

# Contents

<b>Preface to the first edition</b> . . . . .	xi
<b>Preface to the second edition</b> . . . . .	xv
<b>List of figures</b> . . . . .	xvii
<b>List of tables</b> . . . . .	xxiii
<b>List of symbols</b> . . . . .	xxv
<b>List of abbreviations</b> . . . . .	xxix
<b>1 Introduction</b> . . . . .	1
<b>2 Drift ice material</b> . . . . .	11
2.1 Sea ice cover. . . . .	11
2.1.1 Sea ice landscape. . . . .	12
2.1.2 Sea ice zones. . . . .	17
2.1.3 Sea ice charting. . . . .	18
2.2 Ice floes to drift ice particles. . . . .	21
2.2.1 Scales. . . . .	21
2.2.2 Size and shape of ice floes . . . . .	25
2.3 Sea ice growth and melting. . . . .	32
2.3.1 Freezing of seawater . . . . .	32
2.3.2 Ice growth . . . . .	33
2.3.3 Melting of sea ice . . . . .	39
2.3.4 Numerical modelling of ice thermodynamics . . . . .	42
2.4 Ice thickness distribution . . . . .	45
2.4.1 Mechanical ice growth. . . . .	45
2.4.2 Measurement methods. . . . .	47
2.4.3 Ice thickness distribution . . . . .	50

2.5	Sea ice ridges . . . . .	53
2.5.1	Structure of ridges . . . . .	53
2.5.2	Statistical distributions of ridge size and occurrence . . . . .	56
2.5.3	Ridging measures . . . . .	58
2.5.4	Hummocked ice . . . . .	60
2.5.5	Total thickness of deformed ice . . . . .	60
2.6	Drift ice state . . . . .	61
<b>3</b>	<b>Ice kinematics . . . . .</b>	<b>65</b>
3.1	Description of ice velocity field . . . . .	65
3.1.1	Motion of a single floe . . . . .	66
3.1.2	Continuum deformation . . . . .	67
3.2	Observations . . . . .	73
3.2.1	Methods . . . . .	73
3.2.2	Characteristics of observed sea ice drift . . . . .	78
3.2.3	Strain-rate and vorticity . . . . .	85
3.2.4	Deformation structures . . . . .	89
3.3	Stochastic modelling . . . . .	91
3.3.1	Two-dimensional notion using complex variables . . . . .	91
3.3.2	Mean sea ice drift field in the Arctic Ocean . . . . .	92
3.3.3	Diffusion . . . . .	93
3.3.4	Random walk . . . . .	94
3.3.5	Self-correcting simple forecasting . . . . .	94
3.4	Conservation of ice . . . . .	96
3.4.1	Ice states based on ice categories . . . . .	98
3.4.2	Ice thickness distribution . . . . .	100
<b>4</b>	<b>Sea ice rheology . . . . .</b>	<b>107</b>
4.1	General . . . . .	107
4.1.1	Rheological models . . . . .	109
4.1.2	Internal stress of drift ice . . . . .	112
4.1.3	Internal friction . . . . .	114
4.2	Viscous laws . . . . .	116
4.2.1	Linear viscous model . . . . .	116
4.2.2	Nonlinear viscous model . . . . .	118
4.3	Plastic laws . . . . .	120
4.3.1	Plastic drift ice . . . . .	120
4.3.2	Mohr-Coulomb rheology . . . . .	125
4.3.3	AIDJEX elastic-plastic rheology . . . . .	126
4.3.4	Hibler's viscous-plastic rheology . . . . .	128
4.4	Granular floe collision models . . . . .	132
4.5	Scaling of ice strength . . . . .	136
<b>5</b>	<b>Equation of drift ice motion . . . . .</b>	<b>143</b>
5.1	Derivation of the equation of motion . . . . .	143
5.1.1	Fundamental equation . . . . .	143

