Simulation of Montane Snowpacks for the Preservation of the Wolverine (*Gulo gulo luscus*) in the Western U.S.

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1 Background

Persistent spring snowpack has been shown to be important for wolverine habitat. Future snow conditions are uncertain due to the effects of climate change.

•The wolverine was considered for Endangered Species status in 2014. However, the U.S. Fish and Wildlife Service (FWS) concluded that it did not warrant listing due to significant uncertainty about the effects of climate change on wolverine habitat in the future.

•Previous work by McKelvey et al. (2011) and Copeland (2010) projected dire losses in snowpack, albeit their simulations were very coarse (~6km) and considered "flat" pixels using VIC.

•These studies failed to take into account fine-scale topographical features—slope and aspect—that are crucial for snowpack evolution.

We simulate snowpack at **much higher-resolution (250 m)** than previous studies across two montane domains. We validate historical simulations, then simulate snowpack under future climate scenarios from global circulation models using the *delta method*.

2 Study Domains and Data

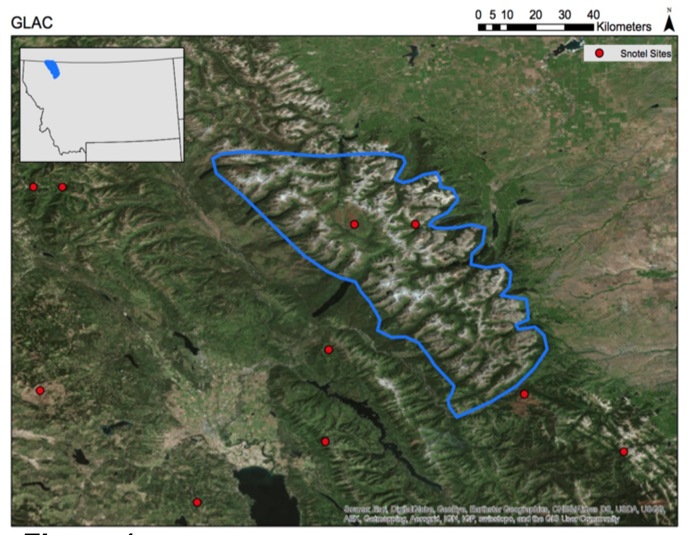
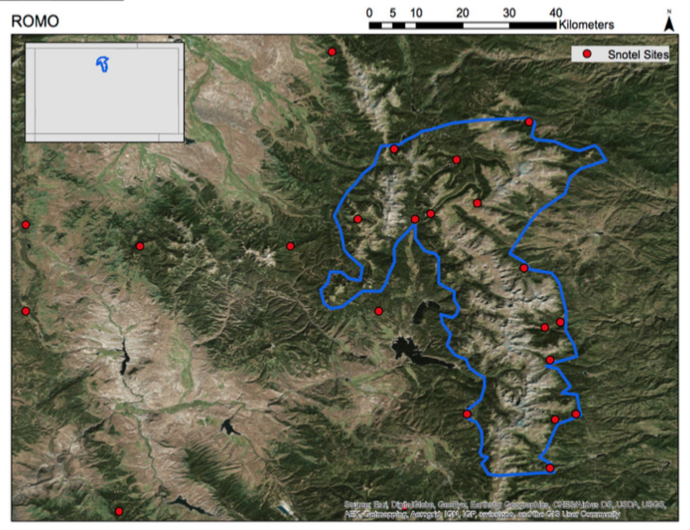


Figure 1.

- Two study areas of approximately 1000km^2 in size were chosen due to time and computational constraints.
- Highest priority area is the "Crown of the Continent" region in Montana (Fig. 1)



- Second area chosen is in and adjacent to Rocky Mountain National park.
- These areas bracket a range of habitat conditions for the wolverine from low elevation in Glacier NP to very high elevation in Rocky Mountain NP.

Figure 2.

Fig. 1: Domain in Glacier National Park (GLAC) outlined in blue. SNOTEL gage locations in red.
Fig. 2: Domain in Rocky Mountain National Park (ROMO) in blue. SNOTEL gage locations in red.

