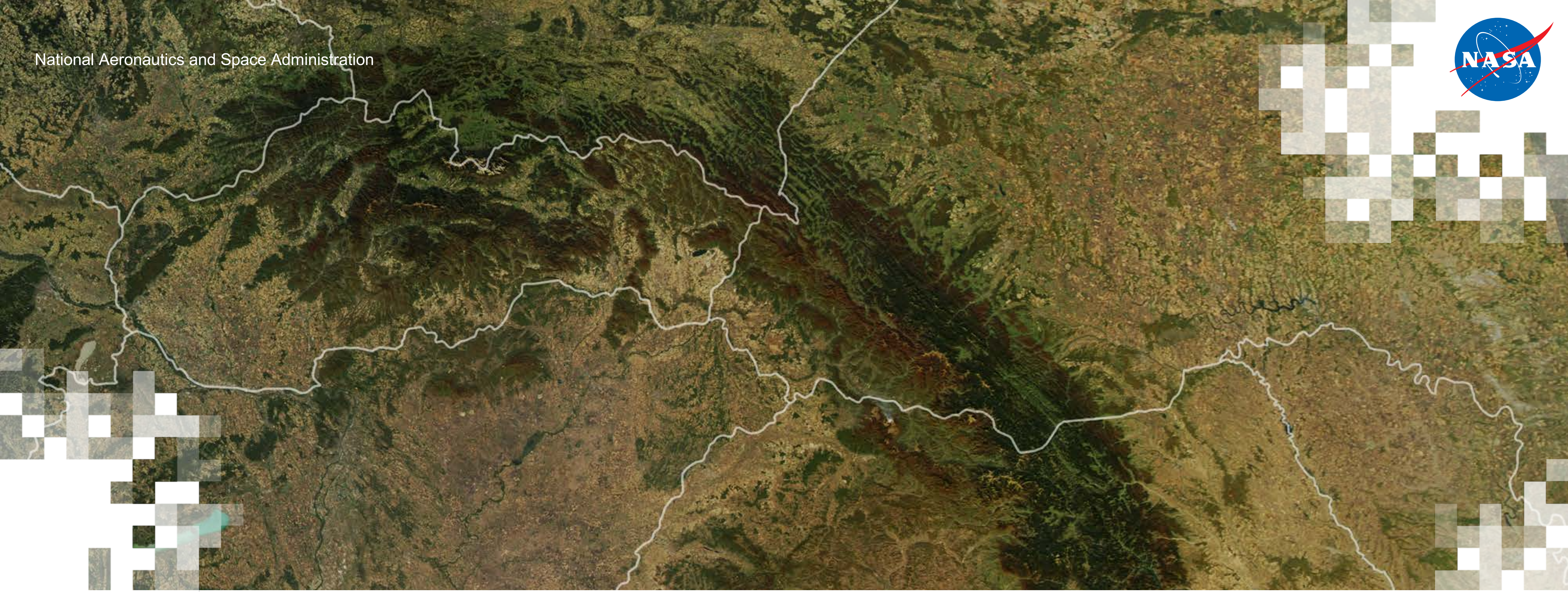


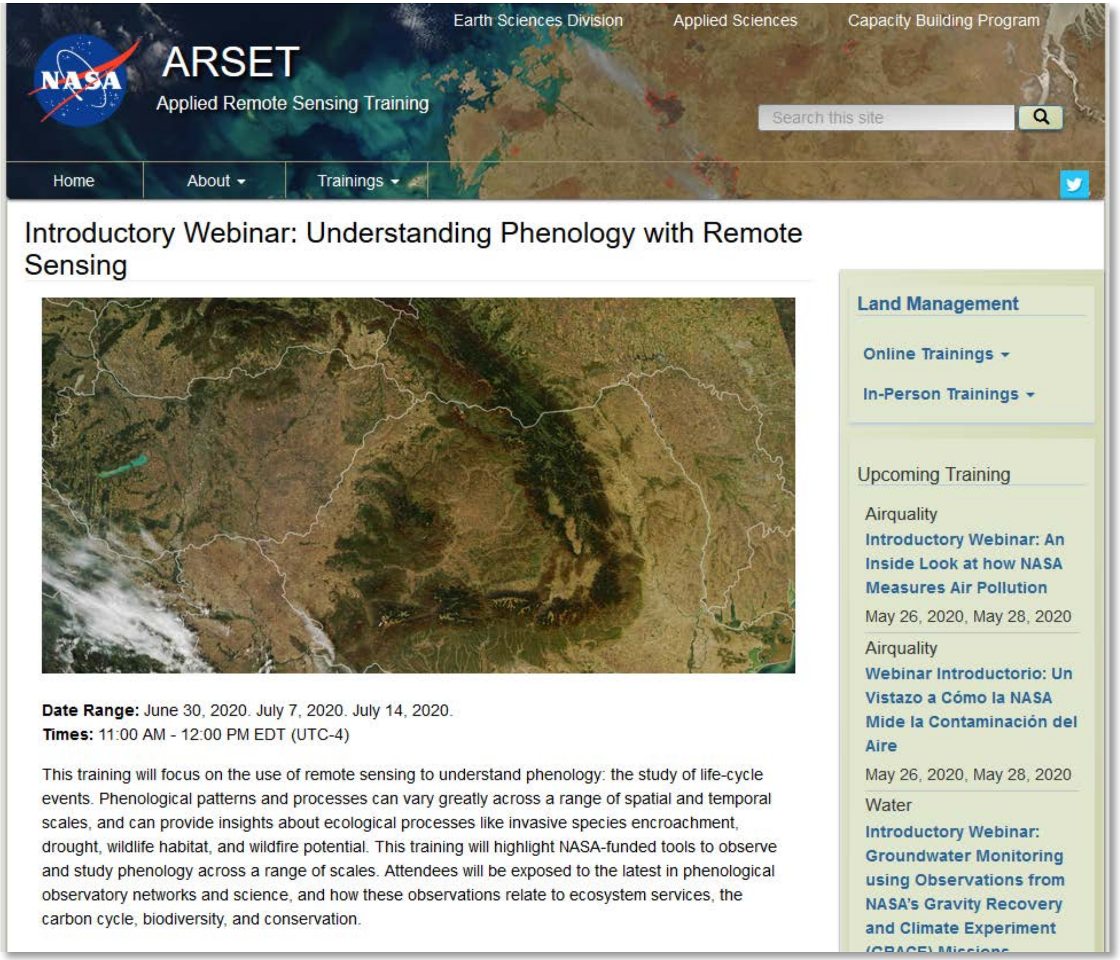
Tracking Vegetation Phenology with Remote Sensing

Amber McCullum and Juan Torres-Pérez

July 14, 2020

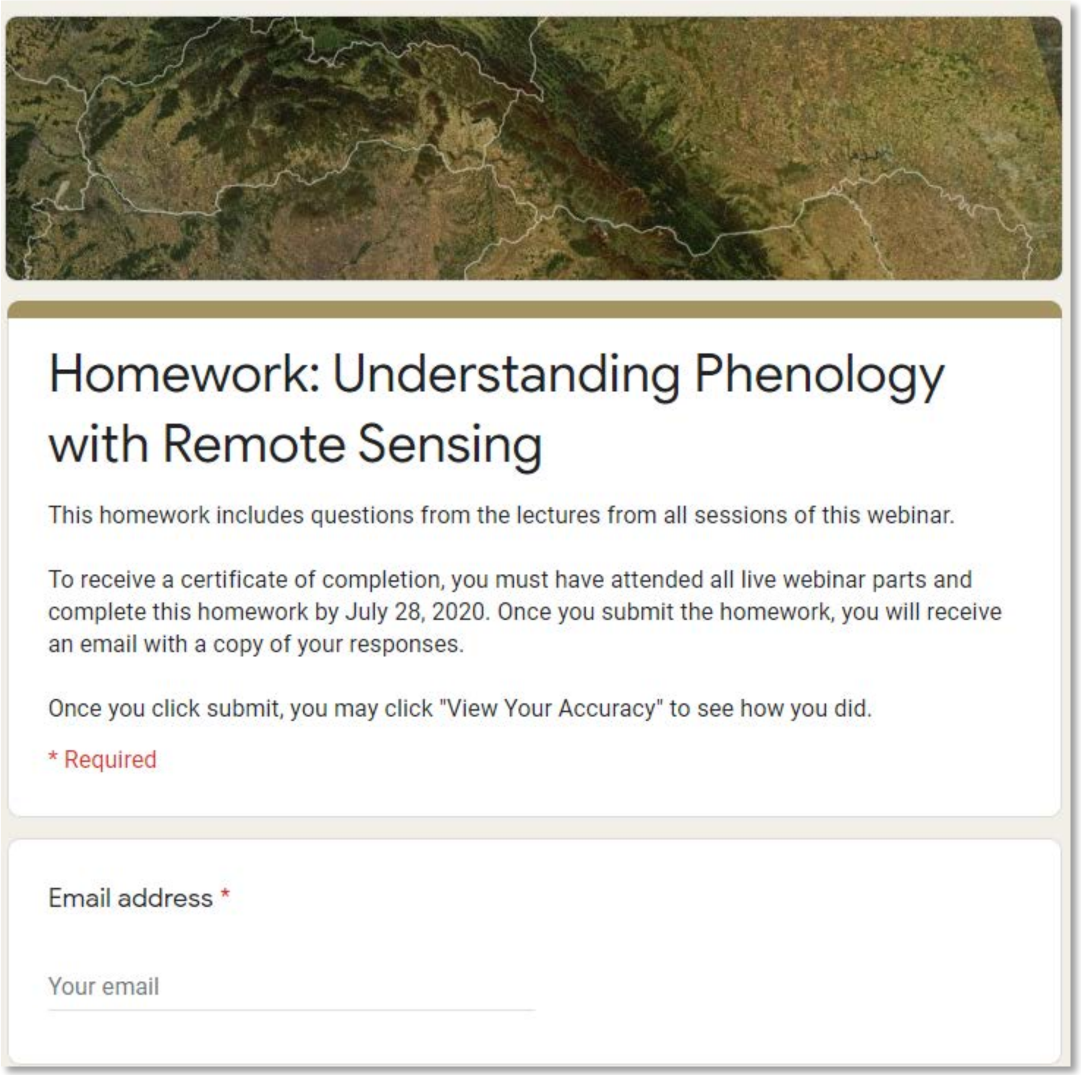
Course Structure and Materials

- Three, 1-hour sessions on **June 30, July 7, and July 14**
- Recordings, slides, and homework assignments can be found after each session at:
  – https://arset.gsfc.nasa.gov/land/webinars/phenology
- Prerequisites:
  – Fundamentals of Remote Sensing
- Q&A: Following each lecture and/or by email at:
  - amberjean.mccullum@nasa.gov
  - juan.l.torresperez@nasa.gov



Homework and Certificates

- **Homework:**
  - One homework assignment
  - Answers must be submitted via Google Forms
- **Certificate of Completion:**
  - Attend all three live webinars
  - Complete the homework assignment by **Thursday, July 28th** (access from ARSET website)
  - You will receive certificates approximately two months after completion of the course from: marines.martins@ssaihq.com



Homework: Understanding Phenology with Remote Sensing

This homework includes questions from the lectures from all sessions of this webinar.

To receive a certificate of completion, you must have attended all live webinar parts and complete this homework by July 28, 2020. Once you submit the homework, you will receive an email with a copy of your responses.

Once you click submit, you may click "View Your Accuracy" to see how you did.

* Required

Email address *

Your email

Course Outline

Part 1:Overview of Phenology and Remote Sensing

Part 2: Scales of Phenology and National Networks

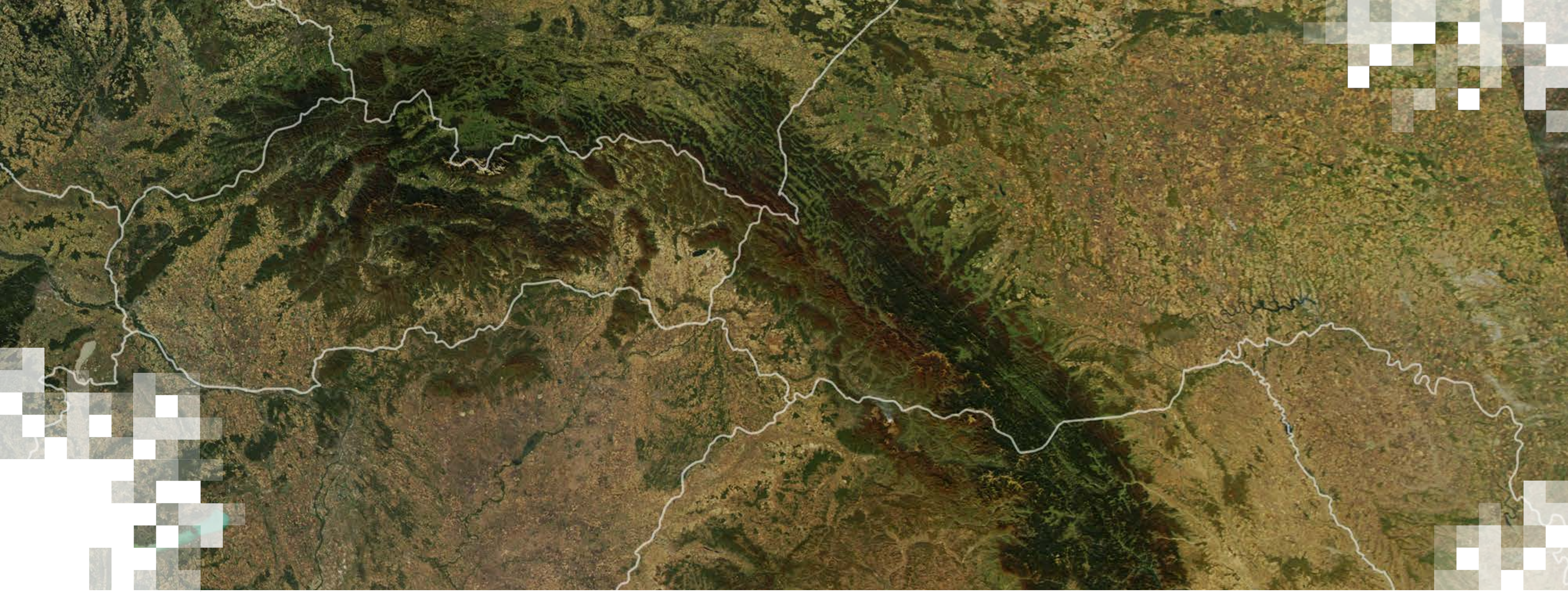
Part 3: Examples of Multi-Scalar Analyses

Learning Objectives

By the end of this presentation, you will be able to:

- Understand various metrics and methods for evaluating land surface phenology

- Identify multiple applications for satellite and near-surface remote sensing alongside ground-based data networks
  - National Products of Spring Onset
  - Green Wave Modeling
  - PhenoCam and VIIRS
  - Urbanization and Phenology



Metrics for Evaluating LSP

Phenological Metrics

- Key variables estimated with remote sensing:
  - Start of Season (SOS)
  - End of Season (EOS)
  - Maximum NDVI
  - Duration
  - Amplitude

Start of Season (SOS) for Kansas, 2018

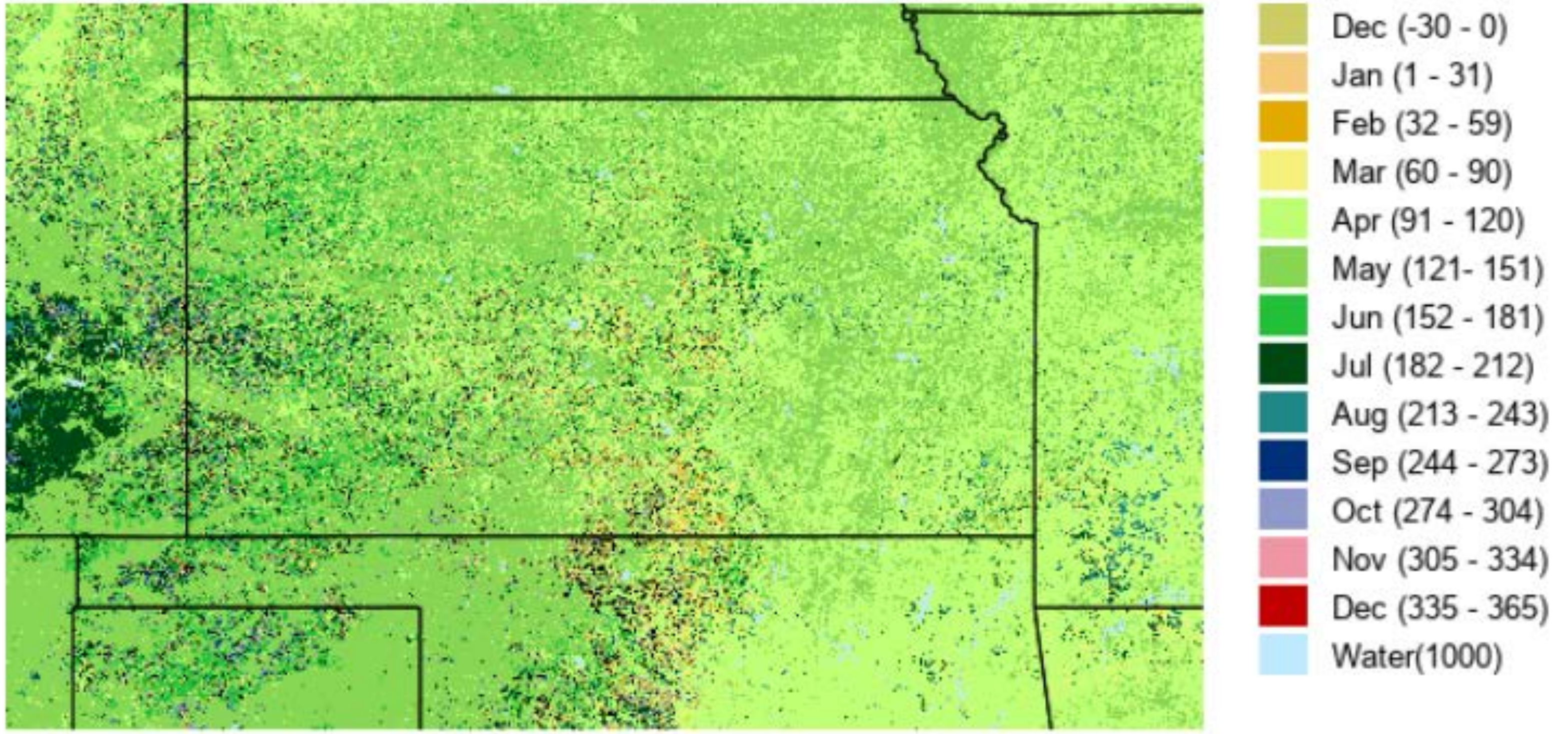


Image Credit: USGS

Start of Season

- **Start of Season Time (SOST)**
  – Day of year identified as having a consistent <u>upward</u> trend in time series NDVI
- **Start of Season NDVI (SOSN)**
  – NDVI value (or baseline) identified at the day of year identified as a consistent <u>upward</u> trend in time series NDVI

