Uncertainty Analysis Applied to an Arctic and Boreal Ecosystem Model

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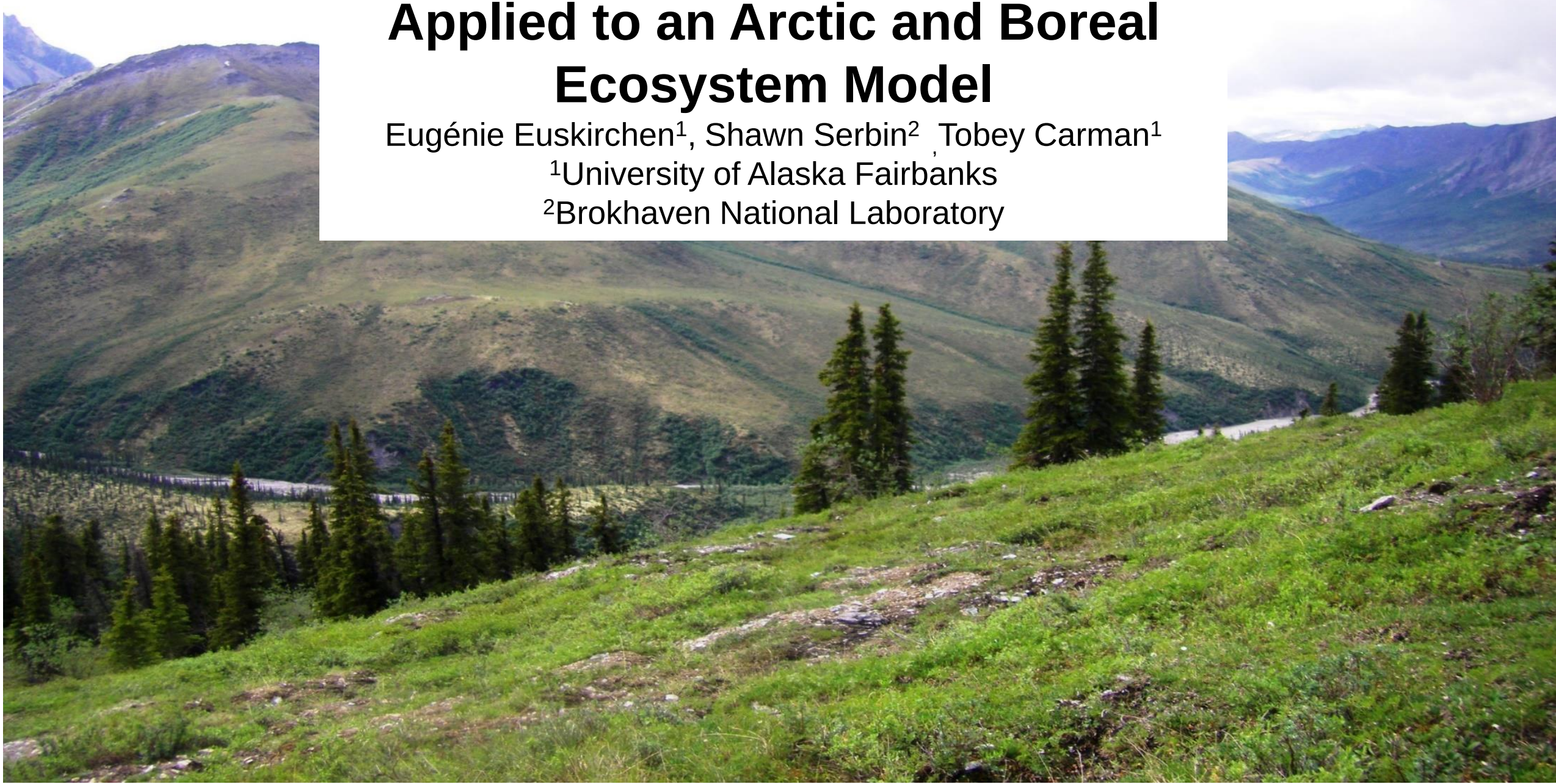

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DOE: NGEE Arctic

DOE: Arctic Shrub Expansion, Plant Functional Trait Variation, and Effects on Belowground Carbon Cycling

USGS: Integrated Ecosystem Model for Alaska and Northwest Canada

Sources of model uncertainty

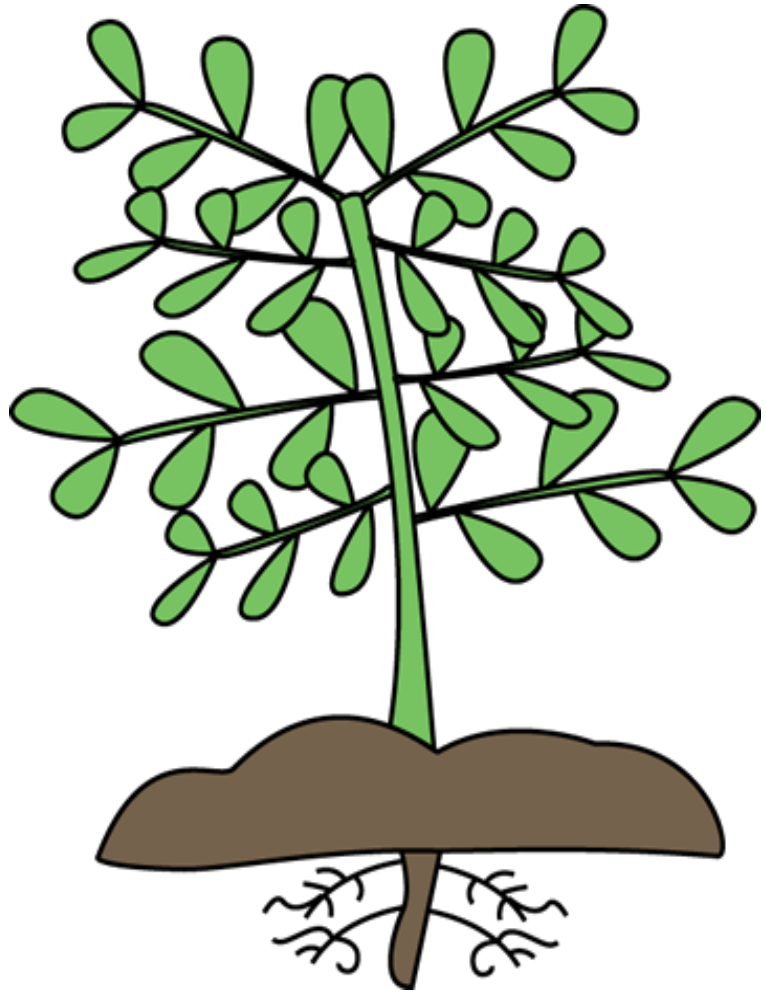
- System complexity
- Validation data
- Driving input climate
- Model parameters

Prediction becomes more effective when models are well informed by data.

Plant traits and the carbon cycle

Plant trait: A vegetation property that drives or regulates a specific process

Plant function	Plant traits (e.g., parameters that we can test in this framework)
Light competition	E.g., extinction coefficient, SLA
Light utilization	E.g. LAI, albedo
Vegetation and soil carbon storage	E.g. g_{cmax}, optimal photosynthetic temperatures
Nutrient uptake and cycling	E.g. Labile N, fine root allocation
Fluxes: NPP and ER	E.g. LAI, optimal photosynthetic temperatures, gcmax



Rationale

- Even if the model-observations agree, still important to address overall parameter uncertainty

- Need an efficient means to test PFT descriptions and iteratively test parameterization w/ new data

- “But there is a critical need to deepen their work on uncertainty including propagation of parameter uncertainty and model-data fusion.”

Goals

- Quantitatively assess the uncertainties in a terrestrial ecosystem model for a wide range of community types across Alaska, and plant functional types (PFTs) within these communities

