Table S1: The characteristics of GTN-P sites used in this study. The soil temperature measurements were available at different depths for each site, ranging from 0.01m to 1m, and may change during the observational period. The data were resampled to similar depths before analysis. The vegetation type at those sites are dominated by tundra.

Site name	ID	Location	Elevation (m)	Temporal period*
West Dock (old instrument)	WD1	148.552°W, 70.374°N	3	2005-2015
West Dock (New Instrument)	WDN	148.552°W, 70.374°N	3	2009-2015
Deadhorse	DH	148.465°W, 70.161°N	16	2006-2014
Deadhorse 1	DH1	148.466°W, 70.162°N	16	2010-2015
Franklin Bluffs (dry)_b	FBD	148.721°W, 69.674°N	123	2007-2015
Franklin Bluffs (surface)	FBW	148.722°W, 69.655°N	130	2001-2015
Franklin Bluffs (wet)_b	FB1	148.722°W, 69.655°N	130	2007-2015
Sagwon MAT	SagMAT	148.7°W, 69.428°N	278	2007-2015
Sagwon MNT	SagMNT	148.674°W, 69.433°N	278	2005-2015
Happy Valley 1_b	HV1(b)	148.848°W, 69.147°N	309	2009-2015
Happy Valley 1_ib	HV1(ib)	148.848°W, 69.147°N	309	2009-2015
Imnaviat 1	IM1	149.352°W, 68.640°N	298	2007-2015
Galbraith Lake	GL	149.502°W, 68.477°N	316	2005-2015

***** missing data may exist during the observational period.

Table S2: Mean bias and RMSE values (unit: days) of model simulated and in-situ observed zero-curtain period at the two Prudhoe Meadow SoilSCAPE nodes (S5 & S6) from 2016 to 2017. The zero-curtain period was determined using a similar cutoff value, i.e. δ [Eq. 9], for both in-situ dielectric constant observations and model simulated unfrozen water content. The statistics were averaged for all soil depths (from 13 cm to 55 cm below soil surface). The SoilSCAPE measurements were resampled to the model soil depth (13cm, 23cm, 33cm, 45 cm and 55cm) before comparison.

	cutoff = 0.1		cutoff = 0.15		cutoff = 0.2	
	Bias	RMSE	Bias	RMSE	Bias	RMSE
2016	-8.3	15.9	-6.6	9.0	5.0	11.0
2017	12.9	15.1	10.2	11.7	26.2	27.1

