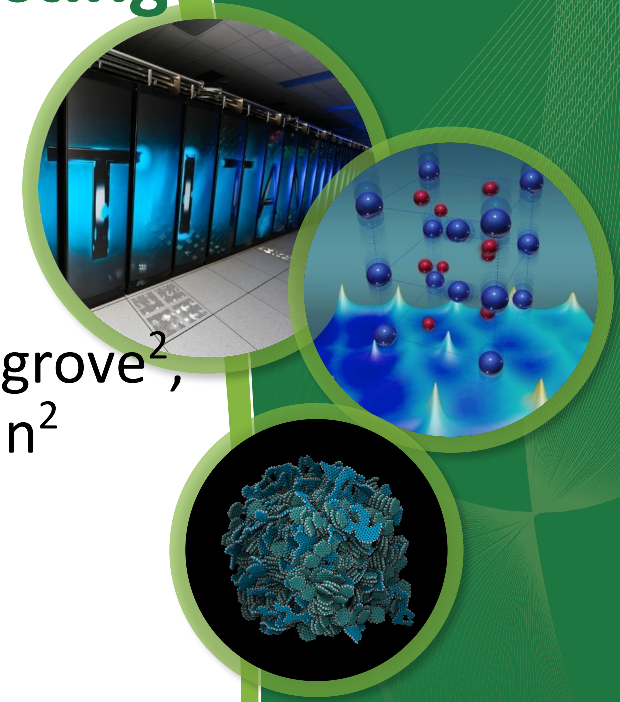
# Predominant Environmental Factors Controlling and Predicting Phenological Seasonality



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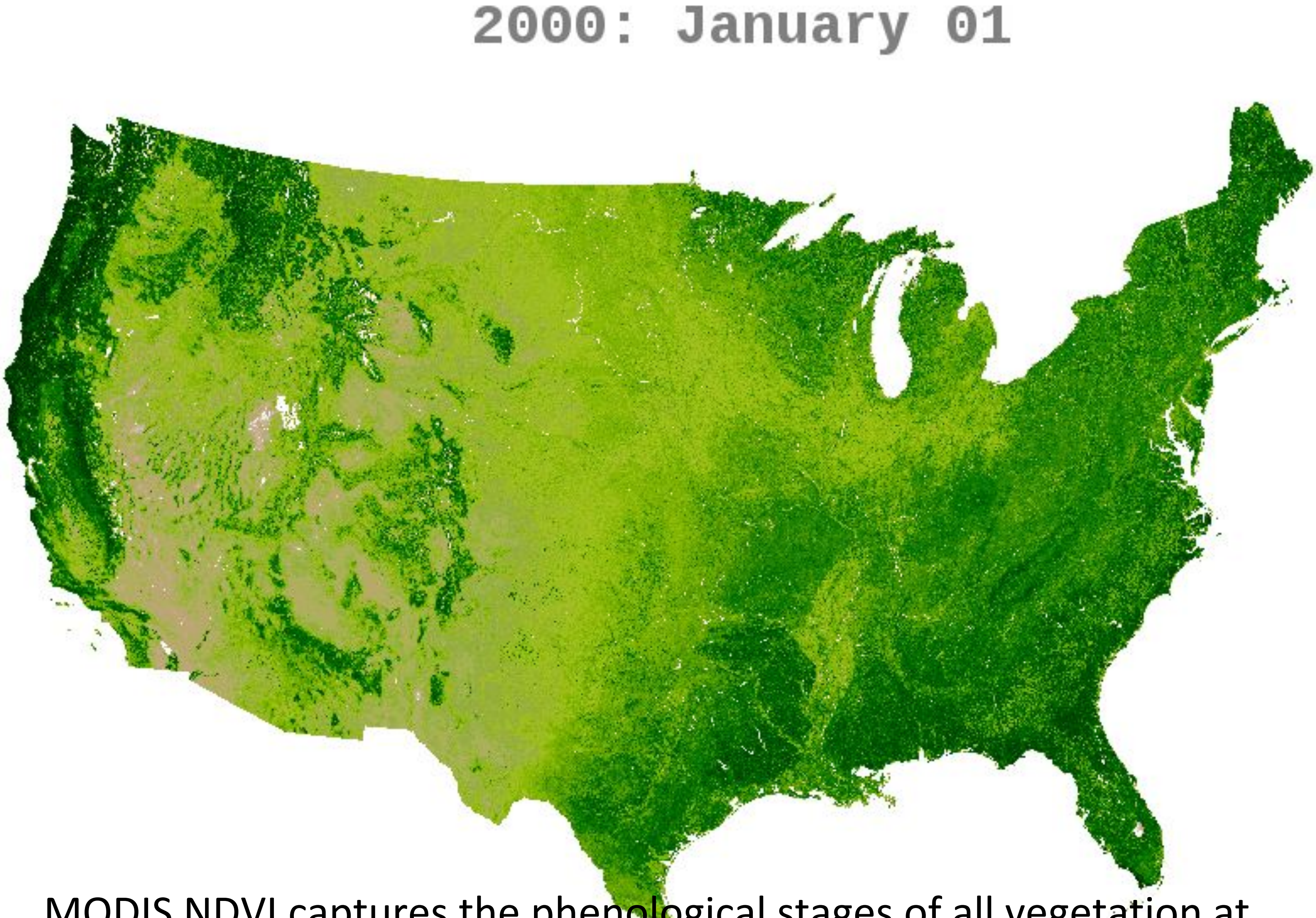
# Onset of seasons are important!

- **Land Surface Phenology (LSP)** is remote sensing based observation of seasonal pattern and variation in vegetation.
- Understanding and predicting onset of phenological seasons are of ecological, conservation, economical and management interest.
- Onset of seasons (and phenology in general) are sensitive to weather/climate.
- Variability and trends in onset of phenological seasons are key indicators of climate change.



MODIS NDVI captures the phenological stages of all vegetation at 250m resolution, every 8 days.

# Phenological Seasons

At 250m resolution MODIS captures the phenology of mixed vegetation types, not a particular species.

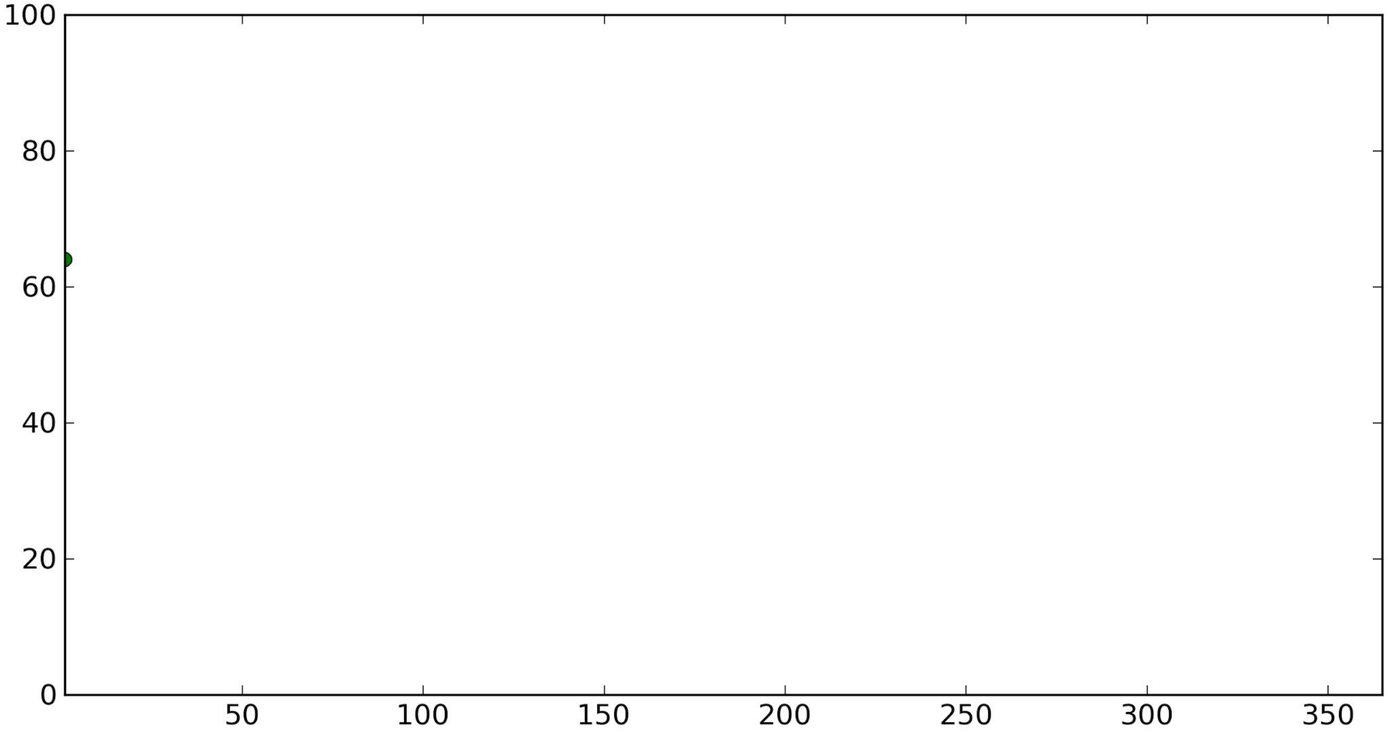
We define phenological growth stages as indicator of onset of seasons using LSP.

1. 20 % Left: “Start of Spring”
2. 80 % Left: “Start of Summer”
3. Max. NDVI Greenness: “Season Peak”
4. 80 % Right: “Start of the Fall”
5. 20% Right: “Start of Winter”

Provides non-species specific phenological milestones, that can be applied across all vegetation across CONUS.

# Phenological Seasons

MODIS LSP (2000) for a pixel in Great Smoky Mountains.



Phenological seasons defined are not observable (like bud burst, leaf color/incision etc.) but are consistent with LSP and allows continental (to global) scale analysis.

# What are our goals

- What are the key environmental drivers for onset of the phenological seasons.
- And how do these drivers vary in their dominance across different vegetation types within CONUS.
- Where and when are the phenological season predictable based on environmental drivers.
- Understand inter-annual variability in onset of seasons and if some vegetation types are more sensitive to environmental drivers than others.

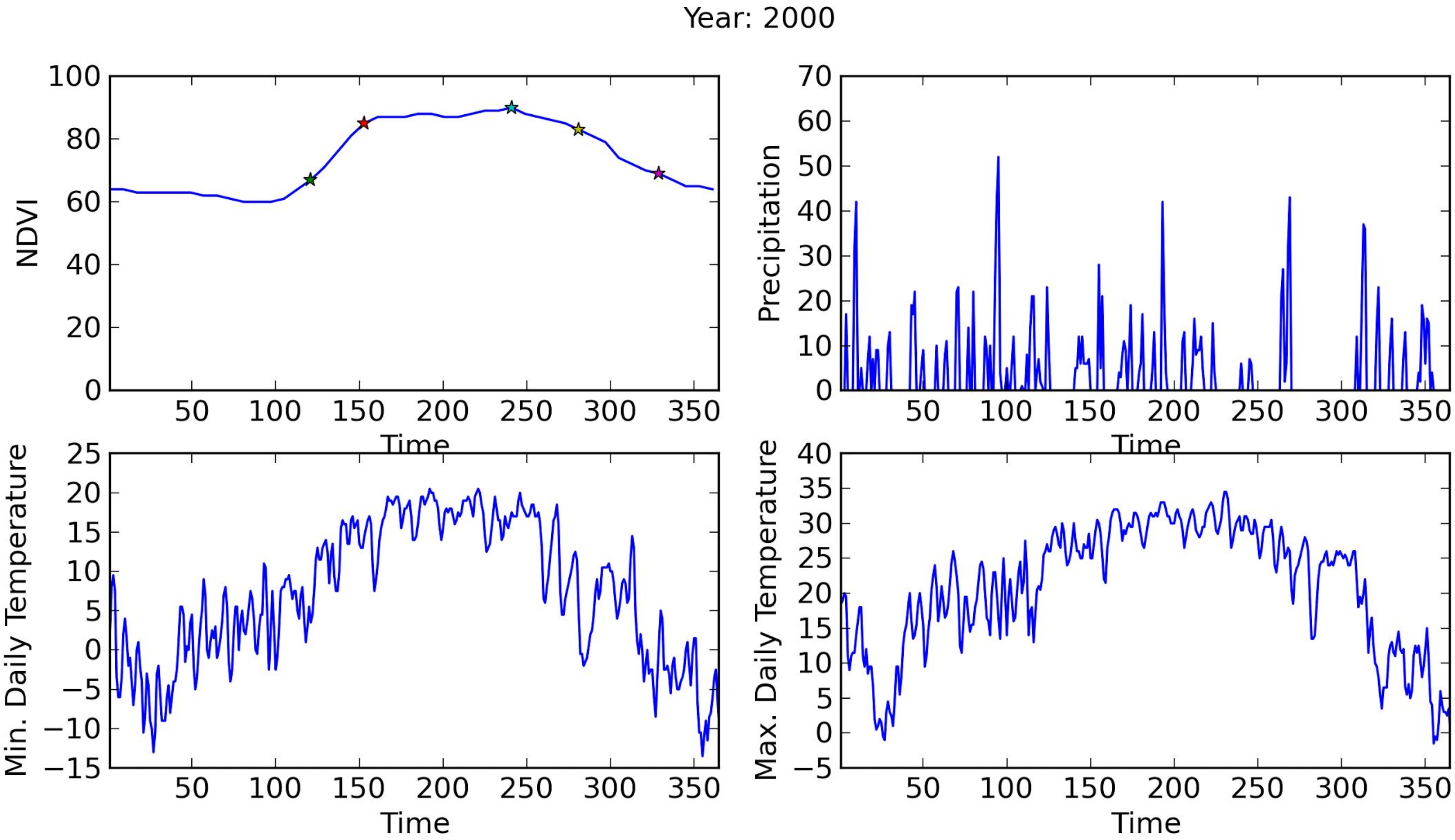
# Predictor variables from DAYMET

The Daymet dataset provides gridded estimates of daily weather parameters. Seven surface weather parameters are available at a daily time step, 1 km x 1 km spatial resolution, with a North American spatial extent.

