Appendix

A1 Further Monographs

Following monographs are listed, which are recommended for a further study. These are limited on micrometeorological and measuring technique textbooks.

Further Micrometeorological Literature

Arya, SP (1999) Air pollution meteorology and dispersion. Oxford University Press, New York, Oxford, 310 pp.

Arya, SP (2001) Introduction to micrometeorology. Academic Press, San Diego, 415 pp.

Bailey, WG, Oke, TR, Rouse, WR (Editors) (1997) The surface climate of Canada. Mc Gill-Queen's University Press, Montreal, Kingston, 369 pp.

Bendix, J (2004) Geländeklimatologie. Borntraeger, Berlin, Stuttgart, 282 pp.

Blackadar, AK (1997) Turbulence and diffusion in the atmosphere. Springer, Berlin, Heidelberg, 185 pp.

Campbell, GS, Norman, JM (1998) Introduction to environmental biophysics. Springer, New York, 286 pp.

Garratt, JR (1992) The atmospheric boundary layer. Cambridge University Press, Cambridge, 316 pp.

Geiger, R, Aron, RH, Todhunter, P (1995) The climate near the ground. Friedr. Vieweg & Sohn Verlagsges. mbH, Braunschweig, Wiesbaden, 528 pp.

Helbig, A, Baumüller, J, Kerschgens, J (Editors) (1999) Stadtklima und Luftreinhaltung. Springer, Berlin, Heidelberg, 467 pp.

Jones, HG (1992) Plants and microclimate. Cambridge Univ. Press, Cambridge, 428 pp.

Kaimal, JC, Finnigan, JJ (1994) Atmospheric boundary layer flows: Their structure and measurement. Oxford University Press, New York, NY, 289 pp.

Kantha, LH, Clayson, CA (2000) Small scale processes in geophysical fluid flows. Academic Press, San Diego, 883 pp.

Lee, X, Massman, WJ, Law, B (Editors) (2004) Handbook of micrometeorology: A guide for surface flux measurement and analysis. Kluwer, Dordrecht, 250 pp.

Monteith, JL, Unsworth, MH (1990) Principles of environmental physics. Edward Arnold, London, 291 pp.

Oke, TR (1987) Boundary layer climates. Methuen, New York, 435 pp.

Stull, RB (1988) An Introduction to boundary layer meteorology. Kluwer Acad. Publ., Dordrecht, Boston, London, 666 pp.

Further Measuring Technique Literature

Bentley, JP (2005) Principles of measurement systems. Pearson Prentice Hall, Harlow, 528 pp.

Brock, FV, Richardson, SJ (2001) Meteorological measurement systems. Oxford University Press, New York, 290 pp.

DeFelice, TP (1998) An introduction to meteorological Instrumentation and measurement. Prentice Hall, Upper Saddle River, 229 pp.

Dobson, F, Hasse, L, Davis, R (Editors) (1980) Air-sea interaction, Instruments and methods. Plenum Press, New York, 679 pp.

Kaimal, JC, Finnigan, JJ (1994) Atmospheric boundary layer flows: Their structure and measurement. Oxford University Press, New York, NY, 289 pp.

A2 Use of SI-Units

The following table includes important SI-units used in the book. The basic units are **bold** highlighted.

name	SI-unit	unit	calculation
length	**meter**	**m**	
time	**second**	**s**	
velocity		$m\ s^{-1}$	$1\ km\ h^{-1} = (1/3.6)\ m\ s^{-1}$
acceleration		$m\ s^{-2}$	
mass	**kilogram**	**kg**	
density		$kg\ m^{-3}$	
impulse		$kg\ m\ s^{-1}$	$1\ kg\ m\ s^{-1} = 1\ N\ s$
force	Newton	N	$1\ N = 1\ kg\ m\ s^{-2}$
pressure, friction	Pascal	Pa	$1\ Pa = 1\ N\ m^{-2}$ $1\ Pa = 1\ kg\ m^{-1}\ s^{-2}$
air pressure	hektopascal	hPa	1 hPa = 100 Pa
work, energy	Joule	J	1 J = 1 N m = 1 W s $1\ J = 1\ kg\ m^2\ s^{-2}$
power	Watt	W	$1\ W = 1\ J\ s^{-1} = 1\ N\ m\ s^{-1}$ $1\ W = 1\ kg\ m^2\ s^{-3}$
energy flux density		$W\ m^{-2}$	$1\ W\ m^{-2} = 1\ kg\ s^{-3}$
temperature	**Kelvin**	**K**	
Celsius-temperature		°C	0°C = 273.15 K
temperature difference		K	

A3 Constants and Important Parameters

Even though the accuracy of meteorological measurements is at most only 3–5 significant digits, the following physical constants are given with errors expressed in ppm, because sometimes in the literature different values are reported.

