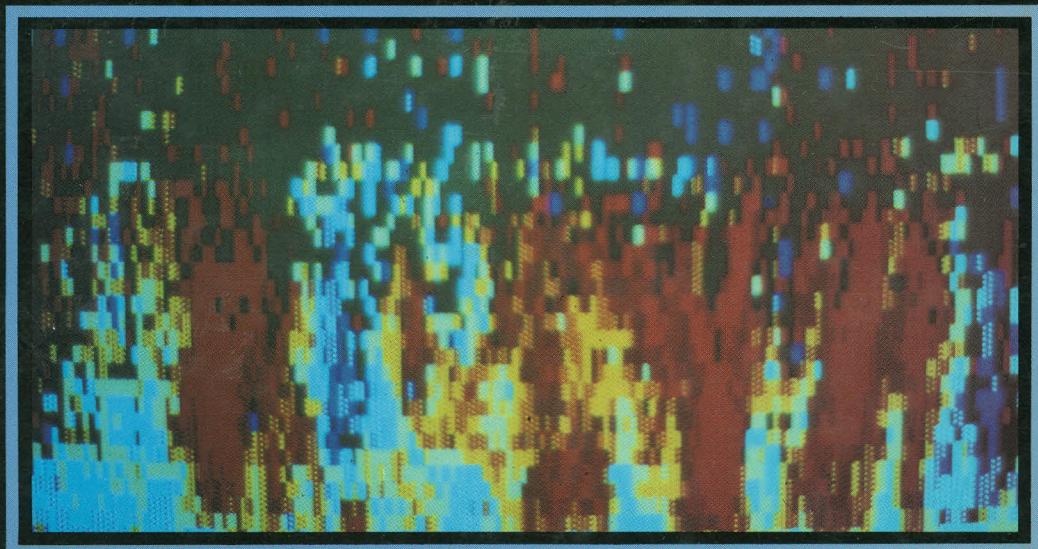


Structure of the Atmospheric Boundary Layer



ZBIGNIEW SORBJAN

PRENTICE HALL ADVANCED REFERENCE SERIES

PHYSICAL AND LIFE SCIENCES



STRUCTURE OF THE ATMOSPHERIC BOUNDARY LAYER

Zbigniew Sorbjan

*Associate Professor of Atmospheric Sciences
The University of Wisconsin, Milwaukee
Adjunct at the Warsaw Polytechnic University, Poland*

**INSTITUT
FOR METEOROLOGIE U. KLIMATOLOGI**
UNIVERSITÄT HANNOVER
HERRENHAUSER STR. 2 • 3000 HANNOVER 21

2791 3464



PRENTICE HALL, Englewood Cliffs, New Jersey 07632

CONTENTS

PREFACE xi

LIST OF SYMBOLS xiii

1 INTRODUCTION 1

- 1.1 General Remarks 1
- 1.2 Historical Notes 9

2 EQUATIONS 12

- 2.1 The Continuity Equation 12
- 2.2 The Navier–Stokes Equations 14
- 2.3 The Equation of State 18
- 2.4 The First Law of Thermodynamics 19
- 2.5 Simplification of the Basic Equations 21
- 2.6 Averaging Procedures 24
- 2.7 Further Simplifications 29

3 STRUCTURE OF TURBULENCE 33

- 3.1 Transition and Instabilities 33
- 3.2 Statistical Description of Turbulence 40
- 3.3 Scales of Turbulent Flow 46
- 3.4 Equations of Higher Moment 48
- 3.5 Budgets of Turbulent Fluxes and Variances 51
 - 3.5.1 Balance of turbulent kinetic energy 51
 - 3.5.2 Heat flux balance 55
 - 3.5.3 Momentum flux balance 61
 - 3.5.4 Temperature and humidity variance and covariance balances 63

4 SIMILARITY 67

- 4.1 Dimensional Analysis and Similarity 67
- 4.2 The Monin–Obukhov Similarity Theory 69
 - 4.2.1 Free convection regime 71
 - 4.2.2 Neutral regime 72
 - 4.2.3 Very stable regime 72
 - 4.2.4 Empirical verification 73
- 4.3 The Rossby Number Similarity Theory 80
- 4.4 Local Similarity Theory 94
 - 4.4.1 Stable boundary layer 96
 - 4.4.2 Convective boundary layer 102

5 SPECTRAL ANALYSIS 125

- 5.1 General Considerations 125
- 5.2 Energy Spectra 125
- 5.3 Cross Spectra 127
- 5.4 Spatial Spectra 128
- 5.5 Spectral Curve-Fitting 134
- 5.6 Spectra and Cospectra in the Surface Layer 137
- 5.7 Spectra and Cospectra in the Mixed Layer 142
- 5.8 Spectra and Cospectra in the Stable Outer Layer 150

6 MODELING 159

- 6.1 General Remarks 159
- 6.2 Integral Models 161
- 6.3 First-Order Closures 168
 - 6.3.1 Flow in the surface layer 171
 - 6.3.2 The Ekman model 174
 - 6.3.3 Effects of baroclinicity 177
 - 6.3.4 Effects of thermal stability 181
 - 6.3.5 Effects of slightly inclined terrain 185
 - 6.3.6 The effects of nonstationarity 190
- 6.4 Nonlocal Closures 199
- 6.5 Higher-Order Closures 201
 - 6.5.1 The momentum flux equation 203
 - 6.5.2 The heat flux equation 208
 - 6.5.3 The temperature variance equation 211
 - 6.5.4 The dissipation rate equation 212
- 6.6 Large Eddy Simulation Models 215

7 DIFFUSION 224

- 7.1 General Considerations 224
- 7.2 The Statistical Theory of Diffusion 226
- 7.3 K-Theory Models 235
- 7.4 Gaussian Models 240
- 7.5 Laboratory and Large Eddy Simulation Experiments 243
- 7.6 Higher-Order Closure Models 249
- 7.7 Monte Carlo Methods 252

8 MEASUREMENTS 257

- 8.1 Introduction 257
- 8.2 Sensors 257
 - 8.2.1 Wind sensors 257
 - 8.2.2 Temperature sensors 262
 - 8.2.3 Measurements of humidity fluctuations 263
 - 8.2.4 Measurements of concentration 264
 - 8.2.5 Static and dynamic characteristics of sensors 265
- 8.3 Platforms 267
 - 8.3.1 Aircraft measurements 267
 - 8.3.2 Balloons 270
- 8.4 Remote Ground-Based Observing Systems 271
 - 8.4.1 Radars 272
 - 8.4.2 Lidars 274
 - 8.4.3 Sodars 275
- 8.5 Averaging of Measured Quantities 280
- 8.6 Major Field Experiments 283
 - 8.6.1 The 1953 Great Plains experiment 283
 - 8.6.2 The 1967 Wangara experiment 283
 - 8.6.3 The 1968 Kansas experiment 284
 - 8.6.4 The 1973 Minnesota experiment 285
- Epilogue 287

APPENDIX 289

- A.1 Fourier Analysis 289
- A.2 The Sweeping Method 291
- A.3 Vector Operators 292

REFERENCES 295**INDEX 309**