We developed five predictor variables from DAYMET.

1. Heat sum above 5°C since Jan 1 (daily max. temp.)
2. Cold sum below 5°C since Jan 1 (daily min. temp.)
3. Precip. sum since March 1 (rainfall)
4. Photoperiod (day length)
5. Humidity (vapor pressure deficit)

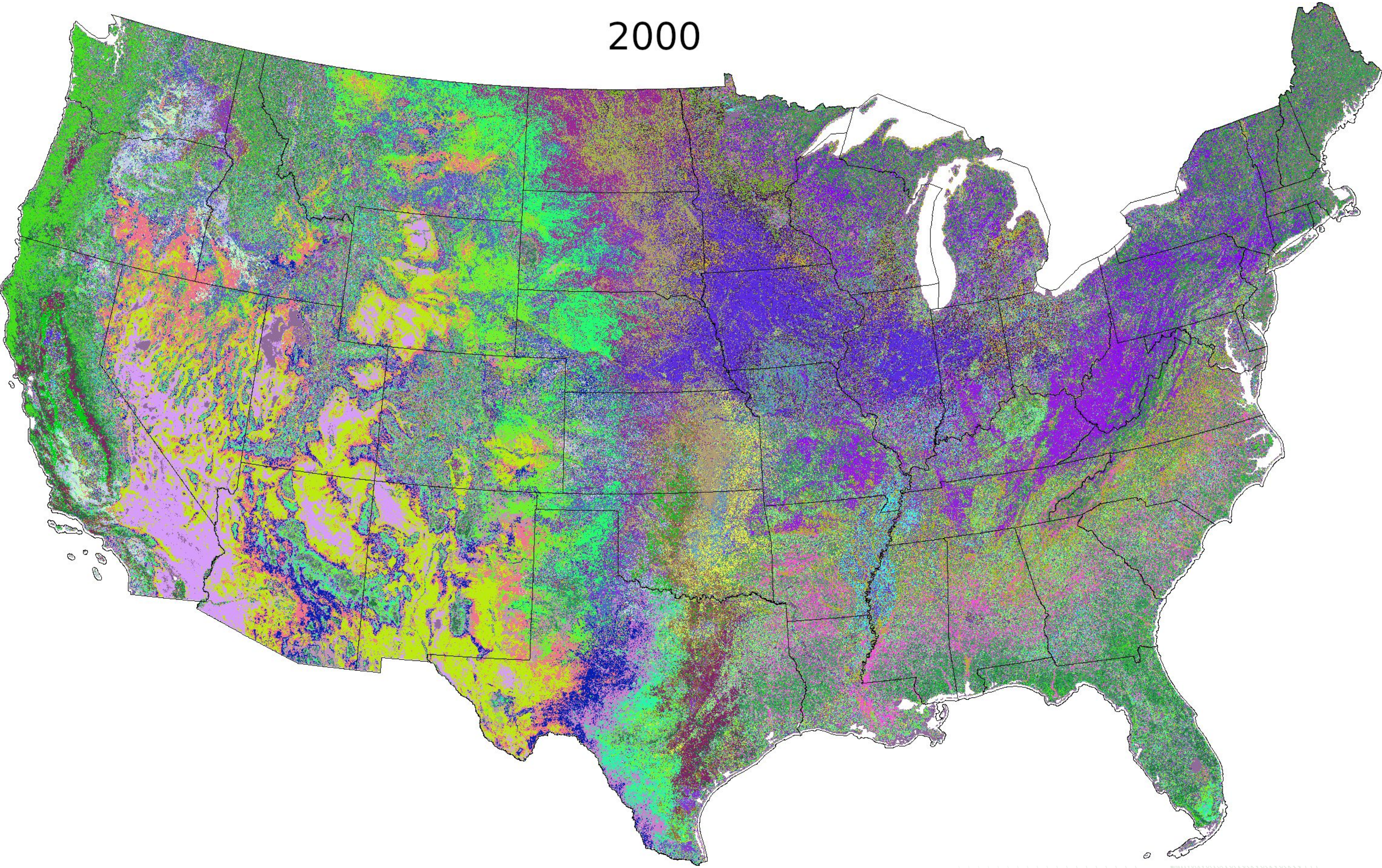
The variables were selected to capture broad environmental drivers for all vegetation types in CONUS.



Example pixel in GSMNP show how variability in meteorology corresponds to variability in phenology.

# LSP based segmentation of the landscape

- Diverse set of environmental conditions, vegetation composition and diversity leads to a diverse phenological response of vegetation across CONUS.
- We use “***Phenoregions***” to segment the landscape in regions of similar phenology for our analysis.
- “***Phenoregions***” are developed using a unsupervised classification approach on entire MODIS NDVI record to create a phenological similar regions across CONUS. “***Phenoregions***” are dynamic in nature, owing to dynamic vegetation phenology, and thus capture temporal (inter- and intra-annual) variability in vegetation greenness.

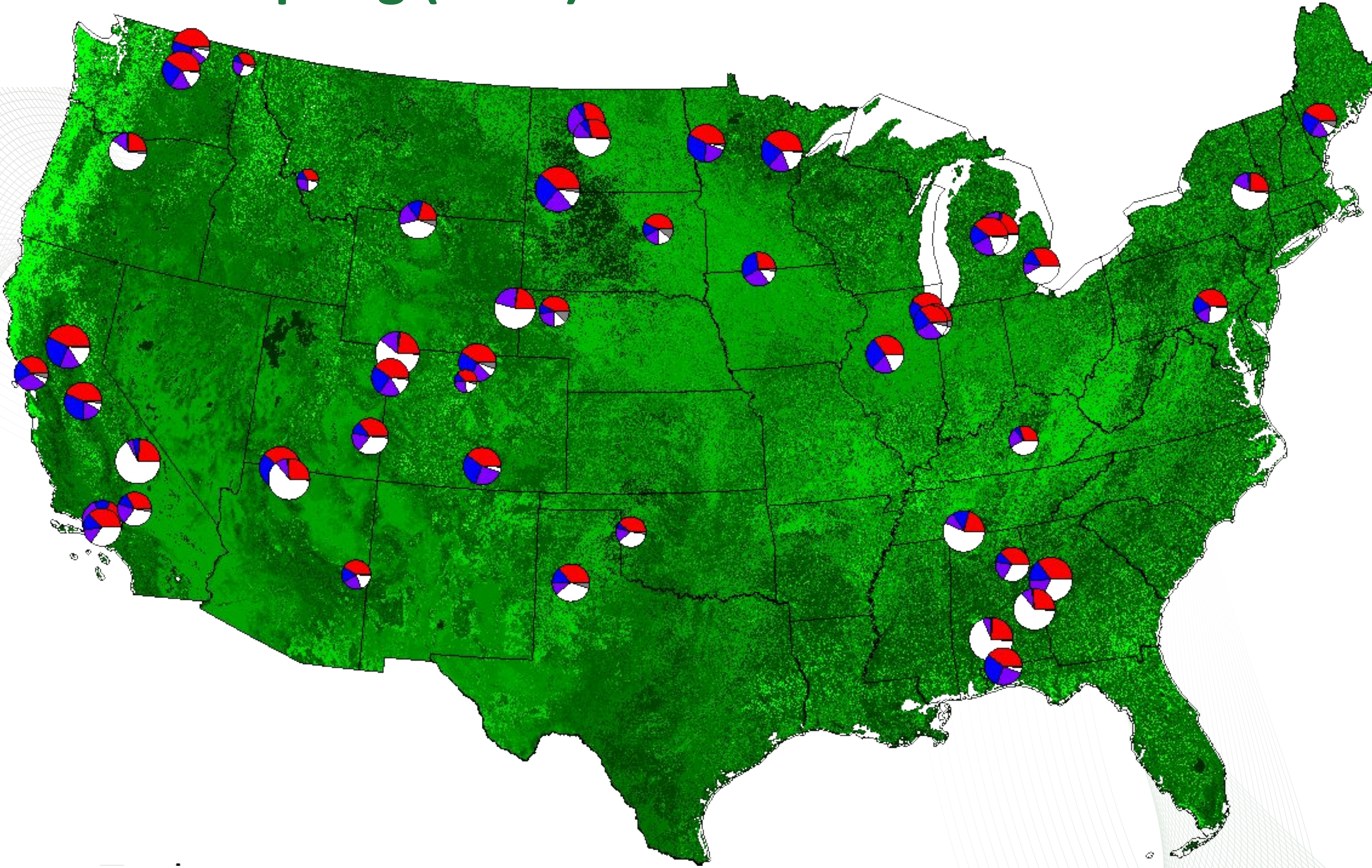


50 Phenoregions across CONUS used in our study

# Methodology

- DAYMET derived predictors have different units of measurement.
- Standardize all variables between 0 and 1 based on min/max observed over the record.
- Fit multi-linear regression models within each phenoregion, each year, for each each of the five phenological seasons.
- Regression coefficients from multi-linear regression models can be compared and ranked to show the importance of predictor variable.
- Rank five predictor variables in order of influence:
  - for each season
  - in each year
  - in each phenoregion

# Start of Spring (2000)



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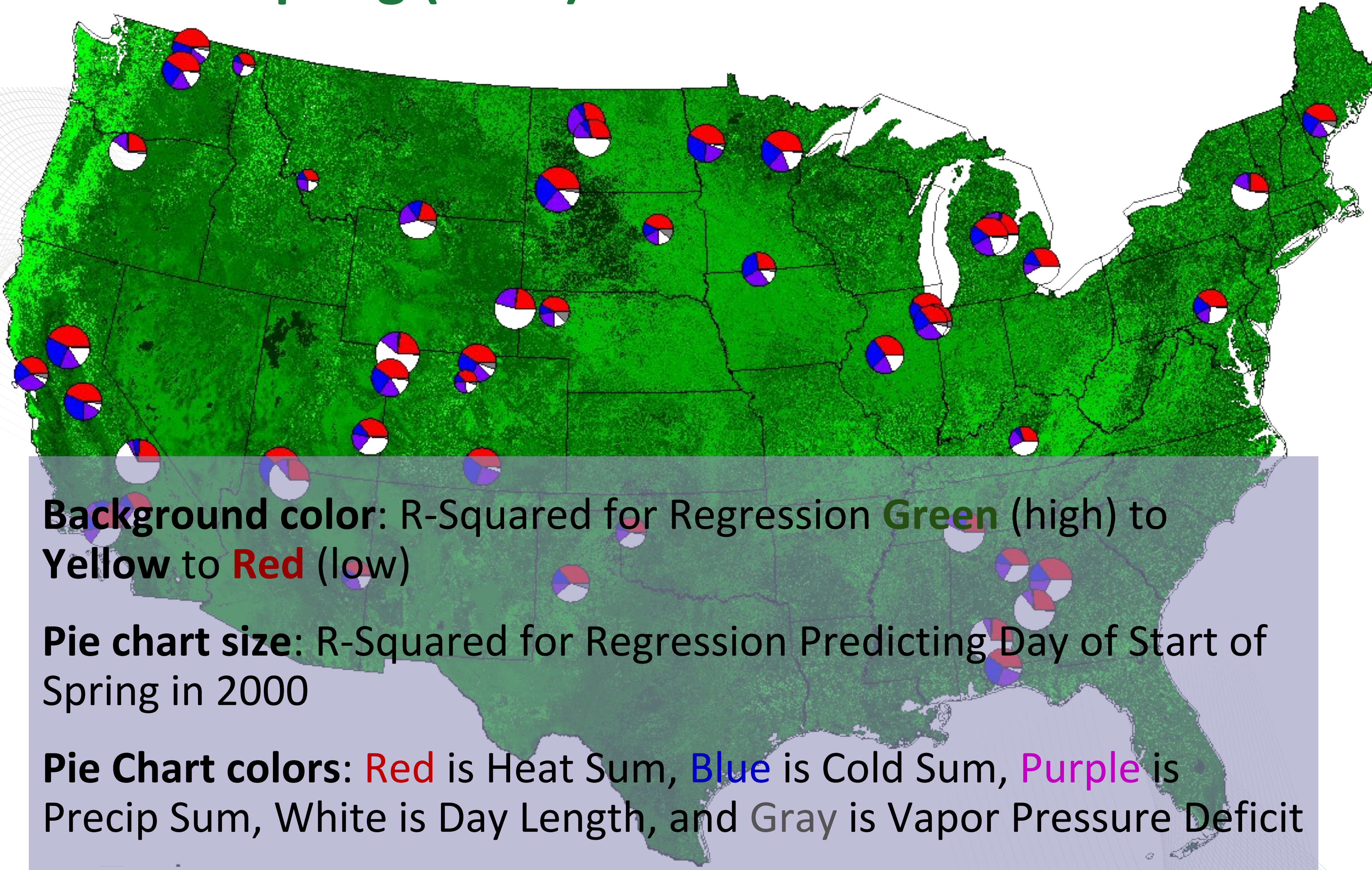
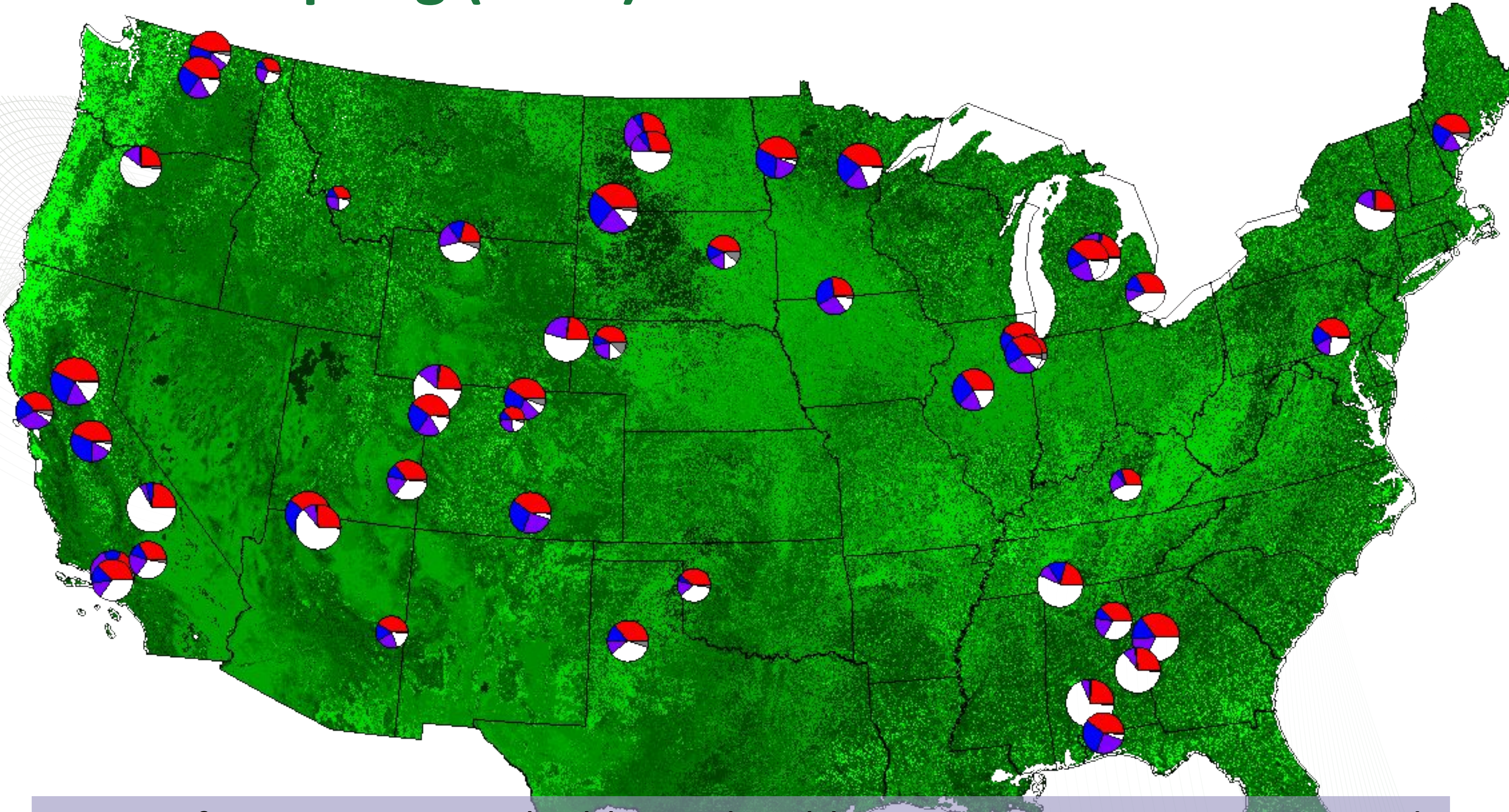


