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

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Phenological regulation of ecosystem processes and climate system feedbacks

...and ecologically important, too: reproduction, competition, herbivory, etc.
Phenology and climate change...

Spring keeps coming earlier for birds, bees, trees
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.

In central California, the first of the field skirt 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.

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."
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!
Camera technical specifications

Spectral response

- 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

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

**VIS** = **NDVI**?
Seasonal cycles from camera imagery

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
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 CO₂ and H₂O
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