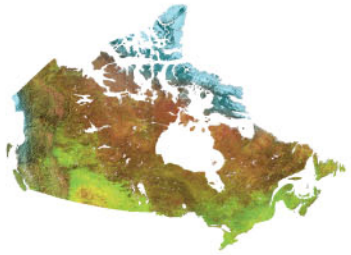
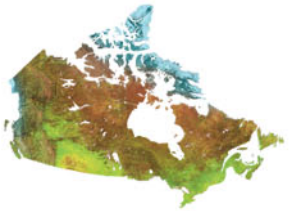


NRCan-Determined GPS Velocity Fields: Contributions to the definition of the Stable North American Reference Frame (SNARF)

J.A. Henton, M.R. Craymer, M. Piraszewski, & E. Lapelle

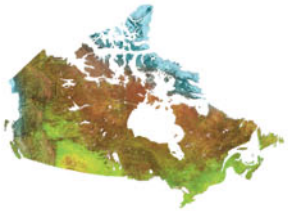
Natural Resources Canada, Geodetic Survey Division (CCRS)

Outline



- *INTRODUCTION*
  - Brief Introduction to the SNARF Initiative
  - NAREF Initiative & Contributors
  - NAREF Weekly Solutions from NRCan
- *NAREF VELOCITY SOLUTIONS*
  - Cumulative Solution Strategy
  - Velocity Field Results
- *CBN VELOCITY SOLUTIONS*
  - Introduction to the CBN
  - Cumulative Solution Strategy
  - Velocity Field Results
- *NAREF + CBN INTEGRATION*
- *FUTURE WORK*
- *ACKNOWLEDGEMENTS*

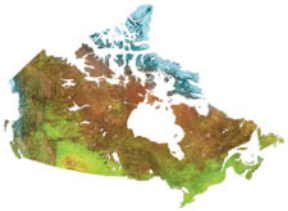
SNARF Initiative



- In 2003, the Stable North American Reference Frame (SNARF) Working Group was established under the auspices of UNAVCO, Inc. and IAG Regional Sub-Commission 1.3c for North America especially to address needs for the U.S.-led EarthScope project.
- The SNARF initiative will provide a consistent reference system in which scientific and geomatics results (*e.g.* positions in tectonically active areas) can be produced and inter-compared.
- Defined largely by GPS velocity solutions, SNARF will be a regional reference frame fixed to the "stable" North American plate.
- GPS velocity solutions are also used to determine an semi-empirical model of post-glacial rebound based upon a novel assimilation technique that combines GPS velocities with geophysical models.
- Over the next few years SNARF will be incrementally improved through further research and as more accurate velocity solutions become available.

→ ***The goal is to define a regional reference frame that is consistent and stable at the sub-mm/yr level throughout North America.***

NAREF Initiative

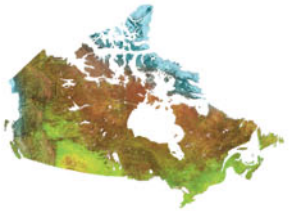


NORTH AMERICAN REFERENCE FRAME (NAREF) OBJECTIVES

IAG Sub-commission 1.3c
(Regional Reference Frames for North America)

- **To densify the ITRF reference frame in North America**
- **Consolidate regional networks into a continental one**
- **Integrate into ITRF via IGS global network**
- **Produce coordinate solutions**
  - **Weekly solutions/combinations**
  - **Cumulative solutions with velocity estimates**

NAREF Contributors (1/2)



Regional Weekly Solutions (up to week 1399):

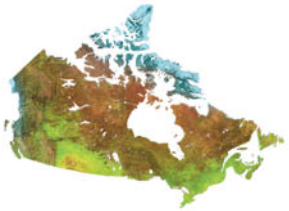
- NRCan/GSD Bernese Solutions (GSB) ~ 112 stations;
- NRCan/GSD Gipsy Solutions (GSG) ~ 43 stations;
- NRCan/PGC Bernese Solution (PGC) ~ 55 stations;
- NGS CORS solutions (NGS) ~ 820 stations;
  (only ~569 used in NAREF combination)

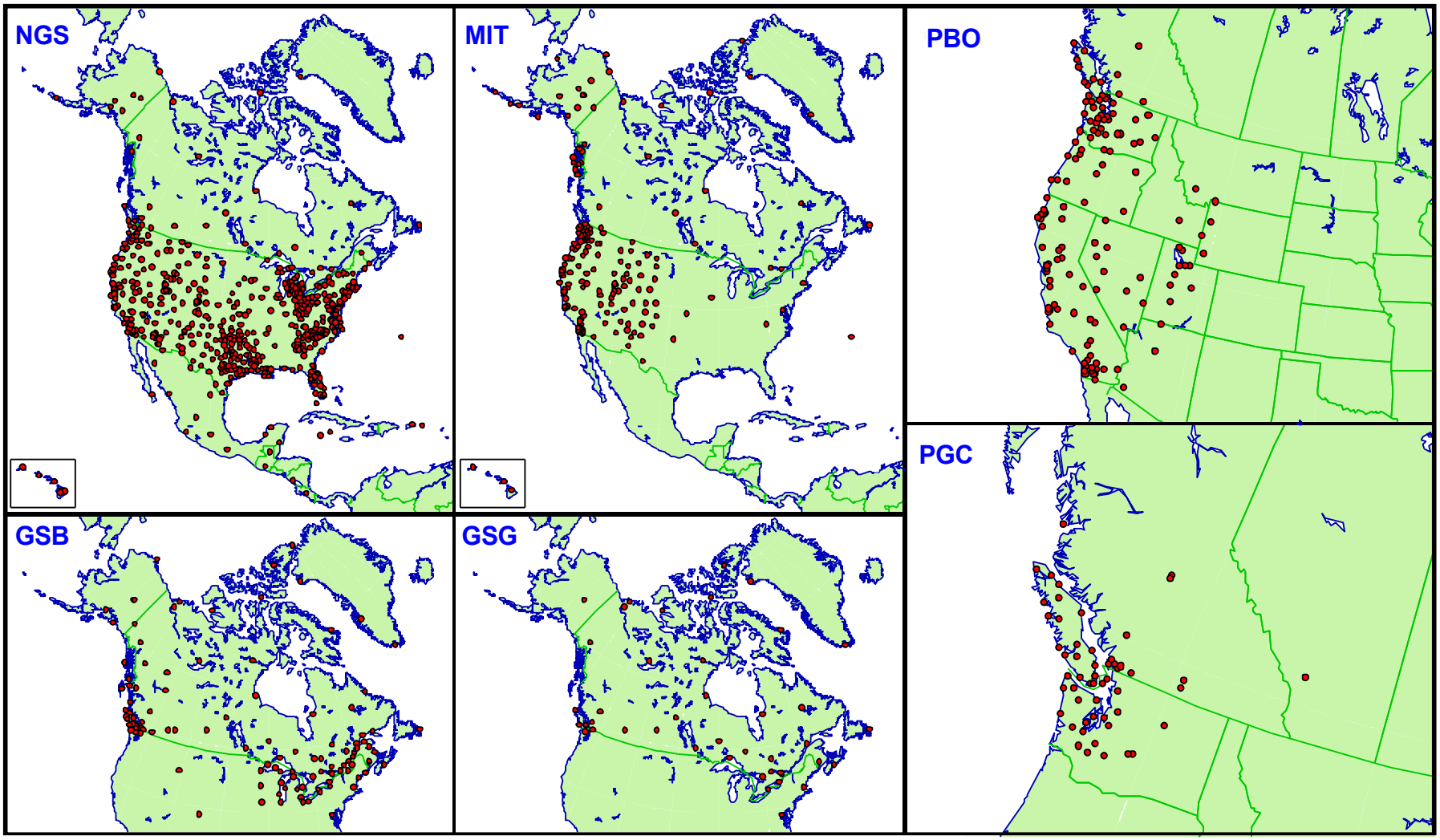
Regional Daily Solutions:

- MIT PBO solutions (MIT) ~ 670 sites;
  (only ~183 used in NAREF combination)
- SIO PBO solutions (PBO) ~ 700 sites;
  (only ~ 140 used in NAREF combination)

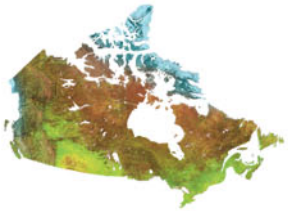
→ *NRCan/GSD combines these daily solutions into weekly solutions prior to NAREF combination*

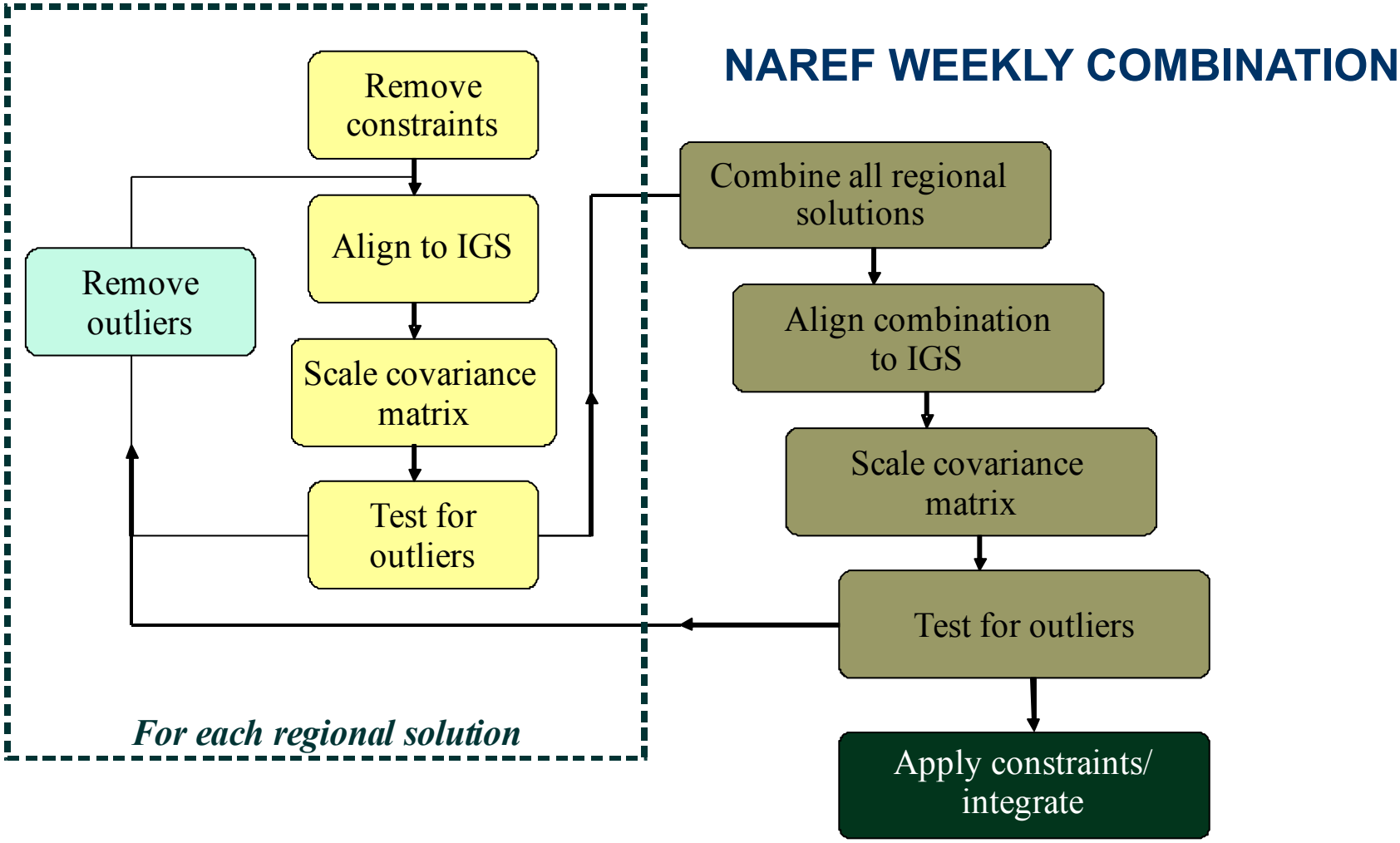
NAREF Contributors (2/2)



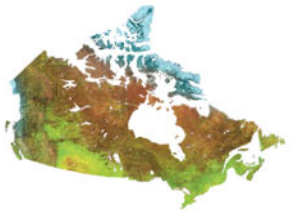


NAREF Weekly Solutions





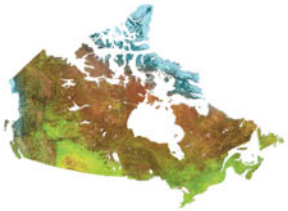
NAREF Site Redundancy



Stations Common to Multiple NAREF Contributions (GPS Week 1399)					
6 Solutions	5 Solutions	4 Solutions	3 Solutions	2 Solutions	1 Solution
3	7	21	95	94	488

