

# Contents

Preface .....	VII
1 Introduction .....	1
1.1 The necessity for measurements .....	2
1.2 Definition of a measurement .....	3
1.3 Historical aspects .....	4
2 Measurement basics .....	7
2.1 Overview of methods .....	7
2.1.1 Direct and indirect methods .....	7
2.1.2 In-situ and remote sensing methods .....	7
2.1.3 Instantaneous and integrating methods .....	8
2.1.4 On-line and off-line methods, post-processing .....	9
2.1.5 Flux measurements .....	9
2.2 Main measurement principles .....	10
2.3 Measurements by inversion .....	12
2.3.1 Inversion with one variable .....	12
2.3.2 Inversion with more than one variable .....	14
2.3.3 Well-posed and ill-posed problems .....	16
2.4 Measurement instruments .....	16
2.4.1 Active and passive instruments .....	16
2.4.2 Analogue and digital instruments .....	17
2.5 Measurement platforms .....	18
2.6 Measurement variables .....	22
2.7 General characteristics of measured data .....	23
2.8 Data logging .....	26
2.9 Quality assurance/quality control .....	27
3 In-situ measurements of state variables .....	29
3.1 Thermometers .....	29
3.1.1 Liquid-in-glass thermometers .....	31
3.1.2 Bimetal thermometers .....	33
3.1.3 Resistance thermometers, thermistors .....	34
3.1.4 Thermocouples, thermopiles .....	35
3.1.5 Sonic thermometry .....	36
3.1.6 Measurement of infrared radiation .....	37
3.1.7 Soil thermometer .....	38
3.1.8 Recommendations for temperature measurements .....	38
3.2 Measuring moisture .....	40
3.2.1 Hygrometer .....	43
3.2.2 Psychrometers .....	44
3.2.3 Dewpoint determination .....	45
3.2.4 Capacitive methods .....	46

3.2.5	Recommendations for humidity measurements . . . . .	46
3.3	Pressure sensors. . . . .	47
3.3.1	Barometers . . . . .	48
3.3.2	Hypsometers . . . . .	50
3.3.3	Electronic barometers . . . . .	51
3.3.4	Microbarometer. . . . .	52
3.3.5	Pressure balance . . . . .	52
3.3.6	Recommendations for pressure measurements . . . . .	53
3.4	Wind measurements . . . . .	53
3.4.1	Estimation from visual observations . . . . .	57
3.4.2	Wind direction. . . . .	57
3.4.3	Cup anemometer . . . . .	58
3.4.4	Pressure tube . . . . .	59
3.4.5	Hot wire anemometer . . . . .	61
3.4.6	Ultrasonic anemometer . . . . .	61
3.4.7	Propeller anemometer . . . . .	62
3.4.8	Recommendations for wind measurements . . . . .	63
4	In-situ methods for observing liquid water and ice . . . . .	64
4.1	Precipitation. . . . .	64
4.1.1	Rain sensors (Present Weather Sensors) . . . . .	65
4.1.2	Rain gauges (totalisators) . . . . .	66
4.1.3	Pluviographs . . . . .	67
4.1.4	Disdrometer. . . . .	67
4.1.5	Special instruments for snow . . . . .	68
4.1.6	Recommendations for precipitation measurements . . . . .	69
4.2	Soil moisture . . . . .	70
4.2.1	Gravimetric methods. . . . .	70
4.2.2	Neutron probes . . . . .	70
4.2.3	Time domain reflectrometry (TDR) . . . . .	70
4.2.4	Tensiometers . . . . .	71
4.2.5	Resistance block tensiometer . . . . .	71
4.2.6	Recommendations for soil moisture measurements . . . . .	72
5	In-situ measurement of trace substances . . . . .	73
5.1	Measurement of trace gases. . . . .	74
5.1.1	Physical methods. . . . .	76
5.1.2	Chemical methods. . . . .	81
5.1.3	Recommendations for the measurement of trace gases . . . . .	84
5.2	Particle measurements. . . . .	84
5.2.1	Determination of the particle mass . . . . .	85
5.2.2	Measuring particle size distributions . . . . .	88
5.2.3	Measurement of the chemical composition of particles . . . . .	92
5.2.4	Measuring the particle structure . . . . .	94

5.2.5	Saltiphon . . . . .	94
5.2.6	Recommendations for particle measurements . . . . .	94
5.3	Olfactometry . . . . .	95
5.4	Radioactivity . . . . .	96
5.4.1	Counter tubes . . . . .	96
5.4.2	Scintillation counters. . . . .	97
5.4.3	Recommendations for radioactivity monitoring . . . . .	97
6	In-situ flux measurements. . . . .	98
6.1	Measuring radiation. . . . .	98
6.1.1	Measuring direct solar radiation . . . . .	100
6.1.2	Measuring shortwave irradiance . . . . .	100
6.1.3	Measuring longwave irradiance . . . . .	103
6.1.4	Measuring the total irradiance. . . . .	103
6.1.5	Measuring chill . . . . .	104
6.1.6	Sunshine recorder . . . . .	104
6.1.7	Recommendations for radiation measurements . . . . .	105
6.2	Visual range. . . . .	105
6.3	Micrometeorological flux measurements . . . . .	106
6.3.1	Cuvettes. . . . .	108
6.3.2	Surface chambers . . . . .	108
6.3.3	Mass balance method . . . . .	110
6.3.4	Inferential method . . . . .	110
6.3.5	Gradient method . . . . .	111
6.3.6	Bowen-ratio method . . . . .	112
6.3.7	Flux variance method . . . . .	112
6.3.8	Dissipation method . . . . .	113
6.3.9	Eddy covariance method . . . . .	113
6.3.10	Eddy accumulation methods . . . . .	117
6.3.11	Disjunct eddy covariance method . . . . .	118
6.3.12	Recommendations for the measurement of turbulent fluxes . . . . .	118
6.4	Evaporation . . . . .	119
6.4.1	Atmometers . . . . .	119
6.4.2	Lysimeters . . . . .	120
6.4.3	Evaporation pans and tanks. . . . .	121
6.4.4	Recommendations for evaporation measurements . . . . .	121
6.5	Soil heat flux. . . . .	122
6.6	Inverse emission flux modelling . . . . .	122
7	Remote sensing methods . . . . .	124
7.1	Basics of remote sensing . . . . .	124
7.2	Active sounding methods . . . . .	129
7.2.1	RADAR. . . . .	129

