Summary Report: Spatial and Temporal Scaling in Continental-Scale Ecology Workshop, 11-12 June 2012, Boulder, CO USA

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ABSTRACT

The National Ecological Observatory Network (NEON) sponsored a Workshop on Spatial and Temporal Scaling in Ecology that took place in Boulder, CO on June 11-12, 2012. The workshop addressed the influence of scale on the interpretation of ecological variation, particularly in the context of continental-scale terrestrial ecology. The workshop took place at the Millennium Harvest House Hotel in Boulder, Colorado. Approximately 50 researchers participated. Invited oral presentations will inform participants of current and emerging developments in addressing spatial and temporal scaling issues in ecological sciences. Topical breakout sessions were also held to address critical questions in scaling from ground-based field measurements to airborne and satellite remote sensing. The goal was to obtain inputs from the research community to provide guidance in developing the NEON scaling strategy across its measurement inventory. The workshop focused on three primary questions that extended over a range of scales: combining airborne and satellite remote sensing data to initialize, constrain, and test vegetation and biogeochemical models; how to facilitate better ground-based field sampling strategies and their integration with instrumental measurements using high-resolution airborne data; and, how to characterize source area topographic and vegetation heterogeneity with airborne data as an aid to explain observed variability from flux towers, and these issues were addressed in topical breakout sessions.

Keywords: Spatial scaling, hierarchical modeling, ecology

1. INTRODUCTION

Understanding the functional response of ecosystems across multiple spatial and temporal scales is one of the fundamental challenges in ecology. A workshop focused on scaling ecological data from local and regional scales to the continental scale was hosted by the National Ecological Observatory Network (NEON) on 11-12 June 2012 in Boulder, Colorado and attended by over 50 researchers. The workshop addressed key issues associated with the influence of scale on the interpretation of ecological variation, particularly in the context of continental-scale terrestrial ecology. These questions are particularly relevant to NEON, the first ecological observation platform designed to assess the natural and human causes of and the biological consequences of environmental change at large scales.

NEON is focused on questions that relate to grand challenges in environmental science, are relevant to large regions, and cannot be addressed with traditional ecological approaches. Its goal is to provide the data and data methodologies needed to improve our understanding of and ability to forecast the impacts of climate change, land-use change, and invasive species on ecosystem structure and function – specifically including biodiversity, biochemistry, ecohydrology, and infectious disease. NEON will collect consistent, calibrated data from 60 sites in the continental US, Alaska, Hawaii, and Puerto Rico over 30 years. Because NEON's native and acquired data span satellite and airborne remote sensing, tower, aquatic and soil-based instrumentation, field observations and collections, and geographic/demographic data, a number of scaling strategies will be employed. Of particular interest to this workshop was the role remote sensing plays as a critical link between scales and how the capabilities of the new NEON airborne platform can be exploited to transform plot measurements of vegetation structure to "scaled observations" in land surface models.

The workshop focused on three primary questions that extended over a range of scales: combining airborne and satellite remote sensing data to initialize, constrain, and test vegetation and biogeochemical models; how to facilitate better ground-based field sampling strategies and their integration with instrumental measurements using high-resolution airborne data; and, how to characterize source area topographic and vegetation heterogeneity with airborne data as an aid to explain observed variability from flux towers, and these issues were addressed in topical breakout sessions.

In upcoming years, more provisional data will become available as NEON sites and observing systems come online, providing researchers with access to multi-scale data sets to begin developing and assessing models at large scales. This includes airborne LiDAR and spectroscopic data at intermediate scales from the NEON Airborne Platform suitable for bridging between the scale of individual trees and shrubs to stand scales and to the scale of satellite based remote sensing. Developing the tools and understanding to utilize the broad range of data that will be available from the NEON observatory and other observing systems several years down the road as NEON full operational status will be the focus of future workshops. The presentations from this meeting are available at www.neoninc.org.

2. WORKSHOP SUMMARY

The workshop was set up to have invited presentations in the mornings and topical breakout session on the afternoon. The emphasis of the workshop was on scaling between satellite-airborne, satellite-tower, airborne-tower, and satellite-airborne-tower.

Workshop Foci:

1. Approaches to combine airborne and satellite remote sensing data to initialize, constrain and test vegetation and biogeochemical models;
2. Facilitating better ground-based field sampling strategies and their integration with instrumental measurements using high-resolution airborne data;
3. Characterizing source area topographic and vegetation heterogeneity with airborne data as an aid to explaining observed variability in tower fluxes.

Understanding the functioning of ecosystems and how they will respond across large-scales to changes in climate, land-use and invasive species requires careful measurements of both drivers and responses over multiple spatial and temporal scales. NEON, funded by the National Science Foundation, is the first continental-scale ecological observation platform designed to assess both the human causes and the biological consequences of environmental change at large scales. NEON science focuses explicitly on questions that relate to grand challenges in environmental science, are relevant to large regions, and cannot be addressed with traditional ecological approaches. Its goal is to provide the data and data methodologies needed to improve our understanding of and ability to forecast the impacts of climate change, land use change, and invasive species on ecosystem structure and function – specifically including biodiversity, biogeochemistry, ecohydrology and infectious disease. NEON will collect consistent, calibrated data from 60 sites in the continental US, Alaska, Hawaii, and Puerto Rico over 30 years. Because NEON's native and acquired data span satellite and airborne remote sensing, tower, aquatic, and soil-based instrumentation, field observations and collections, and geographic/demographic data, a number of scaling strategies will be employed. Of particular interest to this workshop is the role remote sensing data plays as a critical link among scales and how the capabilities of the new NEON airborne observation platform can be exploited to transform plot measurements of vegetation structure to "scaled observations" at 1-km scale land model grids.