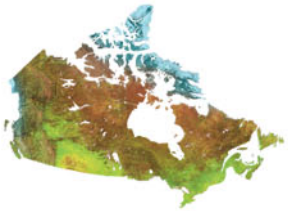
Stations Common Between NAREF Contributions (GPS Week 1399)						
Solution	NRCan Bernese	NRCan Gipsy	MIT	NGS	PBO	NRCan PGC
NRCan Bernese	112	43	28	45	16	20
NRCan Gipsy	43	43	17	38	8	9
MIT	28	17	183	121	99	25
NGS	45	38	121	569	99	19
PBO	16	8	99	99	140	37
NRCan PGC	20	9	25	19	37	55

NAREF Cumulative Solution (1/2)



- **Constraints removed from weekly solutions**
- **Weekly solutions aligned to subset of NA sites in the IGS05 realization of ITRF2005:**
  - **11 reliable North American continuous GPS sites;**
  - **Each weekly solution aligned to IGS05 at epoch of week;**
  - **7 parameter alignment of coordinates (3 translations, 3 rotations & scale change);**
- **All aligned weekly solutions combined together (summation of normals) & site velocities estimated**
- **Apply equivalancy constraints on the estimated velocities for sites where appropriate ($v_1 = v_2 = v_3$…)**
- **NAREF cumulative solution re-aligned to subset of IGS05**
  - **14 parameter alignment (3 translations, 3 rotations & scale change and their time rates of change)**
- **NAREF cumulative solution then constrained to the coordinates and velocities of IGS05.**

NAREF Cumulative Solution (2/2)

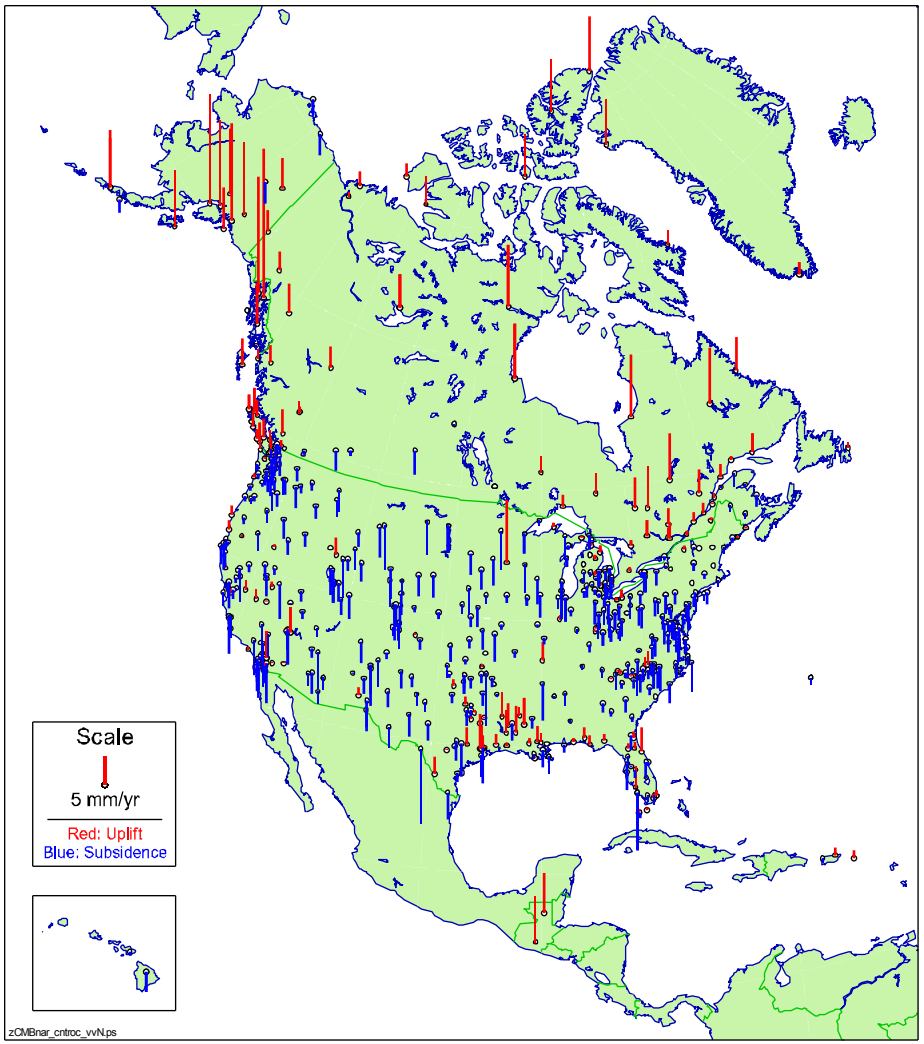


Descriptive Statistics for the NAREF Cumulative Solution	
Number of NAREF Weekly Solutions Used for Cumulation Solution	305
Time Span of NAREF Solutions Used (GPS Weeks)	1095-1399
Total Number of Stations Available from NAREF Weekly Solutions	906
Number of Stations Used in Cumulative Solution (*see note below*)	578
Total Number of Coordinate & Velocity Parameters Determined	4374

