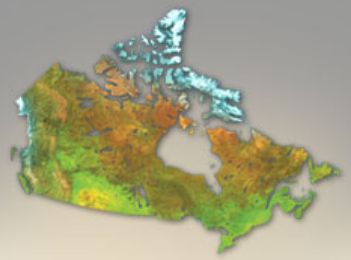
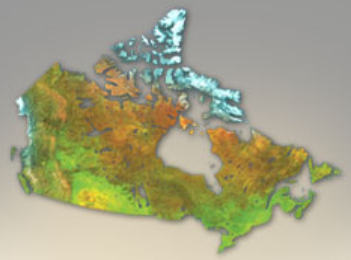


NAD83(CSRS) Velocity Model

NAD83 Realizations
GPS Velocity Field
Velocity Grid Generation
NAD83 Reconciliation Tests
Comparison with GIA Models

Mike Craymer, Joe Henton, Mike Piraszewski, Earl Lapelle

Canadian Geodetic Reference Systems Committee Meeting
April 21-22, 2008



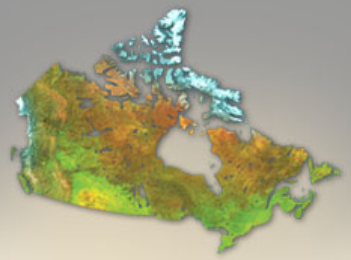
NAD83 Realizations

Details provided in comments of CACS coordinate files on CGRSC FTP site

Version (epoch)	Frame	Adopted	Description
v0	Original	1986-1993	Horizontal adjustments
v2 (1997.0)	CSRS98*	1998	Transformed from ITRF96
v3 (1997.0)		2000	Transformed from ITRF97 First complete CBN
v4 (2002.0)		2002	Transformed from ITRF2000
v5 (2006.0)		2009	Transformed from ITRF2005**

* Adopted ITRF-NAD83 transformation (CSRS98=CSRS)

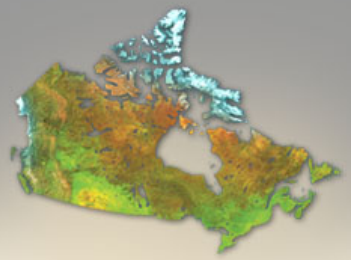
** New ITRF2008 to be introduced end of 2009 but…
Will have to wait to reprocess with new orbits (mid to end 2010)
Make v5.0 public in mean time (CBN solution same as used for velocity model)



Provincial NAD83 Realizations

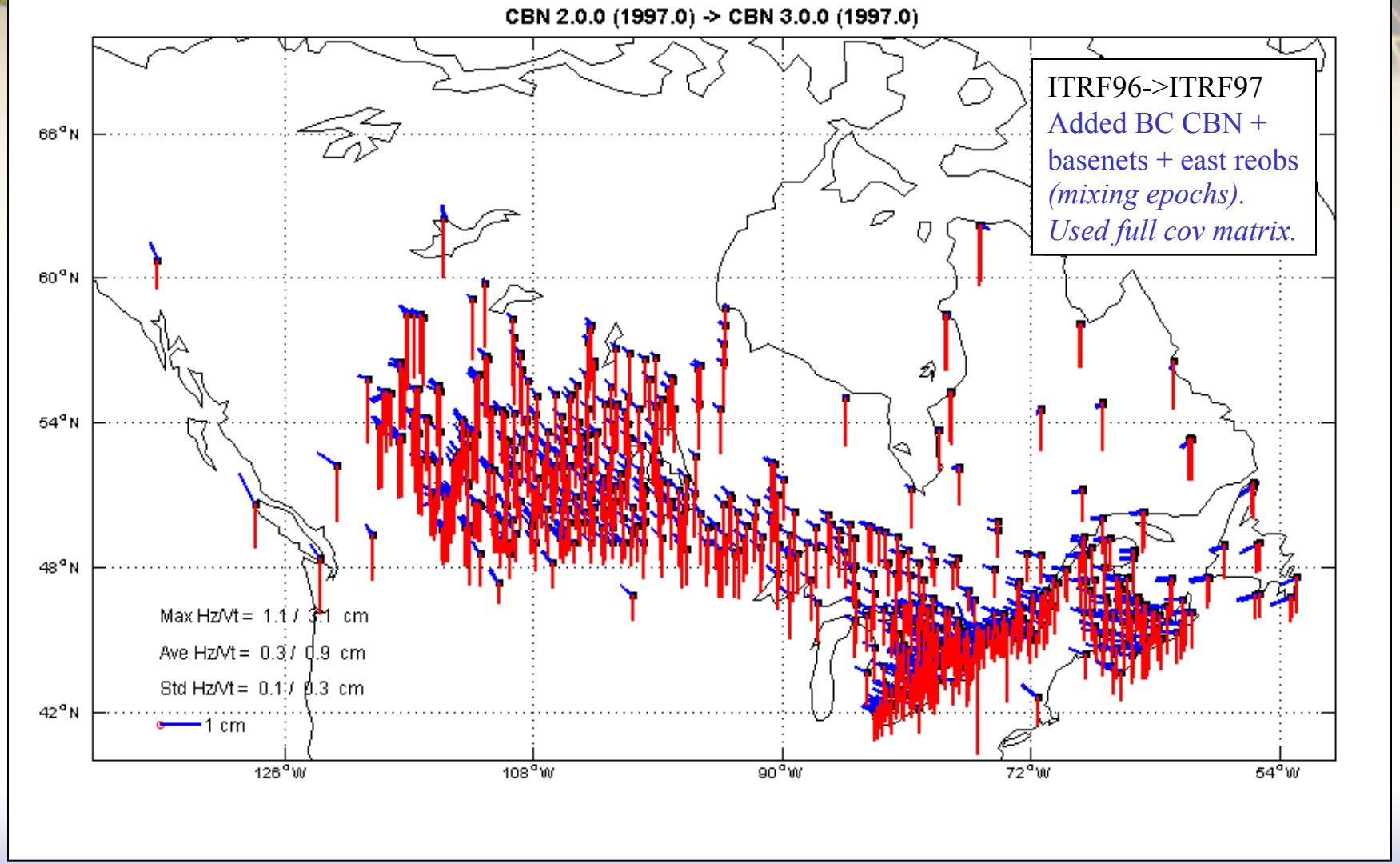
- NAD83 CBN realizations used by provinces

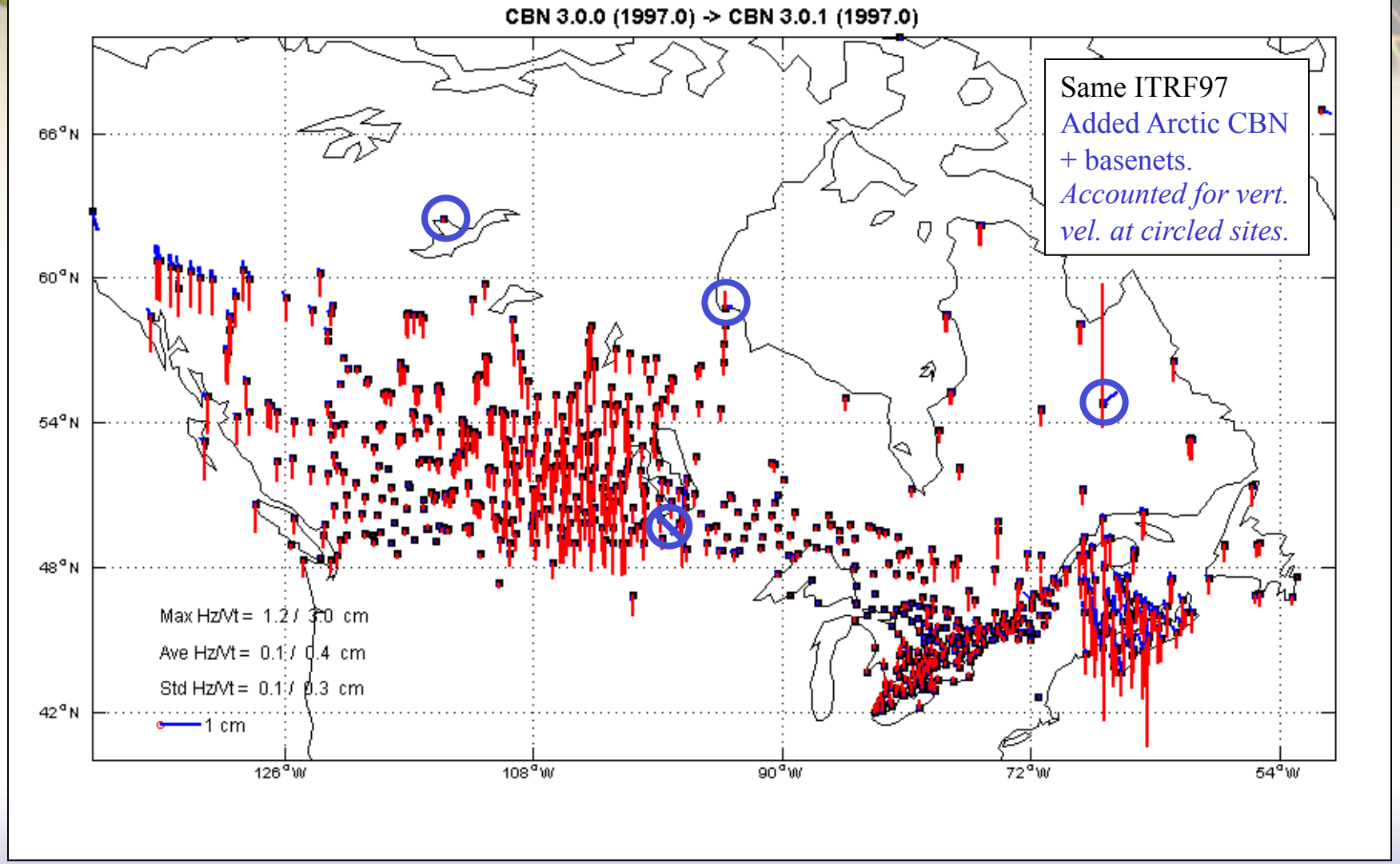
GSD	v4.0 (2002.0) + v4.0.0 (2002.0)
BC	v4.0.0 (2002.0) ; Van. Is. public v3.0 (1997.0)
AB	v4.0.0 (2002.0) for 1140 subset, v0 elsewhere; scientific v4.0.0
SK	v2.0.0 (1997.0)
MB	v2.0.0 (1997.0); moving to v3.0.1
ON	v3.0.1 (1997.0) for 6600 subset; v0 elsewhere
QC	v2.0.0 (1997.0) & v0
NB	v2.0.0 (1997.0) on HPN
PEI	v2.0.0 (1997.0) on HPN; NAD27 elsewhere
NS	v3.0.0 (1997.0) on HPN; ATS77 elsewhere
NL	v0; scientific v3.0.0 (1997.0) subset
Territories	v4.0.0 (2002.0)

