



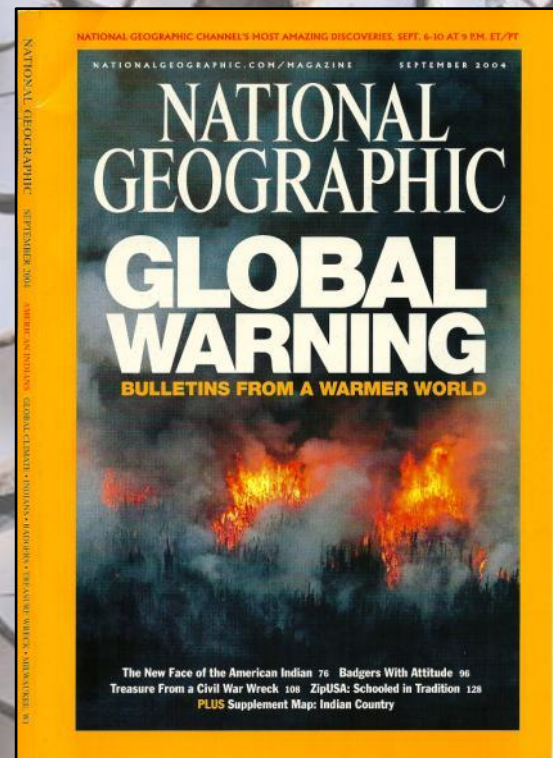
Lecture #1

Introduction to Phenology, the Science of the Seasons

Alisa Hove, Susan Mazer, and Brian Haggerty
University of California, Santa Barbara



Global concern about climate change



Global concern about climate change



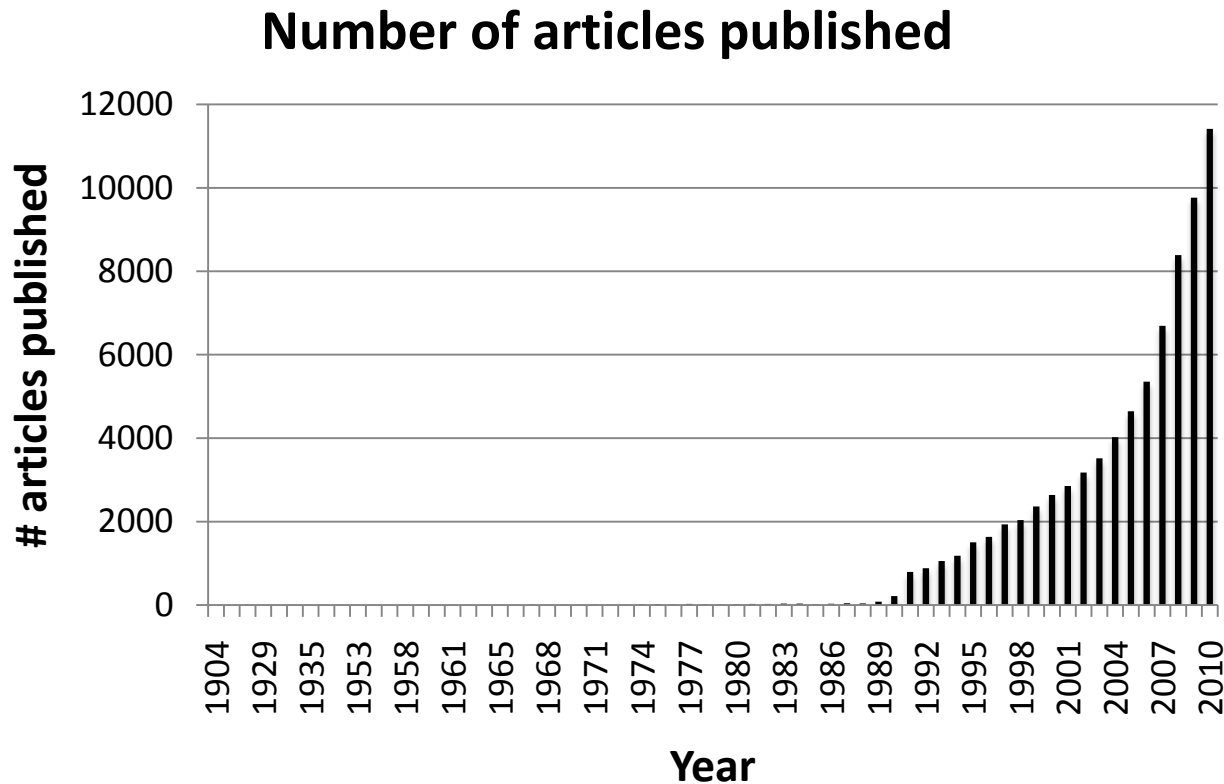
“We need to treat climate change not as a long-term threat to our environment but as an immediate threat to our security and prosperity” - John Ashton, United Kingdom Ambassador on Climate Change to the United Nations(2011)

Increasing research on climate change

Recent search on “**climate change**” of the **Web of Science** database found over **83,000** journal articles published between 1904 and 2011

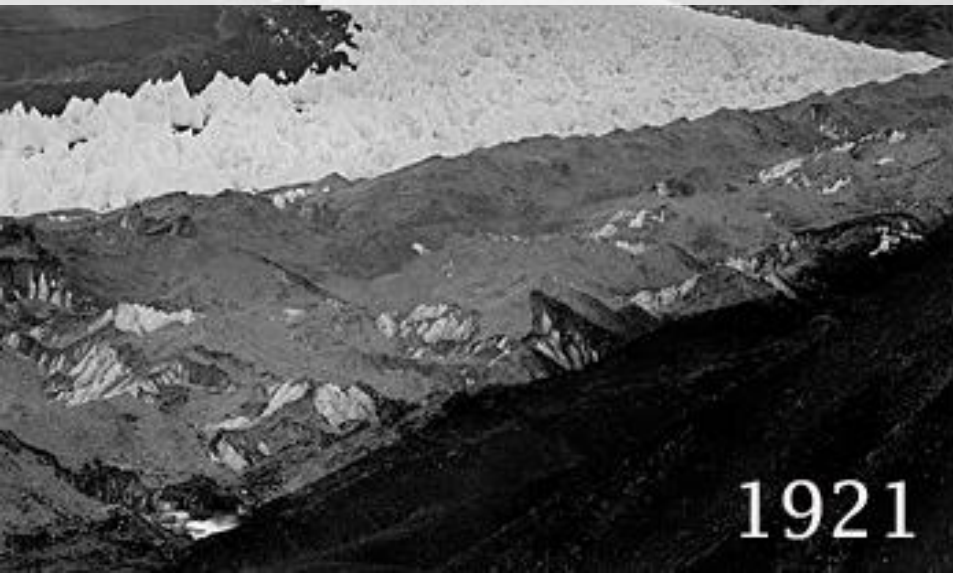
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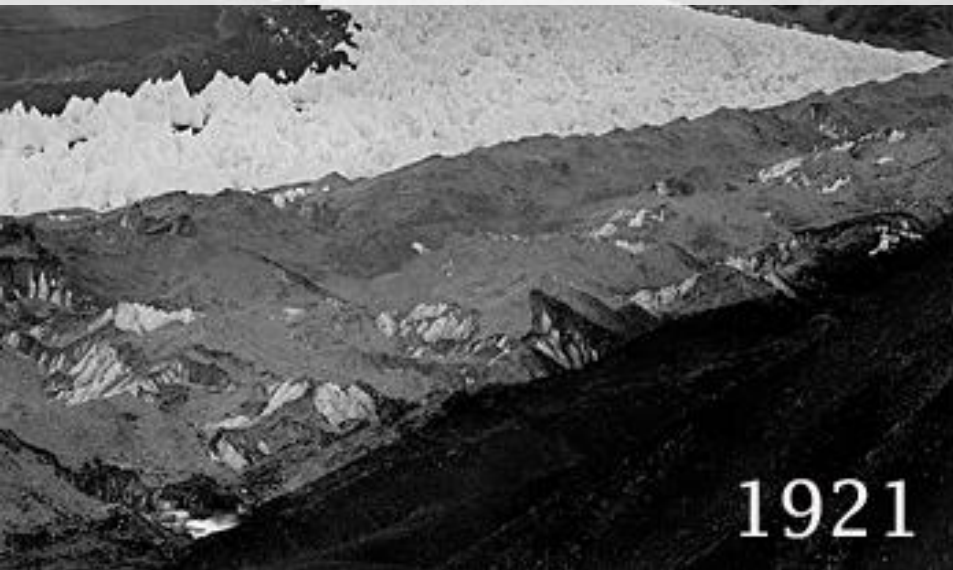


Comparing historical photos with present-day images provides evidence of climate change





Comparing historical photos with present-day images provides evidence of climate change



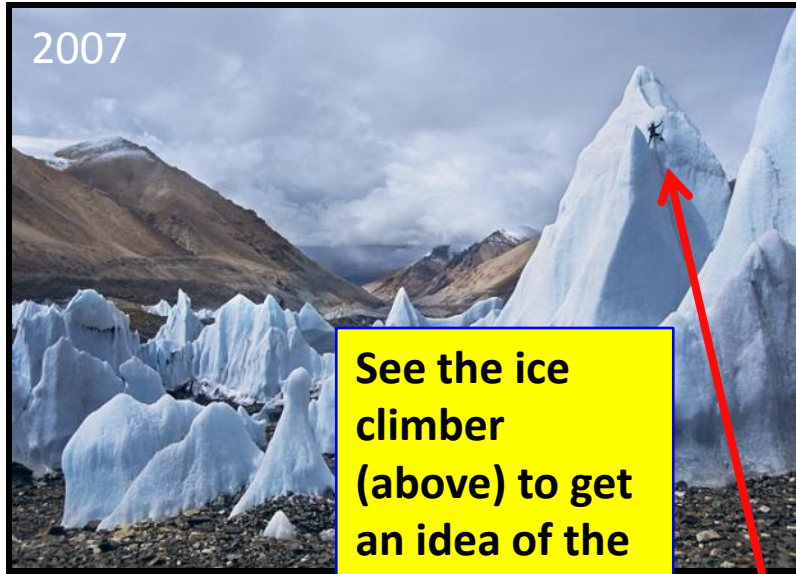
Rongbuk Glacier and Mt. Everest

Large amounts of glacial ice have been lost



Main Rongbuk Glacier, Mt. Everest

Large amounts of ice have been lost



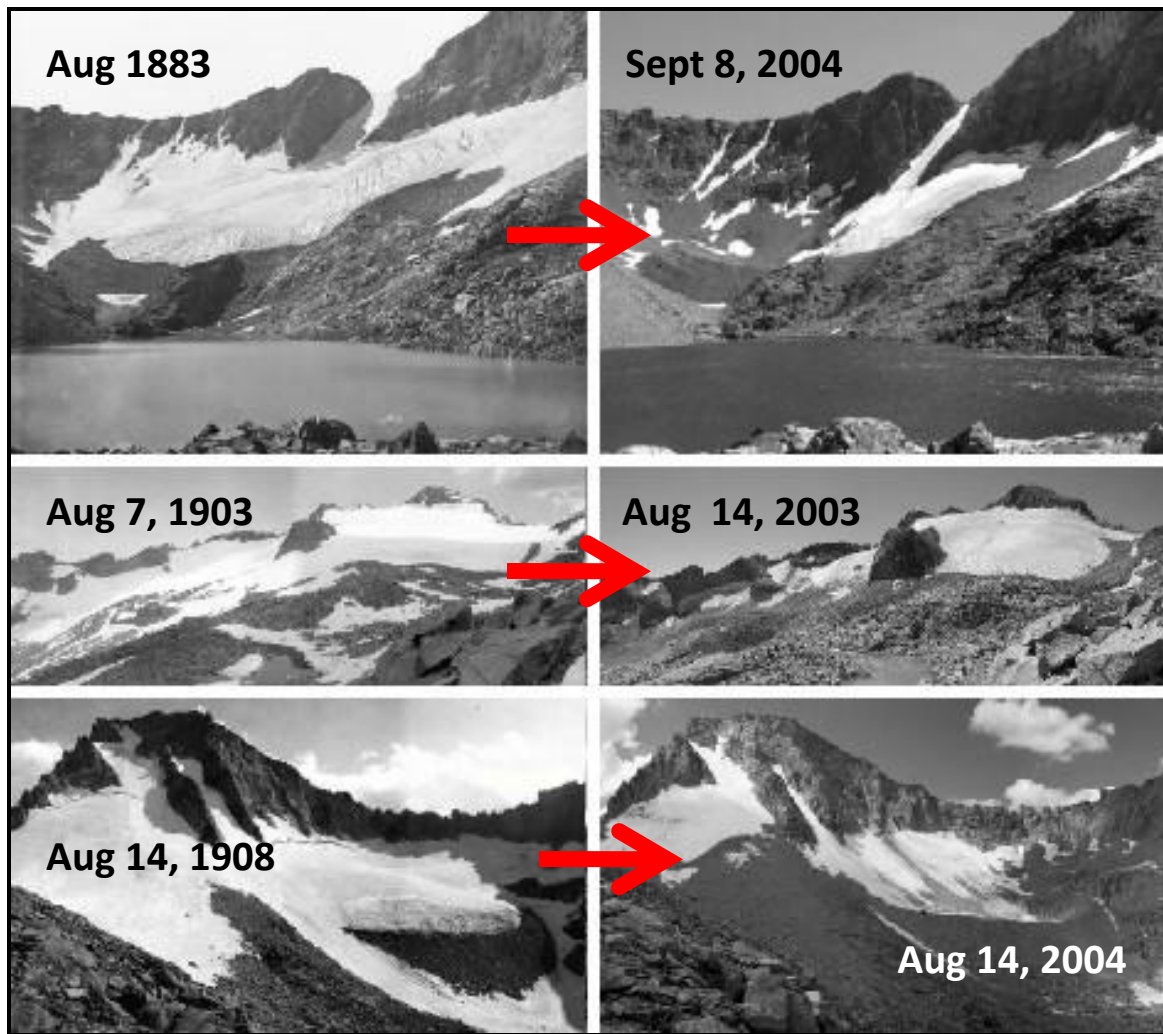
2007

See the ice climber (above) to get an idea of the glacier's size!