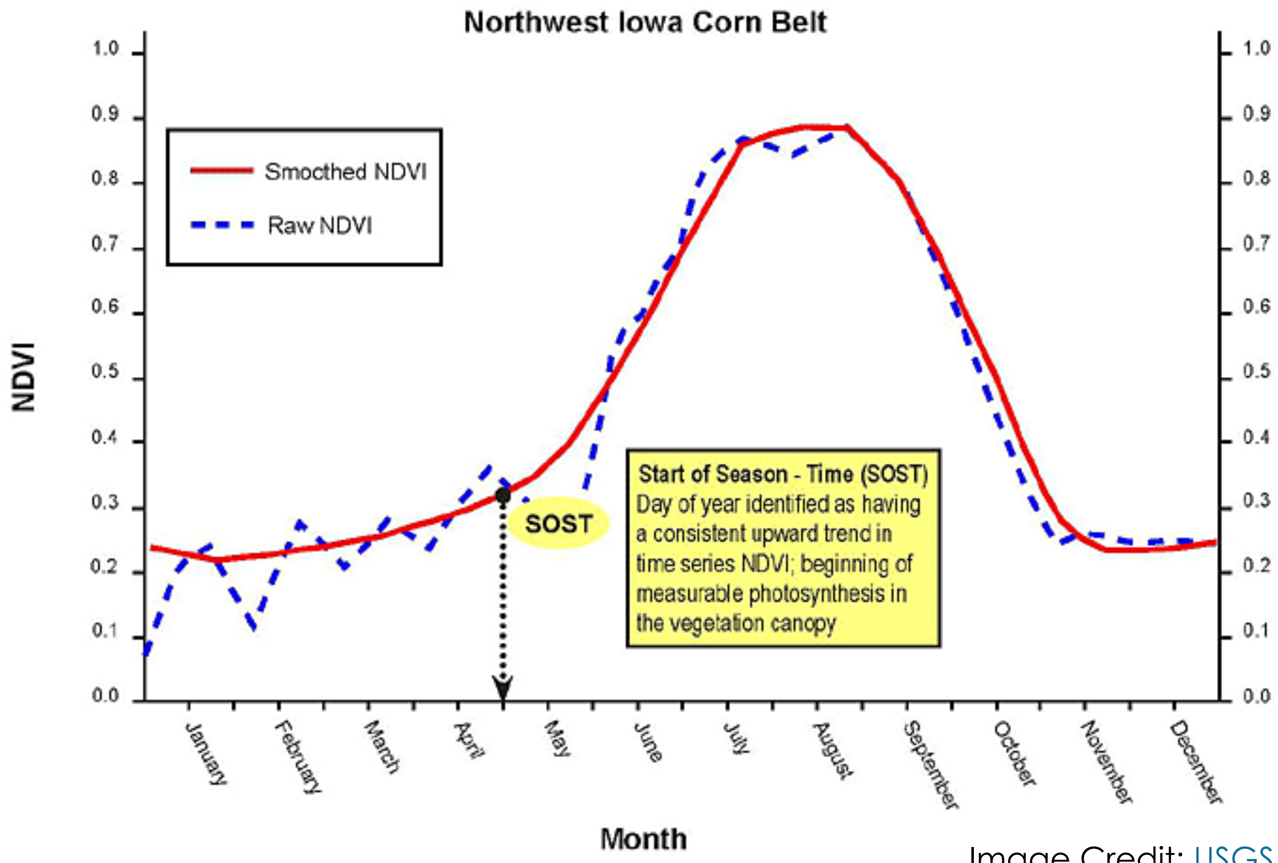


Image Credit: USGS

End of Season

- **End of Season Time (EOST)**
  - Day of year identified at the end of a consistent <u>downward</u> trend in time series NDVI

- **End of Season NDVI (SOSN)**
  - NDVI value corresponding with the day of year identified at the end of a consistent <u>downward</u> trend in time series NDVI

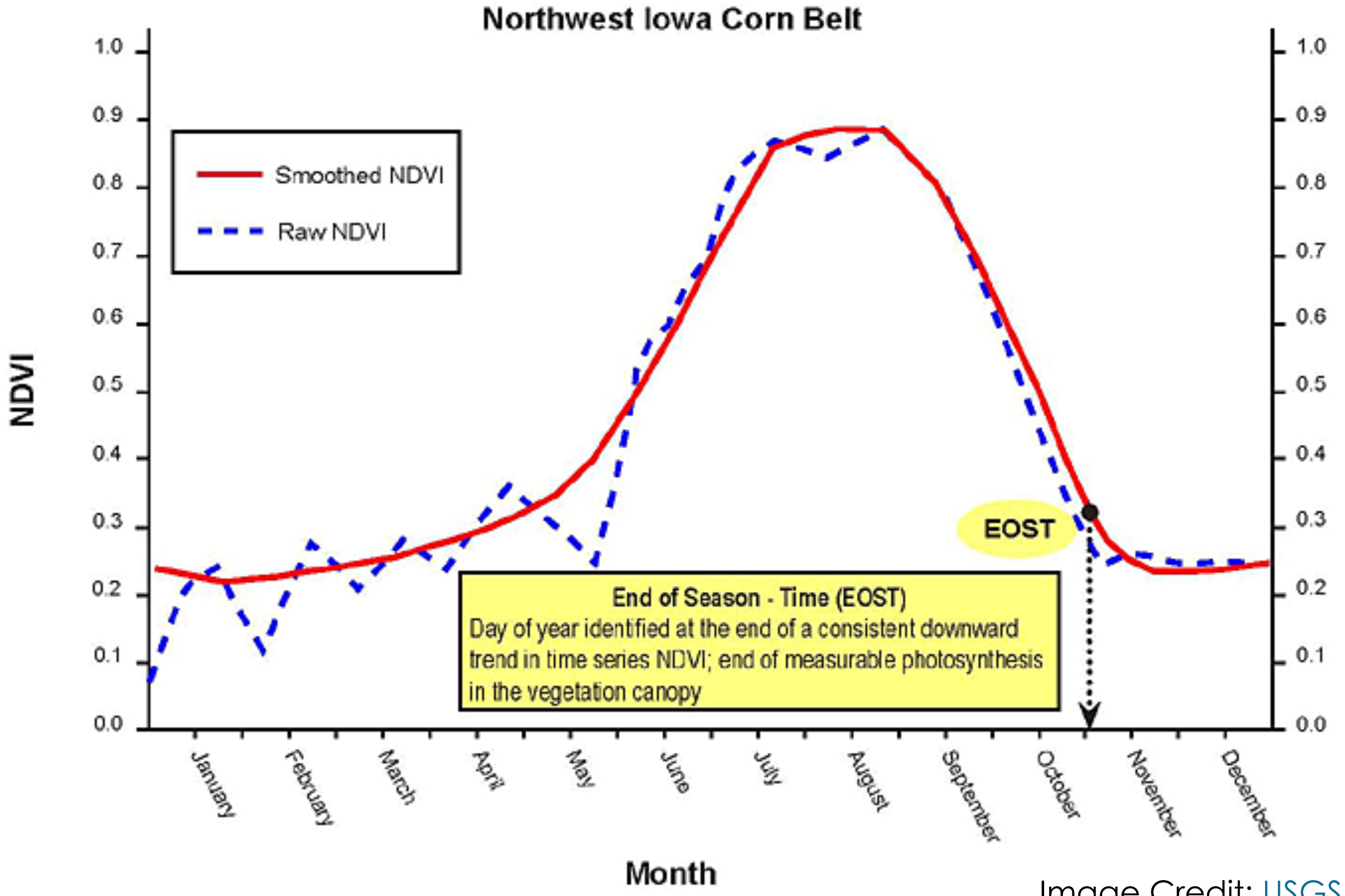


Image Credit: USGS

Max, Duration, Amplitude

- **Maximum NDVI (MAXN)**
  – Maximum NDVI in an annual time series
- **Duration (DUR)**
  – Number of days from the Start of Season Time (SOST) until the End of Season Time (EOST)
- **Amplitude (AMP)**
  – Difference between Maximum NDVI (MAXN) and Start of Season NDVI (SONS)

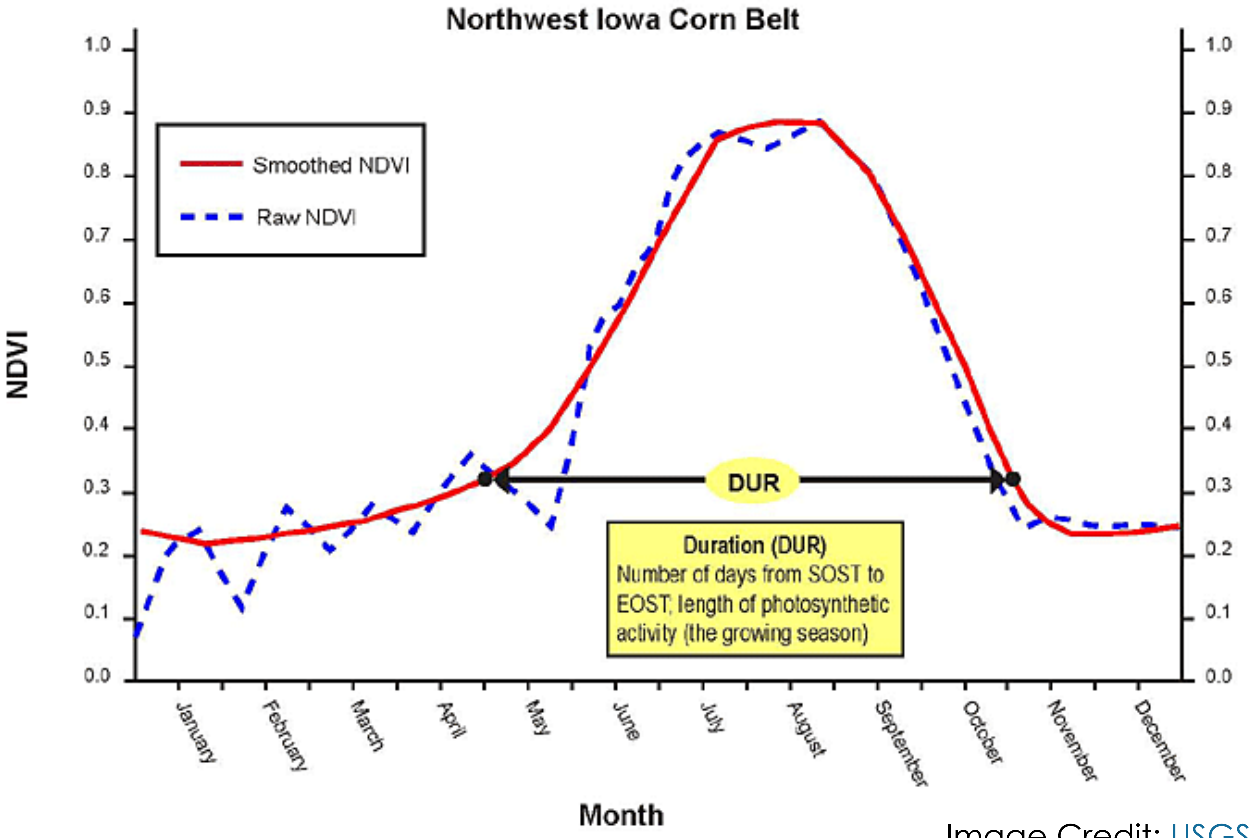
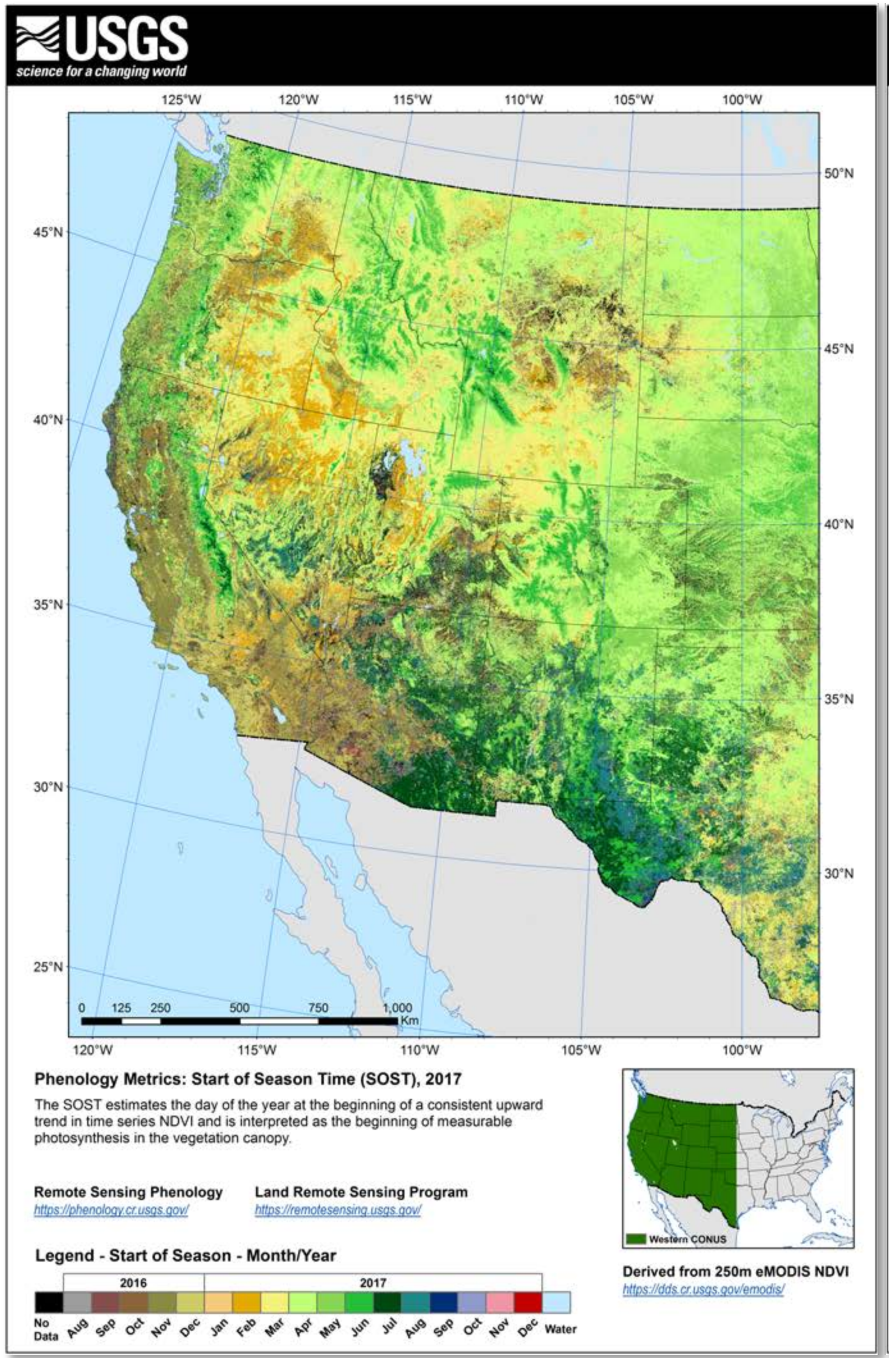
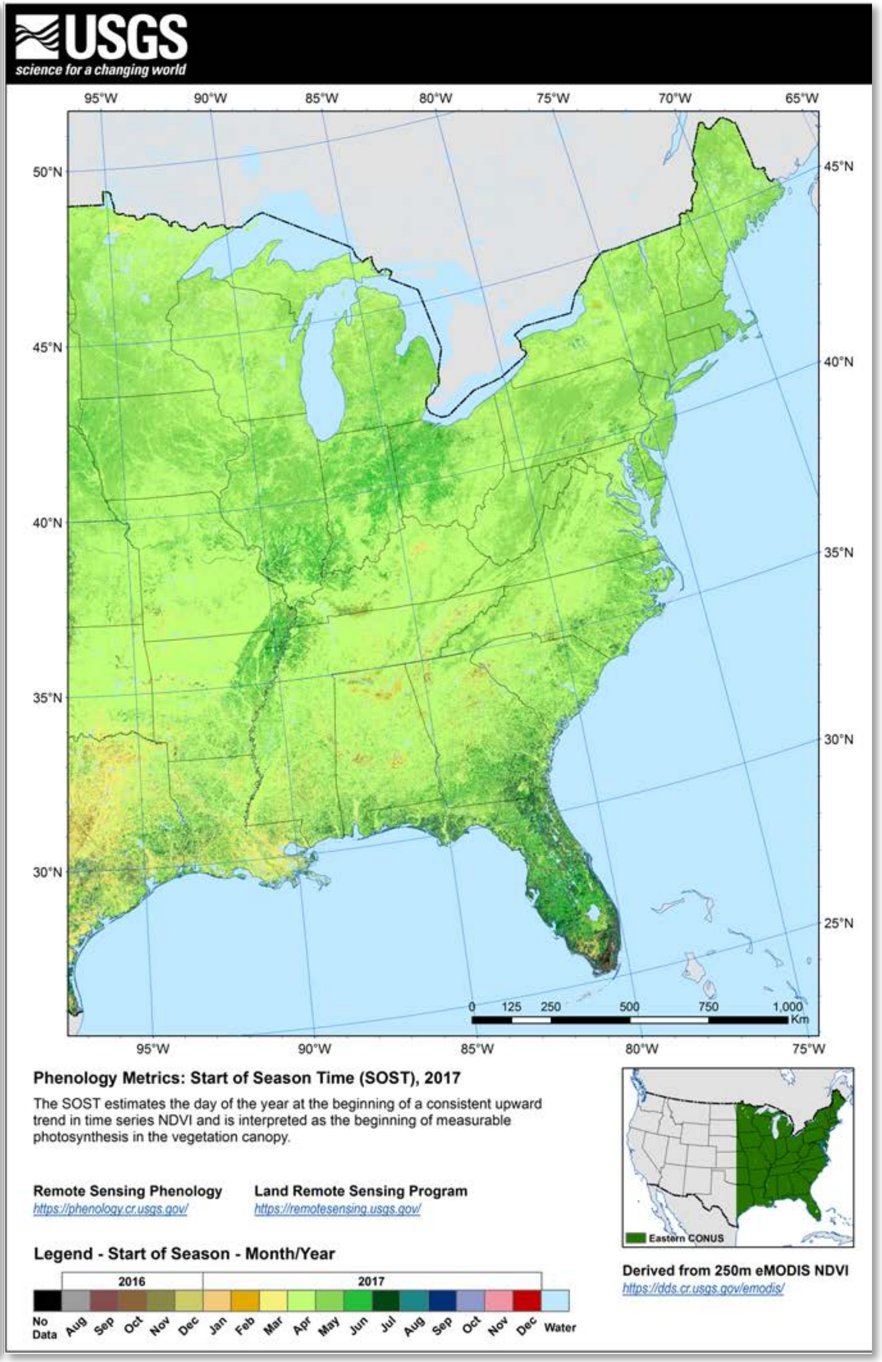


