Less Snow or More Snow? The challenge of developing snow cover change scenarios for the Baffin Bay-Davis Strait region.

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ABSTRACT

The complex topography of the Baffin Bay-Davis Strait (BBDS) region, the presence of strong gradients (air temperature, humidity, sea-surface temperature, sea ice), and a significant fraction of land ice pose challenges for generating snow cover change scenarios for the Adaptation Actions for a Changing Arctic (AACA) assessment. Analysis of snow cover change projections from a 16 member climate model ensemble from the CMIP5 archive show that the sign, magnitude and rate of projected snow cover change over the BBDS region varies with snow cover variable, season, emission scenario, climate model, land ice masking, and downscaling. Annual maximum SWE is projected to remain at close to current levels under all emission scenarios but seasonal SWE values are projected to undergo large decreases over the May-October period. Snow cover duration (SCD) scenario results are sensitive to the emission scenario with models projections under the lower *rcp4.5* emission scenario stabilizing to within about 10% of current levels before the end of the 21st C. This contrasts with the "business as usual" *rcp8.5* scenario that is characterized by accelerating SCD reduction. The onset date of snow cover is projected to change faster than snow-off date in response to air temperature feedbacks from a longer open water period. The climate models greatly underestimate observed trends of decreasing snow cover duration over the region as well as the interannual variability.

Keywords: snow cover, scenarios, Baffin Bay-Davis Strait region

INTRODUCTION

The Adaptation Actions for a Changing Arctic Assessment (ACAA) was requested by the Arctic Council to "produce information to assist local decision-makers and stakeholders in three pilot regions in developing adaptation tools and strategies to better deal with climate change and other pertinent environmental stressors" (http://www.amap.no/adaptation-actions-for-a-changing-arctic-part-c). The focus of ACAA is on understanding the interactions of multiple drivers of change (environmental, economic, and societal). AACA will deliver final integrated reports to the Arctic Council at the 2017 Ministerial Meeting in Washington DC. The objective of this study was to provide information on observed and projected rates of snow cover change for input to the AACA regional study for the Baffin Bay-Davis Strait region (BBDS), one of the three AACA focus regions (see location map at http://www.amap.no/adaptation-actions-for-a-changing-arctic-part-c).

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DRIVERS OF SNOW COVER CHANGE

Arctic snow cover responds to multiple drivers and feedbacks (e.g. warming, increased moisture availability, changing vegetation, increased frequency of winter thaws and rain-on-snow). A schematic of some of the main drivers influencing Arctic snow cover are shown in Figure 1. These drivers and feedbacks interact with local terrain (slope, aspect, elevation, topography, vegetation) to produce spatially, temporally, and seasonally varying responses in Arctic snow cover. Climate models capture most of the important large-scale processes and feedbacks involved in the observed amplification of climate warming over the Arctic (Pithan and Mauritsen, 2014). However, the current CMIP5 generation of climate models are known to underestimate the sensitivity of snow cover to warming (Brutel-Vuilmet, 2013) and to underestimate observed reductions in snow cover over the Arctic (Derksen and Brown 2012). Inadequate treatment of snow-vegetation interactions in climate models (Essery, 2013; Thackeray et al. 2014; Wang et al. 2015) is considered to be one of the main reasons contributing to the lack of temperature sensitivity and to the observed large spread in model snow albedo feedback (Qu and Hall, 2013).

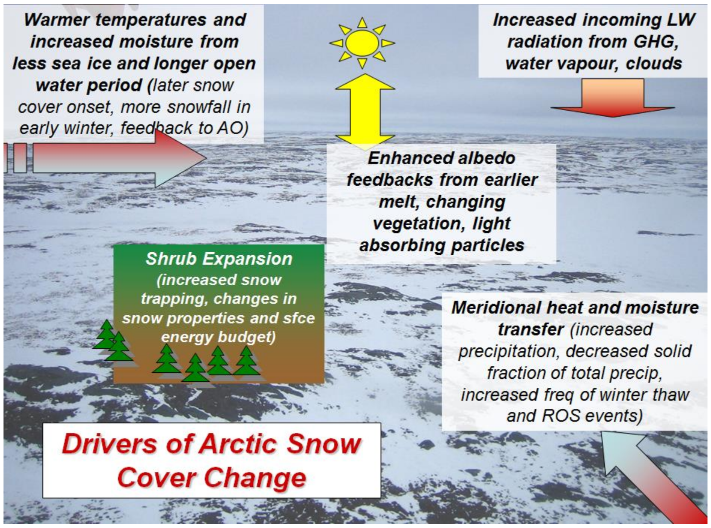

Figure 1. Schematic of some of the main environmental drivers and feedbacks influencing Arctic snow cover. Background photo courtesy of Andrew Rees.

