Using digital cameras to monitoring vegetation phenology: *Insights from PhenoCam*

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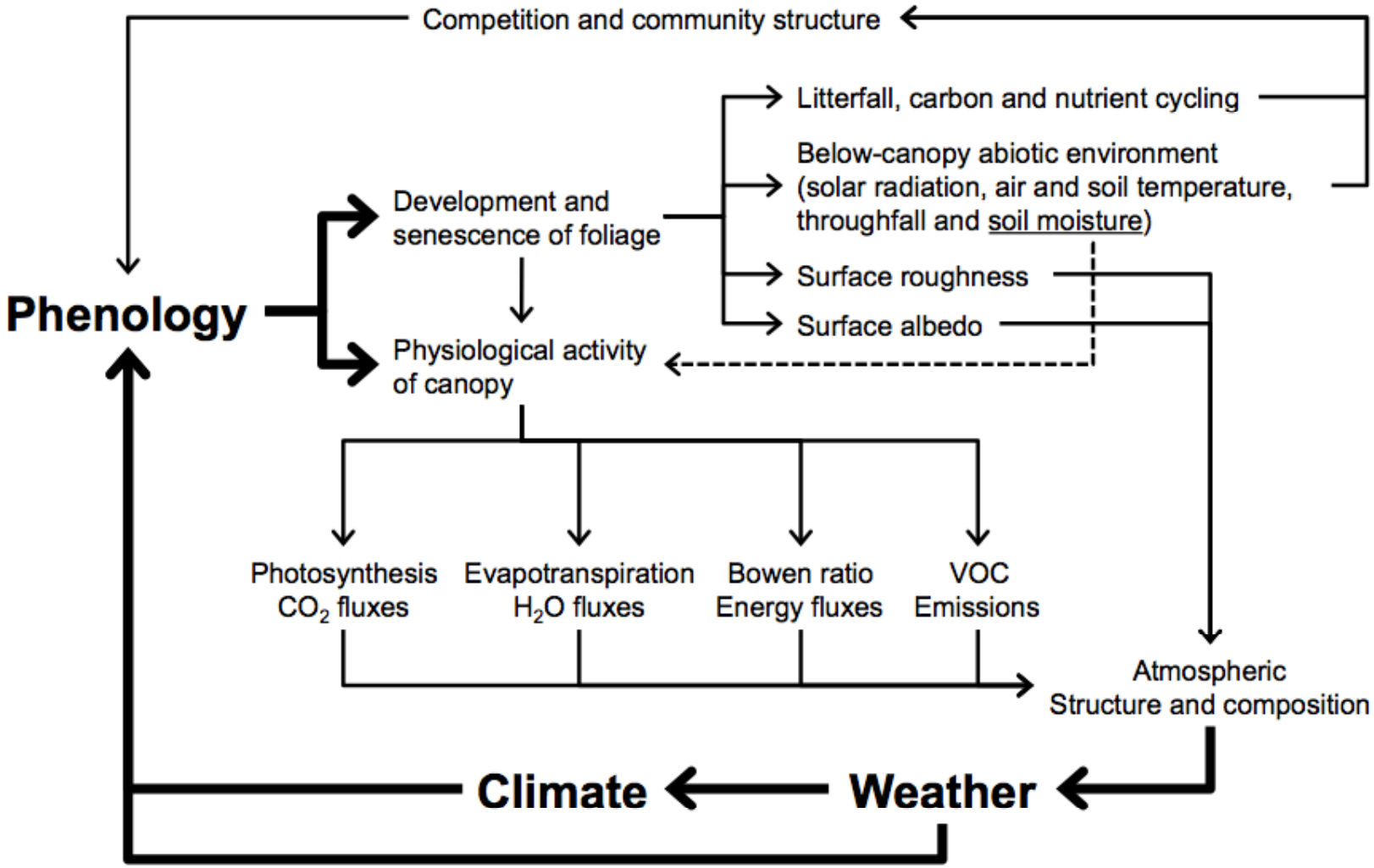
I thank my PhenoCam collaborators for their contributions to this work.
I gratefully acknowledge funding support from the Northeastern States Research Cooperative and the National Science Foundation.

Phenological regulation of ecosystem processes and climate system feedbacks



…and ecologically important, too: reproduction, competition, herbivory, etc.

Phenology and climate change…

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Spring keeps coming earlier for birds, bees, trees

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Enlarge By Pablo Martinez Monsivais, AP

Visitors take a stroll under the cherry blossoms along the Tidal Basin in Washington in this March 30, 2007 file photo. The National Park Service announced its prediction on March 6, 2008, that most of the cherry trees circling the Tidal Basin will be in peak bloom when the National Cherry Blossom Festival begins on March 29. Thirty years ago, the trees usually waited to bloom until around April 5.

By Seth Borenstein, AP Science Writer

WASHINGTON — The capital's famous cherry trees are primed to burst out in a perfect pink peak about the end of this month. Thirty years ago, the trees usually waited to bloom till around April 5.

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What's this?

In central California, the first of the field skipper sachem, a drab little butterfly, was fluttering about on March 12. Just 25 years ago, that creature predictably emerged there anywhere from mid-April to mid-May.

COMPLETE COVERAGE: Climate change, weather research

And sneezes are coming earlier in Philadelphia. On March 9, when allergist Dr. Donald Dvorin set up his monitor, maple pollen was already heavy in the air. Less than two decades ago, that pollen couldn't be measured until late April.

Pollen is bursting. Critters are stirring. Buds are swelling. Biologists are worrying.

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WARMING WORLD

The Earth's surface temperature has risen by more than 1°F since accurate measurements began in 1860.

57.7°

MARCH 19, 2008

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SEARCH

Fall Canceled After 3 Billion Seasons

NOVEMBER 7, 2007 | ISSUE 43•45

WASHINGTON, DC—Fall, the long- running series of shorter days and cooler nights, was canceled earlier this week after nearly 3 billion seasons on Earth, sources reported Tuesday.

The classic period of the year, which once occupied a coveted slot between summer and winter, will be replaced by new, stifling humidity levels, near-constant sunshine, and almost no precipitation for months.

