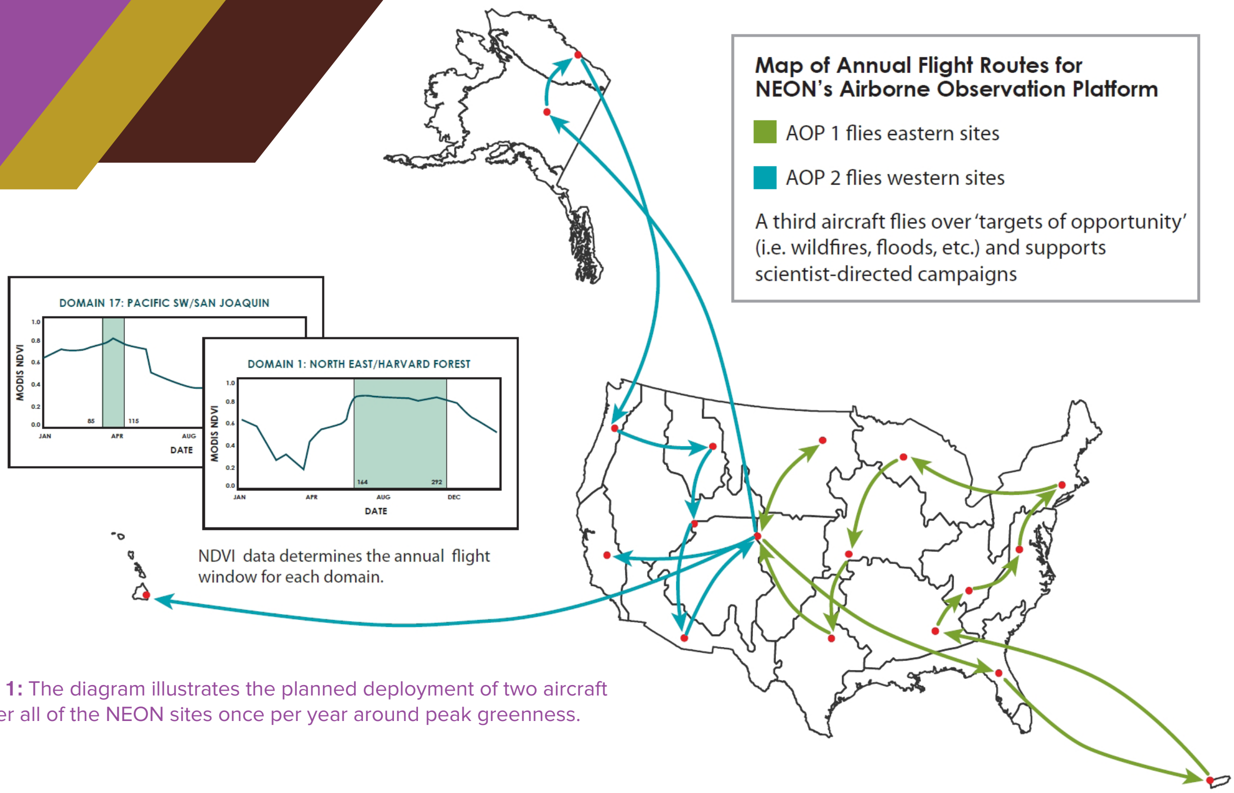

Figure 1: The diagram illustrates the planned deployment of two aircraft to cover all of the NEON sites once per year around peak greenness.

ECOLOGICAL MAPPING

Using Integrated LiDAR and Hyperspectral Airborne Remote Sensing at NEON

National Ecological Observatory Network

The National Ecological Observatory Network (NEON) is a continental-scale ecological observation system that supports the study of critical ecological issues. The NEON mission is to enable understanding and forecasting of the impacts of climate change, land use change and invasive species on continental-scale ecology – by providing infrastructure and consistent methodologies to support research and education in these areas. NEON is sponsored by the National Science Foundation.

