NEON SCIENTIFIC DATA PRODUCTS CATALOG

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A	05/15/2009	NEON.MGMT.DPS.000010.CRE	Initial Release
A.1	08/21/2009		Changes to improve explanations of data product linkage to NEON design and the rationale for 5 data levels. Modifications to account for removal of basic towers soil surface flux chambers and other scope modifications in the observatory design. Modifications to account for changed management structure for science product teams.
B	09/22/2009	NEON.MGMT.DPS.000067.CRE	Approval of submitted changes
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1 SCOPE AND DESCRIPTION

This document describes the high-level scientific data products for the National Ecological Observatory Network (NEON). High-level scientific data products will be developed in order to fulfill the NEON mission to understand the effects of climate change, land use change and invasive species on ecological processes and to enable ecological forecasting. The data products described in this document are primarily intended to serve the scientific community although they may be useful to other communities such as educators and public policy specialists. Specific products aimed at students, educators, decision makers, and the public will be described elsewhere. The intended audiences of this document are the NEON project staff, management, and advisors, NSF, and the scientific community.

The selection of high-level scientific data products follows the concepts put forth in the NOD (AD[02]). The NOD follows logically the conceptual design of NEON put forth in the ISEP (AD[01]). The ISEP encompasses, distills, and supersedes a library of NEON planning documents developed by hundreds of scientists over a decade. Input to the selection of the data products following the publication ISEP was provided by numerous NEON sponsored workshops and Tiger Team activities throughout 2007 and 2008.

High-level data products have been selected to maximize utility to the scientific community balanced with the resources available to the observatory. Selection of high-level data products is constrained by the basic information provided by the observatory scientific components (AOP, AQU/STR, FIU, FSU, and LUAP). For this foundational ecological observatory project, the selection of high-level data products is the result of trade-off between scientific desires and technical and budgetary reality. We have endeavored to capture the critical essence of the observatory in the current NEON design a portion of which is documented below.

The current initial selection of data product has not been through a review cycle by the scientific community and the NEON Science Technology and Education advisory committee. Therefore, we consider this a preliminary selection that will be modified based on future inputs. The scientific data products are being developed to serve the community and they will be constructed, maintained and modified based on community input.

2 RELATED DOCUMENTS AND ACRONYMS

2.1 Applicable Documents

AD[01]	NEON.DSDV.NPR.00000.PLA – NEON Integrated Science and Education Plan (ISEP)
AD[02]	NEON.DSDV.NPR.000001.REP – NEON Observatory Design Requirements (NOD)
AD[03]	NEON.MGMT.DPS.005000.PLA – NEON High Level Data Products Management Plan

2.2 Reference Documents

RD[01]	NEON.MGMT.NPR.000008.GEN NEON Glossary of Abbreviations
RD[02}	
RD[03]	
RD[04]	

2.3 Acronyms

Abbreviation or Acronym	**Non-abbreviated reference**
AD	Applicable Drawing
AOP	Airborne Observation Platform
AQU/STR	Aquatic/STREON unit
CI	Cyber-Infrastructure
DCS	Domain Chief Scientist
ECS	Experiment Chief Scientist
FIU	Fundamental Instrument Unit
FSU	Fundamental Sentinel Unit
GPS	Global Positioning System
ICD	Interface Control Document
IMU	Inertial Measurement Unit
ISEP	*Integrated Science and Education Plan for the National Ecological Observatory Network* (AD[01])
LAI	Leaf Area Index
LUAP	Land Use Analysis Package
NTAD	National Transportation Atlas Database
NEON	National Ecological Observatory Network
NOD	*NEON Observatory Design* (AD[02])
NSF	National Science Foundation
PAD-US	Protected Areas Database of the United States
STREON	The STReam Observation Network Experiment
VPD	Vapor Pressure Deficit
WBD	Watershed Boundaries Dataset

3 EXECUTIVE SUMMARY

The National Ecological Observatory Network (NEON) will provide a physical and information infrastructure to enable understanding and forecasting of the impacts of climate change, land use change and invasive species on continental-scale ecology. The NEON design derives from the environmental Grand Challenges and the need to answer scientific questions (AD[02]). These questions, in turn, define the measurements and observations carried out through the scientific subsystems. In order to provide the necessary information infrastructure, NEON data from observations and experiments must be processed in sophisticated ways. These may range from averaging or smoothing for easy visualization up to processing through models for inference of parameters or unobserved quantities. NEON information will be made available to the scientific community, students, educators, decision makers and the public through the NEON cyberinfrastructure. Collectively, the information provided by NEON will be distributed as data products.

This document describes the high-level data products (Level 4 as described below). These products must fulfill the observatory requirements as expressed in the NOD (AD[02]). The requirements for observatory infrastructure include the need to “provide usable information to scientists, teachers, students, citizens, governmental and non-governmental decision makers” [NOD (AD[02])]. This information must be provided across seven NEON challenge themes (biodiversity, biogeochemistry, climate change, ecohydrology, infectious disease, invasive species, and land use change) as a foundation to “detect and quantify ecological responses to climate, land use and biological invasion” and to “to establish the link between ecological cause and effect” [NOD (AD[02])]. NEON high-level data products should enable ecological forecasts and analyses at a continental scale and facilitate the observation of decadal scale changes against a background of seasonal-to-interannual variability. The data products have been chosen to maximize utility to the community and to enable analysis of cause and effect in ecosystems and forecasting of the future states of ecosystems.

The current initial selection of data product has not been through a review cycle by the scientific community and the NEON Science Technology and Education advisory committee. Therefore, we consider this a preliminary selection that will be modified based on future inputs. The scientific data products are being developed to serve the community and they will be constructed, maintained and modified based on community input.

In order to organize the production and presentation of the NEON data products, NEON will use a parsimonious series of 5 data product levels. These start at raw data (Level 0) and proceed to calibration (Level 1). There are optional steps for temporal (Level 2) and spatial (Level 3) rectification. Only the highest stages of processed data products (Level 4) are presented in this document. These products derived from level 1, 2 and/or 3 data represent a range of complexities from simple summaries to complex analyses. This selection of data product levels is sufficient to inform the data users of the nature of a product and to guide internal management and cyberinfrastructure processes. It is not necessary for all data products to proceed uniformly from Level 0 to Level 4.

Data products for NEON levels 0, 1, 2, and 3 are derived primarily from a single instrument, observer, or a specific sampling location. These products are associated with the four principal observatory scientific sub-systems described in the *NEON Observatory Design* (AD[02]): Fundamental Sentinel Unit (FSU), the Fundamental Instrument Unit (FIU), the Airborne Observation Platform (AOP), and the Land Use Analysis

Package (LUAP). These components scale ecological observations from the organismal level (FSU), to airsheds and watersheds (FIU), to small regions (~300 km^2; AOP) and on to the national or continental scale using data sets collected outside of NEON (LUAP). For practical purposes, the FSU and FIU components are now managed as three scientific sub-systems that include the terrestrial portions of FSU and FIU that are referred to by those names and an Aquatic sub-system that manages both organismal and instrumental measurements in streams and ponds. The aquatic sub-system referred to as Aquatic-STREON (AQU/STR) also manages the Stream Observational Network Experiment (STREON).

Level 1 through 3 data products are associated with a specific NEON observational or experimental component (e.g. AOP,AQU/STR, FIU, or FSU) and are organized and identified according to those components. Level 4 data generally combine information from more than one instrument, observer, or sampling sites. These products are organized in six data suites: Bioclimate and biophysics; biodiversity; biogeochemistry; ecohydrology; infectious disease; and land use. The goal of this taxonomy is to group together data of similar types with a minimum of overlap and ambiguity among suites.

Data products in the Bioclimate and Biophysics suite derive mainly from lower level data on weather, solar radiation, plant physiological responses, and aspects of ecosystem structure. NEON will produce 18 high-level products many of which represent summaries of point measurements of ecosystem climatic forcings. Some measurements such as leaf area index (LAI), albedo, and the fraction of photosynthetically active radiation absorbed by the vegetation canopy (fPAR) will be retrieved from remote sensing products from both the AOP and satellite sensors. The Bioclimate and Biophysics suite traces directly to the climate and biogeochemistry NEON challenge areas. Vegetation has critical feedbacks to the atmosphere. Key aspects of bioclimate and biophysics are related to surface energy balance.

The 31 high-level data products in the Biodiversity suite are derived from lower level data on diversity, demography, and phenology collected in the Fundamental Sentinel Unit (FSU) and the Aquatic/STREON unit. This category traces directly to the biodiversity NEON challenge area and also supports the invasive species challenge area. The high-level data products in the biodiversity cover a range of measurements of the NEON sentinel organisms. There are three carefully selected high-level products in this section that require a large investment of NEON resources. These products are Invasive plant risk maps, Ecosystem Structure Maps and Soil microbial metagenomes. The invasive plant risk maps build on existing research and highlight the importance of invasive species to continental scale ecology. These maps should motivate field and experimental studies related to specific invasions and enable improved forecasting of species invasions. The Ecosystem structure map produced for all regions overflown by the Airborne Observation Platform (AOP) and soil microbial metagenome products select transformational areas of research where NEON investment will enable more profound analysis for the advancement of ecology.

NEON will produce 28 high-level data products in Biogeochemistry suite related to carbon dynamics, nutrient dynamics, and air and water quality. The carbon dynamics products relate to terrestrial and aquatic ecosystem productivity and derive mainly from lower level data on soil and plant measurements in AQU/STR, FSU, and FIU (aquatic array, vegetation plots, soil array and eddy flux). At broader geographic scales data from the airborne remote sensing (AOP) and satellite remote sensing play an important role. Vegetation has critical feedbacks to the atmosphere. The balance of carbon and productivity depend upon vegetation atmosphere exchange. Nutrient data focus primarily on nitrogen and phosphorus stocks and fluxes in both terrestrial and aquatic systems. NEON will measure several important aspects of water quality including nutrients, oxygen, and turbidity, and air quality including nitrogen deposition and ozone deposition. The air and water quality data trace directly to the climate change and biogeochemistry NEON challenge areas. Chemical climate, including airborne gases and particles and it is changing as rapidly as or more rapidly than the physical climate.

NEON will make several significant investments in the biogeochemistry area including development of an annually updated vegetation biomass map for the NEON Realm. While labor intensive to construct initially, this product is important to enable forecasting and analysis both for model initialization or validation. Regional and national maps of ecosystem carbon exchange (gross and net exchange components) were selected for special emphasis because of their wide applicability and the ability to validate models through comparison with atmospheric CO2 measurements. The strength of this validation is that it puts a top-down constraint on all NEON vegetation productivity measurements. Finally, NEON will invest heavily in improvement of the quantification of below-ground productivity. Currently, labor-intensive manual analysis of below-ground mini-rhyzotron data is a major impediment to research progress in productivity studies. NEON investment in this area will enable future analysis and forecasting of below ground productivity by provision of both extensive data sets and analysis routines.

The Ecohydrology suite contains 10 high-level data products that derive mainly from lower level data from the AQU/STR and FIU airshed and watershed based measurements. Measurements at the scale of the soil-survey and AOP sub-regions and the NEON realm will be spatially extrapolated with geographic data and remote sensing products. The products in this category traces directly to the climate change and ecohydrology NEON challenge areas. The products such as water balance and soil moisture relate to the tightly coupled water and energy exchange between the ecosystem and the atmosphere or the complex of hydrology and geomorphological controls over aquatic environments. NEON will invest heavily in two products that quantify ecosystem-atmosphere exchange. First a soil moisture product of national extent will be used to enable model initialization, calibration, and validation (Ecohydrology_003). Second a related national model of water balance (Ecohydrology_006) will be implemented together with ecosystem carbon exchange (Biogeochemistry_019). These two products are critical to enabling forecasting of the effects of future climate change effects on vegetation.

Seven high-level data products in the Infectious Disease suite derive from lower level data from the FSU. These products summarize the low level data and provide views of the variation in disease prevalence in space and time. The focus is on the zoonotic diseases West Nile virus and Lyme disease and also dengue fever that is likely to spread as the climate of the US warms. This data product suite traces directly to the infectious disease NEON challenge area.

High-level data products in the Land Use suite derive mainly from data sources outside of NEON. This category traces directly to the land use change NEON challenge area and it also supports analysis and forecasting in all of the other NEON challenge areas. The selection of outside data includes basic environmental properties (e.g. elevation, soil classification, and climate) and the resulting land expressions of climate, ecology, and human activity (e.g. land cover classification). All of the products are selected carefully to enable analysis, modeling, and forecasting. Data will be presented at a limited number of regular time intervals (1, 5 or 10 years) and on consistent map projections using a regular grid of (10, 30, 100 or 1000 m) dependent upon the product. For products covering the full NEON Realm, this implies the need to carefully downscale existing data to the 9.8 x 10^6 grid cells of 1 km^2 area chosen for consistency with present and future satellite data products.

Most of the high-level land use suite data products are derived from outside sources including much information from government agencies such as the USGS and NOAA. As a result, there are relatively few data products that require large investments by NEON. An important exception is the data product mapping historical land cover classification. While historical data exist, building a data set that uses consistent definitions across time will require a large development effort. This data is critical for ecological models used in hindcasting efforts and to initialize models for analysis and understanding of important ecological legacies resulting from historical land use.

NEON data products will change dynamically along with ecological conditions and the advancement of knowledge with inputs from the scientific community, NEON staff and management. The NEON Science, Technology, and Education Advisory Committee (STEAC) will be the primary advisory body for assessment of the status of data products. The STEAC will evaluate information compiled by the NEON staff and make recommendations for modification of existing data products and development of new data products. NEON Inc. will evaluate this advice and implement STEAC priorities that are consistent with the NEON mission, observatory requirements, and available resources.

4 HIGH-LEVEL DATA PRODUCTS

4.1 Data Products Concept

NEON is designed to provide a physical and information infrastructure to enable understanding and forecasting of the impacts of climate change, land use change and invasive species on continental-scale ecology. The NEON design derives from the environmental Grand Challenges and the need to answer scientific questions (AD[02]). These questions, in turn, define the measurements and observations carried out through the scientific subsystems (Figure 1). In order to provide the necessary information infrastructure, NEON data from observations and experiments will need to be processed in sophisticated ways. These may range from averaging or smoothing for easy visualization up to processing through models for inference of parameters or unobserved quantities. NEON information will be made available to the scientific community, students, educators, decision makers and the public through the NEON cyberinfrastructure. Collectively, the information provided by NEON will be distributed as *data products*.

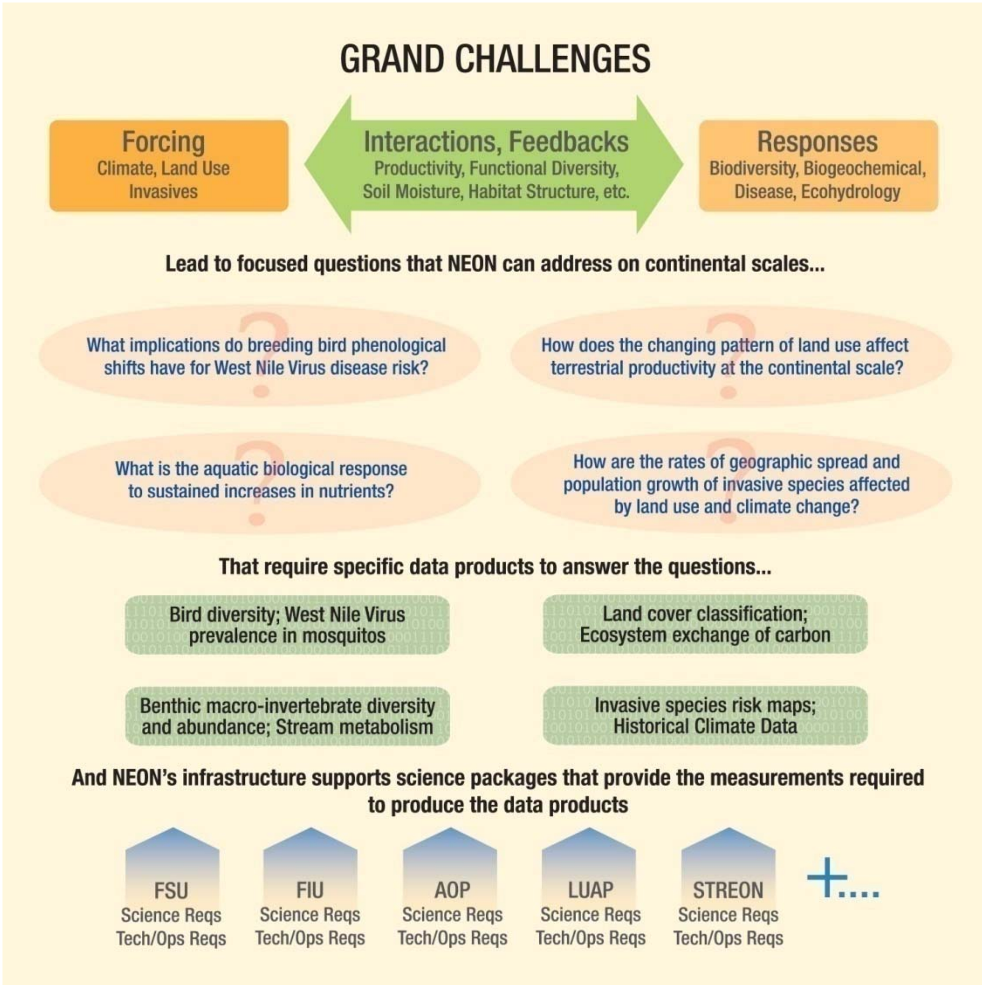

Figure 1 The NEON Design Process (AD[02])

An example of NEON data products and their production is presented as an illustration. The Fundamental Instrument Unit (FIU) measures water, carbon and energy budget components at high temporal frequency. Observations may be missing when an instrument fails, or conditions do not meet required assumptions, causing data gaps. Many quantities desired must be computed or inferred from the measurements made. Data processing steps for biophysical data typically then involve:

1. Calculation of basic physical quantities from measurements (for example, carbon flux is computed from CO_2 concentration and wind data).
2. Calculation of key quantities during data gaps using statistical models to allow calculation of temporal averages of integrals (e.g. monthly or annual totals).
3. Calculation of desired quantities from basic quantities. For example evaporation and transpiration from be inferred from their sum, the latent heat flux; and photosynthesis and respiration may be inferred from net ecosystem exchange.

4. Inference of parametric information from calculated quantities. For example, from inferred photosynthesis and transpiration, water use efficiency may be computed.
5. Estimation of process controls from observed, calculated and parametric quantities. For example, the effect of drought on water use efficiency between statistically normal and dry years can be estimated from inter-annual variations in precipitation, soil moisture, transpiration and photosynthesis.

Analogous processing flows will be followed for other data types. For example, population estimates will be computed from small mammal data using mark-recapture models. Population parameters (fecundity, mortality, etc) will be calculated from population estimates.

Different NEON users will be interested in different levels of data. A research biophysicist might be interested in data from the earlier steps in the example given above, whereas an agricultural economist might need the sensitivity estimated in step (5) for including in a forecast of climate change impacts on the farm sector.

Producing NEON high-level data products will follow a number of steps:

1. Identification and retrieval of large numbers of data types
2. Associating calibration and validation information with these data sets
3. Processing these data sets through algorithms
4. Storing and documenting the outputs
5. Repeating steps 1-4 to produce high-level data products (e.g., parametric results).

Developing the NEON high-level data production procedures will require coordinating:

1. Algorithm science (identification and validation of the models used)
2. Applied mathematics and statistics (identification and validation of the solution or estimation procedures)
3. Computational science (identification and optimization of the computational procedures used)
4. Informatics (documentation and curation of the information produced).

4.2 Selection of Scientific Data Products

The selection of low-level (0 through 3) data products is limited by the measurements produced by the observatory. Based on the discussion above, one can easily see that the number of possible NEON level 4 data products is vast. Practical constraints of time and effort impose limits on the data products to be built during NEON construction. Similar constraints will apply to new and replacement data products added to the observatory during the operations phase (see Section 10). Ultimately the selection of level 4 data products must fulfill the observatory requirements as expressed in the NOD (AD [02]). The seven requirements for observatory infrastructure include the need to "provide usable information to scientists, teachers, students, citizens, governmental and non-governmental decision makers [NOD (AD [02])]." This information must be provided across seven NEON challenge themes [NOD (AD[02])] (see section 3.4) as a foundation to "detect and quantify ecological responses to climate, land use and biological invasion" and to "to establish the link between ecological cause and effect" [NOD (AD [02])]. NEON level 4 data products should enable ecological forecasts and analyses at a continental scale and facilitate the observation of decadal scale changes against a background of seasonal-to-interannual variability.

The current initial selection of data product has not been through a review cycle by the scientific community and the NEON Science Technology and Education advisory committee. Therefore, we consider this a preliminary selection that will be modified based on future inputs. The scientific data products are being developed to serve the community and they will be constructed, maintained and modified based on community input.

4.3 Data Product Levels

NEON will publish data products for science, education, outreach, and decision support. The data products published by NEON will include raw measurement data and scientific data products from calibrated measurements (including the associated calibration data) through high-level products that combine multiple measurements and may involve considerable assumptions and interpretation. In order to organize the production and presentation of the NEON data products, NEON will use a parsimonious series of data product levels. This minimum number of levels is sufficient to inform the data users of the nature of a product and to guide internal management and cyberinfrastructure processes. A description of data product levels is presented in Table 1. It is not necessary for all data products to proceed uniformly from Level 0 to Level 4.

Data at Level 0 is the data received by the NEON cyberinfrastructure, whether it is generated by an automated instrument or entered by a human observer. The Level 0 data is provided in the original (engineering) measurement units. The Level 1 observatory data are generally the lowest level of scientifically useful data. Those data have been through a quality control process and have been calibrated to scientific units. Higher level data products are used along with Level 1 data in scientific research. Data products at levels 2 and 3 are generally derived from Level 1 data. Level 4 data products may be derived from a combination of data products at levels 1, 2, and/or 3.

Table 1 Definition of Data Product Levels for NEON.

Level 0	Raw data from instrumental or human observations.
Level 1	Calibrated data generally from a single instrument, observer, or field sampling area. These data may include information on data quality.
Level 2	Combinations of level 1 data used to create a gap filled data stream that may replace a level 1 product. Generally, products at this level this will reflect a stream from a single instrument, observer, or field sampling area. Annotations will indicate the gap filling approach employed.
Level 3	Level 1 and /or 2 data mapped on a uniform space-time grid.
Level 4	Derived products using levels 1, 2 and/or 3 data. Products at this level may combine observations from more than one instrument, observer, and/or sampling area.

4.3.1 Examples of Data Products by Level

4.3.1.1 Example 1 (FIU)

In order to estimate the net ecosystem exchange of carbon dioxide with the atmosphere in forested ecosystems, it is common to include a term for carbon storage in the canopy below the measurement height for eddy fluxes. This term is estimated by integration of carbon dioxide mixing ratings over a range of heights from the height of the sonic anemometer in an eddy covariance system to the ground. Mixing ratios are usually measured sequentially at more than one level in a vertical profile using a system of valves.

<u>Level 0.</u> Raw output of an infra-red gas analyzer measuring carbon dioxide at 6 individual heights (C01, C02, C03, C04, C05, C06).

<u>Level 1.</u> Calibrated values of carbon dioxide dry air mixing ratios at 6 individual heights. (C11, C12, C13, C14, C15, C16)

> *When a valve was faulty, data at a given level might be unreliable (e.g. the valve did not open at level 3, therefore C13 was unavailable), the filled value of C13 concentration profile could be estimated using a curve-fit based on the other 5 levels producing an estimated mixing ratio C23.*

<u>Level 2.</u> Calibrated values of dry air carbon dioxide mixing ratios at 6 individual heights including filled values. (C21, C22, C23, C24, C25, C26).

> *When no values were missing, Level 1 and Level 2 data for this example would be equivalent.*

<u>Level 3.</u> Not applicable. This product is associated with a single x,y coordinate and will not be gridded.

<u>Level 4.</u> Integrated mass of carbon dioxide stored beneath the sonic anemometer measurement height estimated from the Level 2 concentration data and atmospheric pressure.

4.3.1.2 Example 2 (FSU)

An estimate of above-ground vegetation biomass in a forest plot may combine tree, vine, and herbaceous components. The biomass for an individual tree is often made with an allometric equation that relates diameter at breast height (1.3 m), total tree height, and wood density based on tree species to tree biomass. Tree diameter is calculated from tree circumference. Tree height is calculated from measured angles and horizontal distance to the observer. Vine biomass is estimated using similar equations. Herbaceous biomass is measured by harvesting small plots and oven drying the collected material.

Level 0. Field measurements of tree circumference, angles and distances used to calculate tree height, and species identification.

Level 1. Calculated tree diameter and height with applicable instrument calibrations applied. Wood density based on literature values from a look-up table. Tree biomass is calculated from these three values and an allometric equation.

> *In some cases, no density value is available for a species or the species of the measured tree is unknown. In this case, an average density value for the region or plot could be employed.*

Level 2. Tree diameter and height and wood density based upon a regional average value. Tree biomass calculated from an allometric equation using these values.

> *When all diameter, height, and density values are known, Level 2 data is equivalent to Level 1 data.*

Level 3. Tree biomass plotted on a standardized geospatial grid.

