Evaluation of Passive Microwave Snow Water Equivalent Algorithms for GlobSnow

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Outline:

1. Overview of GlobSnow evaluation strategy
2. Algorithm assessment: Eurasia, Finland, Canada
3. Evaluation of the prototype GlobSnow SWE dataset
4. Future evaluation issues

GlobSnow SWE Algorithm Evaluation Strategy

GlobSnow evaluation criteria:

Minimum **three algorithms** evaluated over **three regions** for at least **three years** and evaluated with **multiple independent reference datasets**.

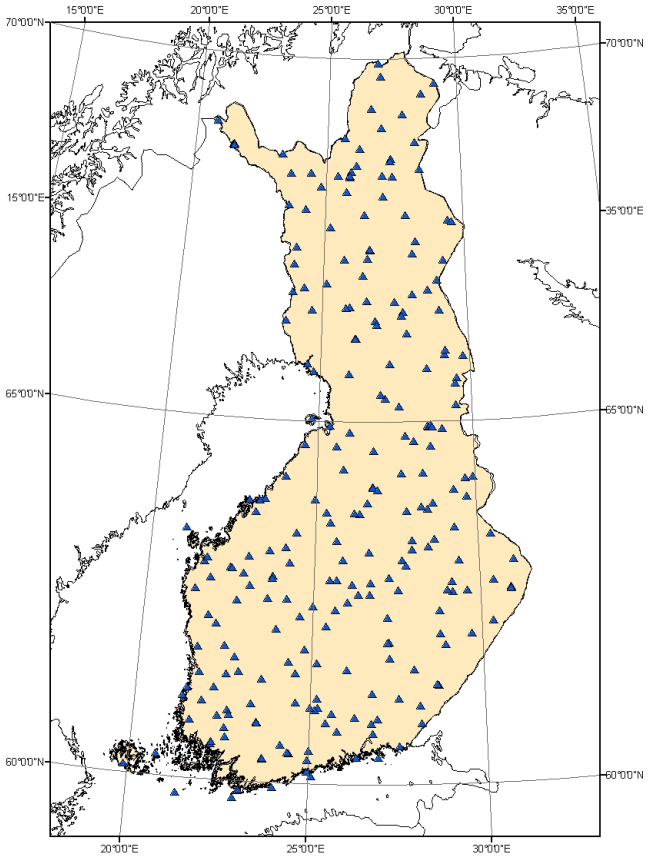
This has produced the most thorough inter-comparison of satellite derived SWE datasets to date.

Full description of the SWE algorithm evaluation provided in the GlobSnow Design Justification File, available via the GlobSnow website: ***globsnow.fmi.fi***

GlobSnow SWE Algorithm Evaluation Strategy: Algorithms

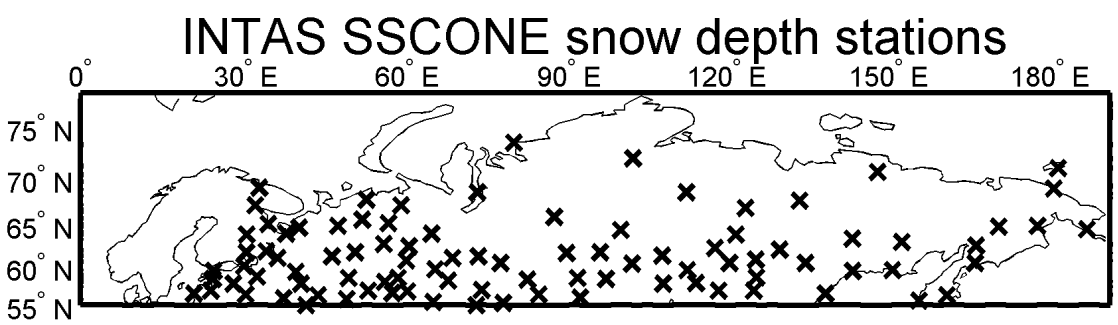
Algorithm	Description	Eurasia	Finland	Canada
Finnish Meteorological Institute	Assimilation of satellite data with *in situ* observations	Yes	Yes	Yes
Environment Canada	Suite of empirical, land cover specific algorithms	Yes	Yes	Yes
Chang et al.	Original channel difference algorithm	Yes	No	No
SPD	Spectral polarization difference	Yes	No	No
Armstrong/Brodzik	Updated channel difference algorithm	Yes	No	No
NASA AMSR-E	Standard AMSR-E SWE product	No	Yes	Yes

GlobSnow SWE Algorithm Evaluation Strategy: Reference Datasets



Finnish snow course observations:

- Monthly/bi-monthly measurements
- National network of +100 snow courses
- 2 - 4 km in length



INTAS SSCONE data:

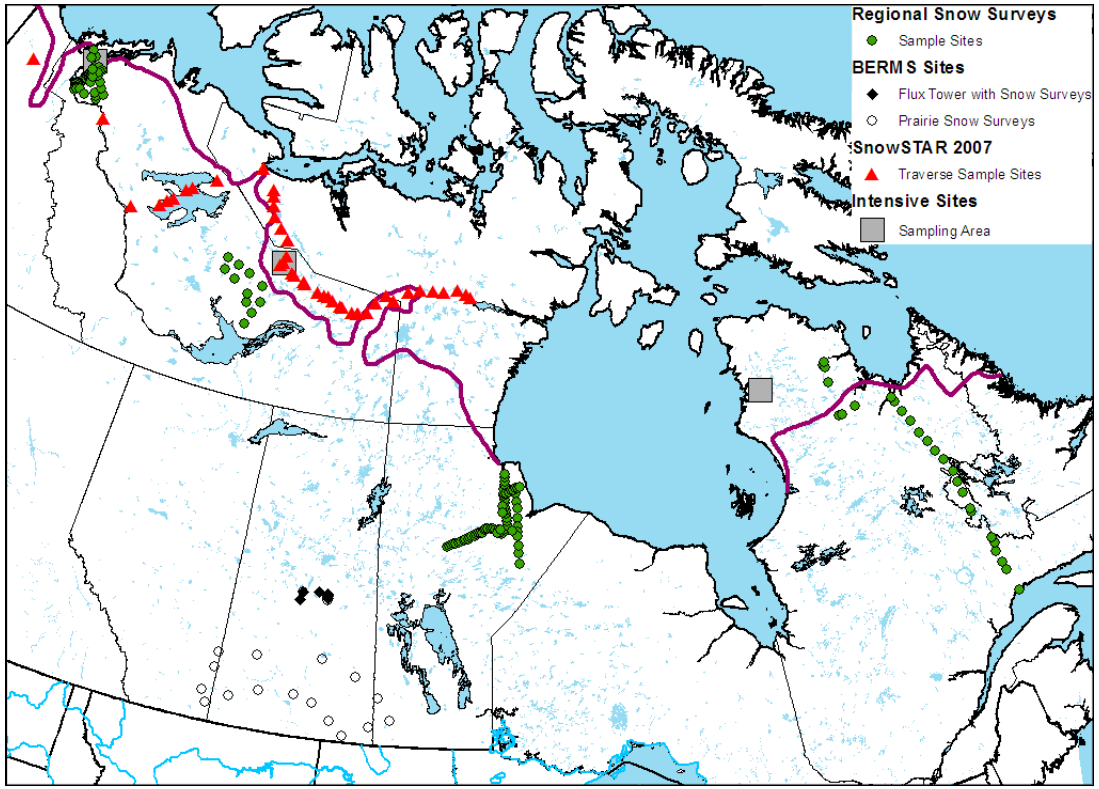
223 snow depth stations from the former USSR and Russia (WMO)

- Point snow depth measurements
- Data used in the FMI algorithm for kriging interpolation (not used for validation)

