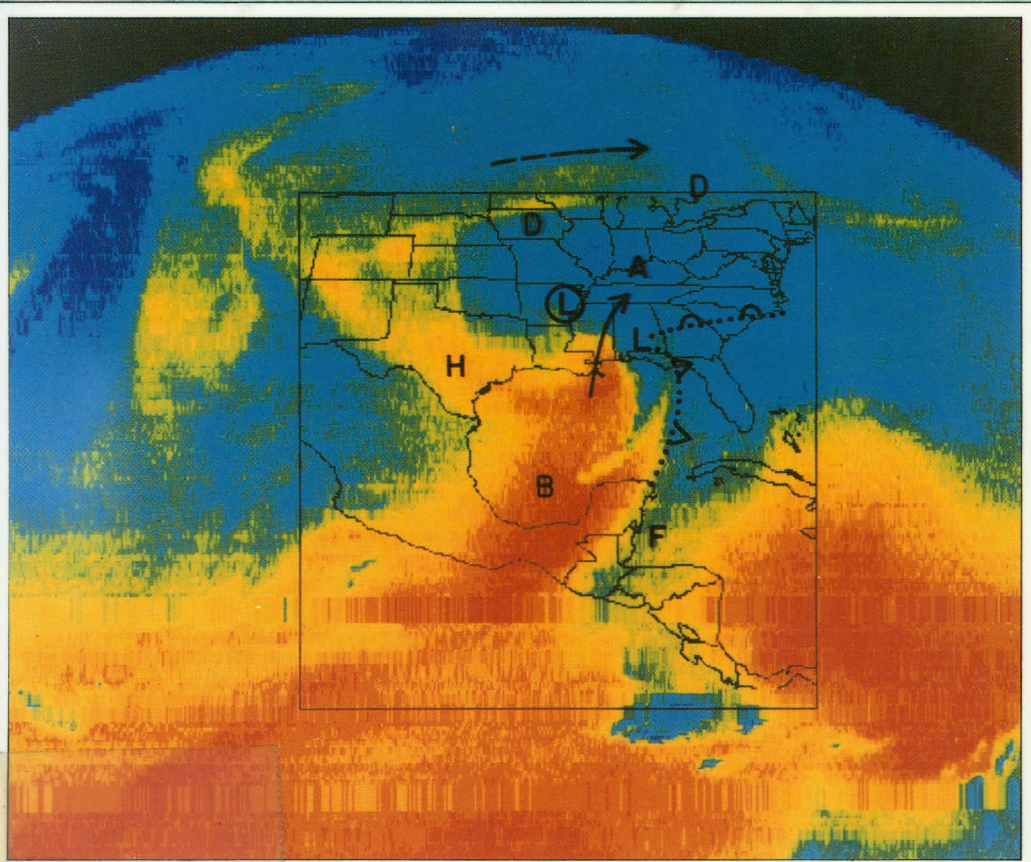


MID-LATITUDE WEATHER SYSTEMS



T.N. CARLSON

ROUTLEDGE
R

MID-LATITUDE WEATHER SYSTEMS

TOBY N. CARLSON

*Professor of Meteorology
The Pennsylvania State University*



London and New York

Contents

Dedication	page vii
Preface	ix
Acknowledgements	xv
1 Introduction and mathematical definitions	1
1.1 Introduction	1
1.2 Basic units and equations	3
Problems	25
Further reading	26
2 Vorticity and vertical motion	27
2.1 Vorticity	28
2.2 Vertical motion and continuity	44
Problems	51
Further reading	51
3 The vorticity and thermodynamic equations	52
3.1 The vorticity equation	52
3.2 The thermodynamic equation	68
Problems	77
Further reading	78
4 Quasi-geostrophic forcing of vertical motions and surface pressure tendency	79
4.1 Derivation of the quasi-geostrophic omega equation	80
4.2 A simple model for ω_d	86
4.3 Pressure tendency equation	93
4.4 An example of cyclogenesis as forced by the upper flow pattern	102
Problems	105
Further reading	107
5 Quasi-geostrophic energetics	108
5.1 Available potential energy	111
5.2 Energy transformation; eddy and zonal components	115

