Linking and Comparing Models to Explore the Impacts of Ecosystem Change in Alaska and Northwest Canada

Eugénie Euskirchen & the Integrated Ecosystem Model (IEM) Team

UNIVERSITY OF ALASKA FAIRBANKS

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Arctic, Western Alaska, Northwest Boreal, and North Pacific LCCs

Background

How to asses the effects of climate change on ecosystem services?

Need tools capable of forecasting how landscape structure and function might change in response to climate change

- **Vegetation shifts**
- **Drought stress**
- **Fire**
- **Permafrost integrity**

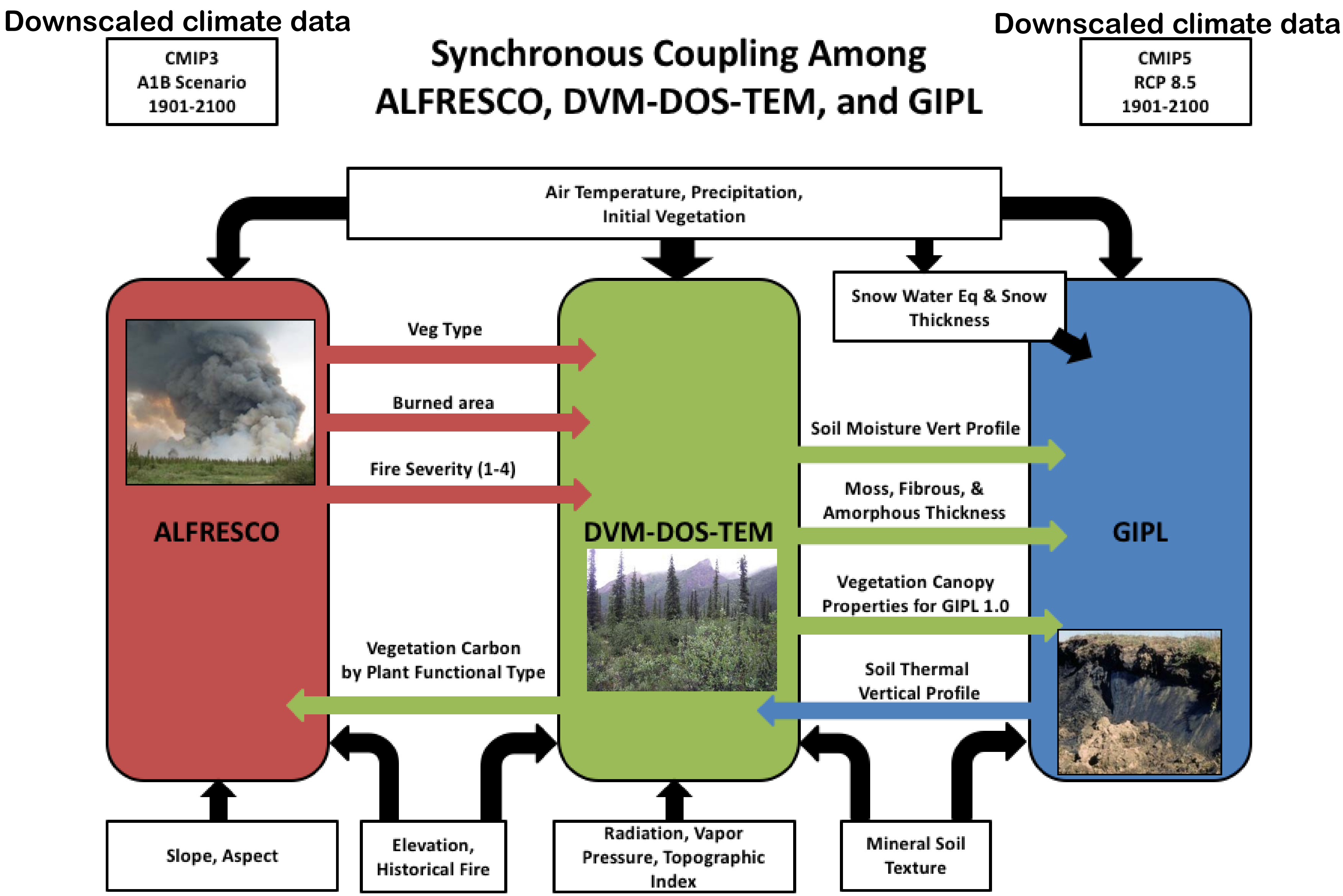
Space **Time**

Integrated Ecosystem Model for Alaska and Northwest Canada (IEM)

A *support tool* to inform:

- Response of ecosystems to climate & land cover/use change
- Processes that affect species and habitats
- Development of impact models
- Assessments of natural resource responses
- Adaptation and management responses

What are the Components of the IEM?



Model coupling: time step synchronization, dynamic data sharing, storage

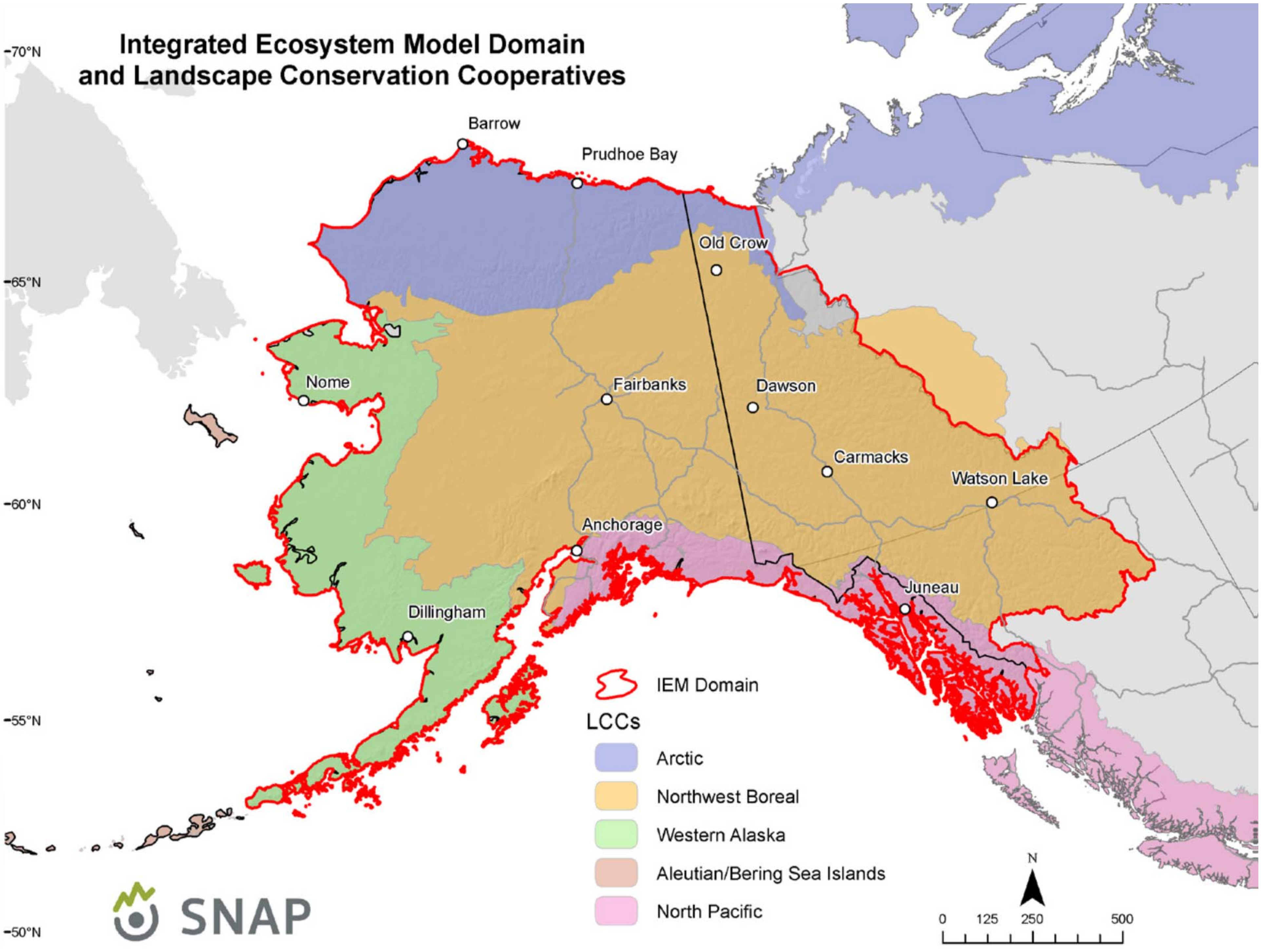
Example outputs:

- Vegetation cover
- Vegetation shifts
- Vegetation growth
- Species composition
- Fire occurrence
- Fire size
- Surface hydrology
- Snow cover
- Snow depth
- Permafrost depth
- Active layer depth
- C Stocks / Fluxes
- N Stocks/ Fluxes
- Atmospheric heating

Example applications:

- Habitat / forage (caribou, reindeer, moose, migratory birds, etc.)
- Fire susceptibility- tundra & boreal
- Access to subsistence resources
- Changing plant biodiversity
- Areas most vulnerable to degradation (e.g, with increased tourism & development)

Conservation & Resource Management Decisions



Integrated Ecosystem Model Domain
and Landscape Conservation Cooperatives
70°N
65°N
60°N
55°N
50°N
Barrow
Prudhoe Bay
Old Crow
Nome
Fairbanks
Dawson
Carmacks
Watson Lake
Anchorage
Juneau
Dillingham
IEM Domain
LCCs
Arctic
Northwest Boreal
Western Alaska
Aleutian/Bering Sea Islands
North Pacific
N
0
125
250
500
SNAP

