

Deutsche  
Forschungsgemeinschaft

# **Dynamics and Chemistry of Hydrometeors**

Final Report of the Collaborative  
Research Centre 233 "Dynamik und  
Chemie der Hydrometeore"

Edited by  
Ruprecht Jaenicke

Collaborative Research Centres

 **WILEY-VCH**

**DFG**

# Contents

<b>1</b>	<b>Introduction and Survey</b> . . . . .	<b>1</b>
	<i>Ruprecht Jaenicke</i>	
	 <b>Part I</b>	
	<b>The Field Campaigns of the Collaborative Research Centre 233</b> . . . . .	<b>7</b>
<b>2</b>	<b>Measuring Strategies of the Field Experiments CLEOPATRA, FELDEX and NORDEX of the Collaborative Research Centre</b>	<b>9</b>
	<i>Wolfgang Jaeschke, Norbert Beltz, and Lothar Schütz</i>	
2.1	Introduction – Experiences from Previous Field Experiments	9
2.2	Strategy of Aircraft Measurements During CLEOPATRA . . .	11
2.3	Cloud Experiment FELDEX95 . . . . .	19
2.4	Measuring Strategies During NORDEX96 . . . . .	26
2.5	Summary . . . . .	33
<b>3</b>	<b>Instrumentation of the Do 128 D-IBUF for Airborne Measurements at Different Campaigns of the Collaborative Research Centre</b> . . . . .	<b>35</b>
	<i>Jutta Brinkmann, Volker Dreiling, Berthold Friederich, Rolf Hankers, Sabine Matthias-Maser, and Lothar Schütz</i>	
3.1	Aircraft . . . . .	35
3.2	Atmospheric Aerosol Particle Probing . . . . .	36
3.3	Cloud Water Sampling . . . . .	40
3.4	Conclusion . . . . .	43

<b>Part II</b>	
	<b>Numerical Modelling, Cloud Condensation Nuclei, Wet Deposition, and Boundary Cloud Layers . . . . .</b> 45
<b>4</b>	<b>Theoretical Investigations of the Wet Deposition of Atmospheric Pollutants . . . . .</b> 47 <i>Hans R. Pruppacher, Andrea I. Flossmann, and Sabine C. Wurzler</i>
4.1	Introduction . . . . . 47
4.2	Model Description . . . . . 49
4.3	Some Selected Model Results . . . . . 54
4.4	Summary and Conclusion . . . . . 66
<b>5</b>	<b>On the Relevance of Parameterized Supersaturation Spectra for the CCN Number Concentration . . . . .</b> 71 <i>Fritz Herbert and Ulrike Wacker</i>
<b>6</b>	<b>Explicit Microphysical Simulations of Boundary Layer Clouds over the Sea and over Vegetated Land Surfaces . . . . .</b> 81 <i>Martina Flender, Thomas Trautmann, Christine Wanner, and Wilford Zdunkowski</i>
6.1	Introduction . . . . . 81
6.2	Evolution of Precipitating Boundary Layer Clouds over the Sea . . . . . 82
6.3	Multicomponent Dynamics of Cloud Droplet Spectra . . . . . 88
6.4	The Influence of High Vegetation on the Atmospheric Boundary Layer . . . . . 94
6.5	Concluding Remarks . . . . . 104
<b>7</b>	<b>Theoretical and Numerical Investigations on the Multiphase Chemistry of Stratiform Clouds . . . . .</b> 106 <i>Andreas Bott</i>
7.1	Introduction . . . . . 107
7.2	Description of CHEMISTRA . . . . . 110
7.3	Model Results . . . . . 113
7.4	Summary and Conclusions . . . . . 125

<b>8</b>	<b>The Influence of Aerosols on the Photochemistry of the Atmosphere</b> . . . . .	130
	<i>Paul J. Crutzen, Rolf Sander, and Rainer Vogt</i>	
8.1	Introduction . . . . .	130
8.2	Model Description . . . . .	131
8.3	Halogen Chemistry in the Polluted MBL . . . . .	136
8.4	Halogen Chemistry in the Unpolluted MBL . . . . .	140
8.5	Conclusions . . . . .	144
<b>Part III</b>		
	<b>Experiments and Observations in Campaigns and Independent Separate Projects</b> . . . . .	149
<b>9</b>	<b>A Wind Tunnel Experimental Study of the Wet Deposition of Atmospheric Pollutants</b> . . . . .	151
	<i>Hans R. Pruppacher and Subir K. Mitra</i>	
<b>10</b>	<b>The Chemical Content of Rain- and Fog Drops as a Function of Drop Size</b> . . . . .	166
	<i>Knut Bächmann, Peter Ebert, Antje Mainka, and Birgit Tenberken</i>	
10.1	Introduction . . . . .	166
10.2	Development of Analytical Methods . . . . .	167
10.3	Dependence of the Chemical Solute Concentration on the Radius of Raindrops . . . . .	172
10.4	Investigation of the Solute Concentration of Single Rain-, Cloud and Fog Drops . . . . .	179
10.5	Summary . . . . .	184
<b>11</b>	<b>The Primary Biological Aerosol in a Multiphase System</b> . . . . .	186
	<i>Sabine Matthias-Maser, Sabine Gruber, Berit Bogs, and Ruprecht Jaenicke</i>	
11.1	Significance of PBAP . . . . .	186
11.2	The Size Distribution in the Atmosphere . . . . .	187
11.3	The Size Distribution in Rainwater . . . . .	190
11.4	The Size Distribution in Cloud Water . . . . .	192
11.5	Conclusions . . . . .	193

