The NEON 2013 Airborne Campaign at Domain 17 Terrestrial and Aquatic Sites in California

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ABSTRACT

The National Ecological Observatory Network (NEON) 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 ranging from open woodland at 200 to 520 m elevation dominated by oaks (blue and interior live oaks) and digger pine in the San Joaquin Experiment Range (NEON core site) to mixed conifer/deciduous forest at 1100 m elevation at the Soaproot Saddle relocatable site, red fir dominated forest at elevations of 1775 to 3038 m at the Teakettle relocatable site, and mid-to-high elevation mixed-conifer riparian forest between 1500 and 2120 m elevation at the Providence Creek aquatic site. 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 (AOP-1), which includes a high-resolution NEON imaging spectrometer (NIS), a small-footprint waveform-recording LiDAR and a high-resolution digital camera integrated onboard a DeHavilland DHC-6 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, and Rochester Institute of Technology. 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.

Keywords: Airborne remote sensing, imaging spectroscopy

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1 INTRODUCTION

The National Ecological Observatory Network (NEON) 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 are located in central California, extending over a large elevation gradient from the southern foothills to the upper steppe of the Sierra Nevada Mountains (Figure 1). The sites cover diverse ecological sub-regions along an elevation gradient ranging from open woodland at 200 to 520 m elevation dominated by oaks (blue and interior live oaks) and digger pine in the San Joaquin Experiment Range (SJER) (NEON core site) to mixed conifer/deciduous forest at 1100 m elevation at the Soaproot Saddle relocatable site, and red fir dominated forest at elevations above 2,300 m at the Teakettle relocatable site. The D17 sites (SJER, Soaproot Saddle and Teakettle) were chosen by NEON specifically to study the effects of changing precipitation (from rain to snow-dominated) and ecological variability across the elevation gradient due to warming induced changes to the boundary-layer.

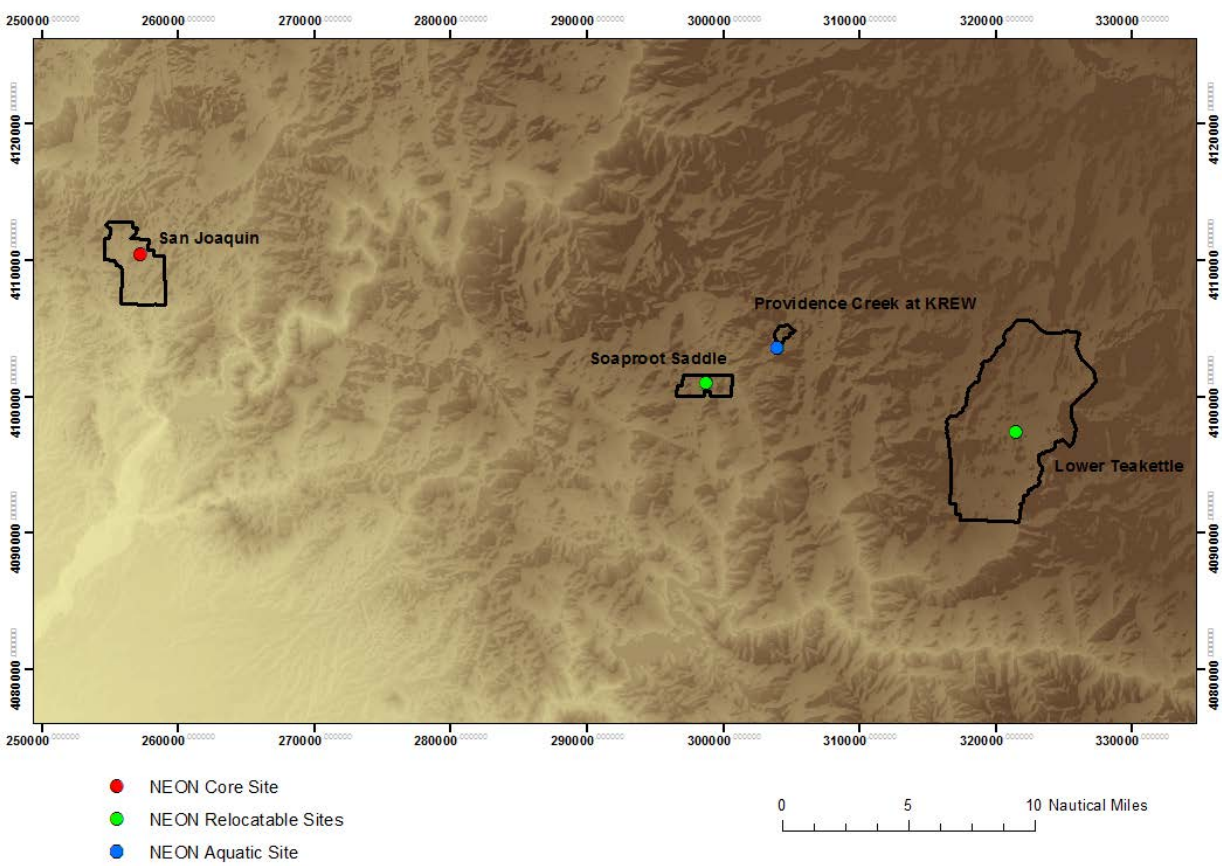


Figure 1: Relative location of NEON core, relocatable and aquatic sites along an elevation gradient in the Sierra Nevada Mountains

The NEON observatory design is based on a multi-scaled sampling strategy employing systematically deployed ground-based sensors, field sampling, high-resolution airborne remote sensing and integration of national geospatial information[1]. An important goal of this strategy is developing the capability to extrapolate relationships between climate variability, land-use changes and invasive species and their ecological consequences in areas not directly sampled by the NEON facilities. Airborne remote sensing plays a critical role in the scaling strategy through acquisition of measurements at the scale of individual shrubs and larger plants over hundreds of square kilometers around each of the NEON sites. Spatially explicit data from airborne observation serve to bridge scales from individual organisms and stands, as captured by plot and tower observations, to that of satellite based remote sensing[2].

The primary objectives of the 2013 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[3]. Airborne remote sensing measurements were made using the full NEON Airborne Observatory Platform instrument payload (AOP-1), which includes NEON's high-resolution imaging spectrometer (NIS), a small-footprint waveform-recording LiDAR, and a high-resolution digital camera integrated onboard a DeHavilland DHC-6 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 airborne measurements and in collaboration with field research teams from the University of California, Davis, the University of Wisconsin, Madison, and Rochester Institute of Technology. In addition to validating the airborne measurements, the collection of coincident field measurements provides an opportunity to evaluate approaches being developed at NEON for integrating field-, site- and remote sensing-based data from across a range of spatial scales. 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, as well as field measurements acquired to support the ongoing NASA Ecological Spectral Information System (EcoSIS) Project[4].

2 NEON DOMAIN 17 CORE AND RELOCATABLE SITES

The San Joaquin Experimental Range core wildland site is operated by the U.S. Forest Service. The site is located in the foothills of the Sierra Nevada Mountains, about 32 km north of Fresno, CA (Figure 2). According to the website http://www.fs.fed.us/psw/ef/san_joaquin/, the climate is Mediterranean, with about 486 mm of rain falling from October or November to April or May. Winters are cool and wet, with frequent frosts and monthly mean temperatures between 4 and 10 °C. Summers are hot and dry, with maximum daily temperatures commonly exceeding 38 °C and

[1] M. Keller, D. S. Schimel, W. W. Hargrove, and F. M. Hoffman, "A continental strategy for the National Ecological Observatory Network," *Frontiers in Ecology and the Environment* 6 no. 5 (2008): 282-284 [doi: 10.1890/1540-9295(2008)6[282:ACSFTN]2.0.CO;2].
[2] Schimel, D.S., et. al., "NEON Science Strategy: Enabling Continental Scale Ecological Forecasting," http://www.neoninc.org/sites/default/files/NEON_Strategy_2011u2.pdf.
[3] NASA Research Announcement "Research Opportunities in Space and Earth Sciences (ROSES) 2011" (NNH11ZDA001N) posted on the NASA research opportunity homepage, http://nspires.nasaprs.com/ (select "Solicitations" then "Open Solicitations" then "NNH11ZDA001N").
[4] "NEON Collaborates with EcoSIS Team on New Spectral Data Resource," http://www.neoninc.org/news/neon-collaborates-ecosis-team-new-spectral-data-resource.

monthly mean temperatures ranging from 24 to 27 °C. San Joaquin contains open woodland dominated by blue oak (*Quercus douglasii*), interior live oak (*Quercus wislizeni*) and grey pine (*Pinus sabiniana*), with scattered shrubs and a nearly continuous cover of herbaceous plants (Figure 3). Swales occur in low areas between rises.

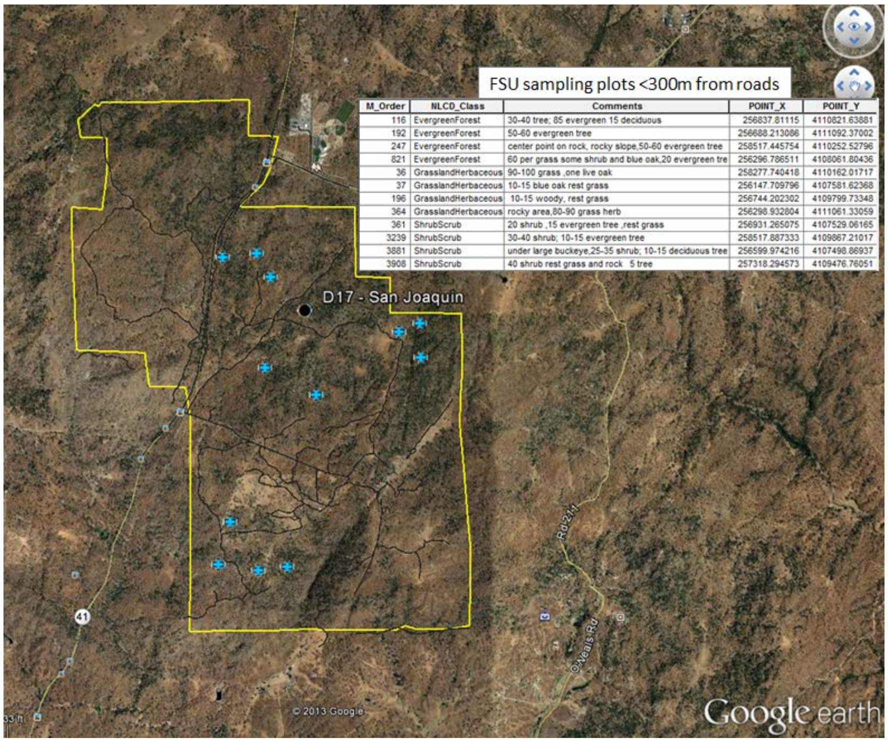


Figure 2: San Joaquin Experimental Range with subset of Terrestrial Observation System (TOS) sampling sites < 300m from roads

Figure 3: Oak Savanna vegetation at the San Joaquin Experimental Range core site

The Soaproot Saddle site lies in an intermediate location along the elevation gradient from the San Joaquin Valley to the upper Sierra Nevada (Figure 4). The site is located at approximately 1100 m in elevation on a lower steppe in the Sierras but at a higher elevation than San Joaquin. The ecosystem is composed of a mixed deciduous/conifer forest dominated by ponderosa pine (*Pinus ponderosa*) and incense cedar (*Calocedrus decurrens*) in an open canopy with trees and shrubs of various heights, and a dense forest floor dominated by sage (Figure 5). Topography is complex with coarse, large hills and valleys. This site is receives approximately 20% snow and 80% rain, and captures the snow-rain transition. The NEON tower site is situated on the top of a knoll in the saddle area.

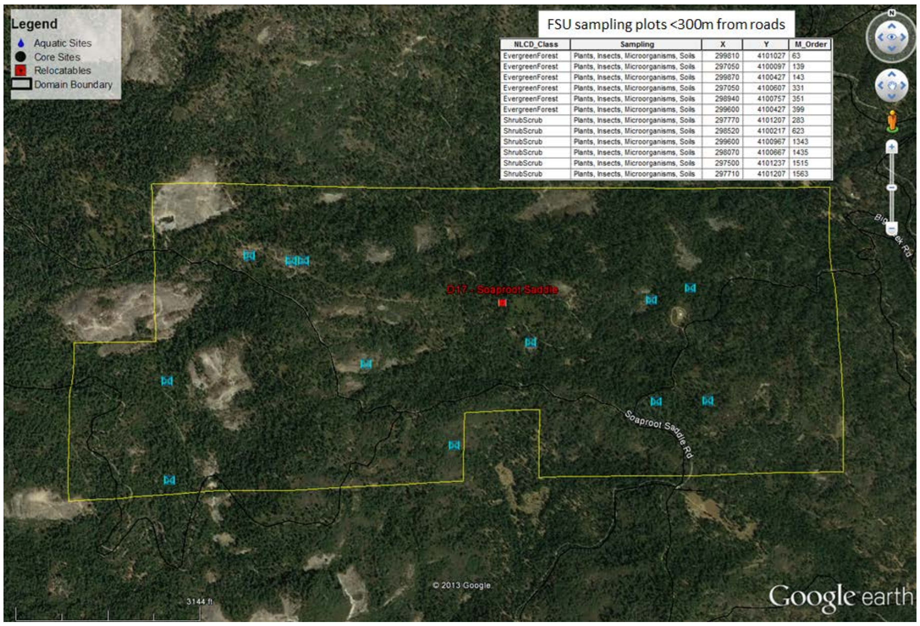
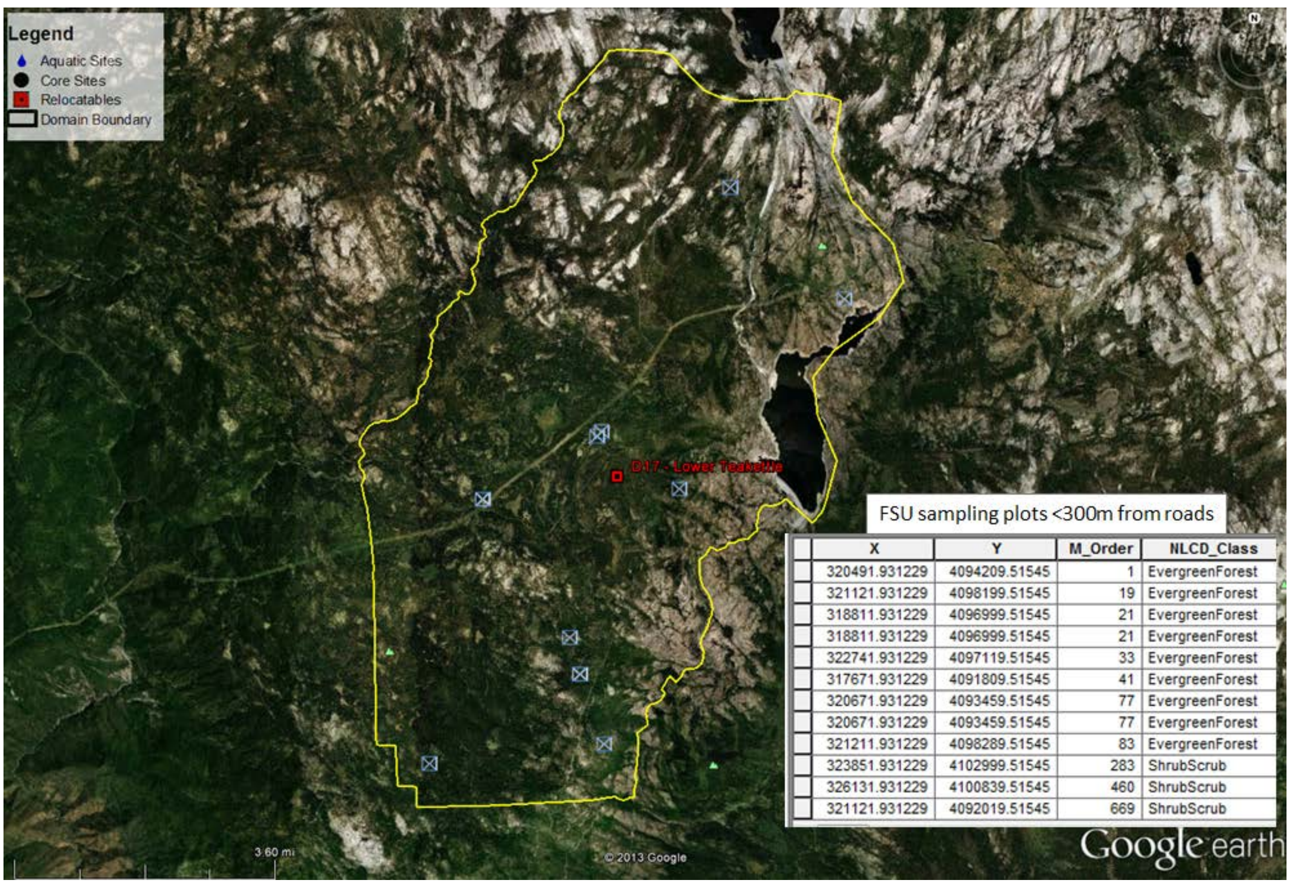


Figure 4: Soaproot Saddle with subset of TOS sampling sites < 300m from roads

Figure 5: Mixed conifer/deciduous forest and granite outcrops at Soaproot Saddle relocatable site

The Teakettle Experimental Forest straddles the upper steppe and lower mountain areas, at higher elevations (1775-3038 m) than the Soaproot Saddle relocatable site (Figure 6). Climate at Teakettle is typical of the Sierra Nevada range: hot and dry summers with mild, moist winters.[5] Most of the annual precipitation falls as snow between November and May, and snow accumulations generally persist until late May or early June. Teakettle is dominated by four main forest types: mixed conifer forest which covers 65 percent of the site, predominantly between 1,900 and 2,300 m in elevation; Jeffrey pine (*Pinus jeffreyi*) covers about 5 percent of the area, and is prevalent on shallow soil conditions within the mixed-conifer type; and red fir (*Abies magnifica*) covers 28 percent of Teakettle, at elevations above 2,300 m except for moist locations where lodgepole pine (*Pinus contorta*) is dominant. The ecosystem in the immediate area of the tower site and within the tower airshed is a diverse, naturally regenerating mixed stand of red fir, ponderosa pine, Jeffery's pine and white fir (*Abies concolor*). Age structure is very diverse. Mean canopy height is ~ 35 m, but some individual trees are emergent, occasionally exceeding 50 m in height (Figure 7).



X	Y	M_Order	NLCD_Class
320491.931229	4094209.51545	1	EvergreenForest
321121.931229	4098199.51545	19	EvergreenForest
318811.931229	4096999.51545	21	EvergreenForest
318811.931229	4096999.51545	21	EvergreenForest
322741.931229	4097119.51545	33	EvergreenForest
317671.931229	4091809.51545	41	EvergreenForest
320671.931229	4093459.51545	77	EvergreenForest
320671.931229	4093459.51545	77	EvergreenForest
321211.931229	4098289.51545	83	EvergreenForest
323851.931229	4102999.51545	283	ShrubScrub
326131.931229	4100839.51545	460	ShrubScrub
321121.931229	4092019.51545	669	ShrubScrub

[5] Pacific Southwest Research Station, http://www.fs.fed.us/psw/ef/teakettle/.

Figure 6: Teakettle with subset of TOS sampling sites < 300m from roads

Figure 7: Mixed conifer forest at the Teakettle relocatable site

Providence Creek is located in the King's River Experimental Watershed (KREW) in the east of Shaver Lake in the Sierra National Forest, and drains a small watershed of 1.3 km^2 of mixed conifer forest at 1500-2120 m elevation (Figure 8). The riparian canopy consists of mixed Douglas fir (*Pseudotsuga menziesii*), white fir and lodgepole pine, among others (Figure 9). The surface water flow regime of Providence Creek is dominated by the annual wet season in the low Sierra Nevada Mountains.

Figure 8: King's River Experimental Watershed (KREW) and the Providence Creek aquatic site (southern tip of watershed)

Figure 9: Mixed-evergreen forest at Providence Creek aquatic site

3 NEON'S AIRBORNE OBSERVATION PLATFORM (AOP)

The NEON Airborne Observation Platform (AOP) aircraft-mounted remote sensing instrumentation consists of the NEON imaging spectrometer (NIS), a high fidelity visible-to-shortwave infrared (VSWIR) imaging spectrometer based on the AVIRIS Next-Generation Imaging Spectrometer (AVIRISng)[6] designed to quantify plant species identity and function; an Optec Gemini small-footprint waveform-recording LiDAR to measure vegetation structure and heterogeneity; and an Optech D8900 high-resolution digital camera to capture co-registered features of representative land use including roads, impervious surfaces, and built structures (Figure 10). The LiDAR and camera are configured as an integrated system. A high accuracy, high precision global positioning system (GPS) and inertial measurement unit (IMU) are incorporated into the LiDAR to enable collection of payload position and attitude information during science data collection. A second GPS-IMU, the SDN500 (formerly a CMIGITS unit), is integrated within the imaging spectrometer assembly to provide a critical GPS time stamp to relate sensor measurements to one another while functioning as a backup should the LiDAR unit fail during flight. The payload is highly integrated, such that measurements are made simultaneously so that the ground pixel locations from the sensors can be accurately registered to better than 0.1 pixel. The remote sensing payload is designed to be compatible with the low altitude DeHavilland DHC-6 Twin Otter research aircraft, an ideal platform for conducting surveys of terrestrial ecosystems (Figure 11). Once in operational mode, NEON will operate three AOP payloads, of which two will largely be dedicated to annual surveys of NEON sites, and the third dedicated to targets of opportunity supporting NSF Principal Investigator requests for data acquisitions over non-NEON sites.

[6] Kampe, T.U., G.P. Asner, R.O. Green, M. Eastwood, B.R. Johnson, and M. Kuester, "Advances in airborne remote sensing of ecosystem processes and properties – Toward high-quality measurements at a global scale," *Proc. SPIE 7809*, 78090J-1 (2010), [doi:10.1117/12,859455].

