Eddy Flux and Meteorology over Deciduous Forest, Prairie, and Soybean Ecosystems in Missouri, USA, during the Total Solar Eclipse of 2017

Summary:

Eddy fluxes and meteorology data are reported at high temporal resolution for three flux tower sites in Mid-Missouri before, during, and after the Total Solar Eclipse of August 21, 2017. Mid-Missouri experienced up to 2 minutes and 40 seconds of totality at around solar noon during the eclipse (Fig. 1). The sites are located in deciduous oak-hickory forest, native prairie, and soybean ecosystems (Table 1 and Fig. 3). Eddy fluxes were computed using a wavelet-based approach that permitted the calculation of two-minute mean fluxes without losing low frequency flux contributions (Fig. 2). During the eclipse, standard meteorological variables were sampled and recorded at 5 second intervals. The two-minute means of fluxes and meteorology are reported.

This data product includes three NetCDF files (identically structured), each containing data from one flux tower site.

These data have been reported and analyzed in Wood et al. (2019).

Wood, JD, Sadler EJ, Fox NI, Greer ST, Gu L, Guinan PE, Lupo AR, Market PS, Rochette SM, Speck A, and White LD (2019). **Land-atmosphere Responses to a Total Solar Eclipse in Three Ecosystems with Contrasting Structure and Physiology**, Journal of Geophysical Research: Atmospheres, 124, 530–543, https://doi.org/10.1029/2018JD029630

Table 1. Characteristics of the three eddy covariance flux tower sites in mid-Missouri.

Site	Network (Site ID)	IGBP class	Latitude	Longitude	Elevation (meters amsl)	References
Forest	AmeriFlux (US-MOz)	DBF	38.7441	-92.2000	212	Gu et al., (2016)
Soybean	LTAR (CMRB-ASP)	CRO	39.2298	-92.1168	263	Wood et al., (2019); Sadler et al., (2015)
Prairie	LTAR (CMRB-TP)	GRA	38.9491	-91.9951	272	Wood et al., (2019)

