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List of Symbols

Only the principal symbols are listed. A scalar is indicated by italics type, a vector by bold face upright type and a tensor by sans serif upright type.

$\mathbf{0}$	zero vector
I	unit tensor
$\mathbf{a}$	acceleration ($= \mathrm{d}\mathbf{v}/\mathrm{d}t = \mathrm{d}^2\mathbf{x}/\mathrm{d}t^2$)
a_b	basal melting (-freezing) rate in the vertical direction
$a_\mathrm{b}^\perp$	basal melting (-freezing) rate
$a_\mathrm{m}^\perp$	volume flux through the CTS
a_s	accumulation-ablation function (surface mass balance) in the vertical direction
$a_\mathrm{s}^\perp$	accumulation-ablation function (surface mass balance)
b	z-coordinate of the ice base
b_0	isostatically relaxed value for b without ice load
c	(1) specific heat in general (2) specific heat of ice [$= (146.3 + 7.253\,T[\mathrm{K}])\,\mathrm{J\,kg^{-1}K^{-1}}$] (3) specific heat of firn (Sect. 9.2)
$c^\perp$	calving rate
d_e	effective strain rate
$\mathbf{e}_i$	set of orthonormal basis vectors (in the present configuration κ_t)
$\mathbf{e}_\mathrm{t}$	tangential unit vector
$\mathbf{f}$	volume force
$f(\sigma_\mathrm{e})$	creep function
$f^\star(\mathbf{n})$	orientation distribution function [$= \rho^\star(\mathbf{n})/\rho$]
$\mathbf{g}$, g	gravitational acceleration ($= 9.81\,\mathrm{m\,s^{-2}}$)

g	density of arbitrary physical quantity
g_s	arbitrary physical quantity per unit mass (“specific ...”)
h	(1) z-coordinate of the ice surface (2) specific enthalpy ($= u + p/\rho$; Sect. 9.3)
$\mathbf{j}$	diffusive water mass flux in temperate ice
k	enthalpy diffusivity
$\dot{m}_\mathrm{b}^\mathrm{w}$	water mass flux into the base
$\mathbf{n}$	(1) unit normal vector (2) orientation (direction of the c-axis; Sect. 9.1)
n	stress exponent ($= 3$)
p	(1) pressure (2) production density of arbitrary physical quantity (Chapter 3)
$p(\rho, T)$	thermodynamic pressure
p_visc	viscous pressure
p_tot	total pressure $[= p(\rho, T) + p_\mathrm{visc}]$
p_sw	hydrostatic pressure of sea water
p_sea	hydrostatic pressure of sea water at the ice-sea interface
p, q	basal sliding exponents
$\mathbf{q}$	heat flux
$\mathbf{q}^\star(\mathbf{n})$	orientation flux
$\mathbf{q}_\mathrm{l}$	latent heat flux in temperate ice
$\mathbf{q}_\mathrm{s}$	sensible heat flux in temperate ice
q	load per unit area
$q_\mathrm{geo}^\perp$	geothermal heat flux
$q_\mathrm{sea}^\perp$	heat flux on the sea side of the ice-sea interface
r	specific radiation power
s	supply density of arbitrary physical quantity
t	Cauchy stress tensor
t^D	Cauchy stress deviator $[= \mathsf{t} - (\frac{1}{3}\,\mathrm{tr}\,\mathsf{t})\,\mathsf{I}]$
t_lith	stress at the lithosphere side of the ice-lithosphere interface
t_sea	stress at the sea side of the ice-sea interface
$\mathbf{t}_\mathbf{n}$	stress vector
t	time
$[t]$	typical time-scale
$\mathbf{u}$	displacement
$\mathbf{u}^\star(\mathbf{n})$	orientation transition rate
u	specific internal energy
$\mathbf{v}$	velocity ($= \mathrm{d}\mathbf{x}/\mathrm{d}t$)

