Evaluation of land surface model representation of phenology:

An analysis of model runs submitted to the NACP Interim Site Synthesis

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The Importance of Phenology

- Highly sensitive to **global change**: “Phenology … is perhaps the simplest process in which to track changes in the ecology of species in response to climate change” (IPCC AR4: *Climate Change 2007 – Impacts, Adaptation and Vulnerability,* page 99)
- Controls **feedbacks** to the **climate** system (albedo, surface energy balance, CO_2 exchange, VOCs)
- A factor in **ecological interactions** (productivity, competition, pollination, seed dispersal)
- Relevant to land **management** (agriculture, forestry, invasive plants and pests) and **human health** (transport of allergens and disease vectors)

Summary and take-home messages

- Analysis of seasonality of LAI, GEP, NEE from 14 ecosystem models and land surface schemes
- For deciduous sites:
  - Large biases in growing season length
    - Spring onset predicted to start too early
    - Autumn senescence predicted end too late
  - Models do not represent interannual variability in start/end of growing season
  - Model biases for GPP during phenological transition periods are large: +160 ± 145 g C m^{-2} y^{-1} (spring), +75 ± 130 g C m^{-2} y^{-1} (autumn)
- Raises questions about
  - Seasonality of other feedbacks to climate system
  - Forecasts of phenological response to climate change

North American Carbon Program
Interim Site Synthesis

“The objective of this activity is to establish a quantitative framework that allows NACP investigators to answer the question:

Are the various measurement and modeling estimates of carbon fluxes at individual sites consistent with each other - and if not, why?”

http://nacp.ornl.gov/mast-dc/int_synthesis.shtml

Objectives

Broad view of phenology that includes seasonality of both canopy structure (LAI) and ecosystem processes (GEP, gross ecosystem photosynthesis)

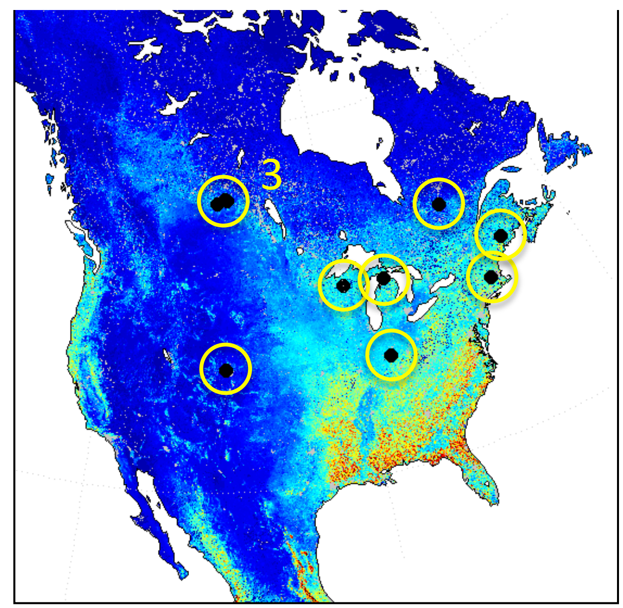
(1) To assess the accuracy with which different models predicted spring and autumn phenological transitions;
(2) To evaluate how these patterns vary between deciduous and evergreen forest types; and
(3) To quantify how much of the total error in modeling annual GEP can be attributed to errors in modeling the spring and autumn phenological transitions

This analysis complements others being conducted as part of the NACP Site Synthesis (see session B51L: North American Carbon Program Synthesis Results, Friday morning).

