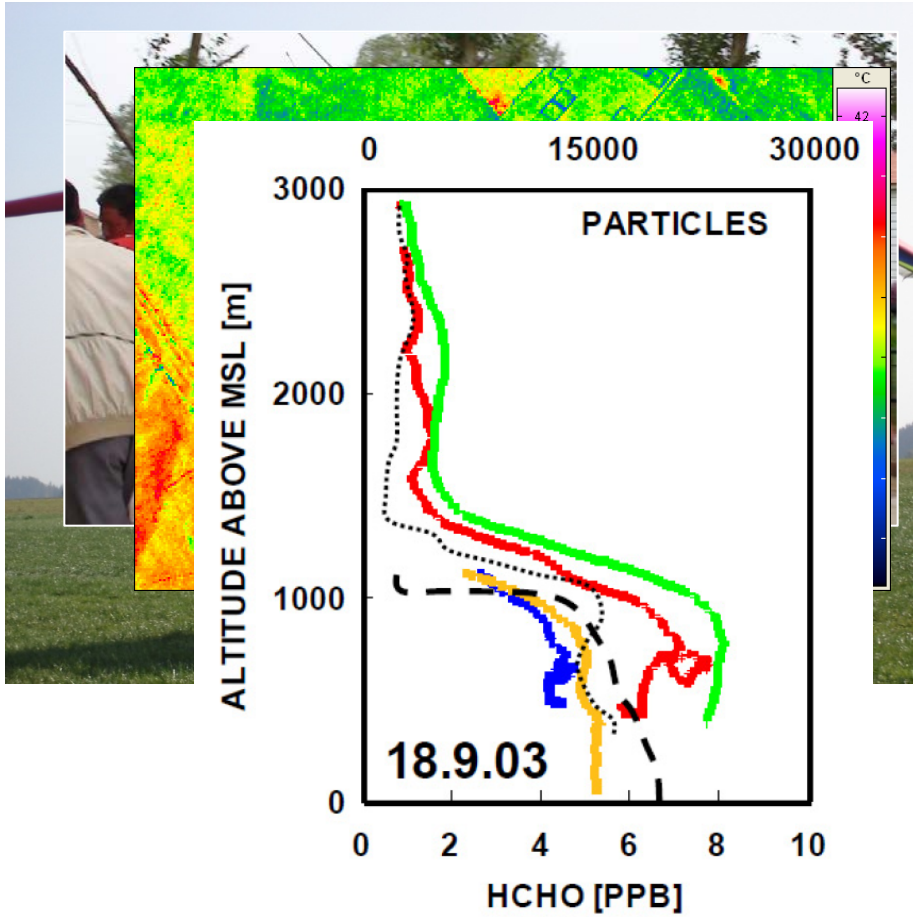
Weight-shift microlight aircraft

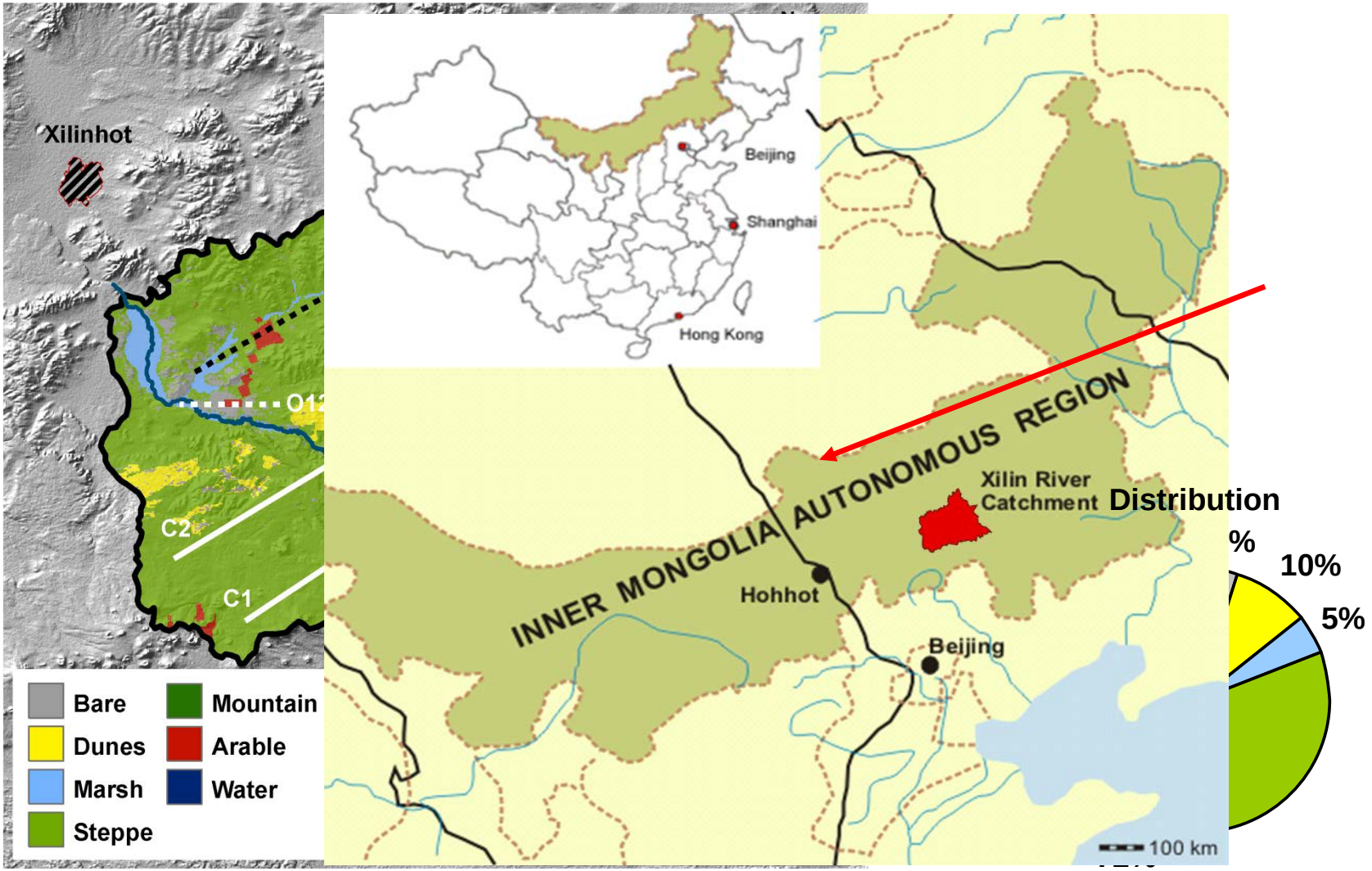
- Easy transport and certification
- Existing sensor package
  - Surface imagery
  - Aerosols and radiation
- Eddy Covariance Fluxes?

