Project Title

International Space Station (ISS) Hyperspectral Collection Support for the National Ecological Observation Network (NEON)

Proposer

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Section I: Background and Overview

Abstract

The National Ecological Observatory Network (NEON) is the first national ecological observatory for the U.S. and is wholly-funded by the National Science Foundation. NEON partitioned the continental U.S., Alaska, Puerto Rico and Hawaii into 20 distinct ecological regions. As part of the effort to collect ecological data of these regions, NEON will use three next generation AVIRIS sensors (AVIRISng), referred to as NEON Imaging Spectrometers (NIS), to collect hyperspectral imagery of these sites. While NEON will utilize its NIS hyperspectral sensors with the utmost efficiency, there still will be times when data collection is not possible for logistical, mechanical, weather, etc., reasons. Because of these situations, it's essential to make every effort to collect the desired data from available high-quality asset. The International Space Station (ISS) with the 128-channel HICO Visible Near InfraRed (VNIR) hyperspectral sensor aboard is just such an asset. While HICO does not possess the spectral or spatial fidelity of the AVIRISng, it is certainly a powerful tool capable of providing the necessary temporal coverage that NEON needs to fulfill its mission. In instances where NEON's NIS is able to collect and the ISS is passing over, it will be a fantastic opportunity to augment the NIS data and help calibrate both sensors. Therefore, we request that, within the limitations of the ISS orbit, that all of the NEON collection sites be permanently added to HICO's acquisition list.

Background

The National Ecological Observatory Network (NEON) is a continental-scale observatory designed to gather and provide 30 years of ecological data on the impacts of climate change, land use change and invasive species on natural resources and biodiversity. NEON is a project of the National Science Foundation, with many other cooperating U.S. agencies and NGOs.

NEON is designed to gather and synthesize data on the impacts of climate change, land use change and invasive species on natural resources and biodiversity. Data will be collected from 106 sites (60 terrestrial, 36 aquatic and 10 aquatic experimental) across the U.S. (including Alaska, Hawaii and Puerto Rico) using instrument measurements and field sampling. The sites have been strategically selected to represent different regions of vegetation, landforms, climate, and ecosystem performance. NEON will combine site-based data with remotely sensed data and existing continental-scale data sets (e.g., satellite data) to provide a range of scaled data products that can be used to describe changes in the nation's ecosystem through space and time.

A decade of discussion and planning by the ecological research community led to the design and data requirements of NEON. The resulting strategy unites point and process observations with remote sensing and spatial data to develop spatial-temporal analyses and forecasts. NEON will observe both the human causes and the biological consequences of environmental change, a key feature of the project. Environmental monitoring networks typically observe either the causes of change (such as climate change, air pollution, and land cover change) or the effects of change (such as phenology and the distribution of avian populations). Rarely do environmental networks provide integrated observations of aspects of both cause and effect to allow increased understanding of the underlying processes.

The biosphere, Earth's living component, is one of our planet's most complex and fascinating systems and is also the source of many vital services to humanity (Millennium Ecosystem Assessment, 2005). The biosphere is arguably the least understood of these systems dynamically interacting with the physical, chemical, and geologic processes operating on Earth. The biosphere and the physical Earth System are effectively connected over diurnal, seasonal, and annual cycles. Just as importantly, critical interactions occur over millennial scales and longer. Currently, the ability to observe or reconstruct long-term coupled behavior between living and nonliving components of the Earth System is limited and must be improved to support long-term ecological forecasting. Additionally, while humanity now affects nearly the entire biosphere, our understanding of how the biosphere operates in these landscapes is limited because most studies focus on organisms in pristine or minimally altered ecosystems (Vitousek et al., 1997). We must develop a better understanding of the physiology, distribution, and evolution of organisms in human-dominated landscapes.

Living systems interact with each other and with the rest of the Earth System at many scales from the cellular to the continental levels. At a small scale, individual plants exchange energy and matter with the atmosphere to support growth. At the continental scale, exchange between biotic components, the atmosphere, and surface water affect climate and hydrology. Individual organisms interact directly with each other locally, but the movement of invasive or pathogenic species can change the biota of entire continents. This process has repeatedly occurred throughout geologic time as continents have moved over the surface of the Earth. Understanding the role of organisms and their biology in the Earth System requires coordinated analysis of patterns from small-scale mechanisms within cells to global-scale fluxes. Understanding the patterns of movement and distribution of organisms is also important, as is the development and coordination of methods for quantifying the various scales of biological activity.

