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Uncertainty in Snow Cover Datasets: Guidance for SnowPEx

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Outline

- What is out there? Snow products and datasets (GCW inventory!)
- Why are we doing this? What are the science questions/applications?
- CC context – where is snow cover expected to undergo the greatest changes; where is the uncertainty in projected change highest?
- Experience from working with multiple datasets (between-dataset variability, standardization, regridding…)
- Recommendations for SnowPEx

What snow information is out there?

- Major increase in the sources of snow cover information over the past ~10-15 years:
  - Satellite-derived (e.g. MODIS, AMSR-E, AVHRR, NOAA-CDR, NIC-IMS, GlobSnow-SE)
  - New sensors and/or technology (e.g. GRACE, GPS)
  - Operational analysis products (e.g. IMS, CMC, SNODAS)
  - Reanalyses (e.g. ERA-interim, MERRA, CFSR, GLDAS) and reanalysis-driven reconstructions (e.g. Liston and Hiemstra 2011)
  - New online and gridded collections of historical in situ data (e.g. Russian snow depth and snow survey data, GHCN-daily)
- Can be major differences between information sources related to the way snow is measured and/or analyzed as well as issues such as technological bias, discontinuities in measurement methods, changing data streams in reanalyses, biases in surface networks, different spatial interpolation methods etc
- A major challenge for users to decide what snow cover information is best suited to their needs
- Documentation is rudimentary in many cases and may not address issues such as homogeneity, spurious values e.g. major discontinuity discovered in MERRA-land SWE during intercomparison with other datasets

GCW snow product/dataset inventory

- Development of inventory of snow products and datasets including some assessment of QA recommended as a priority action item at GCW SnowWatch meeting in Toronto Jan 2013 – also contributes to SnowPEx and vice versa
- Preliminary discussions held at Boone ESC, June 2014
- Definitions:
  - **Snow product** : produced for near-real time clients, supported by institutional mandate, on-going
  - **Snow dataset**: for R&D applications, non-real time, covers specific time period, often one-off in nature
- Criteria to include dataset/product in inventory:
  - Data must be freely available
  - Data must be supported (i.e. there is an ongoing institutional or PI commitment to support the dataset)

What information should be included in the inventory?

- Concise, up-to-date summary of a dataset's key characteristics (period, resolution, method following GCOS ECV reporting recommendations)
- Should include clear statements about any caveats (e.g. missing data, inhomogeneities, known biases etc) **GCW added-value**
- Should include some assessment of the utility of a dataset based on PI and research community experience (e.g. potential applications, citations of publications using the data, known limitations, results of previous evaluations) **GCW added-value**
- Zero-order inventory being compiled by R Brown for circulation to identified dataset/data product PIs and to the snow research community for updating and feedback
- Data inventory to be housed and maintained at GCW as a "live document" e.g. ***SnowPEx results will be incorporated as they become available***

Why are we doing SnowPEx?

WCRP CliC imperative: *[Need for]* m*ore comprehensive, quality-controlled observational, observationally-based, and proxy datasets of cryospheric variables suitable for a range of research and model evaluation activities*

Spatial and temporal scales and snow cover variables vary with users' particular needs/questions: has implications for the variables and regions selected for evaluating products, and the evaluation strategy

Non real-time users:

- Climate monitoring – BAMS, IPCC (monthly, SCE, SWE @ **hemispheric scale**)
- Climate model evaluation (daily, monthly gridded SCF and SWE @ **50-200 km**)

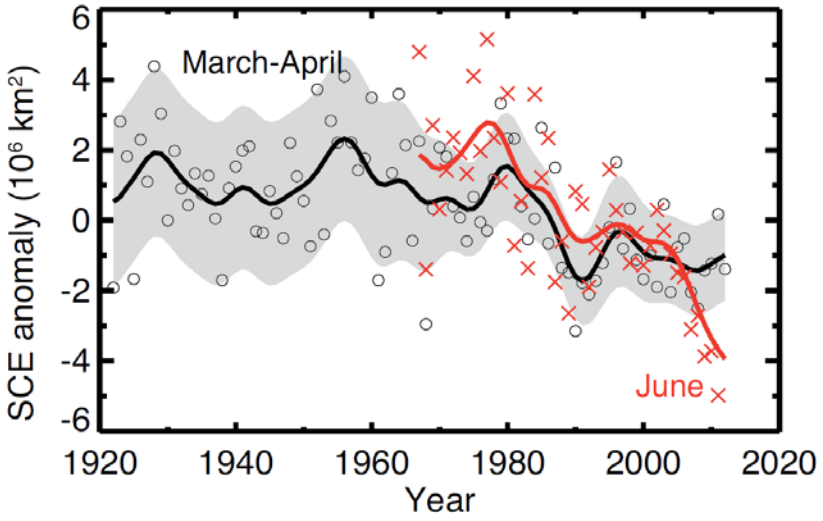
Real-time users:

- Water resource mgmt (daily gridded SWE, basin scale @ **1-10 km**)
- NWP (12 hours, gridded snow presence/absence, Sdep, SWE @ **1-25 km**)

Science priorities for SnowPEx?

Are there particular high profile science questions/needs that SnowPEx should consider in developing the evaluation strategy? Implications for variables, regions, evaluation methodology

- Monitoring snowpack in semi-arid regions (**fresh water supply**)
- Improved estimates of trends in hemispheric SCE and SWE for input to next IPCC assessment (**global cryospheric monitoring**)



Ecocentric
All things green, from conservation to Capitol Hill

CLIMATE SCIENCE

Why Dwindling Snow — Thanks Largely to Climate Change — Might Dry Out Los Angeles

Southern California depends on the mountain snowpack for part of its water — and that snow is about to get less reliable

By Bryan Walsh @bryanrwalsh | June 17, 2013 | 66 Comments

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While the national government remains slow to deal with climate change, many cities have been moving ahead. Why the difference? Well, cities tend to be more homogenous politically, which makes any kind of decisive action easier to push through. But the real reason is that city managers know they will be the first ones forced to deal with the likely consequences of global warming: rising sea levels and flooding, deadly heat waves and water struggles. New York City didn't just come out last week with the most comprehensive climate-adaptation plan in the world because Mayor Michael Bloomberg is a global-warming believer. The experience of Hurricane Sandy last year — which cost the city

Walter Bibikow / Getty Images

The Sierra Nevada snowpack is a vital source of water for California

For the next IPCC SnowPEx should aim to produce multi-dataset estimates of trends in NH SCE and SWE