7.2.2	Windprofilers . . . . .	133
7.2.3	SODAR . . . . .	135
7.2.4	RASS . . . . .	141
7.2.5	LIDAR . . . . .	143
7.2.6	Further LIDAR techniques . . . . .	151
7.3	Active path-averaging methods . . . . .	152
7.3.1	Scintillometers . . . . .	152
7.3.2	FTIR . . . . .	153
7.3.3	DOAS . . . . .	155
7.3.4	Quantum cascade laser . . . . .	156
7.4	Passive methods . . . . .	157
7.4.1	Radiometers . . . . .	157
7.4.2	Photometers . . . . .	159
7.4.3	Infrared-Interferometer . . . . .	160
7.5	Tomography . . . . .	160
7.5.1	Simultaneous Iterative Reconstruction Technique (SIRT) . . . . .	161
7.5.2	Algebraic Reconstruction Technique (ART) . . . . .	161
7.5.3	Smooth Basis Function Minimization (SBFM) . . . . .	162
8	Remote sensing of atmospheric state variables . . . . .	163
8.1	Temperature . . . . .	163
8.1.1	Near-surface temperatures . . . . .	163
8.1.2	Temperature profiles . . . . .	164
8.2	Gaseous humidity . . . . .	167
8.2.1	Integral water vapour content . . . . .	167
8.2.2	Vertical profiles . . . . .	167
8.2.3	Large-scale humidity distribution . . . . .	168
8.3	Wind and turbulence . . . . .	170
8.3.1	Small-scale near-surface turbulence . . . . .	170
8.3.2	Horizontal wind fields . . . . .	171
8.3.3	Vertical wind profiles . . . . .	172
8.3.4	Turbulence profiles . . . . .	176
8.3.5	Cloud winds . . . . .	176
8.3.6	Ionospheric winds . . . . .	176
8.4	Mixing-layer heights . . . . .	177
8.4.1	LIDAR . . . . .	177
8.4.2	SODAR . . . . .	179
8.5	Turbulent fluxes . . . . .	180
8.6	Ionospheric electron densities . . . . .	181
8.7	Recommendations for remote sensing of state variables . . . . .	181
9	Remote sensing of water and ice . . . . .	184
9.1	Precipitation . . . . .	184
9.1.1	RADAR . . . . .	184

9.1.2	Precipitation measurements from satellites . . . . .	186
9.2	Clouds . . . . .	187
9.2.1	Cloud base . . . . .	187
9.2.2	Cloud cover . . . . .	188
9.2.3	Cloud movement . . . . .	188
9.2.4	Water content . . . . .	189
9.3	Recommendations for remote sensing of liquid water and ice . . . . .	189
10	Remote sensing of trace substances . . . . .	190
10.1	Trace gases . . . . .	190
10.1.1	Horizontal path-averaging methods . . . . .	191
10.1.2	Vertical column densities . . . . .	191
10.1.3	Sounding methods . . . . .	192
10.2	Aerosols . . . . .	193
10.2.1	Aerosol optical depths (AOD) . . . . .	194
10.2.2	Sounding methods . . . . .	195
10.3	Recommendations for remote sensing of trace substances . . . . .	197
11	Remote sensing of surface properties . . . . .	198
11.1	Properties of the solid surface . . . . .	199
11.1.1	Surface roughness . . . . .	199
11.1.2	Land surface temperature . . . . .	199
11.1.3	Soil moisture . . . . .	199
11.1.4	Vegetation . . . . .	200
11.1.5	Snow and ice . . . . .	201
11.1.6	Fires . . . . .	201
11.2	Properties of the ocean surface . . . . .	202
11.2.1	Altitudes of the sea surface . . . . .	202
11.2.2	Wave heights . . . . .	202
11.2.3	Sea surface temperature . . . . .	203
11.2.4	Salinity . . . . .	203
11.2.5	Ocean currents . . . . .	204
11.2.6	Ice cover, size of ice floes . . . . .	204
11.2.7	Algae and suspended sediment concentrations . . . . .	204
12	Remote sensing of electrical phenomena . . . . .	205
12.1	Spherics . . . . .	205
12.1.1	Directional analyses . . . . .	205
12.1.2	Distance analyses . . . . .	205
12.2	Optical lightning detection . . . . .	206
13	Outlook on new developments . . . . .	207

Literature.....	209
Subject index .....	231
Appendix: Technical guidelines and standards .....	241
Index to the Appendix .....	255