1 km^2 spatial scale

Dataset extent

January 2006—December 2100

Spatial resolution: 1000 meters

Map data © OpenStreetMap contributors

Tiles by MapQuest

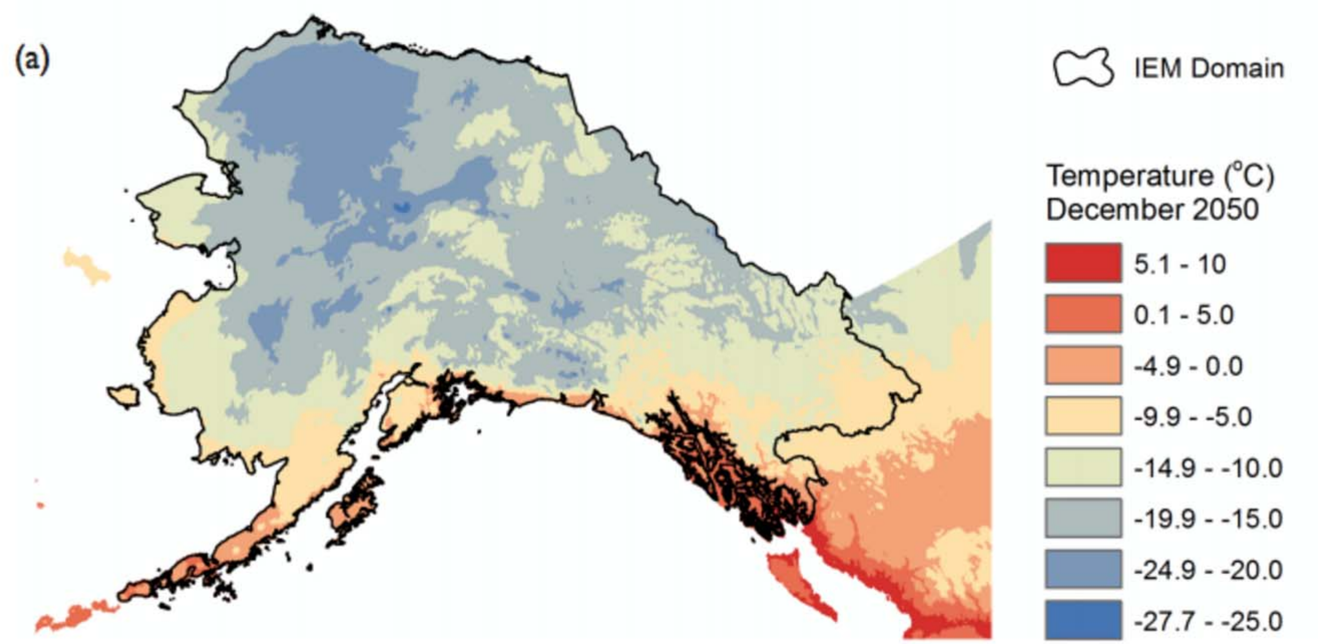
License

Creative Commons Attribution 4.0

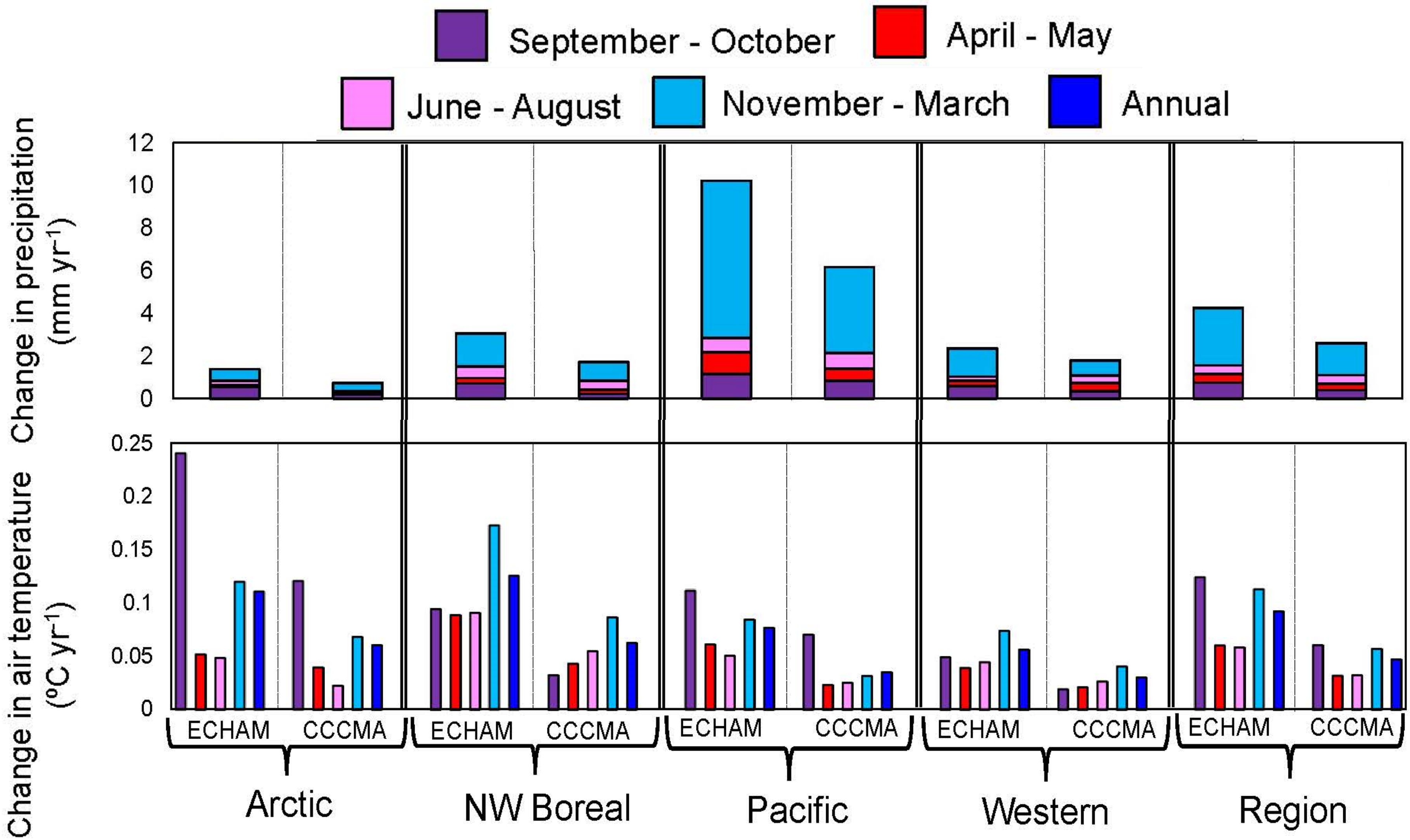
Dataset | Groups | Activity Stream | Related | Manage

Projected Monthly Temperature - 1 km AR5 4.5/6.0/8.5 - MONTHLY

- **Downscaled climate data (https://www.snap.uaf.edu/)**

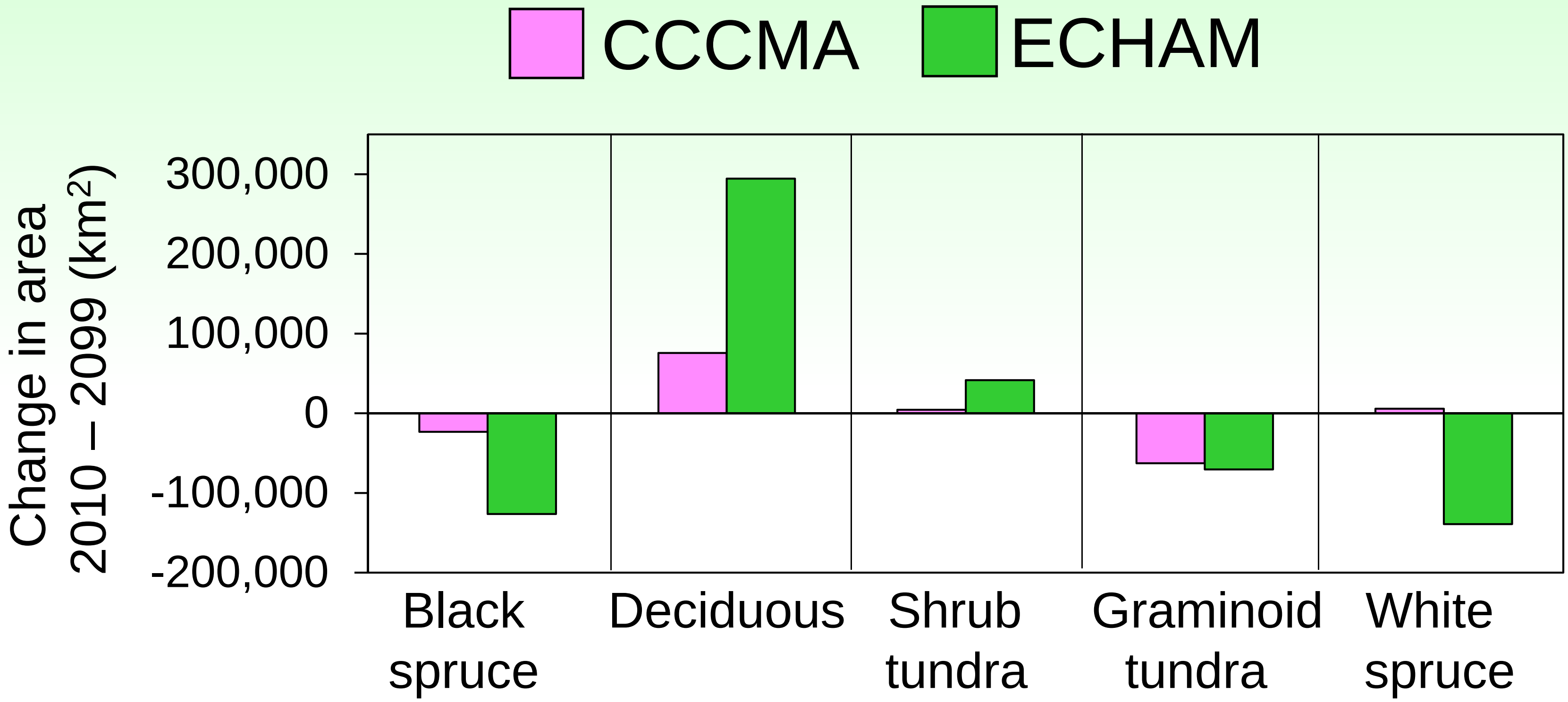


This set of files includes downscaled projections of monthly mean temperatures (in degrees Celsius, no unit conversion necessary) for each month of every year from January 2006 - December 2100 at 1x1 kilometer spatial resolution. Each file represents a single month in a given year. The original SNAP downscaled temperature product at 2x2 kilometer spatial scale was resampled to a 1x1 kilometer spatial scale using a bilinear interpolation for input in the Integrated Ecosystem Model (IEM).