The values listed are taken from the 1986 calculations of Cohen and Taylor (1986) and the international temperature scale ITS-90 as given by Sonntag (1990):

constant	symbol	value	error
standard values			
standard air pressure	p_0	1013.25 hPa	
standard temperature	T_0	273.15 K = 0°C	
temperature of the triple point of water		273.16 K	
acceleration due to gravity at lat.. 45°	g	9.80665 m s^{-2}	
general constants			
velocity of the light in vacuum	c	299 792 458 m s^{-1}	exact
Planck's constant	h	6.626 0755(40) 10^{-34} J s	0.60
physical-chemical constants			
Avogadro number	N_A	6.022 1367(36) 10^{23} mol^{-1}	0.59
atom mass ^{12}C/12	m_u	1.660 5402(10) 10^{-27} kg	0.59
universal gas constant	R	8.314 510(70) J mol^{-1} K^{-1}	8.4
Boltzmann constant R/N_A	k	1.380 658(12) J K^{-1}	8.4
molar volume (ideal gas)	RT_0/p_0	22.414 10(19) l mol^{-1}	8.4
Stefan-Boltzmann constant	σ_{SB}	5.670 51(19) 10^{-8} W m^{-2} K^{-4}	34
Wien's constant	$\lambda_{max}\,T$	2.897 756(24) 10^{-3} m K	8.4
thermo-dynamical constants			
molar mass of dry air	M_L	0.028 9645(5) kg mol^{-1}	17
molar mass of water vapor	M_W	0.018 01528(50) kg mol^{-1}	27
ratio M_W/M_L	γ	0.62198(2)	33
gas constant of dry air	R_L	287.058 6(55) J kg^{-1} K^{-1}	19
gas constant of water vapor	R_W	461.525 (13) J kg^{-1} K^{-1}	29

The following quantities are valid for 1013.25 hPa and 15°C, if no other remark is given (Stull 1988):

quantity	symbol	value	remark
air			
specific heat of dry air at constant pressure	$(c_p)_L$	1004.67 J kg^{-1} K^{-1}	1)
specific heat of moist air at constant pressure	c_p	$= c_{pL}$ (1+0.84 q), q in kg kg^{-1}	
specific heat of dry air at constant volume	$(c_v)_L$	718 J kg^{-1} K^{-1}	1)
ratio of the specific heats	$(c_p/c_v)_L$	= 7/5 = 1.4	1)
ratio of the gas constant and the specific heat for dry air	$(R_L/c_p)_L$	= 2/7 = 0.286	1)
density	ρ_L	1.225 kg m^{-3}	
	ρ_{L0}	1.2923 kg m^{-3}, 0°C	1)
kinematic molecular viscosity	υ	1.461 10^{-5} m^2 s^{-1}	
molecular thermal conductivity	υ_T	2.06 10^{-5} m^2 s^{-1}	
dynamic molecular viscosity	$\mu=\rho_L/\upsilon$	1.789 10^{-5} kg m^{-1} s	
molecular thermal diffusivity	$a_T= \upsilon_T \cdot \rho_L \cdot c_{PL}$	2.53 10^{-2} W m^{-1} K^{-1}	
psychrometric constant (water)		6.53 10^{-4} (1+0.000944 t‘) p K^{-1}	2)
psychrometric constant (ice)		5.75 10^{-4} p K^{-1}	2)
water and water vapor			
specific heat of water vapor at constant pressure	$(c_p)_W$	1846 J kg^{-1} K^{-1}	
specific heat of water vapor at constant volume	$(c_v)_W$	1389 J kg^{-1} K^{-1}	
ratio of the specific heats	$(c_p/c_v)_W$	= 4/3 =1.333	
ratio of the gas constant and the specific heat	$(R_L/c_p)_W$	= 1/4 = 0.25	
density of water	ρ_W	1025 kg m^{-3}	
latent heat of vaporization	λ	(2.501 –0.00237 t) 10^6 J kg^{-1}	
other quantities			
Coriolis parameter	f	1.458 10^{-4} sin φ s^{-1}	1)
solar constant	S	energy units: – 1368 W m^{-2} kinematic units: – 1.125 K m s^{-1}	3)
constant gravity acceleration	g_0	9.80 m s^{-2}	

1) identical data in Landolt-Börnstein (Fischer 1988) according to WMO recommendations

2) Sonntag (1990)

3) Glickman (2000) and Houghton (2001)

Temperature dependent quantities (Fischer 1988):

temperature	specific heat capacity in 10^3 J kg^{-1} K^{-1}		latent heat in 10^6 J kg^{-1}		
	ice	water	vaporization	fusion	sublimation
–20	1.959	4.35	2.5494	0.2889	2.8387
–10	2.031	4.27	2.5247	0.3119	2.8366
0	2.106	4.2178	2.50084	0.3337	2.8345
5		4.2023	2.4891		
10		4.1923	2.4774		
15		4.1680	2.4656		
20		4.1818	2.4535		
25		4.1797	2.4418		
30		4.1785	2.4300		
35		4.1780	2.4183		
40		4.1785	2.4062		

A4 Further Equations

Calculation of Astronomical Quantities

In some applications, it is often necessary to determine the solar inclination angle as a function of time. The following approximations for some of these calculations must be applied in several steps:

To determine the declination of the sun, δ, the latitude of the sun, φ_s, must first be calculated (Holtslag and van Ulden 1983)

$$\varphi_S = 4.871 + 0.0175\,DOY + 0.033\ \sin(0.0175\,DOY), \tag{A1}$$

where *DOY* is the day of the year where the 1st of January has the number 1.

