Synthesis of land cover and land use, climatic and societal changes in drylands of Central Asia

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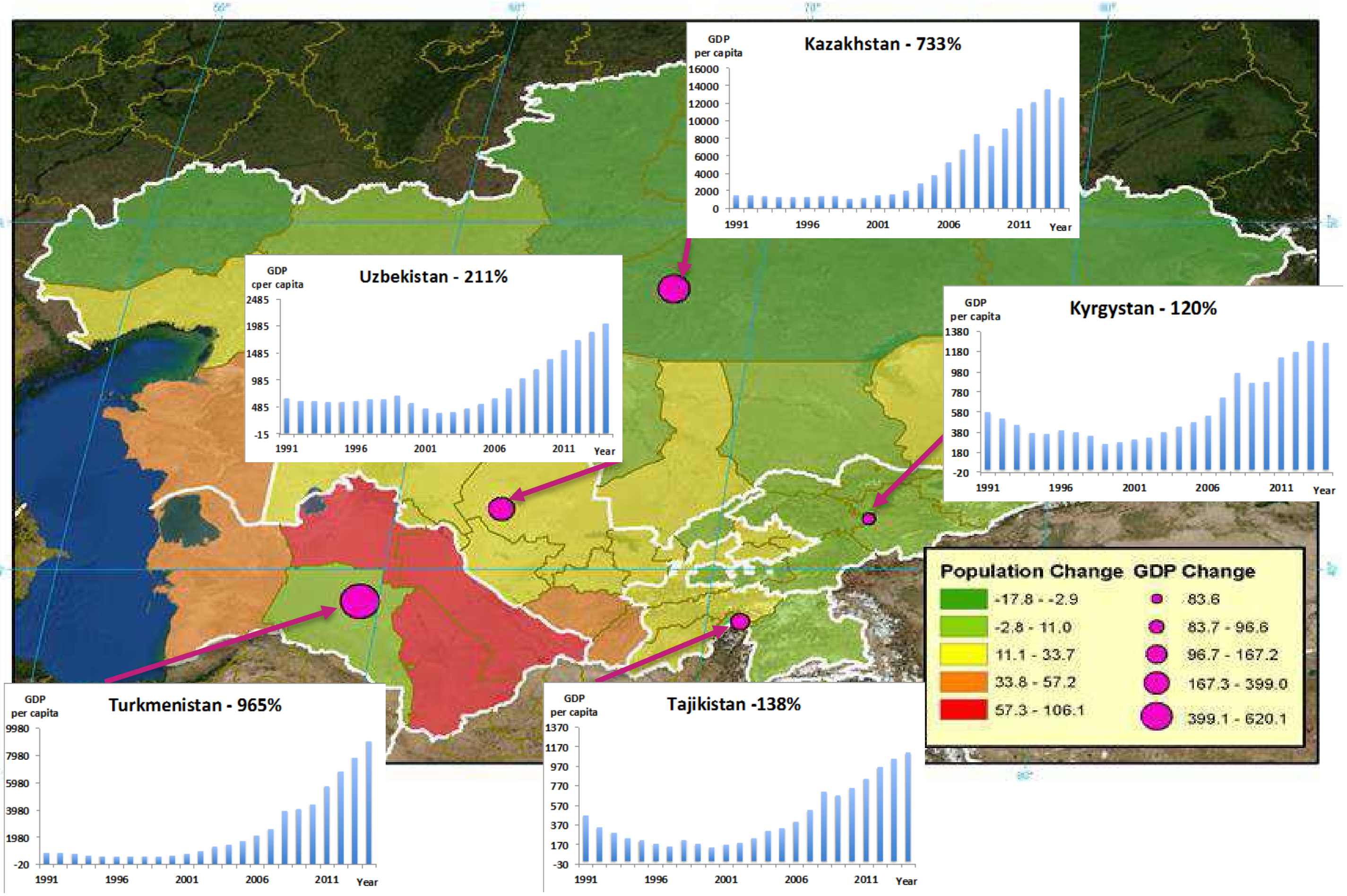
NASA Land-Cover and Land-Use Change Science Team Meeting
Rockville, Maryland, 04/18/2016 : 04/19/2016

Land-Cover / Land-Use Change Program



A map of the study domain showing changes (2010 vs.1990) in GPD (%) by country and population change by district (oblast). Graphs show annual changes in GDP (%) by country from 1991 to 2014

Specific objectives include:

(1) synthesis of the scope of changes in LCLU and related institutional, socio-economic, and climatic factors,

(2) analyses of LCLU change trajectories and the relationship with major human and natural drivers, and

(3) assessment of consequences of land use changes on food and water security in the context of socioeconomic transformations.

1. Synthesis of the scope of changes

<u>Hypothesis #1:</u> change in land use and land cover in Central Asia has been driven by a combination of institutional, socio-economic, and natural (climatic) factors that resulted in non uniform distribution of changes across the region.

We carried out a comprehensive change analysis focused on land surface metrics based on different portions of the electromagnetic spectrum → not only the vegetation indices.

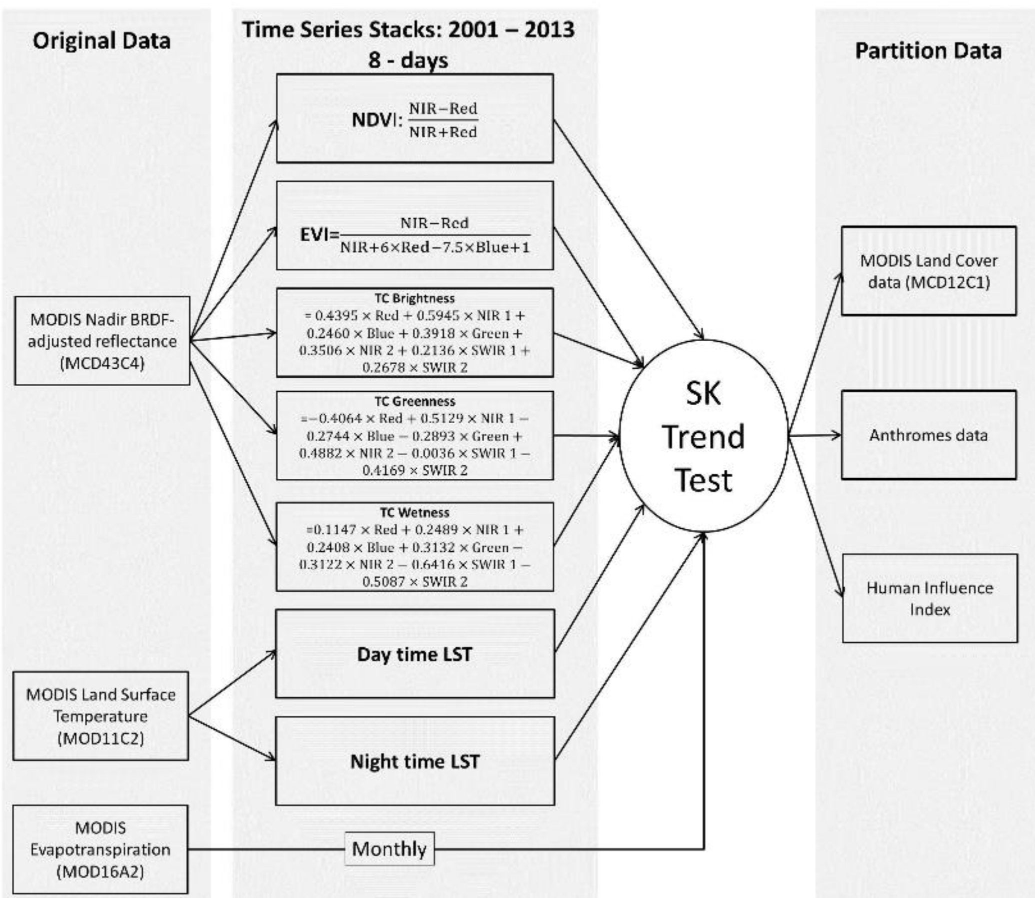
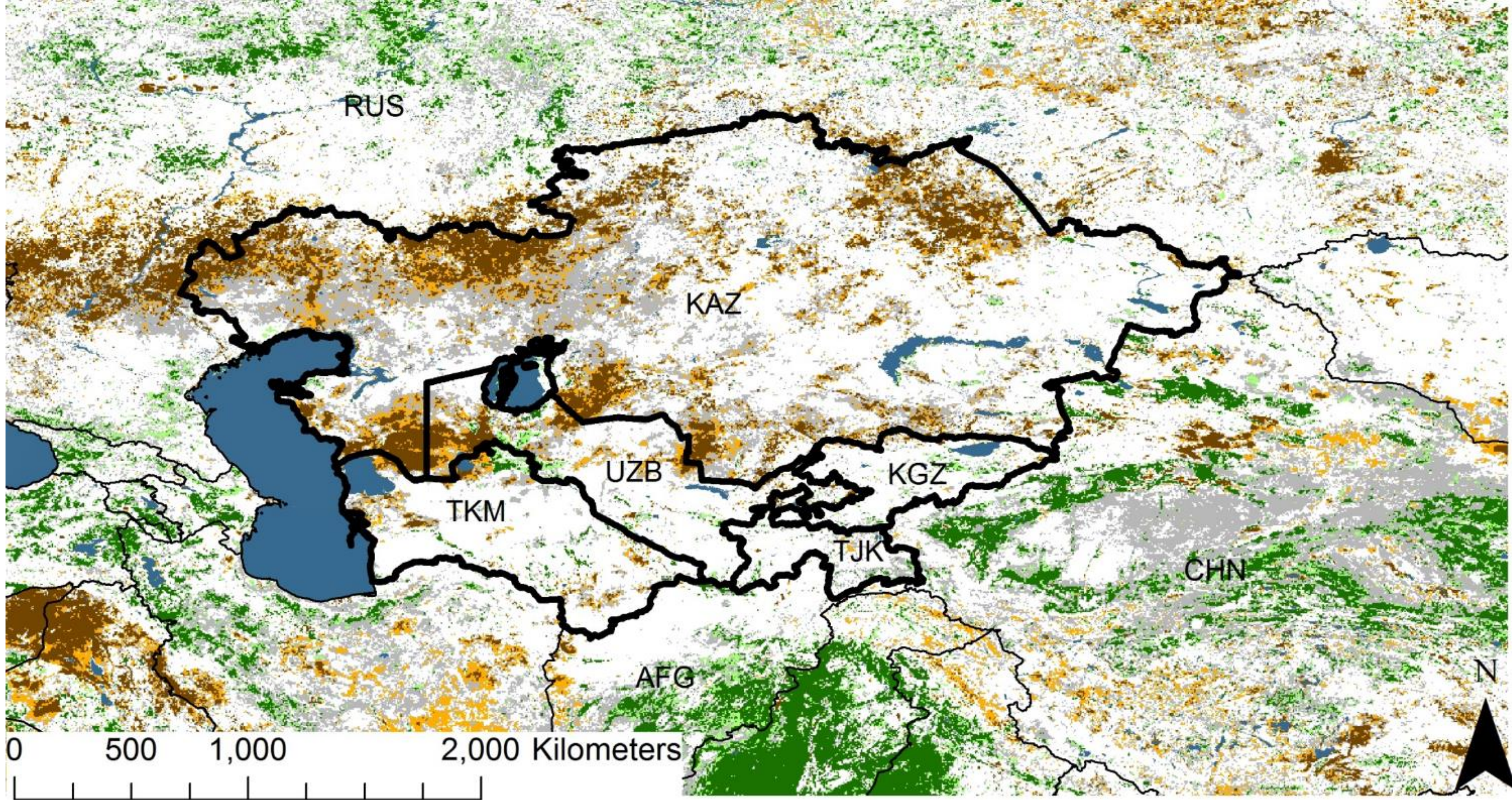


Figure describes the original data, the stacked indices, the SK (Seasonal Kendall) non-parametric trend test and the partition datasets

K.M. de Beurs et al, 2015

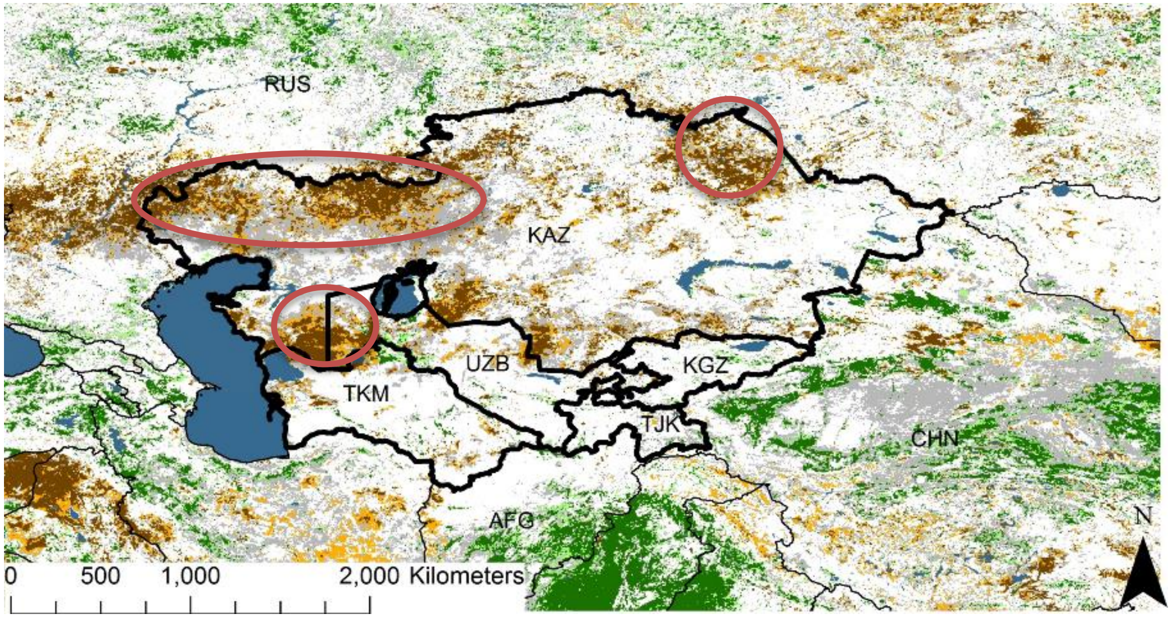


<u>Combined Vegetation Indexes changes (NDVI, EVI, TC Greenness)</u>

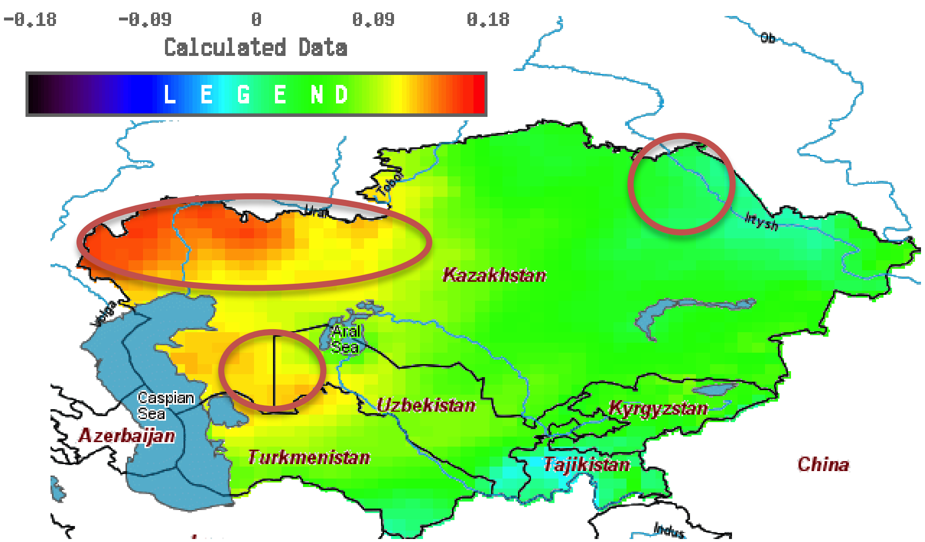
- Dark brown: significant declines in vegetation in all three vegetation indices
- Orange: declines in at least two vegetation indices.
- Dark green: significant increases in vegetation in all three vegetation indices.
- Light green: significant increases in at least two indices.
- Grey: changes (positive or negative) in just one of three vegetation indices.