"As much as we'd like to see it stay, fall will not be returning for another season," National Weather Service president John Hayes announced during a muggy press conference Nov. 6. "Fall had a great run, but sadly, times have changed."

ENLARGE IMAGE

A BELOVED CLASSIC COMES TO AN END
Some of fall's most memorable moments

1841: Leaves crumple gently underfoot

Said Hayes: "Frankly, we're amazed it lasted as long as it did."

Though it came as a surprise to many, the cancellation was not without its share of warning

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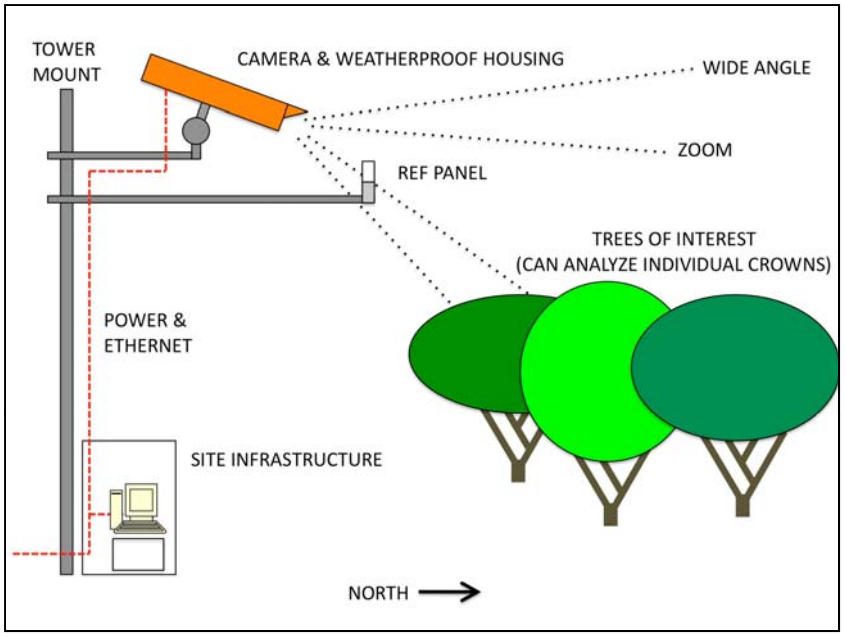
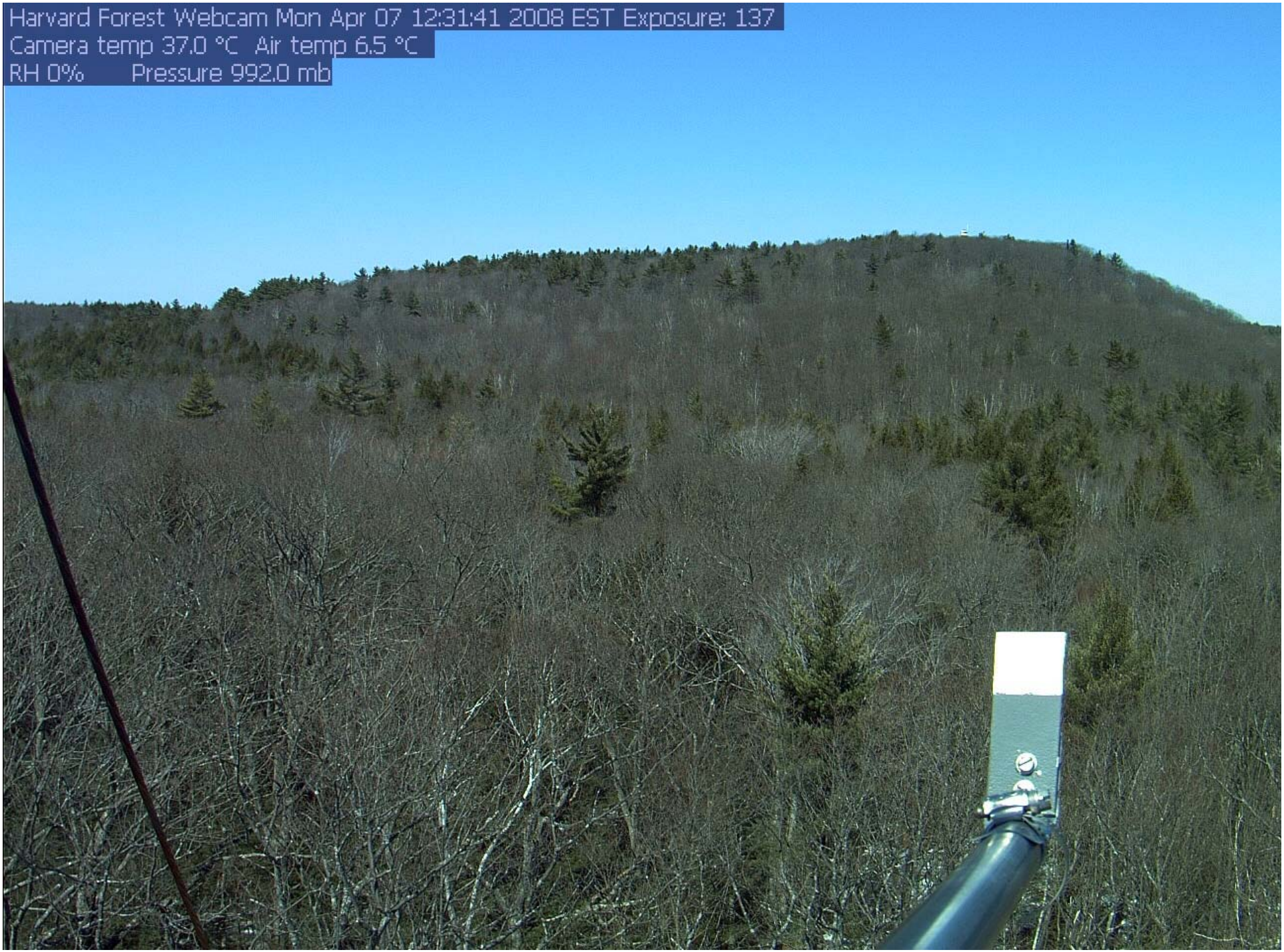
Webcam monitoring of phenology