$\mathbf{v}^\star(\mathbf{n})$	orientation-dependent velocity
$\mathbf{v}_\mathrm{b}$	basal sliding velocity
$\mathbf{v}_\mathrm{gl}$	velocity at the grounding line
$\mathbf{v}_\mathrm{h}$	horizontal velocity
$\mathbf{v}_\mathrm{i}$	ice velocity in temperate ice
$\mathbf{v}_\mathrm{sea}$	velocity of subglacial sea water
$\mathbf{v}_\mathrm{w}$	water velocity in temperate ice
$\mathbf{w}$	velocity of a singular surface
w	vertical displacement of the lithosphere
w_ss	steady-state value of w
$\mathbf{x}$	position vector (in the present configuration κ_t)
x, y	horizontal Cartesian coordinates
z	vertical Cartesian coordinate
z_l	z-coordinate of the lithosphere surface
z_m	z-coordinate of the CTS
z_sl	z-coordinate of the mean sea level

$A(T')$	rate factor
$A_\mathrm{t}(W)$	rate factor of temperate ice
$\mathcal{A}$	deformability of polycrystalline ice
$\mathcal{A}^\star(\mathbf{n})$	crystallite deformability
A_0	pre-exponential constant $(= 3.985 \times 10^{-13}\,\mathrm{s^{-1}\,Pa^{-3}}$ for $T' \le 263.15\,\mathrm{K}$, $= 1.916 \times 10^{3}\,\mathrm{s^{-1}\,Pa^{-3}}$ for $T' > 263.15\,\mathrm{K})$
B	left Cauchy Green tensor ($= \mathsf{V}^2$)
$B(T')$	associated rate factor
C	right Cauchy Green tensor ($= \mathsf{U}^2$)
C_b	basal sliding coefficient
C_wi	water-ice drag coefficient ($\approx 2.5 \times 10^{-3}$)
D	strain-rate (stretching) tensor $[= (\mathsf{L} + \mathsf{L}^\mathrm{T})/2\,]$
D^D	strain-rate (stretching) deviator $[= \mathsf{D} - (\frac{1}{3}\,\mathrm{tr}\,\mathsf{D})\,\mathsf{I}\,]$
D	diffusivity of the ice surface
D_a	diffusivity of the asthenosphere
$\mathbf{E}_A$	set of orthonormal basis vectors (in the reference configuration κ_r)
E	(1) flow enhancement factor (2) Young's modulus
$E(\mathcal{A})$	anisotropic flow enhancement factor
E_s	stress enhancement factor

F	deformation gradient ($=\mathrm{Grad}\,\mathbf{x}$)
F_b	implicit representation of the ice base ($=b-z$)
F_cf	implicit representation of the calving front
F_gl	implicit representation of the grounding line
F_m	implicit representation of the cold-temperate transition surface ($=z-z_\mathrm{m}$)
F_s	implicit representation of the ice surface ($=z-h$)
Fr	Froude number [$=[U]^2/(g[H])$]
H	displacement gradient ($=\mathrm{Grad}\,\mathbf{u}=\mathsf{F}-\mathsf{I}$)
H	(1) thickness in general (2) ice thickness ($=h-b$)
H_a	thickness of the asthenosphere
H_l	thickness of the lithosphere
$[H]$	typical vertical extent
J	Jacobian of the deformation gradient ($=\det\mathsf{F}$)
K	flexural stiffness
K_l	flexural stiffness of the lithosphere ($\approx 10^{25}\,\mathrm{N\,m}$)
L	velocity gradient ($=\mathrm{grad}\,\mathbf{v}$)
L	latent heat of ice ($=3.35\times10^5\,\mathrm{J\,kg^{-1}}$)
L_r	radius of relative stiffness [$=(K_\mathrm{l}/(\rho_\mathrm{a}g))^{1/4}$]
$[L]$	typical horizontal extent
M	water mass production rate in temperate ice
N	membrane stress
$\mathbf{N}_\mathrm{b}$, N_b	basal normal stress
$[P]$	typical pressure
$\mathcal{P}_\mathrm{m}^\mathrm{w}$	water surface production rate at the CTS
$\mathbf{Q}$	horizontal volume flux
Q	activation energy ($=\ \ 60\,\mathrm{kJ\,mol^{-1}}$ for $T'\le 263.15\,\mathrm{K}$, $=139\,\mathrm{kJ\,mol^{-1}}$ for $T'>263.15\,\mathrm{K}$)
R	rotation tensor ($=\mathsf{F}\cdot\mathsf{U}^{-1}=\mathsf{V}^{-1}\cdot\mathsf{F}$)
R	universal gas constant ($=8.314\,\mathrm{J\,mol^{-1}\,K^{-1}}$)
Ro	Rossby number [$=[U]/(2\Omega[L])$]
T	temperature
T_m	pressure melting temperature
T_0	melting temperature at standard pressure ($=273.15\,\mathrm{K}$)
T'	temperature relative to the pressure melting point ($=T-T_\mathrm{m}+T_0$)
T_cf	temperature at the calving front
T_gl	temperature at the grounding line