de Beurs et al, 2015

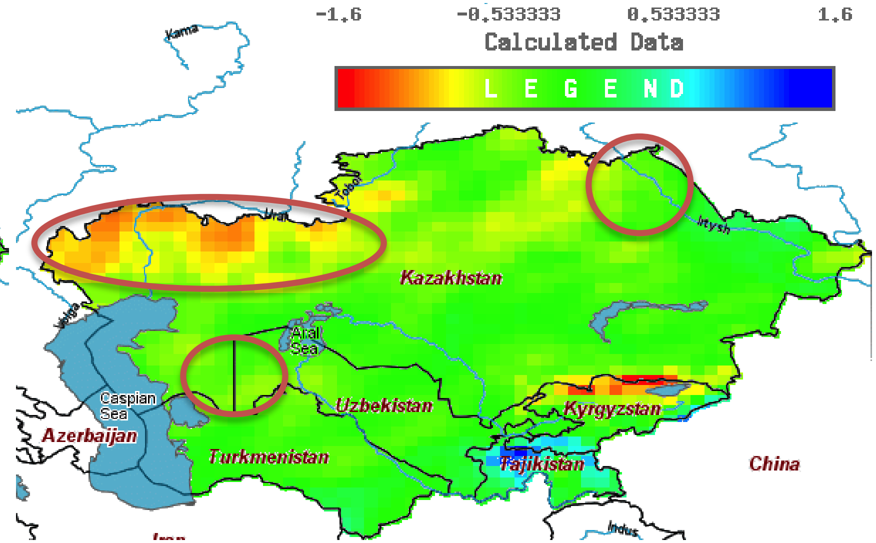
The change in Vegetation Indexes can be partly explained with climatic conditions



MODIS based VI change

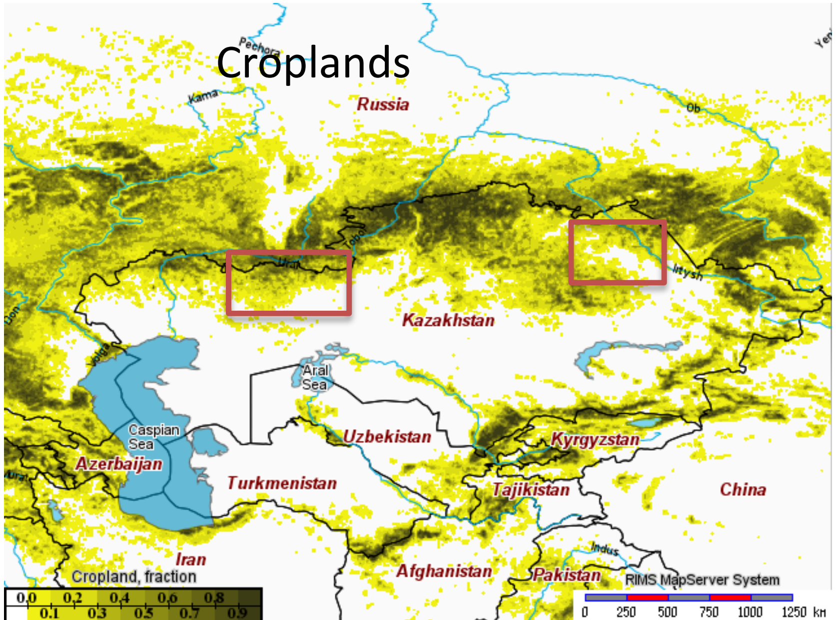


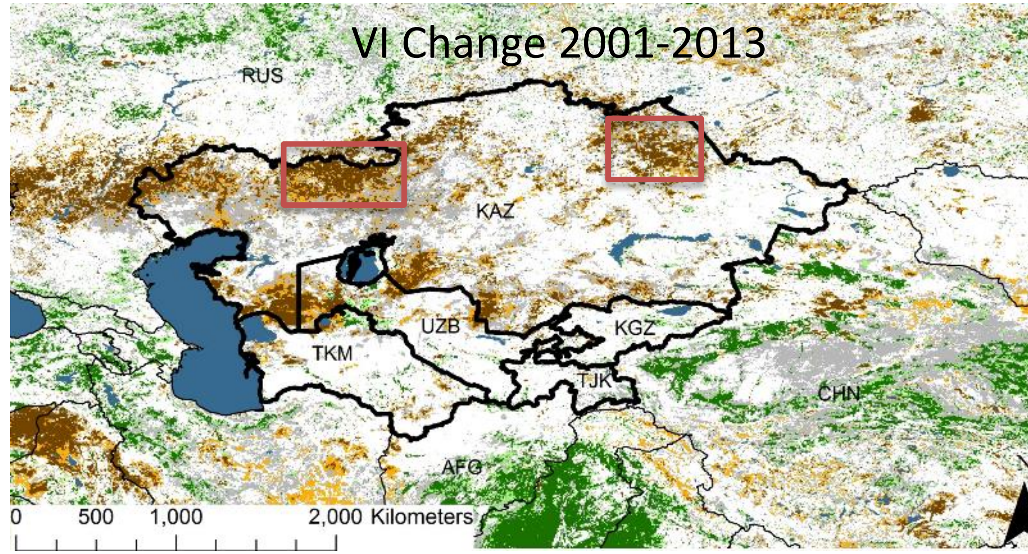
Change of mean Air Temperature for vegetative period (April-October) over 2001-2015 based on MERRA (slope)

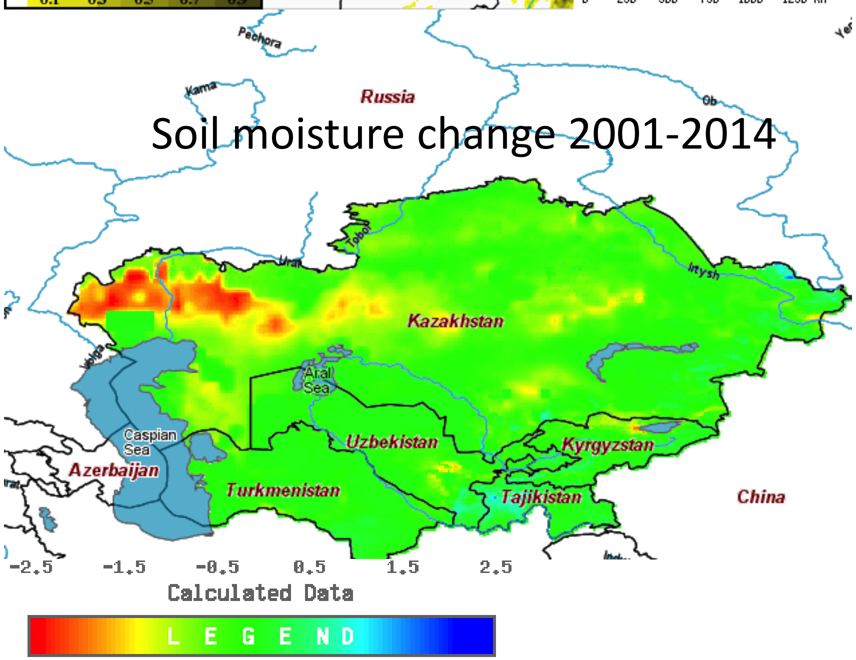


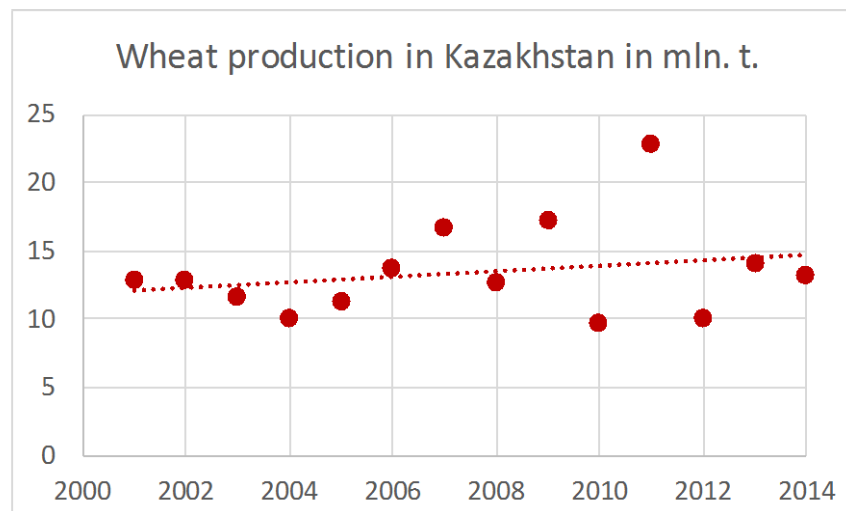
Change of total precipitation for vegetative period (April-October) over 2001-2015 based on MERRA (slope)

Observed change in vegetation and crop production

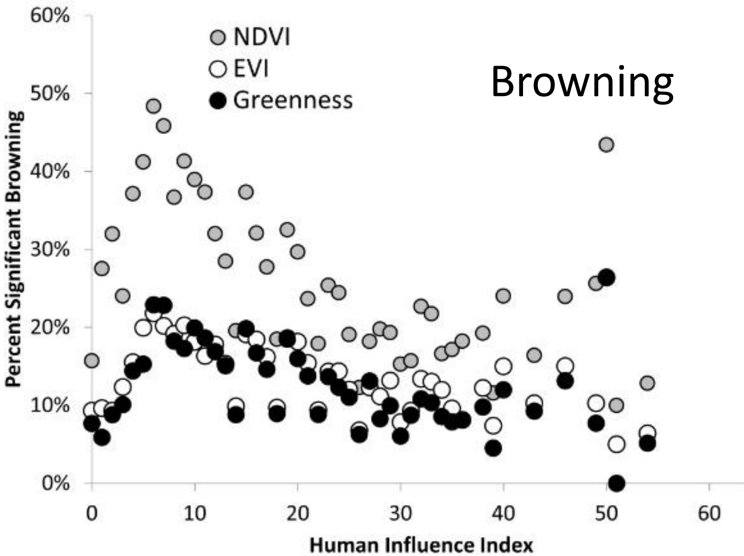




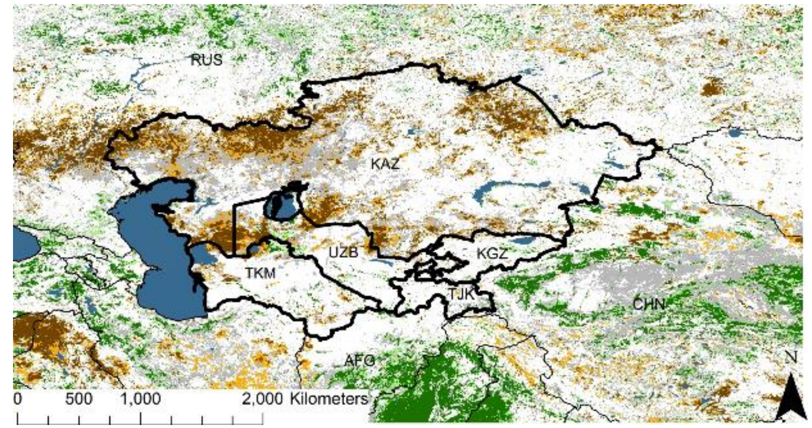


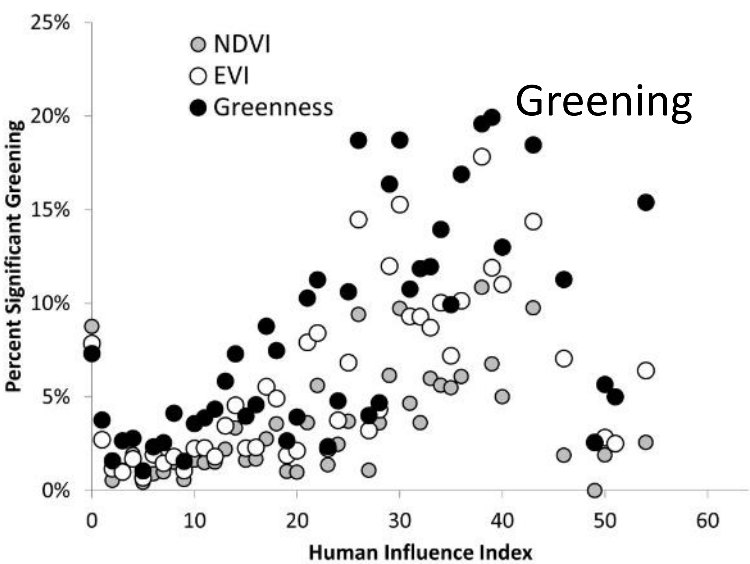


Land cover changes vs human influence

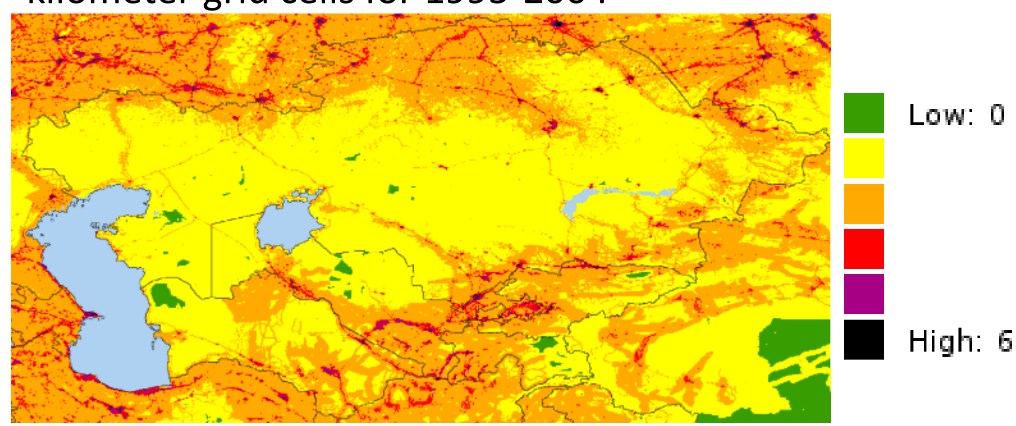


Combined VI changes (NDVI, EVI, TC Greenness)





