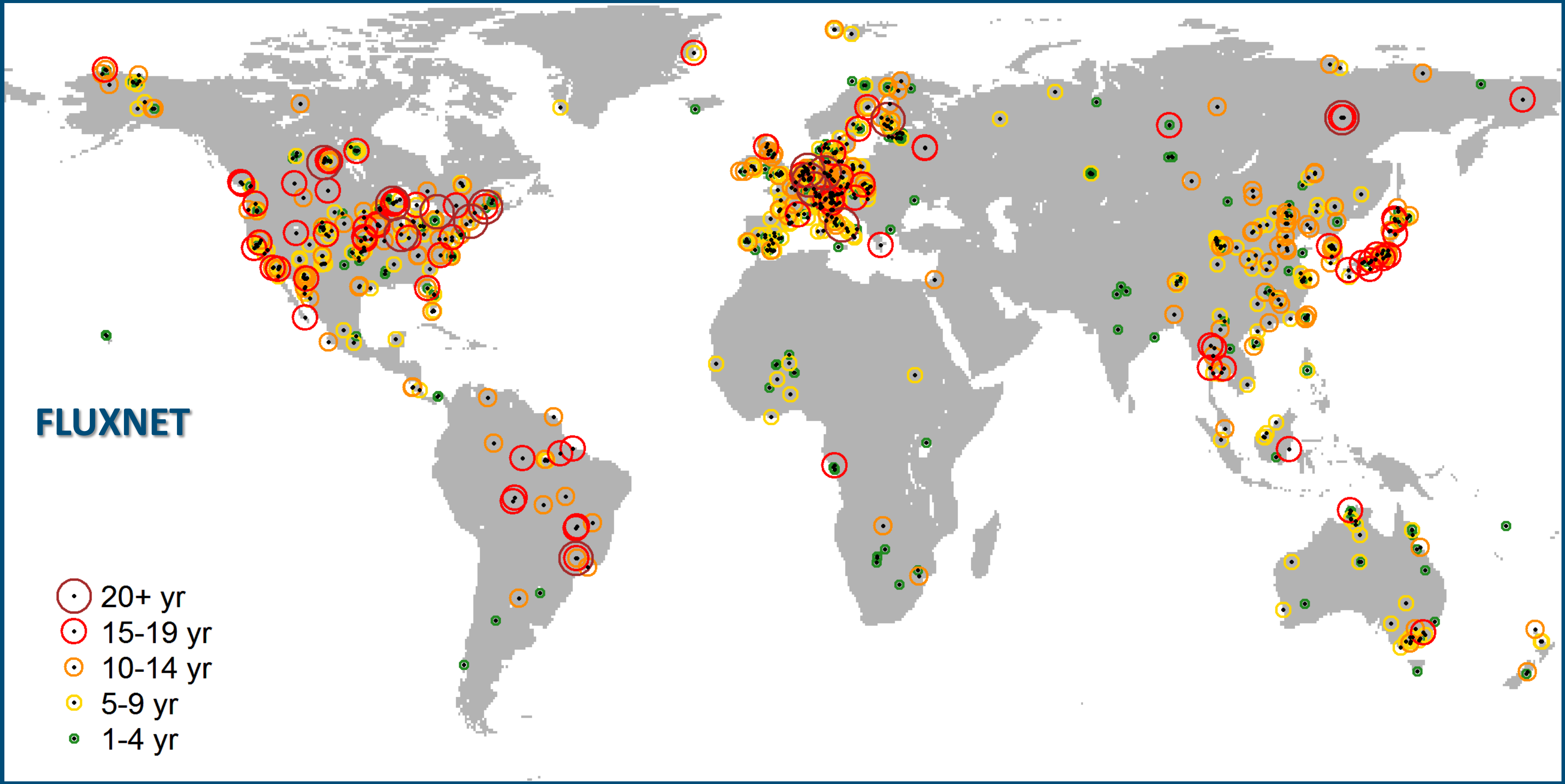
Ecological Synthesis

The art of scalable science

Trevor F. Keenan
UC Berkeley
Lawrence Berkeley National Lab.

FLUXNET: Global measurements of earth-atmosphere exchange



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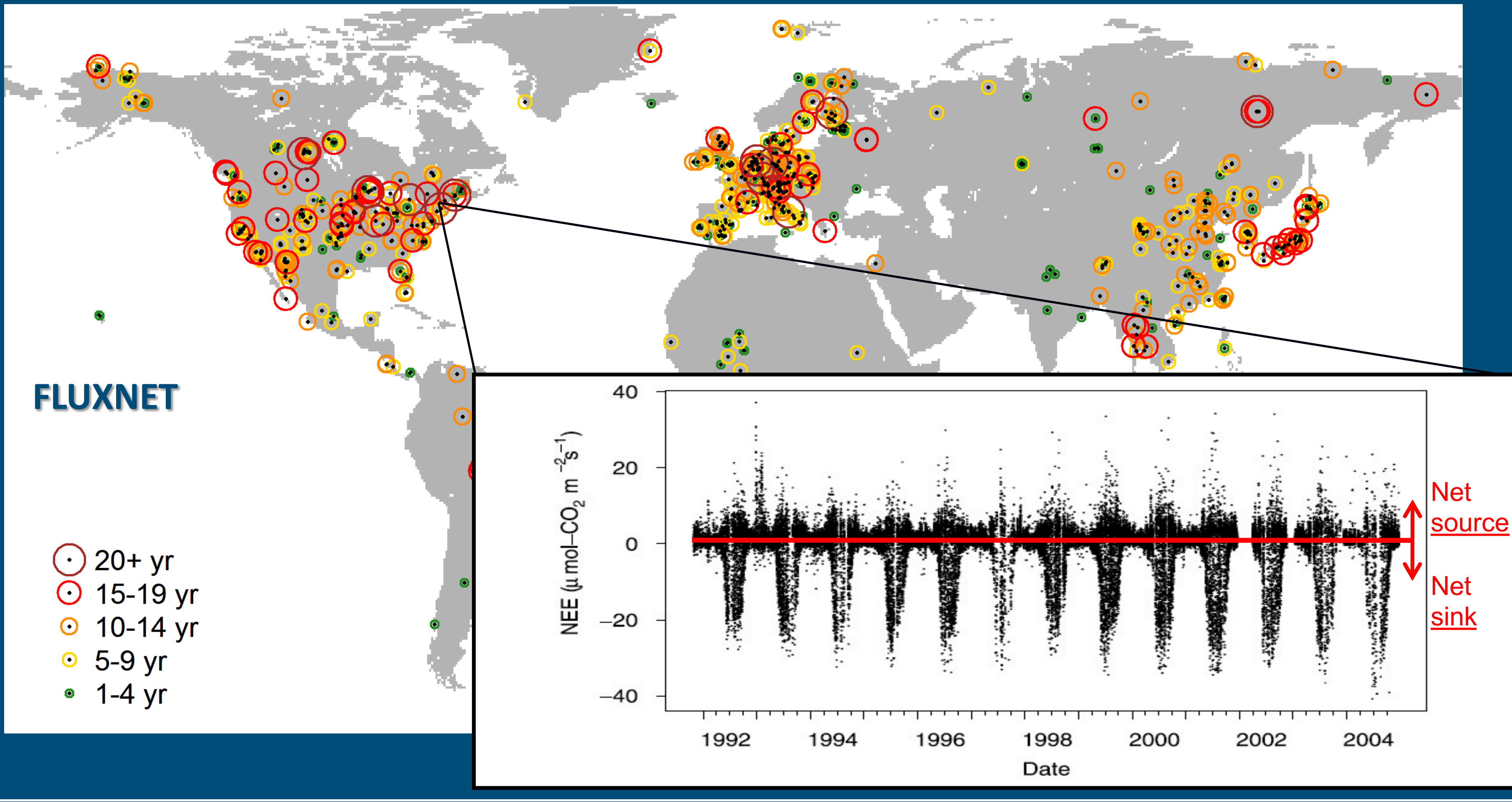
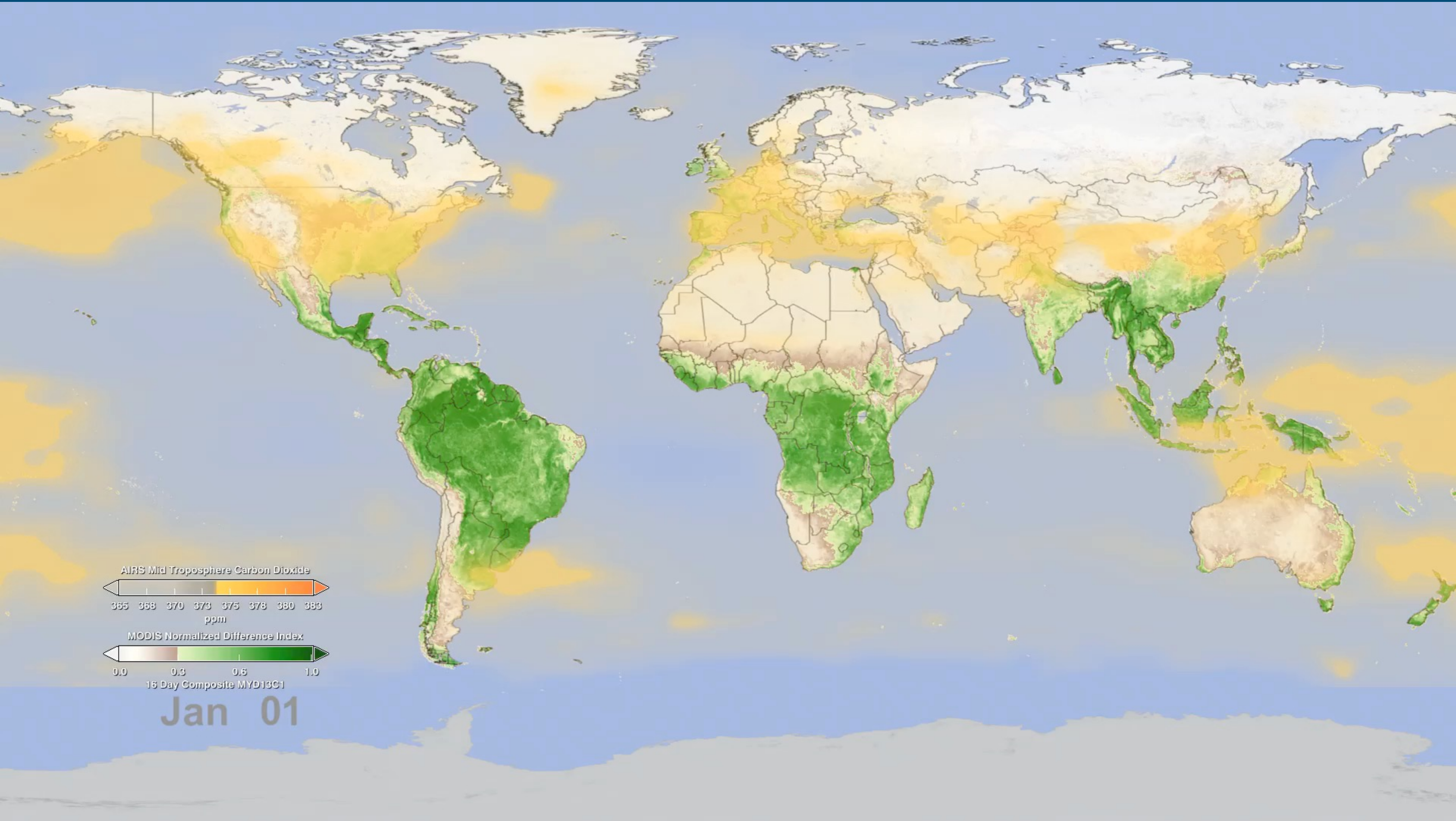


