Current climate changes over Eastern Siberia and their impact on permafrost landscapes, ecosystem dynamics, and hydrological regime

NASA # NEWS/04-1-0000-0071

Larry D. Hinzman[1], Vladimir E. Romanovsky[2], and Kenji Yoshikawa[3]

[1] International Arctic Research Center, University of Alaska Fairbanks 907-474-7331ffldh@uaf.edu

[2] Geophysical Institute, University of Alaska Fairbanks, 907-474-7459 ffver@uaf.edu

[3] Water and Environmental Research Center, University of Alaska Fairbanks, 907-474-6090 ffky@uaf.edu

400

Introduction

The climatic and hydrologic regimes of Arctic and Subarctic rivers are strongly impacted by the permafrost distribution within their watersheds. Rivers that collect their waters entirely from watersheds with continuous permafrost distribution practically cease their discharge into the Arctic Ocean during the winter. In contrast, the larger arctic rivers, which extend their watersheds into the regions with discontinuous permafrost or even into the permafrost-free areas (Ob', Yenisei, Lena, Mackenzie), continue to discharge a significant amount of water into the Arctic Ocean during the entire winter. Moreover, the ratio of "winter" to "summer" discharge decrease among the Great Siberian Rivers (Ob', Yenisei, Lena) accordingly to the extent of permafrost in their watersheds. Based on this observation, it becomes obvious that the seasonality in the arctic river discharge can change significantly with a warmer climate. The predicted warming in this century will be significant enough to start permafrost degradation in many areas in the Northern Hemisphere (Anisimov et al., 2001; IPCC, 1996, 2001; Sazonova et al., 2001). Degradation of permafrost will significantly change the permafrost spatial extent and can affect its vertical thickness. As a result, conditions of groundwater recharge, flow, discharge and storage will be altered considerably, increasing the role of subsurface flow in the water balance. Altogether, it will change the seasonality of the arctic river discharge into the Arctic Ocean, increasing winter flow, and it will probably increase the total discharge as well. During winter, all other sources of river discharge but groundwater accumulate in unfrozen zones within permafrost (taliks) and are locked in temporary storage as snow or ice. Taking into account the observed increase in permafrost temperatures in Siberia over the same period of time (Pavlov, 1994; Romanovsky et al., 2001a and 2001b), the most reasonable explanation of changes in the winter river discharge is the permafrost dynamics within the Siberian river watersheds and especially in the upper parts of their basins where permafrost is the warmest and already discontinuous.

Objectives

The overall goal of the proposed research is to obtain a deeper understanding of coupled thermal and hydrogeological processes of heat and water exchange within different permafrost zones along the Lena River and to use this understanding for prediction of changes in arctic river discharge into the Arctic Ocean as a result of climate warming and permafrost degradation.

1. Developing the physically based numerical models of ground water recharge/discharge, and subsurface flow and storage in the permafrost-affected hydrostratigraphic units at typical locations within the Lena River basin.
2. Estimate the two- and three-dimensional permafrost dynamics within these units as a response to climate change during the 21st century.
3. Assess the effect of these changes in permafrost characteristics on the hydrology and hydrogeology within the Lena River basin and, as a result, on the Lena River discharge patterns.
4. Assess and quantify the impact of these changes across Siberia and throughout the Arctic.

FIGURE 1. Three proposed intensive research sites within the Lena River basin.

PROPOSED RESEARCH

1. Existing data acquisition

a. Meteorological data

b. The Lena River and its tributaries (Aldan, Timpton, Chulman) hydrological data

c. Results of special hydrogeological and permafrost research

d. Permafrost temperatures and active layer thickness dynamics

FIGURE 2. Historical variability of the Groundwater (icing) discharge (for example: ASTER imagery;left, and Leffingwell, 1919; light).

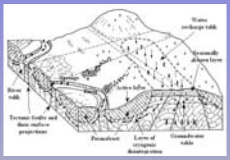

FIGURE 3 Principal diagram of the permafrost and hydrogeological conditions within the first (southernmost) proposed site of intensive investigations.