Human Influence Index Dataset is a global dataset of 1-kilometer grid cells for 1995-2004

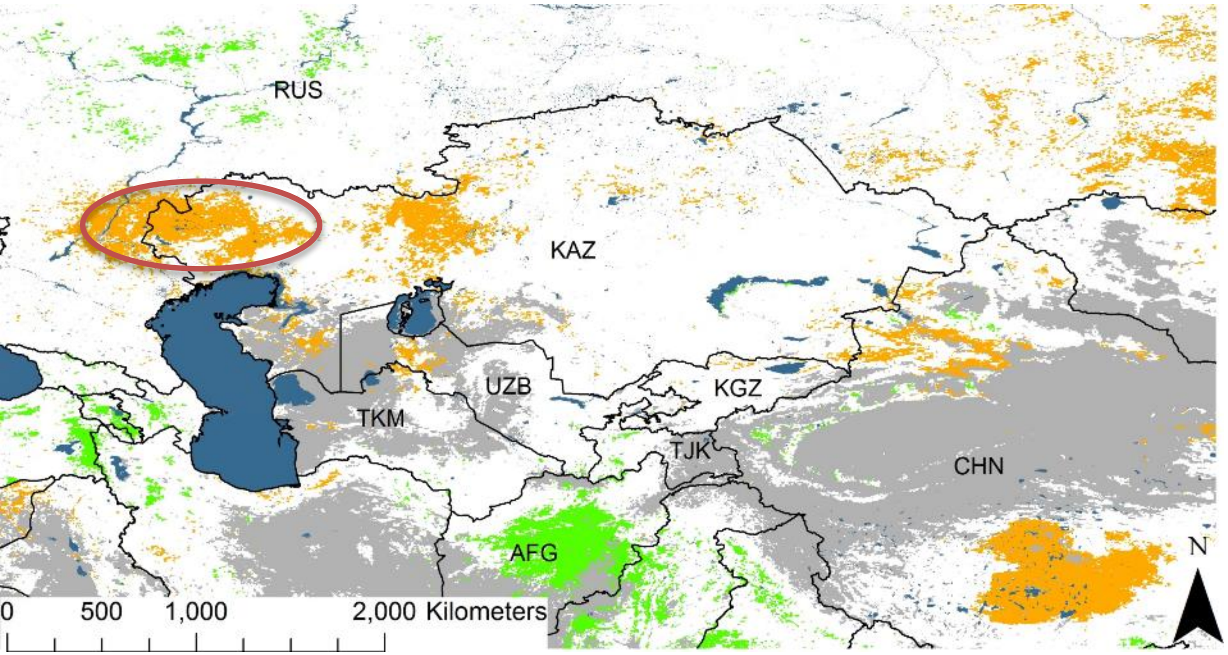


-Land surface is more stable in the heavily populated areas where human impacts have already occurred

-Greatest changes are occurring in the moderately populated areas where development is ongoing.

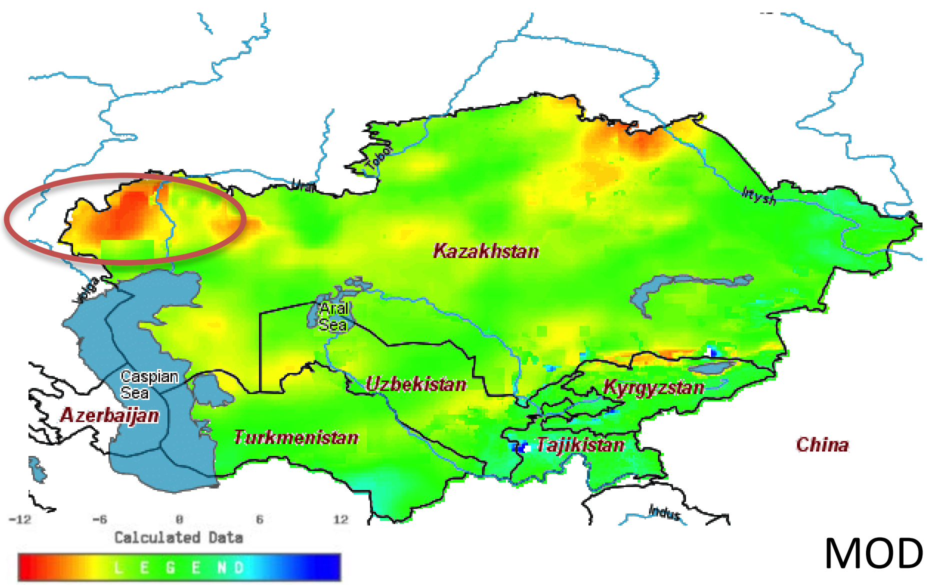
We suggest that future research should be focused on the moderately populated regions, where the greatest and most rapid changes are occurring.

de Beurs et al, 2015



Evapotranspiration changes between 2001 and 2013 (MODIS-based)

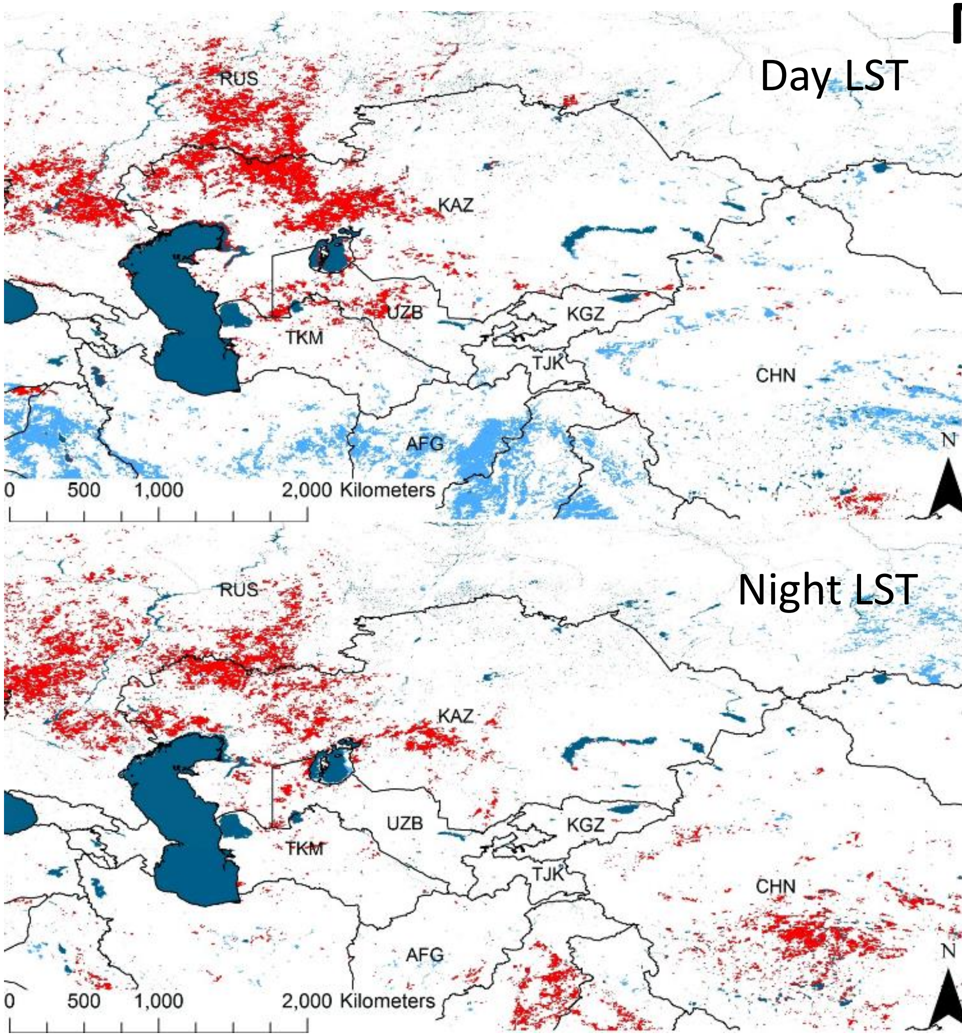
- Orange: significant negative changes (p<0.01)
- Green: significant positive changes (p<0.01).
- Areas in grey are masked out as a result of missing ET data.
- Dark blue is water. White indicates no significant change.



Evapotranspiration changes between 2001 and 2014 (WBM-TrANS with MERRA input)

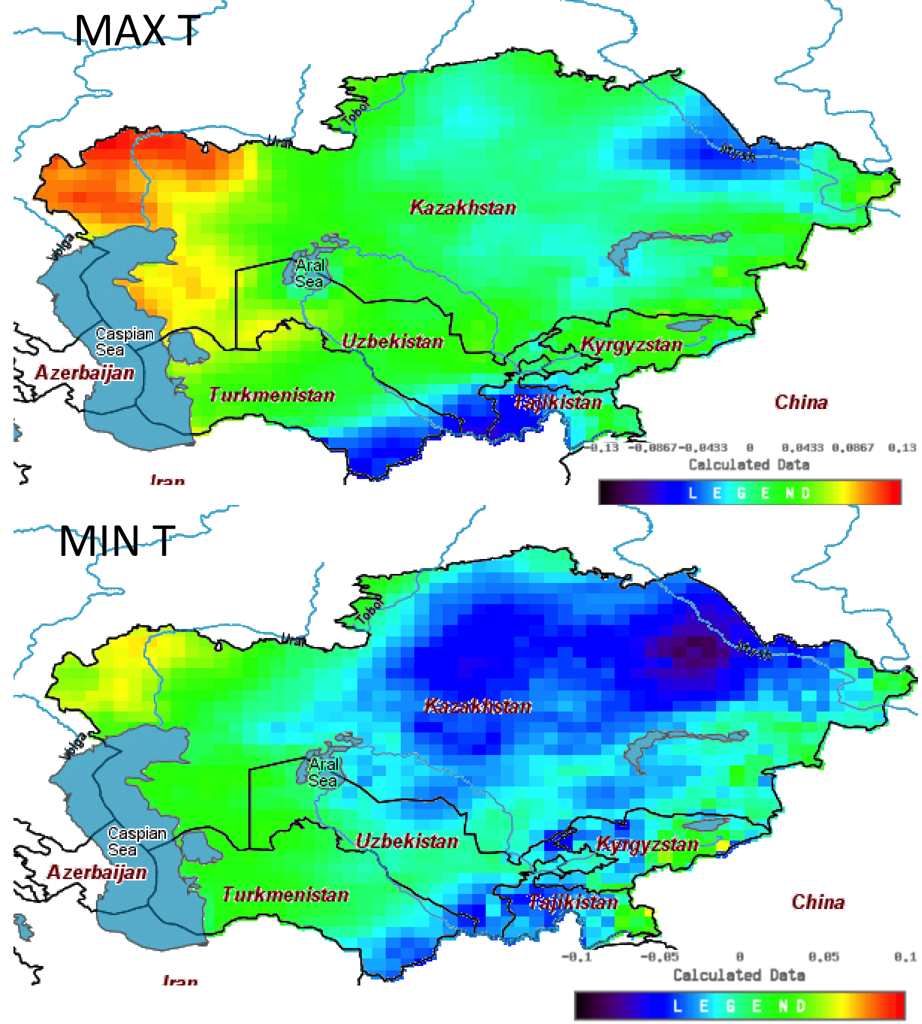
MODIS and Hydrological model demonstrate similar patterns of ET changes in western Kazakhstan

