Workshop Report
Joint NEON-NCAR-Community Workshop: Predicting life in the Earth system – linking the geosciences and ecology
April 09, 2019 - April 11, 2019

Meeting Goals:

This National Science Foundation (NSF)-sponsored joint National Center for Atmospheric Research (NCAR) and National Ecological Observatory Network (NEON) workshop was an opportunity to bring together members of the atmospheric science and ecological communities to advance the capability of Earth system prediction to include terrestrial ecosystems and biological resources. The workshop's overarching theme focused on convergent research between the geosciences and ecology for ecological forecasting and prediction at subseasonal to seasonal, interannual to decadal, and centennial timescales. Specific goals were to:

- Bring together atmospheric scientists and ecologists to leverage the expertise, facilitate further engagement, and promote synergies among those research communities to observe, monitor, and model ecosystems and atmosphere-ecosystem interactions in a changing planet;
- Highlight progress and accomplishments in ecological forecasting and prediction and to identify observational, infrastructure (both data services and community models), and computational challenges that limit current capabilities; and
- Identify new initiatives, collaborations, and science questions.

The deliverables of this workshop were envisioned as manuscripts and working group collaborations related to the following subtopics:

- NEON & NCAR observations—e.g. How might the atmospheric and ecological modelling communities exploit NEON data and NCAR observing facilities? What gaps exist and how might they be mitigated?
- Data infrastructure—e.g. What are best practices and innovations that can be shared to enhance user community accessibility and usability of data products? What are the tools or higher-level data products that can be derived from NCAR and NEON data that can deliver the most benefit to the atmospheric and ecological communities?
- Environmental forecasts, predictions, and predictability—e.g. What ecological states and processes can we predict/forecast with our current models and observational networks, and on what timescales? What do we (as a society) want and need to predict/forecast? What are the gaps?

Workshop Organization:

Workshop organization was a joint NCAR-NEON effort led by Gordon Bonan (NCAR) and Michael SanClements (NEON) and supported by a steering committee comprised of NCAR, NEON, and university scientists.

Steering Committee Chairs

- Gordon Bonan, *NCAR*; Senior Scientist, Climate and Global Dynamics
- Mike SanClements, *NEON*; Lead, Terrestrial Instrument Science

Steering Committee Members

- Rebecca Morss, *NCAR*; Deputy Director Mesoscale and Microscale Meteorology Laboratory; expertise in weather forecast systems and risk communication
- Claire Lunch, *NEON*; expertise in data science, carbon cycle, biosphere-atmosphere feedbacks, and plant- and ecosystem-scale adaptation to novel environments

- Michael Dietze, *Boston University*; expertise in ecological forecasting, with interest in the ways that iterative forecasts can improve and accelerate basic environmental science, while at the same time making that science more directly relevant to society
- Douglas Schuster, *NCAR*; head of Data Engineering and Curation Section (Computational and Information Systems Laboratory); expertise in data curation, documentation, and management
- Britt Stephens, *NCAR*; Senior Scientist, Earth Observing Laboratory; expertise in measurement technologies and the carbon cycle
- Andrew Fox; *University of Arizona* (visiting NCAR); expertise in data assimilation and ecological predictions
- Abigail Swann; *University of Washington*; expertise in atmospheric science and biosphere-atmosphere coupling
- Adrian Rocha; *University of Notre Dame*; expertise in biological and environmental controls on ecosystem exchanges of mass and energy, using tools such as eddy covariance, remote sensing, and ground-based measures of ecosystem physiology to address these topics

Participants **(Full list in Appendix A):**

Participation consisted of staff from NEON, NCAR, and the broader scientific community (e.g. universities) and was carefully balanced to include diversity across gender, career stage, institution type, and scientific discipline. To this end, we included an open application process that was advertised via the NEON website, popular and relevant scientific listserves, and social media. We received sixteen applicants, ultimately accepting seven from this process. Applicants were treated as full meeting participants.

Meeting Structure (Workshop Agenda -Appendix B): *A folder containing all presentations and meeting notes may be found here:* https://drive.google.com/drive/folders/1BiGi3-ofrl7LnNVTlNBy95-dX2KiB6__

This workshop was structured around the three subtopics (i.e. NEON & NCAR Observations, Environmental Forecasts and Predictions, and Data Infrastructures). All participants were asked to provide their primary and secondary subtopic of interest prior to the workshop and we were able to schedule all participants as speakers within their primary choice.