3 MODIS and SNOTEL Products Comparison

Approach: Calibration and validation of DHSVM historical snow covered area (SCA) against MODIS satellite snow cover and depth against SNOTEL snow water equivalent (SWE).

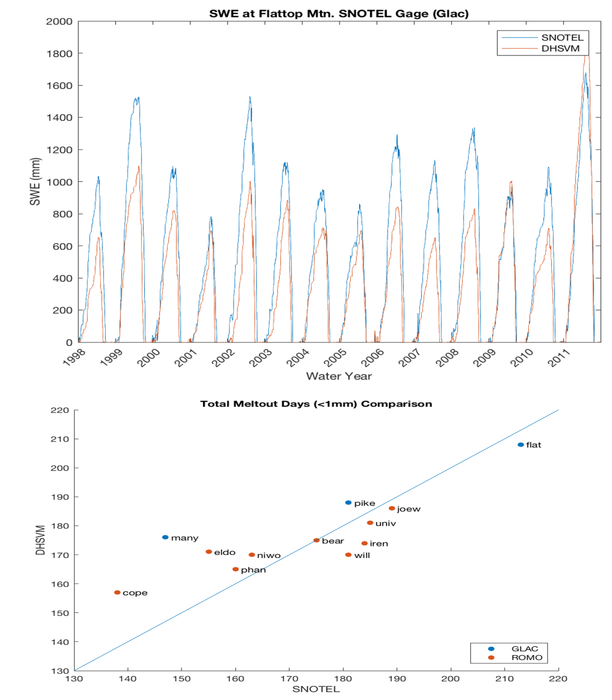


Figure 3.

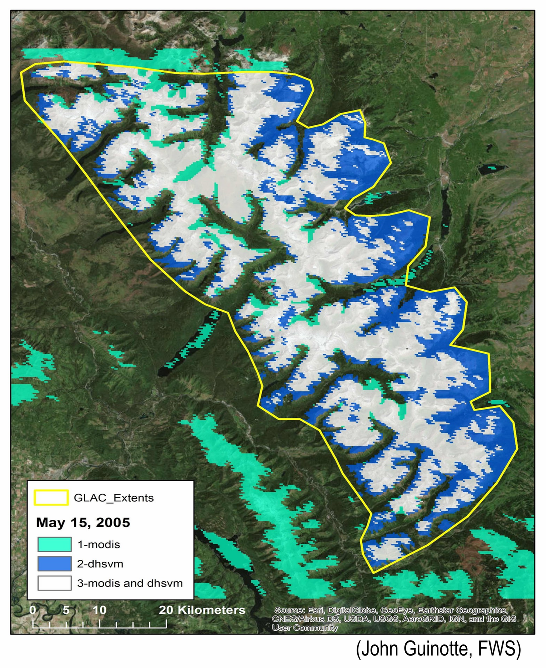


Figure 4.

Fig. 3: a) Annual SWE comparison for WY1998-2013 at Flattop Mtn SNOTEL gage. b) Comparison of average day of year of melt out for gages in GLAC and ROMO. Fig 4: MODIS vs. DHSVM snow-covered area difference map.

Key scientific questions of this study:

•How vulnerable are species such as the wolverine (*Gulo gulo luscus*) that rely on snowpack for habitat and denning to changes in snowpack?

•What is the expected influence of climate change on the retention of spring snowpack in the foreseeable future?

•How do fine-scale topographical features like terrain, slope, and aspect influence the depth and extent of snowpack in montane regions?

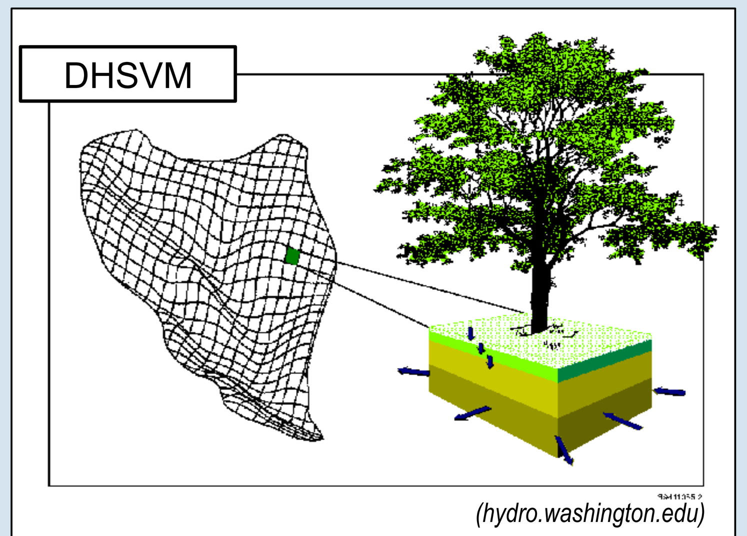
4 Methods for High-Resolution Simulation in DHSVM

