# NEXT GENERATION ECOSYSTEM EXPERIMENTS - TROPICS

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U.S. DEPARTMENT OF ENERGY | Office of Science

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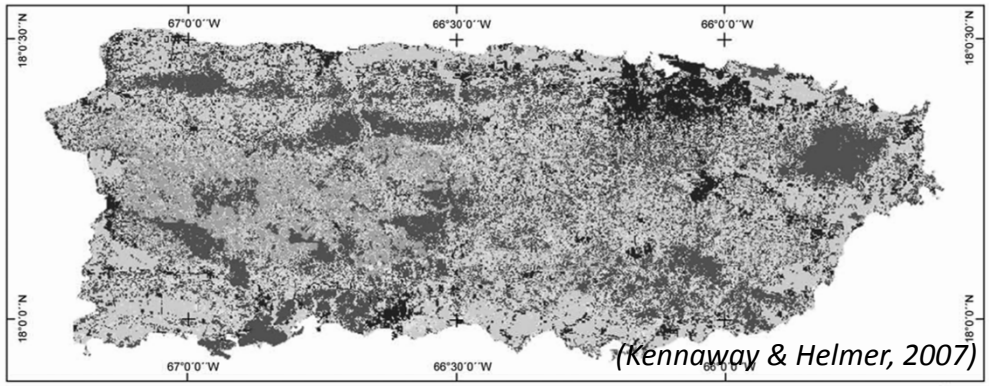
# Why NGEE-Tropics?

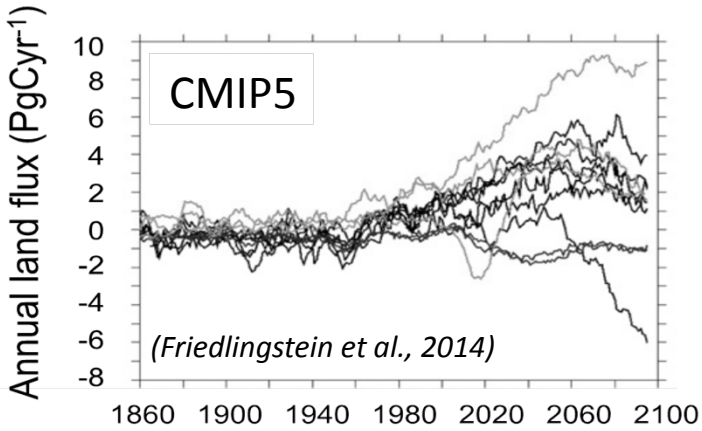
- Tropical forests cycle more carbon and water than any other biome, and play critical roles in determining the Earth's energy balance
- Large uncertainties in tropical forest response to a changing atmosphere and a warming climate
- With 21st century warming, novel "no analog" climates emerge, potential for drought
- Large source/sink carbon fluxes from complex anthropogenic landscapes

*Secondary forest a key carbon sink in the tropics*

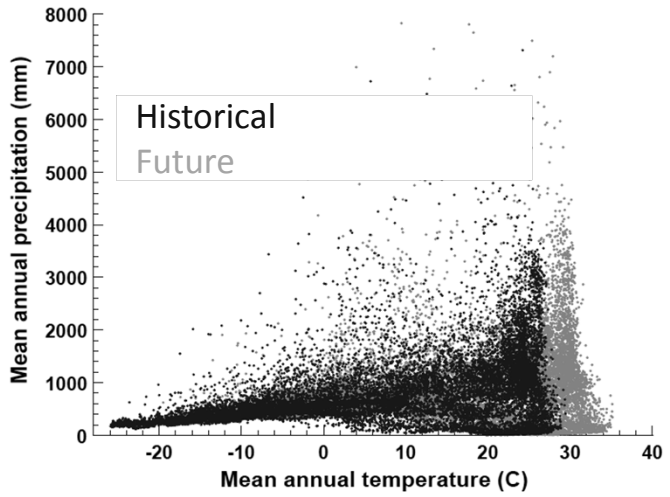


*(Kennaway & Helmer, 2007)*

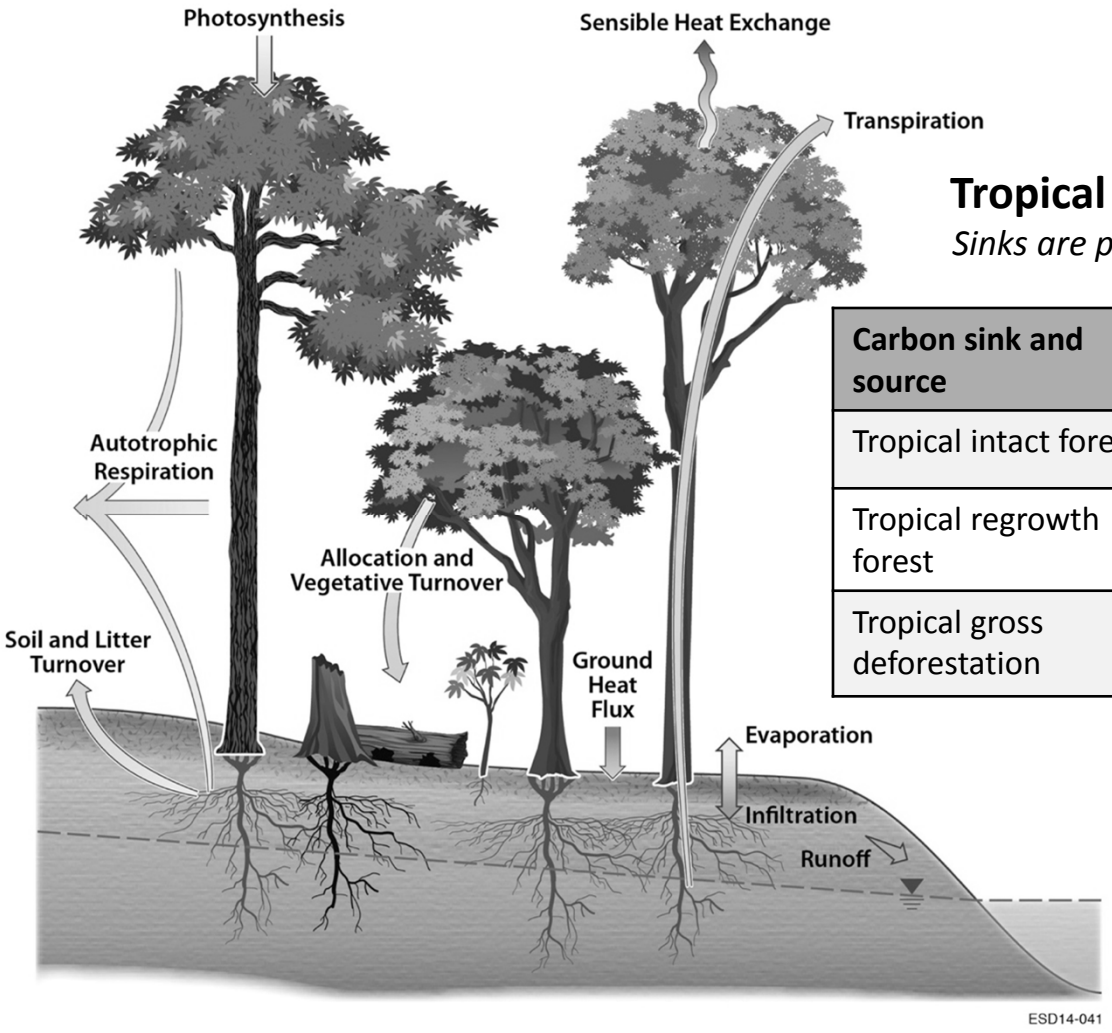
*Future terrestrial carbon sink uncertainty in ESMs*