Significant trends in day night LST from MODIS over 2001-2013

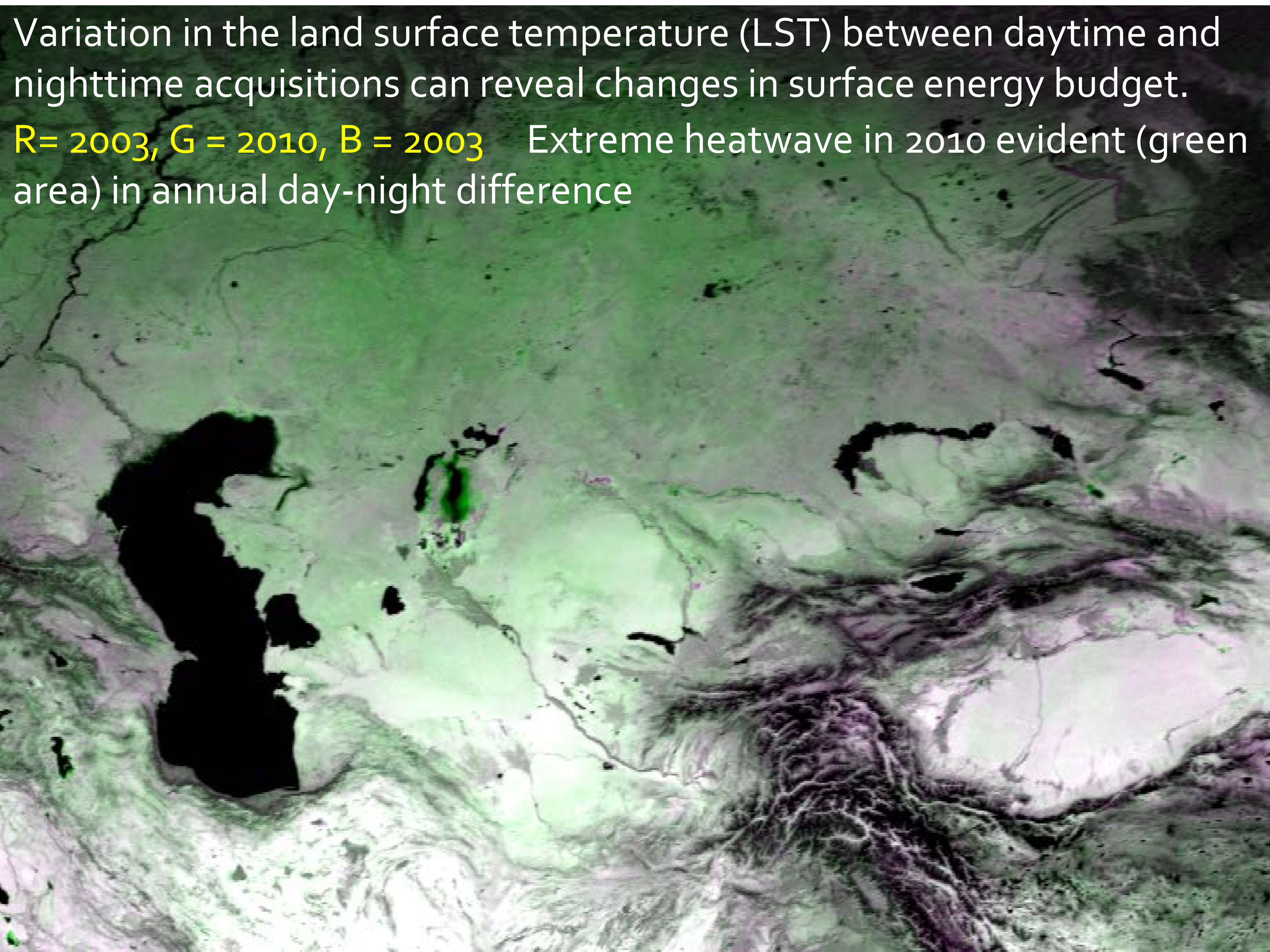


Warming : red; Cooling: lighter blue.
Darker blue is water. White indicates no significant change (de Beurs et al, 2015)

Linear slope of mean annual daily max and min air temperature from MERRA over 2001-2015



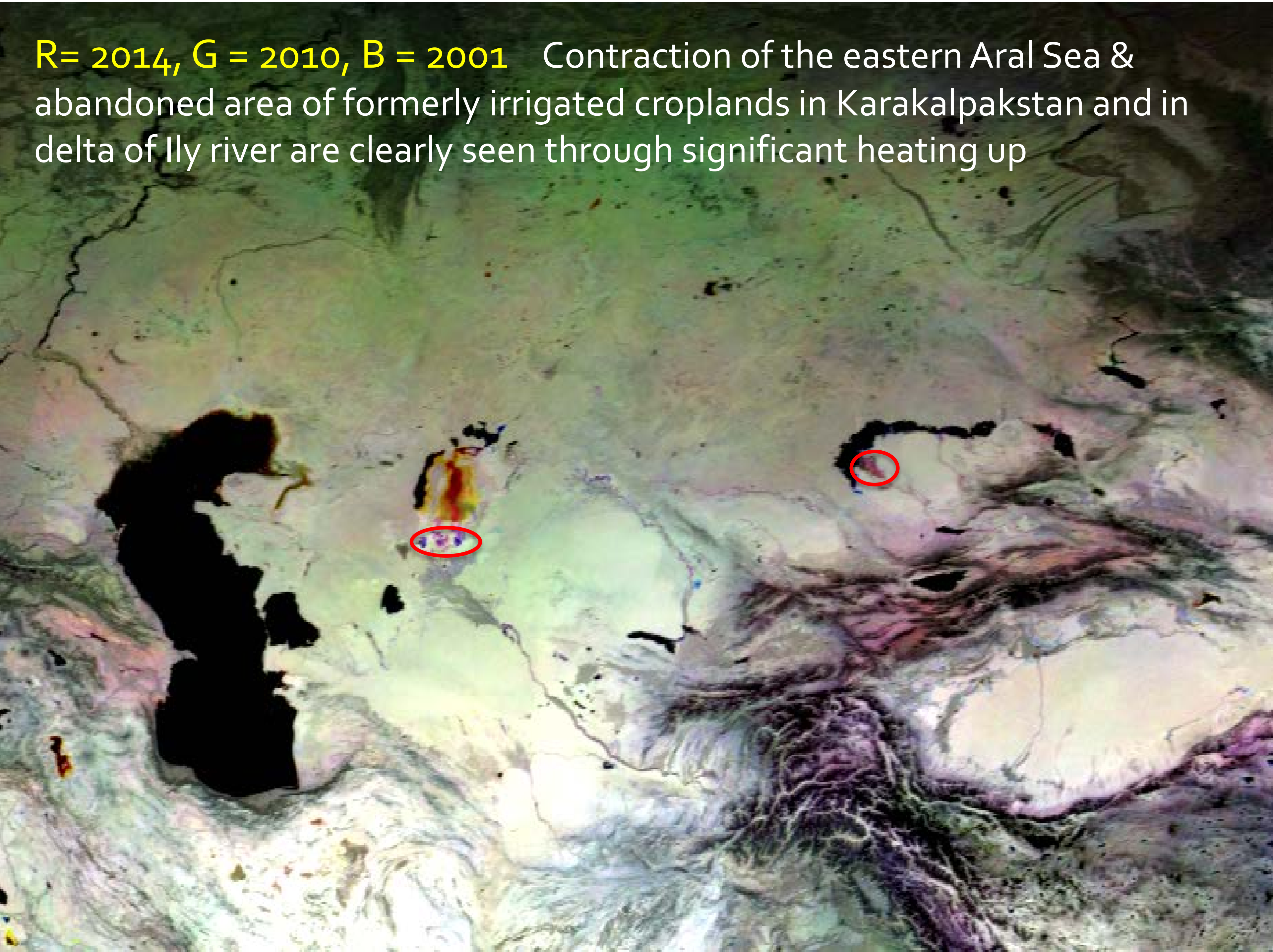
There are some common warming tendencies in West Kazakhstan



Variation in the land surface temperature (LST) between daytime and nighttime acquisitions can reveal changes in surface energy budget.

R= 2003, G = 2010, B = 2003 Extreme heatwave in 2010 evident (green area) in annual day-night difference

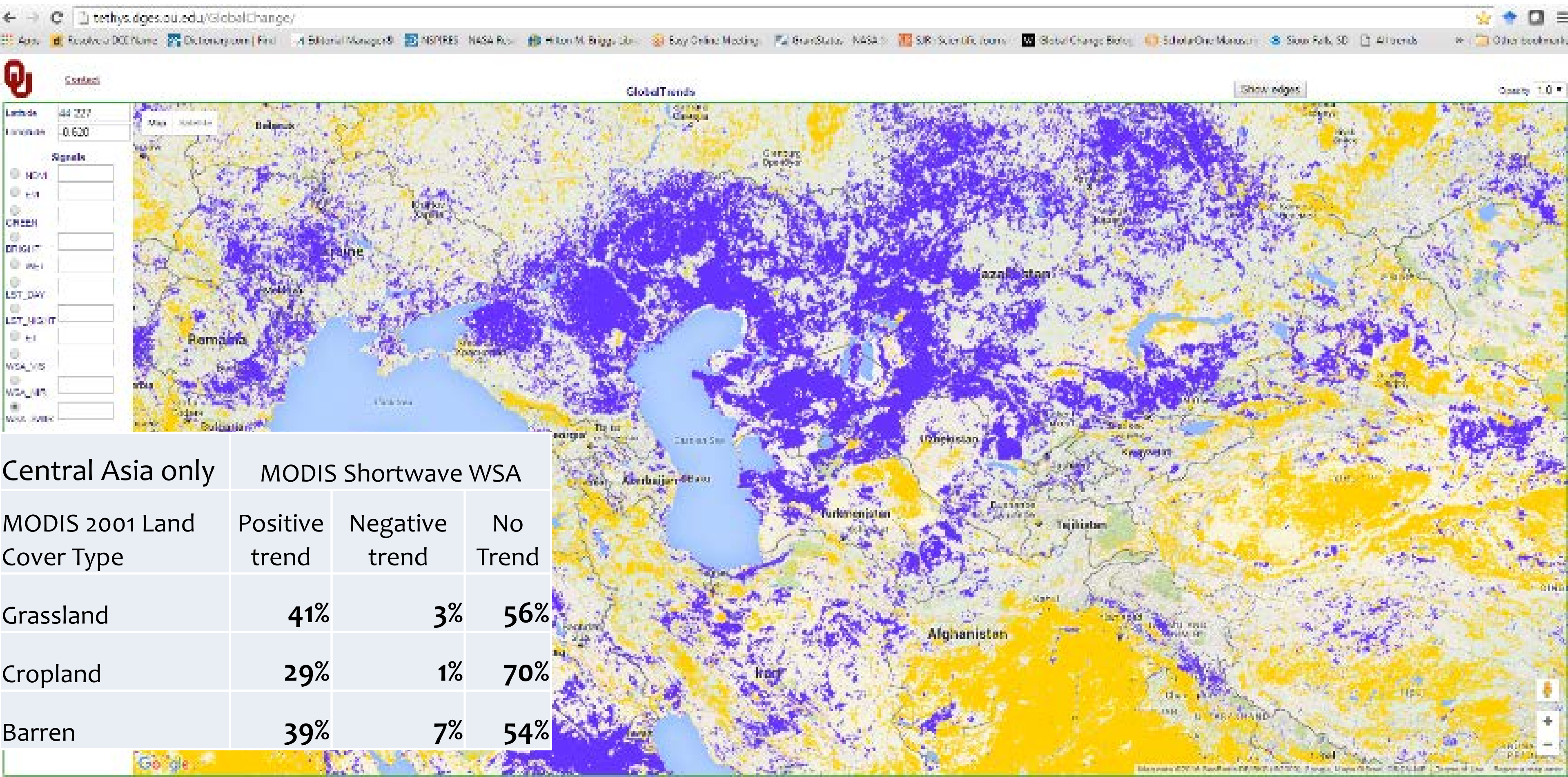
R= 2014, G = 2010, B = 2001 Contraction of the eastern Aral Sea & abandoned area of formerly irrigated croplands in Karakalpakstan and in delta of Ily river are clearly seen through significant heating up



Significant trends in MODIS shortwave White Sky Albedo across Central Asia & vicinity: 2001-2014

Significant ($p \leq 0.01$) trends are displayed in **purple for increases** and **orange for decreases**. Spatial resolution of the MODIS data is 0.05°.

Trends viewer available at http://tethys.dges.ou.edu/GlobalChange



Central Asia only	MODIS Shortwave WSA		
MODIS 2001 Land Cover Type	Positive trend	Negative trend	No Trend
Grassland	41%	3%	56%
Cropland	29%	1%	70%
Barren	39%	7%	54%

2. Analyses of LCLU change trajectories in Central Asia and major driving forces

Hypothesis #2: trajectories and the rate of land use change differ among the five countries because of certain differences in the rate of the privatization processes, state regulations, infrastructures (including water availability and demand), demographic pressure (population growth/migration), poverty, and change in livestock.

Method: analysis of LCLU changes per country along with chronology of agrarian reforms
(include socio-economical indicators)
(include climatic data time series)

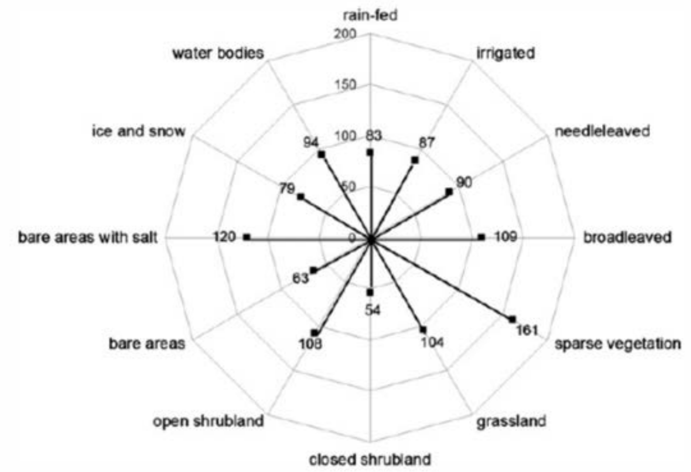


Fig. 10. Proportion of classified land cover in 2009 (black numbers) compared to classified situation in 2001 (100% line) for each class.

