Land Surface Phenology, Eddy Covariance Tower Sites, North America, 2017-2021

Get Data

Documentation Revision Date: 2023-03-16

Dataset Version: 1

Summary

This land surface phenology (LSP) dataset provides spatially explicit data related to the timing of phenological changes such as the start, peak, and end of vegetation activity, vegetation index metrics and associated quality assurance flags. The data are for the growing seasons of 2017-2021 for 10-km x 10-km windows centered over 104 eddy covariance towers at AmeriFlux and National Ecological Observatory Network (NEON) sites. The dataset is derived at 3-m spatial resolution from PlanetScope imagery across a range of plant functional types and climates in North America. These LSP data can be used to assess satellite-based LSP products, to evaluate predictions from land surface models, and to analyze processes controlling the seasonality of ecosystem-scale carbon, water, and energy fluxes. The data are provided in NetCDF format along with geospatial area-of-interest information and visualizations of the analysis window for each site in GeoJSON and HTML formats.

There are a total of 728 files. There are seven files for each of the 104 eddy covariance tower sites: five data files in NetCDF format (one for each year in 2017-2021), one HTML interactive map (.html), and one GeoJSON file.

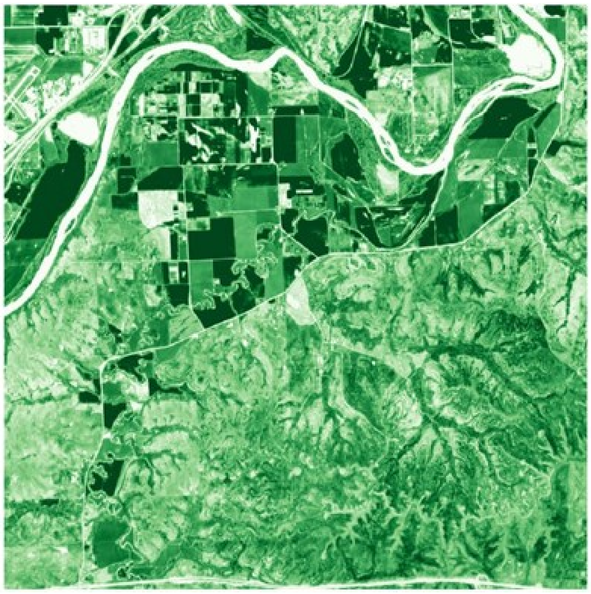

Figure 1. EVI amplitude at Konza Prairie Biological Station in 2019.

Citation

Moon, M., A.D. Richardson, T. Milliman, and M.A. Friedl. 2023. Land Surface Phenology, Eddy Covariance Tower Sites, North America, 2017-2021. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/2033

Table of Contents

1. Dataset Overview

This land surface phenology (LSP) dataset provides spatially explicit data related to the timing of phenological changes such as the start, peak, and end of vegetation activity, vegetation index metrics and associated quality assurance flags. The data are for the growing seasons of 2017-2021 for 10-km x 10-km windows centered over 104 eddy covariance towers at AmeriFlux and National Ecological Observatory Network (NEON) sites. The dataset is derived at 3-m spatial resolution from PlanetScope imagery across a range of plant functional types and climates in North America. These LSP data can be used to assess satellite-based LSP products, to evaluate predictions from land surface models, and to analyze processes controlling the seasonality of ecosystem-scale carbon, water, and energy fluxes. The data are provided in NetCDF format along with geospatial area-of-interest information and visualizations of the analysis window for each site in GeoJSON and HTML formats.

Related publications

Bolton, D.K., J.M. Gray, E.K. Melaas, M. Moon, L. Eklundh, and M.A. Friedl. 2020. Continental-scale land surface phenology from harmonized Landsat 8 and Sentinel-2 imagery. Remote Sensing of Environment 240:111685. https://doi.org/10.1016/j.rse.2020.111685

Moon, M., A.D. Richardson, and M.A. Friedl. 2021. Multiscale assessment of land surface phenology from harmonized Landsat 8 and Sentinel-2, PlanetScope, and PhenoCam imagery. Remote Sensing of Environment 266:112716. https://doi.org/10.1016/j.rse.2021.112716

Acknowledgments

This work was supported by NASA grants 80NSSC18K0334 and 80NSSC21K1974, and by NSF award number 1702627. The development of PhenoCam has been funded by the Northeastern States Research Cooperative, NSF's Macrosystems Biology Program (awards EF-1065029 and EF-1702697), and DOE's Regional and Global Climate Modeling Program (award DE-SC0016011). We also gratefully acknowledge NASA's Commercial Smallsat Data Acquisition (CSDA) Program, which provided access to the PlanetScope imagery used in this study.

