The Stable North American Reference Frame (SNARF)

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and the
SNARF Working Group

GSD S&T Presentation

May 31, 2006

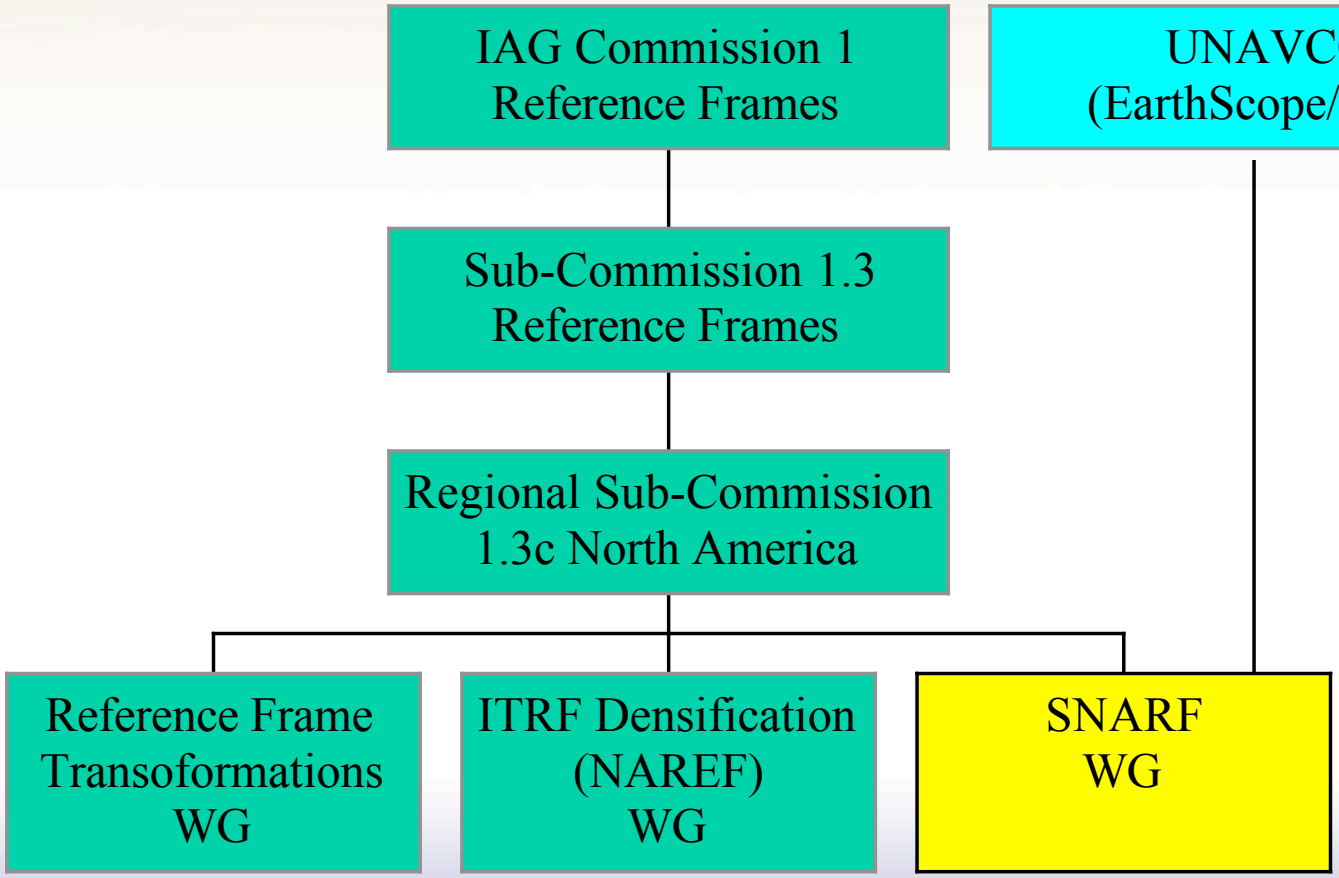
Abstract

Regional reference frames fixed to the stable part of a tectonic plate are often required 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 the IAG Regional Sub-Commission 1.3c for North America to address such pressing needs for 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 addressed several issues that must be dealt with to properly define such regional frames, 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 will be used to define a no-net rotation condition, (3) the modeling of any significant intra-plate motions using a relatively dense GPS velocity field, and (4) the generation and distribution of products for general use. In the case of 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 differs by a rotation rate that brings the rotation of the stable part of North America to rest. The first release of SNARF provides a rotation rate vector that transforms ITRF2000 velocities into the SNARF frame, and an initial reference frame defined as a list of selected sites, epoch coordinates and velocities in a Cartesian system. Over the next few years SNARF will be incrementally improved through further research.

Outline

- **Objective & rationale**
- **Issues addressed**
- **SNARF v1.0 results**
- **Future improvements**
- **Long term maintenance**

Working Group



Working Group Members

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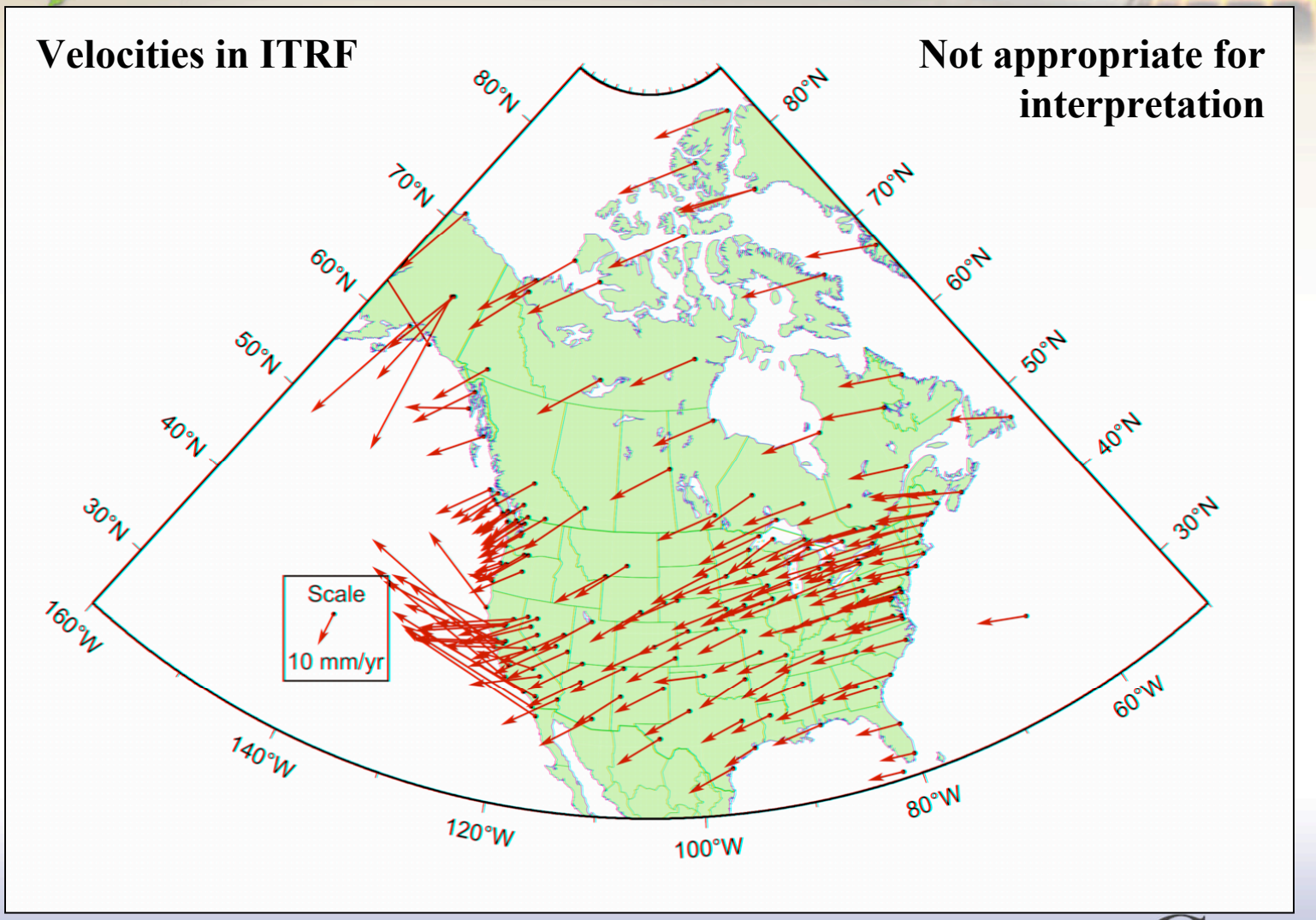
Objective & Rationale

