Can we use regional runoff models for correcting time series of absolute gravimetry?

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Abstract

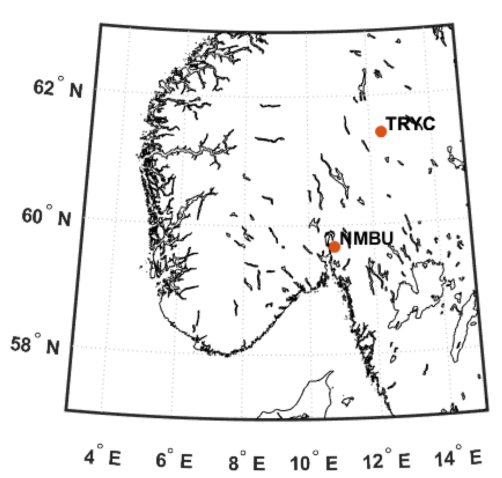
Absolute gravity time series are available at various stations in Norway. The data have mainly been used for investigation of secular variations due to glacial isostatic adjustment. Previous work indicates that some of the estimated gravity trends suffer from unmodeled geophysical effects, like hydrological mass variations. Here we try to correct for hydrological effects by employing a combination of global and regional hydrological models. We use gravity data at two locations in the Norwegian network (NMBU and TRYC) which have frequently been observed with the absolute gravimeter FG5-226. For computing the gravity corrections, we test various Global Hydrological Models (GHMs) and combine them with a Regional Runoff Model (RRM) for Norway, run by the Norwegian Water Resources and Energy Directorate (NVE). We distinguish between an outer and an inner zone. In the outer zone, Newtonian attraction and loading effects are derived from the GHMs, while the RRM is used in the inner zone. Both types of models provide information on soil moisture and snow layers. The RRM provides groundwater variations in addition. Furthermore, we try to consider the 'umbrella effect' that accounts for local disturbances in subsurface water flow caused by the existence of the building in which the gravity site is located. After reducing the GIA trend, both NMBU and TRYC gravity time series show different amplitude and pattern. NMBU shows a lower amplitude, and with no prominent periodic pattern in the data, while TRYC shows the opposite. Significant discrepancies occurring in the NMBU gravity dataset between 2014 and 2015 are likely due to an instrumental effect, such as maintenance. The total modelled hydrological signal ranges from -4 and 4 µGal. Application of the correction reduces the standard deviation in the gravity time series, at its best, by about 33% or 0.8 µGal for NMBU, and by about 43% or two µGal for TRYC. Secular gravity rates have been derived from both, the uncorrected and the corrected time series. We find that application of the hydrological correction improves the fit of the computed secular gravity rates as compared to rates derived from the state-of-the-art Fennoscandian land uplift model NKG2016LU_abs. The uncorrected trends are 75% and 50% of the expected trend (0.77 and 1.12 µGal/year), while the hydrological corrections improve the fit to 82% and 93% for NMBU and TRYC, respectively.

Motivation

In Norway, FG5-type absolute gravity observation have been extensively used to monitor gravity changes due to glacial isostatic adjustment (GIA) in the last decades. Ophaug et al. (2016) found that most sites with repeated absolute gravity observations are reliable candidates for GIA studies. However, they also stress that at some sites, the observed secular gravity trend might still be affected by unmodeled geophysical effects, such as the effect of local hydrology. As most of the gravity sites are not equipped with a set of hydrological instruments, modeling such a local hydrological effect is challenging. The Norwegian Water Resources and Energy Directorate (NVE) has developed a high-resolution gridded regional runoff model (RRM) for Norway. The model provides local water storage variation with a higher spatial resolution than typical Global Hydrological Models (GHMs), and as such might improve the computed hydrological gravity effect.