The Distributed Hydrology Soil Vegetation Model explicitly represents the effects of topography and vegetation on water fluxes through a domain. It was run for the historic period from water year 1998-2013 and for five scenarios of future change. The results for the historic period were validated against SNOTEL observing stations and against MODIS snow cover. Key points:

1.Significant Snow Depth: A value of 0.5m snow depth (equivalent to 0.2m of SWE) was used as a proxy for "significant snow depth" usable by the wolverine. A snow depth:SWE ratio of 2.5 was assumed from SNOTEL data.

2.Delta Method: The future climate model scenarios were downscaled using the "delta method", which applies change factors from the climate models to the historic temperature and precipitation forcings used by DHSVM.

3.Extreme Years: Wet, dry, and near-normal representative case study years were identified and analyzed for their response to future climate perturbations.



DHVSM is a physically-based hydrologic model that represents effects of topography, soil, and vegetation. It solves the energy and water balance at each grid cell and timestep.

Table 1: Summary of modeling methods used in this study versus previously by McKelvey et al. (2011) and Littelll et al. (2011).

	McKelvey (Littell)	This Study
Spatial Resolution (modeling)	VIC model - 6km	DHSVM model - 250m
Spatial Extent	Westwide except California and Great Basin	ROMO and GLAC study areas, near and above treeline
Process differences	"Flat" pixels	Slope, aspect, shading
Validation	None specific to snow	Comparison to SNOTEL and MODIS.
Future Scenarios	Delta Method; "2045";"2085"; from 3 GCMs spanning westwide temperature changes.	Delta Method: "2055" from 5 GCMs spanning regional changes in temperature and precipitation

5 Results: Climate Change Bearings on Snowpack

Results show a decrease in SWE across all 5 diverse climate scenarios (selected to encompass CMIP5 GCMs range in precipitation and temperature) in both regions, as compared to the historical simulation. Greatest losses in snowpack appear in scenarios with the greatest temperature increase (HadGEM2, scenario 4 below). Patterns of snow retention on northeast-facing slopes in the Glacier National Park area and on north-northwest-facing slopes in the Rocky Mountain National Park area become exacerbated in warm/dry years. Wet/snowy years are likely to retain snow in similar amounts in the near- and above-treeline zones simulated in this study.

