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Micrometeorological Problems of Air Pollution Studies

THOMAS FOKEN

University of Bayreuth, BayCEER, Bayreuth and
MikroMeteorologische Beratung, Bischberg

Micrometeorology

Micrometeorology is a part of Meteorology that deals with observations and processes in the smaller scales of time and space, approximately smaller than 1 km and one day. Micrometeorological processes are limited to shallow layers with frictional influence. Therefore, the subject of micrometeorology is the bottom of the atmospheric boundary layer, namely, the surface layer. Exchange processes of energy, gases, etc., between the atmosphere and the underlying surface (water, soil, plants) are important topics.

What is Micrometeorology ?

- **Micrometeorology has a strong focus in basic research**
- **The interaction ecosystem – atmosphere (climate) is micrometeorology**
- **Modelling and measurement of fluxes at the Earth surface is micrometeorology**
- **Atmospheric chemistry and micrometeorology are coupled by the Damköhler-number**
- **Micrometeorology is the theoretical basis of applied meteorology**

Applied Meteorology

Applied Meteorology						
Hydro-meteorology	Technical Meteorology			Biometeorology		
	Construction Meteorology	Traffic Meteorology	Industrial Meteorology	Agricultural Meteorology	Forest Meteorology	Human Biometeorology
		Transport Meteorology		Phe-nology		

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Applied Meteorology

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Hydro-meteorology	Technical Meteorology			Biometeorology		
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		Transport Meteorology		Phenology		

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Air Pollution Studies are related to Applied Meteorology

Pasquill classes

with the standard deviation of the wind direction

Pasquill class	description	σ_{φ}
A	extreme unstable	25
B	unstable	20
C	light unstable	15
D	neutral	10
E	light stable	5
F	stable	2.5

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Strong relationship to the heterogeneity of the surface (Footprint)

Pasquill classes with wind and cloud classes

surface wind ms ⁻¹	irradiation at day			cloudiness at night	
	strong clouds: 0/8–2/8	moderate clouds: 3/8–5/8	low clouds: 6/8–8/8	thin clouds or ≥ 4/8	≤ 3/8
< 2	A	A-B	B		
2	A-B	B	C	E	F
4	B	B-C	C	D	E
6	C	C-D	D	D	D
> 6	C	D	D	D	D

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Strong relationship to visual observations

Pasquill classes

with the standard deviation of the wind direction

Pasquill class	description	Obukhov length L	z/L for z=10 m
A	extreme unstable	- 30	- 0.33
B	unstable	- 100	- 0.1
C	light unstable	- 300	- 0.033
D	neutral	5000	0.002
E	light stable	250	0.04
F	stable	60	0.17

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Strong relationship to micrometeorological measurements

Pasquill classes

with the standard deviation of the wind direction

Pasquill class	description	Obukhov length L	z/L for z=10 m
A	extreme unstable	-30	-0.33
B	unstable	-100	-0.1
C	light unstable	-300	-0.033
D	neutral	500	0.002
E	light stable	250	0.04
F	stable	80	0.17

momentum exchange

$$L = - \frac{u_*^3}{\kappa \frac{g}{\theta_v} \overline{w' \theta_v'}}$$

buoyancy flux
(sensible heat flux and density effect of latent heat flux)

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Strong relationship to micrometeorological measurements

Simple Gaussian distribution function

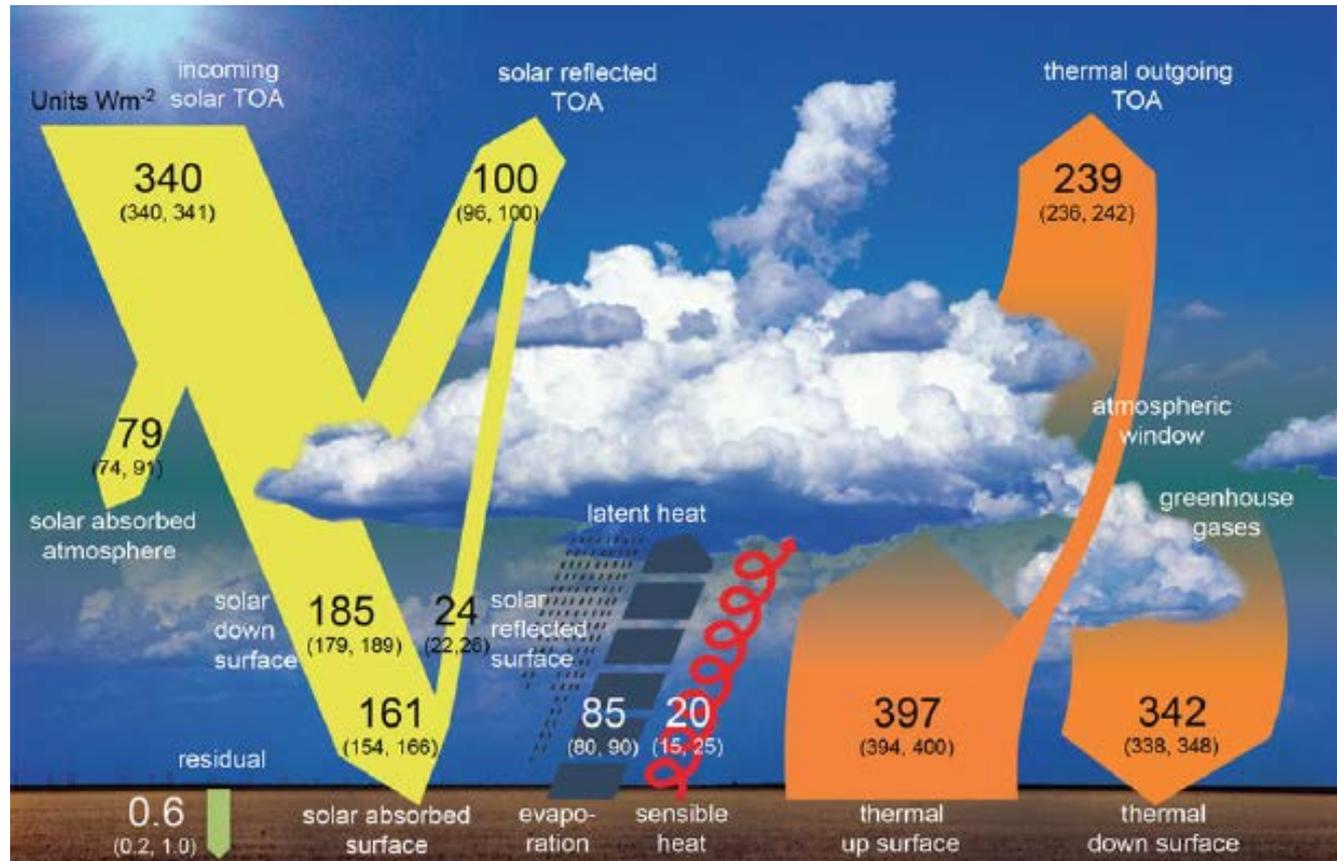
$$F(x) = \frac{1}{u dt}$$

$$G(y) = \frac{1}{\sqrt{2\pi} \sigma_v} \exp\left(-\frac{y^2}{2\sigma_v^2}\right)$$

$$H(z) = \frac{1}{\sqrt{2\pi} \sigma_w} \exp\left(-\frac{z^2}{2\sigma_w^2}\right)$$

