Glaciers and Climate Change

Johannes Oerlemans



CONTENTS

1.	Introducti	ion	1
2.	Basic coi	ncepts	5
	2.1	Where do glaciers form?	5
	2.2	Specific balance, equilibrium line, snow line	6
	2.3	The thermal regime	8
	2.4	Flow of ice	9
	2.5	Mass balance and continuity	10
	2.6	Traces in the landscape	10
	2.7	Historical glacier records	11
3.	The micro-climate of a valley glacier		
	3.1	Introduction	15
	3.2	Solar radiation - geometric factors	18
	3.3	Solar radiation - atmospheric effects	20
	3.4	The surface albedo	23
	3.5	Longwave radiation	26
	3.6	The atmospheric boundary layer over glaciers	28
	3.7	Turbulence and boundary-layer profiles	30
	3.8	Turbulent fluxes	32
	3.9	A simple model of the glacier wind	34
	3.10	Micro-climate and large-scale weather	37
4.	Modelling	glacier mass balance	41
	4.1	Introduction	41
	4.2	Measurements	41
	4.3	Calculating melt	44
	4.4	A simple analytical mass balance model	45
	4.5	A simple numerical mass balance model	48
	4.6	More comprehensive modelling	49
	4.7	Modelled sensitivity of the mean specific balance	50
	4.8	Modelled balance gradients	51
	4.9	The seasonal sensitivity characterictic (SSC)	52
5.	Modelling	the geometry and flow of a valley glacier	57
	5.1	Introduction	57
	5.2	Ice deformation: simple shearing flow	58
	5.3	Perfect plasticity	60
	5.4	A very simple glacier model	60
	5.5	Sliding	61
	5.6	A numerical ice-flow model	62
6.	Calculation	ons for a glacier of constant width	67
	6.1	Introduction	67
	6.2	A basic experiment	67
	6.3	Varying the equilibrium-line alitude	68
	6.4	Back to the analytical model	69
	6.5	A more complicated bed	70
	6.6	Characteristic time scales	71
	6.7	The role of the balance gradient	72
	6.8	Response time derived from the simple analytic model	73

7.	Mor	e realistic geometry	7		
	7.1	Area-elevation distribution	7		
	7.2	Extending the simple analytical model	7		
	7.3	Adjusting the numerical model for a varying glacier width	7		
	7.4	Shape factors	78		
	7.5	Numerical experiments for varying glacier width	79		
	7.6	Complex geometry	8		
8.	Numerical modelling of real glaciers: Nigardsbreen, Rhonegletscher, Abramov Glacier and Franz-Josef Glacier				
	8.1	From a topographic map to a parameterization of the 3-d geometry	8		
	8.2	Nigardsbreen, Rhonegletscher, Abramov Glacier and Franz-Josef Glacier	. 8		
	8.3	Response times	88		
	8.4	The observed records of glacier length	89		
	8.5	Dynamic calibration	90		
	8.6	Advance and retreat	9		
9.	Climatic interpretation of glacier fluctuations				
	9.1	Introduction	93		
	9.2	Inverse modelling	9		
	9.3	Another look at glacier fluctuations of small amplitude	97		
	9.4	Inverse modelling with flow-line models	98		
	9.5	Climate noise in glacier records	99		
	9.6	Simulating glacier fluctuations from climate records	102		
	9.7	Mean specific balance as a climate indicator?	103		
	9.8	Glacier models and climate models	104		
10.	The	The global picture and sea-level rise			
	10.1	World-wide glacier retreat	109		
	10.2	Glaciers and sea-level change	11		
	10.3	· · · · · · · · · · · · · · · · · · ·	116		
•	10.4		117		
	10.5	A discussion of the Antarctic ice sheet	119		
	10.6	Sea-level rise, land ice and thermal expansion	12 ⁻		
11.	The	The future of glaciers			
	11.1	Introduction	125		
	11.2	The EISMINT-study of glaciers in the 21st-century	125		
	11.3	·	130		
	11.4	Climate change and melt-water discharge from glaciers	132		
12.	The future of glacier research				
	12.1	Introduction	135		
	12.2	Using satellite data: optical sensors	135		
	12.3	Using satellite data: microwaves	140		
	12.4	The role of in situ measurements	144		
	12.5	The role of modelling	14		