Constraints on Intra-Continental Strain Rates and Glacial Isostatic Adjustment from Thousands of GPS Velocities

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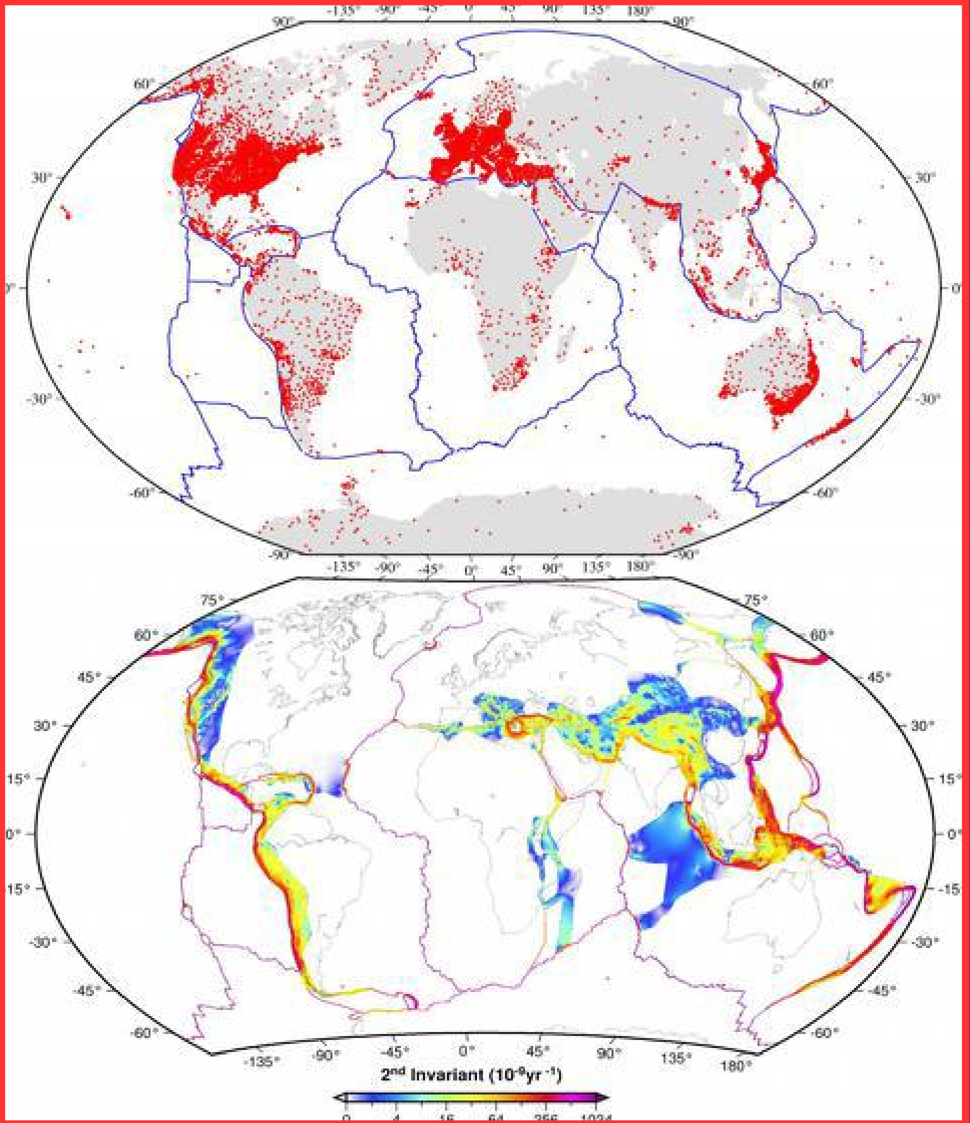


The Nevada Geodetic Laboratory (NGL) processes all publicly available CGPS RINEX data in the world (16,000+, figure left) using GIPSY PPP

