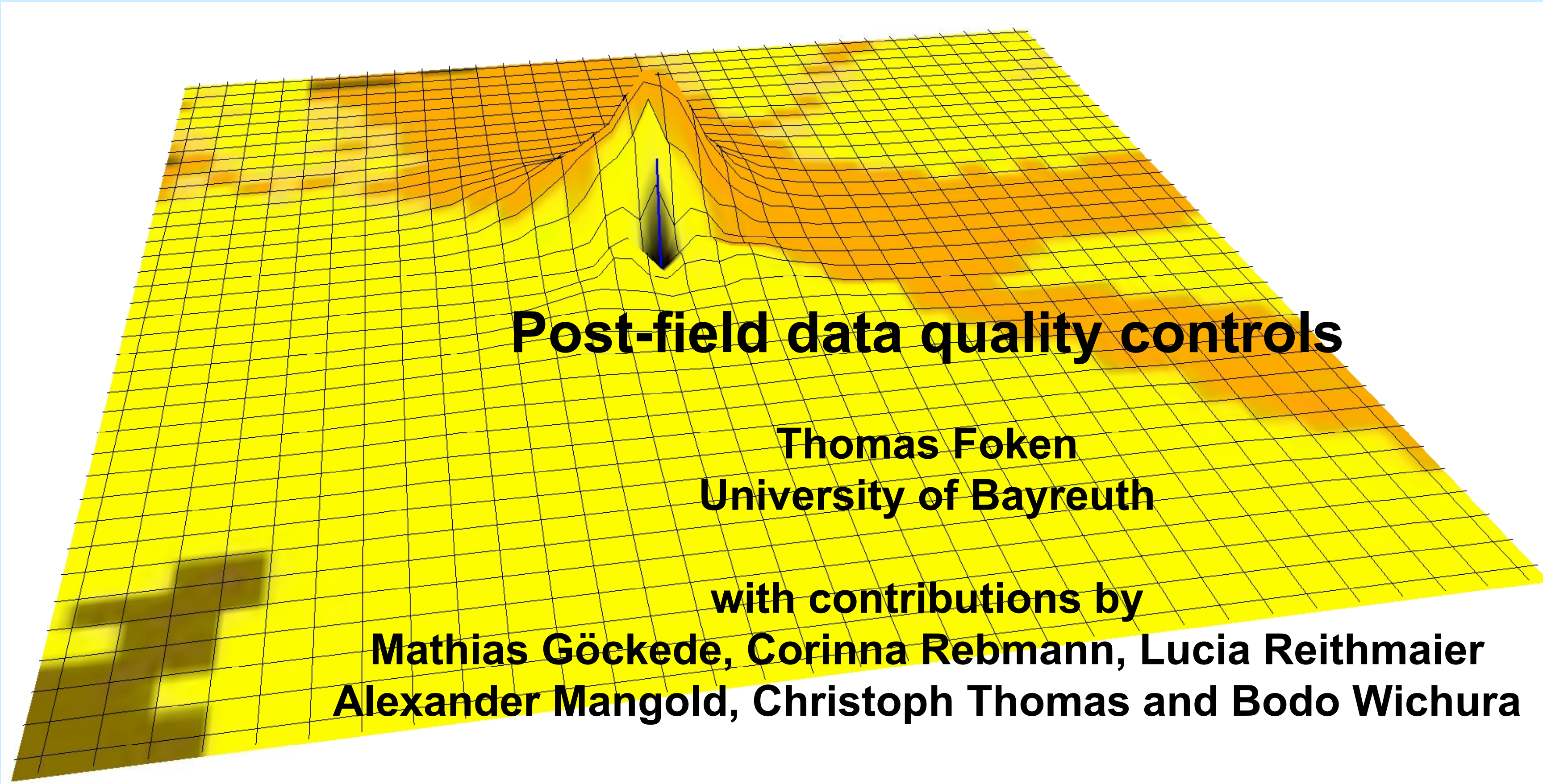


Post-field data quality controls

Thomas Foken
University of Bayreuth

with contributions by
Mathias Göckede, Corinna Rebmann, Lucia Reithmaier
Alexander Mangold, Christoph Thomas and Bodo Wichura

Content

1. Introduction (QA/QC)
2. Quality tests for eddy covariance measurements
3. Definition of suitable integral turbulence characteristics
4. Footprint dependent data quality
5. The data and site quality control programme of CARBOEUROFLUX
6. Examples for 3 different sites*
7. Further influences on the data quality (turbulent scales)
8. Conclusion

* not in the copy of the transparencies

Quality Assurance (QA) for Carbon Dioxide Measuring Programmes

1. Specification of user requirements	**partly done**
2. Specification of the measuring system	**later done: Moncrieff et al. (1997) Aubinet et al. (2000)**
3. Use of a suitable measuring field	**often no ideal sites**
4. Definition of necessary calibrations	**later done: Moncrieff et al. (1997) Aubinet et al. (2000) and other**
5. Definition of the quality control	**THIS PAPER**
6. Quality evaluation	
7. Correction action	**later done: Moncrieff et al. (1997) Aubinet et al. (2000) and other**
8. Feedback from the user of the data	**should be discussed**

Shearman, R. J., 1992: Quality Assurance in the observation area of the Meteorological Office. Meteorol. Mag. **121**, 212-216

Reasons for Errors of the Eddy-Covariance Method

Not fulfilled theory

- Horizontal homogeneity
- Steady state conditions
- Co-ordinate system

Meteorological problems

- Internal boundary layers
- Surface layer height
- Gravity waves
- No turbulence

Sensor configuration

- Flow distortion
- Sensor separation
- Measuring height
- Tilt error

Quality tests

Correction methods

Quality Control (QA)
for Carbon Dioxide Measuring Programmes

1. Raw data test: Spikes	Højstrup (1993) Vickers & Mahrt (1997)
2. Raw data test: Sampling errors	Haugen (1978) Vickers & Mahrt (1997) and other
3. Raw data test: Amplitude resolution	Vickers & Mahrt (1997)
4. Raw data test: Absolute electrical and meteorological limits	Vickers & Mahrt (1997) and other
5. Raw data test: Steps, dropouts	Mahrt (1991) Vickers & Mahrt (1997)
6. Steady state test: trends, statistic	Vickers & Mahrt (1997)
7. Steady state test: comparison of statistics	Foken & Wichura (1996)
8. Turbulence test: Correlation coefficient	Kaimal & Finnigan (1994)
9. Turbulence test: Integral turbulence characteristics	Foken & Wichura (1996)

Influences on the Eddy-Covariance Method indicated with the tests

Steady state test

- Horizontal homogeneity
- Steady state conditions

Integral characteristics

- Internal boundary layers
- Surface layer height
- Gravity waves
- No turbulence
- Horizontal homogeneity

Further influences:

- Flow distortion
- Sensor separation
- Measuring height
- Tilt error
- Co-ordinate system

Quality Test for the Eddy-Covariance Method

1. Steady State Test

- **Mean flux determined from short time intervals**

$$\left(\overline{x'y'}\right)_i = \frac{1}{N-1}\left[\sum_j x_j \cdot y_j - \frac{1}{N}\left(\sum_j x_j \cdot \sum_j y_j\right)\right]$$

$$\overline{x'y'} = \frac{1}{M}\sum_i \left(\overline{x'y'}\right)_i$$

- **Mean flux determined for the time seria**

$$\overline{x'y'} = \frac{1}{M \cdot N - 1}\left[\sum_i \left(\sum_j x_j \cdot y_j\right)_i - \frac{1}{M \cdot N}\sum_i \left(\sum_j x_j \cdot \sum_j y_j\right)_i\right]$$

- **Steady state conditions: difference of both parameters < 20-30 %**

Foken, T., Wichura, B., 1996. Tools for quality assessment of surface-based flux measurements. Agric. & Forest Meteorol., **78**: 83-105.

Quality Test for the Eddy-Covariance Method

2. Test on developed turbulence

- **Integral turbulence characteristics for wind components**

$$\frac{\sigma_x}{u_*} = a_1 \left| \varphi_m \left(z/L \right) \right|^{-\frac{1}{2}}$$

- **Integral turbulence characteristics for scalars**

$$\frac{\sigma_y}{u_*} = a_2 \left| \left(z/L \right) \varphi_h \left(z/L \right) \right|^{-\frac{1}{2}}$$

- **Developed turbulence: difference between experimental and model data <20-30 %**

Foken, T., Wichura, B., 1996. Tools for quality assessment of surface-based flux measurements. Agric. & Forest Meteorol., **78**: 83-105.

Definition of the quality test parameters

steady state test		integral turbulence characteristics	
class	range	class	range
1	0 - 15 %	1	0 - 15 %
2	16 - 30 %	2	16 - 30 %
3	31 - 50 %	3	31 - 50 %
4	51 - 75 %	4	51 - 75 %
5	76 - 100 %	5	76 - 100 %
6	101 - 250 %	6	101 - 250 %
7	251 - 500 %	7	251 - 500 %
8	501 - 1000 %	8	501 - 1000 %
9	> 1000 %	9	> 1000 %

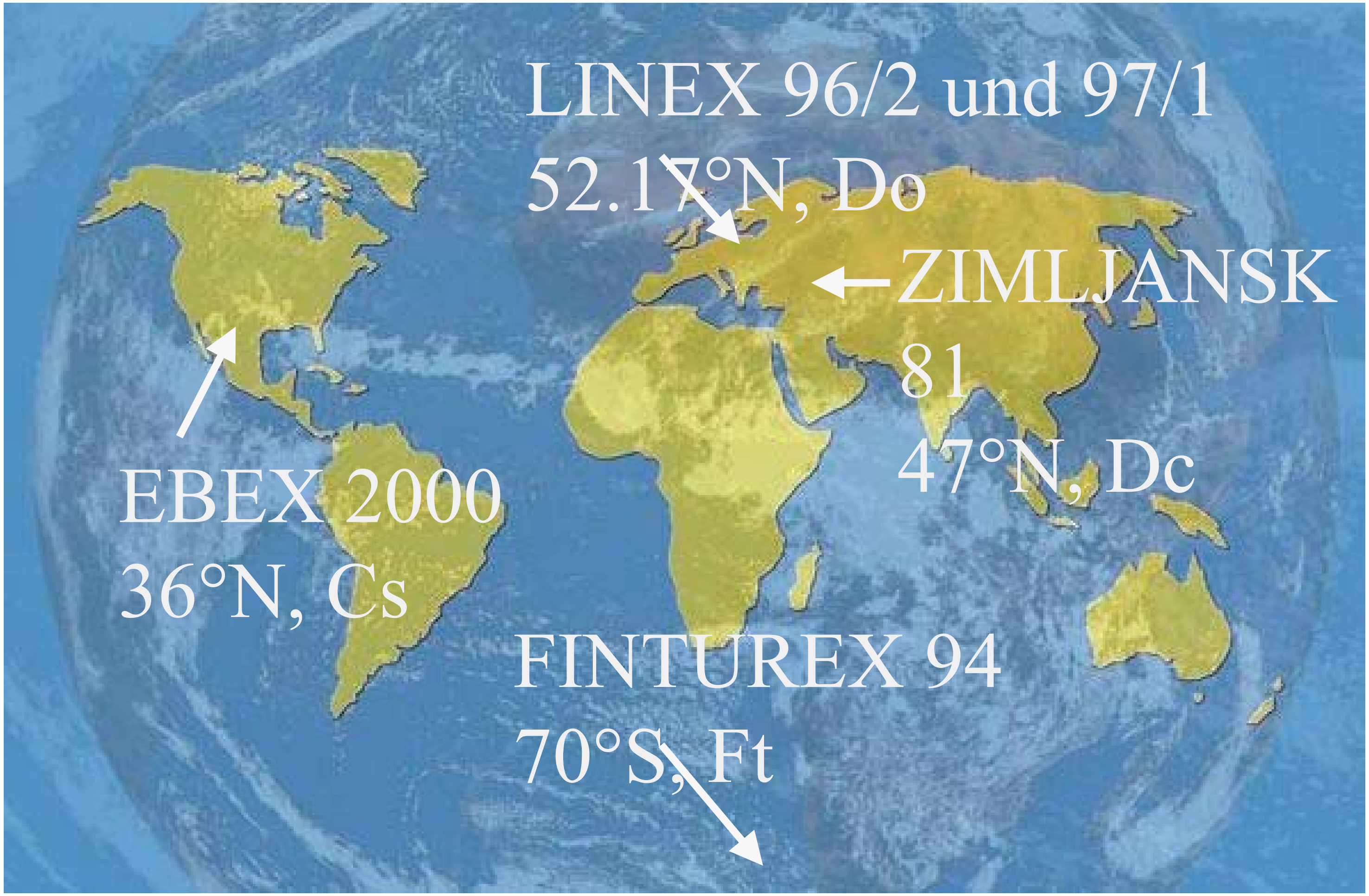
quality class	steady state	integral turbulence charactersitics
1	1	1-2
2	2	1-2
3	1-2	3
4	3	1-2
5	4	3-4
6	5	3-4
7	5	5
8	6-8	= 8
9	one parameter 9	

