NATURAL RESOURCES CANADA • Geodetic Survey Division

SNARF 1.0
An Regional Reference Frame for North America

The SNARF Working Group

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UNAVCO

Abstract

Regional reference frames fixed to the stable part of a tectonic plate are often required for national spatial reference systems and to facilitate geophysical interpretation and inter-comparison of geodetic solutions of crustal motions. In 2003, the Stable North American Reference Frame (SNARF) Working Group was established under the auspices of UNAVCO and IAG Regional Sub-Commission 1.3c to address the needs of the EarthScope project. The goal is to define a regional reference frame stable at the sub-mm/yr level. The SNARF Working Group identified and dealt with several issues in order to define and generate such a regional frame, including (1) the selection of "frame sites" based on geologic and engineering criteria for stability, (2) the selection of a subset of "datum sites" which represent the stable part of the plate and were used to define the no-net rotation condition, (3) the modeling of both the vertical and horizontal effects of glacial isostatic adjustment using a relatively dense GPS velocity field, and (4) the generation and distribution of products for general use, in particular for Earthscope investigators. For SNARF, the vertical datum is consistent with ITRF2000 in that the center of mass of the whole Earth system is taken to be the origin while the horizontal datum is effectively defined by a rotation rate that brings the horizontal motion of the stable part of North America to rest. Version 1.0 of the SNARF reference frame can be realized either by the rotation vector that transforms ITRF2000 coordinates and velocities into SNARF or through a set of epoch coordinates and velocities for the SNARF frame sites. Over the next few years SNARF will be incrementally improved through further research and refinement of the GPS solutions used in its definition.

Outline

- **Objective & rationale**
- **SNARF approach**
- **SNARF products & their use**
- **Future improvements**
- **Long term maintenance**

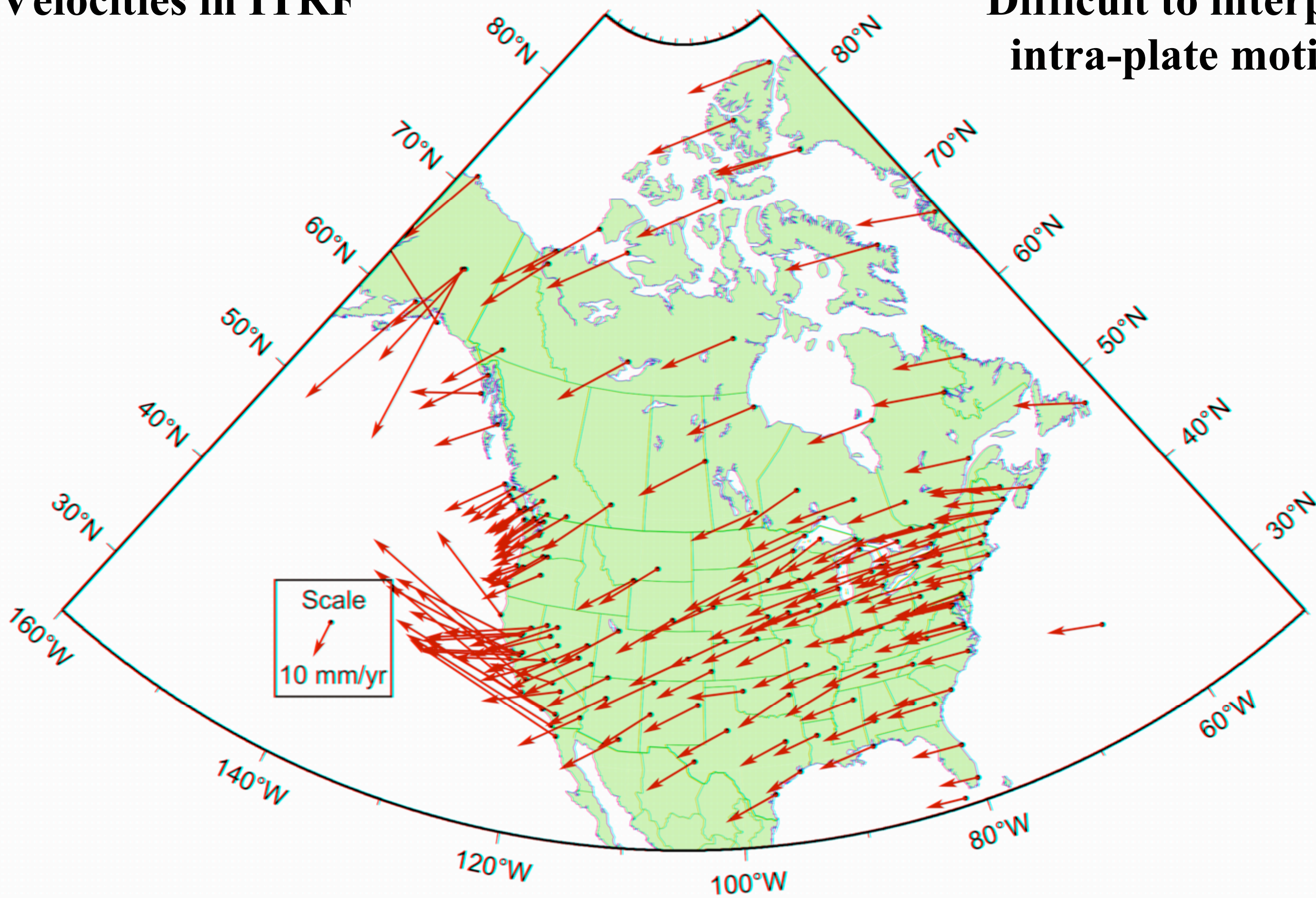
Objective

- **Define a reference frame that represents the stable interior of North America**
- **To provide a standard to facilitate**
  - Geophysical interpretation
  - Inter-comparison of solutions
- **Easier to interpret intra-plate (relative) motions**
- **Primarily for EarthScope/PBO studies**

Why Not Use ITRF?