The declination angle is given by:

$$\delta = \arcsin(0.398 \sin \varphi_S) \tag{A2}$$

To determine the position of the sun, the “hour angle” h

$$h = \frac{2\pi\, t_H}{\Delta t_d} \tag{A3}$$

must be calculated which gives the angular difference between δ and the zenith of the sun (Liou 1992), where t_H is the time distance to culmination of the sun in seconds and Δt_d = 86400 s is the duration of a full rotation of the Earth. It is necessary to apply the equation of time (*EQT*), which gives the difference between the true and the averaged local time. From tables of the time equation (Neckel and Montenbruck 1999) for 15° E and 50 °N and the year 2000 Göckede (2000) calculated an approximation equation:

$$EQT = \sum_{n=0}^{12} x_n \, DOY^n \tag{A4}$$

The coefficients are listed in the following table:

n	x_n	n	x_n
12	1.67050145E-27	5	–3.35088054E-09
11	–3.94339477E-24	4	2.29121835E-07
10	4.05537695E-21	3	–9.77373856E-06
9	–2.37686237E-18	2	1.23393733E-04
8	8.72332216E-16	1	6.69458473E-03
7	–2.07900028E-13	0	4.87707231E-02
6	3.25188650E-11		

The time distance to culmination of the sun, t_H, for Central European Time is given by

$$t_H = \left\{ t - \left[12 + EQT + \frac{(15-\lambda)4}{60} \right] \right\} 3600\,, \tag{A5}$$

where t: time in hours, and λ is longitude.

With the latitude ψ in radians of a location, the angle of inclination of the sun can be determined for any time:

$$\sin\varphi = \sin\delta \sin\psi + \cos\delta \cos\psi \cos h \tag{A6}$$

To determine the incoming extraterrestrial radiation at the upper border of the atmosphere from the solar constant the variability of the distance between the sun and the Earth must be taken into account

$$K\downarrow_{extraterr.} = S\left(\frac{r_0}{r}\right)^2 \sin\varphi\,, \tag{A7}$$

where r_0 is the mean distance of the Earth from the Sun (149 597 870.66 km) and r is the actual distance. The ratio of both can be determined according to Hartmann (1994) as a Fourier series

$$\left(\frac{r_0}{r}\right)^2 = \sum_{n=0}^{2} a_n \cos(n\,\theta_d) + b_n \sin(n\,\theta_d) \tag{A8}$$

with

$$\theta_d = \frac{2\pi\, DOY}{265} \tag{A9}$$

where in the case of a leap year the denominator is 266. The coefficients for Eq. (A8) are given in the following table:

n	a_n	b_n
0	1.000110	
1	0.034221	0.001280
2	0.000719	0.000077

Universal Functions

Even though the universal function formulated by Businger *et al.* (1971) and later modified by Högström (1988) are widely used, knowledge of other universal functions may be quite useful for different research activities. The following table is based on works of Dyer (1974), Yaglom (1977), Foken (1990), and Andreas (2002). The values the von-Kármán constant, κ, used in the formulations are given. The notation, 0.40*, indicates that the original function was re-calculated by Högström (1988) using κ =0.40.

reference	κ	universal function for momentum exchange
Swinbank (1964)	–	$\frac{z}{L}\left(1-e^{z/L}\right)^{-1} \quad z/L<0$
Swinbank (1968)	0.40	$0.613\left(-z/L\right)^{-0.2} \quad -0.1 \geq z/L \geq -2$
Tschalikov (1968)	0.40	$1+7.74\, z/L \quad z/L>0.04$
Zilitinkevich and. Tschalikov (1968)	0.434	$1+1.45\, z/L \quad -0.15<z/L<0$
		$0.41\left(-z/L\right)^{-1/3} \quad -1.2<z/L<-0.15$
		$1+9.9\, z/L \quad 0<z/L$
	0.40*	$1+1.38\, z/L \quad -0.15<z/L<0$
		$0.42\left(-z/L\right)^{-1/3} \quad -1.2<z/L<-0.15$
		$1+9.4\, z/L \quad 0<z/L$
Webb (1970)	–	$1+4.5\, z/L \quad z/L<-0.03$
Dyer and Hicks (1970)	0.41	$\left(1-16\, z/L\right)^{-1/4} \quad -1<z/L<0$

reference	κ	universal function for momentum exchange
Businger *et al.* (1971)	0.35	$(1-15\,z/L)^{-1/4} \quad -2<z/L<0$ $1+4.7\,z/L \quad 0<z/L<1$
	0.40*	$(1-19{,}3\,z/L)^{-1/4} \quad -2<z/L<0$ $1+6\,z/L \quad 0<z/L<1$
Dyer (1974)	0.41	$(1-16\,z/L)^{-1/4} \quad -1<z/L<0$ $1+5\,z/L \quad 0<z/L$
Dyer (1974)	0.40*	$(1-15.2\,z/L)^{-1/4} \quad -1<z/L<0$ $1+4.8\,z/L \quad 0<z/L$
Skeib (1980), see also: Foken and. Skeib (1983) and Foken (1990)	0.40 0.40*	$1 \quad -0.0625<z/L<0.125$ $\left(\frac{z/L}{-0.0625}\right)^{-1/4} \quad -2<z/L<-0.0625$ $\frac{z/L}{0.125} \quad 0.125<z/L<2$
Gavrilov and Petrov (1981)	0.40	$(1-8\,z/L)^{-1/3} \quad z/L<0$ $1+5\,z/L \quad 0<z/L$
Dyer and. Bradley (1982)	0.40 0.40*	$(1-28\,z/L)^{-1/4} \quad z/L<0$
Beljaars and Holtslag (1991)	0.40	$1+z/L+\frac{2}{3}z/L\,(6-0.35\,z/L)\cdot e^{-0.35z/L} \quad 0<z/L$
King *et al.* (1996)	0.40	$1+5.7\,z/L\le 12 \quad 0<z/L$
Handorf *et al.* (1999)	0.40	$1+5\,z/L \quad 0<z/L<0.6$ $4 \quad 0.6<z/L$