Image Credit: USGS


USGS
science for a changing world
Phenology Metrics: Start of Season Time (SOST), 2017
The SOST estimates the day of the year at the beginning of a consistent upward trend in time series NDVI and is interpreted as the beginning of measurable photosynthesis in the vegetation canopy.
Remote Sensing Phenology
https://phenology.cr.usgs.gov/
Land Remote Sensing Program
https://remotesensing.usgs.gov/
Western CONUS
Derived from 250m eMODIS NDVI
https://dds.cr.usgs.gov/emodis/
Legend - Start of Season - Month/Year
2016
2017
No Data
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Water
0 125 250 500 750 1,000 Km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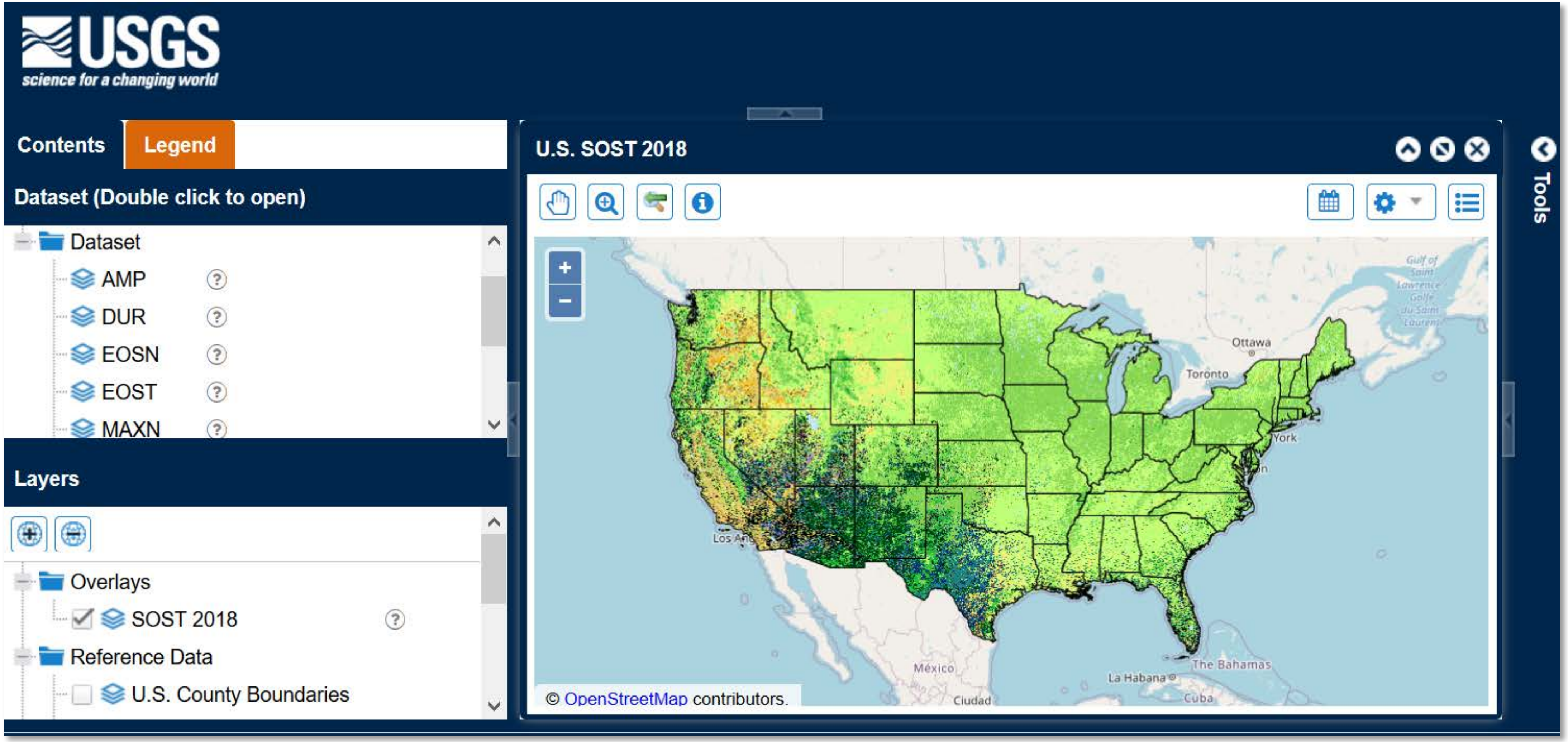
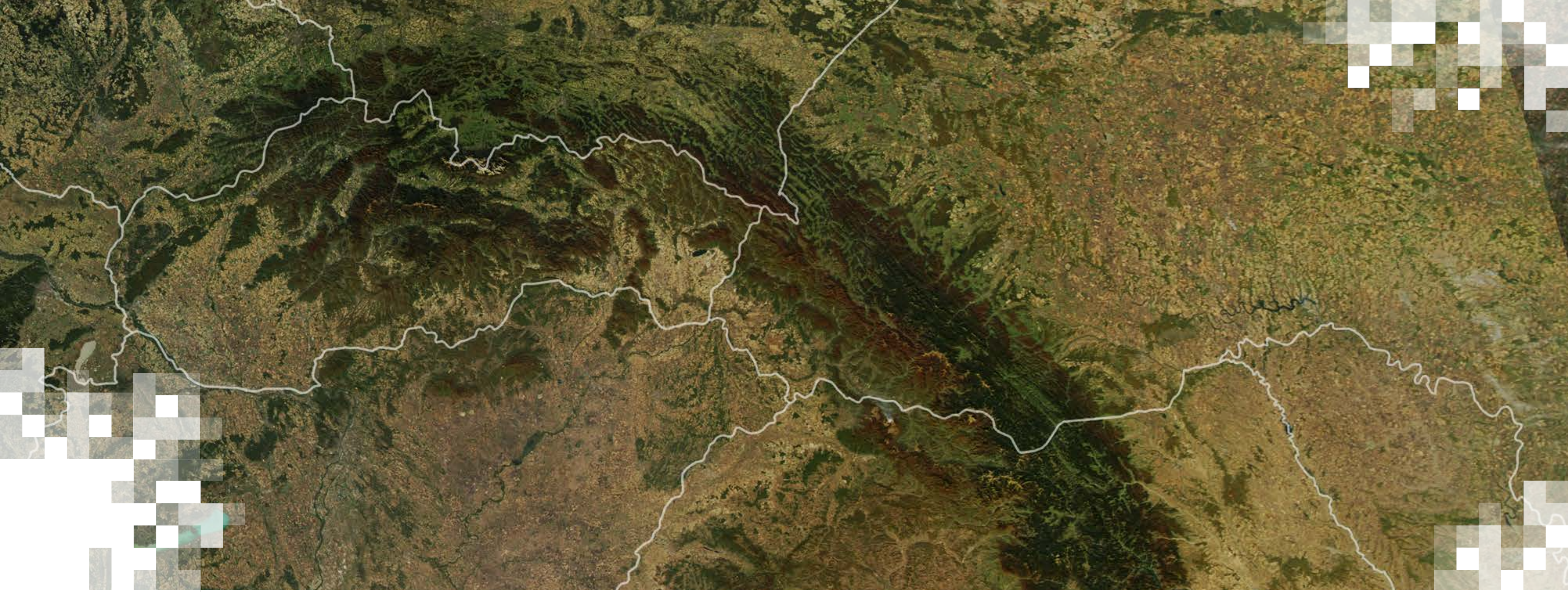
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Water
0 125 250 500 750 1,000 Km

USGS Phenology Viewer



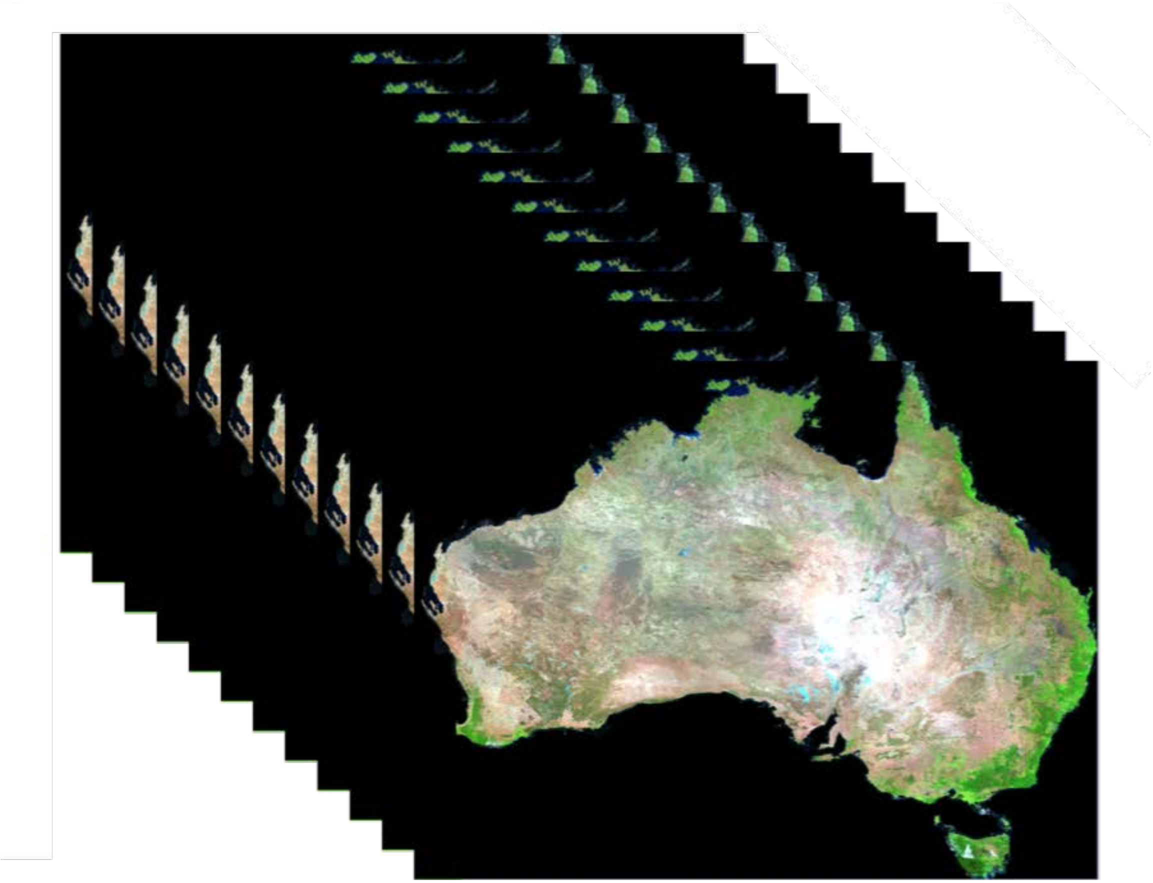
https://phenology.cr.usgs.gov/viewer/



Methods for Evaluating LSP

Methods for evaluating seasonal metrics

- Time Series Analysis: This is critical to most LSP metrics and is used for all the below methods.
  - Threshold Values
  - Inflection Points
  - Rates of Change
  - Delayed Moving Average



Stack of Landsat images of Australia. Image Credit: WELD

Noise Reduction in Time Series

- Earth's atmosphere, changing illumination patterns, and satellite angles can introduce noise.
- Most noise reduces NDVI values.
- MANY techniques for how to address noise:
  - Filtering
  - Compositing
  - Smoothing

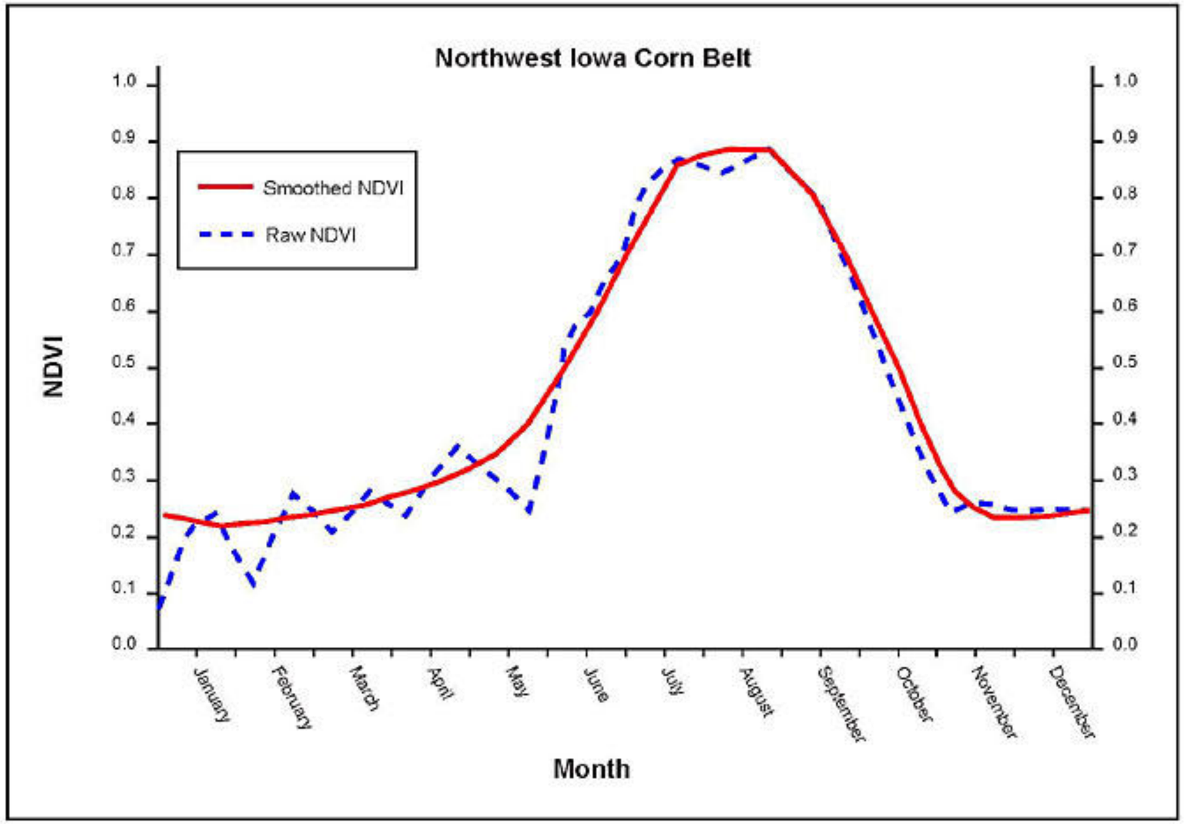


Image Credit: USGS

Threshold Values

- Threshold Values: When vegetation activity is to begin, peak, or end.
- Can be pre-defined or relative

Pre-defined:

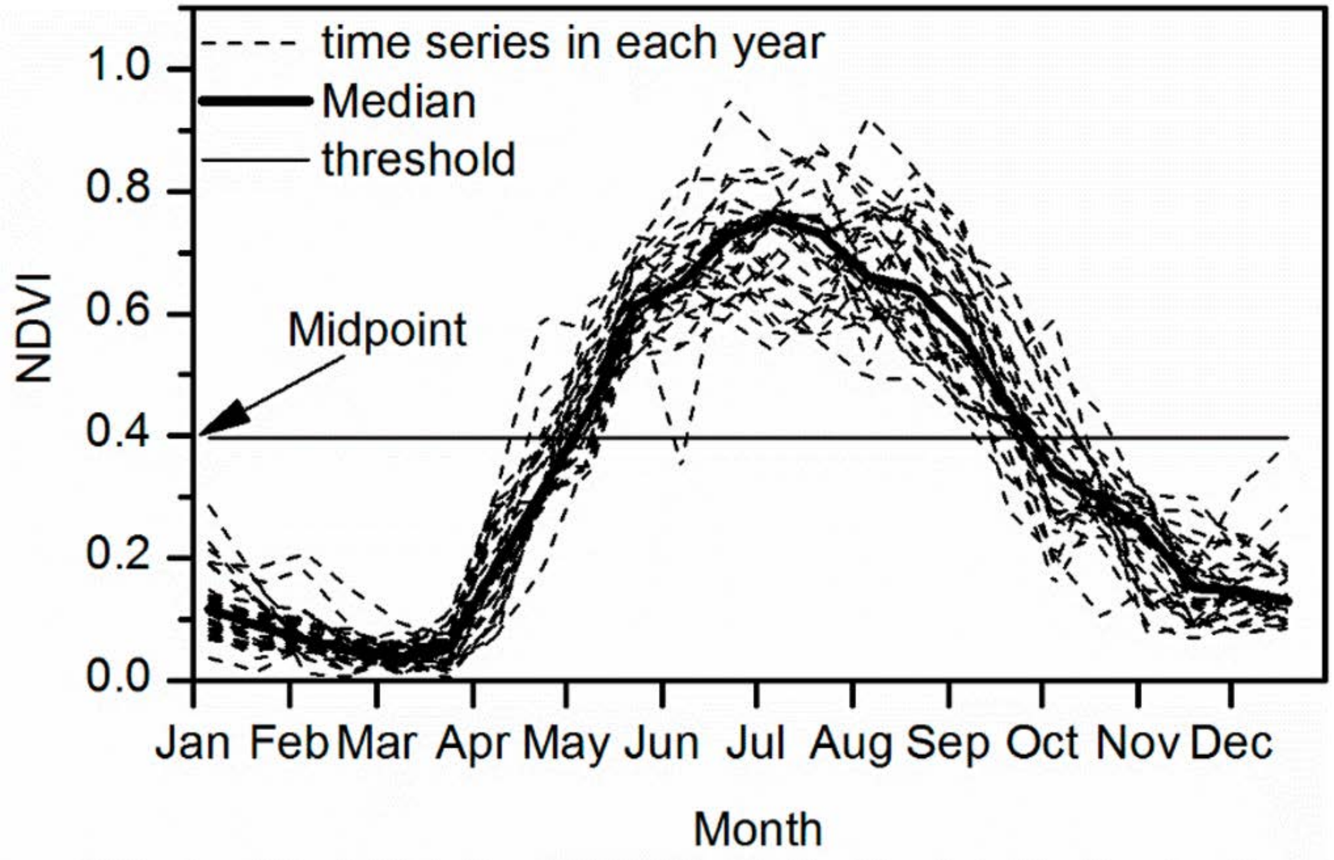
- A set threshold NDVI
  - Ex: NDVI threshold set at 0.099 and the SOS is when NDVI values reaches this value