GEOGRPHY OF BAFFIN BAY-DAVIS STRAIT REGION

The geography of the BBDS Region poses a number of challenges for monitoring snow cover changes and for developing snow changes scenarios. The region is characterized by strong North-South temperature and moisture gradients, steep elevation gradients along the coast, and has important local sources of winter precipitation from polynyas (Boon et al. 2011). The high coastal mountains act as a barrier to moisture moving inland from Baffin Bay which gives rise to strong topographic variation in snow cover (Fig. 2) and conditions that favour glacier and ice cap development in elevated coastal areas. Approximately 40% of the land area in the BBDS region is classified as land ice by the climate models used to develop the AACA snow cover change scenarios.

OBSERVED SNOW COVER TRENDS

Analysis of in situ and satellite estimates of snow cover duration suggest the BBDS region has ~3 weeks less snow cover now than in 1950 (Fig. 3). Station data show that most of the decrease is related to a later start to the snow cover season reflecting the enhanced warming observed in the fall season over the region (Rapaic et al. 2015). CMIP5 climate models underestimate the observed decreases in SCD over the region by a factor of ~4. Annual maximum snow depths at Canadian climate stations in the region show a ~20% decrease since 1950 (Brown et al. 2015) but this may not be representative: snow depths at climate stations are monitored in open grassed areas, often near airports, that may not be representative of snow condition in natural vegetated areas. For example, these observations will not reflect the impact of shrub expansion over tundra

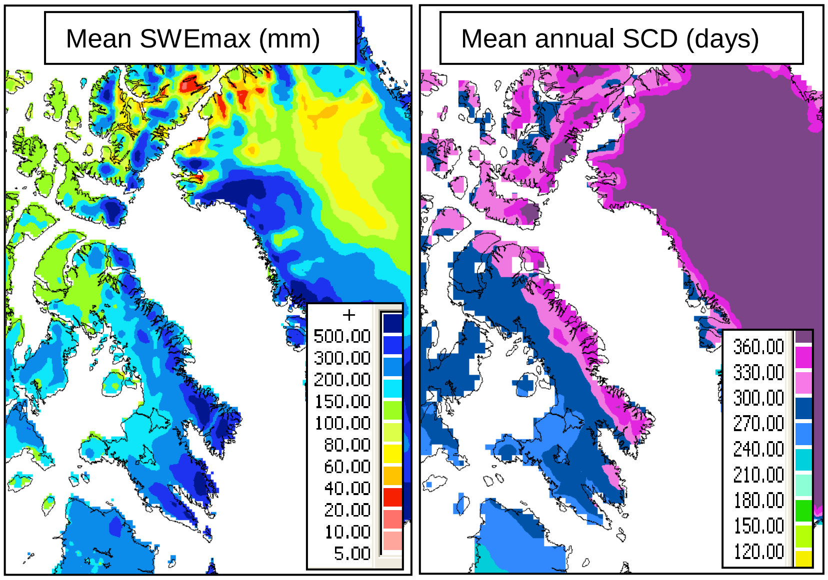

Figure 2. Left: mean annual maximum snow water equivalent (mm) over 1979-2009 from the Artic snow cover reconstruction of Liston and Hiemstra (2011). Right: mean annual snow cover duration (days) over 1998-2014 from the NOAA IMS-24 km daily snow cover extent analysis (Helfrich et al. 2007).

that has important impacts on snow accumulation, snowpack physical properties (Marsh et al. 2010; Loranty and Goetz 2012). There is insufficient snow course data in the region for analyzing trends in annual maximum snow accumulation (SWEmax), and trend estimates from various gridded datasets such as GlobSnow (Takala et al. 2011), the Liston and Hiemstra (2011) reconstruction, and reanalyses such as MERRA and ERA-interim show little agreement in the magnitude or spatial pattern of SWEmax trends over the region.