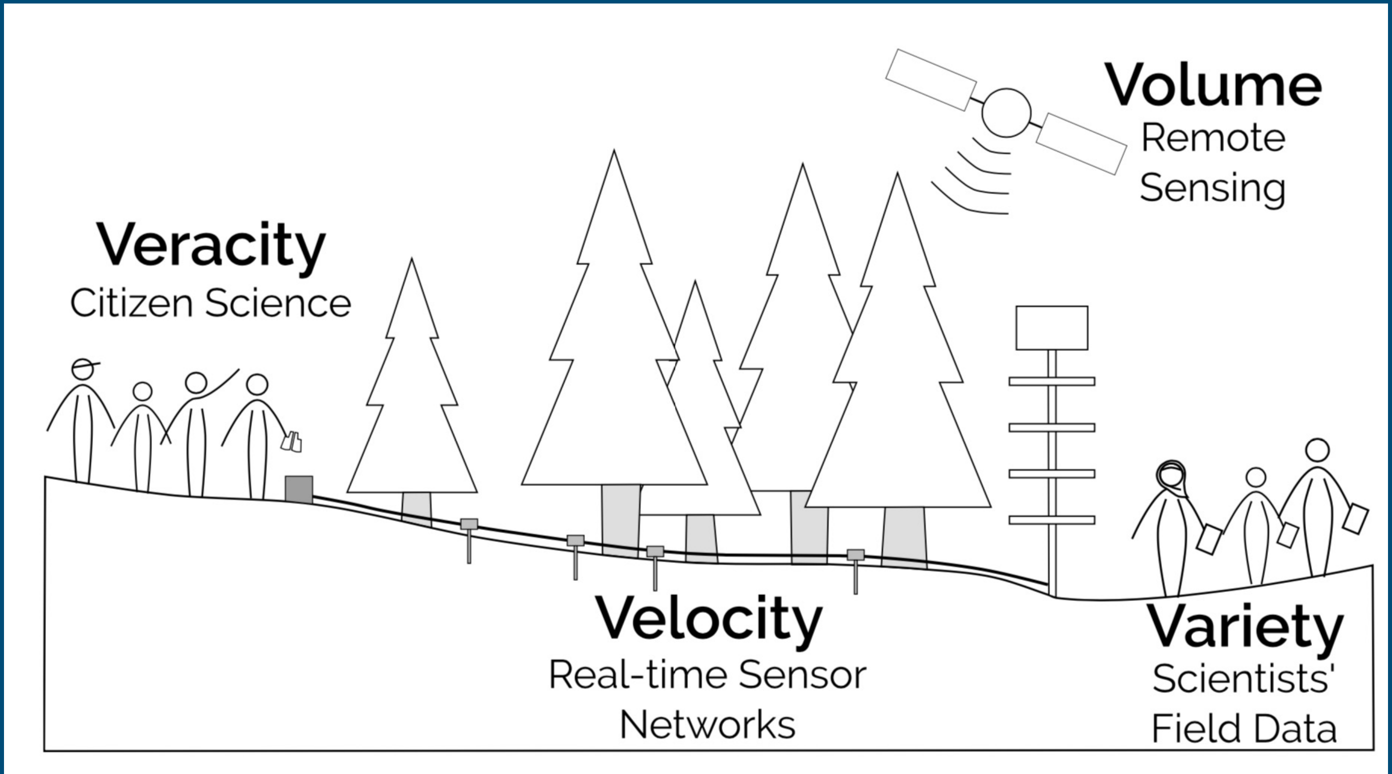
The Terrestrial Carbon Cycle



NASA Scientific Visualization Studio

http://svs.gsfc.nasa.gov/goto?3947

‘Ecosystem Science’ joins the league of big data.



Farley et al., 2018

Today’s big data is tomorrow’s drop in the hard drive

Worldwide data volume doubled nine times between 2006 and 2011, with exponential growth continuing this decade (Chen et al. 2014)

Growth has outpaced the annual doubling in computing power predicted by Moore’s law (Olofson and Eastwood 2014)

Ecosystems (2017) 20: 274–283
DOI: 10.1007/s10021-016-0075-y
ECOSYSTEMS
CrossMark

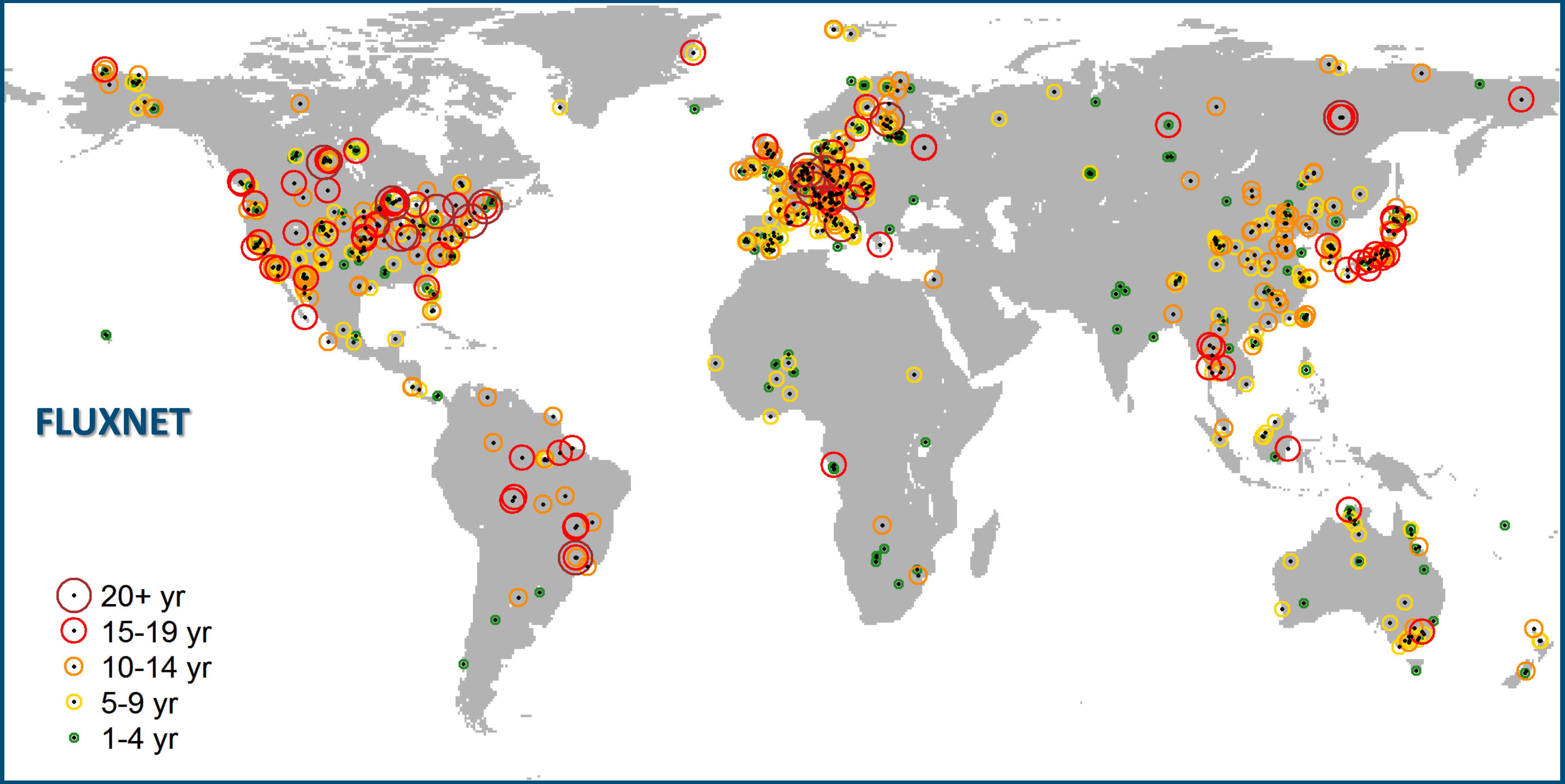
20th Anniversary Paper

The Next Decade of Big Data in Ecosystem Science

S. L. LaDeau,* B. A. Han, E. J. Rosi-Marshall, and K. C. Weathers

Cary Institute of Ecosystem Studies, Millbrook, New York 12545, USA

FLUXNET: Global measurements of earth-atmosphere exchange



Today’s big data is tomorrow’s drop in the hard drive

FORUM

The “Data-rich but Information-poor” Syndrome in Water Quality Monitoring

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ABSTRACT / Water quality monitoring conducted routinely over time at fixed sites has been a part of most water quality management efforts for many years. It has been assumed that such monitoring plays a major role in management. However, the lack of routine data analysis, and reporting of information derived from such analysis, points up the fact that the exact nature of the role of routine, fixed-station monitoring is poorly defined.

There is a need to very clearly define this role in the design of such systems if routine monitoring is to efficiently and effectively meet the information expectations placed on it. Design of routine monitoring systems will therefore have to consider not only the where, what, and when of sampling, but also why. A framework for including the “why” of monitoring in the design process is proposed and experience with using the framework in New Zealand is discussed.