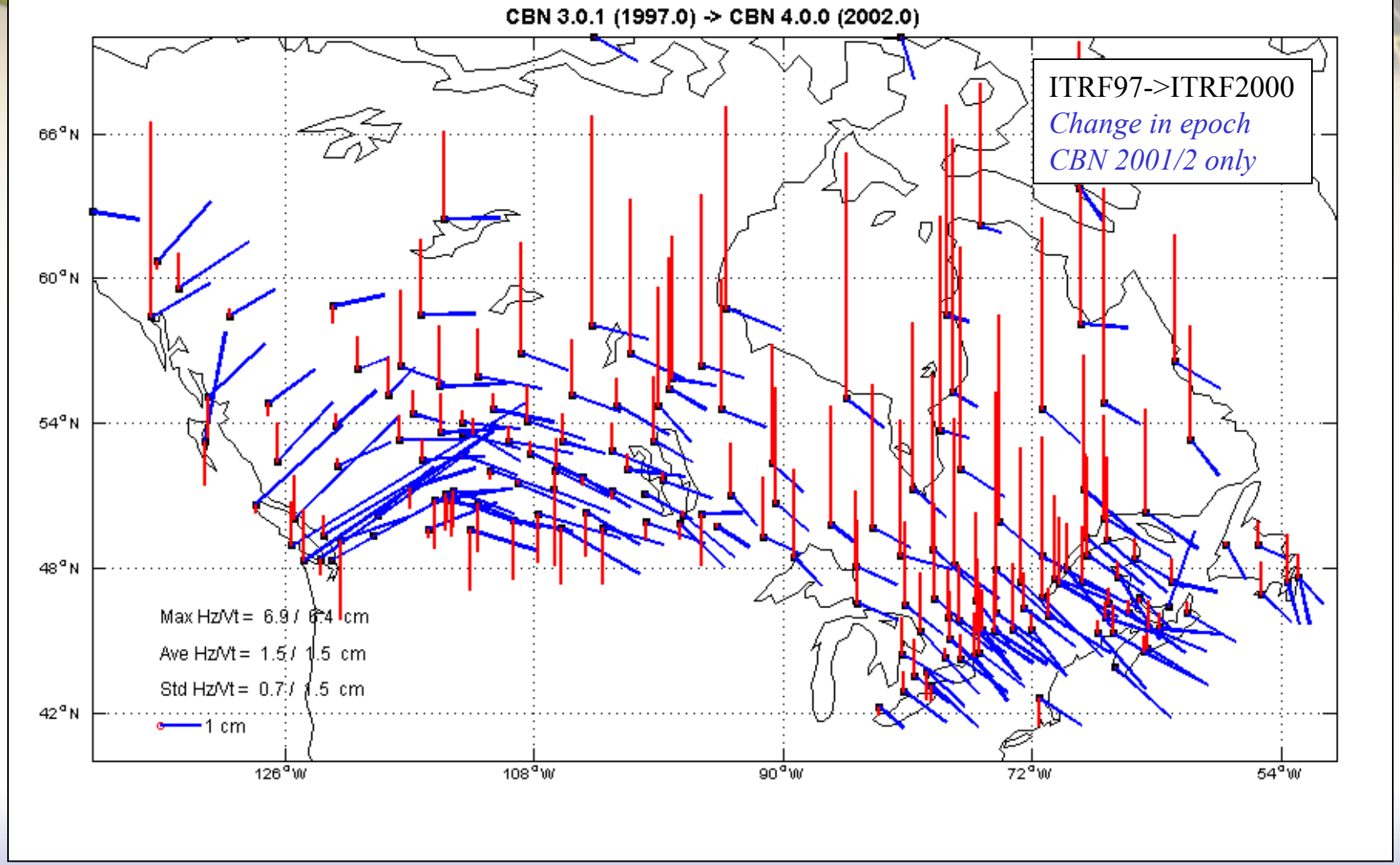


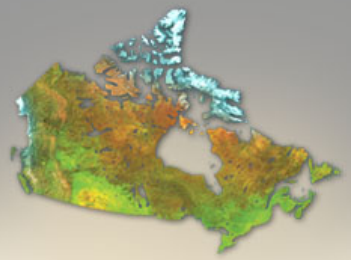
Differences in Realizations

- Changes in ITRF
  - Mainly more data at CACS sites => more reliable coordinates/velocities
- Vertical differences primarily due to crustal motion between epochs
  - *Affects PPP significantly !*
    PPP results at epoch of observation, not epoch of NAD83 realization
  - Can predict most of difference with velocity models
- Horizontal differences almost entirely due to NUVEL-1A bias
  - May need to replace NUVEL-1A (revise ITRF-NAD83 transformation)
- Can't reconcile differences between v2 & v3 with velocity model


CBN 2.0.0 (1997.0) -> CBN 3.0.0 (1997.0)
ITRF96->ITRF97
Added BC CBN +
basenets + east reobs
(mixing epochs).
Used full cov matrix.
66°N
60°N
54°N
48°N
42°N
126°W
108°W
90°W
72°W
54°W
Max Hz/Vt = 1.1 / 3.1 cm
Ave Hz/Vt = 0.3 / 0.9 cm
Std Hz/Vt = 0.1 / 0.3 cm
1 cm


CBN 3.0.0 (1997.0) -> CBN 3.0.1 (1997.0)
Same ITRF97
Added Arctic CBN + basenets.
Accounted for vert. vel. at circled sites.
66°N
60°N
54°N
48°N
42°N
126°W
108°W
90°W
72°W
54°W
Max Hz/Vt = 1.2 / 3.0 cm
Ave Hz/Vt = 0.1 / 0.4 cm
Std Hz/Vt = 0.1 / 0.3 cm
1 cm

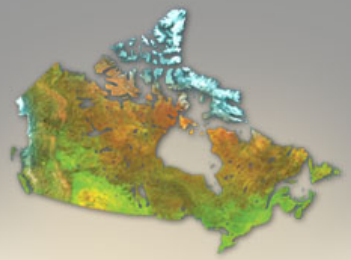

CBN 3.0.1 (1997.0) -> CBN 4.0.0 (2002.0)
ITRF97->ITRF2000
Change in epoch
CBN 2001/2 only
66°N
60°N
54°N
48°N
42°N
126°W
108°W
90°W
72°W
54°W
Max Hz/Vt = 6.9 / 6.4 cm
Ave Hz/Vt = 1.5 / 1.5 cm
Std Hz/Vt = 0.7 / 1.5 cm
1 cm



Reconciling NAD83(CSRS) Realizations

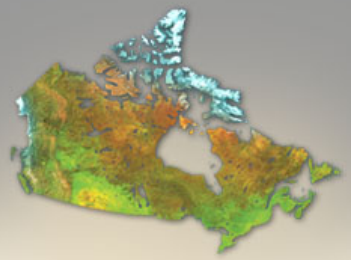
- Distortion modelling (e.g., NTv2)
  - Models coordinate differences only between pairs of realizations/ epochs
  - Cannot be used with other realizations and epochs
  - *Will not work with PPP* (solutions can be at any epoch)

- Velocity (crustal motion) modelling
  - Most of the differences are due to crustal motion
  - Can transform coordinates to any epoch/realization
  - *Suitable for PPP*
  - Can't reconcile v2 & v3 (same epoch)



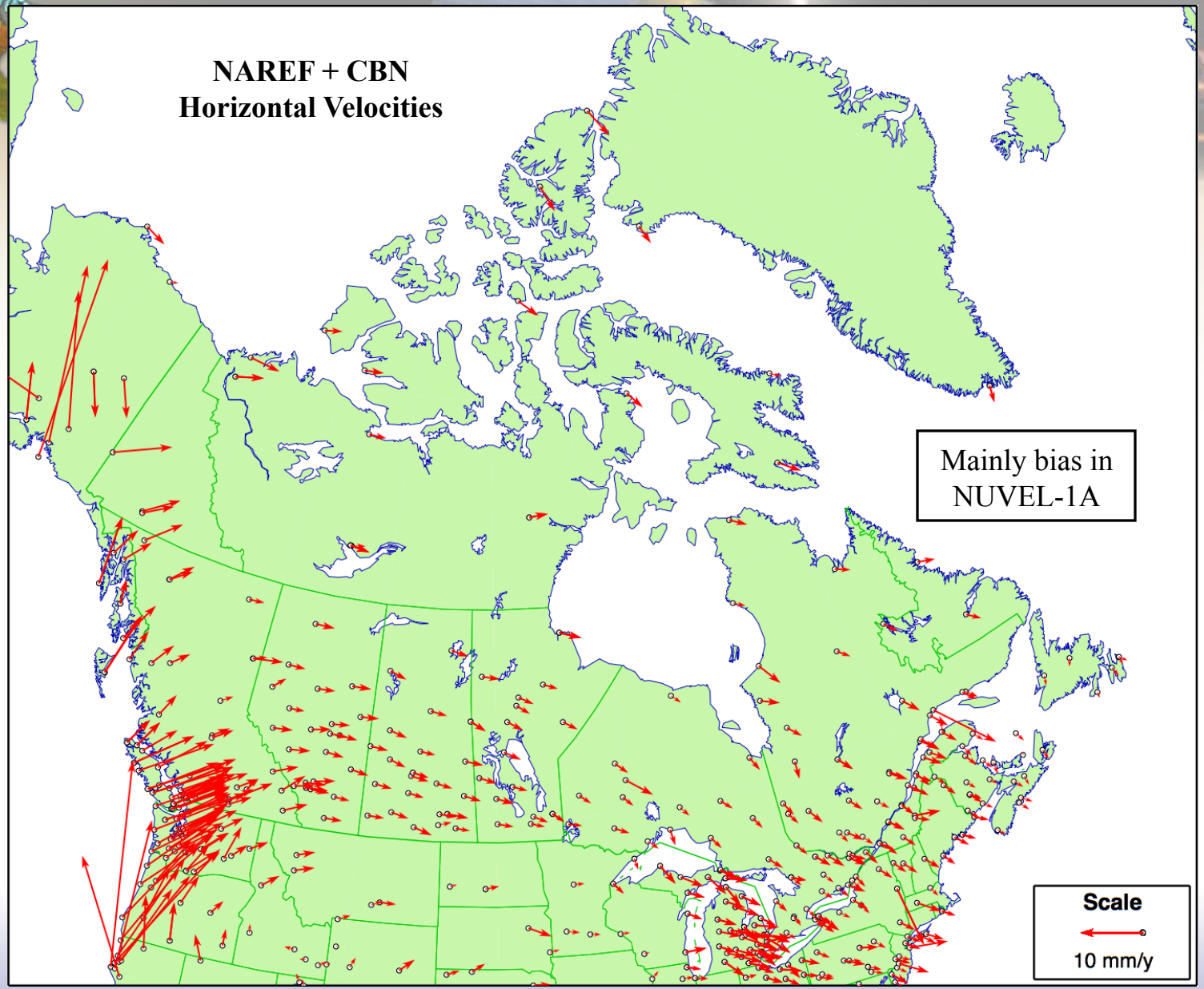
Types of Velocity Models

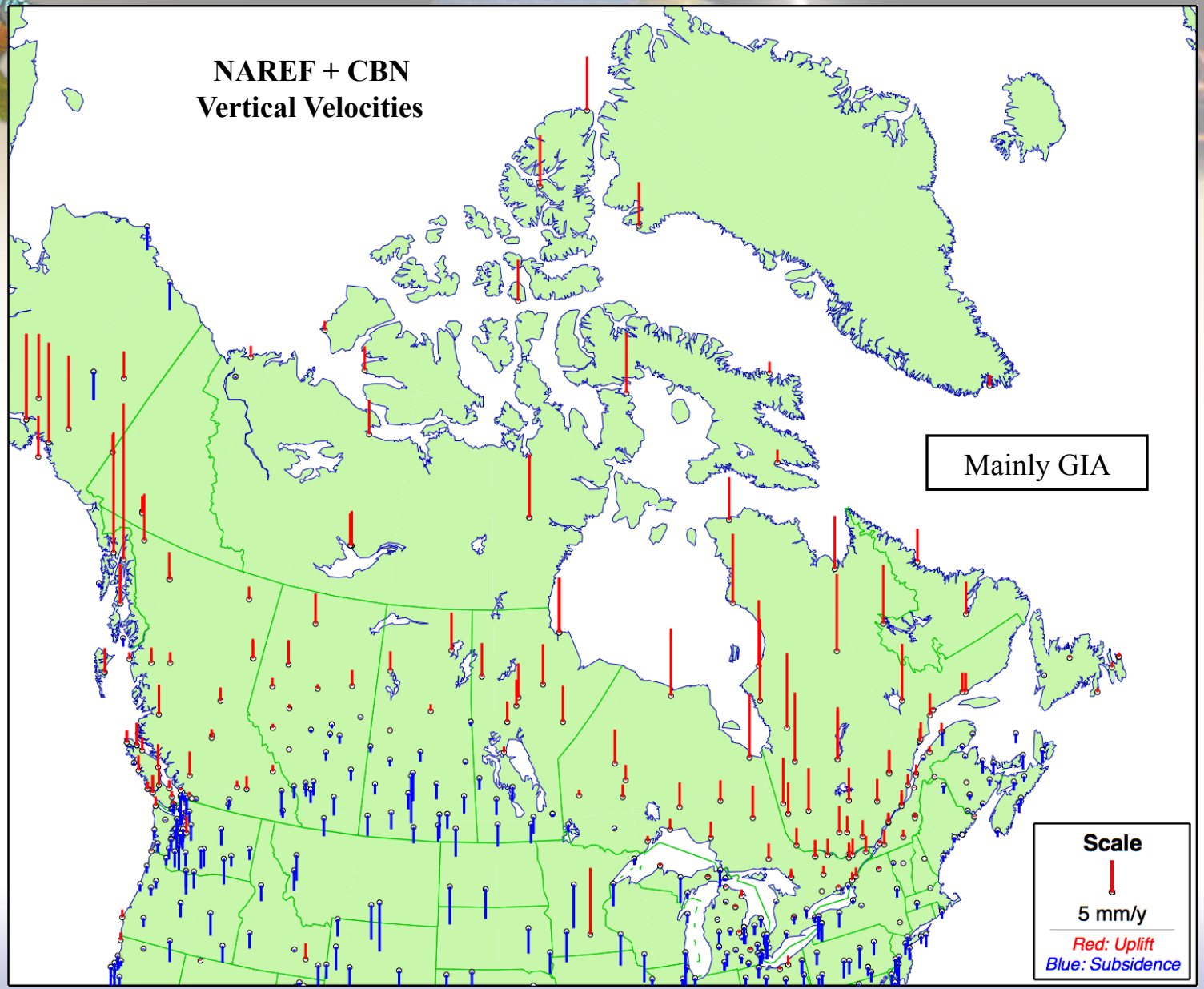
- Interpolation of CACS/CBN velocities – horizontal & vertical
  - Not likely very reliable in regions with few CACS/CBN
- GIA models (e.g., ICE-5g) – vertical only
  - Not always consistent with GPS results (reference frame issues)
  - Doesn't model tectonic deformations (Van. Is.)
- Hybrid GPS + ICE model (e.g., SNARF) – horizontal & vertical
  - ICE model effectively provides better interpolation between GPS sites
  - Doesn't presently model tectonic deformations but could be adapted
  - SNARF v1.0 based on ICE-1 and 2 GPS solutions
  - SNARF v2.0 based on ICE-5g and more/better GPS solutions -- still waiting!
- *Use interpolation of CACS/CBN velocities until SNARF model ready*