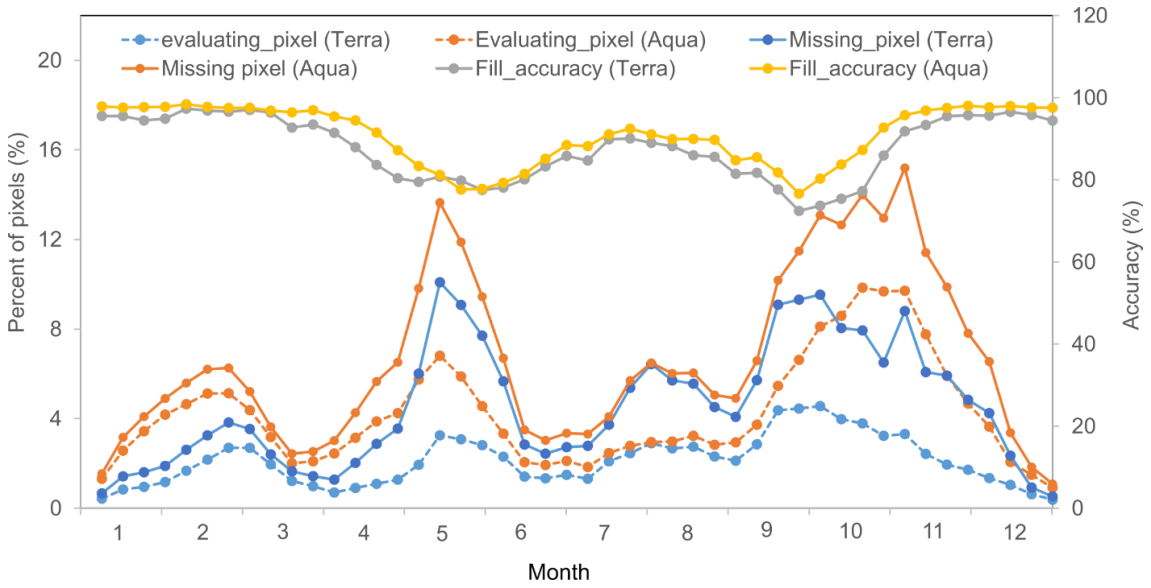


Figure S1: The accuracy of the spatial filter algorithm that was used to fill the cloud contaminated pixels in the MODIS SCE data. The percentage of total cloud contamined pixels was shown as "Missing pixel". Terra MODIS SCE data were used to evaluate the accuracy of filling pixels in Aqua MODIS SCE data, and vice versa. The percentage of pixels that were cloud covered in Terra (or Aqua) but were clear in Aqua (or Terra) was shown as "evaluating pixel". Generally, Aqua MODIS shows a greater cloud coverage than Terra MODIS.

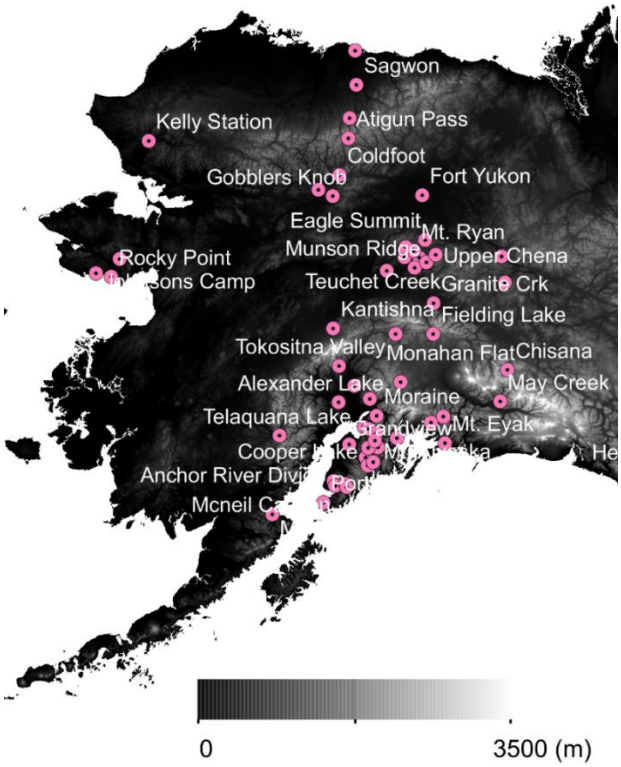


Figure S2: The locations of SNOTEL sites in Alaska.

