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Dynamically Downscaled Projections of Phenological Changes across the Contiguous United States

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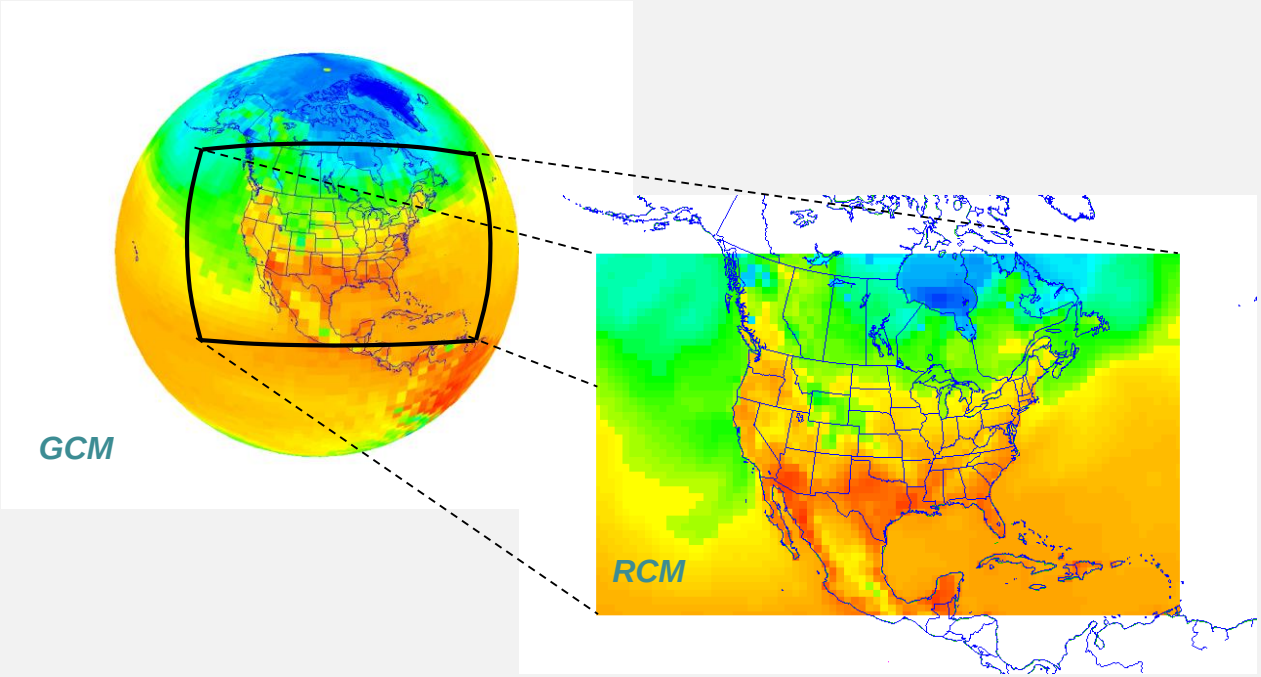
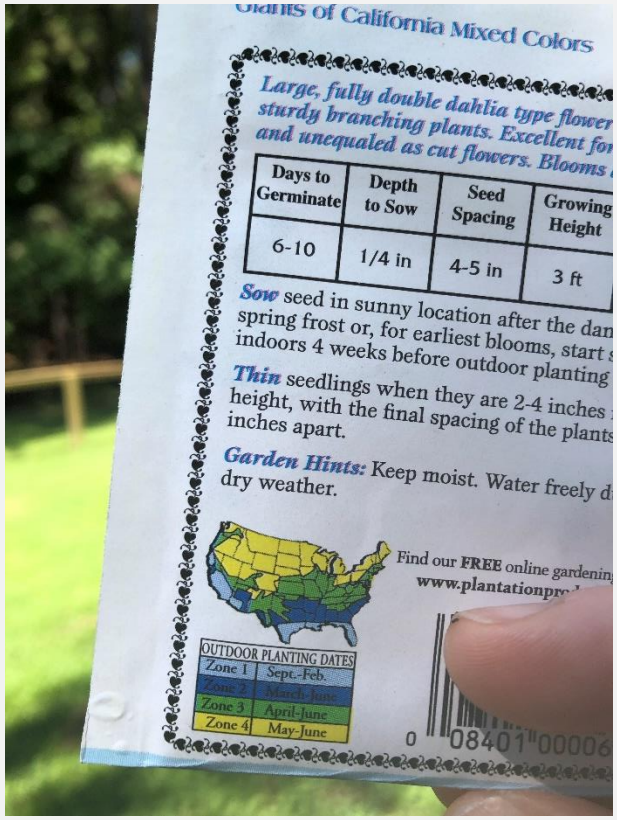