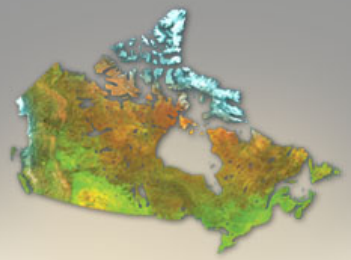


NAREF+CBN Velocity Solution

- NAREF solution (continuous GPS)
  - Based on combination of 6 weekly regional solutions
  - Using data up to Nov/06 (relative phase centers)
- CBN solution (episodic GPS)
  - Based on 27 survey campaigns
  - Main campaigns: 1994-1997,1999,2000
2001-2002
2005-2006
- Combined NAREF and CBN into a single velocity solution
  - Aligned and constrained to ITRF2005 coordinates & velocities
  - Transformed to NAD83(CSRS) *(Test grid was in ITRF2005)*


NAREF + CBN
Horizontal Velocities
Mainly bias in
NUVEL-1A
Scale
10 mm/y

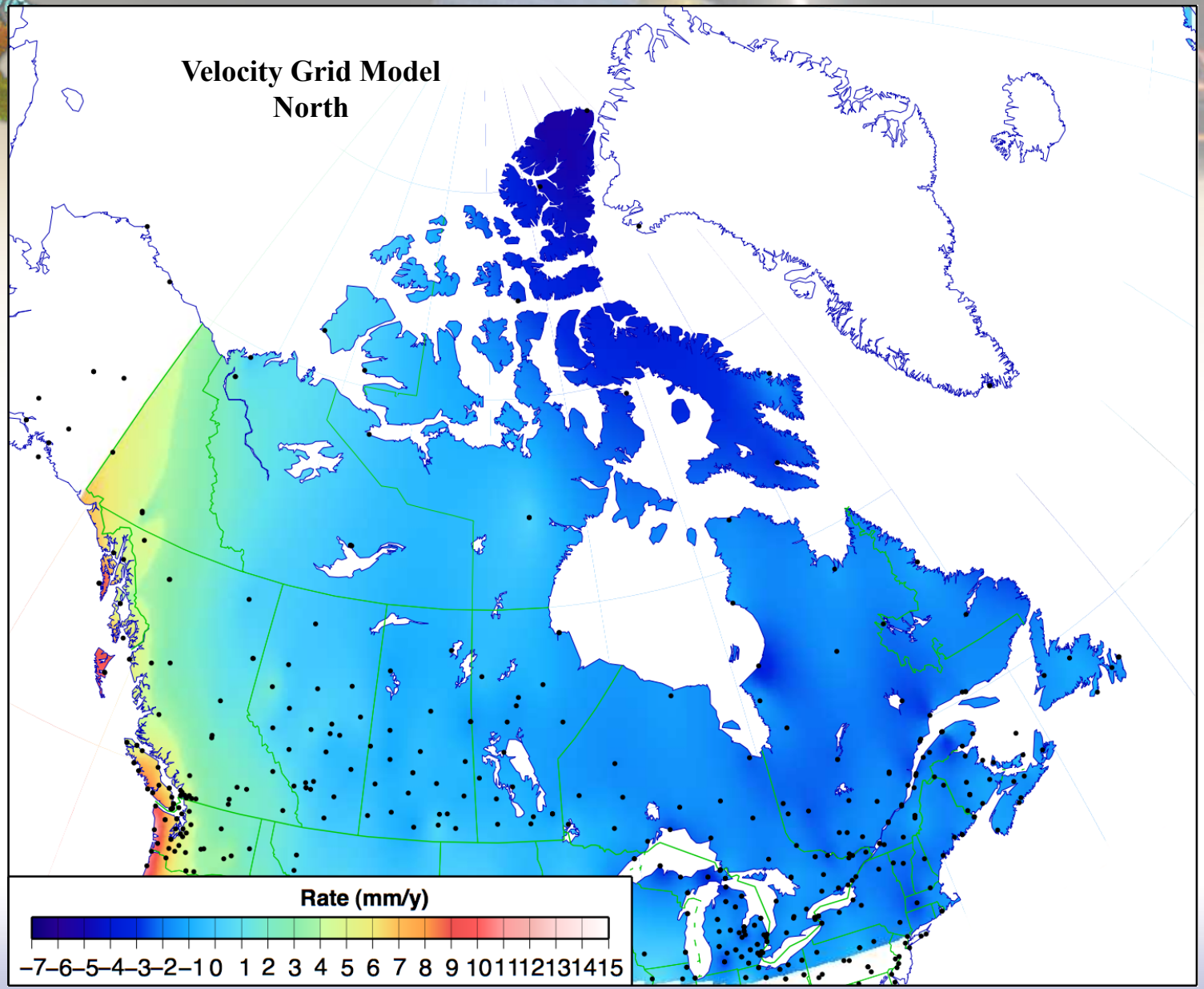

NAREF + CBN
Vertical Velocities
Mainly GIA
Scale
5 mm/y
Red: Uplift
Blue: Subsidence



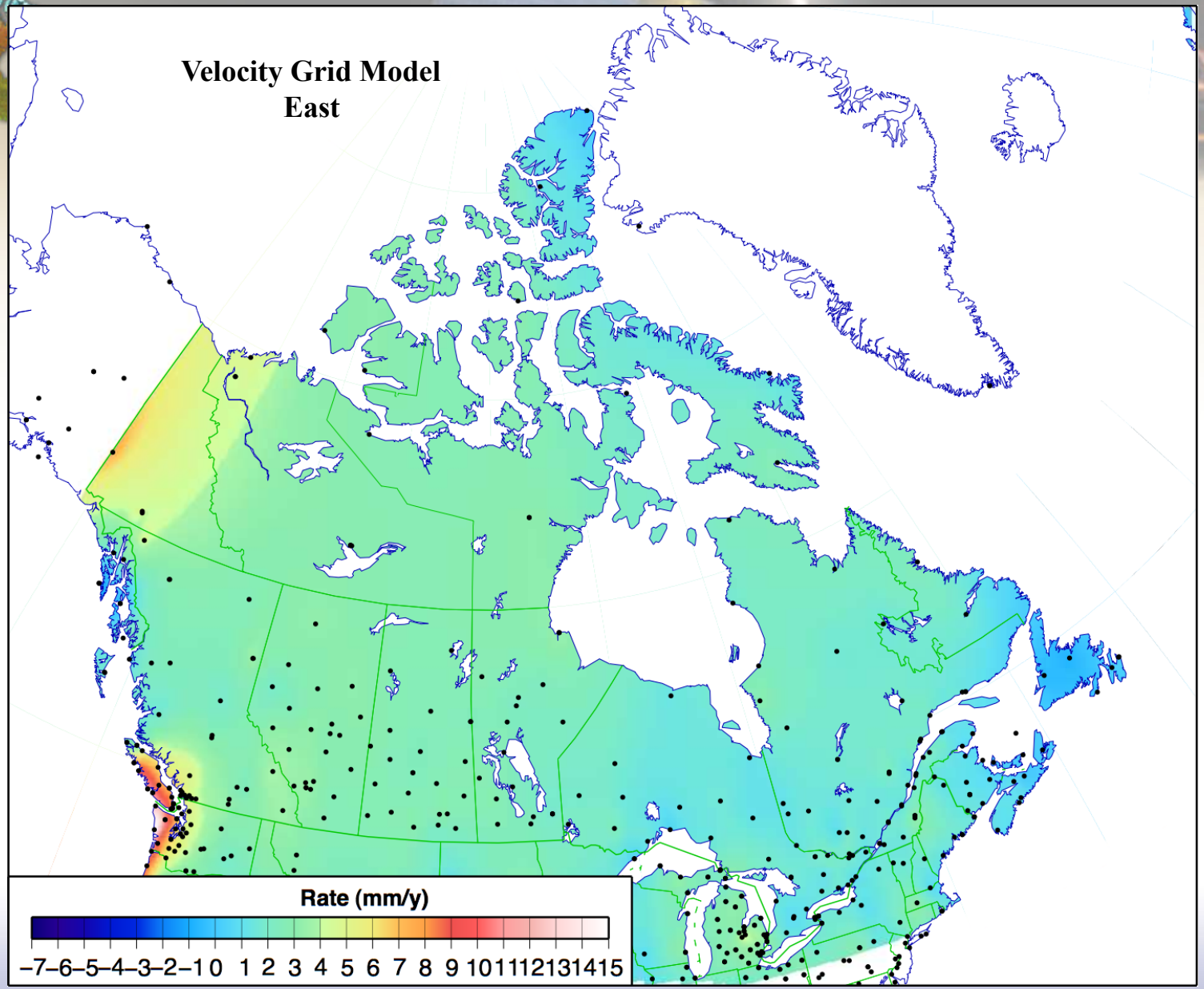
Velocity Grid Generation

- Separate grids generated for north/east/vertical velocities
- Used GMT (Generic Mapping Tools) for gridding
  - blockmean
    - Averages velocities over 1 deg x 0.5 deg blocks (grid cells)
    - Generally only one CBN or CACS station per block
  - surface
    - Adjustable tension continuous curvature surface gridding algorithm
    - Grid size: 0.25 deg x 0.25 deg Tension: 0.25
      - T=0 is minimum curvature (can produce spurious oscillations in surface)
      - T=0.25 recommended value for most applications
- Removed 6 outlier stations
  - N: SEPT, PICL, HDF1 E: LUSE H: SAK4, BCIN
  - Caused anomalous local uplift/subsidence features in grid

