



Uncertainty Analysis Applied to an Arctic and Boreal Ecosystem Model

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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

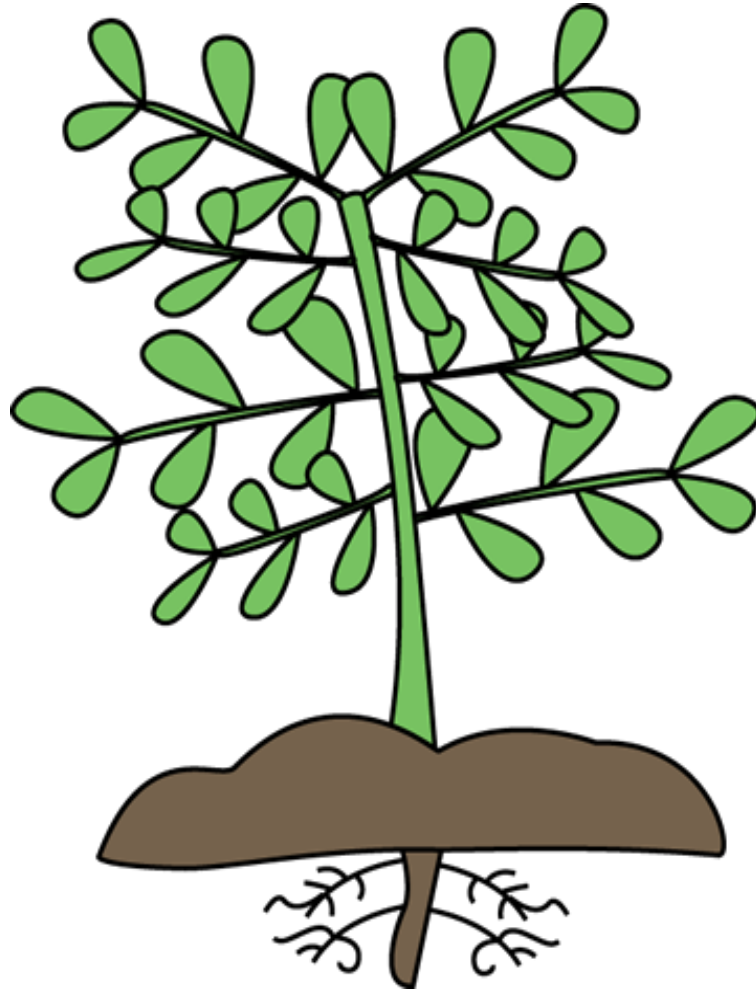
Light competition

Light utilization

Vegetation and soil
carbon storage

Nutrient uptake and
cycling

Fluxes: NPP and ER



Plant traits (e.g., parameters that we can test in this framework)