**Strong relationship standard deviations of wind components
(micrometeorological measurements and parametrizations)**

Energy Fluxes at The Earth Surface

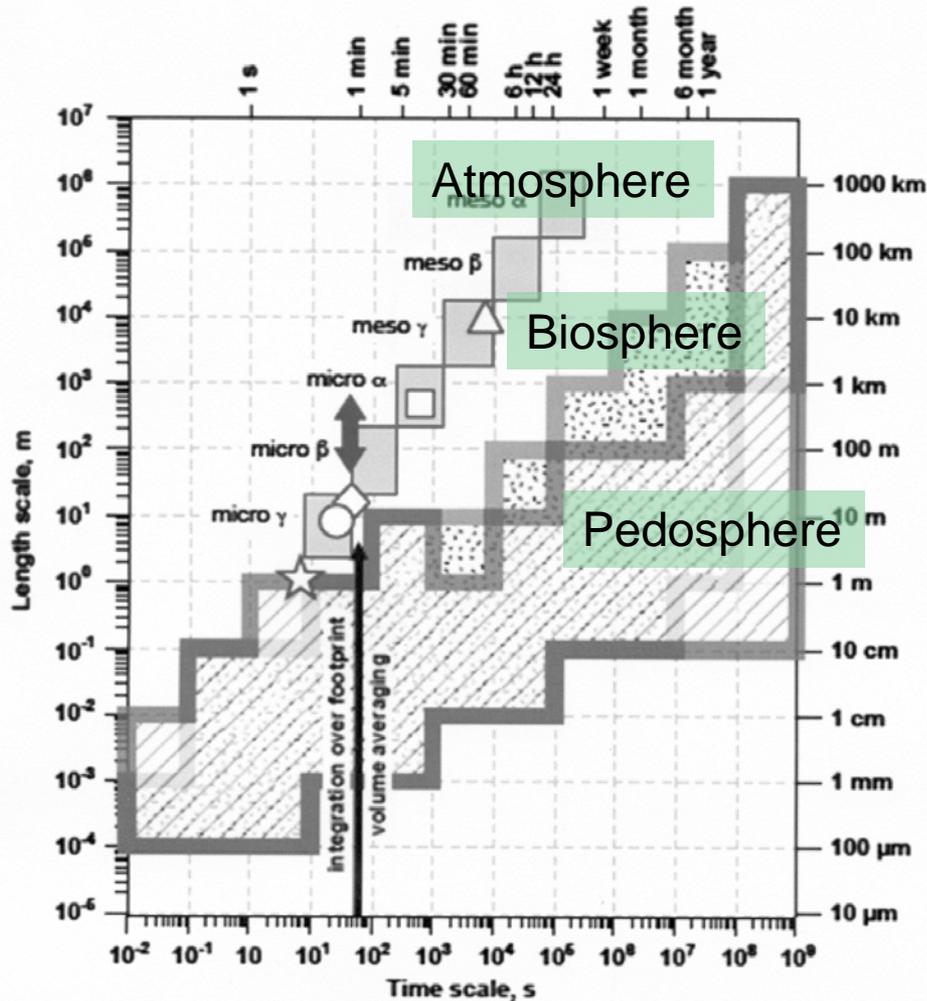


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Content

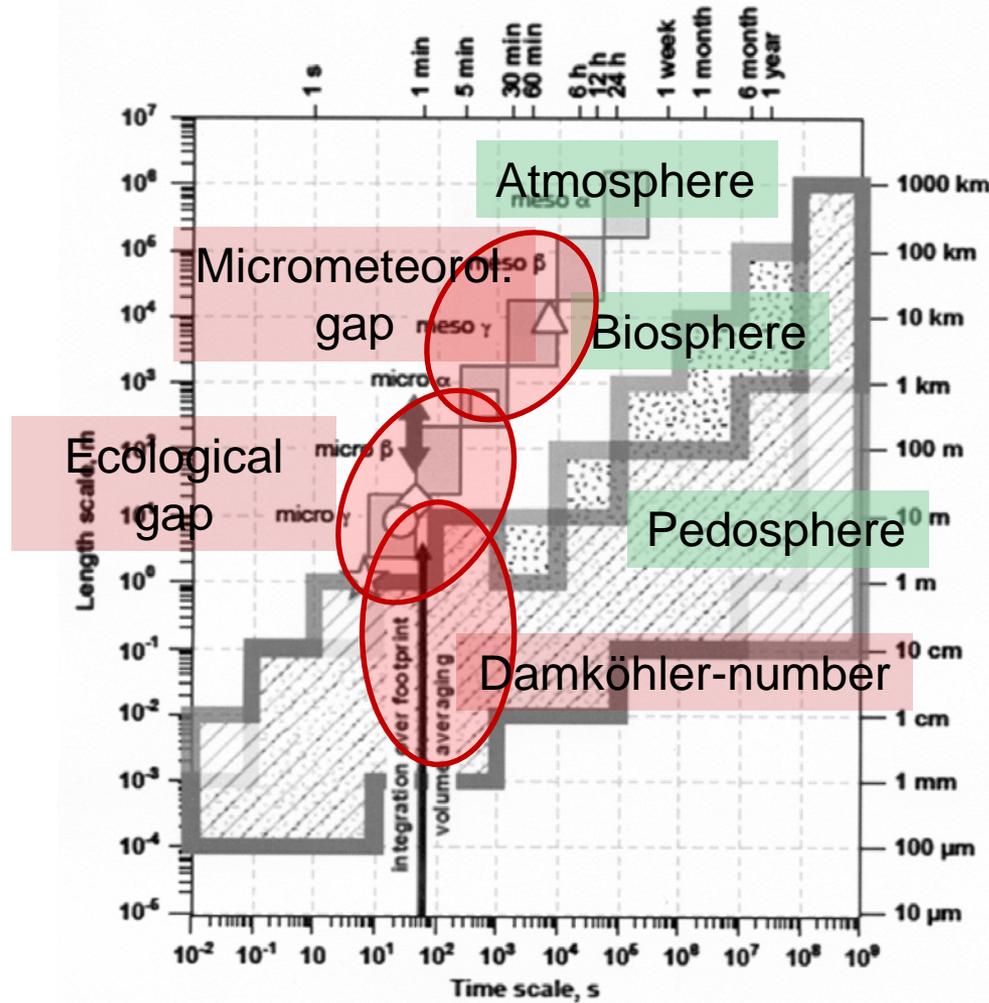
- **Scales of Micrometeorology**
- **Footprint Concept**
- **Energy Balance closure Problem**
- **Coherent structures**
- **Trace gas fluxes**

