Keeping an eye on the carbon balance: linking canopy development and net ecosystem exchange using a webcam

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Why observe phenology within FLUXNET?

Phenology is the study of the timing of lifecycle events, especially as influenced by the seasons and the changes in weather patterns from year to year. The oldest phenological records, observations of cherry flowering at the Royal Court in Kyoto date back to 705 AD, and are still maintained to this day across Japan where the Japanese Meteorological Agency use these data to provide weekly forecast maps of expected blooming dates (http://www.jma.go.jp/jma/en/News/sakura.html). Robert Marsham, the father of modern phenological recording, was a wealthy landowner and amateur naturalist who recorded "indications of spring" in Norfolk, England, beginning in 1736. His family maintained these records until the 1950s. In the modern era, phenology has gained a new impetus, as people realize that such records, if sustained over many years, can reveal how plants and animals respond to climate change. Moreover, phenological events such as the spring leaf-out and the autumn fall exert a strong control on both spatial and temporal patterns of the carbon cycle. Phenology also influences hydrologic processes, as spring leaf-out is accompanied by a marked increase in evapotranspiration, and nutrient cycling as autumn senescence results in a flush of fresh litter (nutrient) input to the forest floor. Phenology is a robust integrator of the effects of climate change on natural systems (Schwartz et al., 2006; IPCC 2007), and it is recognized that improved monitoring of phenology on local-to-continental scales is needed. Historically, phenological observations were a pastime of amateur naturalists (e.g. the Marsham family) and reliable records were often dependent on the skills and effort of the observer. The increased demand for international co-operation and standardisation in this area led to the creation of many large-scale phenological monitoring networks such as the International Phenology Garden (IPG) program (http://www.agrar.huberlin.de/struktur/institute/pfb/struktur/agrarmet/phaenologie/ipg) (founded in 1957), the Global Phenological Monitoring (GPM) program (http://www.agrar.huberlin.de/struktur/institute/pfb/struktur/agrarmet/phaenologie/gpm) (established in 1998) as well as the recently-established USA-National Phenology Network (http://www.usanpn.org) and associated regional networks (e.g., http://www.verpn.org). These networks have focused on developing standardized protocols for phenological observations, and ensuring overlap between plant species found across locations. Although there are obvious advantages in creating explicit linkages between these phenological networks and flux monitoring networks for the purpose of understanding patterns and processes controlling carbon budgets across a broad range of scales, explicit activities to assess the impact of phenology on ecosystem carbon balance are still somewhat lacking within the carbon cycle community. The reasons are clear: long-term observations, otherwise called 'monitoring' are not popular with those that sponsor research in this area; three or five year projects are the norm, when in practice much longer records are required to detect long-term trends and their relationships to climatic drivers. There is however, evidence for a shift in attitudes. Keeling’s measurements of atmospheric CO₂ concentrations, that began in 1958, are an outstanding example of the value long-term monitoring represents in the context of a changing world (Nisbet, 2007). Moreover, continuous eddy covariance measurements of CO₂ fluxes began in the early 1990s at a handful of sites. Every year, more and more sites have been added to FLUXNET, and many of these are now providing useful long term data not only with regard to spatial patterns of carbon uptake and release, but also in relation to the influence of phenology on carbon sequestration. One example of a synergy between phenology and flux monitoring networks in Europe has occurred between the Tharandt International Phenological Garden (also one of the 24 GPM gardens) and the nearby Carboeurope-IP site Anchor Station Tharandt over the past 12 years (Niemand et al., 2005; Grünwald & Bernhofer, 2007). Using the standard observations from both networks it was demonstrated that the appearance of the Maitrieb (May shoot) for Norway spruce is correlated with annual estimates of ecosystem gross primary productivity (GPP) and net ecosystem productivity (NEP) (with the exception of the extreme drought event of 2003 in Europe). This indicates that the earlier appearance of shoots potentially increases the length of the growing season, leading to a greater annual carbon sequestration. Mean March-April temperatures were correlated with the data of May shoot, indicating a potential scalar for GPP and NEP when coupled to longer time-series from such IPG records. Similarly, an analysis coupling budburst observations and CO₂ flux measurements at the Howland (since 1996) and Harvard (since 1992) Ameriflux sites indicated that earlier budburst resulted in greater springtime GPP (5 g C m⁻² per 1 day advancement of budburst date), but these increases in carbon uptake were offset by increases in springtime ecosystem respiration (RE), resulting in an uncertain effect (not significantly different from zero) on springtime...
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NEP (Richardson et al., in preparation).