*Climate change – into novel regimes*



# Tropical Forests and the Global Carbon Cycle




## Tropical forest carbon budgets (Pg C $yr^{-1}$)

*Sinks are positive values; sources are negative values*

| Carbon sink and source | 1990-1999 | 2000-2007 | 1990-2007 |
|---|---|---|---|
| Tropical intact forest | 1.33 ± 0.35 | 1.02 ± 0.47 | 1.19 ± 0.41 |
| Tropical regrowth forest | 1.57 ± 0.50 | 1.72 ± 0.54 | 1.64 ± 0.52 |
| Tropical gross deforestation | −3.03 ± 0.49 | −2.82 ± 0.45 | −2.94 ± 0.47* |

*(Pan et al., 2011)*

*-0.9 ± 0.5 Pg C $yr^{-1}$ globally for 2005-2014

2014 fossil fuel emissions 9.8 ± 0.5 Pg C $yr^{-1}$
36% (3.5 Pg C $yr^{-1}$) remained in the atmosphere

*(Global Carbon Project 2015)*

# NGEE-Tropics Goal and Questions

***Overarching Goal***

- Develop a predictive understanding of tropical forest carbon balance and climate system feedbacks to changing environmental drivers over the 21st Century.

***Grand Deliverable***

- A representative, **process-rich tropical forest ecosystem model**, extending from bedrock to the top of the vegetative canopy-atmosphere interface, in which the evolution and feedbacks of tropical ecosystems in a changing climate can be modeled at the scale/resolution of a next generation Earth System Model grid cell (~10 x 10 $km^2$ resolution)

***Overarching Questions***

- How do tropical forest ecosystems respond to changing temperature, precipitation, and atmospheric $CO_2$ concentration?
- How do disturbance and land-use change in tropical forests affect carbon, water and energy fluxes?
- How will the response of tropical forests to climate change be modulated by spatial and temporal heterogeneity in belowground processes?

# NGEE-Tropics Objectives

***Q1.*** How do tropical forest ecosystems respond to changing temperature, precipitation, and atmospheric CO2 concentration?

***Q2.*** How do disturbance and land-use change in tropical forests affect carbon, water and energy fluxes?

***Q3.*** How will the response of tropical forests to climate change be mediated by spatial and temporal heterogeneity in belowground processes?

**RO1** Forest response to droughts

**RO2** C uptake and allocation responses to temperature and CO2

**RO3** Vegetation dynamics under natural disturbance regimes

**RO4** Anthropogenic disturbance and recovery

**RO5** Spatial and temporal variability of water

**RO6** Nutrient availability and controls on ecosystem processes

**Traits** Trait trade-offs across sites (FO1)

**Manaus** Hydrology-carbon cycle interactions (FO1)

**Pantropical** Baseline measurements (FO2)

**Puerto Rico** Nutrient-land use interactions (FO1)

**Pantropical** Identify Phase 2 field sites (FO3)

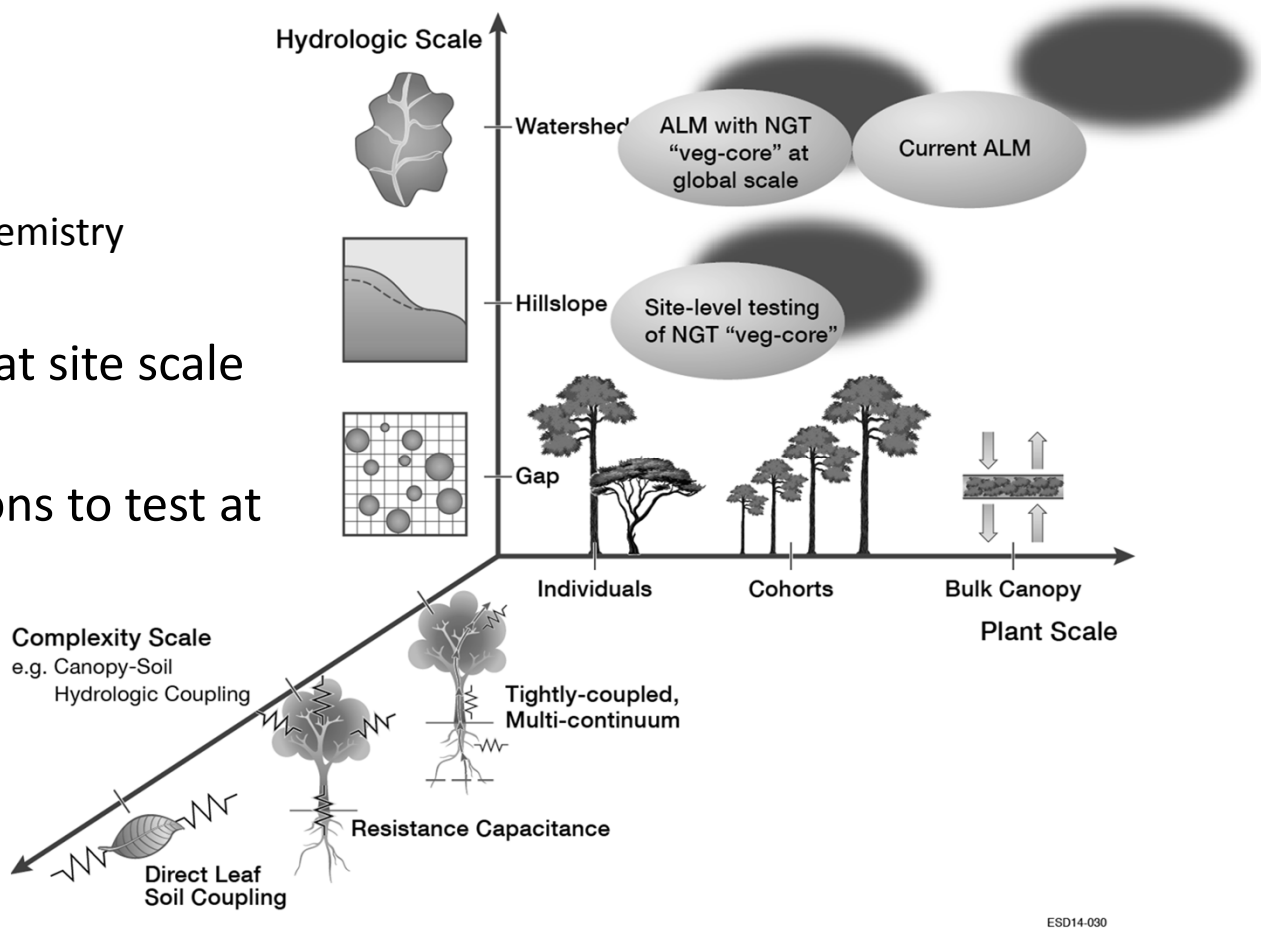
**MO1:** Tropical model testbeds for UA, UQ
**MO2:** Methods for plant trait distribution shifts
**MO3:** Spatial scaling approaches
**MO4:** Complexity scaling framework

