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Sea Level Change and Vertical Crustal Motion in the Canadian Arctic Based on GPS and Tide Gauges: Challenges and Preliminary Results

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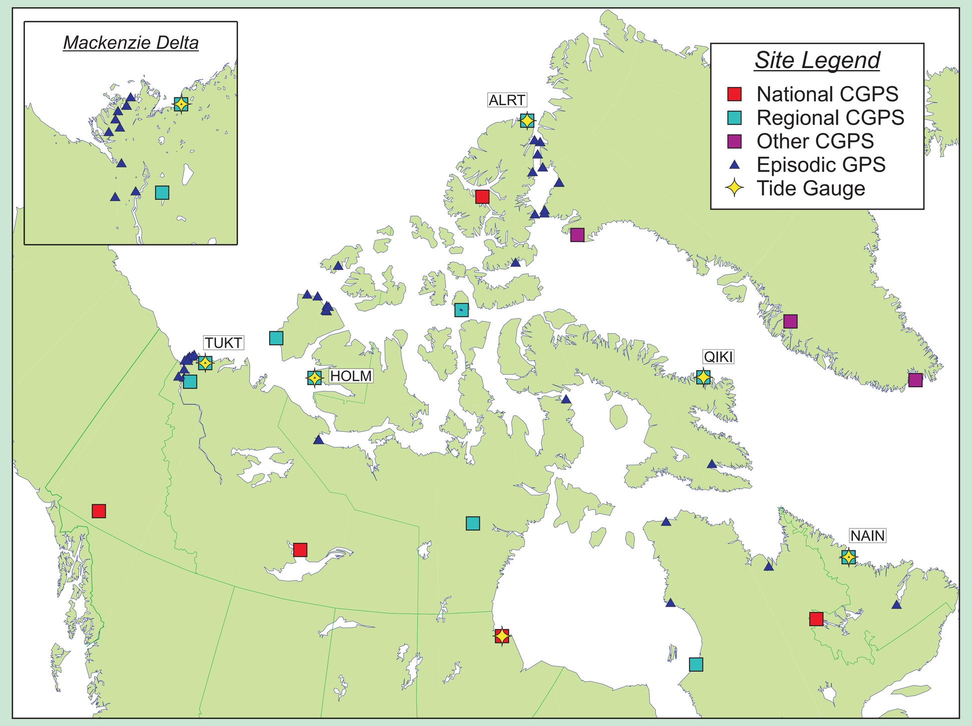
INTRODUCTION

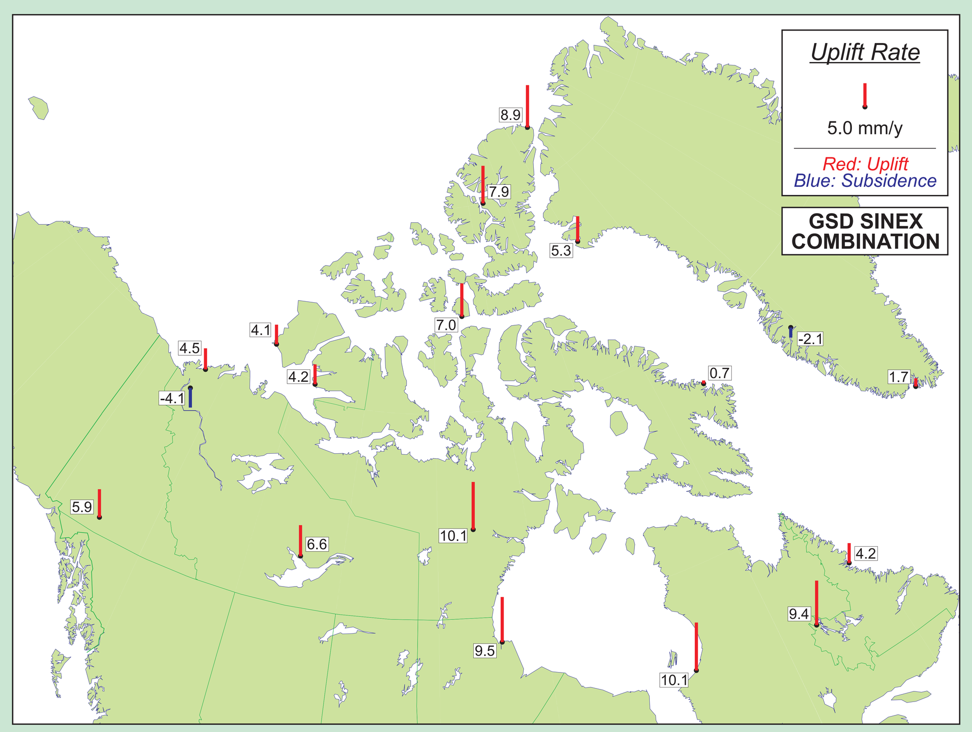
A network of several continuous GPS (CGPS) stations co-located with tide gauges has been established in the Canadian Arctic with the aim of directly measuring changes in absolute sea level. The tide gauge data provide measurements of relative sea level with respect to the crust upon which the tide gauge is anchored. The GPS data enable us to determine the absolute vertical velocity of the crust at each tide gauge with respect to a global reference frame. Combining the two allows us to determine absolute changes in Arctic sea level with respect to the global frame.

