Measuring forest carbon flux phenology: A comparison of several contemporary methods

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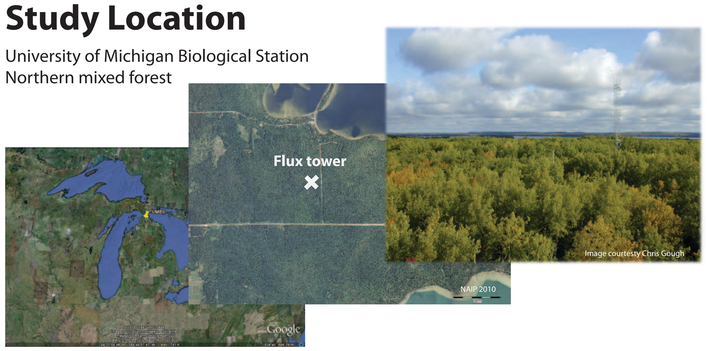
Introduction

Accurately describing the timing, location, and magnitude of plant canopy phenological events is vital for understanding temporal and spatial variability of ecosystem-atmosphere fluxes of mass and energy[1-4]. There are currently numerous data sources that can be used to track interannual variability in the timing of phenological transitions. Choosing the appropriate data source for estimating the timing of these annually recurring events can be challenging. Our study investigated the performance of phenology data sources for estimating interannual variability in the timing of seasonal transitions in forest-atmosphere CO_2 exchange. Data sources were selected based on the criteria of being commonly available at Ameriflux research sites. We compared phenology metrics from these data sources directly to transitions in NEE measured over a deciduous forest (UMBS). The results provide a side by side comparison of three ground- and ten satellite-based phenology data sources, with different temporal and spatial resolutions, for estimating these transitions.

Study Location

University of Michigan Biological Station
Northern mixed forest



Carbon Flux Phenology

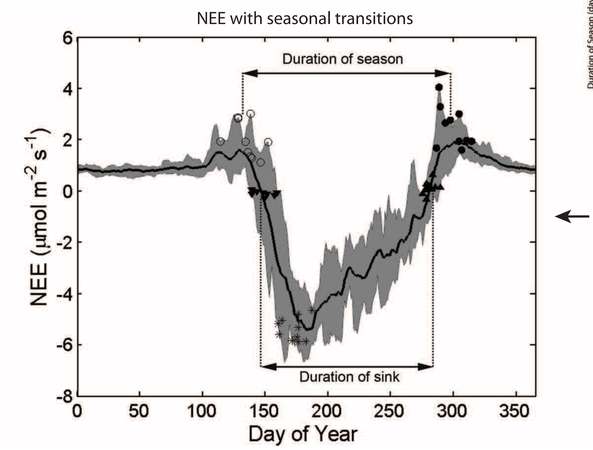


Figure 1. Summary of 11 years of daily averaged NEE with dates of phenological transitions. The bold line is the mean daily NEE. The upper and lower bounds of the shaded region represent the maximum and minimum NEE observed at each day of year. Eight seasonal features of carbon flux phenology were identified in 11 years of NEE measured at UMBS: **Start of season** (SOS) (○), **Sink** (▼), **Peak** (✱), **Source** (▲), **End of season** (EOS) (●), **Duration of season** (EOS-SOS), **Duration of sink** (Source-Sink), and **Amplitude** (NEE at the Peak).

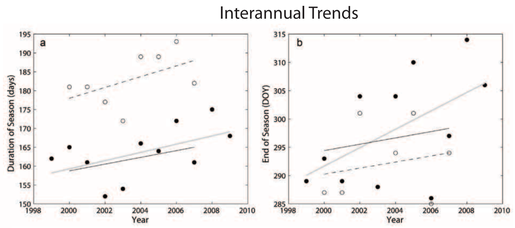


Figure 2. Interannual trends ($p<0.08$) in (a) duration of season and (b) end of season (EOS). In both cases, the LAI-2000 data source produced the highest performing metrics for estimating each of these phenological features (see Figs. 6f and 7b). The gray line is the least squares fit to NEE observations (●). The dashed line is the least squares fit to the LAI-2000 metrics (○), and the solid black line is the least square fit to NEE-derived metrics for the same years that LAI-2000 observations were available.

Phenology Data Sources

We used data from ground- and satellite-based instruments to estimate the timing of seasonal transitions in CO_2 flux (Table 1). Ground-based measurements included **Plant Area Index** (PAI) (LAI-2000 Plant Canopy Analyzer, Licor) and daily averaged canopy **albedo** (CNR1 4-channel net radiometer, Kipp & Zonen) and **fraction of absorbed PAR** (fPAR) (LI-190 quantum sensor, Licor). Satellite data were MODIS 250 m spatial resolution, 16-day composite vegetation indices (MOD13Q1, **NDVI** and **EVI**) and 1 km spatial resolution, 8-day composite **LAI** (MOD15A2) data products. MODIS data consisted of 7 km x 7 km (784 pixels for NDVI and EVI or 49 pixels for LAI) grids, where the central pixel in each grid was co-located with the UMBS flux tower (Fig. 3). Logistic curves[5] were fit to the time series observations from each data source (Fig. 4).

