Glacier mass balance in high-arctic areas with anomalous gravity

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Research Projects:

TDXS DLR XTI_GLAC0249 (GEODESIA)
http://tandemx-science.dlr.de/

FP7 Space GMES GA.263165 (MAIRES)
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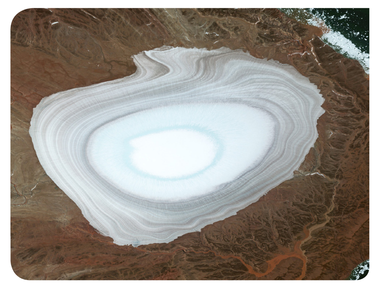


1. Abstract

The present research is devoted to studying gravity-driven impacts on glacier mass balance in the outer periphery of four Eurasian shelf seas characterized with a very cold, dry climate and episodic character of winter precipitation. As main study objects we had chosen a dozen northernmost insular ice caps, tens to hundreds of square kilometres in extent, situated in a close vicinity of strong gravity anomalies. 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.

2. Rationale

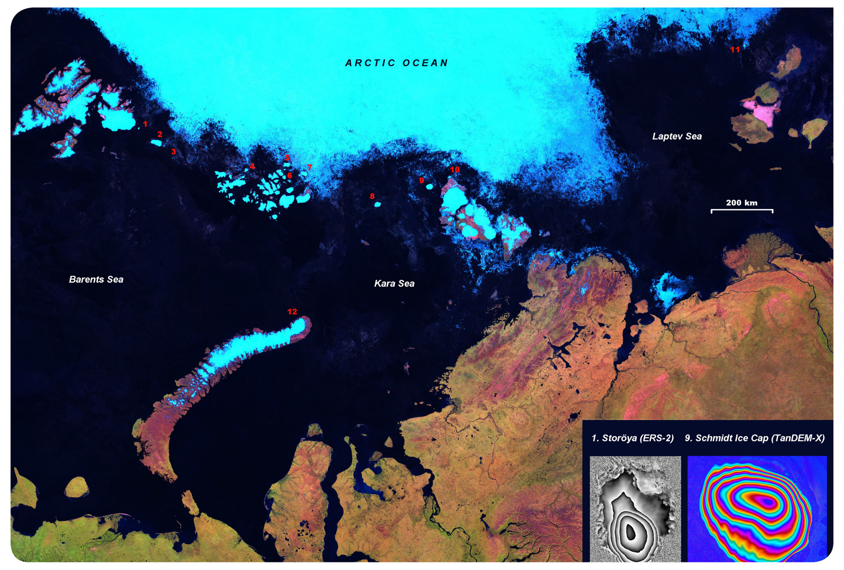
All known glaciological models describing the evolution of Arctic land- and sea-ice masses in changing climate treat the Earth's gravity as horizontally constant, but it isn't. In the High Arctic, the strength of the gravitational field varies considerably across even short distances under the influence 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.

3. Data & Method

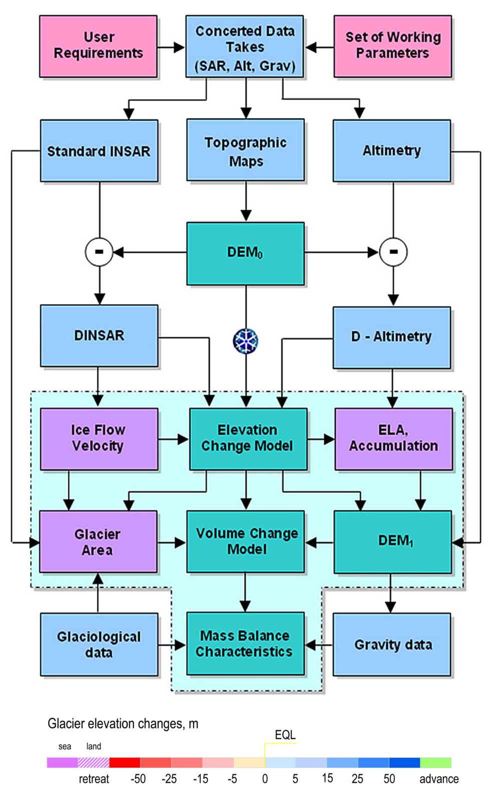
The overall mapping of medium-term (from decadal to half-centennial) changes in glacier volumes and quantification of mass balance characteristics in the study region was performed by comparing reference elevation models of study glaciers derived from Russian topographic maps 1:200,000 (CI = 20 or 40 m) representing the glacier state as in the 1950s-1980s with modern elevation data obtained from satellite radar interferometry (ERS, TanDEM) and lidar altimetry (ICESat) of 2010s. 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). 20-year long records of daily precipitation obtained from 57 coastal stations were involved in causality analysis.

