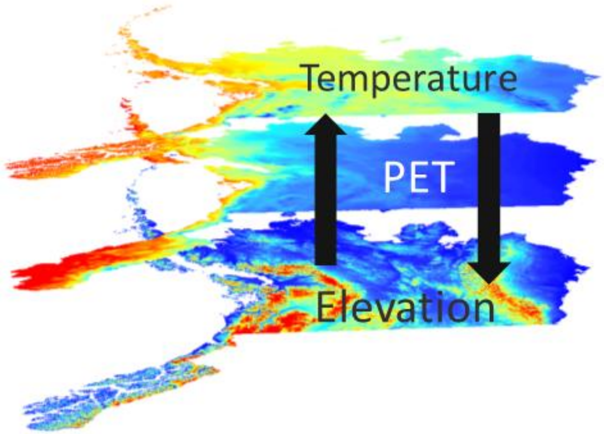
Quantifying impacts of scaling on environmental controls and spatial heterogeneity of soil organic carbon

Umakant Mishra

01/29/2016

Motivation

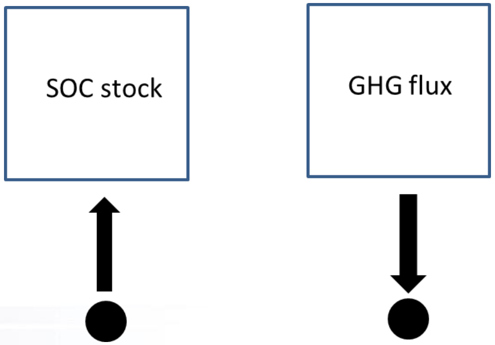
- **Land surface interacts with atmosphere at different spatial scales; spatial heterogeneity of land surface affects the land-atmosphere exchanges of energy, moisture, and greenhouse gases (Li and Avissar, 1993; Clark et al., 2011; Riley and Shen 2014).**



- **Understanding the causes and consequences of spatial heterogeneity in ecosystem function is challenging, and if used appropriately it will enhance our knowledge of pools, fluxes, and regulating factors of carbon dynamics (Turner and Chapin, 2005; Riley et al., 2014).**

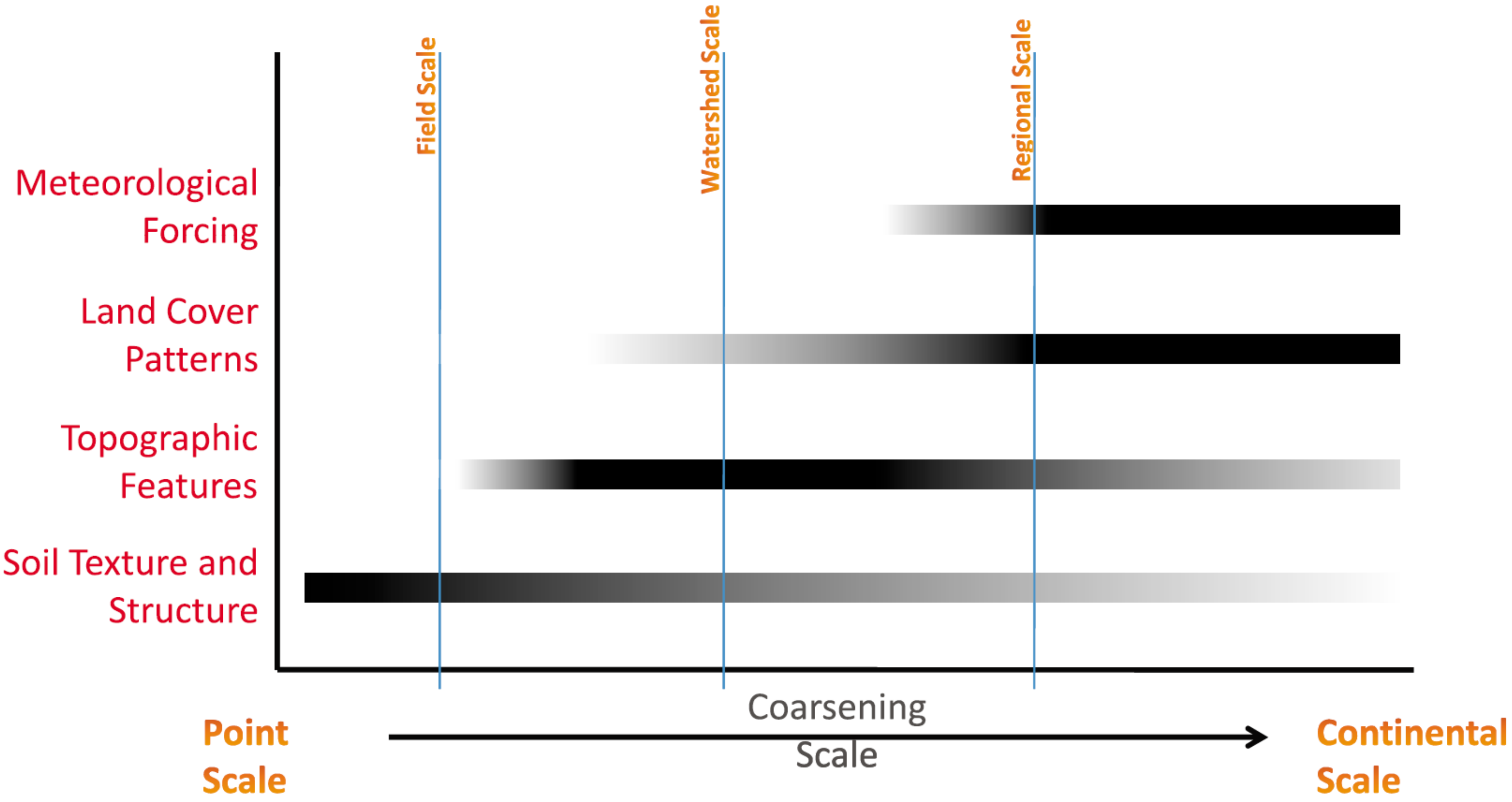

(Source: Soil Horizons)

- **We often use information collected at one spatial scale to infer properties or processes at either smaller or larger scales (Li and Rodell, 2013).**