Several factors affect our ability to obtain reliable estimates from these measurements, including monumentation, various kinds of noise and systematic biases, equipment type and changes, and, most importantly, the length of the time series. Some of these factors will be discussed in relation to our experiences from the past several years. Although based only on three to five years of data, we provide some preliminary results of crustal motion and sea level change and compare these to estimates reported by others. We also estimate the level of accuracy we might expect with longer time series and mention proposals for expanding this network in the near future.



Map of tide gauge and GPS sites in the Canadian north. This work focuses on preliminary results from five recently established tide gauges and their collocated GPS sites: ALRT (Alert), HOLM (Holman), NAIN (Nain), QIKI (Qikiqtarjuaq), and TUKT (Tuktoyaktuk).

GPS VERTICAL VELOCITIES



Observed CGPS vertical rates. Preliminary results from the SINEX combination of weekly GPS solutions in Canada exhibit a spatially coherent pattern of uplift largely consistent with post-glacial rebound.

To determine individual station velocities we systematically combine national CGPS solutions for each week into a single Canada-wide, multi-epoch cumulative solution. In order to generate time series of consistent, high-accuracy coordinates for velocity estimation, it is necessary to ensure consistency in the realization of the reference frame. We accomplish this by aligning each of the national weekly solutions to the IGS realization of ITRF using a subset of stations from a recent IGS cumulative solution for the IGS global network. We ensure consistent and realistic weighting of the individual CGPS solutions through the estimation of variance components relative to the IGS global solution. After the weekly solutions are aligned and weighted, they are combined together in a simultaneous cumulative solution for velocities at each site.

GPS PROCESSING

- ❖ Bernese GPS Software Version 5
- ❖ Double-differenced observations
- ❖ 120 second data sampling
- ❖ 10° elevation cut off
- ❖ Fixed IGS precise orbits & ERPs
- ❖ Tropospheric zenith delays (every 2 hours)
- ❖ Niell mapping function (wet & dry)
- ❖ No tropospheric gradients
- ❖ QIF ambiguity resolution
- ❖ CRS4.0 ocean loading model
- ❖ 4 IGS reference frame sites aligned to IGS weekly coordinates (ALGO, DRAO, SCH2, YELL)

VELOCITY ESTIMATION

Combined 305 weekly GPS solutions from week 1095 to week 1399

Using SINEX combination software:
- GSD SINEX Software (v*BDA*) by Rémi Ferland
- Used for official IGS global combinations