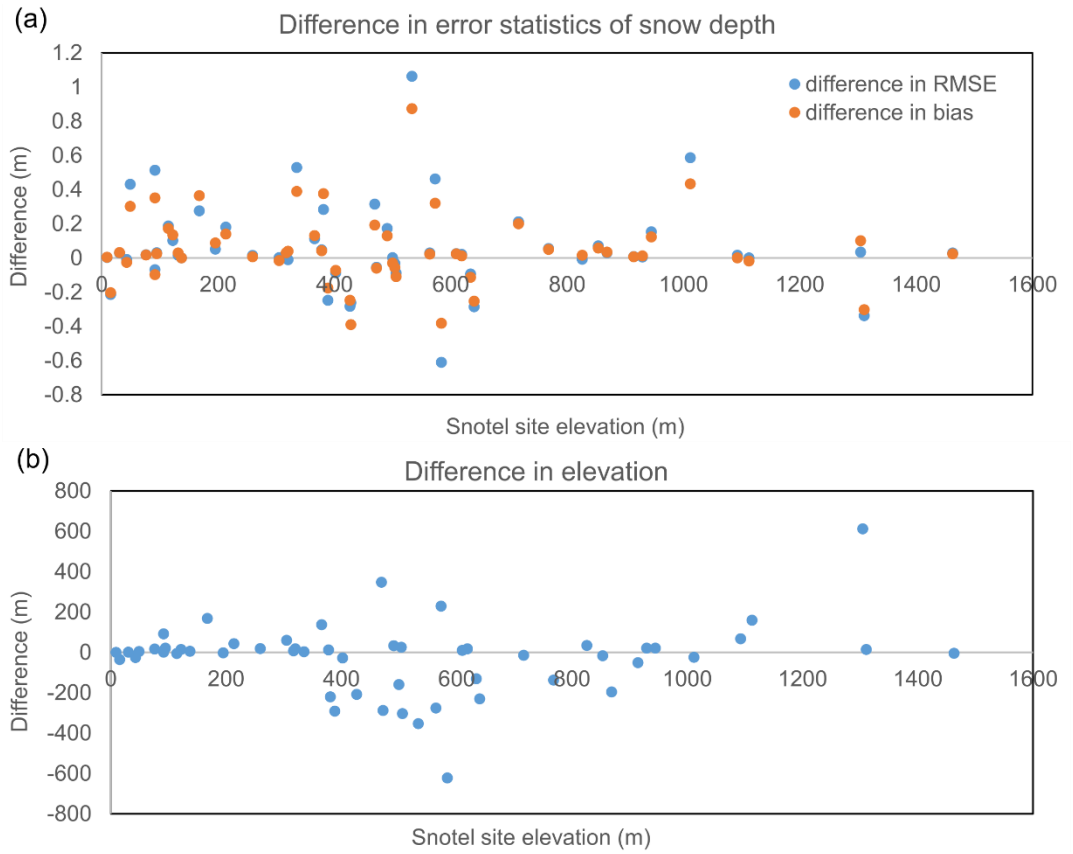


Figure S3: a) The difference in error statistics of the snow depth data derived from the two studies (Yi et al. 2018 versus this study) against SNOTEL in-situ measurements. A positve difference in RMSE or bias indicates lower errors of the snow depth estimates using the downscaling scheme developed in this study. b) The difference between the in-situ elevation recorded at the SNOTEL sites, and the elevation exacted from the USGS DEM data (used for the downscaling scheme) at the 1-km grid encompassing the site.

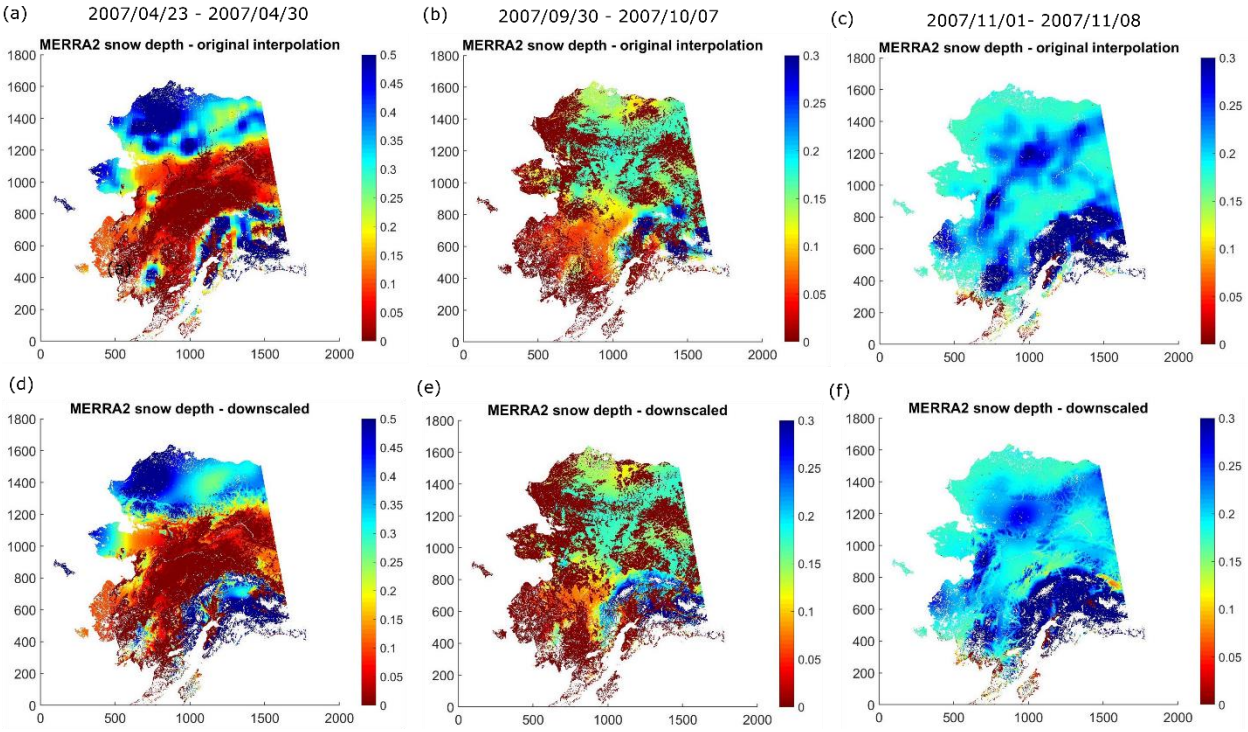


Figure S4: Comparings of interpolated MERRA-2 snow depth data (1-km) at different seasons using different spatial interpolation schemes: a-c) original spatial interpolation scheme (Yi et al., 2018); d-f) the downscaling scheme developed in this study.