Foken, T., Wichura, B., 1996. Tools for quality assessment of surface-based flux measurements. Agric. & Forest Meteorol., **78**: 83-105.

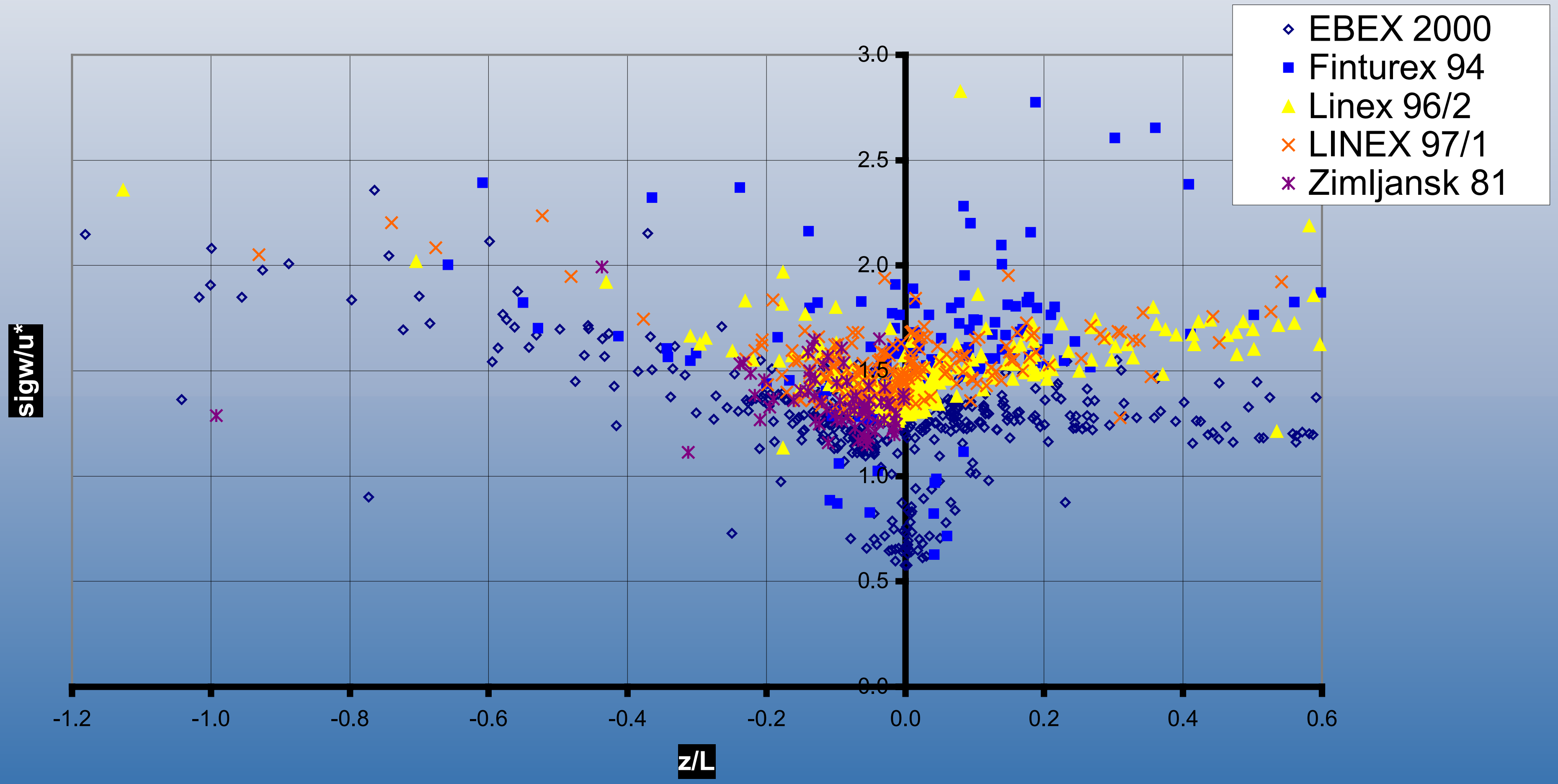
parameter unpublished

additional tests on horizontal orientation and mean vertical wind velocity

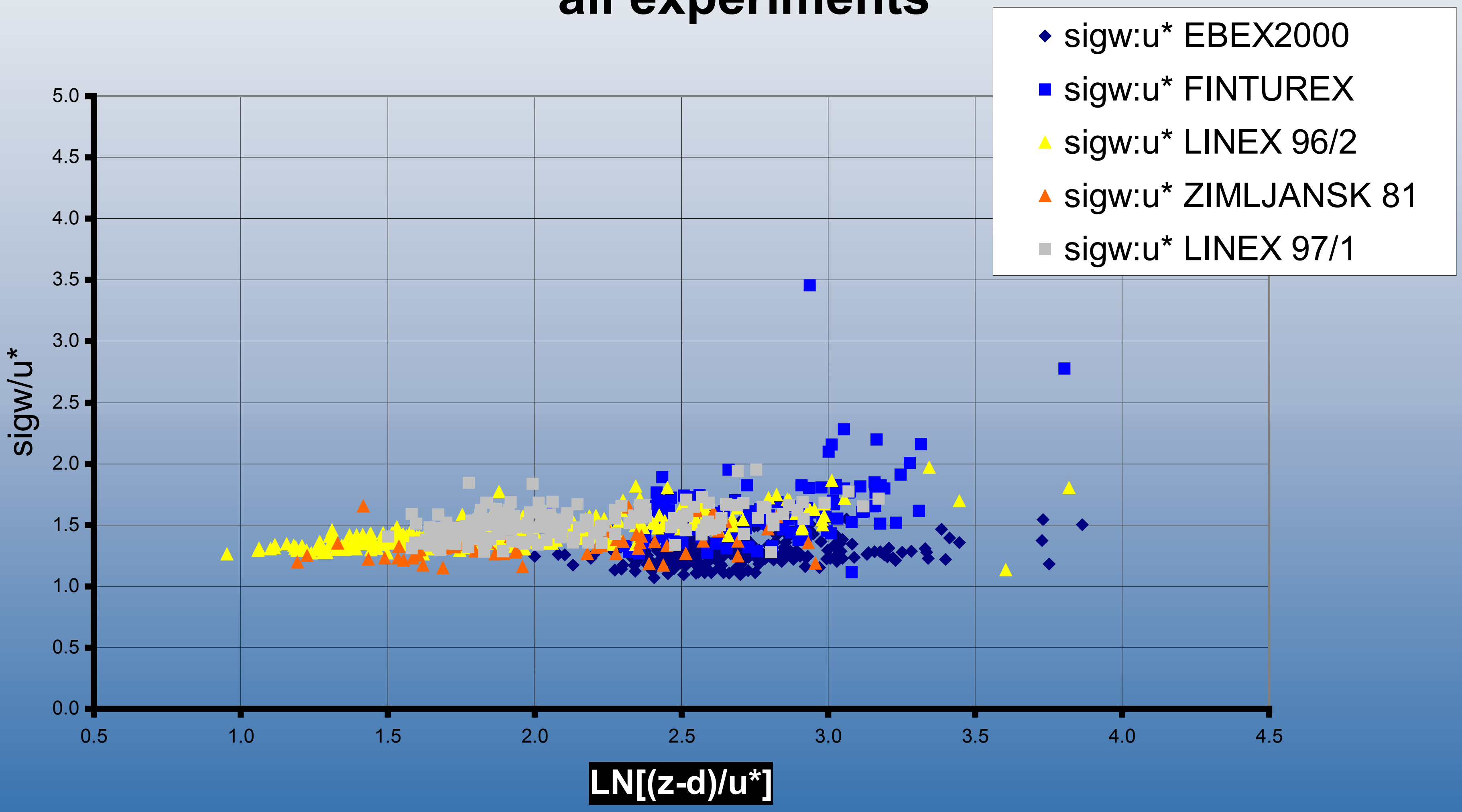
Data sets for integral turbulence characteristics



