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The Satellite Snow Product Intercomparison and Evaluation Experiment (Snow Water Equivalent): Potential Datasets, Protocols, Metrics, and Open Issues

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***Reference Data*: Kelly Elder, Alan Barr…**
***Modeling/Reanalysis Groups*: Rolf Reichle, Eric Brun…**

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- Objectives and background
- Currently available SWE products and levels of validation
- Challenge #1: How do we best perform comparisons with ground reference measurements?
- Challenge #2: How to integrate non-EO gridded SWE products?
- Challenge #3: Approach to multi-dataset trend analysis?
- Summary of open issues

SWE Inter-Comparison Objectives

- Intercompare and evaluate hemispheric passive microwave derived SWE products generated by different algorithms, assessing the product quality by objective means.
- Evaluate and intercompare temporal SWE trends in order to achieve well-founded uncertainty estimates for climate change monitoring.
- Identify recommendations and needs for further improvements in monitoring seasonal snow parameters from EO data.

Unique considerations for SWE:

1. Limited number and time series (AMSR-E) of EO-derived SWE products
2. Inclusion of non-EO gridded products
3. Challenges for alpine areas

Overall goal for this workshop: achieve ***community consensus*** on datasets, protocols, metrics, work plan, etc.

Moving forward, all publications should be combined efforts from the satellite Pis, key field dataset contributors, etc.

Satellite Derived SWE Products

- Rely on satellite passive microwave measurements: reasonable measurement frequencies, orbital characteristics, etc. for snow applications, but limited by coarse spatial resolution.
- Early algorithm approaches: static, empirical, hemispheric versus regional
- Current algorithm approaches: dynamic, include forward emission modeling, standalone versus synergistic

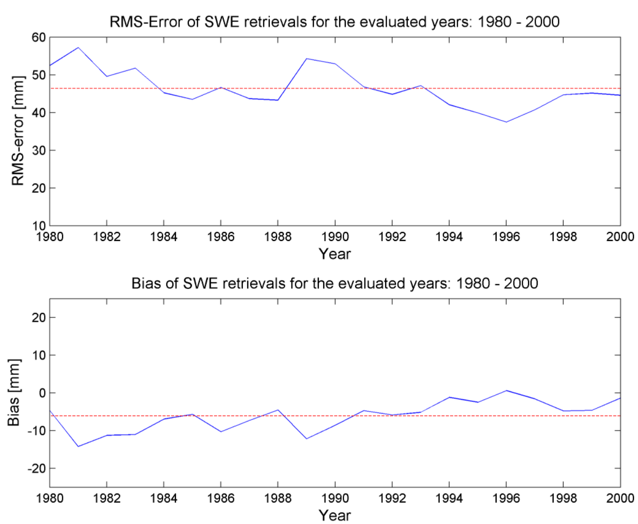
Candidate SnowPEx SWE Datasets

Dataset	Method	Domain	Time Period	Resolutions	Contact	Reference
ESA GlobSnow	Microwave + ground stations	Non-alpine northern hemisphere	1979-present	Daily/weekly/monthly 25 km	K. Luojus	Takala et al., 2011
NASA AMSR-E (standard)	Standalone microwave	Northern hemisphere	2002-2011	Daily/monthly 25 km	R. Kelly; M. Tedesco	Kelly 2009
NASA AMSR-E (prototype)	Microwave + ground station climatology	Northern hemisphere	2002-2011	Daily/monthly 25 km	M. Tedesco	TBD
JAXA AMSR-E/2	Standalone microwave	Northern hemisphere	2013-present	Daily/monthly 25 km	R. Kelly	Kelly 2009
CMA AMSR-E/FY-3	Semi-empirical, regression based	China			Shengli Wu	TBD

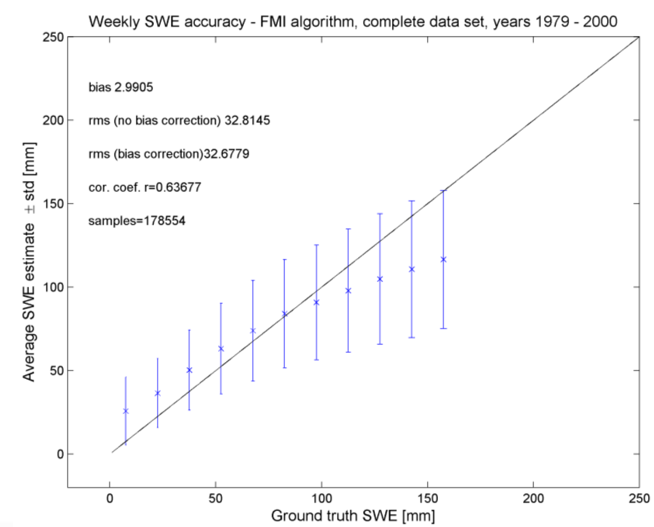
Spatial coverage	Northern Hemisphere (masking of sub-regions is permitted)
Time period	Minimum 2002 onwards (covers AMRE-E period); complete through 2010 As long as possible for trend analysis
Temporal resolution	Daily/Weekly?
Grid	EASE-Grid 25 km northern