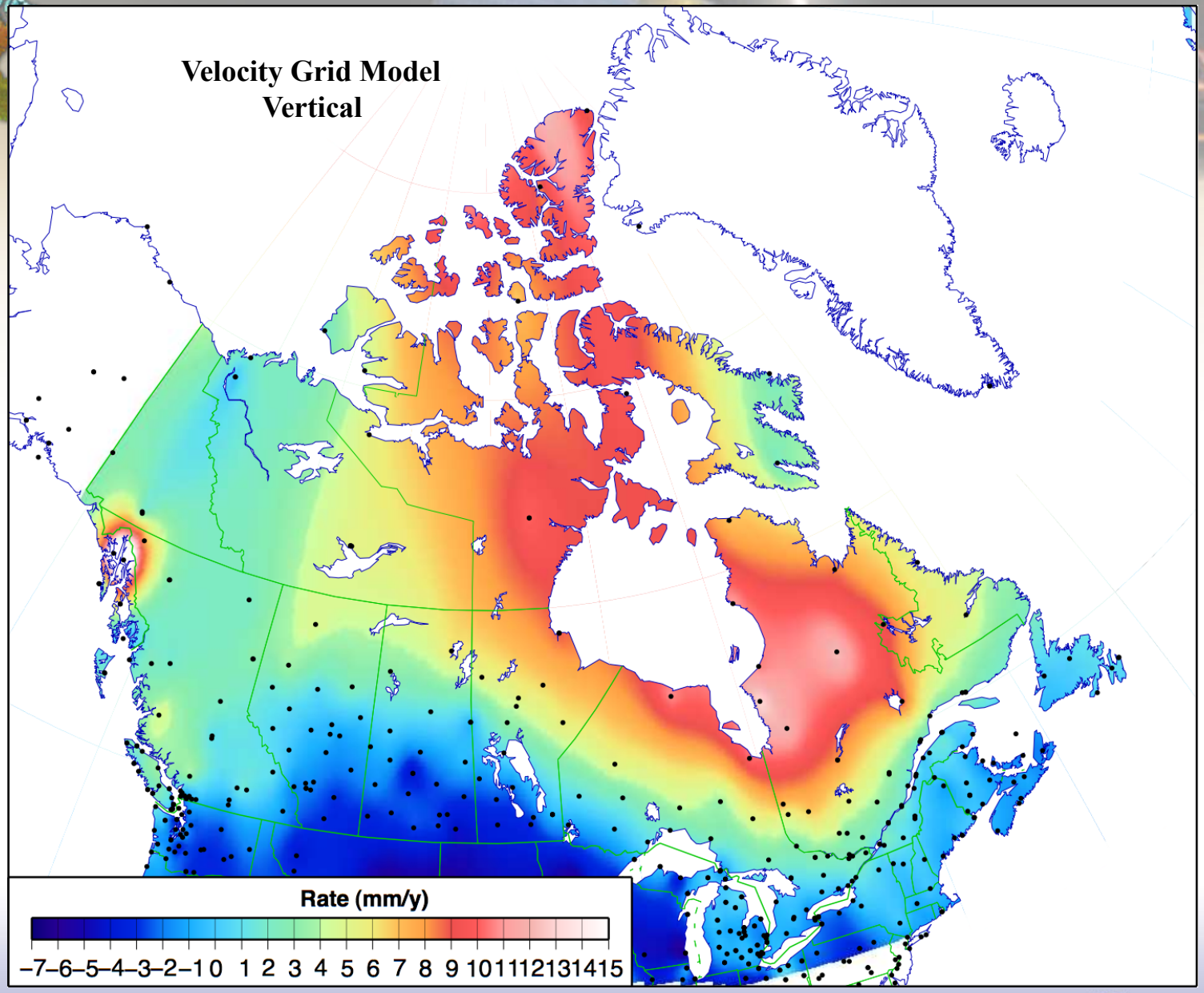
Velocity Grid Model North



Velocity Grid Model East



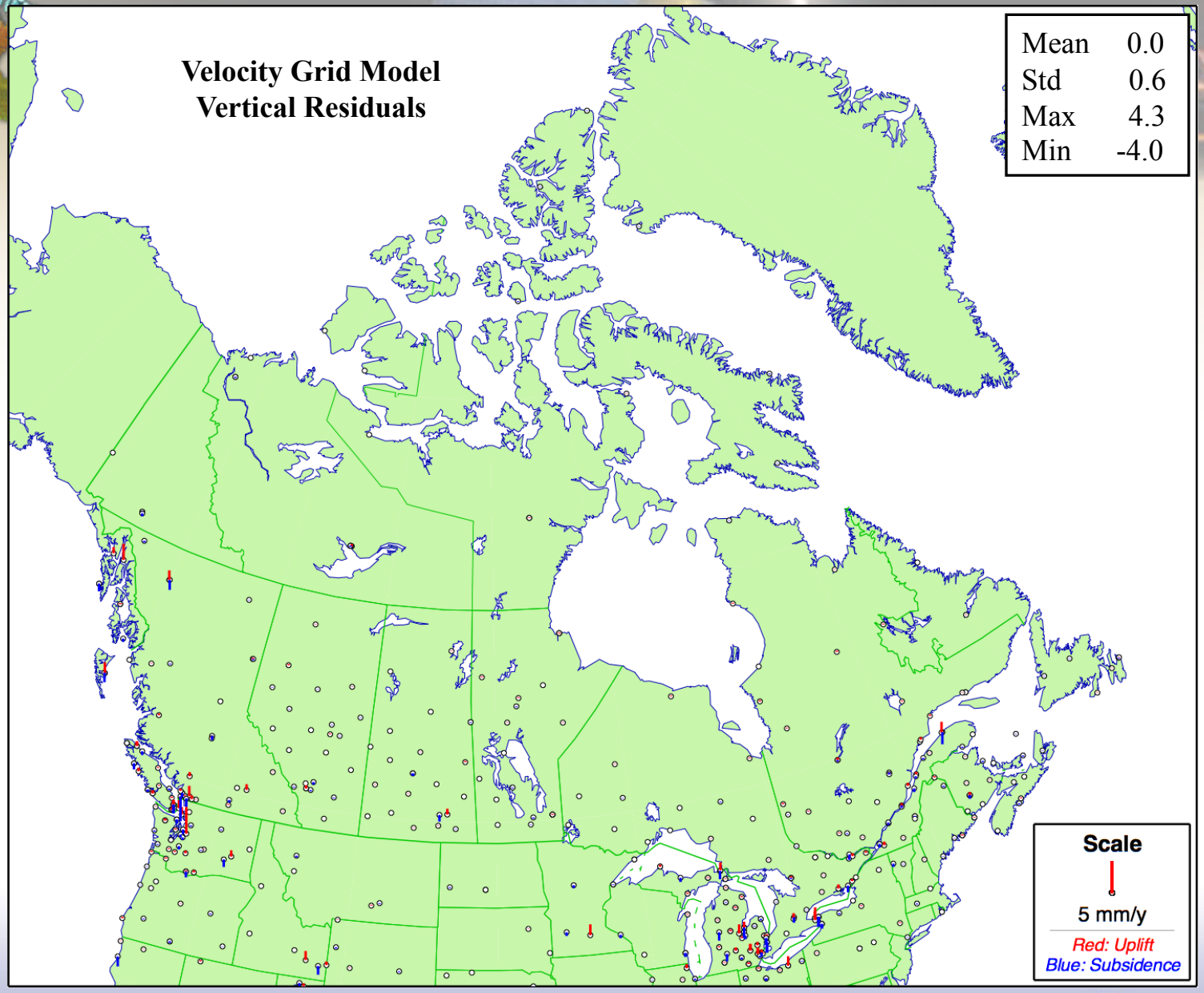
Velocity Grid Model
Vertical

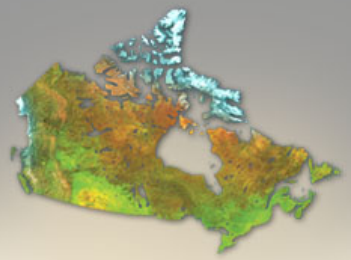


Velocity Grid Model
Horizontal Residuals

	N	E
Mean	0.0	0.0
Std	0.4	0.4
Max	2.7	1.9
Min	-1.9	-1.6

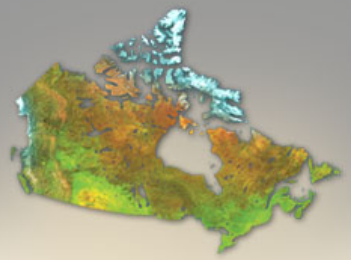
Scale
10 mm/y


Velocity Grid Model
Vertical Residuals
Mean 0.0
Std 0.6
Max 4.3
Min -4.0
Scale
5 mm/y
Red: Uplift
Blue: Subsidence



NAD83 Reconciliation Tests

- Using public CBN solutions
  - Different realizations based on different ITRF's
  - Not same solutions as used for grid
  - Comparing CBN v4.0.0 (2002.0) with other realizations
    - Propagated v4.0.0 from 2002.0 to 1997.0 using velocity grid
    - Compared to: CBN v2.0.0 (1997.0)
CBN v3.0.0 (1997.0)
CBN v3.0.1 (1997.0) -- no real diff. from v3.0.0
  - Can't reconcile differences between v2.0.0, v3.0.0, v3.0.1
- *Need to test velocity grid with PPP solutions (independent tests)*



CBN v4.0.0 (2002.0) - CBN v2.0.0 (1997.0)

Expressed differences as average velocities
(divided by 5 yr)