Scales of Micrometeorology



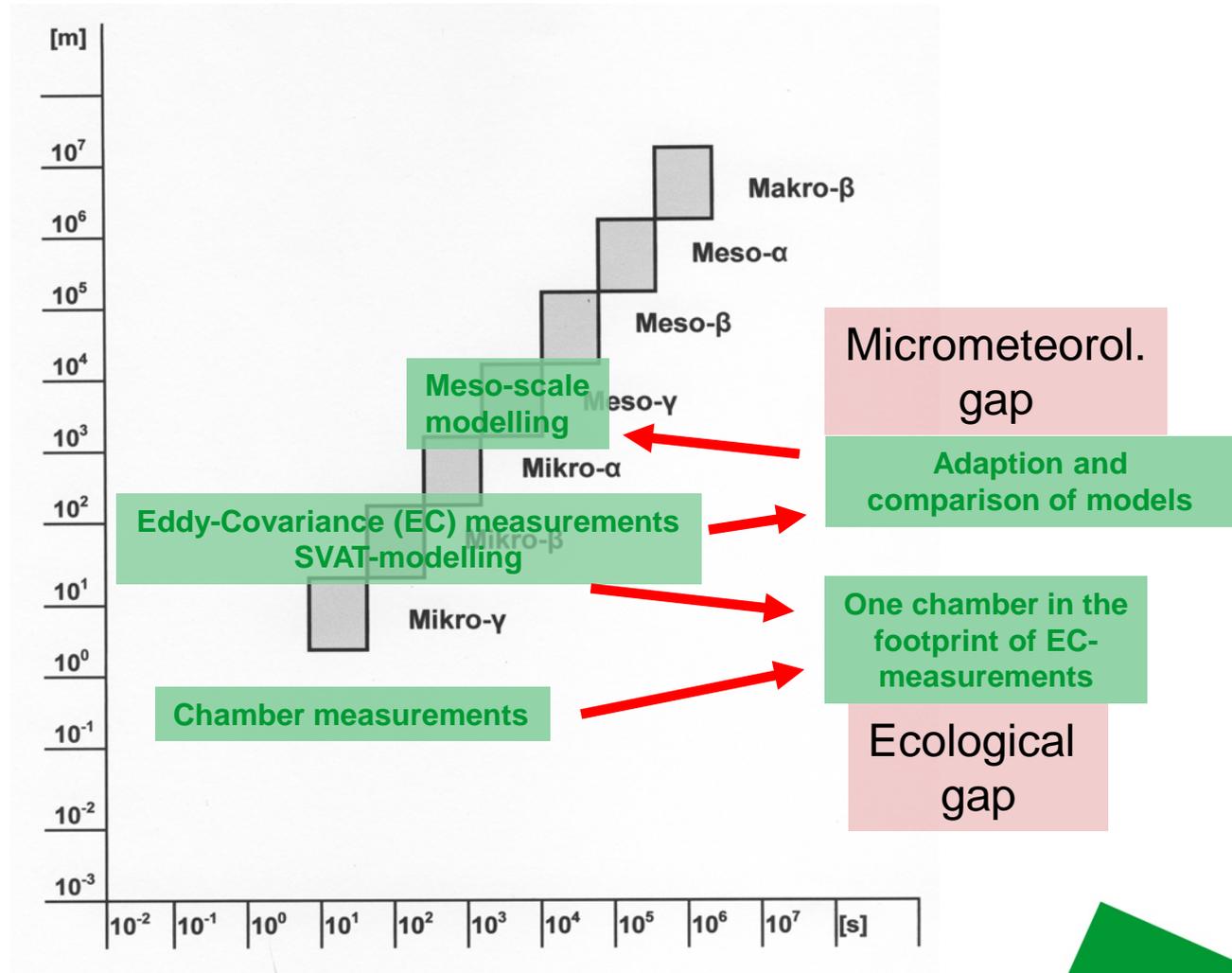
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Scales of Micrometeorology - Problems

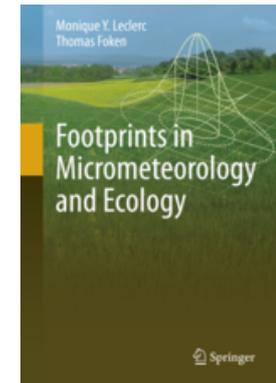
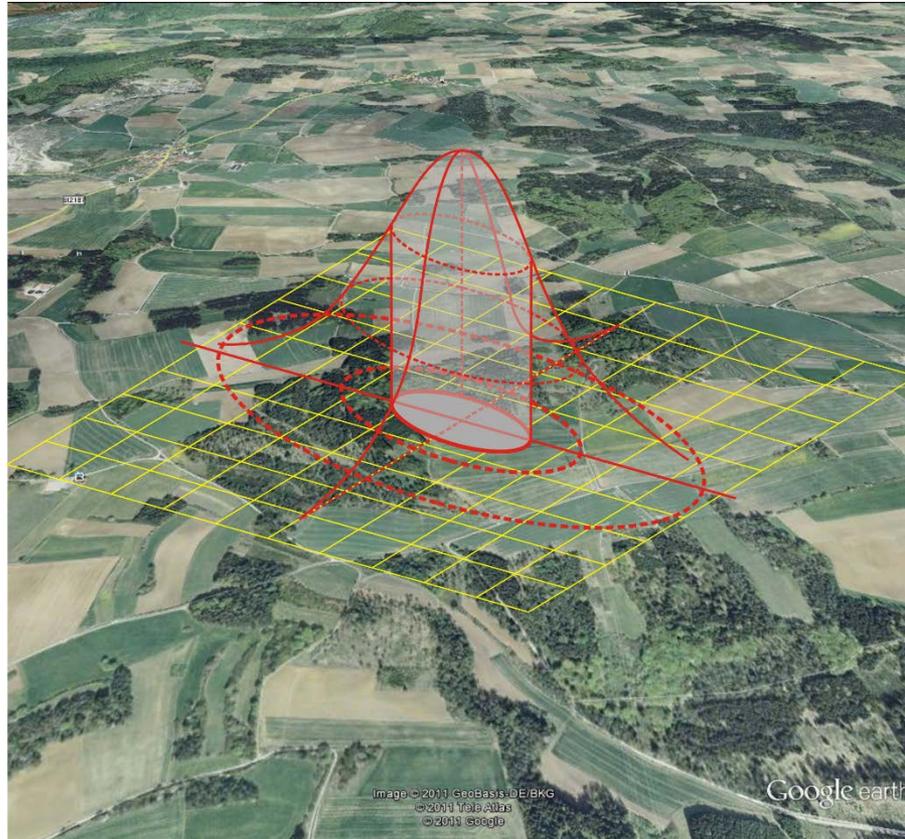