- Downscaling is the process of using global climate model (GCM) output to drive a finer-scale limited-area regional climate model (RCM), which adds value through:
  - Improved representation of finer-scale processes & features (e.g., topography) due to finer grid resolution
  - Scale-appropriate physics
  - Increased temporal resolution

Phenological indicators (PI)

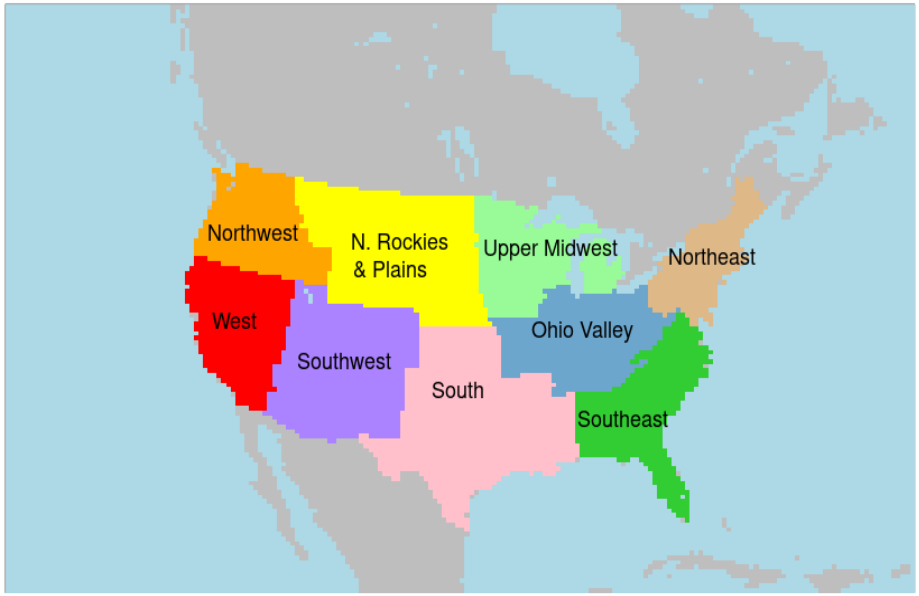
- Phenology examines the responses of plants & animals to seasonal changes
- Here, PI are examined that relate to the period of wintertime dormancy in plants & onset of spring
- Why examine PI?
  - Availability of *hourly data*
  - Focus on *transitional seasons* instead of winter/summer extremes



When do I plant these Zinnia seeds in my back yard?

Simulations

- Weather Research & Forecasting (WRF) model version 3.4.1, with 36-km domain
- Driven by two CMIP5 global models, using Representative Concentration Pathway (RCP) 8.5
  - Community Earth System Model (CESM)
  - Geophysical Fluid Dynamics Laboratory (GFDL) Coupled Model (CM3)
- Additional run using RCP 4.5 not shown
- Time periods
  - Historical: 1995-2005
  - Future: 2025-2100



Natl. Centers for Environmental Information (NCEI) regions on WRF domain

Chilling Units (CU)

- Deciduous fruit trees and other plants benefit from a period of dormancy or “rest” in cooler temperatures before the growing season occurs
- Observational studies show temperatures around 6° C most favorable for rest completion

Table 1. Conversion of selected temperatures to Chill Units.