- **Define a reference frame that represents the stable interior of North America**
- **Why?**
  - More appropriate frame to describe relative motions of
    - Sites in N.A.
    - Sites spanning adjacent plate boundaries
  - Provides standardization to facilitate
    - Geophysical interpretation
    - Inter-comparison of solutions
    - Primarily for EarthScope/PBO studies

Why Not Use ITRF?



Why Not Use NNR-NUVEL-1A

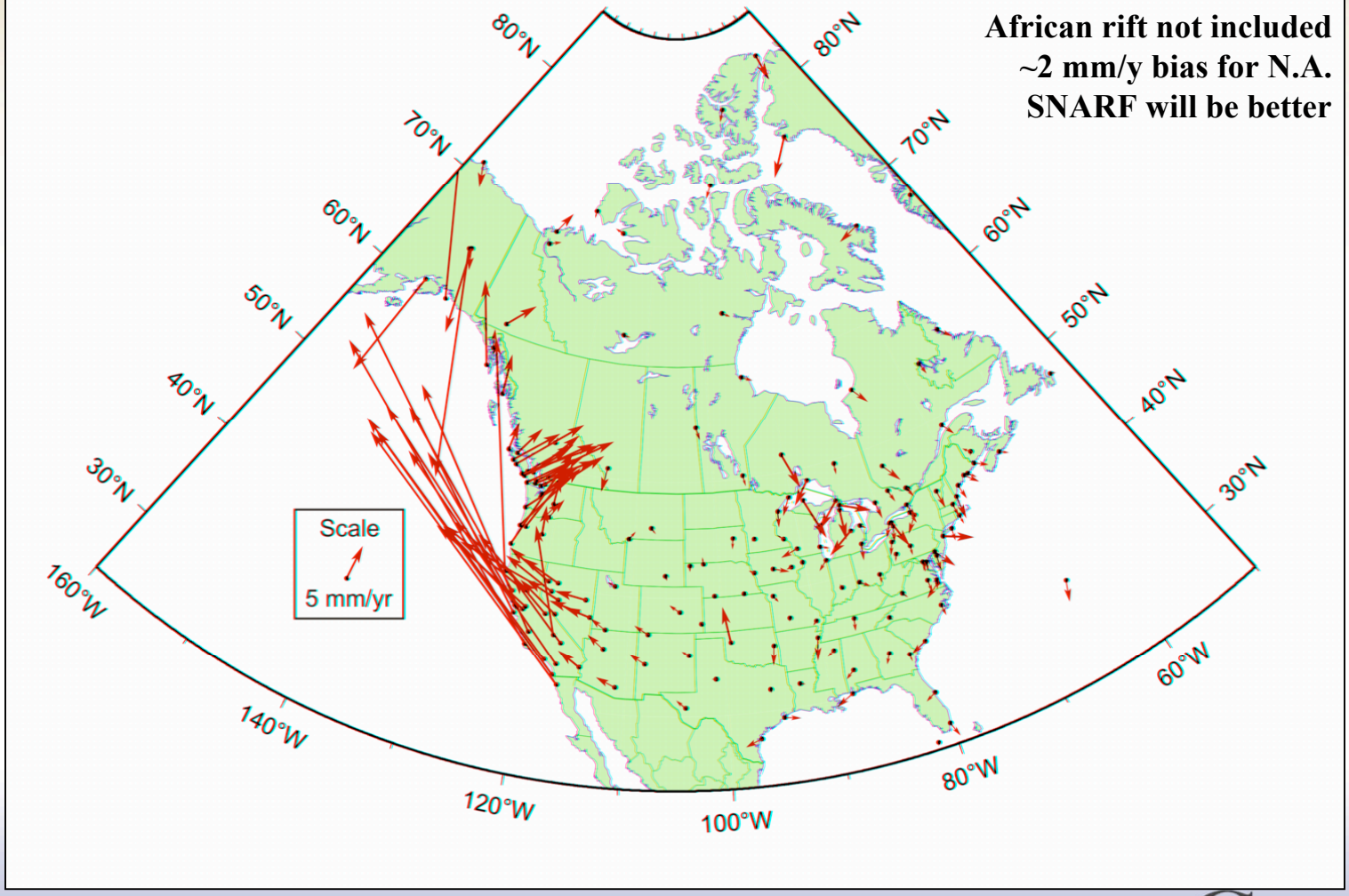
Velocities w.r.t. NUVEL

Has known deficiencies

African rift not included

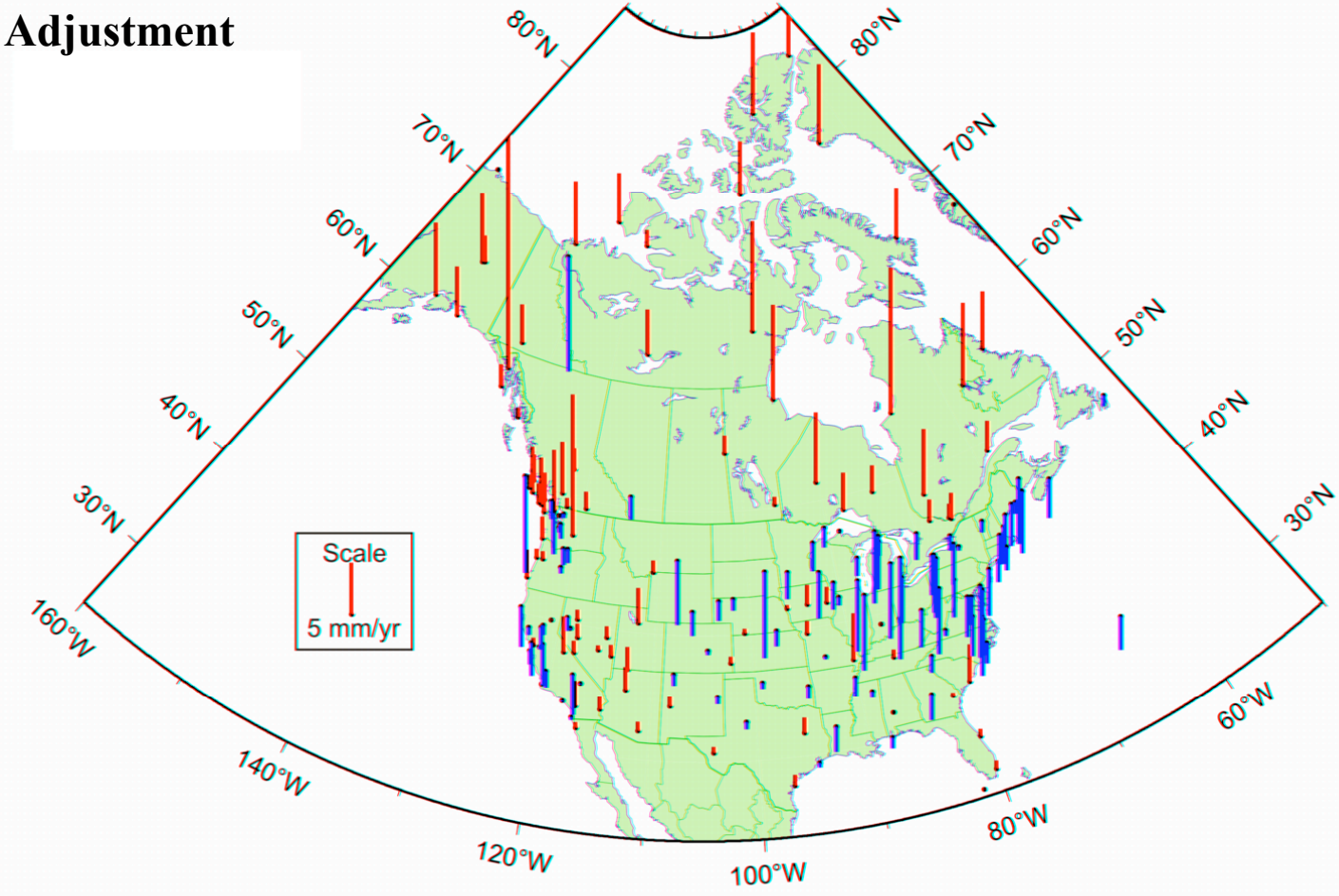
~2 mm/y bias for N.A.

SNARF will be better



Significant Vertical Velocities

Due to Glacial Isostatic Adjustment



Issues Addressed by SNARF WG

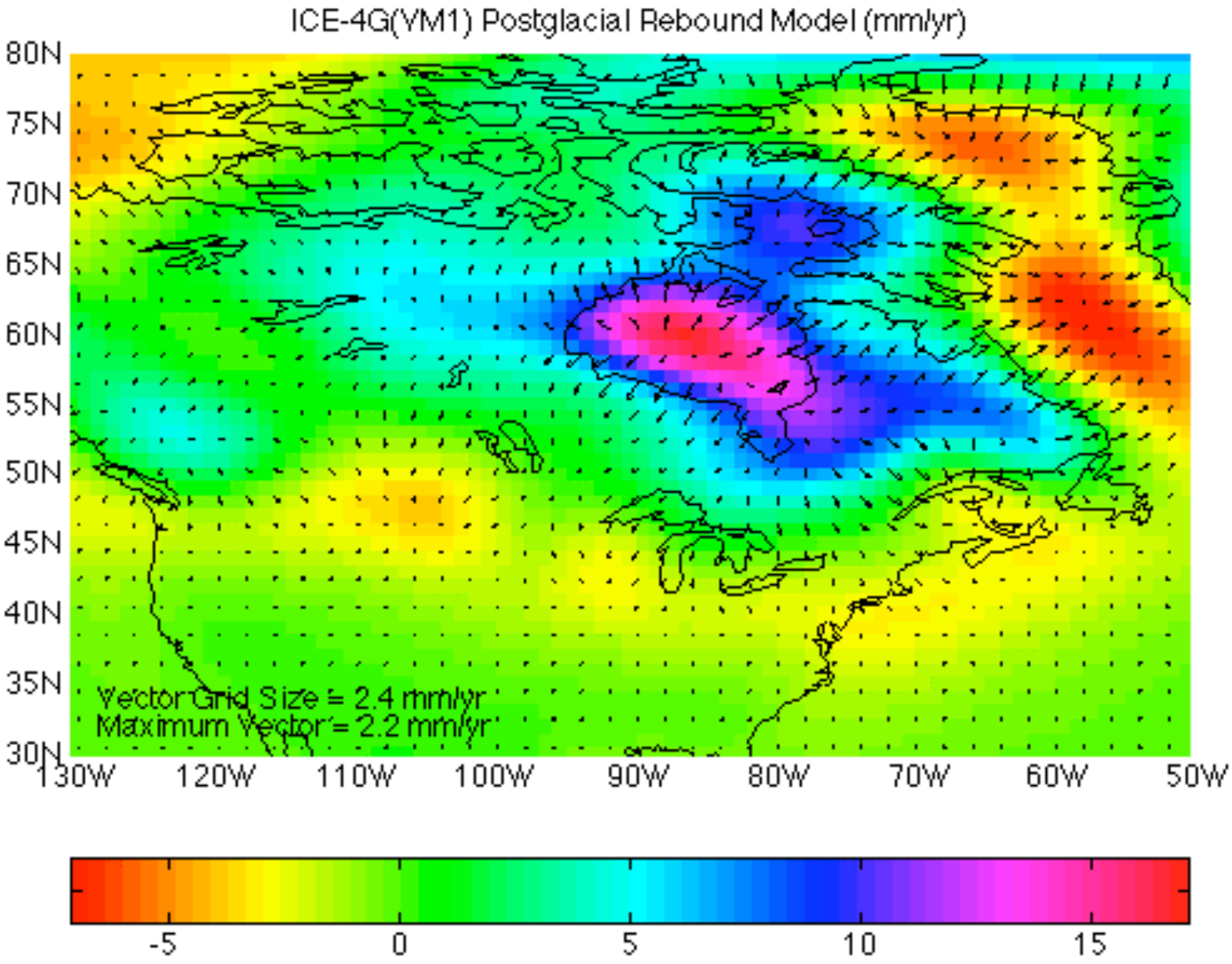
1) **Selection of "frame" sites**
2) **Selection of "datum" sites**
3) **Intra-plate motions**
4) **Products to be distributed**
5) **Product use**

1) Selection of Frame Sites

- **Sites that will be used to *represent* the frame**
- **Sites for which velocity can be reliably estimated**
- **Selection criteria**
  - Geologic considerations (mainly for datum sites)
  - Stable monumentation
  - High-quality equipment
  - High-quailty data
  - Data span >3 yr

2) Selection of Datum Sites

- **Subset of frame sites**
- **Sites that are used to *define* the reference frame**
- **Represents the stable part of North America**
- **Sites affected by GIA not included initially**
  - GIA has a horizontal component (see figure)
  - Affects estimation of plate rotation vector
  - May include GIA sites in future versions
    - Once a reliable GIA model can be determined
    - GIA sites further from plate rotation pole will improve rotation vector


ICE-4G(VM1) Postglacial Rebound Model (mm/yr)
80N
75N
70N
65N
60N
55N
50N
45N
40N
35N
30N
130W
120W
110W
100W
90W
80W
70W
60W
50W
Vector Grid Size = 2.4 mm/yr
Maximum Vector = 2.2 mm/yr
-5
0
5
10
15