**DO1:** Infrastructure for data synthesis supporting analysis products, model parameterization and benchmarking
**DO2:** Portal providing unified access to community data
**DO3:** A repository for NGEE Tropics data

ESD14-071

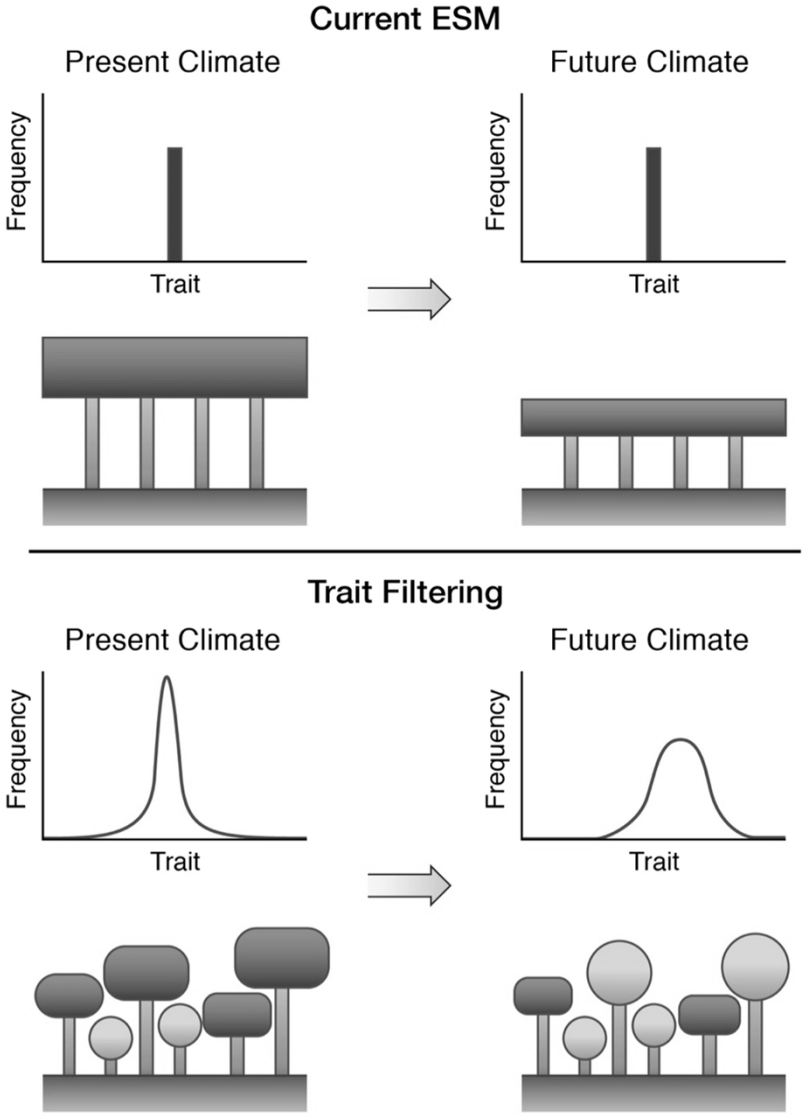
# NGEE-Tropics Modeling Strategy

- Develop a new vegetation model, built around a demographic core
- Develop improved process representations
  - Plant hydraulics
  - Hydrology
  - Plant and soil biogeochemistry
  - Effects of land use
- Testing and validation at site scale across tropics
- ILAMB-type observations to test at larger scales