The Steering Committee for the Workshop was:
Steve Berukoff (NEON)
Robert Green (JPL)
Thomas Kampe (NEON)
Elizabeth Middleton (NASA GSFC)
Paul Moorcroft (Harvard University)
David Moore (University of Arizona)
Paul Stoy (Montana State University)
Dean Urban (Duke University)
Diane Wickland (NASA Terrestrial Ecology Program)

2.1 Workshop Summary

Monday, 11 June 2012

8:00 to 8:30 am Registration – 1st Floor Millennium Room

8:30 to 9:00 am Welcome/Meeting Overview

Session I: Ecological Observations & Modeling – 1st Floor Millennium Room

9:00 to 9:20 am Topical Questions in Scaling Ecological Data (Paul Stoy, Montana State University)

9:20 to 9:40 am National Ecological Observatory Network Overview (D. Schimel, NEON)

9:40 to 10:00 am The NEON Airborne Observatory (T. Kampe, NEON)

10:00 to 10:20 am NEON Data Assimilation and Ecological Modeling Framework (A. Fox, NEON)

10:20 to 10:40 am Coffee Break

10:40 to 11:00 am Predicting Ecosystem Dynamics at Regional Scales (Paul Moorcroft, Harvard University)

11:00 to 11:20 am The High Resolution Remote Sensing Conundrum (Jarlath O'Neil-Dunne, University of Vermont)

11:20 to 11:40 am Data Assimilation with Non-Separable Space-Time Process Covariance

(Paul Duffy, Neptune Consulting)*

Dr. P. Duffy was unable to attend as a result of complications from the High Park Fire. Stephan Metzger gave the talk "Environmental response functions - relating eddy-covariance flux measurements to ecosystem drivers," in his place at the 11:20 am timeslot on Monday, June 11, 2013.

11:40 to 12:00 am Assimilation of remote sensing and in-situ measurements into the USGS General Ensemble Biogeochemical Modeling System (GEMS) – Shuguang Liu, USGS

12:00 – 1:00 pm Lunch

Session II: Breakout Sessions (1:00 – 4:00 PM) – Rooms will be assigned after am break

Topic 1.1: How do you link remote sensing and flux measurements across scales?

Topic 1.2: How do you observe vegetation across scales?

Topic 1.3: How do you incorporate modeling in analysis across scales?

5:00 PM Social – Garden Patio

Tuesday 12 June 2012

Session III: Linking Topographic and Vegetation Heterogeneity with Airborne Data – 1st Floor Millennium room

9:00 to 9:20 am Scaling chemical and biophysical retrievals from imaging spectroscopy data through space and time (Philip A. Townsend and Aditya Singh, University of Wisconsin – Madison, Department of Forest and Wildlife Ecology)

9:20 to 9:40 am Operational sampling and scaling approach using field measurements and high-resolution remote sensing for mapping sagebrush habitat (Collin Homer and Cam Aldridge, USGS)

9:40 to 10:00 am The NEON terrestrial sampling design: local data for continental understanding (Dave Barnett, NEON)

10:00 to 10:20 am Linking Flux Tower and In Situ Measurements to Remote Sensing Biophysical Properties (Carol Mladinisch and Dean Anderson, USGS)

10:20 to 10:40 am Linking Hyperion remote sensing data to flux measurements at numerous sites (Fred Huemmrich, NASA GSFC)

10:40 to 11:00 am Coffee Break

Session IV: Bridging the Scales from Airborne to Satellite

11:00 to 11:20 am Scaling from the Field to the Satellite: Relating Growth Form and Physiological Traits to Understanding How Ecosystems Function (Susan Ustin, Department of Land, Air, and Water Resources, Center for Spatial Technologies and Remote Sensing (CSTARS) University of California, Davis)

11:20 to 11:40 am Scaling from AVIRIS to HyspIRI resolutions in urban ecosystems (Dar Roberts, UCSB)

11:40 to 12:00 am Scaling Biological Data From Core Sites to the Continent (Thomas Stohlgren, USGS)

12:00 to 12:20 am Spatial and temporal scaling in addressing land use and land cover related research (Willem van Leeuwen, University of Arizona)

12:20 – 1:20 pm Lunch

Session V: Breakout Sessions (1:20 – 3:45 PM)

Topic 2.1: How do you link remote sensing and flux measurements across scales?

Topic 2.2: How do you observe vegetation across scales?

Topic 2.3: How do you incorporate modeling in analysis across scales?

3:45 – 4:00 pm Coffee Break – 1st Floor Millennium Room

4:00 – 5:00 pm Breakout Session Report out – 1st Floor Millennium Room

Brief synopses of the morning talks are provided in the following section.

