xii		
Henry Stommel xiv	The Scientific Work of Henry Stommel Arnold B. Arons	xiv
	A Theoretical Model of Henry Stommel George Veronis	xix
	Notes Related to Stommel's Early Years in Woods Hole <i>Raymond B. Montgomery</i>	xxiv
	Henry Stommel G.E.R. Deacon	xxv
Life and Work of	Henry Stommel—On the Light Side F.C. Fuglister	xxvi

Henry Stommel

Preface

Introduction ²

Part One General Ocean Circulation S

Ι

Deep Circulation of the World Ocean Bruce A. Warren 6

2

The Water Masses of the World Ocean: Some Results of a Fine-Scale Census L. V. Worthington 42

I.I Introduction	6
1.2 Historical Development of Ideas about the Deep Circulation	7
1.3 A Dynamical Framework	11
1.4 Sources of Deep Water	15
1.5 Deep Western Boundary Currents in the World Ocean	26
r.6 Why Is There a Deep Thermohaline Circulation At All? Notes	38 40
2.1	
Introduction	42
2.2 Methods of Describing the Oceans	43
2.3 The World Water Masses As They Exist in the Second Half of This Century	44
2.4 The Formation of Water Masses	57
Appendix: Census of World-Ocean Water Masses with Division by Bivariate (°C \times °/00) Classes and Rank by Volume	60
vi	

Contents

3 On the Mid Denth	3.1 Introduction	70
On the Mid-Depth Circulation of the World Ocean	3.2 The Circulation of the Upper Waters and Their Contribution to the Mid-Depths	70
Joseph L .Reid 70	3.3 The Use of Geostrophy	72
	3.4 The Mid-Depth Circulation of the Atlantic Ocean from Core Analysis and Vertical Geostrophic Shear	74
	3.5 Studies of Total Transport and Layers	79
	3.6 Mid-Depth Studies Using Isopycnal Analysis	81
	3.7 Comparison of Relative Geostrophic Flow at Mid-Depth with Numerical Models of Transport	85
	3.8 Mid-Depth Patterns in the World Ocean	91
	3.9 Comparison of the Maps of Shear Field and Characteristics	109
	3.10 Conclusion	110
4	4.1 Introduction	
The Gulf Stream System	4.2	112
N. P. Fofonoff	The Gulf Stream System 4.3	113
112	The Florida Current 4.4	113
	The Gulf Stream	123
<u>.</u>	4.5 The North Atlantic Current	133
	4.6 Summary and Conclusions	137
5	5.1	
5 Dynamics of	Introduction and Summary	140
Large-Scale Ocean Circulation	5.2 The Equations for Large-Scale Dynamics	142
George Veronis	5.3 The Quasi-Geostrophic Equations and the β -Plane	144
140	5.4 Ekman Layers	147
	5.5 Steady Linear Models of the Wind-Driven Circulation	149
	5.6 Preliminary Nonlinear Considerations	153
	5.7 Why Does the Gulf Steam Leave the Coast?	157
	5.8 Thermohaline Circulation	158

vii Contents

5.9 Free Waves for a Constant-Depth Two-Layer Ocean on the β -Plane	164
5.10 Effect of Bottom Topography on Quasi-Geostrophic Waves	165
5.11 Baroclinic Instability	169
5.12 Effect of Nonlinearity and Turbulence	174
Notes	183
6.1 Introduction	184
6.2 Observations	185
6.3 Theories	188
6.4 Discussion	195
7.1 Introduction	198
7.2 Estuarine Circulation in the Middle Atlantic Bight	199
7.3 Continental-Shelf Circulation	207
Appendix: Annual Air–Sea Interaction Cycles and Mean Runoff for the Middle Atlantic Bight	230
Notes	233
110100	~ <u>)</u>)

6

Equatorial Currents: Observations and Theory Ants Leetmaa,

Julian P. McCreary, Jr., and Dennis W. Moore 184

7

On Estuarine and Continental-Shelf Circulation in the Middle Atlantic Bight Robert C. Beardsley and William C. Boicourt 198