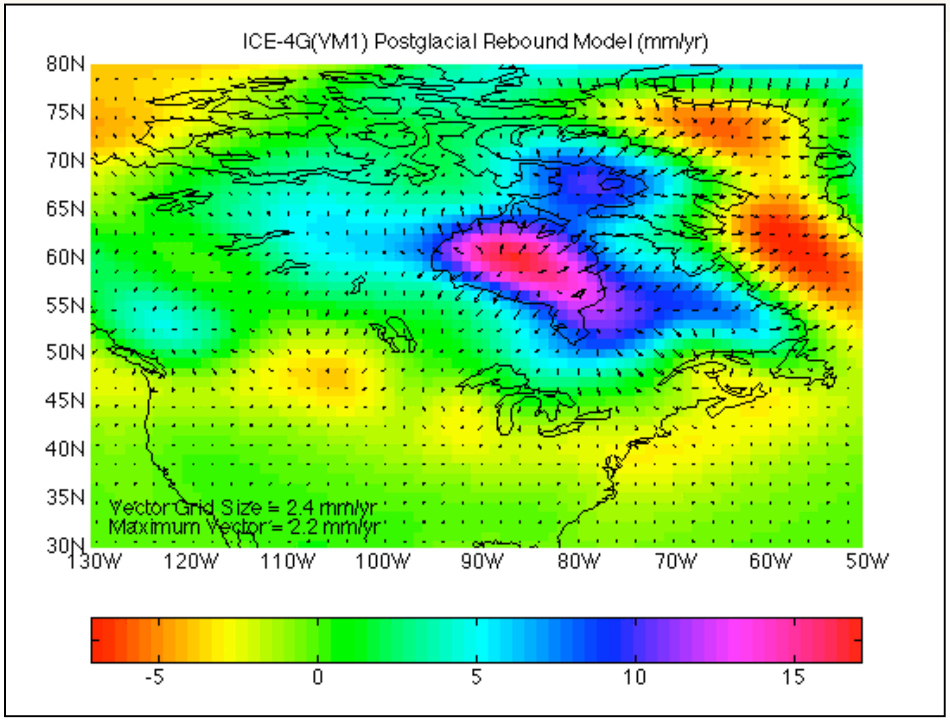
Velocities in ITRF

Difficult to interpret intra-plate motions

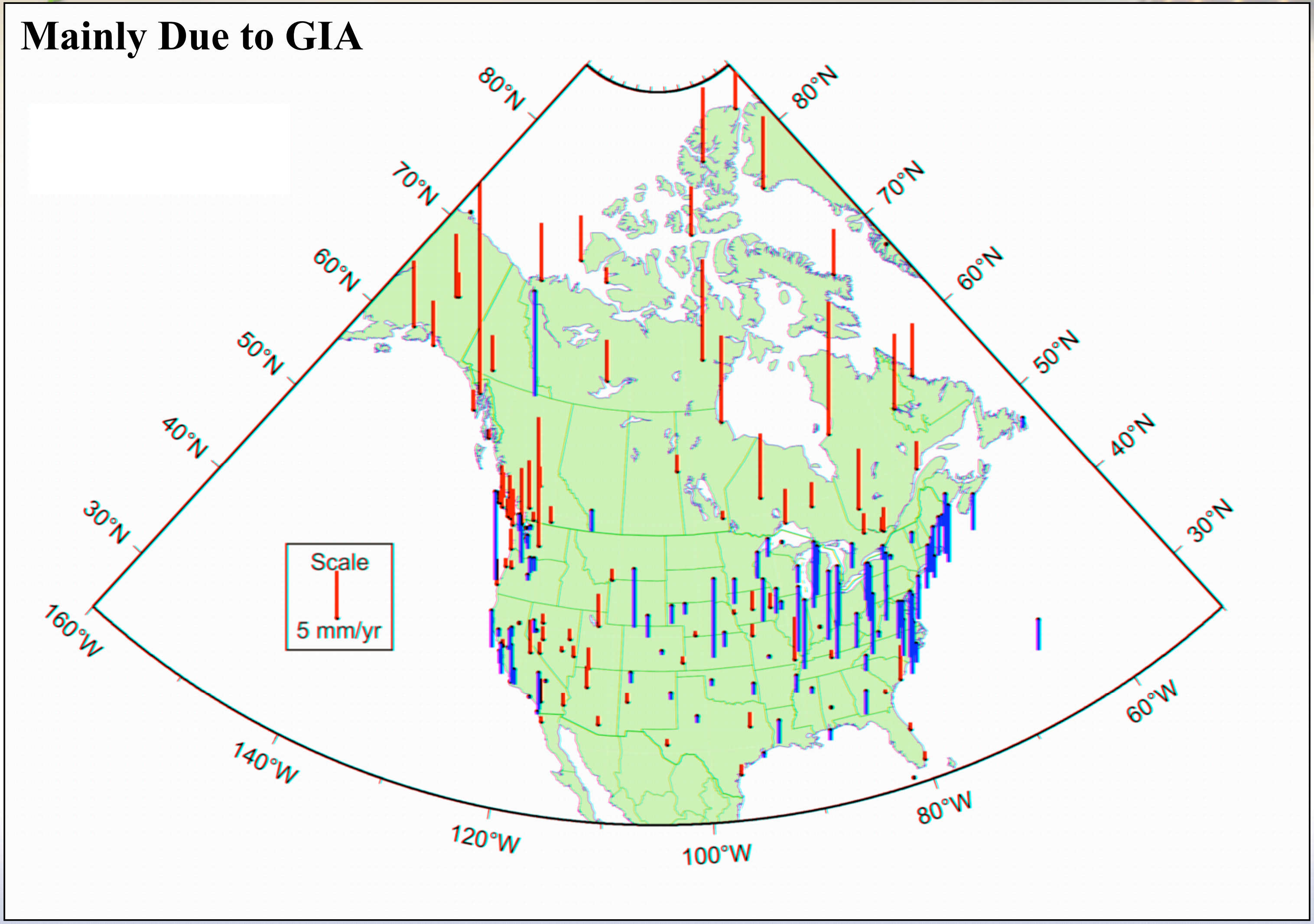


Intra-Plate Motions

- **Largest from glacial isostatic adjustment (GIA)**
  - Needs to be removed to study non-GIA motions
  - Difficult to choose a GIA model
  - No concensus on Earth & ice models
  - ***Attempt to model GIA using GPS as constraints***



CGPS Vertical Velocities