Enabling a Better Understanding of Continental-Scale Ecology

NEON is designed to gather and synthesize data on the impacts of climate change, land use change and invasive species on natural resources and biodiversity. Data will be collected from 106 sites (60 terrestrial, 36 aquatic and 10 aquatic experimental) across the U.S. (including Alaska, Hawaii and Puerto Rico) using instrument measurements and field sampling. The sites have been strategically selected to represent different regions of vegetation, landforms, climate and ecosystem performance.

BY KEITH **KRAUSE**, THOMAS **KAMPE**, AND JOHN **MUSINSKY**

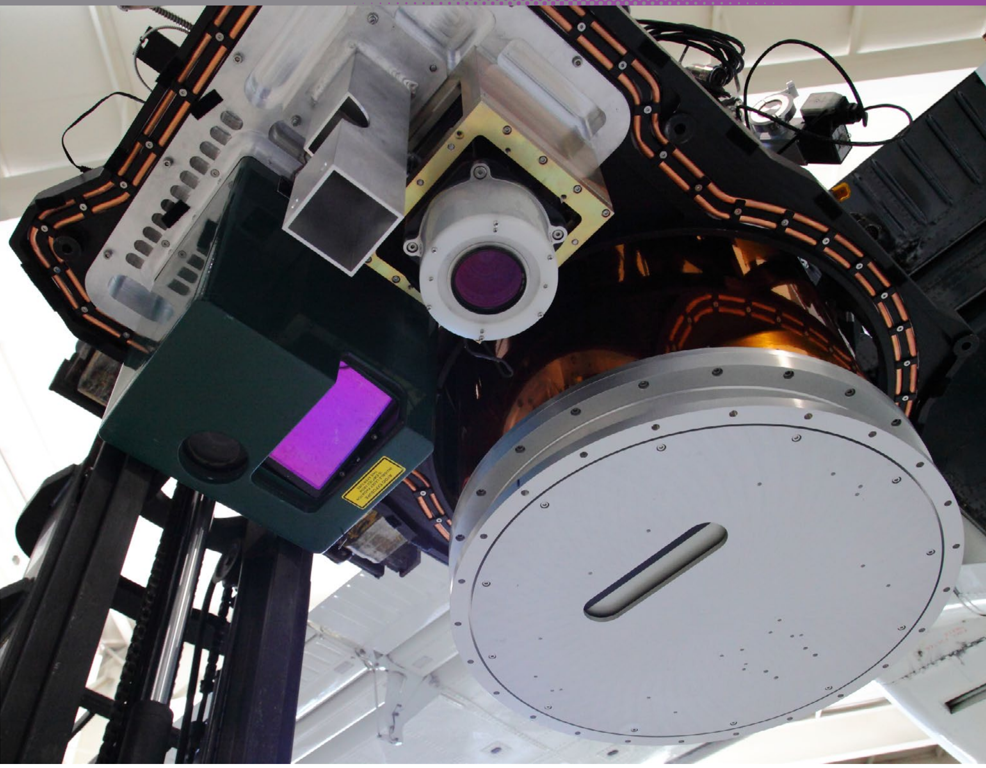

Figure 2: The image to the left shows the imaging spectrometer, waveform LiDAR and digital camera mounted in a common rigid frame during integration into a Twin Otter aircraft shown below.