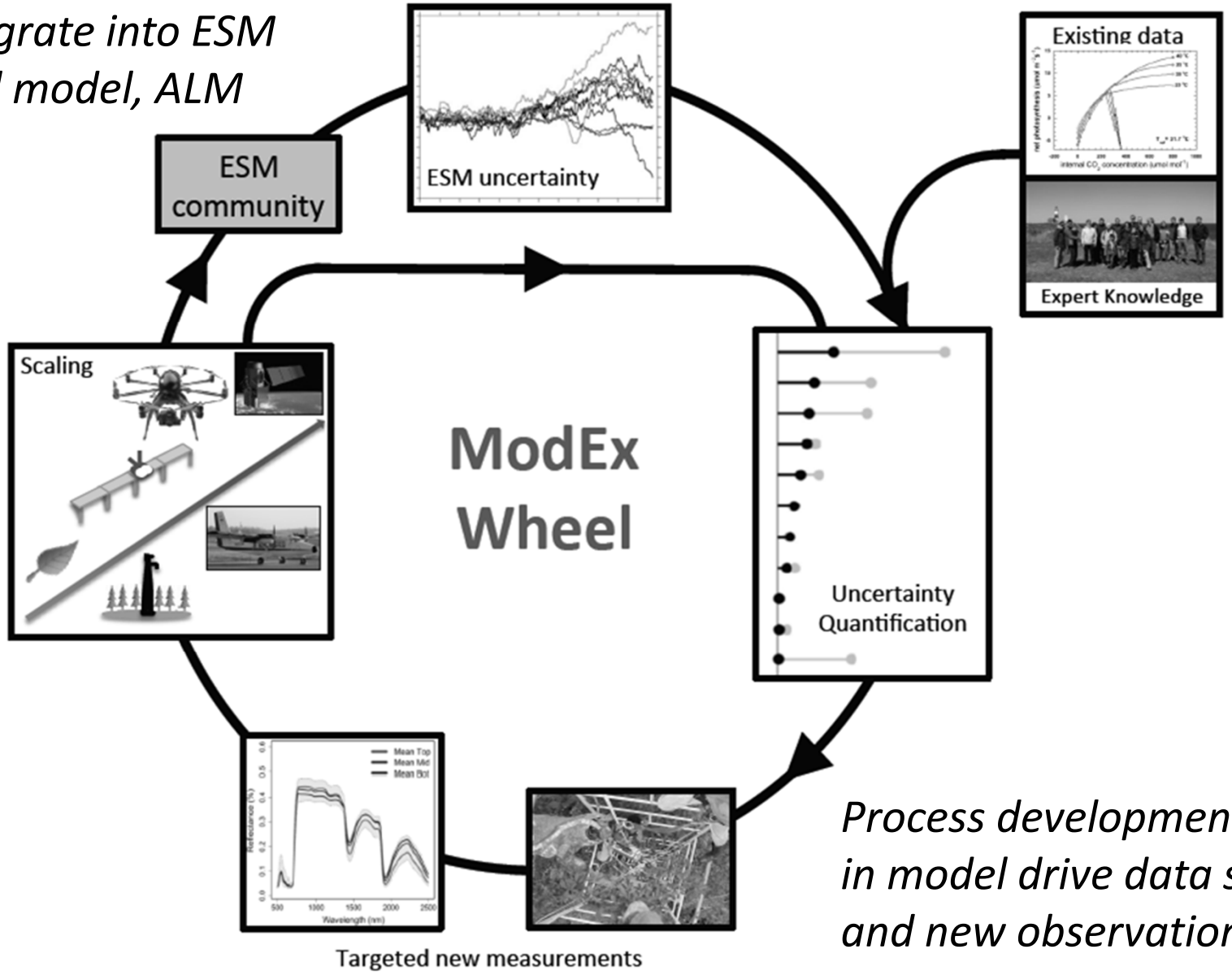
# Novel Trait-Enabled Modeling Approach

- In current ESMs plant traits are static and lack diversity, limiting forest response
- Start with greater diversity that is important to ecosystem processes
- Plant interactions in response to climate change determines which types — therefore trait values — are most successful
- Trait filtering occurs through differential mortality; mortality linked directly to C fluxes



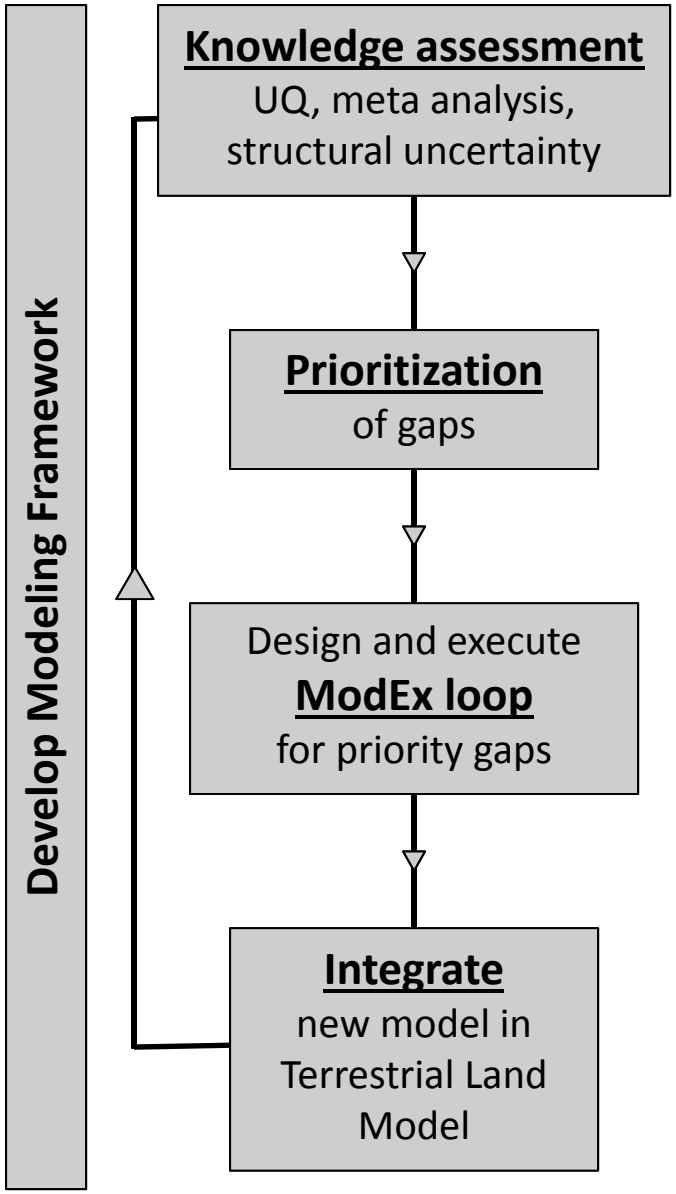
# Integrated Model-Experiment (ModEx) Studies

