Using FLUXNET Data to Improve Models of Vegetation Phenology

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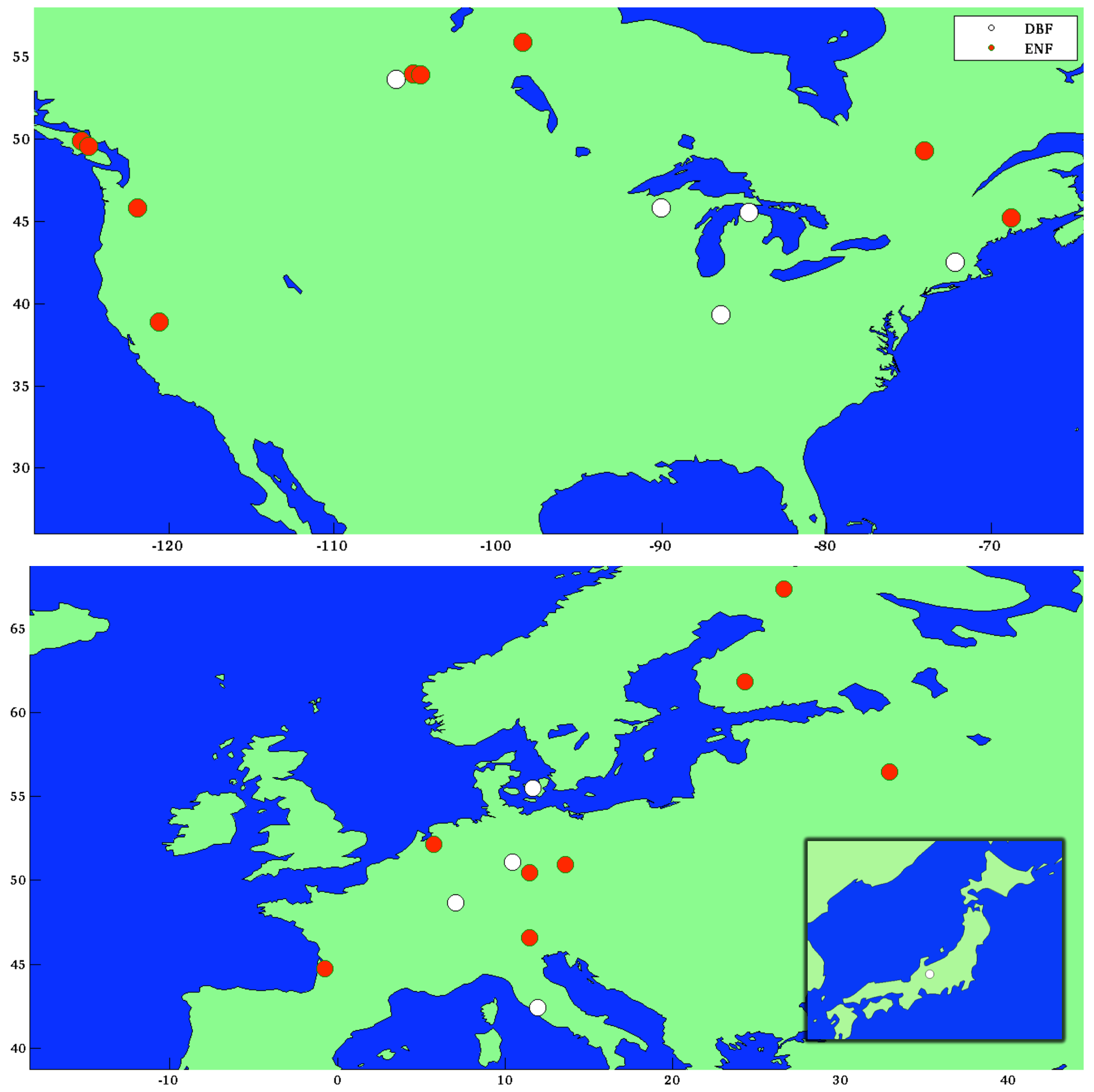
Abstract