2007

Comparison of historic and present-day photos taken at similar times of the year in the Sierra Nevada, California



Dana Glacier

Lyell Glacier

Darwin Glacier

Phenology is the study of seasonal biological events observed in plants, animals, or microbes



Timing of migration

Studying **seasonal biological events** of plants, animals, or microbes is another way to evaluate the effects of global climate change



Timing of migration

Climate influences the **phenology** of biological processes that affect our daily lives

HAZARDS



CULTURE



HEALTH





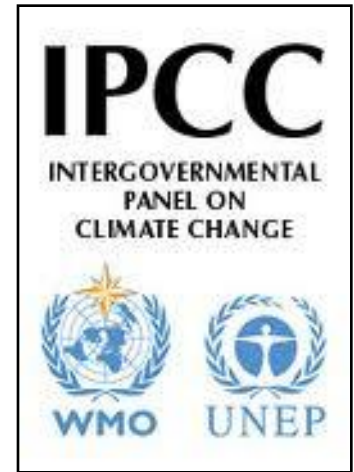
Outline

- I. **Climate Change Crash Course:** Brief overview of **climate change** science
- II. **Introduction to phenology**
- III. **Methods:** How is phenology studied?
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Scientific consensus on climate change

IPCC established in 1988 and formed several **working groups (WG's)**

- WG1: Science of climate system & climate change
- WG2: Vulnerability of socio-economic & natural systems
- WG3: Mitigating climate change



Assessment Reports: 1990, 1995, 2001, 2007

Climate
Change

Intro to
Phenology

Methods

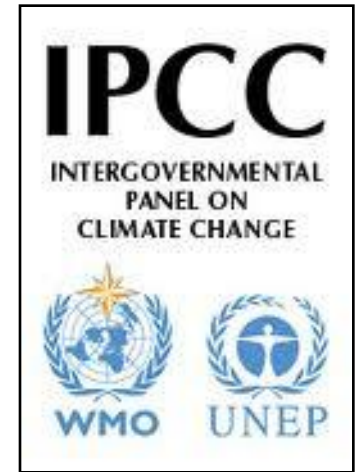
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Climate
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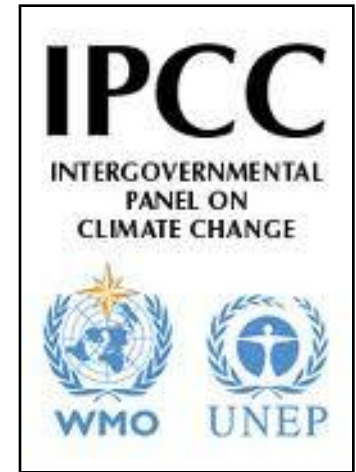
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**Climate
Change**

**Intro to
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Methods

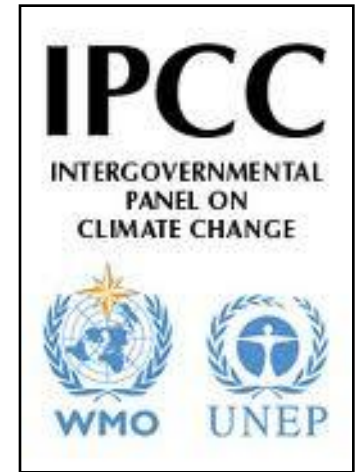
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Nobel Peace
Prize 2007

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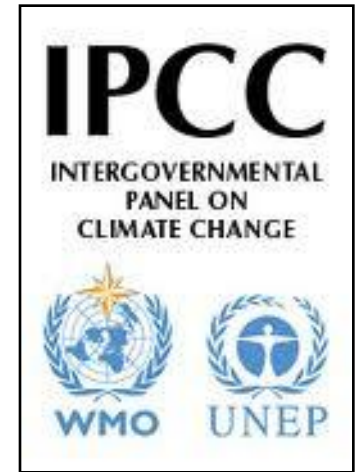
“Climategate”



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Assessment Reports: 1990, 1995, 2001, 2007

Climate scientists have been **cleared** of fraud following
independent investigations conducted by:

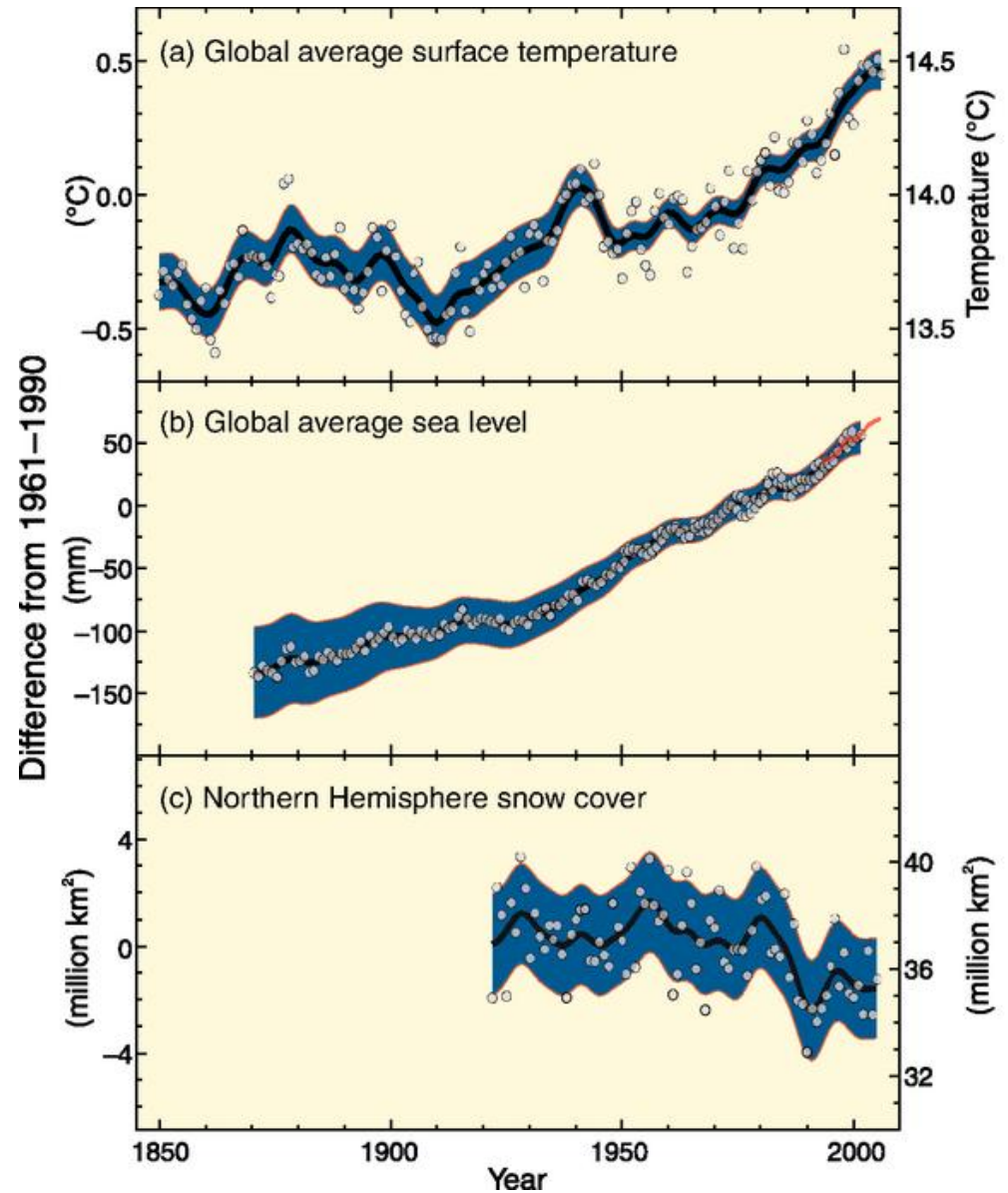
- UK House of Commons
- US National Research Council
- Scotland's Judicial Appointments Board
- US Dept. of Commerce at the behest of Sen. James Inhofe (R, OK)

“Climategate”