Level 4. Plot level biomass summing tree, vine, and herbaceous components.

4.3.1.3 Example 3 (AOP)

Data collected by the airborne spectrometer on a flight above a NEON site will be used to determine the total canopy nitrogen. Total canopy nitrogen will be compared across a transect of nitrogen deposition levels over a number of years in order to test the hypothesis that increasing deposition leads to increasing canopy nitrogen and by inference, increasing photosynthetic capacity.

Level 0. Digital output from imaging spectrometer; GPS/IMU signals raw voltages data from the spectrometer.

Level 1. Geo-referenced and rectified surface spectral reflectance at high resolution (1-3 meters) along each flight track Data calibrated and processed to a radiance and reflectance values at the native resolution of the measurement.

Level 2. Not applicable.

Level 3. Mosaic of upper-canopy leaf nitrogen data corresponding to individual flight lines remapped to NEON 10-meter grid.

Level 4. Total canopy leaf nitrogen computed from LEVEL 3 AOP data and ground-based data from similar ecosystems displayed on a uniform NEON geospatial grid.

4.3.2 Comparison of NEON Data Product Levels with the CODMAC Standard

NEON data product levels are consistent with national standards. In particular, the NEON levels parallel levels developed by the National Research Council Committee on Data Management, Archiving, and Computing (CODMAC). The NASA EOS program follows a slight variation of the CODMAC standard (http://nasascience.nasa.gov/earth-science/earth-science-data-centers/earth-science-data-terminology-and-formats/). A comparison of NEON and CODMAC levels is presented in Table 2 below along with the level definitions. CODMAC levels were developed in the 1970's for satellite data. At that time data transmission and processing limitations required a greater attention to lower level data products. CODMAC also was biased toward the production of geospatially gridded data.

Table 2 A Comparison of NEON and CODMAC Data Product Level Definitions

NEON Level	NEON Data Product Level Definition	CODMAC Level	CODMAC Data Product Level Definition
0	Raw data from instrumental or human observations.	0	Reconstructed, unprocessed instrument/payload data at full resolution; any and all communications artifacts, e.g. synchronization frames, communications headers, duplicate data removed.
		1A	Reconstructed, unprocessed instrument data at full resolution, time-referenced, and annotated with ancillary information, including radiometric and geometric calibration coefficients and georeferencing parameters, e.g., platform ephemeric, computed and appended but not applied to the Level 0 data.
		1B	Level 1A data that have been processed to sensor units (not all instruments will have a Level 1B equivalent).

NEON Level	NEON Data Product Level Definition	CODMAC Level	CODMAC Data Product Level Definition
1	Calibrated data generally from a single instrument, observer, or field sampling area. These data may include information on data quality.	2	Derived geophysical variables at the same resolution and location as the Level 1 source data.
2	Combinations of level 1 data used to create a gap filled data stream that may replace a level 1 product. Generally, products at this level this will reflect a stream from a single instrument, observer, or field sampling area. Annotations will indicate the gap filling approach employed.	2	Derived geophysical variables at the same resolution and location as the Level 1 source data.
3	Level 1 and /or 2 data mapped on a uniform space-time grid.	3	Variables mapped on uniform space-time grid scales, usually with some completeness and consistency.
4	Derived products using levels 1, 2 and/or 3 data. Products at this level may combine observations from more than one instruments and/or observers.	4	Model output or results from analyses of lower level data, e.g. variables derived from multiple measurements.

4.4 NEON Data Product Organization

Data products for NEON levels 0, 1, 2, and 3 are derived primarily from a single instrument, observer, or a specific sampling location. These products are associated with the four principal observatory scientific sub-systems described in the *NEON Observatory Design* (AD[02]): Fundamental Sentinel Unit (FSU), the Fundamental Instrument Unit (FIU), the Airborne Observation Platform (AOP), and the Land Use Analysis Package (LUAP). These components scale ecological observations from the organismal level (FSU), to airsheds and watersheds (FIU), to small regions (~300 km^2; AOP) and on to the national or continental scale using data sets collected outside of NEON (LUAP). For practical purposes, the FSU and FIU components are now managed as three scientific sub-systems that include the terrestrial portions of FSU and FIU that are referred to by those names and an Aquatic sub-system that manages both organismal and instrumental measurements in streams and ponds. The aquatic sub-system referred to as Aquatic-STREON (AQU/STR) also manages the Stream Observational Network Experiment (STREON).

Level 4 data products may combine data from one or more components of the observatory. Therefore, they will be organized according to a structure that clearly traces to the NEON challenges in the areas of biodiversity, biogeochemistry, climate change, ecohydrology, infectious disease, invasive species, and land use. These seven NEON challenge areas require overlapping data and therefore they do not provide an optimal taxonomy for data products. Instead NEON will classify level 4 data products into a set of *data suites.* The six data suites used by NEON are:

Bioclimate and Biophysics	Biodiversity
Biogeochemistry	Ecohydrology
Infectious Disease	Land Use

The goal of this taxonomy is to group together data of similar types with a minimum of overlap and ambiguity among suites.

In the following six sections of this document, we describe the high-level data products associated with each data suite. Introductory sections describe the general themes covered by the data products in each suite. Thereafter, individual data products are listed in tabular format. Each data product has several descriptors.

Product Number: The product numbers follow the format Suite_Name_xxx.y, where the suite name and the number xxx.y form a unique identifier. The number "xxx" is the product identifier and the "y" represents sub-products. Sub-products share substantially similar algorithms and all are implemented at the same temporal and spatial resolution.

Product Title: A brief descriptive name for the product and, where applicable, sub-products.

Effort: A parametric estimate for the full-time equivalent effort for the Science product team to develop and commission the product. Time required for the cyberinfrastructure product team to develop code is not included in this effort estimate but should generally be proportional to the scientific effort. The codes (A through E) represent increasing levels of efforts as expressed in Table 3.

Table 3 Levels of Effort Required for Development of Data Products

Level	COMPLEXITY	EFFORT
A	simple transformation of data	Days to weeks
B	model/algorithm exists needs minor modifications	Weeks to months
C	model/algorithm exists needs major modifications	2 to 6 months
D	significant development effort required	6 to 12 months
E	major development effort	12 to 36 months

Priority: An estimate for the order of production of the data products. Assuming a five-year observatory construction period, priority 1 items should be completed during the first year of construction, priority 2 items during the second year and so forth.

Product Level: As described in Table 1 above.

Temporal Resolution: The finest level of temporal resolution for which the product will be available. High-level products often summarize a substantial amount of data and are aggregated to longer time periods than raw data or lower level data products available to investigators.

Replicates: This describes the number of individual spatial points or areas for which the data product will be presented. For example, a data product to be produced at all advanced towers will have 60 replicates in the observatory (20 core sites + 40 relocatable sites). This descriptor does not refer to replicates in the sampling design of the low-level data collected to support this product.

Spatial Extent: This describes the area covered by an individual replicate. The most common values follow here.

> Point – a data product related to a single x,y (z) coordinate (e.g a sensible heat flux from measurements made at an eddy covariance tower. Point data includes towers, soil arrays, and aquatic arrays.
>
> Soil survey sub-region – The area of detailed soil survey available at a core or relocatable site.
>
> AOP sub-region – The area covered by AOP flights, nominally 400 km^2 for each study area (core and relocatable sites).
>
> NEON Realm – The area covered by all 20 NEON domains. This includes the territory of the 50 United States, Puerto Rico, and the U.S. Virgin Islands.

Replicated at: The locations applicable to this data product.

Spatial Resolution: The finest spatial resolution (linear dimension) for which the data product will be presented. High-level products often summarize a substantial amount of data and are aggregated to larger spatial scales than raw data or lower level data products also available to investigators.

Description: Each product description gives a brief explanation of the importance and uses of the product along with information on the units for the product, low-level data and algorithms used to derive the product.

5 BIOCLIMATE AND BIOPHYSICS DATA PRODUCTS

The 18 high-level data products in the bioclimate and biophysics suite derive mainly from lower level data on weather, solar radiation, plant physiological responses, and aspects of ecosystem structure. Most of these products represent summaries of point measurements made at NEON towers. Some measurements such as leaf area index (LAI) and albedo will be retrieved from remote sensing products from the AOP and from satellites. The Bioclimate and Biophysics suite traces directly to the climate and biogeochemistry NEON challenge areas. Vegetation has critical feedbacks to the atmosphere. Key aspects of bioclimate and biophysics are related to surface energy balance.

<table>
<tr><td rowspan="4">Product Number: Bioclimate_001

Sub-products:
Bioclimate_001.1
Bioclimate_001.2
Bioclimate_001.3
Bioclimate_001.4
Bioclimate_001.5</td><td colspan="2">Product Title: Summary weather statistics
Bioclimate_001.1 = Air temperature
Bioclimate_001.2 = Relative humidity
Bioclimate_001.3 = Precipitation
Bioclimate_001.4 = Incoming PAR
Bioclimate_001.5 = Soil temperature</td><td rowspan="4">Effort: A
Priority: 1</td></tr>
<tr><td>Product Level: 4</td><td>Temporal Resolution: 1 day, 1 month, 1 year</td></tr>
<tr><td>Replicates: 60</td><td>Spatial Extent: Point</td></tr>
<tr><td>Replicated at: Advanced towers</td><td>Spatial Resolution: NA</td></tr>
<tr><td colspan="4">Product Description: This product will present summary statistics for biometeorological variables for all NEON weather stations. Statistics for intensive variables will include means, standard deviations, maxima, and minima for periods of days, months, and years. For extensive variables, totals will be calculated for the same time periods.</td></tr>
</table>

Product Number: Bioclimate_002	**Product Title:** Sensible and latent heat fluxes Bioclimate_002.1 = Sensible heat flux Bioclimate_002.2 = Latent heat flux		**Effort: B** **Priority: 1**
Sub-products: Bioclimate_002.1 Bioclimate_002.2	**Product Level:** 4	**Temporal Resolution:** 0.5 hour	
	Replicates: 60	**Spatial Extent:** Point	
	Replicated at: Advanced Towers	**Spatial Resolution:** NA	

Product Description: Sensible and latent heat fluxes are estimated based on the eddy covariance technique from using a sonic anemometer used to measure vertical winds and air temperature and an infra-red gas analyzer (or alternative) to measure water vapor. These fluxes are required for understanding of ecosystem energy and water balance at high temporal frequency and integrated spatial scale at the ecosystem-level (Loescher, Gholz, Jacobs, & Oberbauer, 2005; Loescher, et al., 2006). Both fluxes include turbulent and storage components. Generally, in ecosystems with plant canopies > 0.5 in height, the flux is quantified using both terms. In plant canopies < 0.5 m in height only the turbulent flux is calculated.

Sensible Heat Flux

$$H = \underbrace{\left(\frac{M_a C_p}{V}\right)\left(\overline{w'T_s'} - \left(0.000321 T_k \overline{w'q'}\right)\right)}_{I} + \underbrace{C_p \rho_a \int_{Z_0}^{z_y} \frac{\partial T_a}{\partial t} + S_{wt} C_{pw} LAI \int_{z_0}^{z_y} \frac{\partial T_a}{\partial t}}_{II}$$

Eq. 4.01

where, H is sensible heat (W m^{-2}), M_a is the molecular weight of dry air (0.0289644 kg mol^{-1}); C_p is the specific heat of dry air (1004.84 J K^{-1} kg^{-1}); V is the molar volume of air [$V = \frac{RT_k}{P}$ where, R is the ideal gas constant (0.082 L atm K^{-1} mol^{-1}), and P is atmospheric pressure (1.10325 atm)] (m^3 mol^{-1}); $\overline{w't'}$ is the time-averaged (30-min) covariance of vertical wind velocities (m °C s^{-1}), w (m s^{-1}) and sonic temperature, T_s (K); T_k is the actual air temperature (K) estimated from the sonic temperature (Kaimal & Gaynor, 1991); $\overline{w'q'}$ is the time-averaged covariance (m mmol water s^{-1} mol air^{-1}) of w and water vapor, q (mmol mol^{-1}); S_{wt} is the specific weight of leaf water (kg m^{-3} of leaf area), C_{pw} is the heat capacity of water (J kg^{-1} H_2O K^{-1}), LAI is the leaf area index (m^2 m^{-2}), T_a is the aspirated air temperature measured by PRT, Z_y is the height of the air column determined by the tower top (m), and Z_0 is the ground surface (m).

Latent Heat Flux

$$\lambda E = \underbrace{\frac{\lambda M_w \overline{w'q'}}{V \cdot 1000}}_{I} + \underbrace{V M_w \lambda \int_{Z_0}^{Zy} \frac{\partial q}{\partial t}}_{II}$$

Eq. 4.02

Where, λE is the latent energy flux (W m^{-2}), λ is the latent heat of vaporization of water (2500.8 - 2.3668 T_s, J g^{-1}, List 1951), M_w is the molecular weight of water (18.015 g mol^{-1}). Other definitions follow those above.

Product Number: Bioclimate_003 Sub-products:	**Product Title:** Vapor pressure deficit (VPD)		**Effort: A** **Priority: 1**
	Product Level: 4	**Temporal Resolution:** 0.5 hour	
	Replicates: 60	**Spatial Extent:** Point	
	Replicated at: Advanced towers	**Spatial Resolution:** NA	

Product Description: The vapor pressure deficit (kPa) is the difference between saturated water vapor pressure and the actual water vapor pressure. The VPD is used to determine baseline curves for plant-based measures of water status and is frequently used in models as an input to regulate plant stomatal and bulk canopy conductances. Measurements of actual water vapor pressure are based on a variety of instruments including relative humidity sensors, and infra-red and laser gas analyzers.

Product Number: Bioclimate_004 Sub-products:	**Product Title:** Leaf area index (LAI) map		**Effort: D** **Priority: 3**
	Product Level: 4	**Temporal Resolution:** 10 days	
	Replicates: 60	**Spatial Extent:** AOP Footprint	
	Replicated at: Core and relocatable sites AOP footprints	**Spatial Resolution:** 100 m	

Product Description: Leaf area index (LAI) is traditionally defined as the one-sided area of leaves per unit ground area (Monteith & Unsworth, 1990). For needle leaf species, the projected needle area on the ground is used (Chen, Rich, Gower, Norman, & Plummer, 1997). LAI is used in ecological models as a basic variable regulating productivity. LAI may also be useful for estimation of other canopy properties such as nutrient contents. The optimal algorithm for estimation of LAI from AOP LiDAR and/or spectroscopy data has not been determined. However, LAI is related to both spectral and structural properties of canopies (Morsdorf, Kotz, Meier, Itten, & Allgower, 2006). LAI is rarely measured directly except in fully deciduous forests (Clark, Olivas, Oberbauer, Clark, & Ryan, 2008; Gower, Kucharik, & Norman, 1999; Leuschner, Voss, Foetzki, & Clases, 2006). AOP remote sensing retrievals of LAI will be compared to retrievals from ground based hemispherical photographs (Rich, 1990) or ground based measurements of gap fraction (Norman & Welles, 1983).

Leaf Area Index (LAI) can be provided directly from LiDAR measurements, spectrometer measurements, or as a merged data product (LiDAR + spectrometer). A LAI product based on NDVI derived from the merged LiDAR/spectrometer data is relatively straightforward to obtain (Roberts, Green, & Adams, 1997), but the relationship between NDVI and leaf area becomes asymptotic at leaf areas greater than ~3, although positive relationships between leaf area index and NDVI have been published as high as 13 for some conifers (Spanner, Pierce, Running, & Peterson, 1990b). This LAI product could be provided relatively quickly in the NEON timeline with minimal development, but will require an assessment of biases with respect to ground-based measurements and satellite (i.e., MODIS) measurements over different ecosystems. An alternative LAI product obtained using canopy radiative transfer model inversion of merged LiDAR/spectrometer data has been developed (Asner, Nepstad, Cardinot, & Ray, 2004), but is still a research product and it has been utilized exclusively in tropical ecosystems. Implementation of this class of algorithm will require significant algorithm and software development in addition to validation over different ecosystems in NEON domains.

Product Number: Bioclimate_005 Sub-products:	**Product Title:** Leaf area index map		**Effort: C** **Priority: 3**
	Product Level: 4	**Temporal Resolution:** 10 days	
	Replicates: 1	**Spatial Extent:** NEON Realm	
	Replicated at: NEON Realm	**Spatial Resolution:** 1000 m	

Product Description: Leaf area index (LAI) is traditionally defined as the one-sided area of leaves per unit ground area (Monteith & Unsworth, 1990). For needle leaf species, the projected needle area on the ground is used (Chen, et al., 1997). LAI is used in ecological models as a basic variable regulating productivity. LAI may also be useful for estimation of other canopy properties such as nutrient contents. LAI can be retrieved from spaceborne multispectral sensors such as MODIS. NEON will follow the theoretical approach established for MODIS (Knyazikhin, et al., 1999). LAI retrievals from the AOP and estimations from 60 towers will be used in a data assimilation framework to adjust and improve the spaceborne retrievals.

Product Number: Bioclimate_006 Sub-products: Bioclimate_006.1 Bioclimate_006.2 Bioclimate_006.3	**Product Title:** Aerodynamic, Bulk Canopy, and Canopy Conductances Bioclimate_006.1 = Aerodynamic conductance Bioclimate_006.2 = Bulk Canopy conductance Bioclimate_006.3 = Canopy conductance		**Effort: B** **Priority: 2**
	Product Level: 4	**Temporal Resolution:** 0.5 hour	
	Replicates: 60	**Spatial Extent:** Point	
	Replicated at: Advanced towers	**Spatial Resolution:** NA	

Product Description: Conductances are a measure of the physical ability to transport mass and/or energy. They are used to model water balance, gap fill energy fluxes, estimate the transport of mass such as spores and pollen, and deposition of particulates (size dependant). They are estimated through a suite of instrumentation that includes 3-d sonic anemometry, vertical wind profiles, and sensible, latent heat and momentum fluxes (Kaimal & Finnigan, 1994; Loescher, et al., 2004; Loescher, et al., 2005; Monteith & Unsworth, 1990).

Aerodynamic conductance (g_a); based on Monin-Obukov similarity theory, a negative exponential wind profile is assumed hence, aerodynamic conductance will be estimated by;

$$g_a = \frac{k^2 u}{\left[\ln\left(\frac{z_y - d}{z_m}\right)\right]^2 + \ln\left(\frac{z_y - d}{z_m}\right)[\ln(\frac{z_m}{z_y}) + \Psi_m - \Psi_h]}$$

Eq. 4.03

where, *k* is Von Karmen's constant (0.40 dimensionless), u horizontal windspeed (m s^{-1}), Z_y is measurement height (m), *d* is the zero-plane displacement (m), Z_m is the aerodynamic roughness length, and Ψ_m and Ψ_h are the diabatic correction factors (m) for momentum and sensible heat, respectively (Arya, 1988; Yasuda, 1988) for stable atmospheres;

$$\Psi_M = \Psi_H = 6\ln(1+\zeta) \quad \text{Eq. 4.04}$$

and in unstable conditions,

$$\Psi_H = -2\ln[\frac{1+(1-16\zeta)^{0.5}}{2};\Psi_M = 0.6\Psi_H \quad \text{Eq. 4.05}$$

Diabatic correction factors are a function of stability (i.e., Monin-Obukov length) and are explained in Denmead and Bradley (1985), Kaimal and Finnigan (1994), and Panofsky and Dutton (1984).

Bulk canopy conductance (g_b) will be estimated by,

$$g_b = \frac{g_a}{\frac{\Delta H}{C_p \lambda E} - 1} + \frac{\lambda E}{\rho_a D_y} \quad \text{Eq. 4.06}$$

where Δ is the rate of change in the saturation of specific humidity with temperature (kPa K^{-1}), and D_y is the specific humidity deficit at the tower top, Z_y (kg kg^{-1}), and

Canopy conductance due to momentum transfer, (g_m) will be estimated as,

$$g_m = \frac{M_v u*^2}{u} \quad \text{Eq. 4.07}$$

Product Number: **Bioclimate_007**	**Product Title:** Atmospheric Stability; Monin-Obukhov Length (L)		**Effort: A** **Priority: 1**
Sub-products:	**Product Level:** 4	**Temporal Resolution:** 0.5 hour	
	Replicates: 60	**Spatial Extent:** Point	
	Replicated at: Advanced towers	**Spatial Resolution:** Point estimates at advanced Towers	

Product Description: Along with the Richardson number, the Monin-Obukhov Length (L) is one of the best established parameters of atmospheric stability (Monteith & Unsworth, 1990).

ζ is a stability parameter; a ratio of convective to mechanical turbulent production,

$$\zeta = -\frac{z_y - d}{L};\ L = \frac{-\rho_a C_p T_a u^{*3}}{gkH} \qquad \text{Eq. 4.08}$$

and *L* is the Monin-Obukov length (m), ρ_a is the density of air (kg m^{-3}), C_p is the specific heat capacity of air (J kg^{-1} K^{-1}), T_a is aspirated air temperature at Z_y (K), u* is a velocity scale derived from the square root of Reynold's stresses, $u^* = \left[\left(\overline{w'u'}\right)^2 + \left(\overline{w'v'}\right)^2\right]^{0.25}$ (m s^{-1}), g is acceleration due to gravity (m s^{-2}), k = von Karman's constant (0.40), and H is the sensible heat flux density (J m^{-2} s^{-1}, (Monteith & Unsworth, 1990)).

Product Number: **Bioclimate_008**	**Product Title:** Atmospheric Stability: Richardson number (Ri)		**Effort: A** **Priority: 1**
Sub-products:	**Product Level:** 4	**Temporal Resolution:** 0.5 hour	
	Replicates: 60	**Spatial Extent:** Point	
	Replicated at: Advanced towers	**Spatial Resolution:** Point estimates at FIU Towers	

Product Description: Along with the Monin-Obukhov Length number (see Bioclimate_006), the Richardson number (Ri) is one of the best established parameters of atmospheric stability (Monteith & Unsworth, 1990).

$$Ri = \left(\frac{g}{T_a}\frac{\partial T_a}{\partial z}\right) \Big/ \left(\frac{\partial u}{\partial z}\right)^2 \qquad \text{Eq. 4.09}$$

Where, *u* is mean horizontal wind velocity (m s^{-1}).

Product Number: **Bioclimate_009**	**Product Title:** Albedo		**Effort: A** **Priority: 1**
Sub-products:	**Product Level:** 4	**Temporal Resolution:** 0.5 hour	
	Replicates: 60	**Spatial Extent:** Point	
	Replicated at: Advanced towers	**Spatial Resolution:** Point estimates at FIU towers, <100 m / AOP footprint	

Product Description: Albedo or reflection coefficient is the fraction of the integrated solar spectrum energy reflected by the ecosystem surface (Monteith & Unsworth, 1990, pp. 77-78). Albedo is a critical variable in estimation of the surface energy budget in meteorological and climate models. Albedo at tower sites will be calculated from downwelling and upwelling long-and short-wave radiation measured above the vegetation canopy.

Product Number: Bioclimate_010 Sub-products:	**Product Title:** Albedo map (AOP)		**Effort: B** **Priority: 3**
	Product Level: 4	**Temporal Resolution:** 1 year	
	Replicates: 60	**Spatial Extent:** AOP Footprint	
	Replicated at: AOP Footprints	**Spatial Resolution:** 100 m	

Product Description: Albedo or reflection coefficient is the fraction of the integrated solar spectrum energy reflected by the ecosystem surface (Monteith & Unsworth, 1990). Changes of albedo at small scales provides information on plant succession, canopy complexity, conversion from bare soil to vegetation, and change in soil moisture (Chapin III, Matson, & Mooney, 2002). Increasing surface roughness as vegetation canopies mature increase mechanical turbulence and mixing and are accompanied by a decrease in albedo. Albedo products will be provided from surface reflectance data derived from AOP radiances, following correction for molecular scattering, aerosols and water vapor. A broadband integrated albedo product, as well as spectral albedo products at 0.47 um, 0.555 um, 0.67 um, 0.858 um, 1.24 um, 1.64 um, 2.13 um, will be provided. These spectral albedo products correspond to the MODIS Albedo products.

Product Number: Bioclimate_011 Sub-products:	**Product Title:** Albedo map (LUAP)		**Effort: B** **Priority: 3**
	Product Level: 4	**Temporal Resolution:** 10 days	
	Replicates: 1	**Spatial Extent:** NEON Realm	
	Replicated at: NEON Realm	**Spatial Resolution:** 1000 m	

Product Description: Albedo or reflection coefficient is the fraction of the integrated solar spectrum energy reflected by the ecosystem surface (Monteith & Unsworth, 1990, pp. 77-78). Albedo is a critical variable in estimation of the surface energy budget in meteorological and climate models. Spectral land surface albedo is an important parameter for describing the radiative properties of the Earth providing information on ecosystem classification useful for describing the productivity and characteristics of the land surfaces. Albedo can be retrieved from spaceborne multispectral sensors such as MODIS. NEON will follow the theoretical approach established for MODIS (Strahler & Members, 1999). Albedo retrievals from the AOP and estimations from 60 towers will be used in a data assimilation framework to adjust and improve the spaceborne retrievals. These products will provide information on natural and human interactions, such as anthropogenic, meteorological, and phenological effects on local to regional climatological trends. These products are integral parts in a variety of research areas, such as energy balance studies, modeling of land use and land use change, as well as biophysical and meteorological studies.