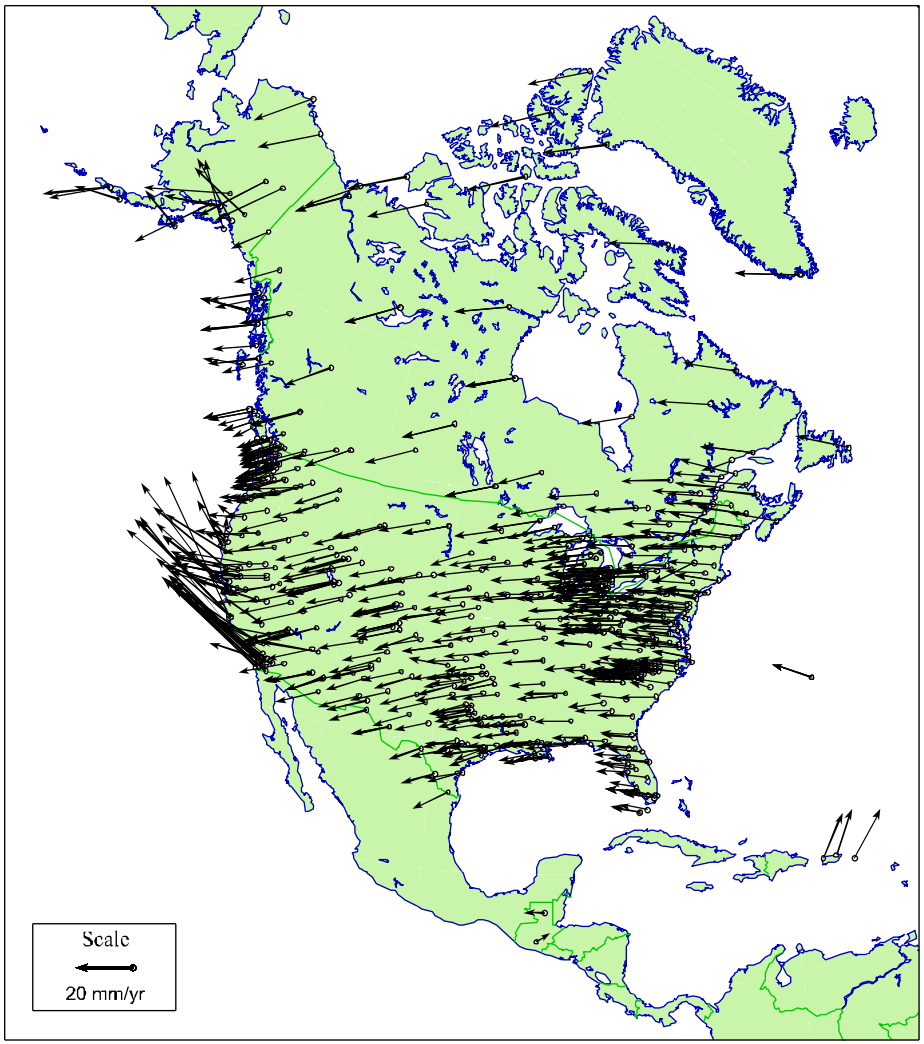
REASONS FOR EXCLUDING STATIONS FROM THE CUMULATIVE SOLUTION

- Short (less than ~2 years) data/time span – primary reason to date: ~260 sites omitted
- Collocated/redundant sites (mainly USCG sites): ~50 sites omitted
- "Bad" (noisy, gappy, multiple offsets, etc.) coordinate time series: ~20 sites omitted

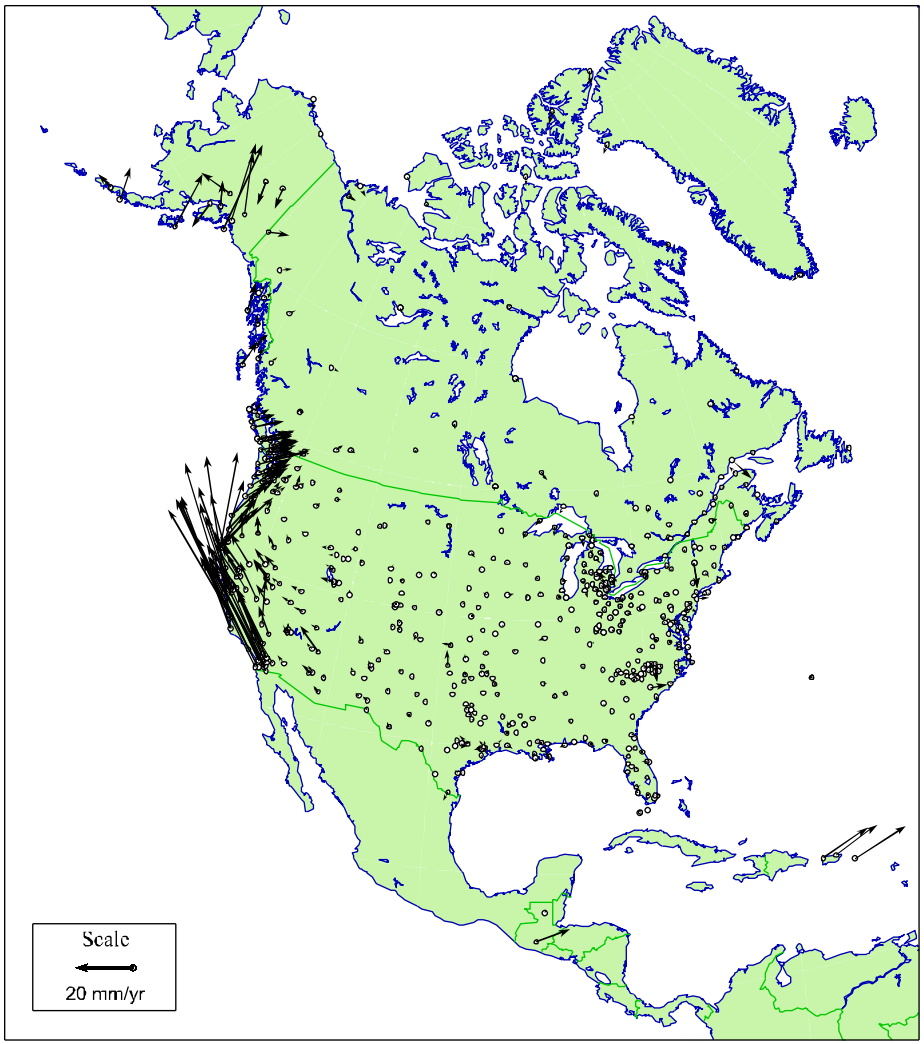
NAREF Vertical Velocities



NAREF Horizontal Velocities (1/2)



NAREF Horizontal Velocities (2/2)



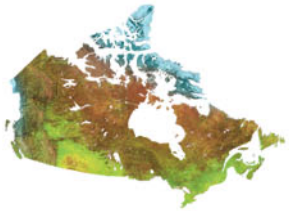
NAREF residual horizontal velocities after the removal of the velocities predicted by the ITRF2005 rotation pole for the North American plate (NOAM).