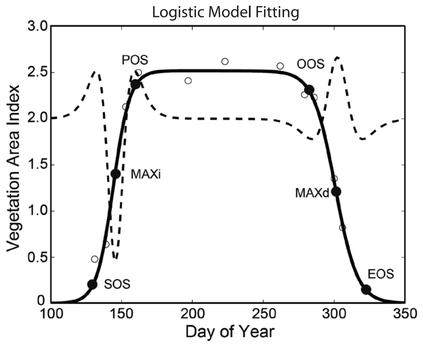


Figure 4. Six phenology metrics are identified by the third derivative (dashed line) of the logistic curve (solid line) fit to observations (open circles). Metrics include start of season (SOS), maximum spring increase (MAXi), peak of season (POS), onset of senescence (OOS), maximum fall decrease (MAXd), end of season (EOS), and amplitude (the difference between the minimum and maximum values of the curve).

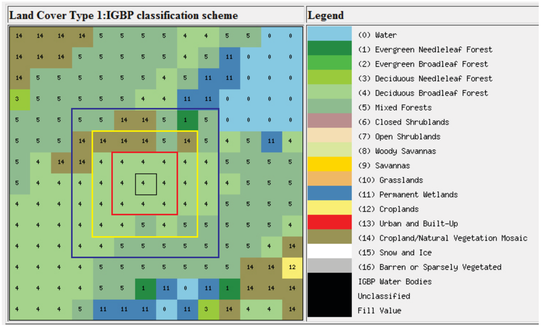


Figure 3. MODIS IGBP Land Cover Classification (http://www.daac.ornl.gov) of the 49 km^2 region surrounding the UMBS flux tower. Center 1 km X 1 km pixel (black box) is co-located with the flux tower. Spatial averages of MODIS LAI were calculated for 3 km X 3 km (red box), 5 km X 5 km (yellow box), and 7 km X 7 km (blue box). Similar spatial averaging at 250 m, 750 m, and 1500 m were conducted for NDVI and EVI.

Table 1. Summary of phenology data characteristics. Spatial resolution refers to the minimum size of the sampling unit whereas spatial representation refers to the area averaged for each data source. Similarly, sampling frequency is the actual sampling frequency, whereas averaging period is the number of days over which each data source is averaged.

Data Source	Variable	Spatial Resolution	Spatial Representation	Sampling Frequency	Averaging Period (days)	Years Data Available
MODIS	NDVI250m	250 m	0.06 km^2 (1 pixel)	1 day	16	2001-2009
MODIS	NDVI750m	250 m	0.56 km^2 (3x3 pixels)	1 day	16	2001-2009
MODIS	NDVI1500m	250 m	2.25 km^2 (5x5 pixels)	1 day	16	2001-2009
MODIS	EVI250m	250 m	0.06 km^2 (1 pixel)	1 day	16	2001-2009
MODIS	EVI750m	250 m	0.56 km^2 (3x3 pixels)	1 day	16	2001-2009
MODIS	EVI1500m	250 m	2.25 km^2 (5x5 pixels)	1 day	16	2001-2009
MODIS	LAI1km	1 km	1 km^2 (1 pixel)	1 day	8	2001-2009
MODIS	LAI3km	1 km	9 km^2 (3x3 pixels)	1 day	8	2001-2009
MODIS	LAI5km	1 km	25 km^2 (5x5 pixels)	1 day	8	2001-2009
MODIS	LAI7km	1 km	49 km^2 (7x7 pixels)	1 day	8	2001-2009
Quantum sensor	fPAR	hemispherical	point	1 min	1	2002-2007
LAI-2000	LAI2000	hemispherical	3600 m^2 (100-140 points)	7-14 days	N/A	2000-2007
Net radiometer	Albedo	hemispherical	point	1 min	1	2005-2009

Results

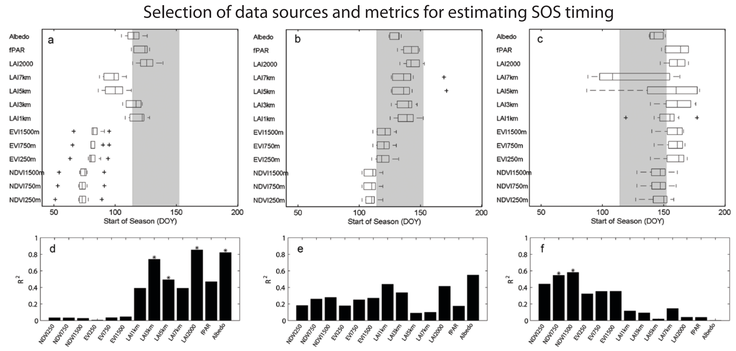
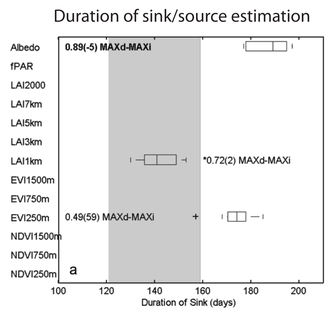