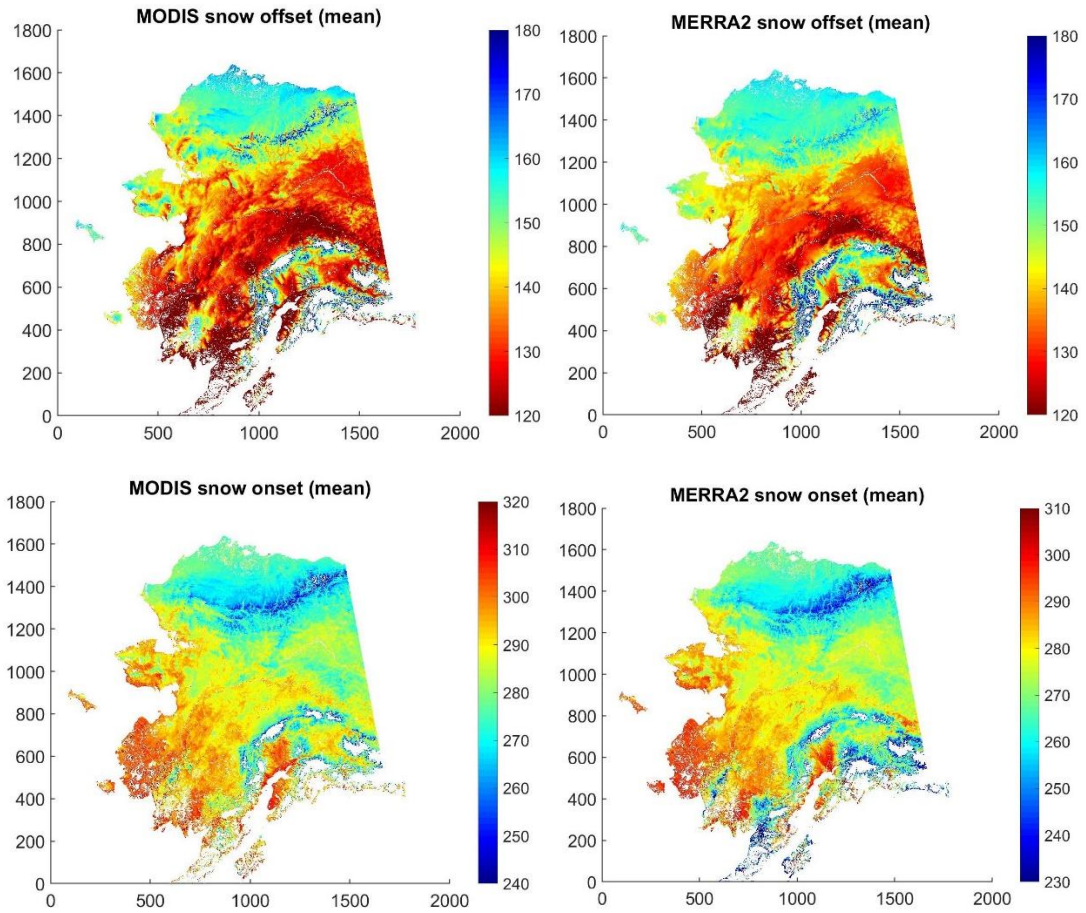


Figure S5: Comparisons of mean snow offset and onset derived from MODIS SCE data and downscaled MERRA-2 snow depth data averaged from 2001 to 2016.

