**Multi-sensor Fusion to Determine Agricultural Sensitivity to Climate Variability in South Asia**

**Second Year Project Report Nov 2014 – May 2015**

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Project Team:

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**Project Summary:**

 The project uses multiple sources of satellite imagery to examine the sensitivity of agriculture in South Asia to climate variability.South Asia is at the forefront of concerns about future food security. Population growth, continuing rural poverty, water shortages, stagnating yields, and climate change all contribute to these concerns. Despite agricultural intensification over the last several decades, agriculture in the region remains highly sensitive to monsoonal rainfall. Detailed understanding of this climate sensitivity is hampered by the coarse scales of previous studies conducted with data at the level of national and sub-national administrative units.

The project focuses on the sensitivity of cropping intensity (number of crops per year) to variability in rainfall. We are using data from MODIS, Landsat, Quickbird, WorldView, Tropical Rainfall Mapping Mission (TRMM), and other sensors to establish annual estimates of cropping patterns and rainfall anomalies. We are using time series of MODIS Enhanced Vegetation Index (EVI) to identify number of crops and agricultural productivity based on phenological profiles. Higher resolution Landsat, Quickbird and Worldview data in selected locations enable us to quantify landscape heterogeneity at the 250m scale. Other available, district-level, sub-district level non-satellite data and field data on dominant crop type, size of land holdings, yields and demographic variables such as labor availability will enable us to explore factors associated with agricultural sensitivity to climate variability.

 The ultimate goal of the project is to enable risk mapping and inform effective approaches for adaptation to climate variability in the region. Data sets on cropping patterns at 250m resolution and aggregated to district level for each year from 2000 to present will be made available to the community of researchers investigating climate impacts on agriculture.

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# Progress to date:

We have made substantial progress in developing an accurate and validated method to determine cropping intensity. We have compared multiple methods based on MODIS time series analysis, EOF analysis of MODIS data, and Landsat time series. The Quickbird and Worldview data (available to NASA PIs) has been used for validation and calibration. We have compared the results with agricultural census data.

We have published (see publications below) results of our work to compare data sources and algorithms to determine cropping intensity over the two study regions. Results indicate that Landsat time series provides higher accuracy in mapping cropping intensity than MODIS data, but that MODIS data performs reasonably well. Work to apply this algorithm at a national scale is underway with manuscripts in preparation.

The main emphasis in this reporting period has been on refining the algorithm for mapping cropping intensity and interpretation of the climatic and demographic factors associated with variability in cropping intensity. We have found a strong association with winter temperature, a surprising result given the common emphasis on monsoon rainfall as a driver of crop productivity.

We have carried out considerable analysis on two focal areas to develop methods and understanding of relationships between cropping intensity and climate variability. These areas have been selected to represent a range of conditions (subsistence to market crops) and to be in places familiar to the investigators where data sources and field logistics are known. The two areas are in north-west India in the state of Gujarat and central India in the state of Madhya Pradesh. We have collected field data, assembled MODIS, Landsat, TRMM, Quickbird, and Worldview data, and developed products of winter cropped area for 2000 to present for both site. We have published several papers on the results in these focal regions (see publications below).

 Future work on the project includes finalizing manuscripts about the mapping of crop intensity at the national scale, attribution of variability in cropping intensity to climate, management (e.g. irrigation) and demographic factors. Based on the results from mapping cropping intensity, we are also exploring several other aspects including the implications for water demand, human wildlife conflict, and measures of human well-being such as nutrition.

Several projects have spun off from this NASA-funded project, including funding from Google Earth Engine to implement the algorithm in the google platform, an Indo-US Science Forum held in February 2014, a funded effort on incorporation of adaptation to climate variability in crop modeling, and further proposals to explore the impacts of changes in cropping intensity on nutrition (see list of other projects below).

# Plans for next reporting period:

In the coming reporting period, we plan to do the following:

 Test additional approaches for the algorithm to map cropping intensity using the large database of available Landsat data.

 Submit for publication a manuscript for a special issue in Regional Environmental Change based on the results for central India.

Prepare for publication results from mapping cropping intensity at a national scale of winter cropping area to the national scale and attribution to climate and demographic factors.

 Finalize results and prepare for publication results about the role of different type of irrigation (canal, shallow well, tube well) in winter cropping and the sensitivity to climate variability.

**Publications to date:**

Mondal, P., Jain, M., DeFries, R., Galford, G., Small, C. 2015. Sensitivity of crop cover to climate variability: Insights from two Indian agro-ecoregions. *Journal of Environmental Management* 148, 21-30.

Mondal, P., Jain, M., Robertson, A., Galford, G., Small, C., DeFries, R. 2014. Winter crop sensitivity to inter-annual climate variability in central India. *Climatic Change* 126, 61-76.

Jain, M., Mondal, P., DeFries, R., Small, C., Galford, G. 2013. Mapping cropping intensity of smallholder farms: acomparison of methods using multiple sensors. *Remote Sensing of Environment* 134, 210-223.

