Strategies for Measuring Surface Fluxes in Orographic Terrain

Thomas Foken

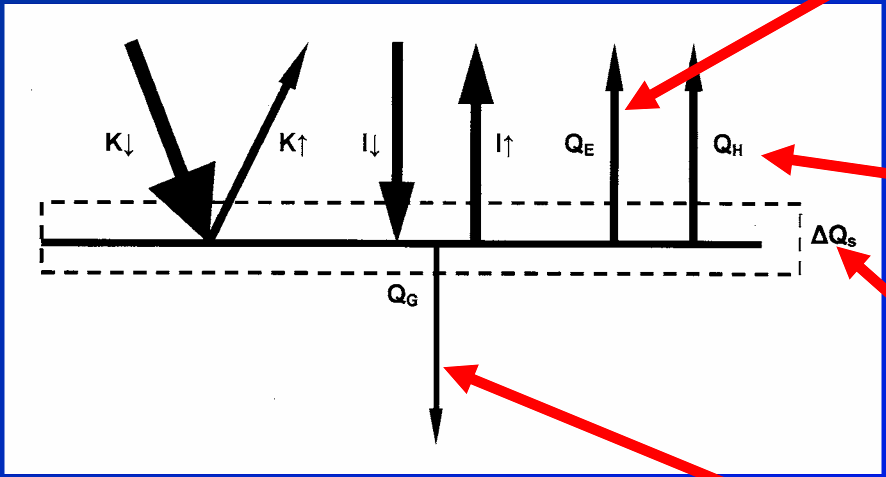
Department of Micrometeorology
University of Bayreuth

Content

1. Surface fluxes and convection
2. Experimental setup
3. Accuracy of surface fluxes
4. Quality assurance and control
5. Energy balance closure
6. Sensor and software requirements
7. Conclusion

Surface fluxes and convection

Net radiation



Latent heat flux
(moist convection)

Sensible heat flux
(thermal convection)

Storage

Soil heat flux
&
Soil moisture

Furthermore necessary:
Surface layer Deardorff velocity

Scaling of fluxes and convection

	thermal scaling	dynamical scaling
Surface layer	$T_* = -\frac{\left(\overline{w'T_v'}\right)}{u_*}$	u_*
limit (5-50 m):	$\frac{z}{L} = \frac{z \cdot \kappa \cdot g \cdot T_*}{T_v \cdot u_*^2} \quad \langle \quad -1$	
Convective layer	$w_* = \left[\frac{g \cdot z_i}{\theta_v}\left(\overline{w'\theta_v'}\right)\right]^{1/3}$	

Remark 1: Coherent structures are already generated in the surface layer. There is a connection to such structures in the boundary layer.

Remark 2: There is no remote sensing technique available to determine these parameters.

Surface fluxes and convection

Surface fluxes are relevant for the generation of convection:

- Flat terrain without topographic effects (Upper Rhein valley)
- Combination of surface heating and topographically indicated convection (Alpine pumping)

Relevant homogeneous surface area's to generate convection:

- About 500 m found by Shen and Leclerc (1995): Quart. J. Roy. Meteorol. Soc. 121, 1209-1228.
- About 2 km found by Fiedler (EGU 2005) from aircraft measurements.

An analysis of aircraft measurements is necessary to find relevant scales and sites in the target area

Experimental setup

Building up of at least 3 Main Sites at convection generating area's (2 in the valley, 1 in the mountains and single measurements in between)

- The central point of the main site has eddy-covariance surface flux measurements, the complete radiation balance, soil temperature and moisture, temperature and wind profile and probably also scintillometer and Sodar-RASS measurements.
- At least 2 additional eddy covariance and net radiation station.
- Determination of a flux composite (tile approach)

- 'Mesonet' weather stations and probably also Bowen ratio or Modified Bowen ratio systems in the whole area

- This setup was discussed with Dr. Steve Oncley (NCAR) during EGU 2005

Accuracy of surface fluxes

Radiation measurements according to the BSRN standard

Parameter	Sensor	Accuracy 1990 in W m^{-2}	Accuracy 1995 in W m^{-2}
Global radiation (short wave)	Pyranometer	15	5
Long wave radiation	Pyrgeometer	30	10