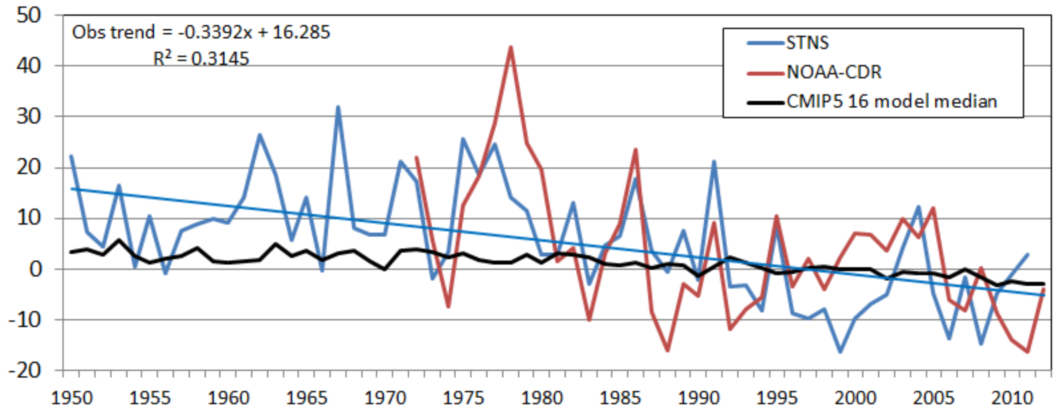

Figure 3. Historical variability in regionally-averaged annual snow cover duration (anomalies with respect to 1981-2010 average) over the Canadian land areas of the BBDS region from in situ snow depth observations (STNS) and the NOAA visible satellite Climate Data Record (NOAA-CDR, Estilow et al. 2015). The solid black line is the median anomaly from 16 CMIP5 model historical runs.

SNOW COVER CHANGE PROJECTIONS

Snow cover change projections for the BBDS region were obtained from the SWIPA update (Brown et al. 2016) which are based on monthly snow cover and SWE output from 16 independent CMIP5 models for the *historical* (1986-2005), *rcp4.5* (2006-2100) and *rcp8.5* (2006-2100) experiments. Maps of relative change were obtained using three 20-year scenario windows; near-term 2016-2035, mid-term 2046-2065 and long-term 2081-2100, with respect to a 1986-2005 reference period. The variables included were annual and seasonal snow cover duration (SCD), monthly SWE and SWEmax, with model output interpolated to a common 200 km polar stereographic grid for calculation of statistics and contouring. The 200 km grid is close to the median resolution of the 16 models included. SCD was also computed over the first (SCD_fall: Aug-Jan) and second (SCD_spr: Feb-Jul) halves of the snow season to capture variability and change in snow cover onset and snow-off dates. Regionally-averaged results were computed over non-glacier gridpoints in the BBDS domain approximated by the latitude/longitude box 60-85°N, 45-95°W. Land ice points were excluded because snow accumulation is not treated consistently in models in regions of permanent snow cover. This also means the results are more relevant to lower elevated coastal regions where most of the population is located. The spatial pattern of the 16-model median and upper and lower quartiles of projected SWEmax and annual SCD change for *rcp4.5* and *8.5* are shown in Figures 4a,b and 5a,b for the pan-Arctic region. Regionally-averaged time series of SWEmax and SCD are provided in Figures 6-8, and change in monthly SWE in Figure 9. The following main points can be made from the CMIP5 model results:

• The BBDS region straddles the zone where climate models project increasing SWEmax in response to increasing winter precipitation (Fig. 4). This suggests that the sign and magnitude of SWEmax change over the BBDS region is likely to be highly sensitive to local-regional scale differences in topography and precipitation.

• Annual maximum SWE shows little response to warming in the BBDS region (-10 to +15% range by 2100 for *rcp8.5*) and is relatively insensitive to emission scenario (Fig. 6). However, large relative reductions in SWE of 60-100% are projected to take place in the May-October period (Fig. 9).

• Annual SCD shows strong sensitivity to warming with decreases of 15-25% projected by 2100 for *rcp8.5* (Fig. 7). SCD is also sensitive to the emission scenario: *rcp4.5* results indicate a stabilization of snow cover duration towards the end of the 21st C at levels about 5% lower than today while *rcp8.5* results indicate accelerating reduction in SCD throughout the 21st C.

• Snow cover is projected to decrease more rapidly in the start of the snow season than the end of the snow season (Fig. 8). This feature is also seen in snow cover trends from in situ observations.

The averaging of climate model results to a 200 km grid is not optimal for the BBDS region in light of the complex topography of the region and the previously documented strong spatial gradients in snow cover. To provide more detailed information on the spatial pattern of changes, snow cover change scenarios were also generated from the CanRCM4 regional climate model (Scinocca et al. 2015) 0.22° Arctic CORDEX experiment (run 1). A single model's output must be treated with some caution but the results (not shown) indicated strong coastal gradients in SWEmax change in several areas (e.g. southern Baffin Island, southwestern Greenland, Ellesmere Island) with decreases along the coastal margins and increases over high elevation further inland. SCD projected decreases also showed evidence of sharp coastal gradient. The stronger snow cover-climate response in coastal regions is consistent with the conclusions of Brown and Mote (2009) of higher snow cover-climate sensitivity in marine areas related to their relatively warmer cold season temperatures and higher precipitation.