**Presentations (\*=new presentations in this reporting period):**

Jain, M., Fishman, R., Mondal, P., Galford, G., Naeem, S., DeFries, R., Irrigation as an Adaptation Strategy to Rainfall Variability in India. American Geophysical Union Fall Meeting. 15-19 December 2014, San Francisco, California. Poster Presentation.

DeFries, R., Mondal, P., Jain, M., and Galford, G., Climate Sensitivity of Cropping Intensity in India, NASA Synthesis Workshop on Land Use and Land Cover Dynamics in South and Southeast Asia, Nov. 3-4, 2014, Kathmandu, Nepal.

Jain, M., Fishman, R., Mondal, P., Galford, G., Naeem, S., DeFries, R., Irrigation as an Adaptation Strategy to Rainfall Variability in India. Global Land Project Open Science Meeting. 19-21 March 2014, Berlin, Germany. Oral Presentation

Jain, M., Fishman, R., Mondal, P., Galford, G., Naeem, S., DeFries, R., Irrigation as an Adaptation Strategy to Rainfall Variability in India. American Geophysical Union Fall Meeting. 9-13 December 2013, San Francisco, California. Poster Presentation.

Jain, M., Mondal, P., Small, C., Galford, G., DeFries, R. Mapping cropping intensity of smallholder farms in South Asia:A comparison of MODIS, Landsat, and mixture model techniques. American Geophysical Union Fall Meeting. 9-13 December 2013, San Francisco, California. Invited Oral Presentation.

Mondal, P., Jain, M., DeFries, R., Galford, G., Small, C. Climate sensitivity of smallholder farmers across multiple agro-ecological zones in India. Global Land Project Open Science Meeting. 19-21 March 2014, Berlin, Germany. Oral Presentation.

Mondal, P., Jain, M., DeFries, R., Galford, G., Small, C. Sensitivity of crop cover to inter-annual climate variability:Insights from two Indian agro-ecoregions. IUSSTF Indo-US bilateral workshop. 20-21 February 2014, Bengaluru, India. Oral Presentation.

Mondal, P., Jain, M., Robertson, A., Galford, G., Small, C., DeFries, R. Winter crop sensitivity to inter-annual climate variability in central India. Kanha-Pench Landscape Symposium. 16-18 February 2014, Mocha, India. Oral Presentation.

Mondal, P., Jain, M., DeFries, R., Galford, G., Small, C. Impacts of Changing Climate on Agricultural Variability: Implications for Smallholder Farmers in India. American Geophysical Union Fall Meeting. 9-13 December 2013, San Francisco, California. Poster Presentation.

Mondal, P., Jain, M., DeFries, R., Galford, G, Small, C. Agricultural susceptibility to climate variability: Insight from two Indian agro-ecoregions. NASA Land-Cover and Land-Use Change Science Team Meeting. 2-4 April 2013, Rockville, Maryland. Poster Presentation.

Jain, M., Small, C., Mondal, P., Galford, G., DeFries, R. Mapping Cropped Area of Smallholder Farms in SouthAsia. NASA Land-Cover and Land-Use Change Science Team Meeting. 2-4 April 2013, Rockville, Maryland. Poster Presentation.

Mondal, P., DeFries, R., Jain, M., Robertson, A., Galford, G., Small, C. 2012. A multi-sensor approach to identify crop sensitivity related to climate variability in Central India. American Geophysical Union Fall Meeting. 3-7 December 2012, San Francisco, California. Poster Presentation.

Jain, M., Mondal, P., Small, C., Galford, G., DeFries, R. 2012. Mapping cropping intensity of smallholder farms in South Asia: A comparison of MODIS, Landsat, and mixture model techniques. NASA Land-Cover and Land-Use Change Science Team Meeting. 3-5 April 2012, Rockville, Maryland. Poster Presentation.

DeFries, R., Mondal, P., Jain, M., Small, C., and Galford. G., “Multi-sensor Fusion to Determine Agricultural Sensitivity to Climate Variability in South Asia”, Coimbatore, India, January 2013.

DeFries, R., Mondal, P., Jain, M., Small, C., and Galford. G.“Multi-sensor Fusion to Determine Agricultural Sensitivity to Climate Variability in South Asia”, NASA Science Team Meeting, April 2013.

**Publications in preparation:**

Jain, M., Fishman, R., Mondal, P., Galford, G., Naeem, S., DeFries, R., Irrigation as an Adaptation Strategy to Rainfall Variability in India. *In Prep.* To be submitted to *Nature Climate Change.*

Mondal, P., Jain, M., Zukowski, M., Galford, G., DeFries, R. Quantifying fluctuations in winter cropped area in the Central Indian Highlands: Implications for landscape-level management. *In Prep.* To be submitted to *Regional Environmental Change.*

**Funded follow up projects:**

Google Earth Engine Research Award for “The sensitivity of agricultural output to climate variability across smallholder farms in South Asia”

Lamont Climate Center sponsored project on “Assessing agricultural adaptation strategies for reducing winter crop sensitivity to future climate variability in central India”

Indo-US Science and Technology Forum: Indo-US Bilateral Workshop on “Adaptation of rural communities to climate change: Bridging the gap between academia and community workers and identifying research needs”, held Feb 2014.