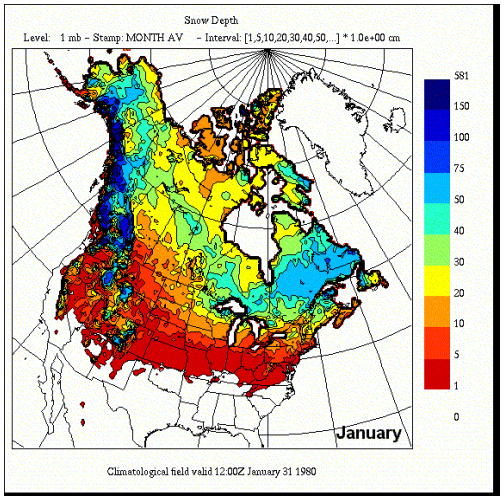
450 snow path stations used as validation data

- Snow course measurements
- Snow path and depth station data are independent

GlobSnow SWE Algorithm Evaluation Strategy: Reference Datasets



Environment Canada research datasets



Start Date	12-Mar-1998
End Date	Ongoing
Domain	Global
Temporal Resolution	Daily
Spatial Resolution	1/3 degree
Variables	Depth; Density

Canadian Meteorological Centre daily gridded global snow depth analysis

GlobSnow SWE Algorithm Evaluation Strategy

Validation Level 1: Grid cell retrieval vs. Multiple sub-grid measurements:
Environment Canada tundra snow surveys

Validation Level 2: Grid cell retrieval vs. Individual grid cell measurements:
INTAS-SCONE data

Validation Level 3: Grid cell retrievals vs. Grid cell analysis:
Canadian Meteorological Centre Daily Gridded Global Snow Depth Analysis

Validation Level 4: Time series evaluation:
Boreal Ecosystem Monitoring and Modelling Sites

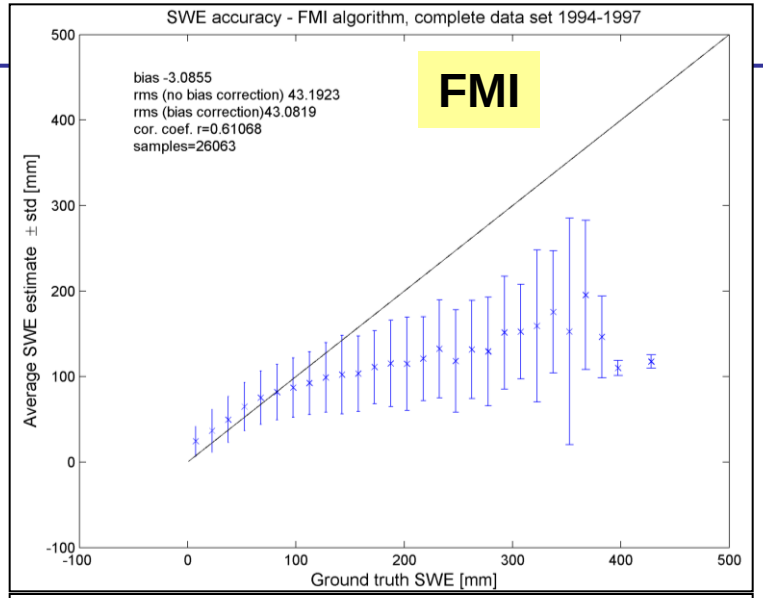
1994/95 – 1996/97: Eurasia (SSM/I)
2005/06 – 2007/08: North America and Finland (AMSR-E)

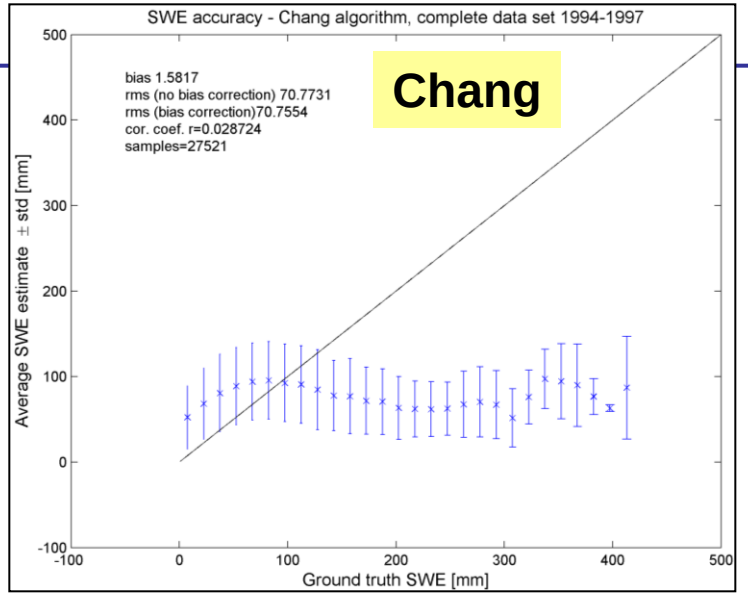
Inter-Comparison Results: Eurasia

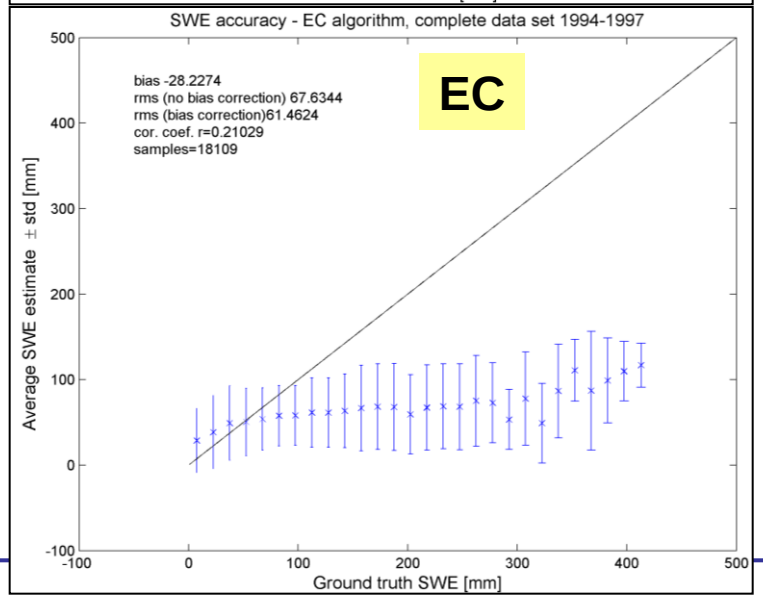
Algorithm	*RMSE*	*Bias*	*Correlation*	*Unbiased RMSE*	*Samples*
Finnish Meteorological Institute	43.2 mm	-3.1 mm	0.61	43.1 mm	26063
Environment Canada	67.6 mm	-28.2 mm	0.21	61.5 mm	18109
Chang(asc) Chang(desc)	71.6 mm 70.7 mm	-8.4 mm 1.6 mm	0.01 0.02	71.1 mm 70.8 mm	26726 27521
SPD (asc) SPD (desc)	67.1 mm 63.9 mm	-12.7 mm -3.1 mm	0.05 0.12	65.9 mm 63.9 mm	29559 29451
Armstrong/Brodzik (asc) Armstrong/Brodzik (desc)	72.3 mm 73.7 mm	-44.1 mm -42.9 mm	0.04 0.03	57.3 mm 59.9 mm	21796 24791

- FMI algorithm clearly the strongest performer.
- EC algorithm impacted by lack of 10.7 GHz on SSM/I.

Inter-Comparison Results: Eurasia







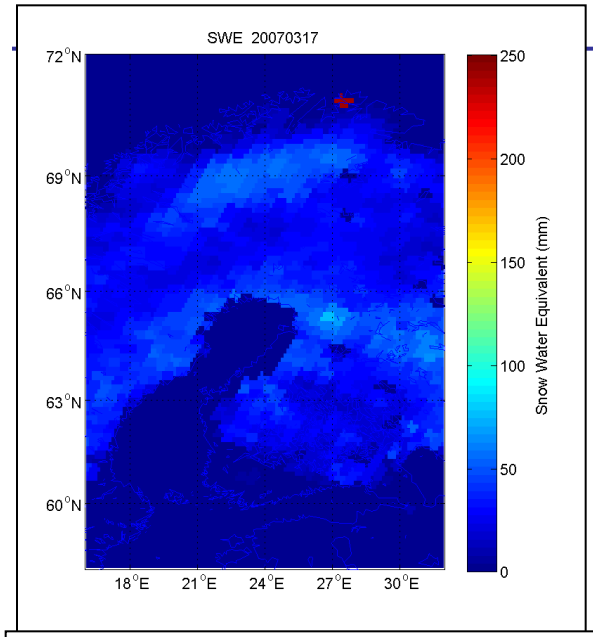
- All algorithms lose sensitivity as SWE exceeds ~120 mm.
- Assimilation approach allows FMI algorithm to retain some sensitivity to almost 200 mm.