Validation of Current SWE Products

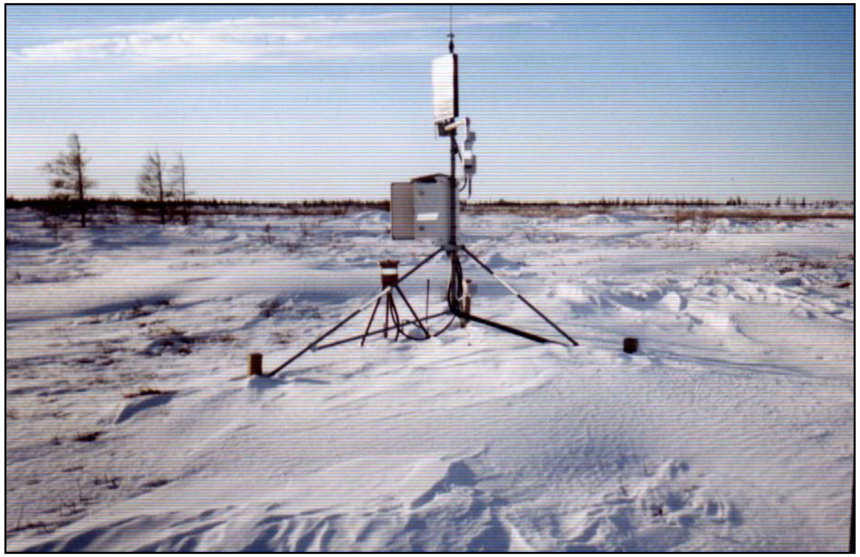
Stage 1 Validation	Product accuracy is assessed from a small (typically < 30) set of locations and time periods by comparison with in situ or other suitable reference data.
Stage 2 Validation	Product accuracy is estimated over ***a significant set of locations*** and ***time periods*** by comparison with reference in situ or other suitable reference data***. Spatial and temporal consistency of the product and with similar products*** has been evaluated over globally representative locations and time periods. ***Results are published in the peer-reviewed literature***.
Stage 3 Validation	***Uncertainties in the product and its associated structure are well quantified from comparison with reference in situ or other suitable reference data***. Uncertainties are characterised in a statistically robust way over multiple locations and time periods representing global conditions. Spatial and temporal consistency of the product and with similar products has been evaluated over globally representative locations and periods. Results are published in the peer-reviewed literature.
Stage 4 Validation	Validation results for stage 3 are systematically updated when new product versions are released and as the time-series expands.



- Passive microwave derived SWE product validation has not moved beyond CEOS stage 2
- Objective for SnowPEx is to achieve stage 3



Challenge #1: How to best perform comparisons with ground reference measurements?



Surface Networks for Validation

Typical approach is to use climate station or snow course measurements for point versus area comparison:

- Maximizes the sample size, but representativeness of the measurements is a major source of uncertainty
- Retrieval techniques such as GlobSnow utilize climate station measurements as part of the retrieval

Alternative approaches:

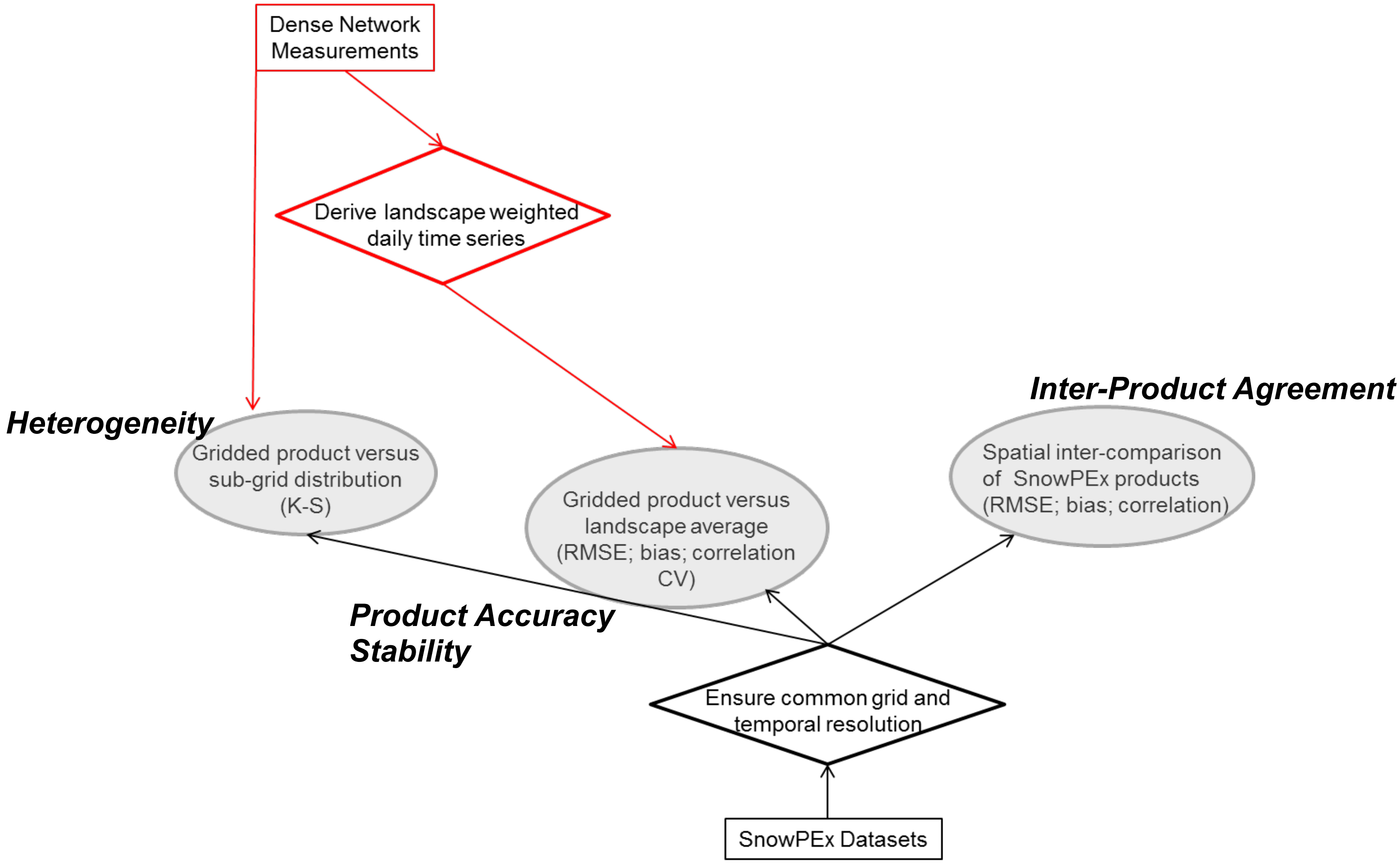
- Differentiate dense from sparse networks (as is being done for SMAP) and focus on the best available data. More limited sample size but should result in a more meaningful comparison.
- Produce gridded SWE products for regions with sufficient site density

