Contents

Pı	refac	е	x
1	Intr	roductory remarks	1
2	Sim	ple energy balance climate models	5
	Exe	rcises	17
3	Effe	ect of transport on composition.	19
	3.1	General considerations	19
		3.1.1 Equations of continuity	24
	3.2	4-box transport model	25
	Exe	rcise	30
4	'Sta	atics' of a rotating system	33
	4.1	Geostrophy and hydrostaticity	33
	4.2	Scale height and thickness	37
	4.3	Thermal wind and pressure	
		coordinates	39
	Exe	rcises	41
5	Obs	served atmospheric structures	45
	5.1	General remarks	45
	5.2	Daily and monthly maps	49
	5.3	Zonal means	67
	0.0	5.3.1 Seasonal means	67
		5.3.2 Zonal inhomogeneity and rôle of analysis	72
		5.3.3 Middle atmosphere	78
		5 3 4 Quasi-hiennial and semiannual oscillations	78

		5.3.5 Stratospheric sudden warmings 84					
	5.4	Short period phenomena					
6	Equ	ations of motion 91					
	6.1	Coordinate systems and					
		conservation					
	6.2	Newton's second law – for fluids					
	6.3	Energy					
	6.4	\vec{K} and σ_{ij}					
	6.5	Equations of state					
	6.6	Rotating coordinate frame					
	6.7	Spherical coordinates					
	6.8	Scaling					
	6.9	Hydrostaticity					
	6.10	Geostrophy					
	Exer	cises					
7	Symmetric circulation models 109						
	7.1	Historical review					
	7.2	Held and Hou calculations					
		7.2.1 Hide's theorem and its application					
		7.2.2 Simplified calculations					
		7.2.3 Comparison of simple and numerical results 130					
	7.3	Summary and difficulties					
		7.3.1 Remarks on cumulus convection					
		7.3.2 Preliminary summary					
	7.4	Asymmetry about the equator					
	Exer	cises					
8	Inte	rnal Gravity Waves: Basics 149					
Ü	8.1	Some general remarks on waves					
	0.1	8.1.1 Group and signal velocity					
	8.2	Heuristic theory (no rotation)					
	8.3	Linearization					
	8.4	Eliassen-Palm theorems					
	0.4	8.4.1 Super-rotation of Venus' atmosphere					
	8.5	Energy flux					
	8.6	A remark about 'eddies'					
	0.0	11 10mm about cautes 100					

Contents	vii
0.0110.0110.0	V 13

	8.7	Formal	mathematical treatment
		8.7.1	Shallow water limit and internal modes 167
		8.7.2	Equivalent depth
		Equiva	lent depths
	8.8	Numer	ical algorithm
		8.8.1	Specifying Basic States
		8.8.2	Finite Difference Approximations
		8.8.3	Numerical Algorithm
		8.8.4	Testing the Algorithm
	Exer	cises	
9	Δtm	osnher	ric tides 175
U	9.1	-	and the 'scientific method'
	9.2	-	ations
	9.3		198
	0.0	9.3.1	Laplace's tidal equation
			Vertical structure equation
		9.3.3	Simplified Laplace's tidal equation
		9.3.4	Overall procedure
		9.3.5	Semidiurnal and diurnal solutions – Hough functions . 208
		9.3.6	Lunar semidiurnal tide
	Exer		
10	Vari	ahla R	asic States 217
10			Basic States)
	10.1	WKBJ	analysis
	10.2	Critica	l level behavior
		10.2.1	Richardson number
		10.2.2	Conditions for absorption
		10.2.3	Linear and nonlinear limits
	10.3	Dampi	ng and momentum
		deposit	ion
		10.3.1	Violation of the second Eliassen-Palm
			theorem
	10.4	Quasi-l	piennial oscillation
	Exer	cises	

11	Ross	sby waves 23	3
	11.1	Shallow water equations	3
	11.2	Rossby waves	6
		11.2.1 Planetary scale internal stationary waves	9
		11.2.2 Free oscillations	
	11.3	Remark on Kelvin waves: The case of $v' \equiv 0$	
		cises	
12	Vort	cicity and quasi-geostrophy 24	5
	12.1	Preliminary remarks	5
		12.1.1 Interpretation of vorticity	5
	12.2	Vorticity in Shallow Water	7
		12.2.1 Filtered Rossby waves	9
	12.3	Quasi-geostrophic shallow	
		water theory	1
		12.3.1 Rossby radius	
		12.3.2 Rossby number expansion	
	12.4	Quasi-geostrophy in a stratified,	
		compressible atmosphere	6
		12.4.1 Pseudo potential vorticity	
	Exer	cises	
13	The	generation of eddies by instability 26	1
		Remarks	1
		Instability	
		13.2.1 Buoyant convection	
		13.2.2 Rayleigh–Benard instability	
		13.2.3 Convective adjustment and gravity wave breaking 26	
		13.2.4 Reversal of mesopause temperature	
		gradient	6
		13.2.5 Kelvin-Helmholtz instability	
		13.2.6 Radiating and growing solutions	
	13.3	Instability of meteorological	
		disturbances; baroclinic and	
		barotropic instability	9
		13.3.1 A necessary condition for instability	
	13.4	The Kelvin-Orr mechanism	
		Two-level baroclinic model 28	

Contents	ix
----------	----

13.6 Climate	4
13.7 Geometric stabilization	8
13.8 Energetics of meteorological	
disturbances	9
13.9 Available potential energy	4
13.10Some things about energy to think about	7
Exercises	9
Postscript 30	1
References 30	3