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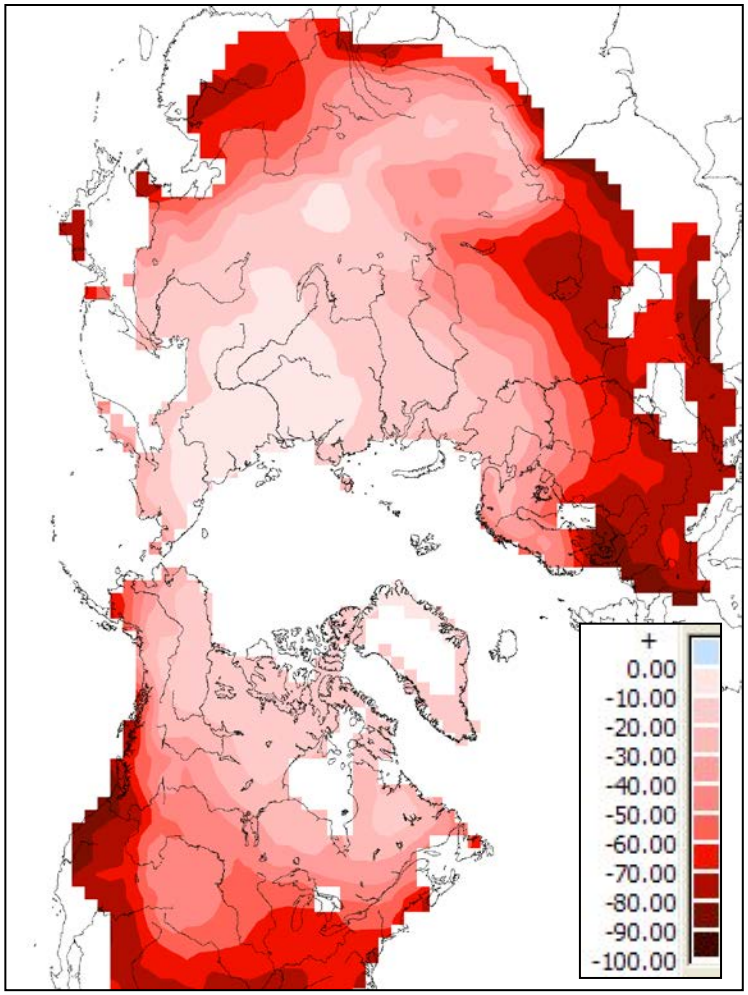
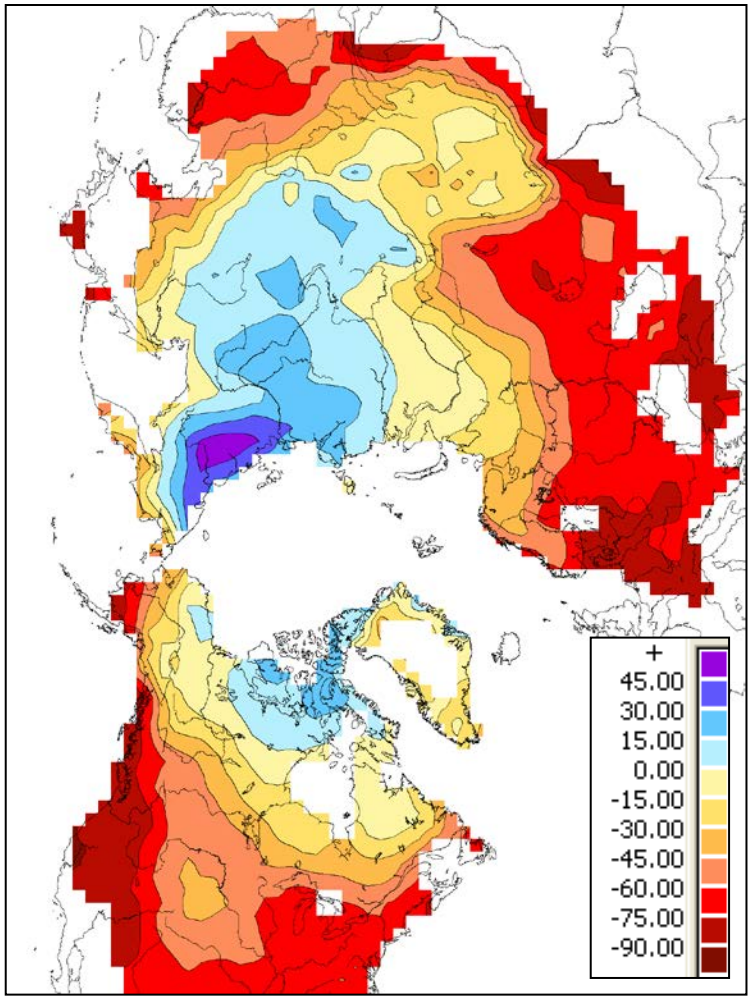
Do projected changes in snow cover due to CC provide any guidance for SnowPEx?

Mean % change in SCD



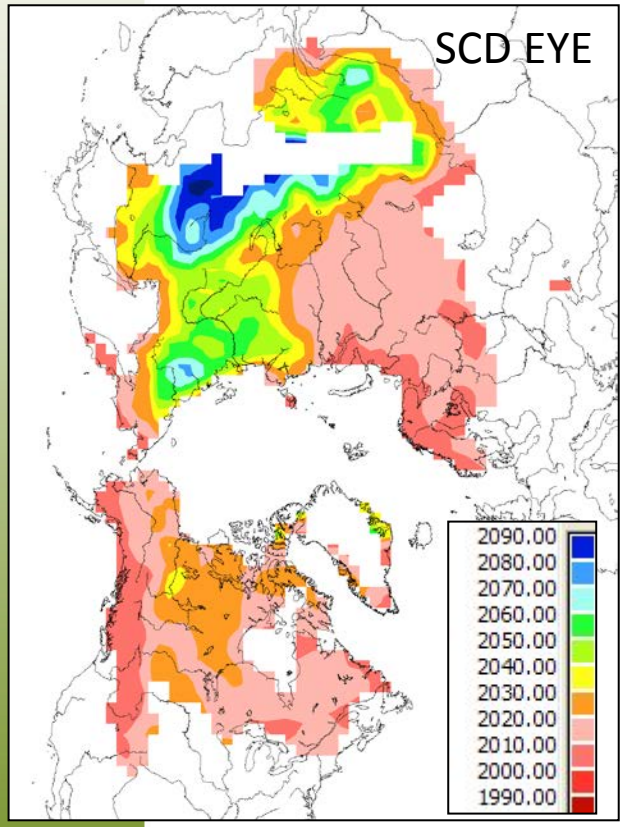
Mean % change in SWEmax

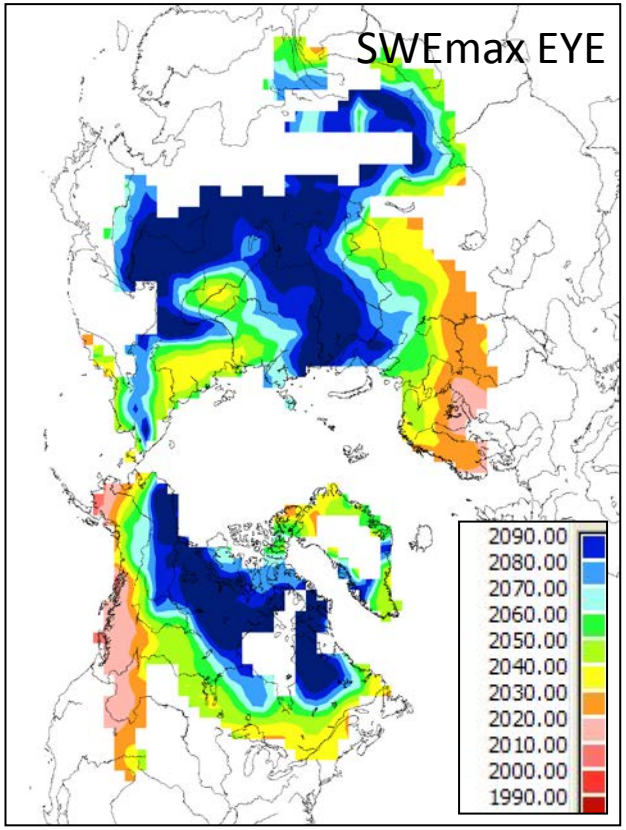


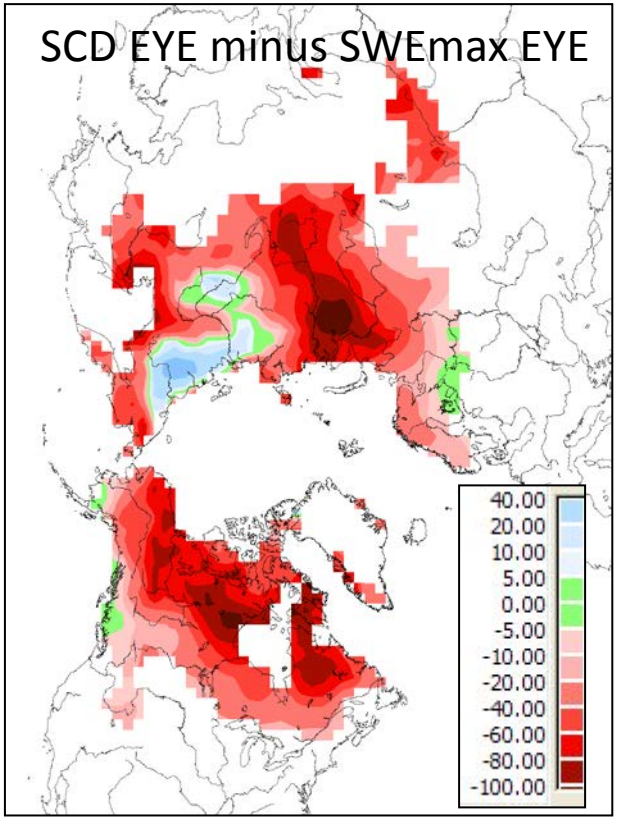
Projected mean change in snow cover from 8 CMIP5 models, rcp8.5

Expected year of CC signal emergence (EYE) in snow cover

Expected year of climate signal emergence (EYE) in snow cover from 8 CMIP5 models, rcp8.5

