Integrating GIA models with GNSS data: Testing models against a new Canadian velocity field

Canada
Natural Resources Canada / Ressources naturelles Canada

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ABSTRACT

GIA and elastic models are important inputs for the vertical component of Canada's updated crustal velocity model, which has been developed as part of the realization of its NAD83(CSRS) 3-dimensional geodetic reference frame. The GNSS-based velocity model is used to propagate coordinates to different reference epochs, and to support scientific studies such as natural hazards and earthquakes, and sea level rise. The vertical component combines GIA and elastic models with a new up-to-date velocity field generated using continuous and high accuracy campaign GNSS data in Canada, Greenland and surrounding areas of the USA. Including GIA and elastic models is particularly important for northern Canada, which has both a sparse GPS station network and high rates of GIA-induced crustal motion. Before being incorporated into the vertical velocity model, GIA and elastic models were tested against the new velocity field. A Kriging technique is used to merge the models with the GNSS data, generating a hybrid velocity grid and its uncertainty estimates. Here we present the results of the comparisons between our new velocity field and a suite of GIA/elastic models, and describe how the geophysical models are integrated with the GNSS data.

1. GPS VELOCITIES

Continuous GPS Solutions

- Daily solutions using Bernese GNSS Software v5.2
- CODE 'repro2' precise orbits
- IGS absolute antenna calibrations
- 50 global IGS stations define IGS14 reference frame
- Ionospheric-free L3 baselines with tropo estimation for long baselines to IGS reference frame stations

Multi-Year Combination and Velocity Field

- 923 weekly (2000-01-02 to 2017-09-06) & 111 campaign solutions
  - Full covariance information
  - Translation, rotation & scale determined for each input solution
- Combined cumulative solution of weekly solutions
  - All station positions & velocities estimated simultaneously
  - Variance factor for each solution estimated and applied
  - Input station coordinate residuals >20 mm (5σ) rejected
  - Solution aligned to IGS14
- Residuals between cumulative solution and IGS14 rejected when
  - >20 mm (5σ) for positions
  - >10 mm/yr (5σ) for velocities
- Velocity outliers identified by comparison with nearby stations and removed before comparison and incorporation with GIA models. These sites typically have short time series, monument stability issues, or are known to be in areas with anomalous local motion.

Campaign GPS Solutions

- Multiple (3-4) 24 hr occupations of each site for each campaign
- Same Bernese processing as for continuous sites

Canadian Base Network (CBN)

- Network of stable pillar monuments
- Forced centering antenna mounts
- 58 survey campaigns from 1994 to 2016

Regional Campaigns

- Pacific Geoscience Center Yukon: 22 campaigns (1999-2011)
- Eastern Canada Deformation Array: 20 campaigns (2005-2016)
- Haida Gwaii: 8 campaigns (1998-2013)