10 Study Sites: 5 DBF, 5 ENF

Site	Name	Country	Lat. °N	Long. °W	IGBP	Reference
Ca-Oas	SSA Old Aspen	Canada	53.63	106.20	DBF	Barr et al. (2006)
US-Ha1	Harvard Forest (EMS Tower)	USA	42.54	72.17	DBF	Urbanski et al. (2007)
US-MMS	Morgan Monroe State Forest	USA	39.32	86.41	DBF	Schmid et al. (2000)
US-UMB	Univ. of Mich. Biological Station	USA	45.56	84.71	DBF	Gough et al. (2008)
US-WCr	Willow Creek	USA	45.81	90.08	DBF	Cook et al. (2004)
Ca-Obs	SSA Old Black Spruce	Canada	53.99	105.12	ENF	Kljun et al. (2006)
Ca-Ojp	SSA Old Jack Pine	Canada	53.92	104.69	ENF	Kljun et al. (2006)
Ca-Qfo	Chibougamau (Mature Forest)	Canada	49.69	74.34	ENF	Bergeron et al. (2007)
US-Ho1	Howland Forest (Main Tower)	USA	45.20	68.74	ENF	Hollinger et al. (2004)
US-NR1	Niwot Ridge	USA	40.03	105.55	ENF	Monson et al. (2002)

- NACP Priority 1 sites
  - AmeriFlux/Fluxnet-Canada
  - Long-term flux and biometric data
  - Summer active/winter dormant ecosystems
- Data processing, gap filling, NEE partitioning according to common procedure (Barr et al. in prep).
- For DBF sites, seasonal LAI trajectory estimated from f_{APAR} measurements

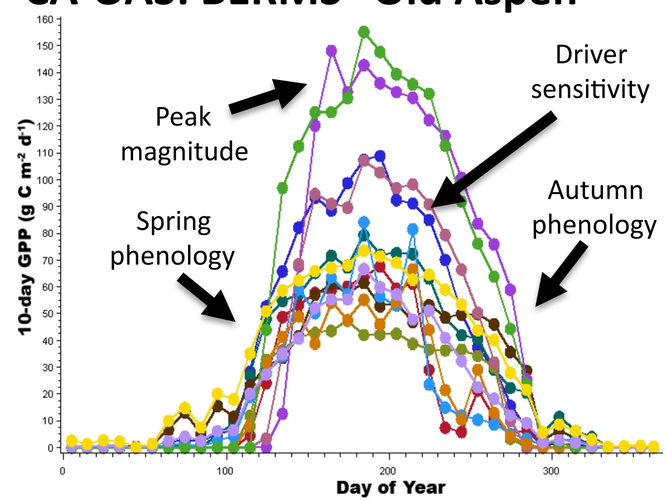


14 Models

- Includes ecosystem models run for individual sites, and land surface schemes from coupled biosphere-atmosphere "earth system" models
- Model output provided by modeling teams, following NACP protocol
  - Analysis centers on seasonality of LAI, GPP, NEE
  - Not all models provided all output for all sites
  - LAI prognostic in some models, prescribed in others (but in all cases, relatively simplistic treatment of phenology and LAI)
- Analysis restricted to those models with some semblance of the correct seasonal cycle
  - Models differ in magnitude of peak fluxes, phenology (timing) of seasonal changes, and high-frequency sensitivity to drivers

Model Name	Reference
BEPS	Ju et al. (2006)
Biome-BGC	Thornton et al. (2002)
Can-IBIS	El Maayar et al. (2002)
CN-CLASS	Arain et al. (2006)
DLEM	Tian et al. (2009)
Ecosys	Grant et al. (2009)
ED2	Medvigy et al. (2009)
ISAM	Jain and Yang (2005)
LoTEC	Hanson et al. (2004)
LPJ	Sitch et al. (2003)
ORCHIDEE	Krinner et al. (2005)
SiB3	Baker et al. (2008)
SiBCASA	Schaefer et al. (2009)
SSiB2	Zhan et al. (2003)