E.g., extinction coefficient, SLA

E.g. LAI, albedo

E.g. g_{cmax} , optimal photosynthetic temperatures

E.g. Labile N, fine root allocation

E.g. LAI, optimal photosynthetic temperatures, g_{cmax}

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

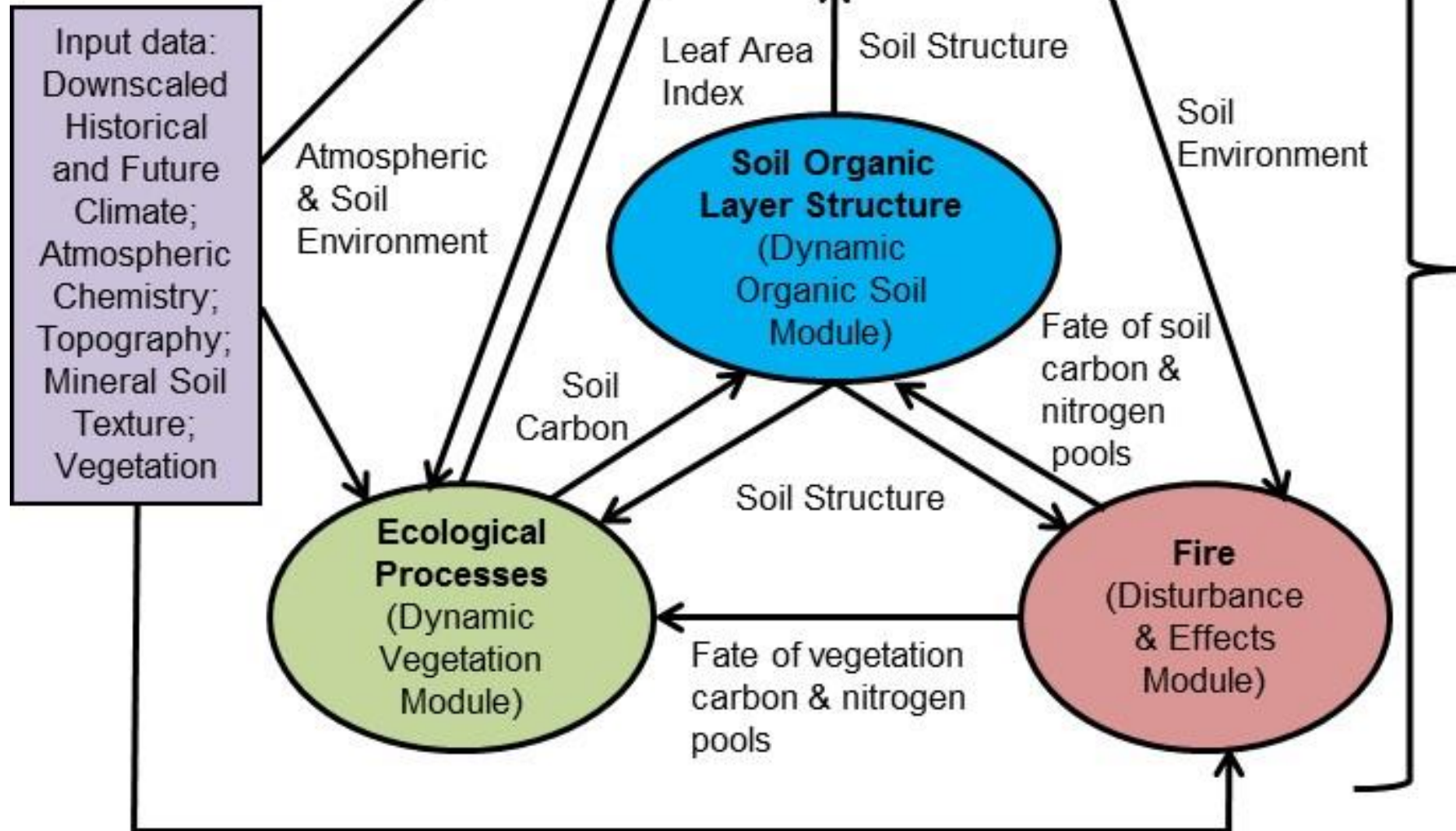


Key questions to address

- 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			

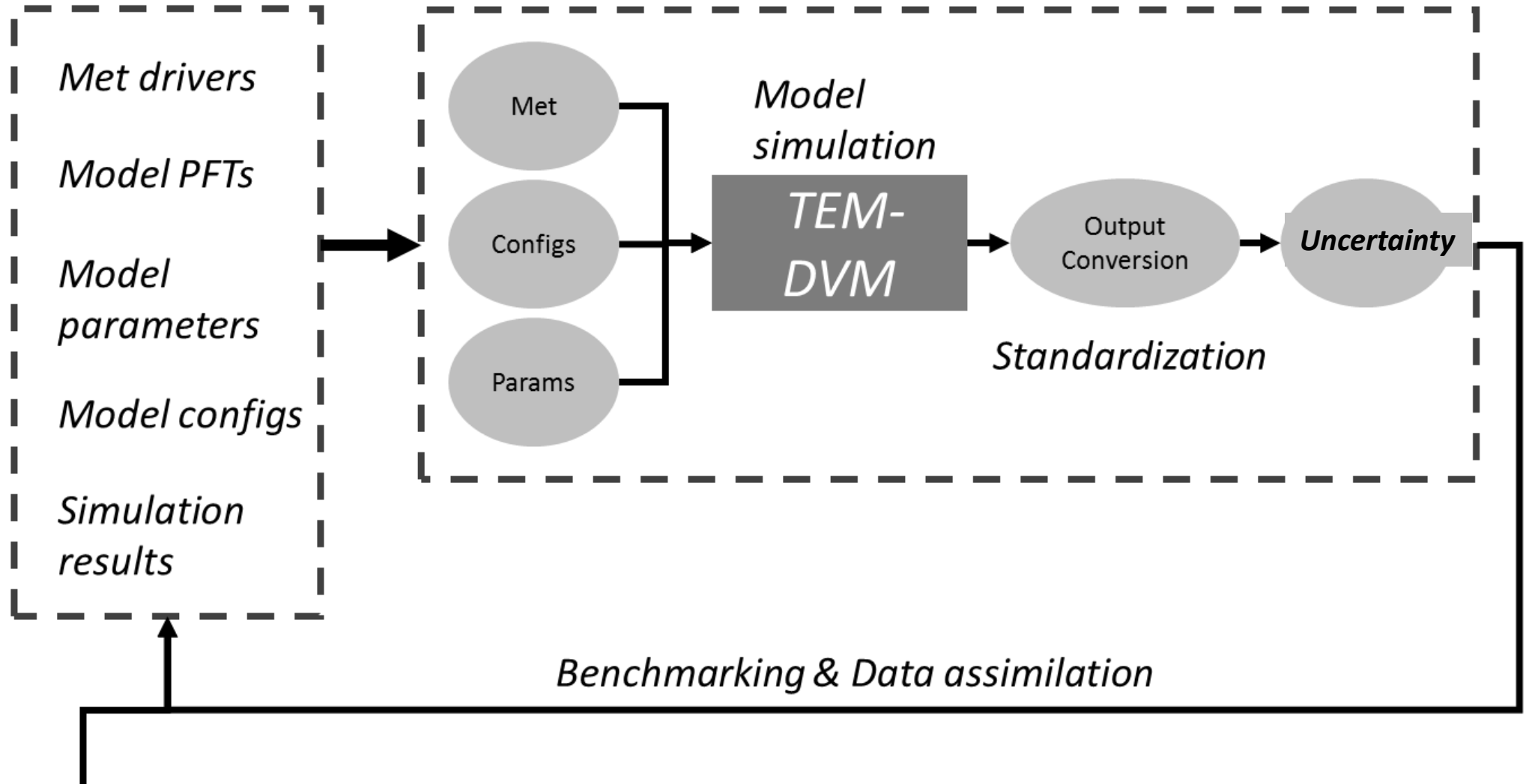


Manages
the flow of
information
into and out
of an
ecosystem
model.



Predictive Ecosystem Analyzer (PEcAn)

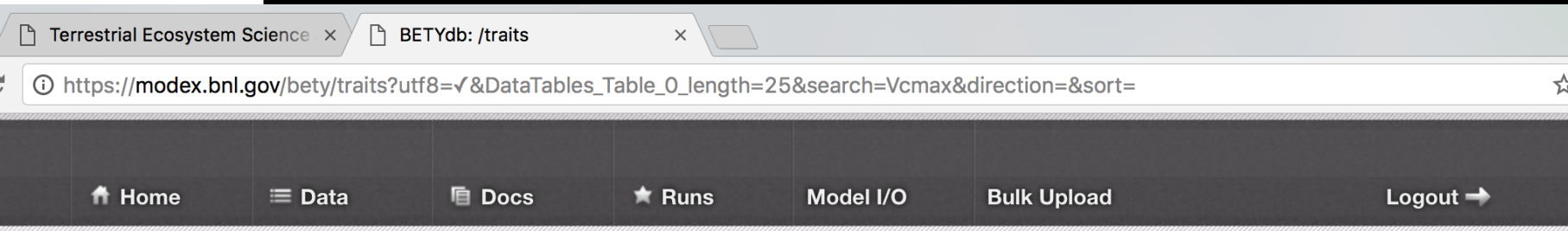
<https://modex.bnl.gov>



New information (e.g. data, drivers, PFT descriptions)

<http://pecanproject.github.io/>

PEcAn Database



<https://modex.bnl.gov/bety>

Listing Traits

New Trait

25 ▾ records per page

Search:

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	<div>passed ▾</div>	<div>4.Public ▾</div>	<div><div>🔍</div><div>✎</div><div>🗑</div></div>
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	<div>passed ▾</div>	<div>4.Public ▾</div>	<div><div>🔍</div><div>✎</div><div>🗑</div></div>
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	<div>passed ▾</div>	<div>4.Public ▾</div>	<div><div>🔍</div><div>✎</div><div>🗑</div></div>
Vcmax - umol CO2	Quercus prinus		51.1	SE = 3.2, n = 9	Turnbull 2001 Photosynthetic	The Black Rock Forest - Highlands	TurnLU : Lower Catchment Uppe	<div>passed ▾</div>	<div>4.Public ▾</div>	<div><div>🔍</div><div>✎</div></div>

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

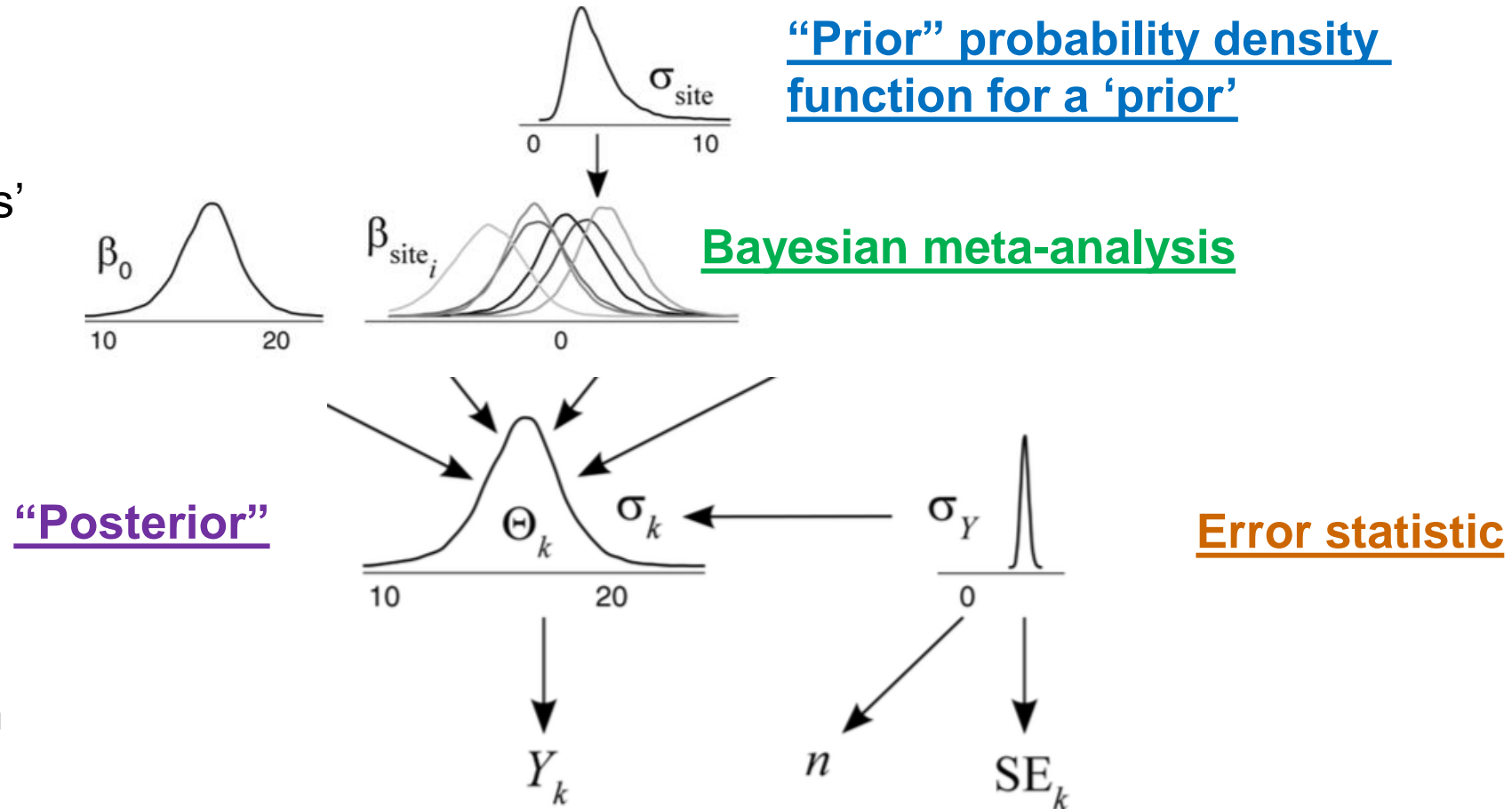
Tracks data provenance:
Site
Date
Species
Treatment
etc.