- Identify parameters and processes most in need of further data constraint

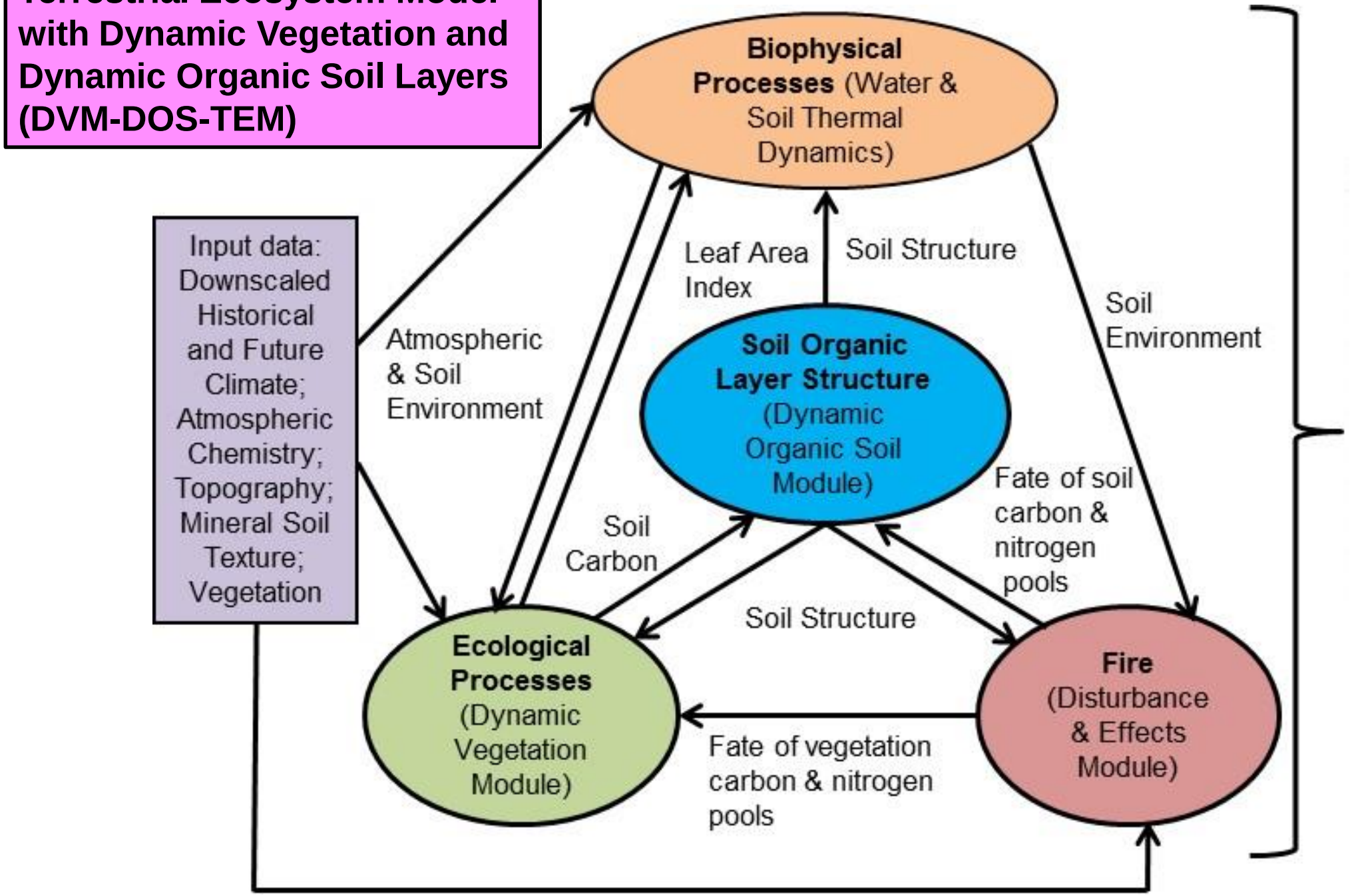
Key questions to address

- Which plant functional traits contribute most to model variability in high latitude ecosystems? Does this change geographically?

- Across 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 uncertainty the most

Terrestrial Ecosystem Model with Dynamic Vegetation and Dynamic Organic Soil Layers (DVM-DOS-TEM)



Black spruce forest	White spruce forest	Deciduous forest	Shrub tundra	Tussock tundra	Wet sedge tundra	Heath tundra
Black spruce	White spruce	Aspen trees	Salix	Betula	Salix/ other decid. shrubs	Betula
Deciduous shrubs	Salix	Birch trees	Betula	Deciduous shrubs	Sedges	Other decid. shrubs
Ledum	Betula / other decid. shrubs	Decid. shrubs	Other decid. shrubs	Evergreen shrubs	Grasses	Evergreen shrubs
Other evergr. shrubs	Evergreen shrubs	Evergr. shrubs	Evergreen shrubs	Sedges	Forbs	Forbs
Sedges	Sedges	Sedges	Sedges	Forbs	Lichens	Lichens
Forbs	Forbs	Forbs	Forbs	Lichens	Featherms.	Moss
Grasses	Grasses	Grasses	Grasses	Featherms.	Sphagnum	
Moss	Lichens	Lichens	Lichens	Sphagnum		
	Featherms.	Mosses	Featherms			

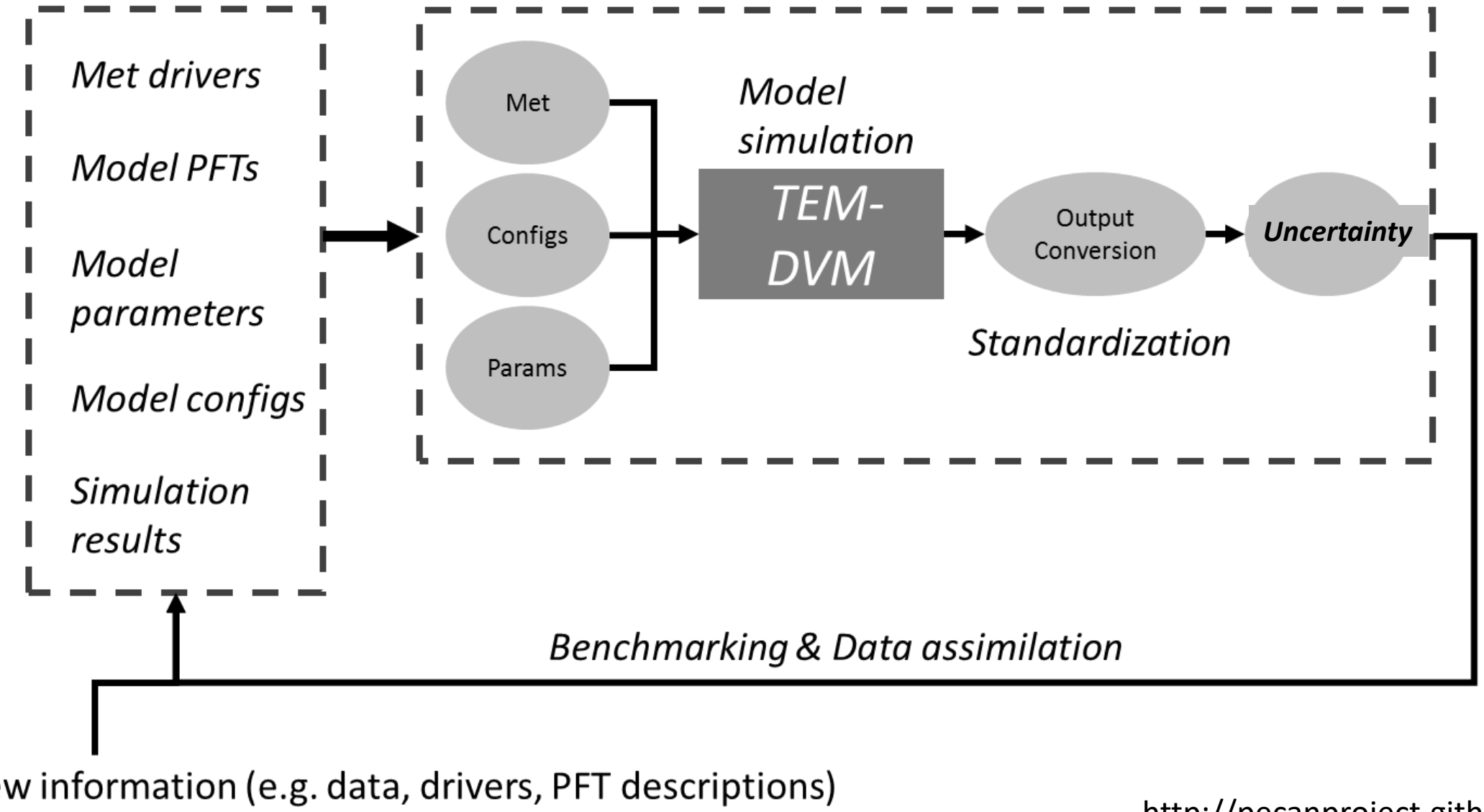
Predictive Ecosystem Analyzer (PEcAn)

Manages the flow of information into and out of an ecosystem model.

BETYdb

https://modex.bnl.gov

PEcAn



http://pecanproject.github.io/

PEcAn Database

Terrestrial Ecosystem Science | BETYdb: /traits

https://modex.bnl.gov/bety/traits?utf8=✓&DataTables_Table_0_length=25&search=Vcmax&direction=&sort=

Home | Data | Docs | Runs | Model I/O | Bulk Upload | Logout

https://modex.bnl.gov/bety

Listing Traits

New Trait

25 records per page Search: Vcmax

Trait	Species	Cultivar	Mean	Statistics	Citation	Site	Treatment	QA/QC	Access Level	Actions
Vcmax - umol CO2 m-2 s-1	Quercus rubra		48.9	SE = 2.8, n = 9	Turnbull 2001 Photosynthetic chara...	The Black Rock Forest - Highlands Province NY, US	TurnUL : Upper Catchment Lowe - Turnbull 2001	passed	4.Public	
Vcmax - umol CO2 m-2 s-1	Quercus rubra		41.2	SE = 3.3, n = 9	Turnbull 2001 Photosynthetic chara...	The Black Rock Forest - Highlands Province NY, US	TurnLL : Lower Catchment Lowe - Turnbull 2001	passed	4.Public	
Vcmax - umol CO2 m-2 s-1	Quercus prinus		49.3	SE = 2.8, n = 9	Turnbull 2001 Photosynthetic chara...	The Black Rock Forest - Highlands Province NY, US	TurnUU : Upper Catchment Uppe - Turnbull 2001	passed	4.Public	
Vcmax - umol CO2	Quercus prinus		51.1	SE = 3.2, n = 9	Turnbull 2001 Photosynthetic	The Black Rock Forest - Highlands	TurnLU : Lower Catchment Uppe	passed	4.Public	

