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EVALUATION OF SNOW WATER EQUIVALENT DATASETS OVER THE SAINT-MAURICE RIVER BASIN REGION OF SOUTHERN QUÉBEC

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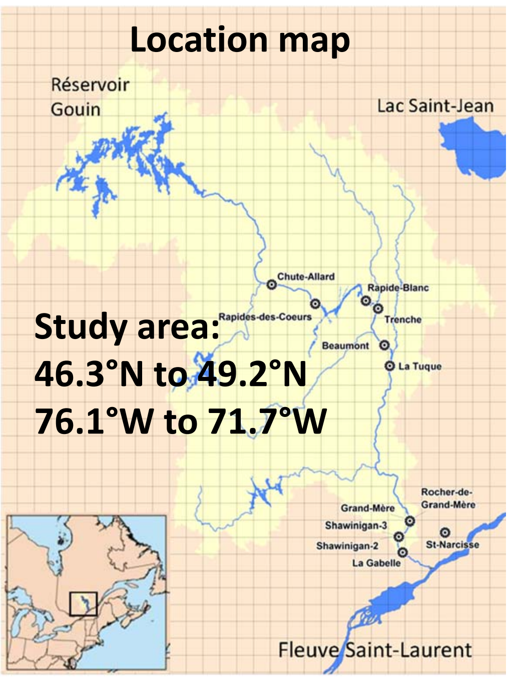
Canada

Study Background and Rationale

- Knowledge of the maximum amount of water stored in the seasonal snowpack prior to snow melt (SWEM) is critical information for Hydro-Quebec (H-Q) reservoir management
- To date satellite-based SWE products have not met H-Q accuracy requirements (±15%) needed to support operational decision
- As a contribution to the international Snow Product Intercomparison and Evaluation Experiment (SnowPEx) snow product evaluation project, H-Q provided 10-km kriged snow survey data over the Saint-Maurice Basin area for a 35 year period (1980-2014) to evaluate a range of currently available SWE products
- The Saint-Maurice Basin (SMB) has one of the highest density snow survey networks in the province, and includes 11 hydroelectric power-generating facilities with a total installed capacity of 2030 MW
- SWE and solid precipitation products were evaluated on their ability to represent the spatial and temporal variability in SWEM over the basin
- Results published in Brown et al. (2018) *Hydrological Processes*, 32(17), pp.2748-2764

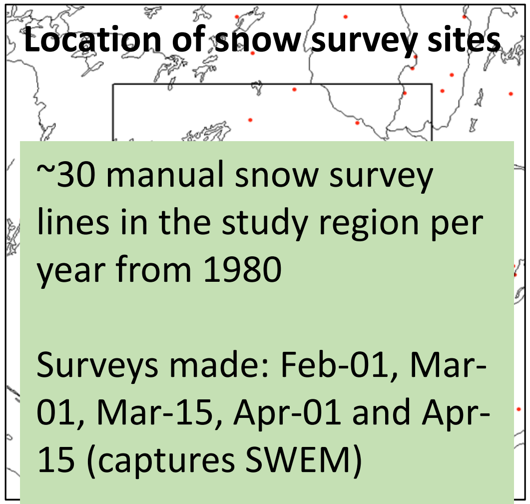
Saint-Maurice Basin Characteristics

Region covers the transition zone from mixed broadleaf forest to southern coniferous forest

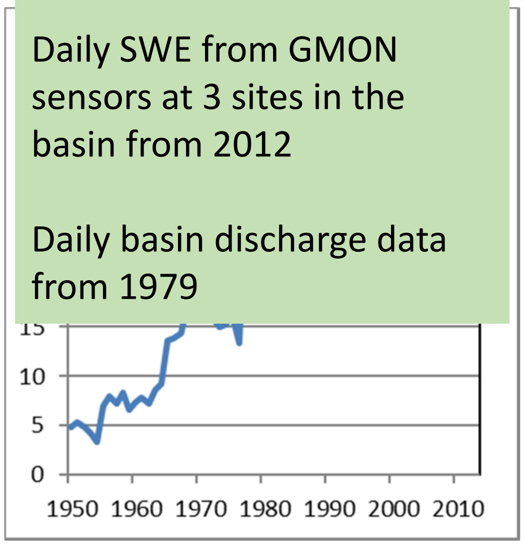


Study area:
46.3°N to 49.2°N
76.1°W to 71.7°W

Basin Area = 43,300 km²



- ~30 manual snow survey lines in the study region per year from 1980
- Surveys made: Feb-01, Mar-01, Mar-15, Apr-01 and Apr-15 (captures SWEM)
- Daily SWE from GMON sensors at 3 sites in the basin from 2012
- Daily basin discharge data from 1979



