Title of Grant / Cooperative Agreement:	Assessing Wetland Hydroperiod and Soil Moisture with Remote Sensing: A Demonstation for the NASA Plum Brook Station Year 2
Type of Report:	Summary of Research
Name of Principal Investigator:	Colin Brooks
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Name and Address of recipient's institution:	Michigan Technological University, 1400 Townsend Dr., Houghton, MI 49931
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Reference 14 CFR § 1260.28 Patent Rights *(abbreviated below)*
The Recipient shall include a list of any Subject Inventions required to be disclosed during the preceding year in the performance report, technical report, or renewal proposal. A complete list (or a negative statement) for the entire award period shall be included in the summary of research.

Subject inventions include any new process, machine, manufacture, or composition of matter, including software, and improvements to, or new applications of, existing processes, machines, manufactures, and compositions of matter, including software.

Have any Subject Inventions / New Technology Items resulted from work performed under this Grant / Cooperative Agreement?	No ◉	Yes ○
If yes a complete listing should be provided here: Details can be provided in the body of the Summary of Research report.		

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A Final Inventory Report of Federally Owned Property, including equipment where title was taken by the Government, will be submitted by the Recipient no later than 60 days after the expiration date of the grant. Negative responses for Final Inventory Reports are required.

Is there any Federally Owned Property, either Government Furnished or Grantee Acquired, in the custody of the Recipient?	No ◉	Yes ○
If yes please attach a complete listing including information as set forth at § 1260.134(f)(1).		

Attach the Summary of Research text behind this cover sheet.

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Reports shall be in the English language, informal in nature, and ordinarily not exceed three pages (not counting bibliographies, abstracts, and lists of other media).

A Summary of Research (or Educational Activity Report in the case of Education Grants) is due within 90 days after the expiration date of the grant, regardless of whether or not support is continued under another grant. This report shall be a comprehensive summary of significant accomplishments during the duration of the grant.

SUMMARY OF RESEARCH: ASSESSING WETLAND HYDROPERIOD AND SOIL MOISTURE WITH REMOTE SENSING: A DEMONSTRATION FOR THE NASA PLUM BROOK STATION YEAR 2

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Primary Goal: Assist with the evaluation and measuring of wetlands hydroperiod at the Plum Brook Station using multi-source remote sensing data as part of a larger effort on projecting climate change-related impacts on the station's wetland ecosystems.

MTRI expanded on the multi-source remote sensing capabilities to help estimate and measure hydroperiod and the relative soil moisture of wetlands at NASA's Plum Brook Station. Multi-source remote sensing capabilities are useful in estimating and measuring hydroperiod and relative soil moisture of wetlands. This is important as a changing regional climate has several potential risks for wetland ecosystem function. The year two analysis built on the first year of the project by acquiring and analyzing remote sensing data for additional dates and types of imagery, combined with focused field work. Five deliverables were planned and completed: 1) Show the relative length of hydroperiod using available remote sensing datasets 2) Date linked table of wetlands extent over time for all feasible non-forested wetlands 3) Utilize LIDAR data to measure topographic height above sea level of all wetlands, wetland to catchment area radio, slope of wetlands, and other useful variables 4) A demonstration of how analyzed results from multiple remote sensing data sources can help with wetlands vulnerability assessment 5) A MTRI style report summarizing year 2 results.

This report serves as a descriptive summary of our completion of these our deliverables. Additionally, two formal meetings were held with Larry Liou and Amanda Sprinzl to provide project updates and receive direction on outputs. These were held on 2/26/15 and 9/17/15 at the Plum Brook Station.

Principal Component Analysis (PCA) is a multi-variate statistical technique used to identify dominant spatial and temporal backscatter signatures. PCA reduces the information contained in the temporal dataset to the first few new Principal Component (PC) images. Some advantages of PCA include the ability to filter out temporal autocorrelation and reduce speckle to the higher order PC images. A PCA was performed using ERDAS Imagine on a time series of PALSAR dates. Hydroperiod maps were created by separating the PALSAR dates into two date ranges, 2006-2008 and 2010, and performing an unsupervised classification on the PCAs (Figure 1).

