Impacts of Land Cover and Land Use Change on Water and Energy Cycle of Caspian Sea Drainage Basin

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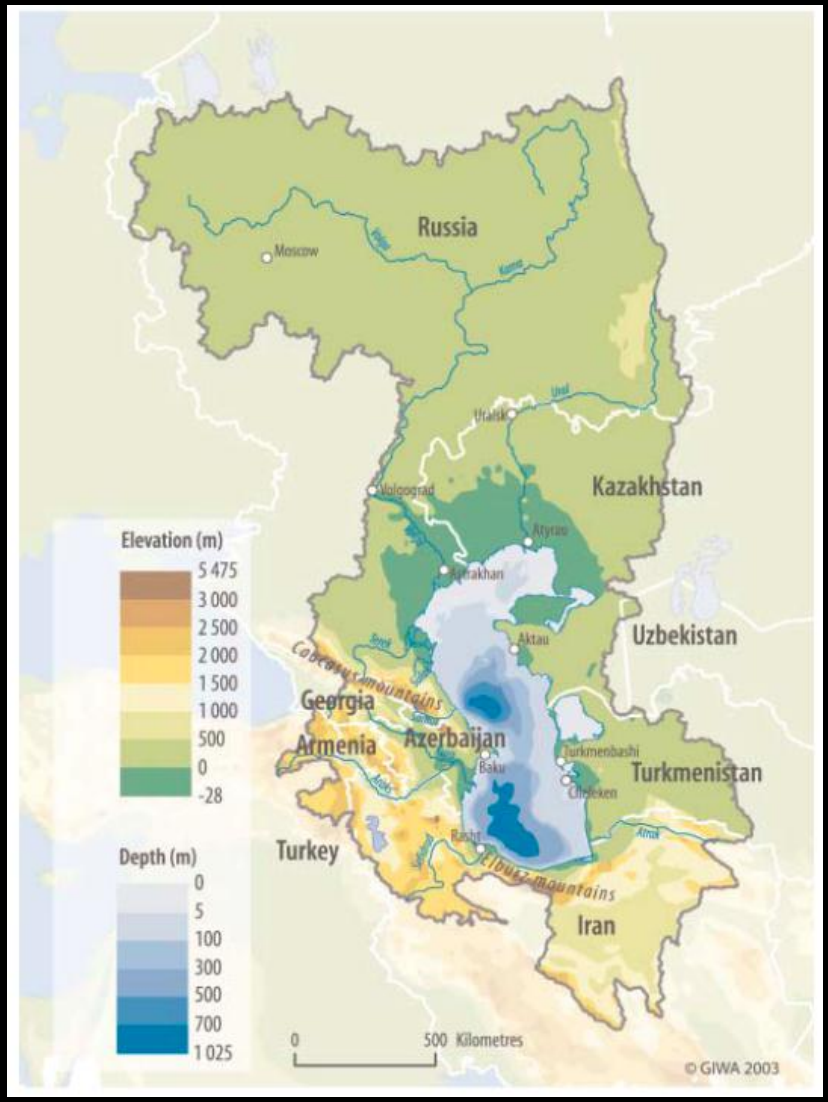
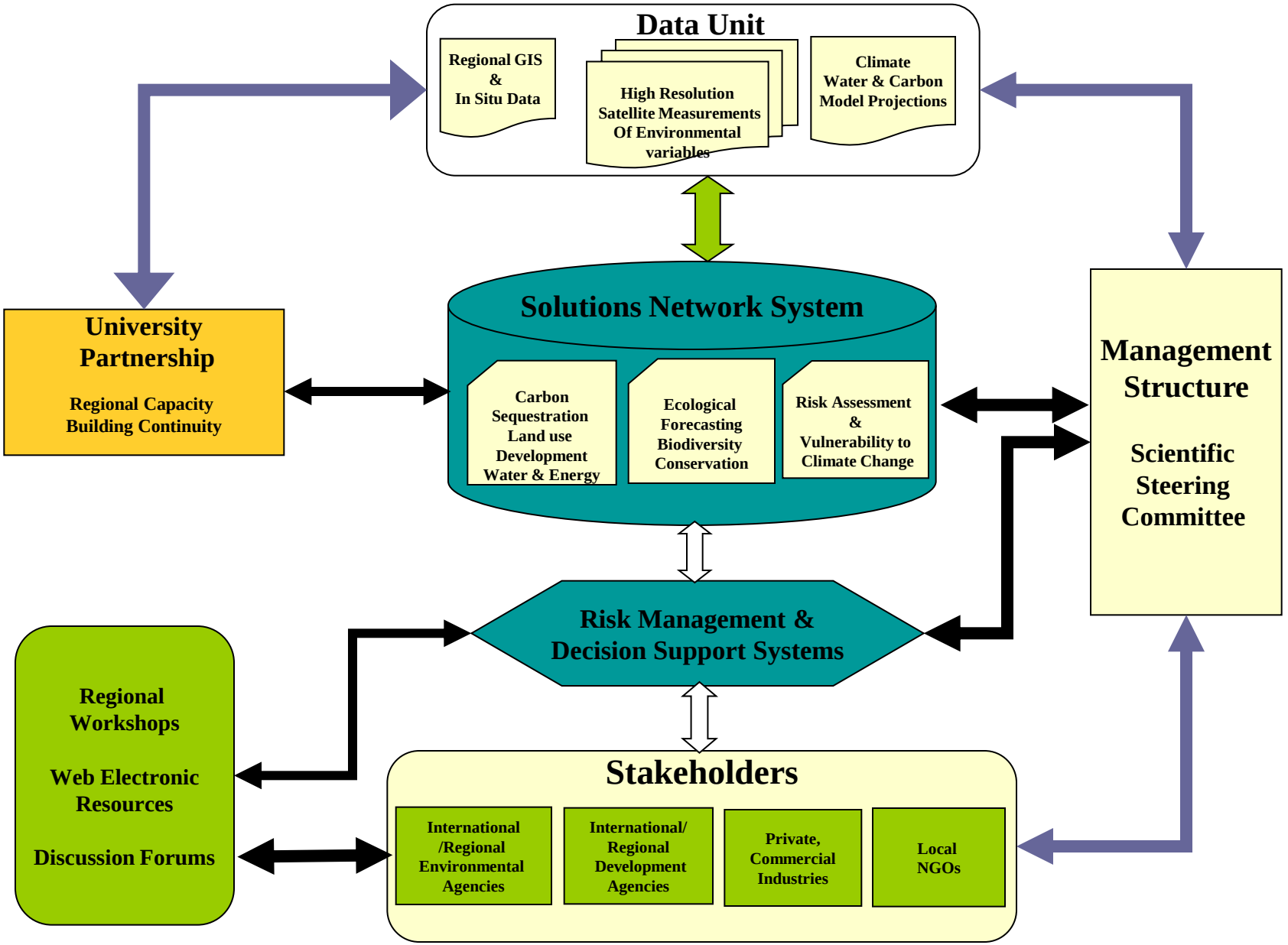


Caspian Sea Environment

Specific Science Questions:

1. What is the impact of human induced changes of land, sea and coast on Caspian Hydrological and Ecosystem Function?
2. How does regional and global climate change and variability impact the Caspian ecosystem?
3. How can regional development be sustained along with the Caspian conservation of resources and nature?

Scientific and Decision Support System for a Sustainable Environment in the Caspian Sea Region



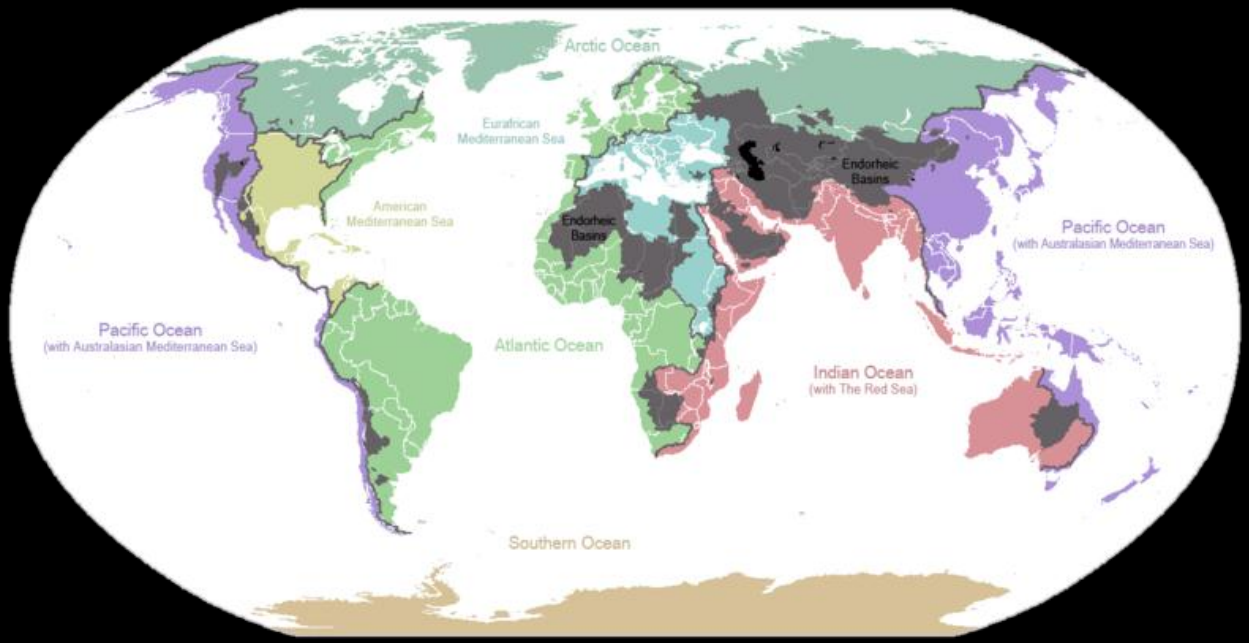
Land Use & Climate Interact

Purpose of the Pilot study

1. **Produce a land cover map of the region at MODIS scale resolution.**
2. **Develop land use change over two decades, 1990-2010 using a combination of MODIS and Landsat Data**
3. **Characterize changes and identify drivers of change in the region.**
4. **Develop a series of ecological and hydrological parameters to be used in regional distributed coupled hydrological models**

Caspian Sea Basin

Largest Endorheic Drainage Basin in the World



1. Largest land-locked body of water on earth (occupies the vast European and Asian territory between approx. 33-58 N latitude and 30-62 E longitude
2. Caspian drainage basin is ~ 3.5 Million km2 (world's largest watershed and annual runoff) with 130 rivers flowing into the sea with Volga contributes 80% of runoff.
3. Being a closed body and large basin, the system can filter high frequency water budget and is a good indicator of interdecadal and long term climate change
4. Being a closed system hydrological and biogeochemical processes are intimately linked (water, energy, resources) Any changes in land impacts the hydrology and ecosystem & vise versa.
5. Caspian has drastic sea level change due to climate and hydrological processes.

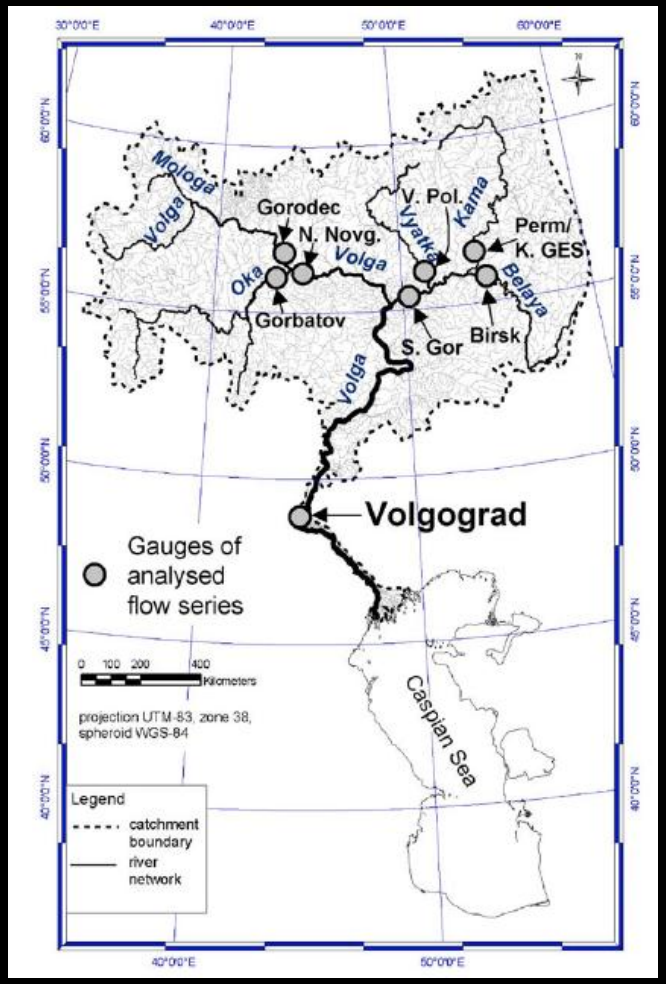
Caspian Ecosystems and Biodiversity

1. The unique geographical position of the Caspian Sea at the meridian border of the subcontinents of Europe and Asia and sublatitudinal borders of natural zones of steppe, deserts, and subtropics of the temperate zone of the Eastern Hemisphere .

2. The region has a large diversity of typical (zonal-subzonal) and ecotone (transitional) types of habitats both offshore and onshore.

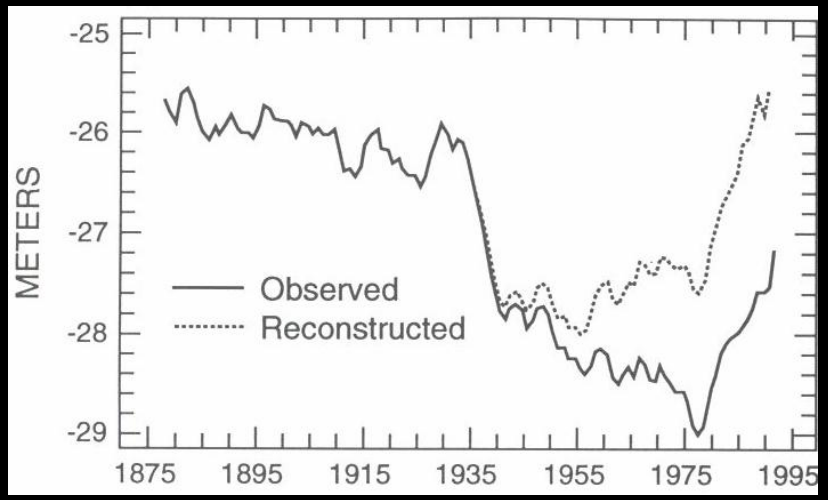
3. The Caspian lies at the crossroads of migration routes and it has been estimated that up to 10 million birds stop over in the region each year in spring and autumn.

