Snow cover mapping by assimilation of satellite observations and in situ snow depth measurements

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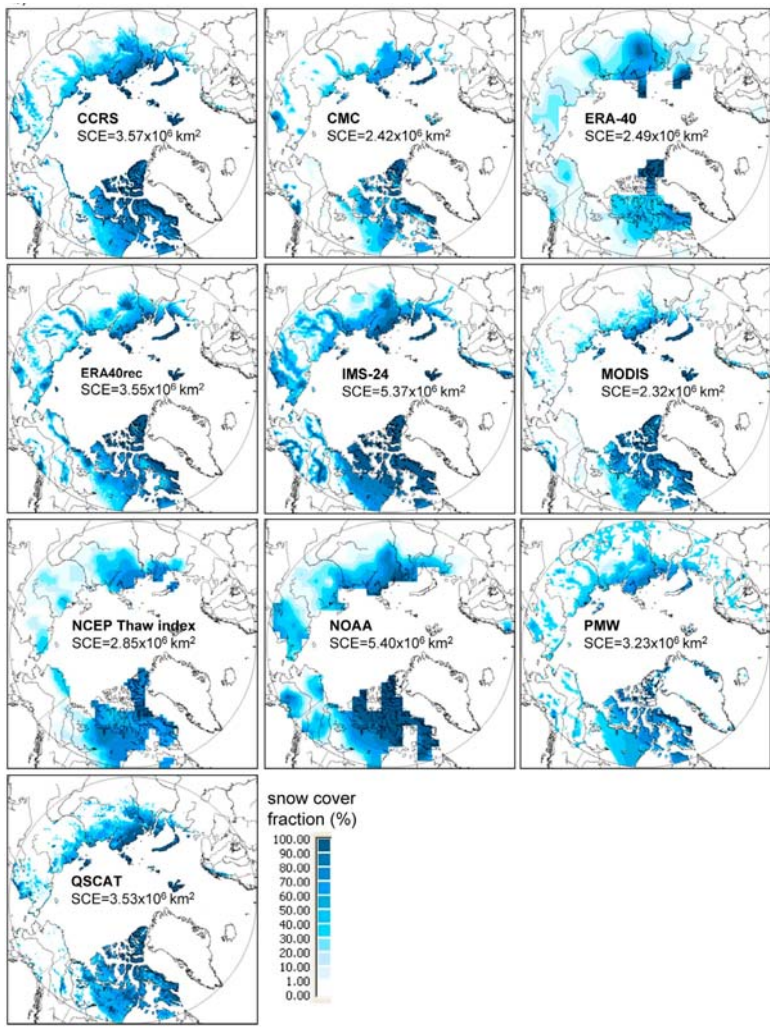
Outline

Global Climate Observing System requirement: Systematic daily 1km snow cover with 90% agreement to in situ estimates.

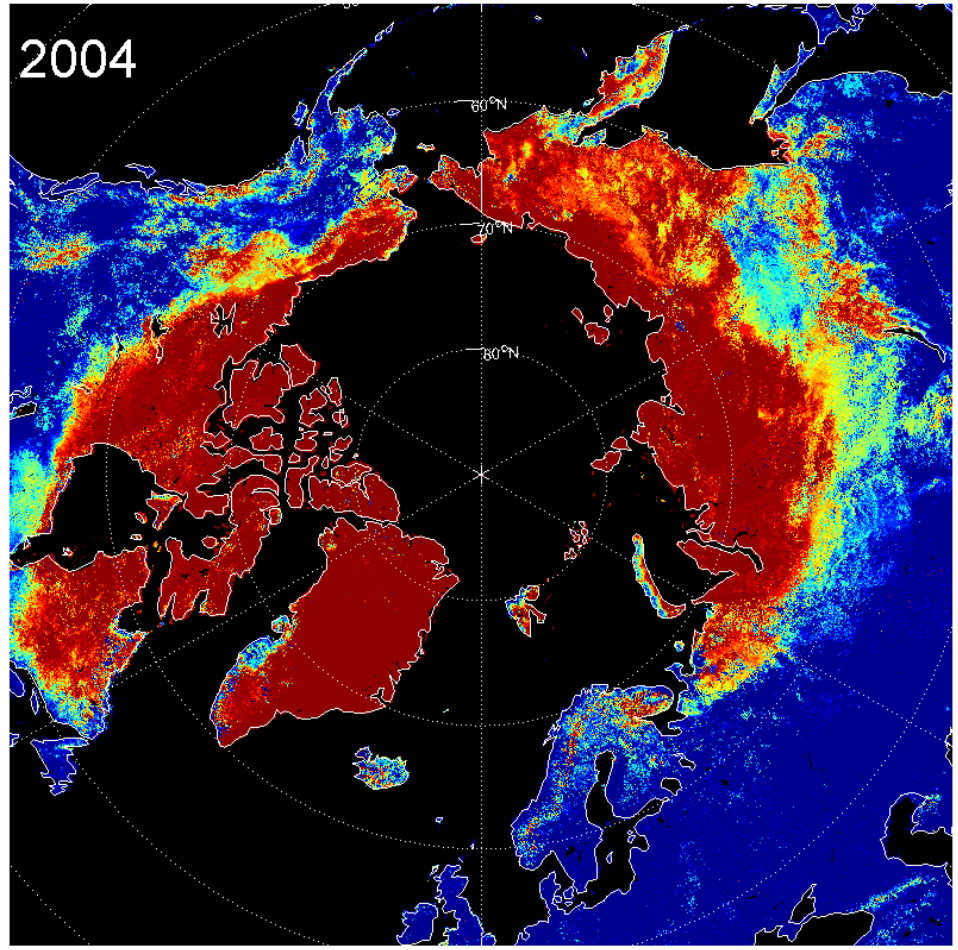
- Issues with current solutions.
- Data assimilation model and approach.
- Satellite and in-situ Earth Observation inputs.
- Sample results.
- Verification over Canada.
- Next steps.