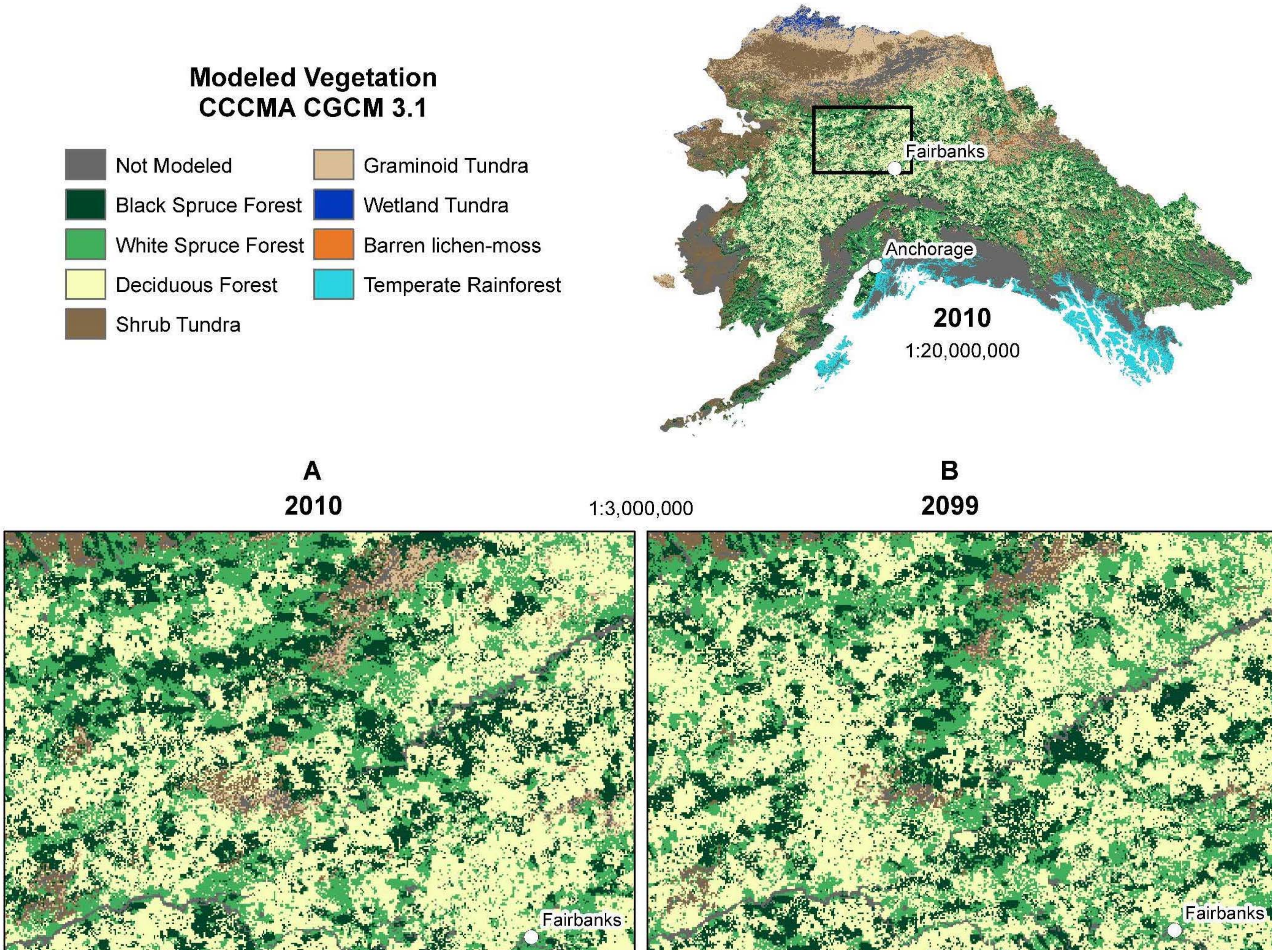


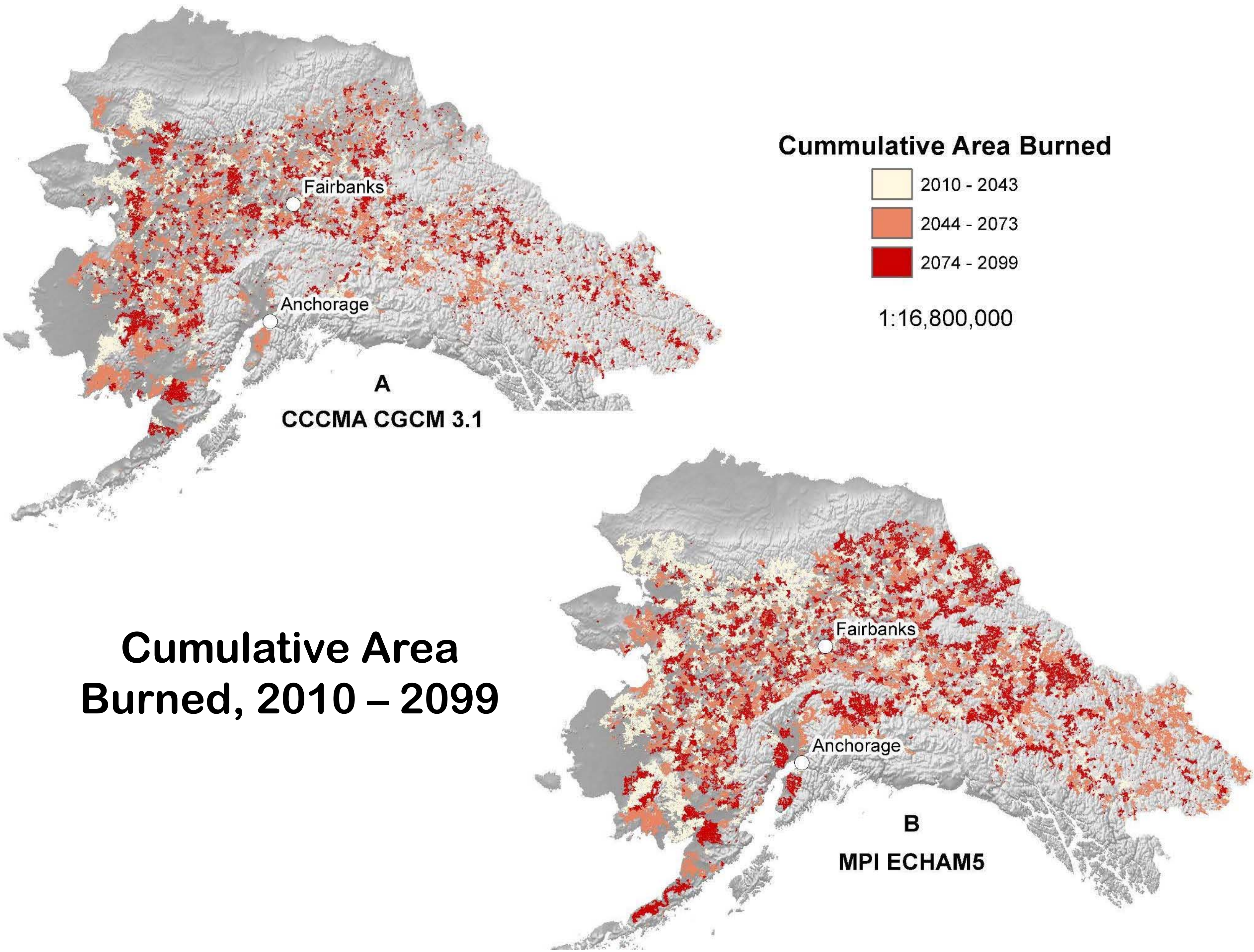
Changes in precipitation and temperature, 2010 – 2099, AIB Scenario

Region-wide changes in vegetation due to fire, treeline advance, shrubification, and drought, 2010 - 2099

