



Introduction to Circulating Atmospheres

Ian N. James

CAMBRIDGE ATMOSPHERIC AND
SPACE SCIENCE SERIES

Introduction to circulating atmospheres

Ian N. James

University of Reading



CAMBRIDGE
UNIVERSITY PRESS

Contents

<i>Preface</i>	page xi
<i>Notation</i>	xix
1 The governing physical laws	1
1.1 The first law of thermodynamics	1
1.2 Conservation of matter	5
1.3 Newton's second law of motion	6
1.4 Coordinate systems	9
1.5 Hydrostatic balance and its implications	10
1.6 Vorticity	14
1.7 The quasi-geostrophic approximation	16
1.8 Potential vorticity and the omega equation	21
1.9 Ertel's potential vorticity	24
1.10 Problems	26
2 Observing and modelling global circulations	28
2.1 Averaging the atmosphere	28
2.2 The global observing network	32
2.3 Numerical weather prediction models	39
2.4 The analysis-forecast cycle	45
2.5 Global circulation models	49
2.6 Problems	59
3 The atmospheric heat engine	62
3.1 Global energy balance	62
3.2 Local radiative balance	66
3.3 Thermodynamics of fluid motion	69
3.4 Observed atmospheric heating	73
3.5 Problems	77
4 The zonal mean meridional circulation	80
4.1 Observational basis	80

4.2	The Held–Hou model of the Hadley circulation	85
4.3	More realistic models of the Hadley circulation	93
4.4	Zonal mean circulation in midlatitudes	100
4.5	A Lagrangian view of the meridional circulation	107
4.6	Problems	110
5	Transient disturbances in the midlatitudes	112
5.1	Timescales of atmospheric motion	112
5.2	The structure of transient eddies	117
5.3	Atmospheric energetics	128
5.4	Theories of baroclinic instability	138
5.5	Baroclinic lifecycles and high frequency transients	153
5.6	Problems	161
6	Wave propagation and steady eddies	164
6.1	Observations of steady eddies	164
6.2	Barotropic model	171
6.3	Application to observed steady eddies	184
6.4	Vertical propagation of Rossby waves	190
6.5	The Eliassen–Palm flux	196
6.6	Eliassen–Palm fluxes and baroclinic lifecycles	201
6.7	Problems	204
7	Three-dimensional aspects of the global circulation	208
7.1	Zonal variations in the tropics	208
7.2	Monsoon circulations	217
7.3	Midlatitude storm zones and jets	220
7.4	Interactions between transient and steady eddies	230
7.5	The global transport of water vapour	243
7.6	Problems	253
8	Low frequency variability of the circulation	255
8.1	Low frequency transients	255
8.2	Teleconnection patterns	256
8.3	Stratospheric oscillations	271
8.4	Intraseasonal oscillation	277
8.5	The Southern Oscillation	281
8.6	Blocking of the midlatitude flow	286
8.7	Chaos and ultra low frequency variability	291
8.8	Problems	300
9	The stratosphere	302
9.1	The seasonal cycle of the stratospheric circulation	302
9.2	Wave propagation and mean flow interactions	312
9.3	The production and transport of ozone	321

9.4	Exchange of matter across the tropopause	331
9.5	Problems	340
10	Planetary atmospheres and other fluid systems	342
10.1	Major influences on planetary circulations	342
10.2	Terrestrial circulations	350
10.3	Slowly rotating atmospheres	359
10.4	The atmospheric circulation of the giant planets	366
10.5	Large scale ocean circulation	373
10.6	Laboratory systems	376
10.7	Problems	384
<i>Appendix</i>	Solutions to Problems	386
<i>Bibliography</i>		407
<i>References</i>		412
<i>Index</i>		417