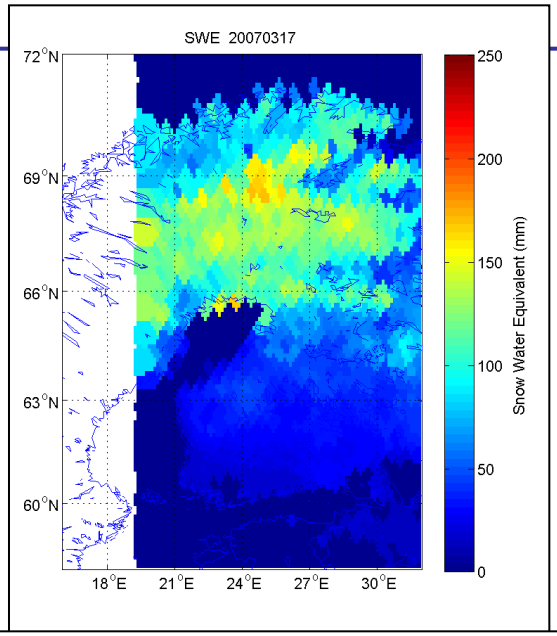
Inter-Comparison Results: Finland

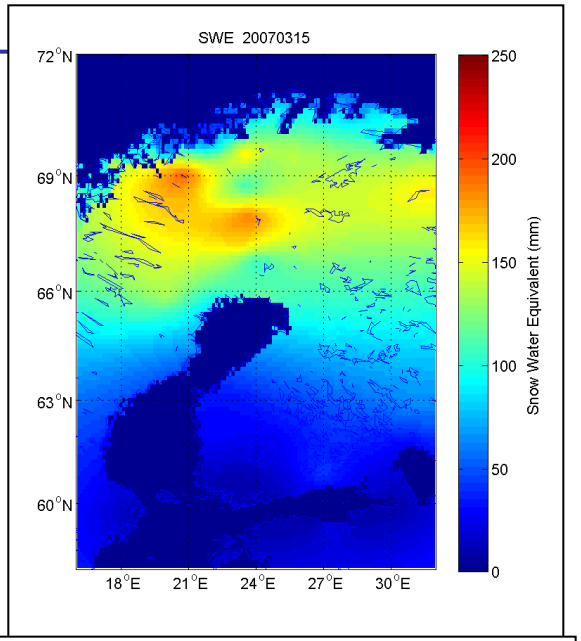
Algorithm	*RMSE*	*Bias*	*Correlation*	*Unbiased RMSE*	*Samples*
NASA AMSR-E	64.2	-47	0.14	43.6	1386
Environment Canada	47.6	-23	0.58	41.7	1278
Finnish Meteorological Institute	34.4	1.7	0.79	34.4	1523

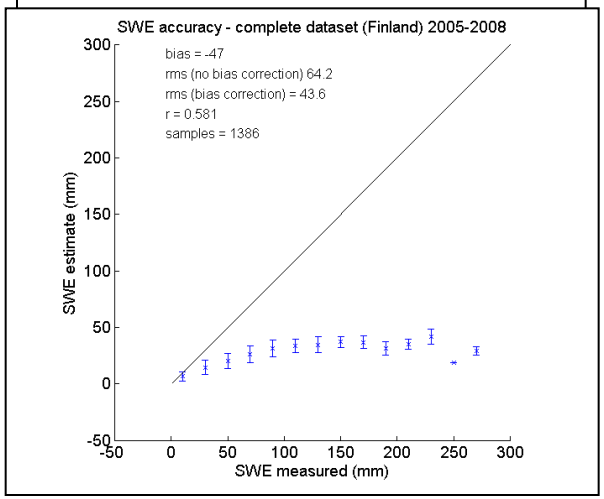
- FMI algorithm the strongest performer.
- EC algorithm performance improved compared to Eurasia due to use of AMSR-E vs. SSM/I data

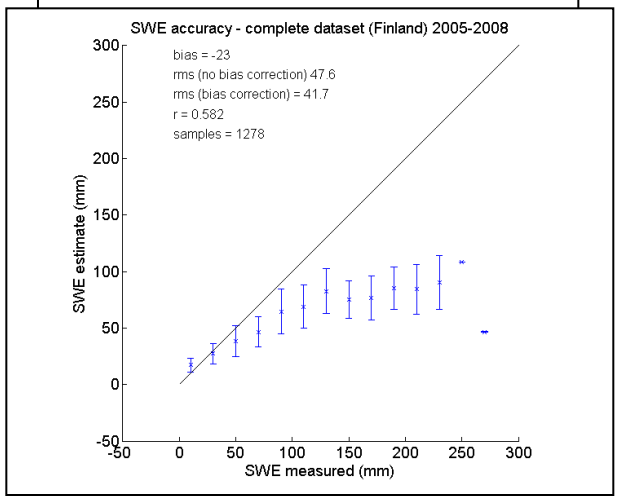
Inter-Comparison Results: Finland

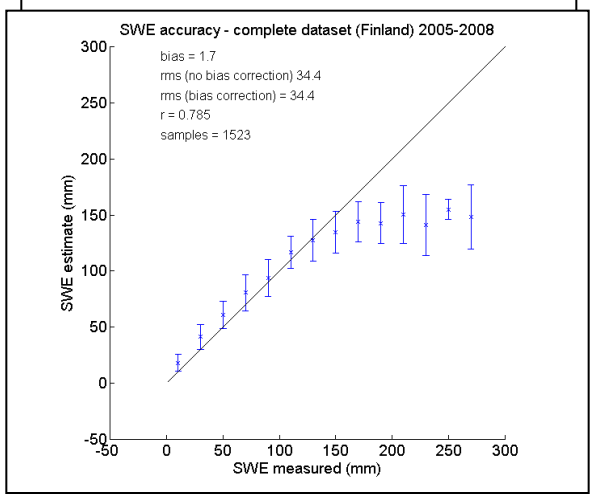












Inter-Comparison Results: Canada

RMSE (mm)	EC	NASA	FMI
Tundra	**20**	**65**	**50**
Northern Boreal	**50**	**74**	**77**
Southern Boreal	**32**	**33**	**24**
BERMS	**32**	**28**	**24**
Prairie	**21**	**37**	**32**
r	EC	NASA	FMI
Tundra			
Northern Boreal	**0.71**	**0.00**	**0.24**
Southern Boreal	**0.61**	**0.63**	**0.70**
BERMS	**0.72**	**0.82**	**0.84**
Prairie	**0.59**	**0.41**	**0.23**

Environment Canada research datasets

Inter-Comparison Results: Canada

- SWE estimated from CMC analysis following snow cover classes for Sturm et al. (1995) and using monthly mean snow densities from Brown and Mote (2009).

- Care must be taken in considering the CMC analysis as 'ground – truth' due to a tendency for SWE underestimation because observations come from clearings with a bias to low snow depth (Brown and Mote, 2009).