$$F = \overline{w'c'}$$

- High ratio of climb rate / true airspeed

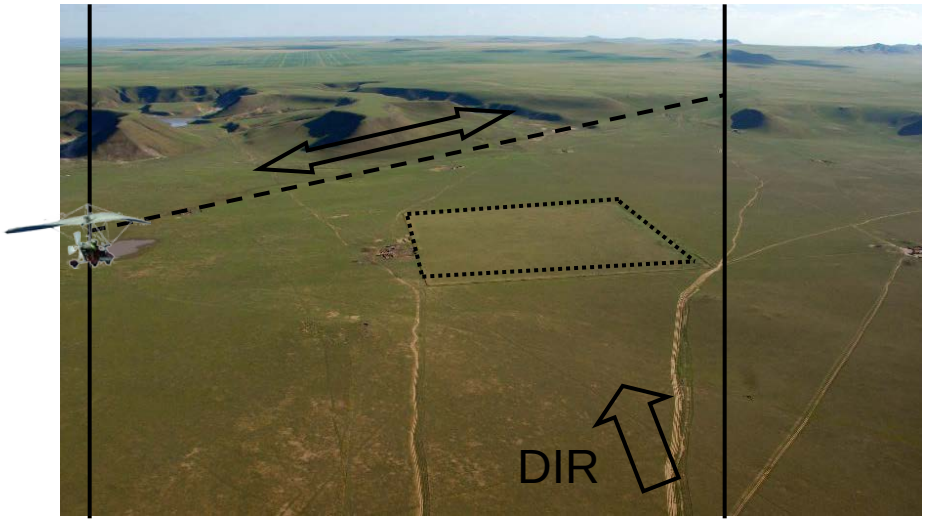


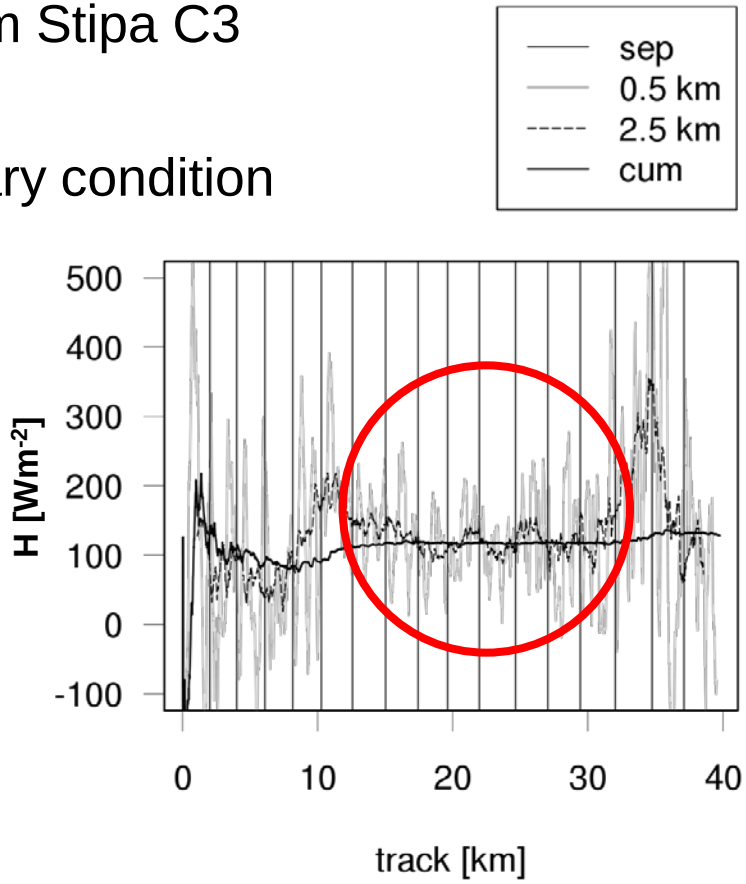
Spatially representative flux measurements



What is the spatial resolution of aircraft measurements?

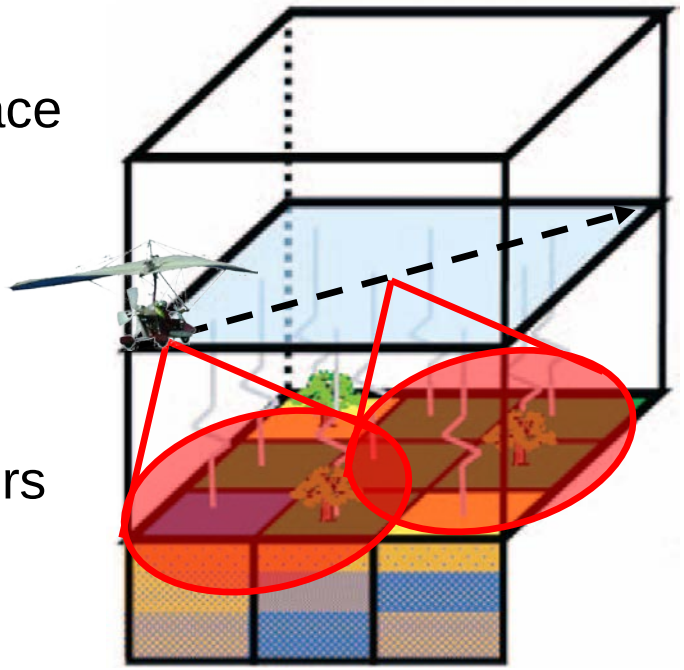
- flight altitude 50 m above ground
- 2 km flight legs downwind of 400 x 400 m Stipa C3
- Stipa flux signal resolved during stationary condition





Linking the measurement to surface properties

- Measured flux is linear combination of surface feature contributions



Mengelkamp et al. (2006)