Need to ensure sampling across the primary snow-climate classes

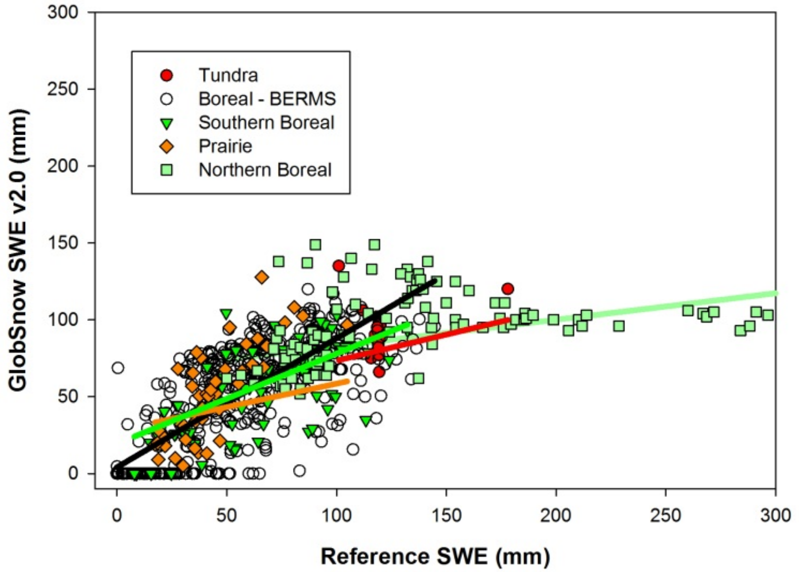
Potential Dense/High Quality Surface Observations

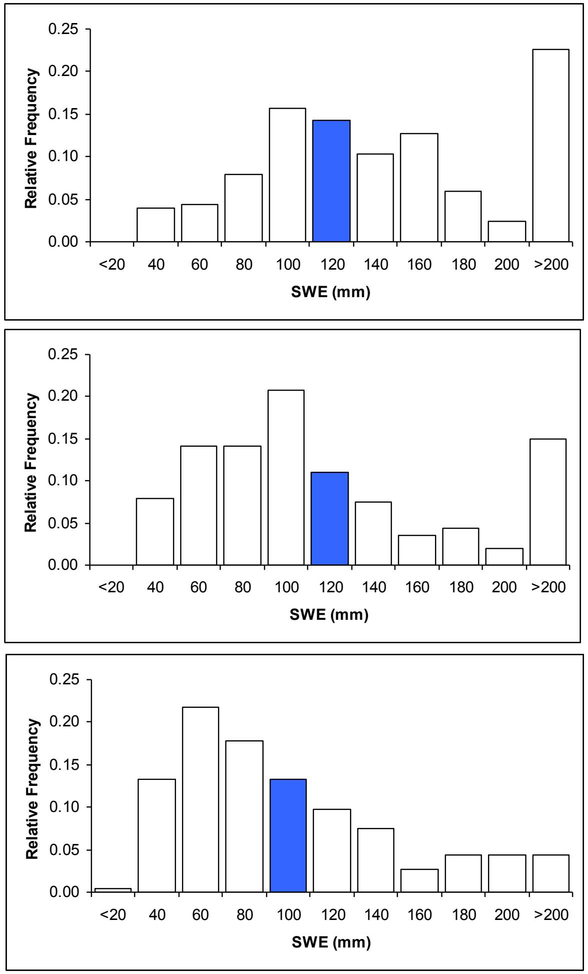
Dataset	***Region***	***Snow Class***	***Method***	***Time Period***	***Temporal Resolution***	***Contact***
Boreal Ecosystem Research and Monitoring Sites	Saskatchewan	Taiga	Sonic snow depth	1997-2014	Daily	H Wheater, U. Sask
Environment Canada – Bratt's Lake	Saskatchewan	Prairie	Sonic snow depth; manual surveys	2011-	Daily	C Smith, EC
FMI – Sodankyla	Finland	Taiga	Sonic snow depth; cosmic	19xx-2014	Daily	J. Pulliainen, FMI
EC – Olympics 2010	Southern coast mountains	Alpine	Sonic snow depth	2008-2010	Daily	C. Derksen, EC
Trail Valley Creek	Northwest Territories	Tundra	Sonic snow depth	2002-2014	Daily (may be gaps in mid-winter)	P. Marsh, WLU
Fraser	Colorado	Alpine	TBD	19xx-2014	Daily	K. Elder, USFS
Finnish Environment Institute Snow Surveys	Finland	Taiga	Manual snow course	19xx-2014	Monthly	S. Metsämaäki, SYKE
RusHydroMet Snow Surveys	Russia	Taiga; Tundra	Manual snow course	1966-2014	Bi-weekly	O. Bulygina, RIHMI-WDC
Hydro-Quebec Snow Survey Network	Quebec	Taiga	Kriged snow course	1970-2005	SWEmax	D. Tapsoba, IREQ

