Terrestrial Ecology Research Synthesis on Phenology/Seasonality/Climate interactions

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Thank you to all the people who provided input for this talk

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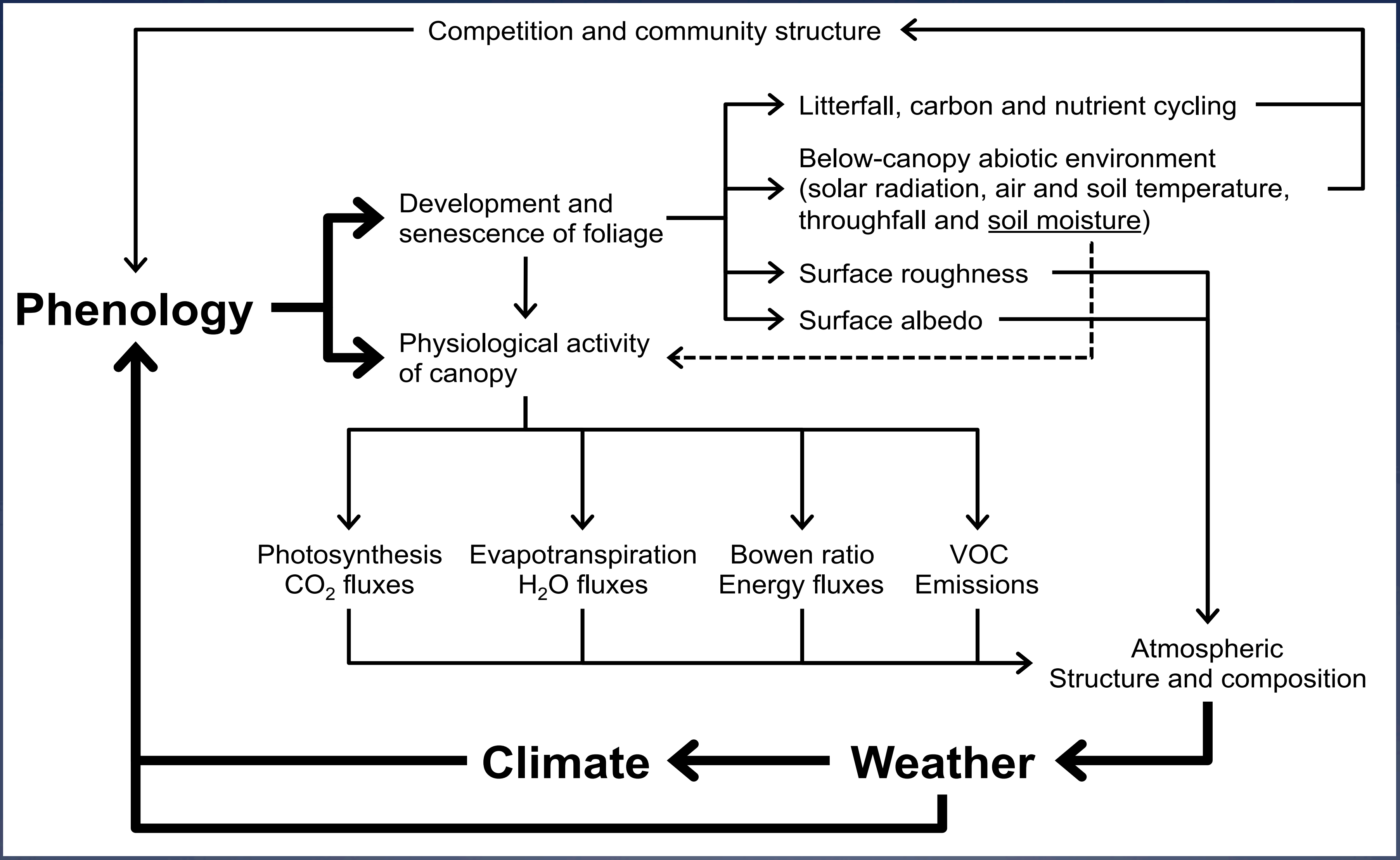
Danilo Dragoni	Indiana University
Dave Nelson	Appalachian Laboratory, UMCES
Eli Melaas	Boston University
John Kimball	University of Montana
John Mustard	Brown University
Kyle McDonald	The City College of New York
Mark Friedl	Boston University
Matt Jones	University of Montana
Ranga Myneni	Boston University
Scott Goetz	Woods Hole Research Center
Steven Guinn	Appalachian Laboratory, UMCES
Steven Keller	Appalachian Laboratory, UMCES
Xi Yang	Brown University
Xu Liang	Boston University and UCLA

Renewed interest in the importance of phenology

* It is an old tradition, but has seen a rebirth as an interdisciplinary science in the field of systems ecology, biometeorology, environmental biology and physiological ecology.
* Due to feedbacks to climate, phenological responses to weather and anthropogenic climate change have strong societal relevance.

Did Thoreau study plant physiology?

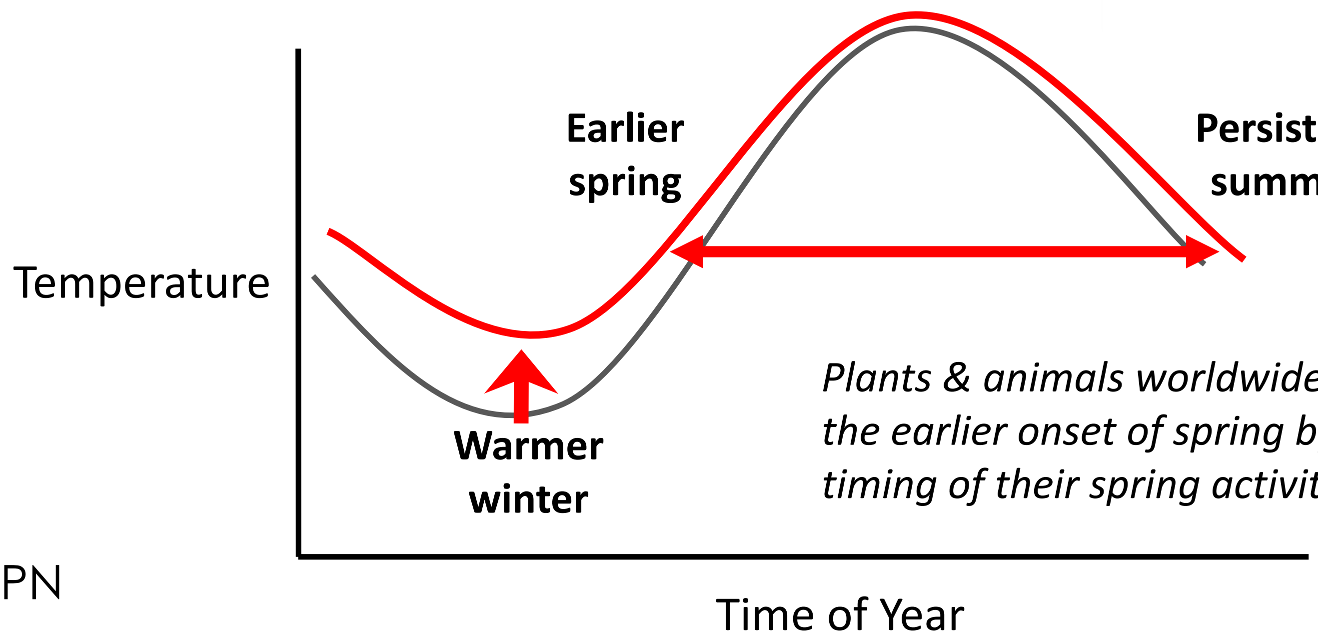
Phenology influences climate – ecosystem feedbacks



Richardson et al. 2013 AFM

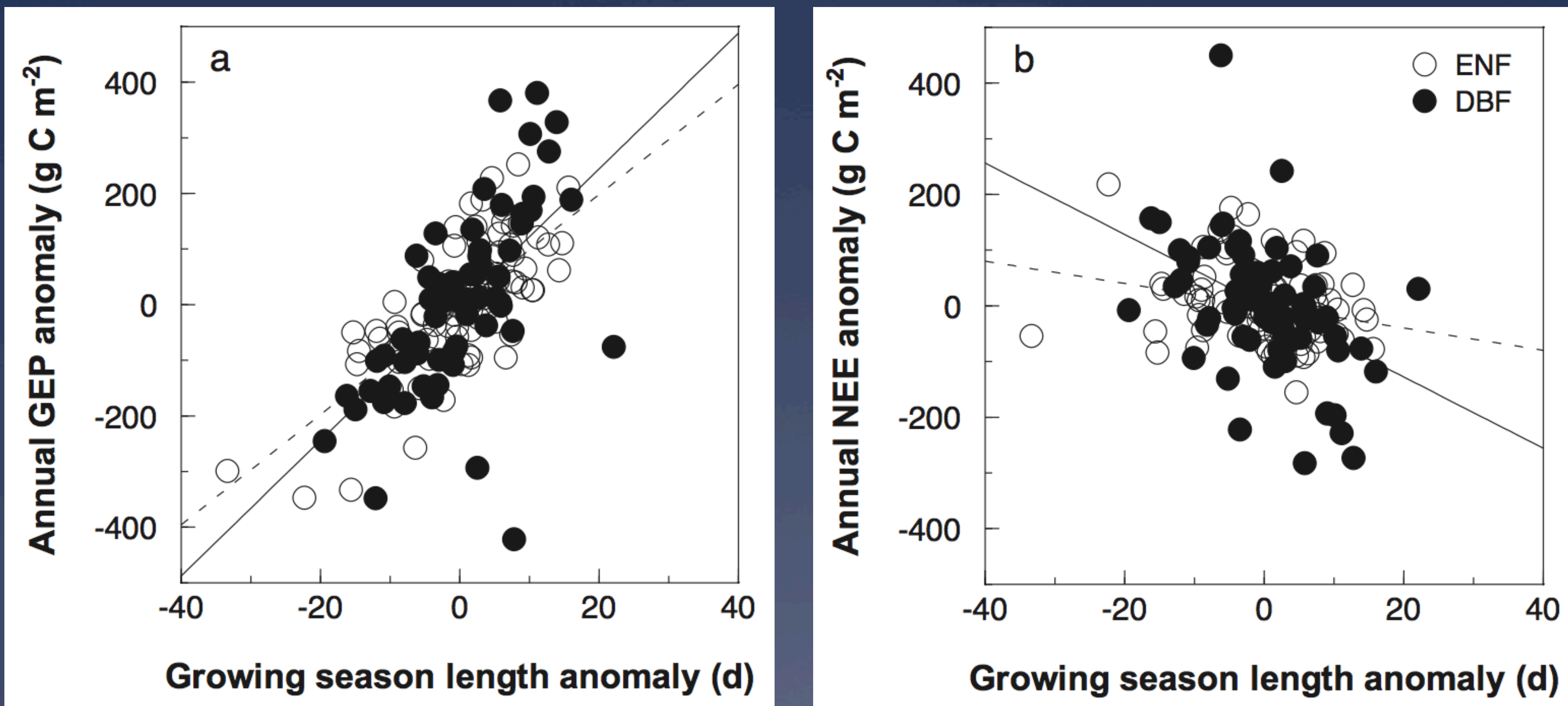
Does a longer growing season make trees grow bigger?

Winter chilling - cGDD - photoperiod - CDD



NPN

Ecosystem respiration reduces photosynthetic gains of a longer growing season by ~50%

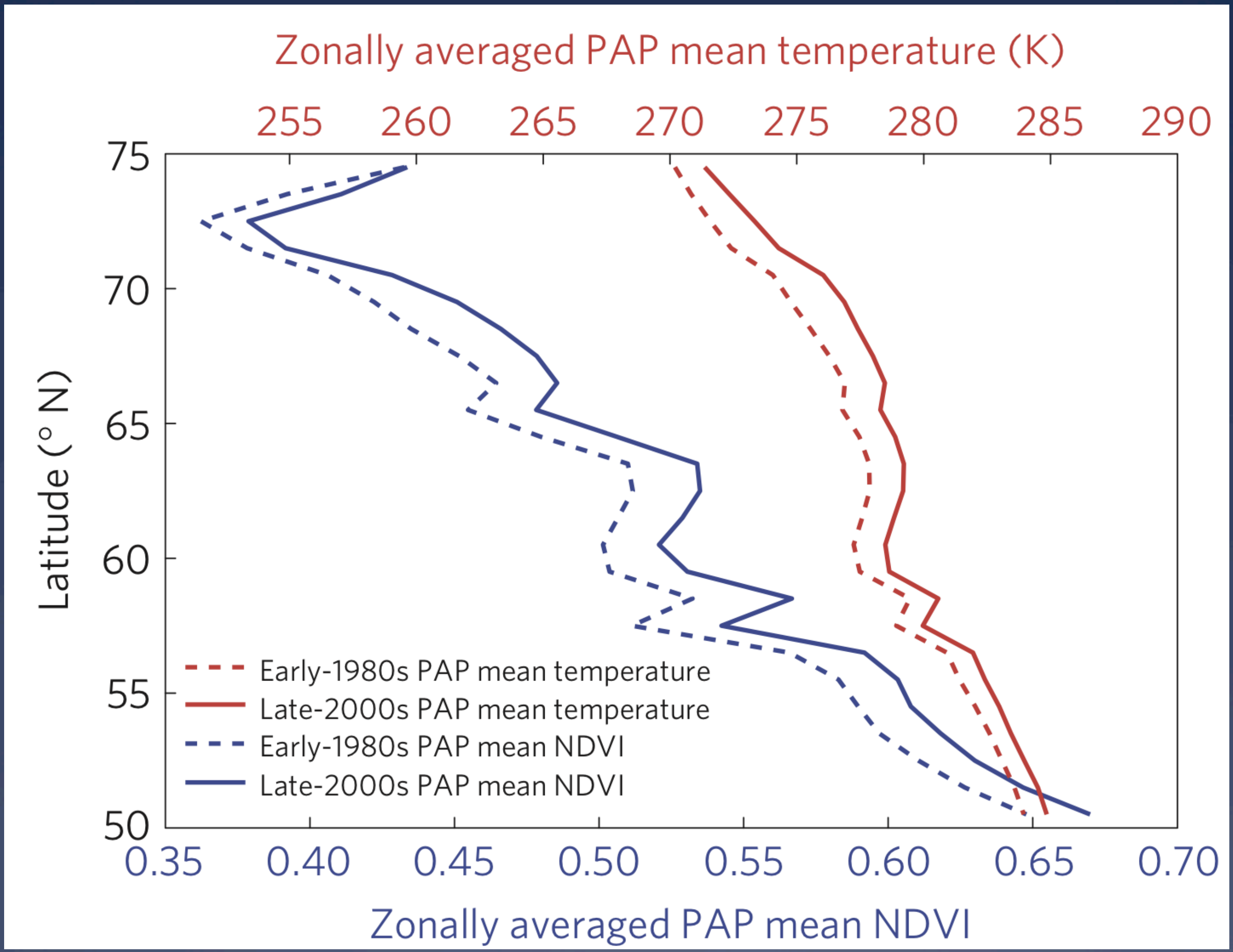


Richardson et al. 2010 Philosoph. Trans. R. Soc.