Relative:

- Uses multiple seasons to find relative changes in NDVI
- Long term mean
- Baseline year
- NDVI ratios

Threshold Values: Midpoint

- Example: Seasonal midpoint NDVI (SMN) - Uses relative reference values to derive the Start of Season (SOS)
  - Multi-year median NDVI calculated
  - Threshold defined as midpoint between min and max NDVI
  - Ties the threshold to the seasonal amplitude of individual pixels (the dynamic characteristics)

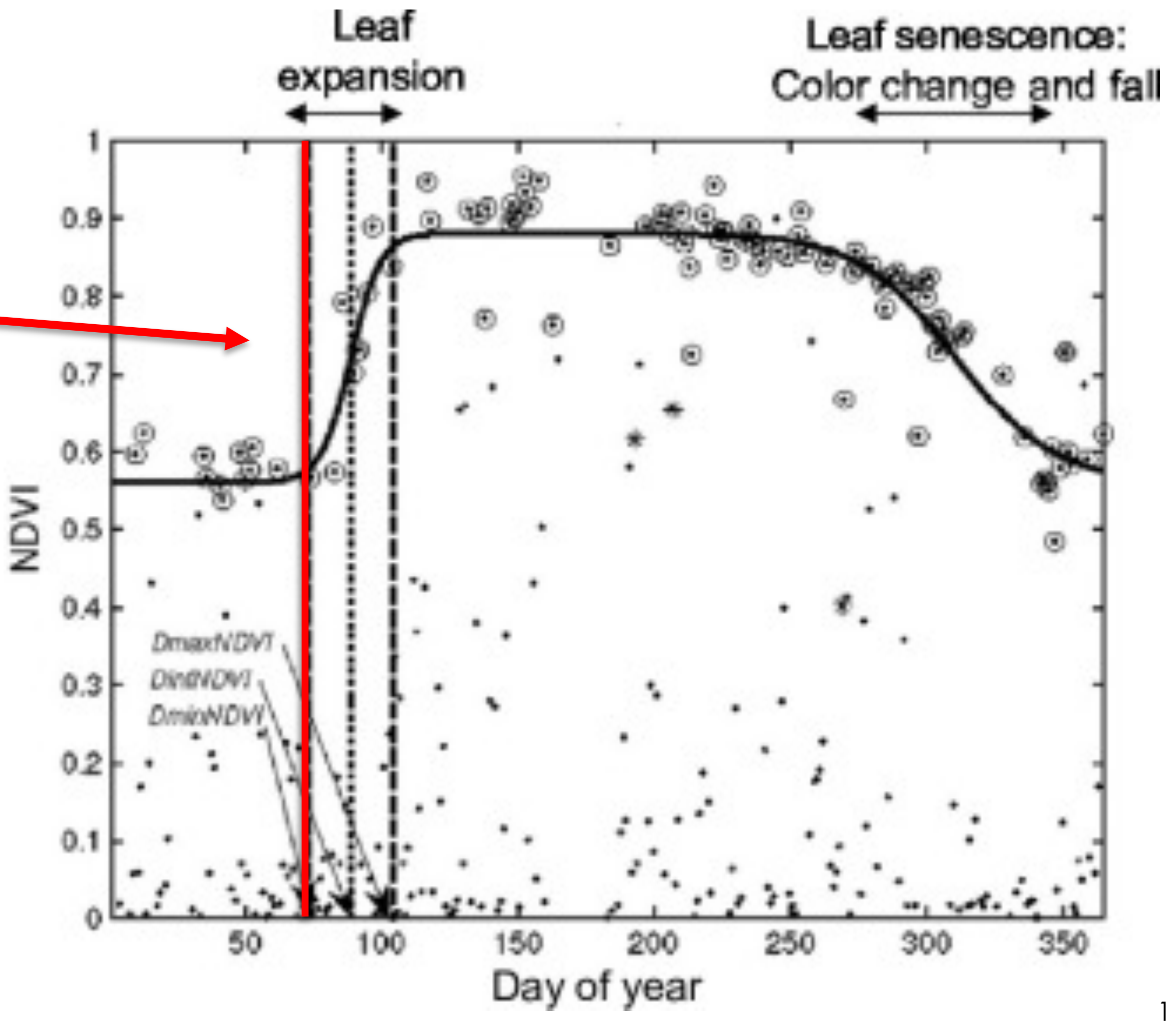


Midpoint example. Image Credit: [Ge et al 2016]

Inflection Points

- The time when the time series changes direction (from concave upward to concave downward).
- From Decreasing to Increasing = SOS
- From Increasing to Decreasing = EOS

Inflection Point



Seasonal trajectory of the NDVI after daily measurements by the MODIS sensor (MOD09GQK product) during a given year on a deciduous stand. Image Credit: [Guyon and Breda, 2016]

Delayed Moving Average (DMA)

- Predicted values based on previous time series observations in NDVI.
- Current NDVI compared to moving average of previous values
- Trend Change: When smoothed NDVI values are larger or smaller than predicted by DMA.
  - Start of Growing Season (SOS): Smoothed NDVI **Larger** than DMA predictions.
  - End of Growing Season (EOS): Smoothed NDVI **Smaller** than DMA predictions.

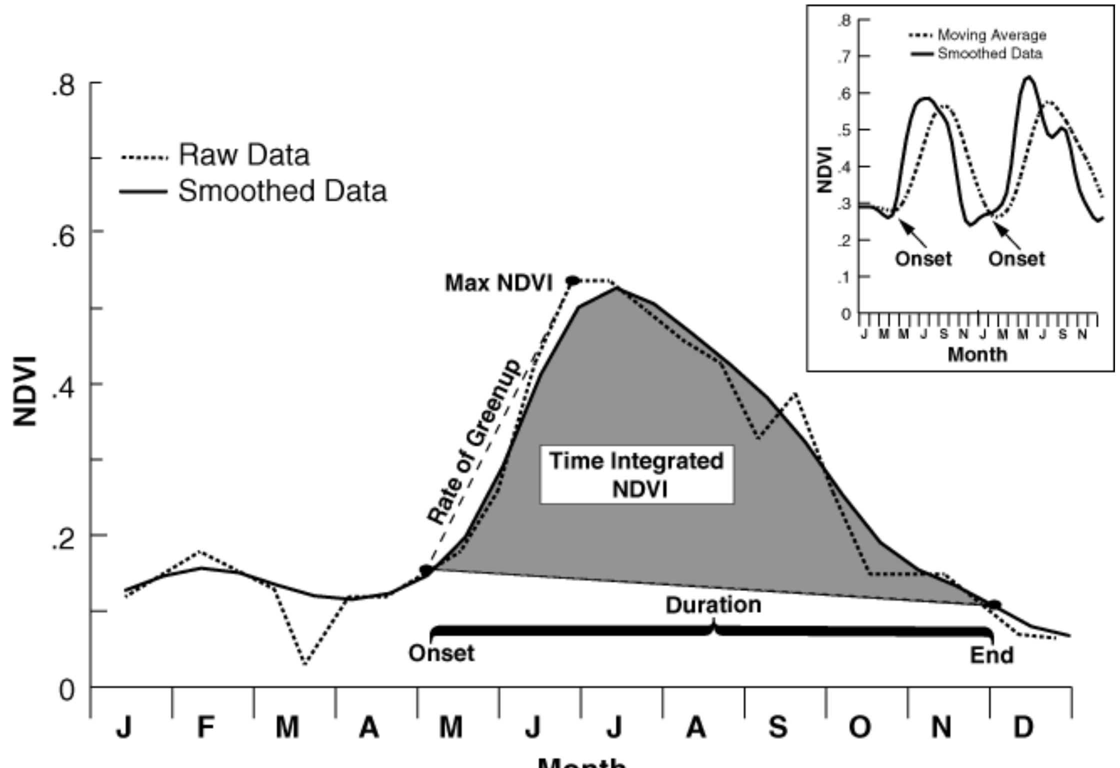
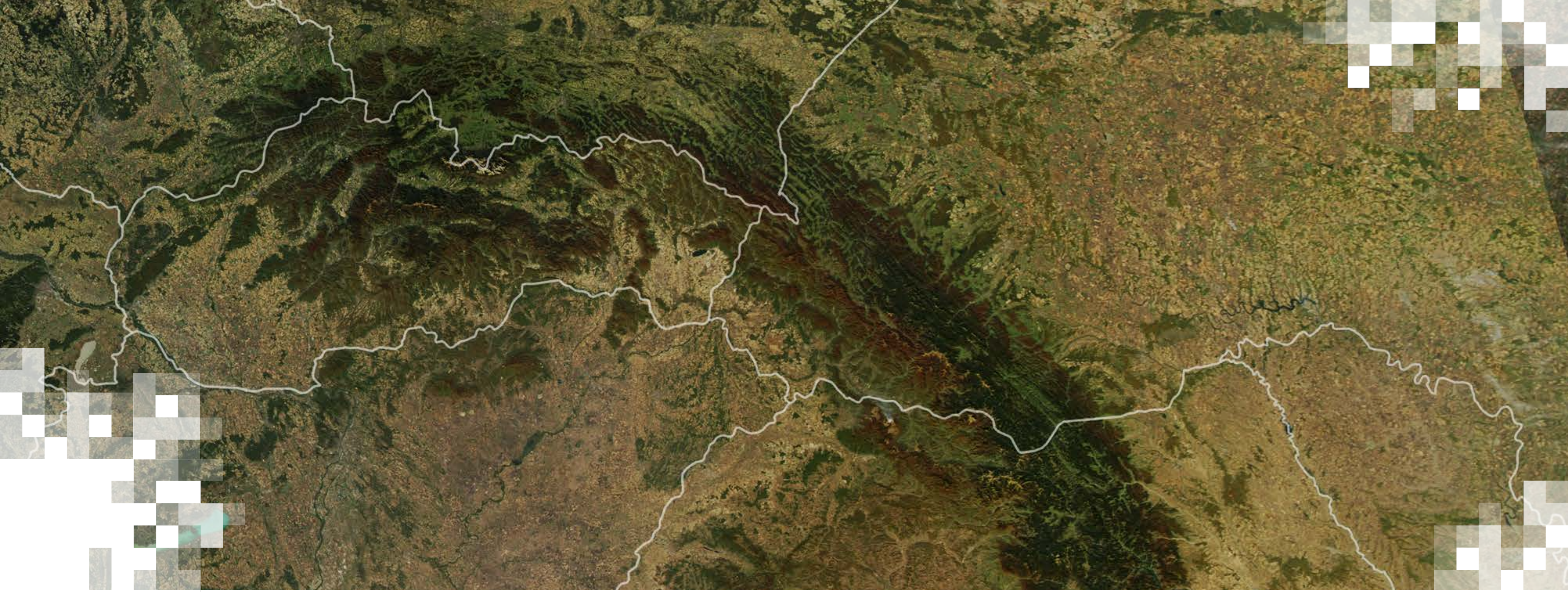


Figure 3
Reed and Sayler, 1997, "A Method for Deriving Phenological Metrics from Satellite Data, Colorado 1991-1995"
USGS EROS Data Center

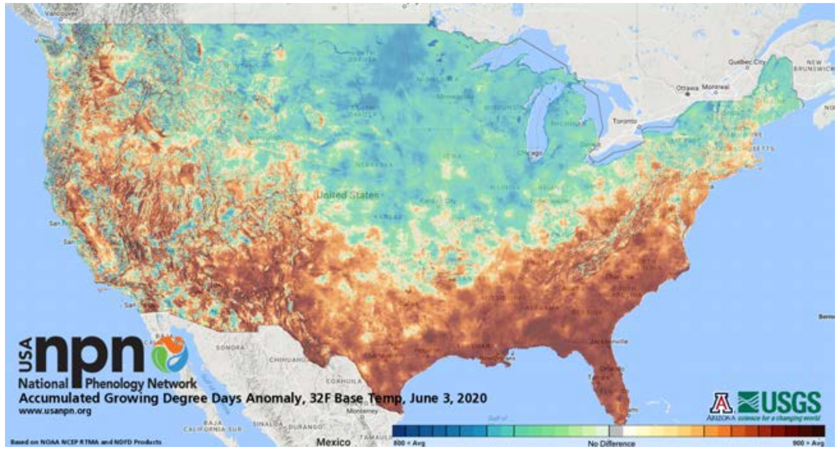
Image Credit: Reed and Sagler, 1997



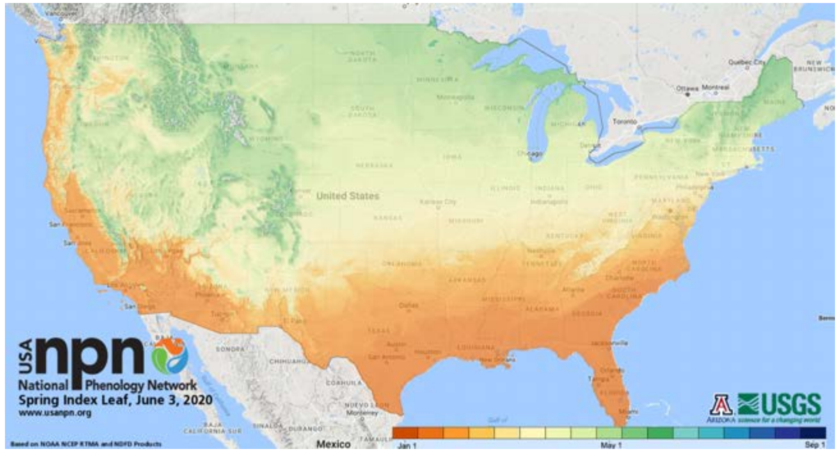
Case Studies: NPN Gridded Products

NPN and Gridded Products

- Research Need: Gridded real-time, short-term forecasted, and historical maps of phenological events, patterns, and trends.
  - Assist with many phenology research questions
  - Relate back to ecosystem dynamics and climate change
- Primary Products:
  - Accumulated Growing Degree Days (AGDD)
  - Extended Spring Indices



AGDD Anomalies for June 3rd, 2020



Spring Leaf Index, for June 3rd, 2020

How does this spring compare to "normal"?