**Background color**: R-Squared for Regression **Green** (high) to **Yellow** to **Red** (low)

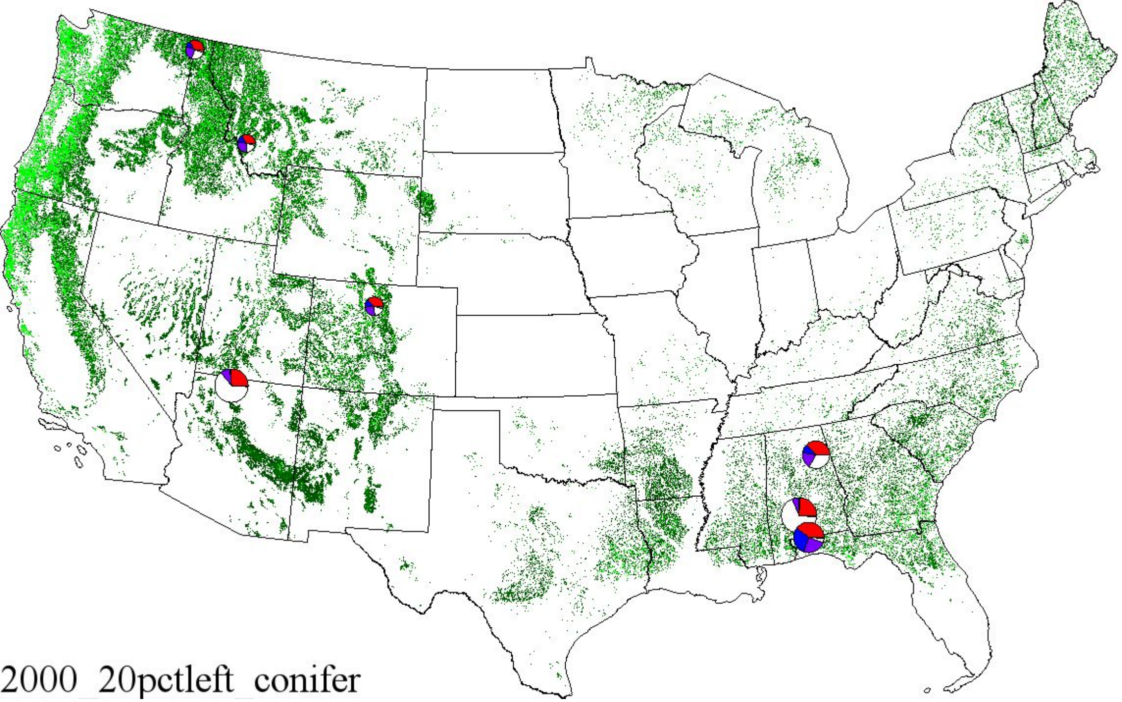
**Pie chart size**: R-Squared for Regression Predicting Day of Start of Spring in 2000

**Pie Chart colors**: Red is Heat Sum, Blue is Cold Sum, Purple is Precip Sum, White is Day Length, and Gray is Vapor Pressure Deficit

# Start of Spring (2000)



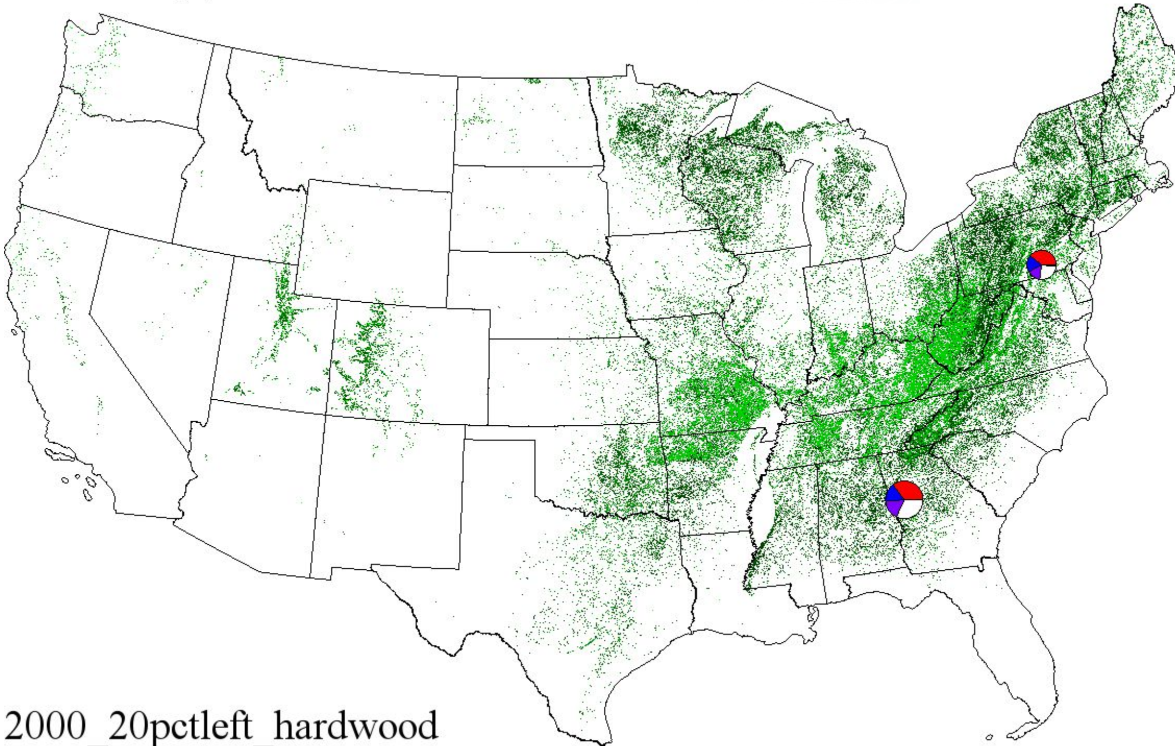
Onset of spring season is highly predictable across CONUS. Heat sum and photoperiod are dominant controls in Eastern US, while precipitation plays an increasingly important role in croplands/grasslands and Western US..



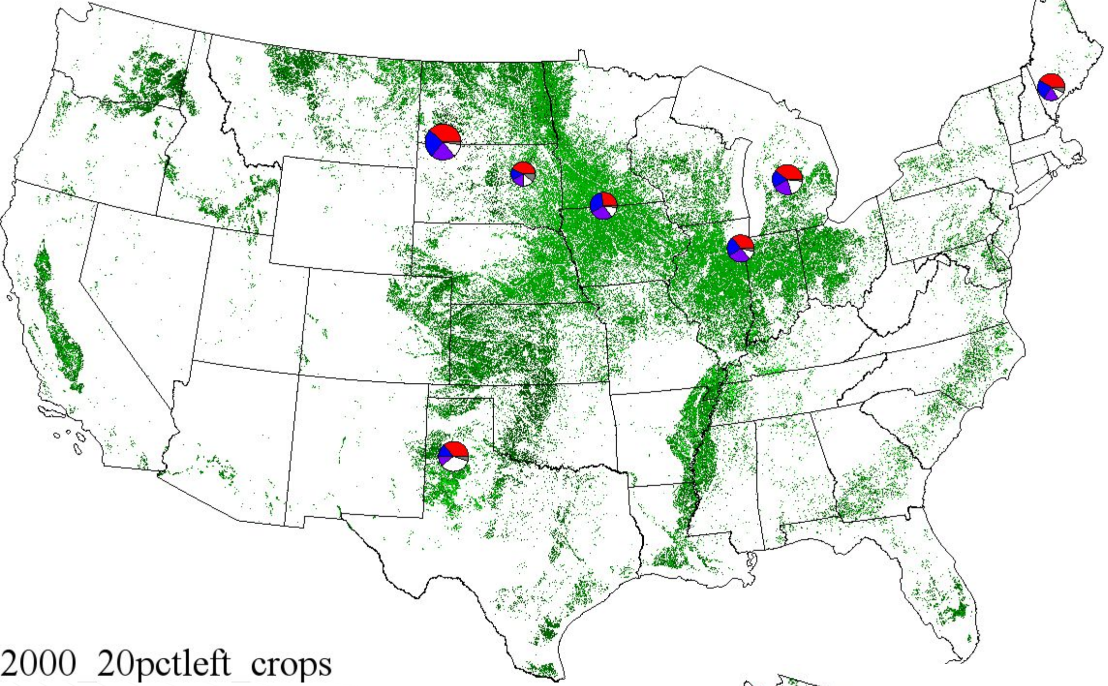
2000_20pctleft_conifer

Onset of spring in conifers is driven by heat and cold sum, and photoperiod. Precipitation is key in some places.

Temperature (both heat and cold sum) if the most dominant driver for onset of spring in Eastern US. Photoperiod also plays an important role.