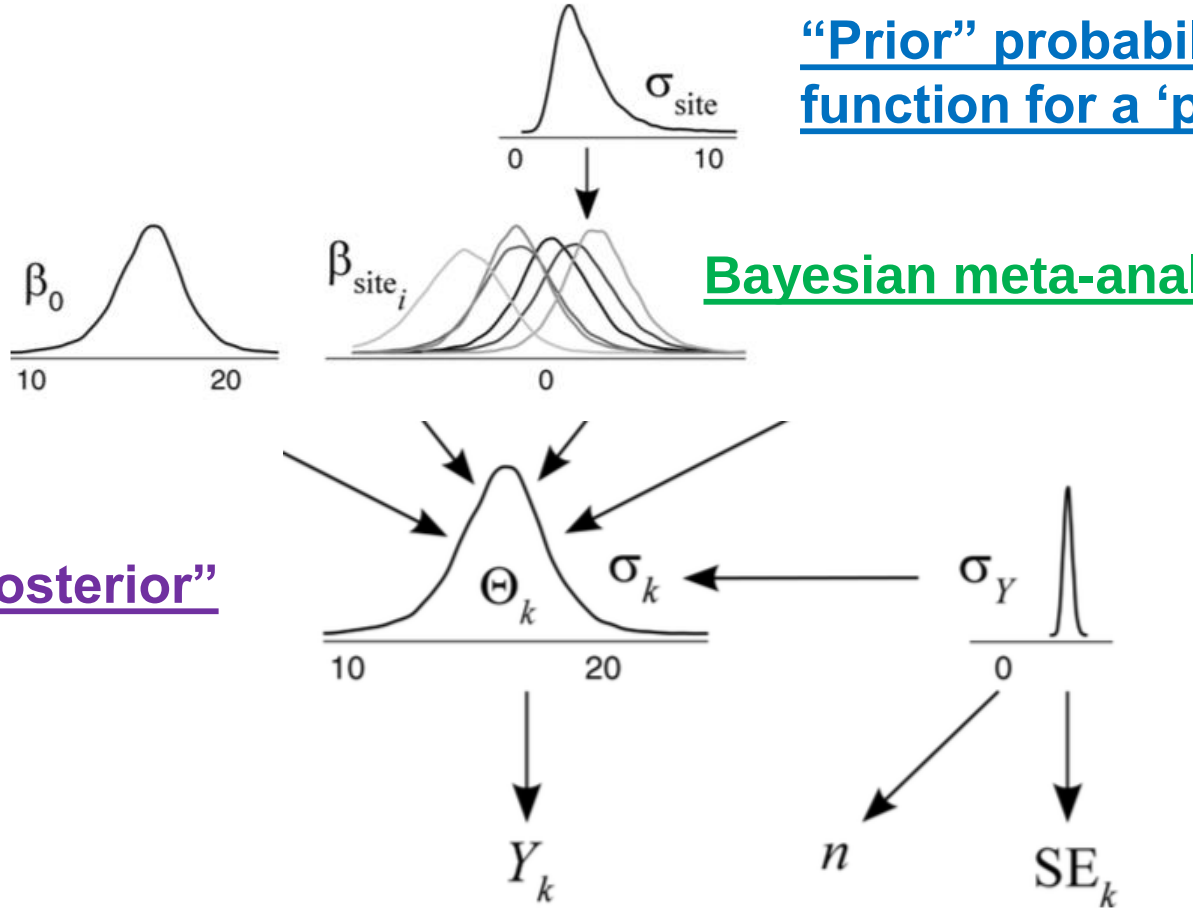
Includes information on the 'priors': The range of values that a model parameter can take.

Tracks data provenance:
Site
Date
Species
Treatment
etc.

PEcAn meta-analysis (parameterization)

Trait information from the database, including the 'priors' is synthesized in a Bayesian meta-analysis.

This results in a 'posterior' distribution that summarizes the uncertainty in each parameter.



"Prior" probability density function for a 'prior'

Bayesian meta-analysis

"Posterior"

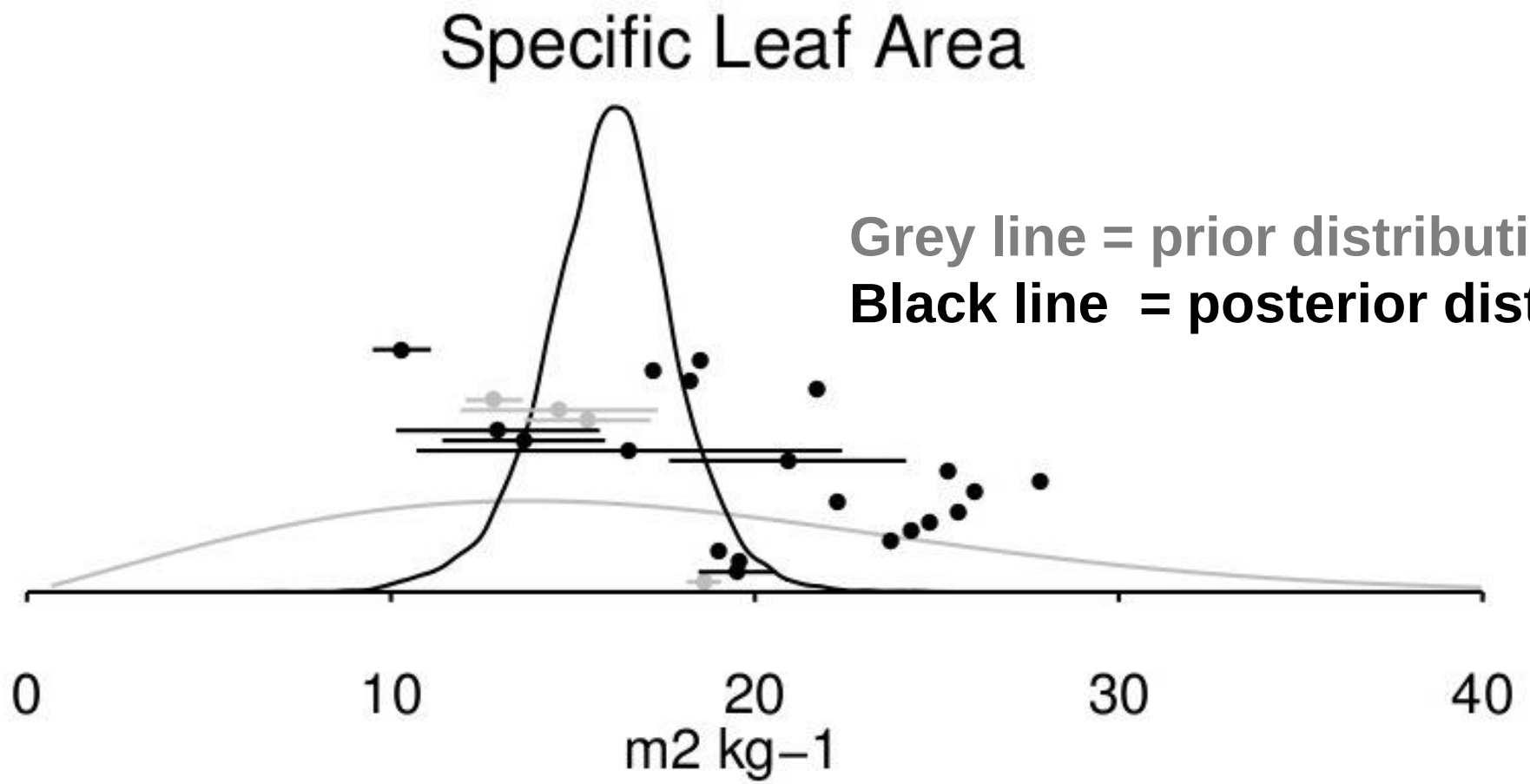
Error statistic

Model ensemble simulations with the ecosystem model = a set (500) of model runs with parameter values drawn from the meta-analysis posterior estimates of plant traits (sampling distributions).