Most time-series available at geodesy.unr.edu

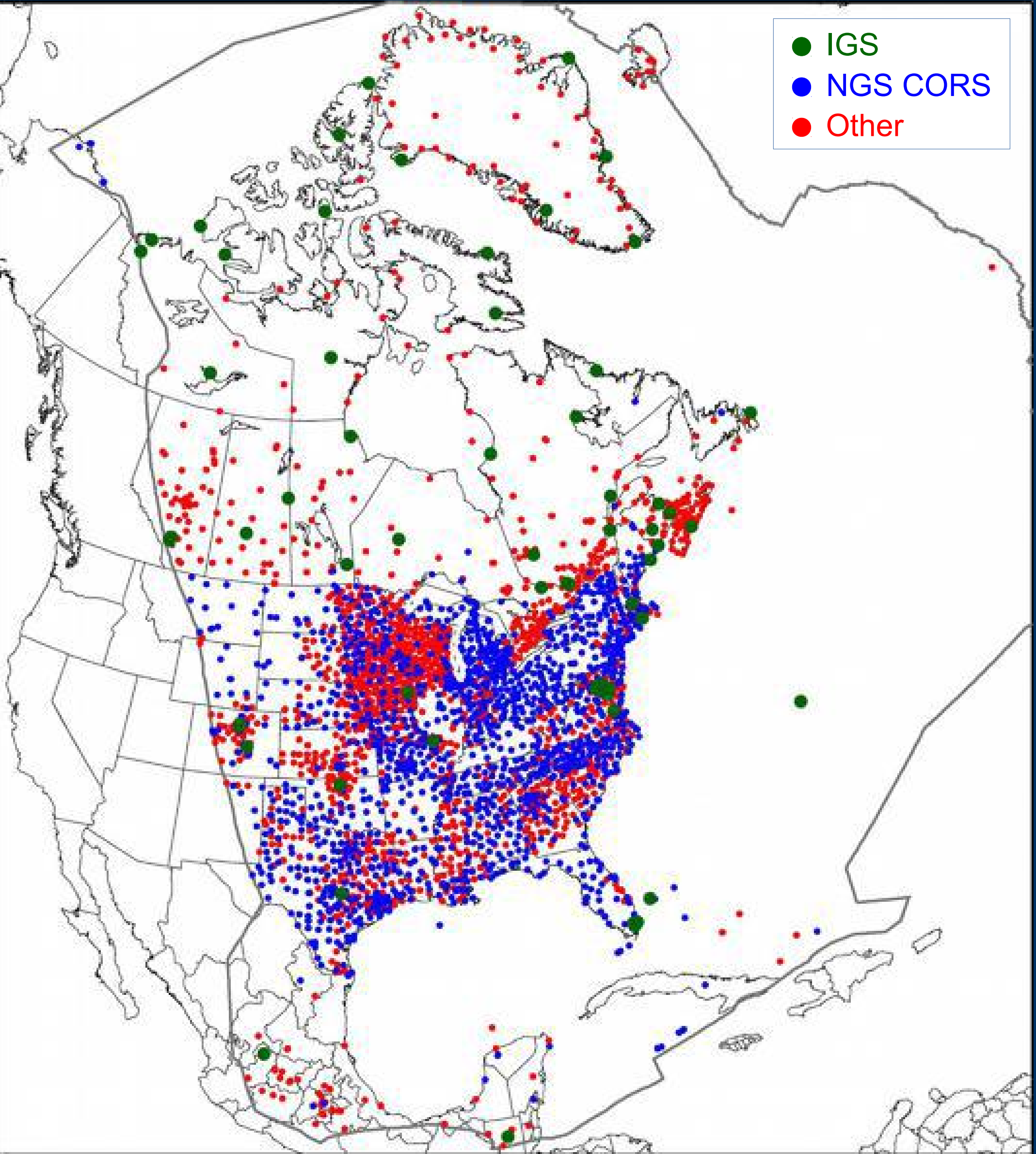
Many applications: plate tectonics, GIA, sea-level, hydrology, earthquakes, reference frames, ionosphere, troposphere….more….

Global Strain Rate Model v2.1 (figure left) [*Kreemer et al.*, 2014] most recent representation of strain accumulation in plate boundaries

+ Already used for earthquake rate forecasts [*Bird and Kreemer*, 2015, *Bird et al.*, 2015]

