National Snow and Ice Data Center
Supporting Cryospheric Research Since 1976

Land Data Assimilation for Seasonal Prediction and Beyond: The Arctic Case

Andrew G. Slater

Uncertainty in Numerical Forecasting

(1) Model Structure

- Parameterizations
- Piecing together components
- Numerical methods

(2) Model Forcing

- Spatial & Temporal structure

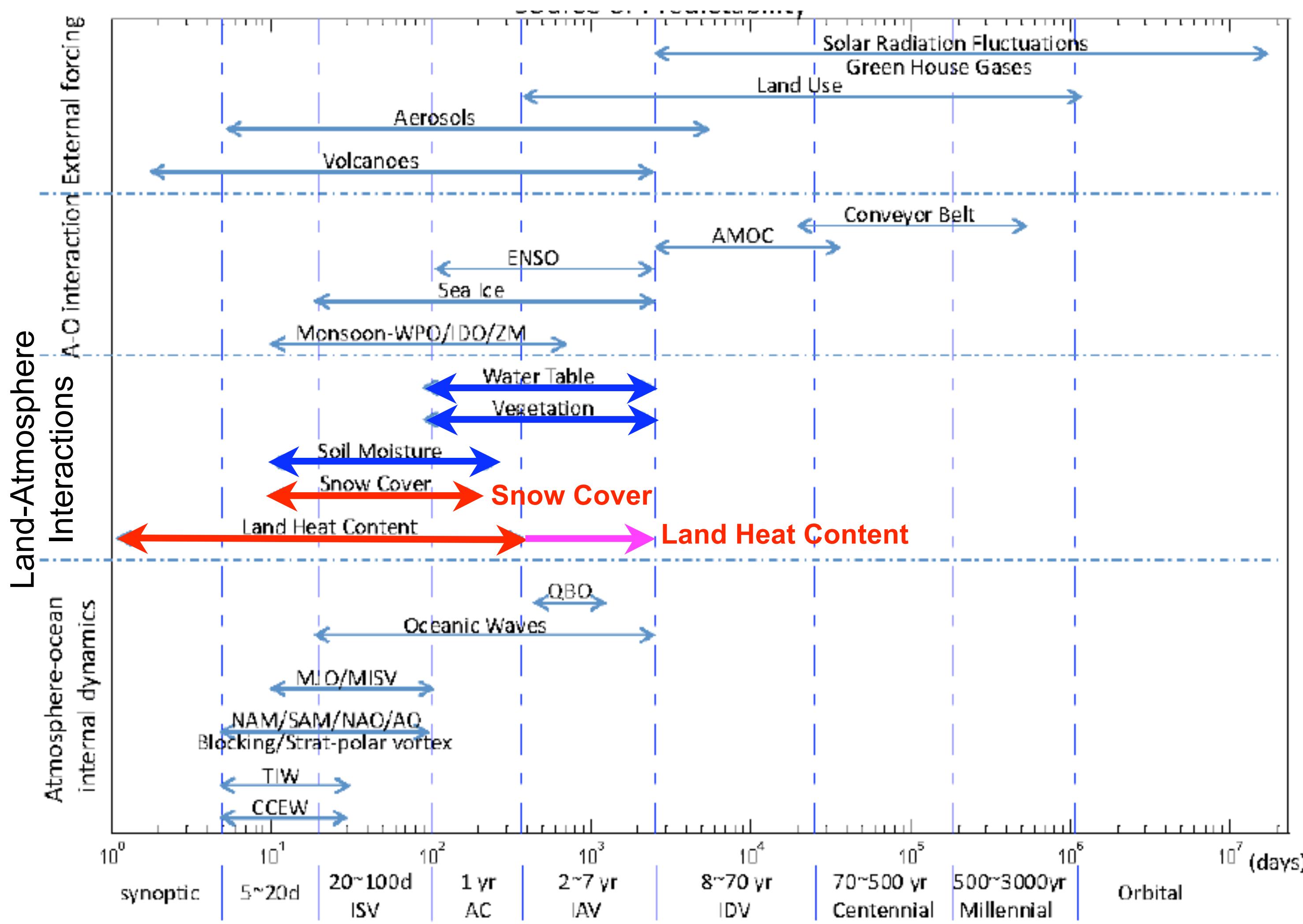
(3) Parameter Data

- Soils & Vegetation, type and distribution

(4) Initial Conditions

- Influences trajectory (forecasting = IVP)

Sources of Predictability



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NAS Report: Assessment of Intraseasonal to Interannual Climate Prediction

An Assimilation Scheme: The Kalman Filter

1. $\mathbf{X}_t^- = \mathbf{A}\mathbf{X}_{t-1} + \mathbf{B}f_t$

2. $\mathbf{K}_t = \mathbf{P}_t\mathbf{H}^T(\mathbf{H}\mathbf{P}_t\mathbf{H}^T + \mathbf{R})^{-1}$

3. $\mathbf{X}_t^+ = \mathbf{X}_t^- + \mathbf{K}_t(\mathbf{z}_t - \mathbf{H}\mathbf{X}_t^-)$

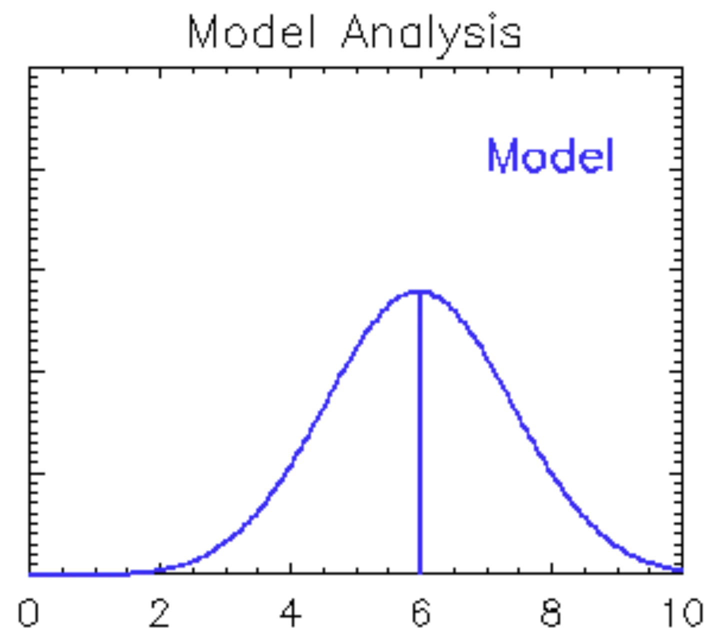
- **X** – model state vector
- **P** – model error
- **H** – measurement model
  - equating quantities
- **R** – observational error
  - representativeness error
  - measurement error
- **K** – Kalman gain
  - relate obs and states
- **z** - observations

Optimized Assimilation : Scalar Example

Our **Model** predicts : $X^{-} = 6$

Model error variance : $P = \sigma^2_x = 2$

Assume $H = 1$ (no impact)



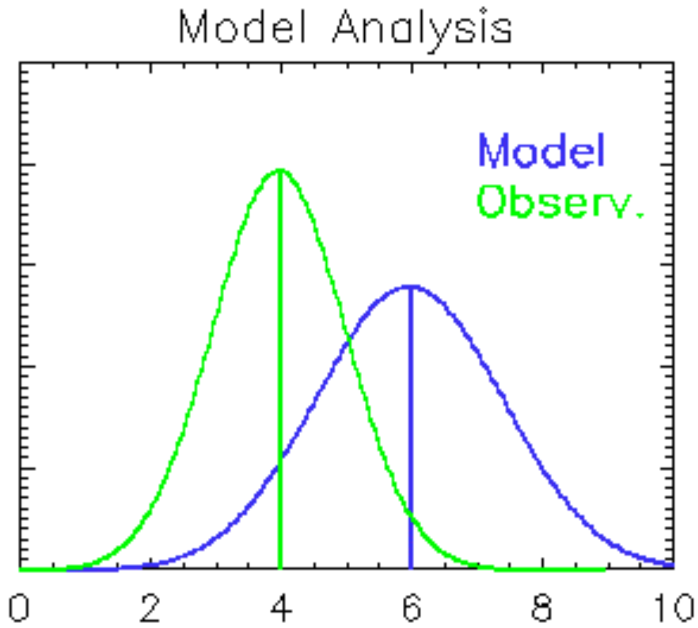
Optimized Assimilation : Scalar Example

Our **Observations** say : Z = 4

Obs. error variance : $R = \sigma^2_z = 1$

Gain = 2/(2 + 1) = 0.66

Analysis = 6 + 0.66(4 – 6)



Optimized Assimilation : Scalar Example

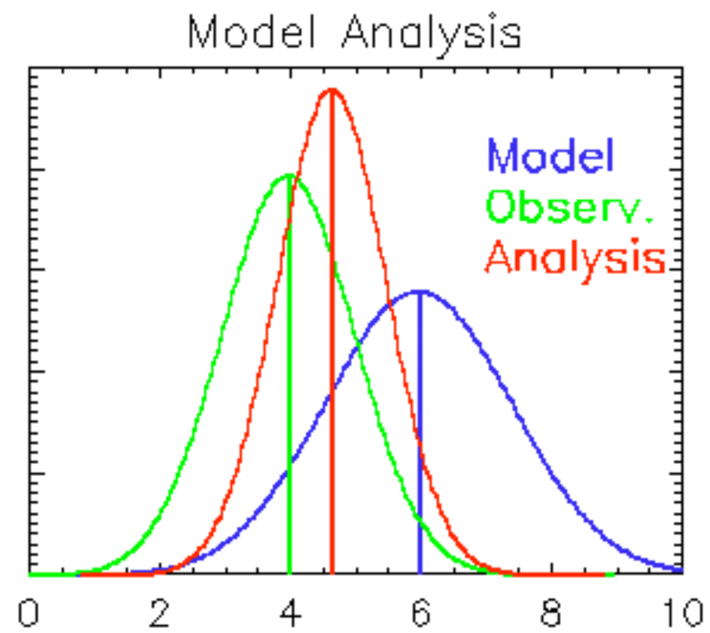
Combined **Model** and **Observations** say :