Product Number: Bioclimate_012 Sub-products:	**Product Title:** Aerosol optical depth (AOD)		**Effort: B** **Priority: 1**
	Product Level: 4	**Temporal Resolution:** 0.25 hour	
	Replicates: 40	**Spatial Extent:** Point	
	Replicated at: Advanced towers	**Spatial Resolution:** NA	
Product Description: Aerosol optical depth (AOD) is a quantitative measure of the extinction of solar radiation by aerosol scattering and absorption between the point of observation and the top of the atmosphere. It is a measure of the integrated columnar aerosol load and the single most important parameter for evaluating direct radiative forcing. AOD is determined from the ground through measurements of the spectral transmission of solar radiation through the atmosphere using sunphotometers or filter radiometers pointed directly at the sun (Holben, et al., 1998). The higher the AOD value, the more aerosols are within a column. The total spectral optical depth is the sum of the Rayleigh and aerosol optical depth after correction for gaseous absorption. Routine ground based AOD observations provide calibration and validation of AOD retrievals from satellites and to correct for aerosol effects in the retrieval of other satellite products. The Ångström exponent that gives an indication of the column integrated aerosol size distribution can be derived from simultaneous AOD measurements at several wavelengths. Measurements of AOD will be provided from sunphotometers with multiple narrowband 10-nm spectral channels in the visible and near-infrared region, with center wavelengths at 340, 380, 440, 500, 675, 870, and 1020 nm. An additional 10-nm wide channel centered at 940-nm is used to measure total column water vapor.			

Product Number: Bioclimate_013 Sub-products:	**Product Title:** Total column water vapor		**Effort: B** **Priority: 1**
	Product Level: 4	**Temporal Resolution:** 0.25 hour	
	Replicates: 40	**Spatial Extent:** Point	
	Replicated at: Advanced towers	**Spatial Resolution:** NA	
Product Description: Total column water vapor is retrieved from the spectral extinction of direct beam extinction in the strong 940-nm water vapor absorption band in accordance with the Beer-Bouger Law. A sunphotometer with a 10-nm channel positioned at the peak of absorption provides a measurement that is quite insensitive to the type of atmosphere present during calibration and measurement with less than 1% variability under extreme atmospheric conditions (Halthore, Eck, Holben, & Markham, 1997). Sunphotometers provide a measure of water column abundance that is relatively insensitive to the atmospheric lapse rate. This contrasts with measurements from other instruments such as the Raman LiDAR or microwave radiometers that must be calibrated against radiosonde measurements.			

Product Number: Bioclimate_014 Sub-products:	**Product Title:** Static potential PAR		**Effort: B** **Priority: 2**
	Product Level: 4	**Temporal Resolution:** 0.5 hour	
	Replicates: 1	**Spatial Extent:** NEON Realm	
	Replicated at: NEON Realm	**Spatial Resolution:** 1000 m	
Product Description: Photosynthetically active radiation (PAR) within the range of wavelengths from 400–700 nm is capable of driving electron transport for photosynthesis. PAR is used in ecological analyses and models of vegetation productivity. Static potential PAR, the maximum available at a given point, provides a reference point for models and analyses. It will be estimated using spectral models (Alados, Foyo-Moreno, Olmo, Alados-Arboledas, & Grupo Fisica, 2002; Gueymard, 1989a, 1989b). For complex terrain, static potential PAR can be adjusted for terrain effects (Wang, et al., 2006).			

Product Number: Bioclimate_015 Sub-products:	**Product Title:** fPAR (Towers)		**Effort: B** **Priority: 1**
	Product Level: 4	**Temporal Resolution:** 0.5 hour	
	Replicates: 60	**Spatial Extent:** Point	
	Replicated at: Advanced towers	**Spatial Resolution:** NA	
Product Description: The fraction of photosynthetically active radiation (PAR) that is absorbed by vegetation defines fPAR. fPAR is expressed as a unitless fraction of the incoming radiation received by the land surface. fPAR will be measured by the ratio of PAR measured above the canopy to PAR measured at the ground surface.			

Product Number: Bioclimate_016 Sub-products:	**Product Title:** fPAR (AOP)		**Effort: B** **Priority: 3**
	Product Level: 4	**Temporal Resolution:** 1 year	
	Replicates: 60	**Spatial Extent:** AOP Footprint	
	Replicated at: AOP Footprint	**Spatial Resolution:** 10 m	
Product Description: fPAR is the Fraction of Absorbed Photosynthetically Active radiation that a plant canopy absorbs for photosynthesis and growth in the 0.4 to 0.7 nm spectral range. fPAR is expressed as a unitless fraction of the incoming radiation received by the land surface. The AOP provides a measure of fPAR based upon vegetative indices such as NDVI (Knyazikhin, et al., 1999).			

Product Number: Bioclimate_017 Sub-products:	**Product Title:** fPAR (Satellite)		**Effort: B** **Priority: 3**
	Product Level: 4	**Temporal Resolution:** 10 days	
	Replicates: 1	**Spatial Extent:** NEON Realm	
	Replicated at: NEON Realm	**Spatial Resolution:** 1000 m	

Product Description: fPAR is the fraction of absorbed Photosynthetically Active Radiation (PAR) in the 0.4 to 0.7 nm spectral range. fPAR is expressed as a unitless fraction of the incoming radiation received by the land surface. NEON will follow the estimation of fPAR by MODIS based upon vegetative indices such as NDVI (Knyazikhin, et al., 1999). A vegetation index that combines NDVI and a scaled value of the photochemical reflectance index (PRI) has been shown to provide more accurate estimates of photosynthetic fluxes and have been correlated with point-based eddy-covariance flux tower measurements in boreal forest (Rahman, Gamon, Fuenes, Roberts, & Prentiss, 2001). Satellite retrievals may be adjusted by assimilation of both tower based (Biogeochemistry_018) and aircraft based (Biogeochemistry_019) fPAR measurements.

Product Number: Bioclimate_018 Sub-products:	**Product Title:** Fire risk probability		**Effort: C** **Priority: 4**
	Product Level: 4	**Temporal Resolution:** 0.5 hour	
	Replicates: 60	**Spatial Extent:** NA	
	Replicated at: Advanced towers	**Spatial Resolution:** Point estimates at soil arrays	

Product Description: Fire risk related to fuel dryness differs among ecosystem types, and is an important resource management tool and to assess hazardous fuel loading and the cost effectiveness of fuel reduction treatments. As well as estimating risks to carbon pools in predictive climate change models. Increased fire risk has shown to be a function of the degree and the rate at which fuels at the ecosystem floor dry. This will be measured by the number of days the Bowen ratio $H/\lambda E$ exceeds 1.3 for more than 6 hours per day. The exact number of days will be adjusted/determined by site-specific fuel conditions (Clark, et al., 2009).

6 BIODIVERSITY DATA PRODUCTS

High-level data products in the biodiversity suite are derived from lower level data on diversity, productivity, demography, and phenology collected in the Aquatic/STREON unit (AQU/STR) and Fundamental Sentinel Unit (FSU). This category traces directly to the biodiversity NEON challenge areas and also supports the invasive species challenge area. The high-level data products in the biodiversity are listed in Table 5. There are three carefully selected high-level products in this section that require a large investment of NEON resources. These products are Invasive plant risk maps (Biodiversity_017), Ecosystem Structure Map (Biodiversity_018) and Soil microbial metagenomes (Biodiversity_022). The invasive plant risk maps build on existing research and highlight the attention that NEON pays to the theme of invasion. The Ecosystem structure map and Soil microbial metagenome products select cutting edge areas where NEON investment will enable more profound analysis for transformational advances in the field.

Species abundance and diversity defined here are applicable to many of the Biodiversity data products listed below. Therefore, we list a number of common definitions here. Relative abundance reflects the population size (number of individuals) of a species relative to other species in the community. Diversity provides a measurement that captures both community richness (number of species) and evenness (relative abundance of species). Both abundance of individual species and diversity can be analyzed as a covariates responding to environmental variables (Siemann, Haarstad, & Tilman, 1997).

Abundance

$$n_i = \frac{\sum \mathrm{x_i}}{\mathrm{m}} \qquad \text{Eq. 5.01}$$

Where n_i is the abundance of a particular species *i*, x_i is the number of individuals of species *i* per sampling unit of a collection event, and m is the number of replicated sampling units in a collection event. Standard error can also be included for sampling that is replicated per collection event.

Relative abundance

$$p_i = \frac{n_i}{\mathrm{N}} \qquad \text{Eq. 5.02}$$

Where p_i is the relative abundance of species *i*, and N is the total number of all individuals of the community or guild of species of interest (e.g., fish, small mammals, or understory plants, etc.).

Diversity

Diversity can be scaled per time interval (day, week, or month, etc.). Several commonly used diversity indices are presented (Begon, Harper, & Townsend, 1996; Magurran, 1998; Rosenzweig, 1995).

Shannon's H:

$$H = -\sum_{i=1}^{S} p_i \ln p_i \qquad \text{Eq. 5.03}$$

Where H is Shannon's H diversity index and S is the total number of species.

Shannon's E:

$$E_H = \frac{H}{\ln S} \qquad \text{Eq. 5.04}$$

Where E_H is Shannon's E diversity index.

Simpson's D:

$$D = \frac{1}{\sum_{i=1}^{S} p_i^2} \qquad \text{Eq. 5.05}$$

Where D is Simpson's D diversity index.

Simpson's E:

$$E_D = \frac{1}{\sum_{i=1}^{S} p_i^2} \times \frac{1}{S} \qquad \text{Eq. 5.06}$$

Where E_D is Simpson's E diversity index.

Product Number: Biodiversity_001 Sub-products: Biodiversity_001.1 Biodiversity_001.2	**Product Title:** Mosquito abundance and diversity Biodiversity_001.1 = Mosquito abundance Biodiversity_001.2 = Mosquito diversity		**Effort: A** **Priority: 1**
	Product Level: 4	**Temporal Resolution:** 1 month	
	Replicates: 60	**Spatial Extent:** Site	
	Replicated at: Core and relocatable sites	**Spatial Resolution:** NA	
Product Description: The abundance of individual mosquito species is important for understanding disease transmission because mosquito species vary significantly in their competency as vectors for specific pathogens (Ebel, Rochlin, Longacker, & Kramer, 2005; Lord, Rutledge, & Tabachnick, 2006). In order to facilitate forecasting risk for particular pathogens (e.g., West Nile Virus), robust estimates of the relative abundance of specific vector species are required (Kilpatrick, et al., 2005). Abundance and diversity of mosquitoes are calculated following equations 5.01 to 5.06. Collecting events are defined by trap-nights and replicates of two types of traps (CO_2 and gravid) will provide different estimates of these variables.			

Product Number: Biodiversity_002 Sub-products: Biodiversity_002.1 Biodiversity_002.2	**Product Title:** Mosquito species distribution maps Biodiversity_002.1 = Mosquito species distribution (native/invasive species) Biodiversity_002.2 = Mosquito species distribution/time		**Effort: B** **Priority: 3**
	Product Level: 4	**Temporal Resolution:** 1 year	
	Replicates: 1	**Spatial Extent:** NEON Realm	
	Replicated at: NEON Realm	**Spatial Resolution:** By site	
Product Description: A mosquito species distribution map will display an interactive graphic locating all of the core and relocatable sites. The graphic will not include data interpolation between sites. The interactive map will allow users to select mosquito species of interest and examine their presence or absence across the observatory at specified time intervals. This map will allow users to rapidly visualize patterns of both native and invasive species ranges at various time scales, using data from data product Biodiversity_001.			

Product Number: Biodiversity_003 Sub-products: Biodiversity_003.1 Biodiversity_003.2	**Product Title:** Ground dwelling beetle abundance and diversity Biodiversity_003.1 = Ground beetle abundance Biodiversity_003.2 = Ground beetle diversity		**Effort: A** **Priority: 1**
	Product Level: 4	**Temporal Resolution:** Seasonal	
	Replicates: 60	**Spatial Extent:** Site	
	Replicated at: Core and relocatable sites	**Spatial Resolution:** NA	
Product Description: The abundance and diversity of ground dwelling beetles are indicators of habitat complexity at middle trophic levels within a given food web (Purtauf, Dauber, & Wolters, 2005). Beetle species are sensitive to environmental changes and therefore they serve as sentinel organisms (Vanbergen, Woodcock, Watt, & Niemela, 2005; Work, et al., 2008). Abundance and diversity of ground dwelling beetles are calculated following equations 5.01 to 5.06. Collecting events are defined by weekly collections from pitfall trap transects.			

Product Number: Biodiversity_004 Sub-products:	**Product Title:** Ground beetle species distribution (native/invasive)		**Effort: B** **Priority: 3**
	Product Level: 4	**Temporal Resolution:** 1 year	
	Replicates: 1	**Spatial Extent:** Site	
	Replicated at: NEON Realm	**Spatial Resolution:** By site	
Product Description: A ground beetle species distribution map will display an interactive graphic of a map locating all of the core and relocatable sites. The graphic will not include data interpolation between sites. The interactive map will allow users to select ground beetle species of interest and examine their presence or absence across the observatory at specified time intervals. This map will allow users to rapidly visualize patterns of both native and invasive species ranges at various time scales using data from data product Biodiversity_003.			

Product Number: Biodiversity_005 Sub-products: Biodiversity_005.1 Biodiversity_005.2 Biodiversity_005.3	**Product Title:** Small mammal abundance, diversity, and density Biodiversity_005.1 = Abundance Biodiversity_005.2 = Diversity Biodiversity_005.3 = Density		**Effort: B** **Priority: 1**
	Product Level: 4	**Temporal Resolution:** Seasonal	
	Replicates: 60	**Spatial Extent:** Site	
	Replicated at: Core and relocatable sites	**Spatial Resolution:** NA	

Product Description: Abundance and diversity of small mammals are calculated following equations 5.01 to 5.06. Collecting events are defined by trap-nights and replicated transects (100 traps each). Density is defined as the number of individuals of a particular species per unit ground area. Collecting events are defined by trap-nights where the traps are arranged in a distance specified web arrangement. Density is an important parameter in disease models where it is used to estimate contact rates involved in the spread of pathogens (e.g., hantaviruses, (Madhav, Wagoner, Douglass, & Mills, 2007)).

Density

$$\hat{D}_n = \frac{\hat{n}_i}{\hat{A}} \qquad \text{Eq. 5.07}$$

Where D_n is an estimate of the population density of a particular species, n_i is the estimated capture-recapture corrected abundance of the species, and A is the estimated area defined by the trapping design and a buffer zone incorporating species range and movement data. Density estimators for cryptic species (such as small, nocturnally active mammals) require estimator models for abundance and area (Parmenter, et al., 2003).

Product Number: Biodiversity_006 Sub-products:	**Product Title:** Small mammal species distribution maps (native/invasive)		**Effort: B** **Priority: 3**
	Product Level: 4	**Temporal Resolution:** 1 year	
	Replicates: 1	**Spatial Extent:** Site	
	Replicated at: NEON Realm	**Spatial Resolution:** By site	

Product Description: A small mammal species distribution map will display an interactive graphic of a map locating all of the core and relocatable sites. The graphic will not include data interpolation between sites. The interactive map will allow users to select small mammal species of interest and examine their presence or absence across the observatory at specified time intervals. This map will allow users to rapidly visualize patterns of both native and invasive species ranges at various time scales using data from data product Biodiversity_005.

Product Number: Biodiversity_007 Sub-products: Biodiversity_007.1 Biodiversity_007.2 Biodiversity_007.3 Biodiversity_007.4 Biodiversity_007.5 Biodiversity_007.6	**Product Title:** *Peromyscus* species demography Biodiversity_007.1 = Body size Biodiversity_007.2 = Mass Biodiversity_007.3 = Sex ratio Biodiversity_007.4 = Reproductive status Biodiversity_007.5 = Age structure Biodiversity_007.6 = Recapture rate		**Effort: B** **Priority: 1**
	Product Level: 4	**Temporal Resolution:** 1 year	
	Replicates: 60	**Spatial Extent:** Site	
	Replicated at: Core and Relocatable sites	**Spatial Resolution:** NA	
Product Description: Small mammal demographic data inform population models and enable monitoring of responses to environmental factors such as climate and productivity. Understanding the population demography and variability inter-annually will allow better predictions of disease outbreaks, such as the delayed density dependent outbreaks of hantavirus observed in Montana (Madhav, et al., 2007). Three times per year, demographic information on small mammal (especially *Peromyscus* species) populations will be collected including body size, mass, sex, reproductive status, population age structure (proportion of adults versus juveniles), and mark-recapture measurements. These data will be summarized as means (averaged across transects for a trapping period with standard error). Graphical summaries of time series (spring, summer, and fall trapping periods) will be provided to visualize changes in population demographics over the course of a breeding season (Nupp & Swihart, 1996; Zwolak & Foresman, 2008).			

Product Number: Biodiversity_008 Sub-products: Biodiversity_008.1 Biodiversity_008.2	**Product Title:** Ectoparasite abundance and diversity (from *Peromyscus* species) Biodiversity_008.1 = Ectoparasite Abundance Biodiversity_008.2 = Ectoparasite Diversity		**Effort: A** **Priority: 1**
	Product Level: 4	**Temporal Resolution:** seasonal	
	Replicates: 60	**Spatial Extent:** Site	
	Replicated at: Core and Relocatable sites	**Spatial Resolution:** NA	
Product Description: Ixodid ticks are the main vectors for *Borrelia burgdorferi*, the pathogen that causes Lyme disease. Coupled with small mammal data, ectoparasite data will enable forecasting human risk of Lyme disease (Eisen, Lane, Fritz, & Eisen, 2006). Abundance and diversity of ectoparasites (e.g., ticks and fleas) from *Peromyscus* species are calculated following equations 5.01 to 5.06. Data will be collected per mouse individual (up to 90 per site per year) and averaged per trapping period.			

Product Number: Biodiversity_009 Sub-products: Biodiversity_009.1 Biodiversity_009.2	**Product Title:** Bird diversity Biodiversity_009.1 = Bird diversity at NEON Sites Biodiversity_009.2 = Bird diversity at National Breeding Bird Survey Sites		**Effort: B** **Priority: 1**
	Product Level: 4	**Temporal Resolution:** seasonal	
	Replicates: 60	**Spatial Extent:** Site	
	Replicated at: Core and relocatable sites	**Spatial Resolution:** NA	
Product Description: Bird diversity is related to several of the grand challenge areas. For example, birds represent a high trophic level and diverse bird communities are indicators of highly functioning food webs (Hechinger & Lafferty, 2005). Additionally, birds are both impacted by and act as a reservoir for some zoonotic pathogens (e.g, West Nile Virus, (LaDeau, Kilpatrick, & Marra, 2007)) and bird community composition responds strongly to land use change (Luther, et al., 2008).Diversity of birds is calculated using equations 5.01 to 5.06. Collecting events are defined by point counts conducted in time and distance defined observation methods.			

Product Number: Biodiversity_010 Sub-products: Biodiversity_010.1 Biodiversity_010.2	**Product Title:** Bird species distribution maps Biodiversity_010.1 = Bird species distribution maps at NEON sites Biodiversity_010.2 = Bird species distribution maps at National Breeding Bird Survey Sites		**Effort: B** **Priority: 3**
	Product Level: 4	**Temporal Resolution:** 1 year	
	Replicates: 60+	**Spatial Extent:** Site	
	Replicated at: Core and relocatable sites	**Spatial Resolution:** NA	
Product Description: A bird species distribution map will display an interactive graphic of a map locating all of the core and relocatable sites as well as all Breeding Bird Survey sites. The graphic will not include data interpolation between sites. NEON will combine bird diversity data collected at the observatory sites (Biodiversity_009) with data from the annual North American Breeding Bird Survey. This will create a database of bird community change through time across the continent. These data will be presented in as an interactive graphic of a map (similar to Biodiverity_010) spanning all of the core and relocatable sites and North American Breeding Bird Survey sites. The graphic will not include data interpolation between sites. The interactive map will allow users to select bird species of interest and examine their presence or absence across the continent at specified time intervals. This map will allow users to rapidly visualize patterns of both native and invasive species ranges at various time scales using data from data product Biodiversity_009 and Breeding Bird Survey data.			

Product Number: Biodiversity_011 Sub-products: Biodiversity_011.1 Biodiversity_011.2	**Product Title:** Mosquito phenology Biodiversity_011.1 = Mosquito species emergence time Biodiversity_011.2 = Mosquito activity period		**Effort: A** **Priority: 1**
	Product Level: 4	**Temporal Resolution:** 1 year	
	Replicates: 60	**Spatial Extent:** Site	
	Replicated at: Core and relocatable sites	**Spatial Resolution:** NA	
Product Description: Mosquito emergence and total activity period (the total number of days that females continue to oviposit) are strongly linked to climate and are expected to respond to climate change (Bradshaw, Zani, & Holzapfel, 2004). Changes in the phenology of mosquito species that act as disease vectors are expected to lead to changes in disease risk (Pascual, Ahumada, Chaves, Rodo, & Bouma, 2006). Mosquito phenology is relevant for regions where peak mosquito activity is seasonal, which includes most NEON domains. Mosquito phenology includes emergence time, which is the date at which adult mosquitoes become active and begin feeding and reproducing, and it is estimated on a species level basis from mosquito collection events (see data product Biodiversity_001).			

Product Number: Biodiversity_012 Sub-products:	**Product Title:** *Peromyscus* breeding activity period		**Effort: A** **Priority: 1**
	Product Level: 4	**Temporal Resolution:** 1 year	
	Replicates: 60	**Spatial Extent:** Site	
	Replicated at: Core and relocatable sites	**Spatial Resolution:** NA	
Product Description: Population dynamics of *Peromyscus* species are directly relevant to understanding shifts in the prevalence of disease, such as Lyme disease and hantavirus (Calisher, et al., 2007; Ostfeld, Canham, Oggenfuss, Winchcombe, & Keesing, 2006). The breeding activity period of mice belonging to the genus *Peromyscus* (e.g., deer mice and white footed mice) refers to the number of days per year that adult mice are reproductively active. The reproductive status of mice is determined three times per year (spring, summer and fall) during trapping events. Together with population demography data (see data product Biodiversity_007), NEON will enable monitoring of the population dynamics of *Peromyscus* species and their response to changes in climate, productivity, and land use.			

Product Number: Biodiversity_013 Sub-products:	**Product Title:** Plant abundance, richness, and diversity (native and non-native species)		**Effort: A** **Priority: 1**
	Product Level: 4	**Temporal Resolution:** 1 year	
	Replicates: 60	**Spatial Extent:** Site	
	Replicated at: Core and relocatable sites	**Spatial Resolution:** NA	

Product Description: This product tracks changes in composition (taxonomic identities in an assemblage) and abundance of native and invasive species through time. Patterns of plant abundance, richness, and diversity are estimated based on successive surveys of sampling units distributed in a geographic area. *Plant abundance* represents the number of individual plants in a population, combining intensity (density within inhabited areas) and prevalence (number and size of inhabited areas) (Townsend, Begon, & Harper, 2008). *Plant richness* is the number of plant species present in a community, and is the simplest way to describe community and regional diversity (Magurran, 1998). *Plant diversity* can be described as the number of different plant species in a particular area weighted by some measure of abundance such as number of individuals or biomass (Townsend, et al., 2008). Species diversity can be decomposed into two components: species richness, which is the number of species in the assemblage, and *species evenness*, which is the relative distribution of individuals among species (Magurran, 1998). NEON will adopt the definitions posed in equations 5.01 to 5.06.

Product Number: Biodiversity_014 Sub-products:	**Product Title:** Plant phenological patterns (3 focal plant species)		**Effort: A** **Priority: 2**
	Product Level: 4	**Temporal Resolution:** 1 year	
	Replicates: 60	**Spatial Extent:** Site	
	Replicated at: Core and relocatable sites	**Spatial Resolution:** NA	

Product Description: This product tracks sensitive and easily observed indicators of biotic responses to climate variability by recording and monitoring the timing and duration of phenological events. The phenological pattern of any life cycle event can be quantitatively defined as a statistical distribution characterized by such parameters as *time of occurrence* (onset, mean, mode), *duration* (range), *synchrony* or *intensity* (variance), and *skewness* (Rathcke & Lacey, 1985). The plant phenological patterns of three selected species in each domain will be derived from standardized, intensive individual observations on leaf and reproductive events based on specific protocols developed by the National Phenology Network (NPN) for broadleaf trees and shrubs, conifers, grasses, and herbs. The frequency of observations will vary among ecosystems and according to species, but observations will occur more frequently during periods of rapid phenological changes (e.g., spring and autumn in north temperate ecosystems), and somewhat less frequently during periods of slow phenological changes (e.g., summer and winter in north temperate ecosystems). The intensity of phenological events is estimated according to an interval scale varying from 1 to 4, with a 25% interval between classes (Fournier, 1974). The percent index of intensity is calculated as:

% intensity = [sum of each individual’s value in the population/maximum value that could be achieved by all individuals in the population(N*4)]*100

Product Number: Biodiversity_015 Sub-products:	**Product Title:** Plant demography (for 3 focal species)		**Effort: C** **Priority: 4**
	Product Level: 4	**Temporal Resolution:** 1 year	
	Replicates: 60	**Spatial Extent:** Site	
	Replicated at: Core and relocatable sites	**Spatial Resolution:** NA	

Product Description: Long-term monitoring of plant populations is an essential tool for understanding and predicting responses of species to long-term climatic change as well as short-term disturbances. In particular, demographic studies can provide information on plant growth, reproduction and survival that is required for understanding the relationships between population responses to climatic variability, invasive species and pests. *Plant demography* describes changes in plant population size and structure through time (Harper, 1977), and how vital rates, such as fecundity and survival, influence population processes and persistence (Boyce, Haridas, Lee, & the, 2006). Population growth models are usually applied to predict population responses to changing climatic variability, invasive species and pests. By examining modules of plants or life –history stages (Harper, White, J, 1974), it is possible to follow the survivorship of cohorts of plant parts or individuals through time. Marked and mapped plants of three focal species within each domain will be monitored over time to assess parameters frequently estimated in plant demography studies, such as survival (the proportion of individuals in a population that survived successive time intervals), life span (the typical length of time that any particular plant species can be expected to live), and population growth (rate of increase of a population size) through time.