3) Intra-Plate Motions

- **Examples:**
  - Deformations at plate boundaries
  - Loading effects
  - *Glacial Isostatic Adjustment (GIA)* -- the dominate signal
- **Difficult to select a particular GIA model**
  - No consensus on Earth's viscosity structure
  - No consensus on ice history
  - Will attempt to model GIA using GPS velocities as constraints on a GIA model

4) SNARF Products

- **Transformation from ITRF2000 to SNARF**
  - Rotation between ITRF2000/IGb00 and SNARF velocity vectors
  - Defines motion of stable North America in ITRF
  - *Effectively defines the SNARF frame*
- **Positions & velocities of frame sites**
  - If velocity of site matches GIA motion, it is on stable part of N.A.
  - Differences represent non-GIA deformations
- **GIA model velocities (horizontal & vertical)**
  - Given on a grid and at frame sites

5) Product Use

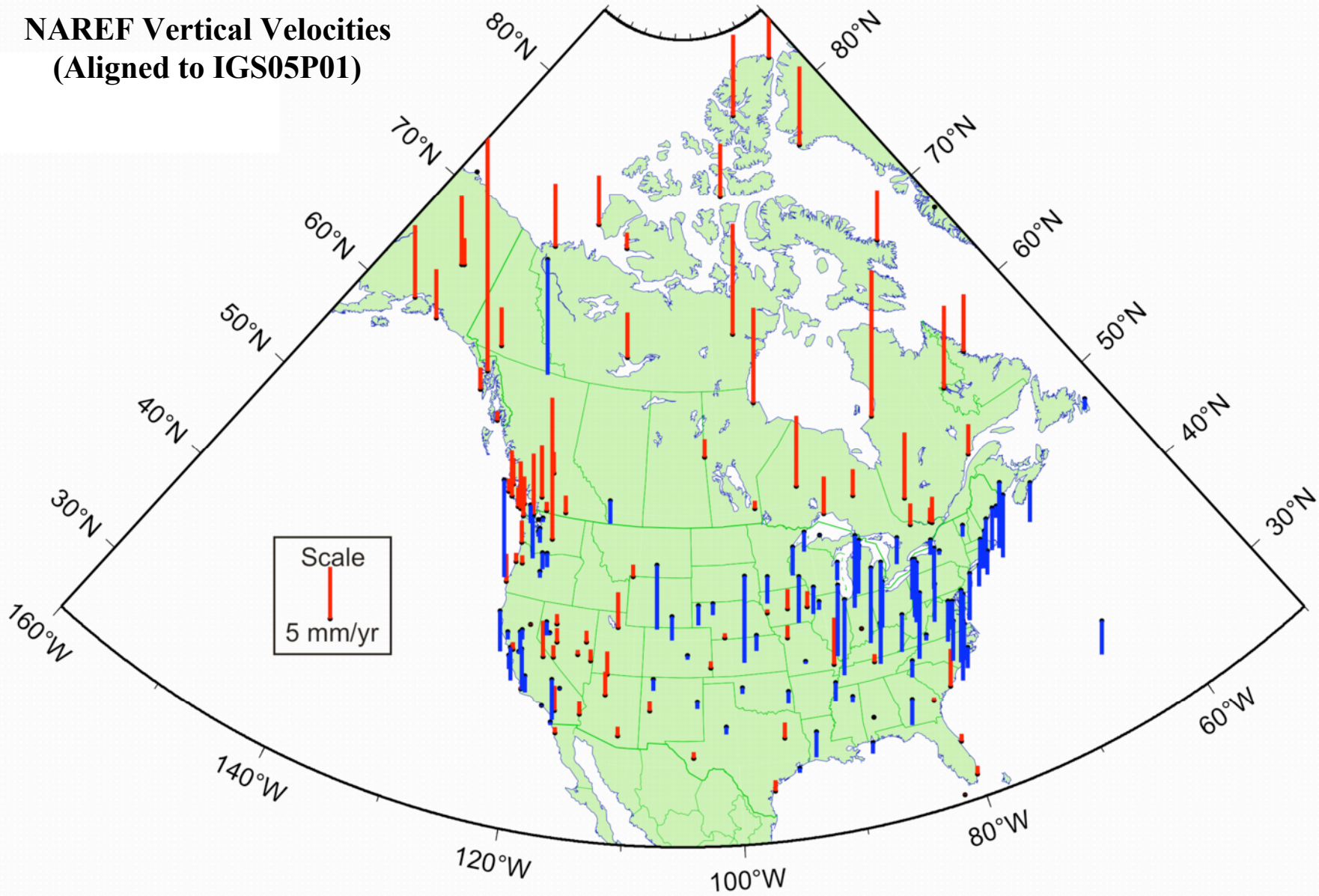
- **GPS data processing**
  - Use IGS products (orbits & polar motion/UT1)
  - In IGb00 realization of ITRF2000 (soon ITRF2005/IGS05?)
- **To obtain SNARF coordinates/velocities**
  - Rotate results into SNARF using adopted rotation vector
  - Could instead fit solution to SNARF frame -- but
    - Need to incorporate many SNARF frame sites in solution
    - Need to cover a large portion of North America
  - Optionally remove adopted GIA model velocities
    - To study non-GIA motions

SNARF v1.0 Results

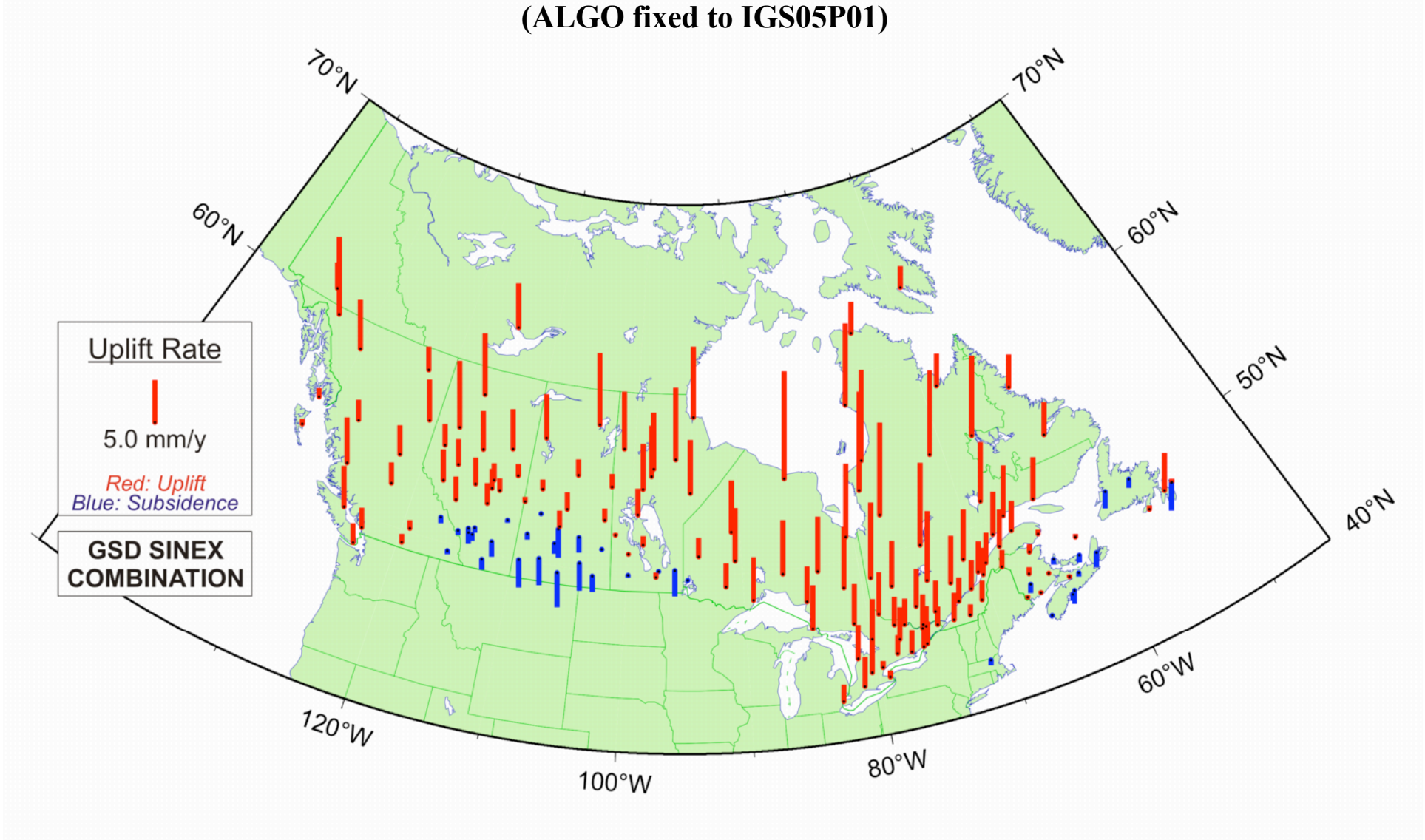
- **Just completed**
- **Based on 3 different velocity solutions** (see plots)
  - GSD NAREF velocity solution (combines several regional solutions)
  - GSD CBN velocity solution
  - Eric Calais (Purdue) velocity solution (US only)
- **Estimated plate rotation vector**
  - Using velocities of SNARF "datum" sites (~120)

