Hydrological changes across Russia resulted from climate variability and human impacts

Alexander Shiklomanov* and Alexander Prussevitch

Water Systems Analysis Group, University of New Hampshire

* Arctic and Antarctic Research Institute, St. Petersburg, Russia

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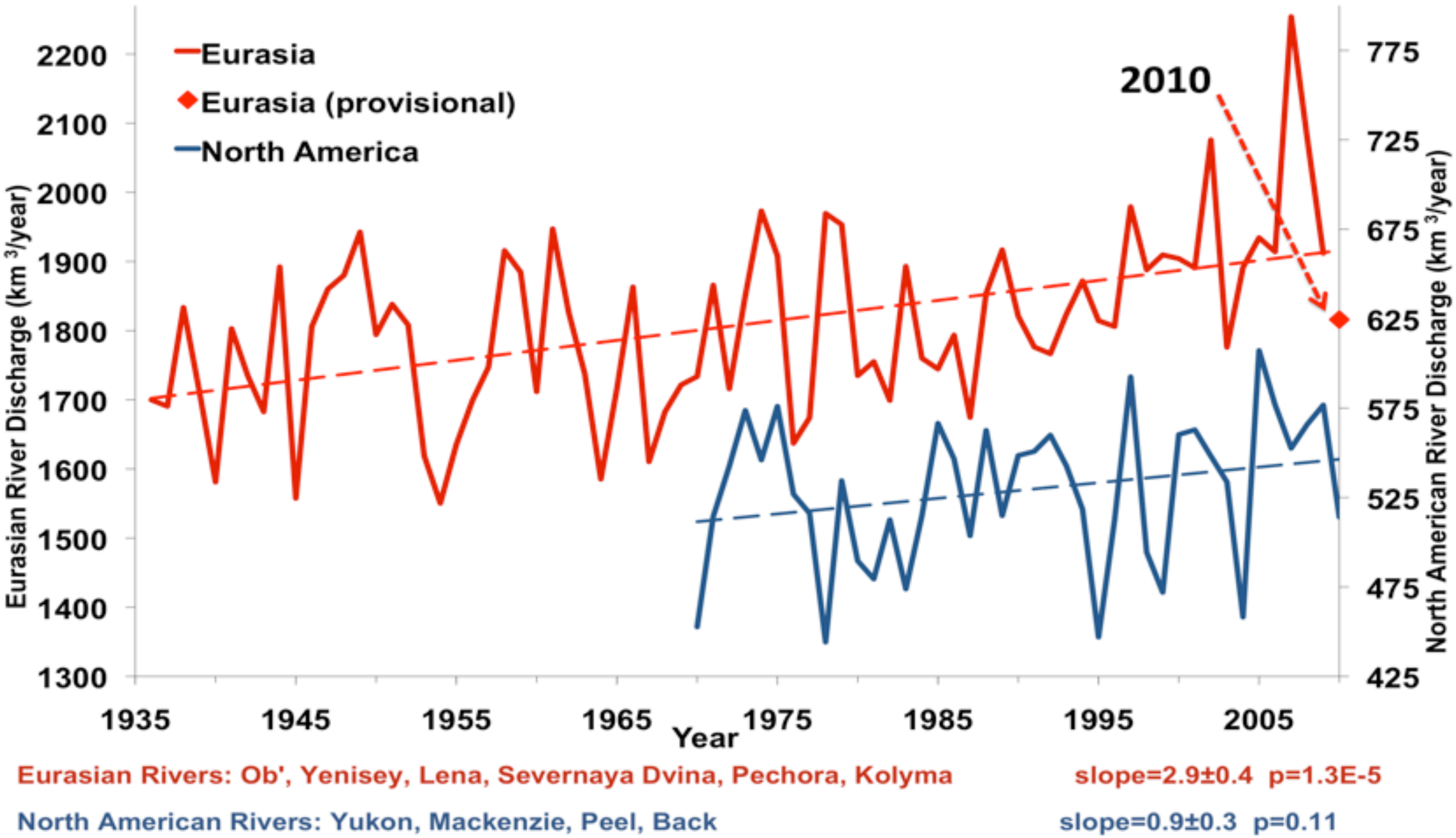
Land-Cover / Land-Use Change Program

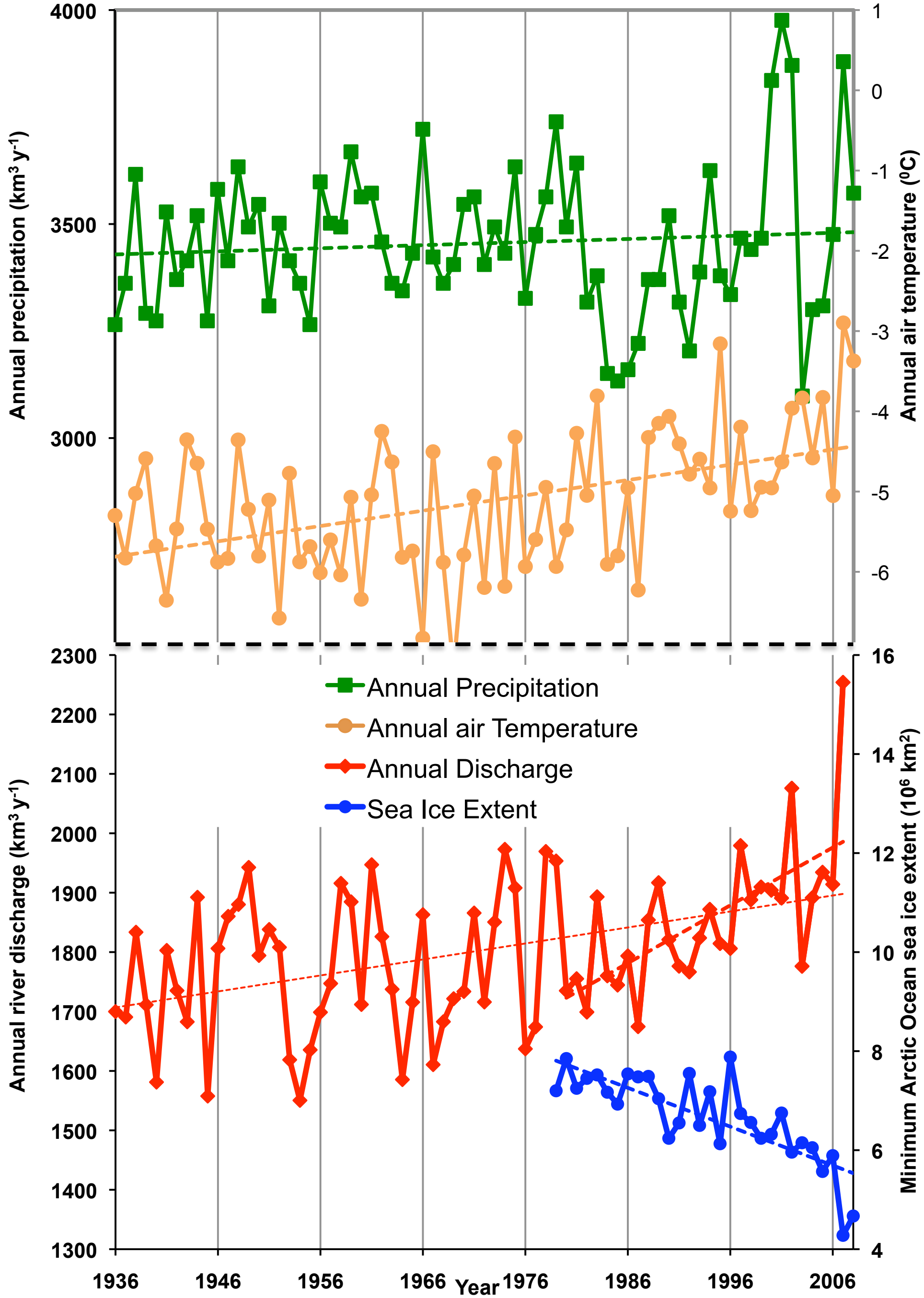
Road Map:

- Observed Hydrological Changes in Russia;
- Human Impact on Hydrology, Example of Yenisey River;
- Future Changes in Regional Hydrology;
- Rapid Integrated Mapping and Analysis System (RIMS).

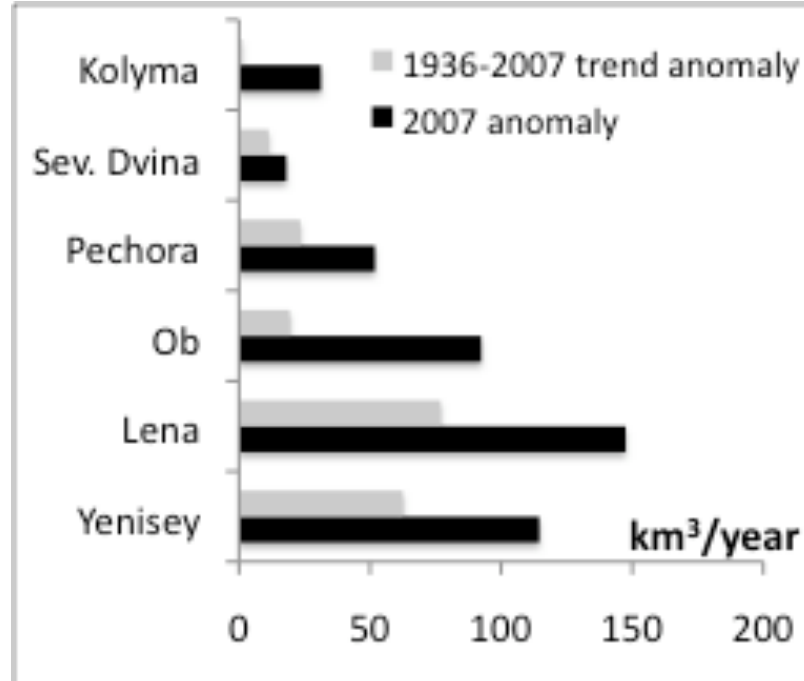
River discharge to the Arctic Ocean is increasing



Total annual discharge to the Arctic Ocean from the six largest rivers in the Eurasian pan-Arctic for the observational period 1936–2009 (from Shiklomanov and Lammers, Arctic Report Card 2011) (red line) and from the four largest North American Arctic rivers over 1970–2010 (blue line). The least squares linear trend are shown as dashed lines. Red diamond shows provisional estimate of Eurasian discharge for 2010



Rivers: Ob', Yenisey, Lena, Severnaya Dvina, Pechora, Kolyma

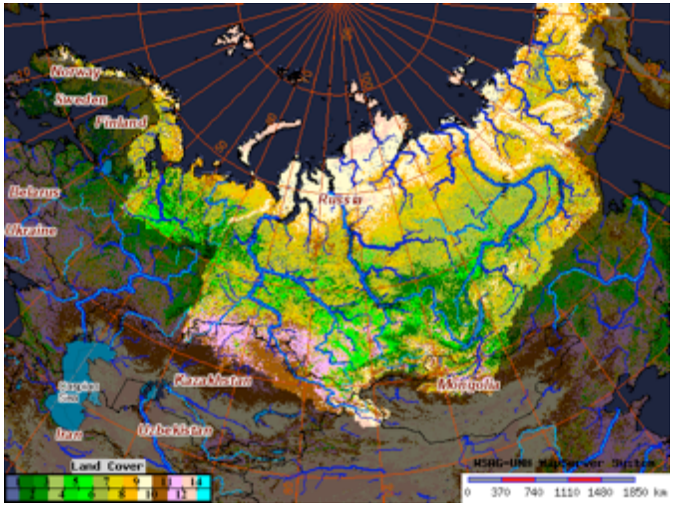


Contribution of individual river basin to the LTM discharge trend and to the 2007 record high discharge (figure above).

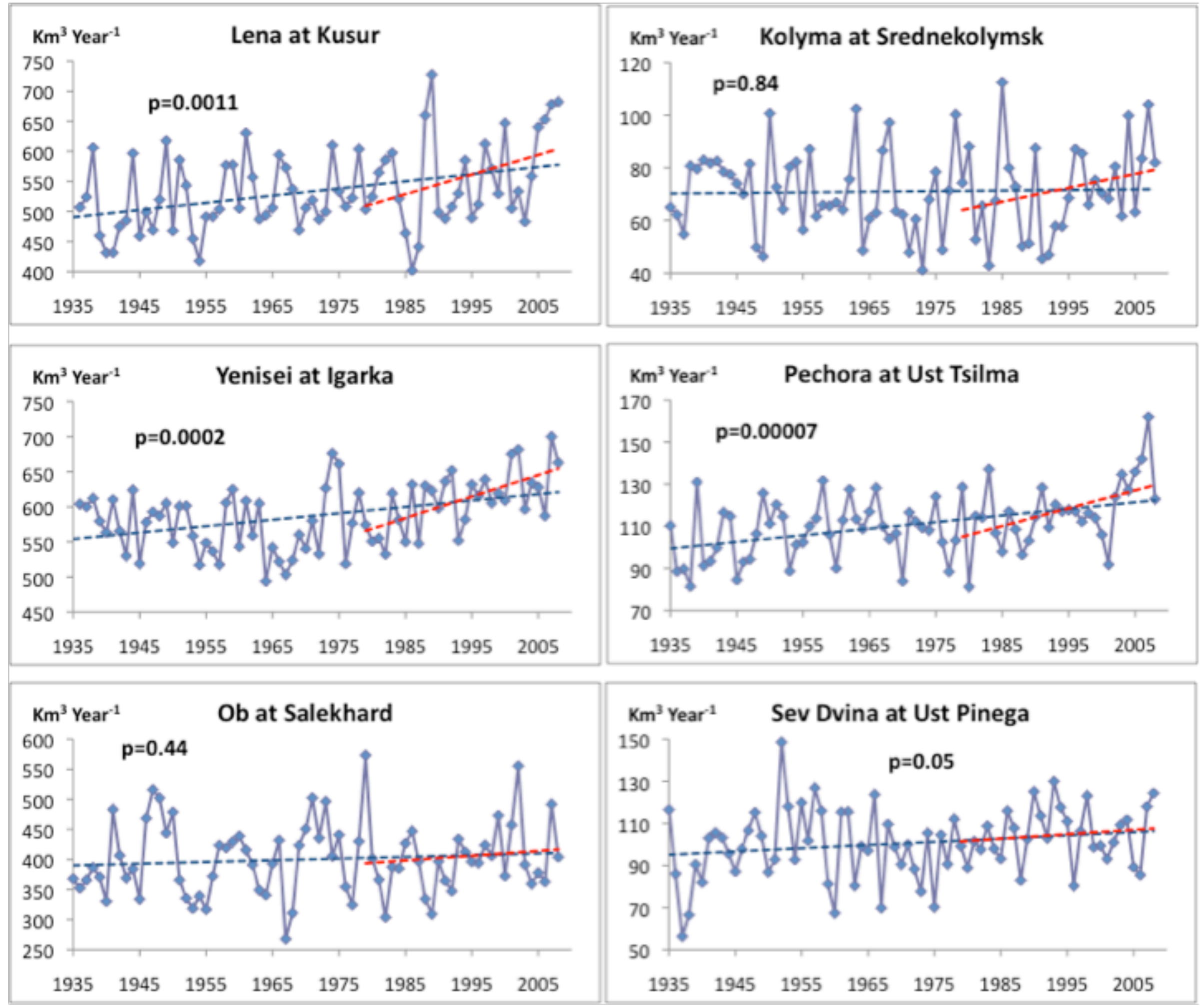
Annual time series of spatially aggregated river discharge, grid cell precipitation, and aggregated Arctic Ocean sea ice coverage (September). River discharge and precipitation data from http://RIMS.unh.edu), sea ice cover from NSIDC (figure to the left).

(Updated from Shiklomanov & Lammers, 2009 ERL)

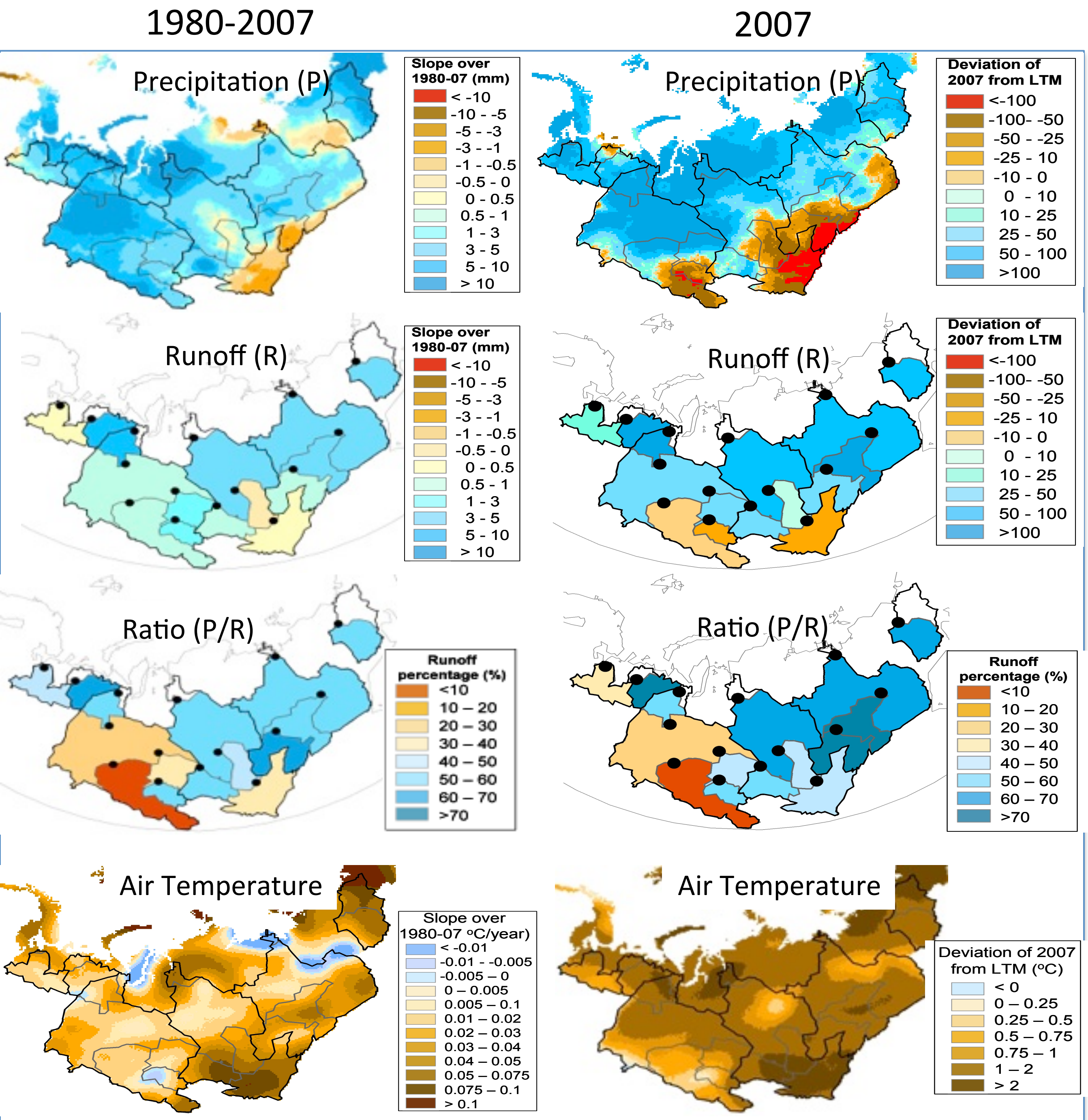
Eurasian Pan-Arctic Drainage Basin



Eurasian pan-Arctic occupies about 75% of Russia as well as parts of Kazakhstan, China and Mongolia



Annual discharge variabilities for largest Russian rivers flowing to the Arctic Ocean over 1936-2008. Dash lines show linear trend lines over 1936-2008 (blue) and over 1980-2008 (red). (html://R-ArcticNet.sr.unh.edu)

