Northern Eurasian Landscapes: Interactions between Humans, Hydrology, Land Cover and Land Use Change

Alexander Shiklomanov¹, Richard Lammers¹, Dmitry Streletsky², Olga Krankina³, Nikolay Shiklomanov², Xiangming Xiao⁴, Oleg Anisimov⁵

¹-University of New Hampshire
²-George Washington University
³-Oregon State University
⁴-Oklahoma State University
⁵-State Hydrological Institute, Russia
The research project is organized around three specific objectives:

**Objective 1:** Understand historical interactions between climate, land cover/land use, and hydrology and to project them into the future.

**Objective 2:** Evaluate the effects of the interrelated changes in hydrology and land cover/land use on humans and identify the vulnerable areas for socio-economic development in Northern Eurasia.

**Objective 3:** Incorporate NASA and affiliated biogeophysical data products, in situ data, modeled results, and human dimensions information into a regional analysis and mapping system for Northern Eurasia. (RIMS)
Acceleration of water cycle in the Eurasian pan-Arctic

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)

Annual time series of spatially aggregated river discharge over the 6 largest Russian basins, precipitation, air temperature and aggregated Arctic Ocean sea ice coverage. (Updated from Shiklomanov & Lammers, 2009 ERL)
Recent Syr Darya R. discharge increases

1) Increased glacier and snow melt at high elevations
2) Decline in human water use
3) Increasing precipitation (but not all data sets show this)
Anomalies of seasonal runoff over 1978-2005 from 1940-1977

*Updated from ACIA, 2005*
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.
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;
Intercomparison of mean annual precipitation for 2000 from NCEP and MERRA re-analysis with UDEL and CRU interpolated observations.
Deviation of mean annual MERRA precipitation over 1995-2011 from LTM over 1978-2011
• Water cycle across Northern Eurasia is accelerated

• The observed changes in river runoff cannot be fully explained with only climatic characteristics change

• Other potential causes of hydrological changes across the Northern Eurasia should be investigated
Study area and locations of experimental watersheds

- Forest loss
- Lake draining
- Vegetation change

- Irrigation
- Complex climate-related changes (freeze-thaw, glacier, wetlands, vegetation, snow etc.)
Land cover disturbances:

MODIS-derived 2000-2005 gross forest cover loss (SDSU)

MODIS-derived 2000-2010 burned area (UMD)


Courtesy to Tatiana Laboda, UMD

Data from the project supported website: http://neespi.sr.unh.edu/maps/
Change in Vegetation: Vegetation Indices derived from MODIS and AVHRR

MODIS NDVI trends for Caspian Sea Basin 2000-09 (courtesy to Saachi Sassan) and for Central European Russia (2000-2007) from NEESPI.sr.unh.edu/maps
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.
Timing and trend in the timing of spring thaw derived from SSM/I have elucidated the thaw correspondence with regional anomalies in annual NPP derived from MODIS and AVHRR. Mean annual variability in springtime thaw for Northern Eurasia (above) is on the order of ±7 days, with corresponding impacts to annual productivity of approximately 1% per day. (McDonald, Kimball, et al., 2004)
Irrigation impact analysis

UNH Gridded Irrigation Area time-series for Northern Eurasia using **Global Irrigated Area Map** (1-km resolution derived from remote sensing data) and historical census data from FAO.

Using UNH hydrological model (WBMplus) we evaluated changes in water demand for irrigation over the long-term period.

Irrigation water demand in the Syr Daria basin continues to increase.
**Research approach:**

- Combined analysis of changes in climate, land cover and hydrological regime for test basins.

- Modeling experiments to understand causes of changes in hydrological regime.

- Simulation of future hydrology using IPCC climate data, water management and LCLUC information.
Future hydroclimatology with WBMPlus and IPCC GCMs

AO GCM presented in NEESPI RIMS web site

<table>
<thead>
<tr>
<th>№</th>
<th>AO GCM</th>
<th>Country</th>
<th>Spatial resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ECHAM5/MPI-OM</td>
<td>Germany</td>
<td>1.9°x1.9°</td>
</tr>
<tr>
<td>2</td>
<td>CGCM3.1(T63) (ccc_t63)</td>
<td>Canada</td>
<td>2.8°x2.8°</td>
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<tr>
<td>3</td>
<td>UKMO-HadCM3</td>
<td>Great Britain</td>
<td>1.25°x1.875°</td>
</tr>
<tr>
<td>4</td>
<td>BCCR-BCM2</td>
<td>Norway</td>
<td>2.8°x2.8°</td>
</tr>
<tr>
<td>5</td>
<td>NCAR_CCSM3</td>
<td>USA</td>
<td>1.4°x1.4°</td>
</tr>
<tr>
<td>6</td>
<td>INM-CM3 PAH</td>
<td>Russia</td>
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<td>7</td>
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</tr>
<tr>
<td>8</td>
<td>MIROC3.2(medres) (ccsr_me)</td>
<td>Japan</td>
<td>2.8°x2.8°</td>
</tr>
</tbody>
</table>