Model ensemble output

LeBauer et al., (2013). Ecological Monographs

PEcAn meta-analysis (parameterization): Takes into account all available data- not just one estimate



LeBauer et al., (2013). Ecological Monographs

PEcAn set-up and simulation

- Assign available data to a distribution (prior) and apply maximum likelihood approach to estimate distribution parameters with additional data (posterior)

- Perform hundreds of model simulations based on parameters varying across their distributions (1990 – 2016)

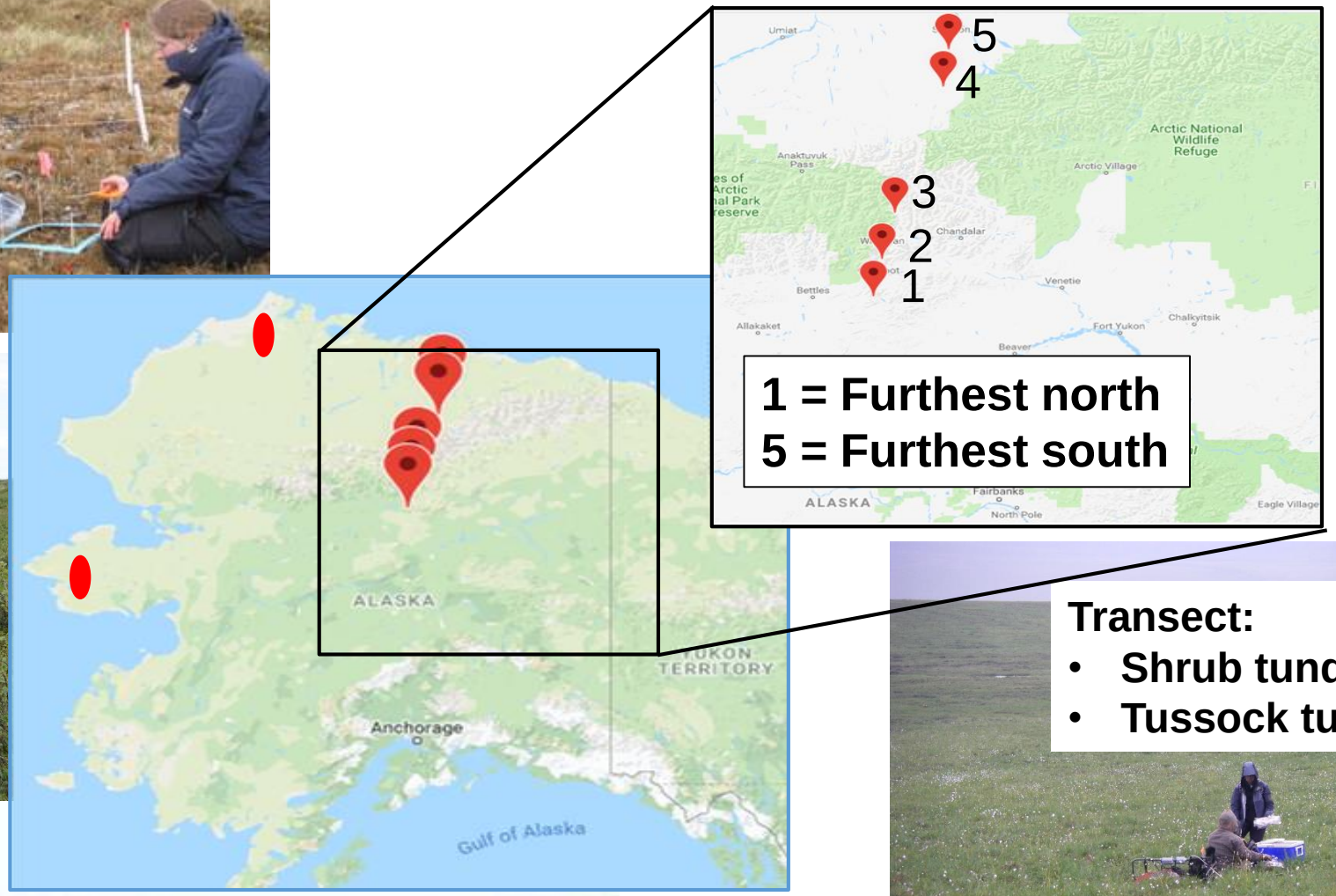
- Ensemble of model outputs from the hundreds of simulations is analyzed with respect to the range of the model results
  - **Sensitivity**: How much a change in a parameter affects model output
  - **Uncertainty**: How much each input parameter contributes to uncertainty in model output (variance decomposition)

PEcAn set-up and simulation: Years 1990 - 2016

Barrow/ Utqiaġvik:
- **Wet sedge tundra**

Nome Peninsula
Kougarok:
- **Shrub tundra**
- **Tussock tundra**
- **Heath tundra**

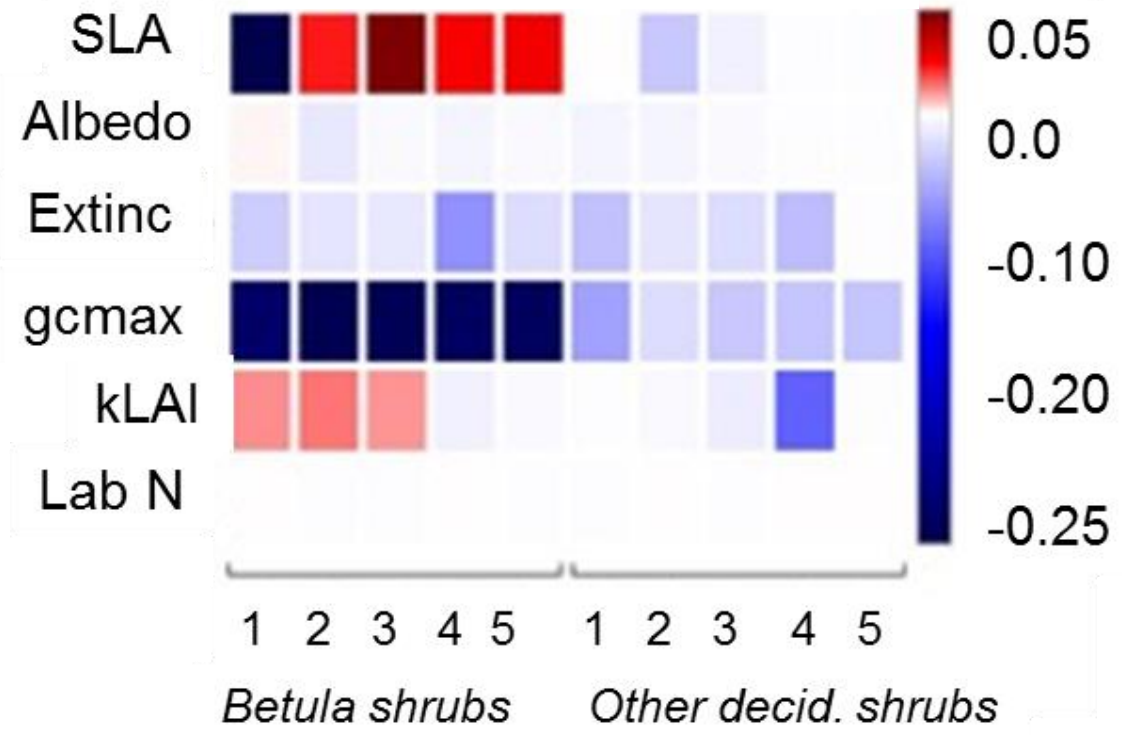
- **Analyzed the four most dominant PFTs from each of the tundra types.**



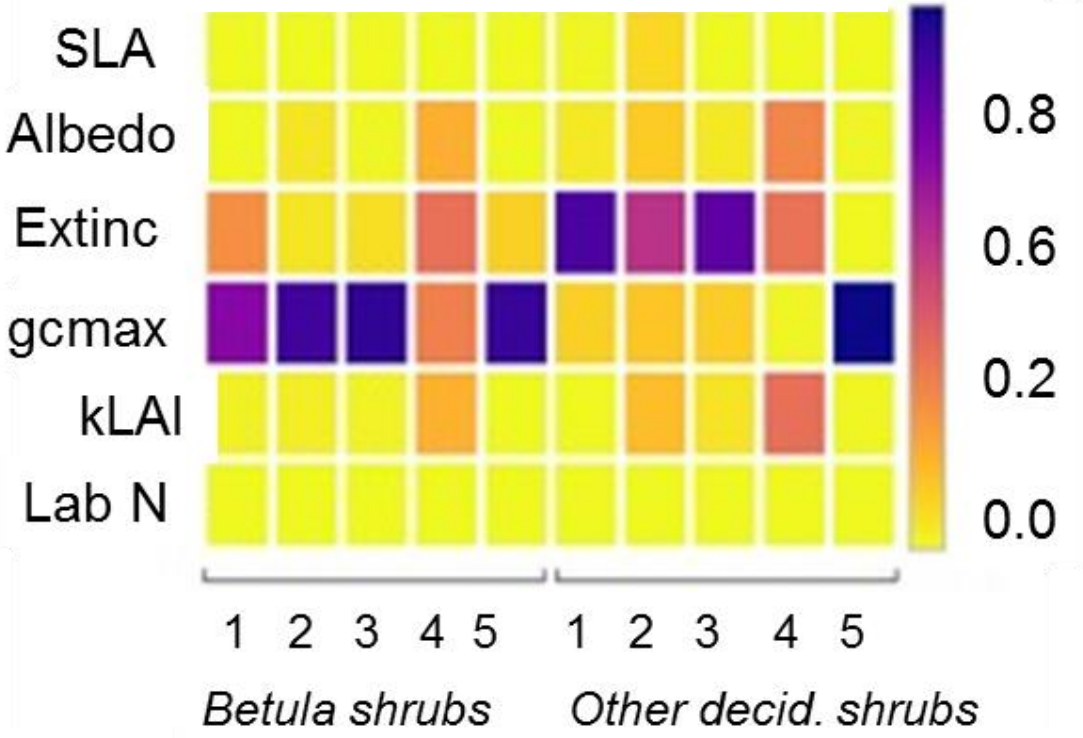
Sensitivity and Uncertainty: NPP of the Shrub Latitudinal Transect