Temperature °C	Temperature °F	Chill units contributed
< 1.4	< 34	0
1.5 – 2.4	35 – 26	0.5
2.5 – 9.1	37 – 48	1
9.2 – 12.4	49 – 54	0.5
12.5 – 15.9	55 – 60	0
16 – 18	61 – 65	−0.5
> 18	> 65	−1

- CU is calculated from hourly 2-m temperatures (T2) using the Utah model (Richardson et al., 1974, Hort. Science)
- Maximum possible CU contribution each hour is 1
- CU accumulate from October 1 to May 1

Effect of Chilling on Fruit Trees

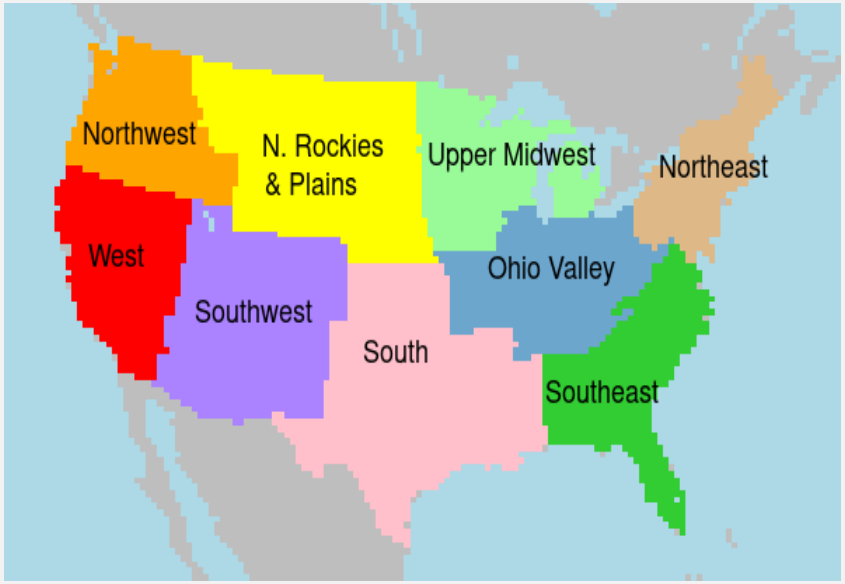
- Most apple & peach trees have chilling requirement of 500-1000 CU
- Too few CU: a poor harvest, as flowering or fruiting is late or does not occur
- Too many CU: breaks dormancy too early, may be damaged by hard freezes or disease

2 varieties of peach trees in Texas, along with their recommended CU

https://www.reporternews.com/story/money/industries/agriculture/2017/04/16/too-few-chill-hours-could-affect-texas-fruit-crop/100465006/