Table 1: AOP Remote Sensing Payload Instrumentation

NEON Imaging Spectrometer		**Waveform LiDAR**		**Digital Camera**	
Spectral range	380-2510 nm	Laser wavelength	1064 nm	Spectral band-pass	400-700 visible
Spectral sampling (FWHM)	6 nm	Laser pulse repetition freq.	Programmable, 33-167 kHz	Field of View	44 degrees
IFOV	1.0 milliradian	Laser pulse width	12 nsec	Ground sampling distance	0.11 m (@ 1000 m AGL)
X-track FOV	34 degrees	Vertical range	65 m nominal	Dynamic range	12 bits
SNR	> 2000 @ 600 nm > 1000 @ 2200 nm	Vertical sampling	1 µsec = 0.3 m	Shutter speed	1/125 to 1/4000
Radiometric accuracy	> 95%	Scan frequency	Programmable, 0-70 Hz		
Spectral calibration	+/- 0.1 nm	Range of flying altitudes	1,000 to 2,500 m		
Spectral uniformity, xtrack	> 95%	Scan angle	Programmable, 0-50°		
Spectral IFOV-variation (in-track)	< 5%	Spatial resolution	< 1 m		

The airborne measurements collected by AOP enable NEON to develop science data products and algorithms that contribute to our understanding of ecosystem processes in the context of land use change, invasive species, and climate variability and change. The AOP remote sensing system takes advantage of the strong synergy between imaging spectroscopy and small-footprint waveform-recording LiDAR to measure plant canopy biogeochemistry and habitat structure characteristics around NEON sites[7]. Invasive plants can be detected both through their spectral properties and their structural properties. Pest and pathogen outbreaks, changes in competitive relations, responses to disturbances like wildfire, and many features of land use are readily observed and quantified using the powerful combination of biochemical and structural information provided by spectroscopy and waveform LiDAR. As an example, the biochemical and physiological properties retrieved from the imaging spectrometer can be affected by structure and the shadowing that occurs within and between vegetation canopies. Waveform LiDAR provides direct measurements of canopy height and crown shape that are key determinants of structure, shadowing, and biomass, but cannot easily distinguish between species or plant functional types or differences in vegetation biochemical and physiological properties. However, when combined, these two technologies provide one of the most powerful sets of ecosystem observations available from an airborne platform.

[7] Asner, G. P, D. E. Knapp, T. Kennedy-Bowdin, M. O. Jones, R. E. Martin, J. Boardman, and C. B. Fields, "Carnegie Airborne Observatory: in-flight fusion of hyperspectral and waveform light detection and ranging (wLiDAR) for three-dimensional studies of ecosystems," *Journal of Applied Remote Sensing* 1, 013536 (2007) [doi: 19.1117/1.2794018].

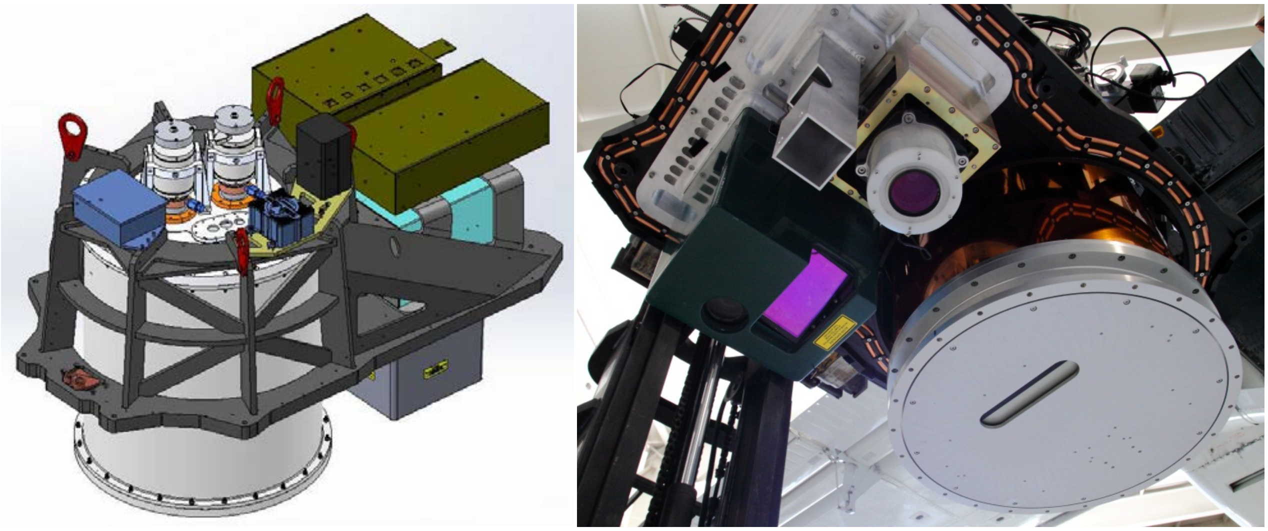


Figure 10: NEON AOP-1 payload

Figure 11: Twin Otter DeHavilland DHC-6 aircraft

AVIRISng was developed at the NASA Jet Propulsion Laboratory to meet the requirements for high performance airborne remote sensing of terrestrial ecosystems[8]. A suite of instruments including the AVIRISng instrument are currently in operation by NASA's Terrestrial Ecosystems Program, the Carnegie Airborne Observatory's Airborne Taxonomic Mapping System (AToMS), and the NEON imaging spectrometers (NIS), all based on the JPL Next-Generation Imaging Spectrometer instrument.

[8] Hamlin, L., R. O. Green, P. Mouroulis, M. Eastwood, I. McCubbin, D. Wilson, D. Randall, M. Dudik, and C. Paine, "Imaging spectrometer science measurements for terrestrial ecology: AVIRIS and the Next Generation AVIRIS characteristics and development status," NASA Earth Science Technology Conference (2010), Accessed 24 June (2010), http://esto.nasa.gov/conferences/estf2010.

The NIS (Figure 12) is a pushbroom instrument that measures the upwelling radiance in 428 narrow spectral bands extending from 380 to 2510 nm with a spectral sampling of 5 nm. It uses a single spectrometer module and focal plane array that eliminates the need for coregistering multiple spectrometer channels to attain the demanding spatial and spectral uniformity required of high fidelity imaging spectrometers for terrestrial ecology applications. Major components of the instrument flight package include the sensor itself, which is housed in a vacuum enclosure, a high precision IMU/GPS, focal plane electronics, on-board calibrator system, operator electronics rack, and an environmental control rack. During operations, the sensor is cryogenically cooled to 150K by two mechanical cryocoolers. The NIS sensor head is mounted onto a vibration isolating interface mount which is designed to interface directly to the seat rails of the aircraft.

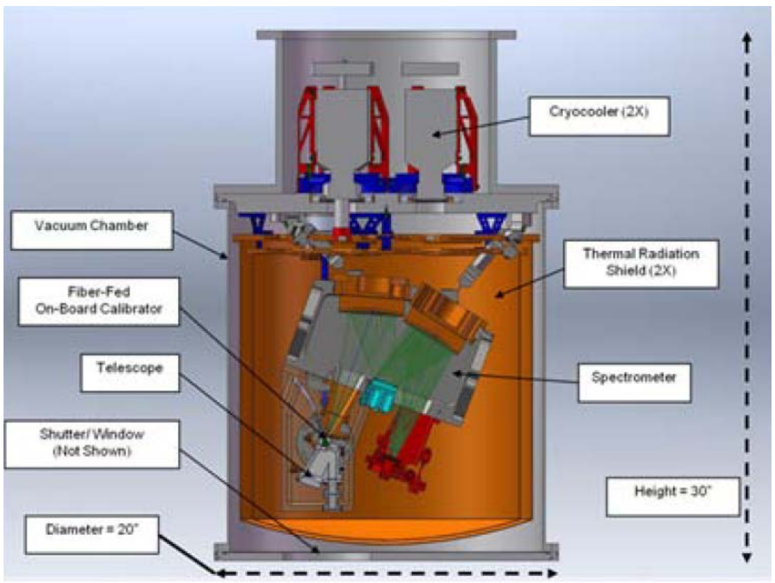


Figure 12: Schematic view of the NEON Imaging Spectrometer (NIS) showing major subsystems

The Optech Gemini small-footprint LiDAR records both discreet range returns and full waveform returns. Discrete returns are used to measure canopy height and to produce bare surface models of underlying terrain. However, the recordable pulse reflections are limited to a small number of vertical returns. In contrast, the waveform LiDAR records the entire time-varying intensity of the returned energy from each laser pulse, allowing for a more complete measurement of understory structure in forested environments. Small footprint waveform LiDAR has been used to determine ecological parameters such as tree height and species classification, leaf area index, and fuel loads of coarse woody debris on the forest floor. Recording the continuous waveform also minimizes the 2-3 meter range ambiguity associated with discrete return LiDAR allowing improved detection of low statue shrubs[9].

[9] Kampe, T.U., B. R. Johnson, M. Kuester, and M. Keller, "NEON: the first continental-scale ecological observatory with airborne remote sensing of vegetation canopy biochemistry and structure," *Journal of Applied Remote Sensing* 4, 043510 (2010) [doi: 10.1117/1.3361375].

3.1 Instrument Calibration

Calibration of the instruments was necessary to identify, quantify and eliminate bias in measurement and ensure consistency among observations spanning multiple years and across instruments on different payloads. NEON AOP calibration of the NIS-1 spectrometer data consisted of two stages:

1. *Calibrating the spectrometer.* In this stage, the spectrometer was used to measure well-characterized radiance sources in the laboratory. These measurements generated data required to calculate absolute radiance from the raw spectrometer output (digital counts). Spectrometer calibration is conducted in the laboratory at periodic intervals to ensure the stability of the calibration.
2. *Calibrating the science data.* In this stage, the raw data from in-flight measurements was converted to absolute radiance using the results of the laboratory calibration. Science data calibration involves correction of artifacts introduced by the focal plane detector, including:
   - dead/bad pixels
   - dark pedestal shift correction
   - electronic ghost correction

Radiometric calibration was then applied using parameters determined in the first phase.

The combination of these methods provides a robust way to verify sensor performance as well as the performance of the algorithm used to convert the raw data to radiance. Long-term behavior of the sensor during a flight season is monitored using the onboard calibration system. If the onboard calibration indicates the sensor or the calibration is no longer valid, a decision is made to collect a vicarious calibration dataset in the field or return the instrument to the lab for further calibration or repair.

3.2 Payload Integration

Before the 2013 flight season and the D17 flight campaign began, improvements were made to the Payload Integration Mount (PIM) design used in the NISDVU (NEON Imaging Spectrometer Design Verification Unit), an earlier prototype of the current NIS. Engineering enhancements to the AOP-1 PIM included: introduction of a modular PIM mounting design to facilitate systems integration into aircraft; engineering improvements to increase strength, rigidity and durability; improved thermal management and cooling capability to maximize instrument performance, reliability and boresight stability; and improved vibration dampening (Table 2).

Table 2: Engineering Improvements to Payload Integration Mount (PIM)

PIM Engineering Improvements	Value Added
Lighter	Increase flight time
Stronger	Meet FAA requirements, add safety
Rigidity	Improve boresight rigidity, leading to better NIS/LiDAR/camera co-registration of features on ground
Thermal control	Improve boresight stability Prevent instrument over-heating Control noise on FPIE (focal plane electronics) box
Modular aft section	Increase flexibility for mounting instruments Eliminate loss of boresight alignment during testing and maintenance
OBC and SOBC now attached to PIM	Minimize variation in OBC (on-board calibration) illumination

3.3 Remote AOP Instrument Monitoring

Improvements were also made to AOP-1 systems monitoring. The harsh conditions that exist in the airborne environment vary significantly from those in the laboratory environment. High temperatures and system failures can be extremely costly and may cause significant setbacks to aircraft operations. If science and technical support staff can be immediately informed of system anomalies or pending or existing system failures, swift corrective action might be taken that reduces downtime and associated costs and increases the likelihood that science data are acquired.

To address this need, AOP developed **monitorNIS**, a software program that monitors a variety of potential system failures while distributing real-time status updates on the current state of the payload (Figure 13). If a system failure is imminent, the monitoring software will immediately send both text and email alerts to AOP staff. During normal system operations, simple status plots are sent to AOP staff at regular intervals to allow them to monitor system status over time (Figure 14, Figure 15).

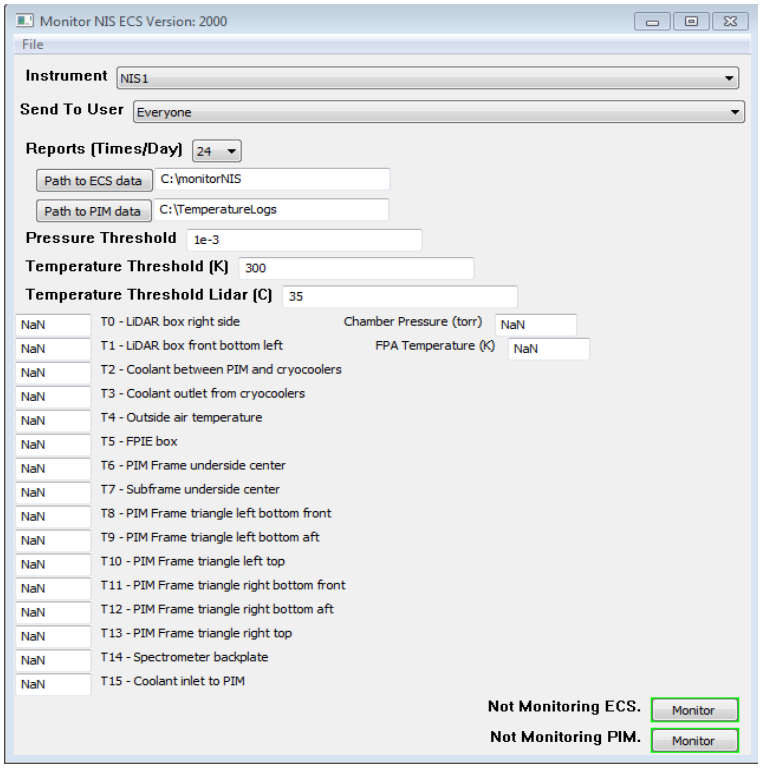


Figure 13: monitorNIS application

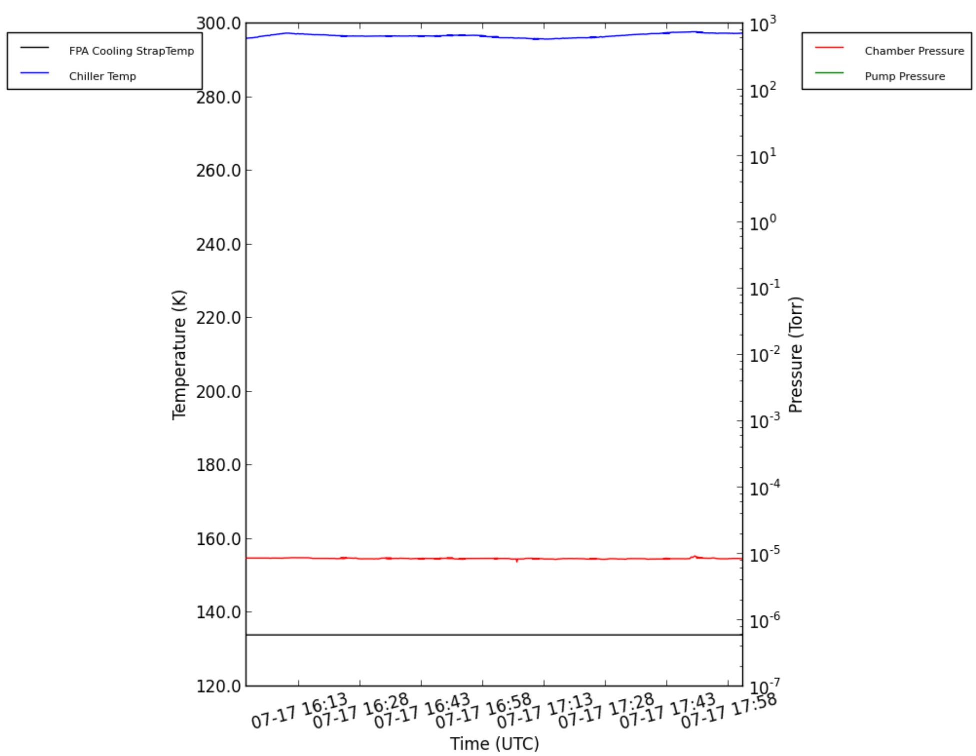


Figure 14: monitorNIS remote monitoring software output

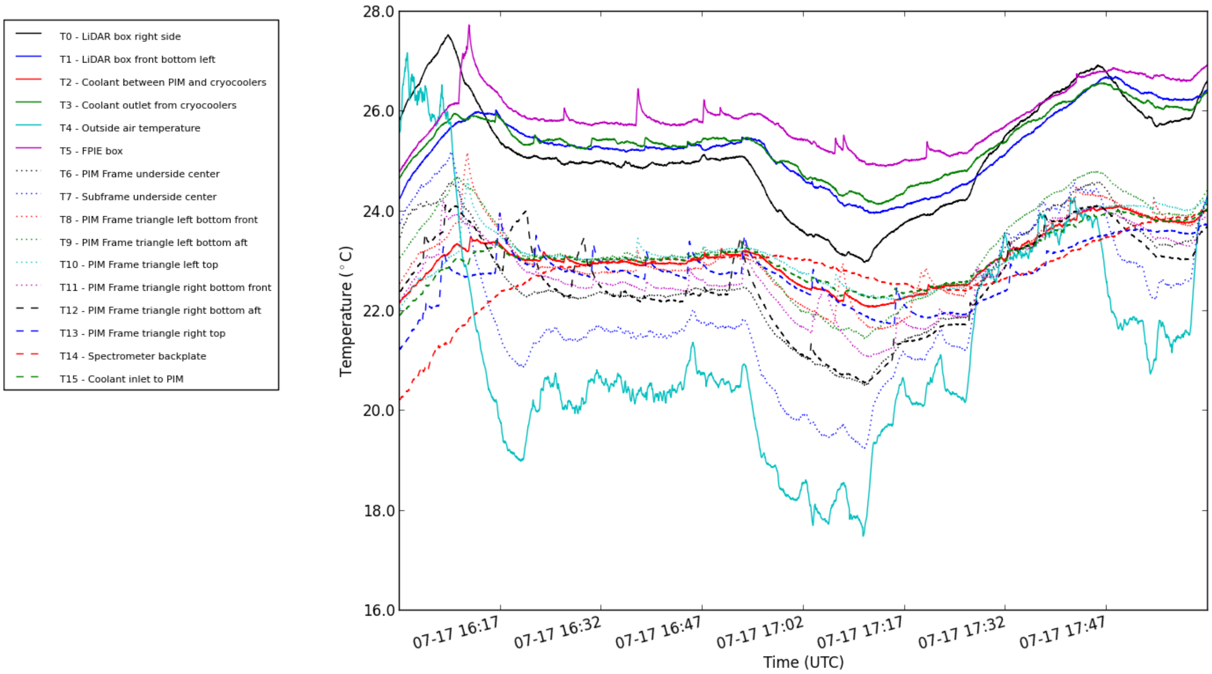


Figure 15: LiDAR and PIM remote monitoring software output

The following common system failures are monitored by the software and result in both an email and text message sent to AOP staff:

- If the temperature associated with a LiDAR thermocouple exceeds a user-defined threshold (nominally 35 C), an alert will be email/text alert will be sent indicating the system is close to exceeding the manufacturer's rated temperature.
- If the NIS spectrometer system enters "Safe Mode", an alert will be sent indicating an error in the environmental control system and requires an attention.
- If either the focal plane temperature or chamber pressure exceeds a user-specified value, the software will email AOP staff that an error has occurred. This is particularly useful if either the spectrometer temperature or pressure deviates from nominal conditions, enabling an AOP instrument scientist to quickly return to the hangar and take corrective action.
- If the Uninterruptible Power Supply (UPS) indicates that ground power has been disrupted, an error message will be sent to AOP staff, allowing for AOP staff to quickly respond to power failure events and take corrective action.

4 AIRCRAFT DEPLOYMENT

The Domain 17 sites were flown June 9-15, 2013 following a series of test and engineering flights conducted in Grand Junction, CO from May 28-June 7 to ensure proper instrument operation and to collect initial boresite and geo-calibration data. The major objectives of the combined Domain 17 airborne and field campaigns were: 1) to obtain domain-wide operational flight and ground sampling experience using the nominal instrument parameters that will be employed during NEON's operational phase; 2) to develop a spectral database of dominant vegetation species in the Domain

17 sites; 3) to obtain an domain-wide set of airborne spectroscopic, discreet LiDAR and waveform LiDAR, and high-resolution photography data for the Domain 17 sites that supports spatial/temporal scaling studies currently underway as part of the NASA HyspIRI Preparatory Airborne Project; and 4) to conduct a transect airborne acquisition across the elevation gradient.

NEON AOP typically aims to collect data at or near the peak of the growing season at each site. For Soaproot Saddle and Teakettle, the timing is less critical since these ecosystems are dominated by conifers. However, SJER has a limited growing season and in order to capture vegetation during its primary growth period, airborne surveys should nominally be scheduled to occur February through April. In 2013, the instrument integration, testing and engineering schedule did not permit a D17 flight campaign during the February-April peak greenness window, but NEON will adhere to this schedule once in operational mode.

A major operational challenge is conforming to the optimal time-of-day for surveying a site. Ideally, research flights will occur between 10:00 am and 2:00 pm local time in order to limit solar angles, thereby minimizing uncertainties in atmospheric correction, limiting the amount of shadowing retrieved in the data, while increasing the intensity of reflected radiation available for spectrometer and camera measurements. However, in practice we found that it was often necessary to initiate surveys earlier in the day (8:00 am-9:00 am) due to mid-to-late morning cirrus and cumulus cloud formation that prevented acquisition of acceptable cloud-free data.

4.1 Flight Planning for Nominal Science Data Acquisition

Determination of the specific flight boxes (delimited areas where remote sensing data should be acquired) at SJER, Soaproot Saddle and Teakettle involved an analysis of the landscape scale ecological, geophysical and bioclimatic attributes and trends most closely associated with the primary science questions NEON is addressing at each site. An effort was made to capture the range of spatial and temporal variability in these attributes -- at each site and across multiple sites – in such a way as to enable the science community to extrapolate across multiple scales, from organisms to landscapes to domain- and continental-scales using a variety of field and remotely sensed data.

SJER is a minimally managed, core wildland site selected by NEON as highly representative of the domain in terms of vegetation, soils/landforms, climate, and ecosystem performance[10]. While SJER (18.2 km^2) is only a moderate size NEON site, it is located at the boundary of a climatic transition zone where historical patterns of temperature and precipitation change significantly from north to south, closely associated with abrupt changes in topography at the southern border of the site (Figure 16, Figure 17). Functional vegetation types reflect this change in climate and topography (Figure 18). To ensure the variability of climate, topography and vegetation were captured within the nominal AOP data acquisition, we extended the flight box beyond the property boundary of SJER to cover the transition zone from cooler temperatures and higher precipitation patterns in the northeast, to warmer temperatures and lower precipitation patterns to the south. Additional criteria for flight box delineation included the importance of capturing land management practices and possible edge

[10] Schimel, D.S., "NEON Observatory Design," NEON Doc. #: NEON.DOC.000001. Rev. D, 05/16/2013.

effects from farming properties 1-2 km to the east of SJER[11]. The maximum extent of the flight box (8.0 km x 9.2 km) was constrained by the flight budget available for data acquisition.

