LCLUC Impacts on Hydrology in Central Asia

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Central Asia (aka Middle Asia)

❖ Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan & Uzbekistan

❖ 4 million km^2: ~50% of CONUS

❖ > 60 million population with low, uneven population density: ~15 persons / km^2

❖ Dearth of data, including few extant regional land cover/land use maps and global land cover maps too broad thematically for change analysis

Agricultural sector has been principal source of extensive land change in Central Asia in recent decades.

- **Virgin Lands program of Khrushchev resulted in the rapid transformation of 36 Mha of steppe into croplands for grain production.** Douglas Jackson WA. 1962. The Virgin and Idle Lands Program Reappraised. *Ann Ass Am Geog* 52:69-79.
- **Impact of decades of water withdrawals from Syr Darya and Amu Darya to irrigate cotton have desiccated and polluted the lands bordering in the Aral Sea.** Micklin PP. 1988. Desiccation of the Aral Sea: A Water Management Disaster in the Soviet Union. *Science* 241: 1170-1176.

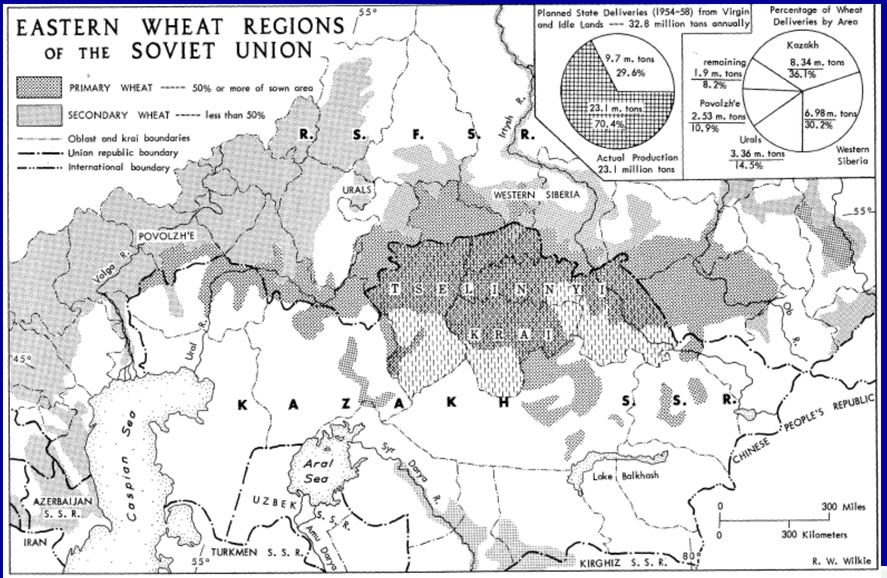
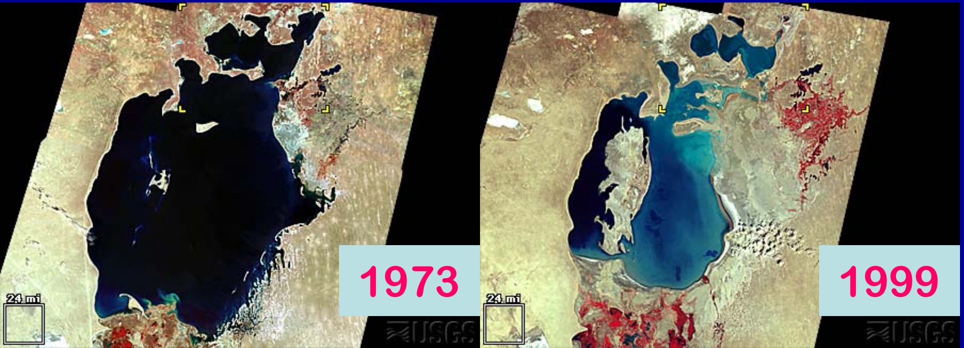


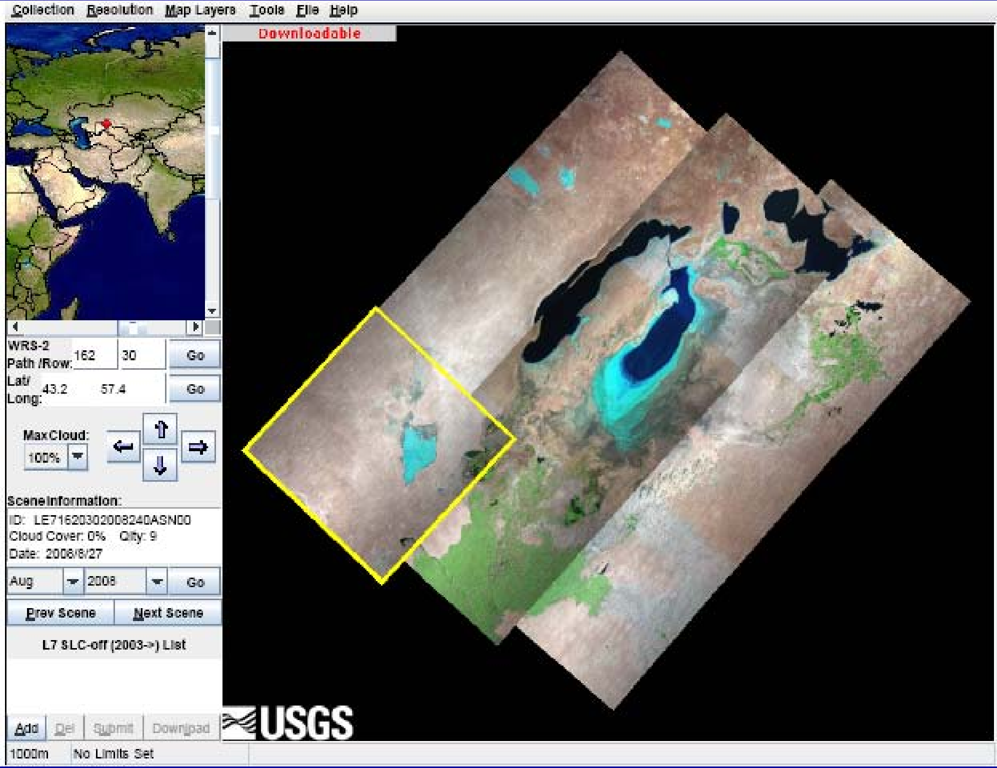
Fig. 1. (Sources: *Atlas Sel'skogo Khoziaistva SSSR* [Moscow, 1960], pp. 106–107, 116; *Narodnoe Khoziaistvo SSSR v 1959 Godu. Statisticheskii ezhegodnik* [Moscow, 1960], p. 373; *Pravda*, March 13, 1961.)



Photos: http://aboutkazakhstan.com/Kazakhstan_Economy_Agriculture.shtml
Images: http://earthshots.usgs.gov/Aral/Aral . Map: Douglas Jackson 1962.

In the past two decades since the collapse of the Soviet Union, there have been three significant aspects of land change affecting hydrology in Central Asia:

1. **Continued land & water degradation caused by intensive irrigated cotton cultivation and the associated environmental crisis of the Aral Sea Basin;**



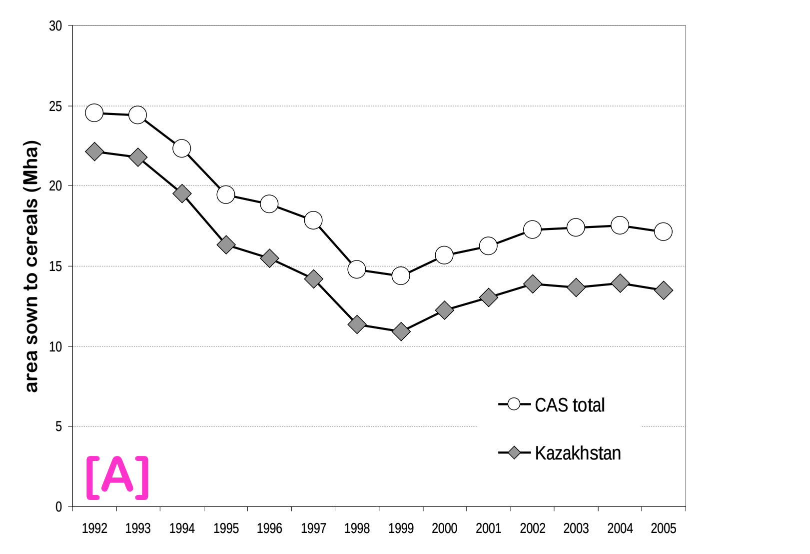
O'Hara S, Wiggs G, Mamedov B, Davidson G, Hubbard R. 2000. Exposure to airborne dust contaminated with pesticide in the Aral Sea region. *The Lancet* 355: 627-628.

Zavialov PO, Kostianoy AG, Emelianov SV, Ni AA, Ishniyazov D, Khan VM, Kudyshkin TV. 2003. Hydrographic survey in the dying Aral Sea. *GRL* 30:1659.

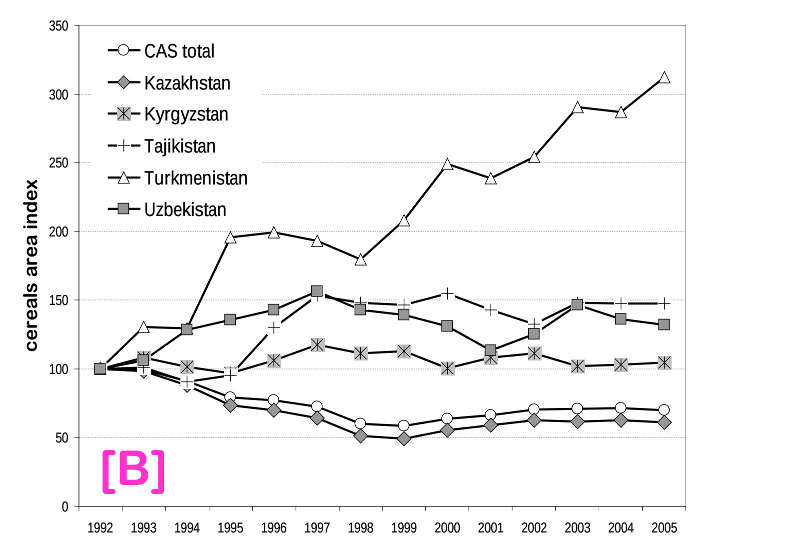
Mirabdullayev IM, Joldasova IM, Mustafaeva ZA, Kazakhbaev S, Lyubimova SA, Tashmukhamedov BA. 2004. Succession of the ecosystems of the Aral Sea during its transition from oligohaline to polyhaline water body. *J Marine Sys* 47(1-4):101-107.

In the past two decades since the collapse of the Soviet Union, there have been three significant aspects of land change affecting hydrology in Central Asia:

2. Deintensification of agriculture in the rain-fed grain cultivation semi-arid zone across northern Kazakhstan; and



[A] Deintensification of grain production in Central Asia is driven by Kazakhstan. Source: FAOSTAT (2007)

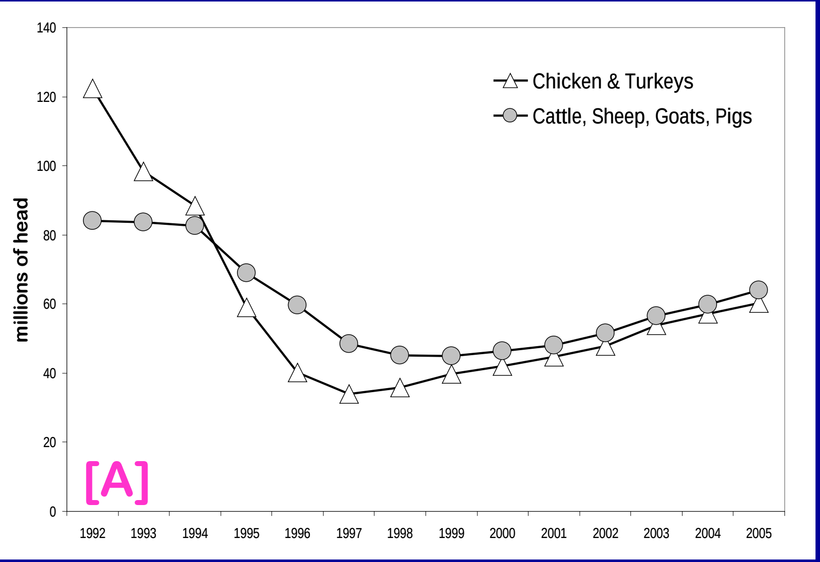


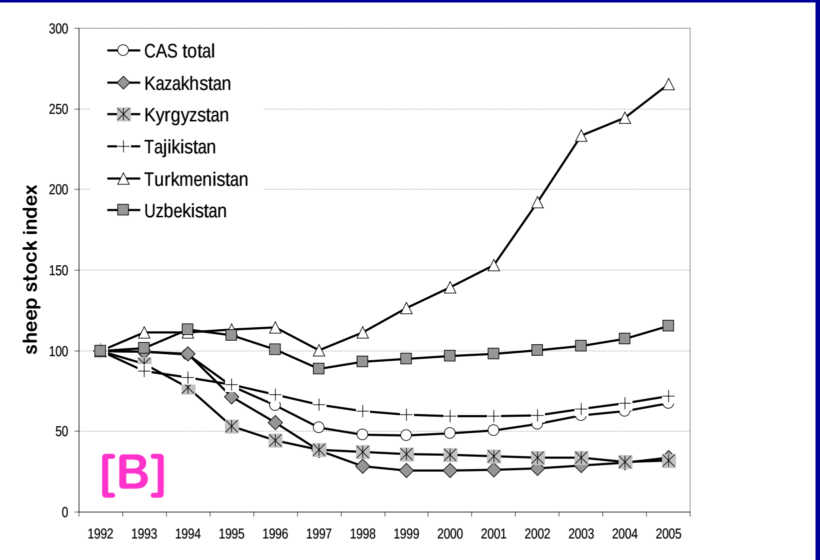
[B] Cereals area indexed to 1992 reveal divergent trajectories as countries adjust crop mix to enhance food security. Source: FAOSTAT (2007)

Lioubimtseva E, Henebry GM. 2009. Climate and environmental change in arid Central Asia: Impacts, vulnerability, and adaptations. *J Arid Environ,* to appear.