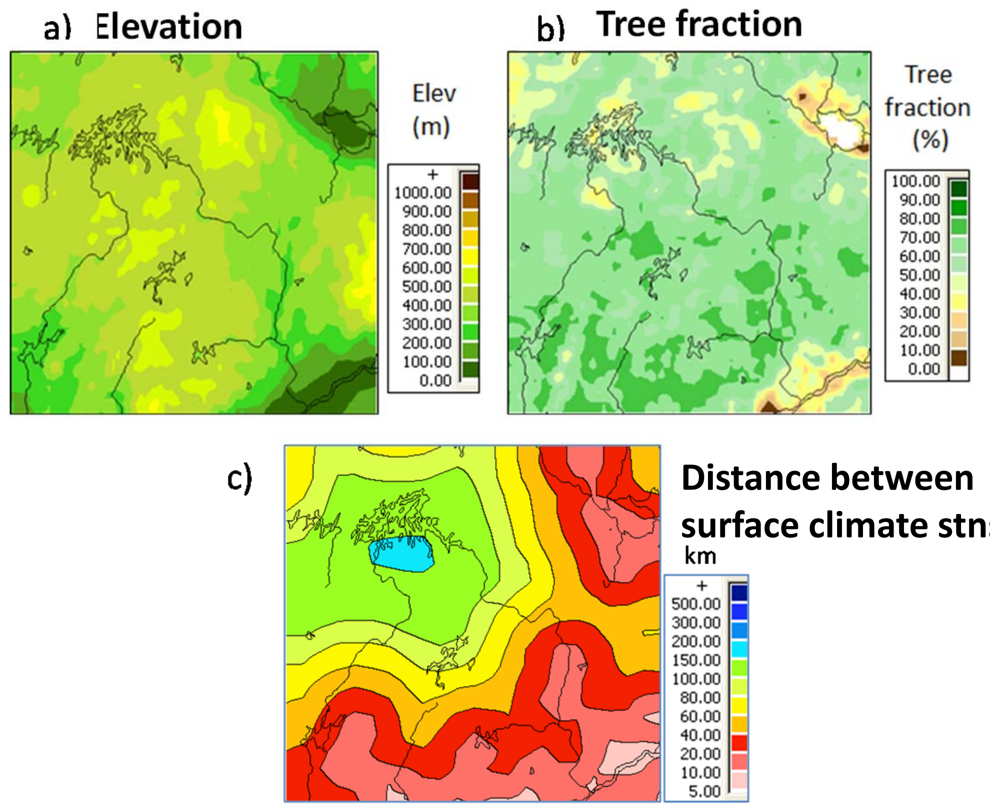
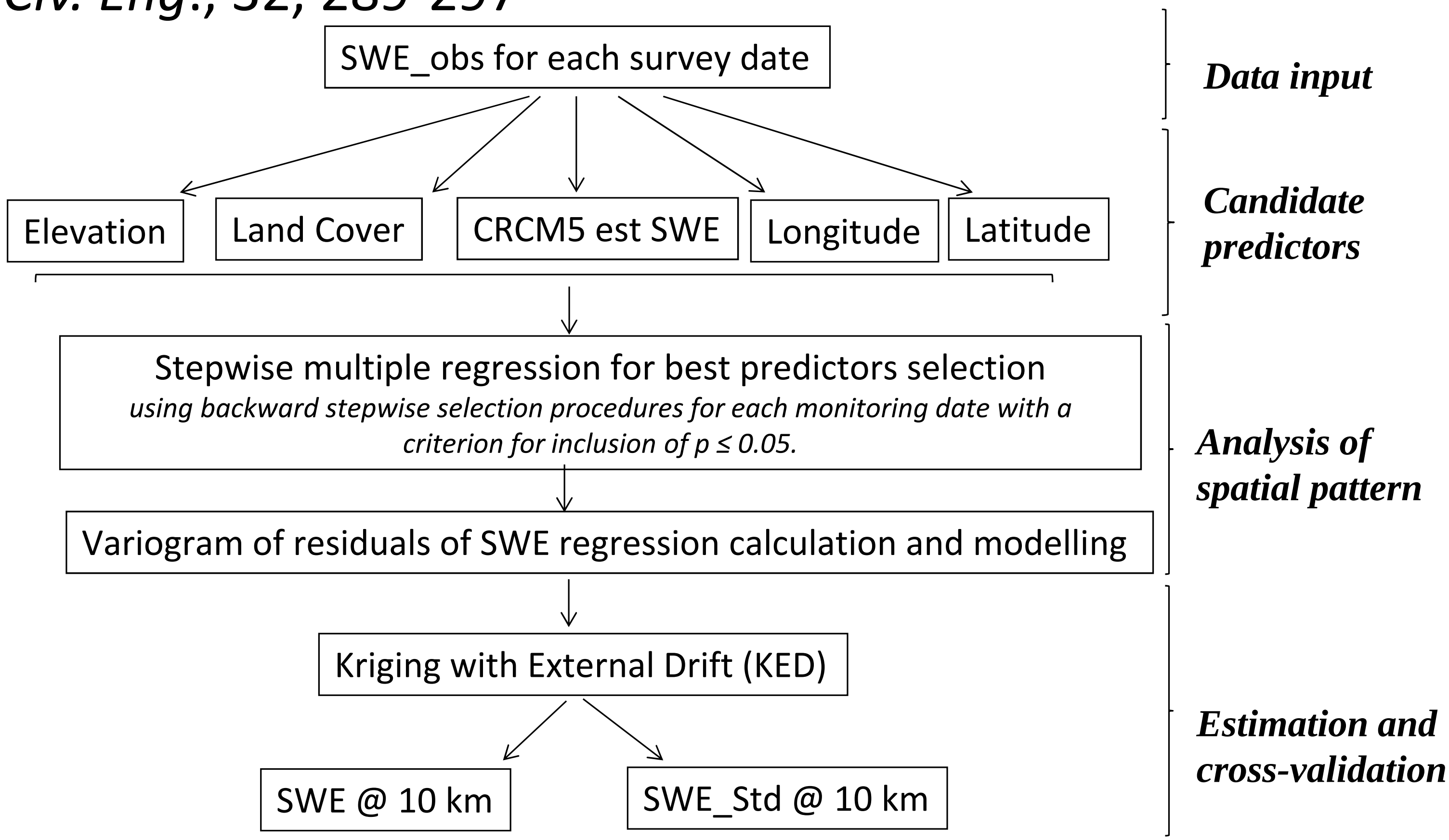