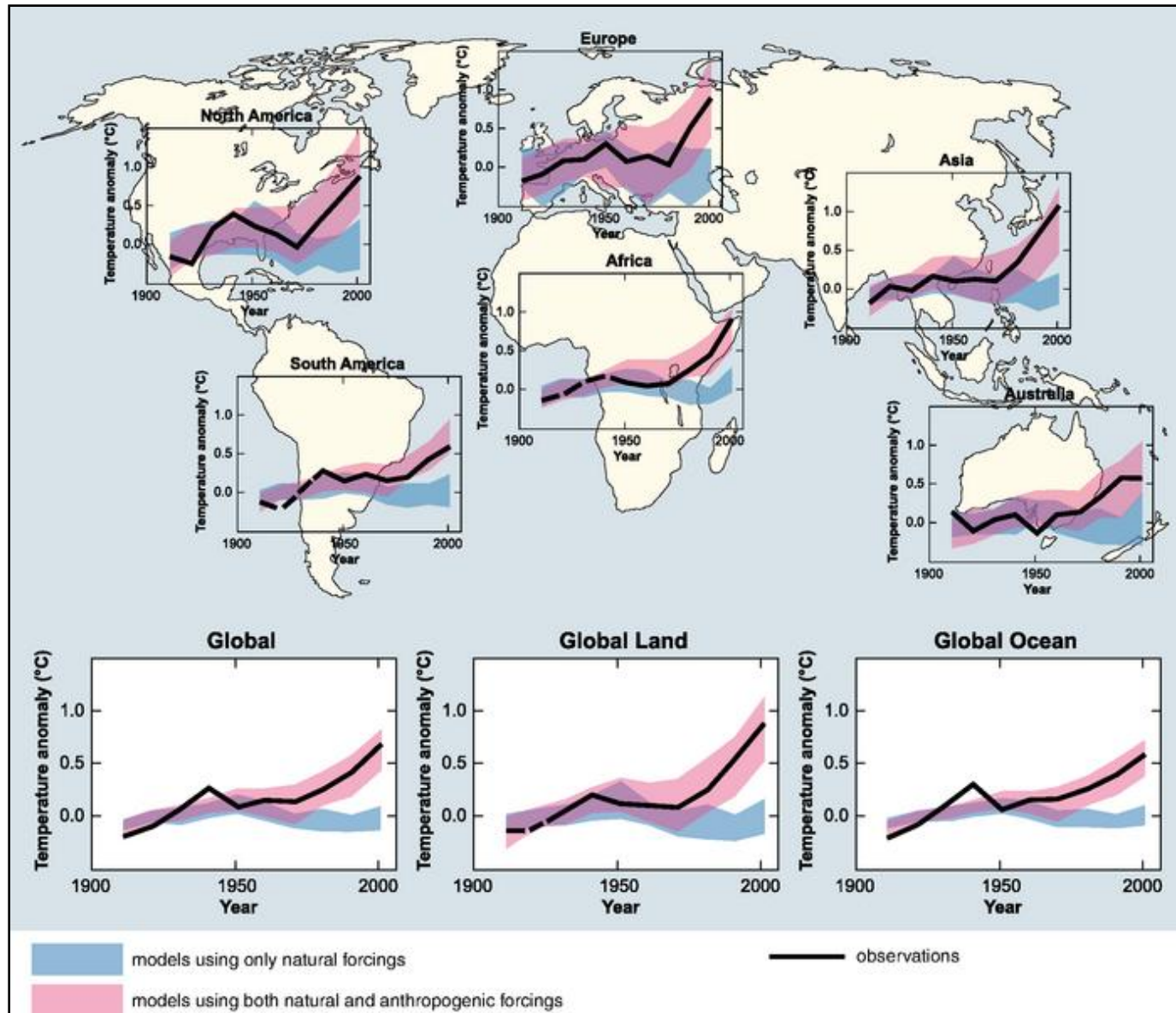


Climate Change: *What is happening?*

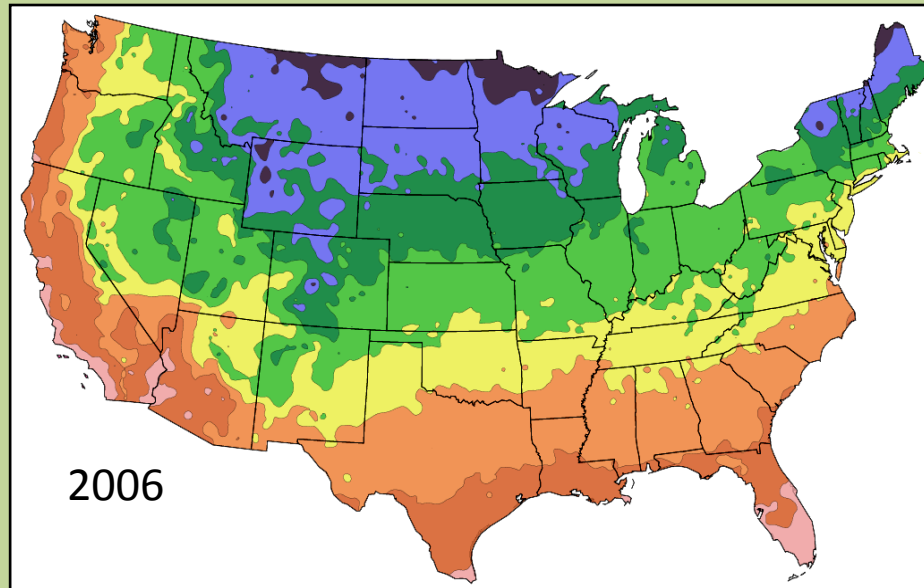
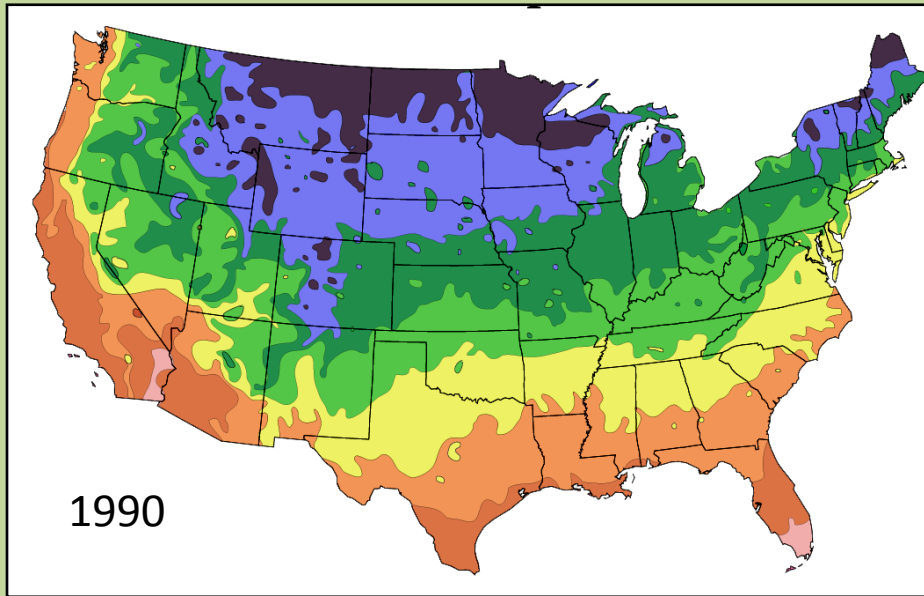
- How is the **climate** changing over time?



“Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level.” – IPCC 2007



U.S. Winter Hardiness Zones



National Arbor Day Foundation

Temperature Changes in the United States

Winter is warming almost twice as fast as summer

Nights are warming faster than days

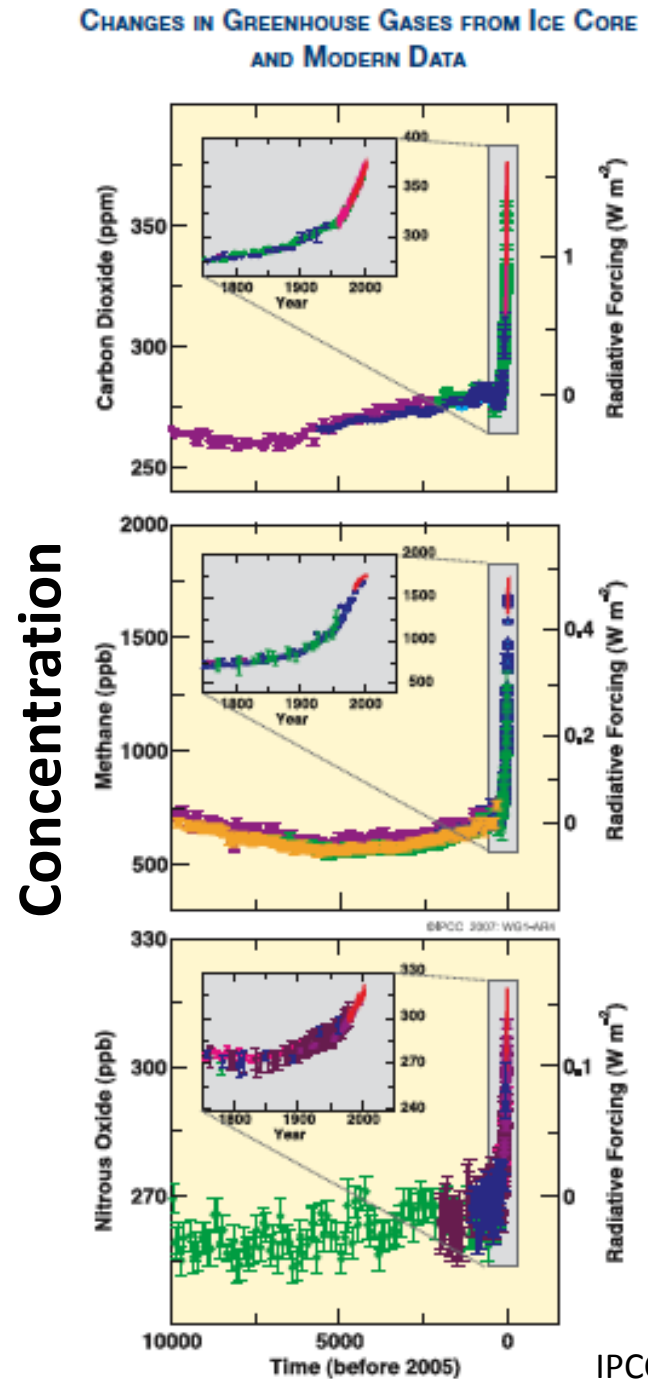
What are some consequences for:

- snow pack & spring thaw?
- plants & animals?
- our agrifood system?

Climate Change: *What is happening?*

What are major **greenhouse gases**?

Which is at the highest concentration?



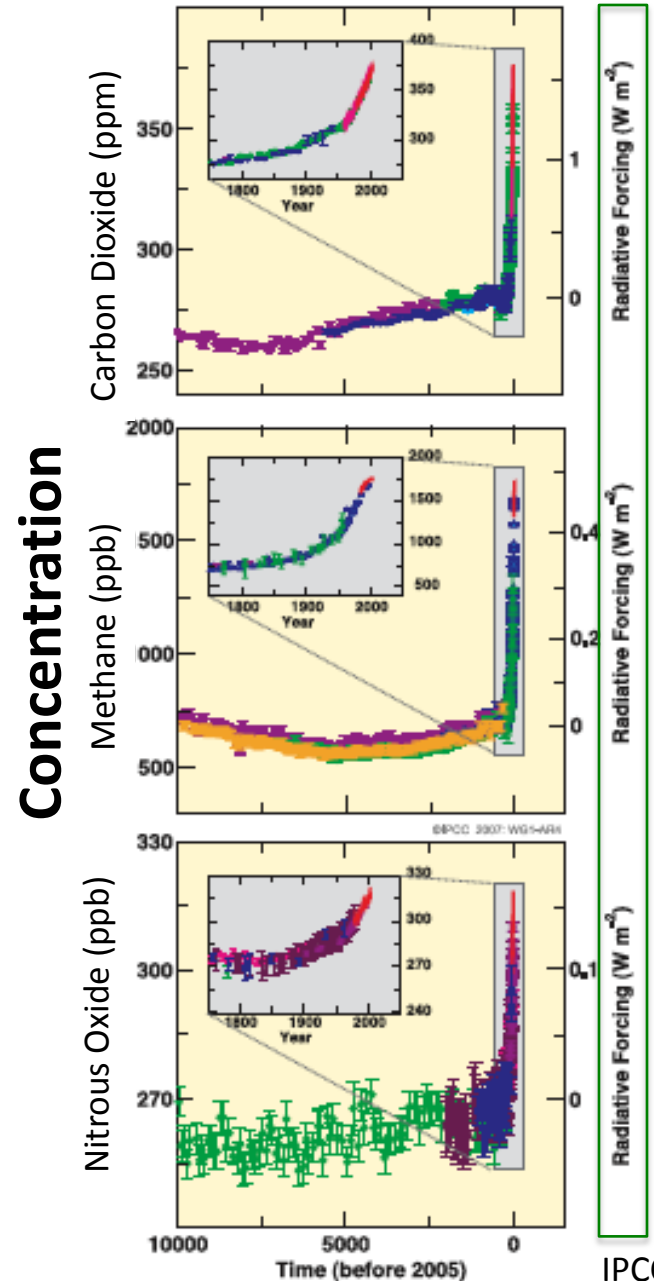
Climate Change:

What is happening?

Radiative Forcing

- a measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system
- an index of a given factor's importance as a potential driver of climate change.

CHANGES IN GREENHOUSE GASES FROM ICE CORE
AND MODERN DATA

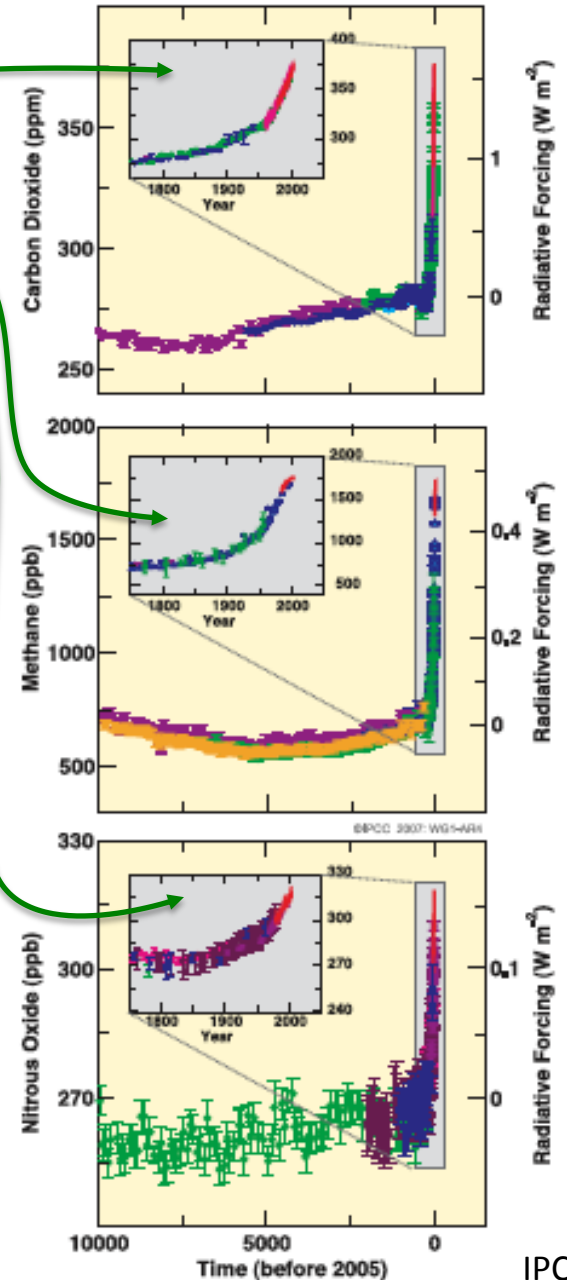


Climate Change: *What is happening?*

Examine the changes in **radiative forcing** from 1800-2000.

Does the observed pattern suggest that CO₂ makes a large contribution to climate change relative to the other gases?