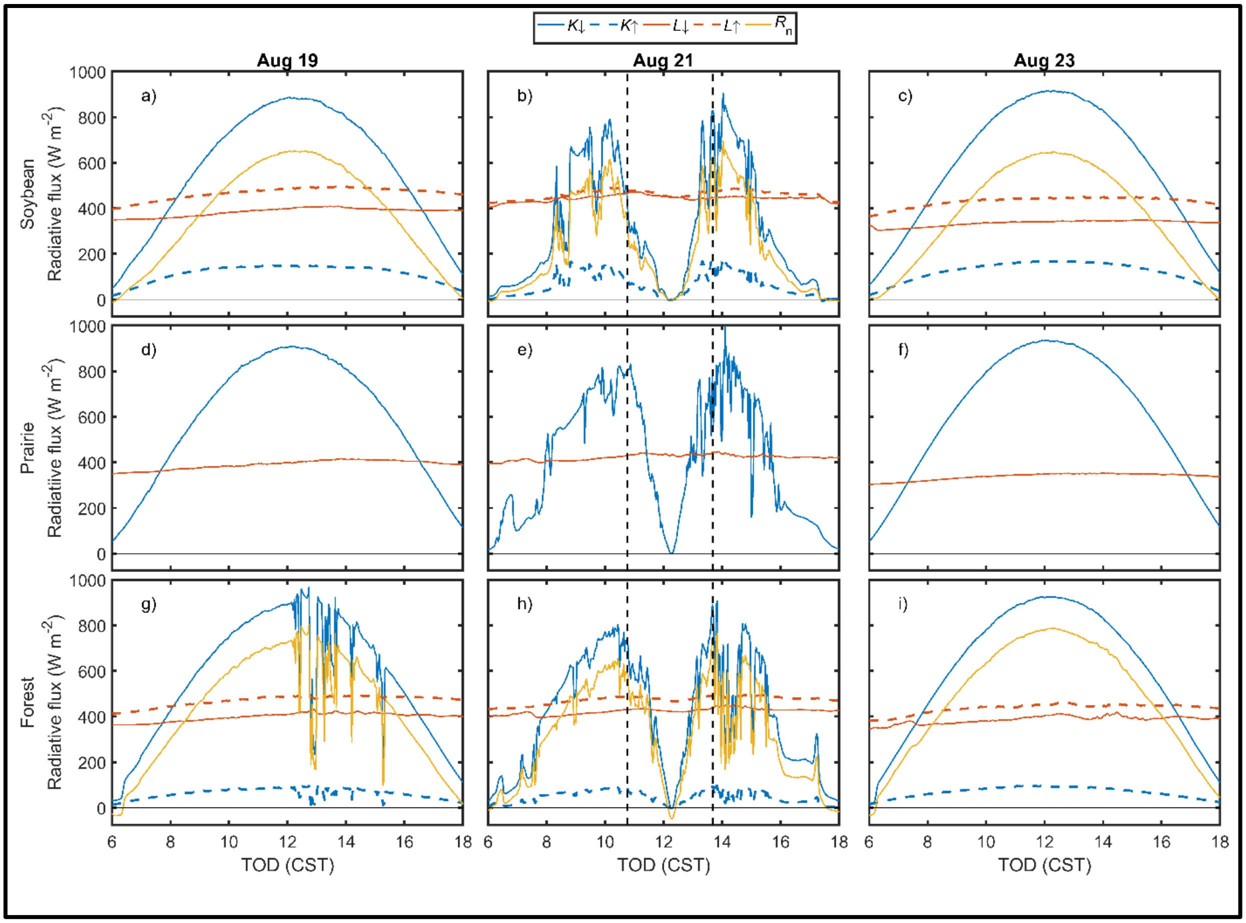

Figure 1. Diurnal cycles of radiation fluxes (2 min means) on the day of the eclipse (2017-Aug-21; middle column) and clear-sky reference days before (2017-Aug-19; left column) and after (2017-Aug-23; right column) the eclipse at the (a, b, c) soybean, (d, e, f) prairie, and (g, h, i) forest sites. $K_\downarrow$ = incoming solar radiation, $K_\uparrow$ = outgoing solar radiation, $L_\downarrow$ = incoming longwave radiation, $L_\uparrow$ = outgoing longwave radiation, R_n = net radiation. The only radiation fluxes measured at the prairie sites were the incoming components ($K_\downarrow$ and $L_\downarrow$). The vertical dashed lines in the middle column panels represent the timing of eclipse 1st and 4th contacts. From Wood, et al., 2019.

Data Citation:

Cite this data set as follows:

Wood, J.D., E.J. Sadler, N.I. Fox, S.T. Greer, L. Gu, P.E. Guinan, A.R. Lupo, P.S. Market, S.M. Rochette, A. Speck, and L.D. White. **Eddy Flux and Meteorology over Deciduous Forest, Prairie, and Soybean Ecosystems in Missouri, USA, during the Total Solar Eclipse of 2017**. Oak Ridge National Laboratory, TES SFA, U.S. Department of Energy, Oak Ridge, Tennessee, U.S.A. https://doi.org/10.25581/ornlsfa.017/1579907

Please include this citation to the related publication:

Wood, JD, Sadler EJ, Fox NI, Greer ST, Gu L, Guinan PE, Lupo AR, Market PS, Rochette SM, Speck A, and White LD (2019). Land-atmosphere Responses to a Total Solar Eclipse in Three Ecosystems with Contrasting Structure and Physiology, Journal of Geophysical Research: Atmospheres, 124, 530–543, https://doi.org/10.1029/2018JD029630

Acknowledgments: This work was partially supported by funding from NASA (grant NNX17AH79G) through the Interdisciplinary Science For Eclipse 2017 program. This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Biological and Environmental Research Program, Climate and Environmental Sciences Division through Oak Ridge National Laboratory's Terrestrial Ecosystem Science-Science Focus Area (JDW and LG). ORNL is managed by UT-Battelle, LLC, for the U.S. Department of Energy under contract DE-AC05-00OR22725. EJS and JDW acknowledge support by USDA-ARS Project Number: 5070-12130-005-00D "Long-term management of water resources in the Central Mississippi River Basin" for the soybean and prairie sites. This material is based upon work supported by the National Science Foundation under Award IIA-1355406 (NIF, PAM and ARL). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation. Tucker Prairie is a preserve of the University of Missouri and managed by the Division of Biological Sciences.