Constraints removed from weekly solutions

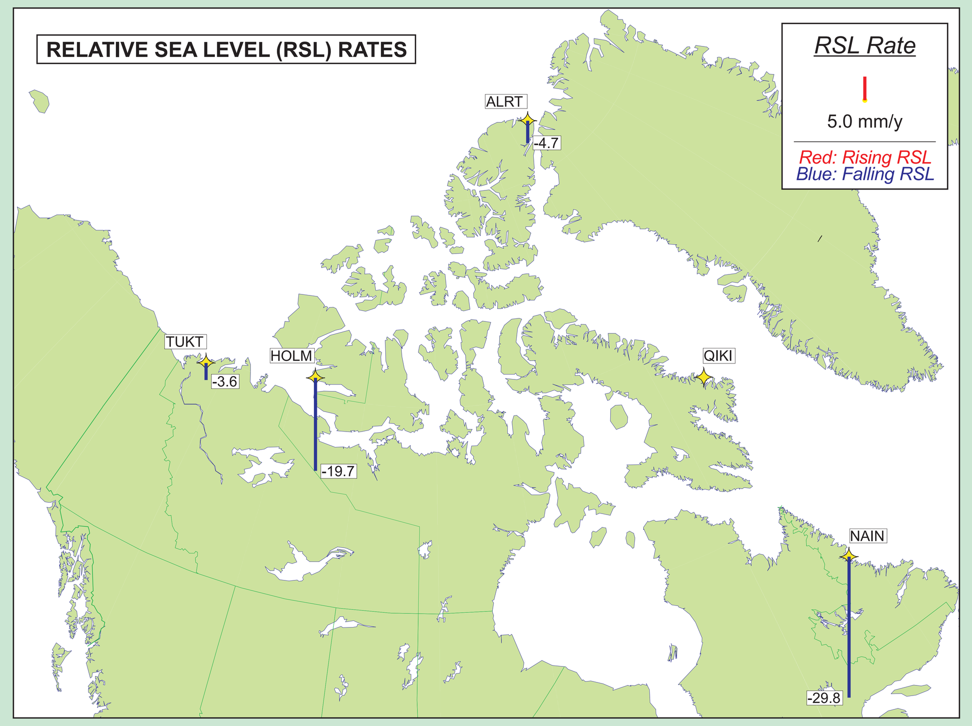
Weekly solutions aligned to subset of Canadian sites in IGS cumulative solution *IGS06P30.snx* at each weekly epoch (3 translations, 3 rotations & scale change)

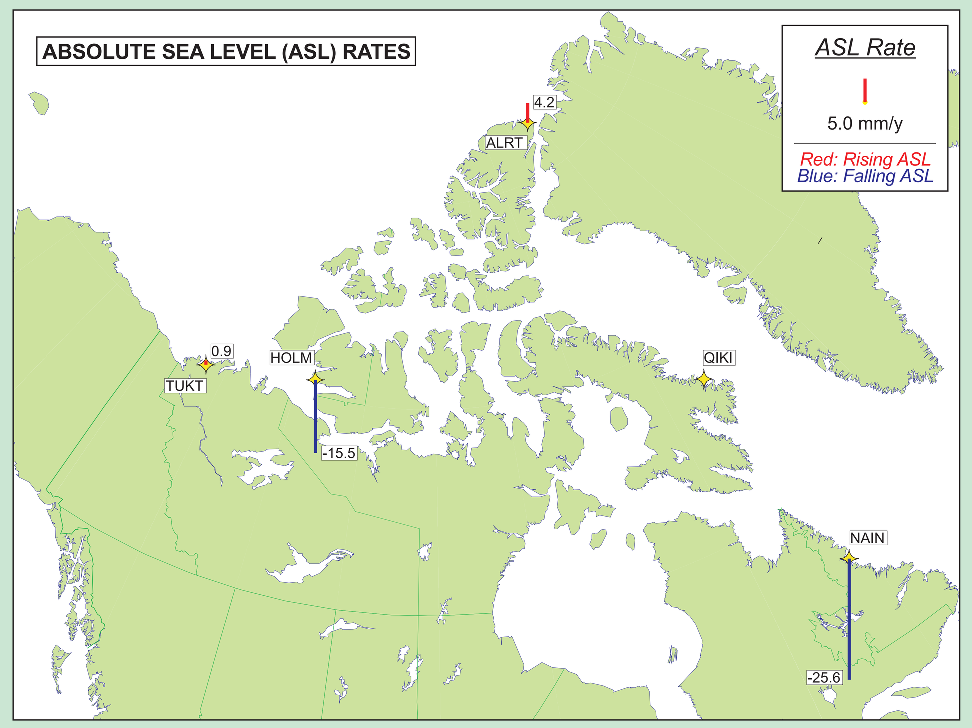
Covariance matrix of each solution scaled by WRMS of residuals from alignment

All aligned & scaled weekly solutions combined together (summation of normals) and velocities estimated

Station ALGO constrained to coordinates and velocities from IGS cumulative solution

SEA LEVEL RATES





Tide Gauges Collocated with CGPS

- ➢ Installed by the Canadian Hydrographic Service (CHS)