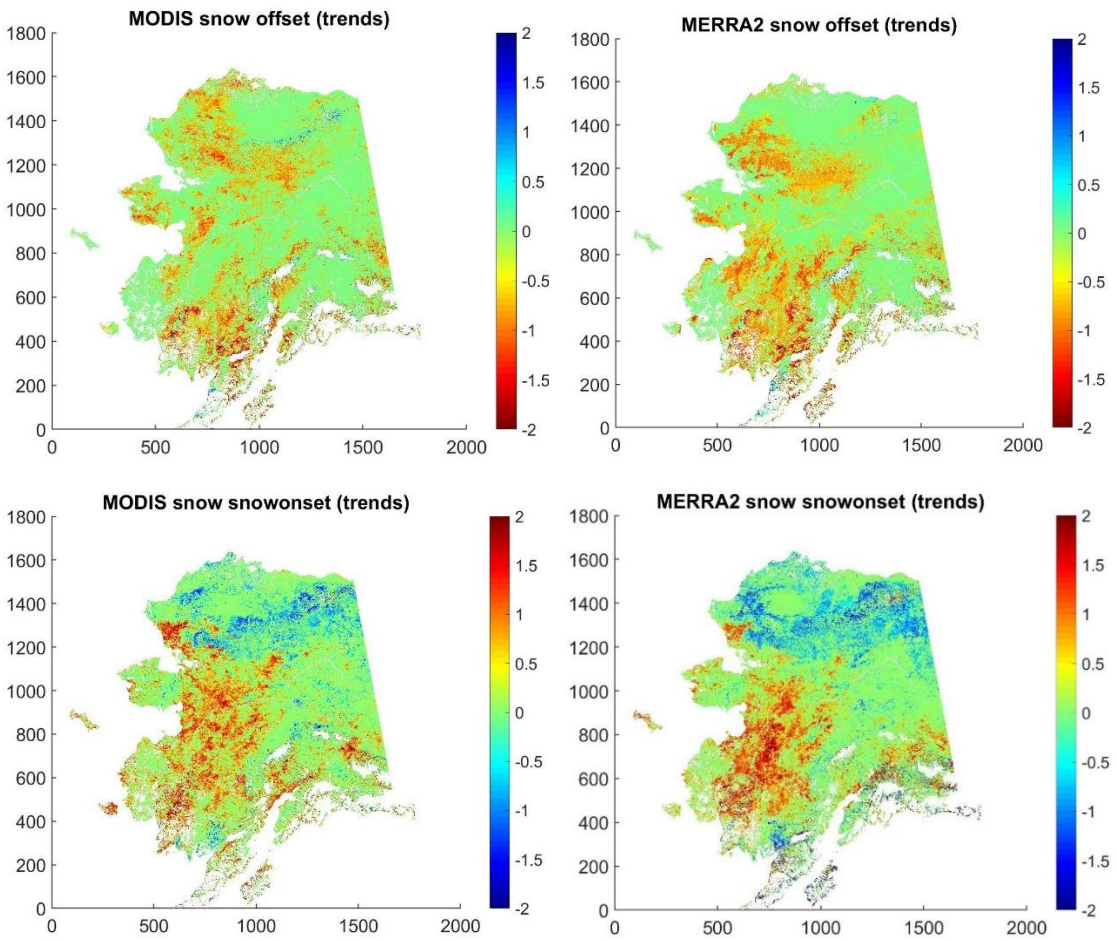


Figure S6: Comparisons of the trends of snow offset and onset derived from MODIS SCE and downscaled MERRA-2 snow depth data averaged from 2001 to 2016.

