Measuring and modeling what you can't see: Plant roots in arctic tundra

(Iversen, Sloan, Sullivan, Euskirchen, McGuire, Norby, Walker, Warren, Wullschleger)

Oak Ridge National Laboratory
University of Alaska, Anchorage
University of Alaska, Fairbanks

Mod-Ex 'in action'

Take-home message:
"Given that available data do not wholly capture the heterogeneity of the Arctic region, it is difficult to know whether models are accurately representing the Arctic landscape. Therefore, the burden of the data-model interaction in tundra ecosystems falls disproportionately on the shoulders of empirical scientists."

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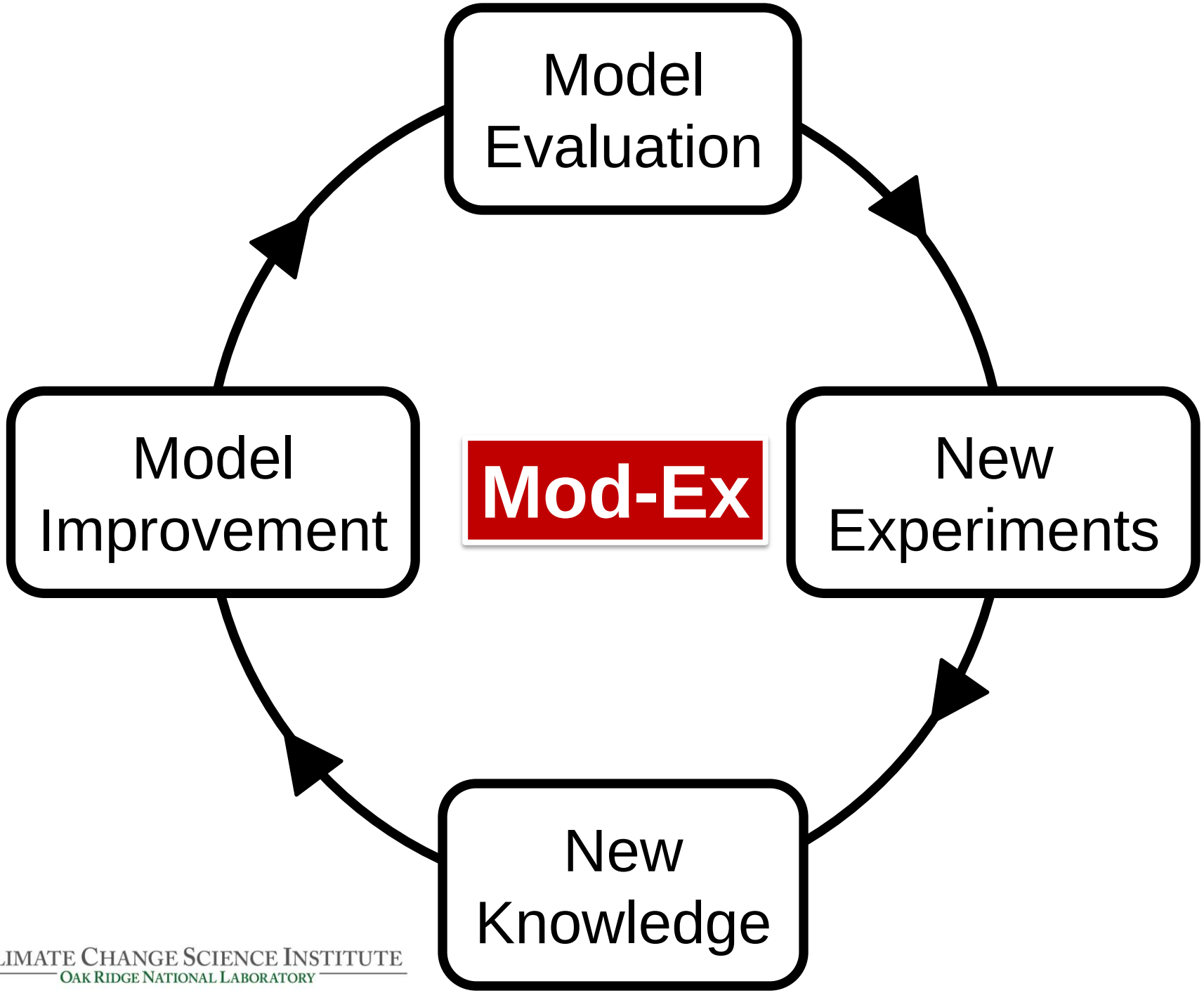
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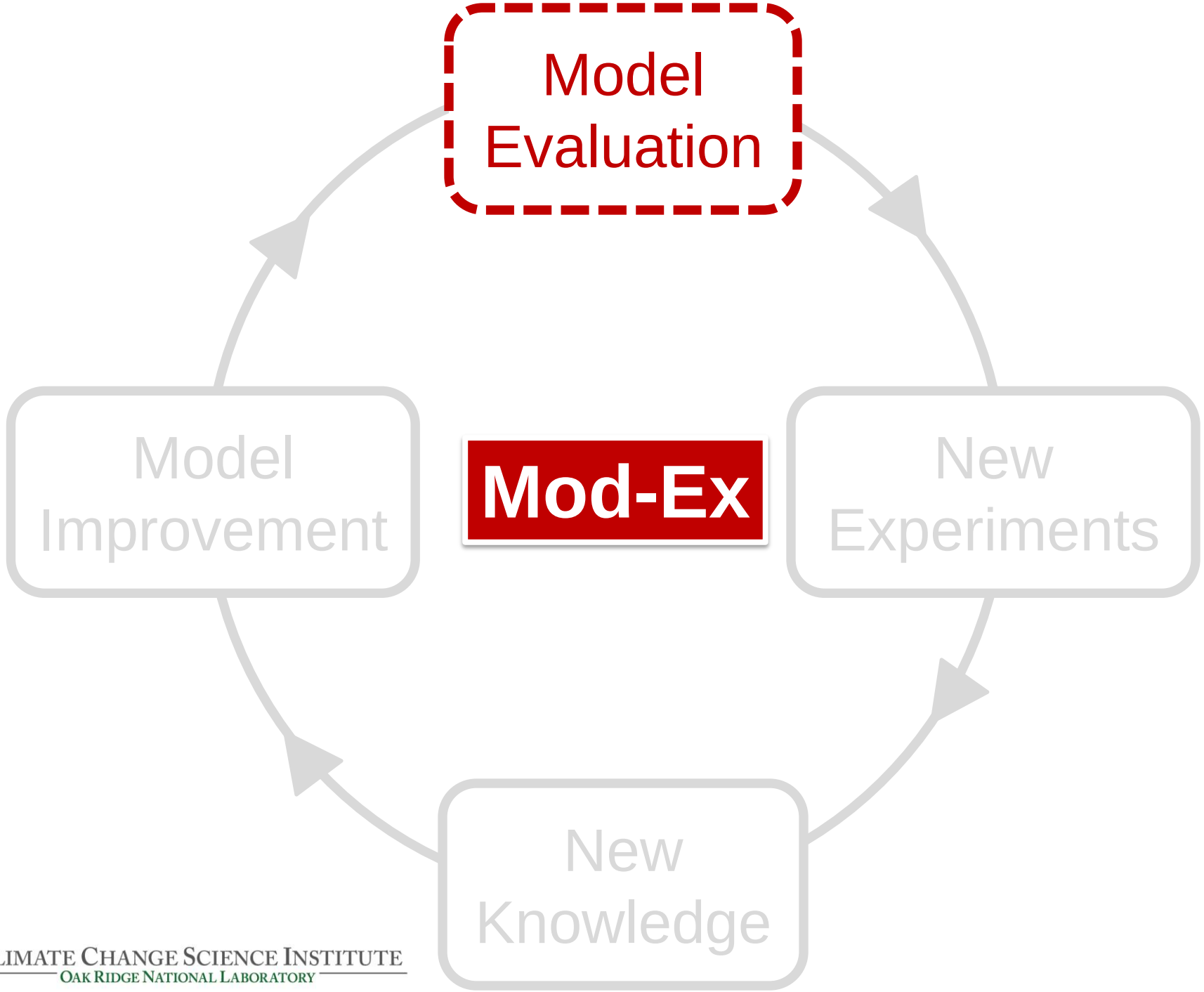
Model Evaluation
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How do models prevalent in tundra literature or in on-going model inter-comparison activities in the Arctic **REPRESENT THE RANGE OF ROOT TRAITS AND PROCESSES** of tundra plant species?

New Phytologist

Review

Tansley review

The unseen iceberg: plant roots in arctic tundra

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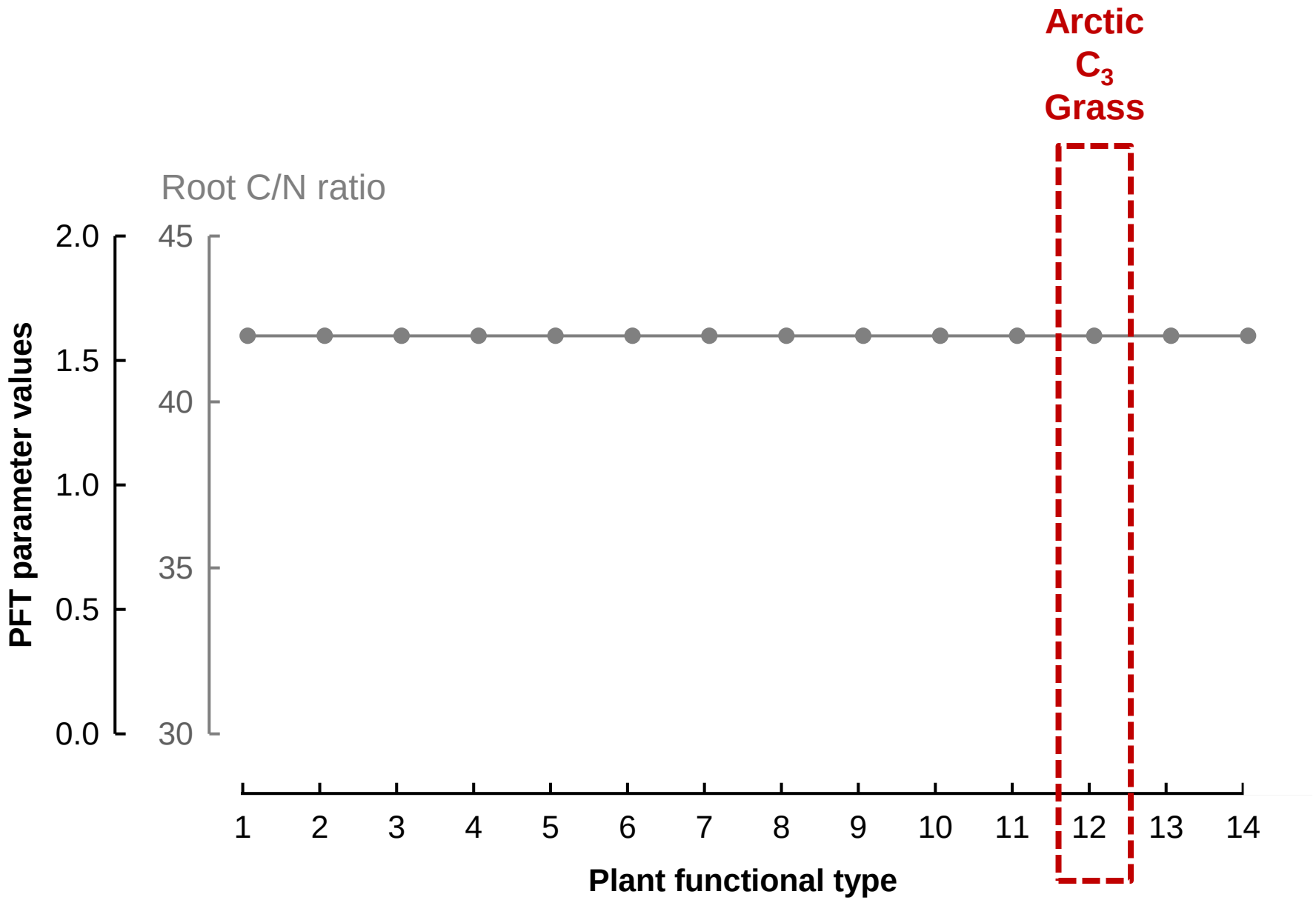
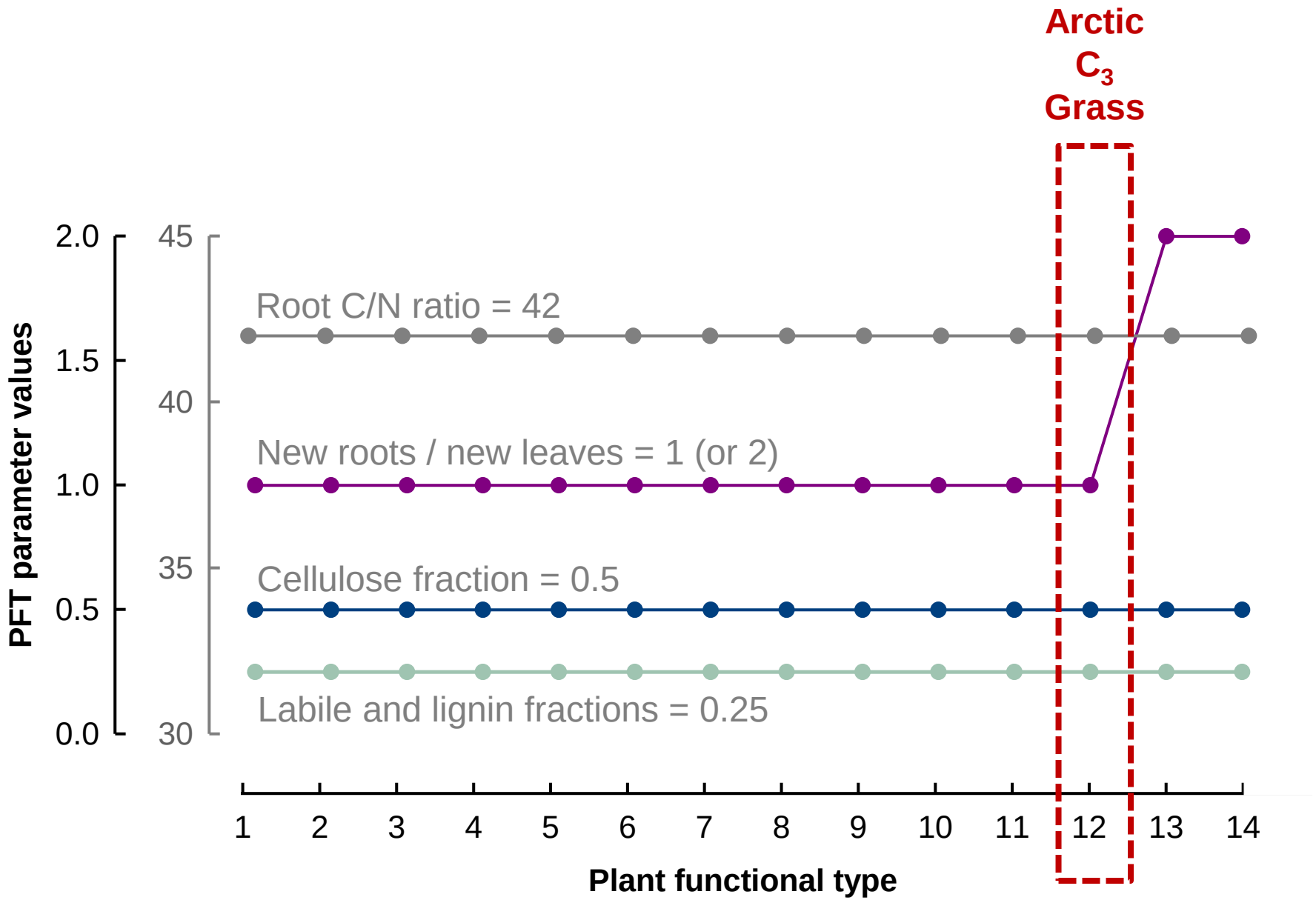
[1]Climate Change Science Institute, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA; [2]Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831-6301, USA; [3]Environment and Natural Resources Institute, University of Alaska, Anchorage, AK 99508, USA; [4]Institute of Arctic Biology, University of Alaska, Fairbanks, AK 99775, USA; [5]US Geological Survey, Alaska Cooperative Fish and Wildlife Research, University of Alaska, Fairbanks, AK 99775, USA