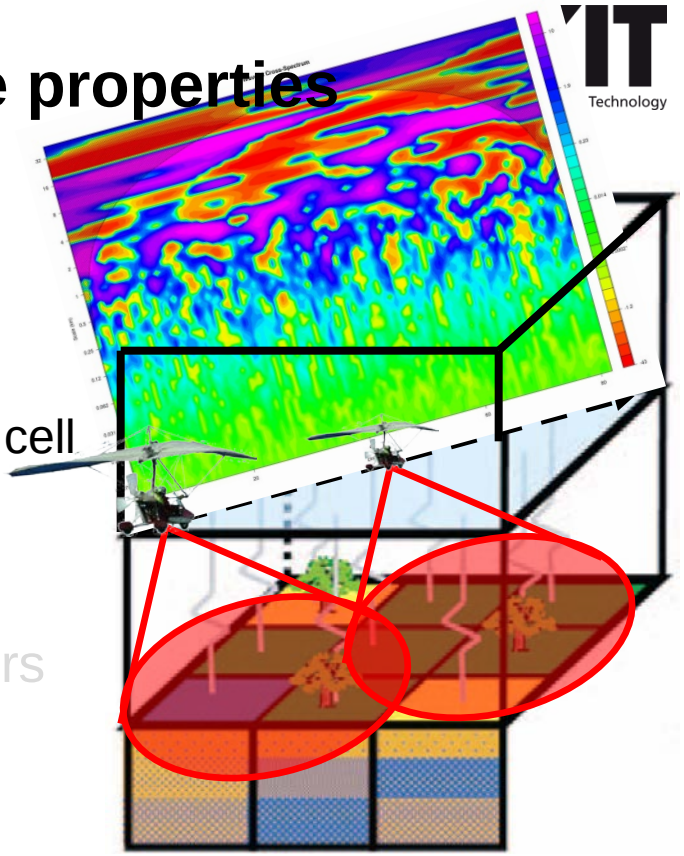
- solve system of N equations for M regressors (Chen et al., 1999):

$$
\begin{aligned}
C_{11}F_1 + C_{12}F_2 + \quad &\cdots \quad + C_{1m}F_m = F_1 \\
C_{21}F_1 + C_{22}F_2 + \quad &\cdots \quad + C_{2m}F_m = F_2 \\
\vdots \qquad\quad &\vdots \qquad\quad \vdots \\
C_{n1}F_1 + C_{n2}F_2 + \quad &\cdots \quad + C_{nm}F_m = F_n
\end{aligned}
$$

N: number of flux samples
M: number of surface feature classes
F_n: measured flux (regressand)
C_{nm}: source weight
F_m: surface feature flux (regressor)

Linking the measurement to surface properties

- Source area of fluxes
  - Footprint model (Kljun et al. 2004 +)
  - Wavelet cross-scalogram: flux above every cell



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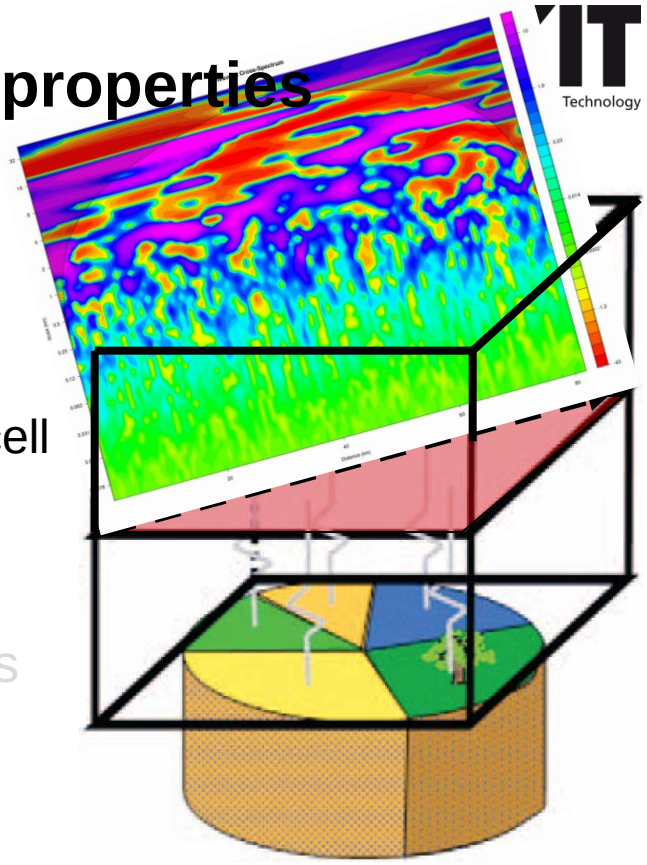