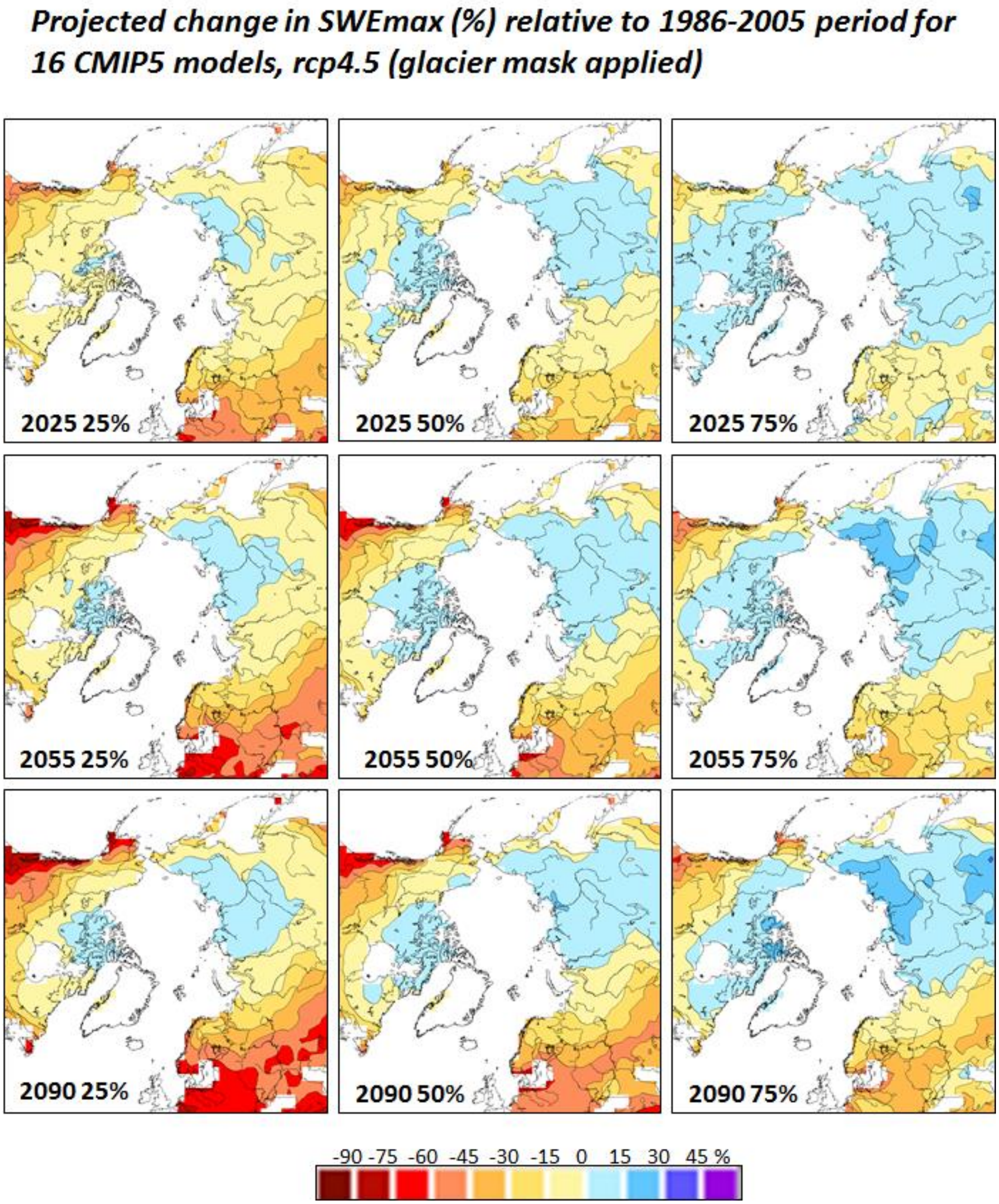

Figure 4a. Projected relative (%) change in mean annual monthly maximum SWE from 16 CMIP5 models for emission scenario *rcp4.5*. Results are shown for the median (50%) and upper (75%) and lower (25%) quartiles. 2025 corresponds to the 2016-2035 average, 2055 to the 2046-2065 average, and 2090 to the 2081-2100 average. Source: SWIPA update report (Brown et al. 2016 in prep).