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Upscaling Concept



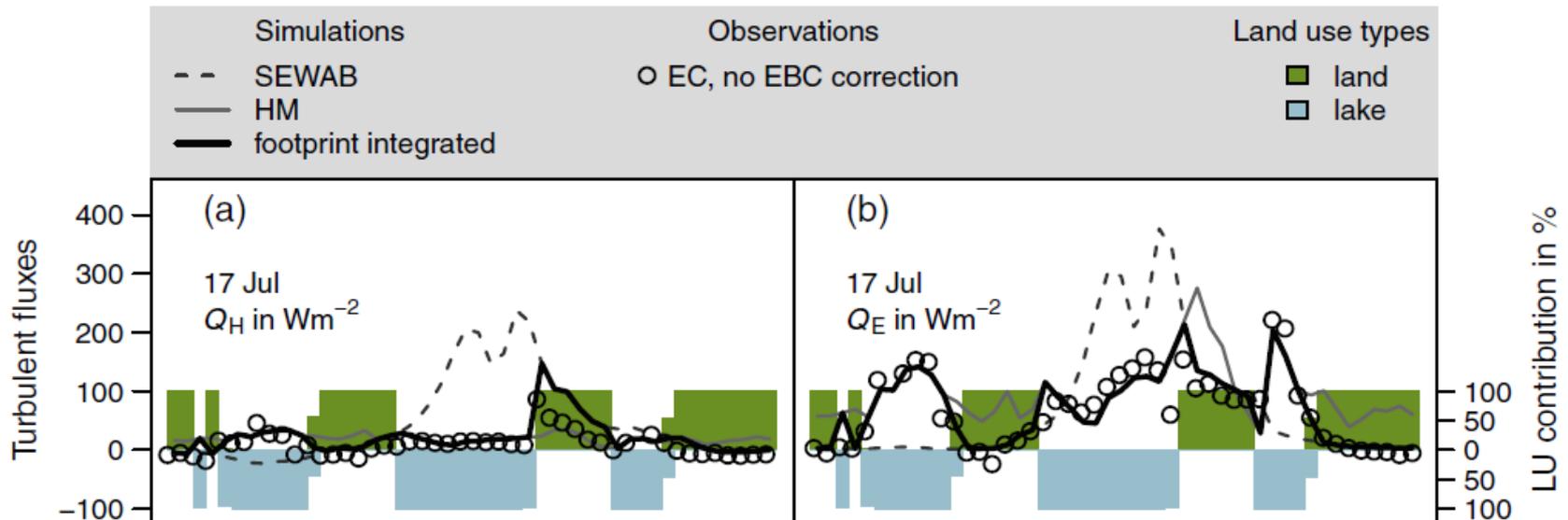
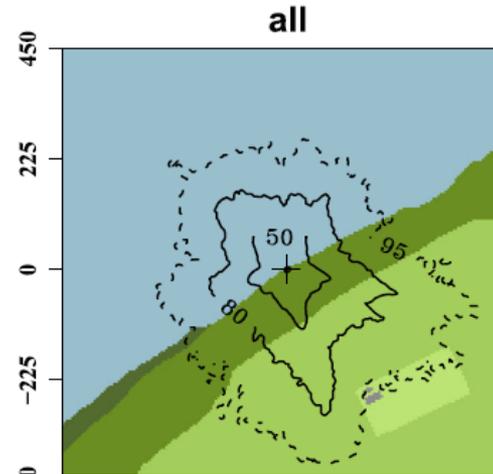
Footprint-Concept for Measurements and Modelling

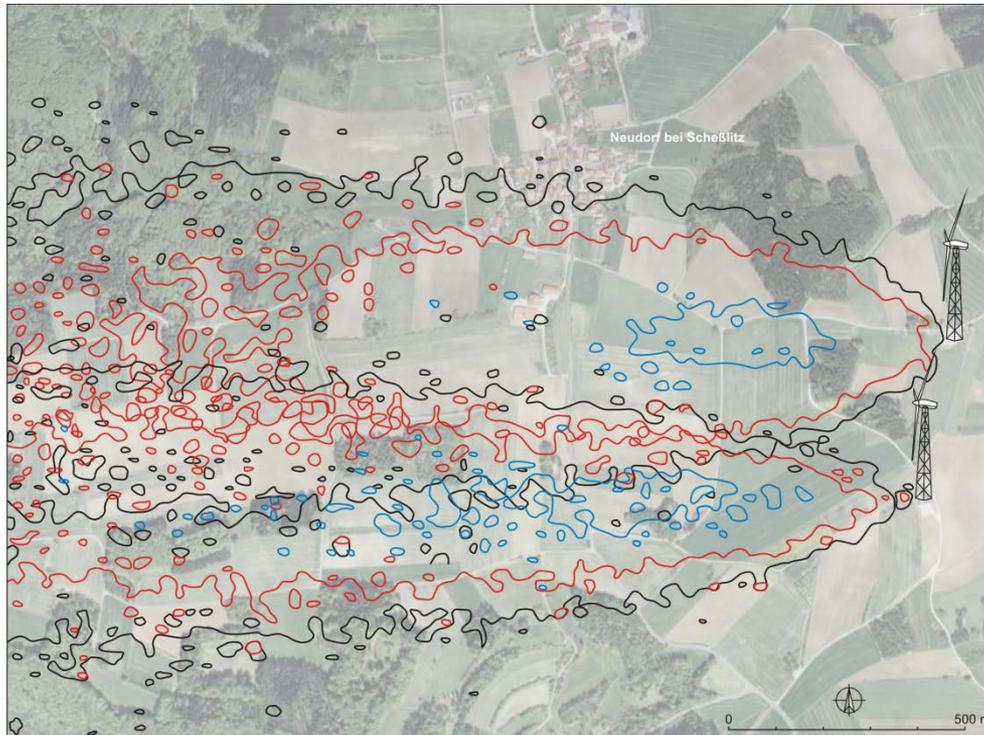


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Fluxes of two different Surfaces in the Footprint Area

© Biermann et al. (2014)