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

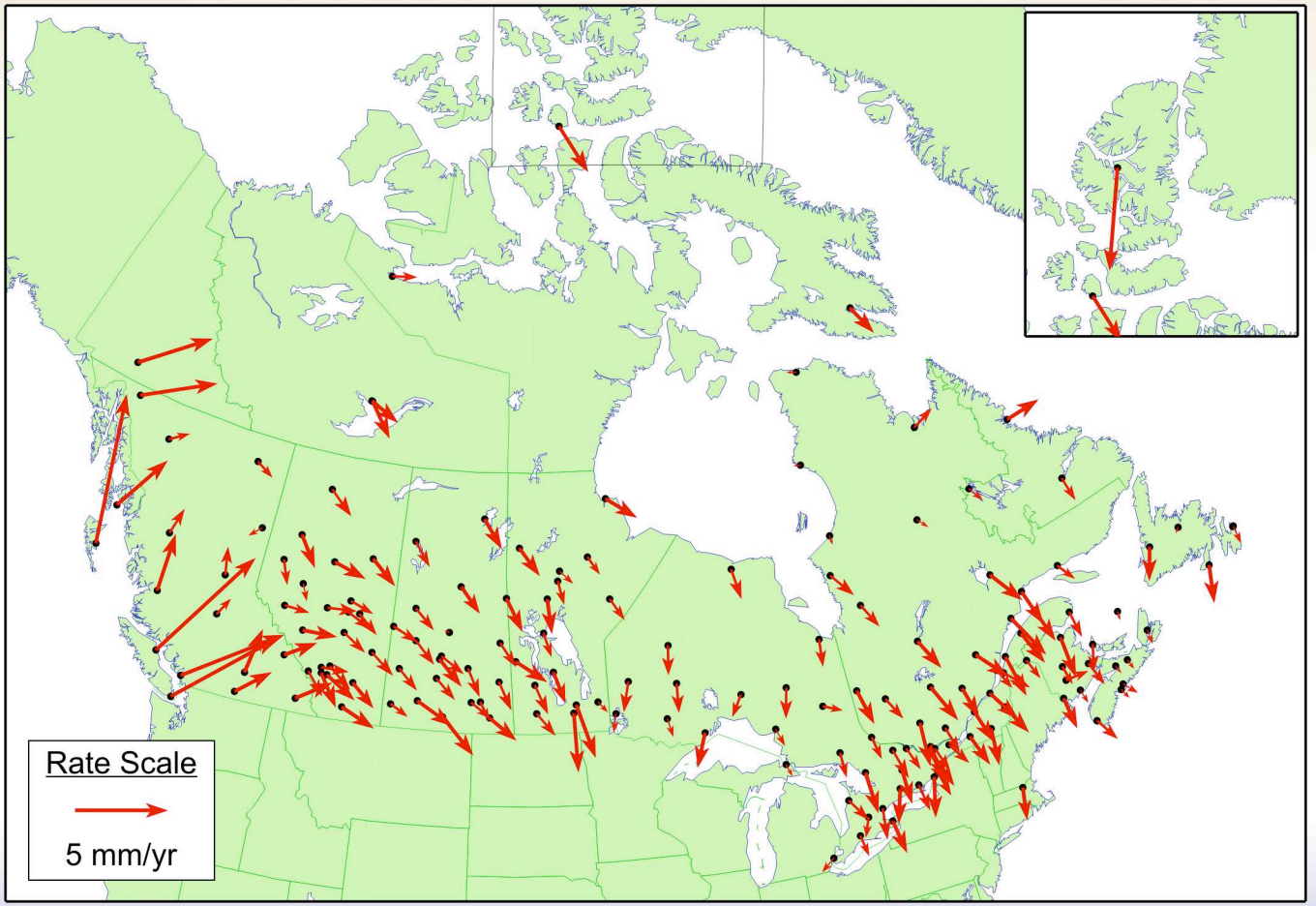
NAREF Vertical Velocities
(Aligned to IGS05P01)