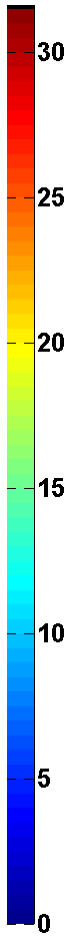
Issues with Arctic snow maps

- NOAA IMS
  - Lake bias.
  - 20 day lag in melt.
- CCRS AVHRR
  - Ephemeral snow.
- NOAA Automated
  - Variable resolution.
- CMC Snow Depth
  - Resolution.
  - Sampling bias.
- MODIS Snow Cover
  - Clouds
- SNOWDAS
  - Limited coverage (only USA)
  - Not systematic



CCRS AVHRR Snow Cover



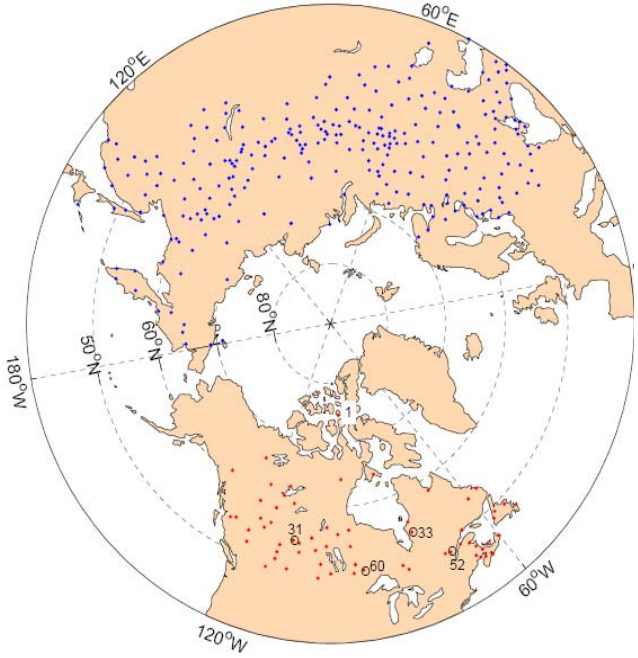


Days Snow Cover during May

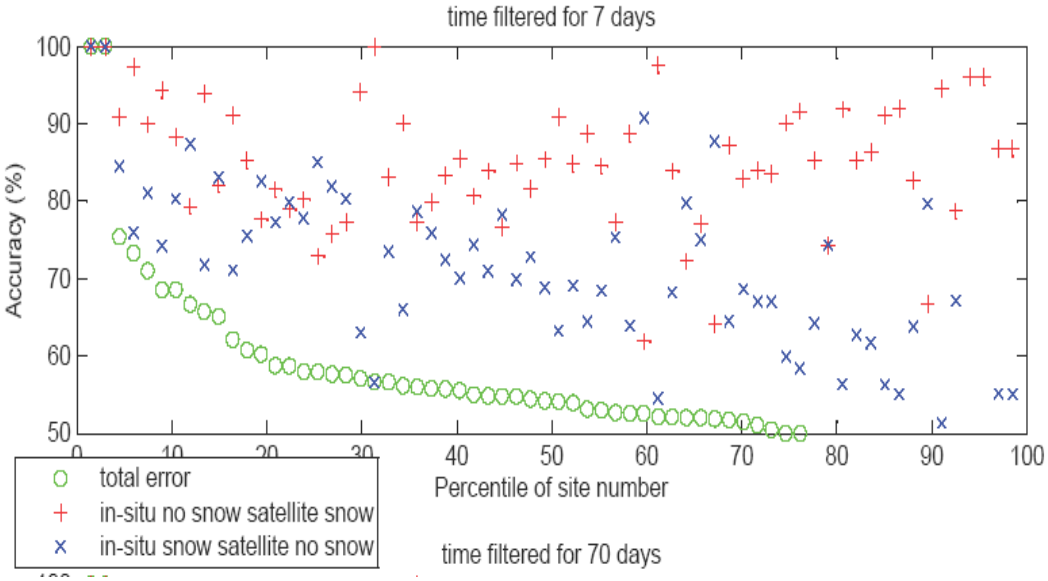
Zhao and Fernandes, 2009, JGR; IPY Polar Data Catalogue

