Validation of the GEOtop Model in a Continuous Permafrost Basin in the Arctic

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Abstract

GEOtop 1.145 is used to model the thermal and hydrological state of the subsurface in the Kuparuk basin, Alaska. GEOtop is a distributed hydrological model with coupled water and energy budgets. The surface energy balance scheme includes sensible, latent and radiative heat fluxes at the air-soil or air-snow interface. The subsurface represents heat fluxes in the vertical and water fluxes in the vertical and horizontal directions. The ERA-Interim atmospheric reanalysis product, which is used to force the model, is compared to meteorological and radiation data from the Kuparuk Basin and other stations on the North Slope of Alaska. The use of ERA-Interim reanalysis to force GEOtop enables large-scale simulations to be performed over areas where in situ meteorological data is sparse, such as the North Slope of Alaska. Model simulations forced by ERA-Interim reanalysis data are validated using borehole observations of soil temperature. Model results will be presented demonstrating the interactions between soil properties, snow cover, vegetation and climate.

GEOtop Model

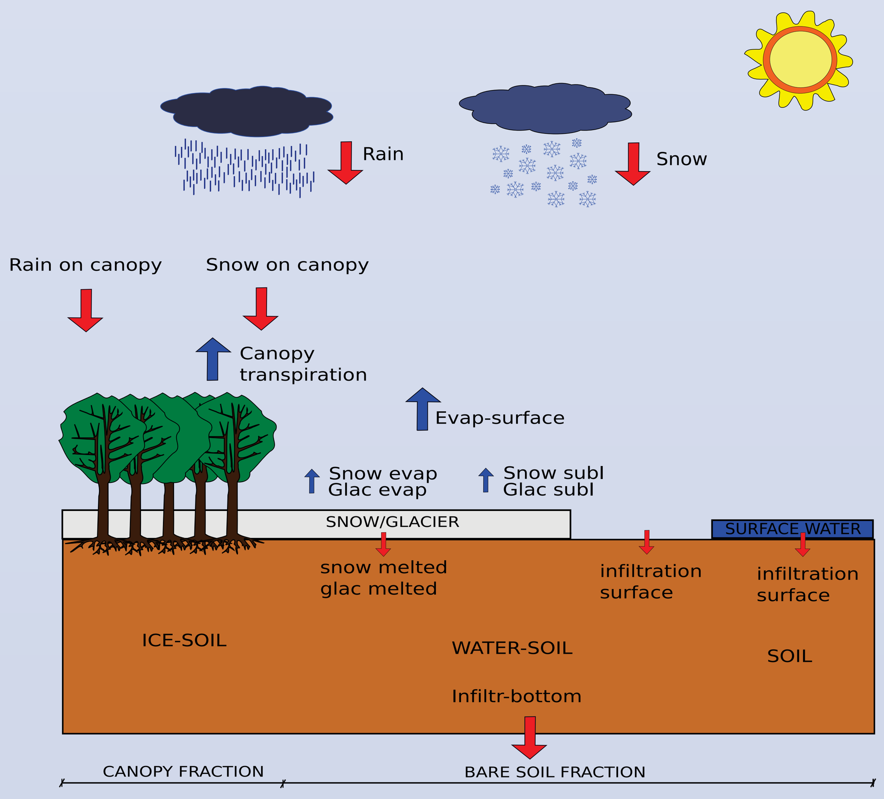


Figure 1: Schematic of GEOtop Model.

Time scales	Time Step	Length Scales	Grid size
1 month - 100 years	1 hour	1-10,000 km^2	1-1000 m

GEOtop is a distributed hydrological model, which has been developed over the past ten years, originally at the Department of Civil and Environmental Engineering of the University of Trento. GEOtop (Bertoldi, 2004; Bertoldi et al., 2006; Rigon et al., 2006; Zanotti et al., 2004) includes a three-dimensional representation of water fluxes in the soil and a one-dimensional description of the energy exchanges at the soil-atmosphere interface. In addition, it includes a detailed representation of the topographic controls on solar radiation. GEOtop has been developed in the past two years to improve the energy balance description and the snow cover module, which now solves the snow energy and water balance in a fully coupled way in a multilayer representation of the snowpack (Endrizzi, 2007). It solves the heat equation using the Crank-Nicolson method and the apparent heat capacity parameterisation method for simulating latent heat has been implemented.