CHANGES IN GREENHOUSE GASES FROM ICE CORE
AND MODERN DATA



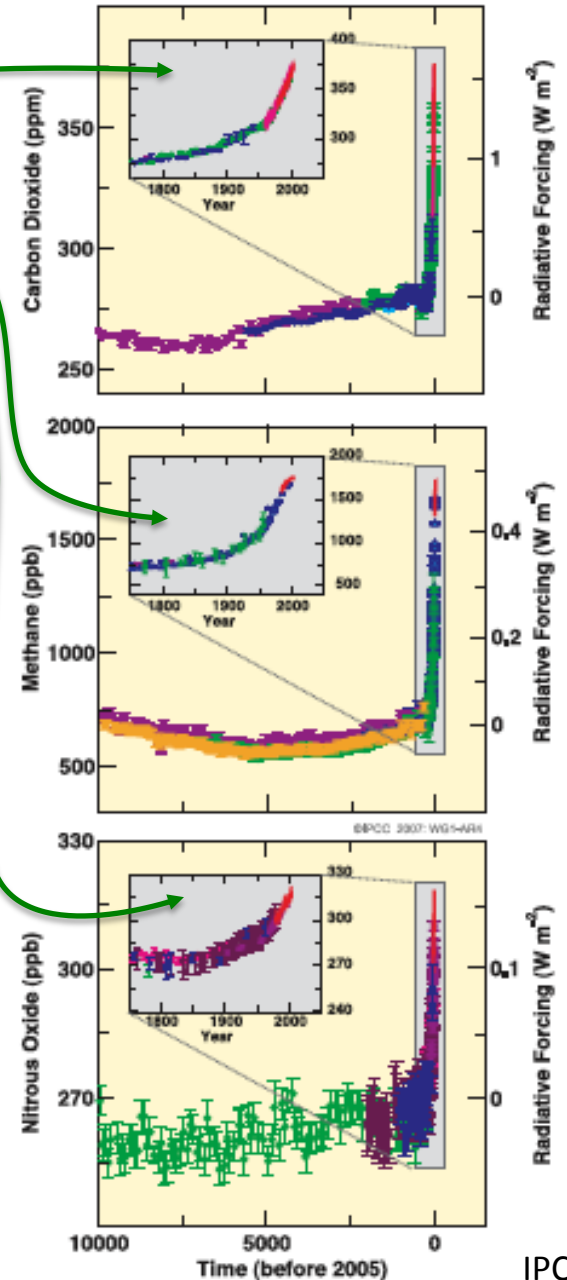
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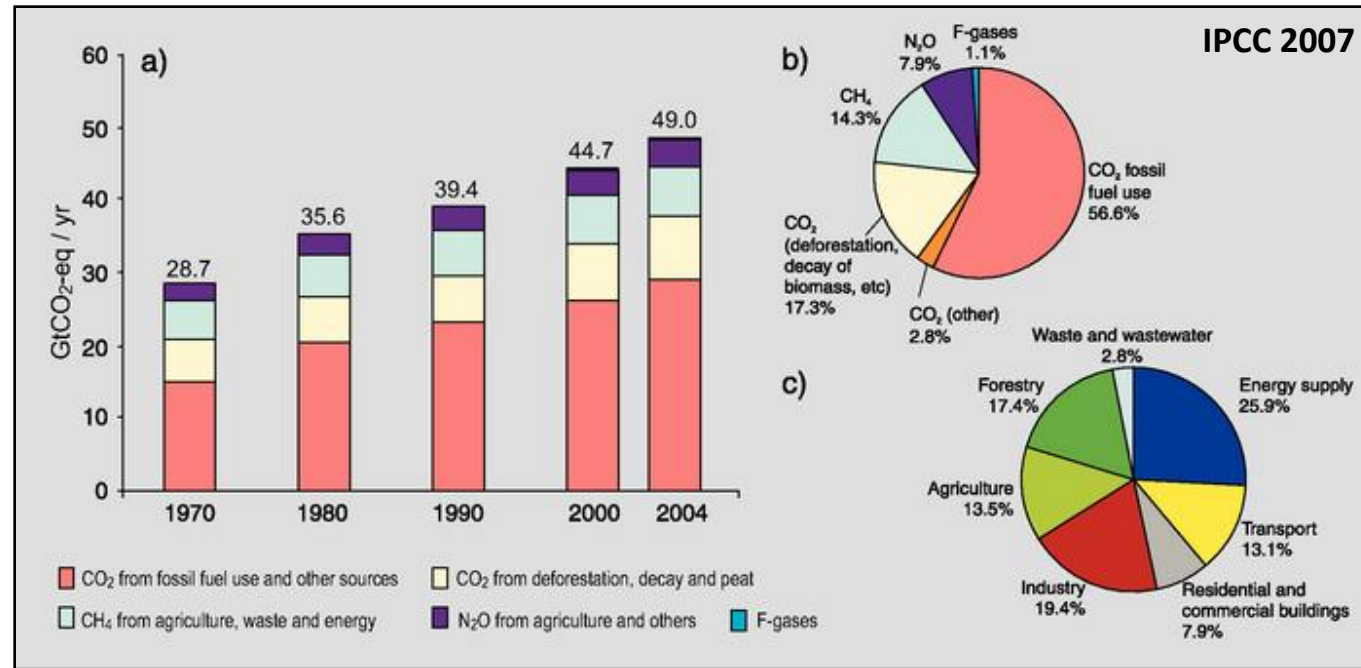
Gas	Change in concentration	Change in radiative forcing
CO ₂	~125 ppm	↑ 1.5
methane	~1000 ppb	↑ 0.5
nitrous oxide	~55 ppb	↑ 0.1

CHANGES IN GREENHOUSE GASES FROM ICE CORE
AND MODERN DATA



Climate Change and atmospheric CO₂

What are the major **anthropogenic** sources of CO₂ emissions?

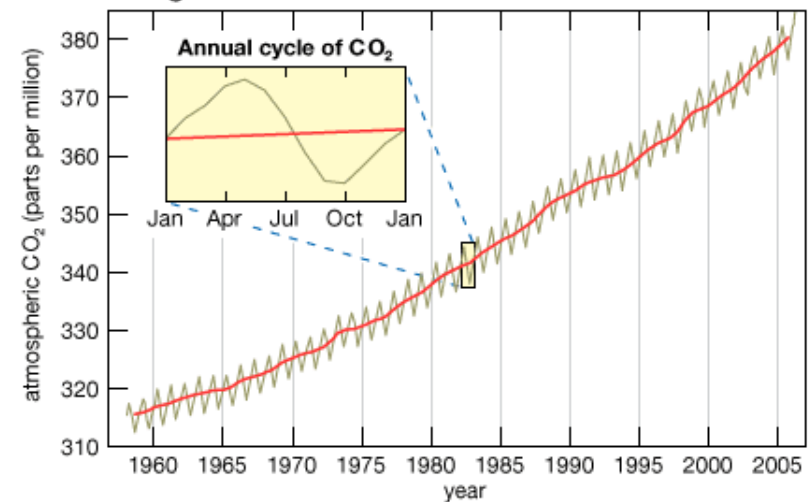


What are the major natural* **biological** causes of atmospheric CO₂ fluctuations?

*non-anthropogenic

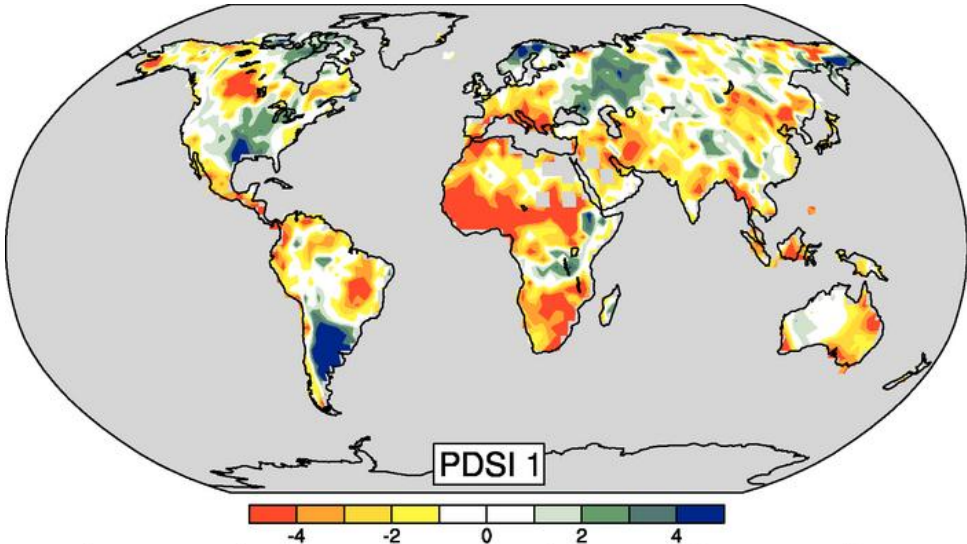
Hint: click on this link to watch a video
[Leaf phenology in Japan](#)

The Keeling Curve

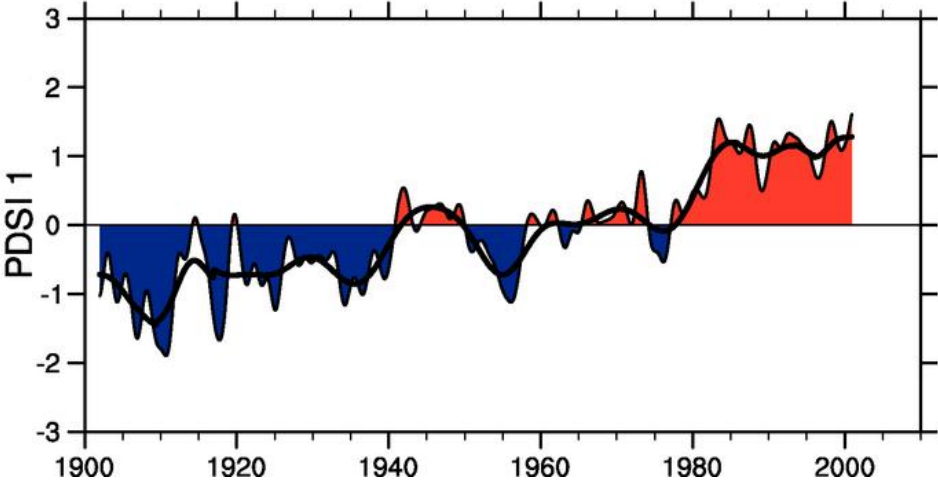


Climate change and precipitation

Drought Index (PDSI 1)

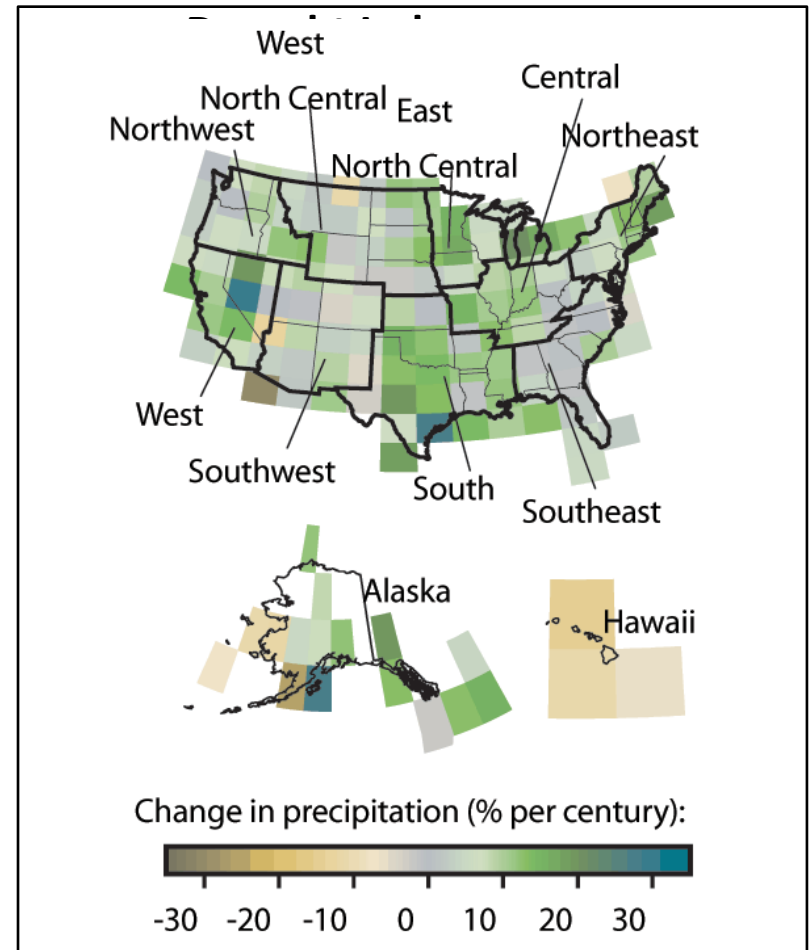


More droughts have been recorded



Climate change and precipitation

Rising temperatures promote **increased evaporative cloud formation**, which can lead to fewer, more intense rain events (**repackaged precipitation**)



Annual *precipitation* trends
1901-2005

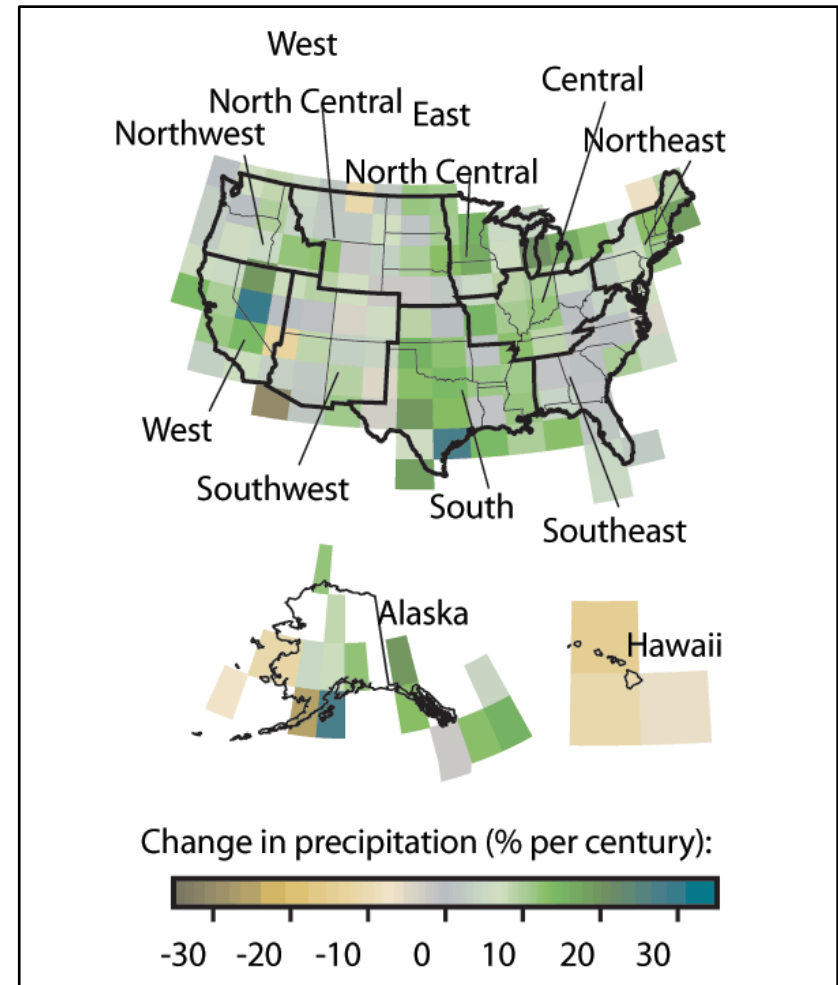
Climate change and precipitation

Rising temperatures promote **increased evaporative cloud formation**, which can lead to fewer, and more intense rain events (**repackaged precipitation**)



- Which regions of the United States have received **less** rain over time?
- Which regions have received **more** rain?