<b>12</b>	<b>In-Situ Measurements of the Cloud Microphysical Structure Using Holography</b>	196
	<i>Stephan Borrmann, Hermann-Josef Vössing, Eva-Maria Uhlig, and Ruprecht Jaenicke</i>	
12.1	Introduction	196
12.2	Methodology	198
12.3	Analyses and Selected Results	200
12.4	Discussion and Conclusions	206
<b>13</b>	<b>Phase Partitioning of Ammonia and Nitric Acid in the Atmospheric Multiphase System</b>	210
	<i>Jens Peter Dierssen, Wolfgang Jaeschke, Werner Haunold, and Martin Schumann</i>	
13.1	Introduction	210
13.2	Experimental	212
13.3	Investigations of the System Gas-Particle Phase	220
13.4	Investigations of the System Gas-Liquid Phase	229
<b>14</b>	<b>Development and Application of a Mobile Measuring Technique for the Estimation of Empirical S(IV)-Oxidation Rates in Natural Orographic Clouds</b>	238
	<i>Udo Krischke and Wolfgang Jaeschke</i>	
14.1	Introduction	238
14.2	Experimental	239
14.3	Kinetic Studies	244
14.4	Results	250
14.5	General Conclusion	256
<b>15</b>	<b>Particle Distribution, Composition, and Processing during Cloud, Fog, and Rain Cycles</b>	261
	<i>Jutta Brinkmann, Eva-Maria Hackenthal, Martina Krämer, Matthias Schüle, Lothar Schütz, and Cornelia Sprengard-Eichel</i>	
15.1	Introduction	261
15.2	Activation of Aerosol Particles in Convective and Cap Clouds	262

15.3	Distribution and Composition of Particulate Matter in the Liquid Phase . . . . .	268
15.4	Water-Soluble and Insoluble Fractions of Atmospheric Aerosol Particles . . . . .	273
15.5	Cloud Processing of Water-Soluble and Insoluble Substances	278
<b>16</b>	<b>Cloud Condensation Nuclei</b> . . . . . <i>Hans-Walter Georgii, Stefan Bürgermeister, Regina Staubes-Diederich, Bettina Schäfer, Peter Otto, Markus Rex, and Heinz Bingemer</i>	<b>285</b>
16.1	Introduction . . . . .	285
16.2	The Formation and Distribution of CCN in the Marine Atmosphere . . . . .	286
16.3	Experimental . . . . .	287
16.4	Results and Discussion . . . . .	287
16.5	Summary . . . . .	296
<b>17</b>	<b>Airborne Measurements of Condensation Nuclei and Cloud Condensation Nuclei Above the Alpine Foothills</b> . . . . . <i>Bettina Schäfer and Hans-Walter Georgii</i>	<b>298</b>
17.1	Introduction . . . . .	298
17.2	Instrumentation . . . . .	299
17.3	Measurements . . . . .	300
17.4	Conclusion . . . . .	304
<b>18</b>	<b>Development and First Application of a 3-Stage Continuous Flow CCN Counter</b> . . . . . <i>Peter Otto, Hans-Walter Georgii, and Heinz Bingemer</i>	<b>306</b>
18.1	Introduction . . . . .	306
18.2	The New CCN Spectrometer . . . . .	307
18.3	CCN Measurements during NORDEX . . . . .	310

<b>Part IV</b>		
	<b>Laboratory Experiments</b> . . . . .	315
<b>19</b>	<b>Photochemical Processes in the Atmospheric Aqueous Phase: Quantum Yields and Photodissociation Frequencies</b> . . . . .	317
	<i>Peter Warneck</i>	
19.1	Introduction . . . . .	317
19.2	Experimental Techniques . . . . .	318
19.3	Quantum Yields . . . . .	319
19.4	Photodissociation Coefficients . . . . .	328
<b>20</b>	<b>Pathways for the Oxidation of SO<sub>2</sub> and NO<sub>2</sub> in Continental Fair Weather Clouds</b> . . . . .	331
	<i>Peter Warneck</i>	
20.1	Introduction . . . . .	331
20.2	Model Description . . . . .	332
20.3	Results and Discussion . . . . .	336
20.4	Conclusions . . . . .	343
<b>21</b>	<b>Photochemical Formation of Hydrogen Peroxide in Atmospheric Droplets: The Role of Iron, Oxalate, and Trace Metals on the H<sub>2</sub>O<sub>2</sub>-Production</b> . . . . .	346
	<i>Jörg Wohlgemuth, Dagmar Pfäfflin, Wolfgang Jaeschke, Felix Deutsch, Peter Hoffmann, and Hugo M. Ortner</i>	
21.1	Introduction . . . . .	346
21.2	Experimental . . . . .	349
21.3	Results and Discussion . . . . .	351
21.4	Summary and Conclusion . . . . .	360
<b>22</b>	<b>Phase Partitioning and Photochemical Degradation of Pesticides in Hydrometeors</b> . . . . .	363
	<i>Wolfgang Jaeschke, Bettina Gath, and Dagmar Pfäfflin</i>	
22.1	Introduction . . . . .	363
22.2	Phase Partitioning . . . . .	367
22.3	Photochemical Degradation . . . . .	377

