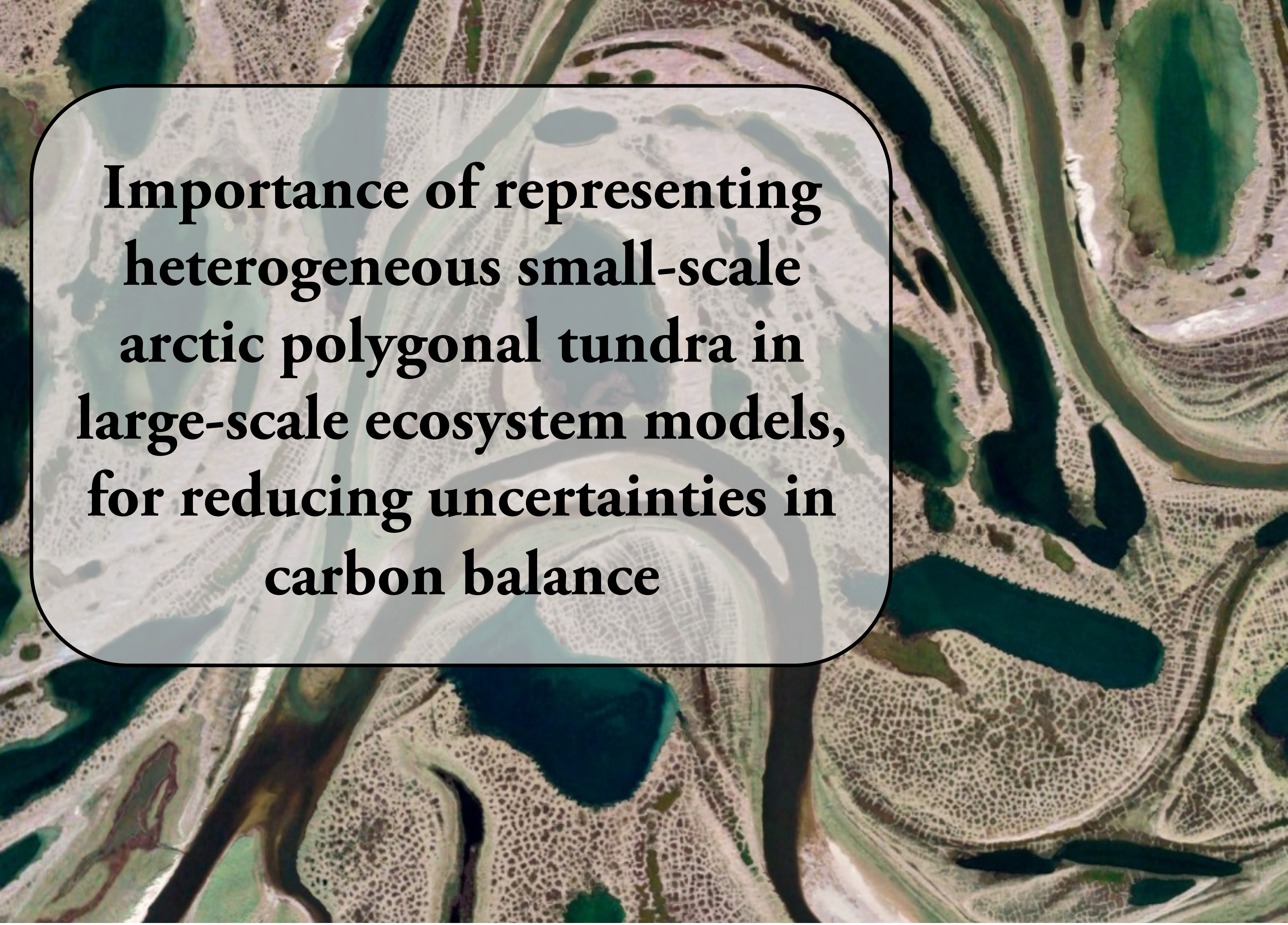
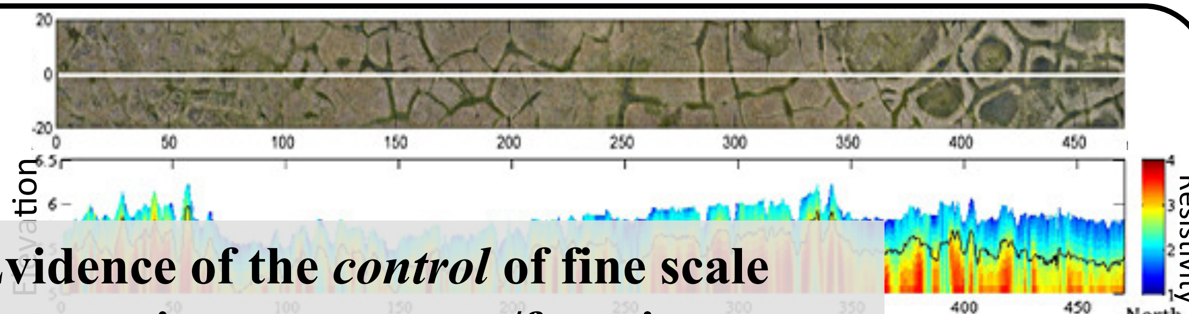


Importance of representing heterogeneous small-scale arctic polygonal tundra in large-scale ecosystem models, for reducing uncertainties in carbon balance

Mark J. Lara, A. David McGuire, Eugenie Euskirchen *et al.*

Heterogeneity of arctic tundra

Microtopography



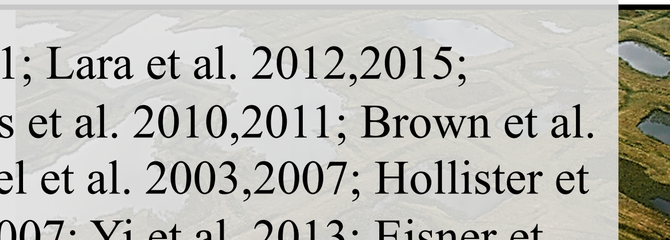
Wainwright *et al.* 2015

Extensive Evidence of the *control* of fine scale tundra heterogeneity on structure/function

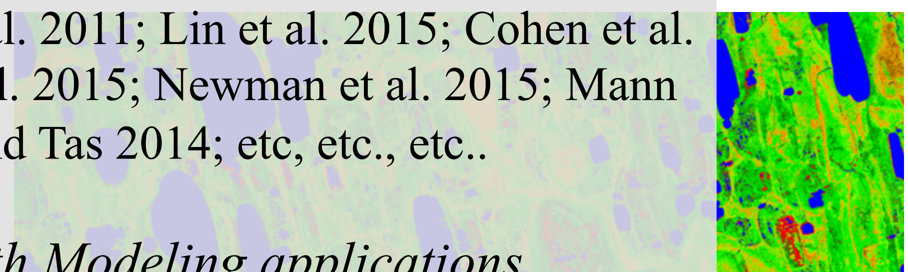
Zona et al. 2010, 2009, 2011; Lara et al. 2012,2015; Villarreal et al. 2012; Olivas et al. 2010,2011; Brown et al. 1980; Lin et al. 2012; Hinkel et al. 2003,2007; Hollister et al. 2005; Oberbauer et al. 2007; Yi et al. 2013; Eisner et al. 2005; Liljedahl et al. 2011; Lin et al. 2015; Cohen et al. 2015; Wainwright et al. 2015; Newman et al. 2015; Mann et al. 2015; Jansson and Tas 2014; etc, etc., etc..

Disconnect with Modeling applications….

Polygonal Tundra Geomorphology

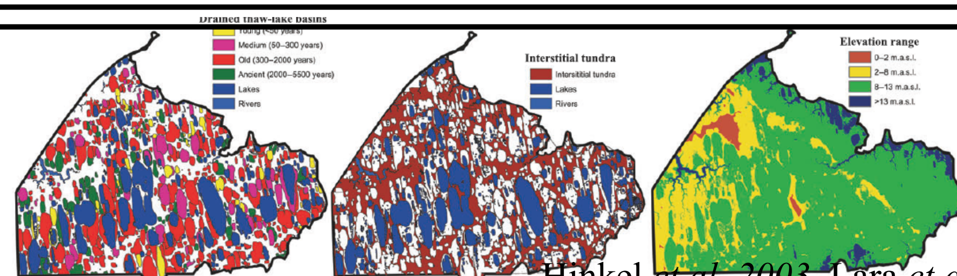


Vegetation Distribution



Lara *et al.* submitted

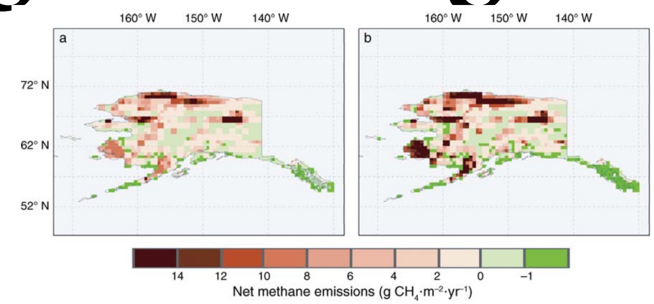
Lakes, DTLBs, Interstitial Tundra



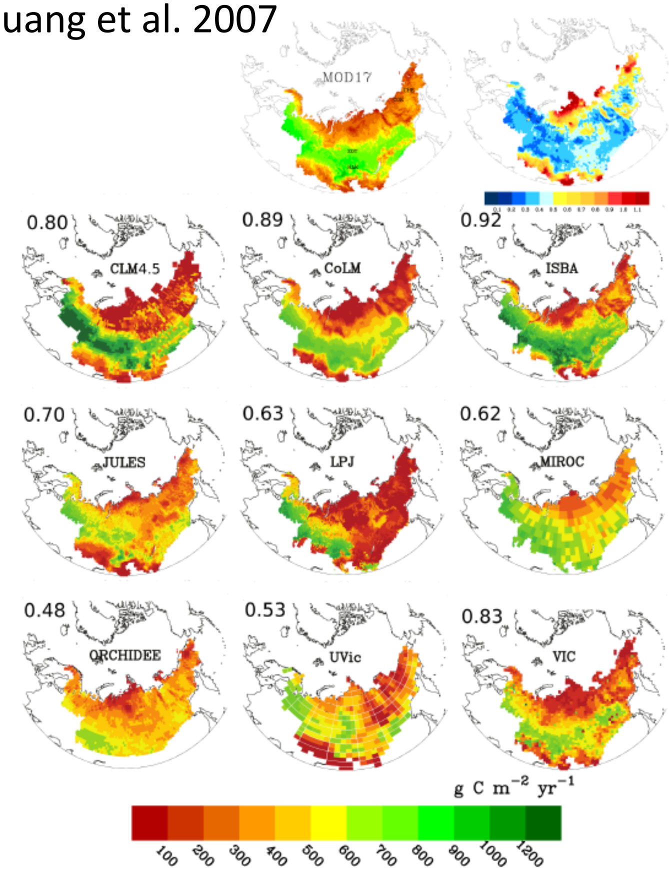
Hinkel *et al.* 2003, Lara *et al.* 2015