2.2 Presentation Summaries

Paul C. Stoy; Montana State University

Topical Questions in Scaling Ecological Data

I will present a brief overview of the concept of scale in Ecology by comparing and contrasting ecological theories of scale with the data-driven scaling approach enabled by NEON's data products. A brief discussion of work by Jarvis, Levin, Allen, Brown, Harte and others will be placed in the context of the so-called 'big data' eScientific philosophy of Gray and others. The goal of the discussion is to introduce data scientists to the ways in which Ecologists have historically thought about scaling for the purposes of bridging the gap between theory and observation, and to add value to NEON's data streams. A major ulterior motive of the presentation is to remind us to not forget about those who had to think harder about scale in an era when data products were not as readily available.

David Schimel; NEON Inc.

National Ecological Observatory Network Overview

[no abstract provided]

Thomas Kampe; NEON Inc.

The Role of the Airborne Observatory Platform in NEON's Scaling Strategy

The National Ecological Observatory Network (NEON) is a continental-scale platform for understanding and forecasting the impacts of climate change, land use change, and invasive species on ecology. To achieve this goal, NEON is building sixty sites in the twenty NEON domains distributed across the continental United States, Hawaii, Alaska, and Puerto Rico. NEON uses a number of different observation systems ranging from terrestrial biological measurements made at the scale of individual organism, to terrestrial instrument measurements employing instrument towers that are fixed in space but provide high temporal sampling of key micrometeorological, bioclimatic, and carbon and energy cycle measurements, to airborne measurements, and to the scale of satellite remote sensing. NEON will provide integrated, traceable, interoperable information (satellite data, national data sets) that ecological modelers and forecasters can use in conjunction with NEON and other data sets, to extend their models to the continental scale. Since NEON aims to resolve small process-level signals, long-term multi-decadal observations are necessary. To meet this need, NEON will operate for 30 years. NEON is currently under construction and will begin full operations in approximately five years.

Airborne remote sensing plays a critical role in the NEON scaling strategy by making annual measurements at the scale of individual organisms (shrubs and larger plants) over hundreds of square kilometers around each of the NEON sites. Measurements from the NEON Airborne Observation Platform (AOP), are designed to bridge the scales from organisms (i.e., trees or shrubs) as captured by plot sampling, to stand scale observations as measured from flux towers, to the scale of satellite based remote sensing. The remote sensing instrumentation aboard each AOP platform include the NEON Imaging Spectrometer (NIS), a next-generation high-fidelity visible-to-shortwave infrared (VSWIR) imaging spectrometer, to quantify plant species identity and function; a small-footprint waveform LIDAR to measure vegetation structure and heterogeneity; and a high-resolution digital camera to capture co-registered features of representative of land use including roads, impervious surfaces, and built structures. NEON will operate three AOP payloads, two largely dedicated to surveys of NEON sites on an annual basis and the third to provide the capacity to respond to targets of opportunity and support investigator requests for specific projects.

Andrew Fox; NEON Inc.

NEON Data Assimilation and Ecological Modeling Framework

We are utilizing data from the continental-scale NEON platform and other monitoring networks (FLUXNET, ICOS, LTER etc.), in conjunction with ever-increasing computing power, land surface model sophistication and new statistical and optimization methodologies to generate high-level data products, such as continental-scale, gridded maps of carbon and energy fluxes.

One method we are using to integrate many observational data streams into high-level data products is to use model-data fusion. In this approach a process model is used to provide an analytical framework for data interpretation, synthesis, interpolation and extrapolation – scaling across space and time. We have developed a data assimilation system coupling the Community Land Model (CLM) with the Data Assimilation Research Testbed (DART), an advanced facility for ensemble data assimilation (DA). CLM simulates terrestrial ecosystem processes including the cycling of energy, water, carbon and nitrogen and so is amenable to assimilating a wide range of observation types, including tower fluxes, leaf area, biomass and canopy chemistry, derived from ground-based, airborne and satellite platforms.

We have investigated if we can use CLM-DART with synthetic and real data (and their associated uncertainties) about the past and current states of an ecosystem to improve our projections of carbon and energy fluxes. We discuss some of the challenges that these experiments have highlighted and other issues we will have to address if we are to fully utilize data assimilation with complex, land surface models such as CLM.

Paul Moorcroft; Harvard University

Predicting Ecosystem Dynamics at Regional Scales

Terrestrial biosphere models are important tools for diagnosing both the current state of the terrestrial carbon cycle and forecasting terrestrial ecosystem responses to global change. In this talk I examine how different forms of ecosystem measurements can be successfully used to develop constrained terrestrial biosphere model formulations that can be used for regional and continental scale ecosystem prediction and forecasting.

Darlath O’Neil-Dunn; University of Vermont

The High-Resolution Remote Sensing Conundrum

For years we thought that the solution to the limitations of our remotely sensed data was higher spatial resolution. While there is no arguing that high resolution data yields more detail, there are a host of challenges related to processing and extracting meaningful information from these data sets. As a single organism (e.g. a tree) may be made up of multiple pixels, the individual pixel becomes a less meaningful unit of analysis. This has implications for not only how we derive information from high resolution remotely sensed data, but also for how we integrate ground-based measurements.

