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Final Report: Human-scale surface energy budget and ground thermal responses to soil moisture and vegetation change in flat and complex terrain

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7. PERFORMING ORGANIZATION NAMES AND ADDRESSES
University of Oklahoma
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14. ABSTRACT

15. SUBJECT TERMS

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RPPR Final Report
as of 21-Oct-2021

Agency Code: 21XD

Proposal Number: 72578EVYIP **Agreement Number: W911NF-18-1-0007**

INVESTIGATOR(S):

Name: Hernan Moreno Ramirez
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Principal: Y

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Report Date: 14-Feb-2021 Date Received: 06-Apr-2021
Final Report for Period Beginning 15-Nov-2017 and Ending 14-Nov-2020
Title: Human-scale surface energy budget and ground thermal responses to soil moisture and vegetation change in flat and complex terrain
Begin Performance Period: 15-Nov-2017 **End Performance Period:** 14-Nov-2020
Report Term: 0-Other
Submitted By: Hernan Moreno Ramirez Email: moreno@utep.edu
Phone: (915) 747-5501
Distribution Statement: 1-Approved for public release; distribution is unlimited.

STEM Degrees: 5 **STEM Participants:** 5

Major Goals: Year 1: Site-scale data analysis and dynamic model parameterization for SEB and STP predictions
(1) Compilation and analysis of 30-min radiation components, energy and water fluxes from eddy-flux and micro-meteorological stations for a typical hydrologic year without observed vegetation disturbances.
Percent accomplished 100%
(2) Collection of data from those years that underwent forest thinning and wildfire at the Flagstaff and Valles Caldera stations aiming to contrast pre- and post-disturbance conditions.
Percent accomplished 100%
(3) extraction of the corresponding drainage watershed that contains the micro-meteorological tower.
Percent accomplished 100%
(4) collection and preparation of of remote sensing data over the selected catchments for coincident periods of analysis (MRMS, MODIS, Landsat, SSURGO, NLCD, DEM, NOAA-NCDC, NASA-NLDAS) ready to use in tRIBS.
Percent accomplished 100%
(5) tRIBS model parameterization according to tower-scale observations without vegetation disturbance for continuous runs.
Percent accomplished 100%
(6) initial cross-site comparative results for a typical summer season dynamics.
Percent accomplished 100%
(7) Eddy covariance tower fetch determination (objective added after last proposal corrections before approval)
Percent accomplished 100%

Year 2: Catchment-scale effects of seasonal vegetation on SEB and STP behavior and predictions
Percent accomplished 100%
(1) Seasonal simulations and numerical investigation of vegetation effects on the dynamics of the SEB and STP a grasslands and desert sites.
Percent accomplished 100%
(2) Consideration of a benchmark base case scenario without including vegetation dynamics to evaluate the gains in modeling skill when considering vegetation phenology and change. Temperatures, soil moisture and energy partitioning values will be used as reference values to assess the benefits of including such dynamics in land-surface energy budget models.
Percent accomplished 100%
(3) Development of a model visualization tool to facilitate output interpretation.
Percent accomplished 100%

Year 3: Catchment-scale effects of abrupt vegetation change on SEB and STP behavior and predictions
Percent accomplished 100%
(1) Investigating the effects of abrupt changes in vegetation through fire and logging on the dynamics of the SEB and STP at the grasslands and forest sites, identifying the main drivers of change and the way the model captures such variability. This activity will involve the consideration of a benchmark base case scenario that includes vegetation phenology but not abrupt changes.
Percent accomplished 100%
(2) Comparison of continuous model simulations including the changes in vegetation as estimated by remotely-sensed platforms. Temperatures, soil moisture and energy partitioning values will be used to assess the observed anomalies in the energy partitioning and soil temperatures, the spatial distribution of such abnormal behavior and the benefits of including such dynamics in land-surface energy budget models to learn about their spatio-temporal variability and potential uncertainties in the modeling.
Percent accomplished 100%

Accomplishments: Please see the adjunct Technical Report to this FR. In it, I have described the major activities, all results (including publications) and key achievements of the project including simulation results and visualization tools.

Training Opportunities: • One-to-one work with mentor: PhD. student Zhen Hong. Directed Studies on Triple Collocation Method to Assess Soil Moisture Products. Mentor Hernan Moreno (Fall 2020).
• One-to-one work with mentor: M.S. student Jorge Celis. Directed Studies on Surface Energy Balance and Distributed Hydrologic Modeling. Mentor Hernan Moreno (Fall 2019).
• One-to-one work with mentor: M.S. student Tri Pham. Directed Studies on Surface Energy Balance and Distributed Hydrologic Modeling. Mentor Hernan Moreno (Fall 2019 and Spring 2020).
• One-to-one work with mentor: Undergraduate student Dakota Maynard. Directed Studies and internship on soil moisture data processing and visualization. Mentor Hernan Moreno (Fall 2019).
• Team members Hernan Moreno and Tri Pham participated in the AGU Fall meeting in San Francisco DC 2019, each presenting their progress and interacting with other scientists.
• Dr. Hernan Moreno was invited speaker at the University of Oklahoma Shell Series Colloquium in October 2019.
• Dr. Hernan Moreno attended to the NCAR Artificial Intelligence in Earth Science workshop during summer 2020.
• Dr. Hernan Moreno attended the annual Information Theory workshop during August 2020.
• One-to-one work with mentor: M.S. student Jorge Celis. Directed Studies on Surface Energy Balance and Distributed Hydrologic Modeling. Mentor Hernan Moreno (Fall 2018, Spring and Summer 2019).
• One-to-one work with mentor: M.S. student Tri Pham. Directed Studies on Surface Energy Balance and Distributed Hydrologic Modeling. Mentor Hernan Moreno (Fall 2018, Spring and Summer 2019).
• One-to-one work with mentor: Undergraduate student Dakota Maynard. Directed Studies and internship on soil moisture data processing and visualization. Mentor Hernan Moreno (Fall 2018, Spring and Summer 2019).
• One-to-one work with mentor: Undergraduate student Maria Valderrama. Directed Studies on model forecasting and assessment. Mentor Hernan Moreno (Fall 2018, Spring and Summer 2019).
• Team members Hernan Moreno, Jorge Celis and Tri Pham participated in the AGU Fall meeting in Washington DC 2018, each presenting their progress and interacting with other scientists.
• Team members Hernan Moreno, Jorge Celis and Tri Pham participated in the Oklahoma Governor's Water Meeting in Fall 2018 presenting advances and interacting with other scientists.
• Dr. Hernan Moreno was invited speaker at the University of Oklahoma water day in Fall 2018.

Results Dissemination: Articles accepted (6) on indexed journals during the execution of the project:

1. Celis J.A., Moreno H.A., Basara J.B., McPherson R.A., Cosh M., Ochsner T., Xiao X., 2021. From Standard Weather Stations to Virtual Micro-Meteorological Towers in Ungauged Sites: Modeling Tool for Surface Energy Fluxes, Evapotranspiration, Soil Temperature, and Soil Moisture Estimations. Remote Sensing 13(7):1271.

2. Moreno, H.A., Gourley, J.J., Pham T.G. and Daniela Spade, 2020. Utility of satellite-derived burn severity to study short- and long-term effects of wildfire on streamflow at the basin scale. Journal of Hydrology. 580, 124244, https://doi.org/10.1016/j.jhydrol.2019.124244

3. Zamanisabzi H., Moreno, H.A., Fovargue, R., Xue, X., Hong, Y., Neeson, T.M., 2019. Comparison of projected water availability and demand reveals future hotspots of water stress in the Red River basin, USA. Journal of Hydrology: Regional Studies 26, 100638.

4. Bayabil, H.K., Fares, A., Sharif, H., Ghebreyesus, D., Moreno, H.A. (in press). Effects of spatial and temporal data aggregation on the performance of the Multi-Radar Multi-Sensor System. Journal of the American Water Resources Association.

5. Alvarez, L.V., Moreno, H.A., Segales, A.R., Pham, T.G., Pillar-Little, E.A., Chilson, P.B. , 2018. Merging Unmanned Aerial Systems (UAS) Imagery and Echo Soundings with an Adaptive Sampling Technique for Bathymetric Surveys. Remote Sensing 10, 1362, doi:0.3390/rs10091362

6. Moreno, H.A., Ogden, F.L, Alvarez, L.V., 2018. Unstructured-Mesh Terrain Analysis and Incident Solar Radiation for Continuous Hydrologic Modeling in Mountain Watersheds. Water, 10(4), 398, doi:10.3390 /w10040398.

