Environment and Climate Change Canada | Environnement et Changement climatique Canada

Canada

Observed and projected trends in seasonal terrestrial snow cover from 'observation' and climate model ensembles (with a focus on Canada)

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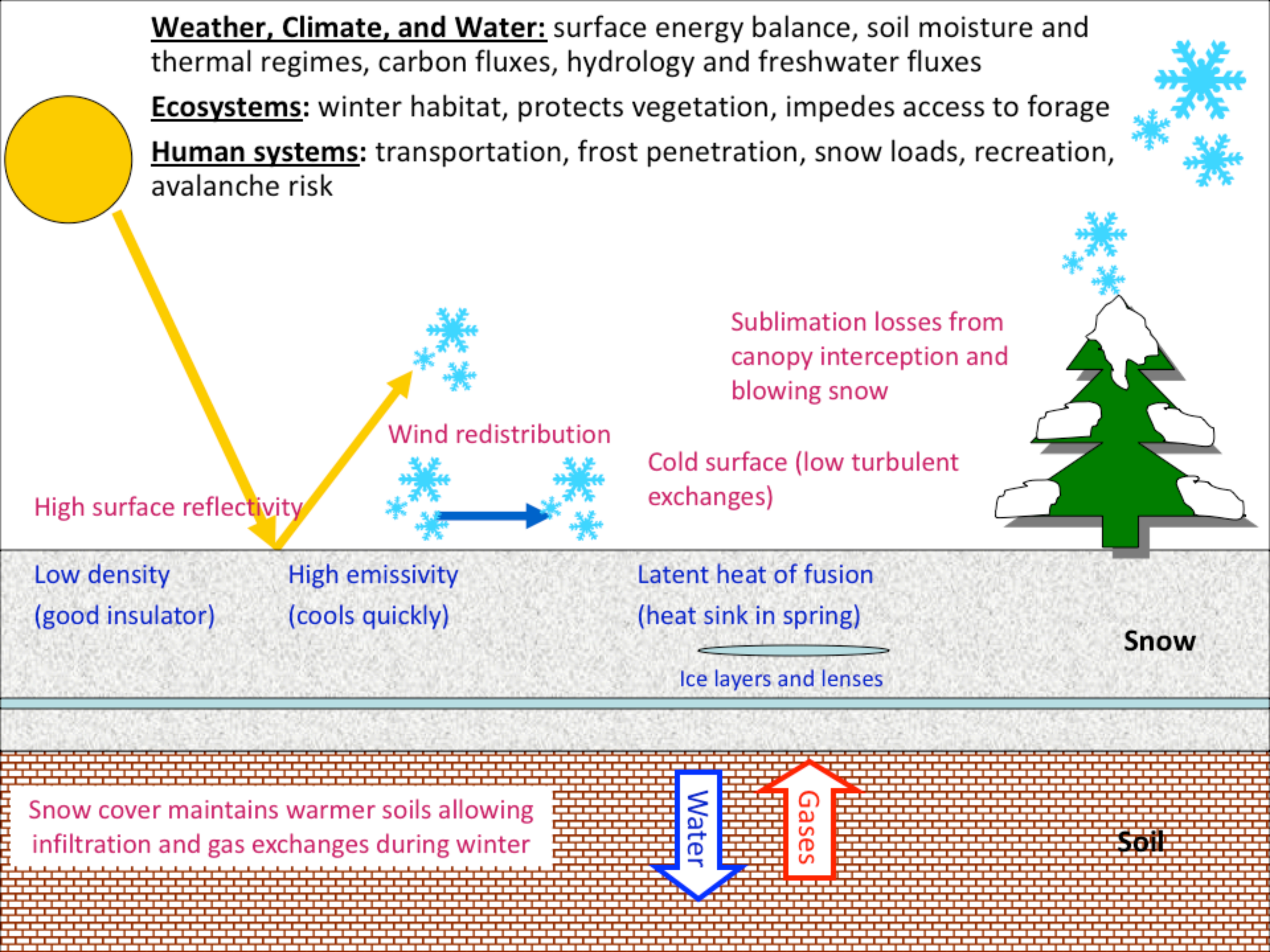
Thanks to our data providers:
Rutgers Global Snow Lab • National Snow and Ice Data Center • World Climate Research Programme Working Group on Coupled Modelling • NASA Global Modeling and Assimilation Office • European Centre for Midrange Weather Forecasting • Vincent Vionnet/Metéo-France


Weather, Climate, and Water: surface energy balance, soil moisture and thermal regimes, carbon fluxes, hydrology and freshwater fluxes
Ecosystems: winter habitat, protects vegetation, impedes access to forage
Human systems: transportation, frost penetration, snow loads, recreation, avalanche risk
Sublimation losses from canopy interception and blowing snow
Wind redistribution
Cold surface (low turbulent exchanges)
High surface reflectivity
Low density (good insulator)
High emissivity (cools quickly)
Latent heat of fusion (heat sink in spring)
Snow
Ice layers and lenses
Snow cover maintains warmer soils allowing infiltration and gas exchanges during winter
Water
Gases
Soil

Observations: Time Series Ensembles

Four snow water equivalent data sources, 1981 to 2015:

1. The Modern-Era Retrospective Analysis for Research and Applications Version 2 (MERRA-2) (Gelaro et al., 2017)
2. The temperature index model described by Brown et al. (2003) reconstructs daily SWE using 6-hourly temperature field and 12-hourly precipitation field inputs from ERA-Interim
3. The physical snowpack model Crocus simulates daily SWE using meteorology from ERA-Interim (Brun et al., 2013)
4. The European Space Agency GlobSnow product derived through a combination of satellite passive microwave data, forward snow emission model simulations, and climate station observations for non-alpine regions of the Northern Hemisphere (Takala et al., 2011)