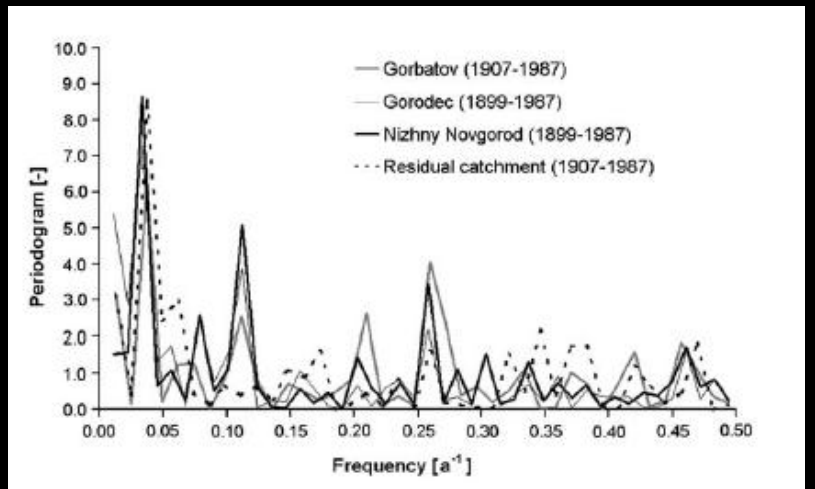
Hydrological Cycle of Caspian Basin



Temperature, Salinity, Evaporative Rate, Kara Bogaz Lake Fluctuations, River runoff and Caspian Bathymetry and warming & cooling cycle, Climate

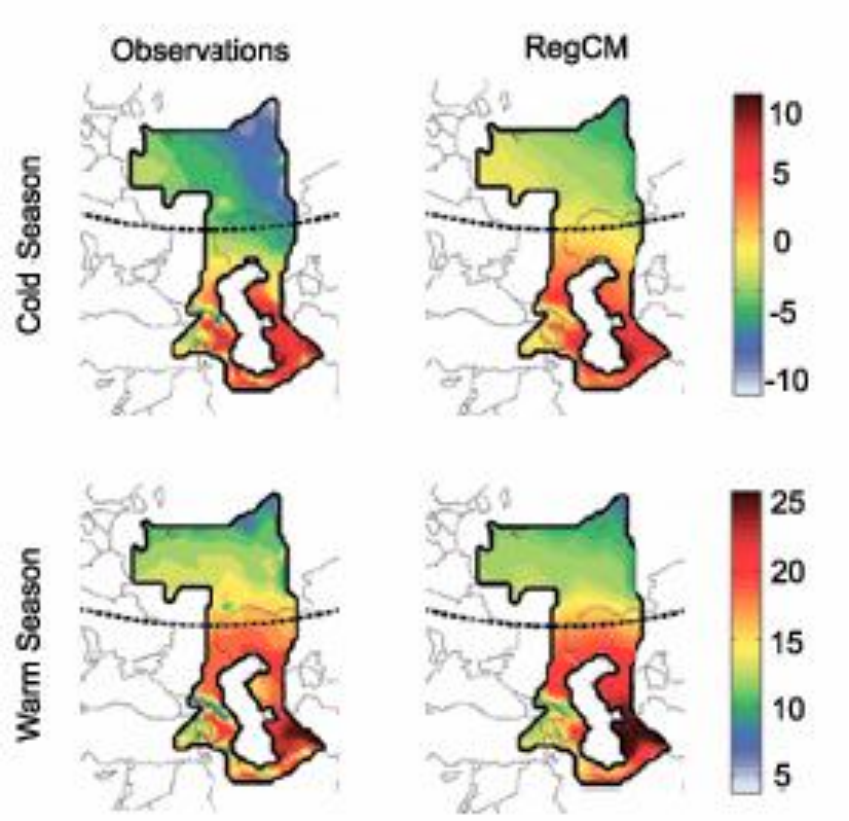
Oscillation of water flow of Volga River Basin and Changes of Caspian Sea Level Dominate the Hydrology of Basin



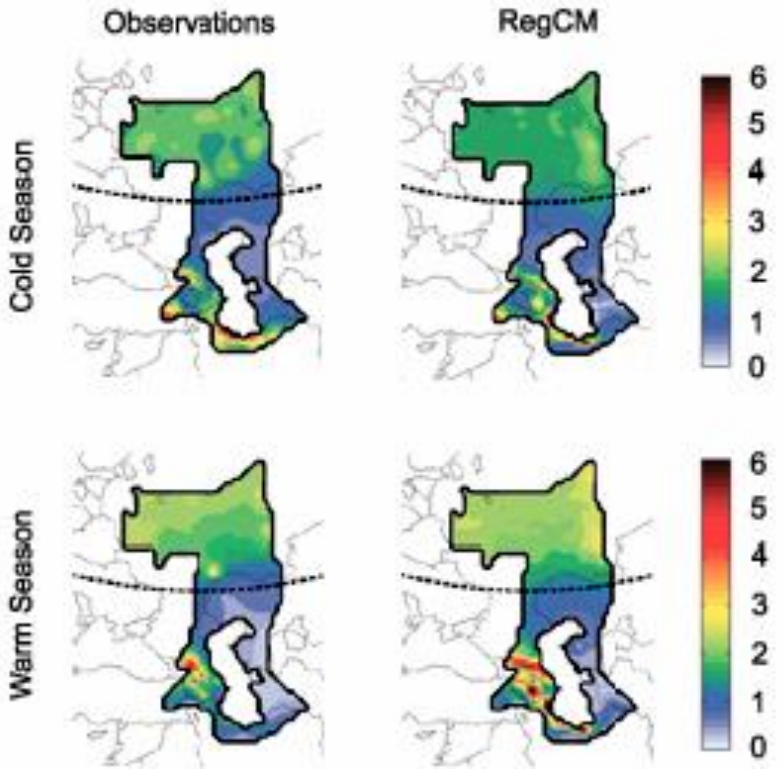


Climate Variations Across the Basin

Surface Temperature (°C)
1950—1990 Climatology



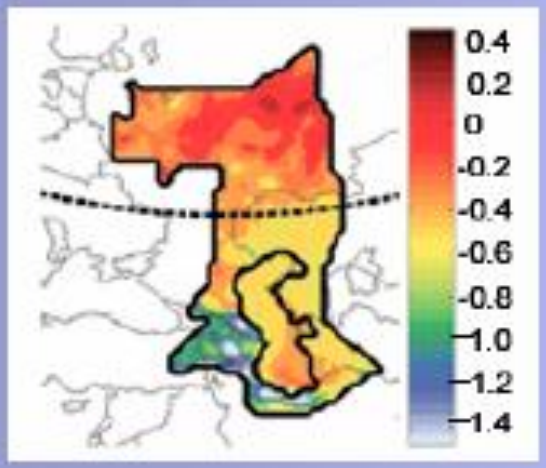
Precipitation (mm day^{-1})
1950—1990 Climatology



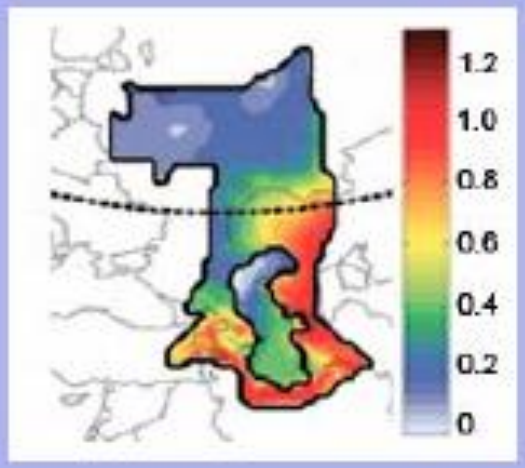
Post-1977 rise climatology **minus** Pre-1977 rise climatology (annual averages)

Elguindi and Gieorgi, 2006)

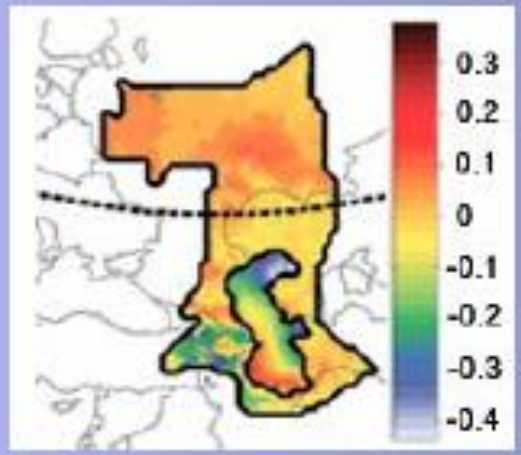
Precipitation (mm day^{-1})



Temperature (°C)



Evaporation (mm day^{-1})

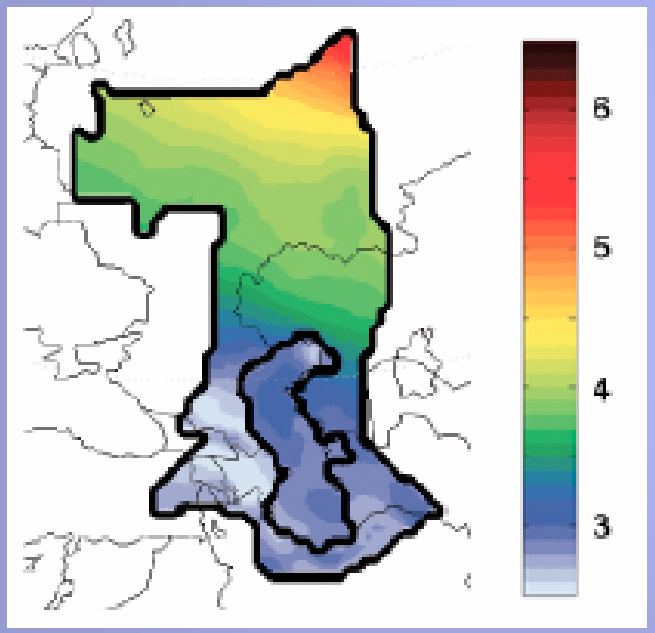


The CSL rise after 1977 was due to changes in the climate during the warm season which led to increases in precip in the northern basin and decreases in evaporation over the sea, resulting in an increase in the overall surplus in the basin's water budget.

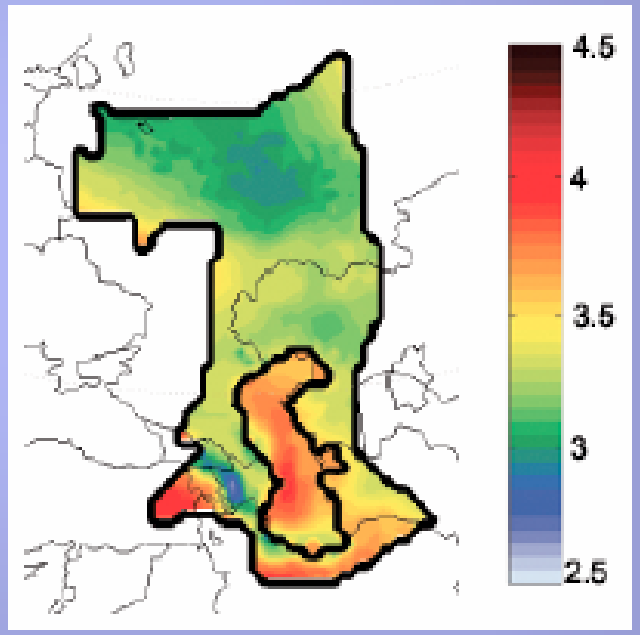
Temperature (°C)

Future Climate (2071—2100) **minus** Present Climate (1961—1990)

Cold Season (Oct-Mar)



Warm Season (Mar-Sept)



Precipitation (mm day^{-1})

Future Climate (2071—2100) **minus** Present Climate (1961—1990)

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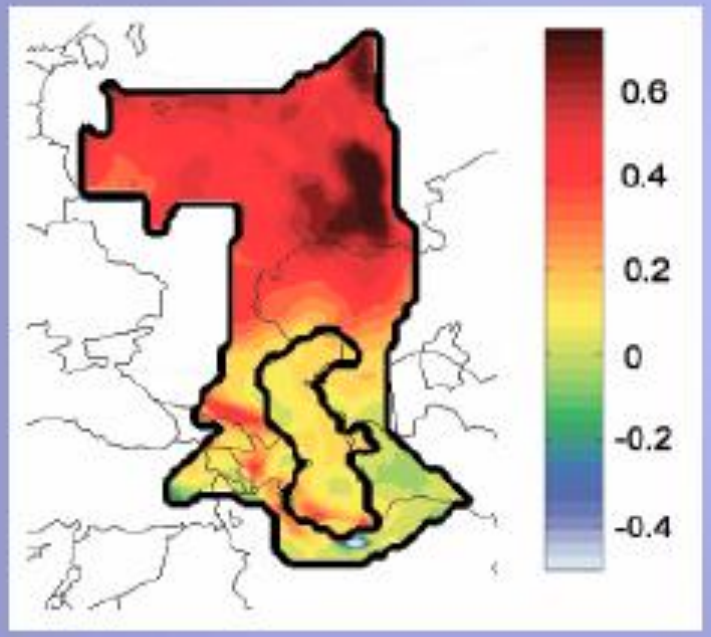
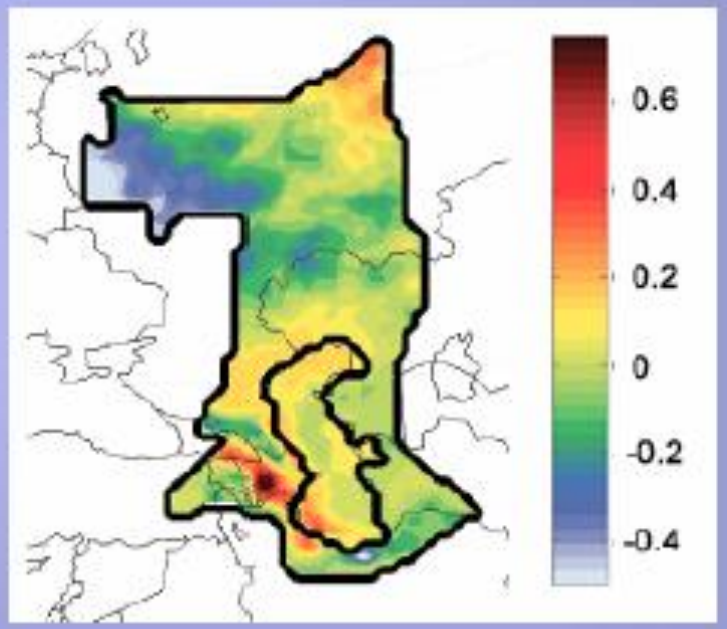
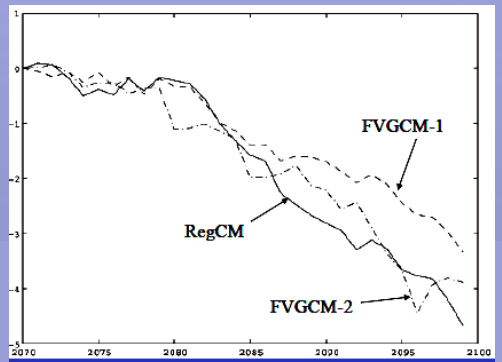