Our **Analysis** is $X^{+} = 4.66$

Analysis variance : $\sigma^2_a = 0.66$

$$\frac{1}{\sigma_a^2} = \frac{1}{\sigma_x^2} + \frac{1}{\sigma_z^2}$$

Analysis Variance



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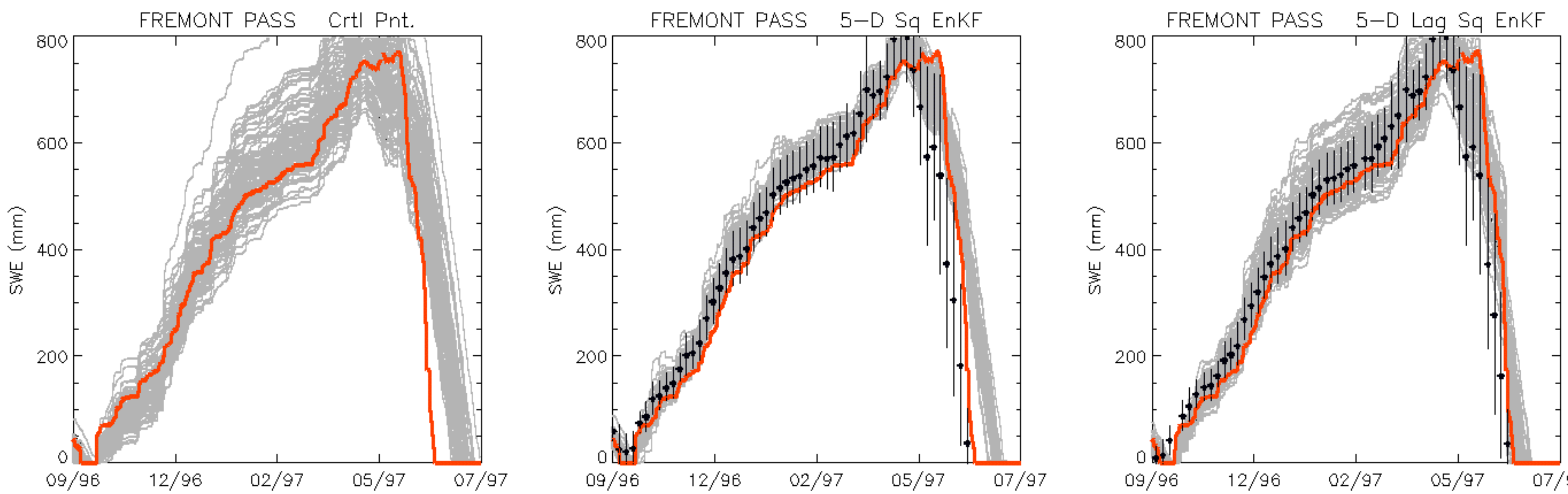
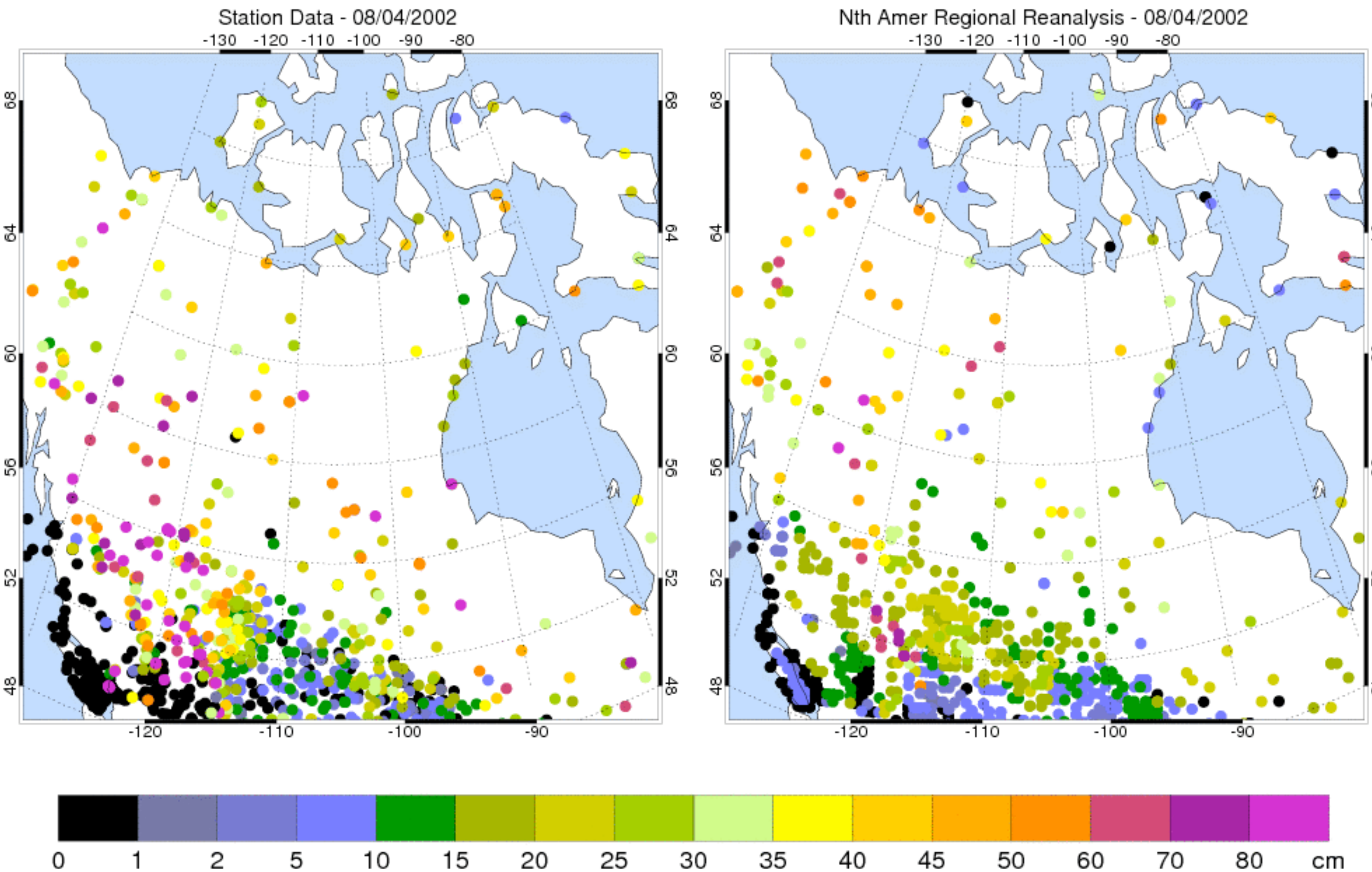
Station Based Snow Data Assimilation

- Good station density
- Unbiased model
- Appropriate error estimation
- Meet assumptions of assimilation scheme
- Successful analysis result



Slater & Clark, 2006, J. Hydromet.

Low Station Distribution in Arctic



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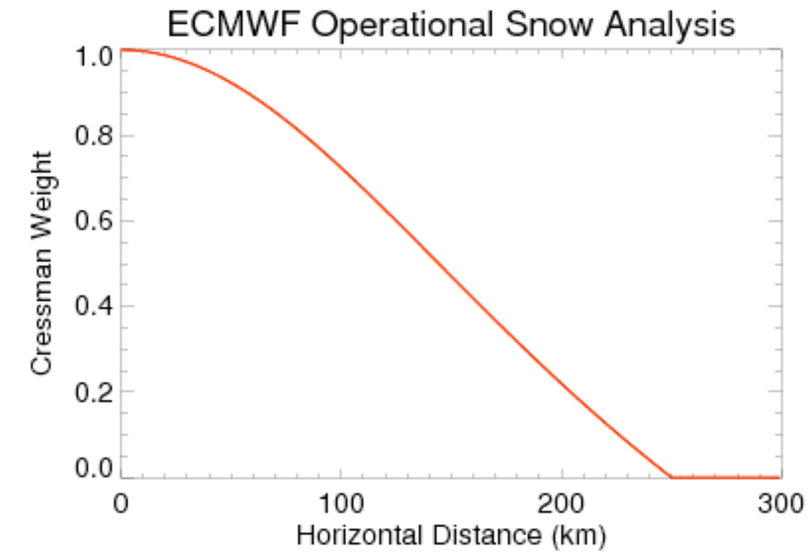
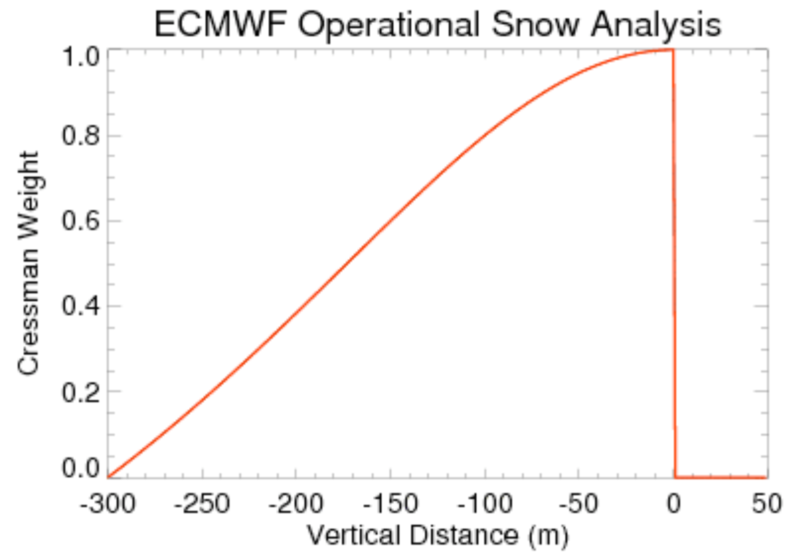
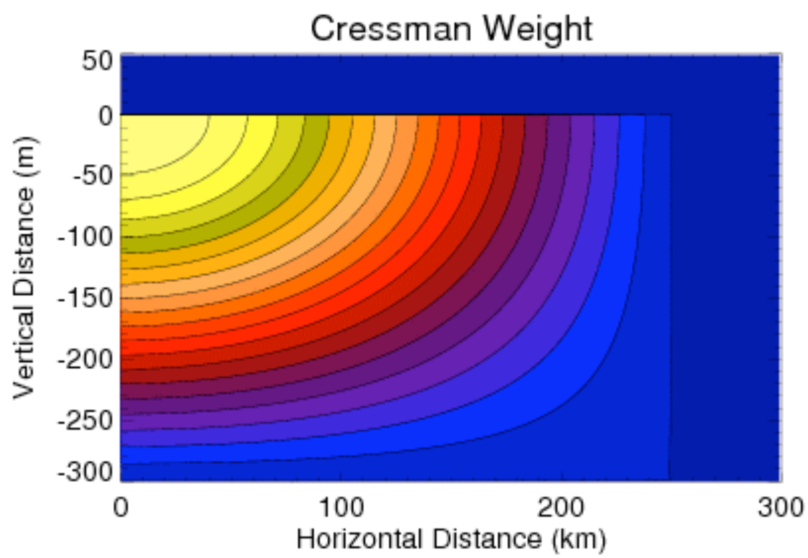
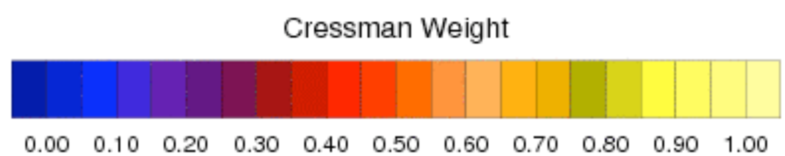
ECMWF Station-based Snow Analysis