SNARF Approach

- **Based on ITRF/IGbv00 at 2003.0**
- **Determine velocity model that bring stable N.A. to rest**
  - GIA motion
  - Rotation rates (plate motion)
  - Translation rates (bias in GPS velocities?)

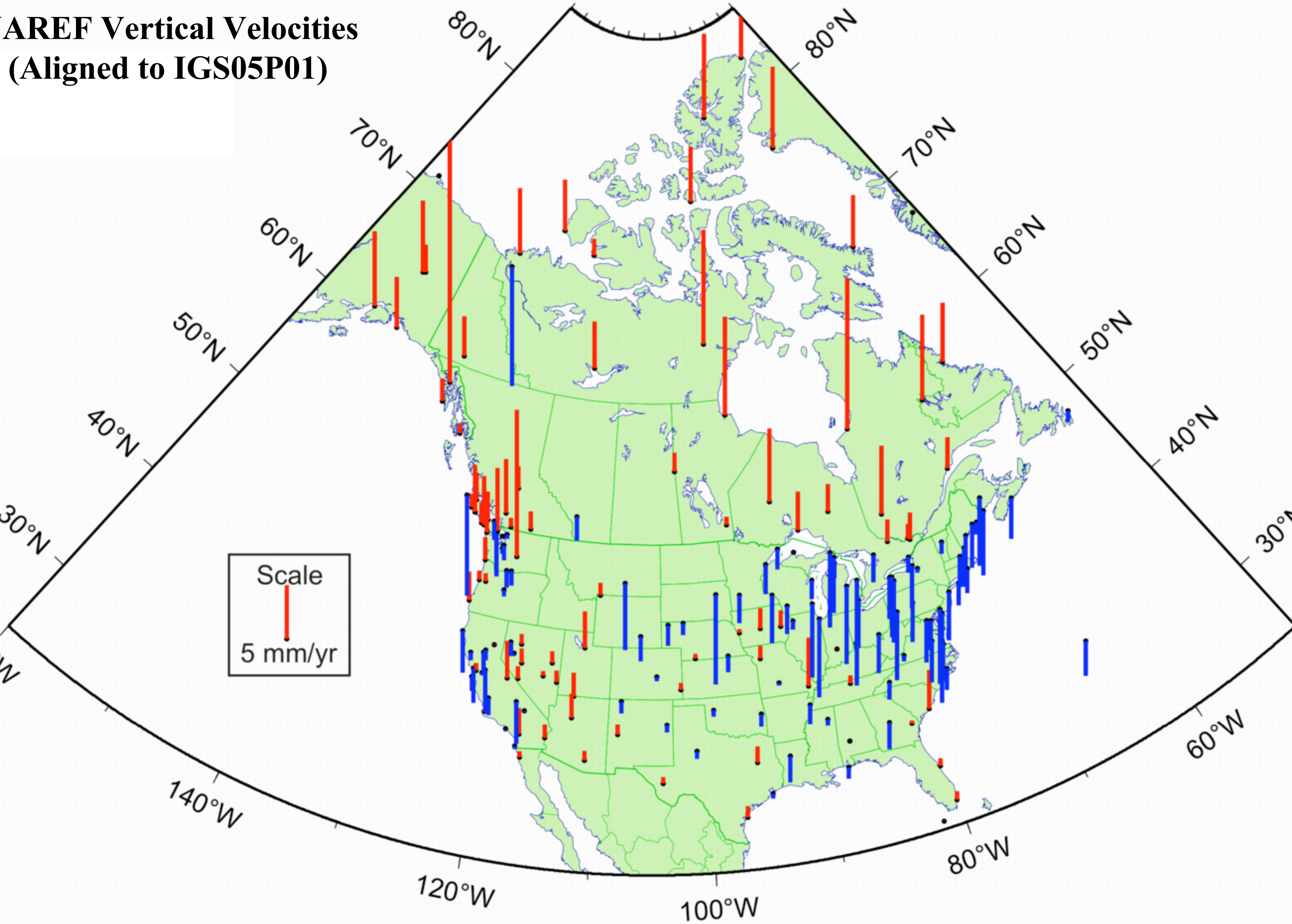
$$\boxed{\vec{V}_{\mathrm{GPS}}(\lambda,\phi) = \vec{V}_{\mathrm{GIA}}(\lambda,\phi) + \delta\vec{\Omega} \times \hat{r}(\lambda,\phi) + \delta\vec{T}}$$