reference	κ	universal function for the exchange of sensible heat, $\alpha_0=1$
Swinbank (1968)	0.40	$0.227\,(-z/L)^{-0.44} \quad -0.1\ge z/L\ge -2$
Tschalikov (1968)	0.40	$1+5.17\,z/L \quad z/L>0.04$

reference	κ	universal function for the exchange of sensible heat, $\alpha_0=1$	
Zilitinkevich and Tschalikov (1968)	0.434	$1+1.45\,z/L$	$-0.15<z/L<0$
		$0.41\left(-z/L\right)^{-1/3}$	$-1.2<z/L<-0.15$
		$1+9.9\,z/L$	$0<z/L$
Zilitinkevich and Tschalikov (1968)	0.40*	$0.95+1.31\,z/L$	$-0.15<z/L<0$
		$0.40\left(-z/L\right)^{-1/3}$	$-1.2<z/L<-0.15$
		$0.95+8.9\,z/L$	$0<z/L$
Webb (1970)	–	$1+4.5\,z/L$	$z/L<-0.03$
Dyer and Hicks (1970)	0,41	$\left(1-16\,z/L\right)^{-1/2}$	$-1<z/L<0$
Businger *et al.* (1971)	0,35	$0.74\left(1-9\,z/L\right)^{-1/2}$	$-2<z/L<0$
		$0.74+4.7\,z/L$	$0<z/L<1$
	0,40*	$0.95\ \left(1-11.6\,z/L\right)^{-1/2}$	$-2<z/L<0$
		$0.95+7.8\,z/L$	$0<z/L<1$
Dyer (1974)	0,41	$\left(1-16\,z/L\right)^{-1/2}$	$-1<z/L<0$
		$1+5\,z/L$	$0<z/L$
	0,40*	$0.95\left(1-15.2\,z/L\right)^{-1/2}$	$-1<z/L<0$
		$0.95+4.5\,z/L$	$0<z/L$
Skeib (1980), see also: Foken and Skeib (1983) and Foken (1990)	0,40	1	$-0.0625<z/L<0.125$
		$\left(\frac{z/L}{-0.0625}\right)^{-1/2}$	$-2<z/L<-0.0625$
		$\left(\frac{z/L}{0.125}\right)^{2}$	$0.125<z/L<2$

reference	κ	universal function for the exchange of sensible heat, $\alpha_0 = 1$
Skeib (1980), see also: Foken and Skeib (1983) and Foken (1990)	0.40*	$0.95 \qquad -0.0625 < z/L < 0.12$ $0.95\left(\frac{z/L}{-0.0625}\right)^{-1/2} \qquad -2 < z/L < -0.0625$ $0.95\left(\frac{z/L}{0.125}\right)^{2} \qquad 0.125 < z/L < 2$
Gavrilov and Petrov (1981)	0.40	$0.65\left[\left(1-35\,z/L\right)^{-1/2}+\frac{0.25}{1+8\left(z/L\right)^{2}}\right] \qquad z/L < 0$ $0.9+6\,z/L \qquad 0 < z/L$
Dyer and Bradley (1982)	0.40 0.40*	$\left(1-14\,z/L\right)^{-1/2} \qquad z/L < 0$
Beljaars and. Holtslag (1991)	0.40	$1+z/L\left(1+\frac{2}{3}\,z/L\right)^{1/2}+\frac{2}{3}\,z/L\left(6-0.35\,z/L\right)e^{-0.35\,z/L}$ $0 < z/L$
King *et al.* (1996)	0.40	$0.95+4.99\,z/L \le 12 \qquad 0 < z/L$
Handorf *et al.* (1999)	0.40	$1+5\,z/L \qquad 0 < z/L < 0.6$ $4 \qquad 0.6 < z/L$

reference	κ	Universal function for the energy dissipation
Wyngaard and Coté (1971)	0.35	$\left[1+0.5\left\|z/L\right\|^{2/3}\right]^{3/2} \qquad z/L < 0$ $\left[1+2.5\left(z/L\right)^{3/5}\right]^{3/2} \qquad z/L > 0$
Thiermann and Graßl (1992)		$\left(1-3\,z/L\right)^{-1}-z/L \qquad z/L < 0$ $\left[1+4\,z/L+16\left(z/L\right)^{2}\right]^{-1/2} \qquad z/L > 0$
Kaimal and Finnigan (1994)		$\left[1+0.5\left\|z/L\right\|^{2/3}\right]^{3/2} \qquad z/L < 0$ $1+5\,z/L \qquad z/L > 0$

reference	κ	Universal function for the energy dissipation
Frenzen and Vogel (2001)		$0.85\left[\left(1-16\,{}^{z}\!/_{L}\right)^{-2/3}-{}^{z}\!/_{L}\right] \qquad {}^{z}\!/_{L}<0$
		$0.85+4.26\,{}^{z}\!/_{L}+2.58\cdot\left({}^{z}\!/_{L}\right)^{2} \qquad {}^{z}\!/_{L}>0$
Hartogensis and DeBruin (2005)		$0.8+2.5\cdot{}^{z}\!/_{L} \qquad {}^{z}\!/_{L}>0$