1 = Furthest north
5 = Furthest south

Model sensitivity to a given parameter



Contribution of each parameter to model uncertainty = variance decomposition



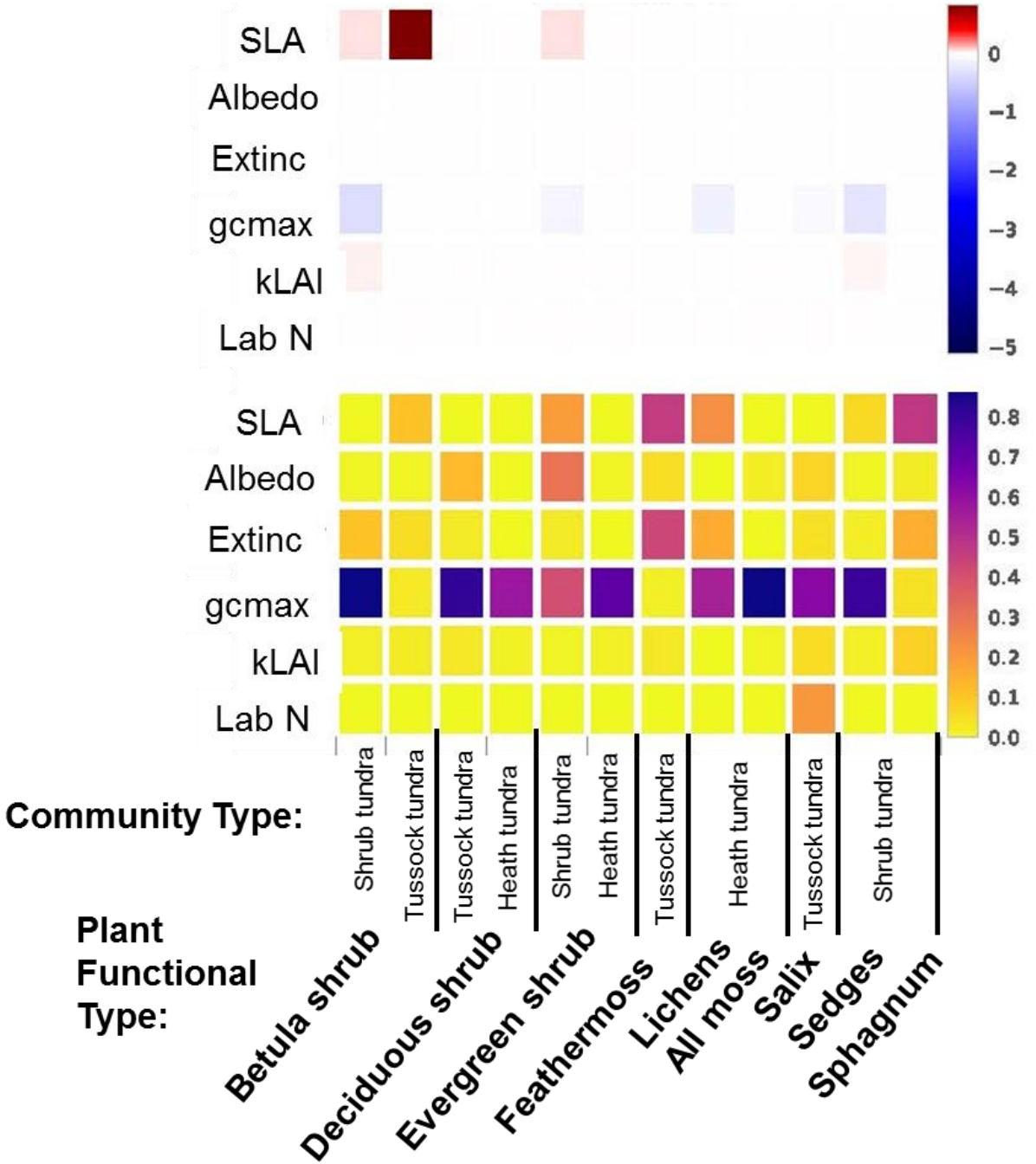
Model sensitivity of 1 means that a model output will double when a given parameter doubles.

SLA = specific leaf area; **Albedo** = shortwave albedo; **Exinc** = extinction coefficient of diffuse light, ***gcmax*** = maximum canopy conductance; **kLAI** = leaf area index scaled by the extinction coefficient; **Lab N** = labile nitrogen concentration

Sensitivity and Uncertainty:

Nome Peninsula Vegetation C

- Shrub Tundra
- Tussock Tundra
- Heath Tundra

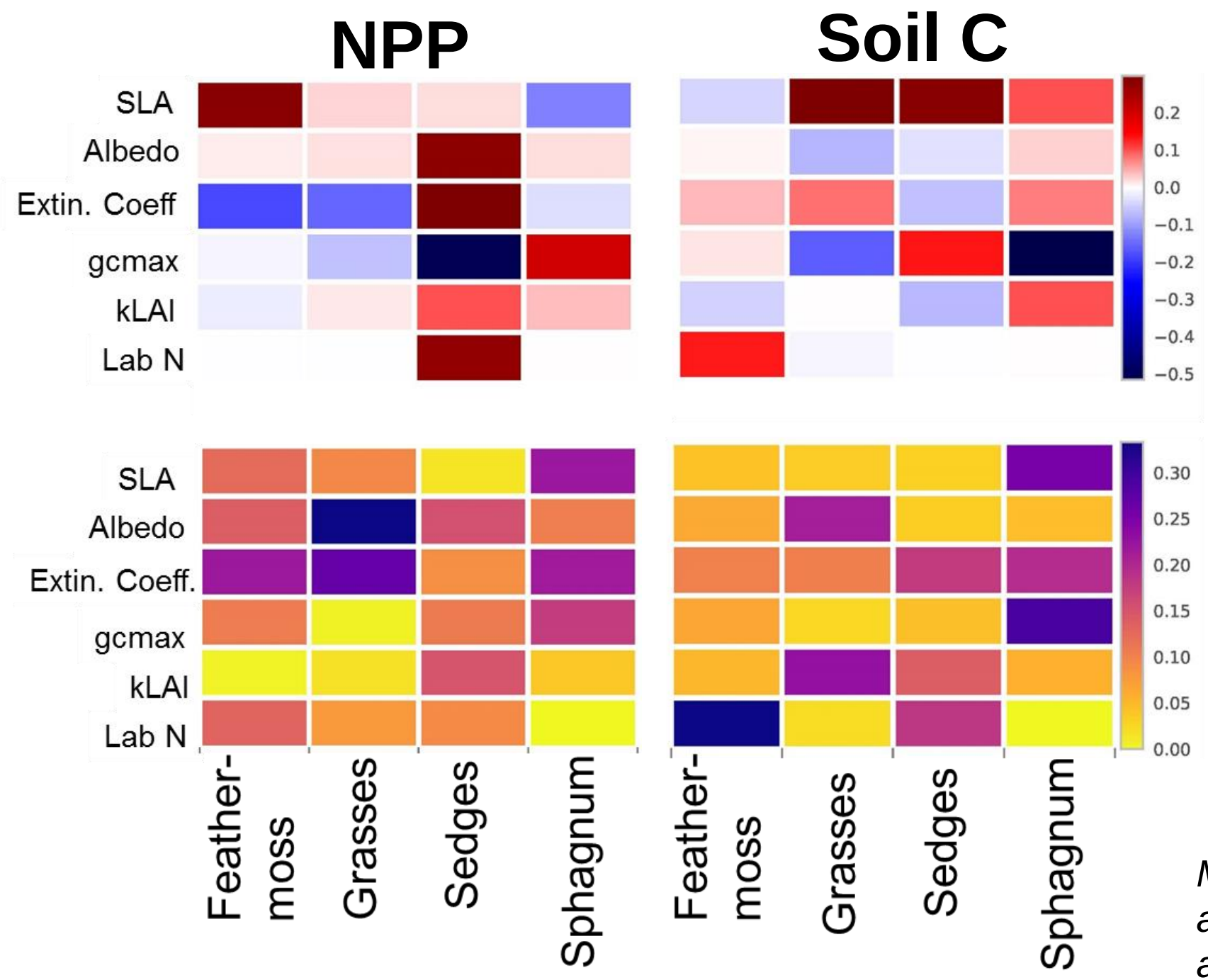


Model sensitivity to a given parameter

Contribution of each parameter to model uncertainty

Model sensitivity of 1 means that a model output will double when a given parameter doubles.

