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# Dual-sensor mapping of mass balance on Russia's northernmost ice caps

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Mass balance of Russia's northernmost ice caps is poorly known and scarcely mapped. Thorough information about glacier fluctuations in the outer periphery of Russian shelf seas is both lacking and highly desired since it may constitute the relevant benchmark for judging and projecting climate change impacts in the entire Arctic. The present study is focussed on geodetic measurements and medium-scale mapping of the mass balance on a dozen insular ice caps, some large and some smaller, homogeneously situated along the Eurasian boundary of Central Arctic Basin. The study region extends for approx. 2.200 km from Victoria and Arthur islands in the west across Rudolph, Eva-Liv, Ushakova, Schmidt and Komsomolets islands in the north to Bennett and Henrietta islands in the east thereby comprising the most distant and least studied ice caps in the Russian Arctic. The situation of insular ice masses close to the edge of summer minimum sea ice proved helpful in analysing spatial asymmetry of glacier accumulation signal.

The overall mapping of glacier elevation changes and quantification of mass balance characteristics in the study region was performed by comparing reference elevation models of study glaciers derived from Russian topographic maps 1:200,000 (CI = 20 or 40 m) representing the glacier state as in the 1950s-1960s with modern elevation data obtained from satellite radar interferometry and lidar altimetry. In total, 14 ERS and 4 TanDEM-X high-quality SAR interferograms of 1995/96 and 2011 were acquired, processed in the standard 2-pass DINSAR manner, geocoded, calibrated, mosaicked and interpreted using reference elevation models and co-located ICESat altimetry data of 2003-2010. The DINSAR analysis revealed the existence of fast-flowing outlet glaciers at Arthur, Rudolph, Eva-Liv and Bennett islands. The calculation of separate mass-balance components is complicated in this case because of generally unknown glacier velocities and ice discharge values for the mid-20th century. Hence only net balance values were determined for those ice caps. Other ice caps belong to the category of slow-moving or passive glaciers with simpler estimation of mass balance characteristics. Glacier elevation changes on several study glaciers were repeatedly determined with ICESat GLA06 data releases 28 and 29, and statistically compared. The root mean square difference between test determinations was given as less than 1 m rms and the lidar oversaturation effect was neglected in further work.

Modern outlines of maritime glacier faces were corrected with the high-resolution optical quicklook imagery obtained from WorldView and QuickBird satellites. The research revealed the reduction of glacier area and general lowering of the glacier surface on most ice caps. Several new islets were discovered due to the glacial retreat in northern parts of Eva-Liv, Schmidt and Komsomolets islands. The cumulative mass budget in the study region remained negative while individual rates of volume change varied from -0.09 $km^3$/a to +0.04 $km^3$/a. Positive values of average mass balance with the maximum accumulation signal of approx. 0.9 m/a were determined on Ushakova, Schmidt and Henrietta ice caps. The results were represented in the form of glacier change maps with 50-m grid at 1:200,000 scale. The vertical accuracy of glacier change maps proved on several small and large ice caps was given as $\pm$ 0.3 m/a rms. Several resultant maps can be accessed at http://dib.joanneum.at/MAIRES/index.php?page=products. Further sub-regional comparison of glacier change maps with climatological, oceanographic, rheological, gravimetric and other ground-truth and EO data showed that spatial changes of insular glaciers are closely dependent on the frequency of precipitation events, water depth, sea ice regime, polynyas and gravity anomalies nearby. New opportunities for validating mass changes on the largest study glaciers and determining their bulk density are expected from the next release of GOCE gravity field data and CryoSat-2 radar altimetry data announced by ESA for 2012.