Product Number: Biodiversity_016 Sub-products:	**Product Title:** Vegetation species distribution map		**Effort:** B **Priority:** 3
	Product Level: 4	**Temporal Resolution:** 5 years	
	Replicates: 1	**Spatial Extent:** NEON Realm	
	Replicated at: NEON Realm	**Spatial Resolution:** 1000 m	

Product Description: A plant species distribution map will display an interactive graphic of a map locating all of the core and relocatable sites. The graphic will not include data interpolation between sites. The data will be presented in as an interactive graphic of a map. The interactive map will allow users to select plant species of interest that occur at NEON sites and examine their presence or absence across the continent at specified time intervals. This map will allow users to rapidly visualize patterns of both native and invasive species ranges at various time scales using data from data product Biodiversity_013.

Product Number: Biodiversity_017 Sub-products:	**Product Title:** Invasive species risk maps		**Effort: E** **Priority: 5**
	Product Level: 4	**Temporal Resolution:** 5 years	
	Replicates: 1	**Spatial Extent:** NEON Realm	
	Replicated at: NEON Realm	**Spatial Resolution:** 1 km	

Product Description: Current distributions of invasive species (plants, animals, and diseases) will be estimated from both NEON and external data, and will be mapped at the continental scale. Risk maps will be generated using several methods including regression approaches and new species-environmental matching models based on maximum entropy (Phillips, Anderson, & Schapire, 2006). These models relate observed species distributions to environmental (climatic, topographic, edaphic) envelopes, and project their spatial shifts (local enrichment or extinction) in response to environmental drivers. Future climate scenarios will then be added to the models to assess potential future invasion patterns (Jarnevich & Stohlgren, 2008). Risk maps of key harmful invasive species will be available to researchers, land managers, counties, states, tribes, and policymakers, and for public education and outreach.

Product Number: Biodiversity_018 Sub-products:	**Product Title:** Ecosystem structure		**Effort: E** **Priority: 4**
	Product Level: 4	**Temporal Resolution:** 1 year	
	Replicates: 60	**Spatial Extent:** AOP Footprint	
	Replicated at: Core & relocatable sites	**Spatial Resolution:** 10 m	

Product Description: With sub-meter scale resolution in both vertical and horizontal remote sensing, the NEON AOP makes it possible to quantify many ecosystem structure variables. These variables will include simple measures derived from LiDAR including canopy height and depth as well as more complex variables that may use both LiDAR and specrometer data such as lacunarity (Frazer, Wulder, & Niemann, 2005), canopy roughness, and canopy stratification (Clark, et al., 2008). With sub-meter high resolution data from a digital camera it is possible to recognize individual tree and shrub canopies (Packalen & Maltamo, 2006; Palace, Keller, Asner, Silva, & Passos, 2007). Direct identification of individual organisms using remote sensing is an enabling technology that can facilitate studies of productivity, demography, biodiversity, and species invasions (Asner, et al., 2008). NEON will develop algorithms for crown identification and mapping based by fusing LiDAR spectrometer, and possibly high-resolution aerial photography data.

<table>
<tr><td rowspan="4">Product Number: Biodiversity_019

Sub-products:</td><td colspan="2">Product Title: Soil microbial diversity</td><td rowspan="4">Effort: C
Priority: 3</td></tr>
<tr><td>Product Level: 4</td><td>Temporal Resolution: 5 years</td></tr>
<tr><td>Replicates: 60</td><td>Spatial Extent: Point Samples</td></tr>
<tr><td>Replicated at: Core and relocatable sites</td><td>Spatial Resolution: NA</td></tr>
<tr><td colspan="4">Product Description: Microbes dominate the total biodiversity of all ecosystems and can structure communities (e.g., food webs) through their relationships with and impacts on key macro-organisms. Much of microbial diversity, however, has not been described, with multiple unknown functions and impacts remaining to be discovered. As microbes and their many roles in ecosystems become better understood, knowledge of the diversity across different landscapes will add valuable data for comparison across the observatory. Sequence analyses provide the most extensive and valuable datasets for quantification of community composition, while bar-coded pyrosequencing provides the most economical and efficient method for generating datasets large enough to adequately determine and compare composition. NEON will produce data on microbial taxonomic richness at the OTU and species level all the way through to phyla. DNA analyses will focus on pyrosequencing of 16S rRNA (bacteria and archaea) and 18S/ITS rRNA (fungi). The 16S rRNA gene is currently used as the primary taxonomic and phylogenetic character for bacteria and archaea. The universal, barcoded 16S rRNA primers for the bacteria (Hamady, Walker, Harris, Gold, & Knight, 2008) will be used to PCR amplify this gene from all soil samples in order to examine the diversity of bacteria and archaea, two major soil microbial taxa that are likely to exhibit significant spatial and temporal variability within and across the NEON domains. The 18S rRNA gene is homologous to the 16S rRNA gene and serves as a primary taxonomic and phylogenetic character in microscopic eukaryotes. A set of universal primers specific for the 18S rRNA gene from fungi have been designed by Knight and Fierer at the University of Colorado (Dr. Robert Knight and Dr. Noah Fierer, personal communication, October 9, 2008). These primers have been tested to ensure their specificity for fungi and will be used to generate similar patterns of temporal and spatial variability in fungi as described above for bacteria and archaea. Following sequence alignment, several analytical processes have been developed to describe and compare sequence diversity. Data products will include phylogenetic trees, tables that describe the relative abundance of sequences belonging to unique phyla, and analyses using the UniFrac algorithm (Lozupone & Knight, 2005) to quantitatively compare the microbial communities.</td></tr>
</table>

Product Number: Biodiversity_020 Sub-products:	**Product Title:** Soil relative microbial abundance		**Effort: C** **Priority: 3**
	Product Level: 4	**Temporal Resolution:** 5 years	
	Replicates: 60	**Spatial Extent:** Point Samples	
	Replicated at: Core and relocatable sites	**Spatial Resolution:** NA	

Product Description: Bacteria, archeae and fungi have unique roles in soil biogeochemical cycles (van der Heijden, Bardgett, & van Straalen, 2008). For example, archaea play a major role in the cycling of nitrogen in soil (e.g., ammonia oxidation, (Leininger, et al., 2006) and their relative abundance may be correlated with nitrogen dynamics. Quantitative PCR (qPCR) permits comparison of the relative abundance of these three microbial groups from single samples. Specific primers and taxon-specific qPCR protocols for bacteria and fungi will yield an approximate taxa ratio, as described in (Fierer, Jackson, Vilgalys, & Jackson, 2005). The archaeal-specific qPCR primer set of Cadillo-Quiroz et al. (2006) that is both archaeal-specific and universal within the archaeal domain will supplement the analysis. Relative abundances of archaea, bacteria, and fungi will be estimated by normalizing qPCR results with domain-specific or fungal-specific primer sets.

Product Number: Biodiversity_021 Sub-products:	**Product Title:** Soil microbial functional diversity		**Effort: C** **Priority: 3**
	Product Level: 4	**Temporal Resolution:** 5 years	
	Replicates: 60	**Spatial Extent:** Point Samples	
	Replicated at: Core and relocatable sites	**Spatial Resolution:** NA	

Product Description: Nitrogen fixation is a crucial process in the nitrogen cycle that is performed only by bacteria and archaea. NEON will take advantage of recent discoveries through analyses of the nifH gene that will serve as a prototype for functional gene assays (Izquierdo & Nusslein, 2006). Functional assays complement data on community composition and provide a means to relate community composition data to key ecosystem functions. The highly conserved nifH gene codes for a subunit of dinitrogenase reductase, an enzyme that provides reductant to dinitrogenase. That in turn is the catalyst for the reduction of N2 to ammonia. Universal primers have been designed for the amplification of nifH from all diazotrophs in environmental samples. The availability of universal primers for the amplification of nifH permits the culture-independent analysis of all organisms capable of fixing nitrogen in any soil. Importantly, this analysis will provide information on the degree of spatial and temporal variation within a functional gene in relationship to small sub-unit ribosonamal RNA genes, and reveal how sampling intensities may need to be adjusted to detect changes in functional genes. Work by the microbial prototype study will field test data collection and lead to the design of the data product.

Product Number: Biodiversity_022 Sub-products:	**Product Title:** Soil microbial metagenomes		**Effort: E** **Priority: 5**
	Product Level: 4	**Temporal Resolution:** 5 years	
	Replicates: 60	**Spatial Extent:** Point Samples	
	Replicated at: Core and relocatable sites	**Spatial Resolution:** NA	

Product Description: Metagenomic libraries provide a record of functional gene data that yield additional depth beyond taxonomic richness (Daniel, 2005). Metagenomic sequence analysis can be used to detect novel organisms, genes, or metabolic pathways. For metagenomic analysis, DNA will be nebulized to form fragments approximately 700 bp in size. These fragments will be then be sequenced. The samples chosen for metagenomics will be based on an analysis of the 16S rRNA genes. Initially, NEON will produce libraries of aligned sequences that allow comparisons of the gene variability across space and time. This field is advancing rapidly and NEON products will need to evolve with the field.

Product Number: Biodiversity_023 Sub-products: Biodiversity_023.1 Biodiversity_023.2 Biodiversity_023.3 Biodiversity_023.4 Biodiversity_023.5 Biodiversity_023.6	**Product Title:** Algae and associated microbial biofilm diversity and abundance at Aquatic and STREON sampling locations. Biodiversity_023.1 = Epilithic algae Biodiversity_023.2 = Planktonic algae Biodiversity_023.3 = Macroalgae Biodiversity_023.4 = Epilithic algae (STREON) Biodiversity_023.5 = Planktonic algae (STREON) Biodiversity_023.6 = Macroalgae (STREON)		**Effort: A** **Priority: 1**
	Product Level: 4	**Temporal Resolution:** 1 year	
	Replicates: 36 (AQU) + 10 (STR)	**Spatial Extent:** Point Samples	
	Replicated at: Core and relocatable aquatic array sites	**Spatial Resolution:** NA	

***Product Description**:* Algae are principle biotic components of biogeochemical cycles, which link terrestrial and aquatic ecosystems. Algal taxonomic and functional diversity corresponds with ecosystem productivity (Weis, Cardinale, Forshay, & Ives, 2007) and rates of nutrient cycling (Mulholland, Steinman, Marzolf, Hart, & Deangelis, 1994). NEON will target epilithic, planktonic, and macro-algae. *Epilithic algae* are attached to rocks and other substrates and are the dominant form in streams. *Planktonic algae* are free-floating algal species that dominate lakes and still-water areas. *Macroalgae* are algal species that are filamentous (i.e. Cladophora), plantlike, colonial, or gelatinous, and may cover large spatial extents in streams and lakes. Microbial biofilms composed of bacteria, protists, and fungi that grow in conjunction with algae, play a key role in organic matter decomposition (Cummins, et al., 1972) and denitrification (Knowles, 1982).

For STREON algal abundance and diversity will be measured in control and treatment experiment baskets.

Diversity: Where appropriate, the taxonomic or functional diversity of algae and the associated microbial biofilm are calculated following equations 5.01 to 5.06.

Abundance: Algal abundance is measured via biovolume (cell counts*average cell volume) and pigment concentrations (chlorophyll and phaeophyton µg/L) where appropriate (Charles, 2002; Moulton, Kennen, Goldstein, & Hambrook, 2002). Algae and the associated biofilm abundance is measured via dry weight (µg/L), ash-free dry mass (µg/L), total carbon content (C µg/L), and % cover quantified at a site where appropriate (Charles, 2002).

These data may serve as a basis for collaboration with other programs (i.e. USGS NAWQA, LTER, EPA E-MAP) to determine distribution limits and shifts in dominant species at the continental scale.

Product Number: Biodiversity_024 Sub-products: Biodiversity_024.1 Biodiversity_024.2 Biodiversity_024.3	**Product Title:** Algae distribution maps Biodiversity_024.1 = Epilithic algae Biodiversity_024.1 = Planktonic algae Biodiversity_024.1 = Macroalgae		**Effort: B** **Priority: 3**
	Product Level: 4	**Temporal Resolution:** 1 year	
	Replicates: 1	**Spatial Extent:** NEON Realm	
	Replicated at: NEON Realm	**Spatial Resolution:** stream reach, lake	
Product Description: An algae taxa distribution map will display an interactive graphic of a map locating all of the core and relocatable sites. The graphic will not include data interpolation between sites. The interactive map will allow users to select algal taxa of interest and examine their presence or absence across the observatory at specified time intervals. This map will allow users to rapidly visualize patterns of both native and invasive species ranges at various time scales using data from data product Biodiversity_023.			

Product Number: Biodiversity_025 Sub-products: Biodiversity_025.1 Biodiversity_025.2 Biodiversity_025.3 Biodiversity_025.4	**Product Title:** Aquatic macrophyte and bryophyte diversity and abundance Biodiversity_025.1 = Macrophyte Biodiversity_025.2 = Bryophyte Biodiversity_025.3 = Macrophyte (STREON) Biodiversity_025.4 = Bryophyte (STREON)		**Effort: A** **Priority: 1**
	Product Level: 4	**Temporal Resolution:** 1 year	
	Replicates: 36 (AQU) + 10 (STR)	**Spatial Extent:** stream reach or lake	
	Replicated at: Core and relocatable aquatic array sites, STREON sites	**Spatial Resolution:** NA	
Product Description: Macrophytes are emergent, rooted aquatic vegetation. Bryophytes are mosses, liverworts, and hornworts that reproduce by means of spores as opposed to seeds. Macrophytes and bryophytes are sensitive indicators of air pollution (Goncalves, Boaventura, & Mouvet, 1992), nutrient enrichment (Orth & Moore, 1983), and changes in algal population dynamics (Jupp & Spence, 1977). Abundance and diversity for macrophytes and bryophytes will be measured in aquatic location stream reaches and in treated STREON stream reaches. **Diversity**: Macrophyte and bryophyte diversity will be calculated from equations 5.03 to 5.06.			

Abundance: Abundance shall be measured in situ using non-destructive methods via the quantification of % cover throughout a stream reach and lake. When appropriate, abundance may also be measured via fresh weight (g/ m^2), ash-free dry mass (g/ m^2), and total carbon content (C g/m^2) (Charles, 2002).

The macrophyte and bryophyte data may serve as a basis for collaboration with other programs (i.e. USGS NAWQA, LTER, EPA E-MAP) to determine distribution limits and shifts in dominant species at the continental scale.

Product Number: Biodiversity_026 Sub-products: Biodiversity_026.1 Biodiversity_026.2	**Product Title:** Aquatic macrophyte and bryophyte distribution map Biodiversity_026.1 = Macrophyte Biodiversity_026.2 = Bryophyte		**Effort: B** **Priority: 3**
	Product Level: 4	**Temporal Resolution:** 1 year	
	Replicates: 1	**Spatial Extent:** NEON realm	
	Replicated at: Core and relocatable aquatic array sites	**Spatial Resolution:** stream reach or lake	
Product Description: An aquatic macrophyte and bryophyte species distribution map will display an interactive graphic of a map locating all of the core and relocatable sites. The graphic will not include data interpolation between sites. The interactive map will allow users to select macrophyte and bryophyte species of interest and examine their presence or absence across the observatory at specified time intervals. This map will allow users to rapidly visualize patterns of both native and invasive species ranges at various time scales using data from data product Biodiversity_024.			

Product Number: Biodiversity_027 Sub-products: Biodiversity_027.1 Biodiversity_027.2	**Product Title:** Benthic macro-invertebrate diversity and abundance Biodiversity_027.1 = Benthic macro-invertebrates Biodiversity_027.2 = Benthic macro-invertebrates (STREON)		**Effort: A** **Priority: 1**
	Product Level: 4	**Temporal Resolution:** 1 year	
	Replicates: 36 (AQU) + 10 (STR)	**Spatial Extent:** Point Samples	
	Replicated at: Core and relocatable aquatic array sites	**Spatial Resolution:** stream reach or lake	

Product Description: Benthic macroinvertebrates influence energy flow and nutrient cycling (Covich, Palmer, & Crowl, 1999). Benthic invertebrate diversity and abundance has been correlated with ecosystem functions such as the rate of decomposition (Solan, Batty, Bulling, & Godbold, 2008) and algal biomass (Hillebrand, 2008). Benthic invertebrate's response to their environment is in the range of months to years (Merritt & Cummins, 1996). NEON will track patterns of invertebrate diversity and abundance in order to assess the how environmental change is integrated across generations.

For STREON benthic macro-invertebrate diversity and abundance will be measured in both control and treatment experiment baskets.

Diversity: Benthic macroinvertebrate diversity will be calculated from equations 5.03 to 5.06.

Abundance: Benthic macroinvertebrate abundance will be calculated as # of individuals / m^3, biovolume (mg/L), and total carbon content (C µg/L) where appropriate (Charles, 2002).

The benthic macroinvertebrate species data may serve as a basis for collaboration with other programs (i.e. USGS NAWQA, LTER, EPA E-MAP) to further our understanding of species' distribution limits and shifts in dominant species at the continental scale.

Product Number: Biodiversity_028 Sub-products:	**Product Title:** Benthic macroinvertebrate distribution map		**Effort: B** **Priority: 3**
	Product Level: 4	**Temporal Resolution:** 1 year	
	Replicates: 1	**Spatial Extent:** NEON Realm	
	Replicated at: NEON Realm	**Spatial Resolution:** NA	

Product Description: A benthic macroinvertebrate species distribution map will display an interactive graphic of a map locating all of the core and relocatable sites. The graphic will not include data interpolation between sites. The interactive map will allow users to select benthic macroinvertebrate species of interest and examine their presence or absence across the observatory at specified time intervals. This map will allow users to rapidly visualize patterns of both native and invasive species ranges at various time scales using data from data product Biodiversity_026.

Product Number: Biodiversity_029 Sub-products:	**Product Title:** Zooplankton diversity and abundance		**Effort: A** **Priority: 1**
	Product Level: 4	**Temporal Resolution:** 1 year	
	Replicates: 6	**Spatial Extent:** Point sample	
	Replicated at: Lake aquatic arrays	**Spatial Resolution:** NA	

Product Description: Zooplankton influence energy flow and nutrient cycling in lake ecosystems (Brett, et al., 1994), much as benthic invertebrates do in streams. We can track patterns of zooplankton diversity and abundance in order to assess the how environmental change is integrated across generations.

Diversity: Zooplankton diversity will be calculated from equations 5.03 to 5.06.

Abundance: Zooplankton abundance shall be calculated as # of individuals / m^3, biovolume (mg/L), and total particulate carbon content (C µg/L) where appropriate (Charles, 2002).

Product Number: Biodiversity_030 Sub-products:	**Product Title:** Fish relative abundance, diversity and richness		**Effort: A** **Priority: 1**
	Product Level: 4	**Temporal Resolution:** 1 year	
	Replicates: 36	**Spatial Extent:** Point Samples	
	Replicated at: Core and relocatable aquatic array sites	**Spatial Resolution:** NA	

Product Description: Fish transfer nutrients along spatial corridors and create biogeochemical hotspots (McIntyre, et al., 2008). Fish response to their environment is longer than invertebrates or algae, thus integrating abiotic conditions over years to decades. When patterns of fish diversity and abundance are combined with those of invertebrates and plants, whole-ecosystem response to environmental change can be assessed.

Diversity: Fish diversity will be calculated from equations 5.03 to 5.06.

Abundance: Fish abundance shall be calculated as # of individuals / reach and *catch per unit effort* following methods from the U.S. Geological Survey's National Water-Quality Assessment Program (Moulton, et al., 2002).

The fish distribution data may serve as a basis for collaboration with existing programs (i.e. USGS NAWQA, LTER) to further our understanding of species' distribution limits and shifts in dominant species at the continental scale.

Product Number: Biodiversity_031 Sub-products:	**Product Title:** Fish distribution map		**Effort: B** **Priority: 3**
	Product Level: 4	**Temporal Resolution:** 1 year	
	Replicates: 1	**Spatial Extent:** NEON Realm	
	Replicated at: Core and relocatable aquatic array sites	**Spatial Resolution:** Stream reach or lake	

Product Description: A fish species distribution map will display an interactive graphic of a map locating all of the core and relocatable sites. The graphic will not include data interpolation between sites. The interactive map will allow users to select fish species of interest and examine their presence or absence across the observatory at specified time intervals. This map will allow users to rapidly visualize patterns of both native and invasive species ranges at various time scales using data from data product Biodiversity_029.

7 BIOGEOCHEMISTRY DATA PRODUCTS

The high-level data products in biogeochemistry suite relate to carbon dynamics, nutrient dynamics, and water and air quality. The carbon dynamics products related to terrestrial and aquatic ecosystem productivity and derive mainly from lower level data on aquatic, soil and plant measurements in the AQU/STR, FSU, and FIU. At broader geographic scales data from the airborne remote sensing (AOP) and satellite remote sensing play an important role. Vegetation has critical feedbacks to the atmosphere. The balance of carbon and productivity depend upon vegetation atmosphere exchange. Nutrient data focus primarily on nitrogen and phosphorus stocks and fluxes in both terrestrial and aquatic systems. NEON will measure several important aspects of water quality including nutrients, oxygen, and turbidity and air quality including nitrogen deposition and ozone deposition. The water and air quality data trace directly to the climate change and biogeochemistry NEON challenge areas. Chemical climate, including airborne gases and particles, is changing as rapidly or more rapidly than the physical climate.

NEON will make several significant investments in the biogeochemistry area including development of an annually updated vegetation biomass map for the NEON Realm. While labor intensive to produce initially, this product is important to enable forecasting and analysis both for model initialization or validation. Regional and national maps of ecosystem carbon exchange (gross and net exchange components) were selected for special emphasis because of their wide applicability and the ability to validate models through comparison with atmospheric CO_2 measurements. The strength of this validation is that it puts a top-down constraint on all NEON vegetation productivity measurements. Finally, NEON will invest heavily in improvement of the estimation of below-ground productivity. Currently, labor-intensive manual analysis of below-ground mini-rhyzotron data is a major impediment to research progress in productivity studies. NEON investment in this area will enable future analysis and forecasting of below ground productivity by provision of both extensive data sets and analysis routines.

Product Number: **Biogeochemistry_001**	**Product Title:** Ozone Deposition		**Effort: B** **Priority: 1**
Sub-products:	**Product Level:** 4	**Temporal Resolution:** 0.5 hour	
	Replicates: 40	**Spatial Extent:** Point	
	Replicated at: Advanced Towers	**Spatial Resolution:** NA	

Product Description: Ozone (O_3) is an EPA criteria pollutant. Ozone directly affects the functioning of both plants and is unhealthful for humans. Ozone concentrations will be measured at two heights above the plant canopy above the roughness surface layer and flux (deposition) will be estimated using the gradient method for the designated time average (Fowler & Duyzer, 1989; Hole, Semb, & Torseth, 2004; Hummelshøj, 1994).

$$FO3 = \frac{ku*}{\ln\left(\frac{z_v - d}{z_y - d}\right) + \Psi_h L(Z_y - d) - \Psi_h L(Z_v - d)} \cdot \frac{[O_3]_{Z_v} - [O_3]_{Z_y}}{1}$$

Eq. 6.01

Where, FO_3 is the vertical ozone flux, k is Von Karman's constant (0.40 dimensionless), u* friction velocity (m s^{-1}), Z_y is the top measurement height (m), Z_v is the lower measurement height (but still above the roughness elements), d is the zero-plane displacement (m), and Ψ_m and Ψ_h are the diabatic correction factors (m) for momentum and sensible heat, respectively (Arya, 1988; Yasuda, 1988) for stable atmospheres;

$$\Psi_M = \Psi_H = 6\ln(1+\zeta)$$

Eq. 6.02

and in unstable conditions,

$$\Psi_H = -2\ln[\frac{1+(1-16\zeta)^{0.5}}{2}; \Psi_M = 0.6\Psi_H$$

Eq. 6.03

Diabatic correction factors are a function of stability (i.e., Monin-Obukov length) and are explained in Denmead and Bradley (1985), Kaimal and Finnigan (1994), and Panofsky and Dutton (1984).