Time series of CO_2 and H_2O exchanges obtained by eddy covariance measurements are a valuable resource for evaluating and improving model representation of seasonal vegetation dynamics. Despite recent efforts, accurate representation of phenology in ecosystem models has been elusive, and current models exhibit unrealistic levels of variability and errors in predictions for both leaf phenology and canopy fluxes. Using micrometeorological and eddy covariance data provided by the FLUXNET 'La Thuile' community database, we evaluated 11 different models driven by air temperature and photoperiod to simulate spatial and temporal variability in phenology. To do this, we used a subset of sites in the La Thuile database in ecosystems with distinct seasons and where air temperature is a primary driver of phenology. We then compared the results from these models with other prediction schemes, including phenology sub-routines currently implemented in land surface parameterizations used in global climate models. The root mean square errors produced by the modified growing degree-day models range from 7-14 days and provided substantial reduction in model errors (14-35 days) relative too current phenology schemes. Results from this study demonstrate that relatively simple variants of widely used phenology models can be used to simulate seasonal dynamics in ecosystem processes with good realism, and by extension, may provide a basis for improved models and predictions of how the phenology and carbon budgets of temperature-sensitive ecosystems will change in the coming decades.

Site Selection

- Our sites are primarily located in temperate and boreal ecosystems, where air temperature and photoperiod are widely understood to be significant drivers of phenology
- Only FLUXNET sites classified as Deciduous Broadleaf (DBF) or Evergreen Needleleaf Forest (ENF) with at least 4 years CO_2 flux and air temperature data were included.
- Site-years with (1) more than 20 days of missing CO_2 flux data, (2) more than 20 days with 0% high-quality data, or (3) missing temperature data between September 21 of the previous year and June 21, were excluded.
- The resulting dataset consisted of 66 and 107 site-years for DBF and ENF sites, respectively (11 DBF sites and 18 ENF sites) across North America, Europe and Japan.