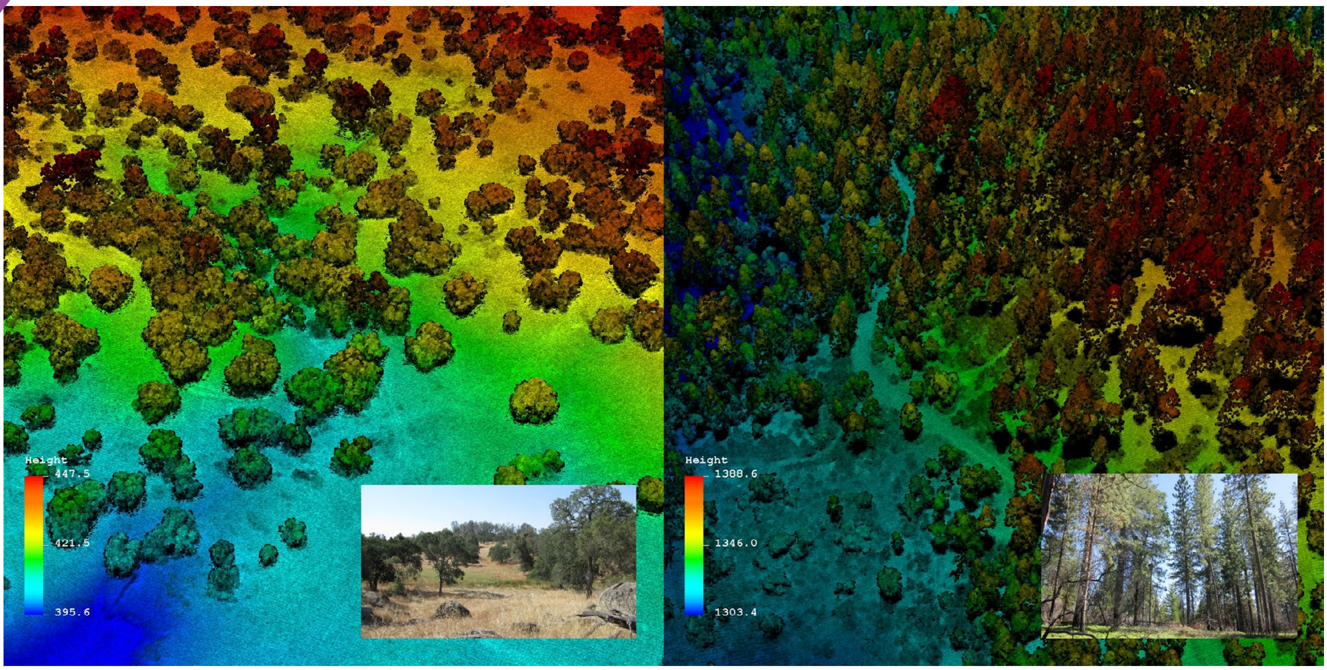

Figure 3: LiDAR point clouds of the San Joaquin Experimental Range (left) and Soaproot Saddle (right) NEON sites. The two sites have different horizontal and vertical 3D structures due to the differences in vegetation cover.

NEON will combine site-based data with remotely sensed data and existing continental-scale data sets (e.g. satellite data) to provide a range of scaled data products that can be used to describe changes in the nation's ecosystem through space and time. NEON's open-access approach to its data and information products will enable scientists, educators, planners, decision makers and the public to map, understand and predict the effects of human activities on ecology and effectively address critical ecological questions and issues.

NEON successfully completed the planning and design phases and entered the construction phase in spring 2012. NEON is currently building sites. Constructing the entire NEON network will take about five years, so NEON expects to be in full operation by approximately 2017. NEON will collect data for 30 years.

Airborne Observation Platform

One of NEON's goals is to provide detailed aerial data about regional landscapes and vegetation. This will be accomplished via the remote sensing arm of NEON, called the Airborne Observation Platform (AOP). Airborne remote sensing plays a critical role in the scaling strategy of the Observatory by making measurements at the scale of individual shrubs (1–3 meters), larger plants and forest canopies (over hundreds of square kilometers). The NEON airborne remote sensing instrumentation is designed to bridge scales from organism and stand scales, as captured by plot and tower observations, to the scale of satellite based remote sensing. The airborne instrumentation will support research on a range of important themes in ecology in response to grand challenges in the study of biodiversity, biogeochemistry, climate change, ecohydrology, infectious disease, invasive species and land use change.

Remote Sensing Instrumentation

Each aircraft will fly a suite of integrated remote sensing instruments consisting of an imaging spectrometer, a waveform light detection and ranging (LiDAR) instrument and a high-resolution digital camera. The AOP instrument suite will provide regional observations of: land use, vegetation structure, biochemical and biophysical properties of vegetation, and ecosystem responses to changes in land use, climate and the movement of invasive species.