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N: number of flux samples
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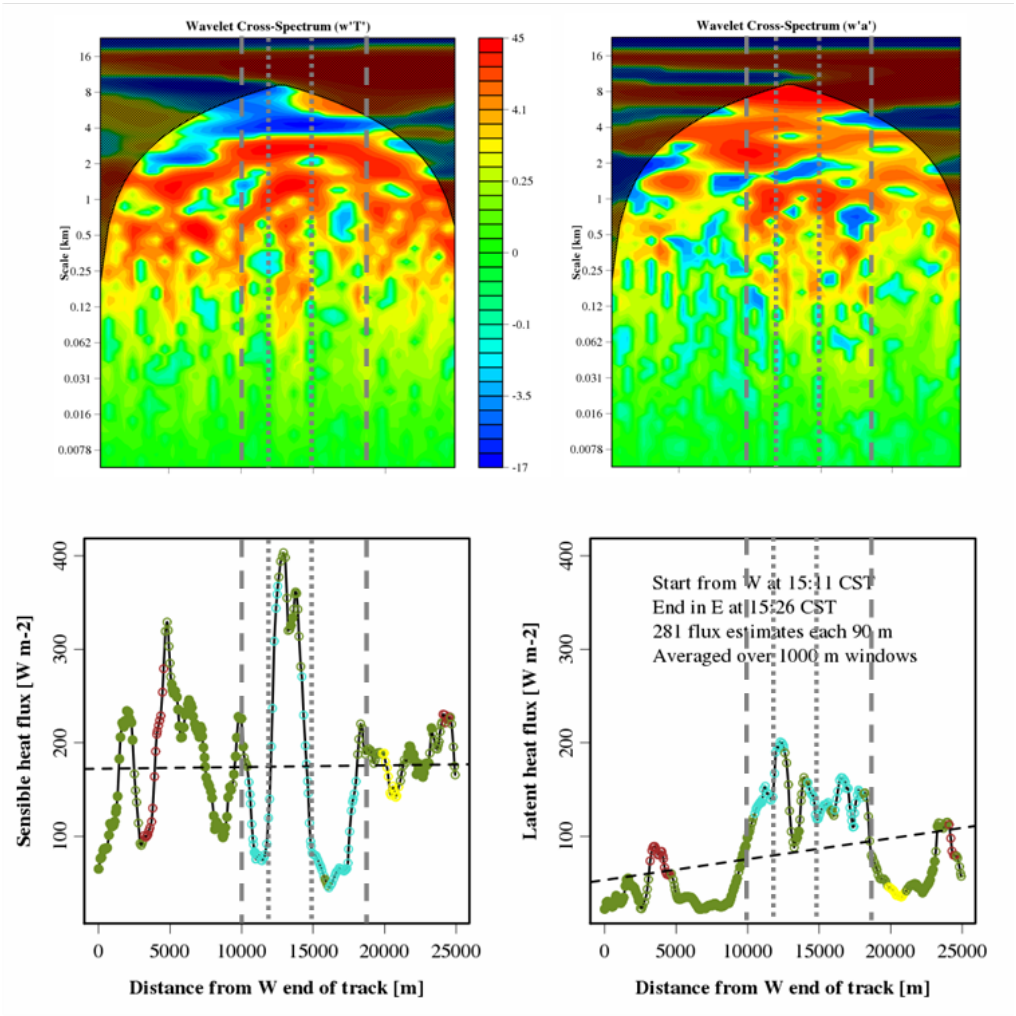
F_n: measured flux (regressand)
C_{nm}: source weight
F_m: surface feature flux (regressor)

‘Tile‘ fluxes for flight on 2009-06-25

$$C_{11}F_1 + C_{12}F_2 + \cdots + C_{1m}F_m = F_{t1}$$
$$C_{21}F_1 + C_{22}F_2 + \cdots + C_{2m}F_m = F_{t2}$$
$$\vdots \qquad \vdots \qquad \vdots$$
$$C_{n1}F_1 + C_{n2}F_2 + \cdots + C_{nm}F_m = F_{tn}$$