Warm Season (Mar-Sept)



- Precipitation increases in the northern basin, especially in the cold season- consistent with other studies-more NAO shift in storm tracks.
- However, there is a substantial decrease in the CSL mainly due to the increase in evaporation over the sea's surface



Caspian Environmental Changes

Construction

Immediate Issues

Pollution

Poaching and unsustainable fishing

Invasive species

Stream flow regulations

De-construction

Long Term Issues

Land cover & land use change

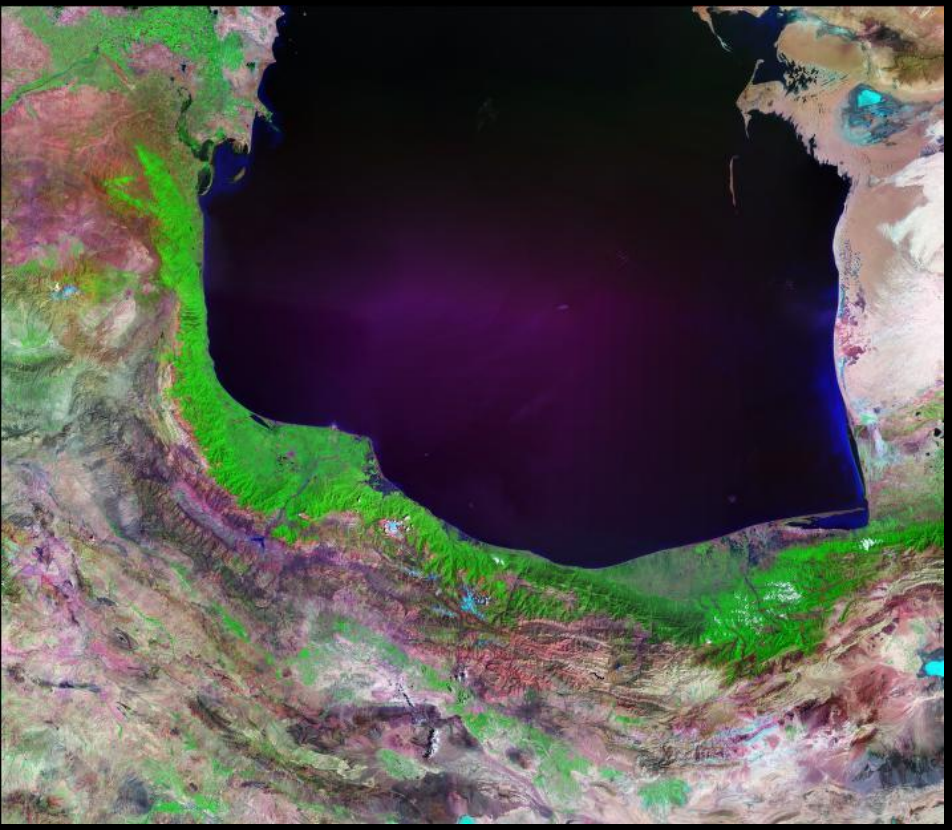
Biodiversity & ecosystem degradation

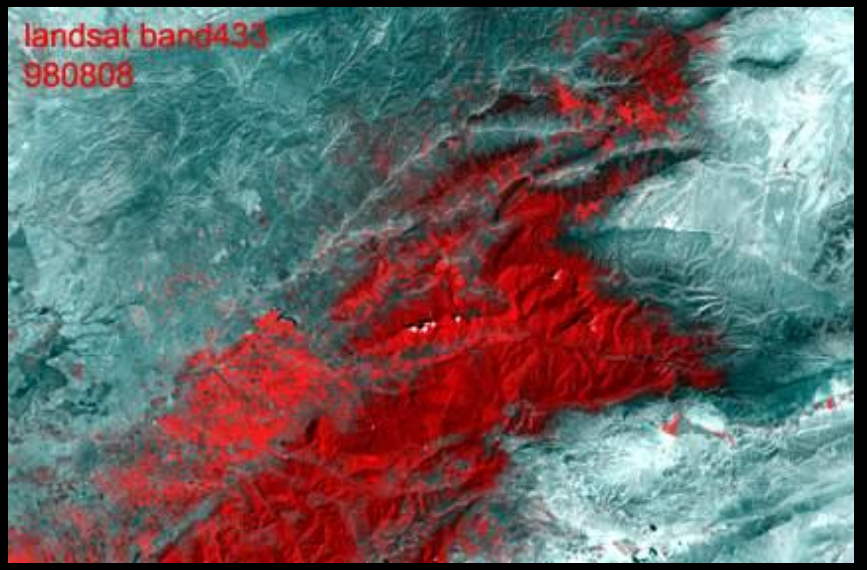
Climate change and variability

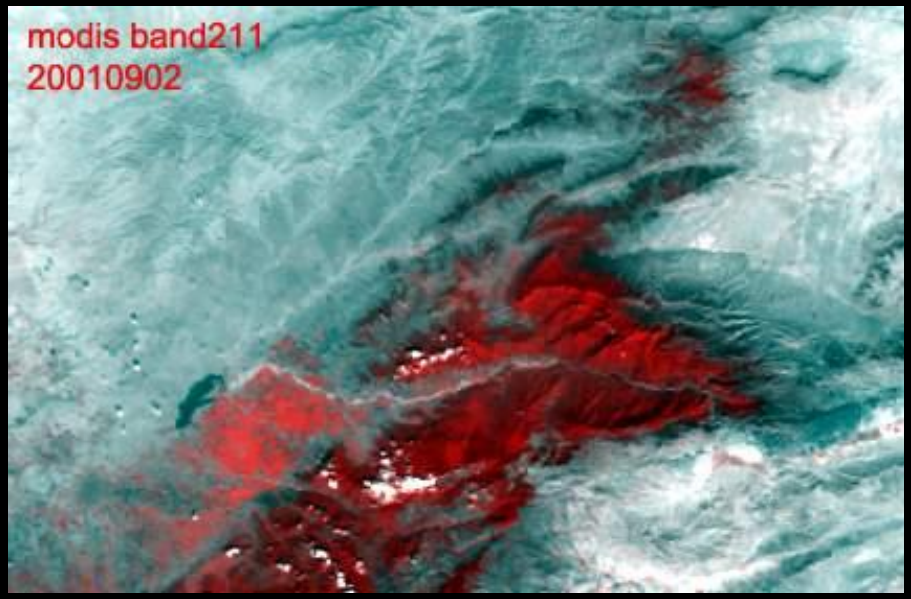
Water and energy cycle

Biogeochemical cycle

Deforestation and Agricultural Development



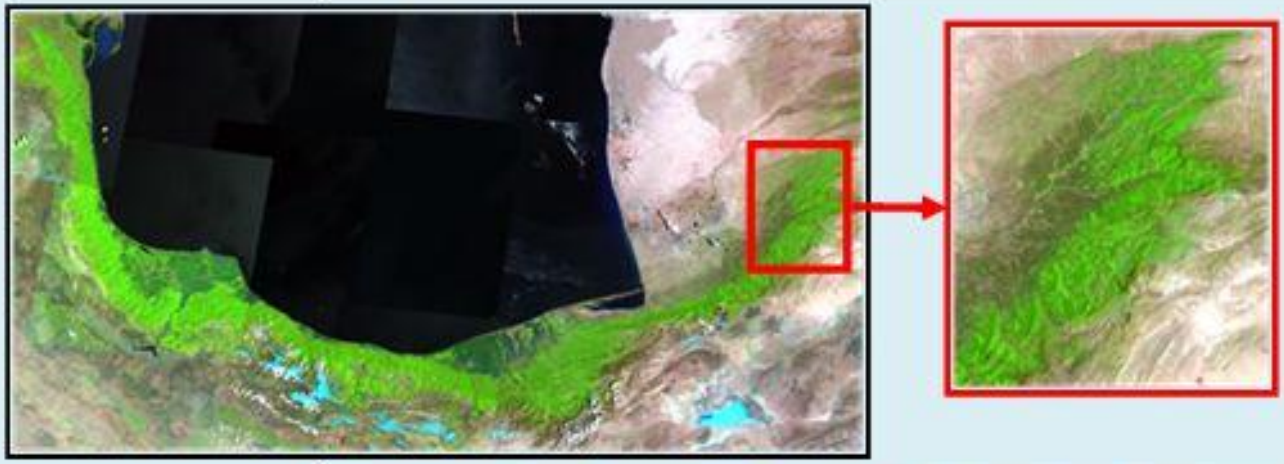




- **Caspian forest in 1963 was 3,420,487 ha . In 1980, total area reduced to 1,900,000 ha, Current estimate is 1,** 800,000 hectares
- **975,000 cubic meters of forests of Gilan are burnt Every year**
- **Average biomass reduction frm 300 tons/ha to 100 tons/ha**
- **Government movement of 6000 forest dweller families to outside forests (5-year plan 1997-2001)**
- **Recent development plans by real estate sector.**

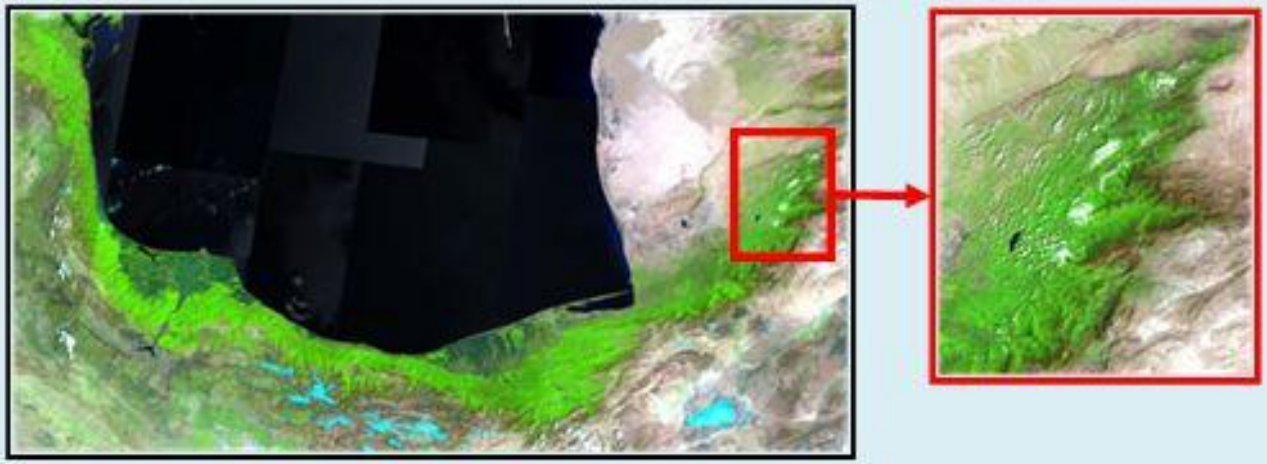
3. Deforestation of the Caspian Forest

Caspian Sea Forest Belt in the 1990s (LandSat TM, band 543)



- *Caspian forest in 1963 was 3,420,487 ha. In 1980, total area reduced to 1,900,000 ha, Current estimate is 1,,800,000 hectares*

Caspian Sea Forest Belt in the 2000s (LandSat ETM^{+}, band 543)



- *975,000 cubic meters of forests of Gilan are burnt every year.*
- *Average biomass reduction from 300 tons/ha to 100 tons/ha.*

Remote Sensing Data

LandSat TM, ETM imagery

NDVI

SRTM elevation data

Snapshots from GOOGLE EARTH
Spatial resolution: ≈5 meter

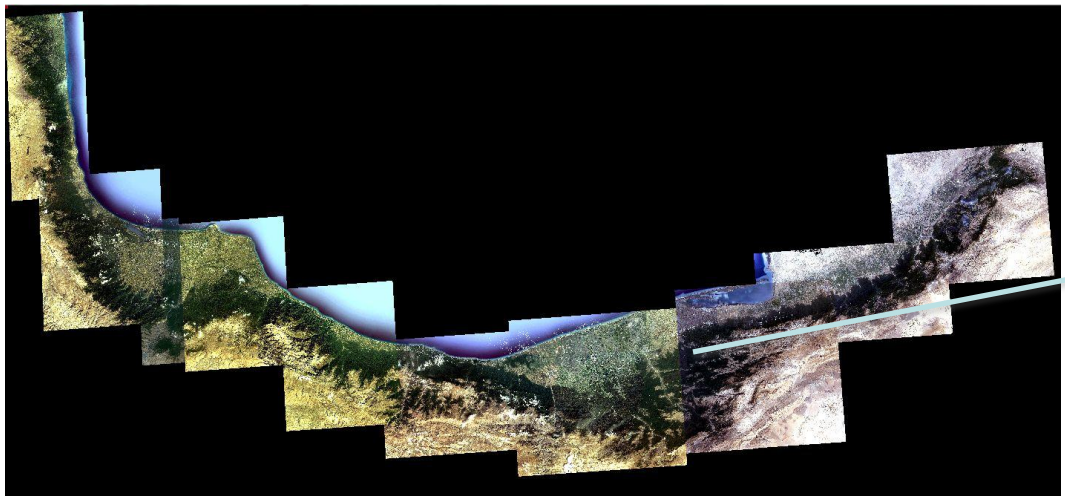


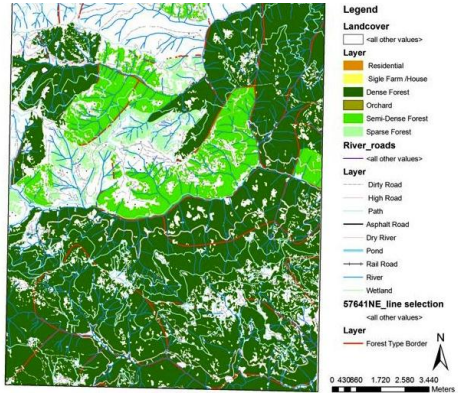
Image Classification & Change Detection

Image Segmentation & Clustering

Supervised Maximum Likelihood

Decision Rule Classifer & class combination

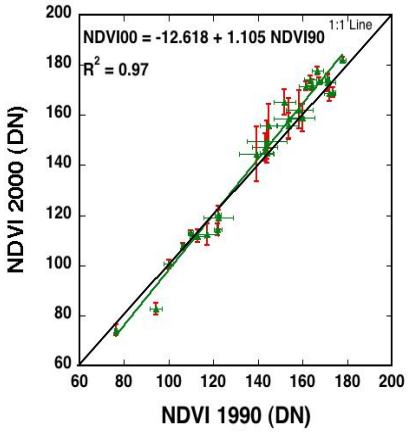
Validation using Google Earth data, field observations, forest ministry GIS layers

