# How much do we know about snow: past, present and future?

**Christopher G. Fletcher**
Department of Geography and Environmental Management, University of Waterloo.

<u>**With major contributions from:**</u>

**Lawrence Mudryk (ECCC)**

**Paul Kushner (UToronto)**

**And colleagues from the CanSISE network.**

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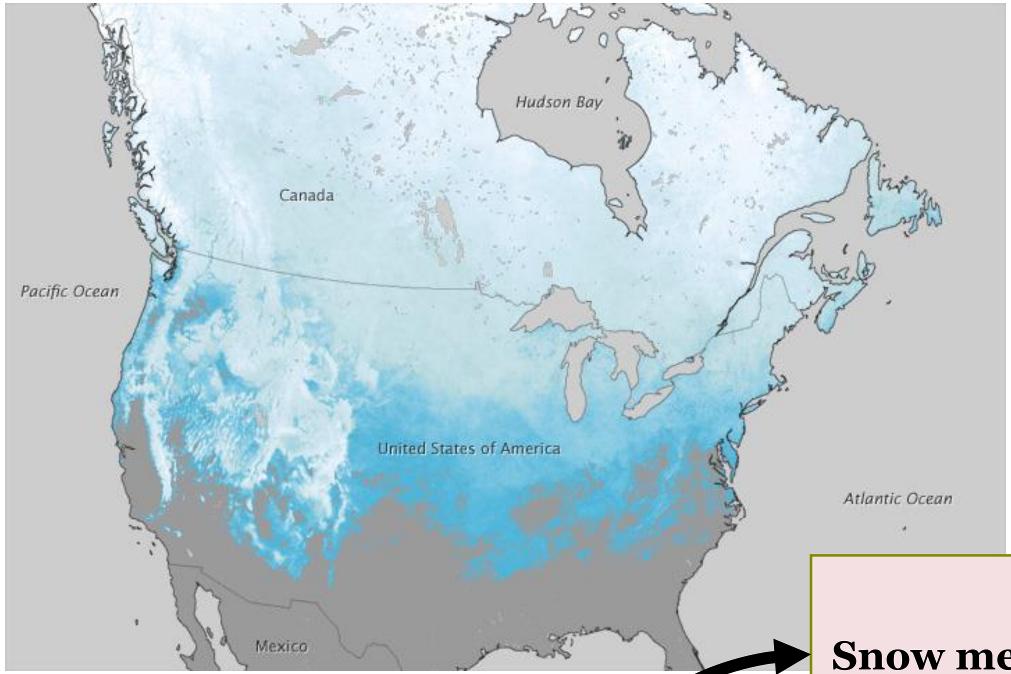
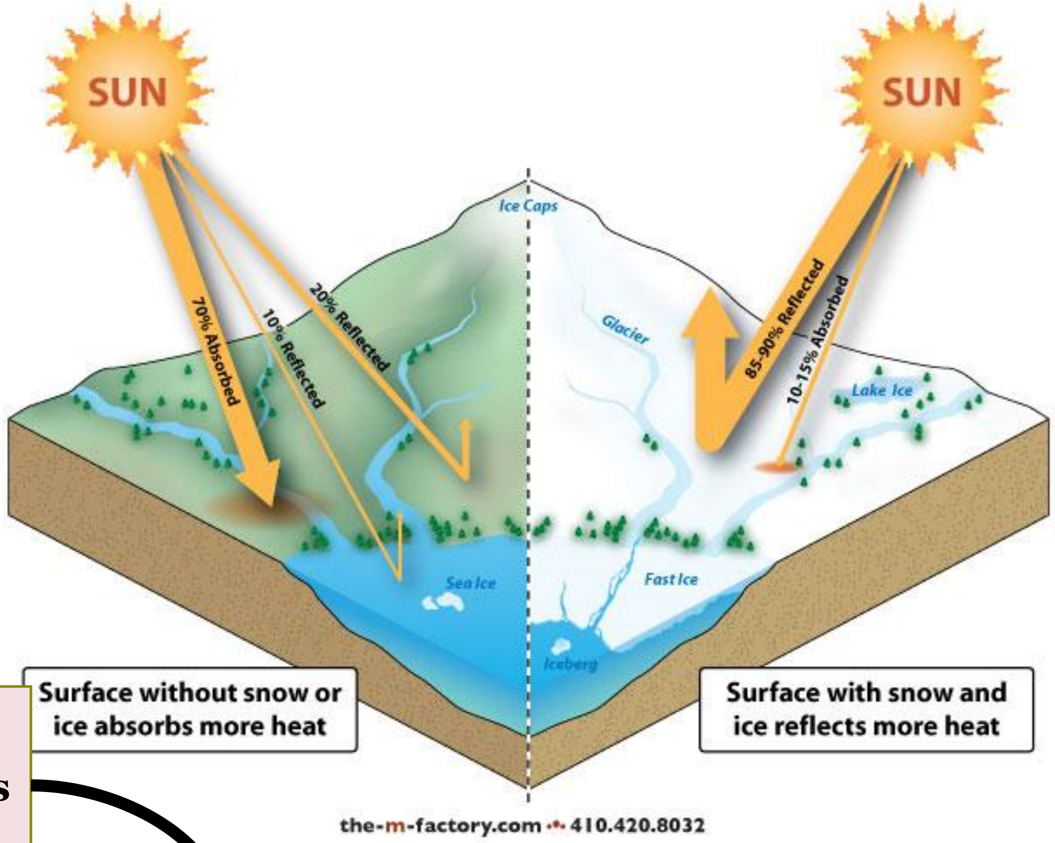
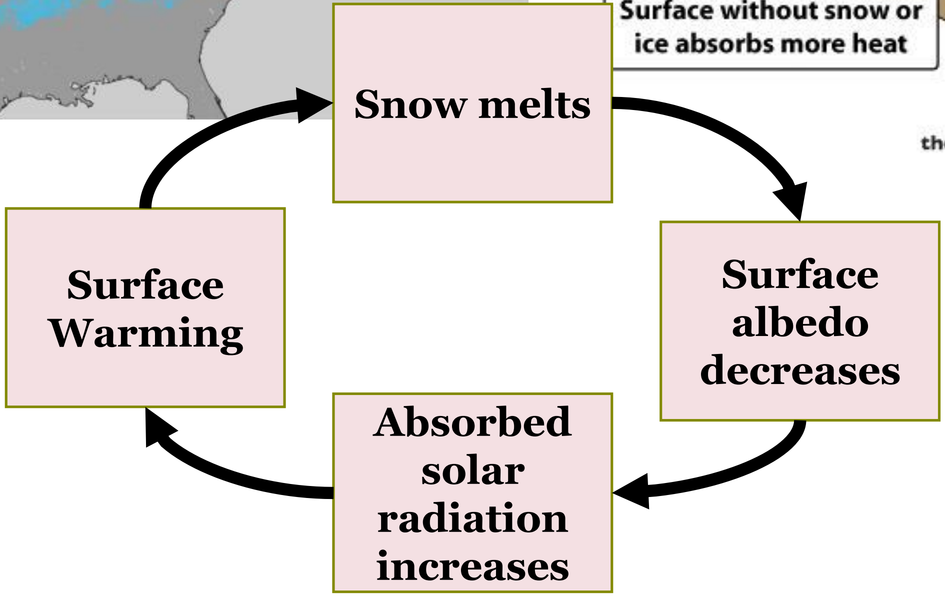
# Importance of snow for climate




