Annual Progress Report: July 2010 – June 2011

**Investigating the Relationship Between Land Use/Land Cover Change,
Hydrologic Cycle, and Climate in Semi-Arid Central Asia**

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Abstract

The purpose of this research is to contribute to an existing investigation [*PI. Chen Xi of Xinjiang Institute of Ecology and Geography*] of the coupled hydrologic and atmospheric processes in semi-arid Central Asia as influenced by changes in land-use and land-cover, as well as climate. Our approach to this contribution has a multi-task framework, combining satellite remote sensing, evaporation models specifically suited to changing soil moisture supply, and coupled vadose zone-groundwater models designed to predict the locations of recharge and discharge areas. In the first task, we will assist in analyzing current and historical satellite imagery to determine the land use and land cover changes related to land surface hydrology in semi-arid western China and in Kazakhstan where irrigated agriculture (oasis development), grazing, and inter-basin water transfers are the main forms of land-cover/land-use transformations. In the second task, we will use simple evaporation models specifically suited to changing moisture supply to investigate the possibility that the partitioning of irrigation input between drainage and evaporation might change as a function of area irrigated area. In our previous LCLUC project, we found strong scale dependence in this partitioning due to feedbacks with the atmosphere (related to the so-called Complementary Relationship between actual and potential evaporation). In the final task, we will help address the issue of land-use and land-cover change impacts on water and soil quality using a coupled groundwater-vadose zone model. Our model is specifically designed to predict spatial distributions of recharge and discharge zones, which is critical for predicting potential locations of salt accumulation. By combining NASA's unique remote sensing capabilities with a coupled surface water-groundwater model within the framework of an existing project, the proposed research will help answering two critical water cycle questions: 1) how do land-use and land-cover changes affect the hydrological fluxes and the water cycle in semi-arid Central Asia? and 2) how can this information be used for sustainable water management practices, especially in the presence of population, development, and climate change pressures? The proposed research also directly supports regional priority areas outlined in this announcement. In particular, by focusing on the semi-arid regions of the NEESPI program where irrigated agricultural development is the major form of transformation on the land surface, the proposed research will aim to understand how different agricultural land-use practices affect coupled surface and atmospheric water cycle and climatic response, as well as what trajectories may take place in the near future. Studies like our ongoing research that help portray water resource impacts of major land use transformations have important implications for developing a science-based framework both for understanding hydrologic vulnerability and for developing sustainable water management practices.

Keywords
Remote Sensing, change detection, agriculture, irrigation, land dynamics, Central Asia, China, local, regional

Social science component: 20%

Project accomplishments during this performance period (July 2010 – June 2011)

1. Mapping irrigated area in Xinjiang

Xinjiang Uygur Autonomous Region lies in northwestern China (Figure 1). The mean annual precipitation is 150 mm and the evaporation ranges from 1000 to 2500 mm, categorizing Xinjiang as an arid and semi-arid region. About 95% of the cropland located in oases in Xinjiang is irrigated (Xinjiang Statistical Yearbook, 2009). During the past 50 years, many areas within Xinjiang have undergone agricultural reclamation as a direct result of population growth and policies aimed at economic development in the western region.
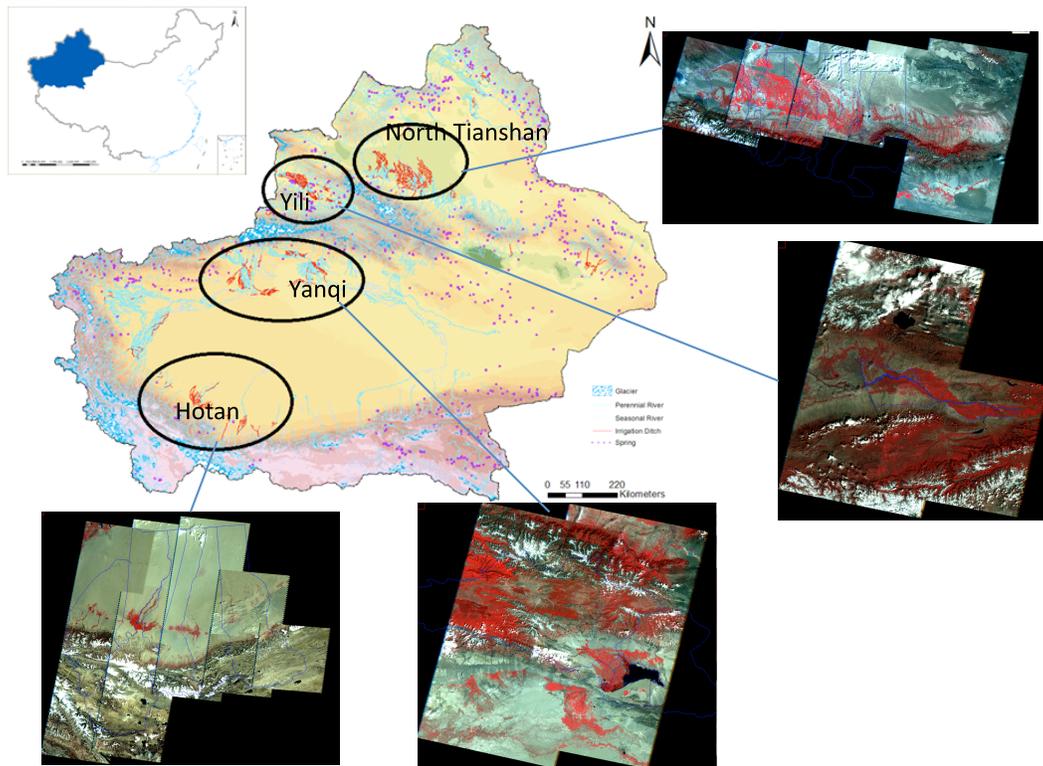
Figure 1. The location of irrigated croplands in Xinjiang, NW China.

