Chapter 31
Phenology in Higher Education: Ground-Based and Spatial Analysis Tools

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Abstract New spatial analysis methods and an increasing amount of remote sensing data are the necessary tools for scaling from ground-based phenological measurements to larger ecosystem, continental, and global processes. However, since remote sensing data and tools are not straightforward to master, training at the higher education level is often necessary. Curricula and training programs linking these integral components of phenological research are sorely needed because the number of people with requisite skills in the use of a growing array of sophisticated analytical tools and collected remote sensing data is still quite small. In this chapter we provide a series of examples of field-based approaches to college- and

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university-level phenological education. We then guide the reader through the resources that are available for the integration of remote sensing with land-based phenological monitoring and suggest potential ways of using these resources.

31.1 Introduction

In 1974, Forest Stearns wrote a chapter on "Phenology and Environmental Education" for the book "Phenology and Seasonality Modeling" edited by Helmut Lieth. Stearns remarked on the utility of phenology as a theme for every level of education because it helps to make the complexity of interactions between organisms and their environment relevant to students (Stearns 1974). However, he found that there were no articles on phenology in *American Biology Teacher* and only one in *Science Teacher*, the two leading science education journals of the day. Almost 40 years later, the interest in phenology among educators, ecologists, botanists, zoologists, geographers, climatologists, and amateur naturalists has increased greatly. As a result, many more phenological education resources are now available online, including indoor and outdoor activities for audiences ranging from K-12 to college students to the general public. In the United States, for example, some agencies and institutions tasked with educating students and the public about climate change have been developing phenology-themed programs, many of which make use of the growing number of internet-based public participation programs. Moreover, phenological education provides a unique opportunity for participants to explore the relationship between science, nature, and themselves. These educational programs help students develop critical thinking skills and an understanding of how science and the natural world affect their daily lives. The program in the U.S. that facilitates the collection, reporting, and interpretation of phenological data among public participation programs and across federal, non-governmental, and academic institutions is the USA National Phenology Network (USA-NPN; www.usanpn.org).

Educational objectives of the USA-NPN include recruiting and training scientists, students, teachers, outdoor educators, land stewards, and community members to contribute accurate phenological data to the growing national database and to participate in its quantitative analysis and interpretation (USA-NPN National Coordinating Office 2012). Other outcomes for participants include understanding the importance of phenology as an indicator of the health of our environment, spending more time engaged in nature, and becoming scientifically literate by engaging in scientific data collection, analysis, and interpretation. A variety of education and training materials are available on the USA-NPN's Education website (www.usanpn.org/education), both specific to its on-line data collection interface, *Nature's Notebook*, as well as to other phenology programs, including a suite of "phenological and climate change literacy" resources designed specifically for K-12, college, and public audiences, created by the Phenology Stewardship Program at the University of California, Santa Barbara (Mazer lab, Department of Ecology, Evolution and Marine Biology). The USA-NPN Education Program is also creating a suite of site-based engagement materials for facilitating community-based phenological education programs. Additional examples of well-known and successful public participation programs include the international Global Learning and Observations to Benefit the Environment (GLOBE) program, Canada's PlantWatch, Project Budburst (USA), and the California Phenology Project (described later in this chapter). Each of these programs offers materials for educators to incorporate the monitoring of plant phenology into the activities of traditional and non-traditional classrooms.

Since phenology is an integrative science drawing from numerous scientific disciplines, there are many topics in environmental science with which to engage students and the public in learning phenology. The interdisciplinary nature of phenological research challenges current and new generations of scientists, educators, and students to learn a variety of Science, Technology, Engineering, and Mathematics (STEM) skills across several disciplines. However, resources for educating certain audiences (e.g., college, university) and disciplines (e.g., remote sensing, spatial analysis) are currently limited. This is especially unfortunate because, while there has been considerable attention paid to promoting the recording of phenological observations by younger students (grades K-12) and citizen scientists, the number of people with requisite skills to use the growing array of sophisticated analytical tools and collected data is still quite small (Dickinson et al. 2010).

New spatial analysis methods and an increasing amount of satellite data are the necessary tools for using ground-based measurements to make inferences about larger ecosystem, continental, and global processes. However, these analytical tools and data sets are not straightforward to master and training is often necessary (Dickinson et al. 2010). Although a small suite of educational and training materials has been developed to address the gaps for undergraduate and post-graduate audiences (described in the field based section below: Haggerty and Mazer 2009; Haggerty et al. 2012a, b; Hove et al. 2012a, b), these resources do not directly link ground-level phenological observations with remotely sensed measurements. Both curricula and training programs to link these integral components of phenological research are sorely needed.