*Integrate into ESM land model, ALM*




*Process development needs in model drive data synthesis and new observations*

# The NGEE-Tropics Phases

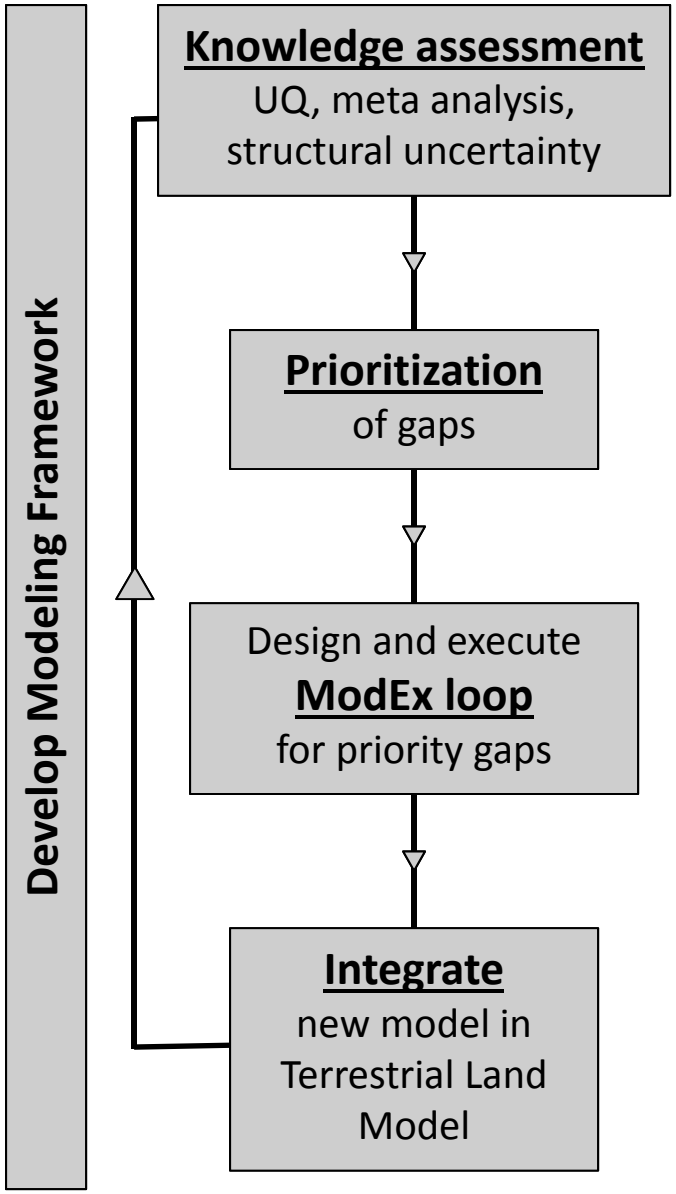



**Phase 1 Milestones**

***Prioritize and demonstrate***

- DOE, national, international partners engaged
- Existing models assessed to identify and prioritize uncertainties
- Data synthesized to benchmark and parameterize priority model processes (pantropical)
- Priority observations and experiments initiated (Pilot Study sites)
- Modeling framework and modules prototyped
- Initial development of pantropical studies for key process gaps (e.g. mortality)

# The NGEE-Tropics Phases




**Phase 2 Milestones**

***Implement and iterate***

- Observations and experiments implemented to address priority uncertainties (pantropical)
- Model modules and parameters developed, tested, and applied using new and synthesized data
- Module coupling prototyped and model framework refined
- Initial coupled model framework applied to high priority science questions
- Benchmarking, UQ and data synthesis applied to define Phase 3 priorities

**Phase 3 Milestones**

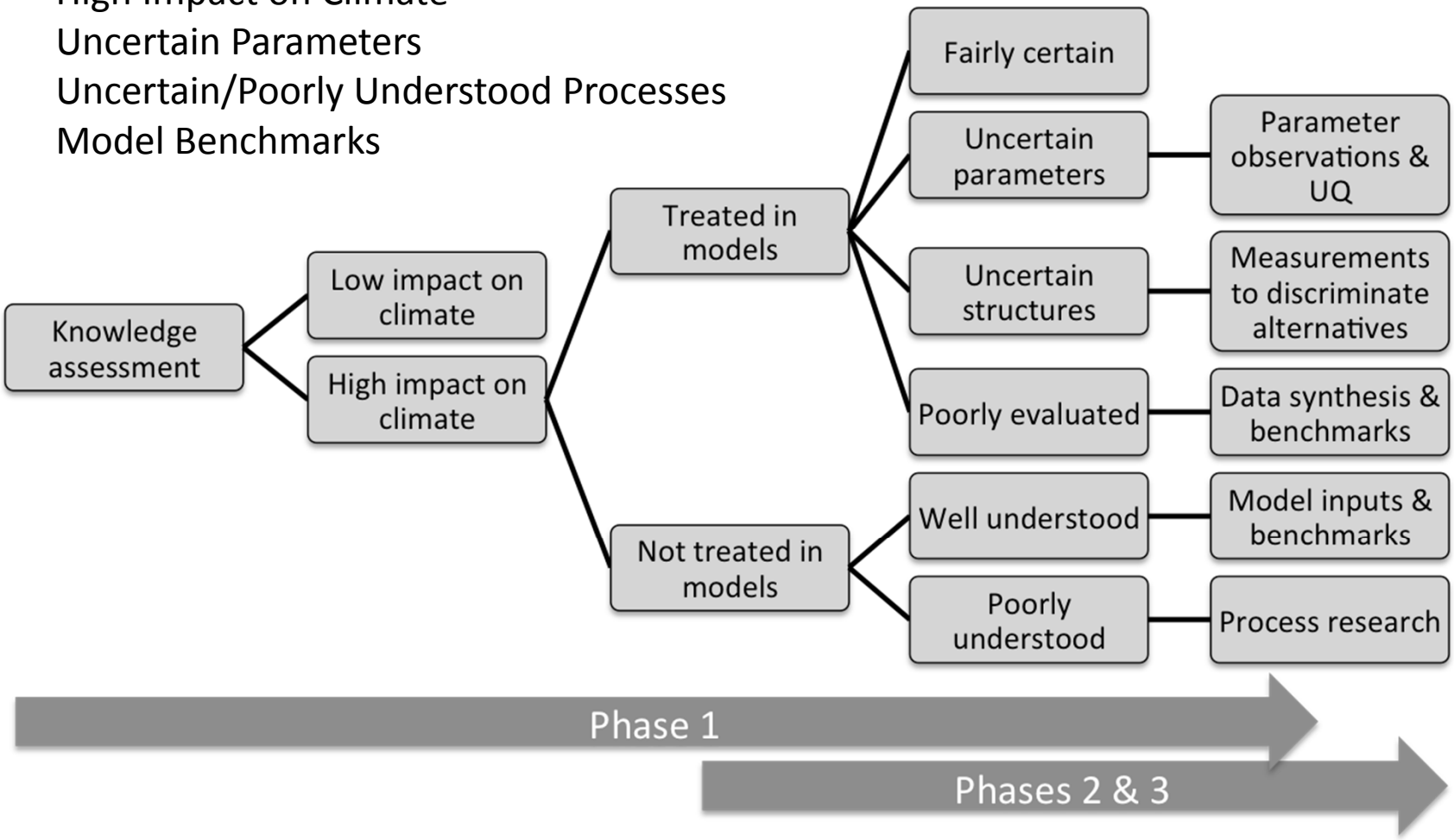
***Integrate and apply***

- Field campaigns continued toward final results and model integration
- Fully coupled model framework applied to high priority science questions
- Tropical model intercomparison project led by NGEE-Tropics team
- A robust model for ESM projection of the future of tropical forests delivered

# Prioritize Knowledge Gaps for Study

***Measurement Priorities***

- High Impact on Climate
- Uncertain Parameters
- Uncertain/Poorly Understood Processes
- Model Benchmarks