CONTENTS

5.3	Energetics of disturbances and the general circulation: a brief overview	118
5.4	The energy cycle; eddy and zonal energy exchanges	120
5.5	Barotropic growth and decay of waves	126
	Problems	128
	Further reading	129
6	Evolution and motion of mid-tropospheric waves: barotropic viewpoint	130
6.1	Conservation of absolute vorticity; constant absolute vorticity	131
6.2	Equivalent barotropic model	139
6.3	Vertical motion and vorticity advection in the equivalent barotropic system	142
6.4	Illustrations of 500 mb steering	147
	Problems	155
	Further reading	157
7	Simple dynamic models of wave/cyclone development: baroclinic viewpoint	158
7.1	Baroclinic development at 500 mb: a two-parameter model	158
7.2	Large-scale developmental changes that occur at 500 mb during cyclogenesis	168
7.3	An illustration of coupled surface and 500 mb development	171
	Problems	175
	Further reading	180
8	Alternative expressions for vertical motion and divergence	181
8.1	Sutcliffe development theorem	182
8.2	Petterssen's development equation	185
8.3	The Trenberth approximation	186
8.4	Mathematical unity of quasi-geostrophic forcing	191
	Problems	191
	Further reading	191
9	Some additional dynamic aspects of the baroclinic wave/cyclone: effects of friction, terrain and diabatic heating	193
9.1	The role of friction in cyclogenesis and cloud formation	193
9.2	Terrain-forced vertical motions: the effects of orography	201
9.3	Diabatic forcing and convective heating	211
	Problems	219
	Further reading	219
10	The evolution of cyclones	221
10.1	Cyclone climatology	224

CONTENTS

10.2	Evolution of the wave/cyclone during cyclogenesis	226
10.3	Cyclone movement	233
10.4	The mature cyclone: a satellite view	234
10.5	Changes occurring at the tropopause	241
10.6	Explosive cyclogenesis: coastal storms	244
10.7	Polar lows	257
	Problems	262
	Further reading	262
11	Optimum wavelength and growth rate of baroclinic waves	265
11.1	A simple two-level model of cyclone growth in a baroclinic atmosphere	268
11.2	Wavelength dependence for cyclone growth	275
11.3	Summary: fundamental influences on cyclogenesis	281
	Problems	282
	Further reading	282
12	Airflow through mid-latitude synoptic-scale disturbances	284
12.1	Isentropic analysis	285
12.2	The frozen-wave approximation	294
12.3	Relative wind isentropic flow through baroclinic waves	297
12.4	Cyclogenesis: the cold conveyor belt	316
12.5	Parcel theory analog for conveyor belts	325
12.6	Downstream development	330
12.7	Blocking	334
	Problems	337
	Further reading	340
13	Kinematics of surface fronts	342
13.1	Synoptic aspects of surface fronts	343
13.2	Frontogenesis and the kinematics of fronts	350
13.3	The deformation vector	359
13.4	Deficiencies in the kinematic explanation of frontogenesis	361
	Problems	362
	Further reading	363
14	Ageostrophic motion and the dynamics of fronts	364
14.1	The four-quadrant model	366
14.2	Isallobaric wind	369
14.3	How a front is made	371
14.4	The Sawyer–Eliassen Q -vector: equations governing transverse/vertical motion	378
14.5	Graphical interpretation: the left-hand rule	393
14.6	A numerical simulation of frontogenesis	397

CONTENTS

14.7	Quasi-geostrophic omega equation	398
	Problems	402
	Further reading	403
15	Upper-tropospheric fronts and jet streaks	404
15.1	Transverse/vertical circulations along jet streaks	406
15.2	Confluent jets	407
15.3	Variants of the four-quadrant model	410
15.4	Movement of jet streaks	413
15.5	Coupled jet streaks	417
15.6	Stratosphere-troposphere exchanges: tropopause folding	420
15.7	Tropopause folding and cyclogenesis	431
15.8	Models of tropopause folding and upper-tropospheric frontogenesis	436
15.9	Turbulence and mixing in upper-level frontal zones	441
	Problems	444
	Further reading	445
16	Mid-tropospheric fronts, elevated mixed layers and the severe storm environment	448
16.1	The elevated mixed layer	449
16.2	Origins of elevated mixed layers	450
16.3	Illustrations of airflow within and below elevated mixed layers	458
16.4	Climatology of the lid	461
16.5	The elevated mixed layer front	464
16.6	Severe local convection and elevated mixed layers	464
16.7	Large-scale aspects of the elevated mixed layer	467
16.8	Ageostrophic motion along the lid edge	473
16.9	Differential soil moisture and static stability	476
	Problems	480
	Further reading	480
	Appendix: list of symbols	482
	Selected references, by subject area	487
	Index	499