We devoted ~ 3/4 of a day to a subtopic, with each having a kickoff talk (20 minutes), followed by a series of (between 9 and 20) five-minute lightning talks. Kickoff speakers were comprised of participants selected by the Steering Committee and were followed immediately by five-minute lightning talks from other attendees who had selected the same primary subtopic. Following completion of lightning talks participants were split into three breakout groups with each group discussing the theme of the preceding talks. We elected to have all participants discuss each subtopic, to be sure we captured the full range of discussion and allow everyone to provide feedback on each subtopic, regardless of their primary and secondary choice. Breakout groups were assigned a facilitator who was provided a set of discussion points to help keep the conversation productive and moving forward. Following discussions, the larger group reconvened with each breakout group reporting back to all participants as a means to find commonalties and share ideas.

In addition to the time devoted to presentations and discussion around each subtopic, the workshop also included an hour-long topical seminar by Dr. Abigail Swann *(University of Washington)* highlighting research at the intersection of ecology, network science, and ecological forecasting. Also featured, was an invited presentation on the co-evolution of the atmospheric and ecological sciences by historian Dr.

Deborah Cohen *(Yale University)* as a means to introduce a unique perspective prior to breakout groups and discussions.

The workshop concluded with a 1.5-hour recap, group discussion, and synthesis aimed at settling on the key workshop findings and the identification of next steps for pursuit during the year-long inter-workshop working period.

Workshop Outcomes and Next Steps:

Most notable over the course of the three-day workshop was the evident utility in bringing these communities together and the clear agreement between participants that there is substantial overlap between NCAR and NEON in terms of (a) modeling and observing the land surface and its terrestrial ecosystems, (b) observational capabilities for the land-atmosphere system including the planetary boundary layer (PBL), and (c) data services; and that the university community would benefit from these synergies across organizations. Specifically, the workshop was successful in identifying multiple tangible activities (numbered list below) aimed at expanding ecological forecasting at the nexus of NCAR and NEON.

To facilitate progress on the multiple objectives identified, we have elected to form five working groups on a volunteer basis that will lead (with input from all interested participants) individual elements of the collective path forward. These are:

1. **Implementing the Community Land Model (CLM5) on NEON Core Sites and Domains:** Stefan Metzger, Dave Durden, Mike SanClements (NEON); Will Weider, Danica Lombardozzi, Gordon Bonan (NCAR); Quinn Thomas (Virginia Tech)

The link between NCAR models and NEON observations is very strong, is at a mature stage, and is ready for immediate follow-up. There is strong interest in setting up CLM5 to run at NEON core terrestrial sites and across NEON ecoclimatic domains, and a modeling-observation working group is being formed. A pilot project is focused on Harvard Forest as a demonstration of quasi-real time modeling, with subsequent extension to other sites. This project has multiple aims including: (a) identifying the technical challenges and model-data requirements; (b) building a collaborative partnership between modelers and observationalists; and (c) building the infrastructure to enable ecologists to contribute to CLM5 development by using the model at NEON sites, adding new process parameterizations or improving upon existing parameterizations, and testing the model against observations. A particular science focus of the project is error characterization (model structure, parameters, initial conditions, meteorological forcing, observational error). An additional goal is to identify the benefits of NEON data to constrain model uncertainty. A second phase of the project is to extend the modeling across NEON ecoclimatic domains. This modeling at core sites and across ecoclimatic domains links directly to efforts at NCAR on subseasonal-to-seasonal and interannual-to-decadal prediction.

2. **Defining the Idea of the 'Super Site':** Mike SanClements (NEON), Ian Faloona (UC, Davis), and Britt Stephens (NCAR)

NCAR observing capabilities can augment NEON observations, and there is strong interest in the 'super site' concept with an expansive field campaign around a NEON core terrestrial site. This would leverage the NEON network for additional measurements (e.g., atmospheric composition and chemistry; linking surface process and PBL) and fill data gaps. Community-driven proposals would augment NEON observations with NSF Lower Atmosphere Observing Facility (LAOF) resources. Additionally, there is the potential to involve data and infrastructure from the Long-term Ecological Research Network (LTER)

due to the high number of NEON-LTER collocated sites. Science benefits would be to: develop process understanding; study heterogeneity in surface fluxes; assess 3-D transport and impacts on eddy flux calculations; and reconcile bottom-up and top-down flux estimates. Super site research could tie into NCAR-wide activities on the boundary layer and atmospheric chemistry. There is much potential, but the details need to be further developed by a working group.