reference	κ	universal function for the temperature structure function parameter
Wyngaard *et al.* (1971b)	0.35	$4.9\left(1-7\,{}^{z}\!/_{L}\right)^{-2/3} \qquad {}^{z}\!/_{L}<0$
		$4.9\left[1+2.75\left({}^{z}\!/_{L}\right)\right] \qquad {}^{z}\!/_{L}>0$
Foken and Kretschmer (1990)	0.4	$\left({}^{0.95}\!/_{\kappa}\right)^{2}\left(1-11.6\,{}^{z}\!/_{L}\right)^{-1/2} \qquad -2<{}^{z}\!/_{L}<0$
		${}^{0.95}\!/_{\kappa^{2}}\left(0.95+7.8\,{}^{z}\!/_{L}\right) \qquad 0<{}^{z}\!/_{L}<1$
Thiermann and Graßl (1992)		$6.34\left[1-7\,{}^{z}\!/_{L}+75\left({}^{z}\!/_{L}\right)^{2}\right]^{-1/3} \qquad {}^{z}\!/_{L}<0$
		$6.34\left[1-7\,{}^{z}\!/_{L}+20\left({}^{z}\!/_{L}\right)^{2}\right]^{1/3} \qquad {}^{z}\!/_{L}>0$
Kaimal and Finnigan (1994)		$5\left(1+6.4\left\|{}^{z}\!/_{L}\right\|\right)^{-2/3} \qquad {}^{z}\!/_{L}<0$
		$4\left(1+3\,{}^{z}\!/_{L}\right) \qquad {}^{z}\!/_{L}>0$
Hartogensis and DeBruin (2005)		$4.7\left[1+1.6\left({}^{z}\!/_{L}\right)^{2/3}\right] \qquad {}^{z}\!/_{L}>0$

Integral Turbulence Characteristics in the Surface Layer

reference	${}^{\sigma_u}\!/_{u_*}$	${}^{\sigma_v}\!/_{u_*}$	stratification
Lumley and Panofsky (1964), Panofsky and Dutton (1984)	2.45	1.9	neutral, unstable
McBean (1971)	2.2	1.9	unstable
Beljaars *et al.* (1983)	2.0	1.75	unstable

reference	σ_u/u_*	σ_v/u_*	stratification
Sorbjan (1986)	2.3		stable
Sorbjan (1987)	2.6		
Foken *et al.* (1991)	2.7		$-0.032 < z/L < 0$
	$4.15\left(z/L\right)^{1/8}$		$z/L < -0.032$
Thomas and Foken (2002)	$0.44\ln\left(\frac{1\,m\,f}{u_*}\right)+3.1$		$-0.2 < z/L < 0.4$

reference	σ_w/u_*	σ_T/T_*	stratification
Lumley and Panofsky (1964), Panofsky and Dutton (1984)	1.45		neutral, unstable
McBean (1971)	1.4	1.6	unstable
Panofsky *et al.* (1977)	$1.3\left(1-2\,z/L\right)^{1/3}$		unstable
Caughey u. Readings (1975)		$\left(z/L\right)^{-1/3}$	unstable
Hicks (1981)	$1.25\left(1-2\,z/L\right)^{1/3}$	$0.95\left(z/L\right)^{-1/3}$	unstable
Caughey u. Readings (1975)		$\left(z/L\right)^{-1/3}$	unstable
Beljaars *et al.* (1983)		$0.95\left(z/L\right)^{-1/3}$	unstable
Sorbjan (1986)	1.6	2.4	stable
Sorbjan (1987)	1.5	3.5	stable
Foken *et al.* (1991)	1.3		$-0.032 < z/L < 0$
	$2.0\left(z/L\right)^{1/8}$		$z/L < -0.032$

reference	σ_w/u_*	σ_T/T_*	stratification
Foken et al. (1991; 1997a)		$1.4(z/L)^{-1/4}$ $0.5(z/L)^{-1/2}$ $(z/L)^{-1/4}$ $(z/L)^{-1/3}$	$0.02 < z/L < 1$ $-0.062 < z/L < 0.02$ $-1 < z/L < -0.062$ $z/L < -1$
Thomas and. Foken (2002)	$0.21\ln\left(\frac{1\,m \cdot f}{u_*}\right) + 6.3$		$-0.2 < z/L < 0.4$

A5 Overall View of Experiments

Experiments for the Investigation of the Surface Layer

The following table lists the important micrometeorological experiments which gave special consideration of the surface layer (Foken 1990; Foken 2006a; Garratt and Hicks 1990; McBean *et al.* 1979); in this table ITCE means *International Turbulence Comparison Experiment*.

experiment	location, time	reference
O'Neill	O'Neill, USA 1953	Lettau (1957)
Kerang	Kerang, Australien 1962	Swinbank and Dyer (1968)
Hay	Hay, Australien 1964	
Hanford	Hanford, USA 1965	Businger *et al.* (1969)
Wangara	Hay, Australia 1967	Hess *et al.* (1981)

experiment	location, time	reference
KANSAS 1968	Kansas, USA. 1968	Izumi (1971)
ITCE-1968	Vancouver, Canada 1968	Miyake *et al.* (1971)
ITCE-1970	Tsimlyansk, Russia 1970	Tsvang *et al.* (1973)
Koorin	Koorin, Australia 1974	Garratt (1980)
ITCE-1976	Conargo, Australia 1976	Dyer (1982)
ITCE-1981	Tsimlyansk, Russia 1981	Tsvang *et al.* (1985)
Lövsta	Lövsta, Sweden 1986	Högström (1990)