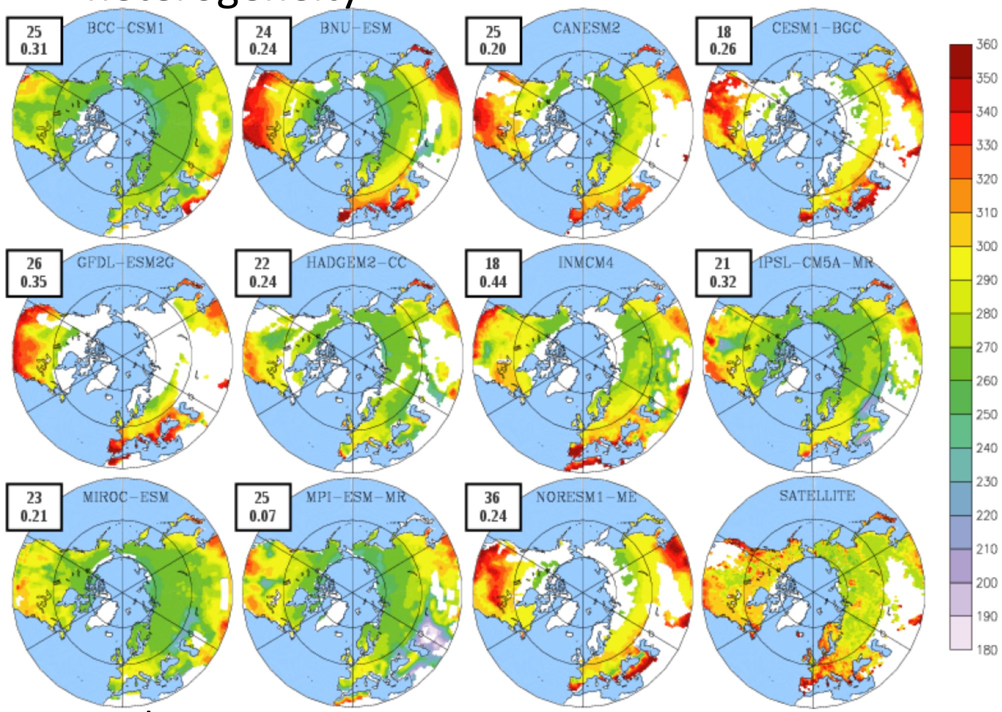
Models representing arctic regions

- Large-scale (panarctic) simulations necessary (25km-0.5°)
  - Patterns, trends, and trajectories of change
- Can we improve tundra representation?
- This study focuses on a data-rich subregion
  1. Change in carbon balance through 2100
  2. Model error associated with decreasing tundra heterogeneity