Table 2 Representation of roots in models commonly used to simulate processes in arctic tundra

Model parameter/ process	ArcVeg C and N cycle Single soil layer	MBL-GEM III C and N cycle Single soil layer	DVM-DOS-TEM C and N cycle Multiple soil layers	LPJ-GUESS WhyMe C cycle Multiple soil layers	CLM4.5-BGC C and N cycle Multiple soil layers	Orchidee-WET C cycle Multiple soil layers
Biomass	B/A = 2–25	Balance of production and mortality	Balance of production and mortality	Balance of production and mortality	Balance of production and mortality	Balance of production and mortality
Production	N/A	*Functional balance*: Nitrogen limitation	*Fixed partitioning*: Target based on field data (root/leaf = 0.1–1.7)	*Functional balance*: Nitrogen, moisture limitation (max root/leaf = 1–5)	*Fixed partitioning* (root/leaf = 1 for arctic PFT)	*Functional balance*: Moisture, light limitation
		Phenology: Constant	*Phenology*: Same as leaves	*Phenology*: Same as leaves	*Phenology*: Same as leaves	*Phenology*: Same as leaves
Turnover	Implicit in whole-plant turnover	Fixed fraction 0.164 yr^{-1} (*c.* 6 yr)	Standing crop/production (1–4 yr)	Fixed fraction 0.5–0.7 yr^{-1} (1.4–2 yr)	Same as leaves (< 1 yr)	Same as leaves (< 1 yr)
Depth distribution	N/A	None	Exponential decay of fraction with depth to maximum rooting depth	70–93 % in upper soil	Double-exponential for water; exponential for C inputs (decoupled from mass)	Exponential (decoupled from mass)
Morphology	N/A	None	None	None	None	None
Chemistry	Implicit in whole-plant N content	Target C : N ratio	Target C : N ratio	N/A	Fixed C : N and labile C: cellulose : lignin	Fixed C : N and lignin : N (implied)
Aerenchyma	N/A	None	None: see peatland DOS-TEM (Fan *et al.*, 2013)	Yes (flood-tolerant C_3 graminoid PFT)	Root porosity differs by PFT; aerenchyma area *f* (NPP, LAI)	Not explicit
Mycorrhizas	N/A	None	None	None	None	None
Water uptake	N/A	N/A	*f* (plant demand, root proportion, SWC)	*f* (plant demand, root proportion, SWC)	*f* (plant demand, root proportion, SWC)	*f* (plant demand, root proportion, SWC)
Root-dependent N uptake	Plants compete for soil N based on NUE	*f* (root N content, air temperature)	*f* (plant demand, root proportion and mass, root respiration, air temperature, SWC, available N)	N/A	None	N/A
Carbon fluxes	*Respiration*: None	*Respiration*: *f* (root N content, root C : N, air temperature)	*Respiration*: *f* (root biomass, air temperature)	*Respiration*: *f* (root biomass, root C : N, soil temperature)	*Respiration*: *f* (root biomass, root C : N, soil temperature)	*Respiration*: *f* (root biomass, root C : N, soil temperature)
	Exudation: None	*Exudation*: None	*Exudation*: None	*Exudation*: 17.5 % of NPP	*Exudation*: None	*Exudation*: None
	CH_4 flux: None	*CH_4 flux*: None	*CH_4 flux*: None (see Fan *et al.*, 2013)	*CH_4 flux*: *f* (cross-sectional area of tillers; phenology; root depth)	*CH_4 flux*: *f* (root porosity, root length, root depth)	*CH_4 flux*: *f* (LAI)
Decomposition	N/A	Root litter allocated to soil pools based on C fractions; decomposition is *f* (SWC, air temperature, microbial efficiency)	*f* (soil temperature, SWC, soil C : N)	*f* (soil temperature, SWC)	Roots allocated to litter pools based on C fractions and N content; decomposition is *f* (soil temperature, SWC, O_2, soil depth, soil mineral N availability)	Roots allocated to litter pools based on C fractions; decomposition is *f* (soil Temperature, SWC)

Iversen *et al.*, 2015 (*New Phytologist*)


Arctic
C_3
Grass
Root C/N ratio
PFT parameter values
2.0
1.5
1.0
0.5
0.0
45
40
35
30
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Plant functional type


Arctic
C_3
Grass
PFT parameter values
2.0
1.5
1.0
0.5
0.0
45
40
35
30
Root C/N ratio = 42
New roots / new leaves = 1 (or 2)
Cellulose fraction = 0.5
Labile and lignin fractions = 0.25
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Plant functional type

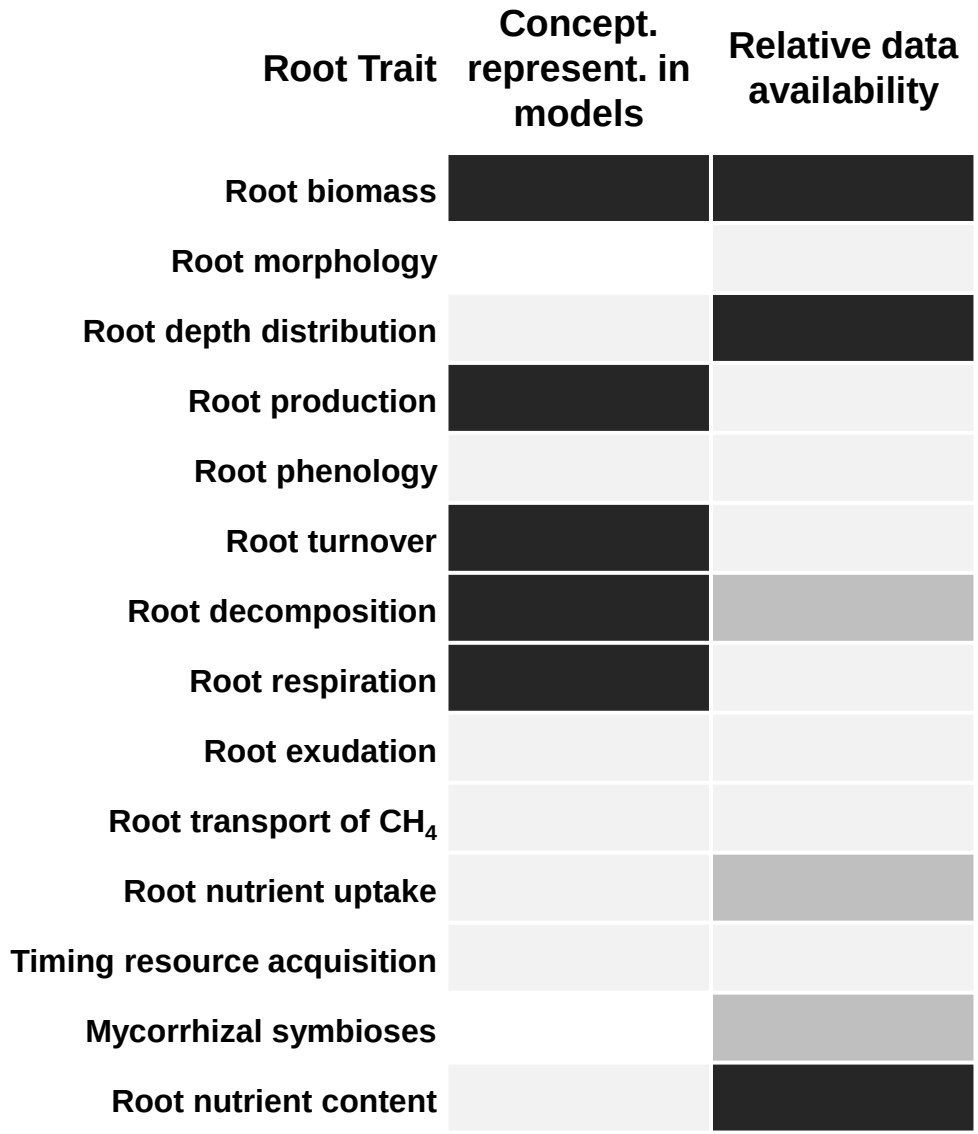
Specific to the Arctic

Root Trait	Concept. represent. in models
Root biomass	Many / Most
Root morphology	None
Root depth distribution	Limited
Root production	Many / Most
Root phenology	Limited
Root turnover	Many / Most
Root decomposition	Many / Most
Root respiration	Many / Most
Root exudation	Limited
Root transport of CH_4	Limited
Root nutrient uptake	Limited
Timing resource acquisition	Limited
Mycorrhizal symbioses	None
Root nutrient content	Limited

Many / Most Some Limited None

Iversen *et al*., 2015 (*New Phytologist*)

Specific to the Arctic



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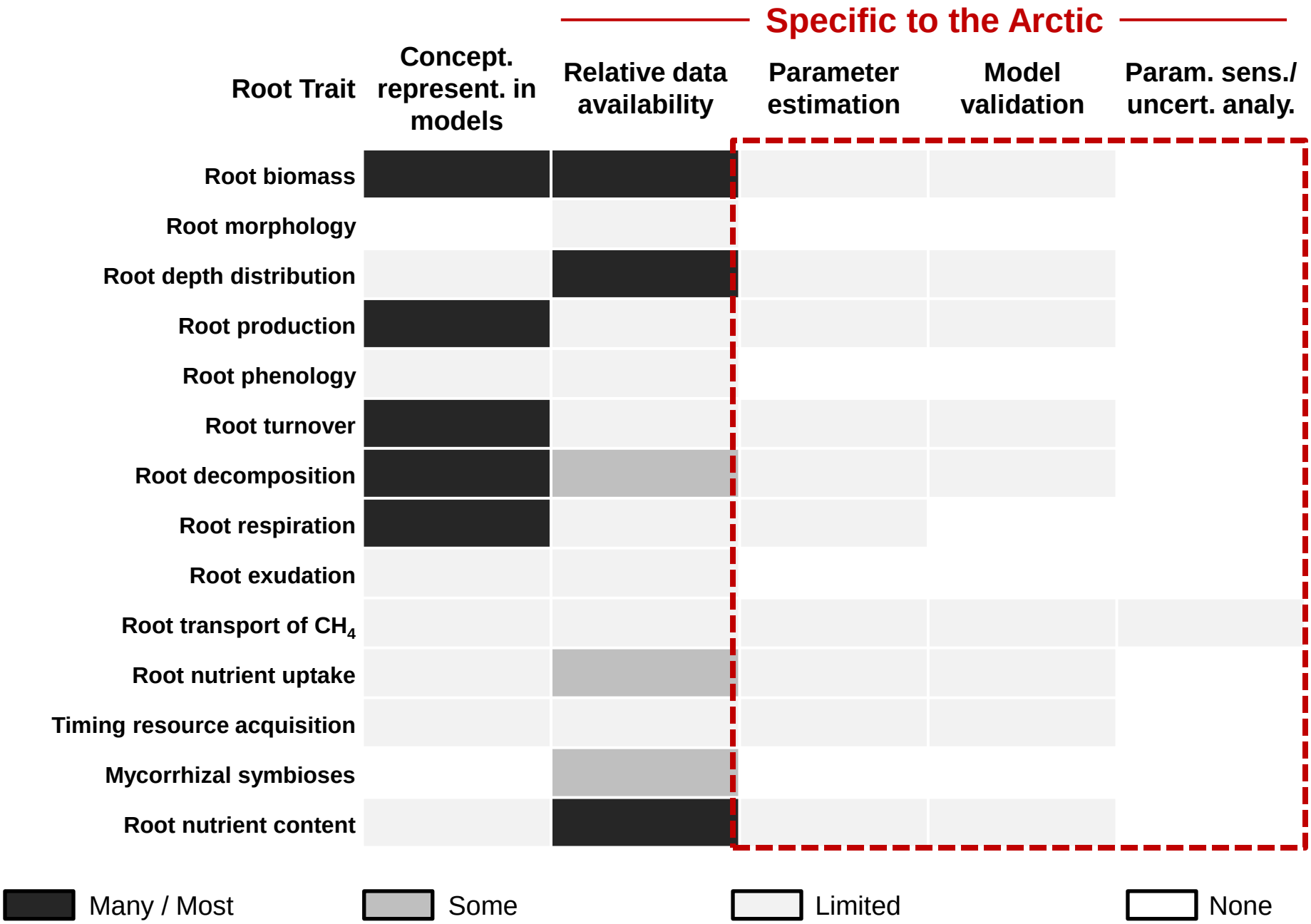


Iversen *et al*., 2015 (*New Phytologist*)