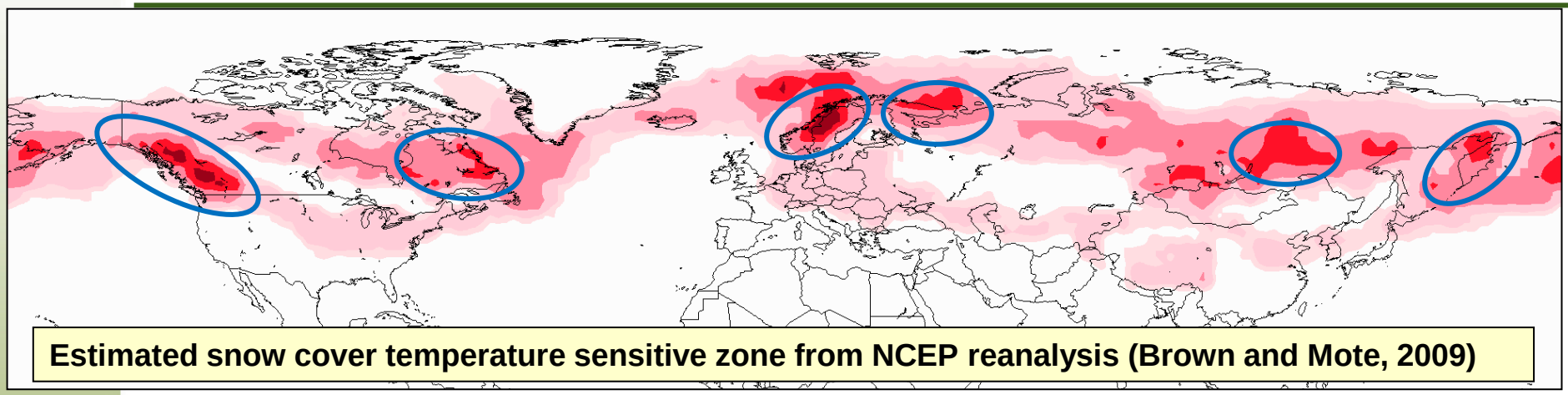






- Earliest CC signals emerge in SCD and SWEmax over western NA and Europe (areas of largest projected decreases in SWEmax)
- SCD signals emerge earlier than SWEmax everywhere except Siberia

Climate model results consistent with estimates of “at risk” snowpack based on observations



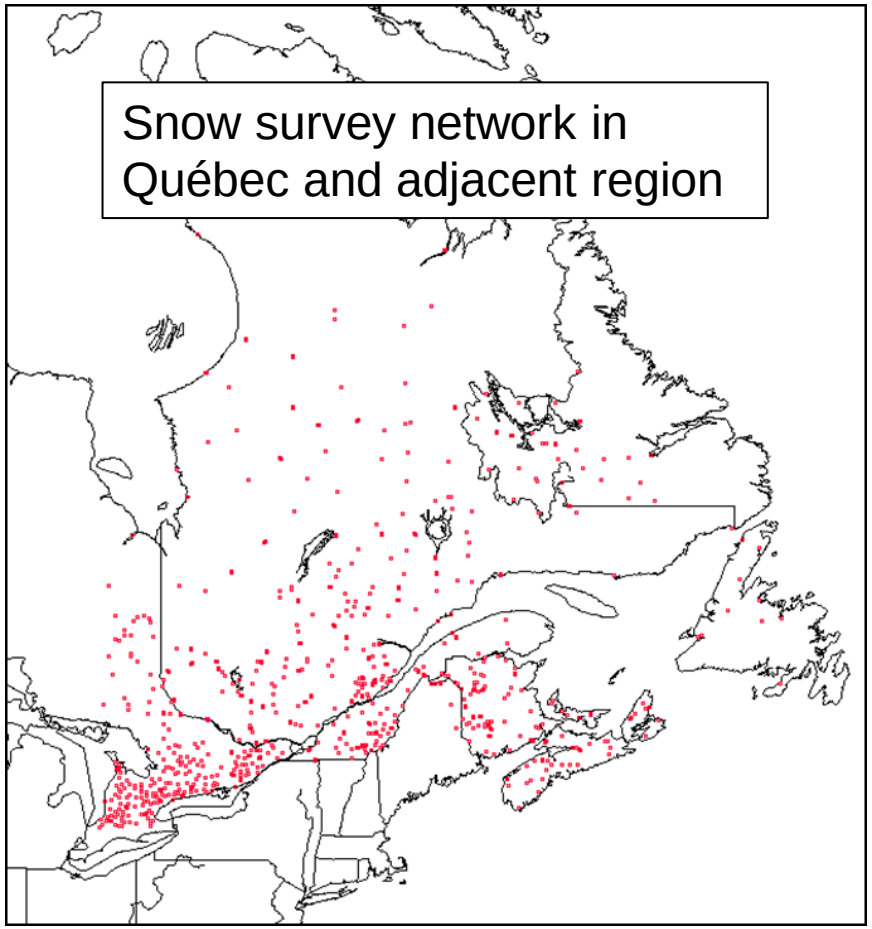
Estimated snow cover temperature sensitive zone from NCEP reanalysis (Brown and Mote, 2009)

Areas with most “at risk” snowpack are regions with high precipitation amounts and winter air temperatures close to freezing

- Western coastal mountains of NA
- Quebec-Labrador
- Scandinavia
- Russia (Kola Peninsula, Lena Basin, Kamchatka Peninsula)
- European Alps (not resolved in the reanalysis used above)

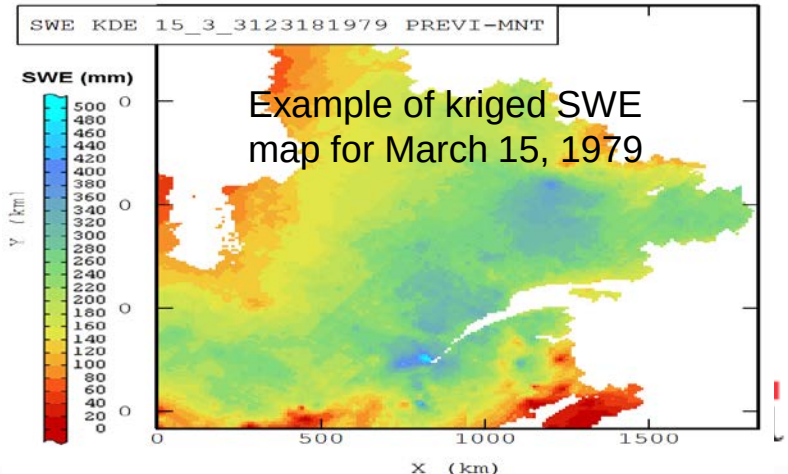
Good surface observations networks exist in most of these regions

Now that you mention it, Québec is a potentially data-rich SnowPEx validation region! Hydro-Quebec have expressed willingness to contribute data to SnowPEx



What Quebec Offers:

- N-S gradient covering main NH land cover classes (agric, mixed hardwood, taiga, tundra)
- Snow survey data from several hundred sites for 40+ years
- 10 km kriged SWE dataset with topography as external drift variable covering 1970-2013 period (Dom. Tapsoba, IREQ)
- GMON SWE obs at 7 stations
- IPY snow transect – sfce, airborne (Langlois et al)