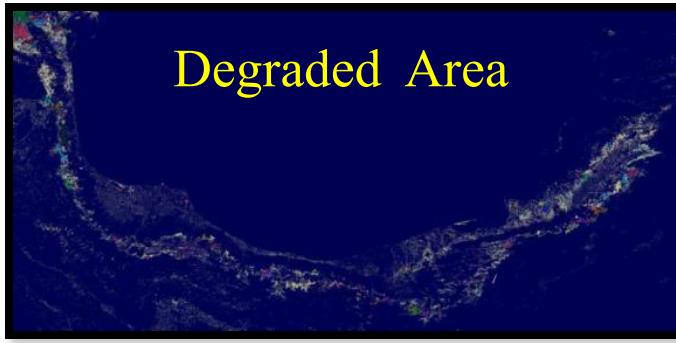


Change detection by class comparison

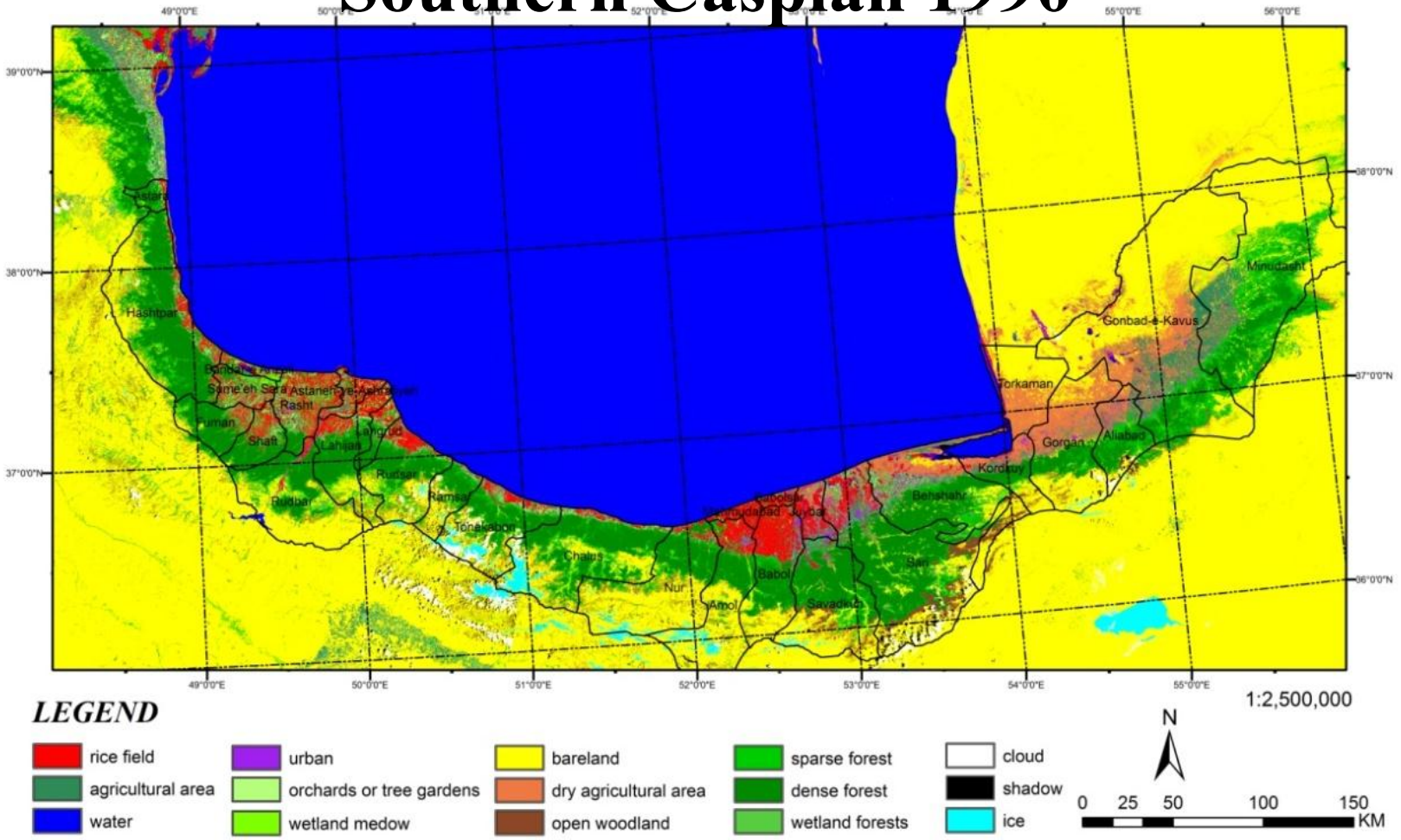
Change detection using band ratio

$$\frac{NDVI_{2000} - NDVI_{1990}}{NDVI_{2000} + NDVI_{1990}}$$



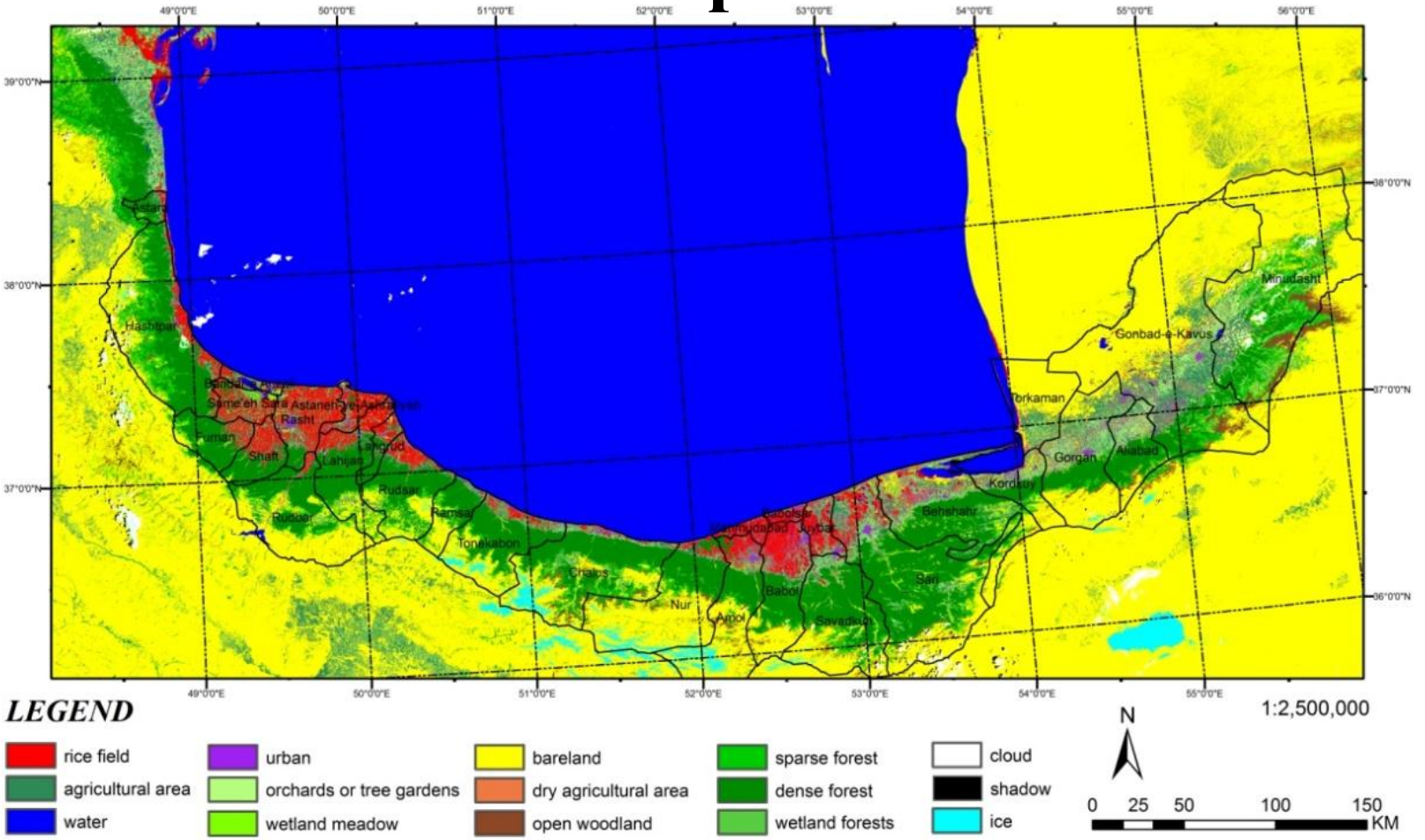


Land Cover Classification
Southern Caspian 1990



Classification and major classes distribution of Northern Iran 1990: rice field 4,258.8558 km² (1.63%), agricultural area: 5,620.2894 km² (2.15%), dry agricultural area: 5,364.1773 km² (2.06%), water: 106,643.6136 km² (40.85%), bare land 103,675.4568 km² (39.71%), urban area 861.9282 km² (0.33%), open woodland 2,871.3330 km² (1.10%), sparse forest 8,792.3736 km² (3.37%), and dense forest 17,154.5850 km² (6.57%).

Land Cover Classification
Southern Caspian 2000



Classification and major classes distribution of Northern Iran 2000: rice field 4,381.4295 km² (1.678%), agricultural area: 10,176.3693 km² (3.898%), dry agricultural area: 734.9850 km² (0.282%), water: 107,205.1092 km² (41.063%), bare land 101,654.31 km² (38.936%), urban area 1,268.7291 km² (0.486%), open woodland 2,164.30 km² (0.83%), sparse forest 6,599.96 km² (2.53%), and dense forest 18,228.67 km² (6.98%).

Field Validation of Land Cover Maps

National Geographic Expedition

1. Revisit the expedition route of the German Naturalist Gmelin from 1770-1774
2. Document the environmental changes along the coastal region
3. Develop the concept of a book on environmental history of the region
5. Develop collaborative projects to study the Caspian Environment
6. Provide material for NGS documentary films and photo essays.

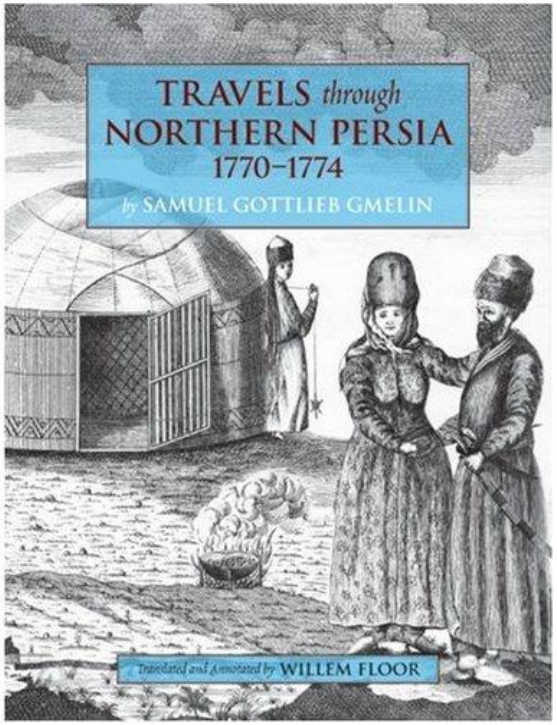
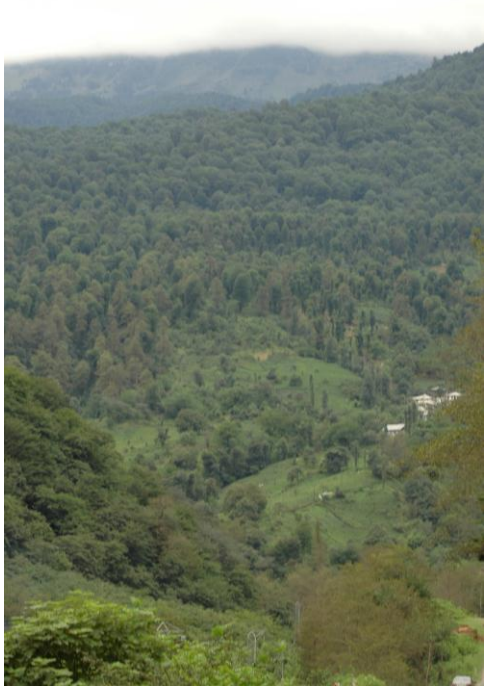
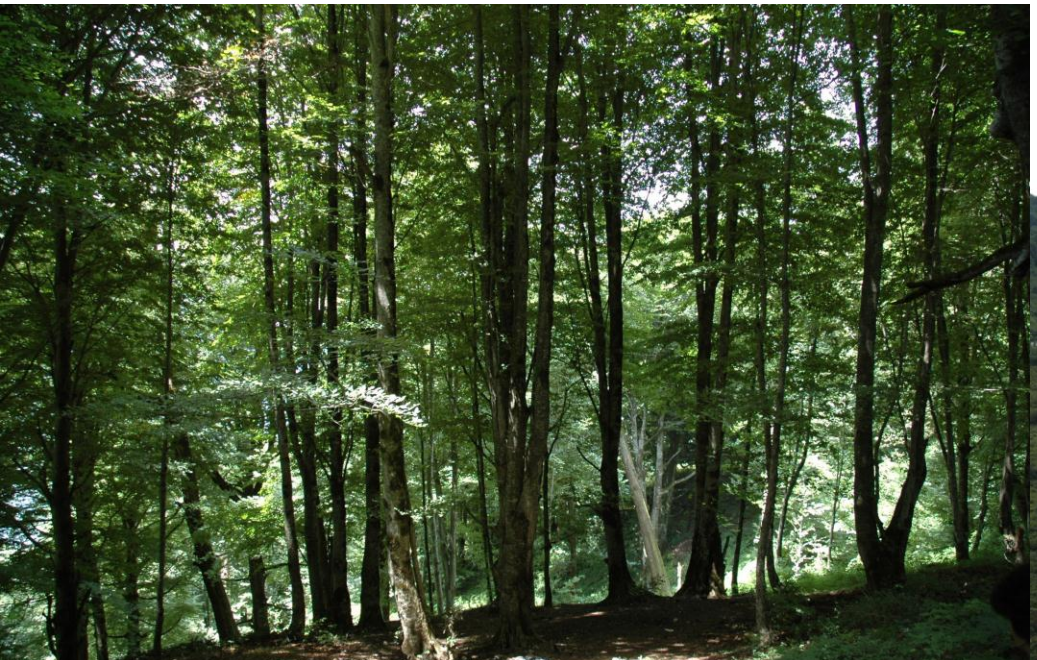


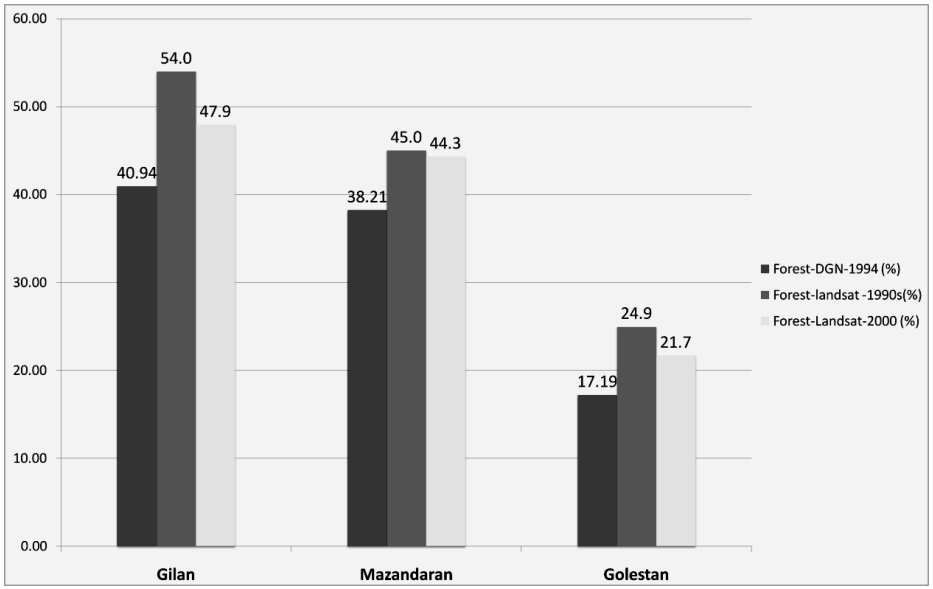
Fig. 7. Caspian Sea water area (by Rodionov, 1994).