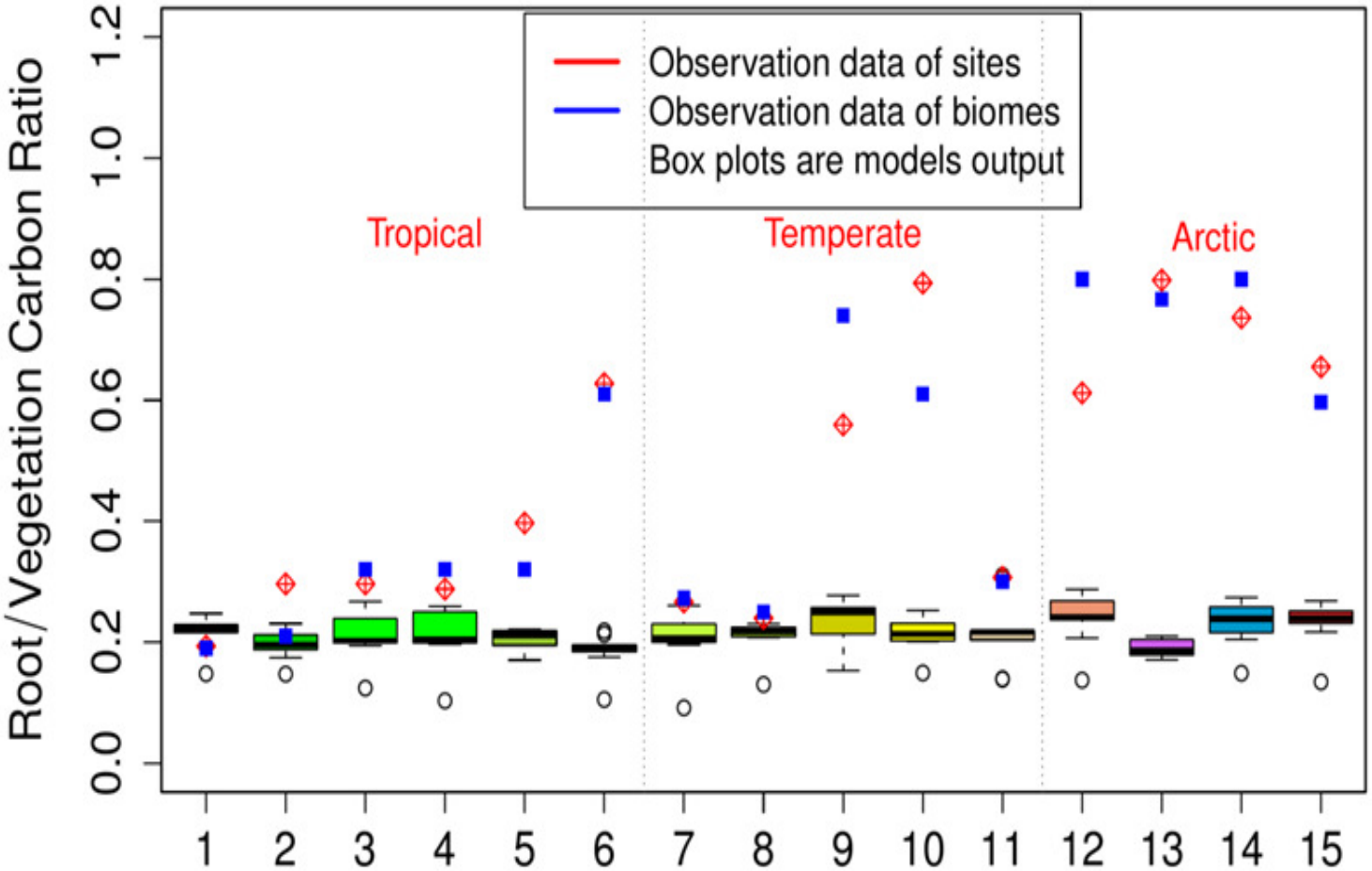
Take home message:

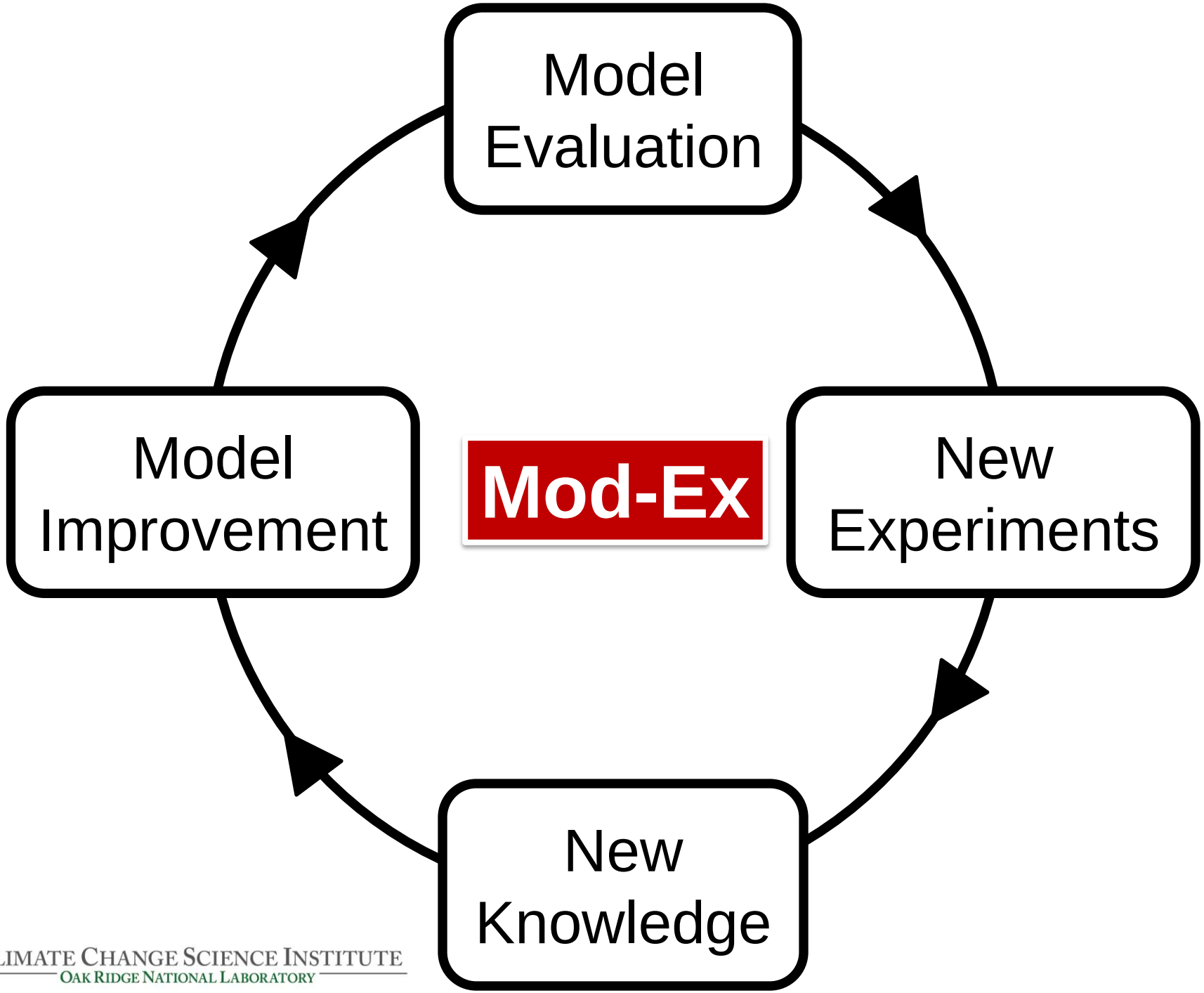
Little, if any, parameter estimation, model validation, or uncertainty/sensitivity analyses have been performed for processes associated with root structure or function in tundra ecosystems.

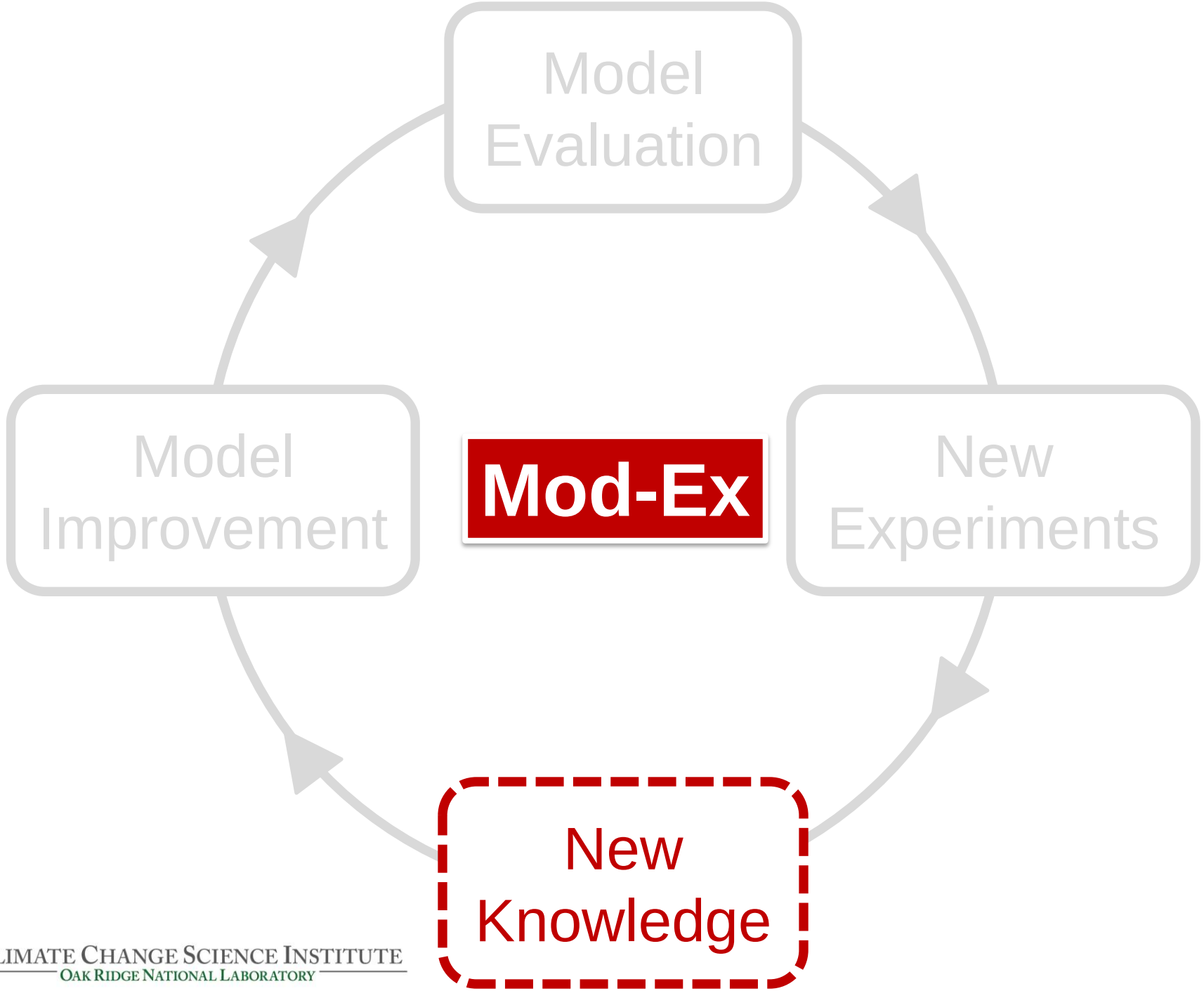
Above-Belowground Vegetation Carbon Allocation in CMIP5 Earth System Models

Xia Song[1,2], Forrest M. Hoffman[2], Xiaofeng Xu[1,2], Colleen M. Iversen[2], Jitendra Kumar[2]
1: University of Texas at El Paso, El Paso, TX, 79902, USA; 2: Climate Change Science Institute and Environmental Science Division, Oak Ridge National Laboratory, Oak Ridge, TN, 37831, USA
(xsong@utep.edu)

Carbon Ratio of Model Output and Observation Data




Model Evaluation
New Experiments
New Knowledge
Model Improvement
Mod-Ex


Model Evaluation
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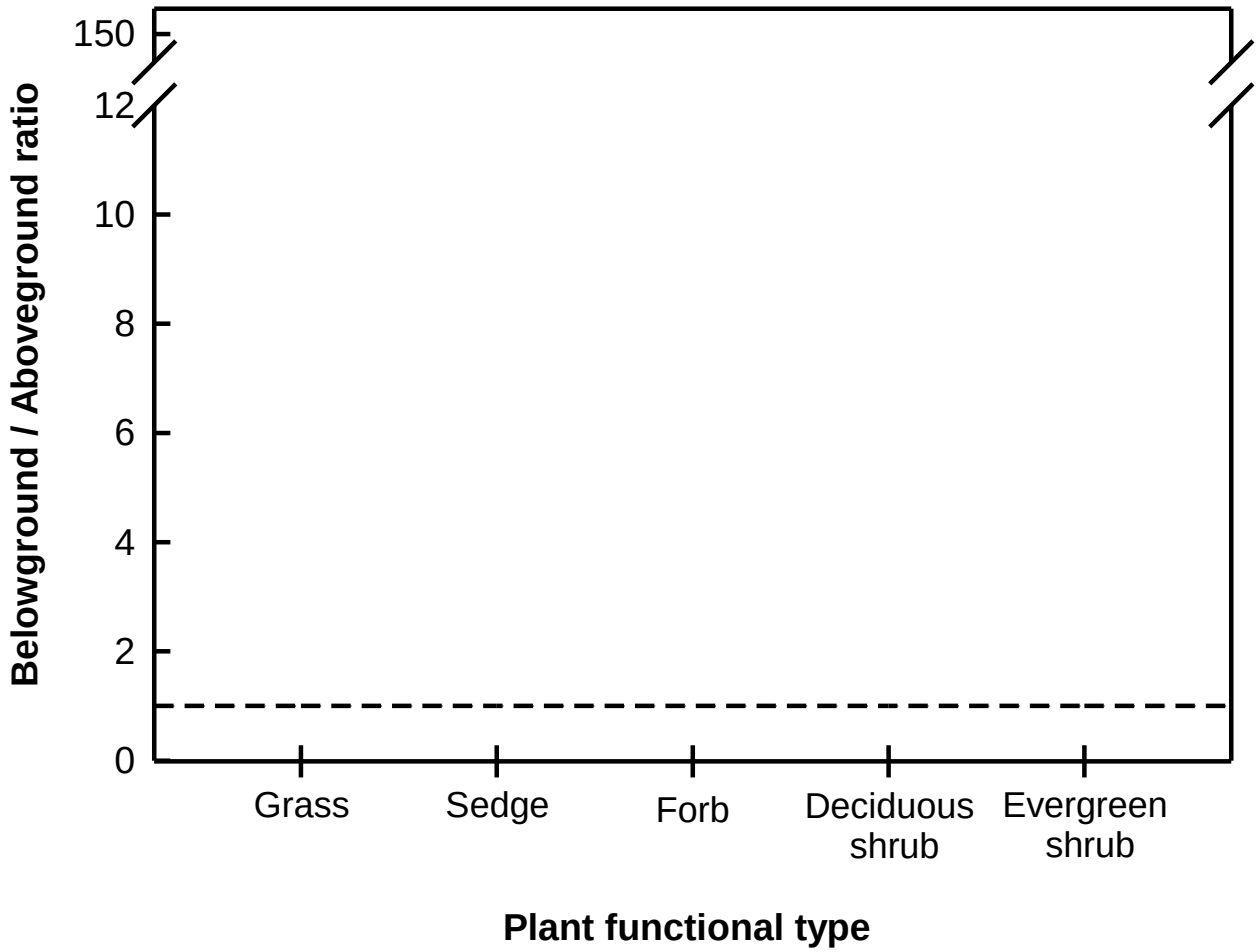
Are different model conceptualizations and parameterizations needed to **ACCURATELY REPRESENT THE RANGE OF ROOT TRAITS AND PROCESSES** of tundra plant species?