v4.0.0(2002.0) - v2.0.0(1997.0)
Ave Horizontal Motion

	N	E
Mean	-0.8	1.8
Std	1.3	0.8
Max	6.1	7.0
Min	-2.9	0.0

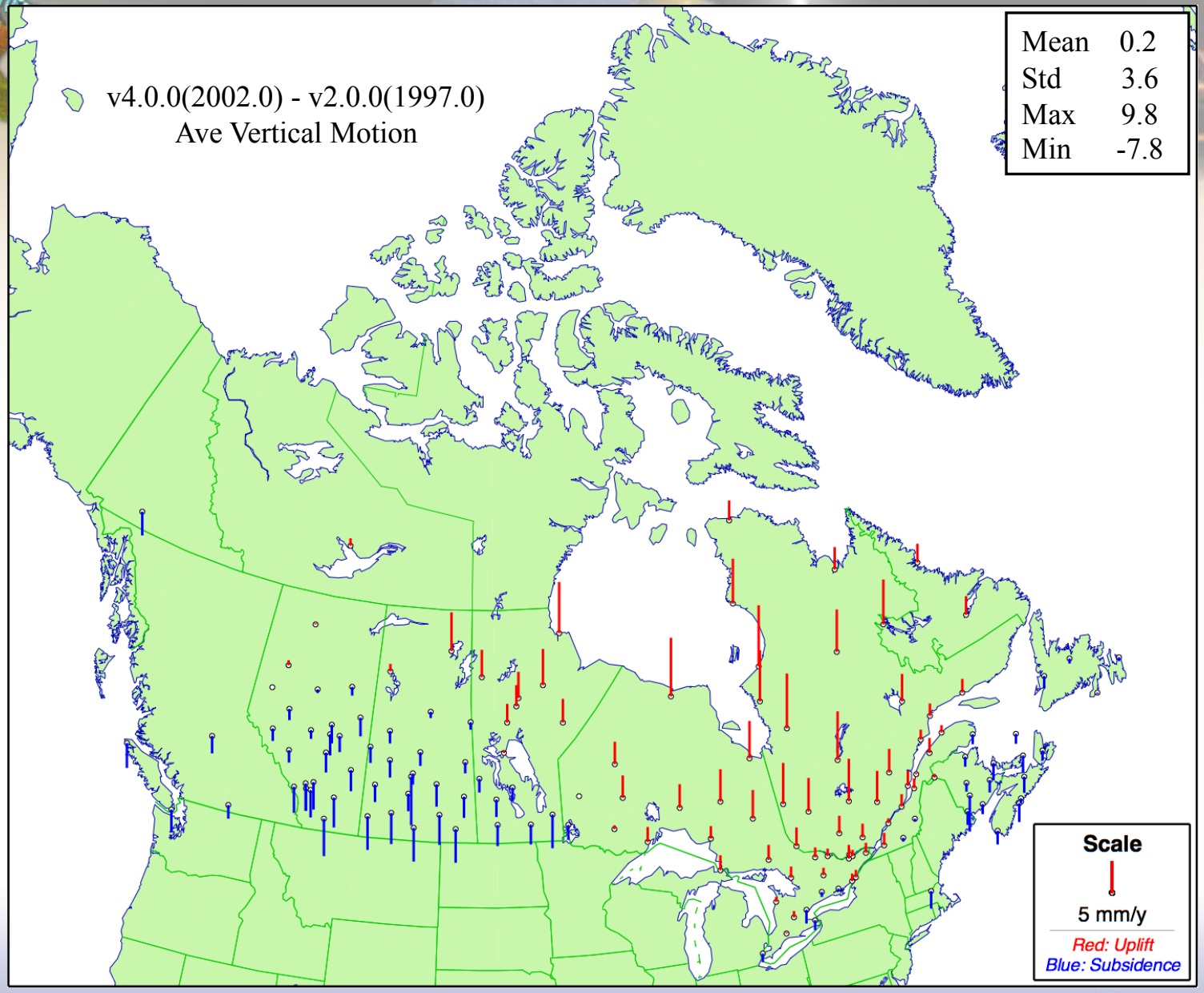
Mainly bias in NUVEL-1A

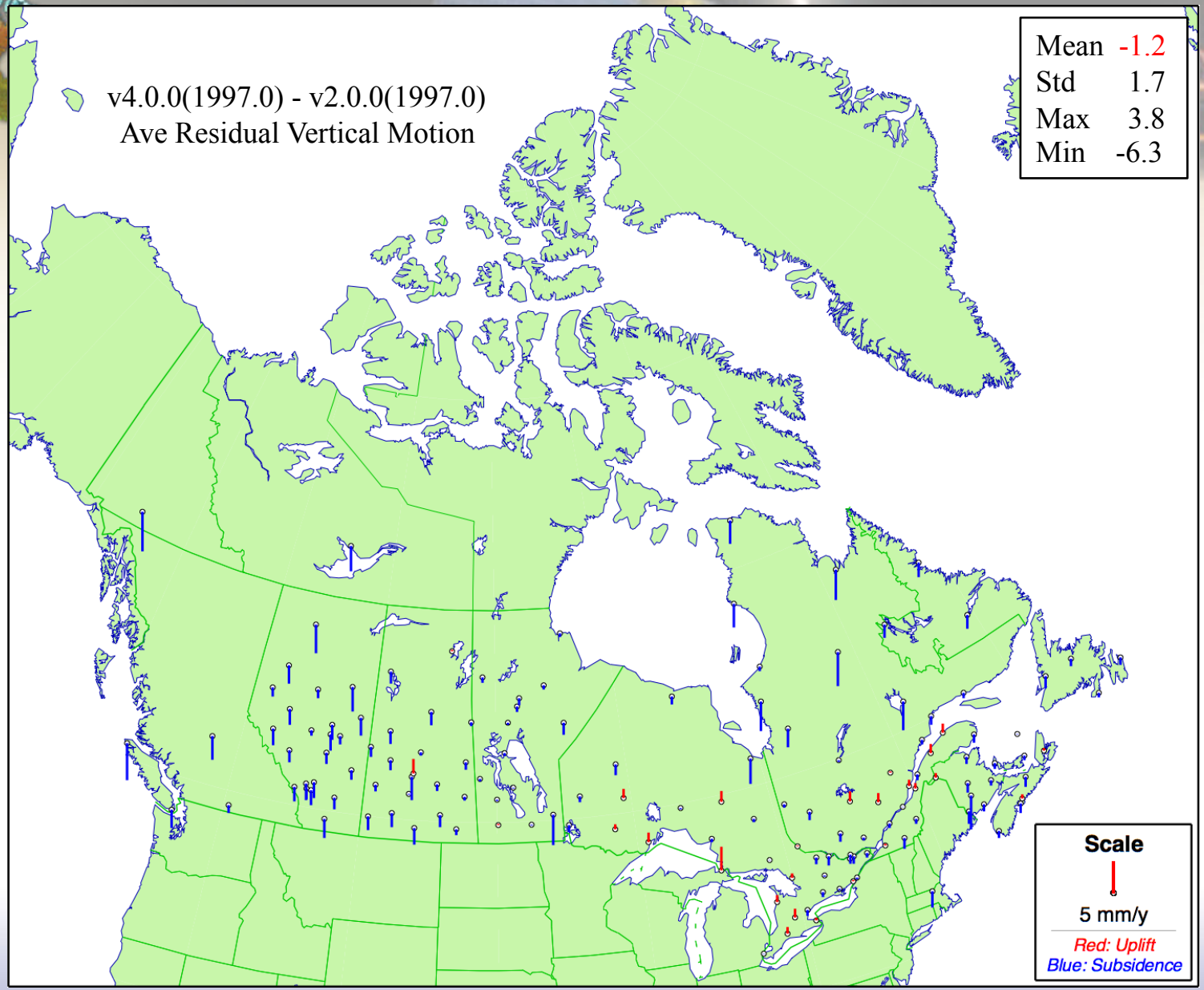
Scale
10 mm/y

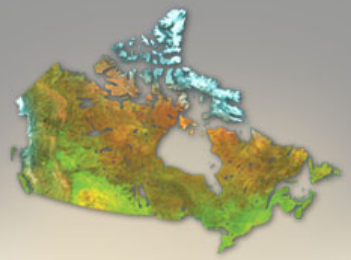
v4.0.0(1997.0) - v2.0.0(1997.0)
Ave Residual Horizontal Motion

	N	E
Mean	-0.3	-0.2
Std	0.8	0.7
Max	4.2	1.6
Min	-1.9	-2.3

Scale
10 mm/y

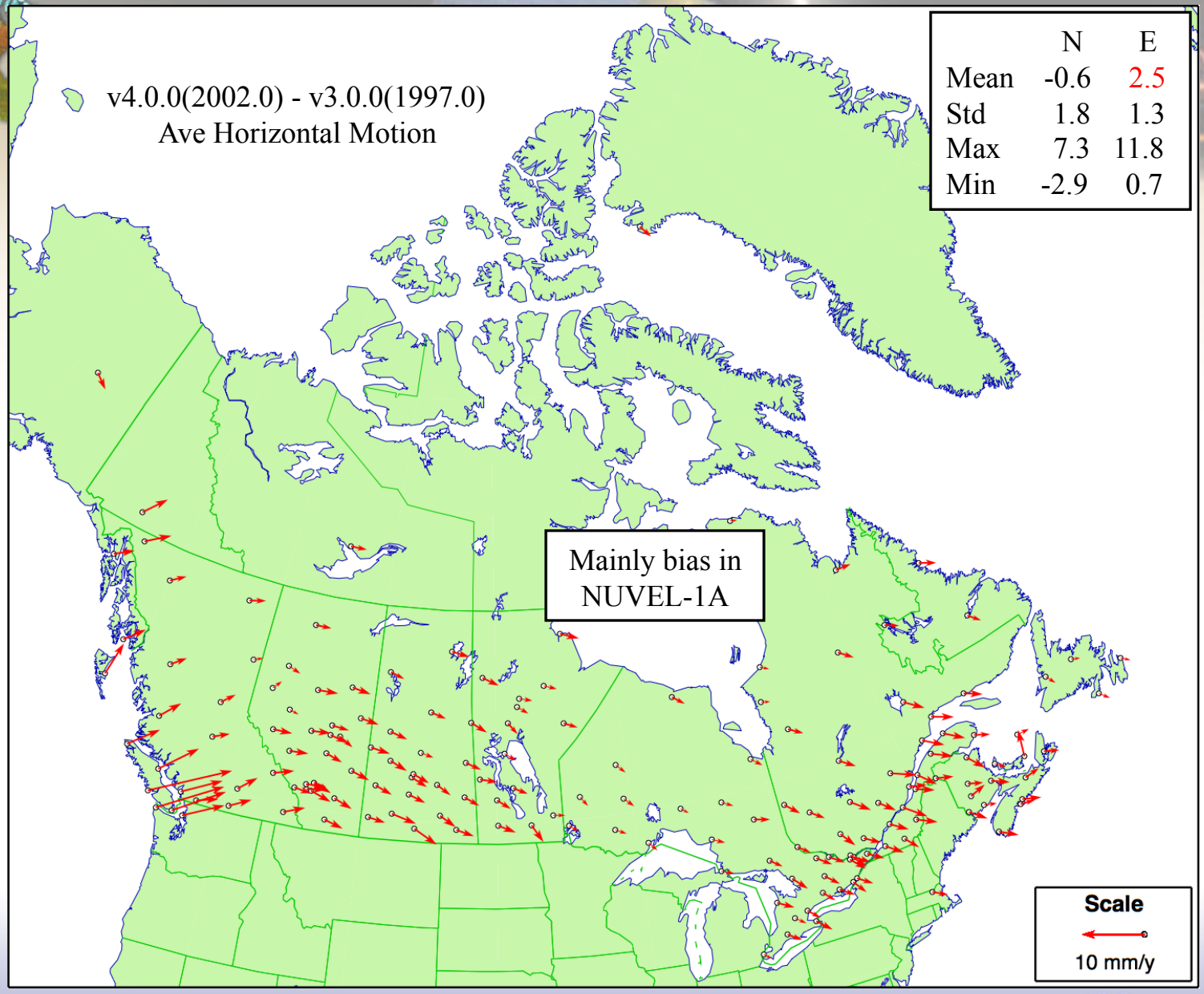

v4.0.0(2002.0) - v2.0.0(1997.0)
Ave Vertical Motion
Mean 0.2
Std 3.6
Max 9.8
Min -7.8
Scale
5 mm/y
Red: Uplift
Blue: Subsidence


v4.0.0(1997.0) - v2.0.0(1997.0)
Ave Residual Vertical Motion
Mean -1.2
Std 1.7
Max 3.8
Min -6.3
Scale
5 mm/y
Red: Uplift
Blue: Subsidence



CBN v4.0.0 (2002.0) - CBN v3.0.0 (1997.0)

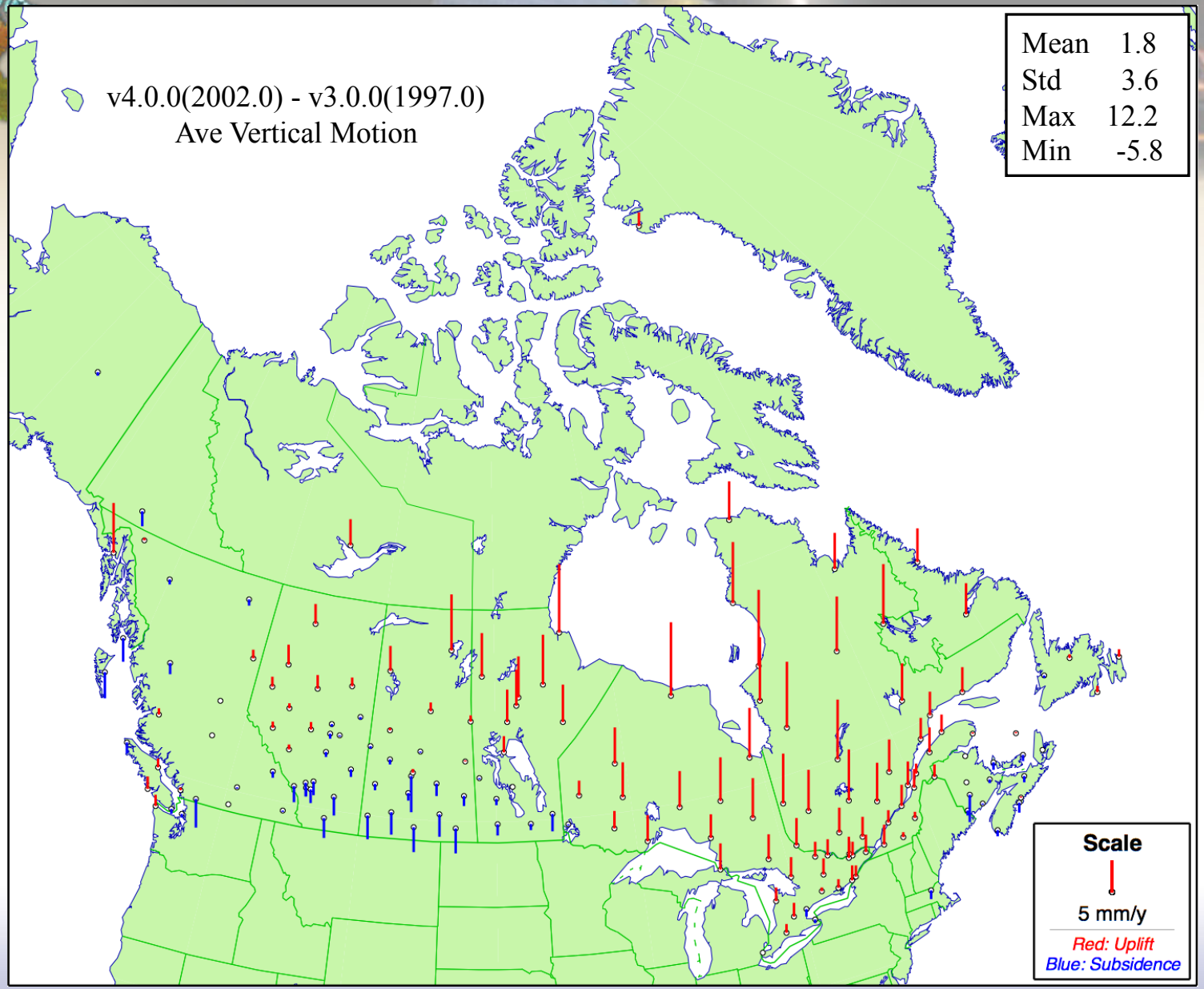
Expressed differences as average velocities
(divided by 5 yr)

