# Contributions of the North American Reference Frame Working Group to the next realization of the Stable North American Reference Frame (SNARF)

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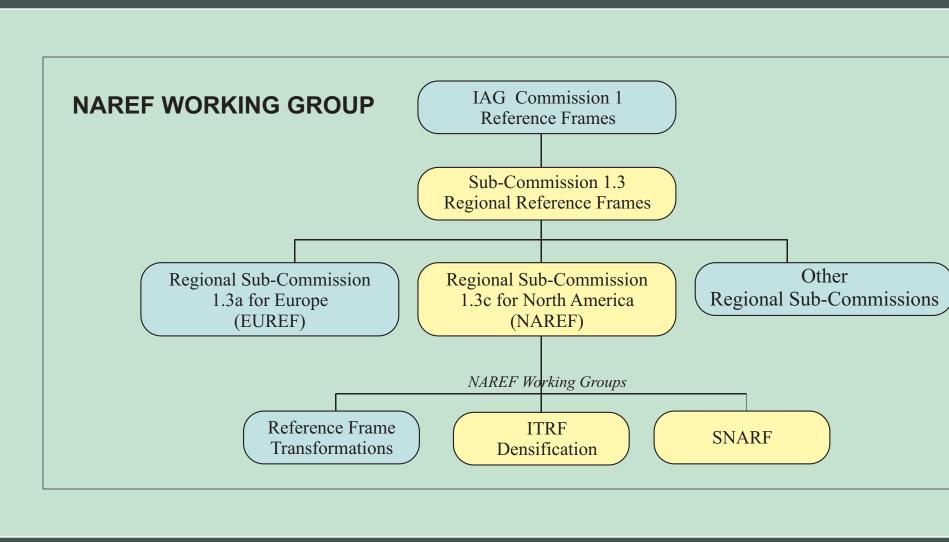
### INTRODUCTION

Since the beginning of 2001, the Geodetic Survey Division of Natural Resources Canada (NRCan) has been playing a leading role in the North American Reference Frame (NAREF) Working Group of IAG Sub-commission 1.3c (Regional Reference Frames for North America). This supports the International Earth Rotation and Reference Frames Service (IERS) and the International GNSS Service (IGS) initiatives to densify the International Terrestrial Reference Frame (ITRF) in North America. The objective is to provide a globally consistent reference frame, including velocity models, procedures and transformations, tied to ITRF in which scientific and geomatics results (e.g., positions in tectonically active areas) can be produced and inter-compared. The NAREF densification network has evolved from a hundred continuously-operating GPS reference stations to nearly 1000. Following internationally accepted densification methodologies, regional North American GPS solutions, from several groups in Canada and the U.S., are combined into a single NAREF weekly solution that is aligned with the ITRF reference frame. The weekly NAREF solutions are subsequently combined into a single cumulative solution to provide estimates of both station coordinates and their velocities with respect to a consistent reference frame throughout North America. In order to provide an increased spatial sampling of crustal deformation throughout Canada, we also estimate velocities at sites of the Canadian Base Network (CBN) by combining over ten years of repeated multiple-epoch (episodic) nitiated in 1994, the CBN is a network of high-stability pillar monuments with forced-centering mounts for GPS receiver antennas. To station velocities, regional CBN solutions for each measurement epoch are systematically combined into a Canada-wide cumulative solution. The resulting NAREF and CBN velocity fields display a high level of spatial- coherence and are being used to evaluate crustal deformations in various parts of the continent and to more accurately determine the motion of stable North America. More specifically these products have been used in the definition of a plate-fixed Stable North American Reference Frame (SNARF) for the Plate Boundary Observatory component of the EarthScope project. In this paper we present the NRCan-determined GPS velocity fields, and the resulting North American rotation pole derived from these efforts. We also describe recent changes in our processing and combination strategies in response to new procedures adopted by the IGS.