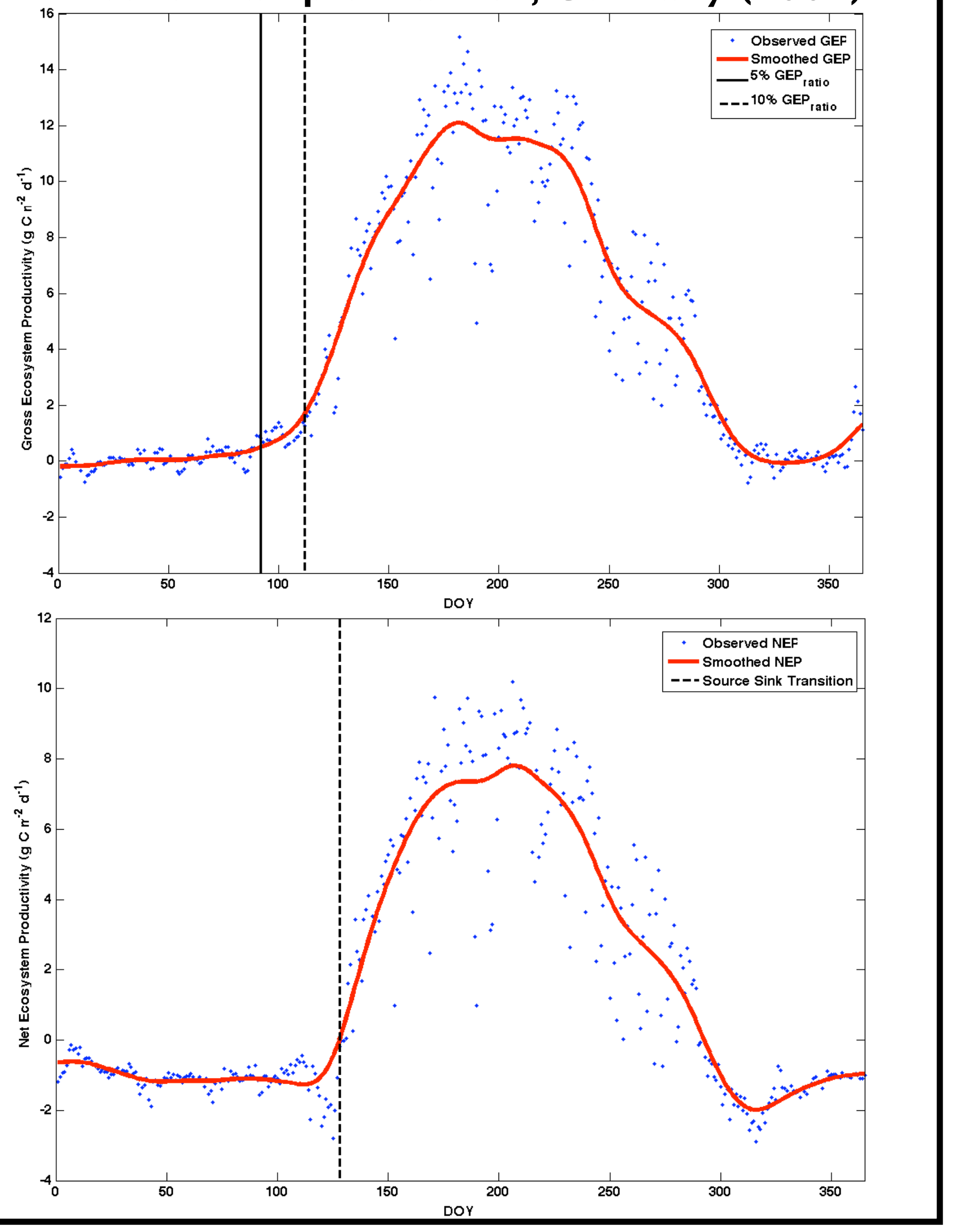
Phenological Models and Metrics

- Three phenology metrics were estimated from smoothed time series of net and gross ecosystem productivity for each site-year.
- Metrics were used to evaluate a suite of growing degree-day models that use either fixed or varying parameters as a linear function of mean annual temperature across sites
- Each model starts accumulation of growing chilling/forcing based on photoperiod (p_0) .
- Models were calibrated using simulated annealing routines based on Monte Carlo techniques, and tested using a four-fold cross-validation.
- The "best" model was selected for each plant functional type using the Akaike Information Criterion (AIC).

Model	Parameters				
Spring Warming 1.1	T_f		F^*		p_0
SW 1.2	$T_f = ax+b$		F^*		p_0
SW 1.3	T_f		$F^* = ax+b$		p_0
SW 1.4	$T_f = ax+b$		$F^* = cx+d$		p_0
SW 2.5			F^*		p_0
SW 2.6			$F^* = ax+b$		p_0
Sequential 1.7	T_f	T_c	F^*	C^*	p_0
SEQ 1.8	$T_f = ax+b$	$T_c = cx+d$	F^*	C^*	p_0
SEQ 1.9	T_f	T_c	F^*	C^*	p_0
SEQ 1.10	T_f	T_c	F^*	$C^* = ax+b$	p_0
SEQ 1.11	$T_f = ax+b$	$T_c = cx+d$	$F^* = ex+f$	$C^* = gx+h$	p_0