Honors and Awards: Nothing to Report

Protocol Activity Status:

Technology Transfer: Nothing to Report

PARTICIPANTS:

Participant Type: PD/PI
Participant: Hernan A. Moreno
Person Months Worked: 1.00 **Funding Support:**
Project Contribution:
National Academy Member: N

Participant Type: Graduate Student (research assistant)
Participant: Zhen Hong
Person Months Worked: 4.00 **Funding Support:**
Project Contribution:
National Academy Member: N

Participant Type: Graduate Student (research assistant)
Participant: Jorge Celis
Person Months Worked: 12.00 **Funding Support:**
Project Contribution:
National Academy Member: N

Participant Type: Graduate Student (research assistant)
Participant: Tri G. Pham
Person Months Worked: 12.00 **Funding Support:**
Project Contribution:
National Academy Member: N

Participant Type: Undergraduate Student
Participant: Dakota Maynard
Person Months Worked: 12.00 **Funding Support:**
Project Contribution:
National Academy Member: N

Participant Type: Undergraduate Student
Participant: Maria Valderrama
Person Months Worked: 6.00 **Funding Support:**
Project Contribution:
National Academy Member: N

ARTICLES:

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: Remote Sensing
Publication Identifier Type: DOI Publication Identifier: 10.3390/rs10091362
Volume: 10 Issue: 9 First Page #: 1362
Date Submitted: 8/30/18 12:00AM Date Published: 8/1/18 5:00AM
Publication Location:
Article Title: Merging Unmanned Aerial Systems (UAS) Imagery and Echo Soundings with an Adaptive Sampling Technique for Bathymetric Surveys
Authors: Laura Alvarez, Hernan Moreno, Antonio Segales, Tri Pham, Elizabeth Pillar-Little, Phillip Chilson
Keywords: unmanned aerial systems; bathymetry; adaptive sampling; structure from motion; echo sounding; geomorphology; hydrology; reservoirs
Abstract: Bathymetric surveying to gather information about depths and underwater terrain is increasingly important to the sciences of hydrology and geomorphology. Submerged terrain change detection, water level, and reservoir storage monitoring demand extensive bathymetric data. Despite often being scarce or unavailable, this information is fundamental to hydrodynamic modeling for imposing boundary conditions and building computational domains. In this manuscript, a novel, low-cost, rapid, and accurate method is developed to measure submerged topography, as an alternative to conventional approaches that require significant economic investments and human power. The method integrates two types of Unmanned Aerial Systems (UAS) sampling techniques. The first couples a small UAS (sUAS) to an echosounder attached to a miniaturized boat for surveying submerged topography in deeper water within the range of accuracy. The second uses Structure from Motion (SfM) photogrammetry to cover shallower water ar
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Acknowledged Federal Support: **Y**

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: Water
Publication Identifier Type: DOI Publication Identifier: 10.3390/w10040398
Volume: 10 Issue: 4 First Page #: 398
Date Submitted: 8/30/18 12:00AM Date Published: 3/1/18 12:00PM
Publication Location:
Article Title: Unstructured-Mesh Terrain Analysis and Incident Solar Radiation for Continuous Hydrologic Modeling in Mountain Watersheds
Authors: Hernan Moreno, Fred Ogden, Laura Alvarez
Keywords: triangular irregular networks; insolation; unstructured mesh; shadow casting; sky-view fraction; remote albedo
Abstract: This article presents a methodology for estimating total incoming solar radiation from Triangular Irregular Network (TIN) topographic meshes. The algorithm also computes terrain slope degree and aspect (slope orientation) and accounts for self shading and cast shadows, sky view fractions for diffuse radiation, remote albedo and atmospheric backscattering, by using a vectorial approach within a topocentric coordinate system establishing geometric relations between groups of TIN elements and the sun position. A normal vector to the surface of each TIN element describes its slope and aspect while spherical trigonometry allows computing a unit vector defining the position of the sun at each hour and day of the year. Sky view fraction, useful to determine diffuse and backscattered radiation, is computed for each TIN element at prescribed azimuth intervals targeting the steepest elevation gradient. A comparison between the sun zenith angle and the steepest gradient allows deciding whether or
Distribution Statement: 3-Distribution authorized to U.S. Government Agencies and their contractors
Acknowledged Federal Support: **Y**

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: Journal of the American Water Resources Association
Publication Identifier Type: DOI Publication Identifier: https://doi.org/10.1111/1752-1688.12799
Volume: Issue: First Page #:
Date Submitted: 9/18/19 12:00AM Date Published: 9/18/19 5:00AM
Publication Location:
Article Title: Effects of Spatial and Temporal Data Aggregation on the Performance of the Multi-Radar Multi-Sensor System
Authors: Haimanote K. Bayabil, Ali Fares, Hatim O. Sharif, Dawit T. Ghebreyesus, Hernan A. Moreno
Keywords: MRMS; gauge rainfall; radar; satellite; probability of detection; Threat Score; false alarm ratio
Abstract: The objectives of this study were to (1) evaluate the performance of the Multi-Radar Multi-Sensor (MRMS) system in capturing precipitation compared to gauge data, and (2) assess the effects of spatial (1–50 km) and temporal (15–120 min) data aggregation scales on the performance of the MRMS system. Point-to-grid comparisons were conducted between 215 rain gauges and the MRMS system. The MRMS system at 1 km spatial and 15 min temporal resolutions captured precipitation reasonably well with average R 2 , root mean square error (RMSE), and percent bias (PBIAS) values of 0.65, 0.5 mm, and 11.9 mm; whereas Threat Score, probability of detection, and false alarm ratio were 0.57, 0.92, and 0.40, respectively. Decreasing temporal resolution from 15 min to two hours resulted in an increase in R 2 and a decrease in RMSE, whereas PBIAS was not affected. Reducing spatial resolution from 1 to 50 km resulted in increases in R 2 and PBIAS, whereas RMSE was decreased. Increasing spatial aggrega...
Distribution Statement: 2-Distribution Limited to U.S. Government agencies only; report contains proprietary info
Acknowledged Federal Support: **Y**

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: Journal of Hydrology
Publication Identifier Type: DOI Publication Identifier: 10.1016/j.jhydrol.2019.124244
Volume: 580 Issue: First Page #: 124244
Date Submitted: 11/15/19 12:00AM Date Published: 1/1/20 6:00AM
Publication Location:
Article Title: Utility of satellite-derived burn severity to study short- and long-term effects of wildfire on streamflow at the basin scale
Authors: Hernan A. Moreno, Jonathan J. Gourley, Tri G. Pham, Daniela M. Spade
Keywords: Wildfire hydrology; Remote sensing hydrology; Normalized Burn Ratio; Post-fire streamflow shifts; Forest hydrology; Land cover change
Abstract: We investigated the changes in hydrologic response in a forested catchment impacted by wildfire in Colorado U.S.A. from the storm event to the inter-annual scales. We also evaluated the utility of a remotely-sensed burn severity index to study post-fire shifts in streamflow. At the storm-scale, we evaluated hydrologic shifts through changes in the effective runoff (Q*/PTot), peak streamflow (Qpk) and response time (TR/TB) from multiple hydrographs, while at seasonal and inter-annual-scales we quantified hydrologic shifts through the runoff fraction (Q/PTot) and flow duration curves. Vegetation anomalies were monitored through comparisons of the Normalized Burn Ratio (NBR) between the burned and a hydrologically-similar, forested, neighboring, unburned catchment. We found short-term acute and long-term chronic transient streamflow shifts from the minute to the inter-annual scales. Flow duration curves indicate an order of magnitude increase in maximum flows. Event-average Q*/PTot increa
Distribution Statement: 2-Distribution Limited to U.S. Government agencies only; report contains proprietary info
Acknowledged Federal Support: **Y**

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: Journal of Hydrology: Regional Studies
Publication Identifier Type: DOI Publication Identifier: https://doi.org/10.1016/j.ejrh.2019.100638
Volume: 26 Issue: First Page #:
Date Submitted: 11/19/19 12:00AM Date Published: 12/1/19 12:00PM
Publication Location:
Article Title: Comparison of projected water availability and demand reveals future hotspots of water stress in the Red River basin, USA
Authors: Hamed Zamanisabzi, Hernan Moreno, Rachel Fovargue, Xianwu Xue, Yang Hong, Thomas Neeson.
Keywords: Drought, U.S. Southern Plains, Water use, Environmental conservation planning, Watershed management
Abstract: We investigated the projected changes in water availability and demand across the Red River to identify regions of potential future water stress. The VIC model was calibrated, validated and then run with ensemble forcing from regionally representative global circulation model (GCM) outputs. For different combinations of representative concentration pathways (RCPs) we evaluated the impacts of climate change on streamflows and water availability throughout the basin. To estimate future water demand, we integrated a series of sector-specific regression models fit to historical water usage per county. Despite discrepancies among GCMs projections, all future scenarios include a strong west-east gradient in water availability. Joint consideration of projected water demand and availability reveals that the distribution of future hotspots of water stress is spatially patchy and generally driven by changes in water demand, rather than availability. These hotspots of future water stress highligh
Distribution Statement: 2-Distribution Limited to U.S. Government agencies only; report contains proprietary info
Acknowledged Federal Support: **Y**