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.

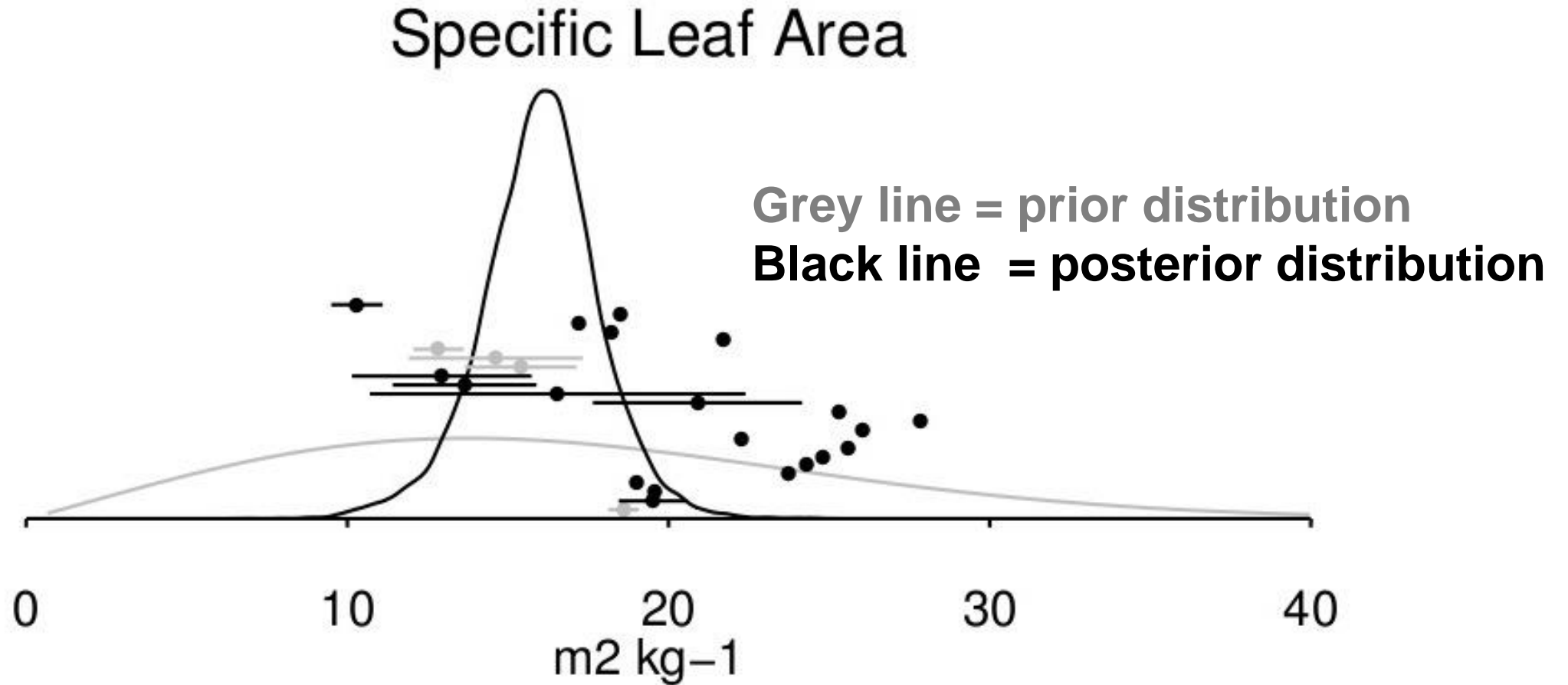


Model ensemble simulations

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

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



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



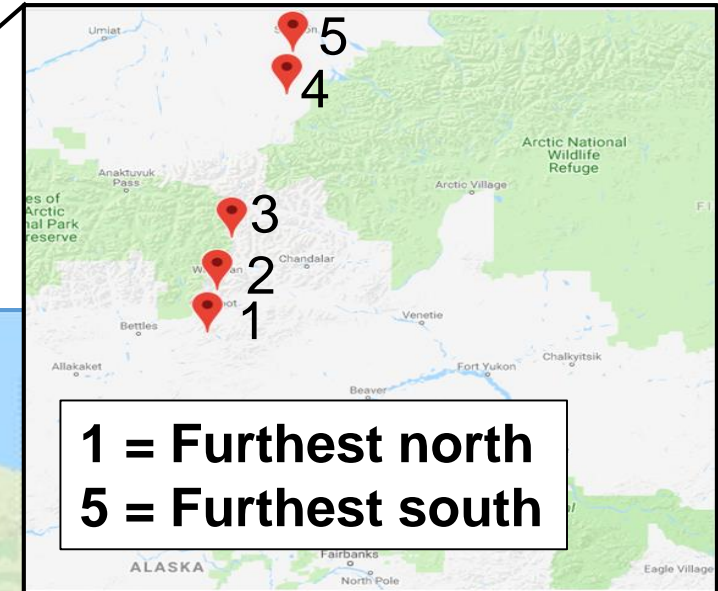
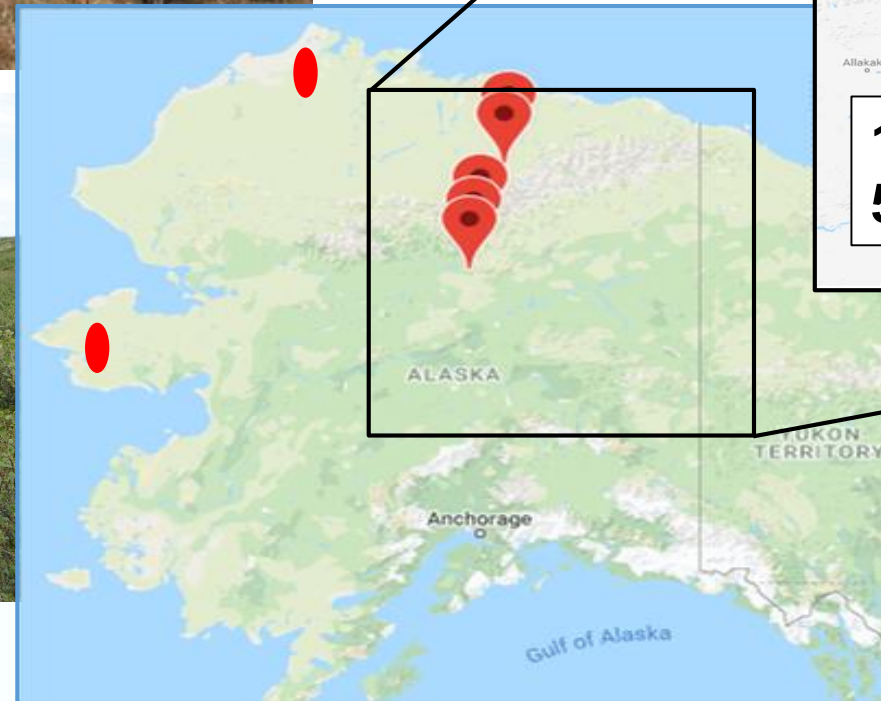
Nome Peninsula