Product Number: Biogeochemistry_002 Sub-products:	**Product Title:** Ozone over threshold		**Effort: A** **Priority: 1**
	Product Level: 4	**Temporal Resolution:** 1.0 hour	
	Replicates: 40	**Spatial Extent:** Point	
	Replicated at: Advanced Towers	**Spatial Resolution:** NA	
Product Description: Measure of plant exposure to O_3 is the temporal sum of hourly O_3 concentrations at or above 0.06 ppm (known as SUM06, units = ppm-h). This measure is used to monitor public health and impacts on (forest) ecosystem health.			

Product Number: Biogeochemistry_003 Sub-products:	**Product Title:** NO_y Deposition		**Effort: B** **Priority: 1**
	Product Level: 4	**Temporal Resolution:** 0.5 hour	
	Replicates: 40	**Spatial Extent:** Point	
	Replicated at: Advanced Towers	**Spatial Resolution:** NA	
Product Description: Gaseous Reactive nitrogen (NO_y) has direct effects on the photochemical production of O_3, acidic deposition to ecosystems, nutrient cycling, and the transport of atmospheric nitrogen from local to-continental scale (Galloway & Cowling, 2002). Reactive nitrogen enters the atmosphere through combustion, soil microbial products, lightning, oceanic emission, and other atmospheric processes. Concentration measurements will be made at the tower top, adjacent to the eddy covariance system. NO_y turbulent flux calculations will be estimated in conjunction with the eddy covariance measurements of buoyancy flux. Buoyancy flux will be measured at 20 Hz, then sub sampled at the same data rate as the NO_y concentration measurements, i.e., 1 Hz. We will correct for the instrument response functions derived from standard additions to the trace gases (~1 Hz measured by chemiluminescence) by applying a low-pass numerical filter to the sonic temperature time series (scalar considered ideal), and re-calculate the buoyancy flux. The ratio of the two results (20 and 1 Hz calculated buoyancy flux) will provide an estimate of the flux lost by instrument smoothing of the high frequency fluctuations. Simple ratio of the 20:1 buoyancy flux will be applied to the 1 Hz $\overline{w'NO_y'}$ flux estimate to adjust the flux measurement to 20 Hz turbulent transport. This estimate will only be the turbulent component, not NEE of NO_y because there is no measurement of the storage flux term, (Horii, et al., 2004, 2006; Munger, et al., 1996)			

Product Number: Biogeochemistry_004 Sub-products:	**Product Title:** Particulate concentration and deposition		**Effort: C** **Priority: 3**
	Product Level: 4	**Temporal Resolution:** Variable	
	Replicates: ~9	**Spatial Extent:** Point	
	Replicated at: Sub-set of advanced Towers	**Spatial Resolution:** NA	

Product Description: Particulates will be measured from the tower top, using an eight-stage cascade impactor and integrated over a time series that minimizes error due to blow-by. The tracer continuity equation will be integrated to define a deposition velocity, and to estimate the deposition of particulates to the ecosystem (Loescher, et al., 2004), in this case,

$$F_p = C_n \cdot V_d \qquad \text{Eq. 6.04}$$

where, F_p is deposition to the canopy (μg m^{-2} s^{-1}), V_d is the deposition velocity to the canopy (mol m^{-2} s^{-1}),. V_d will be estimated using three different methods (i.e., V_{d1}, V_{d2}, V_{d3}), depending on the particulate size, atmospheric loading and removal rates, and particulate composition. Assuming spatial homogeneity in transfer properties, V_{d1} and V_{d2} will be estimated using conductance terms in series analogous to the inverse of electrical resistances, and V_{d3} will be estimated more traditionally by incorporating deposition processes of gravitational settling, diffusion, impaction and interception, such that,

$$V_{d1} = \frac{1}{\frac{1}{g_a} + \frac{1}{g_b}} \cong V_{d2} = \frac{1}{\frac{1}{g_a} + \frac{1}{g_m}} \cong V_{d3} \qquad \text{Eq. 6.05}$$

$$V_{d3} = \left[V_g + \frac{1}{\frac{1}{g_a} + R_s} \right] V \qquad \text{Eq. 6.06}$$

where g_a is aerodynamic conductance in the roughness sub-layer (mol m^{-2} s^{-1}), g_b is the bulk canopy conductance (mol m^{-2} s^{-1}), g_m is the canopy conductance due to momentum transfer, V_g is gravitational setting of particulate (mol m^{-2} s^{-1}), R_s represents the collection efficiency of the canopy due to diffusion, impaction and interception (mol m^{-2} s^{-1}), and V is the molar volume (mol m^{-3}).

The g_b and g_m describes the transfer process at the boundary between the canopy and the atmosphere, and incorporates influences from both physiological and structural controls. Traditionally, g_b has been estimated by scaling leaf-level measurements of stomatal and boundary-layer conductances to the canopy-level (Bigelow, 2001). This is difficult to accomplish in structurally diverse and complex ecosystem. Settling of particulates due to gravitational forces will be calculated as,

$$V_g = \frac{\rho_d d_p 2 g C_c}{18 \nu} \qquad \text{Eq. 6.07}$$

where, ρ_d is the density of the particle (1 g m^{-3}) and d_p its diameter (m), C_c is the a correction due to slip, and v is the kinematic viscosity of air (m^2 s^{-1}). The correction factor will be estimated by,

$$C_c = 1 + \frac{0.133}{d_p}\left(1.142 + 0.558\exp^{-0.999\frac{0.133}{d_p}}\right) \quad \text{Eq. 6.08}$$

The collection efficiency will be estimated by,

$$R_s = \frac{1}{\varepsilon_0 u * R_1(E_b + E_{im} + E_{in})} \quad \text{Eq. 6.09}$$

such that, ε_0 empirical coefficient, R_1 is the fraction of particles to adhere to the surface and estimated with an exponential function of the Stokes number (St = V_gu*/2g) by R_1 = exp (-St0.5), and E_b, E_{im}, and E_{in} are dimensionless efficiencies due to Brownian diffusion, impaction and interception, respectively. E_b will be also based in the Schmidt number, E_b = Sc - 0.66 (Slinn, 1982). E_{im} will be also estimated as a function of the Stokes number (St = V_gu*/2g), given by,

$$E_{im} = \left(\frac{St}{0.8 + St}\right)^2 \quad \text{Eq. 6.10}$$

$$E_{in} = 0.5\left(\frac{dp}{A}\right)^2 \quad \text{Eq. 6.11}$$

where A is a characteristic radius of the canopy, and has been suggested to be 5 for evergreen broadleaved canopies (Zhang, Gong, Padro, & Barrie, 2001). Deposition estimates using V_{d3} will be made for each size class and summed together. Use of all three V_d estimates used here assume no electrical migrations, and no physical or chemical changes in the aerosol.

Because particulates are being added to- and removed from the atmosphere during any measurement period, functional relationships C_n must be estimated to reflect changes in sink-source status. Hence, loading and removal rates to/from the atmosphere will also be estimated by normalizing concentrations on the basis of total rainless (‘dry’) hours sampled (Loescher, et al., 2004), because of daily rain events during our sampling intervals, and precipitation removes aerosols from the atmosphere such that,

$$C_n = C_i \cdot \frac{V}{V_a} \cdot \int_{t=0}^{t=i} \frac{h_d}{h_s} \quad \text{Eq. 6.12}$$

C_n is the normalized particulate density per mol air sampled (μg C mol^{-1}), C_i is the weight of the sample (μg) over the temporal integral *i*, V_a is the total air volume sampled (m^3), V is the molar volume of air (m^3 mol^{-1}), h_d is the fraction of sampling time without precipitation, and h_s is the entire sampling time.

Product Number: Biogeochemistry_005 Sub-products: Biogeochemistry_005.1 Biogeochemistry_005.2 Biogeochemistry_005.3 Biogeochemistry_005.4 Biogeochemistry_005.5 Biogeochemistry_005.6	**Product Title:** Biomass Biogeochemistry_005.1 = Total biomass Biogeochemistry_005.2 = Above-ground biomass Biogeochemistry_005.3 = Above-ground biomass, herbs Biogeochemistry_005.4 = Above-ground biomass, shrub Biogeochemistry_005.5 = Above-ground biomass, tree Biogeochemistry_005.6 = Below-ground biomass		**Effort: A** **Priority: 1**
	Product Level: 4	**Temporal Resolution:** 0.25 to 1 year	
	Replicates: 60	**Spatial Extent:** Site	
	Replicated at: Core and Relocatable sites	**Spatial Resolution:** 100 m	

Product Description: Biomass is defined here as the sum of all live above- and below-ground components (*Total Biomass*), expressed as units of plant dry mass accumulated per unit area (Sala, Jackson, Mooney, & Howarth, 2000). Traditionally, significant components of total live biomass are estimated by area harvested (destructive sampling) or by allometric relationships between measured plant dimensions and total mass (Brown, 1997; Gower, et al., 1999).

Above-ground biomass: the sum of all above-ground components (live tissues* of trees, shrubs, and herbs), expressed in g m^{-2} or kg ha^{-1}

Above-ground biomass, herbs: the mass of all live tissue* of herbs per unit area (g m^{-2} or kg ha^{-1})

Above-ground biomass, shrub: the mass of all live tissue* of shrubs per unit area (g m^{-2} or kg ha^{-1})

Above-ground biomass, tree: the mass of all live tissue* of trees per unit area ((g m^{-2} or kg ha^{-1})

Below-ground biomass: the entire mass of all live roots and other underground structures (e.g. rhizomes) and micorrhyzae (coarse + fine roots), expressed in g m^{-2} or kg ha^{-1}

*Plant live tissues include: wood (or the stalk in the case of non-woody plants), foliage, reproductive tissue, and roots (Gower, et al., 1999).

Product Number: Biogeochemistry_006 Sub-products: Biogeochemistry_006.1 Biogeochemistry_006.2 Biogeochemistry_006.3 Biogeochemistry_006.4 Biogeochemistry_006.5 Biogeochemistry_006.6	**Product Title:** Biomass map, AOP Biogeochemistry_006.1 = Total biomass map Biogeochemistry_006.2 = Above-ground biomass map Biogeochemistry_006.3 = Above-ground biomass, herb map Biogeochemistry_006.4 = Above-ground biomass, shrub map Biogeochemistry_006.5 = Above-ground biomass, tree map Biogeochemistry_006.6 = Below-ground biomass map		**Effort: D** **Priority: 4**
	Product Level: 4	**Temporal Resolution:** 1 year	
	Replicates: 60	**Spatial Extent:** AOP Footprint	
	Replicated at: AOP Footprints	**Spatial Resolution:** 10 m	
Product Description: Biomass is a basic state of the ecosystem that results from integrated productivity. Changes in biomass can be used as one measure of productivity. Biomass measurements can be scaled up to the landscape and regional scales by relation to remotely sensed landscape properties. However, LiDAR data (and possibly LiDAR-spectrometer data fusion) offers the possibility to measure biomass at a regional level. AOP wLiDAR provides 3D structural information on canopies, underlying vegetation, and the terrain below (Asner, et al., 2008). Depending on openness of the canopy, the wLiDAR generally can discriminate between the canopy, understory, and the terrain. Therefore, where there is a regular relationship between biomass and height (Lefsky, et al., 1999) the wLiDAR data can provide a measure of total aboveground biomass, canopy biomass (effectively, a tree map), and for open canopy forests, a measure of understory biomass (effectively, shrubs). Uncertainty in whether the LiDAR shots truly reach the ground (due to dense vegetation) and limits on vertical resolution (~ 15 cm), constrain the ability of the wLiDAR to discriminate herbaceous plants. In croplands or savanna regions, a surface roughness measurement may be the limit of measurement obtained from the wLiDAR. Because AOP cannot measure below-ground biomass, it will be estimated using empirical relations to above-ground biomass. These empirical relationships will be determined based on FUS measurements of biomass in support of Biogeochemistry_007.			

Product Number: Biogeochemistry_007 Sub-products: Biogeochemistry_007.1 Biogeochemistry_007.2 Biogeochemistry_007.3 Biogeochemistry_007.4 Biogeochemistry_007.5 Biogeochemistry_007.6	**Product Title:** Biomass map, realm Biogeochemistry_007.1 = Total biomass map Biogeochemistry_007.2 = Above-ground biomass map Biogeochemistry_007.3 = Above-ground biomass, herb map Biogeochemistry_007.4 = Above-ground biomass, shrub map Biogeochemistry_007.5 = Above-ground biomass, tree map Biogeochemistry_007.6 = Below-ground biomass map		**Effort: E** **Priority: 4**
	Product Level: 4	**Temporal Resolution:** 1 year	
	Replicates: 1	**Spatial Extent:** NEON Realm	
	Replicated at: NEON Realm	**Spatial Resolution:** 1000 m	
Product Description: Biomass is a basic state of the ecosystem that results from integrated productivity. Changes in biomass can be used as one measure of productivity. Local biomass data are compiled by a variety of agencies, most importantly for the US, the Forest Service Forest Inventory and Analysis National Program (http://fia.fs.fed.us/). Biomass measurements can be scaled up to the landscape and regional scales using geographical and statistical analysis and by relation to remotely sensed landscape properties.			

NEON will develop national maps combining both approaches and NEON and outside data sources.

Product Number: Biogeochemistry_008 Sub-products: Biogeochemistry_008.1 Biogeochemistry_008.2 Biogeochemistry_008.3	**Product Title:** Necromass Biogeochemistry_008.1 = Total necromass Biogeochemistry_008.2 = Above-ground necromass Biogeochemistry_008.3 = Below-ground necromass		**Effort: A** **Priority: 1**
	Product Level: 4	**Temporal Resolution:** 0.25 to 1 year	
	Replicates: 60	**Spatial Extent:** Site	
	Replicated at: Core and Relocatable sites	**Spatial Resolution:** 100 m	

Product Description: Necromass is defined here as the sum of all dead above- and below-ground components (*Total Necromass*), expressed as units of dry mass accumulated per unit area. Necromass plays an important role in forests ecosystems accounting for a large fraction of the total carbon pool and nutrient stocks (Chambers, Higuchi, Schimel, Ferreira, & Melack, 2000; Harmon, et al., 1986). Carbon cycling of coarse wood debris (CWD*) is also important for understanding ecosystem response to land use and climate change (Chambers, et al., 2000; Palace, Keller, & Silva, 2008). The mass of fallen CWD and standing dead mass above-ground can be calculated from the product of measured volume of dead material and its respective estimated density (Palace, et al., 2007) sampled in line-intersect transects and plots, respectively. The below-ground necromass can be estimated by collecting and processing soil samples, sorting the material into live and dead roots, and weighing (Lauenroth, 2000), or from above-ground measurements using allometric methods (Clark, et al., 2001).
Above-ground necromass: the sum of all dead above-ground components - fallen or downed coarse wood detritus fractions (CWD) and standing dead wood (snags) - expressed in g m^{-2} or kg ha^{-1} (Harmon, et al., 1986).
Below-ground necromass: similar stocks of dead material found below-ground, i.e., the entire mass of all coarse dead roots and other below-ground structures (e.g. rhizomes), expressed in g m^{-2} or kg ha^{-1}.

* Coarse wood debris (CWD) ≥ 2 cm diameter.

Product Number: Biogeochemistry_009 Sub-products:	**Product Title:** Canopy nitrogen		**Effort: C** **Priority: 3**
	Product Level: 4	**Temporal Resolution:** 1 year	
	Replicates: 60	**Spatial Extent:** AOP Footprint	
	Replicated at: AOP Footprint	**Spatial Resolution:** 10 m	

Product Description: A measure of the nitrogen concentration in vegetation from remotely sensed data provides information to assess changes in ecosystem processes such as nutrient cycling and net primary productivity. A multiple stepwise linear regression is applied to the normalized band-depths highly correlated with laboratory measurements of chemical concentrations (Kokaly & Clark, 1999). Schimel (1995) determined that an accuracy of 0.5% (absolute) N was necessary to distinguish between ecosystems with differences in nitrogen large enough to affect photosynthesis. Sensitivity analyses reported in Kokaly and Clark (1999) indicate that this degree of accuracy can be obtained using the multiple stepwise linear regression algorithm even when accounting for the effects of atmosphere, fractional coverage, and leaf water content. Ground based data will be required to calibrate and validate canopy nitrogen for different ecosystems in the NEON domain.

Product Number: Biogeochemistry_010	**Product Title:** Canopy water content		**Effort: C** **Priority: 3**
Sub-products:	**Product Level:** 4	**Temporal Resolution:** 1 year	
	Replicates: 60	**Spatial Extent:** AOP Footprint	
	Replicated at: AOP Footprint	**Spatial Resolution:** 10 m	

Product Description: Canopy water content provides an instantaneous view of the hydraulic status of the plant canopy. It can also be related to canopy biomass and leaf area as noted below. Canopy water content can be estimated using ratios of spectral reflectance or through spectral fitting. The former may be useful for validation of satellite borne multi-spectral instrument canopy water content retrievals. The spectral fitting approaches are more likely to give accurate estimates. Products using both approaches are contemplated.

Alternative indices for estimating canopy water content exist. The Normalized Difference Water Index (NDWI) combines reflectance at 860 nm (a reference wavelength) and 1240 nm (a liquid water absorption band) and is used for space-borne multi-spectral instruments (i.e., MODIS) (Gao, 1996). The Water Index (Penuelas, Filella, Biel, Serrano, & Save, 1993) has also been reported as a robust index of water content at the leaf and canopy scales. These indices were shown to be reliable indicators of relative water content not only at the leaf and canopy levels but also at the landscape scale (Serrano, Ustin, Roberts, Gamon, & Penuelas, 2000).

Equivalent Water Thickness (EWT) is a measure of the water content within a vegetation canopy. The absorption spectrum of green vegetation in the liquid water bands is expressed as the equivalent thickness of a sheet of liquid water. Roberts et al. (D. A. Roberts, et al., 1997) showed the potential of retrieved EWT (resulting from the atmospheric correction of AVIRIS-measured radiance to apparent surface reflectance) to monitor temporal and spatial variations in water in herbaceous, shrub, and coniferous vegetation.

Table 5.1. Spectral reflectance indices and associated spectral bands (from (Serrano, et al., 2000))

Index	*Method*	*Formulation*	*Reference*
WI	Ratio-based	$R_{865} – R_{972}$	(Penuelas, et al., 1993; Penuelas, Pinol, Ogaya, & Filella, 1997)
NDWI	Ratio-based	$(R_{857} – R_{1241})/ (R_{857} + R_{1241})$	(Gao, 1996)
EWT	Spectral Fitting	R_{867} through R_{1049}	(Green, Conel, & Roberts, 1993)
WT	Spectral fitting	R_{867} through R_{1088}	(D. A. Roberts, et al., 1998)

It is interesting to note that estimates of LAI have been obtained using EWT derived from remote sensing data from AVIRIS. EWT has been shown to provide a more reliable estimate of LAI as compared to LAI estimates based on ratio-based techniques (i.e., NDVI) in cases where LAI > 3 (e.g., coniferous forests) (D. A. Roberts, et al., 1998).

Product Number: Biogeochemistry_011 Sub-products:	**Product Title:** Canopy xanthophyll cycle (PRI)		**Effort: C** **Priority: 3**
	Product Level: 4	**Temporal Resolution:** 1 year	
	Replicates: 60	**Spatial Extent:** AOP Footprint	
	Replicated at: AOP Footprint	**Spatial Resolution:** 10 m	

Product Description: Measurement of the photochemical reflectance index (PRI) serves as an indicator of canopy photosynthetic light-use efficiency (LUE). This link to efficiency occurs because this index detects the response of xanthophyll cycle pigments to changing light conditions (Gamon, Penuelas, & Field, 1992; Rahman, et al., 2001). Classification of biochemicals, such as xanthophylls, requires wavelengths sampling specific biochemical features. The interconversion of xanthophyll cycle pigments can be detected through a change in reflectance at 531 nm. PRI contrasts the reflectance at 531 nm with reflectance at a reference wavelength of 570 nm (Gamon, Serrano, & Surfus, 1997; Penuelas, Filella, & Gamon, 1995). PRI is defined by the equation:

$$PRI = \frac{R_{531} - R_{570}}{R_{531} + R_{570}} \qquad \text{Eq. 6.13}$$

where R represents reflectance and subscripts represents the wavelength in nanometers. PRI is a normalized index, and its values fall between -1 and 1. PRI for green vegetation typically falls between -0.2 and 0.2.

Product Number: Biogeochemistry_012 Sub-products:	**Product Title:** Canopy chlorophyll		**Effort: C** **Priority: 3**
	Product Level: 4	**Temporal Resolution:** 1 year	
	Replicates: 60	**Spatial Extent:** AOP Footprint	
	Replicated at: AOP Footprint	**Spatial Resolution:** 10 m	

Product Description: Canopy chlorophyll is closely related to photosynthetic capacity, vegetation nutrient status, and productivity. Spectral ratios or adjusted spectral ratios are used to quantify chlorophyll content.

NDVI is a spectral ratio for assessing leaf chlorophyll in vegetation based on the strong spectral contrast between chlorophyll absorption of red light and strong scattering of NIR light make it robust over a wide range of conditions. It can, however, saturate in dense vegetation conditions when LAI becomes high. NDVI is also used as a basis for estimating LAI, fPAR, and plant cover. The relationship between NDVI and LAI becomes progressively more asymptotic at LAI values greater than three, in which case the relationships between leaf water index and LAI provide a more accurate measure (D. A. Roberts, et al., 2004). Measurements of NDVI from AOP are complementary to satellite measurements of NDVI (e.g., MODIS) and can serve as tie-points for regional to continental assessments of canopy chlorophyll and productivity.

The Enhanced Vegetation Index (EVI) was developed to improve the NDVI by optimizing the vegetation signal in LAI regions by using the blue reflectance to correct for soil background signals and reduce atmospheric influences, including aerosol scattering. This index is most useful in LAI regions, where the NDVI may saturate.

The Atmospherically Resistant Vegetation Index (ARVI) is an enhancement to the NDVI that is relatively resistant to atmospheric factors (for example, aerosol). It uses the reflectance in blue to correct the red reflectance for atmospheric scattering. It is most useful in regions of high atmospheric aerosol content, including tropical regions contaminated by soot from slash-and-burn agriculture.

Index	*Method*	*Formulation*	*Reference*
NDVI	Ratio-based	$\frac{(R_{895} - R_{675})}{(R_{895} + R_{675})}$	(Penuelas, et al., 1993)
EVI	Ratio-based	$2.5\left(\frac{R_{nir} - R_{red}}{R_{nir} - 6R_{red} - 7.5R_{blue} + 1}\right)$	(Rouse, Haas, Schell, & Deering, 1973)
ARVI	Ratio-based	$\frac{R_{nir} - (2R_{red} - R_{blue})}{R_{nir} + (2R_{red} - R_{blue})}$	(Kaufman & Tanre, 1996)

Validating the canopy chlorophyll content for different ecosystems comprising the NEON domain will require ground based studies.

Product Number: Biogeochemistry_013 Sub-products:	**Product Title:** Canopy lignin		**Effort: D** **Priority: 5**
	Product Level: 4	**Temporal Resolution:** 1 year	
	Replicates: 60	**Spatial Extent:** AOP Footprint	
	Replicated at: AOP Footprint	**Spatial Resolution:** 10 m	

Product Description: Lignin is a carbon-based molecule used by plants for structural components. Lignin is difficult to decompose and the lignin:nitrogen ratio of plant material is a classic indicator of its resistance to decay (Melillo, Aber, & Muratore, 1982). The Normalized Difference Lignin Index (NDLI) is designed to estimate the relative amounts of lignin contained in vegetation canopies. Reflectance at 1754 nm is largely determined by lignin concentration of leaves, as well as the overall foliage biomass of the canopy. Together, leaf lignin concentration and canopy foliar biomass are combined in the 1750 nm range to predict total canopy lignin content. Applications include ecosystem analysis and detection of surface plant litter. The NDLI is experimental (Serrano, Penuelas, & Ustin, 2002). NDLI is defined by the following equation:

$$NDLI = \frac{\log(1/\rho_{1754}) - \log(1/\rho_{1680})}{\log(1/\rho_{1754}) + \log(1/\rho_{1680})} \qquad \text{Eq. 6.14}$$

The value of this index ranges from 0 to 1, with green vegetation generally between 0.005 and 0.05.

Product Number: Biogeochemistry_014 Sub-products: Biogeochemistry_014.1 Biogeochemistry_014.2	**Product Title:** Soil matter organic stocks Biogeochemistry_014.1 = Soil C stock Biogeochemistry_014.2 = Soil N stock		**Effort: A** **Priority: 1**
	Product Level: 4	**Temporal Resolution:** 5 years	
	Replicates: 60	**Spatial Extent:** Site	
	Replicated at: Core and Relocatable sites.	**Spatial Resolution:** 100m	
Product Description: Soil organic matter C and N stocks will be measured as the product of soil bulk density times the C and N concentrations measured by combustion assays of soils sampled according to divisions of the profile from the surface (including litter C and N stocks) to the parent material where this can be reached or to a depth of 1 m.			