Zhuang et al. 2007

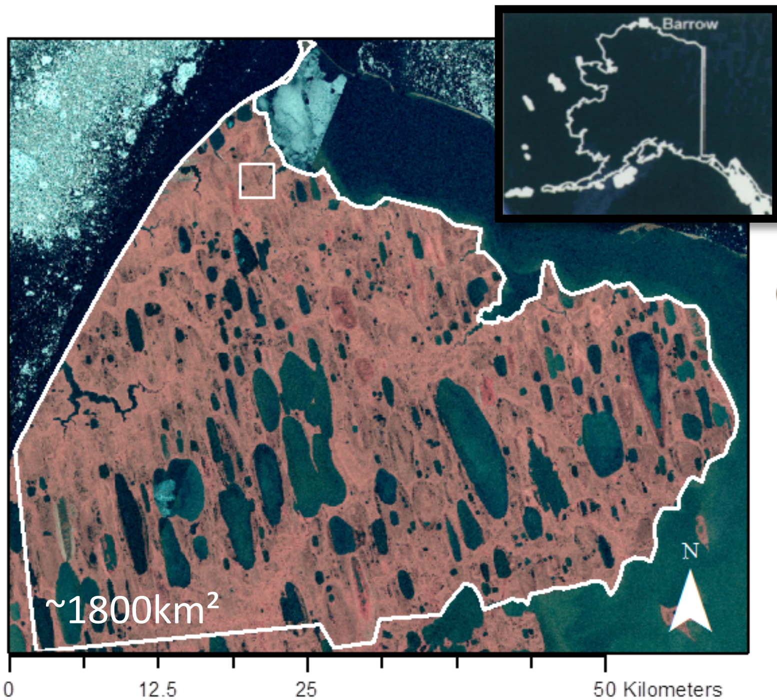


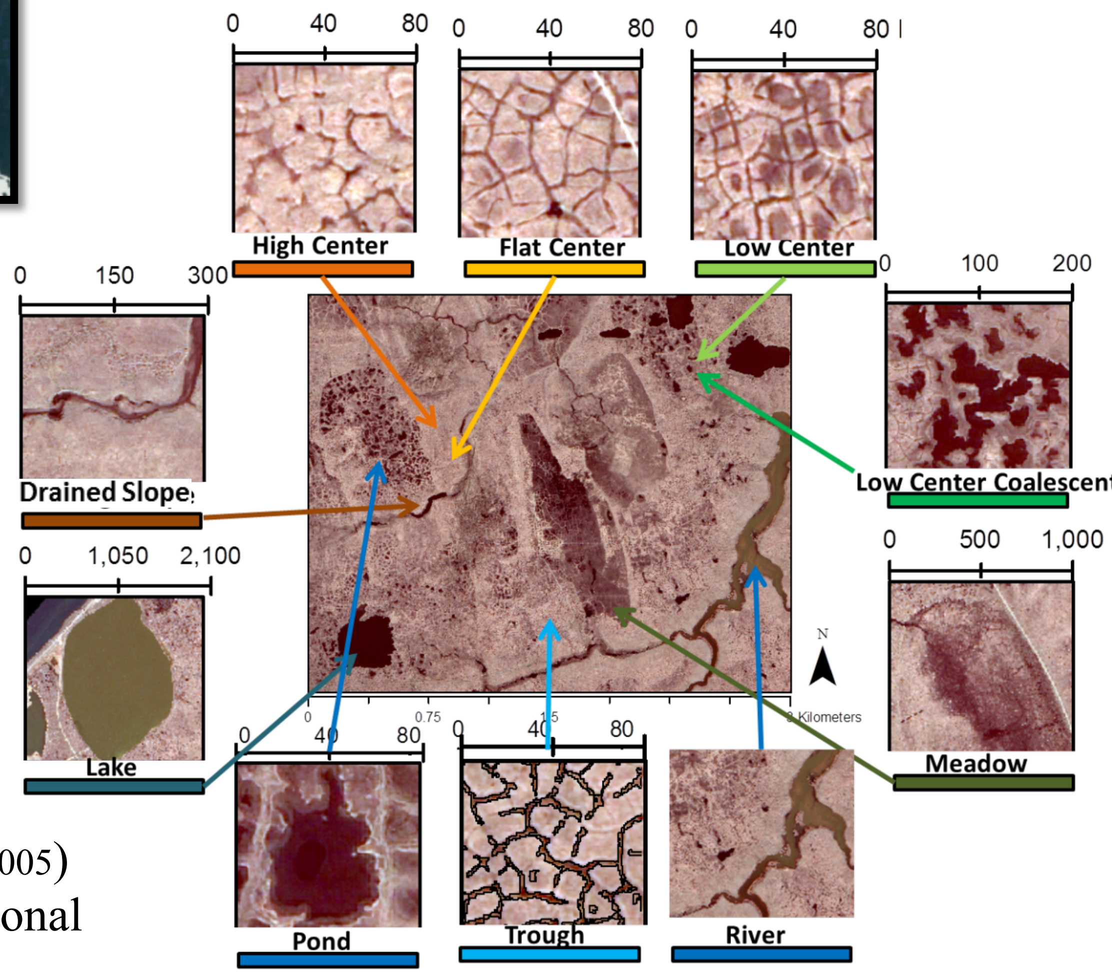


Anav et al. 2013

Rawlings et al. 2015

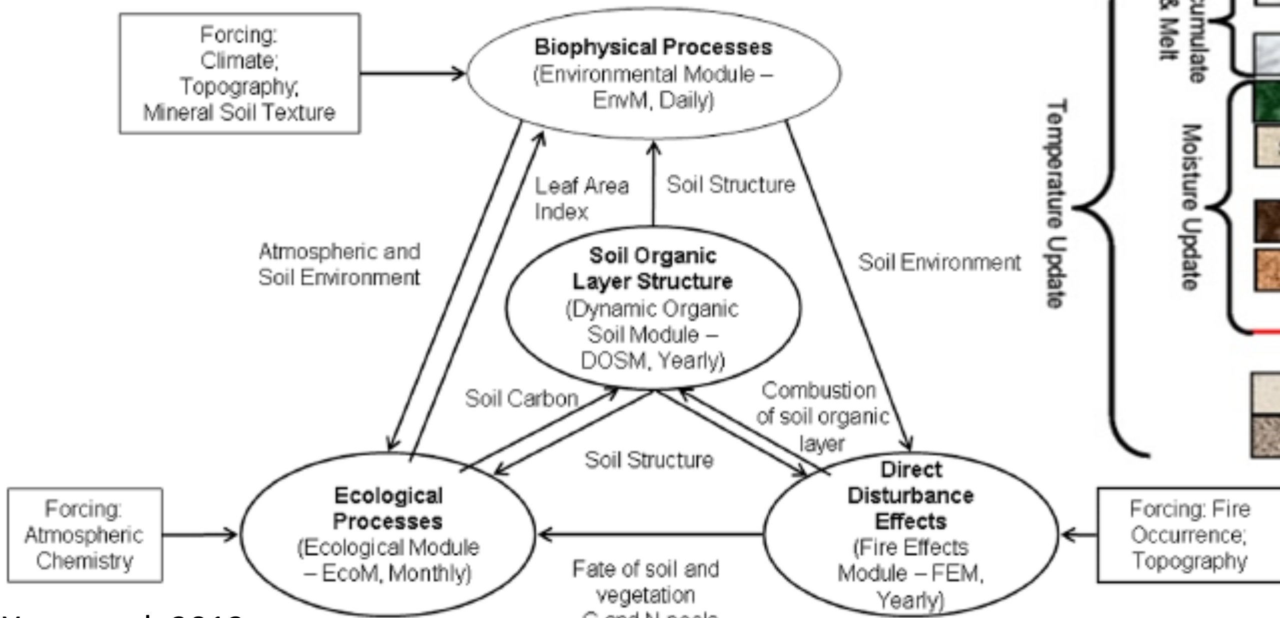
Northern Alaska, Barrow Peninsula

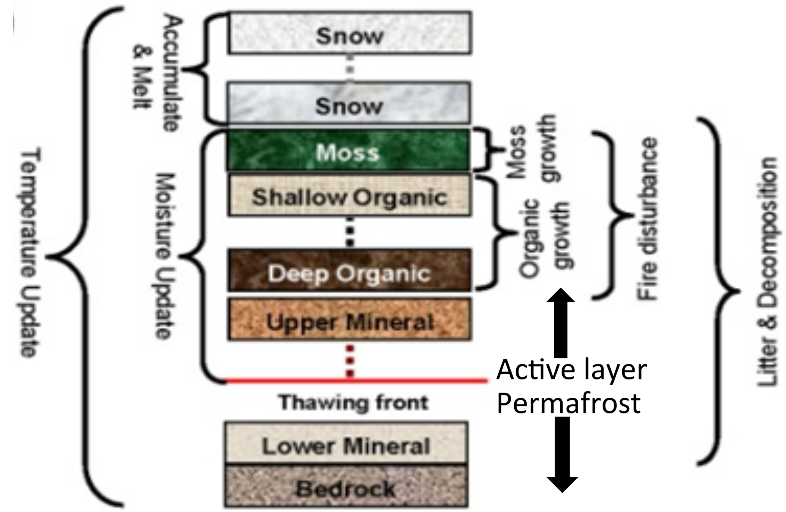




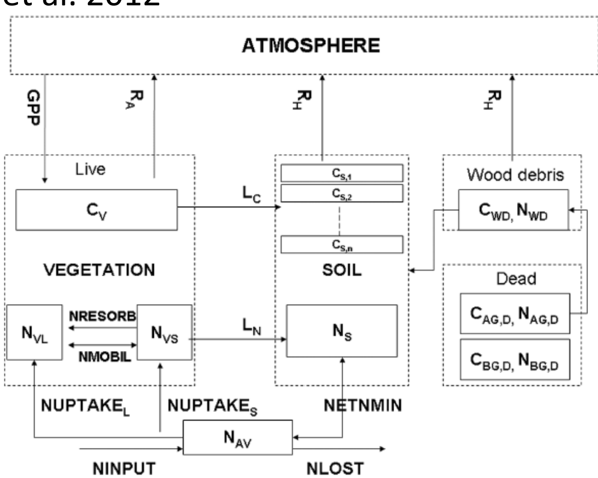
- Northern most point in the US
- Ice-rich continuous permafrost
- Sedge/Grass moss wetland (CAVM 2005)
- Lakes, DTLBs, Interstitial to Polygonal ground

Process model: DOS-TEM



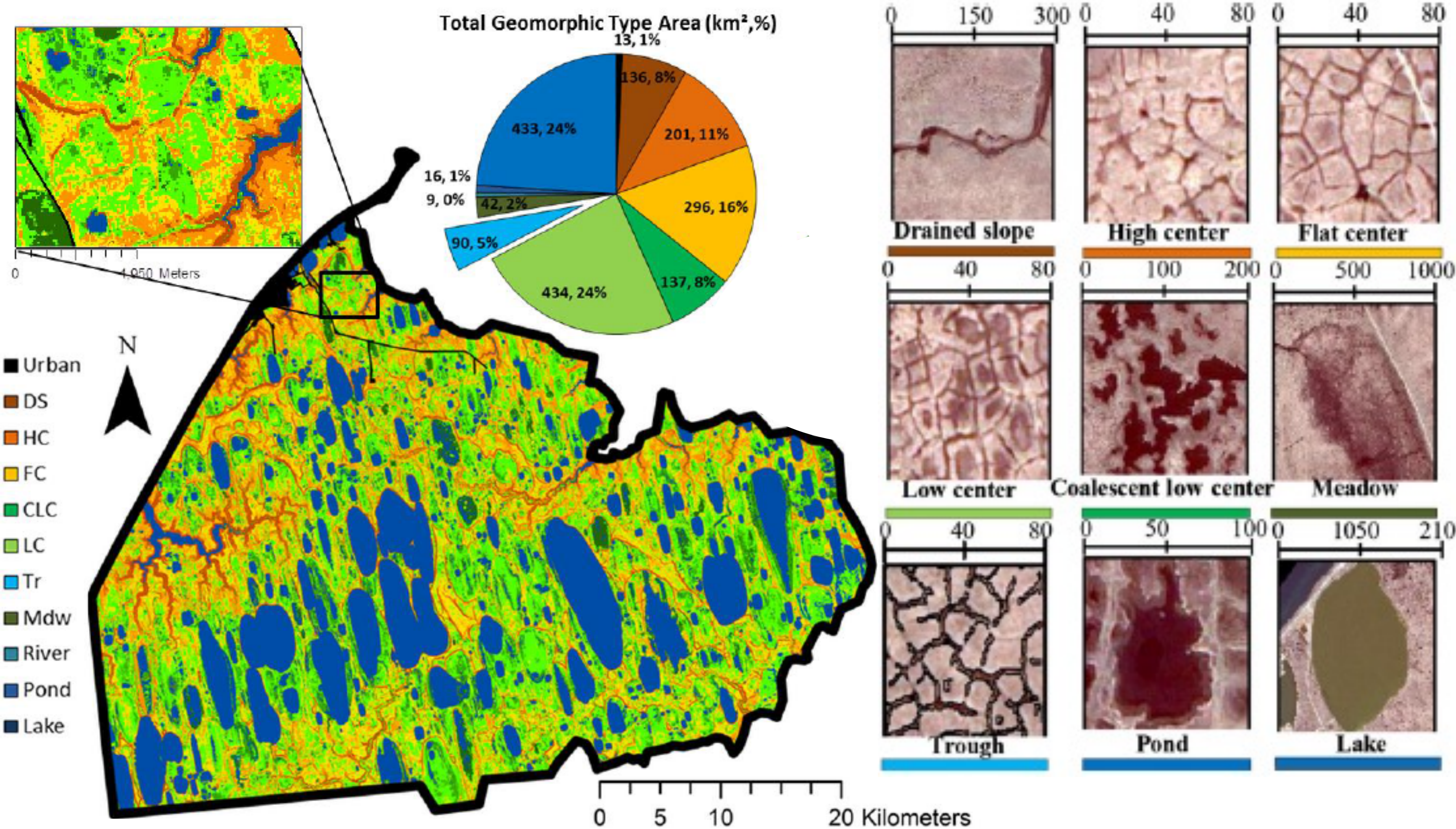


Yuan et al. 2012



- Model extensively tested and implemented arctic & boreal:
    - Genet et al. 2013, Yi et al. 2013, Yuan et al. 2012,Yi et al. 2009,2010
- Operates at a monthly, annual timescale
- Considers active layer dynamics
- Dynamic carbon /nitrogen pools

Tundra Geomorphology Map



Lara *et al.* 2015

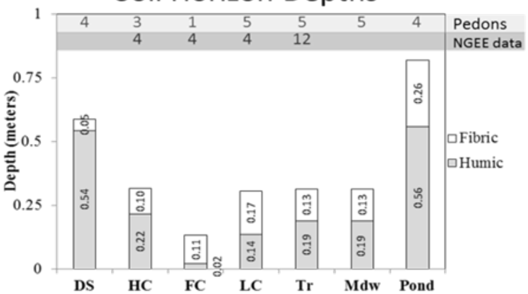
Questions

- How might landscape-level carbon balance change with projected warming through 2100 on the Barrow Peninsula?
- What is the importance of fine-scale polygonal tundra heterogeneity on landscape-level estimates of carbon balance? How much model error may be expected with the (1) increase of spatial representation (0.0009-25km^2) of the tundra landscape, and (2) reduced class (i.e., community/ land cover type) size?

Lara et al., in prep.

