

# Contents

<b>About the Author</b>	<b>xi</b>
<b>Foreword</b>	<b>xiii</b>
<b>Preface</b>	<b>xv</b>
<b>Acknowledgements</b>	<b>xvii</b>
<b>List of Abbreviations</b>	<b>xix</b>
<b>1 Introduction</b>	<b>1</b>
<b>2 Meteorological Basics</b>	<b>5</b>
2.1 Why Does the Wind Blow?	5
2.2 The Vertical Structure of the Atmosphere	6
2.3 Atmospheric Variables and Forces	11
2.3.1 <i>Atmospheric Variables</i>	11
2.3.2 <i>Atmospheric Forces</i>	11
2.3.3 <i>Force Balances and the Geostrophic Wind</i>	13
2.4 Length and Time Scales of Atmospheric Flow	16
2.5 Larger-Scale Systems (aka Weather)	18
2.5.1 <i>Mid-Latitudinal Cyclone (Low-Pressure System)</i>	18
2.5.2 <i>Anticyclones (High-Pressure Systems)</i>	20
2.5.3 <i>Hurricanes</i>	22
2.5.4 <i>Monsoons</i>	23
2.5.5 <i>Climatological Circulations</i>	23
2.6 Summary	27
Exercises	28
<b>3 Measurements</b>	<b>31</b>
3.1 Philosophy: What Does it Mean to Measure?	31
3.2 What Do We Measure?	36
3.3 Measurement Theory, or Different Ways to Treat the Data	37
3.3.1 <i>Are We Good to Go?</i>	42
3.4 Practice	43

3.4.1	<i>Measuring</i>	43
3.4.2	<i>Cup Anemometer</i>	46
3.4.3	<i>Wind Vane</i>	48
3.4.4	<i>Sonic Anemometer</i>	50
3.4.5	<i>Hot Wire</i>	51
3.4.6	<i>Pitot Tube</i>	52
3.4.7	<i>Thermometer</i>	52
3.4.8	<i>Barometer</i>	54
3.4.9	<i>Remote Sensing</i>	54
3.4.10	<i>Ceilometer</i>	60
3.4.11	<i>Weather Balloon or the Radiosonde</i>	62
3.4.12	<i>Satellite-Borne Instruments</i>	62
3.5	Summary	64
	Exercises	65
<b>4</b>	<b>The Wind Profile</b>	<b>67</b>
4.1	A Hand-Waving Way of Deriving the Simple Log Profile	67
4.2	Working with the Log Profile	70
4.3	The Power Law	71
4.4	Averaging Times and Other Dependencies	73
4.5	Two Famous Profiles	74
4.6	Zero-Plane Displacement	76
	4.6.1 <i>Dealing with Forests</i>	76
4.7	Internal Boundary Layers	78
4.8	Stability	80
	4.8.1 <i>Stability in the Surface Layer</i>	82
4.9	Monin–Obukhov Theory	85
	4.9.1 <i>Summary of the Different Stability Parameters</i>	87
4.10	Deviations with Height	88
4.11	Connection with Geostrophic Drag Law	89
4.12	Effect of Orography, Obstacles and Thermal Flows on the Profile	89
4.13	Direction Profile	91
4.14	Summary	91
	Exercises	92
<b>5</b>	<b>Local Flow</b>	<b>95</b>
5.1	Local Effects	96
5.2	Orographic Forcing	96
	5.2.1 <i>Analytical Models</i>	98
	5.2.2 <i>Attached Flow: Flow in Simple Terrain</i>	101
	5.2.3 <i>Detached Flow: Flow in Complex Terrain</i>	103
	5.2.4 <i>More Advanced Models for Flow in Complex Terrain</i>	104
5.3	Roughness	107
5.4	Obstacles	109

5.5	Thermally Driven Flows	111
	5.5.1 <i>Sea/Land Breezes</i>	112
	5.5.2 <i>Ana-/Katabatic Winds</i>	113
5.6	Effect of Stability	115
5.7	Summary	115
	Exercises	116
<b>6</b>	<b>Turbulence</b>	<b>117</b>
6.1	What Generates Turbulence?	119
6.2	Reynolds Decomposition and Averaging	119
6.3	Spectra	121
	6.3.1 <i>Understanding Fourier Analysis and Spectra, a Poor Man/Woman's Approach</i>	122
	6.3.2 <i>Standard Types of Spectra</i>	125
6.4	Measuring Turbulence	128
6.5	Turbulent Loads	130
6.6	Extreme Winds	131
6.7	Summary	132
	Exercises	132
<b>7</b>	<b>Wakes</b>	<b>133</b>
7.1	Turbine-to-Turbine Wakes	135
	7.1.1 <i>The NO Jensen Model</i>	136
	7.1.2 <i>The Ainslie Model</i>	139
	7.1.3 <i>Similarity Theory</i>	142
	7.1.4 <i>Effect on Power</i>	145
	7.1.5 <i>Wake Models, Summary</i>	146
7.2	Several Wind Turbines, that is, a Wind Farm	148
7.3	Advanced Topics	148
	7.3.1 <i>Measuring the Wakes</i>	149
	7.3.2 <i>Onshore/Offshore Wakes</i>	150
	7.3.3 <i>Very Large Wind Farms, State of the Art</i>	151
	7.3.4 <i>Wind Farm to Wind Farm Interaction</i>	151
7.4	Summary	151
	Exercises	152
<b>8</b>	<b>Modelling</b>	<b>153</b>
8.1	Modelling and What it Means	153
8.2	Input	154
8.3	Modelling	154
	8.3.1 <i>Numerical Weather Prediction Models</i>	157
	8.3.2 <i>Sub-Grid Processes</i>	161
8.4	Output	162
8.5	Errors	162

---

8.6	So, What is a Good Model?	163
8.7	Chaos	164
	8.7.1 <i>Ensemble Prediction</i>	166
8.8	Summary	166
	Exercises	167
<b>9</b>	<b>Conclusion</b>	<b>169</b>
<b>A</b>	<b>Cheat Sheet</b>	<b>171</b>
<b>B</b>	<b>Answers to Exercises</b>	<b>175</b>
<b>C</b>	<b>Sample Wind Speed and Direction Data</b>	<b>195</b>
	<b>References</b>	<b>197</b>
	<b>Index</b>	<b>201</b>