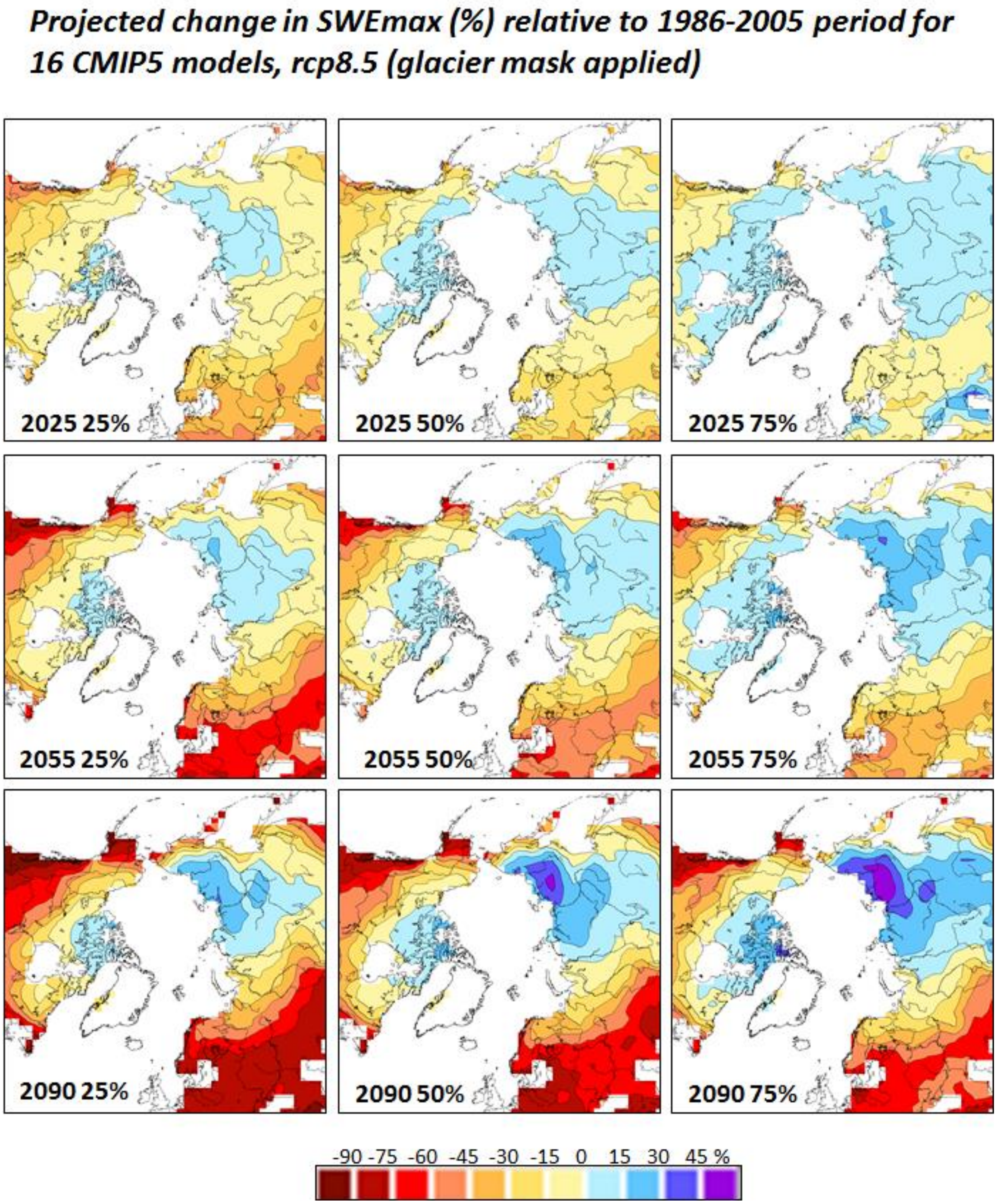

Figure 4b. Same as 4a for emission scenario *rcp8.5*. Source: SWIPA update report (Brown et al. 2016 in prep).