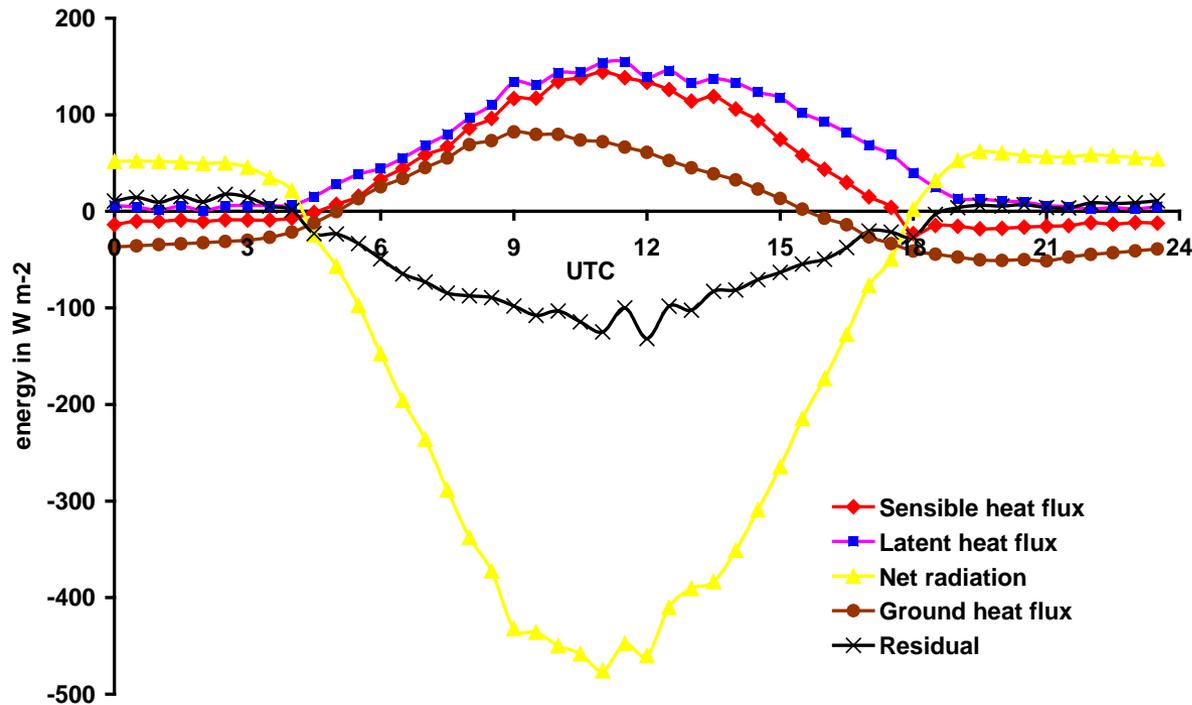
Footprints in an Heterogeneous Landscape Wind Energy Application

Contribution of forest
on the footprint:

Effect level	≥ 90 %		50-90 %		10-50 %		Sum in %
	No.	Sum in %	No.	Sum in %	No.	Sum in %	
Northerly station	1	2	5	7	10	6	14
Southerly station	0	0	2	3	1	<1	3

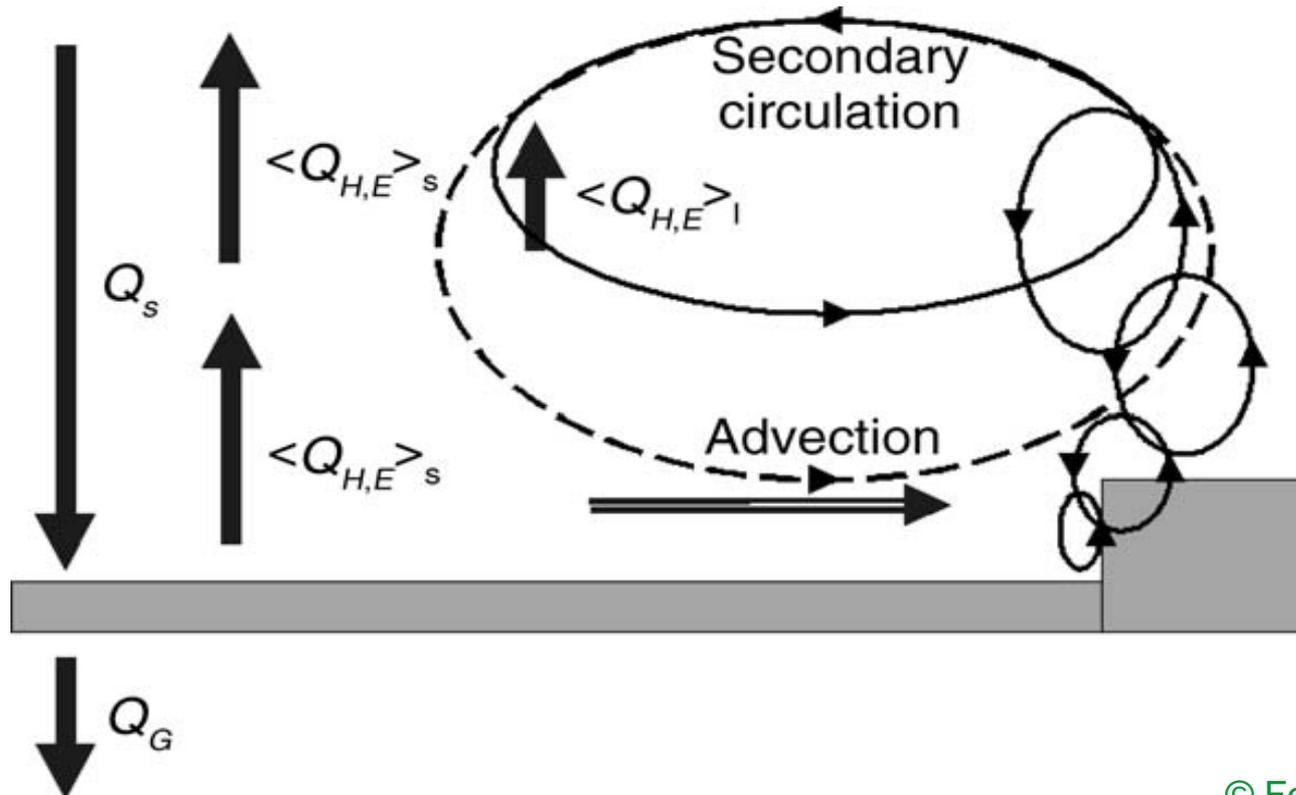
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The Energy Balance Closure Problem