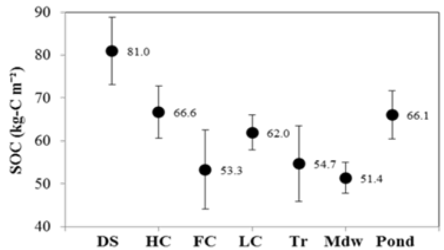
Model Parameterization

Soil Horizon Depths

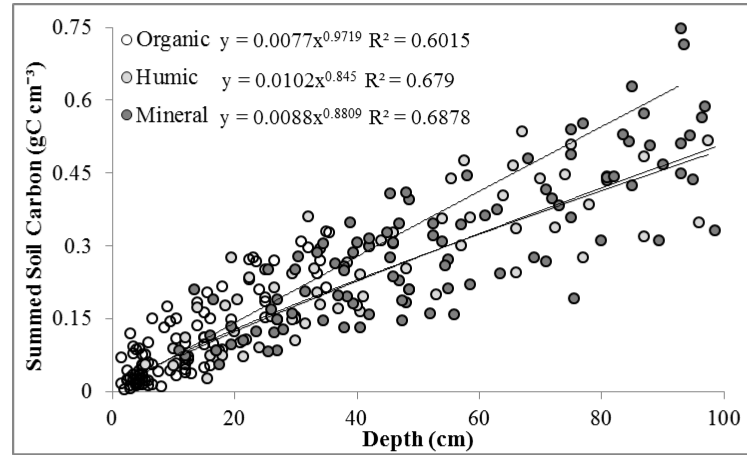


Depth representative pedons: 23
1 m depth of mineral soil

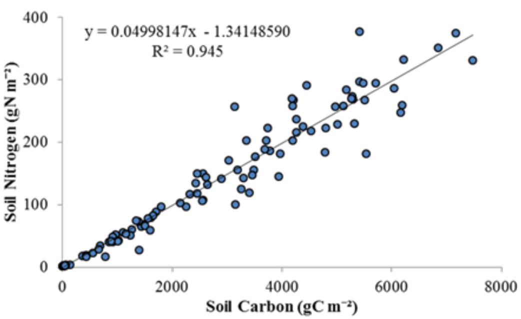
Total Soil Carbon



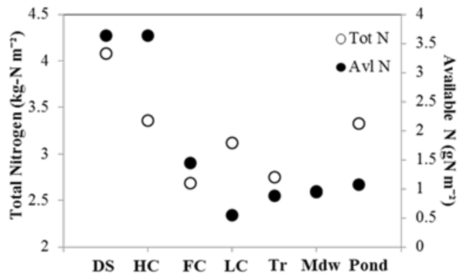
Median soil carbon pedons: 57



Estimating Total Soil N

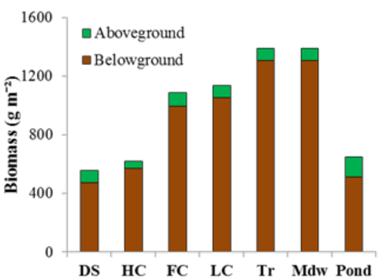


Total and Available Soil N

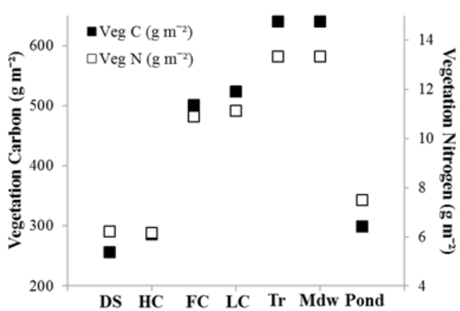


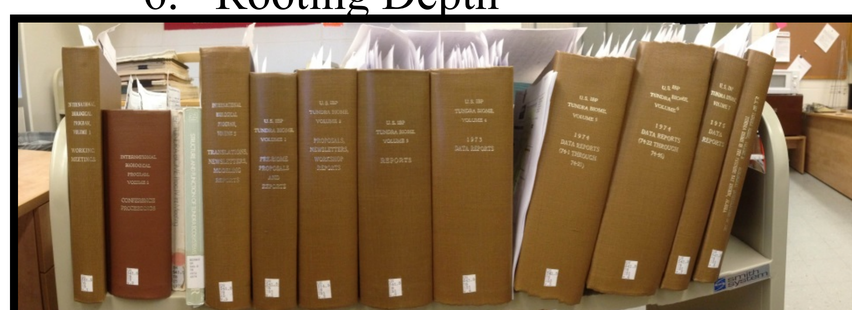
1. Soil Horizon Depth
2. Total Soil Carbon
3. Soil Nitrogen
4. Soil Texture
5. Abv/Below Veg C & N
6. Rooting Depth

Biomass by Geotype



Vegetation Carbon and Nitrogen

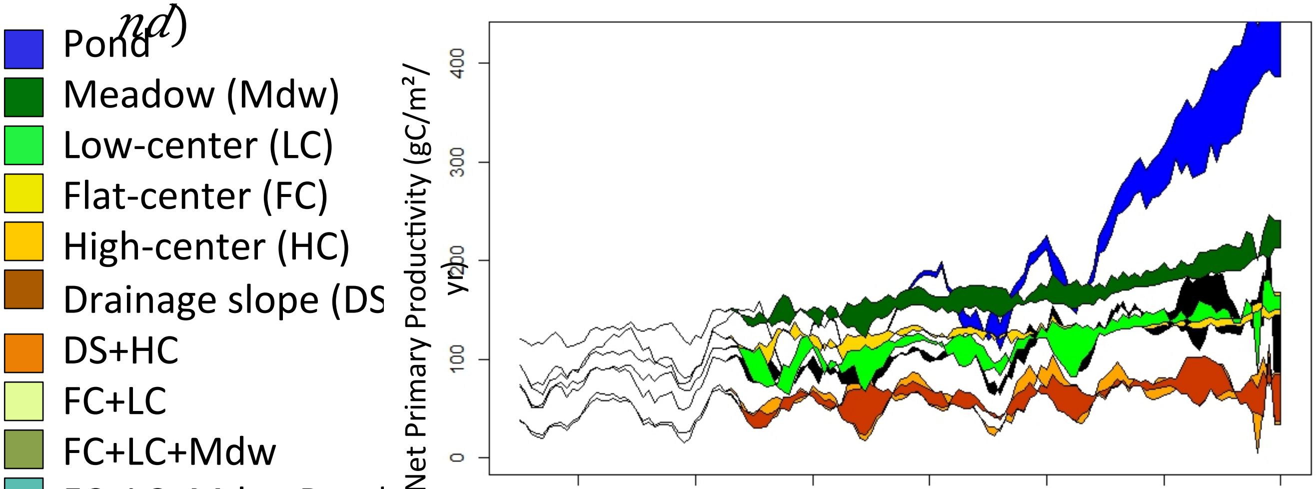




Lara et al., in prep.

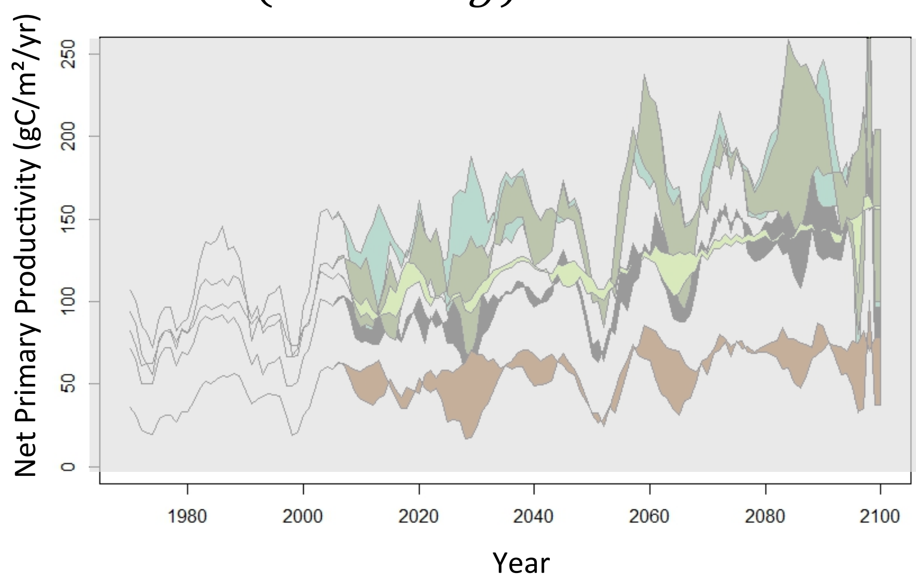
Net Primary Productivity

$$GPP = Cmax \times f(PAR) \times f(Phenology) \times f(mLeafC/yLeafC) \times f(AirTemp) \times f(CO2) \times f(CanopyConduct) \times f(Avln) \times f(unfrozenground)$$



