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Transforming PPP results to different realizations of the NAD83 reference frame in Canada

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ABSTRACT

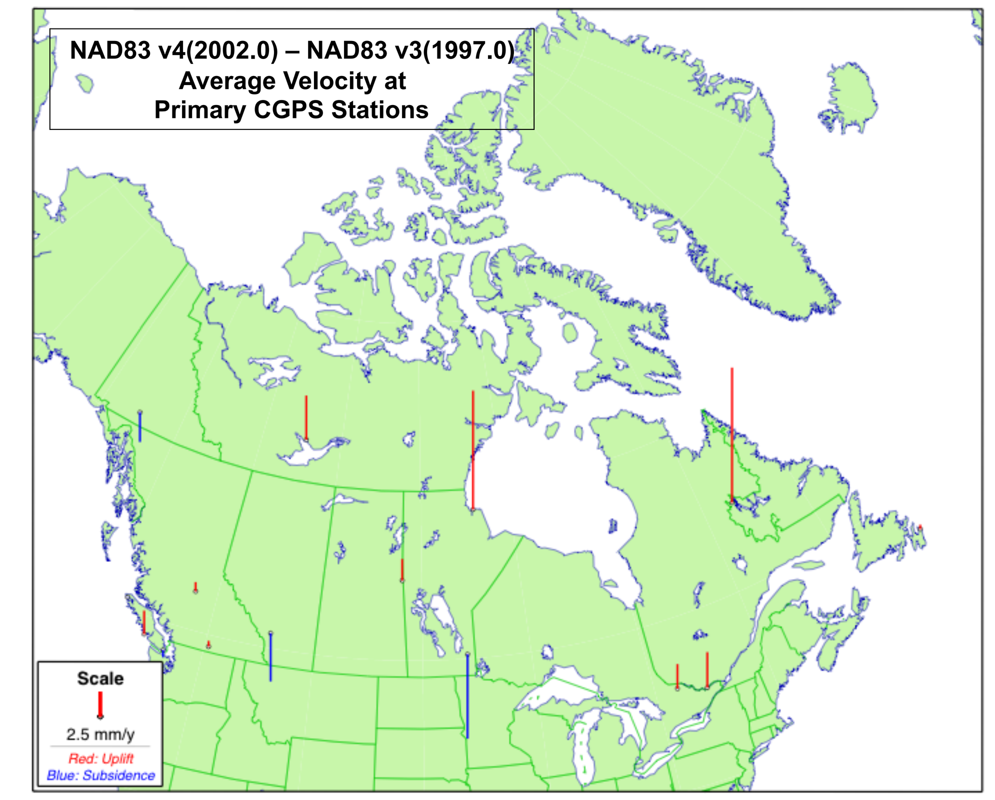
Modern precise point positioning (PPP) methods are very convenient to use but provide their coordinates at the epoch of observation. On the other hand, coordinates in NAD83, the officially adopted reference frame in Canada and the U.S., are expressed at some past reference epoch. Moreover, different realizations of NAD83 used in Canada are expressed at different reference epochs. The PPP positions are therefore incompatible with coordinates in such realizations due to vertical and horizontal crustal motions from glacial isostatic adjustment (GIA), tectonic deformations on the west coast, and an apparent motion from the bias in the NUVEL-1A plate motion estimate adopted in the definition of NAD83. Such PPP positions need to be propagated to the reference epoch of the desired realization of NAD83. Similarly, comparisons of coordinates from different NAD83 realizations require propagating from one reference epoch to another. In an effort to reconcile PPP results and different realizations of NAD83, we have empirically represented both vertical and horizontal crustal deformations throughout Canada using a velocity field based solely on high accuracy continuous and episodic GPS observations. The continuous observations from 2001 to 2006 were obtained from nearly 100 permanent GPS stations, predominately operated by Natural Resources Canada (NRCan) and provincial geodetic agencies. Many of these sites are also part of the International GNSS Service (IGS) global network. Episodic observations from 1994 to 2006 were obtained from repeated occupations of the Canadian Base Network (CBN), which consists of approximately 160 stable pillar-type monuments across the entire country. The CBN enables a much denser spatial sampling of crustal motions although coverage in the far north is still sparse. To improve the reliability of the velocities, NRCan solutions of the continuous GPS data were combined with those from other agencies as part of the North American Reference Frame (NAREF) effort to densify the ITRF in North America. This NAREF solution was combined with our CBN results to obtain a denser velocity grid for interpolating velocities to any location in Canada, thereby enabling the propagation of coordinates to any desired reference epoch. We examine the accuracy of such propagations using both PPP results and also common points in different realizations of NAD83. The accuracy of the vertical GPS velocity field depends directly on the density of the GPS coverage. Consequently, the velocity grid tends to smooth out the actual vertical crustal motions in the far north due to the spatially sparse coverage. On the other hand, the model performs quite well in the southern parts of the country where there is a much greater spatial density of GPS measurements. Except in the tectonically active western region, the bias in the NUVEL-1A model is more accurately represented by the horizontal component of the velocity grid, even in the far north, due to the smooth and predictable pattern of the bias.