Plant functional types (PFTs) in arctic tundra differ in their B/A ratio



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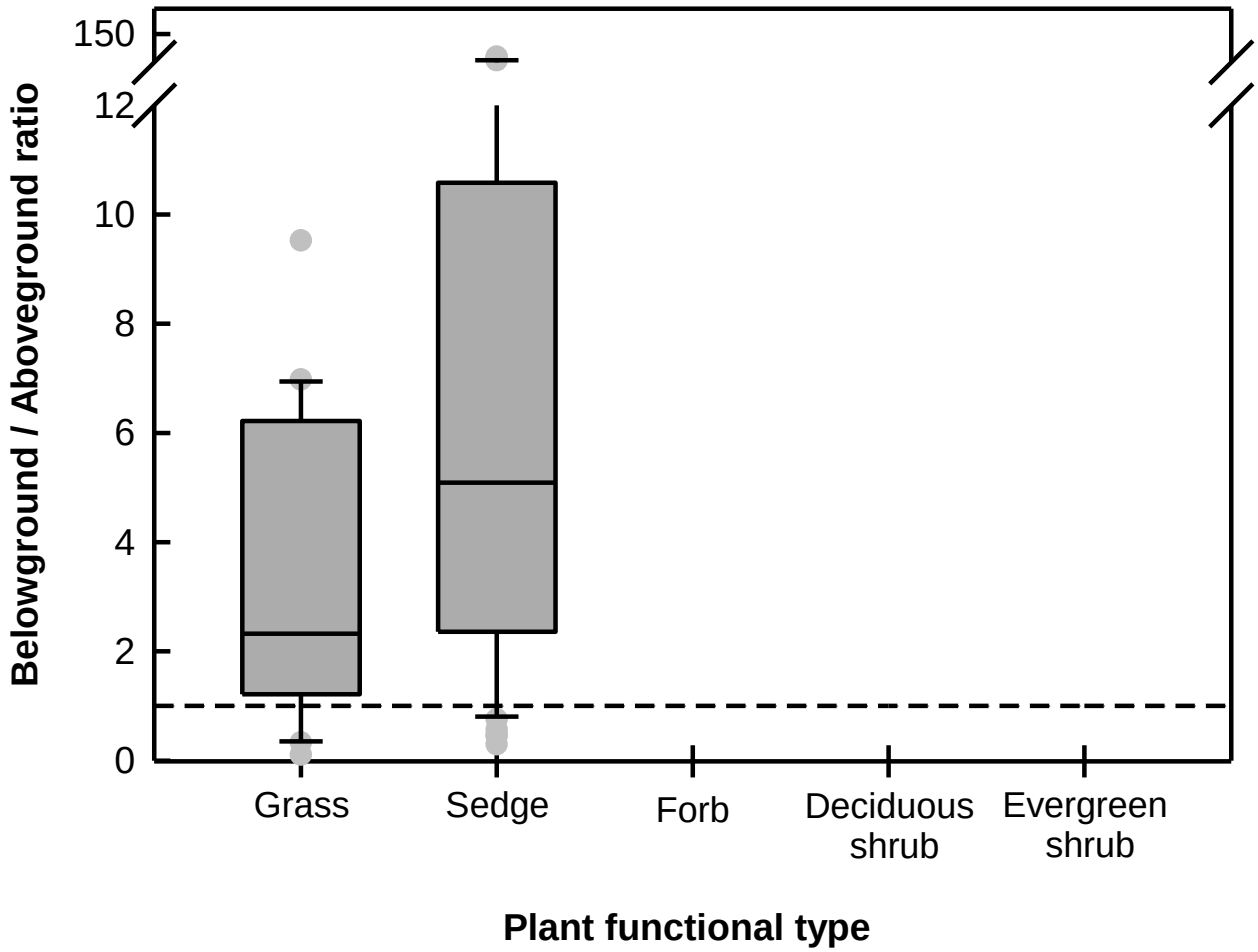

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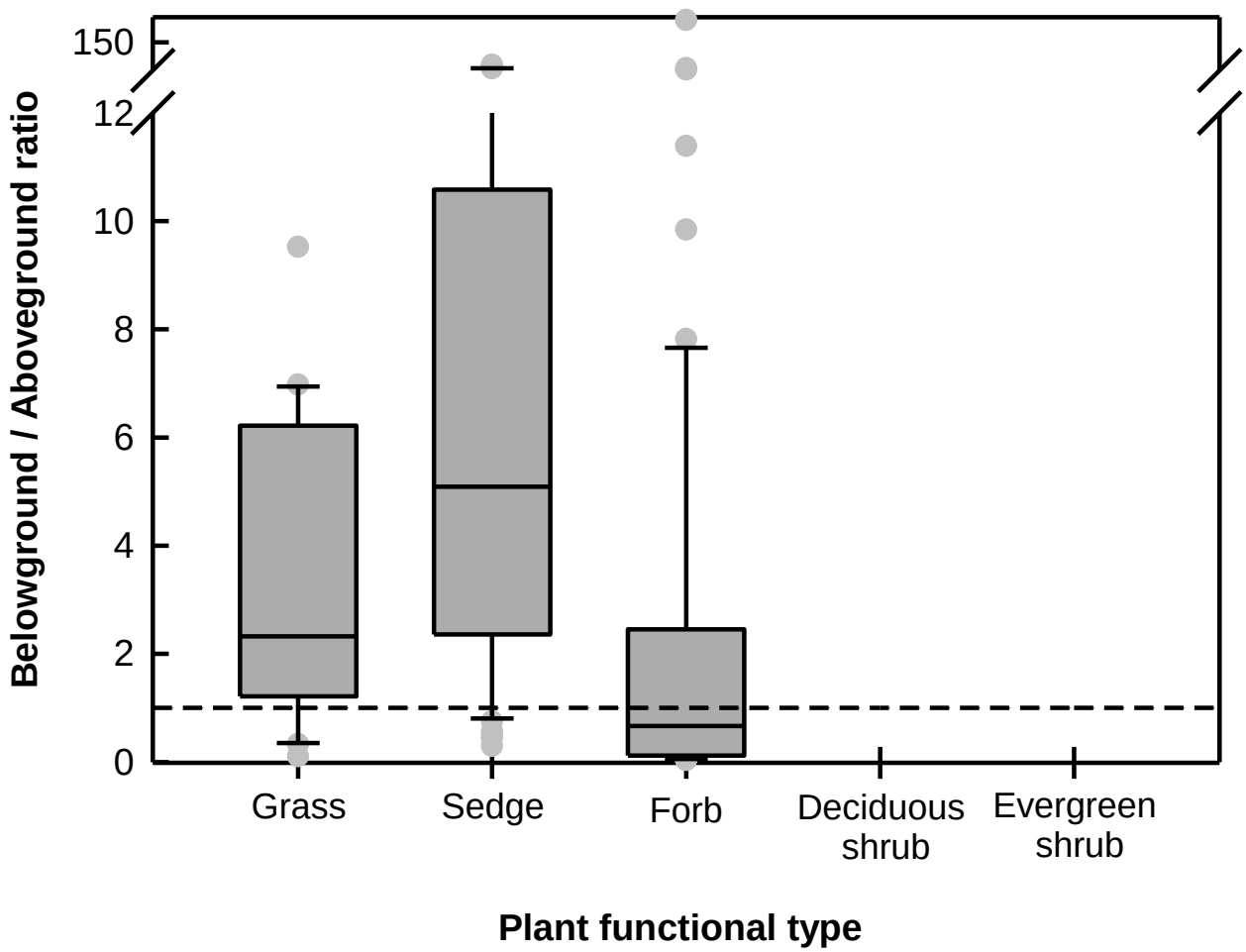

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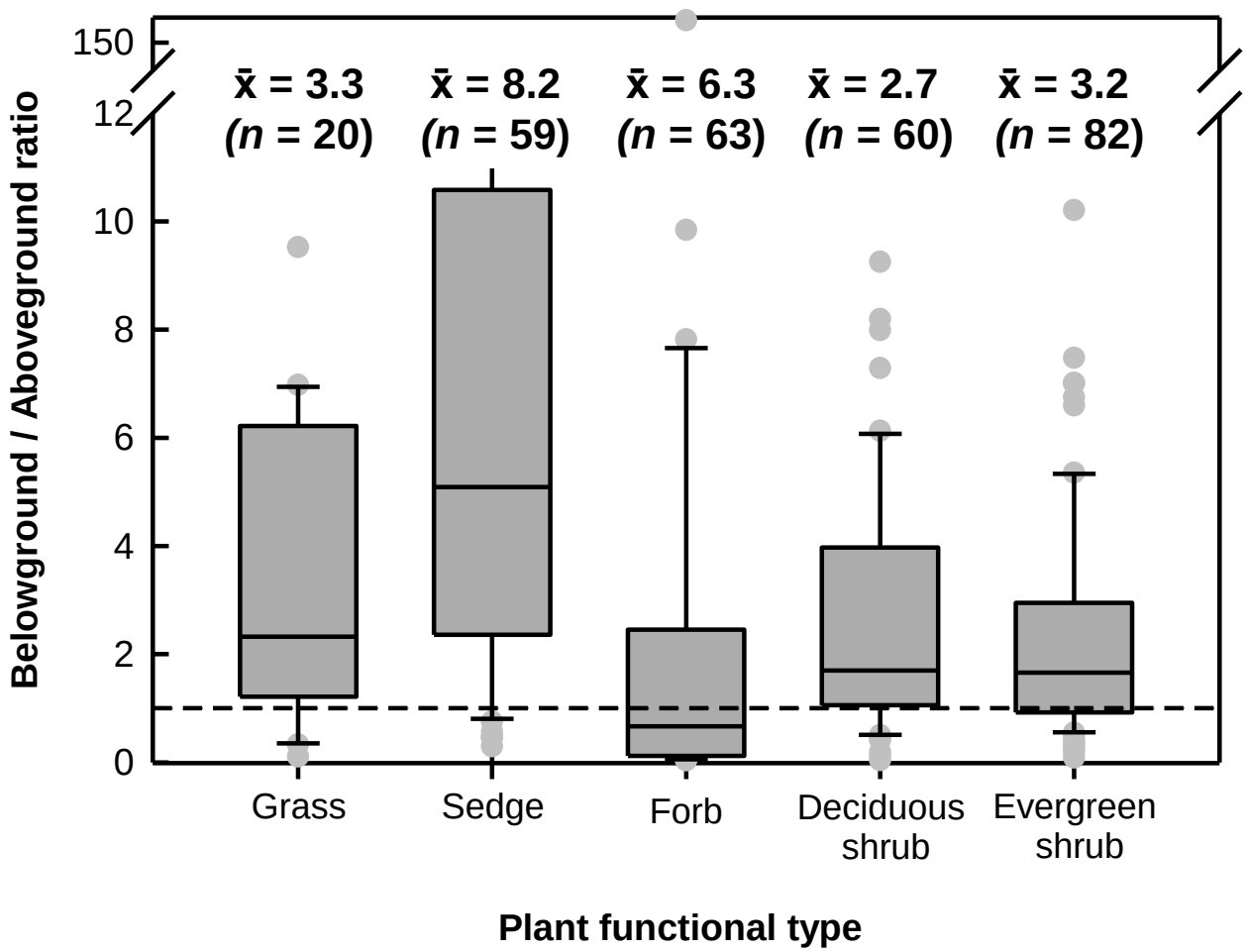

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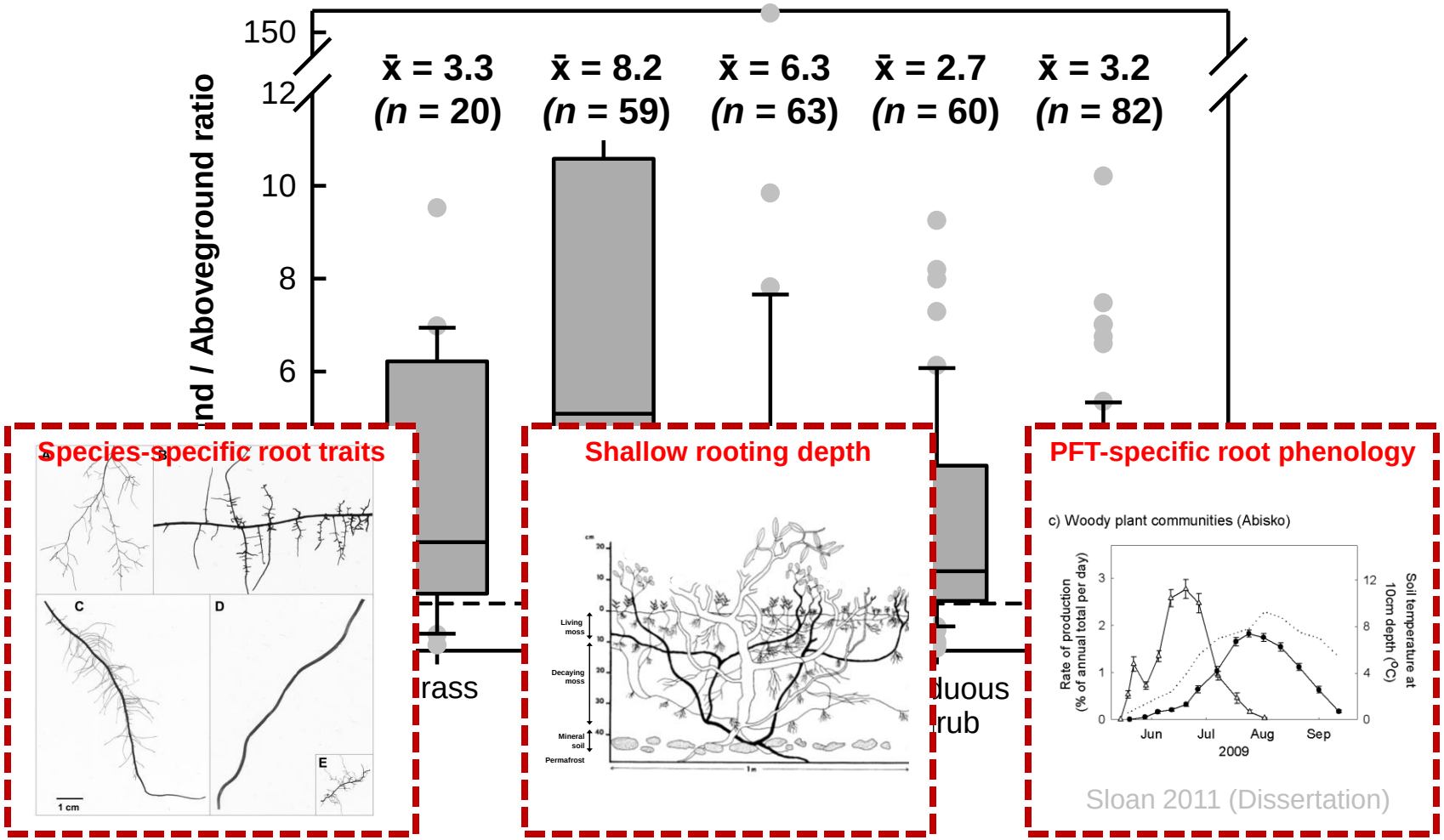