Sensitivity and Uncertainty: Wet Sedge Tundra

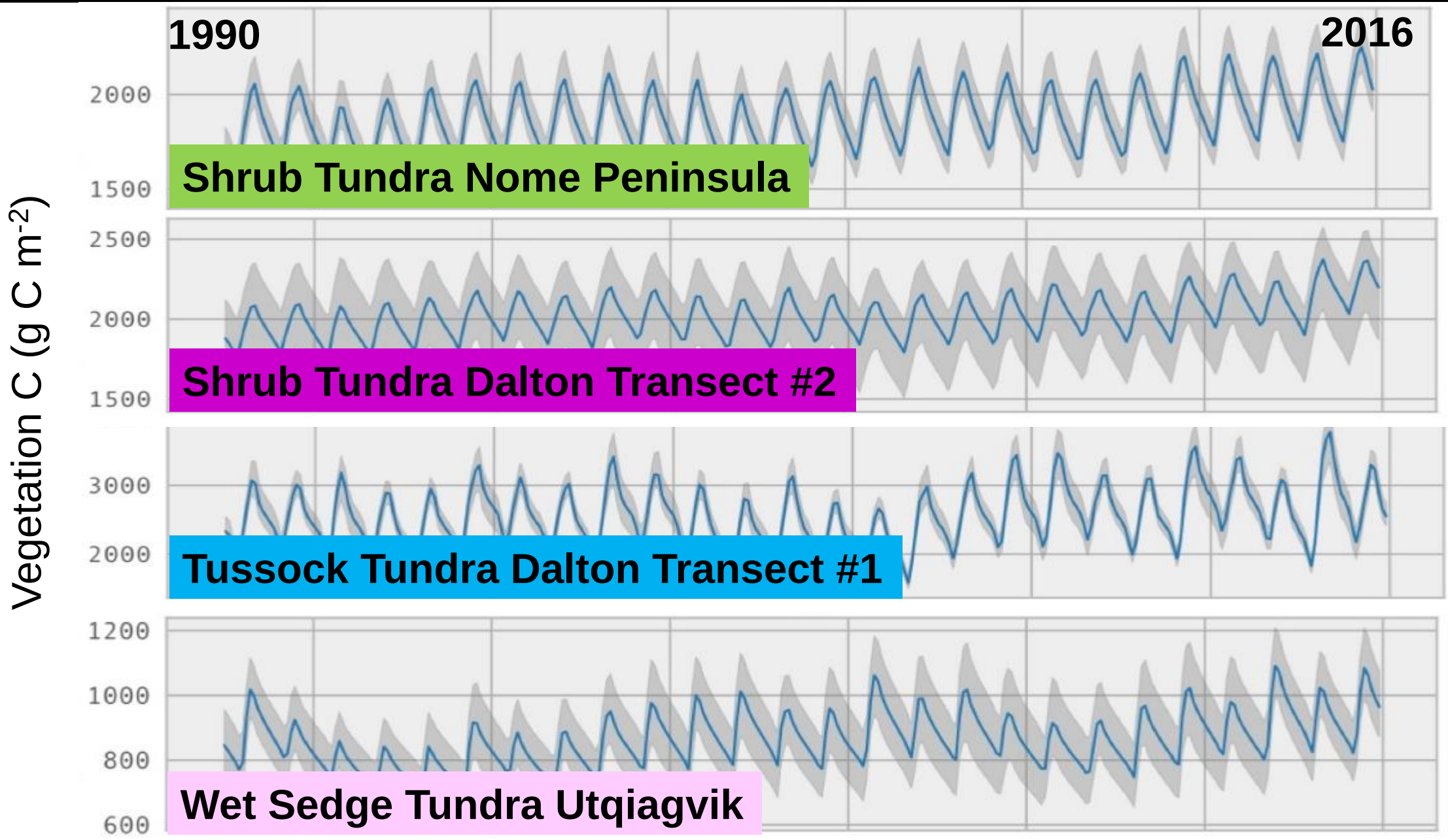


Model sensitivity to a given parameter

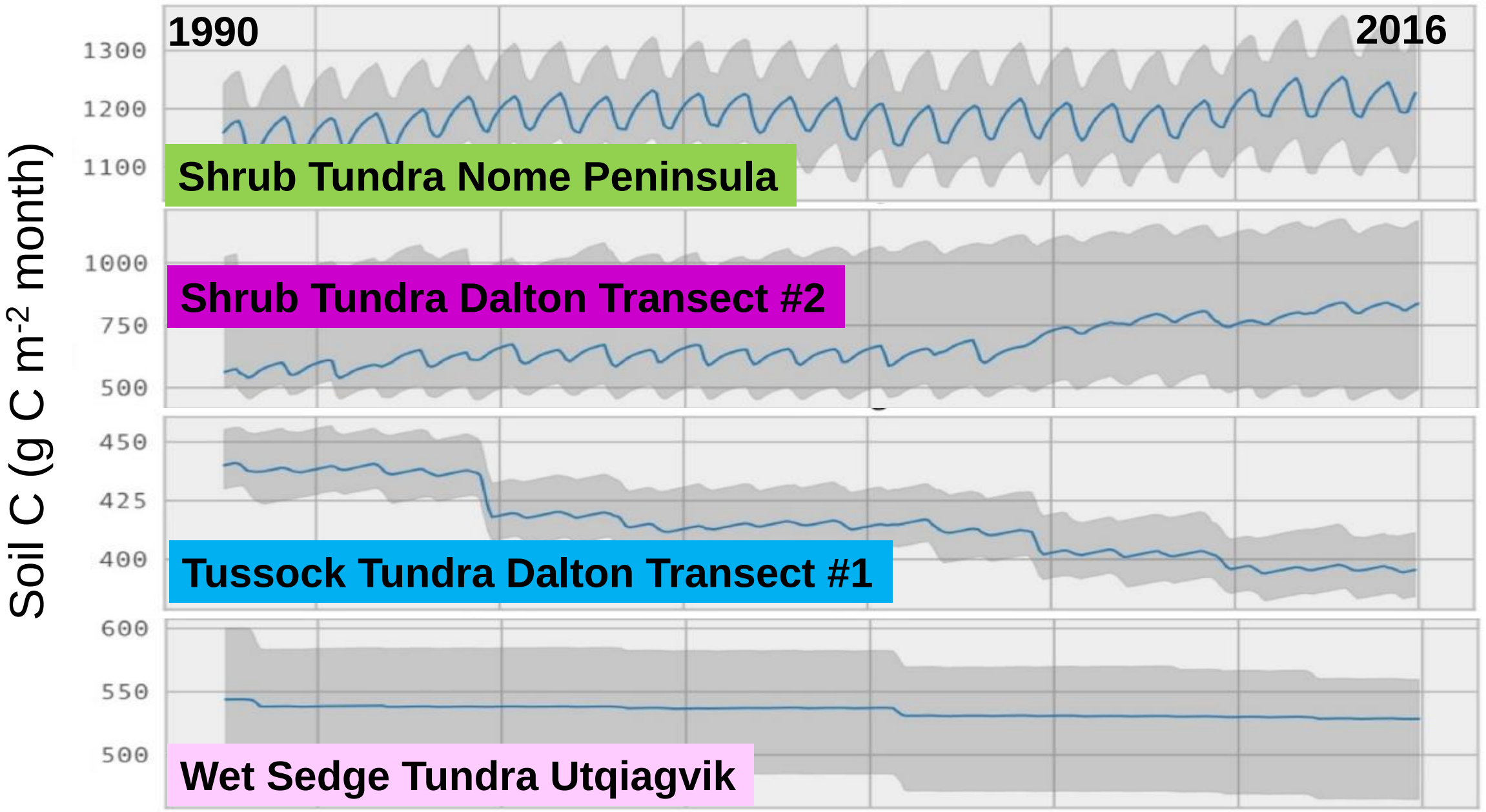
Fraction of model uncertainty caused by a given parameter

Model sensitivity of 1 means that a model output will double when a given parameter doubles.

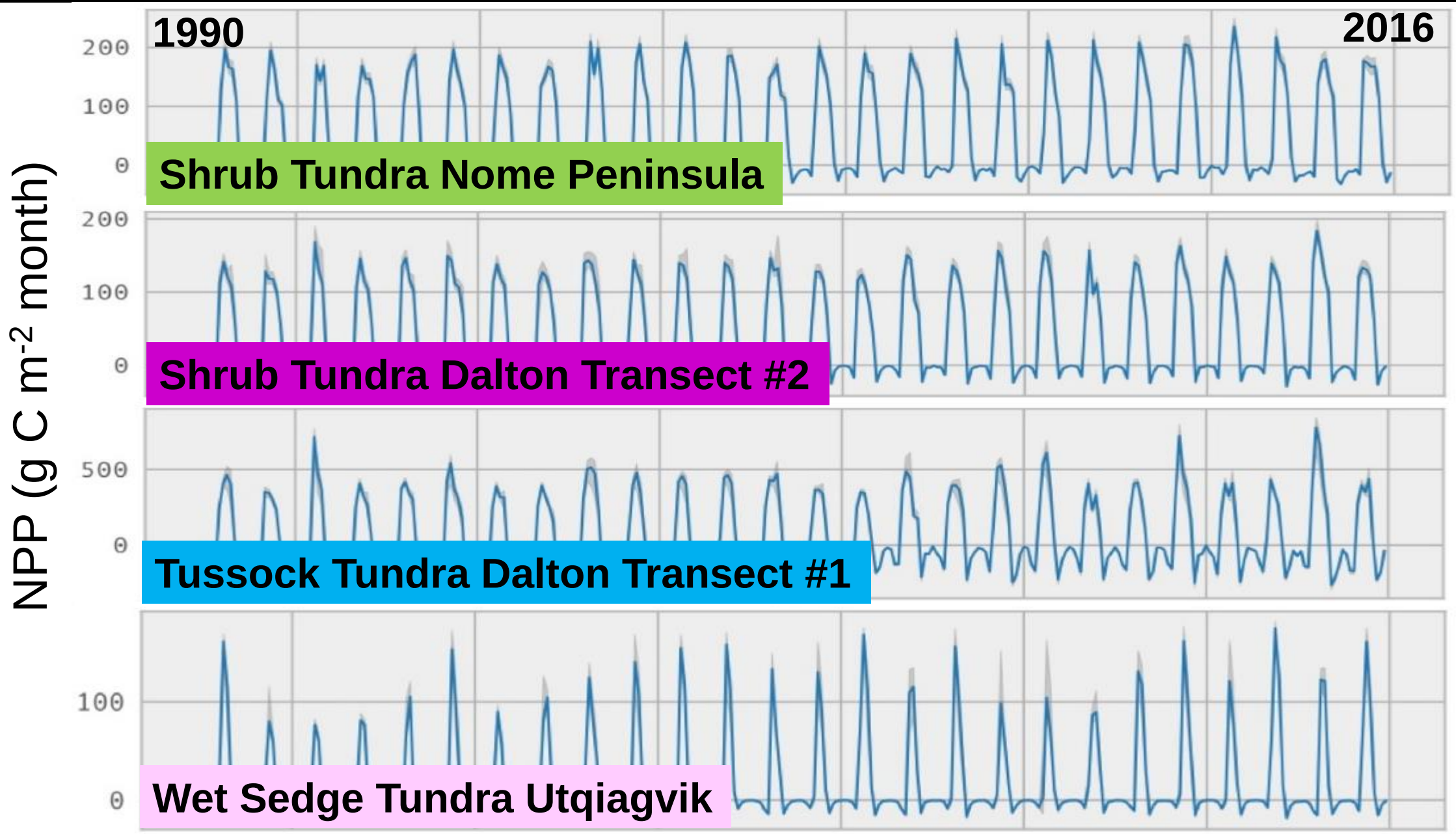
Vegetation C Time Series, 1990 – 2016 (g C m^{-2} month)