1. REALIZATIONS OF THE NAD83 REFERENCE FRAME

- *NAD83 is the official civil reference frame in Canada and the US.*
- *Defined as a time-dependent 7 parameter transformation from ITRF.*
- *Different realizations based on different ITRF's at different epochs.*

Version	*Based on*	*Epoch*
NAD83 v1	*ITRF93*	*Undefined*
NAD83 v2	*ITRF96*	*1997.0*
NAD83 v3	*ITRF97*	*1997.0*
NAD83 v4	*ITRF2000*	*2002.0*
NAD83 v5	*ITRF2005*	*2006.0*

- *Significant differences between realizations at different epochs due to GIA, etc.*
- *Precise Point Positioning (PPP) gives positions at epoch of observations/orbits*
- *Need to propagate PPP positions to required NAD83 epoch – using a velocity model (grid) based upon a GPS velocity field*



2. GPS VELOCITY FIELD

Continuous GPS (NAREF)

- *Using results from the North American Reference Frame (NAREF) Working Group of IAG Sub-Commission 1.3c for North America.*
- *Consolidating regional solutions into a continental one aligned to IGS realization of ITRF a weekly basis.*
- *Using following regional weekly solutions up to GPS week 1399:*

Solution	*# Sites Used*	*From*
NRCan/GSD Bernese (GSB)	*~112*	*2001.0*
NRCan/GSD GIPSY (GSG)	*~ 43*	*2001.0*
NRCan/PGC Bernese (PGC)	*~55*	*2001.0*
NGS/CORS PAGES (NGS)	*~870 (~570 used)*	*2002.0*
SIO GAMIT(PBO)	*~700 (~140 used)*	*2001.0*
MIT PBO (MIT)	*~670 (~185 used)*	*2006.0*

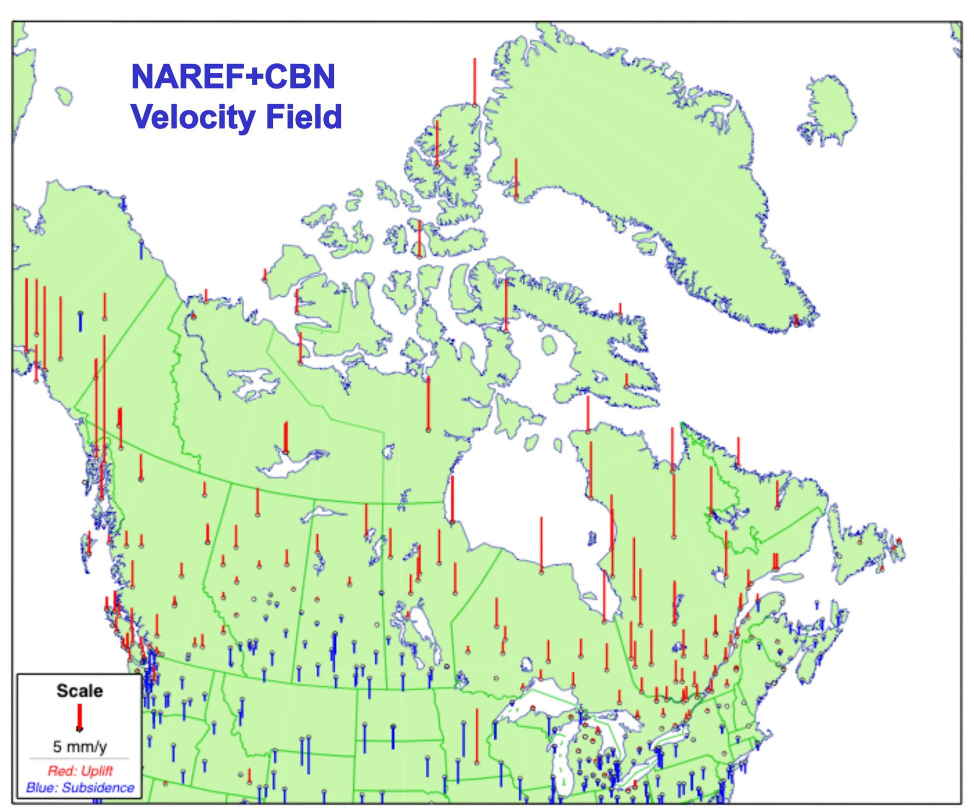
- *Combined weekly NAREF solutions into a "cumulative" solution with velocity estimation.*
  - *All regional solutions using relative phase centers*
  - *⇒ Using solutions only up to GPS week 1399*
- *328 sites rejected due to:*
  - *Short time span (less than 2 years) ~206 sites*
  - *Collocated/redundant sites ~50 sites*
  - *Poor time series (gaps, noisy, offsets) ~20 sites*