Paul Duffy; Neptune Consulting

Data Assimilation with Non-Separable Space-Time Process Covariance

NEON data products utilize multiple platforms with varying spatial resolution to provide unprecedented spatial and temporal coverage of ecological response variables across the continent. These data will allow scientists to explore spatial and temporal covariance structures that were previously difficult to characterize due to a lack of data. In addition, NEON data products will provide ecologists the data necessary to begin to characterize process covariance structures that are non-separable with respect to space and time, an issue that has previously received little attention in ecology. We utilize a data assimilation framework with both simulated and observed data to assess the impact of assimilating data from multiple platforms on trend detection. We also explore simple applications of forecasting using posterior predictive distributions in the presence of non-separable space-time process covariance.

Shuguang Liu; USGU

Assimilation of Remote Sensing and In-Situ Measurements into the

USGS General Ensemble Biogeochemical Modeling System (GEMS)

[no abstract provided]

Philip A. Townsend & Aditya Singh; University of Wisconsin

Scaling Chemical and Biophysical Retrievals from Imaging Spectroscopy Data through Space and Time

Recent and forthcoming developments in imaging spectroscopy will soon provide unprecedented opportunities for assessing ecosystem function. Research has shown that spectroscopic methods have the potential to characterize key plant functional traits such as foliar nitrogen content, specific leaf area (SLA), foliar lignin and cellulose and N15 concentrations across landscapes. Moreover, it has been shown that variables that can be derived from imaging spectroscopy - foliar nitrogen and lignin/cellulose concentrations - characterize leaf lifespan, influence soil C:N ratios and in combination with disturbance events, may be strong controllers of nutrient cycling in natural landscapes.

New methods and improved signal-to-noise of imaging spectroscopy instruments (or hyperspectral imaging) have enabled the assessment of variations in vegetation functional traits across space and time. However, standardized protocols for pre-processing airborne spectroscopic imagery do not exist, in contrast to spectroscopic methods for chemometric analysis. Given the large volume of data forthcoming from the NEON AOP and future spaceborne missions such as HyspIRI and ENMAP, it is essential that assessments be performed to identify the consequences of pre-processing on consistent retrieval of forest traits across images and through time.

Information retrieval from airborne spectroscopic imagery is especially difficult due to the multitude of artifacts in hyperspectral imagery. Whereas atmospheric effects can be partly corrected using established radiative transfer models, other concerns for biophysical retrievals include: differential illumination effects due to complex terrain and occlusions due to clouds and cloud as well as along and across-track brightness gradients due to solar and sensor geometry. Ultimately these issues will affect our ability to scale relationships detected using airborne data to larger regions using satellite measurements. In combination, these effects will manifest themselves in the quality of spectra retrieved from radiative transfer models and thus effect retrievals of key structural and chemical traits of vegetation canopies.

Here, we expand upon the methods we have developed using a large database of spectroscopic imagery (~150 images) collected over three years (2008-2011) across different ecosystems in the US. Sites are located in the Rocky Mountains, the Appalachians and the Upper Midwest, and our objective was to develop empirical algorithms for the retrieval of forest phytochemical and functional traits across sites and years. As noted by Martin et al. (2008), there exists considerable potential to develop cross-site calibrations of imaging spectroscopy data for canopy chemistry, which our research confirms. However, variability in retrieved spectra – even within a single day – can provide challenges to application of generalized algorithms. We compare predictions of canopy chemical traits retrieved using artifact and atmospherically corrected (ACORN, TAFKAA, ATCOR) and uncorrected imagery to suggest a synthesis of the relative accuracies and biases associated with each technique.

Collin Homer & Cameron Aldridge; USGS/EROS

Operational Sampling, Scaling and Monitoring of Sagebrush Habitat, Synergizing Field Measurements with Multiple Scales of Remote Sensing

Sagebrush ecosystems occupy a large portion of the western United States and provide unique ecosystem services. However, these arid and semiarid ecosystems are vulnerable to external disturbances, and a good understanding of the spatial distribution of change rates and patterns is vital. In Wyoming, new remote sensing continuous field products over the entire state were developed using scaled up fractional estimates of habitat components synergizing field plots, QuickBird 2.4m imagery, and Landsat 30m imagery with regression tree models. This approach supports characterization and change monitoring of five cover components (including bare ground, herbaceous, litter, shrub and sagebrush cover) across multiple temporal and spatial scales. For monitoring at local scales, 120 field transects have been annually measured at plot, QuickBird and Landsat scales to gain insights on how well various changing ground conditions can be replicated at different remote sensing scales. Results indicate that higher resolution QuickBird imagery does a good job of replicating the amount and direction of change measured from field plots, with moderate resolution Landsat also performing acceptably well if the application is for larger regional scales. For monitoring at regional scales, component change has been quantified historically for 18 years at the Landsat scale to determine the utility of this approach for quantifying component change over longer time. Observed component change is categorized by types of driving forces such as climate, fire, and human disturbance. Suspected climate induced change areas show reasonable component increase or decrease according to historical precipitation patterns, and have been validated by correlation to PRISM precipitation data.

Dave Barnett; NEON Inc.