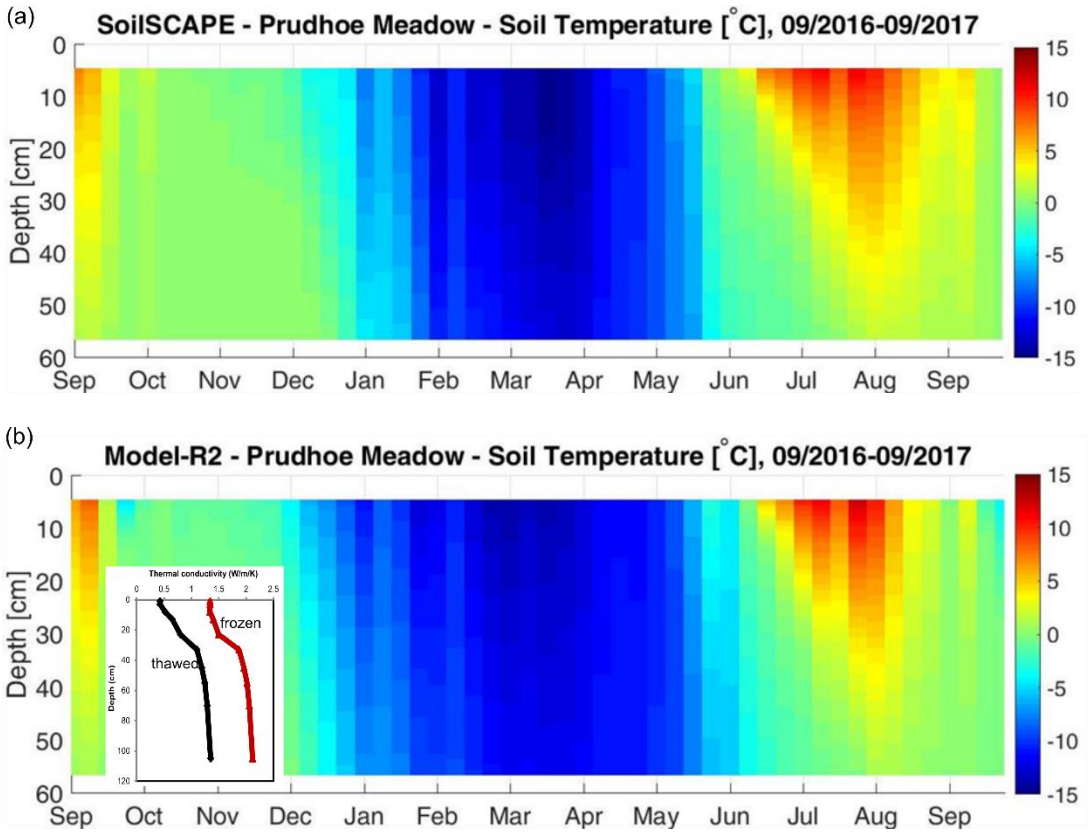


Figure S7: Comparisons of model simulated versus in-situ observed soil temperature time series at the Prudhoe Meadow SoilSCAPE site (S6). Both the in-situ observations and model simulations were plotted at 8-day time step. The model simulations are highly correlated with in-situ data (R>0.97 for all layers), with RMSE values of 2.24 °C (0.05m), 1.60 °C (0.15m), 1.41 °C (0.35m) and 1.30 °C (0.56m). The insert panel is the calibrated soil thermal conductivity profile (0-1m) for thawed (black) and frozen state (red).

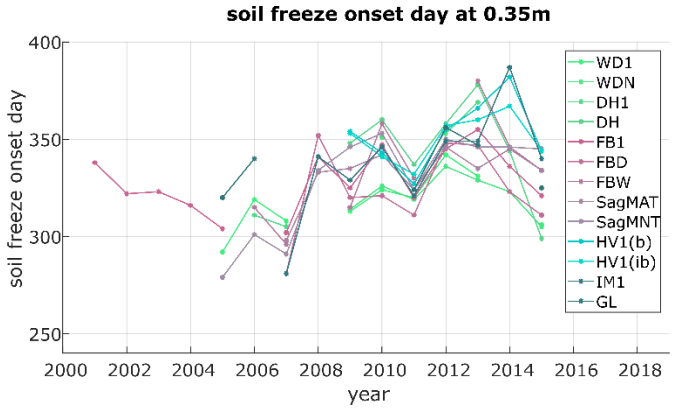


Figure S8: The time series of soil freeze onset at depth of 0.35 m derived from soil temperature measurements at GTN-P sites along the DHN transect.

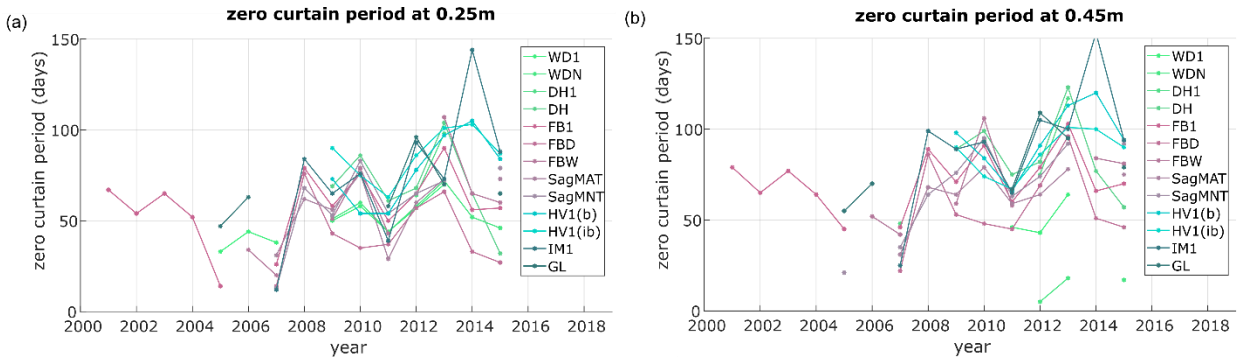


Figure S9: The time series of zero-curtain period at depths of 0.25 m (a) and 0.45 m (b) derived from soil temperature measurements at GTN-P sites along the DHN transect.