NAIN	2001.5
ALRT	2002.5
HOLM	2002.5
TUKT	2003.5
QIKI	2004.5

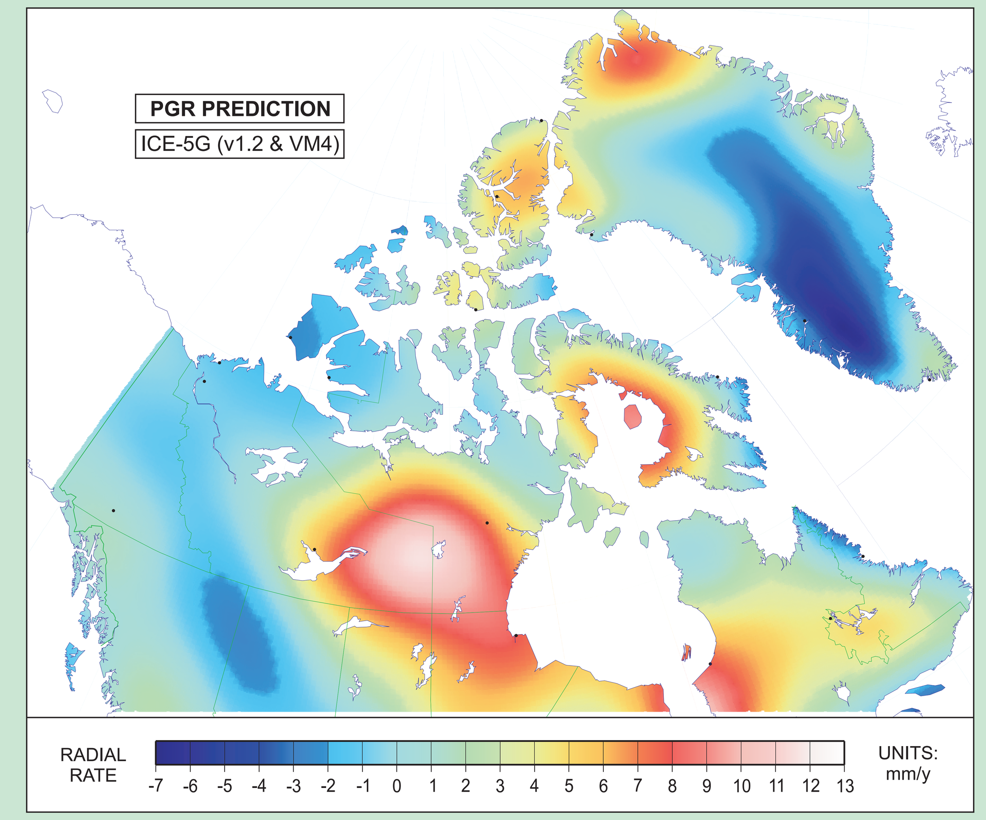
- ➢ Referenced Directly to CGPS

Notes on Tide Gauge Analysis

- ➢ Linear trend regressions (*i.e.* periodic signals were not estimated for results given)
- ➢ Testing with annual & semi-annual components did not greatly affect rate estimates
- ➢ Standard deviations did not change significantly when adding coloured noise
- ➢ RSL trend not estimated for QIKI (time span is too short)
- ➢ Anomalous negative RSL at Nain is thought to be due to instability of the tide gauge installation and is being investigated further
- ➢ Not enough data yet for relative sea level analysis
- ➢ Require data for at least ten years (preferably more)
- ➢ Need to model tidal constituents and oceanographic signals

Monthly Relative Sea Level (RSL) Time Series

GIA PREDICTIONS



Regional map of radial rates predicted from the glacial isostatic adjustment model ICE-5G [Peltier, 2004].

ICE-5G REFERENCES:

Peltier W.R. (2004), Global Glacial Isostasy and the Surface of the Ice-Age Earth: The ICE-5G(VM2) model and GRACE, *Ann Rev Earth Planet Sci 2004*, 32,111-149.

Peltier W.R. (2005), On the Hemispheric Origins of Meltwater Pulse 1A, *Quat Sci Rev*, 24, 1655-1671.

Peltier W.R. & Rosemarie Drummond, (2005/6), Geodetic Signatures of the ICE-5G model of Late Pleistocene Deglaciation, *Geophys J Int.*, (In preparation).

COMPARISON & SUMMARY OF VERTICAL RATES

TABLE 1 - Comparison of GPS uplift rates to other GPS analysis centres.