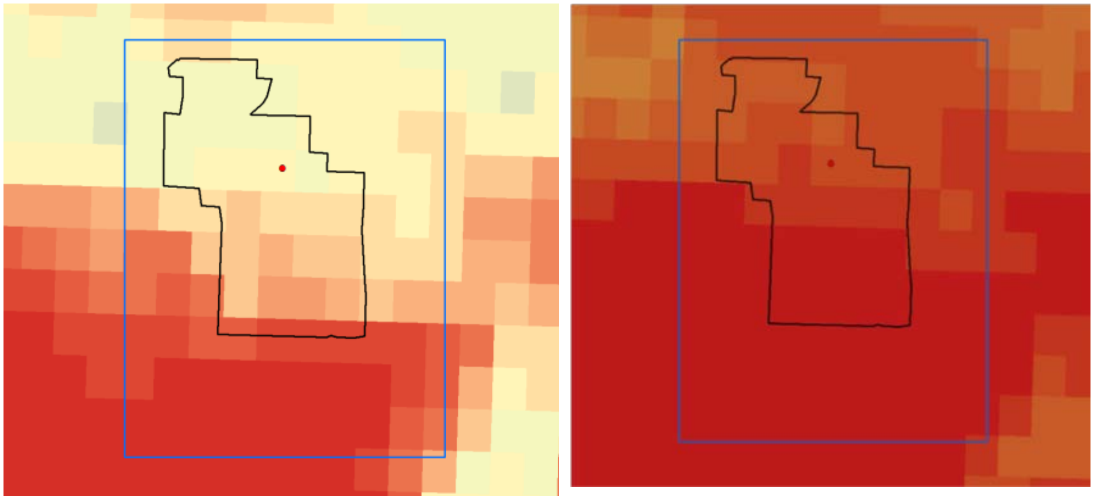


Figure 16: (left) Average Annual Minimum Temperature (1981-2010)[12] and (right) Average Annual Maximum Temperature (1981-2010)[12] in vicinity of SJER (red = higher T°). Flight box outlined in blue.

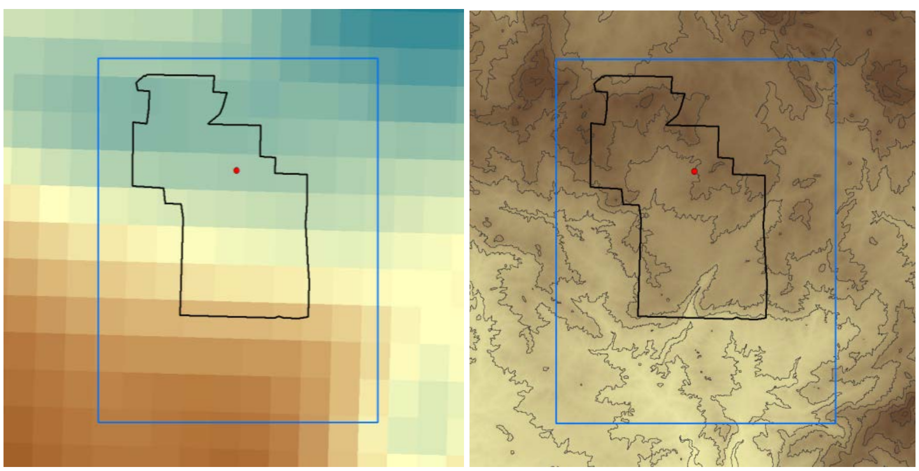


Figure 17: (left) Average Annual Precipitation (1981-2010)[12] and (right) terrain elevations[13] in vicinity of SJER (brown = lower PPT)

[11] Personal communication with R. Denton, SJER Range Conservationist, USDA-USFS.
[12] PRISM Climate Group, Oregon State University, created Feb 2013, http://prism.oregonstate.edu.
[13] Gesch, D.B., 2007, "The National Elevation Dataset," in Maune, D., ed., *Digital Elevation Model Technologies and Applications: The DEM User's Manual*, 2nd Edition: Bethesda, Maryland, American Society for Photogrammetry and Remote Sensing, p. 99-118.

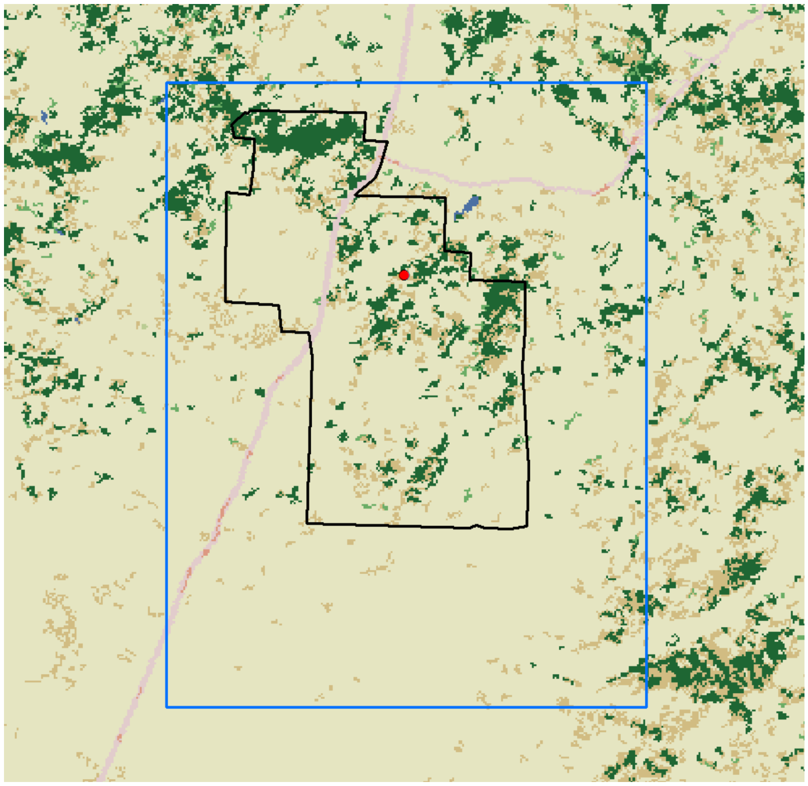


Figure 18: Vegetation types[14] in vicinity of SJER

With one minor exception, the flight lines used to cover the flight boxes for the three terrestrial sites and aquatic site were oriented in a north-south direction for the purpose of minimizing the bidirectional reflectance effects (BRDF) in the airborne spectroscopic data[15]. Thus, flight lines for the SJER property (core site) were oriented north-south; however, for the southern portion of the SJER flight box outside of the SJER property (a lower priority area than the property itself), flight lines were oriented in an east-west direction to minimize flight time and cost (Figure 19). Each day's flight plan also included a cross-strip used to cross-calibrate the LiDAR data swaths to one another.

[14] Fry, J., Xian, G., Jin, S., Dewitz, J., Homer, C., Yang, L., Barnes, C., Herold, N., and Wickham, J., "Completion of the 2006 National Land Cover Database for the Conterminous United States," PE&RS 77, no. 9 (2011):858-864.
[15] Román, M.O., C.K. Gatebe, C.B. Schaaf, R. Poudyal, Z.Wang, M.D. King,, "Variability in surface BRDF at different spatial scales (30 m–500 m) over a mixed agricultural landscape as retrieved from airborne and satellite spectral measurements," *Remote Sensing of Environment*, 115 (2011):2184-2203.

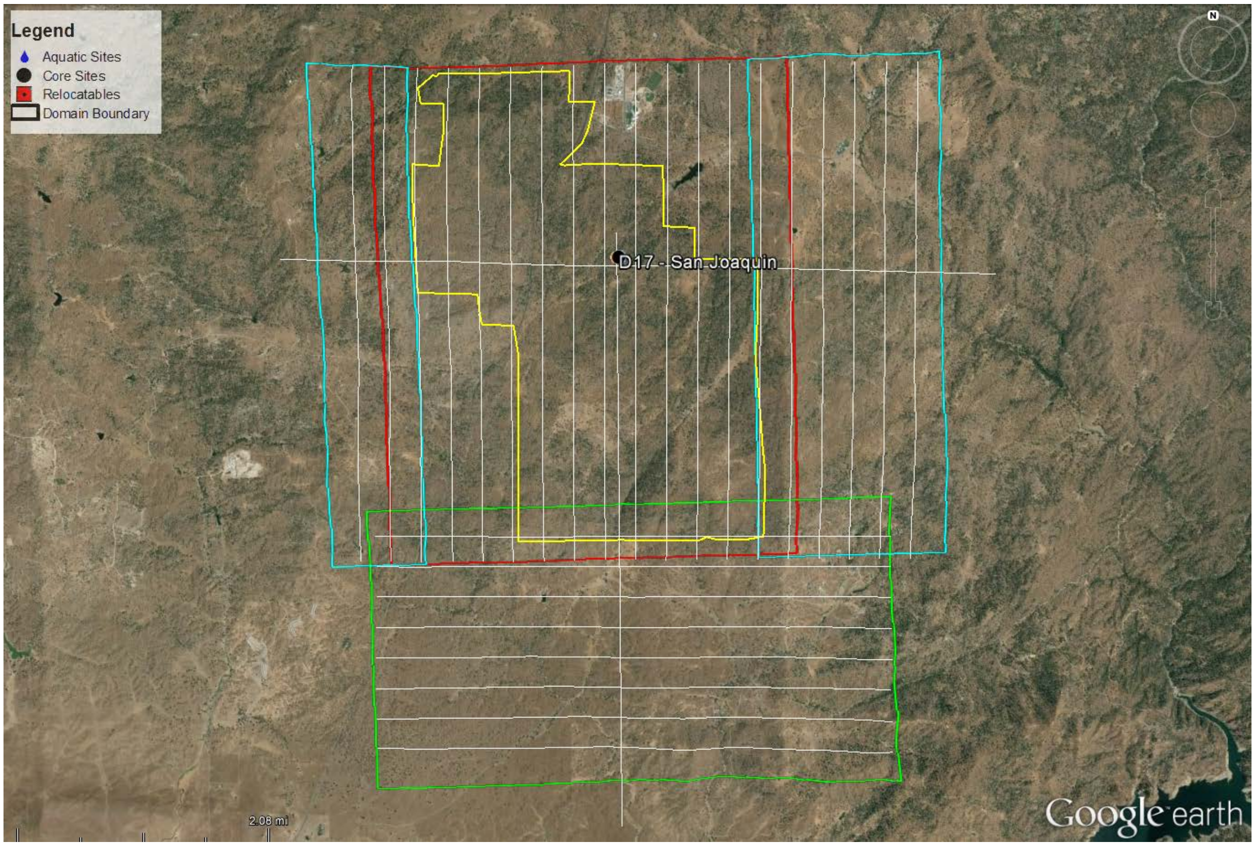


Figure 19: Flight lines for SJER (flight box 1=red; flight box 2=green; flight box 3=blue)

Flight box delineation for the Soaproot Saddle relocatable site followed the same general principles, though the elevation, temperature and precipitation patterns were less variable within the site boundary than within the boundary of SJER (Figure 20, Figure 21). Soaproot Saddle occupies a relatively small area (4.0 km x 1.5 km) with the long axis oriented in an east-west direction, which made north-south flight lines relatively inefficient to fly as most of the flight time would then be spent in turns. Expanding the flight box 1.5 km to the north and 1.5 km to the south of the site enabled us to include areas characterized by greater historical climate variability and topographic variation while improving the efficiency of the flight pattern (Figure 23).

Delineation of the flight box for the Providence creek aquatic site was based exclusively on the boundaries of the associated upstream watershed (King’s River Experimental Watershed - KREW) (Figure 22).

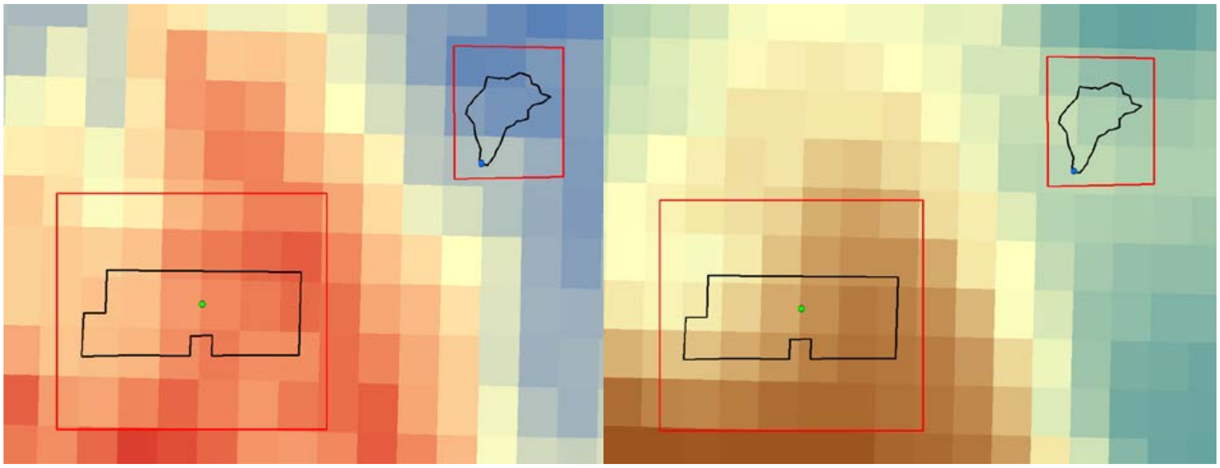


Figure 20: (left) Average Annual Maximum Temperature (1981-2010) and (right) Average Annual Precipitation (1981-2010) in vicinity of Soaproot Saddle (west) and KREW/Providence Creek aquatic site (east). Flight boxes outlined in red.

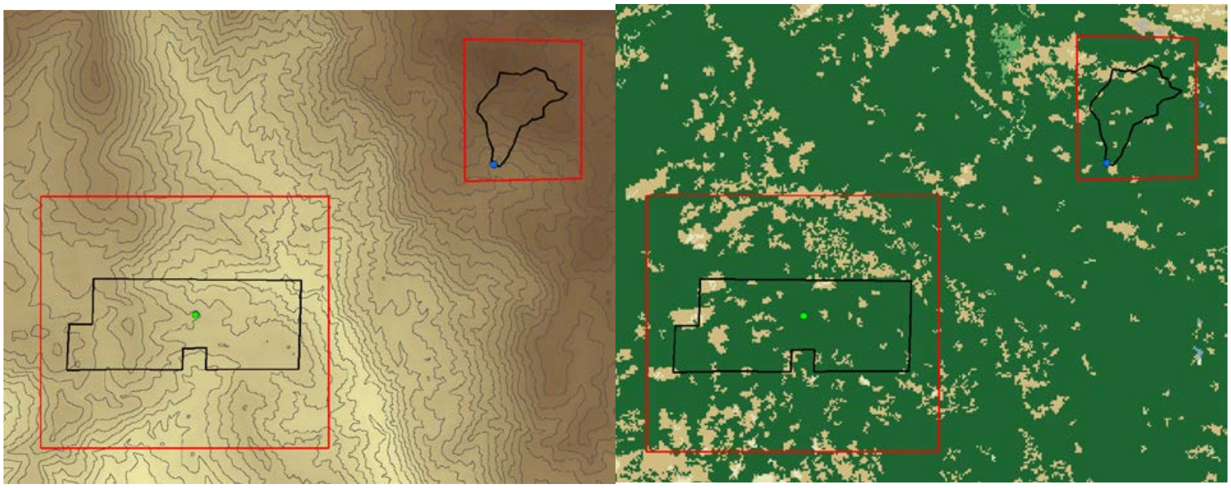


Figure 21: (left) terrain elevations and (right) broad-scale vegetation types in vicinity of Soaproot Saddle

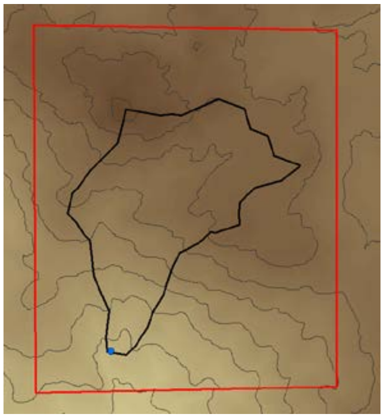


Figure 22: King's River Experimental Watershed boundary. Flight box outlined in red.

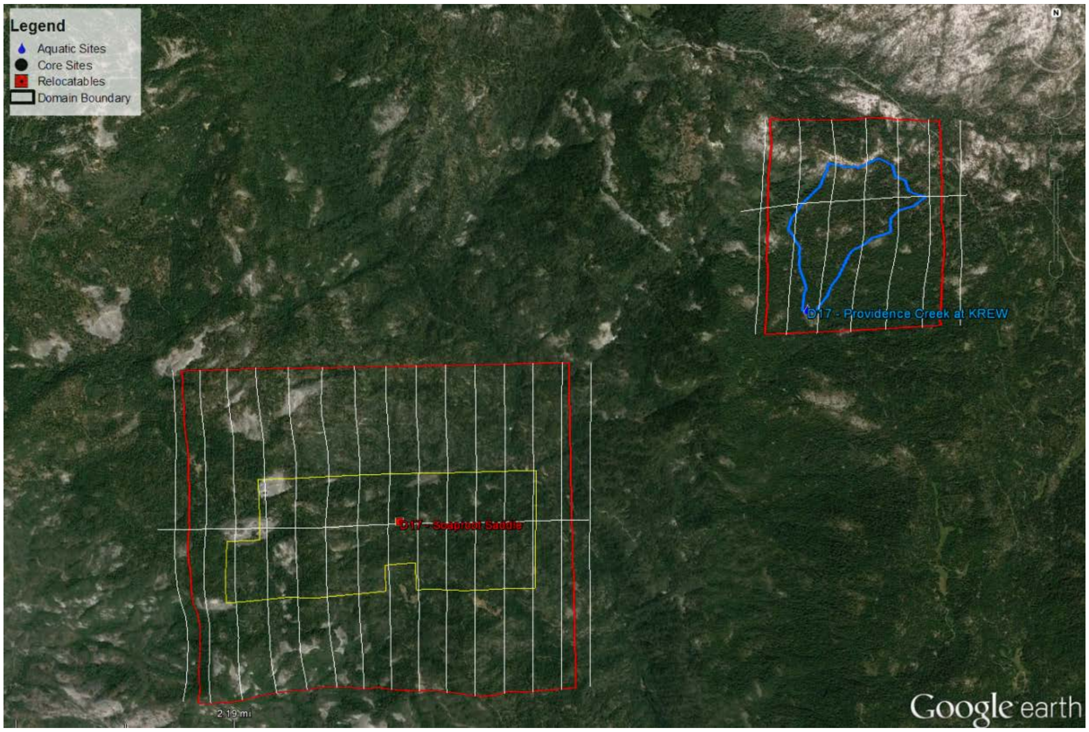


Figure 23: Flight lines for Soaproot Saddle and KREW/Providence Creek aquatic site (flight boxes in red)

Flight box delineation for the Teakettle relocatable site was mainly constrained by the size of the area (100.40 km^2), the diversity of the terrain and the resulting large number of flight hours required to cover the site. The steep mountain slopes and wide range in elevations, in particular, presented unique challenges and limited airborne surveys to the boundary of the site. Since the Teakettle Experimental Range already captures most of the vegetation and climate variability in the area (Figure 24, Figure 25), flight plans were developed to obtain nominal NEON AOP data over the entire site plus an extension to the southeast to enable adequate coverage of the riparian forests that form the southeast boundary of the site (Figure 26). This extension also led to improved flight efficiency since less time would be spent in turns (during which time data acquisition is suspended).

