Monitoring vegetation phenology at scales from individual plants to whole canopies, and from regions to continents: *Insights from the PhenoCam network*

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Phenology: Ubiquitous and cyclical...

“The pulse of our planet” — USA National Phenology Network


... and a sensitive indicator of biological impacts of climate change!!!
Phenological regulation of ecosystem processes and climate system feedbacks

Connecting phenology to processes at multiple scales

Meteorology/Drivers

Phenology Models

Ecosystem Models

Phenology on the ground…

Remote sensing

Spatial

Early

Late

Temporal

Spring

May 1

Autumn

June 28

May 18

Ecosystem function

Micrometeorology: CO$_2$/H$_2$O fluxes
Albedo, roughness, etc
PHENOCAM: http://phenocam.sr.unh.edu/

Partners and collaborators:

DEPARTMENT OF ORGANISMIC AND EVOLUTIONARY BIOLOGY
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Webcam phenology:

“Near surface” remote sensing at high temporal resolution

- Commercially available webcams mounted on towers
- Images sent via FTP to external server every hour
- Image archive yields a permanent visual record
- Quantitative image analysis (RGB channel extraction) to objectively characterize phenological changes
- Focus on individuals or integrate spatially
- Varying length of time series, variable quality of camera/imagery
- Not a calibrated instrument—but neither are humans!
12 Core PHENOCAM sites

- Focus on forested research sites in northeastern US and adjacent 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 sites measuring surface-atmosphere $\text{CO}_2/\text{H}_2\text{O}$ exchange with eddy covariance, as well as complete meteorological data
- Observer records at several sites
- Unique opportunities for outreach/ public engagement
Seasonal cycles from camera imagery

WINTER  SPRING  SUMMER  EARLY AUTUMN  LATE AUTUMN

Seasonality visually obvious (leaves, no leaves)

Quantitative analysis of “greenness”:
“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

Spatial heterogeneity (inter- and intra-specific differences in phenology)
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
Variation in greenup across the canopy

- Split ROI into 16 different zones
- All trees start to green up at the same time ($\approx$ day 125)
- 4x variation in speed of green-up
- 6 day range in half-maximum date
- 50% variation in peak greenness

American beech
Late, slow development (still brown)

Red maple
Early, rapid development (very green)
Interannual variation in phenology

- Later (7 days) spring onset in 2007, but more rapid green-up
- Delayed green-down (13 days) in 2007, but velocity the same
- Later (12 days), but longer (7 days), peak of autumn color
- Patterns consistent with observer records and radiometric measurements ($f_{\text{APAR}}$, broadband NDVI)
Linking greenness to canopy-scale physiology of 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

Howland Forest AmeriFlux site
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
Why stop at regional monitoring?

*PhenoCam takes on North America!*

Images mirrored to server from 50+ sites covering a wide range of ecosystem types. Potential collaboration with AMOS (Archive of Many Outdoor Scenes): ~20,000 cameras!
Looking ahead:
A) Technical/methodological studies

1. Leaf-level studies
   - What leaf- and canopy-level spectral shifts underlie observed RGB changes?

2. Camera Comparison Experiment:
   - 12-15 cameras, different manufacturers, different attributes
     - Design (P&S, security, webcam, etc.), resolution (.25 MP – 10 MP), imaging sensor (CCD vs CMOS), internal processing (none vs. auto), output format (RAW vs JPEG)

3. Leveraging IR Capability:
   - NetCam SC-IR; IR cut filter triggered by software—an NDVI imaging sensor?
     - Exciting, but needs validation and testing
Looking ahead: B) Applications of PhenoCam data

1. Evaluating of RS data products
   - Appropriate scale and resolution for comparison
   - Intermediate link between what satellite “see” and what “happens” on the ground
   - Opportunities to improve RS algorithms?
     • LPV workshop presentation on Friday

2. Investigating links between phenology and ecosystem processes/climate system feedbacks
   - Link seasonality of camera-derived vegetation indices to photosynthesis, surface energy balance, and albedo at AmeriFlux sites
   - Opportunities to improve land surface models?
     • Representation of phenology
     • Representation of phenological control of ecosystem processes
Summary

• Use inexpensive, networked digital cameras as multi-channel imaging sensors
• “Near surface” remote sensing as an alternative to observer-based methods
• Continuous observations, not contaminated by clouds, no need for atmospheric corrections
• Images can be inspected visually or analyzed quantitatively (also: permanent visual record)
• Direct link between what happens on the ground and what is seen from space (e.g. MODIS; potential for validation/improvement of RS algorithms using webcam data)
• Ability to detect both temporal (seasonal and interannual) variation as well as spatial (across canopy) variation in 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
Thank you.

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