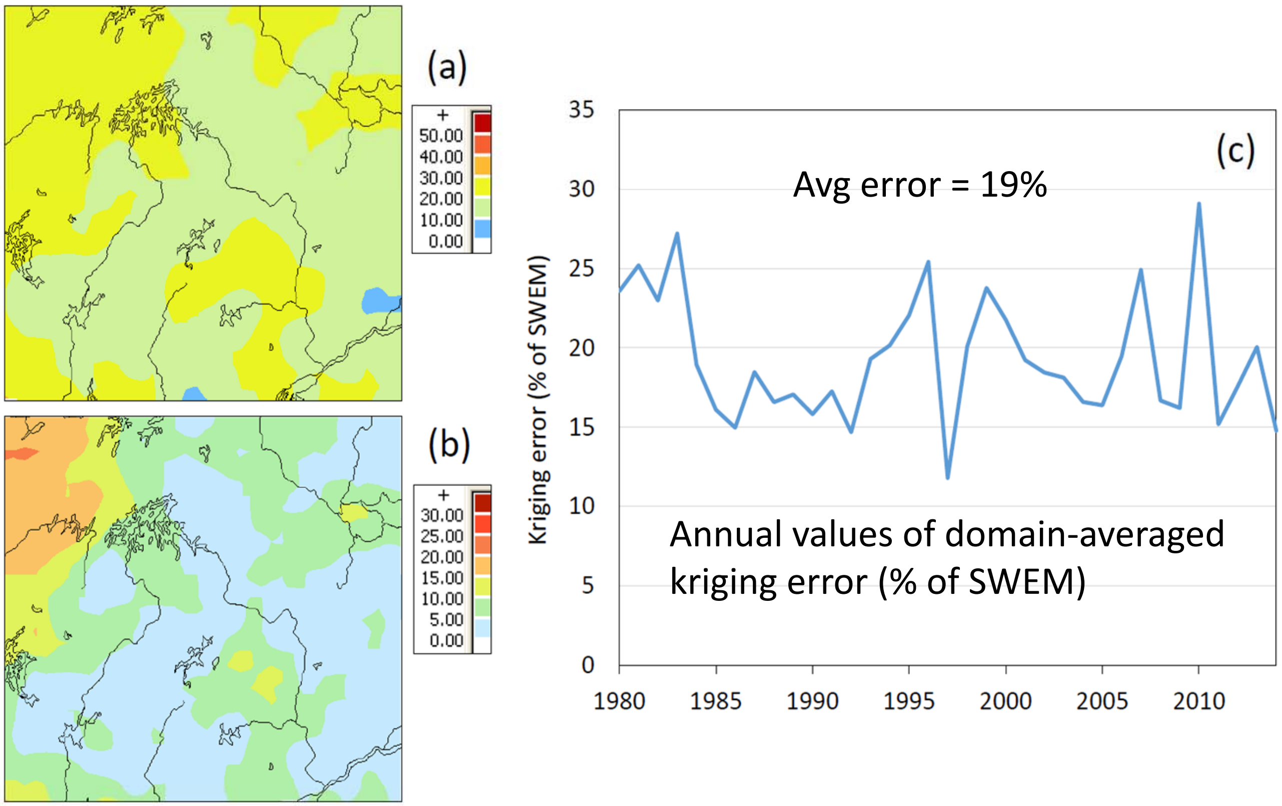
Figure 2: Surface elevations (a) from ETOPO2, forest fraction (b) from Hansen et al. (2006), and distance (km) to nearest surface climate observing station (c).

Interpolation Method – Kriging with External Drift (KED) following Tapsoba et al. (2005) *Can. J. Civ. Eng.*, 32, 289-297