Model Input Parameters

Atmospheric Forcing

ERA-interim reanalysis atmospheric data is used to force the model (inputs required are air temperature, humidity, wind velocity, precipitation, shortwave and longwave radiation) providing a continuous dataset over time (1989-present) and space (resolution of 1.5°).

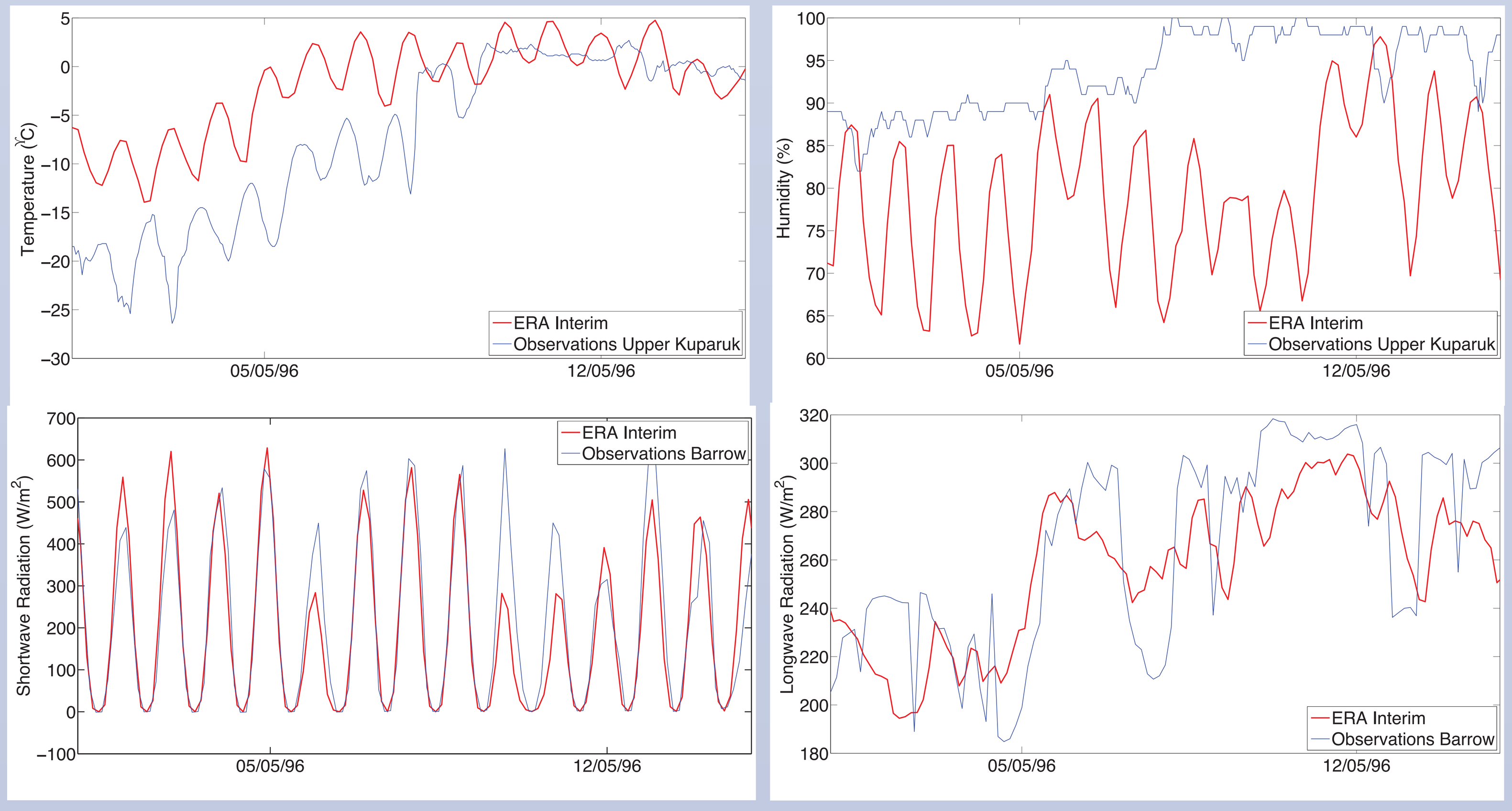
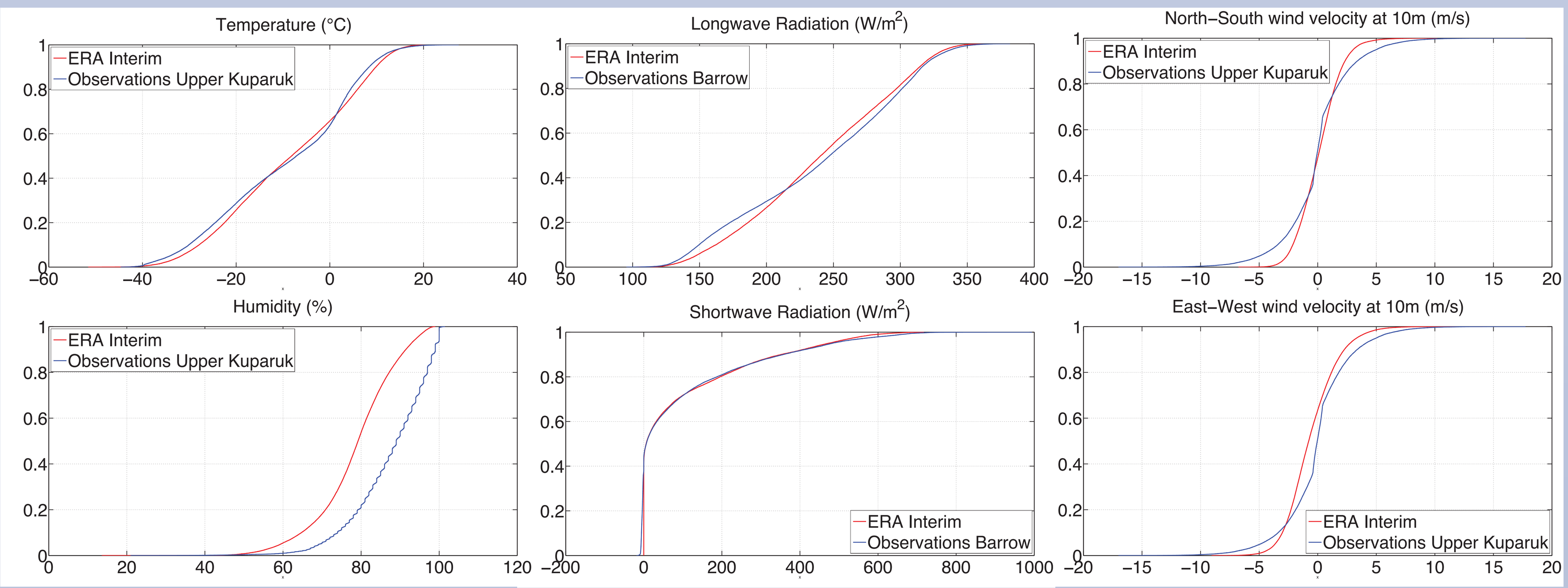


Figure 2: Comparison of ERA interim reanalysis variables with observations from a meteorological station located in Imnavait Basin (Kane & Hinzman, 2011).