Part Two Physical Processes in Oceanography ²³⁵

8

Small-Scale Mixing Processes J. S. Turner 236

9

Internal Waves and Small-Scale Processes *Walter Munk* 264

8.1

Introduction	236
8.2 Preliminary Discussion of Various Mechanisms	237
8.3 Vertical Mixing in the Upper Layers of the Ocean	240
8.4 Mixing in the Interior of the Ocean	245
8.5 Mixing near the Bottom of the Ocean	258
9.1 Introduction	264
9.2 Layered Ocean	268
9.3 Continuously Stratified Ocean	269

viii Contents IO Long Waves and Ocean Tides Myrl C. Hendershott 292

ΙI

Low-Frequency Variability of the Sea Carl Wunsch 342

I 2

Some Varieties of Biological Oceanography J. H. Steele 376

13

The Amplitude of Convection Willem V. R. Malkus 384

9.4	
Turning Depths and Turning Latitudes	271
9.5 Shear	273
9.6 Resonant Interactions	275
9.7 Breaking	276
9.8 Ocean Fine Structure and Microstructure	279
9.9 An Inconclusive Discussion	283
9.10 Conclusion	290
Notes	290
10.1 Introduction	292
10.2 Astronomical Tide-Generating Forces	293
Laplace's Tidal Equations (LTE) and the Long-Wave Equations	295
10.4 Long Waves in the Ocean	297
10.5 The Ocean Surface Tide	317
10.6 Internal Tides	329
10.7 Tidal Studies and the Rest of Oceanography	339
11.1	
Introduction	342
11.2 The Field of Variability of the Ocean	346
Summary and Conclusions	373
12.1	
Introduction	376
12.2 Space and Time Scales of Variation	377
12.3 Ecological Variations	379
12.4 Discussion	381
13.1	
Introduction	384
13.2 Basic Boussinesq Description	385
13.3 Initial Motions	386

ix Contents

13.4387Quantitative Theories for High Rayleigh Number38713.5The Amplitude of Turbulent Convection from Stability
Criteria389

Part Three Techniques of Investigation 395

14

Ocean Instruments and Experiment Design D. James Baker, Jr. 396

15

Geochemical Tracers and Ocean Circulation W. S. Broecker 434

16

The Origin and Development of Laboratory Models and Analogues of the Ocean Circulation *Alan J. Faller* 462

14.1 Observations and the Impact of New Instruments	396
14.2 Instrument Development: Some Principles and History	398
14.3 Examples of Modern Ocean Instruments	402
14.4 Ocean Experiment Design	429
15.1 Introduction	434
15.2 Water-Transport Tracers	435
15.3 Water-Mass Tracers	448
15.4 Modeling Tracer Data	448
15.5 Current Applications	449
15.6 Ventilation of the Deep Sea	450
15.7 Ventilation of the Main Oceanic Thermocline	456
15.8 Formation of Deep Waters	457
15.9 Vertical Mixing Rates	459
16.1 A Brief Philosophy of Laboratory Experimentation	462
16.2 Introduction	463

Introduction	463
16.3 The Experiments of W. S. von Arx	465
16.4 The SAF Model	466
16.5 Experiments with Rotating Covers	468
16.6 A Variety of Interesting Experiments	472
16.7 Concluding Remarks	478

x Contents

Part Four Ocean and Atmosphere 481

I 7 Air-Sea Interaction H. Charnock 482

18

Oceanic Analogues of Large-Scale Atmospheric Motions Jule G. Charney and Glenn R. Flierl 504

Acknowledgments	and
Permissions	
550	

Reference List 554

Index 612

Contributors 622

17.1	
Introduction	482
17.2	
The Surface Layer	483
The Sullace Layer	403
17.3	
The Lower Boundary	486
17.4	
Waves	490
17.5	
The Atmospheric Boundary Layer	495
	775

18.1 Introduction	504
18.2 The General Circulation of Oceans and Atmospheres Compared	505
18.3 The Transient Motions	506
18.4 The Geostrophic Formalism	508
18.5 Linear Quasi-Geostrophic Dynamics of a Stratified Ocean	520
18.6 Friction in Quasi-Geostrophic Systems	525
18.7 Nonlinear Motions	529
18.8 Summary Remarks	544
Appendix: The Quasi-Geostrophic Equations	546
Notes	548