4. Study region

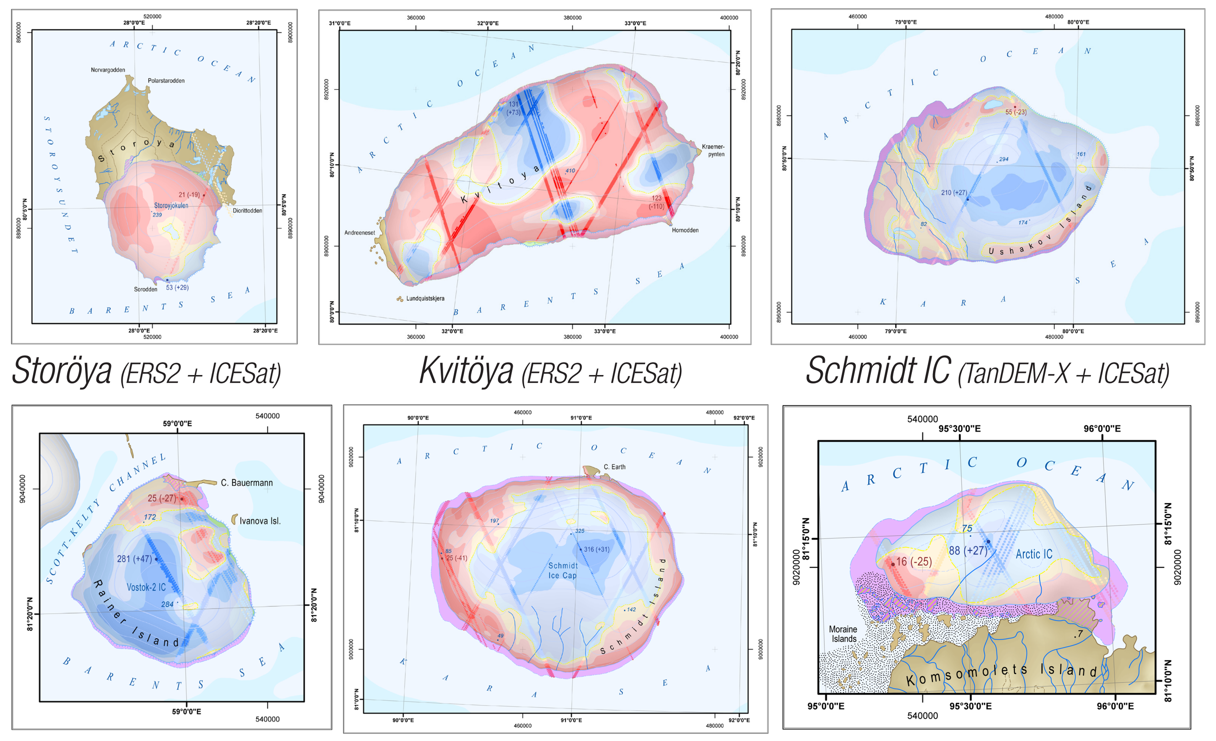
The present research is devoted to studying gravity-driven impacts on glacier mass balance in the outer periphery of four Eurasian shelf seas characterized with a very cold, dry climate and episodic character of winter precipitation. As main study objects we had chosen a dozen northernmost insular ice caps, tens to hundreds of square kilometres in extent, situated in a close vicinity of strong gravity anomalies. 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.