LITFASS-
2003
Germany

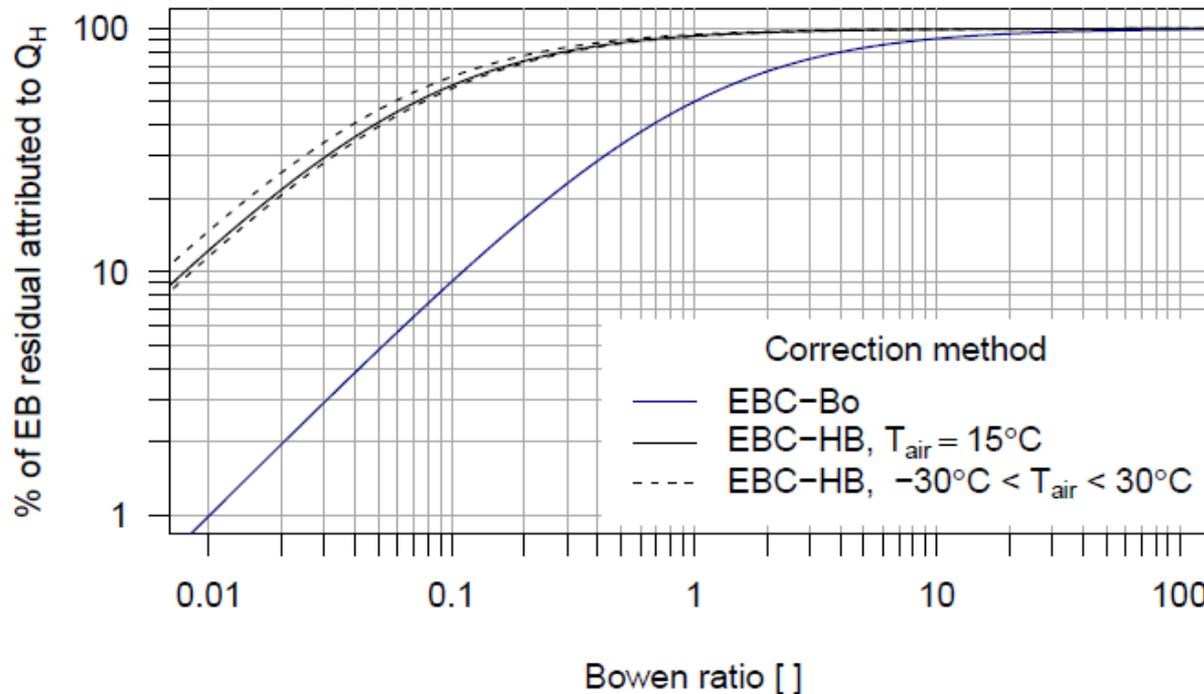
Micro- und meso-turbulent Fluxes



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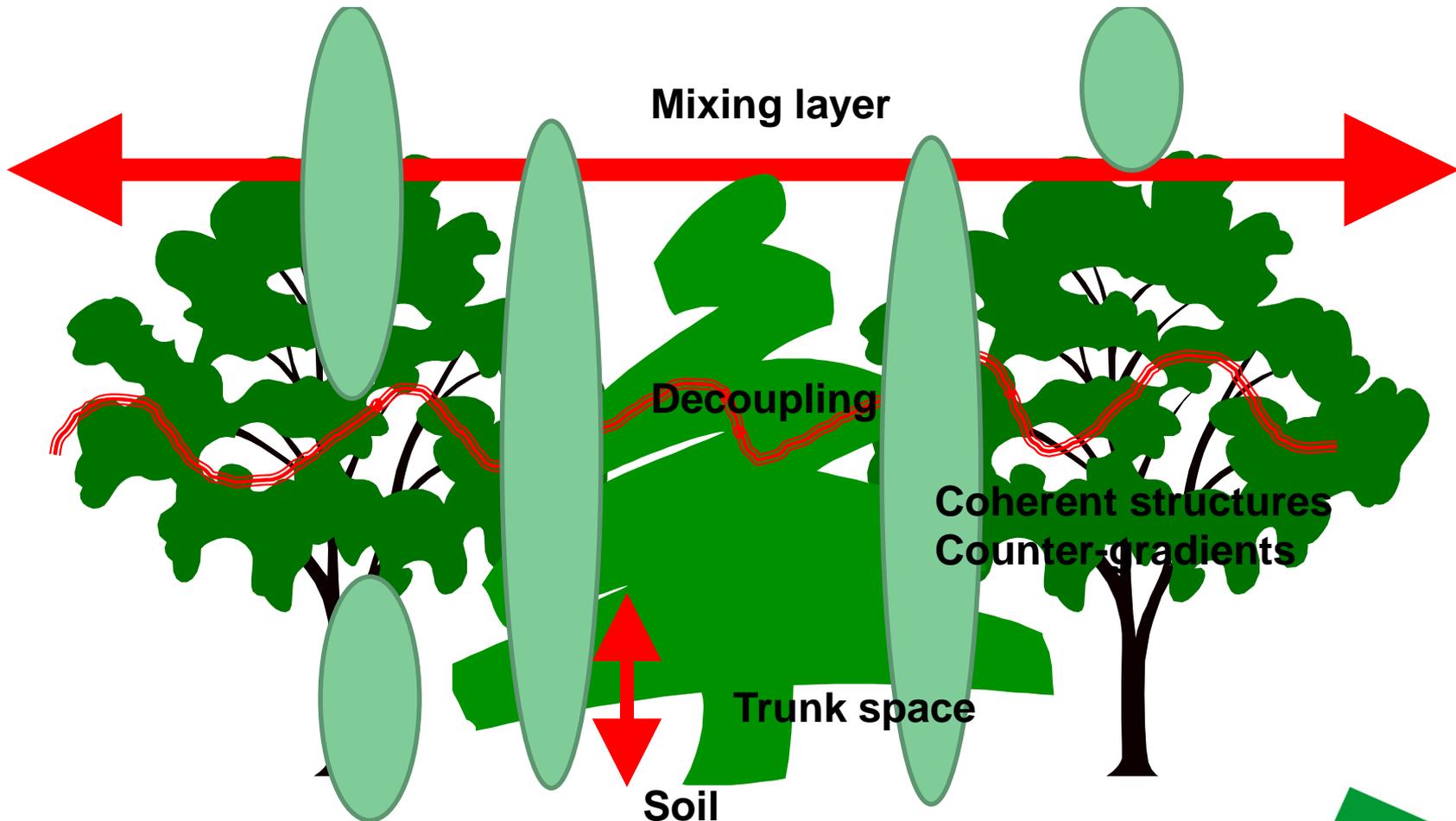
Correction of the Energy Balance Closure

- Correction according to the Bowen ratio © Twine *et al.* (2000)
- Correction according to the buoyancy flux © Charuchittipan *et al.* (2014)