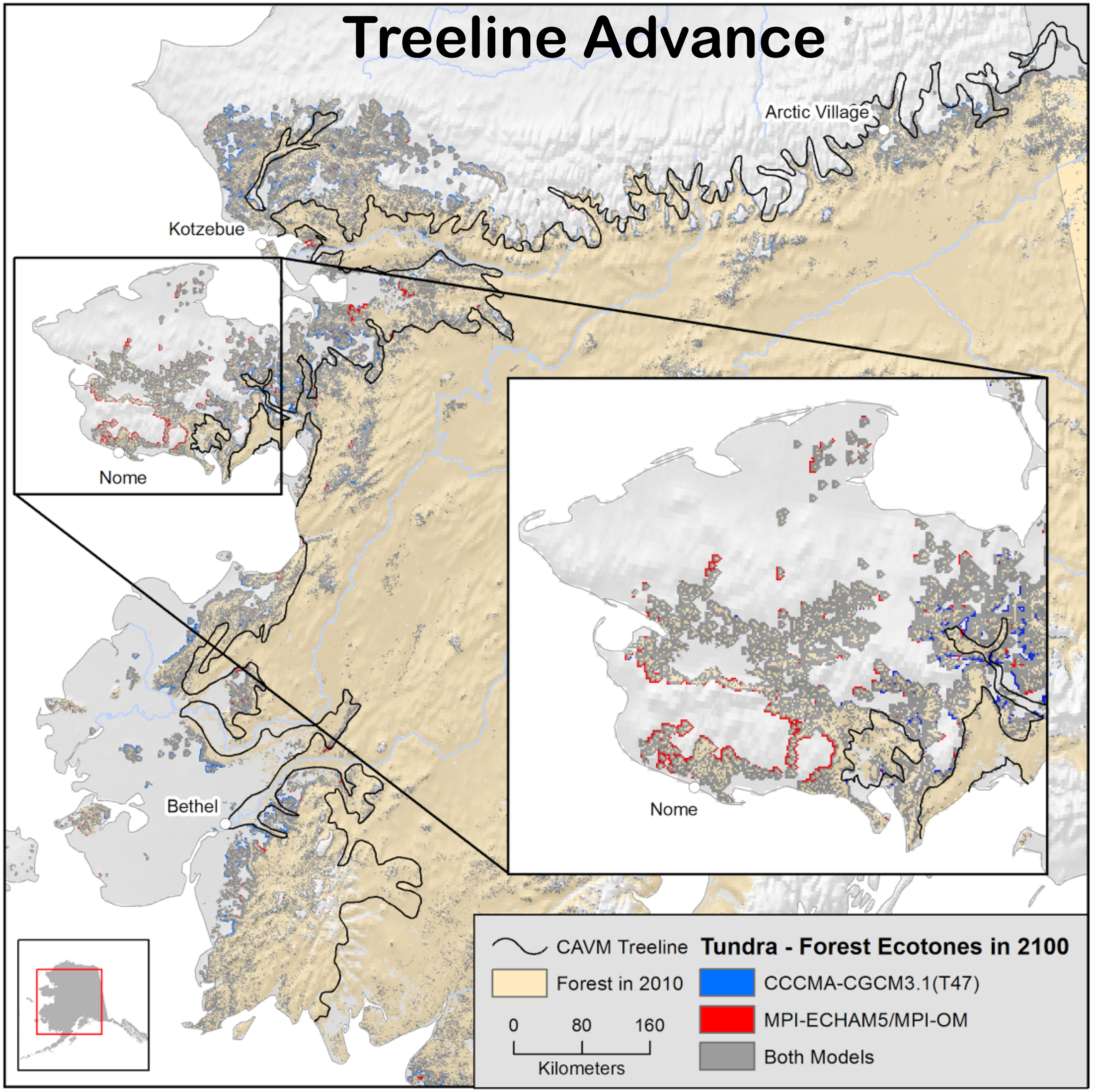


Euskirchen et al., 2016, Environmental Research Letters

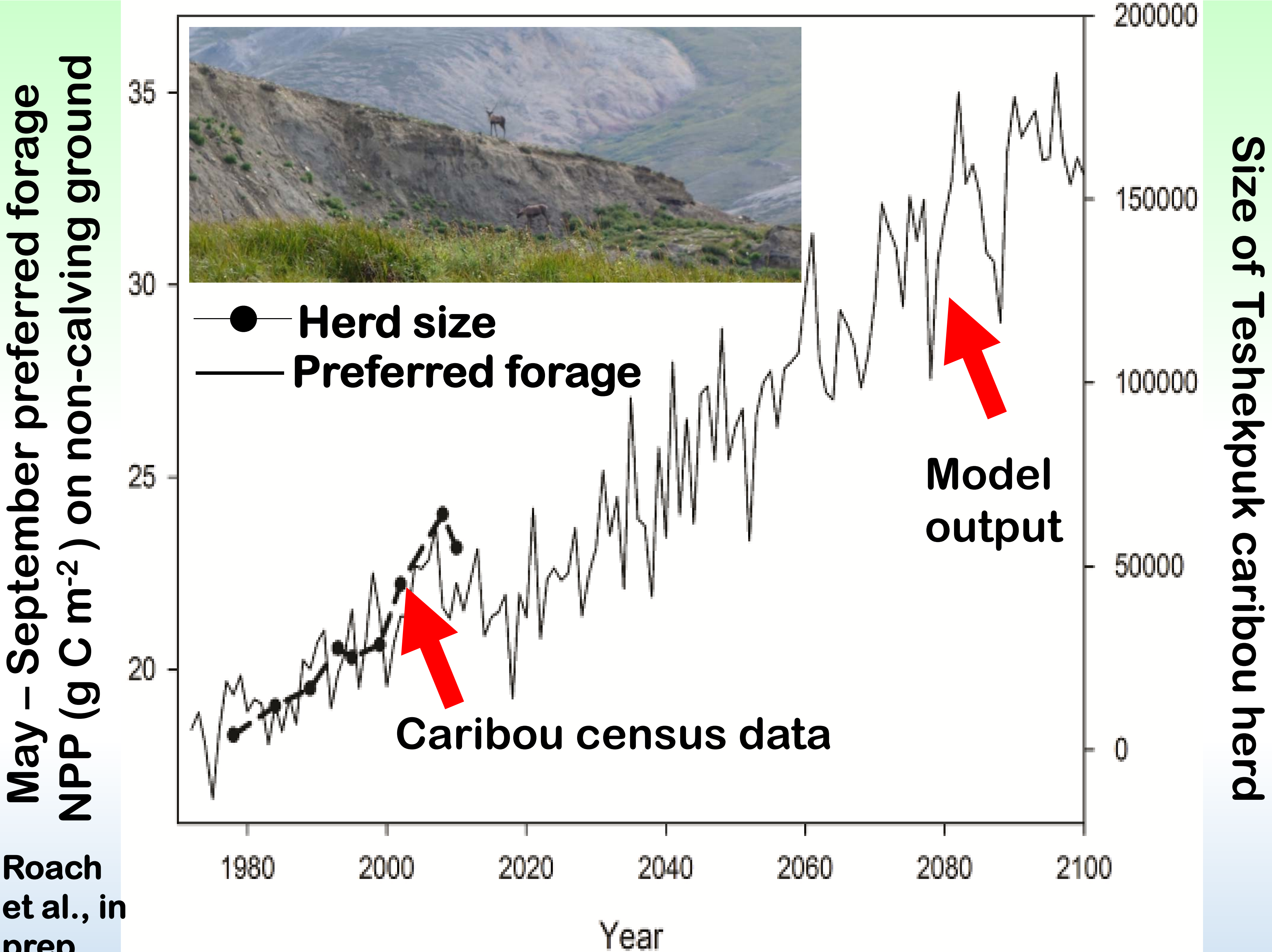

Modeled Vegetation
CCCMA CGCM 3.1
Not Modeled
Black Spruce Forest
White Spruce Forest
Deciduous Forest
Shrub Tundra
Graminoid Tundra
Wetland Tundra
Barren lichen-moss
Temperate Rainforest
Fairbanks
Anchorage
2010
1:20,000,000
A
2010
1:3,000,000
B
2099
Fairbanks
Fairbanks



Cumulative Area Burned, 2010 – 2099

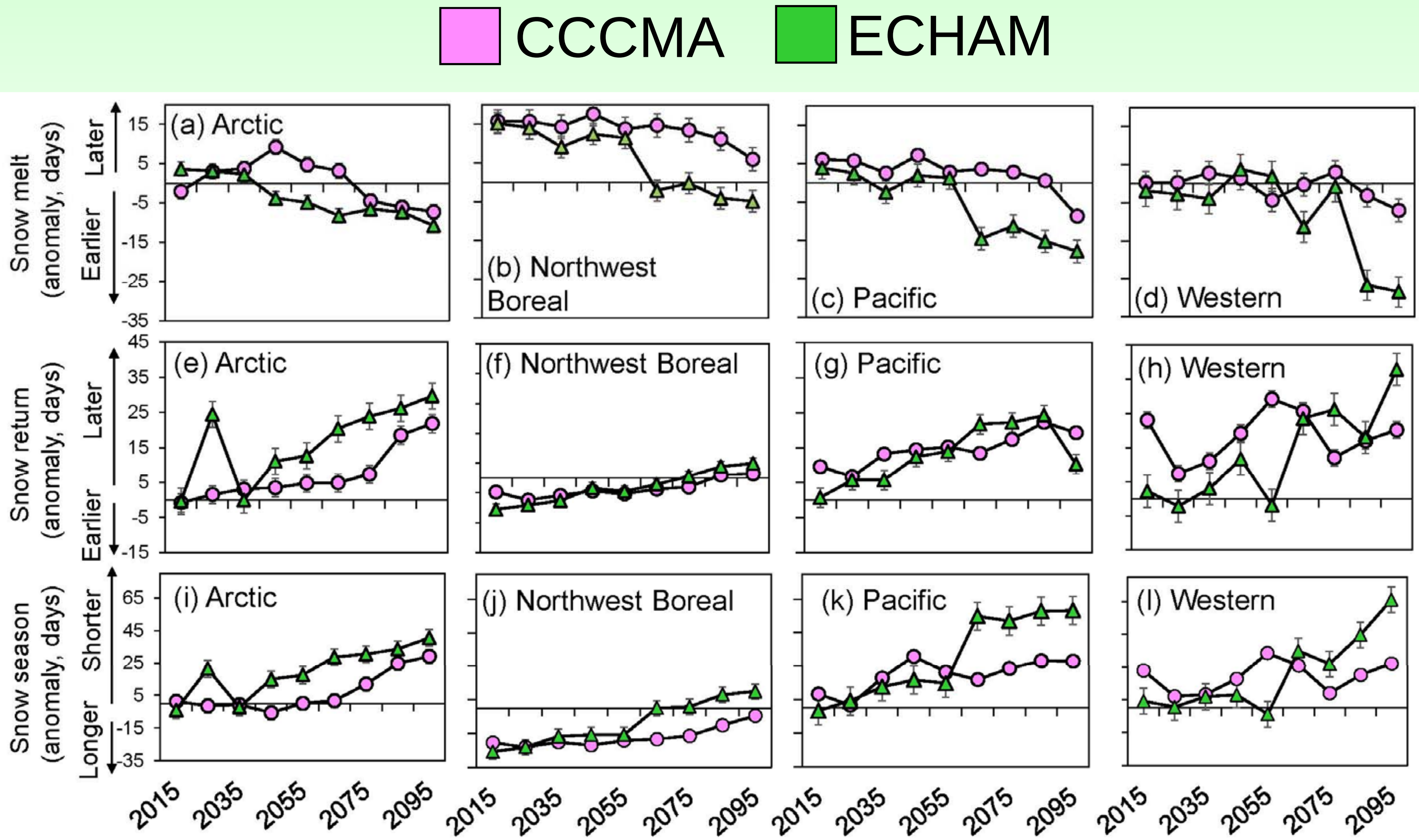


Breen et al., in prep.