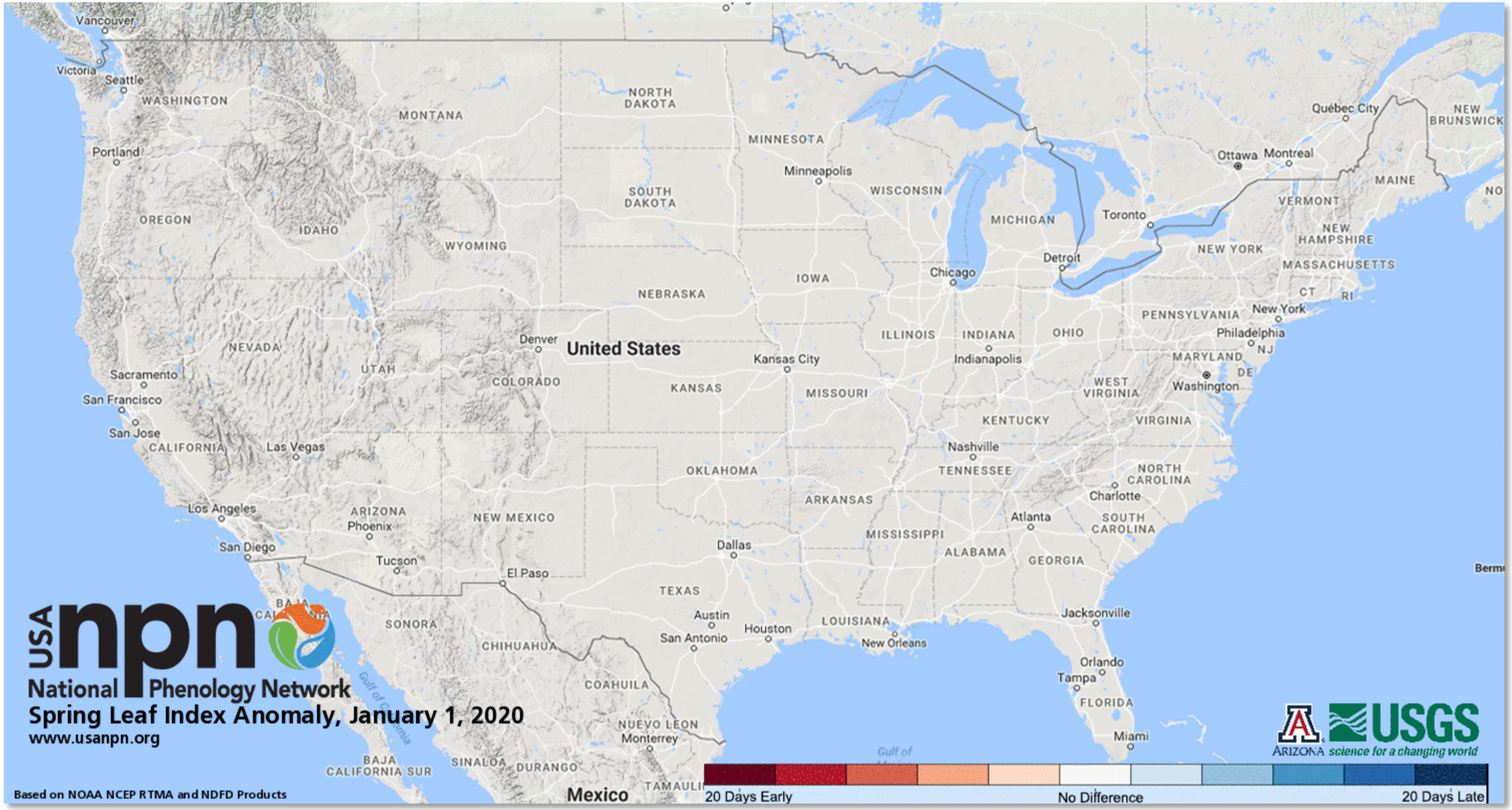
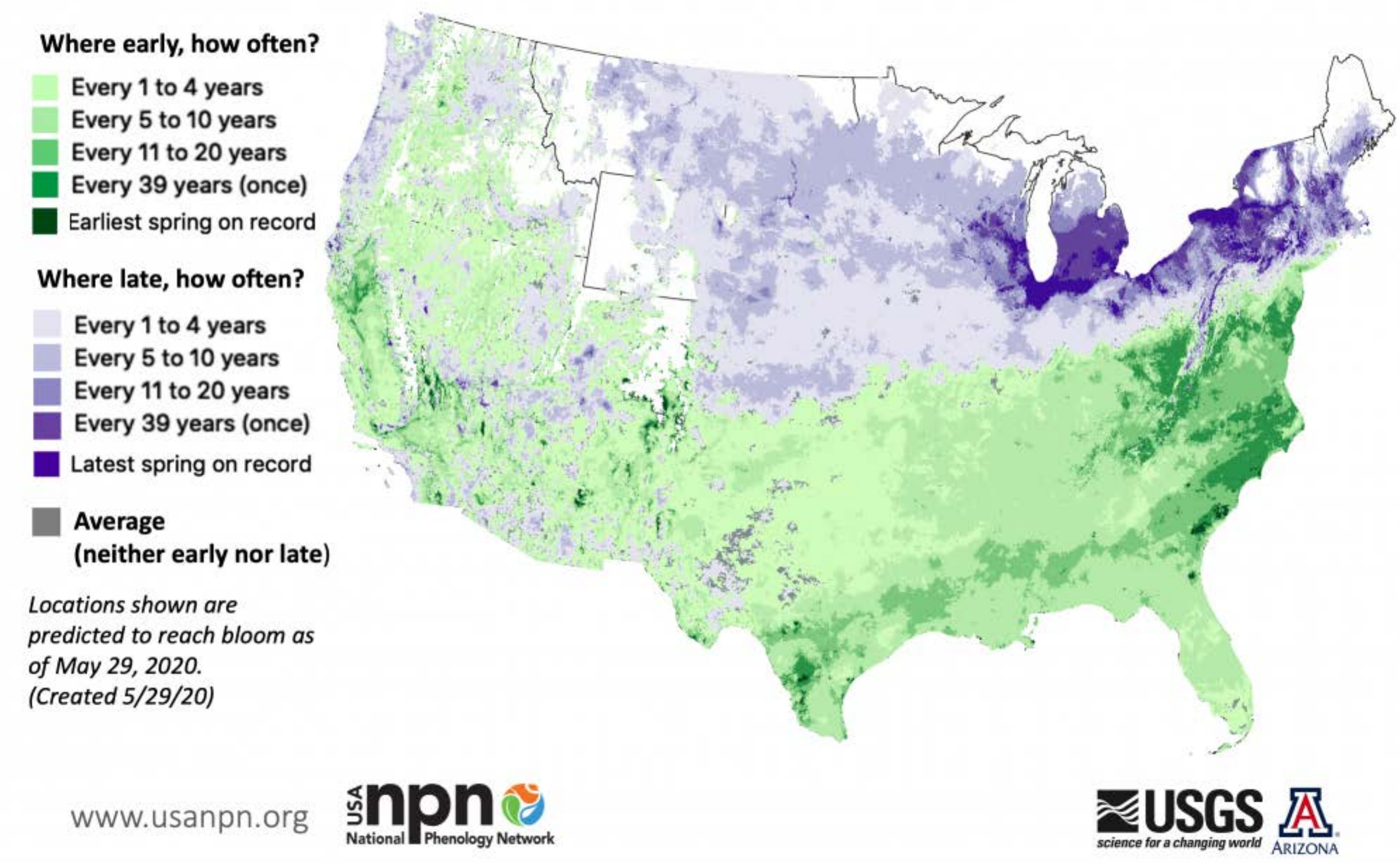


Image Credit: [NPN]()

How often do we see a spring this early or late?



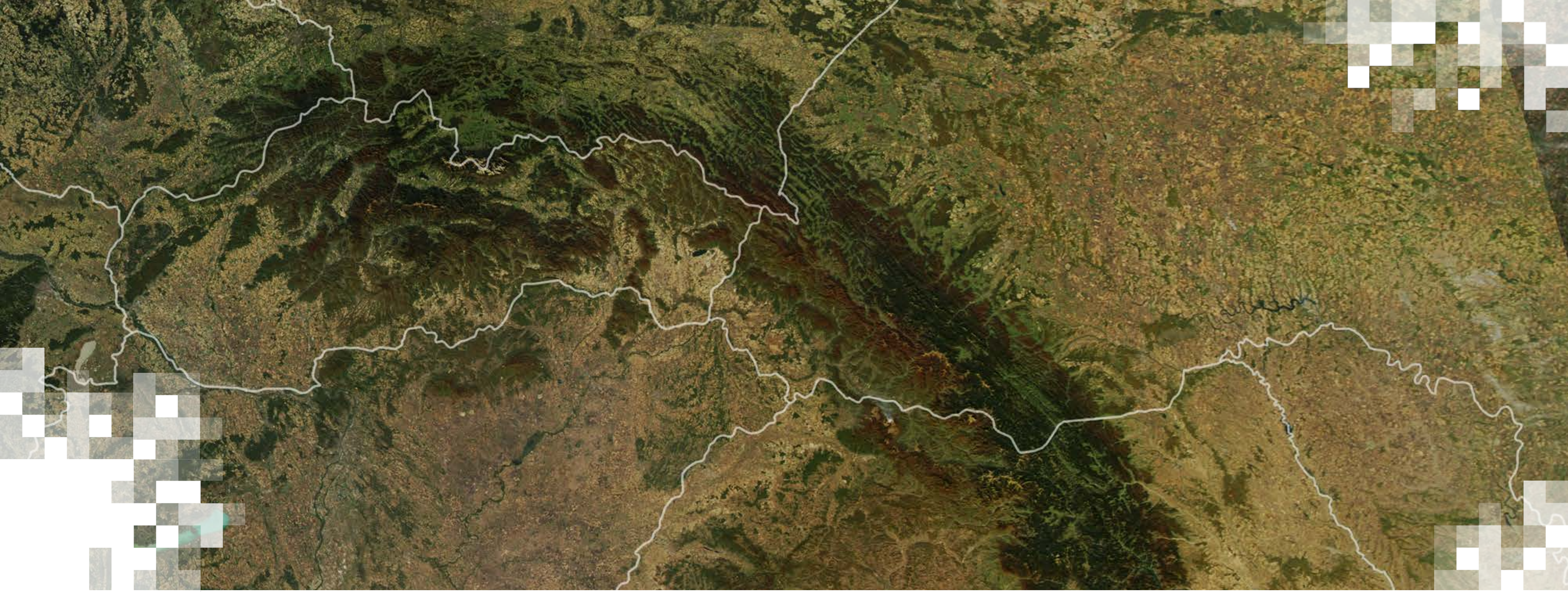
Over a 39-year period of record of spring bloom dates, how often do we see springs like 2020?

Spring Indices: Observational Data

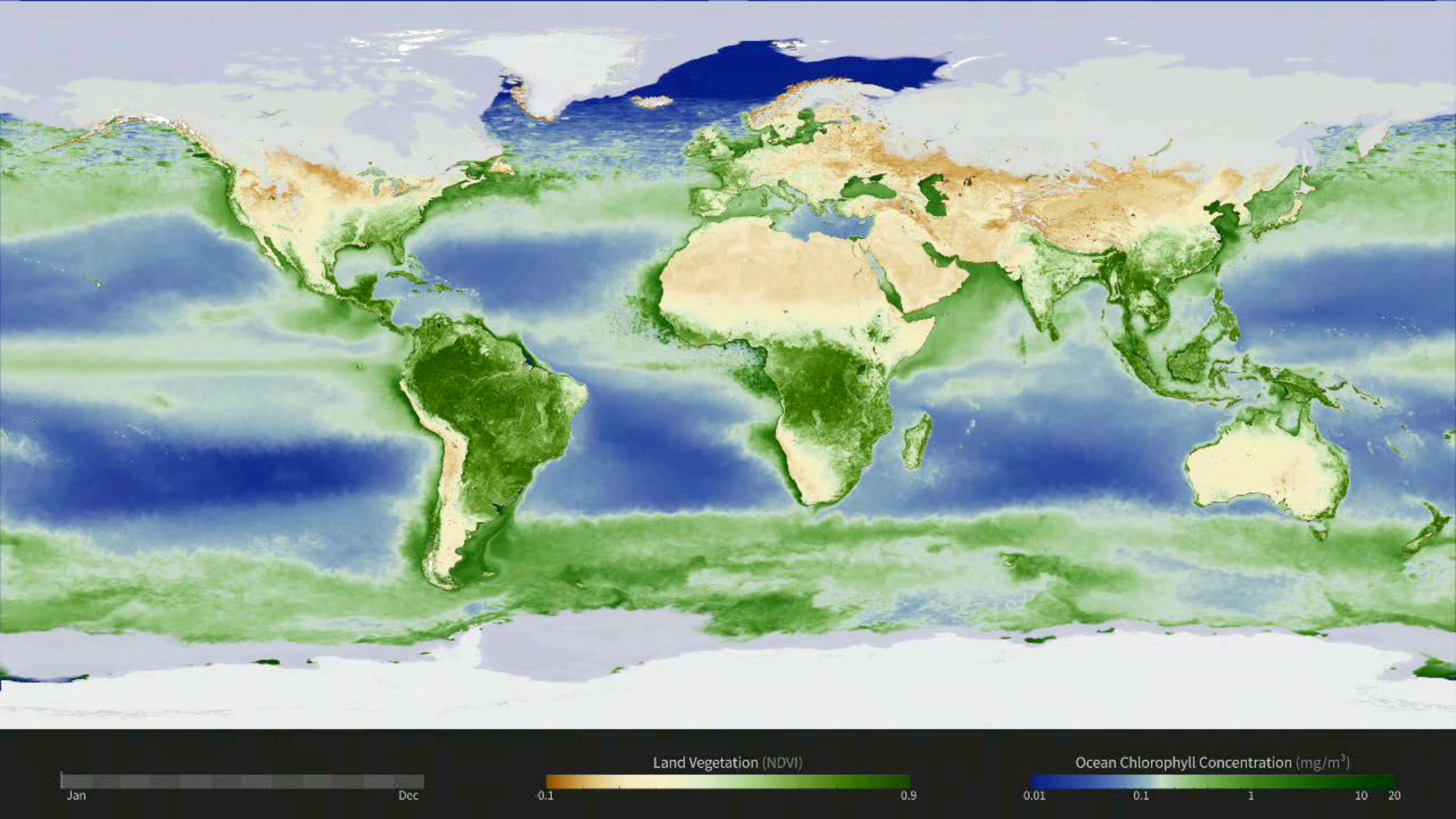
- Track a Lilac Citizen Science Project

Phenophase	Definition	Photo (click to enlarge)
Breaking leaf buds	In at least 3 locations on the plant, a breaking leaf bud is visible. A leaf bud is considered "breaking" once the widest part of the newly emerging leaf has grown beyond the ends of its opening winter bud scales, but before it has fully emerged to expose the leaf stalk (petiole) or leaf base. The leaf is distinguished by its prominent midrib and veins.	
Open flowers	For the whole plant, at least half (50%) of the flower clusters have at least one open fresh flower. The lilac flower cluster is a grouping of many, small individual flowers.	
Full flowering	For the whole plant, virtually all (95-100%) of the flower clusters no longer have any unopened flowers, but many of the flowers are still fresh and have not withered.	

https://www.usanpn.org/nn/TrackaLilac



Case Studies: Green Wave Modeling



Jan
Dec
Land Vegetation (NDVI)
-0.1
0.9
Ocean Chlorophyll Concentration (mg/m3)
0.01
0.1
1
10
20

Green Wave Modeling

- Green Wave: The flush of green that accompanies leaf-out over the course of the spring season, as well as the spread of seasonal color across the country in the autumn.
- Research Objective: Track shifts across the U.S. to validate models, track pollen activity, and identify the timing of fall colors.
- Using Nature's Notebook, citizen scientists can report on:
    - Maples
    - Oaks
    - Poplars
- Observations:
    - Flowers or Flower Buds
    - Open Flowers
    - Pollen Release
    - Colored Leaves
    - Falling Leaves



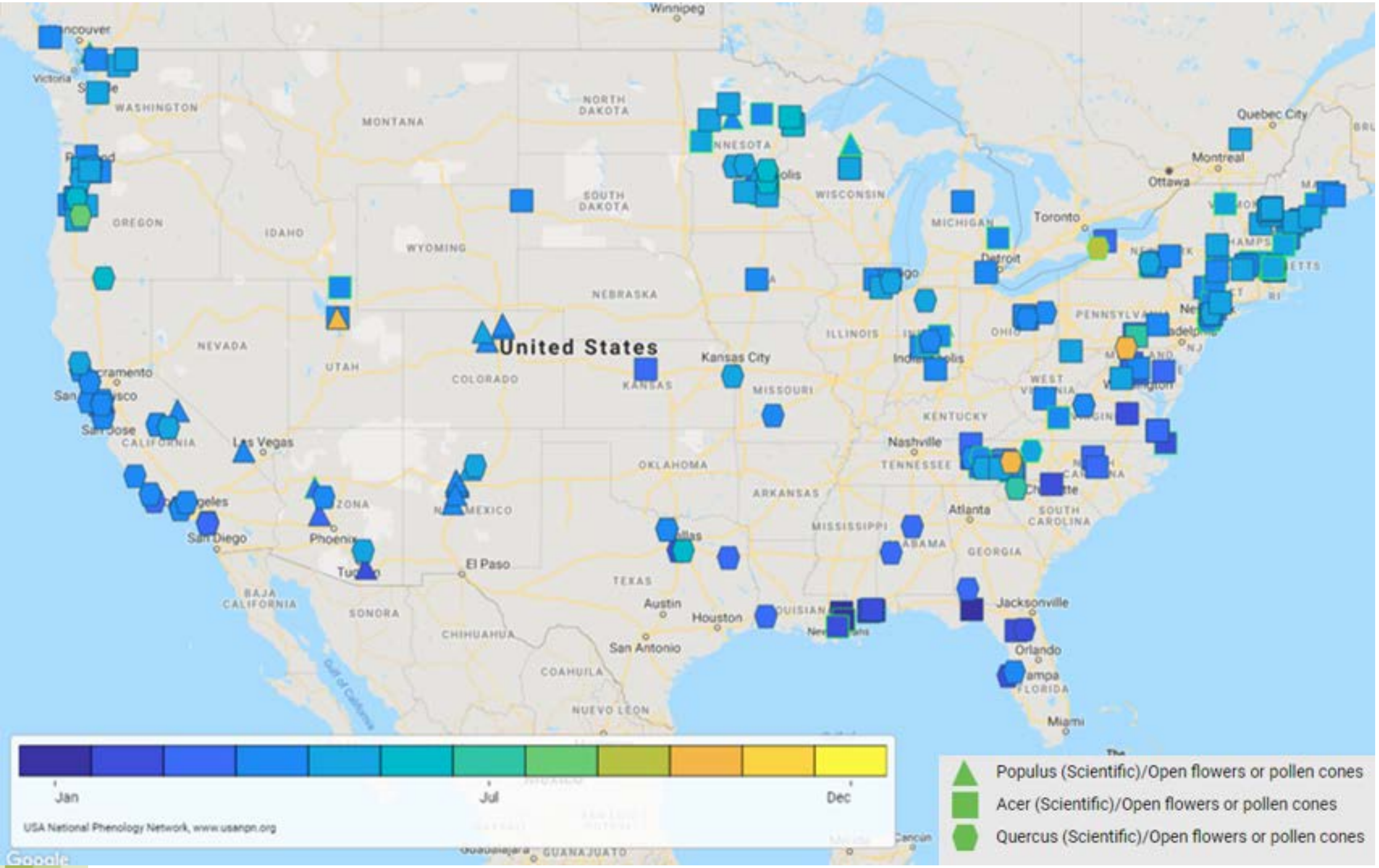

Image Credit: NPN

Greenwave Modeling: 2019 Campaign

- Metrics:
  - 1,504 observers
  - 878 sites
  - Open flowers for 1,600 individual trees
  - Onsets of pollen release for 532 trees
  - Onsets of colored leaves for 2,722 trees
  - 115,000 records added this year on Green wave species from the National Ecological Observatory Network (NEON)