3. **Common Data Infrastructure Needs:** Leads TBD

The workshop identified common goals related to sharing of data, accessibility of data, and making data useful with the overarching objective being joint NCAR-NEON resources that deliver the most benefit to the science community. Specific details need to be developed further by a working group and we are actively seeking leaders for this working group.

4. **Historical Perspective:** Deborah Coen and Gordon Bonan

Climate science and ecology have shared origins in nineteenth-century geography. However, the sciences subsequently splintered into disciplinary perspectives and today are seen as distinctly different (one physical science, the other life science). Yet, there is much common science (e.g., nature-based solutions to climate change such as carbon sequestration via reforestation).

5. **Workshop Perspective Manuscript:** Sydne Record (Bryn Mawr), Adriana Bailey (NCAR), Gordon Bonan, Mike SanClements, and others TBD

This manuscript will focus on disseminating the overall findings of the workshop with regards to new pathways for enabling successful collaborations between the ecological and earth sciences with a focus on Earth system prediction.

<u>Additional Follow-Up Activities:</u>

1. Follow-up Activities at AGU Fall Meeting 2019

Two activities have been proposed for AGU:

a. A session on ecological forecasting (conveners: Mike Dietze, Quinn Thomas, Gordon Bonan)
b. A town hall (Gordon Bonan, Mike San Clements, Stefan Metzger, David Durden, Danica Lombardozzi, Will Wieder, Kyla Dahlin); *NCAR and NEON: Convergence Research Linking the Atmospheric and Biological Sciences at NSF-Sponsored Facilities*

2. Next workshop planning:

- Approximately one-year post initial workshop (i.e. April 2020)
- Format and objectives TBD

Appendix A: Workshop Participants

* Denotes participant selected via open application process

Name	Career Stage	Institution
Stefan Metzger	Early	NEON
Christine Laney	Mid	NEON
David Durden	Early	NEON
Cove Sturtevant	Mid	NEON
Tristan Goulden	Mid	NEON
Kaelin Cawley	Mid	NEON
Eric Sokol	Early	NEON
Mike SanClements	Mid	NEON
Claire Lunch	Mid	NEON
Dave Barnett	Mid	NEON
Rebecca Morss	Senior	NCAR
Douglas Schuster	Mid	NCAR
Andy Fox	Mid	NCAR
Britt Stephens	Senior	NCAR
Gordon Bonan	Senior	NCAR
Danica Lombardozzi	Early	NCAR
Jackie Shuman	Early	NCAR
Adriana Bailey	Early	NCAR
Greg Stossmeister	Mid	NCAR
Will Wieder	Early	NCAR
Dave Lawrence	Senior	NCAR
Ned Patton	Mid	NCAR
Jeff de La Beaujardiere	Senior	NCAR
Jeff Anderson	Senior	NCAR
Olivia Clifton	Early	NCAR

Name	Career Stage	Institution
Tim Hoar	Senior	NCAR
Steve Oncley	Senior	NCAR
Mike Dietze	Mid	Boston University
Abigail Swann	Early	University of Washington
Adrian Rocha	Mid	Notre Dame
Ines Ibanez*	Mid	University of Michigan
Andy Finley	Mid	Michigan State University
Quinn Thomas*	Early	Virginia Tech
Mary Heskel	Early	Macalester
Lejo Flores	Mid	Boise State University
Kyla Dahlin*	Early	Michigan State University
Danielle Christianson	Mid	DOE/LBNL
Dave Bowling	Mid/Senior	University of Utah
Yiqi Luo	Senior	Northern Arizona
Deborah Coen	Senior	Yale
Jennifer Holm	Early	LBNL
NIkki Lovenduski*	Early	CU Boulder
Sydne Record	Early	Bryn Mawr College
Anne Raiho	Early	Notre Dame
Dana Chadwick*	Early	Stanford
Ian Faloona*	Mid	UC Davis
Annmarie Carlton*	Mid	UC Irvine
Nancy Hess	Senior	PNNL/EMSL
Alexey Shiklomanov	Early	PNNL/EMSL