Secondary standard

University of Bayreuth
Department of Micrometeorology
Thomas Foken

Accuracy of surface fluxes

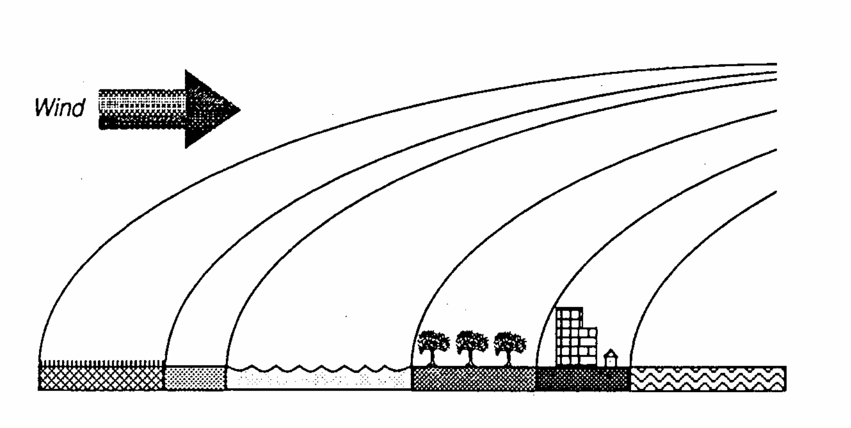
Eddy-covariance measurements according to recent indings (EBEX-2000 in USA and LITFASS-2003 in Germany)

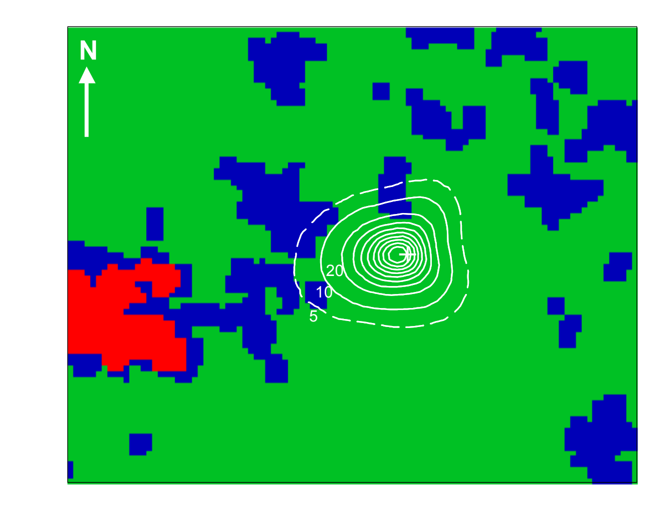
Sonic anemometer	quality class	sensible heat flux	latent heat flux
Type A, e.g. CSAT3	1-3	5% or 10 Wm^{-2}	10% or 20 Wm^{-2}
	4-6	10% or 20 Wm^{-2}	15% or 30 Wm^{-2}
Type B, e.g. USA-1	1-3	10% or 20 Wm^{-2}	15% or 30 Wm^{-2}
	4-6	15% or 30 Wm^{-2}	20% or 40 Wm^{-2}

- Sensor class: Foken, T., and Oncley, S. P. (1995) Bull. Am. Meteorol. Soc. 76, 1191-1193.
- Quality class: Foken, T., and Wichura, B. (1996) Agric. Forest Meteorol. 78, 83-105.