Model Error

- CU bias varies regionally, but Southeast and South are areas of enlarged bias

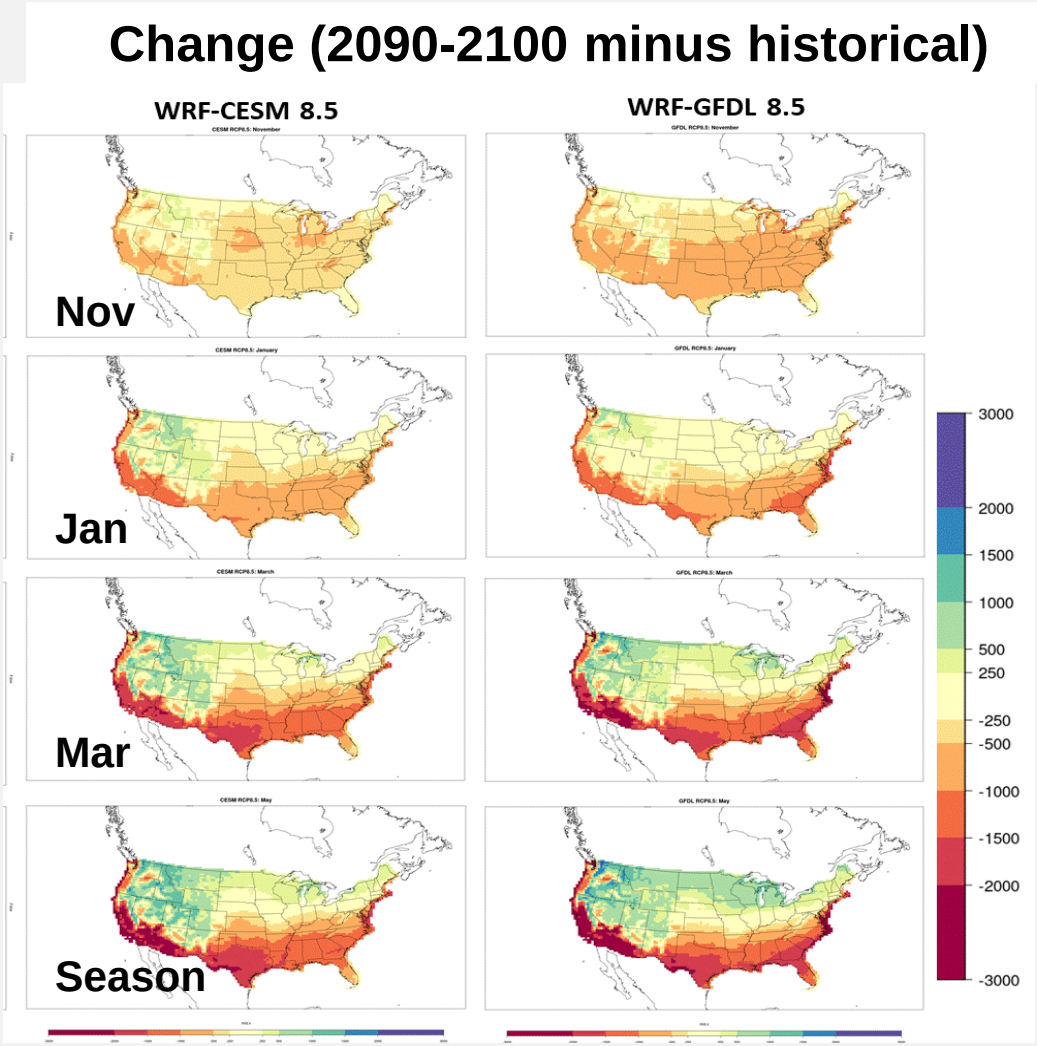


Area	CU	
	CESM	GFDL
CONUS	-176	56
Northwest	-47	-216
West	-41	50
N. Rockies & Plains	66	-63
Southwest	**18**	61
Upper Midwest	-83	**-12**
South	-48	**492**
Ohio Valley	-125	182
Southeast	**-658**	227
Northeast	-251	-175

Simulation-average season-accumulated CU bias, compared to PRISM-derived CU. The max & min absolute bias are bolded.

Projected Change in Chilling Units

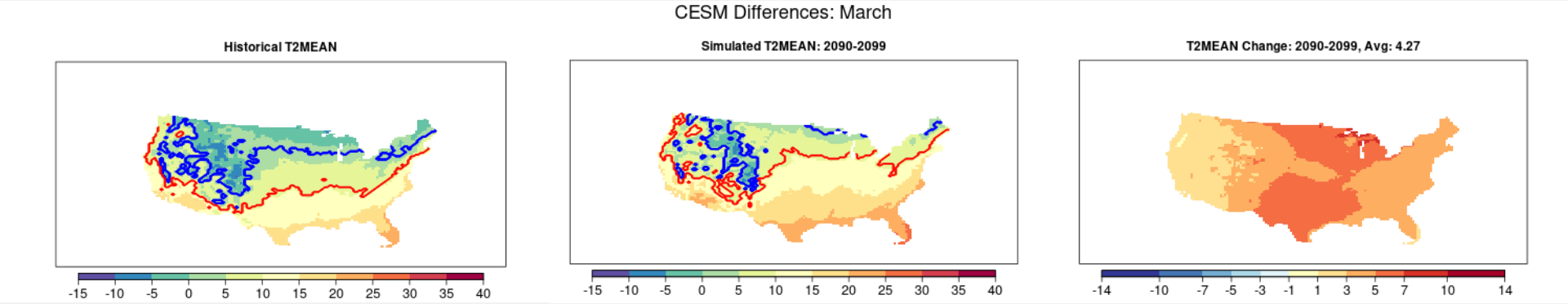
- Decreasing CU, especially in southern CONUS
- Increases in western & northern CONUS in late season
- In most regions & periods, changes exceed model mean abs. error (MAE) under RCP 8.5



Average changes (2090-2100 minus historical values) in accumulated CU for at the end of November, January, March, and the season (1 October – 1 May)

Regional Impact of Warming

- Areas of 5-7° C of warming through central CONUS
- Northern CONUS -> warming T2 produces more frequent temperatures in favored CU range
- Southern CONUS -> warming produces decrease in CU as temperatures too high to positively accumulate CU



Example from March, WRF-CESM8.5 of historical and end-of-century average 2-m temperatures with difference field.