Potential Validation Approach



Validation Examples



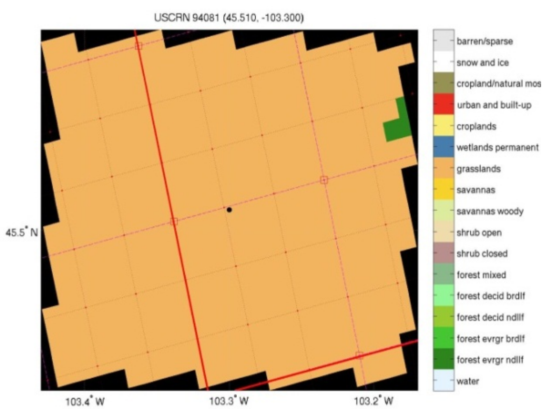


- Comparison of areally weighted point measurements from Canada with GlobSnow v2.0 SWE retrievals
- Statistical distribution of in situ SWE measurements and GlobSnow v2.0 SWE retrievals (blue column) for a grid cell (tundra) near Daring Lake, Canada

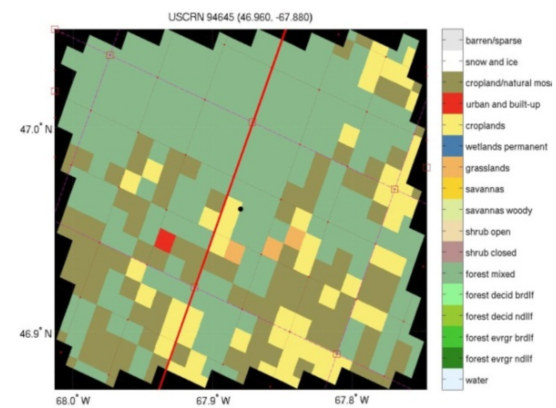
Potential Sparse Surface Observations

Dataset	*Region*	*Snow Class*	*Method*	*Available Time Period*	*Temporal Resolution*	*Distribution and QC*
SnoTel	Western US	Alpine	Snow pillow SWE	1979-2014	Daily	Available online
BC River Forecast Centre	British Columbia, Canada	Alpine	Snow pillow SWE	Variable by station	Daily	Available online
Alberta Environment	Alberta, Canada	Prairie; Taiga; Alpine	Snow pillow SWE	Variable by station	Daily	Available online