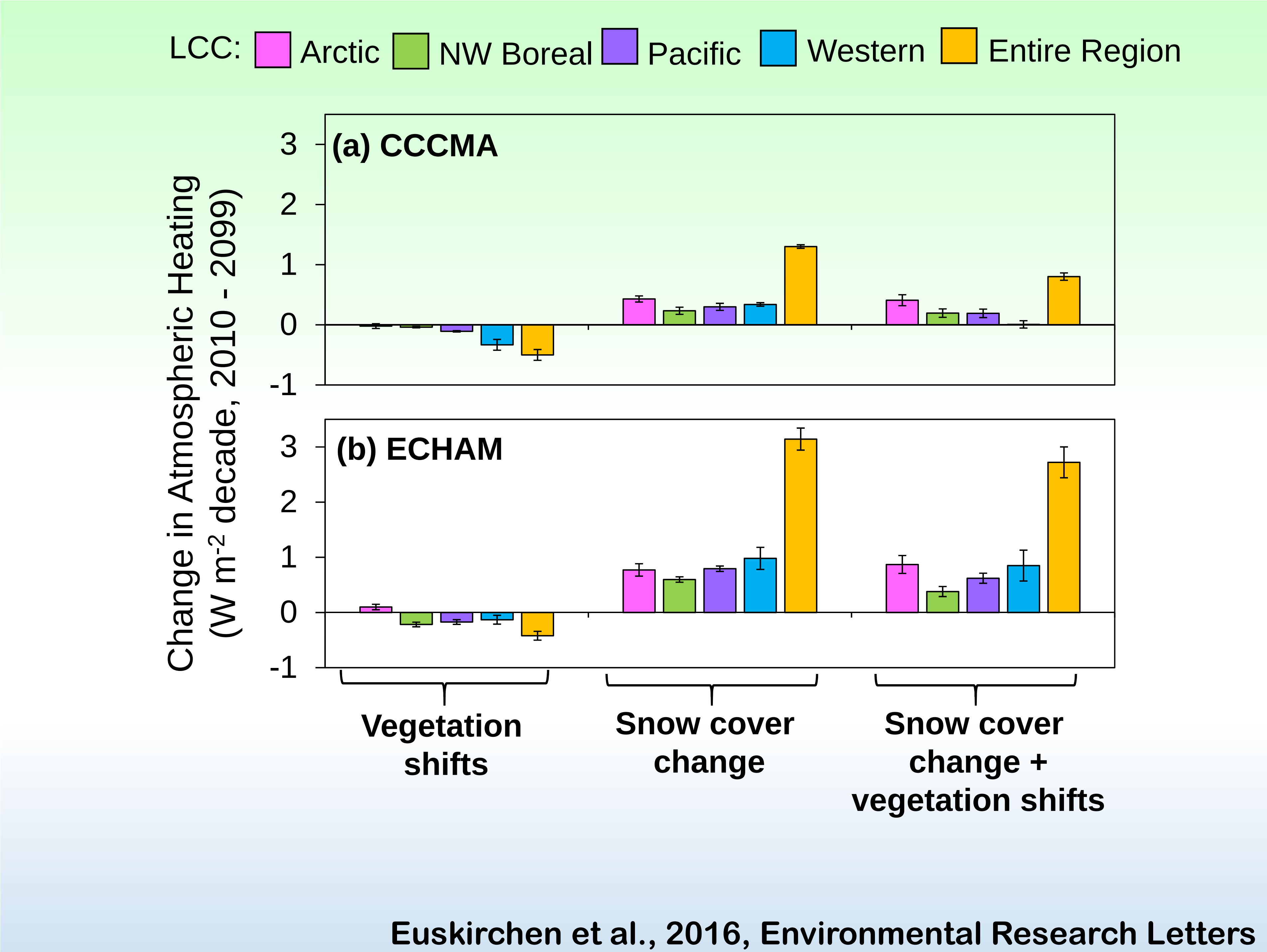


Roach et al., in prep.

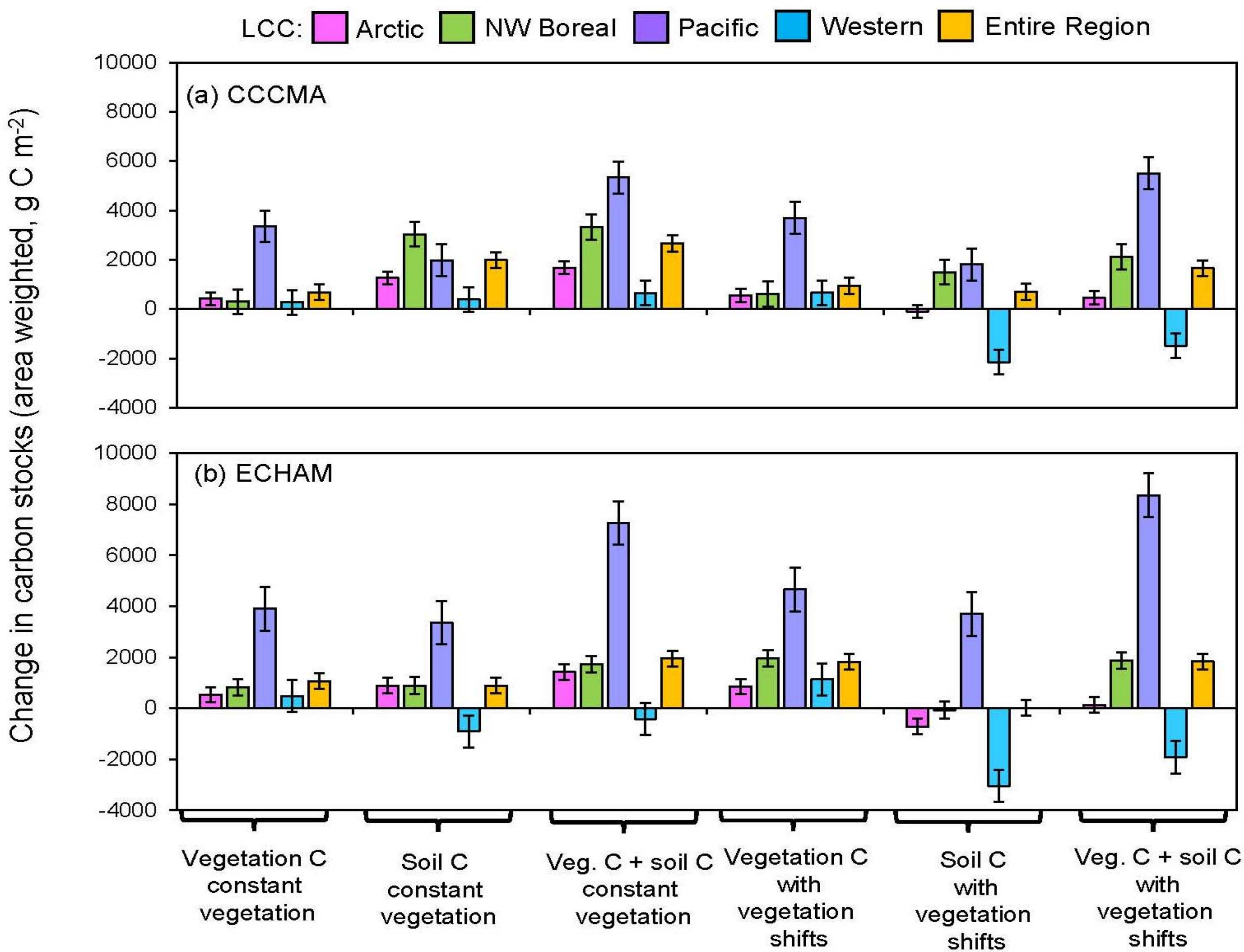
Changes in the duration of the snow season, 2010 - 2099



Euskirchen et al., 2016, Environmental Research Letters



LCC:
Arctic
NW Boreal
Pacific
Western
Entire Region
(a) CCCMA
(b) ECHAM
Change in Atmospheric Heating
(W m-2 decade, 2010 - 2099)
3
2
1
0
-1
Vegetation shifts
Snow cover change
Snow cover change + vegetation shifts
Euskirchen et al., 2016, Environmental Research Letters



LCC: Arctic NW Boreal Pacific Western Entire Region
(a) CCCMA
(b) ECHAM
Change in carbon stocks (area weighted, g C m-2)
10000
8000
6000
4000
2000
0
-2000
-4000
Vegetation C constant vegetation
Soil C constant vegetation
Veg. C + soil C constant vegetation
Vegetation C with vegetation shifts
Soil C with vegetation shifts
Veg. C + soil C with vegetation shifts

Where do we go?

- Permafrost C / nutrients / CH_4 / microbes / winter
- Data – model synthesis (assimilation)
- Assessments of within model uncertainty
- Model comparisons
- What future data collection would help reduce model uncertainty the most?