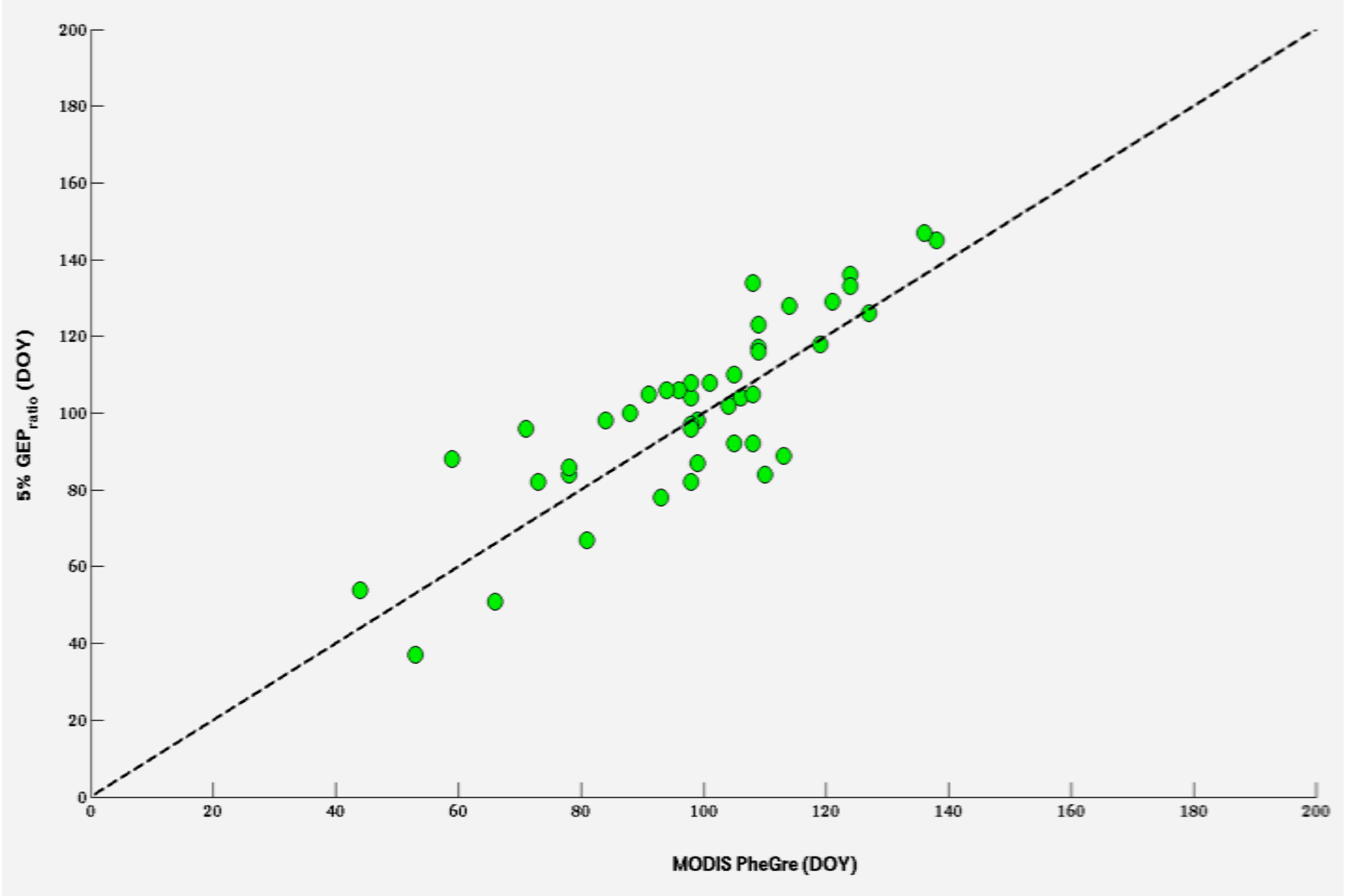
Note: x = Mean Annual Temperature

Metric Example: Hainich, Germany (2001)



Results

- Results from models were compared against three other widely-used approaches for modeling phenology
  1. A standard phenology subroutine (SGDD) where leaf onset occurs when accumulated growing degree-days above 0˚C starting January 1 exceed 100 [*Aber et al. 1996*; *Levis and Bonan 2004*].
  2. The Growing Season Index (GSI), where minimum temperature, photoperiod, and humidity control phenology and spring onset is predicted to occur when GSI = 0.5 [*Jolly et al. 2005*].
  3. A refined version of the soil temperature model (TSOIL) [*Baldocchi et al. 2005*].
- Results show that modified growing degree-day models significantly outperform existing benchmark models.
- Results also show strong correlation between the timing of all three spring metrics and the start of season identified by the MODIS Land Cover Dynamics product (MCD12Q2).