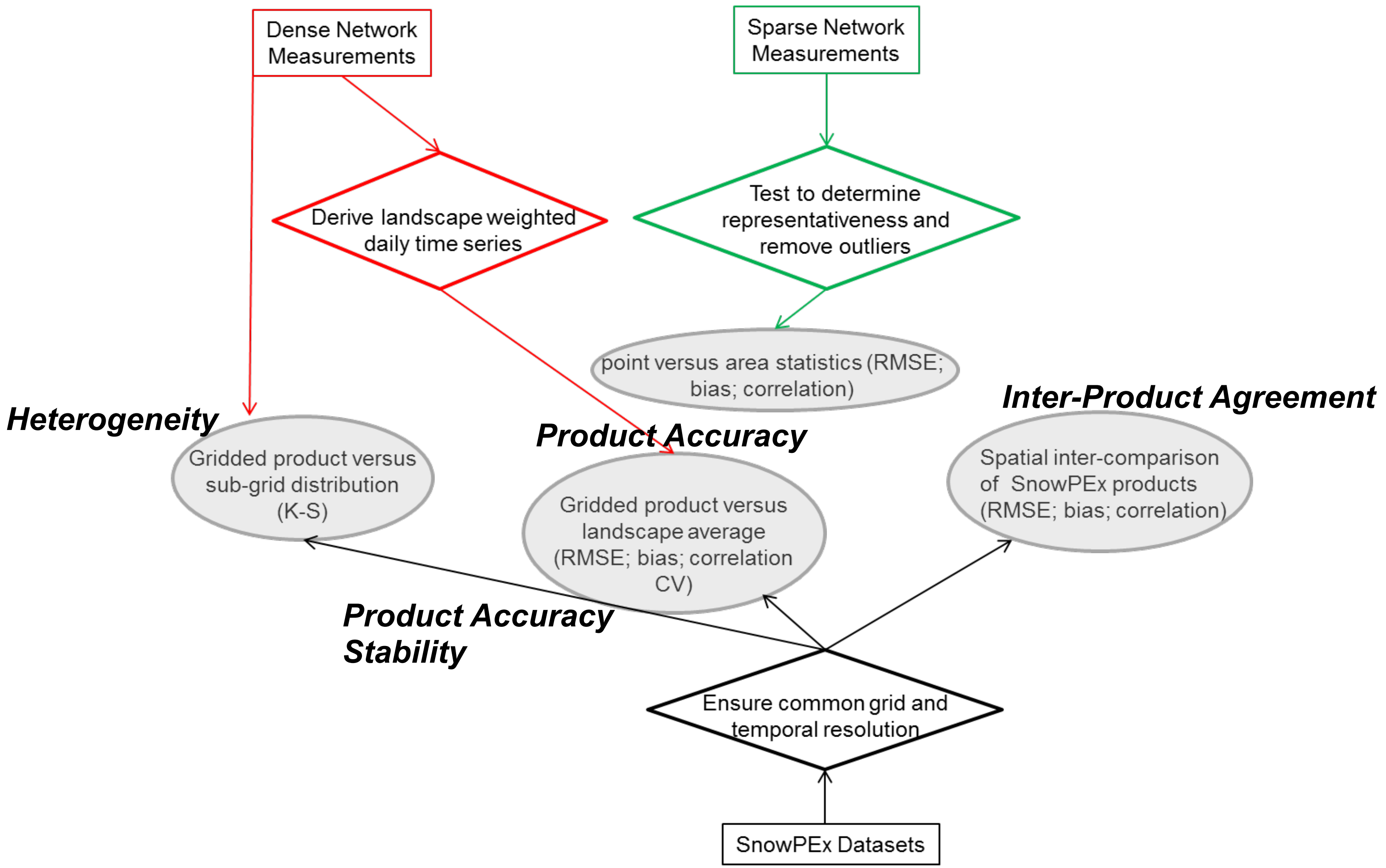
- How to perform a meaningful comparison in mountains at 25 km, even with the available dense networks?
- Sparse networks require pre-screening for site representativeness



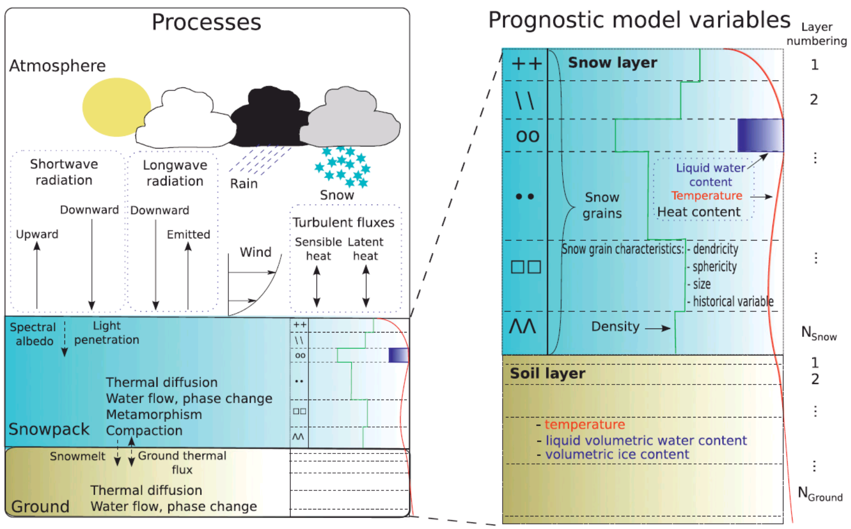
- Example land cover homogeneity for two USCRN stations

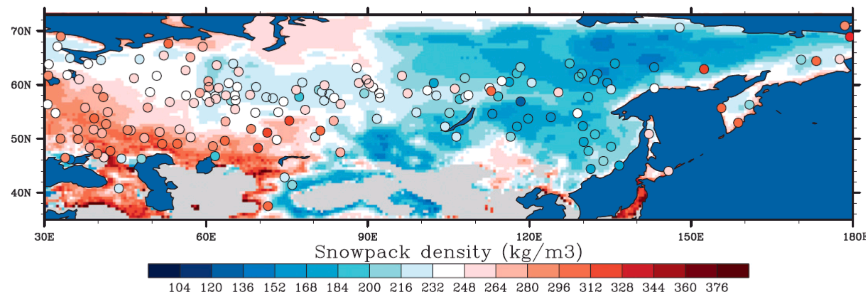


Potential Validation Approach



Challenge #2: How to integrate non-EO gridded SWE products?