Experiments Over Heterogeneous Landscapes

In the last 30 years, many micrometeorological experiments were conducted over heterogeneous landscapes and also included boundary layer processes and air chemical measurements (Mengelkamp *et al.* 2006, added).

experiment	location, time	reference
HAPEX-MOBILHY	France 1986	André *et al.* (1990)
FIFE	Kansas, 1987–1989	Sellers *et al.* (1988)
KUREX-88	Kursk, Russia 1988	Tsvang *et al.* (1991)
HAPEX-SAHEL	Niger, 1990–1992	Goutorbe *et al.* (1994)
SANA	Eisdorf, Melpitz, Germany, 1991	Seiler (1996)
EFEDA	Spain 1990–1991	Bolle *et al.* (1993)
BOREAS	Canada, 1993–1996	Sellers *et al.* (1997)
SHEBA	Arctic 1998	Uttal *et al.* (2002)
LITFASS-98	Lindenberg, Germany, 1998	Beyrich *et al.* (2002b)
CASES-99	Kansas, USA 1999	Poulos *et al.* (2002)
EBEX-2000	near Fresno CA, USA, 2000	Oncley *et al.* (2007)
LITFASS-2003	Lindenberg, Germany, 2003	Beyrich and Mengelkamp (2006)

Other Experiments Referred to in the Text

The following table gives some information about further experiments mentioned in this book.

experiment	location, time	reference
Greenland	Greenland, summer 1991	Ohmura (1992)
FINTUREX	Neumayer station, Antarktica, Jan.–Febr. 1994	Foken (1996), Handorf *et al.* (1999)
LINEX-96/2	Lindenberg, Germany, June 1996	Foken *et al.* (1997a)
LINEX-97/1	Lindenberg, Germany, June 1997	Foken (1998b)
WALDATEM-2003	Waldstein, Germany, May–July 2003	Thomas and Foken (2007a)

A6 Meteorological Measuring Stations

In Chap. 6.2, different types of meteorological measuring stations were defined (Table 6.1). The measuring parameters of these stations (VDI 2006a) are given in the following table, where X indicates necessary parameters and o indicates desirable additional parameters. The measuring parameters include air temperature (t_a), air moisture (f_a), wind velocity (u), precipitation (R_N), global radiation (G), net radiation (Q_s). surface temperature (t_{IR}), photosynthetic active radiation (PAR), soil temperature (t_b), soil heat flux (Q_G), air pressure (p), state of the weather (ww), sensible heat flux (Q_H), latent heat flux (Q_E), deposition (Q_c), shear stress (τ).

The most important parameters are:

type of the station	t_a	f_a	u	dd	R_N	G	Q_S	p	ww
agrometeorological	X	X	X	X	X	X	o	o	
micrometeorological	X	X	X	X	X	o		o	o
micrometeorological with turbulence measurements	X	X	X	X	X	o	X	o	
air pollution	o	o	X	X		X	o	o	o
immission measuring	X	X	X	X	X	X			
disposal site	X	X	X	X	X	o	X		
noise measuring	X		X	X					
traffic measuring		X	X	X					o

type of the station	t_a	f_a	u	dd	R_N	G	Q_S	p	ww
hydrological	o	o	o		X		o		
forest climate	X	X	X	X	X	X	o		
nowcasting	X	X	X	X	X	o		o	X
hobby	X	X	o	o				o	

Additional parameters measured at selected stations are:

type of station	t_{IR}	PAR	t_b	f_b	Q_G	Q_H	Q_E	Q	τ
agrometeorological		o	X	X	o				
micrometeorological									
micrometeorological with turbulence measurements					o	X	X	o	X
air pollution									o
immission measuring									
disposal site									
noise measuring									
traffic measuring	o		o						
hydrological									
forest climate		o	o	o					
nowcasting									
hobby									

A7 Micrometeorological Standards used in Germany

In Germany, Austria, and Switzerland meteorological measuring techniques and some applied meteorological methods are standardized. Some of these standards were incorporated in the international ISO standards. Because these standards are available in English, only the most important standards are given. The relevant standards appear in volume 1B of the "VDI/DIN Handbook on Keeping the Air Clean" (Queitsch 2002; VDI 2006b):

VDI/DIN	sheet	content
3781	2, 4	Dispersion of pollutants in the atmosphere; stack heights
3782	1, 3, 5, 7	Environmental meteorology - Atmospheric dispersion models

VDI/DIN	sheet	content
3783	1, 2, 4, 5, 6, 8, 9, 10, 12	Dispersion of pollutants in the atmosphere; dispersion of emissions by accidental releases
3784	1, 2	Environmental meteorology; cooling towers
3786	1–17	Environmental meteorology – Meteorological measurements
3787	1, 2, 5, 9,10	Environmental meteorology – Climate and air pollution
3788	1	Environmental meteorology – Dispersion of odorants
3789	2, 3	Environmental meteorology – Interactions between atmosphere and surfaces
3790	1, 2, 3	Environmental meteorology – Emissions of gases
3945	1, 3	Environmental meteorology – Atmospheric dispersion models