- **Practical GIA issues**
  - No consensus on Earth & ice models
  - Most Earth models are spherically symmetric but lateral variations are important (Latychev et al, 2004; Wu, 2006)

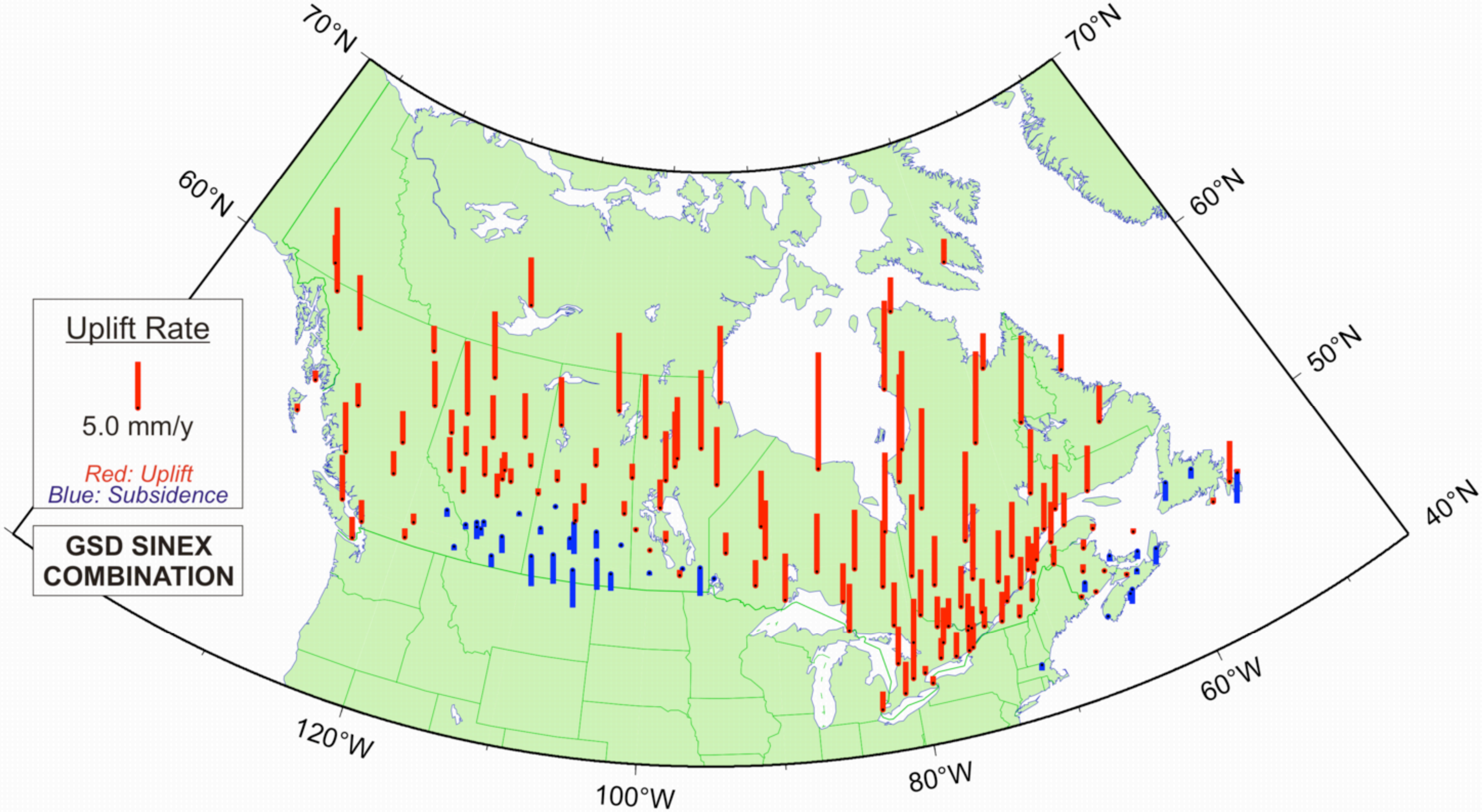
GPS Velocities

- **Based on a combination of 3 solutions in IGb00**
  1) NAREF cumulative solution for North America
     - Combination of 6 regional solutions
  2) Purdue solution for eastern N.A. (Calais et al, JGR 2006)
     - Combination of GAMIT and GIPSY solutions
  3) Canadian Base Network (CBN) solution for Canada
     - 28 high accuracy GPS campaign surveys 1994-2002
- **Solutions combined into a single N.A. solution**
  - Origin & orientation loosely constrained
  - Using only best points (118) based on
    - Stable monumentation
    - >3 year data span

NAREF Vertical Velocities
(Aligned to IGS05P01)



CBN Vertical Velocities
(ALGO constrained to IGS05P01)