2. Data Characteristics

Spatial Coverage: 104 eddy covariance towers at AmeriFlux and National Ecological Observatory Network (NEON) sites in North America

Spatial Resolution: 3 m

Temporal Coverage: 2017-01-01 to 2021-12-31

Temporal Resolution: Annual

Study Areas: Latitude and longitude are given in decimal degrees.

Site	Westernmost Longitude	Easternmost Longitude	Northernmost Latitude	Southernmost Latitude
AmeriFlux and National Ecological Observatory Network Sites in North America	-155.366	-68.8209	68.70759	17.92385

Data File Information

There are a total of 728 files. There are seven files for each of the 104 eddy covariance tower sites: five data files in NetCDF format (.nc4;one for each year in 2017-2021), one HTML interactive map (.html), and one GeoJSON file (.geojson). Table 3 in Section 5 lists the 104 study sites.

Table 1. File names and descriptions. In the file names, "Site" is a combination of the Site Code and Site Full Name for the eddy covariance tower sites listed in Table 3.

File Name	Description	Example File Name
Site_interactive_map.html	Visualizations with the spatial extent of the files. These can be opened in a web browser. A user can zoom in and out and pan interactively. A visible satellite view is the basemap. User note: the HTML code calls in data from web links which may not be permanent.	PR-GU_NEON_Guanica_Forest_interactive_map.html
Site_georeference.geojson	Georeference for the site extent and location in GeoJSON format.	PR-xGU_NEON_Guanica_Forest_georeference.geojson
Site_YYYY.nc	Georeferenced NetCDF (.nc) files where YYYY is 2017 to 2021.	PR-xGU_NEON_Guanica_Forest_PLSP_2017.nc

Table 2. Variables in the NetCDF data files.

Layer Name	Description	Units	Scale Factor	Valid Range	Fill value
NumCycles	Number of phenological cycles detected in target year	Number of cycles	1	0 – 6	32767
First Vegetation Cycle: Largest EVI2 amplitude cycle					
Phenology Timing Metrics					

OGI	Onset Greenness Increase (Date of 15% greenness increase)	Day of year, where 1 indicates January 1 of target year	1	-181 – 548	32767
50PCGI	50 Percent Greenness Increase (Date of 50% greenness increase)	Day of year	1	-181 – 548	32767
OGMx	Onset Greenness Maximum (Date of 90% greenness increase)	Day of year	1	-181 – 548	32767
Peak	Date of Cycle Peak	Day of year	1	1 – 366	32767
OGD	Onset Greenness Decrease (Date of 10% greenness decrease)	Day of year	1	-181 – 548	32767
50PCGD	50 Percent Greenness Decrease (Date of 50% greenness decrease)	Day of year	1	-181 – 548	32767
OGMn	Onset Greenness Minimum (Date of 85% greenness decrease)	Day of year	1	-181 – 548	32767
Vegetation Indices					
EVImax	Maximum two-band Enhanced Vegetation Index (EVI2) during vegetation cycle	-	0.0001	0 – 10000	32767
EVIamp	EVI2 Amplitude during vegetation cycle	-	0.0001	0 – 10000	32767
EVIarea	Integrated EVI2 during vegetation cycle	-	0.01	0 – 32766	32767
Second Vegetation Cycle: Second Largest EVI2 amplitude cycle					
Phenology Timing Metrics					
OGI_2	Onset Greenness Increase (Date of 15% greenness increase)	Day of year	1	-181 – 548	32767
50PCGI_2	50 Percent Greenness Increase (Date of 50% greenness increase)	Day of year	1	-181 – 548	32767
OGMx_2	Onset Greenness Maximum (Date of 90% greenness increase)	Day of year	1	-181 – 548	32767
Peak_2	Date of Cycle Peak	Day of year	1	1 – 366	32767
OGD_2	Onset Greenness Decrease (Date of 10% greenness decrease)	Day of year	1	-181 – 548	32767
50PCGD_2	50 Percent Greenness Decrease (Date of 50% greenness decrease)	Day of year	1	-181 – 548	32767
OGMn_2	Onset Greenness Minimum (Date of 85% greenness decrease)	Day of year	1	-181 – 548	32767
Vegetation Indices					
EVImax_2	EVI2 maximum during vegetation cycle	-	0.0001	0 – 10000	32767
EVIamp_2	EVI2 Amplitude during vegetation cycle	-	0.0001	0 – 10000	32767
EVIarea_2	EVI2 area during vegetation cycle	-	0.01	0 – 32766	32767
Quality Assurance (QA)					
QA	Quality Assurance for first vegetation cycle	-	1	1 – 4	-
QA_2	Quality Assurance for second vegetation cycle	-	1	1 – 4	-
numObs	Number of days with clear observations in calendar year	Days	1	0 – 366	32767