During this performance period, we used Landsat data to map irrigated croplands from 1978 to 2009 in four study areas: Hotan, Yili, Yanqi and North Tianshan (Figure 1). Specifically, we applied Normalized Difference Vegetation Index (NDVI) thresholding method to map out irrigated areas based on differential spectral response between vegetation and non-vegetation plots. The assumption behind this approach was that all vegetated areas are irrigated, regardless of the form of vegetation (i.e. woody vegetation vs. annual crops). To determine the best available image data for irrigation identification, we first used one year of 16-day composited MODIS observations to determine the optimal growing season of each study area (Figure 2). In the second step, we acquired Landsat TM/MSS in dates corresponding to these optimal periods and used the thresholding approach to map the irrigated areas. For areas with single season crop (Figure 2b), the Landsat based NDVI images were thresholded for the growing season. For areas

with multiple season crops (Figure 2c), NDVI images were thresholded for two time periods and the resulting maps were combined using a conditional operation.
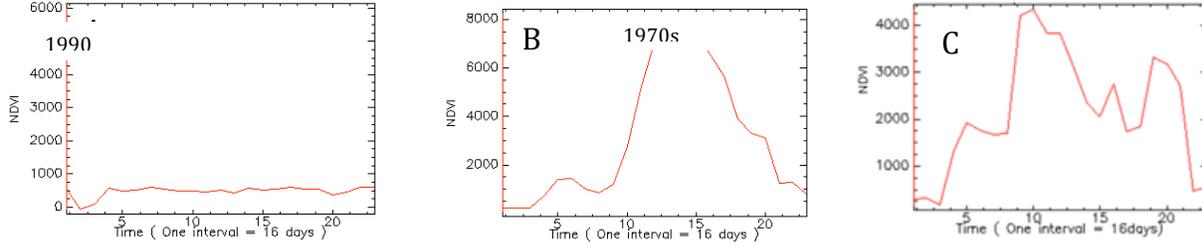
Figure 2. MODIS based vegetation index showing temporal profile of different land cover / land use types. A) desert; B) single crop; C) multiple crops.

Figure 3 shows the irrigated areas in the four study locations from late 1970s to 2009. Croplands expanded during the past 40 years. Based on accuracy assessment work using auxiliary data, such as field work (2010), high resolution images from Google Earth, land use data from previous studies (2000,1990), and visual interpretation of Landsat MSS (1970) a for each of the year. The overall accuracies for all the maps are above 95%, which indicates a   reliable estimate (Table 1). In some cases the statistical data was smaller because of the mismatch between statistical areas and commission errors in remote sensing estimates.