SWE converted to monthly snow cover fraction using a 4 mm threshold

Six surface temperature products, 1981 to 2015:

- ERA-Int, MERRA-1, MERRA-2, JRA-55, JRA-25, and CFSR reanalysis products
- Equal weighting given to each reanalysis center

Projections: Climate Model Ensembles

CMIP5 Multi-model ensemble:

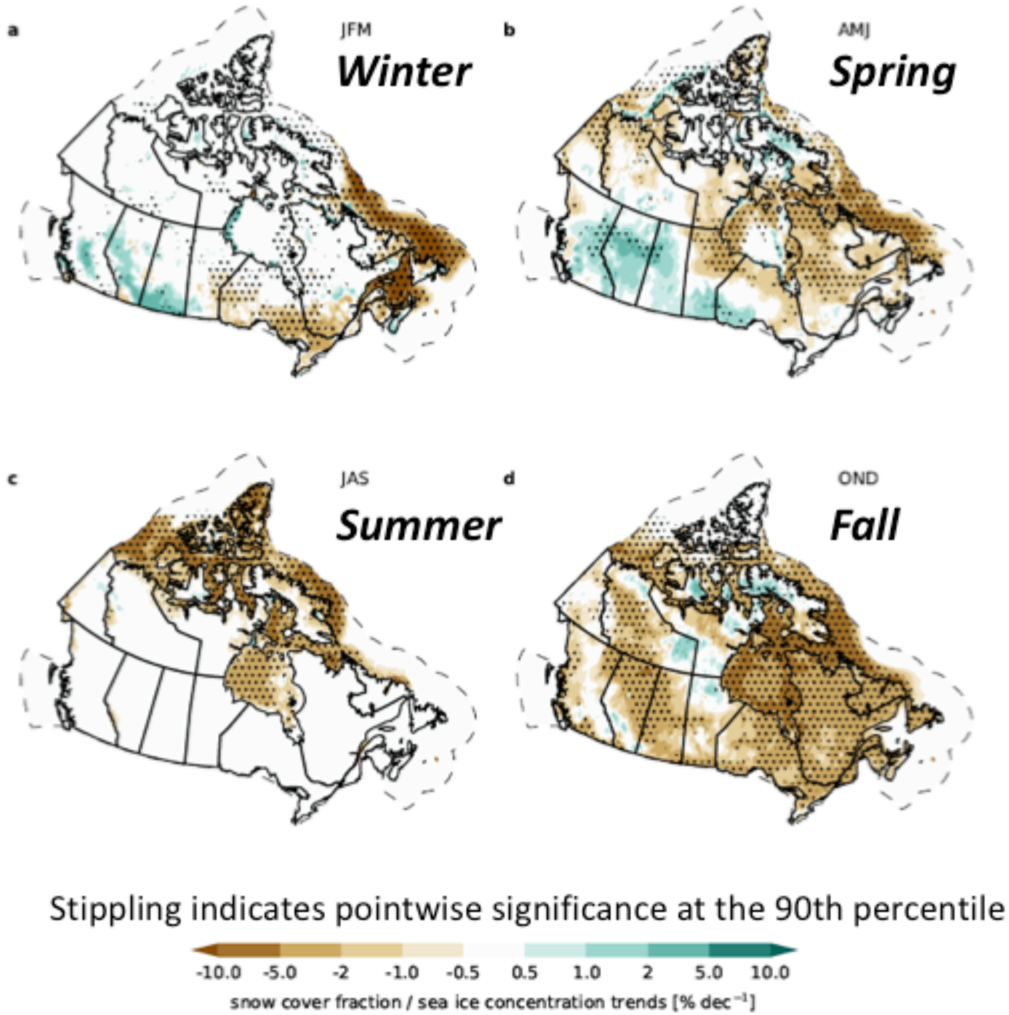
	Model name	Institute	Resolution (lat × lon)	Realizations (historical/RCP8.5)	MAMJ SCE Trend (10^6 km^2 decade^{-1})
A	Beijing Climate Center (BCC) Climate System Model, version 1.1 (BCC_CSM1.1)	BCC	2.8° × 2.8°	3/1	−0.53
B	Beijing Normal University (BNU) Earth System Model (BNU-ESM)	BNU	2.8° × 2.8°	1/1	−0.47
C	Canadian Earth System Model, version 2 (CanESM2)	CCCma	2.8° × 2.8°	5/5 (+50)	−0.78
D	Community Climate System Model, version 4 (CCSM4)	NCAR	0.9° × 1.25°	6/6	−0.55
E	Centre National de Recherches Météorologiques (CNRM) Coupled Global Climate Model, version 5 (CNRM-CM5)	CNRM-CERFACS	1.4° × 1.4°	10/5	−0.44
F	Commonwealth Scientific and Industrial Research Organisation (CSIRO) Mark 3.6 (CSIRO Mk3.6.0)	CSIRO-Queensland Climate Change Centre of Excellence (QCCCE)	1.875° × 1.875°	10/10	−0.27
G	Flexible Global Ocean-Atmosphere-Land System model, gridpoint version 2 (FGOALS-g2)	LASG-Center for Earth System Science (CESS)	2.8° × 2.8°	5/1	−0.50
H	Goddard Institute for Space Studies Model E2 with Russell Ocean Model (GISS-E2-R)	NASA GISS	2.0° × 2.5°	6/1	−0.42
I	Institute of Numerical Mathematics (INM) Climate Model, version 4.0 (INM-CM4.0)	INM	1.5° × 2.0°	1/1	−0.07*
J	Model for Interdisciplinary Research on Climate, version 5 (MIROC5)	MIROC	1.4° × 1.4°	5/3	−0.52
K	MIROC Earth System Model (MIROC-ESM)	MIROC	2.8° × 2.8°	3/1	−0.56
L	Max Planck Institute Earth System Model low resolution (MPI-ESM-LR)	MPI-M	1.875° × 1.875°	3/3	−0.27
M	Meteorological Research Institute (MRI) Coupled General Circulation Model, version 3 (MRI-CGCM3)	MRI	1.121° × 1.125°	3/1	−0.20*
N	Norwegian Earth System Model, version 1 (intermediate resolution), with biogeochemical cycling (NorESM1-ME)	Norwegian Climate Centre (NCC)	1.89° × 2.5°	1/1	−0.49
O	Norwegian Earth System Model, version 1 (intermediate resolution) (NorESM1-M)	NCC	1.89° × 2.5°	3/1	−0.42