### NAREF INITIATIVE

#### NAREF OBJECTIVES

- 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



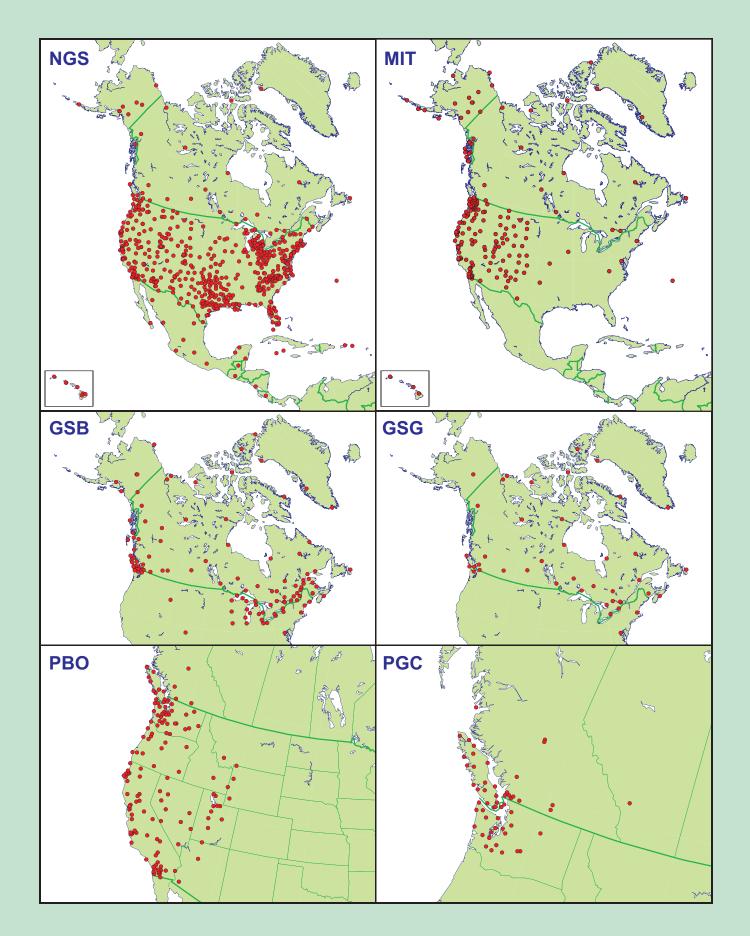
### NAREF SOLUTIONS

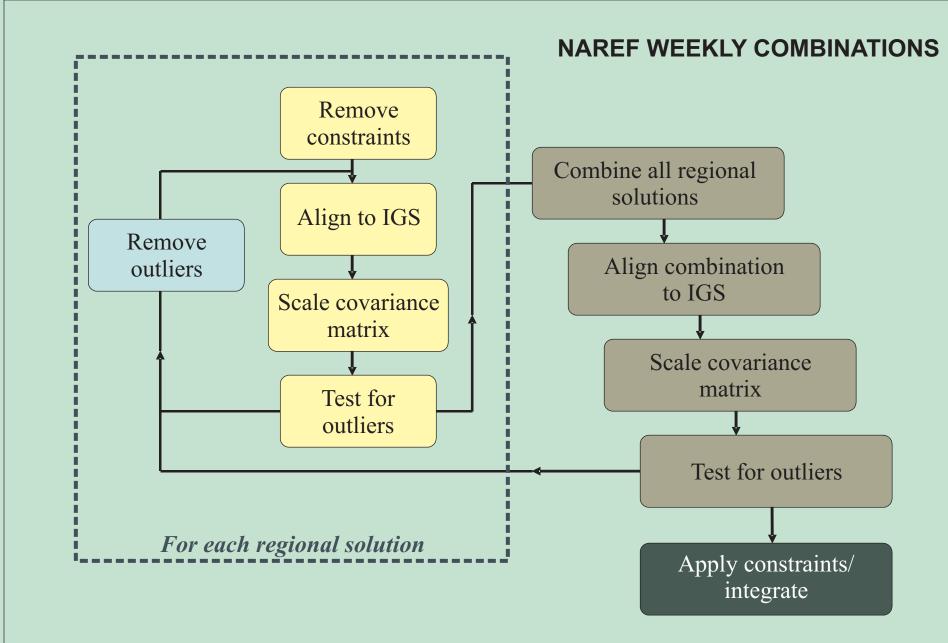
#### NAREF CONTRIBUTORS

- Regional Weekly Solutions (up to week 1399): □ NRCan/GSD Bernese Solutions (GSB) ~ 112 stations;
- $\square$  NRCan/GSD Gipsy Solutions (GSG)  $\sim 43$  stations; □ NRCan/PGC Bernese Solution (PGC) ~ 55 stations;
- NGS CORS solutions (NGS) ~ 820 stations;
- (only ~569 used in NAREF combination)