The imaging spectrometer is used to create an image of the ground at narrow wavelength bands (5nm center wavelength sampling) in the visible to shortwave infrared (400 – 2500 nm) spectral region and provides quantitative information on vegetation cover, abundance, and biophysical and chemical properties.

The full waveform LiDAR operates at a laser wavelength of 1064 nm to provide quantitative information on vegetation cover, height, shape, and vertical structure and underlying terrain. The high spatial-resolution color digital camera provides detailed aerial views of the regional landscape and can be used to determine land cover and provide context as to what ground targets are being measured by the imaging spectrometer and LiDAR instruments.

Concept of Operations

As part of the AOP, the airborne remote sensing instruments will observe ecosystem properties in the region (100-300 km^2) surrounding NEON sites. The high cost of aircraft operations will limit the frequency of standard airborne observations of each site to once per year to detect inter-annual trends. To minimize the phenological contribution to the signal, flights will be planned to occur at each site during a period of peak greenness. Higher temporal frequency data on vegetation function is available from satellite measurements at a coarser spatial resolution.

Two payloads are necessary to cover all of the NEON sites based on the deployment and data collection requirements. An example of the flight deployment is shown in **Figure 1**. A third dedicated payload will also be deployed in response to extreme events to monitor the ecological forcing (e.g., hurricane damage) and response (regrowth after fire), as well as other science directed requests. The remote sensing instruments are mounted in a common rigid frame and installed in a DeHavilland DHC-6 Twin Otter aircraft flying at 1000-2000 m above ground level (AGL) at a speed of typically 100 knots as shown in **Figure 2**. The flight parameters are largely determined by the requirement to achieve meter-scale spectroscopy measurements and simultaneously achieve a sufficient signal-to-noise ratio to retrieve vertical structure from the waveform LiDAR and biogeochemical properties from measured reflectance spectra.

Engineering Flights in the Pacific Southwest

The AOP conducted a series of airborne remote sensing surveys and supporting ground measurements in June 2013 at three NEON terrestrial sites and one NEON aquatic site located in NEON Domain 17 (Pacific Southwest) in California. These sites extend over diverse ecological regions and climate and elevation gradients.

At a lower elevation of 200 to 520 m, the San Joaquin Experiment Range (NEON core site) contains open woodland dominated by oaks (blue and interior live oaks) and gray pine. Soaproot Saddle (NEON relocatable site) sits around an elevation of 1100 m and is a mixed conifer/deciduous forest. Teakettle (relocatable site) is a red fir dominated forest at elevations of 1775 to 3038 m. Finally, the Providence Creek aquatic site consists of a mid-to-high elevation mixed-conifer riparian forest between 1500 and 2120 m. **Figure 3** shows LiDAR point clouds of San Joaquin (left) and Soaproot Saddle (right) which have different horizontal and vertical 3D structures due to the differences in vegetation cover.

The primary objectives of the combined airborne and field campaign were to test the nominal data collection parameters for these sites, evaluate data processing techniques and obtain an initial data set that supports spatial/temporal scaling studies currently underway as part of the NASA HyspIRI Preparatory Airborne Project. Airborne remote sensing measurements were made using the full NEON Airborne Observatory Platform instrument payload integrated onboard a Twin Otter aircraft.

Supporting ground measurements of vegetation spectra and structure, plant species identification and measurements of key atmospheric variables were made in conjunction with the NEON airborne observations at San Joaquin and Soaproot Saddle and in collaboration with field research teams from the University of California, Davis, the University of Wisconsin, Madison, Rochester Institute of Technology, Boston University and University of Massachusetts, Boston.

NEON's airborne observations of Soaproot Saddle were also coincident with the airborne observations of the western Sierra Nevada Mountains made by NASA JPL using the AVIRIS-classic instrument onboard an ER-2 and field measurements acquired to support the ongoing NASA Ecological Spectral Information System (EcoSIS) Project to build more thorough spectral libraries of vegetation and surface materials.