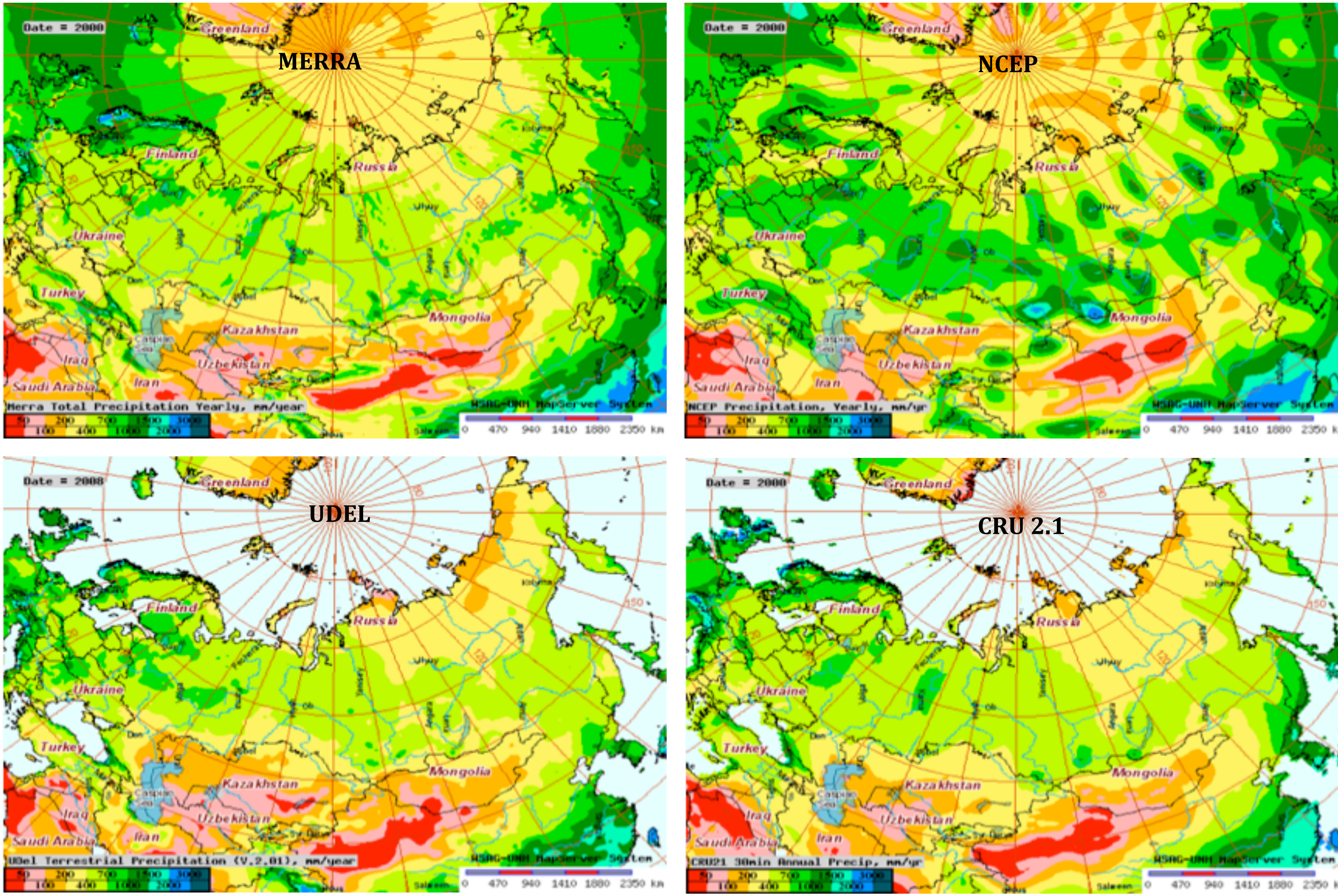


Maps of long term trend and 2007 anomalies in precipitation, river runoff, precipitation/runoff (P/R) ratio and air temperature. River runoff and P/R ratio calculated over 15 inter-station regions as shown by black circles.

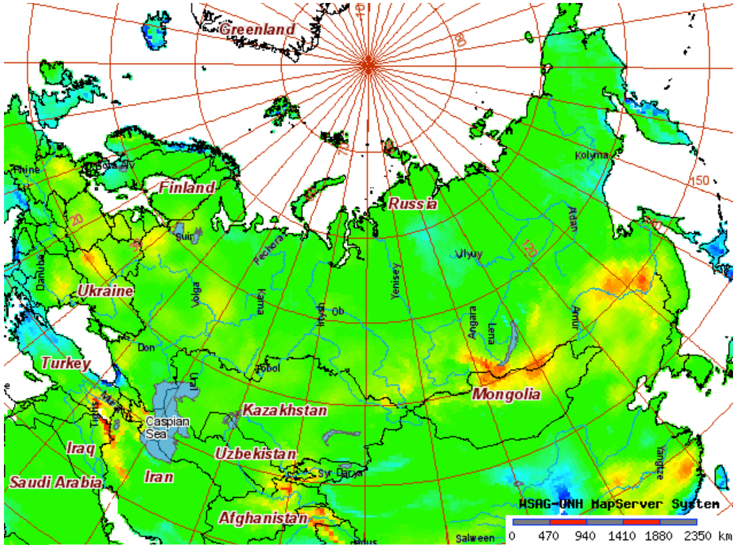
- Similar patterns between long-term changes and the 2007 anomalies
- 2007 is a higher magnitude expression of the ongoing pattern of change over the last 28 years.

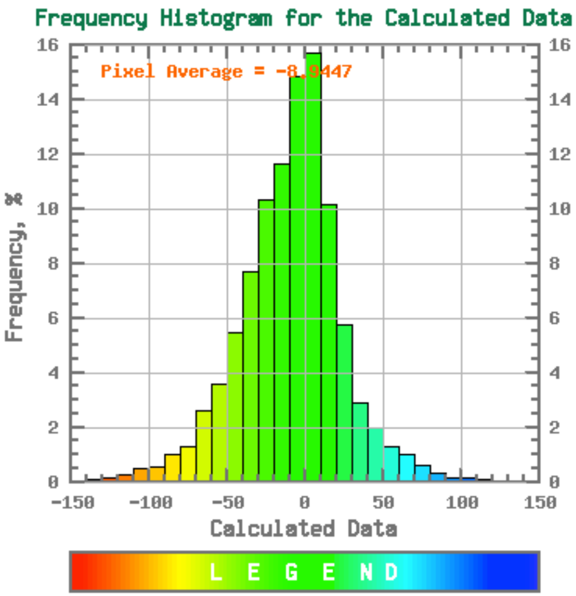
from Shiklomanov & Lammers, 2009 ERL

Intercomparison of mean annual precipitation for 2000 from NCEP and MERRA re-analysis with UDEL and CRU interpolated observations.

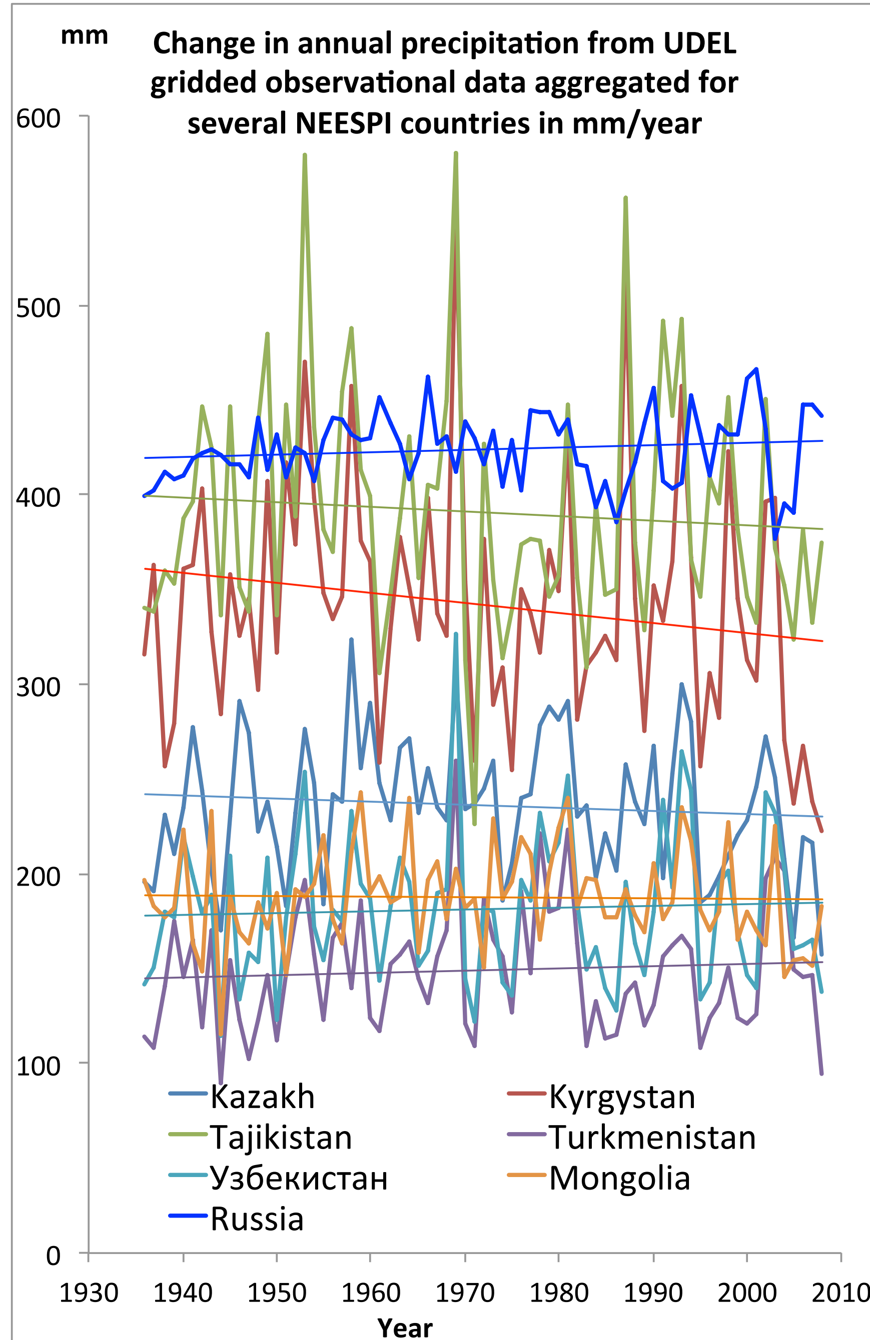


PRECIPITATION CHANGE

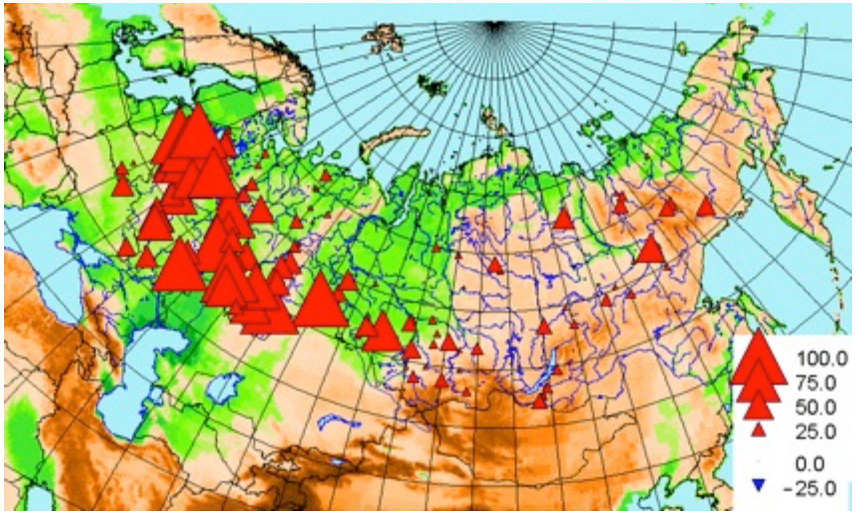




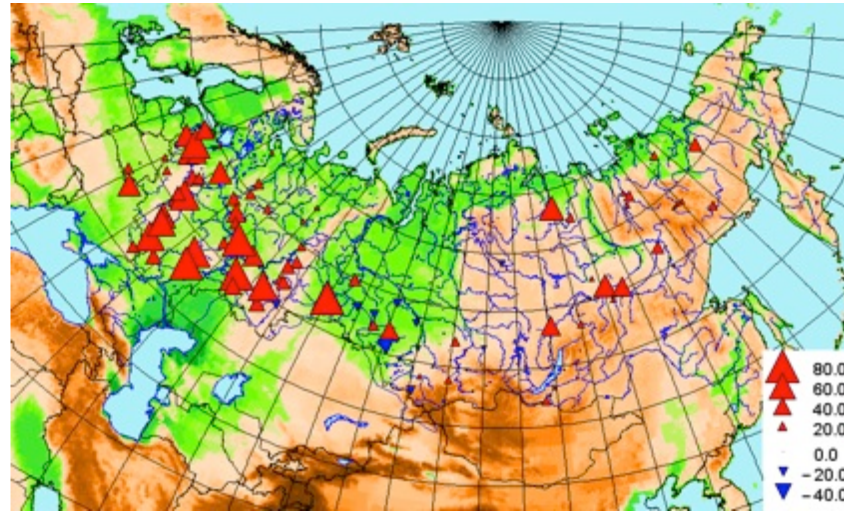
Deviation of mean annual MERRA precipitation over 1995-2011 from LTM over 1978-2011



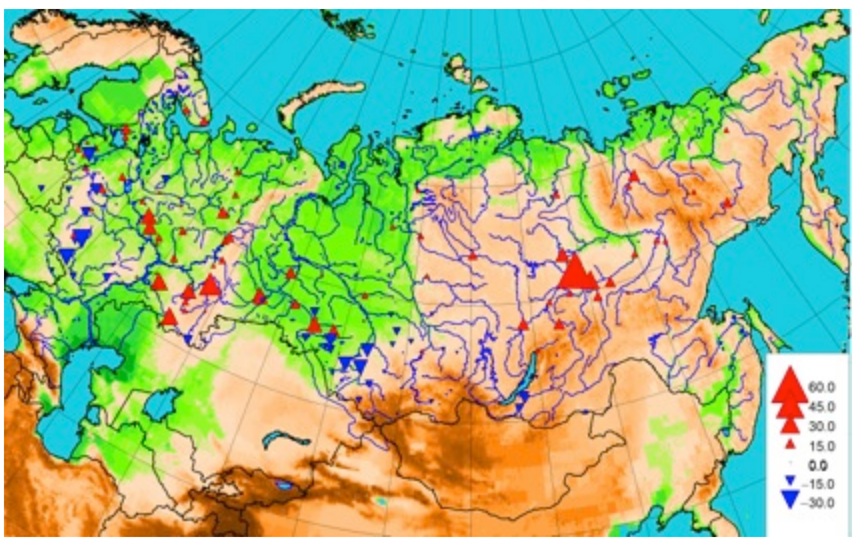
Anomalies of Winter runoff over 1978-2005 (%)



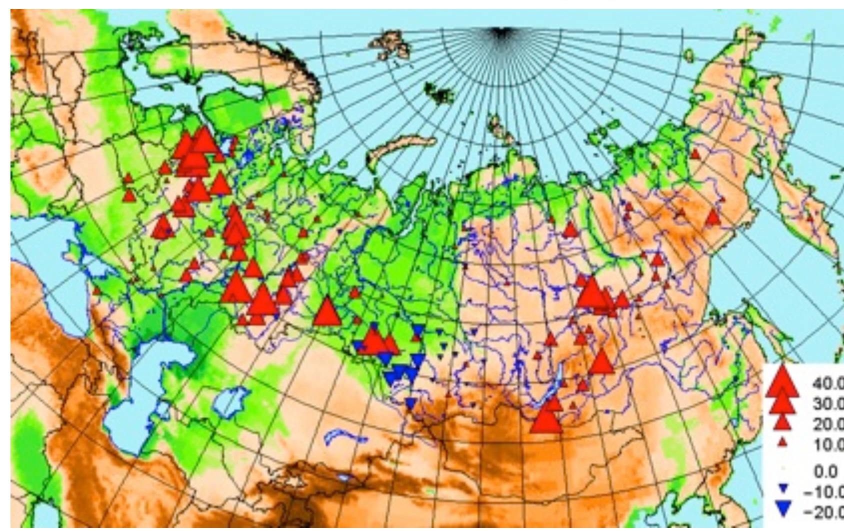
Anomalies of Summer-Fall runoff over 1978-2005 (%)



Anomalies of Spring runoff over 1978-2005 (%)



Anomalies of Annual runoff over 1978-2005 (%)



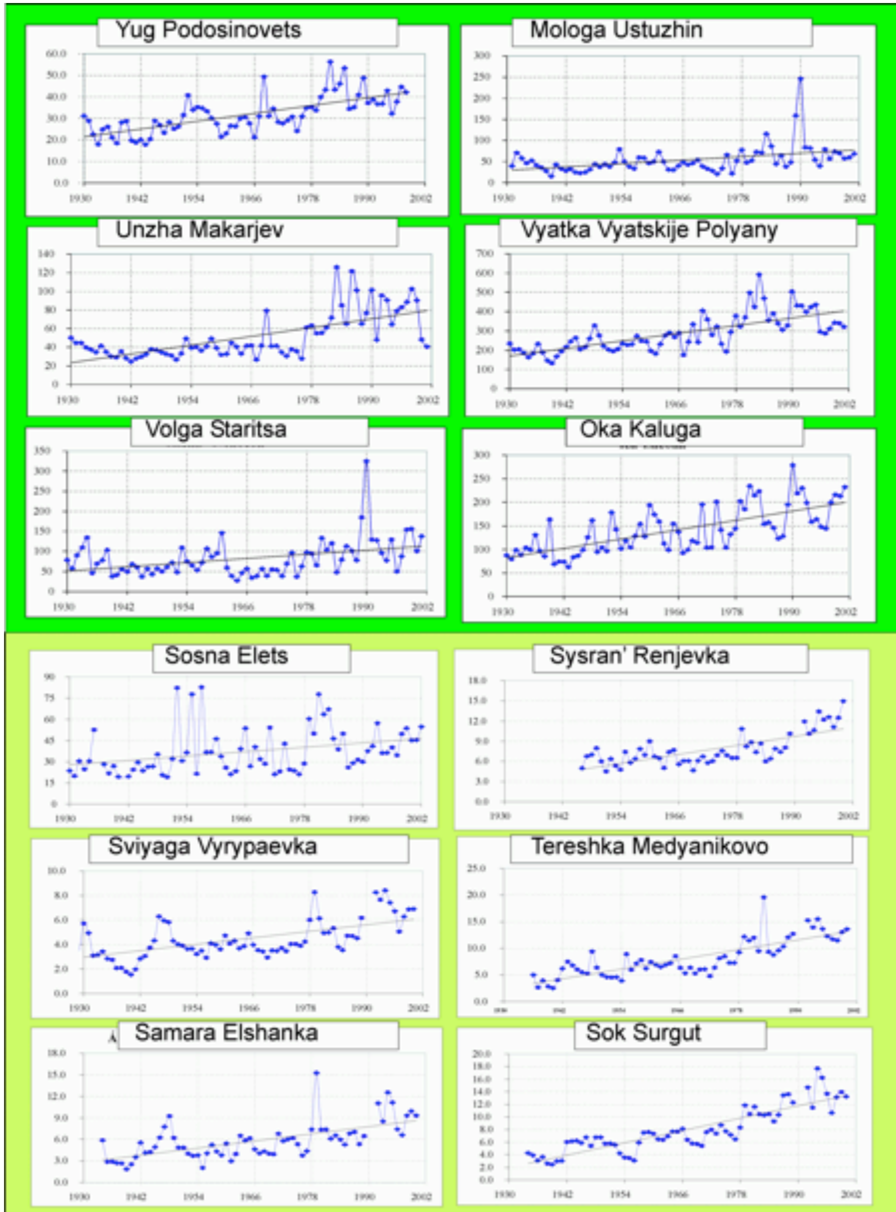
Anomalies of seasonal runoff over 1978-2005 from 1940-1977