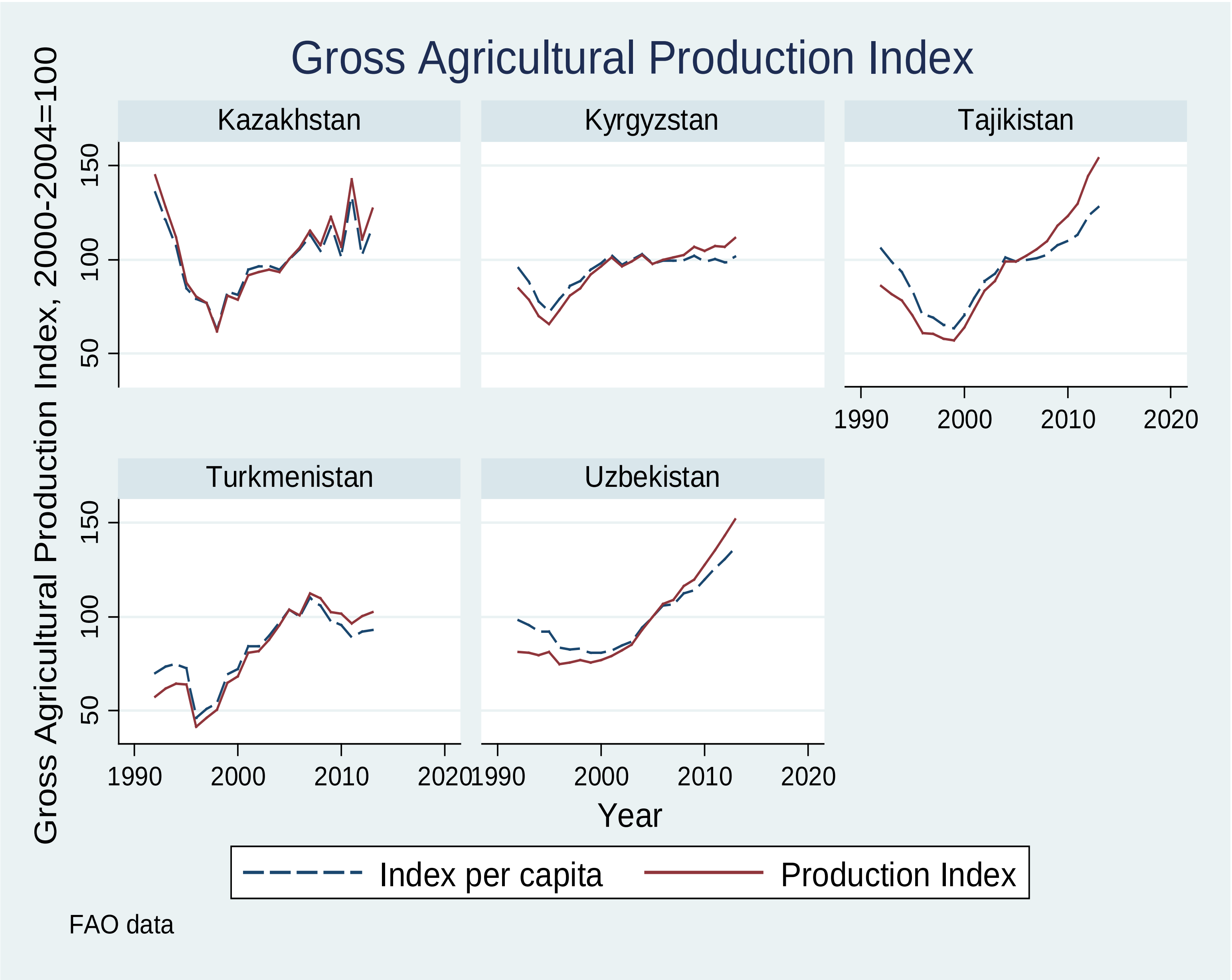
Change in Population and GDP by country

Country	Pop-1990	Pop-2014	Change in %	Change in GDP per capita (%)
Kazakhstan	16,348,000	17,289,110	5.76	733
Kyrgystan	4,391,000	5,834,200	32.87	120
Tajikistan	5,297,000	8,295,840	56.61	138
Turkmenistan	3,668,000	5,307,190	44.69	966
Uzbekistan	20,510,000	30,757,700	49.96	212

Comparative Analysis of Land Reform in Central Asia: 1990-2014

Dimensions of land reform performance

- The land reform performance is compared across the following dimensions:
  - Right to sell land
  - Inheritability
  - Safety of land rights (can they be taken away by the government?)
  - Government imposed restrictions on private cultivation
  - Taxation / Debt
  - Amount of land allocated/ transferred into private hands



Crop production index shows agricultural production for each year relative to the base period 2004-2006. The gross agricultural production index is calculated from the underlying values in international dollars, normalized to the base period 2004-2006.

Comparison of land reform by country

Criteria	Kazakhstan	Kyrgyzstan	Tajikistan	Turkmenistan	Uzbekistan
Is sale of land allowed?	Unclear for agricultural land. Personal vegetable	Yes.	No.	No.	No, land is allocated as leases. The State owns the land.
Is the land plot inheritable?	Yes, private farms and private land plots.	Yes.	Yes.	Yes.	Buildings, houses and other property. Land as attached to
Can allocated land be taken away by the government and if yes, under what conditions?	Yes.	Not clear.	Yes.	Yes.	Yes
Government imposed conditions on private cultivation.	Preference to large farms	Many institutional deficiencies.	Production plans	Production plans	Multiple restrictions.
Taxation	Land tax depends on the land use right.	yes, established in the Land Code.	Farmers pay 17 different taxes.	New farmers get 5 year exemption from taxes & get gov-nt loans at low rates.	Taxes are paid per hectare of land.
Amount of land given/ allocated	In 2002, 41% of land was in individual farms.	In 2008, 78% of arable land was in private ownership (920-940 thousands hectares; 2,043,004 private landowners.).	5–6% of agricultural land -household plots; 60% - dekhan farms; 25% - the state; 4-5% - other agricultural entities and municipalities.	115,000 hectares, or 0.3% of all agricultural land)	The share of peasant farms in arable land approaches 72.1% of irrigated land, most pastures continue to be locked in a small number of remaining enterprises.

Results of the analysis

- Central Asia undergone a significant change in the structure of land ownership and the land reform since 1991.
- Reforms differed across countries.
- Distributing land to small landholder farmers’ households, for individual farm leases and private household plots led to an increase in agricultural output.
- There are multiple obstacles to agricultural productivity.

Obstacles to an increase in agricultural productivity

- Government regulations on what to produce
- “Requests" to "voluntarily" lease allocated farm land back to large commercial farms;
- Poor availability of credit for small farms;
- Indebtedness of dehkan and collective farms in Tajikistan;
- Poor access to machinery for cultivation and high cost of renting it that drains profits from smaller farms;
- Poor information for farmers on updates in the land laws and other legislation in all of the countries
- Poor institutional support.

Water use in Central Asia. A framework

- CA is not water-scarce: it is sufficiently endowed with water (20,525 m^3/year) as compared to the Near East (7,922) or Northern Africa (2,441).
- But….water is mismanaged: CA countries have the highest rate of water consumption per capita in the world (see table)
- But…water is securitized in geopolitical competition (Uzb-Taj, and Uzb-Kyrg) and instrumentalized by authoritarian regimes (Lake of Golden Century in Turk)

	Total water withdrawal per capita (m^3) per country Source: FAO
Turkmenistan	5,415
Uzbekistan	2,358
Kirghizstan	2,015
Tajikistan	1,740
United States	1,550
Kazakhstan	1,304
Israel	281

Water use in agriculture

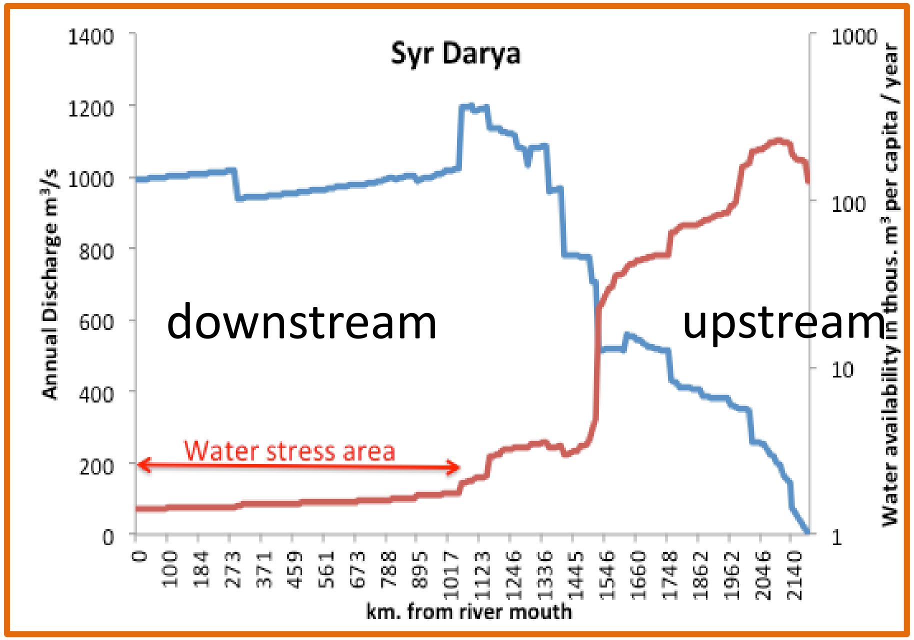
Issues

- Difficulties to extend arable lands due to lack of investments in irrigation
- Development of new water-consuming crops (corn, rice) in the name of food security
- Deterioration of irrigation facilities due to lack of resources invested by the independent states and permanent postponement of maintenance works
- Between 30 and 60% of the water lost through evaporation or leakage
- Farmers divert water in order to irrigate sections of private land
- Lack of local community autonomy: water users associations not trusted by the authorities
- Water privatization either inexistent, or failed / refused by farmers

Consequences

- Increasing amount of land contaminated with salt
- Hundreds of stagnant pools of water, polluted groundwater, or artificial lakes have been created
- Decline in crop quality
- In Taj and Kyrg, about half of rural population without access to centralized water supply systems
- Undrinkable water impacts on population’s health (rise of microbiological contaminations)

Water tracking with WBM for Syr Darya River



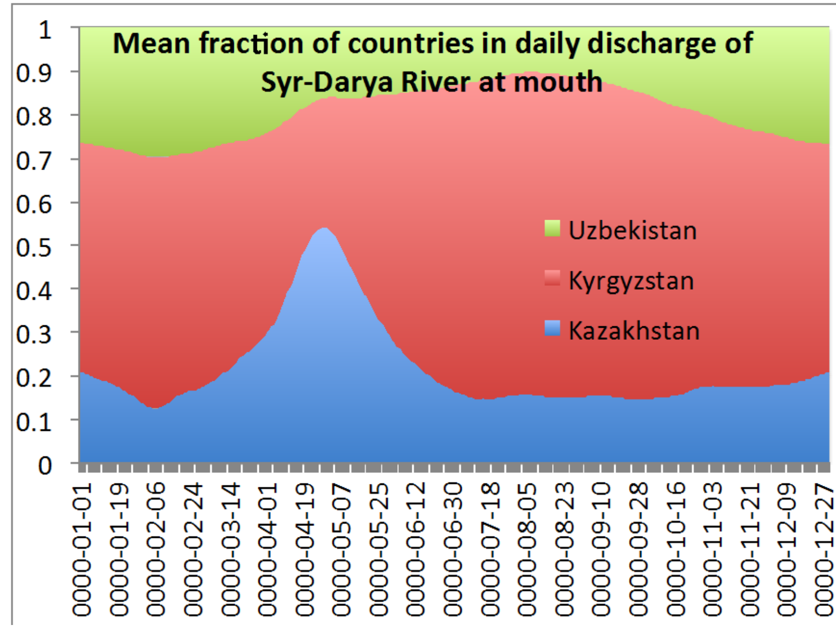
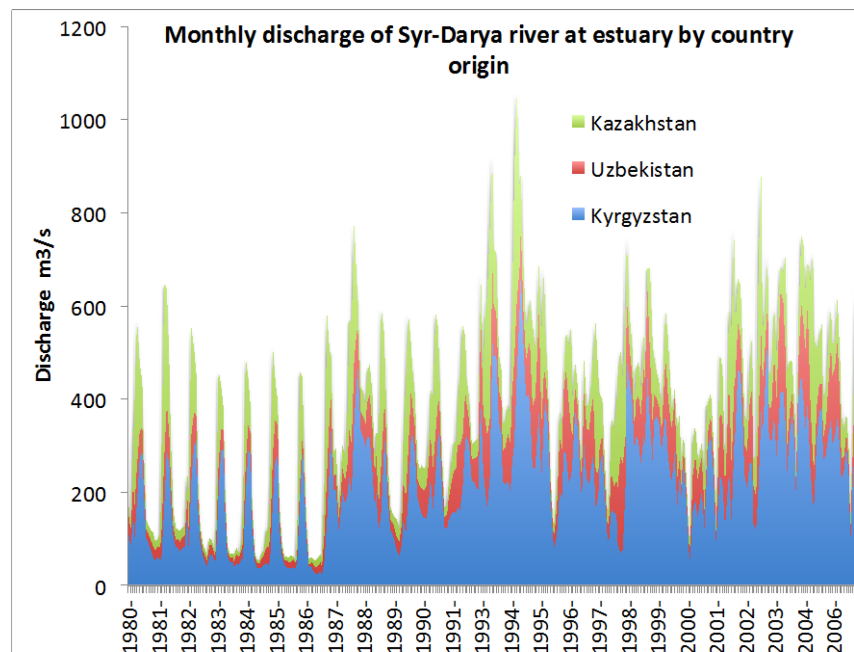


Figure above demonstrates change in long-term mean annual discharge along the main stem of Syr Darya river (blue line) from inlet (right) to outlet (left). Brown line characterizes changes in water availability per capita along the river based on cumulative aggregation of population living in upstream watershed area.