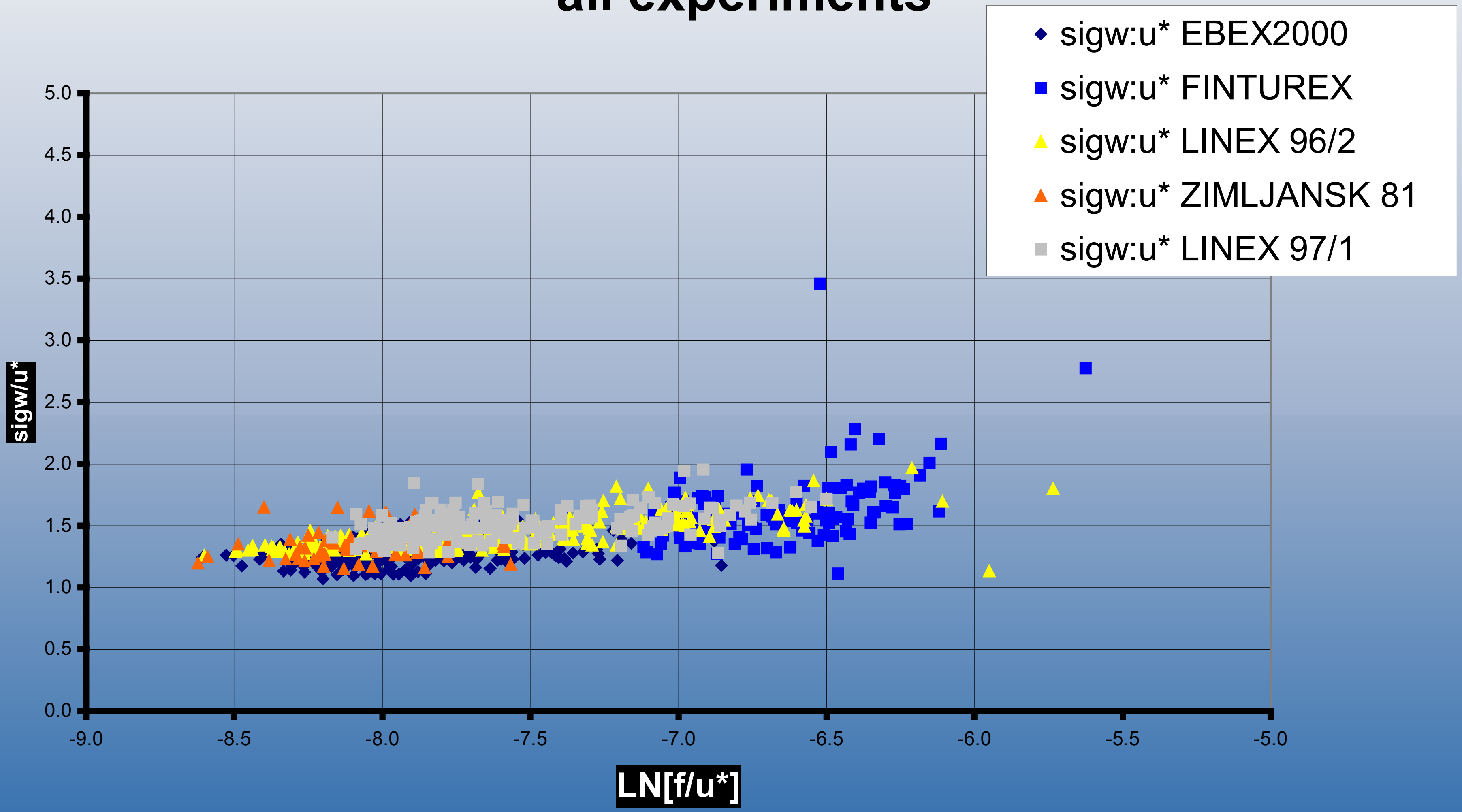
$\sigma_w/u^*_{measured}$ as a function of z/L
all experiments



sigw:u* -0.2<z/L<0.4
all experiments



sigw:u* -0.2<z/L<0.4
all experiments



Re-formulation of the integral turbulence characteristics

<table>
<tr><th rowspan="2">Integral characteristics</th><th colspan="4">Stability range</th></tr>
<tr><th colspan="2">$-3 < z/L < -0.2$</th><th colspan="2">$-0.2 < z/L < 0.4$</th></tr>
<tr><td>σ_w / u_*</td><td colspan="2">$1.3\left(1-2\,\frac{z}{L}\right)^{1/3}$
by Panofsky et al. (1977) and other authors</td><td colspan="2">$0.2\,\ln\left(\frac{z_+ \cdot f}{u_*}\right) + 3.1 \qquad z_+ = 1\,m$</td></tr>
<tr><td>σ_u / u_*</td><td colspan="2">$4.15\left(\left|\frac{z}{L}\right|\right)^{1/8}$
by Foken et al. (1991)</td><td colspan="2">$0.44\,\ln\left(\frac{z_+ \cdot f}{u_*}\right) + 6.3 \qquad z_+ = 1\,m$</td></tr>
<tr><td rowspan="4">σ_T / T_*</td><td colspan="4">Stability range</td></tr>
<tr><td>$z/L < -1$</td><td>$-1 < z/L < -0.0625$</td><td>$-0.0625 < z/L < 0.02$</td><td>$0.02 < z/L$</td></tr>
<tr><td>$\left(\left|\frac{z}{L}\right|\right)^{-1/3}$</td><td>$\left(\left|\frac{z}{L}\right|\right)^{-1/4}$</td><td>$0.5\left(\left|\frac{z}{L}\right|\right)^{-1/2}$</td><td rowspan="2">$1.4\left(\left|\frac{z}{L}\right|\right)^{-1/4}$</td></tr>
<tr><td colspan="3">By Foken et al (1991)</td></tr>
</table>

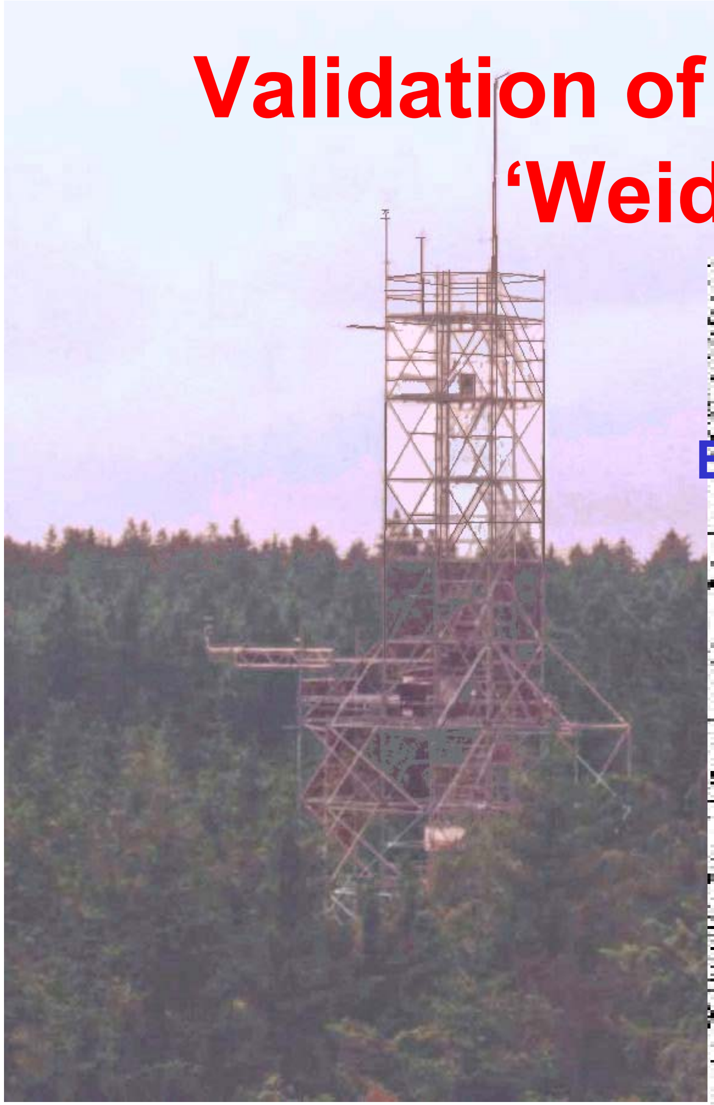
University of Bayreuth
Department of Micrometeorology

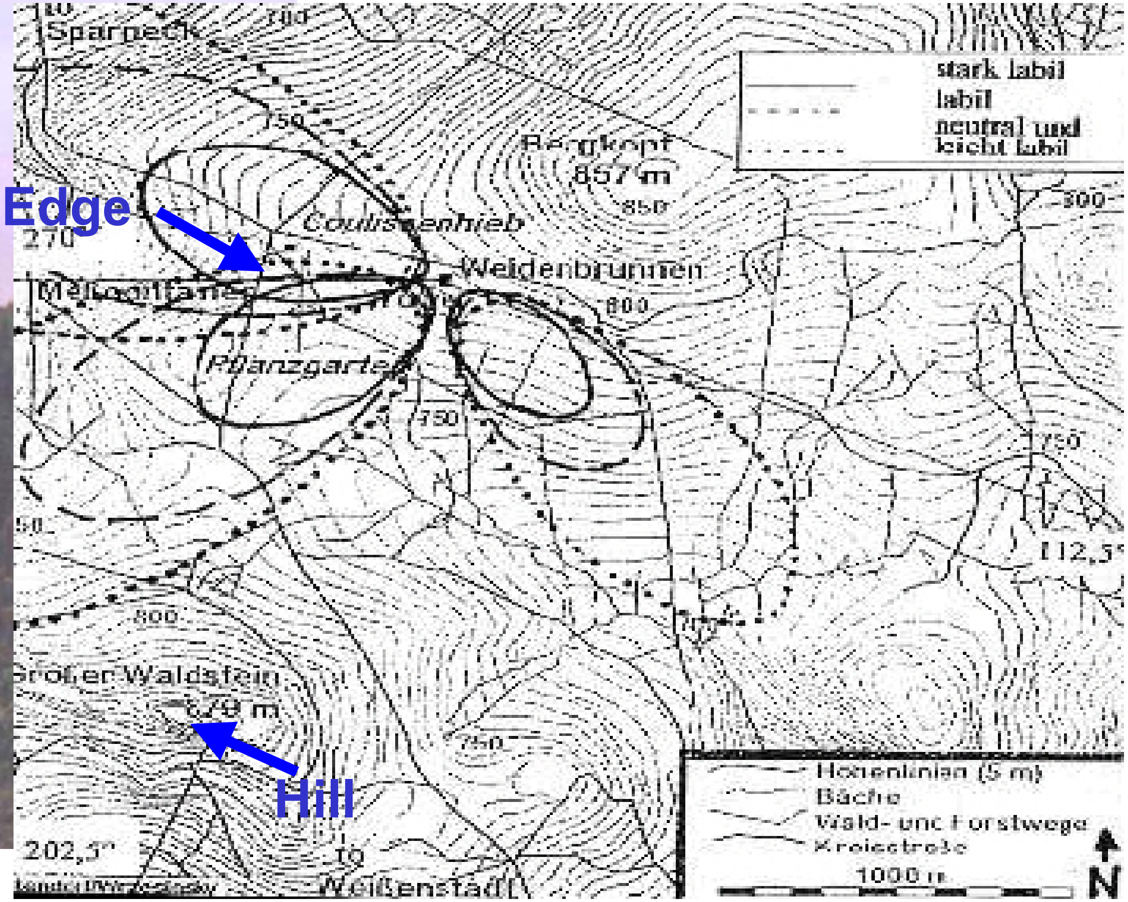
Christoph Thomas
Diploma Thesis

Combination of QC and footprint

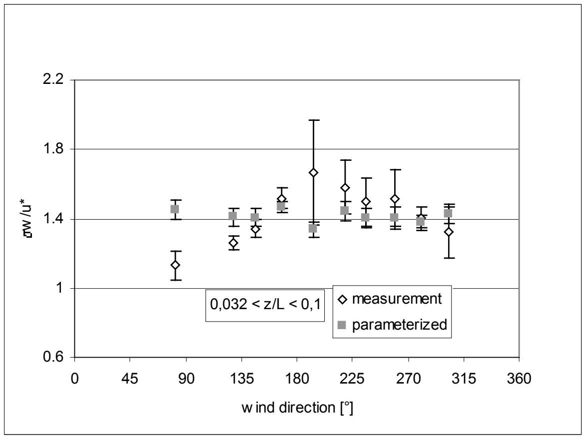
- **Several long term measuring programmes are based on measurements at very complex sites and use footprint models for flux interpretation.**
- **Most of the footprint models are valid only for very limited conditions: homogeneous surface, steady-state conditions, limited stability range, ...**
- **The verification of footprint models is an outstanding problem.**