Top Layer Soil C Time Series, 1990 – 2016 (g C m^{-2} month)



NPP Time Series, Monthly, 1990 – 2016 (g C m^{-2} month)



Recap

1. Latitudinal Transect: Betula and other deciduous shrubs across the latitudinal transect showed differences, as well as a few similarities, in sensitivity and uncertainty

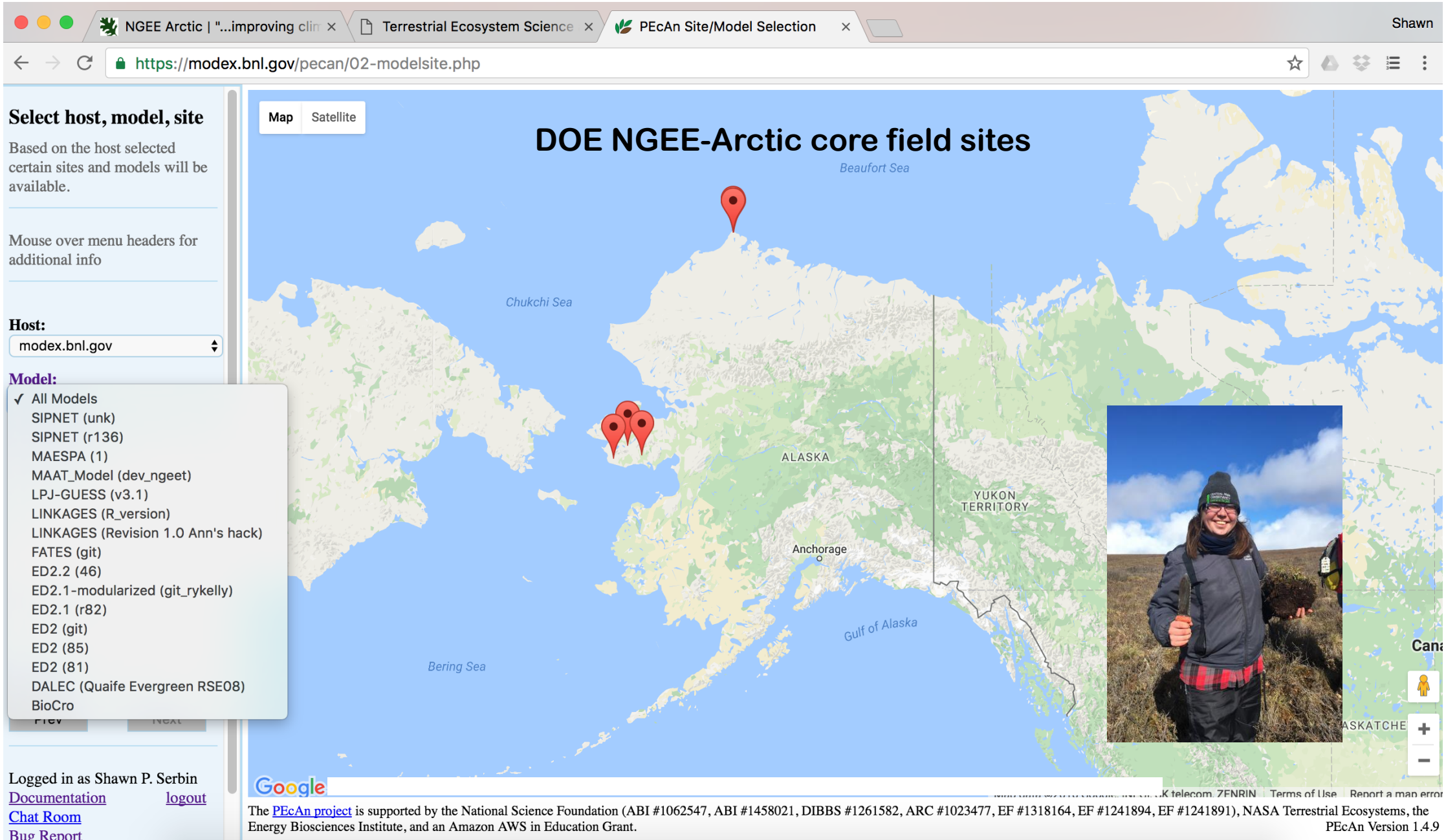
Plus, differences for a given output variable (e.g., NPP vs. Soil C)

2. Nome Peninsula: Shrub tundra, tussock tundra, heath tundra: The same PFTs but found in different tundra (community) types could show opposite sensitivity and uncertainty

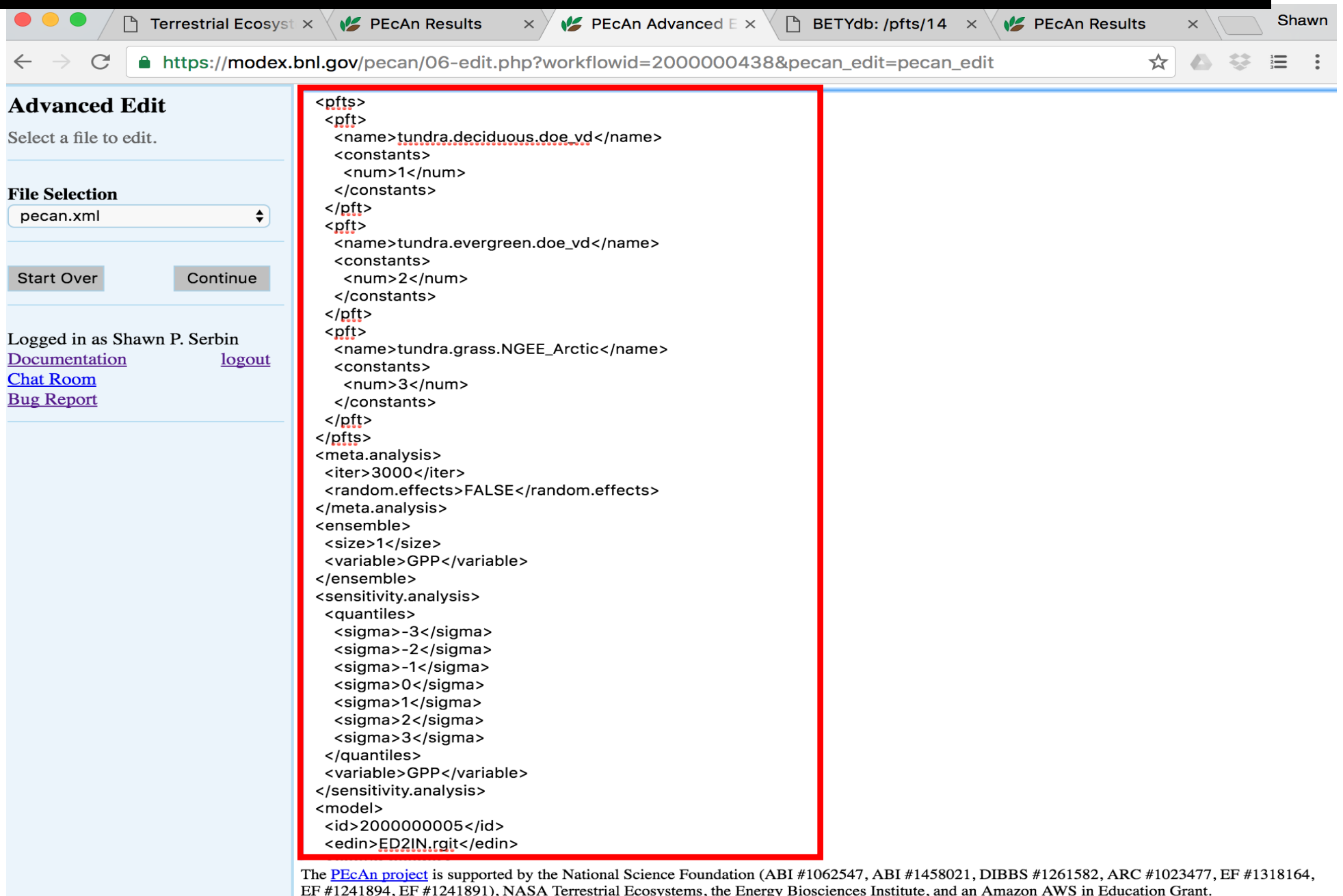
3. Utqiagvik Wet Sedge Tundra: Seemed to show greater sensitivity and uncertainty to broader number of parameters compared to the other tundra types.

