

Contents

Part I Waves and Imbalance

On spontaneous imbalance and ocean turbulence: generalizations of the Paparella–Young epsilon theorem 3

Michael E. McIntyre

1	Introduction	3
2	Spontaneous imbalance	5
3	Epsilon theorems for realistic ocean models	7
4	Specific examples	11
5	Concluding remarks	13
	References	14

Inertia-gravity-wave generation: a geometric-optics approach 17

J. M. Aspden and J. Vanneste

1	Introduction	17
2	Geometric-optics approach	18
3	Applications to simple flows	21
	3.1 Horizontal strain and vertical shear	21
	3.2 Elliptical flow	21
	3.3 Dipole	22
	3.4 Random-strain models	23
4	Discussion	24
	References	25

Parallels between stratification and rotation in hydrodynamics, and between both of them and external magnetic field in magnetohydrodynamics, with applications to nonlinear waves 27

S. Medvedev and V. Zeitlin

1	Introduction	27
2	Models	28
	2.1 2D stratified Boussinesq equations	28
	2.2 2.5D rotating Euler equations	28

2.3	2D magnetohydrodynamics	29
3	Similarity between models I: waves and structures	30
3.1	Linear waves	30
3.2	Structures: nonlinear waves/vortices	31
4	Similarity between models II: geometry	32
4.1	Hamiltonian structure	32
4.2	Geometry of the phase space and nonconstrained dynamical variables	33
4.3	Casting PB to the canonical form	33
5	Triad and quartet wave interactions and wave turbulence (WT) ...	34
5.1	The WT algorithm	34
5.2	Known situations leading to get-it-by-hand solutions for stationary energy spectra in WT	35
5.3	WT: decay spectra for gravity, gyroscopic and Alfvén waves	35
5.4	WT: non-decay spectra for gravity and gyroscopic waves	36
6	Conclusions	36
	References	37
	Generation of an internal tide by surface tide/eddy resonant interactions .	39
	M.-P. Lelong and E. Kunze	
1	Introduction	39
2	Problem definition	40
2.1	Governing equations	40
2.2	Wave-triad interactions	41
2.3	Multiple-scale analysis	42
3	Numerical simulations	45
4	Conclusions	48
	References	49
	Generation of harmonics and sub-harmonics from an internal tide in a uniformly stratified fluid: numerical and laboratory experiments	51
	Ivane Pairaud, Chantal Staquet, Joël Sommeria and Mahdi M. Mahdizadeh	
1	Introduction	51
2	Experimental set-ups	52
2.1	Laboratory experiments	52
2.2	Numerical simulations	54
3	Emission of the wave beam	55
4	Spatial structure of the wave beam	56
5	Parametric instability of the wave beam	57
6	Generation of harmonics	59
7	Conclusion	59
	References	60

Deep ocean mixing by near-inertial waves	63
Victor I. Shrira and William A. Townsend	
1 Introduction	64
2 Basic Equations and WKB	64
3 Mixed Bottom Layer	69
4 Discussion	71
References	72

Part II Turbulence and Convection

Eddies and Circulation: Lessons from Oceans and the GFD Lab	77
Peter B. Rhines	
1 Introduction	77
2 Deep pathways in the oceanic overturning circulation	82
3 Eddies and Rossby waves in the upper ocean	83
4 Notes from the GFD Lab	89
5 Conclusion	91
References	92

Observations on Rapidly Rotating Turbulence	95
P A Davidson, P J Staplehurst and S B Dalziel	
1 Introduction	95
2 How Columnar Eddies Form at Low Ro	97
3 The Experimental Evidence at $Ro \sim 1$	100
4 Why Linear Behaviour at $Ro \sim 1$?	101
5 Why a Cyclone-Anticyclone Asymmetry?	101
6 The Rate of Energy Decay	102
References	103

Equilibration of Inertial Instability in Rotating Flow	105
Daan D.J.A. van Sommeren, George F. Carnevale, Rudolf C. Kloosterziel and Paolo Orlandi	
1 Introduction	105
2 Pure Barotropic Instability	107
3 Pure Inertial Instability	109
4 Full 3D Simulation vs. Prediction	110
5 Discussion	114
References	114

Quasigeostrophic and stratified turbulence in the atmosphere	117
Peter Bartello	
1 Introduction	117
2 Divergent and geostrophic modes	120
3 The numerical configuration	121
4 Results	123
5 Conclusions	126