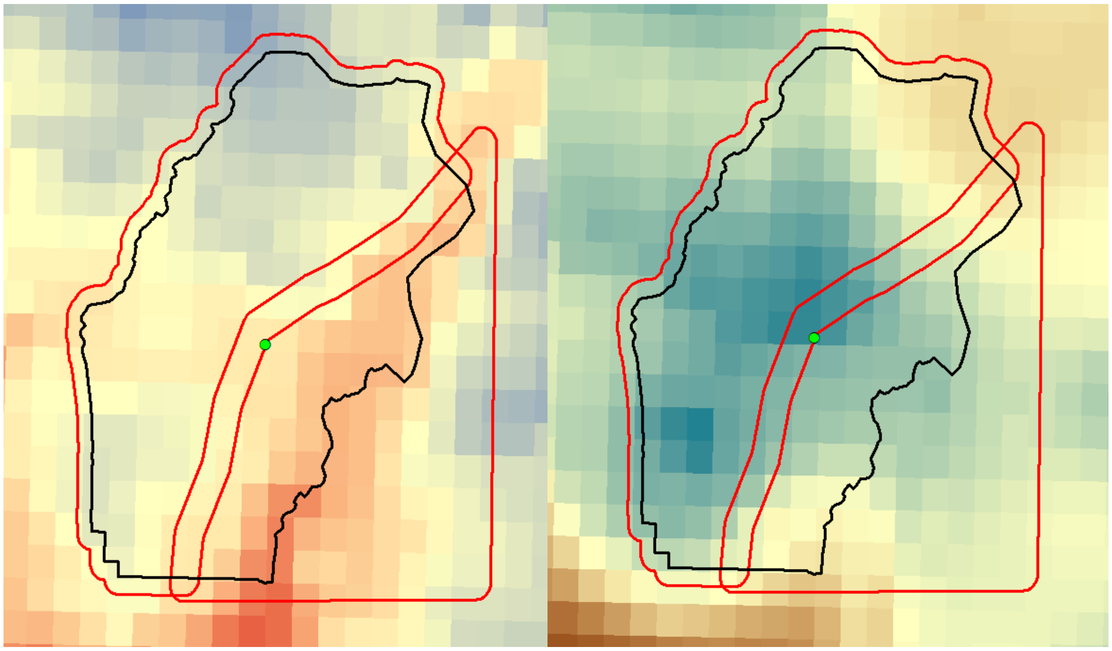


Figure 24: (left) Average Annual Maximum Temperature (1981-2010) and (right) Average Annual Precipitation (1981-2010) in vicinity of Teakettle (flight boxes in red)

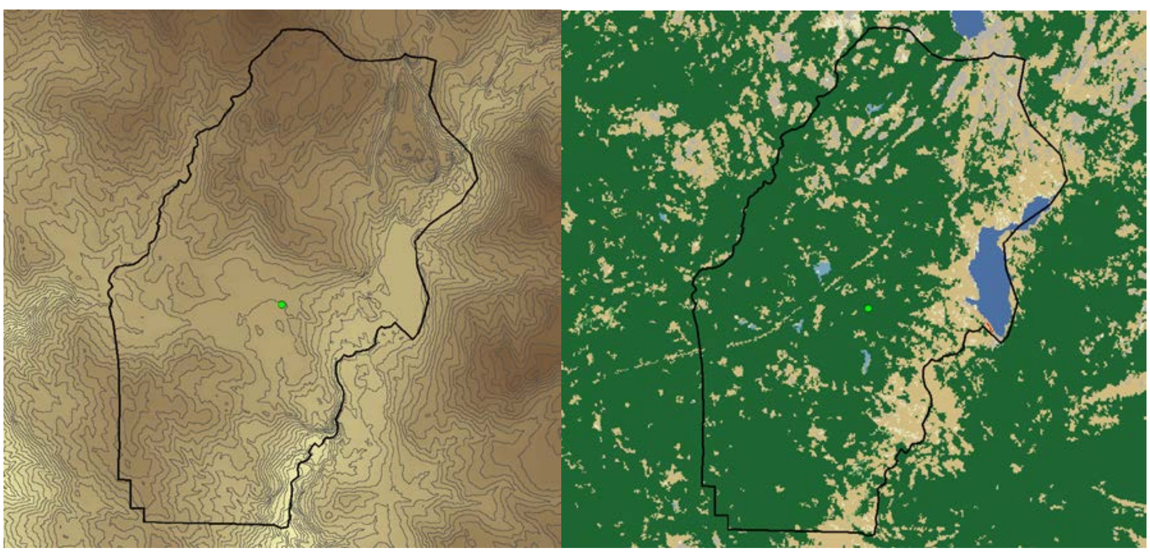


Figure 25: (left) terrain elevations and (right) broad-scale vegetation types in vicinity of Teakettle

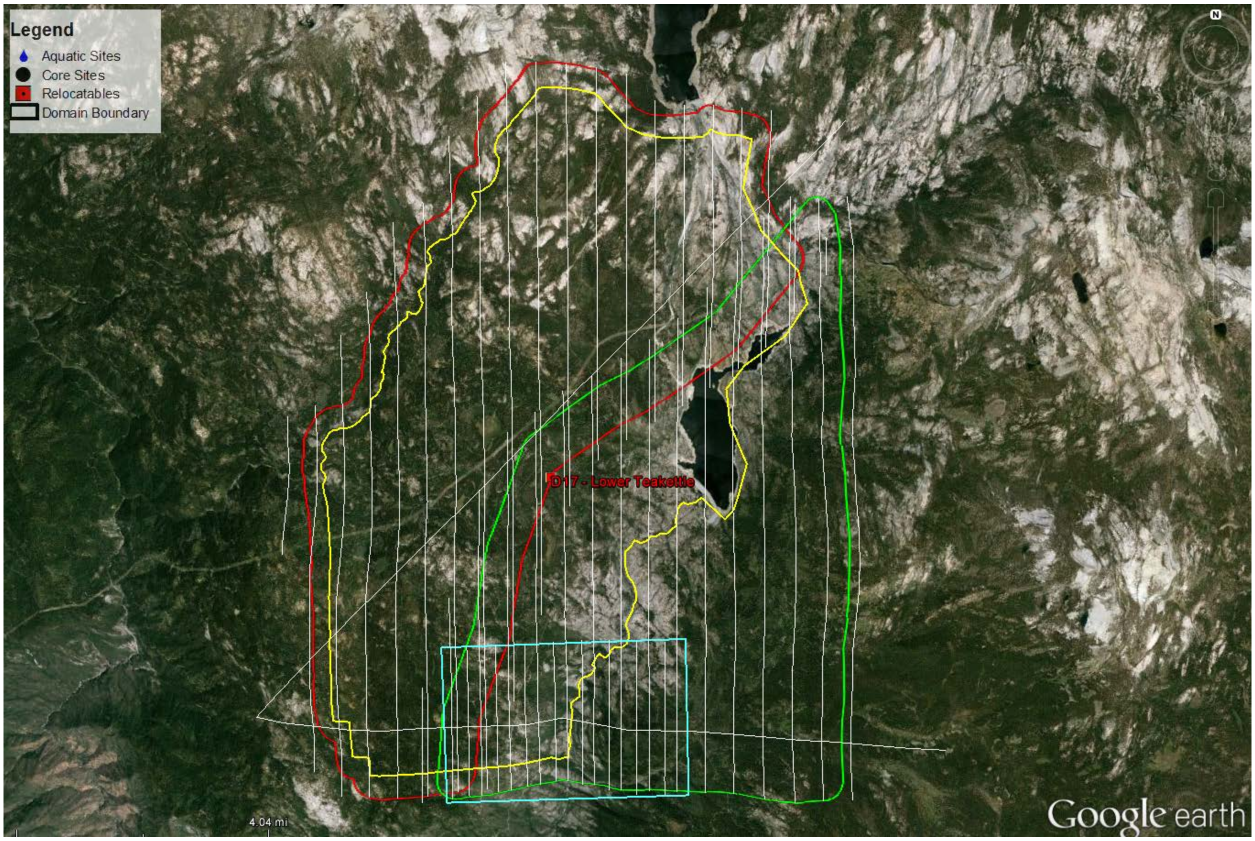


Figure 26: Flight lines for Teakettle (flight box 1=red; flight box 2=green; flight box 3=blue)

An elevation gradient transect was appended to the nominal science flights in SJER, Soaproot Saddle and Teakettle for the purpose of acquiring a narrow swath of remote sensing data covering the range of topography, climate and land cover linking the three terrestrial sites to one another (Figure 27, Figure 28). While it would not be possible to fully calibrate it with field measurements due to its longitudinal extent, the elevation gradient transect would provide additional, spatially contiguous information for tracking vegetation responses to variability in the rain-snow transition due to a warming climate[2]. The transect was delineated to include the NEON tower site locations at SJER, Soaproot Saddle and Teakettle; the McKinley Grove of Giant Sequoias west of Teakettle; and the San Joaquin River riparian zone near Redinger Lake. The McKinley Giant Sequoias Grove provided an opportunity to test the sensitivity of the LiDAR returns over vegetation that exceeds 50m in height. Finally, the San Joaquin River zone represented an area of highly variable terrain (elevation and aspect) as well as potentially unique vegetation structure and type.

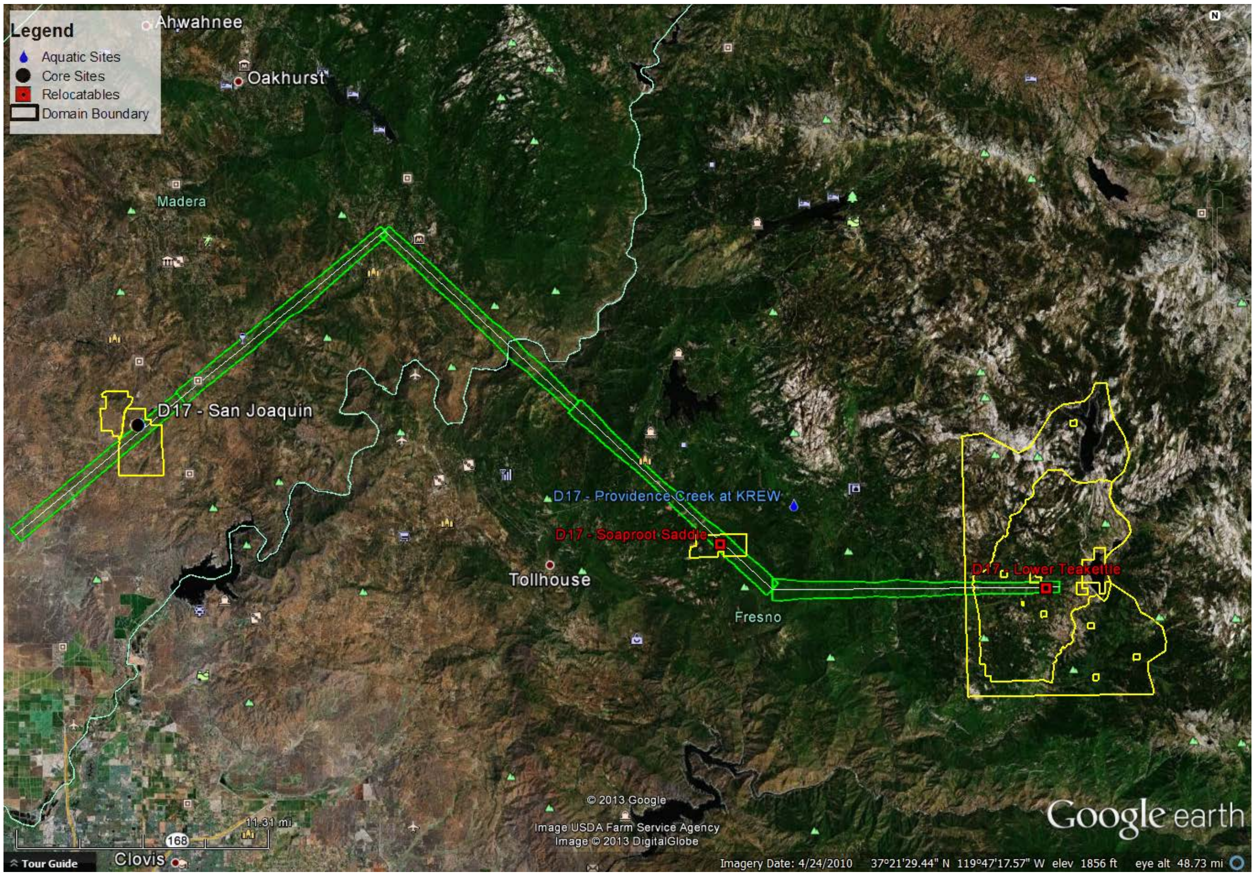


Figure 27: Elevation Gradient Transect

Figure 28: Elevation change along gradient transect from SJER (left) to Teakettle (right)

In addition to nominal data acquisition flights over each terrestrial and aquatic site, AOP conducted two special purpose flights over intact, closed-canopy forest stands in SJER and Soaproot Saddle. The parameters of the flights were modified to acquire multi-angle AOP data to test approaches for characterizing and mitigating BRDF effects in the hyperspectral imagery (Figure 29)[16].

[16] Colgan MS, Baldeck CA, Féret J-B, Asner GP, "Mapping Savanna Tree Species at Ecosystem Scales Using Support Vector Machine Classification and BRDF Correction on Airborne Hyperspectral and LiDAR Data," *Remote Sensing*, 4, no.11 (2012):3462-3480.

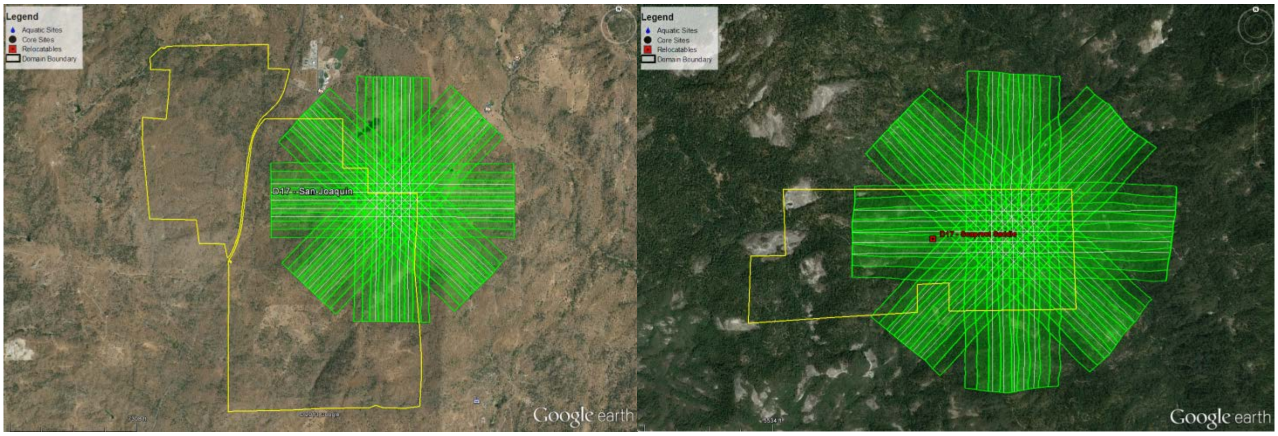


Figure 29: BRDF flight lines in SJER and Soaproot Saddle.

4.2 Flight Parameters

Table 3: Flight parameters for Optech Gemini LiDAR and D8900 digital camera

Site	Date	Mean AGL (m)	Flight Line Overlap (%)	PRF (Hz)	Beam Width	Half Scan Angle (deg)	Scan Freq (Hz)	Photo Overlap (%)	Pixel Res. (m)	Trigger Time (sec)
SJER	6/9, 6/11, 6/13	1000	37.2	100	Wide	18.5	50	50	8.5	5.7
BRDF (SJER)	6/11	1000	37.2	100	Wide	18.5	50	50	8.5	5.7
Soaproot Saddle	6/12	1000	37.2	100	Wide	18.5	50	50	8.5	5.7
Providence Creek	6/12	1000	37.2	100	Wide	18.5	50	50	8.5	5.7
Teakettle	6/14, 6/15	1500	39.7	70	Wide	19.2	33.3	50	12.7	8.6
BRDF (Soaproot)	6/15	1000	37.2	100	Wide	18.5	50	50	8.5	5.7
Elevation Gradient Transect	6/12, 6/14	1500	39.7	70	Wide	19.2	33.3	50	12.7	8.6

The aircraft flew an average 97-knot ground speed with a 30% overlap and 1m pixel resolution for the spectrometer.

The AOP instrument parameters for nominal science data acquisition at the D17 terrestrial and aquatic sites are shown in Table 3. Flight parameters for 1000m mean AGL were maintained for all flights with the exception of Teakettle and the elevation gradient transect flights. For both Teakettle and the elevation gradient transect the mountainous terrain and abrupt changes in elevation made it difficult to acquire LiDAR data using standard flight parameters at 1000m mean AGL without experiencing extensive LiDAR data drop-outs and inter-swath gaps in the spectrometer data. Flight plans and instrument parameters were therefore adjusted to accommodate a mean flight altitude of 1500m, which enabled a more consistent flight pattern and reduced data acquisition time at Teakettle, with the trade-off being a lower points-per-meter squared LiDAR resolution (3.82 ppm^2 @ 1000m AGL vs. 1.7 ppm^2 @ 1500m AGL). All flight altitudes and associated LiDAR parameters were designed to adhere to aided eye-safety ranges for the Gemini instrument.

4.3 D17 Nominal Science Data Acquisition Flights

Flights for the D17 campaign took place from June 9-June 15, 2013 based out of the Fresno Yosemite International Airport in Fresno, CA. The Railroad Valley, NV calibration flight occurred on June 17 during the long-distance transit from Fresno, CA to the Rocky Mountain Municipal Airport in Broomfield, CO. Pre-campaign, we had scheduled the D17 flights to occur June 8-June 18, which included four days of contingency to accommodate poor flying conditions, equipment problems, etc. However, the arrival of the Twin Otter aircraft was delayed by one day due to equipment problems encountered during the pre-season test and engineering flights in Grand Junction, CO.

Table 4 provides a summary of each flight in the campaign. The San Joaquin Experimental Range was flown three times due to high cirrus cloud contamination during the first two flights on June 9 and 11. A cloud-free flight of SJER boxes 1-2 was conducted on the afternoon of June 13, together with a short survey of a fire scar approximately 10 ha in size from a fire earlier that week outside the border of SJER. Soaproot Saddle and KREW/Providence Creek were successfully surveyed on June 12, and sections 2-5 of the elevation gradient transect were acquired during the return to the Fresno airport. Teakettle box 1 was flown on June 14, followed by sections 1-2 of the gradient transect during return to base. The remainder of Teakettle (boxes 2-3) was acquired on the morning of June 15, followed by a second BRDF flight the afternoon of June 15 over Soaproot Saddle. There were no flights on June 10 due to an equipment malfunction that required a one-day road trip to JPL in Pasadena, CA for repair. A morning flight to Teakettle on June 13 was aborted due to lack of navigation data from the IMU to the NIS, likely the result of incorrect system activation.

Table 4: Domain 17 Flight Campaign Summary

Flight ID (cityID-yyyymmdd-DayFlt#Letter)	Wheels Up takeoff time (UTC)		Wheels Down landing time (UTC)		Take-off time (UTC dec.)	Land time (UTC dec.)	Duration (decimal hours)	Cummulative time (decimal hours)	Notes
	hour	minute	hr	min ute					
FR-20130609-A	16	24	19	26	16.40	19.43	3.03	3.03	San Joaquin boxes 1, 2, and most of 3
FR-20130611-A	16	24	20	22	16.40	20.37	3.97	7.00	San Joaquin boxes 1, 2, and San Joaquin BRDF
FR-20130612-A	16	24	19	36	16.40	19.60	3.20	10.20	Soaproot saddle boxes 1 and 2 (Providence Creek), and gradient transect lines 2-5
FR-20130613-A	16	22	17	22	16.37	17.37	1.00	11.20	Teakettle box 1 (priority 1) - flight aborted due to instrument communications problems
FR-20130613-B	20	35	22	33	20.58	22.55	1.97	13.17	Resurvey of San Joaquin boxes 1 & 2 plus fire scar
FR-20130614-A	16	18	19	14	16.30	19.23	2.93	16.10	Teakettle box 1 plus first two sections of gradient transect
FR-20130615-A	16	35	20	3	16.58	20.05	3.47	19.57	Teakettle boxes 2 & 3
FR-20130615-B	22	15	24	12	22.25	24.20	1.95	21.52	BRDF over Soaproot Saddle
FR-20130617-A	16	48	21	35	16.80	21.58	4.78	26.30	Railroad Valley overpasses during ferry from Fresno to Broomfield

Table 5 through Table 13 list the flight line coordinates of the nominal science data collects for each site. Since the aircraft is limited to a maximum of 20° bank during turns in order to maintain GPS fix, flight lines were usually flown in a "race track" or "Zamboni" pattern to minimize the turn-time between flight lines (which accounts for the alternating lat/lon pattern).

Table 5: Flight Lines for San Joaquin Experimental Range - Box 1

	Start		End	
Line	**Latitude**	**Longitude**	**Latitude**	**Longitude**
Cross-strip	37.10848	-119.78139	37.10694	-119.67722
Line 1	37.13105	-119.71173	37.07350	-119.71173
Line 2	37.07335	-119.73887	37.13077	-119.73887
Line 3	37.13100	-119.71625	37.07347	-119.71625
Line 4	37.07333	-119.74339	37.13073	-119.74339
Line 5	37.13096	-119.72078	37.07345	-119.72078
Line 6	37.07331	-119.74791	37.13068	-119.74791
Line 7	37.13091	-119.72530	37.07342	-119.72530
Line 8	37.07328	-119.75243	37.13063	-119.75243
Line 9	37.13086	-119.72982	37.07340	-119.72982
Line 10	37.07326	-119.75696	37.13059	-119.75696
Line 11	37.13082	-119.73434	37.07338	-119.73434
Line 12	37.07323	-119.76148	37.13054	-119.76148

Flight altitude: 4475 ft. above MSL

Table 6: Flight Lines for San Joaquin Experimental Range - Box 2

	Start		End	
Line	**Latitude**	**Longitude**	**Latitude**	**Longitude**
Cross-strip	37.04157	-119.73187	37.11161	-119.73263
Line 2	37.06184	-119.76825	37.06184	-119.69206
Line 3	37.07266	-119.69205	37.07266	-119.76825
Line 4	37.05463	-119.76825	37.05463	-119.69206
Line 5	37.06905	-119.69205	37.06905	-119.76825
Line 6	37.05823	-119.76825	37.05823	-119.69206
Line 7	37.07627	-119.69205	37.07627	-119.76825
Line 8	37.06545	-119.76825	37.06545	-119.69205
Line 9	37.05102	-119.69206	37.05102	-119.76825

Flight altitude: 4000 ft. above MSL

Table 7: Flight Lines for San Joaquin Experimental Range - Box 3

	Start		End	
Line	**Latitude**	**Longitude**	**Latitude**	**Longitude**
Cross-strip	37.10848	-119.78139	37.10694	-119.67722
Line 1	37.13110	-119.70721	37.07352	-119.70721
Line 2	37.07359	-119.69364	37.13122	-119.69364
Line 3	37.13114	-119.70268	37.07354	-119.70268
Line 4	37.07361	-119.68912	37.13122	-119.68912
Line 5	37.13049	-119.76600	37.07322	-119.76600
Line 6	37.07357	-119.69816	37.13119	-119.69816
Line 7	37.13045	-119.77052	37.07322	-119.77052

Flight altitude: 4455 ft. above MSL

Table 8: Flight Lines for Soaproot Saddle

	Start		End	
Line	**Latitude**	**Longitude**	**Latitude**	**Longitude**
Cross-strip	37.03288	-119.29693	37.03323	-119.23365
Line 1	37.01300	-119.23345	37.05246	-119.23345
Line 2	37.05194	-119.26831	37.01234	-119.26831
Line 3	37.01292	-119.23781	37.05246	-119.23781
Line 4	37.05186	-119.27267	37.01225	-119.27267
Line 5	37.01284	-119.24216	37.05244	-119.24216
Line 6	37.05178	-119.27703	37.01217	-119.27703
Line 7	37.01275	-119.24652	37.05236	-119.24652
Line 8	37.05169	-119.28139	37.01209	-119.28139
Line 9	37.01267	-119.25088	37.05228	-119.25088
Line 10	37.05161	-119.28574	37.01200	-119.28574
Line 11	37.01259	-119.25524	37.05219	-119.25524
Line 12	37.05153	-119.29010	37.01197	-119.29010
Line 13	37.01250	-119.25960	37.05211	-119.25960
Line 14	37.05144	-119.29446	37.01197	-119.29446
Line 15	37.01242	-119.26395	37.05203	-119.26395

Flight altitude: 7220 ft. above MSL

Table 9: Flight Lines for KREW/Providence Creek

	Start		End	
Line	**Latitude**	**Longitude**	**Latitude**	**Longitude**
Cross-strip	37.06851	-119.21389	37.06986	-119.18451
Line 1	37.05562	-119.19844	37.07764	-119.19844
Line 2	37.07767	-119.18537	37.05609	-119.18537
Line 3	37.05547	-119.20280	37.07761	-119.20280

Line 4	37.07767	-119.18972	37.05593	-119.18972
Line 5	37.05536	-119.20716	37.07759	-119.20716
Line 6	37.07766	-119.19408	37.05578	-119.19408
Line 7	37.05536	-119.21151	37.07756	-119.21151