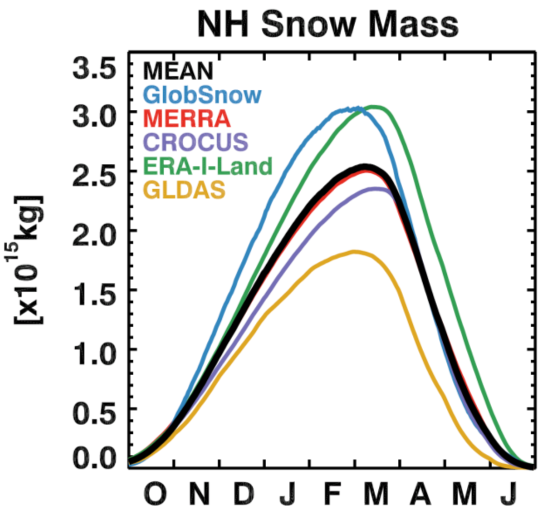




Gridded SWE Products

Considerations:

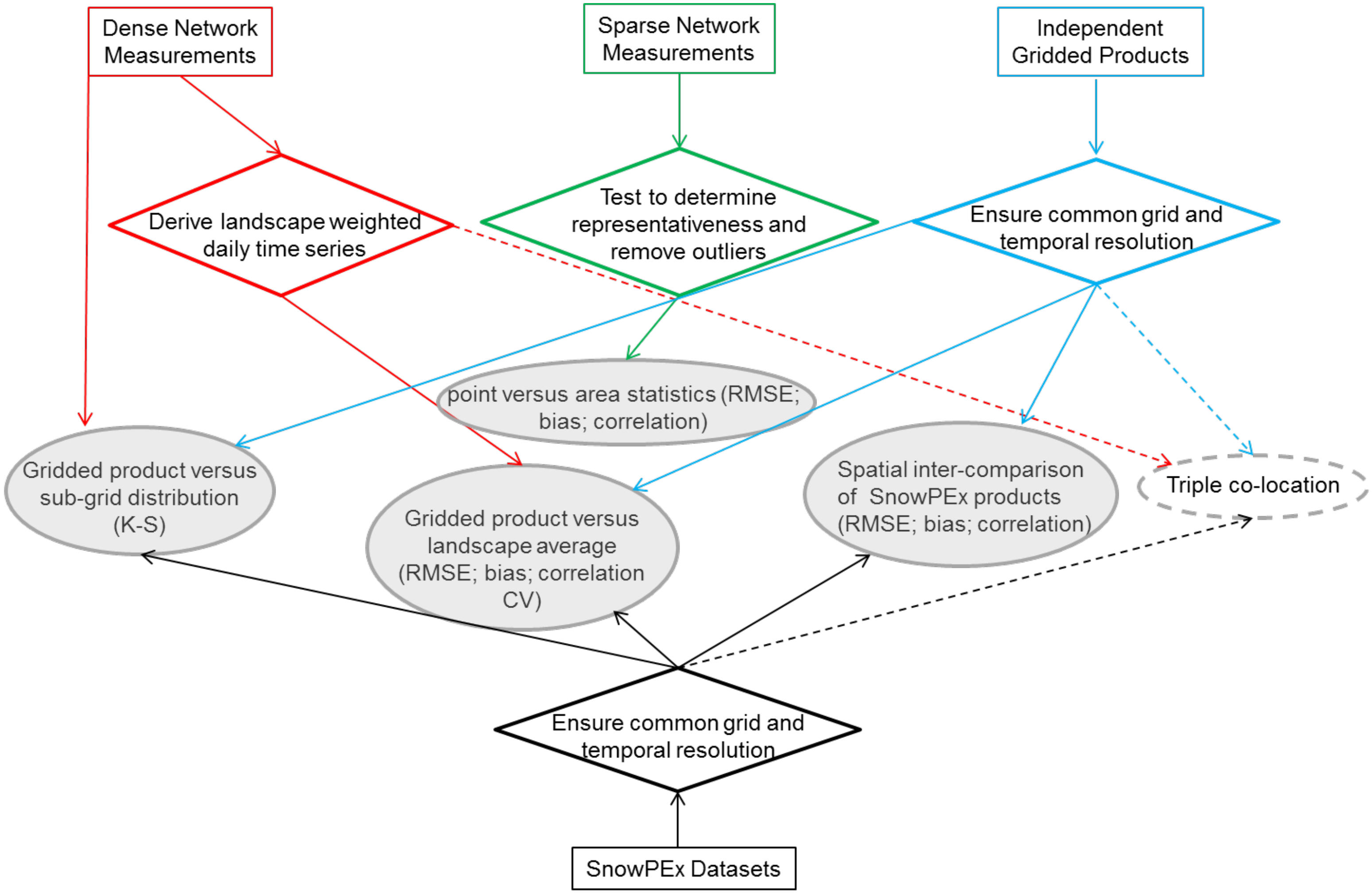
- Limited number of EO derived SWE products
- Short time series (primarily AMSR-E)
- Wide availability of non-EO gridded SWE products with limited validation