Two large initial condition ensembles based on:

1. CESM1-CAM5 (30 realizations, ensemble described in *Kay et al.* [2015])
2. CanESM2 (50 realizations produced in an analogous manner to *Kay et al.*)

Historical Snow Cover Fraction Trends, 1981-2015

Mudryk et al. (2018)

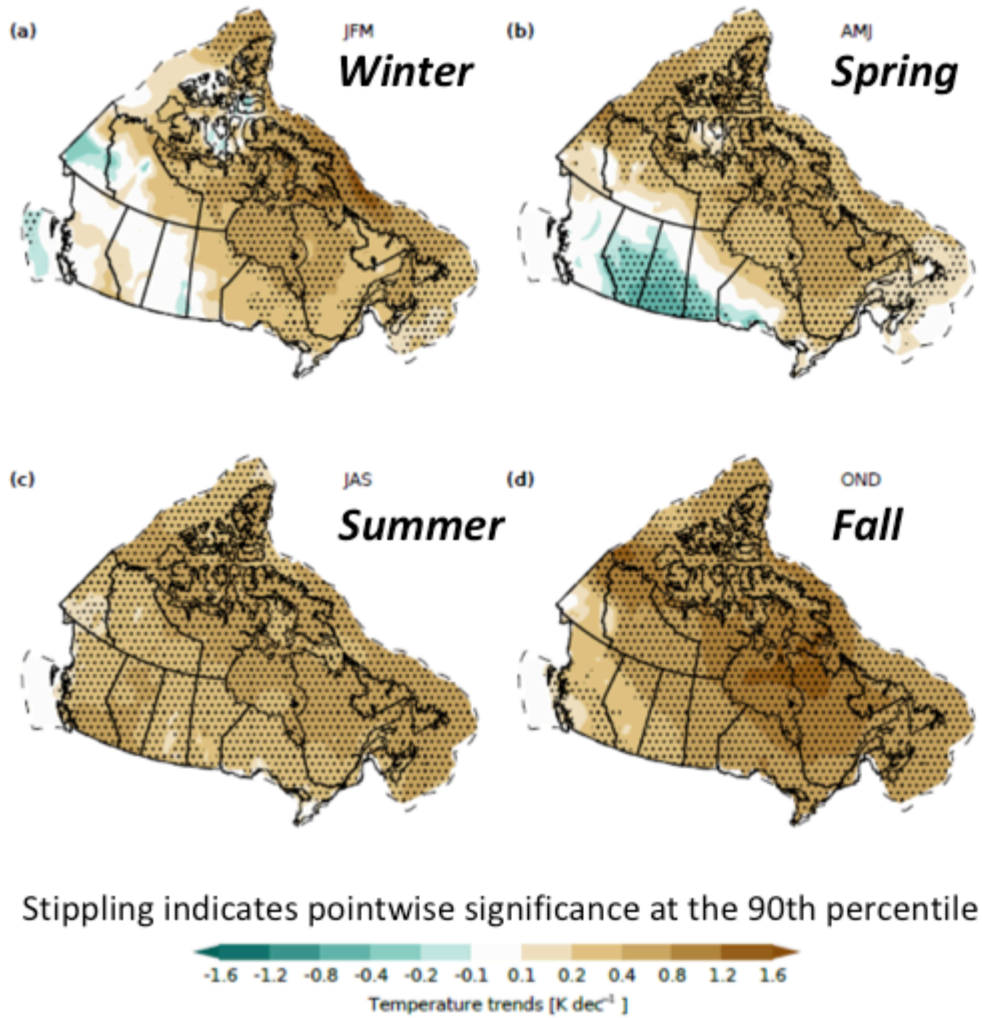


- Largely negative trends in all regions and seasons with the exception of central Canada in winter and spring
- Consistent trends in snow and sea ice across land and marine boundaries
- SCF trends largely consistent with surface observations (*Vincent et al., 2015*) but influenced by period of analysis

Terrestrial snow cover fraction and sea ice concentration trends, 1981–2015

Historical Surface Temperature Trends, 1981-2015

Mudryk et al. (2018)