Data and Documentation Access:

Get Data

For public access to data please visit the ORNL TES-SFA Web Site: https://tes-sfa.ornl.gov/home

Links to Supplemental Data and Information

AmeriFlux: Missouri Ozark / US-MOz (http://ameriflux.lbl.gov/sites/siteinfo/US-MOz)

Central Mississippi River Basin (CMRB) Long-term Agro-Ecosystem Research (LTAR) network site (https://ltar.nal.usda.gov)

Related Data Sets:

TBD

ORNL TES-SFA Data Policy: Archiving, Sharing, and Fair-Use

Project Description

Data from three flux towers in Mid-Missouri were synthesized and analyzed to examine ecosystem responses to the total solar eclipse of 2017. The Missouri Ozark AmeriFlux (MOFLUX) site has been monitored since being established in an oak-hickory (*Quercus-Carya*) forest in 2004 with funding from the ORNL TES-SFA. The soybean and prairie sites were established in 2015 and 2017, respectively, and are funded through the USDA-ARS Long-term Agroecosystem Research Network Program.

Table of Contents:

1. Data Set Overview:

This data set reports meteorological and eddy flux observations in forest, prairie and soybean ecosystems during the total solar eclipse of 2017. Data are reported for daytime periods on eclipse day, and on clear-sky reference days flanking the eclipse day.

2. Data Characteristics:

Spatial Coverage

The towers in Mid-Missouri (Figure 3) are all located in ecosystems with expansive fetch in all directions. The geographic location of each tower is provided in the site boundary table below.

Spatial Resolution

Single point flux towers

Site boundaries: Latitude and longitude given in decimal degrees.

Site	Westernmost Longitude	Easternmost Longitude	Northernmost Latitude	Southernmost Latitude	Elevation (meters amsl)	Geodetic Datum
Forest	-92.2000	-92.2000	38.7441	38.7441	219	WGS84
Soybean	-92.1168	-92.1168	39.2298	39.2298	263	WGS84
Prairie	-91.9951	-91.9951	38.9491	38.9491	272	WGS84

Temporal Coverage

The data cover portions of three days from August 19 through 23, 2017. Data are provided for August 19, 21 (eclipse day), and 23, 2018.

Temporal Resolution

Data are reported as two-minute means.

Data File Description

This data product includes three NetCDF files (identically structured), each containing data from one site. Two-minute average eddy flux and meteorological data are provided for eclipse day (21 August, 2017), and on clear sky reference days flanking the eclipse (19 and 23 August, 2017).

Note: for each day (19, 21, 23 August), data are <u>only provided</u> for between 0400 and 2000 hours local standard time. These were the times for which eddy flux calculations were performed.

There are, therefore, non-uniform time-steps in the data between days – be sure to use the provided timestamps to time-reference data records.

<u>Data Dictionary:</u>

Data files: Data are provided in netcdf4 format in three separate files:

- Forest_eclipse_data.nc
- Soybean_eclipse_data.nc
- Prairie_eclipse_data.nc

Site specific information is provided in the global attributes for each file.

Definition of the NetCDF Global Attributes of each file.

Global Attribute	Definition
TIME_START	Timestamp of first data record
TIME_END	Timestamp of last data record
SITE_NAME	The name of the site
LATITUDE	The site latitude
LONGITUDE	The site longitude
TIME_ZONE	The time zone in which the site is located
IGBP_CLASS	The International Geosphere-Biosphere Program biome classification of the site
VEGETATION_INFO	More specific information on the vegetation.