All land cover types increasing over time, but ponds experience the most change

$$NPP = GPP - (ERm + ERg)$$

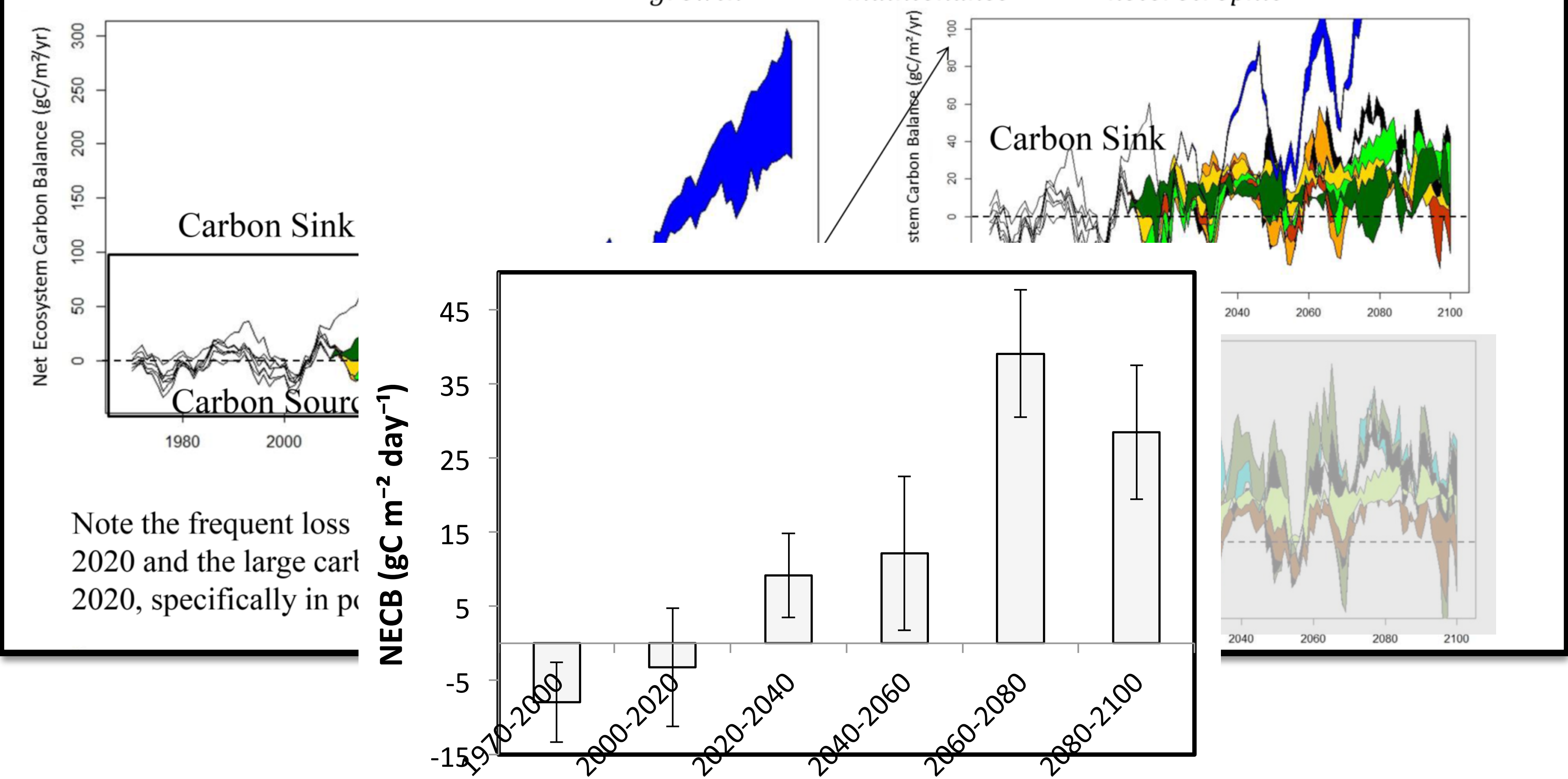


Data for each group was weighted by % cover on the landscape (Lara et al. 2015), reparameterized and recalibrated

Lara et al., in prep.

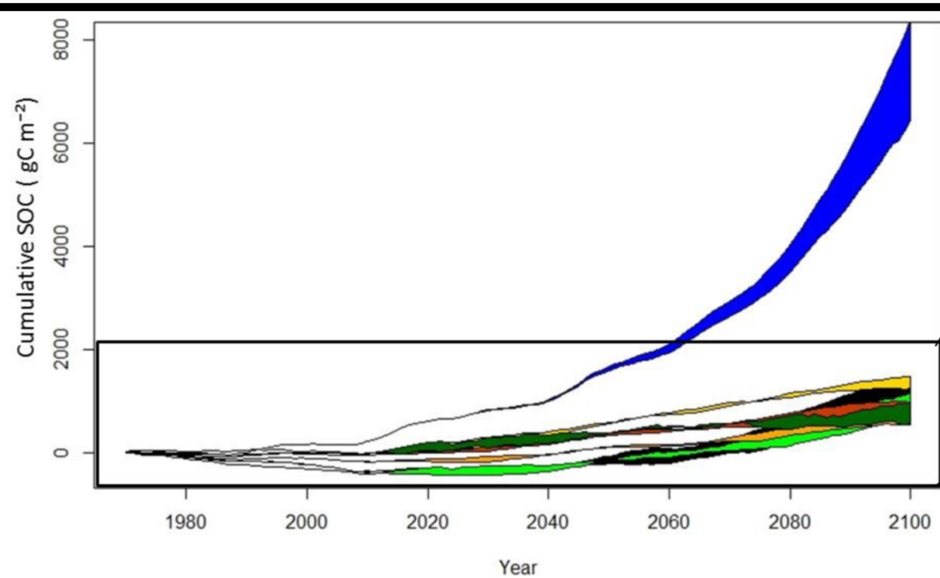
Net Ecosystem Carbon Balance

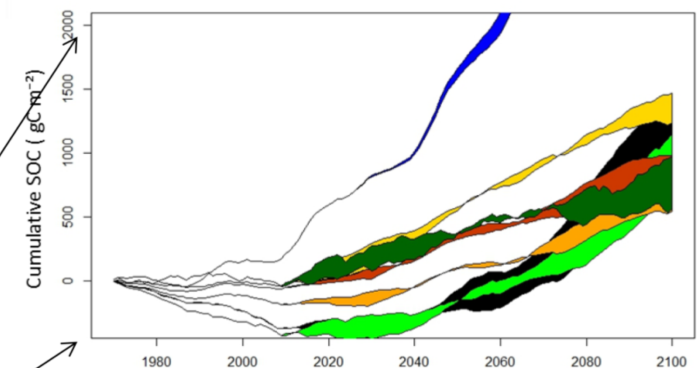
$$NECB = (GPP - (ER_{growth} + ER_{maintenance} + Er_{heterotrophic}))$$

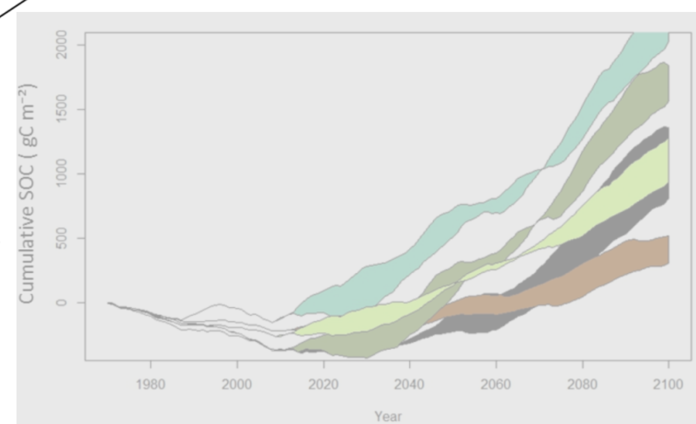


Lara et al., in prep.

Cumulative SOC (gC m^{-2})





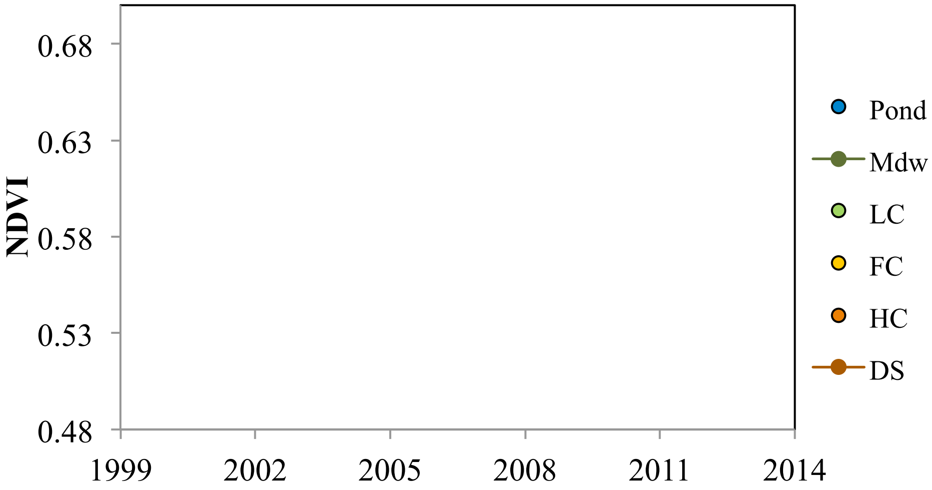


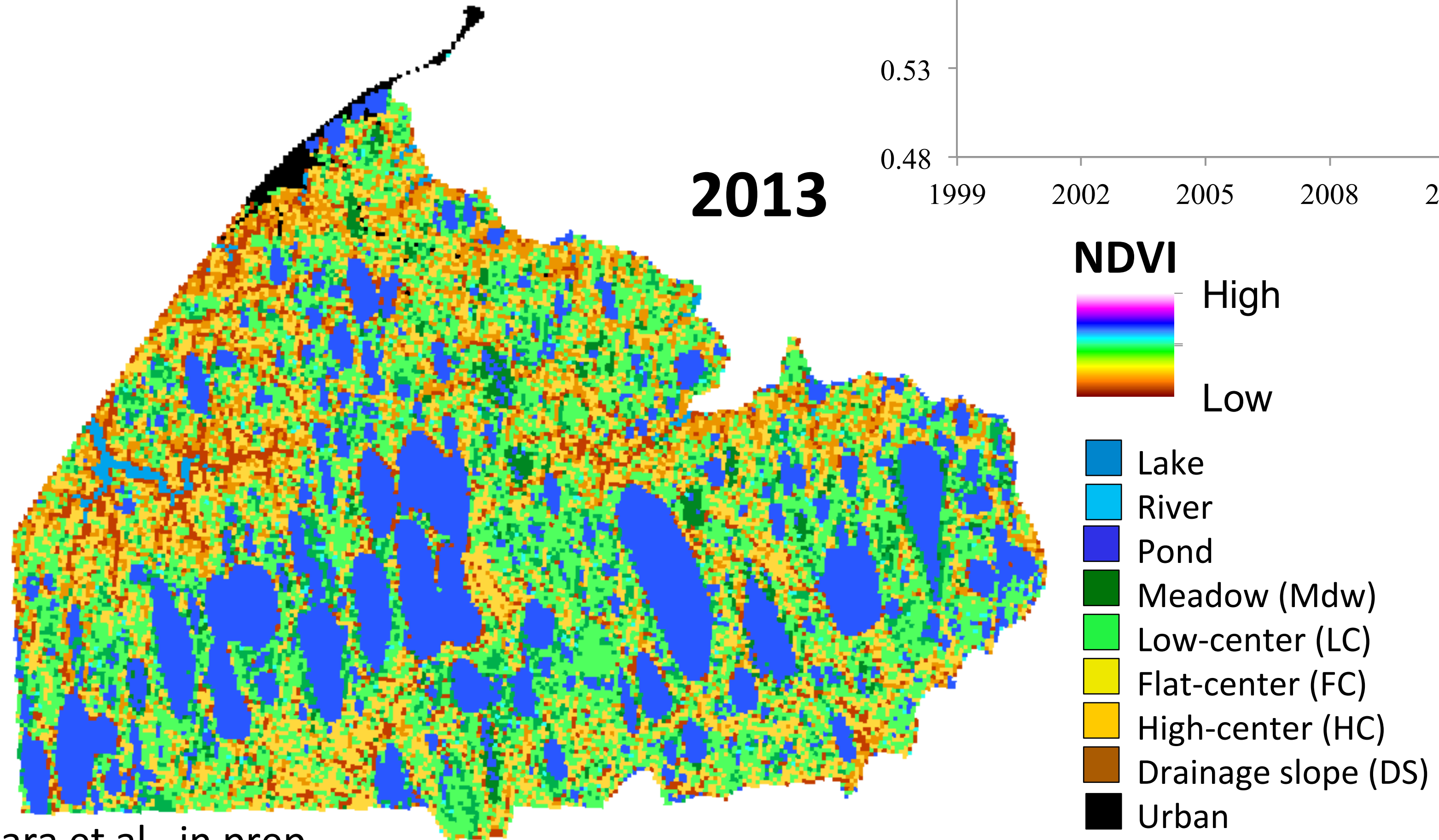
Model simulations for all geomorphic types between 1970 and 2100 for both scenarios CCCMA a2 (top of each curve) and ECHAM5 b1 (bottom of each curve). Area curves indicate climate uncertainty. Panels represent NPP (gCm^{-2} yr^{-1}) top, NECB (gCm^{-2} yr^{-1}) middle, and Cumulative Soil Carbon (gCm^{-2} yr^{-1}). Above dotted line on NECB plots represent carbon sink and below represent carbon source to the atmosphere.