Table 1. Overall accuracy

| Area	Overall Accuracy
Hotan	97.10%
Yanqi	99.60%
North Tianshan	98.50%
Yili	98.90%
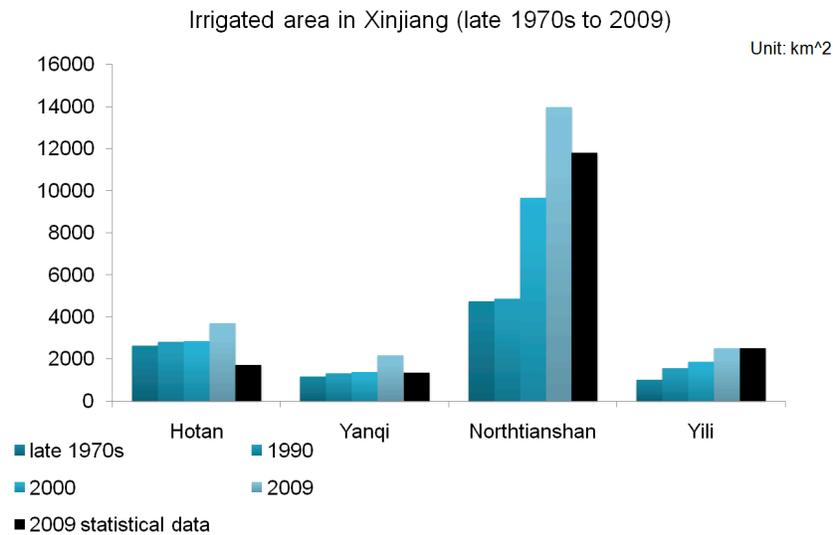
Figure 3. Comparison of irrigated areas in four locations in Xinjiang.

We ran into several limitations of the NDVI thresholding application. For example, it was difficult to separate small natural riparian areas from irrigated areas due to similarities in spectral/seasonal signatures in these vegetation types. Snow cover image helped to map out the woody natural vegetation. Another challenge was to classify different crop types within the irrigated area. One possible solution was using multiple NDVI observations from the same growing season for several years in the hope to capture the spectral responses of crops according to their phenological evolution.

2. Constructing a hydrologic model

The hydrological setting of Hotan: The Hotan River basin is situated between 34°52′ and 40°28′N, and between 77°25′ and 81°43′E, covering an area of 44 870 km^2. Geographically the river basin is on the north piedmont of Kunlun Mountain and in the south edge of Tarim Basin. Close to the Takelamagan Desert, Hotan falls into the climate temperate zone of arid desert with abundant sunlight and heat resources. The mean annual potential evaporation varies from 2159 to 3137 mm. The annual precipitation ranges from 5.4 to 89.6 mm, with an average annual precipitation around 35.6 mm. The mean monthly temperatures range from -4°C in January to 30°C in July, and the mean annual value is 12.2°C.

Groundwater flow is topographically controlled and flows from Kunlun Mt in the south to Takelamagan desert in the north. The majority of groundwater resources is in the form of seepage transformation of surface water including runoff and irrigation water (Figure 4), which is accounting for more than 94% of total groundwater recharge with a value of $3.67×10^9$ m^3 a year (Liu, 2007).
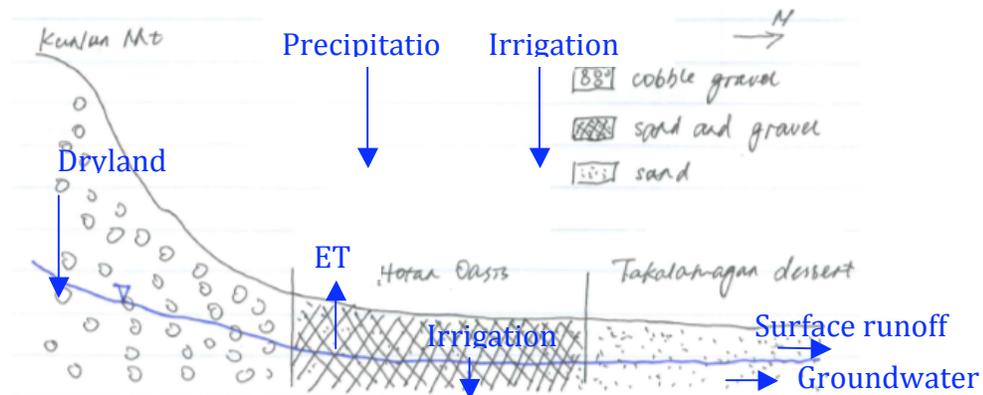
Figure 4. Conceptual diagram of the hydrologic cycle in Hotan area.