In the past two decades since the collapse of the Soviet Union, there have been three significant aspects of land change affecting hydrology in Central Asia:

3. Collapse of livestock production within entire region and divergent national trajectories on the rebound.





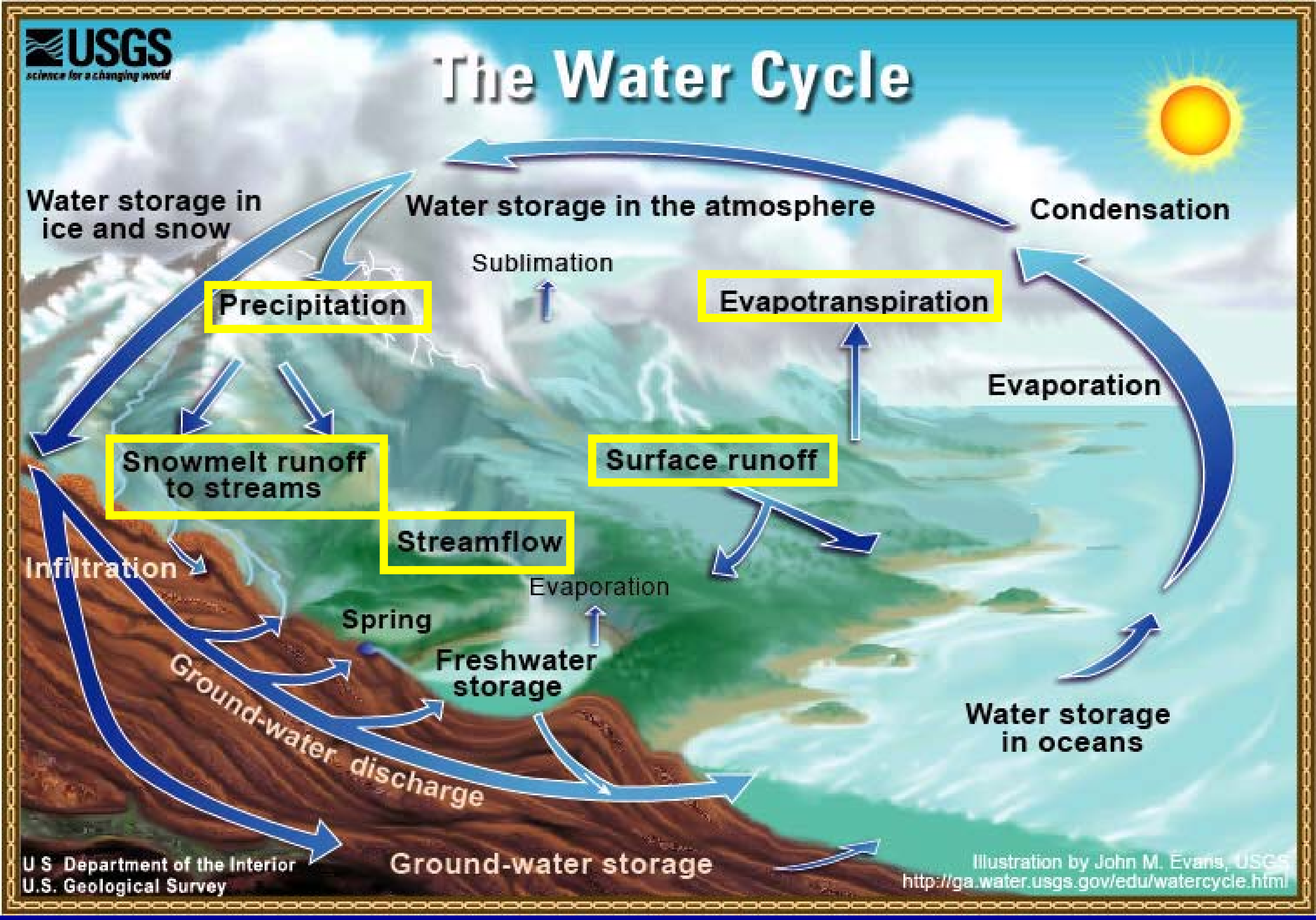
[A] **Stocks of live animals reveal a region-wide collapse and steady recovery.** Source: FAOSTAT (2007).

[B] **Sheep stocks indexed to 1992 reveal divergent national trajectories.** Source: FAOSTAT (2007).

Lioubimtseva E, Henebry GM. 2009. Climate and environmental change in arid Central Asia: Impacts, vulnerability, and adaptations. *J Arid Environ*, to appear.

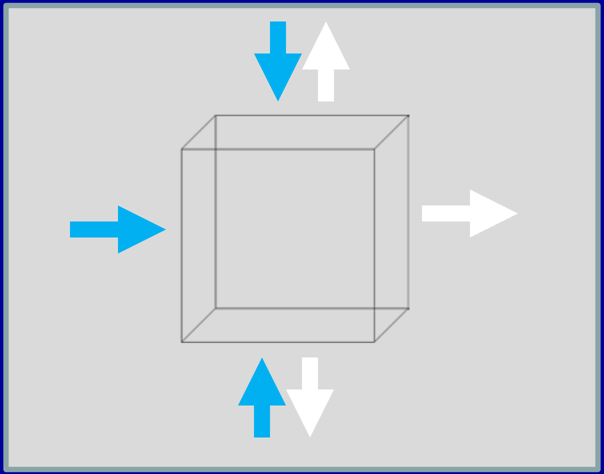
LCLUC in Central Asia has been driven by changes of policies and institutions in the agricultural sector.

What are the impacts on regional hydrology?



Changes in ET affecting precipitation, runoff & streamflow

LCLUC & the Water Cycle



Water Fluxes

control volume for mass balance =
soil surface through root zone

INPUTS

Precipitation
- quantity
- intensity
- timing
- duration
- storm track

Run-on/Interflow
- soil-vegetation complex

Capillary Rise/Hydraulic Lift
- quantity
- seasonality

OUTPUTS

ET/Sublimation
- quantity
- seasonality

Runoff/Snowmelt
- quantity
- seasonality

Deep drainage
- quantity
- seasonality

Timing, Seasonality, Location of Fluxes

LCLUC & the Water Cycle

Water Management Practices

Surface Water Rerouting/Diversion

- Channelization
- Drainage
- Flood control
- Impervious surface area
- Impoundments
- Irrigation/Agricultural Use
- Domestic Use
- Municipal Use
- Industrial/Mining Use

Ground Water Withdrawals

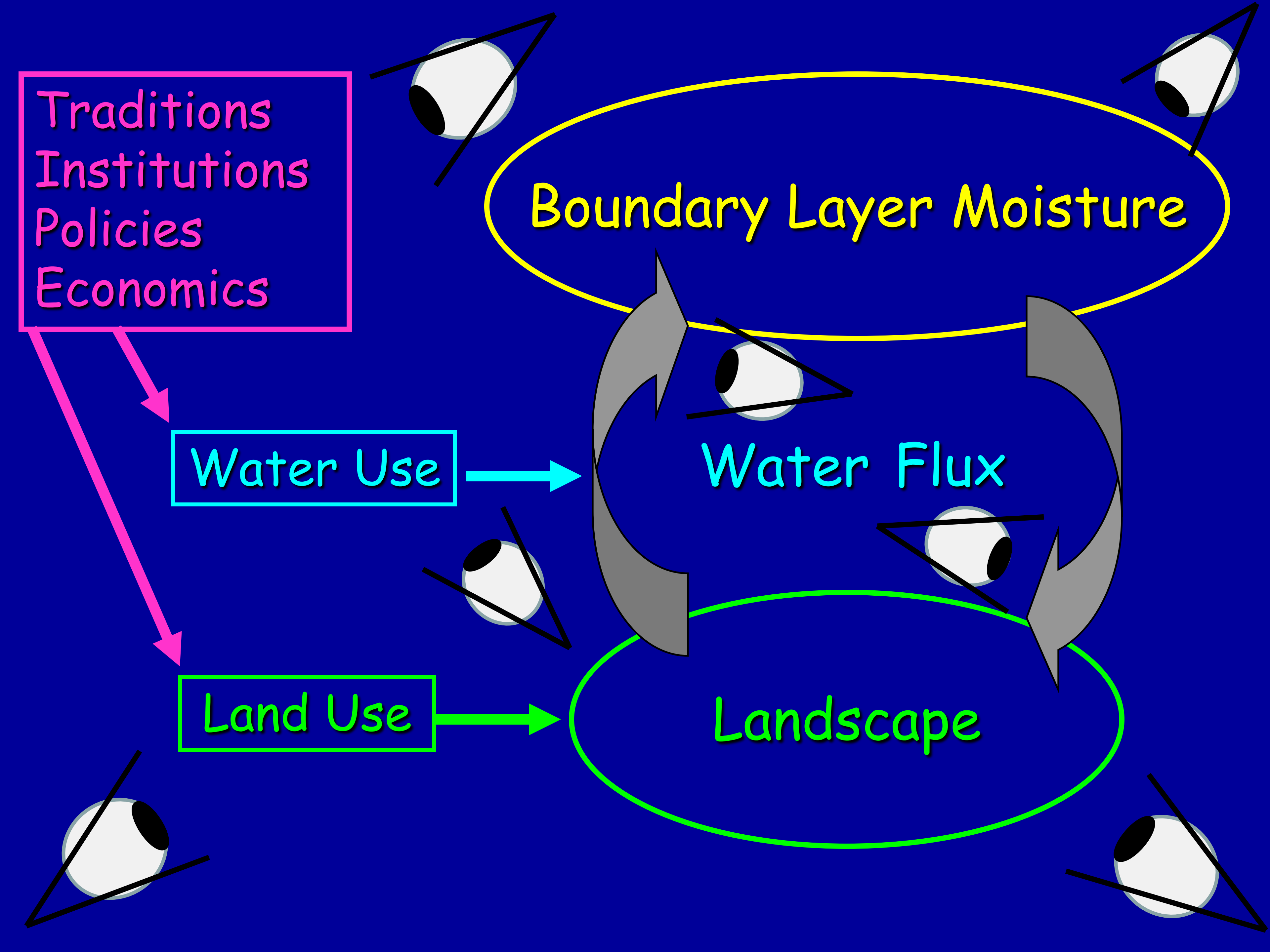
- Irrigation/Agricultural Use
- Domestic Use
- Municipal Use
- Industrial/Mining Use

Conjunctive Use (surface+ground coordination)

LCLUC Impacts on Hydrology

Water Quantity
Water Quality
Erosion/Deposition
Salinization/Land Degradation
Subsidence
Habitat Loss/Creation
Surface Compaction/Sealing
Shifts in Vegetation Community
Sustainability of Land Use

Human Use of Water Modulates Magnitude, Timing, Location of Fluxes & Stocks


Traditions
Institutions
Policies
Economics
Water Use
Land Use
Boundary Layer Moisture
Water Flux
Landscape

Are the data from observational networks in place to enable monitoring & change analysis?

No, they disintegrated in the 1990s, but they are being reconstituted.

Shikolomanov & Lammers: Assembling hydrometeorological data for Central Asia.

Akhmadiyeva & Groisman: Assembling weather & climate data for Kazakhstan.

Akhmadiyeva ZhK, Groisman PY. 2008. General assessment of climate change in Kazakhstan since 1990. *Hydrometeorology and Environment* 2:46-53.

Akhmadiyeva ZhK , Groisman PY. 2008. Recent climatic changes over Kazakhstan. *Eos Trans. AGU,89*(53), *Fall Meet. Suppl.*, Abstract GC41A-0675.

NCDC. 2008. Global Daily Climatology Network: Kazakhstan. 17 pp. [http://www1.ncdc.noaa.gov/pub/data/documentlibrary/tddoc/td9814.pdf]

New updated hydrometeorological station dataset collected at the University of New Hampshire under our LCLUC/NEESPI project.

We used the data (1) to analyze variability of major water balance components across Central Asia and (2) to evaluate reliability of available gridded precipitation and air temperature data from CRU.

Map shows hydrological gages (blue triangles) and gages with water use information (large red triangles).

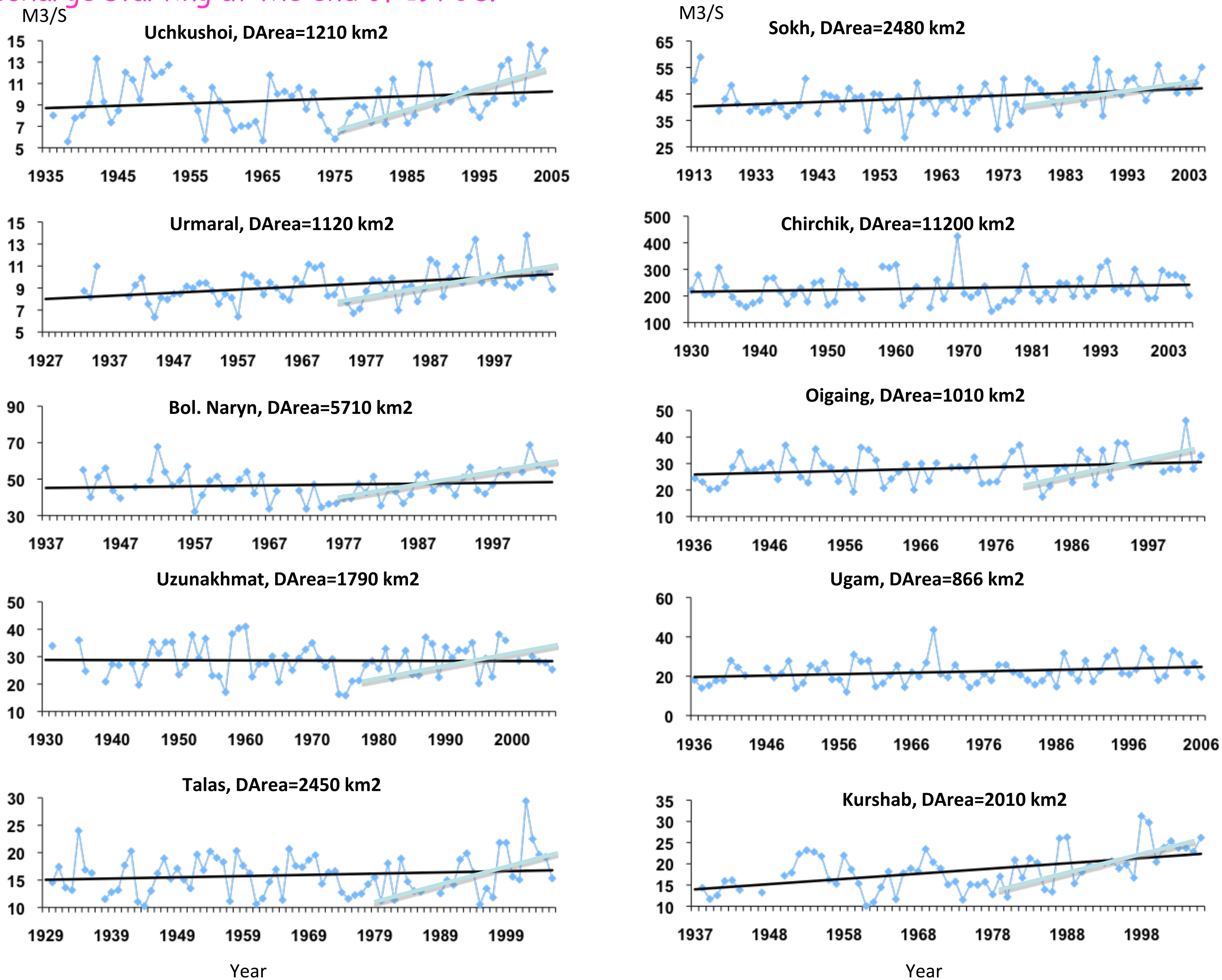
Country	Number of gauges with data: Monthly discharge	Annual discharge	Water use
Kazakhstan	378	379	11
Kyrgyzstan	167	169	3
Tajikistan	128	128	4
Turkmenistan	24	25	6
Uzbekistan	133	133	10
Total	830	834	34