Kougarok:

- Shrub tundra
- Tussock tundra
- Heath tundra



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



Transect:

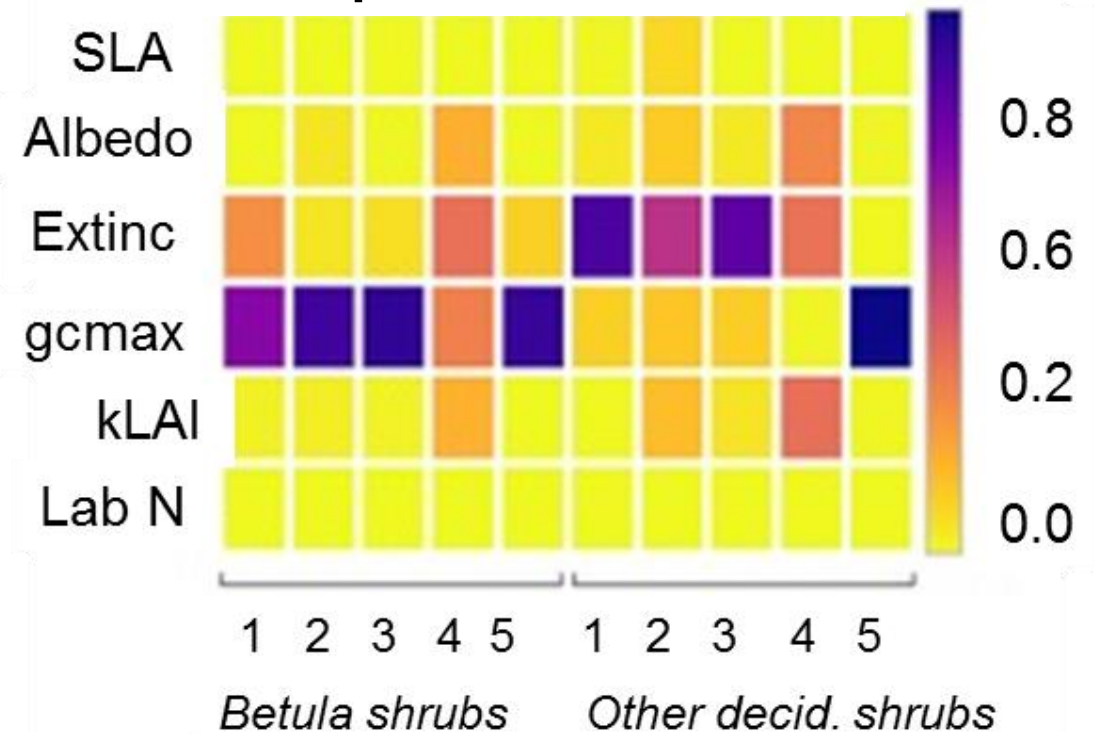
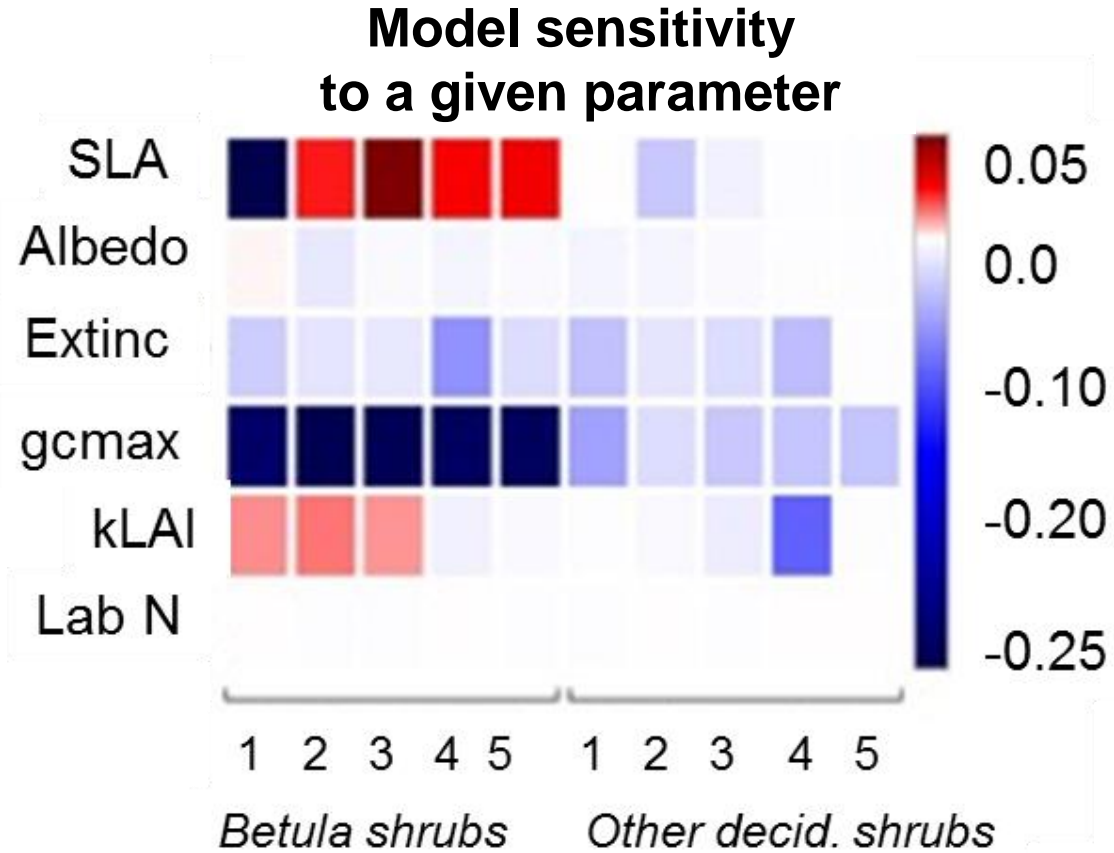
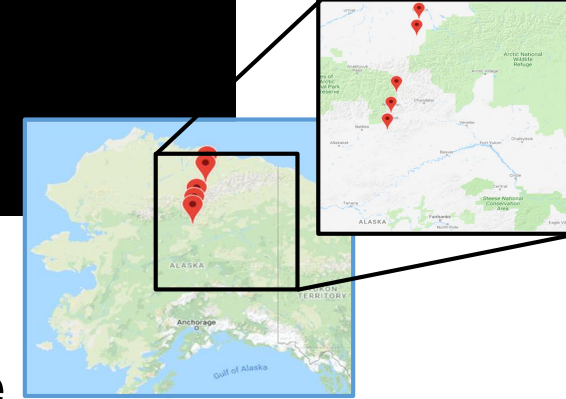
- Shrub tundra
- Tussock tundra