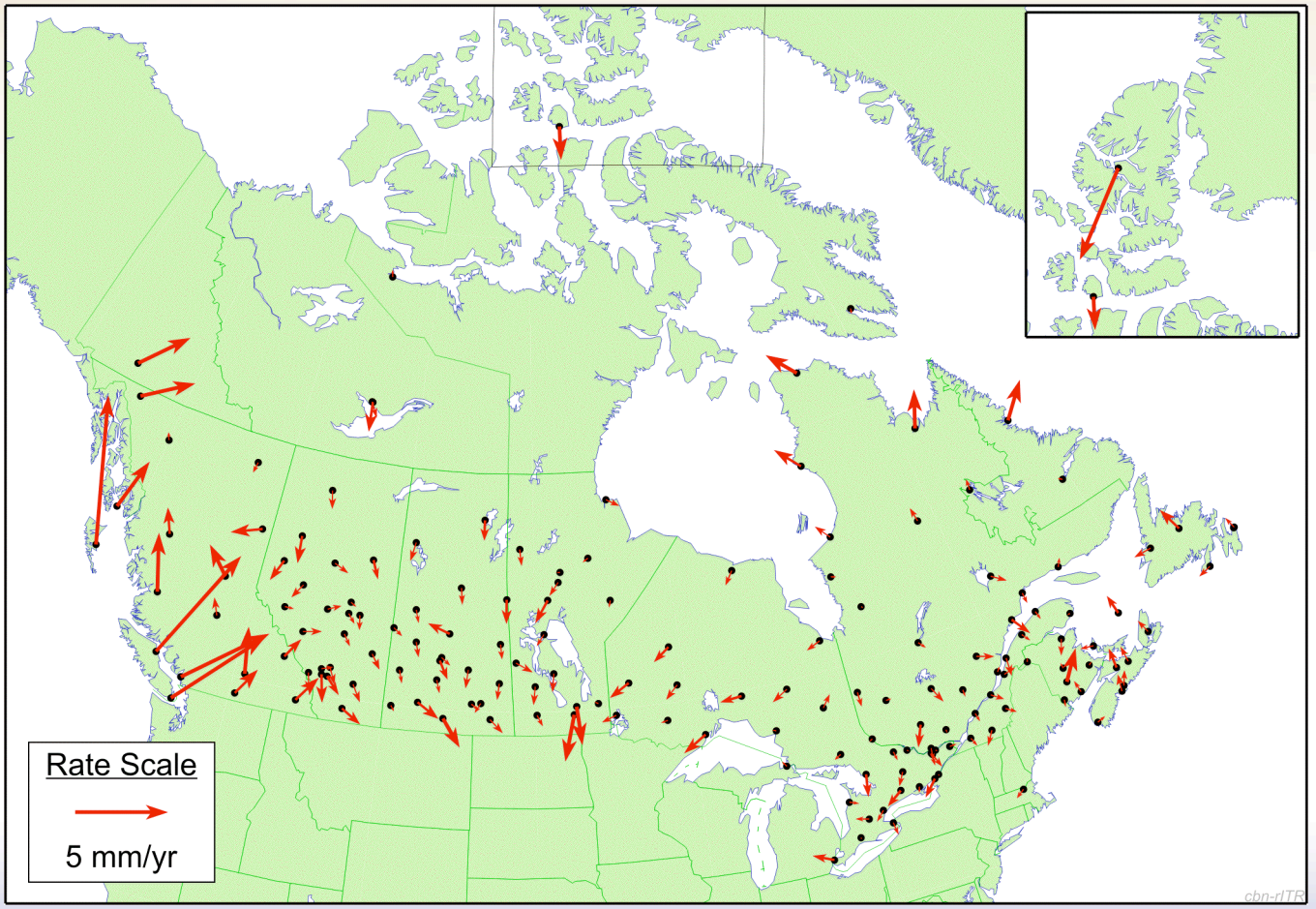
CBN Vertical Velocities
(ALGO fixed to IGS05P01)