SWEM @ 10 km obtained from 5 snow survey maps per season

Mean kriging error (% of SWEM) over 1980-2014

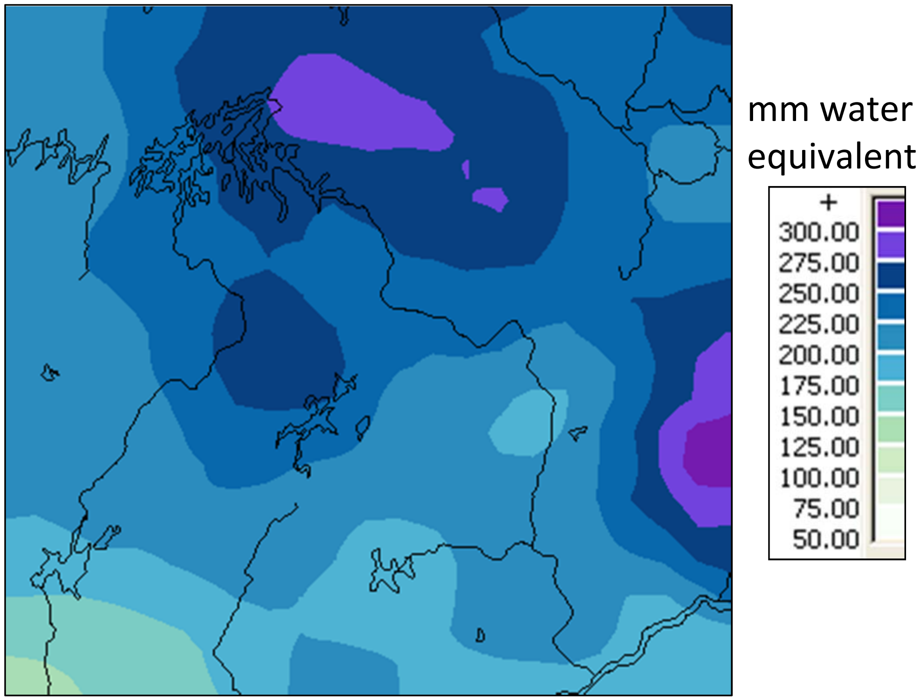


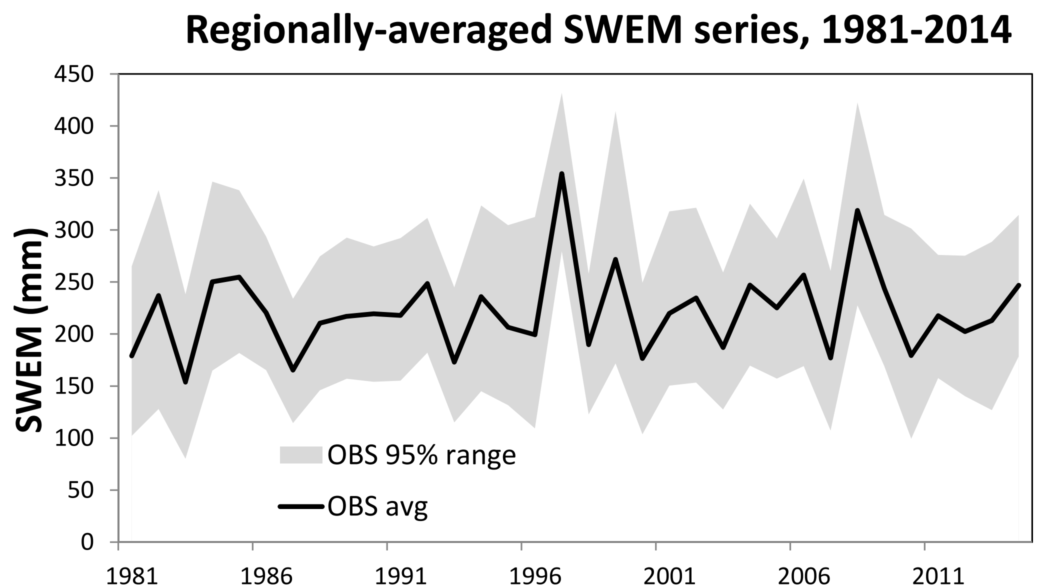
Number of years kriging error exceeds 25%

Estimates of the uncertainty in SWEM estimates made using the Turning Bands Method (Lantuejoul, 2002)

Analysis of the impact of screening out grid points with kriging errors > 25% showed that the effect on dataset evaluation statistics was small

SWEM climatology: average SWEM ranges from 150 mm to > 300 mm
Interannual variability: 150 to 350 mm in regionally-averaged SWEM in low/high SWE years





SWE datasets used in the study

Dataset (acronym)	Period	Resoln.	References
Kriged snow survey data (REF)	1980-2014	10 km	Tapsoba et al. (2005)
Blended-5 (BLD5)	1981-2010	~100 km	Mudryk et al. (2015)
CMC Analysis (CMC)	1999-2016	~35 km	Brown & Brasnett (2010)
ERA-interim reconstruction (ERAR)	1980-2016	~75 km	Brown et al. (2003), Brown & Derksen (2013)
GlobSnow V2 (GLB2)	1980-2014	25 km	Takala et al. (2011)
MERRA (MER1)	1980-2015	~50 km	Rienecker et al. (2011), Stieglitz et al. (2001).
MERRA-2 (MER2)	1981-2015	~50 km	Bosilovich et al. (2016), Reichle et al. (2017)
Princeton Reconstruction (PRIR)	1980-2010	~25 km	Sheffield et al. (2006).
CLASS offline (CLAU, CLAC) ERA-I forcing	1991-2010	~25 km	Verseghy et al. (2017)
CanRCM4 (RCM4) ERA-I forcing	1989-2009	~25 km	Scinocca et al. (2016)
CRCM5 (RCM5) run bbe ERA-I forcing	1980-2014	~25 km	Martynov et al. (2013), Šeparović et al. (2013)