Drought Index



Annual *precipitation* trends 1901-2005

Data from NOAA's National Climate Data Center



*“Phenology... is perhaps the **simplest process** in which to track changes in the ecology of species in response to climate change.” - IPCC 2007*





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What is **phenology**?

Phenology is the study of seasonal biological events observed in plants, animals, or microbes



Timing of migration

Climate
Change

Intro to
Phenology

Methods

Patterns

Phenology &
Climate Change



What is **phenology**?

- Phenology is the study of the timing of plant and animal life cycle stages (e.g., leafing and flowering, emergence of insects, and migration of birds).
- It is also the study of these recurring plant and animal life cycle stages (i.e., **phenophases**) in response to weather and climate.
- From the Greek word ***phaino*** , meaning to show or appear.

USA National Phenology Network, www.usa.npn.org

Climate
Change

Intro to
Phenology

Methods

Patterns

Phenology &
Climate Change

Phenology is the science of the seasons



Spring wildflowers



Dry-down of forest fuels



Forest color change

The seasonal status of plants & animals

Other examples:

- Migration of gray whales
- *Ceanothus* blooms in the chaparral
- Migration of monarch butterflies
- Seasonal availability of local produce



Phenology is the science of the seasons



Spring wildflowers



Dry-down of forest fuels



Forest color change

The seasonal status of plants & animals

Phenology is an integrative science

- Scientific disciplines

Life sciences:

biology, ecology, evolution, botany, zoology, microbiology, physiology, ecosystem ecology, ecoinformatics & more

Physical sciences:

chemistry, physics, meteorology, climatology, geography, hydrology, & more

Phenology is the science of the seasons



Spring wildflowers



Dry-down of forest fuels



Forest color change

The seasonal status of plants & animals

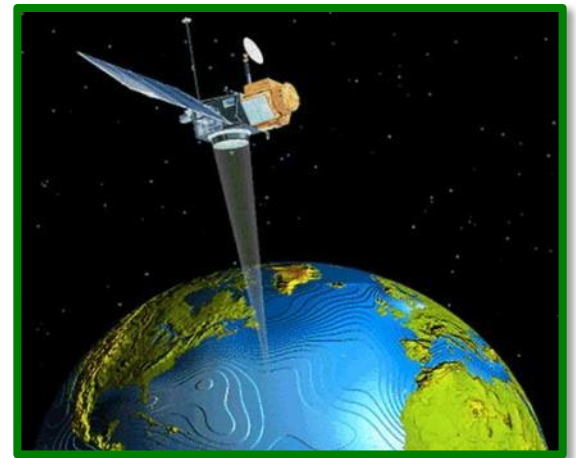
Phenology is an integrative science

Scientific disciplines

- Technology
 - On-the-ground monitoring
 - Remote sensing – cameras, microphones, satellites, weather stations, eddy flux towers
 - On-line data management

Outline

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 - Hands-on data collection
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Collecting phenological data: *hands-on empirical observations*

Examples:

- First flowering date
- Timing of animal emergences (e.g., cicadas)
- Dates when baby animals are observed or fledge
- Arrival dates of migratory animals (e.g., salmon, whales, insects, birds)



Photo: Alisa Hove



Photo: Ned Harris



Photo: Medford Taylor

Climate
Change

Intro to
Phenology

Methods

Patterns

Phenology &
Climate Change

Flowering phenology of an individual within a single flowering season

buds



Elegant clarkia,
Clarkia unguiculata

Photo: Alisa Hove

flowering



Photo: Alisa Hove

fruits

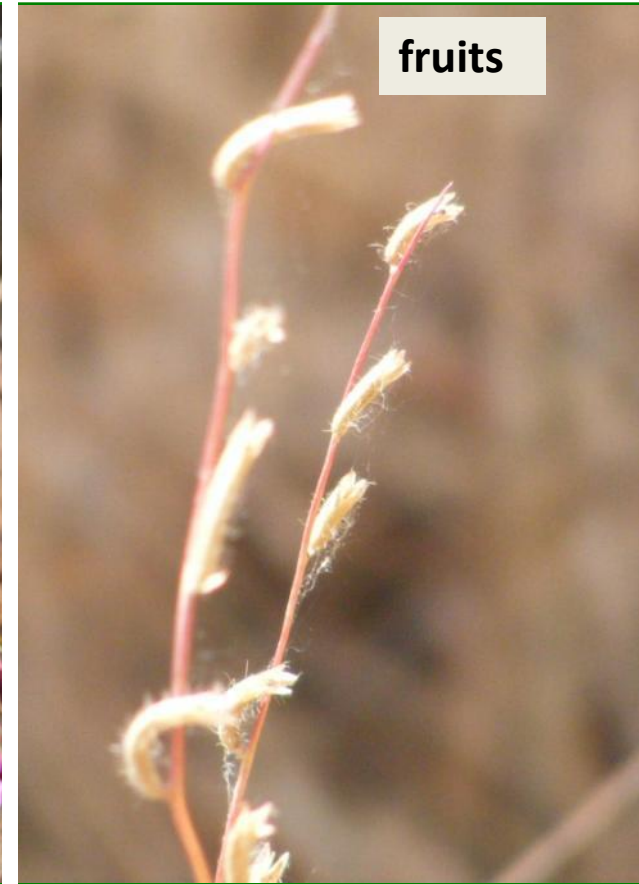


Photo: Jose Montalva

Time



Climate
Change

Intro to
Phenology

Methods

Patterns

Phenology &
Climate Change

Collecting phenological data

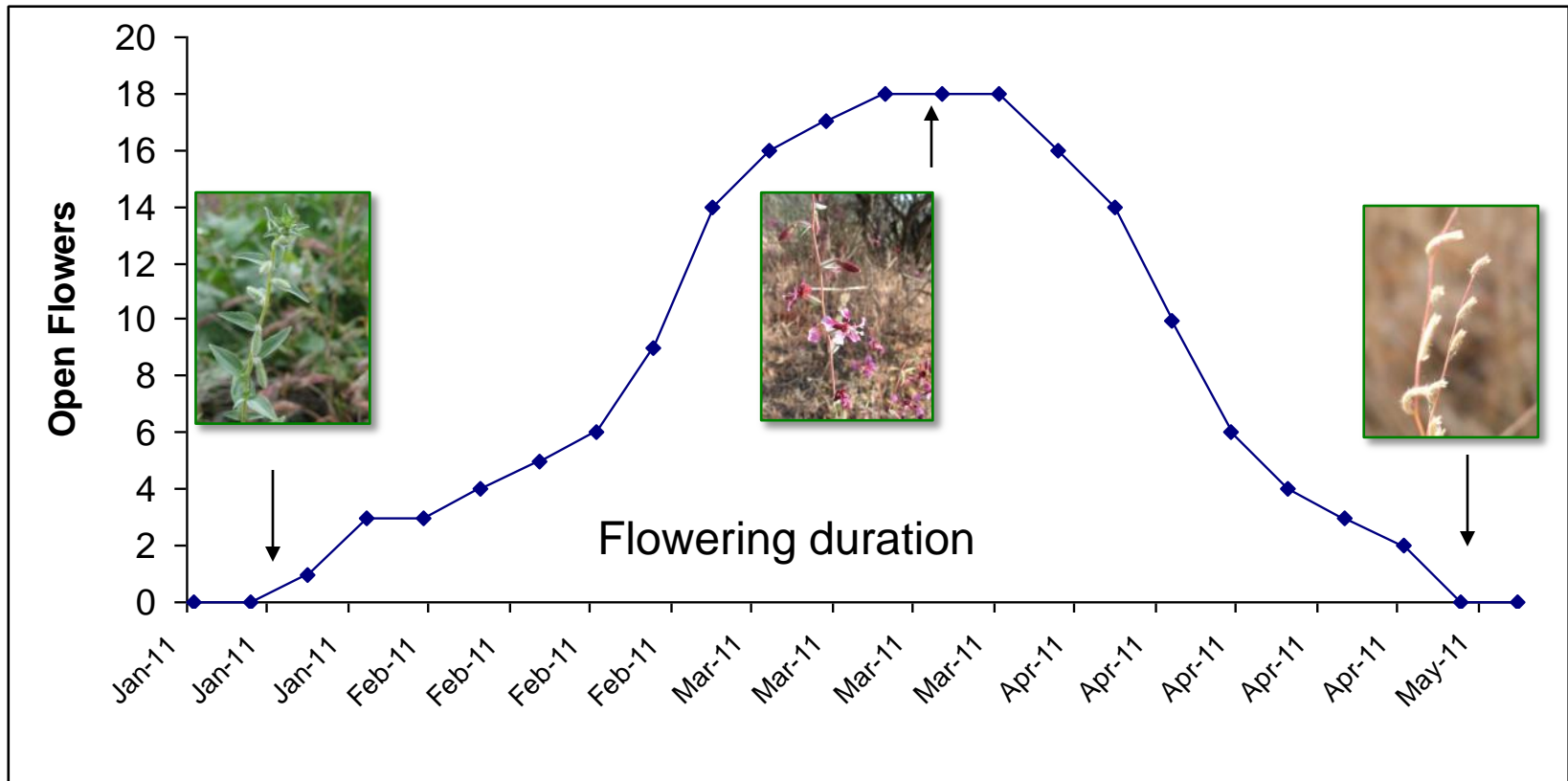
1. Tag individuals or designate areas for sampling
2. Record organisms' seasonal progression



Sample Data Sheet

Plant ID	21 Feb 11 # open flowers	28 Feb 11 # open flowers	5 Mar 11 # open flowers	15 Mar 11 # open flowers
1	0	0	3	15
2	0	1	12	17
3	0	0	5	12
4	0	0	2	6

Phenological schedule of an individual



Climate
Change

Intro to
Phenology

Methods

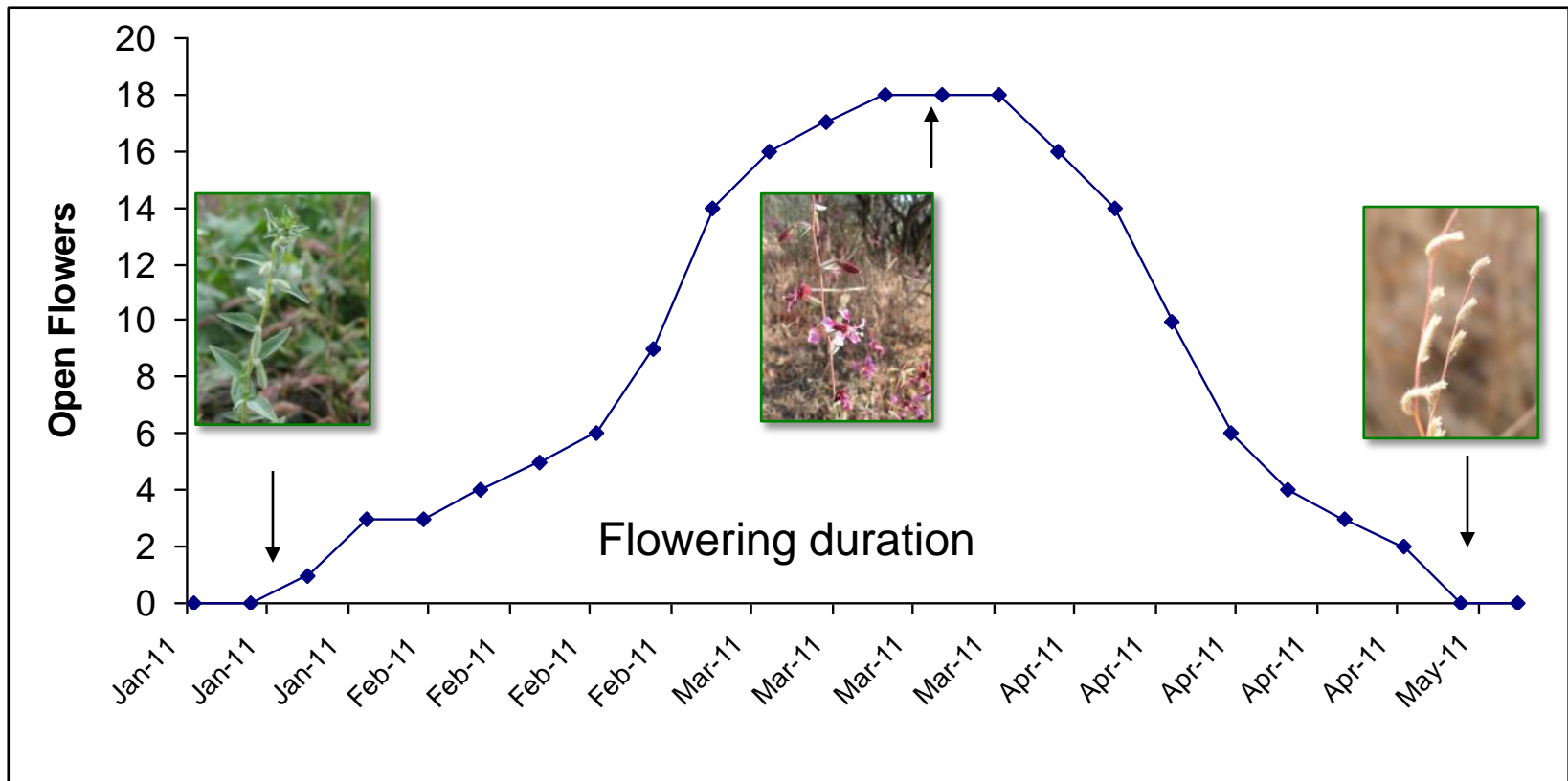
Patterns

Phenology &
Climate Change

Phenological schedule of an individual

Why is the curve shaped this way? --- abiotic vs. biotic **causes**

What are some potential ecological **consequences** of the pattern observed here?