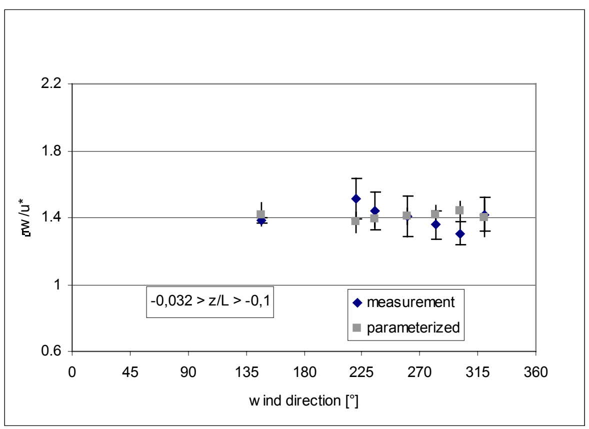
Validation of Footprint Models on the 'Weidenbrunnen' site

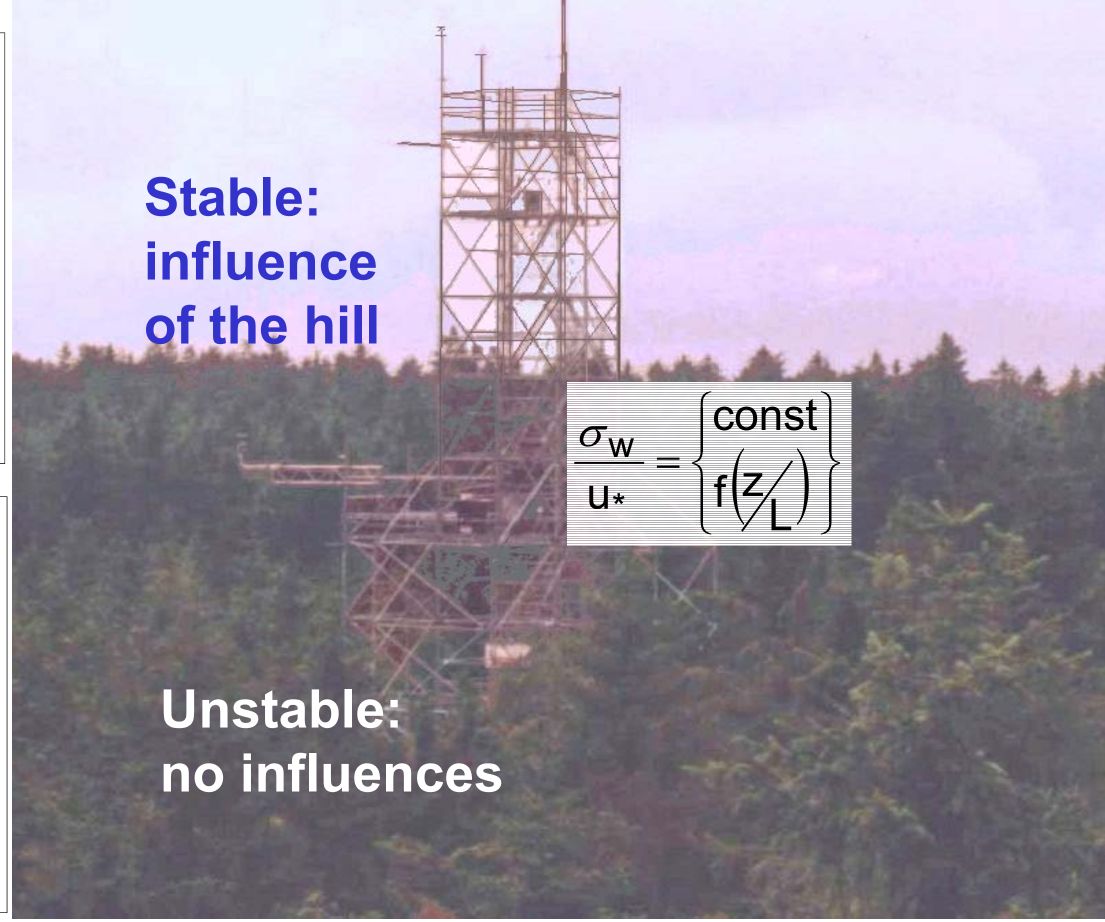




Validation of Footprint Models on the ‘Weidenbrunnen’ site







Stable: influence of the hill

$$\frac{\sigma_w}{u_*} = \left\{ \begin{matrix} \text{const} \\ f\left(z/L\right) \end{matrix} \right\}$$

Unstable: no influences

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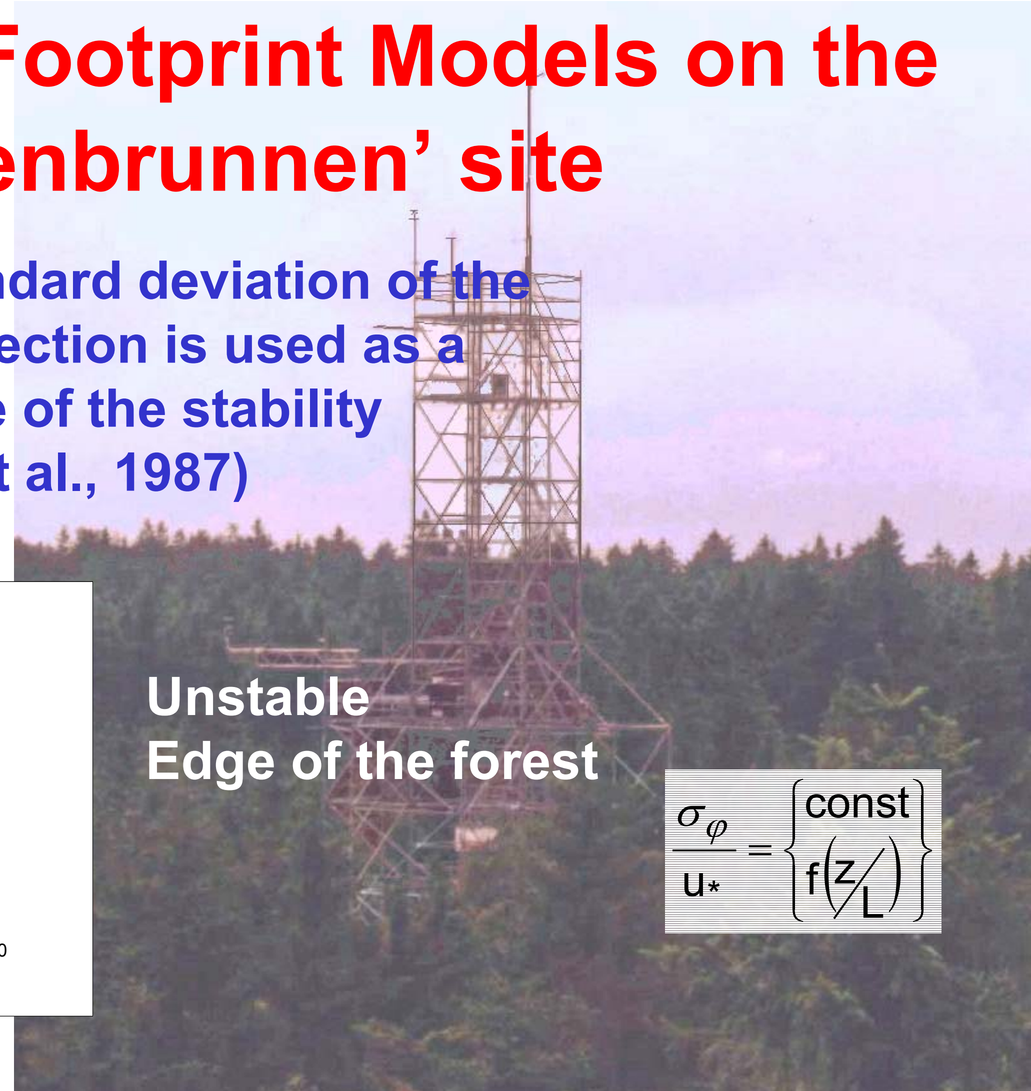
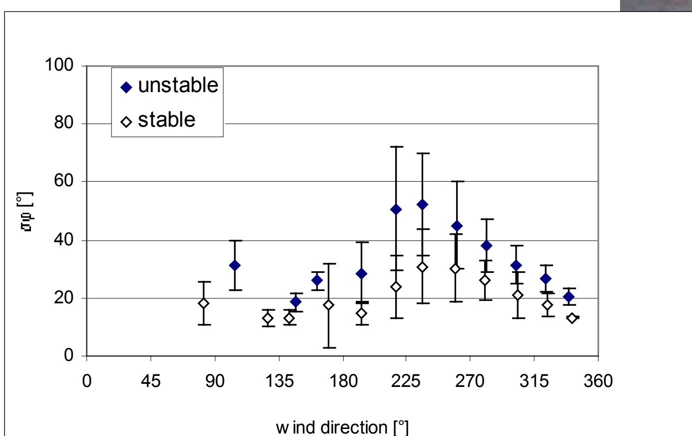
Validation of Footprint Models on the 'Weidenbrunnen' site

The standard deviation of the wind direction is used as a measure of the stability (Hicks et al., 1987)