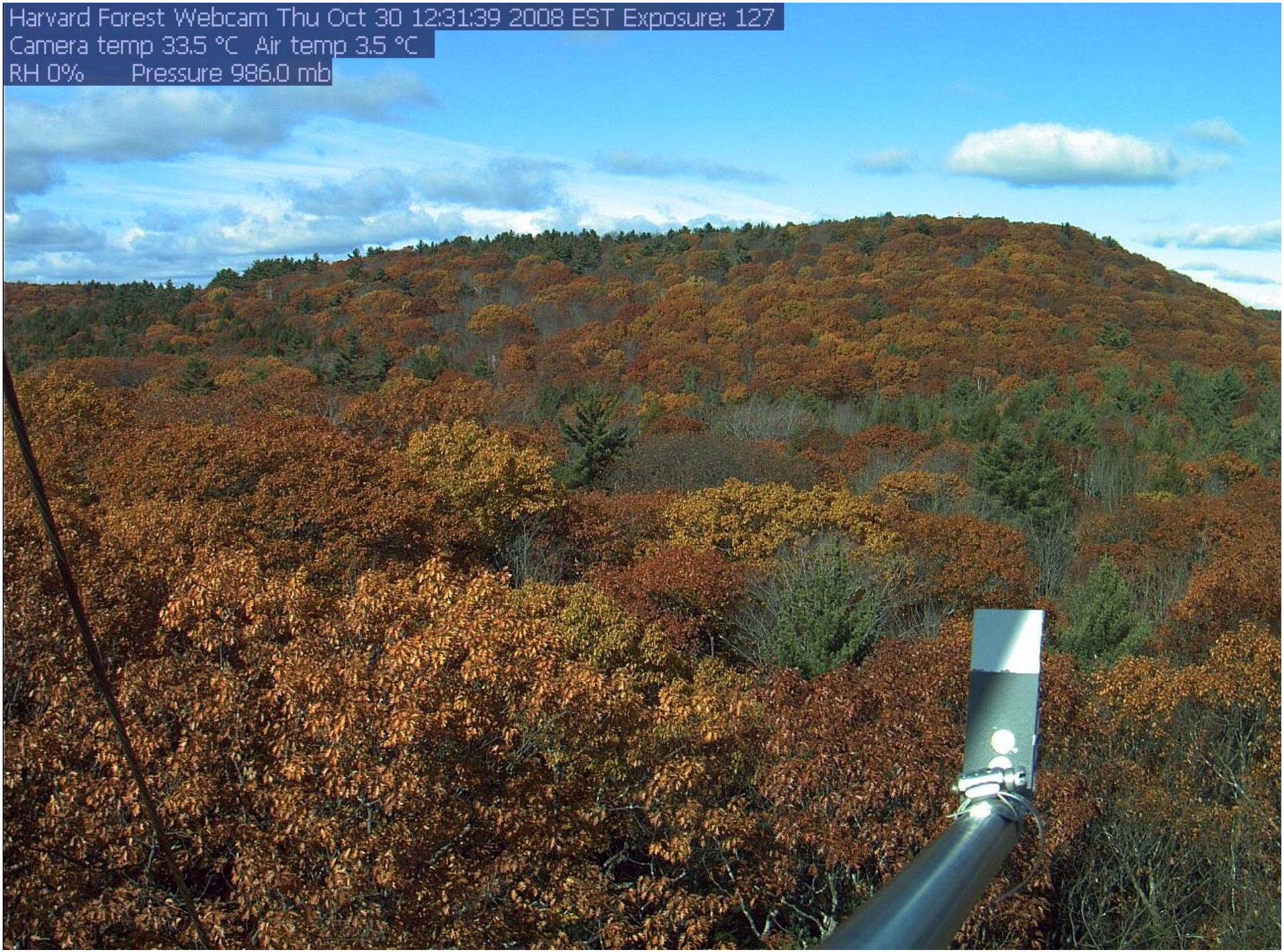
- Commercially available webcam mounted on tower
  - Faces north,15° below horizontal
  - Spatial integration, or individual tree crowns
  - Continuous, with minimal contamination by clouds
- Provides a permanent visual record
- Image analysis (RGB channel extraction) to quantify phenological changes
- Direct link between what is happening on the ground and what is seen by satellites
- Not a calibrated instrument—but neither are field observers!


Harvard Forest Webcam Mon Apr 07 12:31:41 2008 EST Exposure: 137
Camera temp 37.0 °C Air temp 6.5 °C
RH 0% Pressure 992.0 mb


Harvard Forest Webcam Sun May 11 12:01:40 2008 EST Exposure: 127
Camera temp 46.5 °C Air temp 16.0 °C
RH 0% Pressure 971.0 mb

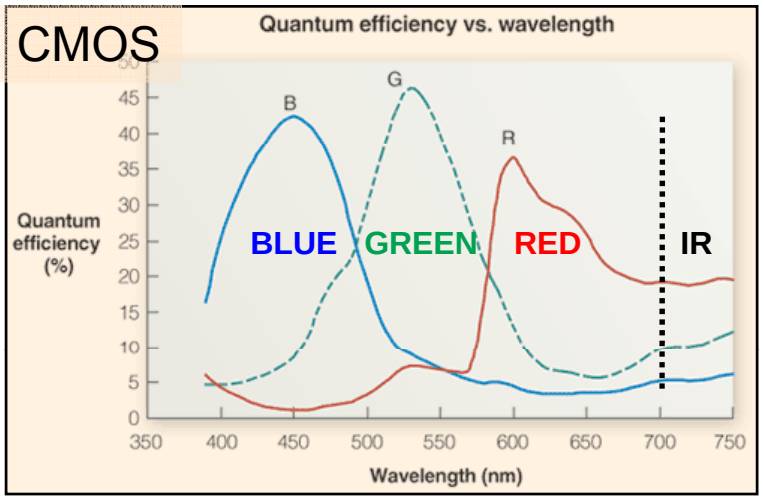

Harvard Forest Webcam Thu Jun 12 13:31:42 2008 EST Exposure: 171
Camera temp 51.5 °C Air temp 22.0 °C
RH 0% Pressure 984.0 mb