Ward et al. 1986. Environmental Management

A post-science vision of the future

- Fishing expeditions through data-mining
- Hypothesis-free science

A post-science vision of the future

- Engage scientists with data gathering
- Foster a broad and deep understanding of the field
- Develop hypothesis guided approaches
- Develop the computational skills needed to test them

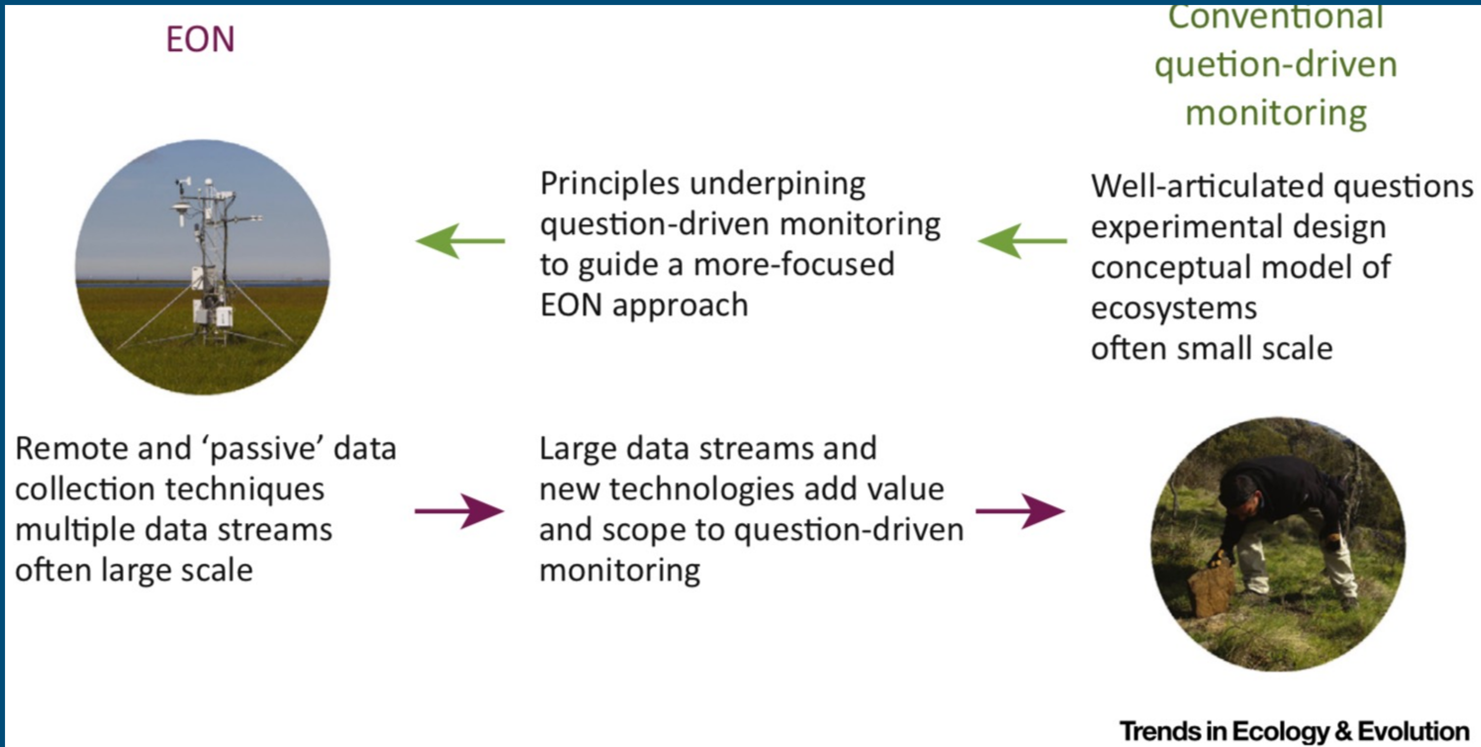
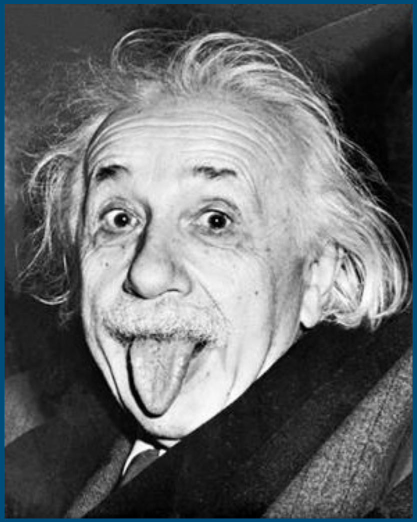


Figure 1. Full Integration of Earth Observation Networks (EONs) and Question-Driven Approaches to Monitoring that Aims to Capture Key Features of Both Kinds Monitoring.

Lindenmayer, Likens & Franklin, 2017

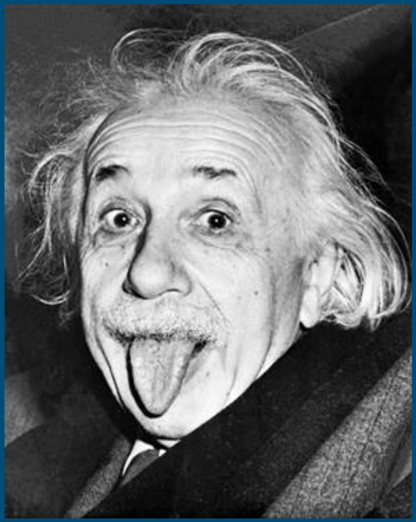


"….forget about the numbers! We must **simplify and idealize** to develop robust understanding."

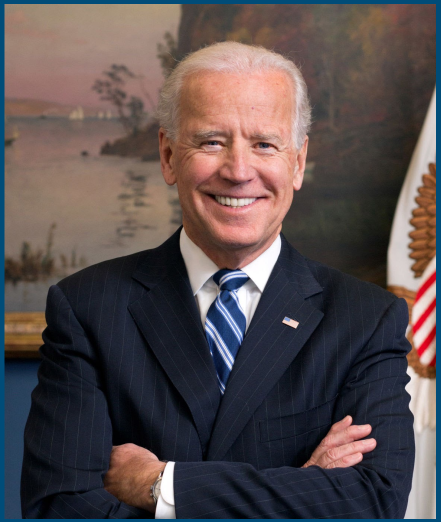
Policy

Theory

Scalable Understanding



"….forget about the numbers! We must **simplify and idealize** to develop robust understanding."

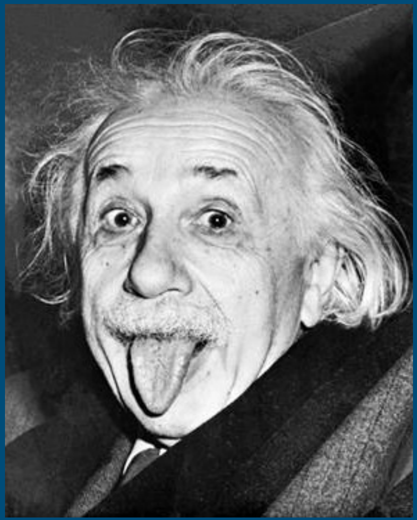


"we need accurate and believable predictions to guide **policy**, which **requires complex models**…."

Policy

Theory

Scalable Understanding



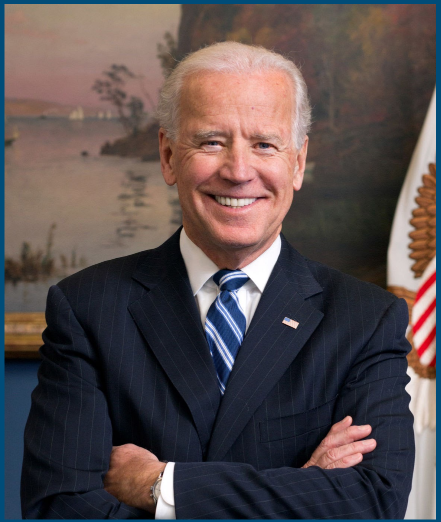
Observations

Theory

Models

Process Understanding

"....forget about the numbers! We must **simplify and idealize** to develop robust understanding."



"we need accurate and believable predictions to guide **policy**, which **requires complex models**...."

Policy

Theory

Scalable Understanding

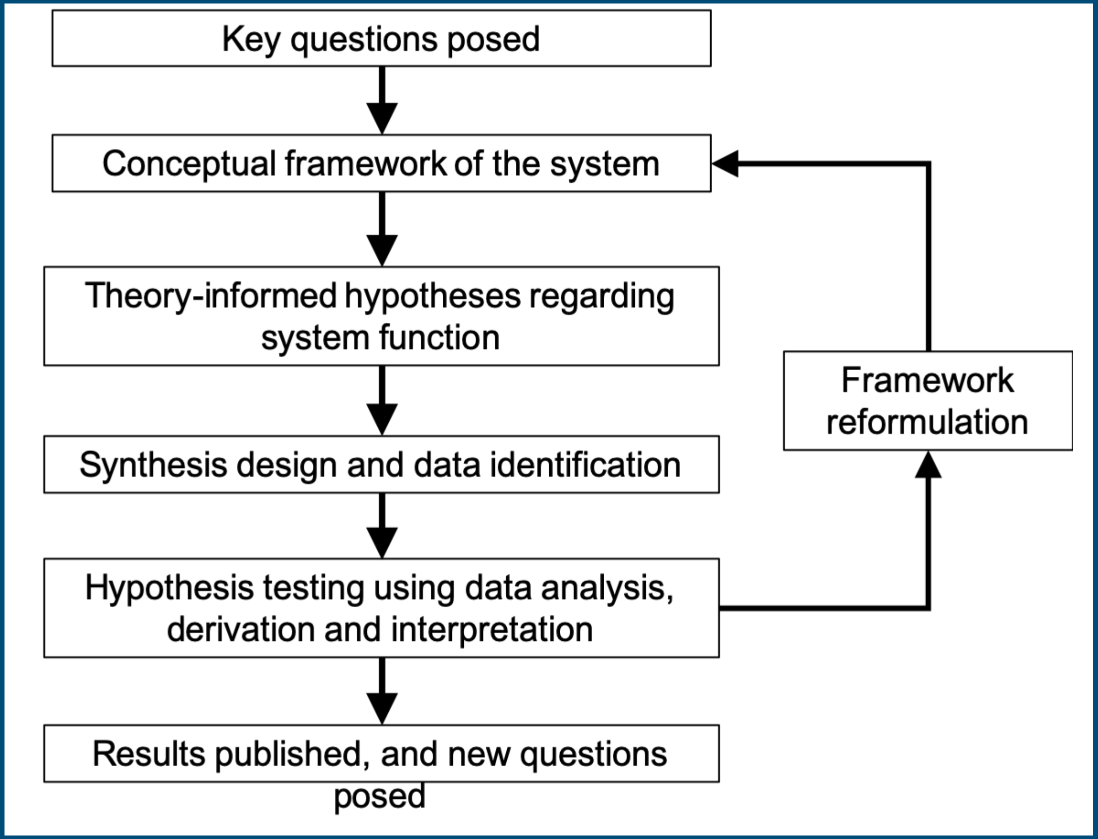
Theoretical framework for synthesis?

Ingredients of an effective synthesis study?

Theoretical framework for synthesis?

Ingredients of an effective synthesis study?

A theoretical framework for synthesis design



Adapted from Lindenmayer and Likens, 2010

Ingredients of an effective synthesis study

- A question!

Ingredients of an effective synthesis study

- A question!

Example 1:

"Examine variability in light use efficiency between sites"

Ingredients of an effective synthesis study

- A question!

Example 1:

"Examine variability in mortality between sites."

Example 2:

"What is the relative magnitude of environmental vs. PFT control of variability in mortality?"