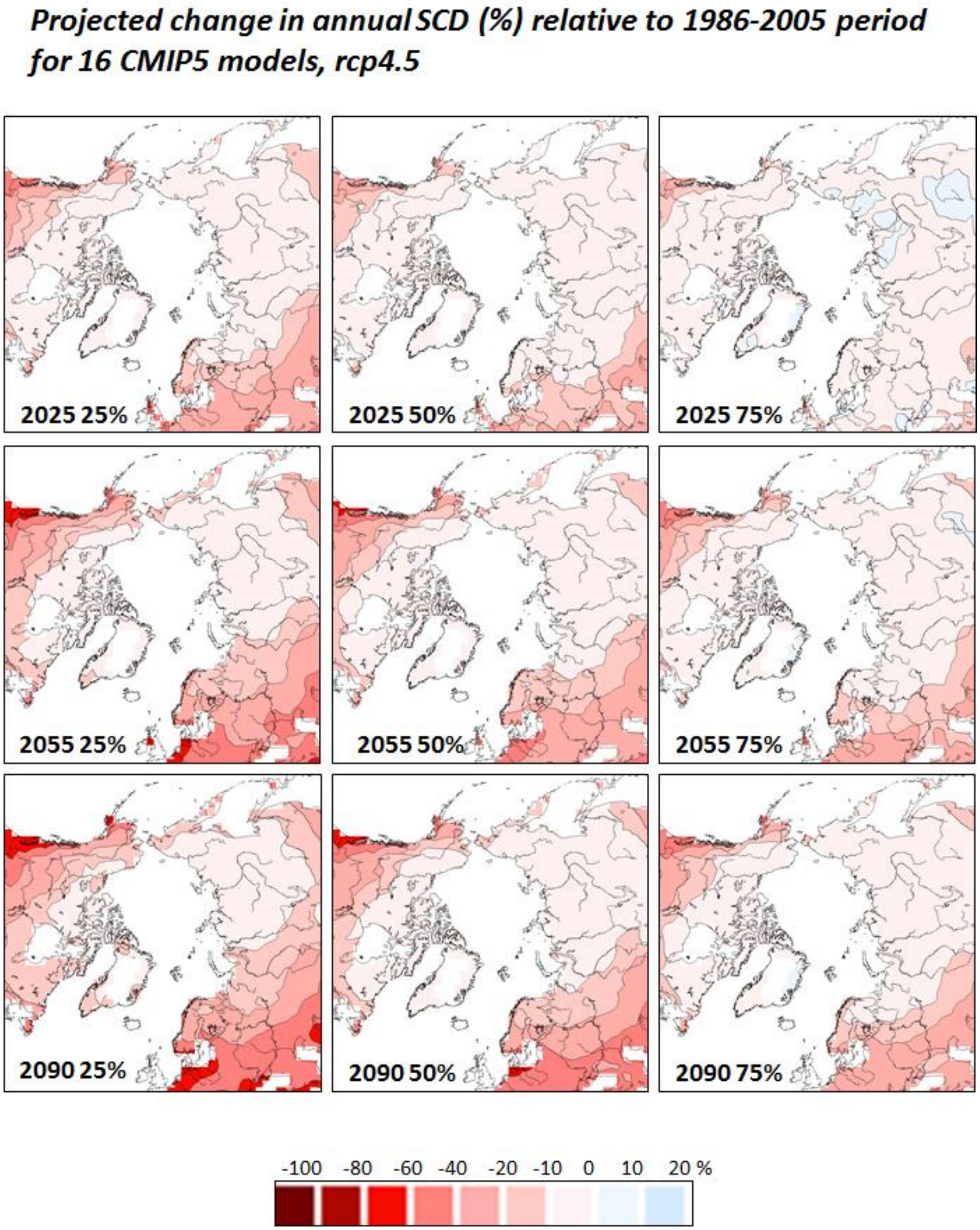

Figure 5a. Projected relative (%) change in mean annual SCD from 16 CMIP5 models for emission scenario *rcp4.5*. Panel organization follows Fig. 4a. Source: SWIPA update report (Brown et al. 2016 in prep).