Feedbacks between temperature, albedo, and ecosystems enhance warming in the northern latitudes

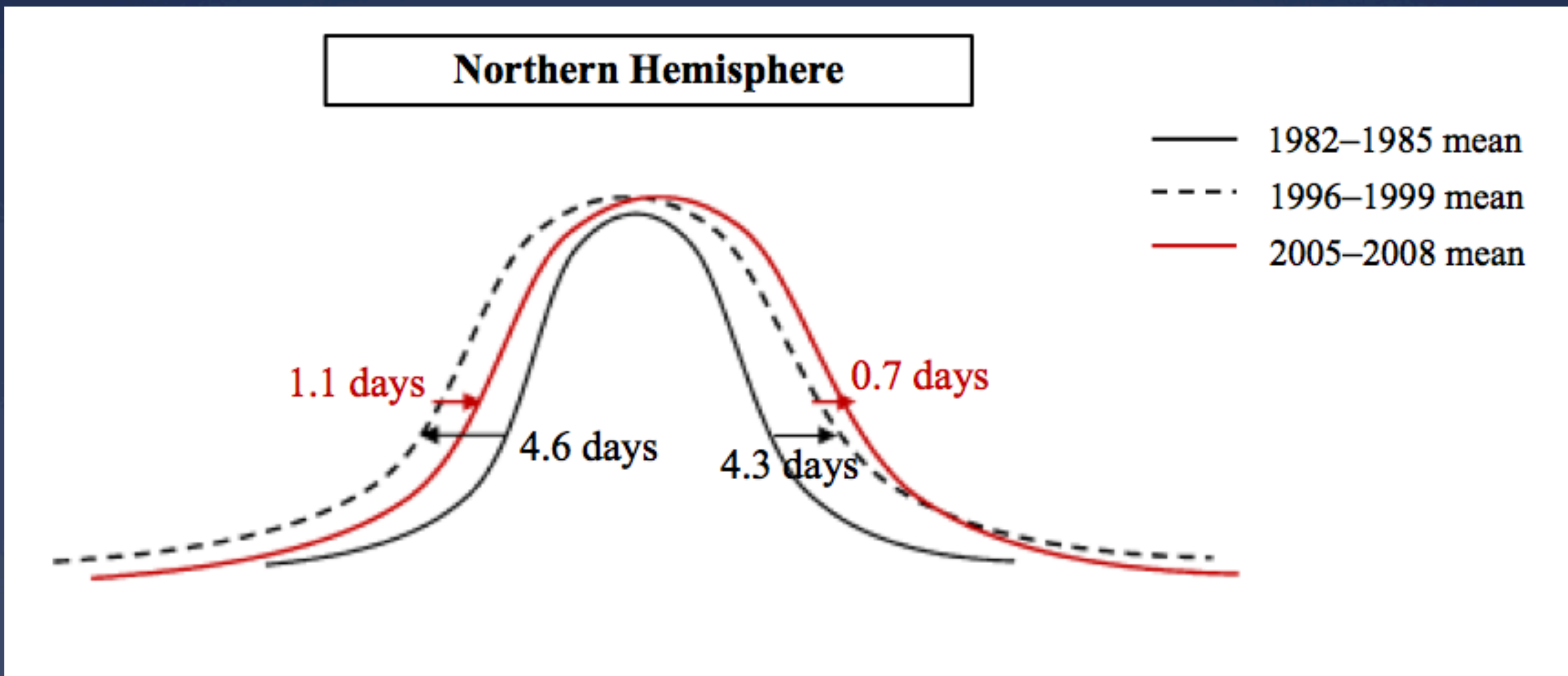
- Greenhouse warming -> reduced albedo -> increased warming and vegetation change (e.g., Chapin et al. 2008)
- Climate seasonality has effectively moved Arctic and Boreal ecosystems ~7 degrees latitude further south, causing increased greenness (Xu Liang et al. 2013)
- Arctic woody plant cover has already begun to increase and projections suggest a 50% increase in area of woody plants by 2050 (Pearson et al. 2013)

Temperature and NDVI throughout northern lands are increasing



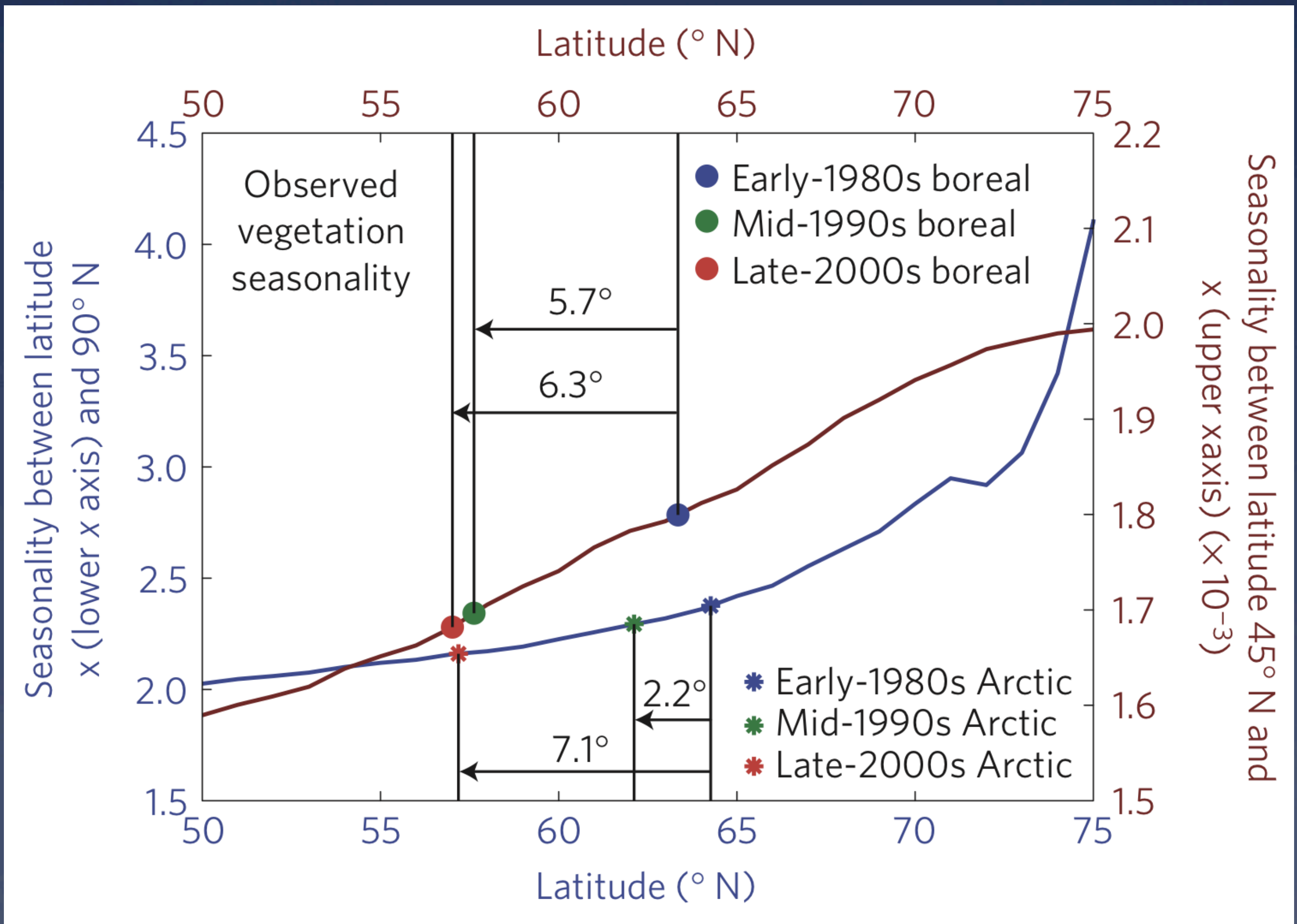
Xu Liang et al 2013 Nature Climate Change

Seasonality of NDVI has decreased as a result of greening



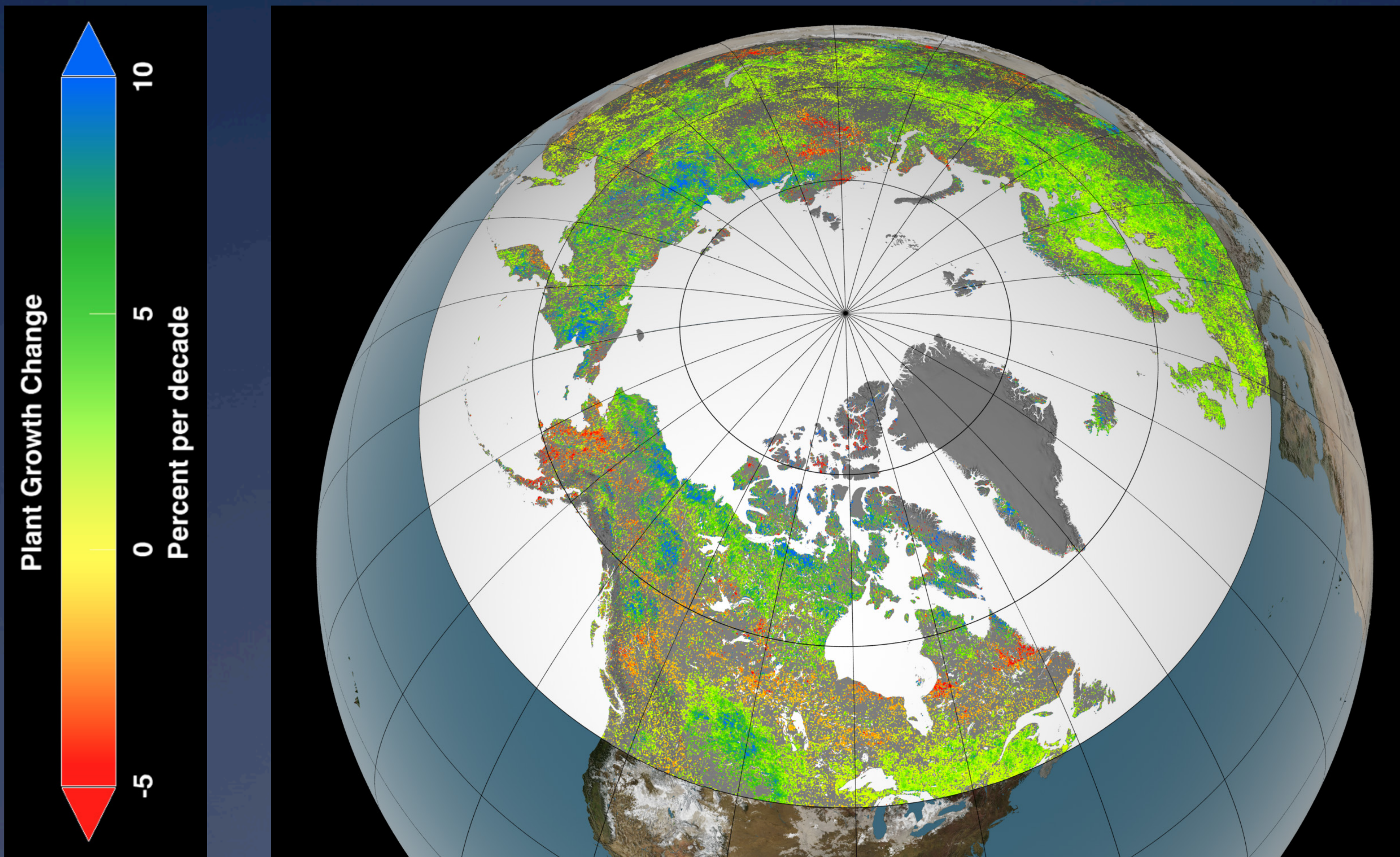
Jeong et al. 2011 Global Change Biology

Decreased seasonality in temperature and NDVI are equivalent to moving arctic and boreal ecosystems 7° south