RMSE					r			
2006	EC	NASA	FMI		2006	EC	NASA	FMI
Pentad 1	25.7	28.0	19.6		Pentad 1	0.36	0.11	0.89
Pentad 7	34.8	38.6	21.1		Pentad 7	0.31	0.17	0.76
Pentad 13	42.9	42.7	27.6		Pentad 13	0.13	0.13	0.75
Pentad 19	55.4	90.7	25.8		Pentad 19	0.41	0.08	0.73
2007	EC	NASA	FMI		2007	EC	NASA	FMI
Pentad 1	29.8	36.2	23.9		Pentad 1	0.14	-0.01	0.57
Pentad 7	40.0	41.4	26.2		Pentad 7	0.27	0.13	0.63
Pentad 13	51.6	45.9	39.0		Pentad 13	0.13	0.19	0.47
Pentad 19	77.7	72.5	36.4		Pentad 19	0.39	0.13	0.73
2008	EC	NASA	FMI		2008	EC	NASA	FMI
Pentad 1	25.9	29.3	26.6		Pentad 1	0.33	0.30	0.66
Pentad 7	40.1	45.2	25.4		Pentad 7	0.26	0.23	0.68
Pentad 13	45.0	49.2	35.5		Pentad 13	0.26	0.14	0.65
Pentad 19	53.7	65.4	36.0		Pentad 19	0.44	0.13	0.69

Canadian Meteorological Centre daily gridded global snow depth analysis

GlobSnow SWE Algorithm Selection

Reference Dataset	EC	NASA or Chang	FMI
Finland: snow courses			
Eurasia: INTAS SSCONE			
Canada: Tundra			
Canada: Northern Boreal			
Canada: Southern Boreal			
Canada: BERMS			
Canada: Prairie			
Canada: CMC			
Meets GlobSnow Criteria:			
Yes			
With Conditions			
No			

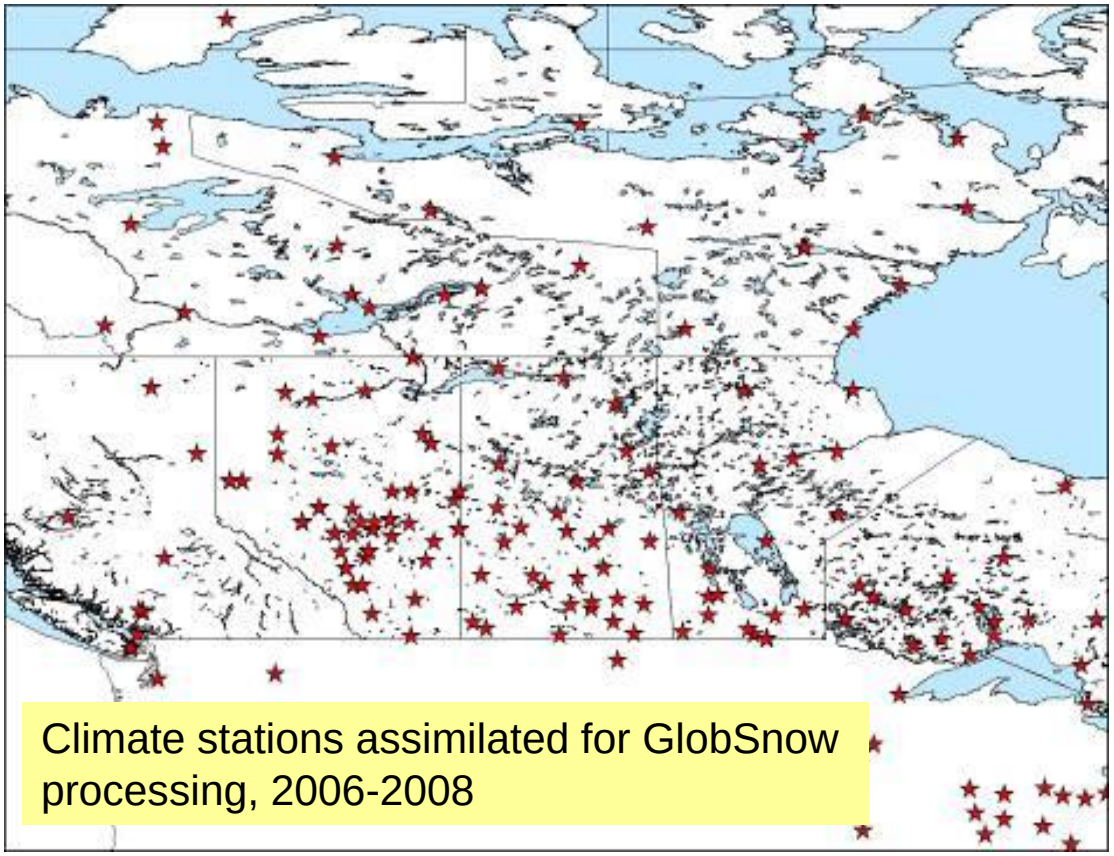
Given (1) these evaluation results, and (2) the uncertainty estimates produced from the method, the FMI algorithm most satisfactorily address the GlobSnow thematic accuracy requirements.

GlobSnow Prototype SWE Evaluation

Land Cover	Reference Dataset	Year	RMSE (mm)		r		Mean Bias (mm)	
			DJF	0.9.1	DJF	0.9.1	DJF	0.9.1
Tundra	Intensive Sites	2005-2007	28	33			-9	7
	SnowSTAR	2007	50	27.5			-46	-24
Northern Boreal	EC Snow Surveys	2005/06	22	24	0.69	0.45	-13	6
		2006/07	102	85	-0.01	-0.13	-78	-56
		SWE <150 mm	25	21	0.70	0.62	-17	4
		All	77	64	0.24	0.29	-48	-28
Southern Boreal	EC Snow Surveys	2005/06	25	17	0.77	0.82	-15	5
		2006/07	27	18	0.61	0.77	-13	-10
		2007/08	21	26	0.67	0.23	1	8
		All	24	21	0.70	0.67	-10	1
Southern Boreal	Boreal Ecosystem	2005/06	30	20	0.87	0.73	-20	-9
	Research and Monitoring Sites	2006/07	21	18	0.80	0.62	0	-3
		2007/08	22	20	0.85	0.72	13	17
		All	24	19	0.84	0.70	-1	4.9
Prairie	EC Snow Surveys	2005/06	32	20	0.34	0.66	3	3
		2006/07	32	23	-0.17	0.09	16	11
		All	32	21	0.23	0.54	7	6

- Reduced RMSE and bias in the prototype dataset
- Improvement evident in two challenging areas: tundra and northern boreal forest