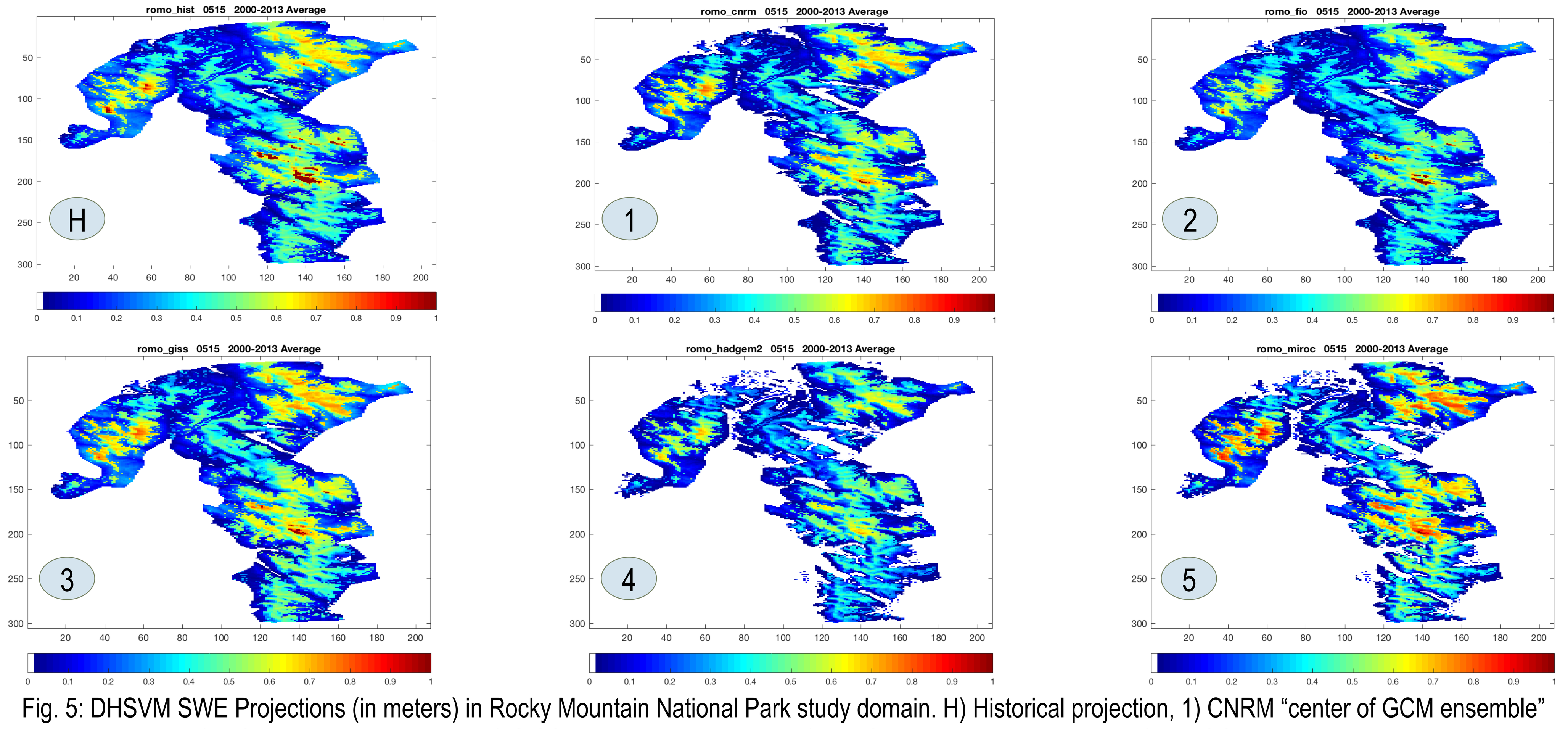


Fig. 5: DHSVM SWE Projections (in meters) in Rocky Mountain National Park study domain. H) Historical projection, 1) CNRM "center of GCM ensemble" projection, 2) FIO "warm dry" projection, 3) GISS "warm wet" projection, 4) HadGEM2 "hot dry" projection, 5) MIROC "hot very wet" projection.

6 Slope, Elevation, and Aspect Dependence

Simulation results show a distinct trend between SWE sensitivity to climate change and slope, elevation, and aspect. Results shown in Figure 6 below suggest a stronger resilience at high elevation, steeper inclines, and north-facing slopes.