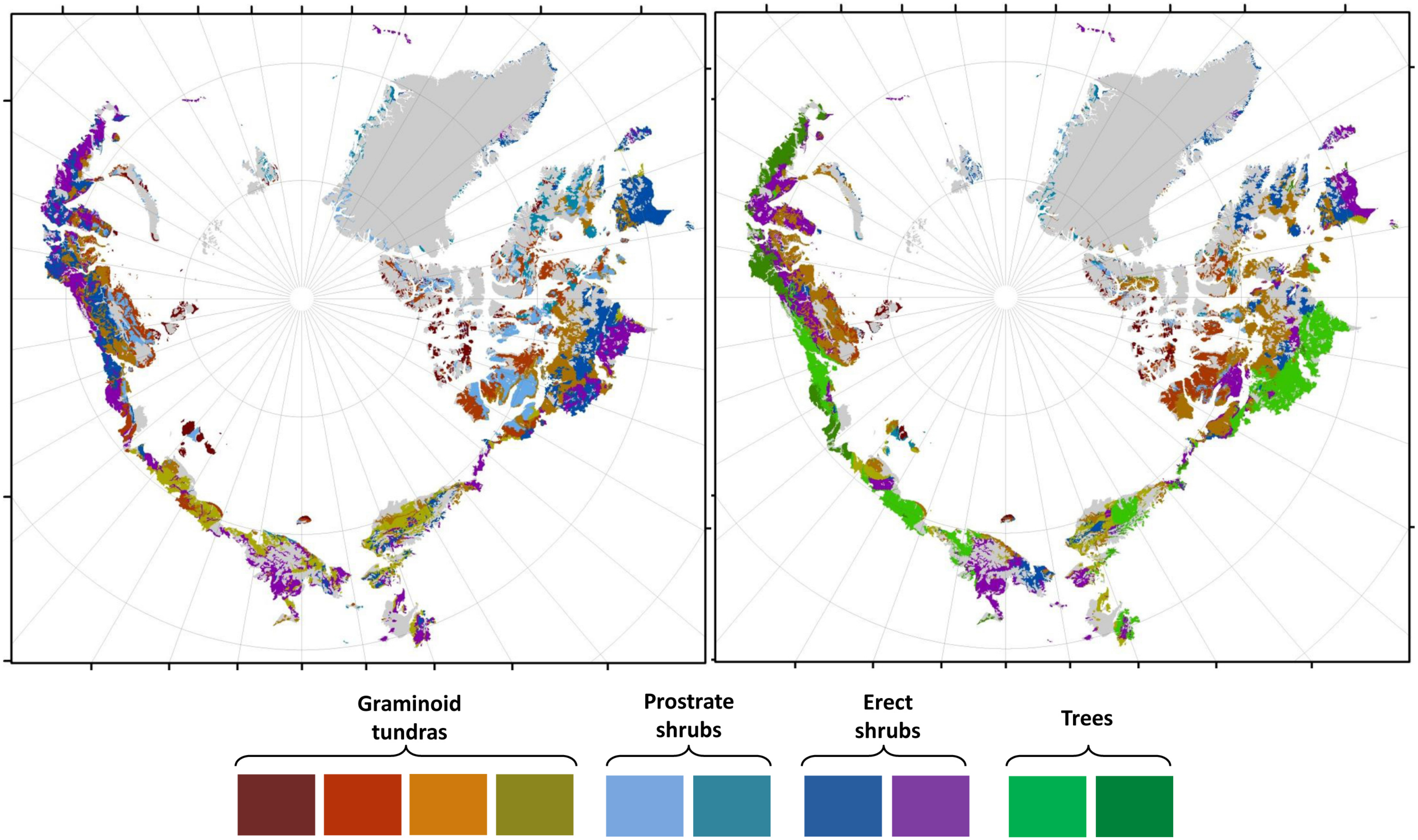
Xu Liang et al 2013 Nature Climate Change

Vegetation greening throughout northern latitudes



Xu Liang et al 2013 Nature Climate Change

Distribution of Arctic Vegetation



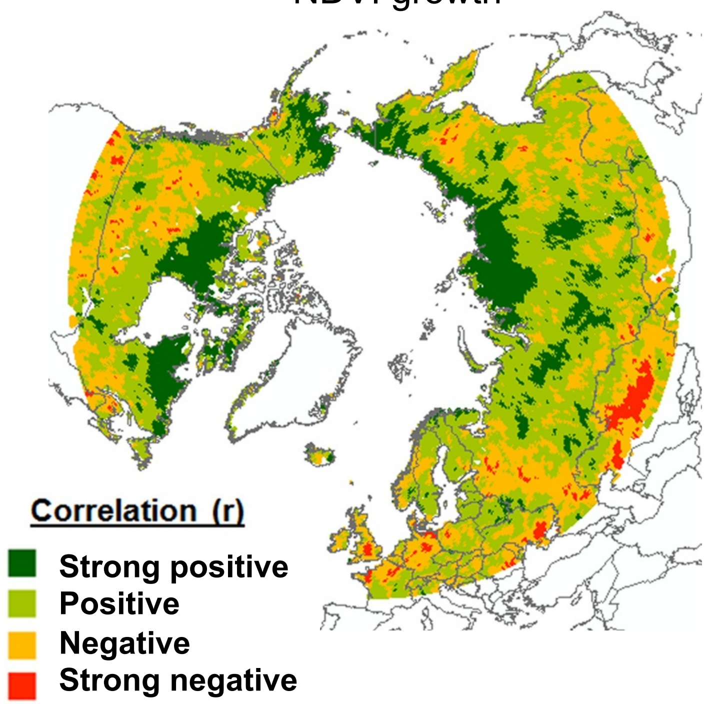
Pearson et al. 2013 Nature Climate Change

Satellite Microwave Detection of Changing Frozen Season Constraints to Productivity

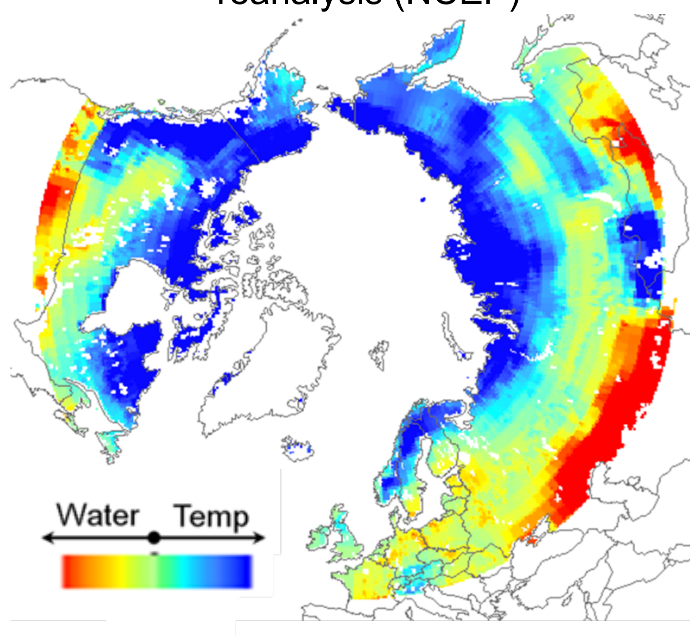
J. Kimball, Y. Kim (UMT), K. Didan (UA), K. McDonald (CUNY)

- [1]32-yr (1979-2010) record of global daily landscape freeze-thaw (FT) dynamics developed from multi-sensor data (SMMR, SSM/I, AMSR-E)
- FT record defines frozen temperature constraints to northern growing seasons
- Longer non-frozen seasons promote [2]NDVI summer growth in cold temperature limited areas; correlation reduced or reversed where growth is limited by water supply

Correlation (r): Non-frozen season vs NDVI growth



Climate constraints to NPP from global reanalysis (NCEP)



[1]Global FT record: **http://freezethaw.ntsg.umt.edu**

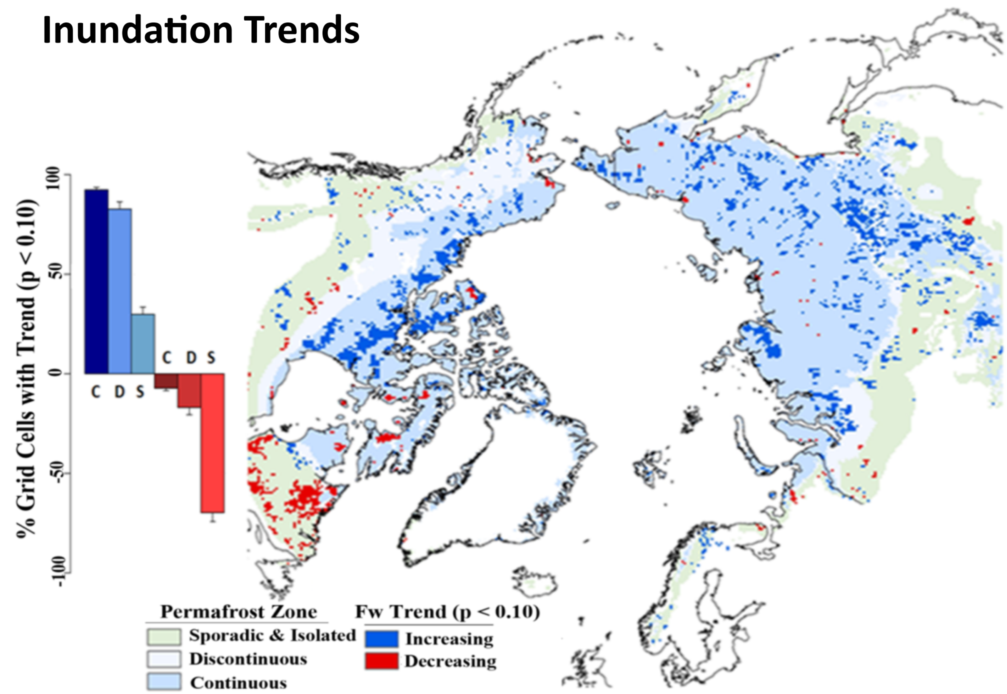
[2]VIP Satellite NDVI record: **http://phenology.arizona.edu**

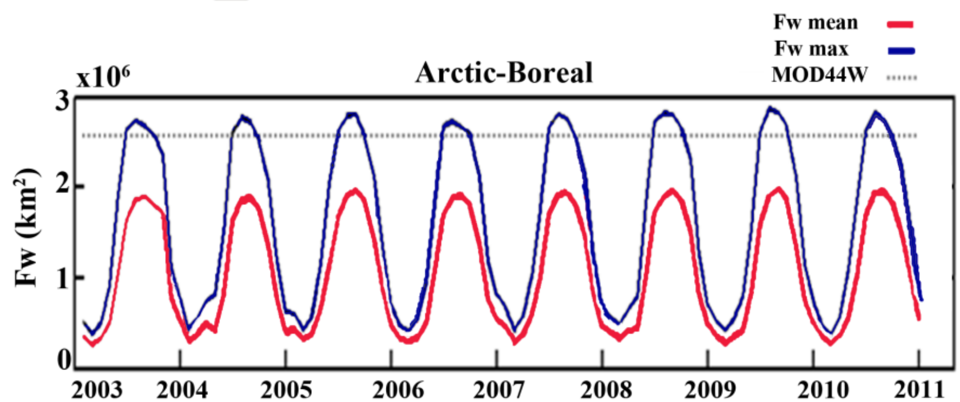
Satellite Microwave Detection of Pan-Arctic Open Water Inundation Changes

J. Kimball, J. Watts, L. Jones (UMT), K. McDonald (CUNY)

- Satellite (AMSR-E) retrievals of daily fractional open water cover (Fw) used for monitoring inundation changes (2003-2010)
- Fw data capture large seasonal & annual inundation dynamics missing from static open water maps
- Contrasting Fw inundation trends found within permafrost (PF) zones: widespread wetting in continuous PF & drying in discontinuous PF
- Fw data are informing regional carbon (CH_4, CO_2) cycle modeling

Inundation Trends



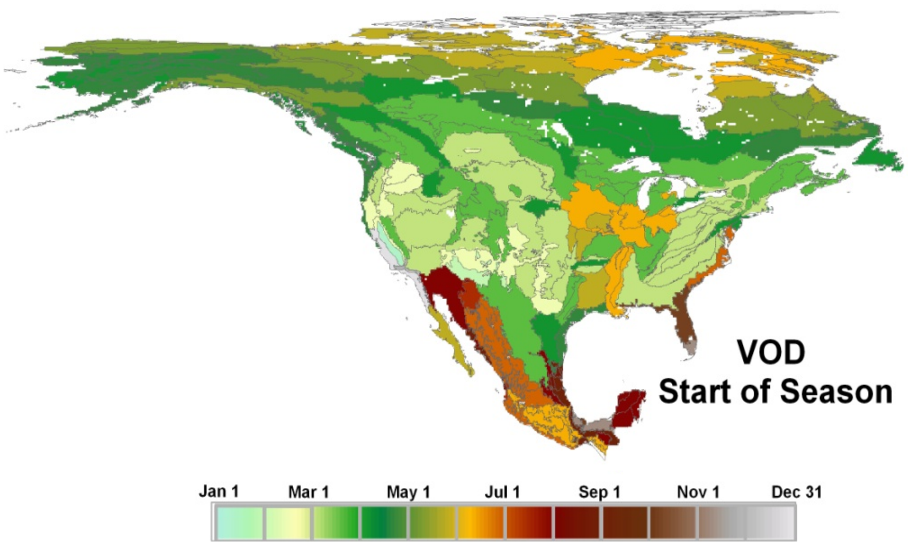


Source: Watts, J. et al. 2012. *Rem. Sens. Environ. 127*

Satellite Microwave Vegetation Optical Depth (VOD) Phenology

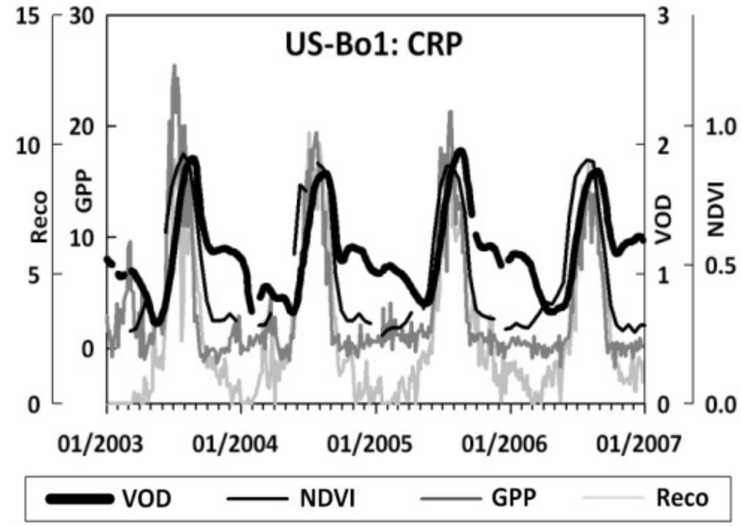
VOD Start of Season & NDVI Greenup

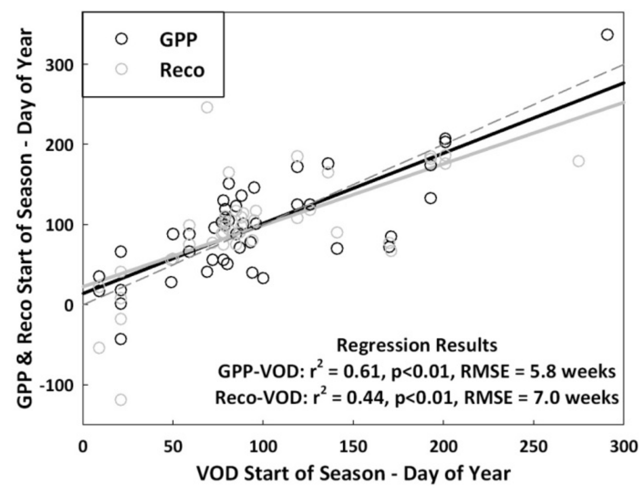
2004 – 2007 Ecoregion (Level III) Means



- VOD measures canopy attenuation of microwave emissions.
- Sensitive to canopy biomass structure and water content changes.
- Synergistic use of microwave and optical-IR data enhances LSP monitoring and understanding.