The National Ecological Observatory Network (NEON) is a bold effort to expand horizons in the science of large-scale ecology, building on recent progress in many fields. NEON's goal is to improve understanding and forecasting of ecological change at continental scales. To achieve this end, NEON is designed as a continental-scale platform for understanding and forecasting the impacts on ecology of climate change, land use change, and invasive species. NEON science focuses explicitly on questions relating to the Grand Challenges in environmental science (National Research Council, 2001), is relevant to large regions, and cannot be addressed with traditional ecological approaches (NEON, 2006). NEON's open access approach to its data and information products will enable scientists, educators, planners, and decision makers to map, understand, and predict primary effects of humans on the natural world and effectively address critical ecological questions and issues.

The observatory will provide physical infrastructure for data collection, but also information infrastructure that will be presented as NEON data products. This includes high-level data products and basic calibrated data products. NEON has developed a preliminary (as of 2010) catalog of high-level scientific data products providing synthesized information to ecologists, other scientists, educators, citizens, and decision makers. Currently, there are 100 high-level data products in the preliminary catalog that are grouped into six data suites: bioclimate, biodiversity, biogeochemistry, ecohydrology, infectious disease, and land use change. This dynamic catalog will change as the state of ecological science advances. NEON is also developing a preliminary (as of 2010) catalog of basic calibrated data products that will be used primarily by specialists. The 539 entries in this catalog will be relatively stable throughout the lifetime of the observatory. The basic calibrated data are produced and organized by the NEON science sub-systems.

The Airborne Observation Platform (AOP) is a remote sensing instrumentation package designed to bridge scales from that of individual plants and stands, captured by plot and tower observations, to that of satellite-based remote sensing. The AOP will survey each NEON site annually, building a robust time series of landscape-scale changes. The AOP will provide meter-scale spatial resolution that will allow measurements at the level of individual organisms or small groups of organisms. It is designed to measure land use change; vegetation canopy biochemistry, structure, and heterogeneity; and changes in vegetation state and performance, including the presence and effects of invasive vegetative species. The direct measurements from the AOP system are spectral radiances, LiDAR returns, and photogrammetric images. However, these data can be analyzed to produce a set of low-high level data products:

- **Canopy chemistry** of individual trees and small (1-2 m) swards of herbaceous vegetation, including many of the direct correlates of photosynthesis and growth, such as nitrogen, chlorophyll, and leaf thickness.

- **Canopy moisture**, which can be estimated because water in plants has a different spectral response than atmospheric water, and which can provide a spatial perspective on water stress.
- **Leaf area** for each tree or small sward, directly estimated from the LiDAR and leaf area distribution, and the vertical distribution of leaf area, estimated from the LiDAR's waveform response.
- **Canopy and landscape structure**, from the three-dimensional distribution of individual trees and herbaceous swards, as well as from leaf area, including both its vertical distribution and its horizontal heterogeneity.
- **Canopy height**, and tree height, allowing allometric estimation of biomass in woody ecosystems and, in many cases, for individual trees.
- **Land cover** and aspects of land use, from interpretation of photogrammetric images and spectral/LiDAR imagery.
- **Diversity**, obtained by measuring the distinctive chemical and structural signatures of species or at least-functional types. When LiDAR and spectral data are combined, in many cases aspects of biodiversity, including distribution of plant invaders may be determined.
- **Disturbance**, detected from spatial patterns (such as canopy gaps) and their change over time. In some cases, disturbances may be detected directly. For example, oil from Deepwater Horizon was mapped using hyperspectral data at sea and in the coastal zone.

The optimal suite of instruments available to provide these capabilities is a high-fidelity visible to shortwave-infrared imaging spectrometer and a waveform LiDAR. These are supported by a high-resolution digital camera to provide information on land use, including roads, impervious surfaces, and human structures. The AOP will also contribute to the understanding of the causes and effects of change in ecosystems as represented by vegetation states and processes. Invasive plants can be detected through both their spectral and structural properties (Penn, 2003; Asner and Vitousek, 2005; Asner et al., 2008). Pest and pathogen outbreaks, changes in competitive relations, responses to disturbances such as wildfire, and many features of land use are also readily observed and quantified using the powerful combination of biochemical and structural information provided by spectroscopy and waveform LiDAR.

The high cost of aircraft operations will limit the frequency of AOP visits to individual NEON sites. Two airborne platforms will be dedicated to the annual survey of NEON sites. To detect interannual trends, NEON will seek to overfly each core and relocatable site annually. To minimize the phenological contribution to the signal, flights will be designed to reach each site during a period of peak greenness (currently defined as the range of dates where MODIS NDVI, that is, the normalized difference vegetation index as measured by the Moderate Resolution Imaging Spectroradiometer instrument, is within 90% of the site maximum). A third airborne platform will be available for deployment in response to extreme events to monitor both causes of change and responses (e.g., hurricane damage and the following regrowth) as well as to support PI requests (e.g., regional surveys of invasive species or phenology).