Country	Monthly discharge		Annual discharge		Water use	
	First Year	Last Year	First Year	Last Year	First Year	Last Year
Kazakhstan	1930	2006	1930	2006	1981	2005
Kyrgyzstan	1910	2006	1910	2006	1981	1990
Tajikistan	1929	1991	1929	1991	1981	1990
Turkmenistan	1936	1985	1930	1991	1981	1990
Uzbekistan	1913	2006	1913	2006	1981	1990

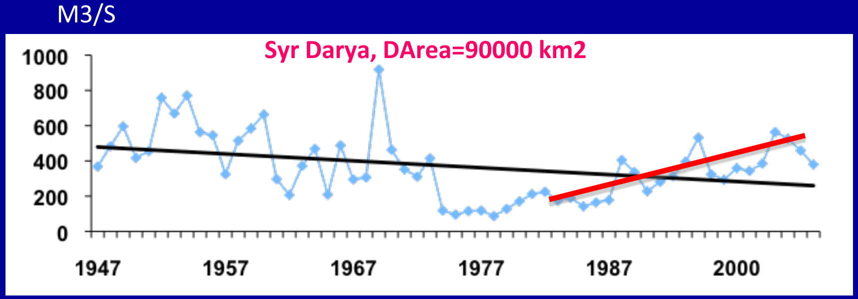
Hydrological data for Tajikistan and Turkmenistan were not updated since collapse of USSR

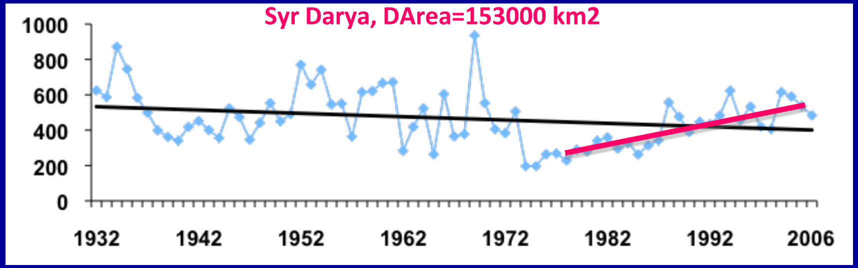
Country	Number of Stations	Monthly air temperature and precipitation	
		First Year	Last Year
Kazakhstan	54	1879	2003
Kyrgyzstan	62	1879	2006
Tajikistan	54	1881	2003
Turkmenistan	16	1883	2003
Uzbekistan	124	1875	2006
Total	310	1875	2006

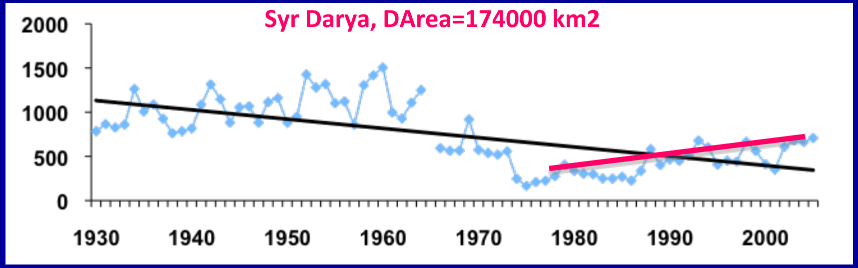
Long-term annual discharge variations for medium size rivers in Tian Shan Mountains (Syr Darya upstream). The rivers do not have significant human impact so any change is a climate signal. There is increasing trend in discharge starting at the end of 1970's.

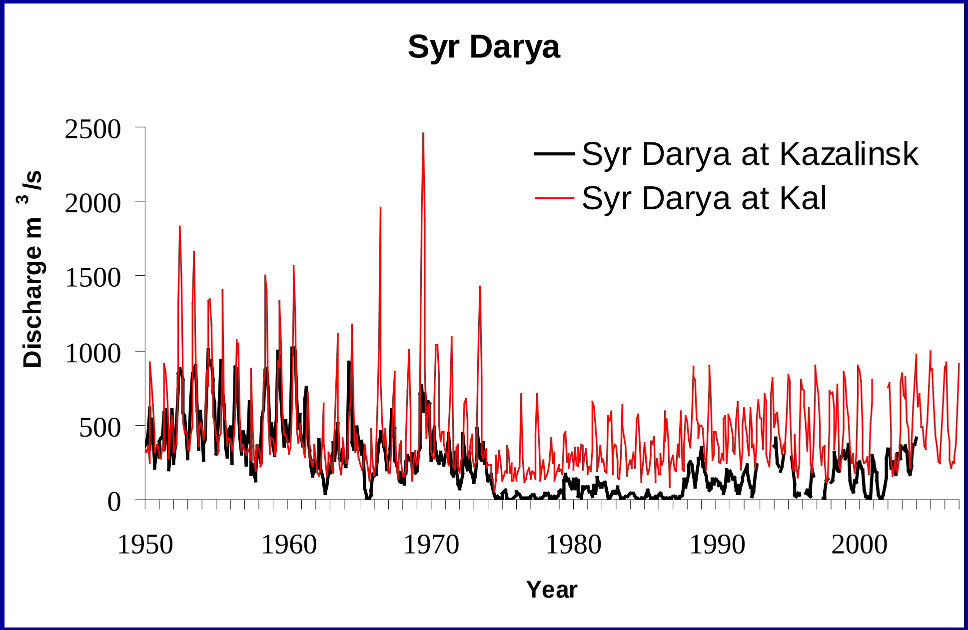


Discharge variations along Syr Darya



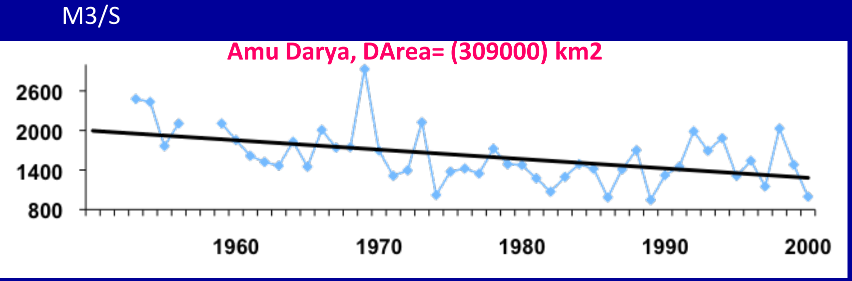


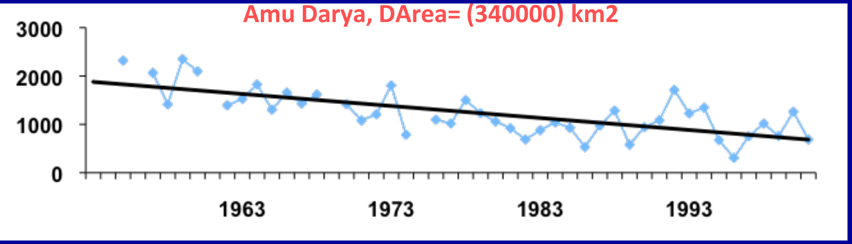


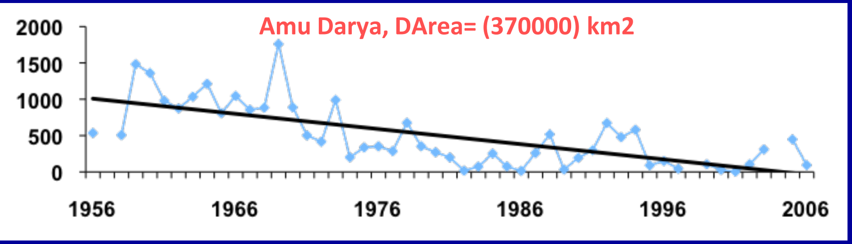


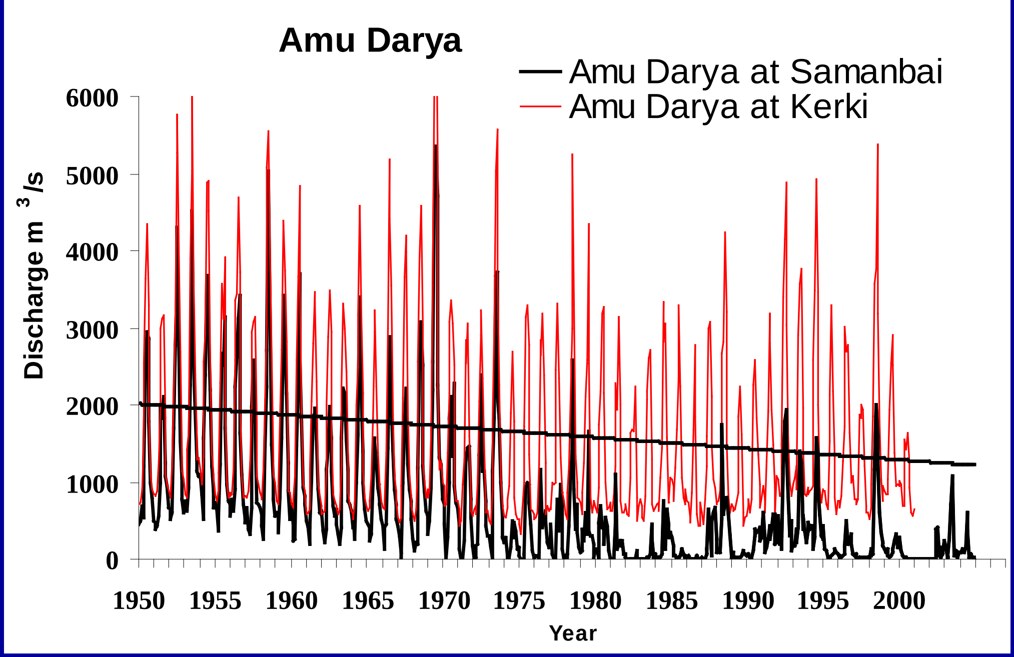
This increasing tendency in discharge is noticeable along large river (Syr Darya) too. It is probably due to more intensive snow and glacier melt in mountains.

Discharge variations along Amu Darya





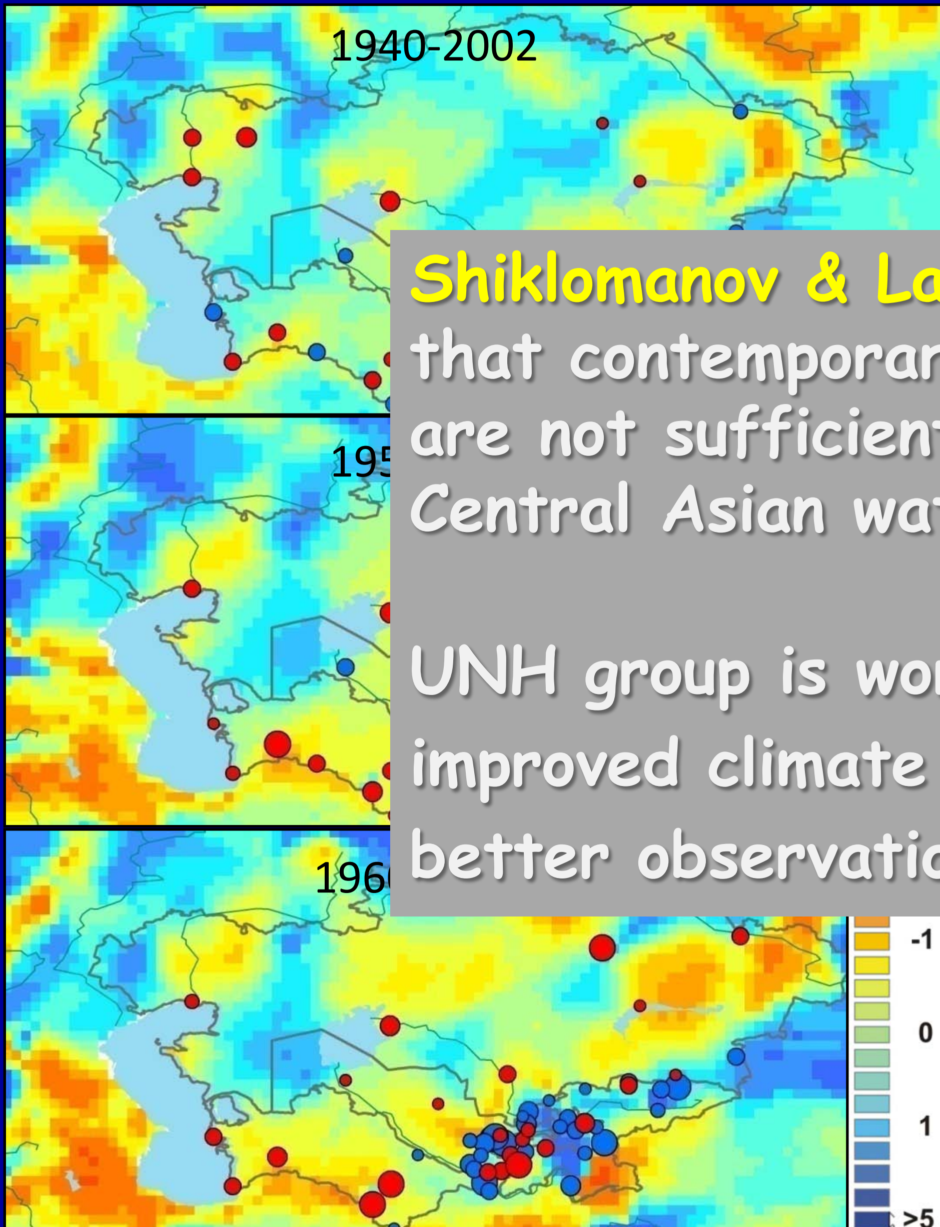




Downstream gages along Amu Darya river do not show such clear changes.