5. Data / workflow



6. Results / Glacier changes (1950-2000s)



Storöya (ERS2 + ICESat) · *Kvitöya (ERS2 + ICESat)* · *Schmidt IC (TanDEM-X + ICESat)* · *Rainer Isl (ERS + ICESat)* · *Ushakova IC (TanDEM-X + ICESat)* · *Arctic IC (ERS2 + ICESat)*

N	Parameter Glacier complex	Maximum height, m	Glacier / Acc area, km²	Elevation change, m/a *	Volume** change, km³	FA gravity an., mGal
1	Storöya	239	28 / 2	-0.36 (+0.3)	-0.36**	+13 … +14
2	Kvitöya	410	690 / 202	-0.5 (+2.0)	-12	+32 … +46
3	Victoria Island	105	6 / 0	-0.2 (-0.1)	-0.06	+24 … +28
4	Arthur Island	275	90 / 23	-0.1 (+0.75)	-0.35	+8 … +13
5	Rudolph Island	461	291 / 59	-0.2 (+1.2)	-3.2	+26 … +31
6	Rainer Island	284	133 / 103	+0.2 (+0.9)	+1.7	+19 … +24
7	Eva-Liv Island	381	268 / 23	-0.1 (+0.4)	-2.2	+11 … +16
8	Ushakova Island	294	326 / 199	+0.12 (+0.5)	+1.9	-10 … +18
9	Schmidt Island	325	438 / 233	0 (+0.6)	+0.2	+1 … +7
10	Arctic Ice Cap	75	106 / 39	0 (+0.5)	-0.1	+12 … +21
11	Bennett Island	412	72 / 45	+0.04 (+0.4)	+0.2	+8 … +12
12	Northern Ice Cap	815	2.260 / 1.290	+0.6 (+2.0)	+35** *	+10 … +43

*) *average change rate (max positive change rate);* **) without ice coasts; ***) *non-controlled value.*

Ambient (dry adiabatic) lapse rate:

$$\Gamma_d = \frac{dT}{dz} = -\frac{g}{c_{pd}} \cong -9.8°C/km$$

Cpd = 1 - specific heat *T(x) = const*

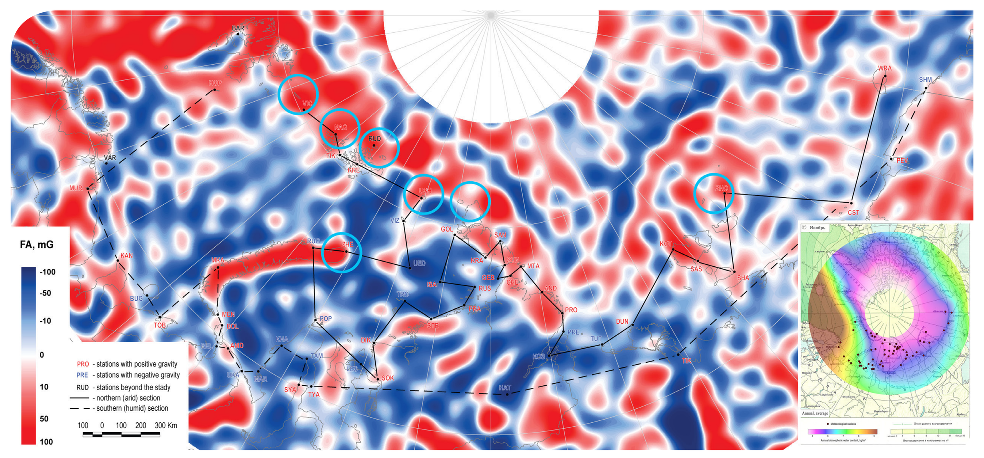
Hydrostatic equilibrium / Pressure gradient:

$$P \cong \rho \cdot z \cdot g \qquad \frac{dP}{dx} \cong \rho \cdot z \cdot \frac{dg}{dx}$$