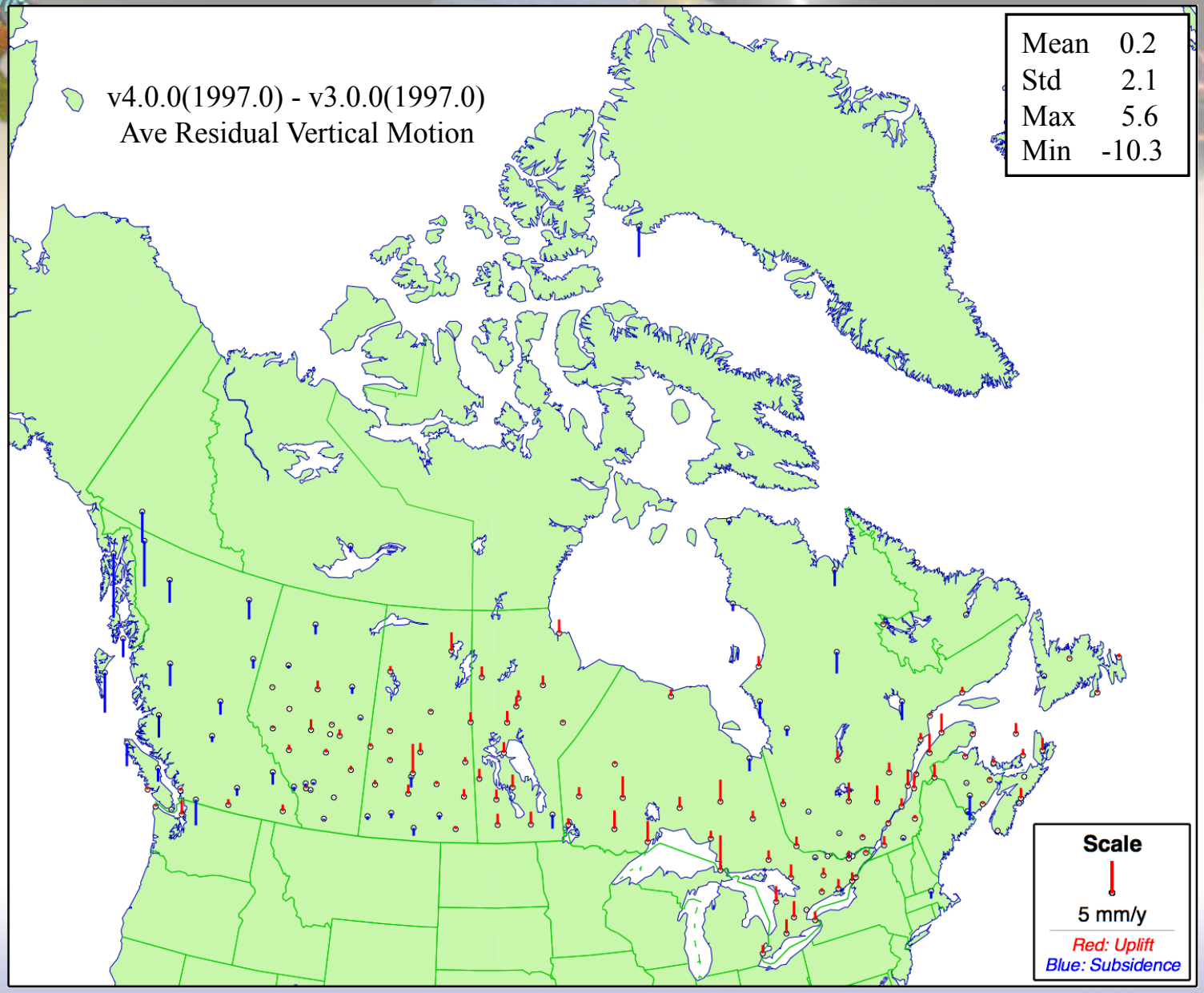

v4.0.0(2002.0) - v3.0.0(1997.0)
Ave Horizontal Motion
N E
Mean -0.6 2.5
Std 1.8 1.3
Max 7.3 11.8
Min -2.9 0.7
Mainly bias in NUVEL-1A
Scale
10 mm/y

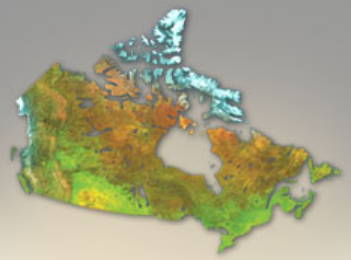
v4.0.0(1997.0) - v3.0.0(1997.0)
Ave Residual Horizontal Motion

	N	E
Mean	-0.2	0.2
Std	1.0	0.8
Max	4.2	2.5
Min	-4.7	-2.9

Scale
10 mm/y

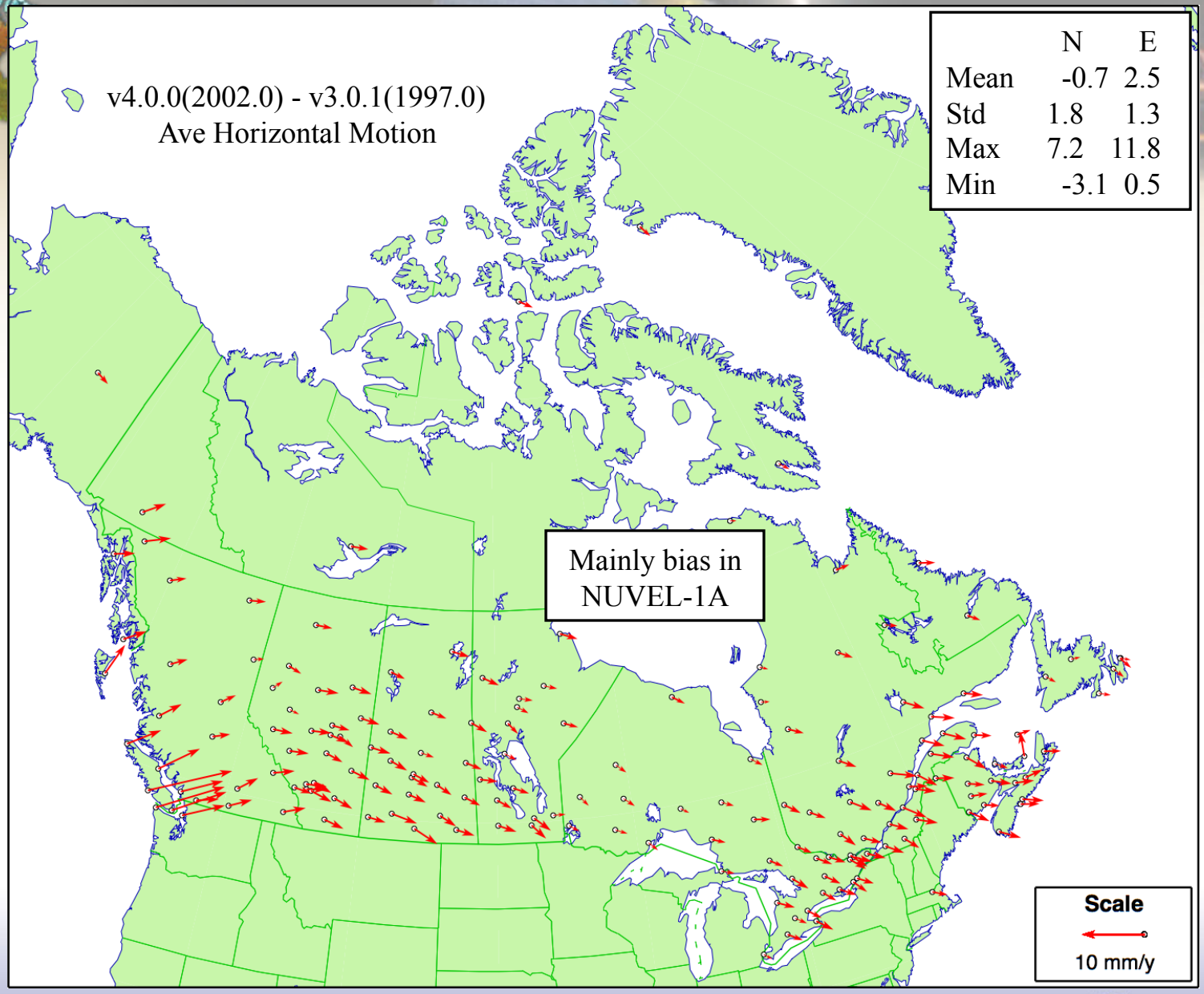

v4.0.0(2002.0) - v3.0.0(1997.0)
Ave Vertical Motion
Mean 1.8
Std 3.6
Max 12.2
Min -5.8
Scale
5 mm/y
Red: Uplift
Blue: Subsidence

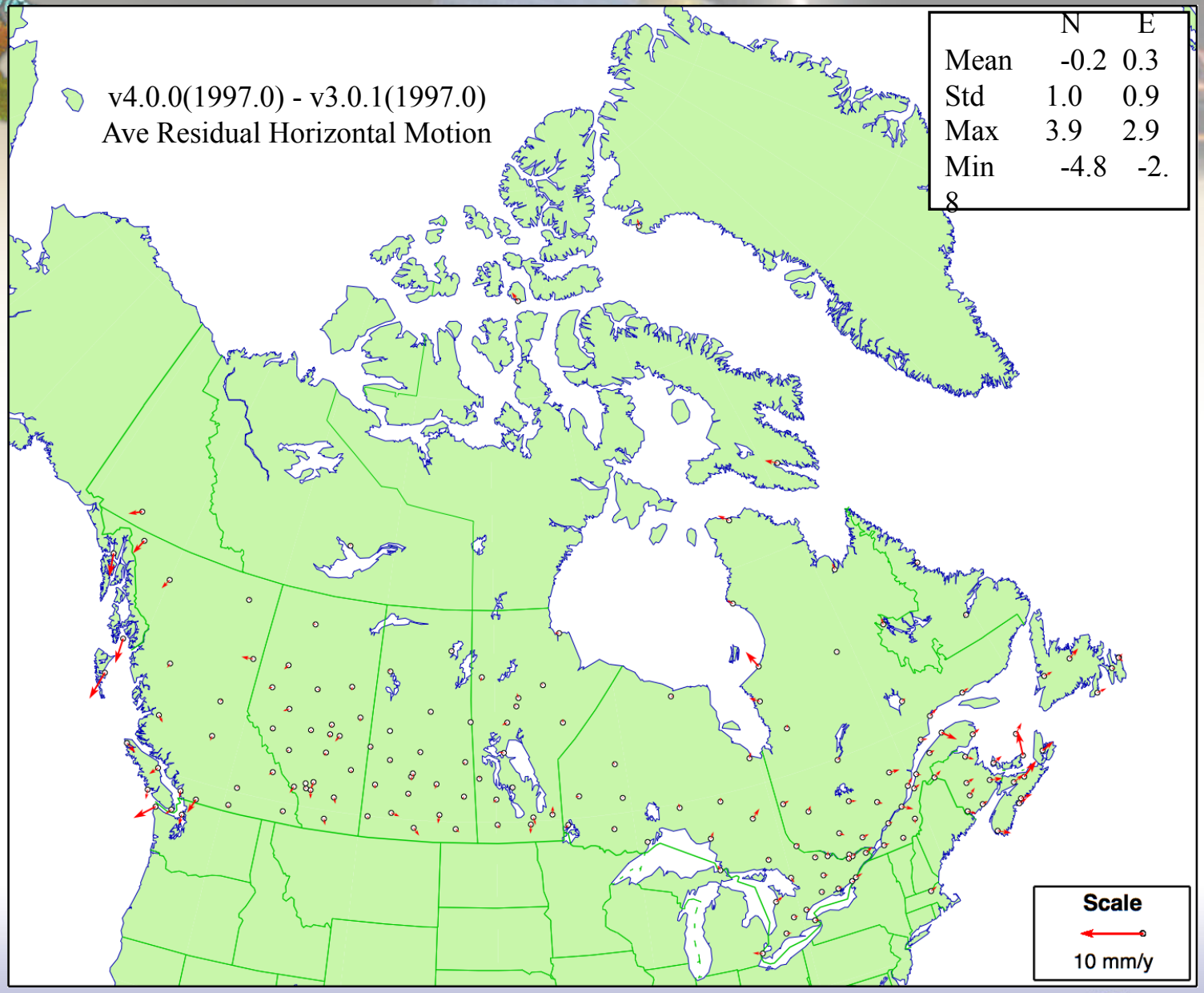

v4.0.0(1997.0) - v3.0.0(1997.0)
Ave Residual Vertical Motion
Mean 0.2
Std 2.1
Max 5.6
Min -10.3
Scale
5 mm/y
Red: Uplift
Blue: Subsidence

