NAREF Analysis & ITRF2004 Densification

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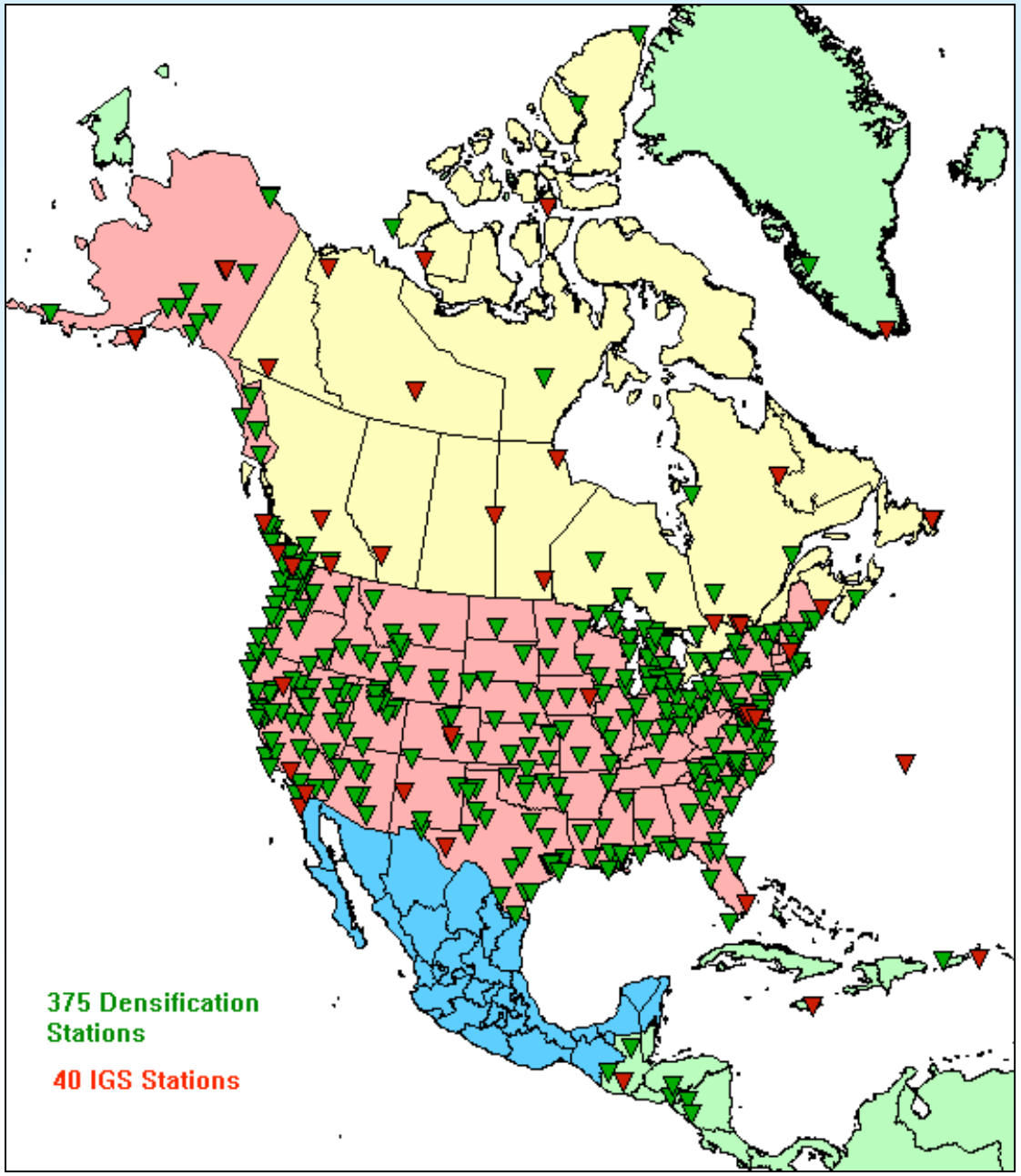
NAREF Working Group

- Densify the ITRF reference frame in NA
  - Densify IGS global network
  - Combine various regional and local networks
- Generate coordinate solutions
  - Weekly combinations of regional solutions
  - Periodic cumulative solutions with velocity estimates
- Provide transformations
  - Between NAD83 and ITRF/IGS

NAREF Combined Densification Network

Reginal Solns Included:

GSD Bernese
GSD GIPSY
NGS PAGES
PGC Bernese
SIO GAMIT



NAREF Combinations

- Combine weekly regional solutions in ITRF/IGS
  - Regular weekly coordinate solutions beginning 2001.0
  - 4 week latency (2 weeks after precise orbits available)
  - Currently 550+ stations (nearly 50 in Canada incl. IGS)
  - Regional solutions based on fixed IGS (precise) orbits
- Combine weekly solutions for cumulative solution
  - Estimation of velocities
  - First one nearly complete
  - Planning to update semi-annually in beginning, then annually
- Software
  - Using Remi Ferland's SINEX Software (used for IGS)
  - Planning to verify with CATREF (used for ITRF) & GLOBK?

ITRF2004 Densification

- Large regional GPS solutions to be considered as densifications of global ITRF2004 solution
  - Want time-integrated solutions (coordinates+velocities)
  - Based on combination of weekly regional solutions
  - As many permanent GPS stations as possible
  - More than 3 years of observations
- NAREF contribution will be based on combination of:
  - NAREF cumulative solution (only about 3 years of obs)
  - NGS cumulative solution of "best" CORS (since 1994)
    To be discussed by Sella & Snay

Preliminary
NAREF Cumulative Solution

- Combined all weekly solutions since 2001.0

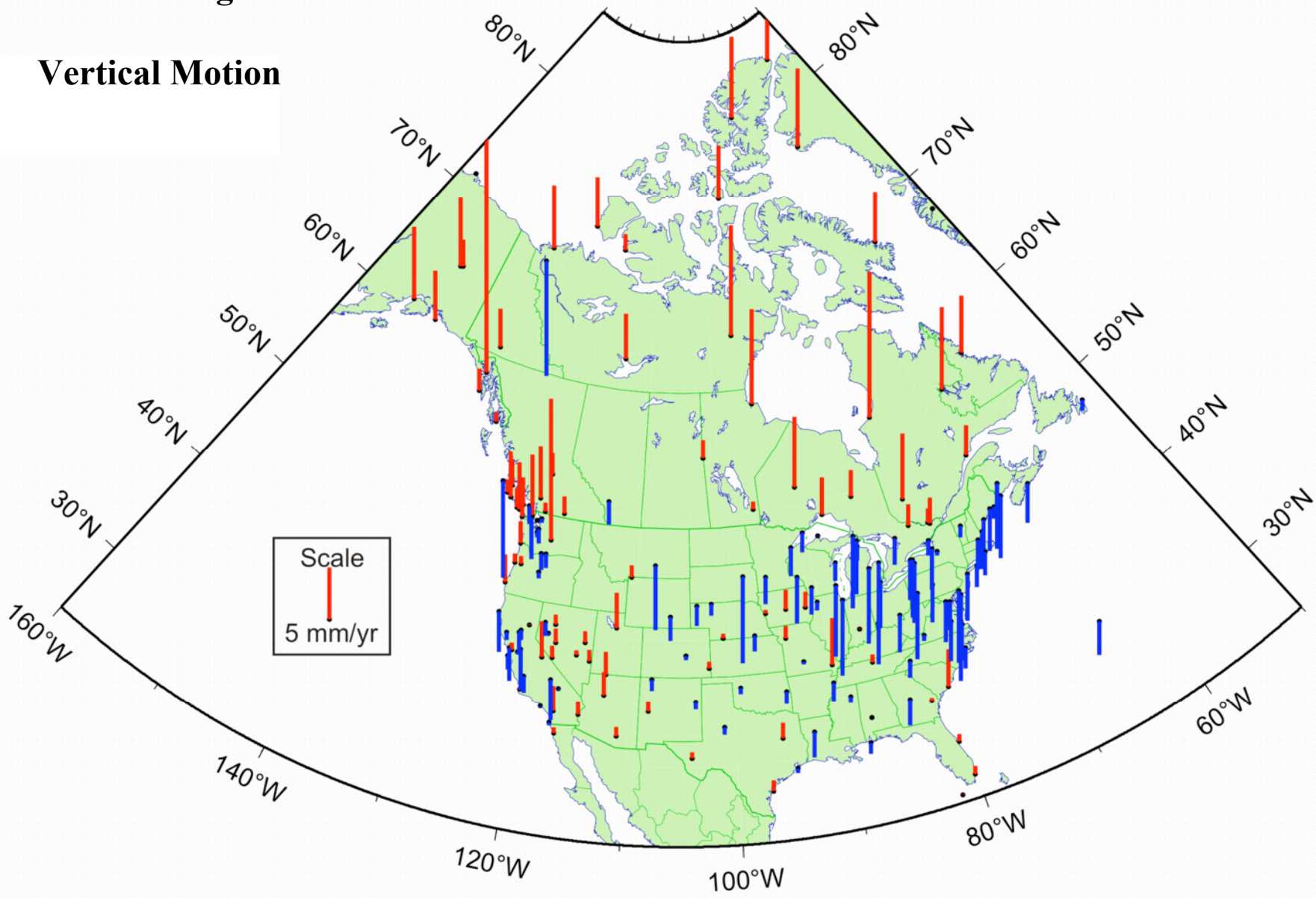
  Canadian Sites

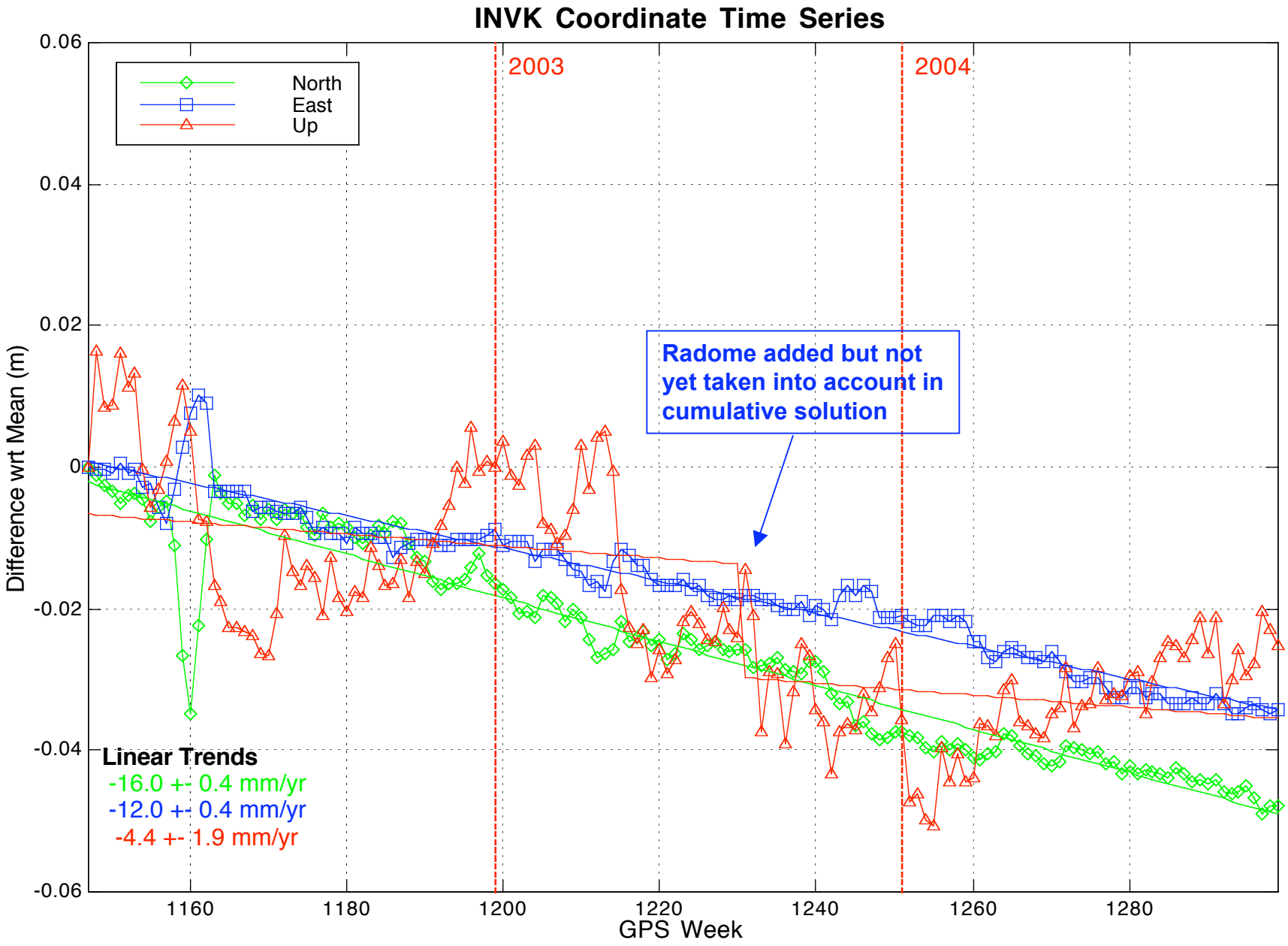
1 stations	4.8 years	10 stations	2-2.5 years
9 stations	3-3.3 years	1 stations	>0.5 years