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: Remote Sensing
Publication Identifier Type: DOI Publication Identifier: 10.3390/rs13071271
Volume: 13 Issue: 7 First Page #: 1271
Date Submitted: 4/6/21 12:00AM Date Published: 3/1/21 7:00AM
Publication Location:
Article Title: From Standard Weather Stations to Virtual Micro-Meteorological Towers in Ungauged Sites: Modeling Tool for Surface Energy Fluxes, Evapotranspiration, Soil Temperature, and Soil Moisture Estimations
Authors: Jorge A. Celis, Hernan A. Moreno, Jeffrey B. Basara, Renee A. McPherson, Michael Cosh, Tyson Ochs
Keywords: virtual eddy covariance towers; hydrologic modeling; energy fluxes; evapotranspiration; soil temperature; soil moisture
Abstract: One of the benefits of training a process-based, land surface model is the capacity to use it in ungauged sites as a complement to standard weather stations for predicting energy fluxes, evapotranspiration, and surface and root-zone soil temperature and moisture. In this study, dynamic (i.e., time-evolving) vegetation parameters were derived from remotely sensed Moderate Resolution Imaging Spectroradiometer (MODIS) imagery and coupled with a physics-based land surface model (tin-based Real-time Integrated Basin Simulator (tRIBS)) at four eddy covariance (EC) sites in south-central U.S. to test the predictability of micro-meteorological, soil-related, and energy flux-related variables. One cropland and one grassland EC site in northern Oklahoma, USA, were used to tune the model with respect to energy fluxes, soil temperature, and moisture. Calibrated model parameters, mostly related to the soil, were then transferred to two other EC sites in Oklahoma with similar soil and vegetation ty
Distribution Statement: 1-Approved for public release; distribution is unlimited.
Acknowledged Federal Support: **Y**

CONFERENCE PAPERS:

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: American Geophysical Union
Date Received: 30-Aug-2018 Conference Date: 11-Dec-2017 Date Published: 15-Dec-2017
Conference Location: New Orleans
Paper Title: Understanding SMAP-L4 soil moisture estimation skill and their dependence with topography, precipitation and vegetation type using Mesonet and Micronet networks
Authors: H, Moreno; J. Basara; E, Thompson; Bertrand, D; Johnston, C.
Acknowledged Federal Support: **N**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: American Geophysical Union
Date Received: 01-Aug-2019 Conference Date: 10-Dec-2018 Date Published: 10-Dec-2018
Conference Location: Washington DC
Paper Title: On the importance of studying the time variability of the eddy flux footprint for hyper-resolution hydrological modeling
Authors: Tri Pham, Hernan A. Moreno, Jason Vogel, Jorge Celis
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: American Geophysical Union
Date Received: 31-Jul-2019 Conference Date: 10-Dec-2018 Date Published:
Conference Location: Washington DC
Paper Title: Process-based modeling of soil moisture, soil temperature and surface energy fluxes in the US southern plains
Authors: Jorge Celis, Hernan A. Moreno, Jason Vogel, Tri Pham
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: American Geophysical Union
Date Received: 31-Jul-2019 Conference Date: 10-Dec-2018 Date Published: 14-Dec-2018
Conference Location: Washington DC
Paper Title: Transient Streamflow Changes after Wildfire in a Forested Catchment
Authors: Hernan A. Moreno, Jonathan Gourley, Tri Pham
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: Oklahoma Governor's Water Conference
Date Received: 31-Jul-2019 Conference Date: 05-Dec-2018 Date Published: 05-Dec-2018
Conference Location: Midwest City, Oklahoma
Paper Title: Process-based modeling of soil moisture, soil temperature, and surface energy fluxes in the U.S. Southern Plains
Authors: Jorge A. Celis, Hernan A. Moreno, Jason Vogel, Tri G. Pham
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: American Geophysical Union
Date Received: 16-Jan-2020 Conference Date: 08-Dec-2019 Date Published: 08-Dec-2019
Conference Location: San Francisco, CA
Paper Title: Effects of vegetation gradual and abrupt change on soil moisture and surface energy fluxes.
Authors: Tri Pham, Hernan Moreno, Jason Vogel, Tyson Ocshner
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: American Geosphysical Union Fall Meeting
Date Received: 16-Jan-2020 Conference Date: 08-Dec-2019 Date Published: 08-Dec-2019
Conference Location: San Francisco, CA
Paper Title: The utility of remote sensing imagery to study transient shifts in streamflow from the event to the interannual scale.
Authors: Hernan Moreno, Jonathan Gourley, Tri Pham
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: American Geophysical Union
Date Received: 06-Apr-2021 Conference Date: 07-Dec-2020 Date Published: 07-Dec-2020
Conference Location: Virtual Due to COVID19
Paper Title: Foot-print Scale Real-time Modeling Tool of Surface Energy Fluxes, Evapotranspiration, Soil Moisture, and Soil Temperature: Application in the the Southern Great Plains.
Authors: Celis, J. A., Moreno, H. A., Basara, J. B., Cosh, M. H., Ochsner, T. E., Xiao, X.
Acknowledged Federal Support: **Y**

DISSERTATIONS:

RPPR Final Report
as of 21-Oct-2021

Publication Type: Thesis or Dissertation
Institution: University of Oklahoma
Date Received: 16-Jan-2020 Completion Date: 12/15/19 7:04PM
Title: PROCESS BASED MODELING OF SURFACE ENERGY FLUXES, EVAPOTRANSPIRATION, SOIL MOISTURE, AND SOIL TEMPERATURE IN THE US SOUTHERN PLAINS
Authors: Jorge A. Celis
Acknowledged Federal Support: **Y**

Publication Type: Thesis or Dissertation
Institution: University of Oklahoma
Date Received: 23-Jul-2020 Completion Date: 6/20/20 4:37AM
Title: Evaluating the effects of vegetation cover and phenology on the components of the surface energy fluxes, soil temperature and its damping depth, soil moisture and the partitioning of evapotranspiration across forest, grassland and desert ecosystems
Authors: Tri G. Pham
Acknowledged Federal Support: **Y**

WEBSITES:

URL: https%3A%2F%2Fvisualtribs.herokuapp.com%2F
Date Received: 26-Mar-2021
Title: VisualtRIBS visualization tool
Description: Visual tRIBS tool to visualize tRIBS outputs of soil moisture, soil temperature, energy components and water in a distributed manner on a google-earth-type engine.

Partners

,

I certify that the information in the report is complete and accurate:
Signature:
Signature Date:

Human-Scale Surface Energy Budget and Ground Thermal Responses to Soil Moisture and Vegetation Change in Flat and Complex Terrain

Proposal Number 72578-EV-YIP

Agreement Number W911NF1810007

Technical Report as part of the

Final Report: 04/06/2021

US Army Research, Development and Engineering Command

Army Research Office

Dr. Hernan A. Moreno, Principal Investigator

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College of Sciences
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Executive summary

This final report compiles achievements and products for the 36 months (11/15/2017-11/15/2020) of execution of this ARO YIP proposal titled "Human-Scale Surface Energy Budget and Ground Thermal Responses to Soil Moisture and Vegetation Change in Flat & Complex Terrain". This report is being submitted on 04/06/2021 due to some delays created by the COVID19 crisis. In summary, we have successfully completed all of the activities proposed for YEARS 1 through 3 including the publication of six (6) scientific articles in indexed journals, the presentation of 13 works at invited colloquiums and seminars and scientific meetings, the publication of two (2) Masters thesis and the training of three (3) graduate and three (3) undergraduate students. Still pending are, at least, three (3) more scientific articles to be submitted during the next weeks (i.e. Hong et al. and Moreno et al.), one PhD dissertation (Hong, Z) and some additional invited talks at regional and national level (i.e. Moreno at AGU/AMS and University of Texas). This technical report lists those articles under review before publication in Section 1. Sections 2 and 3 summarize the scientific products disseminated including published articles (3), posters (2) and invited talks (1) as well as the developed software tools.

1. Articles in process of development (3)

1.1 The roles of biomass productivity, soil moisture and energy availability in the partitioning of evapotranspiration (Moreno et al.) Article in preparation to Water Resources Research Percent completed 90%

Estimating the components of evapotranspiration (ET) across diverse planetary environments is a difficult task due to the lack of spatially- and temporally- continuous water, carbon and energy flux field measurements that support the development of physics-based models. A physics-guided, theoretical approach, supported by machine learning, to partition ET is developed through multiple-year time series of above-canopy water and carbon fluxes, soil moisture and atmospheric variables at three semi-arid sites along an annual precipitation gradient with associated differences in vegetation (grassland, savanna, and shrubland from wettest to driest). The procedure finds independent predic-tors that explain the largest proportion of variability of daily evapotranspiration (ET) and then provides estimates of the components using multi-variate regressions among groups of vegetation and non-vegetation related predictors. Gross ecosystem production (GEP), surface soil moisture (θ_s) and net radiation (R_n), together contribute from 72% to 90% of the variance of ET depending on the site. Both θ_s and GEP dominate ET during cool season (Nov-May) months, particularly at the grassland and shrubland. GEP is the dominant predictor during the warm (monsoon) season (Jul-Oct). Estimated ET are compared with observed data during multiple years. Simulated transpiration (T) are compared with previously published measurements at one site with satisfactory results. During dry and hot cool season and rainy monsoon season and across sites, evaporation (E) was always larger than T, although T was always higher than its average during the warm season, particularly at the wettest, grass site. We find some evidence that the lack of cool season precipitation reduces subsequent, monsoonal T, especially at the two deeper-rooted savanna and shrubland. The mean monthly evaporation efficiency (ET flux per unit change in abiotic forcing, $E_{eff}=\partial W/\partial(R_n\theta_5)$) shows a less variable behavior than the transpiration efficiency (ET flux per unit change in biotic forcing, $T_{eff}=\partial W/\partial GEP$) across sites. The highest E_{eff} rates occur during July to October at the savanna site. The presence of precipitation temporarily increases the values of E_{eff} that return to mean historical in short time. T_{eff} shows maximum positive values during wet monsoon periods. The maximum monsoonal T_{eff} rates found suggest that grassland is a more efficient transpirator per unit of carbon fixed than mesquite or creosote bush.