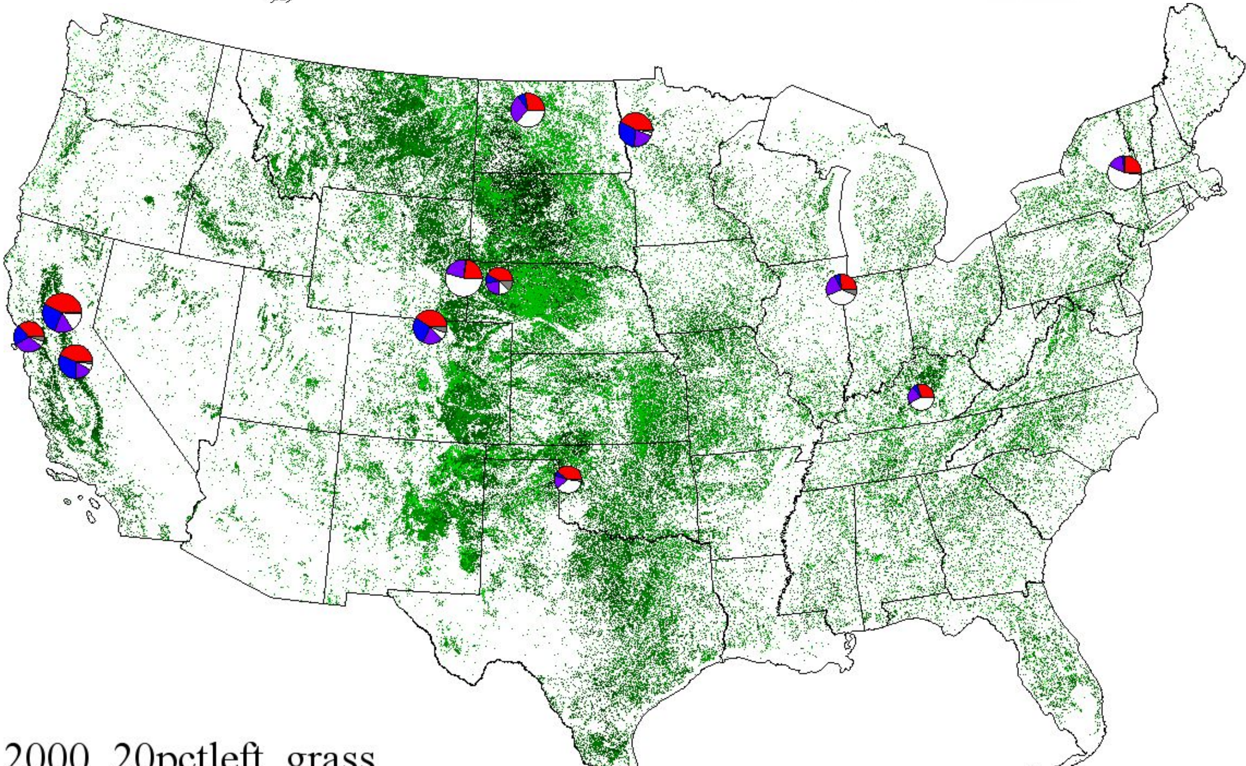
2000_20pctleft_hardwood



2000_20pctleft_crops

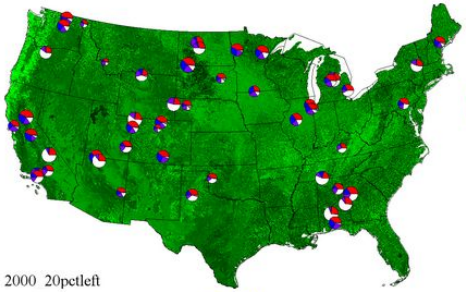
Spring is fairly well predictable in croplands and grasslands.

In addition to heat sum and cold sum, precipitation is a key driver in croplands and grasslands.

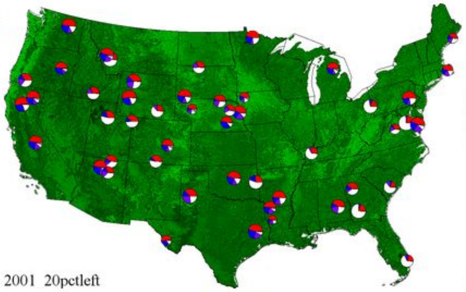


2000_20pctleft_grass

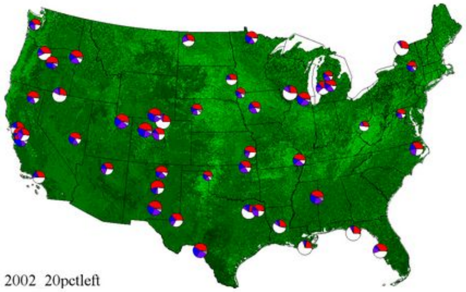
# Inter-annual variability in Spring onset



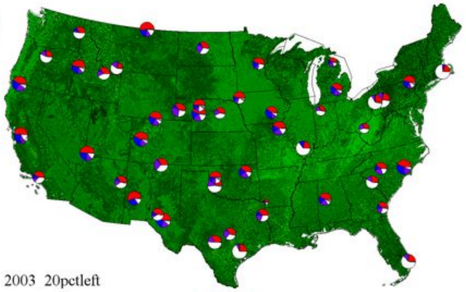
-1.60



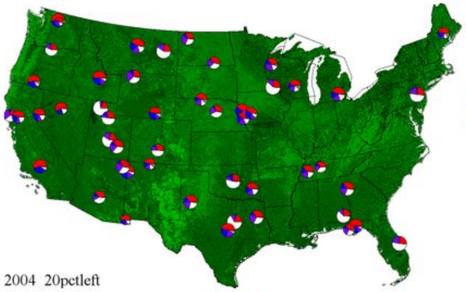
-0.69



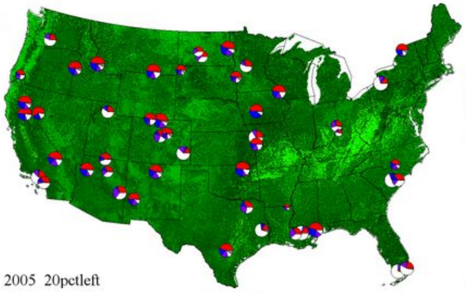
-0.15



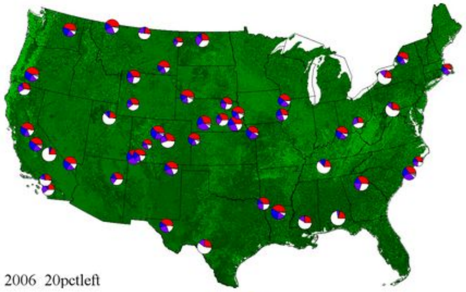
1.03



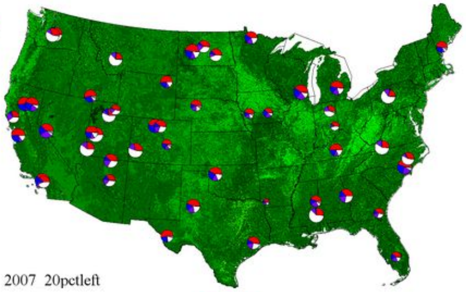
0.27



0.56



-0.81



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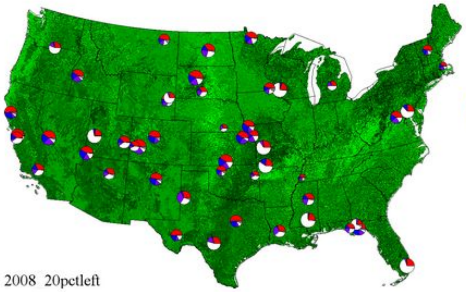
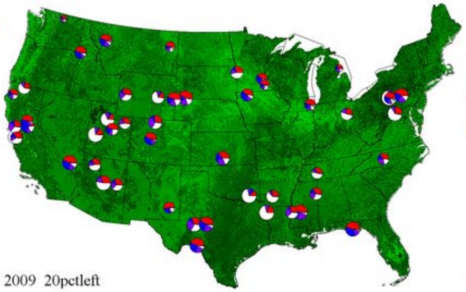
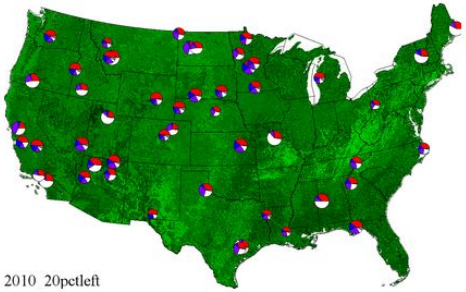