# Phase 1 Integrative ModEx Pilot Studies

***Objectives:*** Demonstrate NGEE Tropics approach for known critical uncertainties; prototype novel field methods

- **Manaus, Brazil Pilot: Hydrology-carbon cycle interactions**

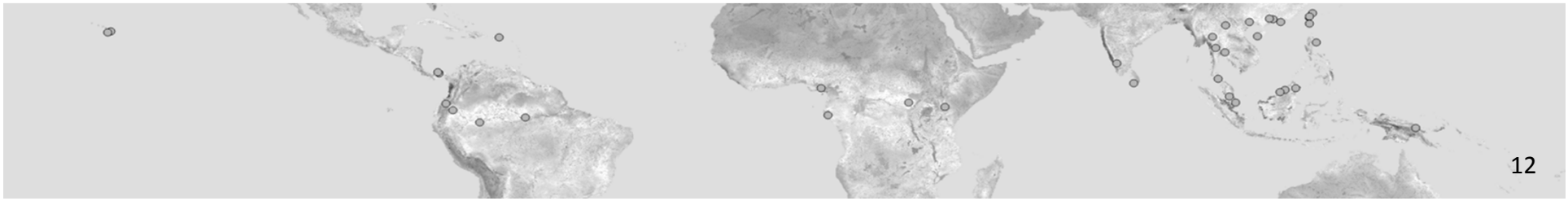
  How do forest carbon and water fluxes respond to water deficits on daily, seasonal and interannual timescales across local topographic moisture gradients?

- **Trait Tradeoffs Pilot: Panama and beyond**

  Can we simulate shifts in plant trait distributions across a rainfall gradient?

- **Puerto Rico Pilot: Nutrient-land use interactions**

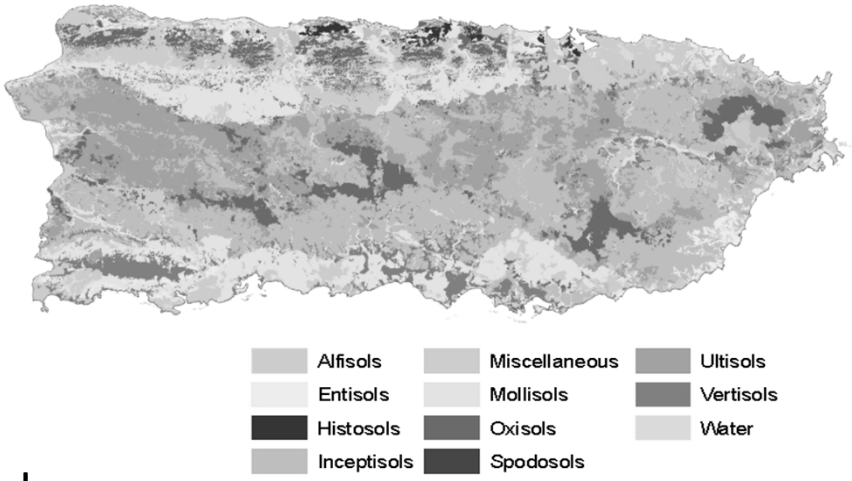
  How does soil nutrient (esp. phosphorus) availability influence plant nutrient acquisition traits, forest productivity and forest development following disturbance?



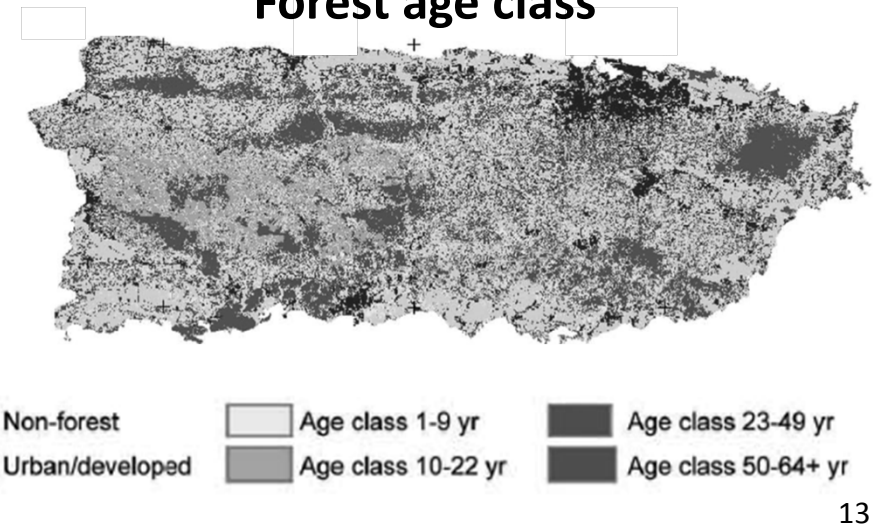
# Puerto Rico Pilot: Nutrient- Land Use Interactions

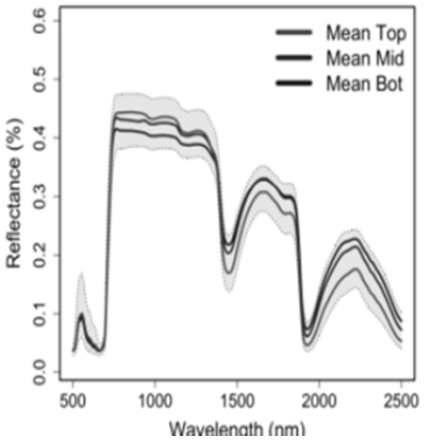
- Transects across soil type and forest development
- Systems biology approach to understanding P availability and plant acquisition via roots
- N availability and N fixation
- Leaf level nutrient analysis and spectral signatures
- Airborne remote sensing to resolve individual canopy trees, leaf spectra to enable scaling from ground-based data