Flight altitude: 9575 ft. above MSL

Table 10: Flight Lines for Teakettle - Box 1

	Start		End	
Line	**Latitude**	**Longitude**	**Latitude**	**Longitude**
Cross-strip	36.95671	-119.08169	37.07671	-118.93247
Line 1	37.07843	-118.96597	37.02379	-118.96597
Line 2	37.04583	-118.93761	37.05371	-118.93761
Line 3	37.07843	-118.97306	37.02011	-118.97306
Line 4	37.03890	-118.94470	37.06063	-118.94470
Line 5	37.07928	-118.98015	37.01686	-118.98015
Line 6	37.03197	-118.95179	37.07755	-118.95179
Line 7	37.08392	-118.98724	37.01327	-118.98724
Line 8	37.02781	-118.95888	37.07839	-118.95888
Line 9	37.08441	-118.99433	37.00927	-118.99433
Line 10	36.94225	-119.02269	37.07850	-119.02269
Line 11	37.08441	-119.00142	37.00004	-119.00142
Line 12	36.94225	-119.02978	37.07152	-119.02978
Line 13	37.08437	-119.00851	36.97807	-119.00851
Line 14	36.94225	-119.03687	37.05957	-119.03687
Line 15	37.08413	-119.01560	36.96051	-119.01560
Line 16	36.94226	-119.04396	37.05566	-119.04396
Line 17	37.02011	-119.06523	36.94692	-119.06523
Line 18	36.94227	-119.05105	37.04236	-119.05105
Line 19	37.01787	-119.07232	36.99055	-119.07232
Line 20	36.94229	-119.05814	37.03406	-119.05814

Flight altitude: 12555 ft. above MSL

Table 11: Flight Lines for Teakettle - Box 2

	Start		End	
Line	**Latitude**	**Longitude**	**Latitude**	**Longitude**
Cross-strip	36.95671	-119.08169	36.95299	-118.90942
Line 1	36.94216	-118.96015	37.05024	-118.96015
Line 2	37.06199	-118.93179	36.94278	-118.93179
Line 3	36.94201	-118.96724	37.04331	-118.96724
Line 4	37.06200	-118.93888	36.94262	-118.93888
Line 5	36.94186	-118.97433	37.03744	-118.97433

Line 6	37.06200	-118.94597	36.94247	-118.94597
Line 7	36.94170	-118.98142	37.03341	-118.98142
Line 8	37.05717	-118.95306	36.94232	-118.95306
Line 9	36.94155	-118.98850	37.02958	-118.98850
Line 10	37.01488	-119.01686	36.94093	-119.01686
Line 11	36.94140	-118.99559	37.02607	-118.99559
Line 12	37.00339	-119.02395	36.94080	-119.02395
Line 13	36.94124	-119.00268	37.02289	-119.00268
Line 14	36.98211	-119.03104	36.94080	-119.03104
Line 15	36.94109	-119.00977	37.01888	-119.00977
Line 16	36.96388	-119.03813	36.94091	-119.03813

Flight altitude: 11935 ft. above MSL

Table 12: Flight Lines for Teakettle - Box 3

	Start		**End**	
Line	**Latitude**	**Longitude**	**Latitude**	**Longitude**
Cross-strip	36.95671	-119.08169	36.95299	-118.90942
Line 1	36.94104	-118.97745	36.97224	-118.97745
Line 2	36.97224	-119.00578	36.94104	-119.00578
Line 3	36.94104	-118.98453	36.97224	-118.98453
Line 4	36.97224	-119.01286	36.94104	-119.01286
Line 5	36.94104	-118.99161	36.97224	-118.99161
Line 6	36.97224	-119.01994	36.94104	-119.01994
Line 7	36.94104	-118.99869	36.97224	-118.99869
Line 8	36.97224	-119.02702	36.94104	-119.02702

Flight altitude: 11195 ft. above MSL

Table 13: Flight Segments for Elevation Gradient Transect

	Start		**End**		**Flight Alt. (ft. above MSL)**
Segment	**Latitude**	**Longitude**	**Latitude**	**Longitude**	
Segment 1	37.00608	-118.99531	37.00384	-119.22090	10860
Segment 2	37.00384	-119.22090	37.12085	-119.37920	9300
Segment 3	37.12085	-119.37920	37.23301	-119.53206	7475
Segment 4	37.23301	-119.53206	37.12595	-119.69800	6805
Segment 5	37.12595	-119.69800	37.03693	-119.83336	5845

The following figures depict the flight tracks and associated spectrometer swaths (non ortho-corrected) of the June 12 Soaproot Saddle/KREW flight (Figure 30), June 13 SJER flight (Figure 31), and June 14-15 Teakettle flights (Figure 32, Figure 33).

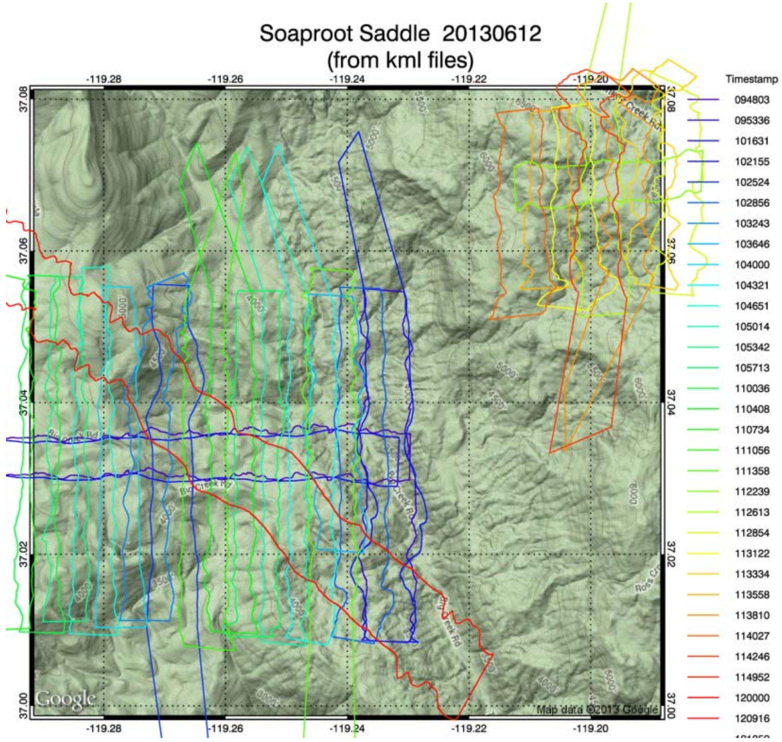


Figure 30: Flight tracks and spectrometer swaths for June 12 flight over Soaproot Saddle and KREW/Providence Creek

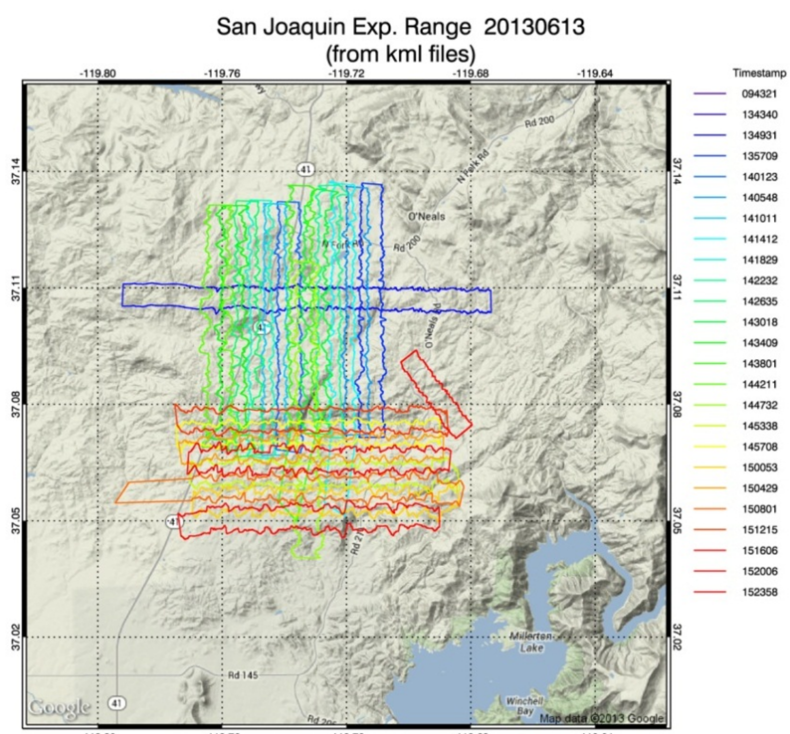


Figure 31: Flight tracks and spectrometer swaths for June 13 flight over SJER

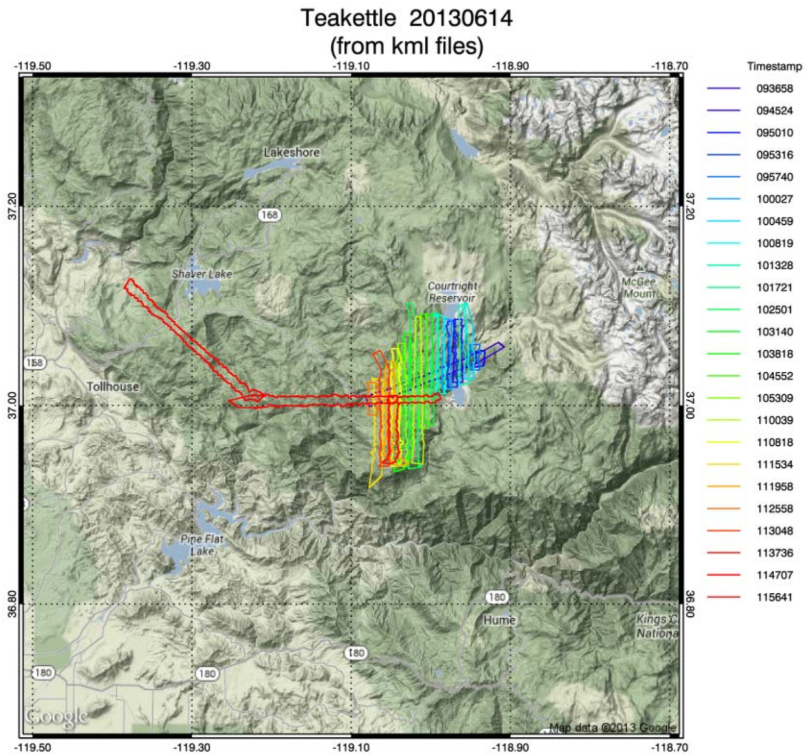


Figure 32: Flight tracks and spectrometer swaths for June 14 flight over Teakettle

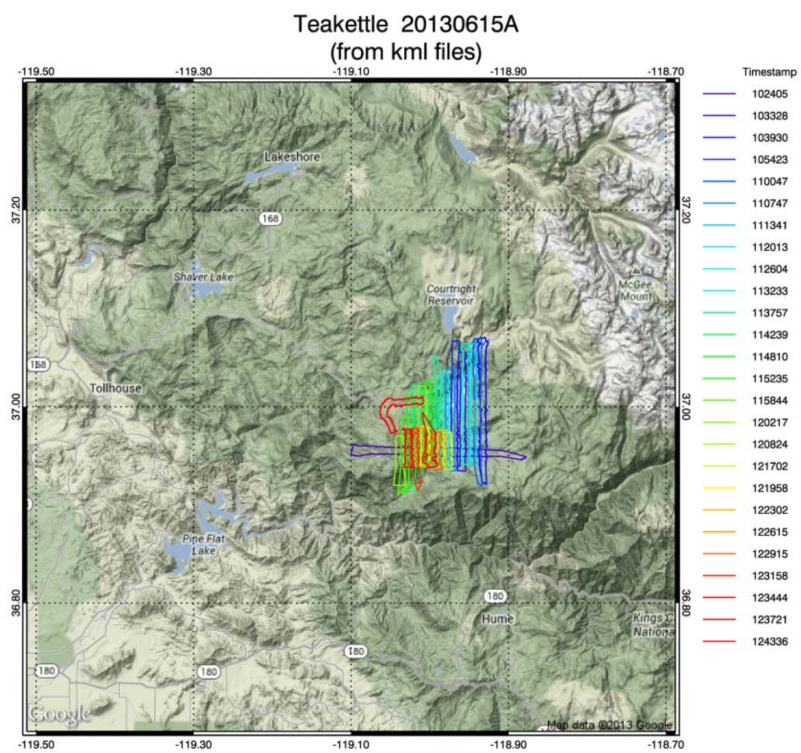


Figure 33: Flight tracks and spectrometer swaths for June 15 flight over Teakettle

5 FIELD DATA COLLECTION

The NEON flight campaign in D17 was held coincident with both the NASA HyspIRI Preparatory Airborne Project and the ongoing NASA Ecological Spectral Information System (EcoSIS) Project (described in 8. COLLABORATIONS below). This allowed multiple groups to leverage field and airborne data collections activities for all three efforts simultaneously.

In conjunction with airborne data acquisition, NEON AOP collects field data that are used to radiometrically calibrate and validate the data produced by the AOP payload and to build a spectral library of the surface reflectance characteristics of the site being flown (Table 14). Field data collection involves non-destructive sampling of the spectral reflectance of dominant plant species and soil/ground surfaces using an Analytical Spectral Devices (ASD) Fieldspec-3 portable field spectrometer.

Table 14: NEON AOP Ground Measurement Instrumentation

Parameter(s) Measured	***Instrument and Measurement Method***
Leaf Area Index (LAI)	LiCOR 2200
Vegetation structure (diameter at breast ht., canopy height and width)	Standard forestry tools
Plant biodiversity	Visual census
Aerosol Optical Depth (AOD)	CIMEL sun photometer
Temperature, pressure, wind speed and direction, relative humidity	Kestrel 4500 Pocket Weather Station
Spectral reflectance of various plant species (350-2500 nm)	ASD FieldSpec 3
Spectral reflectance of calibration target (at 350-2500 nm)	ASD FieldSpec 3
Differential GPS positions	Trimble R5

In addition to the spectral reflectance readings of dominant plants and soil/ground cover substrate, atmospheric data are collected using a CIMEL sun photometer that measures the transmitted solar irradiance as well as the diffuse sky irradiance (the blue portion of the sky). (Figure 34). These data are used to atmospherically correct the airborne imagery. Standardized calibration data are collected by deploying two 10 m x 10 m Tracor reference reflectance tarps of 3% and 48% reflectance (Figure 35). A tripod-mounted Trimble R5 GPS base station is placed in a fixed location to help differentially correct the airborne IMU data and hand-held GPS measurements obtained during field data collection. And a Kestrel digital weather station is located in close proximity to record temperature, barometric pressure, relative humidity and wind speed for use in atmospheric correction.

Figure 34: Setting up the CIMEL sun photometer (left), Trimble GPS base station (middle), Kestrel weather station (right) and Tracor tarp (behind) in SJER.

For the D17 campaign, field teams were sent to SJER and Soaproot Saddle to set up the CIMEL, Trimble base station, tarps and Kestrel electronic weather station at central locations relative to the airborne surveys. ASD field measurements were also collected at distributed plot locations that have been established by NEON's Field Sentinel Unit (FSU) for long-term plant, insect and soil measurements. Ground measurements collected by AOP included vegetation spectra, sub-plot transect spectra, and plant species identification. A NEON FSU team was also in the field with the AOP team to collect vegetation samples (labeled and bagged for subsequent biogeochemistry analyses) and biomass vegetation from each transect site following spectral data collection.

Figure 35: Measuring spectral reflectance with ASD field spectroradiometer over reference reflectance tarp.

The foliar leaf spectra data collected at both SJER and Soaproot Saddle support the NEON flight campaign, the HyspIRI Preparatory Airborne Project and the NASA Ecological Spectral Information System (EcoSIS) Project. Transect subplots and comparisons between spectrometer data collects (e.g., instrument/accessory differences, protocol differences, etc.) were only performed at SJER; these will be used to evaluate NEON ground spectral sampling protocols and will also be used by the EcoSIS project to support assessments of "best field practices" for future spectral data collection efforts.

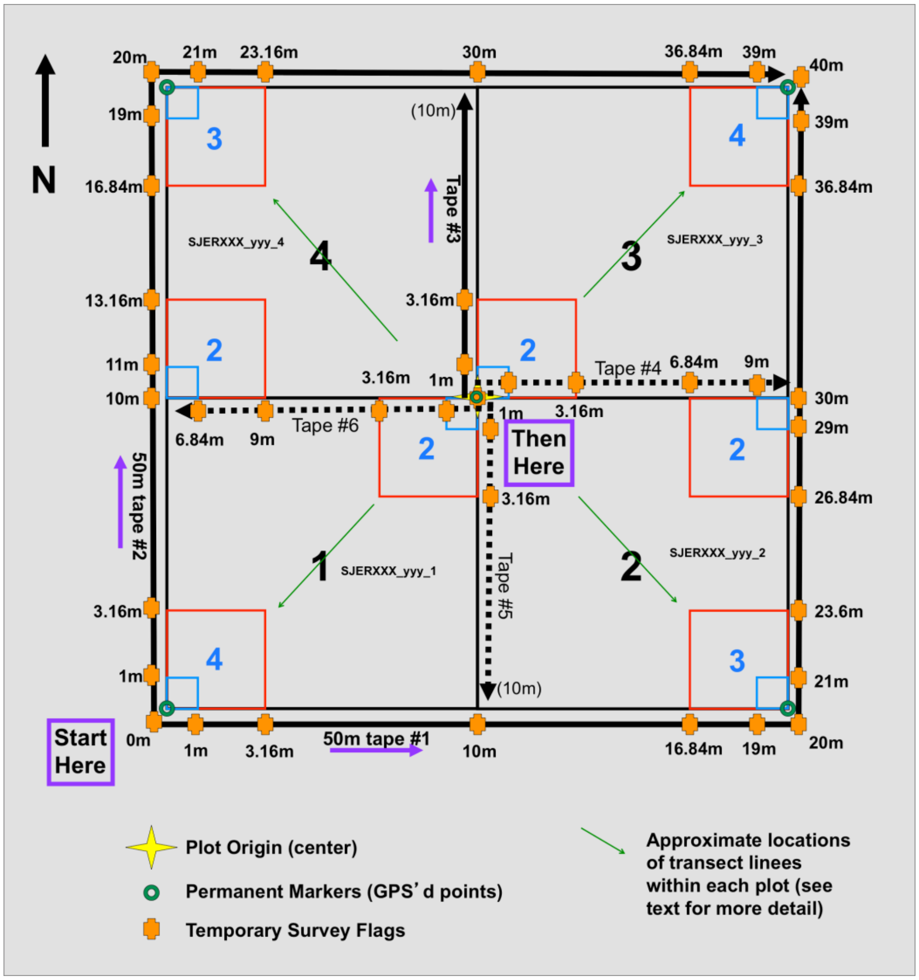


Figure 36: Plot outlines for SJER and Soaproot Saddle[17]

Plots at both SJER and Soaproot Saddle were characterized using the plot-sampling outline illustrated in Figure 36. For the spectral data collections at SJER, transects in the predominantly grassy plots were identified along the diagonals shown in green; along each diagonal, a 2 m long x 20 cm wide transect area was marked off. Foliar data collections were restricted to shrubs/trees identified and marked within the 20 x 20 m plot area. A Spectralon reflectance panel -- mounted and leveled on a tripod and centrally-located in reference to all four transects within a plot – was used to calibrate/validate the ASD spectral measurements of vegetation (Figure 37).

[17] Peet, R.K., T.R. Wentworth, P.S. White, "A flexible, multipurpose method for recording vegetation composition and structure," *Castanea*, 63, no. 3(1998):262-274.

Figure 37: Preparing a Spectralon reflectance panel used to calibrate ASD measurements

The following tables summarize the specific NEON plots where transect/foliar spectral data were collected at SJER and Soaproot Saddle. At SJER, both foliar measurements and transect measurements over vegetation subplots were acquired (Table 15); only foliar measurements were collected at Soaproot Saddle, although a single transect across the granite dome base-station site was also collected (Table 16).

Transect spectral data were acquired using the following protocol: Transects are marked with flags within each quadrant. The ASD is optimized/calibrated before each data collection using the Spectralon reflectance panel. Five spectra are averaged by holding the fore-optic parallel to and 10-12” above the surface of the panel. Spectral measurements of the transect are then collected starting from the center of the plot at the leading edge of the first transect and away from the sun. The ASD operator walks slowly along the 2m transect, collecting five spectra that are averaged while the fore-optic is held parallel to the surface of the ground at approximately 24” height. Finally, five more averaged calibration spectra are collected over the reference reflectance panel (Figure 38).

Figure 38: Transect Protocol: collecting reflectance data over the Spectralon panel (middle); collecting spectra over transect subplot (right)

Table 15: Summary of ASD Spectrometer files for data collected at San Joaquin (SJER).

Domain 17 Core Site: San Joaquin				
Plot - Morton ID	**Cover Type**	**Transect Filename**	**Foliar Filename**	**Comments**
36	Grassland	SJER36-001_1 SJER36-002_2 SJER36-003_3 SJER36-004_4		Only transects; no foliar spectra collected at this site
37	Grassland	SJER37_017_1 SJER37_018_2 SJER37_019_3 SJER37_020_4	SJER37_F025	Four transects; single foliar spectra collected
116	Evergreen Forest	SJER116_009_1 SJER116_010_2 SJER116_011_3 SJER116_012_4	SJER116_F006_bottom SJER116_F006_mid SJER116_F006_top	Foliar spectra collected using UWisc protocol
			SJER116_F007_bottom SJER116_F007_mid SJER116_F007_top	Foliar spectra collected using UWisc protocol
			SJER116_F008	Foliar spectra collected using NEON protocol
			SJER116_F009_bottom SJER116_F009_mid SJER116_F009_top	Foliar spectra collected using UWisc protocol
			SJER116_F010 SJER116_F011 SJER116_F012	Foliar spectra collected using NEON protocol
			SJER116_F013_bottom SJER116_F013_mid SJER116_F013_top	Foliar spectra collected using UWisc protocol
117	Grassland	SJER117_021_1 SJER117_022_2 SJER117_023_3 SJER117_024_4	SJER117_F026 SJER117_F027 SJER117_F028 SJER117_F029	Four transects; foliar spectra collected using NEON protocol
192	Evergreen Forest	SJER192_013_3 SJER192_014_4	SJER192_F014 SJER192_F015 SJER192_F016 SJER192_F017 SJER192_F018	Only two transects at this site; multiple foliar spectra collected using NEON protocol
361	Shrub/Scrub	SJER361_015_3 SJER361_016_4	SJER361_F019 SJER361_F020 SJER361_F021 SJER361_F022 SJER361_F023 SJER361_F024	Only two transects at this site; multiple foliar spectra collected using NEON protocol
916	Shrub/Scrub	SJER916_010_1 SJER916_011_2 SJER916_012_3 SJER916_013_4	SJER916-F001 SJER916-F002 SJER916-F003 SJER916-F004 SJER916-F005	Four transects; foliar spectra collected using NEON protocol

Table 16: Summary of ASD Spectrometer files for data collected at Soaproot Saddle

Domain 17 Core Site: Soaproot Saddle				
Plot - Morton ID	**Cover Type**	**Transect File Name**	**Foliar Filename**	**Comments**
n/a	**n/a**	SR_Quarry_Rock Transect		Transect across granite dome; near basestation site
283	Shrub/Scrub		SOAP283_F101	Foliar spectra collected using NEON protocol
			SOAP283_F102	
			SOAP283_F103	
			SOAP283_F104	
			SOAP283_F105	
			SOAP283_F106	Cedar sample at edge of site; foliar spectra collected using NEON protocol
			SOAP283_F107	
1563	**Shrub/Scrub**		**SOAP283_F108**	**Foliar spectra collected using NEON protocol**
			SOAP283_F109	
			SOAP283_F110	
			SOAP283_F111	
			SOAP283_F112	
555	Shrub/Scrub		SOAP283_F113	Foliar spectra collected using NEON protocol
			SOAP283_F114	
			SOAP283_F115	
			SOAP283_F116	
			SOAP283_F117	

Transect spectral data were collected at SJER to support research deriving bulk nitrogen content of grasses using hyperspectral data; this effort is being led by Dr. Susan Ustin, University of California, Davis. After each spectral transect over the subplots was acquired, the bulk biomass material from each subplot was harvested and bagged. This material will be analyzed for total biomass and bulk nitrogen content. Biomass Nitrogen derived from the ASD spectral data will be compared directly to the laboratory data to validate the algorithm used to derive the biochemical properties from the hyperspectral data. The validated algorithm will be applied to the NEON NIS data to validate larger scale Biomass Nitrogen maps over the SJER area.