3. Application and Derivation

Vegetation phenology is a key control on water, energy, and carbon fluxes in terrestrial ecosystems. Because vegetation canopies are heterogeneous, spatially explicit information related to seasonality in vegetation activity provides valuable information for studies that use eddy covariance measurements to study land-atmosphere interactions. These land surface phenology (LSP) data can be used to assess satellite-based LSP products, to evaluate predictions from land surface models, and to analyze processes controlling the seasonality of ecosystem-scale carbon, water, and energy fluxes.

4. Quality Assessment

Exhaustive technical validation for phenometrics from PlanetScope imagery has been reported in Bolton et al. (2020), suggesting phenological metrics from PlanetScope time series show strong agreement with other independent LSP records and provide fine-scale variations in LSP that are not captured in moderate to coarse resolution of LSP datasets. The previous approach was extended using the most up-to-date independent data sets. Specifically, first, mid-greenup dates (i.e., 50PCGI) and EVI2 seasonal amplitude images for three representative sites were provided. Second, mid- greenup and mid-greendown dates (i.e., 50PCGI and 50PCGD, respectively) from PlanetScope imagery were compared to the independent LSP dataset from HLS time series (i.e., MSLSP30NA V011 (Chu et al., 2021)). Lastly, 50PCGI and 50PCGD from PlanetScope were compared against corresponding values estimated from PhenoCam G_{CC} time series to provide a ground-based basis for assessing the realism and quality of phenometrics from PlanetScope.

Quality assurance metrics for each pixel are included with this dataset.

5. Data Acquisition, Materials, and Methods

A total of 104 AmeriFlux Core Sites were selected covering a range of geographical extents across the US (Novick et al., 2018). Among these, 44 sites are co-registered in the National Ecological Observatory Network (NEON).

Table 3. List of sites.