In this chapter we provide examples of field-based, phenology-themed college- and university-level education and then guide the reader through resources available for the integration of remote sensing with land-based phenological monitoring. We also suggest potential ways of using the resources. As there are many resources available, it is difficult to be comprehensive. The resources discussed here focus primarily on ongoing initiatives in North America that have English language web links. While we are aware of some interesting initiatives going on in other parts of the world, many of their websites are not available in English.

31.2 Field-Based Activities and Examples

To engage all components of the public in nationwide (and international) phenological monitoring efforts, it is essential to: expand educational efforts at the college and university level; provide training in the interpretation of phenological data and its link to climate change; expand public outreach efforts; demonstrate real-world applications of phenology and its relevance to career training and choices; and include phenological training for pre-service and active teachers enrolled in credential or professional development programs. Undergraduate training programs should provide greater breadth and depth particularly in the STEM skills necessary to train the next generation of scientists interested in the intersection of biology, ecology, geography, and climatology. To demonstrate the relationships among these disciplines, undergraduate interdisciplinary programs should promote and illustrate the use of long-term phenological data in scientific research. Overall, there are far fewer phenological educational settings aimed at training young scientists at the undergraduate level than K-12 phenology programs. However, over the past few years, college-based phenology programs have started to develop (Chen 2003; Long and Wyse 2012); both the USA-NPN and the CPP now offer materials appropriate for college settings (http://www.usanpn.org/cpp/education).

Three examples of classroom-based phenology training materials recently designed for undergraduate and post-graduate audiences include: the *Phenology Handbook* (Haggerty and Mazer 2009); the *Primer on Herbarium-Based Phenological Research* for tracking historical trends in flowering phenology (Haggerty et al. 2012a), which includes a sample data set and a guided spreadsheet-based analytical exercise (Haggerty et al. 2012b); and a suite of annotated undergraduate lectures and seminar modules designed to guide discussions of the primary research literature (Hove et al. 2012a, b). All of these materials, and others for K-12 and public audiences, are described and freely available online at the California Phenology Project's education website (www.usanpn.org/cpp/education). These materials may help educators provide a useful entry point into phenological research for their students by introducing the motivation for phenological monitoring, its history in the U.S. and elsewhere, the ecological interpretation of long-term phenological shifts, the links between phenology and climate change, the protocols of the USA-NPN, and the botanical observational skills necessary for the accurate reporting of the phenological status of individual plants.

31.2.1 California Phenology Project

The California Phenology Project (www.usanpn.org/cpp) is the first statewide effort to assess the effects of climate change on California's diverse landscapes. Established in 2010 with funding from the National Park Service Climate Change Response Program, the project includes a citizen science program that contributes data directly to USA-NPN's *Nature's Notebook*. The CPP takes a "train-the-trainer" approach, where training workshops are delivered primarily for participants who will themselves deliver continued training sessions for their staff, for place-based volunteers dedicated to monitoring geo-referenced and labeled plants at particular national parks, and for the public. The long-term aims of the CPP include: testing and refining USA-NPN protocols for ground-based phenological monitoring; creating tools and infrastructure to establish long-term phenological monitoring in California national parks, University of California Natural Reserve System, and public lands; informing decisions routinely made by land managers that depend on the timing of phenological events; and developing materials to help park staff and educators to communicate to the public how the seasonal cycles of natural resources in the parks are affected by inter-annual variation in climate and by climate change.

The CPP was funded initially to establish phenological monitoring programs in seven national parks and recreation areas in California. These pilot parks range from those with high visitation from nearby urban populations (e.g., Santa Monica Mountains National Recreation Area [NRA], Golden Gate NRA, and John Muir National Historic Site) to remote parks with relatively little visitation and a small community of volunteers (e.g., Lassen Volcanic National Park). The pilot parks were also selected to represent a wide range of ecosystems and biogeographic regions. Coastal region chaparral, prairie, and forests are represented by Santa Monica Mountains NRA, Golden Gate NRA, John Muir National Historic Site, and Redwood National and State Parks. Montane plant communities are represented by Lassen Volcanic National Park and Sequoia & Kings Canyon National Parks. Desert communities are represented by Joshua Tree National Park. Several of these parks work actively with outdoor schools and/or local teachers (e.g., NatureBridge, the National Park Service "Parks as Classrooms" and Teacher-Ranger-Teacher programs- www.nps.gov/learn/trt/, and regional school districts) to incorporate phenological monitoring into residential or single-visit programs.