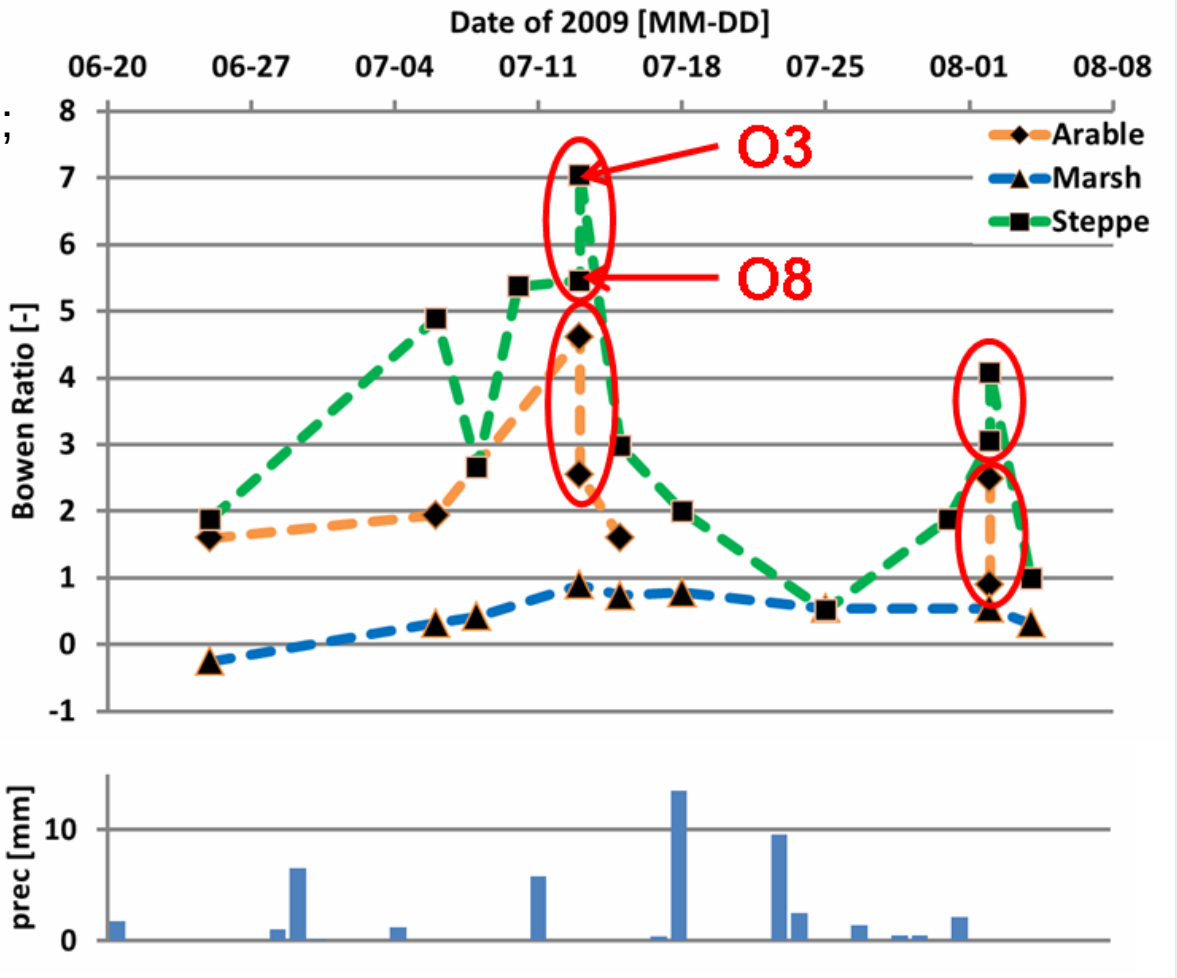
n = 281 flux estimates (F)

m = 3 land cover classes > 10 % average footprint contribution (C)



Bowen ratio of three land cover types

- Flux uncertainty:
  - < 20 % random error;
  - < 10 % slope error.
- But: solely land cover information does not take into account regional climatic gradients.