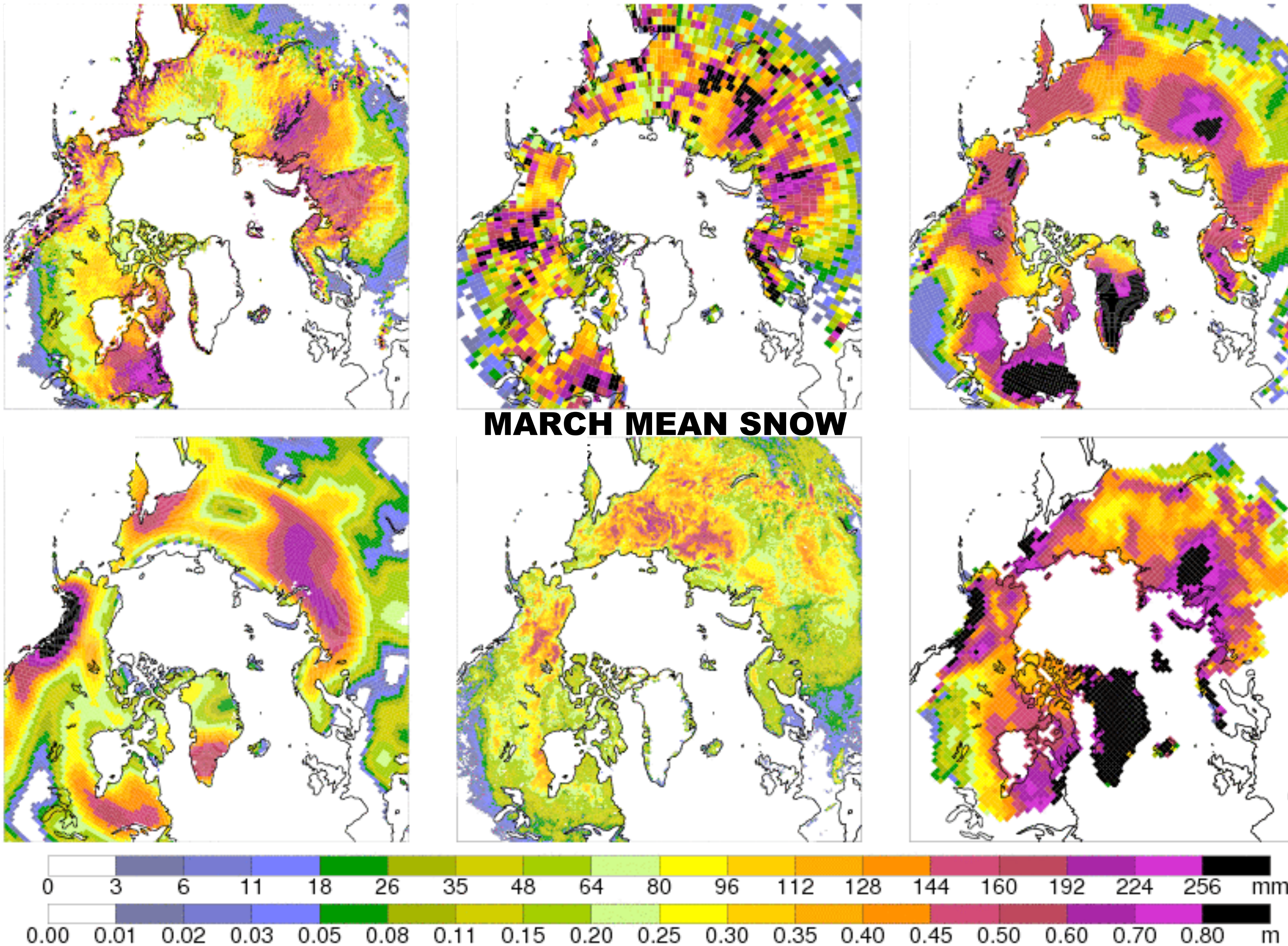




Need two data points for analysis

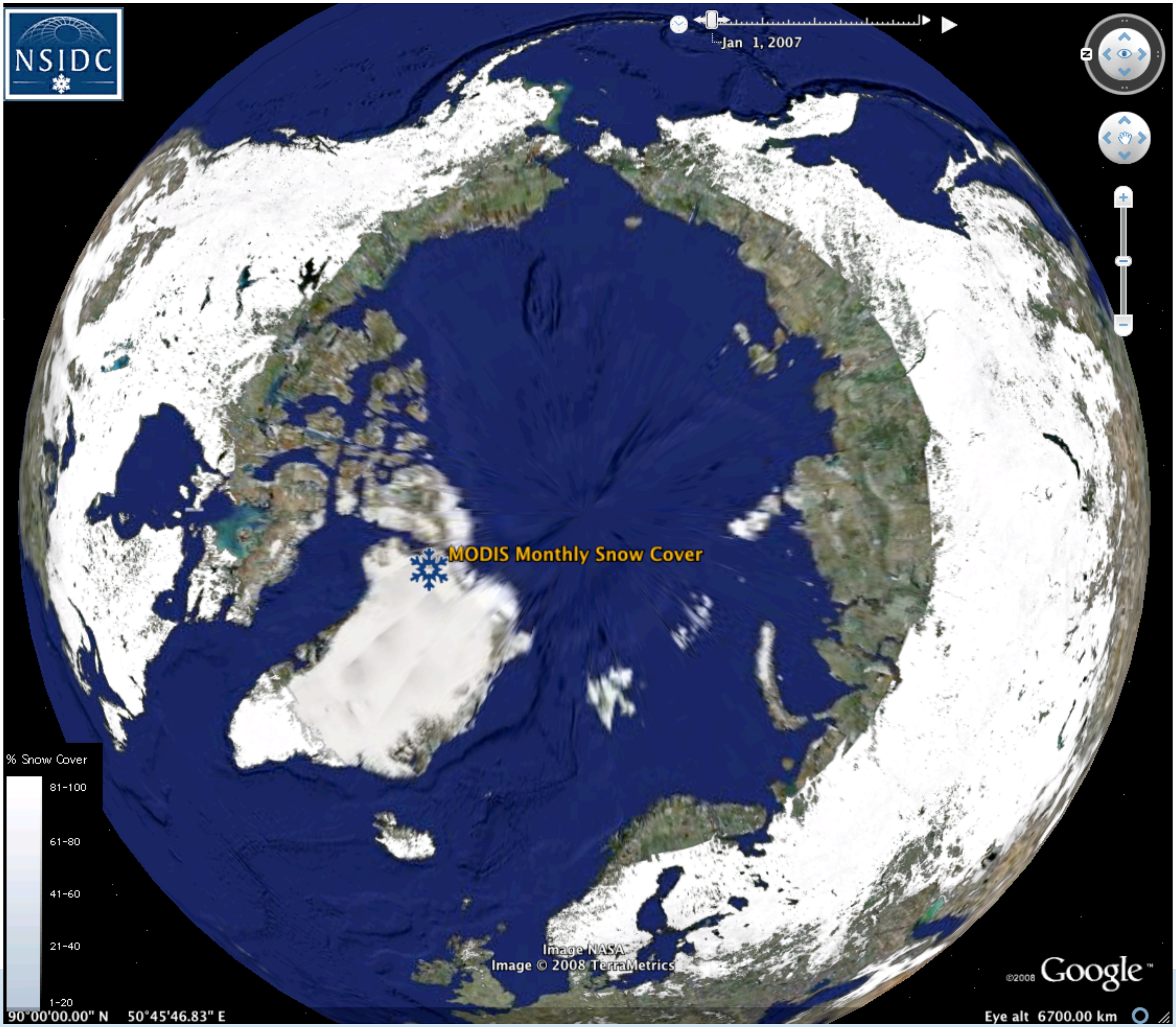


Drusch et al., 2004, *J. Appl. Meteorol.*



GRACE data courtesy Sean Swenson, NCAR

Snow Extent



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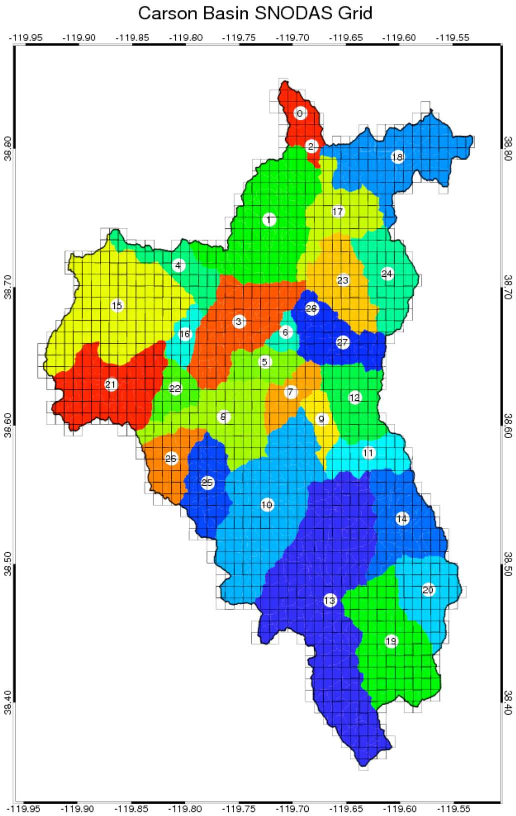
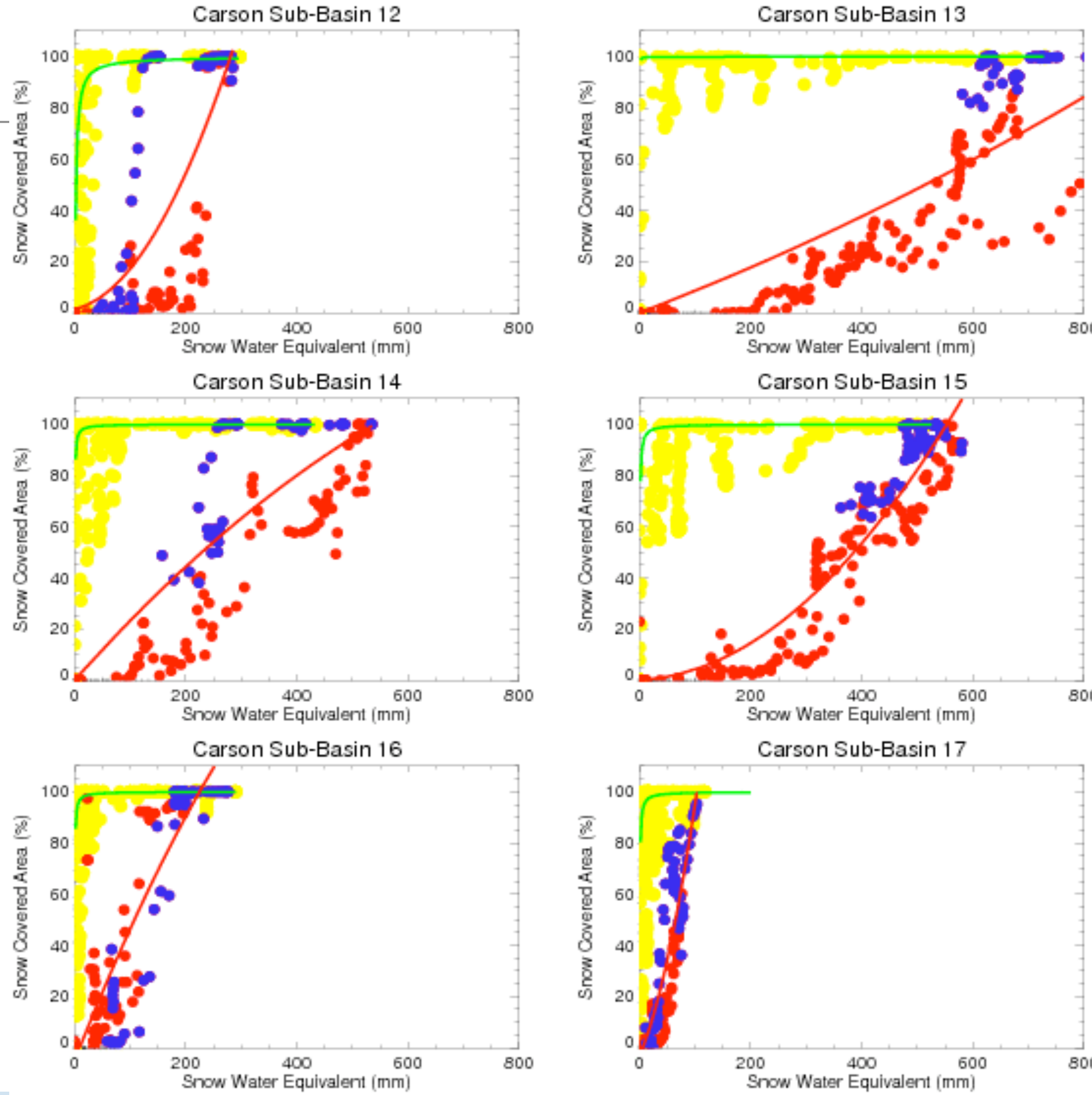
Jan 1, 2007
MODIS Monthly Snow Cover
% Snow Cover
81-100
61-80
41-60
21-40
1-20
Image NASA
Image © 2008 TerraMetrics
©2008 Google
90°00'00.00" N 50°45'46.83" E
Eye alt 6700.00 km

MODIS SCA

vs

SNODAS SWE





Slater, Clark, et al (in prep)

Pan-Arctic Snow Data Prospects