Cropland VOD, NDVI & Tower Flux Time Series

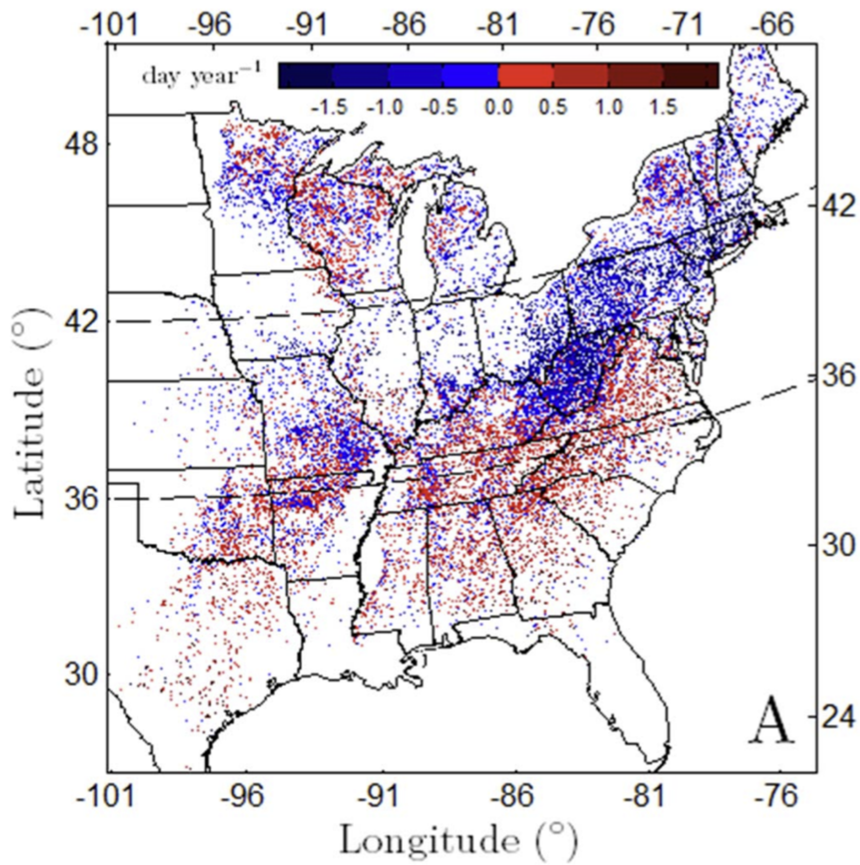




VOD start of season strongly correlated with tower GPP and ecosystem respiration.

Source: Jones M.O. et al., 2012 *Rem. Sens. Environ.*, *115*

Moving further south: Trends in the onset of greenness 1982-2008



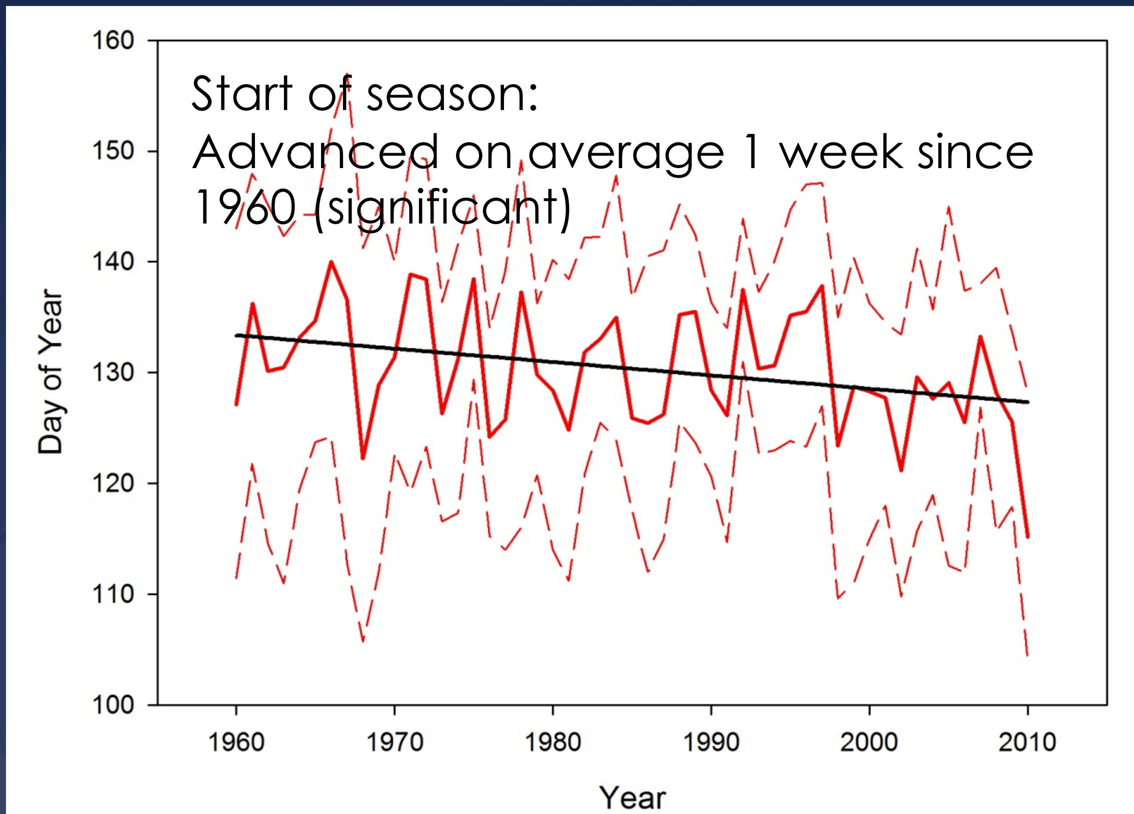
SOS shows widespread negative trends north of 36-40°N

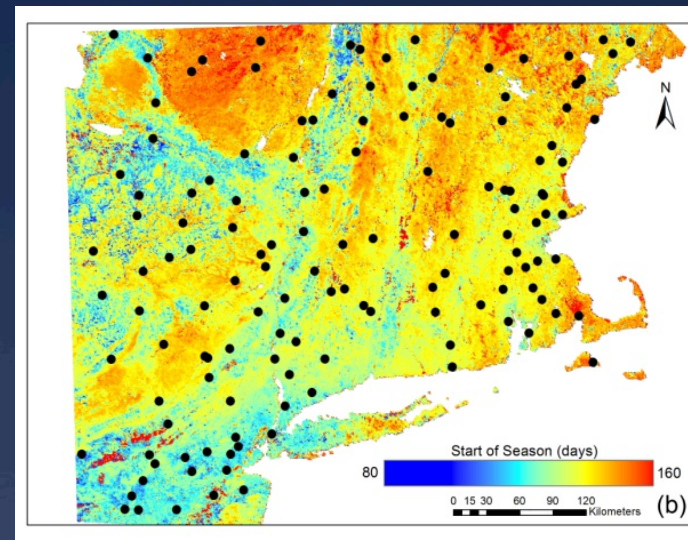
SOS shows no-trend or positive trends South of 36-40°N

Dragoni, D., A.F. Rahman, and H.P. Schmid, 2010 AmeriFlux/NACP Annual meeting

A similar spatial pattern was seen using different AVHRR processing by:
Zhang et al. 2007 GRL and Jeong et al. 2011 GCB

Phenology modeling using onset of greenness from MODIS

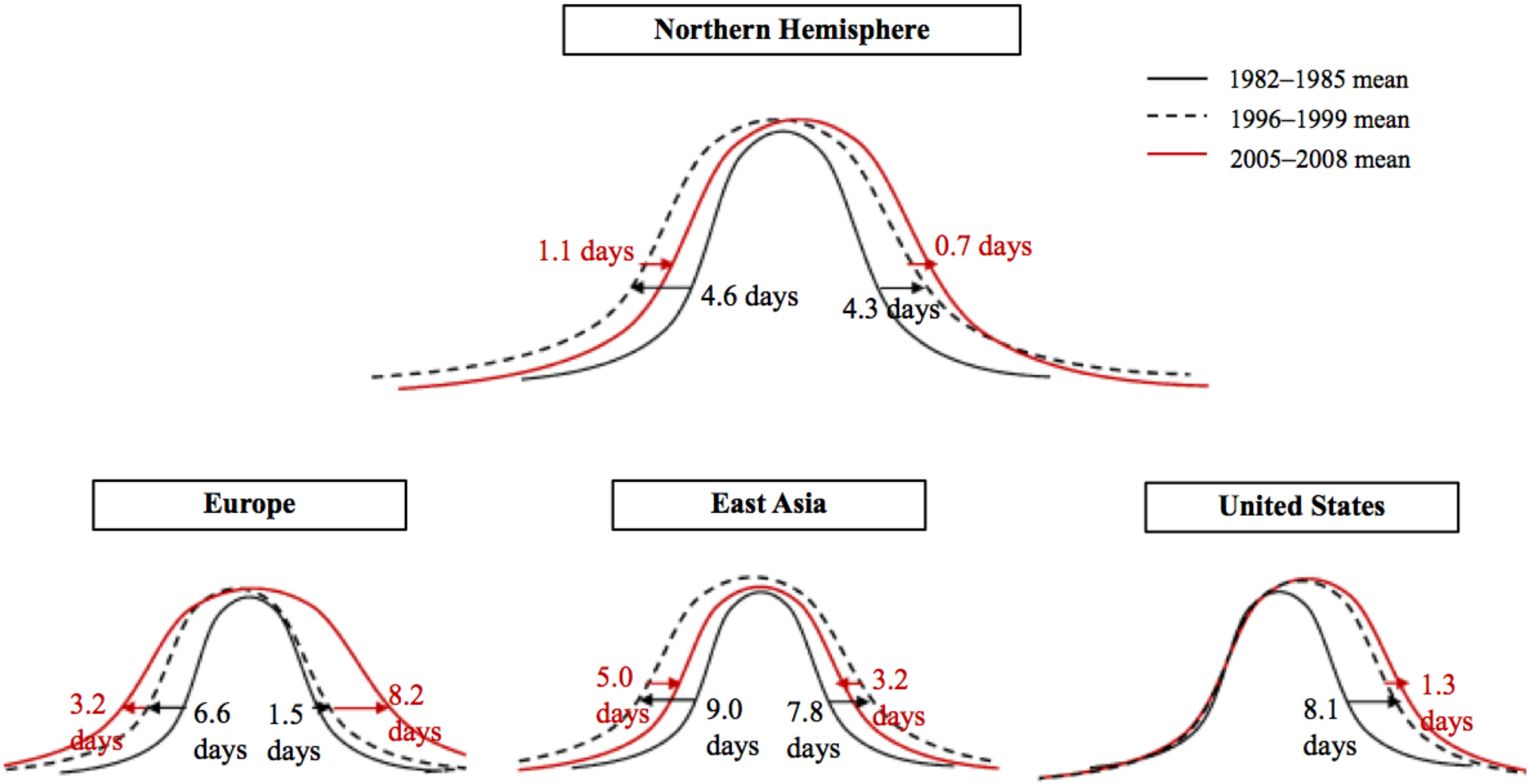




- A retrospective analysis of the vegetation phenology in New England from 1960 to 2010 suggests a significant advancement of Start of season (~ 1 week/50 years)
- Similar trends were not found for the end of season or growing season length.

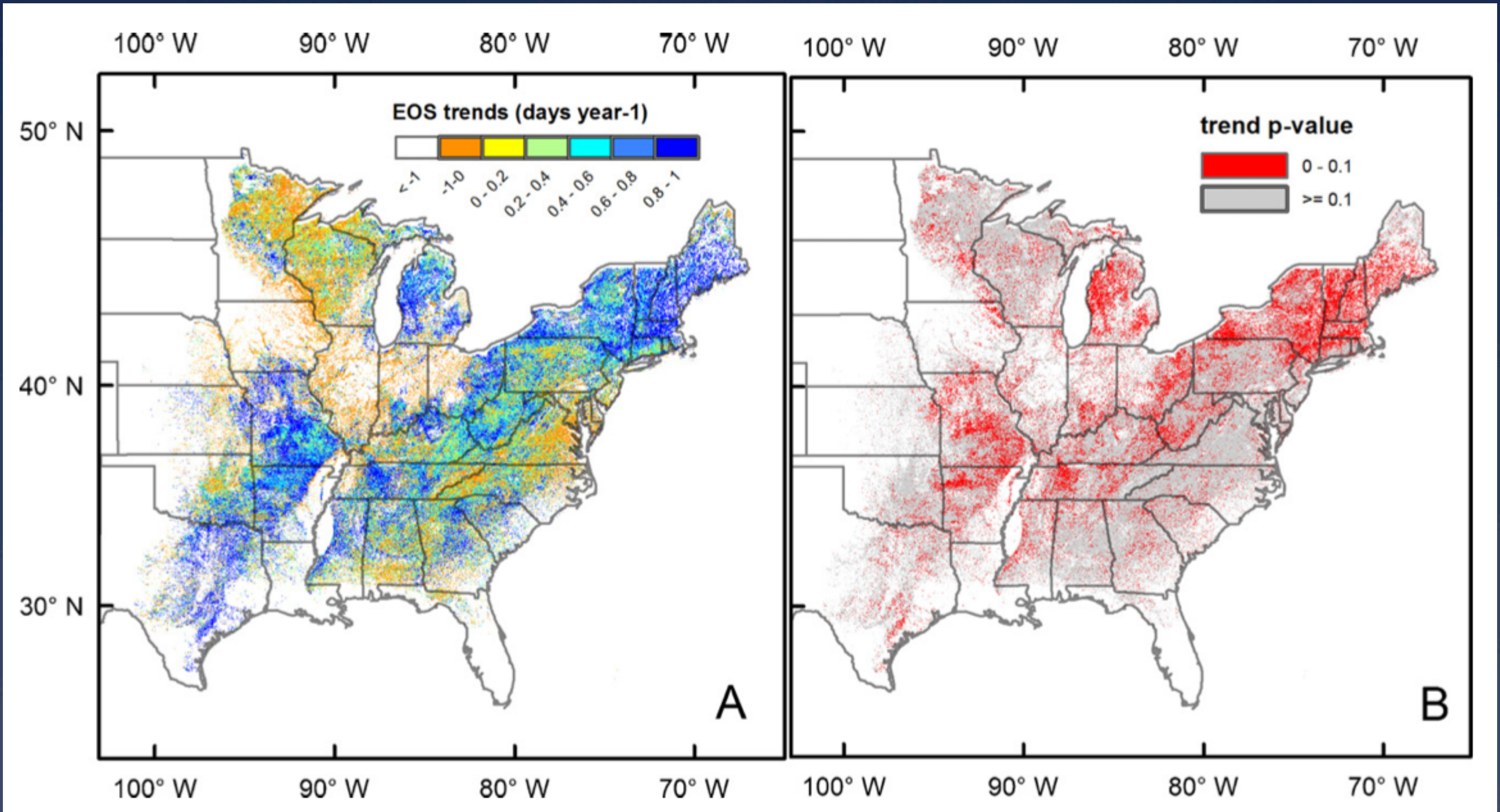
Yang, Mustard, Tang and Xu (2012) JGR-Biogeosciences

