Project Title: Final Maintenance and Refinement of the MODIS Land Cover Product

PI: Mark Friedl, Boston University.

Type of Report: Annual

Time Period: May 28, 2014 – May 27, 2015

Award Number: NNX14AJ35G

Institution: Boston University
881 Commonwealth Avenue
Boston, MA 02215

1. Project Goals

Activities being conducted through this project are designed to support two main goals. First, we are providing short-term maintenance and refinement of the Collection 6 MCD12 product suite (nominally, through the end of this project: 5/27/16). As part of this process we are finalizing code and data sets in support of the Collection 6 MCD12 algorithms. The second goal of this project is to port all source code and datasets that are used to generate the MCD12 products (which include the MODIS Land Cover Type product (MCD12Q1) and the MODIS Land Cover Dynamics product (MCD12Q2)) to NASA's MODIS Adaptive Processing System (MODAPS), thereby allowing NASA to perform long-term maintenance of MCD12 products.

2. Summary of Activities and Accomplishments

Collection 6 reprocessing of land products began in early February 2015. Because the MCD12 algorithms ingest upstream surface reflectance products (most importantly, the Nadir BRDF-Adjusted surface reflectance product from Crystal Schaaf's group), which are not yet available, we have not been able to fully test and evaluate our Collection 6 codes. We anticipate that sufficient collection 6 inputs will be available to exercise the MCD12 algorithms by the end of spring 2015, at which time we will rapidly move toward finalization and delivery of new products and source code to NASA GSFC. In the interim, activities conducted during the reporting period have focused on implementation and testing of operational codes for the collection 6 MCD12 product suites based on Collection 5 data. Below we describe specific steps and activities we have pursued in support of each product.

2.1. Activities in support of the MODIS Land Cover Type Product

1. *Training site database maintenance*. The database of training sites is a key input to the MCD12Q1 algorithm. Ongoing revision, quality assessment, and augmentation of the MODIS global land cover training site database is therefore

an important means for improving product quality. Hence, during the first year of this project we continued activities from previous funding cycles focused on: (1) augmentation of sites in under-represented regions and land cover types, and (2) identification and removal of poorly labeled sites or sites that have experienced land cover change since the launch of MODIS. To this end, the global site database has been edited and improved, new sites have been added, and a substantial number of problematic sites have been removed. A key element of this activity was revising the database to support an LCCS-based classification, which will be included in collection 6.

2. *Spline-smoothing of surface reflectance products*. A key change to both the MCD12Q1 and MCD12Q2 algorithms in collection 6 is that we are pre-processing all of the inputs MODIS time series using penalized cubic smoothing splines. To make this computationally feasible, we have implemented this code to run on GPU's at Boston University's high performance computing facility. This work is essential complete, and is in the final stages of testing, which can only be performed when Collection 6 surface reflectance products are available.
3. *Collection 6 algorithm revisions*. We have made several significant changes to the MCD12Q1 algorithm and product in Collection 6. The main revision is the addition of a new classification layer that conforms to the FAO Land Cover Classification System (LCCS). Implementation of this refinement required extensive code changes to implement a new hierarchical classification model, and revisions to the training site database to support this new layer. Both the code changes and training data updates are complete; however, full testing requires multiple years of Collection 6 surface reflectance data. In the interim, we have been testing the revised algorithm using Collection 5 input data.
4. *Development of methods to stabilize classification results across years*. The final element of our MCD12Q1 algorithm refinement activities focused on methods to stabilize stochastic variation in classification results across years. To this end, we have developed and tested a method that uses Hidden-Markov models that reduce year-to-year spurious variation in classification results, and by extension, provide more accurate and timely representation of land cover changes. Again, this work is essentially complete, and is awaiting final testing when a sufficient time series of Collection 6 inputs are available.