NOAM ITRF2005 Pole (radians/My):

ω_X = 0.000152
ω_Y = -0.003338
ω_Z = -0.000251

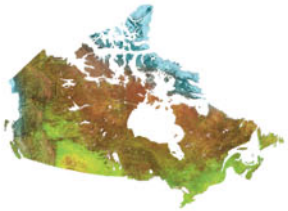
Altamimi, Z., X. Collilieux, J. Legrand, B. Garayt, and C. Boucher (2007), ITRF2005: A new release of the International Reference Frame based on time series of station positions and Earth Orientation Parameters, *J. Geophys. Res., 112*, B09401, doi: 10.1029/2007JB004949

Canadian Base Network (CBN)



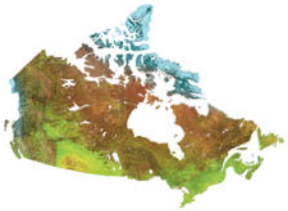
- Network of high-stability pillar monuments with forced-centering mounts for GPS receiver antennas;
- Initiated in 1994;
- Repeated multi-epoch (episodic) GPS measurements;
- Provides an increased spatial sampling of crustal deformation throughout Canada.

CBN Solution Strategy (1/2)



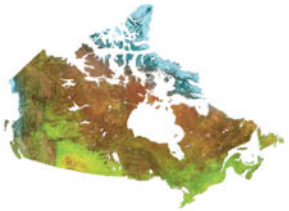
- Episodic campaigns processed with Bernese GPS Software Version 5
- Combining 27 individual CBN solutions (campaigns) from 1994 to 2006
- Using SINEX combination software:
  » GSD SINEX Software by Rémi Ferland (used for official IGS global combinations)
- 1) Constraints removed from individual CBN solutions
- 2) Each CBN solution aligned to IGS realization of ITRF2005 (ITRF_IGS05.snx) at epoch of CBN solution:
  » 3 translations, 3 rotations & scale change

CBN Solution Strategy (2/2)



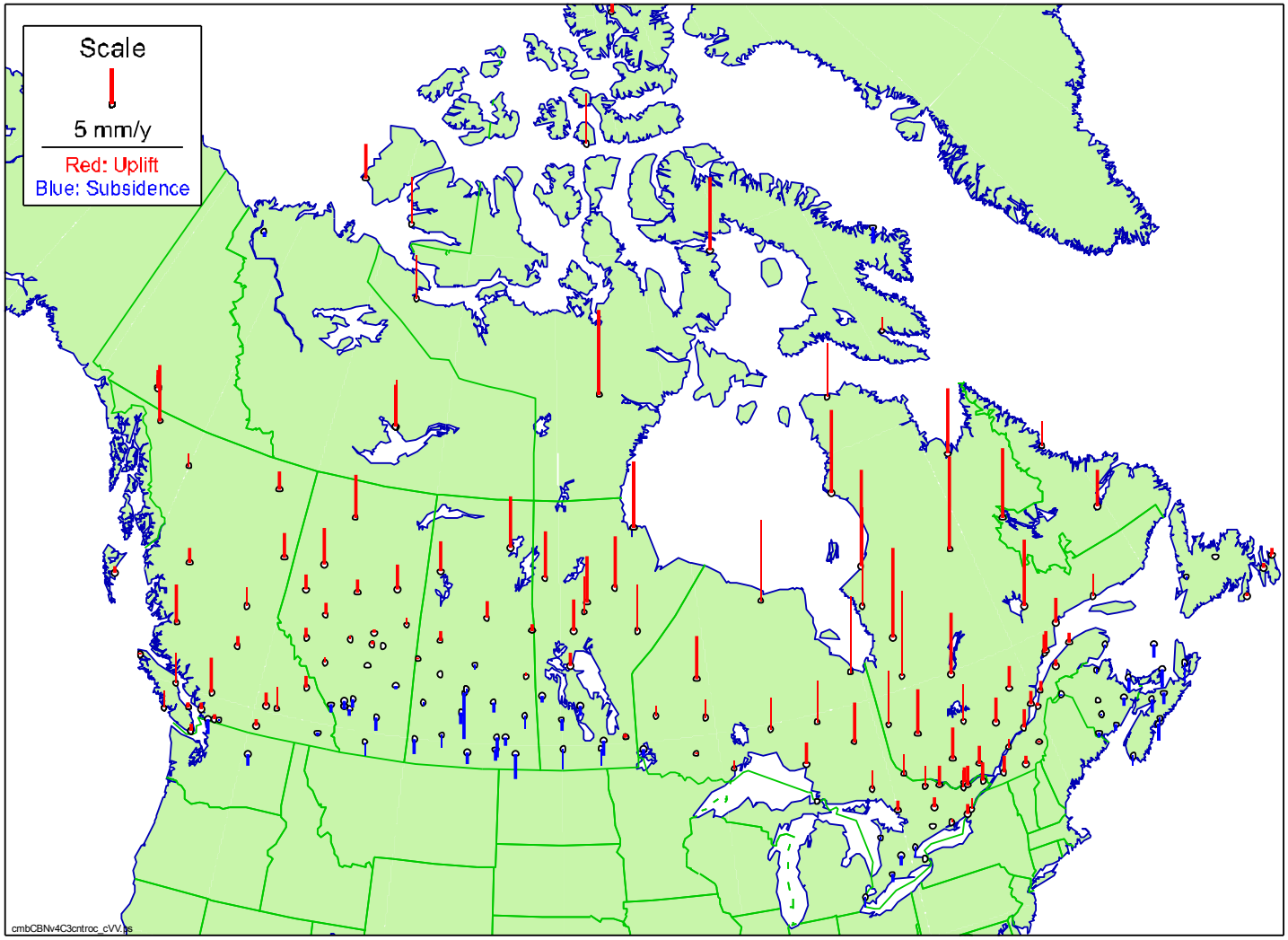
- 3) Covariance matrix of each CBN solution scaled by WRMS of residuals from alignment
- 4) All (scaled) CBN solutions combined together (summation of normals) and site velocities estimated
- 5) Apply equivalency constraints on the estimated velocities for each site where appropriate ($v_1 = v_2 = v_3 \ldots$)
- 6) Re-align CBN cumulative solution to a subset of ITRF2005
  » 14 parameter alignment (3 translations, 3 rotations & scale change and their time rates of change)
- 7) CBN cumulative solution constrained to the coordinates and velocities of a subset of ITRF2005 sites