Some figures of this upcoming publication are next. Figure 1 illustrates the contributions of the different predictors to the estimation of ET. It is evident that GEP, θ_5 and R_n are the most important predictors that explain, at least, 92% of the variability on ET. Figure 2 shows the simulation results of the partitioning algorithm during typical dry and wet years in Santa Rita Arizona. Model was calibrated with sap flow and micro-meteorological measurements in the same stations in Arizona.

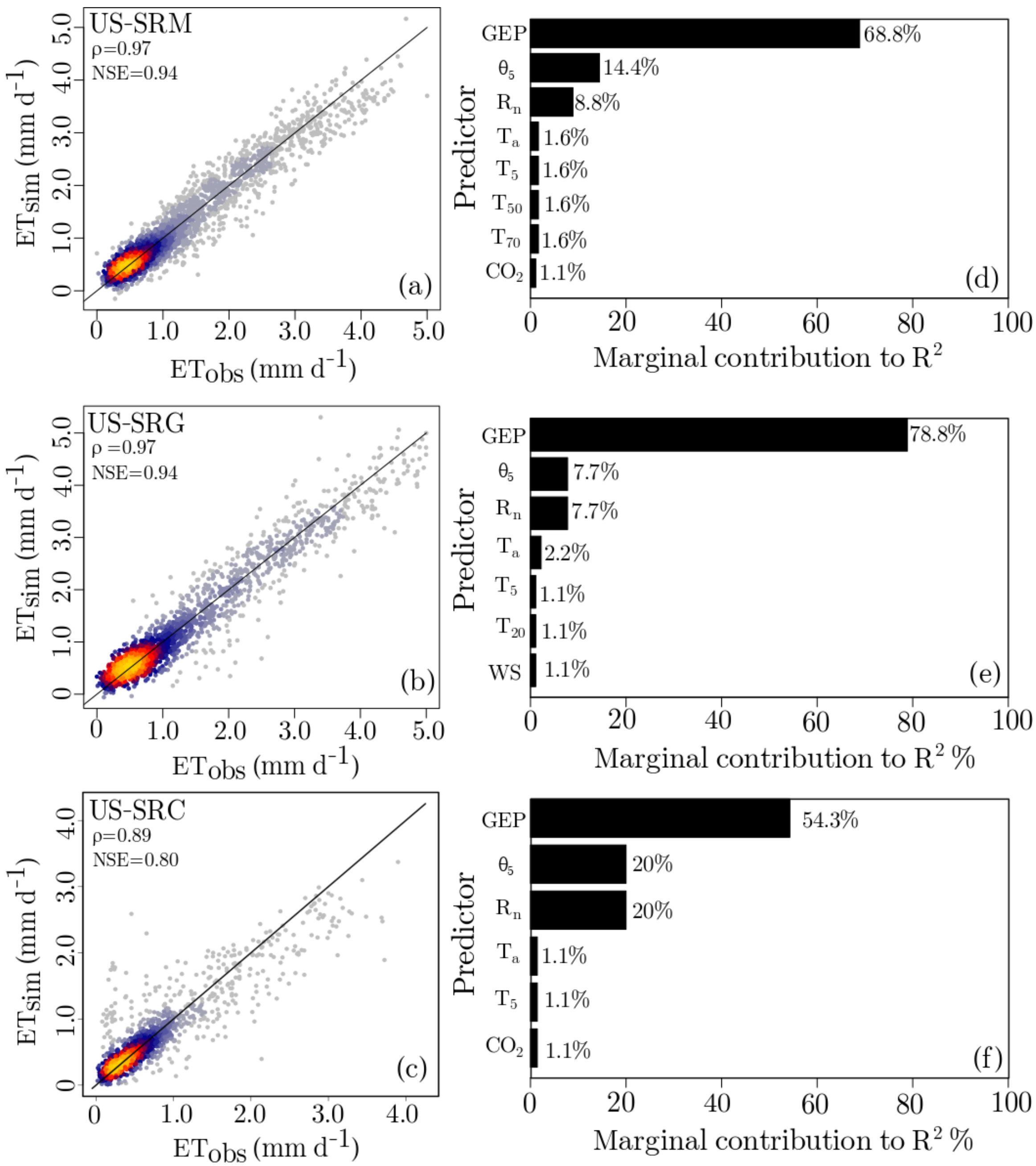

Figure 1. Left column: Simulated Vs. observed daily ET for (a) US-SRM 2004-2014, (b) US-SRG 2008-2014 and (c) US-SRC 2008-2014, using the monthly regression fittting. Pearson correlation (ρ) and Nash-Sutcliffe Model Efficiency (NSE) coefficients were added to each plot. Right column: Best subsets results for the percent contribution of non-redundant predictors to the variability of ETsim at (d) US-SRM, (e) US-SRG and (f) US-SRC.

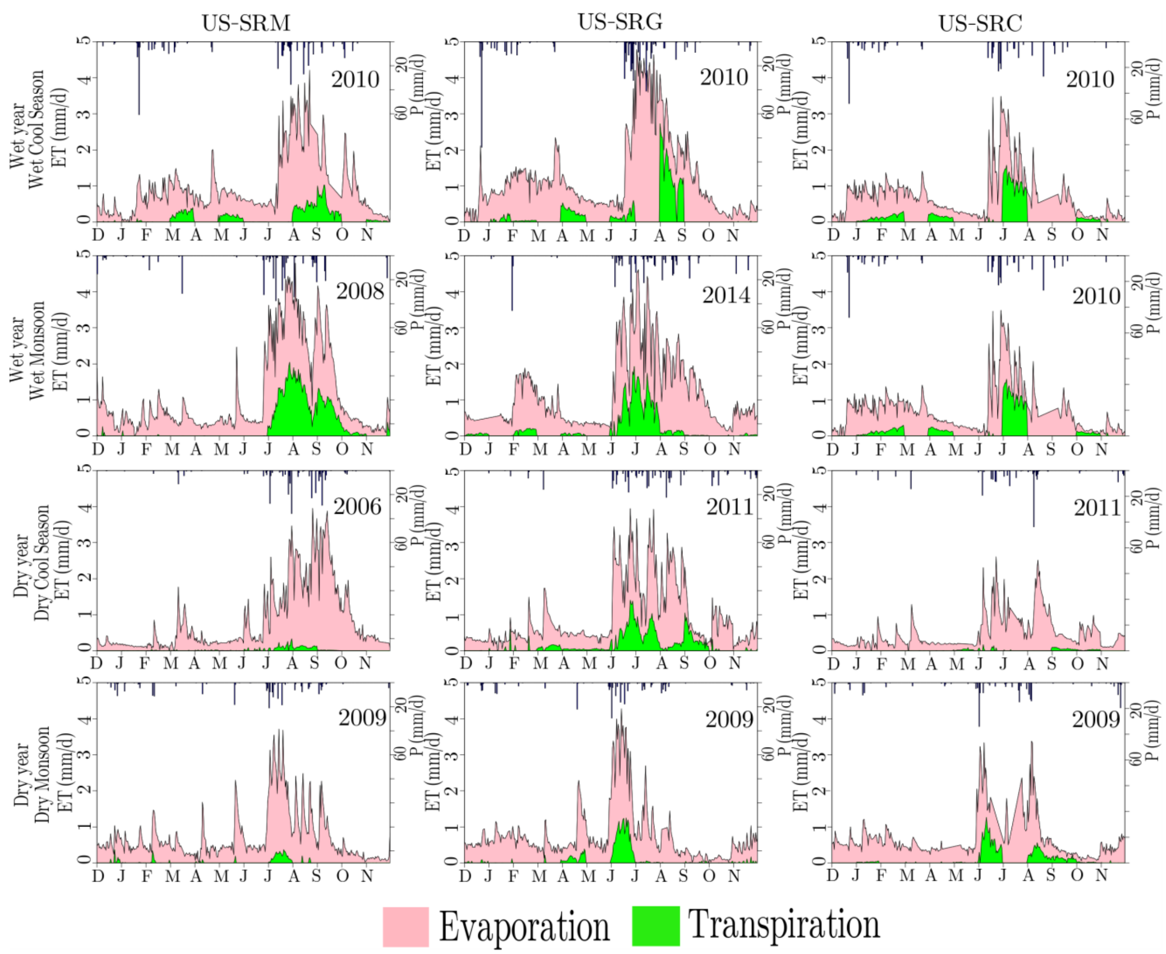

Figure 2. Daily time series of the ET partitioning obtained from the monthly fits and vegetation contribution at US-SRM (left column), US-SRG (central column), US-SRC (right column) for typical wet cool season (top row), wet monsoon (second row), dry cool season (third row) and dry monsoon (fourth row) periods. The cool season period spans from the months of December (antecedent year), January February, March, April and May. Monsoon spans for July, August, September and October.