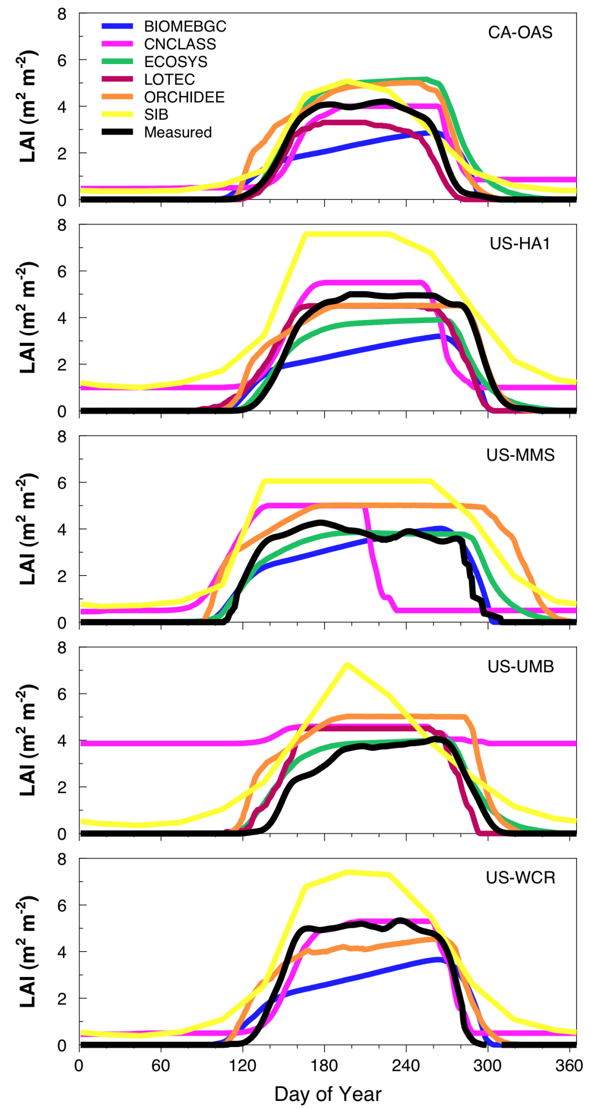
CA-OAS: BERMS "Old Aspen"



Seasonality of LAI

(leaf area index)

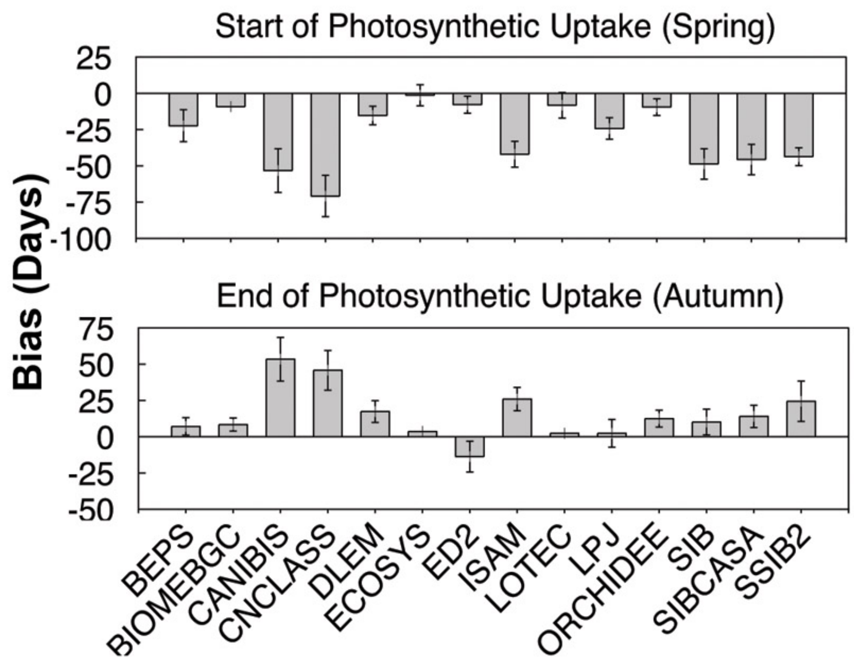
- Obvious errors both in magnitude of peak LAI and timing of changes in LAI
- No model performed well at all 5 DBF sites (some models poor at all sites)
- Models generally predicted spring green-up too early (-13±14 d)
- Slight tendency for bias in autumn (+3±26 d), but greater variability among models
- Most models could explain a significant proportion of the observed interannual variation in spring green-up date (but a large proportion remains unexplained; models could not explain interannual variability in autumn)



Seasonality of GEP
(gross ecosystem photosynthesis)