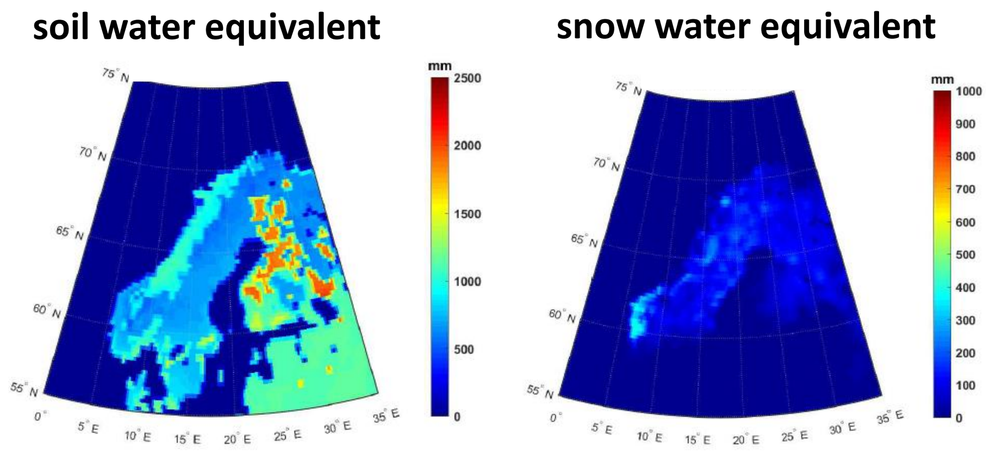
Data

FG5-226 absolute gravity observations



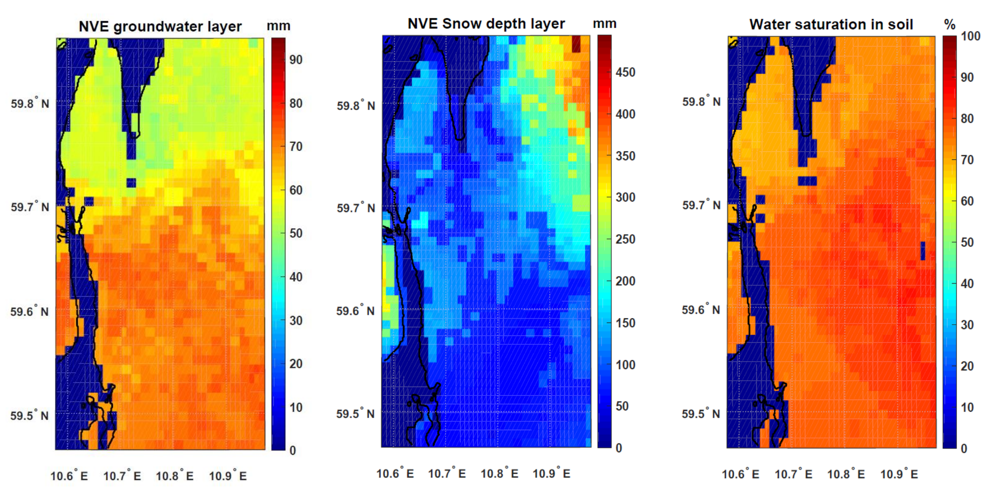
We have considered two gravity sites that have been visited relatively frequently over a considerable period of time, NMBU and TRYC. The gravity observations at NMBU are covering the 2005-2019 period, while they cover the 2005-2008 period at TRYC.

Global Hydrological Models



We test various sub-models of GLDAS and the recent ERA5 model. The soil and snow layers are considered in this work.

Regional Runoff Model

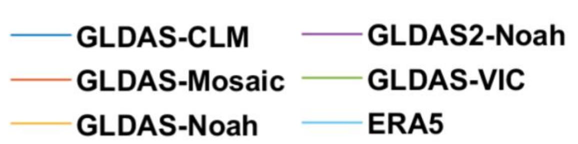


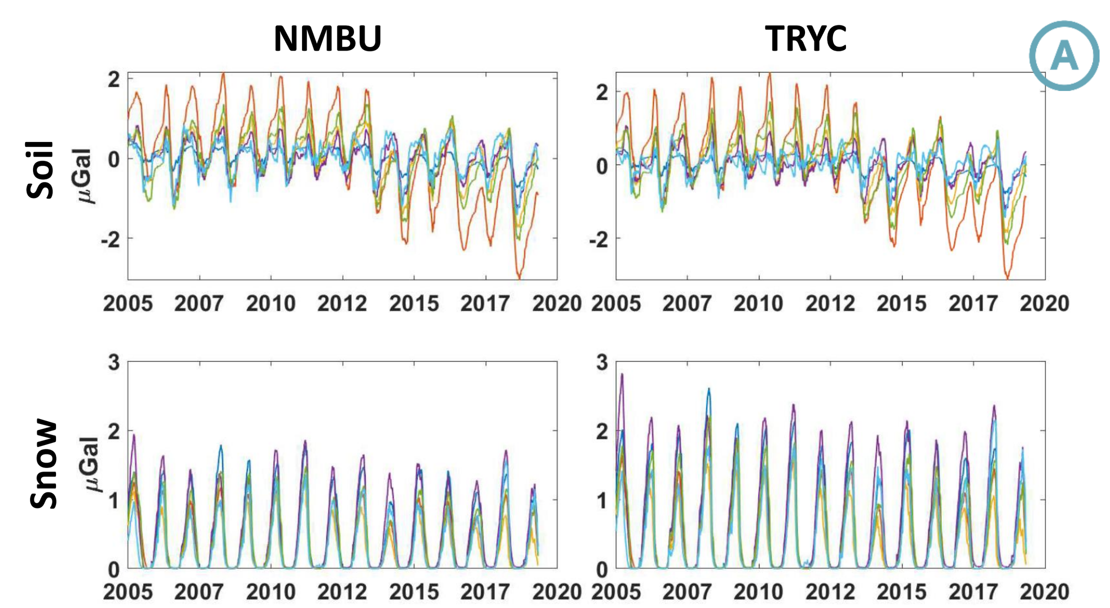
Apart from soil and snow layers, an additional groundwater layer is used. As the soil layer of the RRM is giving the water saturation in the soil, and not the water amount, we need the two additional parameters of soil porosity and soil thickness. We adopt a soil porosity of 30% and take the soil thickness from the global soil model by Pelletier et al. (2016).