Example 3:

"Variability in mortality is driven more by environmental forcings than PFTs."

Ingredients of an effective synthesis study

- A question!
- Formulated theory

Ingredients of an effective synthesis study

- A question!
- Formulated theory

E.g.,

LUE: Is there physiological basis that allows us to predict changes in LUE?

Phenology: What theories exists, how do they differ, and can they be tested?

Ingredients of an effective synthesis study

- A question!
- Formulated theory
- A refined target

Ingredients of an effective synthesis study

- A question!
- Formulated theory
- A refined target
  - More data does not mean better data
  - LUE: cloudy, clear, solar zenith angle, etc.
  - Phenology: Summer, winter, night-time vs day-time
  - WUE: rain, VPD, soil moisture, canopy closure

Ingredients of an effective synthesis study

- A question!
- Formulated theory
- A refined target
- Continual refinement

  - The more you can refine at the small scale, the easier scaling will be

Ingredients of an effective synthesis study

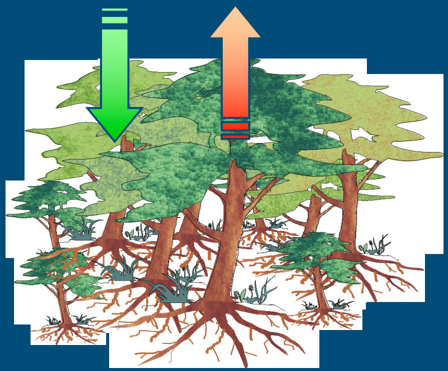
- A question!
- Formulated theory
- A refined target
- Continual refinement
- Start local
    - Start small – a site and year you trust
    - Develop the analysis as fully as possible
    - Think about how the question might scale

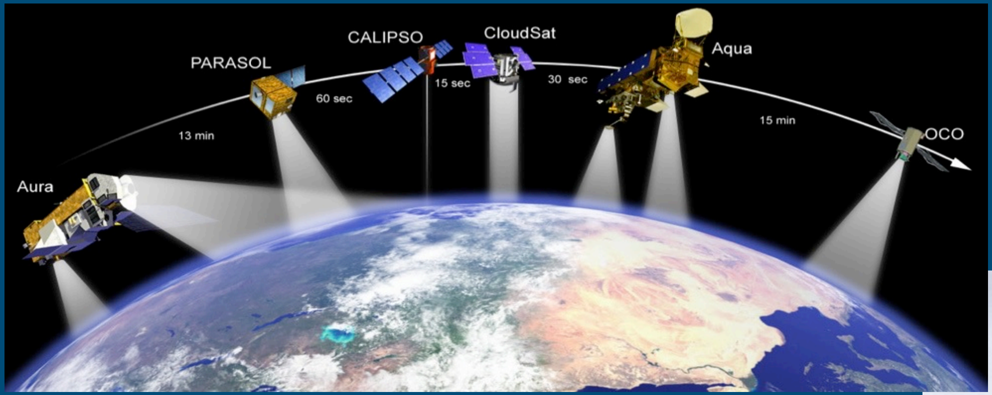
Ingredients of an effective synthesis study

- A question!
- Formulated theory
- A refined target
- Continual refinement
- Start local
- Modularly scaled
  - Think about workflow, function design
  - The utility of intermediates

Ingredients of an effective synthesis study

- A question!
- Formulated theory
- A refined target
- Continual refinement
- Start local
- Modularly scaled
- Ancillary measurements



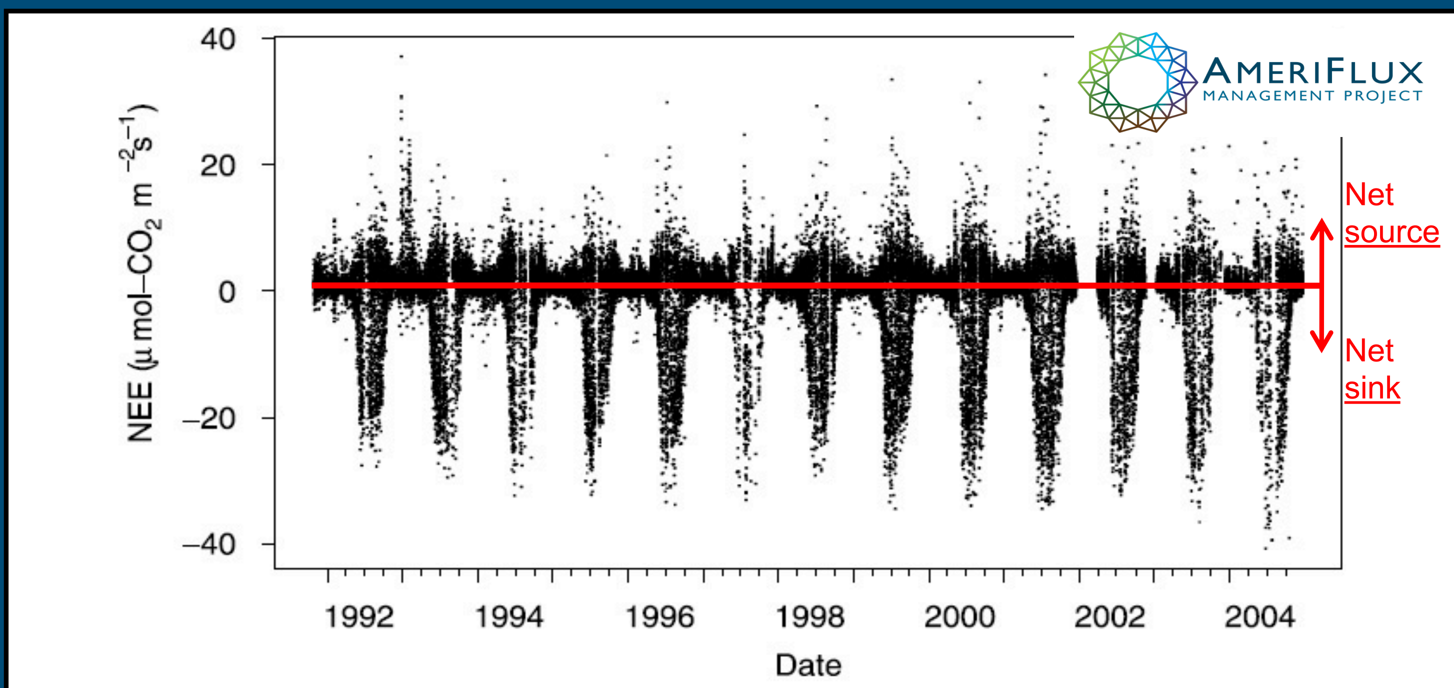


Aura
PARASOL
CALIPSO
CloudSat
Aqua
OCO
13 min
60 sec
15 sec
30 sec
15 min

Long-term changes in ecosystem function at Harvard Forest

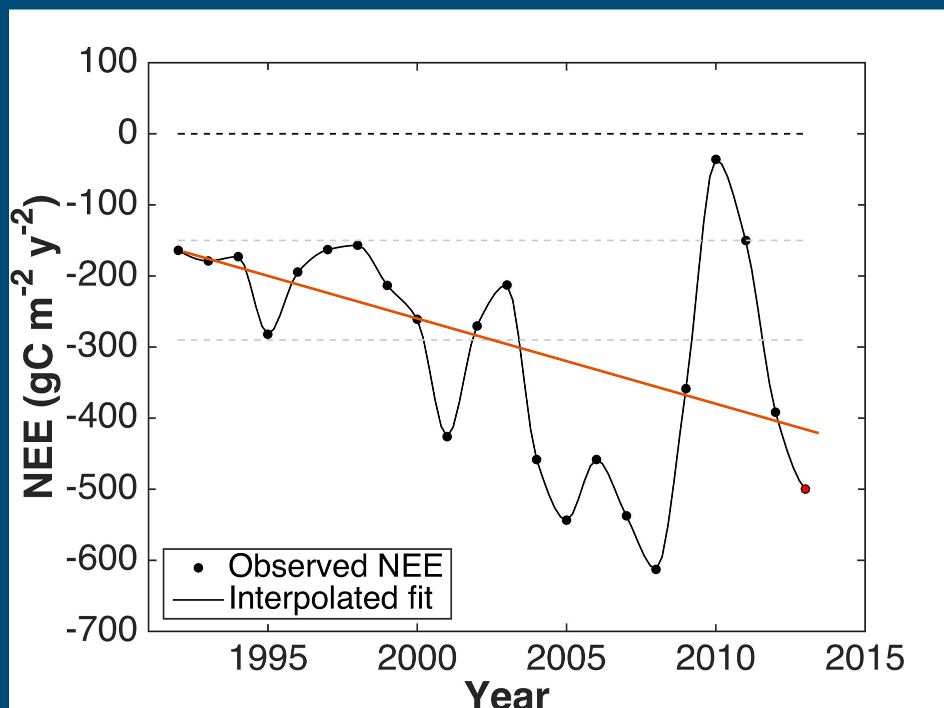
Keenan et al. (2012)

Long-term changes in ecosystem function at Harvard Forest



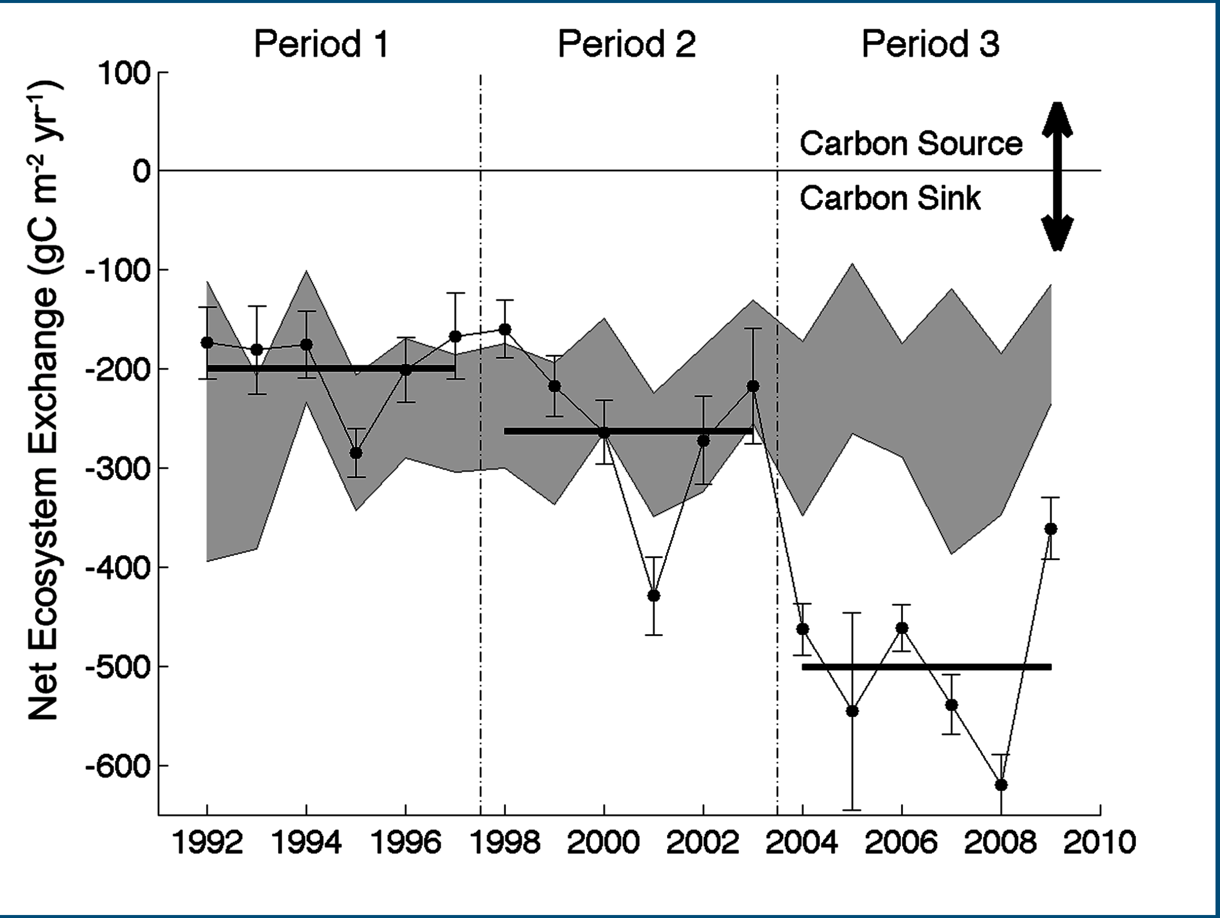
Keenan et al. (2012)