Annual visits inevitably miss important site-level signals such as phenology. Extending airborne observations to the continental scale requires a linkage from the meter-scale regional measurements to satellite measurements. The need to cross scales drives the AOP to observe a substantial area on the ground surrounding each site. Currently we estimate that each AOP site mission will cover approximately 300 km^2, a compromise between area coverage and cost. To support studies at the continental scale, the airborne data will be assimilated into ecological models along with higher-frequency multispectral satellite data, albeit at coarser spatial resolution, as well as data from national databases and the other NEON observational components.

Section II: Detailed Project Plan

1) Research Design and Methodology

a) Research Questions

There are numerous research questions that NEON is attempting to answer. This is the first continental-scale investigation of eco-systems in North America on the impacts of climate change, land use change and invasive species on natural resources and biodiversity. Because NEON is more of a facilitator than actual investigator, these data will be collected and distributed freely via the internet to ecologists, other scientists, and educators around the world to investigate.

b) Research Strategy

i) Significance

NEON is the first of its kind in the United States addressing a large, complex problem. As such, it is prudent to bring to bear all available assets to help assess the current state of the ecology in the U.S. This is a program where all information gathered will be critical in helping the decision-making process as we move forward. Clearly, as you read this proposal and you see the need, because it will have significant impact on the ecological future of the U.S. it means that it is critical that we get this right. Never before has such a large-scale effort been mounted by the U.S. to gain a greater understanding of the ecological health of the U.S.

Ecological health can be measured at many scales. The view from space may be the best large-scale location for such observations. These observations when integrated with smaller-scale observations will provide the needed encompassing perspective to enable a viable understanding of the ecologic state of North America.

The role envisioned by NEON for the Hyperspectral Imager for the Coastal Ocean (HICO) aboard the International Space Station (ISS) is to supplement AOP data collections. The sheer magnitude of the data collection needed for the successful implementation of NEON depends upon timely data collection. Unfortunately, the AOP may not always be able to access each site during peak growing times. While ISS has some limitations due to orbital inclination reaching sites in Alaska, most of the NEON sites will be accessible. Beside logistical concerns, weather always constrains imagery collections especially in the more humid areas so any opportunity to collect additional imagery over these targets is welcome.

ii) Innovation

NEON is attempting to integrate hyperspectral remote sensing with phenomenology and physical measurements. Reflected-light Hyperspectral Imaging (HSI) is particularly sensitive to weather and lighting conditions. One of the goals of NEON is to collect HSI data during peak greenness as determined using the Normalized Difference Vegetation Index (NDVI) from Moderate Resolution Imaging Spectroradiometer (MODIS) data. As such, it is probable that even with three NIS sensors it may not be possible to image all of these sites at the desired time. If we can bring the HSI assets on the ISS into the mix, then the likelihood of collecting imagery of all the sites is much higher. NEON, in collaboration with the ISS, is truly an innovative use for the ISS.

iii) Approach

(1) Experimental Conditions

The goal is to have the HICO instrument augment airborne hyperspectral collections of the NEON sites. As such, it would be best if the areas to be imaged are cloud-free (<15%) with relatively high sun-angle (between 10 am and 2 pm local time). The location should be within 10 degrees of nadir to minimize off-nadir distortion of pixels and lighting variation. Our atmospheric correction algorithms are being developed by Bo-Cai Gao of NRL. So there is a consistency between the algorithms which can be compared between HICO and NIS.

(2) Translation

Translation is not applicable for this study.

(3) Ground-based Experiments

It is anticipated that there will be situations when the NIS and the ISS can co-collect imagery. These data will be used to correlate the response of both instruments under similar conditions. It will also exercise the atmospheric removal algorithms used for HICO. No specific number of overflights of the same area are planned at this point, but they will be a natural outcome of the collaboration between CASIS and NEON. To date, there have been at least two nearly simultaneous collections of imagery by these two instruments.

2) Technical Aspects of Spaceflight

Since the desire of this study is to use existing facilities aboard the ISS, no real technical aspects of spaceflight are necessary as nothing will be launched and added to the ISS.

Section III: Economic Impact of Project Success

As NEON is a wholly-NSF-funded non-profit organization, there was no real effort to estimate the economic impact of the project. Nonetheless, the study of climate change and invasive species can significantly impact areas where agriculture and waterways are threatened by invasive species.

1) **Commercial impact**
   An example of commercial impact involves the Delta Rivers region of California where the State of California has spent $millions to manage and monitor invasive water species such as Egeria. Invasive plants interfere with the commercial navigation of these waterways. From an economic perspective NEON will allow both private and public sectors to focus their money on the most critical aspects of invasive species and develop robust plans to anticipate possible infestations and perform the proper remediation. The savings for identifying and monitoring just one invasive species or deleterious environmental impact will be on the order of $10M - $100M.

2) **Impact relevant to STEM**

   Part of NEON's charter from NSF is to build a web portal for researchers to access these data. The first portions of the website are already visible at:

   http://dataportalreview.ci.neoninternal.org/home.