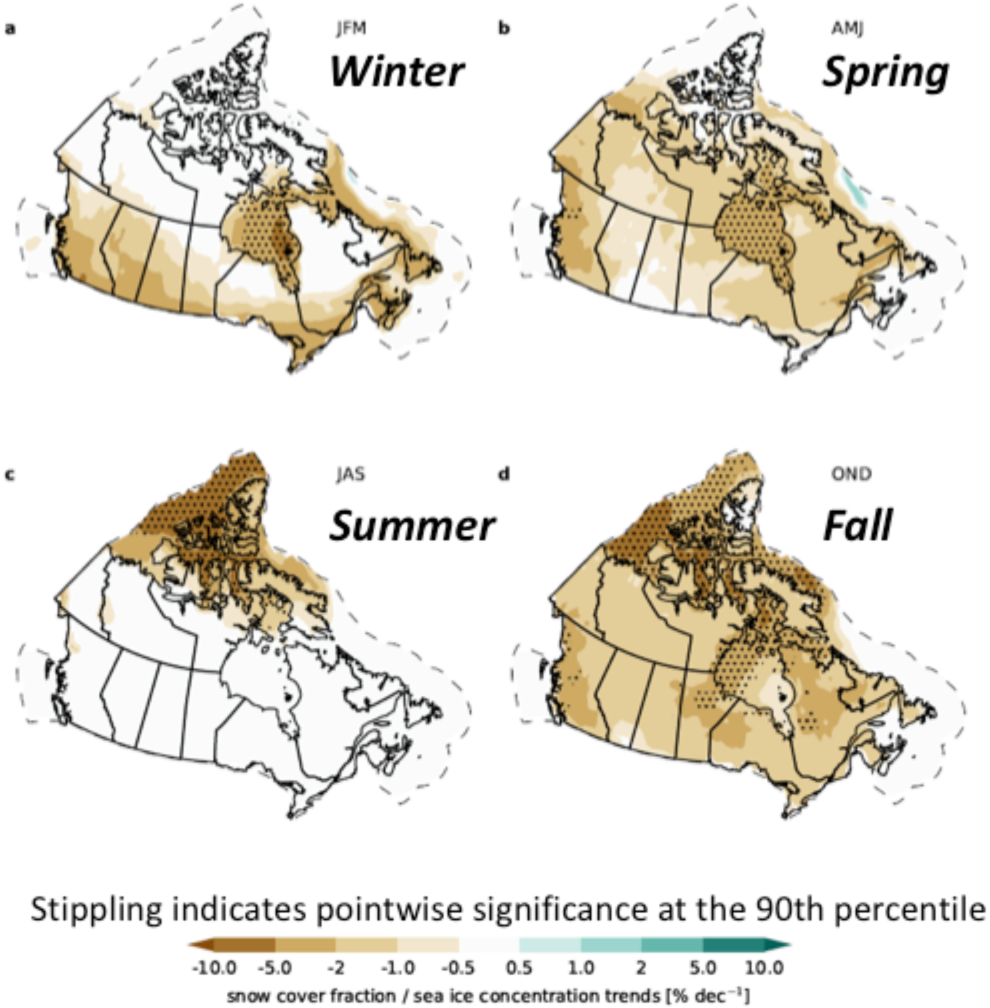
Stippling indicates pointwise significance at the 90th percentile

- Land areas with cooling trends co-located with positive SCF trends
- Winter and spring cooling consistent with the influence of North Pacific SST variability over the last 35 years (*Mudryk et al., 2014*)
- Reanalysis trends are seasonally and spatially consistent with *Rapaic et al.* (2015) analysis of blended homogenized station observations and multiple reanalyses

Trends in surface temperature, 1981–2015

Snow Cover Fraction Projections: 2020-2050 Trends

Mudryk et al. (2018)

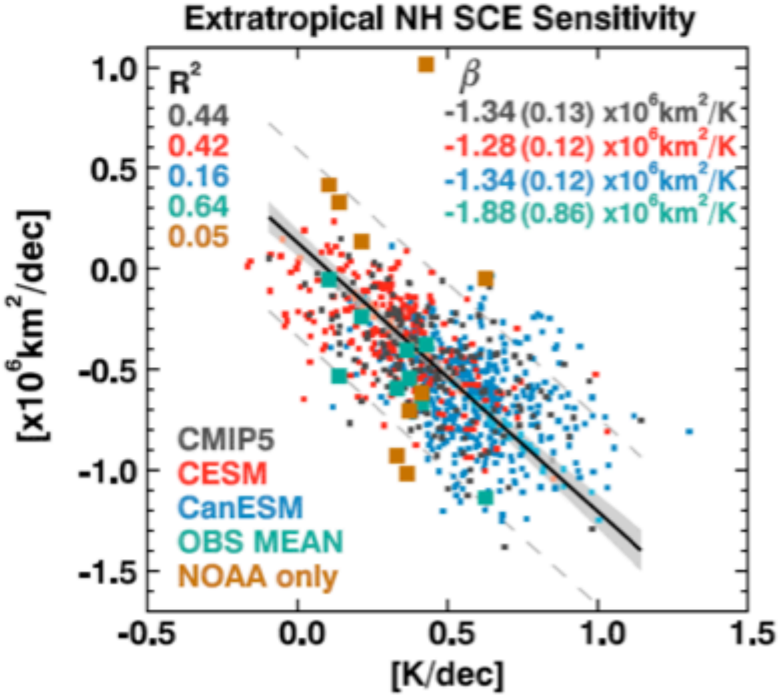


- CMIP5 multi-model ensemble, RCP8.5
- Reduced SCF projected for all seasons due to increased temperature (next slide)
- By end of century, snow cover loss stabilizes under RCP4.5, but not RCP8.5