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

WBMPlus
- WBM + irrigation + reservoirs; 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) 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
The change in seasonal discharge for watersheds located in different climatic and land cover zones. Annual discharge increases from increases in winter and spring discharge. Annual discharge in the southern part of the NEESPI region will significantly decline due to a discharge decrease in the spring and summer-fall periods.
Deterministic Modeling Hydrological System (DMHS or model “Hydrograph”)

- Universal
- Apriori estimation of most parameters
- Distributed
- Time resolution – 24-hour or less
- Forcing climate, land cover, vegetation and soil data

- Output – runoff hydrograph, water balance elements, state variables of soil and snow cover

DMHS “HYDROGRAPH” flowchart

- Precipitation
  - Rain
  - Snow

- Heat energy

- Interception
- Snow cover formation

- Heat dynamics in snow
- Heat dynamics in soil

- Snow melt and water yield

- Infiltration and surface flow

- Water dynamics in soil
- Evaporation

- Initial surface losses

- Channel transformation

- Transformation of underground flow

- Runoff at basin outlet
- Snow cover transformation

- Slope transformation of surface flow
The spatial-computational schematization of the basin

- Suntar-Khayata
- Lower Base
- Vostochnaya
- Suntar
- "golets" area
- mountain tundra
- sparse mountain
- larsh forest
- meteorological station
- representative point
Simulations with models WBMPlus (left plots) and “HYDROGRAPH” (right plots) for Varzob at Dagana, altitude 1500-4500 m, basin area 1270 km²

Annual discharge at Varzob - Dagana
- Observed discharge
- WBMplus simulated discharge

WBMPlus simulated and observed discharge at Varzob-Dagana, 1979
- Simulated
- Observed

Observed discharge
WBMplus simulated discharge
Detrin at Vakhanka river mouth, basin area 5630 km²
Baltic Sea Basin
Lovat at Holm, drainage area 14700 km²
European North of Russia
Nyashenny stream at Kotkino,
basin area 16.1 km²
Understanding of changes in winter runoff
r. Medvenka F=21.5 km²

Contribution to increase in winter river discharge:
Depth of frozen ground – 56%
Winter snowmelt – 38%
Fall soil water content – 6%
Change in forest cover
Kuda at Granovschina, Drainage Area = 7840 km$^2$

Most forest loss in the watershed due to forest cut and new developments
Change in forest cover
Kuda at Granovschina, Dranage Area = 7840 km²

Most forest loss in the watershed due to forest cut and new developments
Without model experiments it is very difficult to evaluate effect of forest change on runoff.

Change in relative runoff after forest cut

Example of a hydrological anomaly during the summer of 2007 in the Alazeya river basin. Significant flooding at Andrushkino (lower right) $F= 19\,800\,\text{km}^2$, 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).
MODIS NDVI trends for Caspian Sea Basin 2000-09 (courtesy to Saachi Sassan) Cropland distribution (lower map)

There is a significant positive trend in summer-fall runoff over long-term period. However, since 2000 this trend has shown negative tendency.
There is a significant positive trend in summer-fall runoff over long-term period. However, since 2000 this trend has shown negative tendency.
Evaluation of the effects of the interrelated changes in climate and land cover/land use on human

RESEARCH QUESTIONS:

• How has environmental change effected Russian Arctic administrative regions through time?

• What are the socioeconomic implications of ongoing air temperature change?

GOAL:

To provide a quantitative cost benefit analysis assessment of environmental change implications for the Russian North
March 17\textsuperscript{th}, 2010: Dmitry Medvedev held a Security Council meeting on preventing national security threats arising from global climate change.

http://eng.kremlin.ru/news/140
“National Security Challenged by Climate Change" *The Barents Observer* (3-23-10).

“The Russian Security Council believes climate change will pose a serious threat to national security, a council representative confirms in a newspaper interview.”
http://www.barentsobserver.com

“Moscow Views Climate Change as a Security Threat, Mulls Creating ‘Climatic Assistance’ Program.” *WindowonEurasia* (3-24-10).

“Russia, as experts around the world agree, is likely to be more profoundly affected by climate change than any other country, and Moscow is now focusing on the security threats global warming may entail not only within the country but in its relations with its closest neighbors.”
http://windowoneurasia.blogspot.com/
Benifits

- Increase of heat supply and length of the growing season will improve the structure of crop production by expanding the planting heat-loving crops, as well as expansion of the north boundary of commercial agriculture.