Product Number: Biogeochemistry_015 Sub-products:	**Product Title:** Soil carbon dioxide flux		**Effort: B** **Priority: 1**
	Product Level: 4	**Temporal Resolution:** 0.5 hour	
	Replicates: 60	**Spatial Extent:** Point	
	Replicated at: Soil arrays	**Spatial Resolution:** NA	

Product Description: For most terrestrial ecosystems, the emission of carbon dioxide (CO_2) from the soil accounts for the majority of the ecosystem respiration. Soil CO_2 flux is an important constraint on ecosystem respiration estimates. Where dissolved losses of CO_2 from the soil are small, the surface CO_2 flux integrates root respiration and below-ground heterotrophic respiration. The soil carbon dioxide (surface) flux will be measured using gradients through the soil profile. This method assumes that the primary process of gas transport from the soil to the atmosphere is driven by diffusion as described by Fick's first law;

$$J = -D\frac{\partial x}{\partial y} \qquad \text{Eq. 6.15}$$

where, J is the scalar flux, D is the diffusivity (or conductance), x the scalar of interest, and z the spatially explicit extent. The flux is calculated using diffusivity and scalar gradient of CO_2 concentration through the soil profile (Moldrup, Olesen, Yamaguchi, Schjonning, & Rolston, 1999; Tang & Baldocchi, 2005; Tang, Baldocchi, Qi, & Xu, 2003);

$$FCO2_G = D_a \frac{\eta - \theta_v^{2.9S}}{\eta} \cdot \int_{Z_0}^{Zy} \partial z \frac{\partial [CO_2]}{\partial t} \qquad \text{Eq. 6.16}$$

where, $FCO2_G$ is the soil CO2 flux (μmol m^{-2} s^{-1}) to the atmosphere derived from the *gradient* of the scalar through the soil profile (z), D_a is the diffusivity of CO_2 in free air and considered constant at 1.29×10^{-6} m^2 s^{-1} (Jones, 1992), θ_v is the volumetric water content (m^{-3} m^{-3}), soil porosity $\eta=(\rho_s-\rho_b)/\rho_s$ is empirically determined during site characterization where ρ_s is density of mineral soil (Mg m^{-3}) and ρ_b is the soil bulk density (Mg m^{-3}, (Jayawardane & Meyer, 1985), *S* (unitless) accounts for the tortuosity of the soil medium with respect to movement of a fluid and it depends upon soil texture and structure (Tang & Baldocchi, 2005).

Product Number: Biogeochemistry_016 Sub-products:	**Product Title:** Fine root production		**Effort: E** **Priority: 3**
	Product Level: 4	**Temporal Resolution:** 1 month	
	Replicates: 60	**Spatial Extent:** Point	
	Replicated at: Soil arrays	**Spatial Resolution:** NA	

Product Description: Fine roots and their associated mycorrhizae represent the interface between plants and the soil for absorption of water and nutrients. They also represent an important portion of plant belowground productivity. Fine root studies in NEON will be anchored by occasional direct measurements in cores to quantify biomass. These laborious measurements will be supplemented by semi-automated minirhizotron studies of fine root growth and turnover. Currently, the technology to acquire images is well-developed while the analysis of images generally requires human intervention and is thus costly. Automated measurements of roots in minirhizotron images is progressing (Zeng, Birchfield, & Wells, 2006) in press. NEON will build on these efforts to develop automated root recognition approaches to quantify root turnover which can then be used to estimate production (Metcalfe, Meir, & Williams, 2007).

Product Number: Biogeochemistry_017 Sub-products: Biogeochemistry_017.1 Biogeochemistry_017.2 Biogeochemistry_017.3	**Product Title:** Ecosystem exchange, tower Biogeochemistry_017.1 = Net Ecosystem Exchange, NEE Biogeochemistry_017.2 = Gross Ecosystem Exchange, GEE Biogeochemistry_017.3 = Ecosystem Respiration, ER		**Effort: B** **Priority: 1**
	Product Level: 4	**Temporal Resolution:** 0.5 hour	
	Replicates: 60	**Spatial Extent:** Point	
	Replicated at: Advanced towers	**Spatial Resolution:** NA	

Product Description: Net Ecosystem Exchange (NEE) is estimated based on the eddy covariance technique from sonic anemometer measurements of vertical winds and an infra-red gas analyzer (or alternative) measurements of CO_2. Gross ecosystem exchange (GEE) and ecosystem respiration (ER) are estimated from NEE and models described below. These products are required for understanding ecosystem carbon balance at high temporal frequency and integrated spatial scales. Daytime and nighttime NEE rates will be separated to quantify the abiotic and biotic controls on uptake, *e.g.,* light response curves, VPD response curves, quantum efficiency, and Ecosystem Respiration (ER), *e.g.,* Q^{10} functions, effects of soil water, respectively.

Gross Ecosystem Exchange (GEE) is the sum of both NEE and ER, and is calculated by,

$$GEE = NEE - ER \qquad \text{Eq. 6.17}$$

The micrometeorological convention is used for NEE, being that NEE is negative when carbon enters the ecosystem and positive when it leaves. This logic follows with GEE estimates, such that,

$$-NEE \cong NPP \qquad \text{Eq. 6.18}$$

Where NPP is net primary productivity (see Biogeochemistry_020)

Covariance (*e.g.,* scalar *x*, velocity *y*)

$$\overline{y'x'} = \frac{\sum_{i=1}^{n} y_i x_i - \left(\overline{y} \cdot \overline{x}\right)}{n} = \sum_{0}^{n} \frac{(w' - \overline{w})(c' - \overline{c})}{n}$$

Eq. 6.19

Where, the overbar indicates a time average (*e.g.,* 30-min time period), primes indicate fluctuations from the mean. Note that block averaging is used.

Equation 6.20 below shows two terms (Terms I and II) that are respectively the turbulent (eddy covariance) and storage components of the measured flux. The storage term is the time derivative of the column integral of concentration. In practice, the shape of the concentration profile is determined from several individual inlets that are sampled sequentially. Where appropriate, in ecosystems with plant canopies > 0.5 in height, the flux is quantified using both terms. In plant canopies < 0.5 m in height only the turbulent term is used. NEE of CO_2 is then calculated by

$$NEE = \underbrace{\frac{\overline{w'c'}}{V}}_{I} + \underbrace{\int_{z_0}^{z_r} \frac{\partial [CO_2]}{\partial t} \partial z}_{II}$$

Eq. 6.20

where, *NEE* is the estimated carbon flux (μmol m^{-2} s^{-1}), $\overline{w'c'}$ is the measured covariance (m s^{-1} μmol C mol^{-1}), and V is the molar volume of air (mol m^{-3}). The change of CO_2 storage between the EC measurement height and the ground and is particularly important during the dusk and dawn transitions.

Product Number: Biogeochemistry_018 Sub-products: Biogeochemistry_018.1 Biogeochemistry_018.2 Biogeochemistry_018.3 Biogeochemistry_018.4 Biogeochemistry_018.5 Biogeochemistry_018.6	**Product Title:** Ecosystem exchange, map, AOP Biogeochemistry_018.1 = NEP Biogeochemistry_018.2 = GPP Biogeochemistry_018.3 = ER Biogeochemistry_018.4 = R_a Biogeochemistry_018.5 = R_h Biogeochemistry_018.6 = NPP		**Effort: D** **Priority: 5**
	Product Level: 4	**Temporal Resolution:** 0.5 hour	
	Replicates: 60	**Spatial Extent:** AOP Footprint	
	Replicated at: AOP Footprint	**Spatial Resolution:** 100 m	
Product Description: Primary Productivity is a basic indicator of ecosystem function. Merged AOP LiDAR/spectrometer data can be used to derive estimates of gross (GPP) and net primary productivity (NPP) (Asner, et al., 2007). These parameters are estimated using LAI, PRI, and canopy N retrievals that can be used to parameterize models such as PnET (Ollinger & Smith, 2005)and CASA-2 (Asner, et al., 2004). Models will be modified in a Bayesian framework to allow assimilation of tower flux data.			

Product Number: Biogeochemistry_019 Sub-products: Biogeochemistry_019.1 Biogeochemistry_019.2 Biogeochemistry_019.3 Biogeochemistry_019.4 Biogeochemistry_019.5 Biogeochemistry_019.6	**Product Title:** Ecosystem exchange of carbon, NEON Realm Biogeochemistry_019.1 = NEP Biogeochemistry_019.2 = GPP Biogeochemistry_019.3 = ER Biogeochemistry_019.4 = R_a Biogeochemistry_019.5 = R_h Biogeochemistry_019.6 = NPP		**Effort: E** **Priority: 5**
	Product Level: 4	**Temporal Resolution:** 1 day	
	Replicates: 1	**Spatial Extent:** NEON Realm	
	Replicated at: NEON Realm	**Spatial Resolution:** 1000 m	
Product Description: Ecosystem exchange of carbon is a key measure of productivity and ecosystem health. Understanding ecosystem carbon exchange at the regional and continental scale is required to diagnose the global carbon cycle where the present uptake of carbon is uncertain and the future uptake of carbon is difficult to predict. A NEON model will be developed to predict carbon exchange over the NEON Realm. The structure of the model is yet undefined however it should incorporate key features of modern ecosystem models including the effects of stand age (Desai, Moorcroft, Bolstad, & Davis, 2007; Moorcroft, Hurtt, & Pacala, 2001) and the ability to use satellite and aircraft remote sensing data as model forcings as is represented by the MODIS productivity products (Zhao, Heinsch, Nemani, & Running, 2005). The model also will have the capability to assimilate tower-based flux data. and will be designed to allow comparison with atmospheric CO_2 concentrations (adjusted for fossil fuel inputs and transport) in an ensemble Kalman-filter framework (e.g NOAA ESRL Carbon Tracker *c.f.* (Peters, et al., 2007); http://www.esrl.noaa.gov/gmd/ccgg/carbontracker/index.html). Predictions of the ecosystem fluxes will be compared to atmospheric CO_2 concentrations. See Biogeochemistry_024 and Biogeochemistry_027 for definition of the productivity components.			

<table>
<tr><td rowspan="4">Product Number: Biogeochemistry_020

Sub-products:
Biogeochemistry_020.1
Biogeochemistry_020.2
Biogeochemistry_020.3
Biogeochemistry_020.4
Biogeochemistry_020.5
Biogeochemistry_020.6</td><td colspan="2">Product Title: Net Primary Productivity
Biogeochemistry_020.1 = Total NPP
Biogeochemistry_020.2 = Above-ground NPP
Biogeochemistry_020.3 = Above-ground NPP, herbs
Biogeochemistry_020.4 = Above-ground NPP, shrubs
Biogeochemistry_020.5 = Above-ground NPP, trees
Biogeochemistry_020.6 = Below-ground NPP</td><td rowspan="4">Effort: A
Priority: 1</td></tr>
<tr><td>Product Level: 4</td><td>Temporal Resolution: 1 year</td></tr>
<tr><td>Replicates: 60</td><td>Spatial Extent: Site</td></tr>
<tr><td>Replicated at: Core and Relocatable sites</td><td>Spatial Resolution: 100 m</td></tr>
</table>

Product Description: The net primary production of terrestrial ecosystems represents the balance between carbon fixation in photosynthesis and carbon loss in plant respiration (Chapin III, et al., 2002; Sala, et al., 2000), or the rate of storage of organic matter in plant tissues in excess of the respiratory utilization by plants (Odum, 1971). In practical terms, net primary production can rarely be assessed in terms of this difference (Clark, et al., 2001; Gower, et al., 1999) as some components are very difficult to measure in the field due to their fast transformation, which involves a high-level of uncertainty, labor and costs. A large part of the NPP is allocated to measureable components as the production of foliage, wood, and root. However, NPP also includes a variety of components that are more difficult to measure (Luyssaert, et al., 2007), i.e., carbon lost by root exudation and/or transferred to mycorhhizae, carbon lost by herbivory, emitted as volatile organic compounds (VOC) and methane (CH4) (Chapin III, et al., 2002).

Practically, the *Net Primary Productivity* (NPP) can be defined as the annual net production of biomass (Gower, et al., 1999), representing the amount of new organic plant material produced and lost by the plants during the end of an interval, and the amount of material that is retained, stocked by the plants during the same interval (D. A. Clark, et al., 2001). In the field, NPP is calculated on measurements of stocks and changes (flux) of live and dead plant materials, and is expressed in units of dry mass per unit area per unit time (g m^{-2} yr^{-1} or kg ha^{-1} yr^{-1}).

In terrestrial ecosystems, large part of NPP is allocated to the production of biomass in different components, above- and below-ground. Aboveground and below-ground components are usually processed separately, and, if measurements for both components are available, Above-ground NPP and Below-ground NPP should be summed to provide *Total NPP* for the site.

To estimate NPP, a comparative sampling strategy will be applied across different ecosystem types, accounting for spatial-dependence of vegetation processes. As NEON encompass a range of ecosystems characterized by small individuals of relatively short lifespan (fast biomass turnover), ecosystems with large individuals of long lifespan (slow turnover), and intermediate ecosystems, a particular suite of field standard methods should be adopted to properly estimate each component of NPP (Fahey, 2007).

Above-ground NPP, herbs: The production of new organic tissue of the ground layer (herbs, forbs, grasses, bryophytes, and lichens) plus the amount of live tissue material that is retained during a time interval. It is calculated on measurements of stocks and changes of live and dead plant materials, and is expressed in units of dry mass per unit area per unit time (g m^{-2} yr^{-1} or kg ha^{-1} yr^{-1}).
Above-ground NPP, shrubs: The production of new organic tissue of shrubs plus the amount of live tissue

material that is retained during a time interval. It is calculated on measurements of stocks and changes of live and dead plant materials, and is expressed in units of dry mass per unit area per unit time (g m^{-2} yr^{-1} or kg ha^{-1} yr^{-1}).
Above-ground NPP, trees: The production of new organic tissue of trees plus the amount of live tissue material that is retained during a time interval. It is calculated on measurements of stocks and changes of live and dead plant materials, and is expressed in units of dry mass per unit area per unit time (g m^{-2} yr^{-1} or kg ha^{-1} yr^{-1}).

Below-ground NPP is estimated as the production on new roots (coarse and fine roots) and the production of mycorrhizae during a specific time interval. Any estimate of below-ground NPP (BNPP) requires an accounting of total root biomass, the percentage of living biomass and annual turnover of live roots. BNPP can be estimated from direct measurements of its components (production of fine and coarse roots) or from above-ground measurements using allometric methods (Fahey, 2007), expressed as g m^{-2} yr^{-1} or kg ha^{-1} yr^{-1}.

Product Number: Biogeochemistry_021 Sub-products:	**Product Title:** Ecosystem water use efficiency (GPP/Tr)		**Effort: A** **Priority: 1**
	Product Level: 4	**Temporal Resolution:** 1 day	
	Replicates: 60	**Spatial Extent:** Point	
	Replicated at: Advanced Towers	**Spatial Resolution:** NA	

Product Description: Ecosystem water use efficiency is used to compare across ecosystems or across time. Ecosystems with high water use efficiency are more resistant to drought. The product is a simple ratio of GPP (Biogeochemistry_019) to transpiration (Ecohydrology_007).

Product Number: Biogeochemistry_022 Sub-products:	**Product Title:** Ecosystem Light use efficiency (GPP/iPAR)		**Effort: A** **Priority: 1**
	Product Level: 4	**Temporal Resolution:** 1 day	
	Replicates: 60	**Spatial Extent:** Point	
	Replicated at: Advanced towers	**Spatial Resolution:** NA	

Product Description: Ecosystem light use efficiency is used to compare across ecosystems or across time. Ecosystems with high light use efficiency are more productive under low light conditions. The product is a simple ratio of GPP (Biogeochemistry_019) to iPAR. iPAR, the intercepted PAR is a product of fPAR (Biogeochemisty_018) times PAR, a basic measurement.

<table>
<tr><td rowspan="4">Product Number:
Biogeochemistry_023

Sub-products:
Biogeochemistry_023.1
Biogeochemistry_023.2
Biogeochemistry_023.3
Biogeochemistry_023.4
Biogeochemistry_023.5
Biogeochemistry_023.6</td><td colspan="2">Product Title: Litterfall
Biogeochemistry_023.1 = Litter C Flux
Biogeochemistry_023.2 = Litter N Flux
Biogeochemistry_023.3 = Litter K Flux
Biogeochemistry_023.4 = Litter P Flux
Biogeochemistry_023.5 = Litter Ca Flux
Biogeochemistry_023.6 = Litter Mg Flux</td><td rowspan="4">Effort: A
Priority: 1</td></tr>
<tr><td>Product Level: 4</td><td>Temporal Resolution: 1 year</td></tr>
<tr><td>Replicates: 60</td><td>Spatial Extent: Site</td></tr>
<tr><td>Replicated at: Core and Relocatable sites</td><td>Spatial Resolution: 100 m</td></tr>
</table>

Product Description: Litterfall represents one of the major processes for transferring nutrients from above-ground vegetation to soils (Vitousek, 1982). Quantitative aspects of litterfall has been frequently investigated to provide an index of production (Proctor, 1983) and to quantify nutrient concentration and flux, a measure of the efficiency of cycling processes (Vitousek, 1982). Litterfall represents the shedding of above-ground plant parts (Chapin III, et al., 2002). The small (or fine) litterfall consist of parts of leaves, flowers, fruits, woody fraction (< 2 cm diameter) and very small parts of different organisms (Proctor, 1983). When combined with *litter standing stock measurements* (the quantity of litter remaining on the ground), it can provide good information about *decomposition rates** (Proctor, 1983).

Litterfall production (or flux) is usually estimated as mass of litter in units of area in annual basis ($g\ m^{-2}\ y^{-1}$ or $t\ ha^{-1}\ yr^{-1}$). Litterfall collected in one year by litter traps is analyzed for the principal elements (C, N, K, P, Ca, and Mg) to calculate mean nutrient concentration (litter mass/litter mineral element concentration), and the n*utrient flux by litterfall,* which is expressed in $kg\ ha^{-1}\ yr^{-1}$.

* The *decomposition quotient (K_L)* estimates the proportion of small litter layer decomposed in one year and is calculated as: $(K_L) = I/X$, where I is the annual litter input to the forest vegetation floor ($g\ m^{-2}\ year^{-1}$ or $t\ ha^{-1}\ year^{-1}$), and X is the mean litter standing crop ($g\ m^{-2}$ or $t\ ha^{-1}$). The value of K_L is an approximation to the proportion of the litter standing crop decomposed in one year (Olsen, 1963). If K_L is greater than 1, the turnover of the litter layer occurs in a year or less. The litter standing crop on the vegetation floor is usually determined by taking periodic samples paired with the litterfall traps.

<table>
<tr><td rowspan="4">Product Number:
Biogeochemistry_024

Sub-products:
Biogeochemistry_024.1
Biogeochemistry_024.2
Biogeochemistry_024.3
Biogeochemistry_024.4
Biogeochemistry_024.5
Biogeochemistry_024.6</td><td colspan="2">Product Title: Litter Turnover (Stock/Flux)
Biogeochemistry_024.1 = Litter C Turnover
Biogeochemistry_024.2 = Litter N Turnover
Biogeochemistry_024.3 = Litter P Turnover
Biogeochemistry_024.4 = Litter K Turnover
Biogeochemistry_024.5 = Litter Ca Turnover
Biogeochemistry_024.6 = Litter Mg Turnover</td><td rowspan="4">Effort : A
Priority : 1</td></tr>
<tr><td>Product Level: 4</td><td>Temporal Resolution: 1 year</td></tr>
<tr><td>Replicates: 60</td><td>Spatial Extent: Site</td></tr>
<tr><td>Replicated at: Core and Relocatable sites</td><td>Spatial Resolution: 100 m</td></tr>
<tr><td colspan="4">Product Description: Litter turnover represents the ratio of the flux of elements (nutrient flux by litterfall) to the pool size (nutrient litter standing stocks). Chemical analysis of litter standing stocks* and litterfall production will provide important features about nutrient turnover in this compartment. The turnover time represents the average time an element spends in a system (pool/input; residence time) (Chapin III, et al., 2002).

*Litter standing stocks (the quantity of litter remaining on the ground) is usually determined as mass of litter in units of area (g m^{-2} or t ha^{-1}), estimated by taking periodic ground samples paired with the litterfall traps. The material collected in one year should be analyzed for the principal elements (C, N, K, P, Ca, and Mg) to calculate the nutrient concentration (litter standing stock mass/mineral element concentration).</td></tr>
</table>

<table>
<tr><td rowspan="4">Product Number:
Biogeochemistry_025

Sub-products:
Biogeochemistry_025.1
Biogeochemistry_025.2
Biogeochemistry_025.3
Biogeochemistry_025.4
Biogeochemistry_025.5
Biogeochemistry_025.6</td><td colspan="2">Product Title: Stream carbon flux
Biogeochemistry_025.1 = Summed C flux
Biogeochemistry_025.2 = DIC Flux
Biogeochemistry_025.3 = DOC Flux
Biogeochemistry_025.4 = TIC Flux
Biogeochemistry_025.5 = TOC Flux
Biogeochemistry_025.6 = POC Flux</td><td rowspan="4">Effort: A
Priority: 1</td></tr>
<tr><td>Product Level: 4</td><td>Temporal Resolution: 1 year</td></tr>
<tr><td>Replicates: 30</td><td>Spatial Extent: Point samples</td></tr>
<tr><td>Replicated at: Aquatic array sites (streams)</td><td>Spatial Resolution: NA</td></tr>
<tr><td colspan="4">Product Description: Aquatic ecosystems integrate terrestrial changes across the landscape and as such are ideal systems to investigate variation in biogeochemical cycles along a continental gradient (McGroddy, Baisden, & Hedin, 2008). Erosion of headwater streams due to change in landuse or climate can alter national carbon budgets (Scott, et al., 2006).

Carbon flux will be calculated from biweekly water sample collections using regression (Runkel, Crawford, & Cohn, 2004) and composite (Aulenbach & Hoopert, 2006) flux estimation models, which estimate continuous nutrient concentrations between sample dates. Data will be presented on an annual basis.</td></tr>
</table>

Product Number: Biogeochemistry_026 Sub-products: Biogeochemistry_026.1 Biogeochemistry_026.2 Biogeochemistry_026.3 Biogeochemistry_026.4 Biogeochemistry_026.5	**Product Title:** Stream nitrogen flux Biogeochemistry_026.1 = Total N Flux Biogeochemistry_026.2 = TDN Flux Biogeochemistry_026.3 = NO3+NO2 Flux Biogeochemistry_026.4 = NH4 Flux Biogeochemistry_026.5 = DON Flux		**Effort: A** **Priority: 1**
	Product Level: 4	**Temporal Resolution:** 1 year	
	Replicates: 30	**Spatial Extent:** Point samples	
	Replicated at: Aquatic array sites (streams)	**Spatial Resolution:** NA	
Product Description: Aquatic ecosystems integrate terrestrial changes across the landscape and as such are ideal systems to investigate variation in biogeochemical cycles along a continental gradient (McGroddy, et al., 2008). Stream ecosystems transport ~25% of the total nitrogen budget from terrestrial ecosystems to terminal freshwater and ocean environments (Boyer, et al., 2006). Nitrogen flux will be calculated from biweekly water sample collections using regression (Runkel, et al., 2004) and composite (Aulenbach & Hoopert, 2006) flux estimation models, which estimate continuous nutrient concentrations between sample dates. Data will be presented on an annual basis.			

Product Number: Biogeochemistry_027 Sub-products: Biogeochemistry_027.1 Biogeochemistry_027.2	**Product Title:** Stream phosphorus flux Biogeochemistry_027.1 = Total P Flux Biogeochemistry_027.2 = Soluble reactive P Flux		**Effort: A** **Priority: 1**
	Product Level: 4	**Temporal Resolution:** 1 year	
	Replicates: 30	**Spatial Extent:** Point samples	
	Replicated at: Aquatic array sites (streams)	**Spatial Resolution:** NA	
Product Description: Streams integrate terrestrial changes across the landscape and as such are ideal systems to investigate variation in biogeochemical cycles along a continental gradient (McGroddy, et al., 2008). Shifts in phosphorous availability due to changes in land-use or climate can alter aquatic ecosystem structure and function (Lampert & Sommer, 2007). Phosphorous flux will be calculated from biweekly water sample collections using regression (Runkel, et al., 2004) and composite (Aulenbach & Hoopert, 2006) flux estimation models, which estimate continuous nutrient concentrations between sample dates. Data will be presented on an annual basis.			

Product Number: Biogeochemistry_028 Sub-products: Biogeochemistry_028.1 Biogeochemistry_028.2 Biogeochemistry_028.3 Biogeochemistry_028.4	**Product Title:** Stream metabolism Biogeochemistry_028.1 = Stream photosynthesis Biogeochemistry_028.2 = Stream respiration Biogeochemistry_028.3 = Stream photosynthesis (STREON) Biogeochemistry_028.4 = Stream respiration (STREON)		**Effort: B** **Priority: 1**
	Product Level: 4	**Temporal Resolution:** 1 year	
	Replicates: 30 (AQU) + 10 (STR)	**Spatial Extent:** Stream reach	
	Replicated at: Aquatic array sites (streams)	**Spatial Resolution:** NA	

Product Description: Headwater streams are key areas of nutrient retention and processing, yet little is known about stream metabolism (production and respiration) due to the short duration of most research on small streams (Roberts, Mulholland, & Hill, 2007). NEON will measure stream metabolism using dissolved oxygen –re-aeration techniques (Bott, 1996; Marzolf, Mulholland, & Steinman, 1994; Mulholland, et al., 2001) at a continental scale.