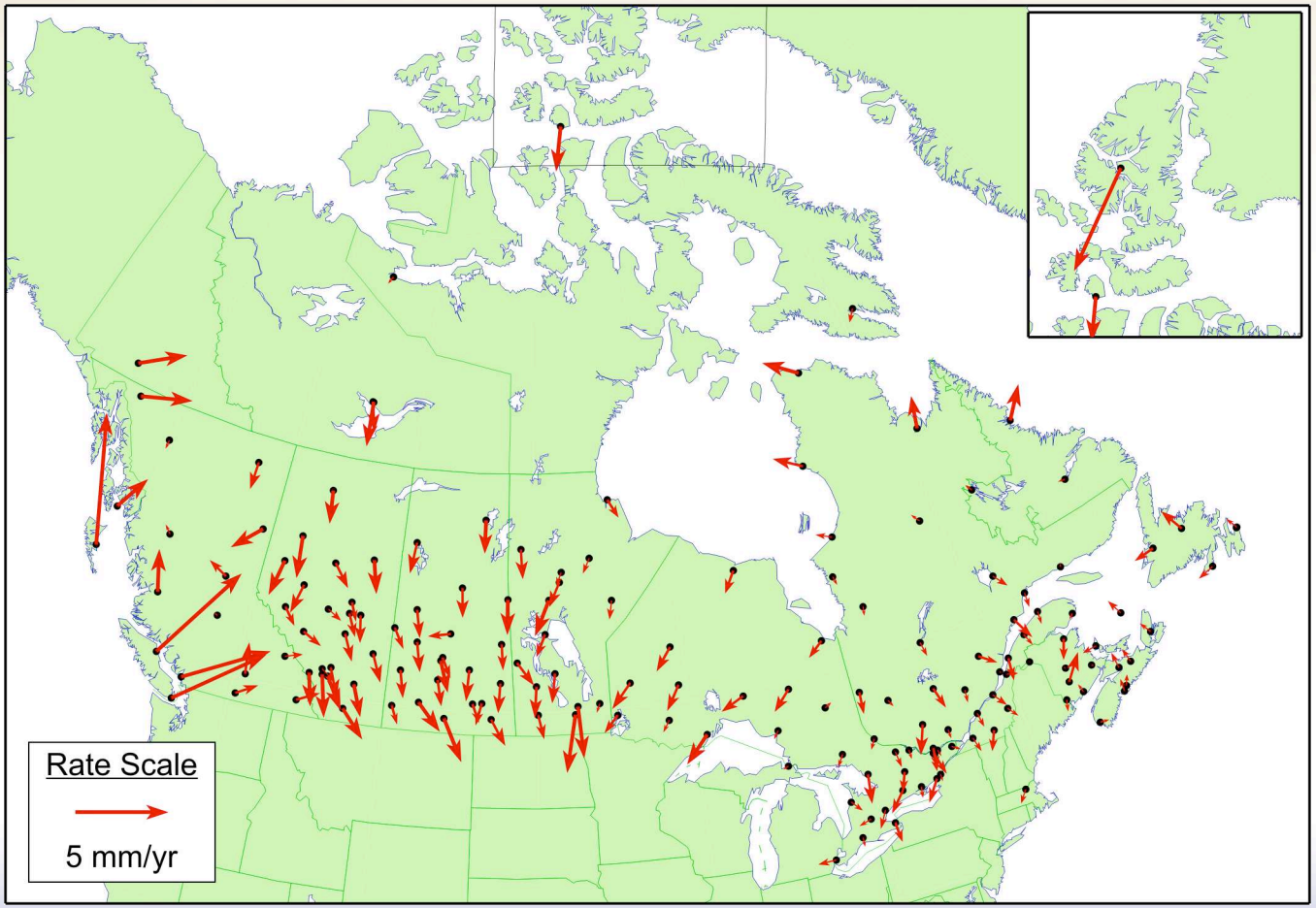
Velocities w.r.t. NUVEL



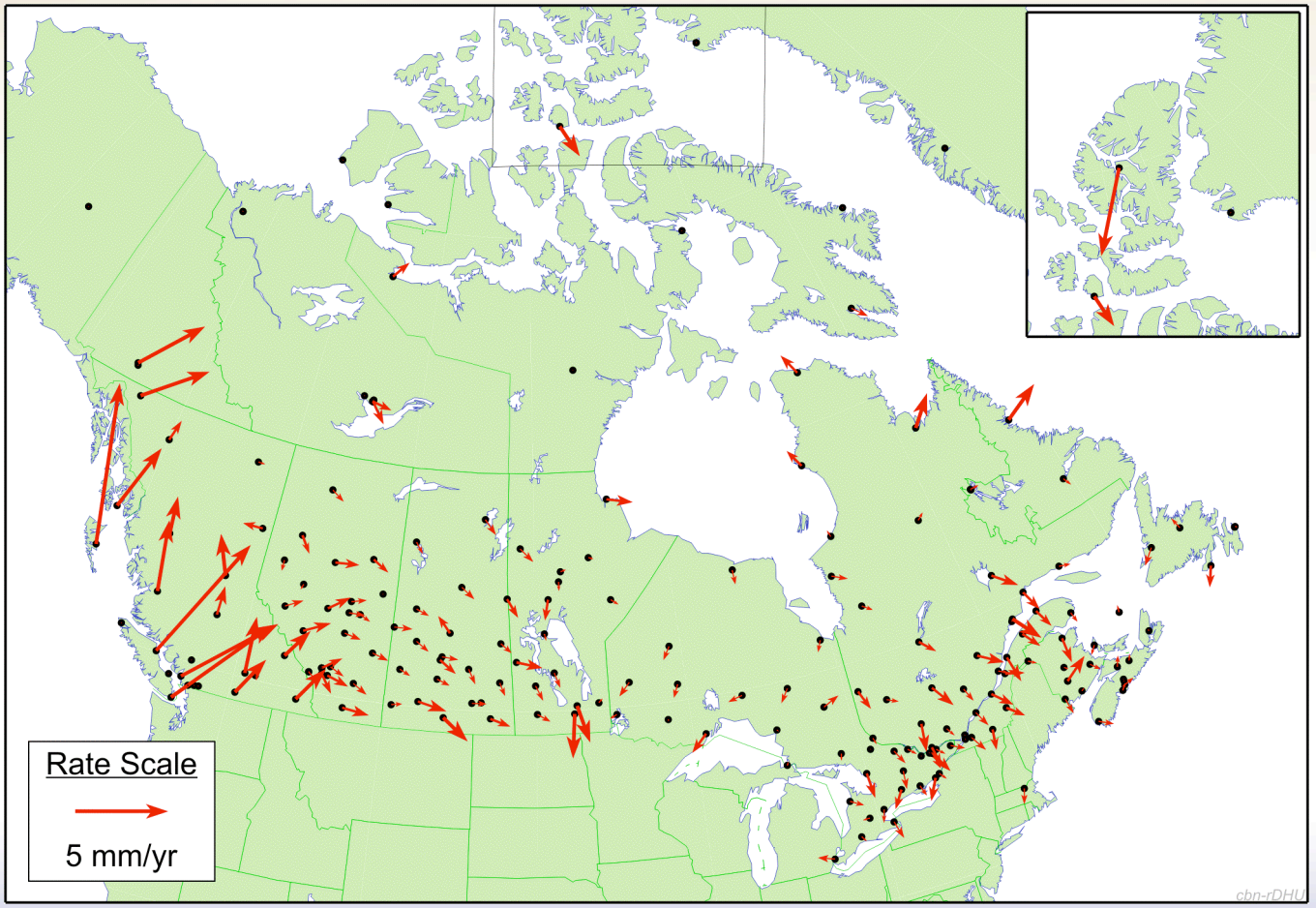
Velocities w.r.t. ITRF2000



Velocities w.r.t. SNARF



Velocities w.r.t. Hutchinson



GIA Model

- **Based on a novel technique by Jim Davis (Harvard-Smithsonian Astrophysical Observatory)**
  - Incorporates GPS velocities into an a priori GIA model
  - Using a Kalman filter
- **GPS velocities**
  - From a NAREF densification solution
    - Combines 5 different weekly solutions from 2001-2004

      NGS SIO NRCan/PGC

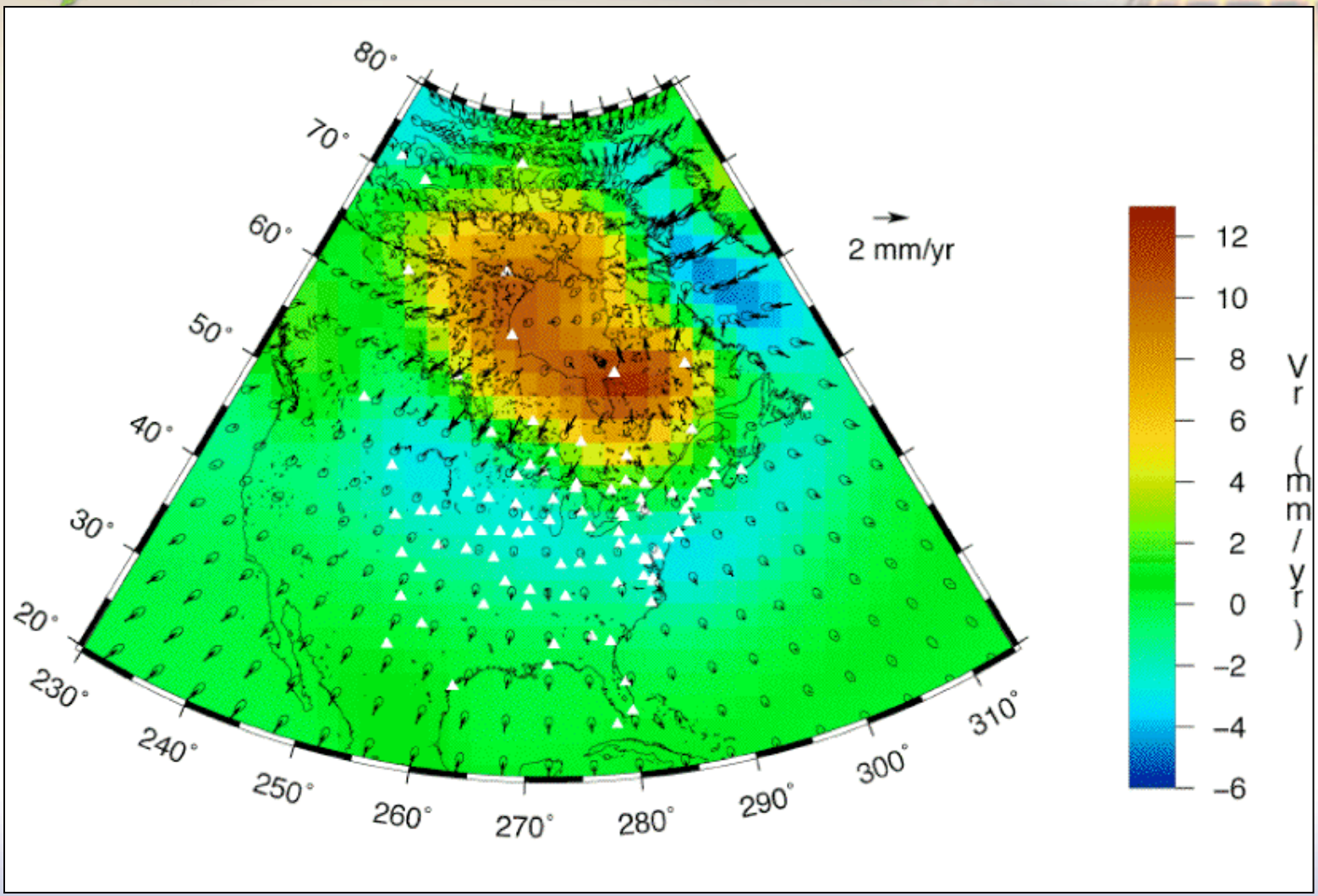
      NRCan/GSD (Bernese & GIPSY)
    - Velocities shown at beginning of presentation
  - Using only sites east of Rocky Mountains

GIA Model (con't)

- **A priori GIA model**
  - Average of a suite of GIA models based on ICE-1
    - Spanning a range of Earth model parameters
    - ICE-1 more appropriate than ICE-3G

      Unable to change some Earth parameters used in ICE-3G)
  - Varying Earth model parameters
    - Lithospheric thicknesses
    - Upper & lower mantle viscosities
  - Variability of models used to construct a covariance matrix for the average model