- Climate change could lead to improved water availability across the Russia.

- Increase in annual runoff improves the conditions for hydropower development

- Air temperature increase will reduce energy consumption during the heating season

Dr. Yury Averyanov, a member of Russia's Security Council

_Rossiiskaya Gazeta_ (3-19-10)

(http://www.rg.ru/2010/03/19/klimat.html)
Challenges

• Climate change can create new international conflicts related to the exploration and production of energy, the use of marine biological resources and transportation routes, drinking water and so on.

• Climate change can increase the risk of conflicts related to water scarcity and food production along the southern Russian borders.

• Polar countries, including the U.S. and its allies are actively expanding their scientific research, economic development and military presence in the Arctic zone. They are making efforts to зкумуте Russia's access to the exploration and development Arctic oil and gas fields.

• Permafrost occupies a two-thirds of the Russia and significant changes are possible in areas with unstable permafrost. Global change will lead to reducing the strength of buildings and engineering structures located in this zone.
Number of heating degree days considers the number of days temperature falls below 8 degrees C

Change from 2000s converted to % of change from 1960s period to show change in days

Source: NCEP 2m Temp Data
INFRASTRUCTURE:
Change in Bearing Capacity

10/01/2009

“...One of the possible reasons of deformations occurred in the wall of “Agriculture of Far North” Research Institute is anomaly warm summer of 2009”
“...The institute was built in 1985”
News.NGS24.ru
Permafrost Construction Principals

More than 75% of engineering structures on permafrost in Russia are built according to the "First Construction Principle", which relies on the freezing strength (bearing capacity) of the frozen ground to support structures.

Bearing Capacity of a “Standard Foundation Pile” imbedded in permafrost is used in Russia as a primary variable for engineering assessment of the permafrost-affected territory.
Buildings in Russian North
The percent of buildings with deformations in some of the Russian northern settlements

<table>
<thead>
<tr>
<th>Location</th>
<th>Population*</th>
<th>Buildings with deformations**, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yakutsk</td>
<td>284,000</td>
<td>9</td>
</tr>
<tr>
<td>Norilsk</td>
<td>205,000</td>
<td>10</td>
</tr>
<tr>
<td>Tiksi</td>
<td>5,600</td>
<td>22</td>
</tr>
<tr>
<td>Dikson</td>
<td>600</td>
<td>35</td>
</tr>
<tr>
<td>Amderma</td>
<td>500</td>
<td>50</td>
</tr>
<tr>
<td>Magadan</td>
<td>99,000</td>
<td>55</td>
</tr>
<tr>
<td>Vorkuta</td>
<td>71,000</td>
<td>80</td>
</tr>
<tr>
<td>Chita</td>
<td>307,000</td>
<td>60</td>
</tr>
</tbody>
</table>

*Federal Department of Statistics on 01.01.2009
**Moscow State University of Civil Engineering (2003)
TRANSPORTATION:
Change in length of winter road season

• **Parameter**: Number of days for the reference periods as a change in %

• **Method**: Days include time from when winter road construction begins in the fall when temperatures drop to below -7°C, and are operational until the spring when temperatures reach 4°C and start to melt, change in number of days during the 1995 - 2005 as a % of 1965 - 1975
Winter Roads: Change in Length of Operation

Change Between 1965-1975 & 1995-2005
- Red: decrease of 10 days or more
- Orange: decrease of 5 to 10 days
- Yellow: decrease of 0 to 5 days
- Light Green: increase of 0 to 5 days
- Blue: increase of 5 to 10 days
- Dark Blue: increase of 10 days or more

Legend:
- Large Cities
- Roads
- Rivers

Source: NCEP 2m Air Temp Data
Supported under this project:

Edited volumes:


Peer-Reviewed Publications


Thesis and Dissertations:


Streletskiy, D.A., 2010. Spatial and Temporal Variability of Active-Layer Thickness at Regional and Circumpolar Scales. Dissertation (PhD). University of Delaware, Department of Geography, Newark, DE.

Regional NASA NEESPI workshops sponsored by the project:

*Hydrological application of changes in land cover and land use across Northern Eurasia* held at the State Hydrological Institute (SHI), Saint Petersburg, Russia, on March 4-6, 2009. (42 participants from 7 countries including USA, Russia, Belorussia, Ukraine, Kazakhstan, Uzbekistan, Kyrgyzstan)

*Hydrological consequences of changes in land cover/use and climate across Northern Eurasia* held at the State Hydrological Institute (SHI), Saint Petersburg, Russia, on February 7-9, 2012 (37 participants from 6 countries including USA, Russia, Belorussia, Kazakhstan, Uzbekistan, Tajikistan)
Thank you