SOC stock

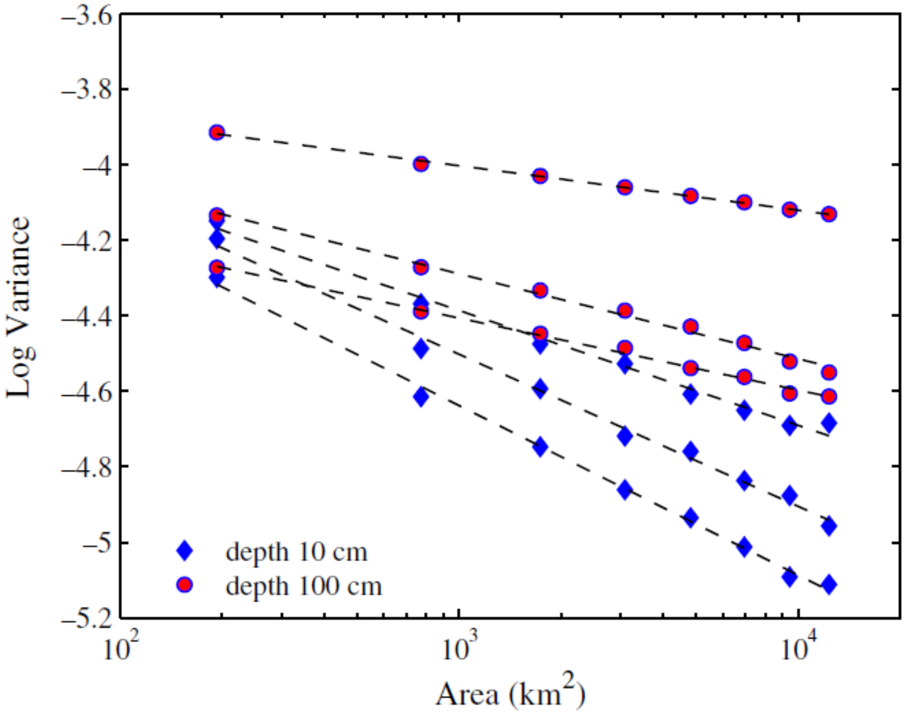
GHG flux

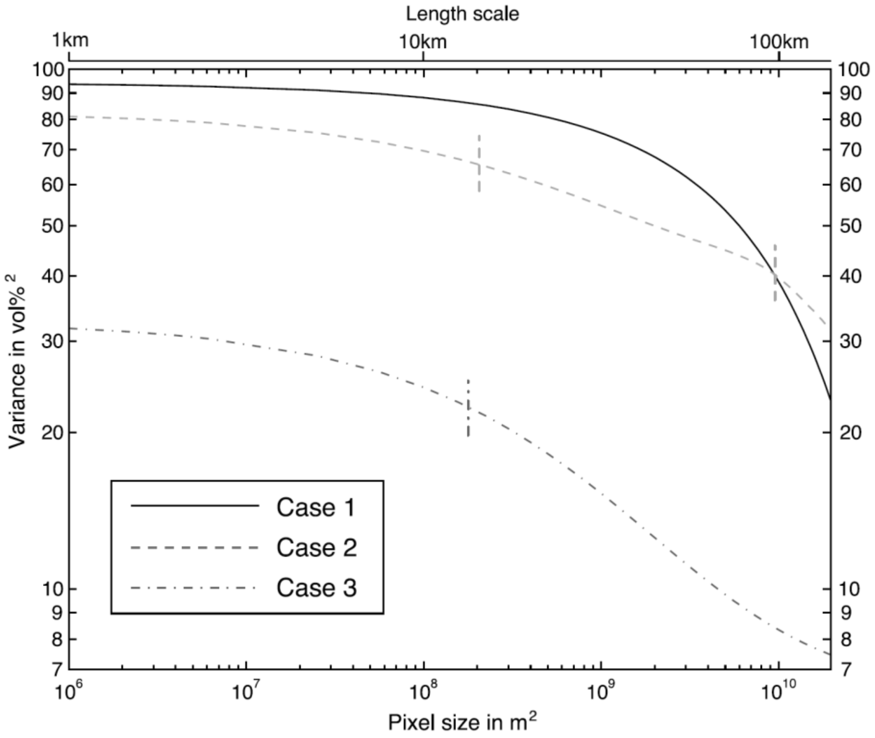
Environmental controls of soil moisture changes with scale



(Crow et al., 2012)

Scaling behavior of soil moisture





Variance of soil moisture decreases linearly with scale (Rodriguez-Iturbe et al., 1995; Manfreda et al., 2007…..)

Log linear relationship of soil moisture with scale does not hold at larger scales (Ryu and Famiglietti, 2006; Joshi and Mohanty, 2010…..)

Soil property at a location is a function of soil-forming factors

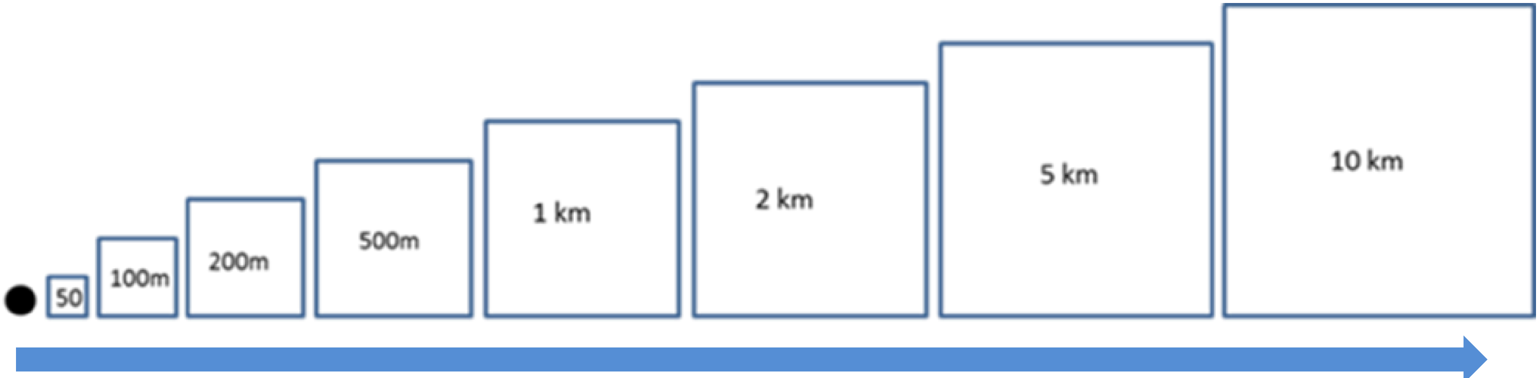
$S_i = f\ (cl, o, r, p, t\ldots.. + \varepsilon)$ (Dokuchaev, 1879; Jenny, 1941; McBratney et al., 2003)

S = soil property at a location i
cl = climate or climatic properties of environment
o = organism or vegetation type or human activity
r = relief or topographic attribute
p = parent material or lithology
t = time since pedogenesis
ε = spatially autocorrelated residuals

Depending on the availability of these information at certain location many forms of this equation has been used in several studies globally

Study objective & schematic methodology

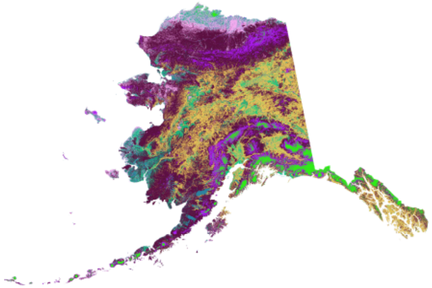
- **Quantify the impact of spatial scaling on environmental controls, spatial heterogeneity, and statistical properties of SOC stocks.**



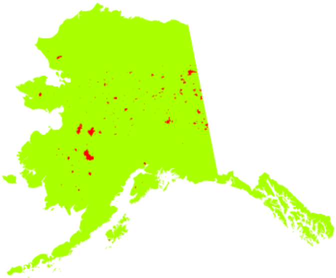
Spatial scaling

- Continuous variables – Bilinear algorithm
- Categorical variables – Nearest neighbor algorithm
- Best subset regressions – Significant predictors at each scale
- Geographically weighted regression – Spatial prediction of SOC stocks