Fletcher: How much do we know about snow?

# Importance of snowmelt for hydrology


**Abstract**

A system for operational snowmelt runoff prediction is described as it is presently being implemented for the Rhein-Felsberg basin of the river Rhein in Switzerland. It incorporates a hydrological snow melt model driven by remote sensing data, synoptic measurements and output of a meteorological forecast model. The system components are discussed and first test results are demonstrated.

plied. The SRM is a conceptual degree-day model, based on daily input of air temperature, precipitation and snow cover extent. The latter is derived from satellite data, which enables near real-time assessment of the snow covered area (Baumgartner et al. 1994).

This paper describes the concept and first tests of an operational snowmelt forecast system as it is presently being implemented for the Swiss test basin Rhein-Felsberg within the frame-work of HydAlp (Hydrology of Alpine and High Latitude Basins). This European re-

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DOI 10.1007/s00382-017-3609-x

**Rain-on-snow events over North America based on two Canadian regional climate models**

**Dae Il Jeong[1] · Laxmi Sushama[1]**

# 1. Canadian snow: blended observations

15 October 2015 MUDRYK ET AL. 8037

## Characterization of Northern Hemisphere Snow Water Equivalent Datasets, 1981–2010

L. R. Mudryk

*Department of Physics, University of Toronto, Toronto, Ontario, Canada*

C. Derksen

*Climate Research Division, Environment Canada, Toronto, Ontario, Canada*

P. J. Kushner

*Department of Physics, University of Toronto, Toronto, Ontario, Canada*

R. Brown

*Climate Research Division, Environment Canada, Ouranos, Montreal, Quebec, C*

CanSISE
Canadian Sea Ice and Snow Evolution Network

**Mudryk, L. R., Derksen, C., Kushner, P. J., & Brown, R.** (2015). Characterization of Northern Hemisphere Snow Water Equivalent Datasets, 1981–2010. *Journal of Climate*, *28*(20), 8037–8051.

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# 1. Canadian snow: blended observations

- For model validation and forcing, there is a need for reliable gridded SWE data
- L. Mudryk (ECCC) led a rigorous study of satellite/reanalysis SWE products
- -> CanSISE daily NH gridded (1° x 1°) SWE product 1981-2010

| Dataset | Abbreviation | Snow scheme | Land model | Forcing data | Resolution | Reference |
|---|---|---|---|---|---|---|
| GlobSnow | GS | Satellite passive microwave + in situ[a] | | | 25 km | Takala et al. (2011) |
| ERA-Interim/Land | E | Simple | HTESSEL | ERA-Interim | 3/4° × 3/4° | Balsamo et al. (2015) |
| MERRA | M | Intermediate | Catchment | MERRA | 1/2° × 2/3° | Rienecker et al. (2011) |
| Crocus | C | Complex | ISBA | ERA-Interim | 1° × 1° | Brun et al. (2013) |
| GLDAS-2 | G2 | Simple | Noah 3.3 | Princeton Meteorological | 1° × 1° | Rodell et al. (2004) |
| GLDAS-1[a] | G1n | Simple | Noah 2.7 | GDAS + CMAP | 1° × 1° | Rodell et al. (2004) |
| | G1m | Simple | Mosaic | | | |
| | G1v | Intermediate | VIC | | | |
| | G1c | Intermediate | CLM | | | |
| Canadian Meteorological Centre[b] | CMC | Simple + in situ[c] | | Global Environmental Multiscale Model (GEM) | 35 km | Brasnett (1999); Brown and Brasnett (2010) |
| MERRA-Land[b] | ML | Intermediate | Catchment | MERRA | 1° × 1° | Reichle et al. (2011) |

[a] GlobSnow is based on combined information from satellite passive microwave retrievals and in situ observations from weather stations. See text for details.
[b] Established SWE datasets that meet the NH domain criteria but which contain temporal discontinuities, as analyzed in section 2c, that compromise their use in the multidataset mean.
[c] CMC computes snow depths based on combined information from in situ observations and a simple snow scheme, driven by temperature and precipitation from GEM. Depths are converted to SWE using climatological snow density information.