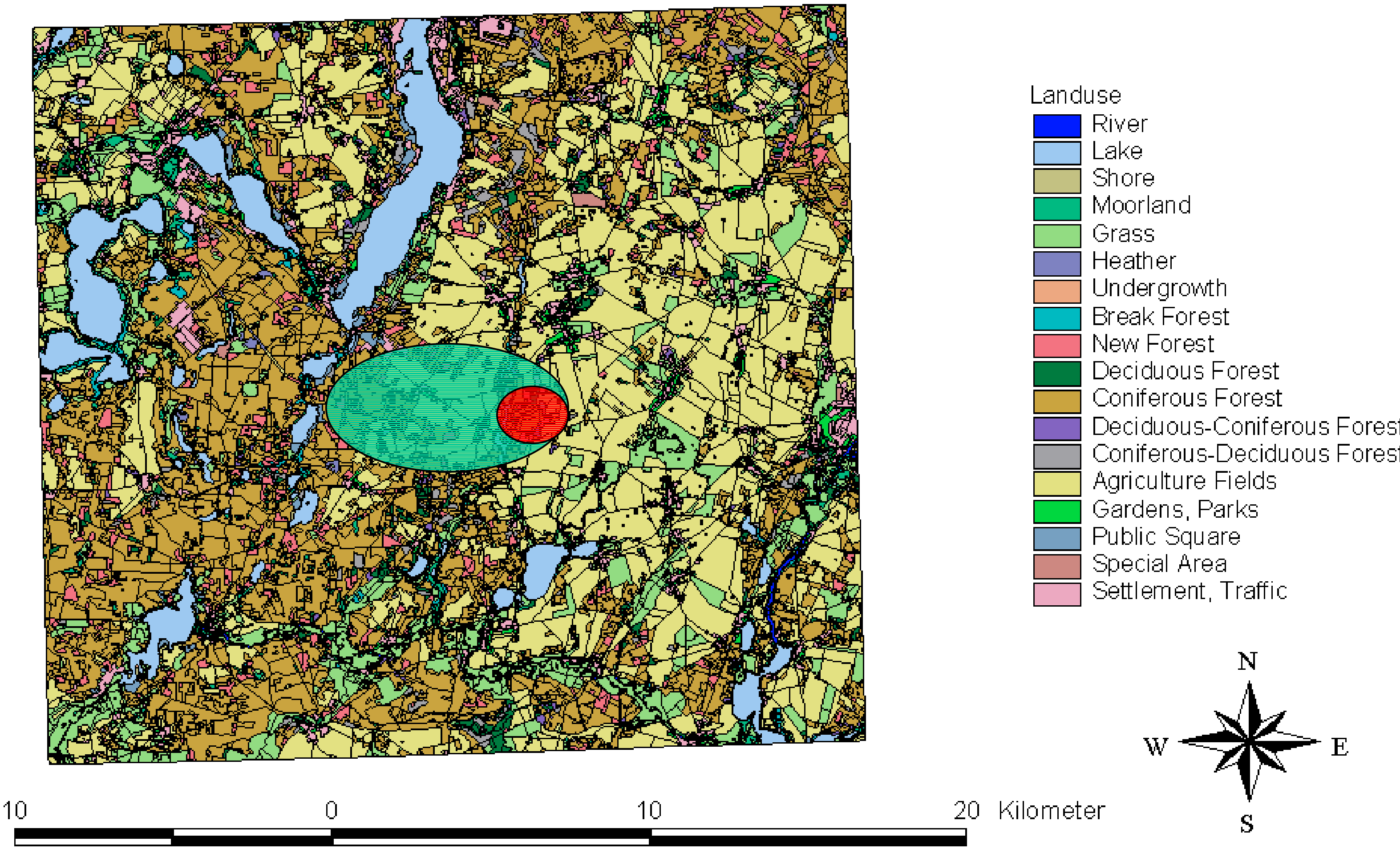




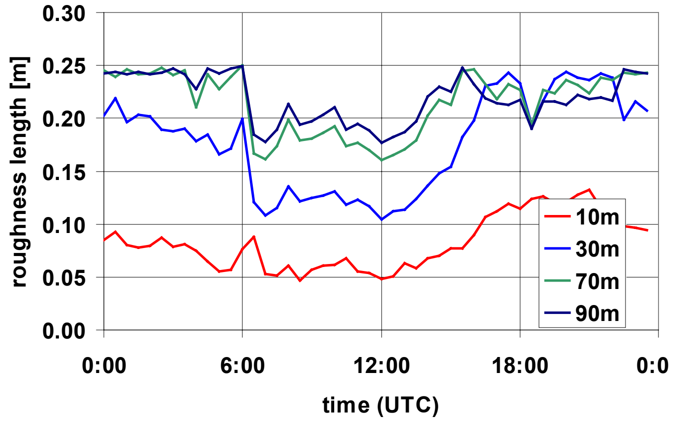
Unstable
Edge of the forest

$$\frac{\sigma_\varphi}{u_*} = \begin{Bmatrix} \text{const} \\ f\left(\frac{z}{L}\right) \end{Bmatrix}$$

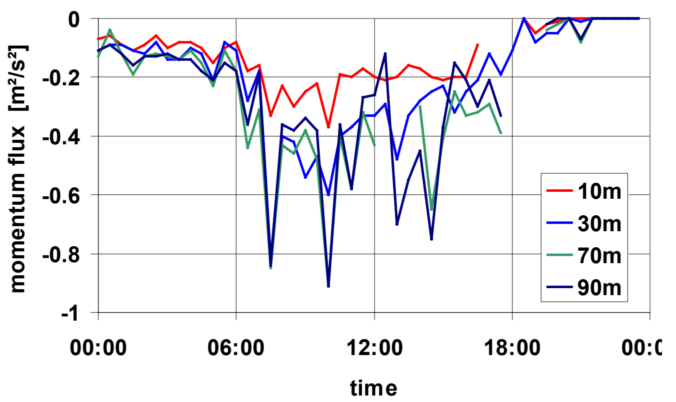
Validation of Footprint Models on the ‘Falkenberg’ site (GM)



Validation of Footprint Models on the 'Falkenberg' site (GM)



Source area dependent roughness length



Source area dependent momentum fluxes

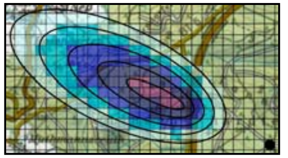
Regionalisation of QC-results

Overview

- Data quality assessment

$$\frac{\sigma_x}{u_*} = c_1 \cdot \left(\left| \frac{z}{L} \right| \right)^{c_2}$$

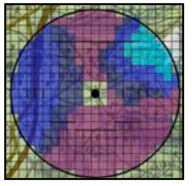
- Footprint analysis: Assignment of weighting factors

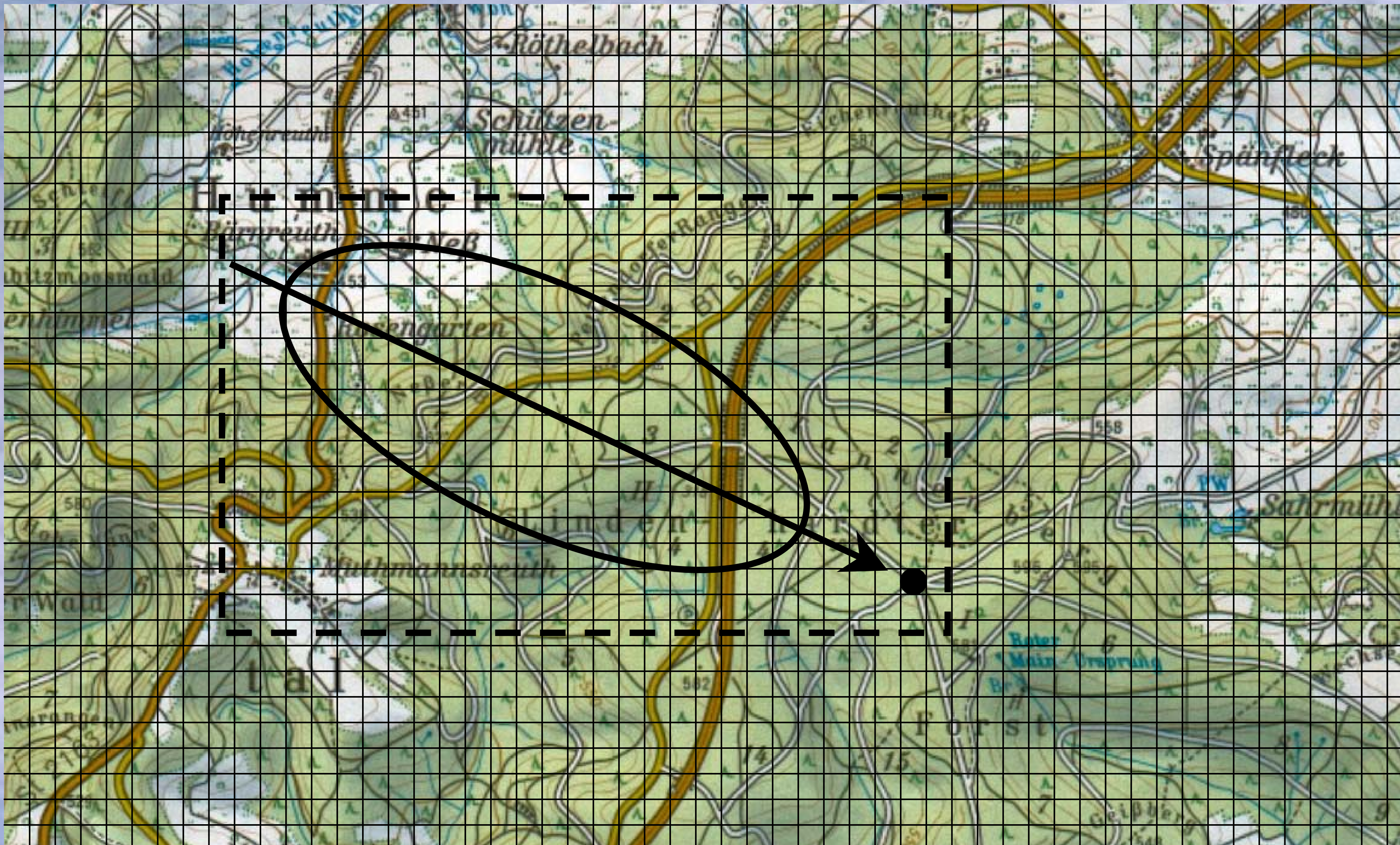


- Collection in database

cell-ID: 25, size: 0.1 x 0.1km, rel. coordinates (13;05)								
No.	time	phi [°]	z/L [-]	u [m/s]	P-Level [%]	QC u_*	QC wT_p	..
1	07:30	115	0.15	1.43	80	5	5	..
2	10:00	85	-0.06	3.57	30	3	3	..
3	..	..	..	..	..	..	..	..

- Computation of the overall performance





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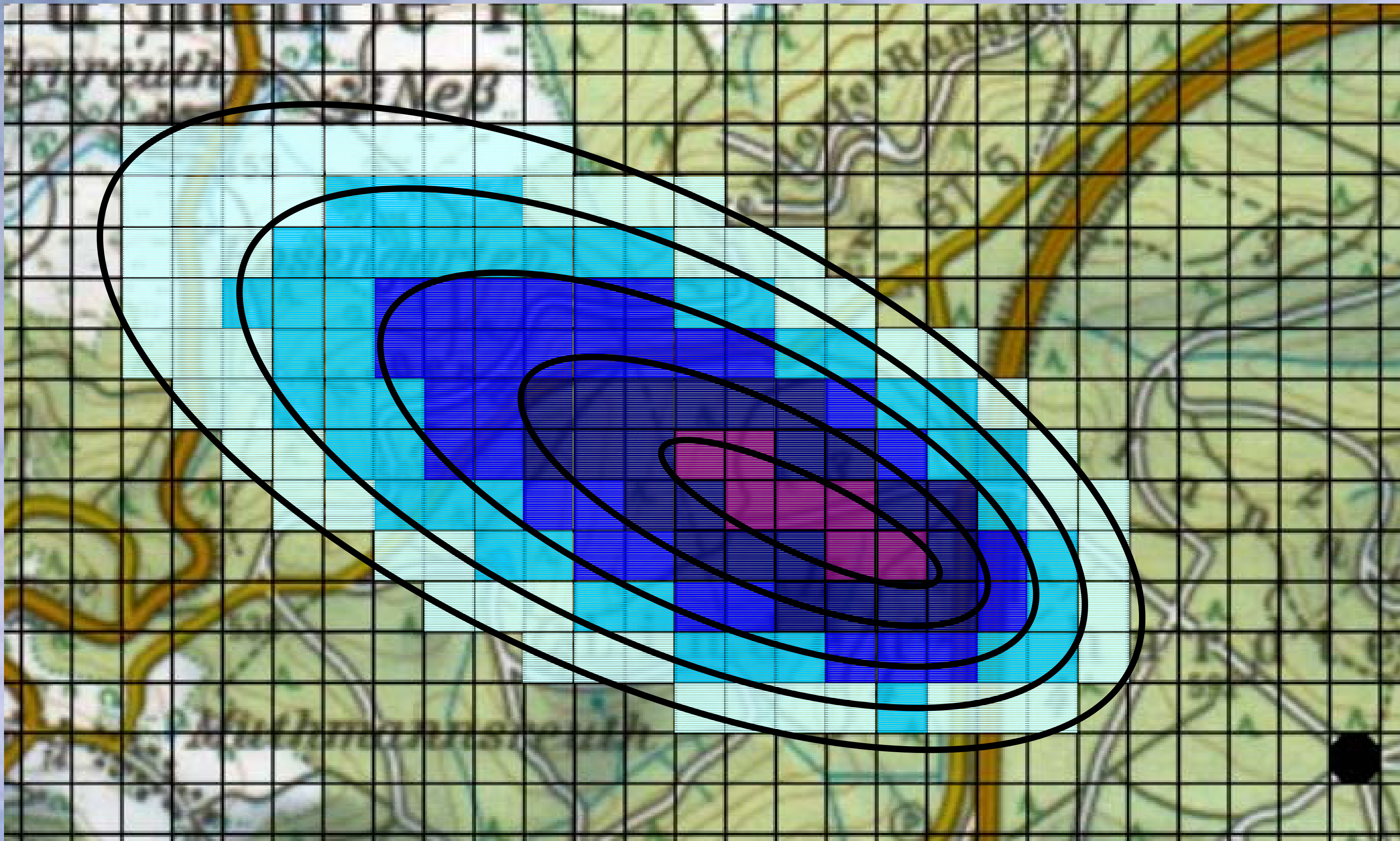