A Priori GIA Model

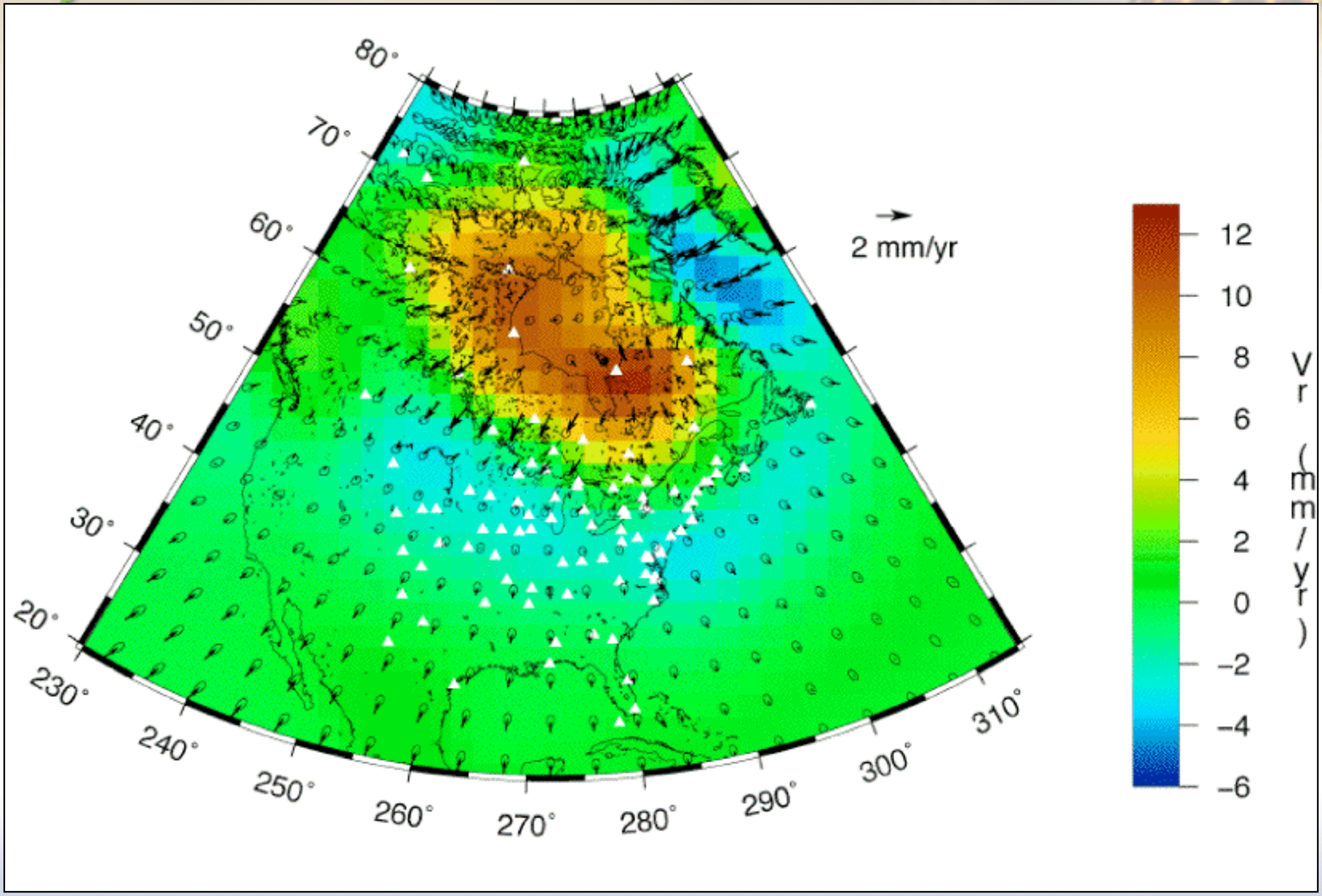
- **Average of a suite of GIA models**
  - Spanning a range of Earth models
  - Ice model based on ICE-1 (Peltier & Andrews, 1976)
    - Easier to work with
    - Some Earth model parameters hard-wired into ICE-3G
  - Varying Earth model parameters
    - Lithospheric thickness
    - Upper & lower mantle viscosities
- **Full covariance matrix**
  - Constructed from variability of suite of models

Assimilation of GPS with GIA Model

- **Combining GPS and GIA velocities**
  - Using full covariance matrices for each
- **Simultaneously estimating**
  - GIA velocities at GPS points
  - GIA velocities at points on a 2°x2° grid (for user interpolation)
    - Adjusted through correlations with GPS points
  - Translation & rotation rates
- **RMS of misfit**