Challenges: Tundra Regions

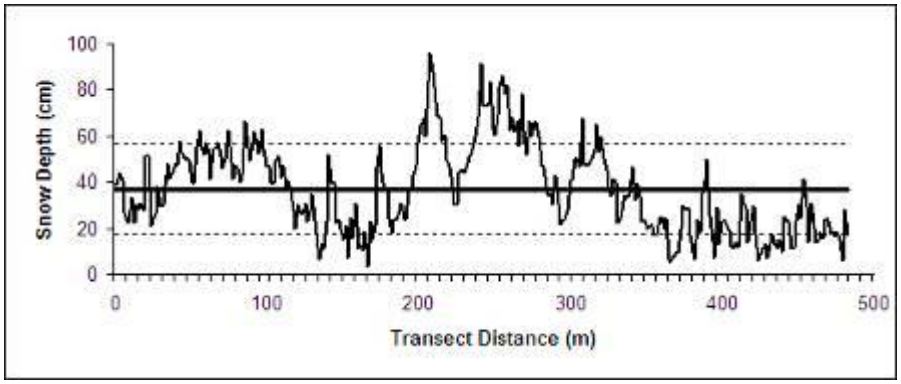


Climate stations assimilated for GlobSnow processing, 2006-2008

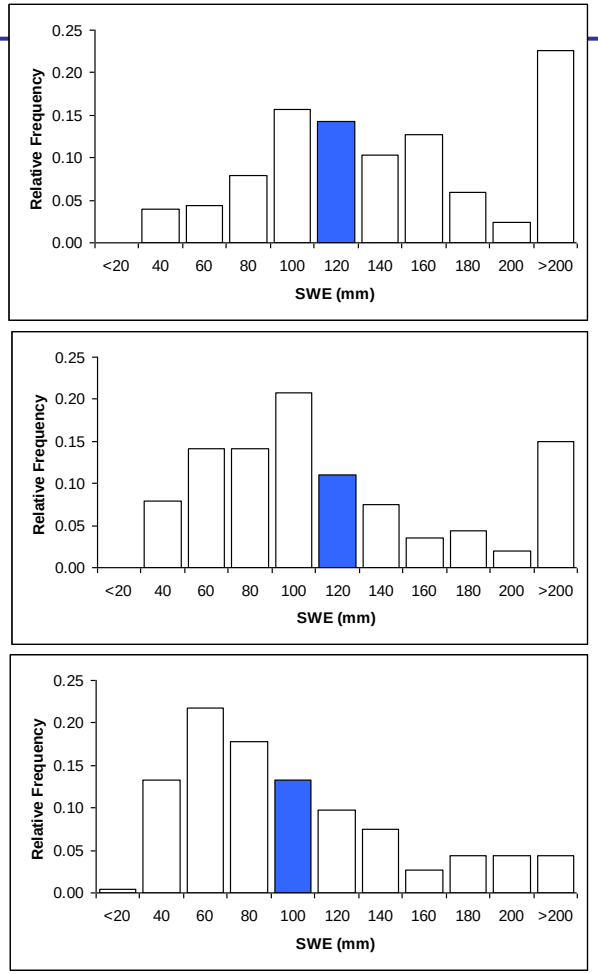
- Very few climate stations across the tundra
- Coastal bias
- High lake fraction (in North America)

Challenges: Tundra Regions

Across the tundra, local scale SWE variability is high.



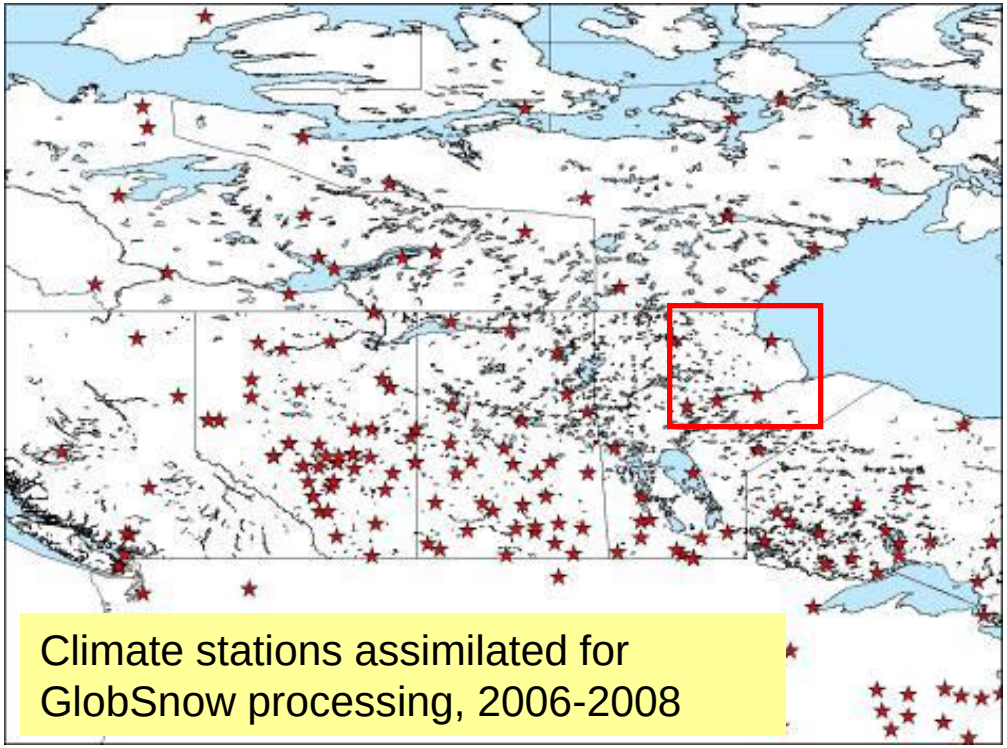
But regional scale variability can be low due to wind redistribution and sublimation loss.



SWE PDF's from intensive tundra field campaigns near Daring Lake, NT

Challenges: Boreal Forest

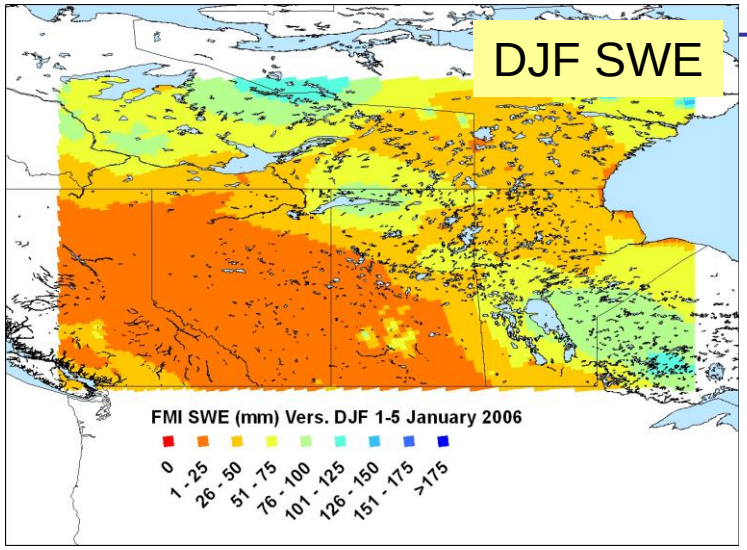
2006	RMSE	Mean Bias	r
Mean SWE = 92 mm	**22**	**-13**	**0.65**
2007	RMSE	Mean Bias	r
Mean SWE = 169 mm	**102**	**-78**	**-0.01**
SWE <150 mm	**34**	**-26**	**0.77**

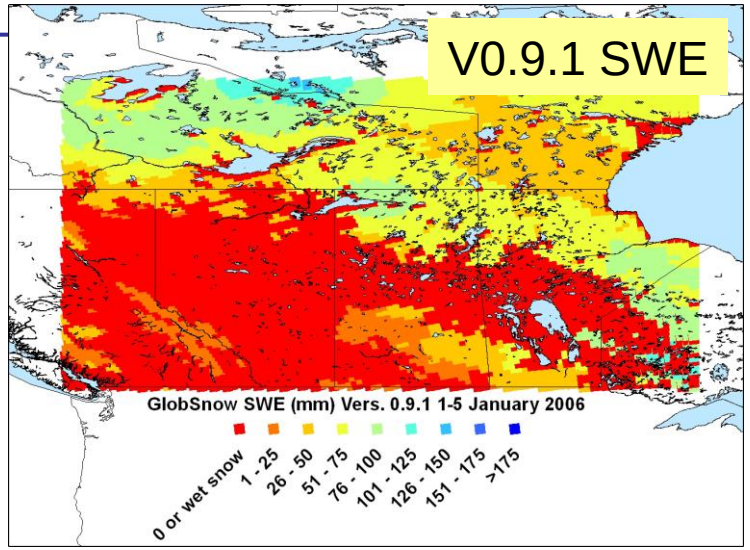


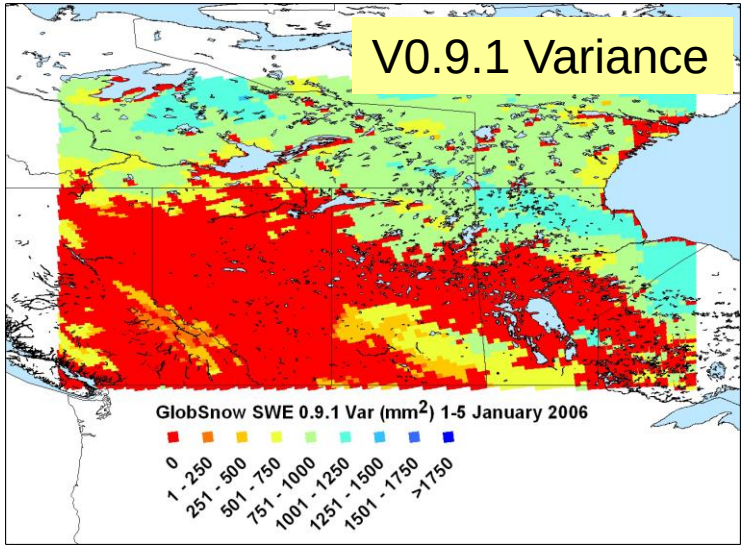
Climate stations assimilated for GlobSnow processing, 2006-2008

