Fundamentals of Glacier Dynamics

C.J. VAN DER VEEN

Glacier Dynamics Group, Byrd Polar Research Center, and Department of Geography, Ohio State University



A.A. BALKEMA/ROTTERDAM/BROOKFIELD/1999

Contents

PF	PREFACE			
1	ICE	IN THE CLIMATE SYSTEM	1	
2	ICE DEFORMATION			
	2.1	Stress and strain	7	
	2.2	Creep of glacier ice	10	
	2.3	Constitutive relation	13	
	2.4	Flow parameters for glacier modelling	15	
	2.5	Fabric effects in glacier ice	17	
	2.6	More about the constitutive relation	21	
	2.7	Creep in axially symmetric ice	23	
	2.8	Testing the flow law for glacier ice	26	
3	MECHANICS OF GLACIER FLOW			
	3.1	Force balance	32	
	3.2	Resistive stresses	33	
	3.3	The force-budget technique	37	
	3.4	Calculating stresses at depth: Theory	43	
	3.5	Calculating stresses at depth: Numerical solution	45	
	3.6	Calculating stresses at depth: Practical considerations	52	
	3.7	Bridging effects	56	
	3.8	Creep closure of englacial tunnels	58	
4	BASAL SLIDING			
	4.1	General concepts	66	
	4.2	Sliding without cavitation	67	
	4.3	Sliding with cavitation	70	
	4.4	Sliding with friction	76	
	4.5	Glacier flow over a soft bed	78	
	4.6	Subglacial hydraulics	84	
	4.7	•	90	
	18	Measurements on basal sliding	96	

VI Contents

5	MODELLING GLACIER FLOW			
	5.1	Lamellar flow	103	
	5.2	Along-flow variations in glacier flow	108	
		Transfer functions	111	
	5.4	Lateral drag	117	
		Glacier flow controlled by lateral drag	124	
		Ice-shelf spreading	127	
	5.7		131	
	5.8	Estimating resistance from lateral drag	140	
6	EQUILIBRIUM PROFILES OF GLACIERS			
	6.1	Perfect plasticity	145	
	6.2	Reconstructing glaciers	148	
	6.3	The continuity equation	151	
	6.4	Steady-state profiles along a flowline	154	
	6.5	The steady-state profile of an axi-symmetric ice sheet	159	
	6.6	The steady-state profile of a free-floating ice shelf	162	
	6.7	Including lateral drag	167	
	6.8	Flow near an ice divide	170	
7	GL	. 177		
	7.1	Conservation of energy	177	
	7.2	Steady-state temperature profiles	180	
	7.3	The effect of horizontal heat advection	185	
	7.4	Thermal response to changes in climate	189	
	7.5	Radiation balance at the surface of a glacier	193	
		Turbulent heat fluxes	198	
	7.7	Thermal properties of firn	203	
	7.8	Calculated firn temperatures at South Pole	206	
8	NU	215		
		Introductory remarks	215	
		Numerical methods	218	
	8.3	, and the second	225	
		Calculating the temperature field	231	
	8.5	Including longitudinal stresses	236	
	8.6	Basal sliding	241	
	8.7	Geodynamics	244	
	8.8	Ice-shelf models	252	
9				
	9.1	A zero-order model	261	
	9.2	Response to random fluctuations in precipitation	264	
	9.3	The height – mass balance feedback	272	

		Contents	VII
	9.4 The total heat budget of an ice sheet		279
	9.5 Interaction between ice flow and heat budget		284
	9.6 The effect of basal lubrication		290
	9.7 Internal oscillations		294
	9.8 The glacial cycles of the Pleistocene		299
10	MOUNTAIN GLACIERS		309
	10.1 General remarks		309
	10.2 Response to changes in surface mass balance		311
	10.3 Tidewater glaciers		318
	10.4 Glacier surges		323
	10.5 Numerical modelling of valley glaciers		331
	10.6 Glaciers and climate change		338
11	THE GREENLAND ICE SHEET		347
	11.1 Physical characteristics		347
	11.2 Modelling ablation: Degree-day method		355
	11.3 Modelling ablation: Energy-balance approach		363
	11.4 Meltwater runoff		372
	11.5 A model of the Greenland Ice Sheet		375
	11.6 Modelled past and future evolution		381
12	THE ANTARCTIC ICE SHEET		388
	12.1 Physical characteristics	•	388
	12.2 Marine instability		395
	12.3 Ice streams		400
	12.4 Mechanical controls on ice streams		406
	12.5 Modelling surface accumulation		413
	12.6 A model of the Antarctic Ice Sheet		426
RE	EFERENCES		437
AC	CKNOWLEDGEMENTS OF FIGURES		459
SU	JBJECT INDEX		460