Harvard Forest Webcam Sun Aug 24 12:01:43 2008 EST Exposure: 169
Camera temp 55.5 °C Air temp 24.0 °C
RH 0% Pressure 982.0 mb


Harvard Forest Webcam Thu Oct 30 12:31:39 2008 EST Exposure: 127
Camera temp 33.5 °C Air temp 3.5 °C
RH 0% Pressure 986.0 mb

Camera technical specifications

Spectral response



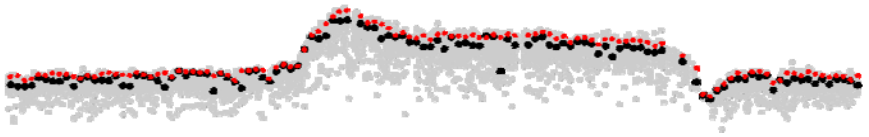
http://images.pennnet.com/articles/vsd/thm/th_0707vsd_prfocus01.gif

= NDVI?

- StarDot **NetCam SC**, 1280 x 960 pixel resolution (1.3 MP), Micron ¼" CMOS sensor
- Fixed white balance (outdoor), auto exposure, variable iris
- RGB images, with IR filter triggered on schedule
- uClinux operating system with built-in web and ftp server
- Images stored as minimally compressed jpeg files, with date and time stamp embedded in filename

Seasonal cycles from camera imagery

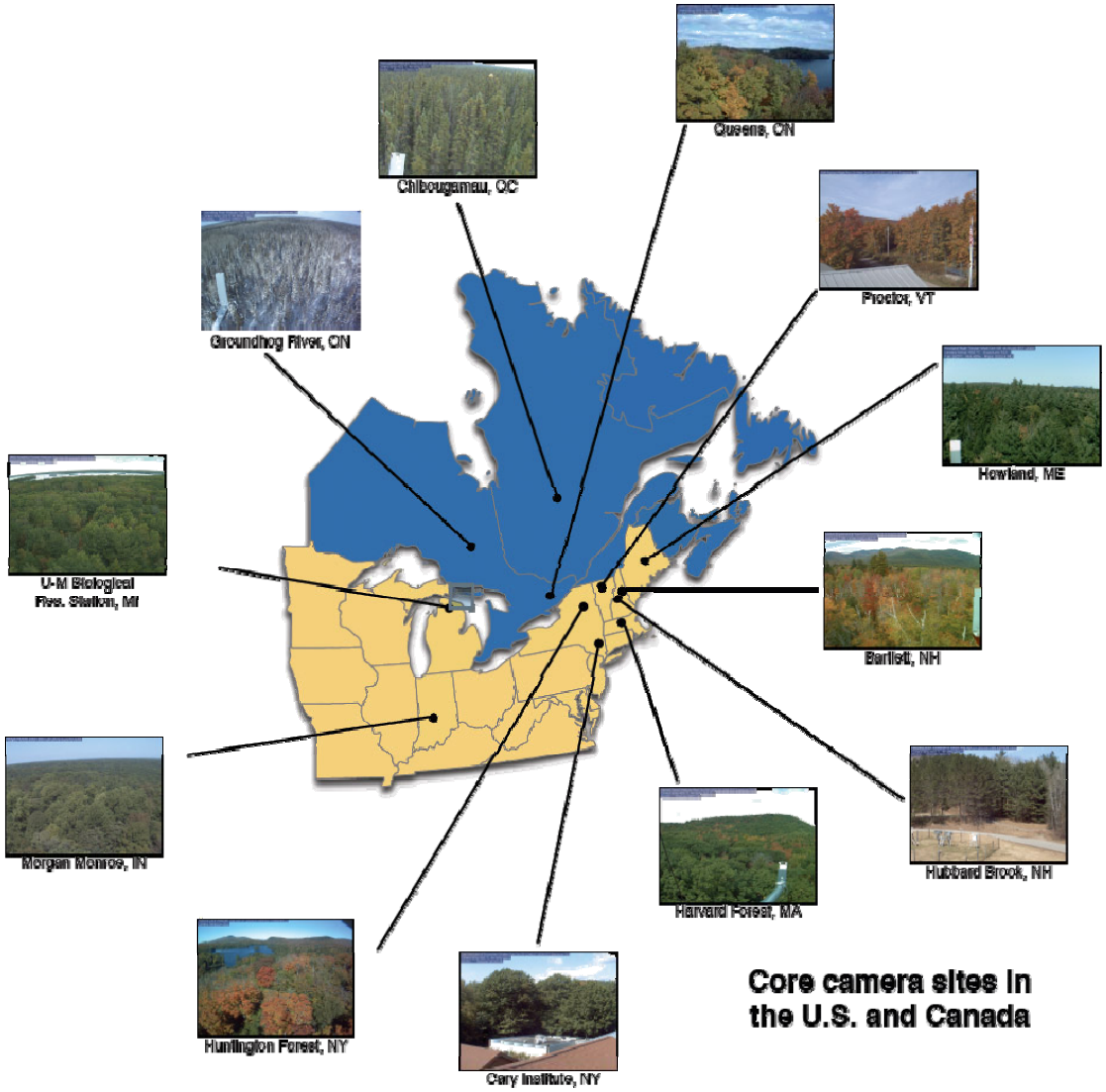
WINTER SPRING SUMMER EARLY AUTUMN LATE AUTUMN



- Seasonality visually obvious (leaves, no leaves)
- Quantitative analysis: timing and rate of changes in canopy greenness (also autumn coloration w/ red channel)
- "Relative Green"
  = Green DN / (Red DN + Green DN + Blue DN)
- "Green Excess"
  = 2 * Green DN – (Red DN + Blue DN)
- Potential for work in other color spaces (e.g. HSV)
- Movie shows RGB transformed to Green Excess, over one year

PhenoCam Network:

12 Core sites in Northeast US/Canada

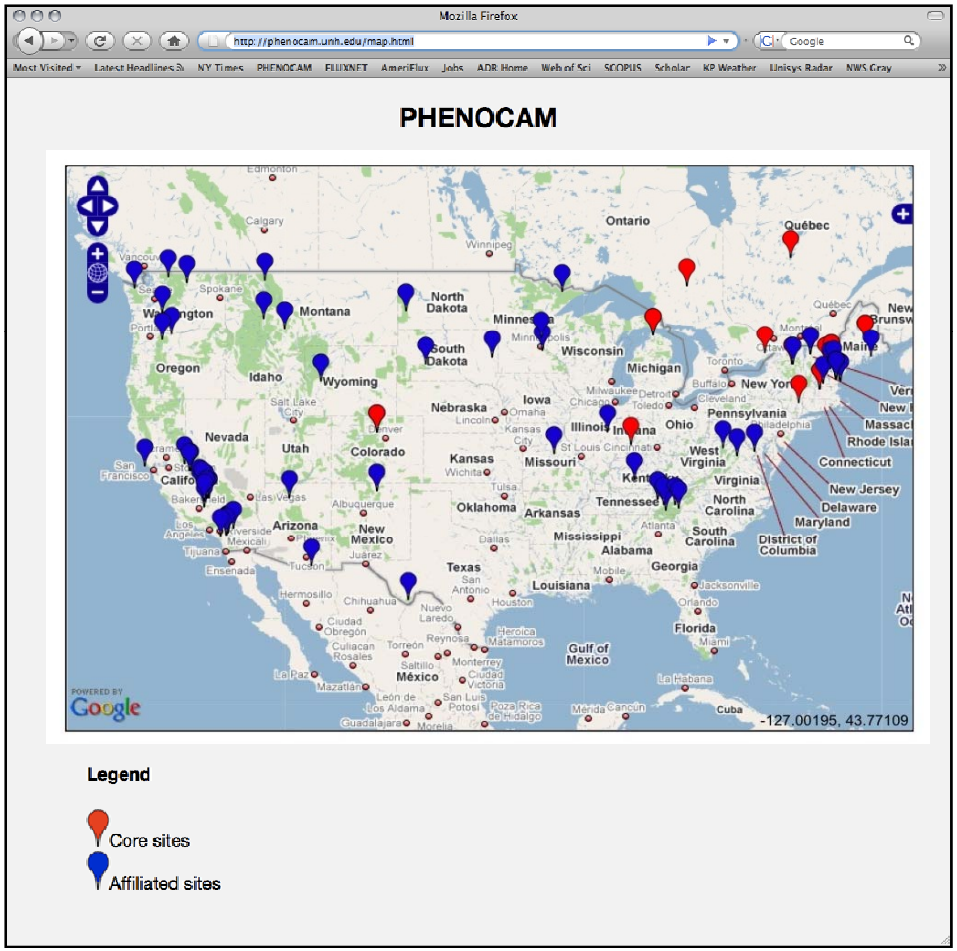


- Sites span 10° latitude and 10° MAT
- Range of forest types: gradation from oak-hickory forests in south, to northern hardwoods (maple-beech-birch), to boreal mixedwood (birch-poplar-fir) and boreal conifer (spruce-fir) in the north
- 8 FLUXNET sites
- Observer records at several sites
- Unique opportunities for outreach/ public engagement

Continental-scale PhenoCam coverage

Some data records 9+ years in length

http: phenocam.sr.unh.edu



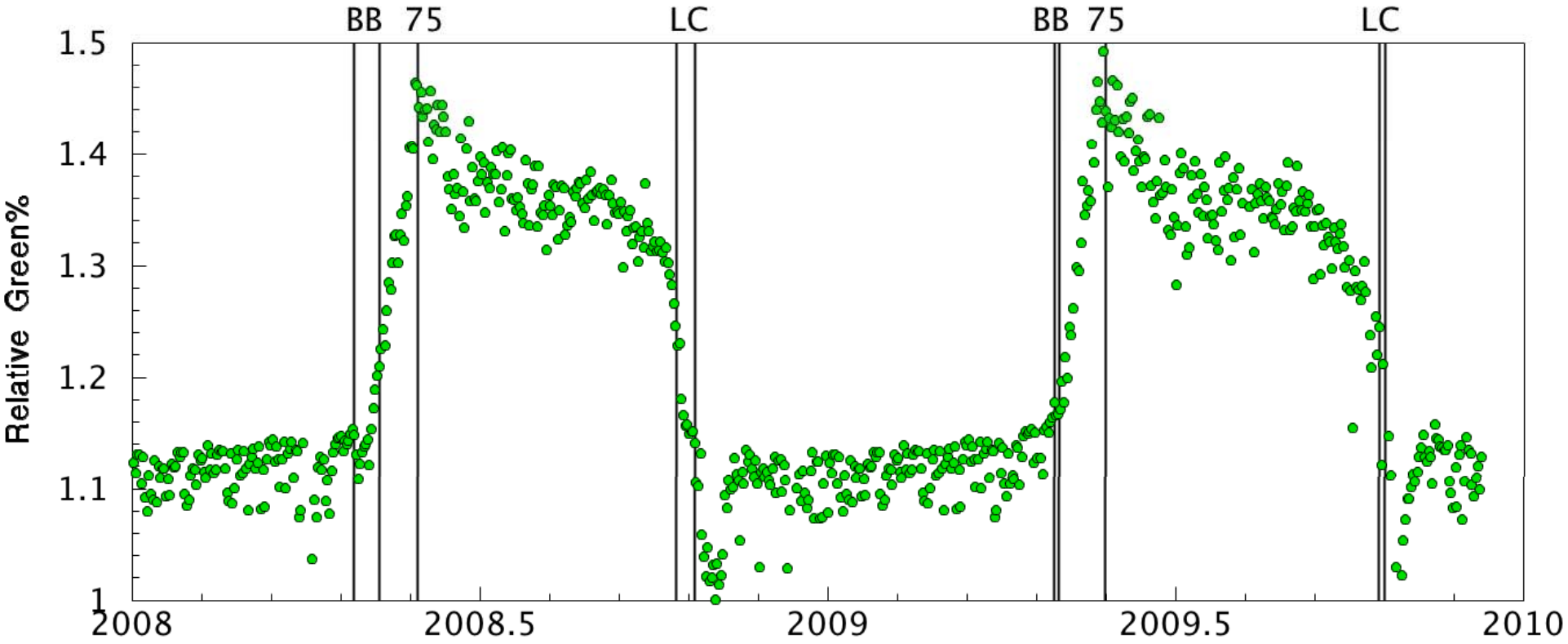
Images mirrored to server 50+ sites covering a wide range of ecosystem types.