Sensitivity and Uncertainty: NPP of the Shrub Latitudinal Transect

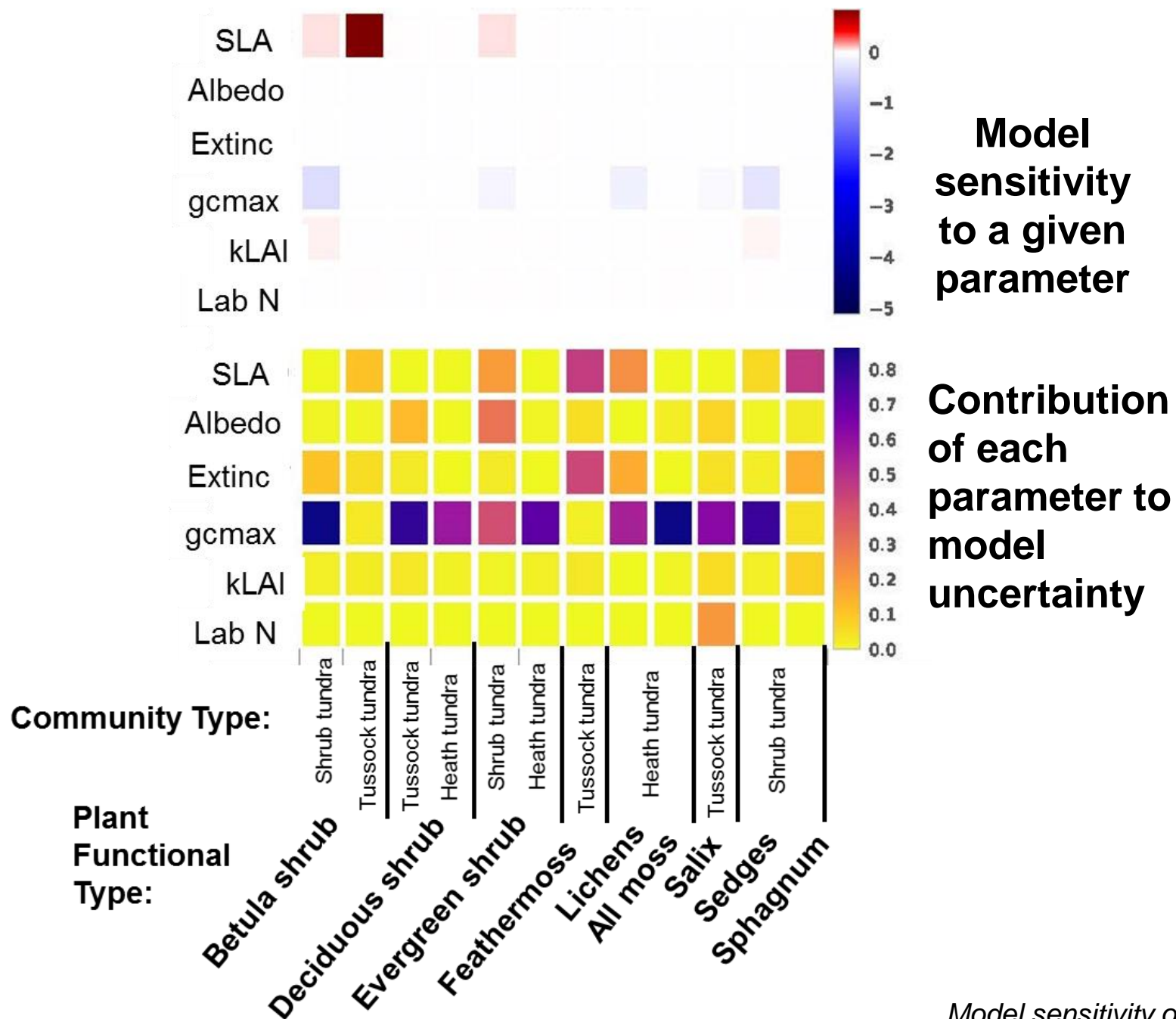
1 = Furthest north
5 = Furthest south

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; **Extinc** = extinction coefficient of diffuse light, **gcmax** = maximum canopy conductance; **kLAI** = leaf area index scaled by the extinction coefficient; **Lab N** = labile nitrogen concentration



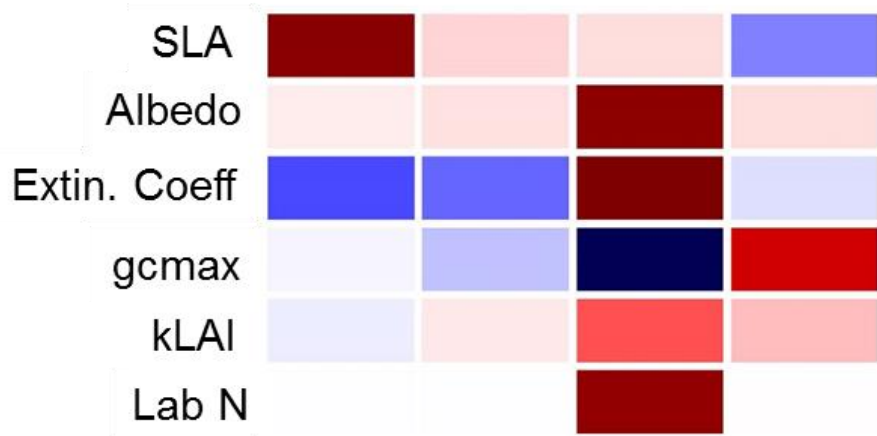
Sensitivity and Uncertainty:

Nome Peninsula Vegetation C

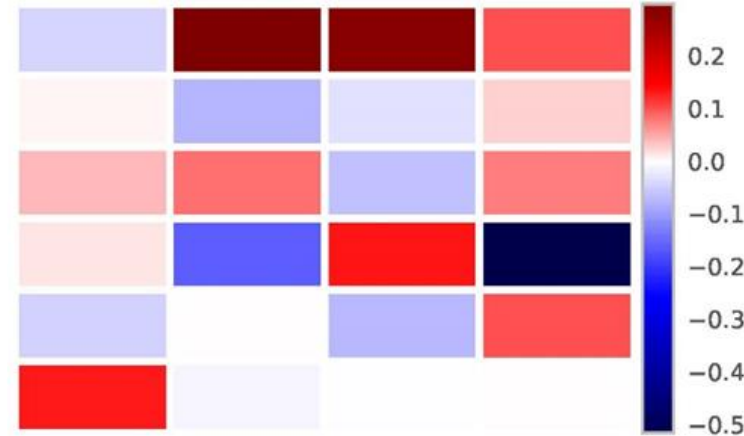
- Shrub Tundra
- Tussock Tundra
- Heath Tundra

