Supplement of The Cryosphere, 15, 4465–4482, 2021
https://doi.org/10.5194/tc-15-4465-2021-supplement

The Cryosphere
Open Access

Supplement of

Mapping seasonal glacier melt across the Hindu Kush Himalaya with time series synthetic aperture radar (SAR)

Corey Scher et al.

Correspondence to: Nicholas C. Steiner (nsteiner@ccny.cuny.edu)

S1 Supplemental Materials

S1.1 Surface Energy Balance Modelling

Measurements from two automated weather stations (AWS) are used to estimate surface energy balance (SEB) and evaluate surface melting conditions over high elevation glaciers. A time series of daily averaged SEB inputs for the Camp II and South Col AWS are shown in Figure S1.

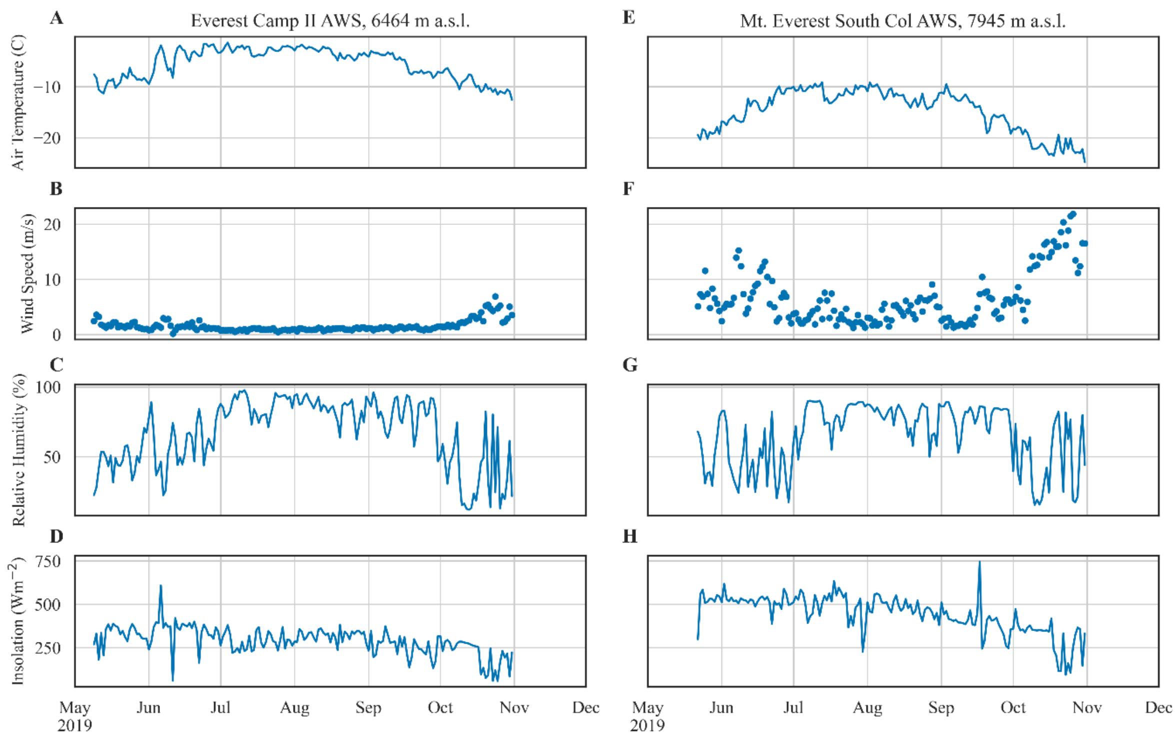

Figure S1: The daily averaged measurements from the Everest Camp II AWS from May to November 2019, used in SEB modelling: (A) air temperature, (B) wind speed, (C) relative humidity, (D) and solar insulation. Similarly, AWS for the South Col AWS station include: (E) air temperature, (F) wind speed, (G) relative humidity, (H) and solar insulation.