New collaboration with AMOS (Archive of Many Outdoor Scenes):

≈20,000 cameras, of which ≈40% may have include vegetation relevant to these efforts

Camera greenness vs. observer records

Uncertainties inherent in both

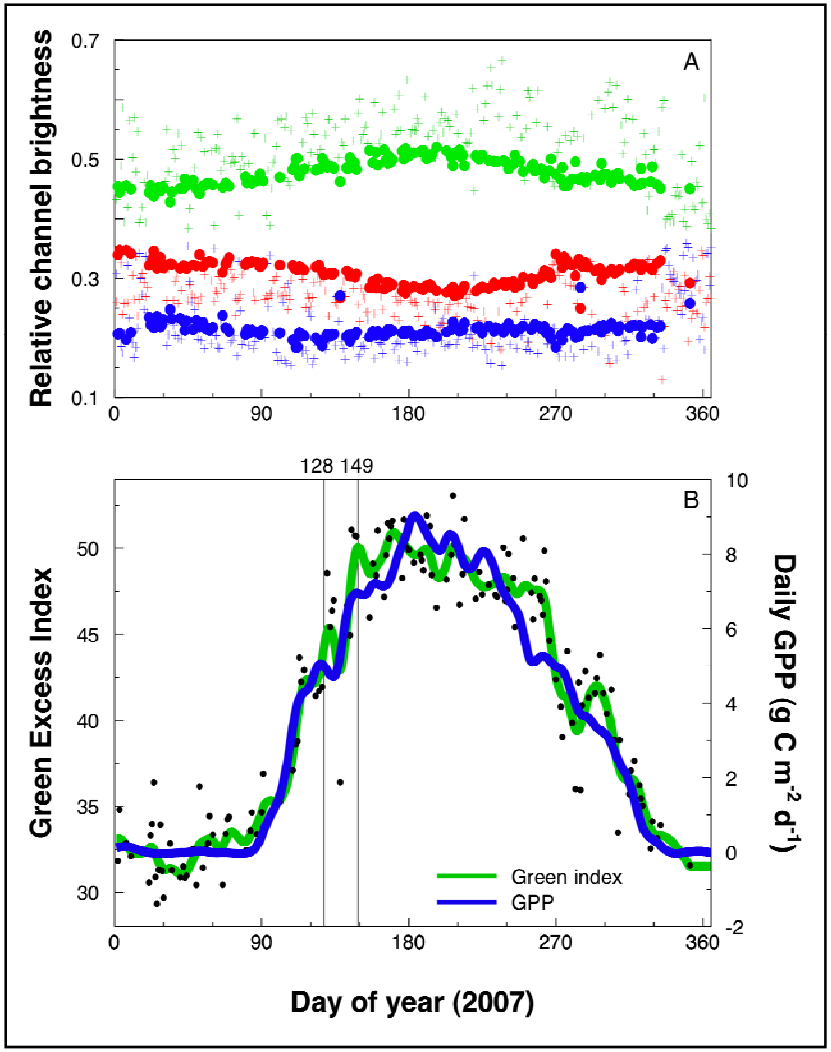


Harvard Forest (2008-2009)

Camera greenness vs. red oak (*Quercus rubra*)