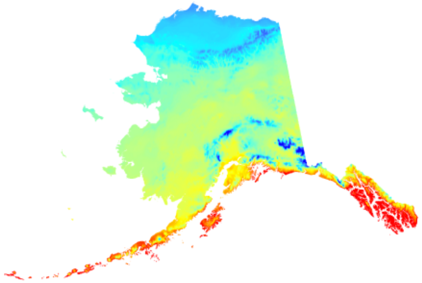
Environmental variables considered in this study



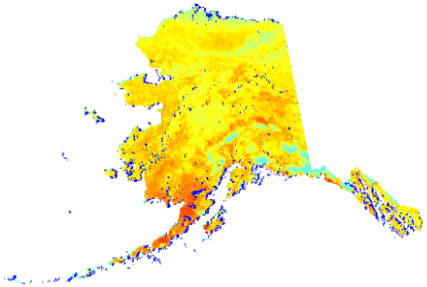
Land cover



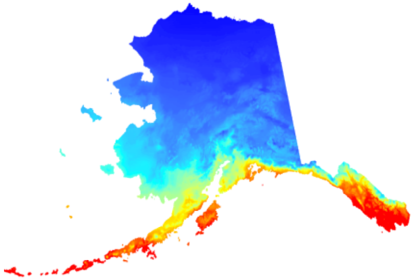
Fire history



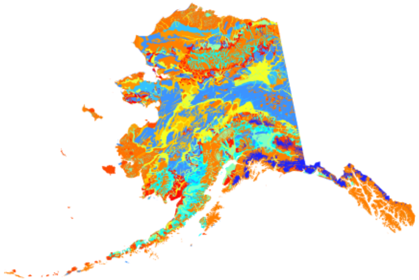
Length of growing season



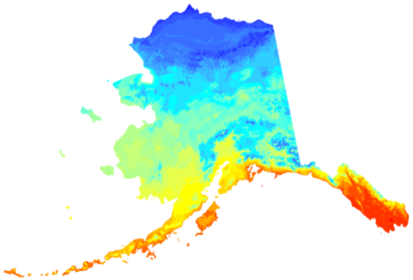
Net primary productivity



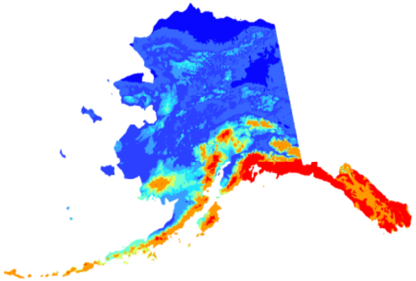
Potential evapotranspiration



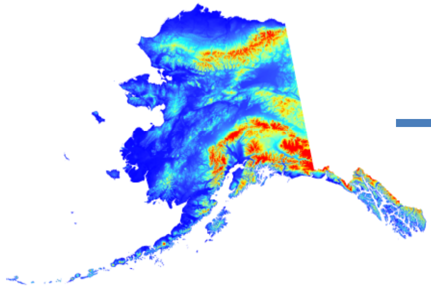
Surficial geology



Temperature



Precipitation

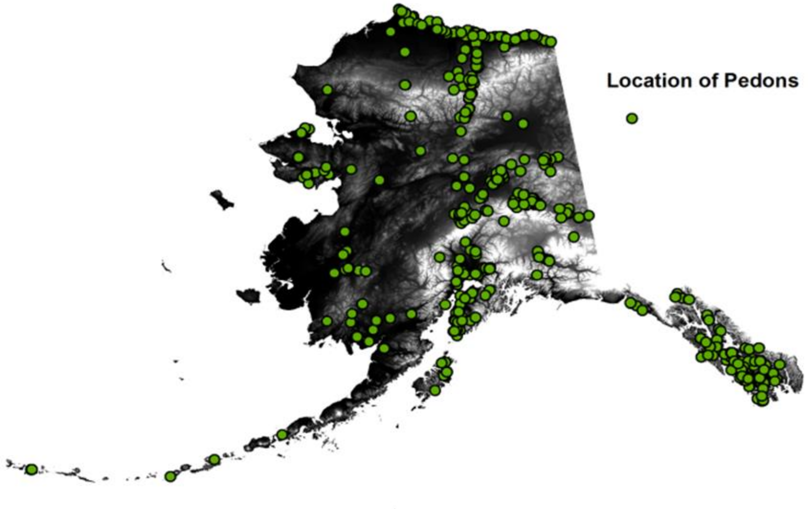


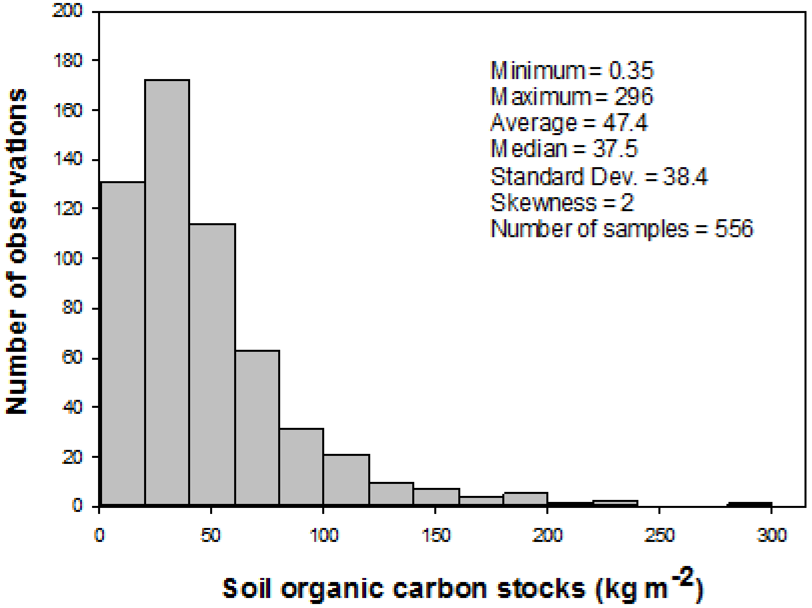
Digital elevation model

Slope, aspect, curvature (plan, profile, and total), upslope contributing area, flow length, soil wetness index, sediment transport index, stream power index, terrain characterization index, and slope aspect index

Topographic attributes

Spatial and statistical distribution of observed SOC stocks





Data sources: NRCS and UAF

- To characterize and describe soil types
- Answer different questions of individual investigators
- Sampling depth ranged from 0.3 – 4.5 m