2.2. Activities in support of the MODIS Land Cover Dynamics Product:

1. *Refinements to Collection 6 source codes and algorithms.* As part of our refinement and maintenance activities we have implemented extensive changes to the core algorithm that is used to generate the MCD12Q2 (MODIS Land Cover Dynamics) Product. First, we have modified the algorithm to use the spline-smoothed inputs described in bullet 2 of Section 2.1. Second, we have revised the algorithm to provide improved and more flexible detection and characterization of seasonal growth cycles. Third, we have modified the algorithm to estimate the timing of phenological transitions based on thresholds

in the amplitude of the estimated spline-curves, which allows more accurate and less biased estimates of the timing of phenophase transitions

2. *Continued collection and analysis of field data*. Validation and calibration activities focused on two main tasks. First, we continued to devote significant effort to compiling and analyzing data from the PhenoCam network (http://phenocam.sr.unh.edu/webcam/) to serve as a basis for product validation. Second, we have investigated a variety of complementary data sources including those from PlantWatch Canada and the National Phenology Network in the United States.
3. *Analysis of phenology in human-modified ecosystems*. We continued efforts focused on using the MCD12Q2 product to characterize phenology in urban and agro-ecosystems, focusing on analyses designed to quantify the magnitude of differences in the timing of phenological events in these systems relative to nearby natural ecosystems.

3. Publication and Presentation of Results

To ensure that research results are widely disseminated and publicly available, we devoted significant energy to writing and presenting results from research activities in journals and at international meetings. Research from this project resulted (in whole or in part) in eleven published papers in refereed journal papers, and seven presentations at international meetings and workshops. See Section 7 below.

4. Personnel

Project staff included 2 research associates, each at 50% FTE. Specifically, Mr. Damien Sulla-Menashe continued as a research associate on the project and was primarily responsible for maintenance and refinement of the MODIS Land Cover Type Product. In addition, Dr. Josh Gray provided support for algorithm refinements and algorithm maintenance related to the Land Cover Dynamics product. The PI (Friedl) provided academic year oversight of all project activities throughout the reporting period, and devoted one half-summer months to this project.

5. Ongoing Activities

Research activities in year 2 will followed the approved work-plan for this project. Specifically, current activities are focused on (1) final preparations for Collection 6 processing, (2) validation and calibration assessment for both MCD12Q1 and MCDQ2 products, (3) production and delivery of the Collection 6 MCD12 products, and (4) porting of source codes for the MCD12 algorithms to NASA GSFC.

6. Budget Management and Projections

Current projections for the second year budget period ending in May of 2015 indicate that the project will be on-budget, within roughly plus/minus 5% of the projected budget for this period.

7. Publications and Presentations During the Reporting Period

Journal Articles

1. Salmon, J.M. M.A. Friedl, S. Frolking, D. Wisser and E. M. Douglas, 2015. Global rain-fed, irrigated, and paddy croplands: A new high-resolution map derived from remote sensing, crop inventories, and climate data. *International Journal of Applied Earth Observation and Geoinformation*, 38, pp. 321-334; doi:10.1016/j.jag.2015.01.014.
2. Gray, J.M, S. Frolking, E.A. Kort, D.K. Ray, C.J. Kucharik, N. Ramankutty’ & M.A. Friedl 2014, Direct human influence on atmospheric CO_2 seasonality from increased cropland productivity, *Nature*, 515, pp 398-401, doi:10.1038/nature13957
3. Glanz, H., L. Carvalho, D. Sulla-Menashe and M.A. Friedl, 2014. A parametric model for classifying land cover and evaluating training data based on mulit-temporal remote sensing data, *ISPRS Journal of Photogrammetry and Remote Sensing*, 97, pp. 219-228; doi: 0.1016/j.isprsjprs.2014.09.004
4. Gray, J.M, M.A. Friedl, S. Frolking, N. Ramankutty, A.Nelson and M. Gumma, 2014. Mapping Asian Cropping Intensity with MODIS. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 7(8), pp. 3373-3379. DOI:10.1109/JSTARS.2014.2344630
5. Sulla-Menashe, D., R. Kennedy, Z. Yang, J. Braaten, O.N. Krankina and M.A. Friedl 2014, Detecting forest disturbance in the Pacific Northwest from MODIS time series using temporal segmentation, *Remote Sensing of Environment*, 151, pp 114-123, DOI: 10.1016/j.rse.2013.07.042.
6. Klosterman, S.T., K. Hufkens, J.M. Gray, E. Melaas, O. Sonnetag, 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. Doi: 10.5194/bg-11-4305-2014.
7. Friedl, M.A., J.M. Gray, E.K. Melaas, A.D. Richardson, K. Hufkens, T.F. Keenan, A. Bailey and J. O'Keefe. 2014. A tale of two springs: using recent climate anomalies to characterize the sensitivity of temperate forest phenology to climate change. *Environmental Research. Letters.* **9** 054006 doi:10.1088/1748-9326/9/5/054006
8. Verma,M., M. A. Friedl, A. D. Richardson, G. Kiely, A. Cescatti, B. E. Law, G. Wohlfahrt, B. Gielen, O. Roupsard, E. J. Moors, P. Toscano, F. P. Vaccari, D. Gianelle, G. Bohrer, A. Varlagin, N. Buchmann, E. van Gorsel, L. Montagnani, and P. Propastin, 2014. Remote sensing of annual terrestrial gross