Image Credit: NPN

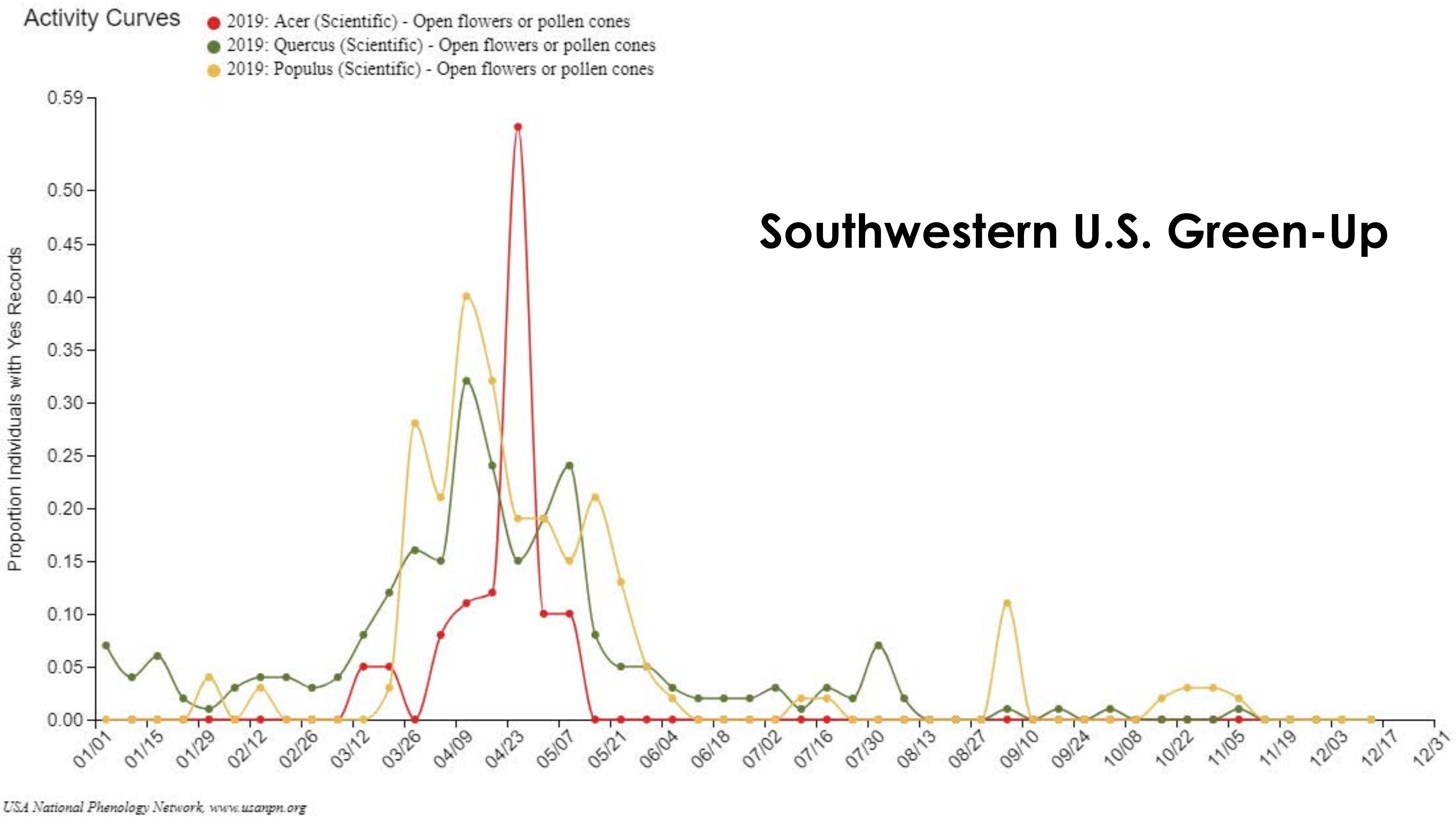
Greenwave Modeling: 2019 Campaign



Sites reporting "yes" for open flowers in Green wave species in 2019. Colors correspond to the time of year open flowers were reported at the site. Shapes denote maples, oaks, or poplars. Green outlines indicate more than one genera observed at that site.

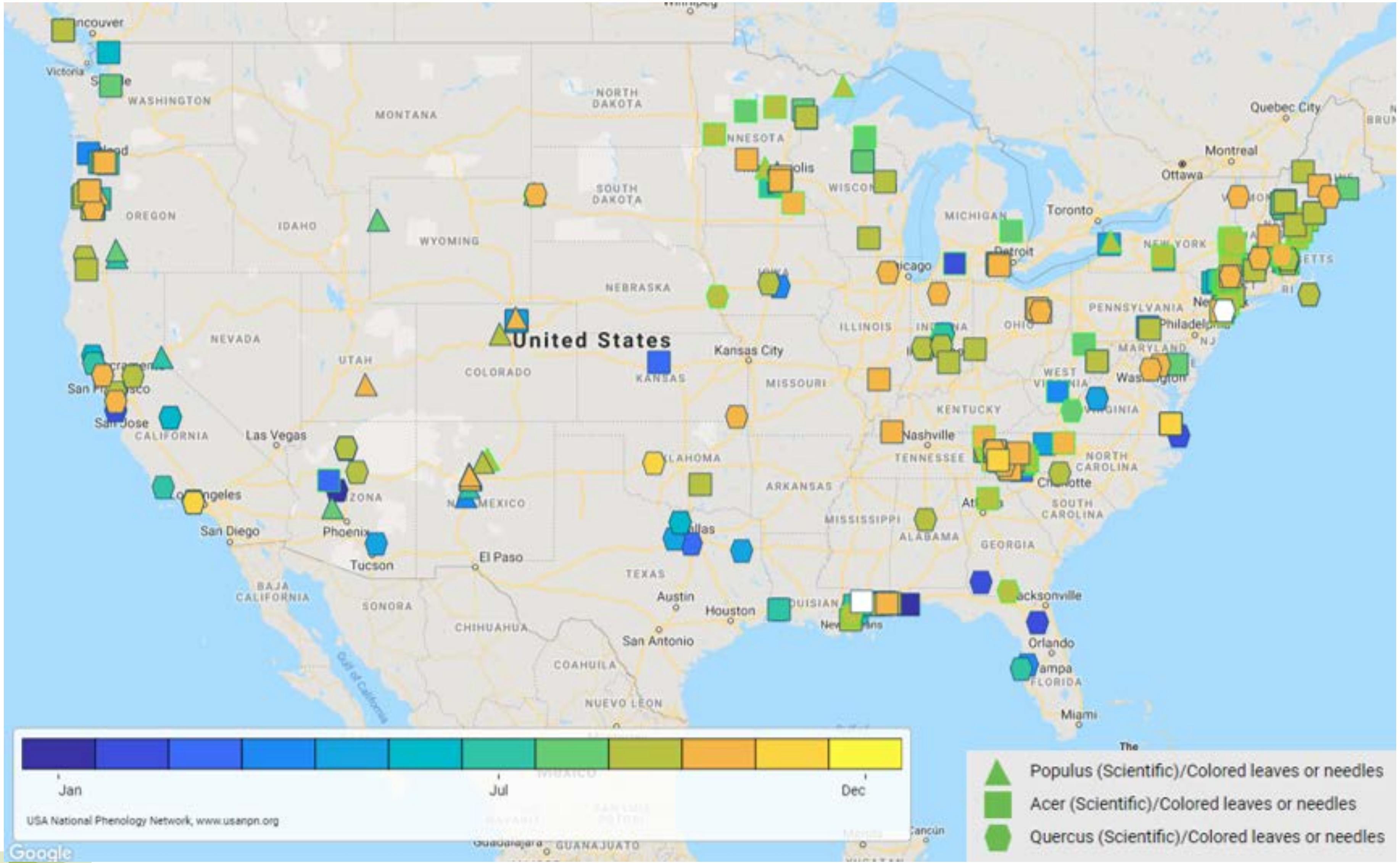
Image Credit: NPN

Greenwave Modeling: 2019 Campaign



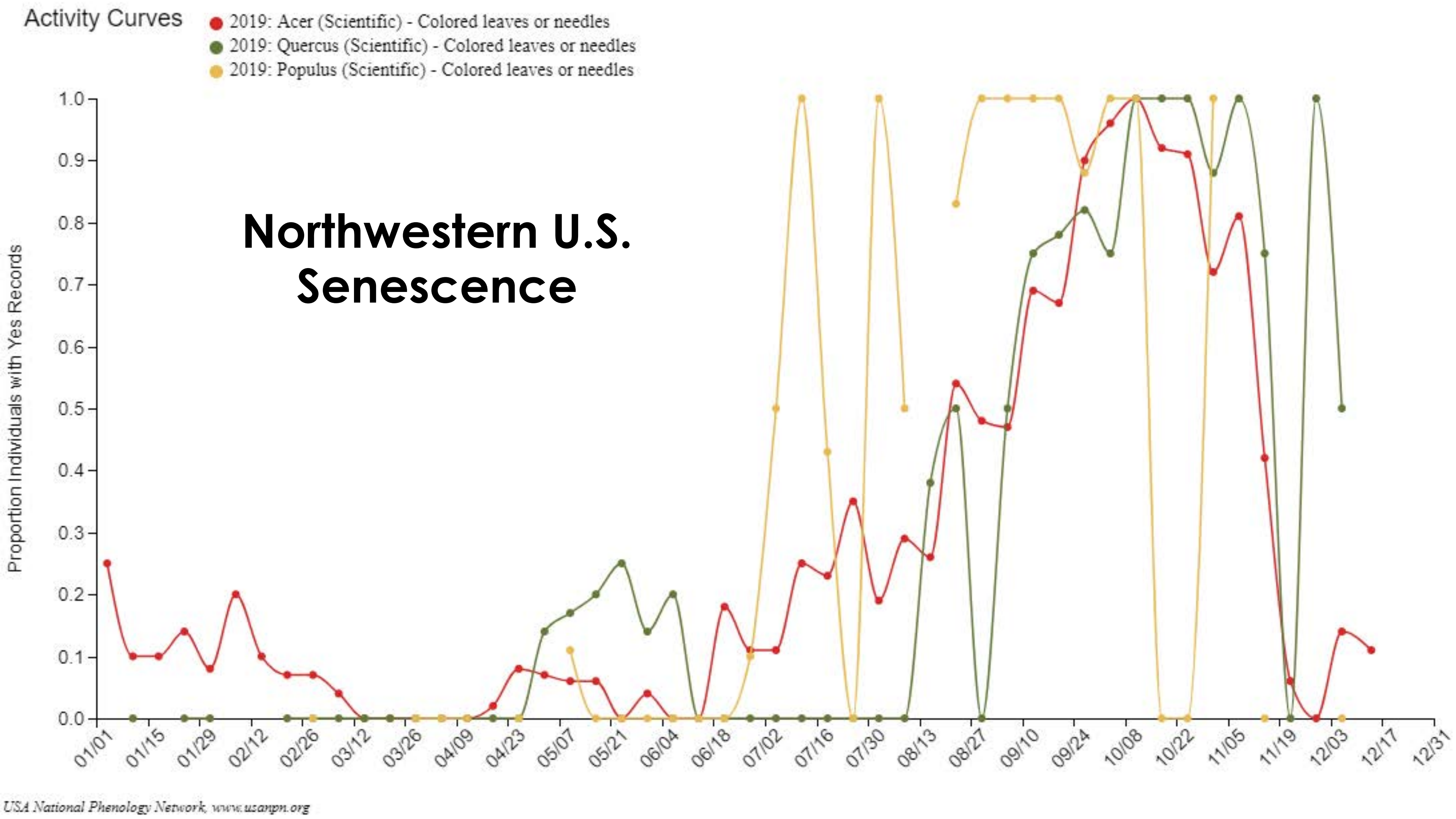
Southwestern U.S. Green-Up

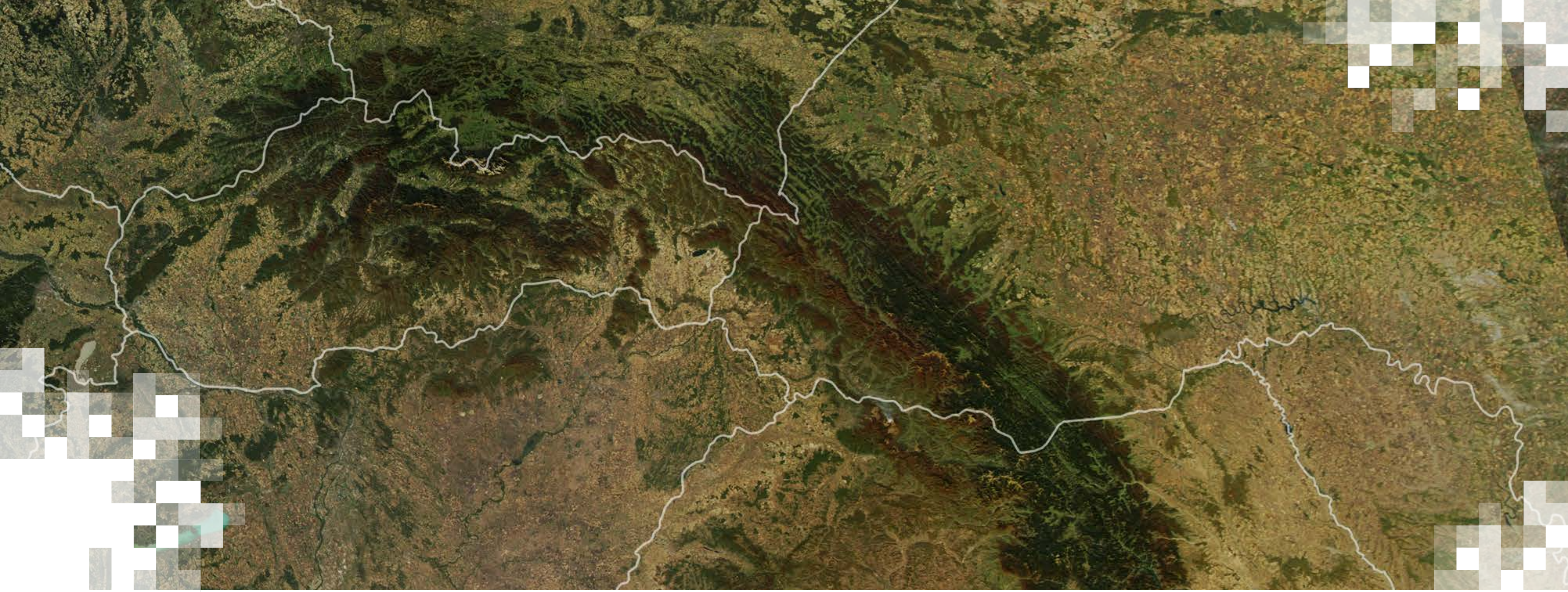
Greenwave Modeling: 2019 Campaign



Sites reporting "yes" for colored leaves in Green wave species in 2019. Colors correspond to the time of year colored leaves were reported at the site. Shapes denote maples, oaks, or poplars. Green outlines indicate more than one genera observed at that site.

Greenwave Modeling: 2019 Campaign





Case Studies: Comparisons of PhenoCam and Satellite Data

PhenoCam Review

- Automated imagery via consumer-grade camera installed overlooking vegetation of interest
- Time lapse of images to identify patterns and shifts in vegetation
  - Most daily repeat times
- Generally RGB; some with near infrared data too

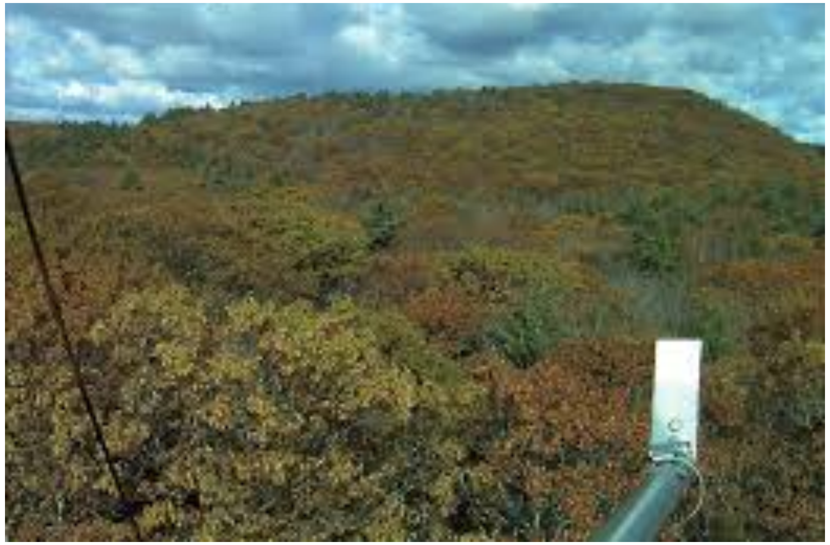


Image Credit: PhenoCam

PhenoCam and VIIRS

- **PhenoCam**
  - Digital Photographs
  - 30 min
  - Red, Green, Blue images
  - Two Vegetation Indices
    - Green Chromatic Coordinate (GCC)
    - Vegetation Contrast Index (VCI)

Image Credit: PhenoCam

- **VIIRS**
  - Satellite Images
  - Daily
  - Red, Green, Blue, Near-infrared
  - Multiple Vegetation Indices
    - Normalized Difference Vegetation Index (NDVI)
    - Enhanced Vegetation Index (EVI)

Image Credit: NASA

Study Site

- Research Question: How does VIIRS LSP data systematically compare to PhenoCam data?
- Konza Prairie Biological Station, Kansas State University, Kansas
- **Start Date:** 2012-03-17 **Last Date:** 2019-12-18
- Metrics Evaluated: Start-of-Spring (**SOS**), End-of-Spring (**EOS**), End-of-Fall (**EOF**), Middle-of-Spring (**MOS**), Middle-of-Fall (**MOF**)

