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A new river discharge and river temperature climatology data set for the pan-Arctic region

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ABSTRACT

Most regional ocean models that use discharge as part of the forcing use relatively coarse river discharge data sets (1°, or ~110 km) compared to the model resolution (typically 1/4° or less), and do not account for seasonal changes in river water temperature. We introduce a new climatological data set of river discharge and river water temperature with 1/6° grid spacing over the Arctic region (Arctic River Discharge and Temperature; ARDAT), incorporating observations from 30 Arctic rivers. The annual mean discharge for all rivers in ARDAT is 2817 ± 330 $km^3\ yr^{-1}$. River water temperatures range between 0 °C in winter to 14.0–17.6 °C in July, leading to a long-term mean monthly heat flux from all rivers of 3.2 ± 0.6 TW, of which 31% is supplied by Alaskan rivers and 69% is supplied by Eurasian rivers. This riverine heat flux is equivalent to 44% of the estimated ocean heat flux associated with the Bering Strait throughflow, but during the spring freshet can be ~10 times as large, suggesting that heat flux associated with Arctic rivers is an important component of the Arctic heat budget on seasonal time scales.

We apply the ARDAT data set to a high-resolution regional ocean-ice model, and compare results to a model integration using a 1° resolution discharge data set. Integrated freshwater content on the Arctic shelves (<200 m) increases by ~3600 km^3 in the ARDAT forced model run compared to the coarser forcing, suggesting that river discharge is contained on the Arctic shelves when forced with the ARDAT data set. Modelled summer heat fluxes over the shelves increase by 8 TW when river water temperature is included, which subsequently reduces basin-wide September sea ice extent by ~10%. Regional differences are larger, where e.g., sea ice extent on the Beaufort shelf is reduced by ~36%. Using a non-linear free surface parameterization along with the ARDAT data set, we find an increase in the sea surface height gradient around river mouths. Geostrophic velocities increase to form quasi-continuous, fast-moving near-shore boundary currents not reproduced using the 1° resolution data set. Omitting river water temperature, or using a lower resolution data set, can therefore lead to incorrect model estimates of coastal transport, sea ice formation/melt rates, and other regional and basin scale processes. Using a high-resolution discharge data set, and accounting for the considerable heat carried by the Arctic rivers is recommended for future modelling efforts.

1. Introduction

The Arctic Ocean is a uniquely structured mediterranean sea with a low salinity surface mixed layer on the order of a few tens of metres thick, on top of a 150–200 m thick halocline layer (Aagaard et al., 1981). The low surface salinity is in part the result of freshwater discharge from some of the largest rivers on the planet, such as the Lena and Yenisey Rivers (Fig. 1; Holmes et al., 2013). Most of the annual river discharge enters the Arctic Ocean over a short period of ~ 2 months, as river ice breaks up and snow melts during the spring freshet between May and June (McClelland et al., 2012). During the spring freshet period, river discharge can reach temperatures of >10 °C (Lammers et al., 2007), indicating that river discharge may contribute significantly to both the Arctic heat and freshwater budget.

The river discharge portion of freshwater input is 18% greater than the relatively fresh (~32.5) water from the Pacific Ocean which enters through the shallow Bering Strait (3200 $km^3\ yr^{-1}$ compared to 2700 $km^3\ yr^{-1}$; Woodgate et al., 2005; Condron

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et al., 2009) and 60% greater than atmospheric sources (2000 km^3 - yr^{-1}; Serreze et al., 2006). Saltier water (35–35.2; Aagaard and Carmack, 1989) enters from the deep North Atlantic creating the halocline layer. Due to the strong dependence of density on salinity at high latitudes (Carmack, 2007), this halocline serves to insulate the surface Arctic Ocean from the warmer, saltier Atlantic layer below (Aagaard et al., 1981). The high lateral and vertical gradients often lead the Arctic Ocean to be considered an estuarine system (e.g., Tully and Barber, 1960; Stigebrandt, 1984; Aagaard and Carmack, 1994; Carmack, 2007; McClelland et al., 2012).

As the global climate warms, both precipitation (Houghton et al., 2001) and air temperatures (Rouse et al., 1997) are predicted to increase. These changes will likely lead to increased and warmer river discharge, potentially affecting factors such as nutrient transport (Manizza et al., 2011; McClelland et al., 2012) or sea ice formation and melt (e.g., Dean et al., 1994; Searcy et al., 1996; Bareiss et al., 1999).

Although modelling studies that focus on the role of Arctic river discharge may resolve the major transport pathways (e.g., Bering Strait and Canadian Arctic Archipelago), they often use a relatively coarse river discharge forcing (1°; Dai and Trenberth, 2002) compared to the model resolution (typically on the order of 1/4° or smaller), and do not account for seasonal changes in the temperature of river water. These models can also underestimate pan-Arctic freshwater budgets. For example, total integrated Arctic freshwater content in the Ocean Circulation and Climate Advanced Model from the National Oceanography Centre is ~58,000 km^3 compared to the observed 74,000 km^3 (Serreze et al., 2006; Jahn et al., 2012), a discrepancy of 22%.