- Procedure
  - Weekly solutions already aligned/combined with IGS weekly
  - Transformed IGS97 solutions to IGb00
  - Removed weekly constraints
  - Combined all weeks together (accumulated normals)
  - Integrated to IGS05P01 cumulative solution
    1) Aligned to IGS (14 parameters)
    2) Combined with IGS (accumulated normals)
  - Gross outliers removed & combination repeated

NAREF Aligned to IGS05P01

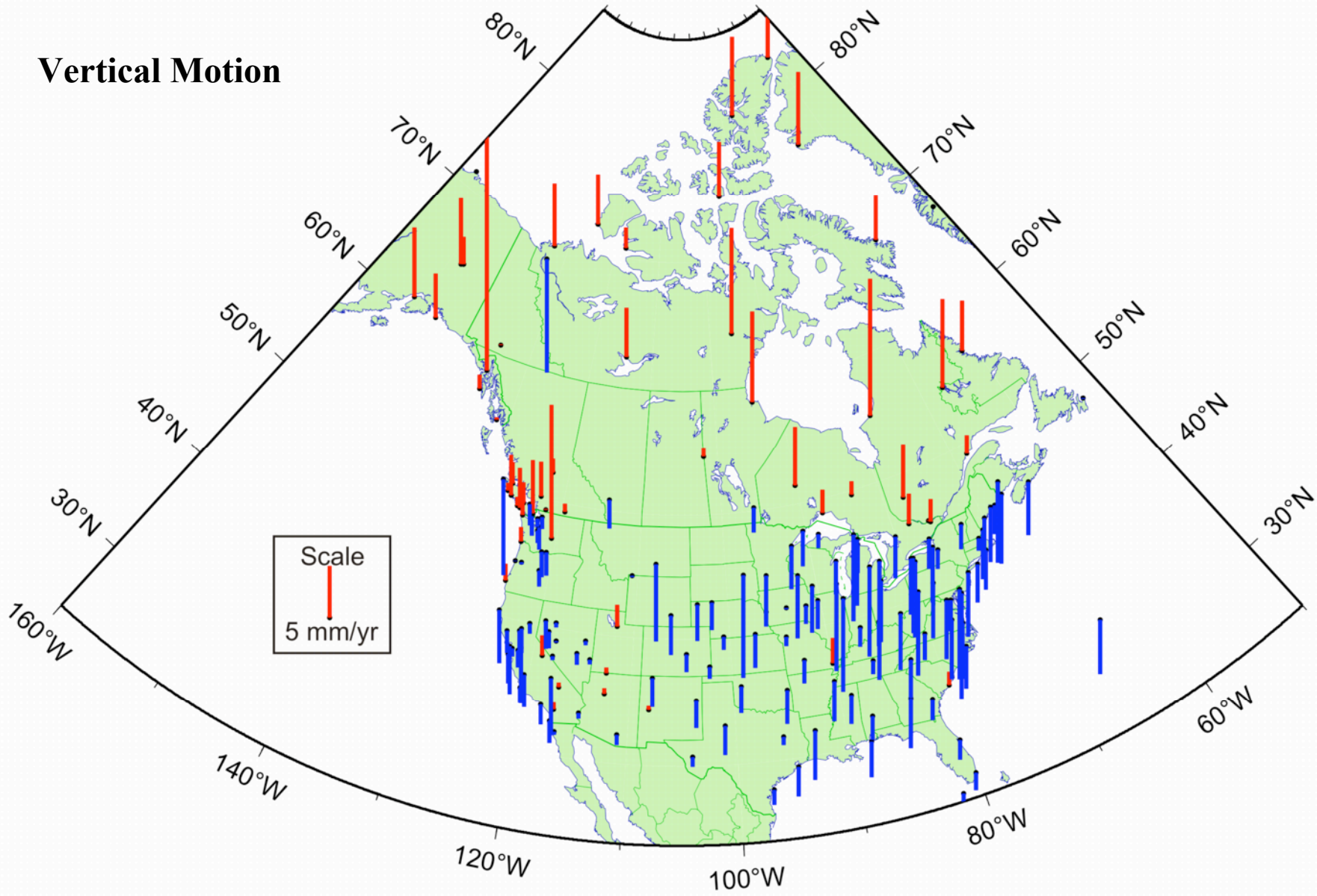
Vertical Motion




INVK Coordinate Time Series
North
East
Up
2003
2004
Radome added but not yet taken into account in cumulative solution
Linear Trends
-16.0 +- 0.4 mm/yr
-12.0 +- 0.4 mm/yr
-4.4 +- 1.9 mm/yr
Difference wrt Mean (m)
GPS Week
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
1160
1180
1200
1220
1240
1260
1280