The seven sites shown in Figure 39 were sampled during the June 2013 NEON field campaign. Where possible, four 2 m x 20 cm transect plots (one in each quadrant) were identified; however, two plots (#192, #361) were only able to support two transects.

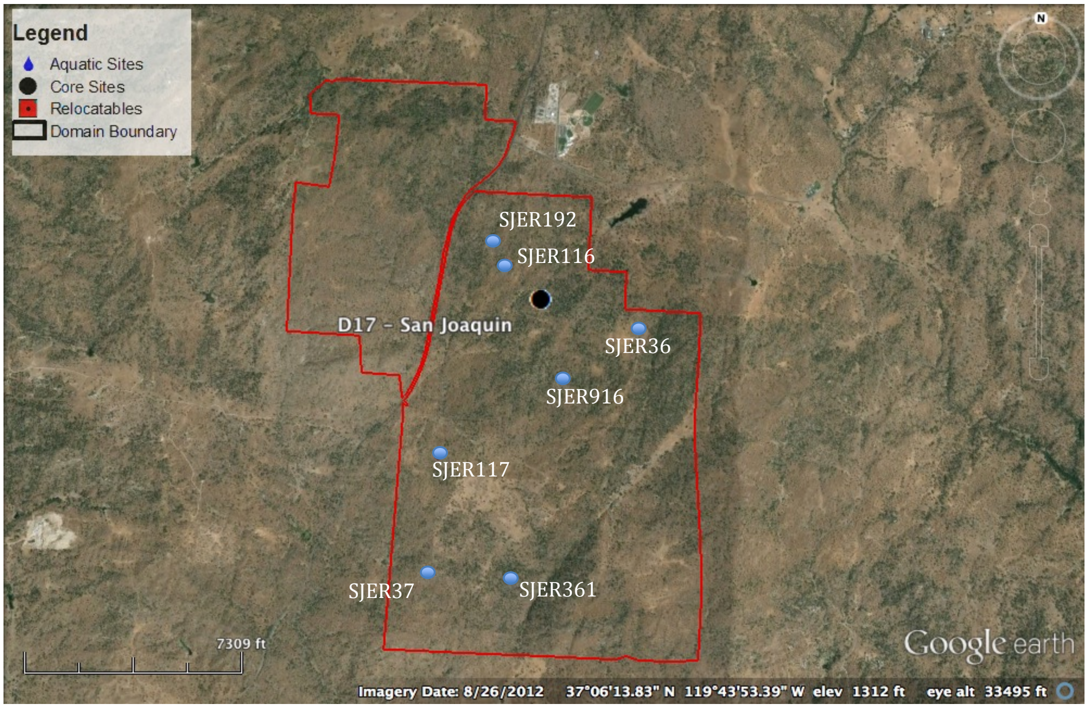


Figure 39: FSU sites sampled as part of the SJER transect/biomass study

During sampling, metadata and site photographs were collected using the Fulcrum Mobile Application – Spectral Transect Collector. Key metadata fields include:

- Domain/Site/Plot descriptive location
- Timestamps and actual GPS location
- Filename
- Instrumentation used
- Data collection protocol
- Field operators
- Acquisition conditions

The goal of the plant canopy and structural measurement sampling was to investigate the variation in elemental content (C, N, P, Ca2+, Mg2+, and K+), isotopic composition (C and N), chlorophyll, and lignin across a range of plant community types, data that could be compared with remote sensing data collected by the NEON Imaging Spectrometer. Figure 40 and Figure 41 show the FSU sites where foliar samples and spectra were acquired during the June 2013 NEON field campaign.

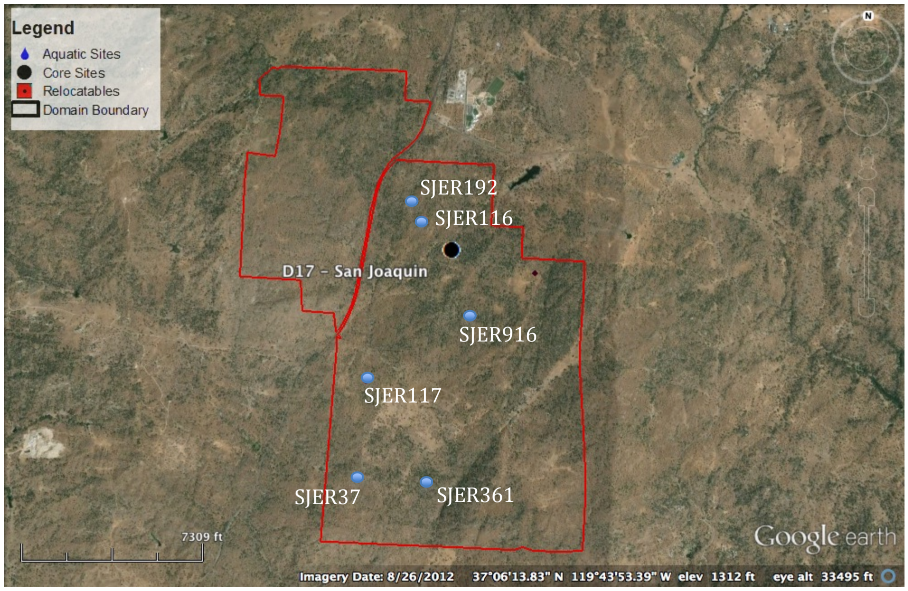


Figure 40: Foliar samples/spectra were collected at six sites at SJER

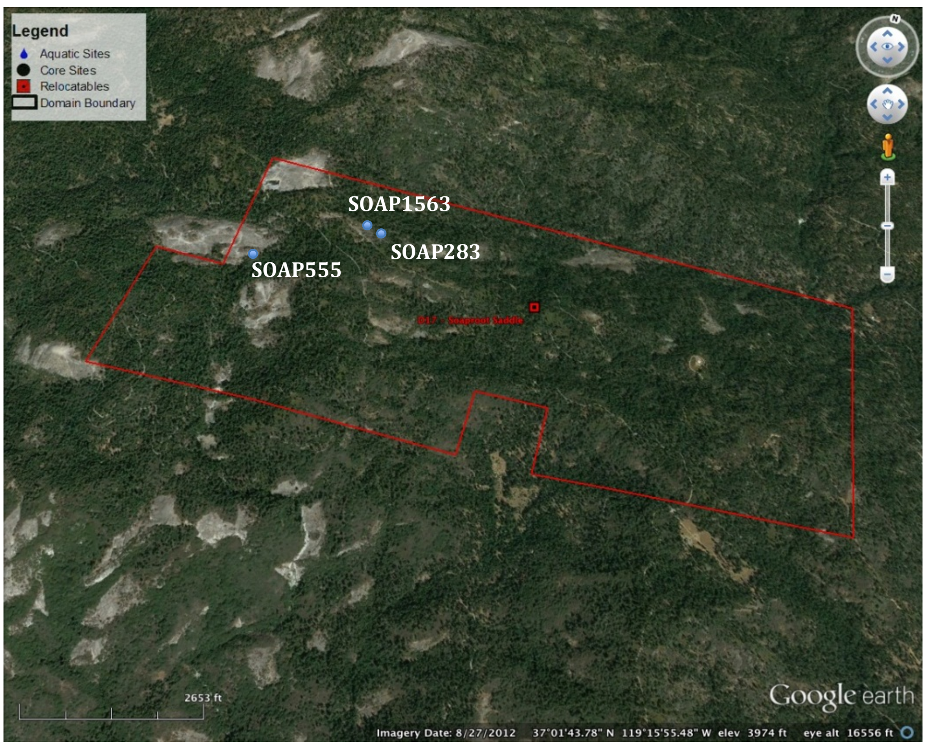


Figure 41: Foliar samples/spectra were collected at six sites at Soaproot Saddle

The NEON sampling methodology utilized the ASD Fieldspec-3 spectrometer together with a detachable plant probe and integrated Spectralon and Black Reflectance discs. Foliar samples were selected from the dominant species (by percent cover/biomass) in the plot, and the trunks of individual trees from which foliar samples were obtained were marked using a unique ID. Foliar samples were collected using the following procedure/protocol: for tall-stature tree species and shrubs, foliar samples were acquired from the top of the crown as per NEON protocol. The height of each sample source was determined using a Laser Range Finder, and leaf catchers were used to retrieve the sample by field personnel wearing clean, powderless gloves.

Figure 42: Collecting foliar samples (trees and shrubs) and spectral data

Foliar spectral data were collected with the plant probe using the following protocol:

- Optimize the ASD
- White reference
- Front of sample (leaf) over the white reference
- White reference
- Back of sample (leaf) over white reference
- White reference
- Black reference
- White reference
- Front of sample over black reference
- White reference
- Back of sample over black reference
- White reference

Field scientists from the University of Wisconsin (UW) were also on-site to acquire data as part of the HyspIRI Airborne Preparatory Campaign. Foliar samples were initially identified using the NEON procedure/protocol described above. Tall-stature tree foliar samples then were collected using the following procedure/protocol: the tree canopy was divided into three height ranges – top, mid, and bottom and samples (consisting of multiple leaf clusters) were collected from each height range. Height was determined using a Laser Range Finder and leaf catchers retrieved the samples (Figure 42). AOP staff members measured reflectance on the leaf samples from each height range and leaf catchers bagged the samples into a single sample bag (as per NEON protocol). Metadata and site photographs were collected using the Fulcrum Mobile Application – Spectral Sample Collector (Figure 43).

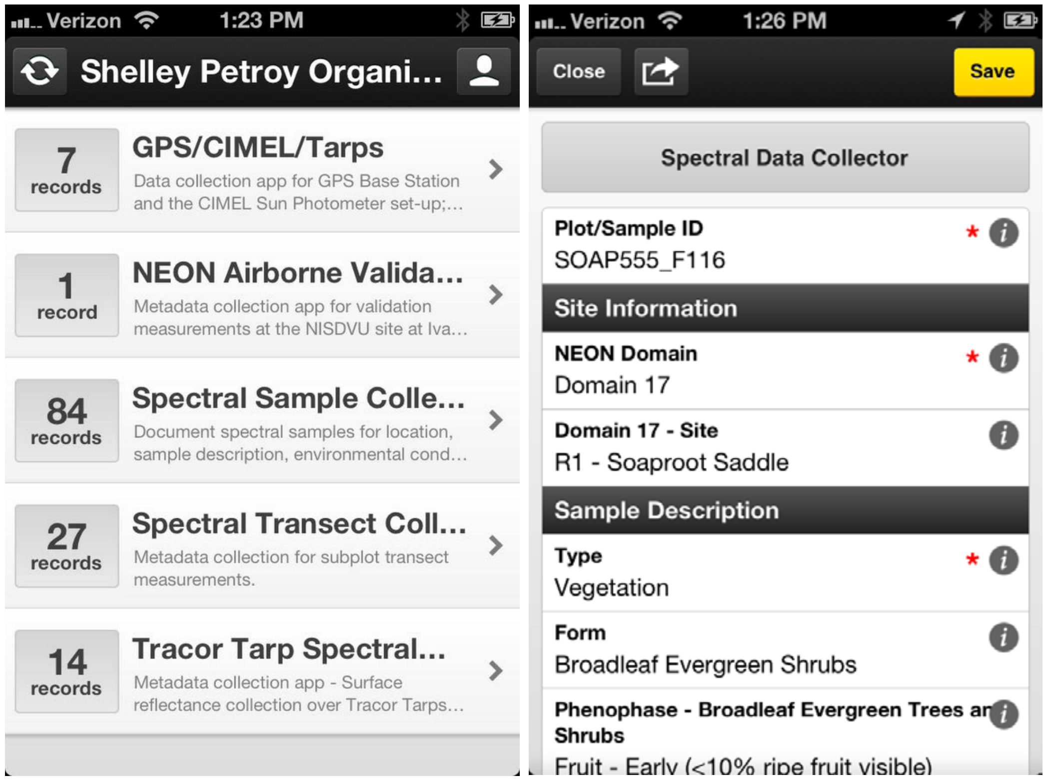


Figure 43: Fulcrum Mobile Application - Spectral Sample Collector screens

Comparison of NEON and UW Spectrometer Data. The initial goal of the instrument cross-comparison was to measure the systematic bias within each ASD instrument in the field. Secondary goals were to compare differences in spectral data collection protocol and methodology. A more thorough test will be conducted under more controlled conditions later in 2013, using a single set of calibrated samples and conducted within each individual laboratory. In addition, several other institutions will be included in this later round-robin effort.

Instrumentation/Accessories Used

- ASD Fieldspec-3 spectrometer
- 8° fore-optic attachment
- Spectralon Reflectance Panel, mounted/leveled on tripod next to UW Spectralon Panel

Sampling Procedure/Protocol

- ASD optimized before each data collection
- NEON Reflectance Panel – 1
    - Five spectra averaged
    - Fore-optic held parallel to the surface of the panel, approximately 10-12” above the panel
- UW Reflectance Panel
    - Five spectra averaged

- Fore-optic held parallel to the surface of the panel, approximately 10-12" above the panel
- Reflectance Panel – 2
    - Five spectra averaged
    - Fore-optic held parallel to the surface of the panel, approximately 10-12" above the panel

6 ATMOSPHERIC CHARACTERIZATION AND CORRECTION

Atmospheric characterization relied on measurements from the CIMEL sun photometer. The Cimel sun photometer, shown in Figure 34, is a ten spectral channel radiometer designed to measure solar irradiance and sky radiance. The spectral channels span the visible to near-infrared portion of the solar-reflective spectrum and are specifically located at 340, 380, 440, 500, 675, 870, 1020, and 1640 nm. Direct solar irradiance measurements from a well-calibrated radiometer can provide total optical depth that can be broken out into separate components as follows:

$$\delta_{\text{total}}(\lambda) = \delta_{\text{Rayleigh}}(\lambda) + \delta_{\text{aerosol}}(\lambda) + \delta_{\text{absorption}}(\lambda) \tag{1}$$

The Rayleigh component, also known as molecular scattering, is accurately predicted with knowlege of atmospheric pressure[18]. The remaining aerosol and absorption components are subsequently derived in the CIMEL processing[19]. In order to characterize aerosol effect across the full spectrum, a power law[20] is assumed with a functional form:

$$\boldsymbol{\delta}_{\textbf{aerosol}}(\lambda) = \boldsymbol{\delta}_{\textbf{aerosol}}(\lambda_o)\left(\frac{\lambda}{\lambda_o}\right)^{-\alpha} \tag{2}$$

where α is the Ångstöm exponent and $\delta_{\text{aerosol}}(\lambda)$ is the aerosol optical depth at reference wavelength λ_0.

7 PRELIMINARY SCIENCE RESULTS

Near simultaneous overflights by the NEON aircraft and the AVIRIS-classic onboard the NASA ER-2 were acquired over the NEON terrestrial sites (San Joaquin Experimental Range, Soaproot Saddle, and Teakettle), as well as the NEON Providence Creek aquatic site. The data from the NEON payload has been processed to engineering-grade Level-1 data products that are now available by request through the NEON web portal.

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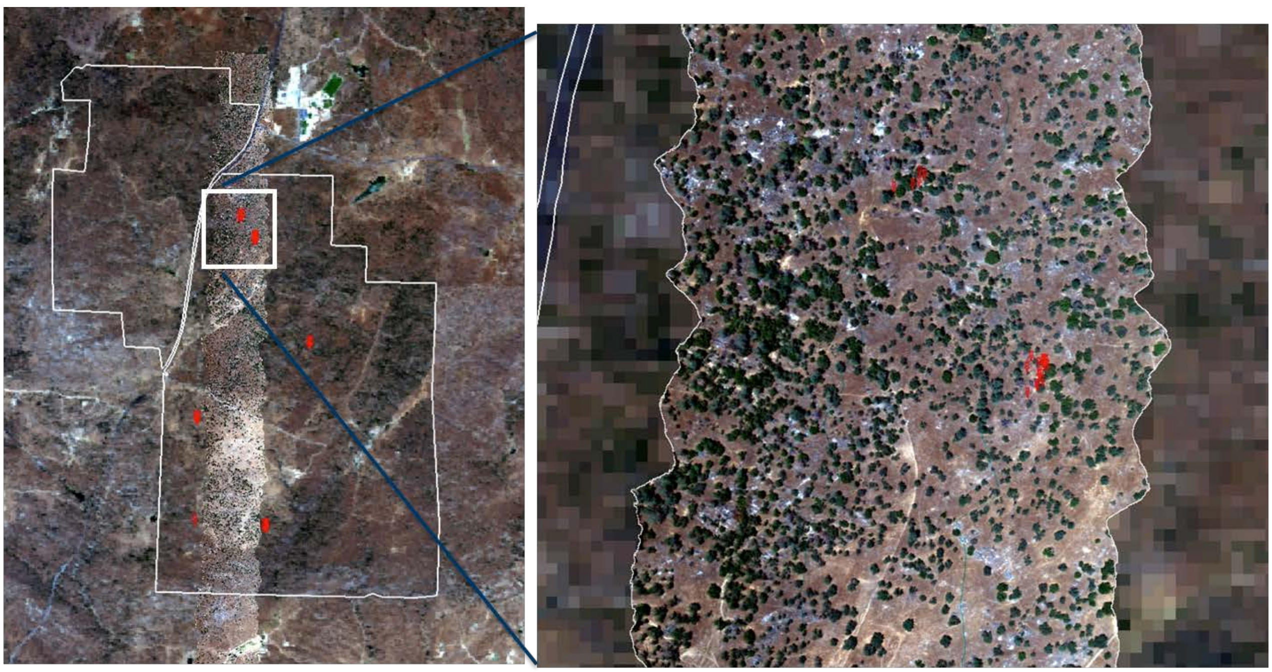
[18] Hoyt, D.V., "A redetermination of Rayleigh optical depth and its application to selected solar radiation problems," *J. Appl. Meteorol.*, 16 (1977):432-436.

[19] Holben, B.N., T.F. Eck, I. Slutsker, D. Tanre, J.P. Buis, A. Setzer, J.A. Reagan, Y.J. Kaufman, T. Nakajima, F. Lavenu, I. Jankowski, A. Smirnov, "AERONET - A federated instrument network and data archive for aerosol characterization," *Rem. Sens. of Env.* 66, no. 1 (1998):1-16.

[20] Ångström, A., "On the atmospheric transmission of sun radiation and on dust in the air," *Geografiska Annaler* 11 (1929):156-166.

The L-1 spectral reflectance data product has been derived from the raw data acquired with the NEON imaging spectrometer. This product is orthorectified and output onto a fixed, uniform spatial grid co-registered to the discrete return LiDAR. Figure 44 provides an example of this data product. This figure shows two NEON AOP flight lines overlaid on the coarser resolution AVIRIS data. As shown in the expanded view at the right, individual trees are easily resolved in the NEON data (~1 m ground sampling distance (GSD)). This is not the case for the 18-m GSD AIVRIS data, and it is readily apparent that the NEON data product could be quite useful for validating or assessing the accuracy of the retrieval of geophysical parameters at the AVIRIS resolution, or AVIRIS data resampled to the HyspIRI spatial resolution (60 m).



AVIRIS Surface Reflectance – 18m spatial resolution

NIS1 Surface Reflectance – 1m spatial resolution
Red push pins mark field sampling sites

Figure 44: NEON Imaging Spectrometer (NIS1) and AVIRIS spectral reflectance acquired over San Joaquin Experimental Range (SJER). The image to the left shows two NEON (NIS1) flight lines running from north to south overlaid on the AVIRIS data. The white polygon is the SJER boundary. The image to the right is an exploded view of the region highlighted by the heavy white square. The NIS1 flight line runs through the center of this image showing the high spatial resolution (1 m) data contrasted with the coarser (18 m) AVIRIS data. Red push pins mark field sampling sites.

The San Joaquin data set provides an interesting case study in that individual trees can be clearly identified surrounded by senescent grasses, making it relatively straightforward to identify species contributing to the reflectance within individual pixels. In contrast to SJER, the mixed conifer/deciduous forest at Soaproot Saddle (Fig. 45) is more of a closed canopy and species identification here will be more difficult.