Horz	0.71 mm/y
Vert	1.30 mm/y

SNARF v1.0 GIA Model

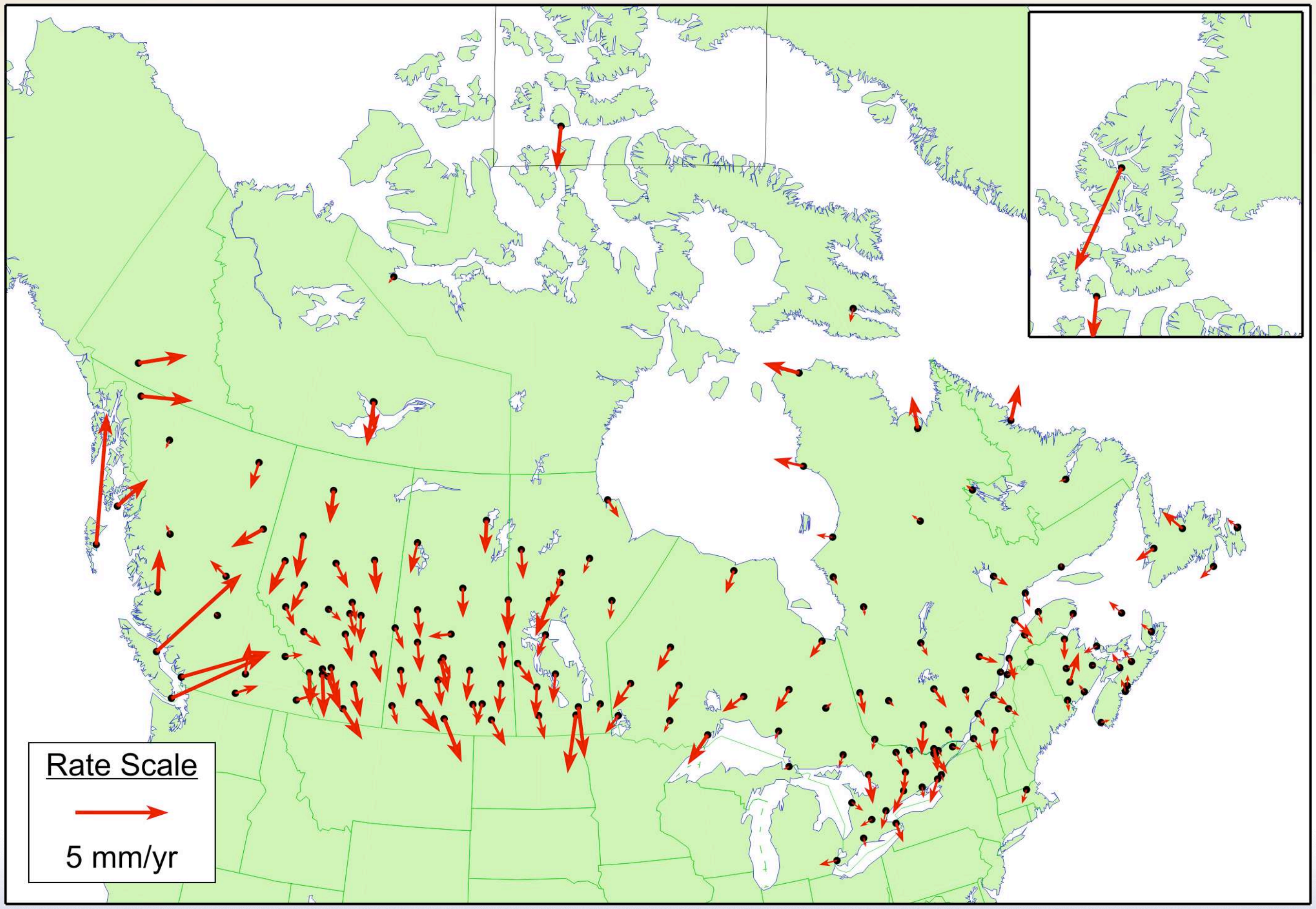


SNARF Products

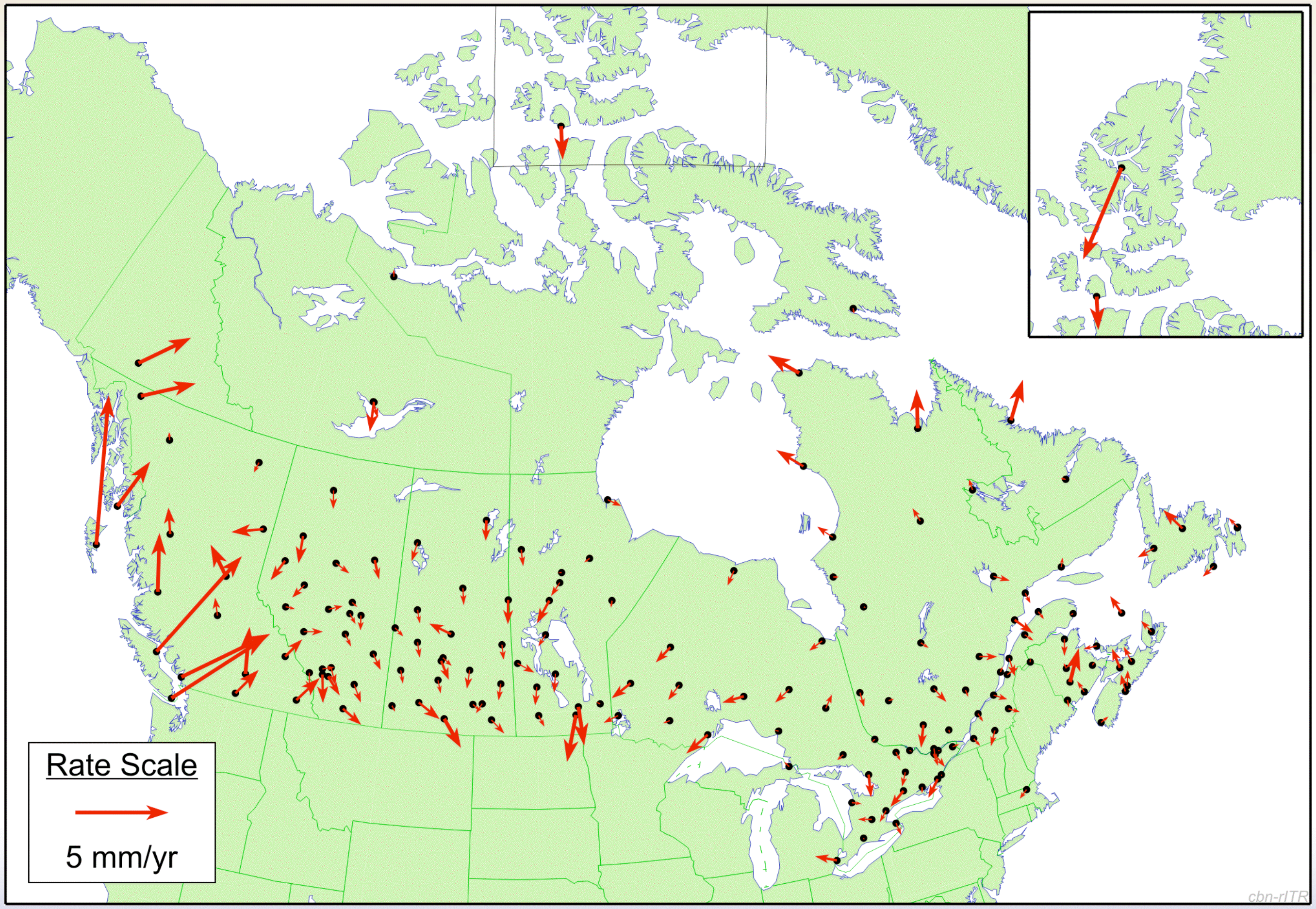
- **Positions & velocities of all GPS sites in SNARF 1.0**
  - If velocity of site matches GIA motion, it is on stable part of N.A.
  - Differences represent non-GIA deformations
  - Official PBO solutions provided in SNARF 1.0
- **GIA model velocities (horizontal & vertical)**
  - Given on a 2°x2° grid and at GPS sites
- **Transformation from ITRF2000 to SNARF**
  - Euler rotation between IGb00 and SNARF velocities