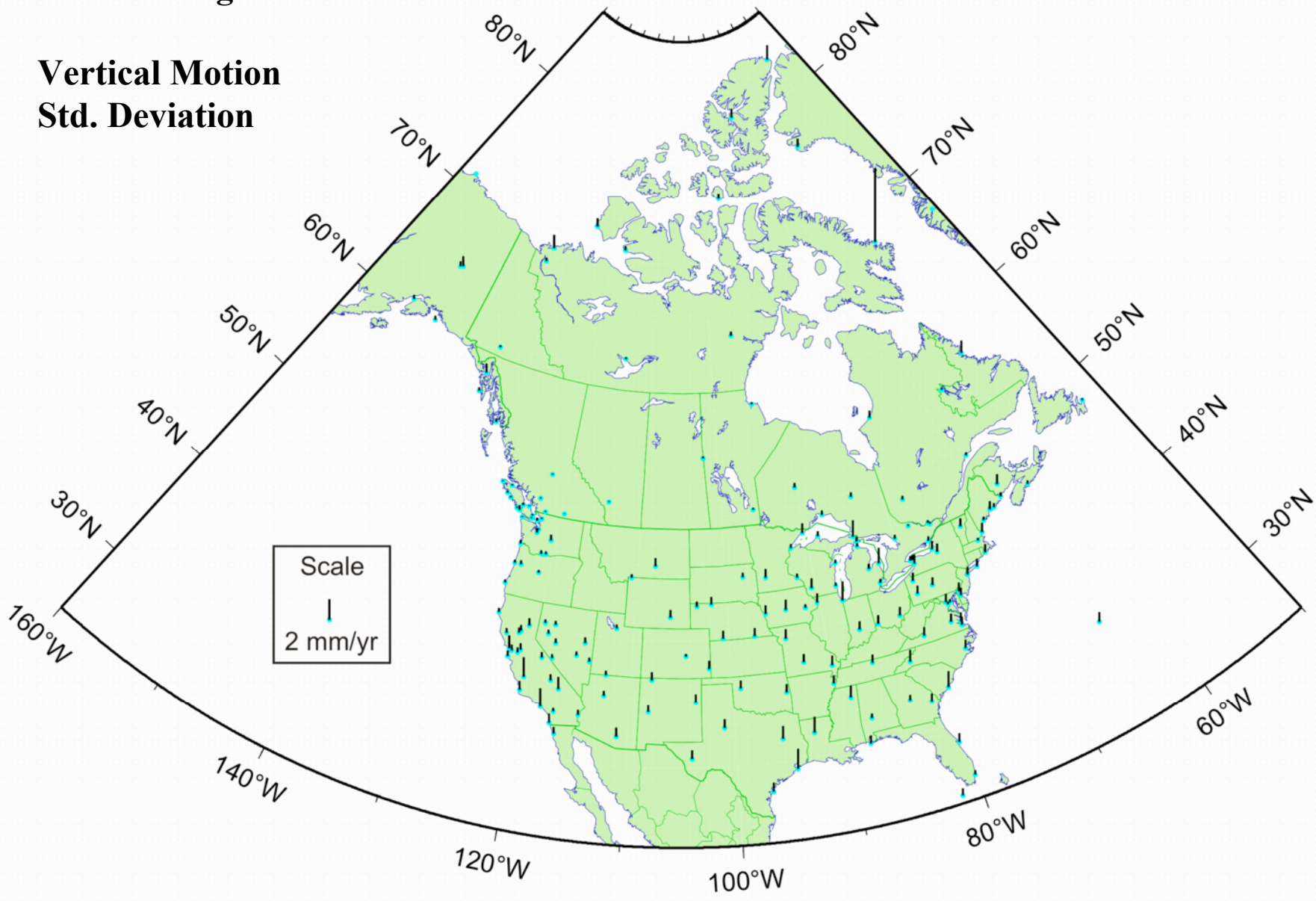
NAREF + IGS05P01

Vertical Motion



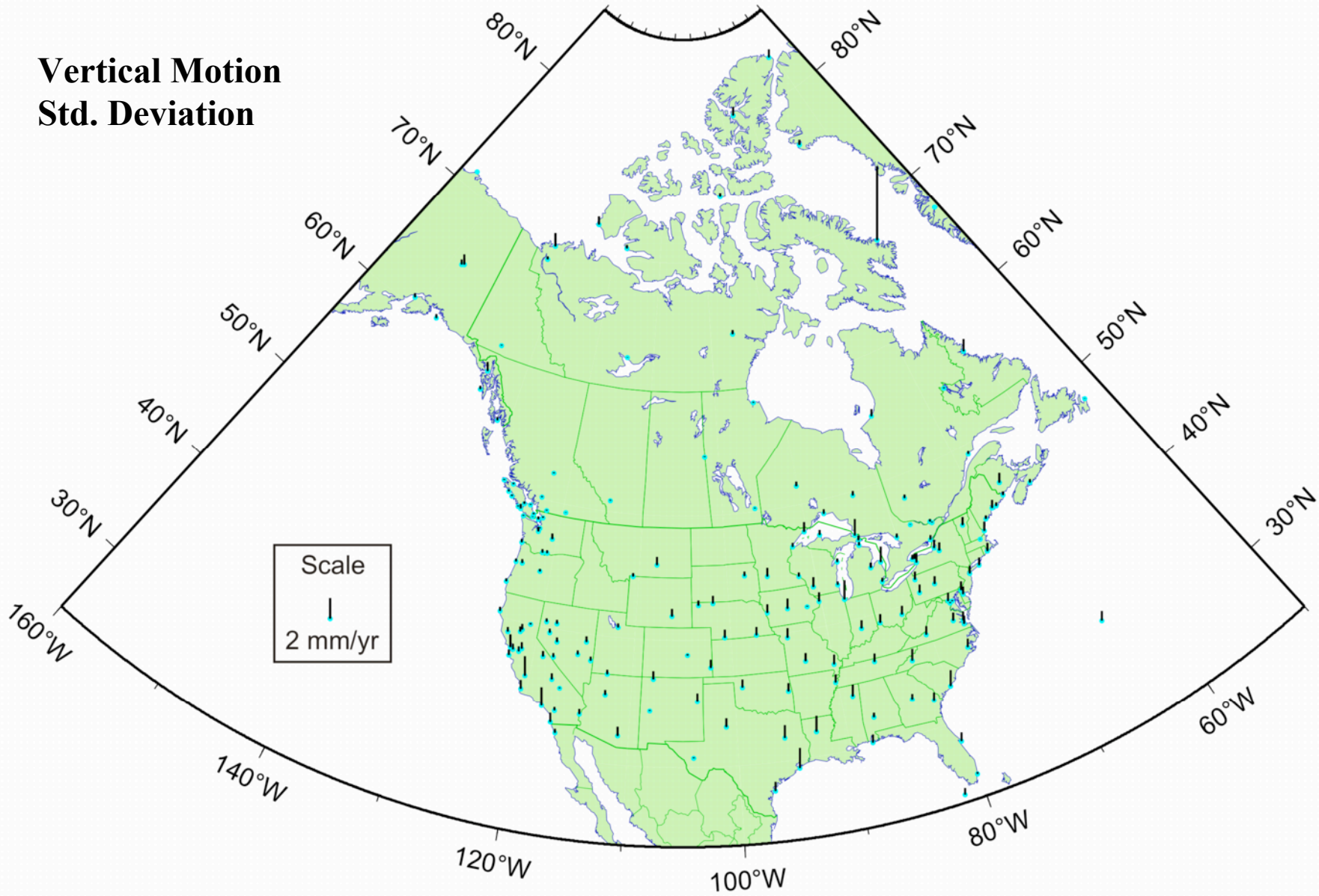
NAREF Aligned to IGS05P01

Vertical Motion
Std. Deviation



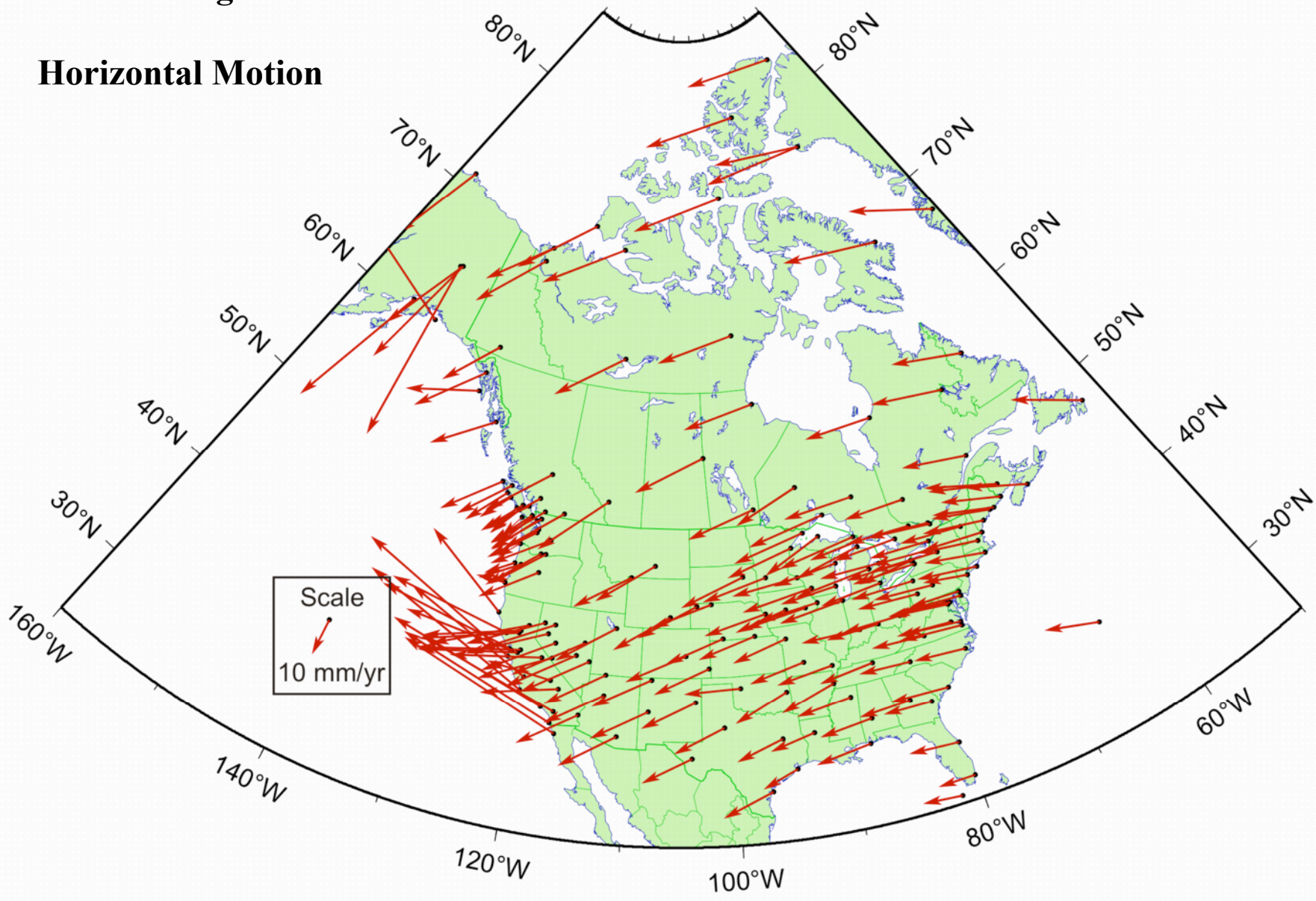
NAREF + IGS05P01

Vertical Motion
Std. Deviation



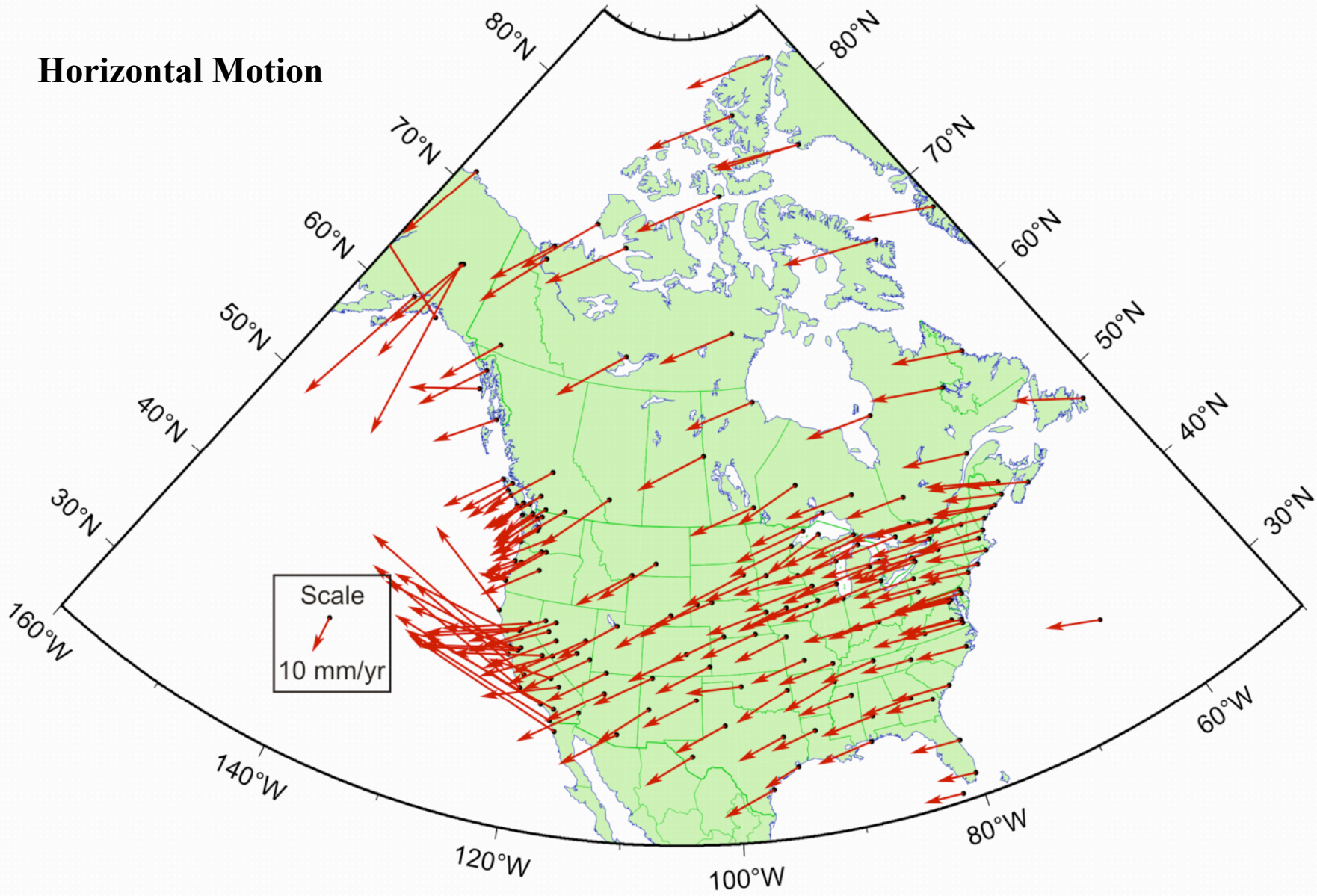
NAREF Aligned to IGS05P01

Horizontal Motion



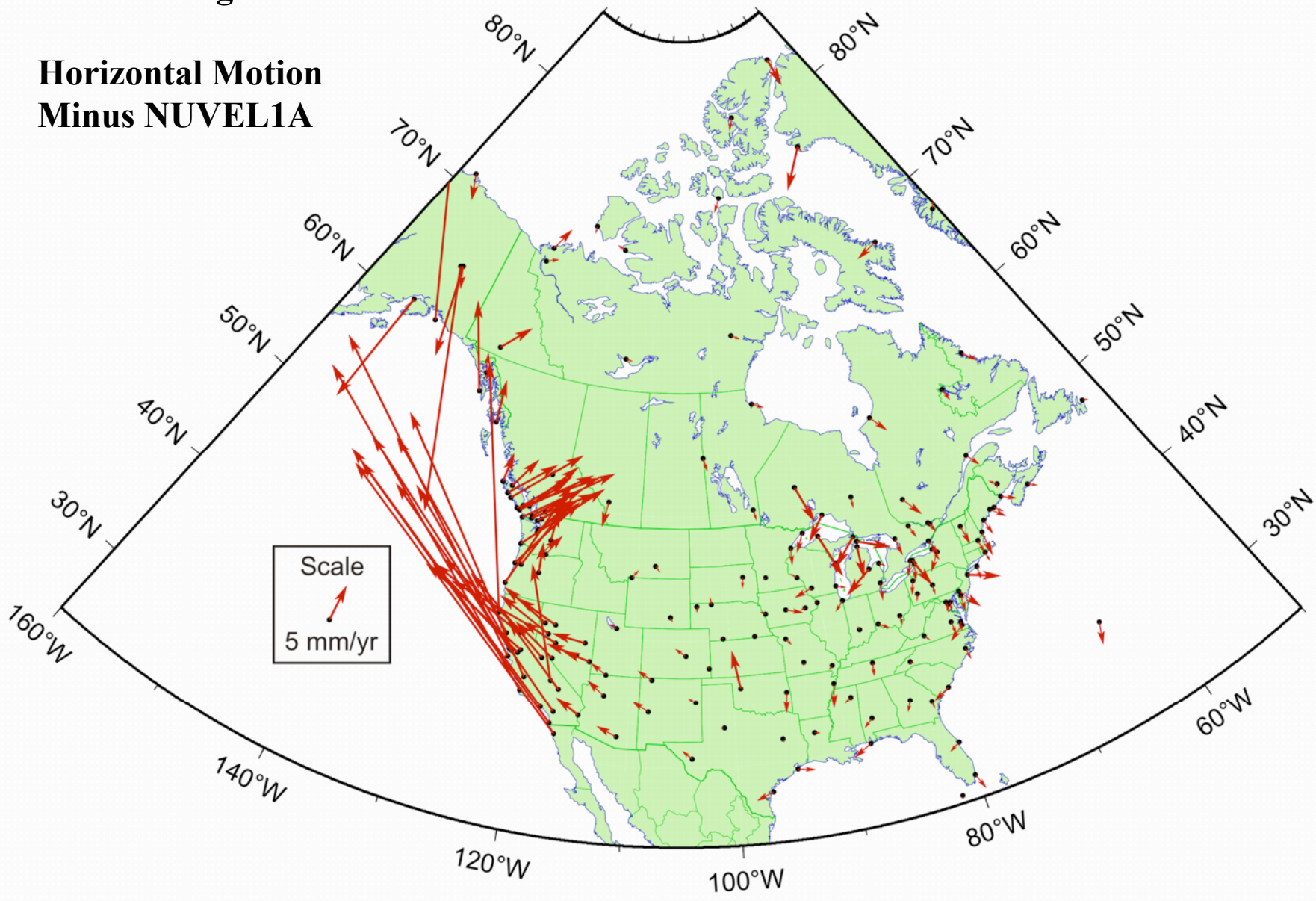
NAREF + IGS05P01

Horizontal Motion



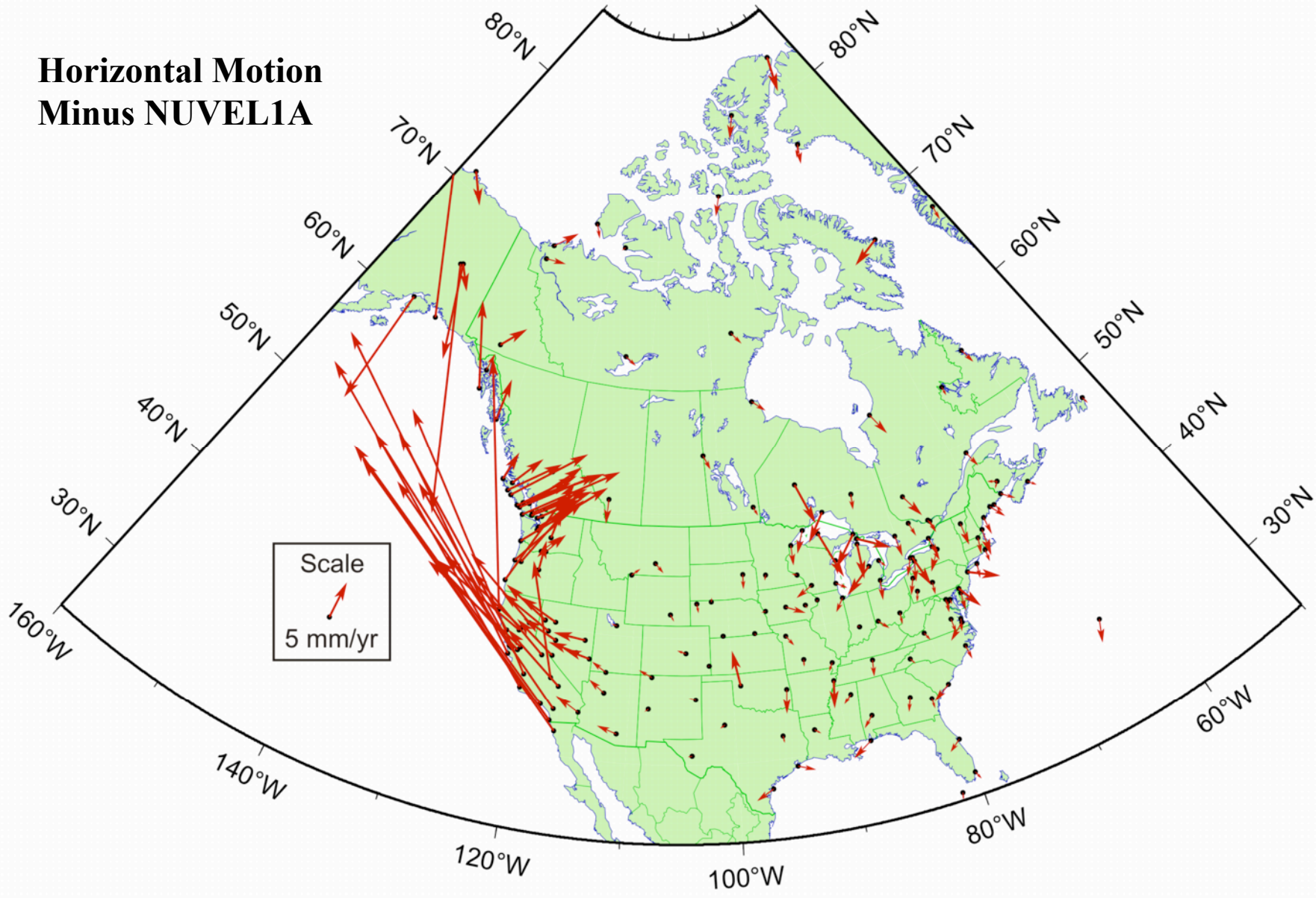
NAREF Aligned to IGS05P01

Horizontal Motion
Minus NUVEL1A