3. Assessment of consequences of land use changes on food and water security

Method: *compilation and analysis of various indicators characterizing anthropogenic and natural impacts on water and food security using observational and modeling data*

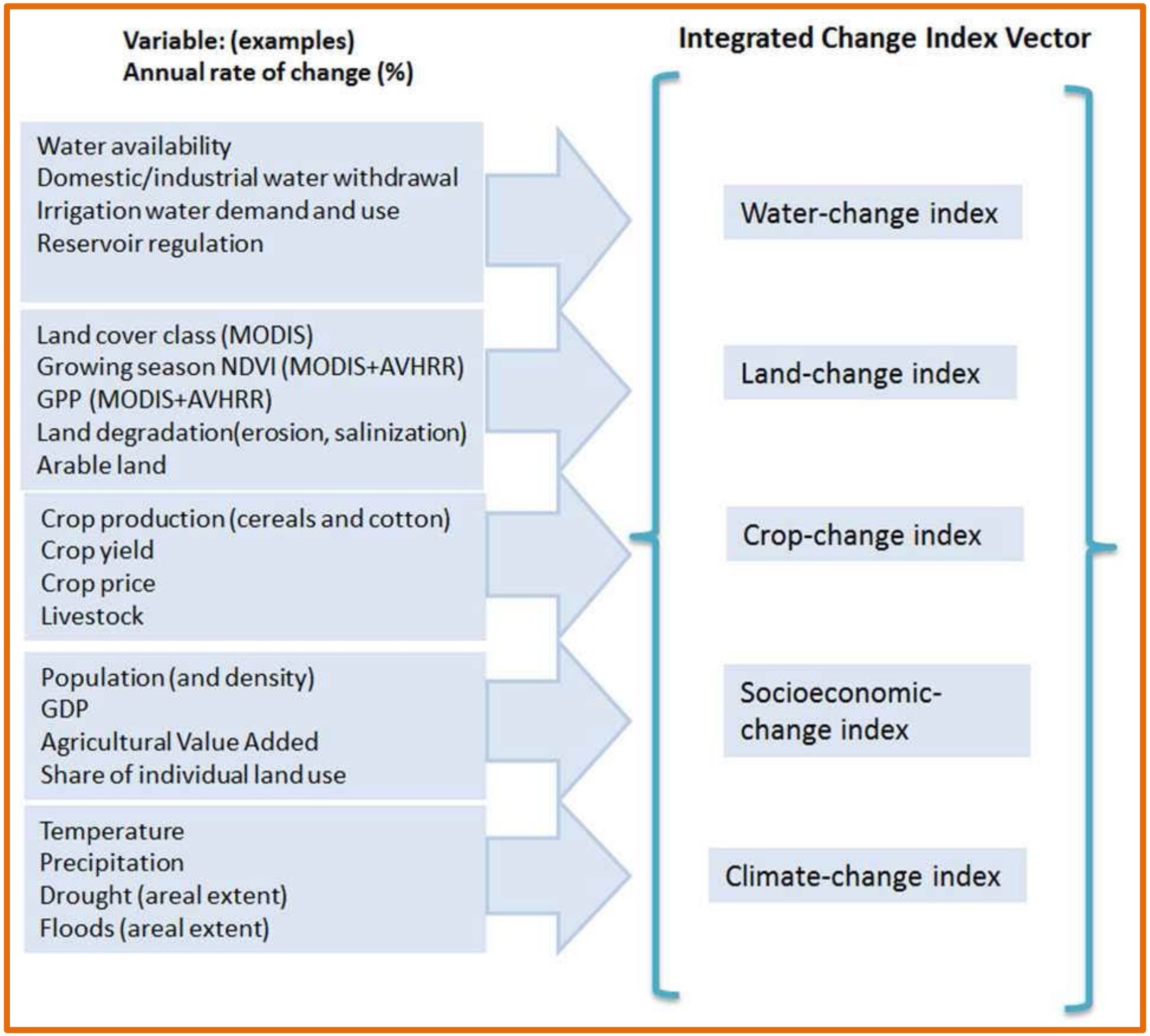
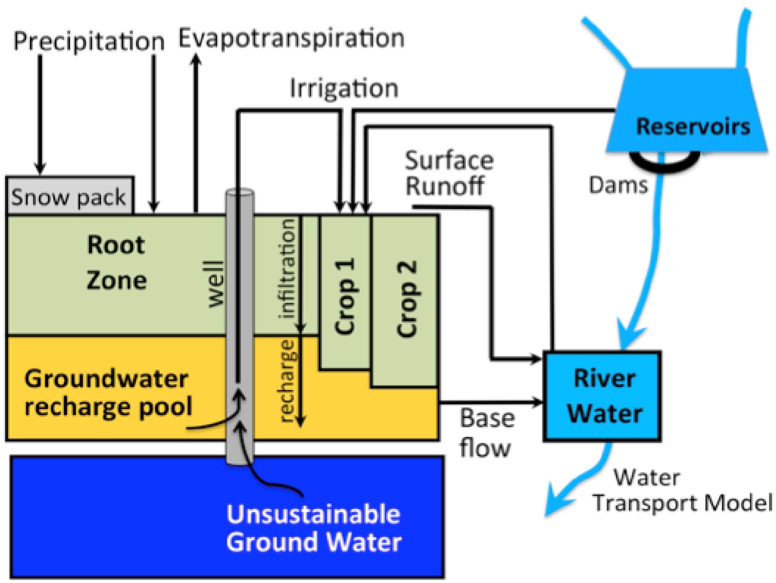


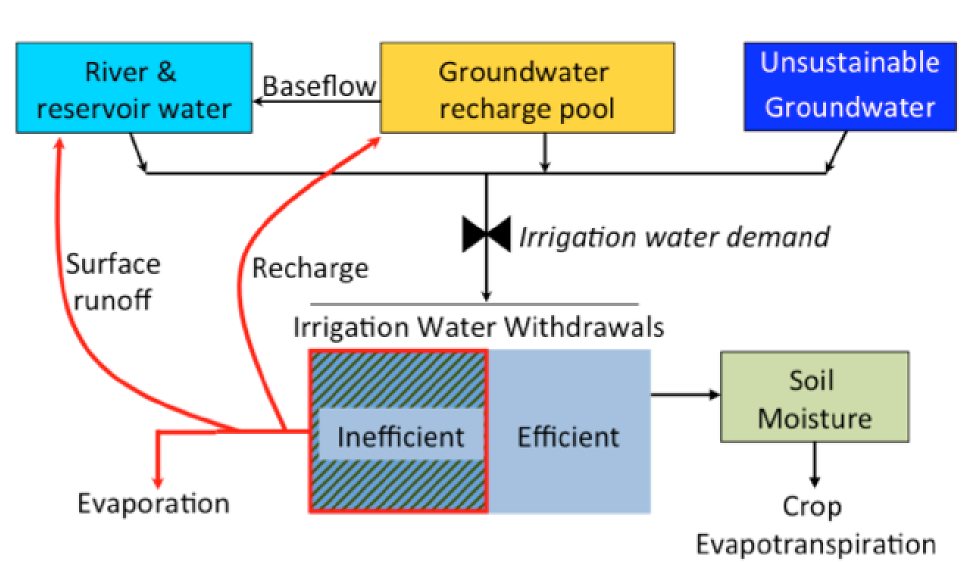
Figure above illustrates the conceptual framework that we envision for our study. We introduce an Integrated Change Index Vector (ICIV) as a measure of change that provides a means to gain insights into a land system from various perspectives. ICIV will be derived starting from a broad set of indicators organized around the six major themes.

UNH WBM was significantly extended to simulate all major anthropogenic impacts, including water withdrawal for irrigation, domestic, industrial and livestock needs, effects of reservoirs and large water transfers.

Water Balance Model (WBM)
Grid cell structure



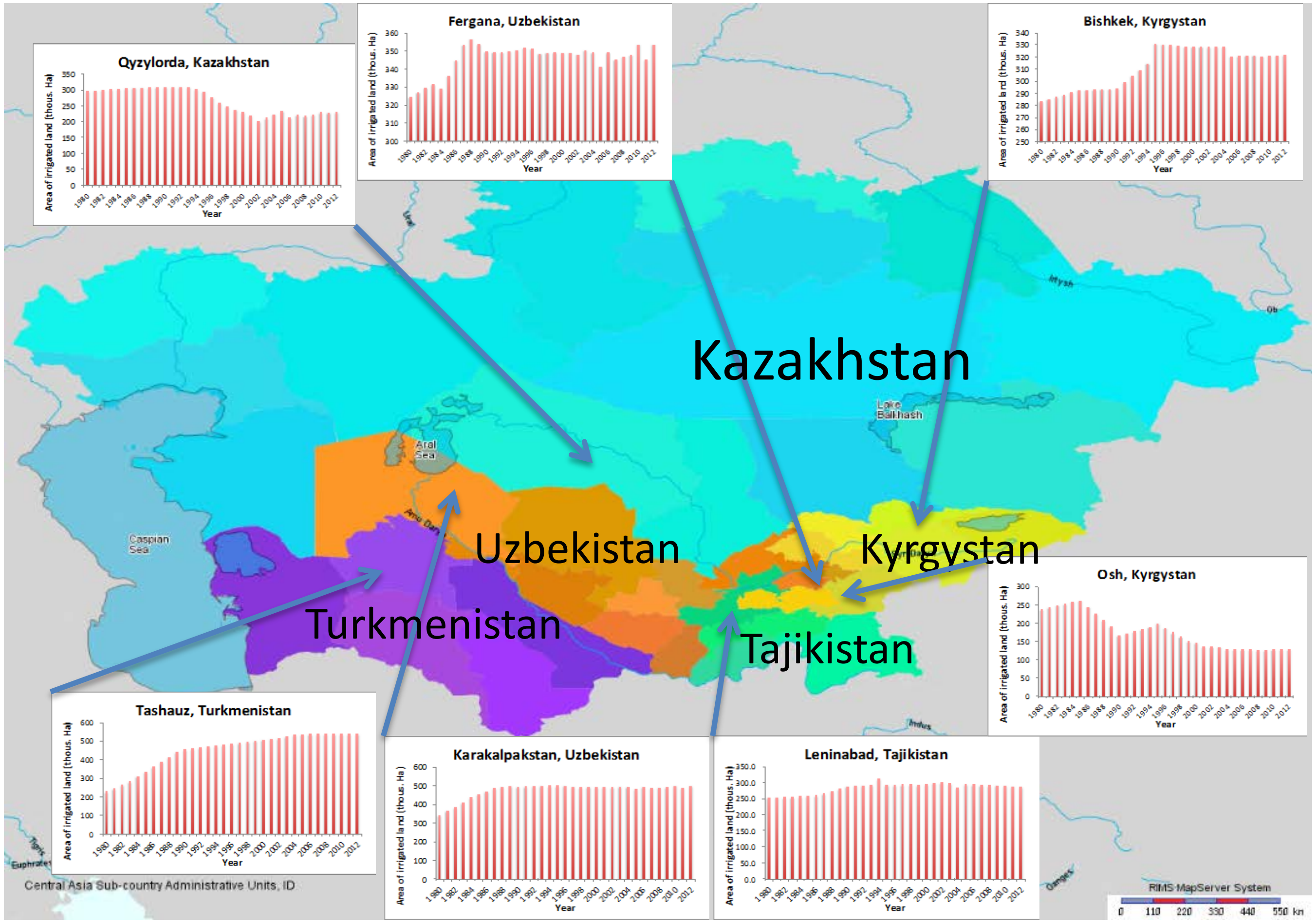
Water tracking system within WBM
Tracks through local and downstream cycles



- Global, gridded hydrology model[6]
- *Inputs*: climate[7], river network, soil properties, crop maps[8], irrigated area maps[8], rooting depth, reservoir operations[9], inter-basin transfers[10]
- *Tracking System:* Unsustainable groundwater is tracked through extraction, runoff from inefficient water use, recharge from inefficient water use, and infiltration to soils. Each water stock (rivers, reservoirs, soil moisture, and groundwater recharge) can be a mixture of unsustainable groundwater and other water sources.

Unsustainable groundwater: groundwater extracted in excess of total groundwater recharge

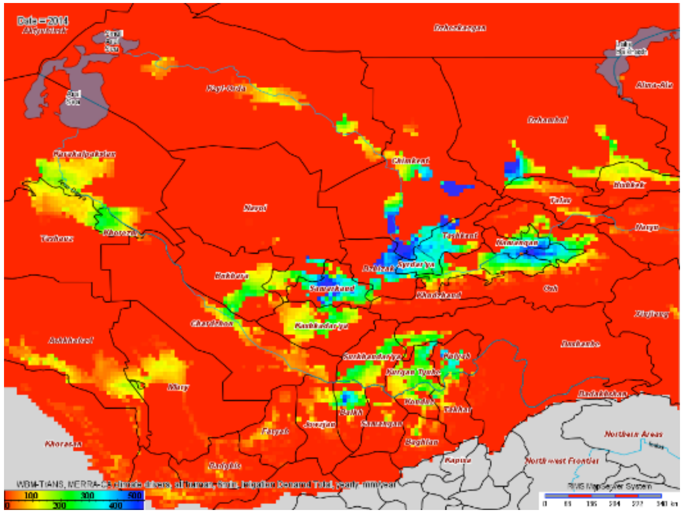
Change in areas of irrigated lands for sub-country administrative units



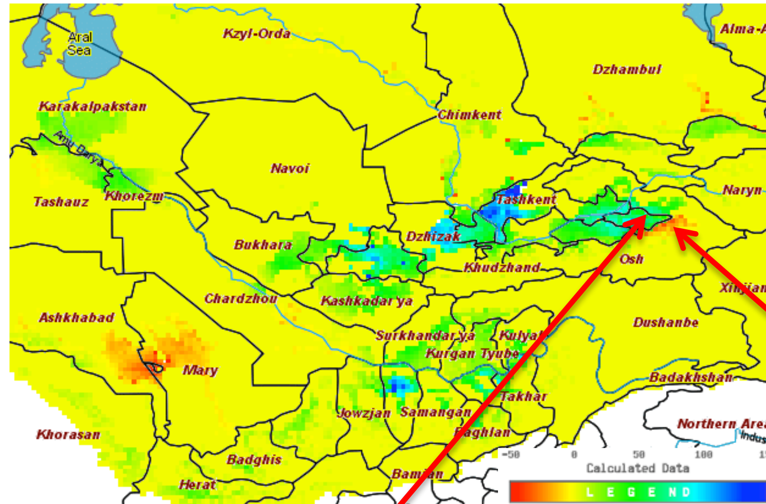
The map shows Central Asian countries and sub-country administrative units. The census data about land use, crops and irrigated area from 1980 to 2013 for the administrative units have been combined with gridded MIRCA2000 rainfed and irrigated crop data to provide the dynamic of land use in WBM-TrANS simulations.