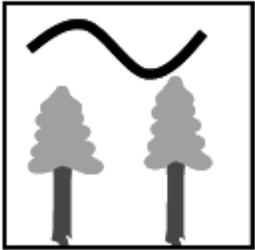
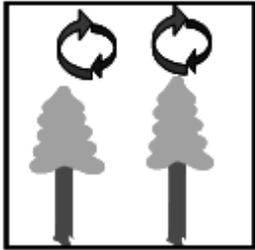
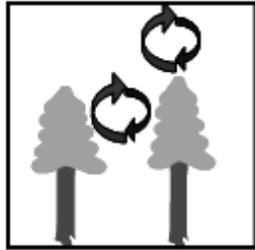
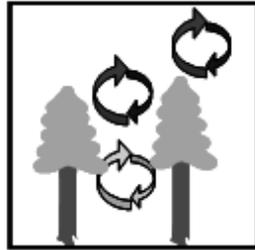
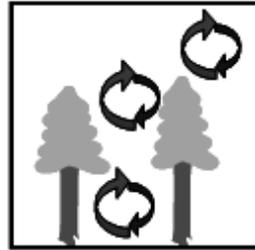


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Tall Vegetation (similar: Urban Areas)



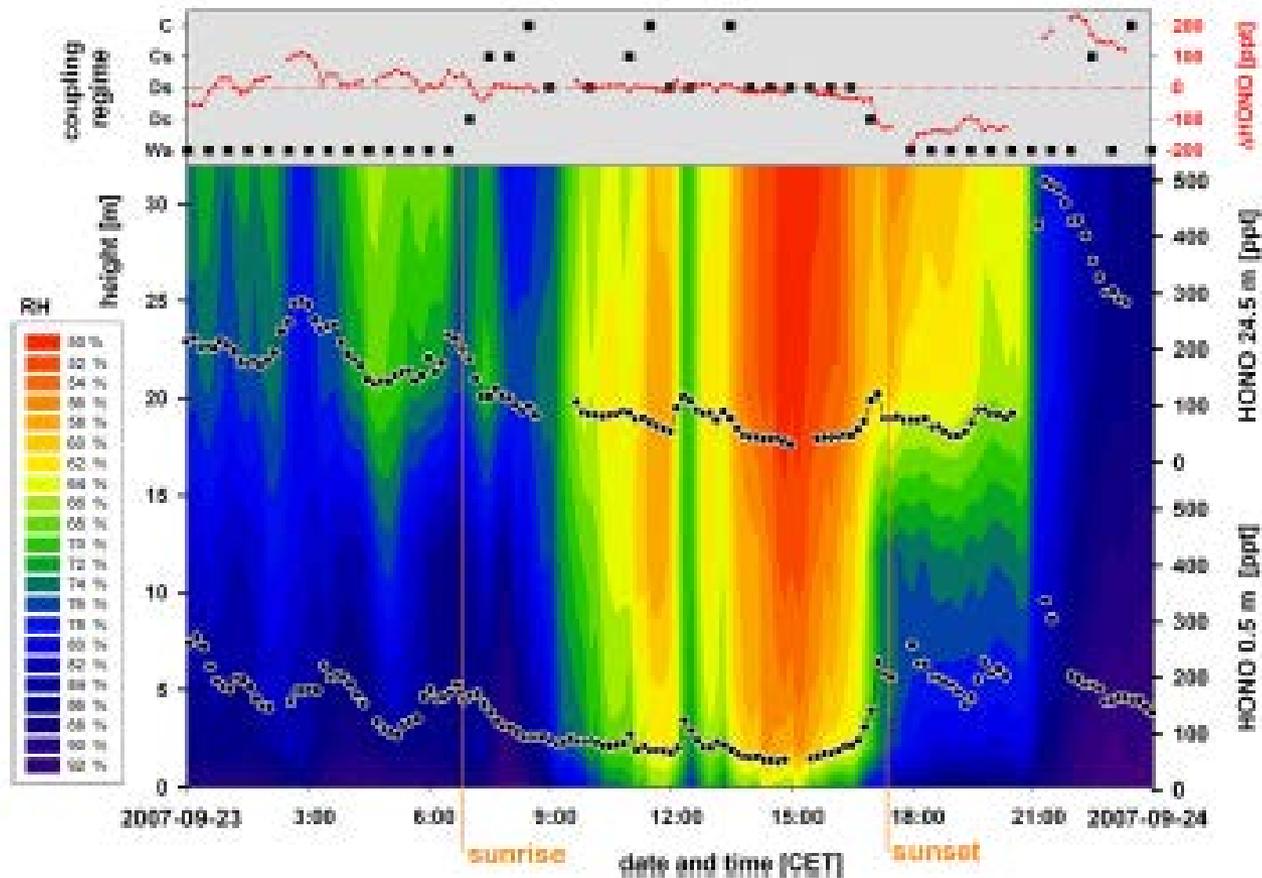
Coupling Regimes

Wa	Dc	Ds	Cs	C
				
Gravity waves above the canopy	Turbulent eddies only above the canopy	Turbulent mixing up to the crown	Occasionally complete mixing of the canopy	Complete mixing of the canopy
No coupling	No coupling	Occasionally weak coupling	Occasionally coupling	Good coupling

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Air Chemistry and Coupling



© Sörgel et al. (2011)