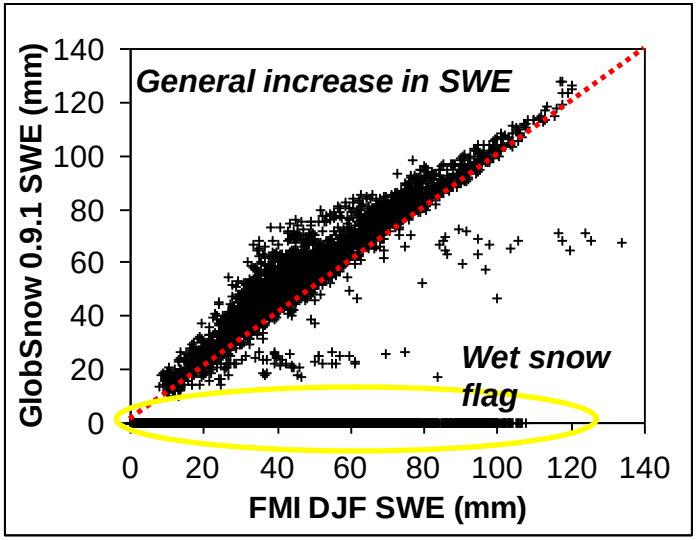
Climate stations are in clearings at airports