Example of kriged SWE map for March 15, 1979

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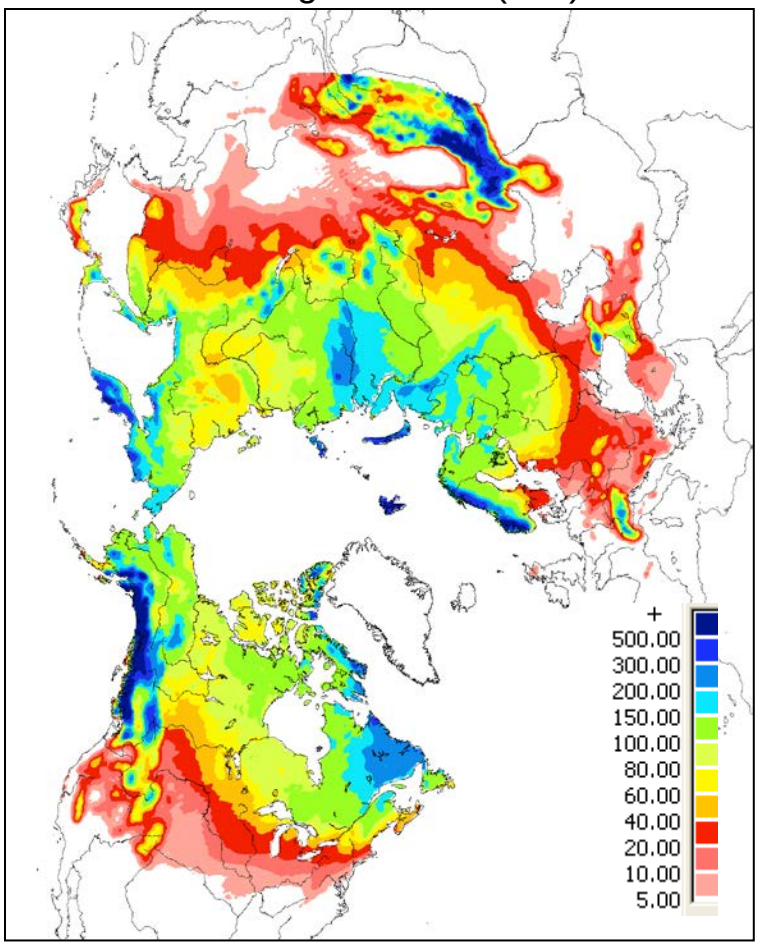
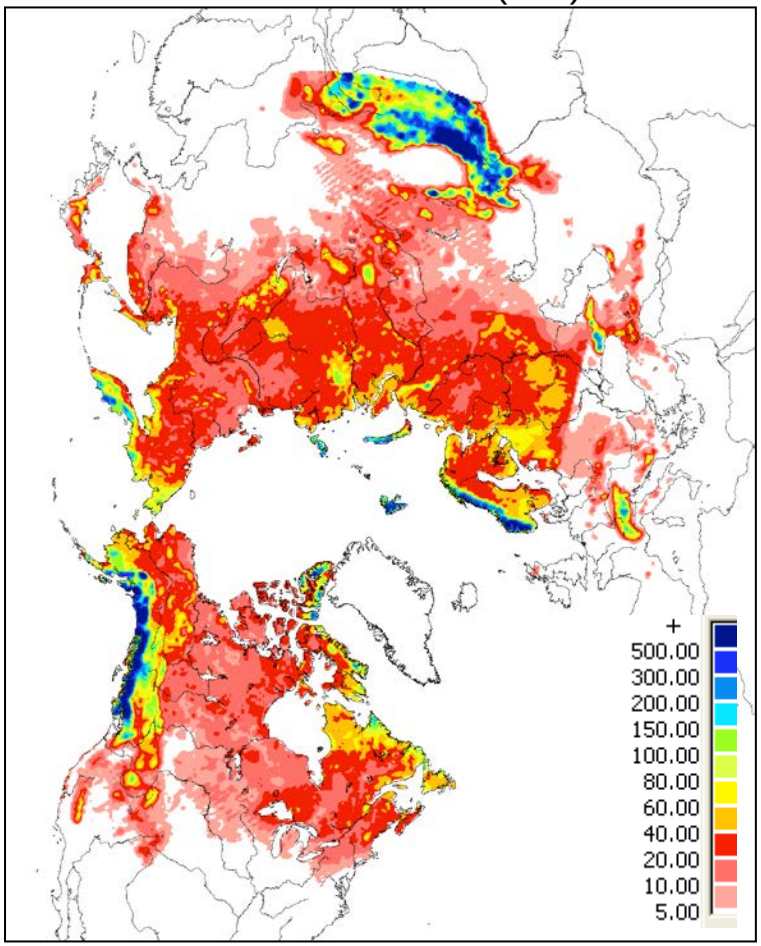
Do uncertainties in observations provide any guidance of where SnowPEx should concentrate evaluation activities? i.e.focus on regions where current products are not doing well

Avg SWEmax (mm)

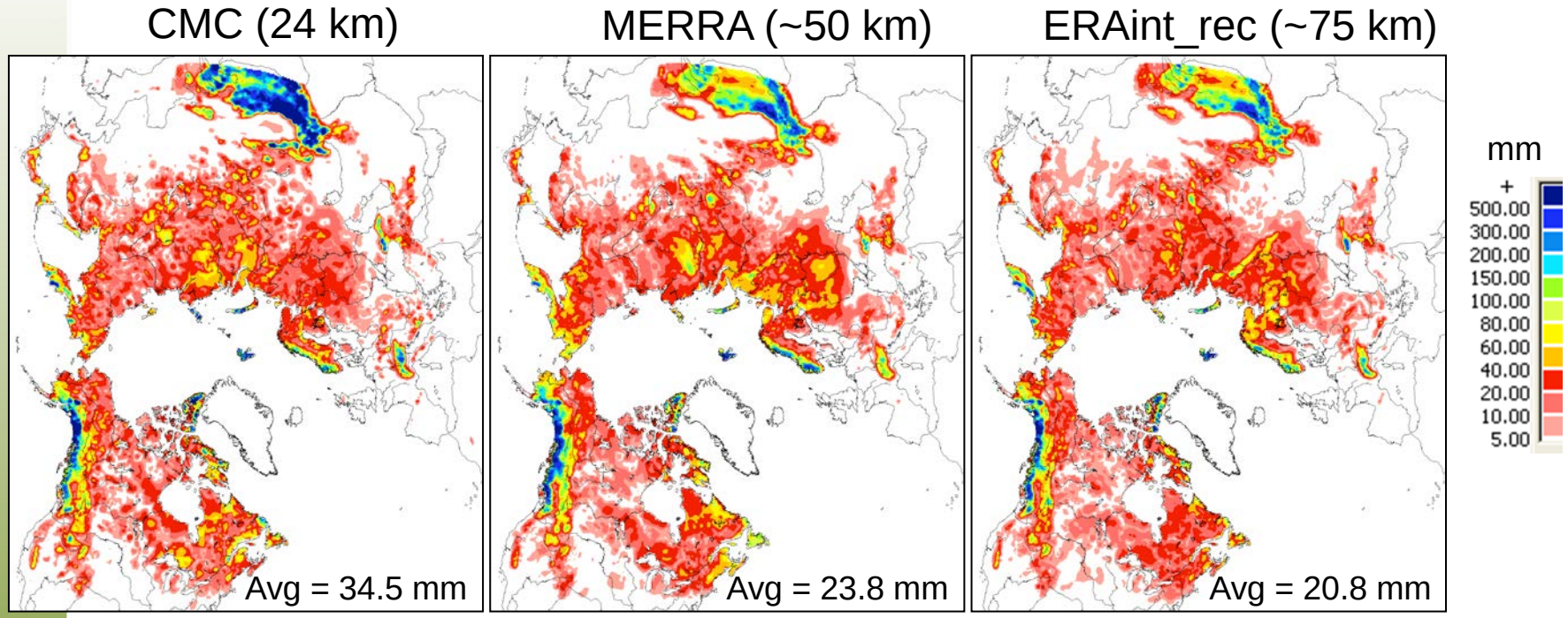


Between-dataset Std (mm)



Between dataset variability in mean annual maximum monthly SWE, 1999-2009 (GlobSnow, L&H, MERRA, CMC, ERA-interim) Minimum of 3 datasets to compute stats. NH land area north of 30°N

SWEmax triple collocation error results for 3 datasets with complete NH coverage (CMC, MERRA, ERAint_rec)



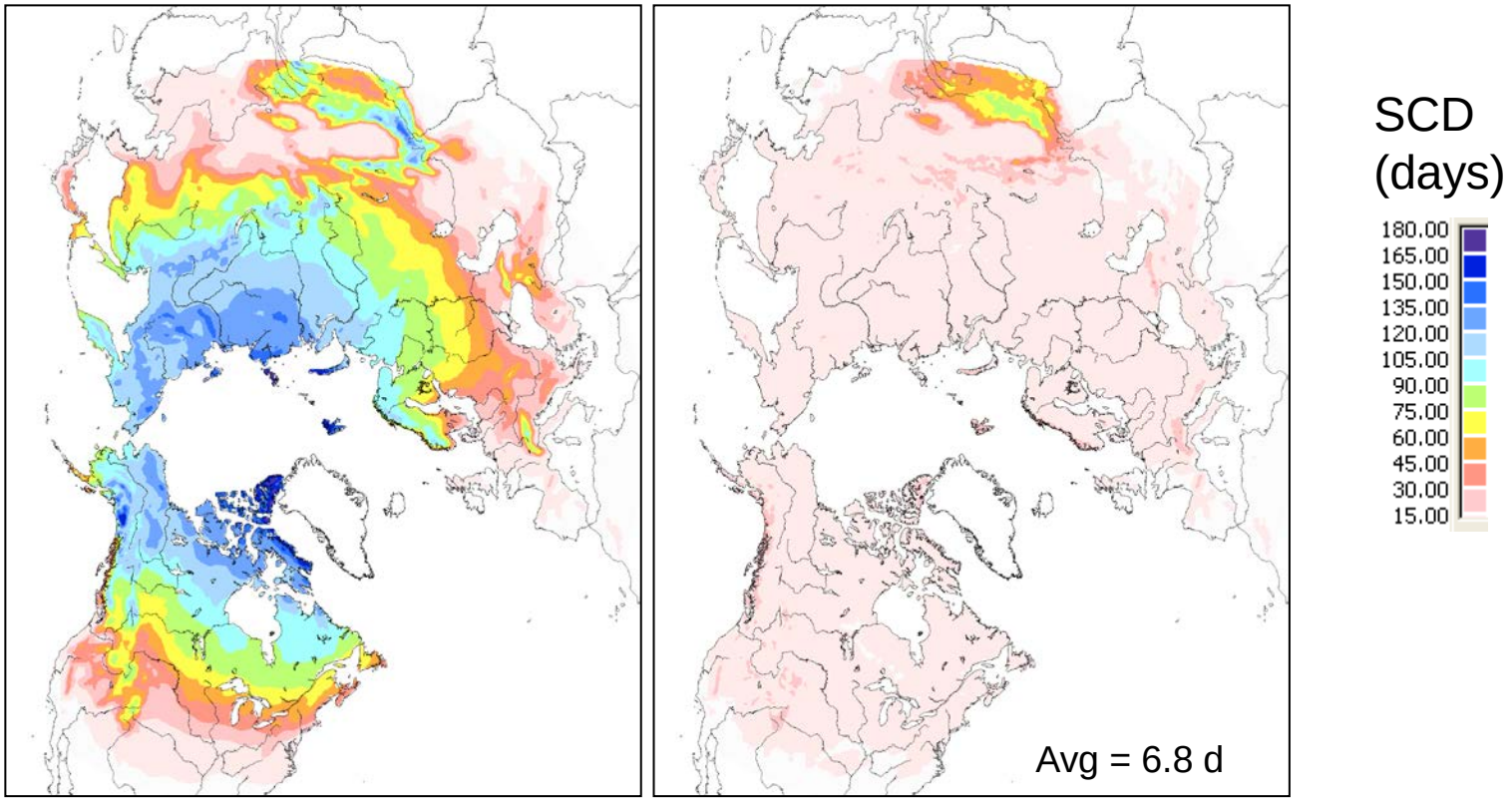
- Uncertainty is relatively evenly spread over all three datasets and is highest in the same regions (mountains)
- Re-gridding data with different resolutions to a common grid contributes to this problem
- Higher SWE values in mountain regions from higher resolution CMC product inflates the TC error (less of a problem with SE where values are bounded)