The CPP offers materials and phenology-themed lesson plans to guide educators using a variety of approaches, including seminar modules (appropriate for advanced undergraduate or graduate education, and including guided discussions of the primary literature), practical instructions for the use of herbarium specimens to detect historical changes in phenology (targeted towards undergraduates and adult citizen scientists), annotated lectures (to introduce university students and citizen scientists to the study of phenology and its link to climate and climate change), hands-on interactive activities (appropriate for middle-school through adult education), outdoor activities (for middle school through adult education), and a step-by-step guide for the construction and use of native plant gardens designed for phenological monitoring.

Plant species adapted to Mediterranean, semi-arid, and arid environments, such as the California chaparral, high- and low-elevation deserts, and the southwestern U.S. present a number of challenges for phenological monitoring whether on-the-ground or remotely sensed. For example, compared to the highly seasonal temperate zone, where the onset of an individual plant's growing season can be clearly defined by the opening of large, dormant, well-protected winter buds and the subsequent synchronous emergence of young leaves, the growing season for many species adapted to Mediterranean, frost-free, and desert environments is poorly defined. Many species of long-lived perennials, shrubs, and trees adapted to these habitats are semi-deciduous and do not produce visible vegetative buds that remain dormant until the growing season is initiated. Rather, they produce leaves opportunistically from meristematic tissue (typically located in the axils of leaves or at stem tips) whenever conditions allow, usually after precipitation events. Consequently, a "growing season" of such plants is an episodic process that can recur multiple times from spring through autumn. The total length of the growing season may be determined as much by the temporal distribution of rainfall events as by the total amount of rain occurring during the wet season. Compared to the temperate zone, where the end of the growing season is determined by the onset of cool temperatures and the timing of the first frost, the termination of annual growth is not well-defined in frost-free environments of the western and southwestern U.S.

Consequently, participants in phenological monitoring networks who observe plants in these environments must be counseled that the onset of vegetative growth may occur multiple times throughout the year, such that capturing all of these events requires an extended period of vigilance that is not essential in more seasonal environments. When the California Phenology Project offers training events focusing on these species (e.g., *Adenostoma fasciculatum*, *Baccharis pilularis*, *Coleogyne ramosissima*, *Eriogonum fasciculatum*, *Larrea tridentata*, and *Mimulus auriantiacus*), instructors take care to point out the locations on plants (apical meristems) where new growth (both vegetative and reproductive) occurs. This training helps participants to seek evidence for newly occurring leaf growth in the absence of large, conspicuous buds.

31.2.2 Phenology Gardens and Trails

Phenology gardens are planned landscapes established for the purpose of monitoring plant and animal phenology. Phenology gardens have been planted and monitored by agricultural climatologists since the 1950s to study and better predict growing seasons across Europe (International Phenology Gardens) and across the U.S. (Lilac Phenology Network). Although established with short-term interests in mind, accumulated data from these projects have helped to form the foundation of knowledge about long-term phenological responses to climate change in Europe (Menzel 2000; Chmielewski and Rotzer 2001) and the U.S. (Cayan et al. 2001; Primack and Miller-Rushing 2009). With careful planning such gardens are able to distinguish environmentally-induced from genetically-based variation in phenology and to detect genetic variation in the phenological response to climate change.

More recently, the educational values of phenology gardens are being identified and developed. In *Phenology Gardens: a practical guide for integrating phenology into garden planning and education* (Haggerty et al. 2012c), the authors provide conceptual background and suggestions for planning and establishing phenology gardens to maximize scientific, educational, ecological, and societal goals (including aligning gardens with USA National Phenology Network programs). They also provide case studies from four native plant phenology gardens established in southern coastal California in collaboration with the USA-NPN, US Geological

Survey, and US Fish & Wildlife Service. A network of more than 15 phenology gardens, each containing a similar suite of native plant species, has been established at schools, community centers, and universities in the region, largely due to continued efforts by the Ventura office of the US Fish & Wildlife Service. Phenological data collected in the gardens have been reported to the USA-NPN's *Nature's Notebook*.

The USA-NPN also has developed an implementation guide for creating Phenology Trails, *The Phenology Trail Guide: An experiential education tool for site-based community engagement* (USA-NPN National Coordinating Office 2012). Phenology Trails are networks of *Nature's Notebook* observation sites linked together to provide participants places to visit, enjoy nature, collect data, and learn about supporting organizations and their efforts related to phenological research. Such trails further serve the purpose of collective engagement, meaningful learning, and development of community.