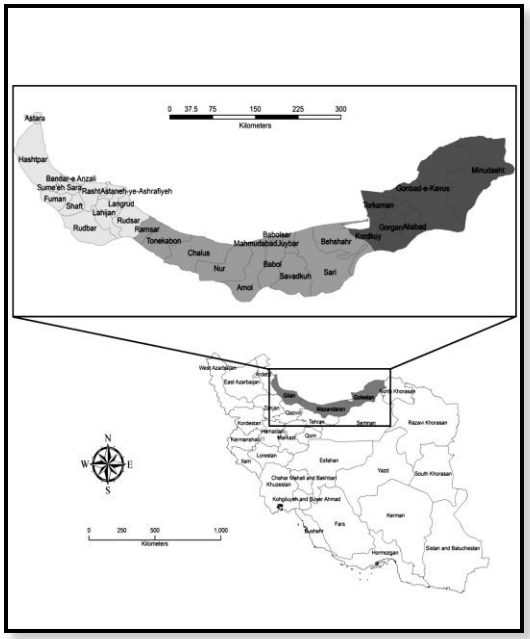
Measurements:
GPS
Land Cover
% Forest Cover
% Canopy Cover
Forest Composition
Tree Density



Change Detection Results



	Sparse Forest (km^2)	Dense Forest(km^2)	Open Woodland(km^2)	Wetland Forest(km^2)
Unclassified	0	0	0	0
rice field	291.52	29.15	0	0.69
agricultural area	242.43	158.65	0.52	1.39
water	4.18	0.69	0	0.1
bare land	122.98	14.7	227.76	0.11
dry agricultural area	1.02	0.59	0	0
woodland	25.26	34.09	8.12	0.03
urban	6.14	2.02	0	0.05
cloud	4.68	9.18	5.43	0
shadow	0.97	0.38	2.17	0.09
ice	1.16	0.19	1.44	0.01
sparse forest	550.55	417.39	104.47	0.89
dense forest	633.39	4534.84	25.89	1.75
orchards or tree gardens	108.89	54.38	0.47	1.39
wetland forests	2.39	4.84	0.04	12.6
wetland meadow	6.14	2.01	0.22	5.68
Class Total	2001.69	5263.1	376.53	24.78
Class Changes	1451.13	728.26	368.4	12.18
Image Difference	-665.65	82.71	-281.86	4.87



The total forest loss in the Caspian forest from 1990 to 2000 was 1718.67 km^2.

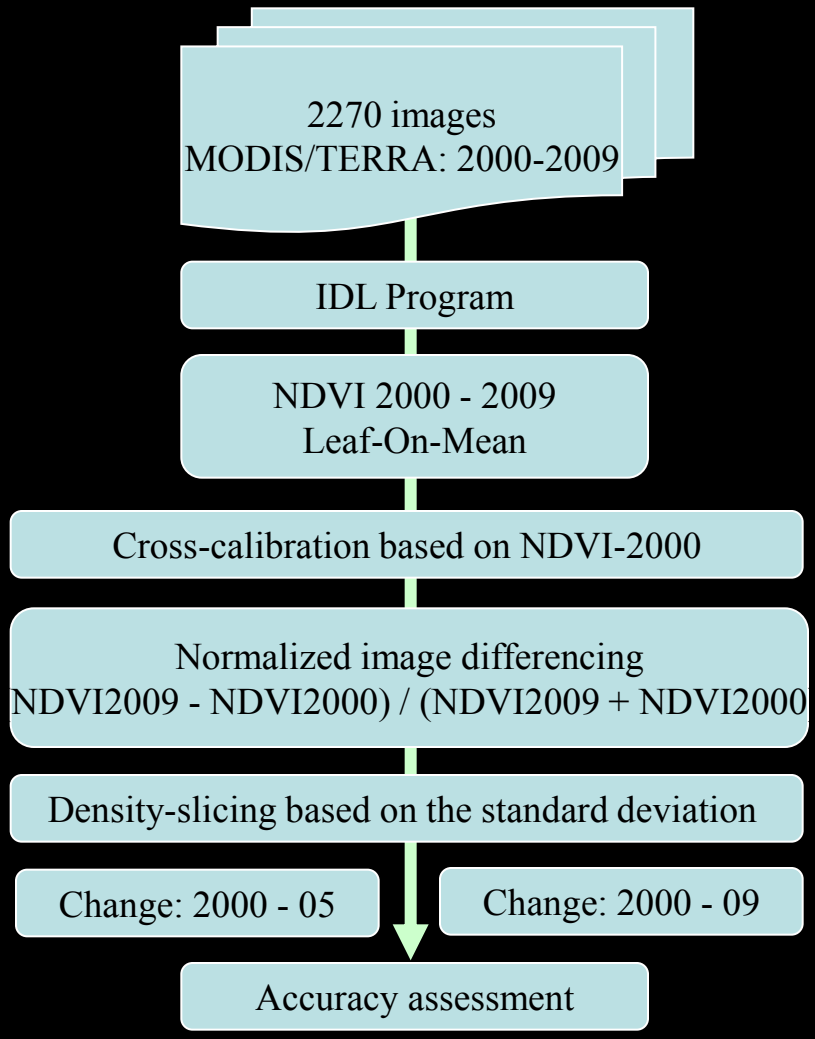
In general, the sparse forest areas mostly changed into bare land (554.43 km^2), agricultural area (551.94 km^2), open woodland (464.3 km^2), and orchards (349.6 km^2);

whereas agricultural area (363.39 km^2), open woodland (336.29 km^2), and orchards (257.17 km^2) consumed a large part of dense forest.

Despite this reduction, forest is still the major land cover type throughout the northern Iran administrative areas, although its share decreased sharply during the 1990s.

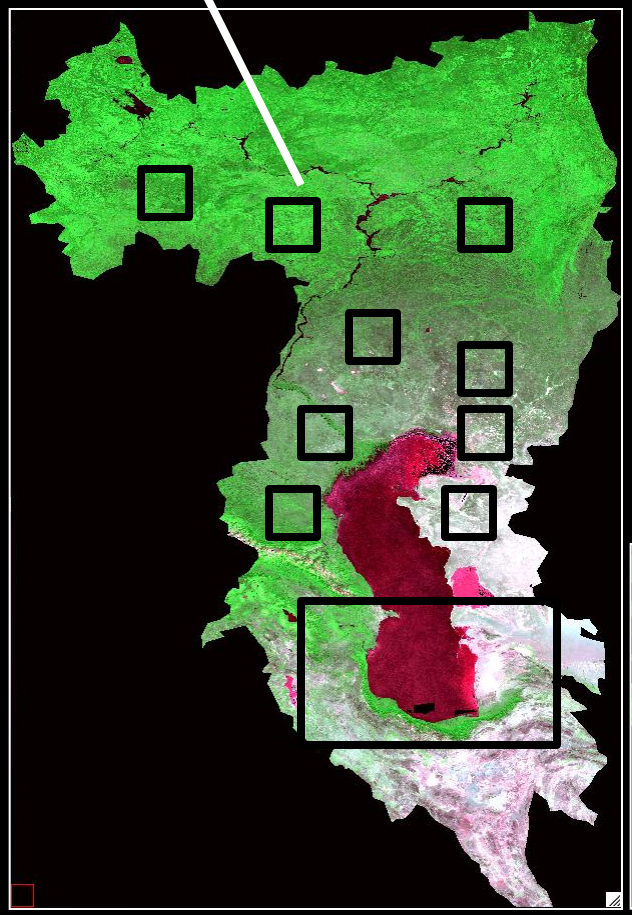
2000-2010 MODIS Change Detection Method

- Combining the 250 m 16-day composite NDVI and EVI and 500 m and 16-day composite surface reflectance data, to develop a set of cloud free seasonal data (including mean and average annual minimum and maximum) over the region.
- Analyzing the changes, using a normalized univariate image differencing on cross-calibrated vegetation indices (NDVI) for 2000, 2005 and 2009 seasonal means.
- Type and spatial accuracy assessment using samples of available Landsat, ASTER, and IKONOS imagery

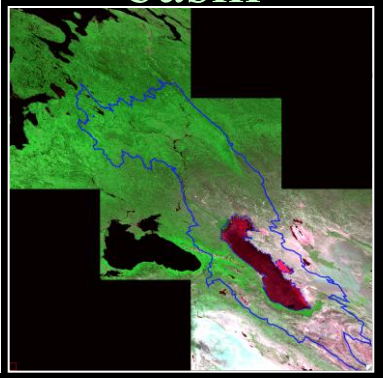


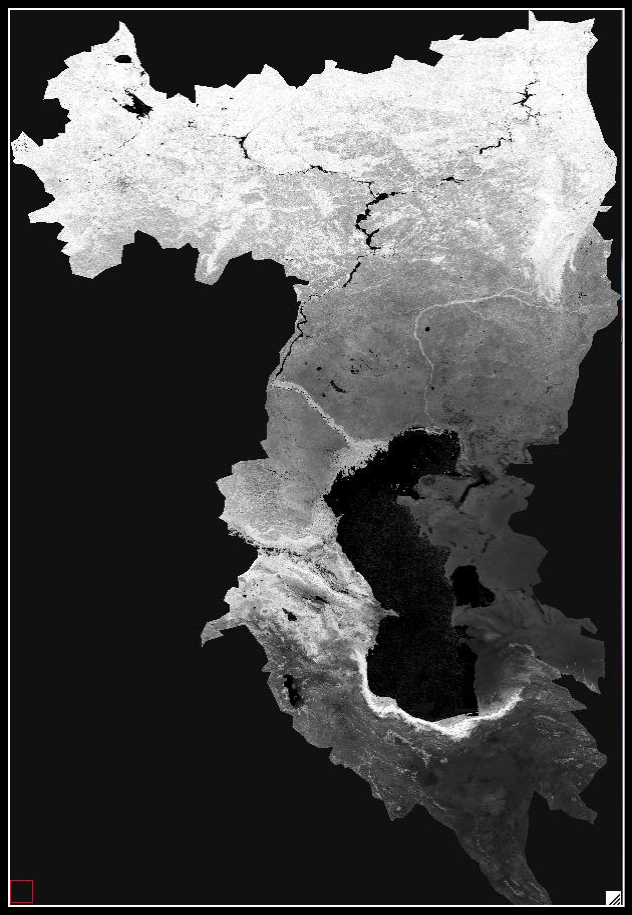
MODIS Data Analysis

Landsat Scenes



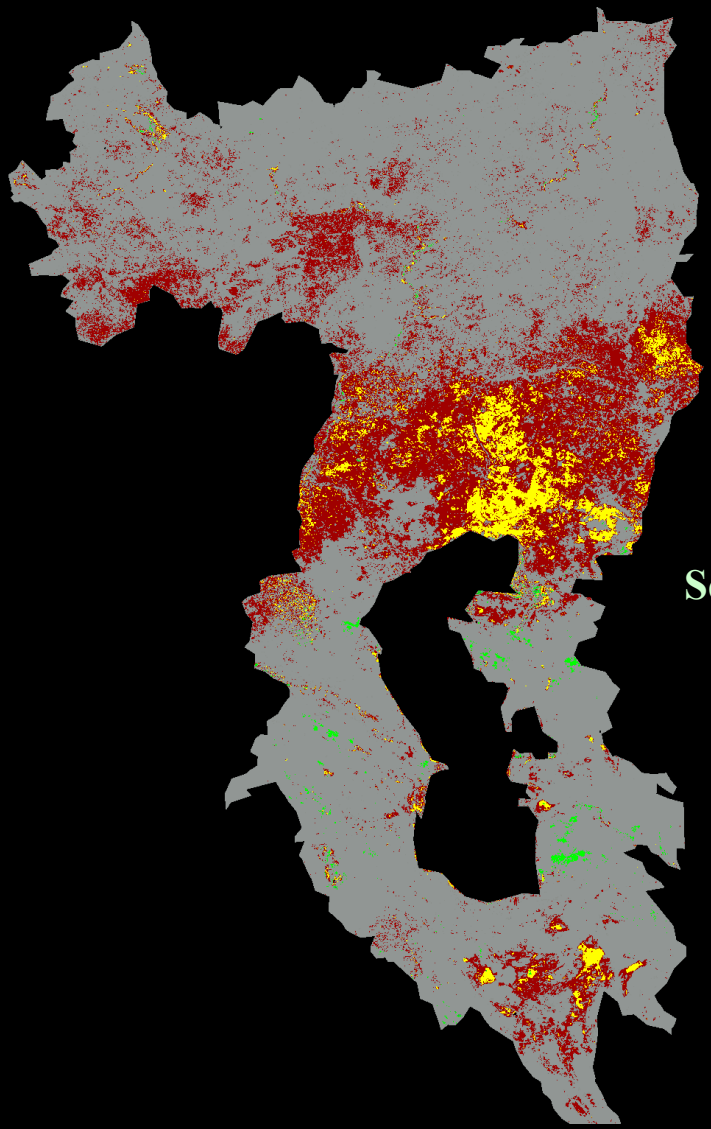
A mosaic of 10 MODIS scenes covers the entire Caspian Sea basin