Because of a lack in the literature on meteorological measuring systems, the VDI/DIN 3786 (Sheets 1–17) and the relevant ISO standards may be of interest to a wide readership:

VDI/DIN	title
DIN ISO 16622	Meteorology – Sonic anemometers/thermometers – Acceptance test methods for mean wind measurements (ISO 16622:2002)
DIN ISO 17713-1	Meteorology – Wind measurements – Part 1: Wind tunnel test methods for rotating anemometer performance (ISO 17713-1:2007)
DIN ISO 17714	Meteorology – Air temperature measurements – Test methods for comparing the performance of thermometer shields/screens and defining important characteristics (ISO/DIS 17714:2004)
VDI 3786 Sheet 1	Environmental meteorology – Meteorological measurements – Fundamentals
VDI 3786 Sheet 2	Environmental meteorology – Meteorological measurements concerning questions of air pollution – Wind
VDI 3786 Sheet 3	Meteorological measurements concerning questions of air pollution; air temperature
VDI 3786 Sheet 4	Meteorological measurements concerning questions of air pollution; air humidity
VDI 3786 Sheet 5	Meteorological measurements concerning questions of air pollution; global radiation, direct solar radiation and net total radiation
VDI 3786 Sheet 6	Meteorological measurements of air pollution; turbidity of ground-level atmosphere standard visibility
VDI 3786 Sheet 7	Meteorological measurements concerning questions of air pollution; precipitation
VDI 3786 Sheet 8	Meteorological measurements; concerning questions of air pollution; aerological measurements

VDI/DIN	title
VDI 3786 Sheet 9	Environmental Meteorology – Meteorological measurements – Visual weather observations
VDI/DIN	title
VDI 3786 Sheet 10	Environmental meteorology; measurement of the atmospheric turbidity due to aerosol particles with sunphotometers
VDI 3786 Sheet 11	Environmental meteorology; determination of the vertical wind profile by Doppler SODAR systems
VDI 3786 Sheet 12	Environmental meteorology – Meteorological measurements – Turbulence measurements with sonic anemometers
VDI 3786 Sheet 13	Environmental meteorology – Meteorological measurements – Measuring station
VDI 3786 Sheet 14	Environmental meteorology – Ground-based remote sensing of the wind vector – Doppler wind LIDAR
VDI 3786 Sheet 15	Environmental meteorology – Ground-based remote sensing of visual range – Visual-range lidar
VDI 3786 Sheet 16	Environmental meteorology – Measurement of atmospheric pressure
VDI 3786 Sheet 17	Environmental meteorology – Ground-based remote sensing of the wind vector – Wind profiler radar

A8 Available Eddy-Covariance Software

The following software can be used for eddy-covariance measurements (VDI 2008) and some of them were compared in Mauder (2008; 2007b):

name	reference
EdiRe	The University of Edinburgh Institute of Atmospheric and Environmental Science Crew Building, The King's Buildings West Mains Road EDINBURGH EH9 3JN http://www.geos.ed.ac.uk/abs/research/micromet/EdiRe/
ECPack	Department of Meteorology and Air Quality Wageningen University and Research Duivendaal 2 NL 6701 AP Wageningen http://www.met.wau.nl/index.html?http://www.met.wau.nl/projects /jep/

name	reference
EddyMess	Dr. Olaf Kolle Max-Planck-Institute for Biogeochemistry Hans-Knöll-Str. 10 D-07749 Jena, Germany
TK2	University of Bayreuth Dept. of Micrometeorology D-95440 Bayreuth, Germany http://www.bayceer.uni-bayreuth.de/mm/de/software/software/software_dl.php

A9 Glossary

Advection: Transport of properties of the air (momentum, temperature, water vapor, *etc.*) by the wind. As a rule, horizontal transport is understood. Because of advection, air properties change in both horizontal coordinates, and the conditions are no longer homogeneous. Vertical advection is the vertical movement air due to mass continuity rather than buoyancy, *i.e.* convection.

Atmospheric window: Frequency range of electromagnetic waves, which pass through the atmosphere with little absorption. Within this frequency range, remote sensing methods of the surface properties can be applied. The most important atmospheric windows are in the visible range from 0.3 to 0.9 µm, in the IR-range from 8 to 13 µm, and in the microwave range for wave lengths greater than 1 mm.

Bolometer: A device for measuring radiant energy by using thermally-sensitive electric sensors (thermocouple, thermistor, platinum wire).

Calm: State of the atmosphere with no discernible air motion. The calm-threshold is the threshold speed of cup anemometers, which is about 0.3 ms^{-1}. A wind direction can not be determined under these circumstances.

CET: Abbreviation of Central European Time. It is the mean local time at 15° longitude, and differs from UTC by 1 h.

Clausius-Clapeyron equation: Clapeyron 1834 established and Clausius 1850 gave the reasons for the equations for the temperature dependence of equilibrium water-vapor pressure at saturation. Because of the equation's strong exponential dependence on temperature, the atmosphere can take significantly more water at high temperatures than at lower temperatures, and therefore can store more latent heat.

Climate element: Meteorological and other parameters that characterize (singly or in combinations) different climate types. These are state variables and fluxes.