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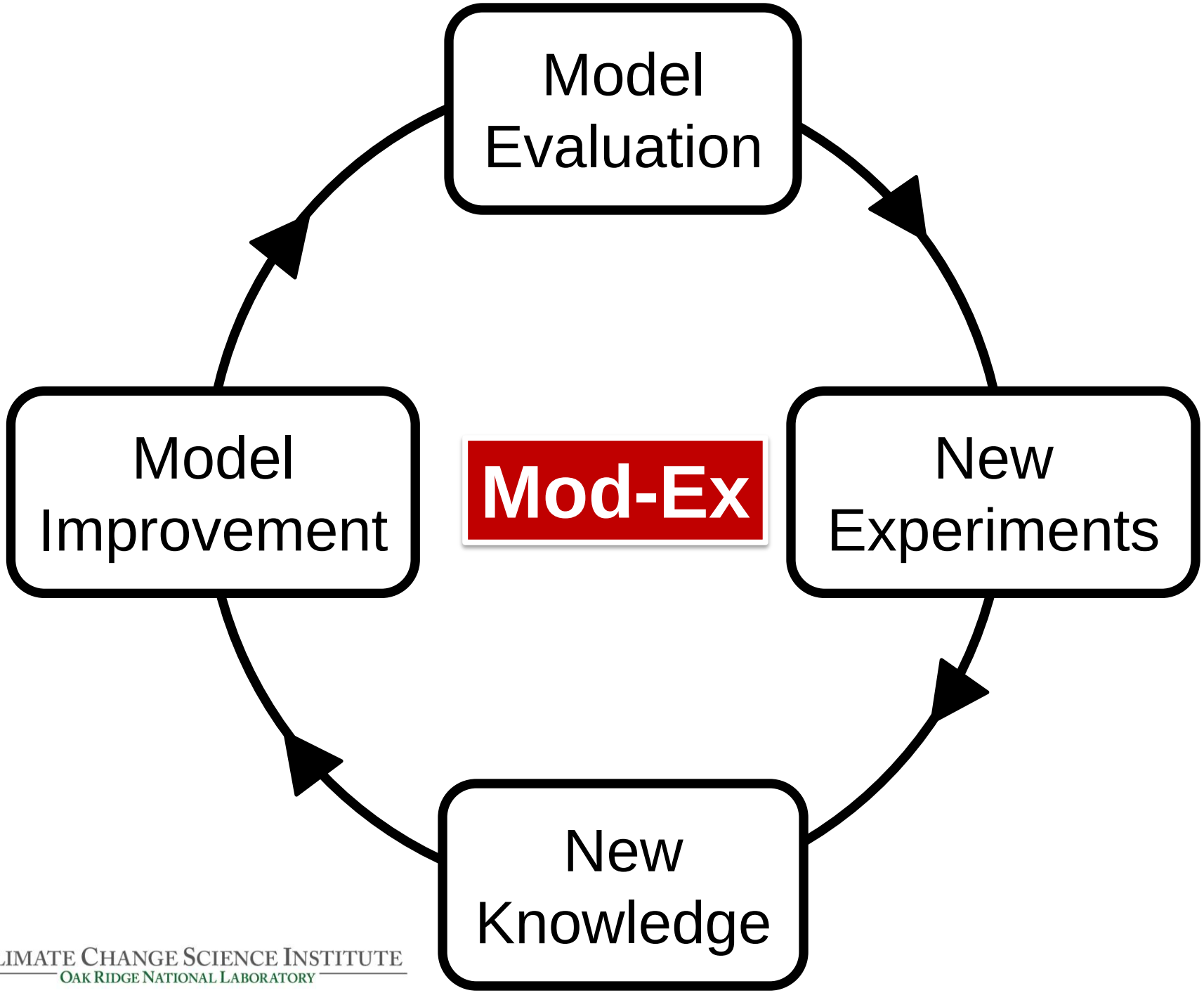
Iversen *et al.*, 2015 (*New Phytologist*)

Take home messages:

- Tundra plant species allocate a large fraction of their biomass belowground, and tend to be more shallowly-rooted, have a longer root lifespan, higher root nutrient content, and greater ability to grow and acquire nutrients at low temperatures than temperate cousins.
- However, available data do not wholly capture heterogeneity of belowground plant traits across the Arctic.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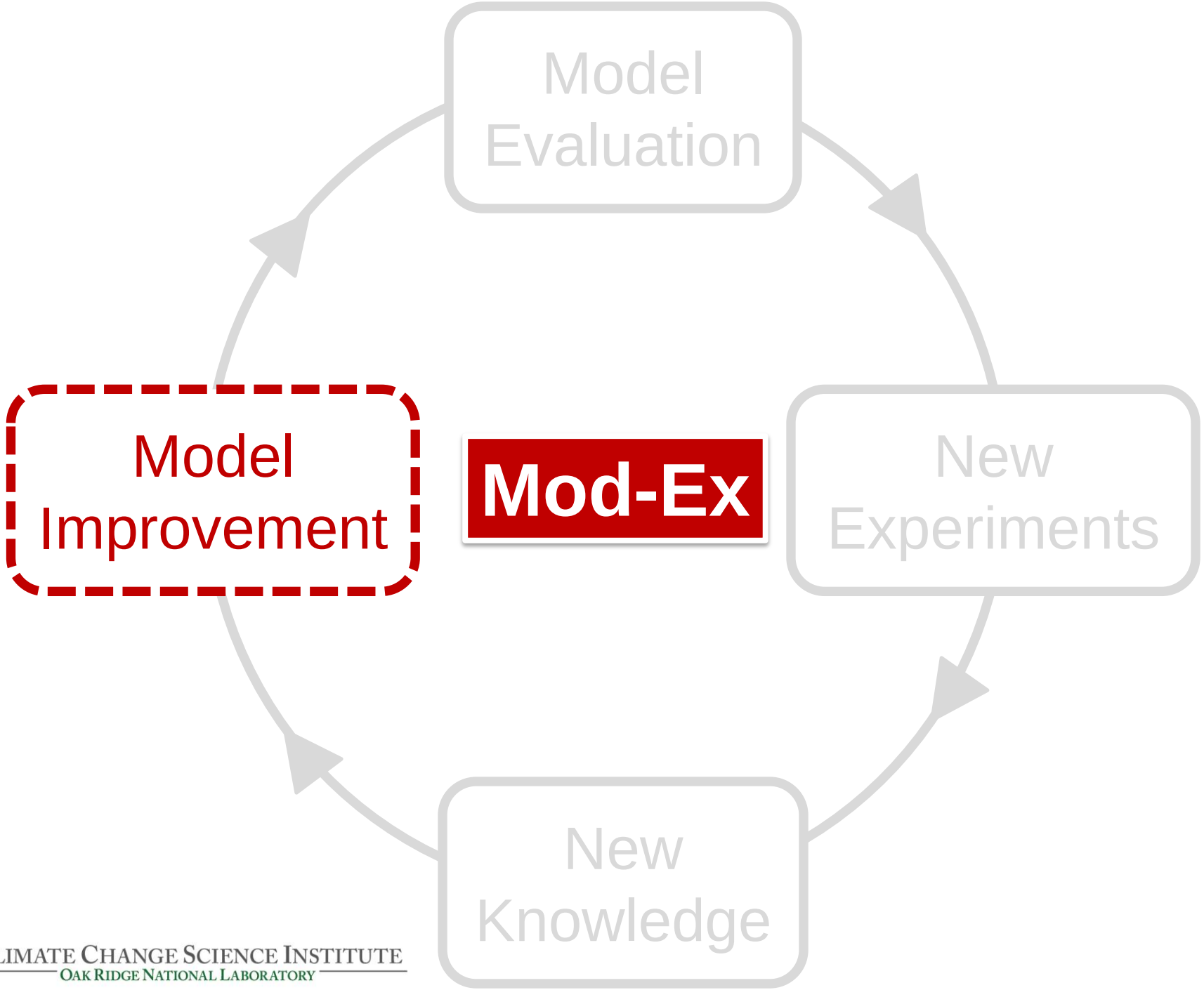
Model Evaluation
New Experiments
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Mod-Ex

In a series of workshops, we have worked to develop a **PATH FORWARD*** to improve the representation of fine roots in terrestrial biosphere models.

***Funded by DOE BER.**

1. A ROOT TRAIT DATABASE:

Develop a **ROOT TRAIT DATABASE**, and let it guide our priorities for future data collection.

Find out more about the Roots in Models story at:

HTTP://WEB.ORNL.GOV/~CIZ/ROOTS_IN_MODELS.HTML

2. Improved model interface:

Develop a **MODULARIZED VERSION OF THE COMMUNITY LAND MODEL** to test effects of environmental drivers on root and rhizosphere dynamics, and effects of changing model parameters on ecosystem processes.

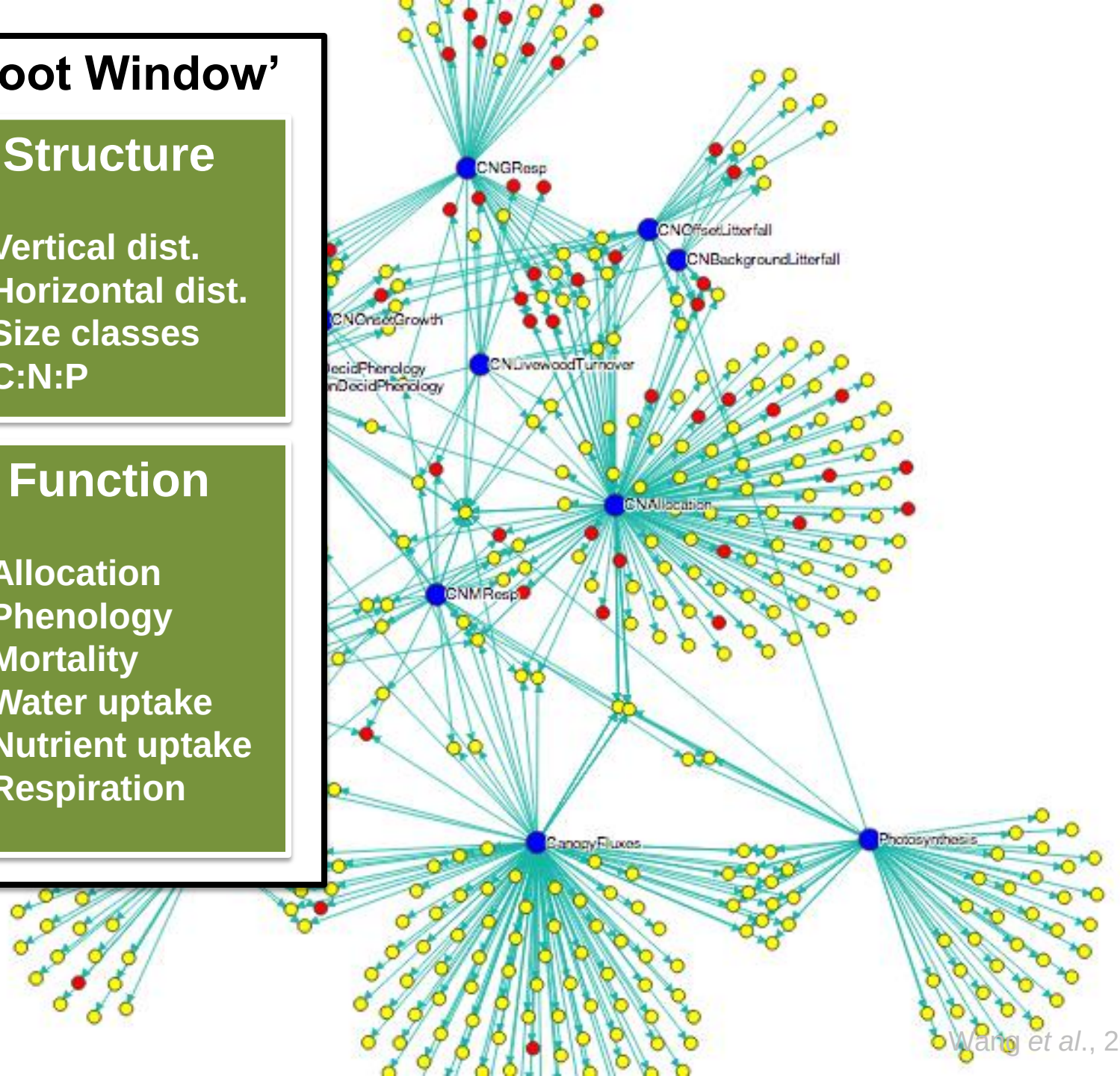
‘Root Window’

Structure

- Vertical dist.
- Horizontal dist.
- Size classes
- C:N:P

Function

- Allocation
- Phenology
- Mortality
- Water uptake
- Nutrient uptake
- Respiration



Wang *et al*., 2014 (*EMS*)

3. Continue to solicit community input:

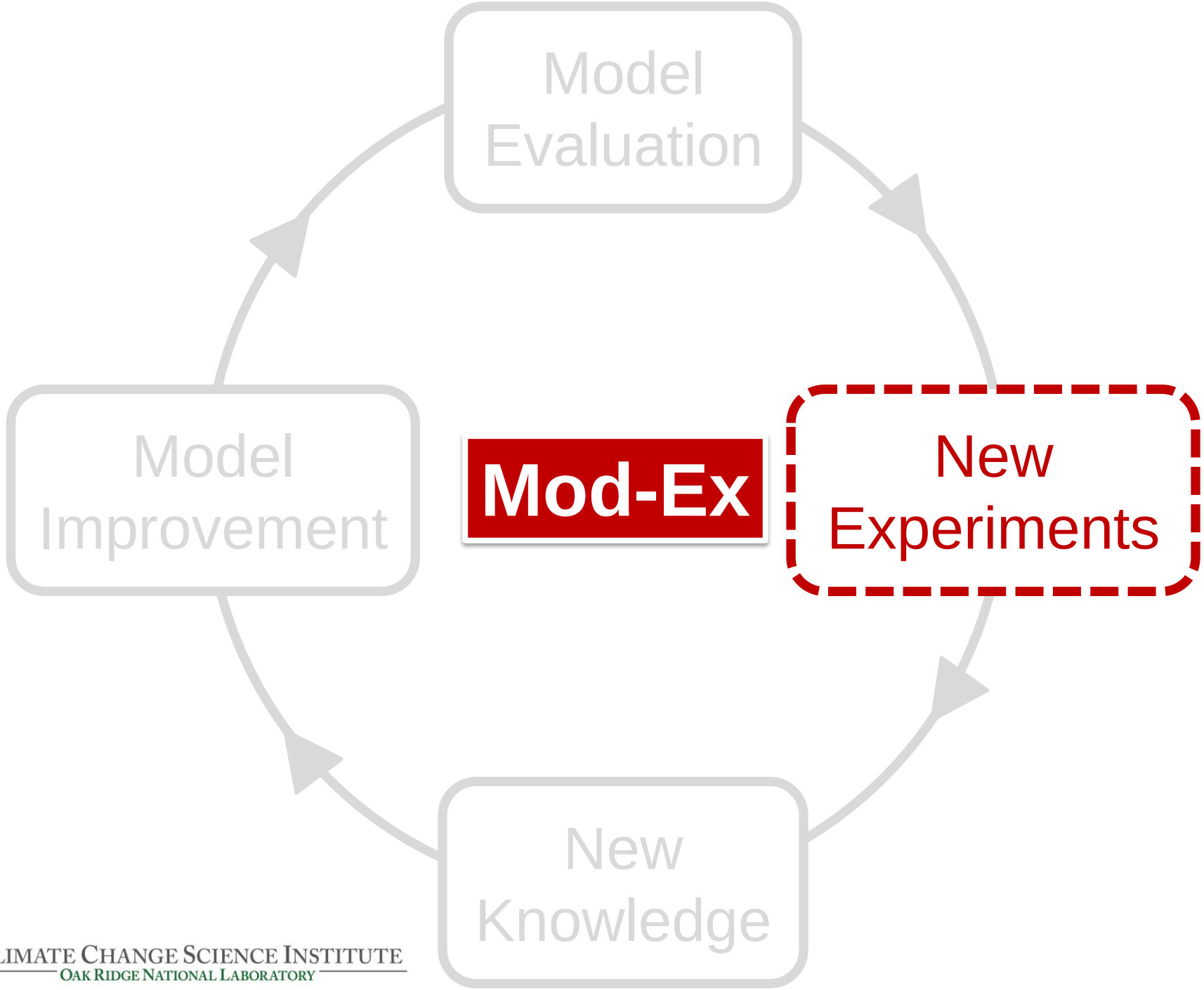
Gain a **CONSENSUS FROM THE BROADER COMMUNITY** on the relative importance of different root traits.