Annual observed precipitation variation from CRU 30’ grids and station data

Grids of linear slopes over periods are shown



Station trends over 1940-2002

Linear Trend	Total	Significant P<0.05
		6
		7

Shiklomanov & Lammers conclude that contemporary gridded fields are not sufficient to simulate Central Asian water balance.

UNH group is working to produce improved climate drivers based on better observational coverage.

ver 1950-2002

		Significant P<0.05
		3
		9

ver 1960-2002

Linear Trend	Total	Significant P<0.05
Positive	30	2
Negative	32	9

Another Perspective: Recent Trends

Working with the data of Akhmadiyeva & Groisman, my group at SDSU has investigated recent trends in Accumulated Growing Degree-Days (AGDD) and Accumulated Daily Precipitation (APPT) for Kazakhstan[1]

Three AGDD base temperatures: 0 °C, 4 °C, 10 °C.

Two temporal spans: 1991-2006 and 2000-2006.

Seasonal resolution: composites 1st & 15th of March through September

Trend analysis using nonparametric Season Kendall test corrected for first order autocorrelation.[2]

And compared the APPT trends with those in the Global Precipitation Analysis (GPCC) 0.5 degree monthly grids[3]

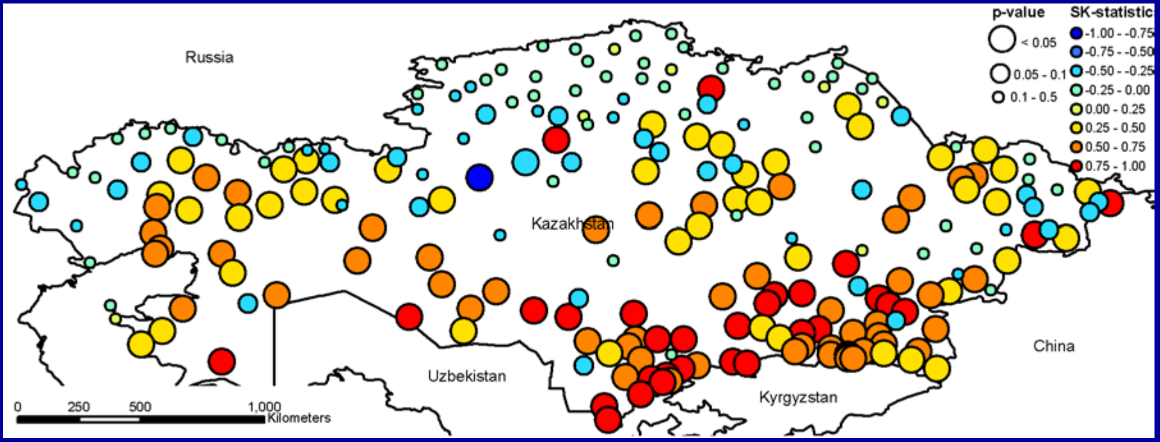
[1] Wright CK, de Beurs KM, Akhmadiyeva ZhK, Groisman PY, Henebry GM. *In review.* Recent temperature and precipitation trends in Kazakhstan reveal significant changes in growing season weather *Environmental Research Letters*.

[2] de Beurs KM, Henebry GM. 2004. Trend analysis of the Pathfinder AVHRR Land (PAL) NDVI data for the deserts of Central Asia. *IEEE Geoscience and Remote Sensing Letters*. 1(4): 282-286. doi:10.1109/LGRS.2004.834805.

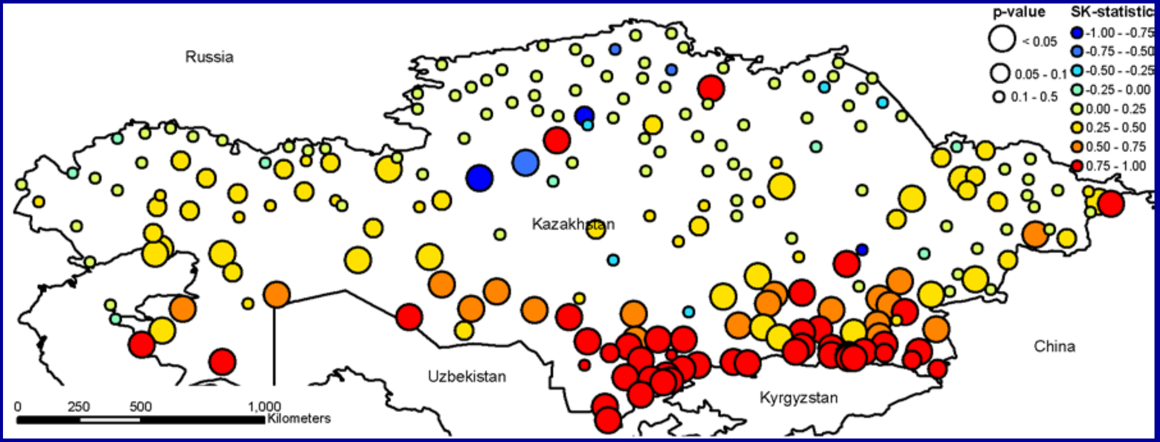
[3] Schneider U, Fuchs T, Meyer-Christoffer A and Rudolf B 2008 *Global Precipitation Analysis Products of the GPCC*. Global Precipitation Climatology Centre (GPCC), DWD, Internet Publication, 1-12 (http://gpcc.dwd.de).

AGDD Trends 1991-2006 at 3 Base Temperatures

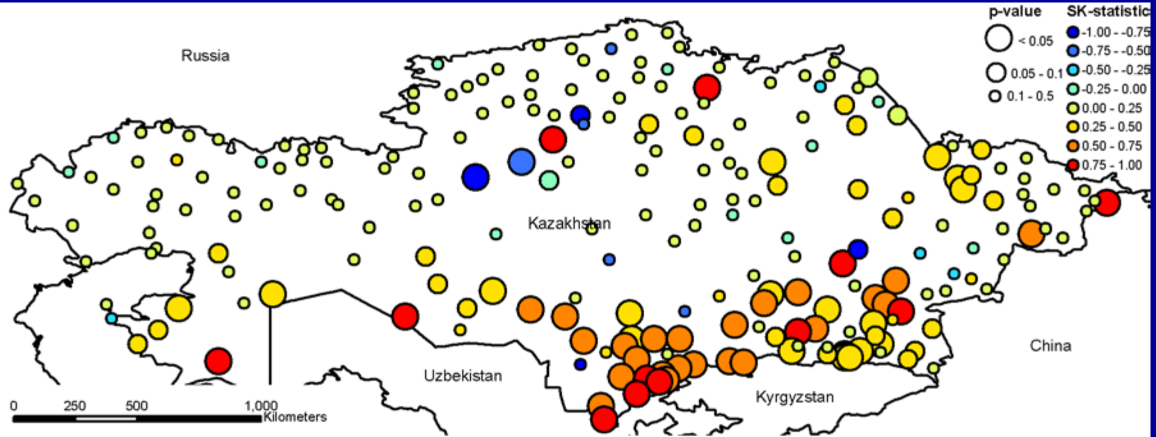
0° C



4° C



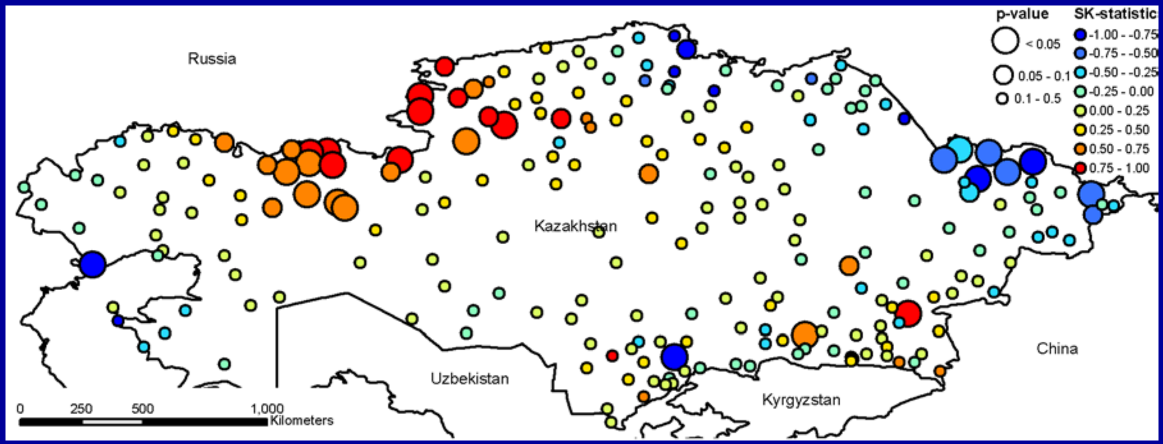
10° C



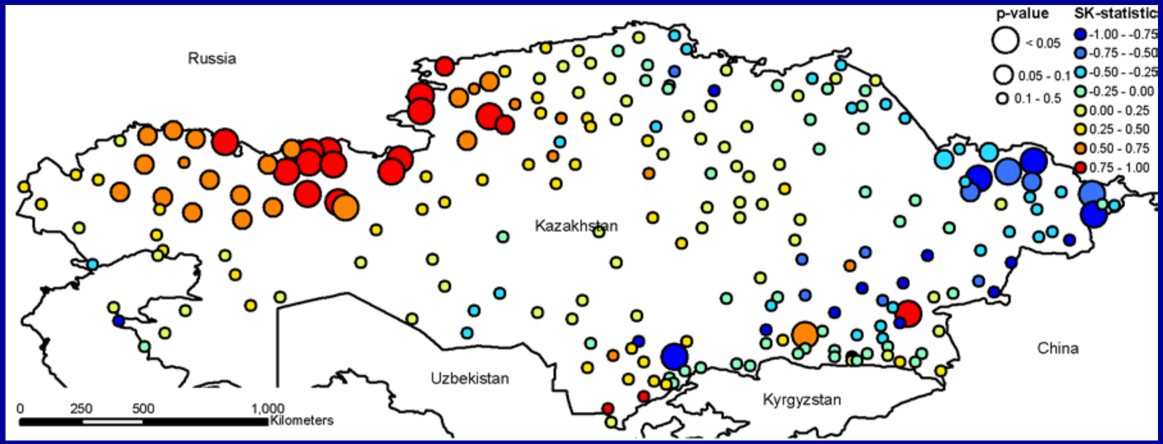
Significant early to mid season warming in south & southeast

AGDD Trends 2000-2006 at 3 Base Temperatures

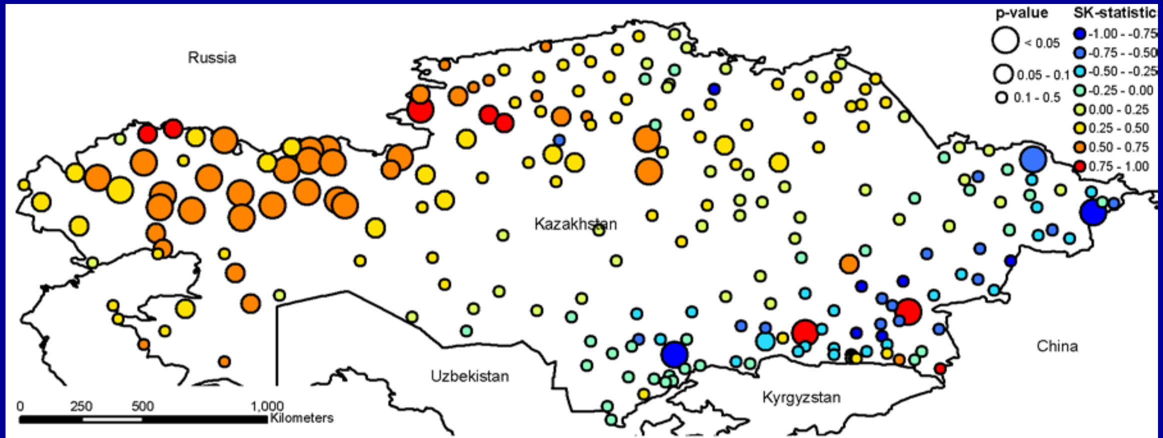
Significant early to mid season warming in northwest KZ