Mosaic of the final high quality MODIS data sets: (left) Band 321 color composite for 2000, (right) NDVI Annual Mean for 2000

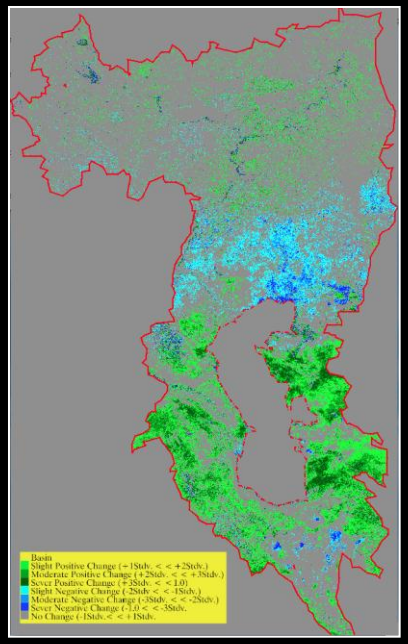
Change Detection 2000 - 2005



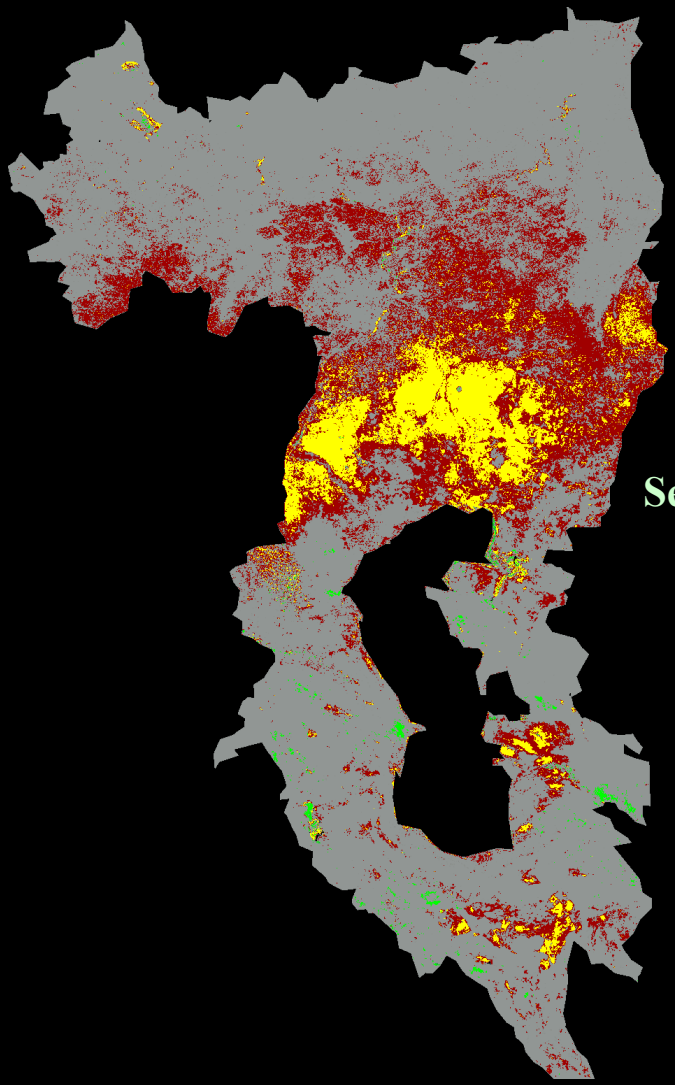
Density slice range	Nr. of Points	Area (km^2)	%
-1.0000 to -0.1950	734,863	39,437.42	1.08
-0.1950 to -0.1300	1,290,389	69,250.48	1.89
-0.1300 to -0.0650	4,353,230	233,621.99	6.38
0.0650 to 0.1300	9,464,864	507,944.76	13.88
0.1300 to 0.1950	3,595,613	192,963.45	5.27
0.1950 to 1.0000	1,833,336	98,388.46	2.69

Seasonal (leaf-on) Mean NDVI-2005 is cross-calibrated to NDVI-2000

Landsat Validation:
Threshold Significance of Change

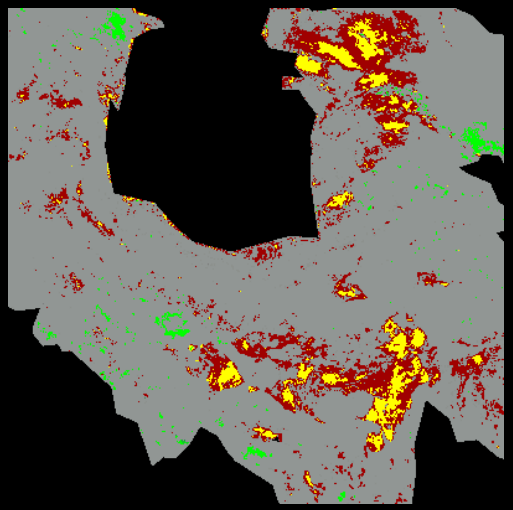


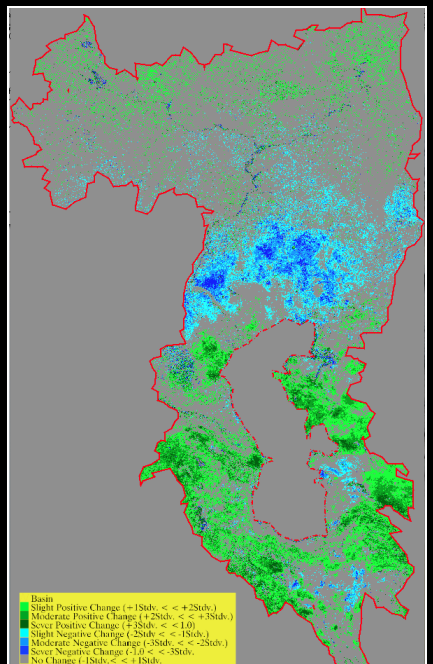
Change Detection 2000 - 2009

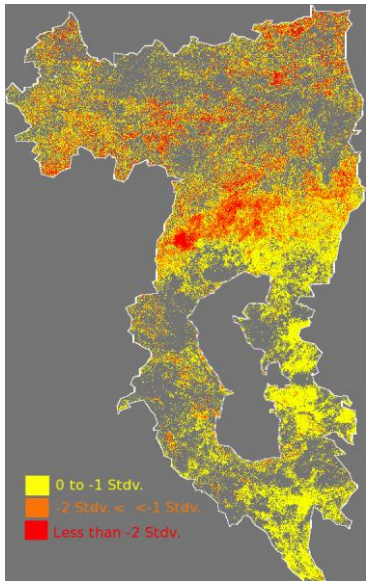


Density slice range	Nr. of Points	Area (km^2)	%
-1.0000 to -0.2190	915,991	49,157.90	1.34
-0.2190 to -0.1460	1,290,389	126,339.19	3.45
-0.1460 to -0.0730	5,429,405	291,376.38	7.96
0.0730 to 0.1460	10,046,782	539,174.18	14.73
0.1460 to 0.2190	3,597,521	193,065.84	5.28
0.2190 to 1.0000	1,387,321	74,452.46	2.03

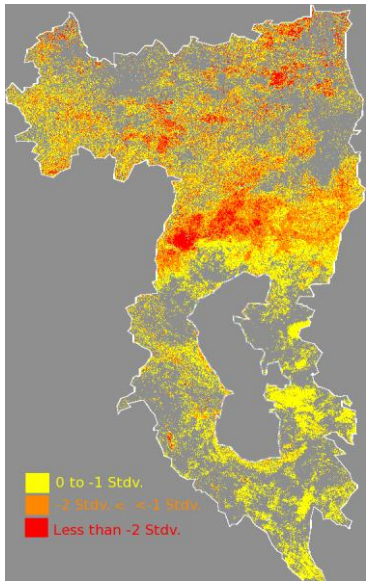
Seasonal (leaf-on) Mean NDVI-2009 is cross-calibrated to NDVI-2000