For the United States, a growing season extension is evident



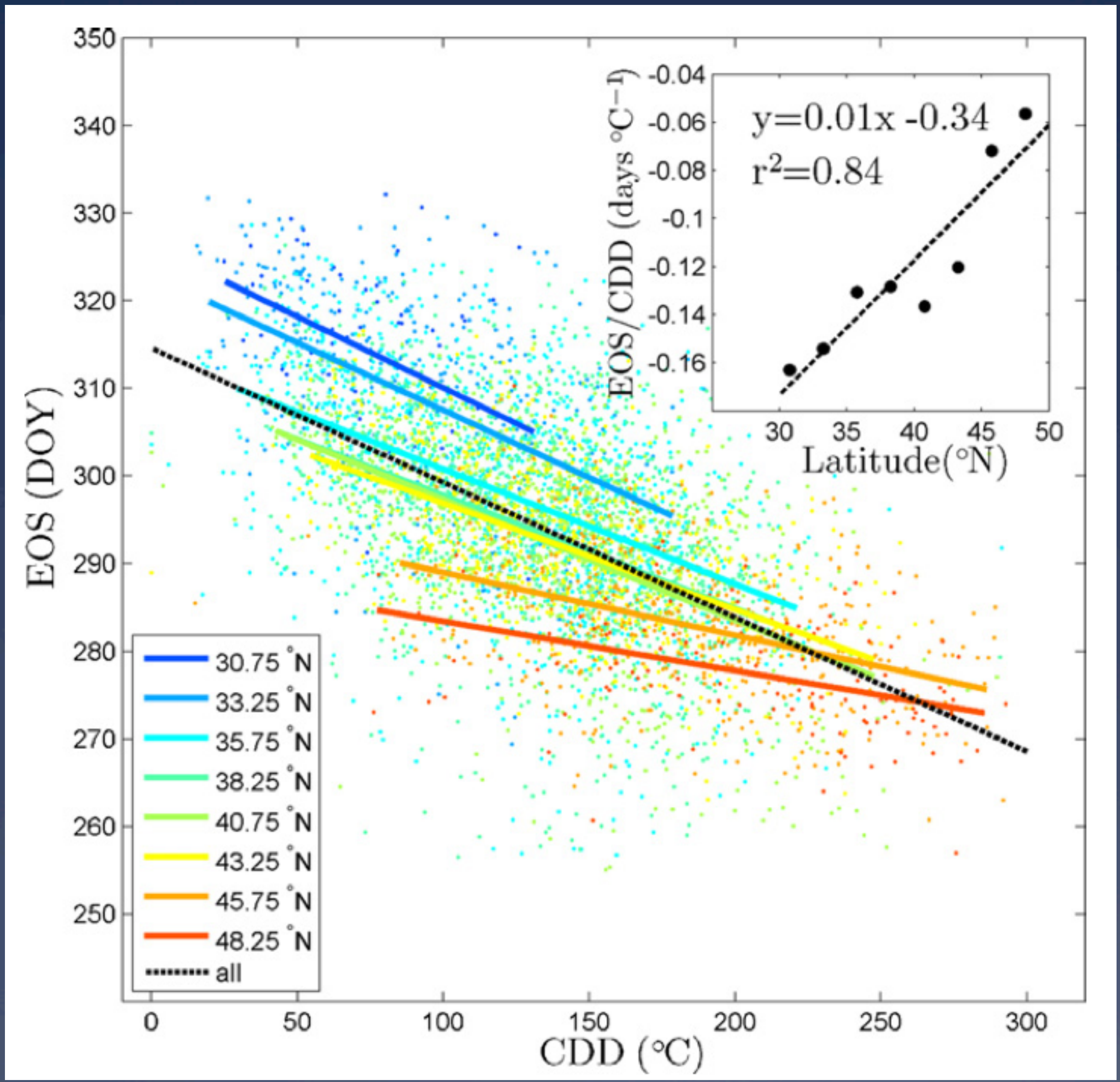
Jeong et al. 2011 Global Change Biology

End of season trends are significant throughout much of the USA



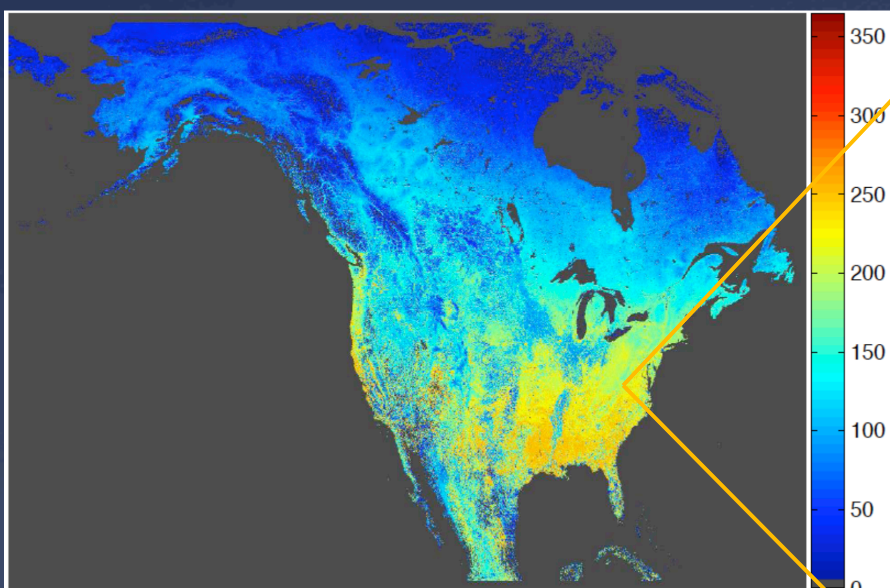
Dragoni and Rahman (2012) AgForMet

Environmental controls on the end of season decrease with increasing latitude

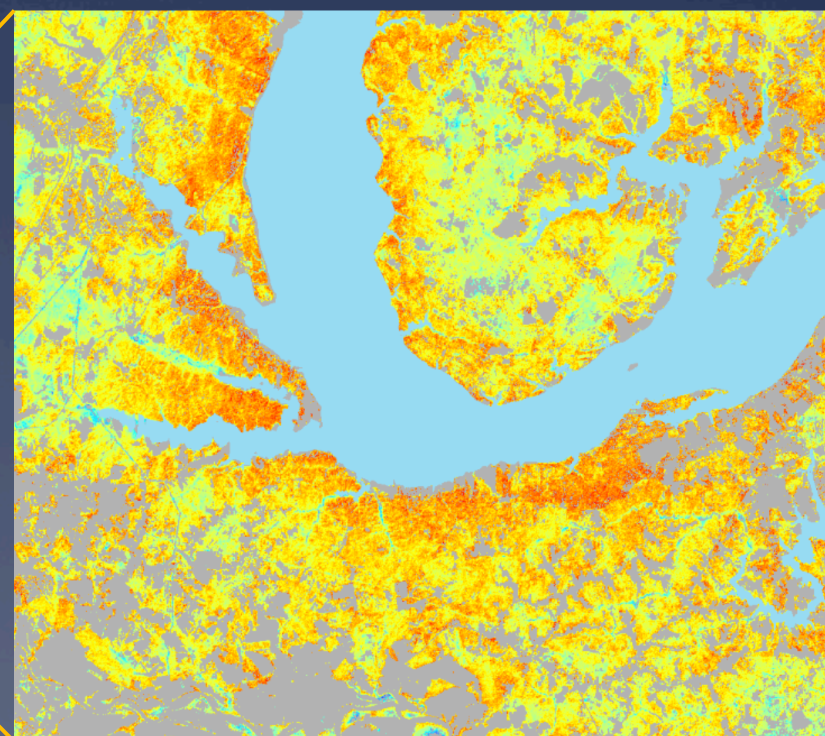


Dragoni and Rahman (2012) AgForMet

Fine-grain spatial patterns in phenology are required to attain further understanding

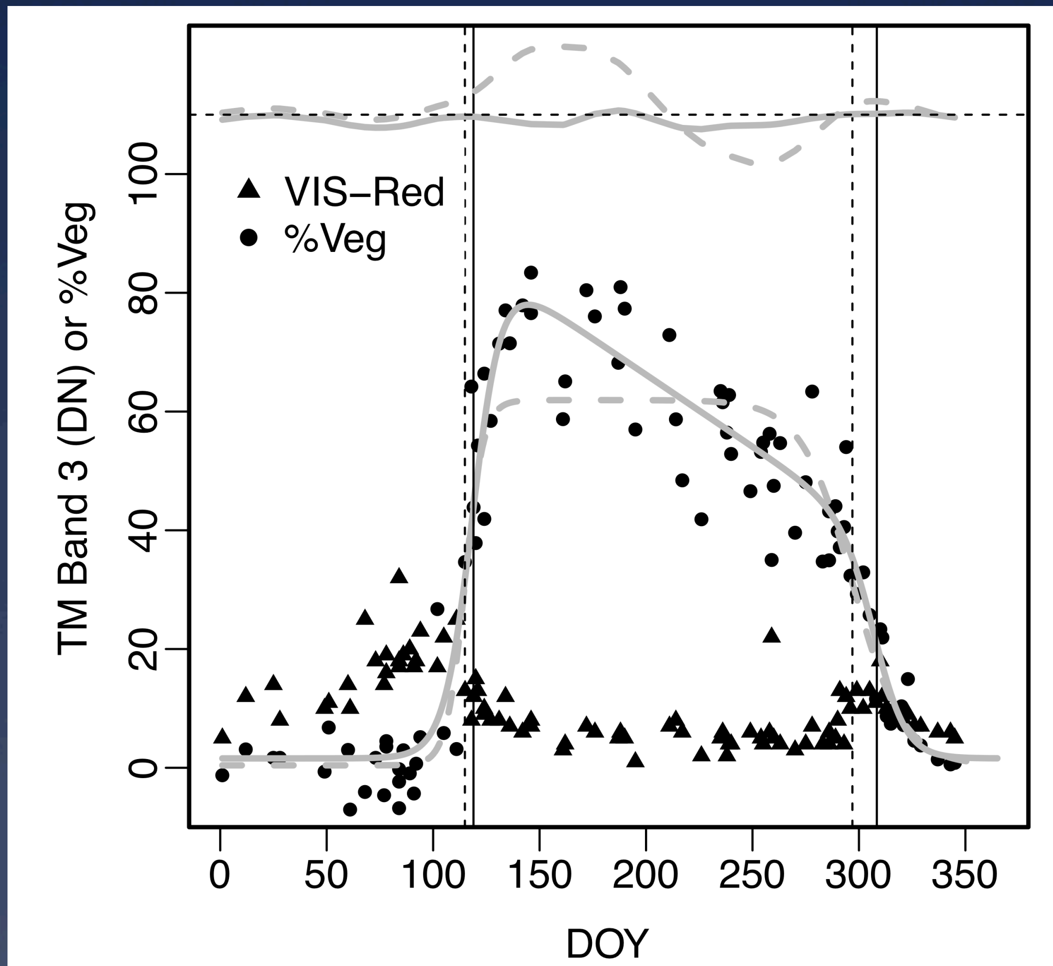


Mean growing Season Length (days) from Ganguly et al. 2010



Elmore et al. (2012) GCB

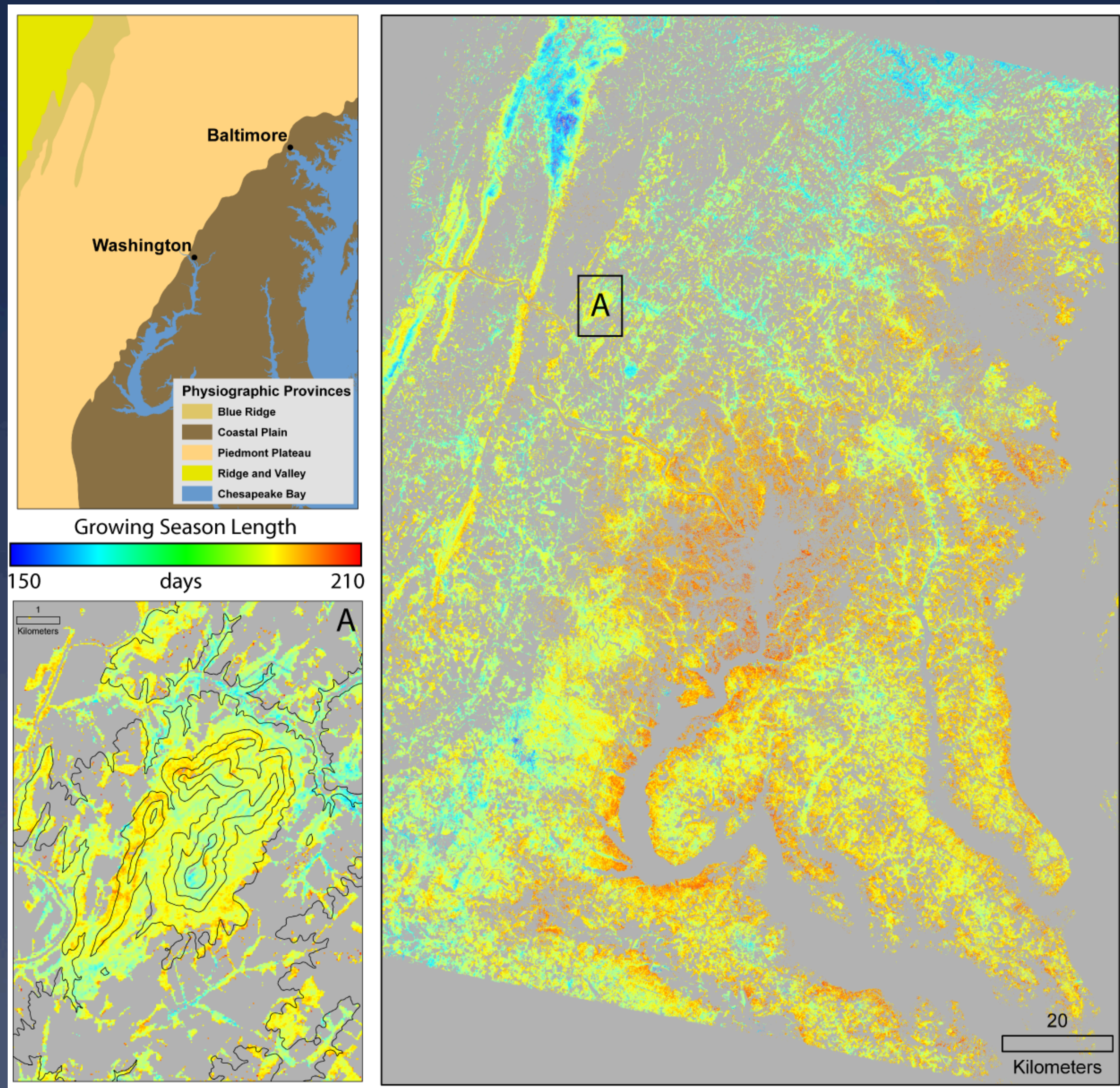
Average phenology from Landsat



$$v(t,\mathbf{m}) = m_1 + (m_2 - m_7 \cdot t)\left(\frac{1}{1+e^{(m'_3 - t)/m'_4}} - \frac{1}{1+e^{(m'_5 - t)/m'_6}}\right)$$

