

Contents

1 Topography of the ocean floor	See Subvolume V/3a
2 In-situ instruments and measuring techniques	See Subvolume V/3a
3 Properties of sea water	See Subvolume V/3a
4 Ocean circulation	See Subvolume V/3b
5 Ocean turbulence.	See Subvolume V/3b
6 Ocean waves	
6.1 Classification and basic features (L. MAGAARD, L. A. MYSAK)	1
6.1.0 List of symbols	1
6.1.1 Introduction	2
6.1.2 Classification of waves with respect to restoring forces	5
6.1.2.1 Elasticity of the sea water	5
6.1.2.2 Surface tension	5
6.1.2.3 Gravity	7
6.1.2.4 Coriolis force	8
6.1.2.5 Spatial changes of the equilibrium potential vorticity	8
6.1.3 Classification of waves with respect to wave guides	10
6.1.3.1 Internal gravity wave trapping in a thermocline	10
6.1.3.2 Equatorially trapped waves	11
6.1.3.3 Kelvin waves.	12
6.1.3.4 Edge waves	12
6.1.3.5 Trapped topographic Rossby waves	12
6.1.3.6 Waves trapped around islands and seamounts	14
6.1.4 Classification with respect to generating forces or mechanisms	14
6.1.4.1 Astronomical forces.	14
6.1.4.2 Meteorological forces	14
6.1.4.3 Boundary sources.	15
6.1.4.4 Moving bodies	15
6.1.4.5 Mechanisms to enhance existing waves	15
6.1.4.6 Free waves.	15
6.1.4.7 Damping mechanisms	16
6.1.5 References for 6.1	16
6.2 Wind waves and swell (W. ROSENTHAL)	17
6.2.0 List of symbols	17
6.2.1 Introduction	18
6.2.2 The deterministic description of a linear plane wave, its energy and momentum density	18
6.2.3 The energy density spectrum	19
6.2.4 Surface waves in deep water.	21
6.2.4.1 The definition of swell and sea (wind waves)	21
6.2.4.2 The general behavior of wind waves.	22
6.2.4.3 The spectral shape for wind waves	24
6.2.4.3.1 The JONSWAP spectrum	24
6.2.4.3.2 The Kruseman spectrum	25
6.2.4.3.3 The Toba spectrum	25
6.2.4.4 The directional distribution of wave energy.	26
6.2.4.5 The statistical properties of the spectral parameters for wind waves	27

6.2.4.6	Frequently used spectral characteristics to classify sea state	30
6.2.4.7	Parameters to classify sea state from time series	31
6.2.4.8	Visual observations	31
6.2.5	Surface waves in shallow water	32
6.2.5.1	Refraction	32
6.2.5.2	Shoaling of waves.	33
6.2.5.3	Bottom-induced dissipation	34
6.2.5.4	Wave breaking in shallow water	34
6.2.5.5	Statistical behavior of wind waves in shallow water	35
6.2.6	References for 6.2	36
6.3	Internal gravity waves (D. OLBERS).	37
6.3.0	List of symbols and indices	37
6.3.1	Introduction	38
6.3.2	Observational techniques	39
6.3.3	Space-time scales	43
6.3.3.1	Intermediate waves in the deep ocean	44
6.3.3.2	Intermediate waves in the upper ocean.	46
6.3.3.3	Near inertial waves	48
6.3.3.4	Near buoyancy waves	48
6.3.4	Equations of motion	48
6.3.4.1	Equations of motion for a Boussinesq fluid on a f - plane.	48
6.3.4.2	Motions relative to a large-scale mean flow.	50
6.3.4.3	Energy equations	52
6.3.4.4	The w -equation	52
6.3.4.5	Separation into vertical normal modes.	53
6.3.4.6	The w -equation in the presence of a horizontal shear flow	56
6.3.4.7	Complete representation in terms of the state vector	56
6.3.5	Kinematics of linear small-scale waves	59
6.3.5.1	The geometrical optics or WKB approximation	59
6.3.5.2	Description of the wave guide	60
6.3.5.3	Properties of linear small-scale waves	60
6.3.5.4	Turning levels and critical levels	63
6.3.5.5	The planetary wave guide	65
6.3.6	Spectral models	66
6.3.6.1	The cross-spectral matrix	66
6.3.6.2	Consistency tests	67
6.3.6.3	The GM model for the deep ocean wave field	68
6.3.6.4	Upper ocean models	71
6.3.6.5	Near-inertial waves	71
6.3.7	Spectral dynamics	71
6.3.7.1	The radiative transfer equation	71
6.3.7.2	Observational evidence of dynamical relations	73
6.3.7.3	Theoretical estimates of transfer rates	74
6.3.7.3.1	Generation processes	74
6.3.7.3.2	Dissipation mechanisms	76
6.3.7.3.3	Internal transfer processes	77
6.3.7.4	A perspective of the spectral balance	78
6.3.8	References for 6.3	80
6.4	Astronomical tides (W. ZAHHEL)	83
6.4.0	List of symbols	83
6.4.1	The tide-generating potential	86
6.4.2	The tidal dynamical equations.	89
6.4.3	Time dependence of the tidal field of motion	91
6.4.3.1	The linear case and general considerations	91
6.4.3.2	Shallow water tides	100
6.4.3.3	Tide tables.	103

