



An introduction to
**DYNAMIC
METEOROLOGY**

F O U R T H E D I T I O N

James R. Holton

CD-ROM



included

AN INTRODUCTION TO DYNAMIC METEOROLOGY

Fourth Edition

JAMES R. HOLTON
Department of Atmospheric Sciences
University of Washington
Seattle, Washington

D III 87c

DK: 551.511.3, 551.51B.1,

353/4231 INSTITUT
FÜR METEOROLOGIE U. KLIMATOLOGIE
UNIVERSITÄT HANNOVER
HERRENHÄUSER STR. 2 - 30419 HANNOVER



ELSEVIER
ACADEMIC
PRESS

Amsterdam Boston Heidelberg London New York Oxford Paris
San Diego San Francisco Singapore Sydney Tokyo

CONTENTS

PREFACE	xi
---------	----

Chapter 1 Introduction

1.1 The Atmospheric Continuum	1
1.2 Physical Dimensions and Units	2
1.3 Scale Analysis	4
1.4 Fundamental Forces	4
1.5 Noninertial Reference Frames and “Apparent” Forces	10
1.6 Structure of the Static Atmosphere	19
Problems	24
MATLAB Exercises	26
Suggested References	27

Chapter 2 Basic Conservation Laws

2.1 Total Differentiation	29
2.2 The Vectorial Form of the Momentum Equation in Rotating Coordinates	33
2.3 Component Equations in Spherical Coordinates	34
2.4 Scale Analysis of the Equations of Motion	38
2.5 The Continuity Equation	42
2.6 The Thermodynamic Energy Equation	46
2.7 Thermodynamics of the Dry Atmosphere	49

Problems	54
MATLAB Exercises	55
Suggested References	56
Chapter 3 Elementary Applications of the Basic Equations	
3.1 Basic Equations in Isobaric Coordinates	57
3.2 Balanced Flow	60
3.3 Trajectories and Streamlines	68
3.4 The Thermal Wind	70
3.5 Vertical Motion	75
3.6 Surface Pressure Tendency	77
Problems	79
MATLAB Exercises	83
Chapter 4 Circulation and Vorticity	
4.1 The Circulation Theorem	86
4.2 Vorticity	91
4.3 Potential Vorticity	95
4.4 The Vorticity Equation	100
4.5 Vorticity in Barotropic Fluids	106
4.6 The Baroclinic (Ertel) Potential Vorticity Equation	108
Problems	111
MATLAB Exercises	113
Suggested References	114
Chapter 5 The Planetary Boundary Layer	
5.1 Atmospheric Turbulence	116
5.2 Turbulent Kinetic Energy	120
5.3 Planetary Boundary Layer Momentum Equations	122
5.4 Secondary Circulations and Spin Down	131
Problems	136
MATLAB Exercises	137
Suggested References	138
Chapter 6 Synoptic-Scale Motions I: Quasi-geostrophic Analysis	
6.1 The Observed Structure of Extratropical Circulations	140
6.2 The Quasi-Geostrophic Approximation	146
6.3 Quasi-geostrophic Prediction	155
6.4 Diagnosis of the Vertical Motion	164
6.5 Idealized Model of a Baroclinic Disturbance	174
Problems	176
MATLAB Exercises	178
Suggested References	180

Chapter 7 Atmospheric Oscillations: Linear Perturbation Theory

7.1	The Perturbation Method	183
7.2	Properties of Waves	183
7.3	Simple Wave Types	188
7.4	Internal Gravity (Buoyancy) Waves	196
7.5	Gravity Waves Modified by Rotation	204
7.6	Adjustment to Geostrophic Balance	208
7.7	Rosby Waves	213
	Problems	220
	MATLAB Exercises	224
	Suggested References	226

Chapter 8 Synoptic-Scale Motions II: Baroclinic Instability

8.1	Hydrodynamic Instability	229
8.2	Normal Mode Baroclinic Instability: A Two-Layer Model	230
8.3	The Energetics of Baroclinic Waves	242
8.4	Baroclinic Instability of a Continuously Stratified Atmosphere	250
8.5	Growth and Propagation of Neutral Modes	260
	Problems	264
	MATLAB Exercises	266
	Suggested References	267

Chapter 9 Mesoscale Circulations

9.1	Energy Sources for Mesoscale Circulations	269
9.2	Fronts and Frontogenesis	269
9.3	Symmetric Baroclinic Instability	279
9.4	Mountain Waves	284
9.5	Cumulus Convection	289
9.6	Convective Storms	298
9.7	Hurricanes	304
	Problems	309
	MATLAB Exercises	310
	Suggested References	311

Chapter 10 The General Circulation

10.1	The Nature of the Problem	314
10.2	The Zonally Averaged Circulation	316
10.3	The Angular Momentum Budget	329
10.4	The Lorenz Energy Cycle	337
10.5	Longitudinally Dependent Time-Averaged Flow	343
10.6	Low-Frequency Variability	349
10.7	Laboratory Simulation of the General Circulation	354
10.8	Numerical Simulation of the General Circulation	360
	Problems	366

MATLAB Exercises	368
Suggested References	369
Chapter 11 Tropical Dynamics	
11.1 The Observed Structure of Large-Scale Tropical Circulations	371
11.2 Scale Analysis of Large-Scale Tropical Motions	387
11.3 Condensation Heating	391
11.4 Equatorial Wave Theory	394
11.5 Steady Forced Equatorial Motions	400
Problems	403
MATLAB Exercises	404
Suggested References	406
Chapter 12 Middle Atmosphere Dynamics	
12.1 Structure and Circulation of the Middle Atmosphere	408
12.2 The Zonal-Mean Circulation of the Middle Atmosphere	411
12.3 Vertically Propagating Planetary Waves	421
12.4 Sudden Stratospheric Warmings	424
12.5 Waves in the Equatorial Stratosphere	429
12.6 The Quasi-biennial Oscillation	435
12.7 Trace Constituent Transport	440
Problems	445
MATLAB Exercises	446
Suggested References	447
Chapter 13 Numerical Modeling and Prediction	
13.1 Historical Background	449
13.2 Filtering Meteorological Noise	450
13.3 Numerical Approximation of the Equations of Motion	452
13.4 The Barotropic Vorticity Equation in Finite Differences	462
13.5 The Spectral Method	464
13.6 Primitive Equation Models	470
13.7 Data Assimilation	475
13.8 Predictability and Ensemble Prediction Systems	481
Problems	485
MATLAB Exercises	487
Suggested References	490

CONTENTS	ix
Appendix A Useful Constants and Parameters	491
Appendix B List of Symbols	493
Appendix C Vector Analysis	498
Appendix D Moisture Variables	501
Appendix E Standard Atmosphere Data	504
Appendix F Symmetric Baroclinic Oscillations	506
ANSWERS TO SELECTED PROBLEMS	509
BIBLIOGRAPHY	513
INDEX	519
INTERNATIONAL GEOPHYSICS SERIES	531