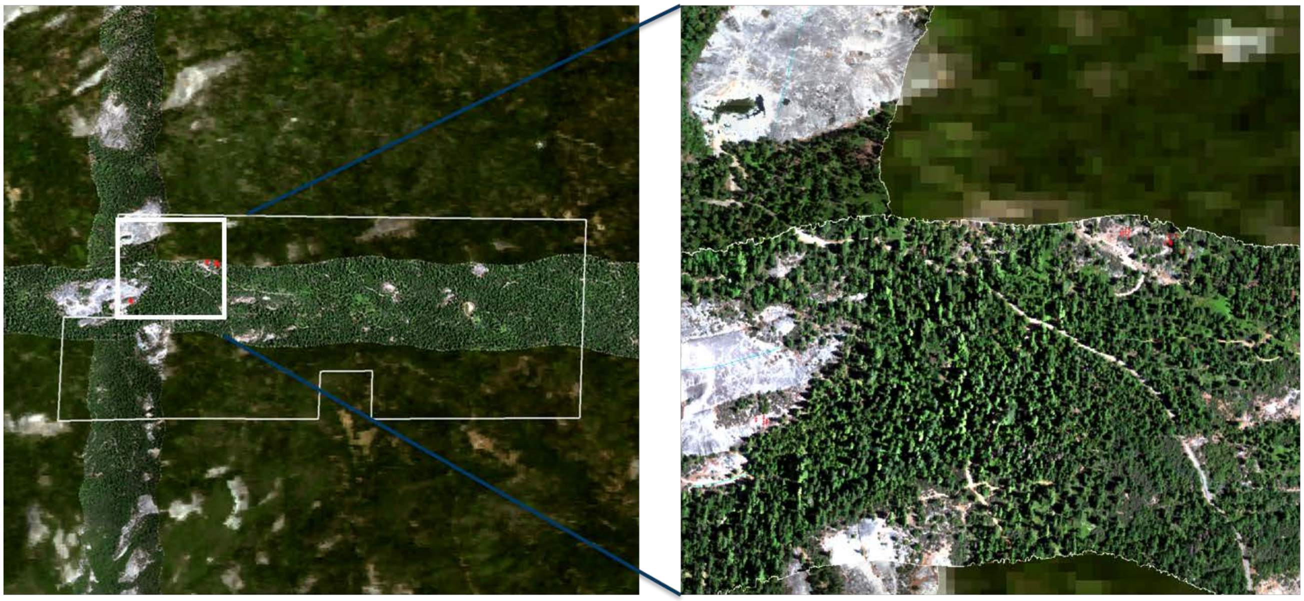


Figure 45: NEON NIS1 and AVIRIS spectral reflectance acquired over Soaproot Saddle. The image to the left shows two NEON (NIS1) flight lines running from north to south overlaid on the AVIRIS data. The white polygon is the SJER boundary. The image to the right is an exploded view of the region highlighted by the heavy white square. The NIS1 flight line runs through the center of this image showing the high spatial resolution (1 m) data contrasted with the coarser (18 m) AVIRIS data. Red push pins mark field sampling sites.

Figure 46 provides an example of metadata available to researchers associated with each field sample collected. A GPS location is provided for each sample as well as photographs of the sample itself and the tree from which it was taken. Field conditions have also been recorded and measured spectra are provided. Figure 47 presents the spectral reflectance for a Live Oak specimen at the San Joaquin Experimental Range as acquired both form the NEON airborne platform and as measured with the field spectrometer. Note that multiple measurements are made of the leaf with the field spectrometer. Measurements are made with the both the upper surface and the lower surface of the leaf oriented facing the spectrometer, and white and black backgrounds are used.

Figure 48 shows the measured spectral reflectance for several plant species in SJER including Blue Oak, Live Oak, and senescent grasses. Both the reflectance measured reflectance from the NEON airborne NIS1 imaging spectrometer and field measured reflectance spectra are shown. The NIS1 data will be used to develop retrieval algorithms for biogeochemistry, land cover and dominant species, biomass and leaf area index. The field and laboratory data will be used to validate airborne data and provide a linkage of higher-level regression algorithms to ground truth. Similarly, these data can be used to validate data products being developed at the HyspIRI-like spatial resolution.

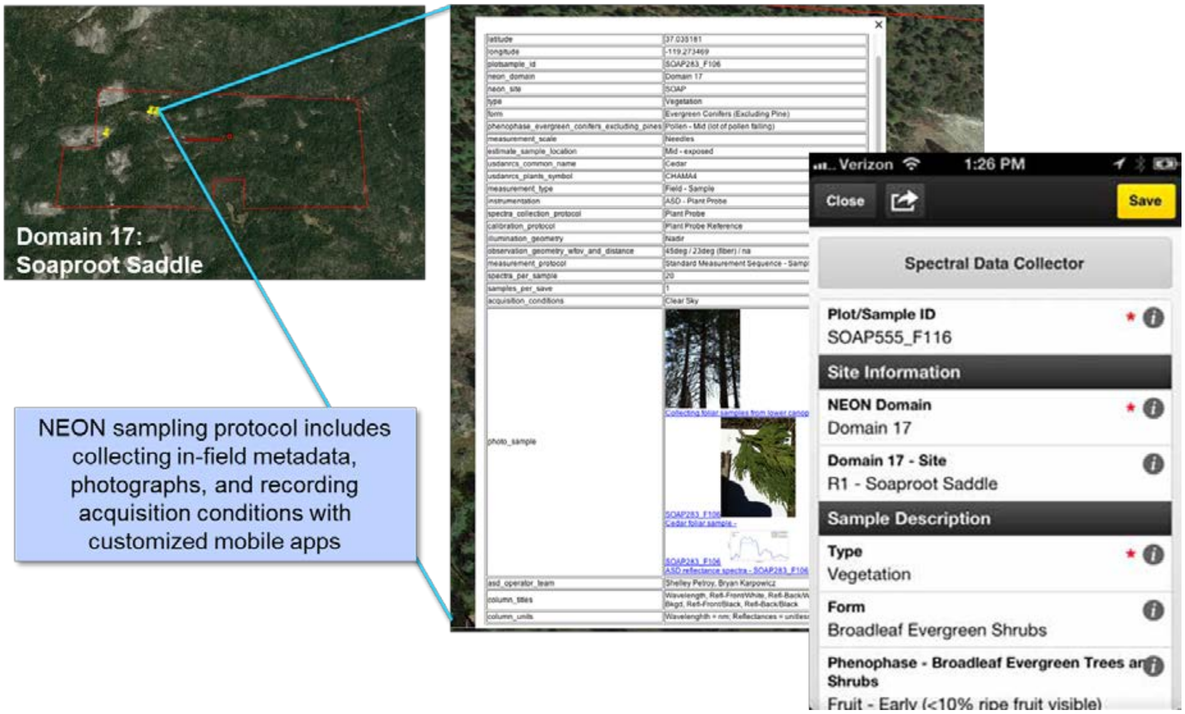


Figure 46: Field Metadata are Displayed Real-time to Support Analysis

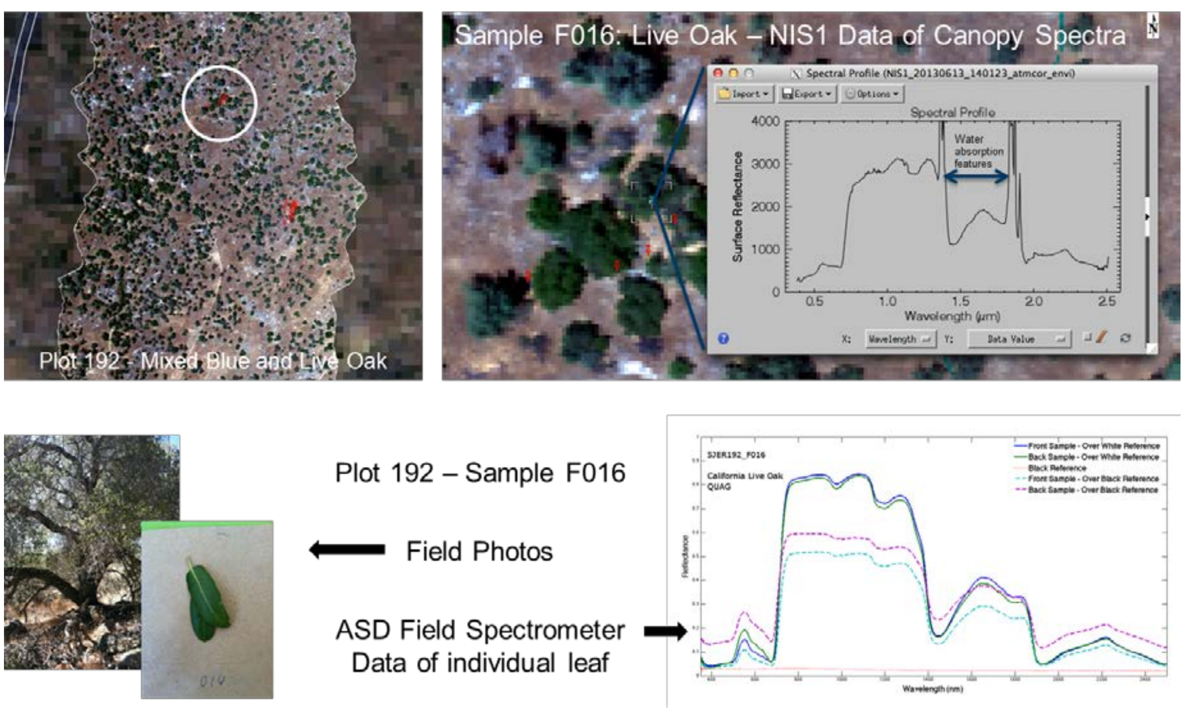


Figure 47: NEON NIS1 Airborne and Field Spectral Data - SJER

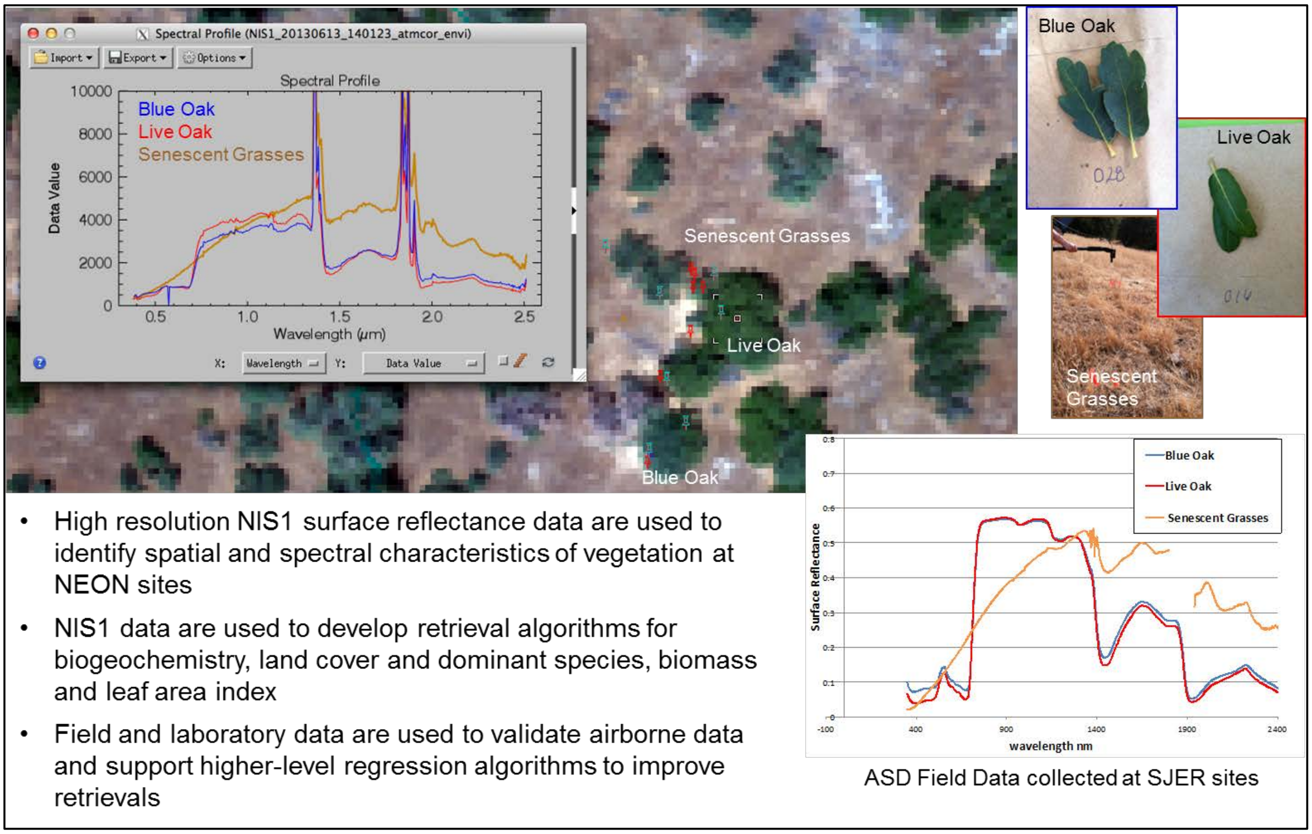


Figure 48: Spectral Reflectance characteristics of vegetation at San Joaquin Experimental Range.

Figure 49 shows a comparison of a preliminary higher-level data product, the Normalized Difference Nitrogen Index (NDNI) as retrieved over San Joaquin Experimental Range from NIS1 imaging spectrometer onboard the NEON airborne platform and AVIRIS onboard the NASA ER-2. NDNI is given by:

$$NDNI = \frac{\left[\log\left(\frac{1}{R_{1510}}\right) - \log\left(\frac{1}{R_{1680}}\right)\right]}{\left[\log\left(\frac{1}{R_{1510}}\right) + \log\left(\frac{1}{R_{1680}}\right)\right]};$$

where, R_{1510} is the reflectance at 1510 nm, and similarly for R_{1680} (*Serrano et al., 2002*). In the case of the NIS1, a spectral sample extends over 6.5 nm. For AVIRIS, spectral sampling is 10 nm. NDNI is based on the fact that reflectance at 1510 nm is largely determined by nitrogen concentration of leaves and overall foliage biomass of the canopy. It is then compared to a reference reflectance at 1680 nm, which contains a similar signal due to foliar biomass, but without the influence of nitrogen absorption. The value of the NDNI index ranges from 0 to 1; a common range for green vegetation is 0.02 to 0.1.

The right-hand image in the figure shows NDNI as retrieved by AVIRIS with the two NIS1 flight lines overlaid. NDNI as retrieved by AVIRIS is within the expected range, but consistently lower than the NDNI as retrieved from the NEON NIS1 imaging spectrometer. This difference is likely to be as least partially attributable to spatial averaging of green vegetation (trees) with senescent grasses in the larger AVIRIS pixels. However, as evident in the expanded left-hand image, illumination effects may also be playing into the NIS1 retrieved NDNI product - the highest NDNI values are consistently observed on the west facing sides of trees. Further investigation is warranted to better understand factors confounding the retrieved product.

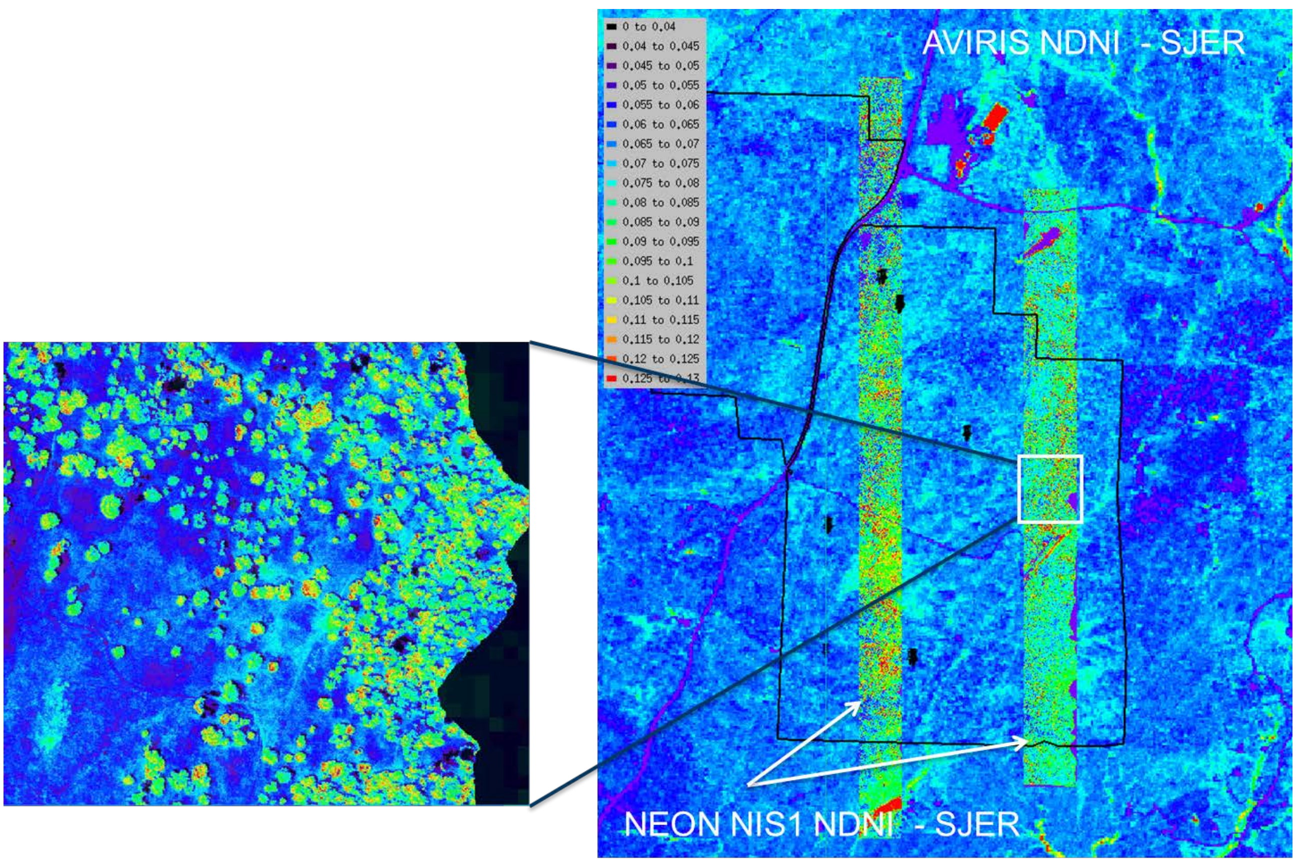


Figure 49: Preliminary Normalized Difference Nitrogen Index (NDNI)as retrieved over San Joaquin Experimental Range by NIS1 and AVIRIS.

Figure 50 shows an image of a rock outcropping at Soaproot Saddle taken from the NEON airborne platform. Visible on the rock outcropping are two Tracor reflectance tarps – the reflectance of the black tarp averaging near 3% throughout the visible to Shortwave infrared, and the reflectance of the white tarp around 48% in the visible region. These tarps were deployed both during the Soaproot Saddle flights and at San Joaquin Experimental Range. The inset shows calibrated spectral radiance acquired over this region at Soaproot Saddle. Shown are spectral radiances for the two Tracor tarps, trees, ground vegetation, granite, and the dirt road. The Tracor tarps are used to validate the atmospheric correction in the conversion of spectral radiance to spectral reflectance.

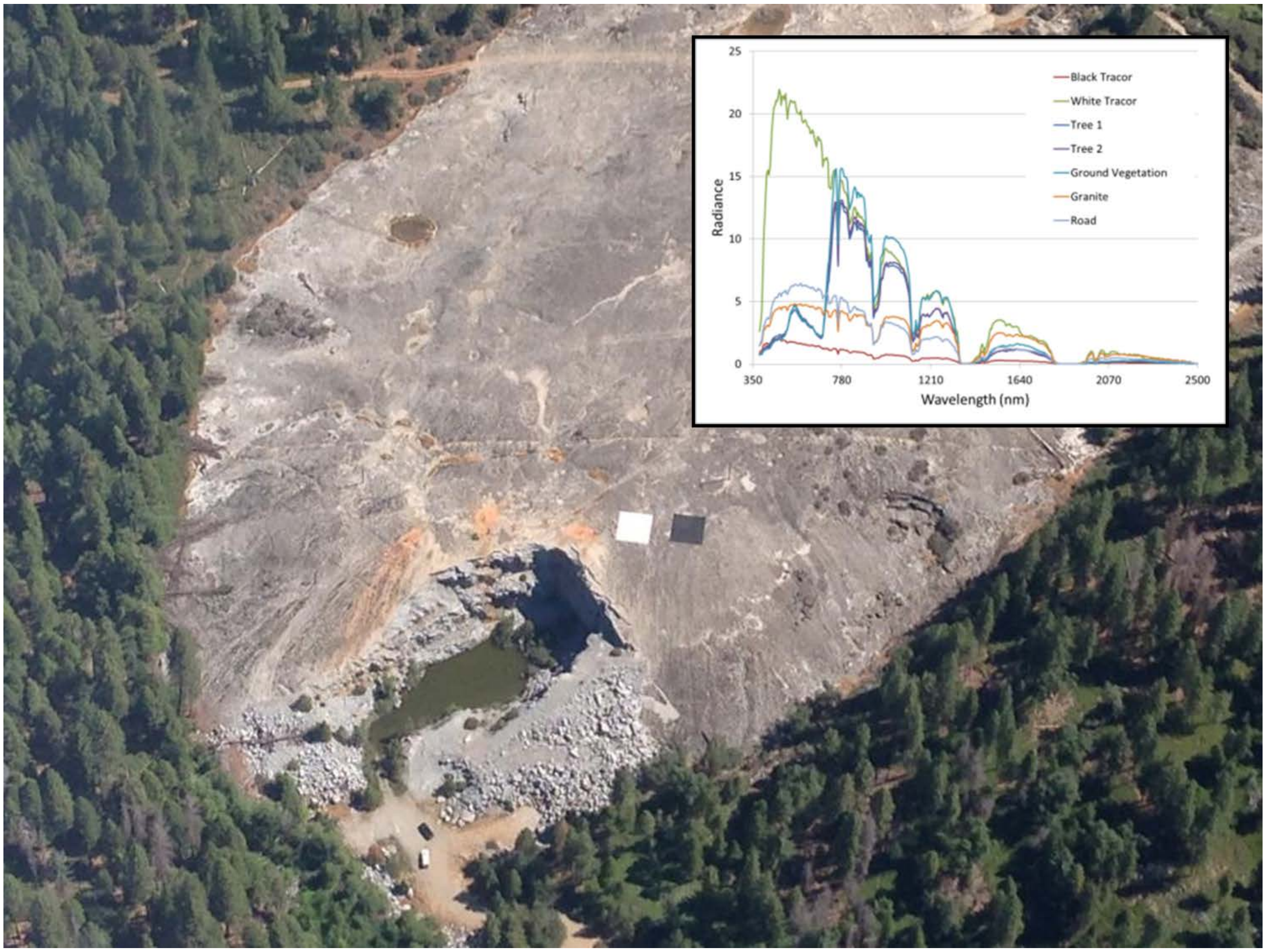


Figure 50: Tracor tarps used as reflectance calibration references. Note the two vehicles at the base of the rock outcropping at the lower left of the image.

Figure 51 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. Engineering-grade L-1 discrete LiDAR data is available for both of these sites, as well as the Providence Creek aquatic site and the Teakettle terrestrial site in standard LAS format. Ground-based LiDAR measurements were conducted at both of these sites by our collaborators. This provides an opportunity to investigate the accuracy of airborne LiDAR data in different vegetation cover. The LiDAR data may prove useful to HyspIRI investigators in better understanding the consequences of vegetation structure in their retrieval algorithms. The waveform L-1 product is currently under development and will be released to the public within 6 months.