1.2 Cross-evaluation of ground-based, satellite and land surface model soil moisture products through the Triple Collocation method across Oklahoma (Hong et al.) Article in Preparation to Remote Sensing Journal <u>Percent completed 90%</u>

Improvements in the field of soil moisture observations and modeling play a vital role in drought, water resources, flooding and landslide management and predictability. Up to date, soil moisture estimates can be obtained through three primary approaches: (1) in situ measurements, (2) remote sensing observations and (3) Land Surface Models (LSM). Each source of soil moisture data has its strengths and weaknesses. However, none of them, at least by themselves, are adequate for providing accurate soil moisture data at high and continuous temporal and spatial resolutions and over multiple scales at once. Therefore, it is useful to combine these three independent data sources to capitalize on the strengths of each and to generate an optimal soil moisture product to facilitate real-world applications. In this study, we apply the Triple Collocation Analysis (TCA) to three independent soil moisture products to characterize their uncertainty of each product. The state of Oklahoma is an ideal domain to test the hypotheses of this work for the presence of a marked west to east climate, vegetation and soils gradients. The comparison and evaluation are conducted with daily data from 01 April 2015 to 01 July 2019, over seven land cover types. The three soil moisture products evaluated include the microwave remote sensing observation Soil Moisture Active Passive (SMAP) L3_SM_P_E (9km, daily), the physically based land surface modeling soil moisture estimates NLDAS_NOAH0125_H (1/8°, hourly), and the in situ soil moisture network of the Oklahoma Mesonet (point, 30 minutes). Results indicate that (1) In general, Mesonet is the most reliable product, reflecting the main spatiotemporal characteristics of soil moisture, while SMAP has the lowest accuracy. The overall root mean square error of Mesonet, Noah, SMAP are 0.054, 0.026, 0.107 m3.m-3, respectively. The overall Pearson correlation coefficient (CC) of Mesonet, Noah, SMAP are 0.805, 0.747, 0.314, respectively. (2) Mesonet has the best performance in shrub/scrub, herbaceuous, hay/pasture and cultivated crops with an average correlation coefficient of 0.785. Noah reaches the best performance in evergreen, mixed and deciduous forest, with an average correlation coefficient of 0.74. SMAP has the lowest correlation coefficient values on all seven land cover types, with an averaged CC of 0.29. The study concludes that the TC method provides not only a new perspective for comparatively assessing multi-source soil moisture products but also a basis for objective data merging to capitalize the strengths of multi-sensor multiplatform soil moisture products.

1.3 Creating an enhanced soil moisture product. (Hong et al.) Article in preparation to Journal of Hydrology <u>Percent completed 50%</u>

Currently, soil moisture estimates can be obtained through three primary approaches: (1) in situ measurements, (2) remote sensing observations and/or (3) Land Surface Model outputs. Each source of soil moisture data has its strengths and weaknesses. However, none of them, at least by themselves, are adequate for providing accurate soil moisture data at high temporal and spatial resolutions. Therefore, it is useful to combine these three independent data sources to capitalize on the strengths of each and to generate an optimal soil moisture product to facilitate real-world applications. There are a number of methods that are commonly used for blending together different soil moisture datasets, including triple collocation (TC) (Stoffelen, 1998) with least square weighting (LSW) and simple averaging (averaging parent datasets using equal weighting). For example, Yilmaz et al. (2012) generated a hybrid soil moisture anomaly product at 0.25° grid by merging model-derived soil moisture, thermal infrared RS-soil moisture, and microwave RS-based soil moisture using TC and LSW. The TC-merged product had less uncertainty, but it did not outperform the simple averaging method. Zeng et al. (2016) also used TC with LSW to blend the soil moisture from two satellite (AMSRE and ASCAT) and one reanalysis soil moisture product (ERA-Interim). Their merged product performed better than simple averaging in the sub-humid and semi-arid regions, but the performances of TC with LSW and simple averaging were similar in arid regions. There are a number of knowledge gaps that still exist, including (1) of the lack of in-situ soil moisture inclusion in product blending. Current studies mainly focus on combining modeled and RS soil moisture, rather than combining all three sources (modeled, RS and in-situ). In-situ measurements can be useful for improving the accuracy of hybrid soil moisture datasets. (2) There is no analyzing of TC and LSW based merging soil moisture product on different land cover types and climate zones. The research proposed here addresses the following research objectives: (1) perform a spatiotemporal analysis of the recent seismicity and industry-related wastewater injection activity in Oklahoma (2) adopt the triple collocation (TC) solution and conduct an assessment and inter-comparison of the SMAP L3, NLDAS Noah LSM and the Oklahoma Mesonet soil moisture products at a state scale. Additionally, analyze relative quality of the soil moisture anomalies of the different soil moisture products over different vegetation scenarios and climate zones within the region (3) Merging the above three soil moisture products and evaluate the performance of merged product over different land cover types and climate zones within the state of Oklahoma.

2. Articles published (6 in total, 3 more in review)

In addition to the articles in preparation, we have published six additional scientific articles to indexed journals as described below. All articles have been reported in the ARO official reporting site. Here is the full summary list:

1. Celis J.A., Moreno H.A., Basara J.B., McPherson R.A., Cosh M., Ochsner T., Xiao X., 2021. From Standard Weather Stations to Virtual Micro-Meteorological Towers in Ungauged Sites: Modeling Tool for Surface Energy Fluxes, Evapotranspiration, Soil Temperature, and Soil Mois- ture Estimations. *Remote Sensing* 13(7):1271. https://doi.org/10.3390/rs13071271

2. Moreno, H.A., Gourley, J.J. Pham, T.G., Spade, D.M., 2020. Utility of satellite-derived burn severity to study short- and long-term effects of wildfire on streamflow at the basin scale. Journal of Hydrology. 580, 124244 https://doi.org/10.1016/j.jhydrol.2019.124244

3. Zamanisabzi H., Moreno, H.A., Fovargue, R., Xue, X., Hong, Y., Neeson, T.M., 2019. Comparison of projected water availability and demand reveals future hotspots of water stress in the Red River basin, USA. Journal of Hydrology: Regional Studies. 26, 100638. https://doi.org/10.1016/j.ejrh.2019.100638

4. Bayabil, H.K., Fares, A., Sharif, H., Ghebreyesus, D., Moreno, H.A., 2019. Effects of spatial and temporal data aggregation on the performance of the Multi-Radar Multi-Sensor System. Journal of the American Water Resources Association. 1-13, https://doi.org/10.1111/1752-1688.12799

5. Alvarez, L.V., Moreno, H.A., Segales, A.R., Pham, T.G., Pillar-Little, E.A., Chilson, P.B. , 2018. Merging Unmanned Aerial Systems (UAS) Imagery and Echo Soundings with an Adaptive Sampling Technique for Bathymetric Surveys. Remote Sensing 10, 1362, doi:0.3390/rs10091362

6. Moreno, H.A., Ogden, F.L, Alvarez, L.V., 2018. Unstructured-Mesh Terrain Analysis and Incident Solar Radiation for Continuous Hydrologic Modeling in Mountain Watersheds. Water, 10(4), 398, doi:10.3390/w10040398.

3. Graduate theses (2 in total, 1 more expected)

1. Pham, Tri 2020. Evaluating the effects of vegetation cover and phenology on the components of the surface energy fluxes, soil temperatures and its damping depth, soil moisture and the partitioning of evapotranspiration across forest, grassland, and desert ecosystems. University of Oklahoma Masters Thesis, 200 p. https://shareok.org/handle/11244/324940

2. Celis, J.A. 2020. Process-based modeling of surface energy fluxes, evapotranspiration, soil moisture and soil temperature in the US southern plains. University of Oklahoma Masters Thesis, 122 p. https://shareok.org/handle/11244/323239

4. Posters, presentations and invited talks (13 in total)

1. Moreno, H.A. 2021. Merging multi-platform sensors, models and artificial intelligence for advanced hydrologic prediction. NOAA Center for Earth System Sciences and Remote Sensing Technologies, Seminar Series. New York. February of 2021. Recorded presentation available here: https://www.cessrst.org/news-and-events/event-detail/seminar-series-tbd-feb-25-2021
2. Hong, Z., Moreno, H.A., Li, Z., Hong, Y. 2021. Cross-evaluation of Ground-based, Satellite and Land Surface Model Soil Moisture Products Through the Triple Collocation Method Across Oklahoma. American Meteorological Society Spring Meeting, Virtual Mode.
3. Celis, J. A., Moreno, H. A., Basara, J. B., Cosh, M. H., Ochsner, T. E., Xiao, X., 2020. Foot-print Scale Real-time Modeling Tool of Surface Energy Fluxes, Evapotranspiration, Soil Moisture, and Soil Temperature: Application in the the Southern Great Plains. American Geo- physical Union Fall Meeting, Virtual Mode
4. Moreno, H.A. 2020. Innovations in Hydrology and Water Sustainability through Distributed Hydrologic Modeling, Machine Learning and Multi-Sensor Observations. Colloquium Speaker. Department of Geological Sciences, University of Texas, El Paso, February 6 of 2020.
5. Moreno, H.A., Gourley, J.J., Pham, T.G., 2019. The utility of remote sensing imagery to study the transient shifts streamflow from the event to the interannual scale. American Geophysical Union Fall Meeting, San Francisco, CA.
6. Pham, T.G., Moreno, H.A., Vogel, J., Oschner, T.E., 2019. Effects of vegetation gradual and abrupt change on soil moisture and surface energy fluxes. American Geophysical Union Fall Meeting, San Francisco, CA.
7. Moreno H.A., 2019. Innovations in Hydrologic Science through the use of process-based, distributed hydrologic modeling, multi-sensor observations and intelligent systems. Shell series colloquium. School of Geosciences, University of Oklahoma, Norman Oklahoma.