**Regional Daily Solutions:** 

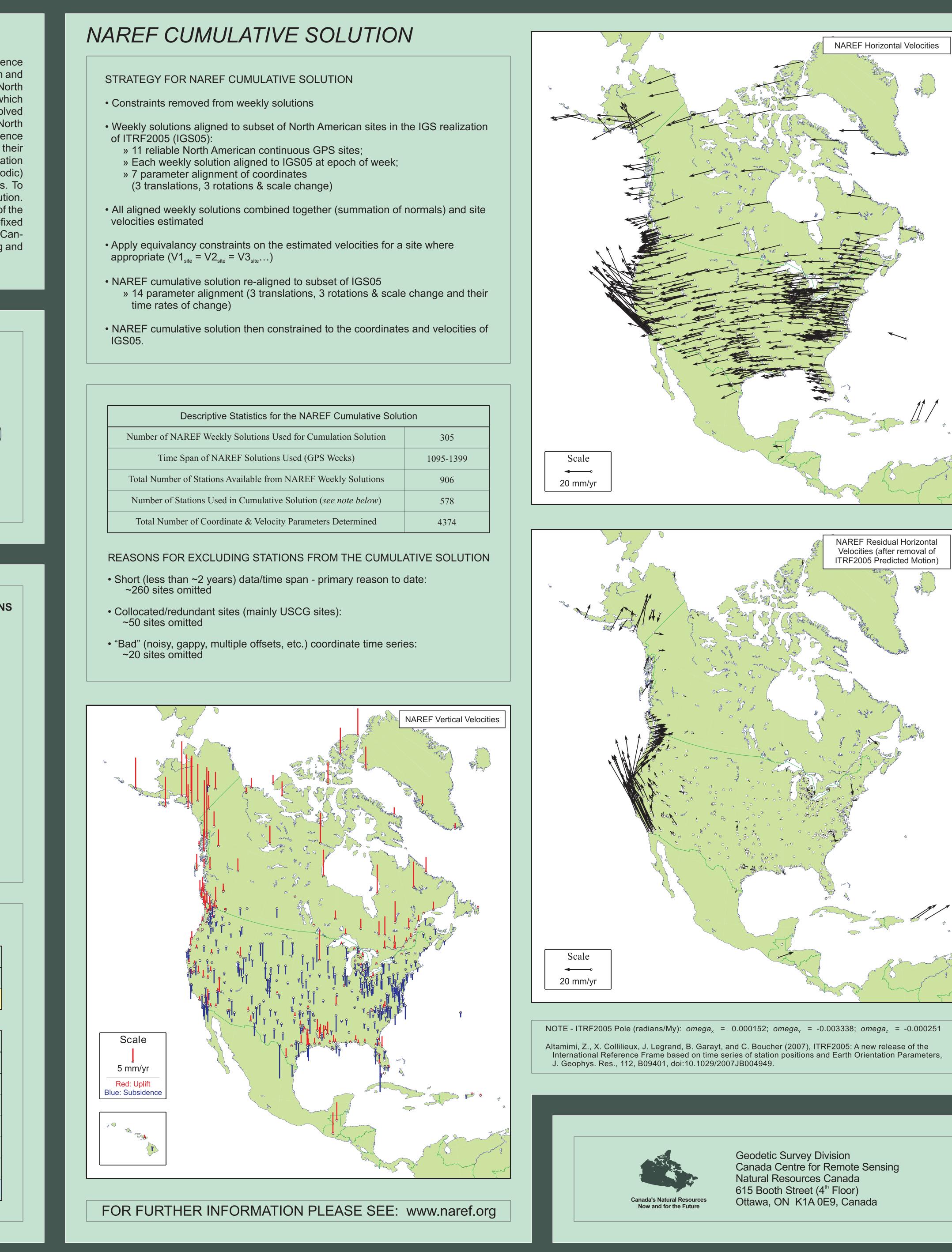
- $\square$  MIT PBO solutions (MIT) ~ 670 sites; (only ~183 used in NAREF combination)
- SIO PBO solutions (PBO) ~ 700 sites;
- (only  $\sim$  140 used in NAREF combination)
- NRCan/GSD combines these daily solutions into
- weekly solutions prior to NAREF combination