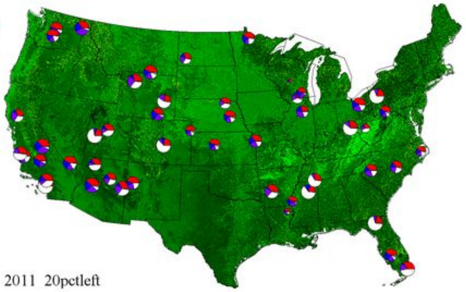
-1.45



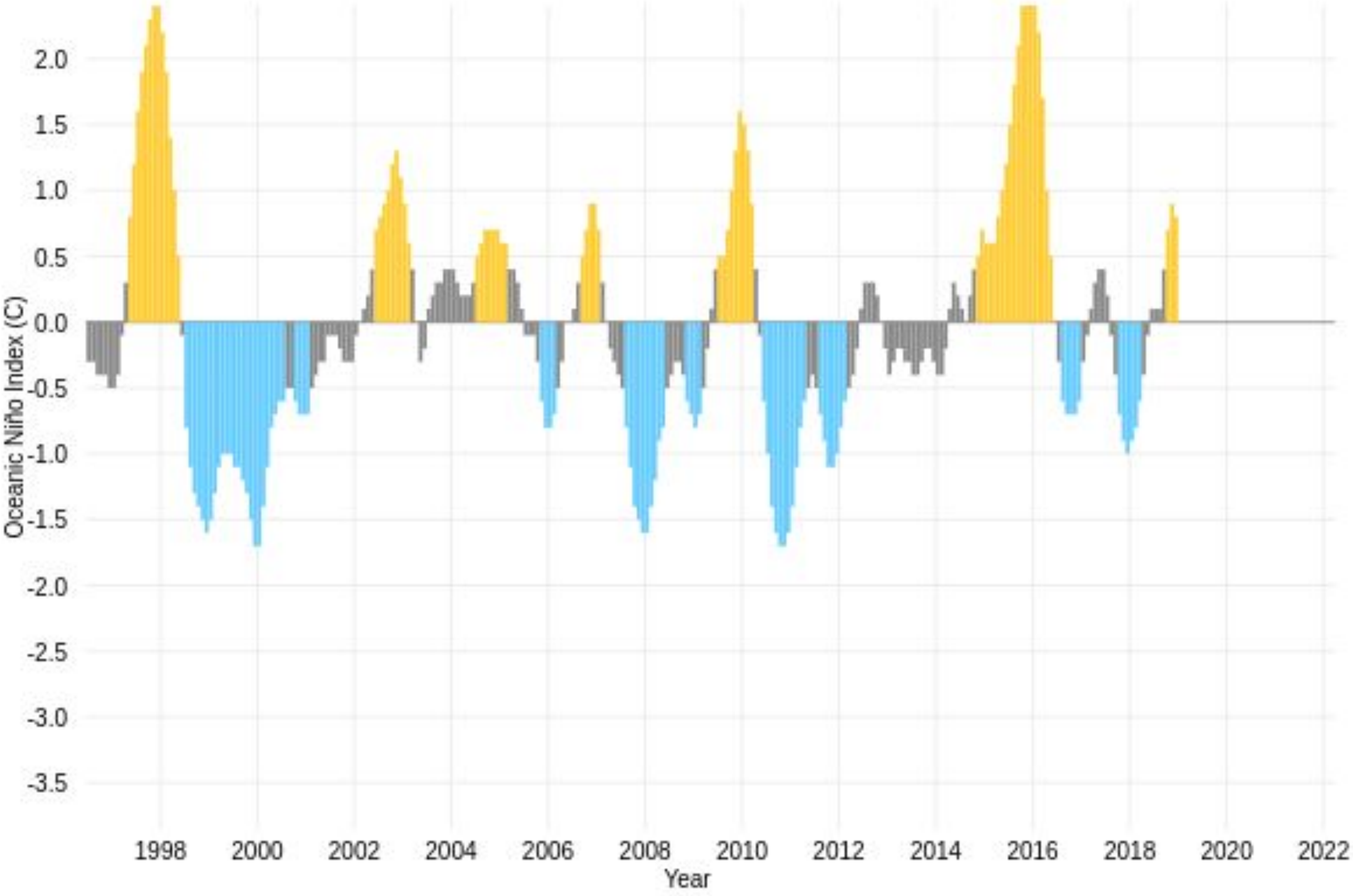
-0.76



1.49



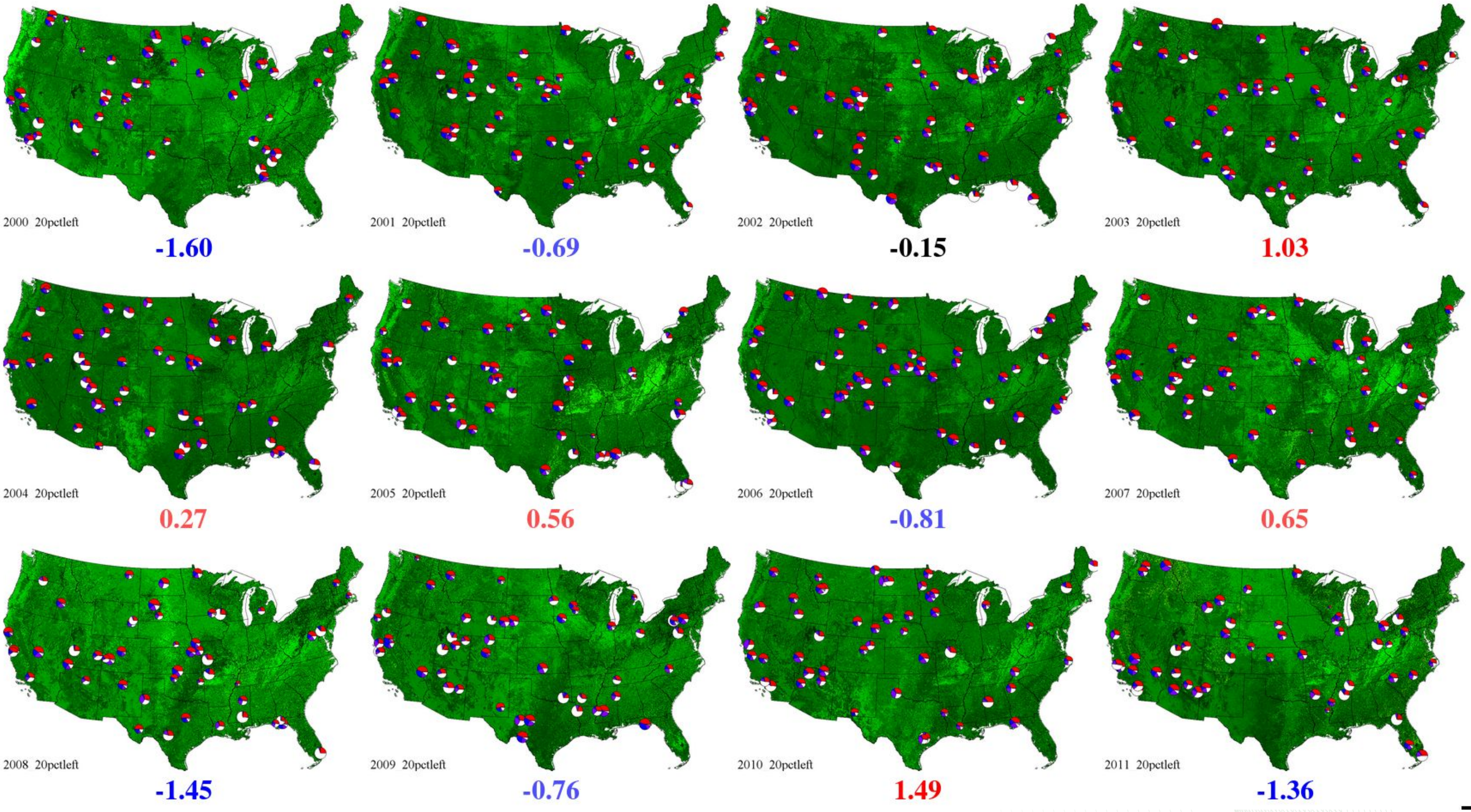
-1.36



El Niño and La Niña events affect the vegetation phenology, and onset of the seasons.

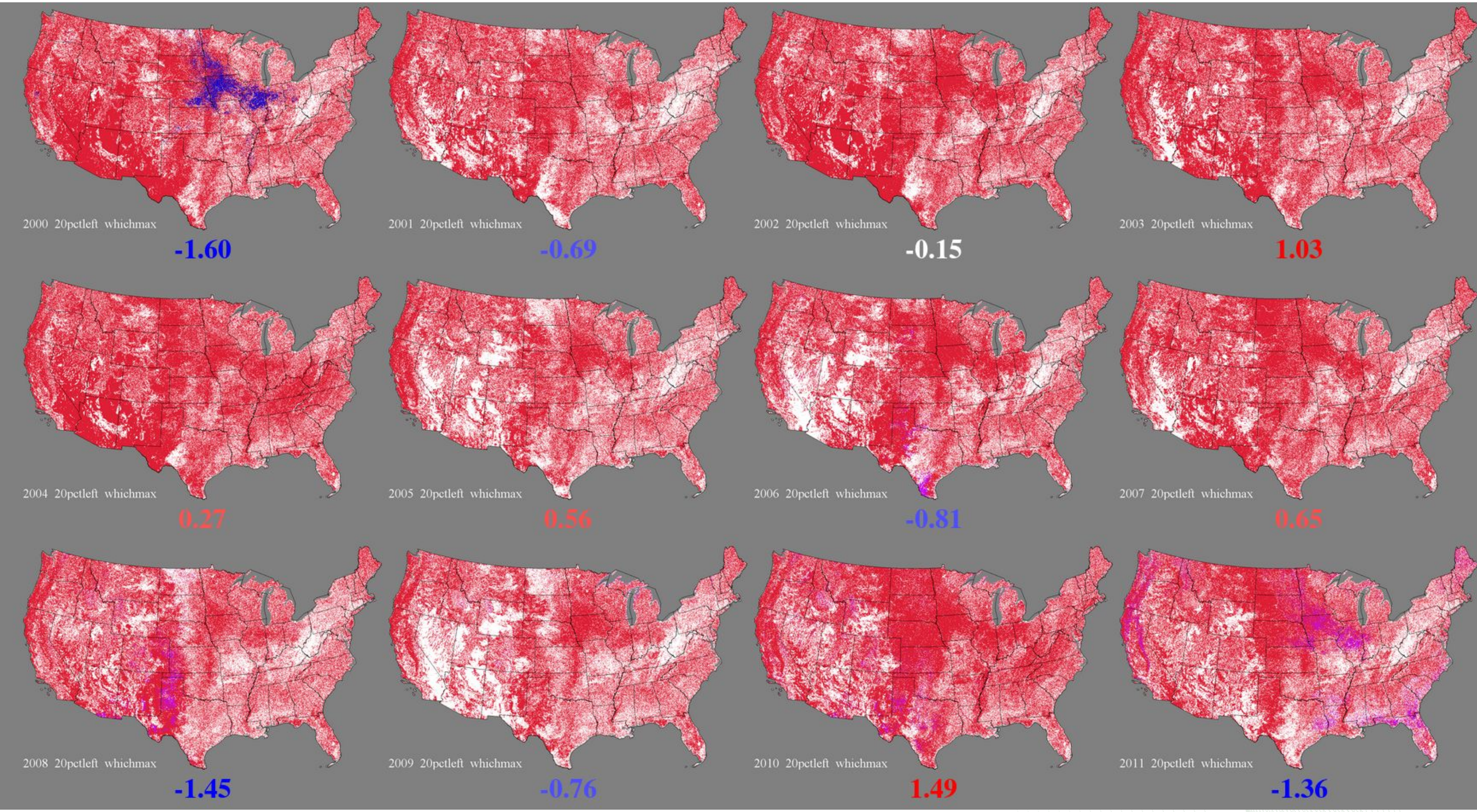
Source: https://www.climate.gov/news-features/understanding-climate/climate-variability-oceanic-ni%C3%B1o-index

# Inter-annual variability in Spring onset



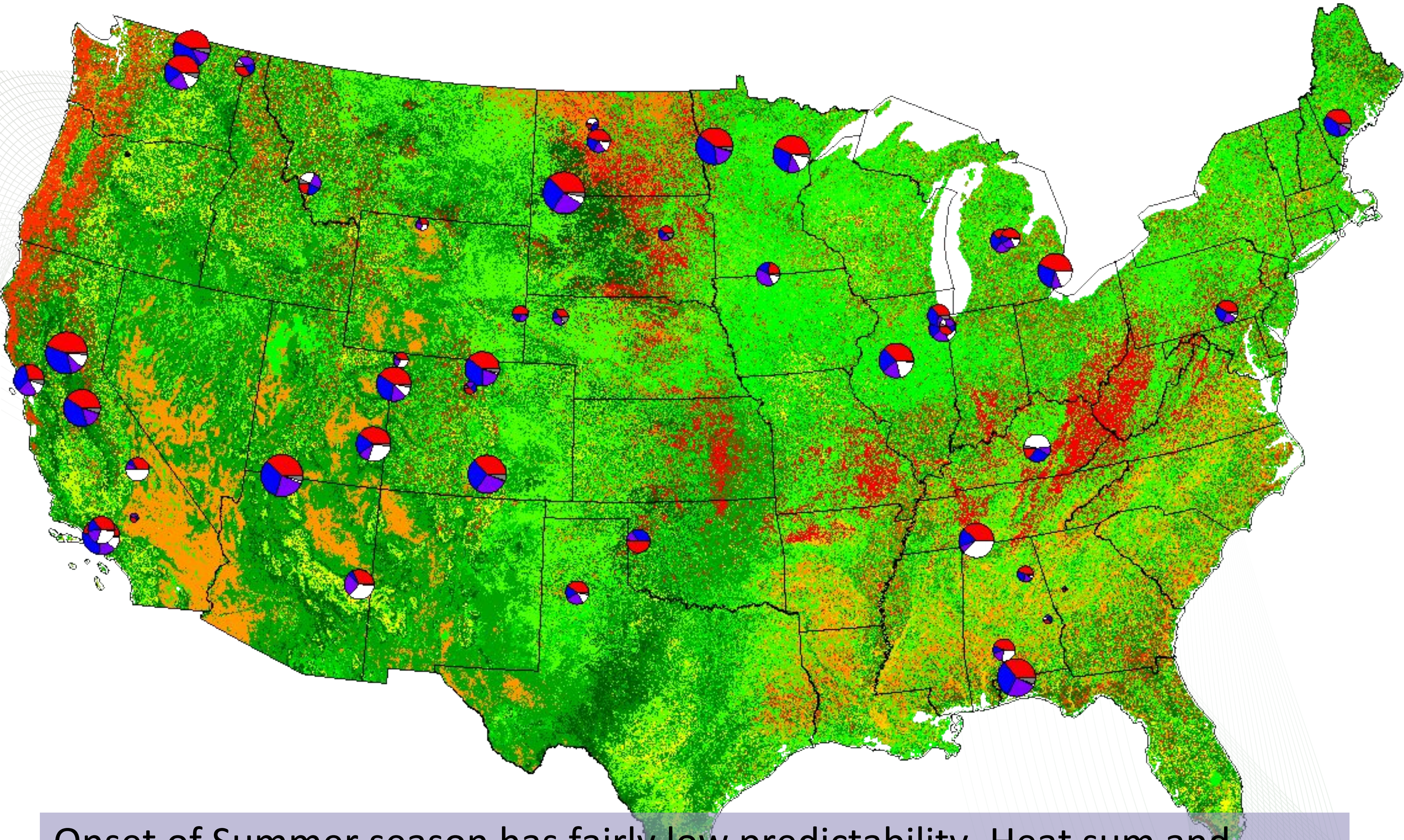
Predictability are reduced especially in La Niña years when precipitation and cold sum are influencing factor.

# Inter-annual variability in Spring onset



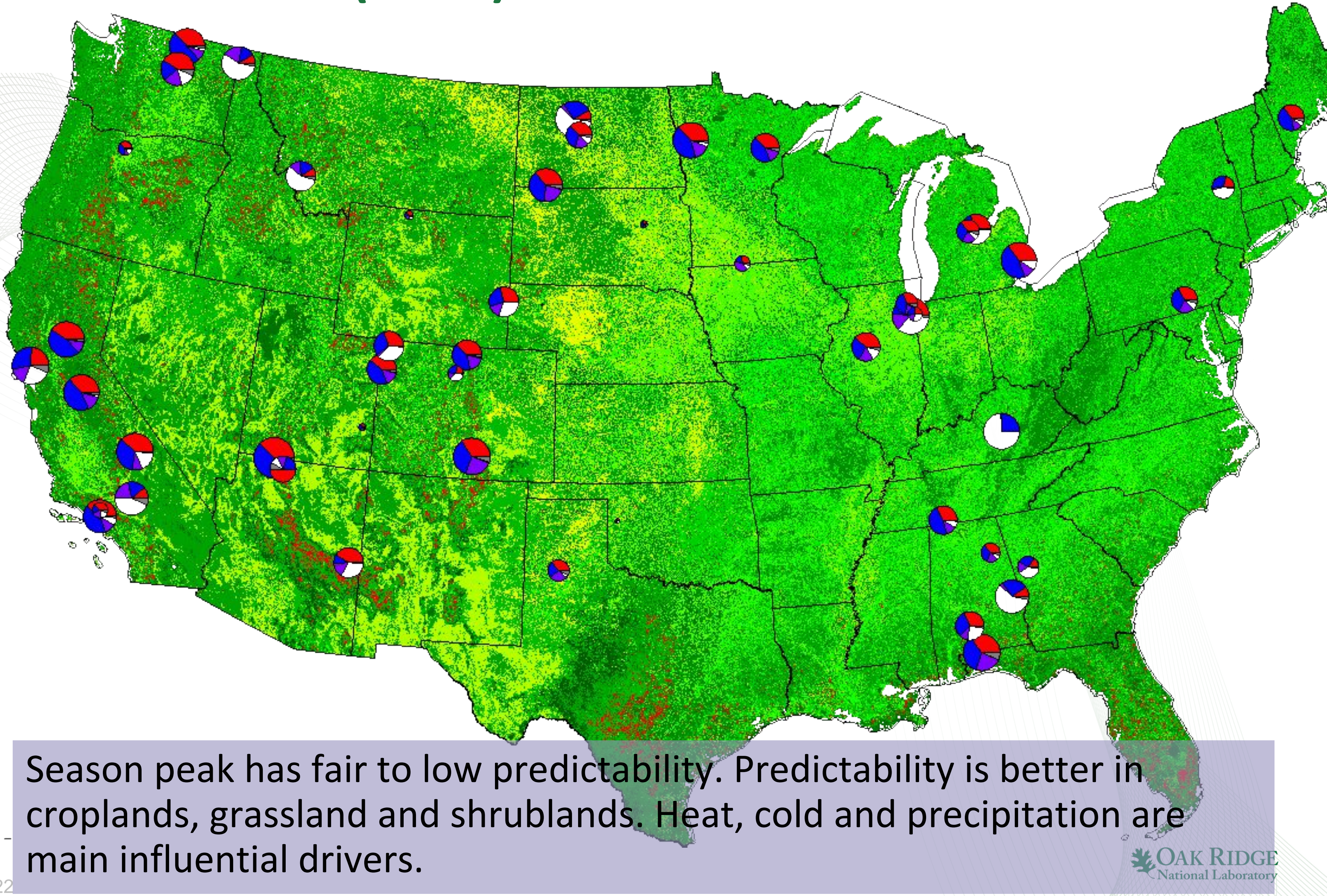
Heat sum is the most dominant driver. However, during La Niña years precipitation and cold sum are influencing factor.