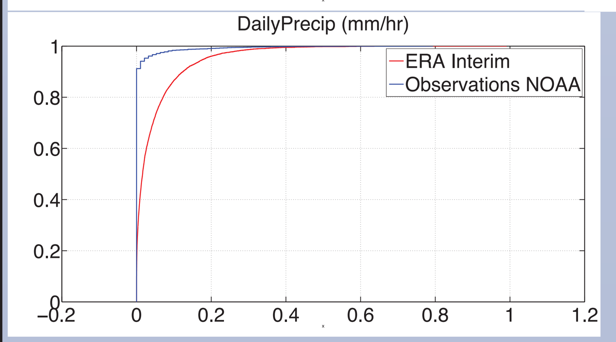


Figure 3. The cumulative density function of the seven atmospheric parameters that force the model ares shown for both ERA-interim reanalysis data and observations. The ERA-interim reanalysis compares well with negligible bias for temperature, longwave and shortwave radiation, a small bias in wind velocity (at higher wind speeds), and a more significant bias in humidity and precipitation. The bias in precipitation from ERA-interim reanalysis compared to observations can be explained, at least in part, by observational underestimation of precipitation due to the technical difficulties of measuring snowfall.

Soil Properties

The soils in the Imnavait Basin have been described as Histic Pergelic Cryaquepts (Hinzman et al., 1991) and are composed of (from the surface downwards) approximately 10 cm of live and dead organic matter, then 5-10 cm of a mixture of partially decomposed organic matter and silt, then a layer of glacial till. The organic soil is porous and saturates and drains quickly, however the mineral soil is usually saturated.

Depth of soil layer (cm)	0-5	5-10	10-15	15-20	20-25	25-40	40-2000
Soil type	Organic	Organic	Organic	Organic	Mineral	Mineral	Mineral
Heat Capacity (Jkg^{-1}K^{-1})	1x10^5	1x10^5	1x10^5	1x10^5	1x10^6	1x10^6	1x10^6
Thermal Conductivity (Wm^{-1}K^{-1})	0.04	0.04	0.04	0.04	0.8	0.8	0.8
Hydraulic Conductivity (cm/s)	19.4	10.4	3.76	0.87	1.42	0.94	0.94

Table 1. Thermal and hydraulic properties of modelled soil profile, which is assumed to have a 20 cm organic layer above mineral soil. 16 layers are modelled in total with a layer thickness of 10 mm at the surface, and the base layer with a thickness of 10 m. The total modelled depth is 20 m.