We estimate the timing of glacier melting at the Camp II and South Col AWS using measurements and SEB modelling. The conservation of energy requires a balance between surface energy that is incoming, outgoing and absorbed. The SEB is computed as the sum of the following surface flux terms:

$$0 = Q_{SW} + Q_{LW} + Q_H + Q_L + Q_G + Q_M \tag{1}$$

Here, Q_{SW} and Q_{LW} are the net shortwave and longwave radiation fluxes. The Q_{SW} is computed using measurements of solar insolation and a constant albedo (α). The Q_{LW} is computed as the difference between measurements of incoming longwave radiant flux at the sensor and outgoing longwave flux computed using surface temperatures and a constant emissivity (ε). The sensible and latent heat flux are Q_H and Q_L, respectively. The glacial heat flux is Q_G and the heat energy available for melting is Q_M. These values are determined using constants and methods used in Matthews, et al (2020) and listed in Table SI.

Table SI: Constant parameters in SEB include aerodynamic roughness (z_0), surface albedo (α), the bulk density of the upper layer of snow/ice (ρ_s), the surface layer thickness (d_s), and emissivity(ε).

Constant	Value	Unit
z_0	$0.9\text{x}10^{-3}$, $5.70\ \text{x}10^{-3}$, $2.7\text{x}10^{-3}$	m
α	0.8	-
ρ_s	530	kg/m^3
d_s	10	cm
ε	0.98	-

A time series of surface fluxes for the Camp II and South Col AWS are shown Figure S2.

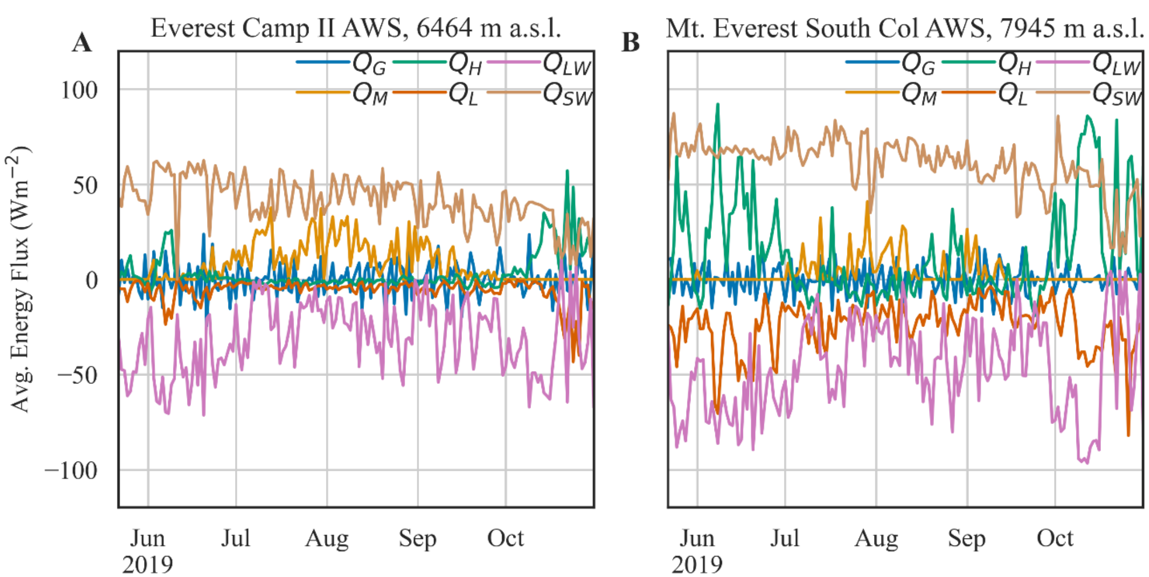

Figure S2: (A) Surface energy fluxes at the Everest Camp II AWS. (B) and at the South Col AWS.