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

NPP

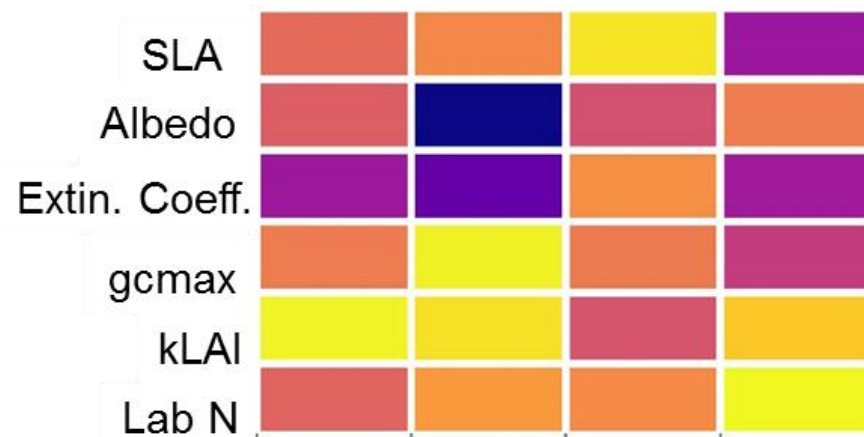


Soil C



Model sensitivity to a given parameter

Sensitivity and Uncertainty: Wet Sedge Tundra

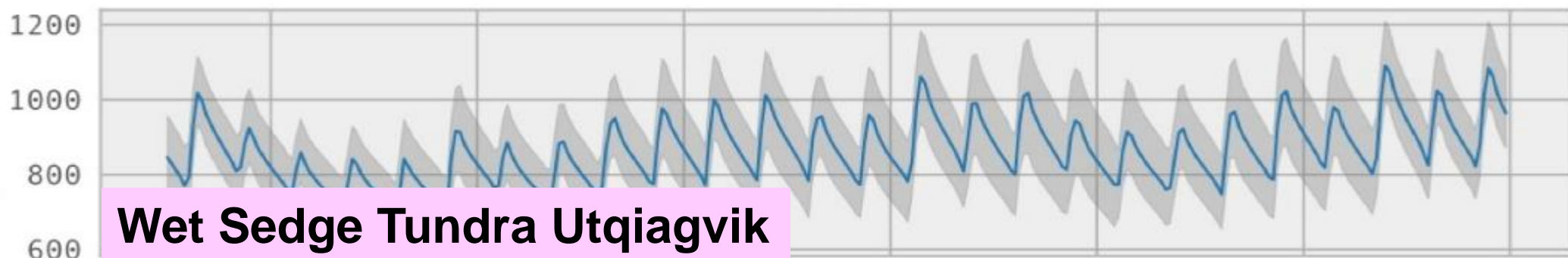
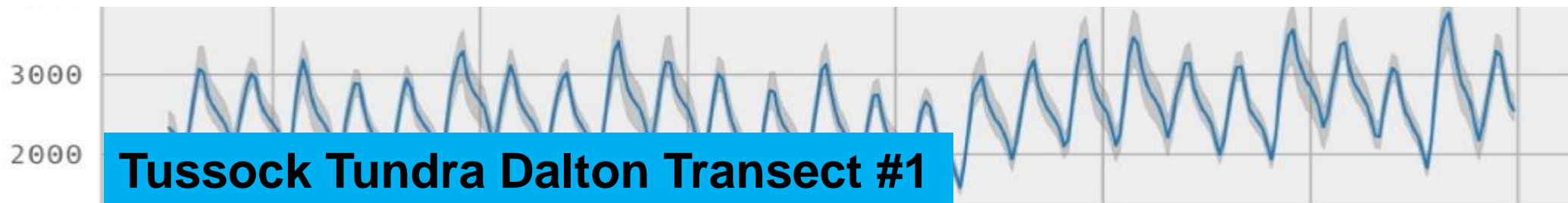
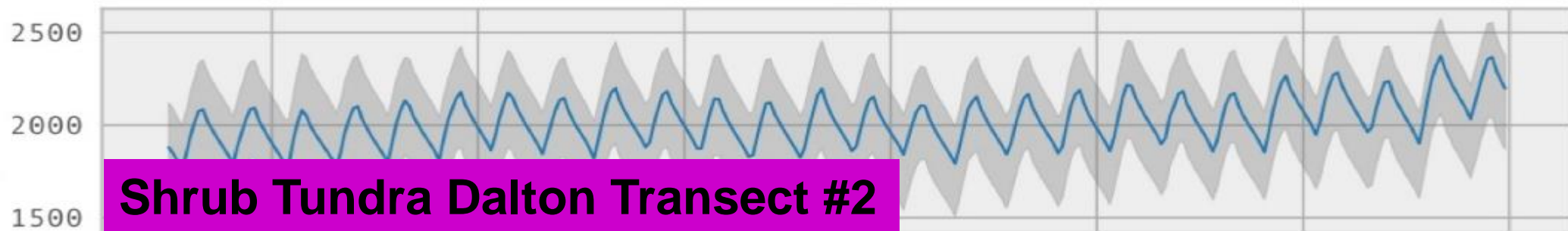
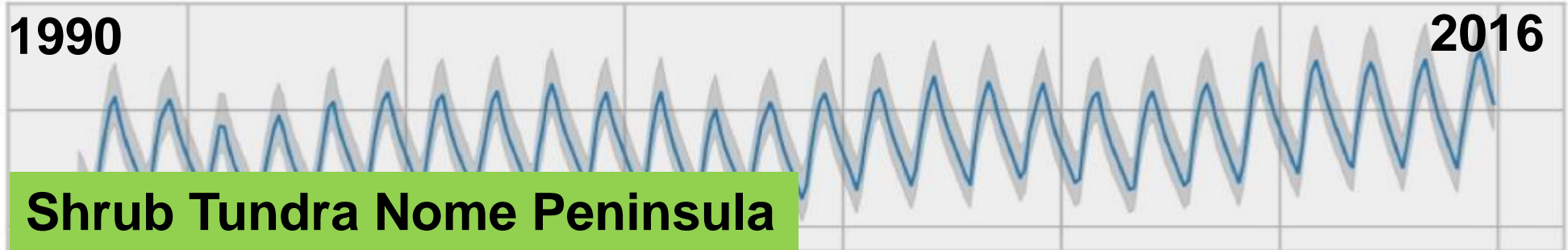