8. Pham, T., Moreno, H.A., Vogel, J., and Celis J. 2018. On the importance of studying the time variability of the eddy flux footprint for hyper-resolution hydrological modeling. American Geophysical Union Fall Meeting, Washington DC.
9. Celis, J., Moreno, H.A., Vogel, J., and Pham T., 2018. Process-based modeling of soil moisture, soil temperature and surface energy fluxes in the US southern plains. American Geophysical Union Fall Meeting, Washington DC.
10. Moreno, H.A., Gourley, J.J. and Pham T., 2018. Transient streamflow changes after wildfire in a forested catchment. American Geophysical Union Fall Meeting, Washington DC.
11. Pham, T., Moreno, H.A., Vogel, J., and Celis J. 2018. On the importance of studying the time variability of the eddy flux footprint for hyper-resolution hydrological modeling. Oklahoma Governor's Water Conference and Research Symposium, Midwest City, OK.
12. Celis, J., Moreno, H.A., Vogel, J., and Pham T., 2018. Process-based modeling of soil moisture, soil temperature and surface energy fluxes in the US southern plains. Oklahoma Governor's Water Conference and Research Symposium, Midwest City, OK.
13. Moreno, H.A. 2018. Hyper-resolution modeling to improve understanding of the water cycle. OU Water Day. Oklahoma water survey. University of Oklahoma Fred Jones Museum.

5. Visual tRIBS tool and user manual

Our research team has created **VisualtRIBS**, a virtual tool in Python for visualizing tRIBS model outputs using a google-earth type of base layouts for immersive deploy of model output variables like digital elevation model, vegetation type and cover, soil types and properties, soil thermal conductivity, soil specific heat capacity, leaf area index (LAI), normalized difference vegetation index (NDVI), soil surface and root-zone soil moisture and temperature, ground heat flux, sensible heat flux, latent heat flux, evapotranspiration, snow accumulation, runoff depth, streamflow and others. Visual tRIBS's user manual is presented next.

5.1 Installation

VisualtRIBS utilizes Python 3.7 which can be downloaded from `https://www.python.org/downloads/`. VisualtRIBS can be downloaded to a local machine and then run through a virtual environment (a) or executed online through a web-based version (b).

a. Using virtual environment

1. Navigate to the project folder using command:

```
cd path/to/project/folder
```

2. Create a virtual environment using command:

```
virtualenv venv
```

3. Activate the virtual environment:

```
source venv/bin/activate
```

4. Install the required packages:

```
pip install -r requirements.txt
```

b. Using web-based version

The web-based version of VisualtRIBS is hosted on Heroku at:

https://visualtribs.herokuapp.com/

No further installation is required.

5.2 User guide

5.2.1 Start the program

To start VisualtRIBS, navigate to the folder using the following:

```
cd path/to/project/folder
```

Start the program with command:

```
python index.py
```

Open an internet browser (Chrome, FireFox) and type the address below in the search bar and hit enter:

5.2.2 Program layout

Figure 3 illustrates a typical VisualtRIBS visualization layout. The left panel shows the file upload options, variable type, and the corresponding UTM zone location of the simulated basin. The right panel shows a high-resolution map with color scheme options (top left) and the type of basemap (top right).

5.2.3 Select the voronoi polygon file (_voi, _voi.#)

To upload the voronoi polygon file from the tRIBS simulation outputs, click the box below Voronoi File (_voi) on the left panel. A pop-up box will open and the selected _voi file will be uploaded.

To upload the voronoi polygon file from parallel simulation, select all the applicable voronoi polygon files (_voi.#) for the basin and upload them. It is necessary that the order of the uploaded voronoi polygon files be the same as the spatial files (_00d.#)

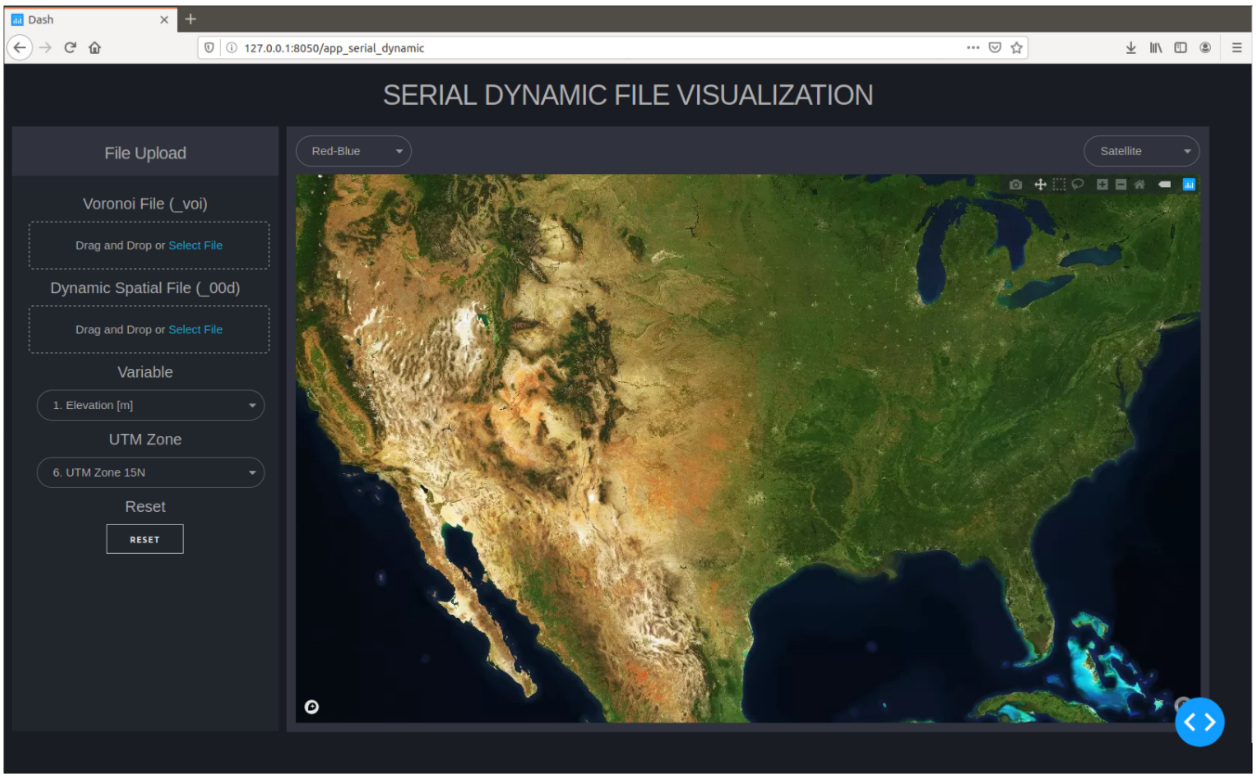

Figure 3. VisualtRIBS Layout

5.2.4 Select the spatially dynamic file (_00d)

To upload the spatial dynamic file, click the box below Spatial Dynamic (_00d) on the left panel, a pop-up box will open and the selected _00d file will be uploaded.

To upload the spatial dynamic file from parallel simulation, select all the applicable spatial dynamic files (_00d.#) for the basin and upload them. It is necessary that the order of the uploaded spatial dynamic files be the same as the voronoi polygon files (_00d.#)

Note: *The order of the uploaded voronoi files must be the same as the order of the uploaded spatial file in parallel visualization, e.g: if you upload **_voi.1, _voi.2, _voi.3** or **_voi.2, _voi.3, _voi.1** for polygon files then the correct order for spatial files is **_00d.1, _00d.2, _00d.3** or **_00d.2, _00d.3, _00d.1**, respectively.*

5.2.5 Select the variable to visualize

To visualize a variable, click on the box below the Variable on the left panel. There are 54 variable names for the spatial dynamic file (_00d) and 55 variable names for the time-integrated spatial file (_00i).

5.2.6 Select a spatial projection

Since tRIBs utilizes Easting/Northing convention for projection, it is necessary to convert the coordinates to the Universal Transverse Mercator Coordinate System (UTM) to project the simulated basins onto the world map. To select corresponding UTM zone of the simulated watershed, click the UTM Zone option on the left panel.

5.2.7 Select a color Scheme

To select a color scheme, click the bar on the top left corner of the map.