NAREF + IGS05P01

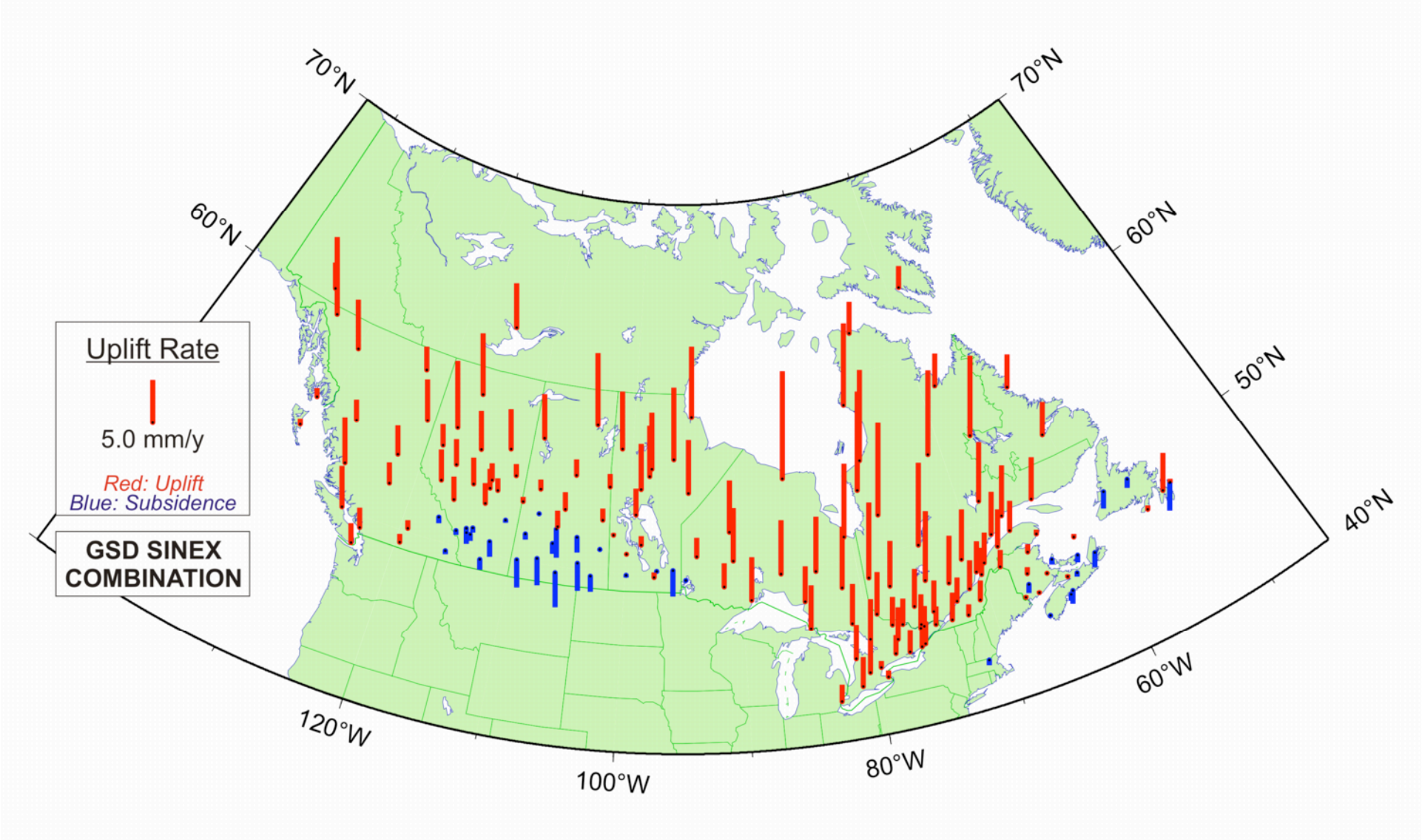
Horizontal Motion
Minus NUVEL1A



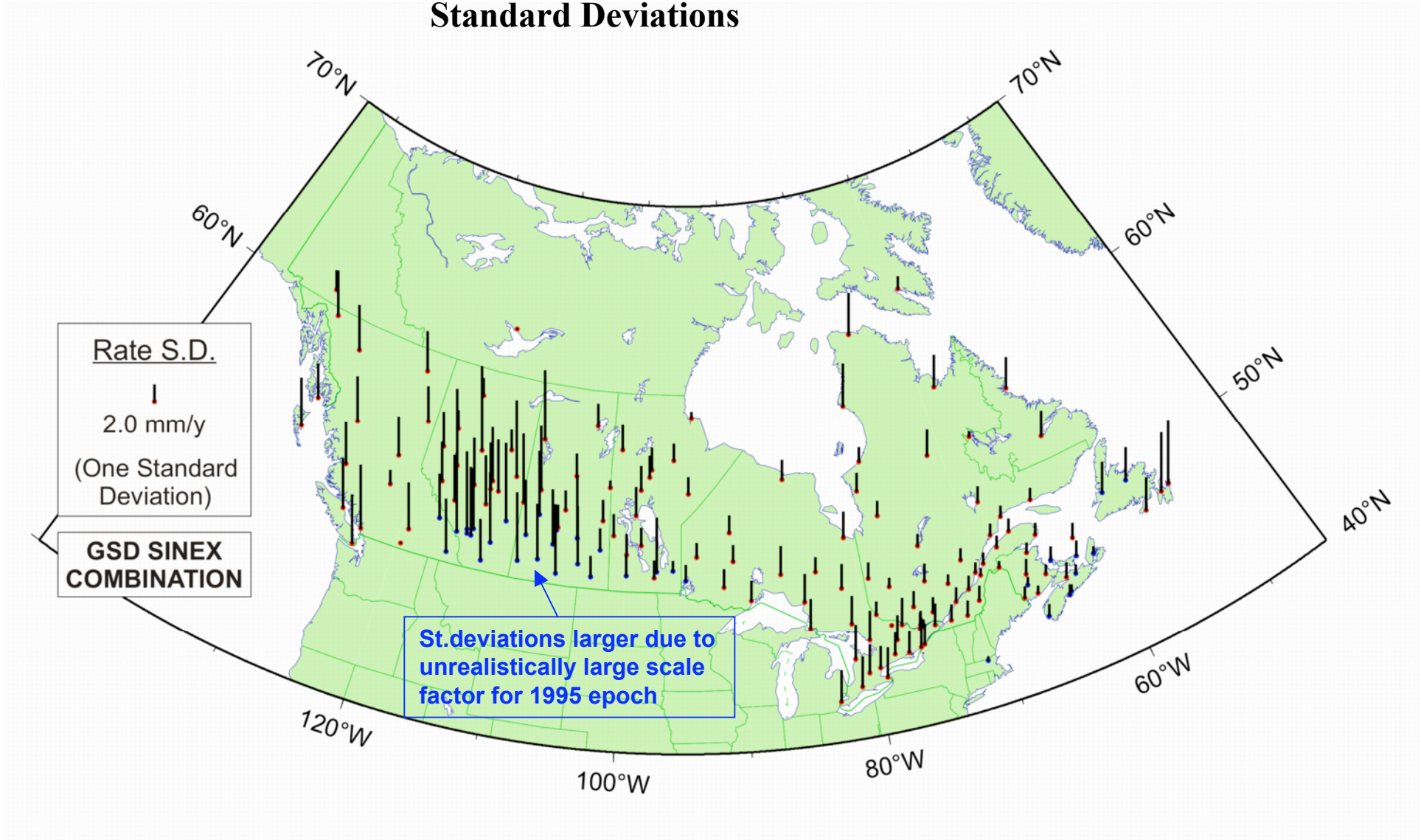
Canadian Base Network (CBN) Analysis

- 1st epoch (CBN 3.1): 1994-1997,1999
  - Weighted all IGS stations to ITRF96 at 1997.0 >> NAD83
- 2nd epoch (CBN 4.0): 2001(E)-2002(W)
  - Weighted DRAO (Penticton) to ITRF2000 at 2002.0 > NAD83
- Differences due to
  - ITRF97 vs. ITRF2000
  - Crustal motion minus NNR-NUVEL1A (included in NAD83)
  - Error in NUVEL1A plate motion model (1-2 mm/y)?
  - Monument motion

