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River Discharge, in Chapter 5, Arctic, State of the Climate in 2010

Alexander I. Shiklomanov

University of New Hampshire, Durham, alex.shiklomanov@unh.edu

Richard B. Lammers

University of New Hampshire, Durham, richard.lammers@unh.edu

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relatively stable on the North Slope of Alaska (Smith et al. 2010), and there was even a slight decrease (0.1°C–0.3°C) in the Alaskan interior during the last three years. The exception has been at Alaskan coastal sites, which have exhibited continuous warming during the last ten years. The warming trend at the Alaskan coastal sites has been particularly pronounced during the last four to five years (Fig. 5.16a). Data obtained in 2010 in Alaska suggest that the observed warming trend along the coast has begun to propagate south towards the northern foothills of the Brooks Range (approximately 200 km inland), where a noticeable warming in the upper 20 m of permafrost has become evident since 2008 (Fig. 5.16b).

A common feature at Alaskan, Canadian, and Russian sites is more significant warming in relatively cold permafrost than in warm permafrost in the same geographical area (Romanovsky et al. 2010b). Permafrost temperature has increased by 1°C to 2°C in northern Russia during the last 30 to 35 years. An especially noticeable temperature increase was observed during the last three years in the Russian Arctic, where the mean annual temperature at 15 m depth increased by > 0.35°C in the Tiksi area and by 0.3°C at 10 m depth in northern European Russia. However, relatively low air temperatures during summer 2009 and the following winter interrupted this warming trend at many locations in the Russian Arctic, especially in the western sector. Data on changes in the active layer thickness (ALT) in the arctic lowlands are less conclusive. In the Alaskan Arctic, ALT experiences a large interannual variability, with no discernible trends; this is likely due to the short length of historical data records and possible surface subsidence upon thawing of the upper, ice-rich permafrost (Streletskiy et al. 2008). At the same time, data from northern Quebec (Smith et al. 2010) and from the Nordic countries (Christiansen et al. 2010) show a distinct increasing trend in ALT during the last two decades.

The last 30 years of increasing permafrost temperatures have resulted in the thawing of permafrost in areas of discontinuous permafrost in Russia (Oberman 2008; Romanovsky et al. 2010a). This is evidenced by changes in the depth and number of taliks (a sub-surface layer of year-round unfrozen ground within permafrost), especially in sandy and sandy loam sediments compared to clay. A massive development of new closed taliks in some areas of the continuous permafrost zone, resulting from increased snow cover and warming permafrost, was responsible for the observed northward movement of

the boundary between continuous and discontinuous permafrost by several tens of kilometers (Oberman and Shesler 2009; Romanovsky et al. 2010a).

3) RIVER DISCHARGE—A. I. Shiklomanov and R. B. Lammers

River discharge from Eurasia to the Arctic Ocean during 1936–2009 increased at a mean rate of $2.7 \pm 0.5 \text{ km}^3 \text{ yr}^{-1}$. For the six largest Eurasian rivers (Severnaya Dvina, Pechora, Ob, Yenisey, Lena, and Kolyma), the most significant positive trend, $12 \text{ km}^3 \text{ yr}^{-1}$, occurred during the last 23 years (1987–2009; Shiklomanov and Lammers 2009). Data available online from the U.S. Geological Survey (<http://waterdata.usgs.gov/ak/nwis>) and Environment Canada (<http://www.wsc.ec.gc.ca/applications/H2O/index-eng.cfm>) for 2009 showed 9% higher discharge

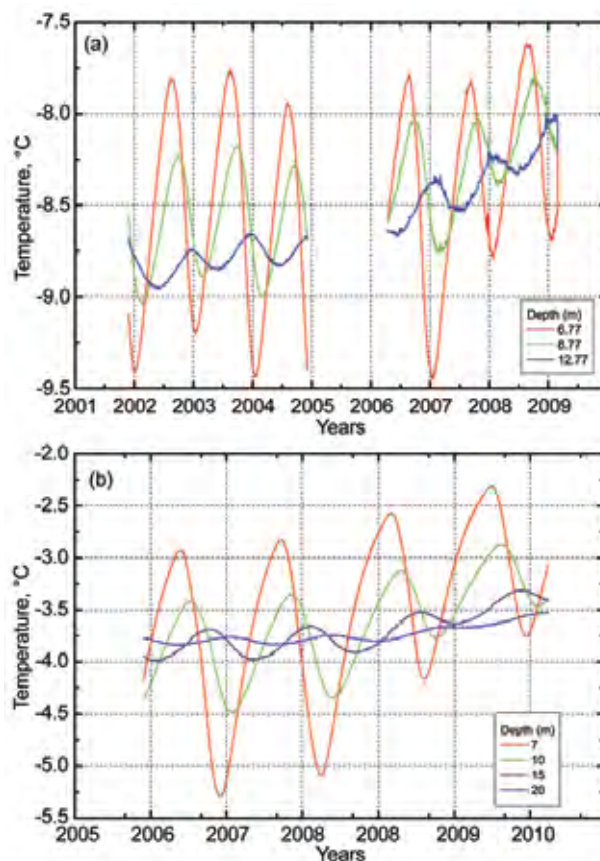


FIG. 5.16. Changes in permafrost temperature (a) between 2002 and 2009 at three different depths at the Barrow Permafrost Observatory on the northernmost coast of Alaska, and (b) between 2006 and 2010 at four different depths at the Innaviat Creek Permafrost Observatory near the Toolik Lake research station, Alaska, approximately 200 km south of the Beaufort Sea coast. Note that the coastal permafrost (a) is colder than the inland permafrost (b). The gap in (a) between 15 May 2005 and 23 Sep 2006 is due to a datalogger malfunction.

over the 1969–2008 mean for the four largest North American rivers (Mackenzie, Yukon, Back, and Peel) flowing into the Arctic.