June

September

November

PhenoCam Vegetation Indices

- Green Chromatic Coordinate (GCC)

$$GCC = \frac{G}{(R + B + G)}$$

- Vegetation Contrast Index

$$VCI = \frac{G}{(R + B)}$$

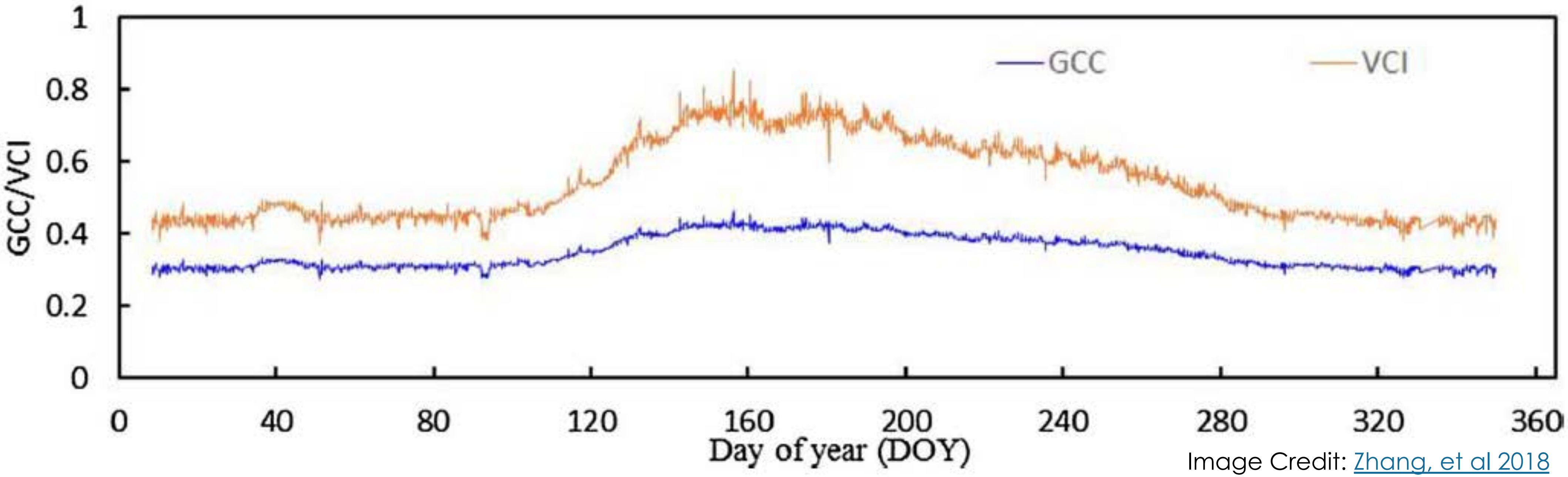


Image Credit: [Zhang, et al 2018]

VIIRS Vegetation Indices

- Normalized Difference Vegetation Index (NDVI)

$$\frac{\textit{Near-Infrared} - \textit{Red}}{\textit{Near-Infrared} + \textit{Red}}$$

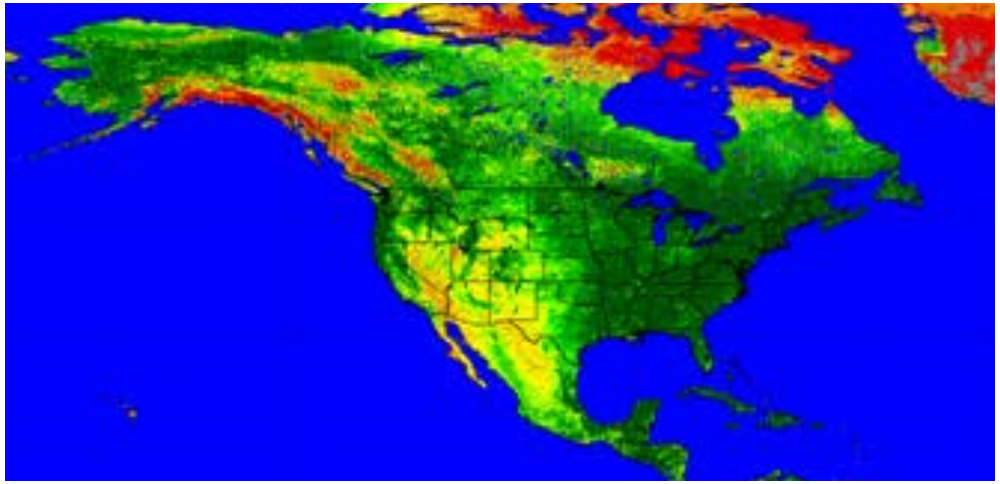


Image Credit: [NASA/NOAA]

- Modified Enhanced Vegetation Index (EVI2)

$$EVI2 = G\left(\frac{\rho_{NIR} - \rho_{red}}{\rho_{NIR} + \rho_{red} + L}\right)$$

- L is the canopy background adjustment (equal to 1)
- C is aerosol resistance coefficient (equal to 2.4)
- G is a gain factor with a value of 2.5.

PhenoCam vs. VIIRS: Comparisons

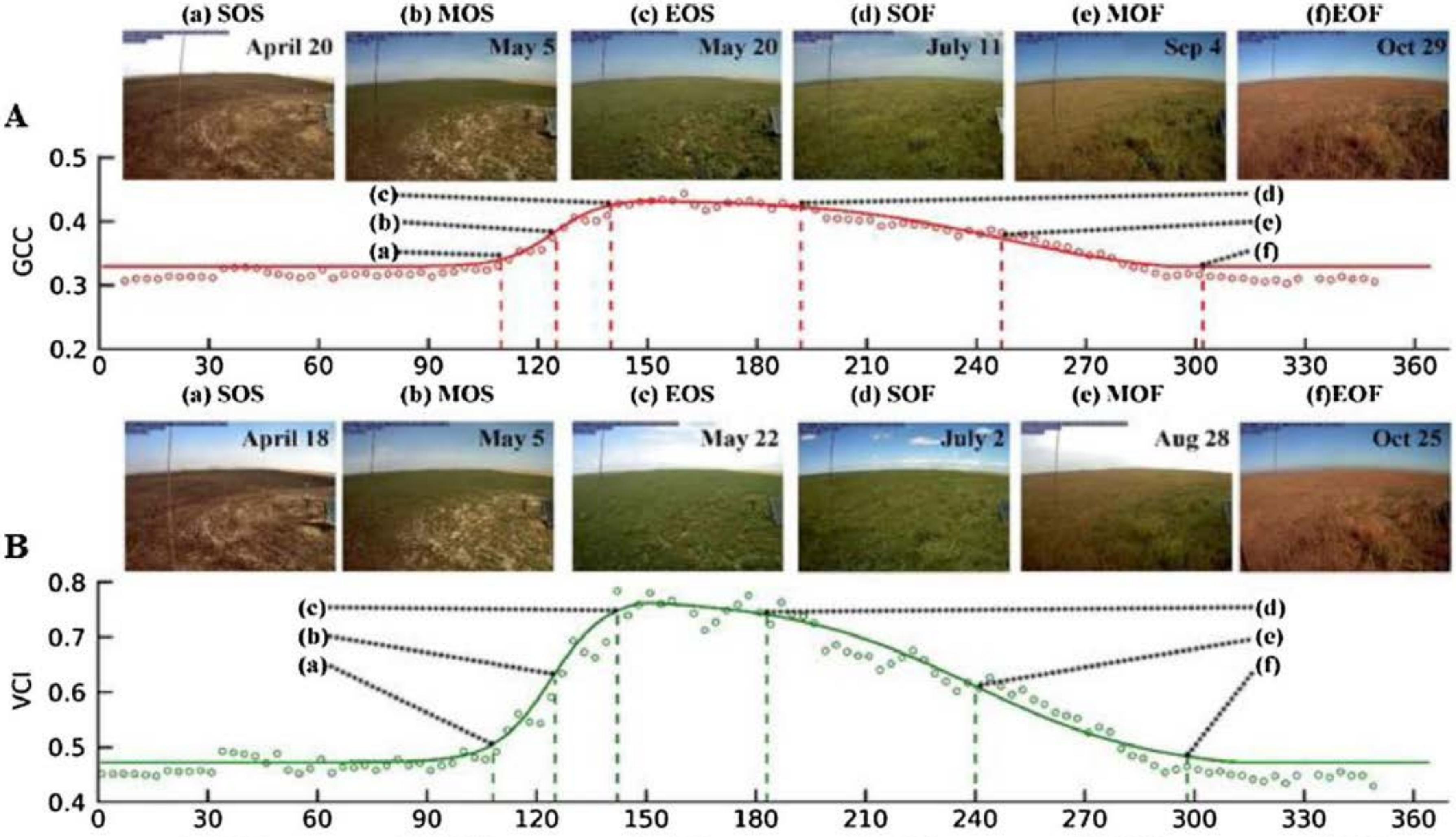


Image Credit: [Zhang, et al 2018]()

PhenoCam vs. VIIRS: Comparisons

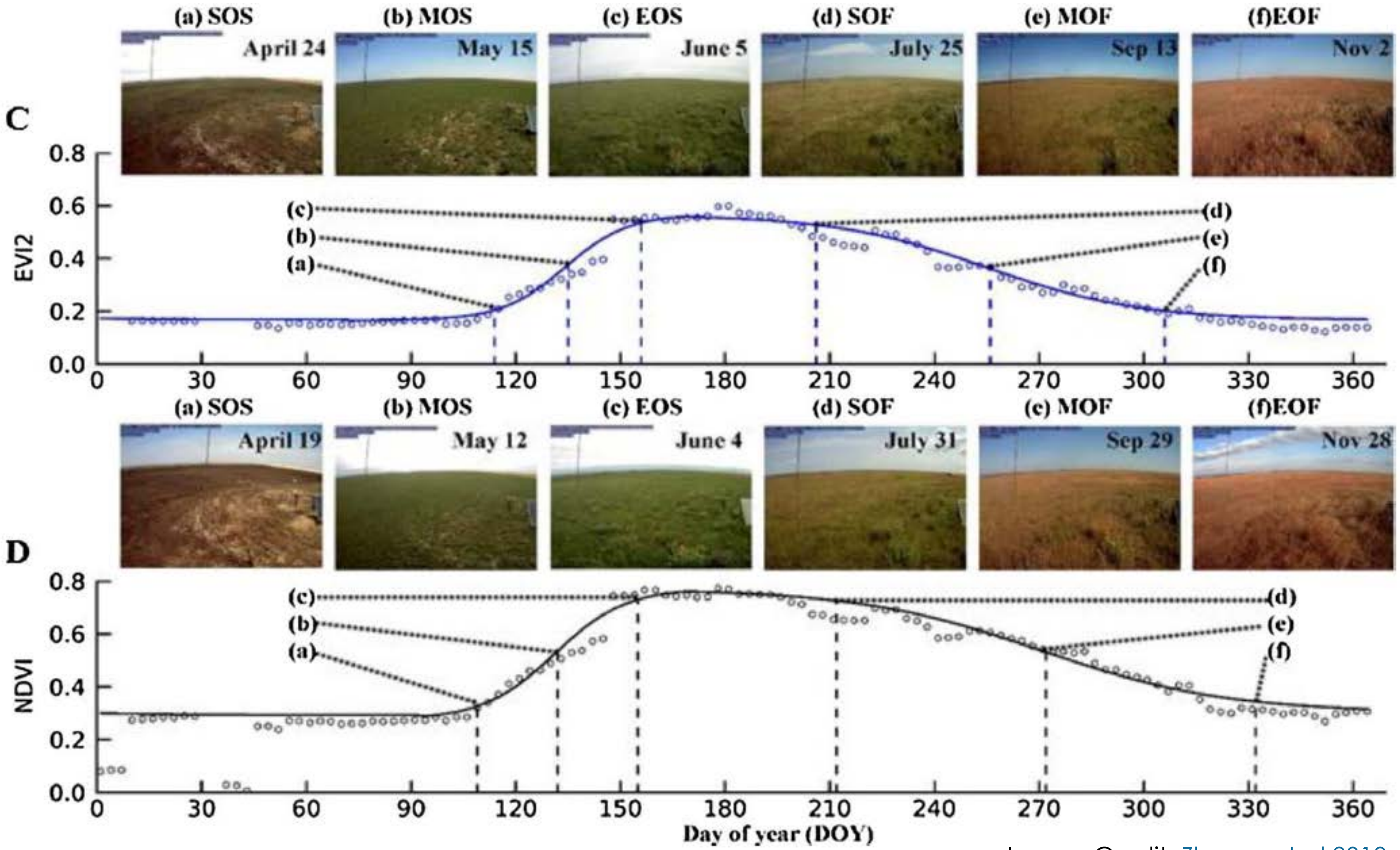


Image Credit: Zhang, et al 2018

VIIRS EVI2 vs. PhenoCam VIC

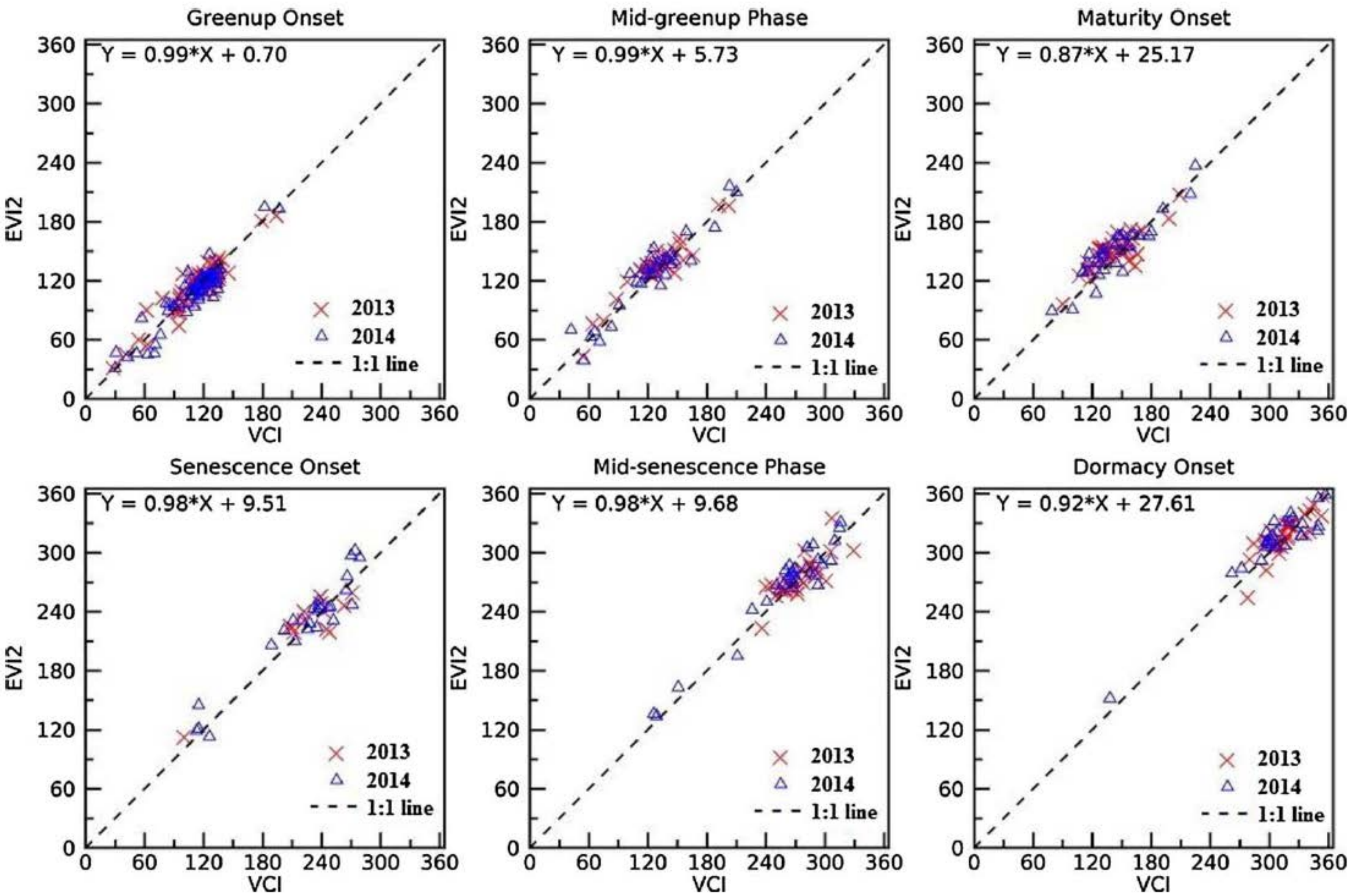
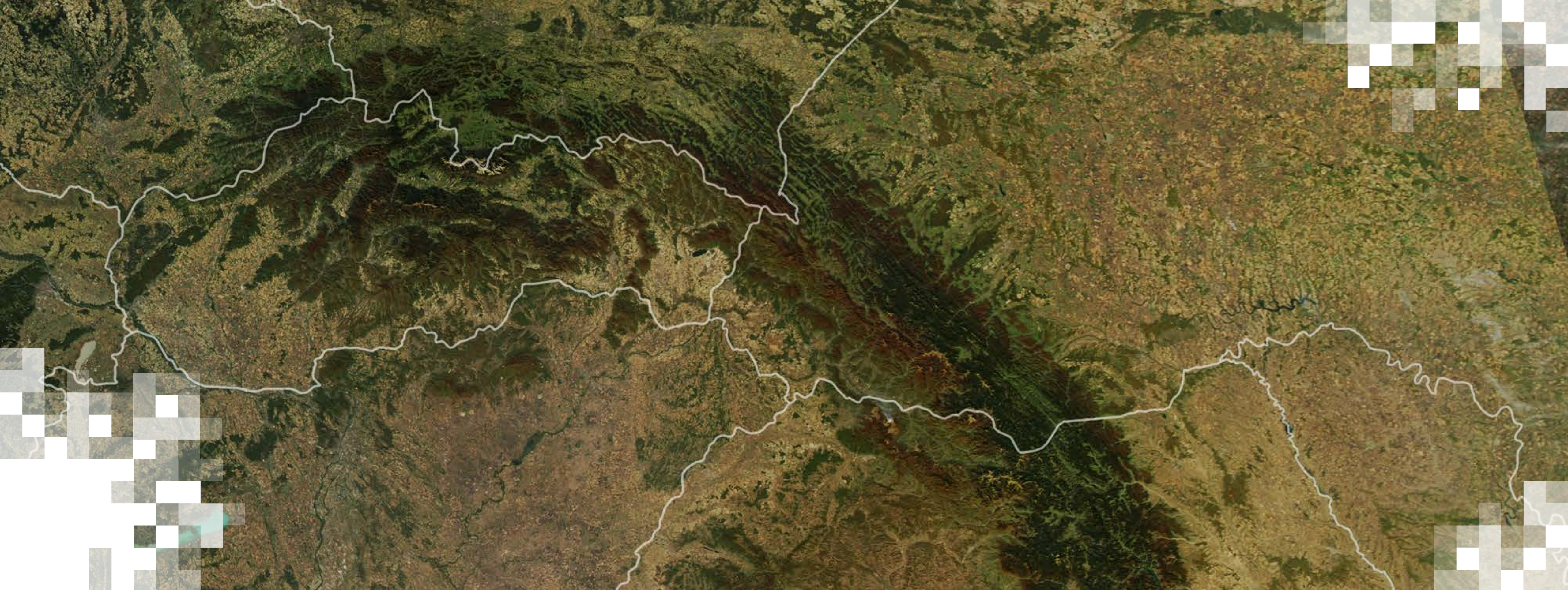


Image Credit: [Zhang, et al 2018]



Case Studies: Effect of Urbanization on Phenology

Urban Heat Islands (UHI)

- A metropolitan area which is significantly warmer than its surroundings.
- According to the EPA, many U.S. cities have air temperatures up to 10°F (5.6°C) warmer than the surrounding natural land cover.