4. Model uncertainty in NPP appears fairly well constrained. Less so for vegetation C and soil C.

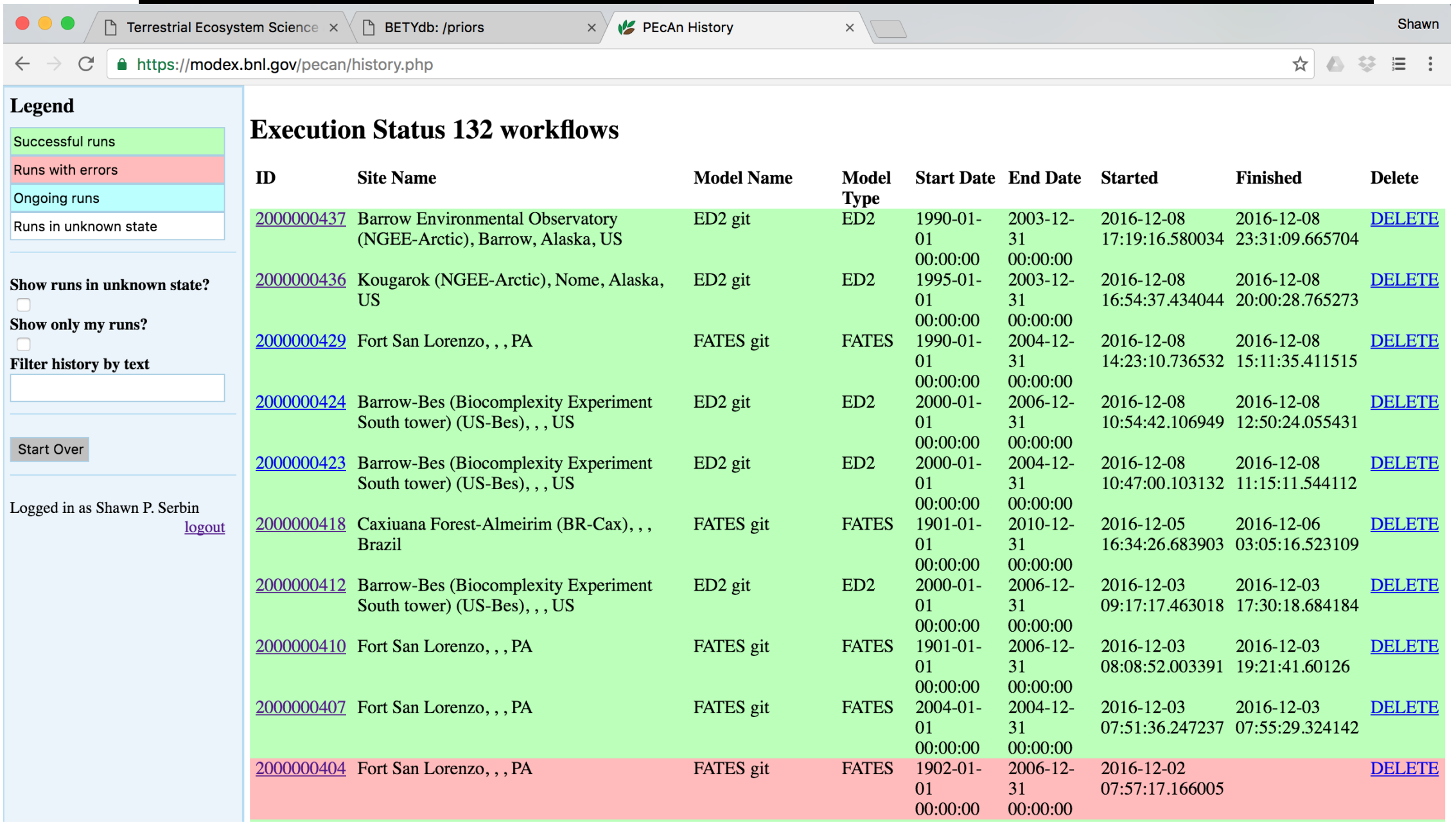
PEcAn – Web interface



PEcAn: Model Setup



PEcAn: Run history & tracking



Example model run through the web interface

https://modex.bnl.gov/shiny/workflowPlot/?workflow_id=2000000437

Workflow Plots

Workflow ID

2000000437

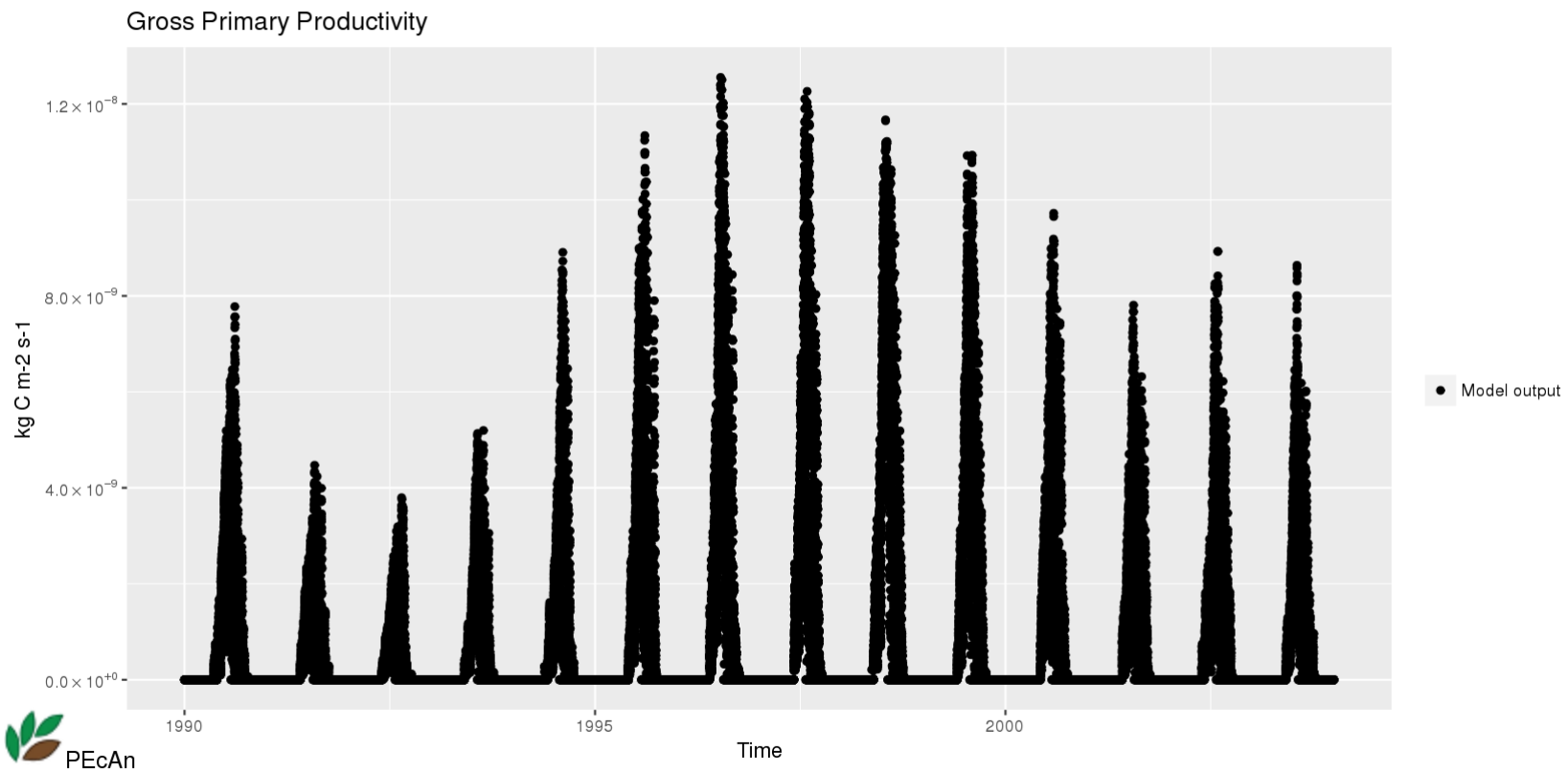
Run ID

2000035561

Variable Name

Gross Primary Productivity

- Gross Primary Productivity
- Heterotrophic Respiration
- Net Ecosystem Exchange
- Net Primary Productivity
- Total Respiration
- Total living biomass
- Total Soil Carbon
- Frozen Layer Thickness



Overall Conclusions

- Provides a framework to provide a thorough and easily reproducible parameter uncertainty analysis

- But, uncertainty is complicated: Need to assess across a range of sites for a given community type: parameters do not necessarily contribute equally to sensitivity or uncertainty at the same community type over an environmental gradient (eg., the Dalton transect)

- Accessibility: key to model improvement
  - Students
  - Empiricists
  - Land managers and decision makers