Hydrological Gravity Modeling

Outer zone effects (≥ 0.05° from computation point)

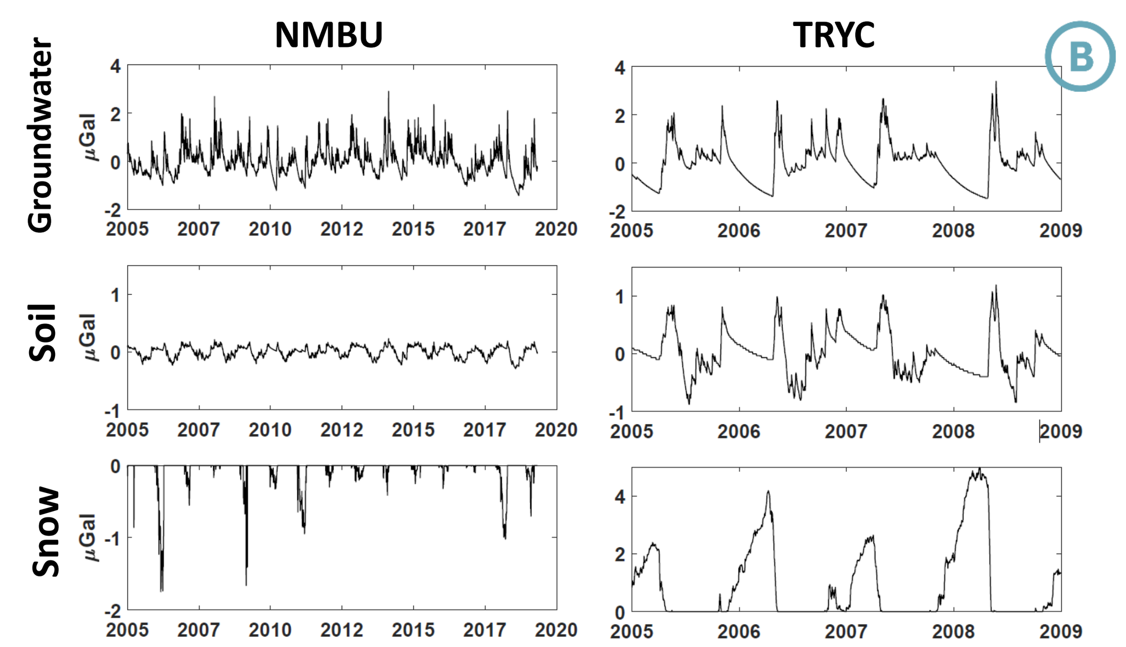
Modeling of the outer zone effect is based on the Matlab tool by Mikolaj et al. (2016). Figure A illustrates the modeled outer zone effects.





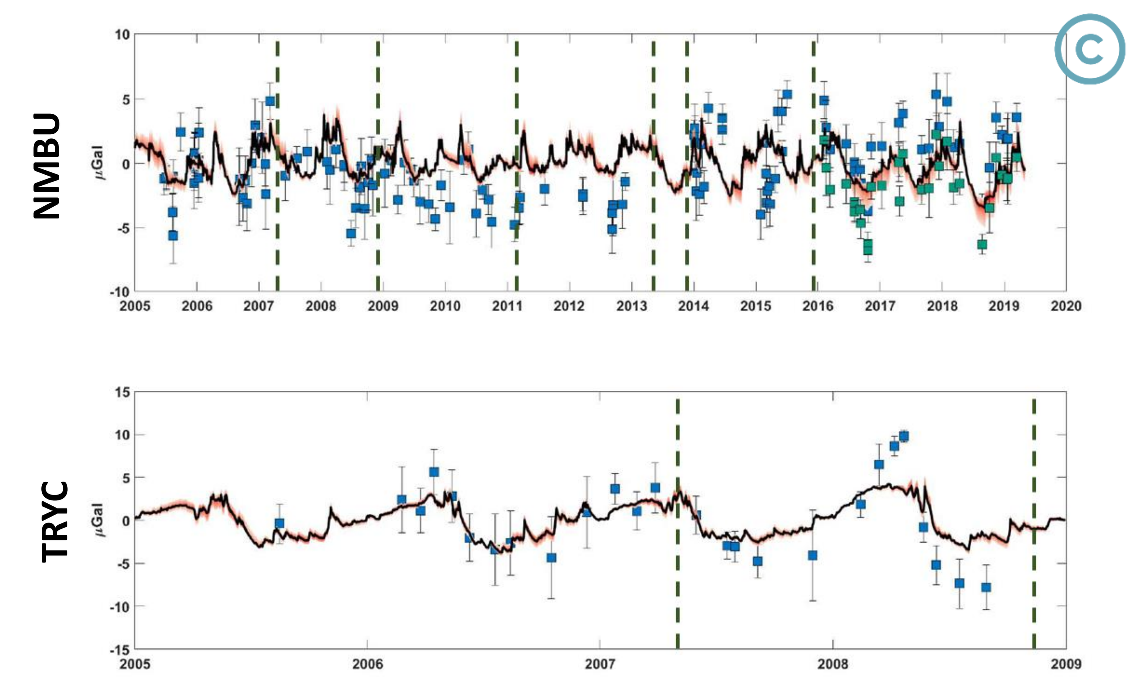
Inner zone effects (< 0.05° from computation point)

