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Introduction

Phenology is the study of periodic plant and animal life cycle events and how these are influenced by seasonal environmental changes. Phenological events such as leaf emergence and senescence exert a direct control on both spatial and temporal patterns of carbon, water, nutrient, and energy cycling throughout all ecosystems on Earth. Furthermore, phenology modulates the abundance and diversity of organisms, their inter-specific interactions, their ecological functions, and regulates many aspects of vegetation feedbacks to the climate system through, for example, seasonal changes in albedo and surface energy balance. It follows, therefore, that phenology has been shown to be a robust integrator of the effects of climate change on natural systems (Schwartz et al. 2006; IPCC 2007) and that there is need for improved monitoring of phenology at local-to-continental scales.



Figure 1. Left: A conceptual model of how phenology influences global processes at various scales (Adapted from Bonan (2002)). Right: Graph showing how the emergence of *N. miltneri* is changing relative to flowering by its host plant (Courtesy of David Inouye).

With recent advances in camera technology, it is now possible to quantify canopy development and phenological state without the subjectivity inherent in observer-based systems. Digital camera images captured throughout time can be analyzed to show stages of phenology across an individual species, plot (Crimmins and Crimmins 2008) or whole ecosystem (Richardson et al. 2007). The National Phenology Network (NPN) and the University of New Hampshire (UNH) are collaborating to use high-resolution networked digital cameras at currently active research sites (e.g., AmeriFlux and LTER) to monitor canopy phenology across the United States. This nation-wide network will be an extension of a pilot network (est. 2008 by A. Richardson) in the Northeast U.S. and adjacent Canada and will provide exceptional insights into spatio-temporal patterns of phenological variation, serve as an effective and continual means of validating satellite remote sensing phenology products, and facilitate analyses of linking phenology to ecosystem function.

National PhenoCam Network

A canopy phenology monitoring network for the United States

When compared to either satellite remote sensing or ground-based field surveys, monitoring phenology using networked cameras ("phenocams") provides a balance between spatial integration and higher temporal resolution. Establishment of a nation-wide phenocam network will allow for up-to-date canopy image availability at many locations across the U.S. Sophisticated web visualization and delivery tools will facilitate scaling from established sites where individual plants are being monitored (Figure 2). The initial effort behind the network will consist of approximately 12 sites across 8 deg. of latitude and 10° C mean annual temperature, including five sites with eddy covariance instrumentation.



Figure 2. Example of a web interface for the National PhenoCam Network showing updated thumbnails of phenocam images (right) from across the nation that correspond to locations on a national map (left).

PhenoCam Network Structure

Tier 1: Camera only. Sites equipped with networked, digital cameras (phenocams) that make continuous observations of canopy state.



Figure 3. Visualization of a Tier 1 monitoring site with archived webcam images, most recent canopy image, and a location map to show exactly where images are being collected.

Tier 2: Camera + ground observer. These sites will be established research locations such as those within the Northeast Regional Phenology Network (NE-RPN, Figure 4) equipped with canopy phenocams in combination with direct observations of phenological events (e.g. flowering, budburst, leafing) recorded by human observers. Data collected by observers will be uploaded to the USA-NPN website and then processed and made available in common format.



Figure 4. Left: A map of the NE-RPN region showing monitoring sites equipped with phenocams with the potential for coupled ground-based observations. Right: Students from a Ticonderoga high school monitor and record on-the-ground phenology of desert plants (Photo credit: Ross Franklin, Associated Press).

Tier 3: Camera + ground observer + radiometric measurements. In addition to features of second tier sites, third tier sites will have calibrated radiometric instruments used to make measurements that can be linked to satellite observations or provide insights into the physical changes in canopy state tied to seasonality. Instrumentation will allow measurements of I_{APAR} calculations of broadband NDVI, and comparisons between ecosystem-level metrics (i.e., GPP) and phenocam "green index" data (Figure 5).

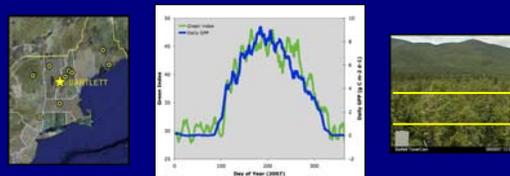


Figure 5. Center: Gross primary productivity (GPP) compared to "green index" data obtained from a phenocam in the Bartlett Forest (map on left). There is a linear correlation between the two data sets of approximately 0.95. The region of interest (ROI) for this phenocam is displayed on the image to the right between the yellow lines. The ROI is analyzed to obtain the green index values displayed on the center graph.

Implementation

The initial goal of the PhenoCam Network is to provide continuous "near" remote sensing of changes in canopy state over time for public webpage viewing in addition to sharing of imagery and data products with site PIs. Two future steps in the formation of the network include (1) evaluation of MODIS phenology products and (2) analysis of links between phenology and ecosystem processes. In previous work, springtime increases in the light-saturated rate of canopy photosynthesis tended to lag changes in canopy green-up, as evaluated from either webcam or radiometric data (Richardson et al. 2007). With improved understanding of these patterns across ecosystems it will be possible to reduce uncertainties in modeling of land surface processes in prognostic climate models. Furthermore, expansion of the pilot network operating in the Northeastern U.S. to a country-wide (or continental-scale) effort will complement the objectives of a recently-established FLUXNET synthesis project (Wingate et al. 2008), which will relate webcam-based phenological indices to seasonal changes in fluxes of carbon and water across a range of ecosystems in North and South America, Europe and Asia.

Key partners in this effort are affiliated with the USDA Forest Service, National Parks Service, NOAA, and research sites within AmeriFlux, FLUXNET Canada/Canadian Carbon Program, and the Long Term Ecological Research (LTER) network (Figure 6). This coming fall, the Rocky Mountain Biological Lab will also be implementing tilt-pan digital cameras on flux towers along an elevational gradient in west-central Colorado.



Figure 6. Maps of AmeriFlux (left) and LTER (right) intensive science monitoring sites that will be key affiliates in the establishment of a National PhenoCam monitoring network.

We are seeking support to more fully develop the concept and prototype for the phenocam network, and to expand the network through the acquisition and establishment of instruments and the development of software programming. For more information about the phenocam network, or to get involved, contact Andrew Richardson (andrewr@solo.sr.unh.edu, 603-868-7654).

References

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