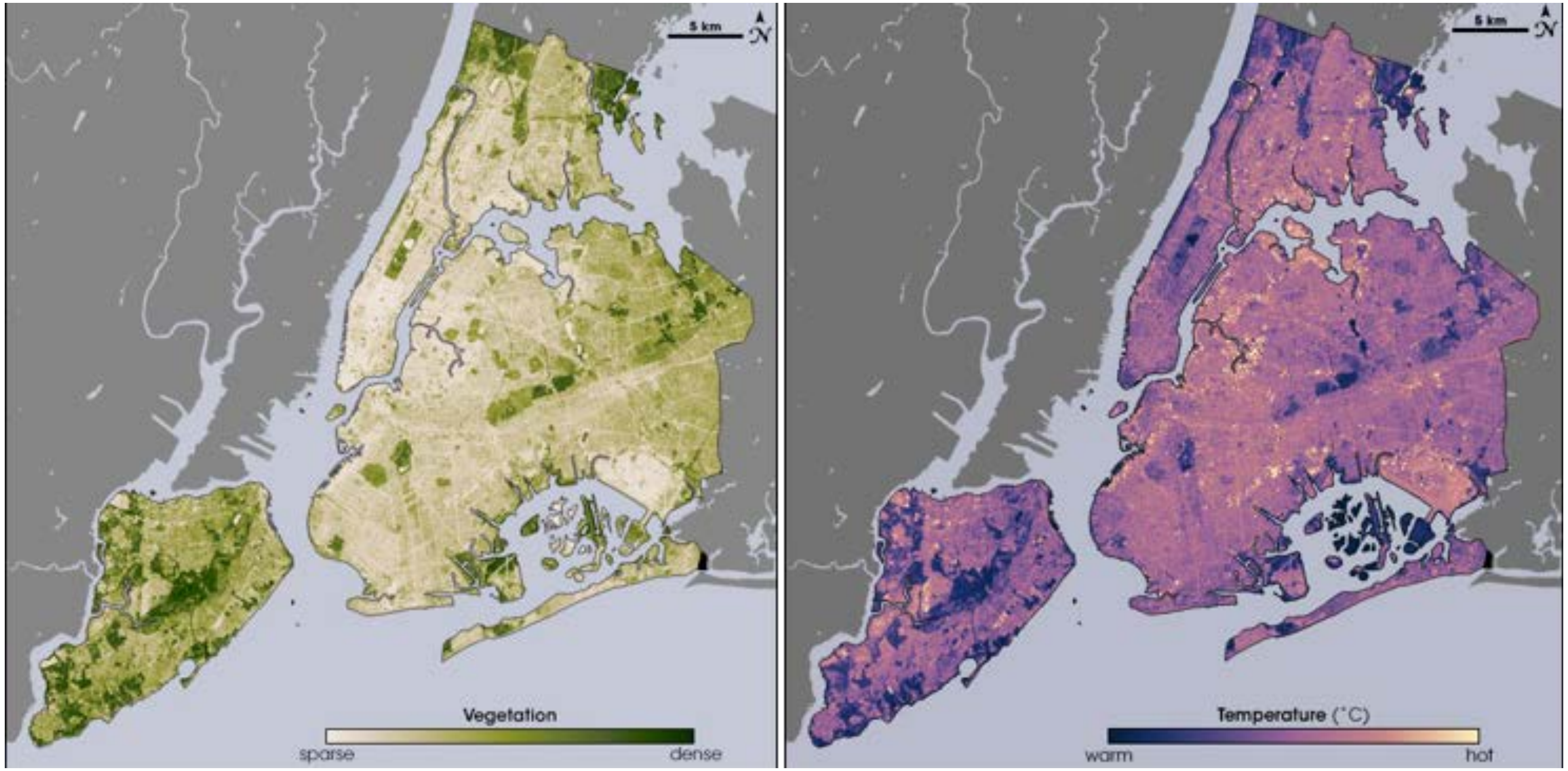


Image Credit: [Robert Simmon/NASA]

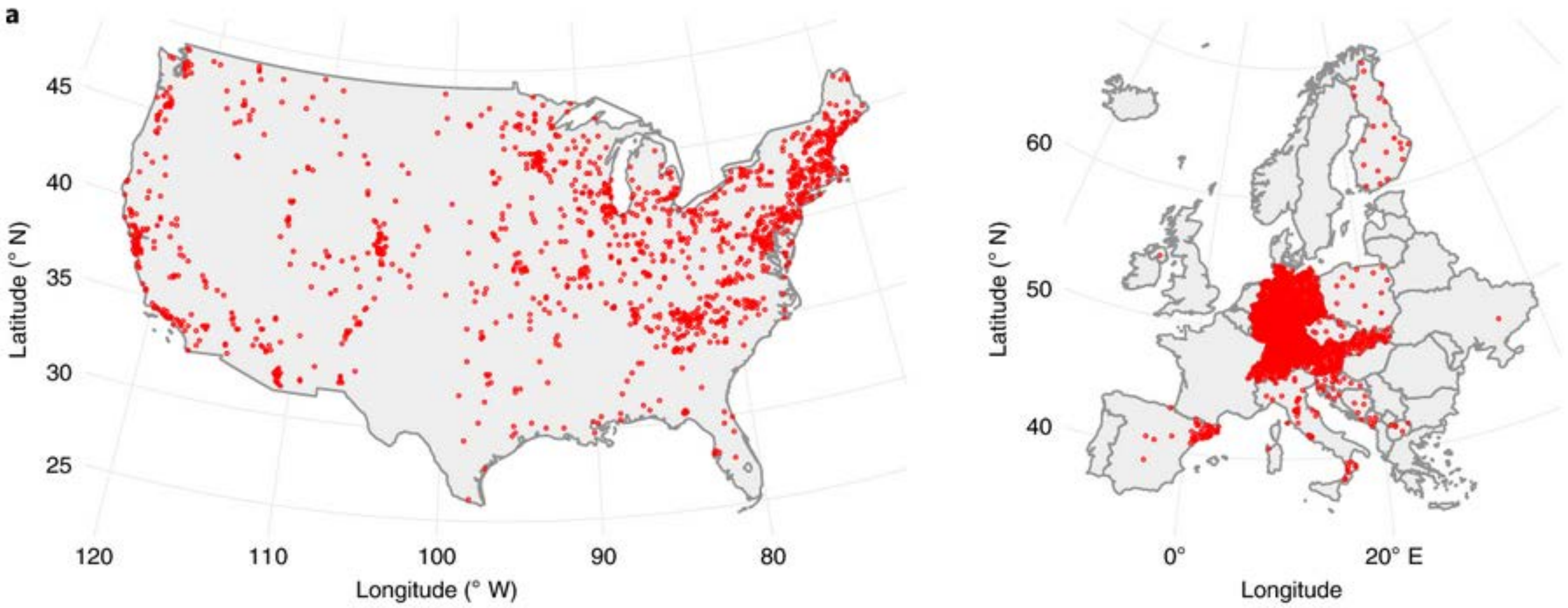
UHIs and Phenology

- Research Question: What are the effects of UHIs on plant phenophases?
  – Changes to these processes can have cascading effects on the ecosystem.
  – Can UHIs be used as a proxy for studying the impacts of climate change (i.e. increases in temperature)?
  – Millions of observations of 136 plant species across the U.S. and Europe
  – Plant flowering and leaf out

Image Credit: Pexels, Jan Krnc

Image Credit: Pexels, Michael Rocha

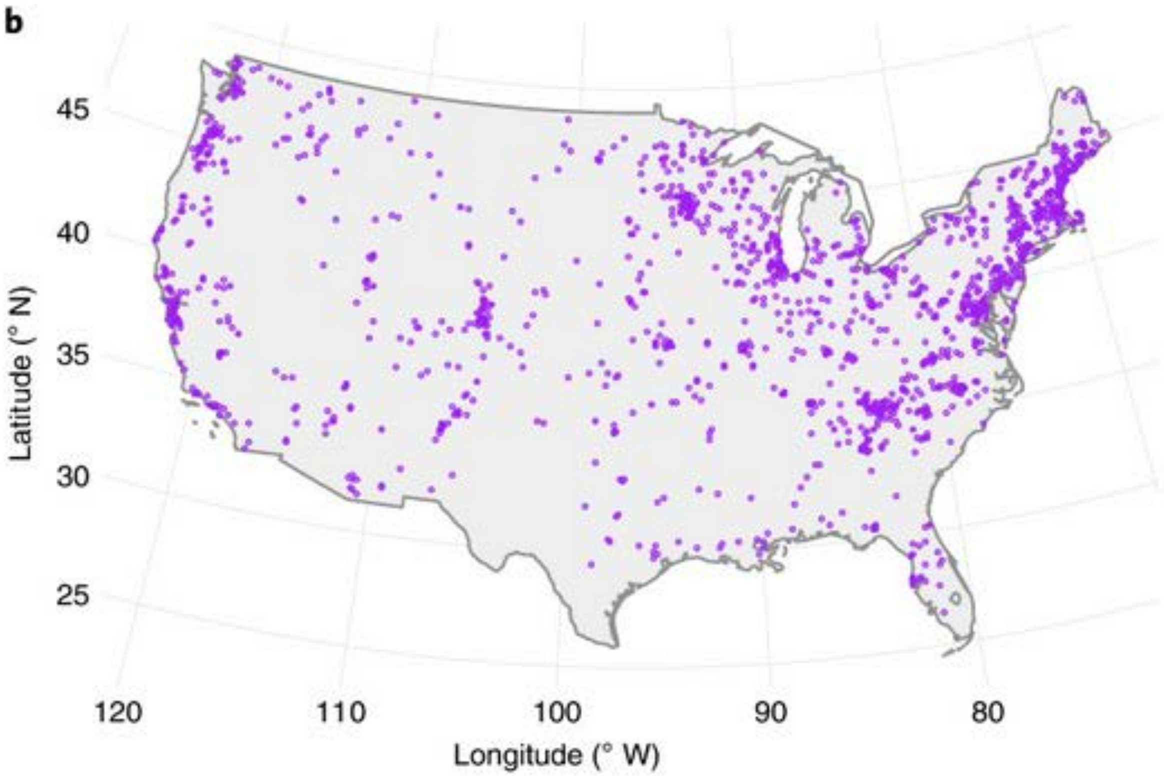
Observations: Leaf Flowering

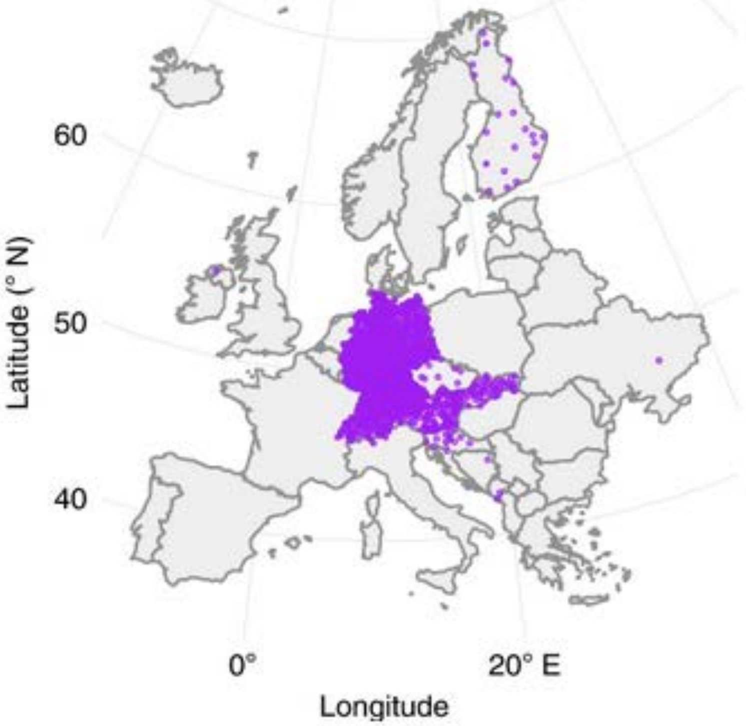


Observations of Leaf Flowering. Image Credit: [Li et al., 2019]

[European Phenology Network]

Observations: Leaf Out

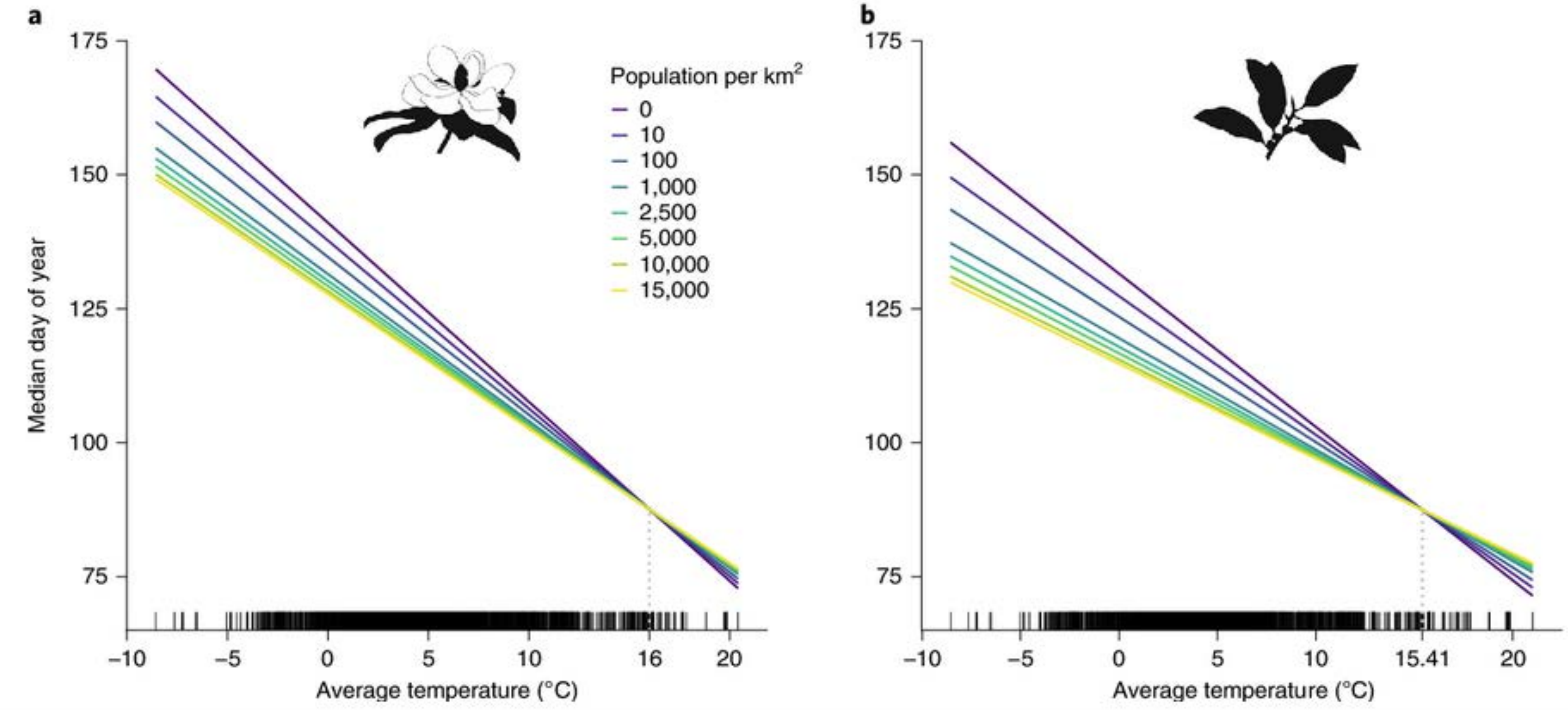




Observations of Leaf Out. Image Credit: Li et al., 2019

Results

- Urbanization shifts seasonal cycles in a nuanced manner.
- However, the influence of human population density on plant flowering and leaf-out depends on the regional temperature. High population density advanced plant phenology in cold areas, but this effect disappeared or even reversed in warm areas.



Results

- Generally, warmer temperatures and higher population density each spurred earlier springs.
- In Cold Regions: Leaves and flowers 20 days earlier in cities with 26,000 or more
- In Warm Regions: Leaves and flowers 4-6 days later in cities with 26,000 or more

New York City

Image Credit: Samuel Stone, Pixabay

Jacksonville

Image Credit: qwesy qwesy / Wikimedia Commons

Results

Plant sensitivity to changes in temperature and urbanization vary by species. Wake robin, Trillium erectum (left) and the the tulip tree, Liriodendron tulipifera (right). Image Credit: [Li]

Summary

- There are many metrics to evaluate land surface phenology (e.g. SOS, EOS) and compare these to ground-based observations.
  - Statistical approaches to the identification of these metrics

- Case Study Examples:
  - Gridded Products of Spring 2020
  - Greenwave Modeling and Citizen Science
  - PhenoCam and VIIRS Comparisons
  - Urbanization and Phenology

- Get involved in national efforts! Find other networks around the globe!

Contacts

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Questions

- Please enter your questions into the Q&A box.
- We will post the questions and answers to the training website following the conclusion of the course.

Thank You!