T_s	ice surface temperature
T_sea	temperature of sea water at the ice-sea interface ($\approx\ -2^\circ\mathrm{C}$)
U	right stretch tensor $[\,=(\mathsf{F}^\mathrm{T}\cdot\mathsf{F})^{1/2}\,]$
$[U]$	typical horizontal velocity
V	left stretch tensor $[\,=(\mathsf{F}\cdot\mathsf{F}^\mathrm{T})^{1/2}\,]$
V	activation volume
W	spin tensor $[\,=(\mathsf{L}-\mathsf{L}^\mathrm{T})/2\,]$
W	water content of temperate ice (mass fraction)
W_s	water content at the ice surface
$[W]$	typical vertical velocity
$\mathbf{X}$	position vector (in the reference configuration κ_r)
α	inclination angle
β	Clausius-Clapeyron constant $(\,=7.42\times10^{-8}\,\mathrm{K\,Pa^{-1}}$ for pure ice, $\;=9.8\;\;\times10^{-8}\,\mathrm{K\,Pa^{-1}}$ for air-saturated glacier ice)
$\gamma_{ij}\ \ (i\neq j)$	shear angle
$\dot\gamma_{ij}\ \ (i\neq j)$	shear rate
$\delta(\cdot)$	Dirac's delta function
δ_{ij}	Kronecker symbol
δ_sea	frictional dissipation at the sea side of the ice-sea interface
ϵ	infinitesimal strain tensor $[\,=(\mathsf{H}+\mathsf{H}^\mathrm{T})/2\,]$
ϵ^D	infinitesimal strain deviator $[\,=\epsilon-(\frac{1}{3}\,\mathrm{tr}\,\epsilon)\,\mathsf{I}\,]$
ε	aspect ratio ($=[H]/[L]=[W]/[U]$)
ε_{ijk}	Levi-Civita symbol
ζ	(1) bulk viscosity ($=\lambda+2\eta/3$) (2) vertical coordinate of the sigma transformation
η	shear viscosity
$\bar\eta$	depth-integrated shear viscosity
ι	constitutive parameter for the orientation transition rate
κ	(1) bulk modulus ($=\lambda+2\mu/3$) (2) heat conductivity in general (3) heat conductivity of ice ($=9.828\,e^{-0.0057\,T[\mathrm{K}]}\,\mathrm{W\,m^{-1}K^{-1}}$) (4) heat conductivity of firn (Sect. 9.2)
κ_r	reference configuration
κ_t	present configuration
λ	(1) 1^st Lamé parameter (2) viscosity coefficient (3) orientation diffusivity (Sect. 9.1)