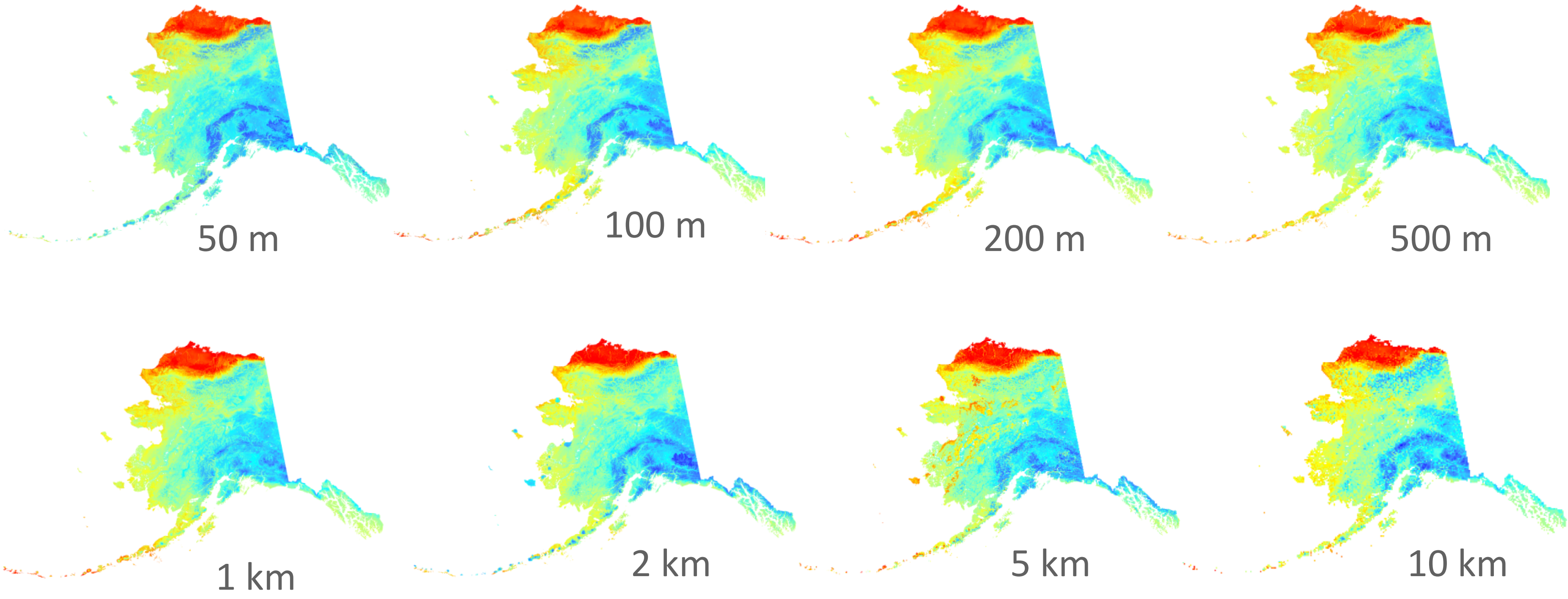
27 MLRAs, 17 land covers, 18 soil suborders

Environmental controllers of SOC changes with scale

Environmental Variables	***Spatial Scale***							
	50 m	*100 m*	*200 m*	*500 m*	*1 km*	*2 km*	*5 km*	*10 km*
Elevation	●	●	●	●	●	●	●	●
Slope								●
Aspect	●							
Soil Wetness Index	●			●			●	
Sediment Transport Index				●				
Temperature	●	●	●	●	●	●	●	●
Potential Evapotranspiration	●	●	●	●	●	●	●	●
Barren	●	●	●				●	●
Scrub	●	●	●	●	●	●	●	●
Herb						●		
Pasture						●	●	
Glacial Moraine				●	●		●	●
Fluvial				●	●	●	●	●
Undifferentiated Mosaic							●	
Coastal delta						●		●
Volcanic mountain						●	●	
Predicted variance	476.5	354	304	263	261	257	256.4	258

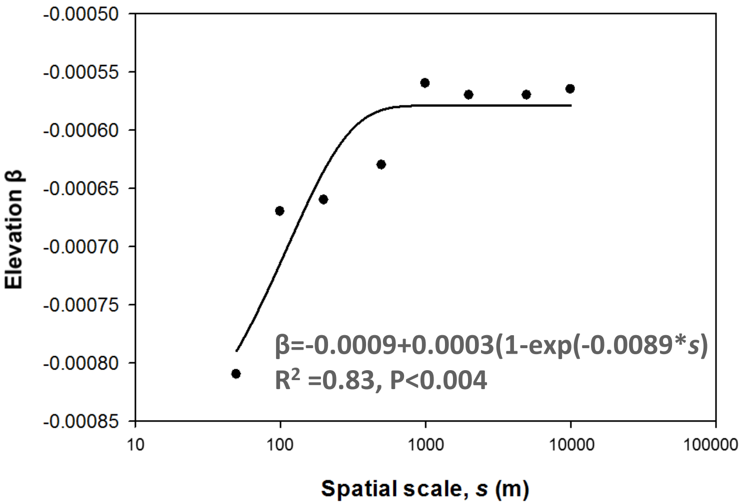
Black dots represent significant predictors at 95% confidence level

Predicted SOC stocks at various scales



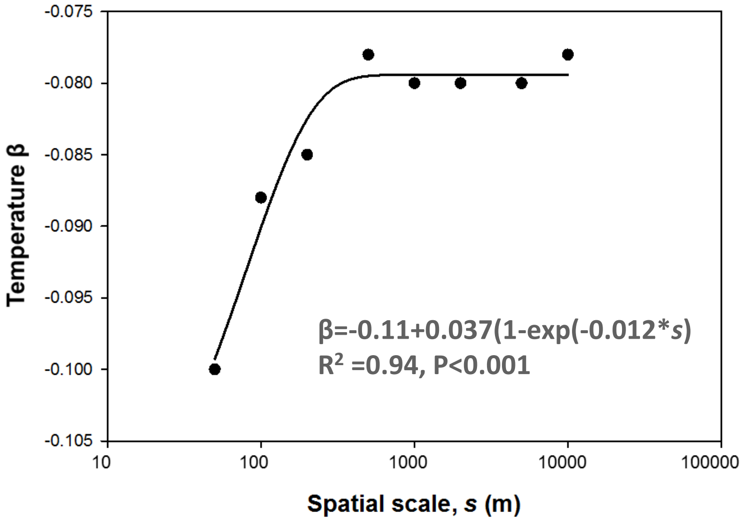
- Statistical properties such as mean, variance, skewness, and kurtosis were calculated from the predicted SOC stocks at each scale.
- Median values of environmental controllers (βs) across Alaska were calculated at each scale.
- Variograms (variance as a function of distance) were calculated at each scale.