Take home messages:

- Model parameter improvements are possible with existing tundra plant data:
- Large root to shoot ratios for tundra plants
- Depth distribution (organic layer)
- Phenology synchronous (graminoids) or asynchronous (shrubs)

There are some things that **WE DON'T UNDERSTAND** well enough to represent in terrestrial biosphere models.

The **NEXT STEPS** in our understanding of roots and their role in the ecosystem involve **NEW QUESTIONS**, **NEW METHODS**, **NEW TECHNOLOGY**, and **IMPROVED REPRESENTATION** of root processes in models of all scales.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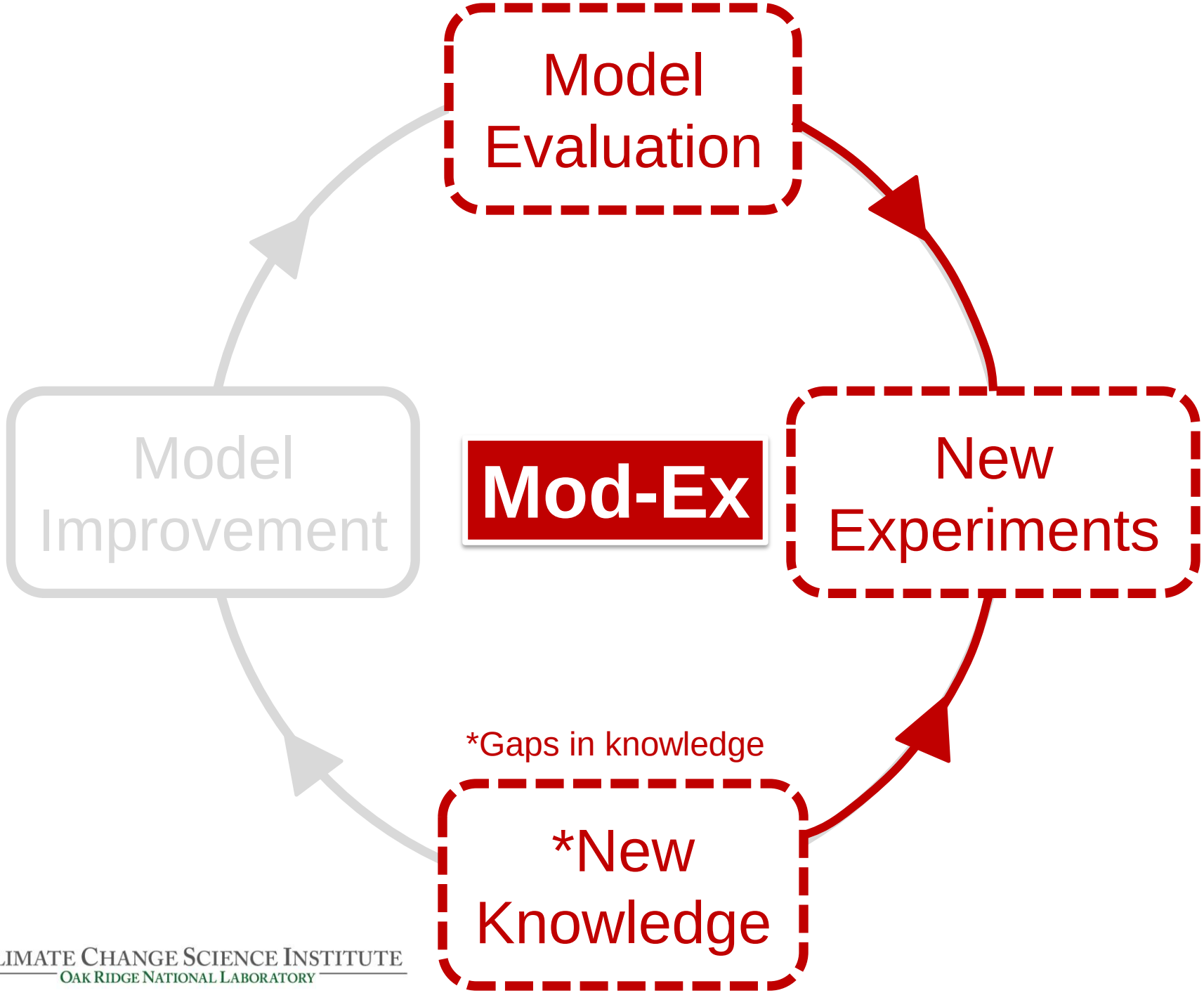
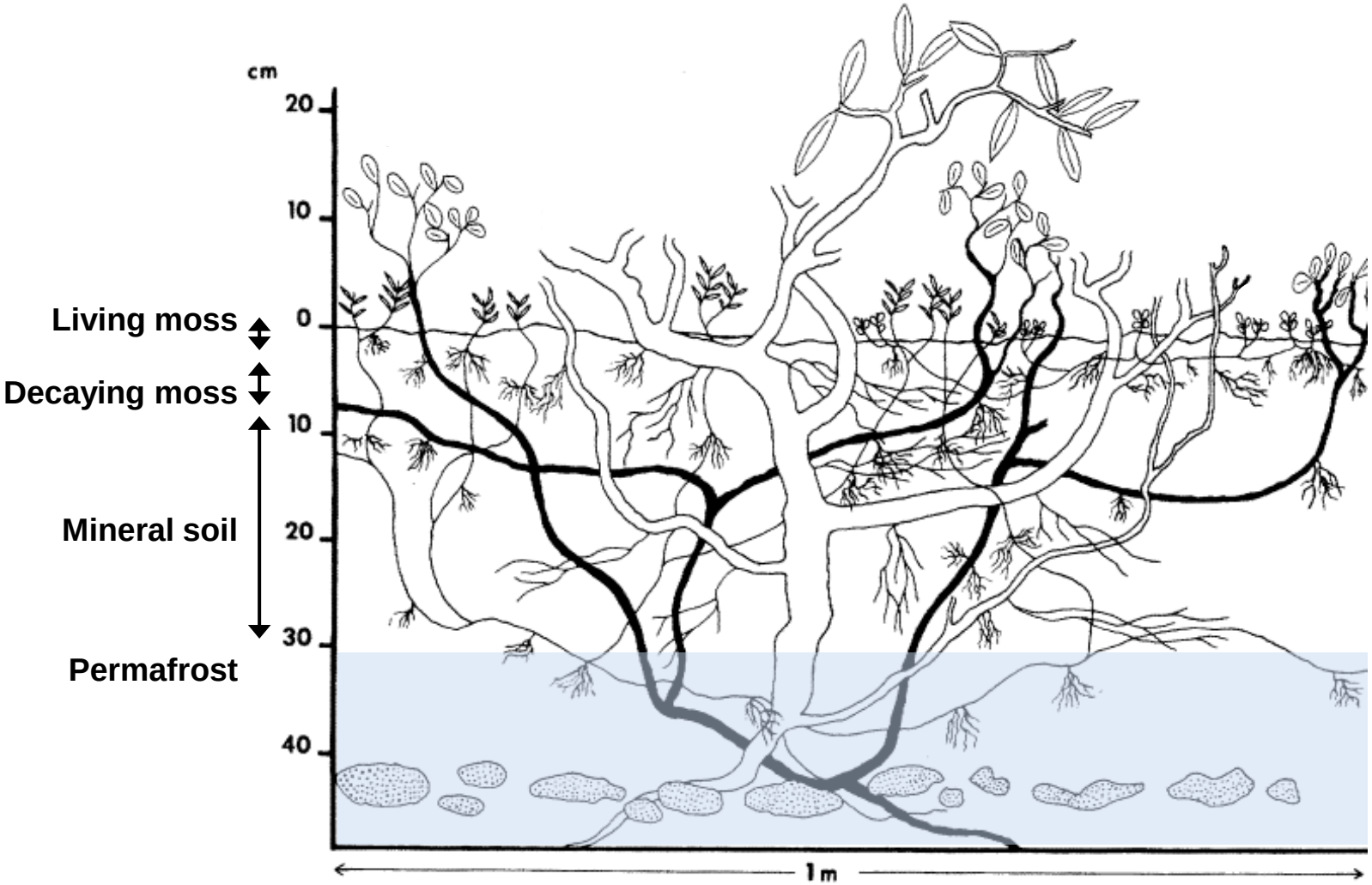

Model Evaluation
New Experiments
*Gaps in knowledge
*New Knowledge
Model Improvement
Mod-Ex

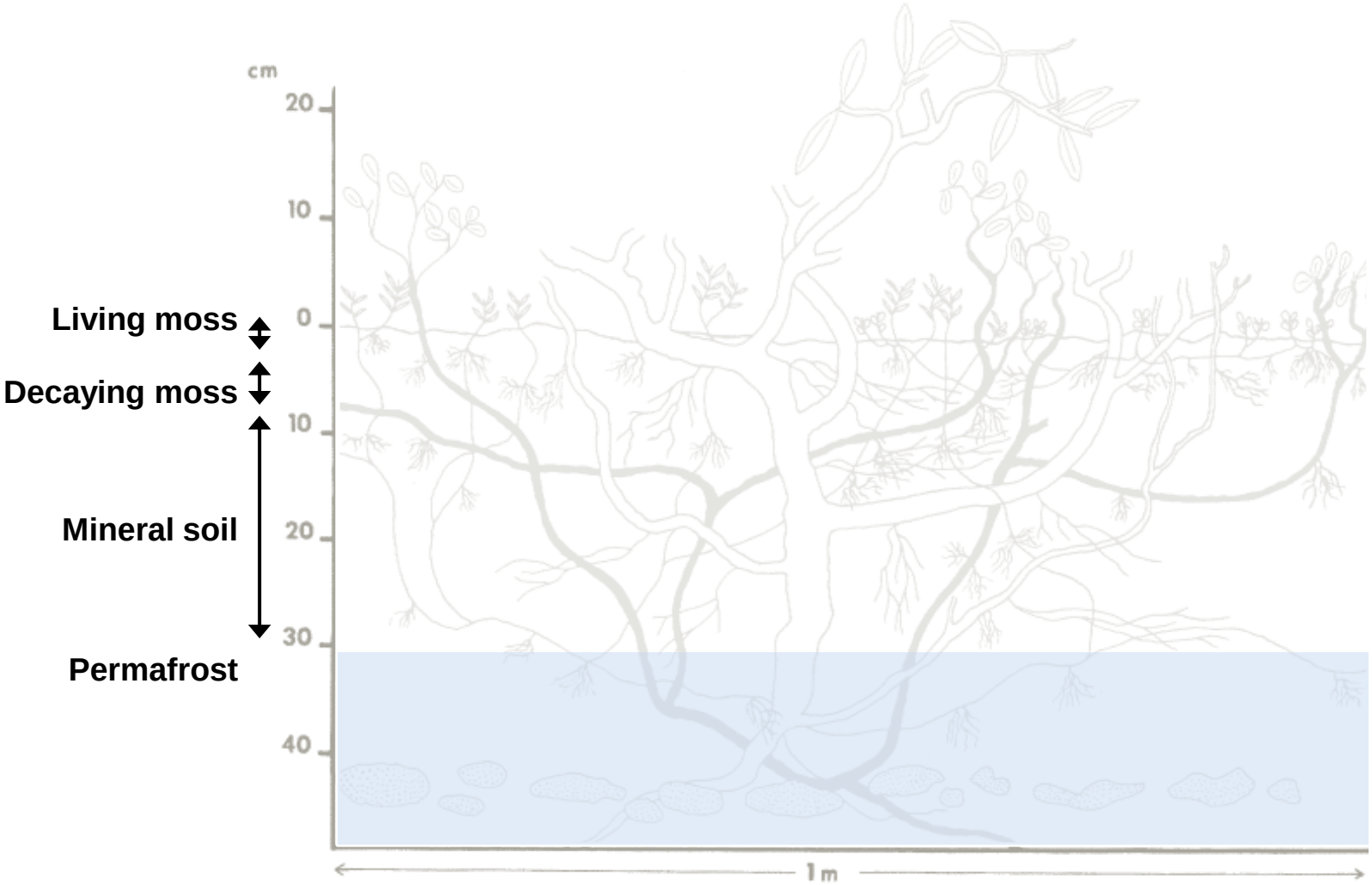
OVERARCHING QUESTION:

What are the **NUTRIENT ACQUISITION STRATEGIES** of dominant tundra plant species?

We focused on three species, **REPRESENTING IMPORTANT PFTS** on the BEO, with different rooting distributions.