Fraction of model uncertainty caused by a given parameter

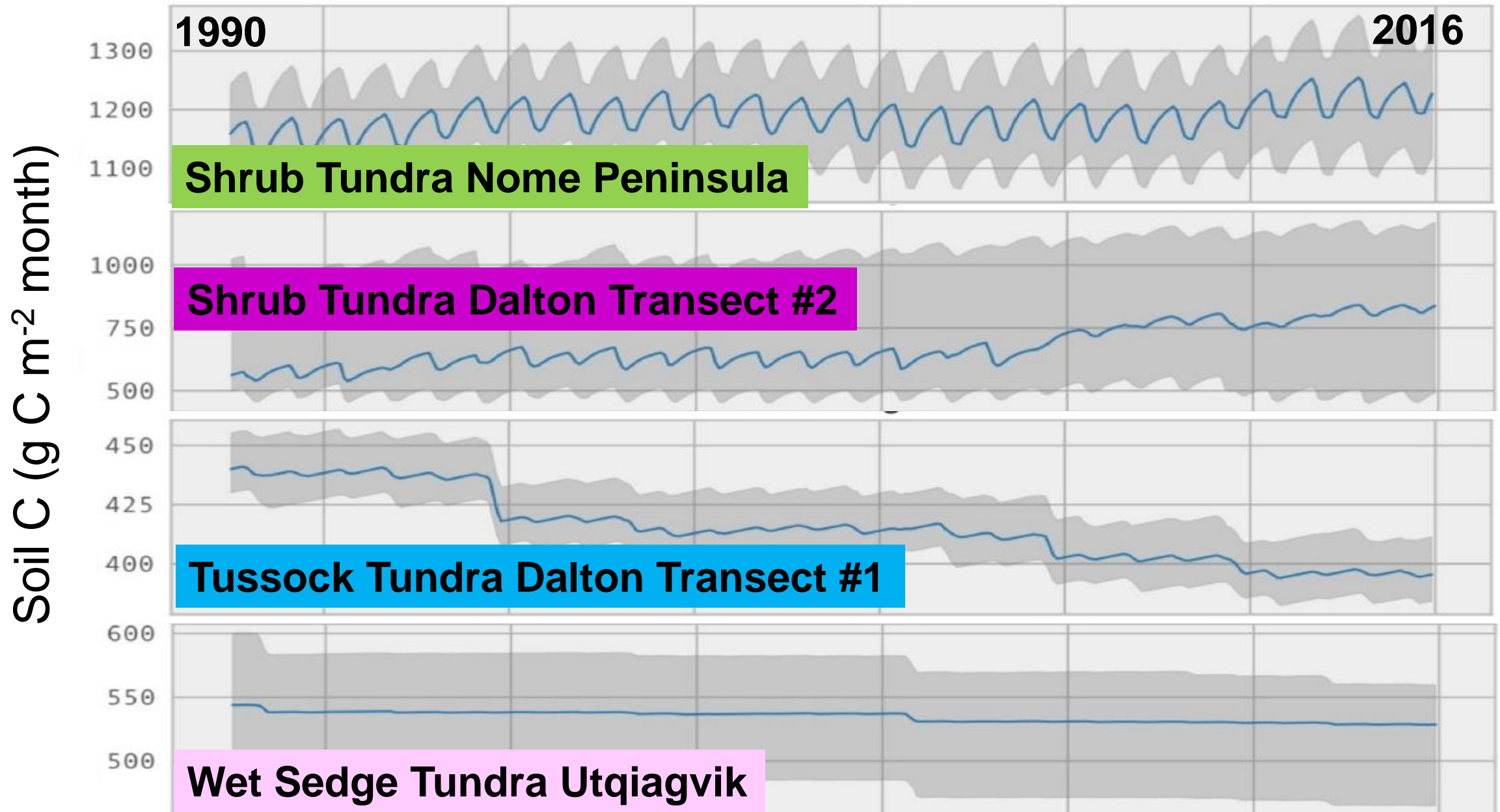
Model sensitivity of 1 means that a model output will double when a given parameter doubles.

Vegetation C Time Series, 1990 – 2016 (g C m⁻² month)

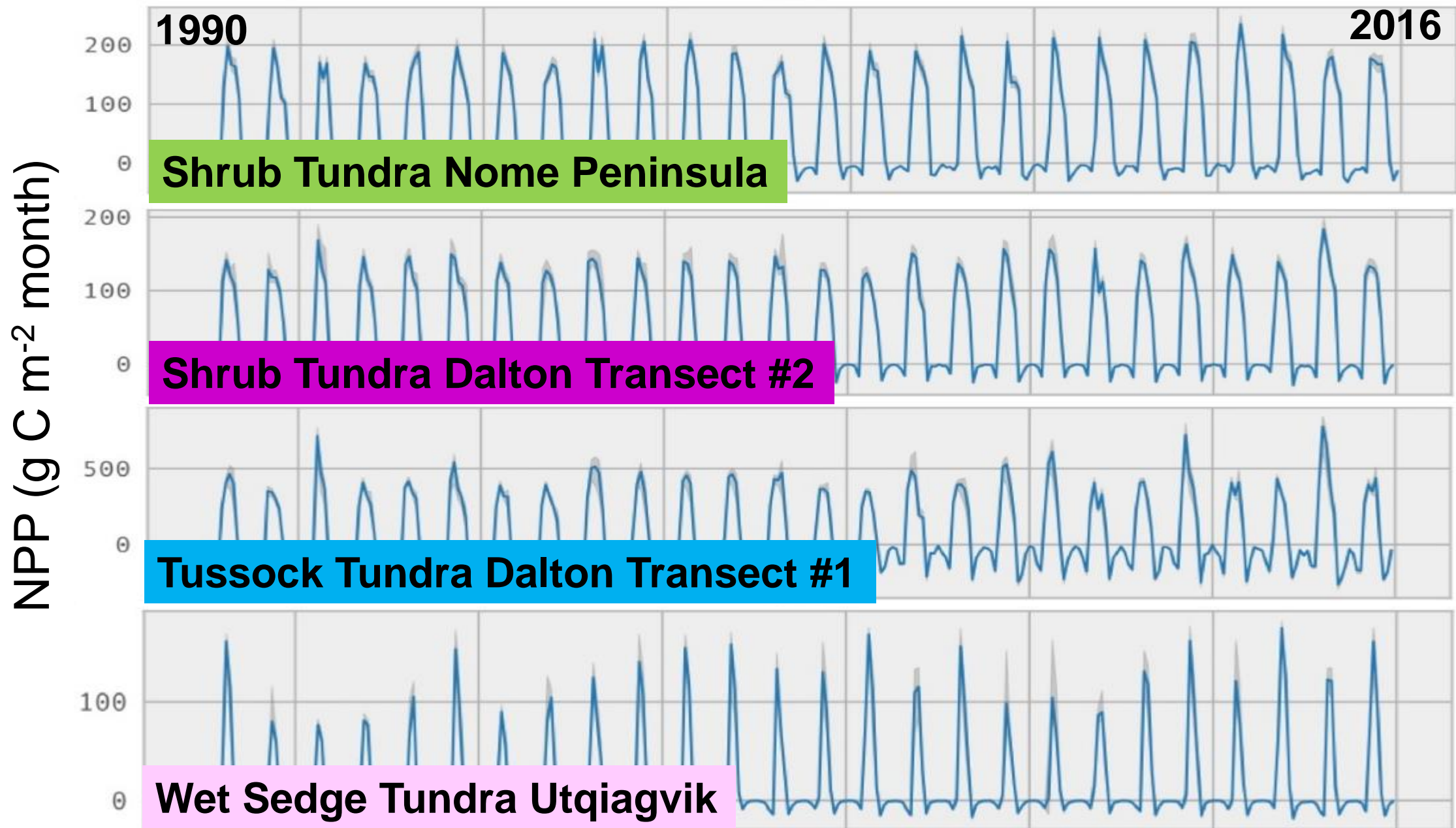
Vegetation C (g C m⁻²)



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

NGEE Arctic | "...improving clin x

Terrestrial Ecosystem Science x

PEcAn Site/Model Selection x

Shawn

← → ↻ <https://modex.bnl.gov/pecan/02-modelsite.php> ☆ ☰ ☱ ☲ ☳ ☴ ☵ ☶ ☷

Select host, model, site

Based on the host selected certain sites and models will be available.

Mouse over menu headers for additional info

Host:
modex.bnl.gov

Model:

- ✓ All Models
- SIPNET (unk)
- SIPNET (r136)
- MAESPA (1)
- MAAT_Model (dev_ngeet)
- LPJ-GUESS (v3.1)
- LINKAGES (R_version)
- LINKAGES (Revision 1.0 Ann's hack)
- FATES (git)
- ED2.2 (46)
- ED2.1-modularized (git_rykelly)
- ED2.1 (r82)
- ED2 (git)
- ED2 (85)
- ED2 (81)
- DALEC (Quaife Evergreen RSE08)
- BioCro

PREV NEXT

Map Satellite

DOE NGEE-Arctic core field sites

Beaufort Sea

Chukchi Sea

ALASKA

YUKON TERRITORY

Anchorage

Gulf of Alaska

Bering Sea

Canada

YUKON TERRITORY

ASKATCHE

Google

Terms of Use Report a map error

Logged in as Shawn P. Serbin

[Documentation](#) [logout](#)

[Chat Room](#)

[Bug Report](#)

The [PEcAn project](#) is supported by the National Science Foundation (ABI #1062547, ABI #1458021, DIBBS #1261582, ARC #1023477, EF #1318164, EF #1241894, EF #1241891), NASA Terrestrial Ecosystems, the Energy Biosciences Institute, and an Amazon AWS in Education Grant.