Officially-distributed river discharge data are usually processed and published after some delay (Shiklomanov et al. 2006). Through cooperation of the State Hydrological Institute and the Arctic and Antarctic Research Institute (AARI) in St. Petersburg, Russia, river discharge is estimated from the most important Russian monitoring sites in near real-time using provisional stage measurements, air temperature, and river ice data (<http://neespi.sr.unh.edu/maps>). Due to limited data availability, this technique cannot currently be applied to estimate near real-time river discharge for sites in North America.

Using this approach, the total annual discharge from the five largest Eurasian rivers (excluding the Kolyma) flowing into the Arctic Ocean in 2010 was estimated to be 1760 km³, which is slightly higher than the long-term (1936–2009) mean of 1737 km³. In 2010 the Yenisey discharge was 6% higher than the long-term mean and the discharge of both the Lena and Ob basins was close to the mean (Fig. 5.17, inset). During the same period, European Russia rivers (Sev. Dvina and Pechora) had 10% lower flow than the long-term mean. This was expected given the very dry and warm summer in 2010 across European Russia (see Sidebar 7.8).

An aggregated hydrograph for the five largest Eurasian rivers, based on provisional discharge estimates for 2010, is compared with discharge variability

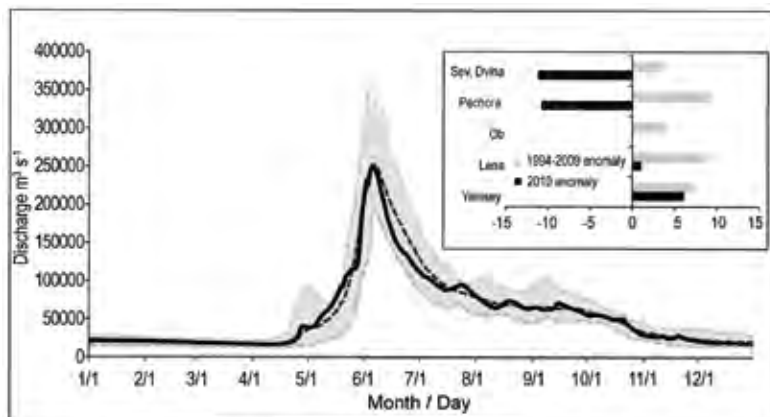


FIG. 5.17. Aggregate daily discharge hydrograph of the five largest rivers in the Eurasian Arctic in 2010 (solid black line) and long-term mean hydrograph (dashed black line) with discharge variation (gray area) during 1994–2009. Inset shows 2010 (black bars) and 1994–2009 (gray bars) anomalies relative to the long-term mean during 1936–2009 for these five rivers. Provisional estimates of annual discharge in 2010 for the five major Eurasian Arctic rivers are based on near real time data.

and the long-term mean hydrograph for 1994–2009, when the anthropogenic impact on discharge of these rivers was relatively stable and all variations can be attributed to the climate (Fig. 5.17). Aggregated 2010 Eurasian river discharge to the Arctic Ocean had an earlier spring snowmelt rise leading up to the peak flow and a more rapid recessional limb as the snowmelt pulse declined in the early summer. This is consistent with 2010 snow cover observations (see section 5e4) and expected changes in timing of river discharge due to increased warming in the region (Shiklomanov et al. 2007).

4) TERRESTRIAL SNOW—C. Derksen and R. Brown

In 2010, a combination of low winter snow accumulation and above-normal spring temperatures created new record-low spring snow cover duration (SCD) over the Arctic since satellite observations began in 1966. Record persistence of the negative phase of the North Atlantic Oscillation (NAO) during the winter of 2009/10 (Cattiaux et al. 2010) favored cold, dry conditions and below-average snow accumulation over large areas of Eurasia and Alaska (Fig. 5.2b). In the spring, the advection of southerly air masses was responsible for high positive air temperature anomalies over much of Eurasia and the western North American Arctic (Fig. 5.2c), which contributed to early snow melt.

Annual SCD anomalies for the 2009/10 snow year (August–July) computed from the NOAA Interactive Multisensor Snow and Ice Mapping System (IMS) 24-km product (Helfrich et al. 2007) show below-average SCD over much of the Arctic land area (Fig. 5.18a). The exception was Scandinavia which, like much of the midlatitude regions, had SCD anomalies that were largely positive. The difference in the sign of the SCD anomalies for the Arctic (positive) versus the midlatitudes (negative) reflects the Warm Arctic–Cold Continent atmospheric circulation pattern described in section 5b. Snow cover duration was computed separately for the first (August–January) and second (February–July) halves of the 2009/10 snow year using the weekly NOAA Climate Data Record (CDR; maintained at Rutgers University) to provide information on changes in the start and end dates of snow cover. While the timing of the onset of snow