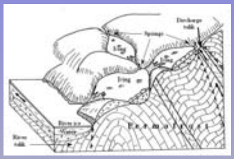

FIGURE 4. Principal diagram of the permafrost and hydrogeological conditions within the third (Tiksi region) proposed site of intensive investigations.

2. Satellite Image Analysis

FIGURE 5. False color Landsat7 ETM+ imagery at Yakutsk region.

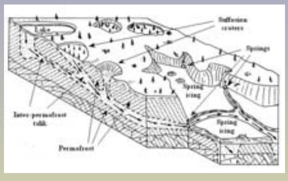

FIGURE 6. Principal diagram of the permafrost and hydrogeological conditions within the second (Yakutsk region) proposed site of intensive investigations.

Thermokarst ponds (lakes) have the highest potential to change the volume of supra-permafrost water stored in permafrost regions. The Central Yakutia Plane is a generally flat area, with steep slopes only between different terraces and alases (thermokarst depressions on "Edoma"; i.e., very ice-rich permafrost). Permafrost in this region is continuous and relatively deep (200 to 500 meters). The climate is very continental and dry. Mean annual air temperature is about -9.7°C. However, the permafrost temperatures here are relatively high (typically between –0.5 and –3.0°C). As a result of warm permafrost temperatures, texture of sediments (predominantly sand and sandy loam), permafrost evolution history, and specific hydrological and hydrogeological conditions, the intra-permafrost taliks and residual thaw layers are very common here (Fig. 6). The configuration and volumes of these taliks and position of residual thaw layer are extremely sensitive to both the climate dynamics and changes in vegetation cover.

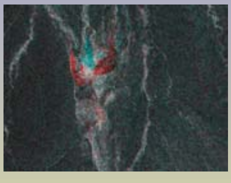

FIGURE 7 False color Synthetic Aperture Radar (SAR) imagery of Kuparuk Icing Field (example). Comparing with other remote sensing data, passive sensor is not requiring minimum cloud cover or daylight. This is one of the biggest advantage to use SAR data. Especially, Study region has limited daylight at the middle of winter and weather being not clear in general.

It is possible to characterize regional changes in groundwater dynamics by examining large spring icings (sourcing from springs as opposed to developing along streams) where the annual changes in thickness is insignificant compared to total area. Icings, also known as naleds or aufeis, are large deposits of ice created during the winter as groundwater discharges at the surface. Their locations are controlled by local geology, terrain, and thermal characteristics of discharge water. In some cases, aufeis deposits source from near-surface water supplies or form at the permafrost boundary. In many other cases, these aufeis fields develop from springs that perforate the permafrost. These subterranean channels remain open (unfrozen) only because of the combination of adequate flow rates and warm temperature. The areal extent of the aufeis, which can be evaluated from satellite imagery and air photographs, is directly related to the groundwater discharge rates (Hall and Roswell, 1981). These discharge rates are indeed an integration of the annual water balance components, and examination of the relative sizes of icing fields provides direct evidence of the changing dynamics of groundwater aquifers. Historical aerial photographs, documentation (such as Leffingwell, 1919; Sumgin, 1941) and satellites images will be compiled for previous icing volume estimation. We will attempt to examine changes in groundwater discharge utilizing archived imagery and data for the previous 50 years. We will conduct field studies to determine groundwater discharge and to quantify the source of the water using chemical and isotopic analyses. We do not expect that the mass of aufeis in the Arctic will play a major role in the freshwater input volume into the Arctic Ocean; however, the temporal variation in the number and locations of these fields may be an important proxy for temporal variations in the permafrost's thermal state and should serve as a clear indicator of groundwater/surface water interactions.