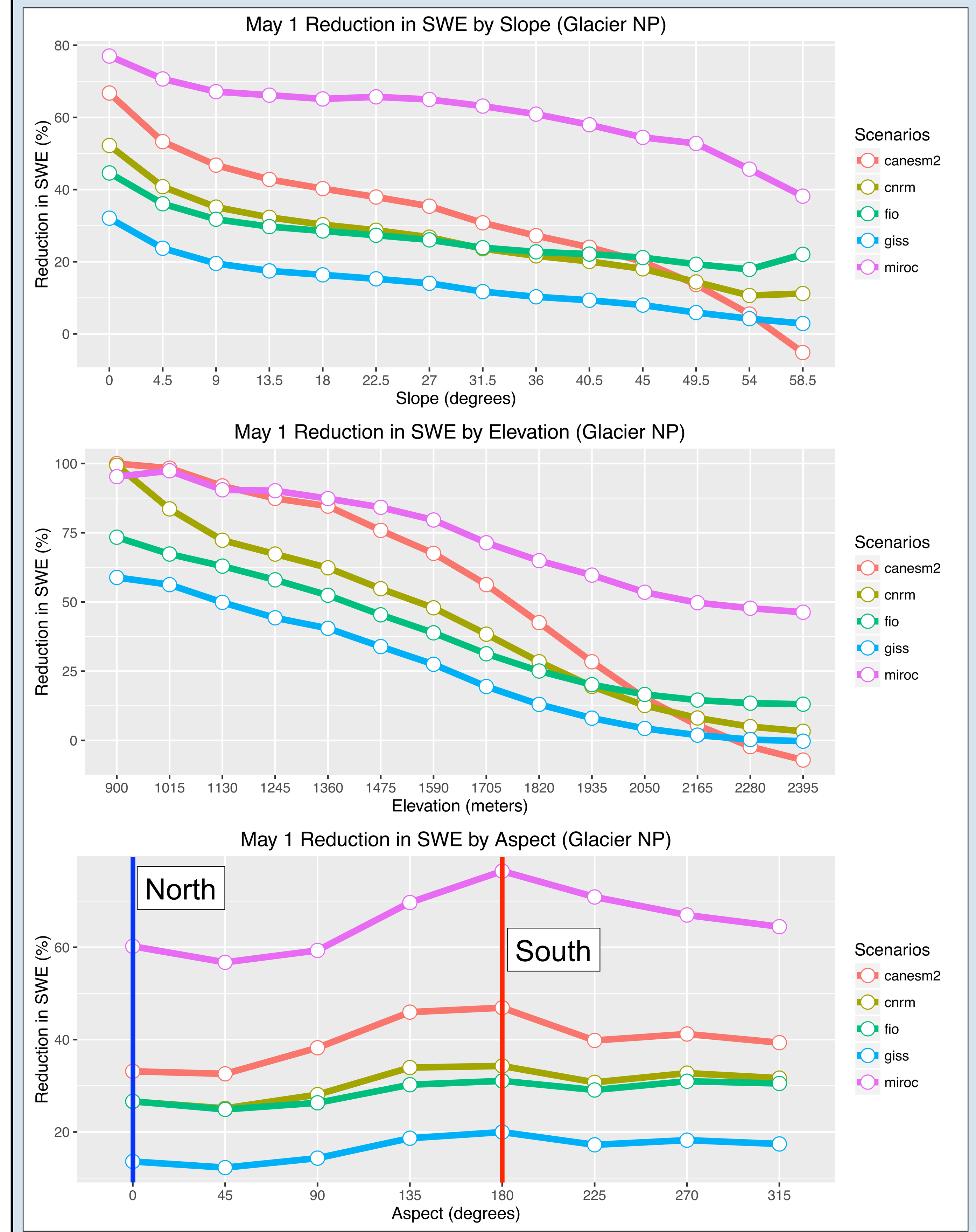


Fig. 6: May 1st average SWE reduction (1998-2013) between 5 climate scenarios and historical simulation in Glacier National Park study area. From top to bottom, slope vs. SWE reduction, elevation vs. SWE reduction, and aspect vs. SWE reduction. CanESM2 is hot/very wet scenario, CNRM is central, FIO is Warm/Dry, GISS is Warm/Wet, and MIROC is Hot/Wet.

7 Major Conclusions and Next Steps

- Results show a decrease in wolverine habitat (snowpack depth greater than 0.5m) universally across all future climate scenarios, accompanied by noticeable fragmentation of habitable area.
- Sensitivity to climate change increases in drought years.
- Snow sensitivity to climate change is greater in south-facing steep slopes at high elevation.
- Applying the data relating SWE sensitivity to predictors such as elevation, slope, aspect, temperature, and precipitation from this study to other areas of the western U.S. will provide a broader picture of the changing landscape within the next 50-100 years. The next step is to construct a statistical model using the relationship between SWE sensitivity and these predictors to the wider western United States to identify broad, spatial patterns.

References: 1. McKelvey et al., 2011 (USDA), 2. Copeland et al., 2010 (USFS), 3. Littell et al., 2011 (UOW), Livneh et al., 2014 (CIRES), Schwartz et al., 2009, (USDA), Morelli et al., 2016 (USGS)

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