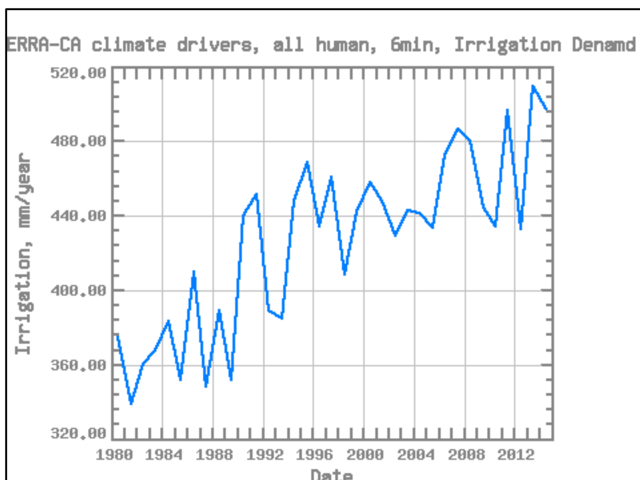
Simulation of water use for irrigation

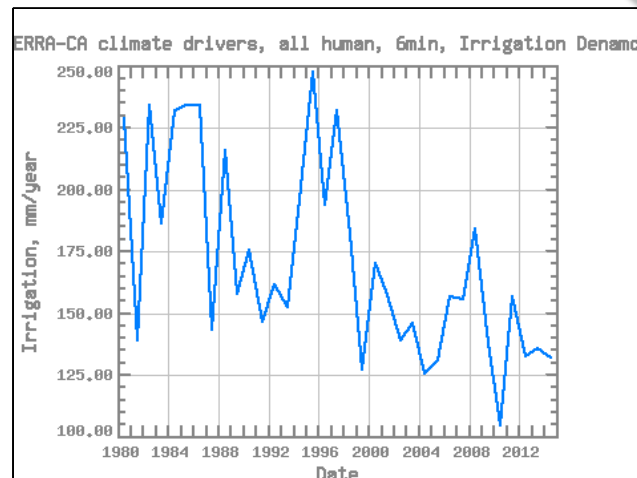
Water demand for irrigation in 2014



Change in water demand for irrigation between 2010-2014 and 1988-1992





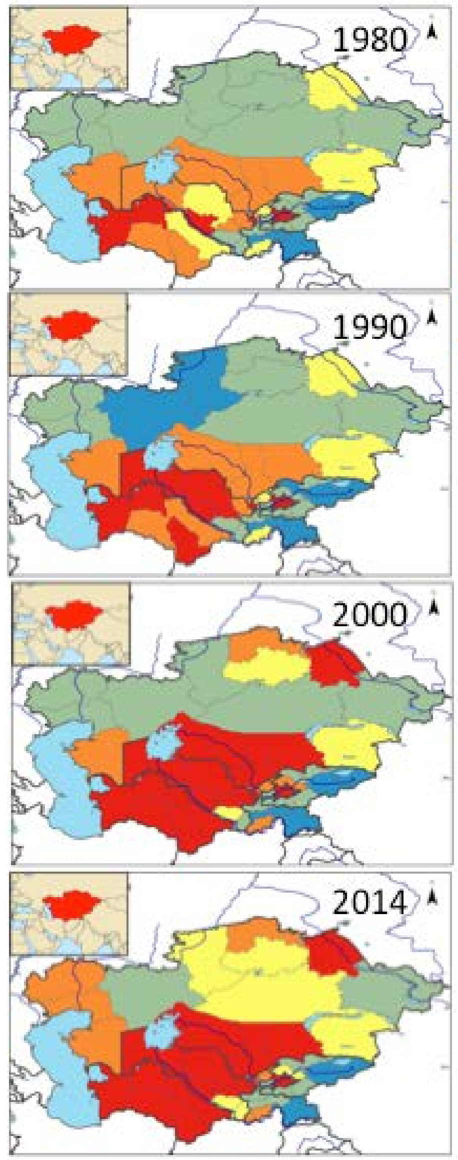


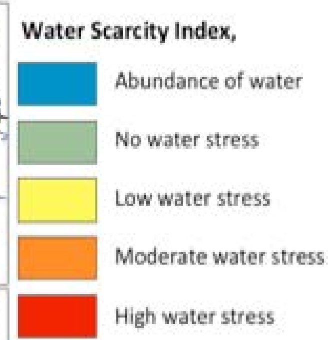
The water demand for irrigation has increased in CA since 1990, however the spatial changes have been heterogeneous due to political and social transformations

Water security evaluation

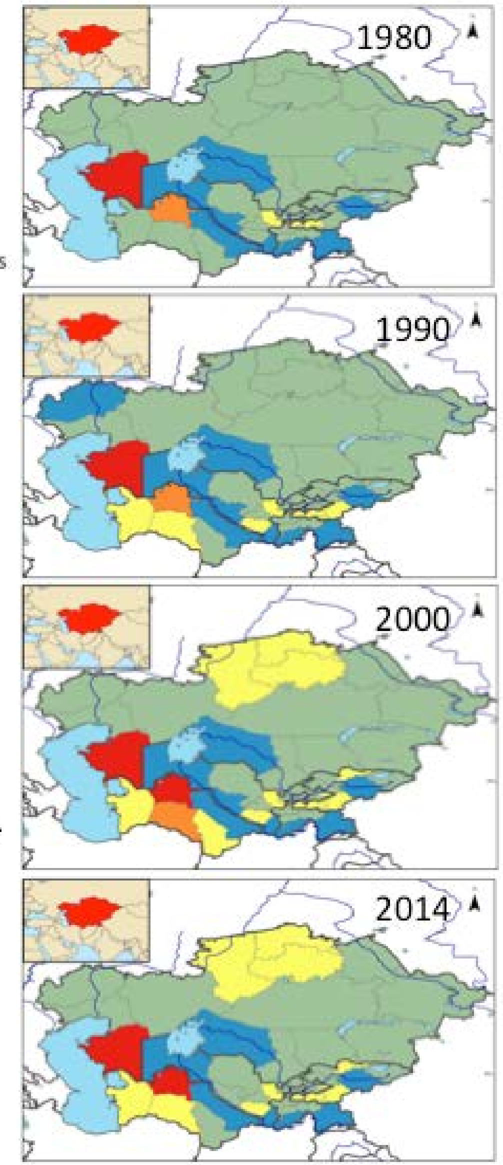
Water Scarcity Index (WSI) combines information about water abstractions and water availability: WSI=W/Q
where W are the freshwater abstractions and Q is the available water.

The calculations of WSI were made simulations using only locally generated water resources (left plots) and total available water resources (including inflow). The results were aggregated for administrative units.





Left plots show water scarcity index (WSI) based on available local water resources only.
Right plots takes into account all local water resources and river inflow from other territories.



Indexes of Water availability and use

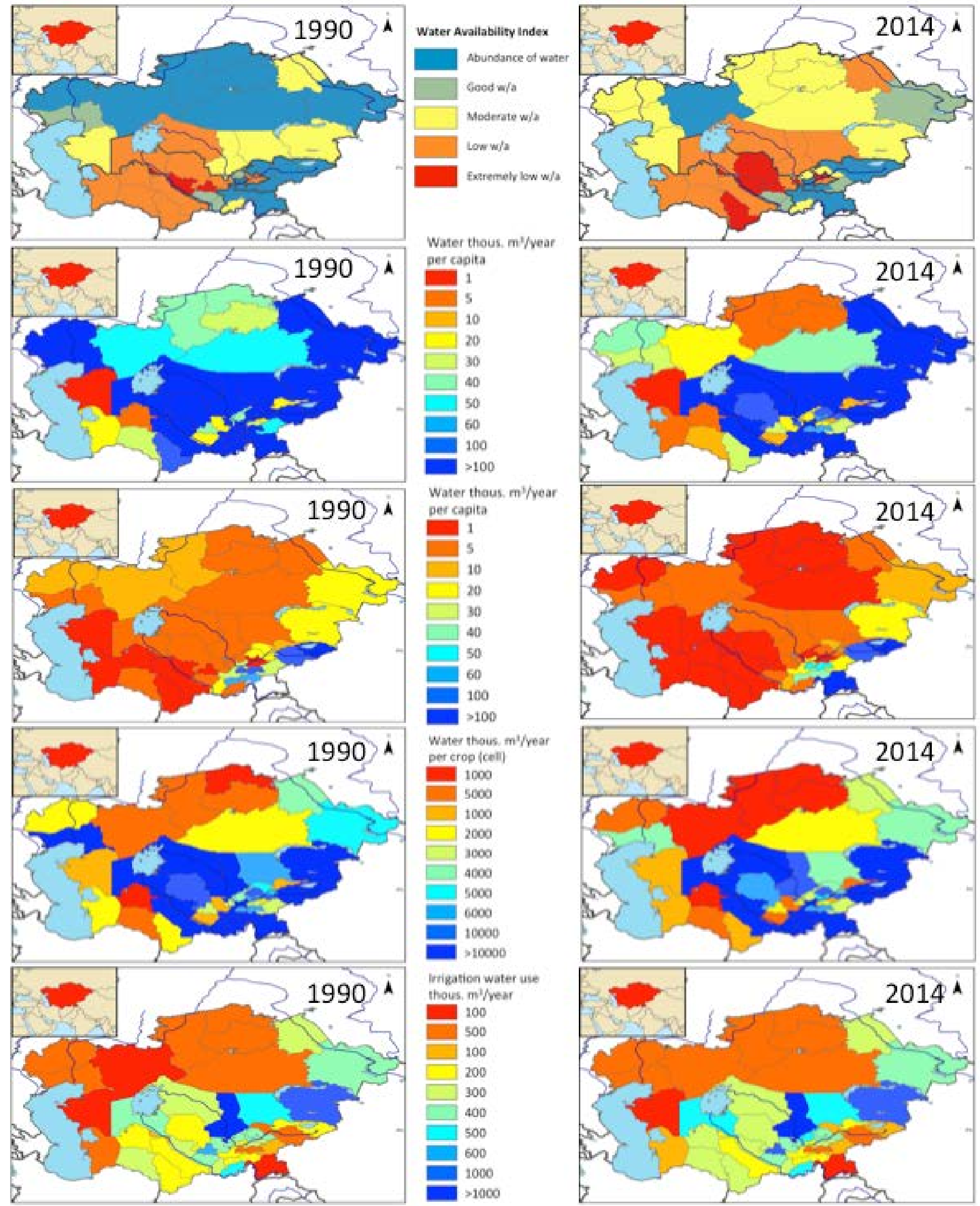
Water Availability Index (WAI)
compares all available water resources to the water demands (i.e. domestic, industrial and agricultural)

Water availability per capita (total)

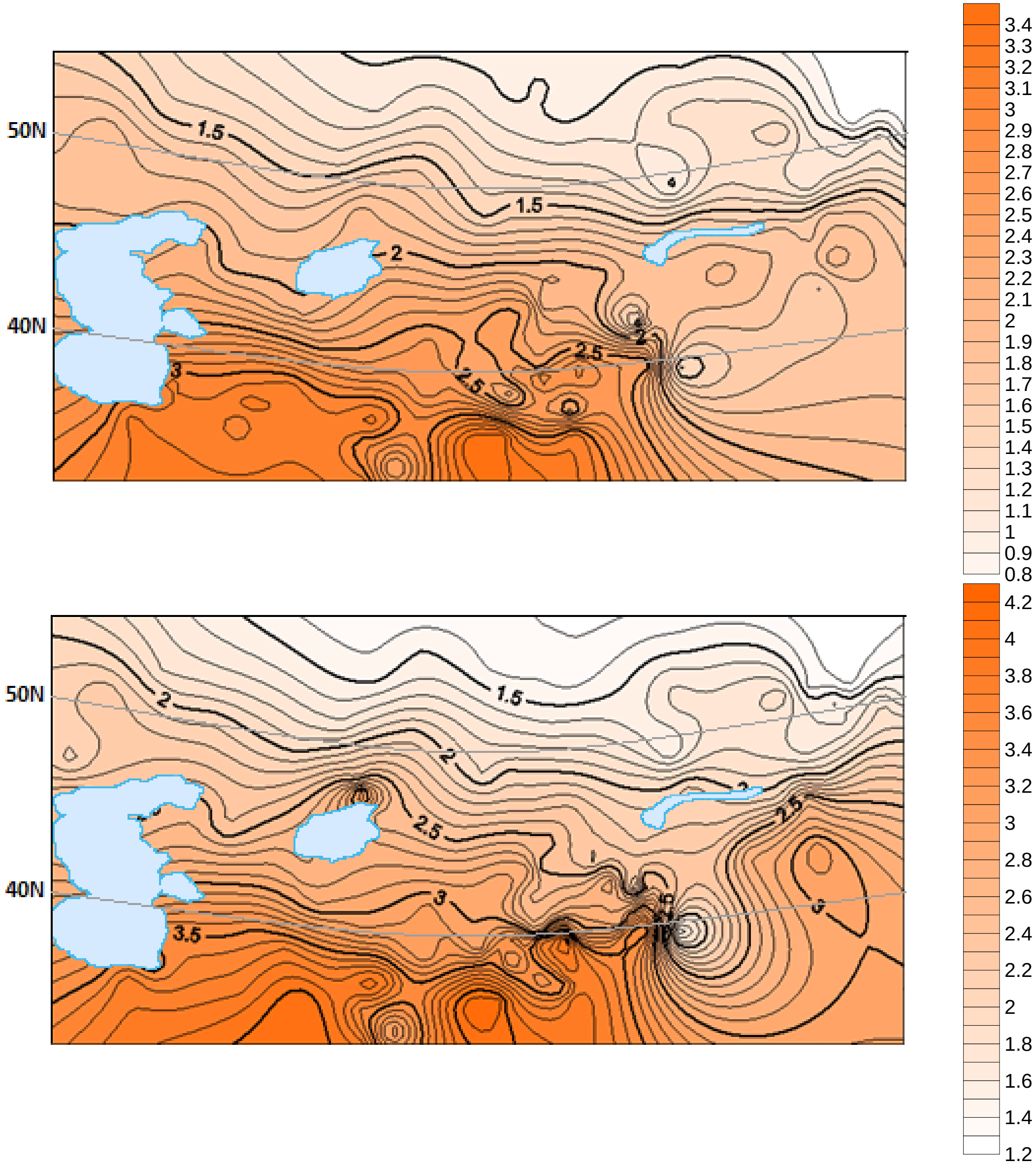
Water availability per capita (local)

Water availability per crop (total)

Irrigation water demand maps



Food security

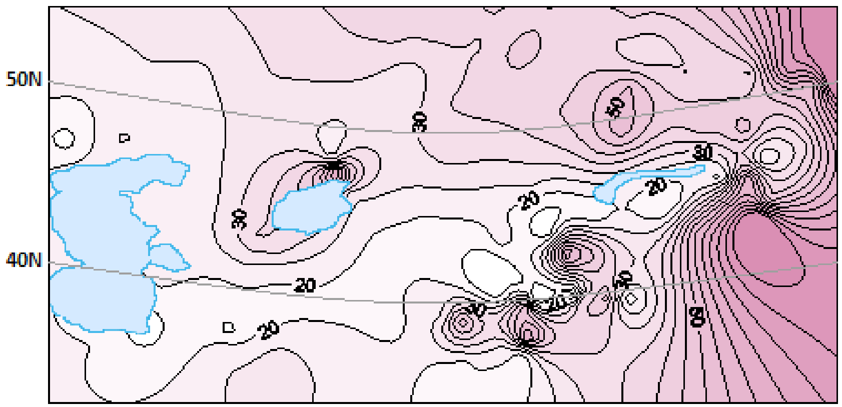


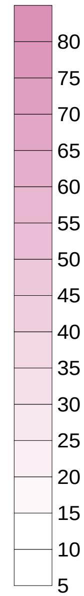
For the growth of different breeds certain values of effective temperature sums are required

Breeds of cotton	The sum of effective temperatures (°C)
Early-ripening	1720 – 1730
Middle-ripening	1795 – 1805
Middle-late	1875 – 1885
Late	1970 – 2100

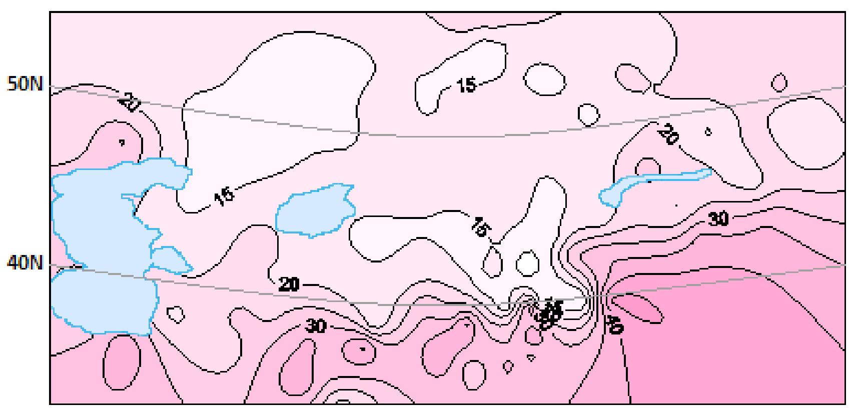
Sums of active air temperatures (1000×°C) calculated over the period with temperatures above 10°C for 1979-2009 (upper) and 2050-2059 (lower).