Strengths of environmental controls of SOC stocks weaken with scale in different mathematical forms



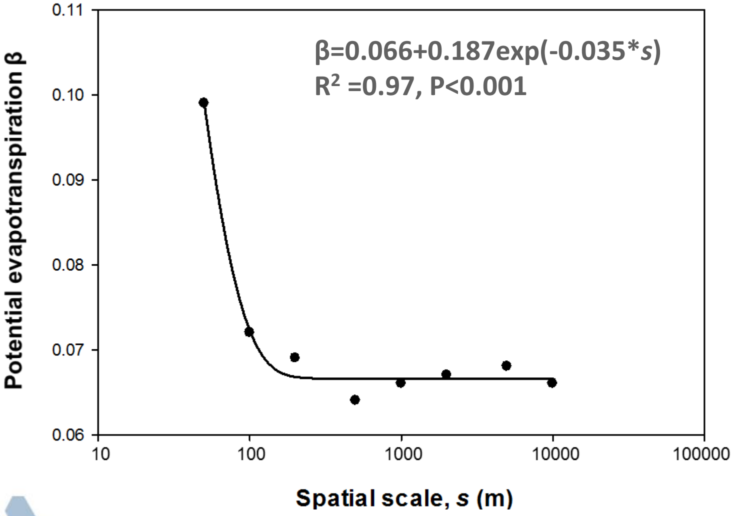
β=-0.0009+0.0003(1-exp(-0.0089*s)

R^2 =0.83, $P<0.004$



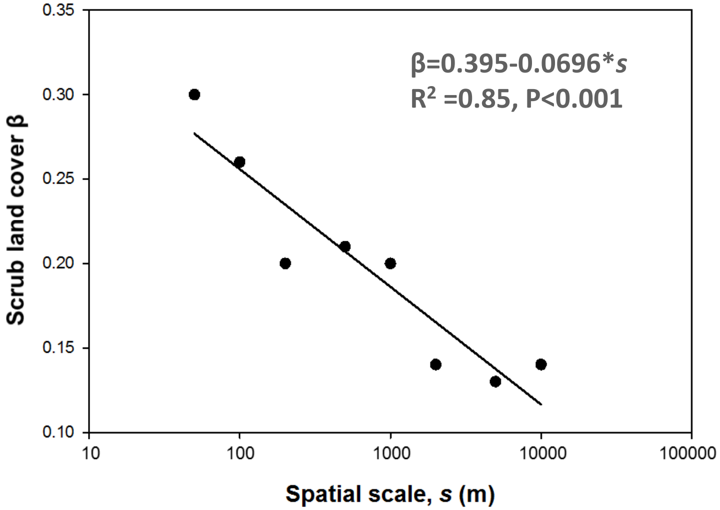
β=-0.11+0.037(1-exp(-0.012*s)

R^2 =0.94, $P<0.001$



β=0.066+0.187exp(-0.035*s)

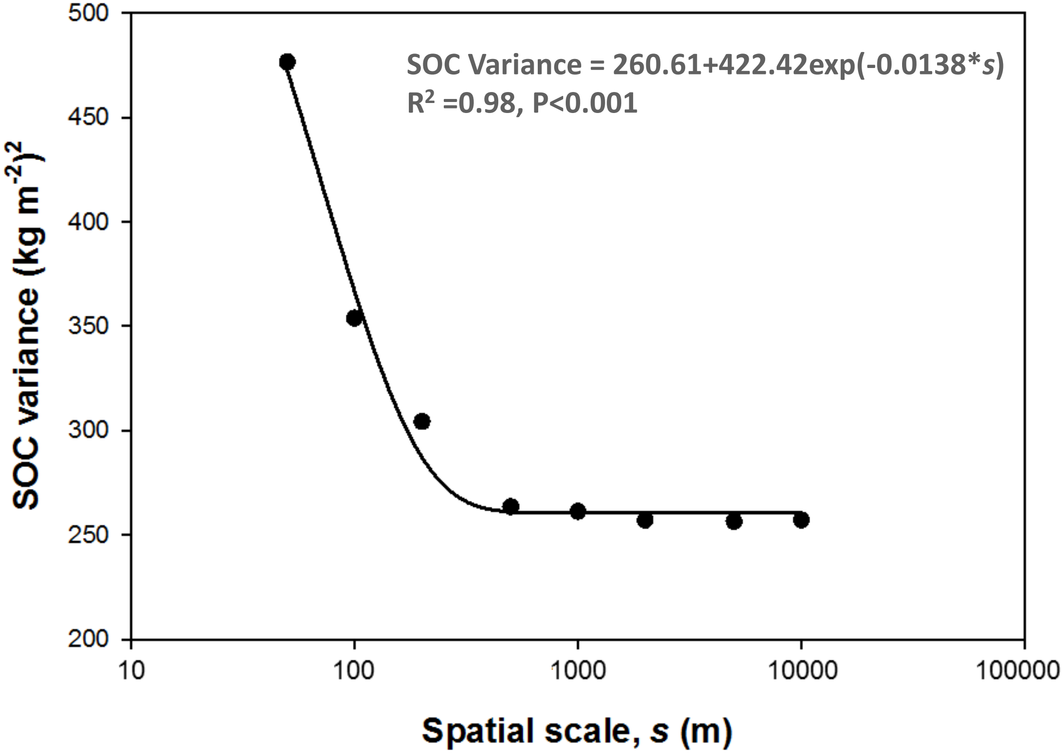
R^2 =0.97, $P<0.001$



β=0.395-0.0696*s

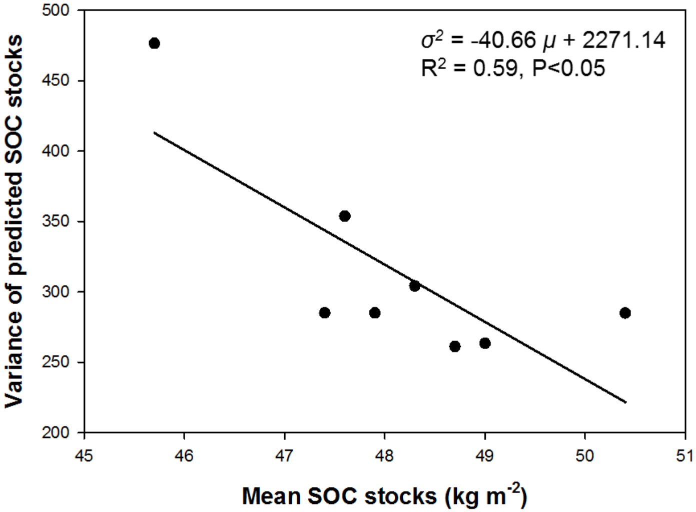
R^2 =0.85, $P<0.001$

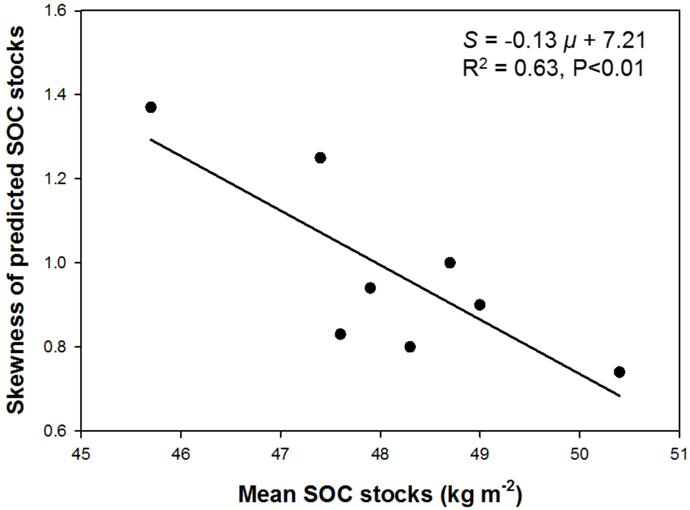
Predicted variance of SOC stocks decreases with scale