Interpolating information from datasets with different intrinsic scales of spatial variability in mountainous regions is a real challenge!

Between dataset variability in mean annual SCD, 1998/99-2008/09 (IMS-24, L&H, MERRA, CMC, ERA-interim)

Minimum of 3 datasets to compute stats; NH land area north of 30°N

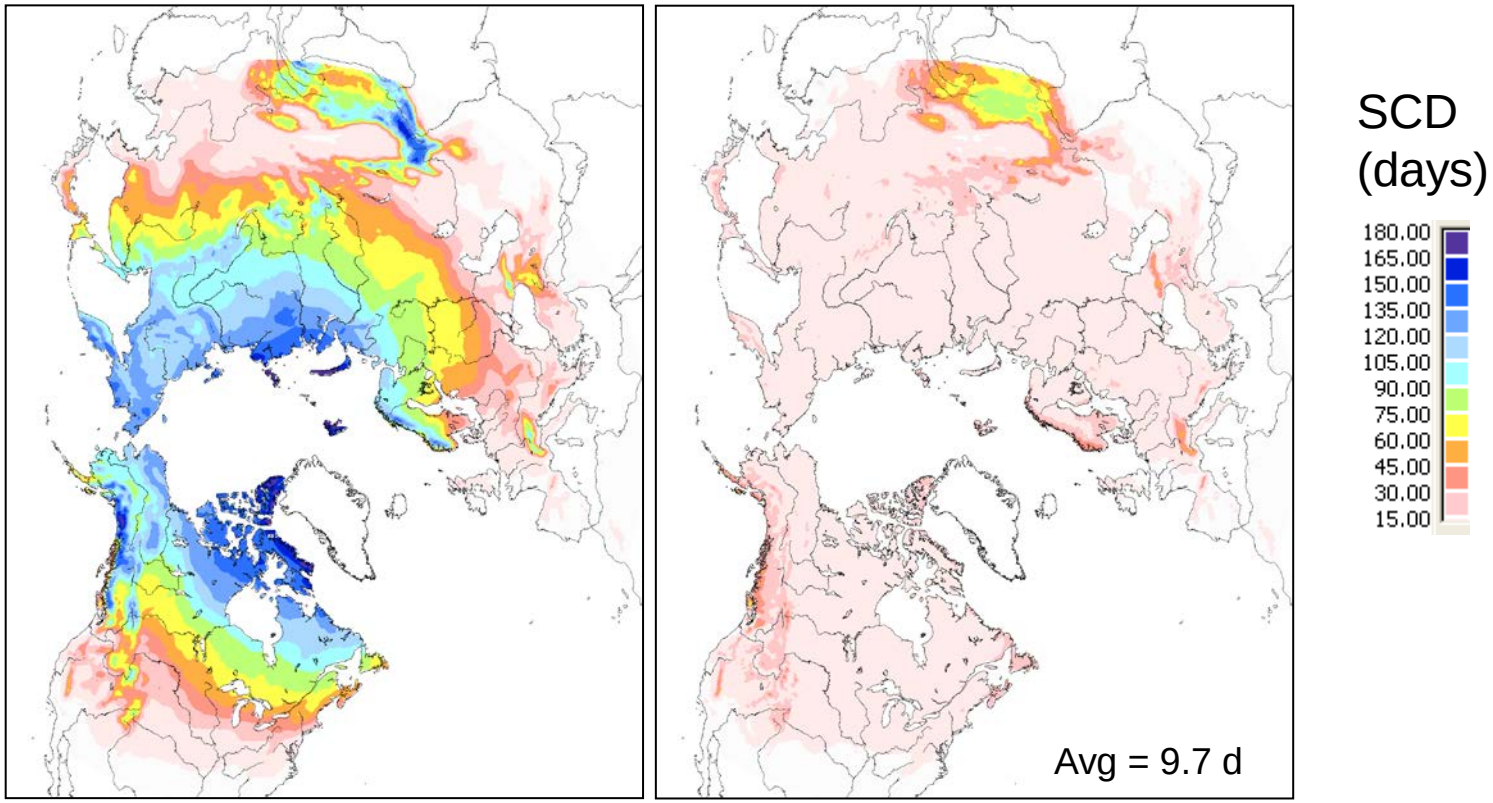
Average SCD and between-dataset stdev in the first half of the snow year (Aug-Jan)



Between dataset variability in mean annual SCD, 1998/99-2008/09 (IMS-24, L&H, MERRA, CMC, ERA-interim)

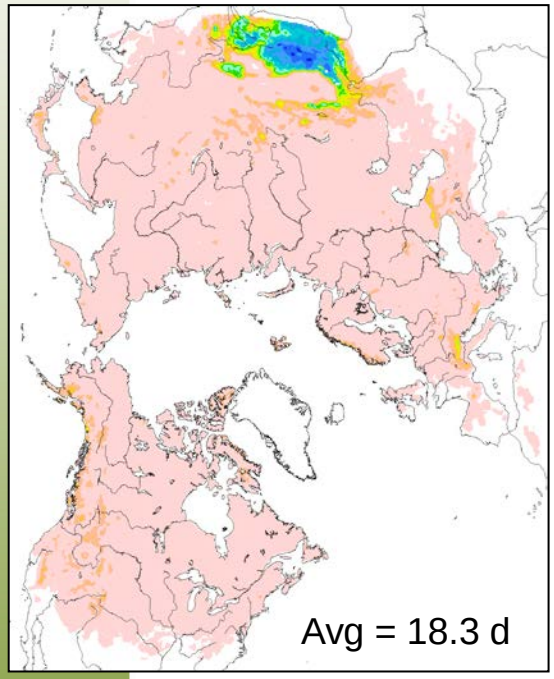
Minimum of 3 datasets to compute stats; NH land area north of 30°N

Average SCD and between-dataset stdev in the second half of the snow year (Feb-Jul)