**Data available at: `https://nsidc.org/data/nsidc-0668`**

Mudryk et al. (2015)

Canadian Sea Ice and Snow Evolution Network

# 2. Trends in Canadian snow (and sea ice) 1981-2015

The Cryosphere, 12, 1157–1176, 2018
https://doi.org/10.5194/tc-12-1157-2018


The Cryosphere
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EGU

## Canadian snow and sea ice: historical trends and projections

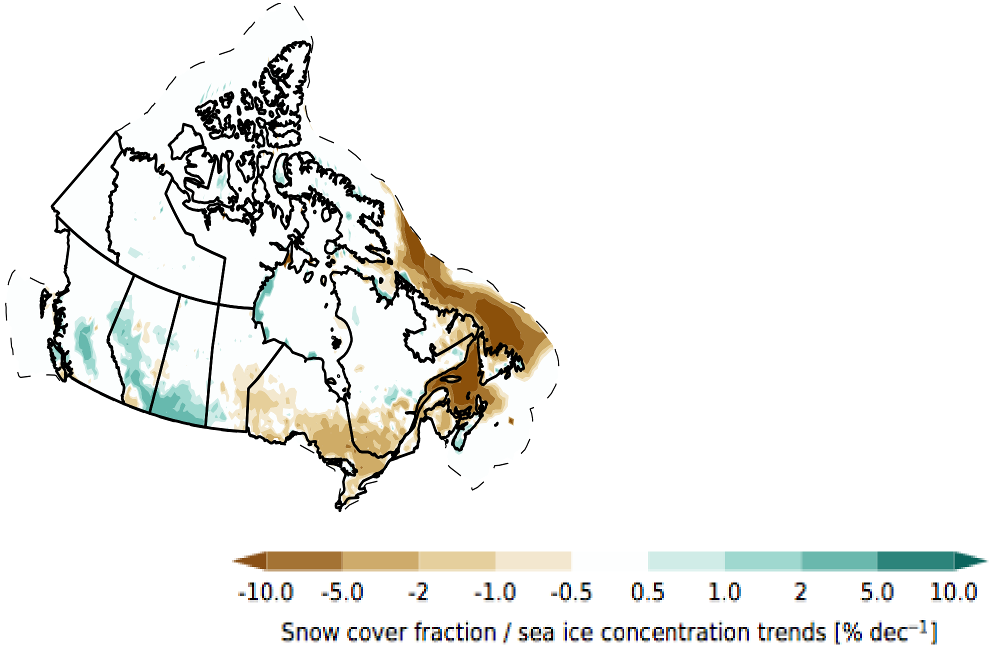
**Lawrence R. Mudryk[1], Chris Derksen[1], Stephen Howell[1], Fred Laliberté[1], Chad Thackeray[2], Reinel Sospedra-Alfonso[3], Vincent Vionnet[4], Paul J. Kushner[5], and Ross Brown[6]**

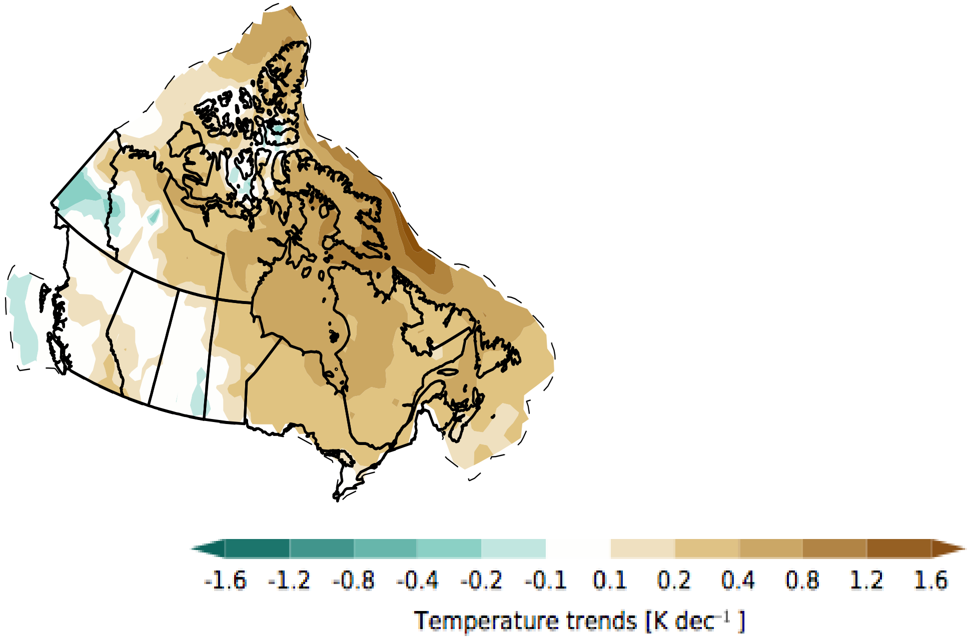
[1]Climate Research Division, Environment and Climate Change Canada, Toronto, Canada
[2]Department of Geography and Environmental Management, University of Waterloo, Waterloo, Canada
[3]Climate Research Division, Environment and Climate Change Canada, Victoria, Canada
[4]Centre National de Recherches Météorologiques, Centre d'Etudes de la Neige, Grenoble, France
[5]Department of Physics, University of Toronto, Toronto, Canada
[6]Climate Research Division, Environment and Climate Change Canada, Montréal, Canada