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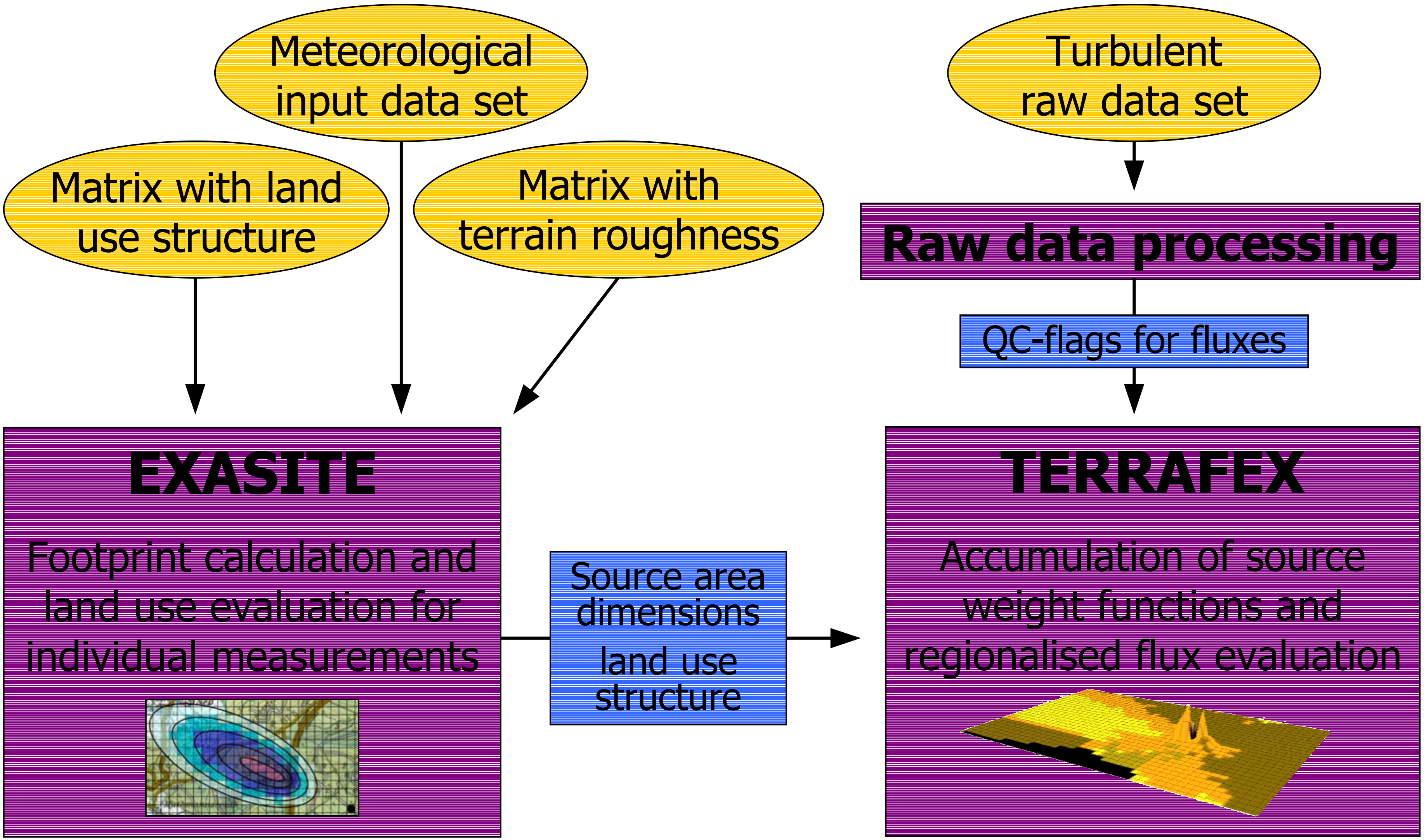
Quality assessement programme



Required data from CARBOEUROFLUX partners

appr. 3-6 month

Raw data (20/10 Hz) or 5 min dispersions and averages:

- the horizontal wind components
- the vertical wind component
- the air temperature
- CO2- and H2O-concentrations
- wind direction (calculated)

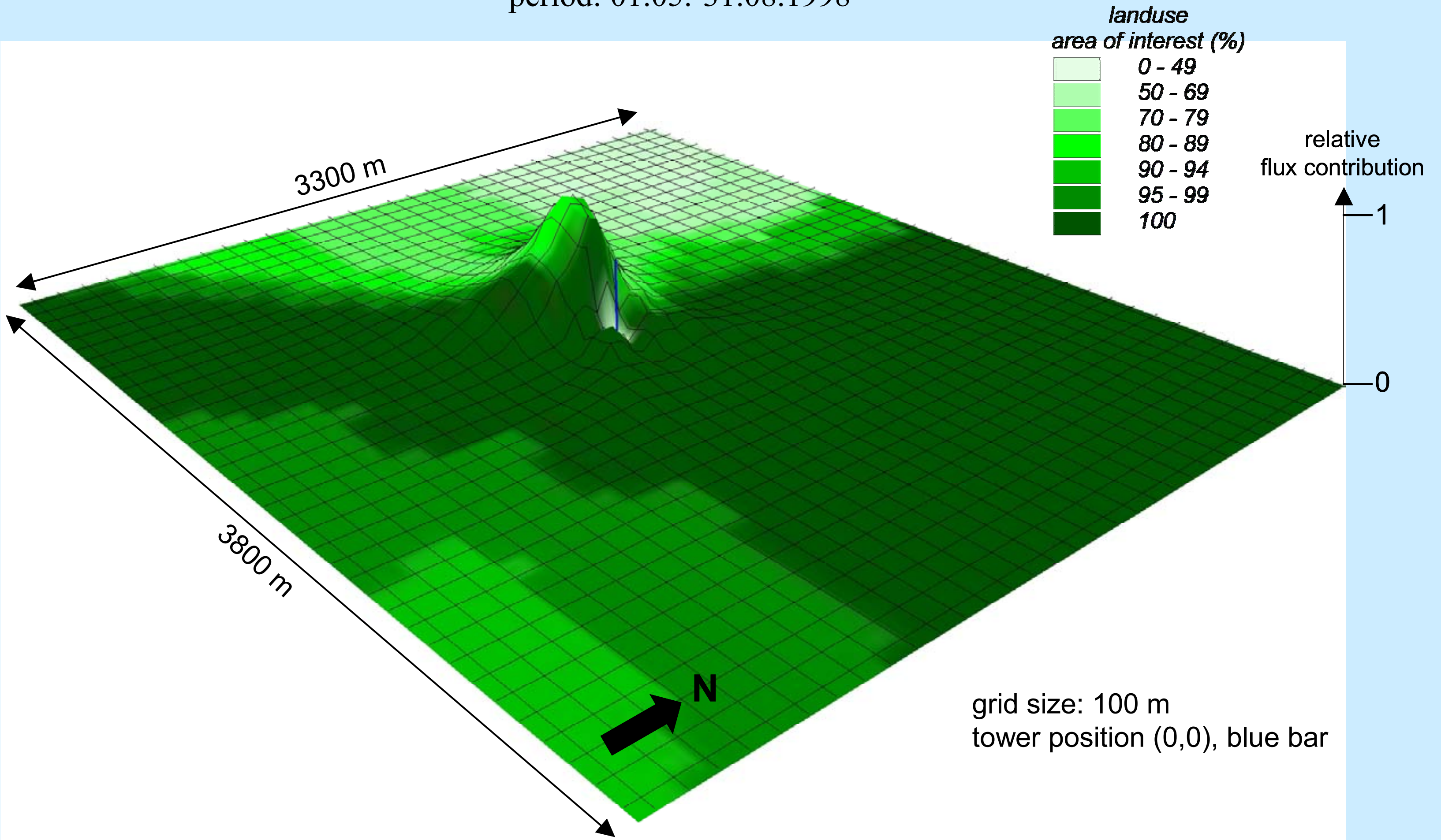
Required data from the database

variable ID number	variable name	measurement unit	variable description	measurement type	measurement frequency
0	date	none	site and date description ("019701131000")		
1	Fc	$\mu mol\ m^{-2}\ s^{-1}$	carbon dioxide	Eddy covariance	30 min
2	H	$W\ m^{-2}$	sensible heat	Eddy covariance	30 min
3	LE	W m-2	latent heat	Eddy covariance	30 min
4	E	mmol m-2 s-1	water vapour	Eddy covariance	30 min
5	TAU	Kg m-1 s-2	momentum	Eddy covariance	30 min
16	Rn	W m-2	net radiation	sensor	30 min
20	Ta	°C	air temperature	sensor	30 min
21	Pa	Kpa	pressure	sensor	30 min
26	Rh	%	relative humidity	sensor	30 min
27	WD	degrees	Wind direction	sensor	30 min
28	WS	$m\ sec^{-1}$	Wind horizontal speed	sensor	30 min