Projected terrestrial snow cover fraction and sea ice concentration trends (% per decade) for 2020–2050 Trends calculated from the multi-model mean of an ensemble of CMIP5 climate models, using a high emission scenario (RCP8.5)

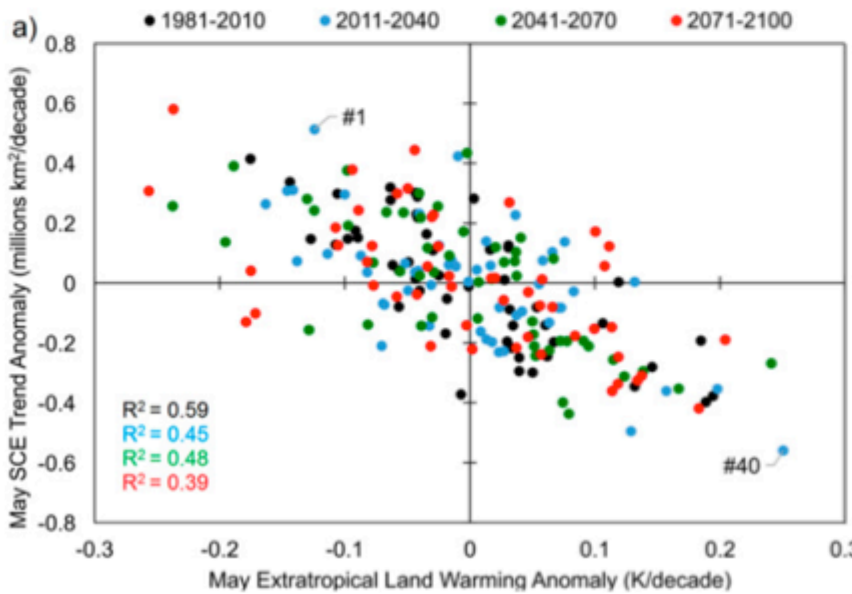
Diagnosing SCF Trends and Projections: Temperature Sensitivity

Mudryk et al. (2017)



Monthly snow cover versus surface air temperature trends (October to June) for individual realizations from CMIP5 (grey), CESM (red), and CanESM (blue) ensembles

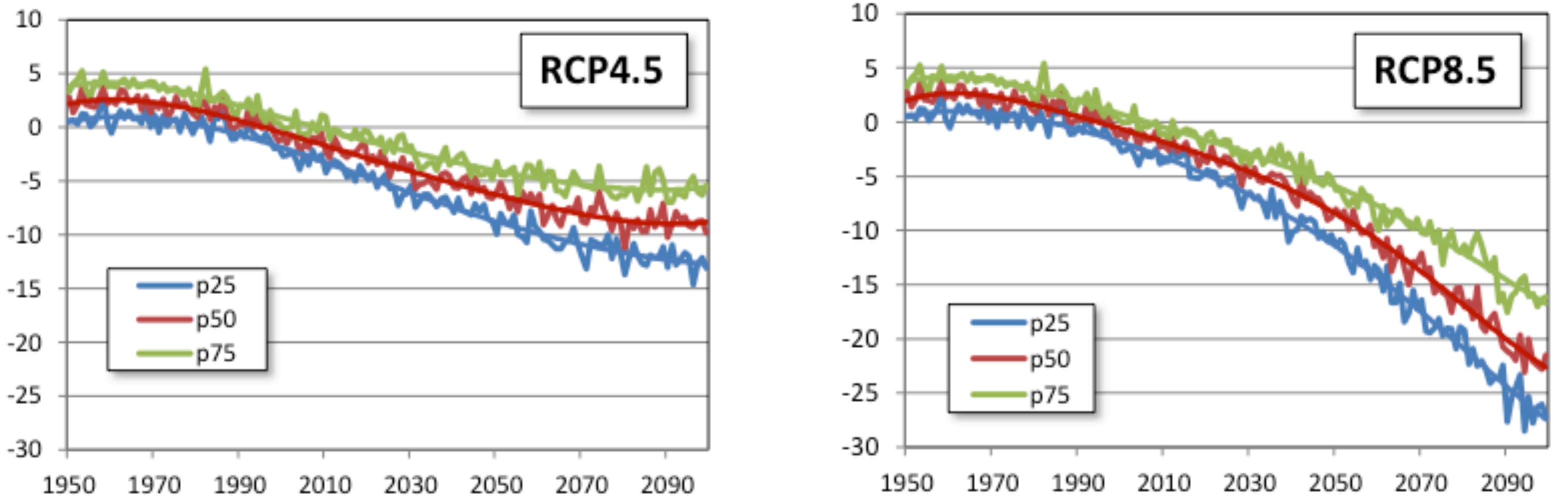
Thackeray et al. (2016)



Relationship between May SCE and NH extratropical land warming anomalies from CanESM2 LE during the historical period (1981–2010) and three future periods

Diagnosing SCF Trends and Projections: Scenario Dependence

Brown et al. (2017)