6.4.4	Open ocean tides	103
6.4.4.1	Tidal oscillations in schematic ocean basins	103
6.4.4.2	Tidal oscillations in the real ocean	108
6.4.5	Co-oscillating tides	116
6.4.6	Vertical distribution of tidal currents	127
6.4.7	References for 6.4	132
7	Upwelling regions (E. MITTELSTADT)	135
7.1	Introduction	135
7.2	Open ocean upwelling zones	135
7.2.1	Equatorial upwelling.	135
7.2.2	Antartic upwelling	138
7.3	Coastal upwelling	140
7.3.1	Peru Current System.	141
7.3.2	California Current System	145
7.3.3	Benguela Current System.	150
7.3.4	Guinea Current System.	152
7.3.5	Canary Current System	153
7.3.6	Portugal Current System	160
7.3.7	Somali Current System.	161
7.3.8	Arabian Sea Upwelling.	163
7.4	References for 7.	163
8	Ice in the ocean (G. KOSLOWSKI)	167
8.0	List of symbols	167
8.1	Structure of sea ice	168
8.1.1	Density of sea ice	168
8.1.2	Porosity of sea ice	169
8.2	Salinity of sea ice	170
8.3	Thermophysical properties of sea ice	172
8.3.1	Specific heat capacity of sea ice	172
8.3.2	Latent heat of fusion of sea ice	172
8.3.3	Thermal conductivity of sea ice	173
8.4	Elastic properties and deformation of sea ice	174
8.5	Strength of sea ice	176
8.5.1	Structural model of strength of sea ice	176
8.5.2	Tensile and flexural strength of sea ice	178
8.5.3	Compressive and shear strength of sea ice.	182
8.5.4	Impact strength of sea ice.	183
8.6	Ice cover characteristics of the world ocean	183
8.6.1	The stages of sea ice development	183
8.6.2	Extent of ice cover.	184
8.6.3	Influence of drift on the state of ice cover	186
8.6.4	General description of ice cover of the polar oceans	187
8.7	References for 8.	189
8.7.1	General references	189
8.7.2	Special references	189
9	Coastal oceanography (H. G. GIERLOFF-EMDEN).	191
9.1	Definitions and spatial extensions	191
9.1.0	Abbreviations.	191
9.1.1	Definitions	192
9.1.2	Units, measurements, and parameters of coastal oceanography.	193