Modeling of the inner zone effect is based on the classic Newtonian attraction of a right rectangular prism by Pluoff (1976). 'Umbrella' effect is also implemented in the model. Figure B displays the modeled inner zone effects.



Total hydrological effects

Figure C shows gravity residuals (blue squares) with their uncertainty and total hydrological effects (solid black line with red area as its percentile) for NMBU (upper panel) and TRYC (lower panel). Green squares represent the shifted gravity values. Dashed lines mark the maintenance events.



Variance Improvement and Secular Gravity Trends

GIA effects have been removed from the data using the gravity-to-uplift ratios of -0.163 µGal mm^{-1} (Olsson et al., 2015) and a recent land uplift model of NKG2016LU_abs. Prior to analysis, the consistency of gravity measurements has been assessed, and we found that instrument maintenance events may have affected the observed gravity. For example, a 2016 laser repair appears to have shifted the mean gravity level by a few uGal.

Table 1 lists weighted standard deviations after applying hydrological corrections. Presented results at NMBU are additionally divided into four time periods aligned with the behavior of measured gravity and maintenance events. Table 2 reveals the estimated secular gravity trend at both sites. The expected gravity trends for NMBU and TRYC respectively are -0.77 and -1.12 µGal yr^{-1}.

Table 1 Weighted standard deviations for both corrected and uncorrected observations (unit in µGal)*. The header indicates the GHMs used for the outer zone effect.*

	GLDAS-CLM	GLDAS-Mosaic	GLDAS-Noah	GLDAS2-Noah	GLDAS-VIC	ERA5	No correction applied
NMBU	2.55	2.98	2.57	2.49	2.66	2.50	2.53
NMBU*	2.32	2.39	2.29	2.29	2.32	2.34	2.54
NMBU (2004-2008)	1.76	1.90	1.76	1.74	1.90	1.75	2.10
NMBU (2009-2013)	1.73	1.54	1.68	1.72	1.60	1.82	1.51
NMBU (2014-2015)	3.38	3.37	3.38	3.49	3.34	3.46	2.66
NMBU (≥ 2016)	1.76	1.80	1.70	1.66	1.75	1.70	2.42
TRYC	4.01	3.91	4.09	2.68	2.66	2.90	4.60

* shifted gravity values after 2016 are applied to the data

Table 2 Estimated gravity rates (unit in µGal yr^{-1}*). % indicates the level of fit to the expected values. The header indicates the GHMs used for the outer zone effect.*

		GLDAS-CLM	GLDAS-Mosaic	GLDAS-Noah	GLDAS2-Noah	GLDAS-VIC	ERA5	No correction applied
NMBU	Rates	-0.58	-0.45	-0.58	-0.62	-0.58	-0.62	-0.58
	%	76.84	59.77	75.86	81.59	76.19	82.08	75.00
TRYC	Rates	-0.81	-0.90	-0.89	-0.78	-1.05	-0.83	-0.61
	%	72.65	80.03	79.32	69.35	93.73	73.88	54.46

Conclusion and Outlook

- We have combined a suite of GHMs with an RRM to compute refined hydrological gravity corrections.
- The presence of the building is lowering the soil gravity effect of soil and gives the opposite sign for snow effects when snow exists on the roof.
- Applying the hydrological correction to FG5 absolute gravity observations reduces the weighted standard deviation by up to 33% or 0.8 µGal for NMBU, and by about 43% or two µGal for TRYC, and the refined computed secular gravity trends show a better fit with the modeled trend for both sites.
- The assumption of soil porosity, soil thickness, how snow accumulates on the roof for each site, and modeling the undefined layer between the soil and groundwater layer should be further investigated

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