CBN Cumulative Solution

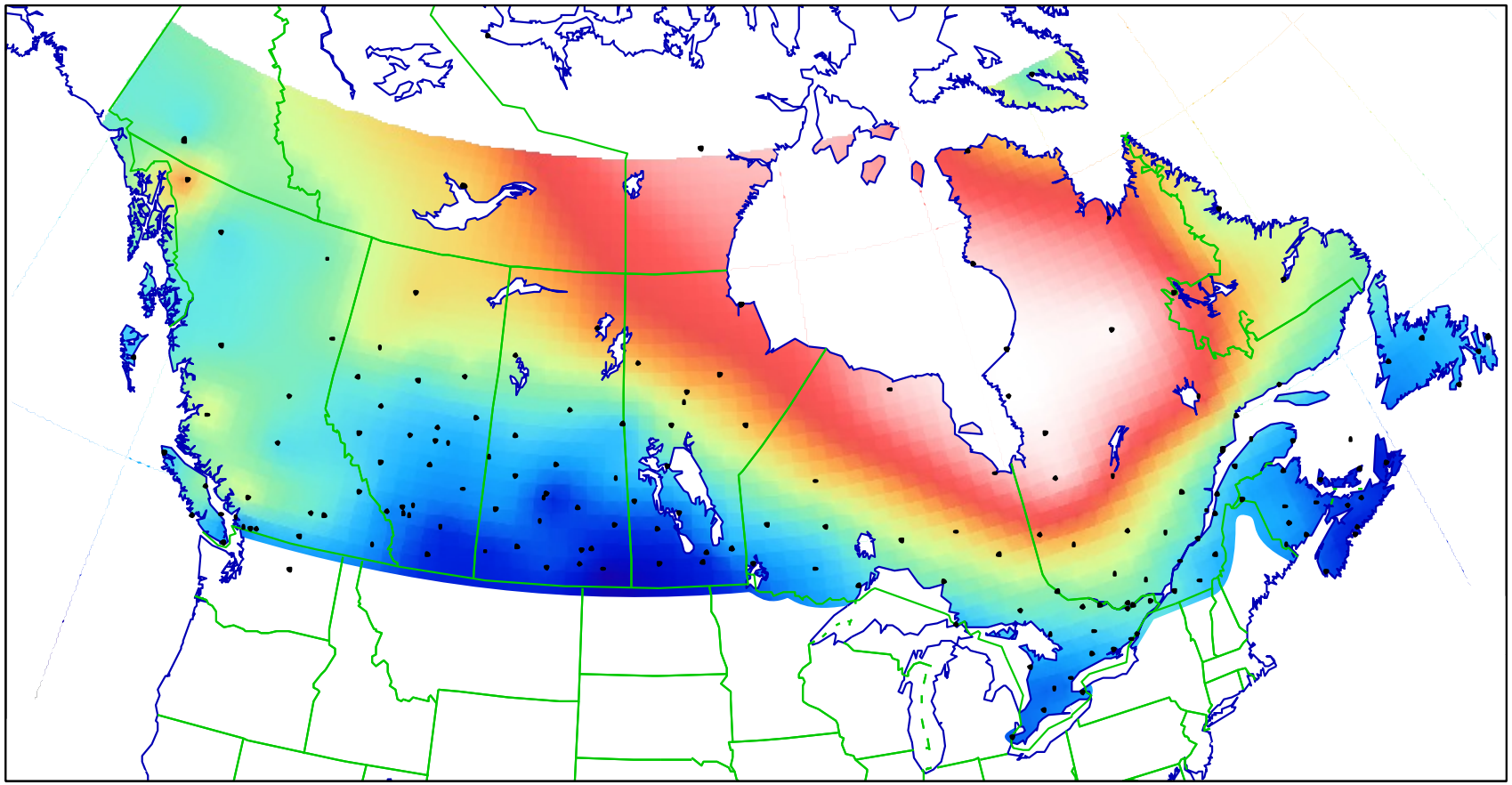


Descriptive Statistics for the CBN Cumulative Solution	
Number of Input Episodic Campaign Solutions	27
Time Span of CBN Solutions (Years)	~12
Number of Stations Used in Cumulative Solution	206
Number of Coordinate & Velocity Parameters	1170

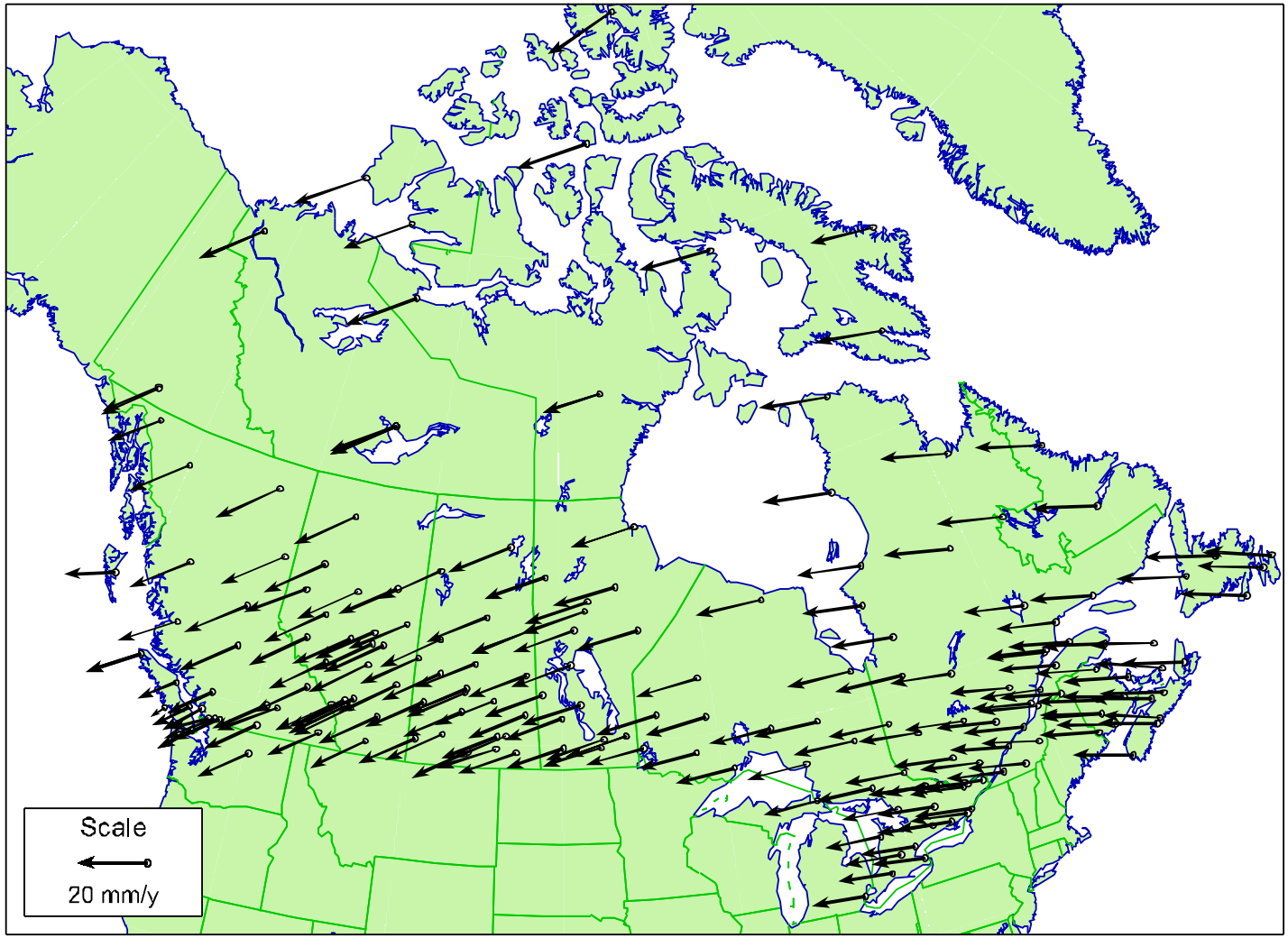
CBN Vertical Velocities (1/2)