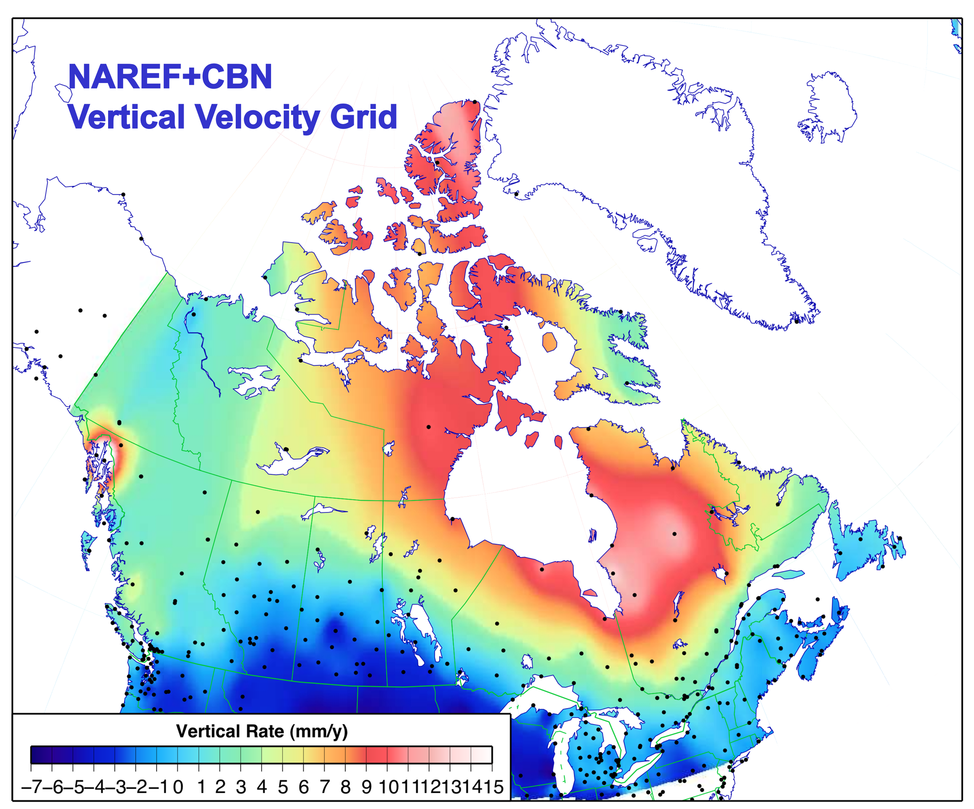
Episodic GPS (CBN)

- *Repeated survey campaigns of the Canadian Base Network*
  - *Network of stable pillar monuments*
  - *Forced centering antenna mounts*
  - *Covers all of Canada (sparser in the north)*
  - *Multiple (3-4) 24 hr occupations of each site*
- *Using 27 repeated survey campaigns from 1994 to 2006.*
  - *1st campaign 1994-1999 (no 1998)*
  - *2nd campaign 2001(east)-2002(west)*
  - *3rd campaign 2005(east)-2006(west)*
  - *Several other smaller campaigns*
- *Each epoch*
  - *Processed with Bernese GPS Software*
  - *Using relative phase centers*
  - *Aligned to IGS realization of ITRF2005*
- *Combined all epochs into a "cumulative" solution with velocity estimation.*

NAREF+CBN Velocity Field

- *Individually re-aligned NAREF & CBN solutions to ITRF2005*
- *Combined together with weighted ITRF2005 constraints (see plot below left)*