Appendix B: Workshop Agenda

NCAR/NEON Workshop
Predicting life in the Earth system: linking the geosciences and ecology
9-11 April 2019
National Center for Atmospheric Research
Mesa Lab, 1850 Table Mesa Drive, Boulder, Colorado

Tuesday April 9:

08:00-08:30 Coffee, refreshments (Main Seminar Room)
08:30-09:15 Workshop overview, goals, introductions (Gordon Bonan, NCAR; Mike SanClements, NEON; Gene Kelly, NEON)

Theme 1: Environmental forecasts and predictions
Progress and accomplishments; research and infrastructure needs

09:15-09:35 Kickoff talk-*From sensors to society: A road-map for ecological forecasting based on SmartReservoir.org* (Quinn Thomas, V Tech)
09:35-10:35 Theme 1 lightning talks (5-min talks)

1 - Jeff Anderson (NCAR)-*The Data Assimilation Research Testbed (DART)*
2 - Dave Barnett (NEON)-*The NEON Design and Facilitation of Ecological Forecasting*
3 - Gordon Bonan (NCAR)- *Predicting Life in the Earth system: Linking the Geosciences and Ecology*
4 - Mike Dietze (Boston University)-*Near Term Iterative Forecasting is a Win-Win*
5 - Andy Finley (Michigan State University)-*Challenges and Opportunities in Geosciences and Ecology Research and Training*
6 - Lejo Flores (Boise State University)-*Ecological Forecasting in Mountain Landscapes*
7 - Andy Fox (University of Arizona)-*Ecological Forecasting with Earth System Models*
8 - Jennifer Holm (DOE/LBNL)-*Environmental Forecasts and Predictions*
9 - Ines Ibanez (University of Michigan)-*Organisms Responses to Novel Environments*
10 - Dave Lawrence (NCAR)-*The Community Land Model (CML)*
11 - Danica Lombardozzi (NCAR)-*Linking Leaves to Global Climate*
12 - Nikki Lovenduski (University of Colorado)-*Ocean Biogeochemical Predictions*

10:35-11:00 Break
11:00-12:00 *Quantifying the Role that Terrestrial Ecosystems Play in Earth's Climate* (Abby Swann, University of Washington)
12:00-13:00 Lunch
13:00-13:40 Theme 1 lightning talks, continued (5-min talks)

13 - Yiqi Luo (Northern Arizona University)-*How to Realize Ecological Forecasting*
14 - Rebecca Morss (NCAR)-*Weather Prediction, Predictability, and Risk Communication Research*
15 - Ned Patton (NCAR)-*Using Turbulence-Resolving Simulation to Understand Biosphere-Atmosphere Exchange*
16 - Anne Raiho (Notre Dame)-*PALEON*
17 - Alexey Shiklomanov (DOE/PNNL)
18 - Jackie Shuman (NCAR)-*The Functionally Assembled Terrestrial Ecosystem Simulator (FATES)*

19 - Eric Sokol (NEON)-*Using Metacommunity Theory and Long-Term Data to Forecast Shifts in Biodiversity*
20 - Will Wieder (NCAR)-*Synthesis, Scaling, and Network Science to Bridge Disciplines and Interests*

13:40-14:10 Historical perspective-*Reimagining the History of Climate Science* (Deborah Coen, Yale)
14:10-15:40 Theme 1 breakout groups (1.5 hours); 3 concurrent subgroups
Group 1: Main Seminar Room
Group 2: Damon Room
Group 3: Fleischmann Building
15:40-16:10 Break; working groups report preparation
16:10-17:00 Working group reports and discussion (Main Seminar Room)
(1-2 slides from each breakout subgroup followed by discussion and planning next steps)
17:00 Adjourn for the day

Wednesday April 10:
08:30-09:00 Coffee, refreshments (Fleischmann Building)
09:00-09:30 Recap of day 1; overview of day 2; questions/discussions

Theme 2: Observations
Observations for process research; observations in support of forecasting