5.2.8 Select a basemap

To select base map, click the bar on the top right of the map. There currently are four (4) options for the basemap:

- Outdoor basemap with street names and elevation contour lines (Figure 4)

- Satellite basemap with high-resolution satellite images without street names (Figure 5)

- Open-Street basemap with detailed street names without elevation contour lines (Figure 6)

- Street: Basemap with high-resolution satellite images and street names (Figure 7)

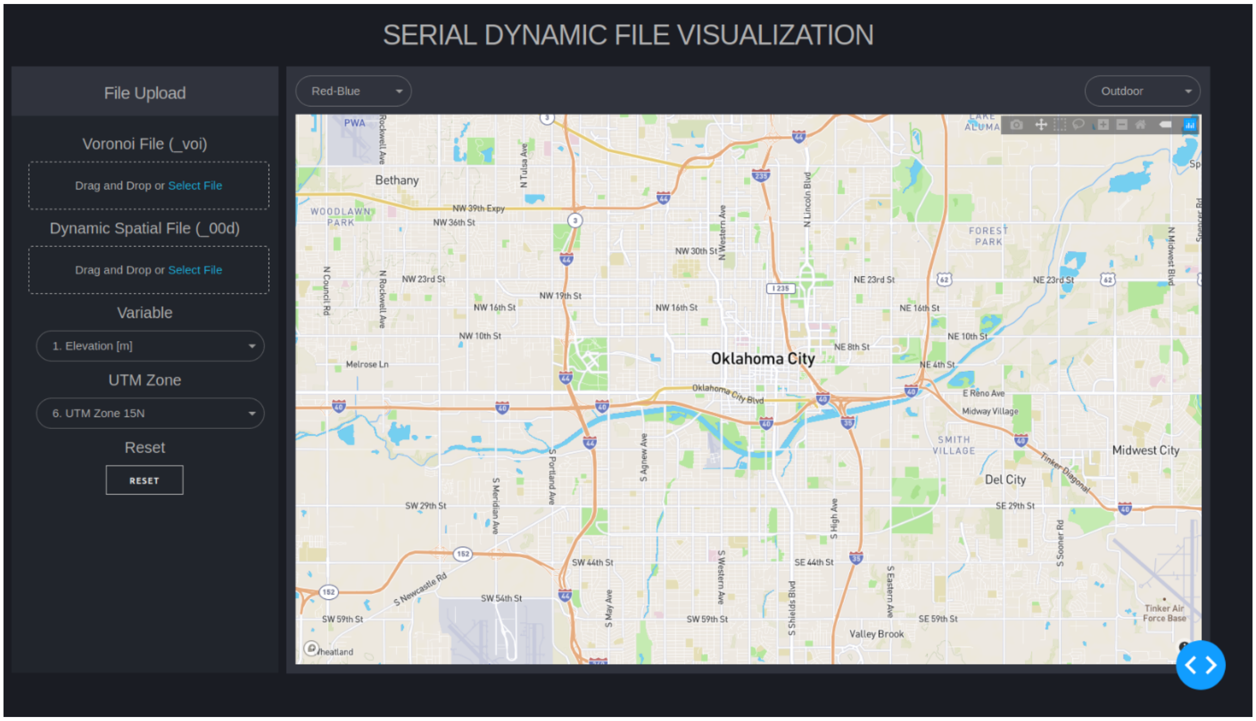

Figure 4. Outdoor basemap

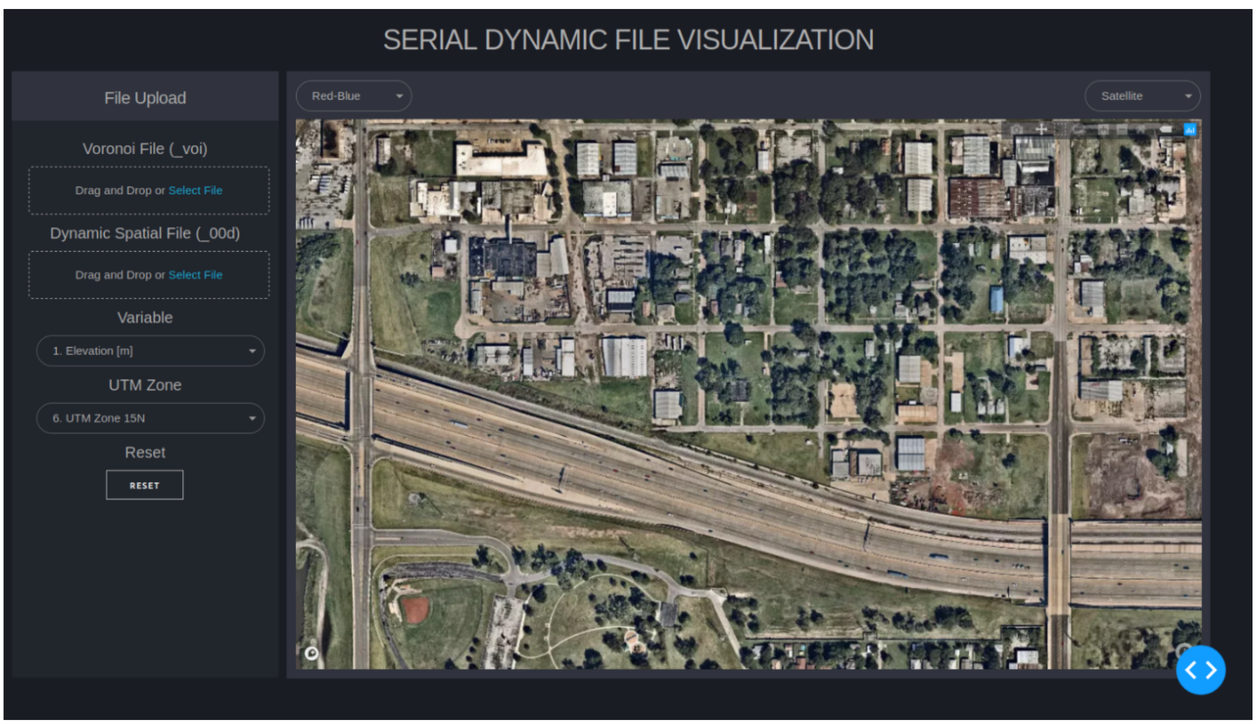

Figure 5. Satellite basemap

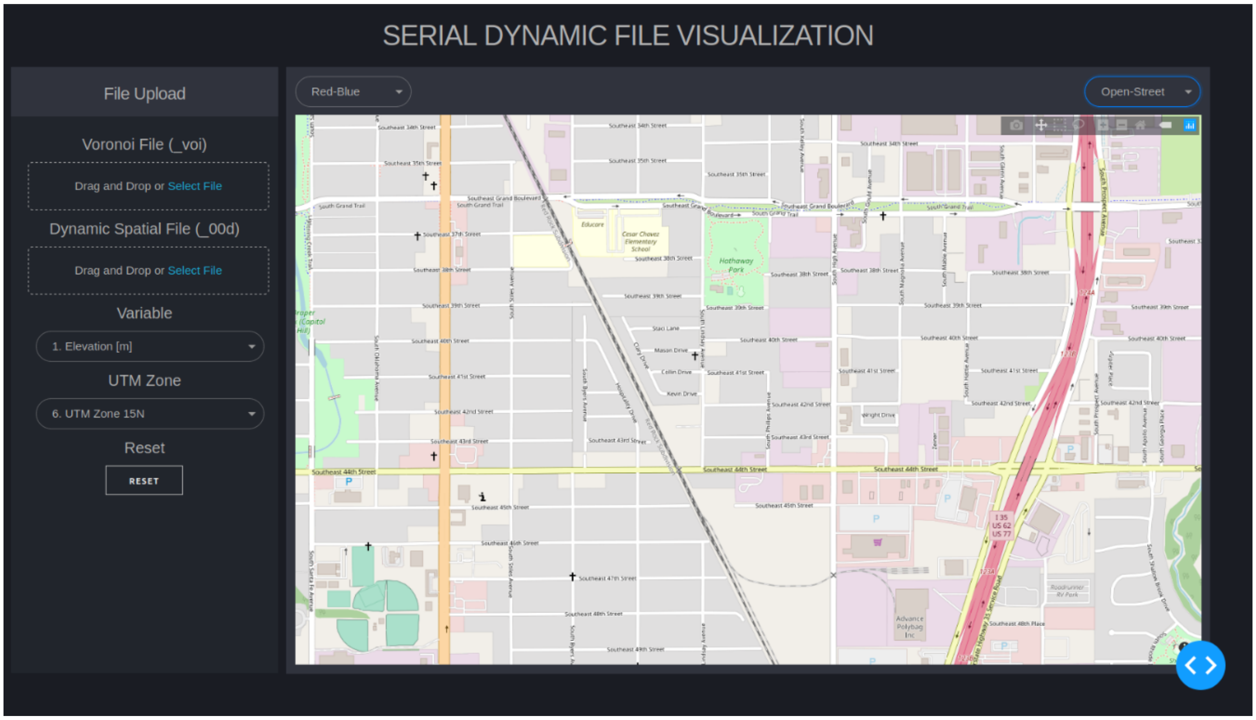

Figure 6. Open-Street basemap

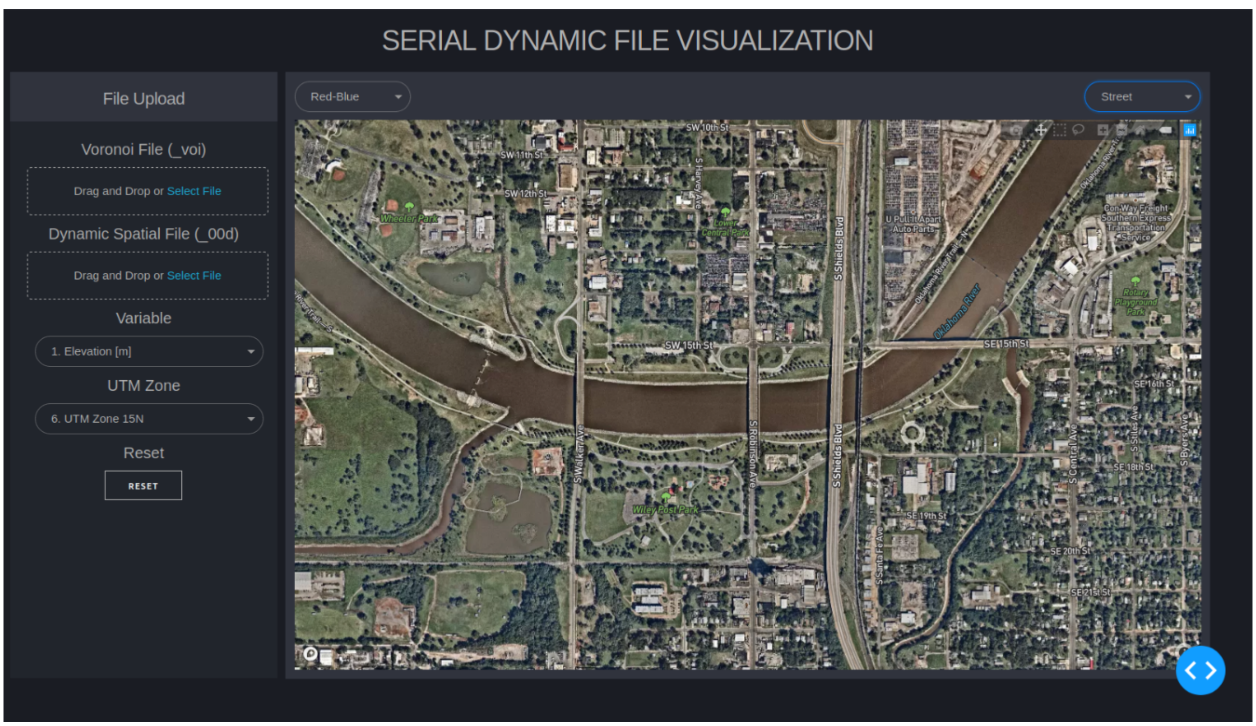

Figure 7. Street basemap

5.2.9 Visualize the variable of interest

After all the options have been set, the tool will automatically read both the voronoi polygon files and the spatial output files, create a corresponding geojson in the background and project the results onto the basemap. To download the results, click on the camera icon at the top right of the basemap.

Note: *Depending on the number of voronoi cells in the simulation basin, the visualization tool can take from 5 seconds (Peachcheater Creek) to 30 seconds (Redondo Creek) to complete the task. If you see the message "updating …",in VisualtRIBS, it means the tool is still running. In this case, please do not reload the page or the uploaded data will be removed from the program memory.*