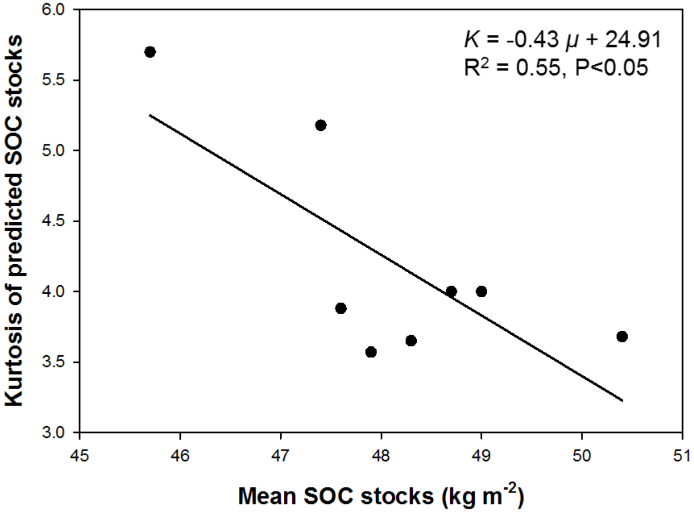


- Predicted variance decreased exponentially with scale, and it didn’t change substantially beyond 500 m.
- The point of inflection of variance curve provides important implication for studies intended to capture spatial heterogeneity of SOC stocks.
- Our result is similar (non linear) with recent findings of soil moisture studies.

Mean value of SOC stocks is linearly related with other statistical properties

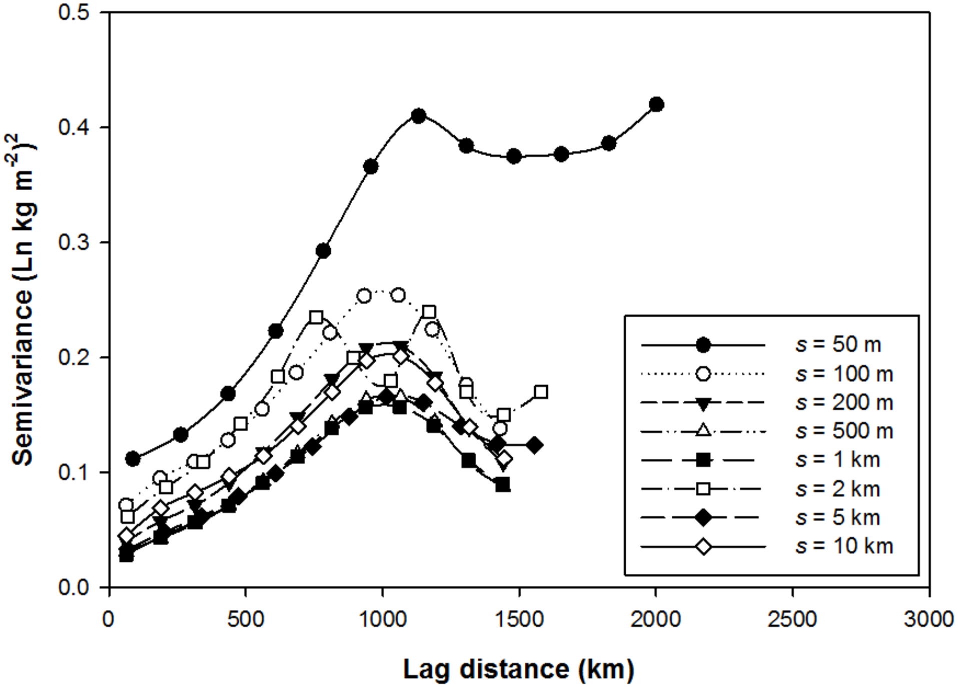


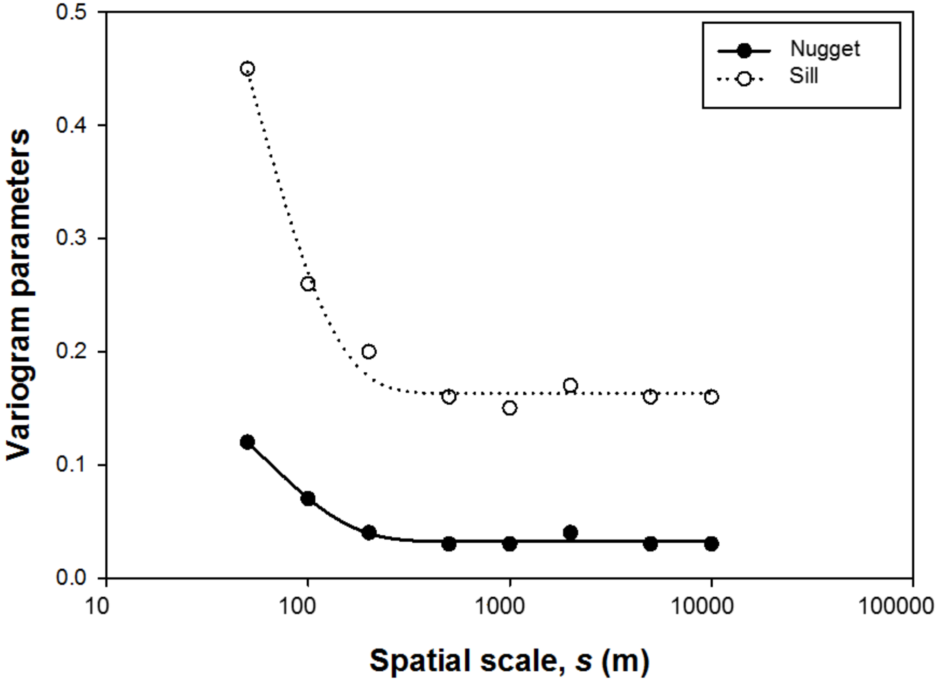




- As the mean value of SOC stock increases, higher-order moments decreases.
- Our results are consistent with findings of soil moisture studies which have reported that mean is often related with other statistical properties but with different mathematical forms.

Calculated variograms and changing parameters with scale





- Spatial correlation length remains more or less constant across scales.
- Both total variance captured by observations (sill) and unstructured spatial variability (nugget) decreases exponentially as scale increases.
- The spatial structure (Nugget/sill ratio) of SOC stocks was similar (< 25%) only up to 100 m.

Major findings

- Environmental controllers of SOC stocks changed with scale, only elevation, temperature, evapotranspiration, and scrub land cover were consistently significant predictors of SOC stocks at all scales.