**Phenological Activities within FLUXNET**

At FLUXNET sites around the world that overlook forests, pastures, and wetlands, we have the opportunity of establishing precision measurements of phenological events by simply mounting networked digital cameras (‘webcams’) and recording daily (or even hourly) images of the vegetation canopy, as recommended by Baldocchi et al. (2005). A recent FLUXNET survey (http://www.geos.ed.ac.uk/homes/lwingate/webcam.html) has uncovered at least 26 such webcams already ‘keeping an eye’ on canopy development (Figure 1). Although this network is in its infancy, it appears to be growing steadily, and already represents some 58 site-years of combined flux and webcam data. A large number of these sites are in Asia where the Phenological Eyes Network was set-up in 2003 to create a much needed validation platform for remote sensing products such as NDVI (http://www.asiaflux.net/newsletter/no21_2007.pdf). It is also promising to learn that this number should continue to grow with the addition of sites in the US National Ecological Observatory Network (www.neoninc.org). However, just as phenological gardens must commit to observations in excess of ten year periods it is also necessary for this webcam activity to maintain a long-term perspective, especially when it comes to unravelling the relationships between forest carbon balance and phenology.

The opportunity presented to us is clear: webcam measurements at FLUXNET sites will reveal the link between phenology and carbon uptake; they will also provide much-needed ground verification of phenology products derived from satellite remote sensing (e.g., MODIS).

The role of the phenology network and citizen scientists

Within FLUXNET a protocol for phenological observations was also created to harmonise phenological observations across flux sites (http://www.fluxdata.org/Datainfo/Dataset%20Doc%20Lib/FLUXNET_phenophase_protocol.pdf). However, initiation of such long term monitoring requires a sustained commitment of human resources (that are typically scarce) and, as a consequence, these observations are not pursued at the majority of flux sites. Several of the phenology networks include a substantial volunteer or “citizen science” component, wherein trained observers track the response of plants using standardized protocols, online data entry forms and visualizations designed and streamlined for the more casual observer (e.g., UK Nature Watch, US Project BudBurst and USA-NPN, and the GLOBE project (Gazal et al., in press). These networks of observers represent a potential bridge between phenological and flux observations, in that data collected by such “citizen scientists” can be used to (a) increase the density of observation sites and species, (b) collect information on presence/absence of

![Figure 1](http://www.geos.ed.ac.uk/homes/lwingate/webcam.html) Global distribution of flux sites with webcams (Agarwal et al., 2008)
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snow, flowers or foliage undetectable to remote sensing platforms, and (c) ground-truth observations from ‘near’ (e.g., camera, or eddy correlation) or ‘far’ remote sensing platforms (e.g., AVHRR, MODIS). Development of a volunteer program for FLUXNET sites would greatly strengthen tools available for the interpretation of eddy flux data.

Towards an international canopy phenology camera network

In situ phenological observations, gas exchange and radiometric signals at the same flux sites are currently required for comparison with remotely sensed products. This is especially the case if we are to understand the apparent contradiction in findings between the CO₂, phenology and remote sensing communities with respect to the timing of canopy green up and senescence and how this relates directly to changes in the atmospheric CO₂ record, especially during spring and autumn in the northern hemisphere (e.g., Piao et al., 2008). This webcam network could soon be in a position to test whether the start, maximum and end of the growing season derived from satellite NDVI data really correspond to the actual start, maximum and end of the growth period of plants as observed in flux sites. Thus the webcam network presents a way to directly link on-the-ground observer records to remotely-sensed data, and moreover to link these to ecosystem physiology measured with flux towers.

The growing webcam network now represents a novel opportunity to implement both regional and global monitoring of phenology at flux sites. Thus efforts to extend the spatial coverage of phenological observations at flux sites through the simple addition of cameras on towers are now required within FLUXNET. In time this network will not only establish an archive of images documenting seasonal and inter-annual changes in forest phenology, but also capture associated variability in forest function and its potential impact on ecosystem carbon balance in response to long-term changes in climate. This multi-scale monitoring of phenology and net ecosystem exchange of CO₂ will enrich our understanding and efforts at modelling not only the impacts of climate on phenology but also the impact of phenology on climate through feedbacks on the carbon and energy cycle of the planet. Moreover, it has the potential to link the CO₂ flux community to the thousands of amateur observers, many of them school-children who will become the next generation of scientists.

As we have illustrated above, webcams are an important way of tracking canopy phenology. The digital images when collected at such regular intervals can be easily assembled into time-lapse movies such as those in Box 1, providing an important product for raising public awareness on phenological and carbon cycle research. The color information of these very same images can also be analyzed to retrieve information on canopy development in both deciduous and evergreen forests as described in Box 1 and 2. If you plan to mount a camera at your flux site in the near future and have any queries for the network please do not hesitate to contact us and we will do our best to help get you started.

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Literature


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