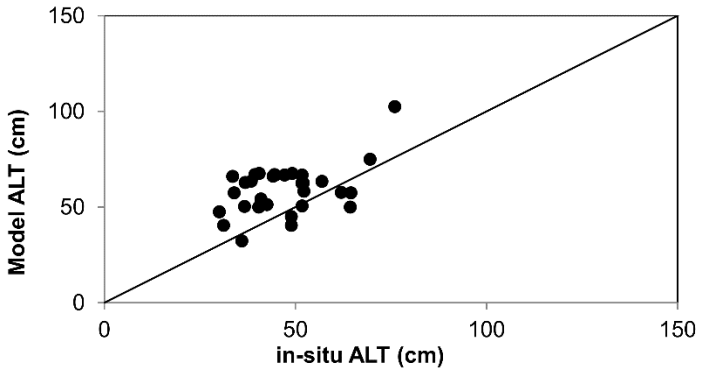


Figure S10: Comparisons of model simulated and observed mean ALT from CALM sites in Arctic Alaska spanning the period from 2001 to 2016.

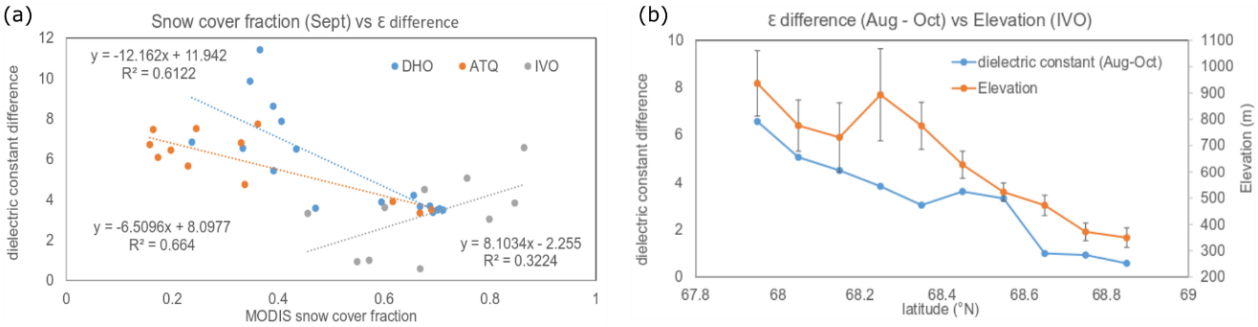
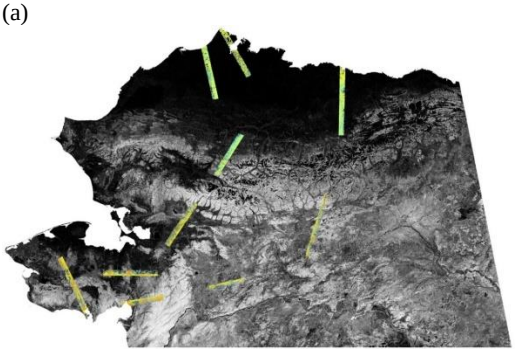


Figure S11: (a) Variations of changes in radar retrieved dielectric constant (ε1) of surface soils between August and early October (August – October) with MODIS SCE in September across 3 radar flights in Arctic Alaska in 2015; b) the latitudinal variations of changes in radar ε1 and elevation at the Ivotuk (IVO) radar flight.

(a)



(b)

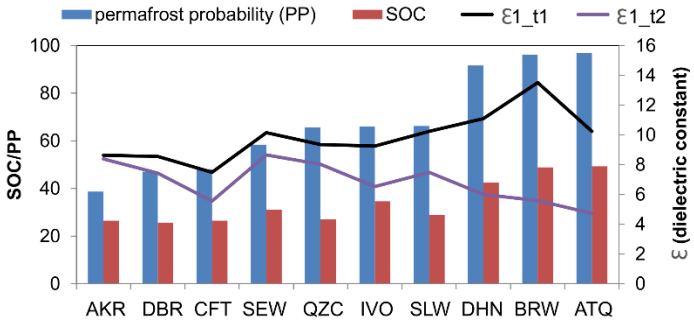


Figure S12: Variations of the radar retrieved surface soil dielectric constant (ε1) in August and October with changes in permafrost probability and soil organic carbon content across the regional AirMOSS P-band radar flight transects in Alaska. The location of the radar flights is shown in panel (a). The radar data were acquired from August and early October 2015. ε1_t1 and ε1_t2 represent the surface soil dielectric constant retrievals in August and October respectively. The three flight transects (DHN, BRW and ATQ) with highest permafrost probability were located in the Alaska North Slope.