0° C



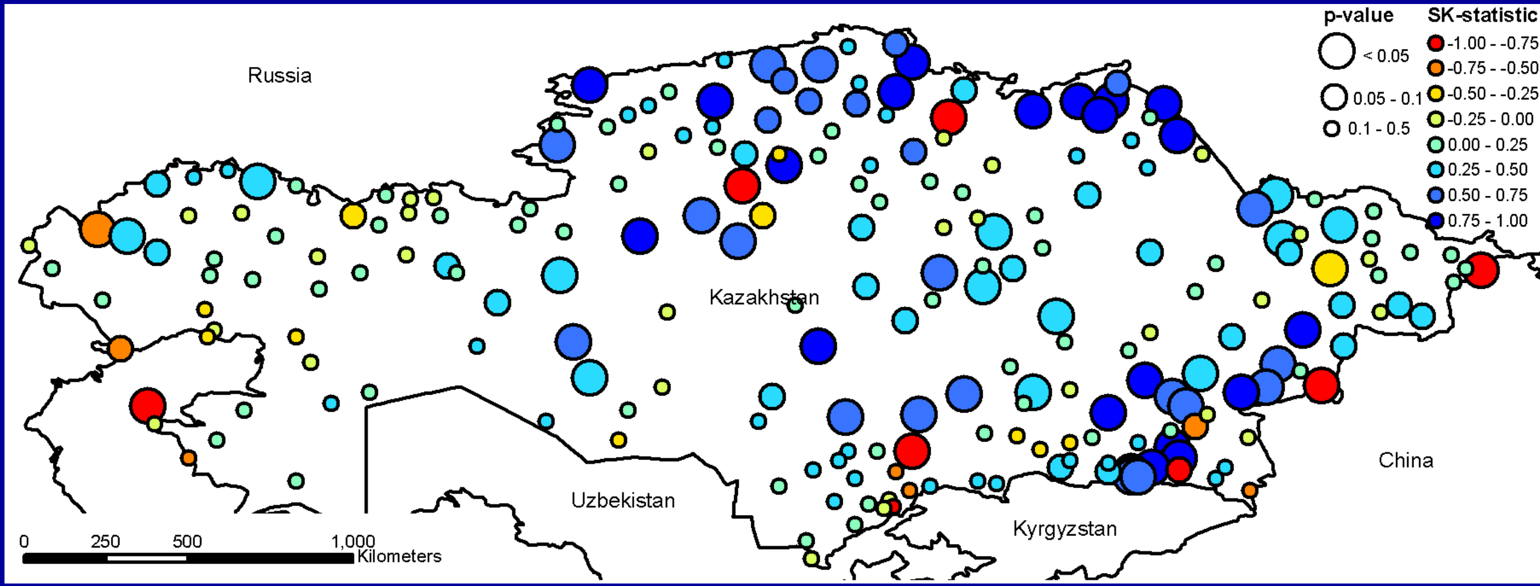
4° C



10° C

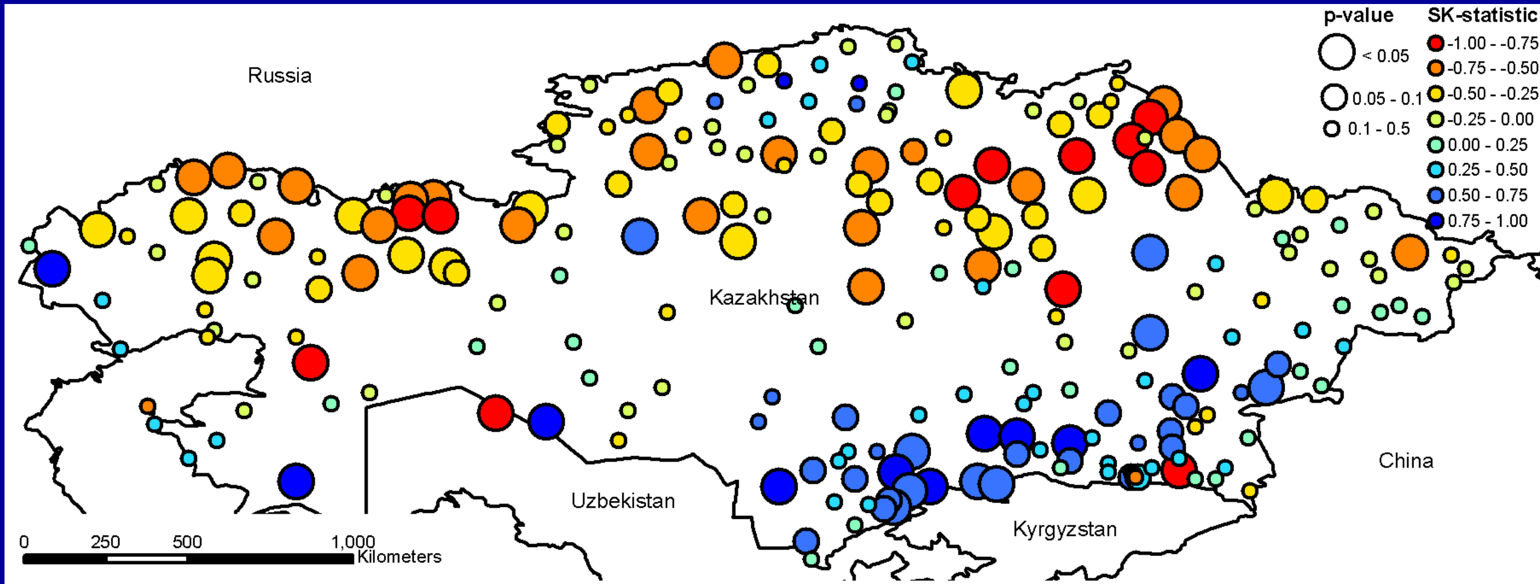
APPT Trends 1991-2006

Generally increasing precip towards eastern KZ

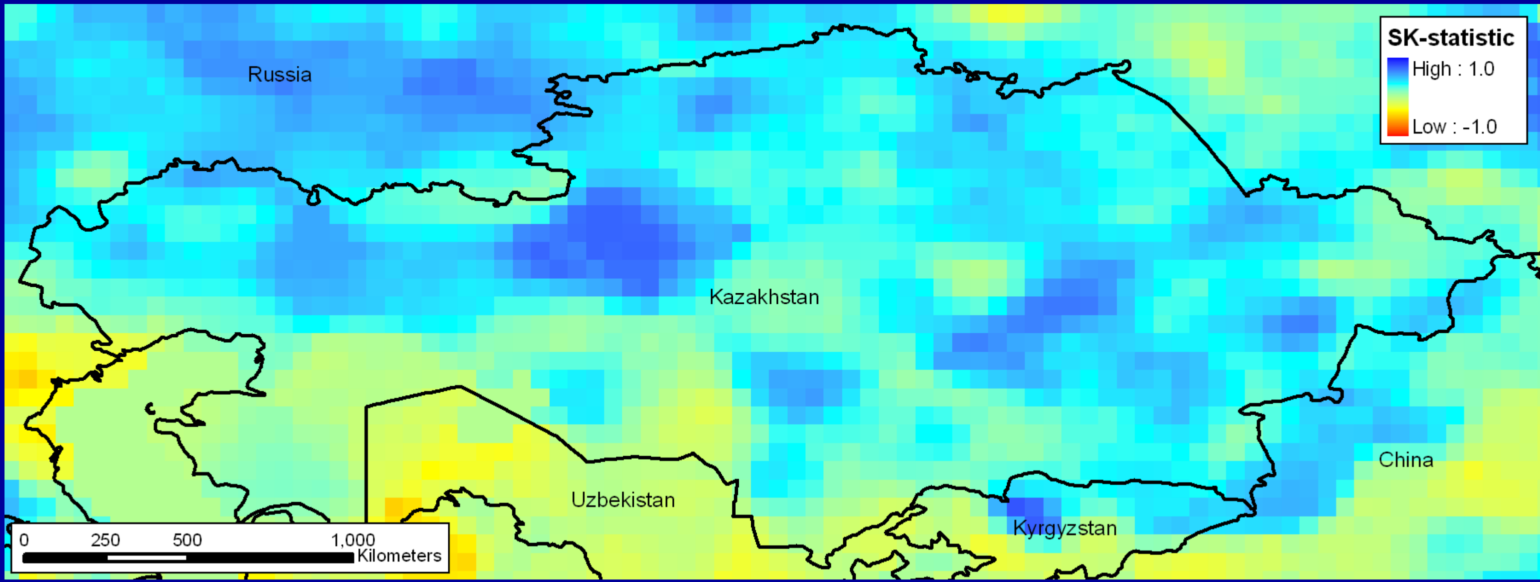


APPT Trends 2000-2006

Drought impacts evident in northern KZ; increasing precipitation along southern flank

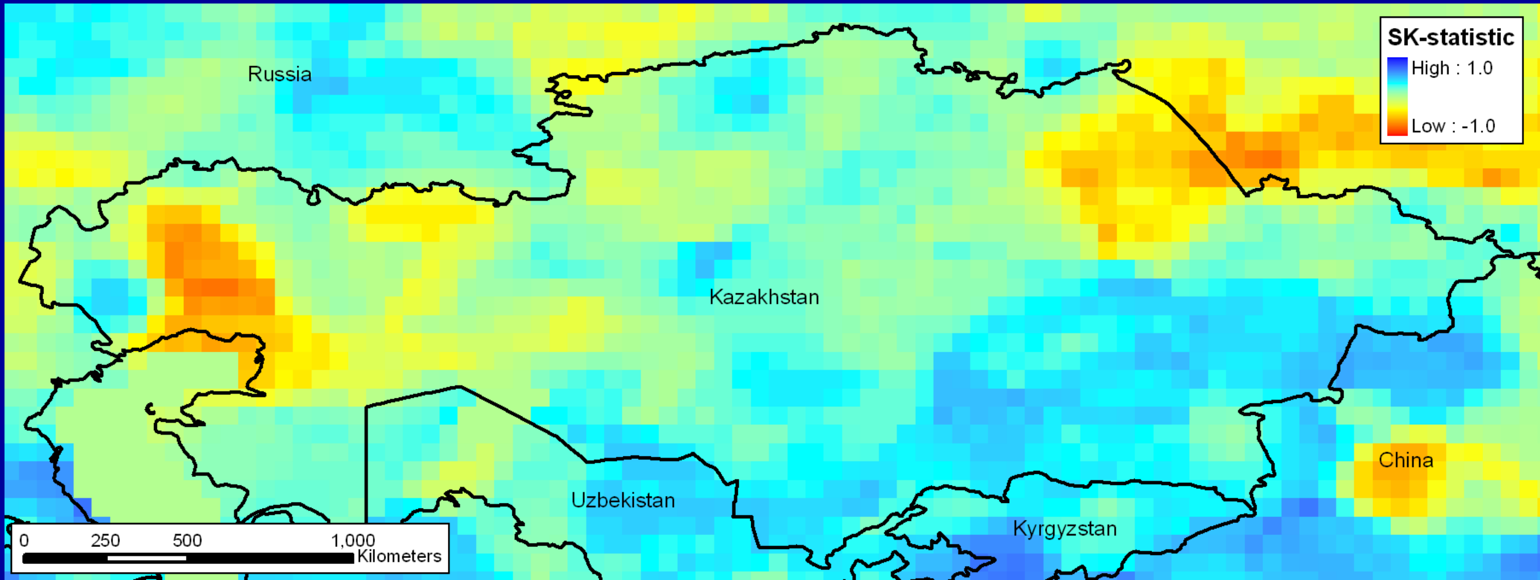


GPCC APPT Trends 1991-2006

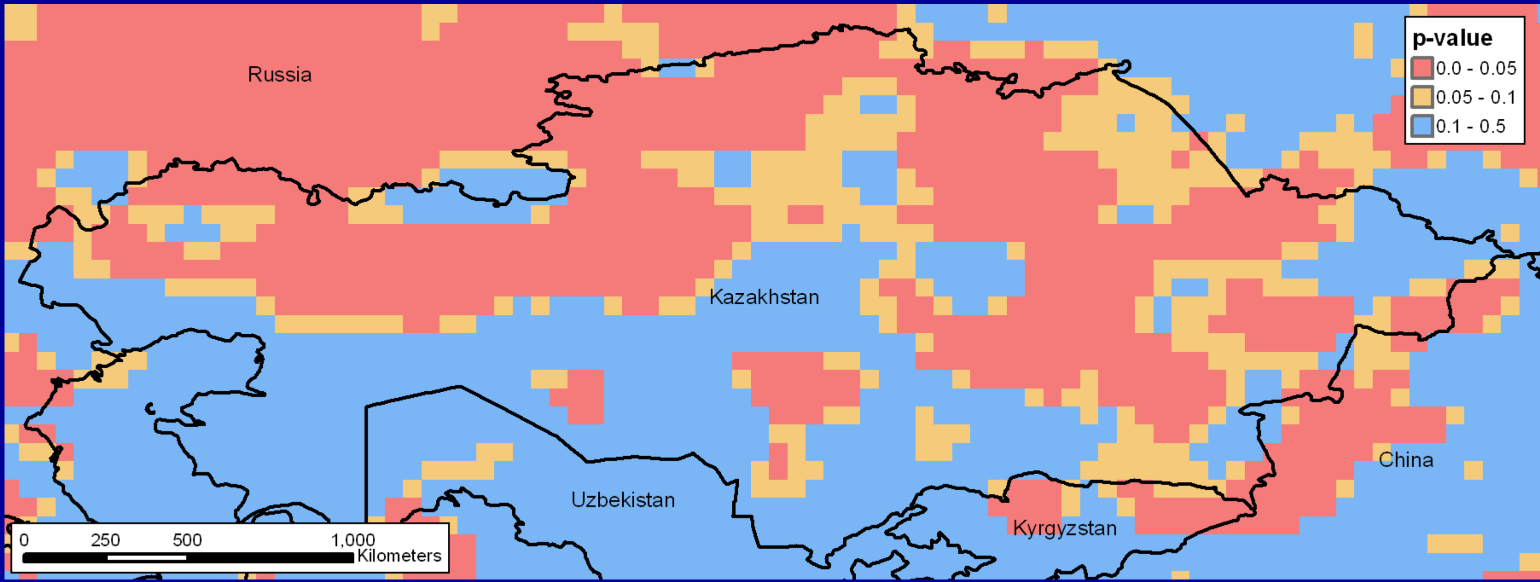


Gridded data shows only weak agreement with the station data and lack of resolution in areas with high relief (SE KZ) despite higher number of stations.