NetCDF Header

The structure of each self-describing NetCDF file is provided below, using the Forest_eclipse_data.nc file as an example:

```
Format: netcdf4

Global Attributes:
        TIME_START     = '201708190400'
        TIME_END       = '201708232000'
        SITE_NAME      = 'MOFLUX (AmeriFlux US-MOz)'
        LATITUDE       = '38.7441'
        LONGITUDE      = '-92.2000'
        TIME_ZONE      = 'CST'
        IGBP_CLASS     = 'DBF'
        VEGETATION_INFO = 'Oak-hickory (Quercus-Carya) forest'

Dimensions:
        NUM_RECORDS = 1440
        DIMtime     = 12

Variables:
   TIMESTAMP_START
        Size:      1440x12
        Dimensions: NUM_RECORDS,DIMtime
        Datatype:   char
        Attributes:
                 long_name = 'ISO timestamp start of averaging period (yyyymmddHHMM)'
                 units     = 'Dimensionless'
                 comment   = 'Time in CST'
   TIMESTAMP_END
        Size:      1440x12
```

```
    Dimensions: NUM_RECORDS,DIMtime
    Datatype:   char
    Attributes:
            long_name = 'ISO timestamp end of averaging period (yyyymmddHHMM)'
            units     = 'Dimensionless'
            comment   = ' Time in CST'
LE
    Size:       1440x1
    Dimensions: NUM_RECORDS
    Datatype:   double
    Attributes:
            long_name = 'Eddy flux of latent heat'
            units     = 'W/m^2'
            comment   = ''
H
    Size:       1440x1
    Dimensions: NUM_RECORDS
    Datatype:   double
    Attributes:
            long_name = 'Eddy flux of sensible heat'
            units     = 'W/m^2'
            comment   = ''
USTAR
    Size:       1440x1
    Dimensions: NUM_RECORDS
    Datatype:   double
    Attributes:
            long_name = 'Friction velocity'
            units     = 'm/s'
            comment   = ''
U_SIGMA
    Size:       1440x1
    Dimensions: NUM_RECORDS
    Datatype:   double
    Attributes:
            long_name = 'Standard deviation of longitudinal wind velocity'
            units     = 'm/s'
            comment   = ''
W_SIGMA
    Size:       1440x1
    Dimensions: NUM_RECORDS
    Datatype:   double
    Attributes:
            long_name = 'Standard deviation of vertical wind velocity'
            units     = 'm/s'
            comment   = ''
ZL
    Size:       1440x1
    Dimensions: NUM_RECORDS
    Datatype:   double
    Attributes:
            long_name = 'Dimensionless stability parameter, (z-d)/L'
            units     = 'Dimensionless'
```

```
            comment   = ''
SW_IN
      Size:      1440x1
      Dimensions: NUM_RECORDS
      Datatype:   double
      Attributes:
            long_name = 'Incoming shortwave radiation'
            units     = 'W/m^2'
            comment   = ''
SW_OUT
      Size:      1440x1
      Dimensions: NUM_RECORDS
      Datatype:   double
      Attributes:
            long_name = 'Outgoing shortwave radiation'
            units     = 'W/m^2'
            comment   = ''
LW_IN
      Size:      1440x1
      Dimensions: NUM_RECORDS
      Datatype:   double
      Attributes:
            long_name = 'Incoming longwave radiation'
            units     = 'W/m^2'
            comment   = ''
LW_OUT
      Size:      1440x1
      Dimensions: NUM_RECORDS
      Datatype:   double
      Attributes:
            long_name = 'Outgoing longwave radiation'
            units     = 'W/m^2'
            comment   = ''
TA
      Size:      1440x1
      Dimensions: NUM_RECORDS
      Datatype:   double
      Attributes:
            long_name = 'Air temperature'
            units     = 'degrees C'
            comment   = ''
VP
      Size:      1440x1
      Dimensions: NUM_RECORDS
      Datatype:   double
      Attributes:
            long_name = 'Atmospheric vapor pressure of water'
            units     = 'kPa'
            comment   = ''
VPD
      Size:      1440x1
      Dimensions: NUM_RECORDS
      Datatype:   double
```

```
    Attributes:
        long_name = 'Vapor pressure deficit of the atmosphere'
        units     = 'kPa'
        comment   = ''
PA
    Size:       1440x1
    Dimensions: NUM_RECORDS
    Datatype:   double
    Attributes:
        long_name = 'Atmospheric pressure'
        units     = 'kPa'
        comment   = ''
WS
    Size:       1440x1
    Dimensions: NUM_RECORDS
    Datatype:   double
    Attributes:
        long_name = 'Mean horizontal wind speed'
        units     = 'm/s'
        comment   = ''
WD
    Size:       1440x1
    Dimensions: NUM_RECORDS
    Datatype:   double
    Attributes:
        long_name = 'Cardinal direction in degrees'
        units     = 'm/s'
        comment   = ''
```

File Use

There are multiple software packages that can work with NetCDF files:

Panoply is good for general file visualization (https://www.giss.nasa.gov/tools/panoply/).