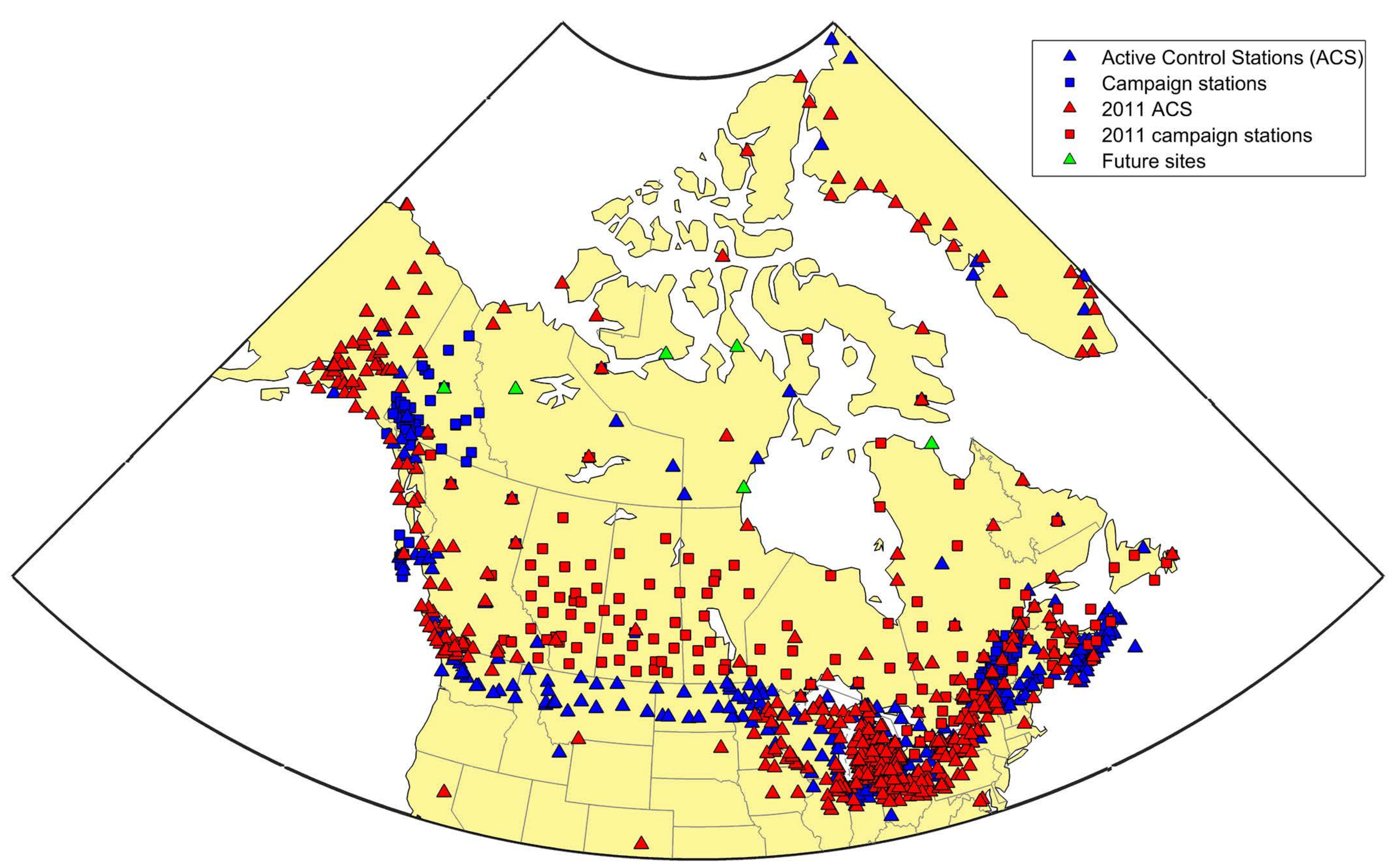


Figure 1. Stations in the new velocity field. Sites in red were in the previous 2011 velocity field, sites in blue are additional sites in the new velocity field, and sites in green are recently installed or future proposed sites not used. Squares are campaign sites and triangles are continuously operating GPS sites (referred to as CACS in Canada and CORS in the US). Some campaign sites have been converted to CACS stations since 2011 (not identified on the map).

2. HYBRID VERTICAL VELOCITY GRID

- After outlier removal the velocity field is integrated with a GIA and elastic model using the remove-compute-restore method.
- Differences between the geophysical models and the velocity field (remove) are interpolated using a kriging technique (compute), then added back to the geophysical models (restore).
- An error grid combines kriging uncertainty with a GIA model uncertainty calculated as the standard deviation of the differences between hybrid grids using each of the available GIA models.
- The hybrid grid shown in Figure 2 uses LaurInnu above 52N transitioning to ICE-6G below 48N.