CanSISE
Canadian Sea Ice and Snow Evolution Network

# 2. Trends in Canadian snow (and sea ice) 1981-2015

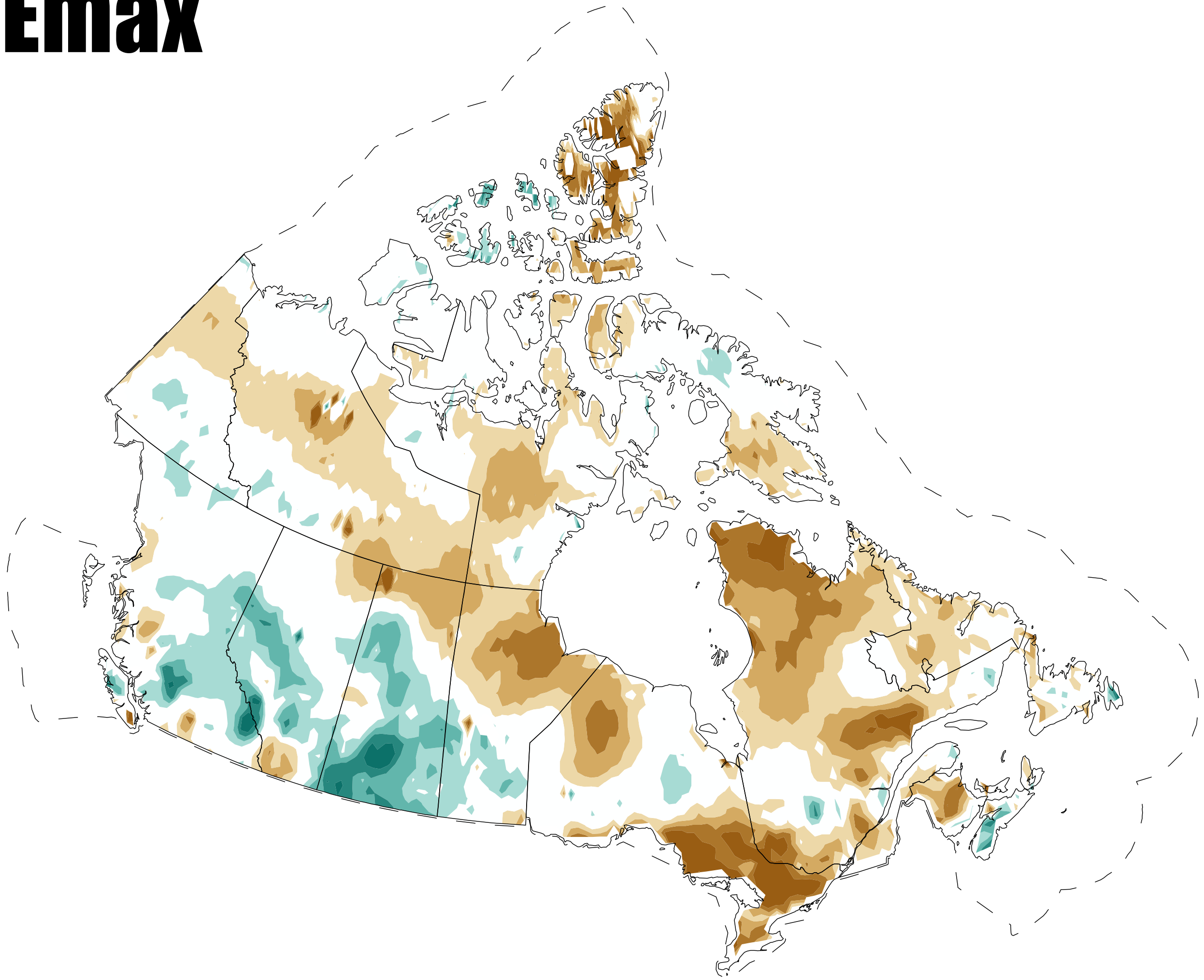
- Wintertime snow cover has declined by 5-10% over eastern Canada
- Springtime declines are 5-10% across the Arctic/subarctic
- Snow gains in western Canada
- Spatial pattern of snow trends is closely tied to temperature trends




Mudryk et al. (2018)

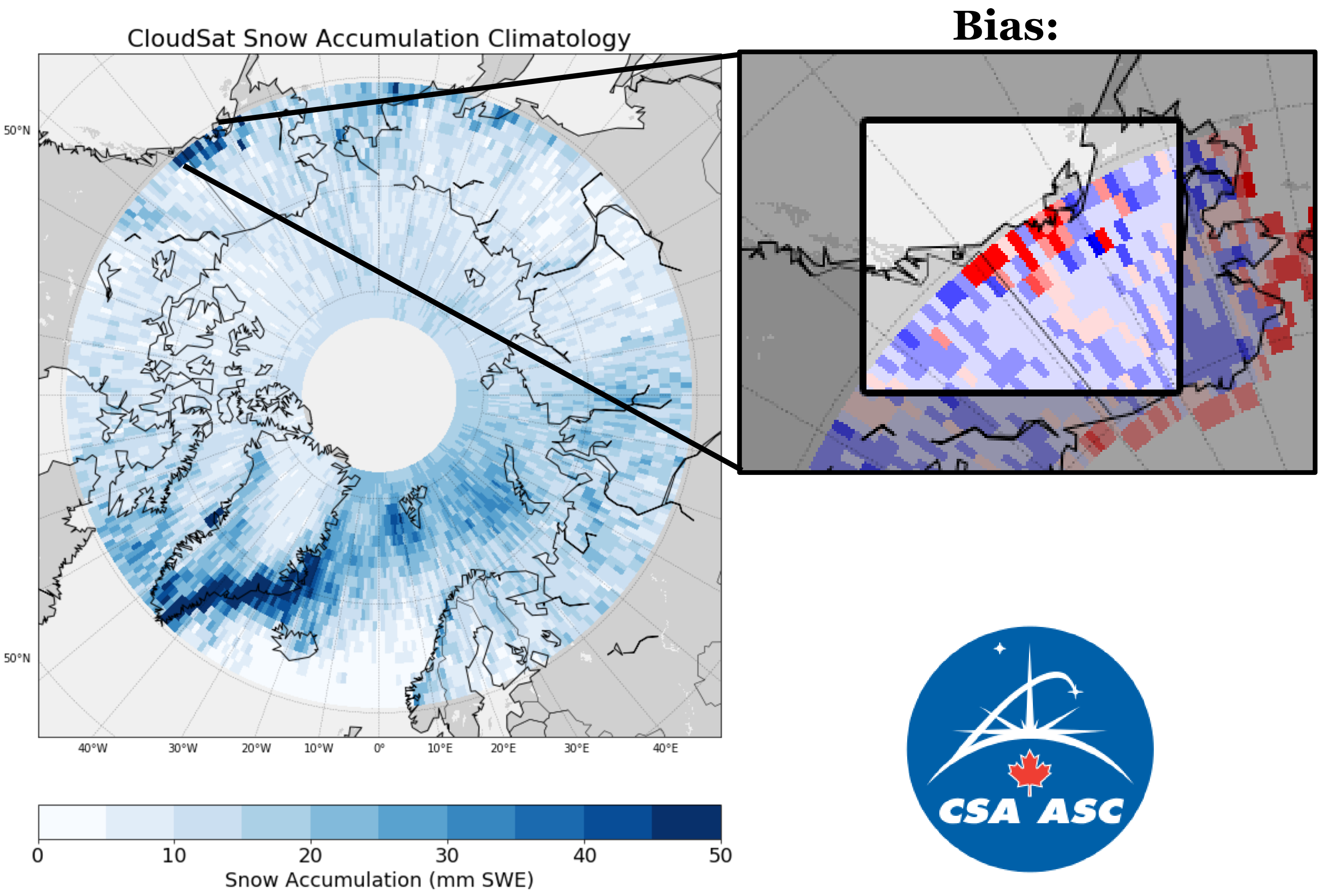
# 2. Trends in SWEmax



Mudryk et al. (2018)