9.1.3	The length of the coasts (horizontal spatial parameters)	195
9.1.3.1	The length of the coastline and the shoreline: modern surveying with remote sensing techniques	198
9.1.4	Vertical spatial extension and reference datum of the coastal zone	200
9.1.4.1	The mean sea level (msl)	200
9.1.4.2	The reference level for depths on nautical charts (chart datum)	202
9.1.4.3	Coastal datums concerning maps and charts	203
9.1.4.4	Tidal datums for the USA	204
9.1.4.5	Tidal datums for the Federal Republic of Germany	205
9.1.5	Spatial extension of coastal zones respecting the Law of the Sea	206
9.1.5.1	Territorial waters	206
9.1.5.2	The delimitation of the coastal zones according to the Law of the Sea	207
9.1.5.3	The spatial extension of coastal zones respecting the Law of the Sea and topographic conditions of the ocean	208
9.1.5.4	The 200-nm Economic Exclusive Zone (EEZ)	210
9.2	Classification of coasts	212
9.2.1	Coastal classification according to the global tectonics	212
9.2.2	Coastal classification according to dynamics of wave characteristics	216
9.3	The high-energy environment of the coastal zone	218
9.3.1	The coastal energy budget	218
9.3.2	Time scale of coastal zone processes	220
9.4	The shore as the interaction zone of sea and land	221
9.4.1	Shore features of steep coasts and interactions	221
9.4.1.1	The mechanism of cliff erosion and platform erosion	222
9.4.1.2	Cliff erosion rates	223
9.4.2	Shore features of depositional coasts and interactions	225
9.4.2.1	The beach profile and slope	225
9.4.2.2	Beach type series from dissipative to reflective characteristics	226
9.4.2.3	Modal beach state, temporal variability and environmental conditions: a classification	226
9.4.2.4	Beach profile mobility in relation to modal beach state and state variability. Classification of a morphodynamic approach	227
9.4.2.5	The Bruun rule relating shore erosion and sea level rising. Long time scale beach variation	229
9.4.2.6	Beaches: hydraulics of sediment transport	230
9.4.2.7	Classification and characteristics of beach material	234
9.4.2.8	Current velocity of water and sediment interaction	237
9.4.2.9	Spatial and temporal scales of crescentic rhythmic features	241
9.5	Wave effects on coasts	244
9.5.1	Wave energy on coasts	244
9.5.2	Characteristics of waves at coasts	246
9.5.3	Breakers and surf zone	249
9.5.3.1	Breaker types	249
9.5.3.2	The breaker and surf zone	252
9.5.4	Transformation of waves approaching the shore	254
9.5.4.1	Velocity, length, height, wave angle	254
9.5.4.2	Wave refraction and wave diffraction	256
9.5.5	Wave-generated currents of the shore zone	258
9.5.5.1	Nearshore circulation cells	258
9.5.5.2	Periodic circulation cells induced by waves at the shore and rhythmic features	260
9.5.6	Catastrophic waves at coasts: tsunamis	262
9.6	Tide effects on coasts	263
9.6.1	Tides as coastal phenomena	263
9.6.1.1	Tidal datums	263
9.6.2	World distribution of tidal types and ranges	264
9.6.3	Tidal panorama of a continent: Australia between three oceans	268

9.6.4	Tidal ranges in polar regions	269
9.6.5	Tidal range phenomena at shore areas	269
9.6.6	Coastal seiches	271
9.6.7	Tidal currents.	272
9.6.8	Coastal zone, tidal process response, models and features	275
9.6.8.1	Inlets, bedforms, ripples	275
9.6.8.2	Tidal prism and tidal basin	276
9.6.8.3	Tidal hydrodynamics: tidal meander channeling and classification	278
9.6.8.4	Exposure and sediments of the wadden sea bottom	282
9.7	Estuaries and lagoons as coastal water bodies	284
9.7.1	Hydrographic conditions	284
9.7.2	Hydrographic classification of estuaries	286
9.7.3	Flushing time	287
9.7.4	Meteorological and climatological stress on estuaries	288
9.7.5	River estuaries	289
9.7.6	Fjord estuaries	289
9.8	Coastal lagoons	294
9.8.1	Definition and classification.	294
9.8.2	Global zonal classification of lagoon features and processes in different climatic zones	295
9.8.3	Configuration of inlet-bay geometry of lagoons and littoral drift	299
9.8.4	Coral atolls as oceanic lagoons	303
9.9	River discharge affecting coastal waters	305
9.9.1	Terrestrial run-off	305
9.9.2	River discharge in polar regions	307
9.9.3	Deltas	309
9.10	Chemical and biological effects on the coastal zone	314
9.10.1	Corrosion, dissolution, evaporation, biochemistry, organic features	314
9.10.2	Zonation of flat coasts caused by chemical and biological processes.	316
9.10.3	Coral reefs and atolls: organic created coasts	317
9.11	Climatologic-meteorologic effects on coasts. Oceanic-atmospheric coupled systems	319
9.11.1	Scales of boundary layers.	319
9.11.2	Wind stress of small space and time scales on coasts	320
9.11.3	Wind stress of medium and large space and time scales on coasts	322
9.11.4	Climatic characteristics related to coastal landscapes	324
9.12	Sea level change and the coastal zone	325
9.12.1	Eustatic changes of the sea level	325
9.12.2	Definitions	325
9.12.3	Eustatic sea level parameters	326
9.12.4	Quaternary sea level history.	327
9.12.5	Change of sea level during the Tertiary	334
9.12.6	Sea level history of geologic ages in relation to coal and oil source rocks	334
9.13	References for 9.	336