The NEON Terrestrial Sampling Design: Local Data for Continental Understanding

The observatory approach is new to organismal ecology. The task of untangling the causes and consequences environmental change across continental scales and over decades required the articulation of principles and constraints capable of guiding local, site-scale measurements operating in the context of a continental-scale observatory network. Drawing from NEON goals, overarching science questions and requirements, and the continental design, NEON developed a statistically robust study design framework. An initial randomization will allow design-based inference and addresses the potential for sampling bias. The design is further structured to capture local heterogeneity, and to facilitate scaling patterns to regional and continental scales. Data and simulation present opportunities to iteratively optimize the design. Design assumptions will be confronted with biological data early in NEON Operations, the Airborne Observation Platform will provide a refined understanding of landscape variability, and sample plot allocation may need to respond to landscape change through time.

Carol Mladinisch & Dean Anderson; USGS

Linking Flux Tower and In-Situ Measurements to Remote Sensing Biophysical Properties

Both the exchanges of greenhouse gases and the available water that sustains forests, rangeland, and urban areas are impacted by climate and land use change. Coincident with these changes, population trends indicate that an increasing percentage of people will be living in cities. In the US, more than half of the population resides in urban areas where there occurs a disproportionate 78% of carbon emissions and 60% of residential water use. Climate and land use changes occurring adjacent to urban areas in the western U.S., such as Denver, result in substantial changes in the coupled cycles of carbon, nitrogen, and water. In turn, these changes impact the fate of greenhouse gases, evapotranspiration (ET), and water availability in urban and adjacent ecosystems. Given predicted changes in climate and land use change, it is increasingly important to understand how regional climate, water availability, and biogeochemical cycles will affect grassland and urban ecosystems. While there are many models that represent carbon cycle and ecosystem processes, there is a gap between these large-scale model outputs and small-scale measurements. Incorporating a "bottom-up" approach we have linked small-scale eddy covariance flux and in situ measurements to key biophysical properties derived from remote sensing data. The biophysical properties of interest were leaf area index (LAI), aboveground biomass (AGB), and land cover (LC) derived from very high resolution remotely sensed data. Our sampling strategy was designed to characterize the vegetation heterogeneity in our grassland and urban study areas. The first phase of our work analyzed the correlation between in situ LAI measurements and LAI-derived from our high resolution airborne HSI and satellite MSI remotely sensed data. We are currently working deriving AGB and LC biophysical properties, as well as determine if we can improve our LAI results, by fusing our optical imagery with lidar data. This paper discusses the phase 1 results of the derived biophysical properties to improve the reliability of large-scale measurement data utilized for climate change studies and modeling within the semi-arid grassland and urban ecosystems.

Fred Huemmrich; NASA GSFC

Linking Ground, Aircraft, and Satellite Remote Sensing Data To Flux Measurements at Numerous Sites

Understanding the dynamics of the global carbon cycle requires an accurate description of the spatial and temporal distribution of photosynthetic CO2 uptake by terrestrial vegetation. Ecosystem light use efficiency (LUE), the ratio of gross ecosystem production (GEP) to photosynthetically active radiation absorbed by plants, is dynamic even over short time periods as it is affected by environmental factors such as temperature, humidity, soil moisture, and nutrient availability.

Changes in LUE are related to plant stress responses that also affect vegetation spectral reflectance characteristics, providing a link between remote sensing and carbon fluxes. In a study in a Maryland cornfield diurnal changes in spectral reflectance were collected throughout two growing seasons along with carbon fluxes measured using eddy covariance techniques. Models driven by the narrow-band Photosynthetic Reflectance Index (PRI) provided good descriptions of GEP, both throughout individual days as well as through the growing season. This algorithm was applied to aircraft imaging spectrometer data to scale GEP estimates up to entire fields. Further, optical approaches have been extended to a global study of LUE by combining data from 33 different flux tower sites from the LaThuile Fluxnet synthesis data set with Hyperion hyperspectral imagery. Multiple approaches using different combinations of reflectance bands have provided good estimates of LUE from Hyperion.

Susan Ustin; University of California, Davis

Scaling from the Field to the Satellite: Relating Growth Form and Physiological Traits to Understanding How Ecosystems Function

The patterns of species distributions determine the functioning of ecosystems across a wide range of time and space scales from biogeochemical cycles and partitioning of the energy budget, to changes in habitat characteristics, and trophic structures and biodiversity. Until recently, we could not bridge between measurements made in the field to the spatial and spectral resolutions of satellite data. While much remains to be learned, we have a basic understanding of the biochemical and biophysical responses of natural systems that can be measured using imaging spectroscopy. And in recent years there has been dramatic progress in measuring the three-dimensional structure of canopies (height, crown diameter and depth, crown gap distribution, biomass, etc.) derived from high resolution Lidar data at both field and airborne scales. Together, these data provide a basis for a more fundamental understanding of how spectral properties scale between measurements on the ground to observations from satellites. I will discuss some issues related to the goal of understanding ecosystem functioning and present examples from a range of habitats and site conditions using ground, airborne and satellite data) to suggest directions for moving forward.