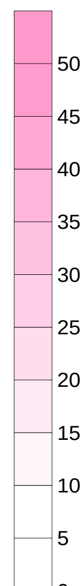
Evaluation of changes in potential thermal resources for cotton



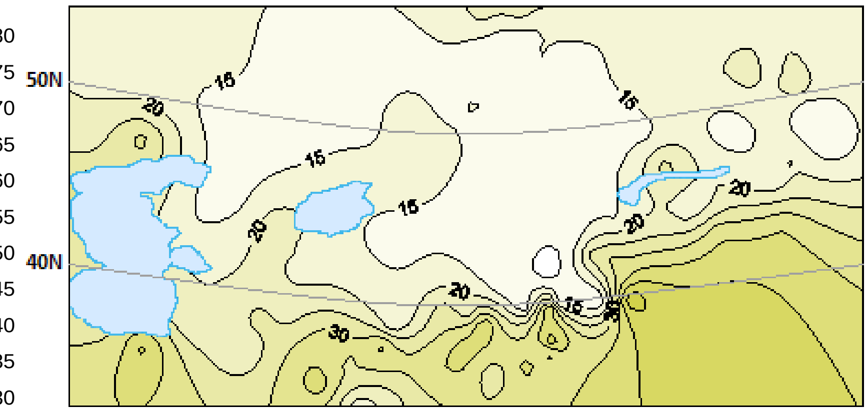


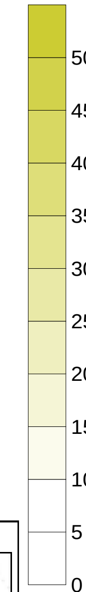
Changes (%) of active temperature sums above 10°C by 2050-2059 relative to baseline period. Scenario RCP8.5



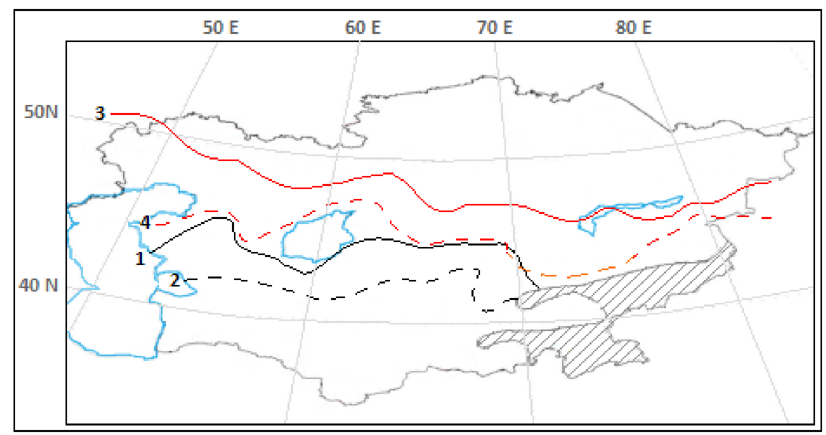


Changes (day) in duration of period with surface air temperatures above 10°C by 2050-2059 relative to baseline period. Scenario RCP8.5





Changes (day) in frost-free period by 2050-2059 relative to baseline period. Scenario RCP8.5

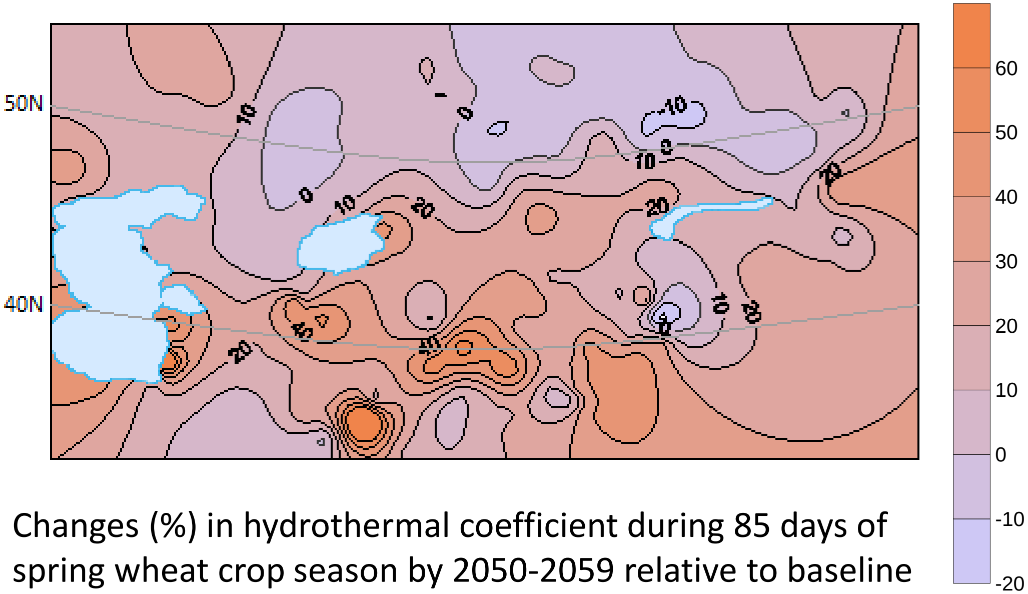


Sufficiency of thermal resources for cotton.

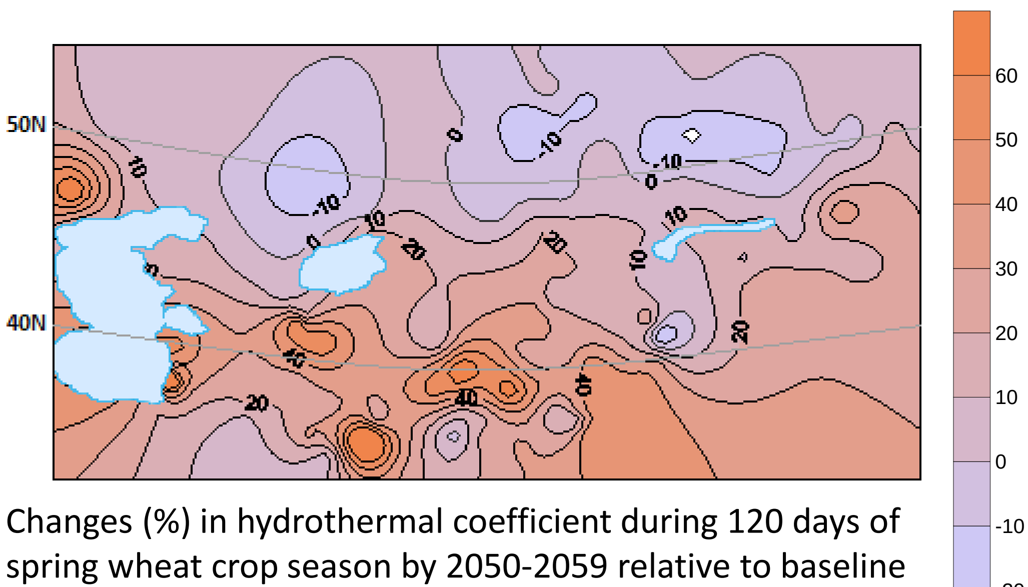
1 and 3 – 99% exceedance probability of thermal resources for early-ripening cotton in 1979-2009 and 2050-2059, respectively;

2 and 4 – 99% exceedance probability of thermal resources for very late (fine-filamented) cotton in 1979-2009 and 2050-2059, respectively

Evaluation of changes in potential hydrothermal resources for wheat



Changes (%) in hydrothermal coefficient during 85 days of spring wheat crop season by 2050-2059 relative to baseline period. Scenario RCP8.5



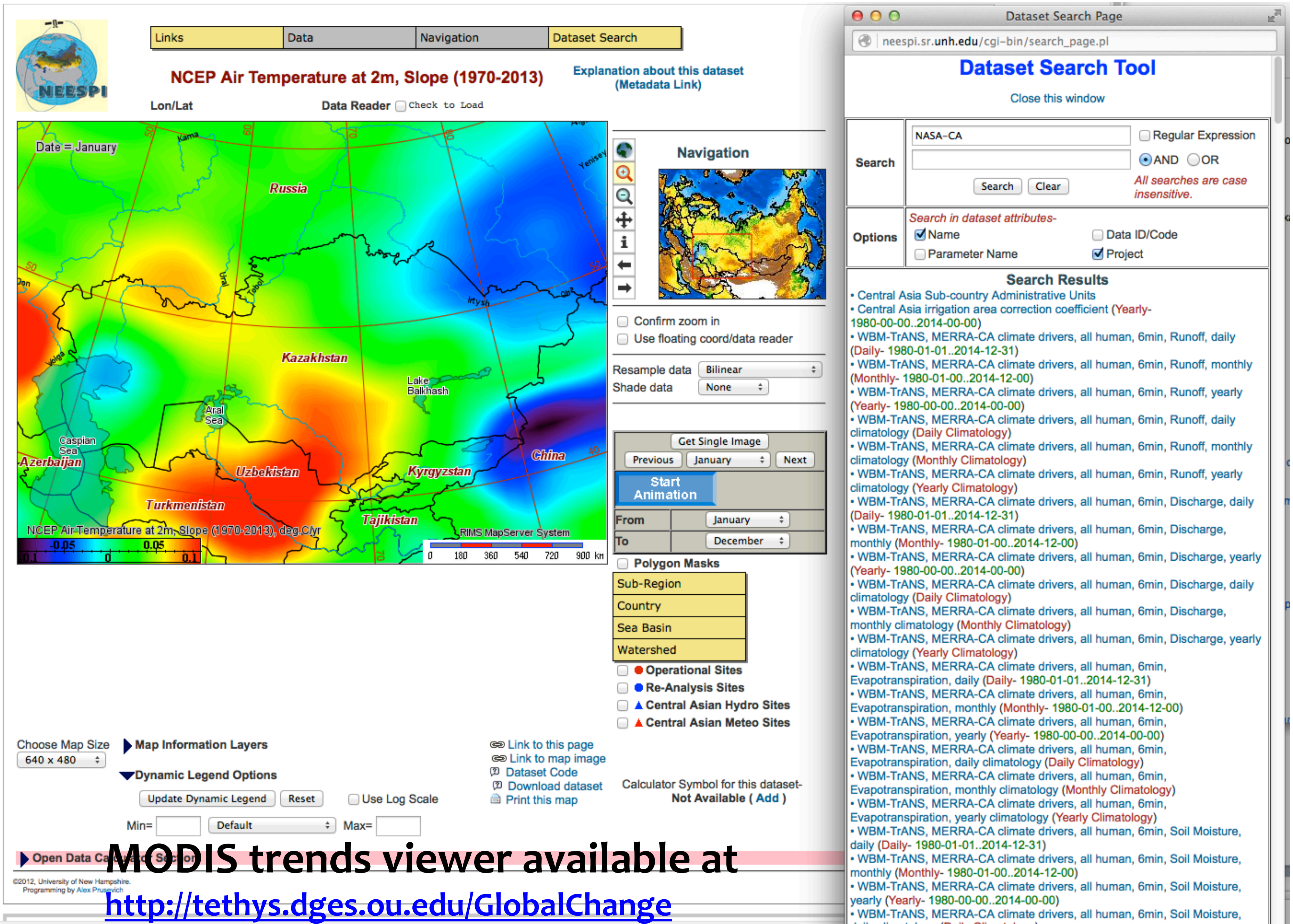
Changes (%) in hydrothermal coefficient during 120 days of spring wheat crop season by 2050-2059 relative to baseline period. Scenario RCP8.5

Selyaninov hydrothermal coefficient (HTC) calculated as follows:

$$HTC = \Sigma P / 0.1 \Sigma T$$

where Σ P is the sum of precipitation during the crop season simulated by regional climate model, Σ T – the sum of simulated temperatures for the same period

Some of our results is available on our website: http://neespi.sr.unh.edu



MODIS trends viewer available at

http://tethys.dges.ou.edu/GlobalChange

Conclusions

- There is a significant declining trend in vegetation over 2001-2013 across Central Asian drylands;
- Climate across the Central Asian drylands tends to be warmer and dryer >> less vegetation;
- Decline in croplands and irrigated areas in many regions >> less vegetation;
- Greatest changes in land use are occurring in the moderately populated areas where development is ongoing;
- Land reforms are very differed across countries and there is no relationship between agricultural productivity and land use practice.
- Central Asian countries are relatively water rich with large water use per capita but bad efficiency of water use and poor international water management are the main problems;
- Climate change, growing population and inefficient water use lead to increasing water scarcity in the region;
- Future climate condition in the region will be favorable for increase of agricultural production in many regions CA;

Further directions:

- Develop and apply an innovative approach to perform a synthesis of changes across land-use and land-cover, water resources, along with the economical changes (i.e., the dynamics of land privatization processes) over the last 30 years. This will be based on individual data sets that we have collected already in years 1 and 2 of the project.

- Identify the set and quantify the most important factors that have been influencing the LCLU dynamics, and perform a comparative analysis on a country-by-country basis to elucidate the role of individual factors affecting these changes.

- Achieve the overall synthesis understanding of the relations between the economics and land and water use dynamics in a comparative fashion among the countries of the Central Asia region.

- Perform the computations of factors representing individual components and then use them in the integrated quantitative analysis to assess the interrelations and correlations among different factors, and assess the role of the combined factor in the affecting LU dynamics.