GPCC APPT Trends 2000-2006

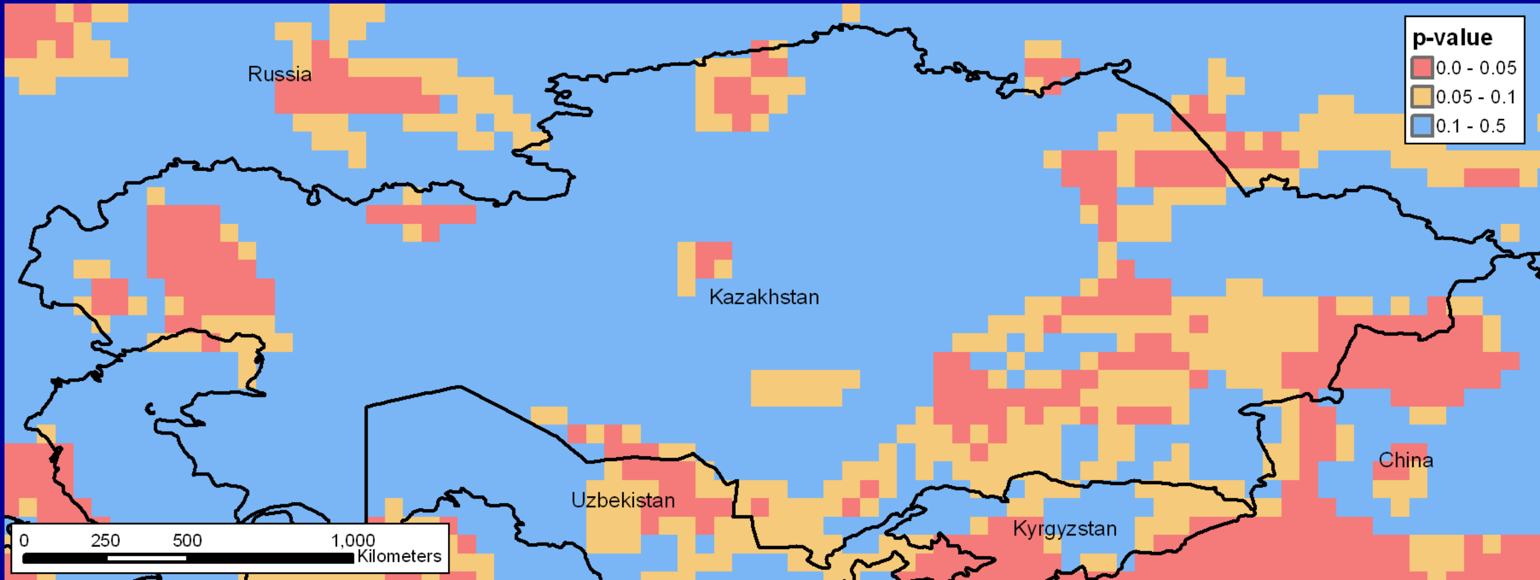


GPCC APPT Trends 1991-2006



Gridded data tends to larger patches of significant trends, which not supported by station data.

GPCC APPT Trends 2000-2006



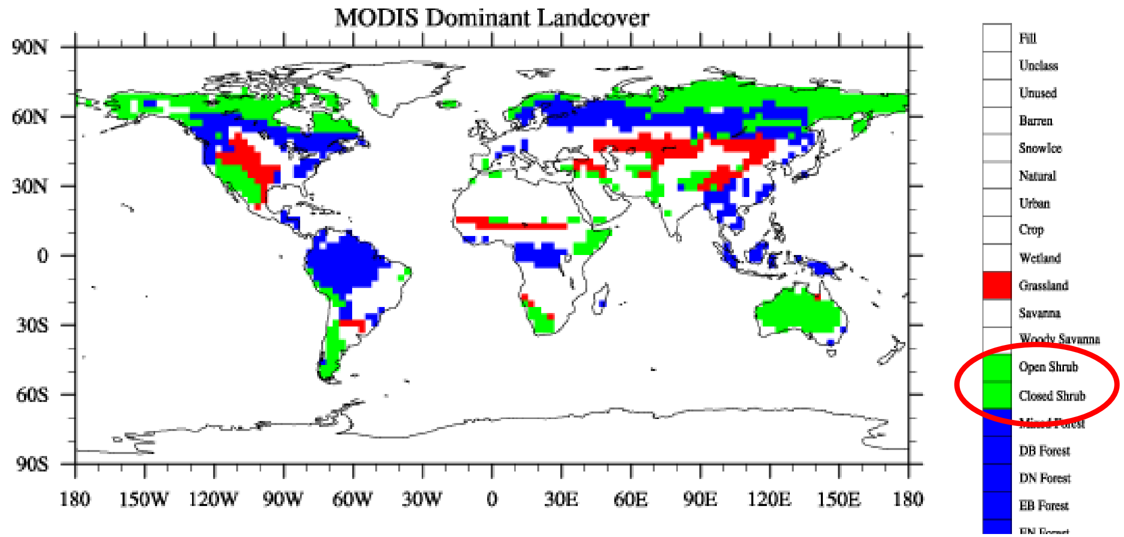
High Type I error rates due to positive temporal & spatial autocorrelation induced by smoothing?

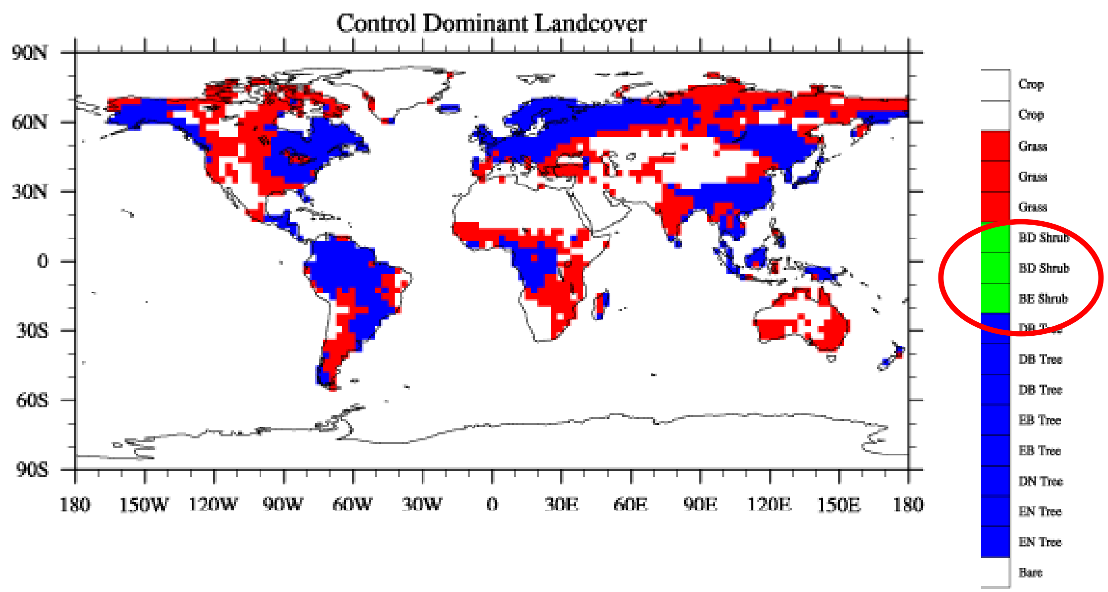
We found

- Significant secular trends in AGDD & APPT since the formal end of the USSR in 1991
- Significant secular trends in AGDD & APPT in the MODIS era (since 2000)
- Dubious trends in gridded precipitation product

Another key aspect of the regional water cycle is the vegetated land cover affecting ET, runoff, and drainage.

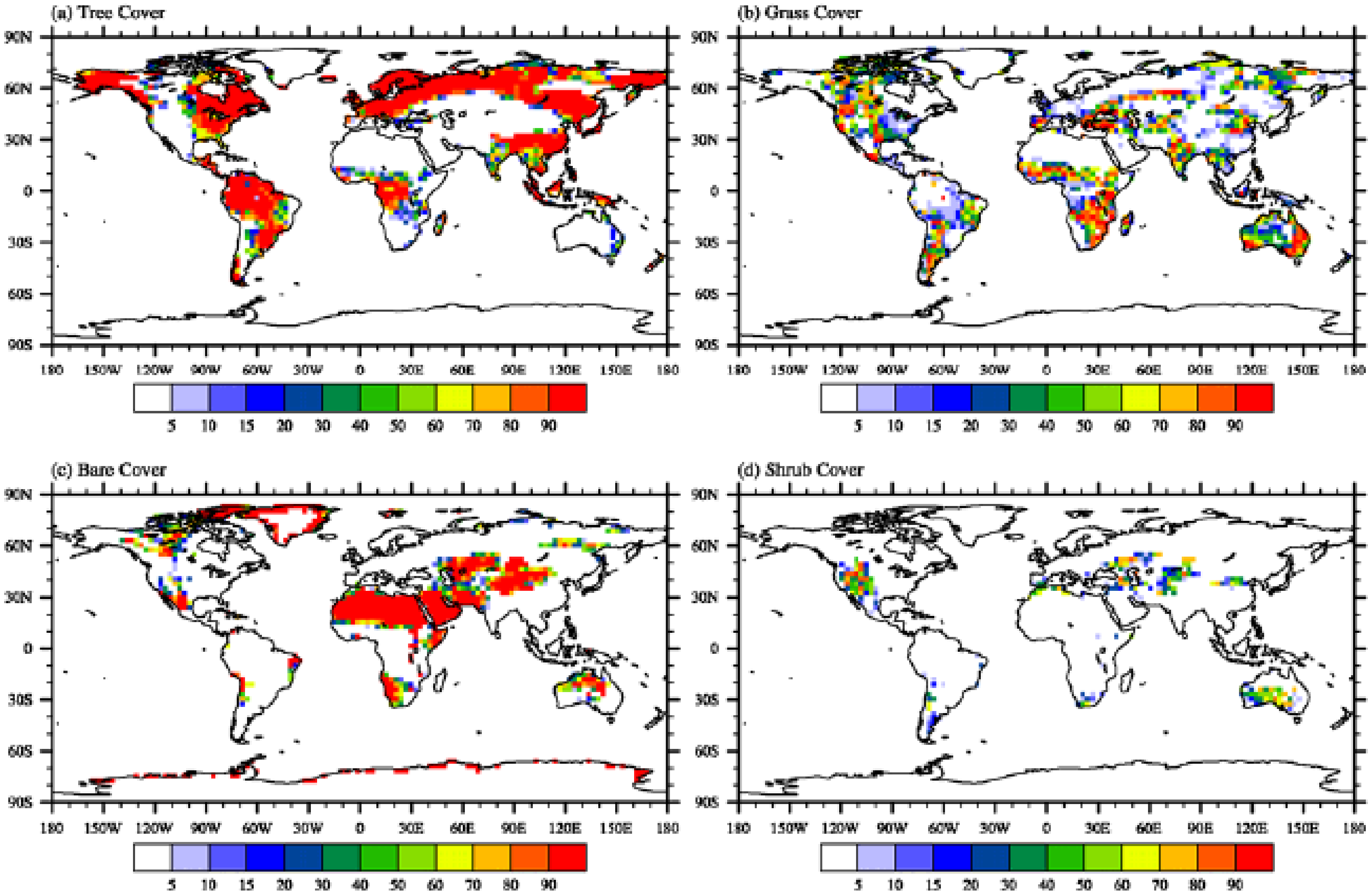
Shrub distribution (Zeng *et al.* 2008)



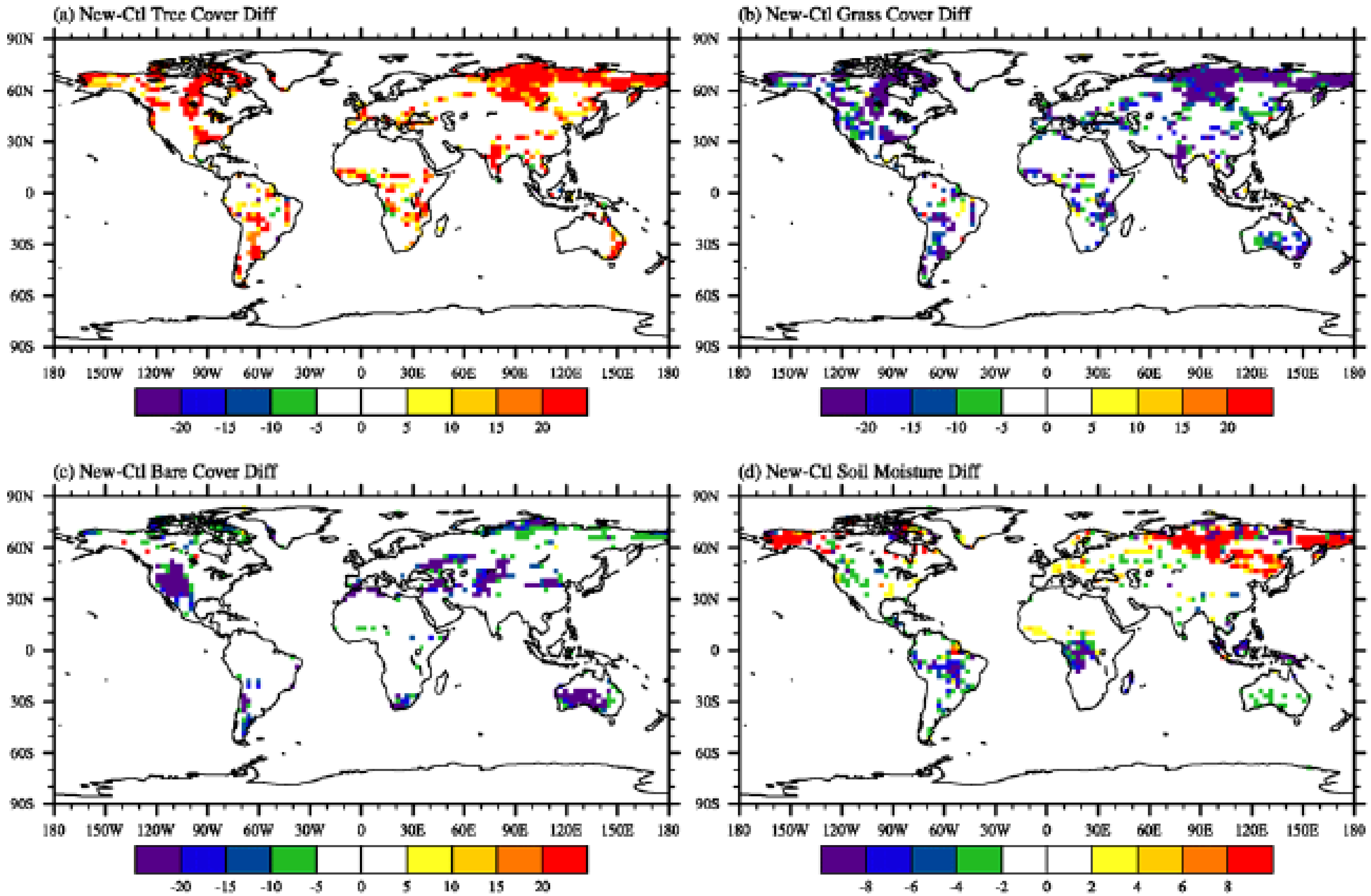


Exclusion of Dynamic Global Vegetation Model (DGVM) and associated carbon cycle is recognized as one of the main deficiencies of IPCC AR4 model simulations. Most of the existing DGVMs do not include shrubs or do not effectively distinguish shrubs from grasses. For instance, shrubs cannot survive in the NCAR DGVM.