Phenology gardens and trails can be established relatively easily in K-12, college, or public settings, thereby creating an outdoor classroom that can be revisited easily over time for phenological monitoring and basic instruction in plant biology. With some planning, phenology gardens can be integrated into many curricular goals and topics for all ages. Thus, phenology gardens provide a valuable setting for developing a broad range of concepts and skills spanning STEM, humanities, and fine arts topics. As such, phenology gardens can provide a single unifying platform for integrative environmental education. For example, Haggerty, Hove, and Mazer developed several activities that use USA-NPN protocols, including *Flight of the Pollinators* (Haggerty et al. 2012d), *Ethnophenology* (Haggerty et al. 2012e), *Phenology Relay Race* (Haggerty 2012a), and standards-aligned lesson plans (Haggerty 2012b). These resources are described and available on the California Phenology Project's education website (www.usanpn.org/cpp/education).

31.2.3 Phenology at Ferrum College

As an illustration we discuss how the study of phenology is integrated into science instructions at Ferrum College (www.ferrum.edu), a small undergraduate college in Virginia. Faculty at Ferrum College have introduced phenology into horticulture and environmental sciences courses by using the Project BudBurst website to teach phenology and climate change. Here are two examples of class assignments.

31.2.3.1 Making Phenological Observations of Campus Species

This module was used in Introductory Horticulture (HOR/AGR 219) at Ferrum College in the spring semester of 2010. This introductory class targets both horticulture and agriculture majors. The purpose of the exercise is to increase student awareness of plant cycles by using the plants in the Ferrum Community Arboretum for observation. Horticulture and agriculture students must make decisions on plant management based upon predicted climate change. These decisions may, for example, include planting dates, germination rate, and pest management. By completing this exercise and monitoring plant phenological schedules, students can begin to understand the complexities of plant cycles as they relate to climate as well as the growth and management of plants in controlled settings. By entering their data into the national database, students in subsequent courses can use these data to discuss phenological trends that may be related to climate change.

In lab, students were told they would be doing an exercise on the phenology of plants. Each student was given a pre-test to determine their familiarity with phenology, plant identification, and plant growth as it relates to climate change. Students were then given a handout obtained from the Project Budburst site and asked to review the information. Following a discussion which focused on phenology of the plant species growing on campus and plant life cycles, the class went to the computer laboratory to log onto the Project BudBurst website (neoninc.org/budburst). After reading the introductory information, they were instructed to enter the online BudBurst guide.

31.2.3.2 Using Project Budburst to Study the Effects of Climate Change on Plant Phenology

The goal of the module developed for this project was to acquaint students with the impacts of climate change on the seasonal biological cycles by having them contribute to a worldwide phenological study. The students recorded and reported their phenological observations using the Project BudBurst website.

Student teams (two students) in *Environmental Sciences and Issues in Appalachia* (ESC 110) participated in this project by choosing a plant (tree, shrub, or annual plant) from the Project BudBurst list of plants of interest. Students made twice-weekly observations and took photos with a digital camera or their cell phones for 7 weeks during the spring semester of 2010 at Ferrum College. Student observations and photos were uploaded to ANGEL, the learning management system at Ferrum College. At the end of the observation period (end of April), each student team had approximately 14 observations and photos. Some student teams did not observe first leaf and most did not observe first bud because of the timing of the spring semester relative to the onset of spring in Ferrum, Virginia (37°59′N, 79°59′W, elevation = 437 m) which starts at the very end of the spring semester. The student collected observations and photos were collated and summarized at the end of the class project by the student project assistant. The data were summarized by plant species and phenophase and then entered into the Project BudBurst database by the student project assistant. Assessment of these class activities was accomplished by administering a pre-test and a post-test and making note of number of observations and photos.

31.3 Remote Sensing

There is a place in college-level classes for the analysis of satellite imagery without the need to provide more than basic knowledge in remote sensing. Students can be introduced to basic remote sensing principles and the tools to download remotely sensed data. In addition, they can learn how to interpret image time series with respect to phenological monitoring. Several resources are available for downloading and processing of satellite data. In this section we limit our discussion to resources that focus directly on links between remote sensing and phenological data.

Land surface phenology (LSP) explores how quasi-periodic events in terrestrial vegetation (e.g., budburst, leaf out, flowering, senescence) appear when observed by remote sensing technologies. LSP can be studied by means of vegetation indices calculated from optical sensors, such as the Advanced Very High Resolution Radiometer (AVHRR) polar orbiting sensors as well as the newer Moderate Resolution Imaging Spectroradiometer (MODIS) sensors on the Terra and Aqua satellites which provide higher spatial resolutions (250–1000m) than the older but still operational AVHRR series (1–8 km). Land surface phenological metrics are primarily based on image time series of vegetation indices (VI). These phenological metrics aim to retrieve onset of greening, timing of the peak of the growing season, senescence, and the growing season length based on analysis of the VI curve (Reed et al. 1994; Zhang et al. 2003, 2004; White et al. 2009; de Beurs and Henebry 2010a). Vegetation indices such as the Normalized Difference Vegetation Index (NDVI) and the Enhanced Vegetation Index (EVI) are surrogate measures for aboveground net primary production, and in recent years, considerable effort has been made to link the global NDVI variability to temperature, precipitation, and atmospheric CO_2 (Myneni et al. 1997; Tucker et al. 2001; Lee et al. 2002; Dye and Tucker 2003; Zhou et al. 2003).