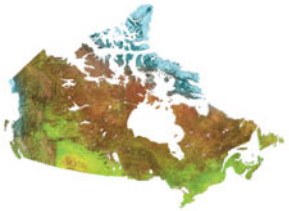
CBN Vertical Velocities (2/2)

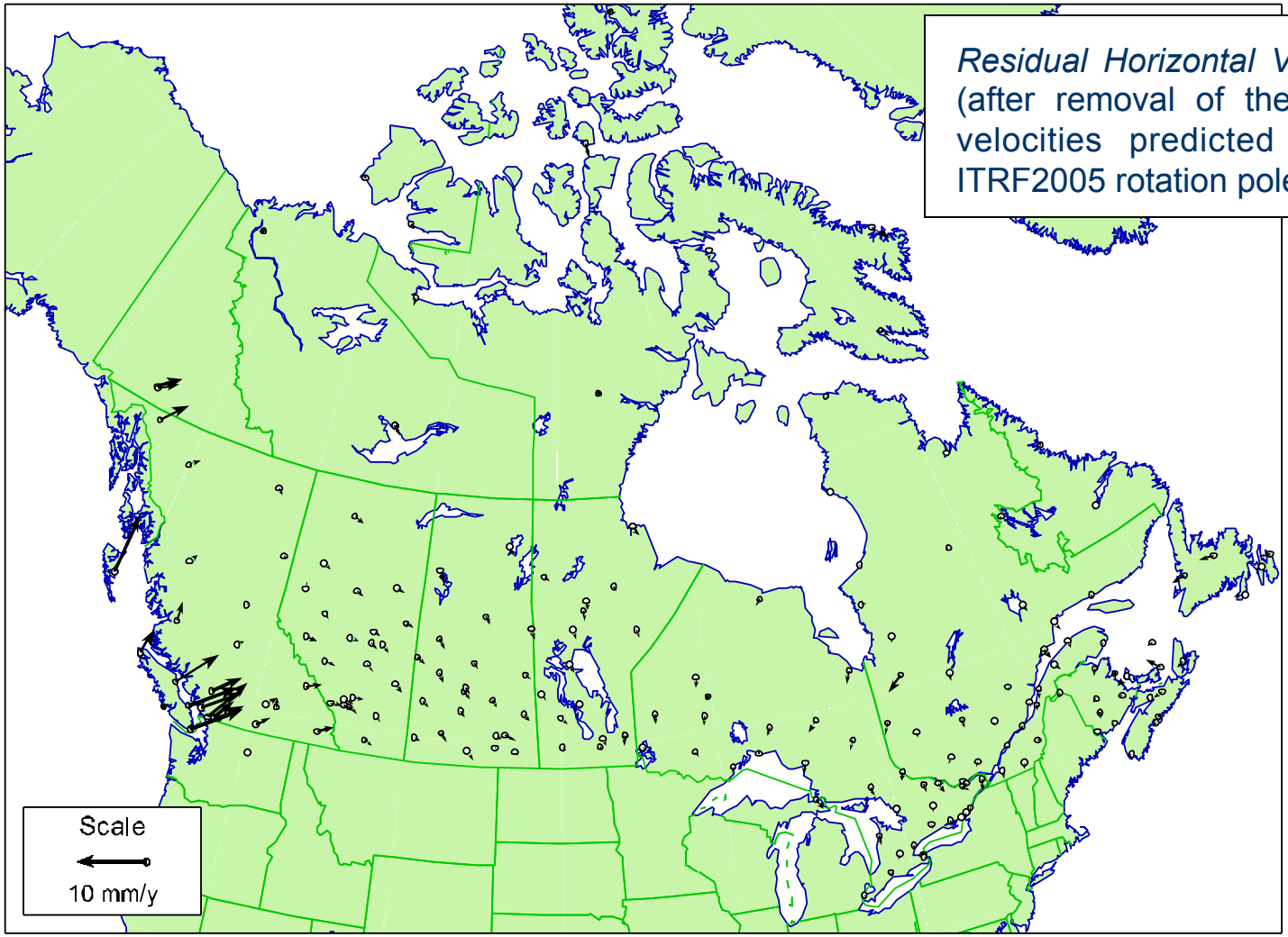


CBN Horizontal Velocities (1/2)



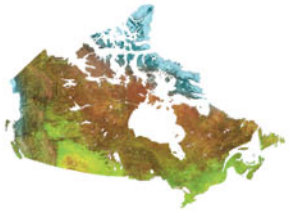
CBN Horizontal Velocities (2/2)





Residual Horizontal Velocities (after removal of the NOAM velocities predicted by the ITRF2005 rotation pole).

NAREF + CBN Integration



- Some past “issues” permitted some small velocity and coordinate biases to remain between the CBN and NAREF solutions.

  (Presumed, in part, related to the different weights/scales of covariance matrices for the CBN, NAREF, & ITRF – particularly w.r.t. alignments).