- Identified spring and autumn dates at which 20%, 50% and 80% of daily GEPmax was achieved
- Models consistently biased towards predicting that photosynthetic uptake starts too early in spring, and ends too late in autumn
- Results similar for all DBF sites (spring error: –28±21 d; autumn error: +15±23 d)
- Errors generally smaller for ENF sites (spring error: –11±15 d; autumn error, +3±14 d)
- "Photosynthetically active period" over-estimated by 6 weeks in deciduous forests, 2 weeks in evergreen forests

US-Ha1: Harvard Forest



Seasonality of NEE

(net ecosystem exchange of CO_2)

- Models predict spring source/sink transition too early, autumn sink/source transition too late
  - Biases differed among models and among sites
  - Larger bias for deciduous sites in spring, evergreen sites in autumn
- Modeling of interannual variability in GEP and NEE transition dates a challenge, especially for deciduous sites, and especially in autumn

- “Error cascade”:

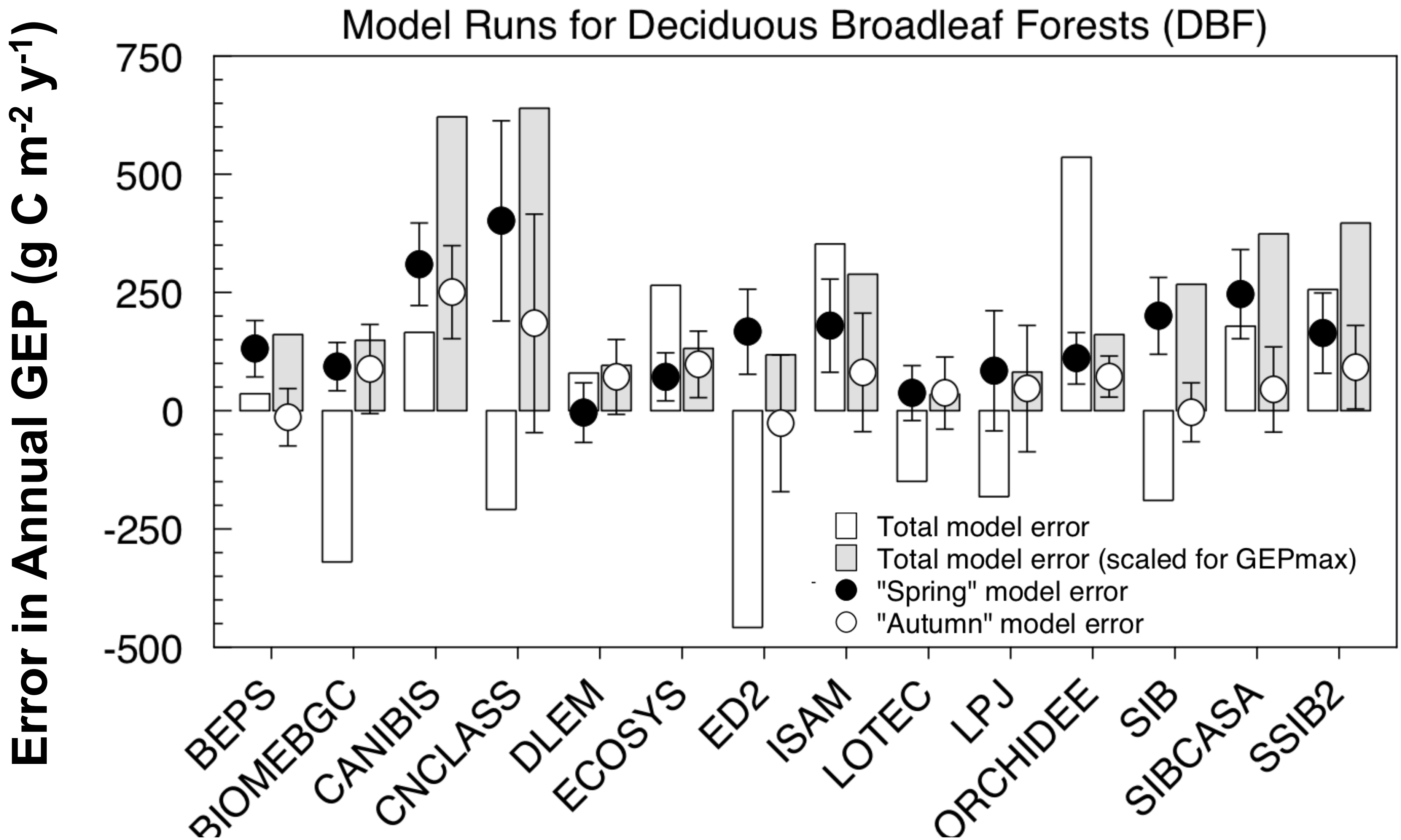
  Errors in LAI

  ⇒ Errors in GEP

  ⇒ Errors in NEE

How much do errors in timing matter?