"People don't understand the earth, but they want to, so they build a model, and then they have two things they don't understand," –

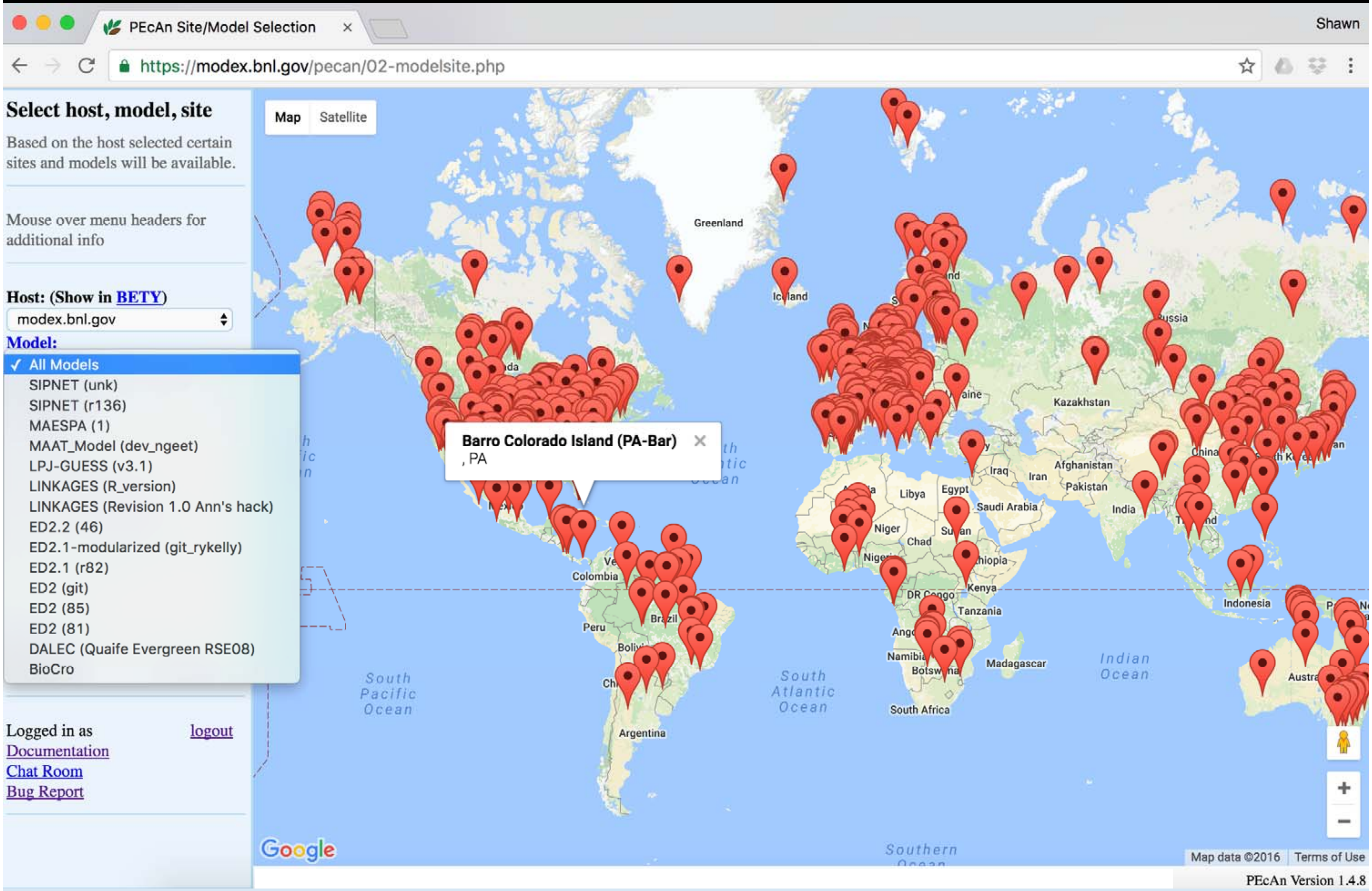
Gerard Roe in "The Whale and the Supercomputer"

Addressing Model Uncertainty

- Terrestrial Ecosystem Model with Dynamic Vegetation (**TEM-DVM**) shows good agreement with observation but overall parameter uncertainty has not been directly addressed
- Need an efficient means to test PFT descriptions and iteratively test parameterization w/ new data
- Requires a framework to track model improvements and guide data collection activities -
  UAF- DOE (Brookhaven National Lab collaboration)



PEcAn - http://pecanproject.github.io/ LeBauer et al., 2012



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Biogeosciences Open Access

Carbon cycle uncertainty in the Alaskan Arctic

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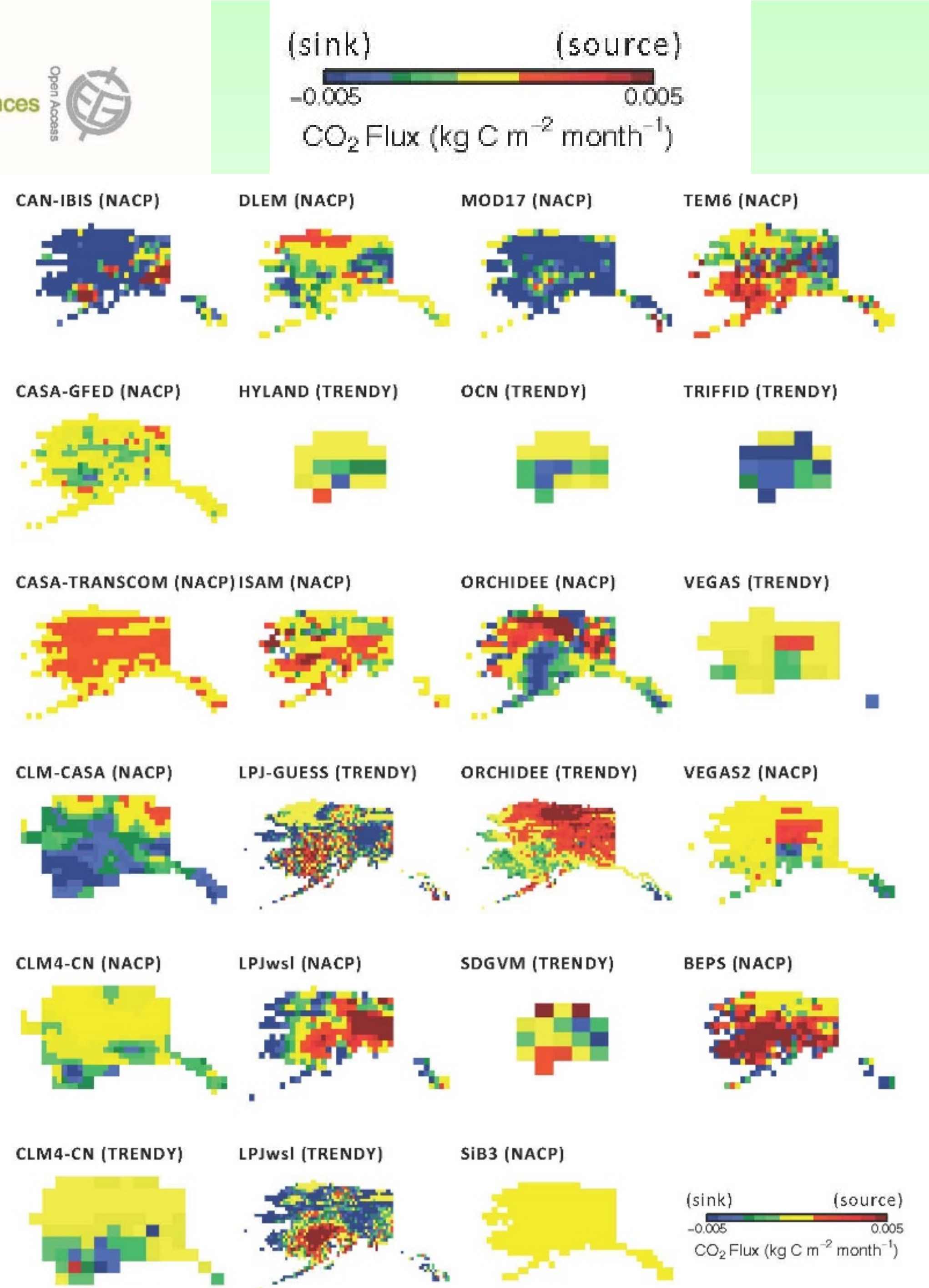
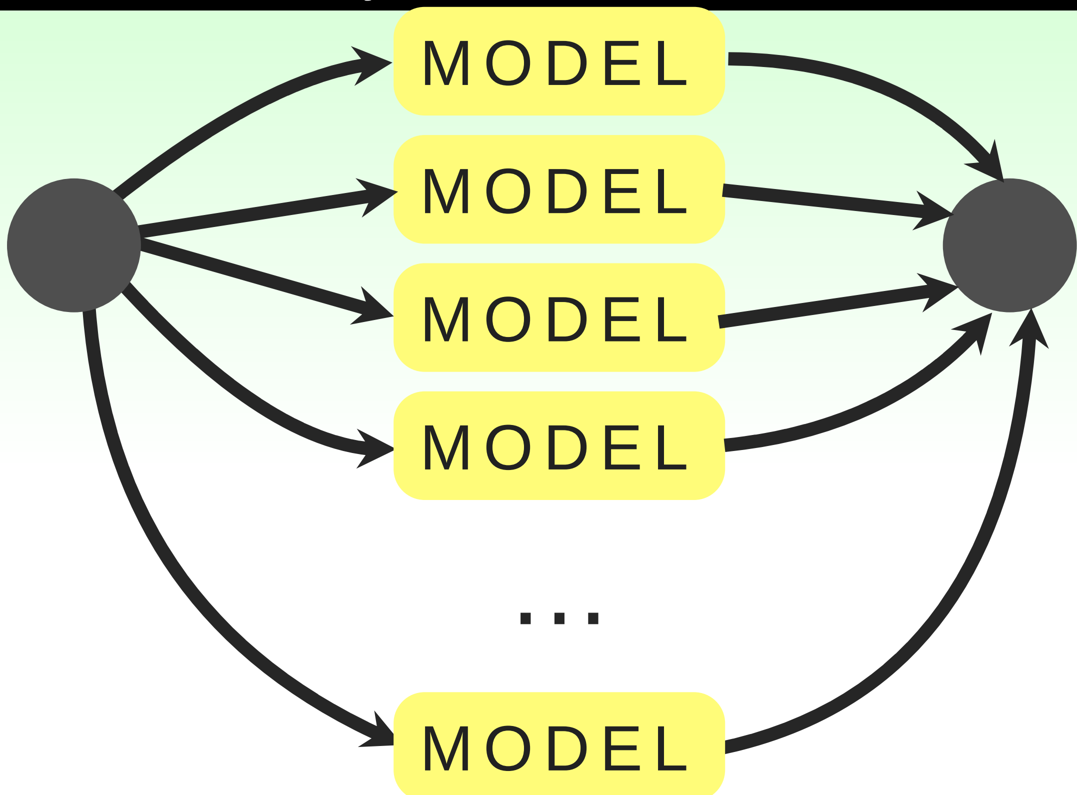