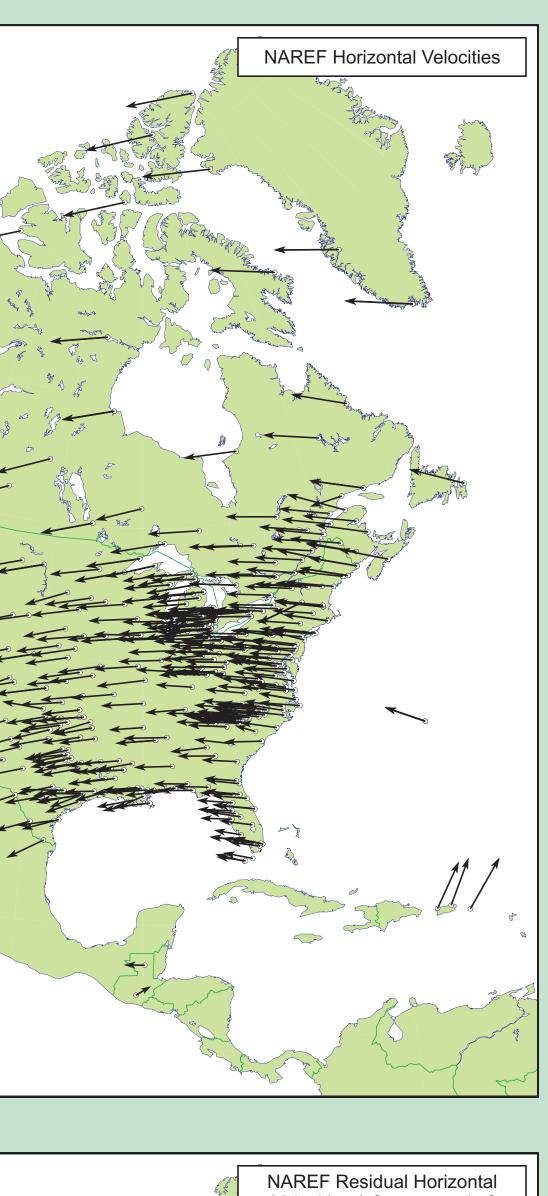


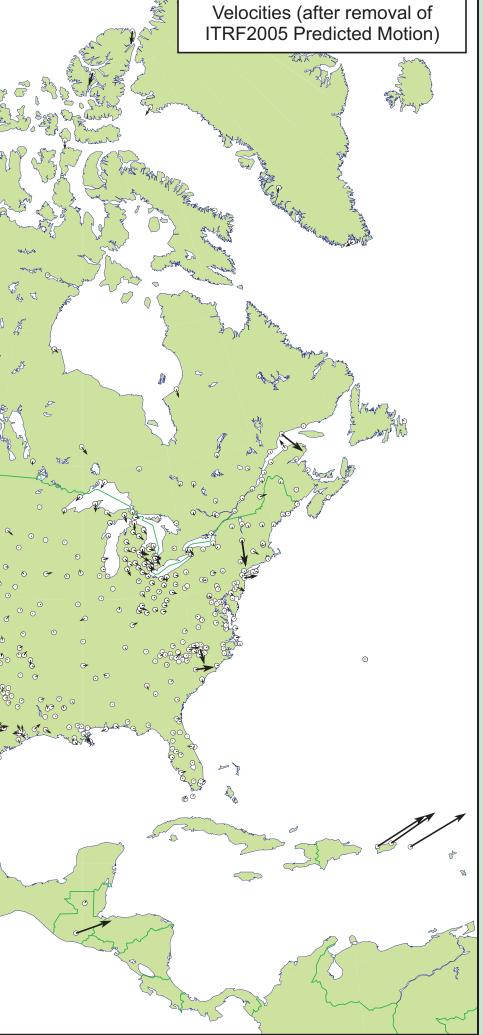


#### STATION REDUNDANCY IN NAREF WEEKLY COMBINATIONS

Stati	ons Commor	n to Multiple	NARE	F Cont	ributions	(GF	PS Week 13	399)
6 Solutions	5 Solutions	s 4 Solutions		3 Solutions		2 Solutions		1 Solutio
3	7	21		95		94		488
Stat	tions Commo	n Between N	IAREI	= Contr	ibutions	(GP	S Week 13	99)
Solution	NRCan Bernese	NRCan Gipsy	N	MIT NGS		•	РВО	NRCa PGC
NRCan Bernese	112	43		28	45		16	20
NRCan Gipsy	43	43		17	38		8	9
MIT	28	17	1	83	121		99	25
NGS	45	38	1	21	569		99	19
PBO	16	8		99	99		140	37
NRCan PGC	20	9		25	19		37	55