As such, LSP provides an important method for detecting responses to climate change in terrestrial ecosystems. Changes in LSP (sometimes erroneously called "greenness") have often been detected as trends in NDVI products over multiple years (e.g. Dye and Tucker 2003; Beck et al. 2006; Julien et al. 2006; Bradley et al. 2007; Potter et al. 2007; de Beurs et al. 2009; White et al. 2009; de Beurs and Henebry 2010b). These changes in the timing or intensity of the phenological signal over multiple years are frequently interpreted as resulting directly from climate change, particularly warming or droughts (Potter and Brooks 2001; de Beurs et al. 2009; Brown et al. 2010). Thus, there is great potential for college and graduate training in LSP and remote sensing to contribute to new generations of climate change scientists.

Although college-level geography classes generally provide students with an introduction to remote sensing and training using remote-sensing software packages such as ERDAS Imagine, PCI Geomatics, or Exelis ENVI, remote sensing classes do not necessarily discuss land surface phenology and how to link these observations with ground level observations of individual plants, populations, or communities. This omission is especially unfortunate given the number of resources that are available to facilitate the use and analysis of long-term image time series. Moreover, even courses that are not specifically focused on remote sensing may now introduce the analysis of satellite imagery in their programs. The tools and data sources discussed in the last section of this chapter are provided as a resource for instructors aiming to enhance their college-level classes by training students not only to collect and to interpret ground level observations, but also to link these observations with satellite observations (Table 31.1).

31.3.1 USGS Remote Sensing Phenology

The USGS website Remote Sensing Phenology provides an overview of how remote sensing can be used to monitor phenology (http://phenology.cr.usgs.gov/index.php). This resource also provides a short explanation of data, sensors, and methods available, and offers the opportunity to download remotely sensed phenological indicators at 1km spatial resolution over the Continental United States (CONUS) derived from AVHRR data. The data are available from 1989 to 2010. The downloaded files are available as png images, which can be viewed in any image viewing program, and as flat binary files in band sequential format that can be opened with specialized remote sensing programs such as Exelis ENVI, ERDAS Imagine, or PCI Geomatica, as well as ESRI ArcMap. While there are no specific educational modules available, the data could be incorporated easily into college classes.

31.3.2 ORNL DAAC (Distributed Active Archive Center for Biogeochemical Dynamics)

The National Laboratory Distributed Active Archive Center (ORNL DAAC; daac.ornl.gov/MODIS/modis.html) provides users with easy-to-use data files in text or GeoTIFF format of MODIS phenology products for any site on land, user-selected area from one pixel up to 200 × 200 km, and time period between 2000 and the present (Table 31.2; SanthanaVannan et al. 2009). In addition, the subsets are online in interactive time series plots that reveal the timing of vegetation events. The products are thus especially well-suited to be used in a college course on the monitoring of land surface phenology. Students are able to select a defined research area using a Google Map interface and then to download subsets of satellite data up to 4,000 km^2. The ORNL DAAC offers the download of most basic MODIS products including vegetation indices (MOD13Q1), leaf area index (LAI), fraction of photosynthetically active radiation (FPAR) (MOD15A2), and gross primary productivity (MOD17A2). The selected data can be downloaded as GeoTIFF files in their original sinusoidal projection. These images can be incorporated into any remote sensing program and ESRI's ArcMap. In addition

Table 31.1 Available resources for land surface phenology in education

	Websites
Remote sensing data sources	
USGS Remote sensing phenology	http://phenology.cr.usgs.gov/index.php
ORNL DAAC Land product subsets	http://daac.ornl.gov/MODIS/modis.shtml
Web-enabled Landsat data	http://weld.cr.usgs.gov/
Vegetation index and phenology	http://measures.arizona.edu/MODIS_Project.php
Phenocam network	http://phenocam.unh.edu/webcam/
Real time phenology monitoring	http://tethys.dges.ou.edu/Twofiles/ and http://tethys.dges.ou.edu/EVI/
Software	
Season	http://tethys.dges.ou.edu/
Timesat	http://www.nateko.lu.se/timesat/timesat.asp