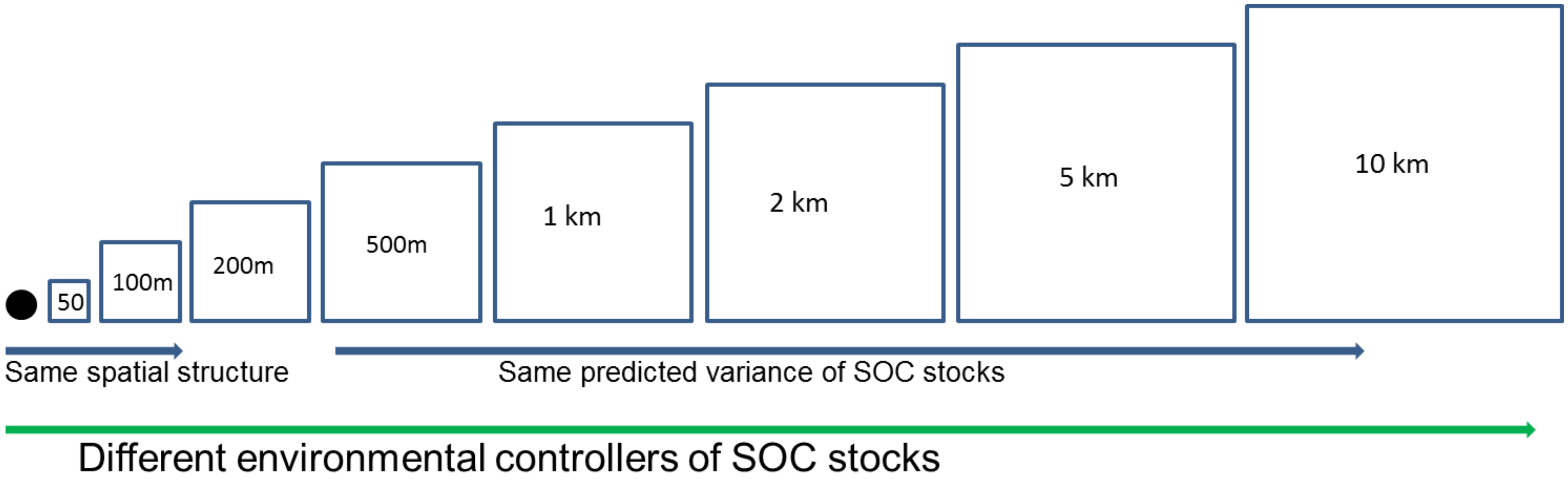
- Strengths of environmental controllers weaken as scale increased, and can be modeled accurately using simple mathematical functions.

- Mean value of SOC stocks were linearly related with its variance, skewness, and kurtosis.

- The variance of SOC stocks decreased exponentially with scale up to 500 m and then remains constant thereafter.

- Observed spatial structure of Arctic\Boreal SOC stocks were only consistent up to 100 m spatial scale.

Summary



Same spatial structure

Same predicted variance of SOC stocks

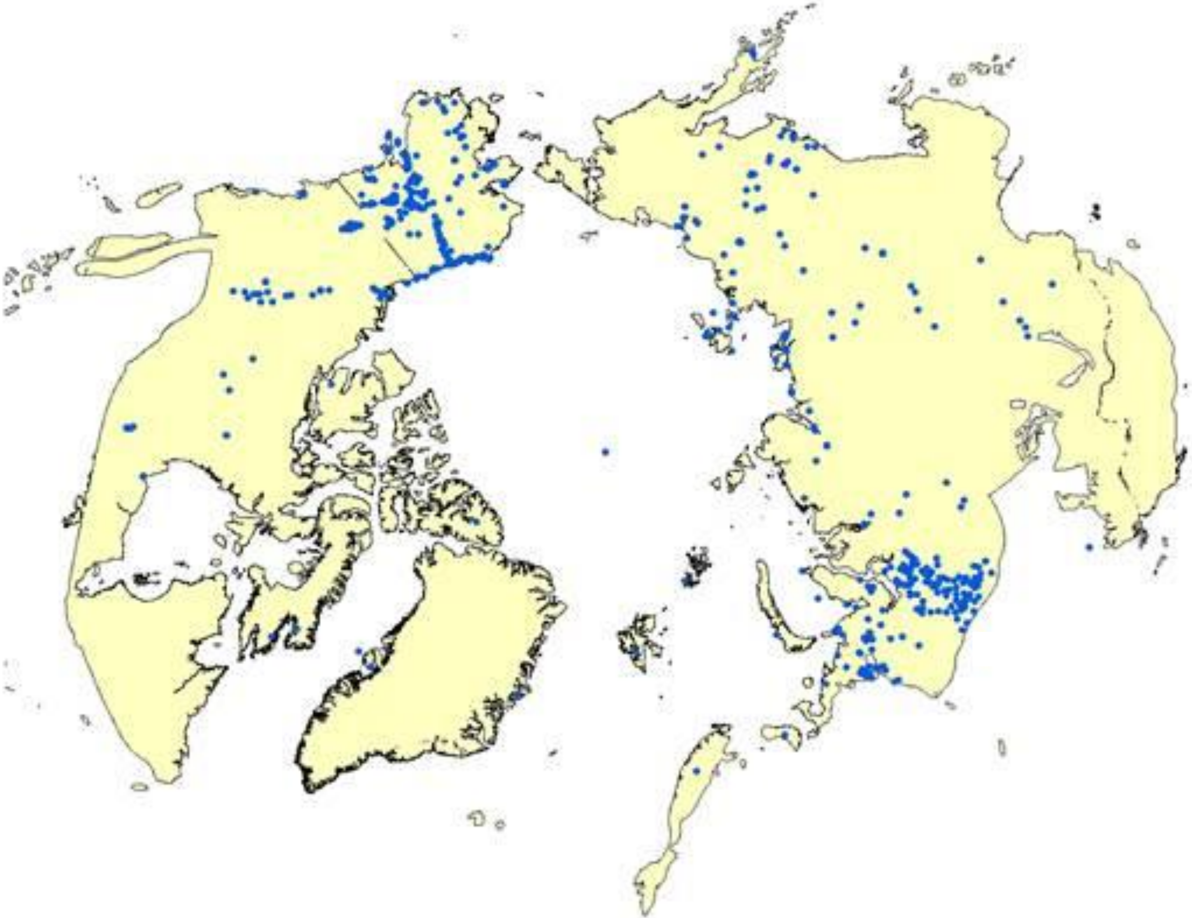
Different environmental controllers of SOC stocks

Further steps:

- **Investigate impacts of scaling on biogeochemistry (C, N, and C:N) at large spatial scales**
- **Identify significant environmental controllers at MLRAs or ecoregion scales.**
- **Figure out how controls of other environmental factors (soil texture's control on SOC stocks) change with scale.**

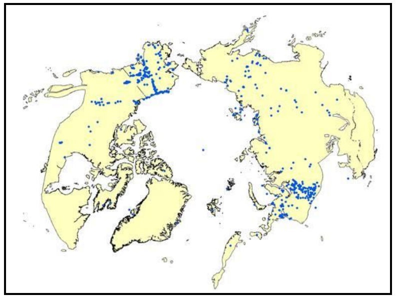
Current effort

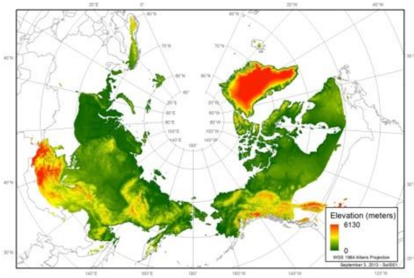
- **Generate a high-resolution SOC map of northern circumpolar region**
- **Investigate the impact of spatial scaling on environmental controls, spatial structure, and statistical properties of carbon and nitrogen stocks**