Definition of the Damköhler-Number

$$Da = \frac{t_d}{t_c} k(c)$$

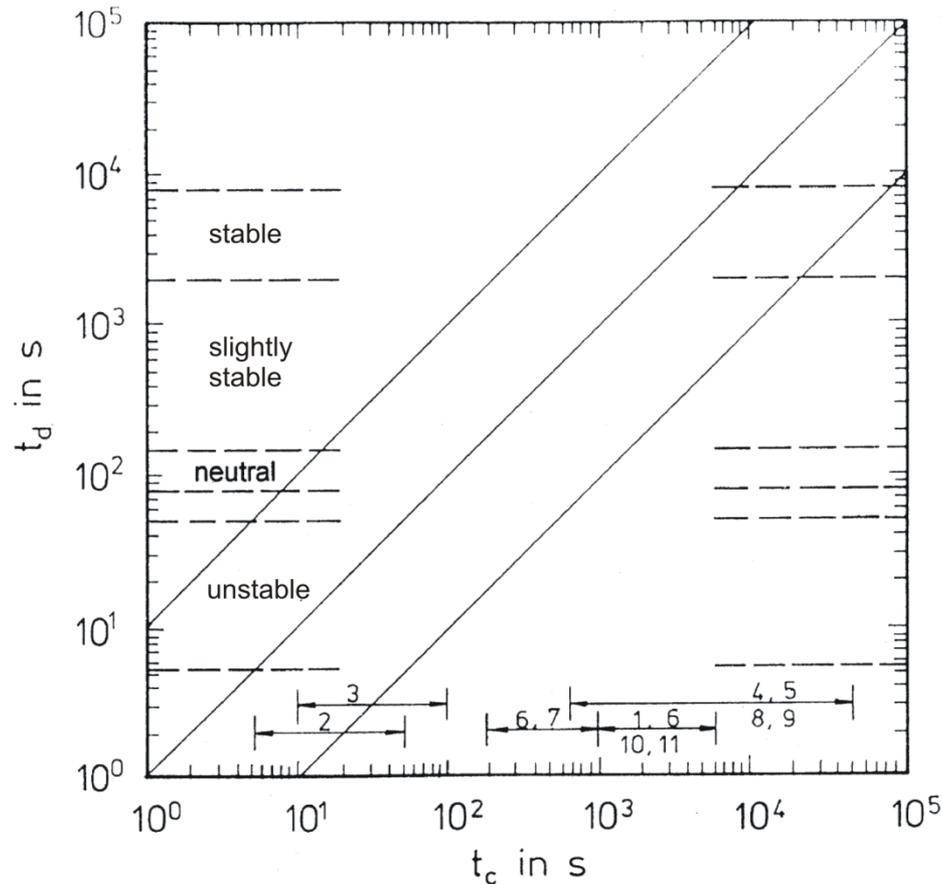
t_d : characteristic transfer time

t_c : characteristic reaction time

k : kinematic reaction constant

c : dimensionless volume averaged concentration

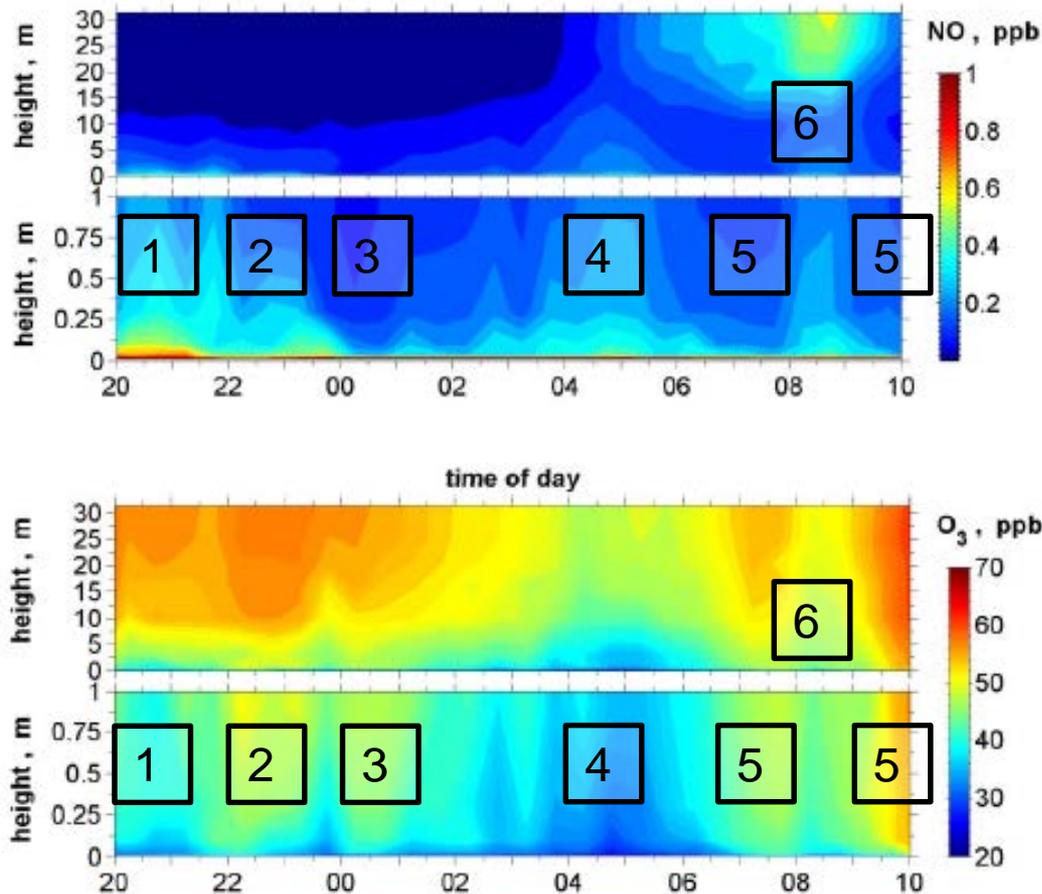
Chemical and atmospheric time scales



- 1: $\text{HO}_2 + \text{HO}_2 \rightarrow \text{H}_2\text{O}_2 + \text{O}_2$
- 2: $\text{HNO}_3 + \text{NH}_3 \leftrightarrow \text{NH}_4\text{NO}_3$
- 3: $\text{O}_3 + \text{NO} \rightarrow \text{NO}_2 + \text{O}_2$
- 4: $\text{O}_3 + \text{Isoprene} \rightarrow$
Reaction products (R)
- 5: $\text{O}_3 + \text{Monoisoprene} \rightarrow \text{R}$
- 6: $\text{NO}_3 + \text{Monoisoprene} \rightarrow \text{R}$
- 7: $\text{NO}_3 + \text{Isoprene} \rightarrow \text{R}$
- 8: $\text{OH} + \text{Isoprene} \rightarrow \text{R}$
- 9: $\text{OH} + \text{Monoisoprene} \rightarrow \text{R}$
- 10: $\text{O}_3 + \text{Olefine} \rightarrow \text{R}$
- 11: $\text{O}_2 + \text{NO}_2 \rightarrow \text{NO} + \text{O}_3$



Reaction NO – O₃ in a forest



- 1: Decoupling close to the ground, $Da > 1$
- 2: Mixing due to gravity waves, $Da < 1$
- 3: Mixing due to Low-Level-Jet, $Da < 1$
- 4: Decoupling of the trunk space, $Da > 1$
- 5: Strong coupling, $Da < 1$
- 6: NO-advection, $Da > 0$

Perspectives in Micrometeorology and Applied Meteorology

- The Monin-Obukhov similarity theory is only a special case. Modified parameterizations are necessary for tall vegetation, stable stratification, polar regions, heterogeneous surfaces etc.
- The interaction of the atmosphere and the ecosystems or urban areas is very complicated. A better process understanding is necessary.
- Reactive chemical processes in the atmosphere must be controlled with the Damköhler-number.
- Applied meteorological methods can be updated with micrometeorological knowledge.
- The progress in Micrometeorology should be applied in air pollution studies

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