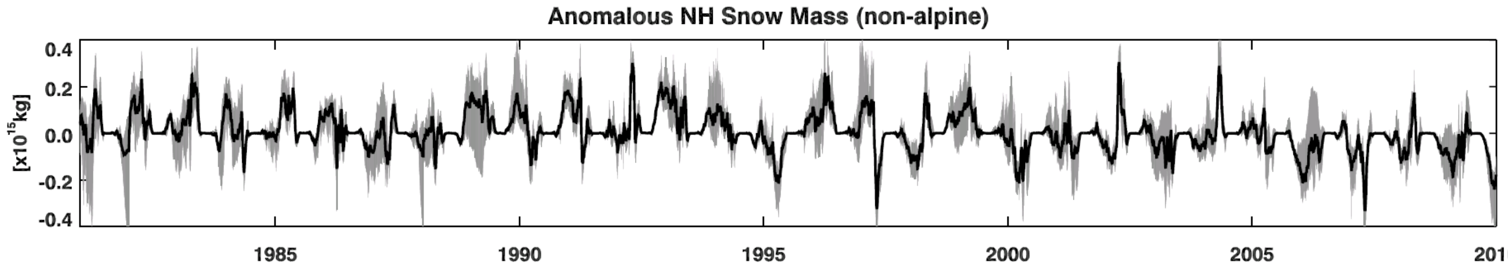
Gridded SWE Products

Dataset	*Method*	*Time Period*	*Res.*	*Comments*	*Reference*
MERRA+ SnowModel	SnowModel driven by downscaled MERRA	1979-2008	10 km	Land areas north of 55N	Liston and Hiemstra, 2011
MERRA-Standard	Catchment land surface model driven by MERRA's AGCM (3DVAR assimilation)	1979-2013	0.5 x 0.67 deg		Rienecker et al., 2011
MERRA-Land	MERRA-standard with revised precip forcing and some hydrological parameterizations	1979-2013	0.5 x 0.67 deg	Discontinuity due to changes to precip forcing	Reichle et al., 2011
GLDAS-Noah	Noah land surface model driven by GLDAS2.0	1948-2010	0.25 x 0.25 deg		Rodell et al., 2004
CMCSnow Analysis	in situ obs + snow model forced by GEM forecast temp/precip fields	1998-2013	35 km	Discontinuity in 2007 due to change in precip forcing	Brasnett, 1999
ERA-interim-HTESSEL (ERA-land)	HTESSEL land surface model driven by ERA-Interim + GPCP v2.1 adjustments	1979-2010	80 km		Balsamo et al., 2013
ERA-interim-CROCUS/ISBA	CROCUS snow model in ISBA forced by ERA-interim; no precip corrections/adjustments	1979-2013	1 x 1 deg	Only recently applied to entire NH, north of 25N	Brun et al., 2013

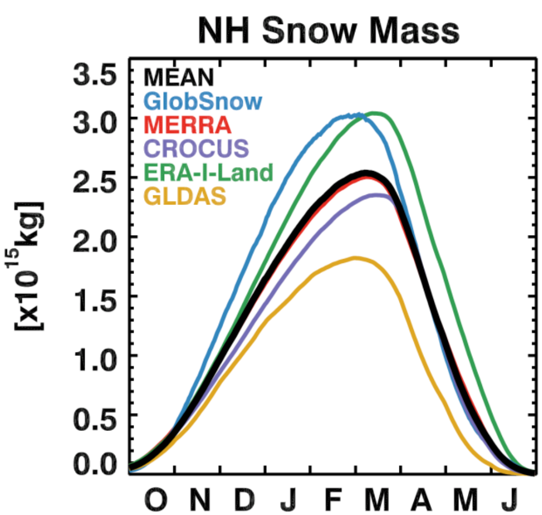
Potential Validation Approach

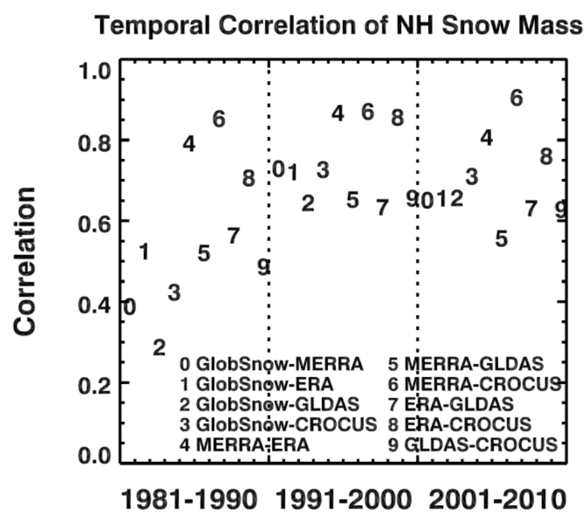


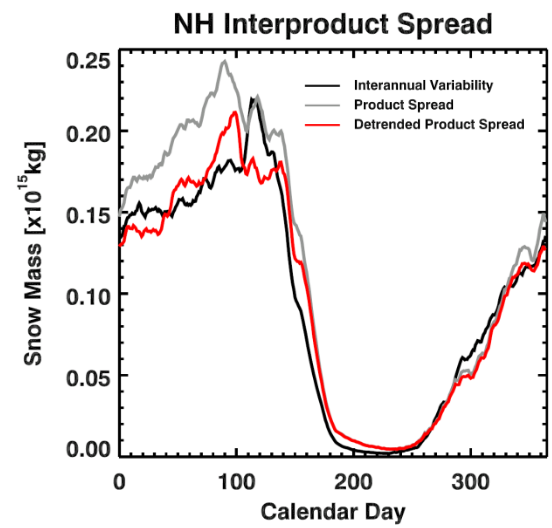
Initial Multi-Dataset SWE Comparisons



- Time series of NH snow mass anomalies for mean SWE product (black) and 5 product range (gray)







- Individual climatologies differ by almost 50%
- Products show reasonable pair-wise correlations
- Spread is comparable to interannual variability