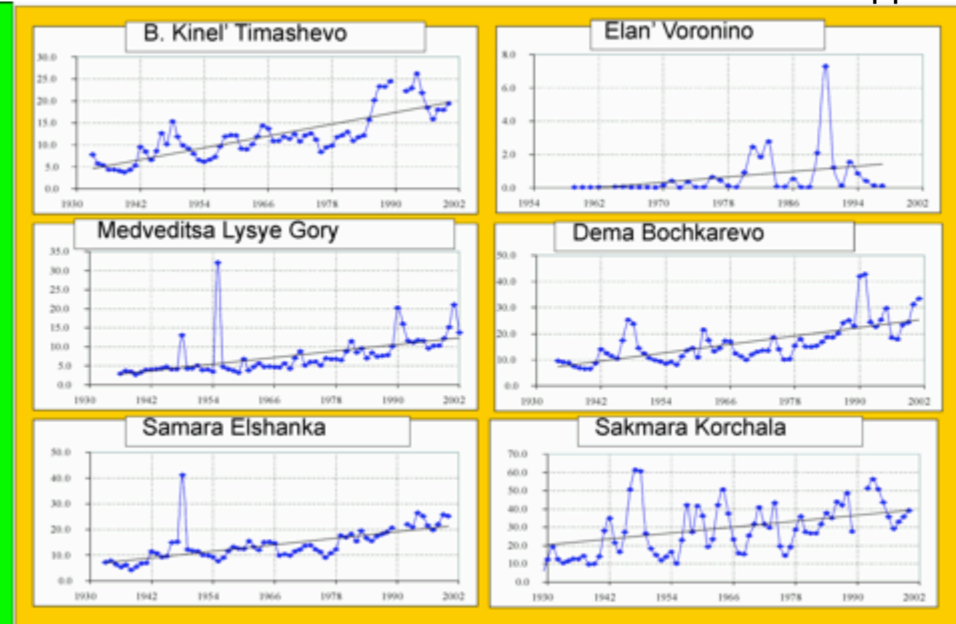
Updated from ACIA, 2005

Annual mean winter river discharge (Dec. to March)

Forest

Steppe





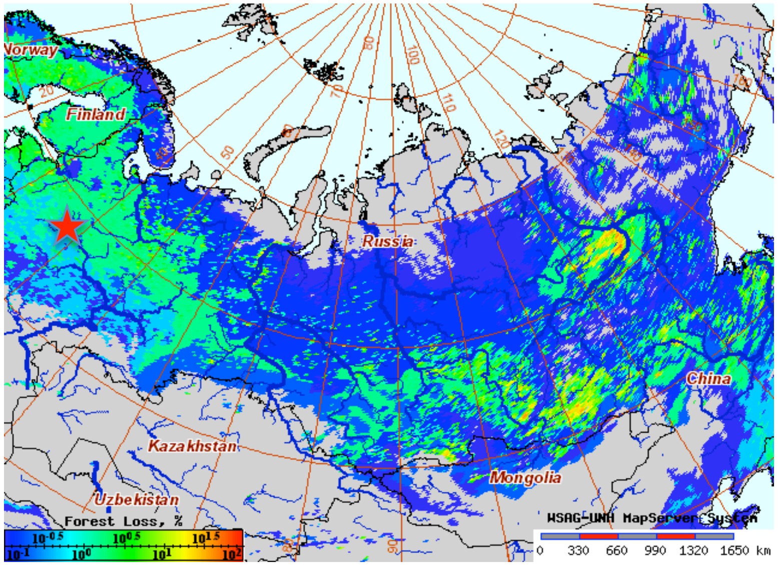
Medium-size drainage basins from European Russia (within NEESPI domain).

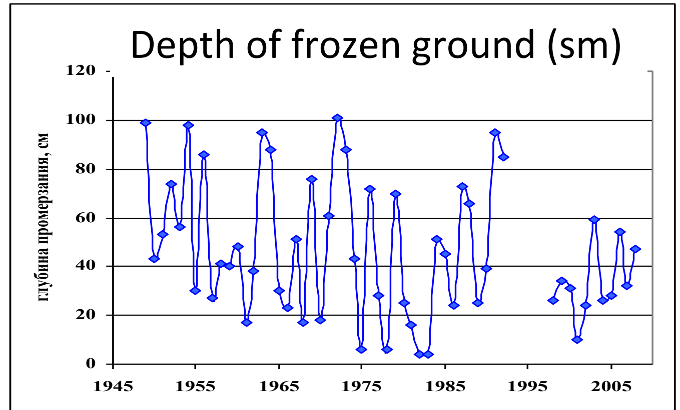
Understanding of causes of such significant changes in river discharge is one of our research tasks.

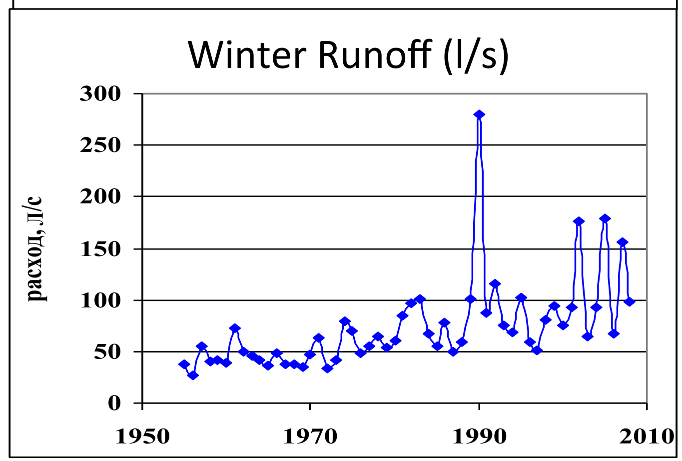
Forest-Steppe

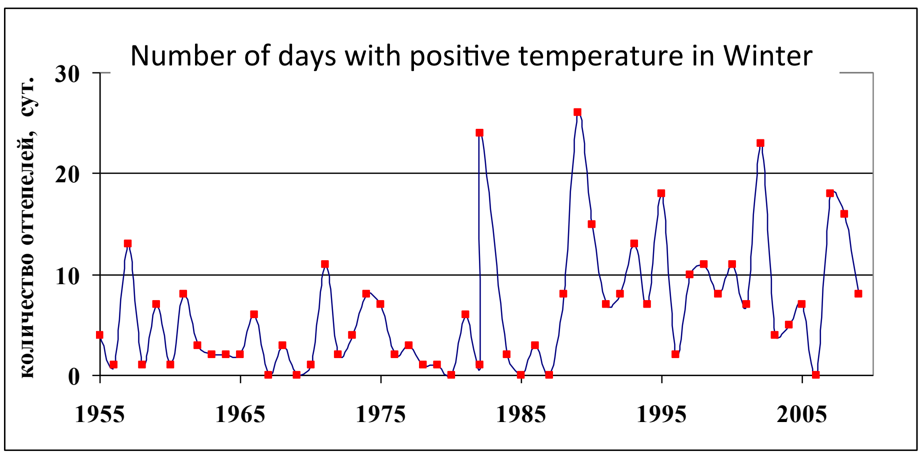
Understanding of changes in winter runoff

r. Medvenka F=21.5 km^2







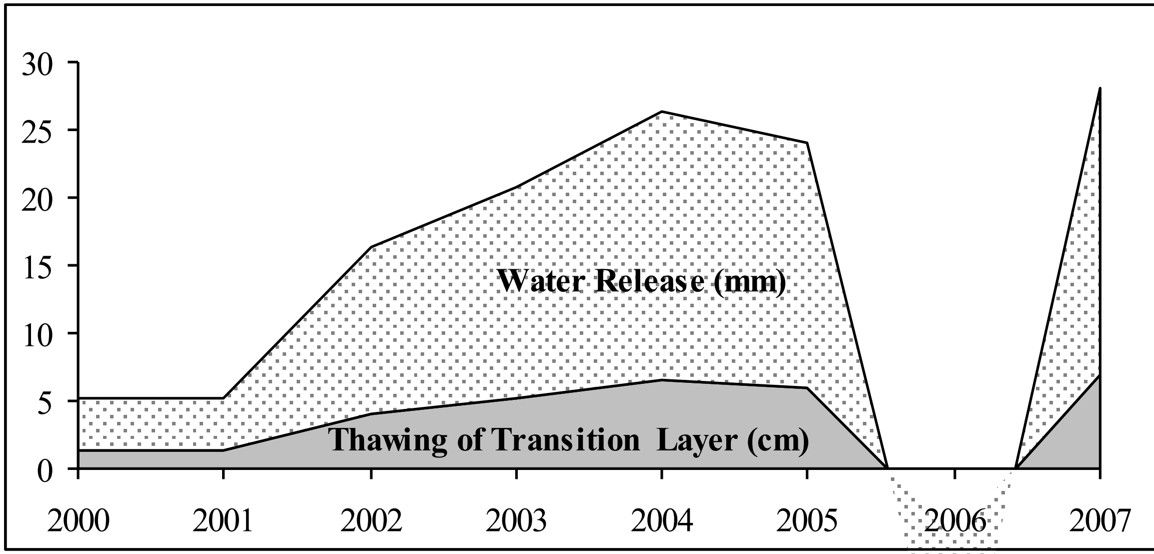


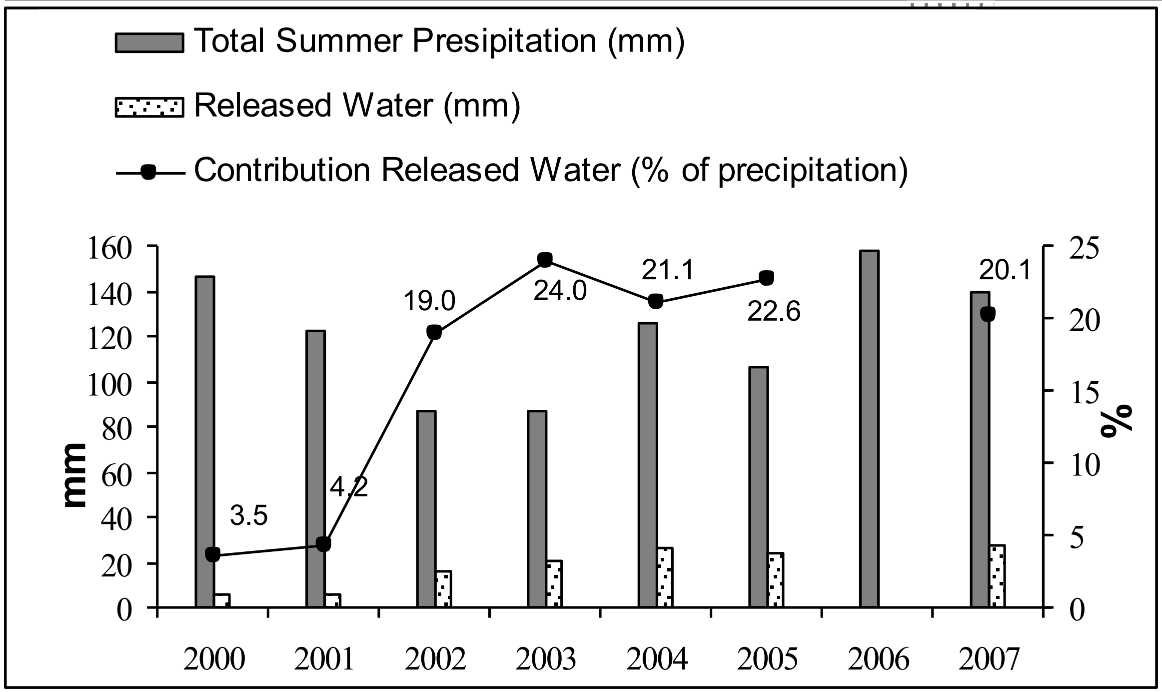
LTM winter runoff (l/s) 1958 -1980	Contribution of different elements into the winter runoff for Medvedka watershed			LTM winter runoff (l/s) 1981-2008
	Fall soil water content	Winter snowmelt	Depth of frozen ground	
49,6	**6**	**38**	**56**	**93,2**

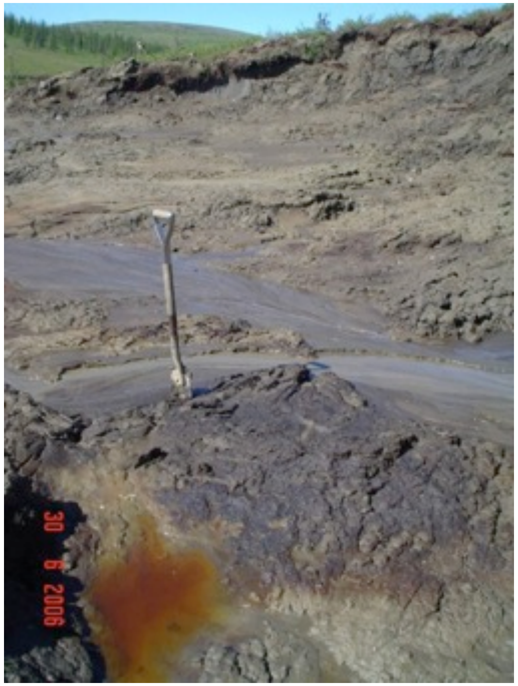
Contribution to increase in winter river discharge: Depth of frozen ground – 56%
Winter snowmelt – 38%
Fall soil water content – 6%

Courtesy to Igor Kaluzhny, SHI, Russia

Dynamic of water release from ice-rich transition layer

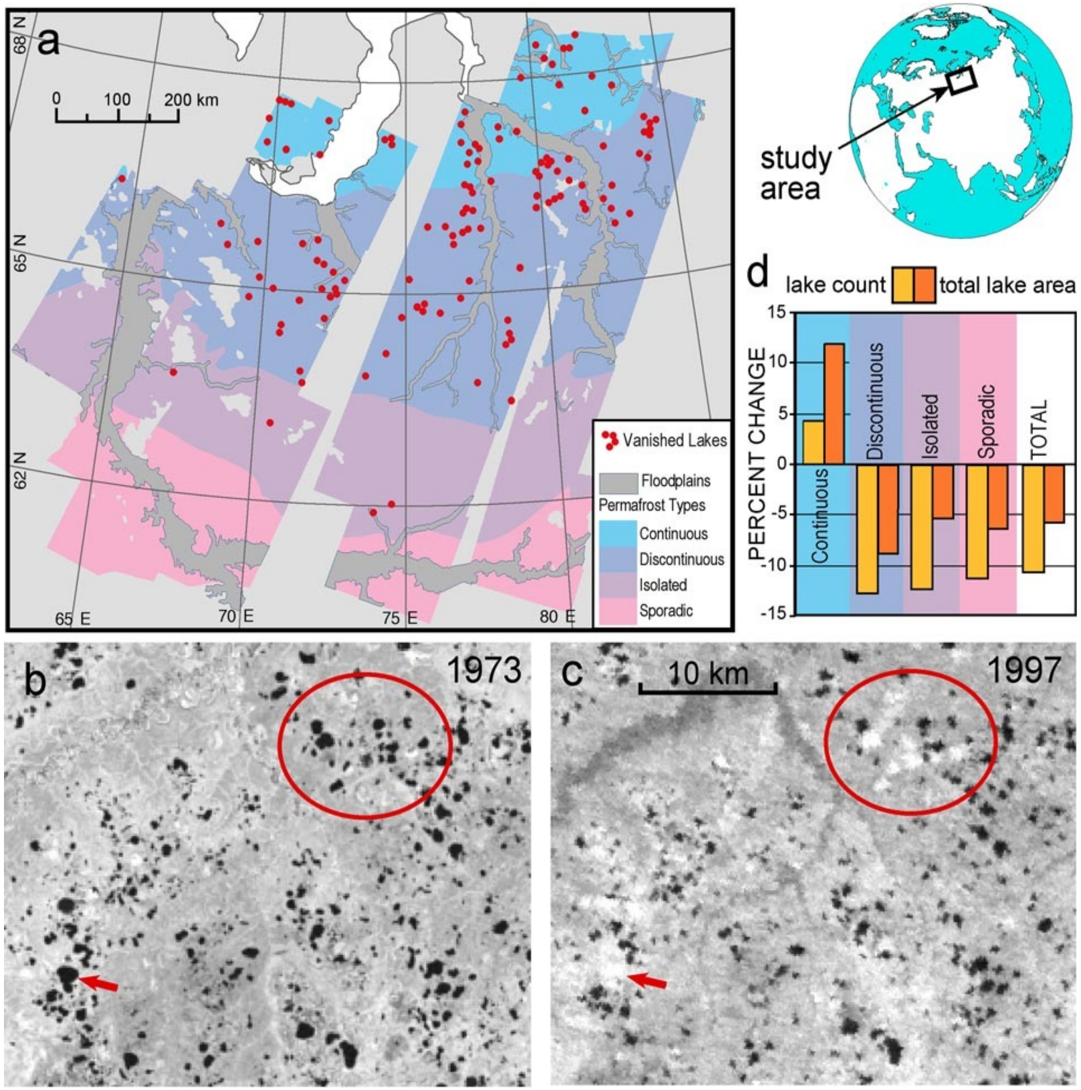






Data by Davydov from Circum Polar Active Layer Monitoring (CALM) Sites in Chersky

Disappearing of lakes in the North Eurasia

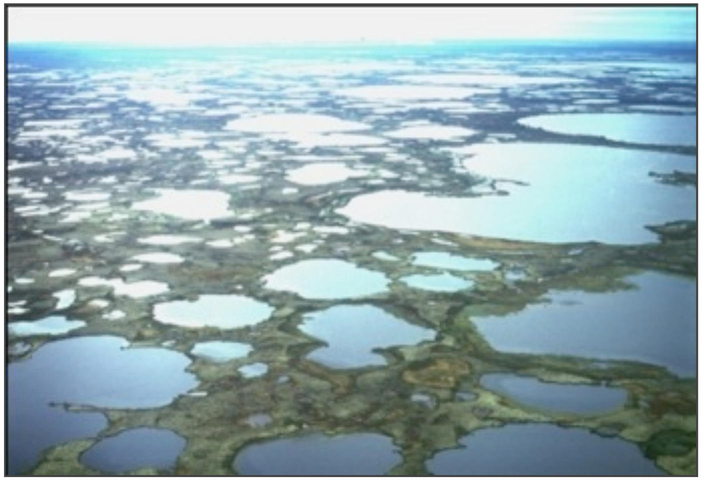


- •Examining temporal variability of ~10,000 West Siberian lakes and ponds
- •Comparing archived Landsat data from early 1970’s w/ contemporary RESURS and MODIS data

Why did the lakes disappear?