primary productivity from MODIS: an assessment using the FLUXNET La Thuile data set, *Biogeosciences*, 11, 2185-2200.

9. Li, L.; Friedl, M.A.; Xin, Q.; Gray, J.; Pan, Y.; Frolking, S, 2014**.** Mapping Crop Cycles in China Using MODIS-EVI Time Series. *Remote Sensing*, *6*, 2473-2493.
10. Huang, X and M.A. Friedl, 2014. Distance metric-based forest cover change detection using MODIS time series, *International Journal of Applied Remote Sensing and Geoinformation*, 29:78-92
11. Keenan, T.F., J. Gray, M.A. Friedl, M. Toomey, G. Bohrer, D. Y. Hollinger, J.W. Munger, J.O'Keefe, H.P. Schmid, I. Sue Wing, B. Yang and A.D. Richardson, 2014. Net carbon uptake has increased through warming-induced changes in temperate forest phenology, *Nature Climate Change*, doi:10.1038/nclimate2253

Conference Presentations and Abstracts

1. Friedl, M.A., E. Melaas, D. Sulla-Menashe and J. Gray (2014). Using Time Series of Landsat Data to Improve Understanding of Short- and Long-Term Changes to Vegetation Phenology in Response to Climate Change (invited), *Fall Meeting of the American Geophysical Union*, Dec 5-9, 2014, San Francisco, CA.
2. Friedl, MA. Characterizing the Sensitivity of Temperate Forest Growing Season Dynamics to Climate Change, *Earth Observation Data for Climate Science,* NASA Earth Exchange (NEX) Virtual Workshop and Challenge, *NASA Ames Research Center,* April 21, 2014.
3. Friedl, MA. Characterizing the Sensitivity of Temperate Forest Growing Season Dynamics to Climate Change, *Arthur Robinson Lecture*, The Ohio State University, Columbus Ohio, April 4, 2014.
4. Keenan, T. Richardson, A., Gray, J. Friedl, M., Toomey, M., Bohrer, G., Hollinger, D., Munger, J., Schmid, H.P., Sue Wing, I. and B. Yang (2014). Net Carbon Uptake Has Increased through Warming-Induced Changes in Temperate Forest Phenology (invited), *Fall Meeting of the American Geophysical Union*, Dec 5-9, 2014, San Francisco, CA.
5. Melaas, K., Friedl, M.A. and Richardson, A. (2014). *Tree species composition influences dependence of climate forcing on spring phenology across temperate deciduous broadleaf forests in Eastern United States, Fall Meeting of the American Geophysical Union*, Dec 5-9, 2014, San Francisco, CA.
6. Gray, J., Frolking, S., Kort, K., Ray, D., Kucharik, C., Ramankutty, N. and M. Friedl (2014). A direct human influence on atmospheric CO2 seasonality from increased cropland productivity, *Fall Meeting of the American Geophysical Union*, Dec 5-9, 2014, San Francisco, CA.
7. Li, L., Friedl, M., Xin, Q., Gray, J., Pan, Y and S. Frolking (2014), Mapping Crop Cycles in China Using MODIS-EVI Time Series, *Fall Meeting of the American Geophysical Union*, Dec 5-9, 2014, San Francisco, CA.