	Z (coverage)	H (Obs to Model)	R (error estimate)
Station Data (Depth & SWE)	**Spotty** **Daily**	**Point vs Area** **Depth to SWE**	**Point vs Grid Box**
Passive Microwave (SWE)	**Global** **Daily**	**Radiance Model**	**Crystal, Veg, Tmp**
Visible – Extent Visible – Volume	**Global** **Daily**	**1km Pixels** **SCA →SWE**	**Ideal** **Poor**
Gravity - GRACE (Mass anomaly)	**Global** **Monthly**	**Huge Area vs Grid box**	**SWE vs other water**

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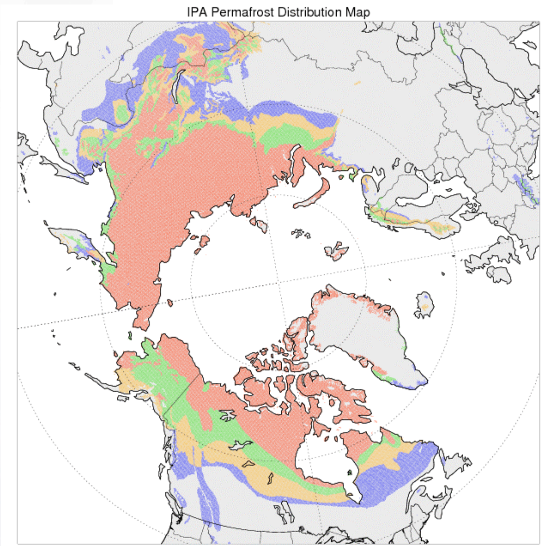
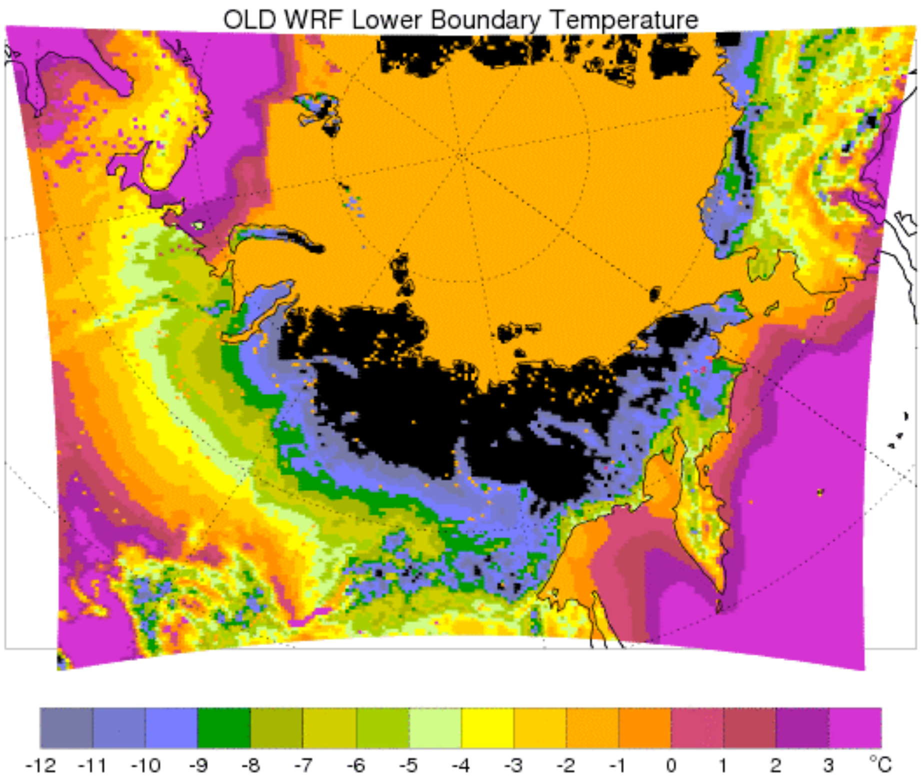
Ground Thermo-Hydro State