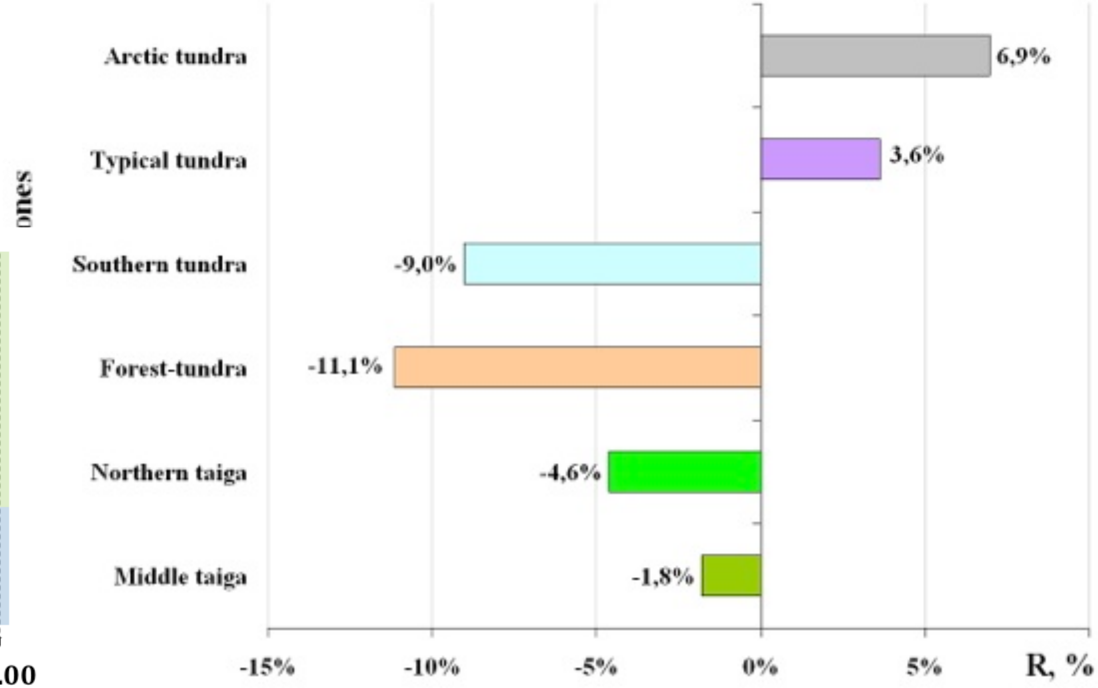
Courtesy Laurence Smith, UCLA

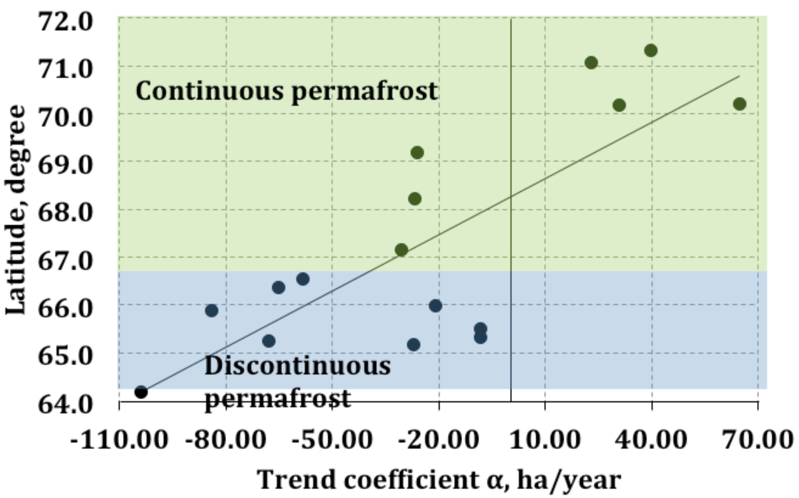
Changes in thermokarst lakes



Results of detailed analysis of Landsat TM for 30 test sites across the Western Siberia over 1973-2009

The average value of relative change of total lake area in different landscape zones.



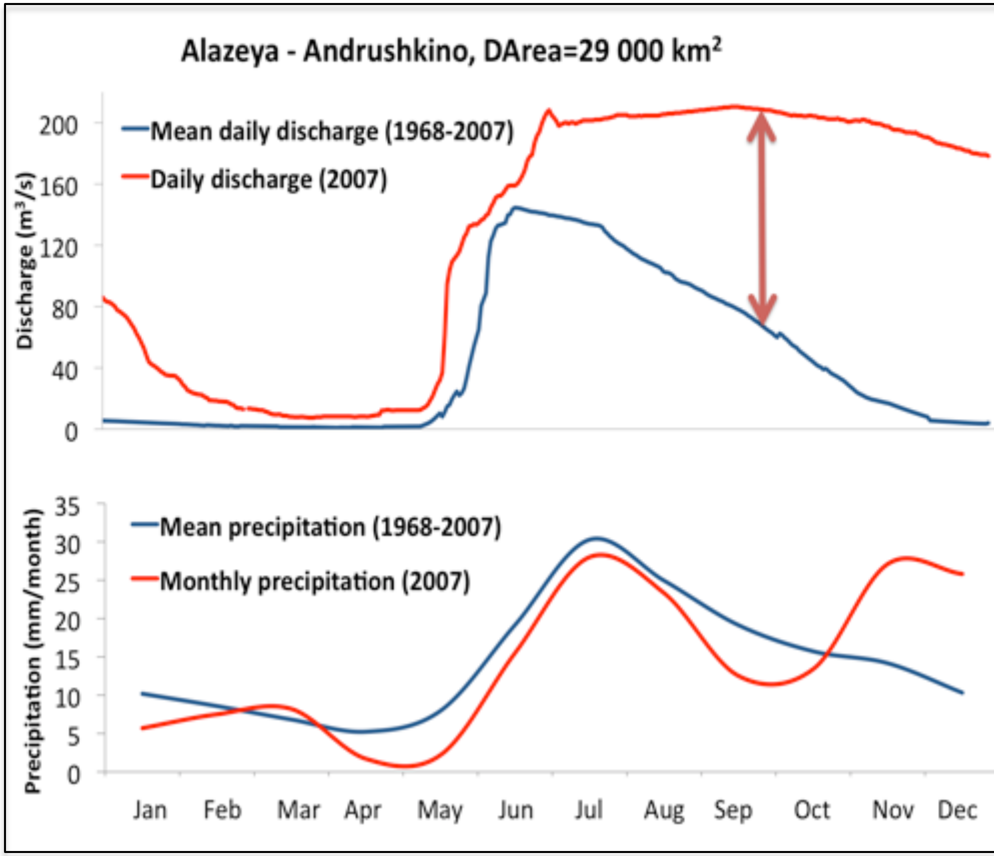


Linear trend coefficients for total area of lakes depending on latitude. Positive values of the coefficient indicate increasing lake area and negative values indicate an average reduction lake area

Shiklomanov, A.I. R.B. Lammers, D. Lettenmaier, Yu. Polischuk, O. Savichev, L.C. Smith, 2012: Hydrological changes: historical analysis, contemporary status and future projections [Chapter 4 in "Regional Environmental Changes in Siberia and Their Global Consequences", Ed. Gutman and Groisman], Springer, in press.

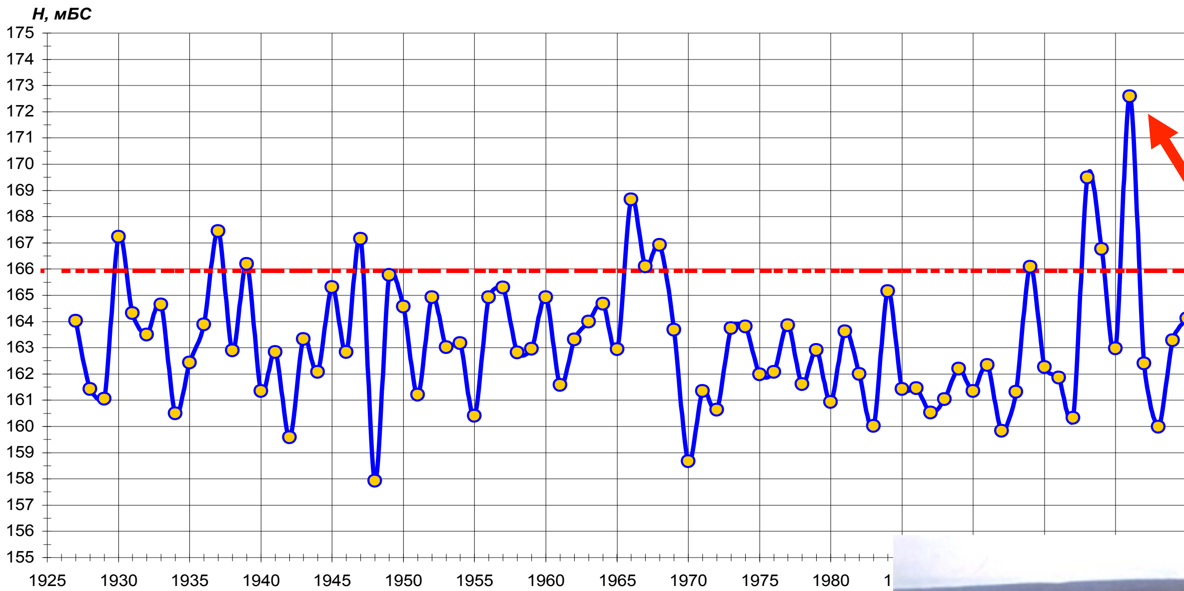
Courtesy to Yu. Polischuk, UGRA University, Russia

Draining of lakes due to permafrost degradation can significantly change river flow regime



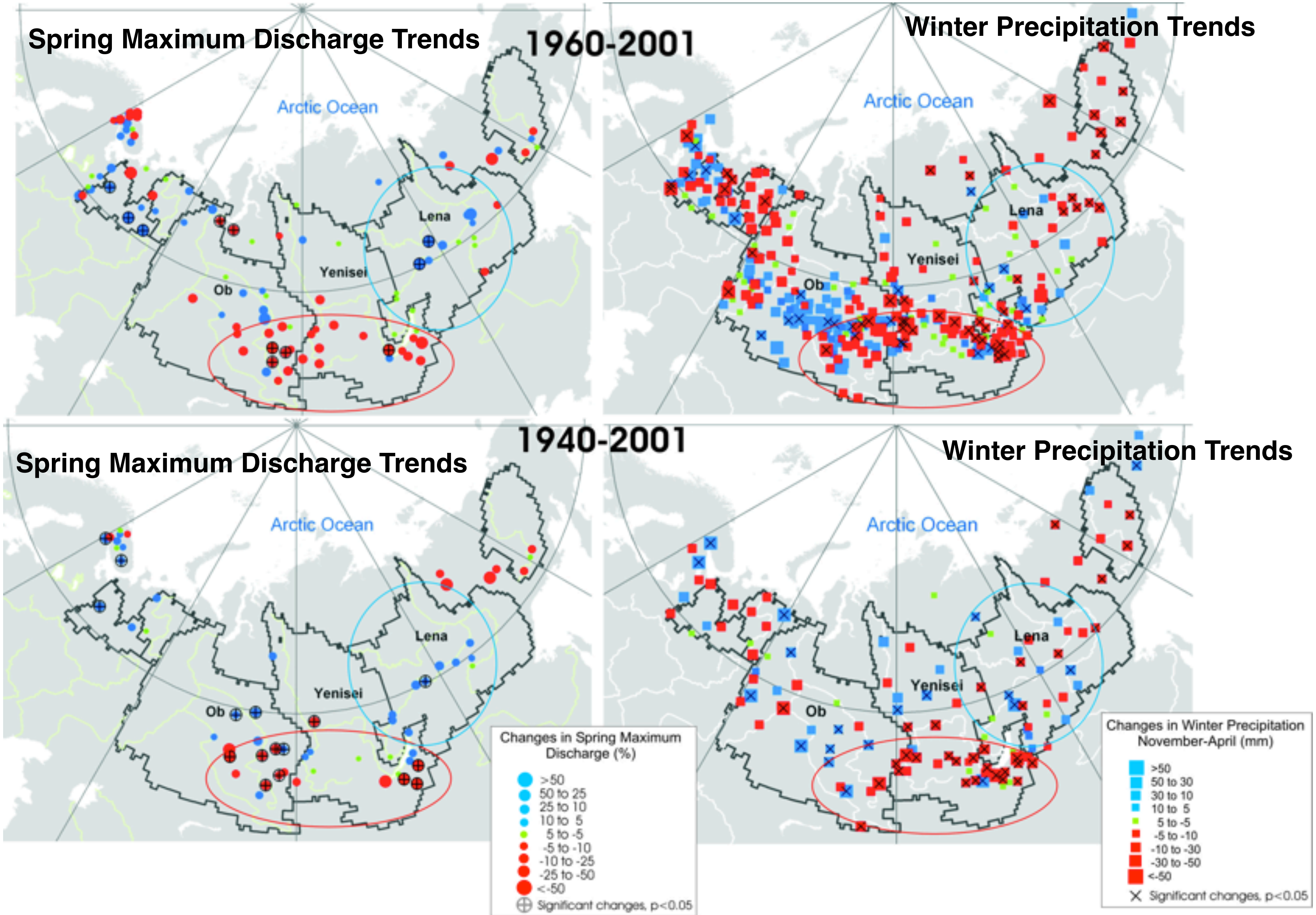
Example of a hydrological anomaly during the summer of 2007 in the Alazeya river basin. Significant flooding at Andrushkino (lower right) resulting from anomalously high summer river discharge (red arrow, upper left) was not the result of basin-wide precipitation (lower left). Subsequent searches for causes yielded drained lakes (upper right). Data: R-ArcticNet & ArcticRIMS; photos: http://igorpodgorny.livejournal.com/187501.html.

Extreme hydrological events



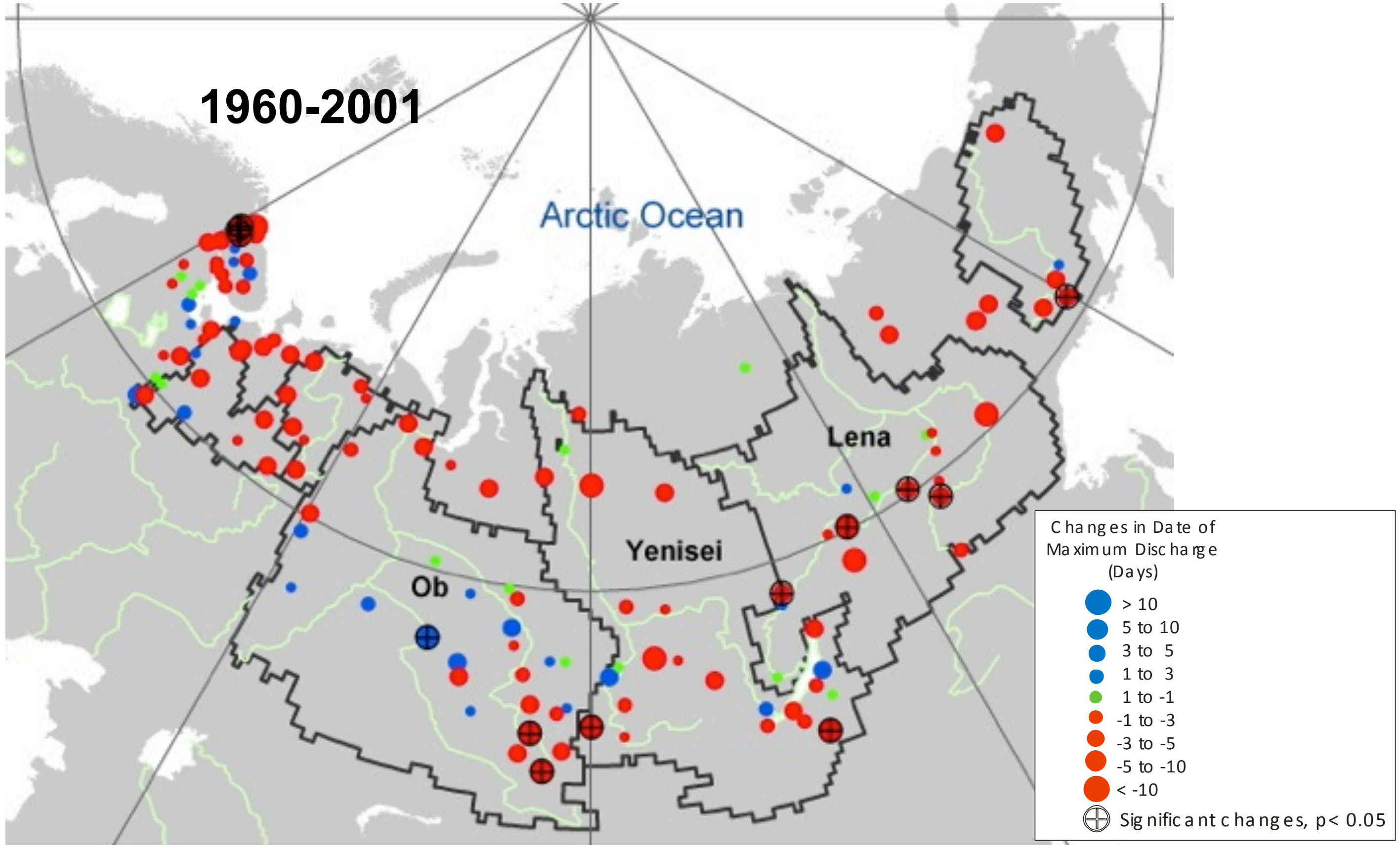
Long-term variations of the maximum water levels on the Lena river at Lensk due to ice jams

The spatial pattern of trends in Nov-Apr precipitation---a snowfall proxy---is broadly consistent with the pattern of observed local runoff trends



Shiklomanov et al, J Geophys Res, 2007

Change in dates of maximum spring daily discharge over 1960-2000



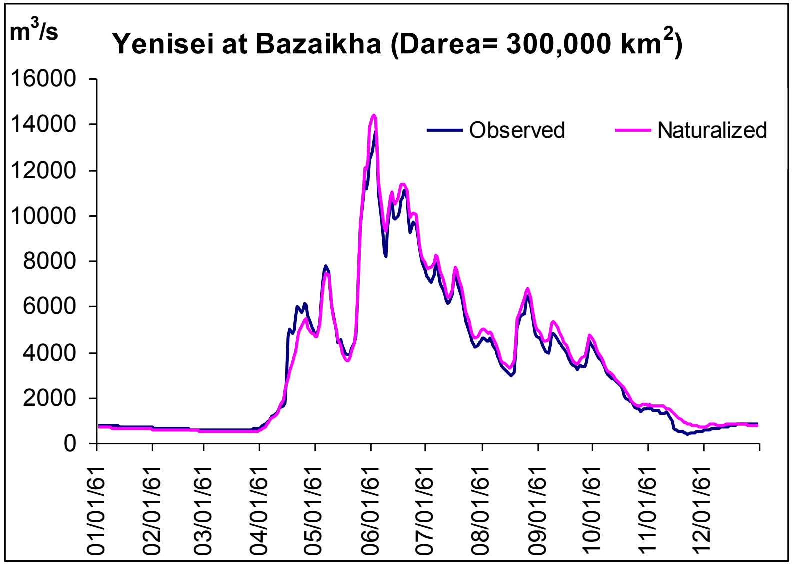
Trend:	Total	Significant	Significant %
Increasing	25	1	4
Decreasing	79	11	14

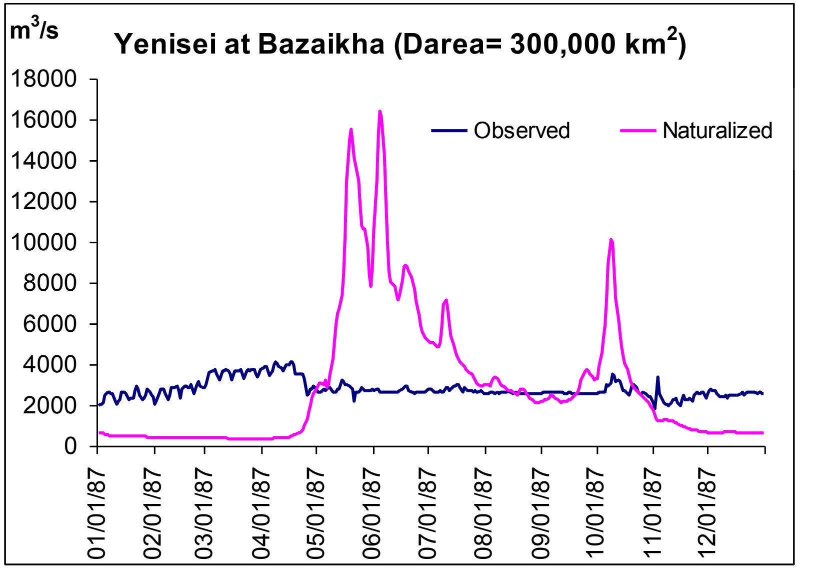
Evidence of earlier snowmelt across North Eurasia