# Start of Summer (2000)

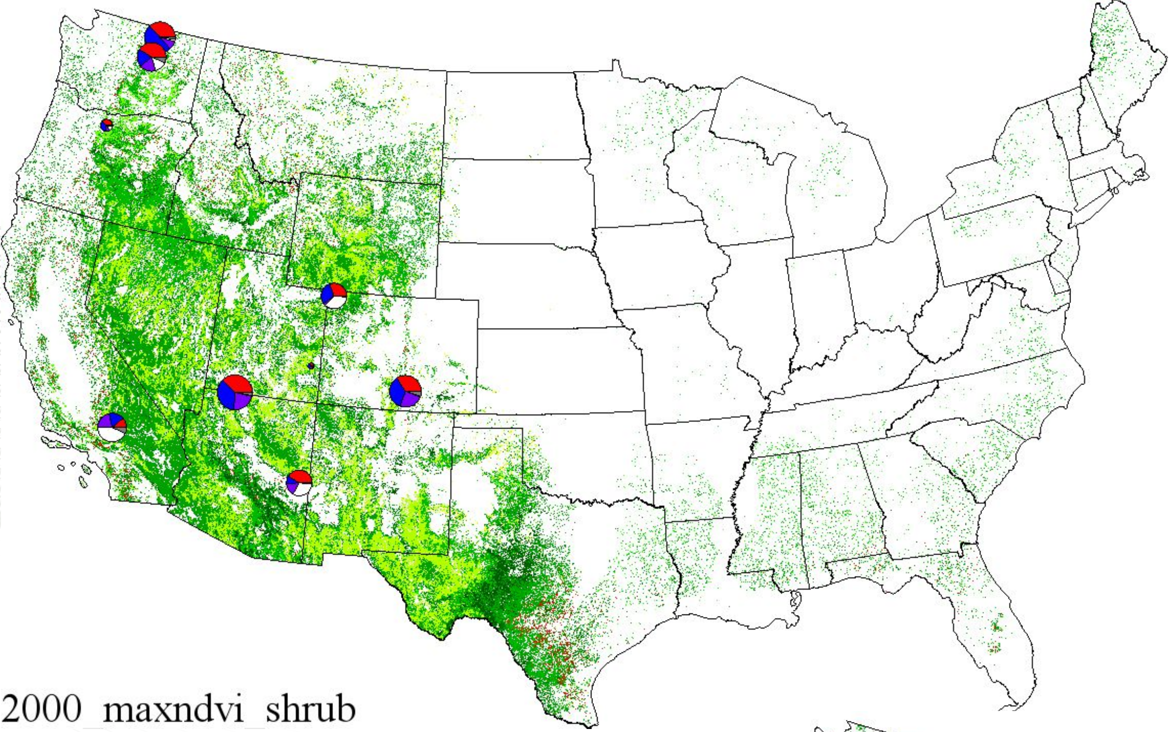


Onset of Summer season has fairly low predictability. Heat sum and precipitation are main influential drivers.

# Season Peak (2000)

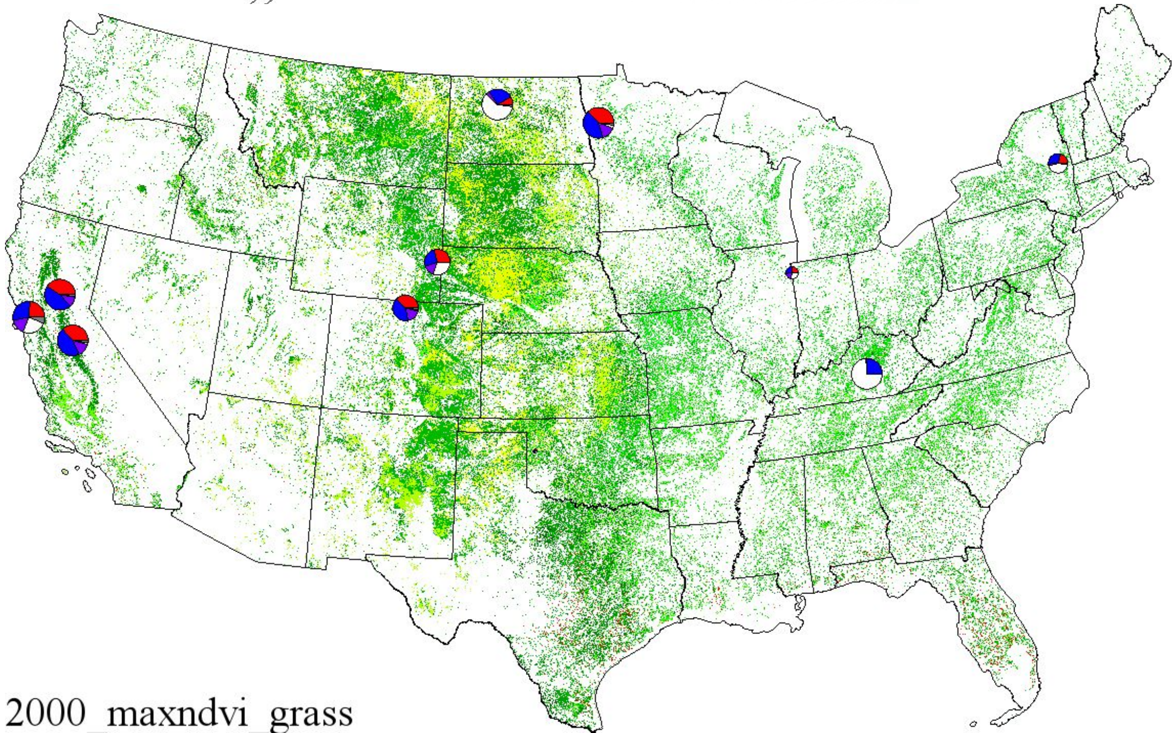


Season peak has fair to low predictability. Predictability is better in croplands, grassland and shrublands. Heat, cold and precipitation are main influential drivers.



2000_maxndvi_shrub

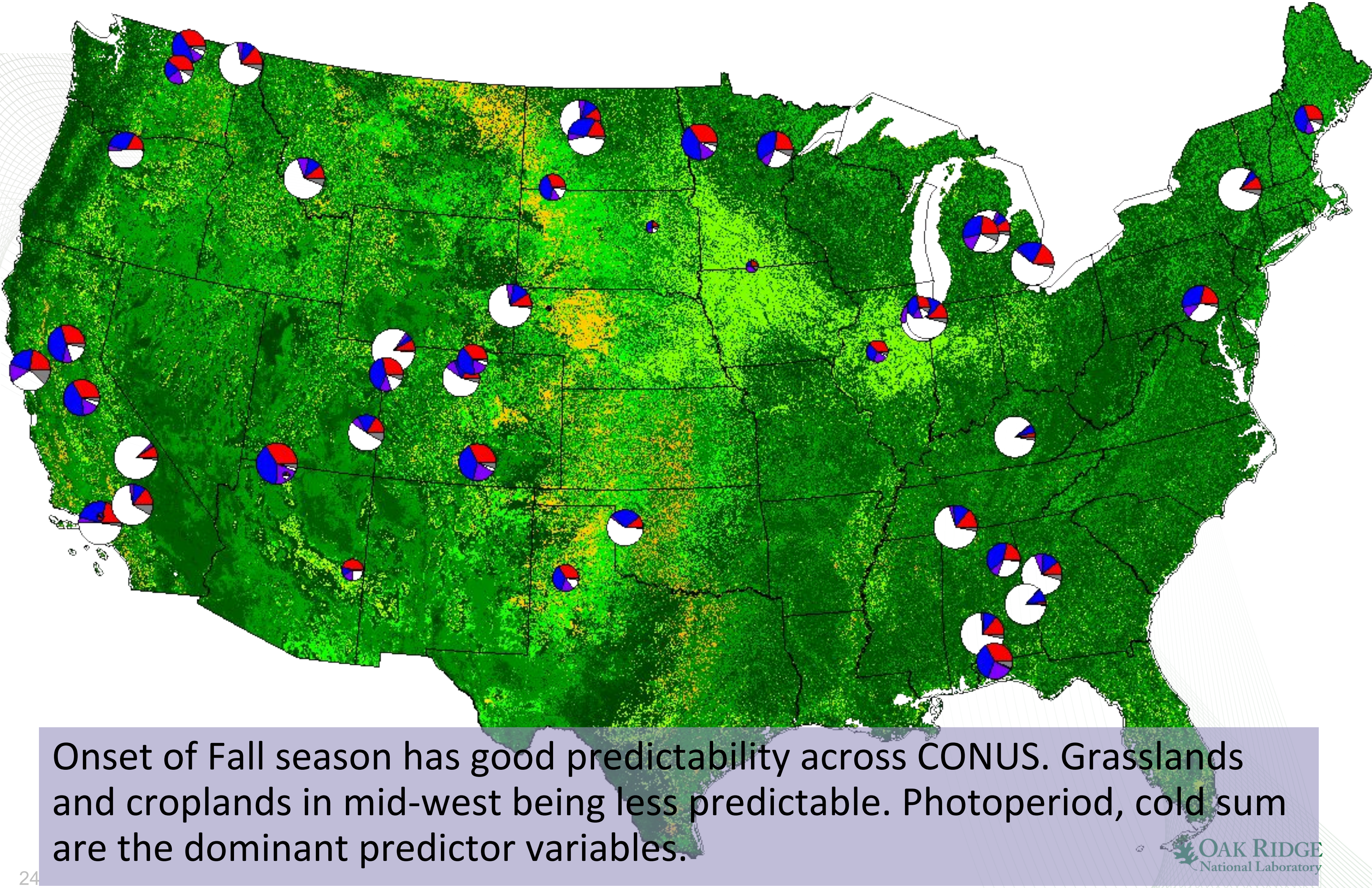
Peak season timing for shrubs and grass have fair predictability.



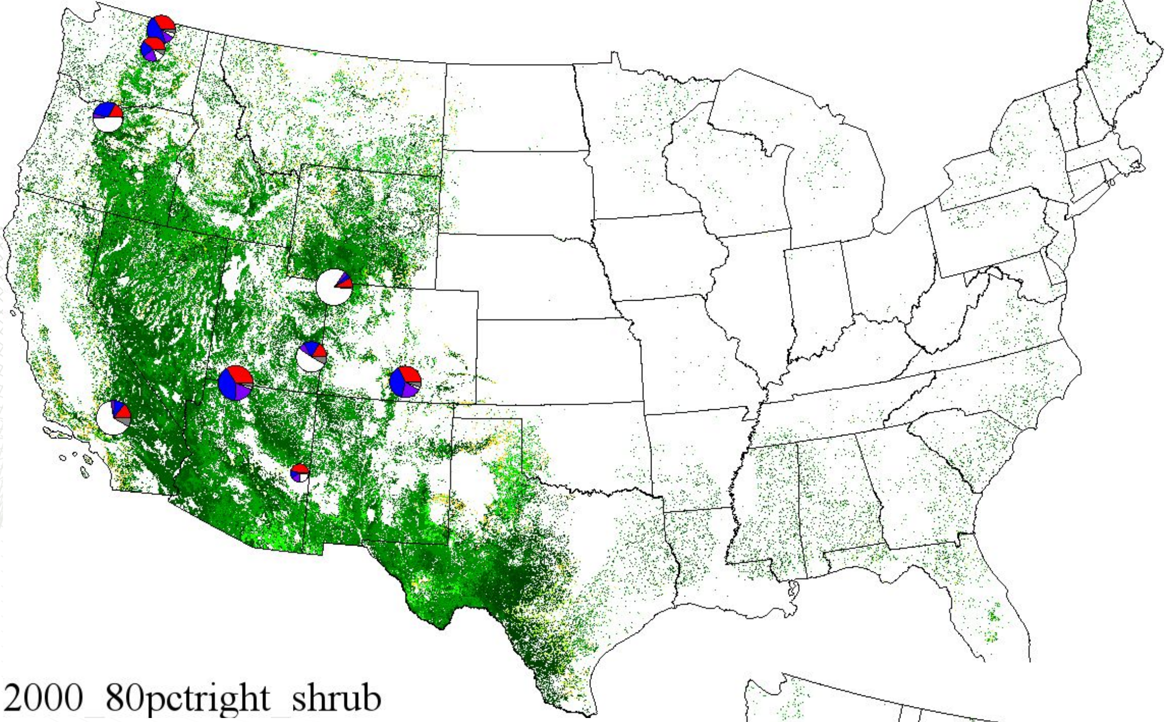
2000_maxndvi_grass

Precipitation is an important driver for predicting season peak in shrublands and grasslands.