Coherence: In generally, coherence is a constant phase relation between two waves. Coherent structures in atmospheric turbulence research are velocity, temperature, and other structures, which are significantly larger and longer-lived than the smallest local eddies (*e.g.* squall lines, convective cells).

Coriolis force: Fictitious force in a rotating coordinate system, and named after the mathematician Coriolis (1792–1843). It is a force normal to the velocity vector causing a deflection to the right in the Northern hemisphere and to the left in the Southern hemisphere.

Coriolis parameter: Twice the value of the angular velocity of the Earth for a certain location of the latitude φ: $f=2\ \Omega \sin \varphi$. At the equator $f = 0$, on the Northern hemisphere positive and on the Southern hemisphere negative.

Dissipation: Conversion of kinetic energy by work against the viscous stresses. Under turbulent conditions, it is the conversion of the kinetic energy of the smallest eddies into heat.

Element, meteorological: *see* climate element

Entrainment: Exchange process at the top of the atmospheric boundary layer, and is due to the actions of eddies that are smaller than those in the mixed layer.

Fetch: Windward distance from a measuring point to a change of the surface properties or an obstacle; extent of a measuring field for micrometeorological research.

Froude number: Dimensionless ratio of the inertia force to the gravity force $Fr=V^2\ L^{-1}\ g^{-1}$ where V is a characteristic velocity and L is a characteristic length. For flow over hills, L is the characteristic distance between hills or obstacles. In these cases, the external Froude number with the Brunt-Väisälä frequency N is used, see Eq. (3.36): $Fr= V\ N^{-1}\ L^{-1}$.

Gas constant: Proportionality factor of the equation of state for ideal gases, and is expressed in mol. In meteorology, the gas constant is expressed in mass units, and a special gas constant for dry air is used. In moist air, the temperature in the equation of state must be replaced by the virtual temperature (see below).

Hysteresis: The change between two states that depends on the way the change occurs, for example, the characteristics of a moisture sensor are different for wetting and drying.

Inversion: An air layer where the temperature increases with the altitude instead of the usual decrease. Inversions are of two types; surface inversion due to longwave radiation from the ground, and elevated or free inversions *e.g.* at the top of the atmospheric boundary layer.

Kelvin-Helmholtz instability: A dynamic instability caused by strong wind shear resulting in breaking waves or billow clouds (Sc, Ac lent). Typically, these occur at inversions or above hills. They also can occur over obstacles and forests.

Leaf area density: The vertical probability density function of the leaf area.

Leaf area index: Ratio of the leaf area (upper side) within a vertical cylinder to the bottom area of the cylinder.

Low-level jet: Vertical band of strong winds in the lower part of the atmospheric boundary layer. For stable stratification, the low-level jet develops at the upper border of the nocturnal surface inversion. Typical heights are 100–300 m, and sometimes lower.

Matrix potential: A measure of the absorption and capillary forces of the solid soil matrix on the soil water. Its absolute value is called tension.

Mixed layer: A layer of strong vertical mixing due to convection resulting in vertically-uniform values of potential temperature and wind speed but decreasing values of moisture. It is often capped by an inversion layer (see above).

MLT: Abbreviation for Mean Local Time. Time related to the meridian of the location and for all locations of the same longitude. The mean local time is the solar time measured from the lower culmination of the sun. It is calculated by addition of 4 min to the universal time (UT) for each degree of longitude in eastward direction (Brockhaus 2003).

Parameterization: Representation of complicated relations in models by more simple combinations of parameters, which are often only valid under certain circumstances.

RLT: Abbreviation for Real Local Time. It is the time related to the meridian of all points on the same longitude. The real local time is the solar time measured from the daily lower culmination of the sun and changes with the time equation, which is the difference between the real and the mean solar time. The time equation is positive if the real solar time earlier culminates than the mean solar time (sun day). It changes between –14 min 24 s (approx. middle of February) and +16 min 21 s (approx. beginning of November). For an approximation relation see A4 (Brockhaus 2003).

Rossby similarity: In the free atmosphere, the Rossby number is the ratio of the inertial force to the Coriolis force. In the atmospheric boundary layer, the roughness Rossby number is the ratio of the friction velocity to the Coriolis parameter, $Ro=u_*/(f\ z_0)$. The friction Rossby number is an assessment of the ageostrophic component of the wind.

Stability of the stratification: The static stability separates turbulent and laminar flow conditions depending on the gradient of the potential temperature (see below). If the potential temperature decreases with height, then the stratification is unstable, but if it increases with height, then the stratification is stable. Due to the effects of vertical wind sheer, the statically-stable range is turbulent up to the critical Richardson number.

Temperature, potential: The temperature of a dry air parcel that is moved adiabatically to a pressure of 1000 hPa, see Eq. (2.60).

Temperature, virtual: The temperature of a dry air parcel if it had the same density as a moist air parcel. The virtual temperature is slightly higher than the temperature of moist air, see Eq. (2.69).

Transmission: Permeability of the atmosphere for radiation. The radiation can be reduced *e.g.* by gases, aerosols, particles, and water droplets.

UTC: Abbreviation for Universal Time Coordinated, a time scale based on the international atomic time by setting the zero point to the zero meridian (Greenwich Meridian) , with the mean solar day as a basic unit. It is the basis for political and scientific time (Brockhaus 2003).

Wind, geostrophic: Wind above the atmospheric boundary layer where pressure gradient force and Coriolis force (see above) are in equilibrium.

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