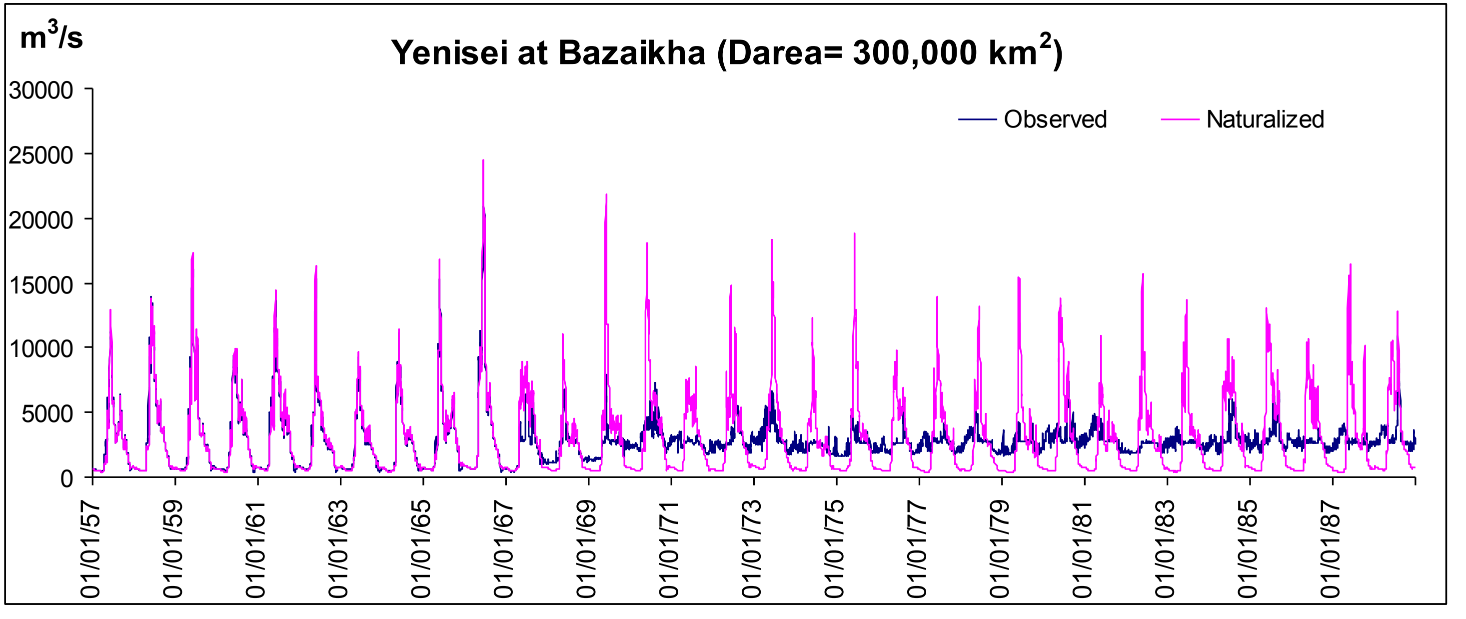
Shiklomanov et al, J Geophys Res, 2007

Human impact on hydrology

Effect of water management on river discharge

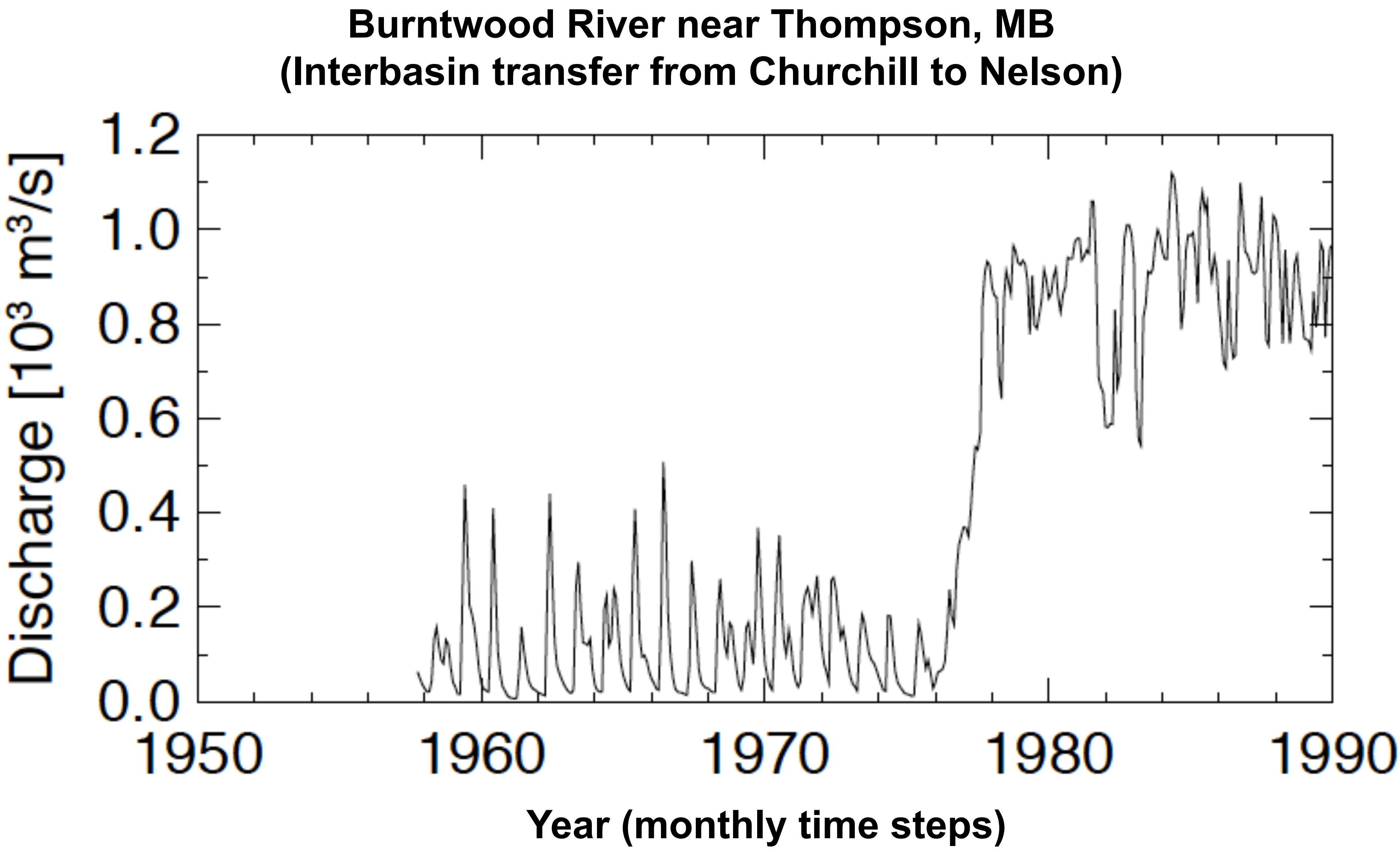






Supported by NSF OPP, grant ARC0612062, PI- Shiklomanov

It could be worse…



This graphic meets
CRTC Canadian
Content Guidelines

Data: Environment Canada – HYDAT National Water Data Archive

Modeling of river discharge to eliminate impacts of reservoirs

Duamel integral $$Q_{(t)} = \int_{0}^{t} Q'_{(t-\tau)} P_{(\tau)} d\tau$$

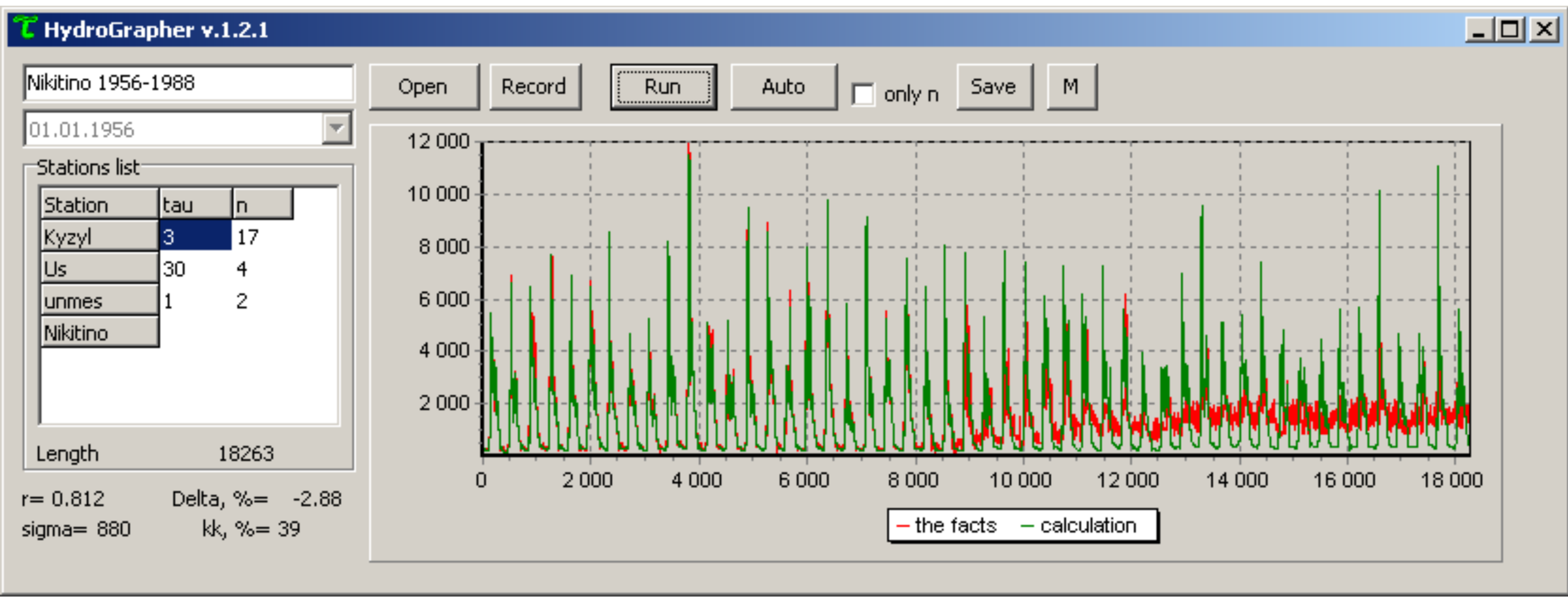
P(t) - the influence function (the travel curve) is approximated with a two-parameter equation suggested by Nash (1958) and Kalinin and Milukov (1959)

$$P(\tau) = \frac{1}{\tau(n-1)!}\left(\frac{t}{\tau}\right)^{n-1} e^{-\left(\frac{t}{\tau}\right)}$$

Selection of parameters is carried out proceeding from a minimum condition of mean square deviation

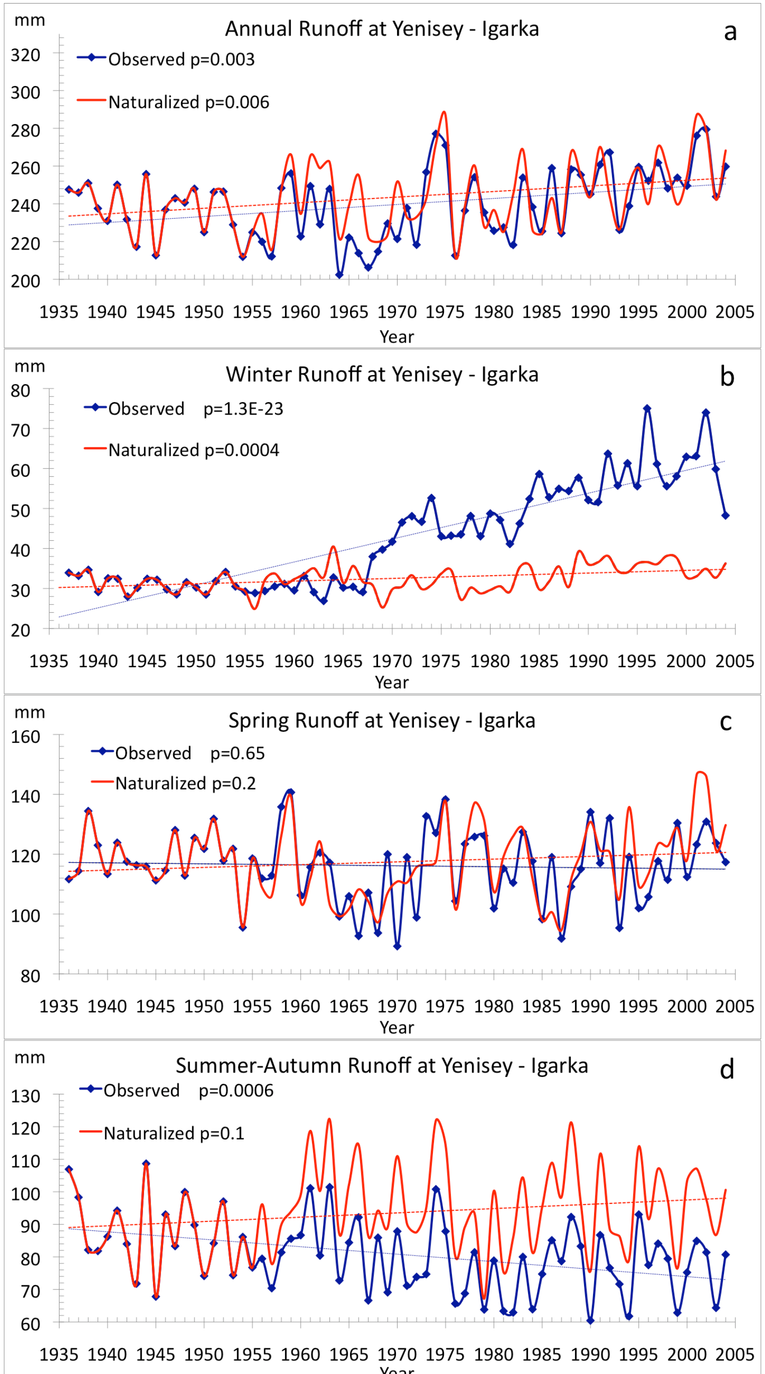
$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}\left(Q_{p,i} - Q_{f,i}\right)^2}{n}}$$

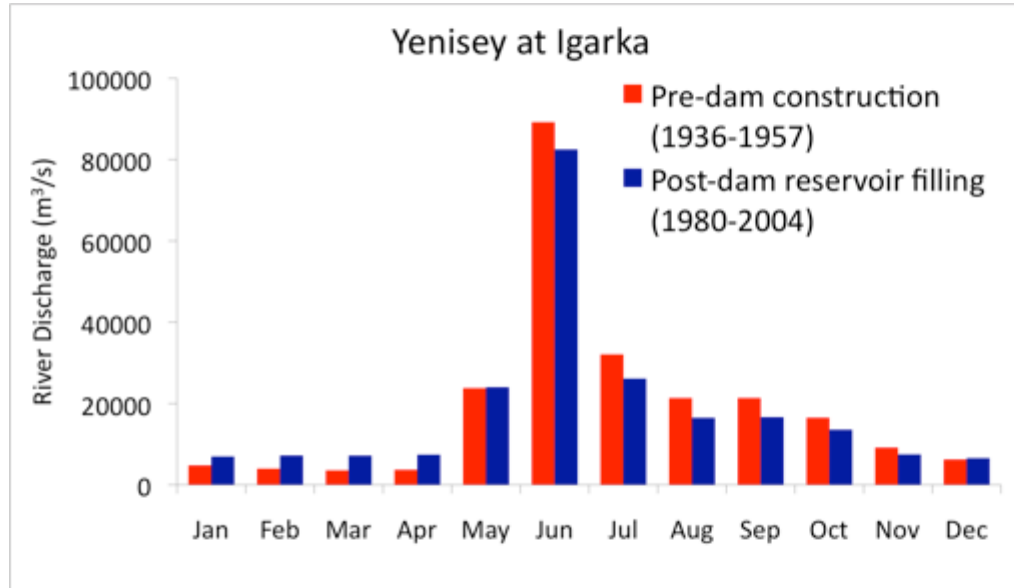
- Computations are made on daily time step for each river reach;
- For each upstream gauge the parameters τ and n are defined;
- Unmeasured (lateral runoff) is estimated by multiplying of total runoff from measured gauges with characteristic runoff formation on K coefficient. Parameters τ and n are defined for lateral runoff as well.
- Optimization procedure is used to define parameters τ and n based on minimization of deviations between observed and naturalized daily discharge



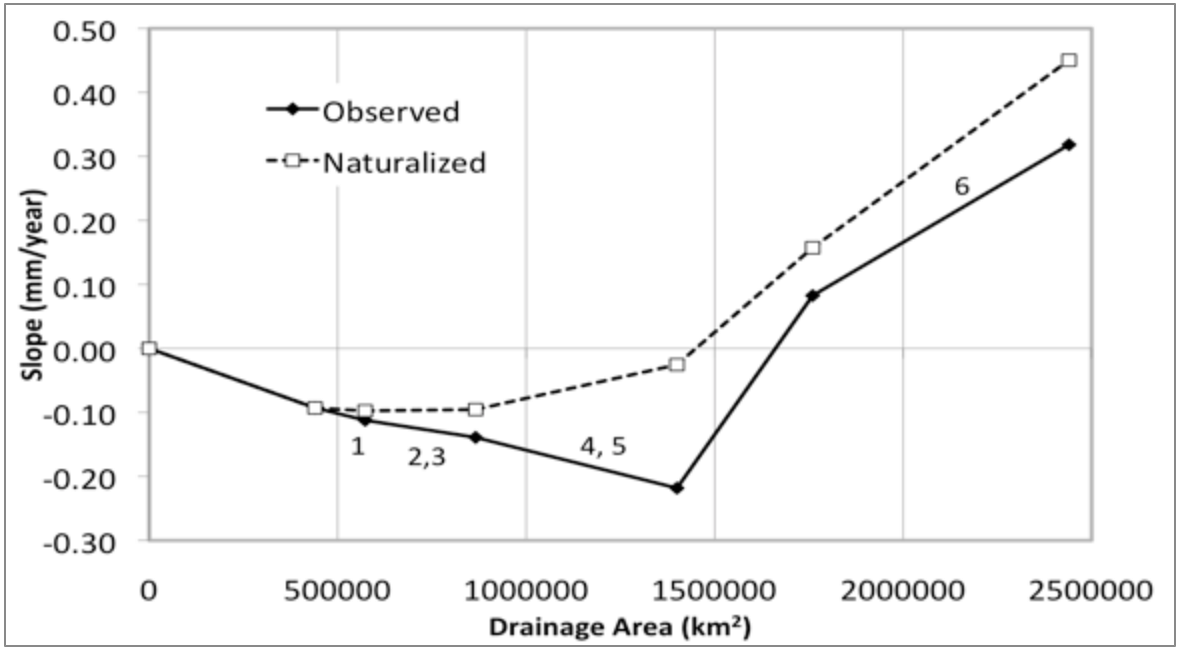
Supported by NSF OPP, grant ARC0612062

Water management impact on seasonal discharge





Time-series of observed and naturalized (reconstructed) river discharge for Yenisey at Igarka over 1936-2004; (a) annual, (b) winter (November to April), (c) spring (May to June), (d) summer-autumn (July to October). Thin dashed lines show linear trends defined from least squares linear regression analysis and p-values represent significance of the trend. Trend is considered significant if $p<0.05$ ($\alpha=95\%$). (*From Shiklomanov & Lammers ERL, 2009*)



Observed and naturalized 1936-2004 annual slopes of the trend line at six gauge locations along the Angara and Yenisey rivers. Integers represent the locations of major dams from Table below.