Map of Study Area: Imnavait Basin

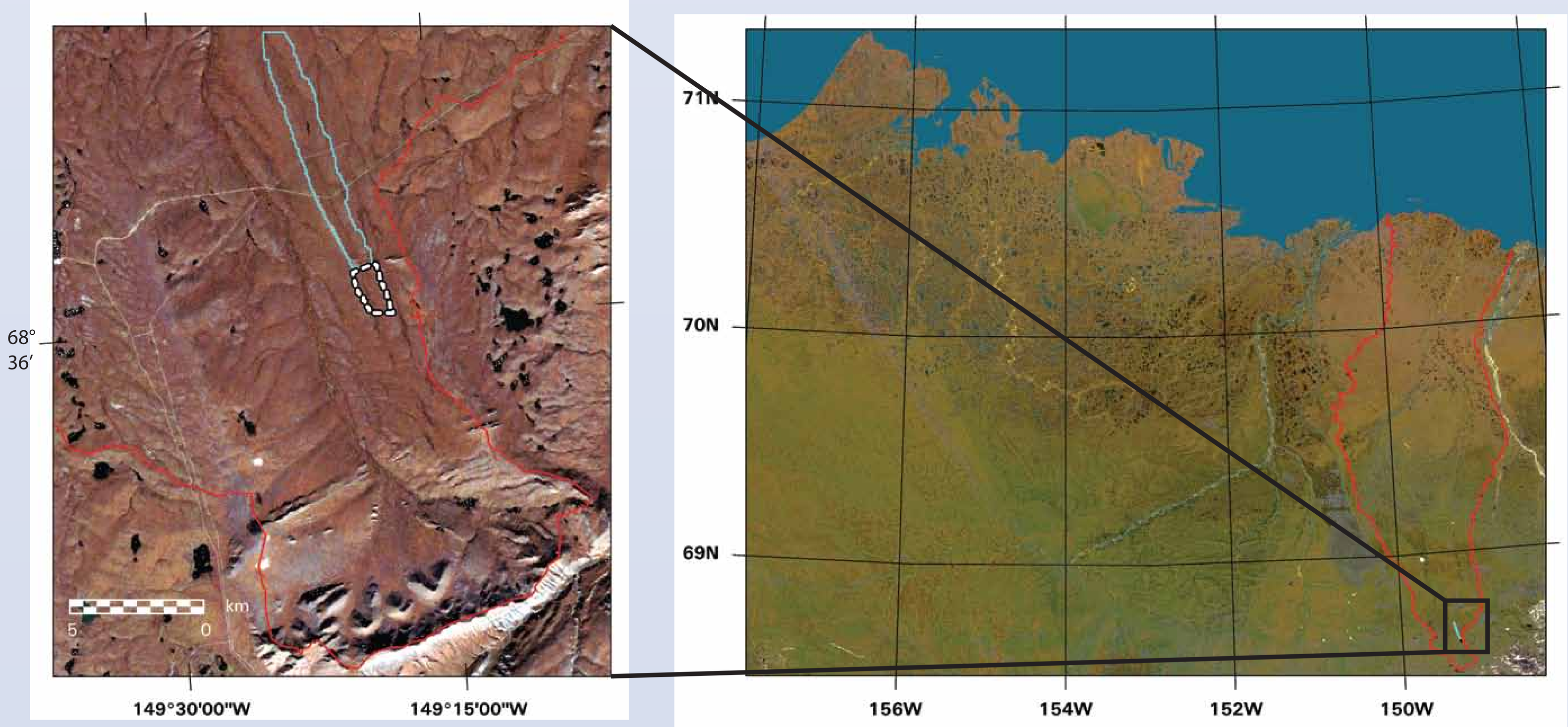


Figure 4: Map showing the Kuparuk Basin (red outline) and the Imnavait Basin (blue outline, inset). 3D simulation performed at 30 m resolution over 2km^2 basin.

Model Results

Figure 5: (a) Spin up of soil temperature (b) Soil temperature 1989-2009 (c) Input air temperature (d) Modelled snow depth