Clouds Limit the use of Satellite Snow Cover Products for Trend Analysis

Global Validation Sites



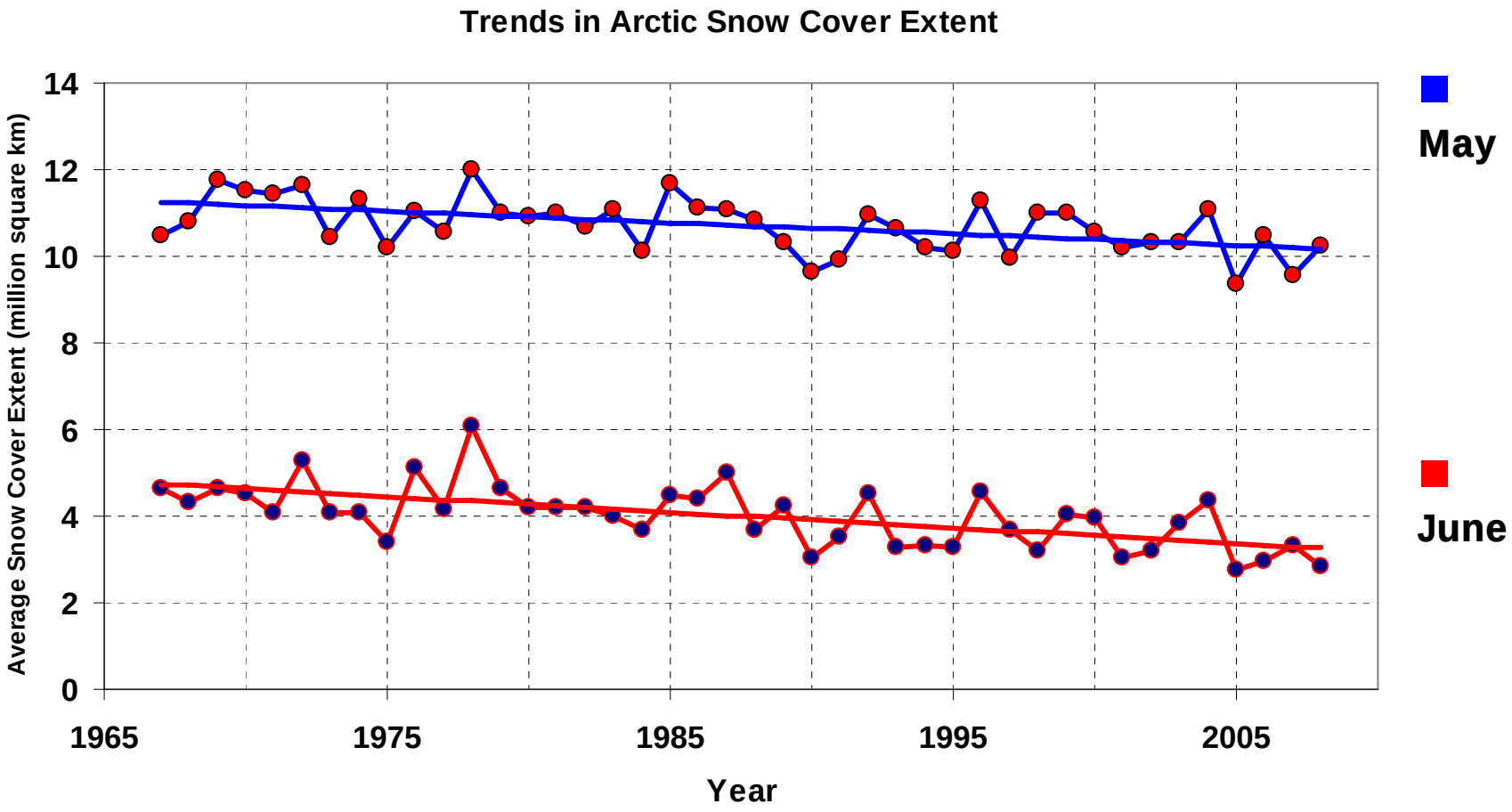
MODIS Accuracy



Satellite products have error in melt date ranging from
3 days (CCRS) to 10days (MODIS) to over 15 days (NOAA) in Arctic.