Solid Precipitation datasets used in the study

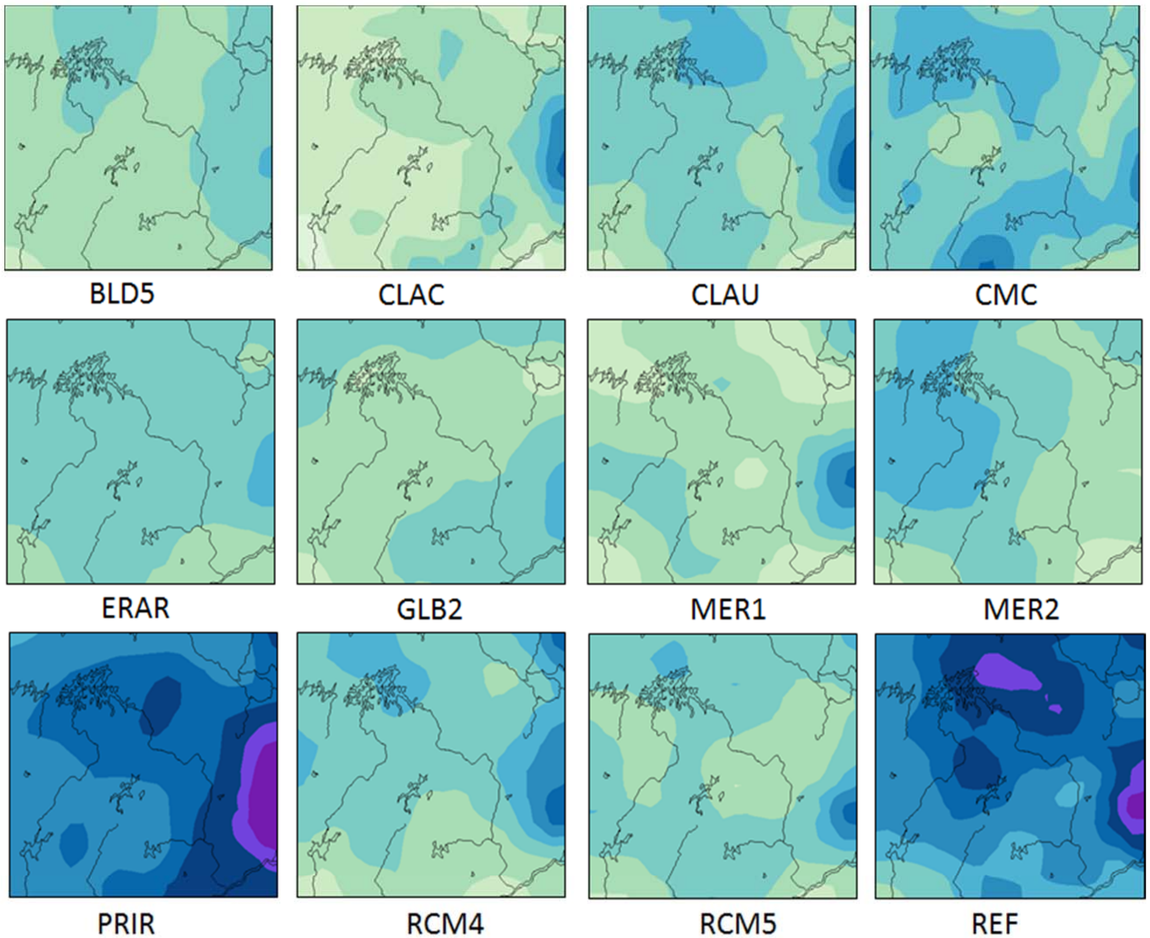
Dataset	Period	Resolution	Reference
AgMERRA Climate Forcing Dataset for Agricultural Modeling (AGME)	1980-2009	~25 km	Ruane et al. (2015)
Climate System Forecast Reanalysis (CFSR)	1980-2014	~40 km	Saha et al. (2010)
CANGRD (CGRD)	1981-2014	~50 km	Milewska et al. (2005)
ERA-interim "prsn" (ERAP)	1980-2014	~75 km	Dee et al. (2011)
ERA-interim reconstruction l (ERAS)	1980-2016	~75 km	Dee et al., (2011)
Global Meteorological Forcing Dataset for Land Surface Modeling (GMFD)	1980-2013	~25 km	Sheffield et al., (2006)
JRA55 Reanalysis (JRA55)	1980-2013	~50 km	Kobayashi et al. (2015)
MERRA Reanalysis (MER1S)	1980-2013	~50 km	Rienecker et al., (2011)
MERRA-2 Reanalysis (MER2S)	1980-2013	~50 km	Bosilovich et al. (2016)

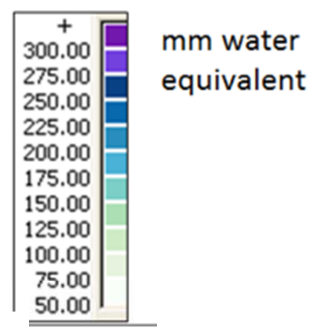
Evaluation Methodology:

- For each SWE dataset, grid point values of SWEM were computed from daily SWE series
- For solid precipitation datasets, the snow season total solid precipitation (SF) was computed as a proxy for SWEM
- Annual SWEM grids were interpolated to the 10-km snow survey grid using an inverse distance weighting of the four nearest points
- Differences in elevation were ignored as this was shown to have only a minor impact on the interpolated SWE over most of the study domain
- Non-zero pairs of grid point observed and estimated SWEM values were evaluated using standard statistical methods including correlation (R), bias, and root-mean-square error (RMSE)
- SWEM evaluated over 1999-2010 (the longest period of common overlap with the reference dataset)

1999-2010 average annual maximum SWE

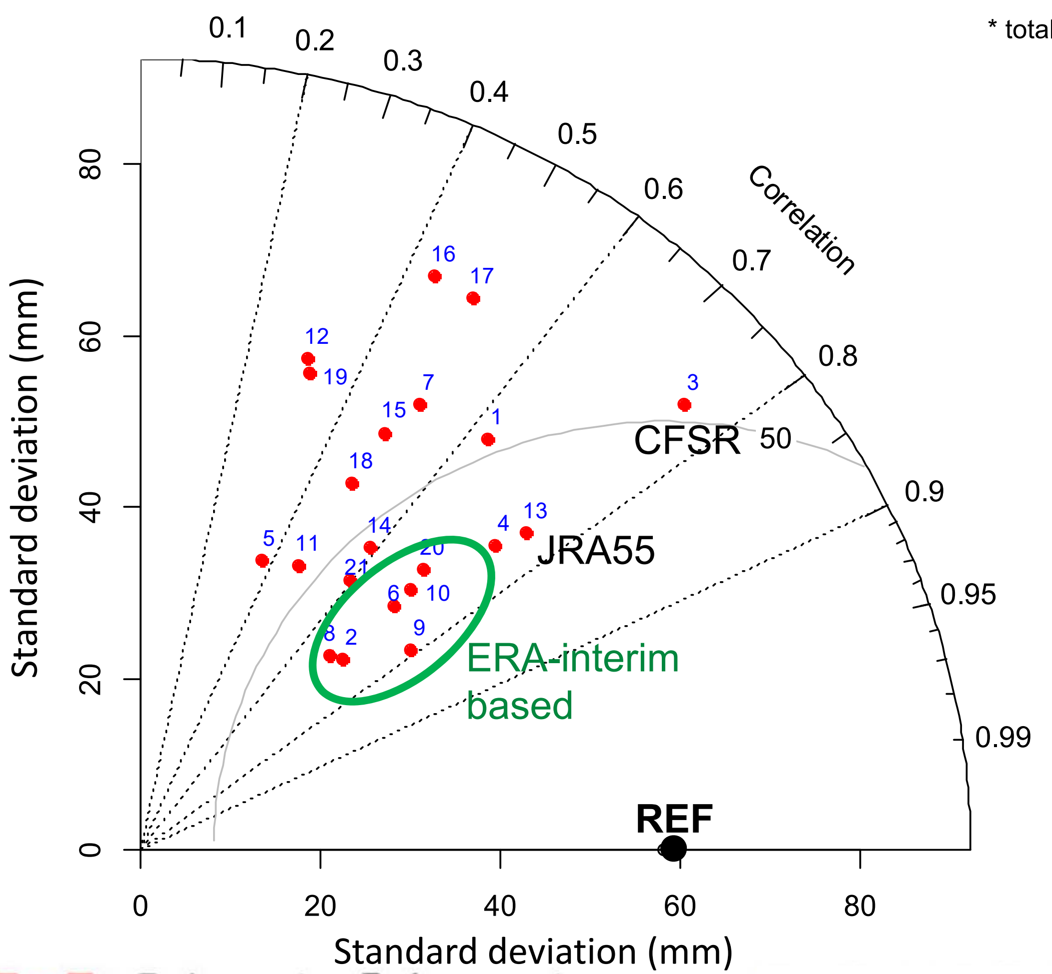
- Most datasets unable able to capture the observed spatial pattern in average SWEM
- Best performance from the CLASS run with ERA-interim precipitation (r=0.73)
- Dataset native resolution had no impact on results





