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Seeing climate through the lives of plants [1]

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Ground observers and satellites monitor plant life cycles and the timing of seasons.

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On a May morning, a gray-haired woman counts the opened blooms on the bud clusters of a lilac branch that is just starting to release its sweet fragrance. She then goes into her house to access an Internet site, where she logs today as the "first bloom" date of her lilac plant. She is helping researchers understand global climate.

Citizen scientists like this woman are forming an eventual network of thousands who will volunteer to make careful and specific local observations of plants and animals. Plant budding and blooming are one aspect of phenology, the study of periodic plant and animal life cycle events that are influenced by environmental changes. In particular, researchers are examining seasonal variations in temperature and precipitation that are driven by weather and climate. Measured as a few degrees of temperature, climate change may seem abstract. Yet these changes can be expressed vividly in the lives of plants and animals.

A long series of data on the timing of phenological events, gathered by observers blanketing a continent, can help scientists monitor climate change and its effects on Earth's life. Toward this goal, a team of researchers, including Bradley Reed at the United States Geological Survey (USGS) in Arizona, and Mark D. Schwartz at the University of Wisconsin-Milwaukee, are growing the USA National Phenology Network (NPN). These researchers are working to join a network of ground observations with satellite-based remote sensing data to create a "wall-to-wall" phenological record of climate in the United States.

Spring's onset from ground and space

"Plant phenology can help us understand global change questions," said Reed, who along with Schwartz is a member of the NPN implementation team. "With global warming, it appears that growing seasons are getting longer. Spring is coming sooner, and fall is beginning later. We've been studying remote sensing data for some time to get an objective answer to those questions," Reed said.

Scientists and citizen volunteers are observing first bloom and first leaf dates of lilacs and other plants to gather data on the timing of spring. These observations, connected with satellite data on plant activity, will help researchers monitor climate and its effects on the biosphere. (Image above and in title graphic courtesy Mark D. Schwartz)

Schwartz and two colleagues studied the onset of spring using observational data on Northern Hemisphere temperatures from 1955 to 2002. Compiling temperature patterns relative to plant development, they calculated dates of first bloom, first leaf, last freeze, first freeze, freeze period, chill dates, and average annual temperature. They concluded that biological spring is indeed arriving earlier in the Northern Hemisphere, coming an average of 1.2 days earlier each decade.

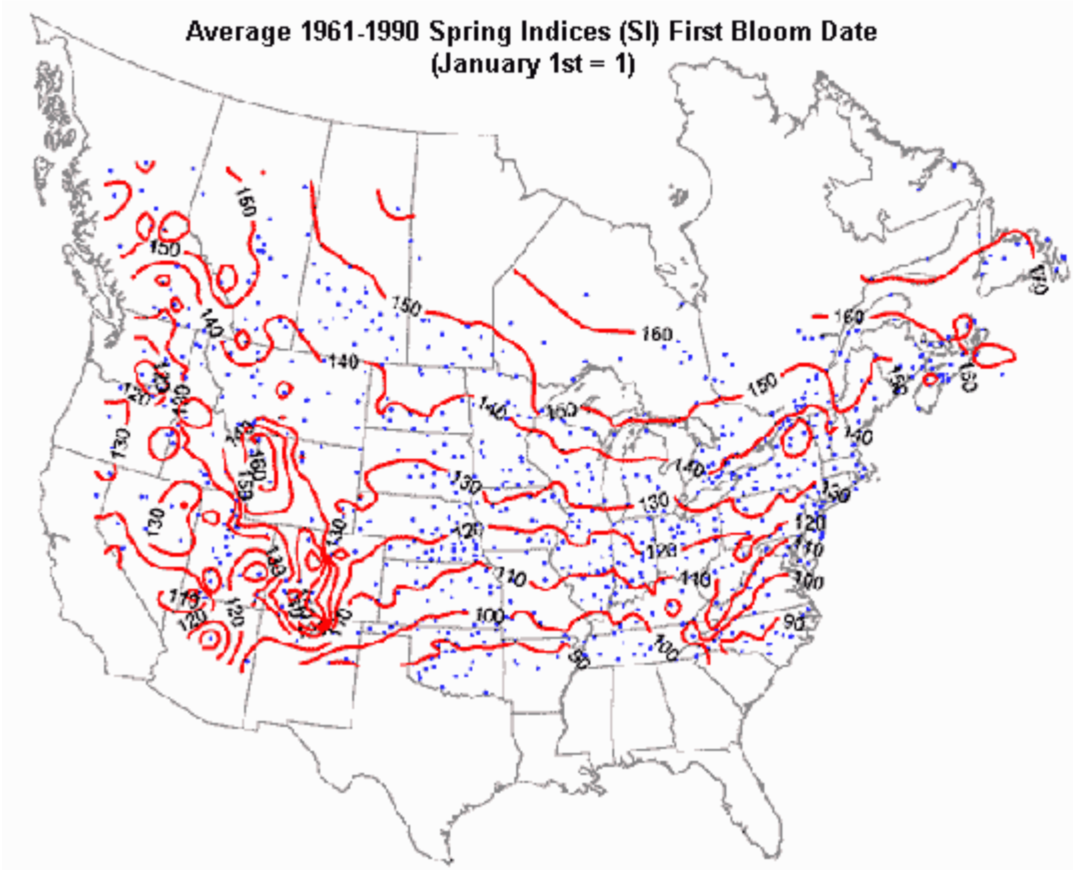
Schwartz said, "Our premise is that phenological response in the spring is a proxy for what's going on with climate. An early warm spring, for example, will impact soil moisture later on, and set off a chain of connections." The effects of a warmer climate are stronger in spring and winter; examining average temperatures for spring and winter alone may reveal sharper variations than the average temperatures for a whole year. Plant activity helps bring these variances to light.