μ	2^{nd} Lamé parameter (shear modulus)
ν	(1) Poisson's ratio (2) water diffusivity in temperate ice (Sect. 9.3)
ξ, φ	horizontal coordinates of the sigma transformation
ρ	(1) density in general (2) density of ice ($= 910\,\mathrm{kg\,m^{-3}}$) (3) density of firn (Sect. 9.2)
$\tilde{\rho}$	relative density of firn ($= \rho/\hat{\rho}_\mathrm{i}$)
$\rho^\star(\mathbf{n})$	orientation mass density
ρ_a	density of the asthenosphere ($= 3300\,\mathrm{kg\,m^{-3}}$)
ρ_i	partial density of ice in temperate ice
$\hat{\rho}_\mathrm{i}$	bulk density of ice ($= 910\,\mathrm{kg\,m^{-3}}$)
ρ_sw	density of sea water ($= 1028\,\mathrm{kg\,m^{-3}}$)
ρ_w	partial density of water in temperate ice
$\hat{\rho}_\mathrm{w}$	bulk density of water ($= 1000\,\mathrm{kg\,m^{-3}}$)
σ_e	effective stress
σ_0	residual stress
τ	time coordinate of the sigma transformation
τ_a	time lag of the relaxing asthenosphere ($\approx 3000\,\mathrm{a}$)
$\boldsymbol{\tau}_\mathrm{b}$, τ_b	basal drag (shear stress)
$\boldsymbol{\tau}_\mathrm{d}$	driving stress
$\boldsymbol{\tau}_\mathrm{sea}$	basal drag (shear stress) induced by circulating sea water
$\boldsymbol{\phi}$	flux density of arbitrary physical quantity
ψ	arbitrary scalar, vector or tensor field
ω	material volume in the present configuration κ_t
$\mathit{\Gamma}$	constitutive parameter for the orientation production rate
$\mathit{\Gamma}^\star(\mathbf{n})$	orientation production rate
$\mathit{\Delta}\zeta$	spacing of vertical coordinate ζ
$\mathit{\Delta}\xi$, $\mathit{\Delta}\varphi$	spacing of horizontal coordinates ξ and φ, respectively
$\mathit{\Delta}\tau$	spacing of time coordinate τ
$[\mathit{\Delta}T]$	typical temperature variation
$\mathit{\Phi}_n$	set of basis functions
$\boldsymbol{\Omega}$, $\mathit{\Omega}$	angular velocity of the Earth ($= 7.2921 \times 10^{-5}\,\mathrm{s^{-1}}$)
$\mathit{\Omega}$	material volume in the reference configuration κ_r

List of Acronyms

AGCM	Atmosphere General Circulation Model
AMSL	Above Mean Sea Level
CAFFE	Continuum-mechanical, Anisotropic Flow model, based on an anisotropic Flow Enhancement factor
CTS	Cold-temperate Transition Surface,
DA	Diffusive Asthenosphere
EAIS	East Antarctic Ice Sheet
EDML	EPICA ice core in Dronning Maud Land
EGIG	Expédition Glaciologique International au Grœnland
EISMINT	European Ice Sheet Modeling INiTiative
EL	Elastic Lithosphere
ELDA	Elastic Lithosphere / Diffusive Asthenosphere
ELRA	Elastic Lithosphere / Relaxing Asthenosphere
EPICA	European Project for Ice Coring in Antarctica
ETH	Eidgenössische Technische Hochschule (Swiss Federal Institute of Technology) Zurich
FESSACODE	Finite Element Shallow Shelf Approximation Code
FOA	First Order Approximation
FS	Full Stokes
GCM	General Circulation Model
GPS	Global Positioning System
GRIP	Greenland Ice Core Project
HEINO	Heinrich Event INtercOmparison
IAI	International Antarctic Institute
IPCC	Intergovernmental Panel on Climate Change

ISMIP	Ice Sheet Model Intercomparison Project
LGM	Last Glacial Maximum
LL	Local Lithosphere
LLDA	Local Lithosphere / Diffusive Asthenosphere
LLRA	Local Lithosphere / Relaxing Asthenosphere
MODIS	MODerate-resolution Imaging Spectroradiometer
NADW	North Atlantic Deep Water
NASA	National Aeronautics and Space Administration
ODE	Ordinary Differential Equation
ODF	Orientation Distribution Function
OGCM	Ocean General Circulation Model
OMD	Orientation Mass Density
QED	Quod Erat Demonstrandum (which was to be demonstrated)
RA	Relaxing Asthenosphere
RIGGS	Ross Ice Shelf Geophysical and Glaciological Survey
SGVE	Self-Gravitating, spherical, Visco-Elastic multi-layer
SIA	Shallow Ice Approximation
SICOPOLIS	SImulation COde for POLythermal Ice Sheets
SSA	Shallow Shelf Approximation
WAIS	West Antarctic Ice Sheet

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