



Glacier mass balance in high-arctic areas with anomalous gravity

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All known glaciological models describing the evolution of Arctic land- and sea-ice masses in changing climate treat the Earth's gravity as horizontally constant, but it isn't. In the High Arctic, the strength of the gravitational field varies considerably across even short distances under the influence of a density gradient, and the magnitude of free air gravity anomalies attains 100 mGal and more. On long-term base, instantaneous deviations of gravity can have a noticeable effect on the regime and mass budget of glaciological objects. At best, the gravity-induced component of ice mass variations can be determined on topographically smooth, open and steady surfaces, like those of arctic planes, regular ice caps and landfast sea ice. The present research is devoted to studying gravity-driven impacts on glacier mass balance in the outer periphery of four Eurasian shelf seas with a very cold, dry climate and rather episodic character of winter precipitation. As main study objects we had chosen a dozen Russia's northernmost insular ice caps, tens to hundreds of square kilometres in extent, situated in a close vicinity of strong gravity anomalies and surrounded with extensive fields of fast and/or drift ice for most of the year. The supposition about gravitational forcing on glacioclimatic settings in the study region is based on the results of quantitative comparison and joint interpretation of existing glacier change maps and available data on the Arctic gravity field and solid precipitation.

The overall mapping of medium-term (from decadal to half-centennial) changes in glacier volumes 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-1980s with modern elevation data obtained from satellite radar interferometry and lidar altimetry. Free-air gravity anomalies were graphically represented in the reference model geometry using Russian gravimetric maps 1:1000000 (1980s), ArcGP grid (2008) and GOCE gravity field data (Release 3, 2009-2011). 25-year long records of daily precipitation obtained from 38 coastal stations were involved in the causality analysis. Strong positive distance-weighted correlation was discovered between the magnitude of geopotential and gravity gradient on one hand and the precipitation amount, annual number of precipitation "events" and glacier elevation changes on the other, while it was noted that the correlation decreases in humid and mountainous areas. Relevant analytical and geophysical explanations were provided and tested using the basic concepts of hydrostatic stress, lapse rate and non-orographic gradient precipitation.

It was concluded that the gravitational impact on the mass balance of arctic maritime ice caps is threefold. 1) Lateral variations of gravity influence directly the ambient lapse rate thereby modulating the atmospheric stability and leading to the increased intensity and frequency of heavy snowfalls over the areas with positive gravity anomalies. 2) Glacier ice deformation, flow, calving and meltwater runoff are gravity-driven phenomena, and the removal of glacier ice is closely interrelated with geopotential variations nearby. 3) Gravity anomalies affect processes of sea ice grow, drift and consolidation resulting in generally lower concentration and lesser thickness of the sea ice found in the aquatories with positive gravity. The advection of moist air to insular ice caps facilitates sea-effect snow events and makes glacier mass balance more positive. The effect is enhanced when the air mass advects toward the centre of positive anomaly. The idea about gradient (deviatoric) precipitation and related cryogravic processes does not contradict to the concept of gravity waves and has some analogy with the hypothesis on "ice lichens" devised by E.Gernet 80 years ago. Further analogies can be learned from another industry, e.g. technical chemistry. Several questions associated with the variability of evaporation, ice nucleation, aerosol deposition and snow redistribution in the heterogeneous field of gravity remain open.