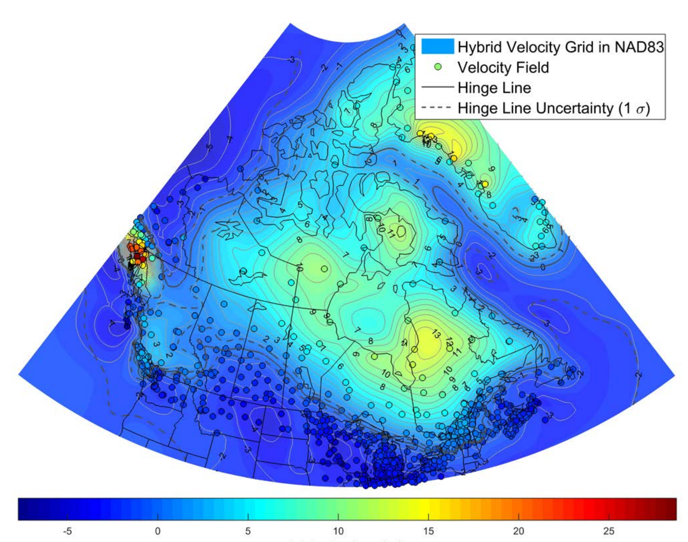
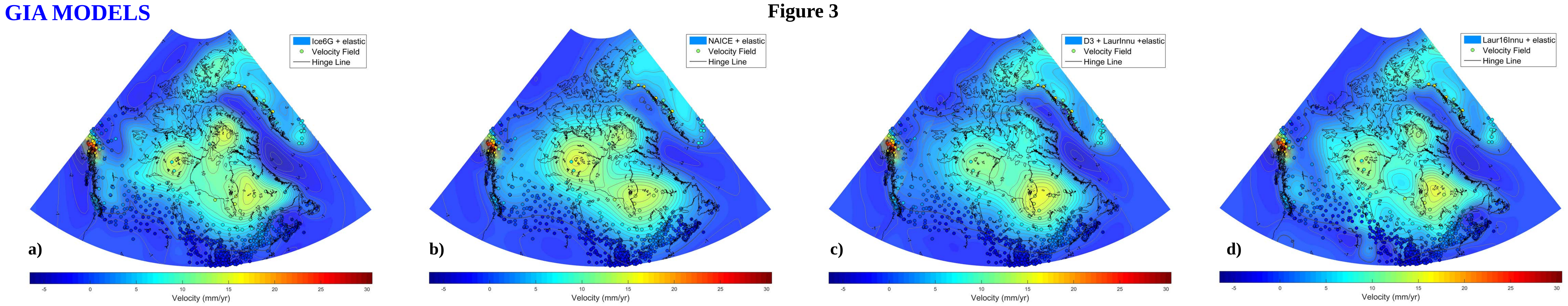


Figure 2. New vertical velocity grid is a hybrid model of GIA and GPS models.

3. GIA MODELS

Figure 3



- Vertical velocities are plotted in Figure 3 for each of the 4 GIA models examined in this study[1,2,3,4].
- GIA models are combined with 'elastic' models for current ice melt in Greenland and northern Canada[4], as well as for Little Ice Age effects in the Alaskan panhandle[5].
- The D3 model[3] is combined with LaurInnu (Figure 3c) to cover sites north of the D3 grid.
- The purely GPS velocity grid (no GIA models included) is given in Figure 4 for comparison with the hybrid grid in Figure 2.
- Model differences are represented in Figure 5 as the standard deviation of the 6 model-to-model differences. Stations recently installed or to be installed in the near future are shown in magenta and may help resolve some of the disagreement between GIA models.

Figure 4

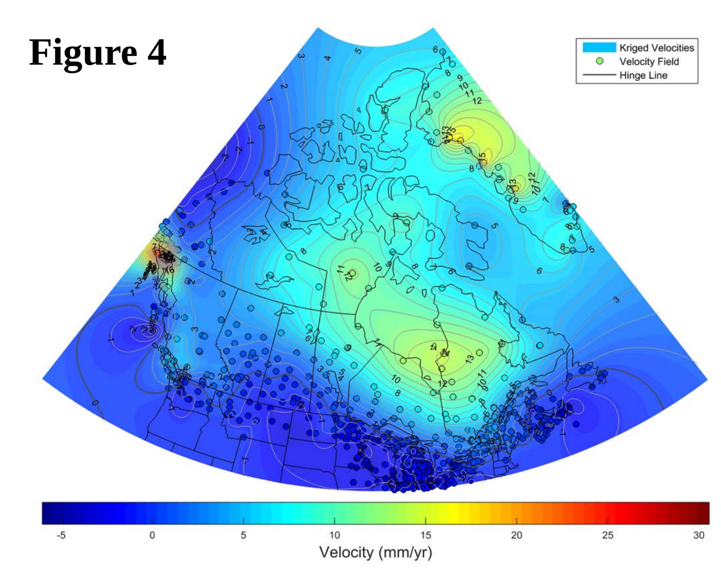
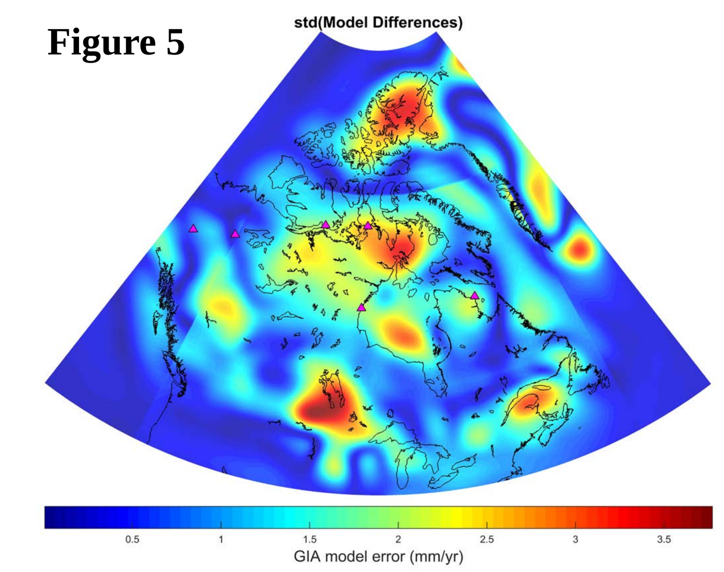


