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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. 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 CO2 exchange. Data sources were selected based on the criteria of being commonly available at Ameriflux research sites, 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.

Phenology Data Sources

We used data from ground- and satellite-based instruments to estimate the timing of seasonal transitions in CO2 flux (Table 1). Ground-based measurements included Plant Area Index (PAI) (LAI-2000 Plant Canopy Analyser, Licor) and daily averaged canopy albedo (CMR 4-channel net radiometer, Kipp & Zonen) and fraction of absorbed PAR (FAPAR) (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 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 UMBF flux tower (Fig. 3). Logistic curves were fit to the time series observations from each data source (Fig. 4).

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.

Study Location
University of Michigan Biological Station
Northern mixed forest

Results

Selection of data sources and metrics for estimating NEE timing

Figure 2. Intermittent 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 performance for estimating each of these phenological features (see Figs. 4f and 7b). The grey line is the least squares fit to NEE observations ( ). The dashed line is the least squares fit to 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.

Figure 3. MODIS GSP Land Cover Classification (https://www.daac.ucar.edu) of the 4 km x 4 km region surrounding the UMBF flux tower center (Fig. 2). For ground-based sensors, LAI is averaged over the pixels from the green vegetation class (yellow box), and LAI from the deciduous forest class (red box). MODIS data consist of 7 km 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 UMBF flux tower (Fig. 3). Logistic curves were fit to the time series observations from each data source (Fig. 4).

Figure 4. A 2-pixel moving average of the annual amplitude phenology metric derived from each data source and the amplitude of the annual NEE.

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 date of (a) SOS (x-axis, 3439), and (c) POS metrics. The grey 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 fit is constructed so that the coefficients reported in lower panels correspond with the box-plots in the upper panels. The results of the analysis presented in this figure are summarized in Fig. 6.

Figure 6. Performance of the autumn phenology metrics (MAXd, OOS, and EOS) from each data source for estimating NEE-derived OOS. The grey region in (a-c) represents the range of OOS observed in the NEE measurements. (d-f) The coefficient of determination for the regressions between NEE OOS and the metrics (d) OOS, (e) MAXd, and (f) EOS derived from each data source. The fit is constructed so that the coefficients reported in upper panels correspond with the box-plots in the lower panels. The results of the analysis presented in this figure are summarized in Fig. 7.

Figure 7. Performance of the autumn phenology metrics (MAXd, OOS, and EOS) from each data source for estimating NEE-derived EOS. The grey region in (a-c) represents the range of EOS observed in the NEE measurements. (d-f) The coefficient of determination for the regressions between NEE EOS and the metrics (d) EOS, (e) MAXd, and (f) OOS derived from each data source. The fit is constructed so that the coefficients reported in lower panels correspond with the box-plots in the upper panels. The results of the analysis presented in this figure are summarized in Fig. 6.