Areas where T2 ≤ 2.5° C are contoured in blue.

Areas where T2 ≥ 9.1° C are contoured in red.

} Range of Max CU

Extended Spring Indices

- Date (relative to January 1) of **leafout (LO)** and **first bloom (FB)**
- Calculated for 3 plants (lilac & 2 varieties of honeysuckle)
- Has been shown to capture the onset of spring in a variety of agricultural and natural plant species, both in subtropical & temperate environments

https://www.thespruce.com/japanese-honeysuckle-vines-2132890

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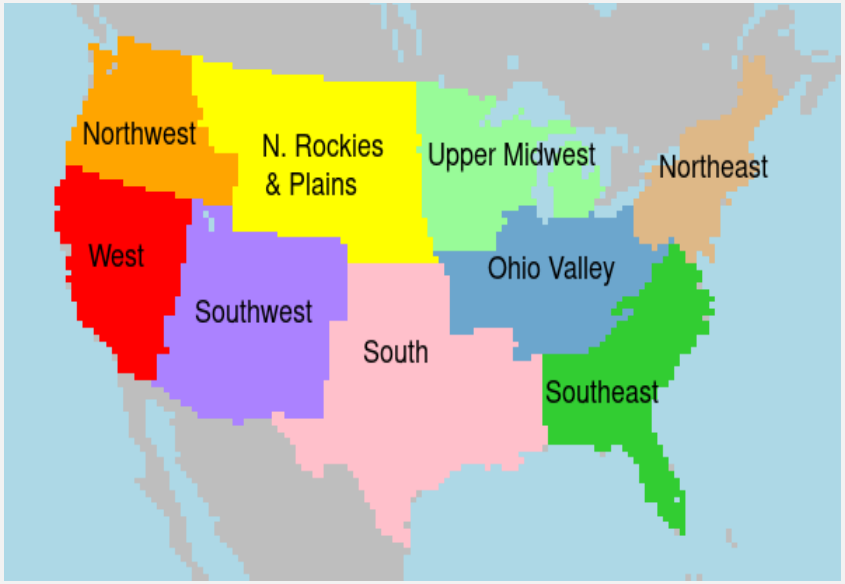
Calculation of Leafout & First Bloom

- Leafout is calculated based on:
  - Number of days since 1 January
  - Recent growing degree hour accumulation (hourly temperature relative to 0.6˚ C)
- First bloom must occur *after* leafout does, and is based on:
  - Number of days since leafout
  - Recent growing degree hour accumulation

- **Frequency of temperature > 0.6˚ C is critical**

Model Error

- Simulated spring onset (both LO and FB) consistently occurs later than observed