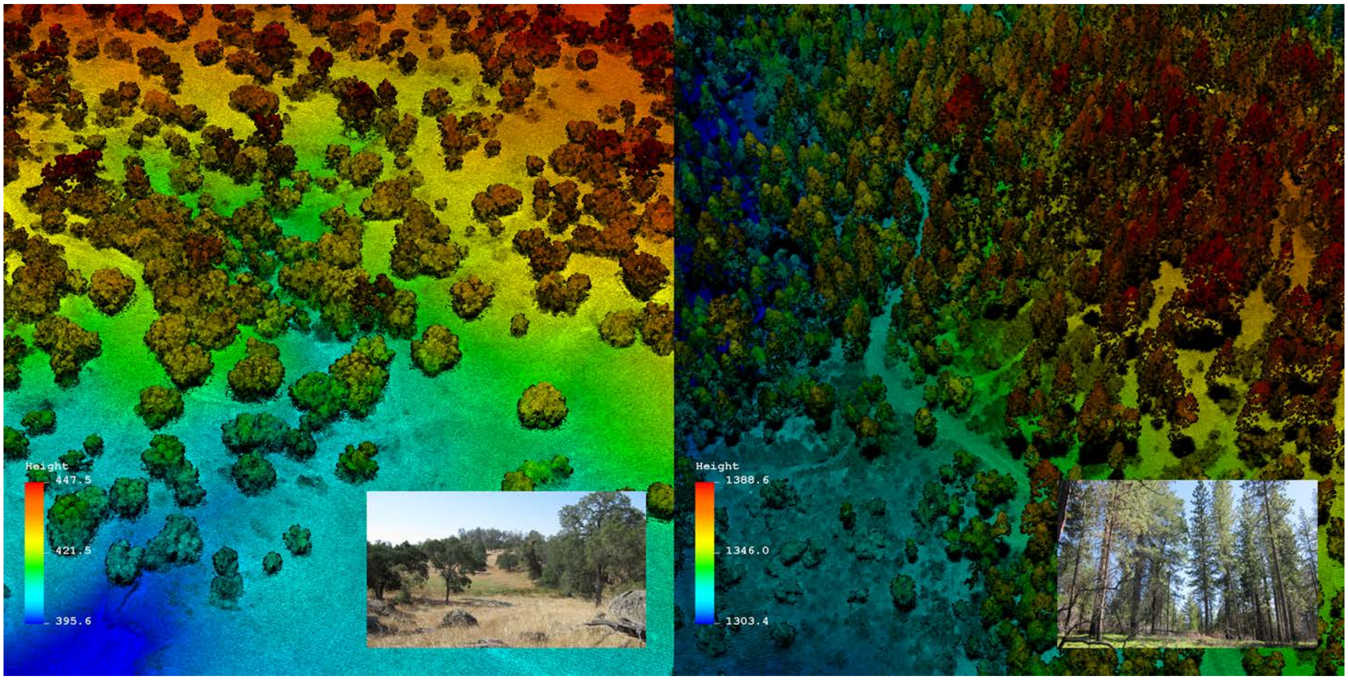


Figure 51: LiDAR point clouds of the San Joaquin Experimental Range (left) and Soaproot Saddle (right) NEON sites. The two sites have different horizontal and vertical 3D structures due to the differences in vegetation cover.

Figure 52 illustrates how higher-level derived products are produced from the L-1 LiDAR data. In the upper right-hand is a RGB spectrometer image of a region of Soaproot Saddle. By subtracting the Canopy Height Model (upper left) from the Digital Surface Model (lower left), produces the Digital Terrain Model (DTM) at the lower right. The DTM is useful for obtaining a better understanding the hydrologic and geomorphic characteristics of the landscape underlying the vegetation. This information was of particular interest to aquatic scientists for the Providence Creek watershed. In Figure 53, the DTM for the Providence Creek watershed is shown with trees removed. This figure has been colorized to indicate height. Good detail of the terrain is evident, and on close inspection, small footpaths can be distinguished along the canyon walls.

As stated previously, the NEON L-1 data products generated from this campaign are being released as engineering-grade. What this means is that algorithms generated by NEON have been used to produce these products. These algorithms are preliminary versions of the data product algorithms being developed to provide science-grade data products once the NEON observatory begins Operations. However, the engineering-grade data products do not include quality flags, nor has a rigorous error budget been established for these products. This is an on-going activity at NEON leading up to release of science-grade data products at or near transition to Operations.

The NEON data products described in this report are available on request. To obtain the data, send an email to aop_data@neoninc.org and the data products will be distributed via portable hard drives.

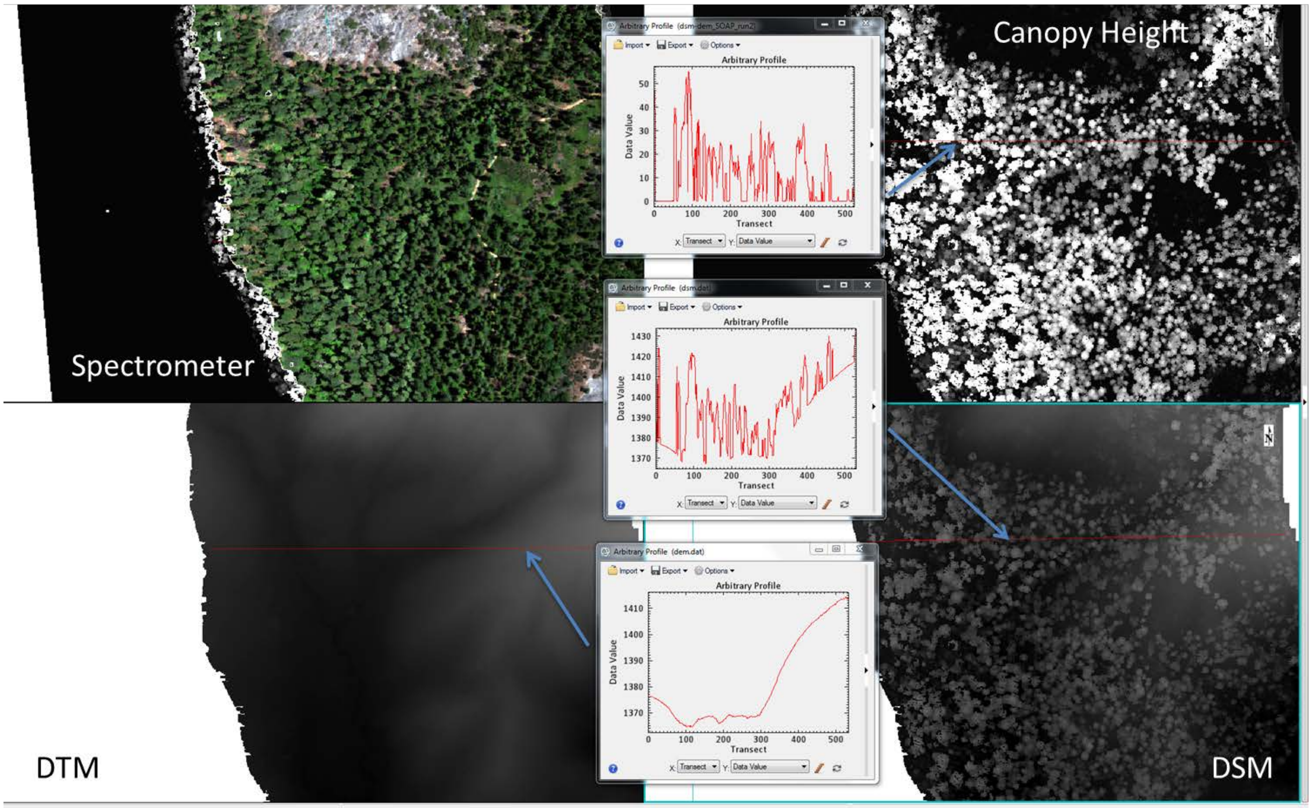


Figure 52: Initial Look at LiDAR data from Soaproot – June 2013

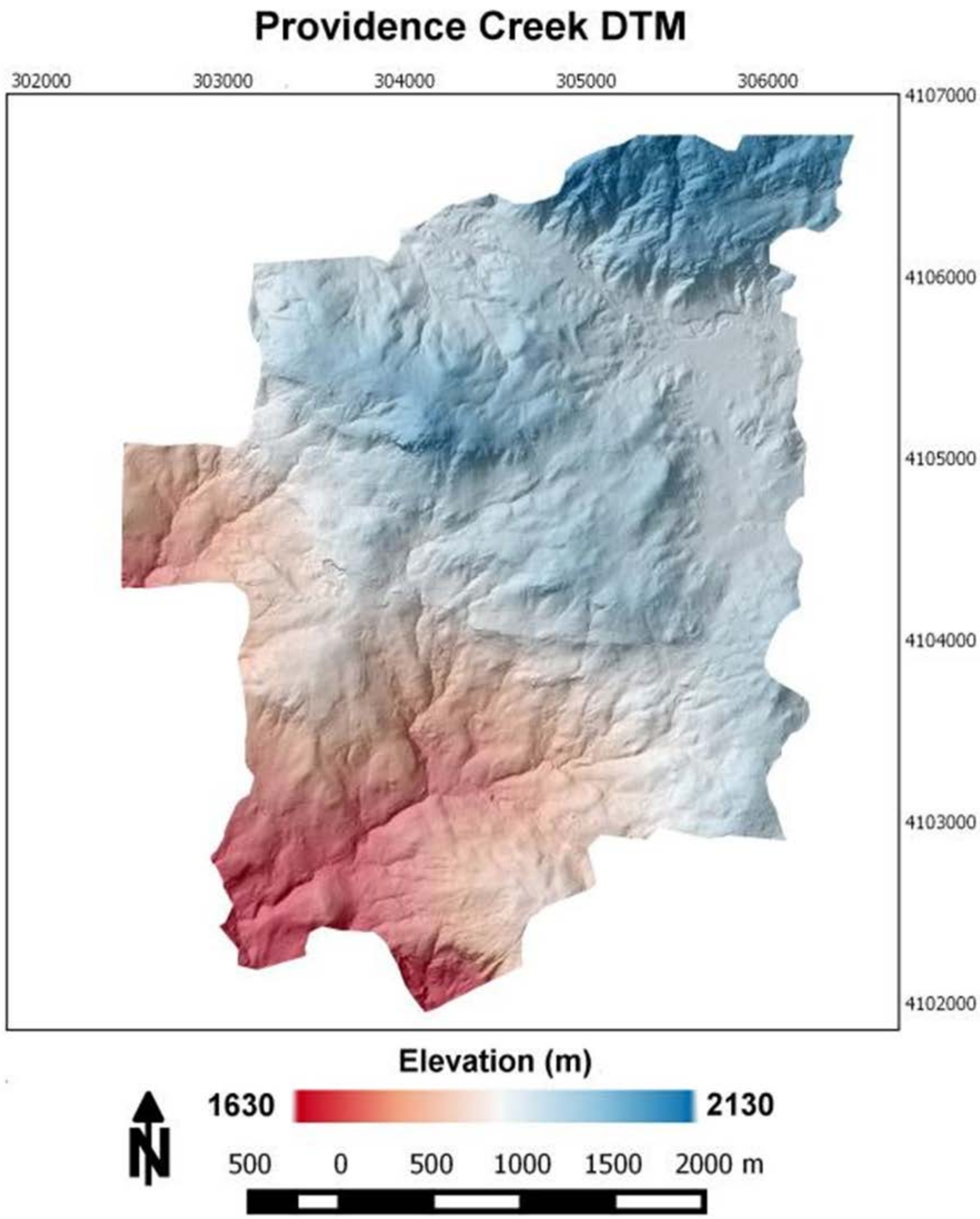


Figure 53: Providence Creek Digital Terrain Map (DTM) – trees removed

8 COLLABORATIONS

8.1 HyspIRI Preparatory Airborne Campaign

In late December 2011, NASA released a call for proposals to support the development of the HyspIRI mission and prepare the community for HyspIRI-enabled science and applications research[21]. The call included plans to fly NASA's Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) and the MODIS/ASTER Airborne Simulator (MASTER) instruments on the NASA ER-2 high-altitude aircraft and acquire data in concert with other instruments for precursor science and applications research. A primary goal of the project was to survey climatic and ecological gradients along transects in California, running from high-elevation regions into the coastal ocean at multiple times over two flight years in order to capture seasonal variation. NASA chose to locate one of the flight boxes to include the NEON D17 core and relocatable sites.

The high-spectral resolution measurements at moderate spatial resolutions promised from the HyspIRI satellite mission will enable long-term, global-scale observations of a number of ecologically important variables, including the spatial patterns of ecosystems, their compositions and diversity, and the impacts of changing climate and land use on ecosystems, functional groups, and their distributions. It is anticipated that airborne and ground-based measurements will be needed to assess the accuracy of these products and to establish empirical relationships between ecological parameters and the satellite measurements. Field and flux tower measurements combined with airborne and satellite observations are also being explored for their use in continental and global scale ecological models. The differing scales and techniques, geo-location errors, heterogeneity in vegetation composition and structure, and the non-linear relationship between remote observations and derived parameters complicate the linkage between satellite, airborne and site-based measurements. The integration of ground-based measurements, airborne spectroscopic and LiDAR measurements from NEON AOP, and high-altitude spectroscopic measurements from AVIRIS provide a path to begin addressing these issues in detail[22]. Since the NISDVU and the VSWIR imaging spectrometer on HyspIRI are essentially of the same basic configuration, the data are directly comparable. Both instruments are of sufficiently high uniformity that the effects of spectral shifts with wavelength or field should be insignificant. Both instruments operate with high SNR over the full visible to shortwave infrared spectral bands, facilitating the discrimination of non-photosynthetic vegetation from background soil and rocks which is critical for automated spectral unmixing algorithms.

In May and June 2013, the HyspIRI Mission Team completed two flight campaigns to acquire "HyspIRI-like" data over large areas of California, and included a flight box over the D17 sites (Figure 54). On June 12, the HyspIRI airborne preparatory mission team flew the AVIRIS-classic on the ER-2 at an altitude of 20 km to acquire spectroscopic data at 20-m ground resolution (the MASTER sensor was not deployed during this flight campaign). These data will be aggregated to 60-m pixels (ground resolution) to simulate HyspIRI acquisitions. The June 12 flight overlapped

[21] HyspIRI Preparatory Airborne Activities and Associated Activities and Associated Science and Applications Research (NNH11ZDA001N - HYSPIRI)
[22] NASA Proposal #:11-HYSPIRI11-0022, "Ecosystem structure & chemistry at NEON California sites," National Ecological Observatory Network, Inc. (03/21/2012).

with the NEON AOP survey of Soaproot Saddle and the elevation gradient transect. The coincident data acquisition between the NEON D17 flight campaign, the "HyspIRI-like" flight campaign and the field measurements obtained by the various groups will provide a multi-scale data set suitable for developing and evaluating spatial-scaling algorithms critical to NEON. The spectroscopic data acquired at fine spatial scales by AOP will be useful for validating data products currently being developed at expected HyspIRI spatial sampling scales. Results from studies using this coupled data set should be extendable to algorithm development for the spaceborne HyspIRI VSWIR instrument. All of NEON's field measurements of vegetation, measurements of atmospheric parameters, and field spectrometer measurements of plants will be made available to HyspIRI investigators.

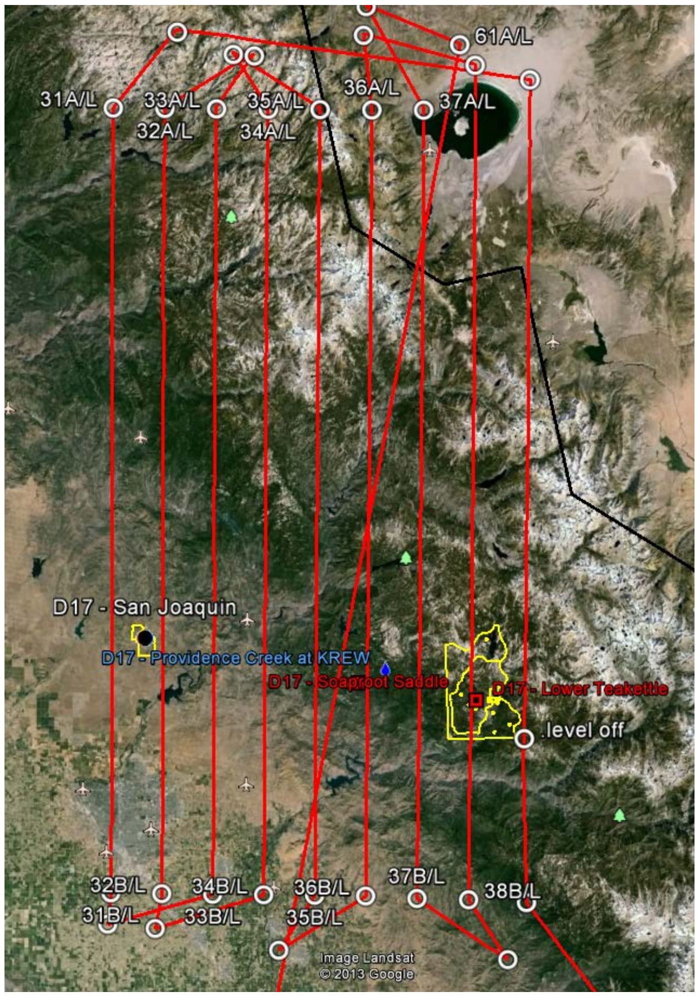


Figure 54: Flight box for the AVIRIS-classic survey of NEON and Yosemite sites as part of the HyspIRI Preparatory Airborne Campaign

8.2 Ecological Spectral Information System (EcoSIS)

In June 2012, NASA solicited proposals for Terrestrial Ecology investigations; the following types of research investigations were requested:

a) Data set development in support of arctic-boreal ecosystem vulnerability research to be conducted in a future Terrestrial Ecology Program-sponsored field campaign.
b) Data set development to meet five top-priority needs of the NASA terrestrial ecological community.
c) Successor studies in the areas of remote sensing science and remote sensing methods development that offer to significantly advance the results of prior NASA Terrestrial Ecology research.

A team of researchers led by Phil Townsend at the University of Wisconsin recently received NASA funding to prototype a new public repository for standardized, high-quality spectral measurements of vegetation. The new project, the Ecological Spectral Information System (EcoSIS/ESIS), is designed to enhance the accessibility and utility of new and existing spectral vegetation data. EcoSIS will both contribute to and draw upon NEON expertise and information resources[23].

Spectrometers collect information about light at many wavelengths within the visible and infrared portions of the spectrum. In the same way that x-rays allow doctors and researchers to glimpse the inner condition of living creatures without dissecting them, spectral data can illuminate the physical structure and chemical condition of plants without destructive analysis. Spectral vegetation data provide researchers with insights into photosynthesis and the way plants utilize light.

EcoSIS will archive and curate a collection of existing and new spectral vegetation data from programs such as NASA's Airborne Visual/Infrared Imaging Spectrometer and Hyperspectral Infrared Imager as well as from NEON. The repository will include spectra collected from field spectrometers, laboratory instruments, and airborne and spaceborne sensors. The repository will also store information about the spectra such as the species types and leaf properties of measured plants.

[23] See “Ecological Spectral Information System (ESIS): Integration of Spectral Data with Measurements of Vegetation Functional Traits,” http://cce.nasa.gov/cgi-bin/terrestrial_ecology/pi_list.pl?project_group_id=968.

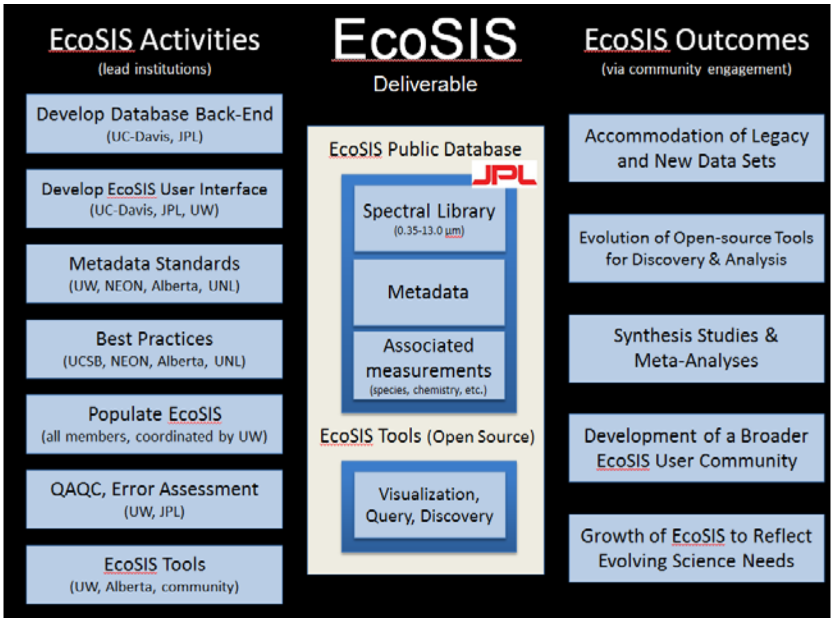


Figure 55: EcoSIS activities and outcomes[24]

EcoSIS will work with collaborators from NEON and other institutions to develop standardized data collection procedures and metadata best practices that will help researchers to more effectively compare and combine datasets from multiple sources and expand the scope of their analyses over larger areas and longer periods of time. NEON Assistant Director for Remote Sensing Tom Kampe and Senior Staff Scientist Shelley Petroy are collaborators on the EcoSIS project.

NEON will contribute field sampling protocols, field and airborne spectroscopic data, and a suite of complementary ecosystem data products from the NEON terrestrial sites, including those from Domain 17 in California. In addition to archiving and sharing spectral data, EcoSIS will develop and provide open-source tools and linked plant databases. These resources will aid researchers in analyzing and visualizing data and in addressing key science questions such as the relationships between spectral data, plant species and plant condition.

EcoSIS data and tools will also aid in the development of methods to scale up site-based measurements over landscapes and regions using remotely sensed information from airborne and satellite-borne instruments. These methods are critical to NEON's ability to provide some of its continental-scale data.

9 CONCLUSION

The 2013 Domain 17 Flight Campaign was completed on June 15, 2013. The campaign was conducted in collaboration with both the NASA HyspIRI Preparatory Airborne Project and the

[24] Townsend, P.,"Ecological Spectral Information System (EcoSIS): Integration of Spectral Data with Measurements of Vegetation Functional Traits," University of Wisconsin-Madison, 2013, http://cce.nasa.gov/.

NASA Ecological Spectral Information System Project, allowing multiple groups to leverage field and airborne data collections activities for all three efforts simultaneously. This campaign is now providing data sets that are being used effectively by the NEON Science teams to develop methods and protocols for ground site sampling, comparison between ground-based and airborne data, and data product development.

10 ACKNOWLEDGEMENTS

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