Climate
Change

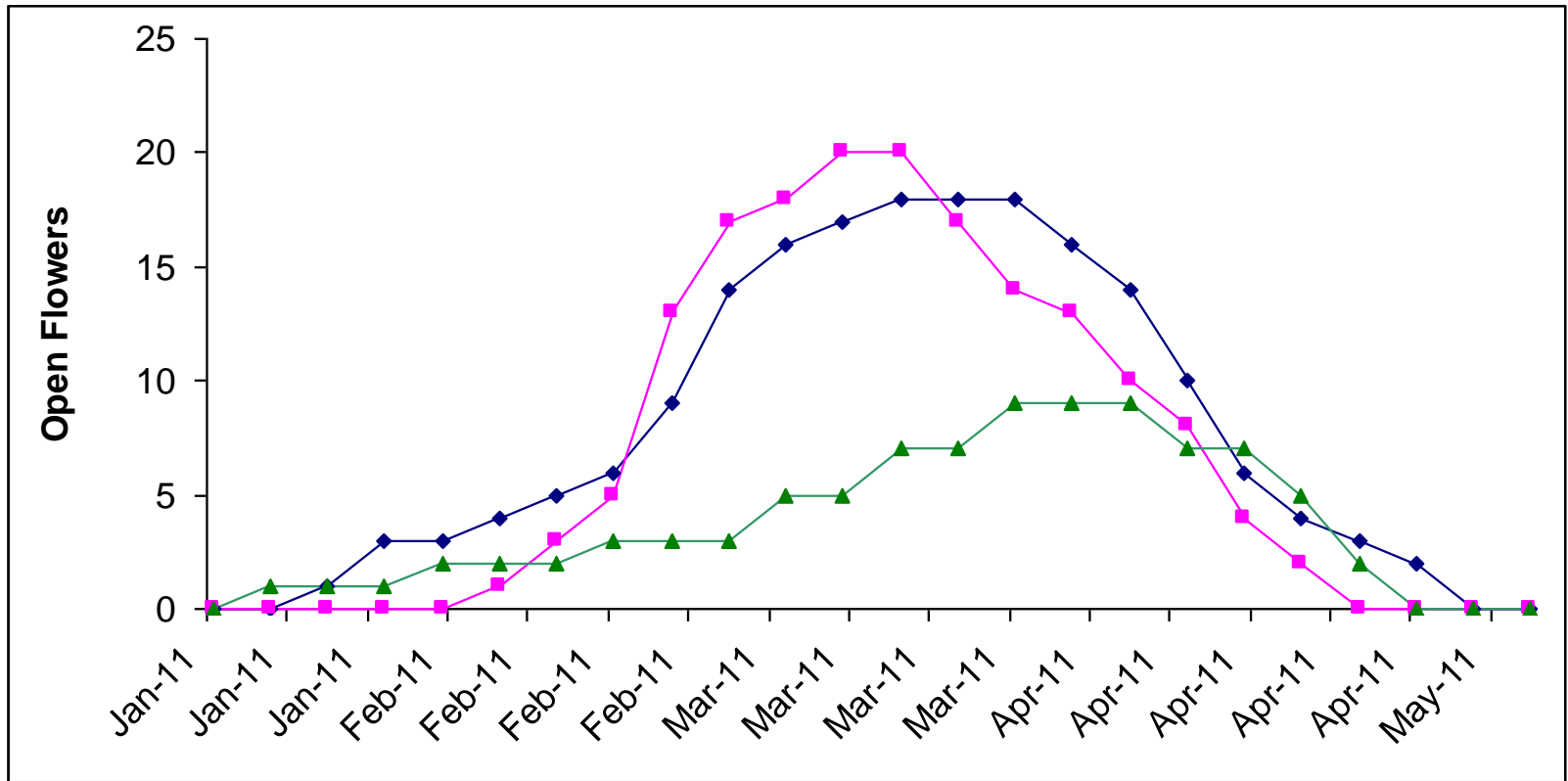
Intro to
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Patterns

Phenology &
Climate Change

Phenological schedule of a population



Climate
Change

Intro to
Phenology

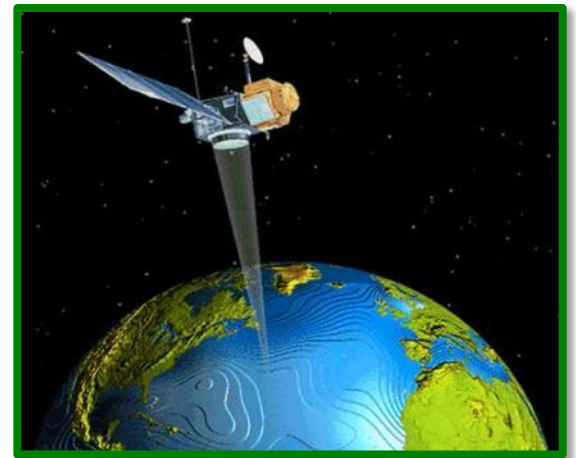
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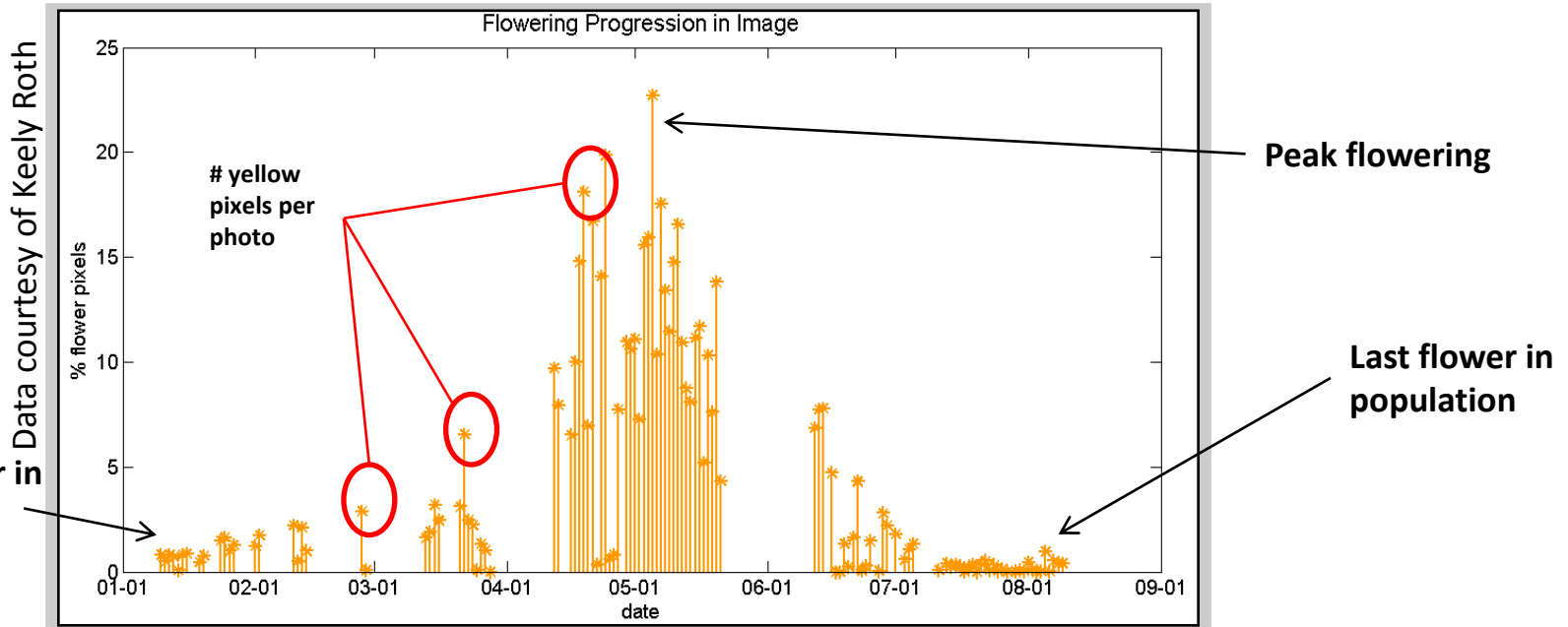
Collecting phenological data: *remote sensing*

Webcams

- Photos taken repeatedly over time
- The number of colored pixels in photos can be used to estimate phenological status

Flowering time-lapse @ Coal Oil Point Natural Reserve, Santa Barbara, CA

Image: Kevin Brown

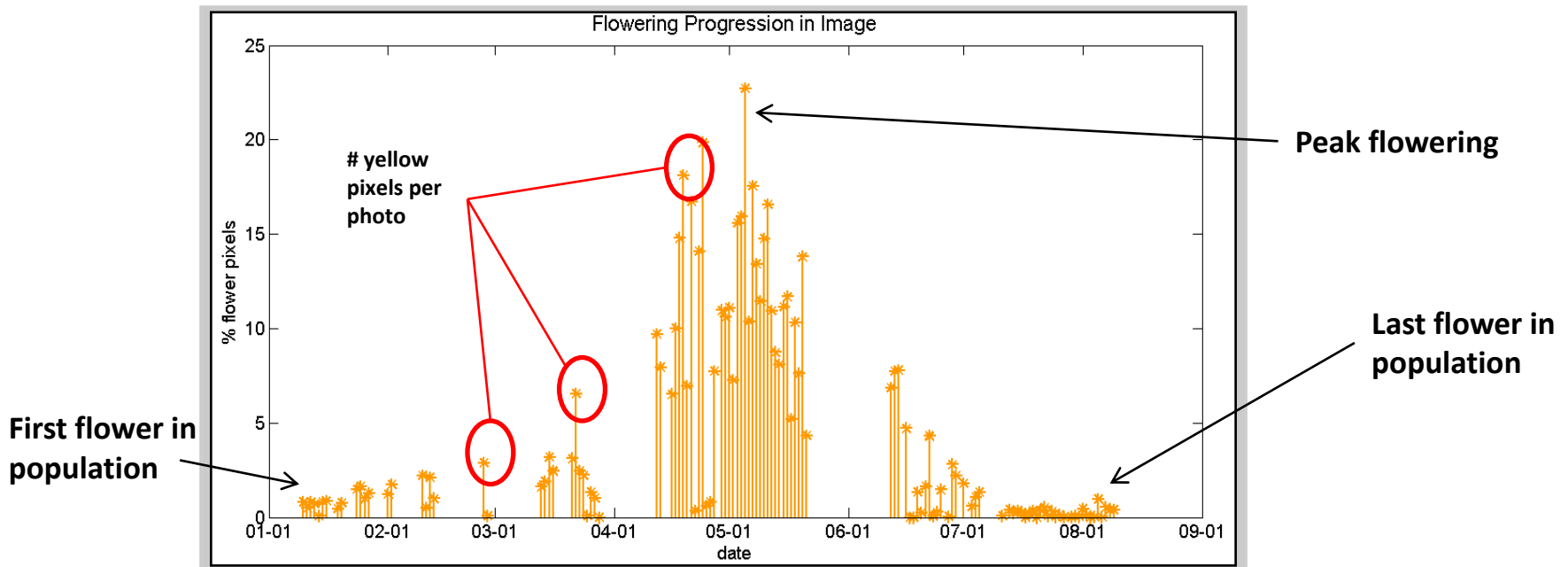


Collecting phenological data: *remote sensing*

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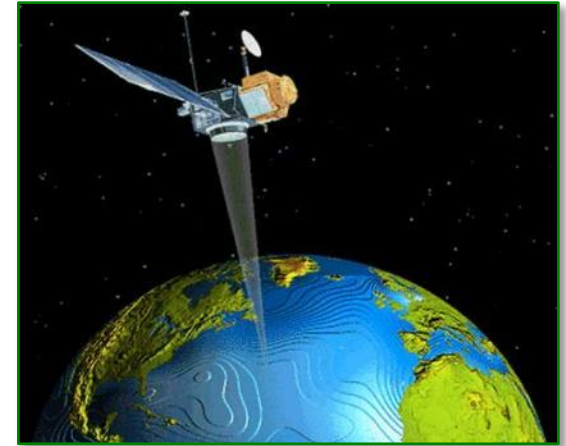
- Can provide phenological measurements *within* a single season (**intra-seasonal**)
- Measurements can be combined across years (**inter-seasonal**) to provide a long-term view of phenology