Remote-sensing instruments, such as the Moderate Resolution Imaging Spectrometer (MODIS), can detect events related to the onset of spring. MODIS detects spring leaf-out, for example, by sensing changes in the amount of energy reflected back from earth. Leaves, because of their chlorophyll and other pigments and special structure, reflect more energy in certain wavelengths than bare ground, bare trees, or dormant grasses. MODIS detects these wavelengths; by comparing reflectance measurements over time, researchers can measure what they call the "leaf area index." MODIS data, distributed on a global scale by the NASA Land Processes Distributed Active Archive Center (LP DAAC), can also estimate the timing of other events tied to seasonal cycles. These indicators include green up and maturity in spring and summer; in fall and winter, MODIS detects senescence, or vegetation decline resulting in fall color change, and dormancy.

But other indicators are best studied on the ground. Schwartz said, "MODIS can detect leaf out, but it's harder to see subtle events like bud break in the satellite data." Reed agreed, saying, "We could tell there was a lot more information in the satellite data than we knew how to extract. The data from the ground network will help us sort this out."

Emphasizing the value of both field and space observations, Schwartz said, "We're not trying to replace remote sensing with the phenological network, but make it more flexible. A lot of my work in the past concentrated on going out in the field and recording phenology by examining individual plants. We want to know what's going on over the whole continent. Having observations on a few trees from an area is not a fair way to compare to a 250-meter MODIS pixel. Instead of looking at a couple of trees, we are now collecting spatially concentrated phenological measurements from hundreds of trees that are more comparable to satellite pixels."

Scaling up the view to a continent is far from simple. Reed said, "Ground observations of phenology are critical for validation of the satellite data. Remotely-sensed phenology is very difficult to validate because of the need for constant observations, which are costly over large areas. The idea is to create an organized network by engaging a large number of different observational communities, and to increase the density of observations."



This graphic depicts Average Spring Indices (SI) First Bloom Dates, an indicator of spring's onset. Researchers modeled the data from field observations and then generated first bloom dates based on historical temperature data. The blue dots indicate the locations of the temperature stations; the numbers indicate the average SI first bloom dates from 1961 to 1990; and the red lines indicate the geographical range of each average. Researchers examined trends for the 1955 to 2002 period at these stations to conclude that spring has been arriving earlier. The graphic also illustrates the spatial variability of the data. Researchers hope to better understand this variability through increased coverage from field observations coupled with satellite-derived phenological data. (Courtesy Mark D. Schwartz)

Effects of climate on life

Long-term, continental-scale phenological records will help researchers measure the impacts of climate change that may not be easily reversible, even if temperatures returned to historical ranges. Schwartz said, "If you think about how surface weather data has been collected by volunteer observers over the last century, and how much better we understand weather phenomena as a result, we need the same sort of dense, ongoing observations of biology. These data will allow us to monitor changes in climate and at the same time understand more about the dynamics of the plant and animal communities."

To illustrate how changes in timing of seasons affect plant reproduction, take the example of a peach tree that is well-adapted to Georgia. Plant it in a northern state, and it continues to leaf out and grow, but seldom produces peaches. Spring's warmth stimulates bloom too early, and then the normal, late spring frosts of the cooler climate nip the developing fruit. Natural variability can also disrupt plant life cycles from year to year. In southwestern Michigan's fruit belt, the influence of nearby Lake Michigan moderates a more slowly warming spring that usually protects fruit crops. But now and then, grape and cherry growers lose their crops to early warm spells or unseasonable frosts.

Even after intense cold, heat, flood, or drought, life will eventually rebound, within normal ranges of climate variability. But persistent change, even if small, can have permanent, rippling effects on an entire ecosystem. "Changes in the onset of spring can disrupt the established synchronization between plants, insects, and birds," Schwartz said. "Insects are adapted to hatch in sync with the life cycles of plants that provide their food supplies, and in turn, insects are food for birds and mammals. And with climate changes, conditions may become more favorable to invasive plants, which then move in more readily and compete with native species. Then native species, and the insects and birds that depend on them, can decline or disappear."