3. Modeling

a. Development of a coupled thermal and hydrological two- and three-dimensional numerical model of the permafrost-hydrogeological processes

b. Development of new interpretation techniques combining remote sensing, numerical simulations and field geophysical investigations

c. Development of specific permafrost-hydrogeological models for typical hydrostratigraphic units within each of three chosen sites

On the scale of kilometers or tens of kilometers (small river watersheds or short sections of the Lena River), we will model the subsurface water flow within the sub-river taliks. Groundwater flow into the river valley will be parameterized using the results from the previous stage of modeling described above. The two- and three-dimensional models of the coupled heat and mass transfer in the sub-river taliks and surrounding permafrost will be used at this stage. **The major task at this stage will be characterizing changes in permafrost distribution and geometry along the river valleys and related changes in summer and winter river discharge.** These modeling results will be validated against observed data.

d. *Change detection of surface water storage components and causal attribution*

e. Research questions addressed through modeling: How does the spatial distribution of soil moisture evolve throughout the summer season? Is the spatial variation consistent between years when local input data exists? If not, what input variables are most sensitive? Could a sustained trend in any of the climate forcing input cause a feedback through soil moisture that would affect active layer depths or vegetative succession? How do the answers to these questions vary between watersheds underlain by continuous permafrost and discontinuous permafrost?

f. Sensitivity analysis and forecast of future changes in the permafrost-hydrogeological system and estimation of the affect on Lena River discharge

g. Development of approaches for scaling of modeling results

We plan to establish a geographic information system (GIS) to facilitate data compilation, integration and visualization. Additionally, these data will be archived for utilization by the broader scientific community at the National Snow and Ice Data Center (NSIDC) through the Arctic Data Climate Center (ADCC). Linking GIS with model analyses allows zoning the areas by a suite of runoff-forming mechanisms. We plan to separate the regions with vein-fracture type of ground water from the regions where laterally extended aquifers with interstitial or pore ground water are more typical. We also plan to delineate areas with different permafrost temperatures and extent, relief, vegetation and soil properties to enable mapping of relative sensitivity to permafrost degradation and thermokarsting. For this purpose we will use the data from our "East Siberian Transect" GIS and map of "Permafrost-Hydrogeological Zoning". Most importantly, we will provide information on changes in the hydrogeological structure of the regions as a result of predicted climate warming. This information should be used for parameterization of changes in the subsurface water flow and storage as a function of changing climate. This parameterization should be incorporated in the suite of spatially distributed hydrological model of different spatial scales. This work is very important for enabling implementation of these results into global and regional models of Ocean-Atmosphere-Land interactions.

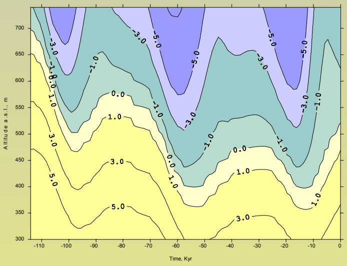

FIGURE 8 Ground temerature dynamics in the valley (deg.C; scenario from Maximova & Romanovsky, 1988)

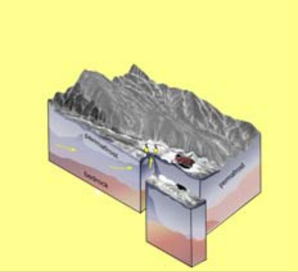

FIGURE 9 Geophysical investigation of groundwater (for example at Kuparuk icing field, Alaska)

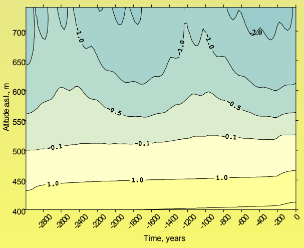

FIGURE 10 Ground temerature dynamics in the valley (deg.C; scenario from Maximova & Romanovsky, 1988 plus 1500 and 208 year cycles adding).

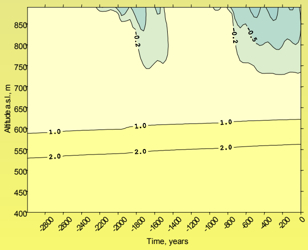

FIGURE 11 Ground temerature dynamics at the upper part of the slope (deg.C; scenario from Maximova & Romanovsky, 1988 - plus 1500 and 208 year cycles adding).