5% Gross Ecosystem Productivity Ratio Index vs. MODIS Phenology green-up dates across all DBF study sites between 2001 and 2005 (R^2 = 0.74); green-up dates are median values across a 9x9 ($6.25 km^2$) window centered on each site

	Modified GDD			Standard GDD		GSI = 0.5		TSOIL	
Spring Onset Metric	Model	RMSE	Bias	RMSE	Bias	RMSE	Bias	RMSE	Bias
All DBF									
Source-Sink Trans.	SW2.6	8.6	0.2	68.6	65.4	41.8	40.2	27.3	13.8
5% GEP_{ratio}	SEQ1.9	18.8	0.0	44.3	32.5	22.7	7.1	34.1	-19.2
10% GEP_{ratio}	SW2.6	17.6	-3.3	53.5	46.9	26.4	21.6	25.4	-4.7
Bor. & Temp. DBF									
Source-Sink Trans.	SW2.6	8.2	-1.2	64.0	61.5	40.5	39.1	25.5	19.3
5% GEP_{ratio}	SEQ1.10	14.9	-0.6	41.5	29.6	22.4	7.1	25.9	-12.5
10% GEP_{ratio}	SEQ1.9	10.4	-2.1	50.2	43.7	25.9	21.3	18.3	1.5
All ENF									
5% GEP_{ratio}	SW1.1	15.5	-0.3	23.5	-14.6	39.5	-35.6	n/a	n/a
10% GEP_{ratio}	SEQ1.10	15.1	1.3	20.7	-4.5	29.9	-25.3	n/a	n/a
Boreal ENF									
5% GEP_{ratio}	SW2.5	14.8	2.2	25.2	-24.0	30.7	-28.4	n/a	n/a
10% GEP_{ratio}	SW2.5	8.9	-0.5	15.8	-15.4	22.2	-19.9	n/a	n/a
Temp. ENF									
5% GEP_{ratio}	SEQ1.7	13.3	-3.0	21.9	-12.4	41.2	-38.1	n/a	n/a
10% GEP_{ratio}	SW1.3	13.1	-0.6	21.7	-1.6	31.7	-26.8	n/a	n/a

References:

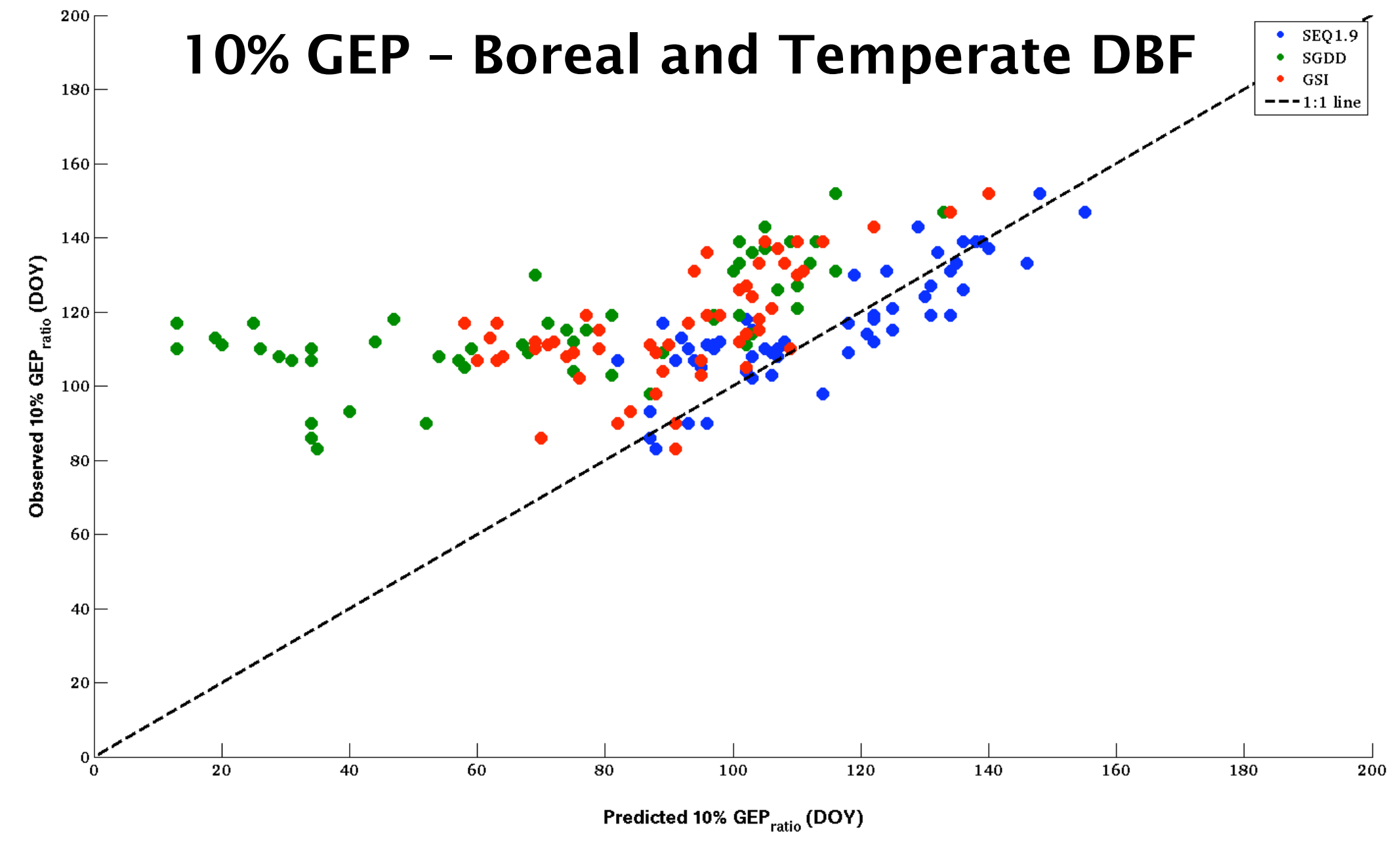
Aber, J.D., P.B. Reich, and M.L. Goulden (1996), Extrapolating leaf CO2 exchange to the canopy: A generalized model of forest photosynthesis compared with measurements by eddy correlation. *Oecologia*, 106, 257-265