Quality Assurance and control

- Internal boundary layers
- Footprint

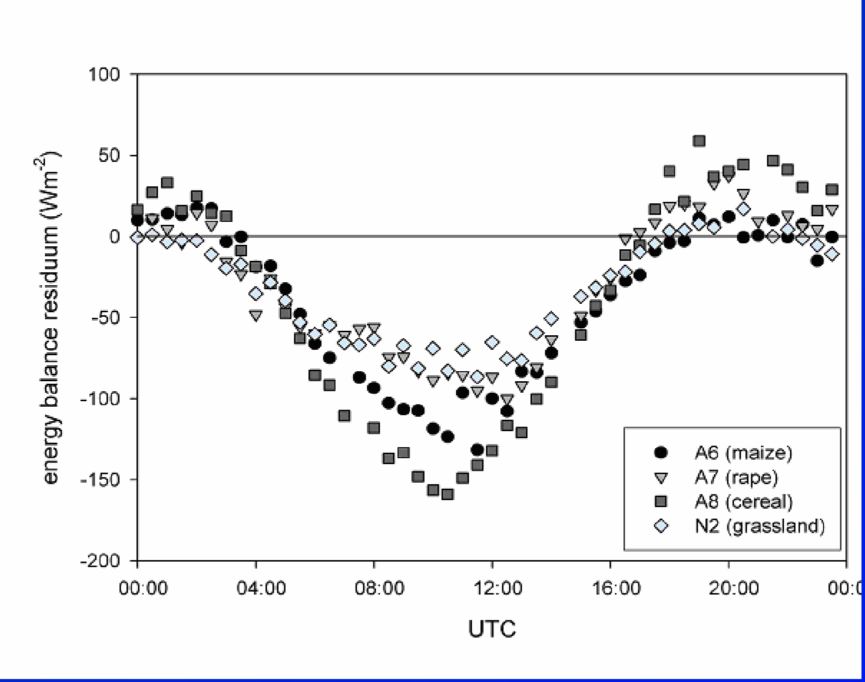




sector in°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°	360°
x in m	29	41	125	360	265	203	211	159	122	81	36	28
δ in m	1.6	1.9	3.4	5.7	4.9	4.3	4.4	3.8	3.3	2.7	1.8	1.6
flux contribution from the target land use area in %												
stable	36	49	81	99	96	92	93	88	81	70	44	35
neutral	51	63	90	100	100	98	98	95	90	82	59	50
unstable	62	74	98	100	100	100	100	100	98	91	70	61

Energy balance closure problem

From measurements the net radiation is larger than the sum of the turbulent fluxes with a residuum up to 200 Wm^{-2}
In contrary: Models close the energy balance



Mean values during LITFASS-2003

- **The residuum is not equal (or according to the Bowen ratio) distributed to the turbulent fluxes!**
- **If the accuracies of all sensor are fulfilled the following reasons should be discussed:**
- **Storage terms (soil measurements)**
- **Advection (profile and cluster measurements)**
- **Structure of the turbulent eddies (software requirements)**

Sensor and software requirements

The following sensors are necessary for the main station:

- Short wave radiation: CM 11 (Kipp & Zonen) or better
- Long wave radiation: PIR (Eppley) or better
- Sonic anemometer: CSAT3 (Campbell) or NUW (NCAR)
- Humidity: Licor 7500

- Additional cluster measurements also CNR1 (Kipp & Zonen, net radiation, HS (Solent, sonic anemometer), KH20 (Campbell, humidity) are possible

- Additionally: Sodar-RASS, Scintillometer

- Eddy covariance software with included data quality program (test during comparison experiment necessary)
- Footprint model (best: Lagrangian type)

Installation of the central point of each cluster

Turbulent fluxes | **Profile measurements** | **Radiation measurements**

Figures from EBEX-2000, Fresno, USA

University of Bayreuth
Department of Micrometeorology
Thomas Foken

Conclusions

- The measurement of the surface energy parameters is an important part to understand the generation of convection and to generate initialization parameters for models.
- At the present time such measurements and calculation should be done according to the standards of recent experiments and programs.
- Each cluster (probably 3-4) should be equipped by one group (e.g. NCAR, UBT, UBa/UPa, UKA?) and the main sensors of the clusters should be compared in spring 2007 (probably at the Boundary Layer Field Site Falkenberg, Observatory Lindenberg).
- Installation of a Mesonet (UKA?)
- The data calculation and quality control incl. footprint analysis should be done by one group.
- Costs: 1 PhD student for each cluster, 1 PhD student for data calculation, traveling costs, limited costs of equipment