3. VELOCITY GRID GENERATION

- *Using GMT (Wessel & Smith, EOS Trans. AGU, 72, 441, 1991)*
  - *Separate north, east, up (vertical) velocity grids*
  - *"blockmean" with 1 deg lon x ½ deg lat block size*
  - *"surface" with 0.25 deg grid & tension 0.25 (min curvature; smoothest for GIA signal)*
  - *Above parameters minimized effect of anomalous velocities for given station spacing*
  - *Vertical grid primarily represents GIA (see plot below)*
  - *Horizontal grids primarily represent tectonic motion on west coast and over estimation of plate motion by NUVEL-1A used in ITRF-NAD83 transformation*
- *Residual fit of velocity field to grid (see plot below)*

Mean	*0.0 mm/y*
StDev	*0.6 mm/y*
Max/Min	*+4.3/-4.0 mm/y*

- *Limitations:*
  - *Too few GPS sites in north*
  - *Unable to properly represent crustal motion in this region*
  - *E.g., Unable to detect uplift "dome" west of Hudson Bay present in ICE-4G and ICE-5G GIA models*

4. PPP TESTING

Quebec (south) – see plots

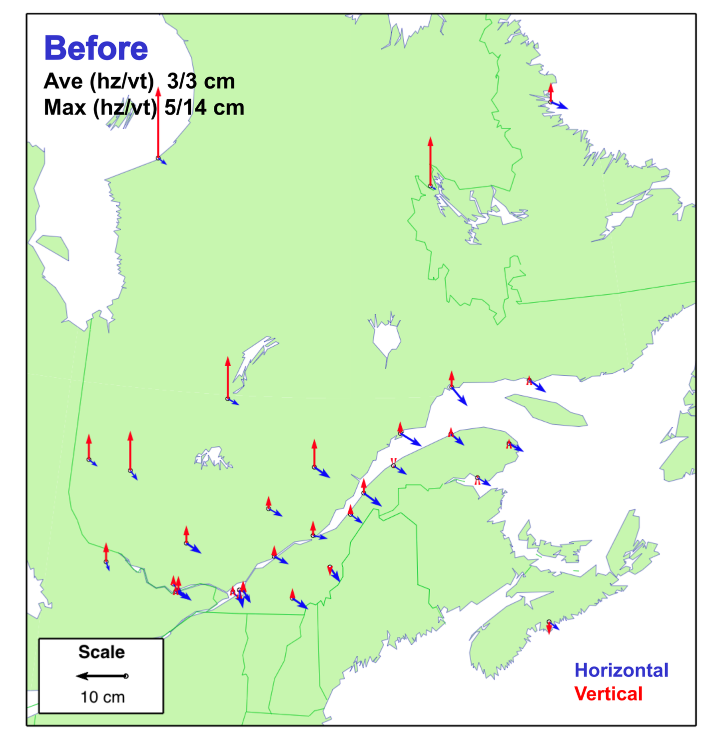
- *Quebec RTK network*
- *Most stations used in velocity field*
- *New observations at 2009.0*
- *Propagated PPP results from 2009.0 to 1997.0*
- *Compared to NAD83 v2 network adjustment (1997.0)*
- *Good horizontal and vertical fit to NAD83v2 at epoch 1997.0*