Long-term changes in ecosystem function at Harvard Forest

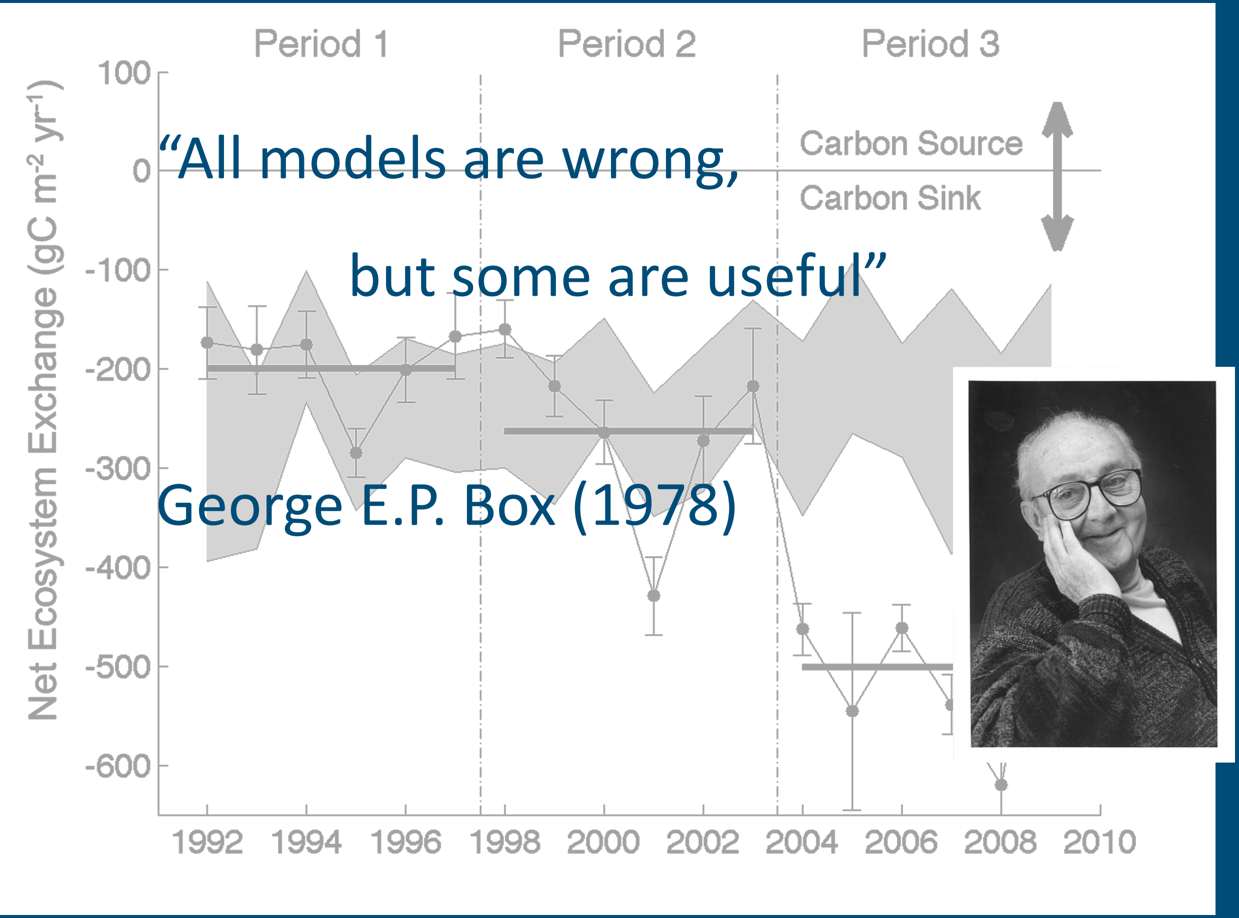


Keenan *et al.* (2012)

Flux-driven modeling at Harvard Forest



Keenan et al. (2012) Global Change Biology



"All models are wrong,

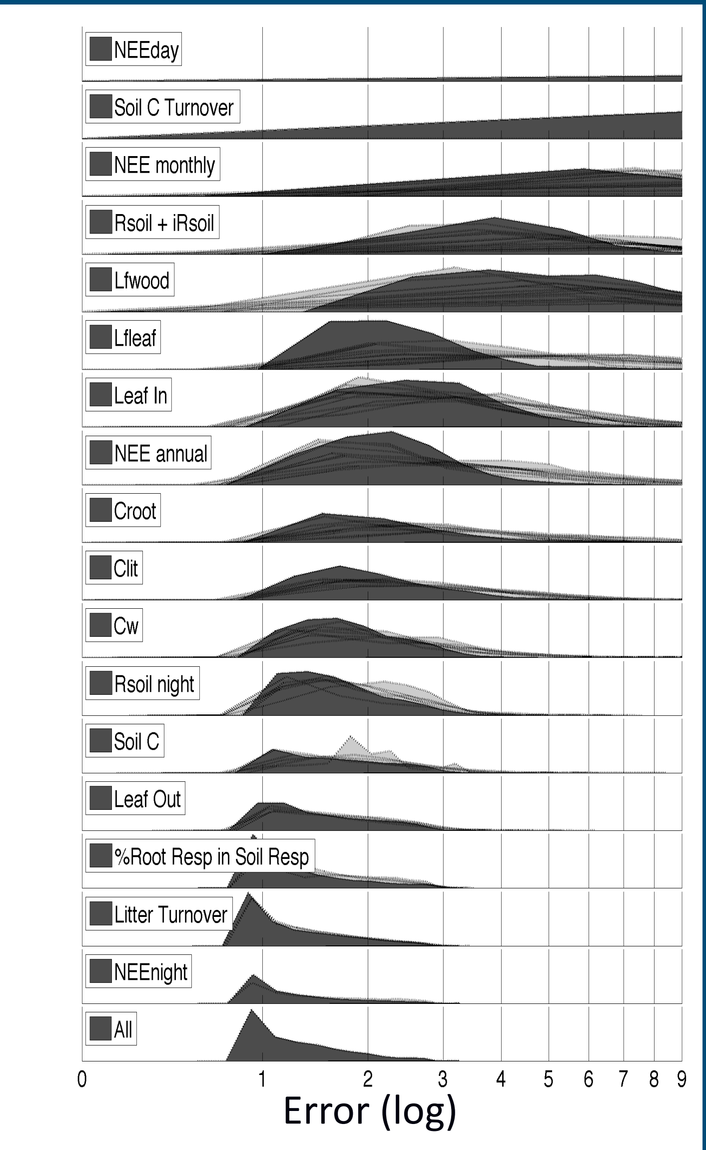
but some are useful"

George E.P. Box (1978)

Data available at Harvard Forest

- Net Ecosystem Exchange (hourly carbon & water fluxes)
- Soil Respiration
- Leaf area
- Leaf litterfall
- Carbon in roots
- Carbon in wood
- Woody litterfall
- Phenology
- Soil carbon turnover rates

Model Performance



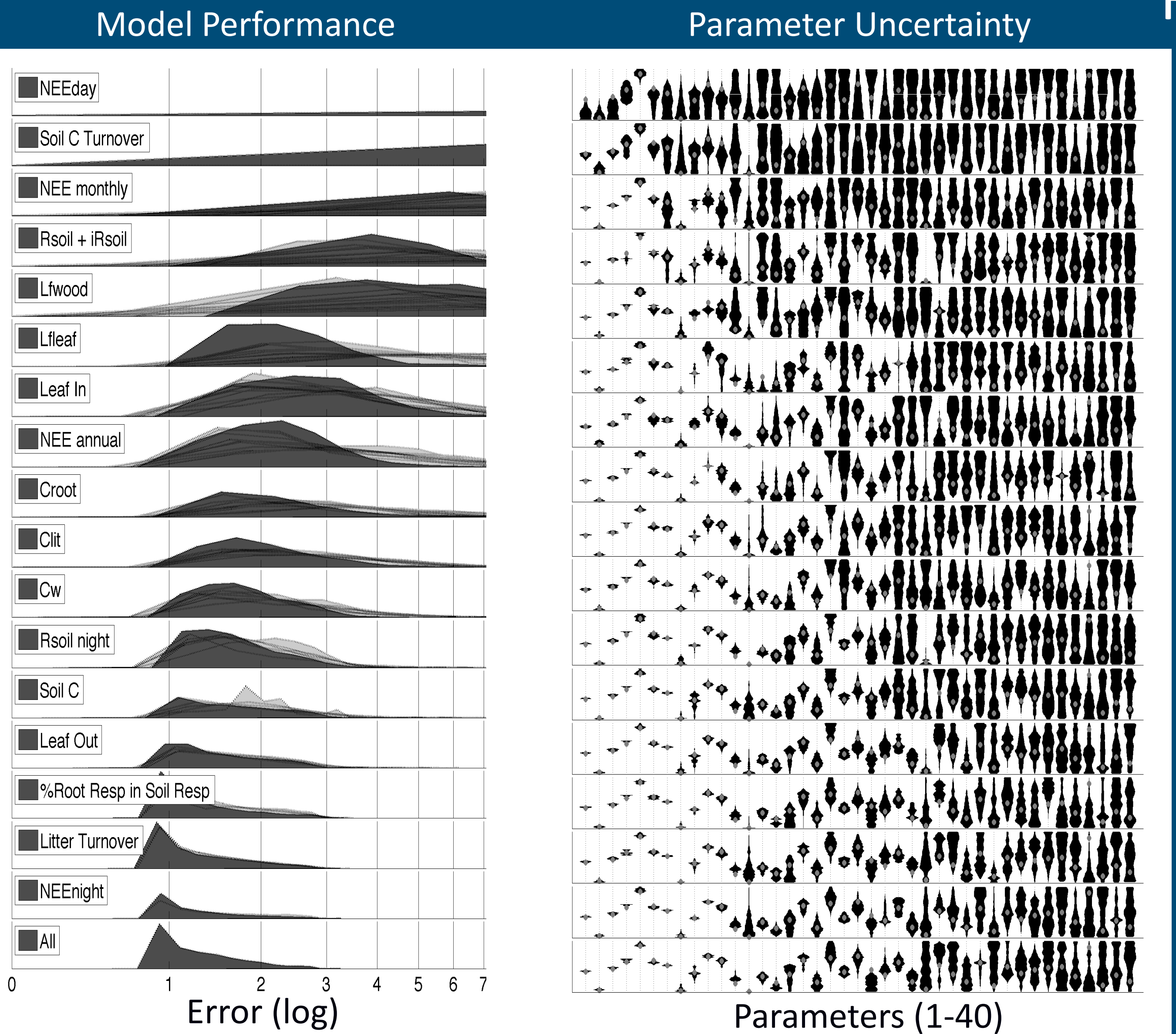
Rate my data:

How much data do we need to measure?

Identifying the most valuable data.

Keenan et al. (2013) Ecological Applications

Rate my data:



How much data do we need to measure?

Identifying the most valuable data.

Keenan et al. (2013) Ecological Applications

Ingredients of an effective synthesis study

- A question!
- Formulated theory
- A refined target
- Continual refinement
- Start local
- Modularly scaled
- Ancillary measurements

Ingredients of an effective synthesis study

- A question!
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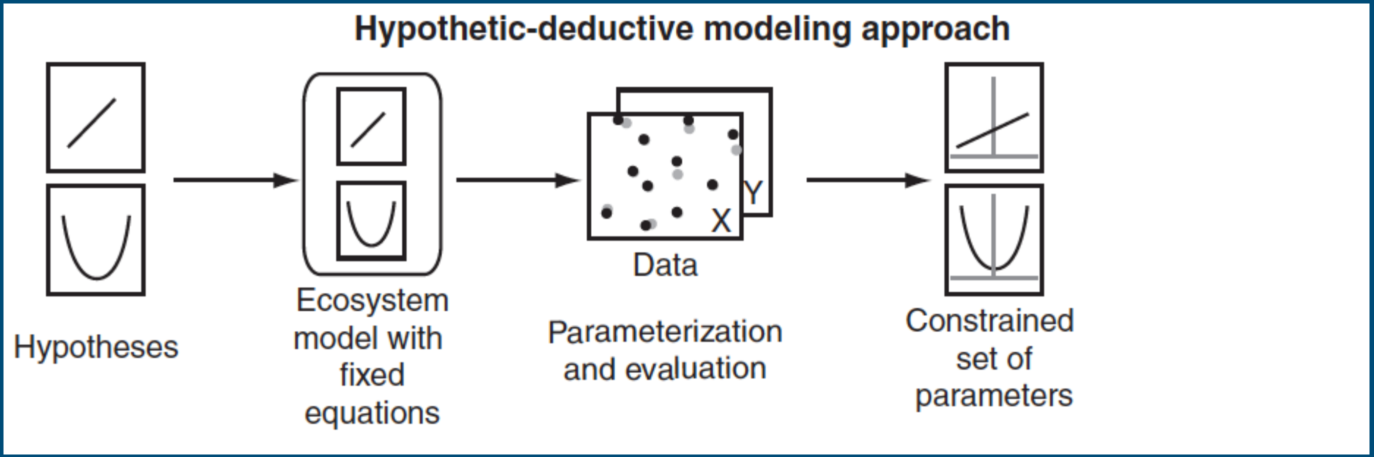
- A refined target
- Continual refinement
- Start local
- Modularly scaled
- Ancillary measurements
- Models to confront

Models

Models

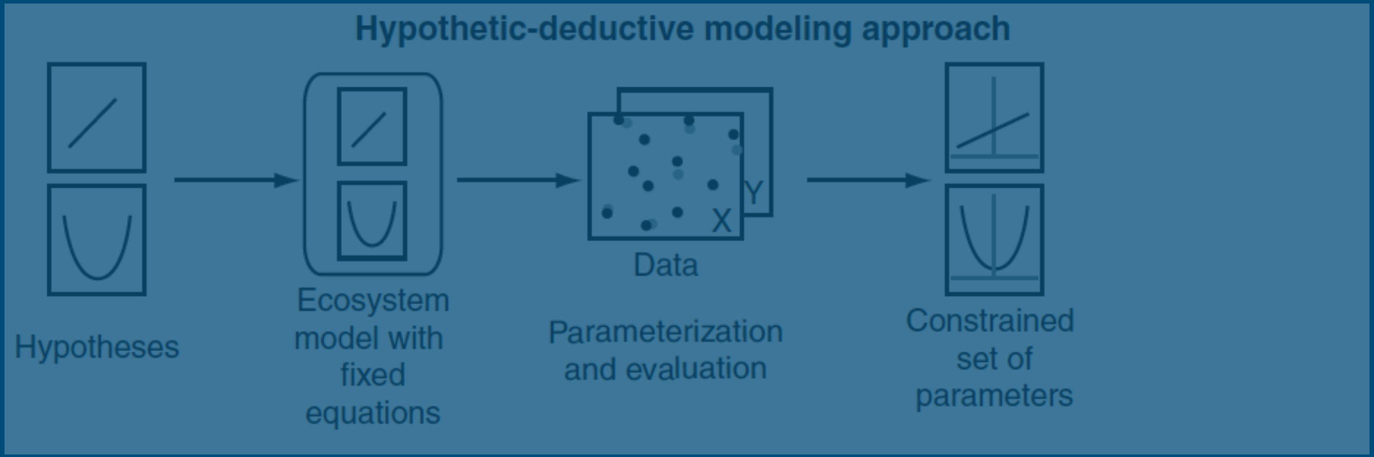
Hypothesis driven / process based:



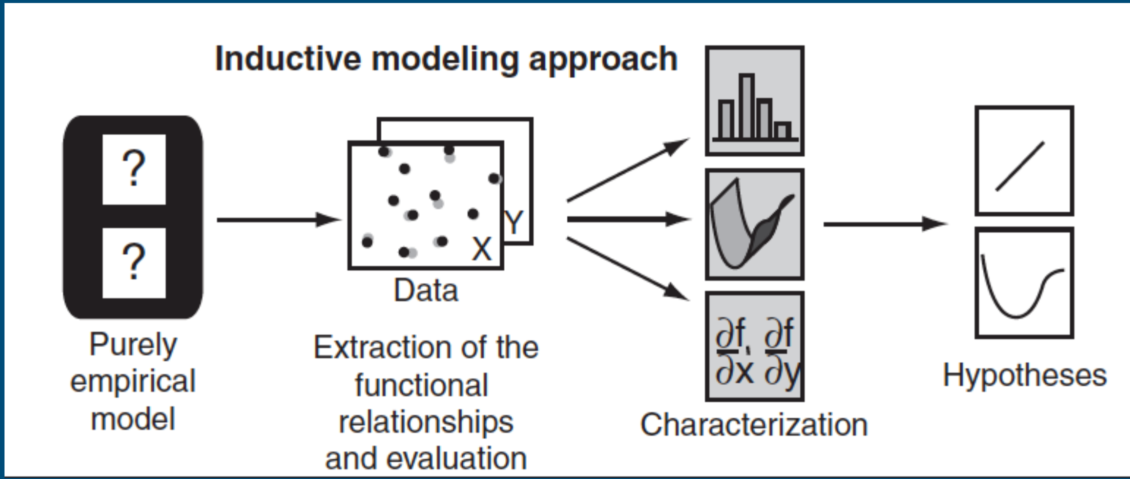
Moffat et al. (2010)

Models

Hypothesis driven / process based:



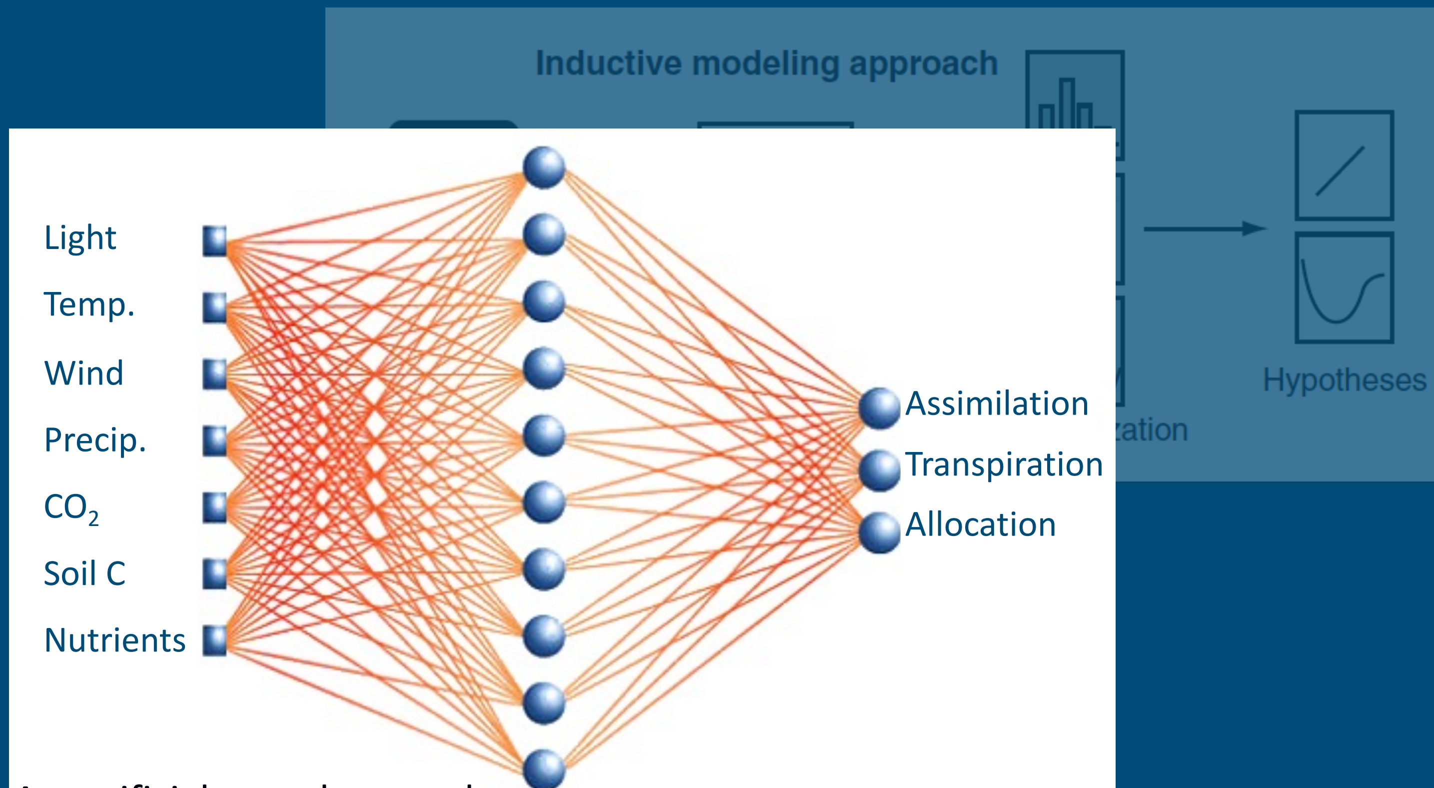
Data mining:



Moffat et al. (2010)

Models

Data mining:



An artificial neural network

Moffat et al. (2010)

Models

- NACP Interim synthesis models (freely available)

  30+ models run at ~40 sites across US and Canada.