# 2b. Post-CanSISE re-examination of blended snow data

- CSA-funded project attempting to use space-based retrievals of surface snow to validate gridded products
- The CloudSat-CPR instrument provides a very useful independent look at surface snow climatology
- Highlights potential problems in gridded data over high topography




CSA ASC

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Unpublished analysis by **Fraser King**, MSc student, University of Waterloo.

# 3. Canadian snow (and sea ice): evaluation of models

The Cryosphere, 12, 1137–1156, 2018
https://doi.org/10.5194/tc-12-1137-2018


The Cryosphere

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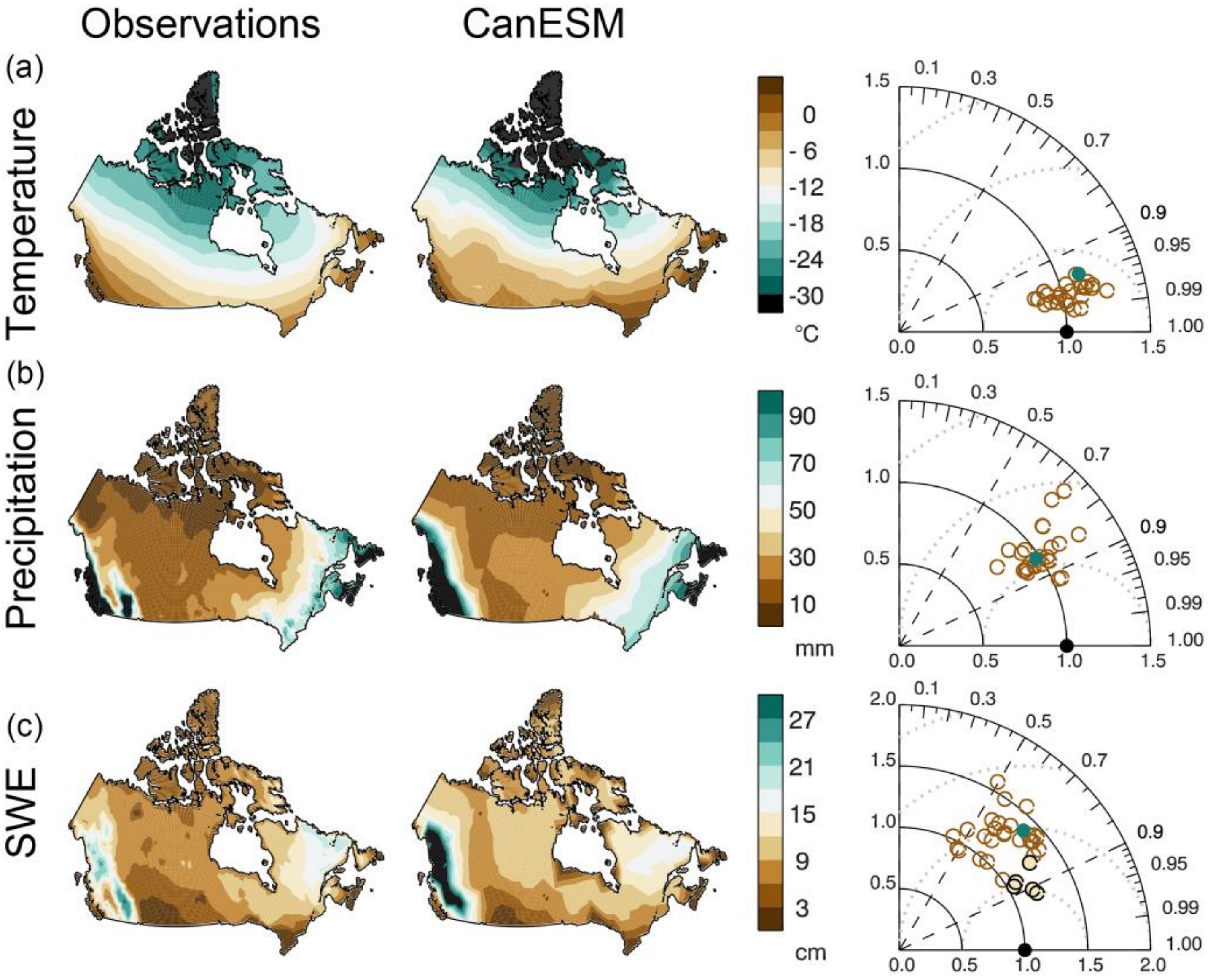
## Canadian snow and sea ice: assessment of snow, sea ice, and related climate processes in Canada's Earth system model and climate-prediction system

Paul J. Kushner[1], Lawrence R. Mudryk[2], William Merryfield[2], Jaison T. Ambadan[3], Aaron Berg[3], Adéline Bichet[4], Ross Brown[2], Chris Derksen[2], Stephen J. Déry[5], Arlan Dirkson[6], Greg Flato[2], Christopher G. Fletcher[7], John C. Fyfe[2], Nathan Gillett[2], Christian Haas[8,9], Stephen Howell[2], Frédéric Laliberté[2], Kelly McCusker[10], Michael Sigmond[2], Reinel Sospedra-Alfonso[2], Neil F. Tandon[2], Chad Thackeray[7], Bruno Tremblay[11], and Francis W. Zwiers[12]