Impact of Errors in Phenology of GEP



Errors across all sites, models, years

Deciduous vs. Evergreen, Spring vs. Autumn

Histograms show frequency distribution of errors in annual GEP, attributed to GEP phenology errors, across all models, sites and years.

Mean error:

Deciduous sites:

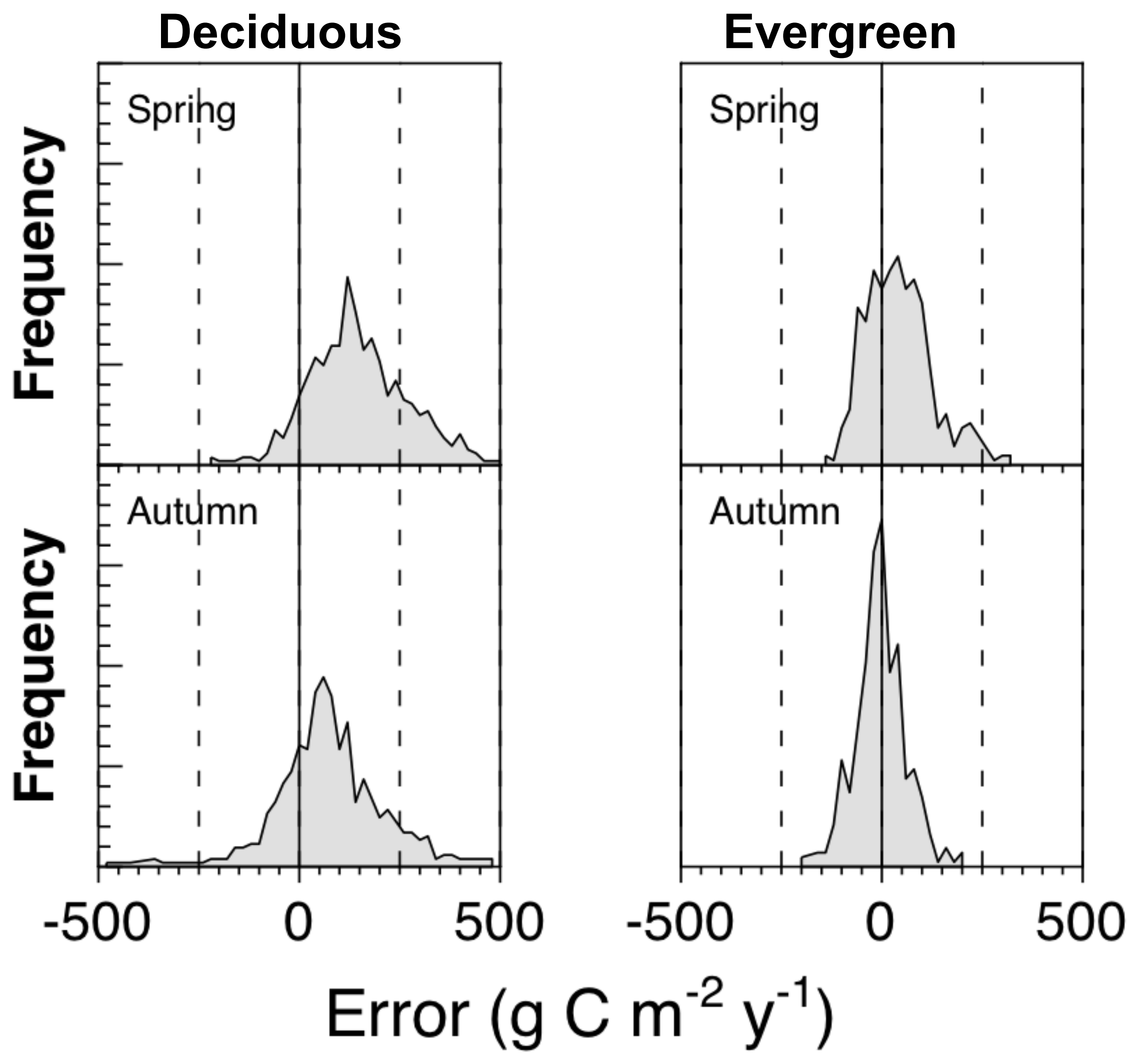
+160±145 g C m^{-2} y^{-1} (spring)