1999-2009 annual SWEmax or total SF values

Evaluation of **temporal and spatial** variability in SWEM



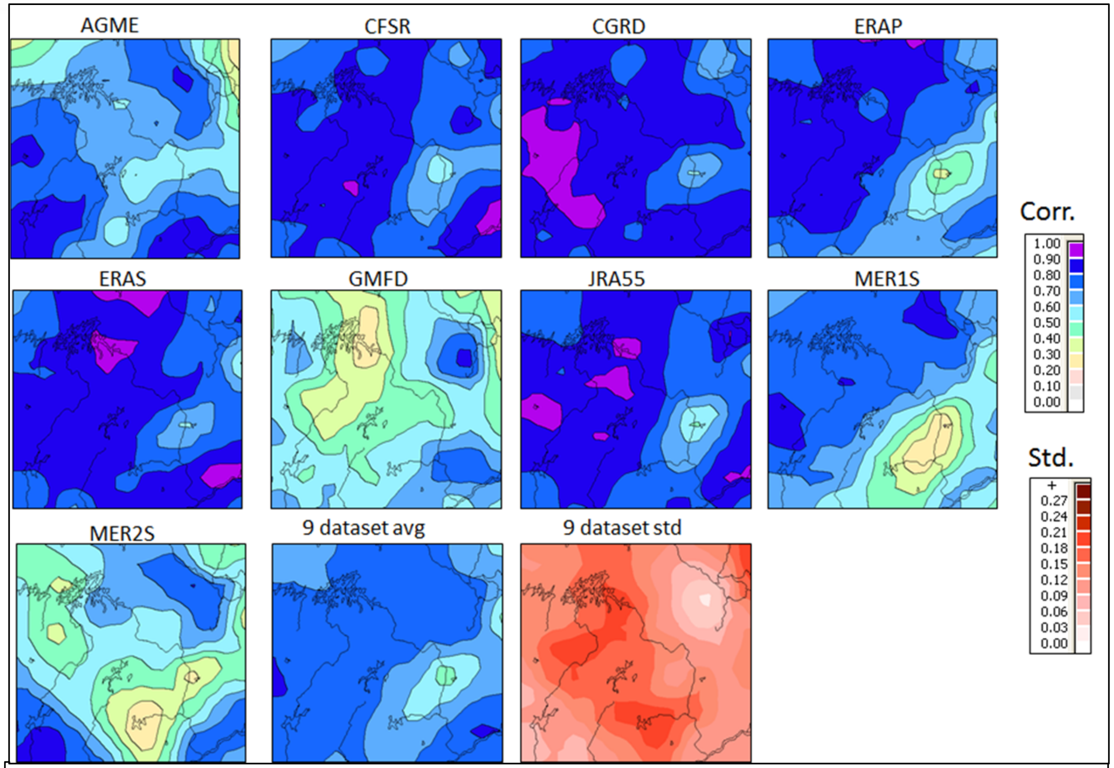
* total snow season snowfall

1	AGME*
2	BLD5
3	CFSR*
4	CGRD*
5	CLAC
6	CLAU
7	CMC
8	ERAP*
9	ERAR
10	ERAS*
11	GLB2
12	GMFD*
13	JRA55*
14	MER1
15	MER1S*
16	MER2
17	MER2S*
18	PRIR
19	PRIS*
20	RCM4
21	RCM5

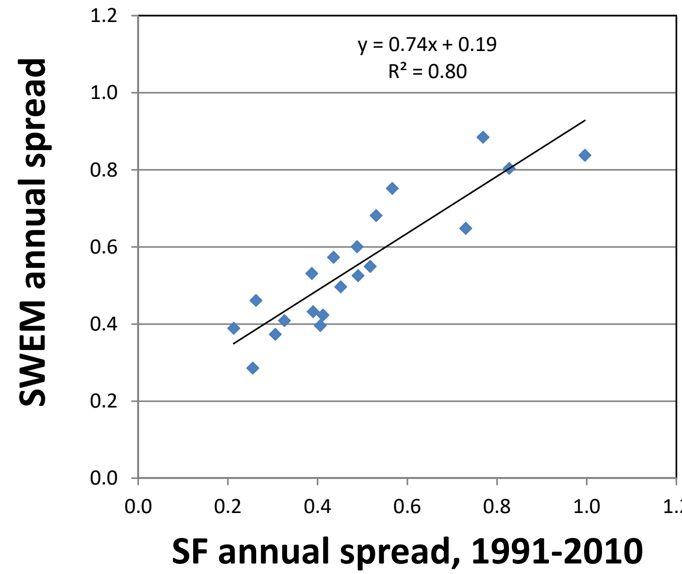
Results Ranked by Correlation

Dataset	R	RMSE (%)	# yrs R ≥ 0.5
ERAR	0.80	34.2	5
CFSR	0.77	80.4	8
CGRD	0.76	23.2	8
JRA55	0.76	45.3	7
BLD5	0.73	39.1	4
ERAS	0.72	20.9	4
CLAU	0.72	35.1	8
ERAP	0.70	22.5	8
RCM4	0.69	35.2	5
AGME	0.65	31.3	3
MER1	0.61	44.6	2
RCM5	0.59	38.2	4
CMC	0.53	35.6	3
MER1S	0.52	44.8	5
MER2S	0.52	54.5	3
GLB2	0.51	41.6	1
PRIR	0.48	24.2	3
MER2	0.45	43.5	3
CLAC	0.38	49.3	5
GMFD	0.32	52.2	0

The importance of getting precip right… between dataset spread in snowfall is the main driver of dataset spread in annual maximum SWE