5.1.2	Vertical integration . . . . .	146
5.1.3	Drift regimes. . . . .	150
5.1.4	Conservation of kinetic energy, divergence and vorticity. . . . .	151
5.2	Atmospheric and oceanic boundary layers . . . . .	153
5.2.1	Planetary boundary layers . . . . .	153
5.2.2	Atmospheric drag force on sea ice . . . . .	160
5.3	Sea ice–ocean interaction . . . . .	164
5.3.1	Oceanic boundary layer beneath drifting ice . . . . .	164
5.3.2	Monin-Obukhov model . . . . .	169
5.3.3	Second order turbulence model . . . . .	171
5.3.4	Shallow waters . . . . .	173
5.4	Scale analysis . . . . .	174
5.4.1	Magnitudes. . . . .	174
5.4.2	Dimensionless form . . . . .	178
5.4.3	Basin scales. . . . .	182
5.5	Dynamics of a single ice floe . . . . .	183
<b>6</b>	<b>Free drift . . . . .</b>	<b>185</b>
6.1	Steady state solution . . . . .	185
6.1.1	Classical case . . . . .	187
6.1.2	One-dimensional channel flow . . . . .	191
6.1.3	Shallow waters . . . . .	193
6.1.4	Linear model . . . . .	194
6.2	Non-steady case . . . . .	195
6.2.1	One-dimensional flow with quadratic surface stresses . . . . .	195
6.2.2	Linear two-dimensional model . . . . .	196
6.2.3	Drif of a single floe . . . . .	197
6.3	Linear coupled ice-ocean model . . . . .	200
6.3.1	General solution . . . . .	200
6.3.2	Inertial oscillations . . . . .	202
6.4	Frequency spectrum of free drift. . . . .	205
6.4.1	Periodic forcing. . . . .	205
6.4.2	Free drift velocity spectrum . . . . .	206
6.4.3	Nonlinear questions. . . . .	207
6.5	Spatial aspects of free drift. . . . .	210
6.5.1	Advection. . . . .	210
6.5.2	Divergence and vorticity . . . . .	211
<b>7</b>	<b>Drift in the presence of internal friction . . . . .</b>	<b>213</b>
7.1	The role of internal friction . . . . .	213
7.1.1	Consequences of internal friction . . . . .	213
7.1.2	Examples . . . . .	215
7.1.3	Landfast ice problem. . . . .	219
7.2	Channel flow of sea ice . . . . .	221
7.2.1	Creep . . . . .	222
7.2.2	Plastic flow. . . . .	223

7.3	Ice drift along coastal boundary . . . . .	226
7.3.1	Influence of the boundary . . . . .	226
7.3.2	Dynamics of the relaxation process . . . . .	226
7.4	Zonal sea ice drift. . . . .	230
7.4.1	Steady-state velocity: wind-driven case . . . . .	232
7.4.2	Stead-state with ocean currents . . . . .	235
7.4.3	Steady-state ice thickness and compactness profiles. . . . .	236
7.4.4	Viscous models . . . . .	238
7.4.5	Marginal ice zone. . . . .	239
7.4.6	Circular ice drift. . . . .	241
7.5	Modelling of ice tank experiments . . . . .	245
7.5.1	Drift ice dynamics in a tank . . . . .	245
7.5.2	Case study. . . . .	248
7.6	Timespace scaling of ice drift. . . . .	251
7.6.1	Frequency spectrum of sea ice drift . . . . .	251
7.6.2	Spatial structures . . . . .	253
7.6.3	Downscaling . . . . .	255
<b>8</b>	<b>Numerical modelling . . . . .</b>	<b>259</b>
8.1	Numerical solutions . . . . .	259
8.1.1	System of equations . . . . .	259
8.1.2	Numerical technology. . . . .	262
8.1.3	Calibration/validation. . . . .	267
8.2	Examples of sea ice dynamics models. . . . .	267
8.2.1	Campbell and Doronin models . . . . .	267
8.2.2	AIDJEX model . . . . .	269
8.2.3	Hibler model . . . . .	270
8.2.4	Baltic Sea model . . . . .	273
8.3	Short-term modelling applications . . . . .	275
8.3.1	Research work . . . . .	275
8.3.2	Sea ice forecasting . . . . .	278
8.4	Oil spills in ice conditions . . . . .	284
8.4.1	General . . . . .	284
8.4.2	<i>Runner-4</i> oil spill in the Gulf of Finland . . . . .	285
8.4.3	Oil spill modelling in ice-covered waters. . . . .	287
8.5	Climate models. . . . .	289
8.5.1	Arctic regions . . . . .	289
8.5.2	Antarctica . . . . .	291
8.5.3	Baltic Sea . . . . .	291
<b>9</b>	<b>Use and need of knowledge on ice drift . . . . .</b>	<b>299</b>
9.1	Science . . . . .	299
9.2	Practice . . . . .	304
9.3	Final comments . . . . .	306

<b>10 Study problems</b> .....	309
10.1 Problems.....	309
10.2 Instructions and solutions.....	313
<b>11 References</b> .....	319
<b>Index</b> .....	339



<http://www.springer.com/978-3-642-04682-7>

The Drift of Sea Ice

Leppäranta, M.

2011, XXX, 350 p., Hardcover

ISBN: 978-3-642-04682-7