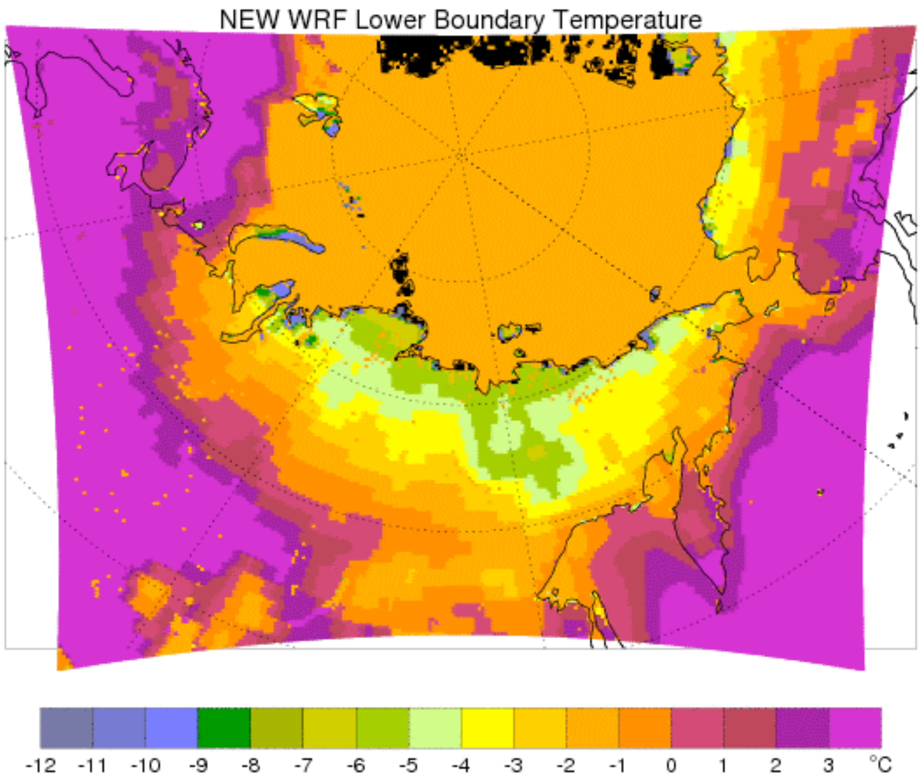
- Soil phase change, latent heat store
- Deep soil heat reservoir
- Altered hydrologic regime