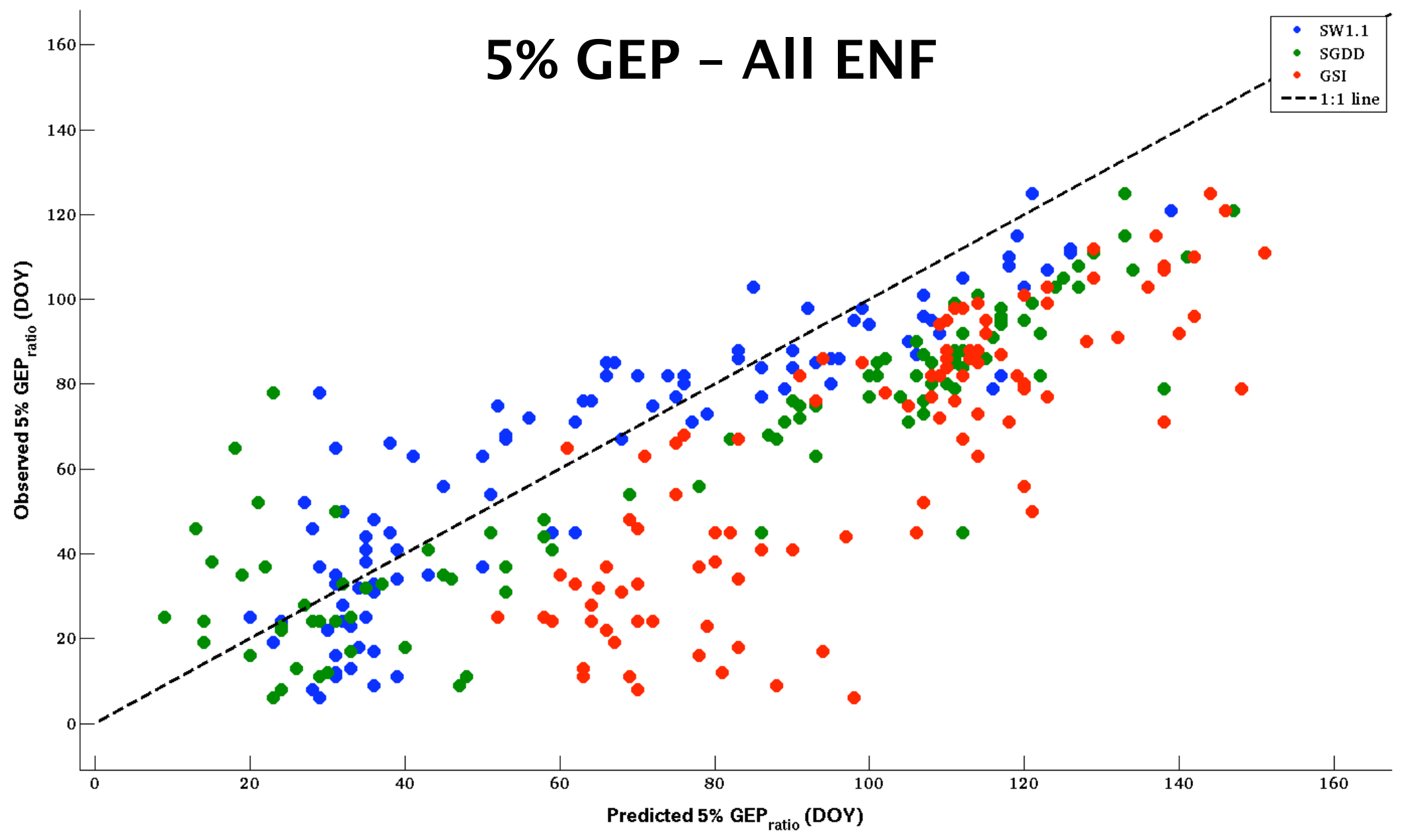
Baldocchi, D.D., T.A. Black, P.S. Curtis, E. Falge, J.D. Fuentes, A. Granie, L. Gu, A. Knohl, K. Pilegaard, H.P. Schmid, R. Valentini, K. Wilson, S. Wofsy, L. Xu, and S. Yamamoto (2005), Predicting the onset of net carbon uptake by deciduous forests with soil temperature and climate data: a synthesis of FLUXNET data. *International Journal of Biometeorology*, 49, 377-387