+ However, intraplate areas have been omitted

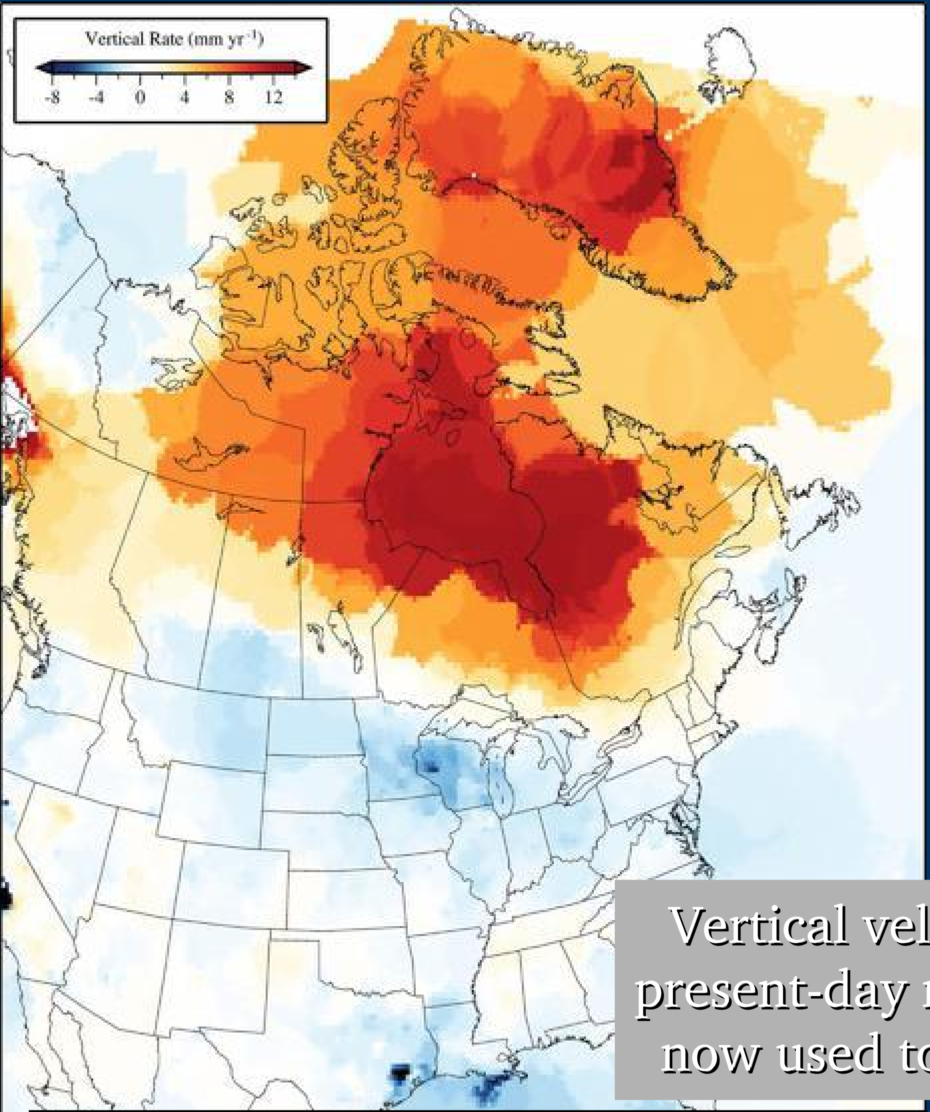
+ Today's Focus: North America



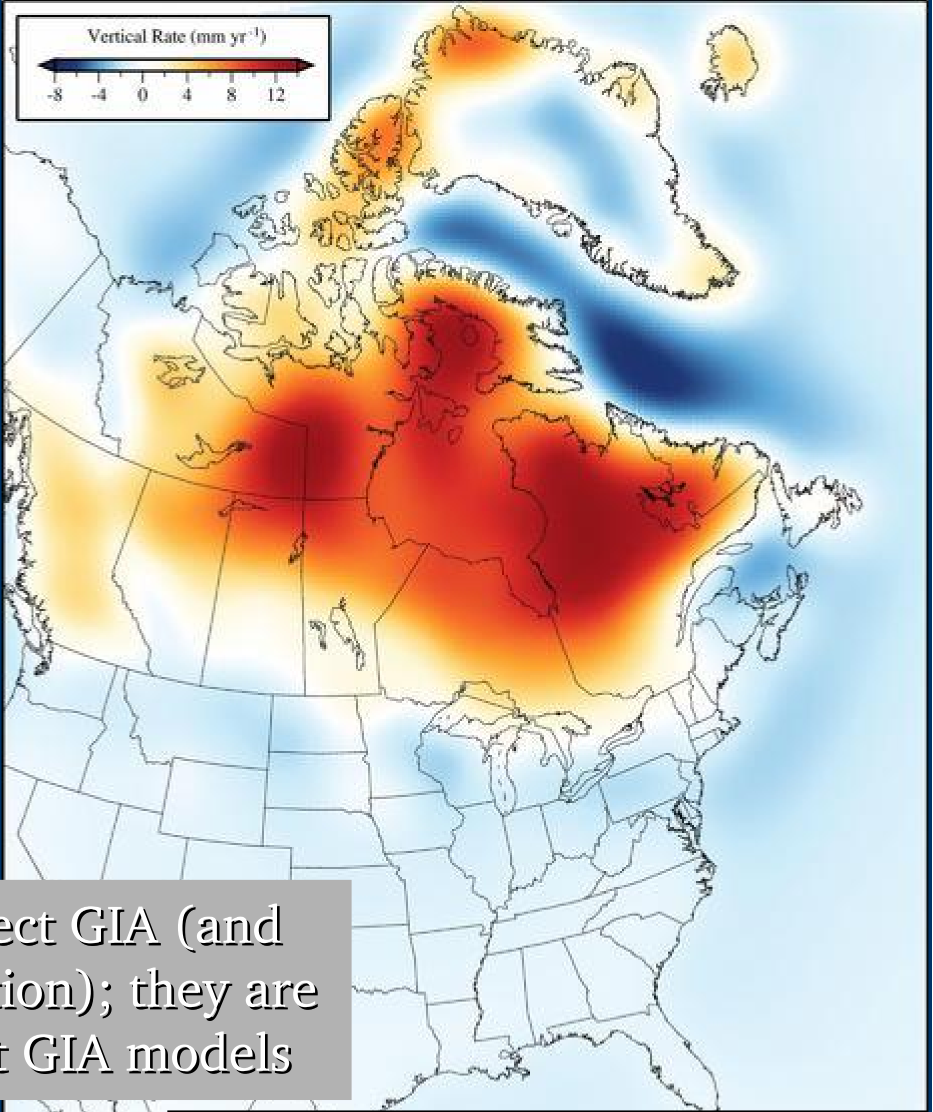
Data Explosion

3879 CGPS stations (incl. CBN) inside stable North America footprint

+ ~1700 are part of NGS CORS
+ Remainder:
  - regional/state networks (DOT, commercial), incl Leica Smartnet
  - PBO backbone
  - NRCan stations, Canada (incl. CBN)
  - CHAIN, Canada
  - Polenet-Greenland + DTU stations