Zhao and Fernandes, 2009, JGR

Ensemble Average Snow Cover Trends 1966-2008



CCRS EO data, along with EC in situ data from 1962, Brown et la., (2010) JGR-Atmospheres.

Research Question

Is there a more objective method to combine different sources of snow cover information to:

- meet Global Climate Observing System needs,
- provide uncertainty estimates,
- cope with varying availability of data,
- work at least as well as the best current methods?

Approach: Data Assimilation

Goal: Continuous daily snow cover estimation with 90% agreement to *in-situ* data 95% of time. Consistent snow depth and SWE estimation.

Obstacles: Temporal sampling, atmospheric and BRDF variability, vegetation and litter masking of snow.

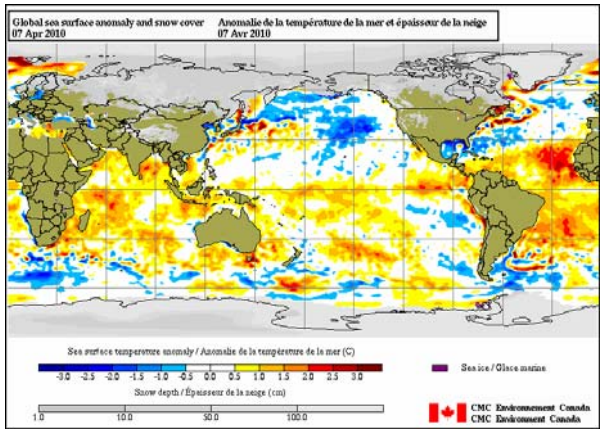
Approach: satellite data assimilation using coupled snow depth, logistic phenology and simple BRDF models.

Input: CMC Snow Depth Analysis

Sensor

Sampling site

Sampling networks

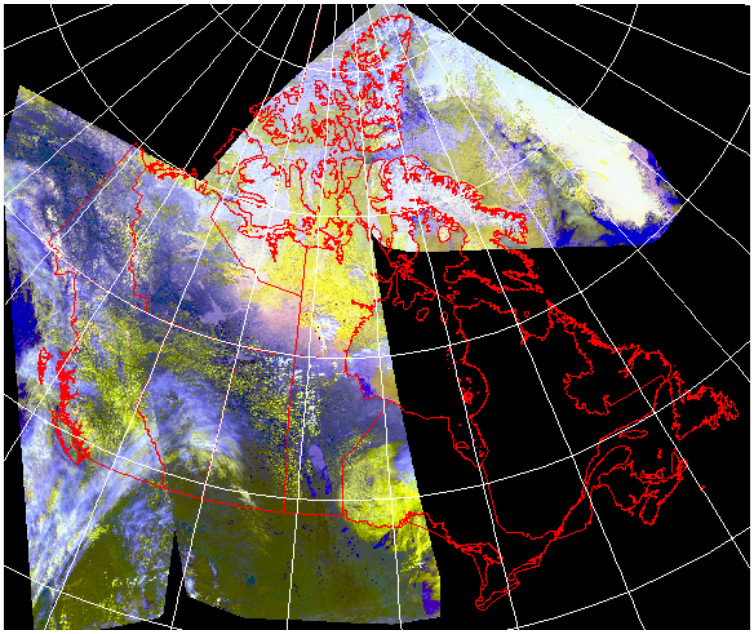


Daily snow depth 1/3 degree

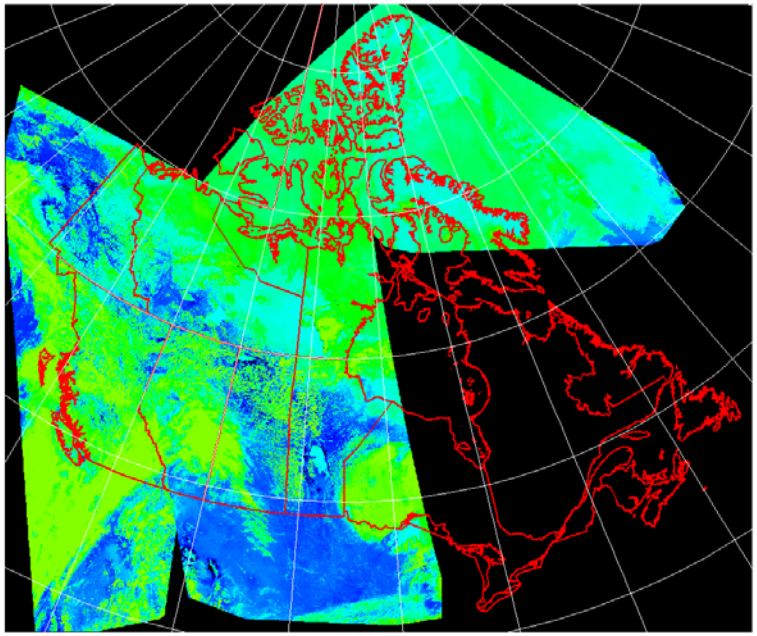
Input: CCRS AVHRR Daily Data

All1km AVHRR observations acquired over Canada since 1982
systematically calibrated and georeferenced
clouds/cloud shadow mask produced using NARR Tsurf.