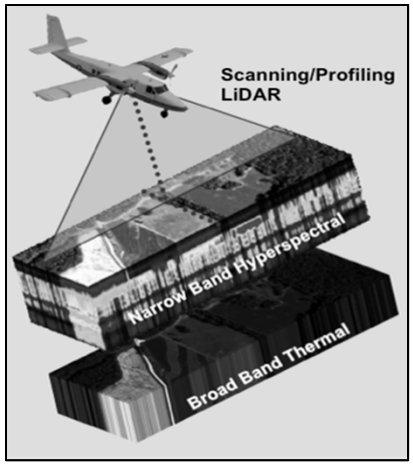
**Soil orders**




**Forest age class**



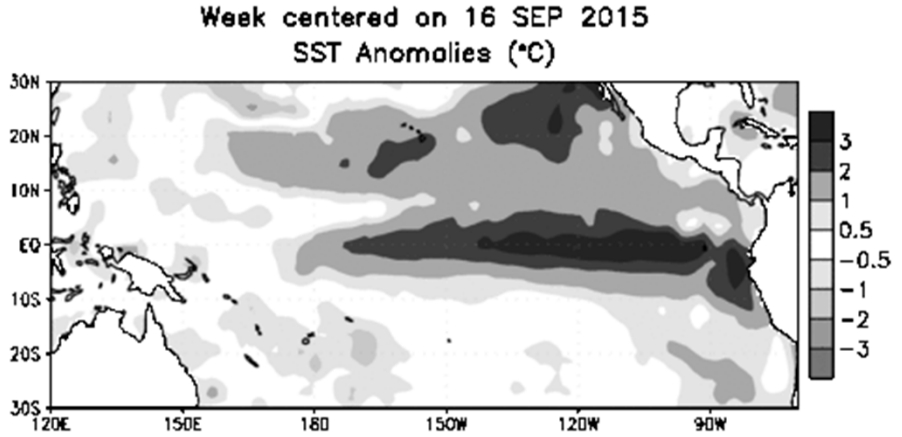
# El Niño Southern Oscillation (ENSO) Effort

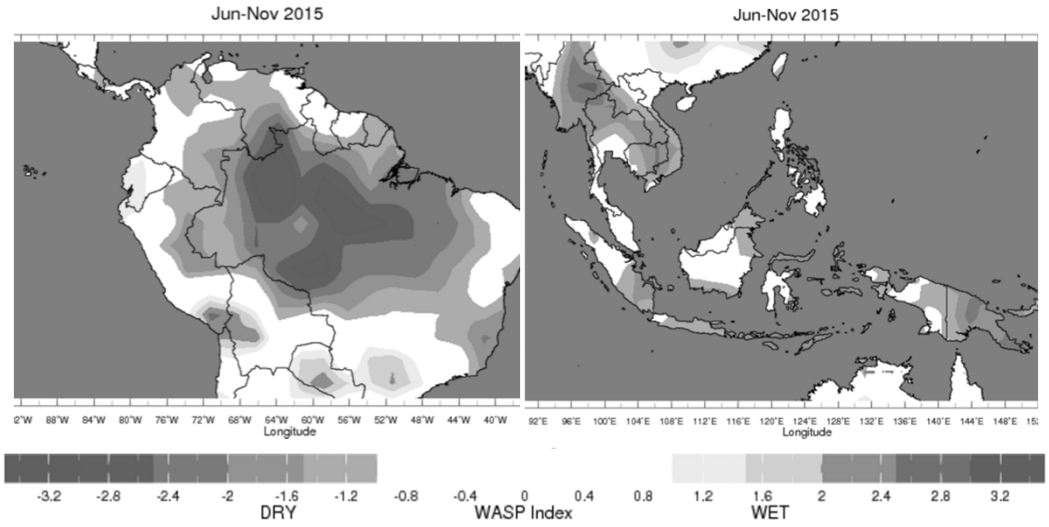
***Motivation***

- Current El Niño strong; ENSO-drought underway in Panama and Brazil
- Drought is relevant to many Phase 1 NGEE-Tropics objectives

***Goals***

1) Quantify drought impacts on tropical forest structure and function
2) Provide data for models
3) Further strengthen our pantropical collaborations