- Plumber2 (freely available)

  10s of models run at ~100 flux sites globally.

- MsTMiP (freely available)

  22 models run globally under different scenarios

- TRENDY (freely available)

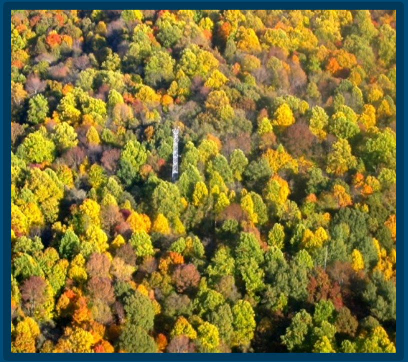
  ~20 DGVMs run globally under different scenarios

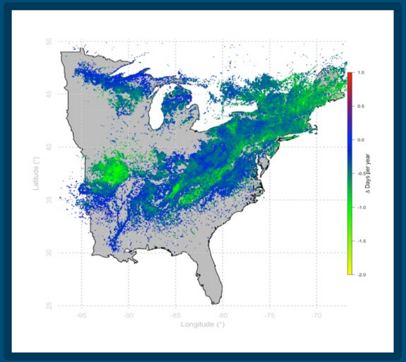
- PEcAn project

Ingredients of a good synthesis study

- A question!
- Formulated theory
- A refined target
- Continual refinement
- Start local
- Modularly scaled
- Ancillary measurements
- Models to confront (last!)

plants -> landscapes -> the globe





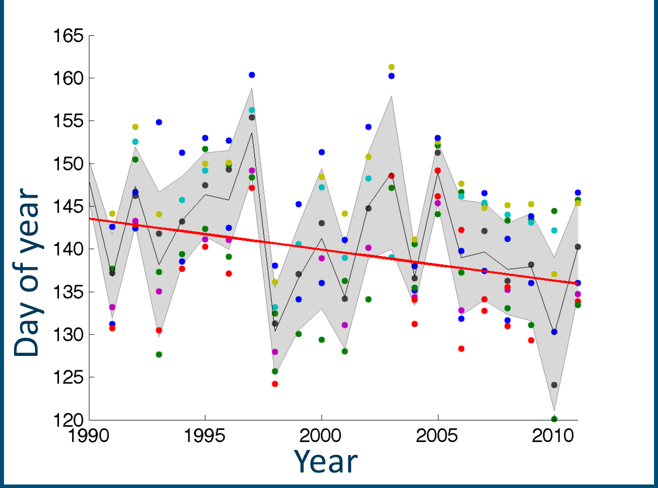
Changes in Phenology

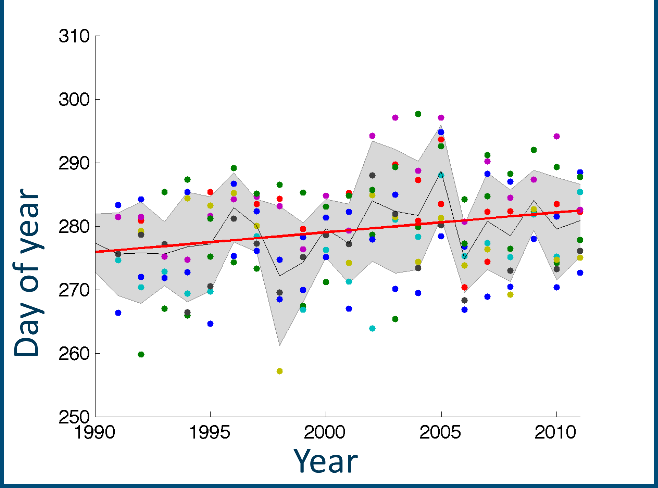
The timing of phenology is changing as the climate warms

1. Spring is getting earlier

2. Autumn is getting later

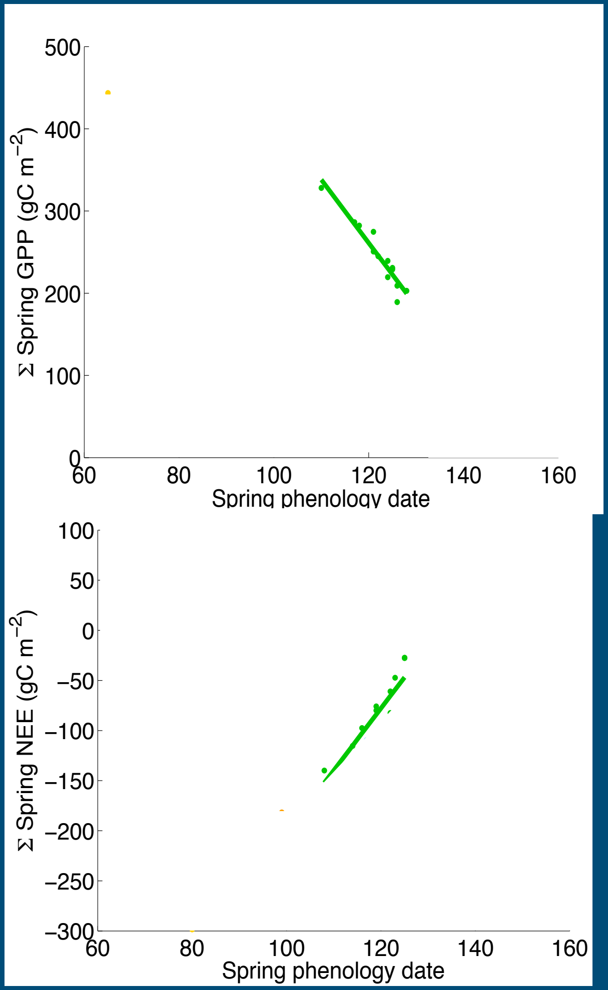
Harvard Forest





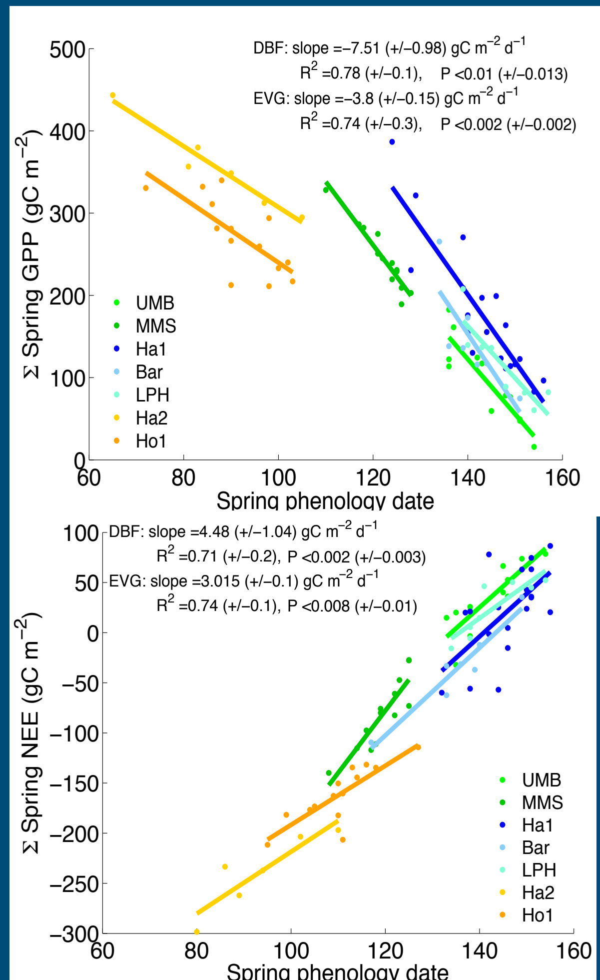
Keenan et al. (2014)

Quantifying the impact on carbon cycling



Keenan et al. (2014)