+75±130 g C m^{-2} y^{-1} (autumn)

Evergreen sites:

+40±80 g C m^{-2} y^{-1} (spring)

-5±65 g C m^{-2} y^{-1} (autumn)



Summary

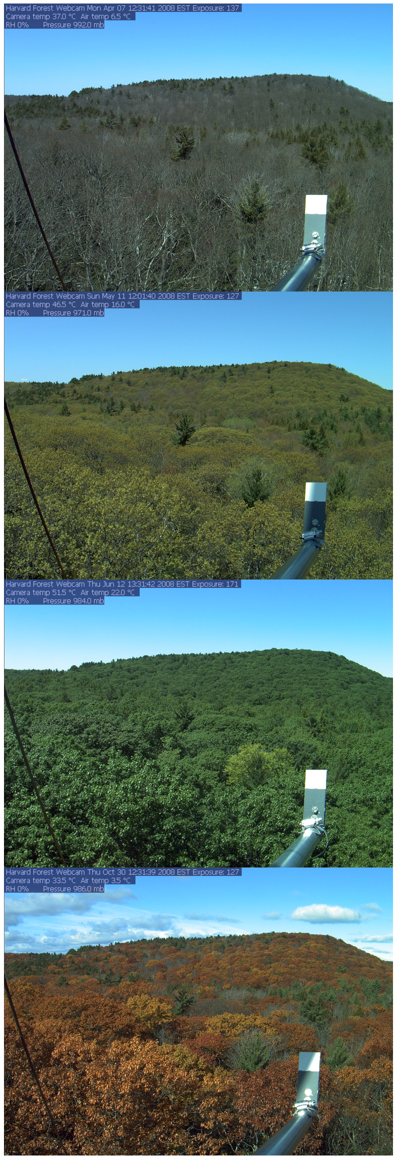
- Most models are biased towards predicting a **growing season that is substantially longer** than the observed growing season for deciduous forest sites
- Most models are unable to predict more than **a small fraction of the observed interannual variability** in spring, and particularly autumn, transitions
- For deciduous sites, errors in modeling the seasonality of leaf area index (LAI) propagate, particularly in spring, directly to errors in modeling the seasonality of gross ecosystem photosynthesis (GEP), and errors in modeling the seasonality of GEP lead directly to errors in modeling the seasonality of net ecosystem exchange

- Accumulated errors in GEP during spring and autumn transition periods, attributed to mis-representation of the seasonality of GEP, are large and highly variable for deciduous sites; combining spring and autumn, the total error is +235 ± 230 g C m^{-2} y^{-1}
- Errors in phenology offset errors associated with under-estimation of the magnitude of the seasonal peak GEP in deciduous sites.
- Thus, compensating errors may lead to erroneous conclusions about model performance at the annual time step.

- Bottom line: NACP Interim Site Synthesis is not a beauty contest… but in terms of phenology, there are no “super models”

Conclusion & Recommendations

- Existing models don't accurately predict phenology (of either canopy structure or ecosystem processes), or the sensitivity of this phenology to variation in environmental drivers
- Existing models are therefore unlikely to accurately predict future responses of phenology to climate change
- These models will also misrepresent the seasonality of key biosphere-atmosphere feedbacks and interactions in coupled model runs
- Multi-year, spatially extensive observational data—e.g. from webcam-based monitoring networks (e.g. PhenoCam) or citizen science efforts (USA National Phenology Network)—should prove valuable in efforts to develop better phenological models



Harvard Forest Webcam