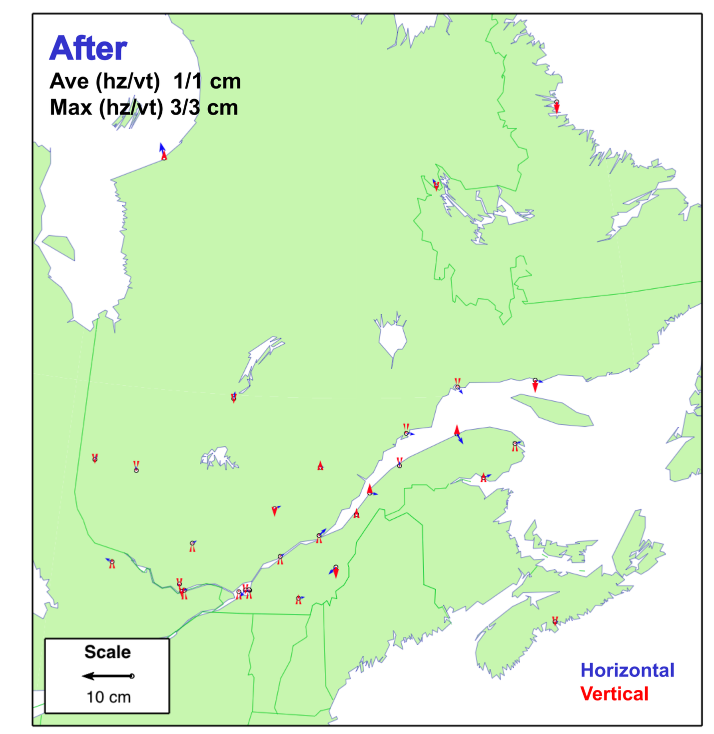
Yukon (north) – see plots

- *NRCan monitoring network*
- *Observations at 2009.6*
- *Propagated PPP results from 2009.6 to 1997.0*
- *Compared to NAD83 v3 network adjustment (1997.0)*
- *Horizontal fit not as good as in Quebec due to few GPS sites used in grid generation (can't model crustal motion properly) – vertical fit worse!*

Quebec PPP Test Results

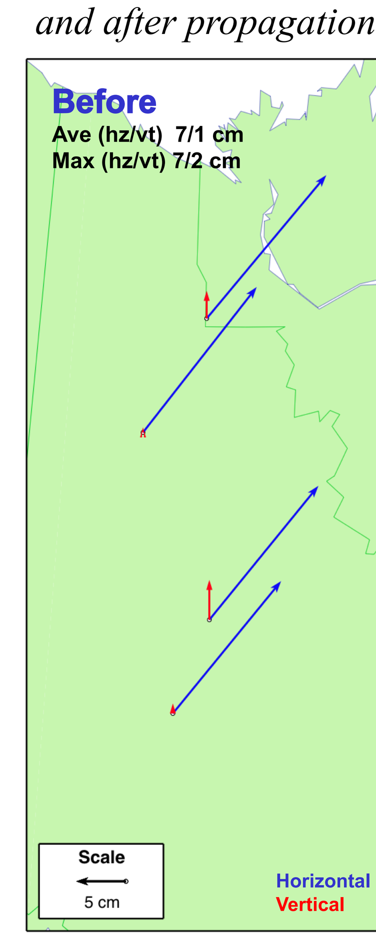
Coordinate differences between PPP results at 2009.0 and NAD83v2 adjustment at 1997.0 before and after propagation of PPP results to 1997.0

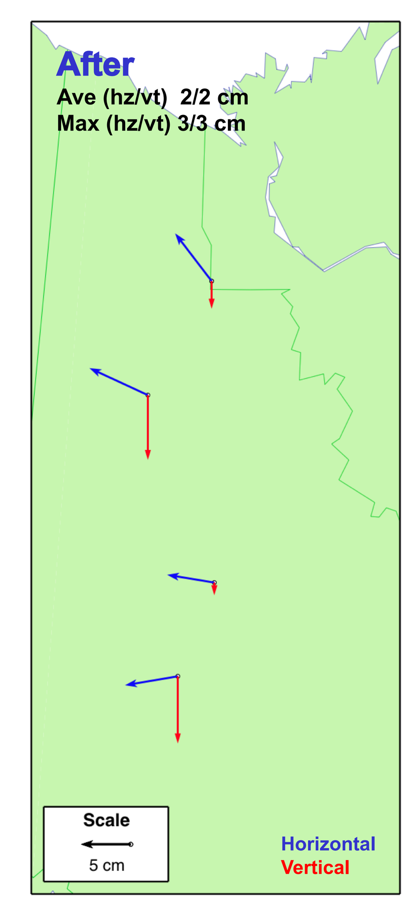




Yukon PPP Test Results

Coordinate differences between PPP result at 2009.6 and NAD83v3 adjustment at 1997.0 before and after propagation of PPP results to 1997.0





5. FURTHER WORK

- *Improve GPS velocity field*
  - *Fourth CBN survey epoch in 2010 & 2011*
  - *Additional GPS sites in north, esp. north of 60 deg latitude*
  - *Reprocess continuous and campaign data with new IGS orbits & absolute antenna phase centers, and data up to 2010*
- *Incorporate GPS velocity field with GIA model for better representation in north (e.g., SNARF or other approach)*

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  - *GSD: Caroline Huot & Brian Donahue*
  - *NGS: Mike Cline & Jim Rohde*
  - *SIO: Peng Fang*
  - *PGC: Herb Dragert*
  - *MIT: Tom Herring*
- *CBN survey campaigns: GSD field personnel*
- *Quebec GPS testing: Yves Tereault*
- *Combination software: Remi Ferland*