Quantifying the impact on carbon cycling



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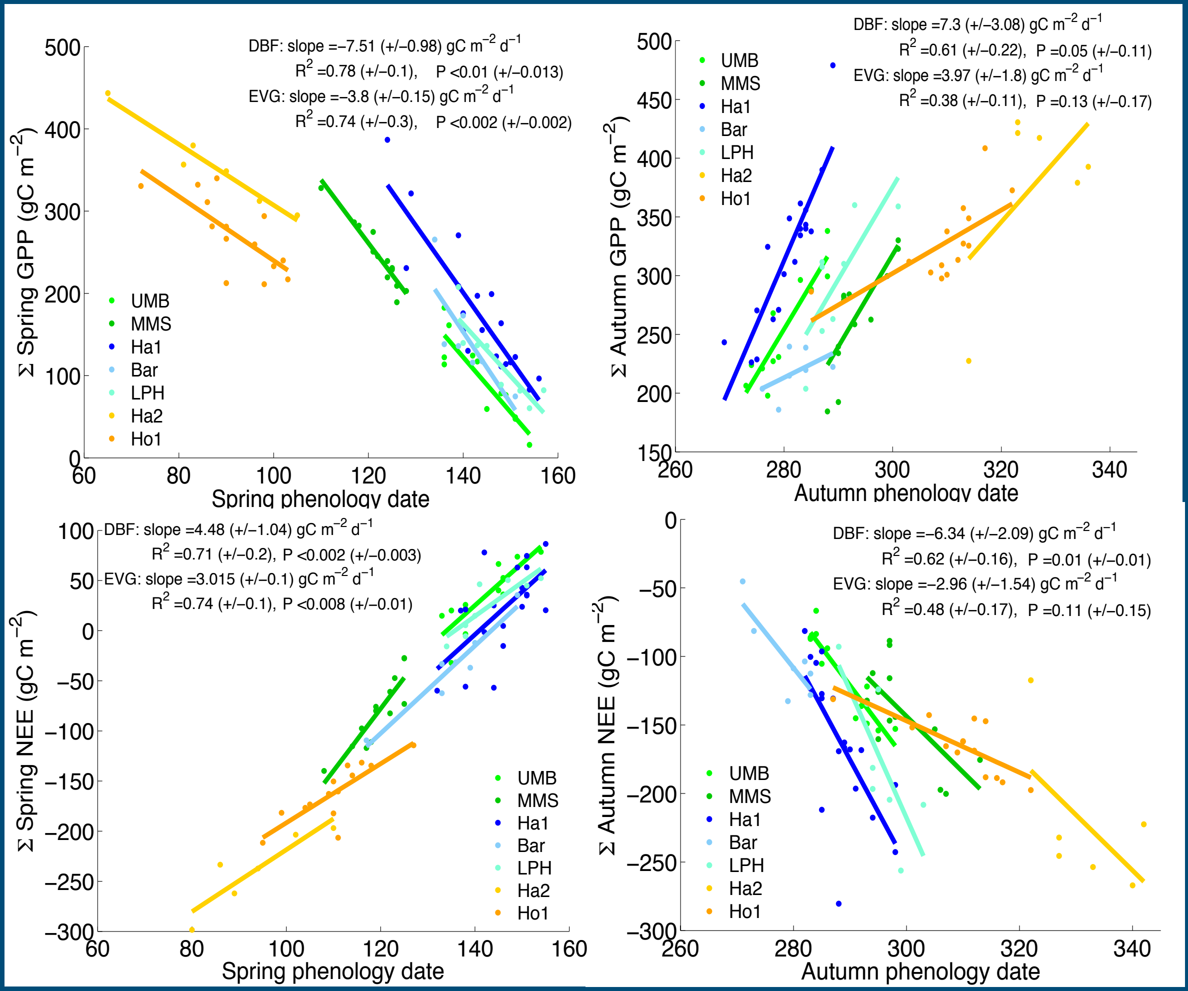

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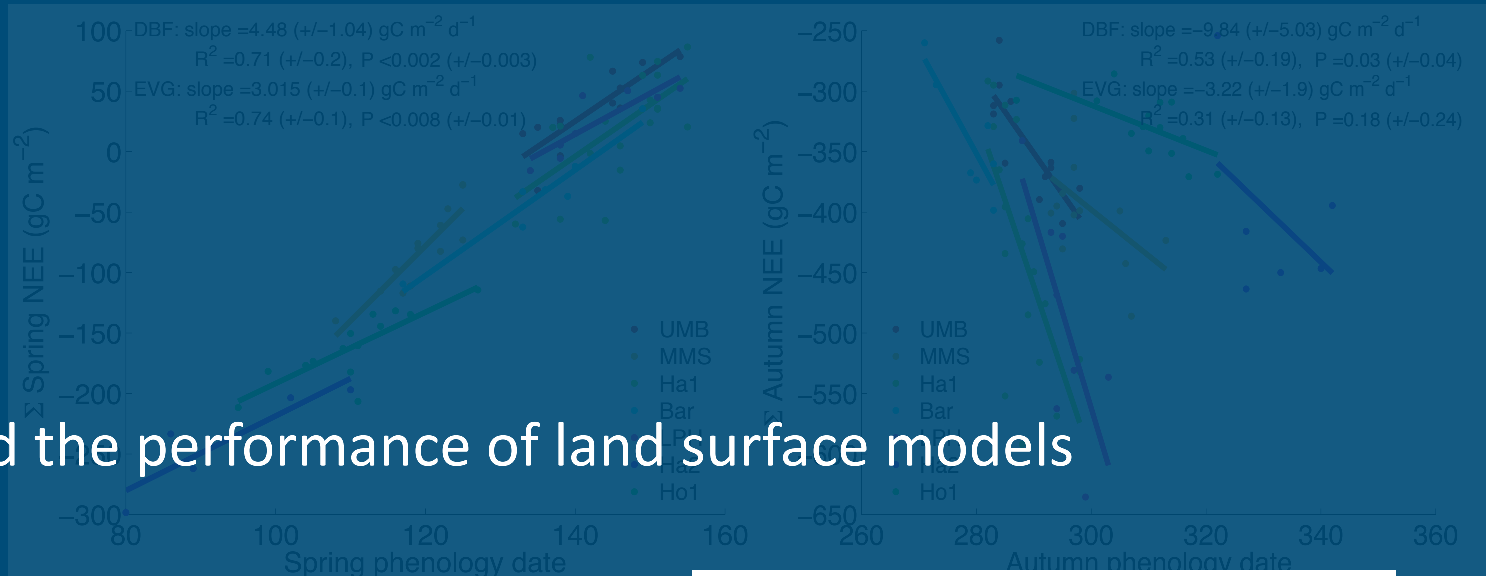
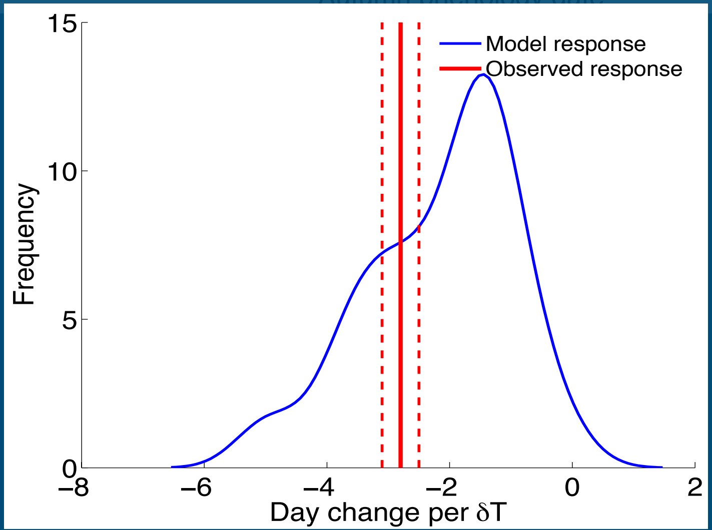
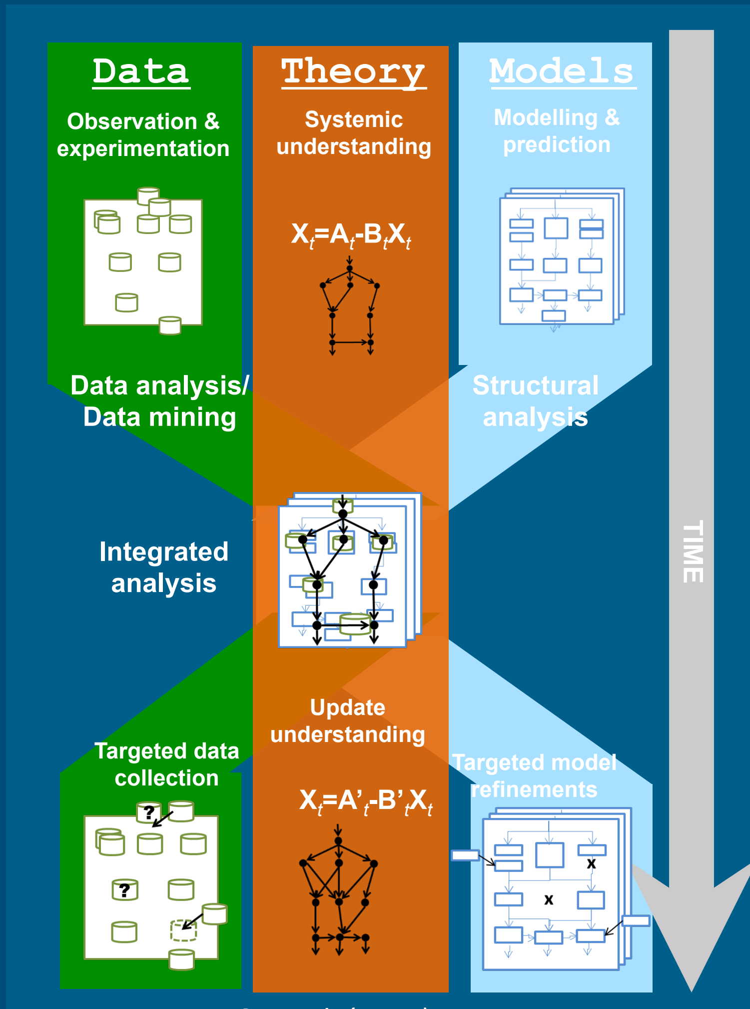


And the performance of land surface models

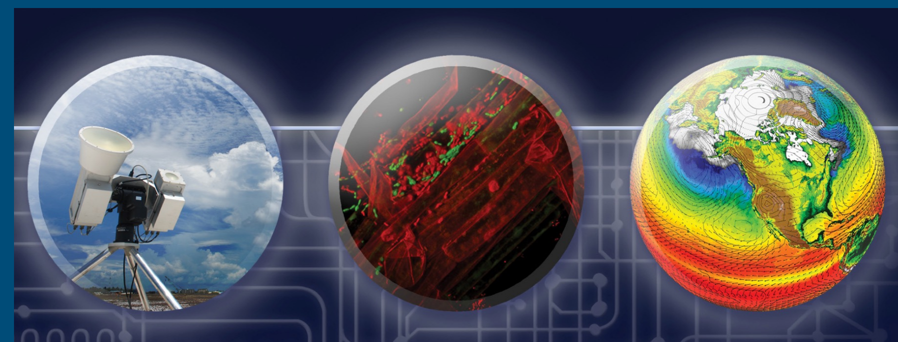


Keenan et al. (2014)

Synthesis



Luo, Keenan, & Smith (2015)



Observations

Theory

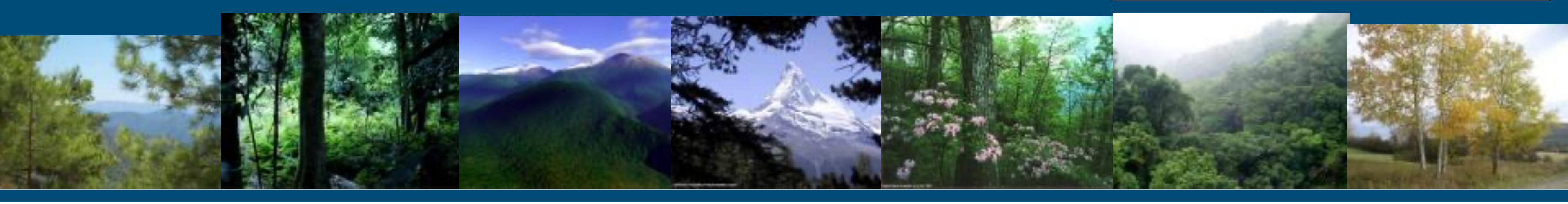
Models

Process understanding

fin

...

Thank you!



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