BB = 50% budburst; 75 = 50% of leaves 75% of final length; LF = 50% leaf color

Seasonality of canopy activity
in evergreen conifer stands

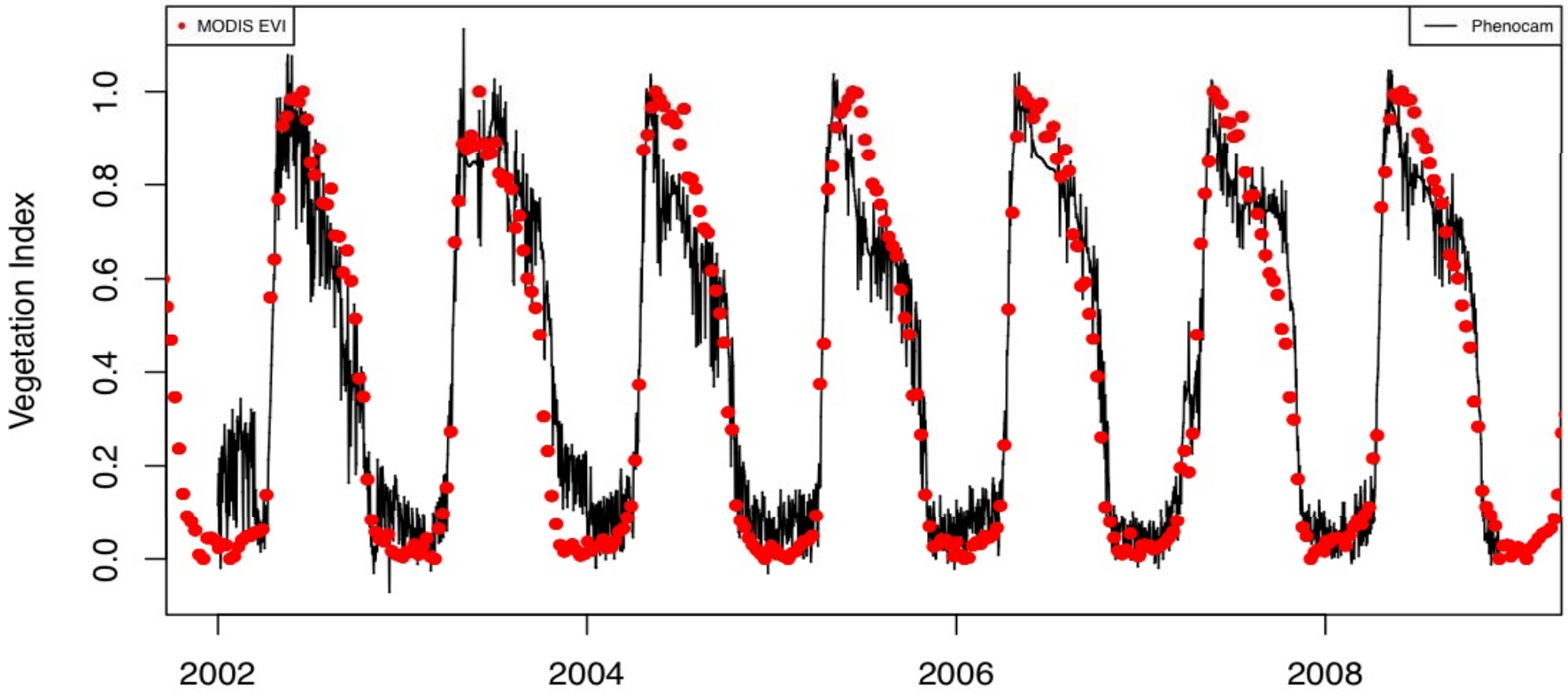


Old-growth evergreen forest:

- Seasonal variation in greenness less pronounced than in deciduous stands
- Spring increases in greenness pre-date budburst by >> 1 month
- Hypothesis: seasonal variation in canopy chlorophyll content (photoprotection in winter)
- Canopy greenness tracks seasonal variation in GPP estimated from eddy covariance measurements

Evaluating satellite remote sensing products:

Camera greenness vs. MODIS EVI



Mammoth Cave, Kentucky (2002-present)

Long-term records, potential to characterize anomalies

Reasonable synchrony in time series

Good signal-to-noise ratio in both

Courtesy Koen Hufkens

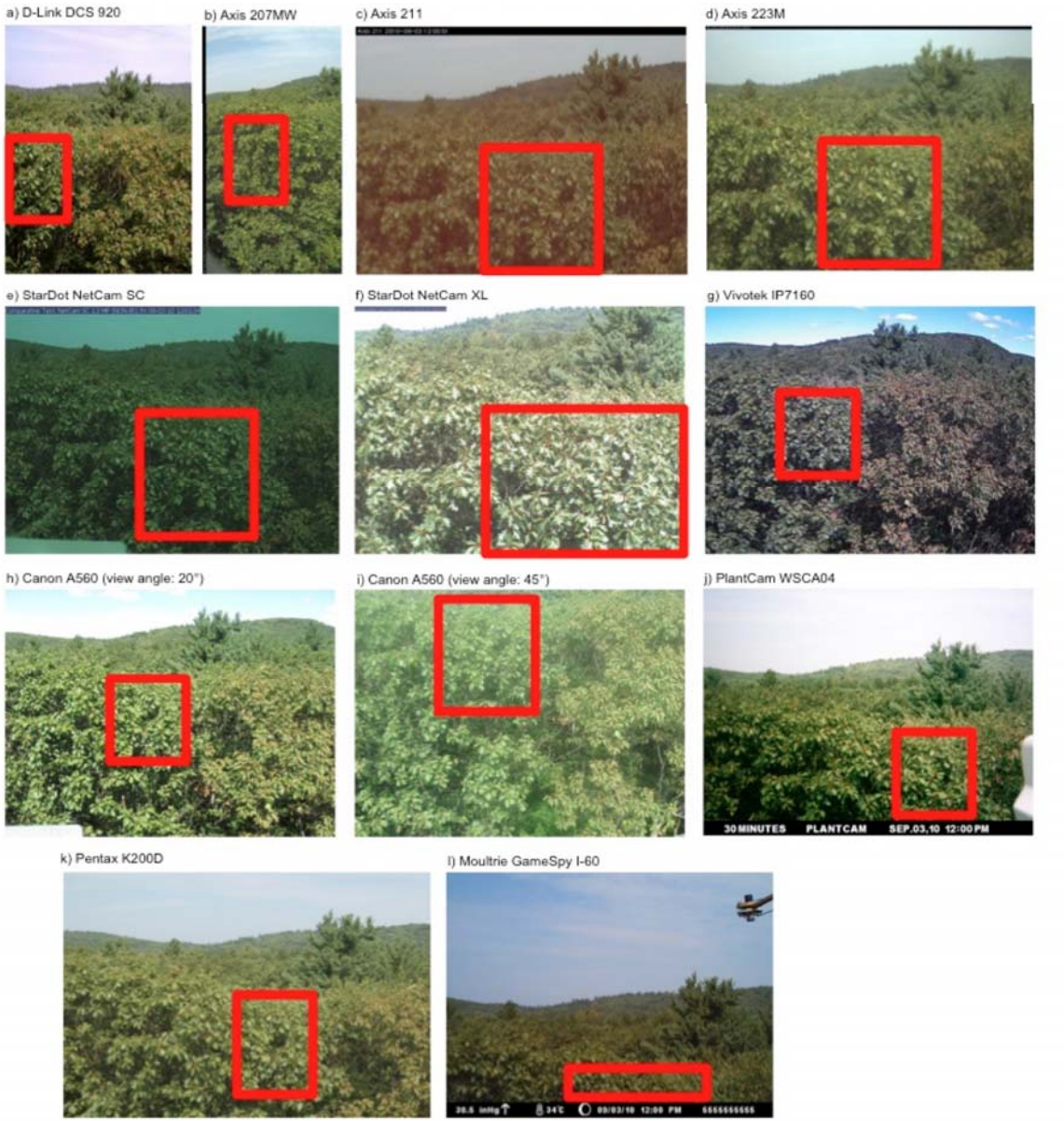
Does camera choice matter?

The CamCom Experiment (Harvard Forest, Summer 2010)

A dozen cameras, different sensors, resolution, exposure control, internal processing, etc.