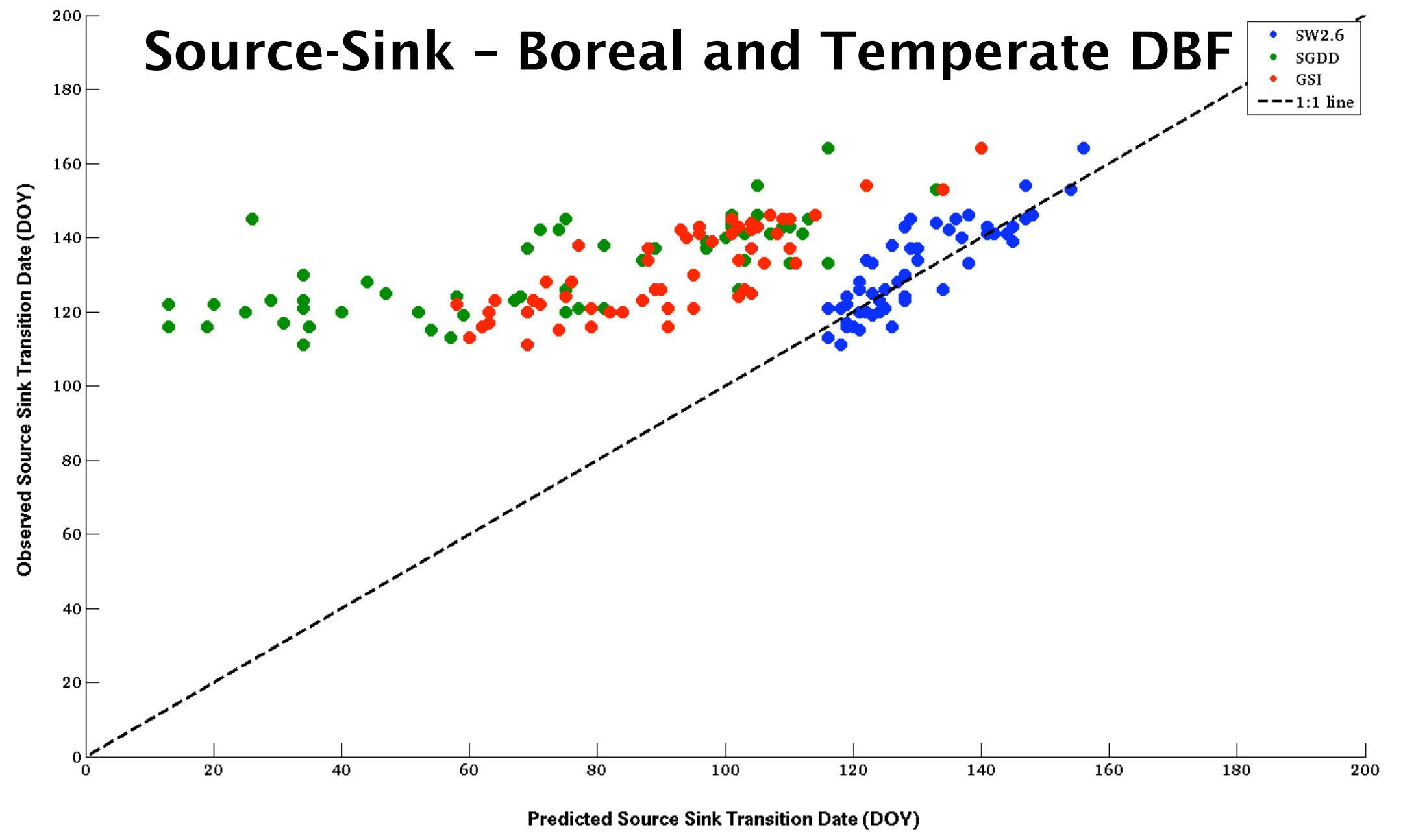
Jolly, W.M., R. Nemani, and S.W. Running (2005), A generalized, bioclimatic index to predict foliar phenology in response to climate, *Global Change Biology*, 11, 619-632

Levis, S., and G.B. Bonan (2004), Simulating springtime temperature patterns in the community atmosphere model coupled to the community land model using prognostic leaf area. *Journal of Climate*, 17, 4531-4540

Discussion







- DBF sites generally require a higher critical accumulation of forcing than ENF sites
- The amount of forcing required across DBF sites varies a function of mean annual temperature
- Incorrect parameterization of photoperiod significantly increases error bias
- Significant differences exist in photoperiod cues and forcing and chilling requirements among land cover groups