People have long recognized the timing of plant, insect, and animal life-cycle events as markers of spring. To better record and understand climate, researchers systematically study the timing of these events. The Milbert's Tortoiseshell butterfly (*Nymphalis milberti*) is a harbinger of spring in many northern areas of North America, often emerging in March. (Courtesy Photos.com)

Understanding these dynamics requires distinguishing natural and local variability from more extensive and persistent climate change. "A phenology network will help us understand variability on a fine scale," Schwartz said. Remote sensing of plant phenology depends on interactions between vegetation, regional climate, soil, and microclimate, and all of these factors can vary across a study area. So researchers must be able to distinguish smaller-scale variability from larger-scale changes. "The ground data will help us understand spatial variability that results from differences in the responses of species and from differences in micro-environments," Schwartz said.

To get this simultaneously broad continental view and at the same time, local ground understanding of plant phenology, researchers face the task of relating satellite pixels to thousands of individual ground sites. To help scale this task down, the NASA Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC) offers the MODIS subsetter, a tool that helps field study researchers work with MODIS vegetation data.

"The subsetted MODIS data helps us with the scale issues involved in a large study area," Schwartz said. "We need frequent data to track phenological events in spring, and over a wide area." Frequent, large volumes of data can be difficult and expensive to work with because of computing requirements and format. The MODIS subsetter allows researchers to pick out the MODIS data pixels that correspond exactly to field sites, and receive the data in either plain (ASCII) or geographically-coded (GeoTIFF) format. The ease of access, smaller data volume, and simple file format make large-scale studies such as a continent-wide ground phenology network more manageable and affordable.

Implementing the network

The idea of a "citizen scientist" network is not new. In the United States, Thomas Jefferson began recruiting volunteer weather observers in 1776. Today, under the direction of the National Weather Service, more than ten thousand volunteers record local temperature and precipitation data. "We are hoping to enlist some of those volunteer weather observers and so make use of a network that already exists," Schwartz said.

The implementation team chose lilacs as key phenology indicators for the NPN. "We based our approach on the experience of agricultural experiment stations of the 1950s and 1960s," Schwartz said. "They chose lilacs, because of their hardiness, broad distribution range, and distinct phenology. And people like receiving lilacs." Volunteers receive lilac plants cloned from cuttings, ensuring that they are genetically identical and will respond the same way to the environment. Lilacs will not grow everywhere, though, so observers may also select other indicator plants, or a plant from a list of natives. The volunteers choose a sunny location and nurture their lilac for one to two years before reporting first leaf and first bloom observations. The team hopes to develop a network of two thousand or more sites across the United States.

In the future, the volunteers may also record animal observations and signs of fall. Schwartz said, "Autumn phenological events have been poorly explored. The kinds of events that occur in autumn, related to first freeze or leaf drop, are often not as sharp." Researchers have been noticing changes in fall, and want to study more closely what they signal. Reed said, "For example, our colleagues in agriculture noticed that temperatures are remaining warmer longer than in the past, after winter wheat has germinated. Winter wheat germinates in late fall and remains dormant until spring. If its growing season is extended in autumn, it becomes more susceptible to pests, affecting yields."

Today, the USA National Phenology Network is growing, thanks to the committed efforts of many researchers who look forward to some day tapping this network for their research. "The development of NPN is totally grass-roots," Reed said. "It's a multidisciplinary science effort, with researchers around the country all working for the same goal. The network will have many applications: knowing how to time agricultural activities, for example, or studying the human health effects of longer allergy seasons."

References

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NOAA's National Weather Service Cooperative Observer Program [4].
Accessed September 19, 2006.

NOAA History: Cooperative Weather Observers [5].
Accessed August 15, 2006.

Related Links

- USA National Phenology Network [6]
- NASA Oak Ridge National Laboratory DAAC [7]
- NASA Land Processes DAAC [8]

About the remote sensing data used	
Satellite	Terra/Aqua
Sensor	Moderate Resolution Imaging Spectroradiometer (MODIS)
Data sets	Leaf Area Index (MOD15A2) [Global [9]] [Subsets [10]] Vegetation Indices (MOD13) [Global [11]] [Subsets [10]] Land Cover Dynamics (MOD12Q2) [Global [12]] [Subsets [10]]
Resolution	250 meters, 500 meters, and 1 kilometer
Parameter	Leaf Area Index (LAI) Fraction of Photosynthetically Active Radiation absorbed by vegetation (FPAR) Normalized difference vegetation index (NDVI) Enhanced vegetation index (EVI) Greenness (increase, maximum, decrease, minimum)
Data center	NASA Oak Ridge National Laboratory DAAC (ORNL DAAC [3]) NASA Land Processes DAAC (LP DAAC [2])
Science funding	National Science Foundation United States Geological Survey

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