CanSISE
Canadian Sea Ice and Snow Evolution Network

# 3. Canadian snow: models vs. observations

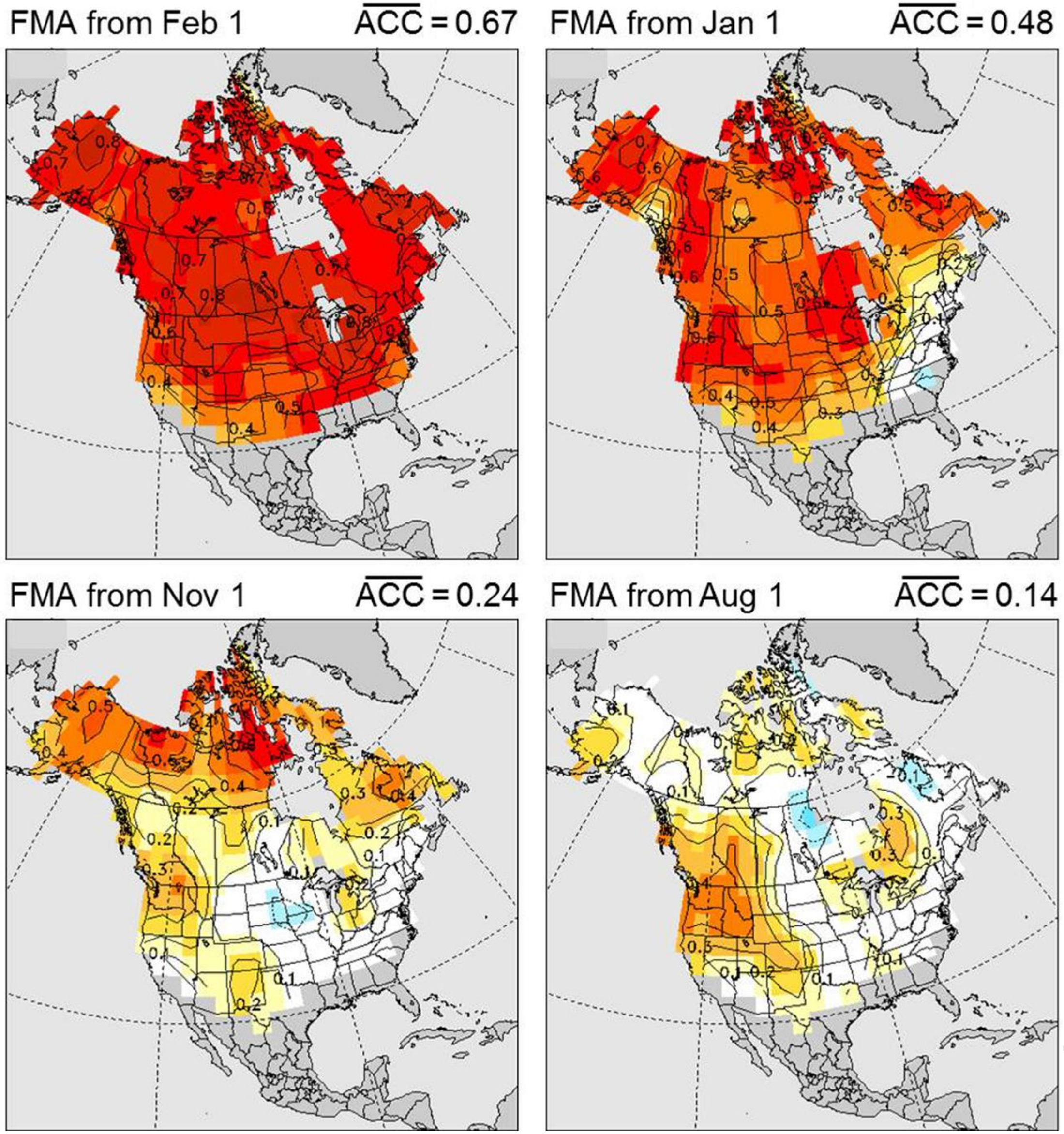
- P. Kushner (U Toronto) led an evaluation of the Canadian Earth System Model (CanESM2)
- All models simulate JFM mean temperature pattern very well
- Larger disagreement for precip and SWE, but CanESM2 is among the best models.




Kushner et al. (2018)

# 3. Canadian snow: SWE prediction skill

- Colleagues at CCCma (Victoria) and U Guelph showed spring SWE is highly predictable from Nov onwards.
- Highest skill is found over the Canadian Arctic/subarctic, and western cordillera
- Lower skill in central/east
- Improved initialisation of surface snow yields much better forecast skill (not shown).




Kushner et al. (2018)

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RLOO
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# 4. Near-term projections of snowpack loss (western US)