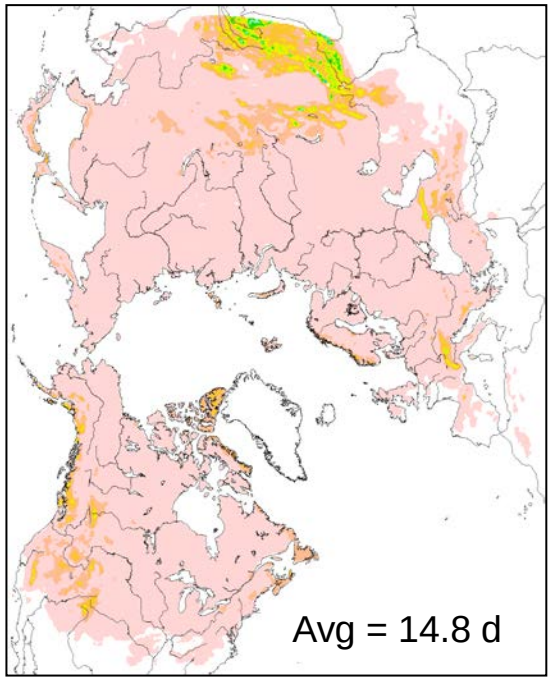


Annual SCD triple collocation error results for CMC, MERRA, IMS

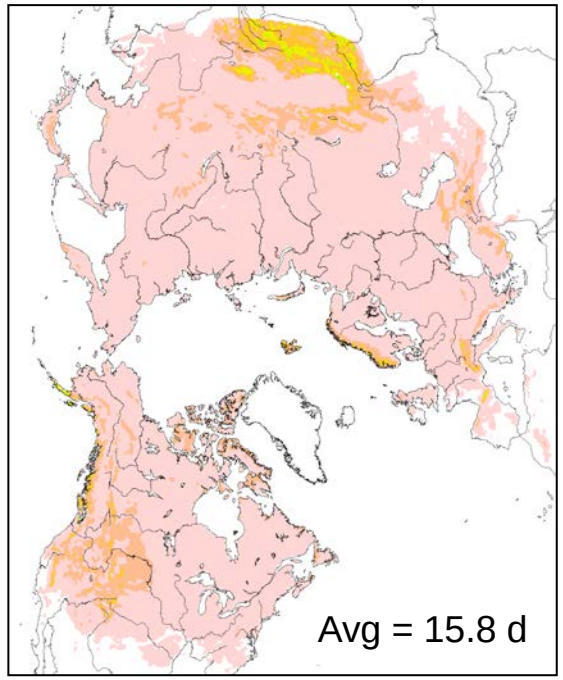
CMC



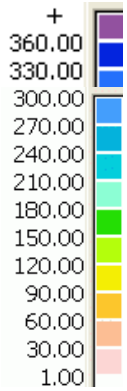
MERRA



IMS-24

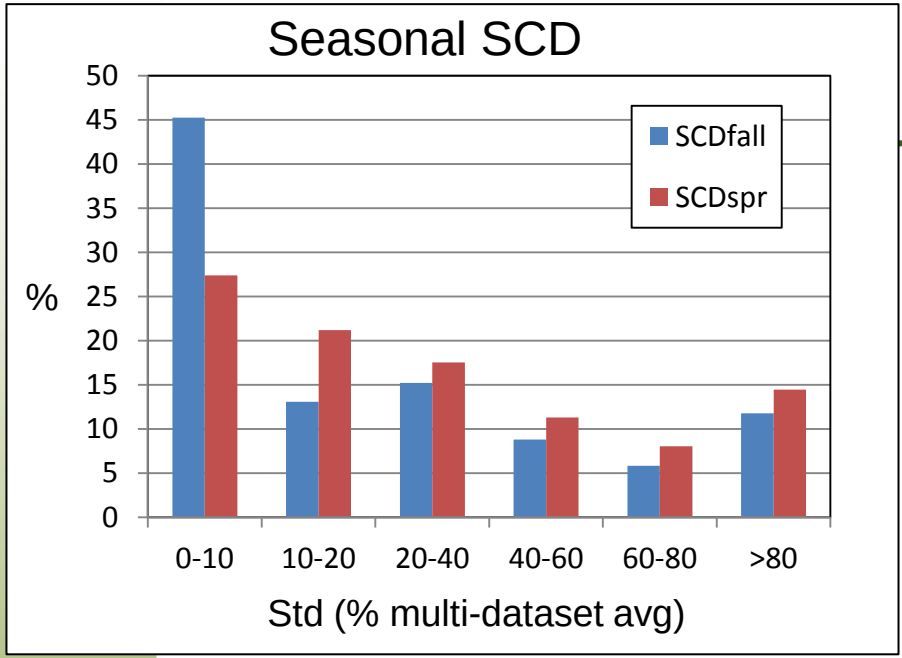


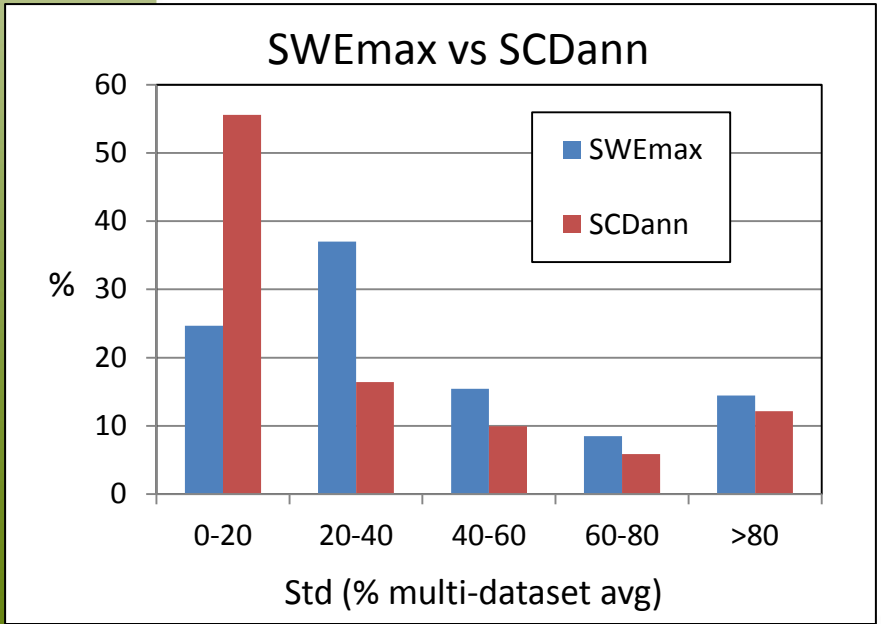
SCD (days)



- Largest uncertainty over Tibetan Plateau
- CMC errors higher on average than the other datasets during the snow onset period

Freq distribution of between-dataset stdev (% of average value) over NH





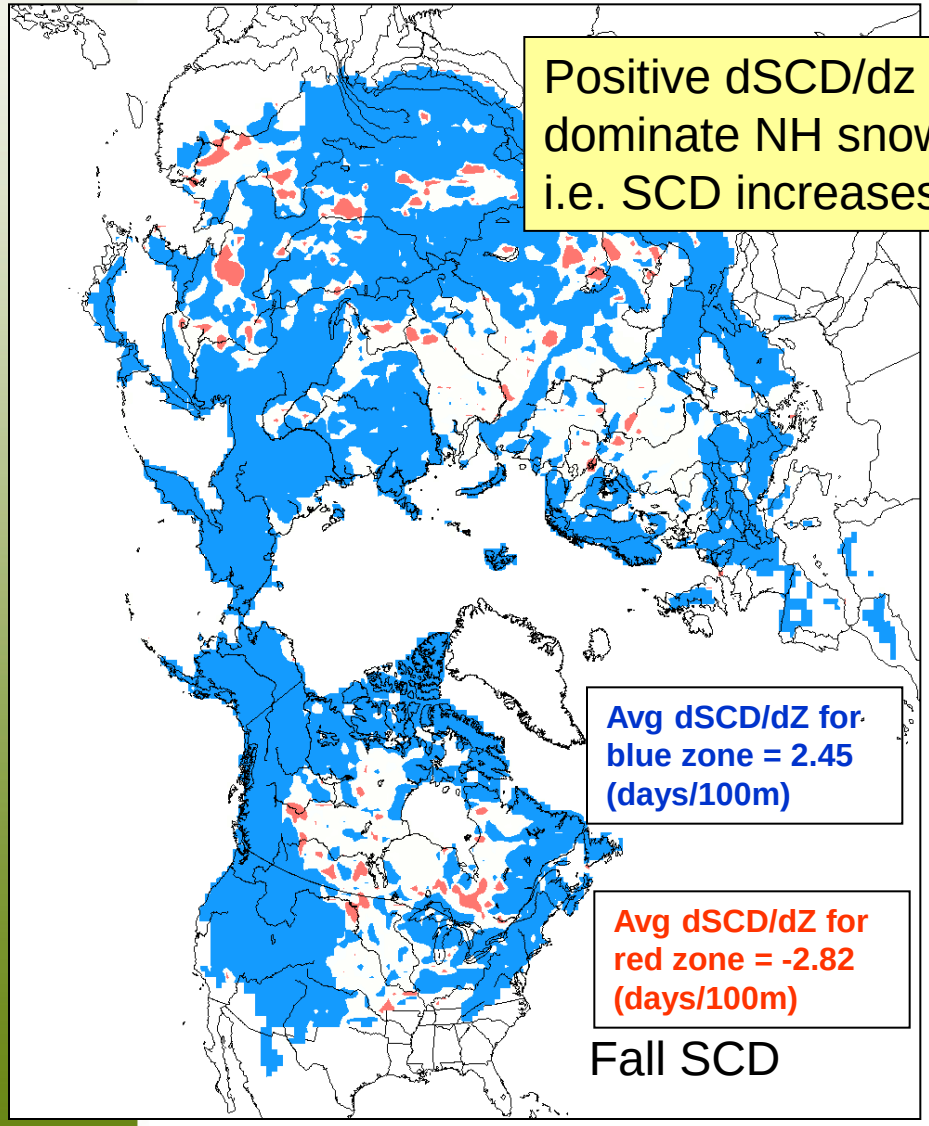
Conclusions:

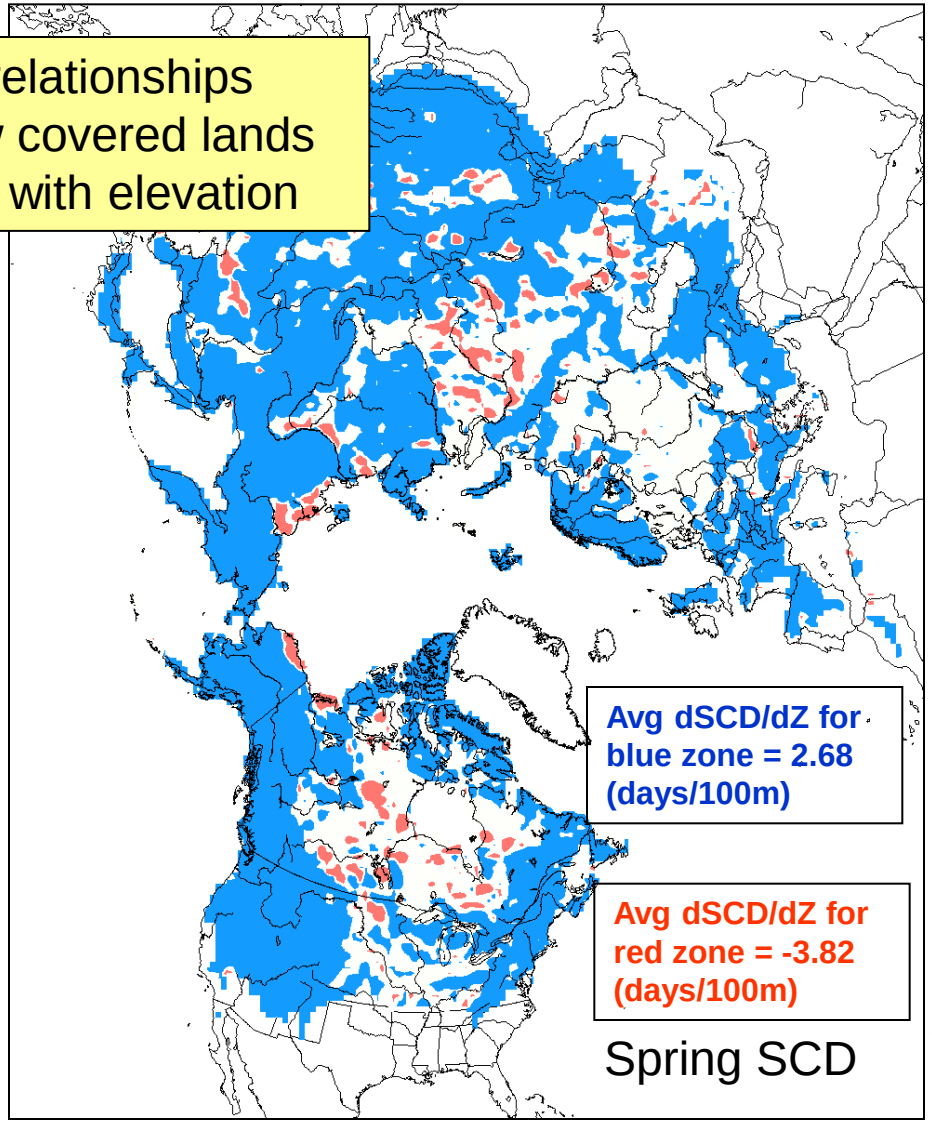
- Between-dataset agreement much better for SCD than SWEmax
- Closer agreement between datasets in the snow-onset period than snow-melt period
- Largest between-dataset variability over temperate maritime mountain regions
- Different dataset resolutions contribute to uncertainty in mountainous regions

Can apply empirically-derived topographic adjustments at the scale of the highest resolution dataset when intercomparing dataset climatologies (example next 2 slides)

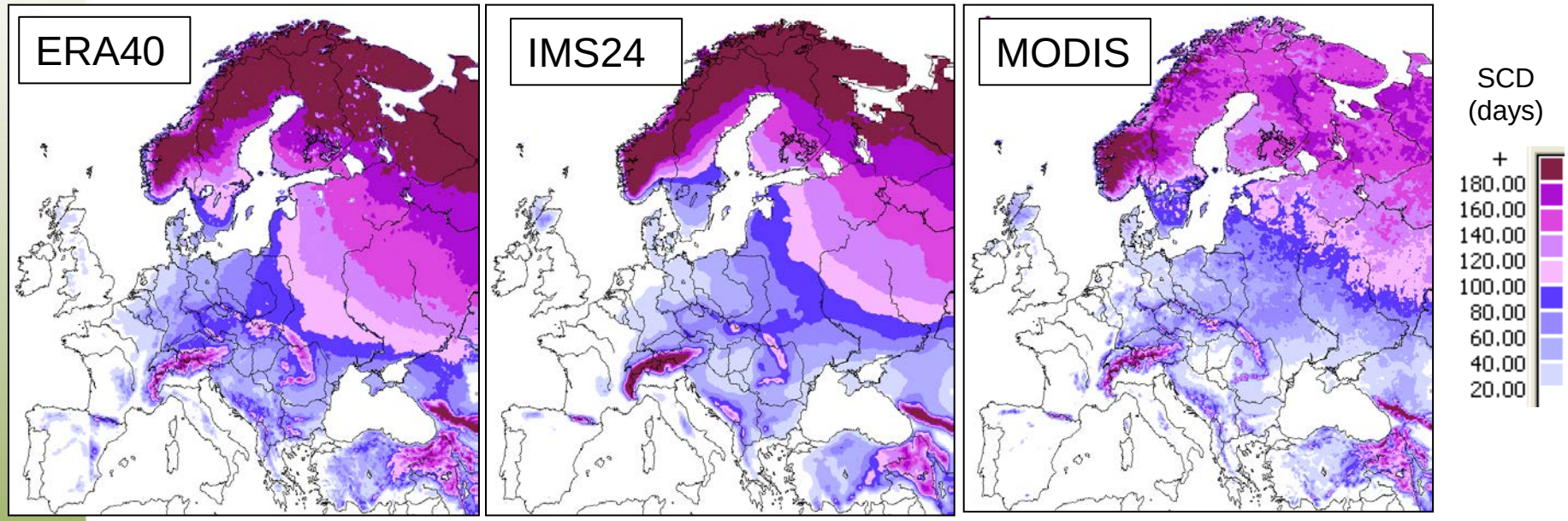
Blue = areas with local statistically signif +ve reln between SCD and elevation

Red = areas with local statistically signif -ve reln between SCD and elevation





Results of empirically adjusting SCD reconstructed from ERA40 (2.5 degree grid) to a 10 km grid with topographic adjustment