One dimensional hydrological model: To assess the effects of land use change on water resources of the Hotan region, we developed a one-dimensional hydrological model and using the local observations to calibrate the 1D model. Figure 5 shows the main hydrologic processes in a control volume.
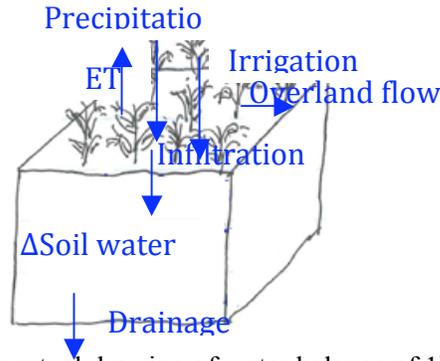
Figure 5. The conceptual drawing of water balance of 1D model.

Data sources: Meteorological data were obtained from the NCDC (Global Summary Of The Day dataset) and UCAR (daily mean downward shortwave at surface) between1948 and 2010.

For estimating evapotranspiration (ET) we used the FAO56 equation (Allen, 1998) to first calculate the reference ET (ET0) and then multiplied this number with the crop coefficient. When applying the FAO56 equation, we assumed the soil heat flux was negligible. In general, the soil heat flux is small compared to R_n and thus is often ignored. Kc is constructed base on the crop types and its growth stages. Table 2 is the Kc value at different stage.

Table 2. Kc value for cotton (Adapted from Allen 1998)

Crop	Initial	Development	Mid Season	Late season	total	Plant Date	Area	Kcini	Kcmid	Kcend
corn	30 days	50 days	55 days	45 days	180 days	April 1	Alar	~0.35	1.2	0.7

For estimating Infiltration we used the minimum number between potential infiltration and precipitation. The potential infiltration depends on the soil characteristics and the previous soil water content. We chose sandy soils and silt loam to calculate the potential infiltration. Soil water storage was determined from the soil water content. We assumed the soil depth is 2000 mm, given that the depth of corn root is around 2 meters. Below 2 meter, the drainage would occur. For the irrigated areas, the input water was from precipitation and irrigation. The infiltration was determined by the minimum value of water supply and potential infiltration. In our model, the overland flow occurs when infiltration rate is larger than potential infiltration rate. For drainage we used the empirical equation from the Huggens and Monke method to calculate the drainage. Drainage happens when the soil water content exceeds the field capacity.