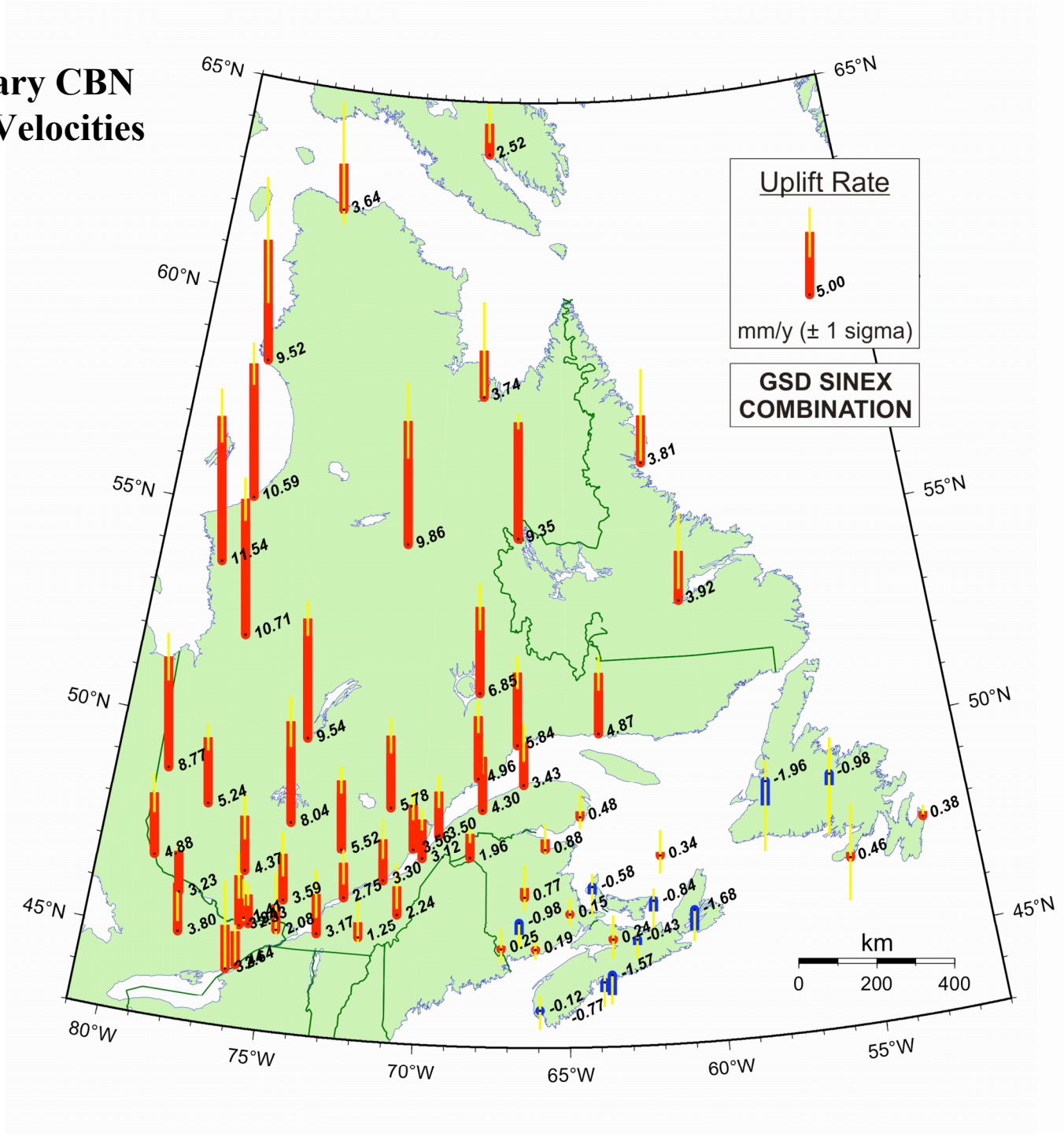
Preliminary CBN Vertical Velocities

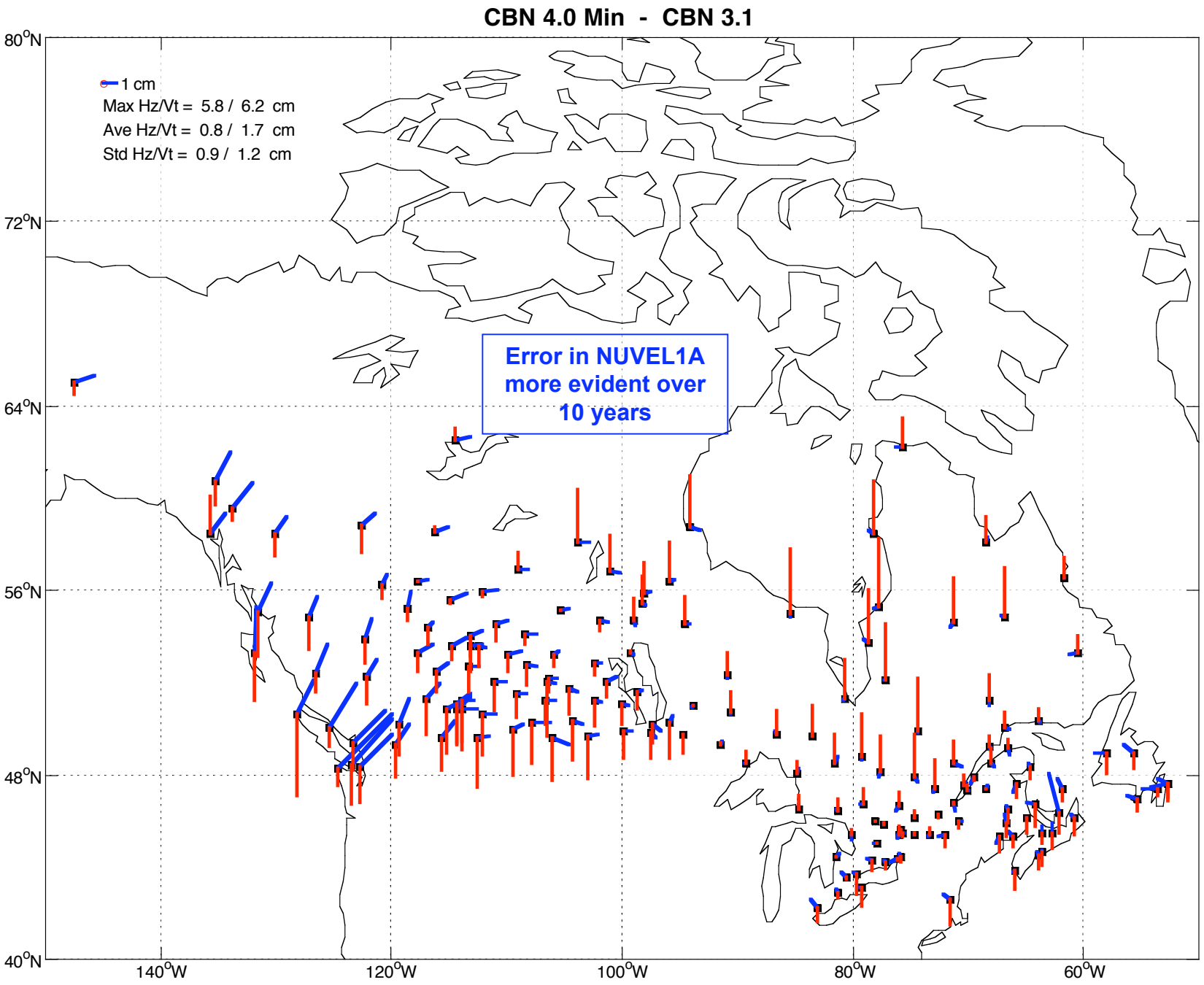


Preliminary CBN Vertical Velocity Standard Deviations



Preliminary CBN Vertical Velocities



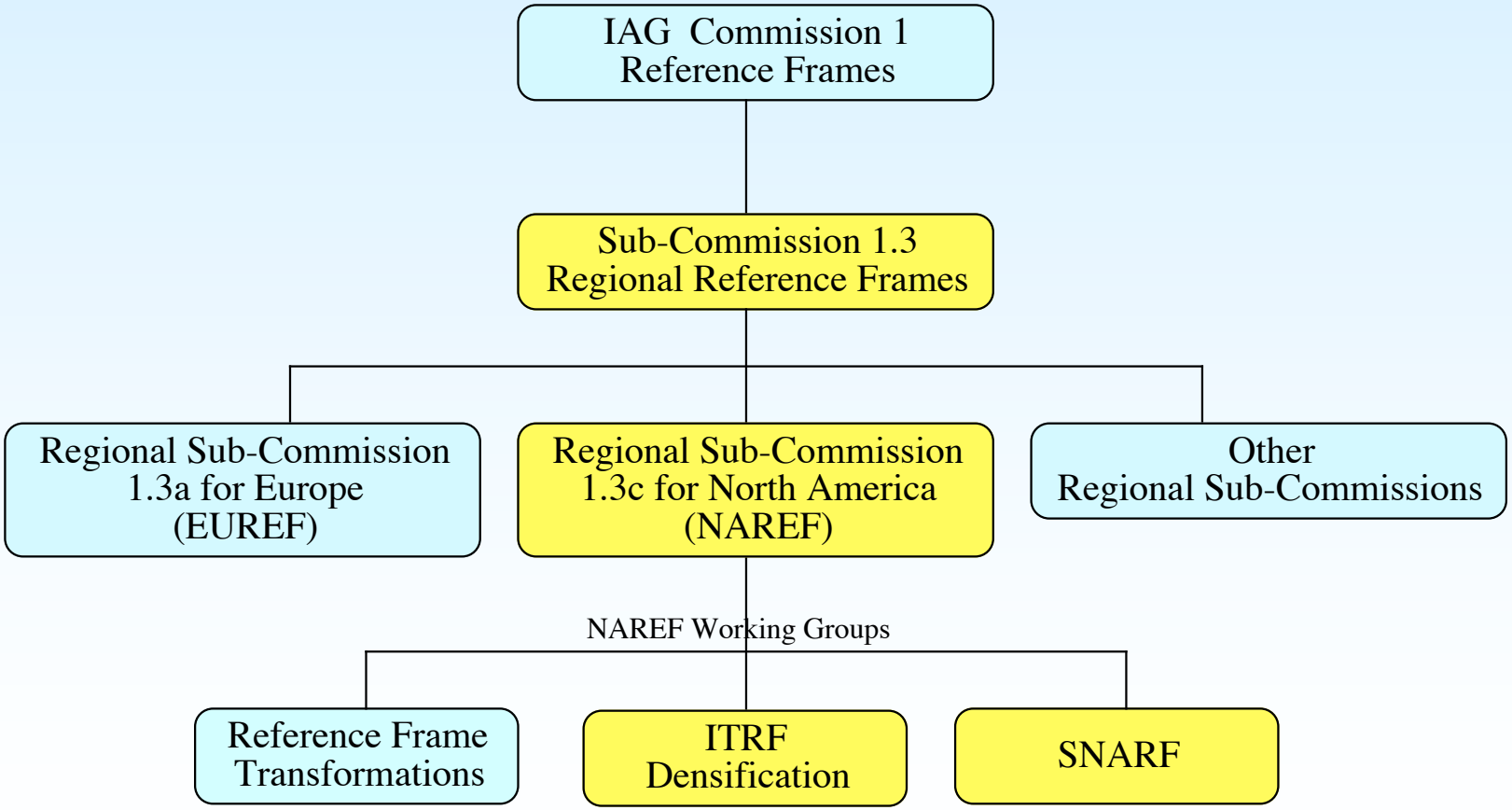

CBN 4.0 Min - CBN 3.1
1 cm
Max Hz/Vt = 5.8 / 6.2 cm
Ave Hz/Vt = 0.8 / 1.7 cm
Std Hz/Vt = 0.9 / 1.2 cm
Error in NUVEL1A more evident over 10 years
80°N
72°N
64°N
56°N
48°N
40°N
140°W
120°W
100°W
80°W
60°W

End

Objective

To provide international focus and cooperation for issues involving the horizontal, vertical, and three-dimensional geodetic control networks of North America, Central America, the Caribbean and Greenland (Denmark).

Structure


IAG Commission 1
Reference Frames
Sub-Commission 1.3
Regional Reference Frames
Regional Sub-Commission
1.3a for Europe
(EUREF)
Regional Sub-Commission
1.3c for North America
(NAREF)
Other
Regional Sub-Commissions
NAREF Working Groups
Reference Frame
Transformations
ITRF
Densification
SNARF

Standards

- Site selection
  - Dual frequency data, 24 hr/day, 10° elevation mask angle
  - Continuous operations (min. 5 days/week)
  - Stable geodetic-quality monumentation (or classify?)
  - Complete & up to date station logs
- Overlapping networks/solutions desired
  - Stations in multiple solutions
  - Allows for outlier detection & relative weighting
  - Average out software “noise”