Figure 5



4. VELOCITY FIELD TO GIA MODEL COMPARISONS

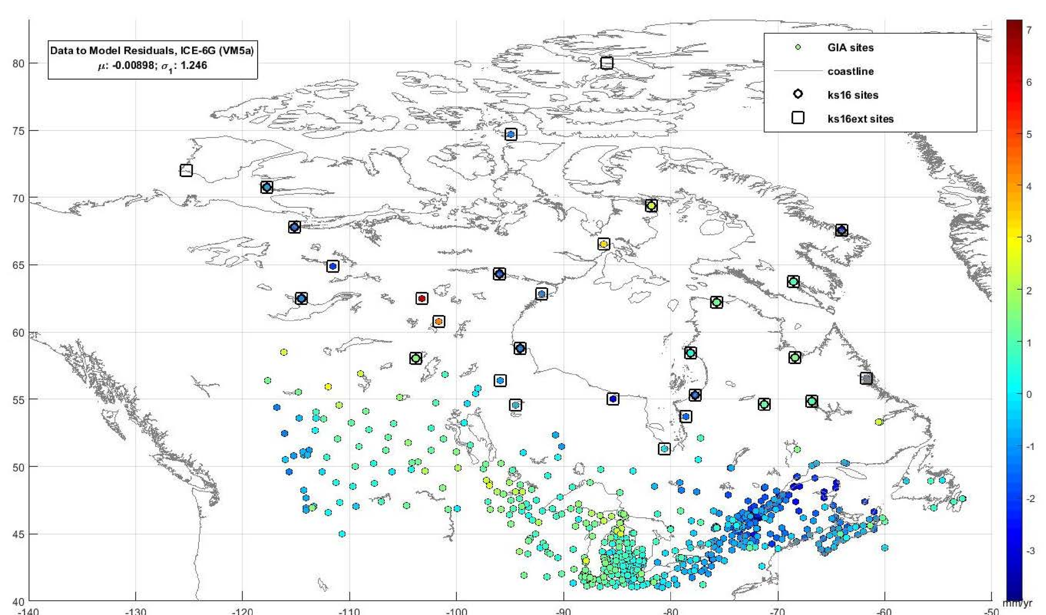
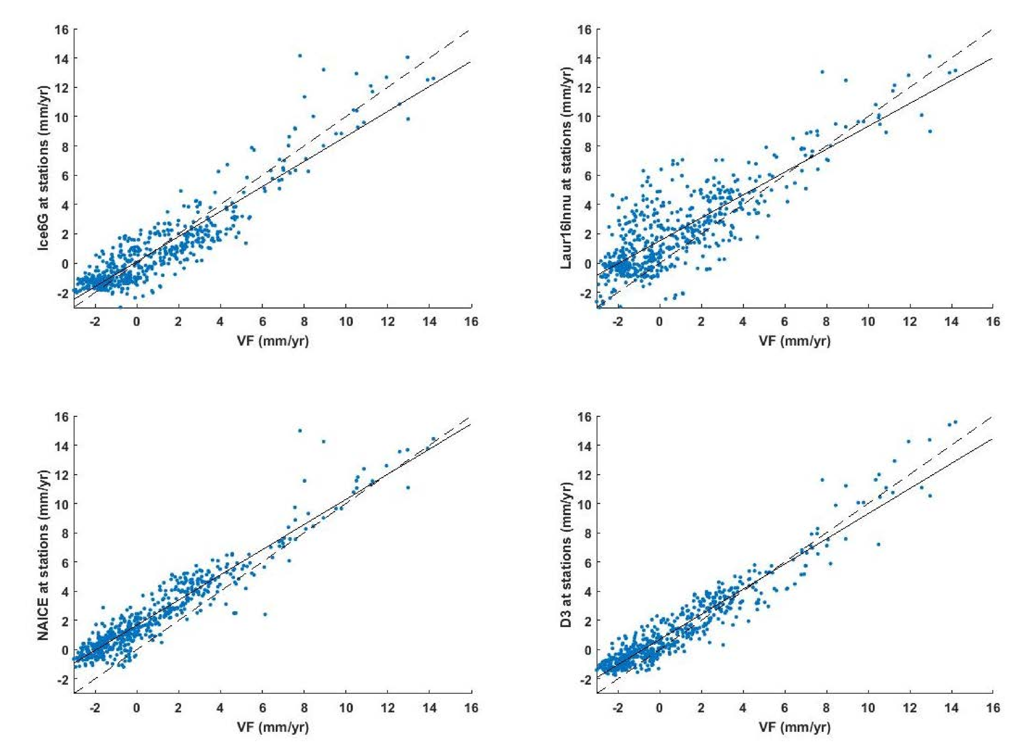