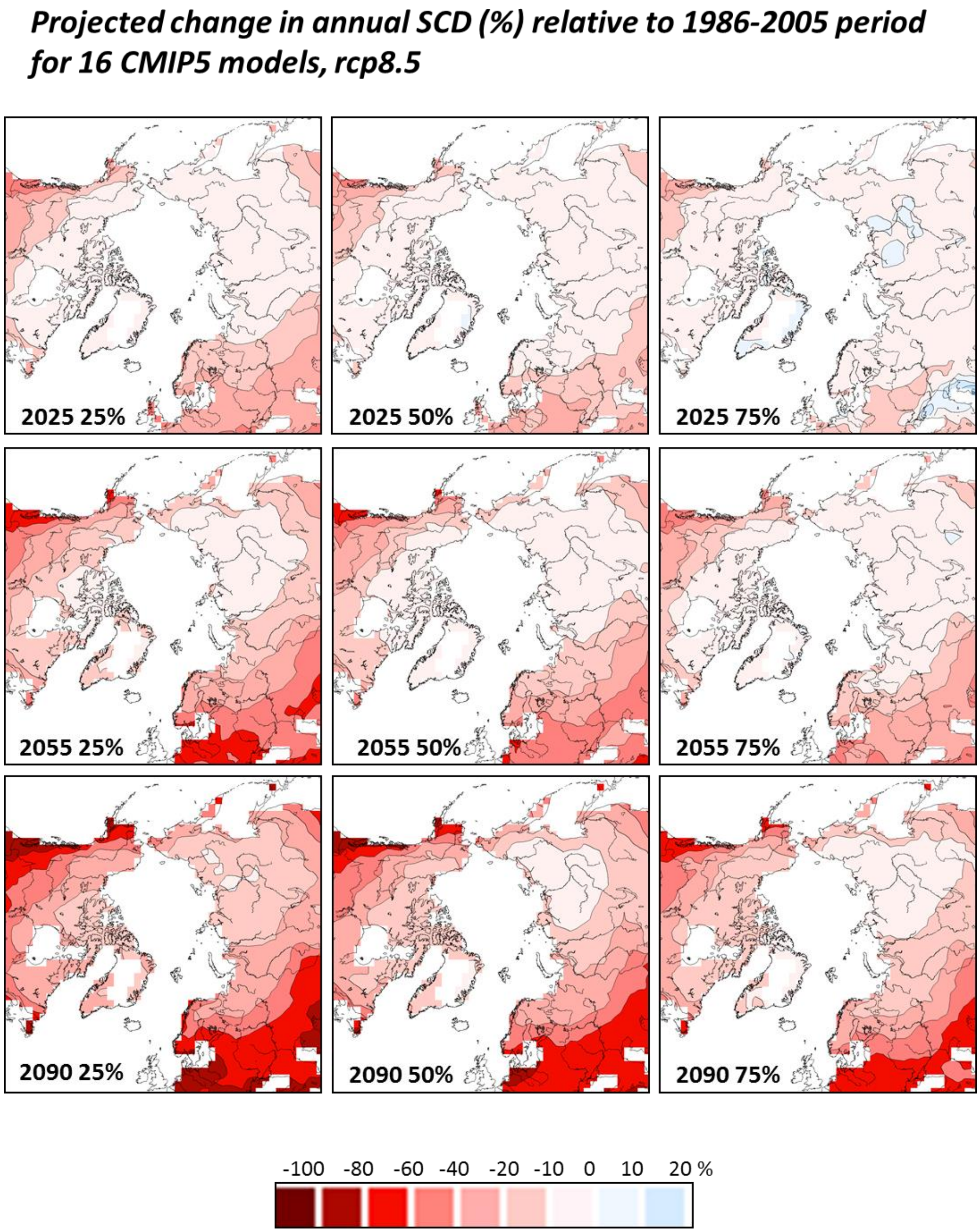

Figure 5b. Same as Fig. 5a for *rcp8.5*. Source: SWIPA update report (Brown et al. 2016 in prep).

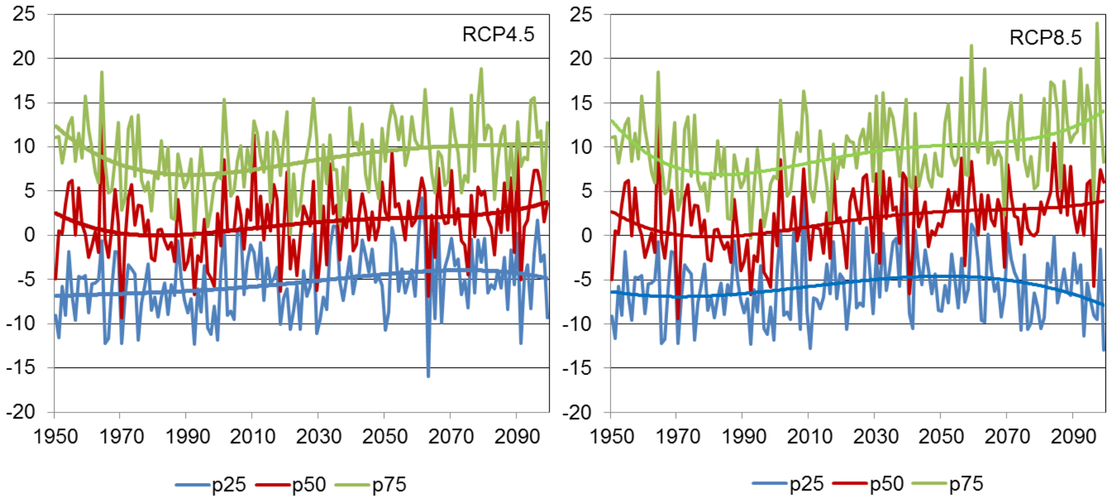

Figure 6. Projected change (%) in regionally-averaged annual maximum snow water storage for all non-glacier land cells in the BBDS region