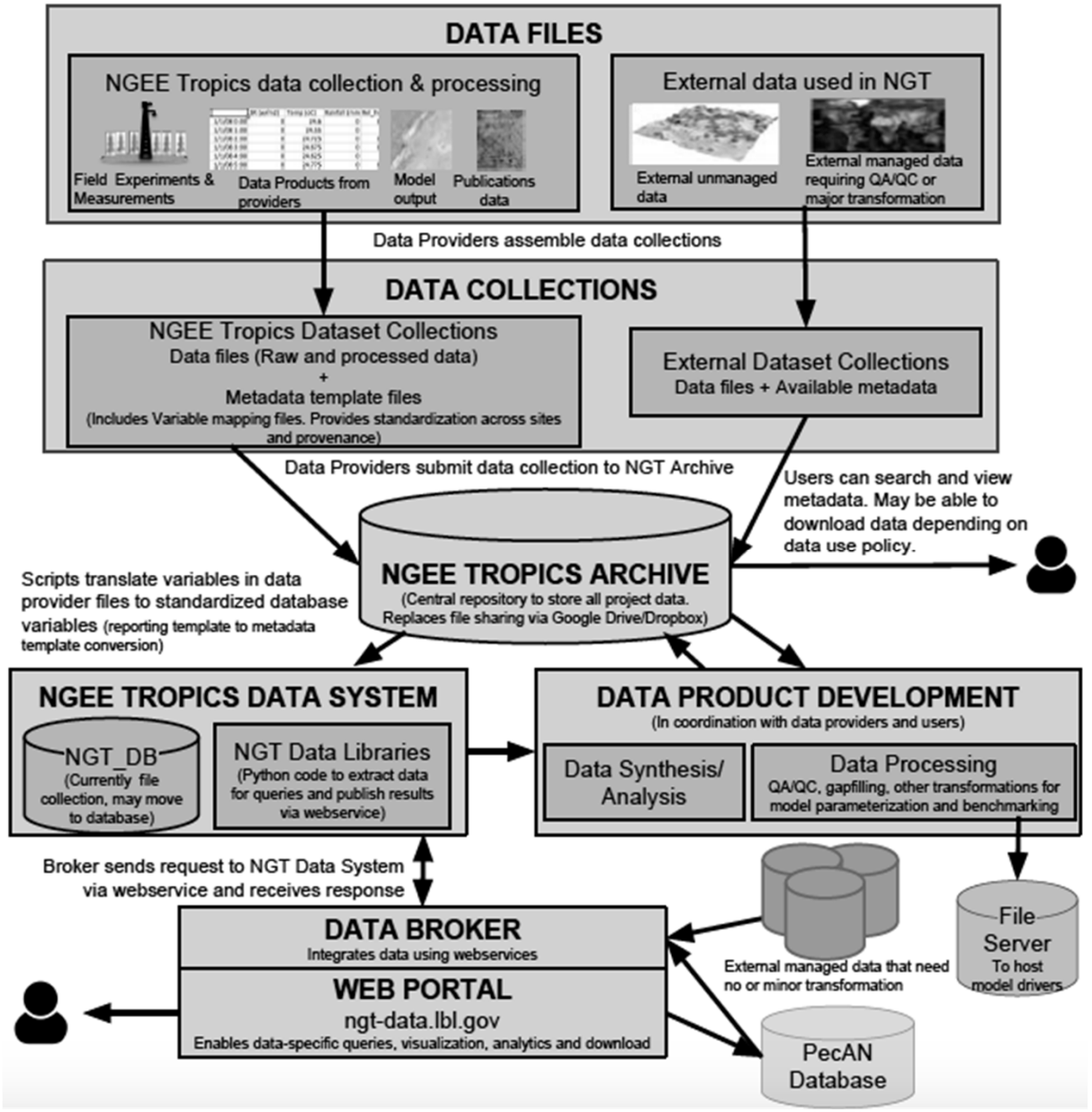



# ModEx Approach to ENSO Measurements

- Measurements in Manaus, Tapajos, and three sites in Panama to understand and test model predictions of plant hydraulic and photosynthetic responses to drought
  - Sapflow, leaf gas exchange, water potential, leaf spectra, $CO_2$ response curves, leaf temperature, whole-tree water relations, soil moisture
- ENSO forest dynamics measurements in Africa, Asia, Pacific and the Americas
- Model predictions: LANL demographic hydraulic module, ED2-Hydro

# Data Management and Synthesis

- NGEE-Tropics Data Archive (to be released end of March) to hold all NGEE Tropics datasets
- Designing templates for metadata reporting and files for ENSO and future datasets
- Creating QA/QC'd gap-filled, site-level drivers for the NGEE-Tropics model
- Will develop web portal to enable queries of NGEE Tropics and partner datasets



# Partnerships Key to Our Success

- Key DOE activities
  - NGEE Arctic partnership on data management, project management, plant traits
  - ACME partnership on vegetation and soil biogeochemistry model development
- International collaborations
  - Collaborations with Instituto Nacional de Pesquisas da Amazônia (INPA) and Large-Scale Biosphere Atmosphere Experiment in Amazonia (LBA) in Brazil on field measurements, data synthesis, modeling
  - Collaboration with ForestGEO Global Network of forest demographic measurements and GEM Network of forest carbon measurements
  - Collaborations with International Institute for Tropical Forestry, Luquillo LTER, and Luquillo CZO in Puerto Rico on measurements of nutrient biogeochemistry and secondary forest development

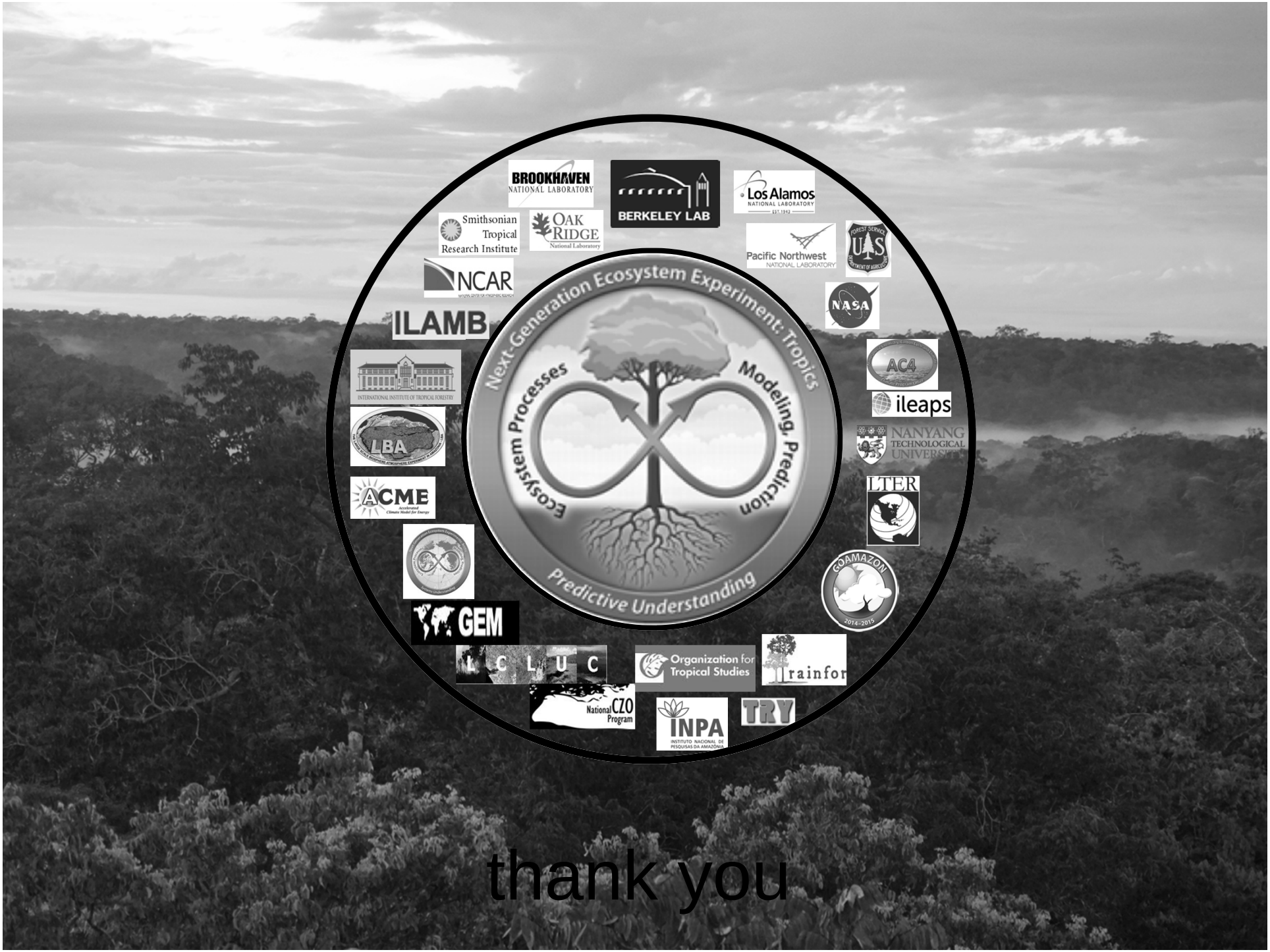
# Transformational Outcomes

***NGEE Tropics will deliver***

- A demographic, trait-enabled vegetation modeling framework that captures how forest complexity influences carbon cycle responses under a changing atmosphere and warming climate

- New model structures rigorously informed and benchmarked with existing data, and new data products generated using our ModEx approach

- Significantly reduced uncertainties in tropical forest ESM carbon cycle feedbacks, and a greatly improved understanding of the role of tropical forests in Earth system functioning over the 21$^{st}$ Century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thank you