Lara et al., in prep.

Landscape-level maxNDVI trends

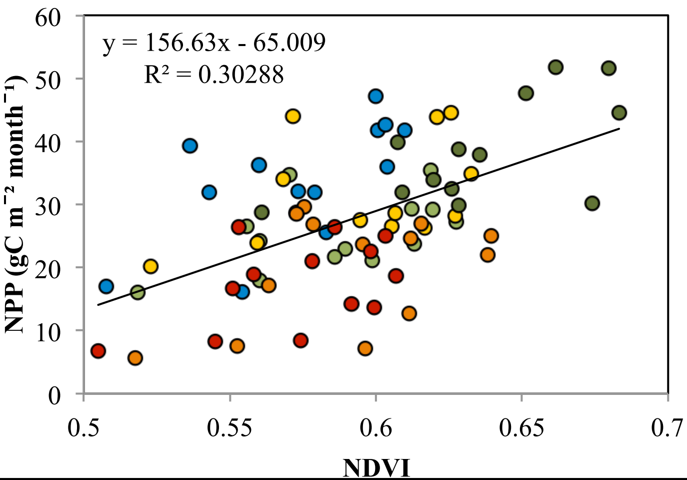
MODIS derived NDVI for each geomorphic type spanning the Barrow Peninsula





Lara et al., in prep.

Model Validation



Geotype	Slope	yint	n	R^2	Pvalue
DS	112.28	-46.906	13	0.23	*0.09624*
HC	112.7	-46.68	13	0.2	0.124137
FC	102.06	-28.988	13	0.18	0.155483
LC	95.365	-30.584	13	0.28	*0.06246*
Mdw	147.11	-55.131	13	0.38	**0.02484**
Pond	198.59	-80.053	13	0.43	**0.015209**
All	156.63	-65.009	78	0.3	< **0.0001**

MODIS satellite NDVI data from early August of 2000-2013 for the Barrow Peninsula regressed against modeled NPP data for Aug. with individual statistics for each geomorphic type.

Sampling Period	Observed Biomass (gm^{-2})	Simulated Biomass (gm^{-2})
1971-72	87.4	86.9
2010-2013	151.1	124

Mean peak growing season (July,Aug.) estimates

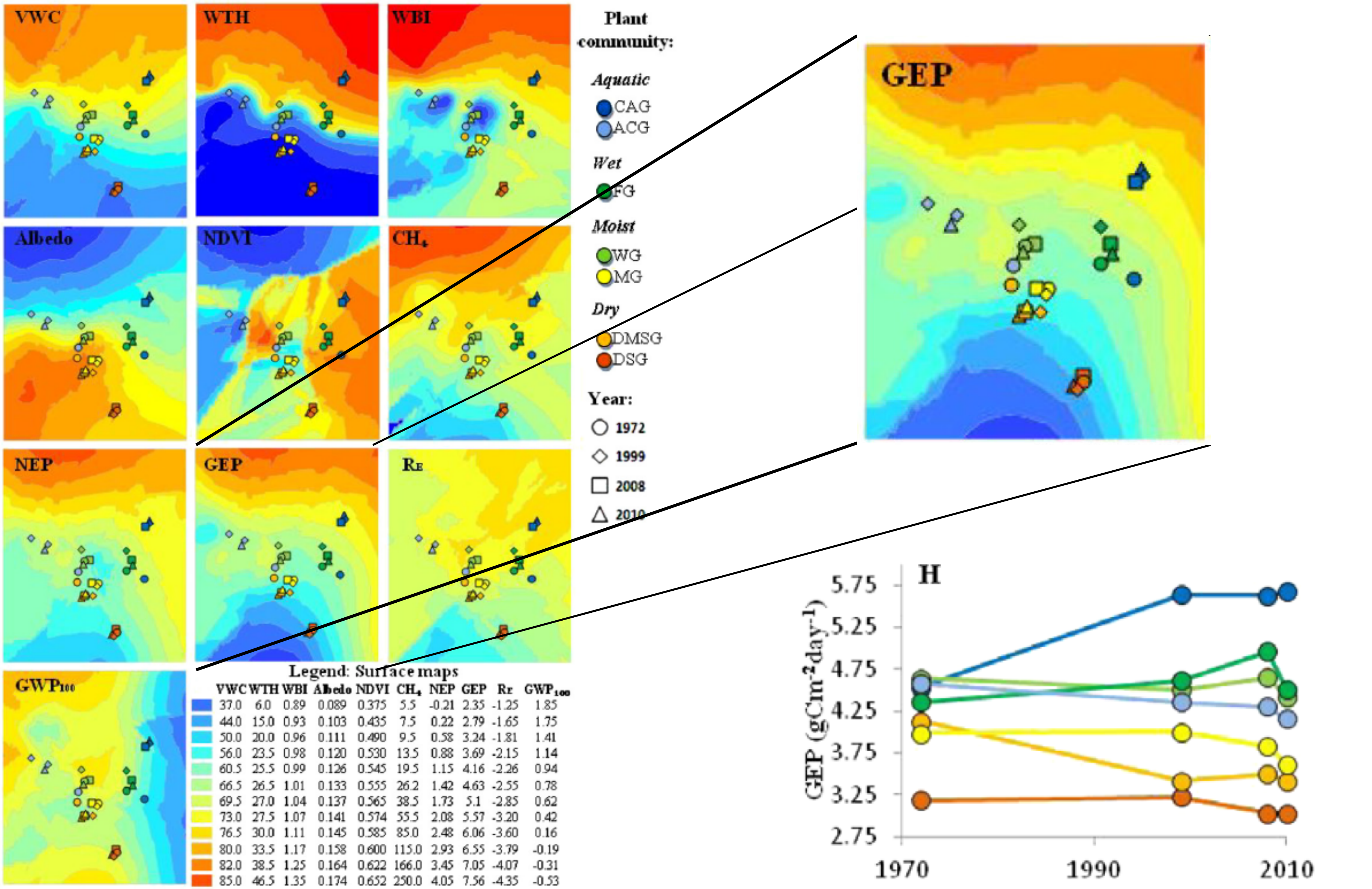
Pond vegetation cover has increased at a higher rate then any other plant community since 1972
- Villarreal et al. 2012

Changes may be attributed to increased Nitrogen
- Lougheed et al. 2011

Repeat photography and resampling data showing the increase of pond vegetation since the early 1970s, with associated model simulated biomass.

Lara et al., in prep.