Here are some simple commands for interacting with NetCDF files in MATLAB.

Command (Type in Command Window)	**Description**
`ncdisp(filename)`	Displays the contents of NetCDF file specified by `filename` in the Command Window (the above file structure was obtained by calling `ncdisp`)
`finfo = ncinfo(filename)`	Returns structure `finfo` that contains all information about NetCDF file specified by `filename`. This can be helpful for automating data extraction.
`ncid = netcdf.open(filename)`	Opens NetCDF file and returns `ncid`, a file identifier that is used as an input for other functions to interact with the file.

Command (Type in Command Window)	**Description**
`varid = netcdf.inqVarID(ncid,varname)`	Queries NetCDF file that has been previously opened and is represented by `ncid` to obtain the identifier for the variable specified by `varname` (a string specifying the name of the variable of interest)
`data = netcdf.getVar(ncid,varid)`	Extracts the variable specified by `varid` that is contained in file `ncid` into MATLAB variable `data`.
`netcdf.close(ncid)`	Closes an open NetCDF file.

The following example code (verified for MATLAB R2017b) will automatically extract all variables from the NetCDF file containing forest data into variables in the MATLAB workspace with the same names.

```
dirname = 'X'; % type the name of the directory where the data file is
stored
fn= 'Forest_eclipse_data'; % file name. example here is for forest data

ncdisp(fullfile(dirname,fn)) % display contents of file to command window
finfo = ncinfo(fullfile(dirname,fn)); % get file info

ncid = netcdf.open(fullfile(dirname,fn),'NOWRITE'); % open file

% loop across all variables and extract each variable into a MATLAB variable
(vector) with the same name.
for i = 1:length(finfo.Variables)
       eval([finfo.Variables(i).Name ' = netcdf.getVar(ncid,
            netcdf.inqVarID(ncid, ''' finfo.Variables(i).Name '''));']);
end

netcdf.close(ncid); % close file
```

3. Data Application and Derivation:

Mid-Missouri experienced up to 2 min 40 s of totality at around solar noon during the total eclipse of 2017. The eclipse responses in three contrasting ecosystems (forest, prairie and soybeans) was examined. Turbulence was suppressed during the eclipse at all sites, however, there was also an amplified signal at the soybean during the passage of a gust front. The eddy fluxes of energy were highly coherent with the solar forcing with the latent and sensible heat fluxes approaching 0 W m^{-2} and changing in direction, respectively. For the prairie site, we estimated a canopy scale time constant for the surface conductance light response of 10 min. Although the eclipse imparted large forcings on surface energy balances, the air temperature response was relatively muted (1.5–2.5 °C decrease) due to the absence of topographic effects and the relatively moist land and atmosphere.

4. Quality Assessment:

These data are considered at **Quality Level 2**. Level 2 indicates a complete, externally consistent data product that has undergone interpretative and diagnostic analyses. The data product has been subjected to quality checks and data management procedures (Level 1).

5. Data Acquisition Materials and Methods:

Measurements and Data Processing

At each site there was a tower instrumented with an eddy covariance system and sensors to measure supporting meteorology. High frequency data were recorded at a sampling frequency of 10 Hz, while supporting meteorology was sampled and recorded at 5 s intervals. Eddy fluxes were computed from the high frequency data using a wavelet-based approach to permit the calculation of two-minute mean fluxes, without losing low frequency flux contributions. Two-minute means were calculated for supporting meteorological observations.