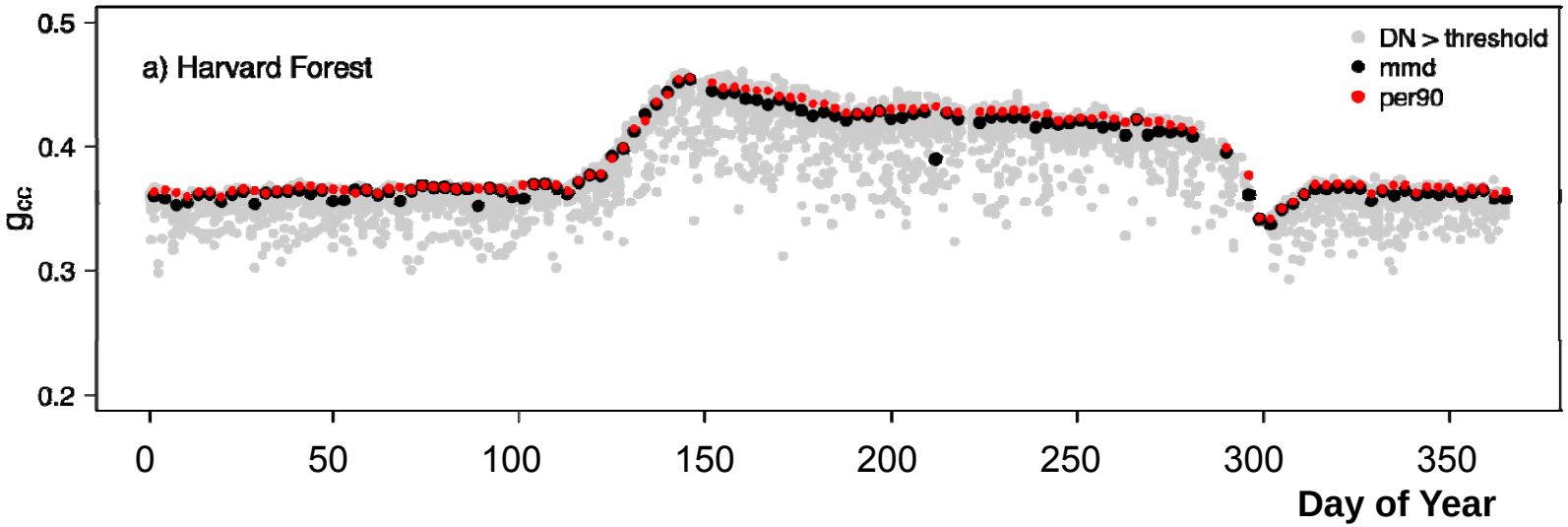
CamCom Experiment
Key results:

- Obvious differences in color balance, resolution
- Surprisingly consistent in retrieved dates of relative canopy green-down (80%, 50%, 20%, etc.): 1 SD ≈ 2-3 d
- High resolution imagery with minimal compression desirable but not strictly necessary



Courtesy Oliver Sonnentag

Developing improved techniques for image processing and filtering



- Record imagery every 30 minutes, dawn to dusk
- RGB values vary with changes in illumination (zenith and azimuth, clouds, aerosols, etc.)
- How to retrieve the “best” time series, filtering out noise but not the underlying phenological signal?
- Recommend a moving window, 90th percentile approach
- Still experimenting with color references etc.

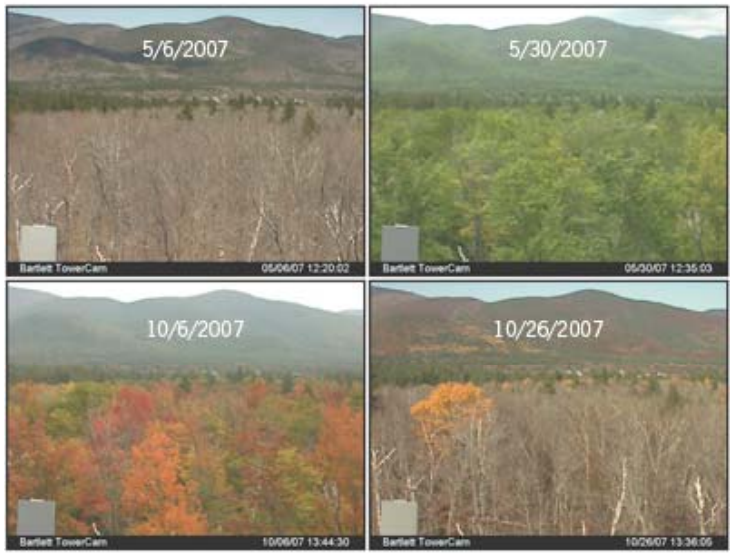
Courtesy Oliver Sonnentag

National Science Foundation
WHERE DISCOVERIES BEGIN

Macrosystems Program - Collaborative Research:

Continental-Scale Monitoring, Modeling and Forecasting of Phenological Responses to Climate Change

- Develop continental-scale data sets on vegetation phenology by expanding PhenoCam network
- Test and improve phenological theory, focusing on dynamic interactions between climate change, phenology, and ecosystem function
  - Identify **environmental controls** (photoperiod, temperature, precipitation)
  - Develop **phenological projections**, with uncertainties, for key PFTs
  - **Forecast impacts** on ecosystem services related to CO_2 and H_2O



PhenoCam Announcements

- **Deploying new cameras** to ≈20 sites over the next year
  - Seeking diversity of vegetation types and climate zones
  - Sites must have internet connectivity; line power preferred
  - We provide the camera and archive the imagery, you provide the infrastructure, ground support, and complementary flux-met data
  - Please speak with me this week if interested

- **Hiring a new postdoc** to conduct modeling and analysis of PhenoCam and FLUXNET data
  - Immediate start is possible
  - Please speak with me this week if interested

Summary

- Use inexpensive, networked digital cameras as multi-channel imaging sensors
- “Near surface” remote sensing as an alternative to observer-based methods for tracking phenology
- Continental-scale monitoring will provide greater insight into spatial and temporal patterns of variation across a range of forest/vegetation types
- Future emphasis on how phenology mediates regional-to-global scale carbon, water and energy budgets in a changing world