Complex AVHRR Vegetation Phenological Trends as a Response to Warming Climates

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Research Reported in News Media

(more than 60 websites)

In brief

Greenup of the P White
By Carl Zimmer 11.05.07 12:00 AM

Spring green-up is coming early; satellite observations, climate Image: Xiaoyang Zhang
Every spring, the Earth's bloom continents turn green.

Spring Timing

Spring green-up—when plant buds burst open at winter's end—has been arriving ahead of schedule in the northern United States for the past twenty-five years, as a result of global warming. In fact, spring has been springing progressively earlier by about a day every three years, according to Xiaoyang Zhang and two colleagues at the National Oceanic and Atmospheric Administration in Camp Springs, Maryland, who examined records of last-bloom dates and satellite images of vegetation to reach their conclusions.

But the trend applies only to plants up north, in southern states, the reverse is true: spring green-up has been arriving later by about a day every seven years. What's going on? Aren't southern states experiencing global warming, too?

Absolutely, Zhang's team says, just a little differently. The effect stems from the fact that most plants going dormant in autumn must remain just so cold for just so long before they can fully respond to the warmth of spring. Northern winters, though truncated, are still cold enough for long enough that plants can leaf out once balmy weather returns. But down south, cool days—already few to start with—have diminished so much that plants' chill requirements aren't always met. When that happens, only additional spring warmth can wake them; hence southern states' progressively later green-up. (Geophysical Research Letters)

Samplings—News from Nature

February 2008

The Warming Earth

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Plant (vegetation) phenology: Annual cycles of vegetation (timing of flowering, budburst, greenup onset, leaf drop, etc.) and how they respond to seasonal climate changes
Outline

1. Background
2. Phenology estimates from AVHRR data
3. Long term trends of phenological pattern
4. Mechanism of long term phenological variations in North America
5. Conclusions
6. Several research issues
Background

Satellite phenology detections

Terrestrial phenology modeling

Global (CO2 and land) Modeling

Species specific phenology modeling

Species specific phenology observations

Climatology of long term satellite-phenology

Climatology of long term species phenology

Terrestrial phenology modeling

Species specific phenology modeling
Background

Vegetation phenology— an effective indicator of climate changes

- Vegetation spring budburst occurs early
- Vegetation growing season becomes longer

Zhu et al. 2001
**Background**

Earlier Phenological Trends Associated with Warming Temperature (linear models)

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**Ecology: Bradley et al.**

- **JULIAN CALENDAR DAY** vs. **MARCH TEMPERATURE (°C)**
- **FLOWERING DATE (DAY OF YEAR)** vs. **JAN-MAR MEAN TEMPERATURE**

- *Anemone nemorosa* in Norfolk, UK

- **GROWING SEASON LENGTH** vs. **MEAN ANNUAL TEMPERATURE**

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**Data of White et al.**
Basic Understanding

• Vegetation spring events are LINEARLY related to mean annual temperature or mean monthly temperature during last several decades.
• Warming climates advance spring vegetation phenological events.
• BUT…
Background
Are There Any Delayed Trends?

Figure 5. Frequency of slopes of linear regressions (trends in days/year) for spring phases in the International Phenological Gardens (1959–1996; only records with more than 20 years of observation included) (after Menzel and Fabian, 2001)
Background

Are There Any Delayed Trends?

Phenology derived from climate-station data (Fitzjarrald et al. (2001), *J. Climate*, 14, 598–614)
What Is the Mechanism for the Delayed Trends?

• Likely associated with elevated CO2 and N in field-controlled experiments (Cleland et al., 2006, PNAS)
• Likely regulated by photoperiod or by a physiological signal other than local temperature (Bradeley et al., 1999, PNAS)
• Don’t know or no explanations in most of the literature
Vegetation Phenology Derived from Long Time Series of AVHRR NDVI Data (GVI-x)
Seasonal Canopy Variation in Temperate Deciduous Forests

From Baldocchi et al., 2001.
Temporal Vegetation Index from Satellite Data and Phenological Matrix

Integrated GVI-x NDVI:

\[ \text{INDVI} = \int_{A}^{D} \left( \frac{c}{1 + e^{a+b(t-d)}} \right) dt \]
A General Logistic Model for Describing Vegetation Growth

\[ V_c(t) = \frac{c}{1 + e^{a+bt}} + d \]

- \( t \) is time in day of year
- \( V_c(t) \) is the green vegetation index (NDVI) at time \( t \)
- \( a \) and \( b \) are fitting parameters
- \( c + d \) is the maximum \( V_c \) value
- \( d \) is the initial background \( V_c \) value
Algorithm for Automatically Determining Vegetation Phenology