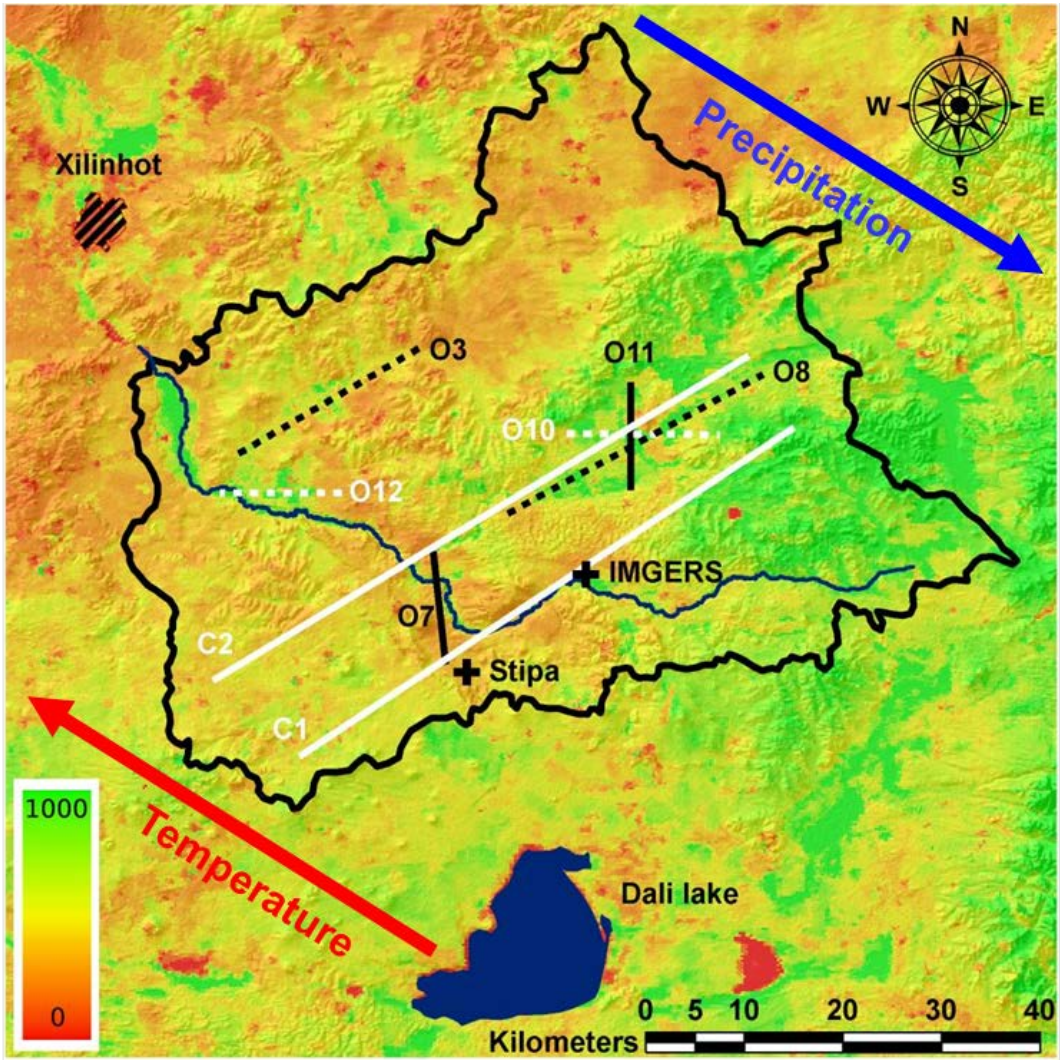


Metzger et al.:

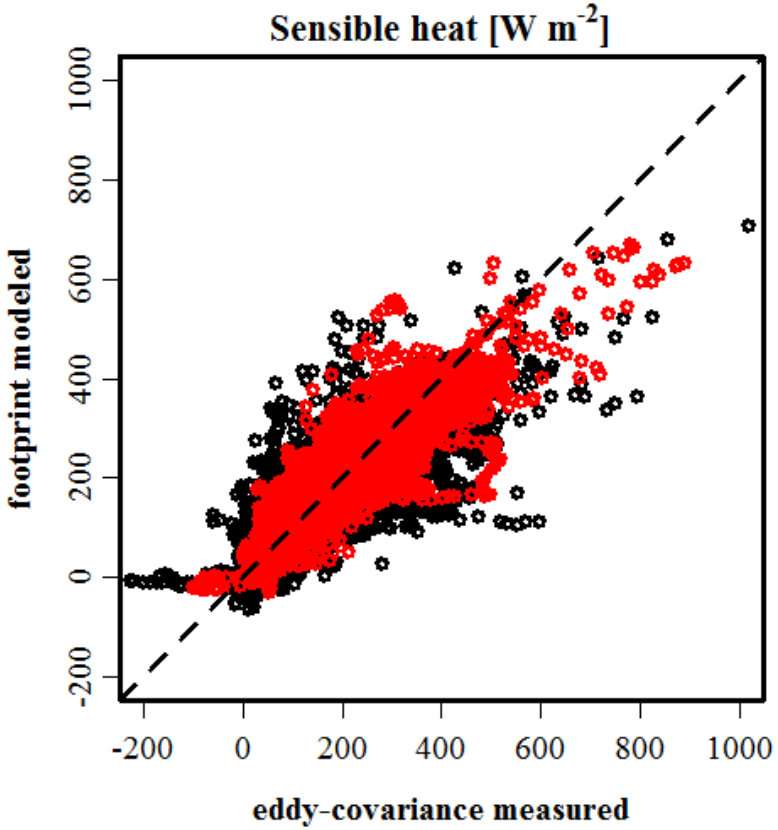
Eddy-covariance flux measurement over complex terrain with weight-shift microlight aircraft. 3rd iLEAPS Science Conference, Garmisch-Partenkirchen, Germany, 18 - 23 September **2011**.