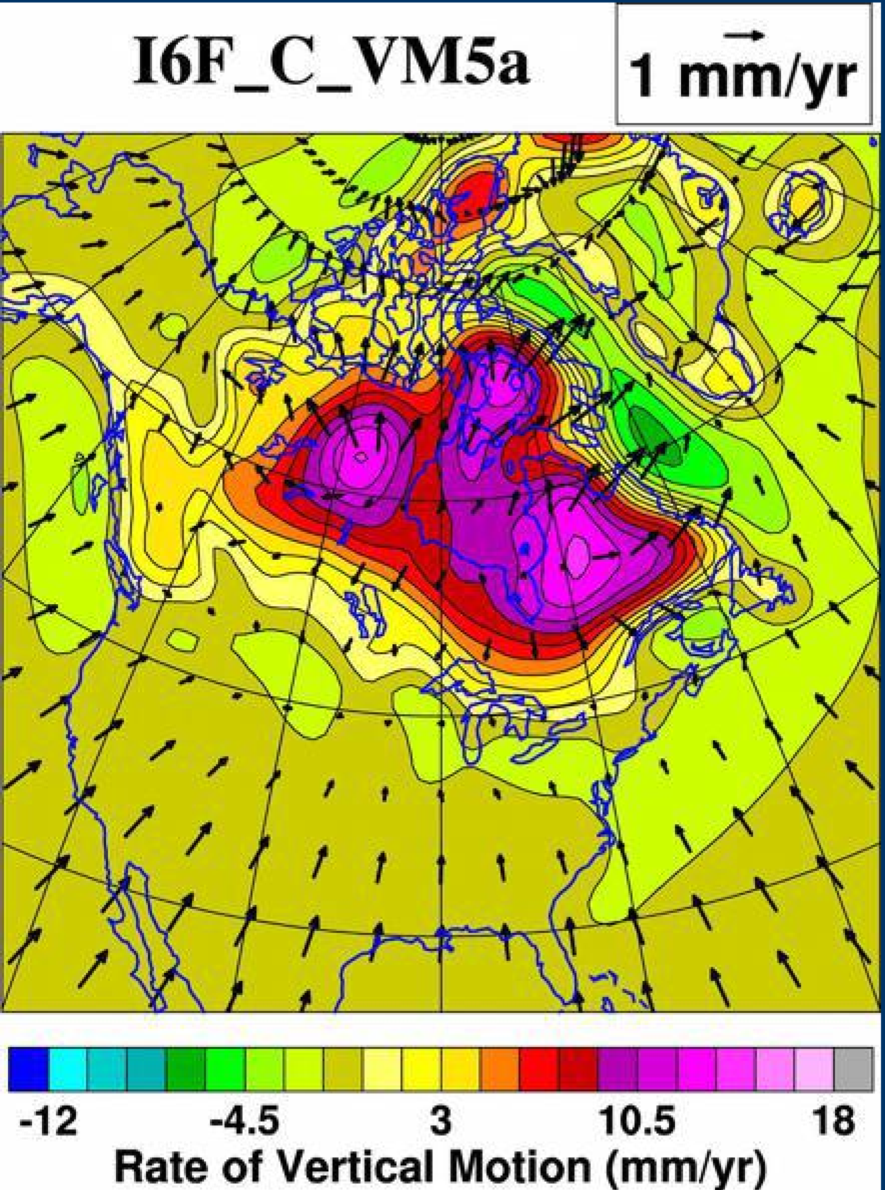


Observed Interpolated Vertical Velocities



ICE6G_C (VM 5a) [*Peltier et al.*, 2015]

Vertical velocities reflect GIA (and present-day mass variation); they are