The rate of curvature change

\[ K' = b^3 c z \left\{ \frac{3z(1 - z)(1 + z)^3 \left[ 2(1 + z)^3 + b^2 c^2 z \right]}{\left[ (1 + z)^4 + (bcz)^2 \right]^{5/2}} - \frac{z^2 (1 + 2z - 5z^2)}{\left[ (1 + z)^4 + (bcz)^2 \right]^{3/2}} \right\} \]
AVHRR Datasets

- NDVI data from weekly 4 km GVI-x NDVI from 1982-2005
- Cloud and snow flag from 4 km GVI-x QA
Snow Flag in GVI-x

Jan. 15-28 2001
Background AVHRR NDVI

0.056 0.36
Phenology Detection in Forests

Mixed forests

- Curve fitted NDVI
- GVIX_NDVI_7d

DOY

NDVI
Phenology Detection in Semiarid Areas
Phenology Shifts in North America (2001)
Interannual Zonal Variations in Greenup Onset
Interannual Trend in Greenup Onset
Phenological Transition Zone in Natural Vegetation Greenup Onset

Asterisks--Change rate in Lilac first bloom dates
What Is the Mechanism of Delayed Phenological Trends?
Species-specific Phenology Modeling

Cannell and Simth, 1983
Thermal Time-chilling Model (Parallel chilling model) for Greenup Onset in Terrestrial Ecosystems

\[ TTR = \alpha + \beta e^{\gamma Cd} \]

*\( TTR \) is the thermal time requirement*

*\( Cd \) is the number of chill days*

*\( \alpha, \beta \) and \( \gamma \) are coefficients*
Temperature data

3-hourly LST data at a spatial resolution of 32 km between 1981 and 2005 from the NCEP North America Regional Reanalysis (Mesinger et al., 2006)

Feb. 5, 1982, 0300UTC
Terrestrial Phenological Model for Greenup Onset in North America

\[ TTR = 56.51 + 677.24e^{-0.0232Cd} \]

\( P < 0.0001 \)

Maximum curvature change rate
Northern Starting Point of Phenological Transition Zone from both AVHRR Data and Modeling
Has winter chilling time decreased and spring temperature increased during last two decades?
Interannual trends in Winter Chilling Days from 1982 to 2005
Interannual trend in Spring Temperature Requirements for Greenup Onsets from 1982 to 2005
Changes in Thermal Time-chilling Curves with Warming Temperature

- **Southern subtropical regions**: Greenup onset with a delayed rate
- **Northern subtropical regions**: Advance rate reduced gradually
- **Middle-high latitudes**: Greenup advance with a large rate

**Graph Legend**
- Year 1
- Year 5
- Year 10
- Year 15
- Year 20

**Axes**
- X-axis: Latitude
- Y-axis: Spring temperature forcing
- Y-axis: Chilling days

**Key Points**
- Year 1: Greenup advance with a large rate
- Year 5: Advance rate reduced gradually
- Year 10: Further reduction in advance rate
- Year 15: Continuation of reduced advance rate
- Year 20: Further stabilization of advance rate
Interannual Changes in the Curves of Thermal Time Requirement

Turning point of sufficient to insufficient chilling days

Thermal time requirements

Latitude (degree)
Interannual trends in the turning points of thermal-chill curves (representing northern starting point of the transition zone)

Slope=0.1 latitude degree per year
Conclusions

• Warming temperature advances greenup onset in mid-high latitudes but delays greenup in low middle latitudes across North America.

• The phenological transition zone has shifted northwards with a rate of 0.1 latitude degree per year.

• The greenup onset will continuously advance with climate warming in high latitudes because plant buds are always fully chilled.

• The advance of greenup onset will slow down around 40°N and the timing of greenup onset between 35°N and 40°N may gradually change from advancing to slowing trends.
Research issues

• Are the delayed trends in southern regions affected by long term variation in precipitation?

• In what types of ecosystems are the delayed trends more significant?

• What is the global climatology of vegetation phenology?

• What’s the long term data records in the onsets of greenup, maturity, senescence, dormancy, growing season greenness (1km)?

• How to monitor vegetation phenology (such as crop germination, pollination, and related disease outbreaks) in real time using new satellite data, such as GOES-R and VIIRS?

• Is it possible to generate long-term fire burn scars using AVHRR vegetation phenology properties and to characterize recovering vegetation phenology.
Burn Scar from AVHRR Time Series (Hayman Fire)
Interannual Variations in NDVI Time Series in Hayman Fire
THANK YOU