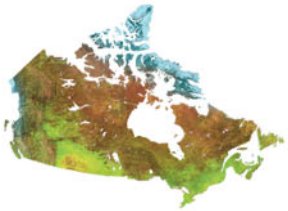
- Re-align (individually) CBN and NAREF unconstrained cumulative solutions to a subset of ITRF2005

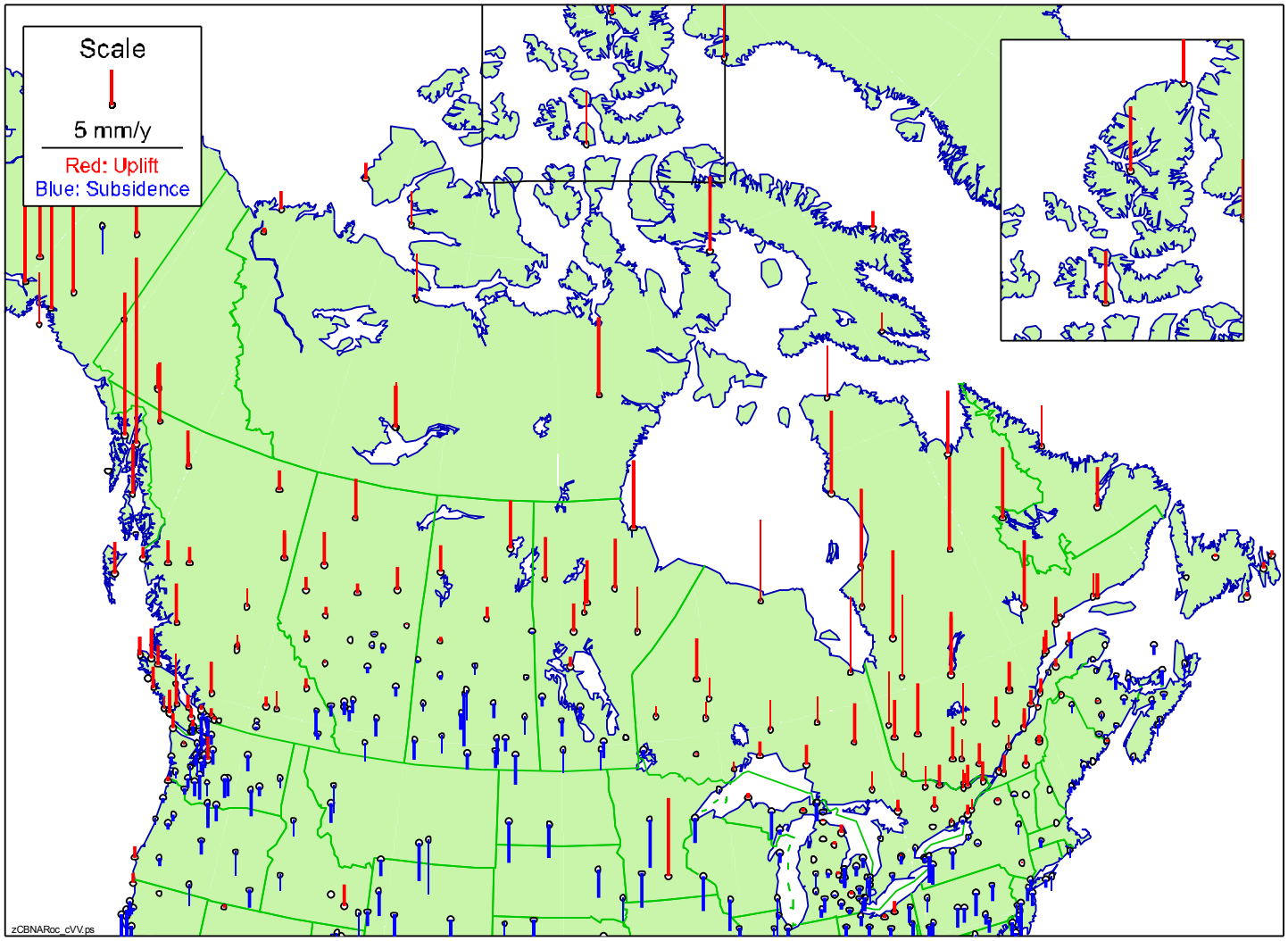
  » 14 parameter alignment (3 translations, 3 rotations & scale change and their time rates of change)

  » Equal weighting of input (*i.e.* CBN or NAREF) and reference (*i.e.* ITRF2005) covariance matrices

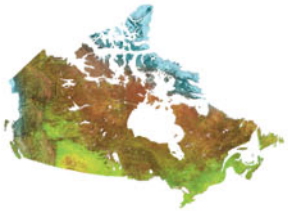
- Aligned CBN and NAREF cumulative solutions simultaneously integrated with the coordinates and velocities of a subset of ITRF2005 solution

CBN + NAREF Vertical Rates





Future Work (1/2)



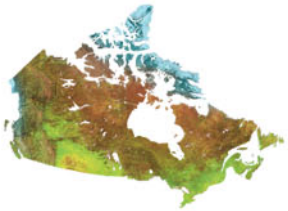
Additional NAREF Redundancy

- Many CORS stations only in one regional solution
- No checks on those stations
- SOPAC to expand it's regional solution to include most CORS

SNARF Maintenance

- Will continue to update NAREF and CBN cumulative solutions for any new SNARF realizations

Future Work (2/2)

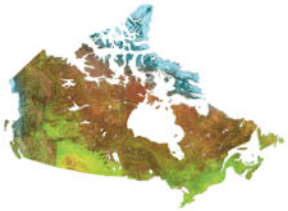


Change in IGS Standards beginning GPS Week 1400

- Adopted ITRF2005
- Introduced absolute phase center variations (PCV) for receivers and satellites antennas
  → Caused bias in time series of coordinates of all stations
- Introduced separate antenna calibrations for antennas with domes
  → Caused additional biases at affected stations only
- NAREF solutions currently stop at GPS Week 1399
- Need to update all old orbits prior to GPS Week 1400
  → IGS effort underway

► *Will need to reprocess all NAREF and CBN solutions*

Acknowledgements



- We wish to acknowledge the following contributors providing regional solutions to the NAREF initiative on a timely basis and with such a high level of accuracy and consistency. The high accuracy and consistency of the NAREF solutions are due to their diligent efforts.
  - Mike Cline and others at the U.S. National Geodetic Survey (NOAA)
  - Peng Fang at the Scripps Orbit and Permanent Array Center (UCSD)
  - Herb Dragert at the Geological Survey of Canada - Pacific (Sidney)
  - Tom Herring at the Massachusetts Institute of Technology
  - Caroline Huot and Brian Donahue at the Geodetic Survey Division (NRCan)
- We also wish to gratefully acknowledge Rémi Ferland at the Geodetic Survey Division (NRCan) for his support and guidance with respect to his SINEX Software suite.
- Finally we thank the dedicated field personnel of NRCan for their valuable role in the collection of the CBN data.

Thank You