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Mudryk et al, EGU, 2014

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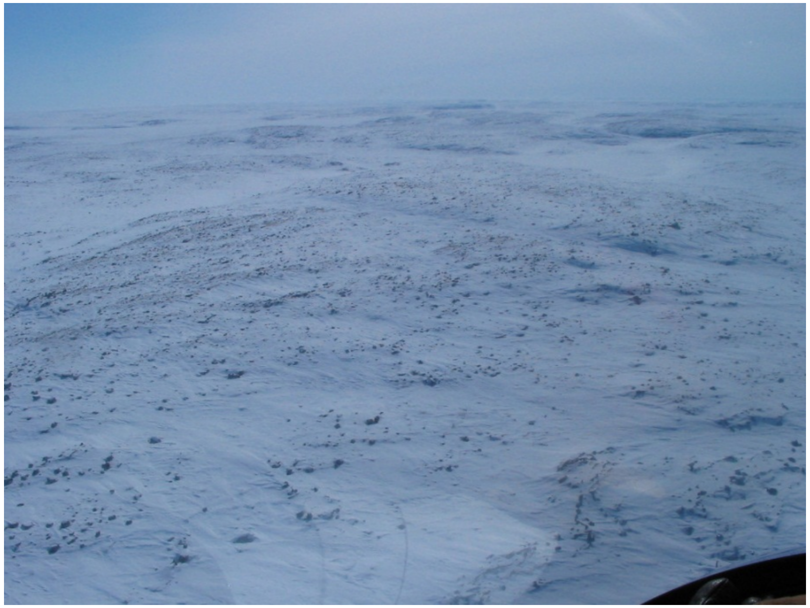
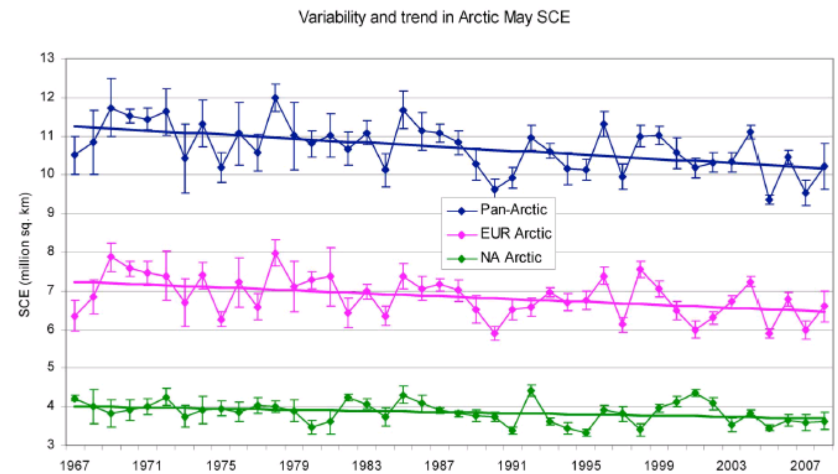
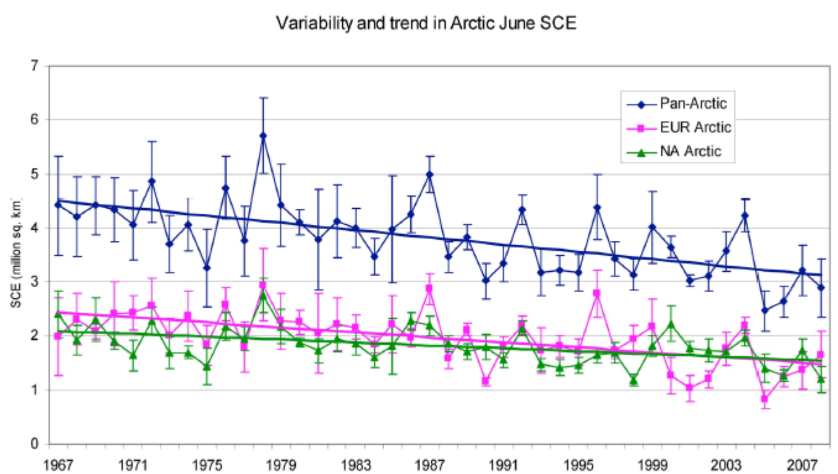
Challenge #3: Approach to multi-dataset trend analysis?



Example of Multi-Dataset Trend Analysis





Estimate of uncertainty in SCE in each year obtained from the standard error (SE):

$$\mathrm{SE} = s/\sqrt{(n-1)}$$

which depends on the standard deviation *s* of *n* data sets included in the average anomaly.

The uncertainty estimates included in linear trend analysis which accounts for errors in the dependent variable.

Method allows variable number of datasets each year.

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Brown et al., 2010

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Summary of Open Issues

Comparison with ground reference measurements

- Should we limit the comparison with ground reference measurements to dense and high quality networks only?
- How do we perform a meaningful comparison in mountains at 25 km, even with the available dense networks? Is there a role here for datasets such as SNODAS or gridded in situ obs?
- What will be the standard time periods (golden years) and temporal resolution (daily versus weekly)?
- Do we limit reference datasets to only bulk snow properties or include more detailed variables (such as snow grain size)

Inter-dataset comparison with independent gridded products

- What is the most meaningful way to include the gridded reference SWE products given that some share common reanalysis meteorology and precipitation forcing?
- Is the triple co-location approach suitable for gridded SWE products?

Multi-dataset trend analysis

- Can datasets used in trend analysis cover different time periods?
- Do we include all gridded SWE products in the trend analysis?
- How do we combine trends from datasets with different masks?
- How best to combine SWE and SE trends?