Surface temperatures (T_s) are computed from the residual downward glacier heat flux, Q_G, and evolved from air temperatures using the iterative approach from Wheler and Flowers (2011).

$$\Delta T_s = \frac{Q_G}{\rho_s c_s d_s}\ \Delta t \tag{S2}$$

Here, ρ_s is the bulk density of the upper layer of snow/ice, d_s is surface layer thickness, c_s is the specific heat capacity of ice (2097 J/kg/K), and Δt is the model time-step (120 seconds). A time series of surface temperatures computed using SEB for the Camp II and South Col AWS are shown in Figure S3.

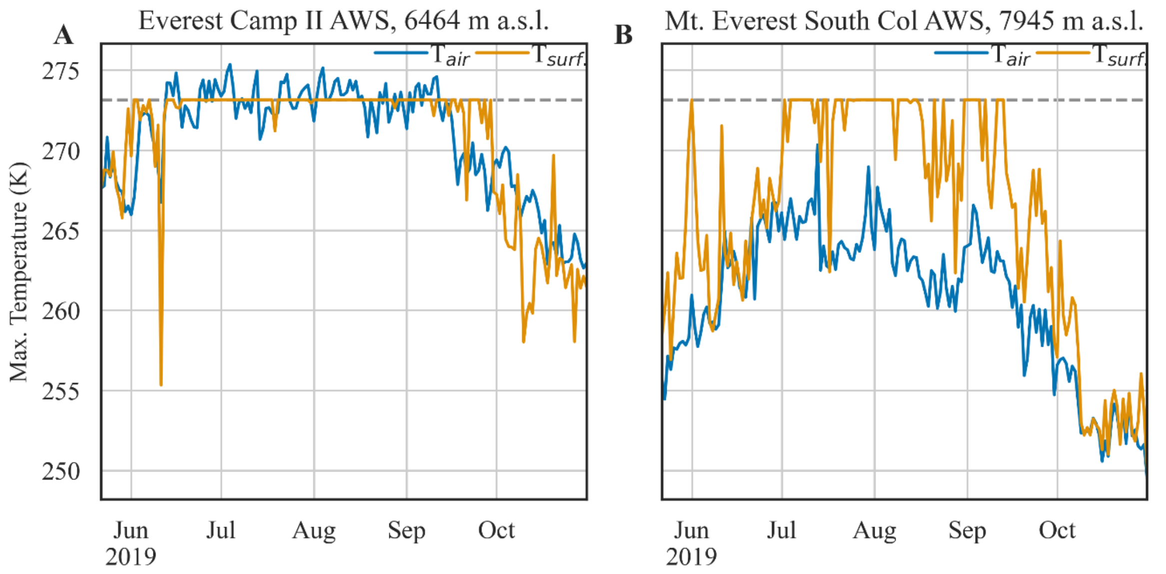

Figure S3: (A) Daily maximum measured air temperatures (T_{air}) and modelled surface temperatures (T_{surf}), in relation to the freezing point, at the Everest Camp II AWS (B) and at the South Col AWS.