Stream metabolism includes the analysis of whole ecosystem gross primary production (GPP), respiration (R), and net ecosystem production (NEP), which are presented in g O_2 m^{-2} d^{-1}.

For STREON (~10 locations) there will be data products for both NEON control and STREON treatment reach.

Product Number: Biogeochemistry_029 Sub-products: Biogeochemistry_029.1 Biogeochemistry_029.2 Biogeochemistry_029.3 Biogeochemistry_029.4 Biogeochemistry_029.5 Biogeochemistry_029.6 Biogeochemistry_029.7	**Product Title:** Nutrient uptake and trace gas dynamics in the STREON experiment Biogeochemistry_029.1 = Uptake rate in +consumer basket Biogeochemistry_029.1 = Uptake rate in –consumer baskets Biogeochemistry_029.3 = Nitrous oxide Biogeochemistry_029.4 = Methane Biogeochemistry_029.5 = Argon Biogeochemistry_029.6 = Nitrogen:Argon ratio Biogeochemistry_029.7 = Hydrogen sulfide		**Effort: A** **Priority: 1**
	Product Level: 4	**Temporal Resolution:** 1 year	
	Replicates: 10	**Spatial Extent:** STREON locations	
	Replicated at: Aquatic array sites (streams)	**Spatial Resolution:** NA	

Product Description: Nutrient uptake will be measured in the experiment baskets during a minimum 8-hour incubation in a closed chamber. Baskets will be injected with a ^{15}N tracer and measured at discrete time intervals in the chamber water and in the algae at the end of the incubation period. The amount of ^{15}N tracer in algae over time is a measure of nutrient uptake. This data product will calculate nutrient uptake rates in experimental baskets with and without top-level consumers.

Trace gas dynamics will be quantified between a control (AQU site) and treatment (STR site) reach. Trace gas concentrations will be used to identify and where possible quantify rates for key anaerobic biogeochemical processes such as methanogenesis and denitrification.

Product Number: Biogeochemistry_030 Sub-products:	**Product Title:** Lake Biogeochemical Dynamics		**Effort: A** **Priority: 1**
	Product Level: 4	**Temporal Resolution:** 1 year	
	Replicates: **6**	**Spatial Extent:** Lake or pond	
	Replicated at: Lakes and ponds	**Spatial Resolution:** NA	

Product Description: Aquatic ecosystems integrate terrestrial changes across the landscape and as such are ideal systems to investigate variation in biogeochemical cycles along a continental gradient (McGroddy, Baisden, & Hedin, 2008). Small ponds and lakes often act as a sink for nutrients, sediment, and runoff from the surrounding watershed.

Lake biogeochemical dynamics will be measured from monthly water sample collections and *in situ* instruments in ponds and lakes and from surrounding sub-surface wells. For example, seasonal changes in water temperature, nitrogen and phosphorous content (constituents known to exhibit rapid response to environmental change) will be assessed. Seasonal data will be summarized on an annual basis for each site.

8 ECOHYDROLOGY DATA PRODUCTS

The ecohydrology suite contains 10 high-level data products that derive mainly from lower level data on from the FIU airshed and watershed based measurements. Measurements at the scale of the soil-survey and AOP sub-regions and the NEON realm will be spatially extrapolated with geographic data and remote sensing products. The products in this category traces directly to the climate change and ecohydrology NEON challenge areas. They relate to the tightly coupled water and energy exchange between the ecosystem and the atmosphere or the complex of hydrology and geomorphological controls over aquatic environments. NEON will invest heavily in two products that quantify. First a soil moisture product of national extent will be used to enable model initialization, calibration, and validation (Ecohydrology_003). Second a related national model of water balance (Ecohydrology_006) will be implemented together with ecosystem carbon exchange (Biogeochemistry_019). These two products are critical to enabling forecasting of the effects of future climate change effects on vegetation.

<table>
<tr><td rowspan="4">Product Number:
Ecohydrology_001

Sub-products:
Ecohydrology_001.1
Ecohydrology_001.2
Ecohydrology_001.3</td><td colspan="2">Product Title: Soil Moisture
Ecohydrology_001.1 = Soil moisture content
Ecohydrology_001.2 = Soil water potential
Ecohydrology_001.3 = Plant available water</td><td rowspan="4">Effort: A
Priority: 1</td></tr>
<tr><td>Product Level: 4</td><td>Temporal Resolution: 0.5 hour</td></tr>
<tr><td>Replicates: 60</td><td>Spatial Extent: Point</td></tr>
<tr><td>Replicated at: Soil arrays</td><td>Spatial Resolution: NA</td></tr>
<tr><td colspan="4">Product Description: Soil moisture is a basic ecosystem property that regulates and is regulated by the activity of plants and soil microorganisms. Soil moisture content will be measured using time or frequency domain reflectometry probes that are sensitive to the change in soil dielectric content. Dielectric content correlates closely with water content, and will be calibrated to each site specific condition and soil (Weitz, Grauel, Keller, & Veldkamp, 1997). Soil moisture content will be expressed three different ways:

Volumetric moisture content (unitless) = Volume of water per volume of soil
Water potential (kPa) = Formally, this is the sum of matric, osmotic, and pressure potential components. Where solute concentrations are relatively constant and where soils are not flooded, the water potential depends mainly on the matric potential. Pressure-volume curves determined during soil characterization will allow us to empirically convert volumetric water content to water potential.
Plant available water (mm) = Plant available water (PAW) will be defined as the difference between soil water potential and permanent wilting point (PWP) integrated through the soil column. Generally, the PWP is defined as -1500 kPa although this may need to be adjusted according to site properties (Jenny, 1980).

Volumetric water content and water potential will be reported by soil layer. Volumetric water content and plant available water will be integrated through the soil profile.</td></tr>
</table>

Product Number: Ecohydrology_002 Sub-products: Ecohydrology_002.1 Ecohydrology_002.2 Ecohydrology_002.3	**Product Title:** Soil moisture (sub-region map) Ecohydrology_002.1 = Soil moisture content sub-region map Ecohydrology_002.2 = Soil water potential sub-region map Ecohydrology_002.3 = Plant available water sub-region map		**Effort: D** **Priority: 4**
	Product Level: 4	**Temporal Resolution:** 0.5 hour	
	Replicates: 60	**Spatial Extent:** Soil survey sub-region	
	Replicated at: Core and relocatable sites soil mapping regions	**Spatial Resolution:** 100 m	
Product Description: Soil moisture (as defined in Ecohydrology_001) will be mapped across the soil survey sub-region for each NEON site by using pedo-transfer functions relating mapped soil classification and geomorphic properties to known moisture contents at measurements sites (Ecohydrology_001) (Pachepsky & Rawls, 2004). High frequency point measurements of soil moisture from soil arrays can be used to predict moisture across the region in a state-space model solved using Markov Chain Monte Carlo methods (Dowd, 2007; Harrison & Stevens, 1976; Sierra, et al., 2008).			

Product Number: Ecohydrology_003 Sub-products: Ecohydrology_003.1 Ecohydrology_003.2 Ecohydrology_003.3	**Product Title:** Soil moisture (NEON Realm map) Ecohydrology_003.1 = Soil moisture content NEON realm map Ecohydrology_003.2 = Soil water potential NEON realm map Ecohydrology_003.3 = Plant available water NEON realm map		**Effort: E** **Priority: 5**
	Product Level: 4	**Temporal Resolution:** 1 day	
	Replicates: 1	**Spatial Extent:** NEON Realm	
	Replicated at: NEON Realm	**Spatial Resolution:** 1000 m	
Product Description: Soil moisture (as defined in Ecohydrology_001) will be mapped across the NEON Realm by using pedo-transfer functions relating mapped soil classification and geomorphic properties to known moisture contents at measurements sites (Ecohydrology_001) (Pachepsky & Rawls, 2004). High frequency point measurements of soil moisture from soil arrays will be assimilated into the ecosystem water balance model (Ecohydrology_005) to predict soil moisture.			

Product Number: Ecohydrology_004 Sub-products: Ecohydrology_004.1 Ecohydrology_004.2 Ecohydrology_004.3 Ecohydrology_004.4 Ecohydrology_004.5 Ecohydrology_004.6	**Product Title:** Water Balance Ecohydrology_004.1 = Evapotranspiration (see latent heat flux) Ecohydrology_004.2 = Transpiration Ecohydrology_004.3 = Evaporation Ecohydrology_004.4 = Precipitation Ecohydrology_004.5 = Throughfall Ecohydrology_004.6 = Runoff + Storage		**Effort: C** **Priority: 3**
	Product Level: 4	**Temporal Resolution:** 0.5 hour	
	Replicates: 60	**Spatial Extent:** Point	
	Replicated at: Advanced Towers	**Spatial Resolution:** NA	

Product Description: Evapotranspiration will be partitioned into ecosystem-level transpiration and evaporation using two methods, i) real-time empirical eddy covariance measured ET (applying unit conversions to λE estimates) constrained by vertical array of leaf wetness sensors (sensitive to both condensation and intercepted water) and laser-based δO^{18} –H_2O values, and ii) modeled using the Penman-Monteith equation (Monteith & Unsworth, 1990) and other empirically measured physical quantities,

$$\lambda E_{pm} = \frac{\Delta R_n + \rho_a C_p [e_s(T_a) - e_a(T_a)] g_a}{[\Delta + \gamma(1 + \frac{g_a}{g_b})] f} \qquad \text{Eq. 7.01}$$

where λE_{pm} is latent energy flux (W m^{-2}), Δ is the is the rate of increase in saturated water vapor pressure with temperature (kPa K^{-1}), e_s is the saturated water vapor pressure at T_a, e_a is the actual ambient water vapor pressure (kPa), g_a is the aerodynamic conductance (mol m^{-2} s^{-1}), λ is the latent heat of vaporization (J kg^{-1}), γ is the psychrometric constant at 25 ºC (0.0665 kPa K^{-1}), g_b is the bulk canopy conductance (mol m^{-2} s^{-1}). To change units of energy to depth, λE_{pm} was multiplied by a conversion factor that included molar volume (V, mol m^{-3}) and the molar weight of water (kg mol^{-1}). The use of the notation λE denotes energy flux (W m^{-2}), and ET, water depth (mm per unit time), hence evapotranspiration depth estimated by Eq X is noted as ET_{pm}.

Throughfall (the amount of liquid water that *falls through* the plant canopy during a precipitation event, mm) will also be estimated by a series of collectors at each soil array, as well as bulk precipitation (mm) at each tower location.

To determine annual ET, and the evaporation of intercepted water by the canopy will be modeled using a Rutter-type model (Calder, I.R., & Murdiyaso, 1986; Loescher, et al., 2006).

$$C = C_{max}[1 - \exp^{-k_i \frac{\sum precip}{C_{max}}}] \qquad \text{Eq. 7.02}$$

Canopy water storage increases exponentially and asymptotically with precipitation to a maximum capacity (C_{max}, mm), and will be estimated at each site during site characterization. $\sum precip$ is the cumulative depth of bulk precipitation that has fallen in any one event (mm). The rate by which the canopy filled with water will be estimated by a unitless fill constant, k_i (e.g., a value of 0.28 is commonly used for broadleaf forests). The stemflow component of interception will be ignored because it is assumed to be a small volumetric flux, i.e., < 2% of bulk precipitation (Neal, et al., 1993; Schroth, da Silva, Wolf, Teixeira, & Zech, 1999). If the amount of free canopy water is less than the amount of modeled ET_{pm}, then the remainder of canopy free water was modeled as transpiration (g_b > 0) not evaporation (i.e., setting g_a/g_b in the denominator of Eq. X to zero, cf. (Bigelow, 2001; Ubarana, 1996), and provides the constraint to separate evaporation from transpiration in any time series.

Runoff + Storage will be estimated by the difference between ET and bulk precipitation.

Product Number: Ecohydrology_005 Sub-products: Ecohydrology_005.1 Ecohydrology_005.2 Ecohydrology_005.3 Ecohydrology_005.4 Ecohydrology_005.5	**Product Title:** Water balance (sub-region map) Ecohydrology_005.1 = Evapotranspiration Ecohydrology_005.2 = Transpiration Ecohydrology_005.3 = Evaporation Ecohydrology_005.4 = Runoff + Storage Ecohydrology_005.5 = Precipitation		**Effort: D** **Priority: 4**
	Product Level: 4	**Temporal Resolution:** 0.5 hour	
	Replicates: 60	**Spatial Extent:** Soil survey sub-region	
	Replicated at: Core and relocatable sites soil mapping regions	**Spatial Resolution:** 100 m	
Product Description: Water balance components (as defined in Ecohydrology_004) will be mapped across the AOP sub-regions by extrapolation from high frequency point measurements of water balance components. These data will used together with vegetation characteristics from the AOP and soil characteristics from regional survey in a state-space model solved using Markov Chain Monte Carlo methods (Dowd, 2007; Harrison & Stevens, 1976; Sierra, et al., 2008) in order to predict water balance components across the approximate 20 km x 20 km maximum) AOP sub-regions.			

Product Number: Ecohydrology_006 Sub-products: Ecohydrology_006.1 Ecohydrology_006.2 Ecohydrology_006.3 Ecohydrology_006.4 Ecohydrology_006.5	**Product Title:** Water Balance (NEON Realm map) Ecohydrology_006.1 = Evapotranspiration Ecohydrology_006.2 = Transpiration Ecohydrology_006.3 = Evaporation Ecohydrology_006.4 = Runoff + Storage Ecohydrology_006.5 = Precipitation		**Effort: E** **Priority: 5**
	Product Level: 4	**Temporal Resolution:** 1 day	
	Replicates: 1	**Spatial Extent:** NEON Realm	
	Replicated at: NEON Realm	**Spatial Resolution:** 1000 m	

Product Description: Ecosystem exchange of water is both a forcing and response in the coupled vegetation atmosphere system. Understanding ecosystem water at the regional and continental scale is required to diagnose the global carbon cycle and the global water cycle. A NEON model will be developed to predict carbon, water, and energy exchange over the NEON Realm (see also Biogeochemistry_026). The structure of the model is yet undefined however it should incorporate key features of modern ecosystem models including the effects of stand age (Desai, et al., 2007; Moorcroft, et al., 2001) and the ability to use satellite and aircraft remote sensing data as model forcings as is represented by the MODIS evapotranspiration products (Mu, Heinsch, Zhao, & Running, 2007). The model also will have the capability to assimilate tower-based flux data.

Product Number: Ecohydrology_007 Sub-products:	**Product Title:** Potential Evapotranspiration (Towers)		**Effort: A** **Priority: 1**
	Product Level: 4	**Temporal Resolution:** 0.5 hour	
	Replicates: 60	**Spatial Extent:** Point	
	Replicated at: Advanced Towers	**Spatial Resolution:** NA	

Product Description: Potential evapotranspiration (PET) estimates the total evapotranspiration from the ecosystem surface through the processes of evaporation and transpiration assuming an unlimited supply of water. PET will be modeled assuming an unlimited supply of water using the Priestly-Taylor equation because of its simplicity and minimal data requirements (Stannard, 1993).

Product Number: Ecohydrology_008 Sub-products:	**Product Title:** Potential Evapotranspiration (NEON Realm map)		**Effort: D** **Priority: 3**
	Product Level: 4	**Temporal Resolution:** 1 day	
	Replicates: 1	**Spatial Extent:** NEON Realm	
	Replicated at: NEON Realm	**Spatial Resolution:** 1000 m	

Product Description: Potential evapotranspiration (PET) estimates the total evapotranspiration from the ecosystem surface through the processes of evaporation and transpiration assuming an unlimited supply of water. PET will be modeled assuming an unlimited supply of water using the Priestly-Taylor equation because of its simplicity and minimal data requirements (Stannard, 1993).

Product Number: Ecohydrology_009	**Product Title:** Stream discharge regime		**Effort: A**
Sub-products:	**Product Level:** 4	**Temporal Resolution:** 1 year	**Priority: 1**
	Replicates: 30	**Spatial Extent:** Core & relocatable aquatic sites	
	Replicated at: Stream reaches (gauges)	**Spatial Resolution:** NA	

Product Description: A suite of hydrologic indices that are of biological relevance (Poff, et al., 1997; Richter, Baumgartner, Powell, & Braun, 1996) will be measured at stream gauging stations and calculated at scales of days, weeks, months, and years where appropriate (Olden & Poff, 2003). Discharge data will be calculated from stream gauging stations.

The discharge (Q) characteristics that included are maximum and minimum discharge(Q_{max}, Q_{min}), mean daily discharge (Q_{daily}), the skew of daily Q (ratio of 10th/90th, 20th/80th and 25th/75th of Q_{daily} percentiles), the coefficient of variation of daily Q, discharge flashiness (average daily change in Q / annual mean Q (Sanborn & Bledsoe, 2006), discharge duration (magnitude of minimum and maximum annual Q of various duration), predictability of low and high Q events (proportion of low- and high- Q events ≥5-year magnitude falling in a 60-day 'seasonal' window), and the rate of change in Q (mean rate of positive, negative, and no changes in Q from one day to the next).

Product Number: Ecohydrology_010	**Product Title:** Stream and lake morphology dynamics		**Effort: B**
Sub-products:	**Product Level:** 4	**Temporal Resolution:** 1 to 5 years	**Priority: 5**
	Replicates: 36	**Spatial Extent:** Core and relocatable aquatic sites	
	Replicated at: Core and relocatable aquatic sites	**Spatial Resolution:** NA	

Product Description: Changes in stream and lake morphology occur when water flow or land-use is altered. Variation in habitat morphology may alter ecosystem structure and function (Allan, 1995). Field measured data will be combined with available information from LUAP and AOP to assess changes in stream and lake morphology.

Stream morphology parameters will include alteration of stream banks, exposed bars, width, depth, pool-riffle complexes, and large woody debris will be assessed on a yearly basis and after extreme flow and geologic events.

Lake morphology parameters will include changes in lake depth, maximum width, fetch, bank and littoral zone morphology, inlet and outlet stream locations, and water residence time. Lake morphology will be assessed every five years and after extreme flow and geologic events.

9 INFECTIOUS DISEASE DATA PRODUCTS

High-level data products in the infectious disease suite derive mainly from lower level data from the FSU. These products summarize the low level data and provide views of the variation in disease prevalence in space and time. This category traces directly to the infectious disease NEON challenge areas. In contrast, to other data product suites the NEON investment in complex models or regional extrapolations is minimal.

Product Number: Disease_001 Sub-products:	**Product Title:** West Nile Virus (WNV) prevalence in mosquitoes		**Effort: A** **Priority: 1**
	Product Level: 4	**Temporal Resolution:** monthly	
	Replicates: 60	**Spatial Extent:** Sites	
	Replicated at: Core and relocatable sites	**Spatial Resolution:** NA	
Product Description: Prevalence is the proportion of samples screened for disease that are positive. Mosquitoes (*Culex* species) collected in traps will be pooled for analysis of West Nile Virus using molecular methods (real-time PCR) to maximize efficiency and reduce costs. Statistical methods using maximum likelihood estimation to produce estimates of prevalence (also referred to as infection rate) in pooled samples with confidence intervals have been developed for use with viral pathogens vectored by mosquitoes (Condotta, Hunter, & Bidochka, 2004; Hepworth, 2005).			

Product Number: Disease_002 Sub-products:	**Product Title:** Dengue prevalence in mosquitoes		**Effort: A** **Priority: 1**
	Product Level: 4	**Temporal Resolution:** monthly	
	Replicates: 24	**Spatial Extent:** Sites (Southern domains)	
	Replicated at: Domains 2,3,4,8,11,14,17,20	**Spatial Resolution:** NA	
Product Description: Prevalence is the proportion of samples screened for disease that are positive. Mosquitoes (*Aedes* species) collected in traps will be pooled for analysis of dengue using molecular methods (real-time PCR) to maximize efficiency and reduce costs. Statistical methods using maximum likelihood estimation to produce estimates of prevalence (also referred to as infection rate) in pooled samples with confidence intervals have been developed for use with viral pathogens vectored by mosquitoes (Condotta, et al., 2004; Hepworth, 2005).			

Product Number: Disease_003 Sub-products: Disease_003.1 Disease_003.2	**Product Title:** Mosquito borne disease distribution map Disease_003.1: West Nile Virus distribution Disease_003.2: Dengue distribution		**Effort: B** **Priority: 3**
	Product Level: 4	**Temporal Resolution:** seasonal	
	Replicates: 1	**Spatial Extent:** Core and Relocatable sites	
	Replicated at: NEON Realm	**Spatial Resolution:** NA	
Product Description: A distribution map for West Nile Virus and Dengue will display an interactive graphic locating all of the core and relocatable sites. The graphic will not include data interpolation between sites. The interactive map will allow users to select diseases of interest and examine their prevalence across the observatory at specified time intervals. This map will provide users with a visual interface to quickly look for patterns of expansion or contraction of disease presence across sites at various time scales, using data from data products Disease_001 and Disease_002.			

Product Number: Disease_004 Sub-products:	**Product Title:** Hantavirus prevalence in deer mice		**Effort: A** **Priority: 1**
	Product Level: 4	**Temporal Resolution:** seasonal	
	Replicates: 60	**Spatial Extent:** Sites	
	Replicated at: Core and relocatable sites	**Spatial Resolution:** NA	
Product Description: Prevalence is the proportion of host individuals screened for disease that are positive. Up to 90 individual deer mice (*Peromyscus maniculatus*) will be screened for hantavirus antibodies per site per year, for sites where deer mice are found. Hantavirus prevalence is positively correlated with host density, see data product Biodiversity_005 (Madhav, et al., 2007).			

Product Number: Disease_005 Sub-products:	**Product Title:** Hantavirus distribution maps		**Effort: B** **Priority: 3**
	Product Level: 4	**Temporal Resolution:** seasonal	
	Replicates: 1	**Spatial Extent:** Sites	
	Replicated at: NEON Realm	**Spatial Resolution:** NA	
Product Description: A hantavirus distribution map will display an interactive graphic of a map locating all of the core and relocatable sites. The graphic will not include data interpolation between sites. The interactive map will allow users to examine hantavirus prevalence as well as human risk for hantaviral pulmonary syndrome across the observatory at specified time intervals. This map will provide users with a visual interface to quickly look for patterns of expansion or contraction of disease presence and risk across sites at various time scales, using data from data product Disease_004.			

Product Number: Disease_006 Sub-products:	**Product Title:** Lyme disease prevalence in *Peromyscus*		**Effort: A** **Priority: 1**
	Product Level: 4	**Temporal Resolution:** seasonal	
	Replicates: 60	**Spatial Extent:** Sites	
	Replicated at: Core and relocatable sites	**Spatial Resolution:** NA	
Product Description: Prevalence is the proportion of host individuals screened for disease that are positive. Up to 90 individual white-footed mice (*Peromyscus leucopus*) will be screened for *Borrelia burdorferi* (Lyme disease pathogen) antibodies per site per year, for sites where white-footed mice are found. *Borrelia burgdorferi* prevalence is positively correlated with host density, see data product Biodiversity_005 (Schauber, Ostfeld, & Evans, 2005).			

Product Number: Disease_007 Sub-products:	**Product Title:** Lyme disease distribution map		**Effort: B** **Priority: 3**
	Product Level: 4	**Temporal Resolution:** seasonal	
	Replicates: 1	**Spatial Extent:** Sites	
	Replicated at: NEON Realm	**Spatial Resolution:** NA	
Product Description: A Lyme disease distribution map will display an interactive graphic of a map locating all of the core and relocatable sites. The graphic will not include data interpolation between sites. The interactive map will allow users to examine prevalence of *Borrelia burgdorferi* in small mammals as well as human risk for Lyme disease across the observatory at specified time intervals. This map will provide users with a visual interface to quickly look for patterns of expansion or contraction of disease presence and risk across sites at various time scales, using data from data product Disease_006.			

10 LAND USE DATA PRODUCTS

High-level data products in the land use suite trace directly to the land use change NEON challenge area and support discovery and modeling in all of the other NEON challenge areas. The selection of outside data includes basic environmental properties (e.g. elevation, soil classification, and historical climate) and the resulting land expressions of climate and human activity (e.g. land cover classification). All of the products are selected carefully to enable analysis, modeling, and forecasting. Data will be presented at a limited number of regular time intervals (1, 5 or 10 years) and on consistent map projections using a regular grid of (10, 30, 100 or 1000 m) dependent upon the product. For products covering the full NEON Realm, this implies the need to carefully downscale existing data to the 9.6 x 10^6 grid cells of 1 km^2 area chosen for consistency with present and future satellite data products.

Most of the high-level land use suite data products are derived from outside sources including much information from government agencies such as the USGS, USDA, and NOAA. The data sources listed, while a good representation of the present state of our knowledge, will be exhaustively reviewed prior to construction.

There are relatively few data products in the land use suite that require large investments by NEON. The two important exceptions the data products mapping historical land cover classification and historical population. While historical data exist for both categories, building data sets that use consistent definitions across historical time will require a large development effort. This data is critical to development of ecological models both for hindcasting efforts to validate models and for analyzing and understanding important ecological legacies resulting from historical land use.