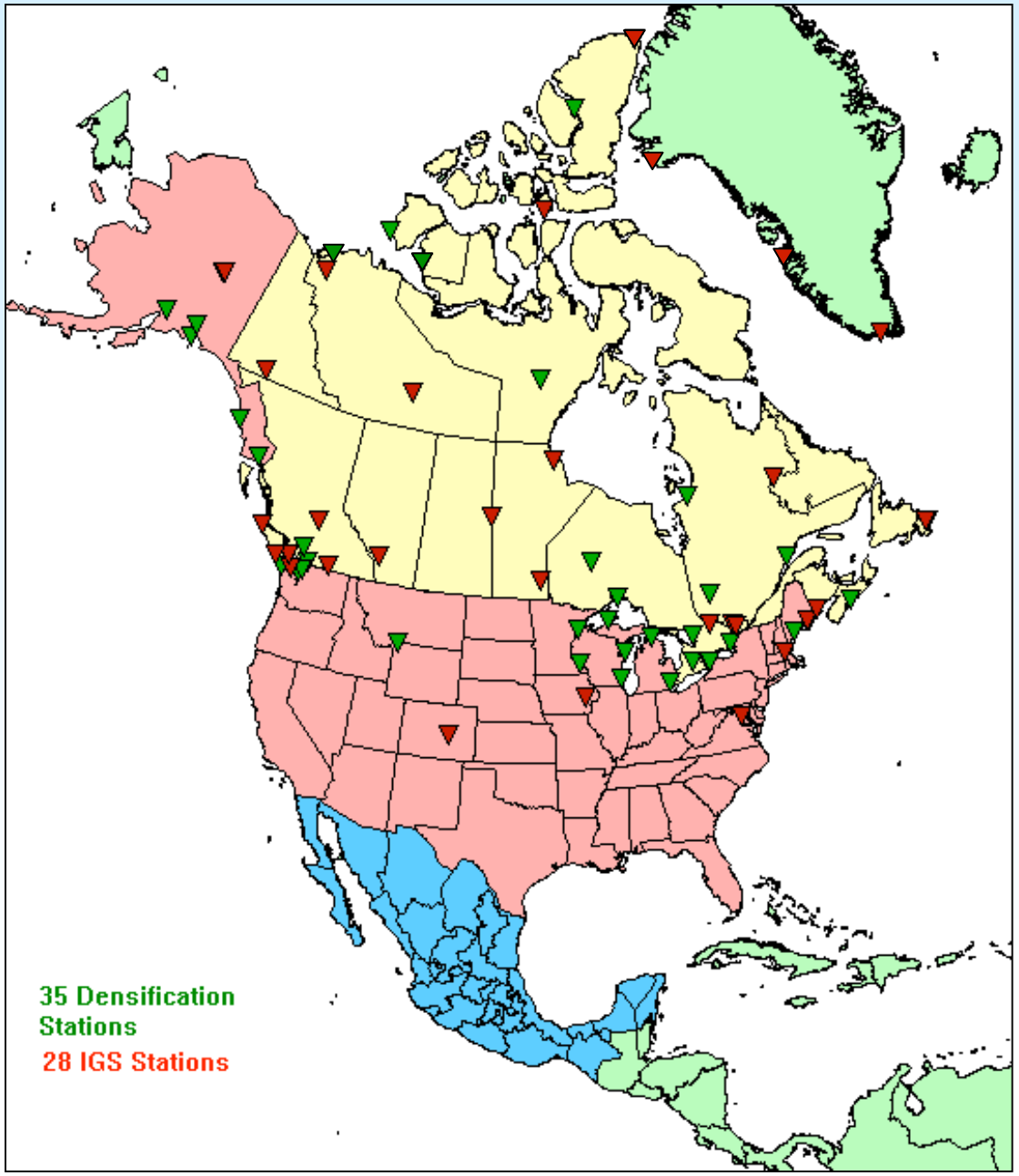
Standards (con't)

- Regional processing
  - Follow IGS & EUREF standards as much as possible
  - Fix IGS orbits & EOPs (preferably "final")
  - Different software essential for quality control checks
- Problems
  - Regional centers operate independently with different objectives
  - Difficult to impose standards
  - Take what we can get

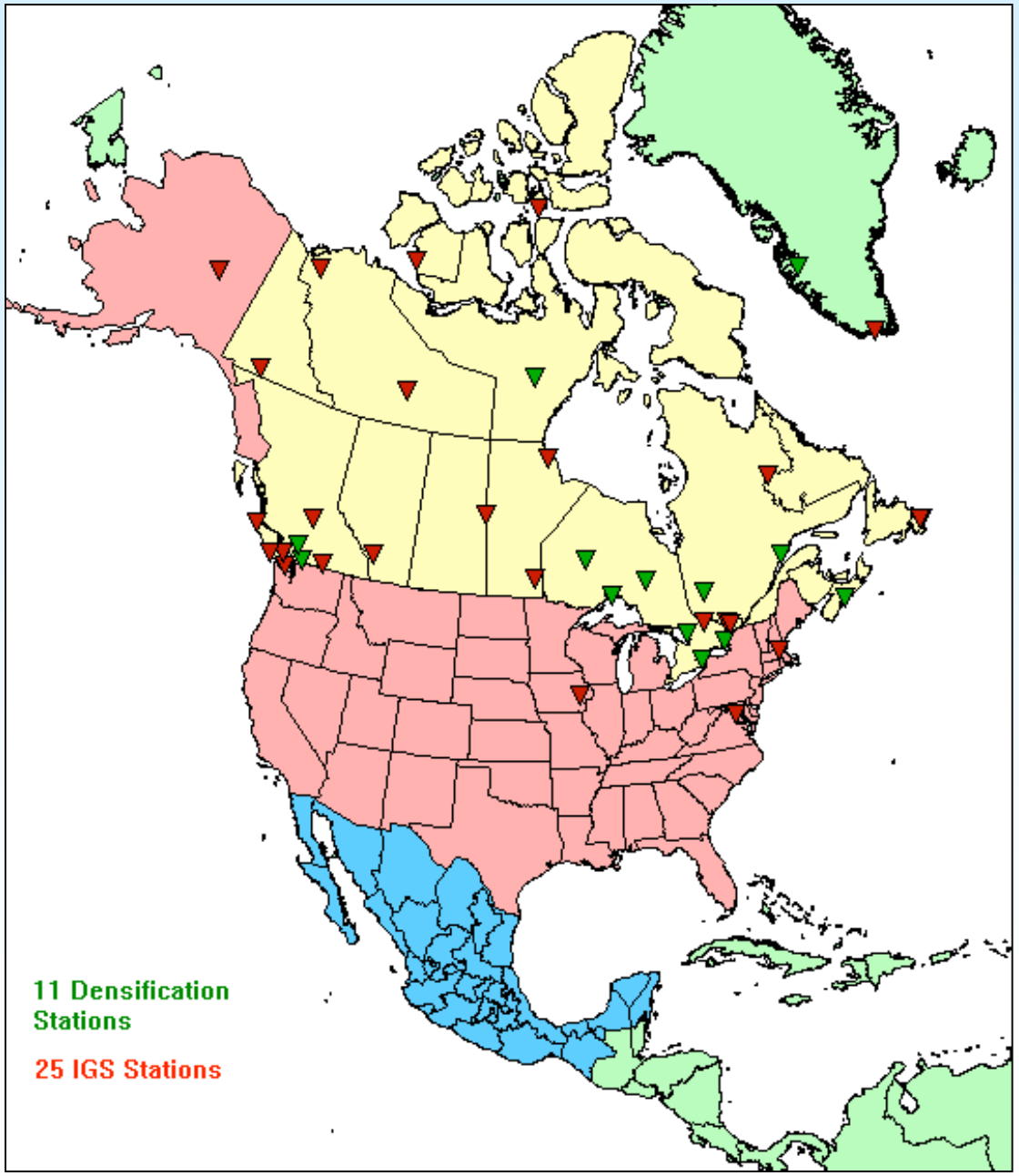
Regional Solutions

- Since 2001.0
  - ✓ GSD Bernese regional network
  - ✓ GSD GIPSY regional network
  - ✓ PGC Western Canada Deformation Array (Bernese)
  - ✓ CORS network (PAGES)
  - ✓ SIO PBO Solution (GAMIT)
- Plan to include more Canadian stations
  - ➢ New 64-bit computer to handle more stations
  - ➢ Add BCACS, Quebec DGPS, others ??

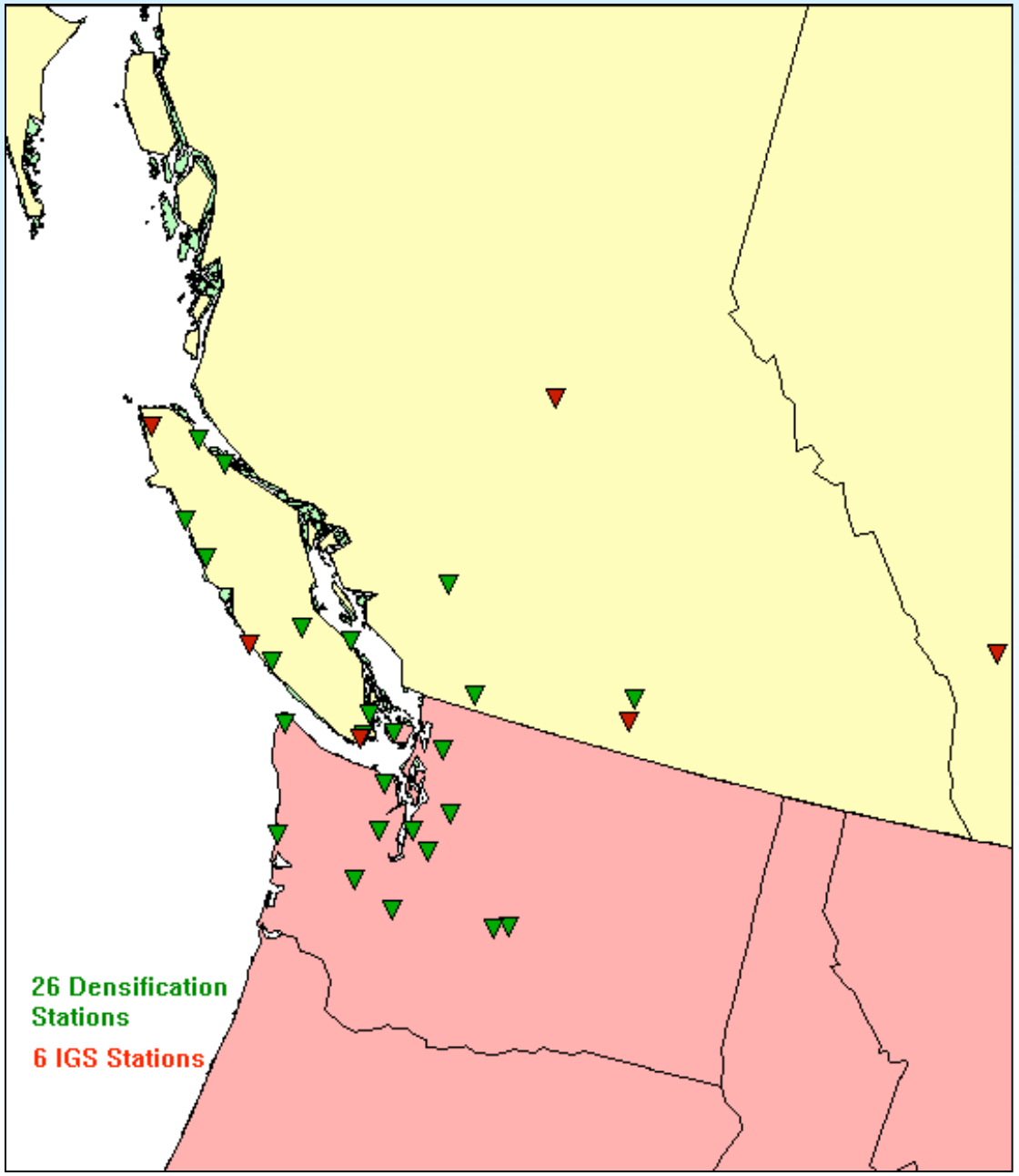
GSD Bernese Regional Network (GSB)