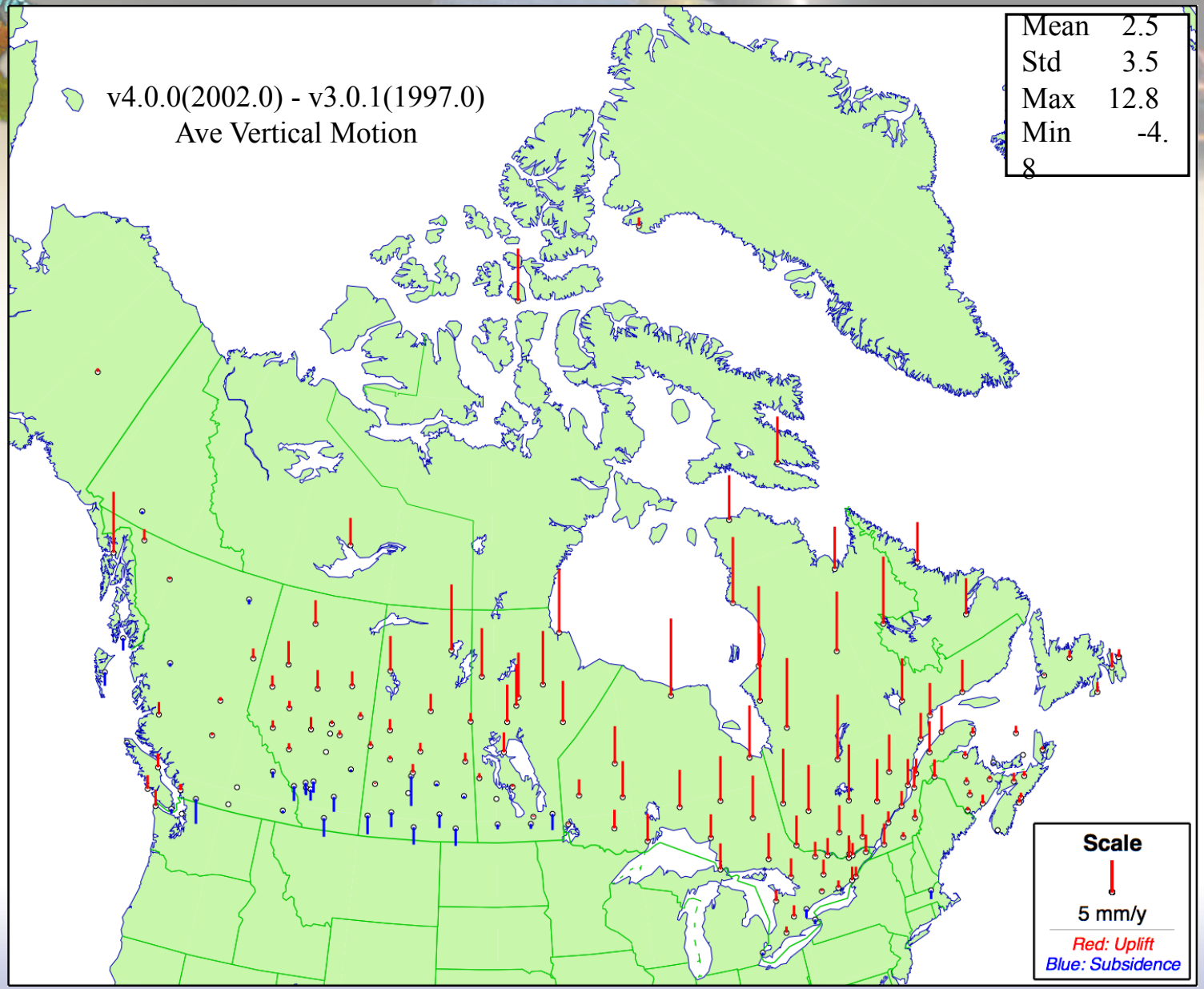


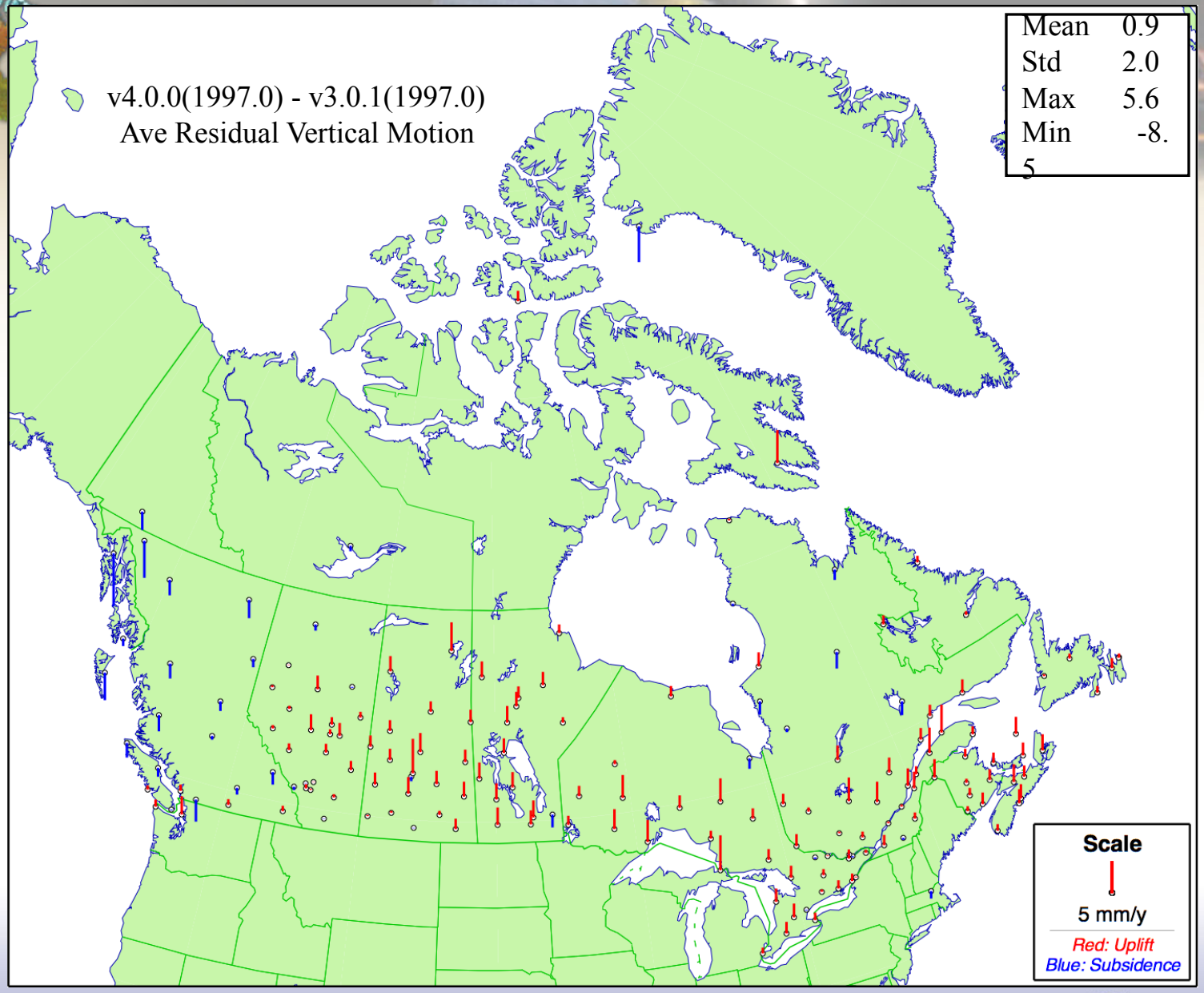
CBN v4.0.0 (2002.0) - CBN v3.0.1 (1997.0)

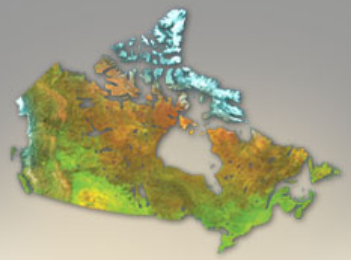
Expressed differences as average velocities
(divided by 5 yr)


v4.0.0(2002.0) - v3.0.1(1997.0)
Ave Horizontal Motion
N E
Mean -0.7 2.5
Std 1.8 1.3
Max 7.2 11.8
Min -3.1 0.5
Mainly bias in NUVEL-1A
Scale
10 mm/y


v4.0.0(1997.0) - v3.0.1(1997.0)
Ave Residual Horizontal Motion
N E
Mean -0.2 0.3
Std 1.0 0.9
Max 3.9 2.9
Min -4.8 -2.8
Scale
10 mm/y