Miller et al., 1982 (*Holarctic Ecology*)



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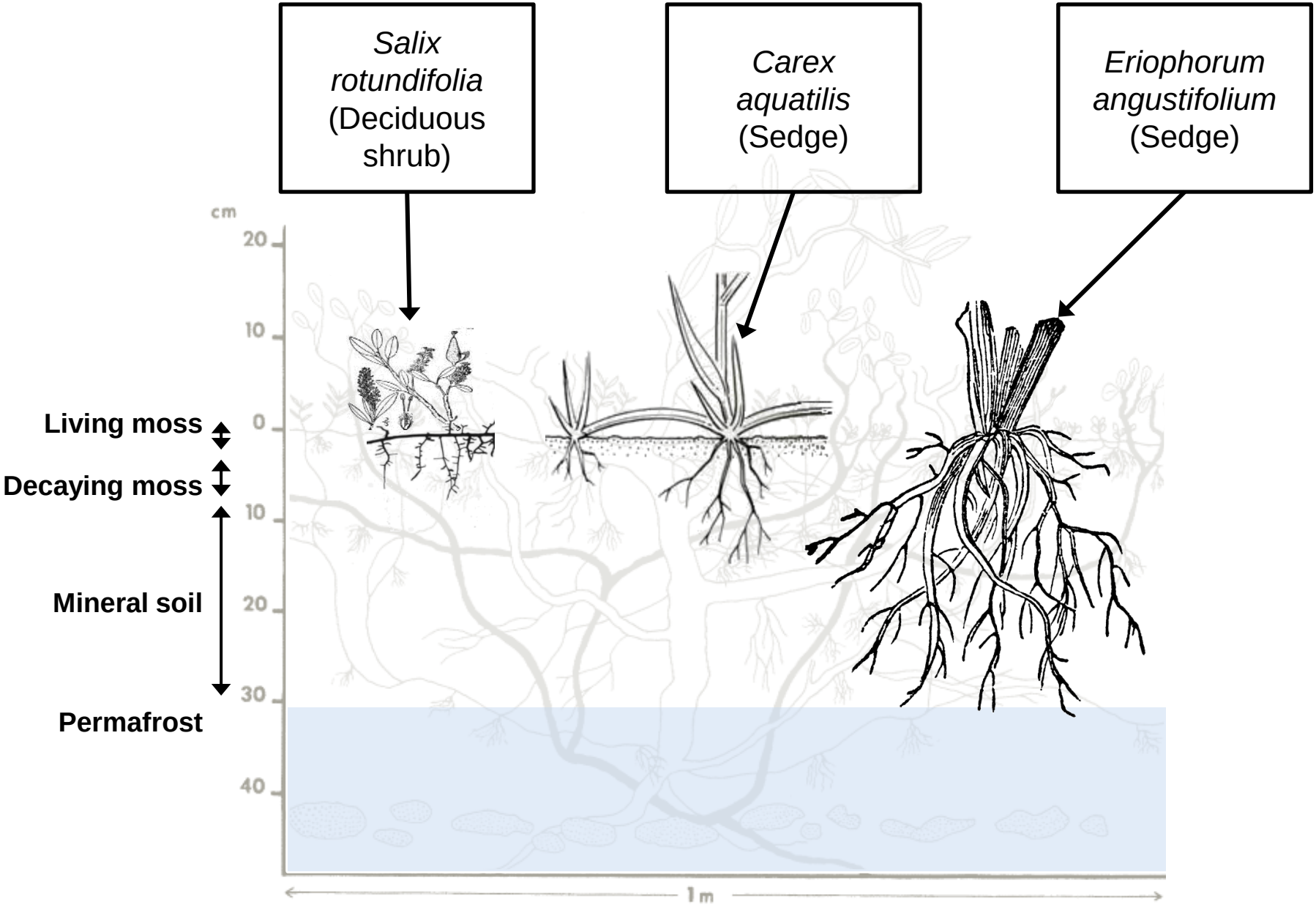

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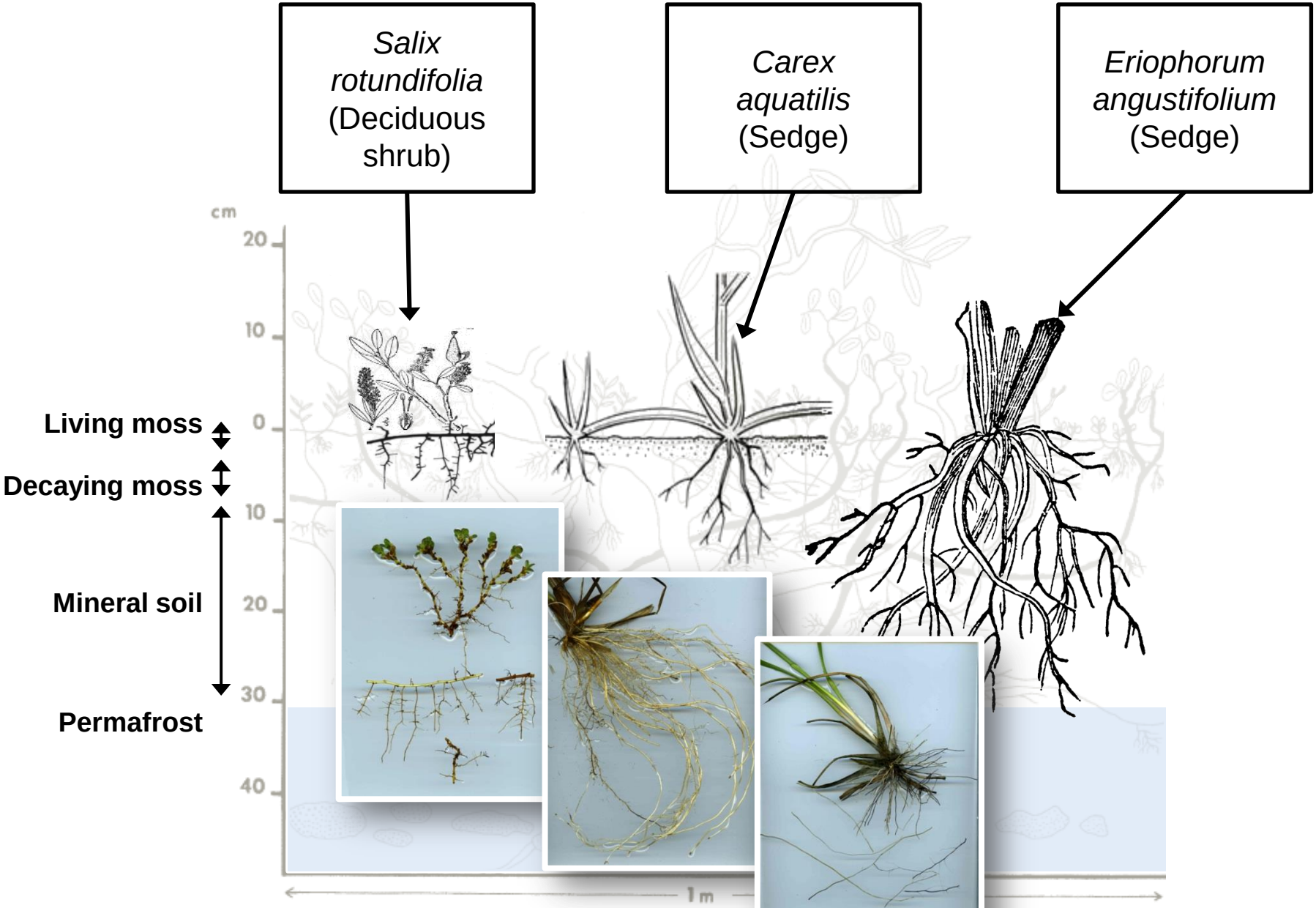
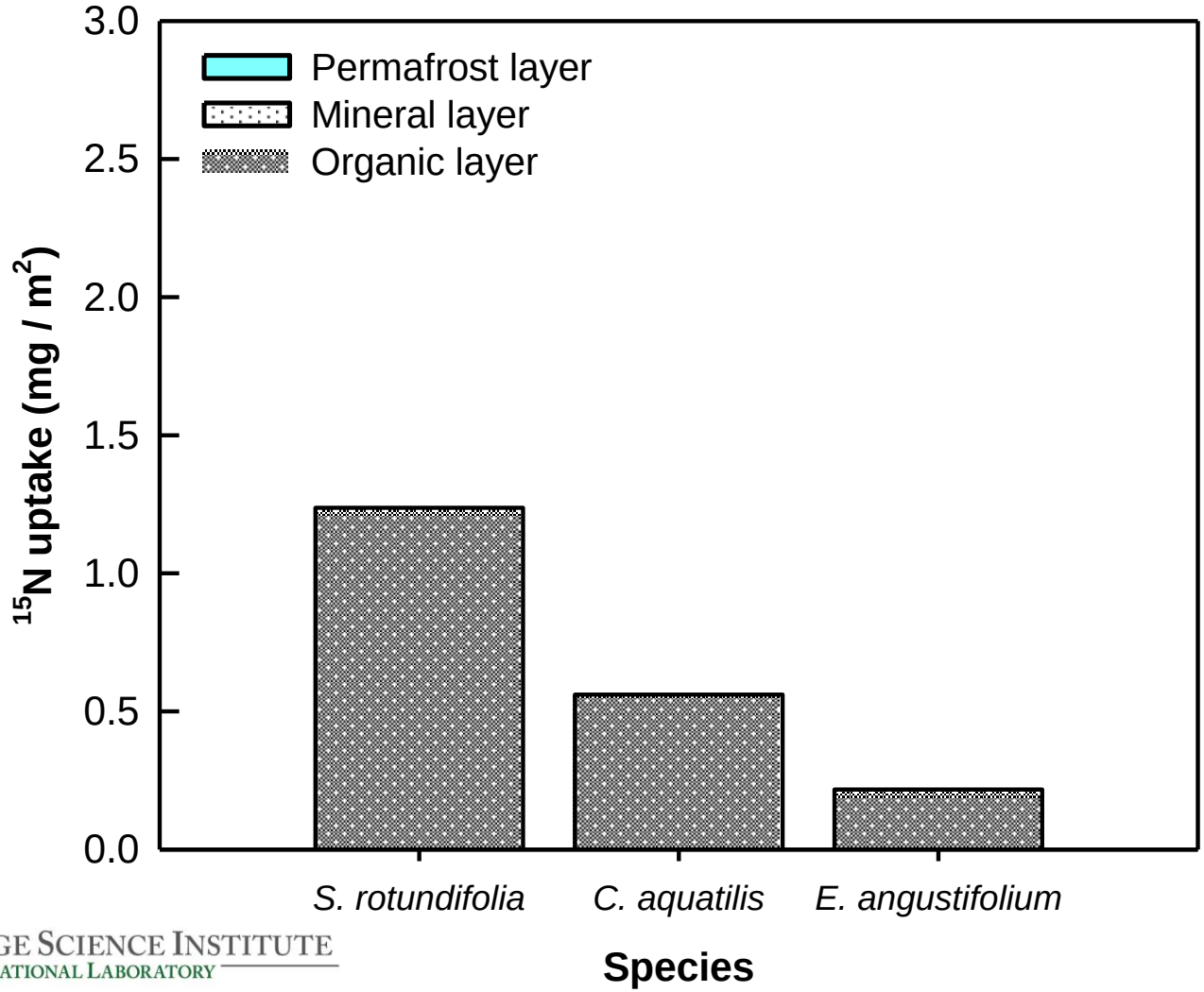
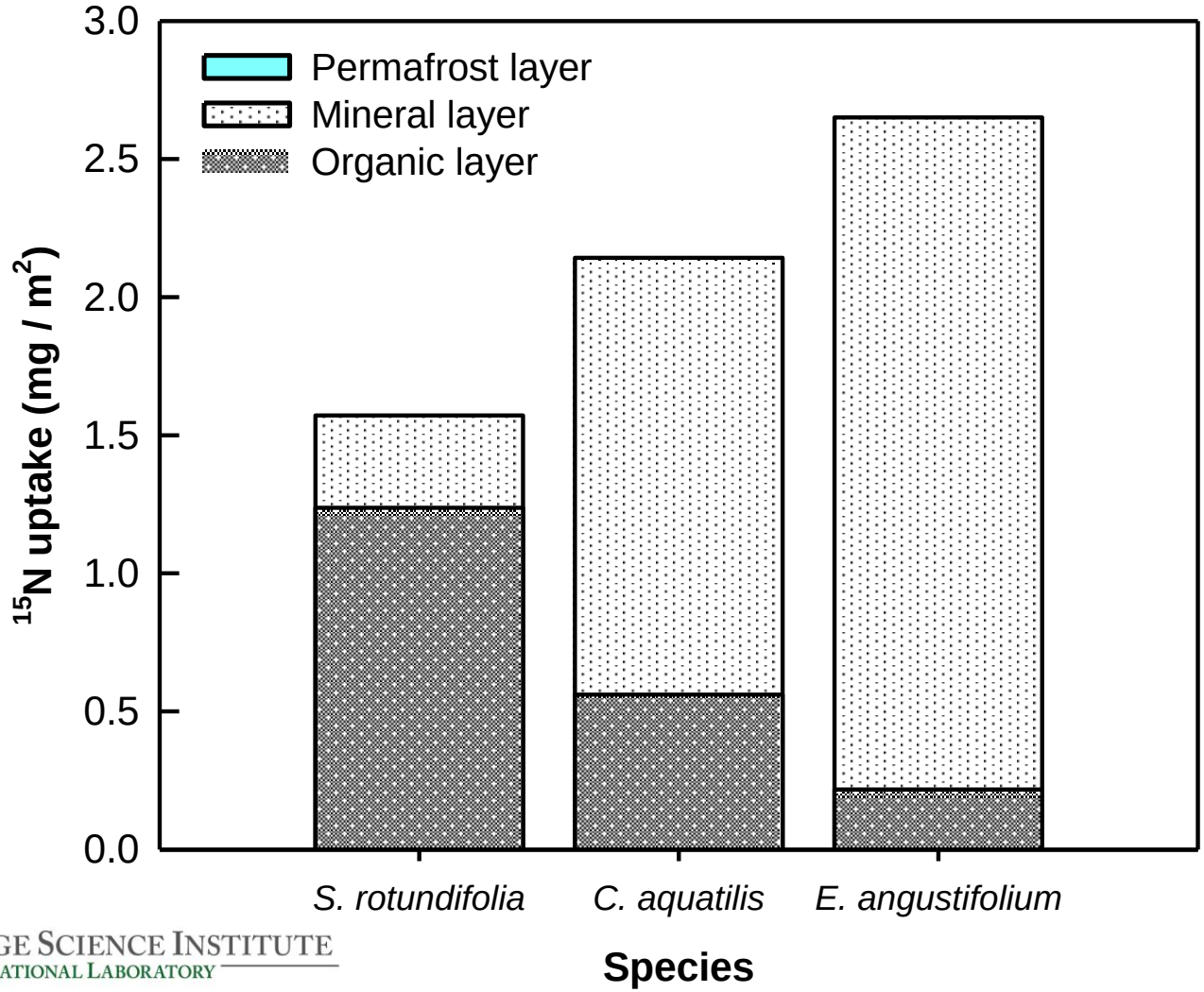


Miller et al., 1982 (*Holarctic Ecology*)