Our preliminary results show that the annual reference ET has been decreasing slightly with a value ranging from 900 to 1300 mm (Figure 6). We also compared the calculated ET0, ETc and the observed ET in 2007 (Figure 7). The calculated ETc and observed ET share a similar pattern but the calculated ETc is often lower than observed ET, especially during the non-growing season.
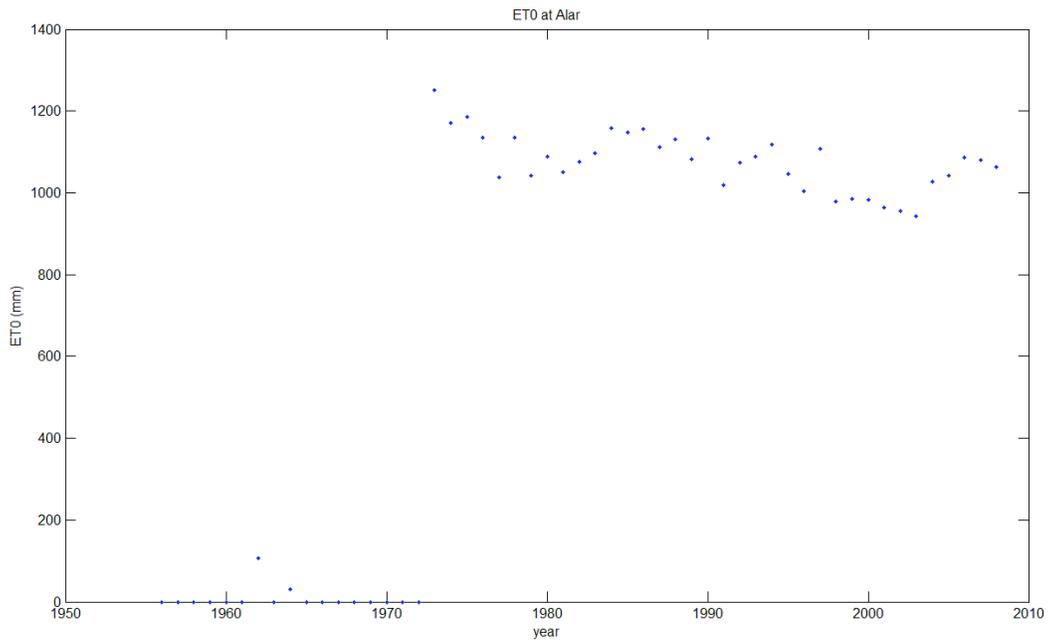
Figure 6. Time series of reference ET for the Alar region in the Tarim basin.
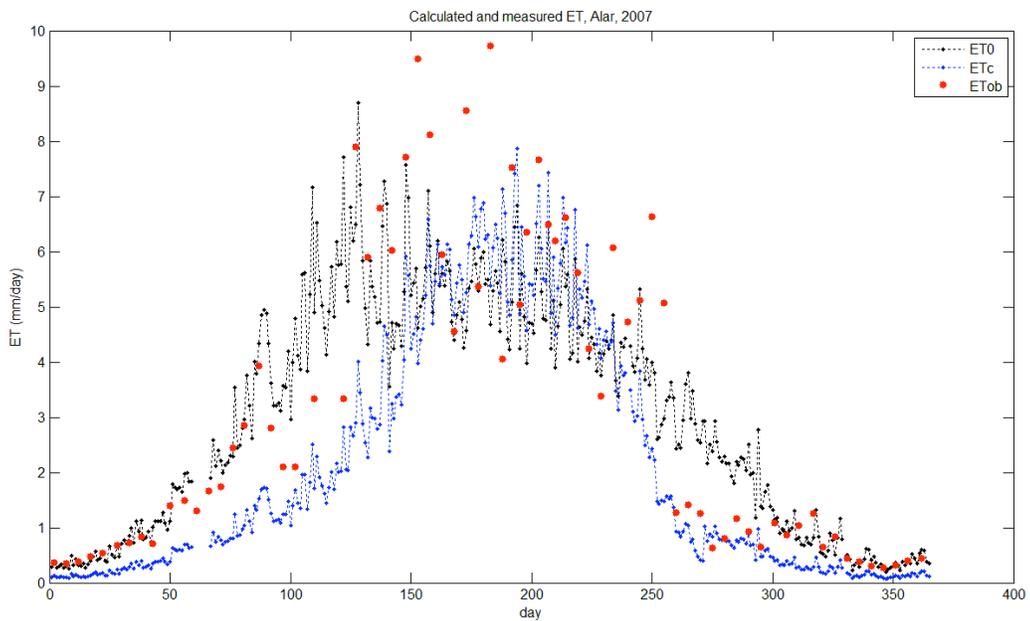
Figure 7. Comparison of reference Et, crop ET and the observed crop ET for the Alar region in the
Tarim basin.

Several challenges exist for the hydrological modeling work. First, figure 7 shows that the calculated ETc is lower than observed ET, especially during the non-growing season. One explanation could be that we did not include soil heat flux in our calculations. In the next phase of our work, we will add this part. Second, we do not yet have access to total irrigation amount used in the Tarim basin. We hope to be able to obtain this information from our colleagues in the region. Finally, crop ET is calculated at daily scale due to the data availability at daily time steps. Infiltration and drainage, however, should be calculated at least at hourly time scales. We will be using several algorithms to decompose the input data for the daily ET calculations into hourly inputs.

Planned activities in the next performance period (July 2011 – June 2012)

The graduate student (Yang Yang) will be visiting Xinjiang from November 2011 to February 2012 in order to validate our hydrological models. In collaboration with Prof. Jean Bahr at UW-Madison, we also began modifying the finite-element groundwater model MODFLOW for our study sites. Our goal is to link MODFLOW vadose zone processes to land surface hydrology that is being modified by changes in land use activities (i.e. irrigated agriculture). This work is first in the area and will give us important clues about how the groundwater situation is evolving under intensive land use change in the region. One of our goals is to apply the same model three different locations with different land use change histories and environmental settings to see if the same problems (e.g. soil salinization, water logging) persist in other location. Yang's long visit to the Xinjiang Institute will help access the data to parameterize/verify the groundwater model which will then be applied to the region under various land use change scenarios.

Publications:

Ozdogan, M., Yang, Y., Allez, G., and *Cervantes, C., 2010. Remote sensing of irrigated agriculture: Opportunities and challenges – A Review, **Remote Sensing**, *2: 2274-2304;* doi:10.3390/rs2092274.

Yang, Y., Ozdogan, M., and Zhang, H.Q., Spatio- temporal characteristics of land-use change in the Yili newly reclaimed area, Xinjiang Province (NW China), **Photogrammetric Engineering and Remote Sensing**, *in preparation.*