nature COMMUNICATIONS

ARTICLE

Received 26 Sep 2016 | Accepted 20 Feb 2017 | Published 18 Apr 2017

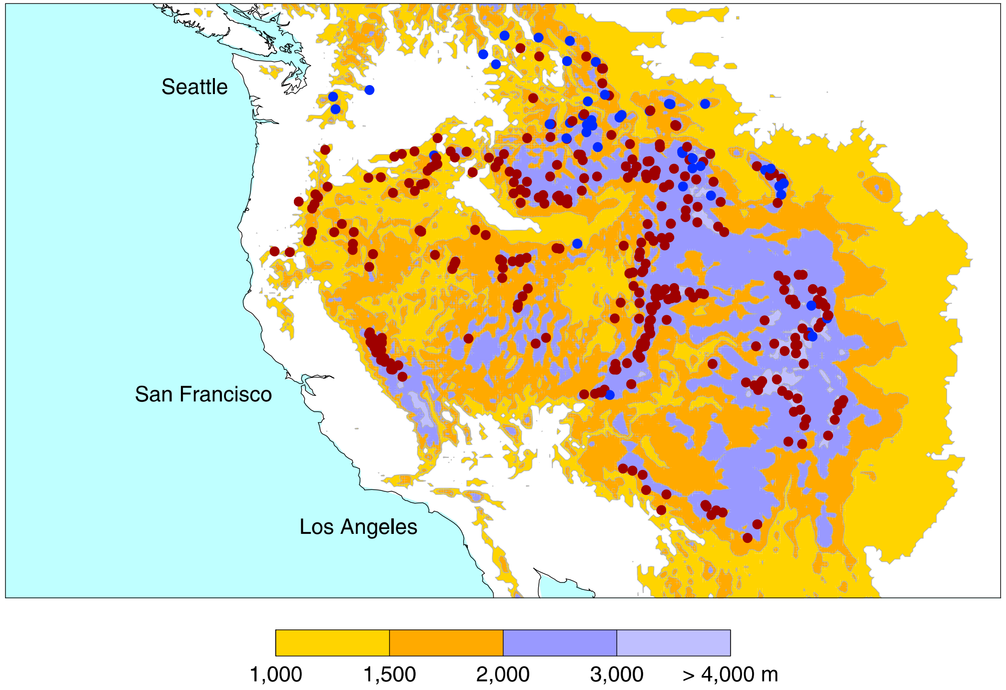
DOI: 10.1038/ncomms14996

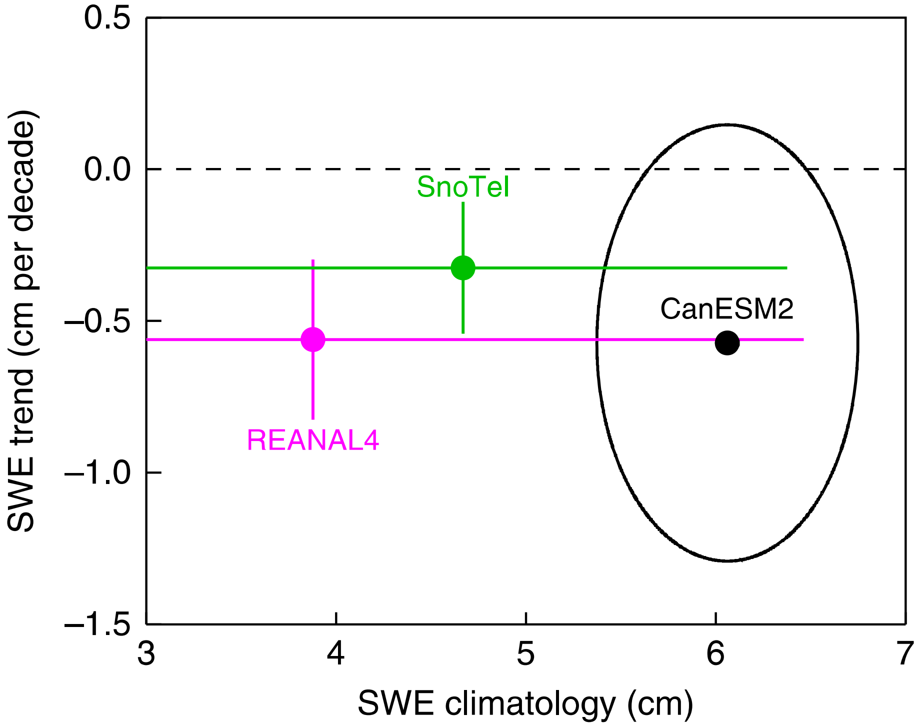
OPEN

## Large near-term projected snowpack loss over the western United States

John C. Fyfe[1], Chris Derksen[2], Lawrence Mudryk[2], Gregory M. Flato[1], Benjamin D. Santer[3], Neil C. Swart[1], Noah P. Molotch[4,5], Xuebin Zhang[2], Hui Wan[2], Vivek K. Arora[1], John Scinocca[1] & Yanjun Jiao[1]