# Start of Fall (2000)



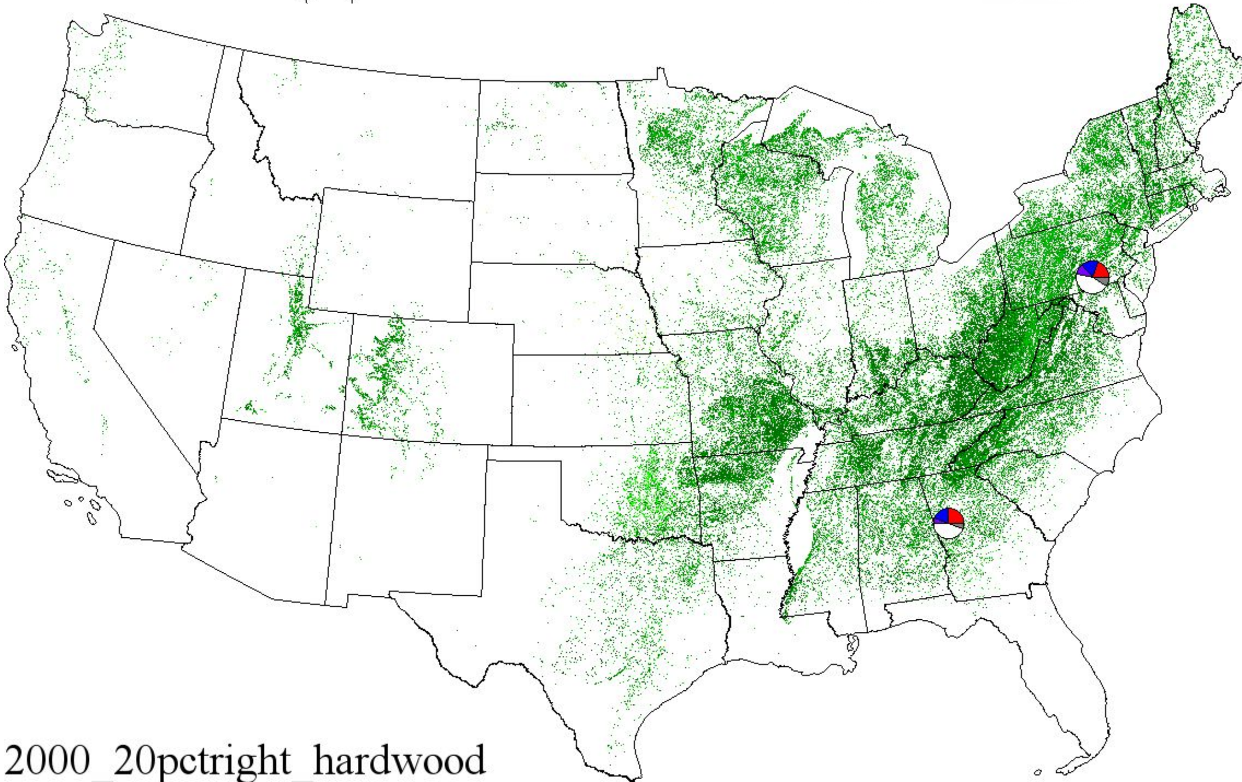
Onset of Fall season has good predictability across CONUS. Grasslands and croplands in mid-west being less predictable. Photoperiod, cold sum are the dominant predictor variables.



2000_80pctright_shrub

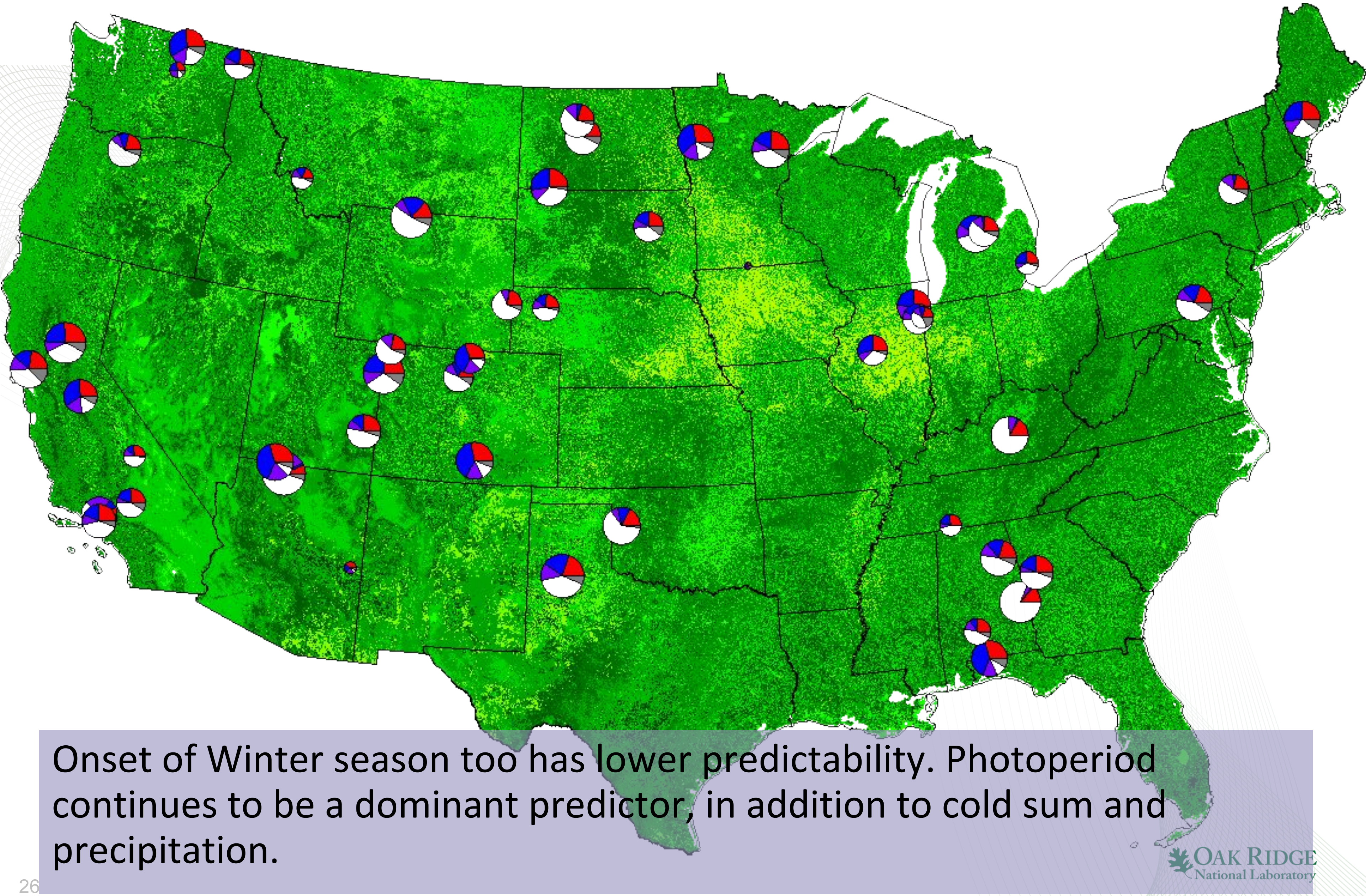
In shrublands in Western US precipitation is an important driver for onset of fall.

Photoperiod is the dominant driver for onset of fall in Eastern US forest ecosystems.



2000_20pctright_hardwood

# Start of Winter (2000)



Onset of Winter season too has lower predictability. Photoperiod continues to be a dominant predictor, in addition to cold sum and precipitation.

# Summary

- Onset of phenological seasons are influenced by not just one but multiple environmental drivers.
- Influence of the predictor variables varies across vegetation types, and across years.
- VPD was not negligible but least dominant driver.
- Dominant controls vary across seasons: heat sum being the key driver for spring and summer; but cold sum and precipitation are dominant drivers for fall and winter.
- ENSO events impact onset of seasons, especially spring and summer.

# Limitations and Future Work

- Calendar year ≠ phenological year
  - we addressing that by defining phenological years, looking at season/long term average to define phenological progressions.
- Early season snow often create an artificial lows in NDVI and % based phenological progress can be skewed.
- We hope to derive the relationship between environmental drivers and phenology across vegetation types to inform land surface models (benchmarking and validation)
- LSP doesn’t capture bud burst, leaf on, flowering, leaf color etc. BUT they may not be needed for continental to global (landscape) scale. There are no bud burst, or leaf colors in the land surface models.

# Thank you for your attention!

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*This research was partially sponsored by the U.S. Department of Agriculture, U.S. Forest Service, Eastern Forest Environmental Threat Assessment Center and the Biological and Environmental Research (BER) Program in the U.S. Department of Energy Office of Science.*

# Predictor variables from DAYMET

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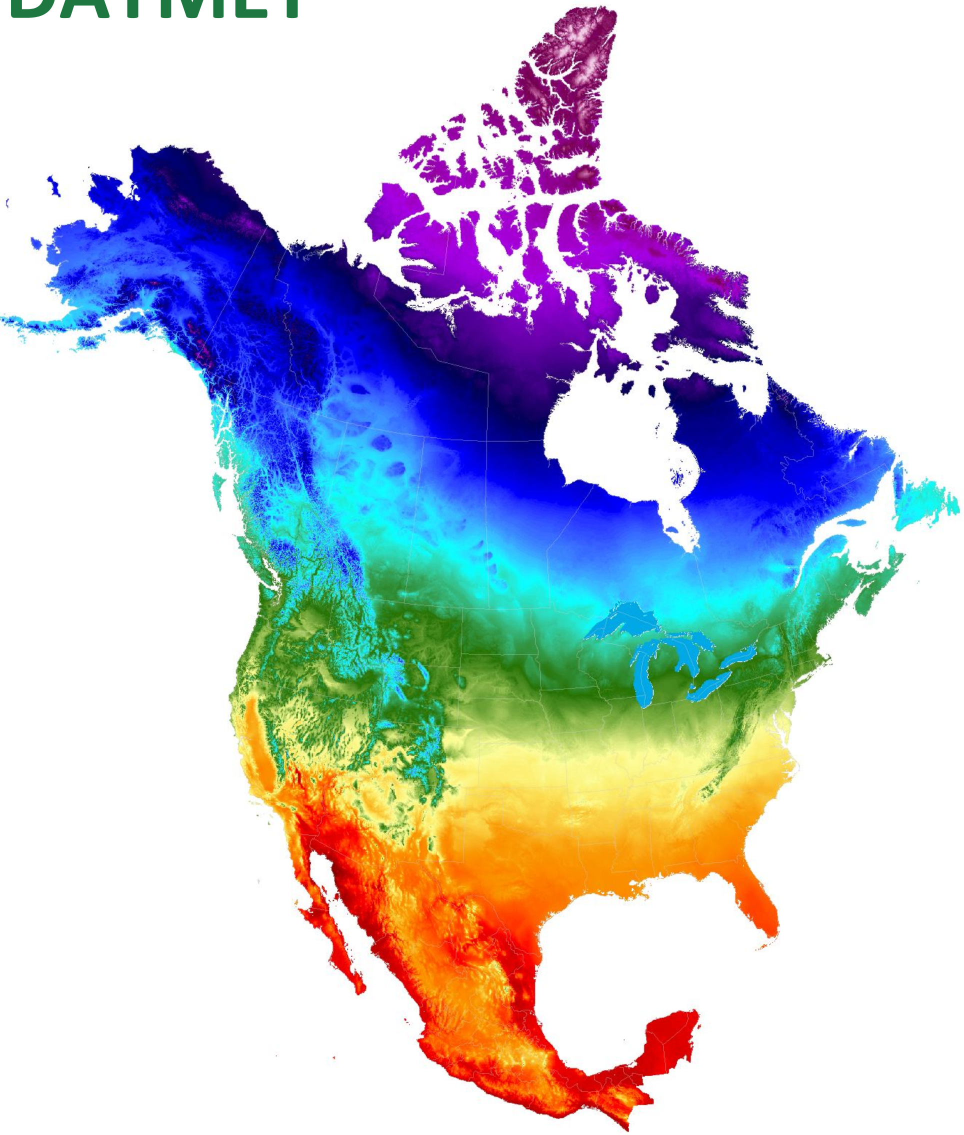
Data available for 1980-2017



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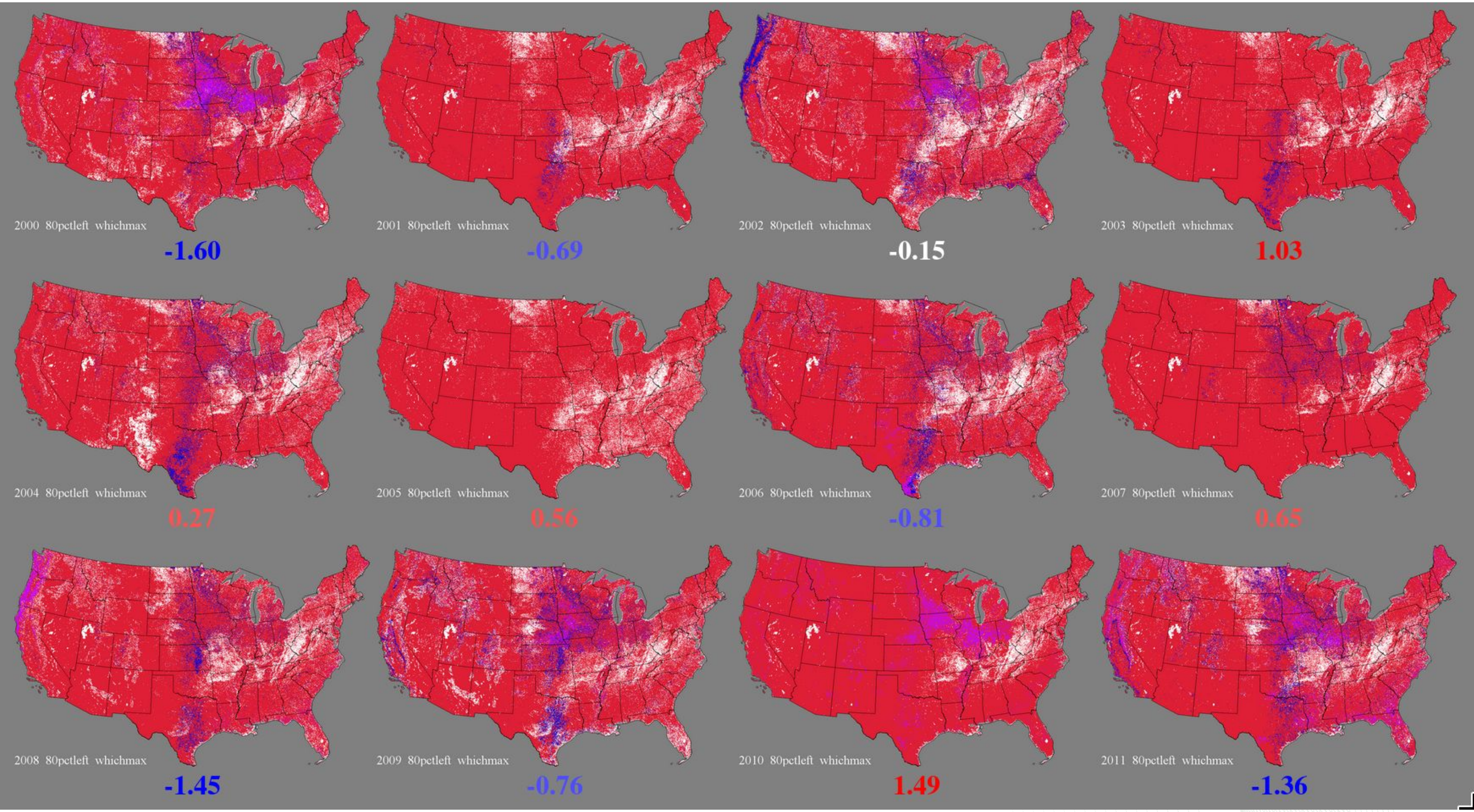
5. Humidity (vapor pressure deficit)