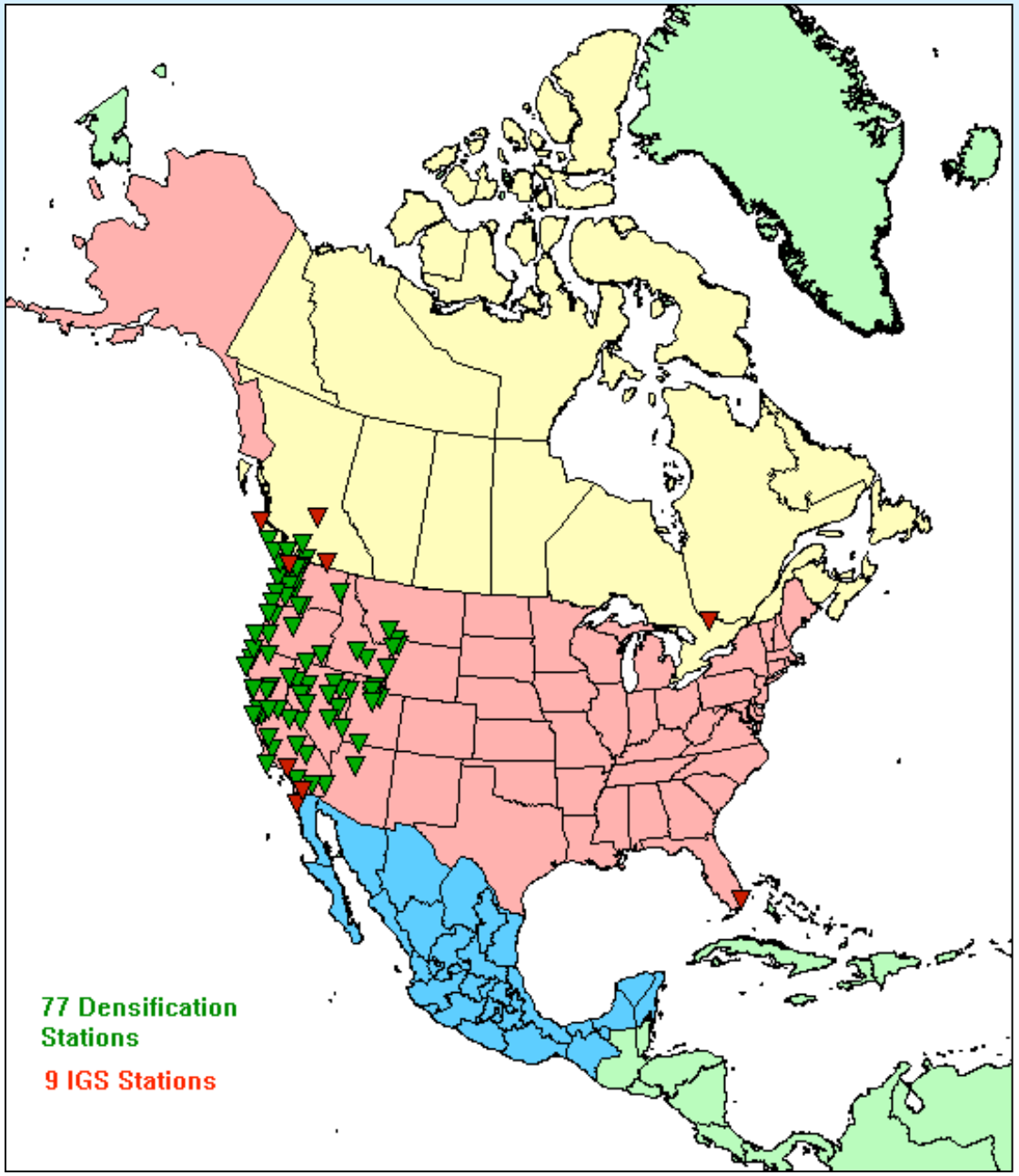
GSD GIPSY Regional Network (GSG)



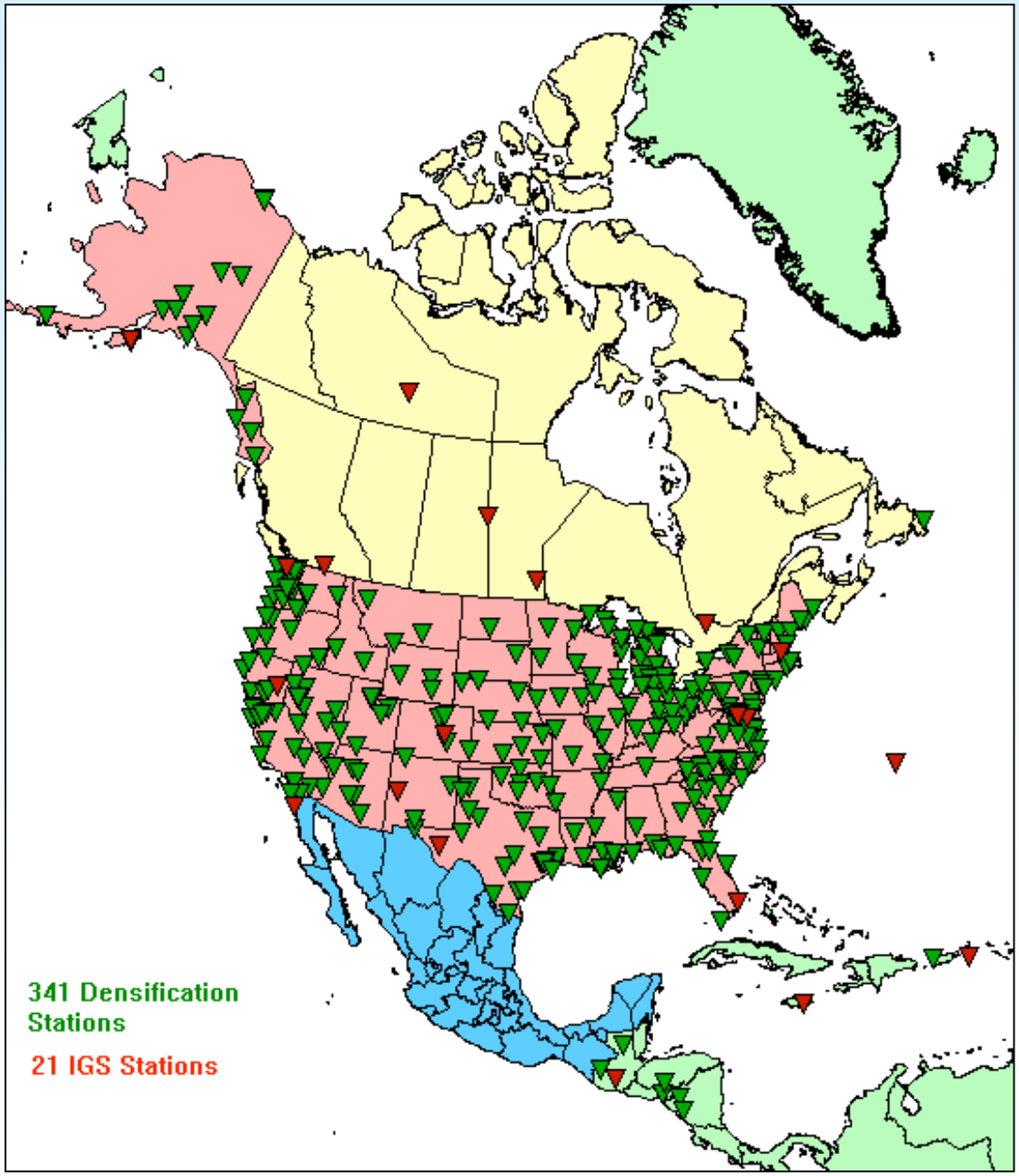
PGC Western Canada Deformation Array (WCDA)



SIO Plate Boundary Observatory (PBO)



NGS CORS Network (NGS)



Combination Method

Alignment of Each Regional Solution

1. A priori datum constraints removed
2. Aligned to IGS weekly solution (3 translations, 3 rotations, scale change)
3. Covariance matrix scaled by WRMS of residuals
4. Residuals tested for outliers (outliers removed –> iterate #2-4)

Combination of Regional Solutions

5. Summation of normals of (scaled) regional solutions
6. Aligned to IGS weekly solution (3 translations., 3 rotations, scale change)
7. Covariance matrix scaled by WRMS of residuals
8. Residuals tested for outliers (outliers removed –> iterate #2-8)
9. Integrated into IGS weekly solution using IGS coordinates & covariance matrix for common stations as weighted pseudo-observations

Problems

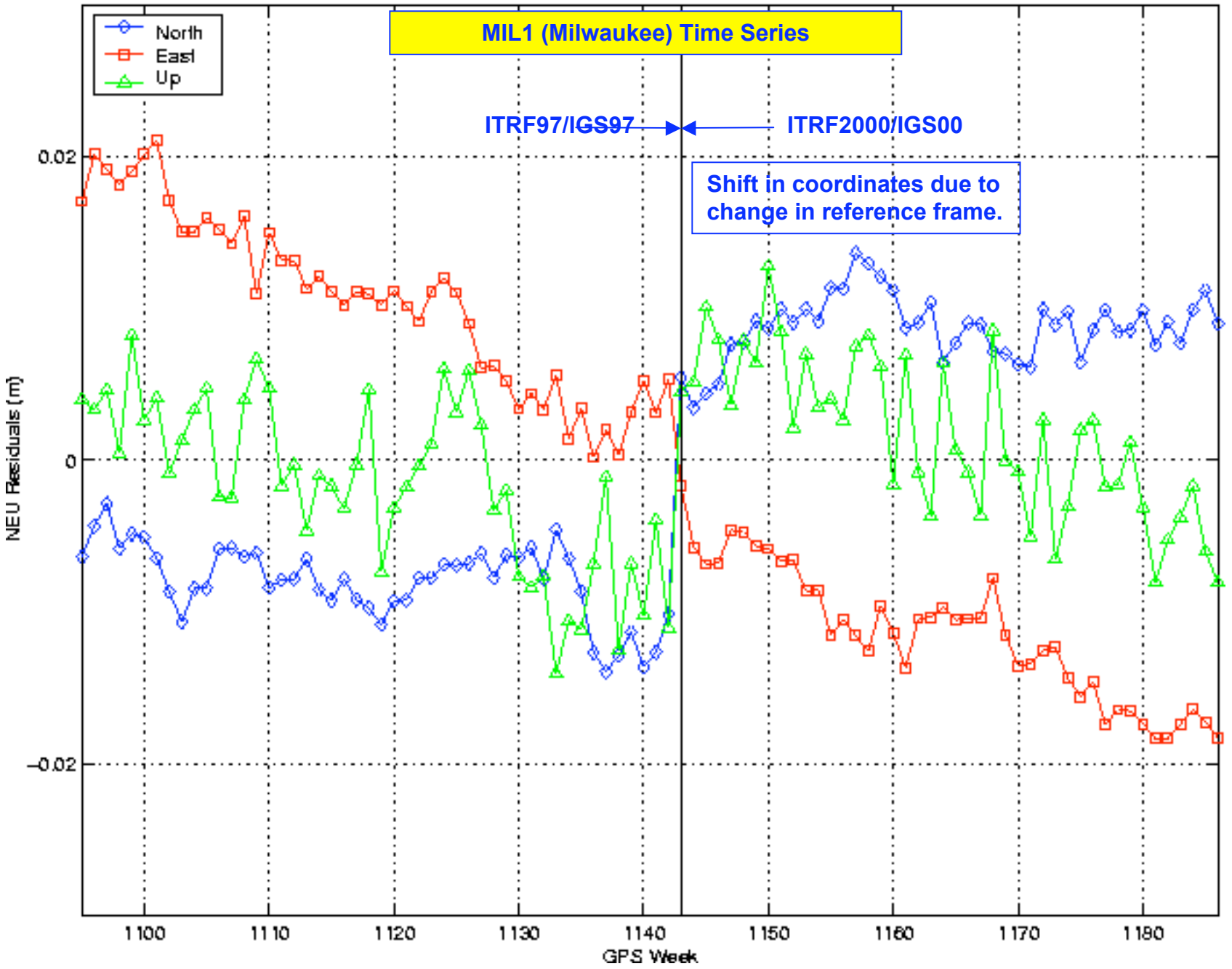
- Meta-data (site logs)
  - Often incomplete and sometimes contradictory
  - Not always updated on a timely basis
  - Verification an on-going & time consuming task
- Uneven redundancy
  - Some stations in many regional solutions
  - But many stations (eg, CORS) in only one solution (no checks on quality)
  - Causes uneven weighting of stations

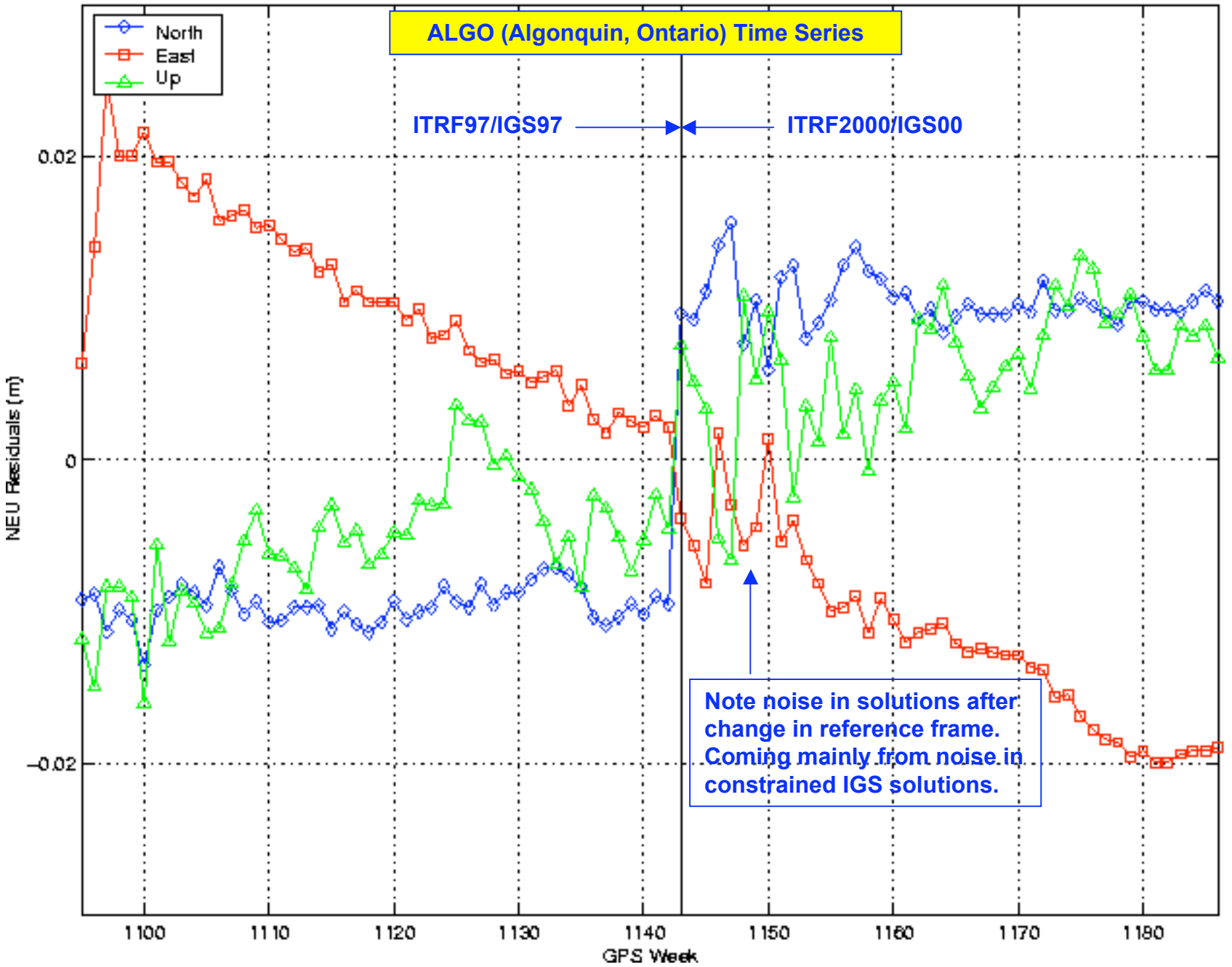
Problems (con't)