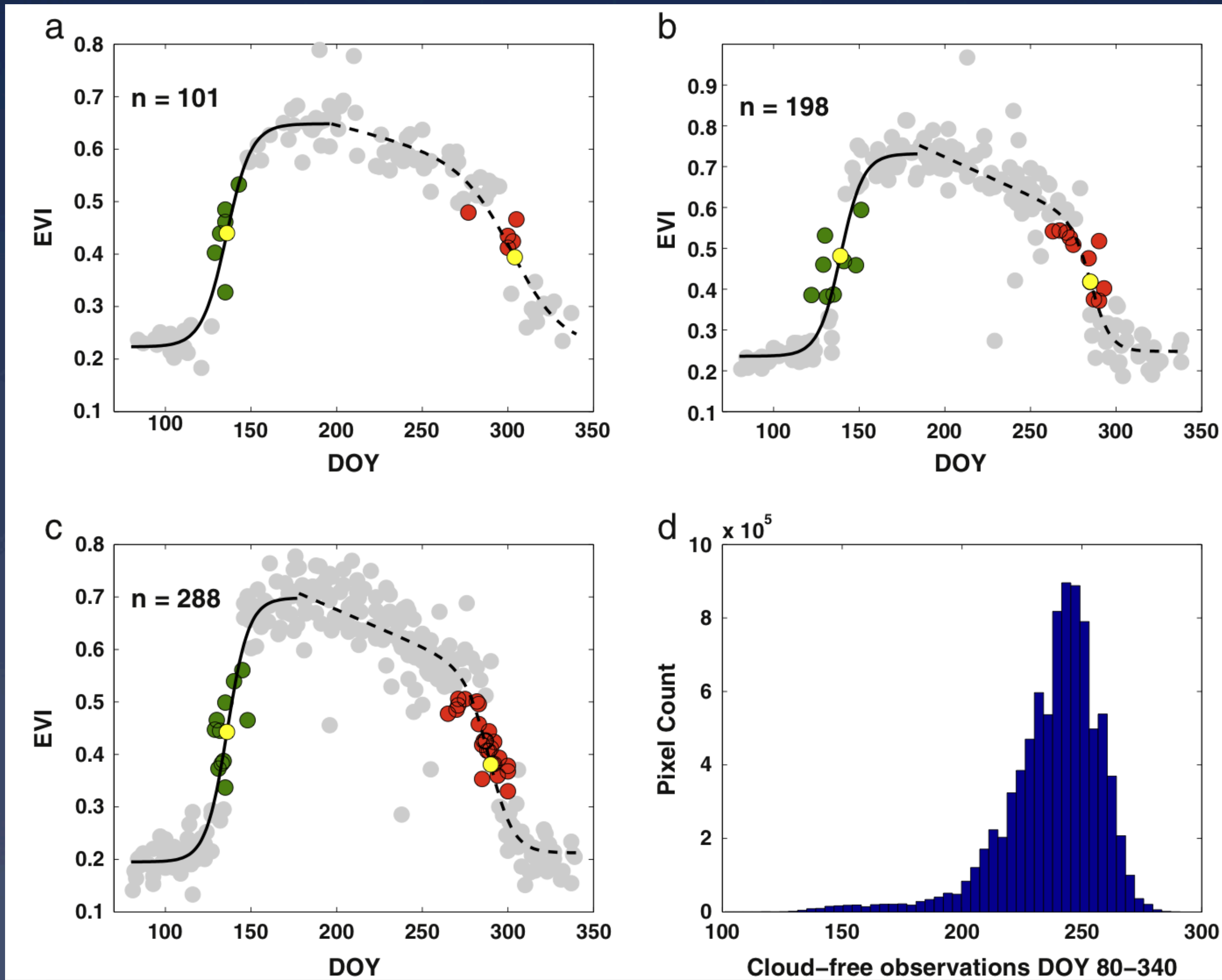
Fisher et al. 2006 RSE; Elmore et al. 2012 GCB; Melaas et al. 2013 RSE

Growing Season Length



Elmore et al. 2012 GCB

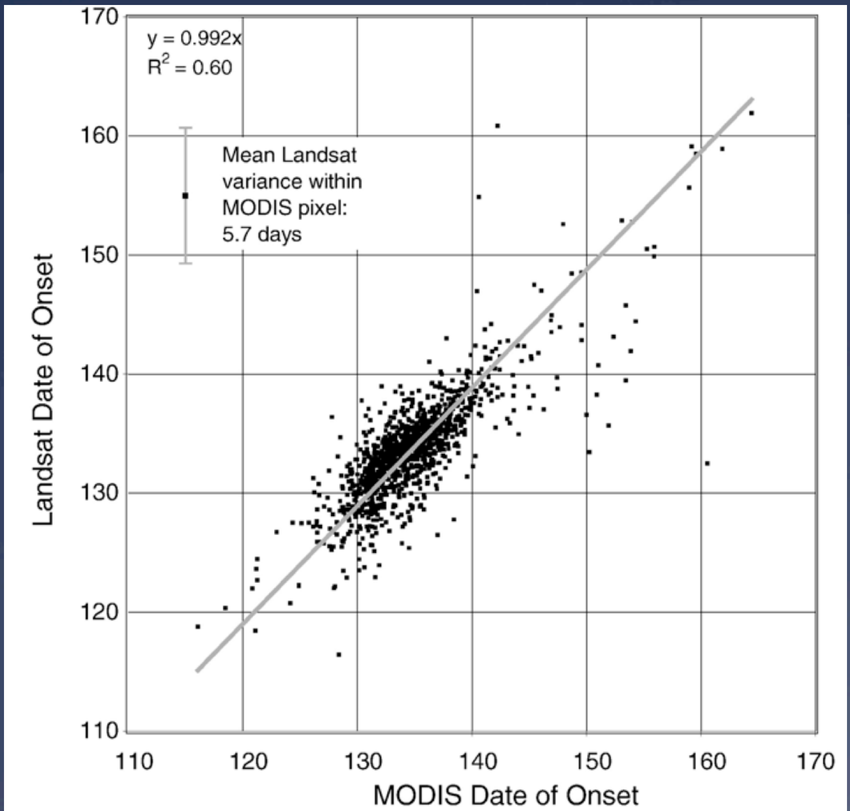
Annual phenology from Landsat



Melaas, Friedl, and Zhu 2013 RSE

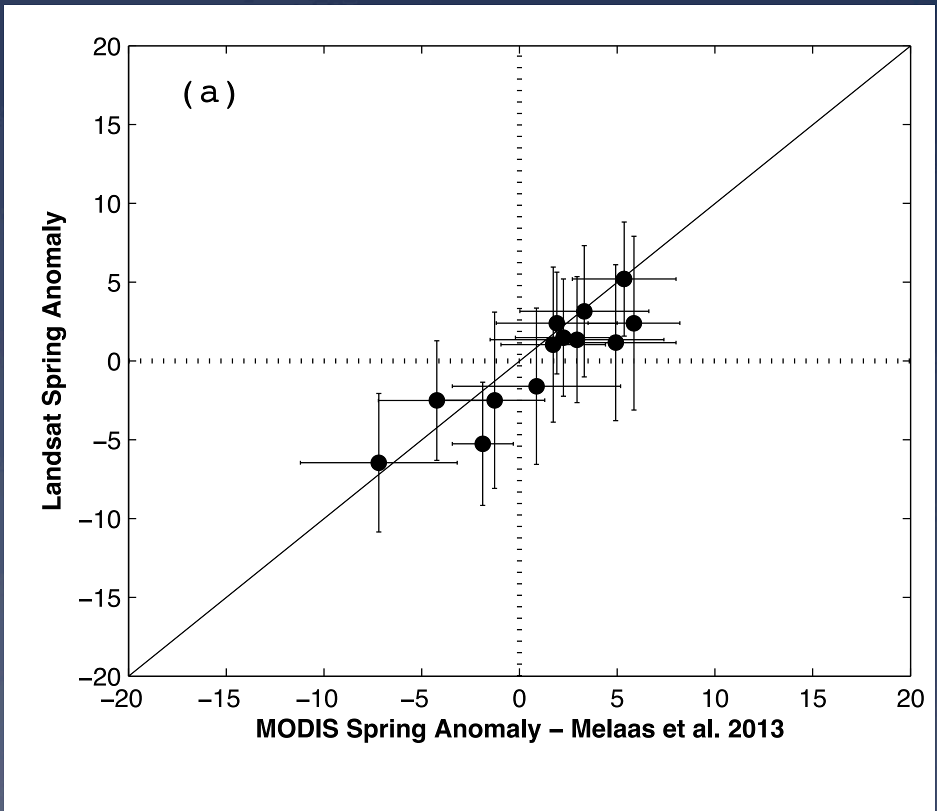
Landsat phenology correlates well with MODIS phenology for deciduous forest pixels

Average spring onset



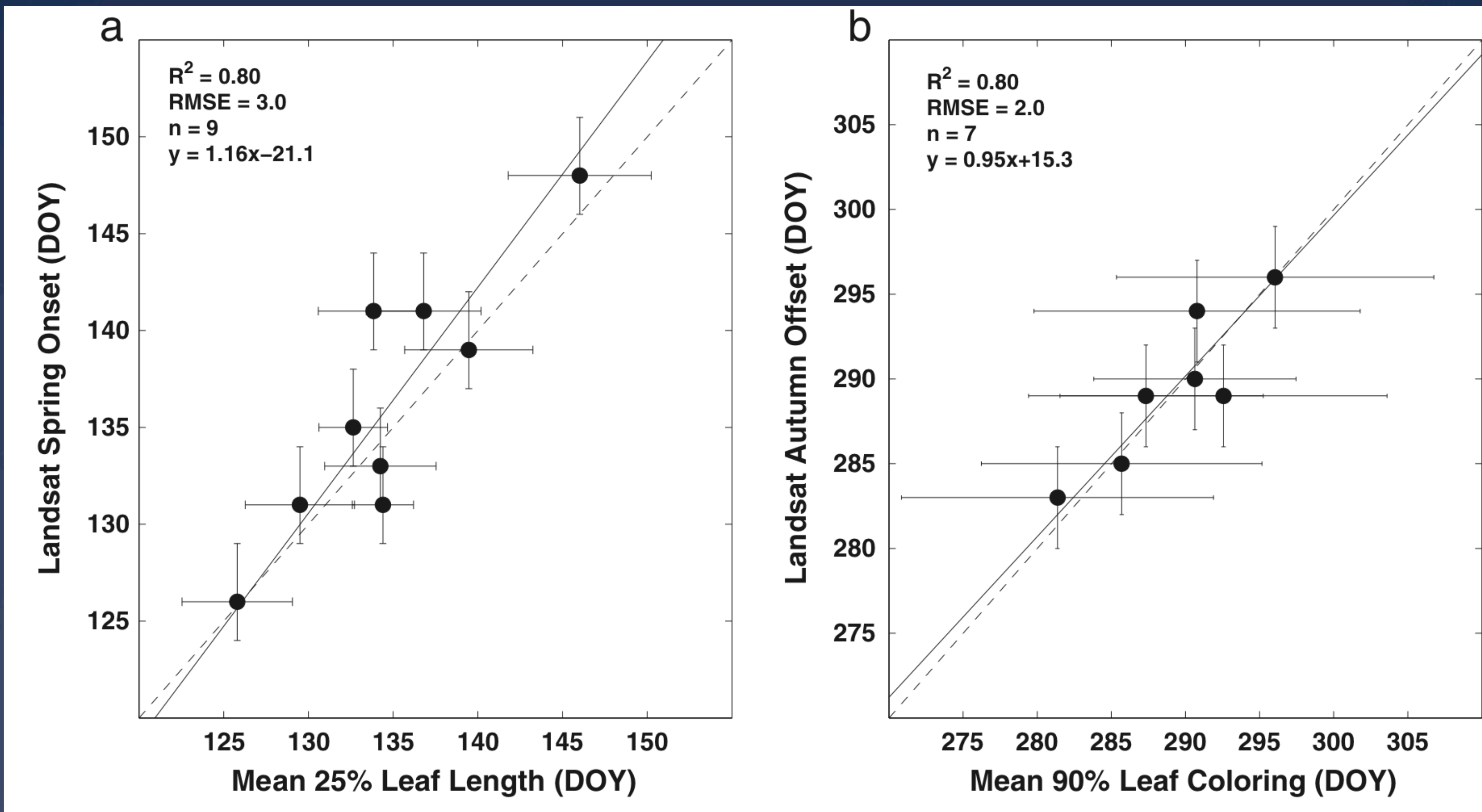
Fisher et al. 2007 RSE

Annual anomaly in spring onset



Melaas et al. 2013 (NASA TEP)

