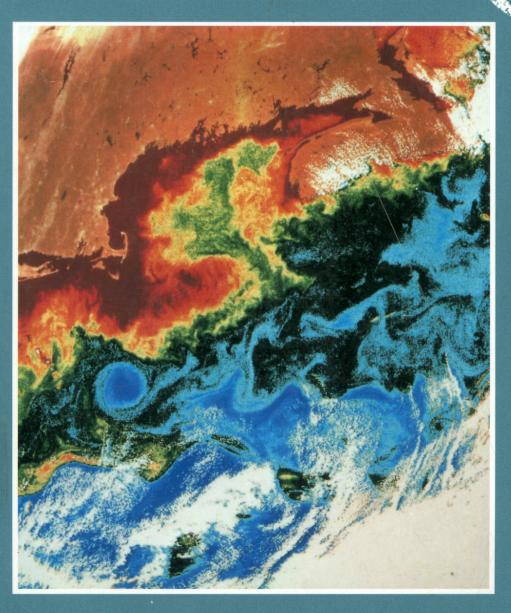
OCEAN CIRCULATION

PREPARED BY AN OPEN UNIVERSITY COURSE TEAM





OCEAN CIRCULATION

PREPARED BY ANGELA COLLING FOR THE COURSE TEAM

LII 64

Dk: 551.465,551,465.63,551.465.7,551.513,551.513.7

352/42/9 INSTITUT
FÜR METEOROLOGIE U. KLIMATOLOGIE
UNIVERSITÄT HANNOVER
HERRENHÄLBER STR. 2-3049 HANNOVER





in association with

THE OPEN UNIVERSITY, WALTON HALL, MILTON KEYNES, MK7 6AA, ENGLAND

CONTENTS

	ABOUT THIS VOLUME		8
	ABOUT THIS SERIES		9
CHAPTER 1	INTRODUCTION		
1.1	THE RADIATION BALANCE OF THE EARTH-OCEAN-ATMOSPHERE SYSTEM		14
1.2	SUMMARY OF CHAPTER 1		16
CHAPTER 2	THE ATMOSPHERE AND THE OCEAN		
2.1	THE GLOBAL WIND SYSTEM		18
2.2 2.2.1 2.2.2	POLEWARD TRANSPORT OF HEAT BY THE ATMOSPHERE Atmospheric circulation in mid-latitudes Vertical convection in the atmosphere		22 22 26
2.3 2.3.1 2.3.2	ATMOSPHERE-OCEAN INTERACTION Easterly waves and tropical cyclones A brief look ahead		29 29 34
2.4	SUMMARY OF CHAPTER 2		35
CHAPTER 3	OCEAN CURRENTS		
			00
3.1 3.1.1 3.1.2	THE ACTION OF WIND ON SURFACE WATERS Frictional coupling with the ocean Ekman motion		39 40 42
3.2	INERTIA CURRENTS		44
3.3 3.3.1 3.3.2 3.3.3 3.3.4	GEOSTROPHIC CURRENTS Pressure gradients in the ocean Barotropic and baroclinic conditions Determination of geostrophic current velocities Pressure, density and dynamic topography		46 46 49 53 60
3.4	DIVERGENCES AND CONVERGENCES		64
3.5 3.5.1 3.5.2	THE ENERGY OF THE OCEAN: SCALES OF MOTION Kinetic energy spectra Eddies		69 69 71
3.6	SUMMARY OF CHAPTER 3		75
CHAPTER 4	THE NORTH ATLANTIC GYRE: OBSERVATIONS AND THEORIES		
4.1 4.1.1	THE GULF STREAM Early observations and theories		79 79
4.2 4.2.1 4.2.2 4.2.3 4.2.4	THE SUBTROPICAL GYRES Vorticity Why is there a Gulf Stream? The equations of motion Investigating the ocean through computer modelling	1	85 85 90 98 102

4.3 4.3.1 4.3.2 4.3.3 4.3.4 4.3.5 4.3.6 4.3.7 4.3.8	MODERN OBSERVATIONS AND STUDIES OF THE NORTH ATLANTIC GYRE The Gulf Stream system Geostrophic flow in the Gulf Stream Insights from MODE Measuring currents directly Mapping the Gulf Stream using water characteristics Gulf Stream 'rings' Other methods of current measurement Modelling the circulation of the North Atlantic COASTAL UPWELLING IN EASTERN BOUNDARY CURRENTS	107 107 109 114 117 122 124 129 131
4.5	THE NORTH ATLANTIC OSCILLATION	137
4.6	SUMMARY OF CHAPTER 4	140
CHAPTER 5	OTHER MAJOR CURRENT SYSTEMS	
5.1 5.1.1 5.1.2	EQUATORIAL CURRENT SYSTEMS The Equatorial Undercurrent Upwelling in low latitudes	143 146 153
5.2 5.2.1 5.2.2	MONSOONAL CIRCULATION Monsoon winds over the Indian Ocean The current system of the Indian Ocean	156 156 157
5.3 5.3.1 5.3.2	THE ROLE OF LONG WAVES IN OCEAN CIRCULATION Oceanic wave guides and Kelvin waves Rossby waves	162 164 167
5.4	EL NIÑO-SOUTHERN OSCILLATION	170
5.5 5.5.1 5.5.2	CIRCULATION IN HIGH LATITUDES The Arctic Sea The Southern Ocean	176 177 181
5.6	SUMMARY OF CHAPTER 5	186
CHAPTER 6	GLOBAL FLUXES AND THE DEEP CIRCULATION	
6.1 6.1.1 6.1.2	THE OCEANIC HEAT BUDGET Solar radiation The heat-budget equation	191 191 192
6.2 6.2.1	CONSERVATION OF SALT Practical application of the principles of conservation and continuity	202 203
6.3 6.3.1 6.3.2	OCEAN WATER MASSES Upper and intermediate water masses Deep and bottom water masses	206 208 213
6.4 6.4.1 6.4.2	OCEANIC MIXING AND TEMPERATURE-SALINITY DIAGRAMS Mixing in the ocean Temperature-salinity diagrams	223 223 225
6.5	NON-CONSERVATIVE AND ARTIFICIAL TRACERS	234
6.6 6.6.1 6.6.2 6.6.3	GLOBAL FLUXES OF HEAT AND FRESHWATER The global thermohaline conveyor The World Ocean Circulation Experiment Oceanography in the 21st century: predicting climatic change	240 240 243 248
6.7	SUMMARY OF CHAPTER 6	250

SUGGESTED FURTHER READING	
ANSWERS AND COMMENTS TO QUESTIONS	25
ACKNOWLEDGEMENTS	27
INDEX	28