ID	Name	River	Long-term discharge (km^3)	Total capacity (km^3)	Operating capacity (km^3)	Filling up Period (years)
1	Irkutskoje	Angara	60.4	48.1	46.4	1956-1960
2	Bratskoje	Angara	91.7	169.3	48.2	1961-1965
3	Ust-Ilimskoje	Angara	101	59.4	2.8	1971-1975
4	Sayano-Shushenskoje	Yenisey	46.7	31.3	15.3	1978-1984
5	Krasnoyarskoje	Yenisey	88.2	73.3	30.4	1966-1970
6	Kureiskoje	Kureika	19.4	18.5	11.2	1985-1987
7	Khantaiskoje	Khantaika	16.6	23.5	17.3	1966-1970

Future Changes in Regional Hydrology

Future hydroclimatology with WBMPlus and IPCC GCMs

AO GCM presented in NEESPI RIMS web site

№	AO GCM	Country	Spatial resolution
1	ECHAM5/MPI-OM	Germany	1.9°x1.9°
2	CGCM3.1(T63) (ccc_t63)	Canada	2.8°x2.8°
3	UKMO-HadCM3	Great Britain	1.25°x1.875°
4	BCCR-BCM2	Norway	2.8°x2.8°
5	NCAR_CCSM3	USA	1.4°x1.4°
6	INM-CM3 PAH	Russia	3.0°x4.0°
7	GFDL-CM2.1	USA	2.0°x2.5°
8	MIROC3.2(medres) (ccsr_me)	Japan	2.8°x2.8°

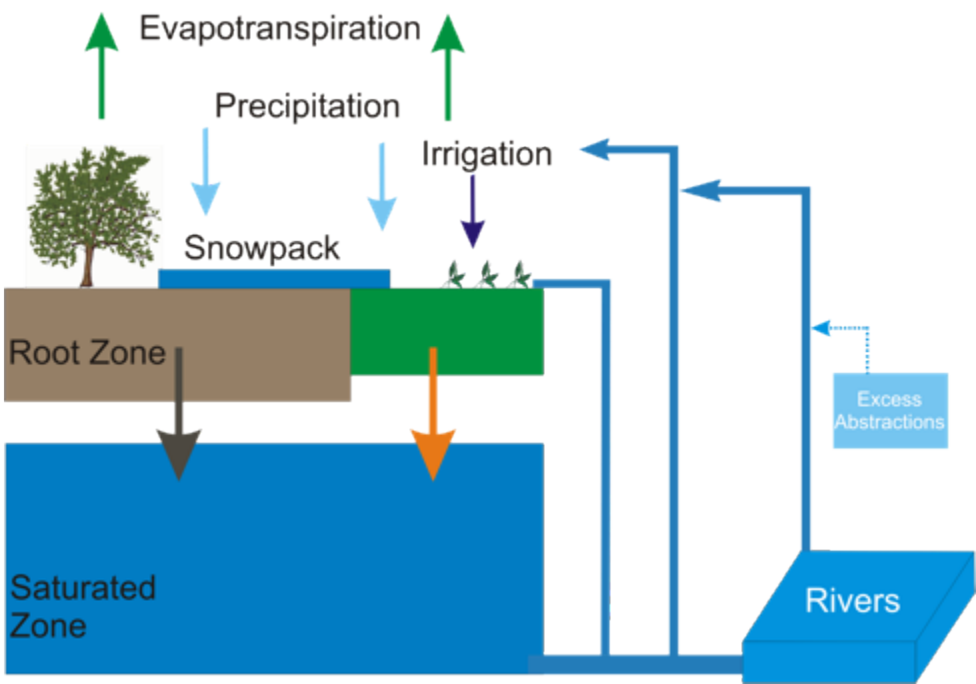
Climate scenarios:
- 20C3M - contemporary
- SRES A1b- future
- SRES A2 - future
- SRES B1 - future

WBMPlus:

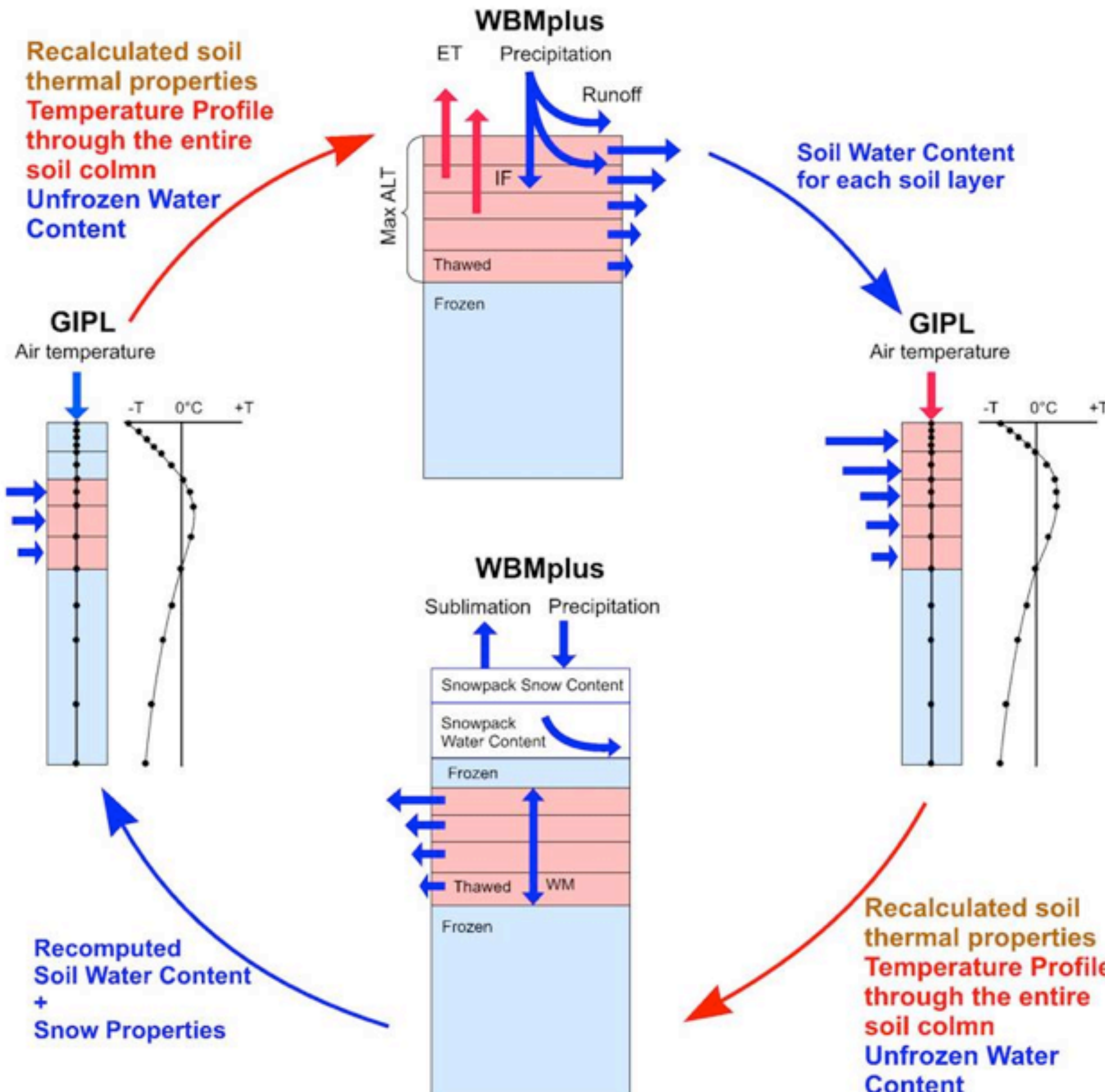
WBM + irrigation + reservoirs + impervious surface; daily time step (real time routing, irrigation, reservoirs)

Model modes: Pristine and Disturbed

Basic Output Parameters: Discharge,
Runoff,
Evapotranspiration,
Soil Moisture,
Snow Depth,
Irrigation Demand

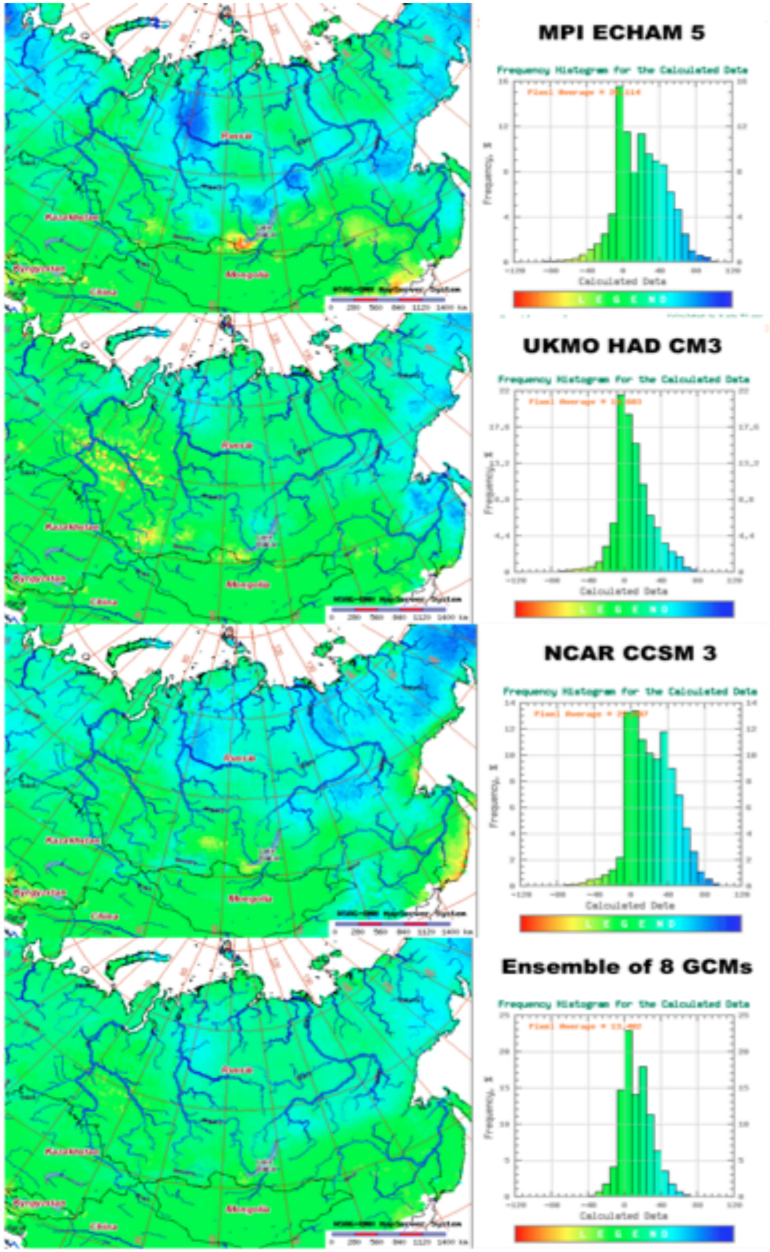


The HydroDynamic Model (HDTM 1.0)

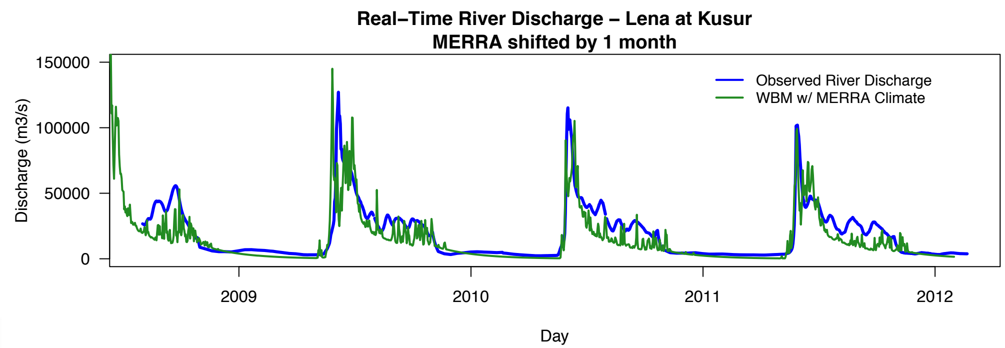


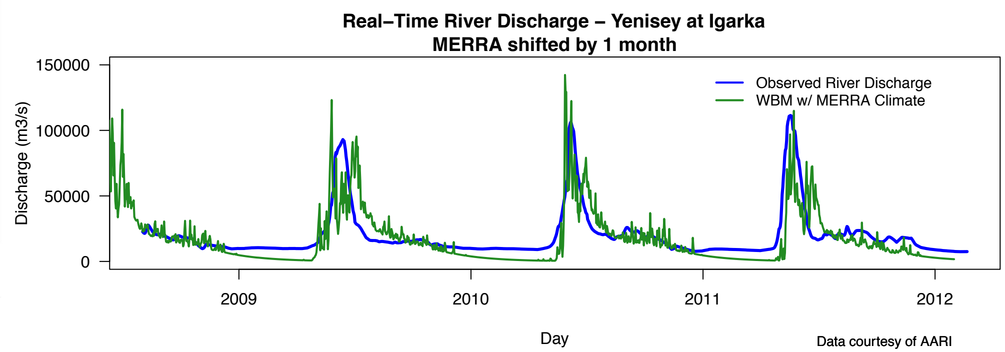
The HydroDynamic Model (HDTM 1.0) couples WBMplus with the Geophysical Institute Permafrost Lab permafrost model (GIPL 2.0, Marchenko et al., 2008) to numerically simulate permafrost and active layer parameters and components of the hydrological cycle taking into account the hydraulic properties of frozen soil.

UNH WBMPlus provides reasonable results for large river basins and monthly time steps.



Deviation of simulated mean annual river runoff over 2040-2060 relative to the long-term observed mean (1959-1999).





Observed and WBMPlus simulated daily river discharge for Lena and Yenisey

Expected changes in the discharges of the largest Pan-Arctic rivers as a result of global climate change (according to different authors)

Author, Year	Climate scenario	River basin	Annual discharge change (%)
Aroa & Bayer 2001	CGCM By 2050	Yenisey Lena Ob Mackenzie Ukon	18 19 -12 20 10
Mokhov and Khon, 2002; 2003	HadCM3 ECHAM4	Yenisey Lena Ob	8 22-24 3-4
Georgievsky et et al., 2003	HadCM3	Lena	12
Manabe & Wetherold, 2003	IS92a by 2035-2065	Yenisey Lena Ob Mackenzie Ukon	13 12 21 21 20
Arnell, 2004	Ensemble of 6 models by 2080 A2 emission B2 emission	Total inflow to the Arctic Ocean	24 18
Nohara et al, 2006	Ensemble of 19 models by 2081-2100 for A1b emission	Yenisey Lena Ob Mackenzie Yukon	16 24 10 16 25
Shiklomanov A., 2010	Ensemble of 8 models for A1b emission by 2050	Yenisey Lena Ob Pechora	18 23 6 7

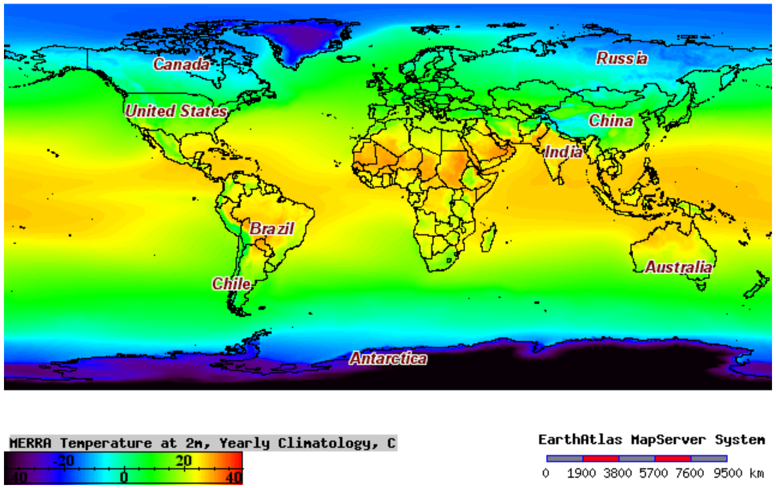
Updated from: Shiklomanov I. A. and A. I. Shiklomanov, 2003: Climate Change and Dynamics of River Discharge into the Arctic Ocean. Water Resources. Vol.30, #6 November 2003, 593-601.

Rapid Integrated Mapping and Analysis System (RIMS)

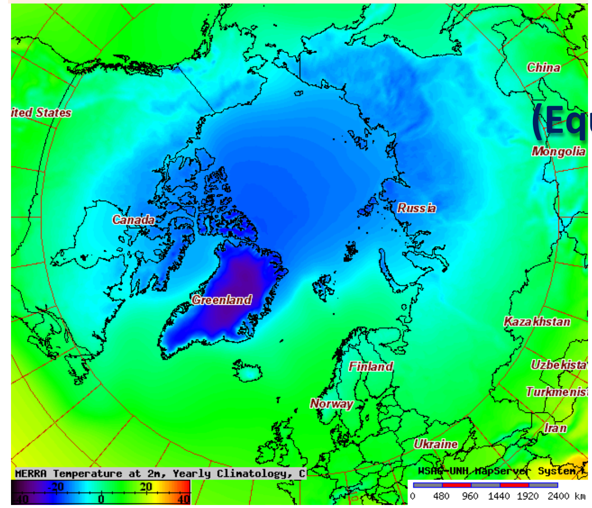
http://earthatlas.sr.unh.edu/maps
http://neespi.sr.unh.edu/maps
http://nh-rims.sr.unh.edu/maps
http://www.riverthreat.net/maps
http://riceghg.sr.unh.edu/maps

Illustration of a Dataset Abstraction with Web Map Services (WMS)

earthatlas.sr.unh.edu/maps



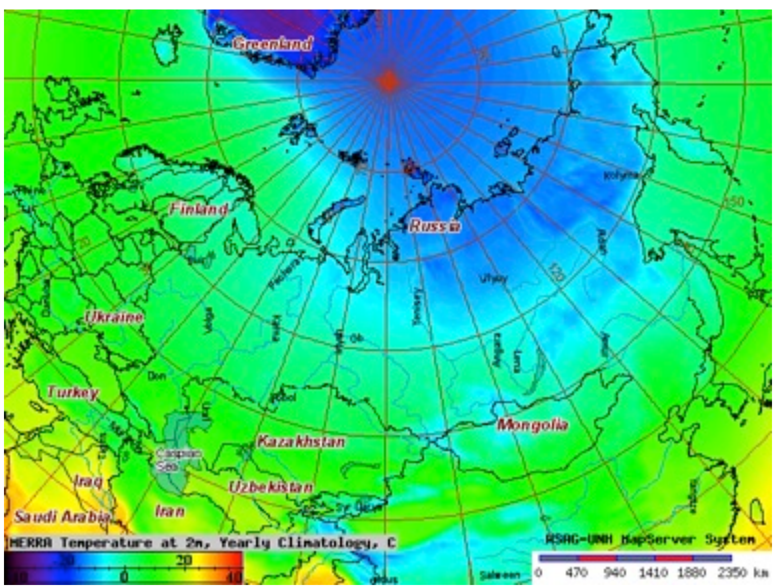
nh-rims.sr.unh.edu/maps

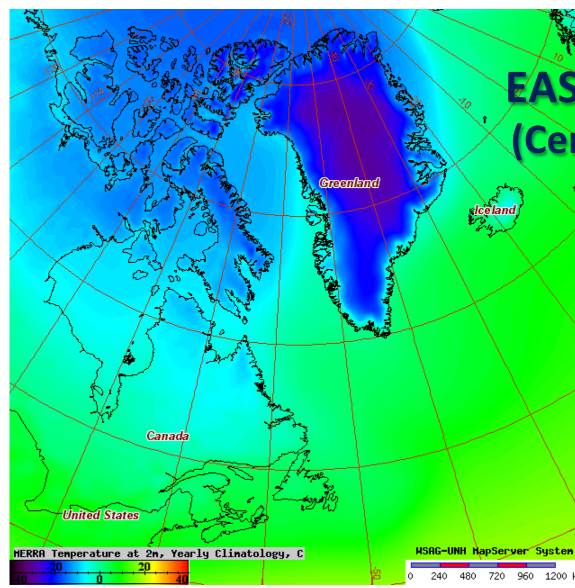


EASE projection
(Equal Area Scalable Earth)
Polar view

In fixed projection like this zooming to Alaska will result in showing it upside down (North down and South up).