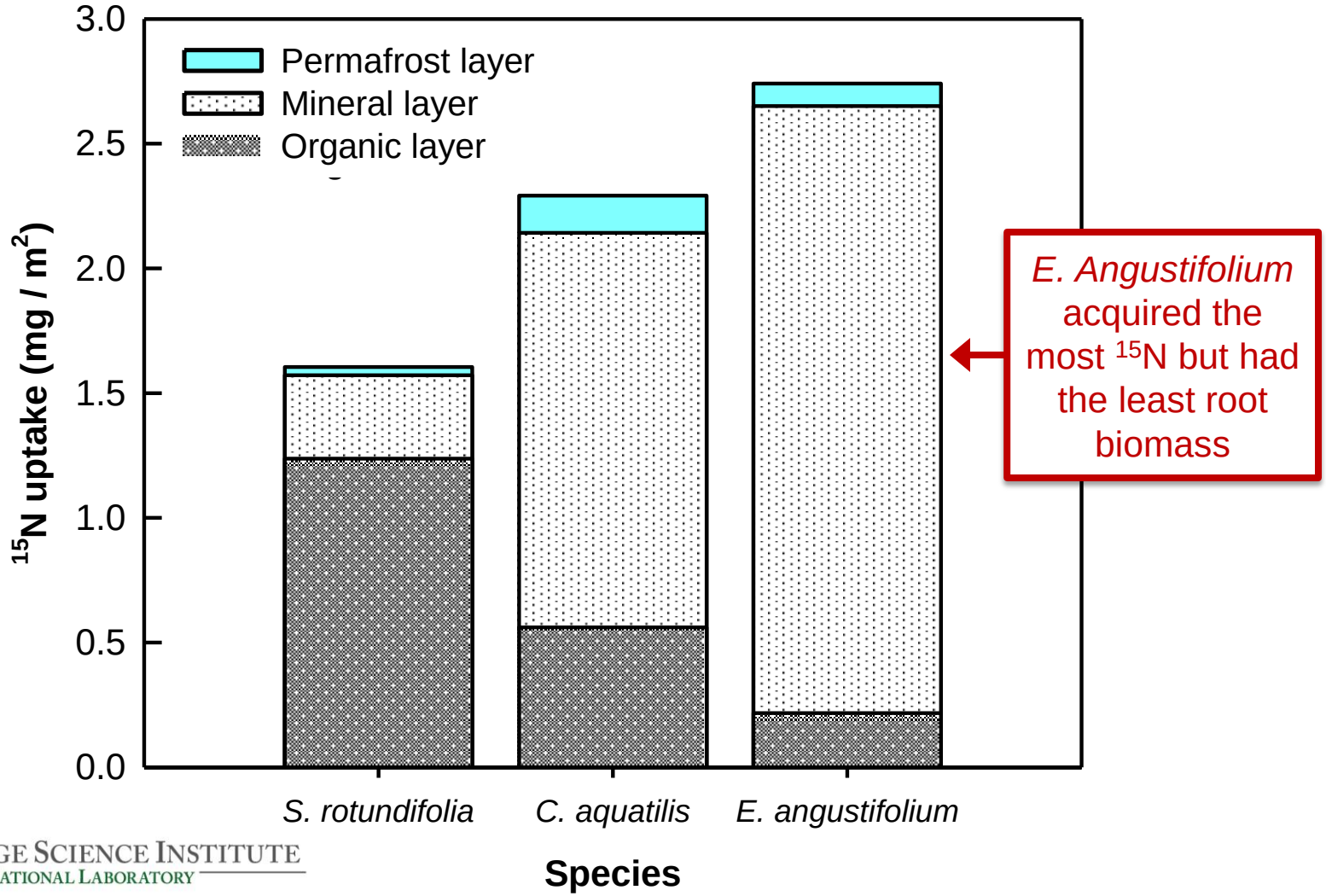
Deciduous shrub *S. rotundifolia* acquired ^{15}N almost exclusively from organic soil layer



Sedges acquired more ^{15}N from mineral soil, though roots mainly in organic soil

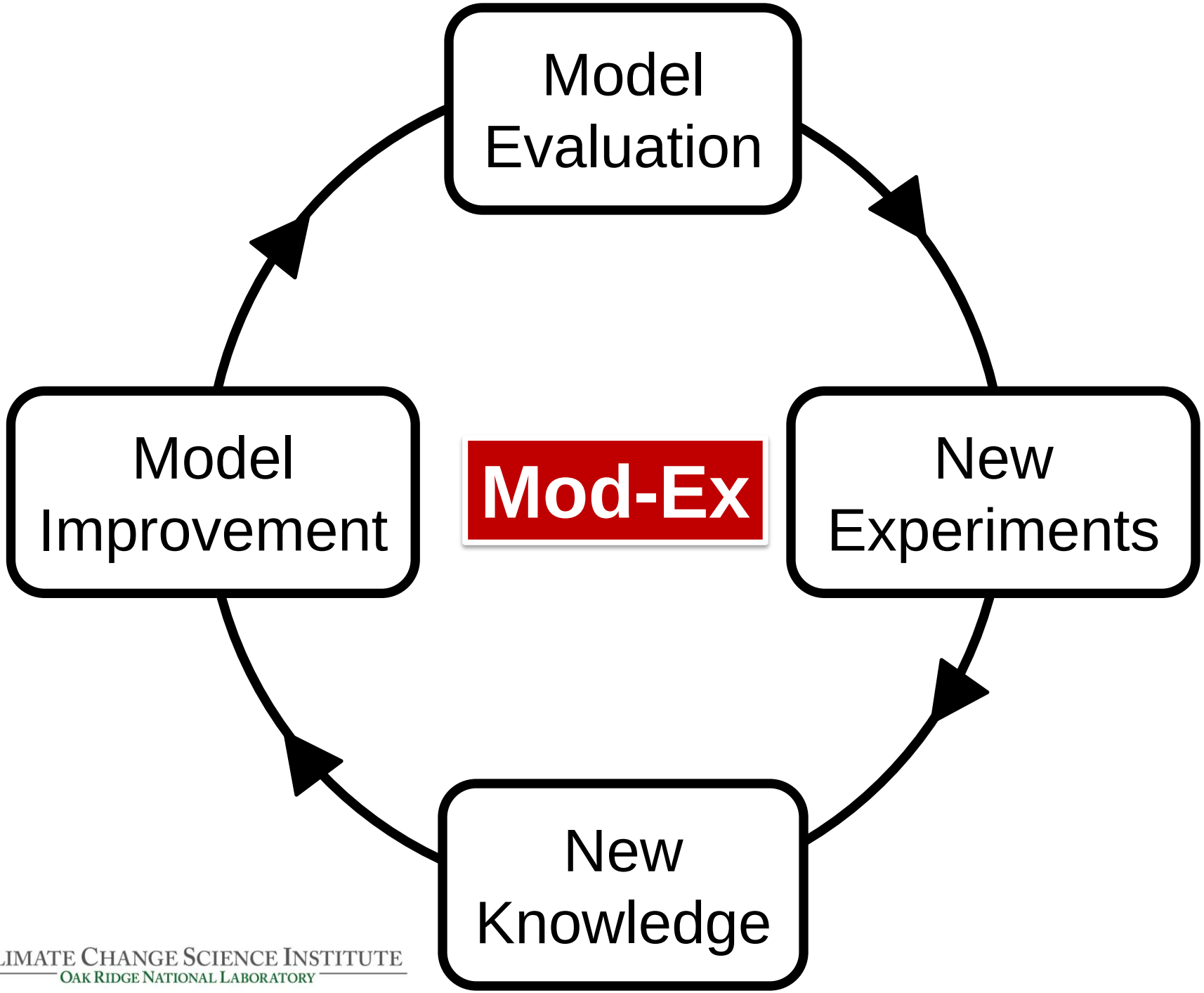


Little ^{15}N acquired near the permafrost boundary in any of the species examined



Take home messages:

Relatively little N was acquired from the permafrost layer, even though N availability was relatively high in deeper soil.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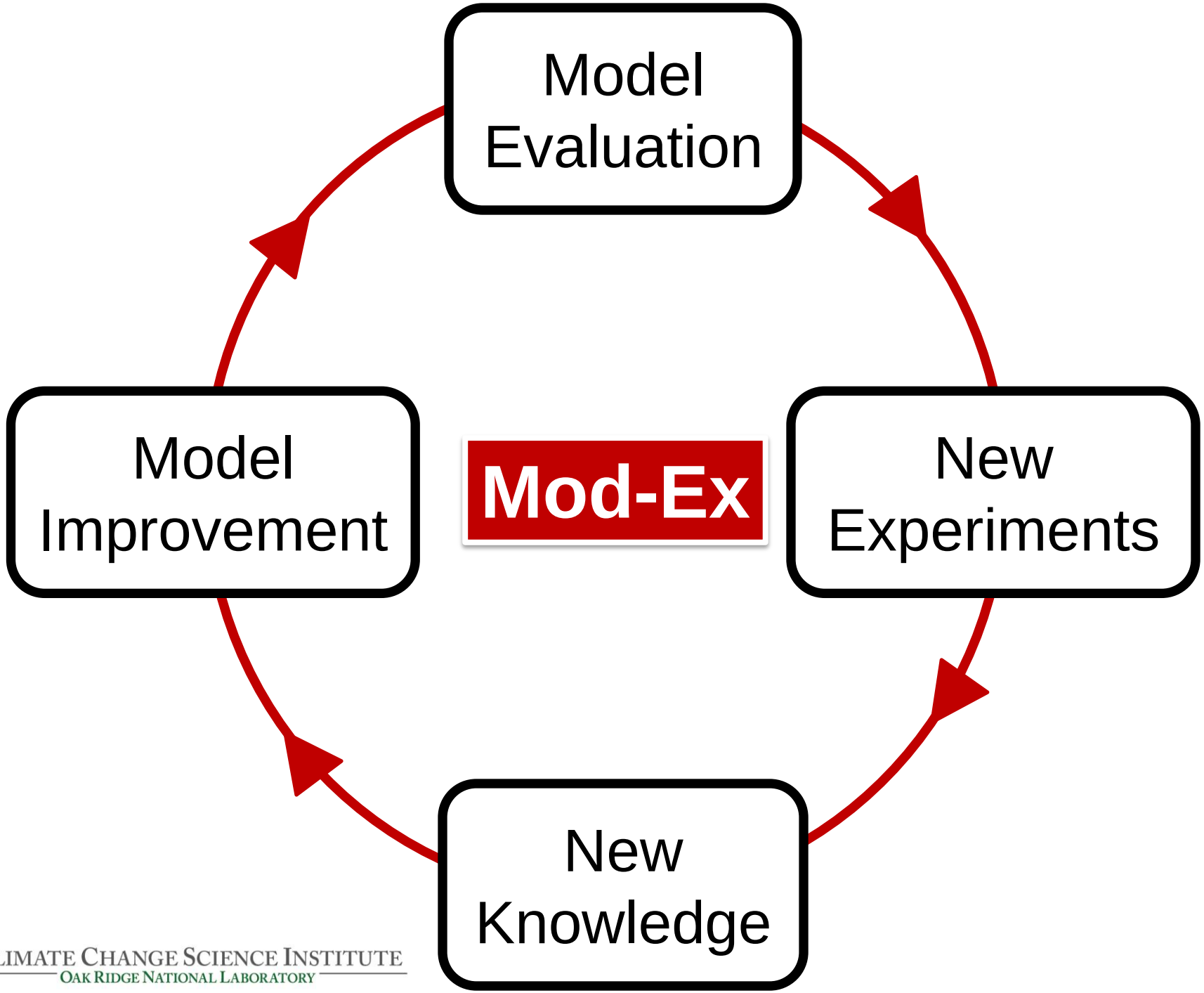

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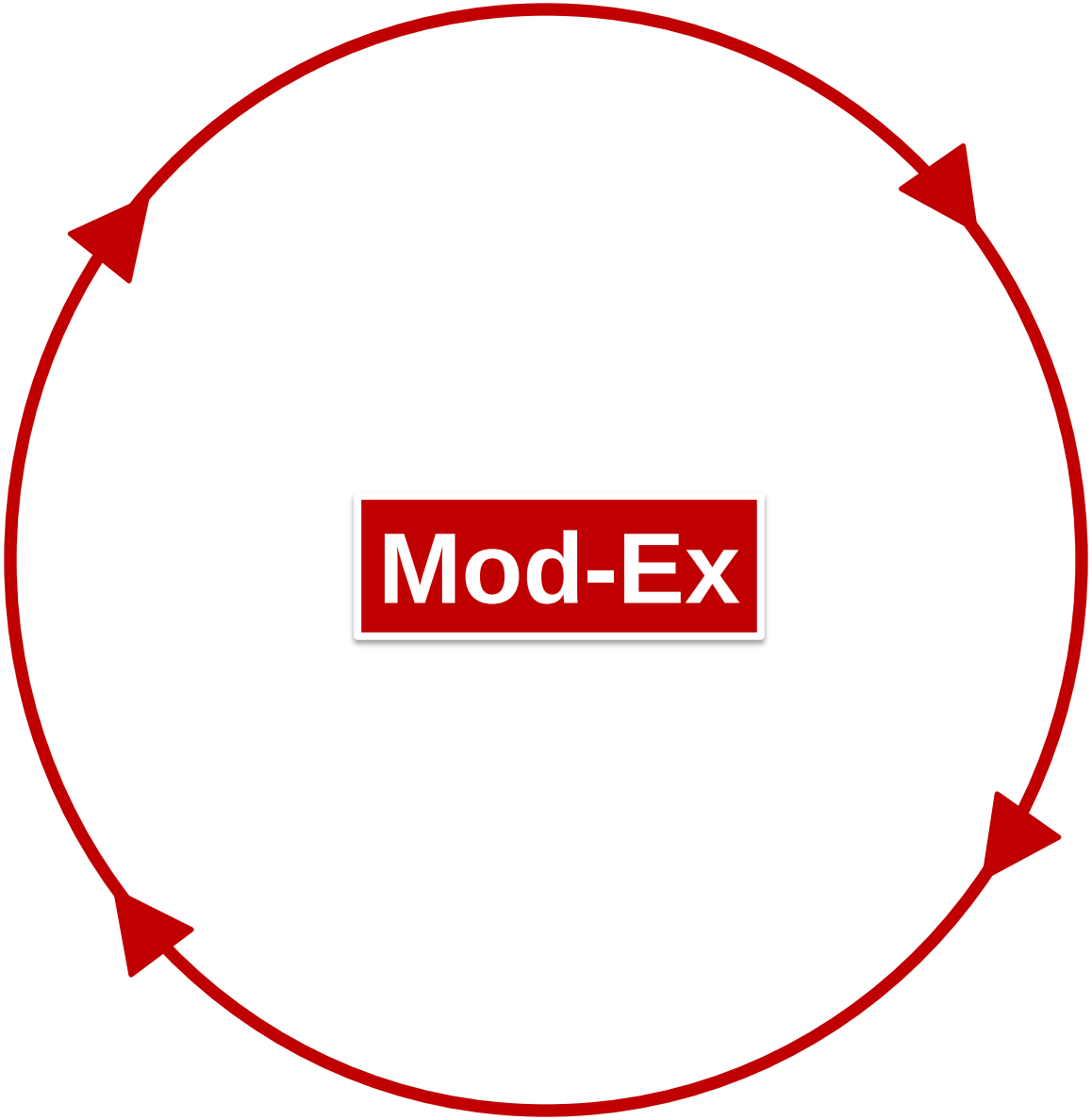
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Garrett Altmann, Deanne Brice, Jonathan Brooks, Kelsey Carter, Joanne Childs, Ryan Cody, Bryan Curtis, Melanie Hahn, Keith Kofoed, Jennifer Liebig, Eitan Shelef, Julia Siegrist, Ingrid Slette, Holly vander Stel, Sarah Wood.