S2 Supplemental Results

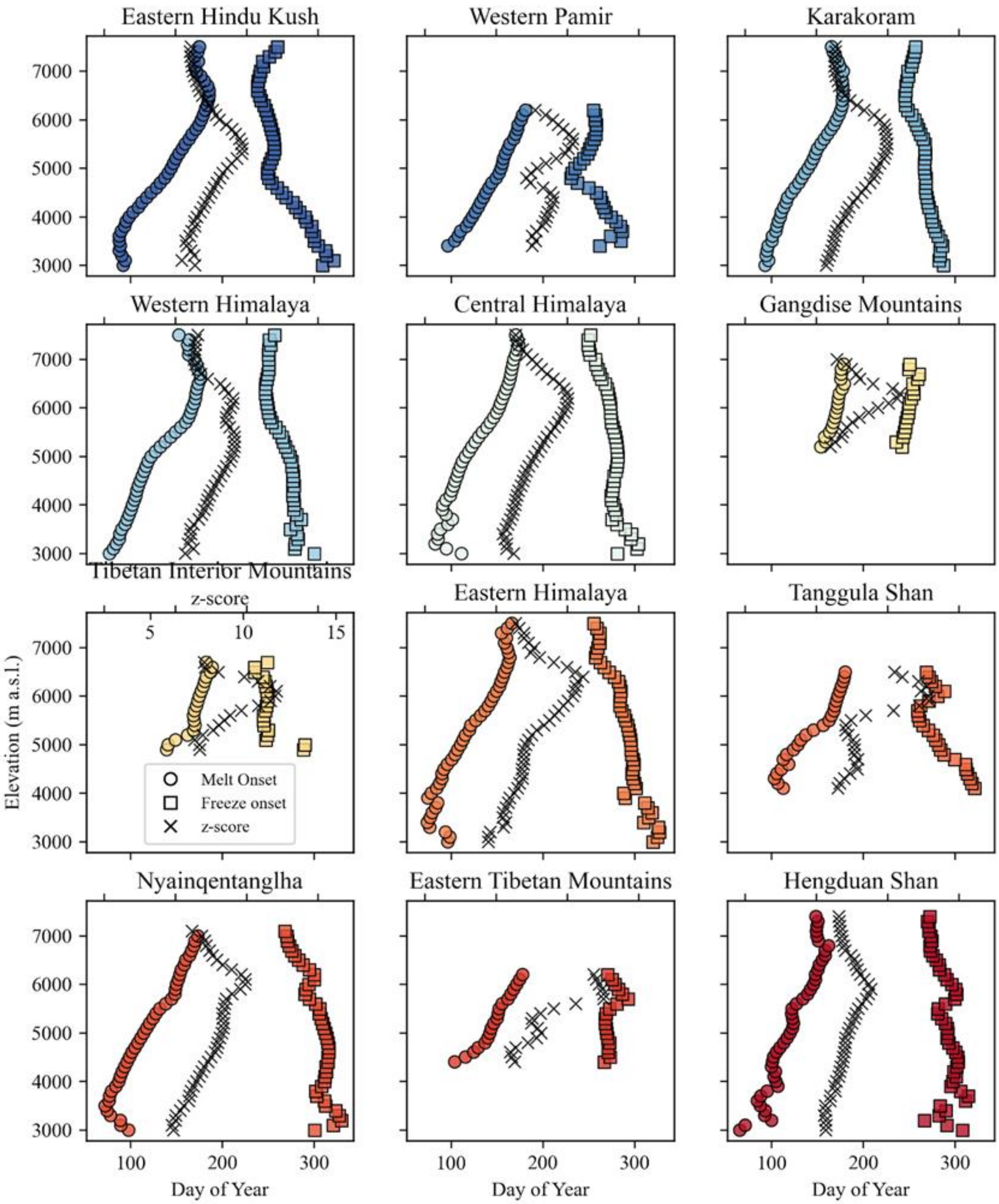

Figure S4: Melt onset (MO), freeze onset (FO), and z-score averaged over 100m elevation bins using the 30m SRTM digital elevation model (Farr, 2007b) and delineations of 12 glacio-climate subregions identified in Bolch, et al. (2019). Z-score maxima across subregions largely correspond to elevation ranges of delayed refreeze.

References

Matthews, T., Perry, L. B., Koch, I., Aryal, D., Khadka, A., Shrestha, D., ... & Mayewski, P. A. (2020). Going to extremes: installing the world's highest weather stations on Mount Everest. Bulletin of the American Meteorological Society, 101(11), E1870-E1890., https://doi.org/10.1175/BAMS-D-19-0198.1

Wheler, B. A., & Flowers, G. E. (2011). Glacier subsurface heat-flux characterizations for energy-balance modelling in the Donjek Range, southwest Yukon, Canada. Journal of Glaciology, 57(201), 121-133, https://doi.org/10.3189/002214311795306709