Table 31.2 Spatial and temporal resolution for MODIS products that provide vegetation phenology

Products	*Short name*	*Nominal spatial resolution (meters)*	*Temporal resolution (days)*
Land cover dynamics	MOD12Q2	500	8
Vegetation indices	MOD13Q1	250	16
Leaf area index and fPAR[a]	MOD15A2	1,000	8
Gross primary productivity	MOD17A2	1,000	8

From https://lpdaac.usgs.gov/products/modis_products_table (Accessed on November 12, 2012)
[a]*fPAR*: fraction of photosynthetically active radiation

to imagery, the ORNL DAAC tool provides a good overview of the selected data within an easily navigable interface. The website also provides a general overview of the land surface phenology (using the MOD12 land surface dynamic product) for the selected area.

The *Remote Sensing and Phenology* class at the University of Oklahoma, co-taught by de Beurs and Hobson, teaches students how to use the ORNL DAAC data. After learning about the MODIS sensors, the quality of the information that they provide, and the different products that are available, the students spend several weeks investigating land surface phenology around the globe using data from the ORNL DAAC. In one exercise, the students are asked to select satellite data from one year for three different areas of the same biome around the world. They use the Season program (described below) to explore the land surface phenology visible in the satellite data and they learn how the land surface phenology can differ within biomes, depending on its location. The students summarize their findings in PowerPoint slides that are discussed collectively in class. Another exercise has the students compare the land surface phenology from different biomes. The students investigate the changes in land surface phenology for these biomes over multiple years. The students in the *Remote Sensing and Phenology* class also conduct ground level phenological monitoring in a small forest on the campus of The University of Oklahoma. This university forest, called Oliver's

Woods, contains a trail with more than 100 geo-referenced trees representing more than 15 different species (oudaily.com/news/2012/may/01/class-collects-information-plant-growing-seasons). Students link these ground-based observations with the MODIS data retrieved from the ORNL DAAC.

31.3.3 Web-Enabled Landsat Data (WELD)

The NASA-funded WELD project provides Landsat 7 ETM + terrain corrected mosaics at several temporal resolutions for the conterminous United States and Alaska. The Landsat 7 images offer 30-m resolution, which is finer than the MODIS (250–500 m) or AVHRR (1–8 km) data that are frequently used for phenological monitoring. In addition to top of atmosphere (TOA) reflectance data, the project delivers NDVI data and several quality flags. The 'what you see is what you get' ordering system allows the ordering of custom size mosaics that are delivered as geotiff data and can easily be incorporated into remote sensing software or ESRI ArcMap. In addition to the ordering of image mosaics, the systems allows for the ordering of time series from a specific 30 m by 30 m area. These data are delivered as text files that can be analyzed easily in spreadsheet software. This last option is particularly interesting for those who do not need entire image mosaics. One interesting exercise for students is to investigate the land surface phenology over a given land cover type across a north–south gradient, for example by selecting one pixel per state from North Dakota to Texas. The data can be plotted in spreadsheet software to investigate the effect of latitude on the development of land surface phenology. Another potential exercise is to compare the land surface phenology of different crop types (e.g., spring wheat, soybeans, corn, and winter wheat), within and across latitudes or elevations.

31.3.4 PhenoCam Network

The PhenoCam network is a continent-wide monitoring effort in North America (focused in the U.S.) that provides automated, near-surface remote sensing through the use of high-resolution webcams. The images are uploaded to the PhenoCam website every half hour (Richardson et al. 2007; www.oeb.harvard.edu/faculty/richardson/phenocam.html) and are available for educational and scientific use after registration (see Chap. 22 in this volume). Although the PhenoCam network does not offer any specific educational opportunities, it is not difficult to incorporate these images into college-level education. For example, when learning how to interpret land surface phenology signals, it is often beneficial for students to observe how each vegetation index corresponds to the phenological progress of vegetation on the ground. While a ground-based investigation close to campus is often ideal, students may supplement these data with observations from other ecosystems, such as those monitored by the phenocams.