GlobSnow Prototype SWE Evaluation: 1-5 January 2006

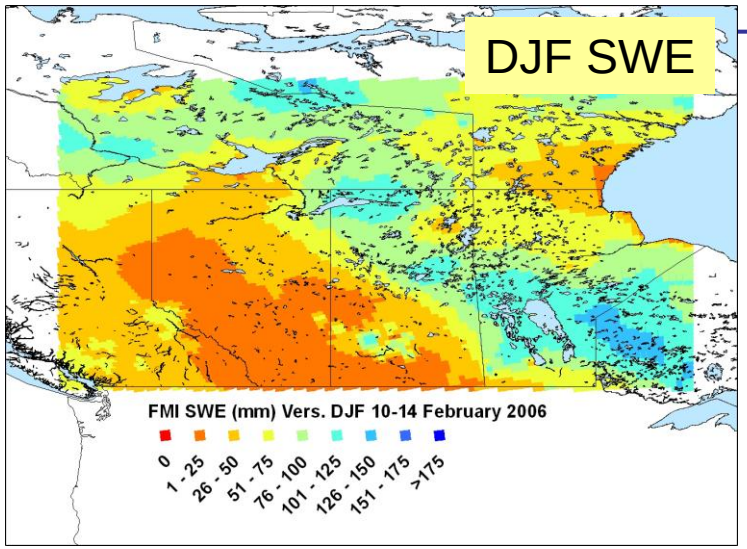


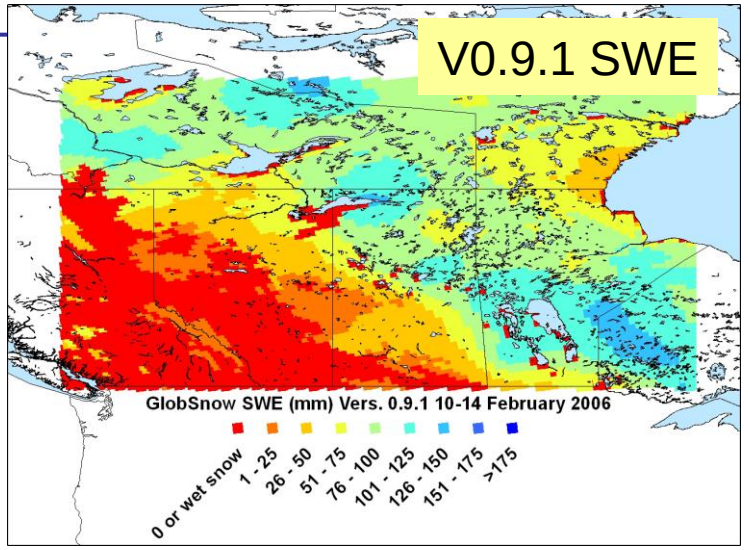


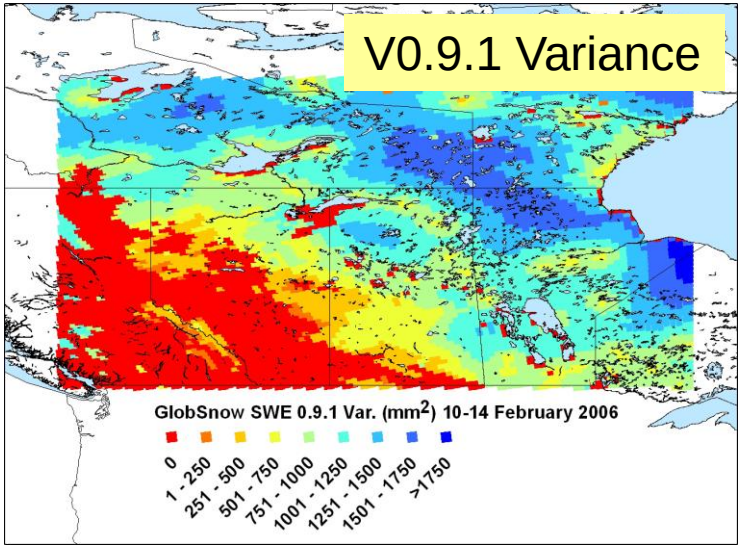


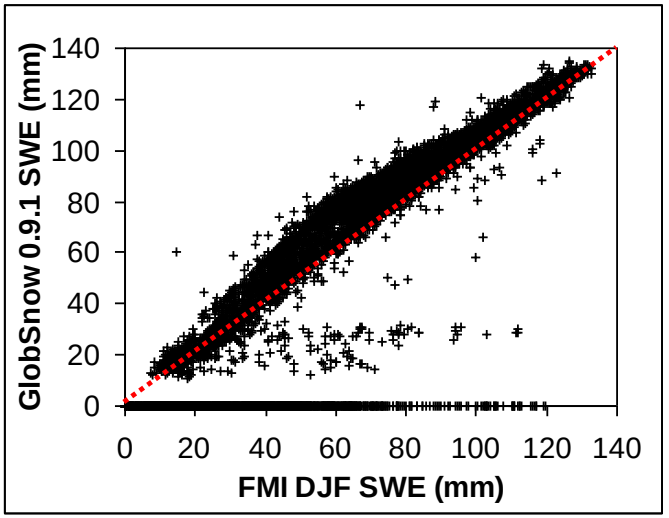


GlobSnow Prototype SWE Evaluation: 10-14 Feb. 2006

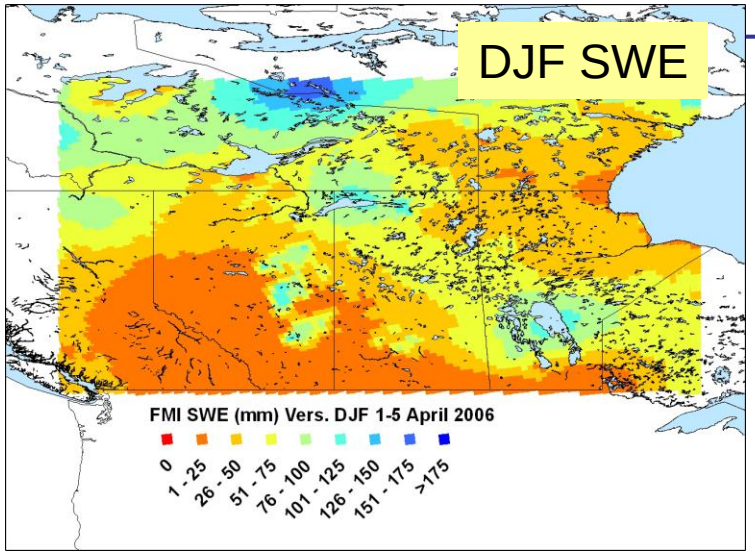


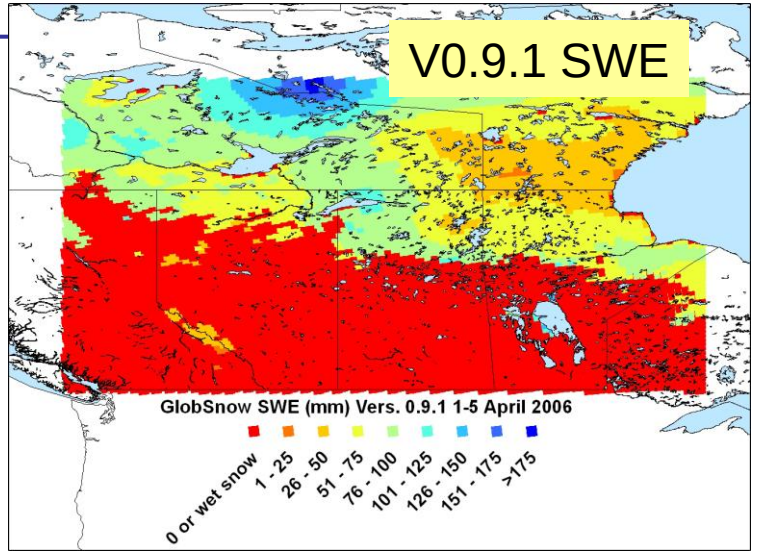


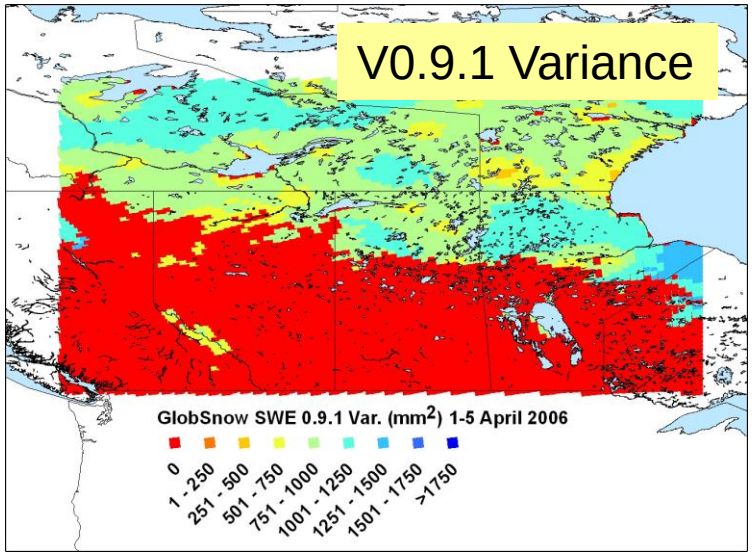


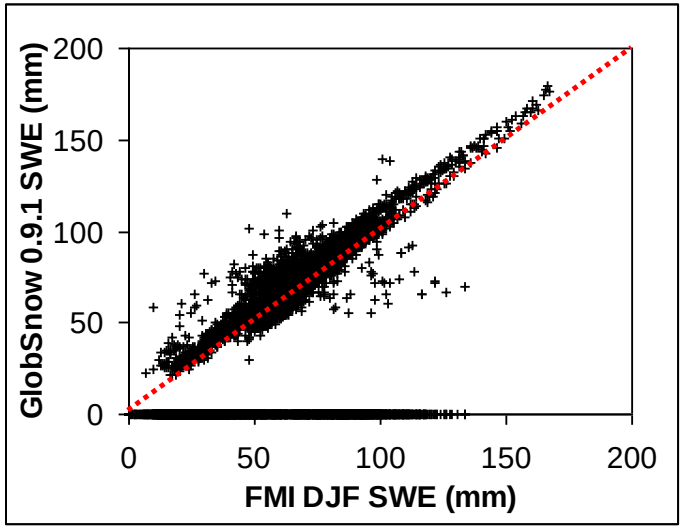


GlobSnow Prototype SWE Evaluation: 1-5 April 2006

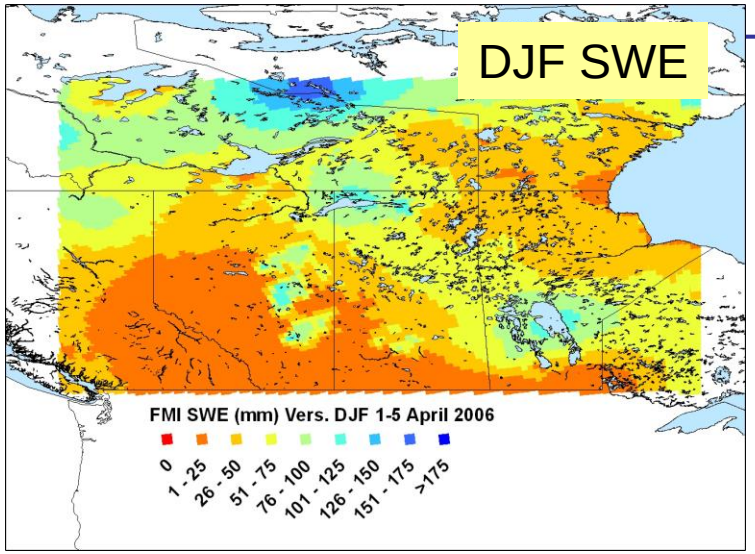


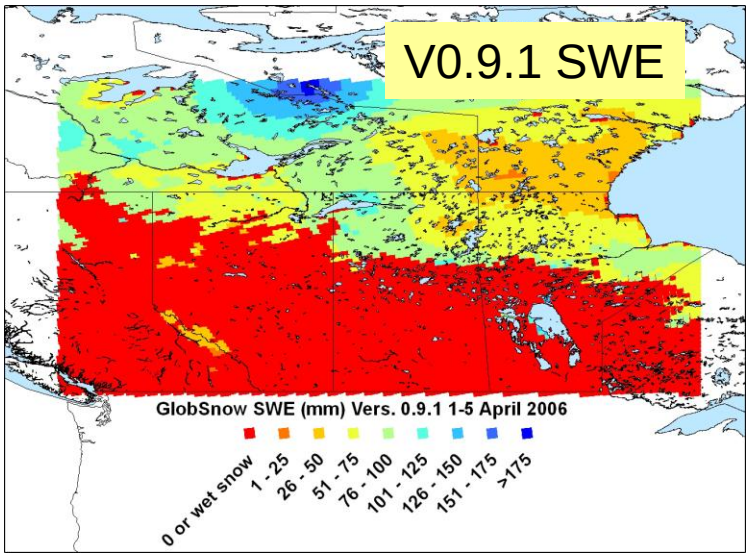


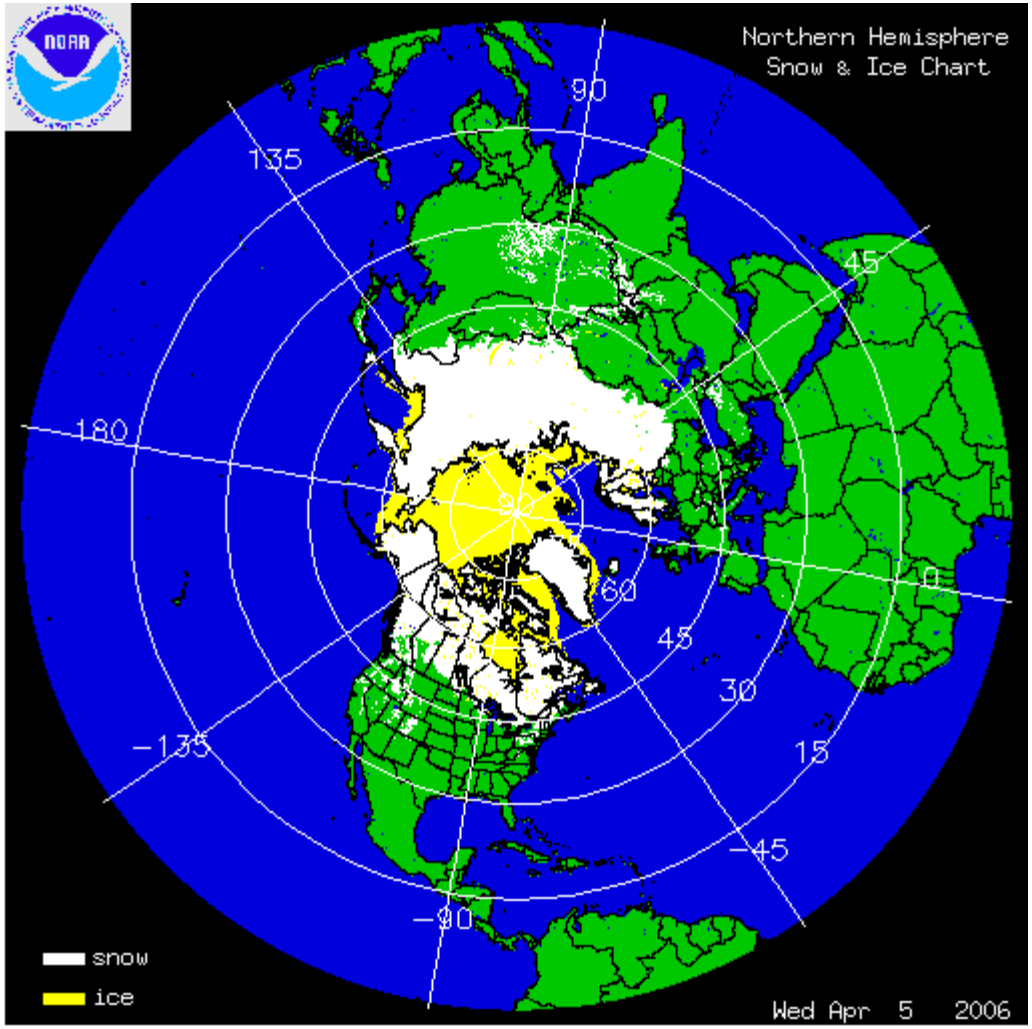




SWE Retrievals in the Marginal Snow Zone







Future Evaluation Issues

Using the complete time series generated in GlobSnow Phase 2, evaluation strategies will differ depending on application.

1. Climatological time series analysis:

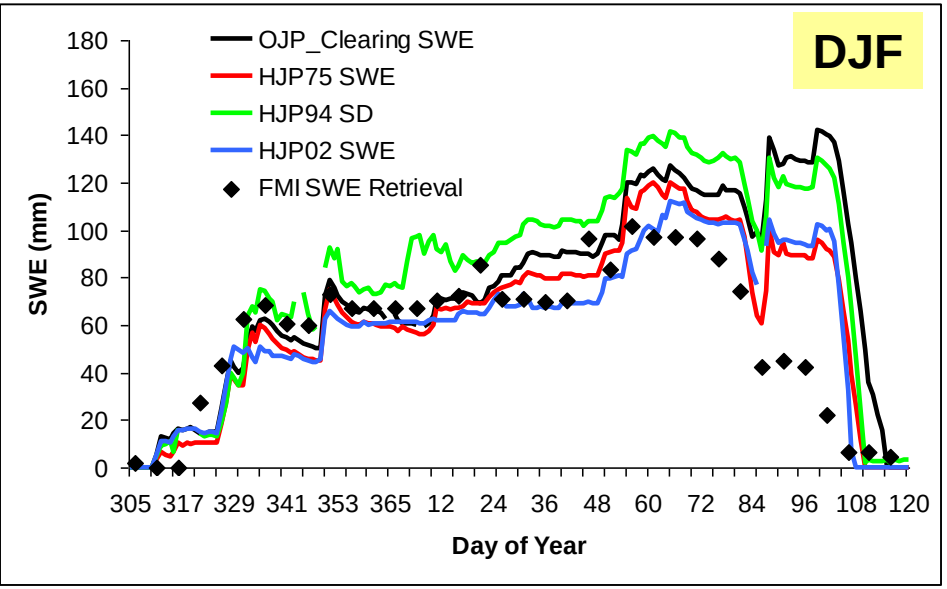
- Attach meaningful error bars on time series
- Account for wet snow mask in SWE time series
- Validate snow-on/snow-off dates

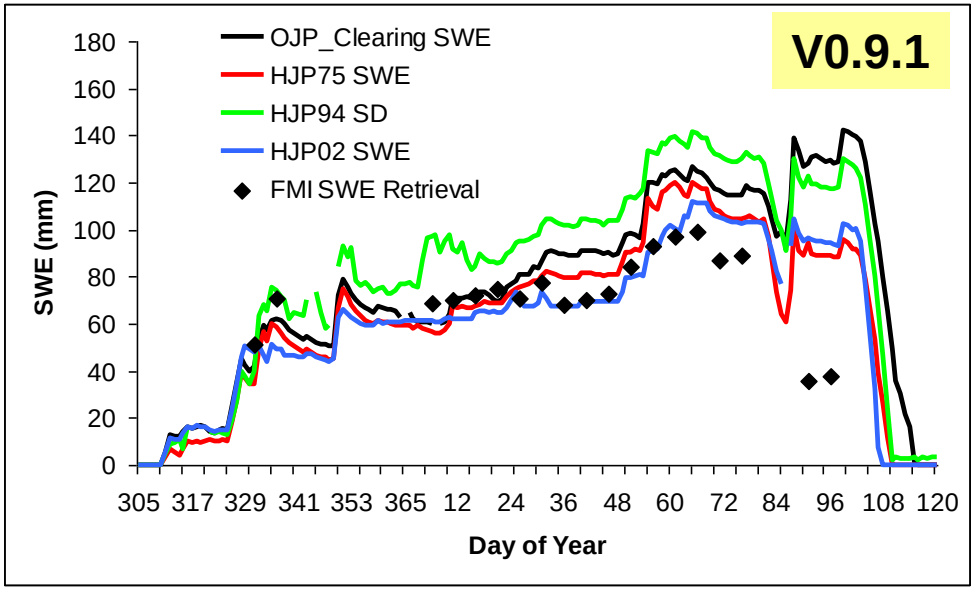
2. Near real time data assimilation:

- Requires grid cell level uncertainty

Future Evaluation Issues