SNARF v1.0 GIA Model



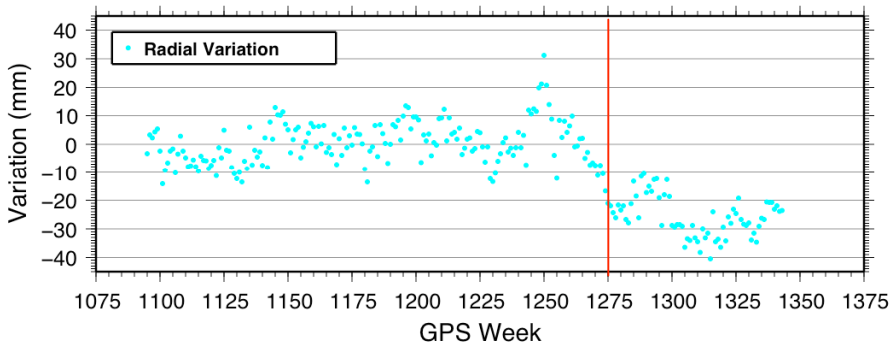
Further Improvements

- **Refine list of "datum" sites -- biggest task**
  - Another 60 available if monumentation can be verified
  - GIA-affected sites may be suitable if GIA model is used
- **New CBN 2005/6 remeasurement**
  - Will improve CBN velocities for both SNARF frame def'n and GIA model
- **Reprocess 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 intra-plate motions**
  - Seasonal variations such as

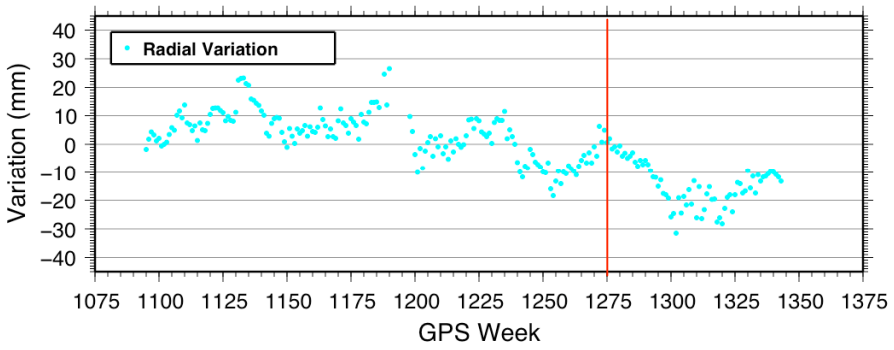
    Hydrologic and atmospheric loading (for day to day realization of SNARF)

GSD Bernese Time Series

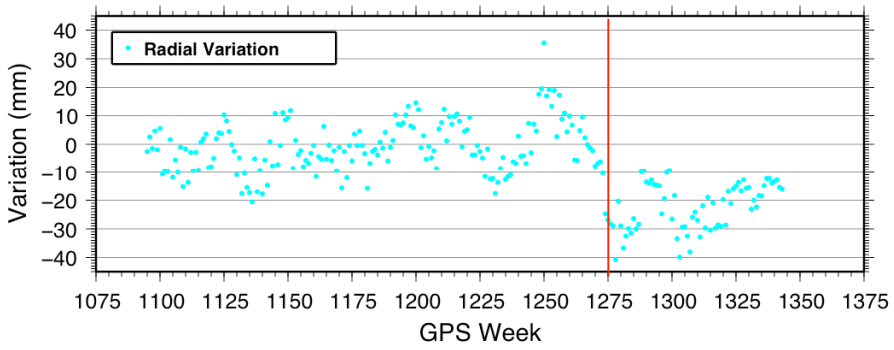
DUBO



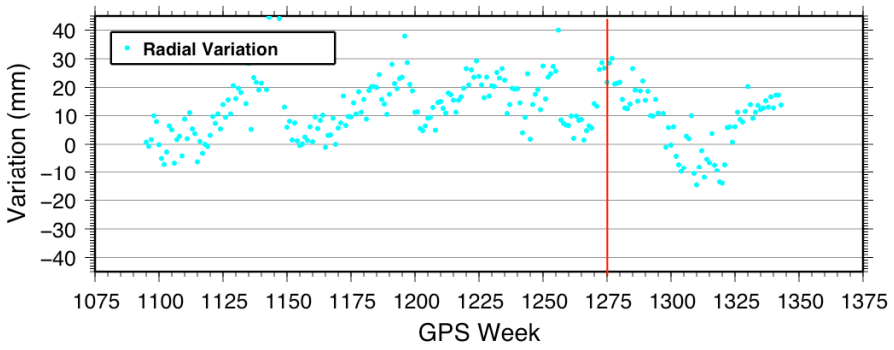
NANO



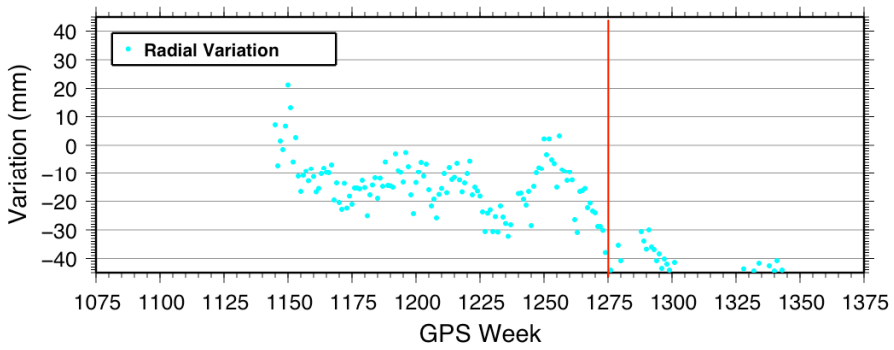
ALGO



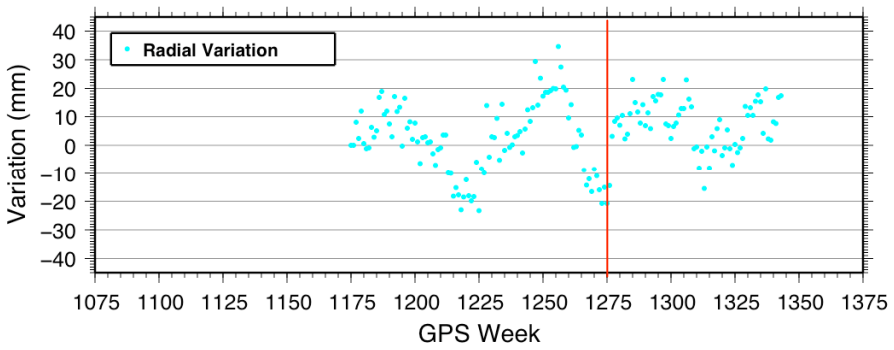
WHIT



HLFX



ALRT



Long Term Maintenance

- **Transition from research to operational mode by 2008**
  - EarthScope/UNAVCO funding runs out
- **National geodetic agencies in Canada & U.S.A.**
  - Can easily produce SNARF products via transformation of their own products; e.g.
    - NAREF regional combinations (weekly & cumulative)
    - CBN epoch & cumulative solutions
- **SNARF may eventually supercede NAD83**
  - NAD 83 offset by 2 m from geocenter (not compatible with GPS)
  - Presently defined in terms of NUVEL-1A plate motion (biased)
  - Will likely adopt SNARF plate motion in interim