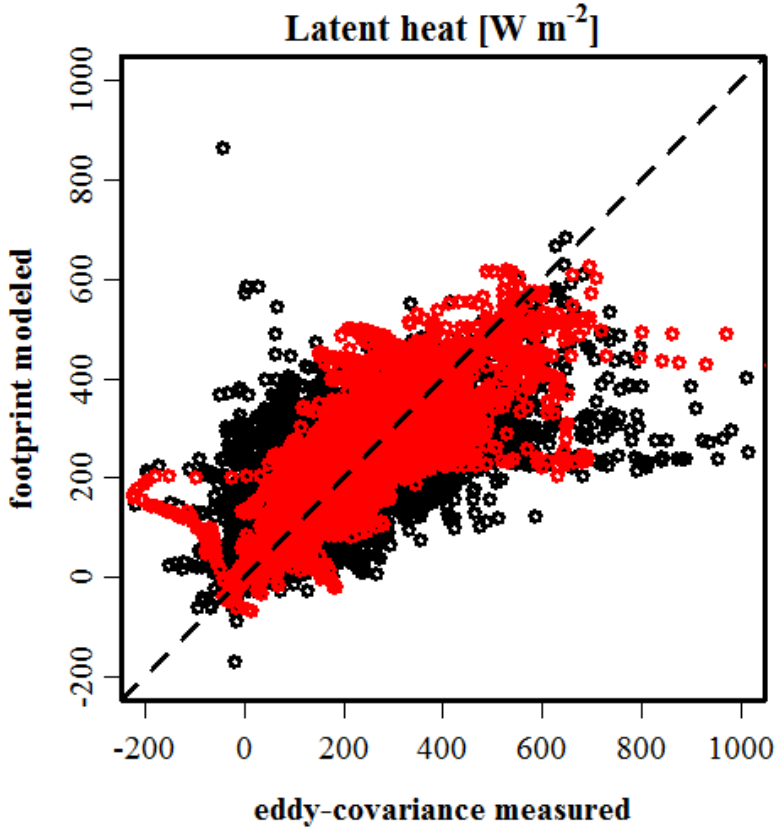
Improvements: MODIS data products as proxy for climatic gradients

- Enhanced vegetation index: moisture sources (r≈0.5)
- Land surface temp.: sensible heat sources (r≈0.3)
- Bi-weekly update, 250 m – 1000 m resolution
- Continuous characterization of land surface



Agreement for 40 flights, 8466 eddy-covariance measurements





Reynolds: Y = 40.62 + 0.68 X, R^2=0.73

Wavelet: Y = 23.18 + 0.85 X, R^2=0.90

Reynolds: Y = 59.84 + 0.57 X, R^2=0.60

Wavelet: Y = 24.32 + 0.84 X, R^2=0.89

Environmental response functions – amalgam or gold?

- Enables…
  - …scalability of results;
  - …assess comparability of measurements from different platforms.

- To do…
  - …time-frequency analysis: wavelet cone of influence? → Empirical mode decomposition (Huang et al., 1998);
  - …accuracy of footprint modeling? → Large eddy simulations;
  - …non-linear environmental response functions? → Multiple layers of information, support vector machines (Cortes & Vapnik, 1995).

- Outlook…
  - …application to tower measurements using AOP land surface data;
  - …intercomparison and site representativeness.

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