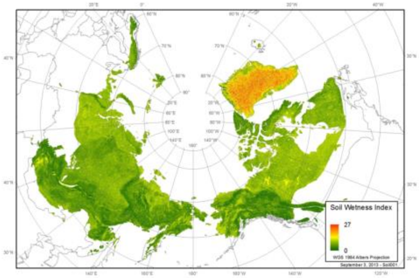


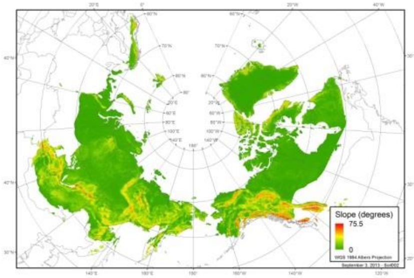
Blue dots are available soil observations (Canadians, Koreans, and Russians)

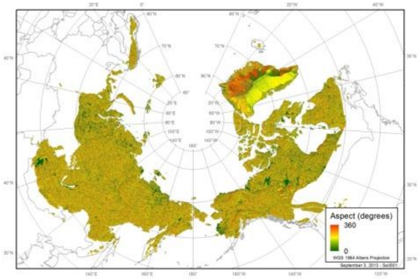
Available pedons & environmental variables

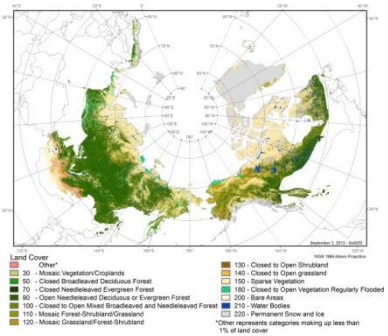


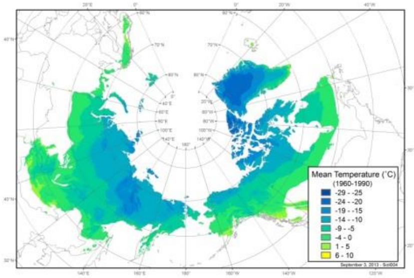


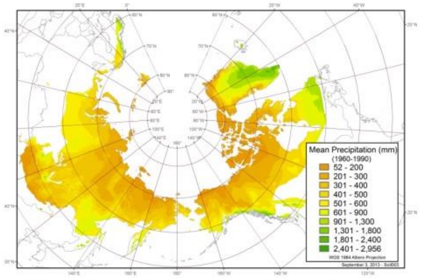




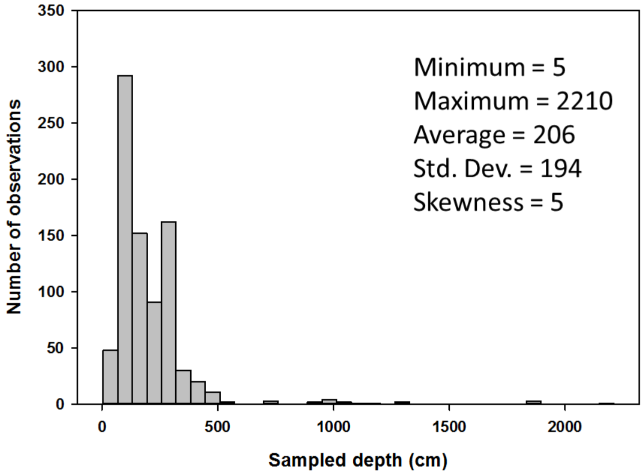




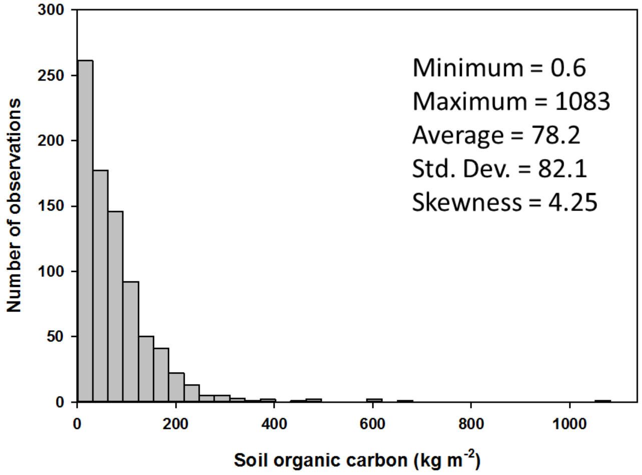




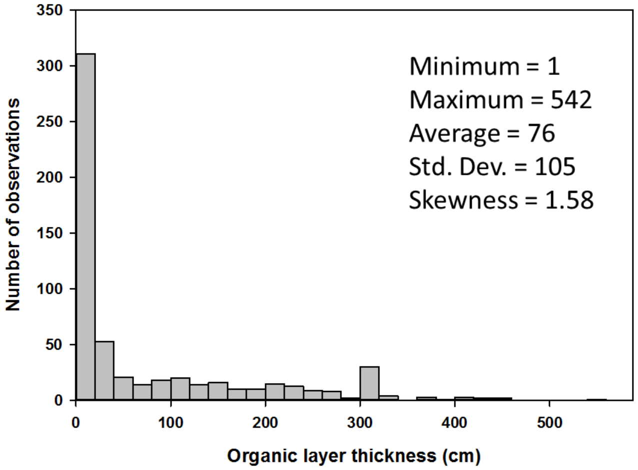
Descriptive statistics of observations



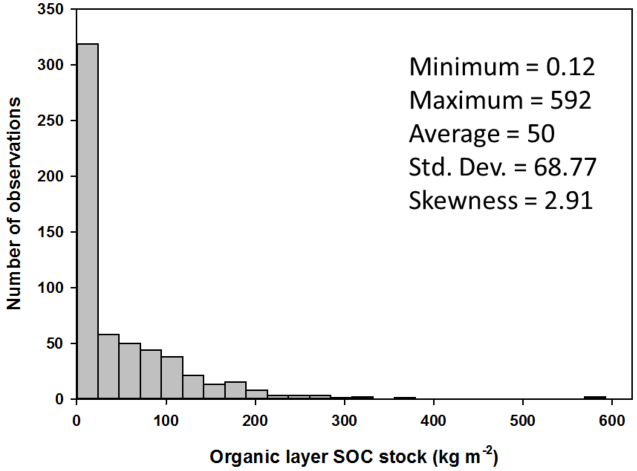
Minimum = 5
Maximum = 2210
Average = 206
Std. Dev. = 194
Skewness = 5



Minimum = 0.6
Maximum = 1083
Average = 78.2
Std. Dev. = 82.1
Skewness = 4.25



Minimum = 1
Maximum = 542
Average = 76
Std. Dev. = 105
Skewness = 1.58



Minimum = 0.12
Maximum = 592
Average = 50
Std. Dev. = 68.77
Skewness = 2.91

Next steps & expected outcomes:

- Conduct several geospatial analyses to predict SOC stocks from 250 m spatial resolution to current ESM grid (~100 km) and ecoregion scales.

- Generate mathematical functions that describe the change in environmental controls, spatial heterogeneity (variance), and spatial structure (nugget/sill ratio) of SOC stocks due to changing scale.

Acknowledgement

DEPARTMENT OF ENERGY • UNITED STATES OF AMERICA

BER – Regional and Global Climate Modeling
BER – Terrestrial Ecosystem Science

Thank you for attention!