Site Code	Site Full Name	Site Code	Site Full Name
PR-xGU	NEON Guanica Forest	US-Var	Vaira Ranch
PR-xLA	NEON Lajas Experimental Station	US-Vcm	Valles Caldera Mixed Conifer
US-ALQ	Allequash Creek Site	US-Vcp	Valles Caldera Ponderosa Pine
US-ARM	ARM Southern Great Plains site	US-Vcs	Valles Caldera Sulphur Springs Mixed Conifer
US-Bi1	Bouldin Island Alfalfa	US-WCr	Willow Creek
US-Bi2	Bouldin Island corn	US-Whs	Walnut Gulch Lucky Hills Shrub
US-BMM	Bangtail Mountain Meadow	US-Wjs	Willard Juniper Savannah
US-BRG	Bayles Road Grassland Tower	US-Wkg	Walnut Gulch Kendall Grasslands
US-CF1	CAF-LTAR Cook East	US-xAB	NEON Abby Road
US-CF2	CAF-LTAR Cook West	US-xAE	NEON Klemme Range Research Station
US-CF3	CAF-LTAR Boyd North	US-xBL	NEON Blandy Experimental Farm
US-CF4	CAF-LTAR Boyd South	US-xBN	NEON Caribou Creek - Poker Flats Watershed
US-Ha1	Harvard Forest EMS Tower	US-xBR	NEON Bartlett Experimental Forest
US-Ha2	Harvard Forest Hemlock Site	US-xCL	NEON LBJ National Grassland
US-HB1	North Inlet Crab Haul Creek	US-xCP	NEON Central Plains Experimental Range
US-HB2	Hobcaw Barony Mature Longleaf Pine	US-xDC	NEON Dakota Coteau Field School
US-HB3	Hobcaw Barony Longleaf Pine Restoration	US-xDJ	NEON Delta Junction
US-Ho1	Howland Forest	US-xDL	NEON Dead Lake
US-ICs	Imnavait Creek Watershed Wet Sedge Tundra	US-xDS	NEON Disney Wilderness Preserve
US-KFS	Kansas Field Station	US-xGR	NEON Great Smoky Mountains National Park
US-Me2	Metolius mature ponderosa pine	US-xHA	NEON Harvard Forest
US-Me6	Metolius Young Pine Burn	US-xHE	NEON Healy
US-MMS	Morgan Monroe State Forest	US-xJE	NEON Jones Ecological Research Center
US-Mpj	Mountainair Pinyon-Juniper Woodland	US-xJR	NEON Jornada LTER
US-Myb	Mayberry Wetland	US-xKA	NEON Konza Prairie Biological Station-Relocatable
US-NC2	NC_Loblolly Plantation	US-xKZ	NEON Konza Prairie Biological Station
US-NC3	NC_Clearcut#3	US-xLE	NEON Lenoir Landing
US-NC4	NC_AlligatorRiver	US-xMB	NEON Moab
US-Ne1	Mead-irrigated continuous maize site	US-xML	NEON Mountain Lake Biological Station
US-Ne2	Mead-irrigated maize-soybean rotation site	US-xNG	NEON Northern Great Plains Research Laboratory
US-Ne3	Mead-rainfed maize-soybean rotation site	US-xNQ	NEON Onaqui-Ault
US-NR1	Niwot Ridge Forest	US-xNW	NEON Niwot Ridge Mountain Research Station
US-PFa	Park Falls	US-xPU	NEON Pu'u Maka'ala Natural Area Reserve
US-Rms	RCEW Mountain Big Sagebrush	US-xRM	NEON Rocky Mountain National Park
US-Ro4	Rosemount Prairie	US-xRN	NEON Oak Ridge National Lab

US-Ro5	Rosemount I18_South	US-xSB	NEON Ordway-Swisher Biological Station
US-Ro6	Rosemount I18_North	US-xSC	NEON Smithsonian Conservation Biology Institute
US-Rws	Reynolds Creek Wyoming big sagebrush	US-xSE	NEON Smithsonian Environmental Research Center
US-Seg	Sevilleta grassland	US-xSJ	NEON San Joaquin Experimental Range
US-Ses	Sevilleta shrubland	US-xSL	NEON North Sterling
US-Sne	Sherman Island Restored Wetland	US-xSP	NEON Soaproot Saddle
US-Snf	Sherman Barn	US-xSR	NEON Santa Rita Experimental Range
US-SRG	Santa Rita Grassland	US-xST	NEON Steigerwaldt Land Services
US-SRM	Santa Rita Mesquite	US-xTA	NEON Talladega National Forest
US-Syv	Sylvania Wilderness Area	US-xTE	NEON Lower Teakettle
US-Ton	Tonzi Ranch	US-xTL	NEON Toolik
US-Tw1	Twitchell Wetland West Pond	US-xTR	NEON Treehaven
US-Tw3	Twitchell Alfalfa	US-xUK	NEON The University of Kansas Field Station
US-Tw4	Twitchell East End Wetland	US-xUN	NEON Univ. of Notre Dame Environmental Research Center
US-Tw5	East Pond Wetland	US-xWD	NEON Woodworth
US-UMB	Univ. of Mich. Biological Station	US-xWR	NEON Wind River Experimental Forest
US-UMd	UMBS Disturbance	US-xYE	NEON Yellowstone Northern Range