GPS SITE	GSD Uplift (mm/y)	JPL Uplift (mm/y)	SOPAC Uplift (mm/y)
ALRT	8.9 ± 0.4	11.9 ± 0.5	9.5 ± 1.6
HOLM	4.2 ± 0.2	5.3 ± 0.3	3.5 ± 1.6
TUKT	4.5 ± 0.4	1.0 ± 0.6	38.0 ± 2.0
NAIN	4.2 ± 0.3	4.4 ± 0.3	(N/A)
QIKI	0.7 ± 0.7	(N/A)	(N/A)

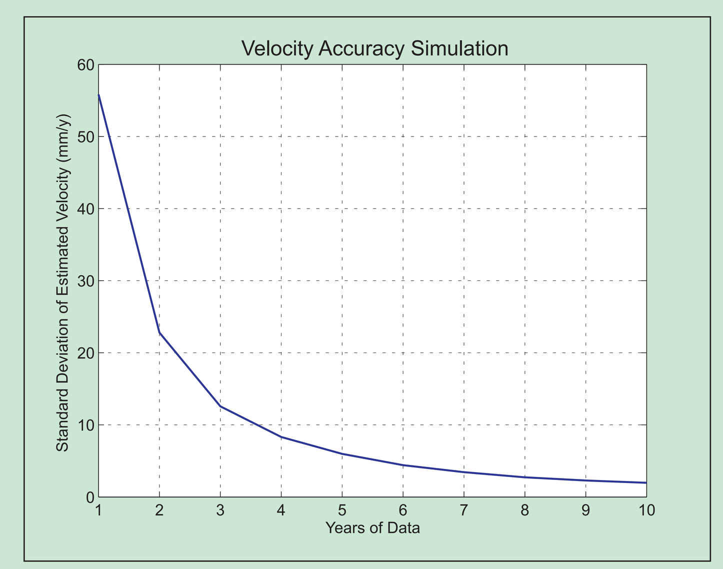
TABLE 2 - Summary of preliminary sea level results presented in this poster.

SITE NAME	GPS Uplift (mm/y)	+	RSL Trend (mm/y)	=	ASL Trend (mm/y)
ALRT	8.9 ± 0.4		-4.7 ± 10.9		4.2 ± 10.9
HOLM	4.2 ± 0.2		-19.7 ± 13.8		-15.5 ± 13.8
TUKT	4.5 ± 0.4		-3.6 ± 25.9		0.9 ± 25.9
NAIN	4.2 ± 0.3		-29.8 ± 10.0		-25.6 ± 10.0
QIKI	0.7 ± 0.7		(Too Short)		(N/A)

TABLE 3 - Comparison of GPS uplift rates to ICE-5G predicted rates for VM4 & VM2.

SITE NAME	GPS Uplift (mm/y)	ICE-5G Prediction (mm/y) VM4	VM2
ALRT	8.9 ± 0.4	3.1	2.2
HOLM	4.2 ± 0.2	-1.6	-1.2
TUKT	4.5 ± 0.4	-1.2	-2.1
NAIN	4.2 ± 0.3	-1.5	-1.2
QIKI	0.7 ± 0.7	-0.7	-0.9

SEA-LEVEL RATE ACCURACY vs TIME SPAN



- ➢ Assumed normally distributed monthly observations
- ➢ Assumed 7 cm sigma for monthly observations based on sample standard deviation of ALRT (Alert) residuals
- ➢ Assumed linear trend (no periodic terms)
- ➢ Will require data for at least ten years to attain standard deviations at a level of 2 mm/y

SUMMARY & FUTURE WORK

- ❖ GPS vertical velocities are typically consistent with rates published by other GPS analysis centers.
- ❖ Preliminary relative sea level trends are not significant yet.
  - Will require longer data span (>10 years)
  - Plan to perform more thorough analysis of tide gauge signals
- ❖ GPS uplift rates for the coastal sites are generally more positive than expected
  - Uplift rates at tide gauge sites discussed in this presentation are generally more positive than radial rates predicted by recent global glacial isostatic adjustment models (*i.e.* IGE-5G).
  - Additional GPS sites in the western Canadian Arctic also exhibit rates that are more positive than expected from on-going coastal geomorphology studies.
  - Will compare with other GPS processing software (*e.g.* GSD's precise point positioning software)
- ❖ IPY proposals to install new CGPS and tide gauge sites.
  - Northern Canada Geodynamics Network (NCGN, also includes absolute gravity)
  - Canadian Arctic Network of Coastal Observatories (CANCO)

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All base maps were produced using GMT [*Wessel and Smith*, 1998].

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