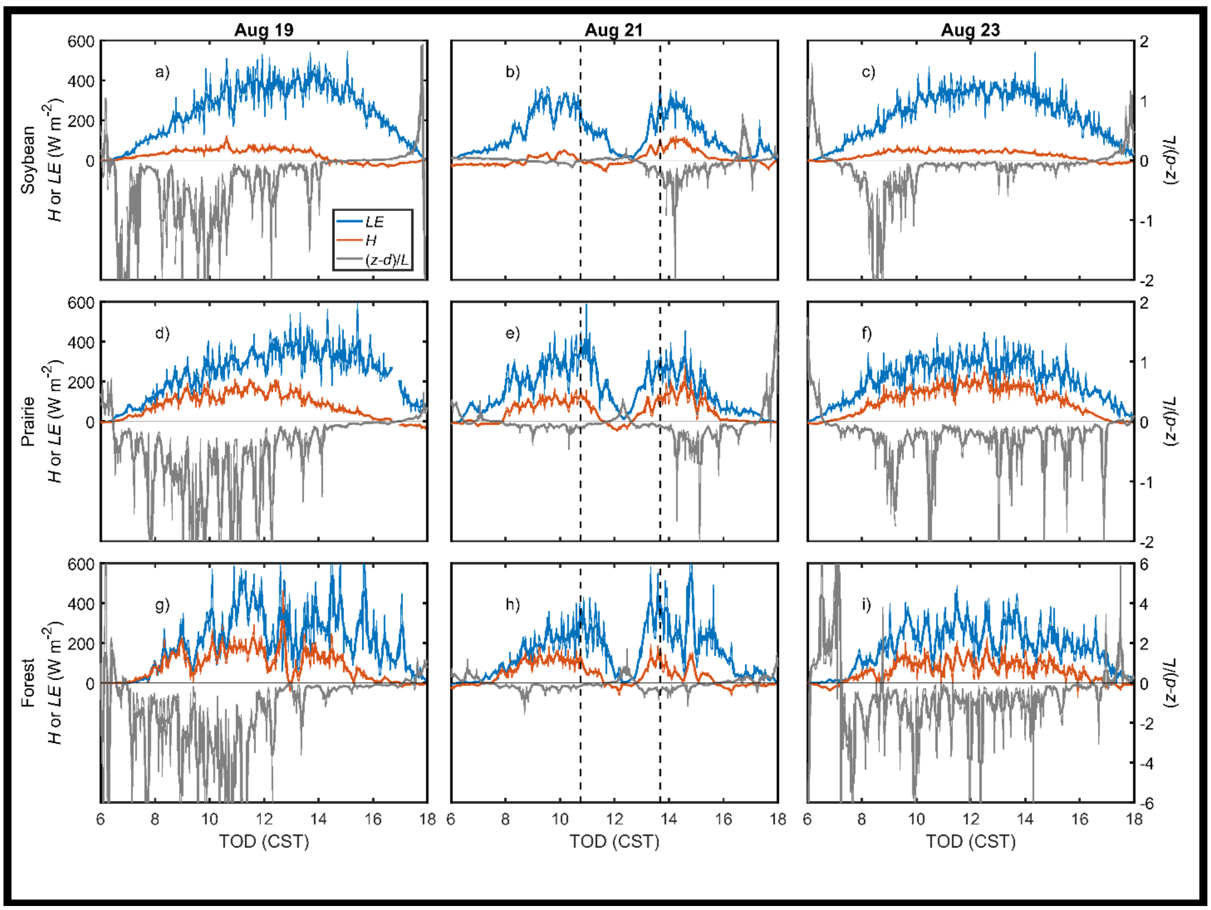

Figure 2. Diurnal cycles of wavelet-based eddy fluxes of latent (*LE*) and sensible (*H*) heat), and the dimensionless stability parameter, (*z-d*)/*L*, on the day of the eclipse (2017-Aug-21; middle column) and clear-sky reference days before (2017-Aug-19; left column) and after (2017-Aug-

23; right column) the eclipse at the (a, b, c) soybean, (d, e, f) prairie, and (g, h, i) forest sites. Note that the y-axis scale for dimensionless stability in the bottom row is different from the top two. Thin lines represent data at 2 min resolution, and the thick lines, 10 min running means. The vertical dashed lines in the middle column panels represent the timing of eclipse 1st and 4th contacts. z = measurement height; d = height of zero plane displacement (estimated as 2/3 canopy height); L = Obukhov length. From Wood, et al., 2019.