Directional TOA Reflectance



Cloud/Cloud Shadow Probability



Data Assimilation Model

- CMC Snow Depth Analysis Model
  - Daily time step degree day snowpack simulation
  - Daily input precip and air temperature
  - Accounts for density and depth vs. area change
- CCRS 1-D Surface Albedo Model
  - Used in Zhao and Fernandes, 2009.
  - Snow albedo model of Khokanovsky (2000)
  - Addition of litter and forest masking effects
  - Logistic vegetation phenology model
- Roujean BRDF Model

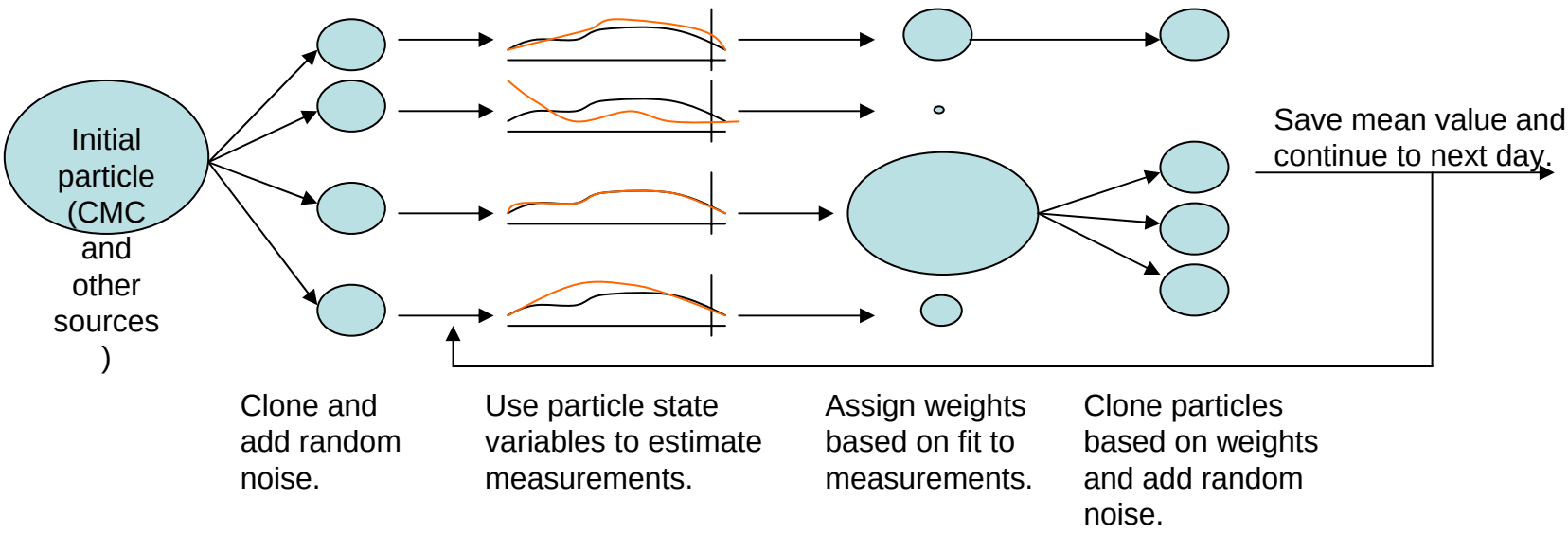
Details of Assimilation Model

- 48 parameters: including element reflectances, BRDF coefficients, snow aging, density and melt coefficients, snow area depletion curve coefficients,
- 15 state variables: including LAI, snow density, snow cover, visible and NIR albedo for pure snow, dirty snow, ground; VIS and NIR TOA reflectance
- 4 forcings: solar & view position, air temp., precip
- 4 observables: visible TOA reflectance, TOA NDVI, CMC snow depth, CMC snow density