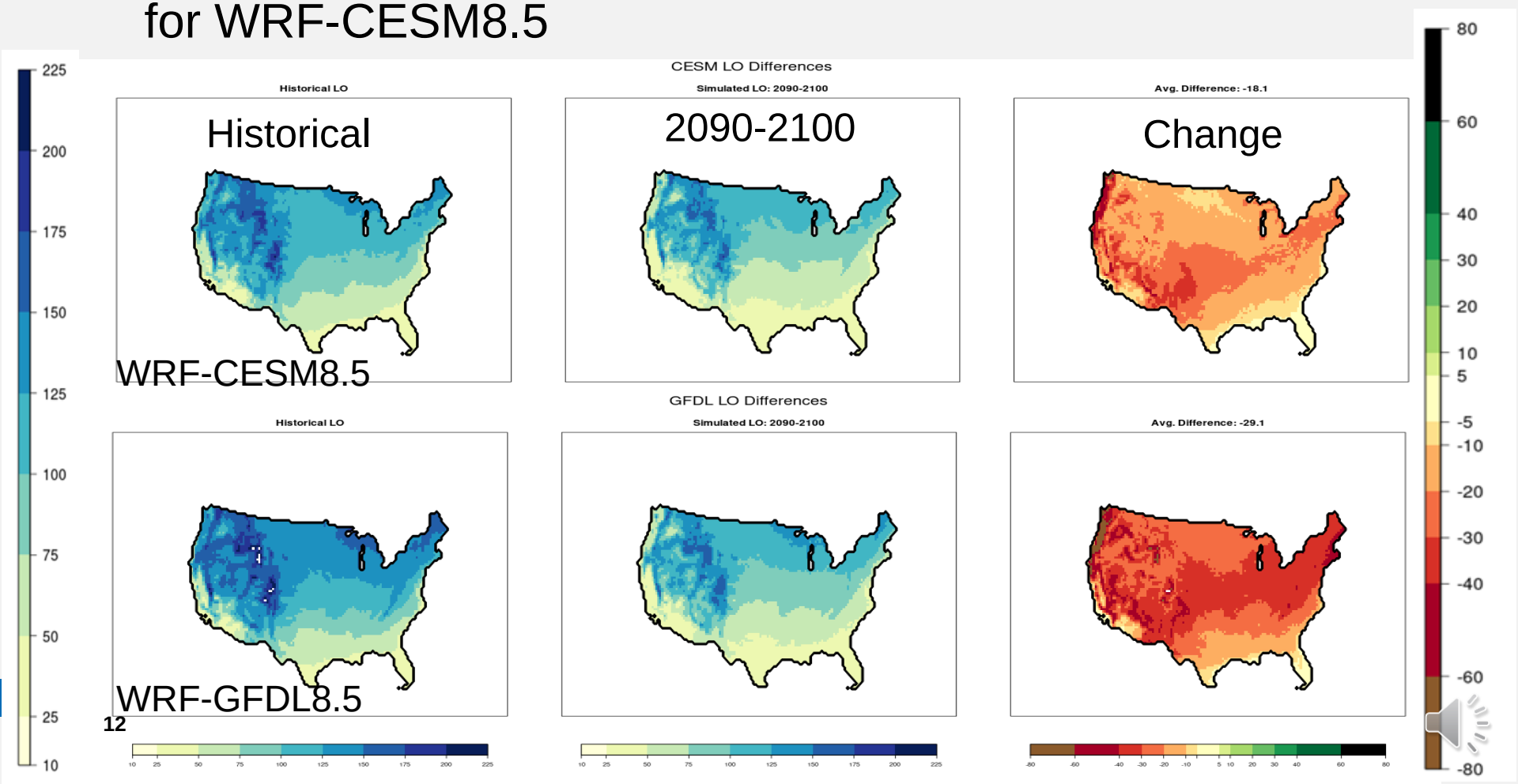


Area	LO		FB	
	CESM	GFDL	CESM	GFDL
CONUS	27.1	41.6	38.9	57.7
Northwest	**42.2**	**55.1**	50.1	**71.3**
West	41.8	54.2	**53.7**	70.9
N. Rockies & Plains	22.7	38.5	30.3	**48.0**
Southwest	41.2	54.5	47.7	63.7
Upper Midwest	**10.9**	**31.8**	**23.7**	48.4
South	29.7	36.1	42.4	56.5
Ohio Valley	21.1	42.3	32.8	55.3
Southeast	22.0	37.3	38.2	60.8
Northeast	14.1	38.2	30.0	57.9

Simulation-average LO and FB bias (in days). The max & min absolute bias for each field are bolded. SI values are compared to Natl. Phenological Network values.