Product Number: Land_Use_001 Sub-products:	**Product Title:** Elevation		**Effort: A** **Priority: 1**
	Product Level: 4	**Temporal Resolution:** NA	
	Replicates: 1	**Spatial Extent:** NEON Realm	
	Replicated at: NEON Realm	**Spatial Resolution:** 30 m	
Product Description: The elevation of any geographic point is its height relative to a defined reference point such as mean sea level (MSL). Elevations are reported in meters MSL. The World Geodetic System 84 (WGS84) geoid will be used to define mean sea level. The National Elevation Dataset (NED) is a candidate digital elevation model (DEM) for use in NEON data products.. The USGS National Elevation Dataset (NED), a mosaic of 7.5-minute elevation data for the United States. The NED is available at both 1 arc second (30 meter) and 1/3 arc second (10 meter) data resolutions. For the conterminous United States, both versions use a geographic coordinate system with a horizontal datum of NAD83 and a vertical datum of NAVD88. Alaska uses NAD27 for the horizontal datum and NAVD29 for the vertical datum.			

Product Number: Land_Use_002 Sub-products:	**Product Title:** Elevation		**Effort: C** **Priority: 2**
	Product Level: 4	**Temporal Resolution:** NA	
	Replicates: 60	**Spatial Extent:** AOP Sub-region	
	Replicated at: Core and relocatable sites	**Spatial Resolution:** 10 m	
Product Description: AOP will provide bare earth elevation data (topographic information with vegetation and man-made structures removed) as a Level-1 product at the 1 m spatial resolution. This data will be available to generate the Level-4 elevation data product at standard NEON spatial resolution (10 m) and mapped to a standard lat-long grid. The USGS National Elevation Dataset (NED), 1/3 arc second resolution (10 meter), is available for comparison to this DEM (See Land_Use_001).			

Product Number: Land_Use_003 Sub-products: Land_Use_003.1 Land_Use_003.2	**Product Title:** Slope and Aspect (NEON Realm) Land_Use_003.1 = Slope Land_Use_003.2 = Aspect		**Effort: A** **Priority: 1**
	Product Level: 4	**Temporal Resolution:** NA	
	Replicates: 1	**Spatial Extent:** NEON Realm	
	Replicated at: NEON Realm	**Spatial Resolution:** 30 m	
Product Description: Slope is the angle which any part of the earth's surface makes with a horizontal datum (Thomas & Goudie, 2000). Aspect is defined as the "orientation of the face of a slope" (Thomas & Goudie, 2000) or for a given point "the steepest downhill direction" (Bolstad, 2008). The USGS Elevation Derivatives for National Applications (EDNA) is available for the entire NEON realm at 30 meter resolution. EDNA is derived from the USGS National Elevation Dataset (NED) (See Land_Use_001).			

Product Number: Land_Use_004 Sub-products: Land_Use_004.1 Land_Use_004.2	**Product Title:** Slope and aspect (AOP) Land_Use_004.1 = Slope Land_Use_004.2 = Aspect		**Effort: C** **Priority: 2**
	Product Level: 4	**Temporal Resolution:** NA	
	Replicates: 1	**Spatial Extent:** AOP Sub-region	
	Replicated at: Core and relocatable sites	**Spatial Resolution:** 30 m	
Product Description: Slope is the derivative of the elevation obtained from AOP LiDAR data (Land_Use_002). This data will be available at a standard NEON spatial resolution (10 m) and mapped to a standard latitude-longitude grid. Aspect is the orientation of the face of the slope (see Land_Use_003).			

Product Number: **Land_Use_005** Sub-products: Land_Use_005.1 Land_Use_005.2 Land_Use_005.3	**Product Title:** Soil Properties (NEON Realm) Land_Use_005.1 = Soil classification Land_Use_005.2 = Soil chemical properties Land_Use_005.3 = Soil physical properties		**Effort: C** **Priority: 2**
	Product Level: 4	**Temporal Resolution:** NA	
	Replicates: 1	**Spatial Extent:** NEON Realm	
	Replicated at: NEON Realm	**Spatial Resolution:** 1000 m	
Product Description: Soil will be classified according to the USDA Soil Taxonomy developed by United Stated Department of Agriculture (USDA) National Cooperative Soil Survey (NCSS). Soil Taxonomy, second edition, defines soil as "a natural body comprised of solids (minerals and organic matter), liquid, and gases that occurs on the land surface, occupies space, and is characterized by one or both of the following: horizons, or layers, that are distinguishable from the initial material as a result of additions, losses, transfers, and transformations of energy and matter or the ability to support rooted plants in a natural environment. The upper limit of soil is the boundary between soil and air, shallow water, live plants, or plant materials that have not begun to decompose. Areas are not considered to have soil if the surface is permanently covered by water too deep (typically more than 2.5 meters) for the growth of rooted plants. The lower boundary that separates soil from the nonsoil underneath is most difficult to define. Soil consists of horizons near the Earth's surface that, in contrast to the underlying parent material, have been altered by the interactions of climate, relief, and living organisms over time. Commonly, soil grades at its lower boundary to hard rock or to earthy materials virtually devoid of animals, roots, or other marks of biological activity. For purposes of classification, the lower boundary of soil is arbitrarily set at 200 cm (Staff, 1999). " The data source for this product is the U.S. General Soil Map (STATSGO2) at the state level and, where appropriate, the Soil Survey Geographic (SSURGO) at the survey area level. Soil physical and chemical properties for each STATSGO2 polygon are documented in the linked Soil Interpretations Record (SIR) database. Soil physical and chemical properties for SSURGO polygons are provided in the linked Map Unit Interpretations Record (MUIR) database.			

Product Number: **Land_Use_006** Sub-products: Land_Use_006.1 Land_Use_006.2 Land_Use_006.3	**Product Title:** Soil Properties (soil-survey sub-region) Land_Use_006.1 = Soil classification Land_Use_006.2 = Soil chemical properties Land_Use_006.3 = Soil physical properties		**Effort: B** **Priority: 5**
	Product Level: 4	**Temporal Resolution:** NA	
	Replicates: 60	**Spatial Extent:** Soil survey sub-region	
	Replicated at: NEON Core and relocatable sites	**Spatial Resolution:** 100 m	
Product Description: Soil and surveyed properties follow the same definitions stated in Land_Use_005. The soil survey sub-region will be defined for each site based on practical considerations during site characterization. Soil survey teams hired by NEON will produce data adequate to map soils at 100 m resolution using detailed soil mapping that already exists for many sites. Where possible, the soil survey sub-region will match the AOP survey region.			

Product Number: Land_Use_007 Sub-products:	**Product Title:** Land cover classification		**Effort: B** **Priority: 2**
	Product Level: 4	**Temporal Resolution:** 5 years	
	Replicates: 1	**Spatial Extent:** NEON Realm	
	Replicated at: NEON Realm	**Spatial Resolution:** 30 m	
Product Description: Land cover is defined as "the physical and biological properties of the land surface" (Comber, Fisher, & Wadsworth, 2005). NEON land cover will follow the classification of the National Land Cover Database 2001 land cover classification produced by the Multi-Resolution Land Characteristics (MRLC) Consortium. The MRLC is a partnership of federal agencies consisting of the U.S. Geological Survey (USGS), the National Oceanic and Atmospheric Administration (NOAA), the U.S. Environmental Protection Agency (EPA), the U.S. Department of Agriculture (USDA), the U.S. Forest Service (USFS), the National Park Service (NPS), the U.S. Fish and Wildlife Service (FWS), the Bureau of Land Management (BLM) and the USDA Natural Resources Conservation Service (NRCS). The NLCD 2001 products are defined in Homer et al. (2004) and at the MRLC website http://www.mrlc.gov/mrlc2k.asp.			

Product Number: Land_Use_008 Sub-products:	**Product Title:** Land Cover Classification, AOP		**Effort: D** **Priority: 4**
	Product Level: 4	**Temporal Resolution:** NA	
	Replicates: 60	**Spatial Extent:** AOP sub-regions	
	Replicated at: AOP sub-regions	**Spatial Resolution:** 10 m	
Product Description: Land cover is defined as "the physical and biological properties of the land surface" (Comber, et al., 2005). All annual AOP scenes will be classified according to the classes of land cover products conforming to the National Land Cover Database 2001 produced by the Multi-Resolution Land Characteristics (MRLC) Consortium. The NLCD 2001 products are defined in Homer et al. (2004) and at the MRLC website http://www.mrlc.gov/mrlc2k.asp. AOP classification will be accomplished by a combination of supervised and unsupervised classification (Duta & Hart, 1973; Freidl & Brodley, 1997). Within vegetation sub-classes, continuous field variables will be developed to estimate proportional coverage of trees, shrubs, herbaceous vegetation and bare earth based on fused spectral and LiDAR data (Asner, et al., 2007; D. A. Roberts, et al., 1998). Spectral mixture analysis of hyperspectral data provides the capability to quantify cover fractions, crop types, and discriminate between biotic components such as photosynthetic vegetation and non-photosynthetic vegetation and abiotic components, including rock, soil, and snow/ice, allowing for sub-classification of additional land cover classes (Huete, 1986; D. A. Roberts, et al., 1998; Settle & Drake, 1993; Smith, Ustin, Adams, & Gillespie, 1990). In urban classes, hyperspectral data, high-resolution digital photography, and LiDAR waveform data and intensity measurements will be used to identify structures, roads, vegetation fraction, and impermeable concrete surfaces (Small & Lu, 2006).			

<table>
<tr><td rowspan="4">Product Number:
Land_Use_009

Sub-products:</td><td colspan="2">Product Title: Streams and rivers (NEON Realm)</td><td rowspan="4">Effort: A
Priority: 1</td></tr>
<tr><td>Product Level: 4</td><td>Temporal Resolution: NA</td></tr>
<tr><td>Replicates: 1</td><td>Spatial Extent: NEON Realm</td></tr>
<tr><td>Replicated at: NEON Realm</td><td>Spatial Resolution: 100 m</td></tr>
<tr><td colspan="4">Product Description: Stream and rivers are bodies of flowing water. The terms for these lotic systems are generally applied to water flowing in a natural channel as opposed to a man-made feature such as a canal. (Water.USGS.gov glossary). The USGS National Hydrography Dataset (medium resolution) provides vector data on streams and rivers at a scale of 1:100,000.</td></tr>
</table>

<table>
<tr><td rowspan="4">Product Number:
Land_Use_010

Sub-products:</td><td colspan="2">Product Title: Streams and rivers (AOP Sub-Region)</td><td rowspan="4">Effort: C
Priority: 3</td></tr>
<tr><td>Product Level: 4</td><td>Temporal Resolution: NA</td></tr>
<tr><td>Replicates: 60</td><td>Spatial Extent: AOP Sub-regions</td></tr>
<tr><td>Replicated at: AOP Sub-regions</td><td>Spatial Resolution: 10 m</td></tr>
<tr><td colspan="4">Product Description: Natural flow paths will be used to define the drainage network from AOP derived DEM (see Land_Use_001). Ground calibration and comparison to USGS Quadrangle maps at 1:24,000 or 1:250,000 scale will be used to define the portions of the drainage network that experience water flow. The USGS National Hydrography Dataset (high resolution) provides vector data at 1:24,000 scale.</td></tr>
</table>

<table>
<tr><td rowspan="4">Product Number:
Land_Use_011

Sub-products:
Land_Use_011.1
Land_Use_011.2</td><td colspan="2">Product Title: Flood plains and Wetlands
Land_Use_011.1 = Floodplains
Land_Use_011.2 = Wetlands</td><td rowspan="4">Effort: C
Priority: 2</td></tr>
<tr><td>Product Level: 4</td><td>Temporal Resolution: 10 years</td></tr>
<tr><td>Replicates: 1</td><td>Spatial Extent: NEON Realm</td></tr>
<tr><td>Replicated at: NEON Realm</td><td>Spatial Resolution: 100 m</td></tr>
<tr><td colspan="4">Product Description: A flood plain is defined as land bordering a stream, built of sediment carried by the stream and dropped in the slack water beyond the influence of the swiftest current (Bryan, 1922). A flood plain may also be defined as the lowland that borders a river, usually dry but subject to flooding ((Hoyt & Langbein, 1955) p. 12.) or as that land outside of the active stream channel described by the perimeter of the maximum probable flood (After (White, 1945) p. 44.). FEMA maps flood areas on a county-by-county basis. A compilation is required to generate a national map.

Wetlands are lands where saturation with water is the dominant factor determining the nature of soil development and the types of plant and animal communities living in the soil and on its surface (Cowardin, Carter, Golet, & LaRoe, 1979). Wetlands vary widely because of regional and local differences in soils, topography, climate, hydrology, water chemistry, vegetation, and other factors, including human disturbance. The USFWS National Wetlands Inventory provides vector data at 1:24,000 scale.</td></tr>
</table>

Product Number: Land_Use_012 Sub-products:	**Product Title:** Dams and control structures		**Effort: A** **Priority: 2**
	Product Level: 4	**Temporal Resolution:** 10 years	
	Replicates: 1	**Spatial Extent:** NEON Realm	
	Replicated at: NEON Realm	**Spatial Resolution:** 100 m	

Product Description: A dam is a man-made structure for impounding water. A control structure is a man-made construction used to manage the flow of water. Dams and control structures "change river hydrology, sediment loads, riparian vegetation, patterns of aggradation and erosion, the migration of organisms, seismic activity, etc." (Thomas & Goudie, 2000).

A dataset describing major dams of the United States is available from the USGS National Atlas (National Atlas; http://www-atlas.usgs.gov/metadata/dams00x020.faq.html). Major dams are defined to be dams "50 feet (15.24 m) or more in height, or with a normal storage capacity of 5,000 acre-feet (6,170,000 m^3) or more, or with a maximum storage capacity of 25,000 acre-feet (30,800,000) or more". The dataset is based on the U.S. Army Corps of Engineers National Inventory of Dams (NID; National Atlas), which collates information about 79,777 dams in the United States and its territories.

Product Number: Land_Use_013 Sub-products:	**Product Title:** Watershed boundaries to level 6 stream order		**Effort: A** **Priority: 2**
	Product Level: 4	**Temporal Resolution:** NA	
	Replicates: 1	**Spatial Extent:** NEON Realm	
	Replicated at: NEON Realm	**Spatial Resolution:** 100 m	

Product Description: A drainage basin is defined by the topographic high or divide that separates adjacent drainage basins. Stream order is a method of numbering streams as part of a drainage basin network. The smallest unbranched mapped tributary is called first order. The confluence of two first order streams is a second order stream. The confluence of two second order streams is a third order, and so on. It is usually necessary to specify the scale of the map used. A first-order stream on a 1:62,500 map, may be a third-order stream on a 1:12,000 map (after (Leopold & Miller, 1956) p. 16.). In this case of NEON, we will follow the definition of stream order accepted by NAWQA based on (Strahler & Members, 1999) to categorize streams. The USGS and USDA Watershed Boundaries Dataset (WBD) provides data at the subwatershed (12 digit) level (USDA, NRCS 2002). This dataset is newer and at a higher resolution than the USGS HUC dataset (8 digit). The WBD is available as a feature dataset of the USGS National Hydrography Dataset.

Product Number: Land_Use_014 Sub-products:	**Product Title:** Watershed boundaries to level 1 stream order (AOP Sub-regions)		**Effort: C** **Priority: 3**
	Product Level: 4	**Temporal Resolution:** 5 years	
	Replicates: 60	**Spatial Extent:** AOP sub-regions	
	Replicated at: AOP sub-regions	**Spatial Resolution:** 10 m	
Product Description: Drainage basins are defined in Land_Use_013. The drainage basin boundaries in the AOP sub-region will be derived from the AOP DEM and will be divided to the level of first-order streams determined according to Land_Use_010.			

Product Number: Land_Use_015 Sub-products:	**Product Title:** Protected areas boundaries		**Effort: C** **Priority: 2**
	Product Level: 4	**Temporal Resolution:** 5 years	
	Replicates: 1	**Spatial Extent:** NEON Realm	
	Replicated at: NEON Realm	**Spatial Resolution:** 30 m	
Product Description: A protected area, as defined by the International Union for Conservation of Nature (IUCN, formerly the World Conservation Union), as "An area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means." The Protected Areas Database of the United States, or PAD-US, contains information about publicly held conservation lands within the U.S. A consortium of federal agencies, state representatives and non-profit organizations, known as the PAD-US Partnership, manages the PAD-US inventory. The USGS Gap Analysis Program, on behalf of the PAD-US Partnership, published the preliminary version of PAD-US in 2009. Version 2 is scheduled for development during the 2010 to 2012 time frame.			

Product Number: Land_Use_016 Sub-products: Land_Use_016.1 Land_Use_016.2 Land_Use_016.3 Land_Use_016.4	**Product Title:** Human population statistics Land_Use_016.1 = Per capita income structure Land_Use_016.2 = Education levels Land_Use_016.3 = Total population Land_Use_016.4 = Population gender and age structure		**Effort: D** **Priority: 4**
	Product Level: 4	**Temporal Resolution:** 5 years	
	Replicates: 1	**Spatial Extent:** NEON Realm	
	Replicated at: NEON Realm	**Spatial Resolution:** 1000 m	
Product Description: NEON will use Bureau of Census data. Conversion of the census data from irregular tracts to the 1000 m level will be done with algorithms that statistically associate human demographic information with features of the land surface.			

Product Number: Land_Use_017 Sub-products: Land_Use_017.1 Land_Use_017.2 Land_Use_017.3 Land_Use_017.4	**Product Title:** Transportation Infrastructure Land_Use_017.1 = Road Network Land_Use_017.2 = Railroad network Land_Use_017.3 = Airports Land_Use_017.4 = Sea and lake ports		**Effort: B** **Priority: 2**
	Product Level: 4	**Temporal Resolution:** 5 years	
	Replicates: 1	**Spatial Extent:** NEON Realm	
	Replicated at: NEON Realm	**Spatial Resolution:** 10 m	
Product Description: Transportation infrastructure is defined to be the road network, railroad network, airports, sea ports and lake ports within the NEON Realm. The U.S. Department of Transportation Bureau of Transportation Statistics provides national transportation infrastructure datasets via the U.S. National Transportation Atlas Database (NTAD). U.S. Highways represents major and minor highways including interstates, U.S. highways, state highways, major roads, and minor roads. U.S. National Transportation Atlas Railroads represents a comprehensive database of the nation's railway system at 1:100,000 scale. The data set covers the 48 contiguous States plus the District of Columbia within United States. U.S. National Atlas Airports represents airports in the United States, Puerto Rico, U.S. Virgin Islands, and U.S. Possessions with airport passenger enplanements of greater than or equal to 100 passengers per year. U.S. Transportation Terminals represents locations within United States for transportation terminals such as bus stations, train stations, marine terminals, and other significant transportation nodes.			

Product Number: Land_Use_018 Sub-products: Land_Use_018.1 Land_Use_018.2 Land_Use_018.3 Land_Use_018.4 Land_Use_018.5	**Product Title:** Agricultural Management Land_Use_018.1 = Livestock densities Land_Use_018.2 = Fertilizer usage Land_Use_018.3 = Tillage Land_Use_018.4 = Crop type Land_Use_018.5 = Plantation forest stand age distribution		**Effort: C** **Priority: 2**
	Product Level: 4	**Temporal Resolution:** 5 years	
	Replicates: 1	**Spatial Extent:** NEON Realm	
	Replicated at: NEON Realm	**Spatial Resolution:** 1000 m	
Product Description: The USDA currently conducts a national census of agriculture at 5-year intervals (http://www.agcensus.usda.gov/Publications/2002/index.asp.). Data from this census are generally available at the county level. Downscaling of the data to the 1000 m level will be done by statistical association of satellite land cover (e.g. (Cardille & Foley, 2003)).			

Product Number: Land_Use_019 Sub-products: Land_Use_019.1 Land_Use_019.2 Land_Use_019.3 Land_Use_019.4 Land_Use_019.5 Land_Use_019.6 Land_Use_019.7	**Product Title:** Industrial Infrastructure Land_Use_019.1 = Heavy industrial plants Land_Use_019.2 = Power generation plants Land_Use_019.3 = High tension power distribution lines Land_Use_019.4 = Refineries Land_Use_019.5 = Chemical industries Land_Use_019.6 = Fertilizer plants Land_Use_019.7 = Cement plants		**Effort: C** **Priority: 4**
	Product Level: 4	**Temporal Resolution:** 5 years	
	Replicates: 1	**Spatial Extent:** NEON Realm	
	Replicated at: NEON Realm	**Spatial Resolution:** 1000 m	
Product Description: Industrial infrastructure consists of the facilities, services, and installations required for the functioning of an industrial economy. Sources of data for these products include the EPA's AIRS database (http://www.epa.gov/enviro/html/airs/index.html) especially the AIRS Facility Subsystem (AFS) that lists "various stationary sources of air pollution, such as electric power plants, steel mills, factories, and universities." Additional data is available from the North American Commission for Environmental Cooperation (http://www.cec.org/naatlas/).			

Product Number: Land_Use_020 Sub-products:	**Product Title:** Potential natural vegetation		**Effort: B** **Priority: 2**
	Product Level: 4	**Temporal Resolution:** NA	
	Replicates: 1	**Spatial Extent:** NEON Realm	
	Replicated at: NEON Realm	**Spatial Resolution:** 1000 m	

Product Description: Potential natural vegetation is the vegetation that would exist in the absence of all human activities (Kuchler, 1964). Sources for this product include the original Küchler potential natural vegetation map (1975) at 1:3,168, 000 scale and derived products such as the USDA Forest Service Küchler Potential Natural Vegetation Groups (Schmidt, Menakis, Hardy, Hann, & Bunnell, 2002), a 1 km^2 gridded data product covering the conterminous US, which adjusted digitized Küchler polygons to match a selected USGS digital elevation model (USGS, 1994) and Fourth Code HUC spatial data. The NEON product will be produced at the 1000m resolution for the entire NEON realm using geospatial modeling techniques such as those employed by Steyaert and Knox (2008).

Product Number: Land_Use_021 Sub-products:	**Product Title:** Historical land cover classification		**Effort: E** **Priority: 5**
	Product Level: 4	**Temporal Resolution:** 10 years	
	Replicates: 1	**Spatial Extent:** NEON Realm	
	Replicated at: NEON Realm	**Spatial Resolution:** 1000 m	

Product Description: Historical land cover is a reconstruction of land cover types at the 1000m level at ten year intervals for the period covering European settlement in the 1500's to the present day. The NEON product will be produced at the 1000 m resolution for the entire NEON realm at a temporal resolution of 10 years using geospatial modeling techniques such as those employed by Steyaert and Knox (2008).

Product Number: Land_Use_022 Sub-products: Land_Use_022.1 Land_Use_022.2 Land_Use_022.3 Land_Use_022.4	**Product Title:** Historical Climate Data Land_Use_022.1 = Minimum temperature Land_Use_022.2 = Maximum temperature Land_Use_022.3 = Mean temperature Land_Use_022.4 = Precipitation		**Effort: C** **Priority: 3**
	Product Level: 4	**Temporal Resolution:** 1 day	
	Replicates: 1	**Spatial Extent:** NEON Realm	
	Replicated at: NEON Realm	**Spatial Resolution:** 1000 m	

Product Description: The United States Historical Climatology Network (USHCN) provides long-term climate records from over 1000 stations across the United States (Quinlan, Karl, & Williams, 1987). Stations in this network meet rigorous criteria for data homogeneity and spatial coverage and temporal coverage from the early years of the 20th Century. The USHCN has been updated many times since it was founded in 1987 (Easterling, Karl, Lawrimore, & Del Greco, 1999; Easterling, Karl, Mason, Hughes, & Bowman, 1996; Hughes, Mason, Karl, & Brower, 1992; Karl, Williams, & Quinlan, 1990). Daily data sets (available at http://cdiac.ornl.gov/epubs/ndp/ushcn/newushcn.html) provide minimum temperature, maximum temperature, precipitation amount, snow amount and depth. Considerably more observation types are available from recent stations and may be added once these basic products are completed. The station data can be gridded to sub-km spatial scales and daily time scale using approaches similar to those developed by the PRISM group (Daly, et al., 2008; Di Luzio, Johnson, Daly, Eischeid, & Arnold, 2008) considering factors such as location, elevation, coastal proximity, topographic facet orientation, vertical atmospheric layer, topographic position, and orographic effects of the terrain.

11 SELECTION OF FUTURE DATA PRODUCT

The current *initial* selection of data products has been chosen to maximize utility to the community by enabling analysis of cause and effect in ecosystems and forecasting of the future states of ecosystems. The selection has been based on input from a broad NEON community and analysis by NEON Inc. management and staff. This catalog of data products serves as a guide for NEON construction. During construction and certainly during observatory observations both the conditions of U.S. ecosystems and the science to study them will change. NEON data products will have to change along with ecological conditions and the advancement of knowledge.

The NEON data products will be modified based on inputs from the scientific community, NEON staff and management. The NEON Science, Technology, and Education Advisory Committee (STEAC) will be the primary advisory body for assessment of the status of data products. The STEAC will evaluate information compiled by the NEON staff and make recommendations for modification of existing data products and development of new data products. NEON Inc. will evaluate this advice and implement STEAC priorities that are consistent with the NEON mission, observatory requirements, and available resources. This process is described in the *NEON Level Data Products Management Plan* (AD[03]).

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