Dar Roberts; University of California, Santa Barbara

Scaling from AVIRIS to HyspIRI Resolutions in Urban Ecosystems

Vegetation in the urban environment plays an important role in modifying urban energy balance and modifying surface runoff. Critical ecosystems services include carbon uptake, reduced energy consumption and removal of various atmospheric pollutants. However, the fine spatial resolution of urban objects, and the very high degree of heterogeneity within cover types, makes these environments very challenging. Imaging spectrometry has considerable potential for identifying plant functional types and species in urban environments, and quantifying biotic and abiotic fractional cover. However, much of this research has focused at fine spatial scales. In this talk, I present research results from urban environments at multiple scales ranging from fine spatial scales (~ 3.5 m) to the 60 m of HyspIRI. I draw upon examples derived from HyMap for the city of Bonn, Germany, AVIRIS from Santa Barbara and simulated HyspIRI. I demonstrate that high accuracies for mapping plant species, functional types and urban materials can be achieved at fine spatial scales, but are likely to be difficult to achieve at 60m. However, fine spatial scales are critical for capturing the spectral diversity needed to develop the spectral libraries required for analyzing HyspIRI. By capturing this spectral diversity, spectral heterogeneity within the urban environment can be accounted for and used to generate stable, accurate estimates of fractional cover at 60 m.

Thomas Stohlgren; USGS

Scaling Biological Data from Core Site to the Continent

Environmental monitoring programs must efficiently describe state shifts. We propose using maximum entropy modeling to select dissimilar sampling sites to capture environmental variability at low cost, and demonstrate a specific application: sample site selection for the Central Plains domain (453,490 km2) of the National Ecological Observatory Network (NEON). We relied on four environmental factors: mean annual temperature and precipitation, elevation, and vegetation type. A “sample site” was defined as a 20 km x 20 km area (equal to NEON's airborne observation platform [AOP] footprint), within which each 1-km2 cell was evaluated for each environmental factor. After each model run, the most environmentally dissimilar site was selected from all potential sample sites. The iterative selection of eight sites captured approximately 80% of the environmental envelope of the domain, an improvement over stratified random sampling and simple random designs for sample site selection. This approach can be widely used for cost-efficient selection of survey and monitoring sites.

Willem Van Leeuwen; University of Arizona

A Hierarchical Landscape Inventory, Monitoring, Assessment and Modeling Framework: Impact of Scales on Land Use and Land Cover

To characterize and assess ecosystem function, structure, and goods and services for a particular region, scales and scaling rules should conform to the complex temporal, spatial and organizational factors that are inherent to the ecosystems under consideration. Scale here refers to the resolution and extent of spatial, temporal and organizational characteristics that govern the interactions among biosphere, hydrosphere, atmosphere, lithosphere and anthroposphere. A nested observation and modeling framework is needed to develop new and use existing land cover and land use data and products at multiple spatial and temporal scales to assess historical and ongoing landscape change. Multiple ground and airborne data sources can be integrated to monitor and assess land surface dynamics such as shrub encroachment, phenology, land cover and land use, woody cover, habitat fragmentation, invasive species and biodiversity. A multi-dimensional data analysis approach takes advantage of the vast array of available remotely sensed data (multispectral, microwave and lidar) that range from coarse to fine spatial resolution, and also provide historical time series data that varies in frequency of acquisition. Integration and synergistic use of multiple data sets can capture the spatial distribution of seasonal and interannual land surface responses to increase understanding of their trajectories and associated impacts. Land surface response variables and changes are derived and validated based on a nested spatial and temporal sampling and analysis approach. These data and products can be used individually or integrated with environmental data such as climate and soil data to model biogeochemical and ecological processes.

3. RECOMMENDATIONS FROM THE WORKSHOP

In Section 3.1, we present the recommendations from the topical working groups. Section 3.2 contains the summary recommendation and findings of the workshop.

3.1 Topical Working Group Recommendations

3.1.1 Scaling Fluxes using Remote Sensing

What scales are we interested in?

- Several Km – e.g., soil moisture remote sensing – very large scale compared to tower measurements
- Agencies desire sub-management scale

What are the most obvious needs in linking remote sensing and fluxes?

- Measurements on the ground for physiological parameters which might be estimated from spectral data.
- Cloud screening – QA/QC and flight conditions
- Sampling issues: clear days, peak biomass, avoid dew
- Co-registration issues
- BRDF effects of changing direction – flights near nadir.

- Algorithms break down at different scales – e.g. LAI algorithm for MODIS/Landsat does not apply at 1m
- Coordinated ground validation?
    - Training and standardization
    - Can we define key measurements which would not be typically recorded by biologists that would be essential to improve comparisons to airborne data
- LAI doesn't change over a day or two but physiology does.

What are the most obvious needs in linking remote sensing and fluxes?

- Consistent standards – averaging time, u*, gapfilling, daily vs sub-daily data availability (NEON?, IKOS)
- Non-'NEE' measurements: Albedo, LE,
- Are sites representative of ecosystem functional types? – sampling uncertainty (flux sites)
- Uncertainty in fluxes?, Uncertainty in RS products? Breaking RS product uncertainty into seasons? Is there a need to rethink the way we report the uncertainty? Need to encourage the USE of existing tags.
- Non-Nadir angle comparisons between tower and satellite presents problems
- How can we relate variable flux tower footprints to remote data
- Use of other satellite and airborne data sources – not just MODIS and Landsat

What methods can be used for comparison?