   Another project already under the auspices of NEON is Project Budburst where citizen scientists monitor plants and record their observations. This approach will be adopted to a large extent by NEON.

Section IV: Budget and Time Frame

NEON has no funding to support the collection of HICO imagery, as such it is hoped that the goals of NEON/ISS/CASIS are similar enough to warrant donation of HICO collection time and data to this effort. Collection efforts have unofficially began via communications with NRL. HICO attempted to collect imagery of the High Park Burn area west of Fort Collins, Colorado last year. Also, HICO collected imagery near Grand Junction, Colorado in May, 2013 when the NIS was collecting imagery in the area. So, the time frame can begin immediately.

Section V: Biographical Sketch

Brian S. Penn

<u>EDUCATION</u>

- PhD, Geology, Colorado School of Mines, 1994.
- MCS, Computer Science, University of Texas at Arlington, 1988.
- BS, Geology and Computer Science, Eastern Michigan University, 1980.

<u>EXPERIENCE</u>

National Ecological Observatory Network, Geospatial Software Engineer, July 2012 to present

Responsible for ingesting Land Use Application Package and Aerial Observation Platform (hyperspectral AVIRISng) data into NEON database.

Hyperspectral Imaging and REE Exploration Consultant, September 2011 to present

Using Hyperspectral Imaging techniques to explore for Rare Earth Elements.

The Boeing Company, February 2000 to September 2011
Engineer/Scientist

Led commercialization of the International Space Station focused on using hyperspectral sensors in the Window Observational Research Facility (WORF) on the Destiny module.

Program Manager/Technical Lead for development of Boeing's Automated Decision Support Environment (ADSE) for INSCOM and 513^{th} Military Intelligence Brigade (MIB) to support unattended ground sensor array.

Technical Lead for Boeing's Opportune Landing Site (OLS). OLS uses multispectral imagery (LANDSAT) and DTED data to locate suitable landing areas for large transport aircraft.

Technical Lead for NASIC Spectral Library hyperspectral data collections. Arranged for, and collected hyperspectral signatures in the field. Sought customer input to develop algorithms and software for advanced multispectral and hyperspectral image exploitation.

Used AVIRIS hyperspectral data to explore for rare earth elements at Mountain Pass, California, Iron Hill, Colorado, and the McClure Mountain Complex, Colorado.

Assisted in NASA Shuttle Columbia recovery efforts in East Texas. While in Texas, I developed software to automate the data reduction processing which resulted in a 6x reduction in processing time for large (> 1 terabyte) hyperspectral data sets.

University of Texas at El Paso, October 1995 to February 2000
Chief Remote Sensing Scientist

Established NASA-funded Pan-American Center for Earth & Environmental Studies (PACES) remote sensing center. Responsible for acquisition of hardware, software, and data for PACES. Directed numerous graduate students interested in remote sensing applications for theses.

Collaborated with the USGS's Spectroscopy Laboratory in Denver, CO and NASA's Jet Propulsion Laboratory in Pasadena, CA. As part of this effort, directed NASA/JPL's Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) flights over the southwestern U.S. from

1996 -1999. Maintained close working relationship with personnel at USGS Spectroscopy Laboratory.

Colorado School of Mines, October 1994 to October 1995
Post-Doctoral Research Associate
Designed/Implemented software to visualize complex geologic sedimentary processes based on non-linear systems.

United States Geological Survey, June 1992 to May 1994
Geologist
Designed graphical event-driven object-oriented computer system to automate data collection process for Argon Geochronology Laboratory at the USGS. in Lakewood, Colorado.

Colorado School of Mines, September 1988 to May 1992
Manager, Artificial Intelligence Laboratory
Established Artificial Intelligence Laboratory funded by Texas Instruments. Responsible for managing hardware and software support and taught short courses.

RECENT PUBLICATIONS

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Penn, B.S., 2003. Using Hyperspectral Imagery to Map Tamarisk in De Beque, Colorado, Tamarisk Symposium, Grand Junction, CO, Oct. 22-24, 2003.

Penn, B.S. and Wolboldt, M. W., 2003. Methods for Detecting Anomalies In AVIRIS Imagery in Proceedings of the Twelfth JPL Workshop on Airborne Earth Science Workshop, Pasadena, California, February 25-28, 2003.

Penn, B. S., 2002. Using Hyperspectral Imagery to Map Roads and Determine Surface Material Types, ASPRS, Pecora 15 + LANDSAT Information IV, Denver, CO, November 10-15, 2002.

Section VI Additional Information

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Vitousek, P. M., Mooney, H. A., Lubchenco, J., and Melillo, J. M. (1997). *Human domination of Earth's* ecosystems. *Science, 277*, 494-499.