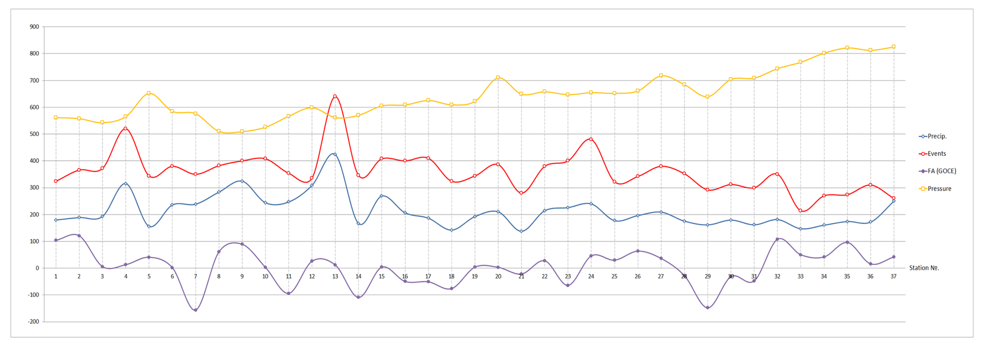
Topography = 0

7. Analysis / Meteodata vs Gravity

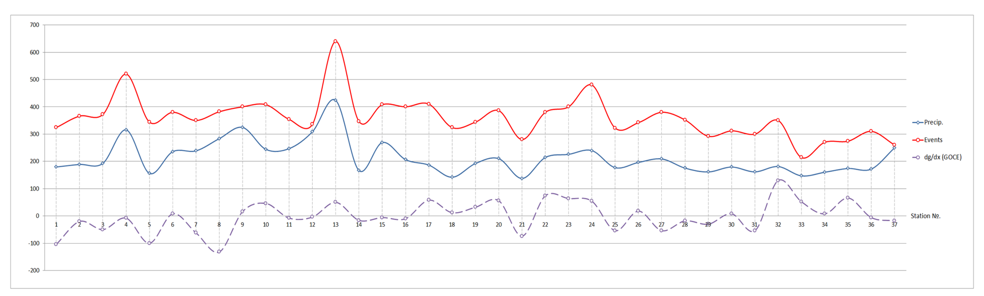
Free air gravity anomaly grid (GOCE R3_TIM) / Atmospheric water content, kg/m²



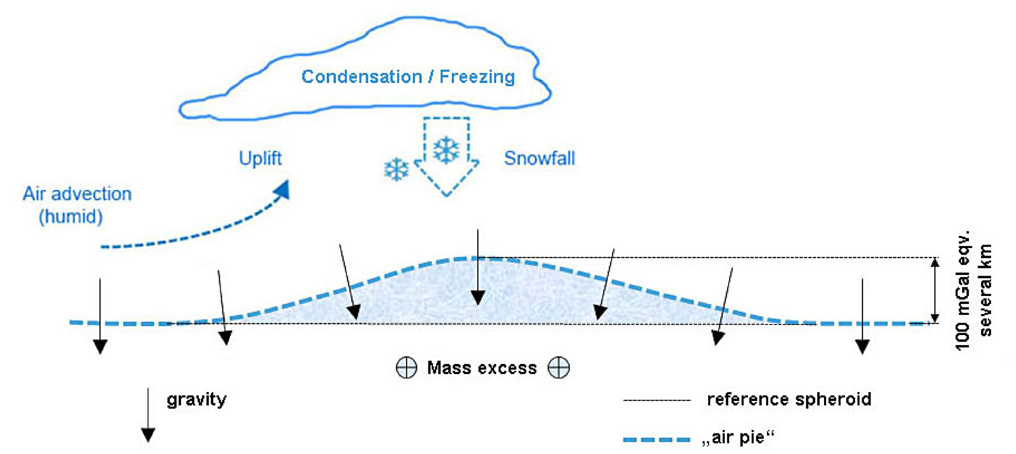
Meteorological characteristics versus GOCE free air gravity anomalies (mGal)



Annual precipitation rate (mm/a) versus horizontal gravity gradients (mGal/km)



8. Analysis / Gradient precipitation



9. Analysis / Sea effect snow

Sea Effect Snow, also called snow squalls, results from cold, arctic air traveling over a relatively warm body of sea water. The cold, dry air picks up the sea moisture and deposits it, in the form of snow, over land (Mitchell, Wikipedia 2012).

10. Conclusions

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. 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.

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