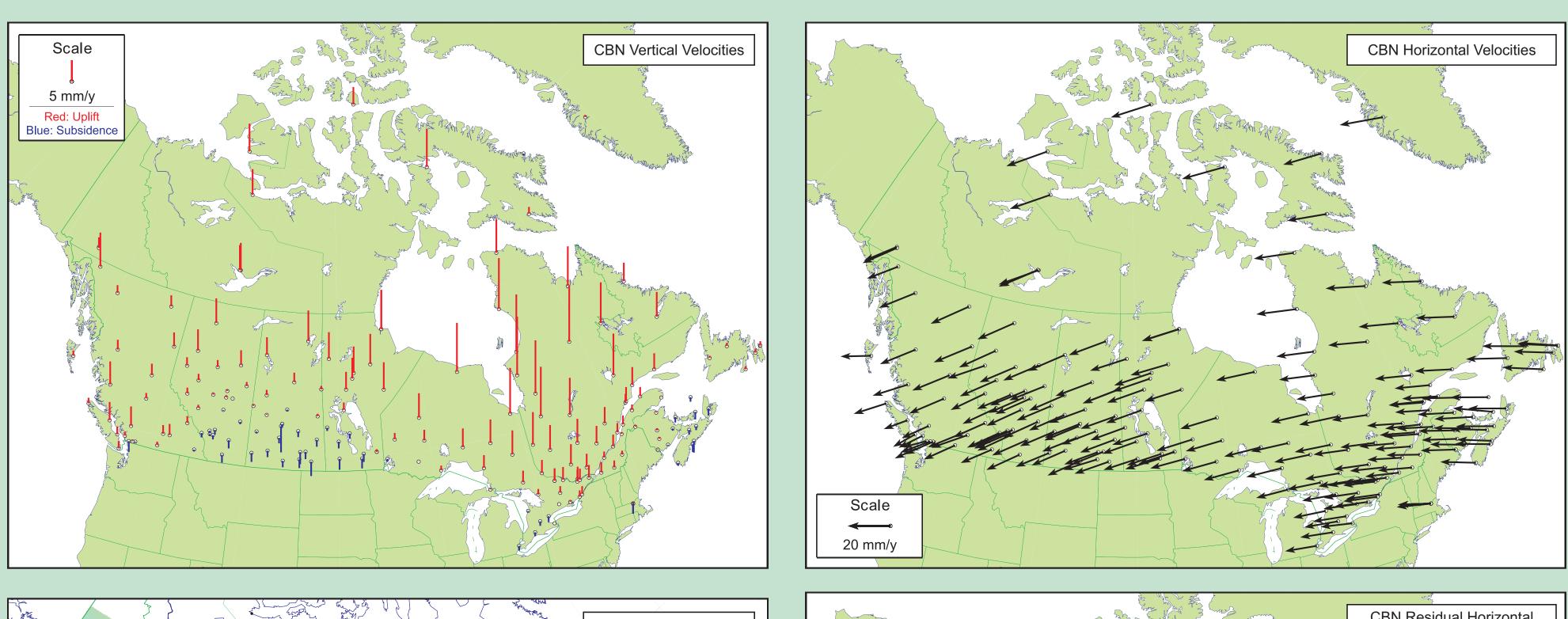


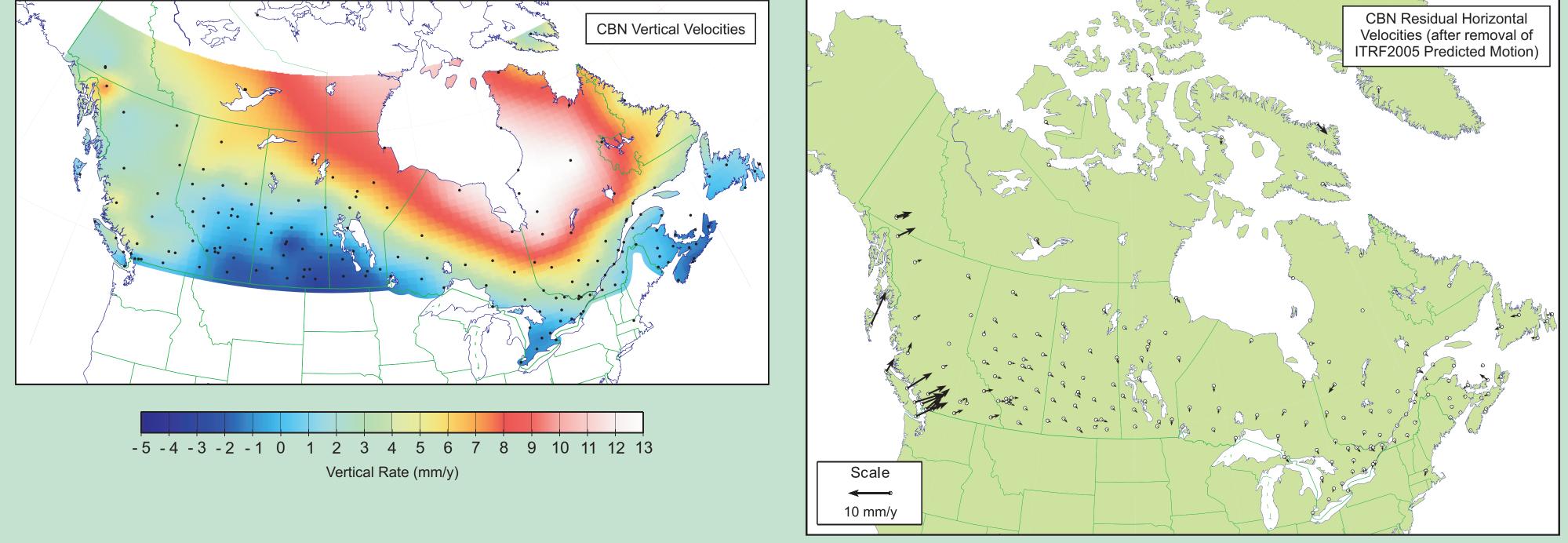
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### **CBN CUMULATIVE SOLUTION**

- STRATEGY FOR CBN CUMULATIVE SOLUTION
- Episodic campaigns processed with Bernese GPS Software Version 5
- Combining 27 individual CBN solutions (campaigns) from 1994 to 2006
- Jsing SINEX combination software: » GSD SINEX Software by Rémi Ferland (used for official IGS global combinations)
- 1) Constraints removed from individual CBN solutions
- 2) Geocentre parameters optionally added to each CBN solution (allows solutions to translate during combination)
- 3) Each CBN solution aligned to IGS realization of ITRF2005 (ITRF\_IGS05.snx) at epoch of CBN solution: » 3 translations, 3 rotations & scale change
- 4) Covariance matrix of each CBN solution scaled by WRMS of residuals from alignment
- 5) All (scaled) CBN solutions combined together (summation of normals) and site velocities estimated
- 6) Apply equivalency constraints on the estimated velocities for each site where appropriate  $(V_1 = V_2 = V_3...)$
- Re-align CBN cumulative solution to subset of the IGS ealization of ITRF2005 (IGS05) » 14 parameter alignment (3 translations, 3 rotations & scale change and their time rates of change)
- CBN cumulative solution constrained to the coordinates and velocities of IGS05

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					





### 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.

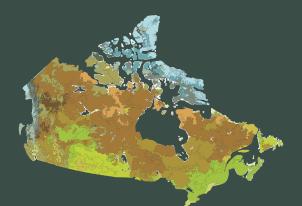
- Mike Cline and others at the U.S. National Geodetic Survey (NOAA)
- Peng Fang at the Scripps Orbit and Permanent Array Center (UCSD)
- Herb Dragert at the Geological Survey of Canada Pacific (Sidney)
- Tom Herring at the Massachusetts Institute of Technology
- Caroline Huot and Brian Donahue at the 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.

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## FUTURE WORK

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