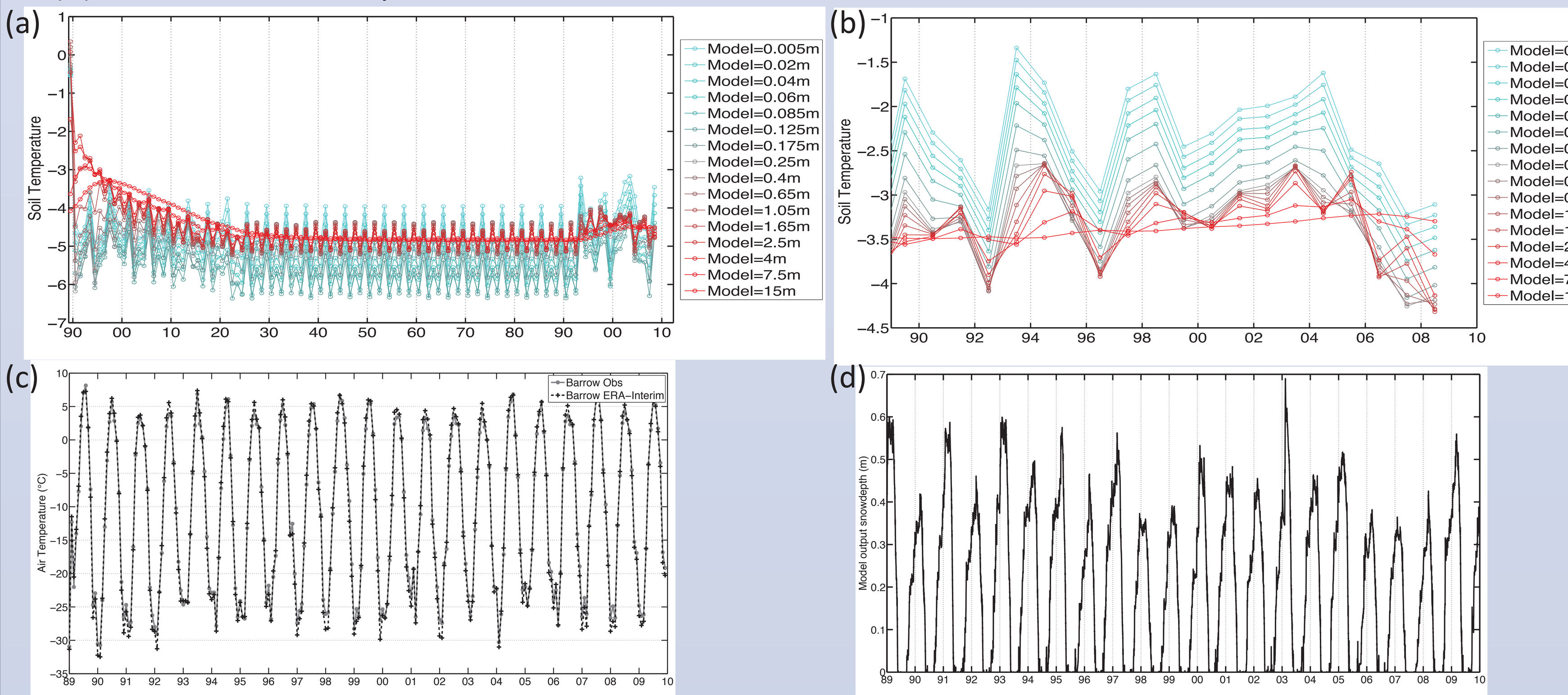
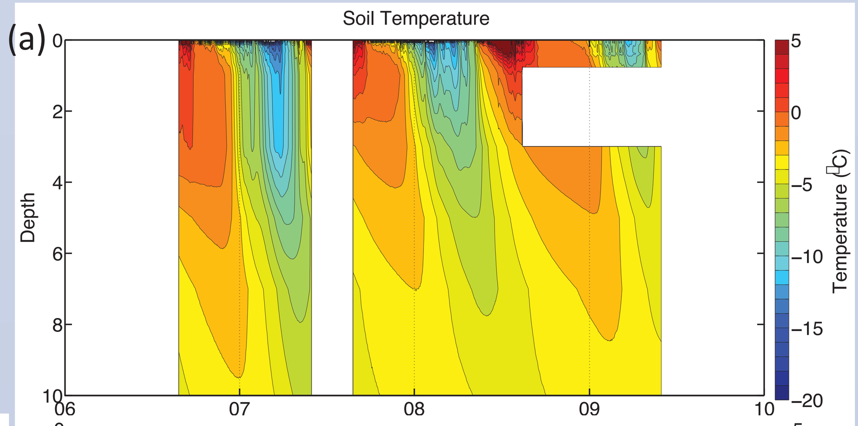


Figure 6. Depth vs time plots from 2006-2009 (a) Observations collected by Romanovsky et al. (NSF projects ARC-0520578 and ARC-0632400) at Imnavait (b)-(c) Point simulation & 3D simulation of soil temperature (d)-(e) Point simulation & 3D difference between model and observations.