Landsat phenology anomalies track observations made at Harvard Forest

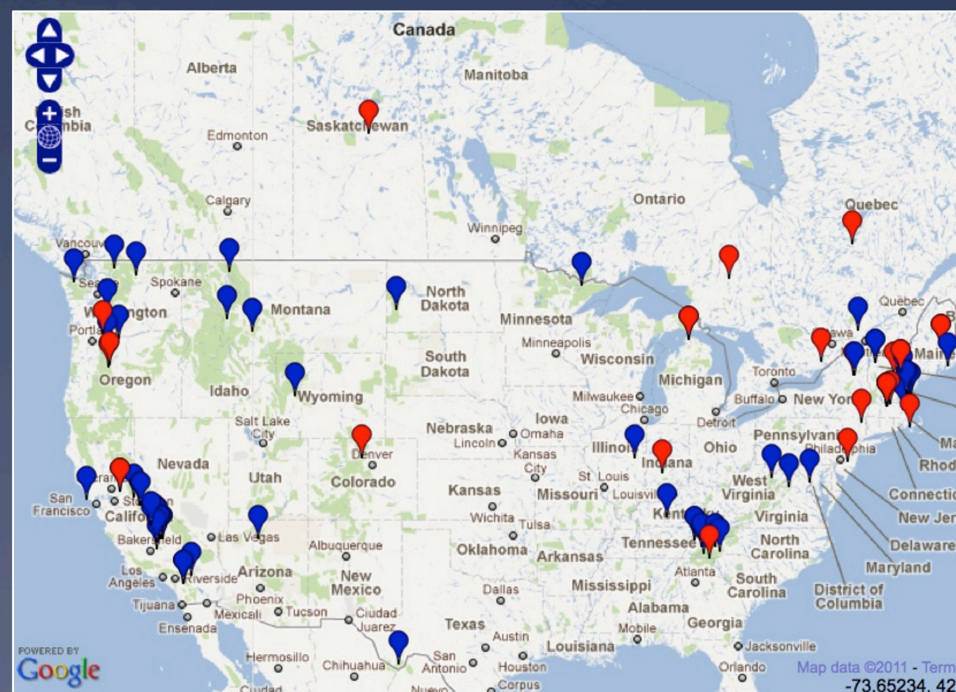


Melaas et al. 2013 RSE

Phenocam

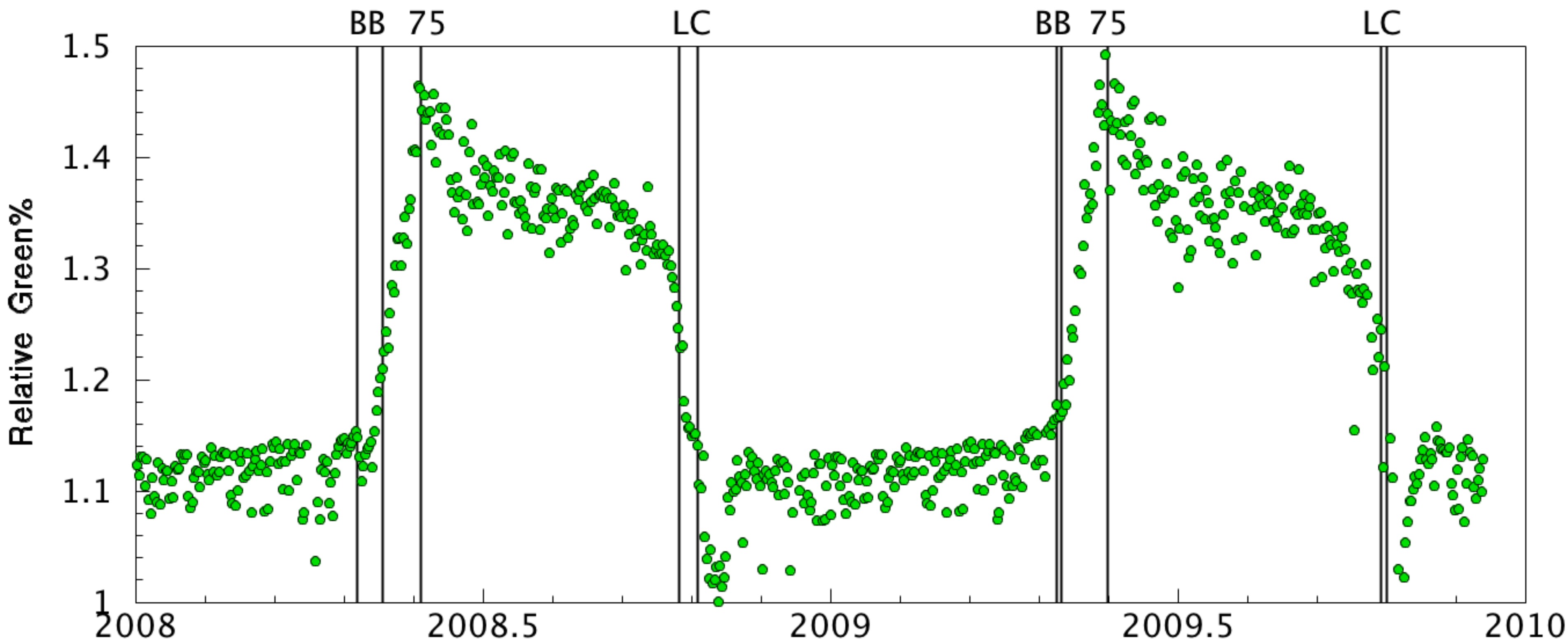
* Automated observations that can be integrated across multiple organisms to give canopy-level information
* Understanding and predicting the impacts of climate change on plants and ecosystems requires better data with which predictive models of phenology can be developed and tested

Andrew Richardson and Phenocam
https://phenocam.sr.unh.edu/webcam/



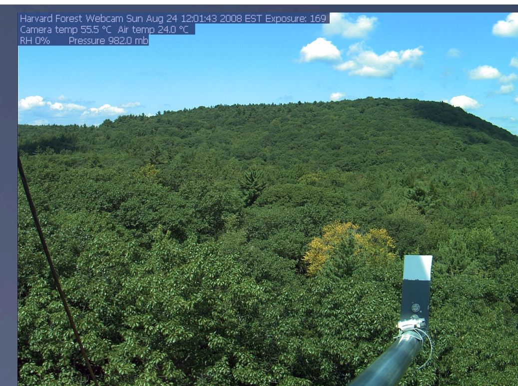
Camera greenness vs. observer records

Uncertainties inherent in both



Harvard Forest (2008-2009)

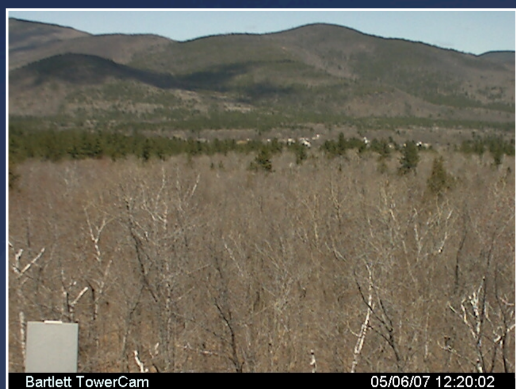
BB = 50% budburst; 75 = 50% of leaves 75% of final length; LC = 50% leaf color



Slide provided by Andrew Richardson

Canopy greenness parallels canopy photosynthesis from eddy covariance

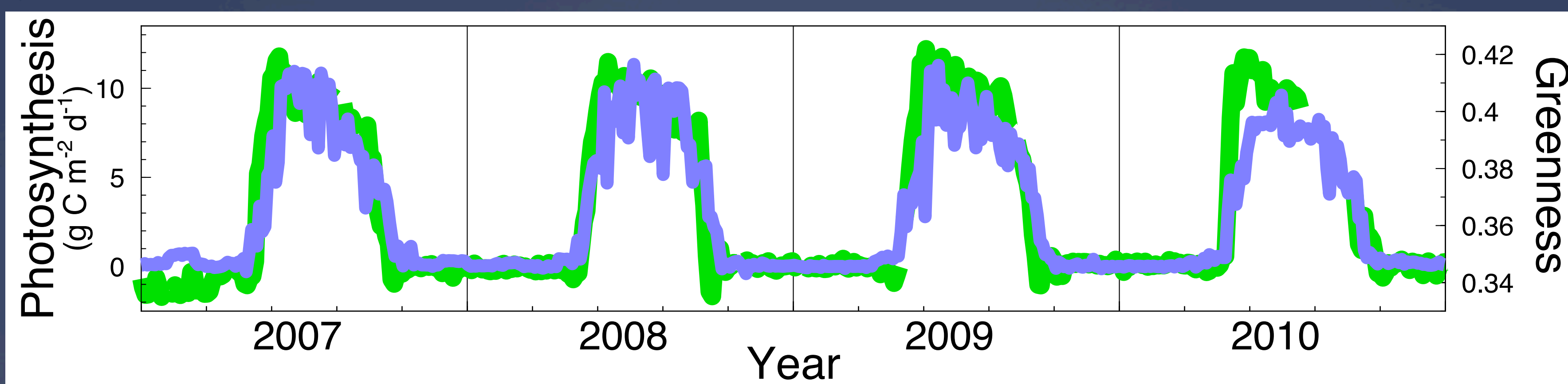
WINTER



SPRING

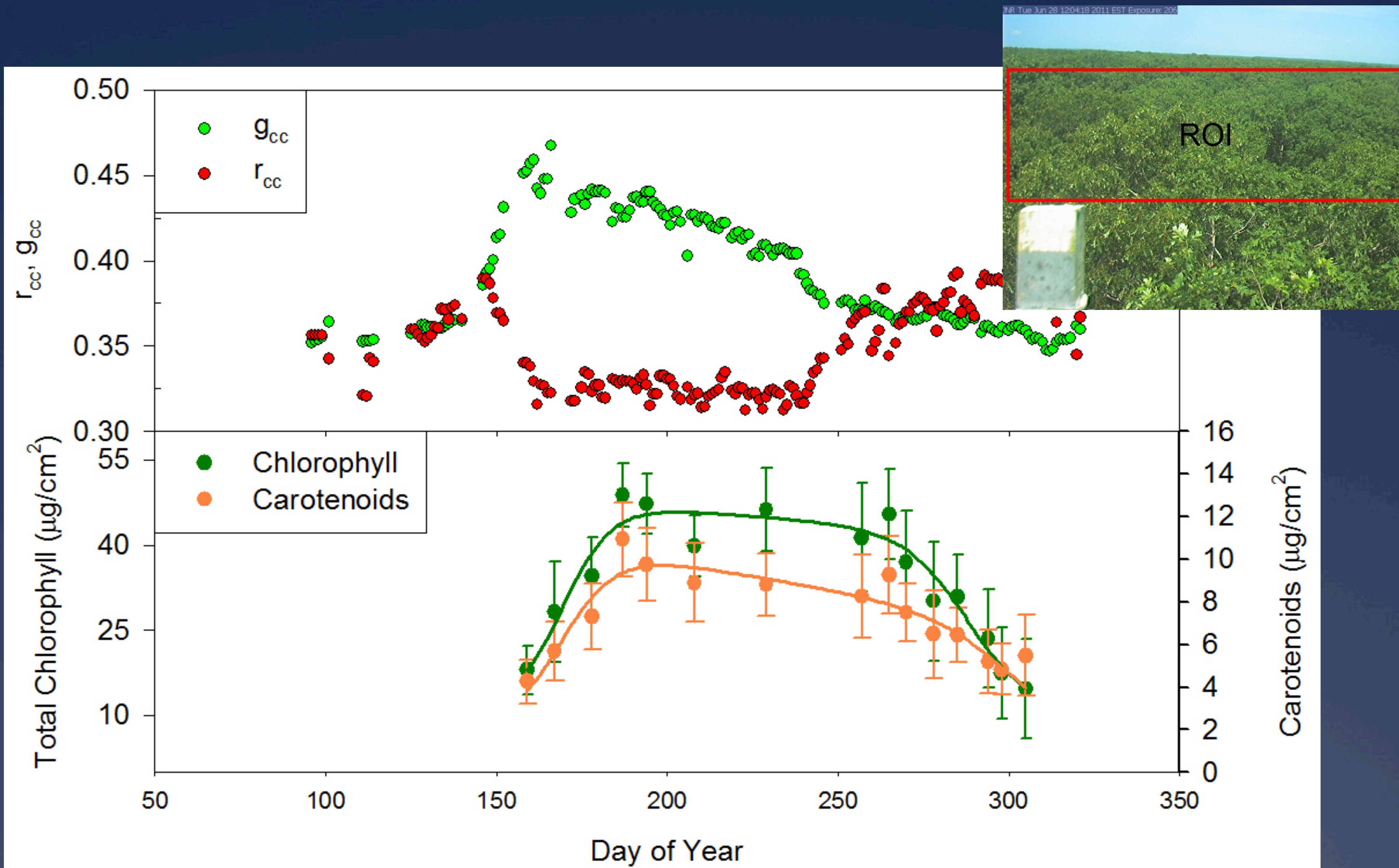
AUTUMN

Data from the Bartlett Experimental Forest AmeriFlux site.