GE3 Waldstein

land use with flux contribution

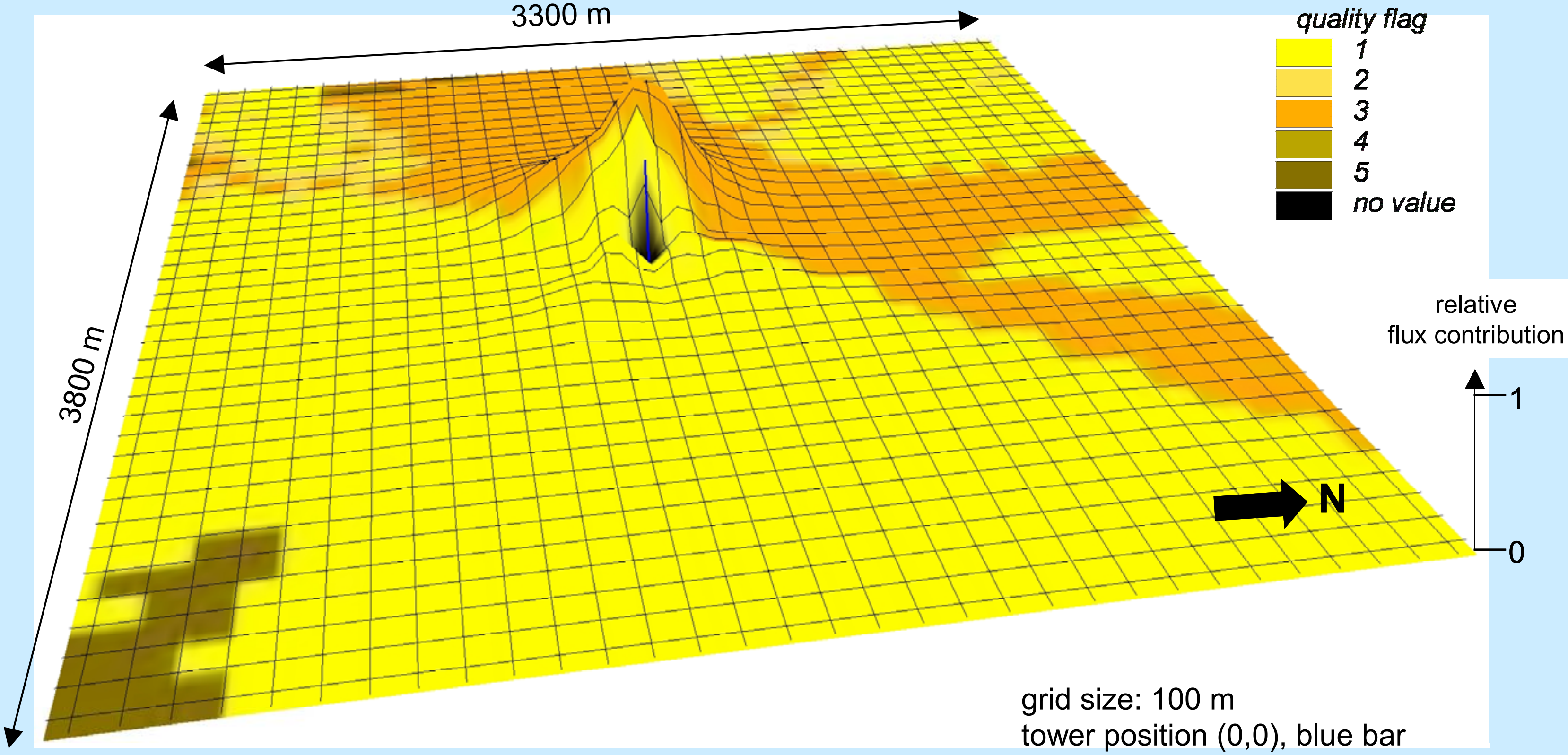
period: 01.05.-31.08.1998



GE3 Waldstein

quality flags for **latent heat flux λE** with flux contribution

period: 01.05.-31.08.1998



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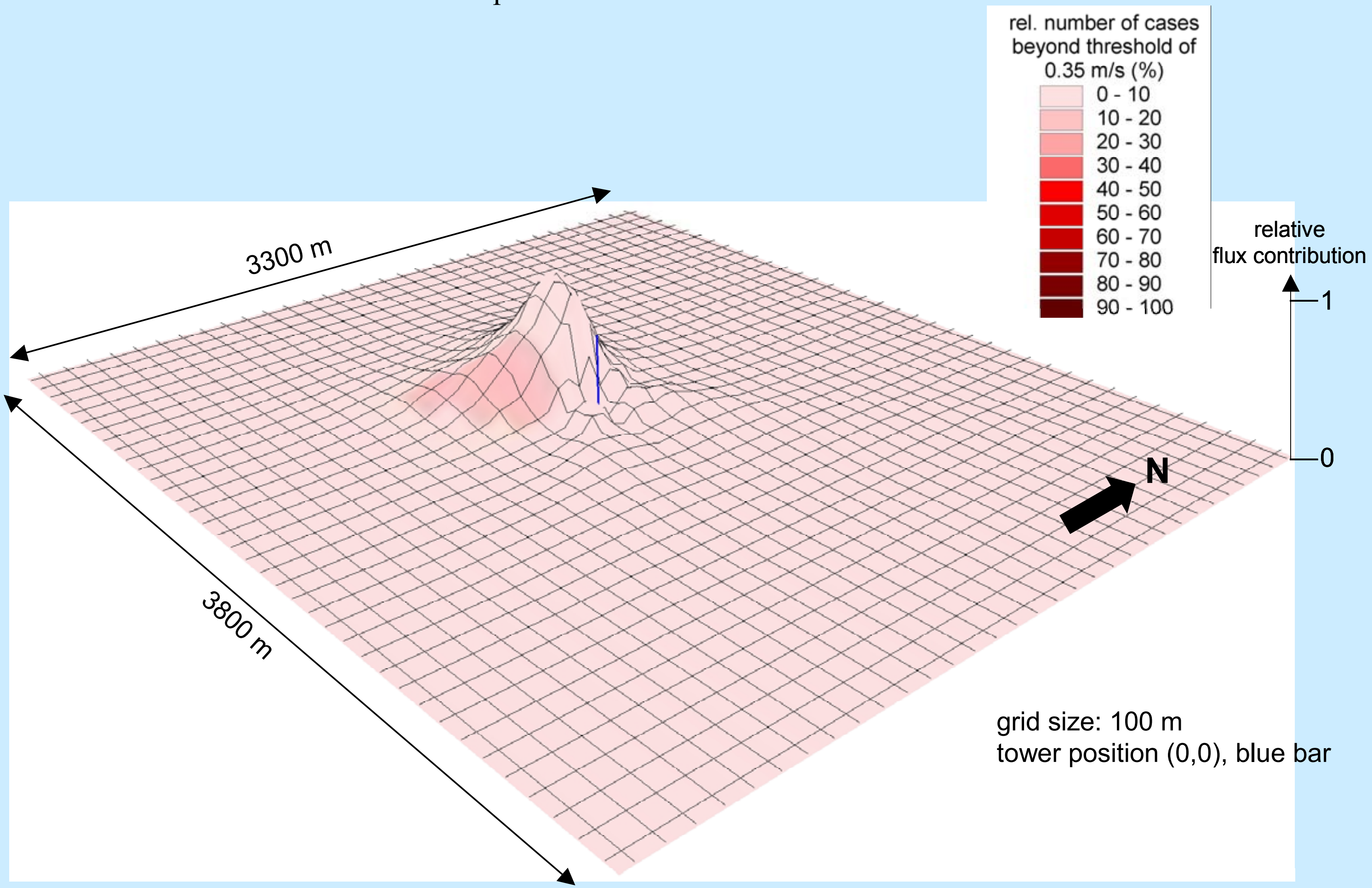
GE3 Waldstein

quality flags for **vertical wind component w** with flux contribution

period: 01.05.-31.08.1998

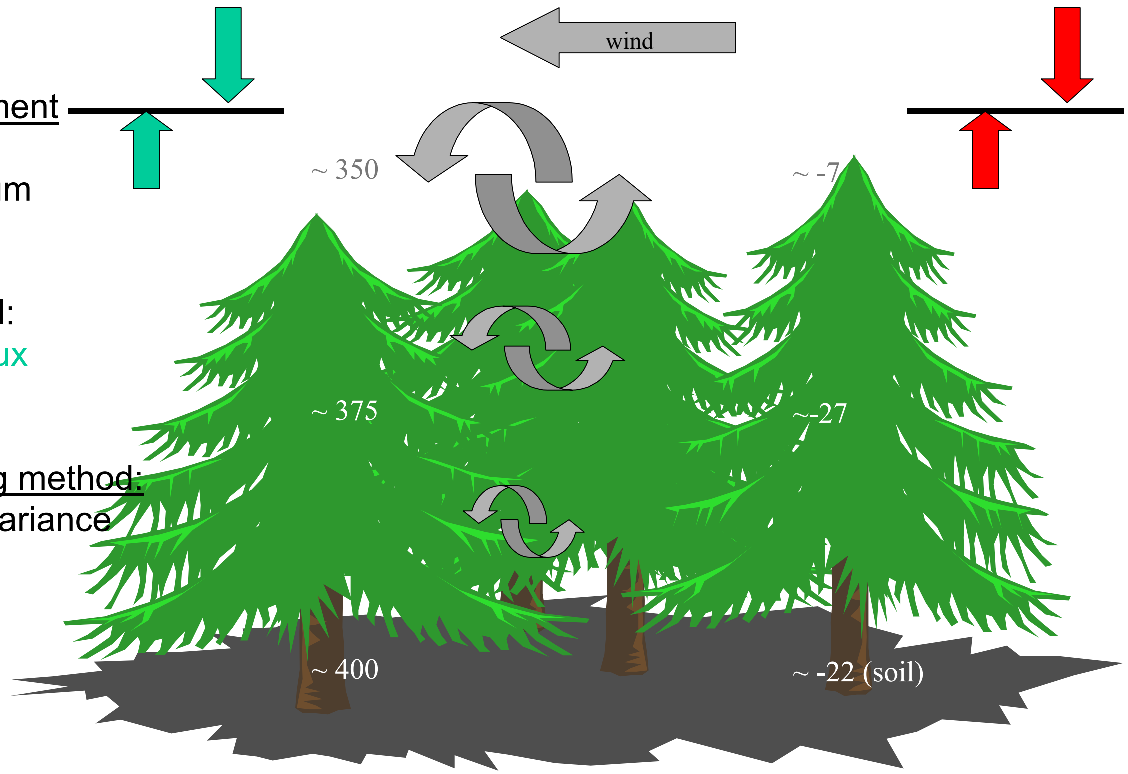


Turbulent exchange of momentum, energy and carbon dioxide above a forest

Balances ?

Measurement
Fluxes of
•Momentum
•Energy
•Matter
special:
CO_2-flux

Measuring method:
Eddy-Covariance



CO2 [ppm] characteristic data (day, spruce forest) $\delta^{13}C$ [‰]

Sources and sinks ?

Processes ?