Flowering time-lapse @ Coal Oil Point Natural Reserve, Santa Barbara, CA



Collecting phenological data: *remote sensing*

Satellite Imagery provides phenological observations across whole landscapes



Vegetation Index

- A **metric** that describes the greenness – relative density and health of plant life – for each pixel in a satellite image

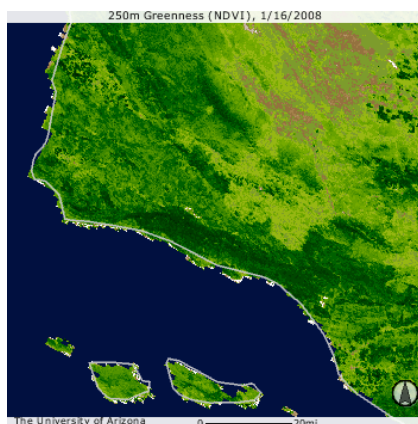
<http://phenology.cr.usgs.gov/index.php>

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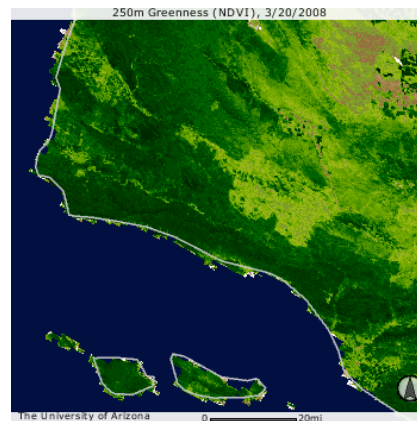
A commonly used vegetation index is the **NDVI**

- **Normalized Difference Vegetation Index**
- Ranges from -1.0 – 1.0
 - < 0.1: no vegetation (e.g., snow, barren rock, sand)
 - 0.2 - 0.5: sparse vegetation (e.g., senescing crops)
 - 0.6 – 0.9: dense vegetation (e.g., dense forests during peak growth)

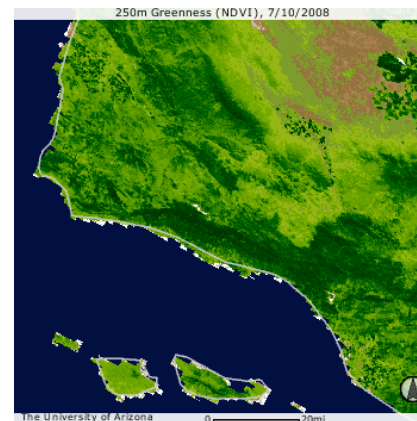
Satellite images of landscape seasonal “green-up” & “brown-down” in Southern California



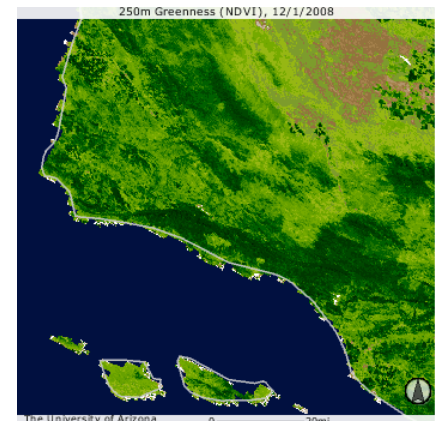
January



March



July



December

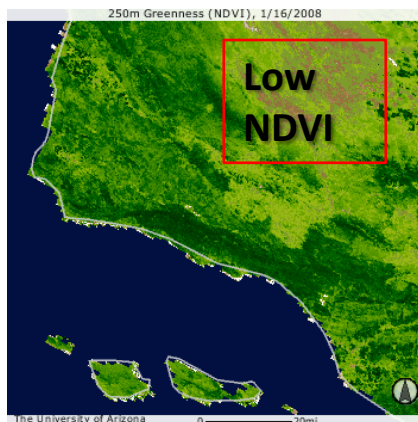
Images: Brian Haggerty

Collecting phenological data: *remote sensing*

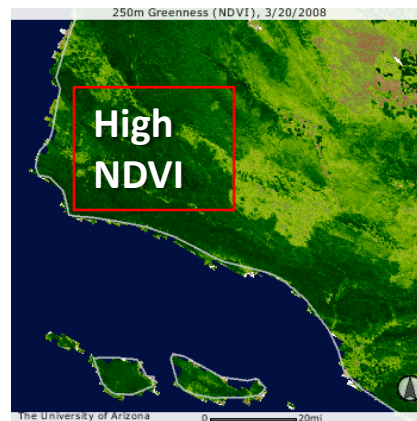
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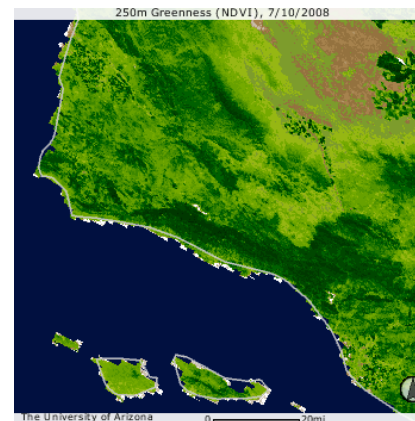
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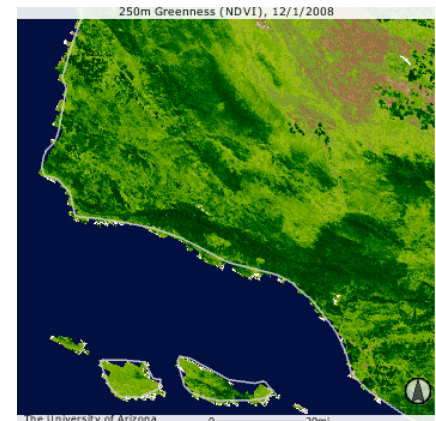
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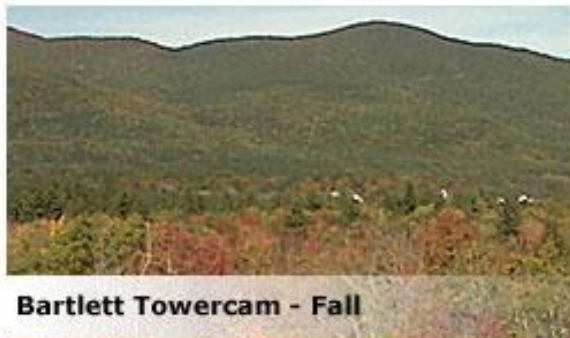
December

Images: Brian Haggerty

● = rough location of Bartlett Experimental Forest on satellite image

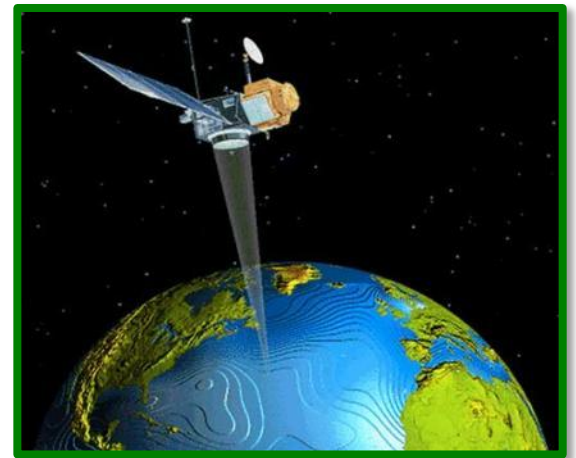
Using remote sensing to visualize phenological changes over time

- Webcam images from the Bartlett Experimental Forest, New Hampshire
- Satellite images showing NDVI in several Northeastern states (including all of New Hampshire!)



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Early phenological observations from Thoreau's journals

"I saw this morning for the first time the bobolink, gold robin [most likely a northern oriole], and kingbird." *May 10, 1853*

- Thoreau made **daily** observations about plants animals every spring from **1851-1858**
- The **phenological data** in Thoreau's journals provided the foundation for ongoing long-term studies of phenology!

WALDEN

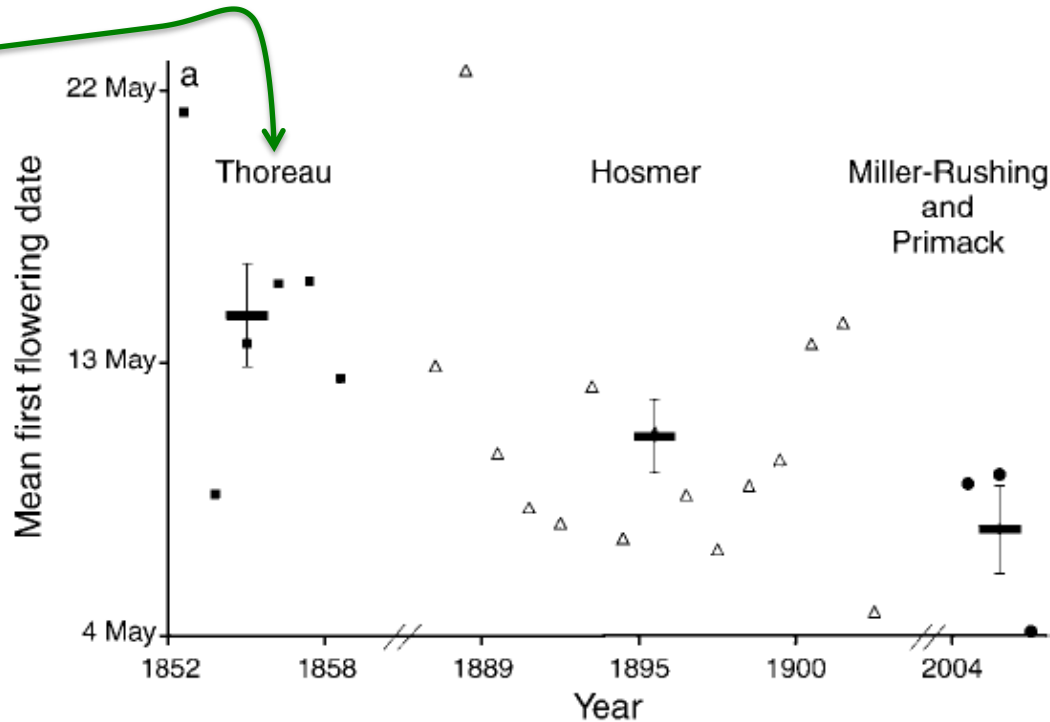


Henry David THOREAU

GLOBAL WARMING AND FLOWERING TIMES IN THOREAU'S CONCORD: A COMMUNITY PERSPECTIVE

ABRAHAM J. MILLER-RUSHING¹ AND RICHARD B. PRIMACK

Department of Biology, Boston University, 5 Cummington Street, Boston, Massachusetts 02215 USA



Herbaria are essential resources for many phenological studies!



Photo: Cheadle Center for Biodiversity and Ecological Restoration

- House specimens that were collected up to hundreds of years ago
- Provide clear examples of plant phenophases at certain dates
- Provide valuable ecological information

Climate
Change

Intro to
Phenology

Methods

Patterns

Phenology &
Climate Change



Outline

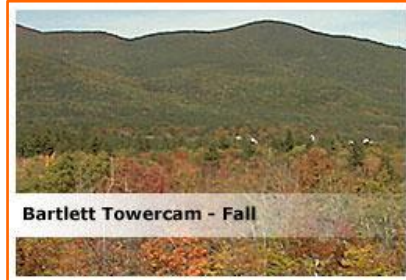
- I. **Climate Change Crash Course:** Brief overview of **climate change** science
- II. **Introduction to phenology**
- III. **Methods:** How is phenology studied?
- IV. **Patterns:** On what **ecological scales** is phenology studied? What are some patterns that have been observed at these scales?
- V. **Phenology and Climate Change:** How does phenological research contribute to our understanding of climate change?