neespi.sr.unh.edu/maps





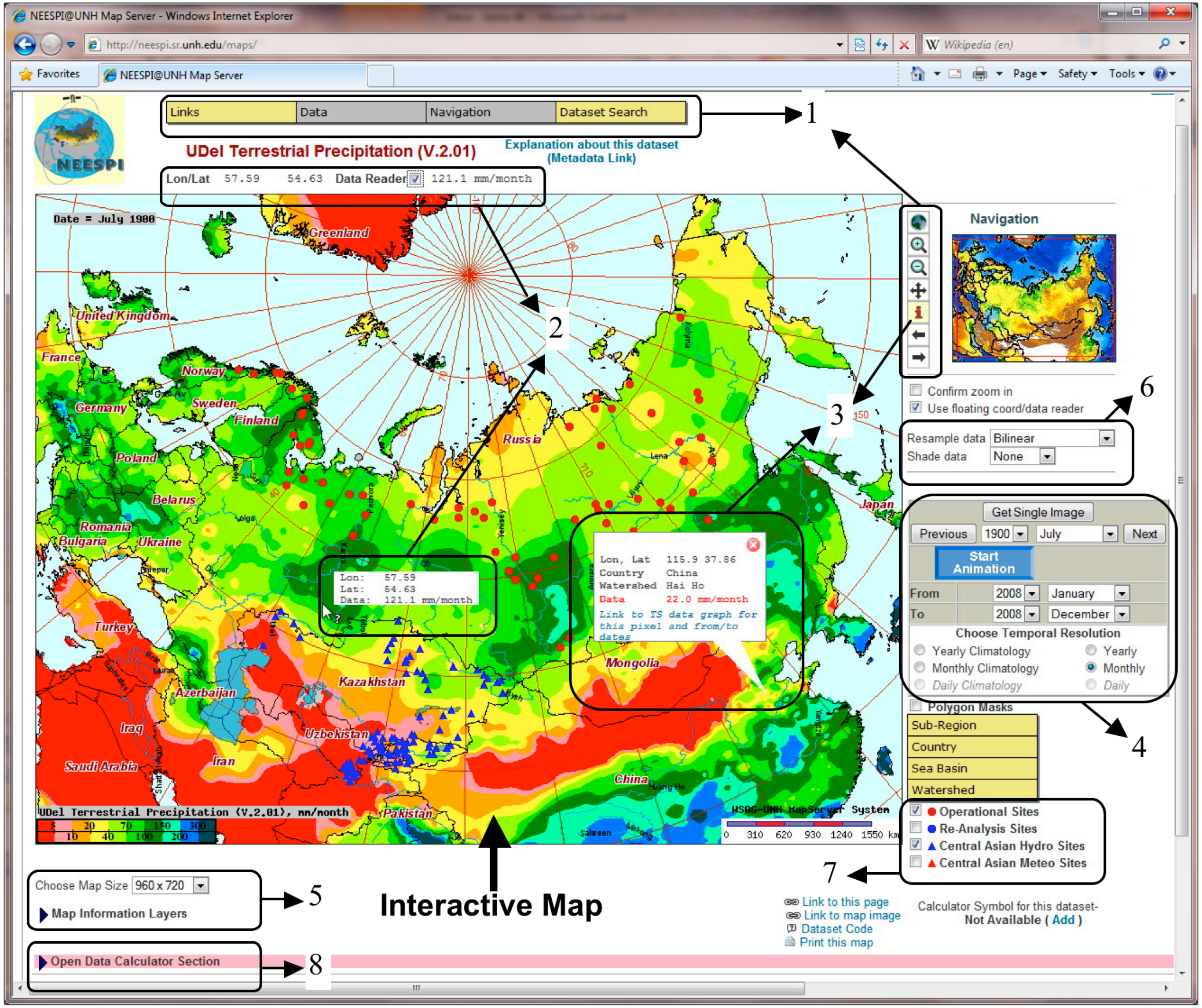
EASE adaptive projection
(Central Meridian to North)

In adaptive projection like this zooming or panning to any geographical area will automatically rotate map view so that North always positioned upward.

NEESPI RIMS

Regional Integrated Mapping and Analysis System

http://neespi.sr.unh.edu/maps



1) data search/selection, spatial navigation, metadata link, etc.;

2) coordinate and map data value reader;

3) pixel query tool (i-tool) gets coordinates, country, watershed, and map data value;

4) time series navigation tool;

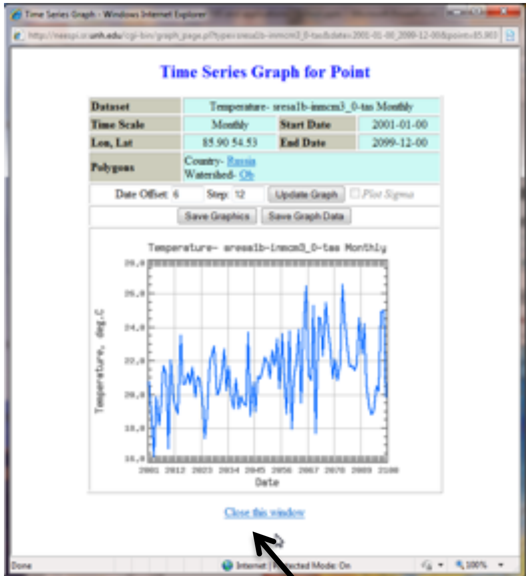
5) map size and base layer choices;

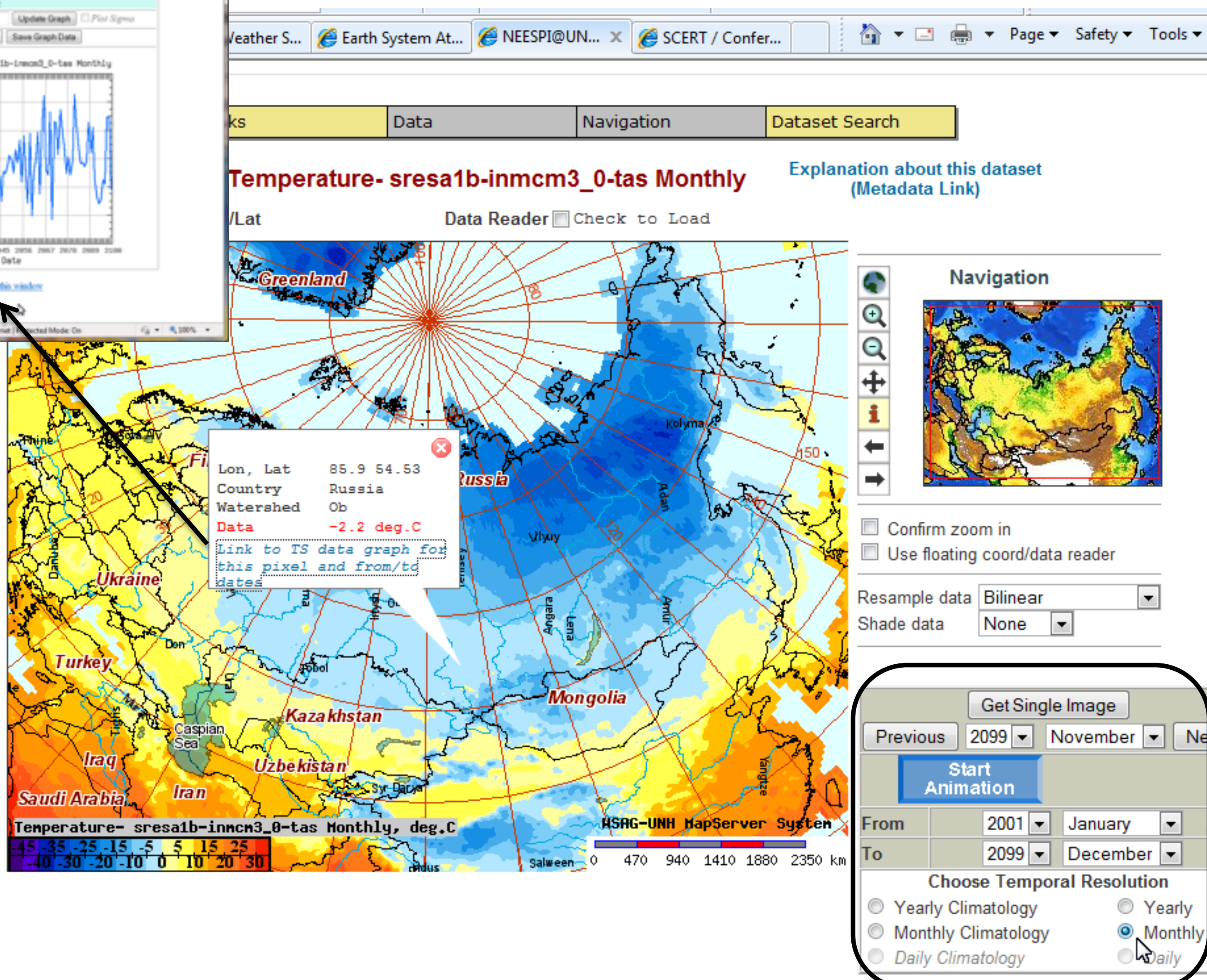
6) data interpolation and shading tools;

7) point/station data list with clickable symbols that open station pages in a separate browser window;

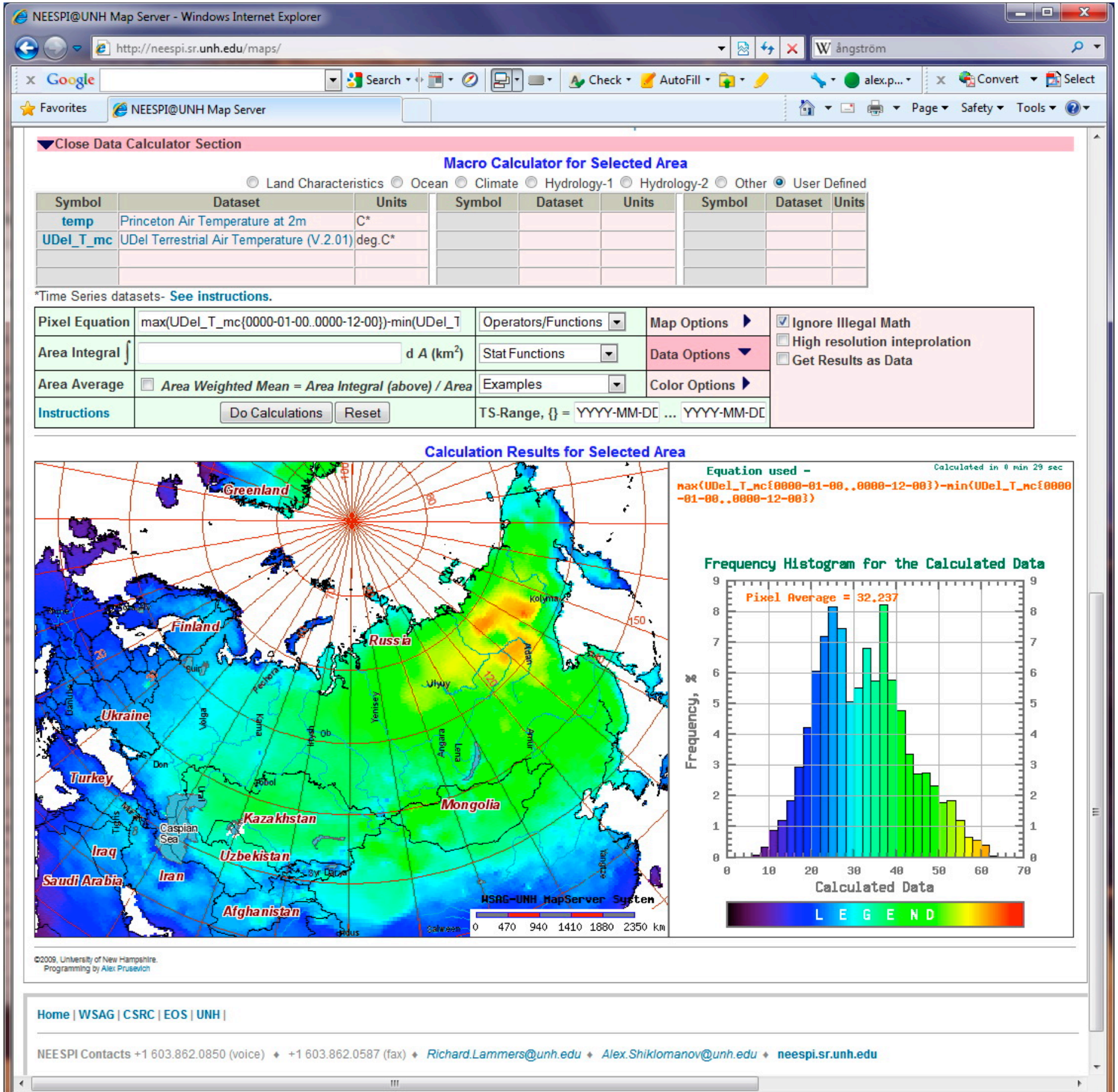
8) fold-out section to run the Data Calculator application to perform mathematical and logical functions over gridded or vector datasets;.

Controls of temporal resolutions





NB



"Data Calculator" Web application that uses RIMS Data Manipulation Service.

Example: Temperature difference between the warmest and coldest month of the year is calculated for the NEESPI

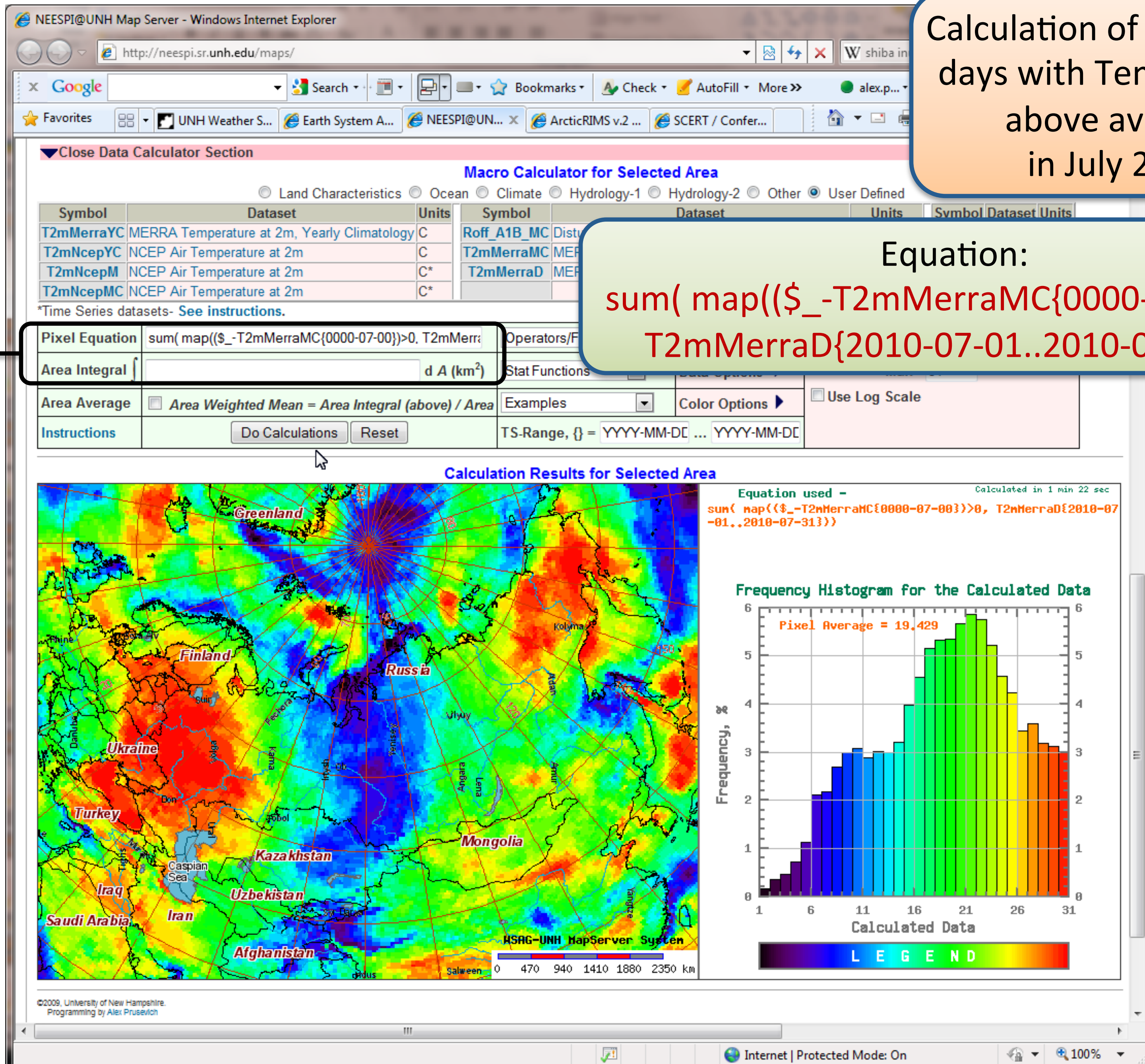
Results are displayed as a map and frequency histogram at the bottom of the Web page.

The Data Calculator

Calculation of number of days with Temperature above average in July 2010

Equation:
sum(map(($_-T2mMerraMC{0000-07-00})>0, T2mMerraD{2010-07-01..2010-07-31}))

NB



Close Data Calculator Section

RIMS 2.0 Geospatial Equation Editor

Macro Calculator for Selected Area

Land Characteristics | Ocean | Climate | Hydrology-1 | Hydrology-2 | Other | User Defined

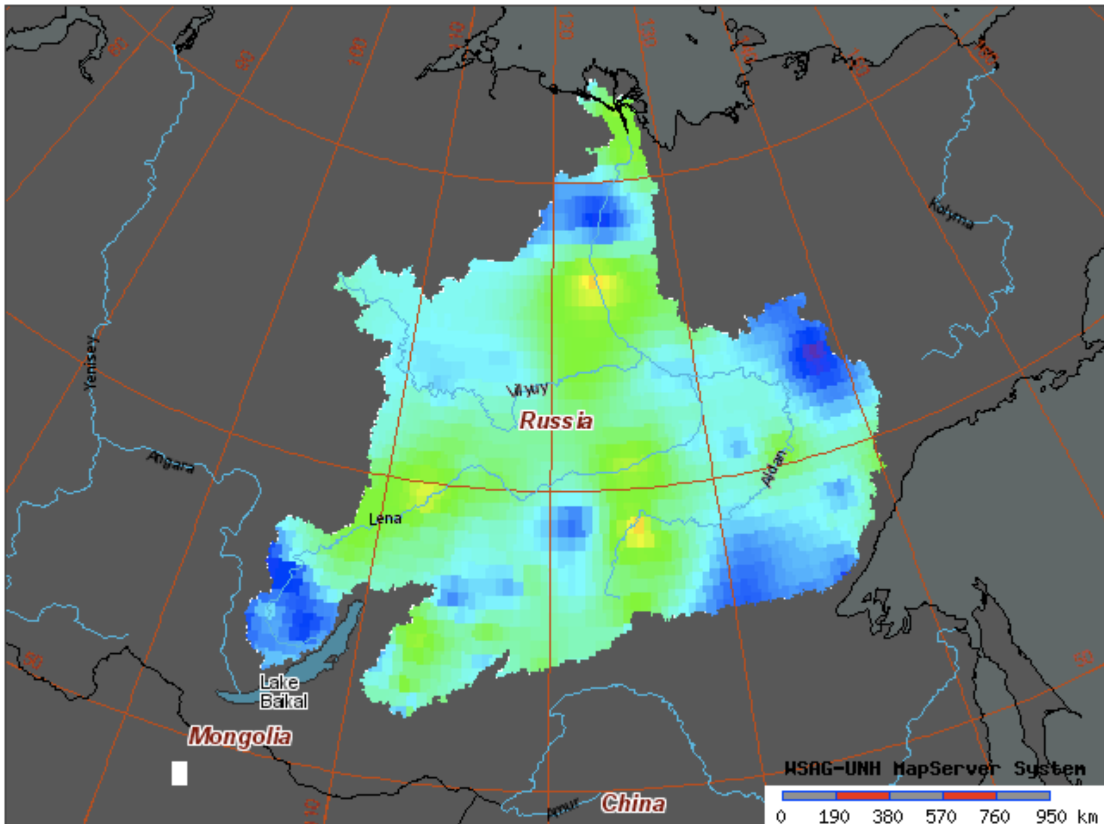
Symbol	Dataset	Units	Symbol	Dataset	Units	Symbol	Dataset	Units
UDEL_Y_P	UDel Terrestrial Precipitation (V.2.01)	mm/year*						
River_basins	Watershed ID							

*Time Series datasets- See instructions.

