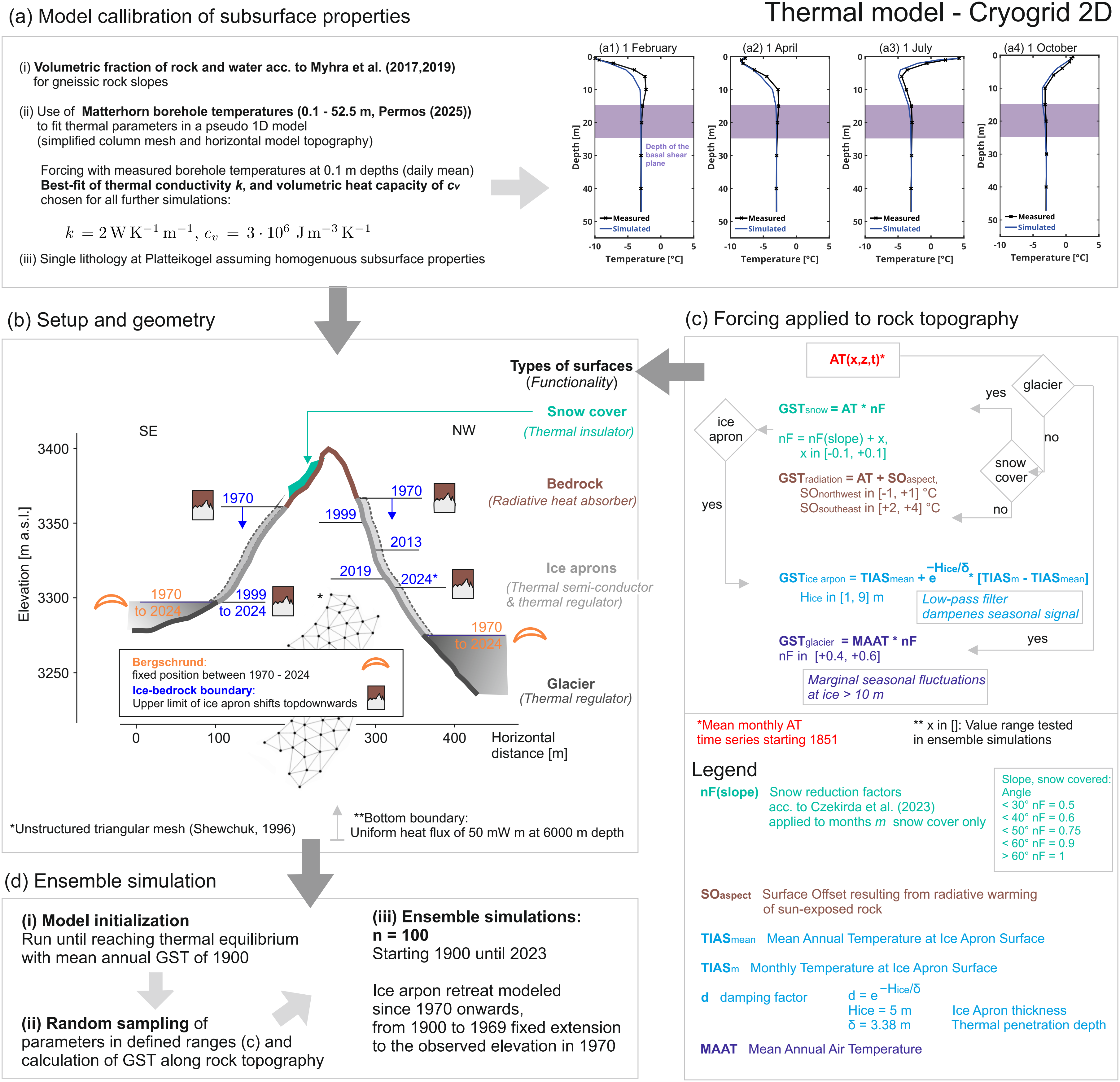

(a) Model callibration of subsurface properties
Thermal model - Cryogrid 2D
(i) Volumetric fraction of rock and water acc. to Myhra et al. (2017,2019)
for gneissic rock slopes
(ii) Use of Matterhorn borehole temperatures (0.1 - 52.5 m, Permos (2025))
to fit thermal parameters in a pseudo 1D model
(simplified column mesh and horizontal model topography)
Forcing with measured borehole temperatures at 0.1 m depths (daily mean)
Best-fit of thermal conductivity k, and volumetric heat capacity of cv
chosen for all further simulations:
$k = 2\,\mathrm{W\,K^{-1}\,m^{-1}},\ c_v = 3 \cdot 10^6\ \mathrm{J\,m^{-3}\,K^{-1}}$
(iii) Single lithology at Platteikogel assuming homogenuous subsurface properties
(a1) 1 February
(a2) 1 April
(a3) 1 July
(a4) 1 October
Depth [m]
Temperature [°C]
Depth of the basal shear plane
Measured
Simulated
(b) Setup and geometry
Types of surfaces
(Functionality)
Snow cover
(Thermal insulator)
Bedrock
(Radiative heat absorber)
Ice aprons
(Thermal semi-conductor & thermal regulator)
Glacier
(Thermal regulator)
SE
NW
Elevation [m a.s.l.]
Horizontal distance [m]
1970
1999
2013
2019
2024*
1970 to 2024
1999 to 2024
Bergschrund:
fixed position between 1970 - 2024
Ice-bedrock boundary:
Upper limit of ice apron shifts topdownwards
*Unstructured triangular mesh (Shewchuk, 1996)
**Bottom boundary:
Uniform heat flux of 50 mW m at 6000 m depth
(c) Forcing applied to rock topography
AT(x,z,t)*
glacier
yes
no
snow cover
ice apron
GSTsnow = AT * nF
nF = nF(slope) + x,
x in [-0.1, +0.1]
GSTradiation = AT + SOaspect,
SOnorthwest in [-1, +1] °C
SOsoutheast in [+2, +4] °C
GSTice arpon = TIASmean + e^(−Hice/δ) * [TIASm - TIASmean]
Hice in [1, 9] m
Low-pass filter dampenes seasonal signal
GSTglacier = MAAT * nF
nF in [+0.4, +0.6]
Marginal seasonal fluctuations at ice > 10 m
*Mean monthly AT
time series starting 1851
** x in []: Value range tested
in ensemble simulations
Legend
nF(slope) Snow reduction factors
acc. to Czekirda et al. (2023)
applied to months m snow cover only
Slope, snow covered:
Angle
< 30° nF = 0.5
< 40° nF = 0.6
< 50° nF = 0.75
< 60° nF = 0.9
> 60° nF = 1
SOaspect Surface Offset resulting from radiative warming
of sun-exposed rock
TIASmean Mean Annual Temperature at Ice Apron Surface
TIASm Monthly Temperature at Ice Apron Surface
d damping factor
d = e^(−Hice/δ)
Hice = 5 m Ice Apron thickness
δ = 3.38 m Thermal penetration depth
MAAT Mean Annual Air Temperature
(d) Ensemble simulation
(i) Model initialization
Run until reaching thermal equilibrium
with mean annual GST of 1900
(ii) Random sampling of
parameters in defined ranges (c) and
calculation of GST along rock topography
(iii) Ensemble simulations:
n = 100
Starting 1900 until 2023
Ice arpon retreat modeled
since 1970 onwards,
from 1900 to 1969 fixed extension
to the observed elevation in 1970