Rapid Response: Mapping the High Park Fire Burn Scar

Summer 2012 was an intense wildfire season throughout the western U.S., and one of the largest of these fires was the High Park Fire in Northern Colorado. The fire destroyed 259 structures, burning an area of about 87,284 acres and costing an estimated 39.2 million dollars. The burned area drains directly into the Cache la Poudre River, a critical water source for northern Colorado communities. As part of a rapid response exercise with RAPID funding from the National Science Foundation, AOP was deployed to map the High Park Fire burn scar in August 2012, October 2012, and June–July 2013. **Figure 4** shows a LiDAR point cloud of a section of the fire burn scar.

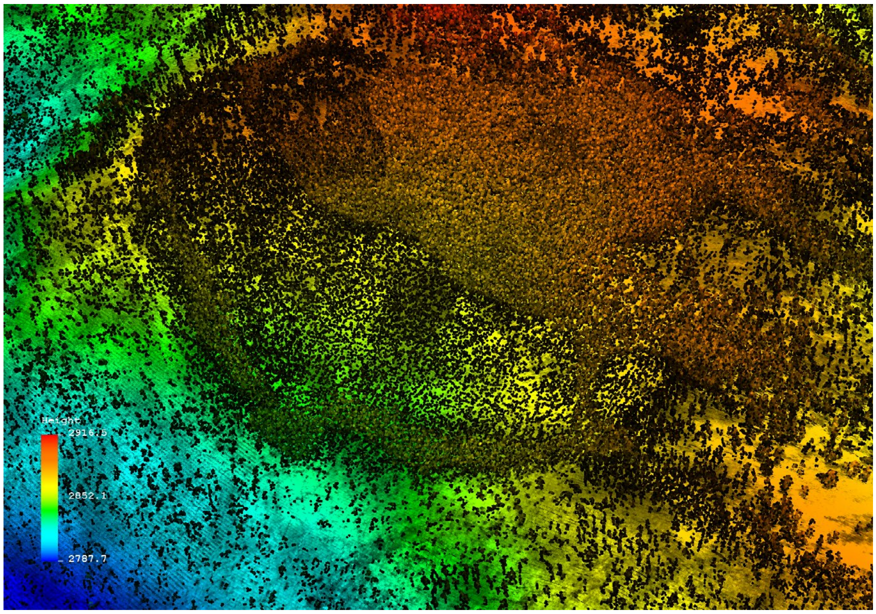

Figure 4: A LiDAR point cloud of a portion of the High Park Fire Burn scar. A complex fire pattern is seen with sections of trees unaffected by the fire, areas partially burned, and regions with severe burning which leave behind dead tree snags.

The primary goal of the exercise was to determine the state of the landscape at the conclusion of the High Park Fire, both within the fire's final boundary and in reference areas outside the fire. With respect to rapid response, the focus was on essential data collection to characterize post-fire conditions, but data collection efforts were designed in the context of two broad categories of science questions for future research. Scientists would like to answer how conditions prior to the fire affected fire behavior/impacts and how fire severity and pattern affected post-fire trajectories.

The focus of this exercise was to collect airborne remote sensing data to characterize the state of the soils, remaining live vegetation and dead vegetation after the burn, along with detailed topography as a precursor to geomorphic and ecohydrological studies. The remote sensing data acquisition was coordinated with a targeted field campaign conducted by Colorado State University and the University of Arizona to collect baseline information on forest composition, structure and three dimensional distribution, soil biota, and rates of erosion and sedimentation. Combining the field and remote sensing datasets will allow an unprecedented assessment of the impact of the fire, provide data products useful to the scientific and management communities, and support future research on post-fire trajectories.

Acknowledgements

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John Musinsky is a staff scientist at NEON and is responsible for developing, implementing, and managing the pathfinder and test airborne remote sensing flight campaigns during NEON's construction phase, and will direct flight operations during Observatory operations.