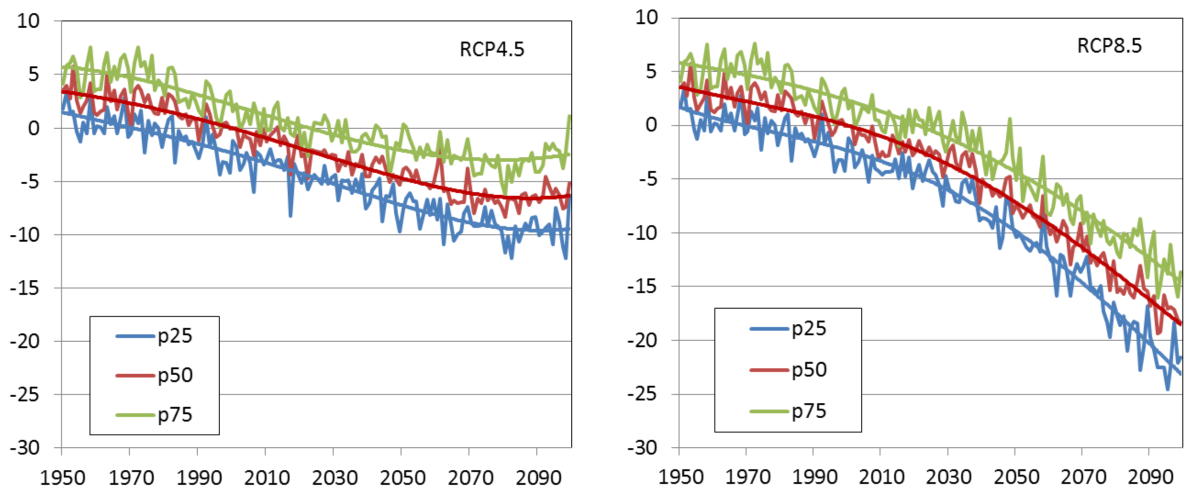

Figure 7. Projected change (%) in regionally-averaged annual SCD for all non-glacier land cells in the BBDS region.

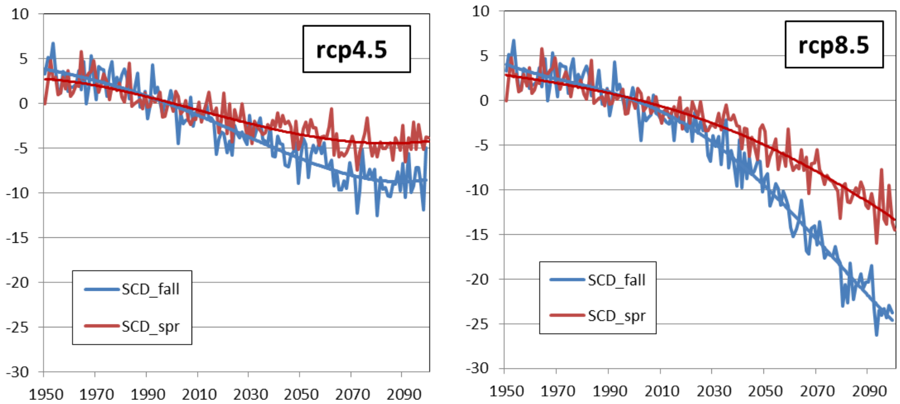

Figure 8. 50th percentiles of projected change in regionally-averaged snow cover duration in the fall and spring halves of the snow season for all land cells in the BBDS region

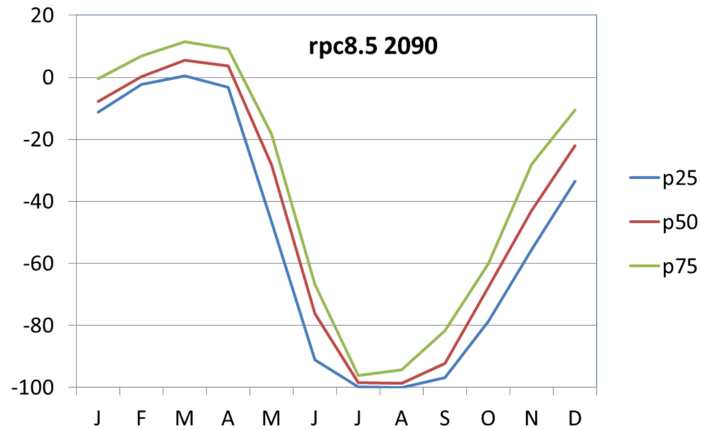

Figure 9. Evolution of projected % change in monthly SWE over BBDS non-glacier land areas (25, 50 and 75% percentiles of 16 CMIP5 model runs)

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