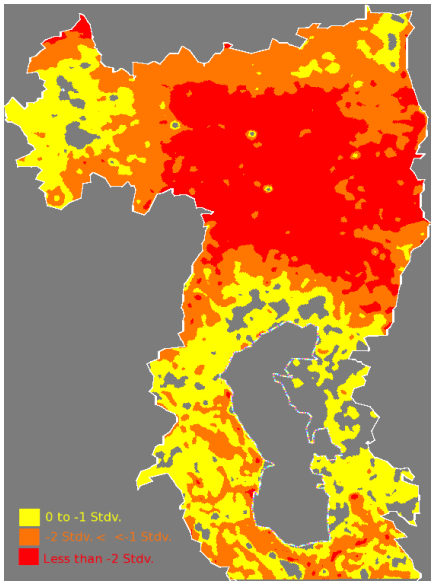




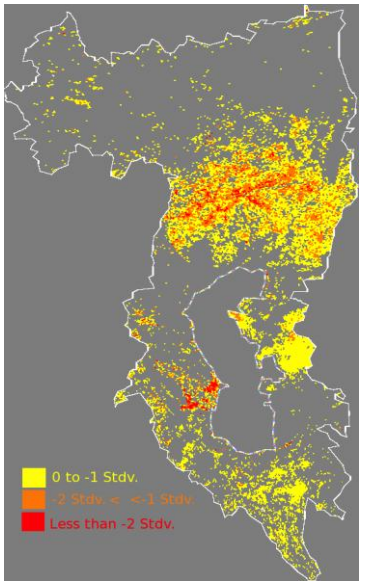
MODIS-EVI-Annual-Trend



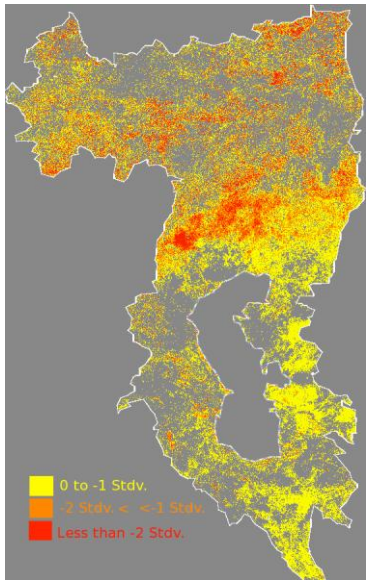
MODIS-NDVI-Annual-Trend



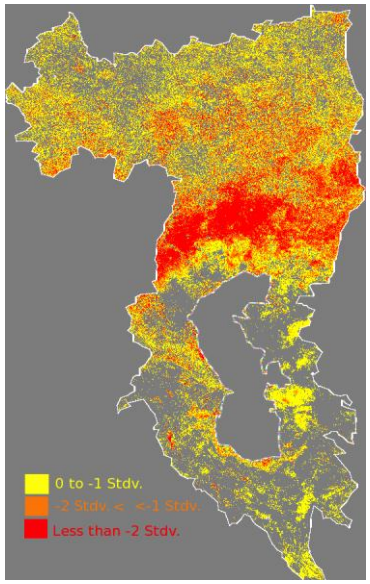
QSCAT-Annual-Trend



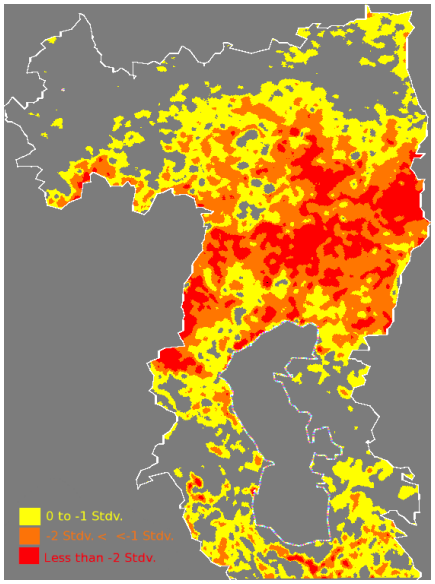
AVHRR-Annual-Trend



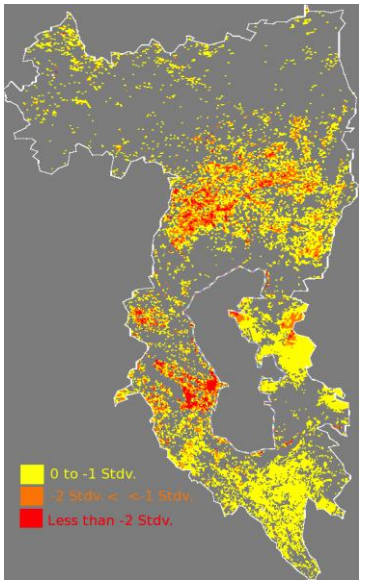
MODIS-EVI-Leaf-on-Trend



MODIS-NDVI-Leaf-on-Trend

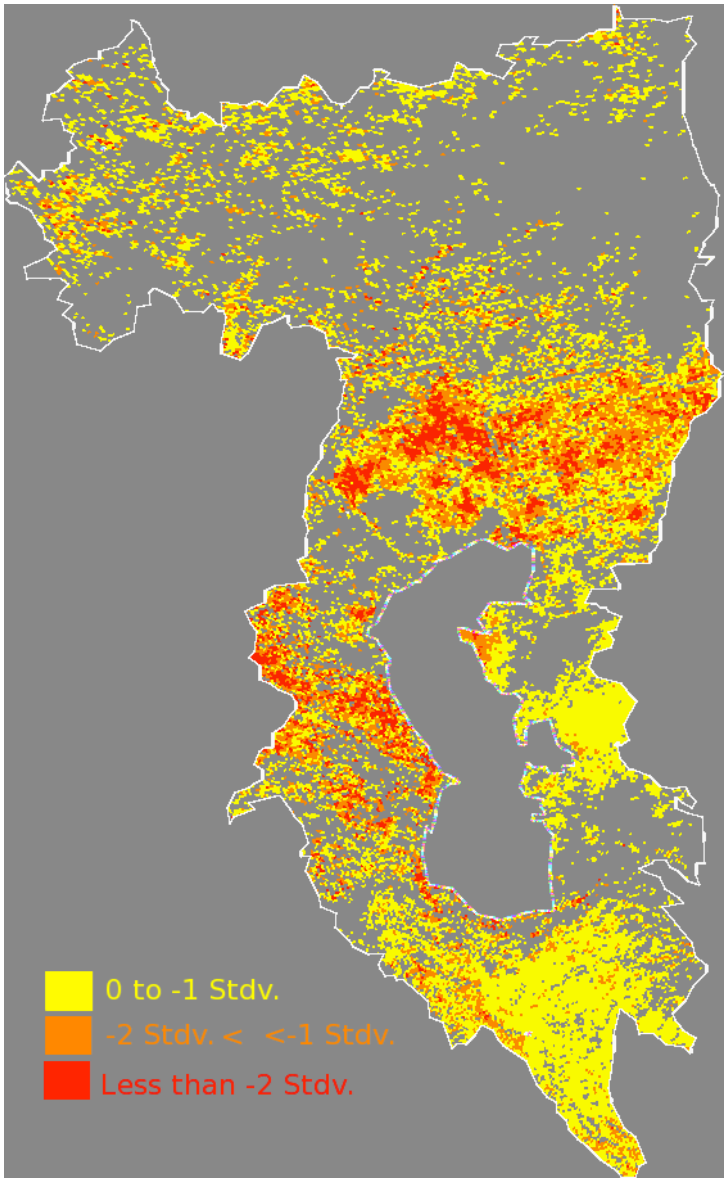


QSCAT-Dry-Season-Trend

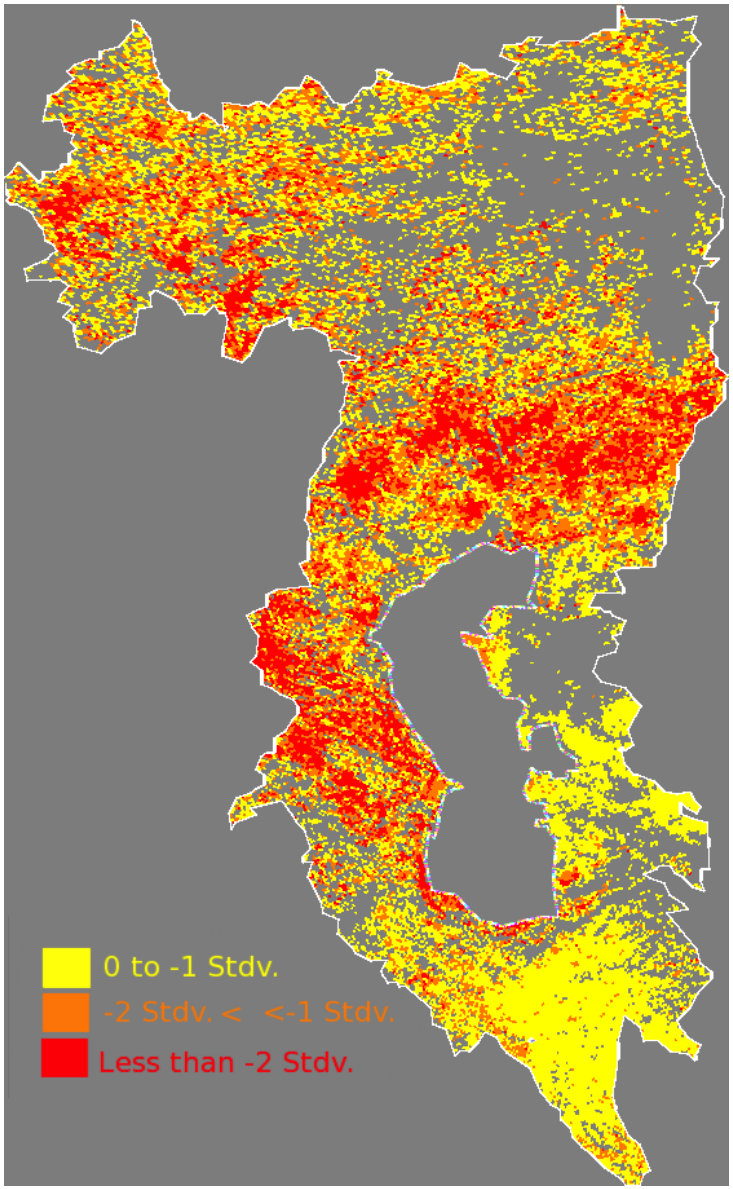


AVHRR-Leaf-on-Trend

Standard Normalized Anomaly

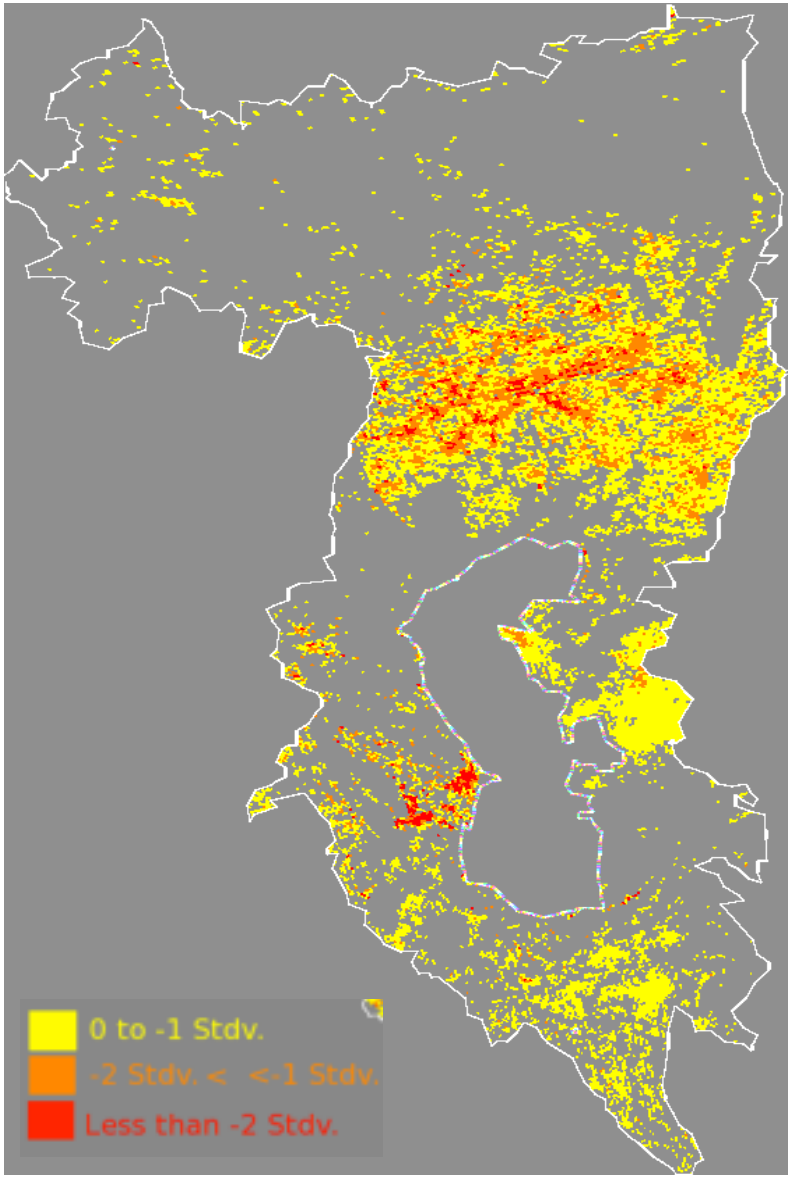


AVHRR_NDVI-Annual-Trend-
1996-2006

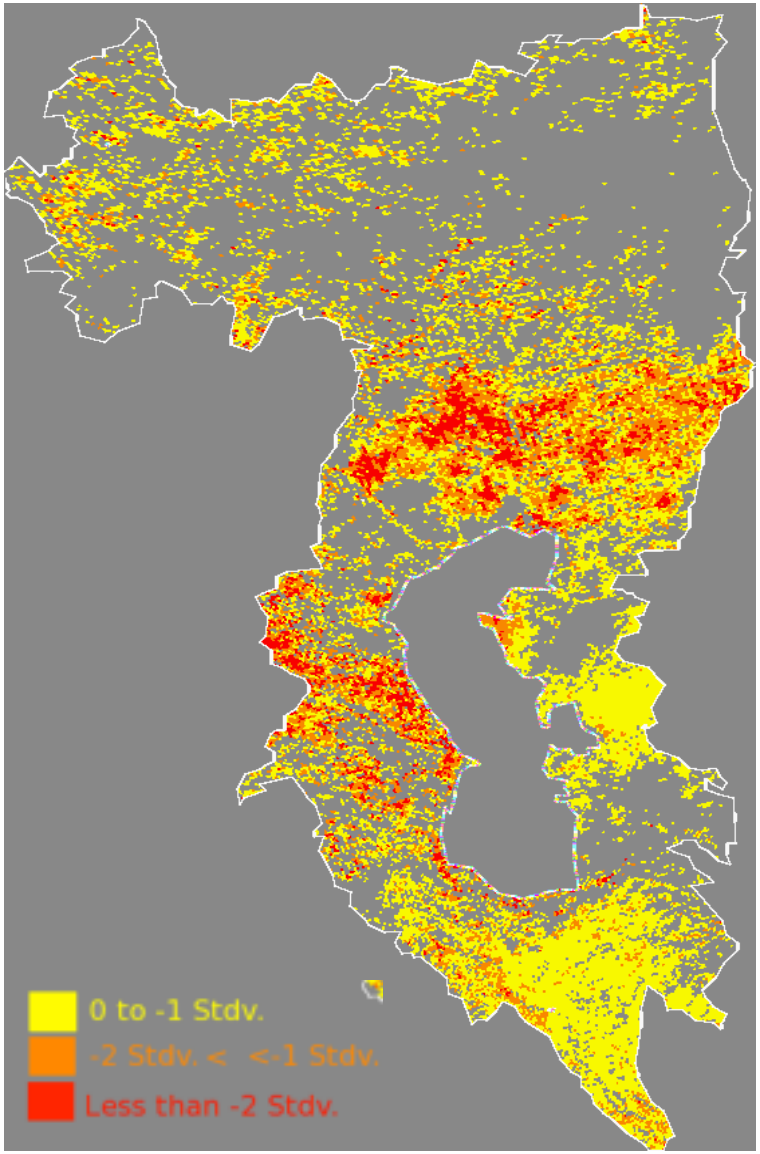


AVHRR_NDVI-Leaf-On-Trend-
1996-2006

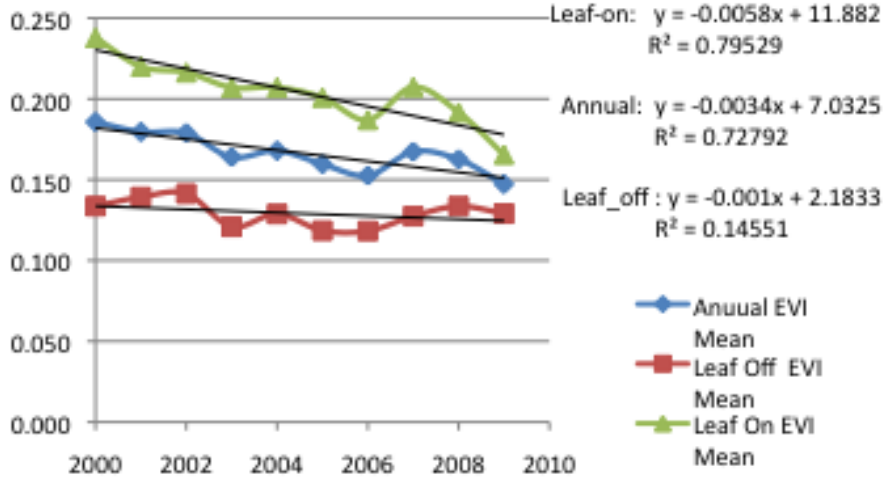
Standard Normalized Anomaly



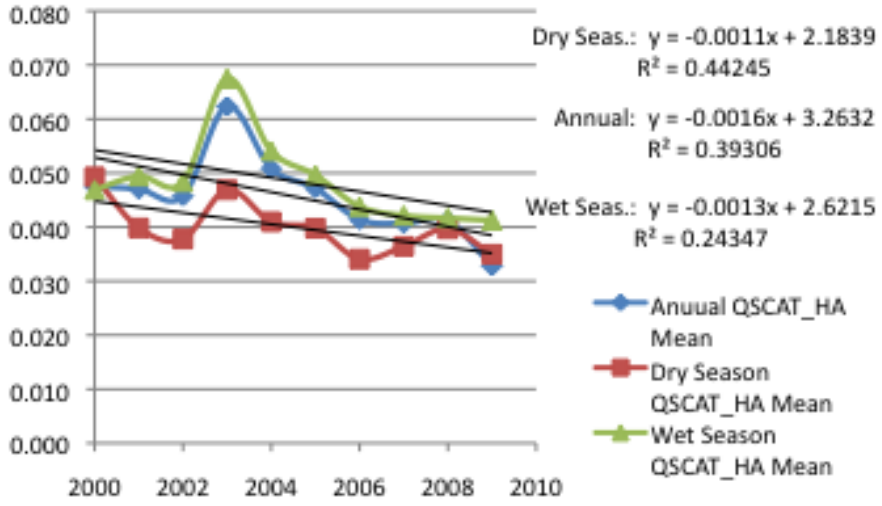
AVHRR_NDVI-Annual-Trend
1982-2006



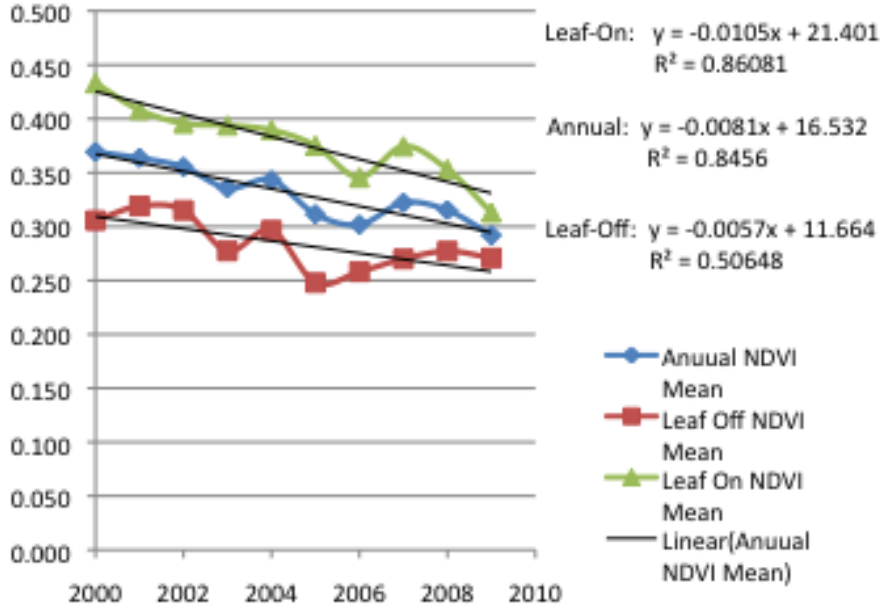
AVHRR_NDVI-Annual-Trend
1996-2006



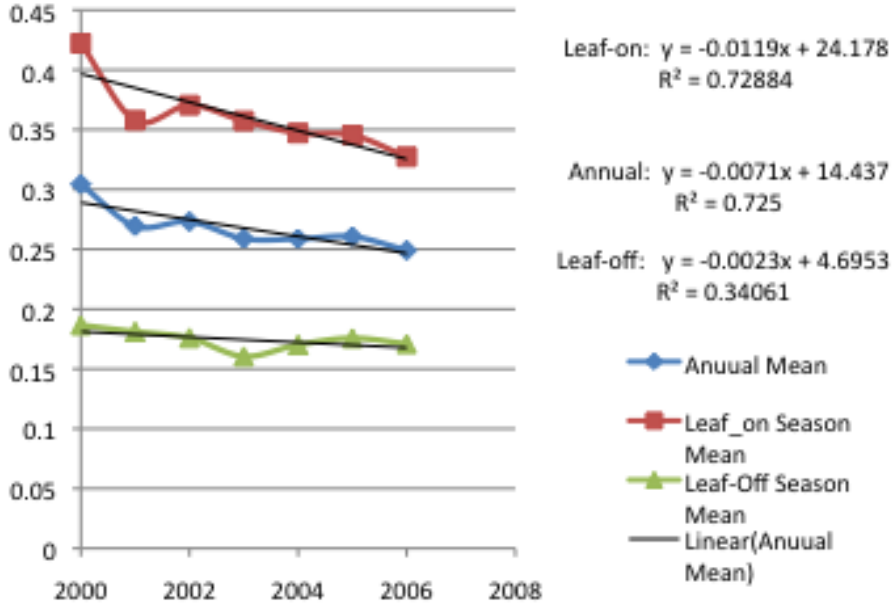
EVI-MODIS-Box (2000-09)