	ω_X	ω_Y	ω_Z	
SNARF 1.0	**0.06588**	**-0.66708**	**-0.08676**	(mas/y)
ITRF2000	0.08316	-0.69084	-0.06120	
NNR-NUVEL-1A	0.0532	-0.7423	-0.0316	

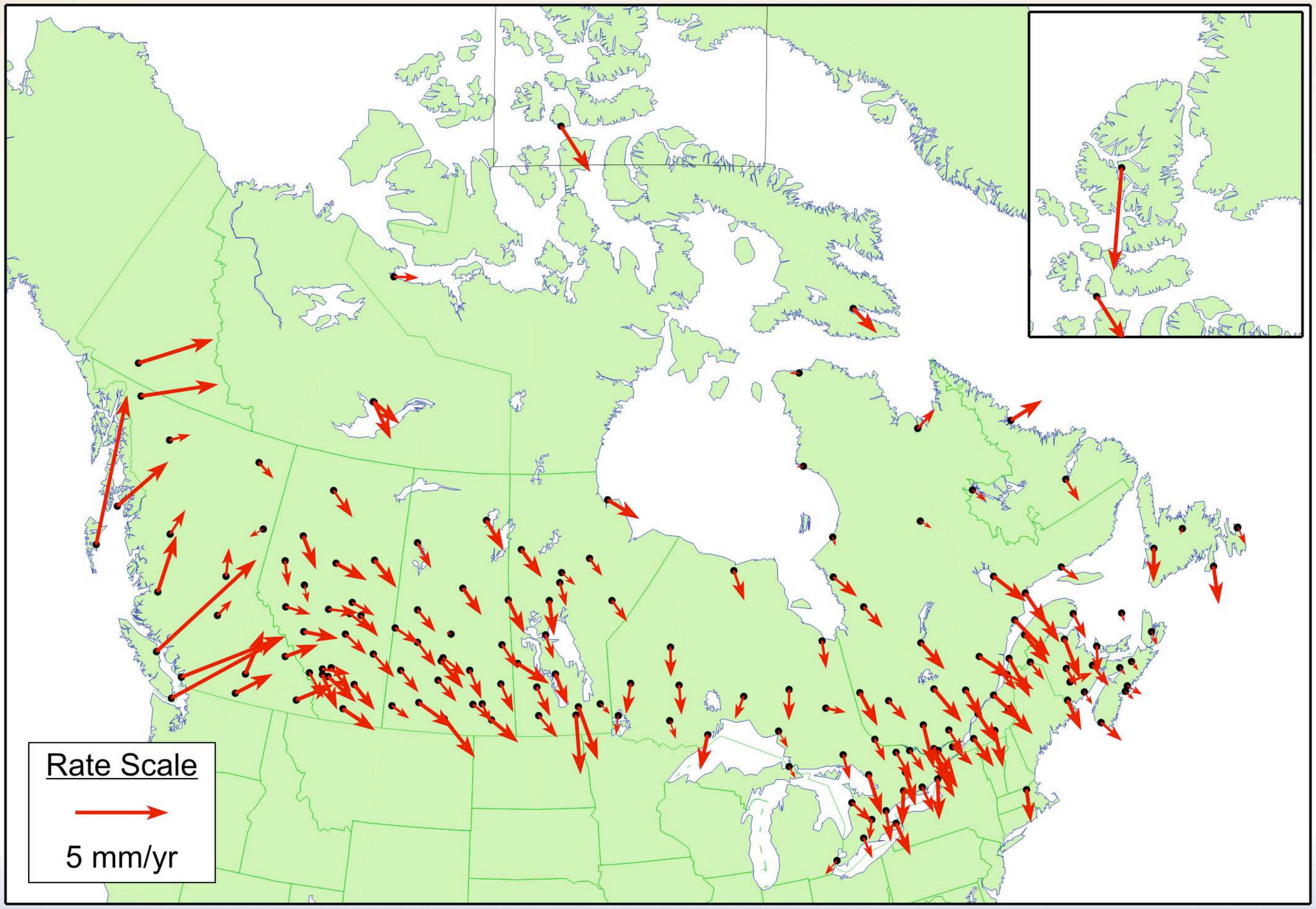
CBN Velocities w.r.t. SNARF



CBN Velocities w.r.t. ITRF2000



CBN Velocities w.r.t. NUVEL-1A



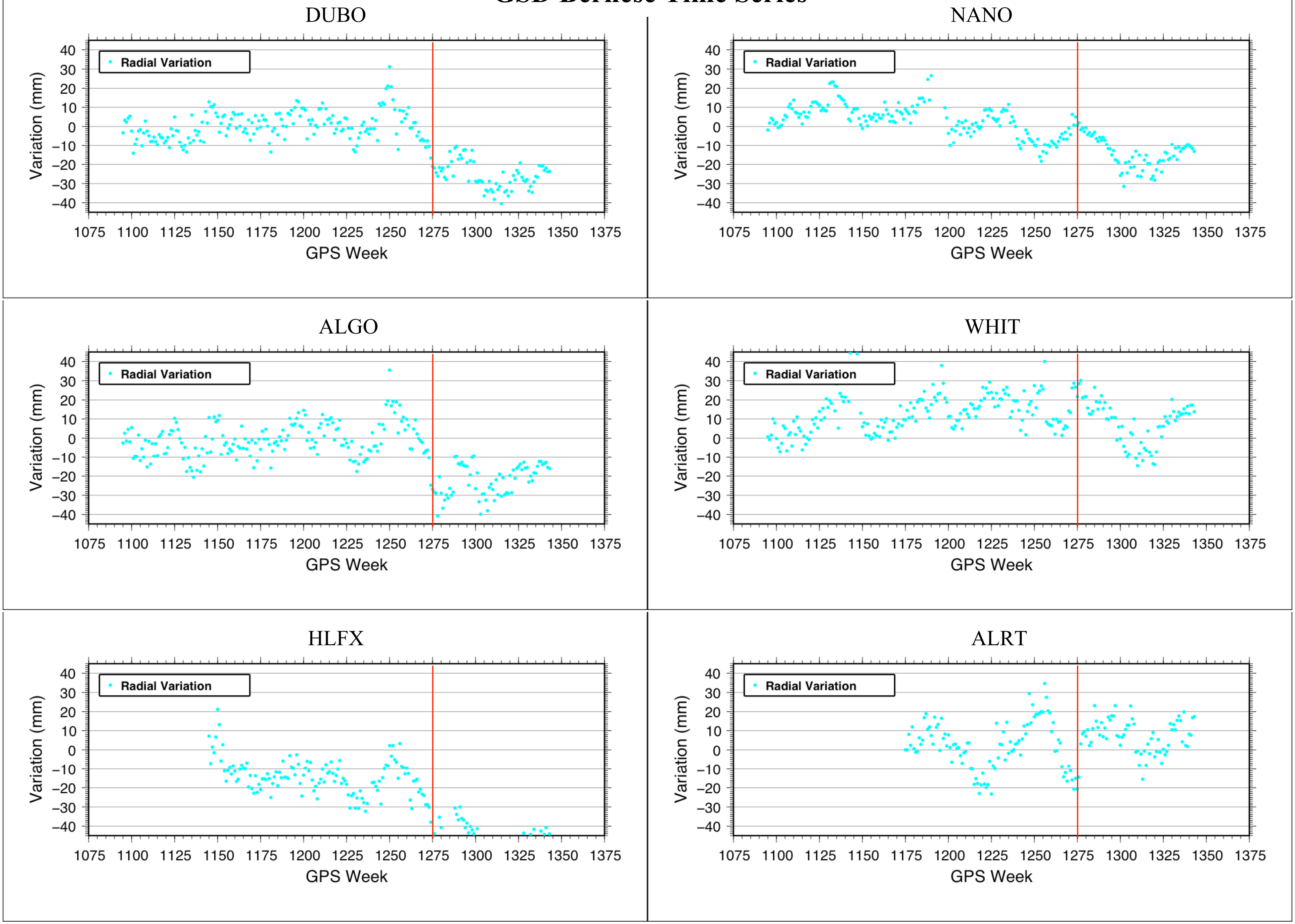
Recommended Product Use

- **GPS data processing**
  - Use IGS products (orbits & polar motion/UT1)
  - Results in IGb00 realization of ITRF2000
- **To obtain SNARF coordinates/velocities, either**
  - Rotate results into SNARF using adopted rotation vector, or
  - Align solution to SNARF frame sites
    - Need to incorporate sufficient number of frame sites
    - Need to cover a large portion of North America
- **Can optionally remove GIA model velocities**
  - To study non-GIA motions

Further Improvements

- **Refine list of "datum" sites -- biggest task**
  - Another 60 available if monumentation can be verified
- **New CBN 2005/6 re-measurement**
  - Will improve CBN velocities for both SNARF frame def'n and GIA model
- **Reprocess/recombine NAREF solutions**
  - BSW contribution contains a bias due to Earth tide bug
  - Caused an offset in time series; velocities too small/negative (see figures)
  - Reprocessing with BSW 5.0
- **Consider modelling non-GIA motions such as**
  - Hydrologic loading
  - Atmospheric loading

GSD Bernese Time Series



Long Term Maintenance

- **Transition from research to operational mode by 2008**
  - EarthScope funding for SNARF workshops runs out
- **National geodetic agencies in Canada & U.S.A.**
  - Expected to take over responsibility for SNARF
  - Can easily provide their own products in SNARF using the adopted transformation from ITRF; e.g.
    - NAREF/CORS solutions (weekly & cumulative)
    - CBN epoch & cumulative solutions
- **SNARF may eventually supercede NAD83**
  - NAD 83 differs by 1.5 m with ITRF/WGS84
  - Presently defined in terms of NUVEL-1A plate motion (biased)

For more information

www.naref.org/snarf

Thank you