- Do we need a flux footprint analysis?
- New sets of needs: physiological measurements at small scale to exploit the spectral airborne data

How can NEON and the community work together to fill these needs?

- Characterizing the complete flux record should be instructive – combining footprint analysis with LIDAR could allow each 30 minute flux to be related to the actual vegetation in the foot print.
- NEON flag for 'footprint representativeness'
- Recommend: provide the foot print statistics to the community
- Is NEON annual repeat cycle sufficient?
    - Depends on what you want to get
    - Peak biomass yes!, Species discrimination not really
    - Flux tower mounted spectrometers to describe seasonality?
    - Standardized timing.
    - Recommendation for NEON to fly AOP multiple times per year – leaves on or off – shoulder periods in spring and fall

How do we scale? Statistical? Process-based models: Fluxes and Remote Imagery

- It will be necessary to use process models of varying complexity
- Fluxes primarily inform the fast processes (e.g., photosynthesis/respiration/evaporation)
- RS can inform slow processes
    - Repeat metrics of structure, biomass and state information on physiological parameters
- Landscape is variable - towers need to be contextualized
    - How much of the landscape is represented by the tower (flux and radiometric contribution)?

What data should be collected during campaigns to support scaling?

- Plant biomass, basal area and height – understory/overstory (biometric plot based)
- Phenology: timing leaf out, litterfall (observations and camera data)
- Leaf and Litter C, N, P, K, Ca, Mg, chlorophyll content (transect annual – coordinated with AOP?)
- Standard ground sampling protocols essential
- Existing protocols (find refs in NVCS docs)
- Define standard protocols with community

- Standardization of lab protocols and machinery used for leaf chemistry very important (standardized machinery).
- Field training course associated with NEON AOP campaigns?
- ESA course, IEEE, GLOBE initiatives
- Absolute need for rigorous training
- Tie in a field course at local university using identical protocols

How much area does AOP need to cover?

- Maximize variability sampled
    - Depends on regional variability (relative to site)
    - Additional sites?
    - Transects to maximize variability
        - Use transit time as an opportunity for transect studies
    - Shape of flight plan needs to be representative
- Increased sampling of spatial variation in flux parameters
    - Moveable observations (tough for tall veg)
    - Distributed network of inexpensive sensors or observations
        - E.g. USA NPN Camera networks to estimate phenology
- Coordinate with SM RS – 36x36km, COSMOS

Land use change and site history – impact on fluxes?

- Will be important for model initialization and scaling
- NEON will be accounting for site history as part of the site characteristics.
- Mesoscale historical effects
- Urbanization effects may be at the mesoscale
- Extend historical context in entire watershed and air-shed
- Airborne photography and satellite remote sensing can contribute
- Soil depth and compaction – influenced by site history

Network Longevity

- 30-year data set will tell a story – maintaining trend detection capability is essential
- Sampling (new flux sites) and processing needs will have to be keep current to reflect changing technologies – maintain trend detection capabilities.
- After baseline variability is assessed – sampling uncertainty (same PFTs - different fluxes e.g. BEAREX, Richardson/Hollinger)
- Lessons from MODIS and Flux tower data – algorithms will need to be revised many times reflecting new knowledge
    - Retain raw data (level 0)
    - Retain provenance
    - Reprocess as needed

3.1.2 Vegetation Breakout Group

- Need to get Level-1 data out for community to begin getting familiar with it
  - Key goal: Get some of these level one data sets out to the community before the next meeting (plus the reference data).
- NEON – establish an algorithm evaluation committee? Evaluate algorithms and give them priorities?
  - Follow NCEAS model – pull together a small group of experts to analyze a common data set to evaluate utility of algorithms, with a goal of publishing the inter-comparisons. The group might meet for a week in Boulder or perhaps Harvard?
  - Should there be a Level-1 assessment? Should there be an independent assessment of surface reflectance and waveform products?
- NEON should post a schedule of expected products, dates when they might be available, who should it be released to, how the evaluation should proceed (some measure of quality?)
  - A schedule of activities should be posted (all elements from flights, to field campaigns, to data processing and scheduled release of products).
- Does NEON desire guidance on spatial scaling studies? (e.g., Guidance on priorities of targets for first flights?)
  - 2012: Harvard, 2013: California (HyspIRI): Identify key scientists for these detailed studies.
  - Who are going to be your beta-testers
- Separate NSF call for science/validation assessment team?
- Reaching 20 sites by year three may be difficult
- Level-1 questions: Atmospheric correction and flight altitude.
  - How will these be decided.
- Develop a plan over the next year for developing spectral libraries.
- Consider additional flights within a year.
- NEON Develop a procedure document (i.e., processing scheme?) What is the processing scheme?
  - Include ground based measurements.
- Develop a good plan for communicating with the "community"
  - Within a small group of scientists
  - With the broader ecological community
- Advocate for densest lidar point density.
- Setup a workshop focusing on Harvard forest data
- Lidar technical work group convening this fall.
- Lidar has a broader flight window than the IS, because it can fly at night or in the evening.
- What are the different working groups envisioned?
  - Lidar technical working group
  - Remote sensing working group
  - Calibration working group (lab, radiometric, spatial, spectral etc).
  - Ground based structure working group.