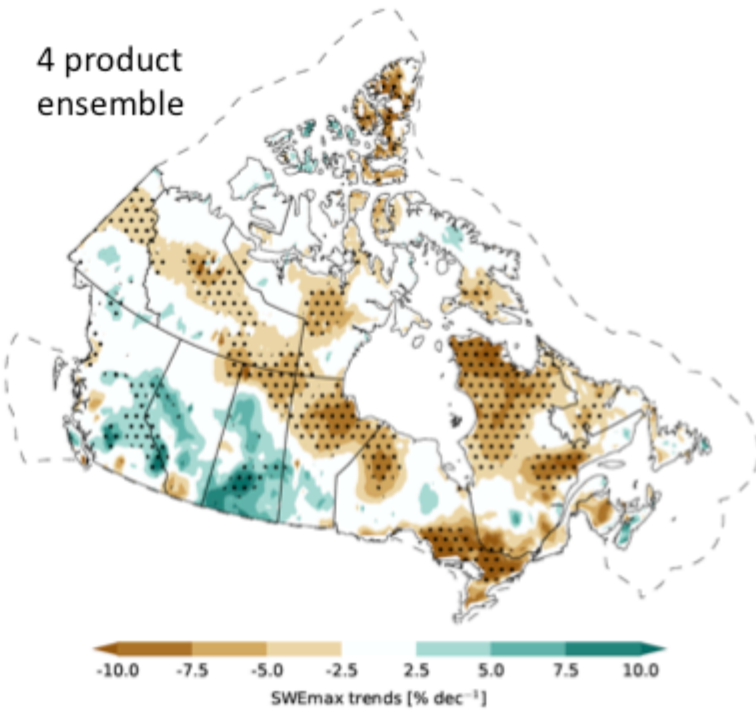


Projected change (%) in Arctic snow cover duration from 16 CMIP5 models

Historical Maximum Snow Water Equivalent Trends and Projections

Mudryk et al. (2018)