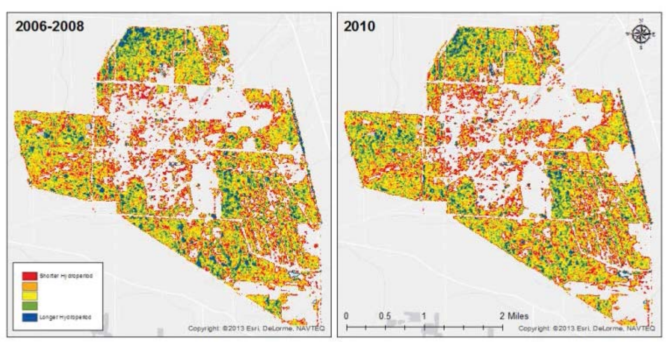

FIGURE 1. HYDROPERIOD MAPS FOR 2006-2008 AND 2010 FOR WOODED AREAS OF THE PLUM BROOK STATION.

Three dates of Radarsat-2 fully polarimetric SAR data were collected in fine beam quad pol mode 3 (FQ3), which has an incidence angle range of 20.9 to 22.9 ° and spatial resolution of 5 x 8 m. This sensor is C-band, 5.6 cm wavelength, with four polarizations HH, HV, VH and VV. To correlate the dataset to soil moisture, dataloggers equipped with four Campbell Scientific CS625 water content reflectometers, a temperature probe and solar panel were deployed in May of 2015 at two woody sites with small trees and three herbaceous sites of homogenous covertype of 100 m x 100 m in size. Images were collected on 20 May, 13 June and 31 July 2015. Since stand structure/biomass affects the scattered signal, standard forestry protocols were used to sample the vegetation. Tree biomass was estimated using species specific allometry based on trunk diameters.

The included sites have biomass ranging from 0.2 (estimated for spring- measured as 0.49 in August at herbaceous site) to 4.0 kg/m^2 and a range of volumetric moisture between 26.4% and 37.1%. The best three algorithms for the dataset at hand for soil moisture are presented in Table 1 and for biomass in Table 2. Best algorithm was determined by strong coefficient of determination (R^2) greater than 0.55, low standard error (SE) significance at 95% confidence of the algorithm and all predictor variables, and low collinearity.

The soil moisture algorithms rely on both polarized linear backscatter and the van Zyl decomposition variables: surface and double bounce. These algorithms offer an improvement over C-VV backscatter (Table 1) alone with a coefficient of determination (R^2) of 0.40 to the polarimetric algorithm with R^2 of 0.75 and a drop in standard error (SE) from 2.83 to 2.06 for the CVV, CHV_dB, and VZdbl algorithm (Table 1).

TABLE 1. TABLE OF ALGORITHMS WITH 3 OR FEWER VARIABLES TO PREDICT SOIL MOISTURE FROM RADARSAT-2 SAR WITH INCIDENCE ANGLE OF AROUND 21°. FOR COMPARISON THE ALGORITHM FOR CVV BACKSCATTER ALONE IS ALSO PROVIDED.

Best Models	R^2	Adj. R^2	p-value	SE
CVV	0.401	0.341	0.027	2.827
CVV, CHV_dB, VZdbl	0.745	0.65	<<0.05	2.063
CVV_db, CHV_dB, VZdbl	0.72	0.61	0.013	2.164
HH/HV, VZ_surf_dB, VZ_dbl	0.70	0.59	0.17	2.235

The biomass algorithms also rely on SAR polarimetry and are an improvement over linearly polarized data alone (e.g. CHH, CHV or CVV) with an increase in R^2 from 0.48 to 0.77 and decrease in the Standard Error (SE) from 1.303 to 0.869 for POLmax as the predictor variable (Table 2). Note that models with CHV and CHH or CVV had insignificant terms and therefore are not reported.