NGEE-Arctic MIP: Addressing model structure uncertainty



Live:
ED2, SIPNET, DALEC, LINKAGES, BIOCRO, PRELES, FATES

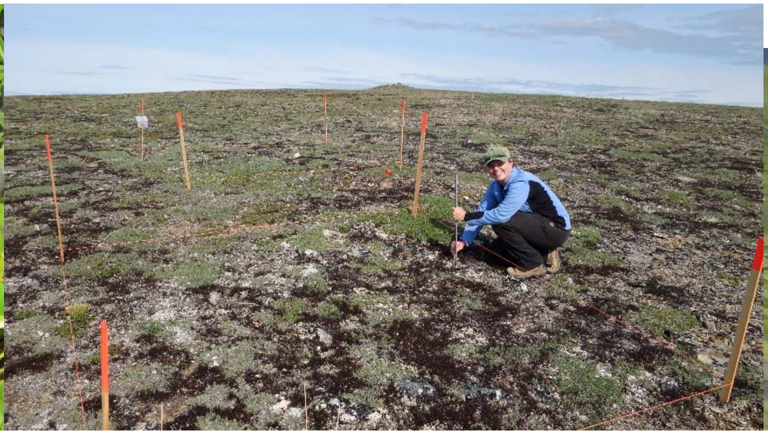
In progress:
TEM, MAESPA, G'DAY, LPJ-GUESS, MAAT, JULES

On deck:
LPJwsl, LANDIS, ACONITE, SIB, SIBCASA, DAYCENT, LM3, LM3-PPA, … *many many more*

- **Compare multiple models with different assumptions for high-latitude ecosystems within the PEcAn framework**
- **Would run under the same forcing climate data, region, and in some cases, input parameters**
- **Enable a custom NGEE-Arctic focused multi model intercomparison project (MIP)**
- **Used to identify new development activities as well as data collection priorities**

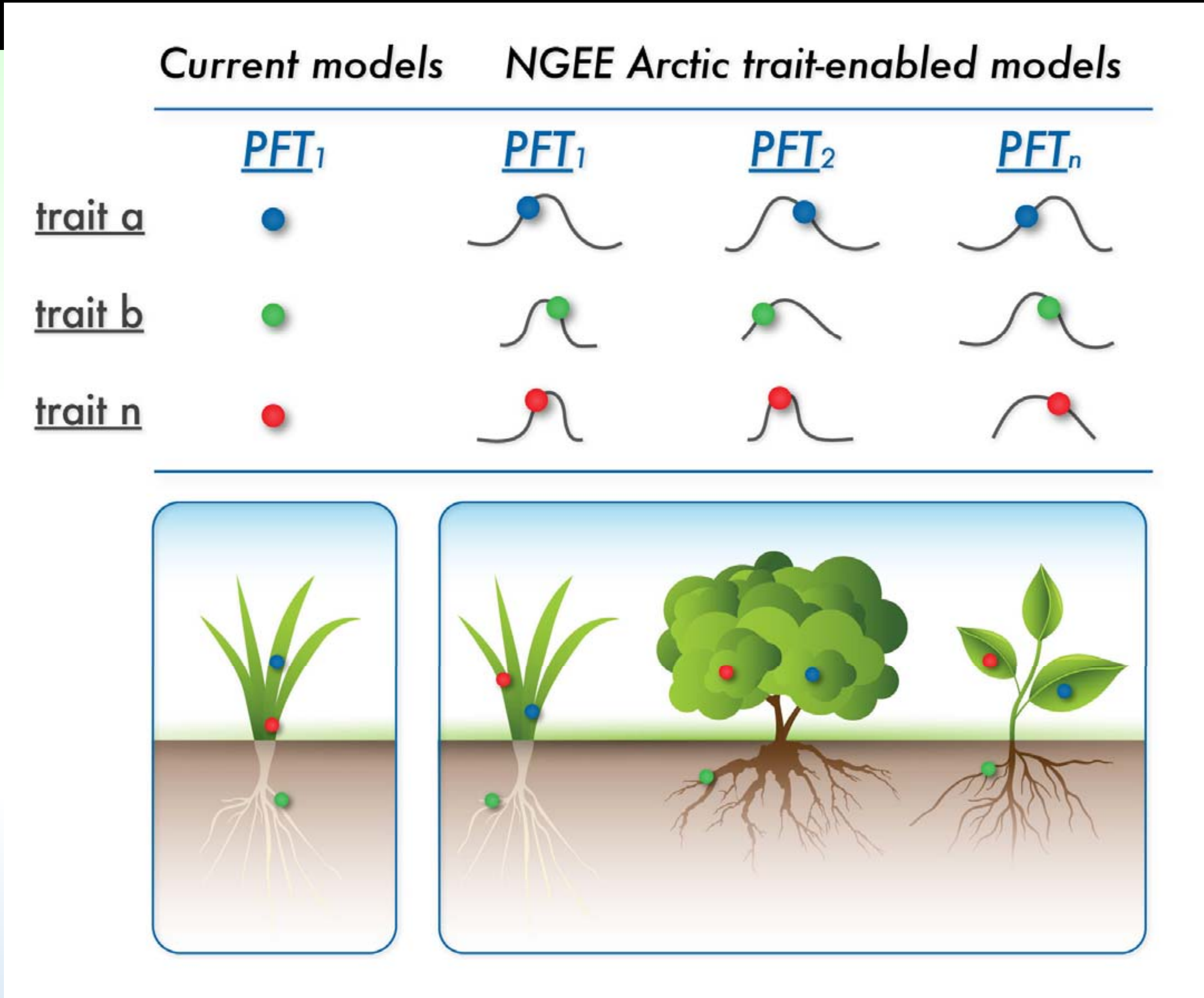
Conclusions

- IEM outputs: changes in vegetation composition related to increases in fire severity and tundra fire, treeline advance, greater C uptake
- Model outputs of preferred caribou storage vis à vis caribou herd size
- Substantial decreases in snow cover: a continued important climate feedback
- Modeling as a tool for management: Important to involve land managers in the modeling process as it progresses
- How to best address within model and across model uncertainty?


to estimate model parameters, propagate parameter uncertainties through to model output, and evaluate the contribution of each
parameter to model uncertainty. We illustrate a comprehensive approach to the estimation of
parameter values, starting with a statement of prior knowledge that is refined by species-level
data using Bayesian meta-analysis; this is the first use of a rigorous meta-analysis to inform the
parameters of a mechanistic ecosystem model.

Models use Plant Functional Types with static trait parameters



Key questions to address

- Which plant functional traits contribute most to model variability?
- Across arctic community types, where do we see the most uncertainty (e.g., shrub tundra vs. tussock tundra vs. heath tundra vs. wet sedge tundra, etc.)
- What future data collection would help reduce model uncertainty the most

Projecting changes in the structure and function of ecosystems in Alaska and northwest Canada: Implications for biogeochemistry, herbivores, and society

Linking models and field studies to

Snow season C release
Thermokarst
Moose distribution
Caribou distribution
Human dimensions component

We are looking for a 20 minute research talk that is integrative and that also points out what you think are the most important scientific issues in your field that should be addressed in the next 5 years. We would like you to address this from your perspective as a modeler, primarily.

- Dynamic vegetation models (DVMs): model the ecophysiological characteristics of plant functional types in terrestrial ecosystems.

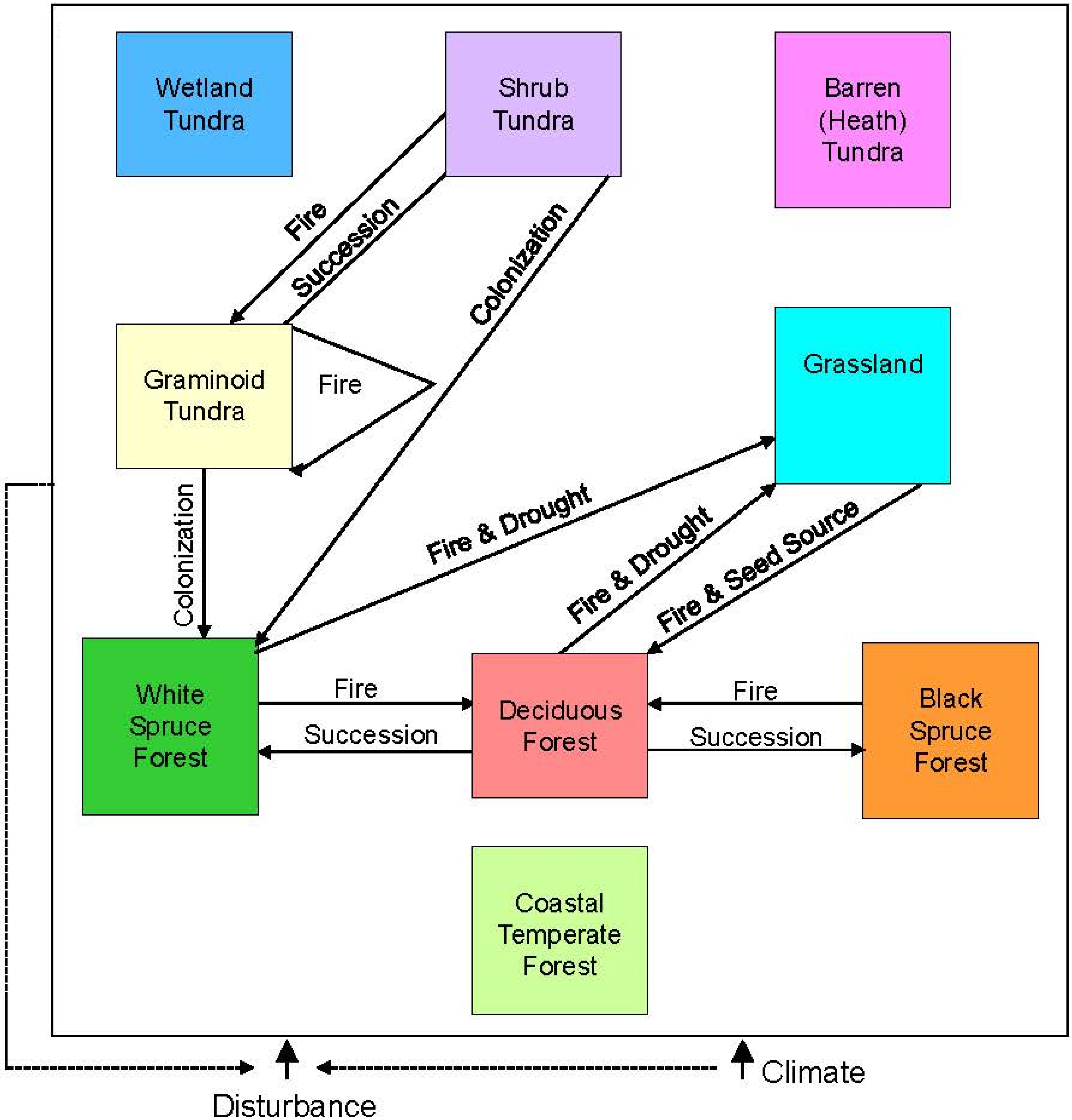
- Disturbance, plant succession, and community composition