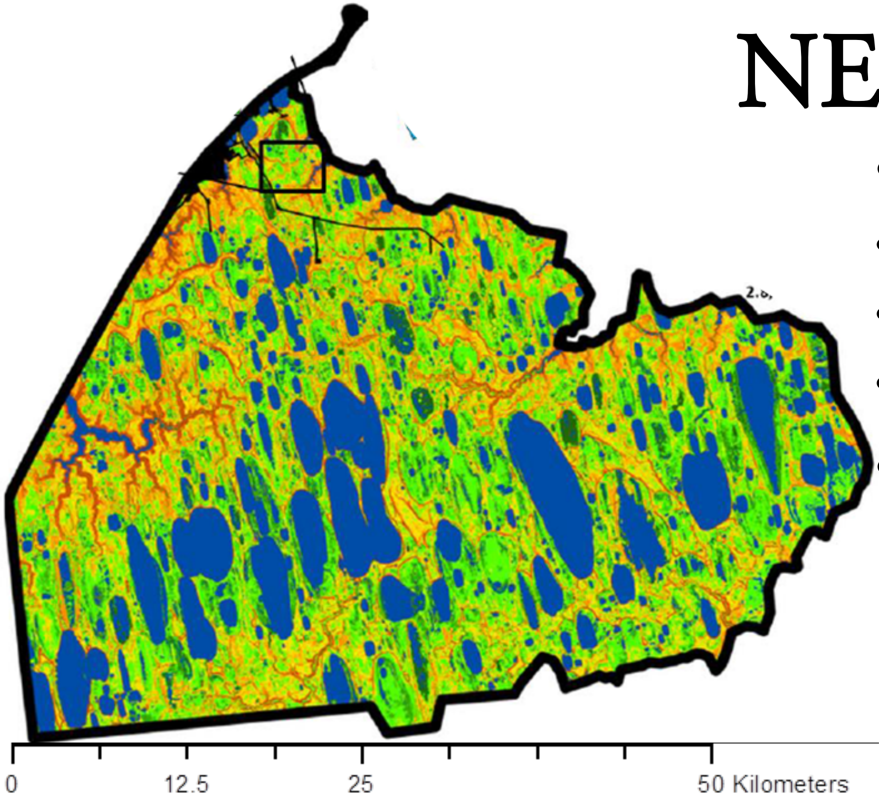
Retrogressive community-level modeling



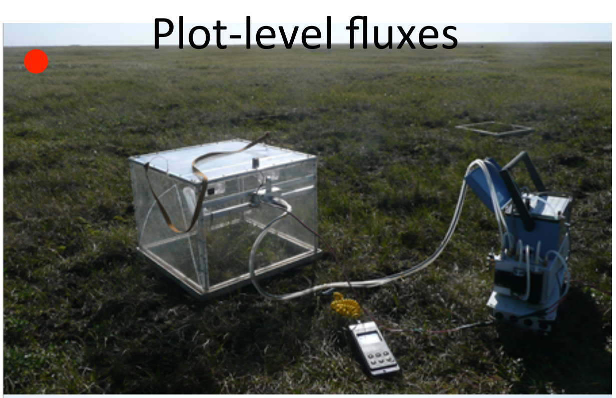
VWC	WTH	WBI	Albedo	NDVI	CH_4	NEP	GEP	R_E	GWP_{100}
37.0	6.0	0.89	0.089	0.375	5.5	-0.21	2.35	-1.25	1.85
44.0	15.0	0.93	0.103	0.435	7.5	0.22	2.79	-1.65	1.75
50.0	20.0	0.96	0.111	0.490	9.5	0.58	3.24	-1.81	1.41
56.0	23.5	0.98	0.120	0.530	13.5	0.88	3.69	-2.15	1.14
60.5	25.5	0.99	0.126	0.545	19.5	1.15	4.16	-2.26	0.94
66.5	26.5	1.01	0.133	0.555	26.2	1.42	4.63	-2.55	0.78
69.5	27.0	1.04	0.137	0.565	38.5	1.73	5.1	-2.85	0.62
73.0	27.5	1.07	0.141	0.574	55.5	2.08	5.57	-3.20	0.42
76.5	30.0	1.11	0.145	0.585	85.0	2.48	6.06	-3.60	0.16
80.0	33.5	1.17	0.158	0.600	115.0	2.93	6.55	-3.79	-0.19
82.0	38.5	1.25	0.164	0.622	166.0	3.45	7.05	-4.07	-0.31
85.0	46.5	1.35	0.174	0.652	250.0	4.05	7.56	-4.35	-0.53

Lara et al., 2012

Observed vs Modeled peak growing season NEE



- **CO_2 exchange**
- NEE: -1024 ± 49 10^6 gC day^{-1}, Lara et al 2015
- NEE: -1431 10^6 gC day^{-1}, Zulueta et al. 2011
- Modeled NEE: -1092 10^6 gC day^{-1}
- **CH_4 exchange**
  - 30 ± 17 10^6 gC day^{-1}, Lara et al. 2015
    - Similar spatial patterns: Zona et al. 2010, Sturtevant & Oechel 2013

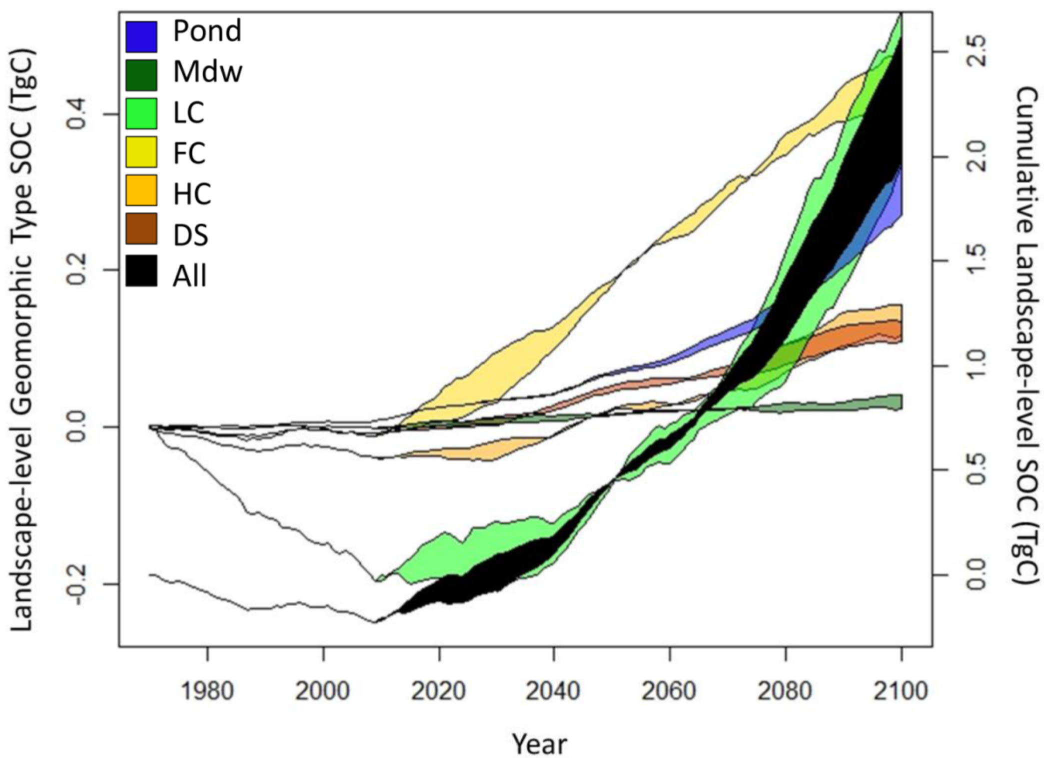


Plots/fluxes =73/365

LANDSCAPE LEVEL Δ SOC BETWEEN 1970-2100

1Teragram(T*g*) $= 1{,}000{,}000{,}000{,}000$ g

Fine scale $= 0.0009km^2$ & *Group* 6



Increased NPP in response to warming, active layer depth, increased nutrient availability, longer growing season, and CO2 fertilization

Though winter respiration is poorly represented

Estimated change in soil carbon by 2100

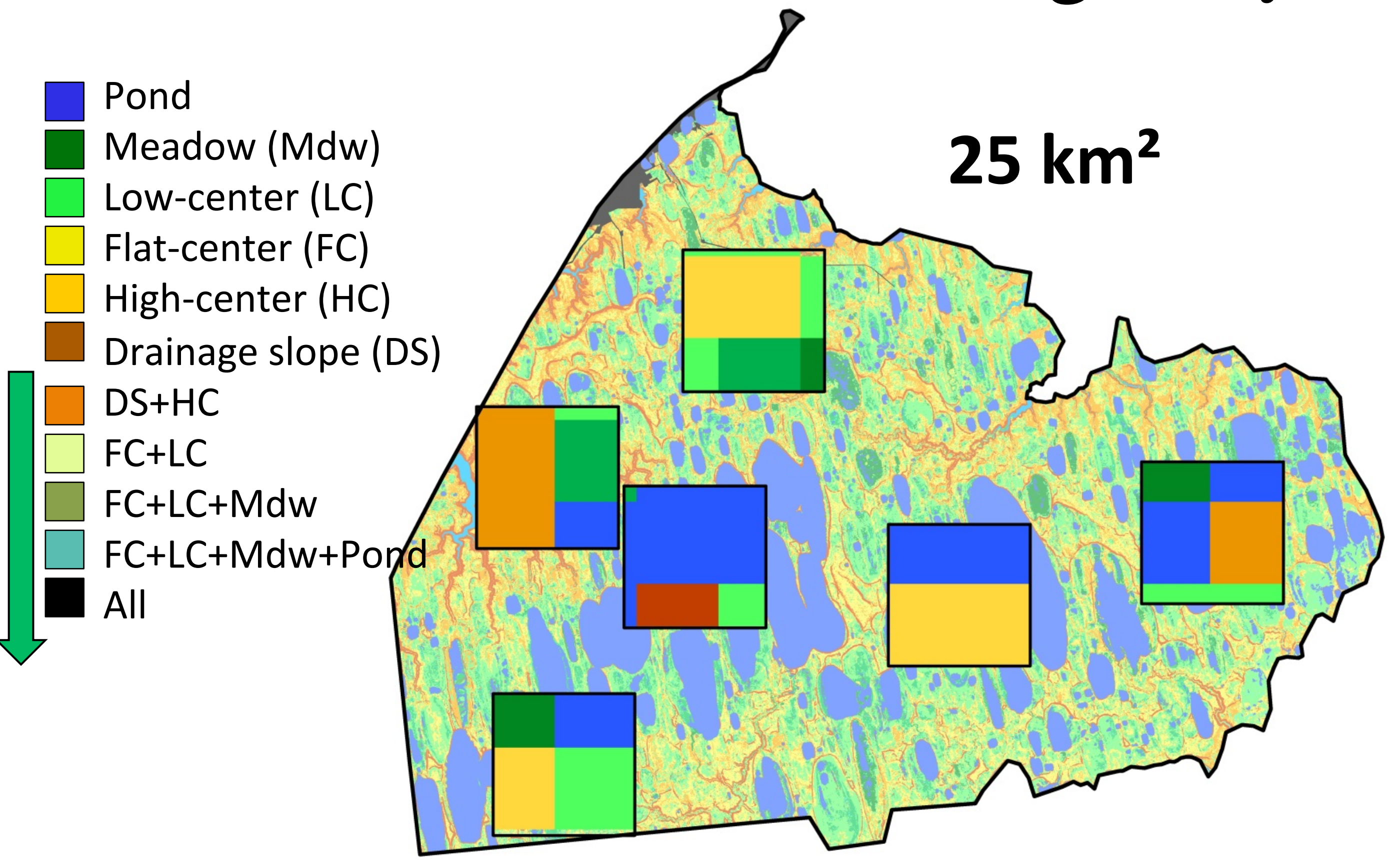
– All classes (black): +2.61 to +1.96 Tg for the Barrow Peninsula

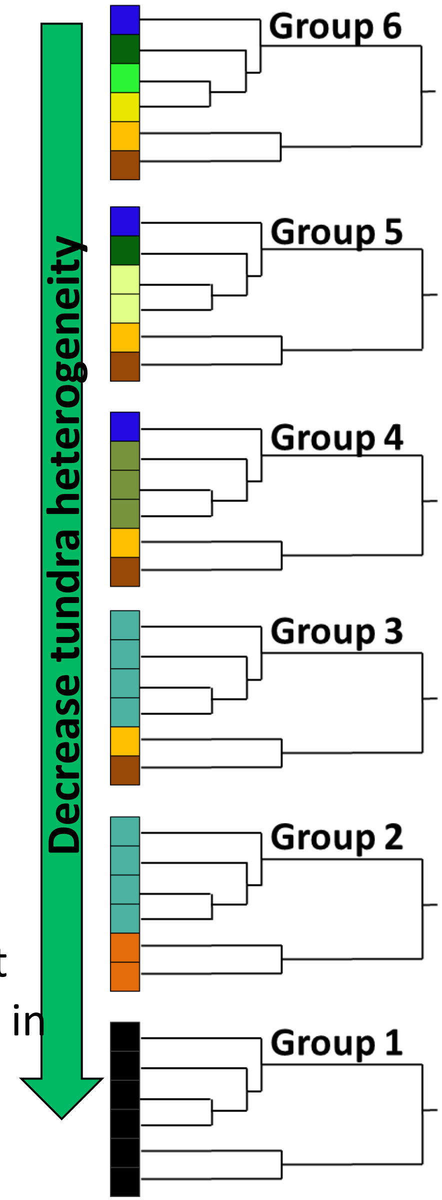
Lara et al., in prep.