TABLE 2. LIST OF ALGORITHMS WITH 3 OR FEWER VARIABLES TO PREDICT BIOMASS BASED ON RADARSAT-2 SAR WITH INCIDENCE ANGLE NEAR 21°. FOR COMPARISON THE ALGORITHM FOR CHV BACKSCATTER ALONE IS ALSO PROVIDED.

Best Models	R^2	Adj. R^2	p-value	SE
CHV	0.48	0.43	0.01	1.303
POLmax	0.765	0.742	<<0.05	0.869
POLmin, Dmax	0.84	0.81	<<0.05	0.753
CPentropy, POLmin	0.84	0.81	<<0.05	0.754

The development of algorithms for both biomass and soil moisture retrieval with biomass < 4.0 kg/m^2 looks promising and should be further pursued along with sites in other regions. The algorithm developed should be applicable to sites within the range of biomass and moisture conditions under which it was developed. However, further investigation into the trend in backscatter at the herbaceous sites which goes against SAR theory should be further investigated.

Wetland area extent was analyzed for thirty-three Plum Brook wetlands. Multiple dates (1995, 2004, 2005, 2006, 2009, 2010, and 2011) and several sources of imagery (National Agricultural Imagery Program - NAIP, Ohio Geographically Referenced Information Program - OGRIP, USGS digital orthophotographs, and the Department of Homeland Security Great Lakes Border Flight) were used for an aerial imagery interpretation-based analysis of wetland extent. The date-linked table created in year one was updated for all the feasible non-forested wetlands. The central idea was that changes in wet area extent could be tracked over time, providing a way to monitor Plum Brook wetland trends. Smaller wet area extents for Plum Brook wetlands may demonstrate likely trends for potentially drier summers, while wetlands with large fluctuations in area could be those more vulnerable to climate change impacts.

2006 LIDAR data for Plum Brook Station was downloaded from the Ohio Statewide Imagery Program. Using QuickTerrain Modeler software, the LIDAR point cloud was processed into a bare earth digital elevation model (DEM). A hillshade representation of that DEM can be seen in Figure 2 (left). Using the DEM it was possible to calculate a variety of topographic parameters including slope and topographic height above seas level (Figure 2 - right).

The five project deliverables were completed, providing demonstrations of how remote sensing data could be used to understand Plum Brook wetland vulnerability. Multi-source remote sensing capabilities are useful in helping to understand and measure hydroperiod and soil moisture of wetlands. The project team recommends additional year three work to: 1) refine field work task to build from this year's soil moisture field effort for Radarsat2-based analysis, but with a more complete field data set 2) An analysis write-up to support submission of a paper to the 2016 AGU meeting 3) Finalize and update the Year 2 analysis results and close gaps 4) Integrate the finalized geospatial products into A. Sprinzl's larger wetland climate vulnerability analysis and 5) Documentation and delivery of finalized data layers, with metadata.

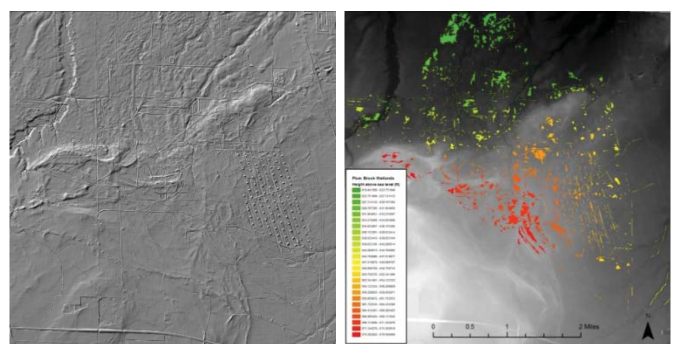

FIGURE 2. A HILLSHADE (LEFT) AND TOPOGRAPHIC HEIGHT ABOVE SEA LEVEL FOR THE PLUM BROOK WETLANDS (RIGHT).