31.3.5 Real Time Phenological Monitoring Application

If we are interested in the analysis of land surface phenology and the coupling of these remotely sensed observations with ground observations, it may not be necessary to learn specialized (and relatively expensive) remote sensing software packages. A freely available online application (tethys.dges.ou.edu/Twofiles/) was developed by de Beurs to enable the monitoring of land surface phenology over North America. The application allows for the selection of one 0.05° by 0.05° area based on a Google Earth map of any location in North America. Upon selection of an area, the application then reveals the average land surface phenology of all available years (currently 2000–2011) based on phenology derived from the MODIS Nadir BRDF-Adjusted Reflectance (NBAR; MOD43C3). The user can request standard errors for the NDVI values based on all years to better understand temporal variability, and then compare the phenological cycle of the current year (now 2012) to that of previous years (Fig. 31.1). The user may calculate the start and end of the growing season based on satellite data by experimenting with different thresholds for the midpoint NDVI method (White et al. 1997). This method was found to be one of the most accurate methods in a large land surface phenology model evaluation study (White et al. 2009). The users can explore the effect of the different thresholds for the estimation of the start and the end of the growing season. Data can be exported as jpeg files and the time series can be transferred to spreadsheets for subsequent analysis. A similar application is available to compare the standard vegetation indices NDVI and EVI.

31.3.6 Season Software

The Season program is a freely available custom developed software package developed by de Beurs (Fig. 31.2) that allows colleges and universities to adopt remote sensing in classes that address phenology. It can ingest and process data from the ORNL DAAC and it provides a range of widely used methods to estimate the start and the end of the growing season. This flexibility enables students to experiment with a range of different methods to enhance their understanding of the differences among methods. Students can investigate individual grid cells and output the information into basic spreadsheet programs or as jpg files that can be incorporated into written reports (Fig. 31.2). They are also able to investigate a range of MODIS products including the basic vegetation indices NDVI and EVI, but also LAI, FPAR, and MODIS land surface temperature. This software was developed for de Beurs' *Remote Sensing and Phenology* classes at Virginia Tech and at The University of Oklahoma. The program also has been successfully used in professional workshops on land surface phenology at conferences of the US Chapter of the International Association for Landscape Ecology (US-IALE) in 2008, 2010, and 2012.

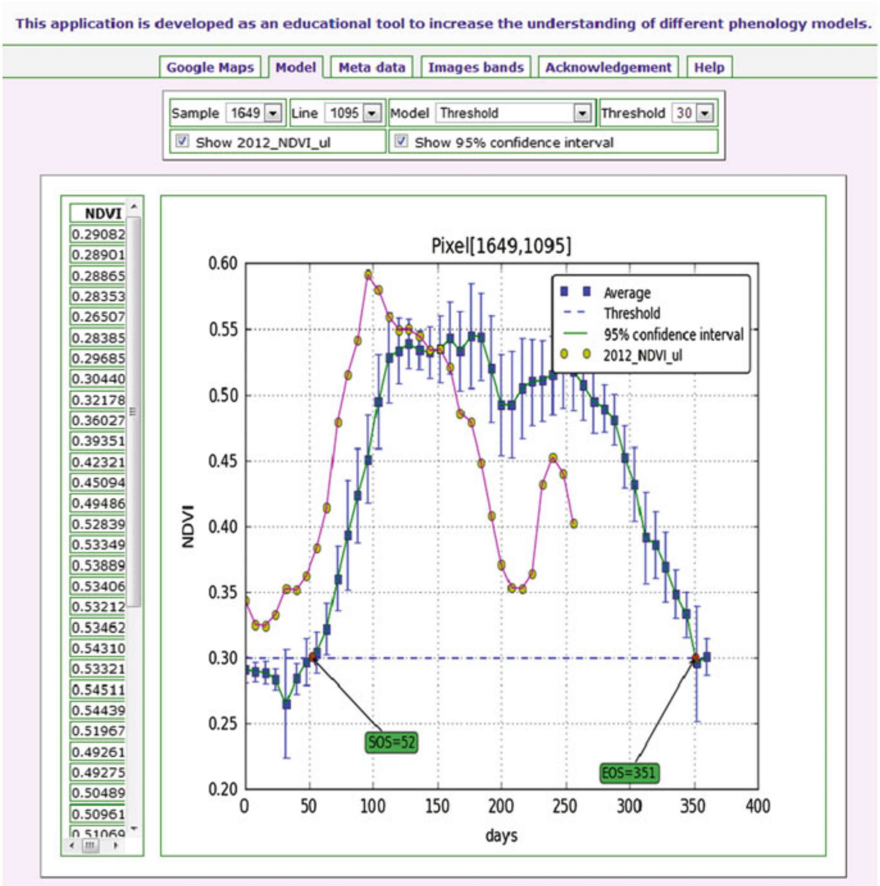

Fig. 31.1 Web application to monitor the phenology based on MODIS BRDF (MOD43C3) data. The figure shows the average NDVI between 2000 and 2011 for The University of Oklahoma in Norman (OK) in *blue*. The *yellow dots* give the current ongoing vegetation development for 2012. It is easy to see that the spring in 2012 has developed more quickly relative to the average of the previous 12 years (The data were downloaded from USGS's Land Processes Distributed Active Archive Center: https://lpdaac.usgs.gov/)