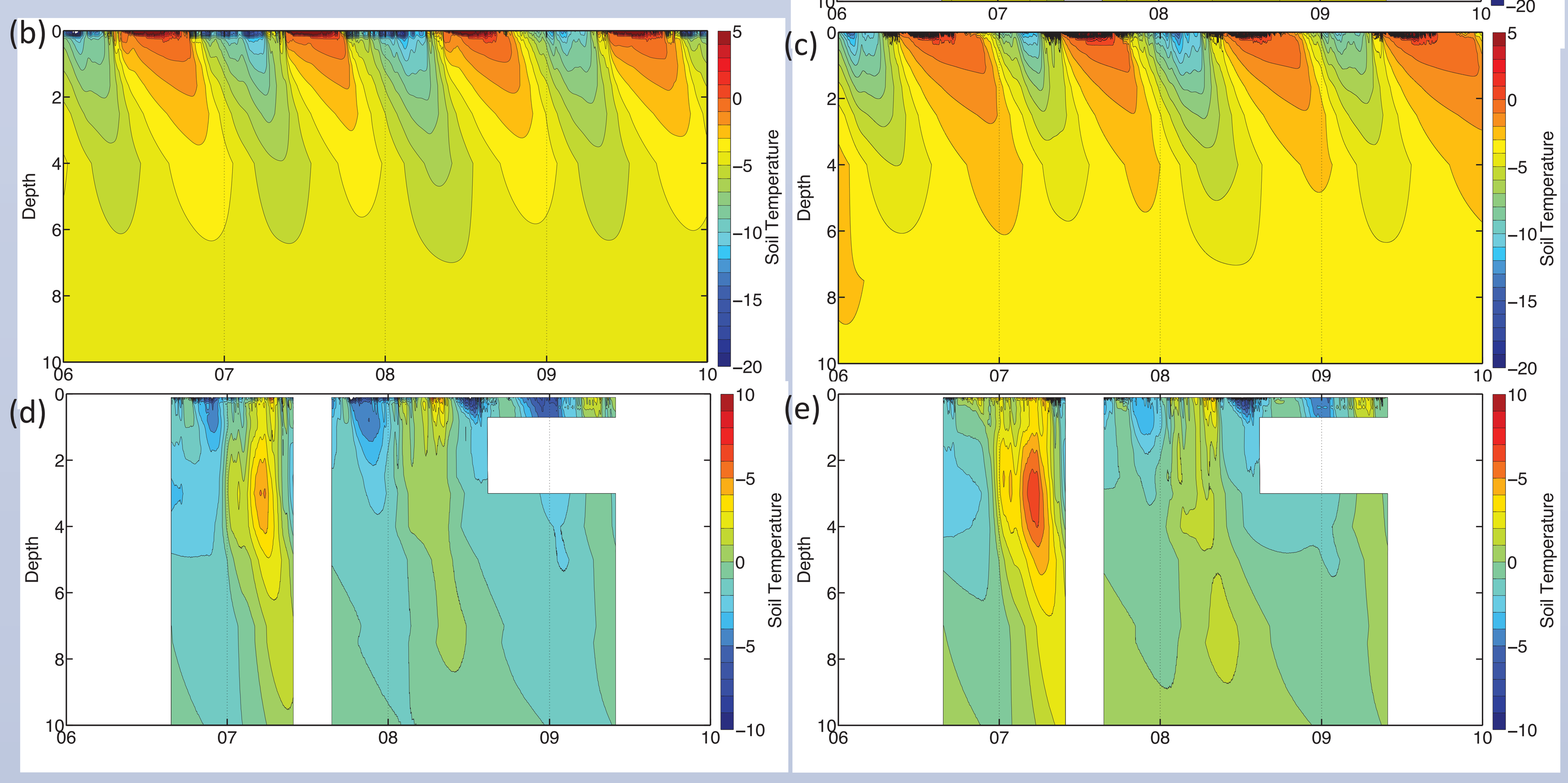
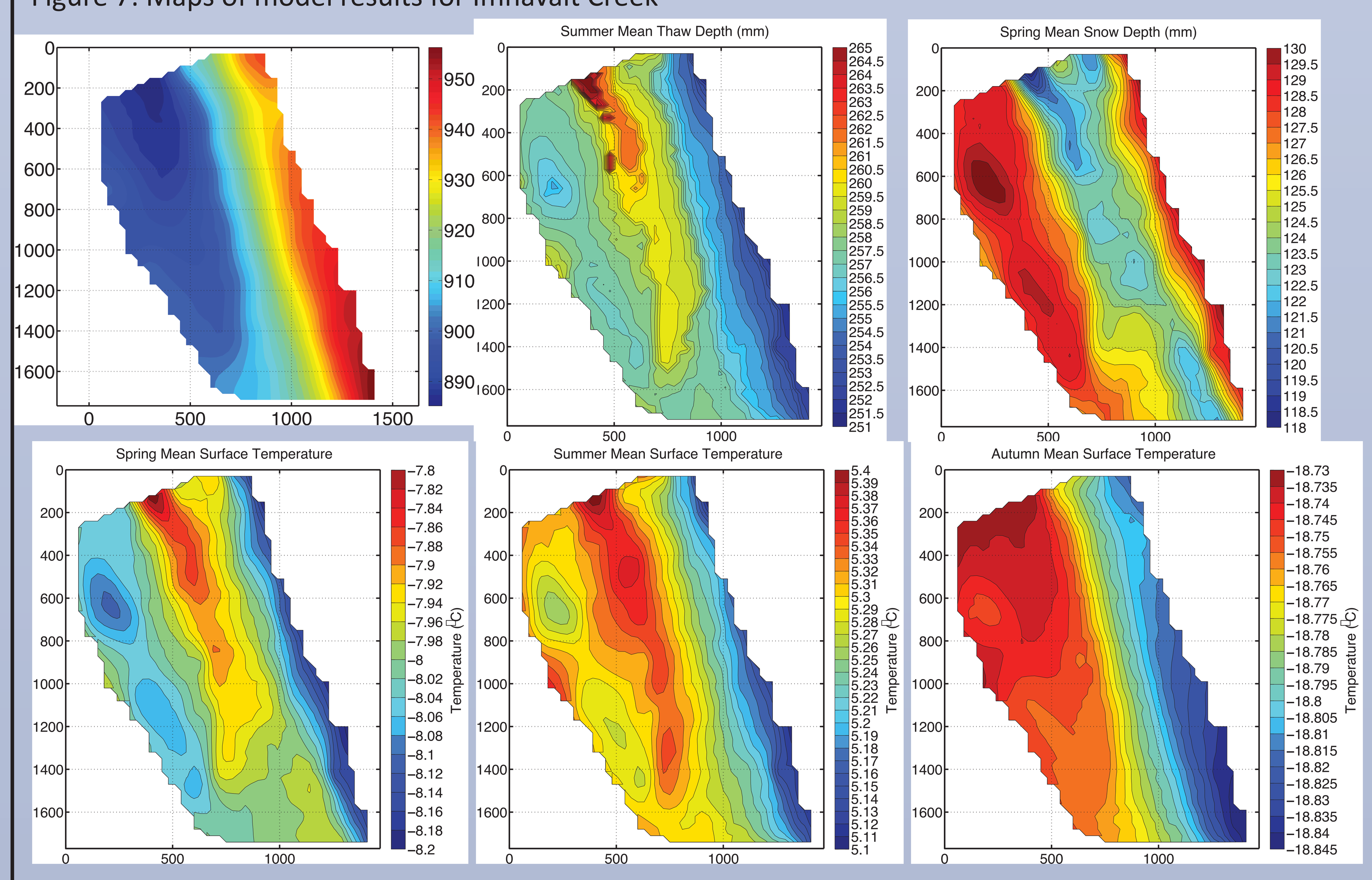


Figure 7: Maps of model results for Imnavait Creek



Summary

Seasonal influences on surface soil temperature:
- Autumn/winter: determined by air temperature
- Spring/summer: determined by snow thickness

Seasonal effect of snow cover:
- Initial autumn thickness greater at higher elevations (as lower air temperatures)
- Later in autumn/winter/spring topographic effect kicks in, countering air temperature effect at low elevations, therefore thickness greater at high and low elevations and lower at mid elevations

Thicker autumn snow cover = warmer surface temperatures; Thicker spring snow cover = cooler surface temperatures

Therefore, general spatial patterns of surface soil temperature:
- Low elevations: warmer than mid elevations in autumn/winter (depending on air temperature), colder than mid elevations in spring/summer (depending on snow thickness of previous winter)
- Mid elevations: between high and low elevation temperatures in autumn/winter , warmer in spring/summer (depending on snow thickness of previous winter)
- High elevations: coldest all year round