Thermal State – Boundary Conditions

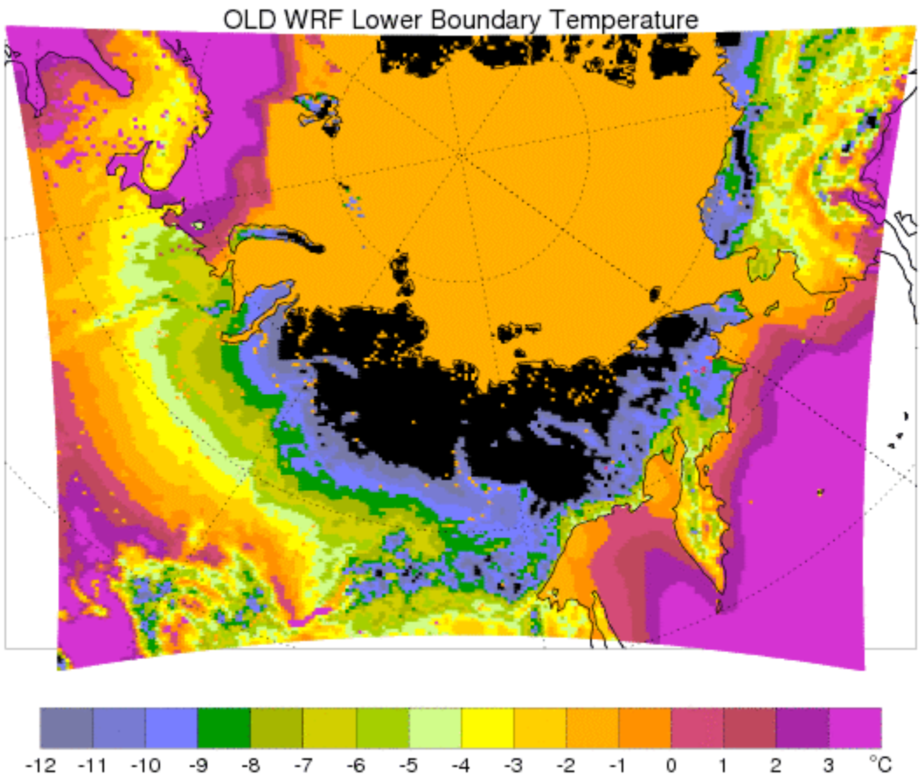


OLD

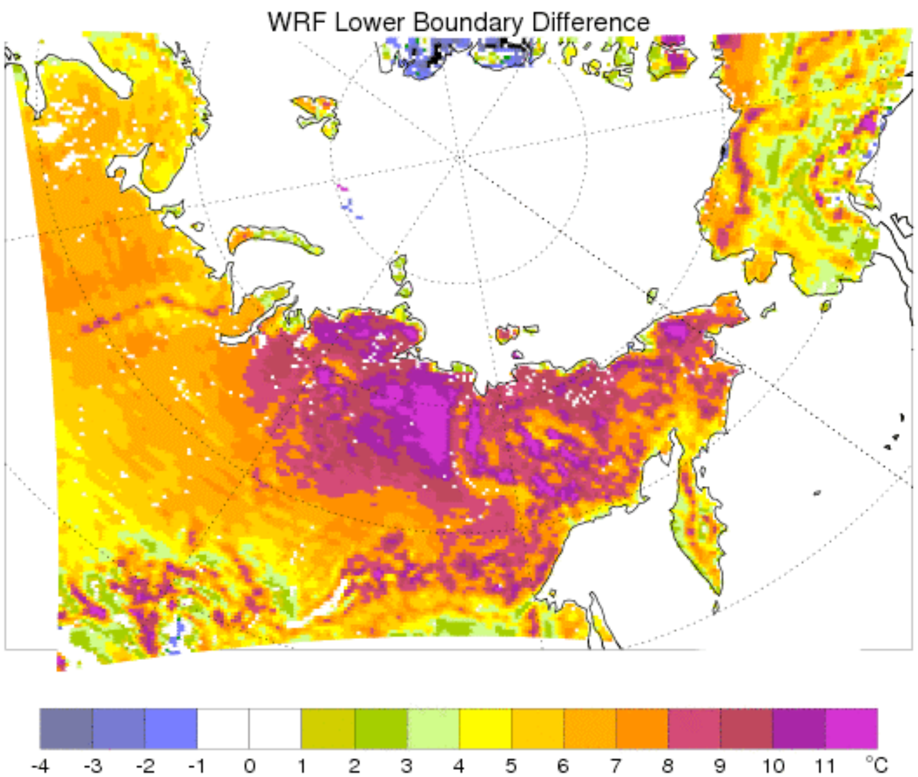


NEW

Thermal State – Boundary Conditions

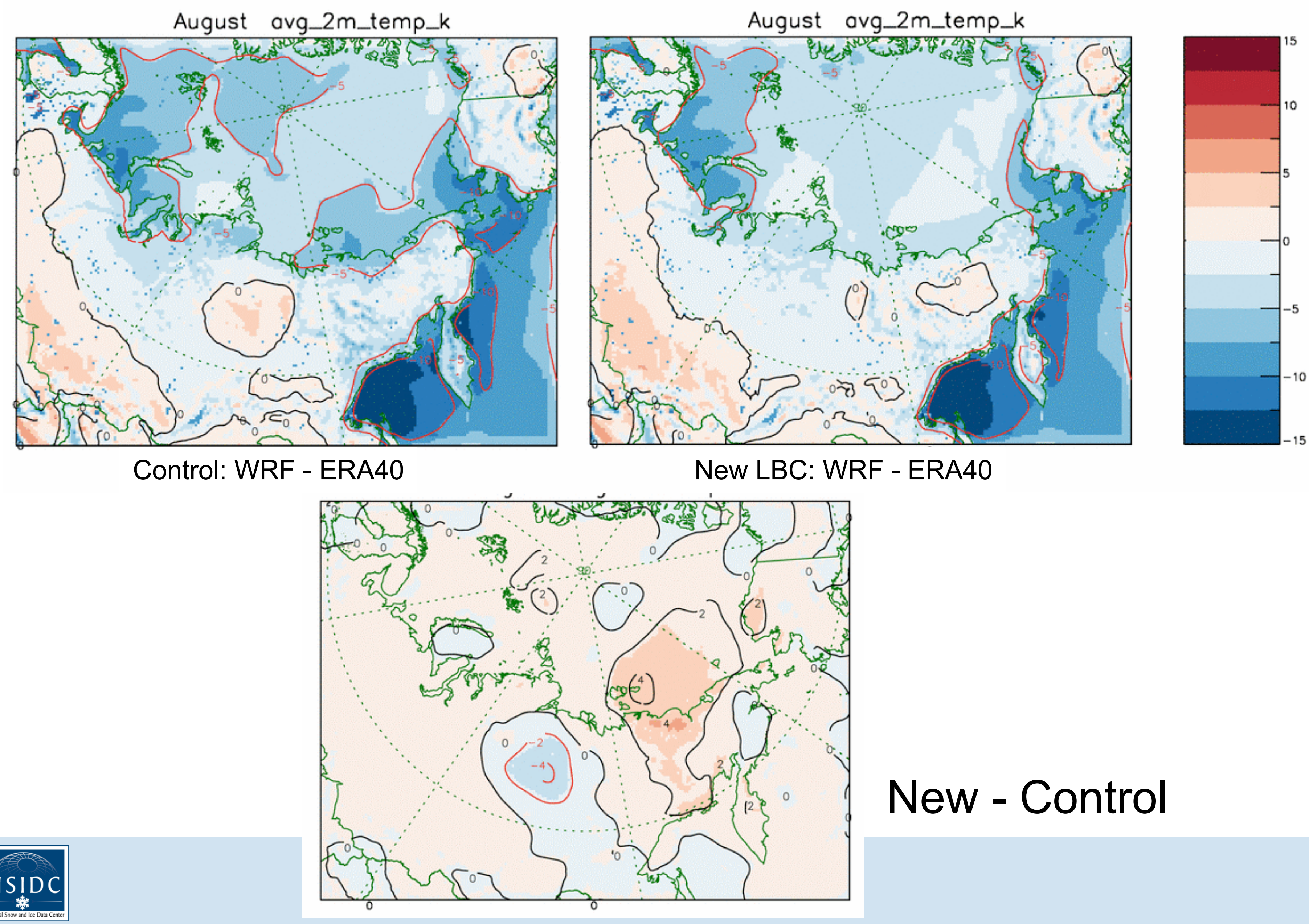


OLD

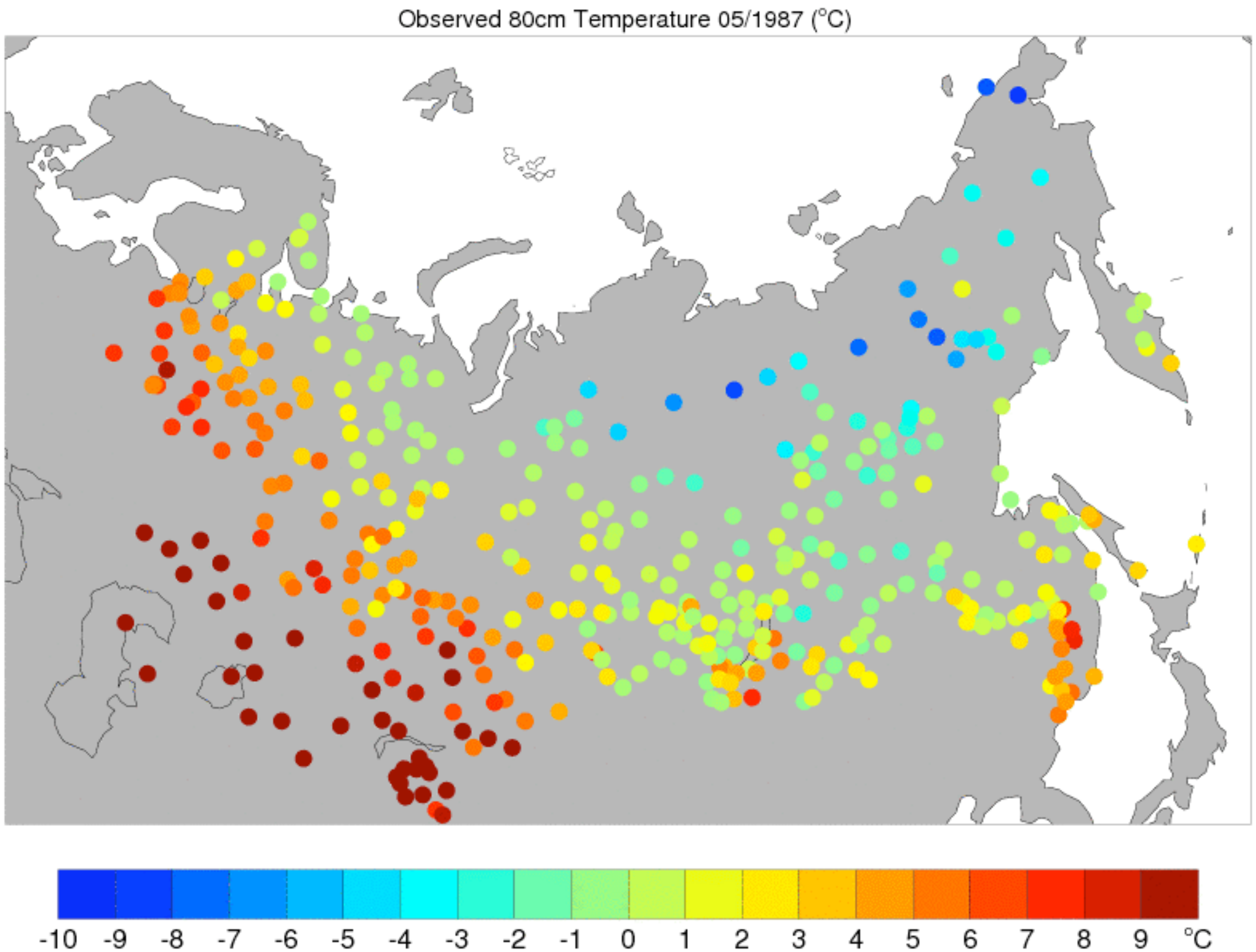


DIFFERENCE

WRF vs ERA-40 2-meter Temperature (AUGUST)



Soil Station Data



- Other regions?
- Land cover type?
- What level of accuracy is needed?
- Change over time

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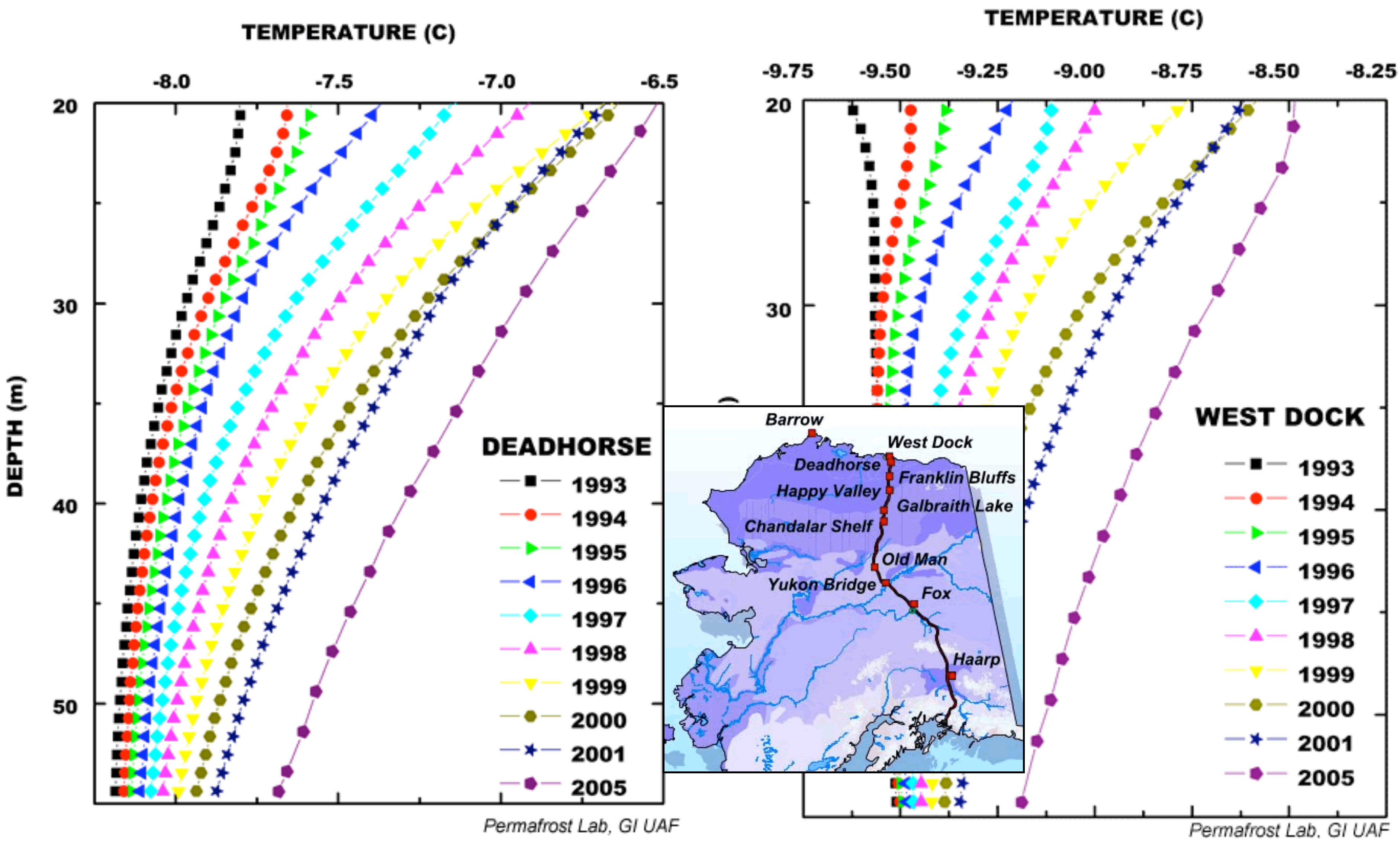
Recent Changes in Permafrost