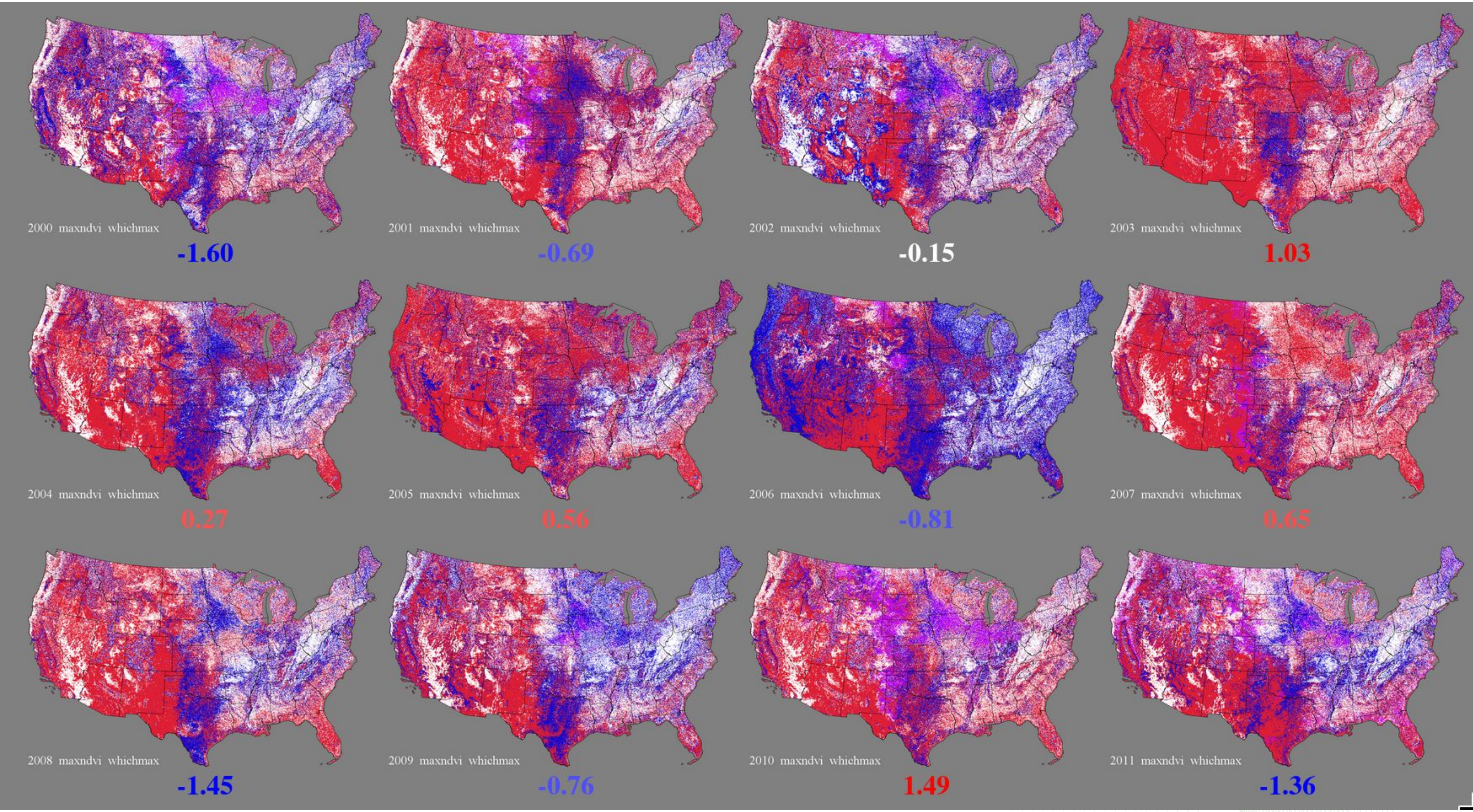
The variables were selected to capture broad environmental drivers for all vegetation types in CONUS.

# Inter-annual variability in start of Summer



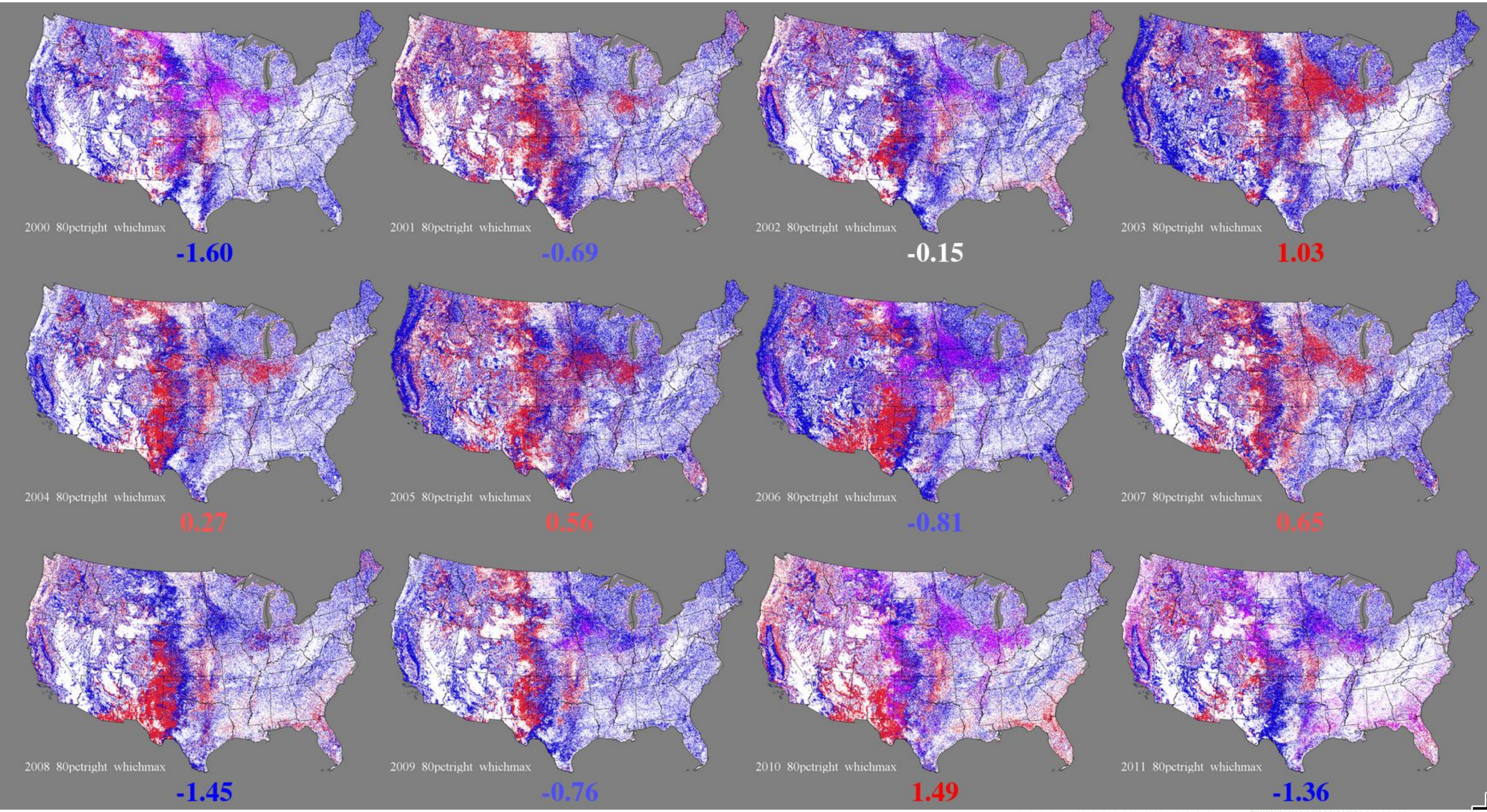
Heat sum and precipitation are main influential drivers.

# Inter-annual variability in season peak



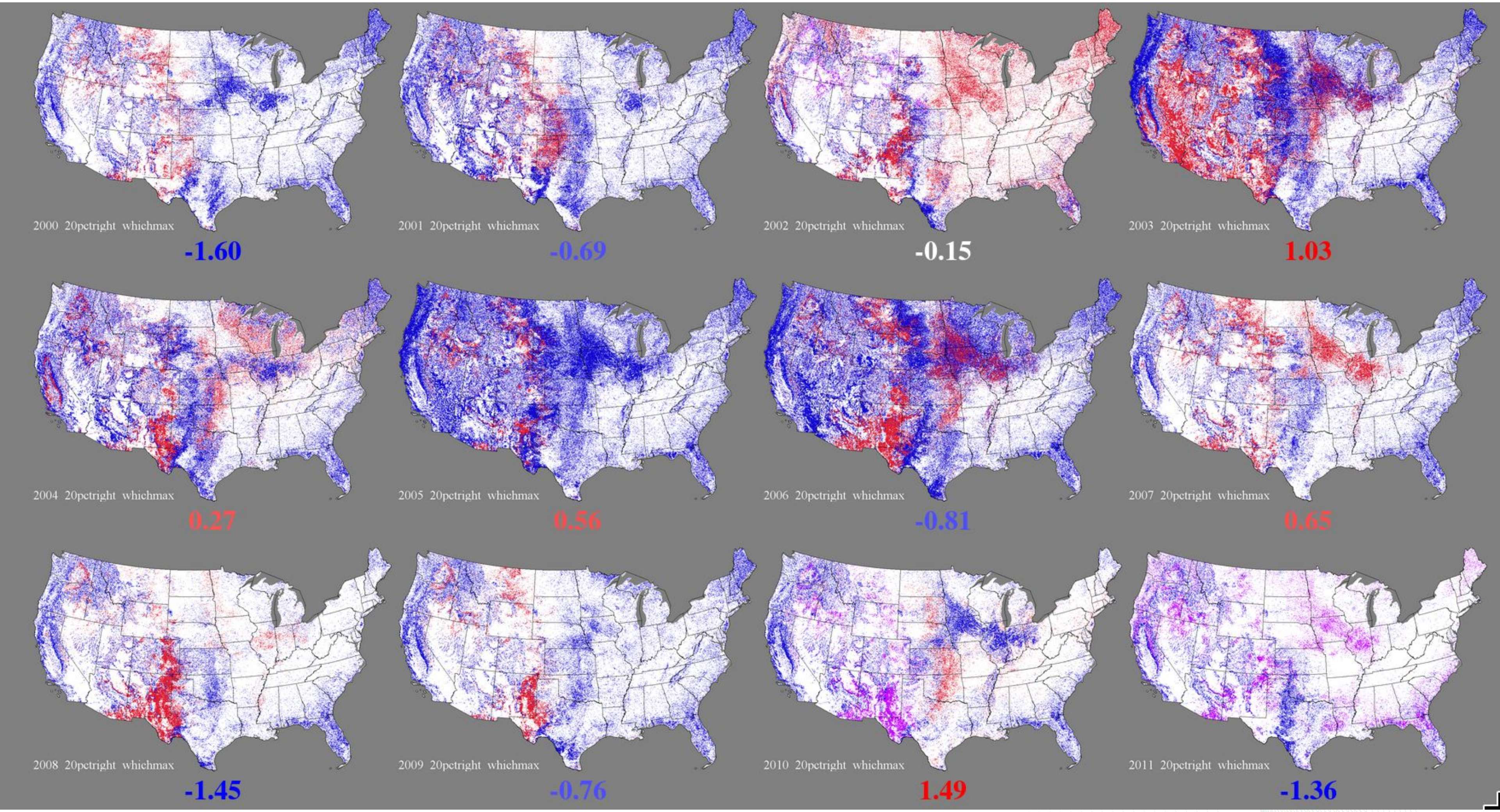
Heat, cold and precipitation are main influential drivers.

# Inter-annual variability in start of Fall



Photoperiod, cold sum are the dominant predictor variables.

# Inter-annual variability in start of Winter



Photoperiod continues to be a dominant predictor, in addition to cold sum and precipitation.