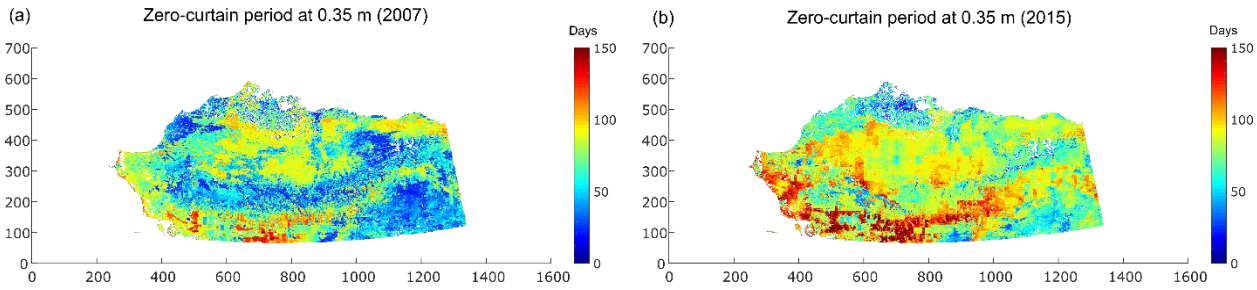


Figure S13: The model simulated zero-curtain period at depth of 0.35m across Arctic Alaska in 2007 and 2015.

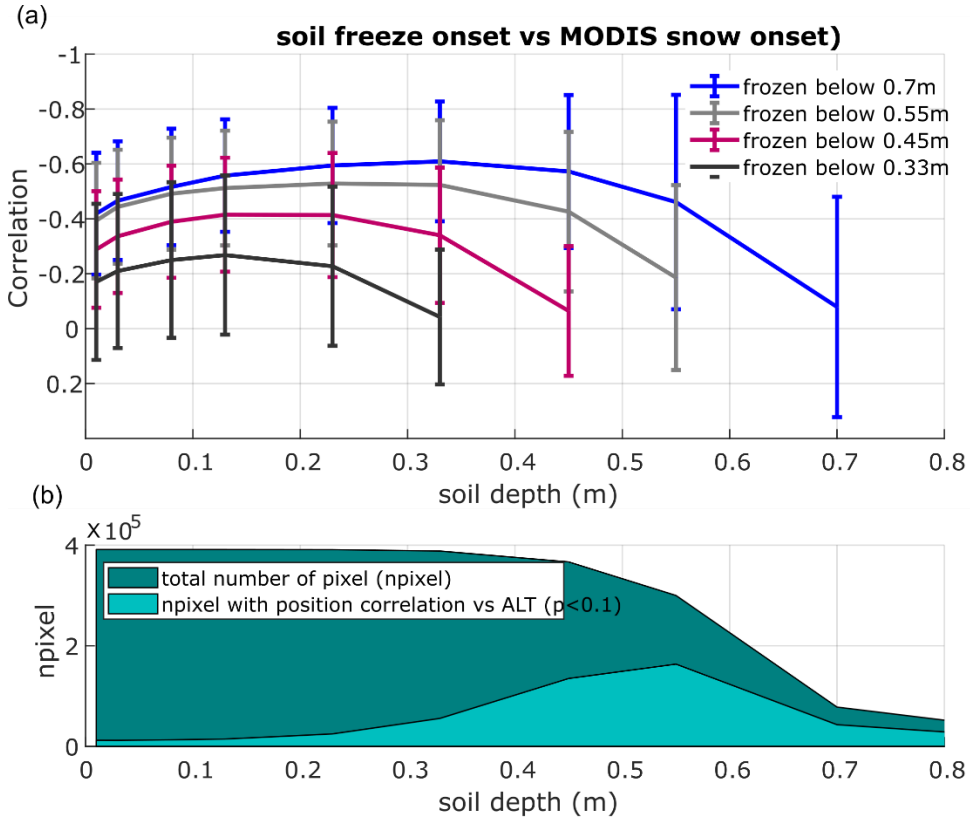


Figure S14: Sensitivity of model simulated soil freeze onset at different depths to MODIS snow onset and model simulated ALT: a) changes in correlations between snow onset and soil freeze onset with depths. The study area was divided into 4 groups: soil column froze below 0.33 m, 0.45 m, 0.55 m, and 0.7 m. The soil column of the majority of the study area froze below 0.7m. b) the proportion of pixels with significant positive correlation between soil freeze onset and ALT at different depths. The total number of unfrozen pixel was shown as "npixel". The correlations in both (a) and (b) were calculated for the period from 2001 to 2016.