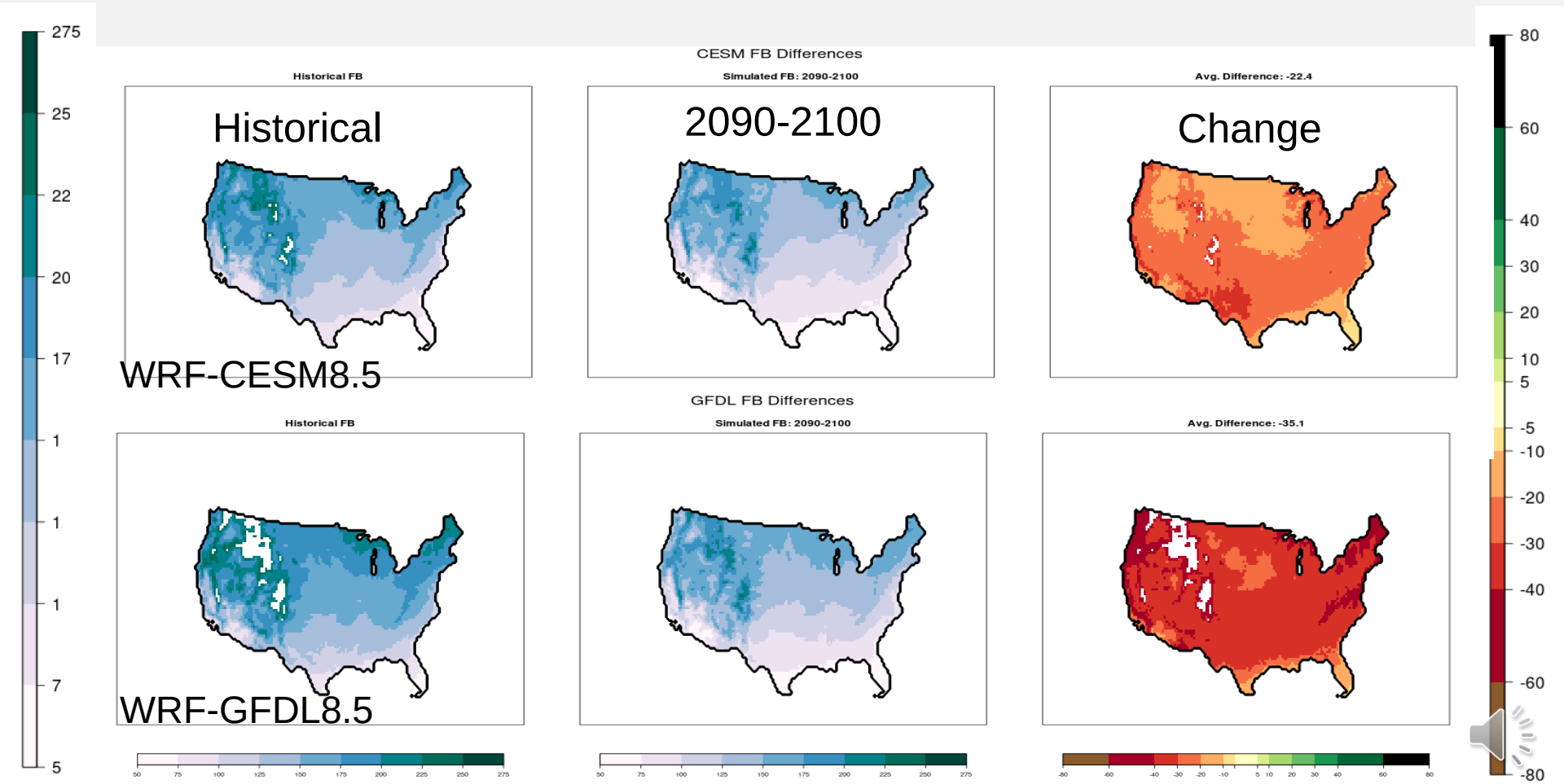
Leafout Change

- LO dates occur earlier in all projected periods
- CONUS-avg: -18 to -29 days by end-of-century under RCP 8.5
- Regional changes exceed MAE in Northeast & Upper Midwest for WRF-CESM8.5



First Bloom Change

- Similar change in spring onset when looking at first bloom
- CONUS-avg: -22 to -35 days by end-of-century
- Regional changes do not exceed MAE



Summary & Future Work

- Summary of PI Change
  - Chilling units: Decreasing CU over southern CONUS, late-season increases to north
  - Spring onset: Spring advancement consistent with IPCC (2014) estimate of -1 to -3 days per decade. But end-of-century changes generally do not exceed model error.
  - Projected changes are similar among model runs

- Future Work
  - Refine projections of PI with planned simulations over 12-km CONUS domain featuring updated physics

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