31.3.7 Timesat Software

Timesat is another freely available software package that is specifically developed for the analysis of image time series to investigate phenology. Timesat allows for the smoothing of satellite image time series using Savitzky-Golay filtering, asymmetrical Gaussian, or double logisitic functions (Jonnson and Eklundh 2002, 2004). The package has been used in a range of scientific studies (Verbesselt et al. 2006; Huemann et al. 2007; Gao et al. 2008), including the development of the MODIS North American Carbon Program phenology product (accweb.nascom.nasa.gov/)

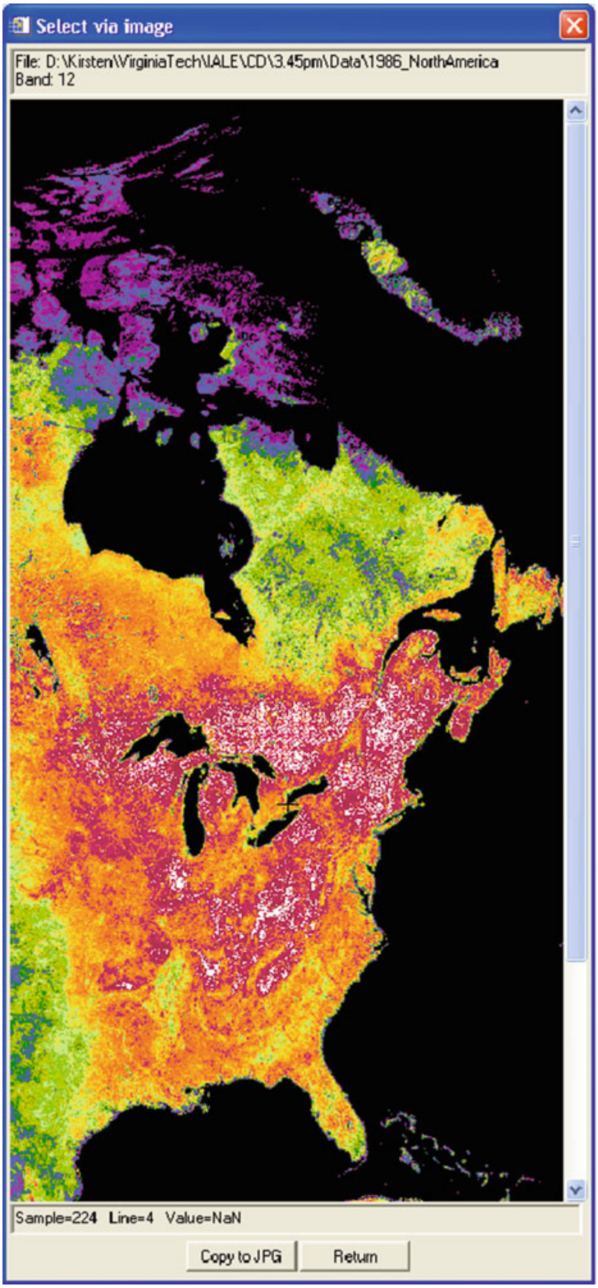

Fig. 31.2 Software to determine land surface phenology variables such as start and end of season

that is currently only available through 2008. Output of the program includes phenological metrics such as the beginning and end of the growing season and smoothed versions of the original input data. While the TIMESAT software is freely available, it is not appropriate for introductory level college courses since there is a relatively steep learning curve. In addition, specialized remote sensing software, such as Exelis ENVI or ERDAS Imagine is necessary to create the input data for TIMESAT. More advanced students, however, may enjoy experimenting with the program.

31.4 Conclusions

The interdisciplinary nature of phenological research challenges current and new generations of scientists, educators, and students to learn a variety of Science, Technology, Engineering, and Mathematics (STEM) skills across several disciplines with the goal of developing the critical thinking skills necessary for understanding human relationships to the natural world. There is an increasing interest in training college and university students in remote sensing and spatial analytical methods. Likewise, working with satellite data and spatial analyses are essential skills for researchers wishing to extrapolate landscape-level processes from ground-based phenological measurements. Curricula and training programs linking these vital aspects of phenological research are just beginning to develop but are sorely needed and can provide post-secondary students engagement in real-world projects, thus informing career choice.

This chapter has discussed a number of resources for training students to take field measurements, such as those provided by Project Budburst and the USA National Phenology Network, as well as tools focused on the analysis of land surface phenology data.

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