# 4. Near-term projections of snowpack loss (western US)

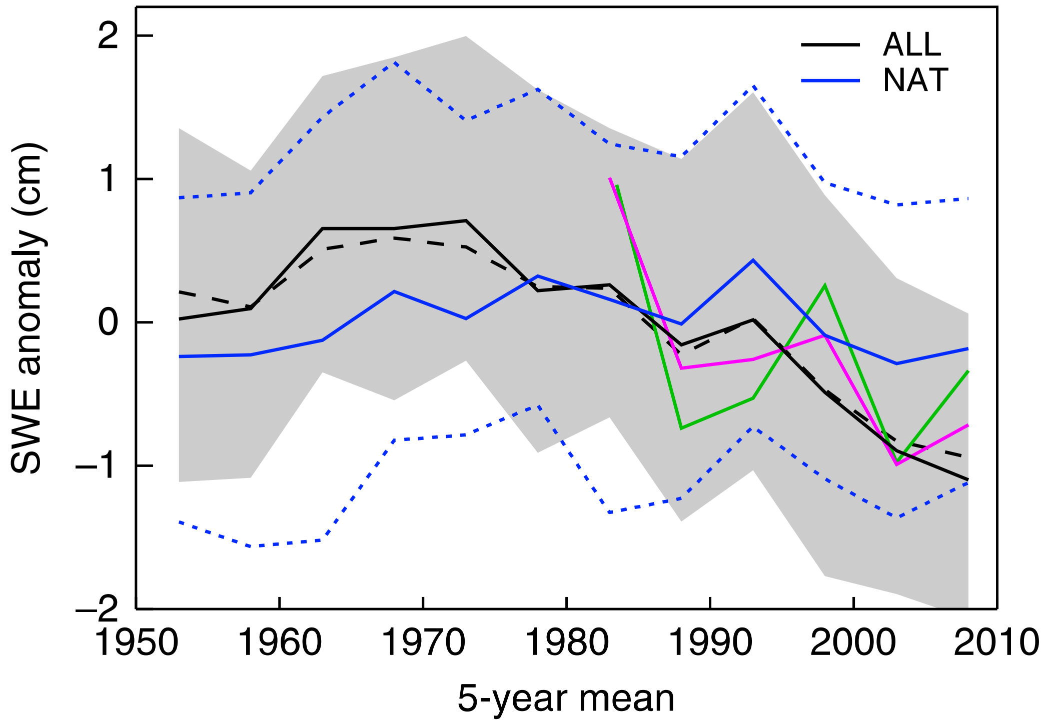


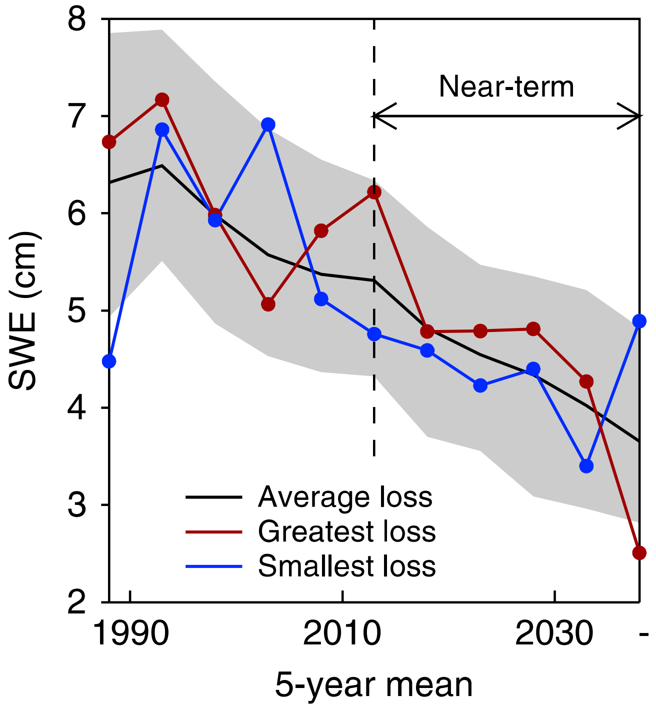




- J. Fyfe (CCCma) led a study showing 10-20% losses in snowpack since 1980
- CanESM2 model is in good agreement with gridded and in situ observations

Fyfe et al. (2017)

# 4. Near-term projections of snowpack loss (western US)




- Observed trends are consistent with historical forcings, but not with “natural only”
- Projections show GHG forcing associated with continued rapid snowpack loss
- However, internal climate variability has a large influence on near-term trends.

Fyfe et al. (2017)


https://uwaterloo.ca/scholar/bmlyons

**Keynote Speakers**:

- Prof Paul Kushner (UToronto)
- Dr Andre Erler (Aquanty Inc)
- Ms Chelsea Mottishaw (City of Dawson Creek)
- Dr Hank Venema (Strategic Community Consulting)
- Dr Stephanie Shifflett (GRCA)

**Number of attendees by sector:**

| | |
|---|---|
| Academia | 7 |
| Government | 6 |
| NGO | 5 |
| Industry | 5 |

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**Workshop Coordinator**: Blaine Lyons, bmlyons@uwaterloo.ca

# The end.


chris.fletcher@uwaterloo.ca

https://uwaterloo.ca/scholar/c5fletch

@ClimoChris

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# 2. Physical controls on SWEmax

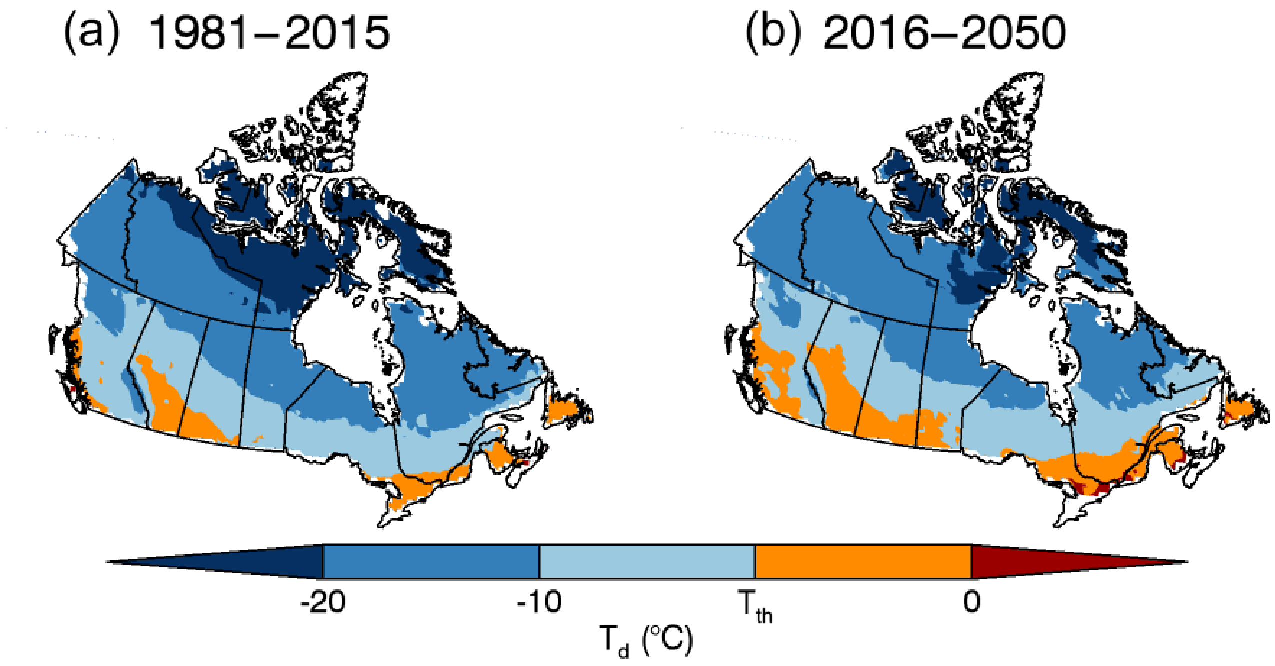


**Figure 12.** Temperature and precipitation controls on March snow water equivalent for historical period **(a)** and projections to 2050 **(b)**. For the data presented here $T_{th} = -5.4\,°C$ (more generally $T_{th} = -5 \pm 1\,°C$). Regions with $T_d < T_{th}$ (blue) have March SWE dominated by precipitation variability while regions with $T_d > T_{th}$ (orange) have March SWE dominated by temperature variability.

Mudryk et al. (2018)