09:30-09:50 Kickoff talk-*Observations at the Intersection of Atmospheric and Ecological Science* (Britt Stephens, NCAR; with NEON input)
09:50-10:30 Theme 2 lightning talks (5-min talks)

1 - Adriana Bailey (NCAR)-*NEON and NCAR = Water Isotopes!*
2 - Dave Bowling (University of Utah)-*Detecting Seasonality of Photosynthesis of Evergreen Forests with Solar-Induced Fluorescence*
3 - Annmarie Carlton (University of California, Irvine)-*Forecasting Atmospheric Composition*
4 - Dana Chadwick (Stanford)-*Utilizing Airborne Remote Imaging Spectroscopy Data for Critical Zone Support*
5 - Olivia Clifton (NCAR)-*Why do we Need Long-Term Measurements of Ozone Dry Deposition*
6 - Kyla Dahlin (Michigan State University)-*Does Understanding Ecological Diversity Improve Forecasts of the Earth system?*
7 - David Durden (NEON)-*The NEON Terrestrial Instrument System (TIS)*
8 - Ian Faloona (University of California, Davis)

10:30-11:00 Break
11:00-11:30 Theme 2 lightning talks, continued (5-min talks)

9 - Tristan Goulden (NEON)-*Introduction to NEON's Airborne Observation Platform*
10 - Mary Heskel (Macalester College)-*Leaf Level Fluxes in an Ecosystem Context*
11 - Steve Oncley (NCAR)-*EOL Tower Flux Observations*
12 - Sydne Record (Bryn Mawr College)-*The importance of Ecological Memory to Forecasting: Insights from LTER-NEON Synergies*
13 - Adrian Rocha (Notre Dame)-*Combining Models and Data to Gain Further Understanding of Arctic Ecosystem Function*
14 - Mike SanClements (NEON)-*NEON's Terrestrial Observations and Assignable Assets*

11:30-12:00 Discussion of potential workshop products
(e.g., science papers, facility requests, proposals, other examples of collaborations)
12:00-13:00 Lunch
13:00-14:30 Theme 2 breakout groups (1.5 hours); 3 concurrent subgroups
Group 1: Main Seminar Room
Group 2: Damon Room
Group 3: Fleischmann Building
14:30-15:00 Break; working groups report preparation
15:00-16:00 Working group reports and discussion (Main Seminar Room)
(1-2 slides from each breakout subgroup followed by discussion and planning next steps)
16:00 -17:00 Information exchange; networking; collaborative discussions; Mesa trail hike
17:00 Adjourn for the day

Thursday April 11:

08:30-09:00 Coffee, refreshments (Main Seminar Room)

Theme 3: Data infrastructure

Data infrastructure to support the modeling and observations

09:00-09:20 Kickoff talk-*Empowering Research Through Data Infrastructure* (Christine Laney, NEON)
09:20-10:05 Theme 3 lightning talks (5-min talks)

1 - Kaelin Cawley (NEON)-*NEON Aquatic Sampling: Linkages to Terrestrial and Atmospheric Ecosystems*
2 - Danielle Christianson (DOE/LBNL)-*Data Management Tools for Earth Science*
3 - Tim Hoar (NCAR)-*Data Assimilation and Data Infrastructure*
4 - Jeff de La Beaujardiere (NCAR)-*Science at Scale*
5 - Claire Lunch (NEON)-*NEON Observational Data Pipeline*
6 - Stefan Metzger (NEON)-*Towards Integrative Scientific Discovery*
7 - Douglas Schuster (NCAR)
8 - Greg Stossmeister (NCAR)
9 - Cove Sturtevant (NEON)-*Data Infrastructure for Automated, Modular, Provenance-Focused Data Processing*

10:05-10:30 Break
10:30-12:00 Theme 3 breakout groups (1.5 hours); 3 concurrent subgroups
Group 1: Damon Room
Group 2: Damon Room (outer seating area)
Group 3: Fleischmann Building
12:00-13:00 Lunch; working groups report preparation
13:00-13:45 Working group reports and discussion (Main Seminar Room)
(1-2 slides from each breakout subgroup followed by discussion and planning next steps)
13:45-14:45 Synthesizing discussion: Next steps, workshop products, planning for follow-up workshop
14:45 Adjourn