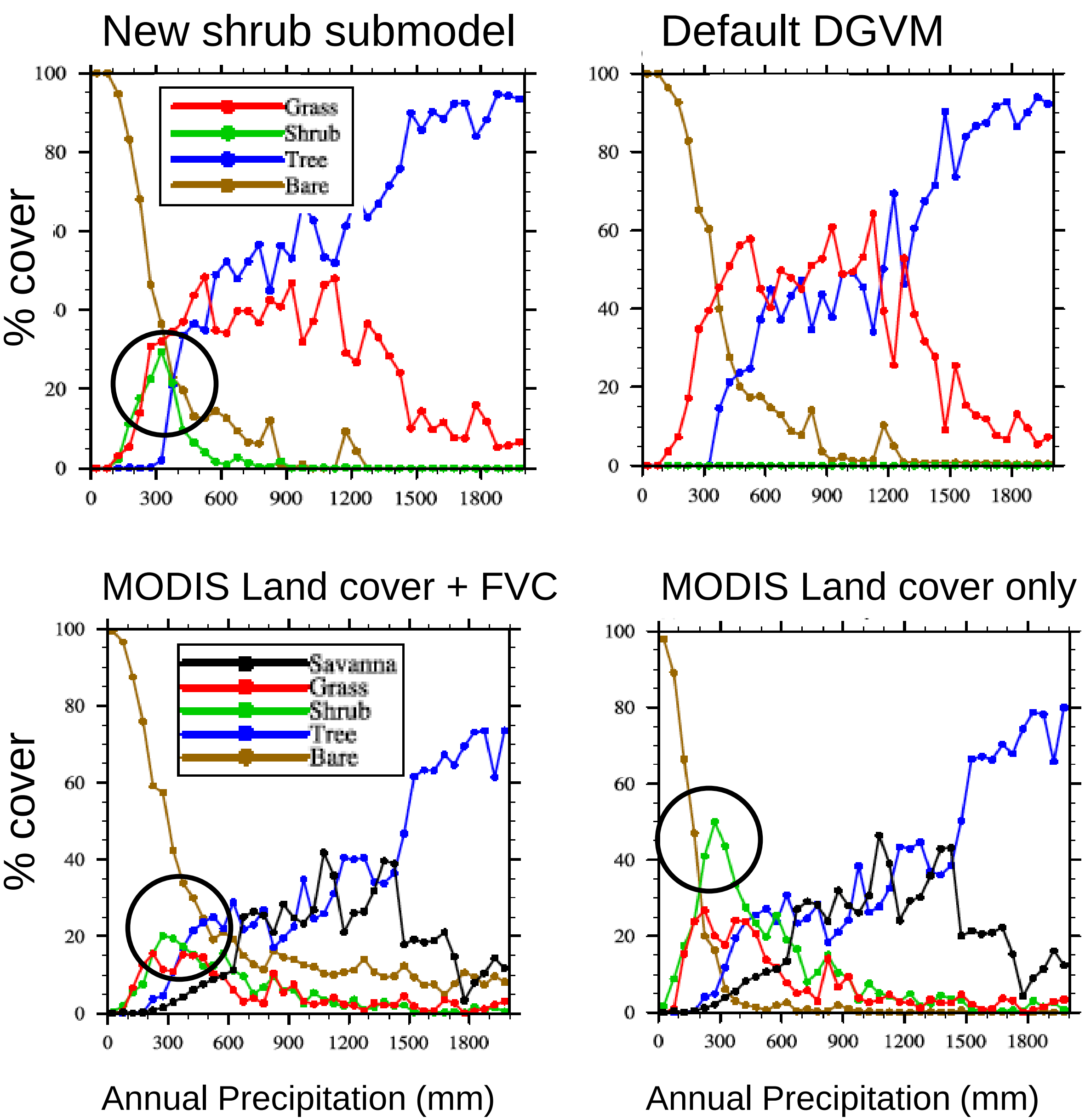
New shrub submodel allows for the global competition of trees, grasses, and shrubs in the NCAR DGVM. Global distribution after 400 yr simulation agrees with MODIS data.



Shrubs grow primarily by **reducing the bare soil coverage** (panel c) and, to a lesser degree, by decreasing the grass coverage; soil moisture is also changed (panel d).



MODEL EVALUATION



Crucial to use **MODIS land cover** product combined with fractional vegetation cover (**FVC**) data set for the DGVM model evaluation (particularly for shrubs).

Shrub coverage peak: around annual precipitation of **300 mm**; grass coverage peak: over a broad range from **400-1100 mm**; **tree** coverage peak: for **1500 mm or higher**.

With the MODIS land cover data **only**, shrub cover is estimated too high (shrub FVC usually < 100%).

Bringing together regional hydrometeorology using a regional climate model (WRF).

Improved model representation of land surface phenology by

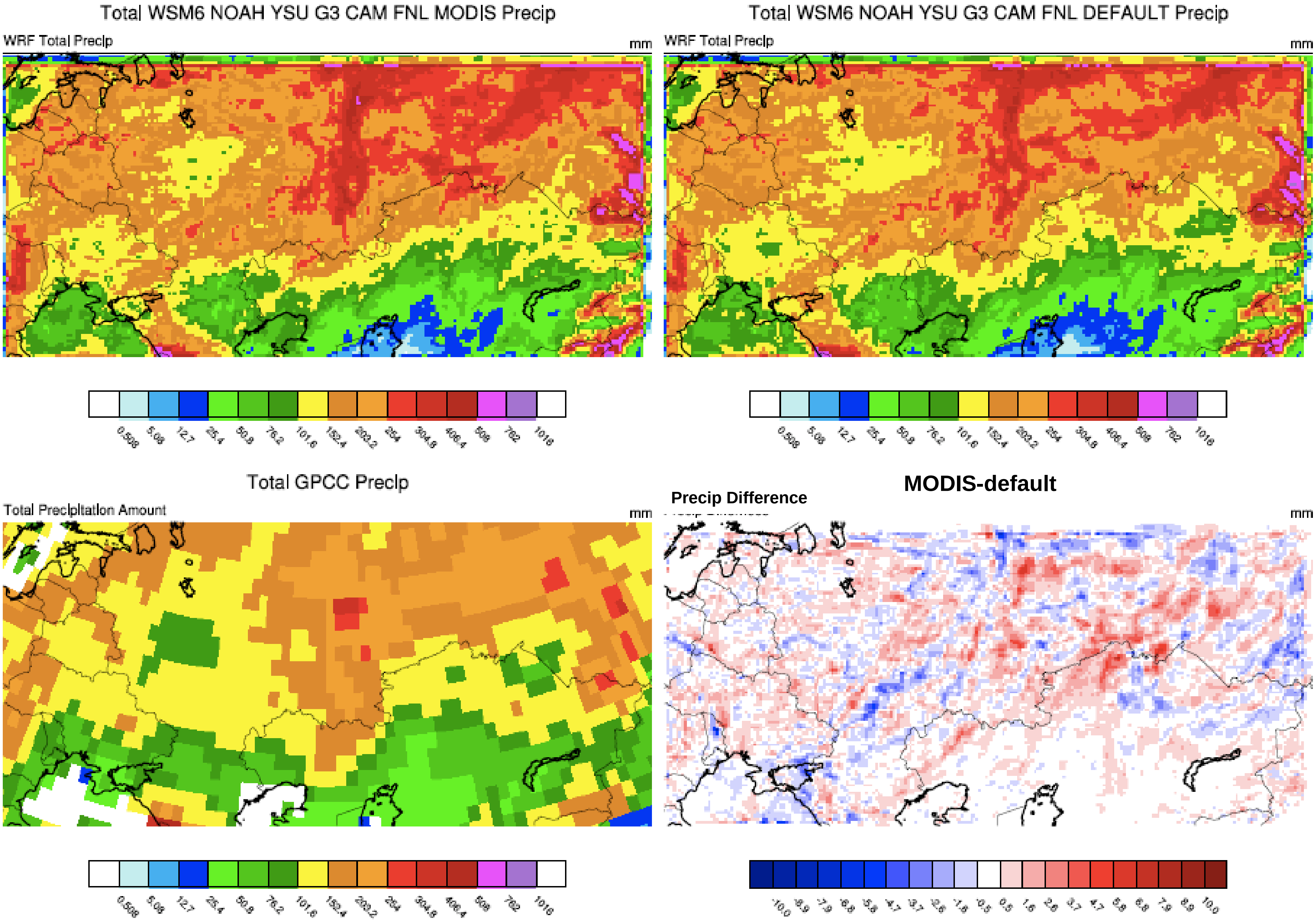
(1) substituting default FVC time series derived from MODIS NBAR NDVI, and
(2) doubling the update frequency to 2X/month.

Compare April-June precipitation fields for

(a) MODIS – Default, and
(b) 2007 – 2003 (high vs low wheat harvest)

Wetter Year

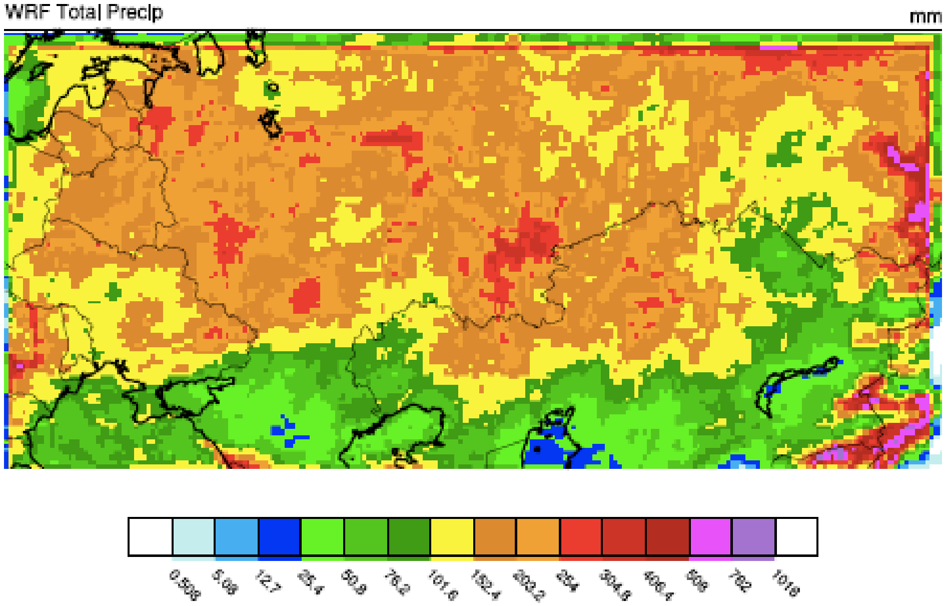
2007-04-01_00z to 2007-07-01_00z



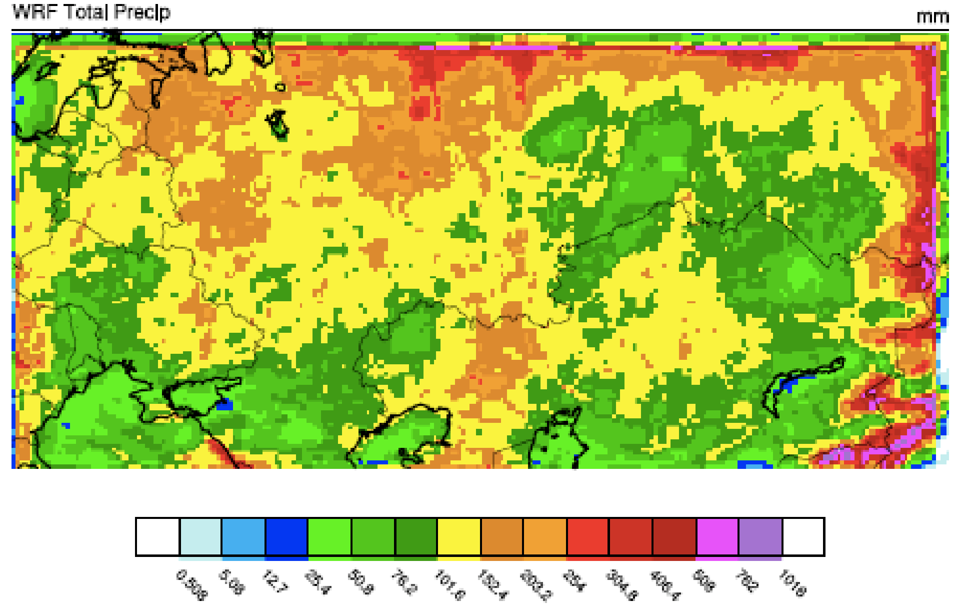
Drier Year

2003-04-01_00z to 2003-07-01_00z

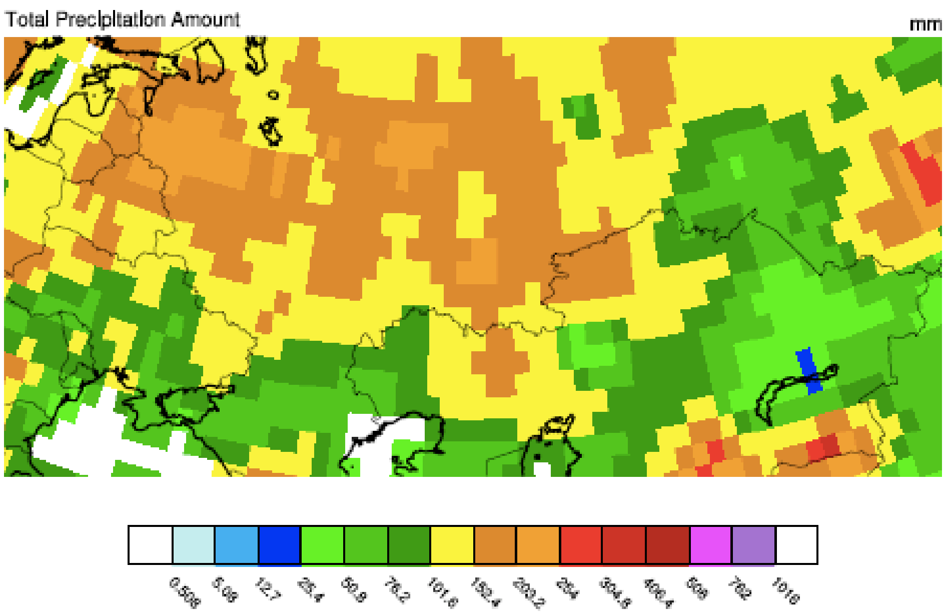
Total WSM6 NOAH YSU G3 CAM FNL MODIS Precip