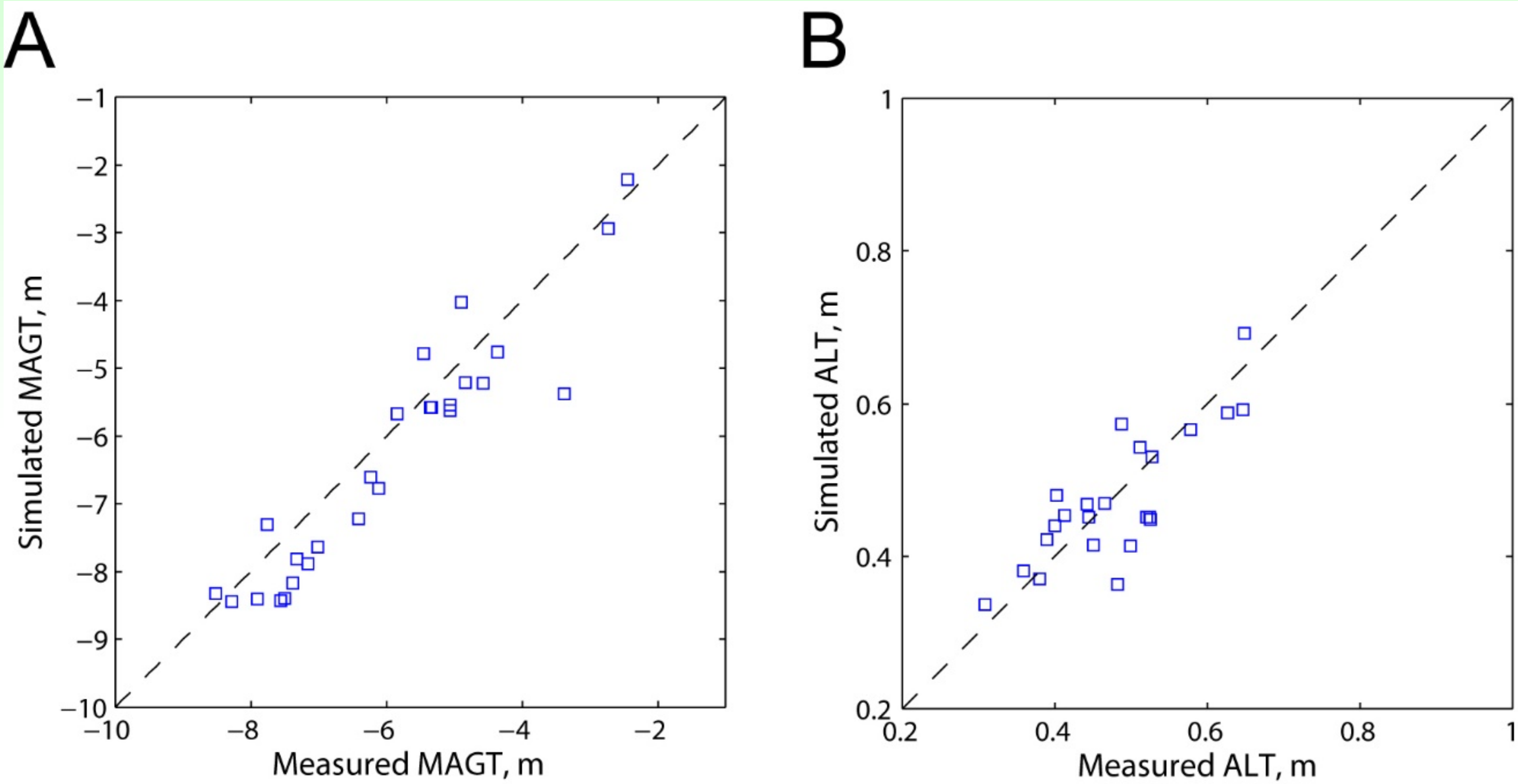
- Additional details: species-level, species-specific traits

- ‘How many species, or what degree of functional diversity, should we incorporate to sustain ecosystem function in modeled ecosystems?’

ALFRESCO State and transition model of ecosystem dynamics

Simulates interactions and feedbacks among fire, climate, vegetation

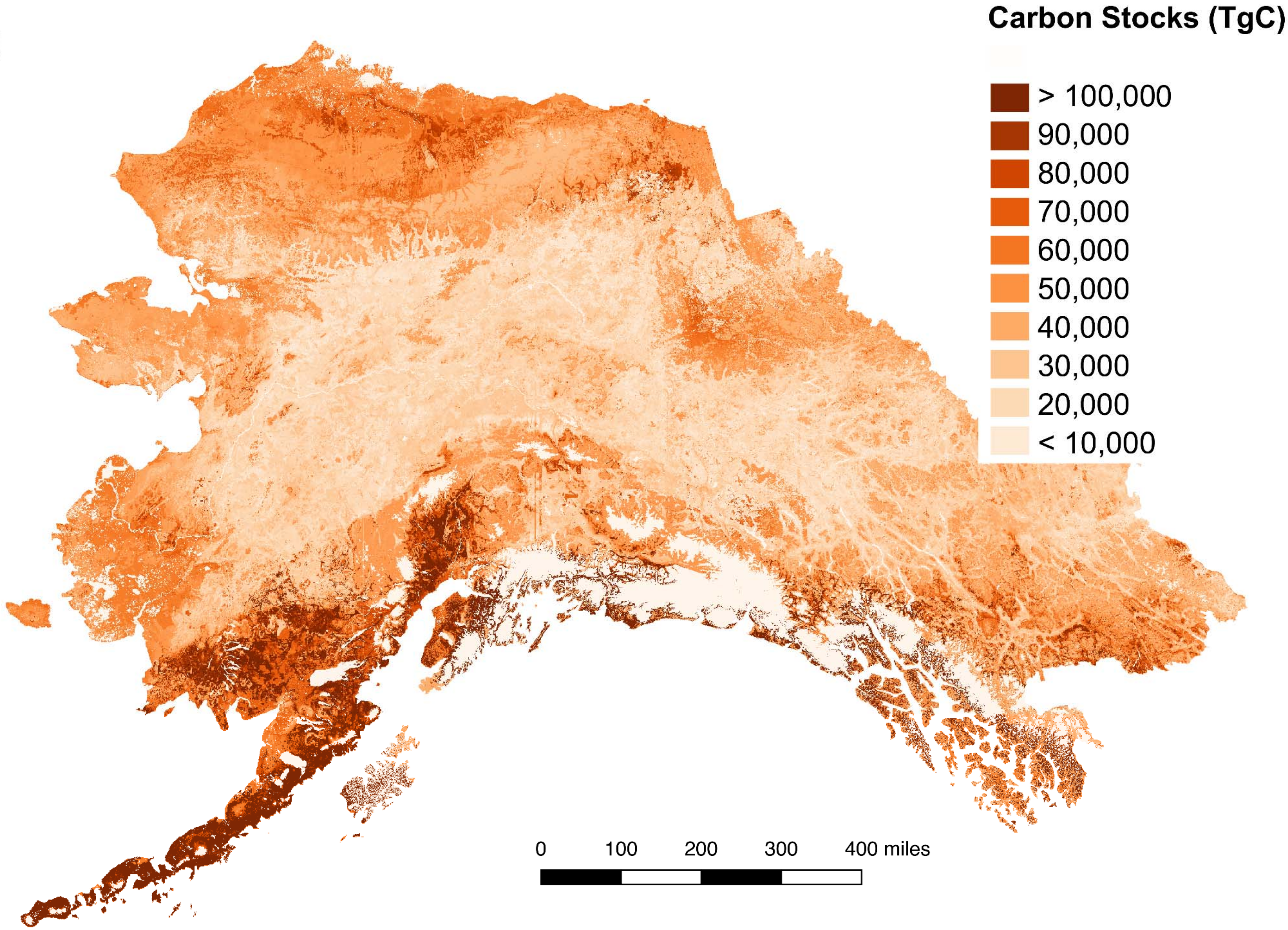



A
B
Simulated MAGT, m
Measured MAGT, m
−1
−2
−3
−4
−5
−6
−7
−8
−9
−10
−10
−8
−6
−4
−2
Simulated ALT, m
Measured ALT, m
1
0.8
0.6
0.4
0.2
0.2
0.4
0.6
0.8
1

IEM Products

- Climate
  - Historical and projected climate data for several scenarios of climate change and for several climate models (available)
- Soil Properties
  - Permafrost distribution, active layer thickness (2013, with updates)
- Disturbance
  - Historical and projected area burned (historical available, projected 2013)
  - Susceptibility to thermokarst (2013)
  - Thermokarst disturbance scenarios and landscape change (2014)
- Landcover and Vegetation
  - Projected treeline (2013, updates)
  - Future distribution of vegetation types (2013, updates)
- Ecosystem Dynamics
  - Carbon fluxes, net primary productivity (2013, updates)

d)


Carbon Stocks (TgC)
> 100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
< 10,000
0
100
200
300
400 miles