Evaluate SWE product fused with the melted area mask.





Validate snow-on/snow-off dates in comparison with snow extent products (merged product with GlobSnow SE?)

Assess internal error estimates versus actual retrieval uncertainty.

Quantify uncertainty in station observations.

NASA ‘MEASURES’ Project

PI: David Robinson, Rutgers University

- **Assess compliance of current NH snow cover products over land, sea ice and the Greenland ice sheet with NRC Climate Data Record (CDR = Earth System Data Record (ESDR)) characteristics**
- **Blend data records using statistical measures to develop enhanced, ESDRs of NH snow conditions**
- **Make the ESDRs and associated products available to the user community via an existing web site (http://climate.rutgers.edu/snowcover/) and encourage their use.**

Conclusions

Thematic accuracy for current SWE datasets:

Global scale:	40mm – 200mm
Regional scale:	20mm – 50mm
GlobSnow target:	25 – 40 mm (SWE < 150mm)

FMI Algorithm:
RMSE = 43.2 mm for Eurasia
RMSE = 33 mm for Eurasia (for SWE <150mm)
RMSE = 34 mm for Finland
RMSE = 21 mm for Canada (for SWE <150 mm)

GlobSnow activities represent the most exhaustive inter-comparison of satellite derived SWE datasets performed to date.