References	128
A Perspective on Submesoscale Geophysical Turbulence	131
James C. McWilliams	
1 The Dynamical Regime of Submesoscale Turbulence	131
2 The Frontogenetic Route	133
3 Other Submesoscale Generation Routes	136
4 Stratified, Non-Rotating Turbulence	139
5 Summary	140
References	140
Spectra and Distribution Functions of Stably Stratified Turbulence	143
Jackson R. Herring & Yoshifumi Kimura	
1 Equations of Motion and their Economical Representation	143
2 Some Historical Comments	145
3 More Recent Numerical Results	147
4 Interpretation of DNS	150
5 Concluding Comments	151
References	153
Modeling mixing in two-dimensional turbulence and stratified fluids	155
Antoine Venaille and Joel Sommeria	
1 Introduction	155
2 An analogy between statistical mechanics of 2D flows and density stratified fluids	157
2.1 Statistical mechanics of 2D flows	157
2.2 Statistical mechanics of stratified fluids	158
3 Relaxation toward statistical equilibrium	161
4 Dissipation of density fluctuations by turbulent cascade	162
5 A simple example: mixing of a two layer stratified fluid	163
6 Coupling the model with an equation for the kinetic energy	165
7 Conclusion and perspectives	166
References	167
The solar tachocline: a study in stably stratified MHD turbulence	169
Steven Tobias	
1 Introduction	169
2 The Solar Tachocline	170
2.1 Properties of the solar tachocline	170
2.2 Why is the tachocline there — and so thin?	172
3 Simplified models of stratified MHD turbulence	174
3.1 The parameter regime	174
3.2 A hierarchy of models	174
3.3 Formation of jets on a magnetised β -plane	175
4 Future directions	176
References	177

Some Unusual Properties of Turbulent Convection and Dynamos in Rotating Spherical Shells 181

F. H. Busse and R. D. Simitev

1	Introduction	181
2	Mathematical formulation of the problem and methods of solution	182
3	Convection in rotating spherical shells	185
4	Chaotic convection	186
5	Distinct turbulent dynamos at identical parameter values	189
6	Concluding remarks	192
	References	192

Part III Instability and Vortex Dynamics

Zigzag instability of the Kármán vortex street in stratified and rotating fluids 197

Axel Deloncle, Paul Billant and Jean-Marc Chomaz

1	Introduction	197
2	Problem formulation	198
	2.1 Pair of vortices in a stratified and rotating fluid	198
	2.2 Kármán vortex street in a stratified and rotating fluid	200
3	Results	202
4	Conclusion	205
	References	205

Instabilities of a columnar vortex in a stratified fluid 207

Patrice Meunier, Nicolas Boulanger, Xavier Riedinger and Stéphane Le

Dizès

1	Introduction	207
2	A Gaussian vortex in a stratified fluid	208
3	Instabilities of a tilted vortex	209
	3.1 Spatial structure of a tilted vortex	209
	3.2 Tilt-induced instabilities	210
	3.3 Consequences	212
4	Radiative instability	212
	4.1 Linear stability analysis	212
	4.2 Experimental evidence?	213
5	Conclusion	214
	References	215

Geostrophic vortex alignment in external shear or strain 217

Xavier Perrot, Xavier Carton and Alan Guillou

1	Introduction	217
2	Physical configuration and model equations	218
3	Evolution of two point-vortices in external strain and rotation	219
4	Nonlinear regimes of finite-area vortices with background strain and rotation	223

5	Conclusions	225
	Appendix: Melnikov Theory	226
	References	227
Equilibrium States of Quasi-geostrophic Point Vortices		229
T. Miyazaki, H. Kimura and S. Hoshi		
1	Introduction	229
2	Quasi-geostrophic Approximation and Equations of Motion	230
3	Equilibrium States of Quasi-geostrophic Point Vortices	232
4	Maximum Entropy Theory	235
4.1	Zero Inverse Temperature State	235
4.2	Positive and Negative Temperature States	236
4.3	Patch Model	236
5	Summary	238
	References	238
Part IV Jets: Formation and Structure		
The structure of zonal jets in shallow water turbulence on the sphere		243
R. K. Scott		
1	Introduction	243
2	Jet undulations	245
3	The potential vorticity staircase	247
4	Equatorial superrotation	248
5	Open questions: the nature of forcing and dissipation	250
	References	251
Jet formation in decaying two-dimensional turbulence on a rotating sphere		253
Shigeo Yoden, Yoshi-Yuki Hayashi, Keiichi Ishioka, Yuji Kitamura, Seiya Nishizawa, Sin-ichi Takehiro, and Michio Yamada		
1	Introduction	254
2	Parameter sweep experiments (Hayashi et al., 2007)	255
3	Ensemble experiments (Kitamura and Ishioka, 2007)	258
4	Summary and Discussion	260
	References	262
Triple cascade behaviour in QG and drift turbulence and generation of zonal jets		265
Sergey Nazarenko, Brenda Quinn		
1	Introduction and the model	265
2	Charney-Hasegawa-Mima model	267
3	Conservation of energy and enstrophy	268
4	Conservation of zonostrophy	268
5	Triple cascade behaviour	270
5.1	Dual cascades in 2D Navier-Stokes turbulence	270

5.2	Triple cascades in CHM turbulence	271
5.3	Alternative argument for zonation	273
6	Numerical study	275
6.1	Centroids	276
6.2	Settings for the weakly nonlinear and the strongly nonlinear runs	277
6.3	Weakly nonlinear case	277
6.4	Strongly nonlinear case	279
7	Summary	281
	References	286
	The HyperCASL algorithm	289
	David G. Dritschel and Jérôme Fontane	
1	Introduction	289
2	Brief Description of the Numerical Algorithm	290
2.1	Fully Lagrangian Advection	291
2.2	Transfer of Diabatic Forcing to Point Vortices	292
3	An Example: A Diabatically-Forced Jet	293
4	Conclusions and Future Extensions	296
	References	297