Total WSM6 NOAH YSU G3 CAM FNL DEFAULT Precip

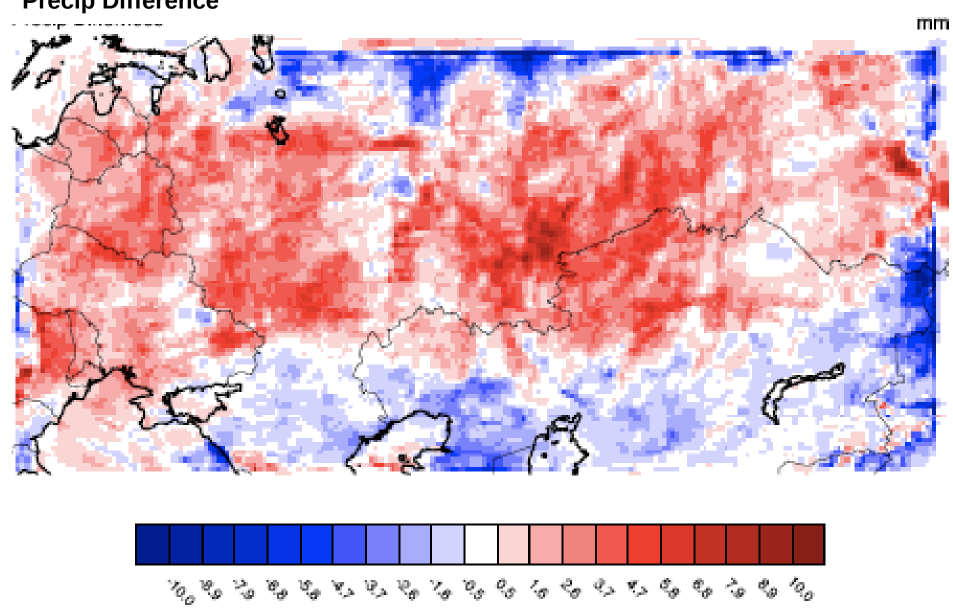


Total GPCC Precip



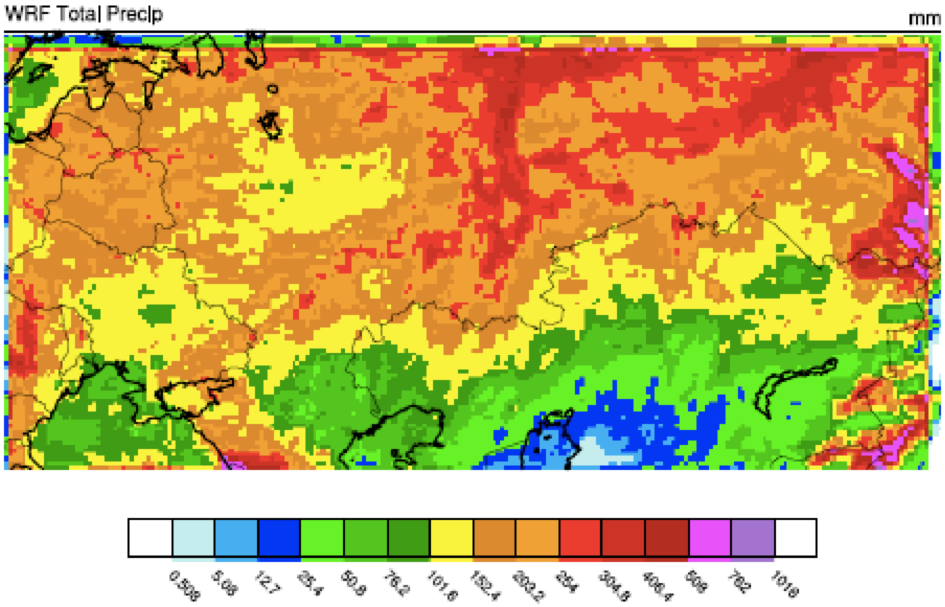
MODIS-default

Precip Difference

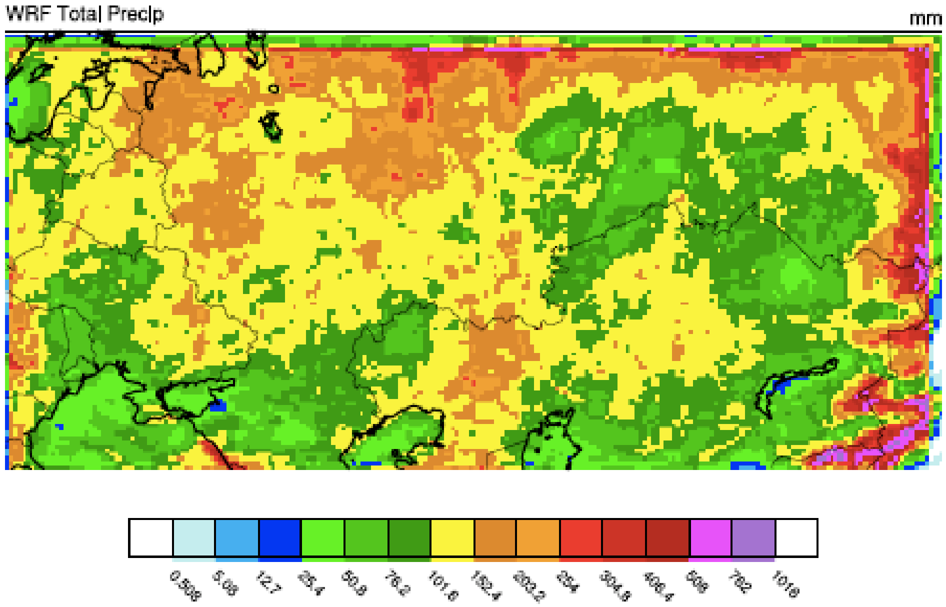


200x-04-01_00z to 200x-07-01_00z

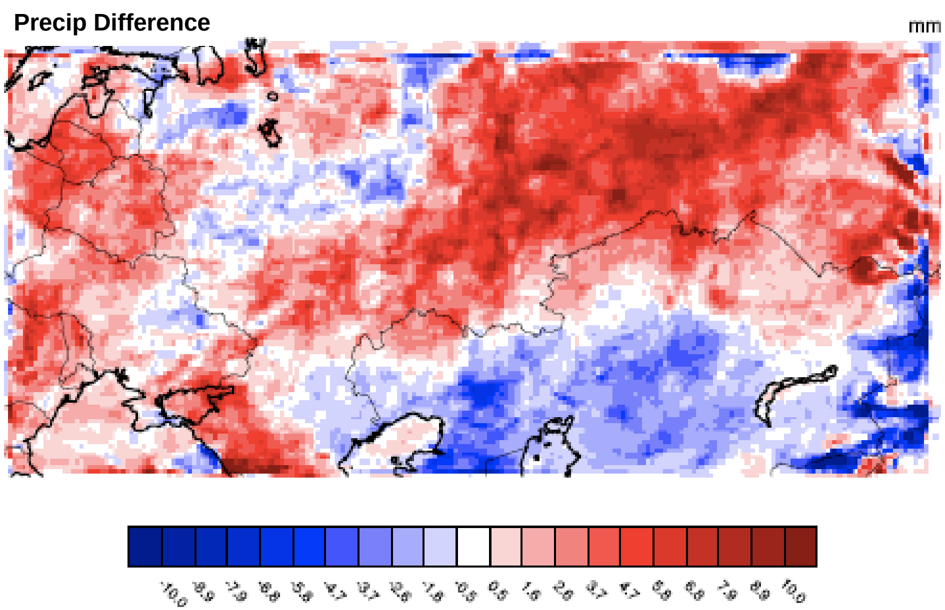
Total WSM6 NOAH YSU G3 CAM FNL DEFAULT 2007 Precip



Total WSM6 NOAH YSU G3 CAM FNL DEFAULT 2003 Precip

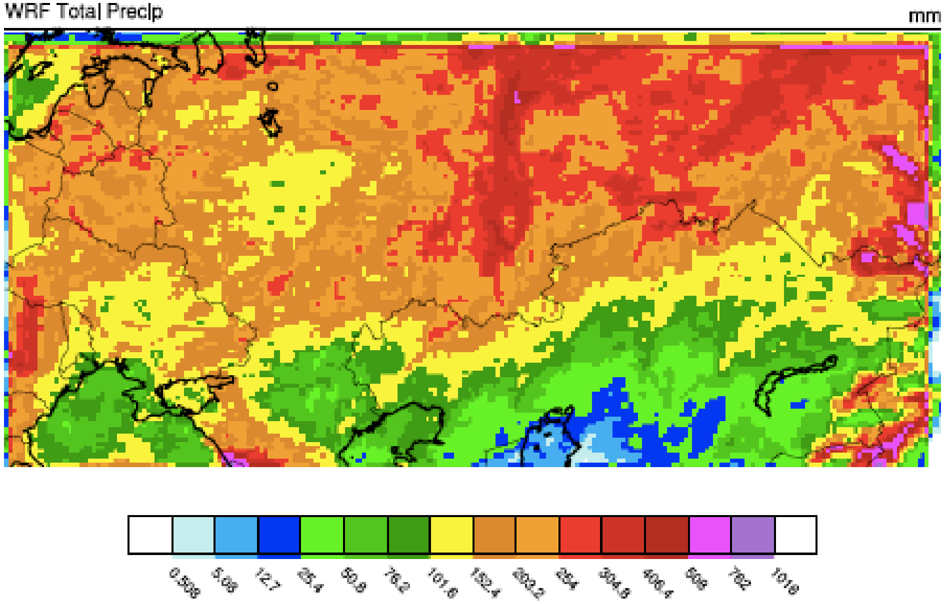


2007-2003 DEFAULT Precip

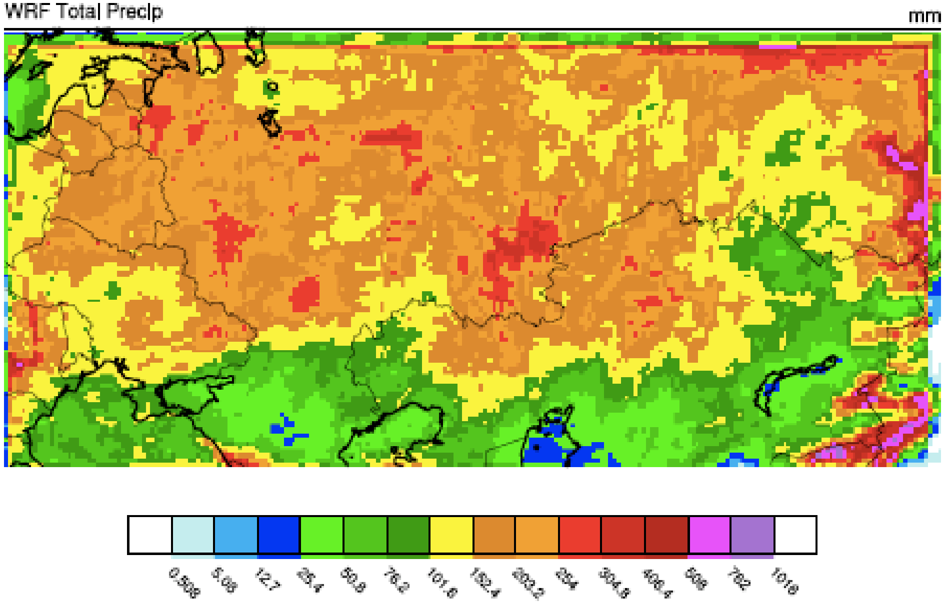


200x-04-01_00z to 200x-07-01_00z

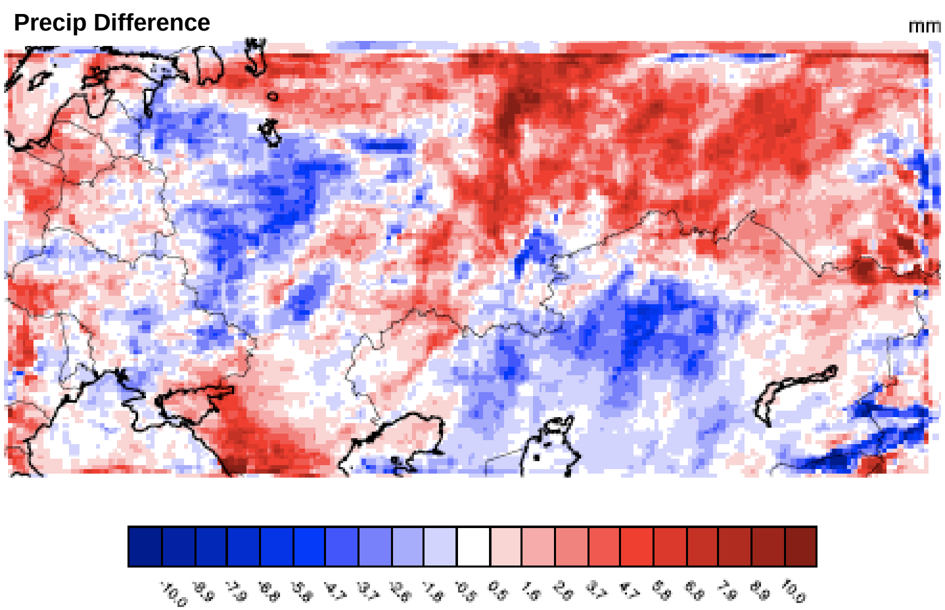
Total WSM6 NOAH YSU G3 CAM FNL MODIS 2007 Precip



Total WSM6 NOAH YSU G3 CAM FNL MODIS 2003 Precip



2007-2003 MODIS Precip



Comparing MODIS to Default FVC:

- Precipitation differences during crop establishment are more pronounced during drier than wetter year;
- Spatial pattern of precipitation has finer-grain with MODIS FVC

Comparing high (2007) and low (2003) wheat harvests:

- Default FVC yields more homogeneous precipitation fields.

To conclude…

Monitoring networks across Central Asia disintegrated during the early 1990s. Significant gaps remain, despite efforts to reconstitute data & networks.

Regional climate models are an appropriate tool for investigating LCLUC impacts on regional hydrology. However, their use assumes sufficient independent data to evaluate the simulations.

Changes in the agricultural sector have had predominant impact on regional hydrology during past two decades by changing ET magnitude and timing.

Observed trends in streamflow appear to be a climate signal; precipitation trends may result from a combination of climatic forcing and land use change.