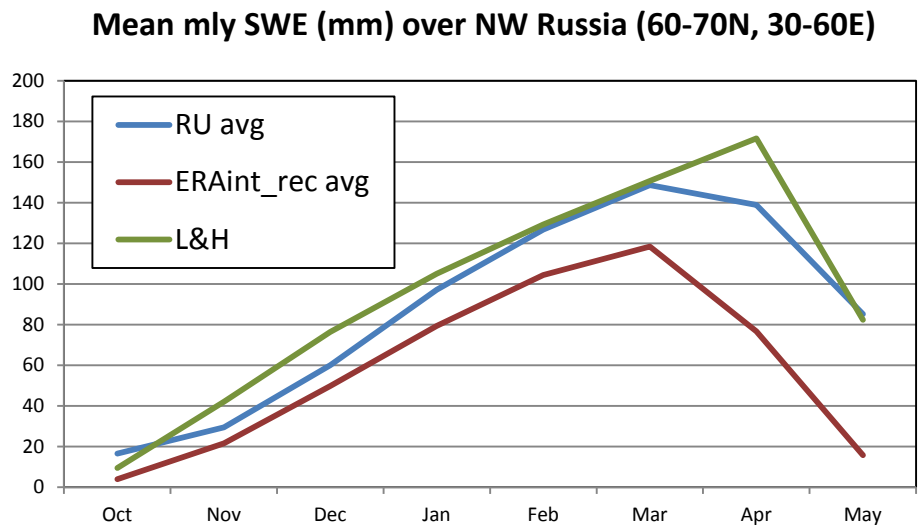


Results are comparable to higher resolution MODIS and IMS-24 datasets

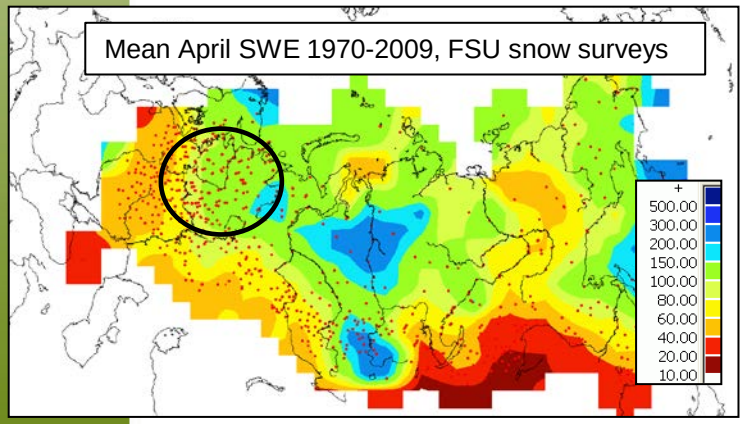
The use of multiple evaluation datasets offer some important advantages in the evaluation process

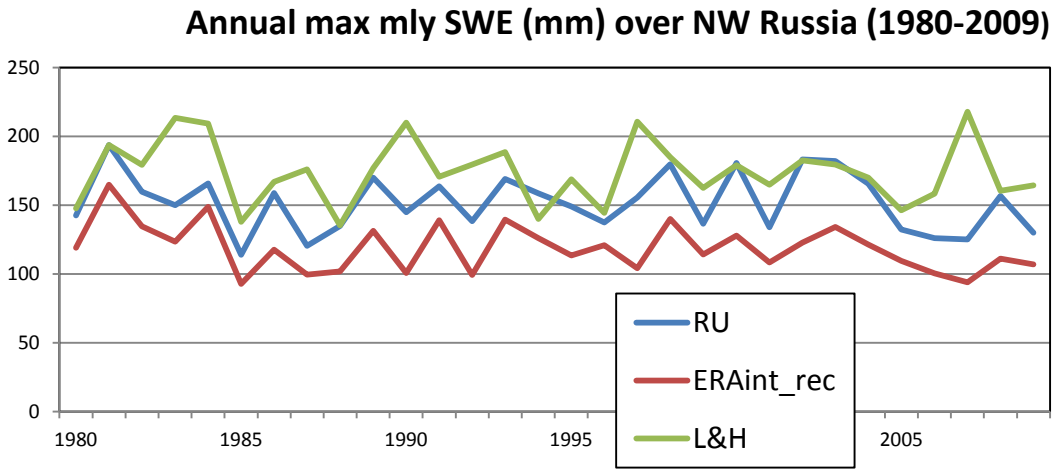
- Allows estimates of annually varying uncertainty in quantities such as hemispheric SCE and SWE
- Allows detection of “outlier datasets” in time and space
- Multi-dataset average SCE found to correlate more highly with related environmental variables such as air temperature
- Climate model evaluations of SCD and SWEmax found to agree more closely with the multi-dataset average than any single dataset (***observation ensemble provides a better estimate of the “true” value***)
- Need to be careful to ground-truth gridded datasets as high between-dataset agreement does not necessarily mean the result converges on reality (e.g. reanalysis and reanalysis-driven datasets share common issues such as over-estimation of precip over high latitudes)

Example of the importance of ground truthing…



Evaluation of Liston and Hiemstra (2011) snow cover reconstruction over NW Russia with surface snow surveys (RU) showed it gave an unbiased estimate of the mean seasonal SWE cycle but failed to capture the interannual variability (r=0.30 compared to r=0.83 for ERA-interim driven reconstruction)





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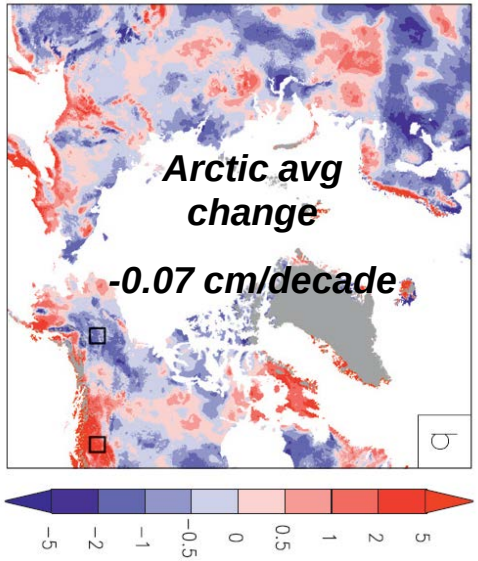
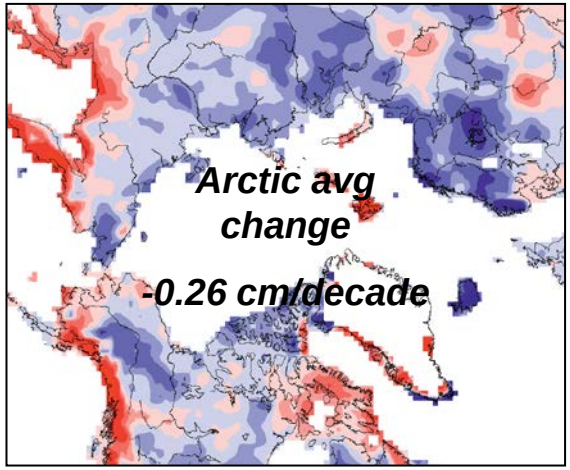
Spatial patterns of trends important in verifying evaluation datasets

Estimated trend in Arctic maximum annual SWE (cm/decade) over 1979-2009 period from four different sources

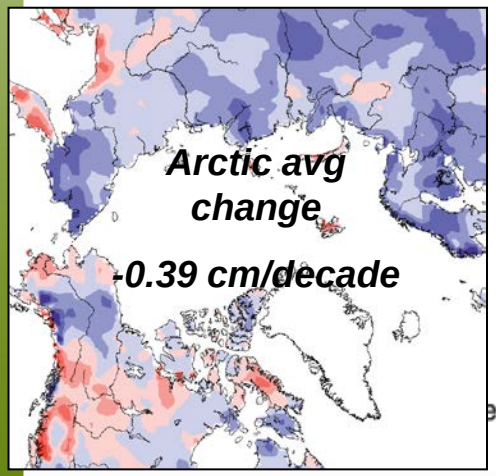
Liston and Hiemstra



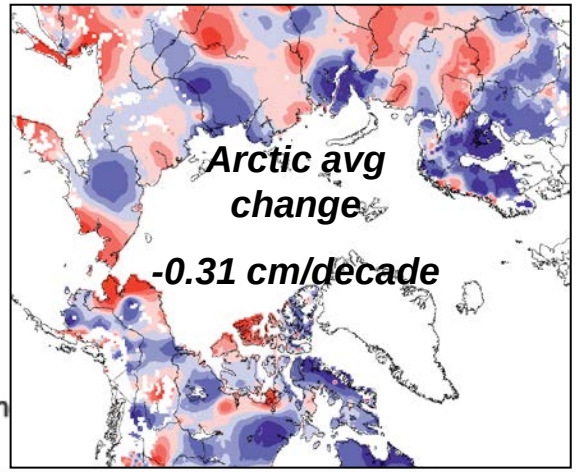
MERRA



ERA-interim reconstruction*



GlobSnow



- Large differences evident in the spatial pattern of trends even though the Arctic average change is similar for three of the datasets
- Comparison of Liston and Hiemstra with MERRA shows the impact of the 10-km downscaling (trend changes sign in some regions e.g. Norwegian coastal mountains)

The quality and homogeneity of precipitation are issues for reanalysis-driven SWE reconstructions

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Some conclusions for SnowPEx

- ***Strong justification for a mountain focus in SnowPEx***:
  - highest temperature sensitivity
  - earliest CC signal
  - largest uncertainties in existing products and datasets
  - huge socioeconomic impacts especially in semi-arid regions (water supply)
  - important regional clusters of in situ data exist in “high risk” snowpack regions

- Not all datasets/products are measuring the same thing – ***standardization of information for inter-comparison is a non-trivial process*** e.g. SCD_{frac} vs SCA_{frac}, interpolation to common grids

- ***Multi-dataset average more reliable than any single product*** (but ground-truthing needed over multiple years for reality check)

- The between dataset uncertainty in current gridded evaluation datasets is much higher for SWEmax than SCD


Thank you for your attention!
Saint-Irénée, Québec