Questions

- How might landscape-level carbon balance change with projected warming through 2100 on the Barrow Peninsula?
- What is the importance of fine-scale polygonal tundra heterogeneity on landscape-level estimates of carbon balance? How much model error may be expected with the (1) increase of spatial representation (0.0009-25km²) of the tundra landscape, and (2) reduced class (i.e., community/ land cover type) size?

Uncertainty evaluation associated with land cover heterogeneity





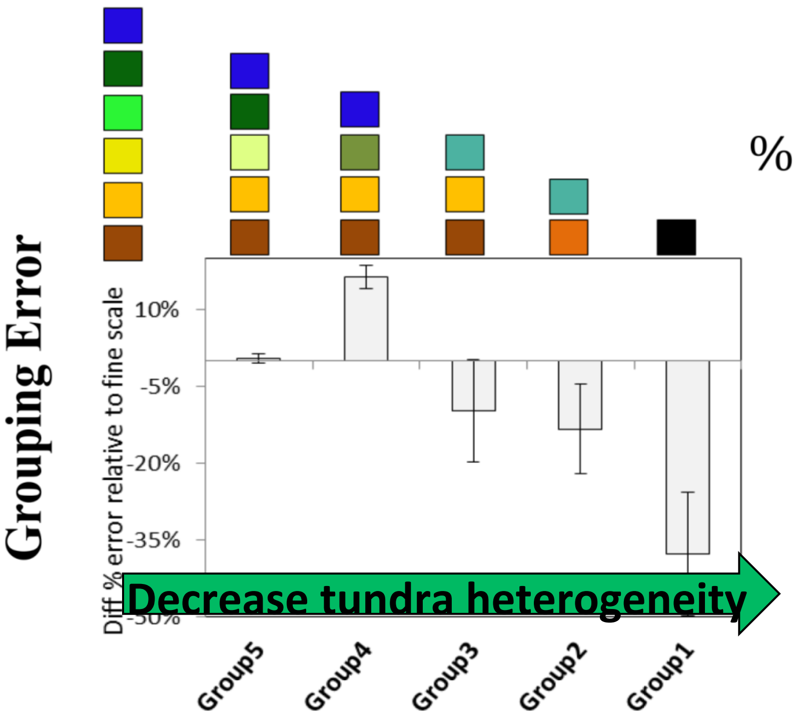
We compare lower resolution model outputs to the fine scale or highest resolution (Group 6 and $0.0009 km^2$) to estimate landscape-level change in carbon balance through 2100.

Lara et al., in prep.

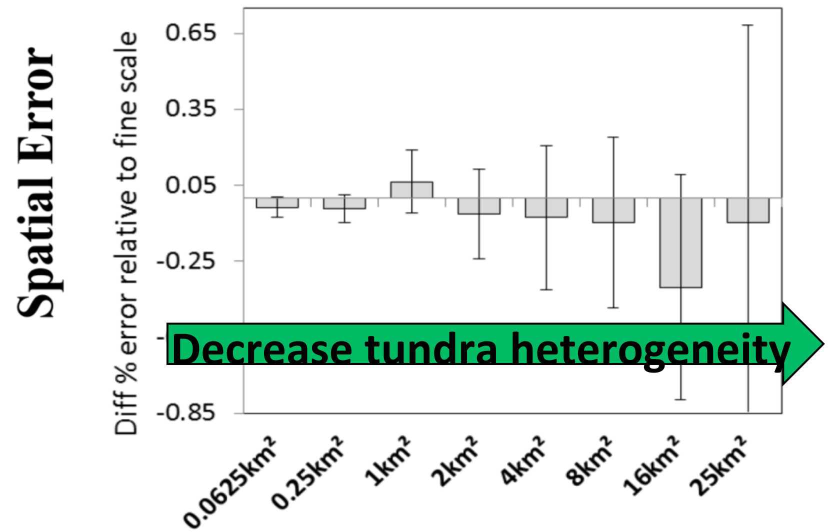
MODEL ERROR

$$\textit{Fine scale} = 0.0009km^2 \;\&\; \textit{Group } 6$$

$$\%\ \textit{Error} = \frac{\Delta SOC \textit{ for Spatial Scale } x \;\&\; \textit{Group } x}{\textit{Fine scale}}$$



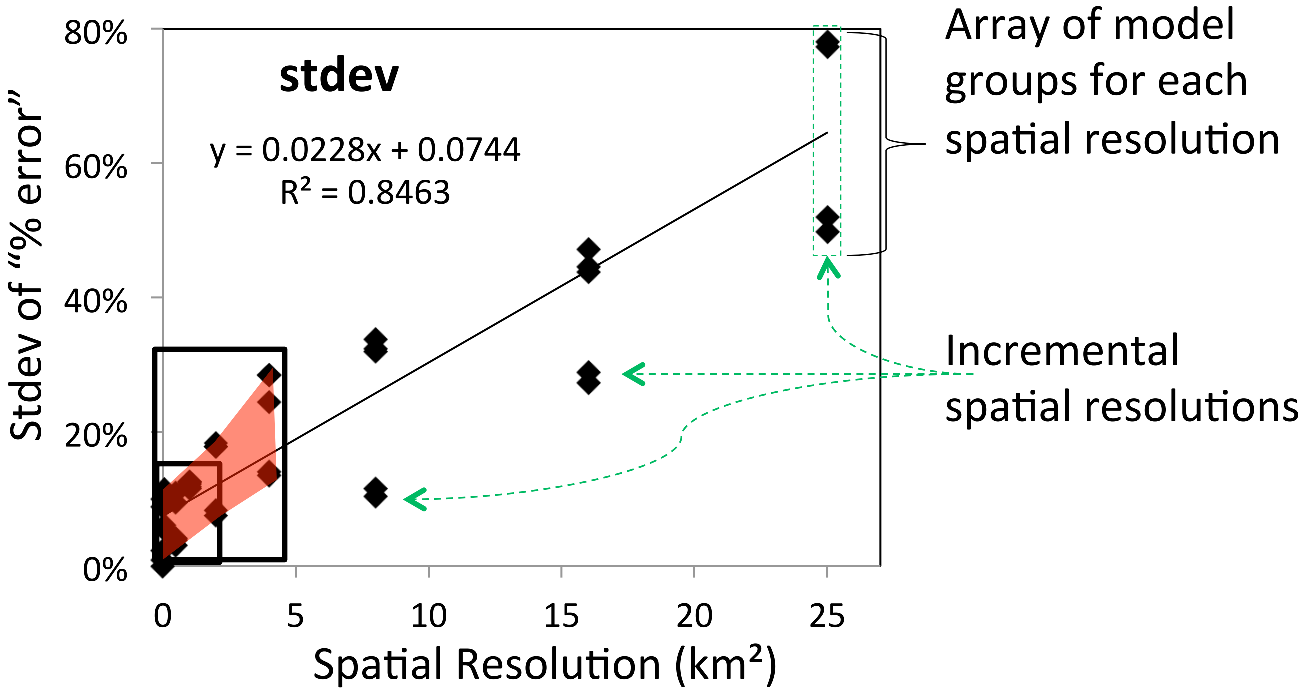
Error increased by decreasing group size (i.e. decreasing landscape heterogeneity). % error estimates were restricted to the highest spatial resolution ("fine scale"), but all groups are considered. Stdev bars are associated to the six 75 km² windows .



Error increased with coarser spatial resolution of tundra geomorphology. % error estimates are restricted to 6 groups ("fine scale"). Stdev bars are associated with the six 75 km² windows.

Lara et al., in prep.

Model error due to increasing spatial resolution/ group size (i.e. decreasing heterogeneity)



Model *error increases ~2.3% for each 1 km² coarsening of spatial resolution.*

Analysis recommends a maximum spatial resolution of ≤2 km² and 2 group size (dry/wet) to minimize error (~10 to 20%) and maximize computational efficiency for large-scale model applications

Lara et al., in prep.

Take Home Messages

- Though we find the CO_2 sink strength to increase (2100), winter processes (after soils freeze) are poorly constrained, and CH_4 dynamics are not considered (in progress)
- Model error increases with decreasing tundra heterogeneity
- *Maximize* computational efficiency, *minimize* model uncertainty (≤2km^2 and 2 groups)
- Methods for integrating across scales of land cover heterogeneity is important for reducing model uncertainty/variability

Acknowledgements

Data Collection/Contacts

- Next Generation Ecosystem Experiments (NGEE-Arctic)
- International Biological Research Program
- Kenneth Hinkel, James Bockhiem, Chris Johnson: soil pedons
- Jerry Brown; IBP data contact

Validation Datasets

- Vanessa Lougheed & Christian Andresen Pond Biomass/repeat photography
- MODIS, NASA

Funding Agencies

- Department of Energy