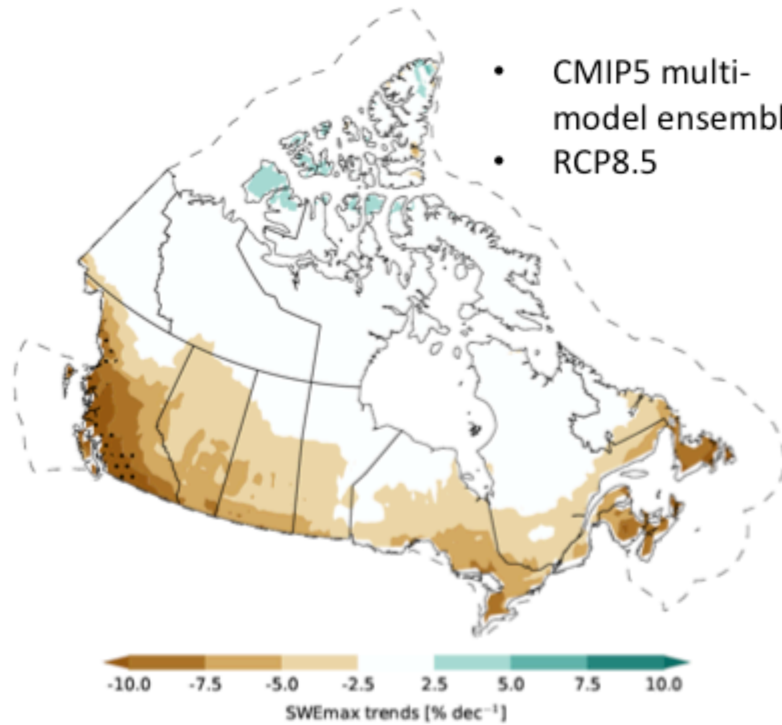
- 4 product ensemble



Stippling indicates pointwise significance at the 90th percentile

SWEmax trends (% per decade) for 1981–2015

- CMIP5 multi-model ensemble
- RCP8.5

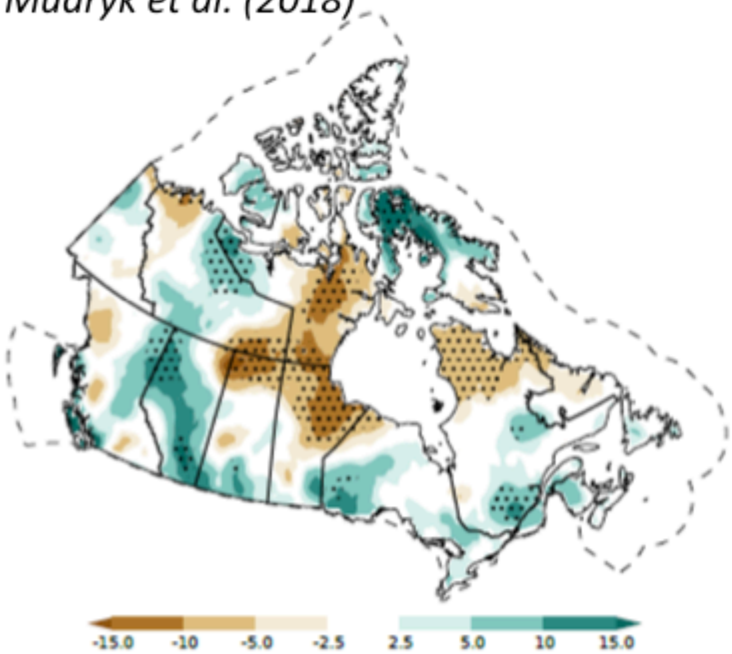


Stippling indicates pointwise significance at the 90th percentile

Projected SWEMax trends (% per decade) for 2020–2050

Diagnosing SWE Trends and Projections

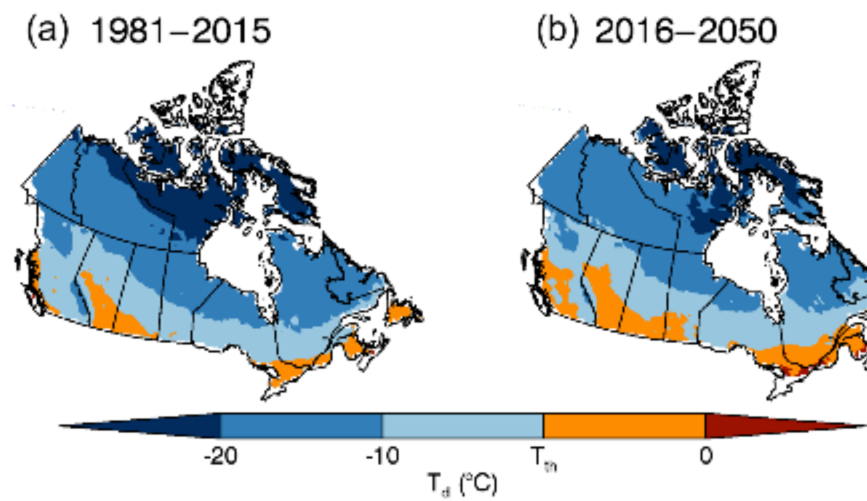
Mudryk et al. (2018)



Stippling indicates pointwise significance at the 90th percentile

Snowfall trends estimated from CANGRID data.

Sospedra-Alfonso and Merryfield (2017)



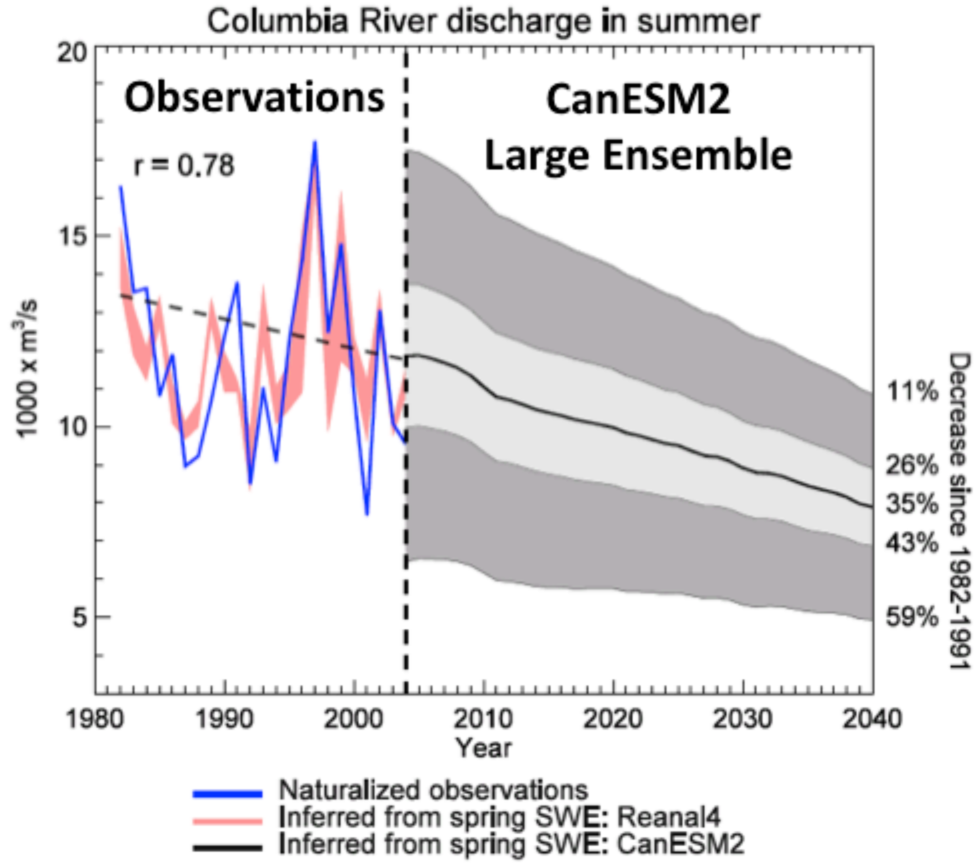
Precipitation Variability

Temperature Variability

Temperature and precipitation controls on March snow water equivalent for historical period (a) and projections to 2050

Impacts of Changing Snow

Fyfe et al. (2017)



Observed and estimated (from simulated spring SWE) summer discharge for the Columbia River watershed, and projected streamflow changes from a large ensemble of CanESM2 simulations

Summary

Spring and fall snow cover sensitivity to warming temperatures: this relationship is now well quantified, and constrains projected changes

Spring snow loss to end century does not stabilize under RCP8.5

SWEmax trends more difficult to project due to influence of temperature and precipitation

Minimal changes in snow accumulation projected over northern regions of Canada because increases in winter precipitation are expected to offset a shorter snow accumulation period

Emerging Activities:

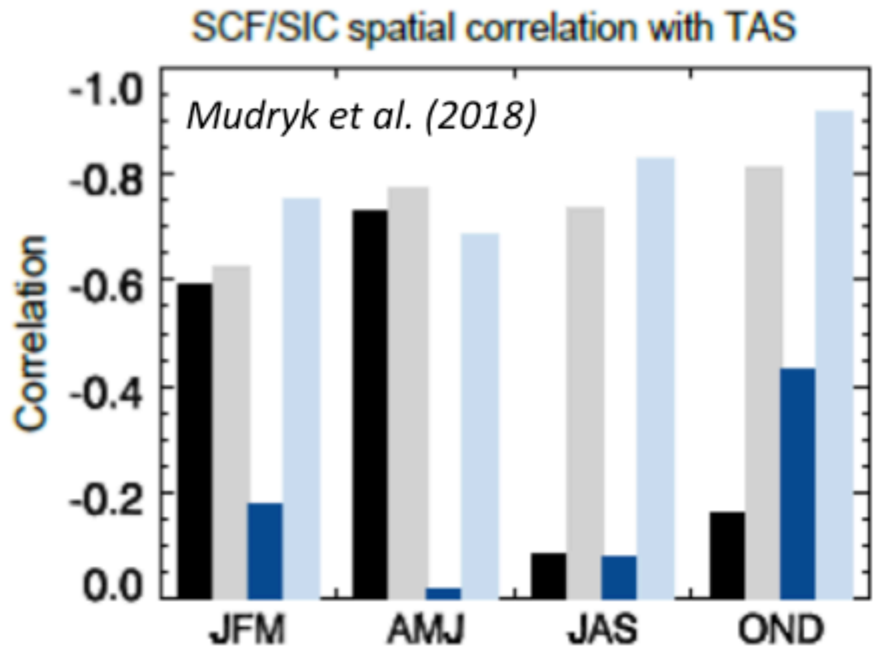
- ESA CCI+: New snow cover climate data records (extent and SWE)
- ESM-SnowMIP: International model assessment exercise at reference sites, plus global offline and coupled simulations with CMIP6 models

Photo: Peter Toose

Diagnosing SCF Trends and Projections: Temperature Sensitivity

Black/gray: snow
Blue: sea ice

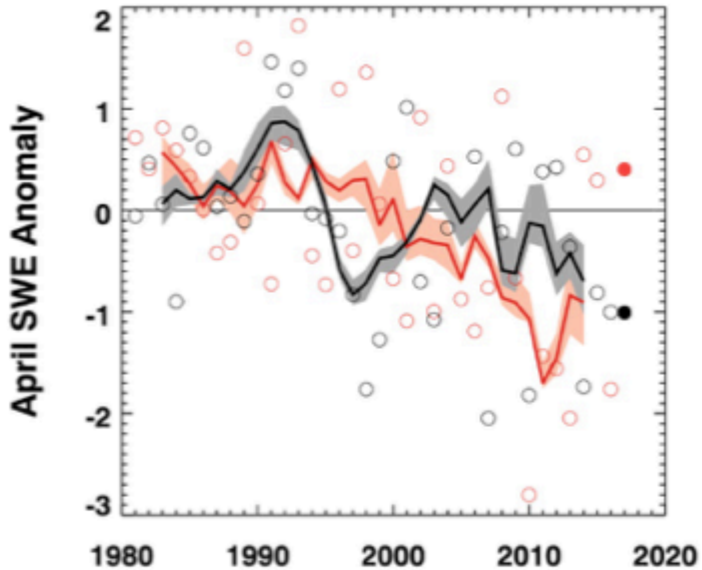
Dark: centred correlation with surface temperature
Light: uncentred correlation with surface temperature



Centred (dark) or uncentred (light) pattern correlation between seasonal TAS trends and seasonal SCF (black) or sea ice concentration (blue)

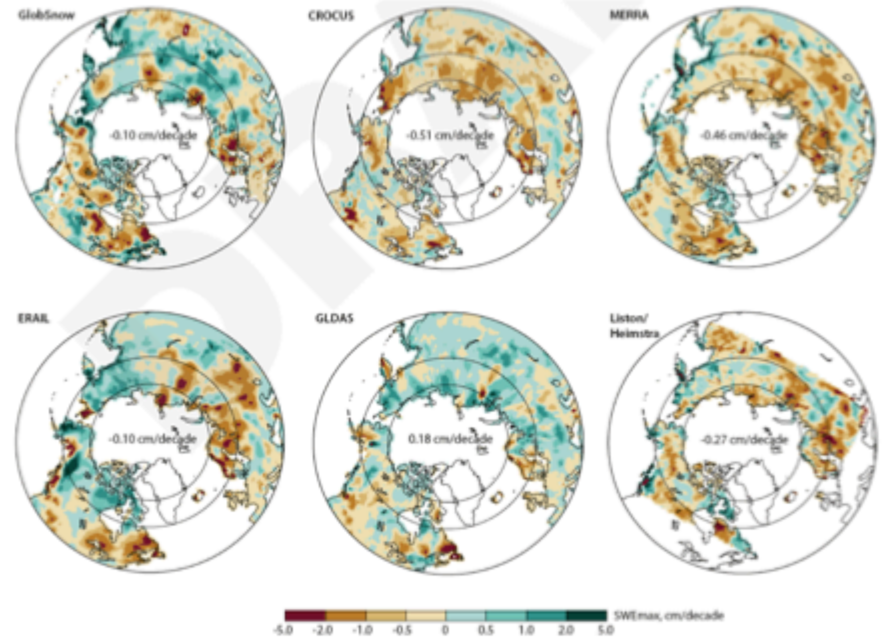
Diagnosing SWE Trends and Projections

Derksen et al. (2018)



Mean April SWE anomalies for Arctic land areas calculated from four independent products for North American (black) and Eurasian (red) sectors of the Arctic.

Brown et al. (2017)



SWE trends, 1981-2010 for 6 independent datasets

- Regionally averaged SWE anomalies are consistent (left) but spatial variability/inconsistency in trends between products is pronounced (right)