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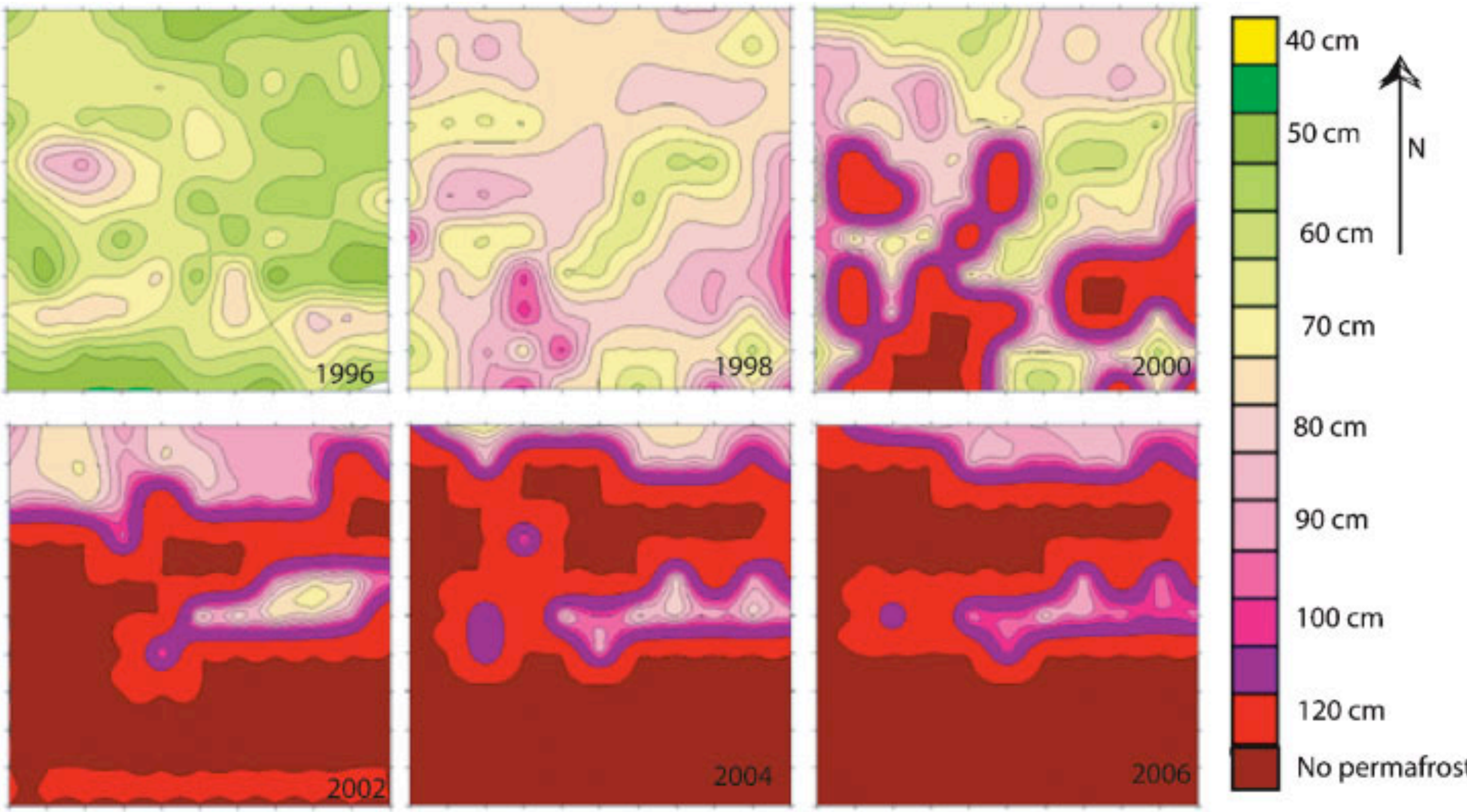
Courtesy: V.E. Romanovsky

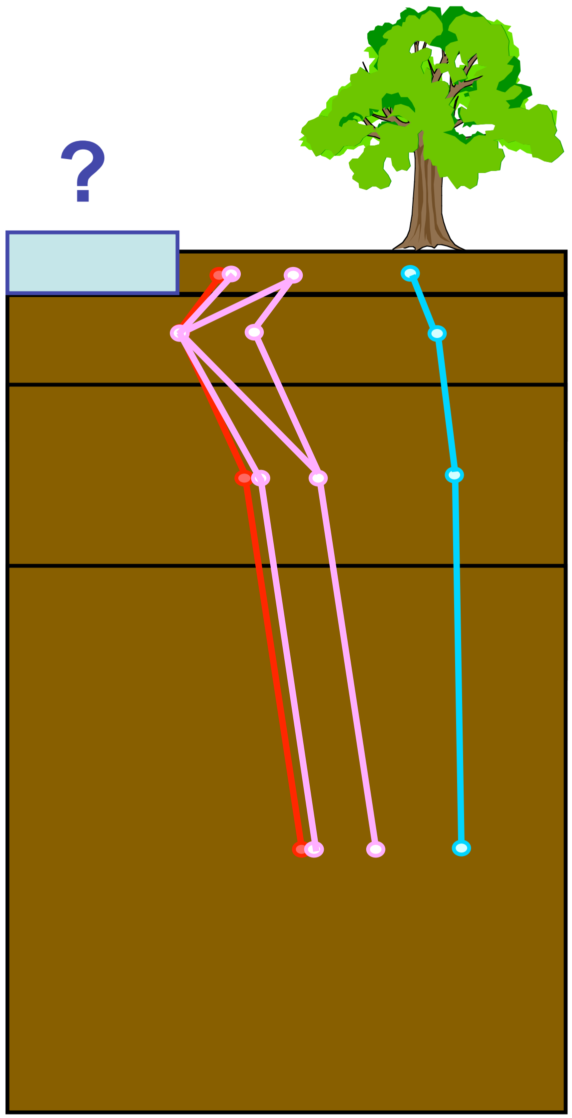
Recent Changes in Permafrost



Spatial and temporal variation in active-layer thickness at Katterjokk, Sweden

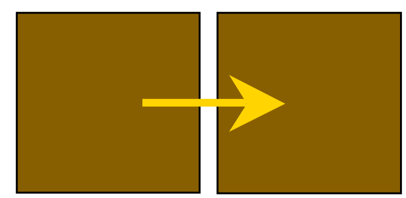
Akerman & Johansson (2008), PPP

Information Propagation



Observed T
Model T
Model Moisture

$$X = \begin{bmatrix} T_1 \\ T_2 \\ T_3 \\ T_4 \\ W_1 \\ W_2 \\ W_3 \\ W_4 \end{bmatrix}$$



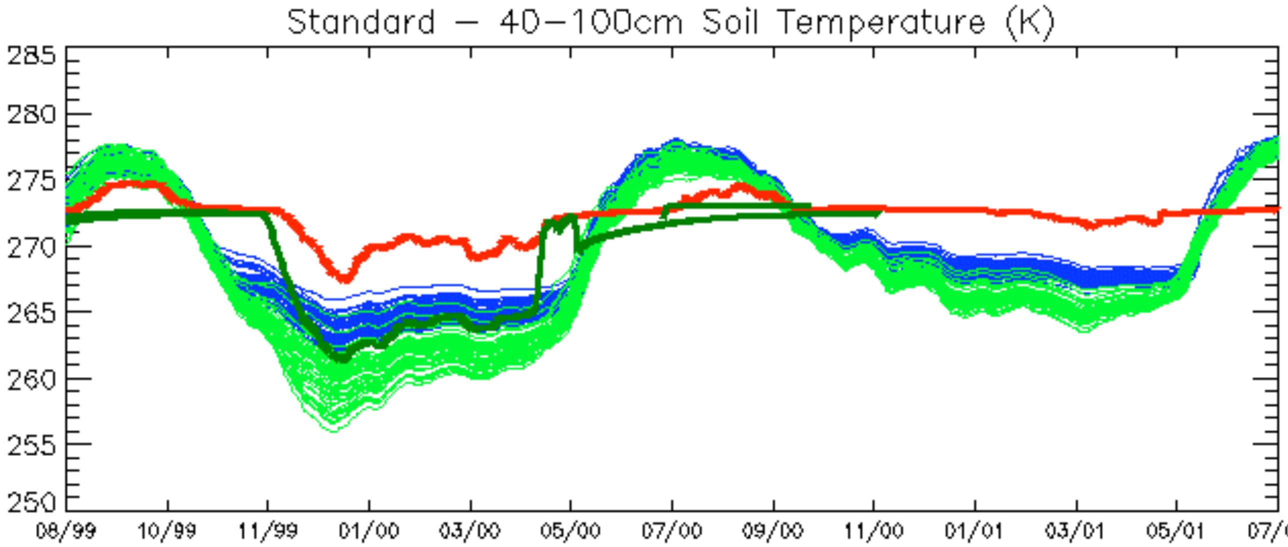
Information Propagation

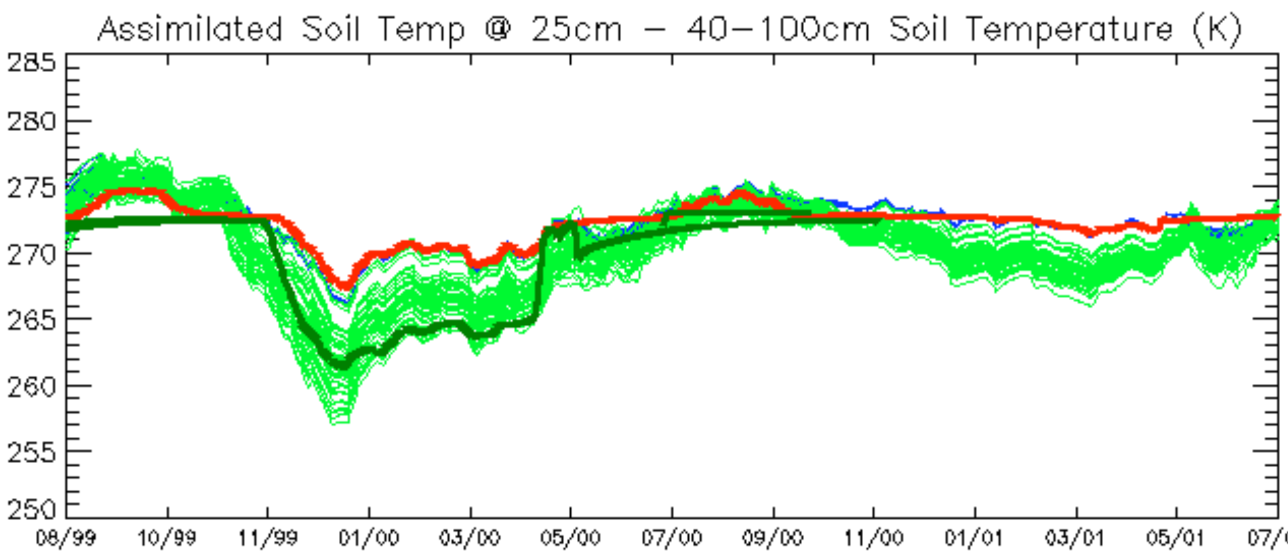
Council : Model

Council : Obs.