Site Descriptions

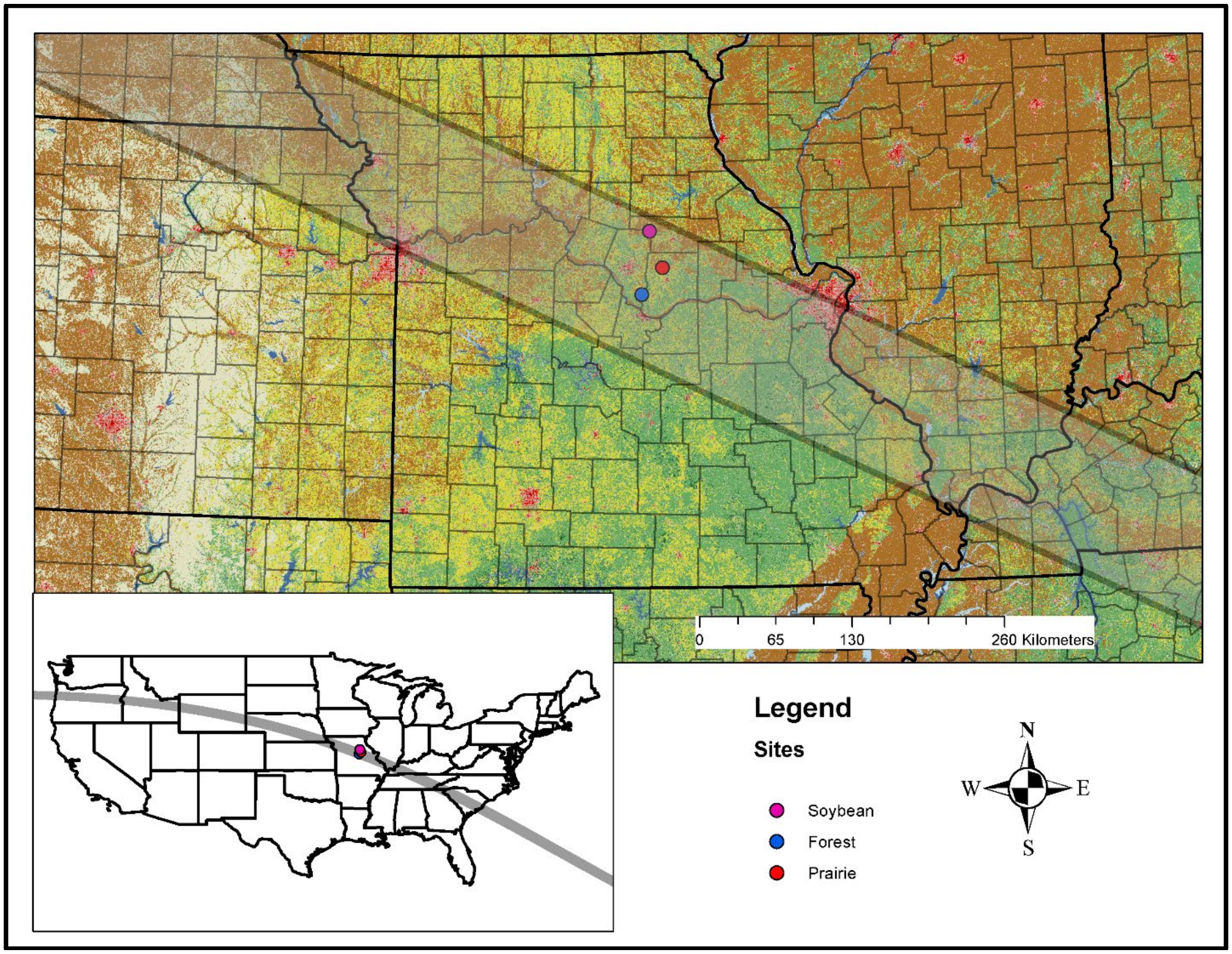

Figure 3. Locations of the three eddy covariance flux tower sites in mid-Missouri relative to the path of totality that is represented by the gray-shaded band. In the main panel, land cover (National Land Cover Database, 2011) is represented by different colors: Brown = cultivated crops, yellow = pasture/hay, light green = deciduous forest, red/pink = urban. The inset map of the conterminous United States also shows the study sites and the path of totality. Source: Wood et al., 2019.

Forest

The MOFLUX forest site is located in the University of Missouri Baskett Wildlife Research area (BWREA), situated in the Ozark region of central Missouri. The site is uniquely located in the ecologically important transitional zone between the central hardwood region and the central grassland region of the US. The land has been publicly owned since the 1930s, and is on a land tract that was forested with the same dominant species before settlement in the early 1800s. BWREA is within the Ozark Border Region of central Missouri. Second-growth upland oak-hickory forests constitute the major vegetation type at the BWREA (Rochow, 1972; Pallardy et al., 1988). Major tree species include white oak (*Quercus alba* L.), black oak (*Q. velutina* Lam.), shagbark hickory (*Carya ovata* (Mill.) K. Koch), sugar maple (*Acer saccharum* Marsh.), and eastern redcedar (*Juniperus virginiana* L.). Although these species co-occur in MOFLUX forests, there are differences in which species dominate in particular locations.