5.3. Visualization Example

Figures 8 and 9 illustrate two visualization examples. Figure 8 shows the "Actual Evaporation" at the Peachcheater Creek basin in OK for a particular simulation time and forcing. Figure 9 illustrates "Sensible heat flux" at Rendondo Creek in NM.

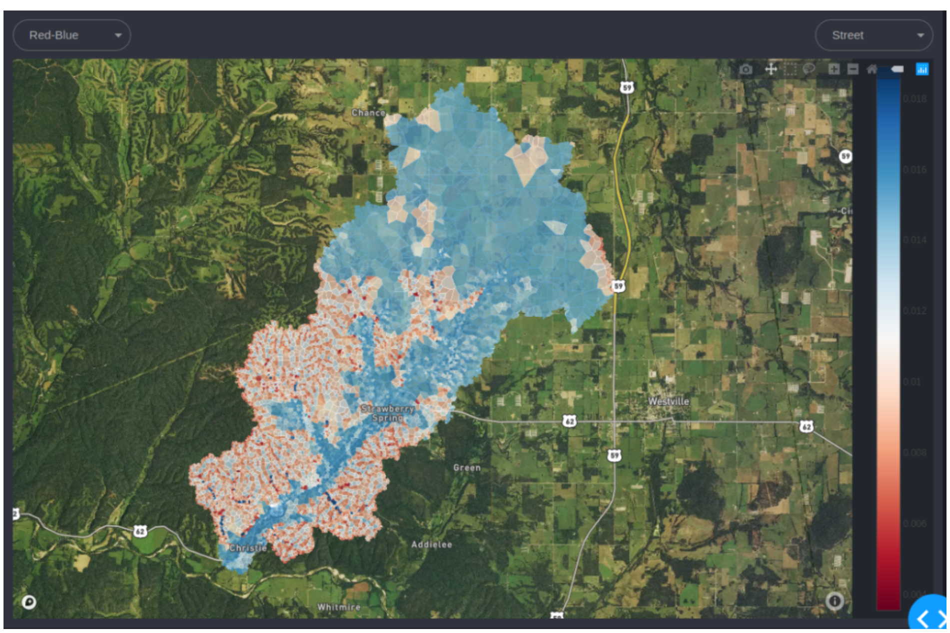

Figure 8. Actual Evaporation at Peacheater Creek, *OK with red-b*lue color scheme.

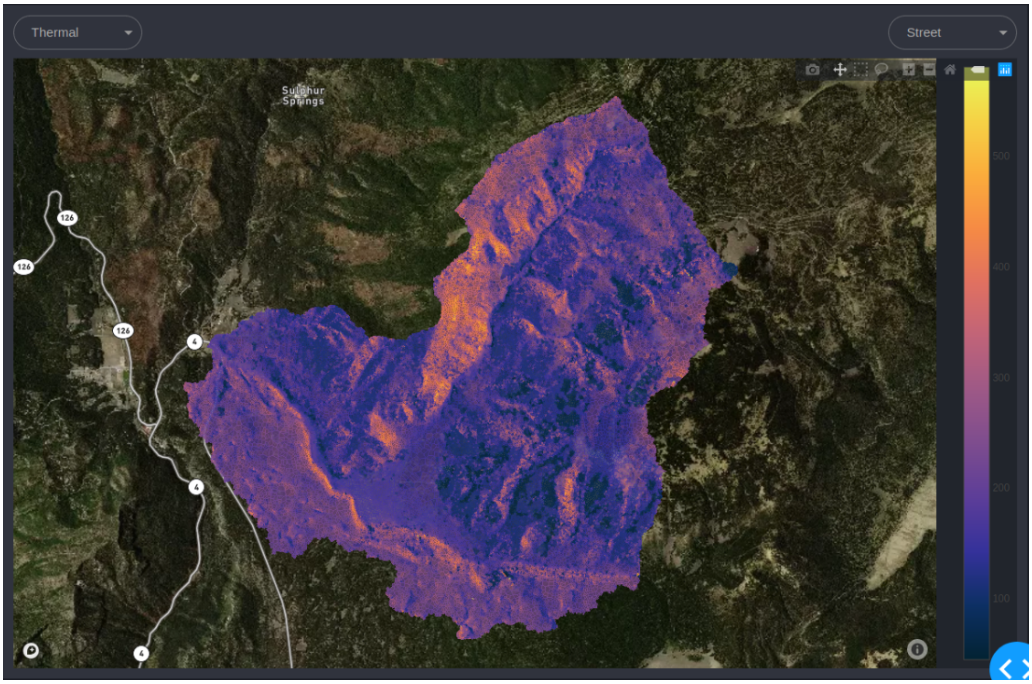

Figure 9. Sensible Heat Flux at Redondo Creek, NM with thermal color scheme.

6. Final assessment of timeline progress

To measure the progress of this YIP proposal from 07/31/19 to 07/31/20 (12 months) of work, we recall the Table 1 (former Table 4 in YIP proposal) to assess what level of completion of each activity we have attained.

Table 1. Project timeline with major tasks and level of completion in percentage.

PROJECT ACTIVITY		YEAR 1			YEAR 2			YEAR 3		
		SPR	SUM	FALL	SPR	SUM	FALL	SPR	SUM	FALL
Hypothesis I	Site-scale data analysis		100							
	Site-scale modeling			100						
	Site and catchment-scale model parameterization					100				
Hypothesis II	Seasonal vegetation catchment-scale modeling						100			
	Static vs seasonal vegetation simulations						100			
	Model visualization tool									100
Hypothesis III	Abrupt vegetation change catchment-scale simulations									100
	Assessing vegetation change effects on SEB and ST									100

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