3.1.3 Modeling Breakout Group

- How do you incorporate modeling in analysis across scales?
  - Give feedback from users to the data generators.
  - Effect of errors on derived products.
  - Accuracy needed versus cost to improve accuracy.
  - For example, how does error in foliar N affect uncertainties in predictions of carbon?
- Get data out to the community as soon as possible to allow feedback for the higher level products so these products are useful to the community.

  - Object orientated versus gridded data
  - Different users will want different format of data.
  - Implementation of community algorithms (object orientated potentially) from the community.
  - Choices of modeling parameters (etc).QA/QC and vetted by community.
- Use meetings such as this for a formal feedback.
  - NEON TWGs
  - NCAR working group model (open to anyone!)
  - Meet multiple times a year (also telecoms)
  - Complex social mechanism (lots of people from different user groups)
  - Community of practice (users, bottom up)
  - Way to continue conversation through time
  - Open working group allows adaptive changes to the direction of the model/data development
- Focus will push direction of data development
  - For example, determine the best collection parameters for Lidar collection. Feedback will translate into mission design
- Pixel-orientated versus organism-orientated data products is a very significant split in data product design
- Assembled object vectors are much more portable to the general community than ~TB datasets.
- Science requirements lead to the who, how, when for generation of the data products.
- Temporal scaling issues require the consistent temporal collection of the site at a given state of greenness?
- Scaling between airborne and space-based systems
  - Prototype data sets for the modelers to use
  - MODIS type products generated AOP data
  - FAPAR between AOP and Landsat/MODIS data levels
    - statistical meaningful differences
    - structural vegetation types
- What initial dataset/ideas should be presented to the community to guide the initial airborne collection parameters to allow the best development of the models/algorithms?
- Scaling is a frontier science area that the NEON observatory enables and it is important to not fix our methods and bring in the general community to guide the direction.
- Provide prototype datasets to the community to enable community feedback to guide algorithm/model development.

3.2 Summary Recommendations

- One overriding desire expressed by a majority of attendees at this meeting was the need for NEON data sets so they could begin exploring how the NEON data at different spatial & temporal data sets could be used in exploring scaling issues. NEON is working towards this goal and it is expected that provisional data will become available within several years.
    - An excellent opportunity for initial multi-scale data sets will result from the NEON participation in the HyspIRI Preparatory Airborne Activities and Associated Science Program. During the summer of 2013, NEON plans to fly the AOP over the Domain 17 NEON sites coincident with overflights of AVIRIS-classic on the NASA ER-2 high-altitude aircraft. The goal is to obtain visible-to-shortwave infrared imagery and lidar data over the NEON sites at normal AOP spatial resolutions (~1 m) in parallel with coarser resolution AVIRIS data (60 m) overextended regions. In addition, several science teams (University of Wisconsin, University of Mass, Boston, RIT, University of Davis, university of California, Santa Barbara) along with NEON staff will be at and near the NEON sites conducting ground measurements and sampling vegetation (lidar, spectral, chemical, etc.). These complimentary data sets which will be opening shared between groups will provide a wealth of data to begin exploring scaling issues from the plant-scale to airborne (AOP) to spaceborne sensor (AVIRIS HyspIRI-like measurements) scales.
    - It is recommended that a follow-on workshop be convened once data from this project becomes available. This could potentially be a joint meeting with the NASA Terrestrial Ecology Program.
- This meeting was a good introductory meeting to engage the broader science community in scaling issues important to NEON. However, specific scientific questions related to spatial/temporal scaling were not explored in depth at this meeting. It is suggested that future meetings be smaller in participation and more focused. Smaller meetings could bring together leading researchers in specific areas to address one or two specific questions. One area that was not adequately addressed in this meeting was the issue of integrating NEON data (at a wide range of temporal and spatial scales) into regional to continental-scale models – how do we begin to explore how to construct hierarchical statistical models to address ecology at the continental scale? Does the NEON sampling strategy provide sufficient spatial representativeness? What other data sets are needed (and should be assimilated into the NEON data processing/archiving infrastructure)? How will uncertainties and biases be addressed (and quantified) in these models?
    - It is strongly recommended that a follow-on workshop be considered that would bring together the leading experts in the field of hierarchical statistical modeling in ecology and address these issues. In all likelihood, this will end up being a series of workshops that will provide critical guidance to the observatory as modeling tools are developed.
- While the focus of the meeting was on scaling in ecology, many of the comments coming out f the Breakout Sessions were not directly related to scaling per se. This was especially true for the Vegetation Working Group. Many of the issues brought up here were more focused on NEON data (and AOP data, more specifically). Many of the points highlighted related to data quality,

the data processing process, external review, and community engagement – all good points, but not directly applicable to addressing scaling issues. Much of this is a result of the timing of the meeting – NOEN and AOP specifically, was still developing the infrastructure (aircraft, remote sensing payload, data processing capabilities) for acquiring when this meeting was held. Many of the meeting attendees did not have a full appreciation of where NEON was in the development process at the time of the meeting. This points to the need for NEON to do a better job in communicating its development status to the broader scientific community – this had been highlighted by the vegetation working group.

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