- Identification of outlier station solutions
  - Difficult and time consuming
  - Need a reliable automated procedure
- Water loading around Great Lakes
  - Affects Great Lakes CORS network
  - 2 foot range in water levels between Spring & Fall
  - 4? foot variations between decades (climate variations)
  - Secular variations due to post-glacial rebound?
  - Loading models possible?

Problems (con't)

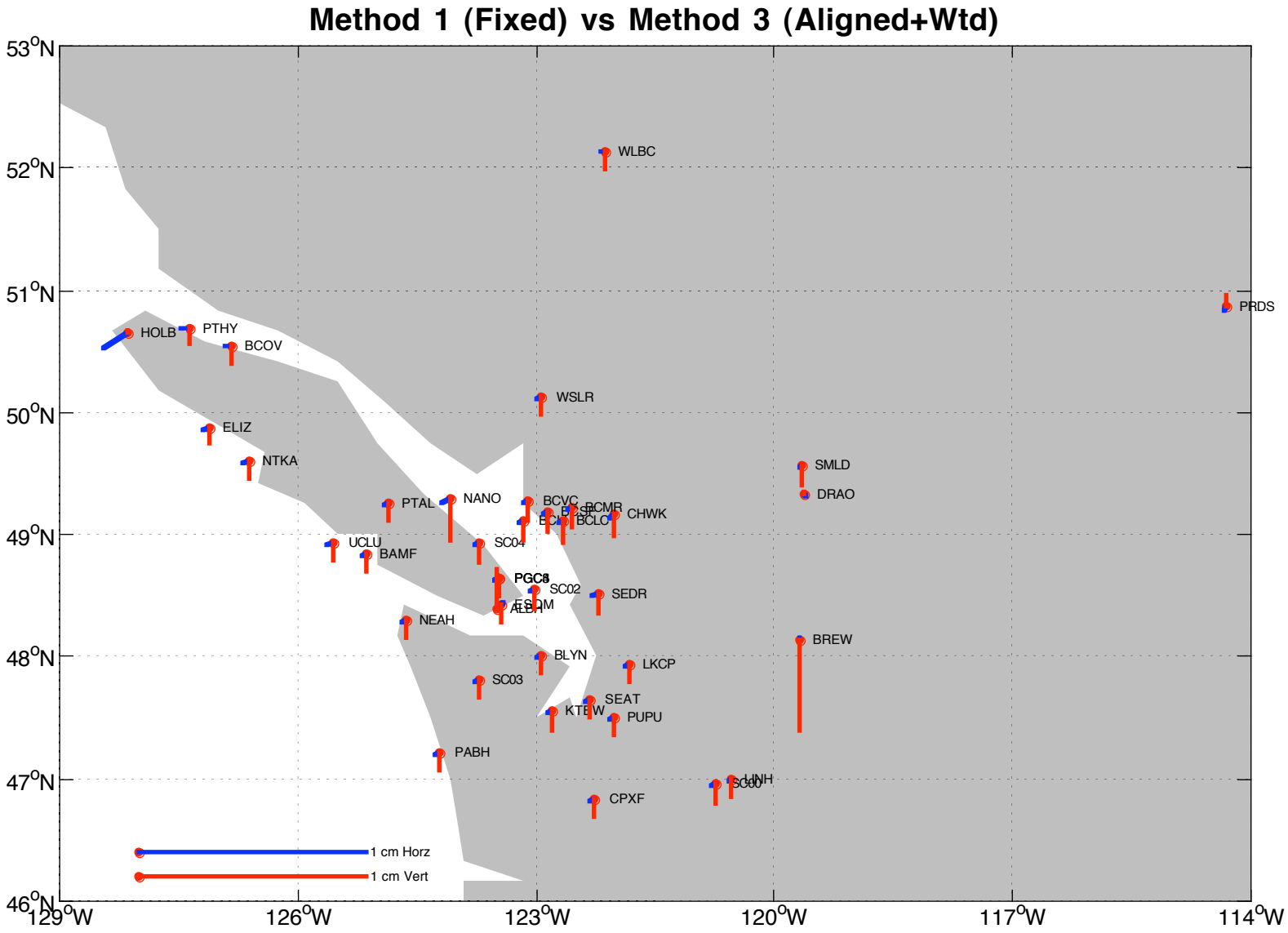
- Changes in reference frames
  - Confusing to users if not explicitly identified (see plot)
  - No reference frame ID block in SINEX format
  - Obtained elevated noise levels at some IGS stations after change from IGS97 to IGS00 (see plot)

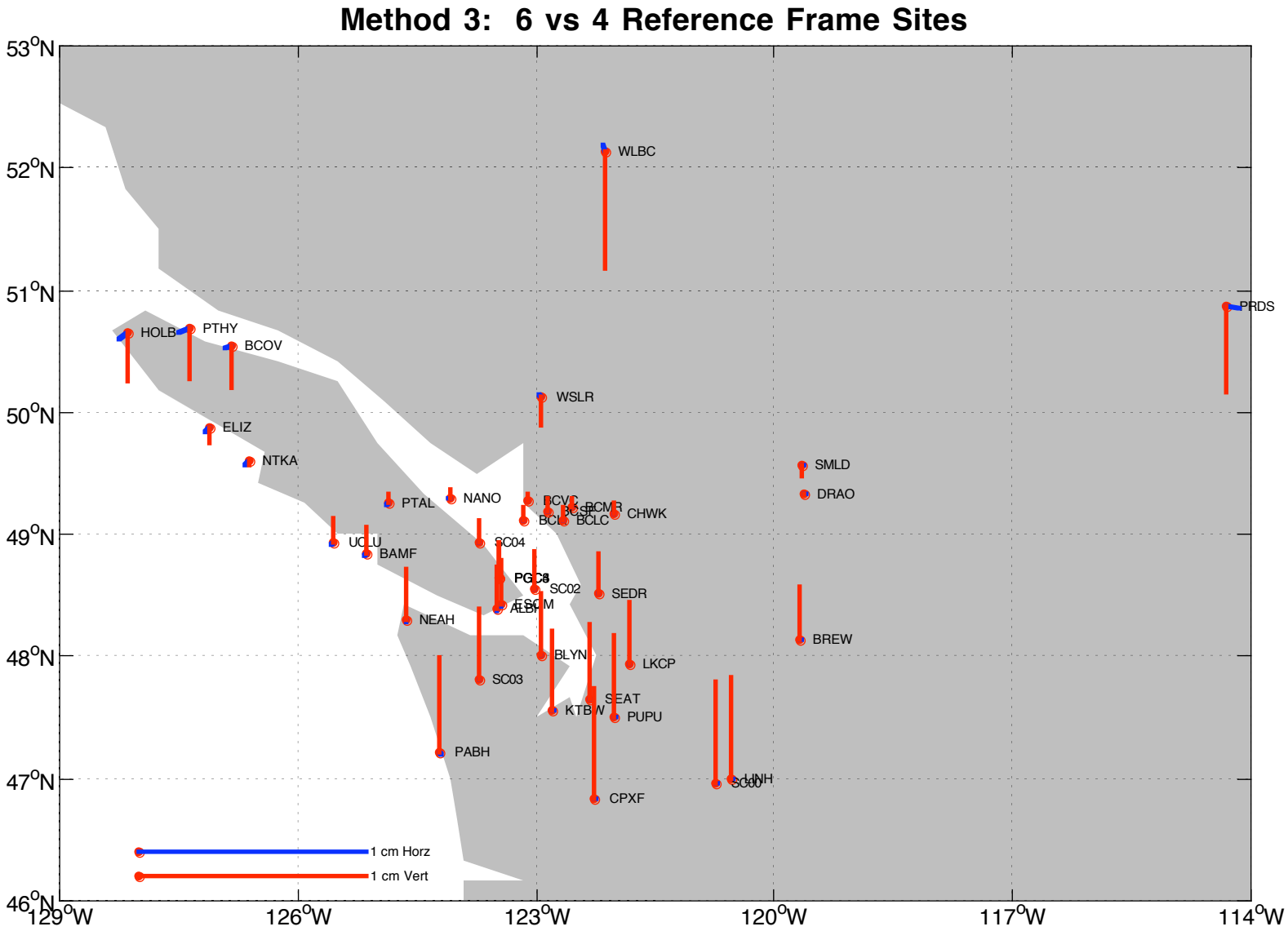

MIL1 (Milwaukee) Time Series
North
East
Up
ITRF97/IGS97
ITRF2000/IGS00
Shift in coordinates due to change in reference frame.
0.02
0
-0.02
NEU Residuals (m)
1100
1110
1120
1130
1140
1150
1160
1170
1180
GPS Week


ALGO (Algonquin, Ontario) Time Series
North
East
Up
ITRF97/IGS97
ITRF2000/IGS00
0.02
0
-0.02
NEU Residuals (m)
1100
1110
1120
1130
1140
1150
1160
1170
1180
GPS Week
Note noise in solutions after change in reference frame. Coming mainly from noise in constrained IGS solutions.

Access to Reference Frames

- Three basic methods of integrating survey into a reference frame:
- Constrain to reference frame stations
  - Fix reference frame stations (least desirable)
  - Weight reference frame stations (use full cov matrix)
- Align/transform to reference frame stations using:
  - Known transformation parameters, or
  - Estimated best fitting parameters
- Combined alignment and weighted constraint
- Results depend on:
  - Method used (see plots)
  - Number of ref. Frame stations used to align or constrain (see plots)


Method 1 (Fixed) vs Method 3 (Aligned+Wtd)
53°N
52°N
51°N
50°N
49°N
48°N
47°N
46°N
129°W
126°W
123°W
120°W
117°W
114°W
WLBC
PRDS
HOLB
PTHY
BCOV
WSLR
ELIZ
NTKA
SMLD
DRAO
PTAL
NANO
BCVC
BCMR
CHWK
BCLO
UCLU
BAMF
SC04
PGC8
SC02
SEDR
ALBH
NEAH
BREW
BLYN
LKCP
SC03
SEAT
KTEW
PUPU
PABH
SC00
CPXF
1 cm Horz
1 cm Vert


Method 3: 6 vs 4 Reference Frame Sites
53°N
52°N
51°N
50°N
49°N
48°N
47°N
46°N
129°W
126°W
123°W
120°W
117°W
114°W
WLBC
PRDS
HOLB
PTHY
BCOV
WSLR
ELIZ
NTKA
SMLD
DRAO
PTAL
NANO
CHWK
UCLU
BAMF
SC04
SC02
SEDR
NEAH
BREW
BLYN
LKCP
SC03
SEAT
KTBW
PUPU
PABH
CPXF
1 cm Horz
1 cm Vert

Proposed Contributions to SNARF

- Vehicle for
  - Providing & maintaining official SNARF products
  - Wider use under auspices of IAG & national geodetic agencies
- Combined regional solutions in SNARF
- Transformations between SNARF and
  - NAD83
  - ITRF/IGS