Image download

A Python script was created to interact with Planet's RESTful API interface (https://developers.planet.com/docs/apis/data/) to search, request, and download the dataset. For each site, an area of interest (AOI) was defined by a 10-km x 10-km polygon centered at the flux tower for each site. This AOI window was chosen because 80% of monthly footprint climatologies at eddy covariance towers range from 10^3 to 10^7 m^2 (Chu et al., 2021). The polygon was loaded as a GeoJson (included with this dataset) and used to submit search requests to the API. The following additional search filters were applied: (1) quality category classified as standard; (2) cloud cover less than or equal to 50%; and (3) ground control as true. Searches were done on a per-year basis between 2016 and 2021. The resulting data set included over 1.8 million unique files with a total volume of 62.2 TB.

Image processing

Low quality pixels were excluded for all 4 bands (i.e., blue, green, red, and near-infrared). Specifically, pixels were excluded if the value of Unusable Data Mask was not 0, which represents the pixel is cloud contaminated or non- images area, or the value of Usable Data Mask is 0, which represents that the pixel is not clear due to snow, shadow, haze, or cloud. Next, all images were cropped using the AOI. For dates with multiple images for the AOI, those images merged into single mosaicked image based on mean surface reflectance values for that date. The resulting database of daily surface reflectance images were sorted in chronological order, sub-divided into 200 sub-areas at each site (i.e., 0.5 km^2 each), and then stored as image stacks to facilitate parallel processing to estimate LSP metrics, where each image stack included all images from 2016 to January 2022.

Retrieving phenological metrics

Land surface phenological (LSP) metrics were estimated using an algorithm adapted from Bolton et al. (2020), which extracts the timing of key phenological transition dates during the growing season (Moon et al., 2021). Prior to LSP estimation, daily images of the two-band Enhanced Vegetation Index (EVI2) data were generated from PlanetScope imagery. EVI2 was used rather than other vegetation indices such as Enhanced Vegetation Index (EVI) or Normalized Difference Vegetation Index (NDVI) because EVI2 is less prone to saturation over dense canopy cover and soil background influences (Jiang, et al., 2008). Therefore, phenological metrics derived from the EVI2 time series tend to have better agreement with PhenoCam observations than those from NDVI time series (Klosterman et al., 2014).

Daily images of EVI2 data were generated from the PlanetScope imagery and then interpolated to create smooth time series of daily EVI2 values at each pixel. Sources of variation related to clouds, atmospheric aerosols, and snow were detected and removed from the EVI2 time series at each pixel based on both data mask layers and outlier detection criteria (i.e., de-spiking and removing negative EVI2 values). Second, the 'background' EVI2 value (i.e., the minimum EVI2 value outside of the growing season) was identified based on the 10^{th} percentile of snow-free EVI2 values at each pixel. Any dates with EVI2 values below the background value were replaced with the background EVI2. Third, penalized cubic smoothing splines were used to create daily EVI2 time series across all years of available data for gap filling and smoothing the time series. Complete details on these steps are given in Bolton et al. (2020).

LSP metrics are estimated for each pixel in up to two growth cycles in each year. If no growth cycles are detected, the algorithm returns NA values. If more than two growth cycles are detected, which is rare but does occur (e.g., alfalfa), the algorithm records seven LSP metrics corresponding to the two growth cycles with the largest EVI2 amplitude. The resulting data set includes seven 'timing' metrics that identify the timing of: greenup onset; mid-greenup; maturity; peak EVI2; greendown onset; mid-greendown, and dormancy. These metrics record the day of year (DOY) when the EVI2 time series exceeds 15%, 50%, and 90% of EVI2 amplitude during the greenup phase, reaches its maximum, and goes below 90%, 50%, and 15% of EVI2 amplitude during the greendown phase. In addition, three additional metrics were recorded that characterize the magnitude of seasonality and total 'greenness' at each pixel in each growth cycle: the EVI2 amplitude, the maximum EVI2, and the growing season integral of EVI2, which is calculated as the sum of daily EVI2 values between the growth cycle start- and end-dates (i.e., from greenup onset to dormancy). See variables listed in Table 2.