Slide provided by Andrew Richardson

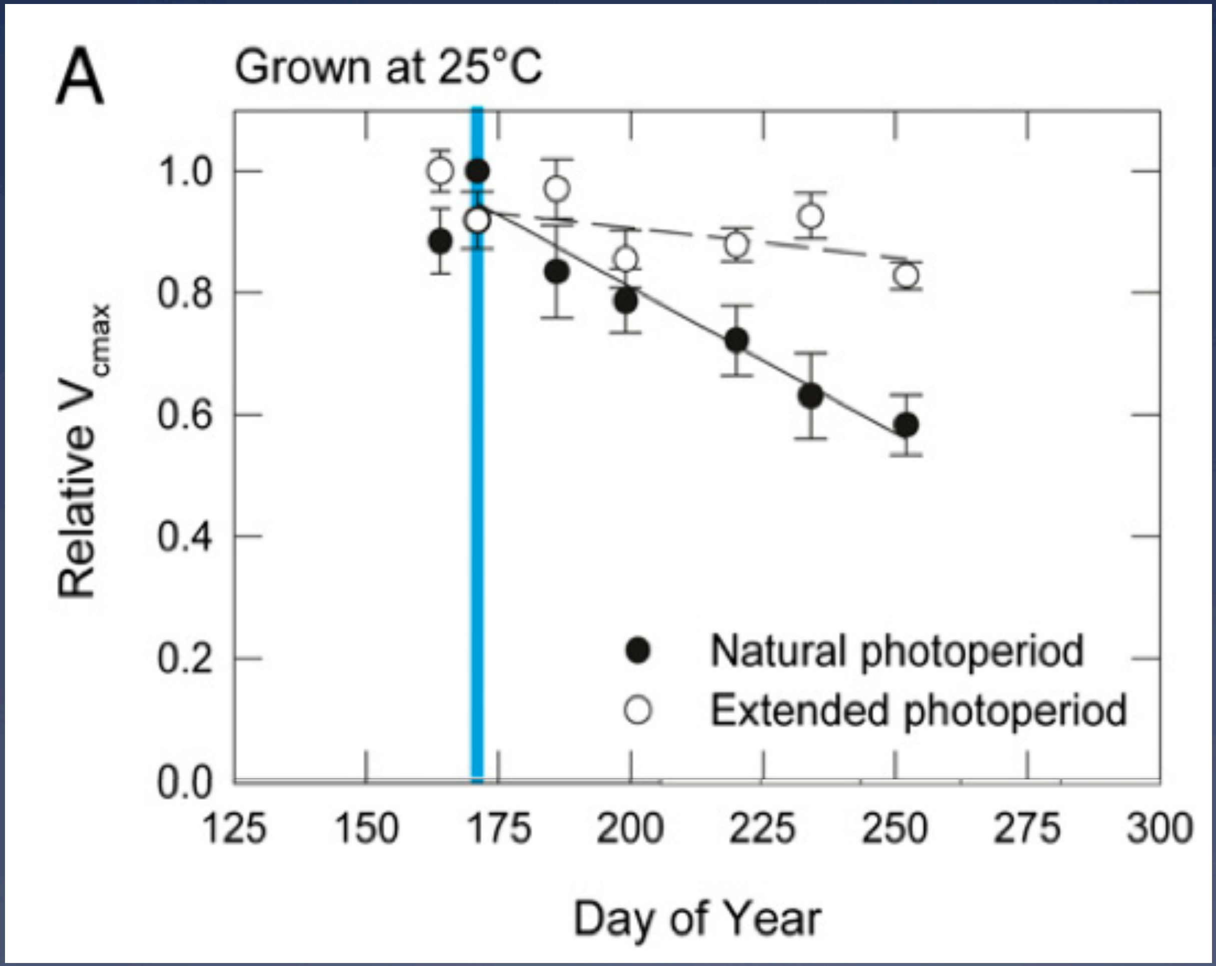
Canopy color and canopy chemistry appear to be "decoupled" in this example from Martha's Vineyard, MA



Yang, Tang and Mustard, in review

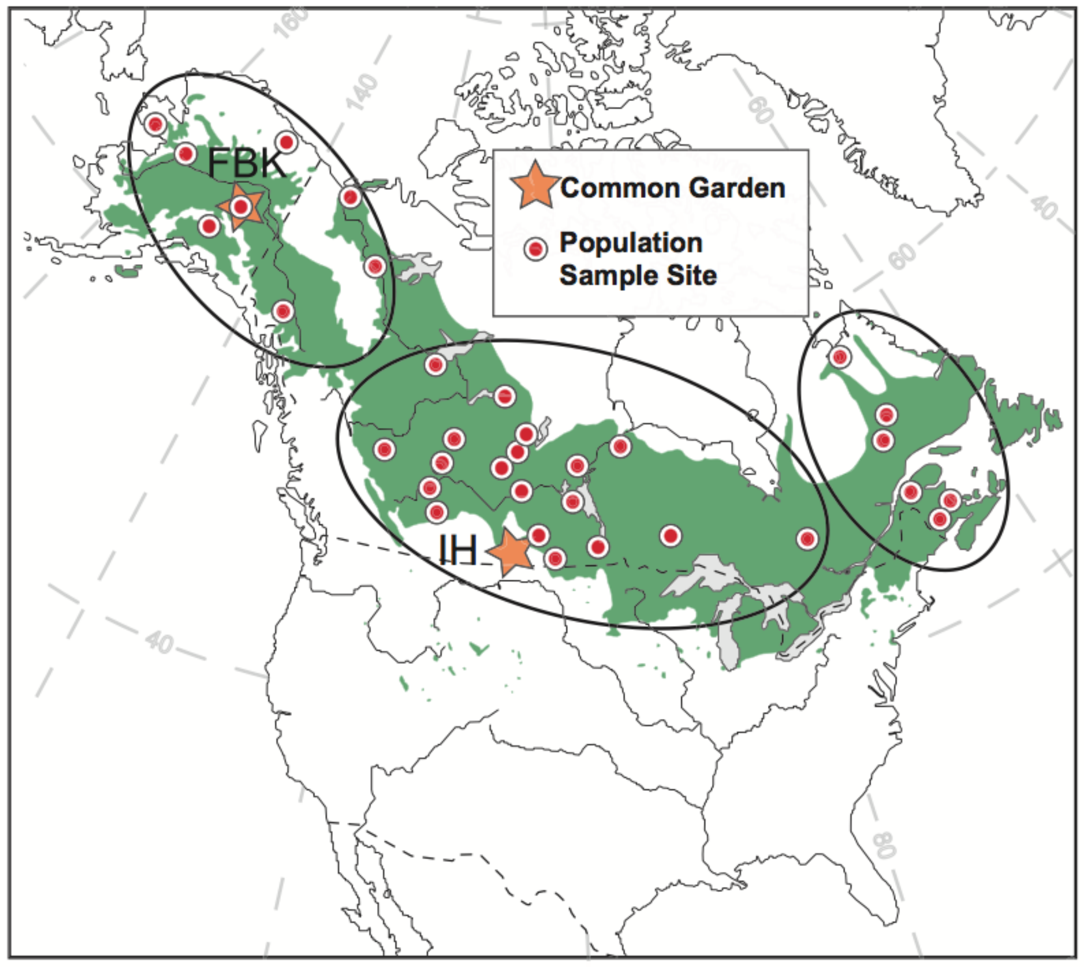
Brown University

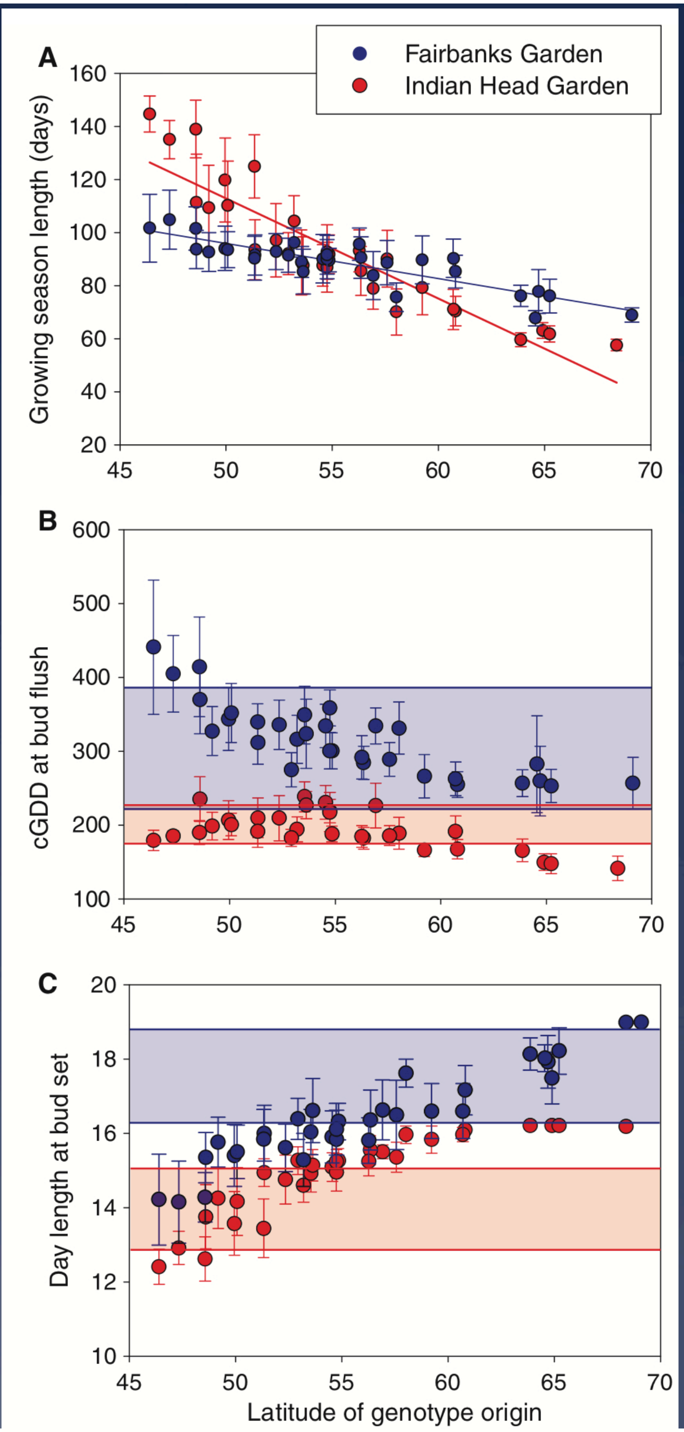
Plants grown under an extended photoperiod do not lose photosynthetic capacity



Bauerle et al. 2012 PNAS

Aspects of Balsam Poplar phenology are determined by photoperiod

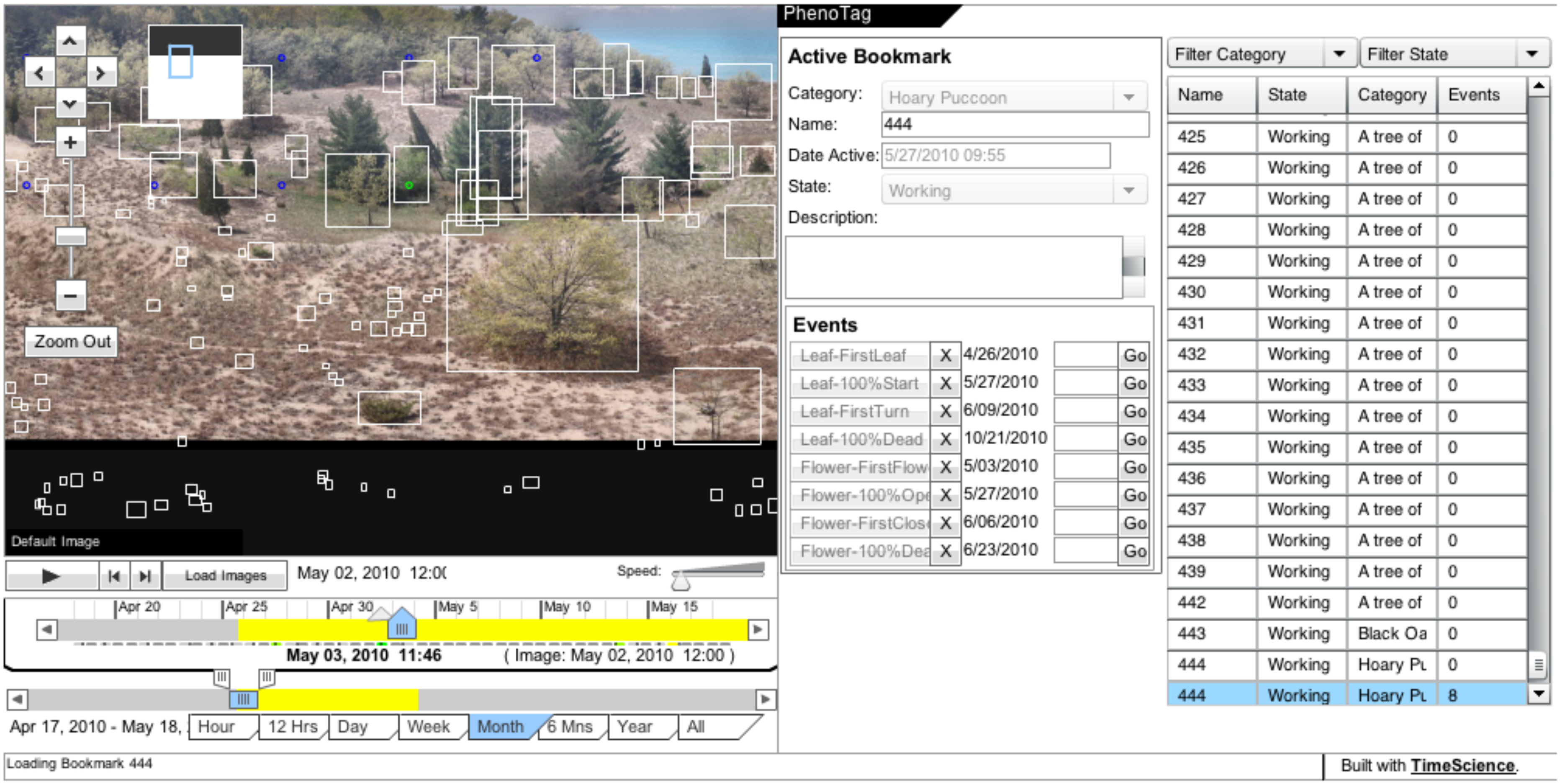




Olson et al. 2012 Molecular Ecology
Keller et al. 2012 Mol. Biol. Evol.

Gigavision.org

Gigavision.org



Its an interesting time to study phenology

* Long records of course-resolution data are available from which to infer changes in growing season length
* New access to medium resolution data (Landsat) sufficient to measure average and annual phenology of forest stands
* New technologies making phenological observations of forest stands and individual organisms practical, combined with new analytical and high throughput sequencing techniques
* Important questions regarding tree adaptation to changes in climate, searching for the genotype-phenotype-environment map

Next steps

* Continue working to replace time on the x-axis with environmental parameters (and photoperiod).
* Incorporate these parameters into terrestrial biosphere models with greater detail (Richardson et al. 2012 GCB)
* Work to bring new types of observations into phenology research (e.g., SMAP)
* Work with plant ecologists to understand and incorporate genotype-phenotype relationships in models of vegetation change

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Xi Yang	Brown University
Xu Liang	Boston University and UCLA