Kougarok : Model

Kougarok : Obs





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Pan-Arctic Ground Thermal State Prospects

	Z (coverage)	H (Obs to Model)	R (error estimate)
Station Data (Temperature)	**Spotty** **Day-Year**	**Point vs Area** **Soil type**	**Point vs Grid Box**
Passive Microwave (Freeze/Thaw)	**Global** **Daily?**	**Radiance Model**	**Snow, Veg**

Future Data

- IPY improved monitoring (more stations)
- InSAR – active layer depth (experimental)
- LiDAR – expensive (experimental)
- SMAP – Level 4 product (2015, model + data assim)

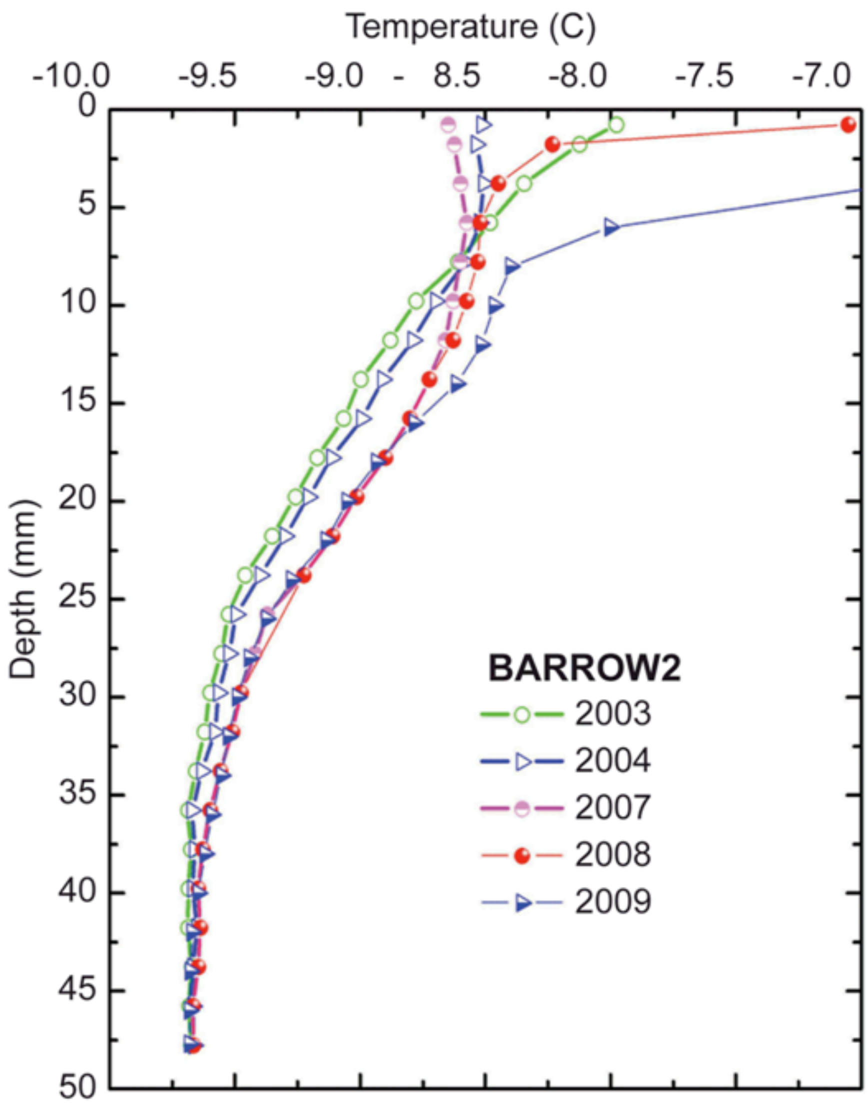
Land Data Assimilation Summary

- Methods being developed
- Data increasing, but less than ideal
- Heterogeneity a big problem

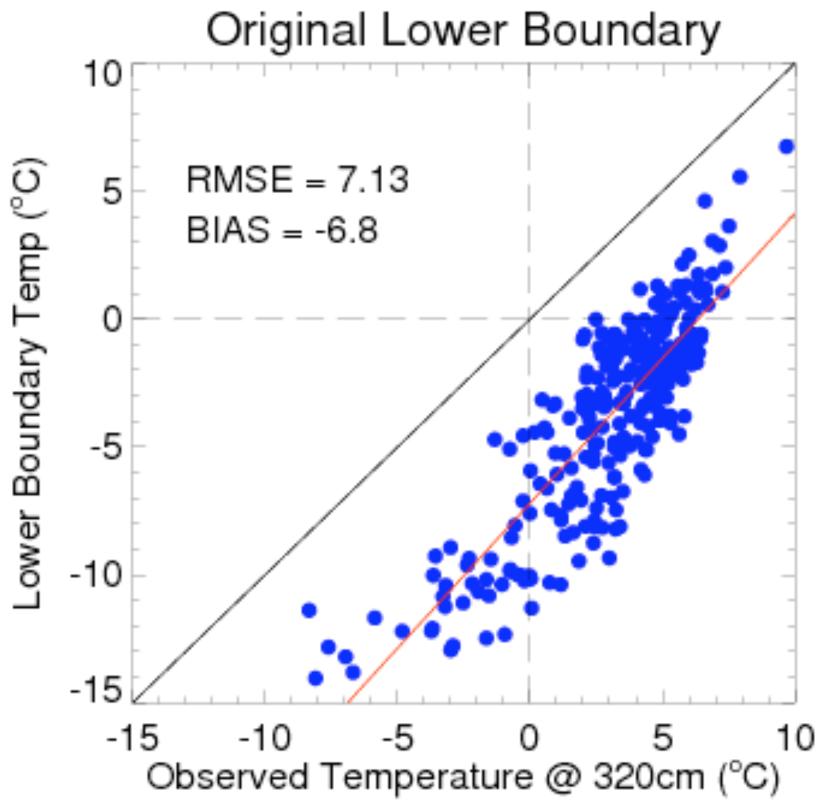
- Initialize model states (single variable, jointly)
- Innovation analysis for model deficiency
  - Parameter uncertainty
  - Structural problems

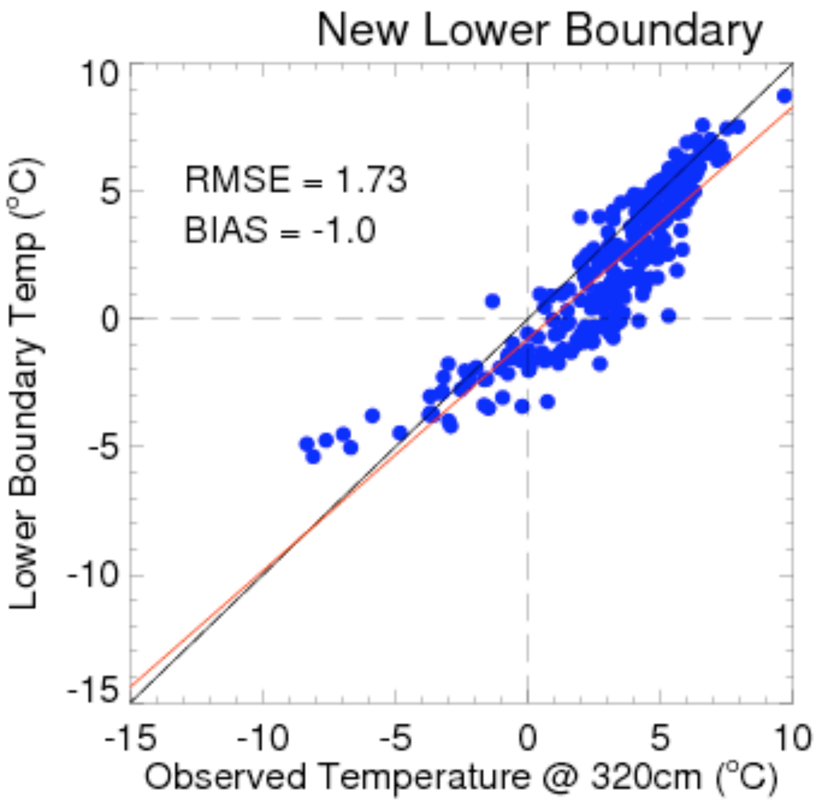
Thanks

Questions?


Temperature (C)
-10.0
-9.5
-9.0
- 8.5
-8.0
-7.5
-7.0
0
5
10
15
20
25
30
35
40
45
50
Depth (mm)
BARROW2
2003
2004
2007
2008
2009

Validation in Eurasia





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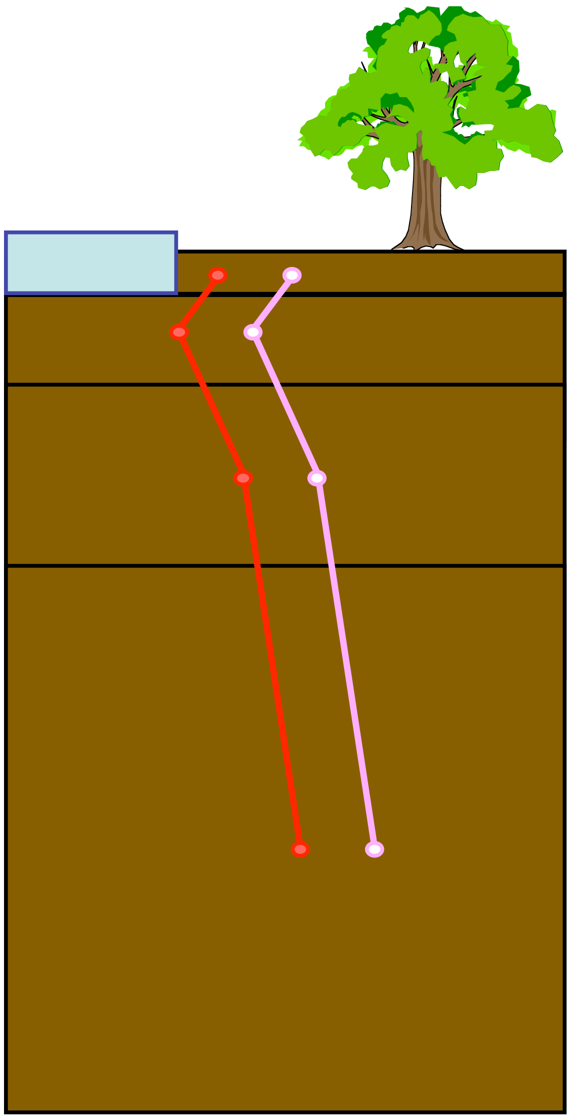

10cm

40cm

100cm

200cm