landscape



Biological scales at which phenological observations can be recorded

ecosystem



community



population



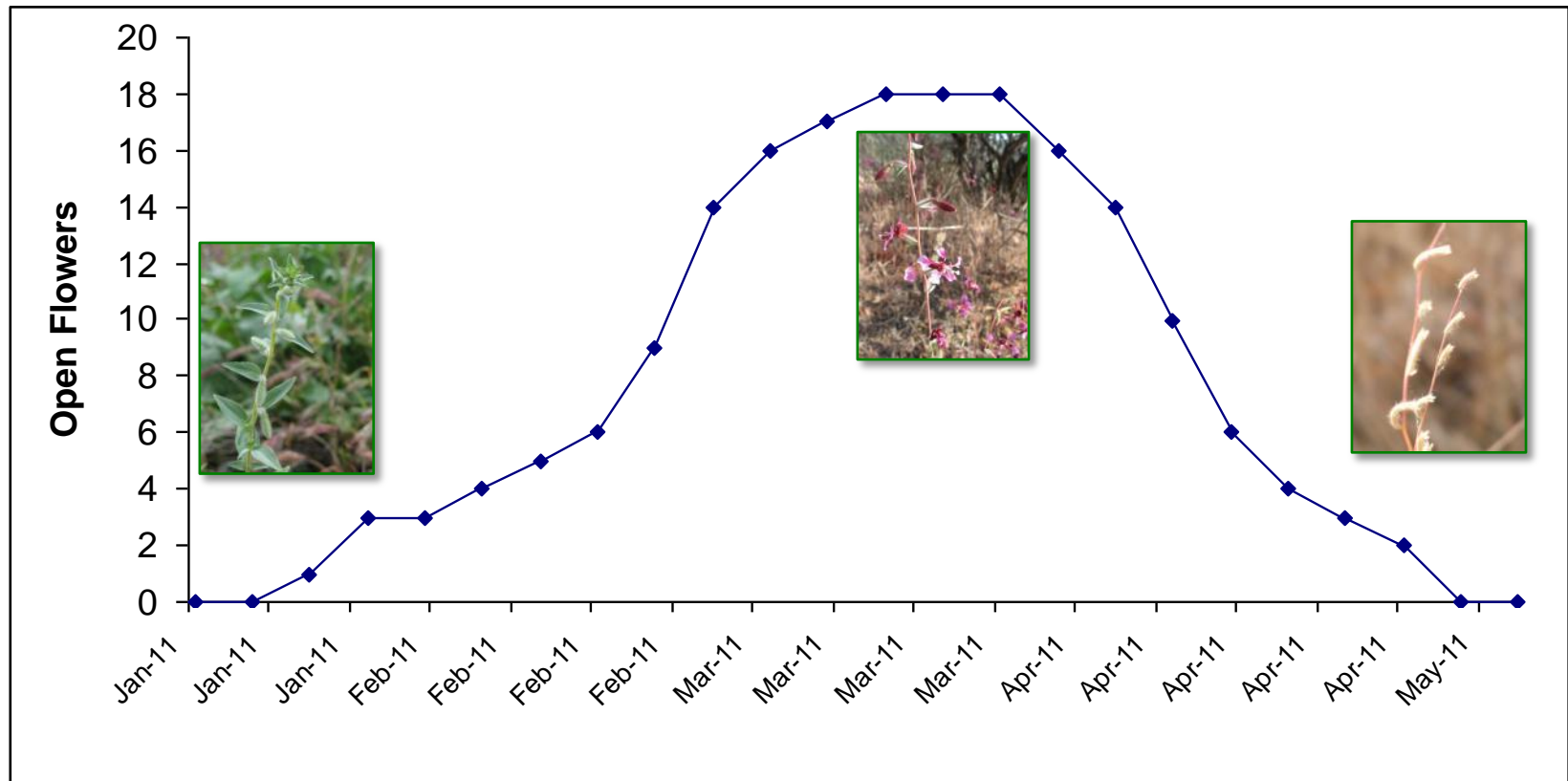
individual



Temporal scales at which phenology is studied

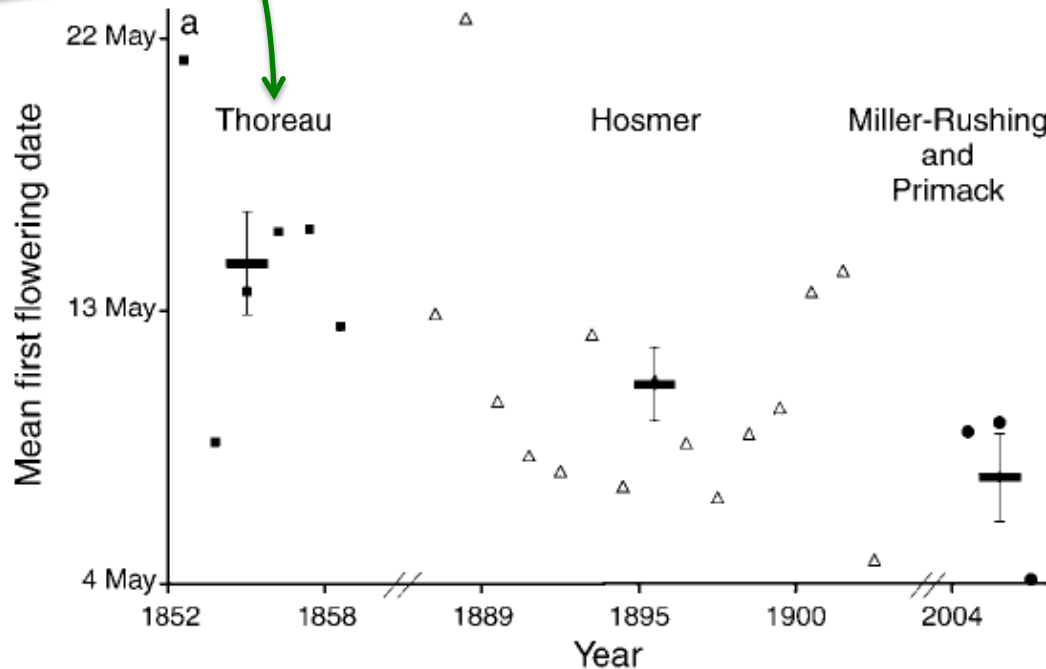
1. **intra**-seasonal: phenological observations within a single season

For example: flowering phenology during from late-winter through spring



Temporal scales at which phenology is studied

2. **inter**-seasonal: phenological observations over multiple years



Miller Rushing and Primack (2008)

Climate Change

Intro to Phenology

Methods

Patterns

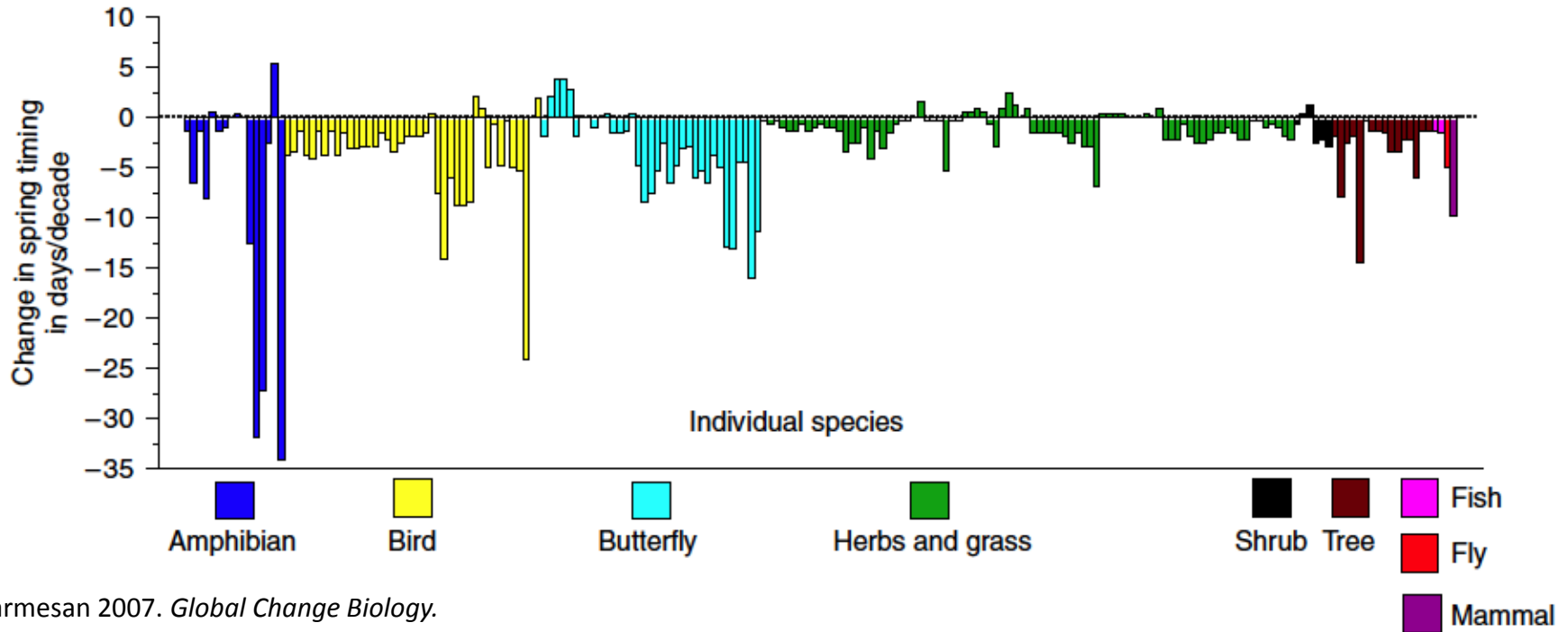
Phenology & Climate Change



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Phenological Responses to Climate Change



Parmesan 2007. *Global Change Biology*.

- Changes in the **timing of spring activity** have been observed in several species
- But the **magnitude** of phenological response depends on type of organism

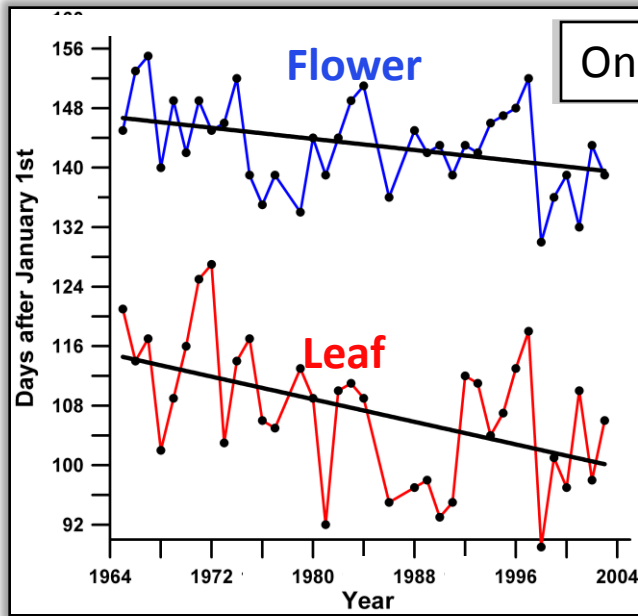
Phenological responses to climate change



Miller-Rushing et al. 2006. *American J. Botany*

Earlier “leaf-out” at Lowell Cemetery in Lowell, Massachusetts

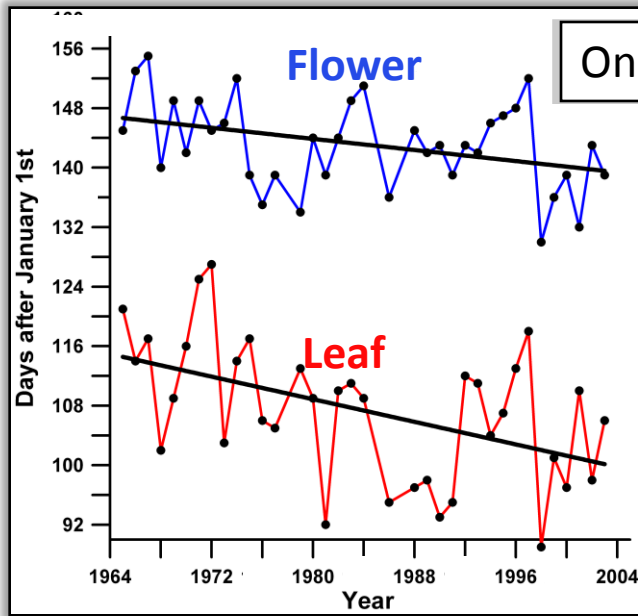
Phenology as a **fingerprint** of climate change



One individual lilac, *in Vermont*



Phenology as a **fingerprint** of climate change



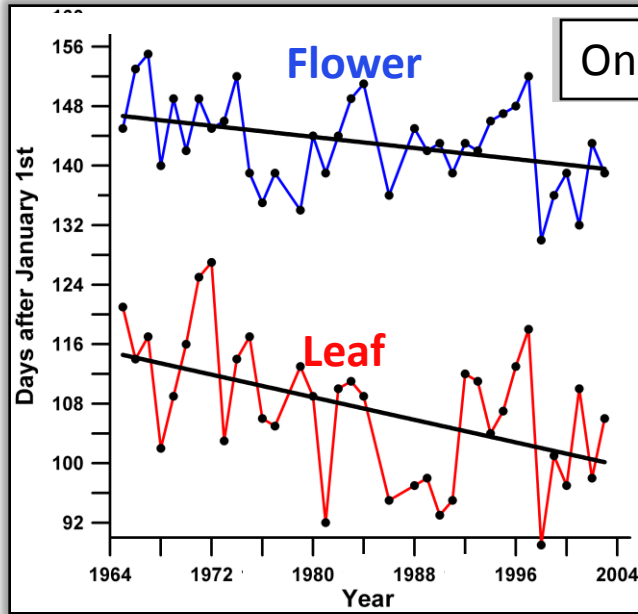
One individual lilac, *in Vermont*



Earlier spring phenology is common among thousands of diverse organisms



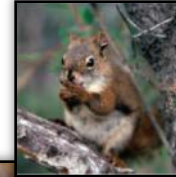
Phenology as a **fingerprint** of climate change



One individual lilac, *in Vermont*



Earlier spring phenology is common among thousands of diverse organisms



Temperature

Earlier
spring

Persistent
summer

Warmer
winter

Plants & animals worldwide are tracking the earlier onset of spring by shifting the timing of their spring activities

Time of Year

Phenology is an indicator of climate change impacts

HAZARDS



CULTURE



HEALTH