Here we present a new climatological river forcing data set for the pan-Arctic region with 1/6° resolution, six times higher than the 1° × 1° resolution data sets currently used. It incorporates observations from 30 Arctic rivers and consists of a climatological seasonal cycle for both river discharge and water temperature. We describe our methods for constructing the new data set in Section 2, before presenting the data set in Section 3. We compare results of two high-resolution ocean-sea ice coupled model runs, one using a 1° resolution forcing with no associated river water temperature, and one incorporating the new discharge/temperature data set. These comparisons include a basin-scale analysis, as well as more focused analyses of differences over the Arctic shelf domain and around the Mackenzie River delta in particular. We discuss our results in Section 4, and present our conclusions in Section 5.

2. Methods

2.1. Data sources

The Arctic River Discharge and Temperature (ARDAT) data set is comprised of monthly mean river discharge and temperature data. Discharge for the Eurasian rivers was obtained from two openly available data sets; R-ArcticNET (http://www.r-arcticnet.sr.unh.edu/v4.0/index.html; Lammers et al., 2001) and the Regional Integrated Hydrological Monitoring System for the Pan-Arctic Landmass (ArcticRIMS; http://rims.unh.edu). Alaskan river discharge observations were downloaded as monthly means from the US Geological Survey's National Water Information System (NWIS; http://waterdata.usgs.gov/nwis). Canadian rivers in Baffin and Hudson Bays were not included in the data set, as we use the definition of the pan-Arctic watershed from Holmes et al. (2013). This only includes rivers that empty into the Arctic Ocean, plus the watershed of the Yukon and all rivers entering the Bering Sea north of the Yukon, although due to the proximity of the watersheds we also include the Kuskokwim River in ARDAT. In all cases, observations from the most downstream station on each river were used. The only exception to this was for the Lena river; the most downstream station on the Lena is at Polyarnaya, within the delta, which receives only 25% of the June discharge when compared to the monitoring station at Kusur.

ARDAT only includes temperature observations for the six largest Arctic rivers (hereafter referred to as the "Big 6" following Holmes et al. (2013); Fig. 1; Table 1). Data for the Eurasian rivers combine observations from the ART-Russia data set (http://www.r-arcticnet.sr.unh.edu/RussianRiverTemperature-Website; Lammers et al., 2007), and the Pan-Arctic River Transport of Nutrients, Organic Matter, and Suspended Sediments (PARTNERS) and Arctic Great Rivers Observatory (AGRO; http://www.arctic-greatrivers.org) projects (McClelland et al., 2008). Temperature observations for Alaskan rivers are also available as part of NWIS.

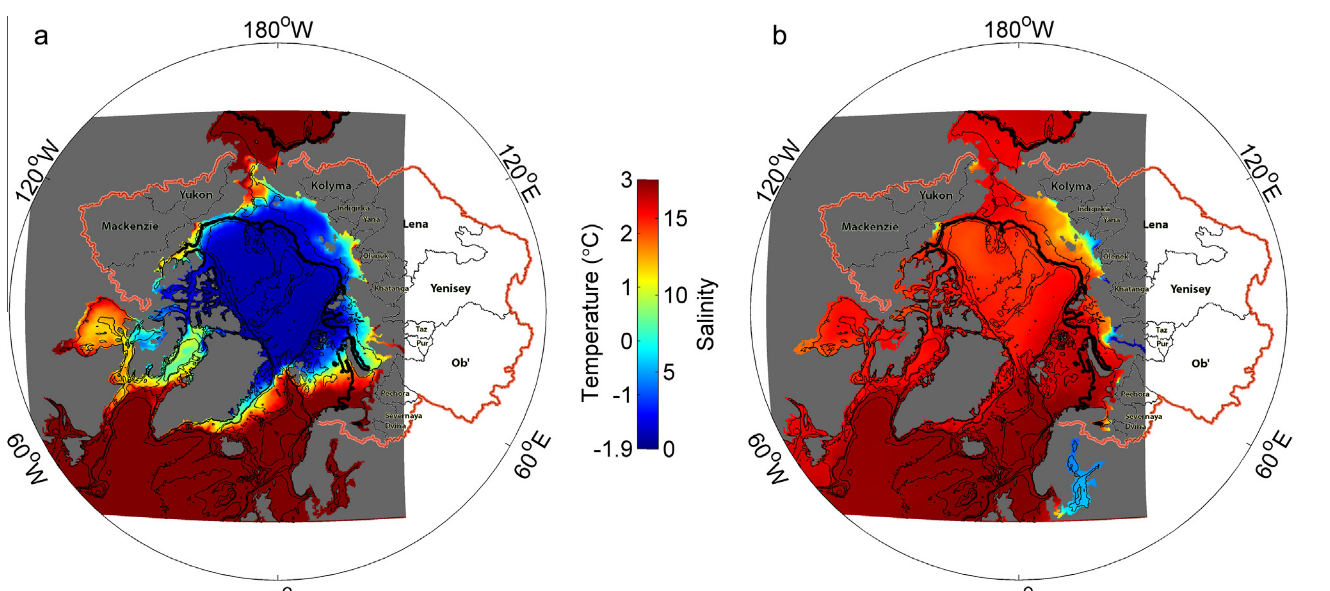

Fig. 1. Map of the "Big 6" Arctic drainage basins, along with the next 8 largest basins in the pan-Arctic watershed (red line; adapted from Holmes et al., 2013). Overlaid is modelled (a) August sea surface temperature (SST) and (b) June sea surface salinity (SSS) from the MITgcm/ECCO2 model. The model land mask is in grey, model bathymetry (200, 500, 1000, 2500 m) is shown as thin black contours; the thick black contour defines the Arctic shelf region referred to in this paper.