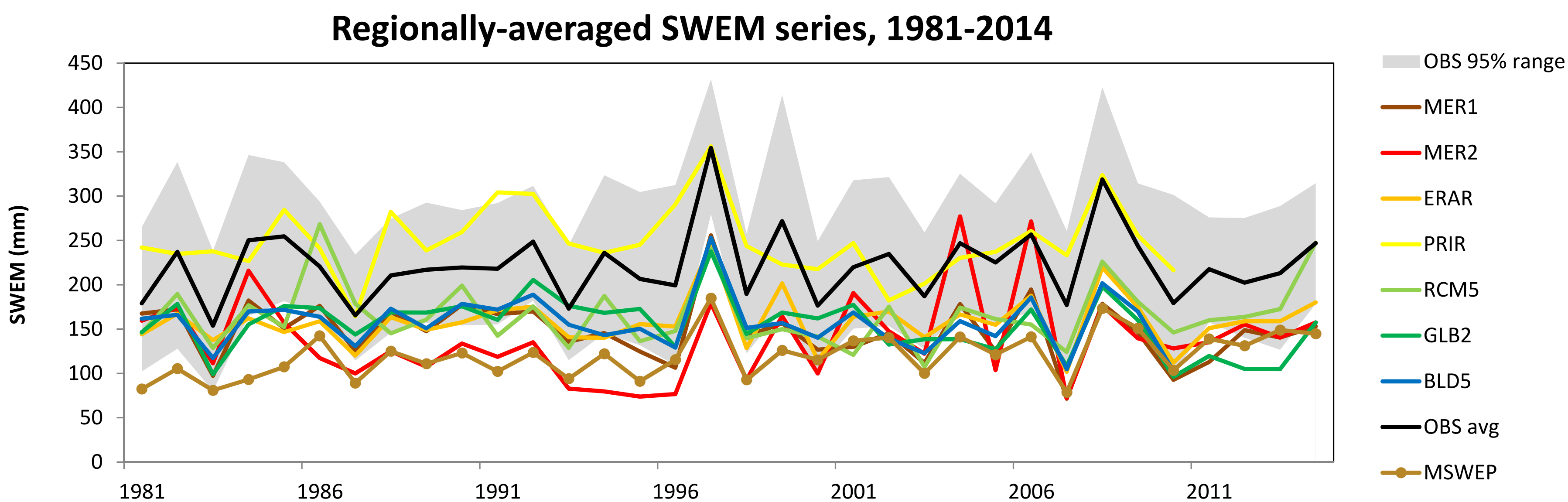


Spatial pattern of detrended grid point correlations between snow season total snowfall values and annual maximum SWE over St-Maurice Basin, Quebec, 1991-2010. (Brown et al. 2018, H-P)



Dataset spread is computed with standardized anomalies and is dimensionless.

Most datasets underestimate regionally-averaged SWEM but the interannual variability is well captured by many of the datasets



Correlation to observed SWEM regional series

MER1	MER2	ERAR	PRIR	RCM5	GLB2	BLD5	MSWEP	ERA5
0.76	0.54	0.89	0.61	0.60	0.66	0.82	0.77	0.71

Is insufficient snowfall a factor in the systematic underprediction?

We estimated the fraction SWEM/SF from three different snowpack models over 1991-2010 (ERAR, CLAU, and MER1).

ERAR = temperature index model   CLAU = single layer EB   MER1 = multi-layer EB

The fraction varies from year-to-year and between models but was typically in the range of 45-60%

This fraction seems low but the seasonal total SF includes snow falling prior to the formation of the seasonal snowpack and snow falling after the date of maximum accumulation

The average observed SWEM over 1991-2010 is 230 mm which suggests that regionally averaged annual snowfall needs to be in the 380-510 mm range to generate annual maximum SWE values that approximate the magnitude of the observations

CFSR is the only snowfall dataset with a mean annual SF within this estimated range.

Dataset	Period	ERA5 correlation to regionally-averaged SWEmax time series
OBS	1991-2010	0.71
ERAR (ERA-interim forcing)	1991-2010	0.80
GLB2	1991-2010	0.80
MER1	1991-2010	0.77
CRCM5 (ERA-interim forcing)	1991-2010	0.56
Blend5 (Mudryk and Derksen, 2017)	1991-2010	0.82
CLASS offline (ERA-interim forcing)	1991-2010	0.79
CMC operational analysis	1999-2014	0.77

STOP PRESS: ERA5 Evaluation

- ERA5 systematically underestimates SWEmax over the southwestern Quebec SnowPEx region similar to most other SWE products.

- ERA5 regionally-averaged SWEmax series are less strongly correlated to the observed SWEmax series over the Quebec SnowPEx region than other products. However, ERA5 is well-correlated (r ~ 0.80) with a number of gridded SWE products including the Blend5 product developed by Mudryk and Derksen (2017).

Take Home Messages:

- None of the SWE datasets evaluated was able to provide estimates of annual maximum SWE (SWEM) within operational requirements of ±15%.
- Insufficient solid precipitation is considered to be the main reasons for systematic underprediction of SWEM by many datasets. Inconsistencies in solid precipitation were also found to have a strong impact on year-to-year variability in SWEM dataset performance and spread.
- Version 3.6.1 of the CLASS land surface scheme driven with ERA-interim output downscaled by Version 5.0.1 of the Canadian Regional Climate Model was the best **physically-based model** at explaining the observed spatial and temporal variability in SWEM (RMSE=33%), and has potential for lower error with adjusted precipitation.
- Operational snow products relying on real-time in situ snow depth observations (CMC and GlobSnow) performed poorly due to a lack of real-time data and the strong local scale variability of point snow depth observations
- The results underscore the need for investing more effort in improving solid precipitation estimates
- The multi-year, 10-km gridded SWEM dataset with error estimates is a useful benchmark for evaluation of SWE products and the performance of land surface and hydrological models

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Thank you for your attention!

Questions?

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