Figure 5. Performance of the springtime phenology metrics (SOS, MAXi, and POS) from each data source for estimating NEE-derived SOS. See Fig. 4 for a description of how these metrics were derived from each data source. (a-c) Boxplots summarize the dates of (a) SOS, (b) MAXi, and (c) POS metrics. The gray region in (a-c) represents the range of SOS observed in the NEE measurements. (d-f) The coefficient of determination for the regressions between NEE SOS and the metrics (d) SOS, (e) MAXi, and (f) POS derived from each data source. The figure is constructed so that the coefficients reported in lower panels correspond with the boxplots in the upper panels. The results of the analysis presented in this figure are summarized in Fig. 6a.



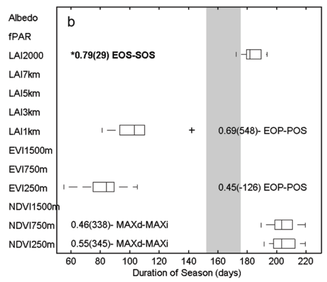


Figure 7. Performance of the data sources for estimating (a) sink duration and (b) season duration. See the Fig. 6 caption for an explanation of the figure components.

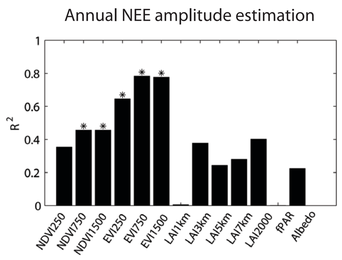


Figure 8. Coefficients of determination from the regressions between the annual amplitude phenology metric derived from each data source and the amplitude of the annual NEE.

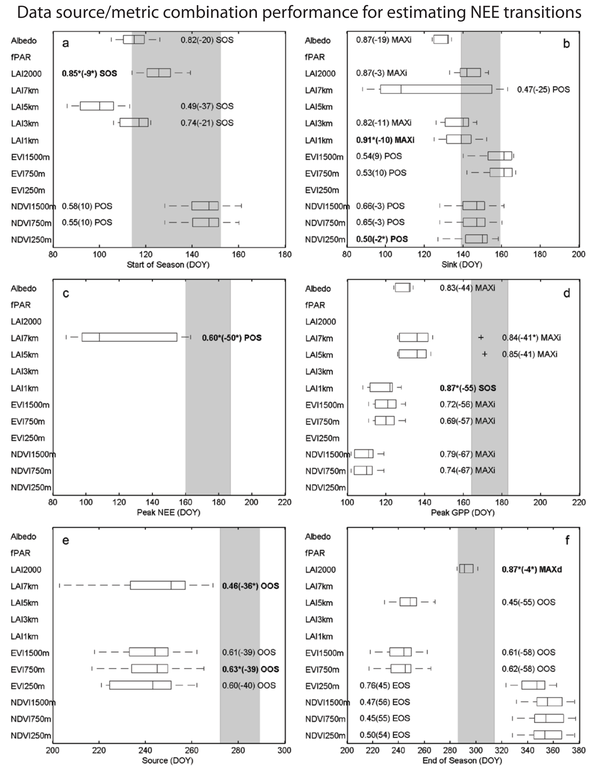


Figure 6. Performance of the phenology data sources for estimating each of the seasonal NEE transition dates, including (a) SOS, (b) SINK, (c) Peak NEE, (d) Peak GPP, (e) SOURCE, and (f) EOS. See Fig. 1 for a description of these NEE transitions. Boxplots are provided only when the correlation was significant. Coefficients of determination are reported along with the mean error (days) in parenthesis and the metric found to be significantly related to the respective NEE transition.

Conclusions

No single phenology data source was able to accurately describe annual patterns of carbon flux phenology. However, for each transition in NEE, the metrics from one or more data sources were significantly ($p<0.05$) correlated with the timing of these recurring events. LAI-type measurements from satellite- and ground-based instruments were most frequently identified as the highest performing for estimating carbon flux transitions relative to other types data. Future studies can combine metrics from several data sources to improve estimates of interannual variability of carbon flux phenology.

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References: **(1)** Cleland, E.E. et al. 2007. *Trends in Ecology and Evolution* 22, 357-365. | **(2)** Hutyra, L.R. et al. 2007. *Journal of Geophysical Research* 112, G03008, doi:10.1029/2006JG000365. | **(3)** Richardson, A.R. et al. 2009. *Tree Physiology* 29, 321-331. | **(4)** Cadule, P. et al. 2010. *Global Biogeochemical Cycles* 24, BG2016, doi:10.1029/2009GB003556. | **(5)** Zhang, X. et al. 2003. *Remote Sensing of Environment* 84, 471-475.