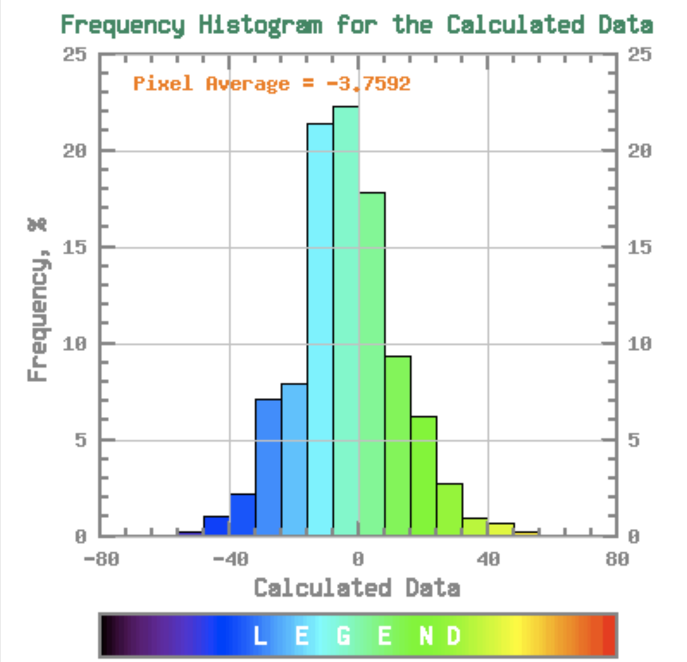
Pixel Equation	ıverage(UDEL_Y_P{1936-00-00..1977-00-00}) if River_basins==9	Operators/Functions	Map Options
Area Integral ∫	d A (km^2)	Stat Functions	Data Options
Area Average	Area Weighted Mean = Area Integral (above) / Area	Examples	Color Options
Instructions	Do Calculations Reset	TS-Range, {} = YYYY-MM-DD ... YYYY-MM-	

Difference between 2 user defined time periods: Precipitation 1978-2004 minus 1936-1977 over Lena river basin with map and histogram.

Calculation Results for Selected Area



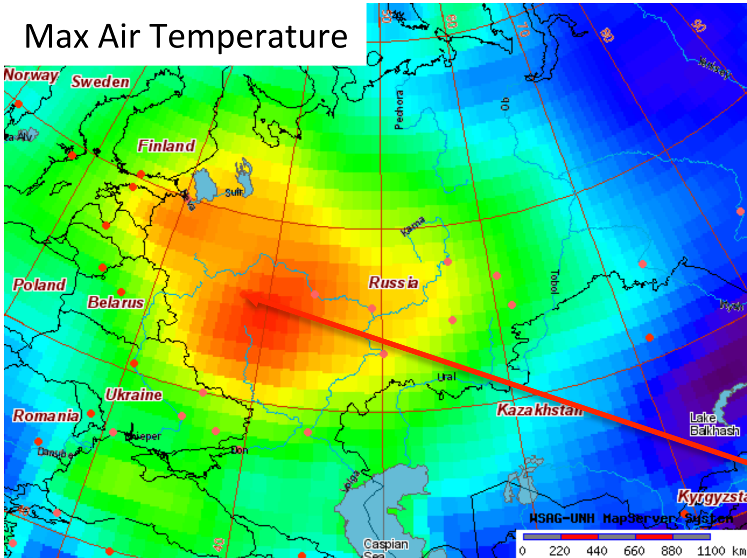
Equ
0..2004-0

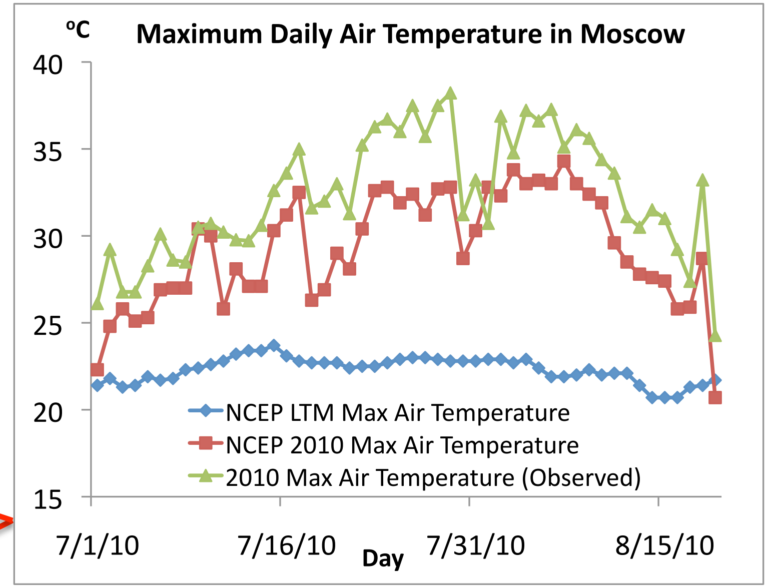


Analysis of air temperature and population in summer 2010

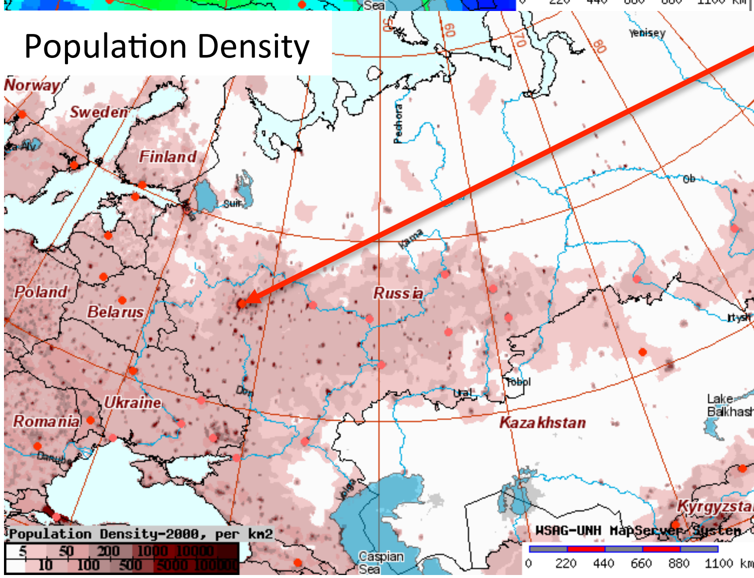
Deviation of daily max air temperature over July2-Aug18, 2010 from LTM

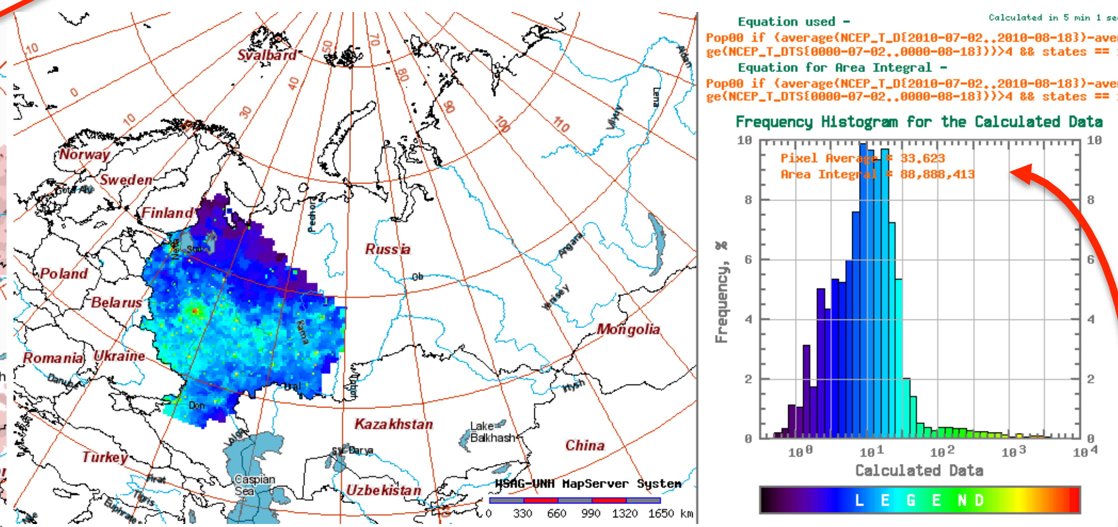
Max Air Temperature





Population Density





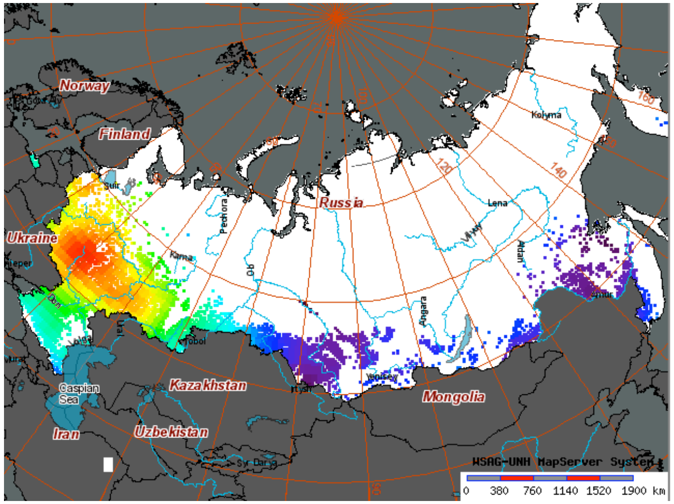
Distribution of population density

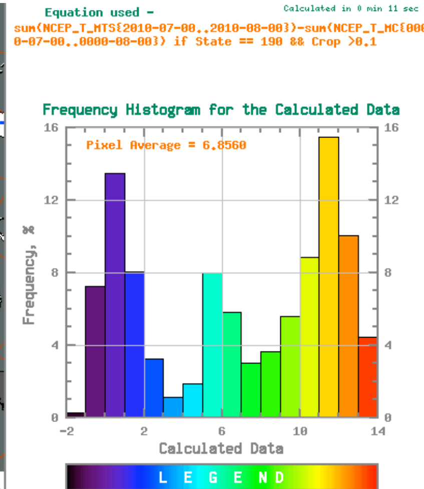
Calculation of area and population in Russia where mean daily air temperature over the period 07-02-2010 to 08-18-2010 was 4^0C higher then LTM. This heat effected about 90 million people or ~ 60% of total Russian population

Anomalies of air temperature and precipitations in summer 2010 from long-term mean over 1985-2010 for Russian cropland area (cropland >10% per grid cell)

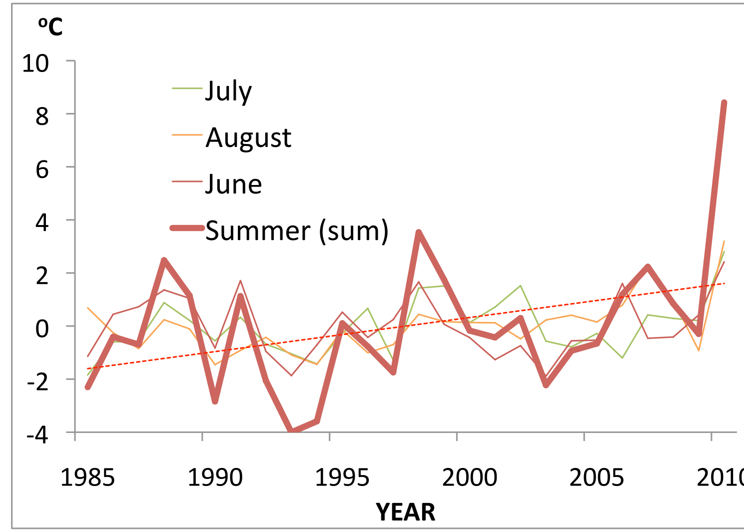
Air Temperature

Anomalies of summer 2010 from LTM



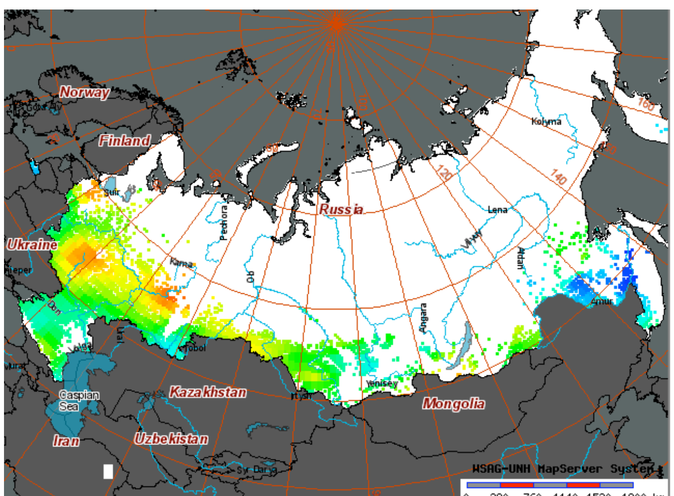


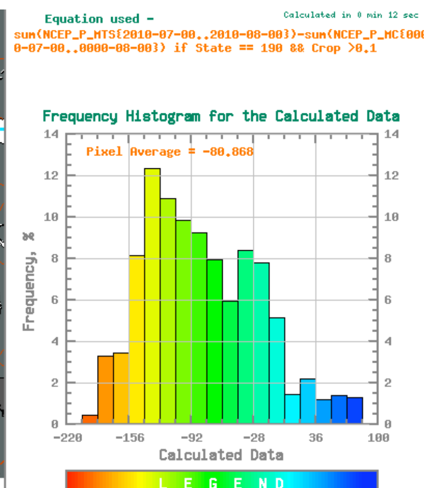
Anomalies of over 1985-2010

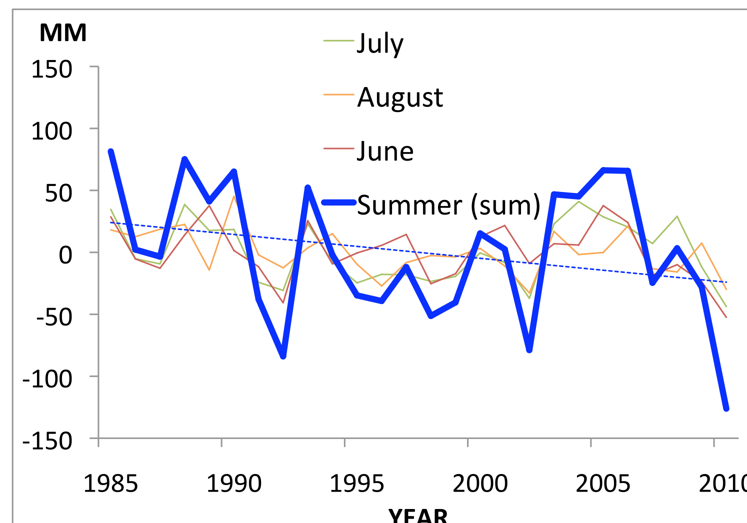


Precipitation

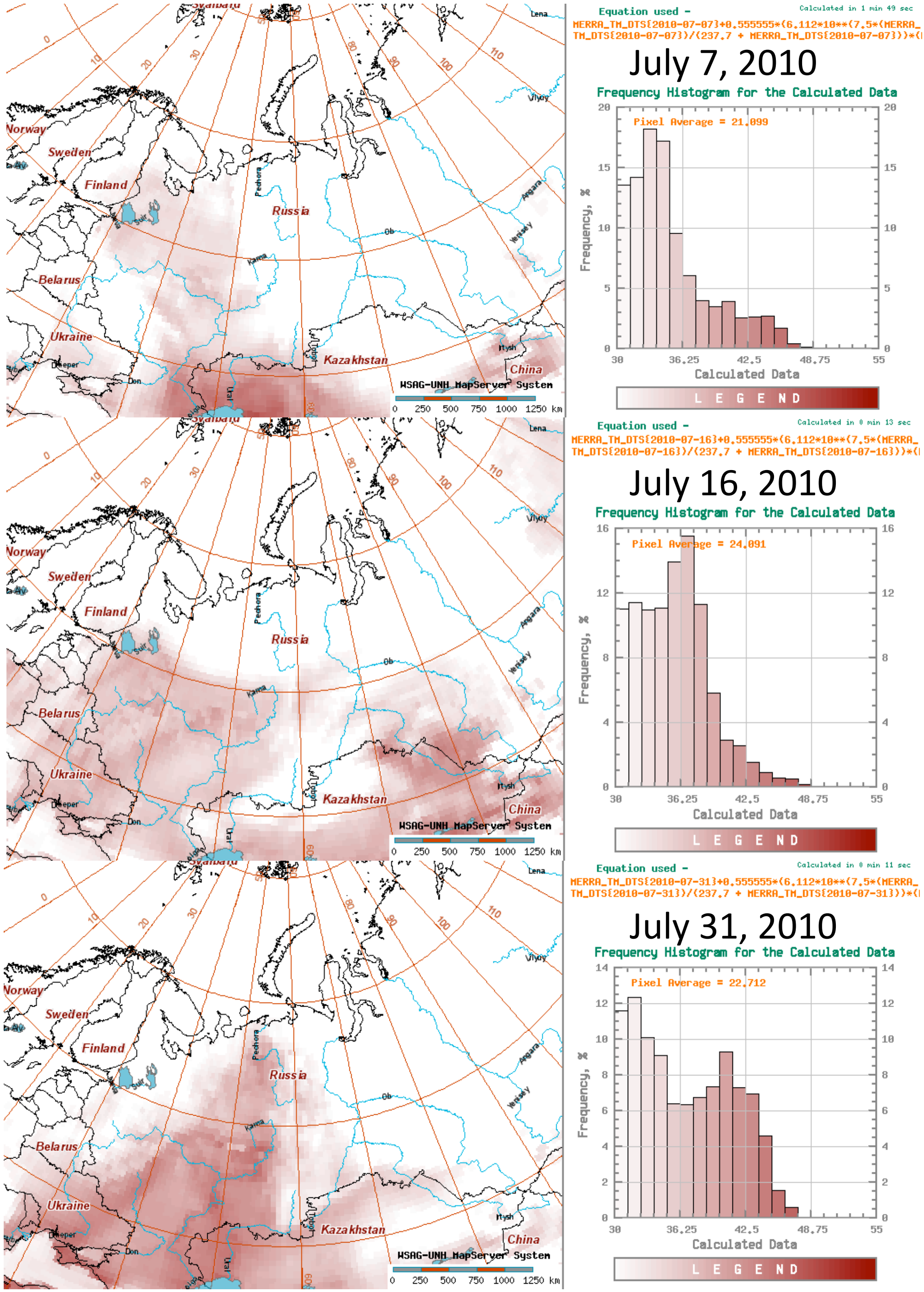
Anomalies of summer 2010 from LTM







2010 wheat yield in Russia was ~40% less than in 2008, 2009



Computation of HUMIDEX (heat wave index used in Canada)

HUMIDEX Value:	Conditions:
30 to 34	Noticeable discomfort
35 to 39	Evident discomfort
40 to 45	Intense discomfort;
Above 45	Dangerous discomfort;
Above 54	Heat stroke probable;

Summary of RIMS data holdings

Earth System Science Data Category	Key Sources	Examples of Major Parameters	Current Dataset Count	
			Source	Source + DataCube
Hydrology	UNH, CCNY	Discharge, runoff, river networks, irrigation, dams	200	250
Past and Present Climate	NASA, NOAA, UDel, Princeton U.	Temperature, precipitation, evapotranspiration (ET), heat radiation, pressure, wind	70	210
	NCEP, MERRA		62	160
Future Climate and Hydrology	IPCC, UNH	Temperature, precipitation, ET, snow, runoff, discharge	680	4100
Remote Sensing	MODIS, UNH, UOklahoma	Vegetation indices, soil moisture, clouds, snow, fires	48	60
Physical Geography	NASA, USGS, UNH	Elevation, bathymetry, Blue Marble, Lon/Lat	28	22
Oceanography	NOAA, NCOF	SST, sea ice	3	4
Land Cover	UM, NASA, USGS	Land cover, vegetation, permafrost, freeze/thaw	60	80
Sociology and Economics	CIESIN, World Bank, US CIA, UNH	Population, GDP, industry, mortality/ birth/malnutrition rates	30	60
Agriculture	UWisc, Various	Crop land, crops, fertilizer loads, greenhouse emissions	160	200
Polygon Masks	UNH	Watershed, sea/ocean catchments, continents, countries, administrative units	18	18
Station Data	UNH, AGS	Hydrology, climate, public health	8	8
		Total	~1400	~5100

Thank you