State Variables

Name	Units	Minimum Value	Maximum Value	Additive Noise	Multiplicative Noise
Leaf Area Index	m2/m2	0.25	15	0.01	0
Plant Litter	m2/m2	0	15	0	0.1
Snow Water Equivalence	mm	0	1000	0	0.1
Snowpack Density	Kg/m2	100	500	0	0.2
Growing Degree Days	°Day	0	100000	0	0
Freezing Degree Days	°Day	0	100000	0	0
Snow Albedo	DIM	0.5	1	0	0.1
Snow Near-Infrared Albedo	DIM	0	1	0	0.1
Cumulative GDD	°Day	0	1	0	0
Cumulative FDD	°Day	0	1	0	0
Snow Cover Fraction	DIM	0	1	0	0.1
Snowpack Albedo	DIM	0	1	0	0.1
Snowpack Near-Infrared Albedo	DIM	0	1	0	0.1
Surface Albedo	DIM	0	1	0	0.1
Surface Near-Infrared Albedo	DIM	0	1	0	0.1

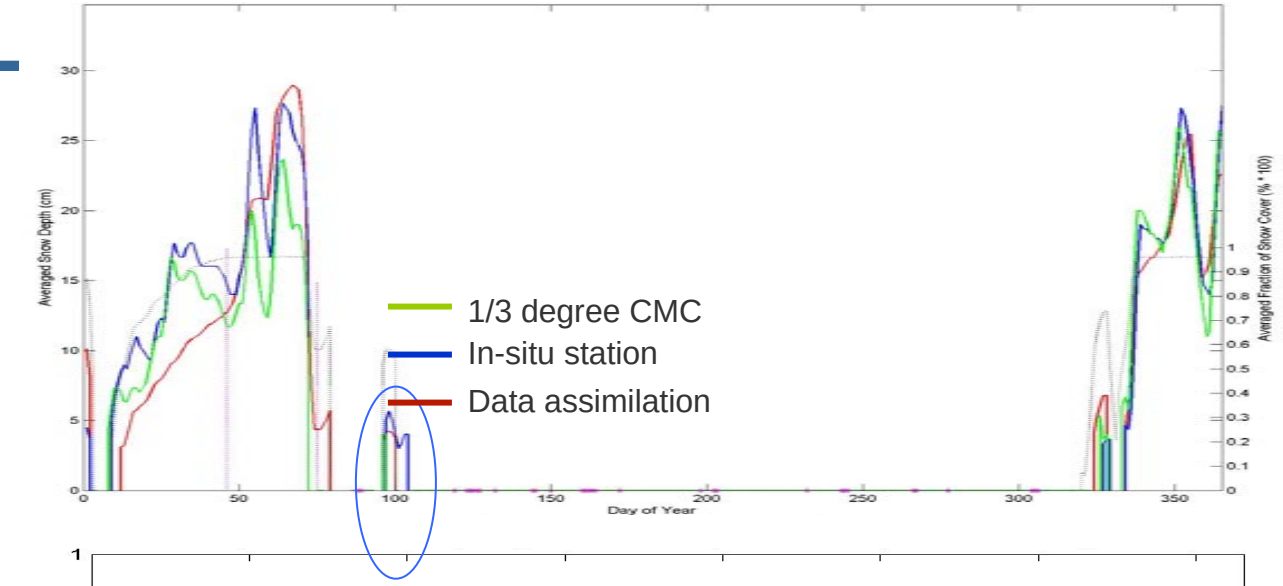
Assimilation Method

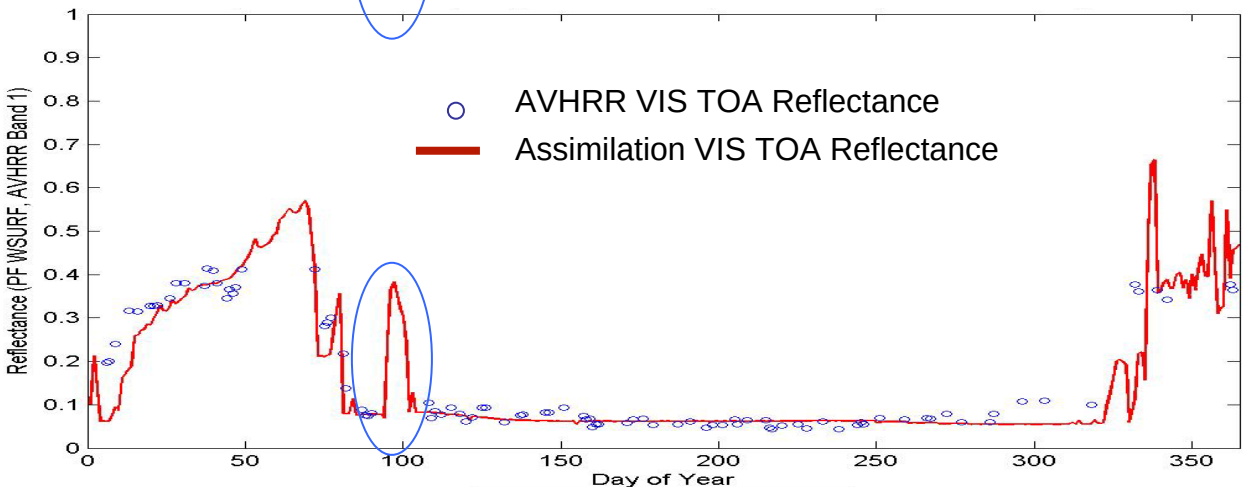


Sequential Particle Smoother with 30day smoothing window (DeFrietas et al. 2008)