Figure 4. View of the forest from the top of the tower looking west during autumn 2017.

Soybean

The soybean (cropland) site is part of the Central Mississippi River Basin (CMRB) Long-term Agro-Ecosystem Research (LTAR) network site (Sadler et al., 2015), approximately 35 km northeast of Columbia MO. The field is under aspirational management that includes an annual winter cover crop and zero tillage (Yost et al., 2017). Prior to seeding the main crop, the cover crop is killed with herbicide and the residue left on the surface. The main crop in 2017 was soybean (*Glycine max*), which is part of a main rotation that also includes corn (*Zea mays* L.) and wheat (*Triticum* spp.).

Figure 5. View of the in the cropland site (looking northwest) that was in soybeans (*Glycine max.*) in 2017 during the eclipse. The red polygon encloses the part of the field in which the flux tower is deployed that is visible from this angle, the bottom of which is cut off.

Prairie

The Tucker Prairie site is located at the Clair L. Kucera Research station, approximately 30 km east of Columbia MO. The 60 ha prairie was owned by the William C. Tucker family for 125 years and then purchased by the University of Missouri in 1957. The National Natural Landmark (1978) and State Natural Area (1998) is owned, managed and maintained by the University of Missouri, with support from the Missouri Department of Conservation. The planosol soils have never been tilled, and the site is representative of poorly-drained prairies that historically covered much of northern Missouri in the Midwest peninsular region [*Drew*, 1947; *Dahlman and Kucera*, 1965; *Kucera et al.*, 1965]. Although there are more than 200 plant species present, the main species are big bluestem (*Andropogon gerardi*) and little bluestem (*A. scoparius*) [*Drew*, 1947; *Dahlman and Kucera*, 1965].

Figure 6. View of Tucker Prairie looking south from the tower.

6. References:

Dahlman, R. C., C. L. Kucera (1965) Root productivity and turnover in native prairie, *Ecology*, *46*, 84–89.

Drew WB (1947) Floristic composition of grazed and ungrazed prairie vegation in north-central Missouri, *Ecology*, *28*(1), 26–41.

Gu L, Pallardy SG, Yang B, Hosman KP, Mao J, Ricciuto D, Shi X, Sun Y (2016) Testing a land model in ecosystem functional space via a comparison of observed and modeled ecosystem flux responses to precipitation regimes and associated stresses in a Central U.S. forest, *Journal of Geophysical Research Biogeosciences*, *121*(7), 1884–1902, doi:10.1002/2015JG003302.

Pallardy SG, Nigh TA, Garrett HE (1988) Changes in Forest Composition in Central Missouri: 1986–1982, *The American Midland Naturalist*, 120, 380–390.

Sadler EJ et al. (2015), Long-term agroecosystem research in the Central Mississippi River Basin: Introduction, establishment, and overview, *Journal of Environmental Quality*, *44*, 3–12, doi:10.2134/jeq2014.11.0481.

Rochow, JJ (1972) A vegetational description of a mid-Missouri forest using gradient analysis techniques, *The American Midland Naturalist*, 87, 377–396.

Wood, JD, Sadler EJ, Fox NI, Greer ST, Gu L, Guinan PE, Lupo AR, Market PS, Rochette SM, Speck A, and White LD (2019). Land-atmosphere Responses to a Total Solar Eclipse in Three Ecosystems with Contrasting Structure and Physiology, Journal of Geophysical Research: Atmospheres, 124, 530–543, https://doi.org/10.1029/2018JD029630.

Yost MA, Kitchen NR, Sudduth KA, Sadler EJ, Drummond ST, Volkmann MR (2017) Long-term impact of a precision agriculture system on grain crop production, *Precision Agriculture*, *18*, 823–842, doi:10.1007/s11119-016-9490-5.

Data Access:

For public access to ORNL TES SFA data please visit the TES SFA Web Site: https://tes-sfa.ornl.gov/home

Contact for Data Access Information: https://mnspruce.ornl.gov/contact