Measurement:
Fluxes of
stabil
isotopes

$\delta^{13}C$-flux

Measuring method:
Eddy-Accumulation

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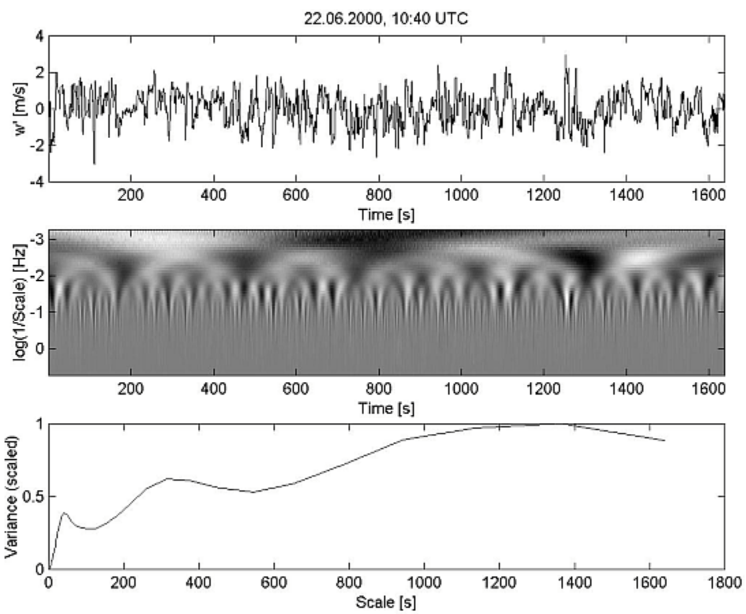
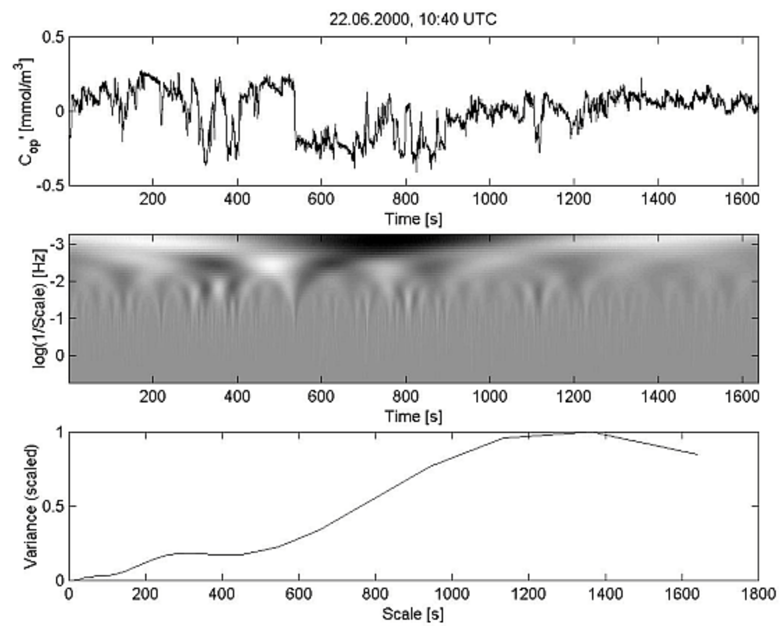
25th Agricultural and Forest Meteorology
20—24 May 2002 in Norfolk, VA
Paper 6.4

Turbulence scales of different signals (using wavelet analysis)

Vertical wind velocity



CO_2 concentration

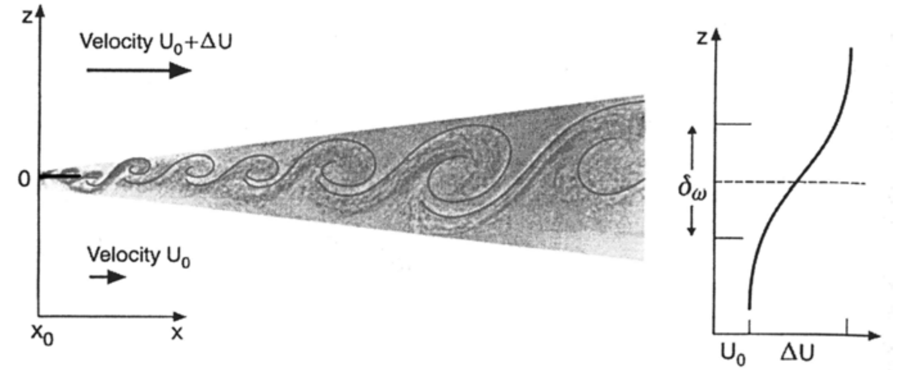


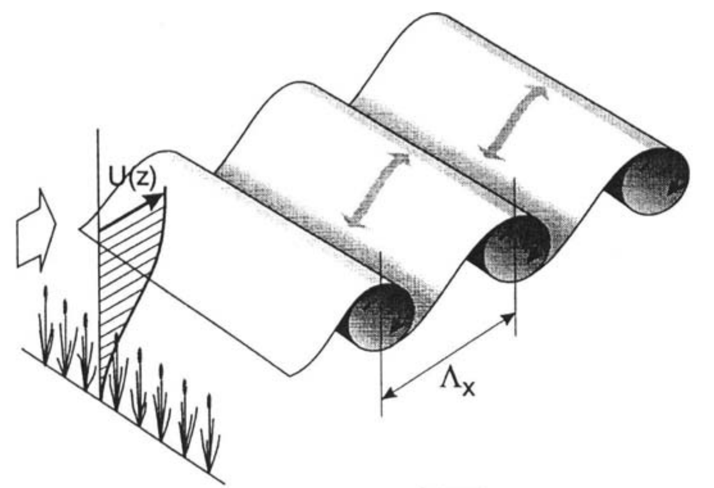
Mixing layer hypothesis

$$L_s = \delta_w / 2 = \frac{u(z_B)}{\left(\partial u / \partial z\right)_{z=z_B}}$$

$$\Lambda_x = m \cdot L_s$$

Developed mixing layer: m = 7...10

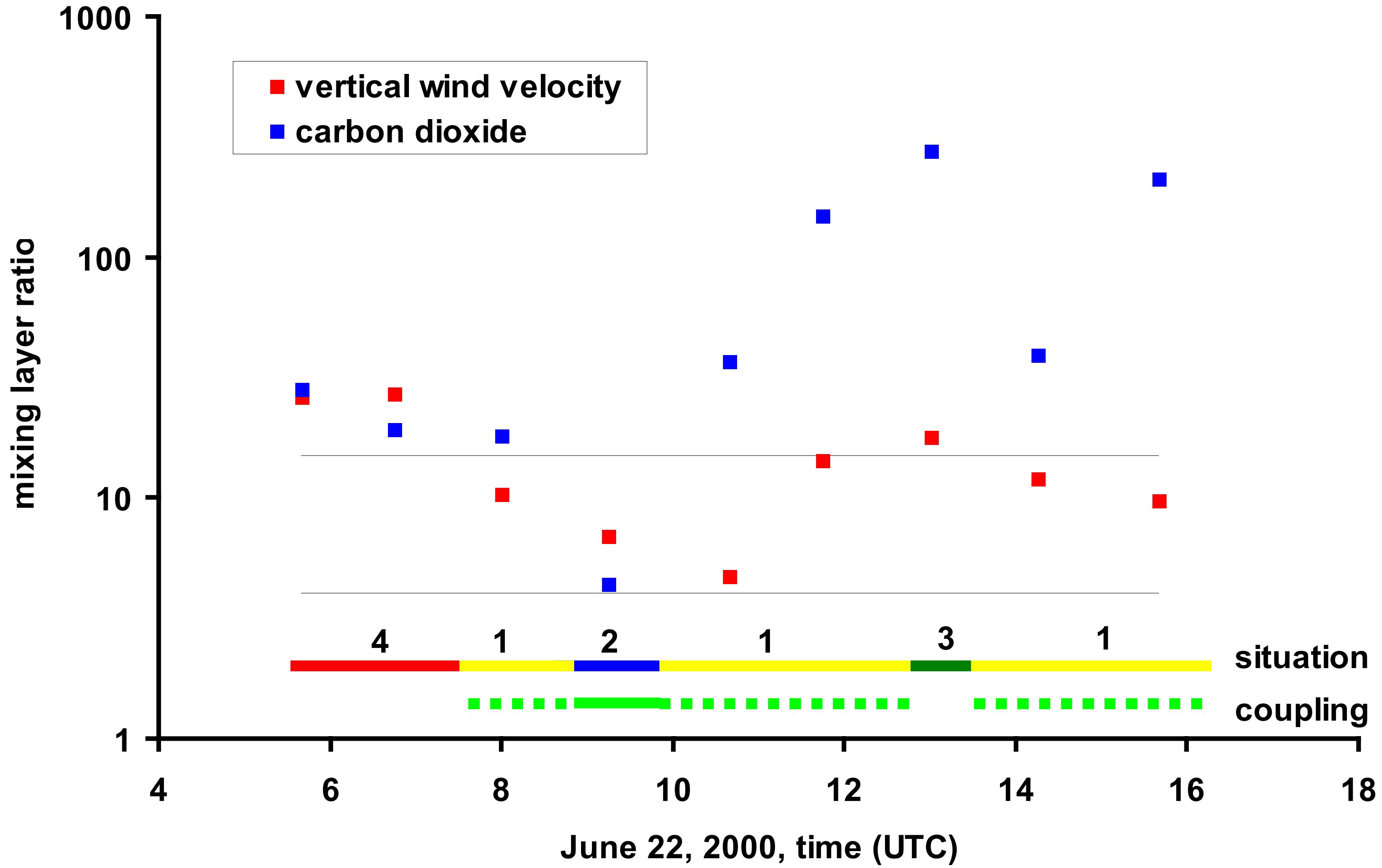




Finnigan, J., 2000.
Annual Review of Fluid Mechanics, **32**: 519-571

Raupach, M. R., Finnigan, J. J., Brunet, Y., 1996.
Boundary-Layer Meteorol., **78**: 351-382.

Daily cycle of different exchange conditions



Conclusions

- **Stationarity tests and tests of the integral turbulence characteristics can be used to check the data quality of eddy covariance measurements.**
- **After a re-formulation of the integral turbulence characteristics a dependence on the Coriolis parameter (pressure gradient) was considered.**
- **Footprint models are helpful to determine the source areas of the fluxes.**
- **Footprint models can be used for QA/QC procedures of long term flux measurements to determine the source areas and to check the data quality.**
- **The integral turbulence scales of the different parameters should be taken into account.**

References

Aubinet, M., Grelle, A., Ibrom, A., Rannik, Ü., Moncrieff, J., Foken, T., Kowalski, A. S., Martin, P. H., Berbigier, P., Bernhofer, C., Clement, R., Elbers, J., Granier, A., Grünwald, T., Morgenstern, K., Pilegaard, K., Rebmann, C., Snijders, W., Valentini, R., Vesala, T., 2000. Estimates of the Annual Net Carbon and Water Exchange of Forests: the EUROFLUX Methodology. Adv. Ecol. Res., **30**: 113-175.

Foken, T., Mangold, A., Rebmann, C., Wichura, B.,2000. Characterization of a complex measuring site for flux measurements. 14th Symposium on Boundary Layer and Turbulence, Aspen, CO, 07-11 Aug. 2000, Am. Meteorol. Soc., Boston, 388-389.

Foken, T., Wichura, B., 1996. Tools for quality assessment of surface-based flux measurements. Agric. & Forest Meteorol., **78**: 83-105.

Højstrup, J., 1993. A statistical data screening procedure. Meas. Sci. Techn., **4**: 153-157.

Kaimal, J. C., Finnigan, J. J., 1994. Atmospheric boundary layer flows: their structure and measurement. Oxford University Press, New York, NY, 289 pp.

Mahrt, L., 1991. Eddy asymmetry in the sheared heated boundary layer. J. Atm. Sci., **48**: 472-492.

Moncrieff, J. B., Massheder, J. M., DeBruin, H., Elbers, J., Friborg, T., Heusinkveld, B., Kabat, P., Scott, S., Søgaard, H., Verhoef, A., 1997. A system to measure surface fluxes of momentum, sensible heat, water vapor and carbon dioxide. J. Hydrol., **188-189**: 589-611.

Shearman, R. J., 1992. Quality assurance in the observation area of the Meteorological Office. Meteorol. Mag., **121**: 212-216.

Thomas, C., Foken, T.,2002. Re-evaluation of integral turbulence characteristics and their parameterisations. 15th Conference on Turbulence and Boundary Layers, Wageningen, NL, 15-19 July 2002, Am. Meteorol. Soc., 129-132.

Vickers, D., Mahrt, L., 1997. Quality control and flux sampling problems for tower and aircraft data. J. Atmosph. & Oceanic Techn., **14**: 512-526.

Wichura, B., Buchmann, N., Foken, T.,2002. Carbon dioxide exchange characteristics above a spruce forest. 25th Symposium on Agricultural and Forest Meteorology, Norfolk, May 20-24, 2002