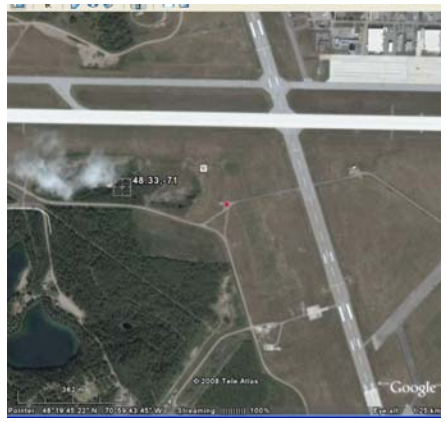
Example: Sudbury Climate Station

Snow Cover

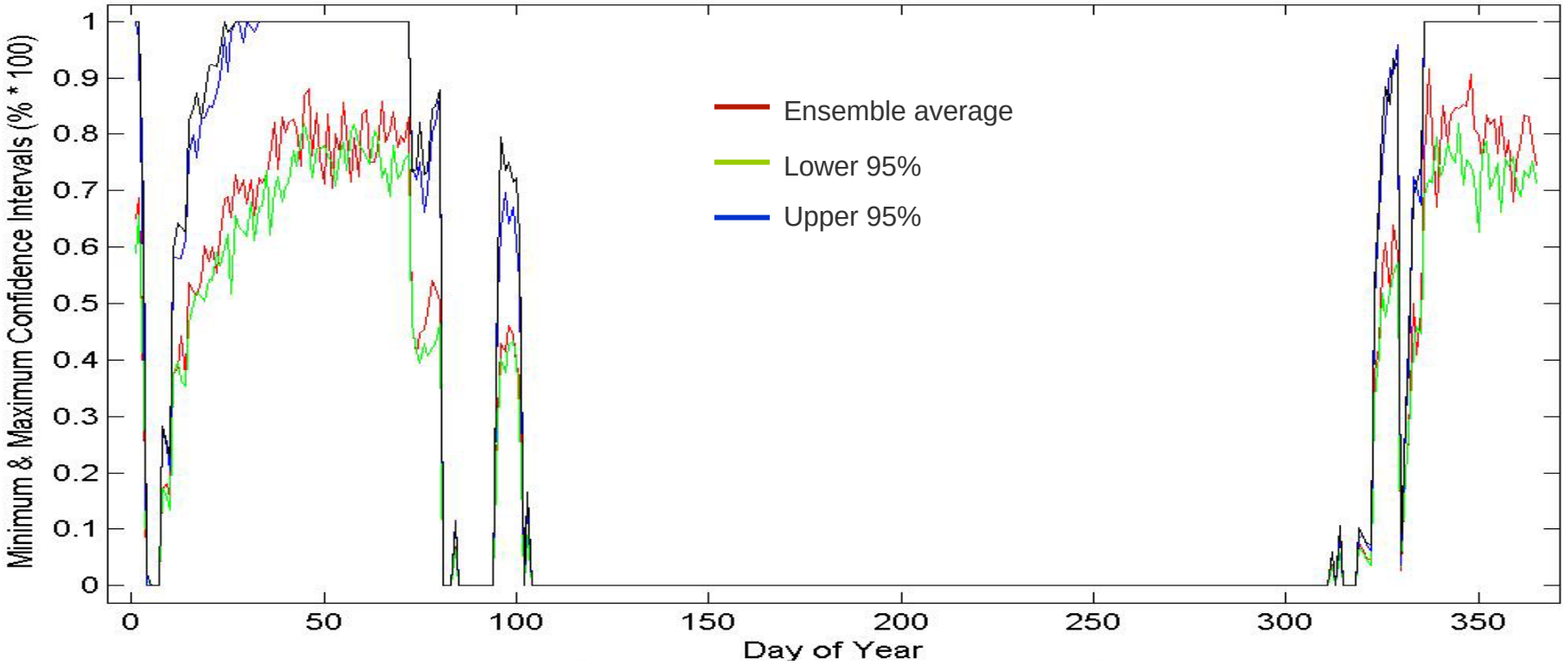




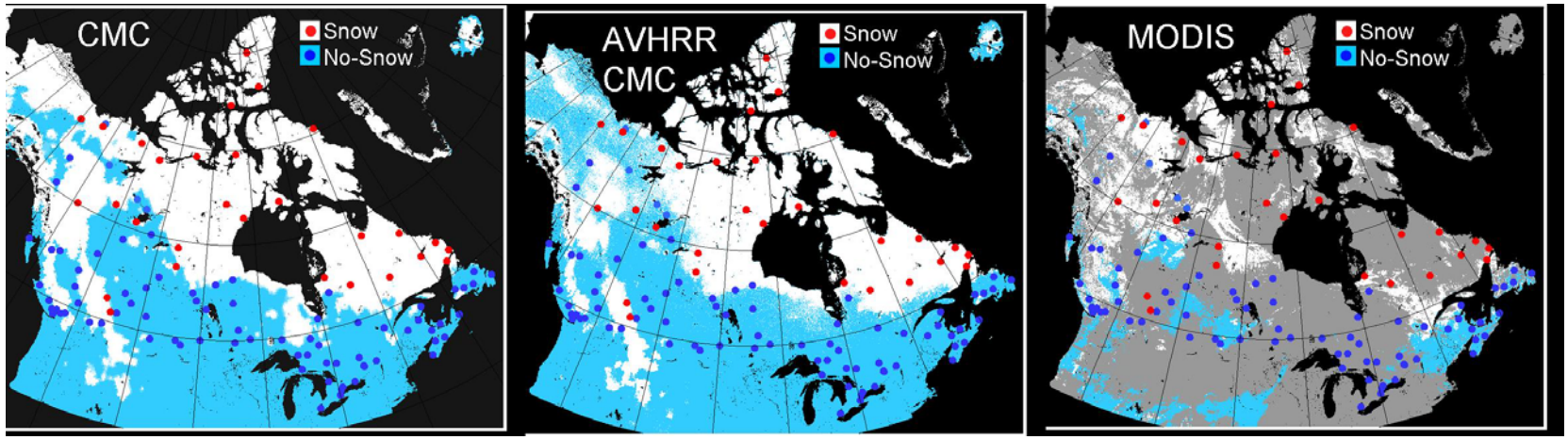
Red = Ensemble mean CMC+AVHRR



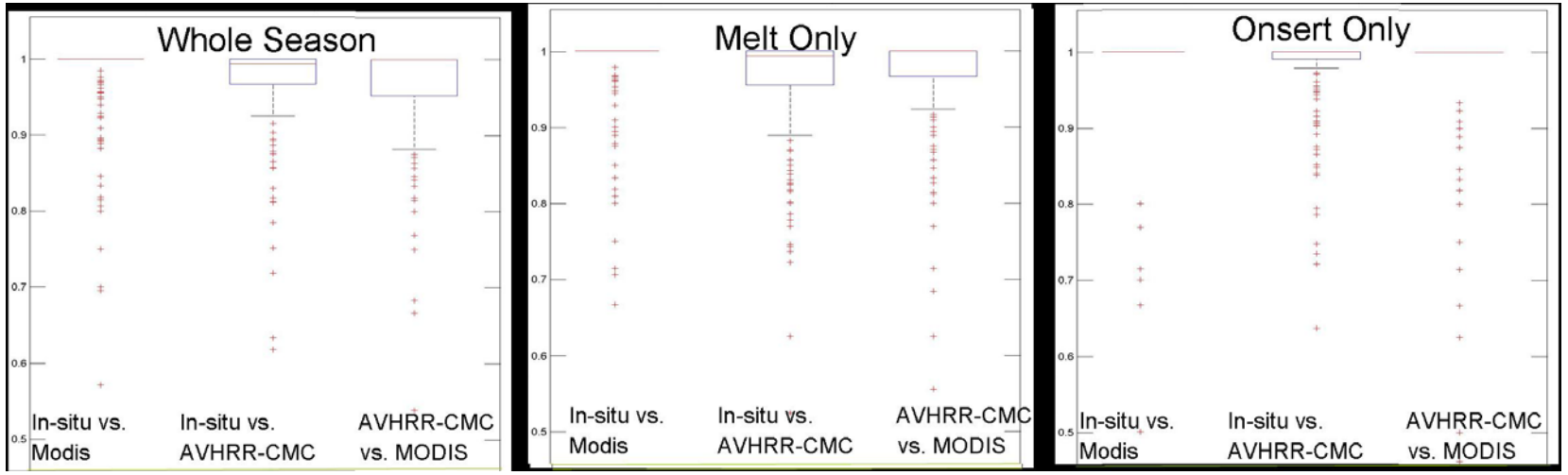
Output : Sudbury Climate Station



Assessment (2006-2009)



Agreement Rate



Conclusions

- Demonstrated combined assimilation of in-situ and AVHRR visible reflectance.
- Method stable over range of land cover.
- Physically consistent gap filling of satellite estimates.
- Landsat based validation now being performed.
- Completion of 1998-2010 period for North Western Hemisphere.
- Potential for global MODIS based products.