Quick-SCATT-Box (2000-09)

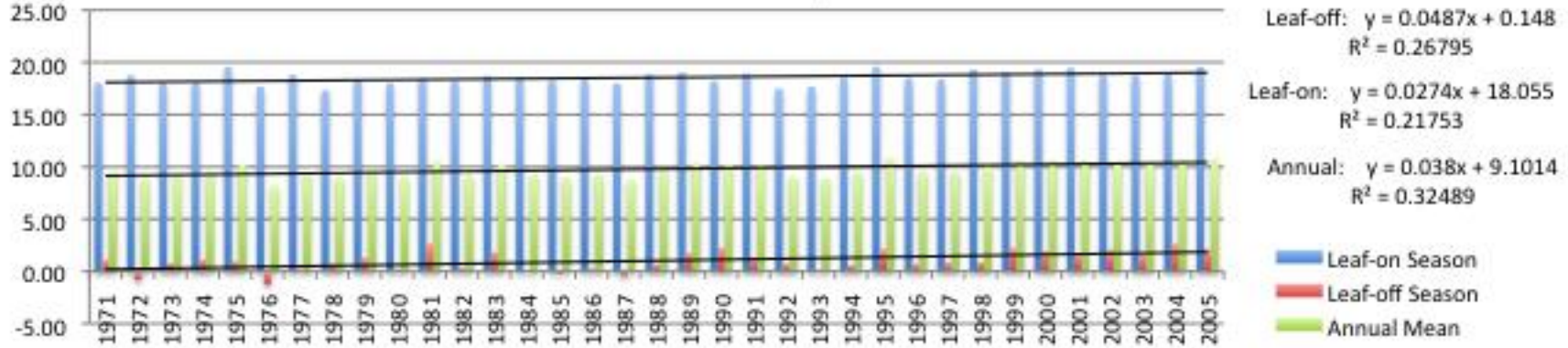


NDVI-MODIS-Box (2000-09)

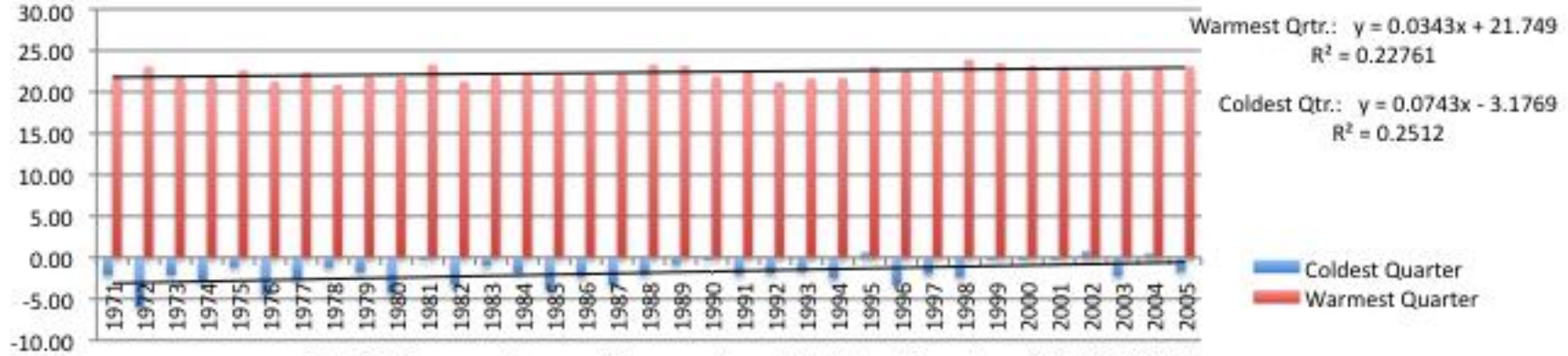


AVHRR-GIMMS-NDVI-Box (2000-06)

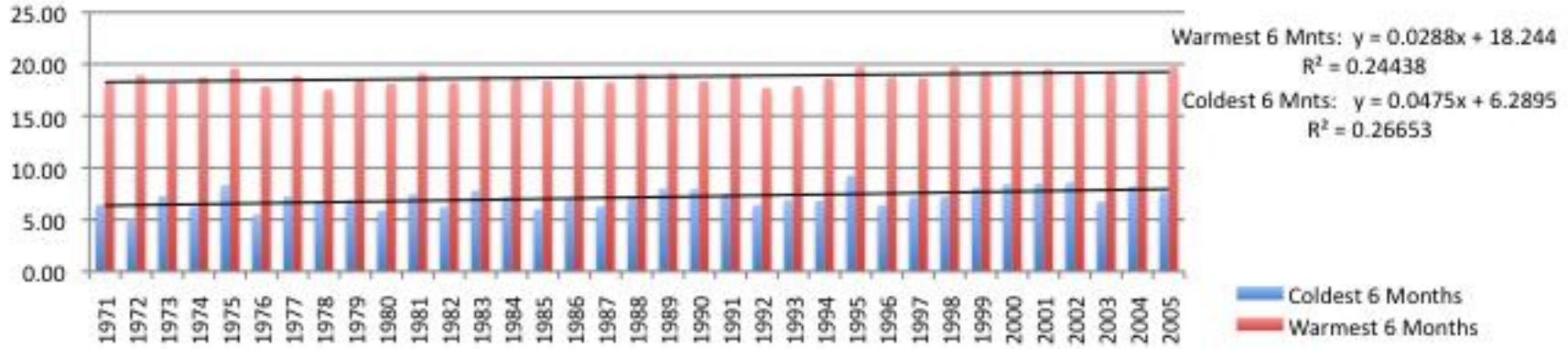
CRU Data - Temperature



Basin Temperature – Annual and Seasonal Means (1971-2005)

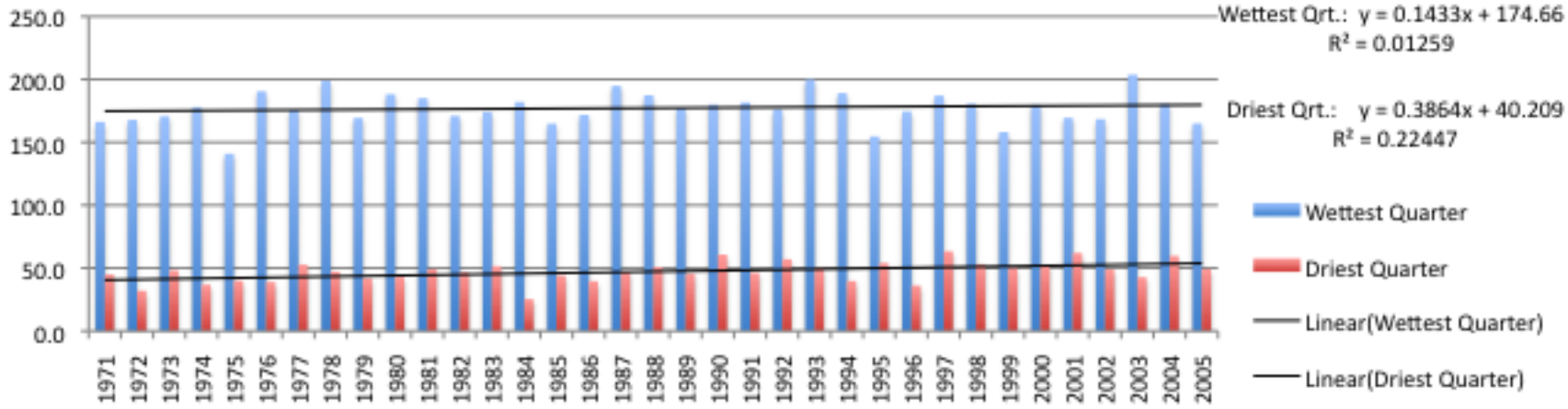


Basin Temperature – Warmest and Coldest Quarter (1971-2005)

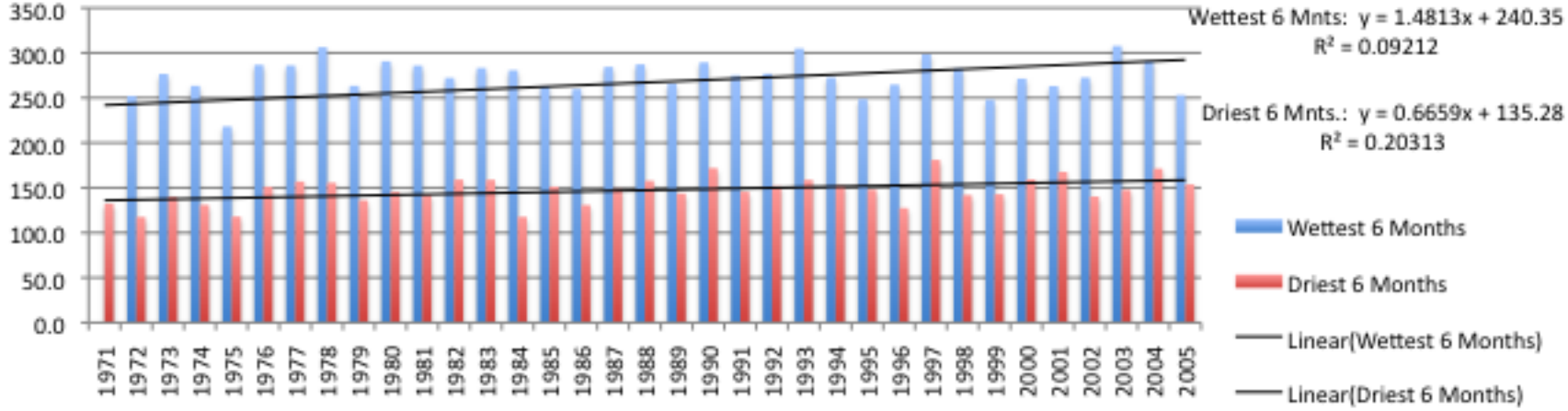


Basin Temperature – Warmest and Coldest Quarter (1971-2005)

CRU Data - Rainfall



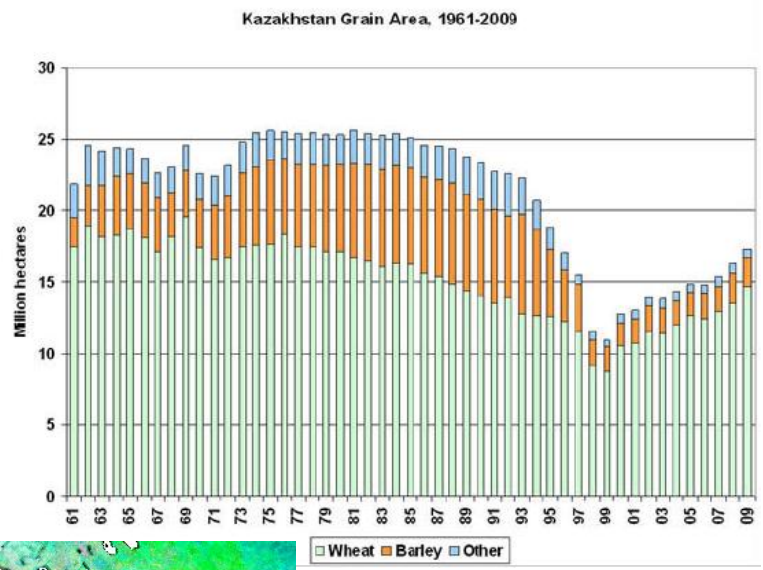
Basin Rainfall – Driest and Wettest Quarter (1971-2005)

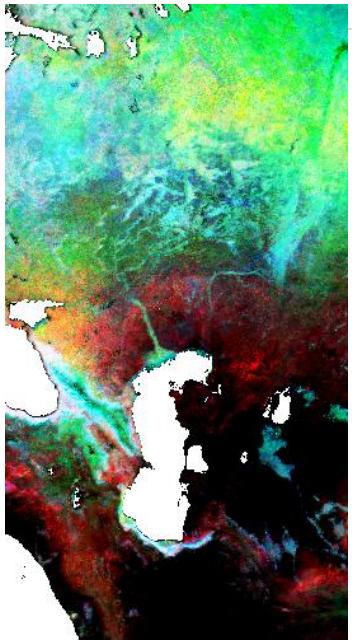


Basin Rainfall – Driest and Wettest 6 Months (1971-2005)

Summary

- Combined land use change and climate explain observations of changes over the past 30 years in hydrology of basin.
- Coupled hydrology and land use and land cover change model will provide the relative contribution of climate and land use.
- New AVHRR, MODIS, and Landsat data can help improving the changes of vegetation cover and land use change.
- We will continue with our publications and look for funding to develop the hydrological study along with gathering validation data.





AVHRR
1981-2011

Publications:

Saatchi, S., Fu, Q., Nouri, A., Hedjazi, A. Mohamadi, S., Changes of forest cover in Caspian Sea Region, Submitted to Remote Sensing, 2011.

Nouri, A. Saatchi, S., Asefi, S., Entekhabi, D., Hedjazi, A., Shiklomanov, A., Interaction of climate and land use change in Caspian Sea Basin, Under Preparation.

Future Work