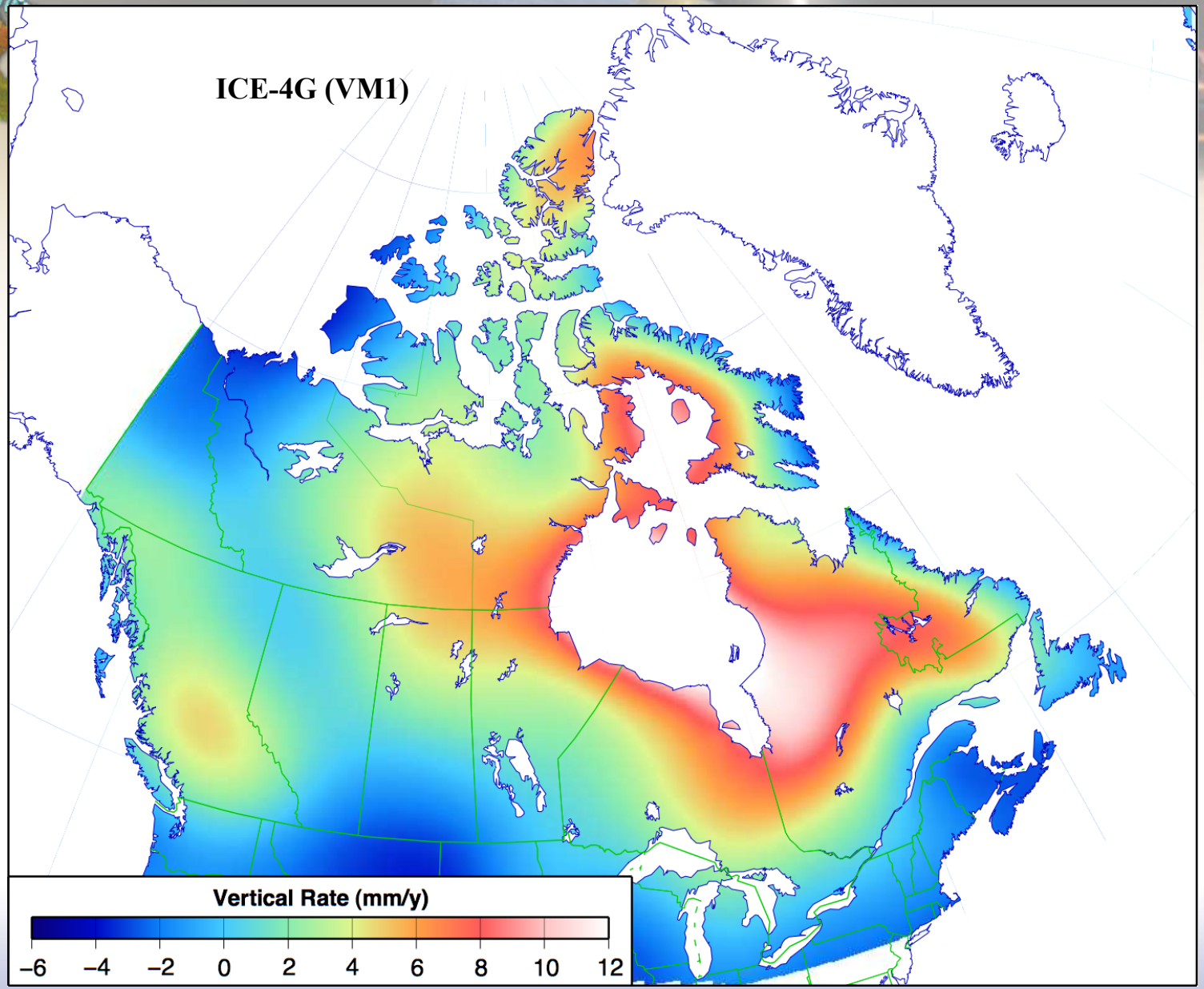

v4.0.0(2002.0) - v3.0.1(1997.0)
Ave Vertical Motion
Mean 2.5
Std 3.5
Max 12.8
Min -4.8
Scale
5 mm/y
Red: Uplift
Blue: Subsidence


v4.0.0(1997.0) - v3.0.1(1997.0)
Ave Residual Vertical Motion
Mean 0.9
Std 2.0
Max 5.6
Min -8.5
Scale
5 mm/y
Red: Uplift
Blue: Subsidence



Comparison with GIA Models

- Using ICE-4G & ICE-5G with different viscosity models
  - ICE-4G with VM1 & VM2
    - VM1 fits better with GPS velocity field
  - ICE-5G with VM2 & VM4
    - VM4 fits better with GPS velocity field
- Using velocity model in ITRF2005 (geocentric)
- Reference frame issues
  - ICE models not in exactly same frame as ITRF
  - Mainly due to motion of geocenter
  - Should align GPS with ICE model or vice-versa (not done here)


ICE-4G (VM1)
Vertical Rate (mm/y)
−6 −4 −2 0 2 4 6 8 10 12

ICE-4G (VM1) - GPS Vertical Residuals

Mean	0.1
Std	2.9
Max	13.4
Min	-23.9

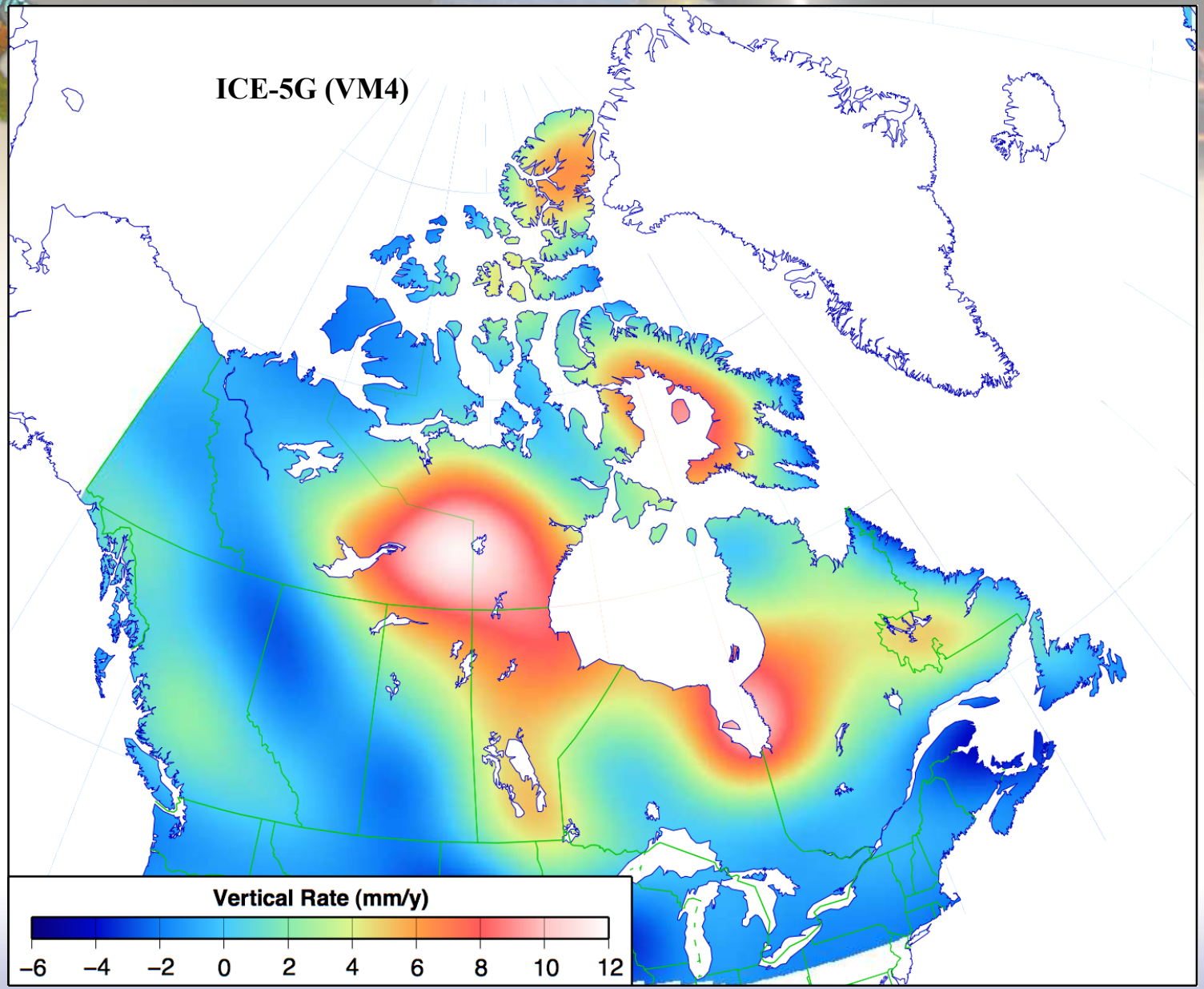
ICE-4G less than GPS in north

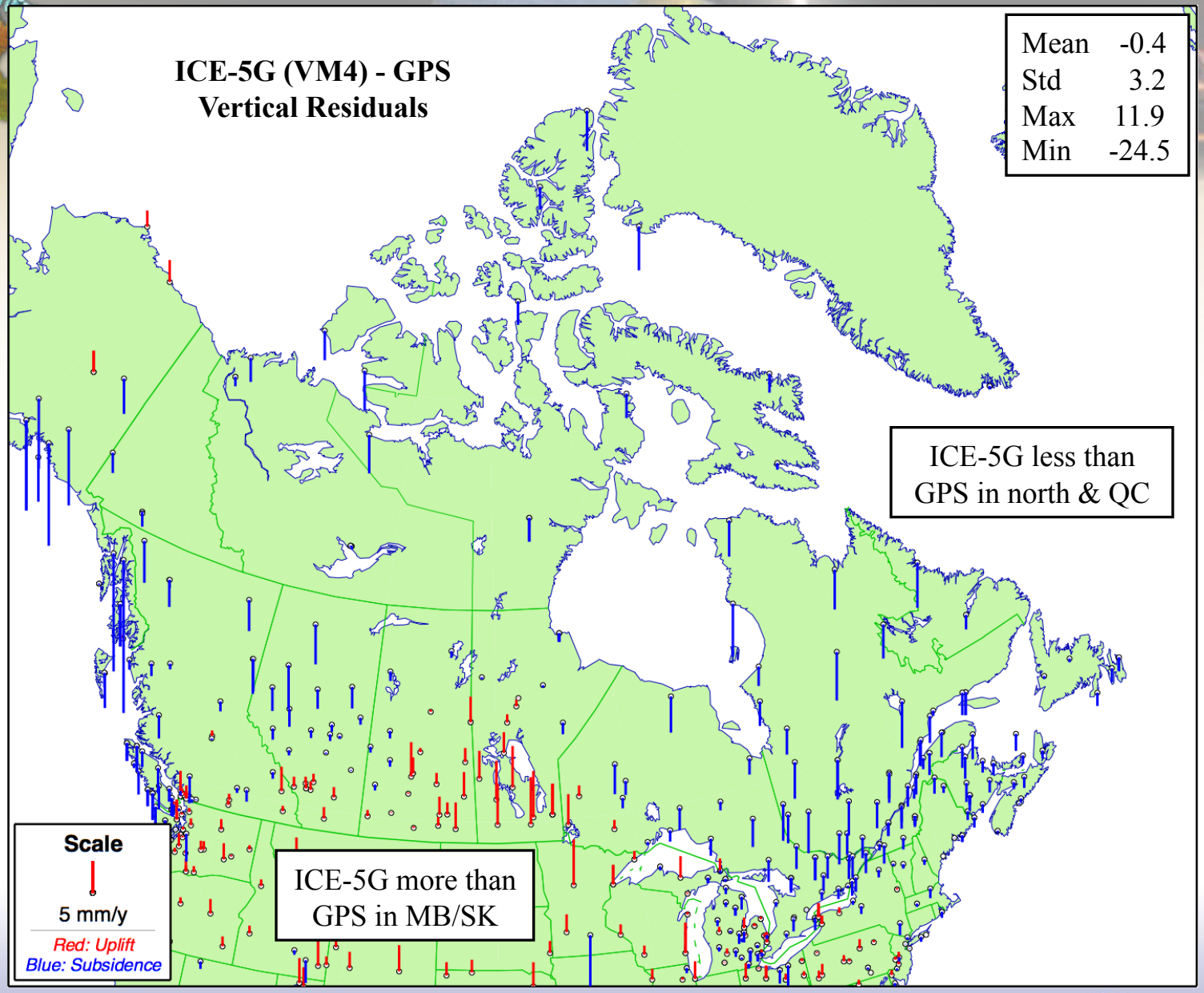
Scale

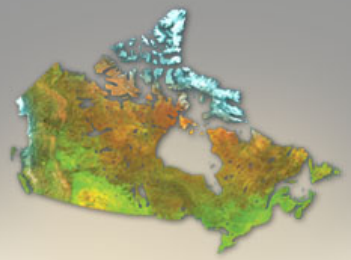
5 mm/y

Red: Uplift

Blue: Subsidence


ICE-5G (VM4)
Vertical Rate (mm/y)
−6 −4 −2 0 2 4 6 8 10 12


ICE-5G (VM4) - GPS
Vertical Residuals
Mean -0.4
Std 3.2
Max 11.9
Min -24.5
ICE-5G less than
GPS in north & QC
ICE-5G more than
GPS in MB/SK
Scale
5 mm/y
Red: Uplift
Blue: Subsidence



Further Work

- Reprocess NAREF & CBN velocity solutions with new IGS orbits
  - Using absolute antenna phase center variations
  - Using more consistent procedures & software
  - New IGS orbits should be available by end of 2009
- Need to wait to receive reprocessed regional solutions
  - Scripps nearly finished (using their own reprocessed orbits)
  - NGS started (using their own reprocessed orbits)
  - NRCan (waiting to use official IGS reprocessed orbits)
  - MIT/PBO (waiting to use official IGS reprocessed orbits)
- New ITRF2008 should also be available by end of 2009