Quality assurance flags

Quality Assurance (QA) layers were estimated at each pixel based on the density of observations and the quality of cubic spline fits during each phase of the growing season. QA value 1 (high quality) was assigned if the correlation coefficient of the relationship between observation versus splined was greater than 0.75 and the length of maximum gap over the segment was less than 30 days; QA value 2 (moderate quality) was assigned if the correlation coefficient of the relationship between observation versus splined is less than 0.75 or the length of maximum gap over the segment was greater than 30 days; QA value 3 (low quality) was assigned if the correlation coefficient of the relationship between observation versus splined was less than 0.75 and the length of maximum gap over the segment was less than 30 days; and QA value 4 was assigned if no cycles detected or the algorithm was not run.

Additional details on methods are provided in Moon et al. (2021).

6. Data Access

These data are available through the Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC).

Land Surface Phenology, Eddy Covariance Tower Sites, North America, 2017-2021

Contact for Data Center Access Information:

- E-mail: uso@daac.ornl.gov
- Telephone: +1 (865) 241-3952

7. References

Bolton, D.K., J.M. Gray, E.K. Melaas, M. Moon, L. Eklundh, and M.A. Friedl. 2020. Continental-scale land surface phenology from harmonized Landsat 8 and Sentinel-2 imagery. Remote Sensing of Environment 240:111685. https://doi.org/10.1016/j.rse.2020.111685

Chu, H., X. Luo, Z. Ouyang, W.S. Chan, S. Dengel, S.C. Biraud, M.S. Torn, S. Metzger, J. Kumar, M.A. Arain, T.J. Arkebauer, D. Baldocchi, C. Bernacchi, D. Billesbach, T.A. Black, P.D. Blanken, G. Bohrer, R. Bracho, S. Brown, N.A. Brunsell, J. Chen, X. Chen, K. Clark, A.R. Desai, T. Duman, D. Durden, S. Fares, I. Forbrich, J.A. Gamon, C.M. Gough, T. Griffis, M. Helbig, D. Hollinger, E. Humphreys, H. Ikawa, H. Iwata, Y. Ju, J.F. Knowles, S.H. Knox, H. Kobayashi, T. Kolb, B. Law, X. Lee, M. Litvak, H. Liu, J.W. Munger, A. Noormets, K. Novick, S.F. Oberbauer, W. Oechel, P. Oikawa, S.A. Papuga, E. Pendall, P. Prajapati, J. Prueger, W.L. Quinton, A.D. Richardson, E.S. Russell, R.L. Scott, G. Starr, R. Staebler, P.C. Stoy, E. Stuart-Haëntjens, O. Sonnentag, R.C. Sullivan, A. Suyker, M. Ueyama, R. Vargas, J.D. Wood, and D. Zona. 2021. Representativeness of eddy-covariance flux footprints for areas surrounding AmeriFlux sites. Agricultural and Forest Meteorology 301–302:108350. https://doi.org/10.1016/j.agrformet.2021.108350

Jiang, Z., A. Huete, K. Didan, and T. Miura. 2008. Development of a two-band enhanced vegetation index without a blue band. Remote Sensing of Environment 112:3833–3845. https://doi.org/10.1016/j.rse.2008.06.006

Klosterman, S.T., K. Hufkens, J.M. Gray, E. Melaas, O. Sonnentag, I. Lavine, L. Mitchell, R. Norman, M.A. Friedl, and A.D. Richardson. 2014. Evaluating remote sensing of deciduous forest phenology at multiple spatial scales using PhenoCam imagery. Biogeosciences 11:4305–4320. https://doi.org/10.5194/bg-11-4305-2014

Moon, M., A.D. Richardson, and M.A. Friedl. 2021. Multiscale assessment of land surface phenology from harmonized Landsat 8 and Sentinel-2, PlanetScope, and PhenoCam imagery. Remote Sensing of Environment 266:112716. https://doi.org/10.1016/j.rse.2021.112716

Novick, K.A., J.A. Biederman, A.R. Desai, M.E. Litvak, D.J. P. Moore, R.L. Scott, and M.S. Torn. 2018. The AmeriFlux network: A coalition of the willing. Agricultural and Forest Meteorology 249:444–456. https://doi.org/10.1016/J.AGRFORMET.2017.10.009