<b>23</b>	<b>Mechanistic Studies on the Metal Catalyzed Autoxidation of Sulfur(IV) Oxides</b> . . . . .	387
	<i>Rudi van Eldik</i>	
23.1	Introduction . . . . .	388
23.2	Iron Catalyzed Autoxidation of Sulfur(IV) Oxides . . . . .	388
23.3	Manganese Catalyzed Autoxidation of Sulfur(IV) Oxides . . . . .	394
23.4	Other Metals and Synergistic Effects . . . . .	395
23.5	Other Metal Catalyzed Reactions . . . . .	396
23.6	Conclusions . . . . .	397
<b>24</b>	<b>Mechanism of the Formation of Organic Acids in the Gas Phase</b> . . . . .	401
	<i>Geert K. Moortgat, Osamu Horie, and Peter Neeb</i>	
24.1	Introduction . . . . .	402
24.2	Ozonolysis of Alkenes . . . . .	403
24.3	Peroxy Radical Reactions . . . . .	429
24.4	Field Measurement Campaigns . . . . .	433
24.5	Conclusions and Atmospheric Relevance . . . . .	434
<b>25</b>	<b>Iron in the Atmosphere</b> . . . . .	440
	<i>Peter Hoffmann, Anatolii Nikolai Dedik, Felix Deutsch, Martin Ebert, Martin Hein, Helmut Hofmann, Karl Heinrich Lieser, Hugo Manfred Ortner, Marina Schwanz, Thomas Sinner, Sigrid Weber, Matthias Weidenauer, and Stefan Weinbruch</i>	
25.1	Introduction . . . . .	440
25.2	Experimental . . . . .	441
25.3	Results . . . . .	447
25.4	Discussion . . . . .	453
25.5	Conclusion . . . . .	460
<b>26</b>	<b>Contribution to the Chemistry in Clouds: A Laboratory Study on the Kinetics and Mechanism of the Oxidation of Sulfur and Nitrogen Compounds by Hydroperoxides in Aqueous Phase</b> . . . . .	468
	<i>Klaus J. Wannowius</i>	
26.1	Introduction . . . . .	468
26.2	Preparation and Properties of the Hydroperoxides Applied . . . . .	470



## Contents

---

26.3	Kinetics and Mechanism of Sulfur(IV) Oxidation by Hydroperoxides . . . . .	487
26.4	Kinetics and Mechanism of the Oxidation of Dimethyl Sulfide and Dimethyl Sulfoxide by Hydroperoxides . . . . .	506
26.5	Kinetics and Mechanism of the Oxidation of Nitrous Acid by Hydroperoxides . . . . .	511
26.6	Kinetic Measurements on the Oxidation of Sulfur(IV) by Nitrous Acid . . . . .	513
26.7	General Reaction Pattern for the Oxidation of Sulfur(IV) and Nitrogen(III) Compounds by Hydroperoxides in Aqueous Solution . . . . .	516
26.8	Atmospheric Relevance of the Laboratory Studies . . . . .	519
 <b>Part V</b>		
	<b>Organization, Structure, Members and Participants of the Collaborative Research Centre 233 . . . . .</b>	<b>529</b>
<b>27</b>	<b>Speakers . . . . .</b>	<b>531</b>
<b>28</b>	<b>Employees and Members . . . . .</b>	<b>532</b>
28.1	Employees from 1986 until 1997 . . . . .	532
28.2	Members from 1986 until 1997 . . . . .	540
<b>29</b>	<b>Involved Institutes . . . . .</b>	<b>541</b>
<b>30</b>	<b>Research Projects . . . . .</b>	<b>542</b>
<b>31</b>	<b>Reporters and Reviewers . . . . .</b>	<b>548</b>
<b>32</b>	<b>Guest Scientists . . . . .</b>	<b>550</b>
<b>33</b>	<b>Cooperate Studies with other Research Institutes . . . . .</b>	<b>556</b>
<b>34</b>	<b>Field Experiments . . . . .</b>	<b>563</b>
<b>35</b>	<b>Financial Support by Means of the Deutsche Forschungsgemeinschaft . . . . .</b>	<b>568</b>