Figure 6. Residuals for all stations in areas expected to be dominated by the GIA signal in the vertical are shown here for the ICE-6G(VM5a) model. Residual statistics for all tested GIA models, summarized in Table 1, are used to help select the model integrated into the hybrid grid. Models are interpolated to the network sites for all comparisons shown in this section.

Figure 7. Direct comparisons between the 4 GIA models and the data for the 'GIA sites' shown in Figure 6. The solid line fits the data; the dotted line is for model = data.



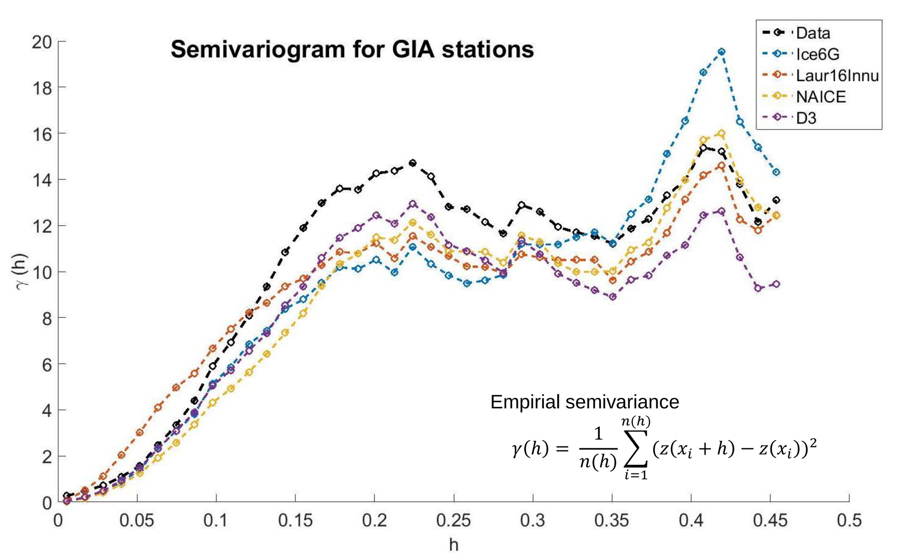


Figure 8. Empirical semivariograms compare the spatial autocorrelation characteristics of the models with those of the data . The semi-variance is roughly the inverse of the covariance or correlation as a function of distance. The semivariograms are divided into 40 distance or lag (h) bins. At close distances, all models except LaurInnu reproduce the observed correlation well. This is because LaurInnu is only tuned to data in sparse areas, including GPS velocities at the ks16 sites in Figure 6. Of the 4 models currently tested, D3 reproduces the semivariogram of the observations most faithfully.

GIA Model	ks16 sites	ks16ext sites	GIA sites	All sites
ICE-6G(VM5a)[1]	1.49	2.14	1.25	1.82
LaurInnu[4]	1.17	1.87	2.23	2.36
NAICE[2]	1.07	2.30	1.86	2.26
D3[3]+LaurInnu	1.70	1.83	1.13	1.72

Table 1 summarises the RMSE between the velocity field and each of the GIA models for 3 subsets of our sites (indicated in the Figure 4 legend), as well as for all the sites. The ks16ext subset is particularly important since that is where data is sparse and the selected GIA model is most needed in our hybrid grid.

6. FURTHER WORK

- Review a larger set of GIA models for testing & integration.
- Update velocity field and hybrid model with new data and proposed new CACS stations in Yukon, Nunavut and northern Quebec.
- Integrate tectonic blocks into horizontal velocity model on the west coast.

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- CGS and provincial geodetic agencies for installation of highly stable CBN monumentation
- CGS field survey personnel for consistently highly accurate GPS survey campaigns

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