PEcAn Version 1.4.9

PEcAn: Model Setup

Advanced Edit
Select a file to edit.

File Selection
pecan.xml

Start Over Continue

Logged in as Shawn P. Serbin
[Documentation](#) [logout](#)
[Chat Room](#)
[Bug Report](#)

```
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  <edin>ED2IN.rgit</edin>
```

PEcAn: Run history & tracking

Terrestrial Ecosystem Science x

BETYdb: /priors x

PEcAn History x

Shawn

← → ↺

https://modex.bnl.gov/pecan/history.php

☆

Legend

Successful runs

Runs with errors

Ongoing runs

Runs in unknown state

Show runs in unknown state?

☐

Show only my runs?

☐

Filter history by text

Start Over

Logged in as Shawn P. Serbin

[logout](#)

Execution Status 132 workflows

ID	Site Name	Model Name	Model Type	Start Date	End Date	Started	Finished	Delete
2000000437	Barrow Environmental Observatory (NGEE-Arctic), Barrow, Alaska, US	ED2 git	ED2	1990-01-01 00:00:00	2003-12-31 00:00:00	2016-12-08 17:19:16.580034	2016-12-08 23:31:09.665704	DELETE
2000000436	Kougarok (NGEE-Arctic), Nome, Alaska, US	ED2 git	ED2	1995-01-01 00:00:00	2003-12-31 00:00:00	2016-12-08 16:54:37.434044	2016-12-08 20:00:28.765273	DELETE
2000000429	Fort San Lorenzo, , , PA	FATES git	FATES	1990-01-01 00:00:00	2004-12-31 00:00:00	2016-12-08 14:23:10.736532	2016-12-08 15:11:35.411515	DELETE
2000000424	Barrow-Bes (Biocomplexity Experiment South tower) (US-Bes), , , US	ED2 git	ED2	2000-01-01 00:00:00	2006-12-31 00:00:00	2016-12-08 10:54:42.106949	2016-12-08 12:50:24.055431	DELETE
2000000423	Barrow-Bes (Biocomplexity Experiment South tower) (US-Bes), , , US	ED2 git	ED2	2000-01-01 00:00:00	2004-12-31 00:00:00	2016-12-08 10:47:00.103132	2016-12-08 11:15:11.544112	DELETE
2000000418	Caxiuana Forest-Almeirim (BR-Cax), , , Brazil	FATES git	FATES	1901-01-01 00:00:00	2010-12-31 00:00:00	2016-12-05 16:34:26.683903	2016-12-06 03:05:16.523109	DELETE
2000000412	Barrow-Bes (Biocomplexity Experiment South tower) (US-Bes), , , US	ED2 git	ED2	2000-01-01 00:00:00	2006-12-31 00:00:00	2016-12-03 09:17:17.463018	2016-12-03 17:30:18.684184	DELETE
2000000410	Fort San Lorenzo, , , PA	FATES git	FATES	1901-01-01 00:00:00	2006-12-31 00:00:00	2016-12-03 08:08:52.003391	2016-12-03 19:21:41.60126	DELETE
2000000407	Fort San Lorenzo, , , PA	FATES git	FATES	2004-01-01 00:00:00	2004-12-31 00:00:00	2016-12-03 07:51:36.247237	2016-12-03 07:55:29.324142	DELETE
2000000404	Fort San Lorenzo, , , PA	FATES git	FATES	1902-01-01 00:00:00	2006-12-31 00:00:00	2016-12-02 07:57:17.166005		DELETE

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

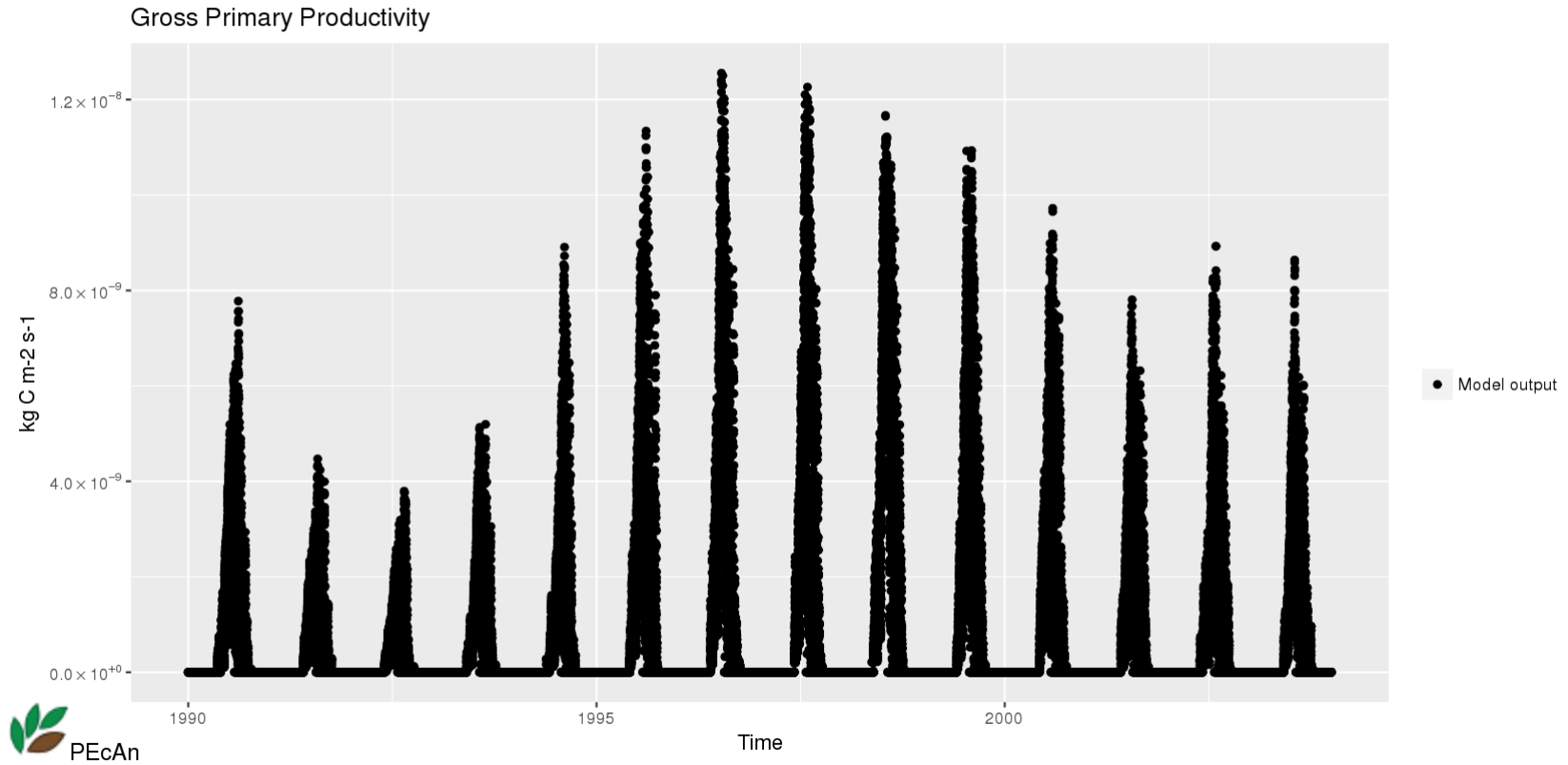
Net Primary Productivity

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