now used to constraint GIA models



Horizontal Constraints

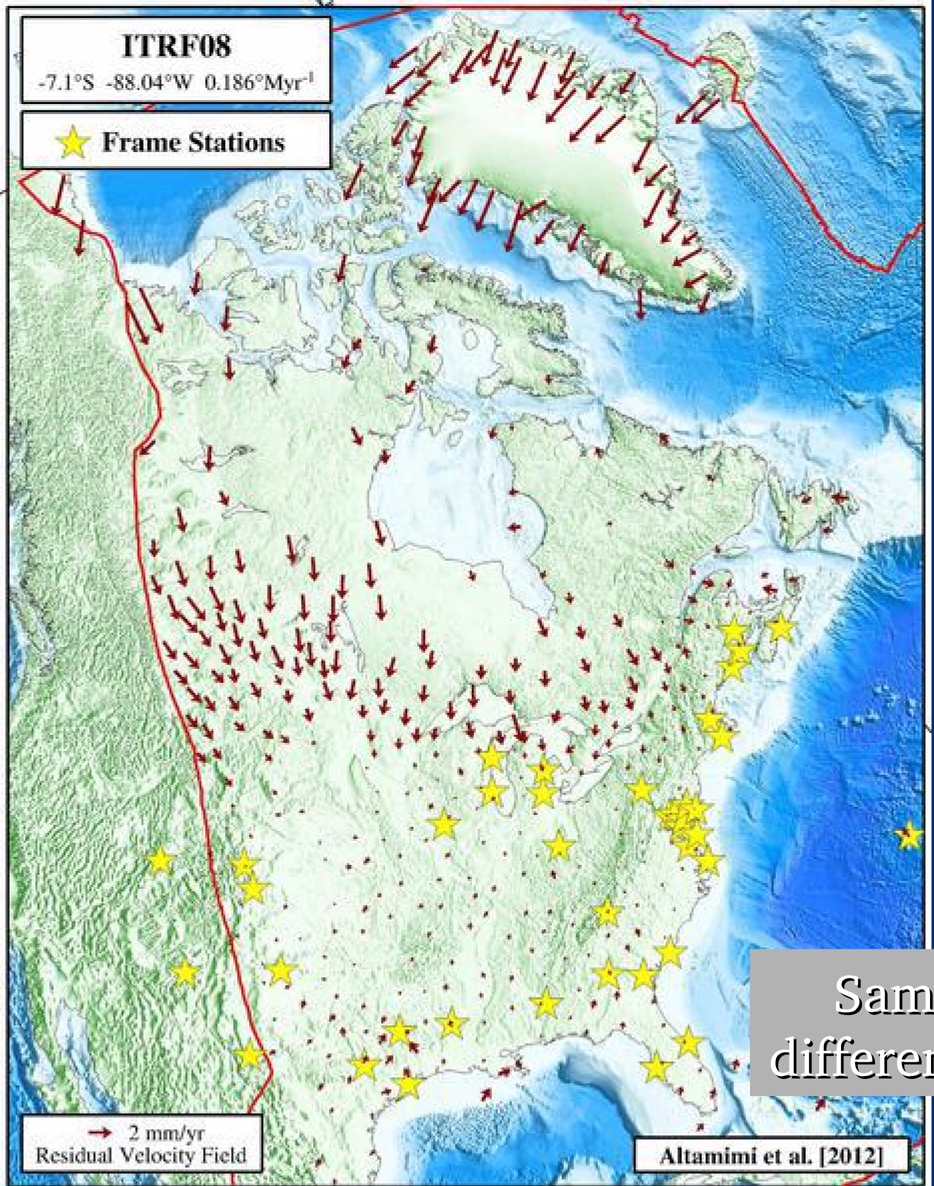
Horizontal deformation can potentially provide powerful constraints on GIA (i.e., viscosity structure)

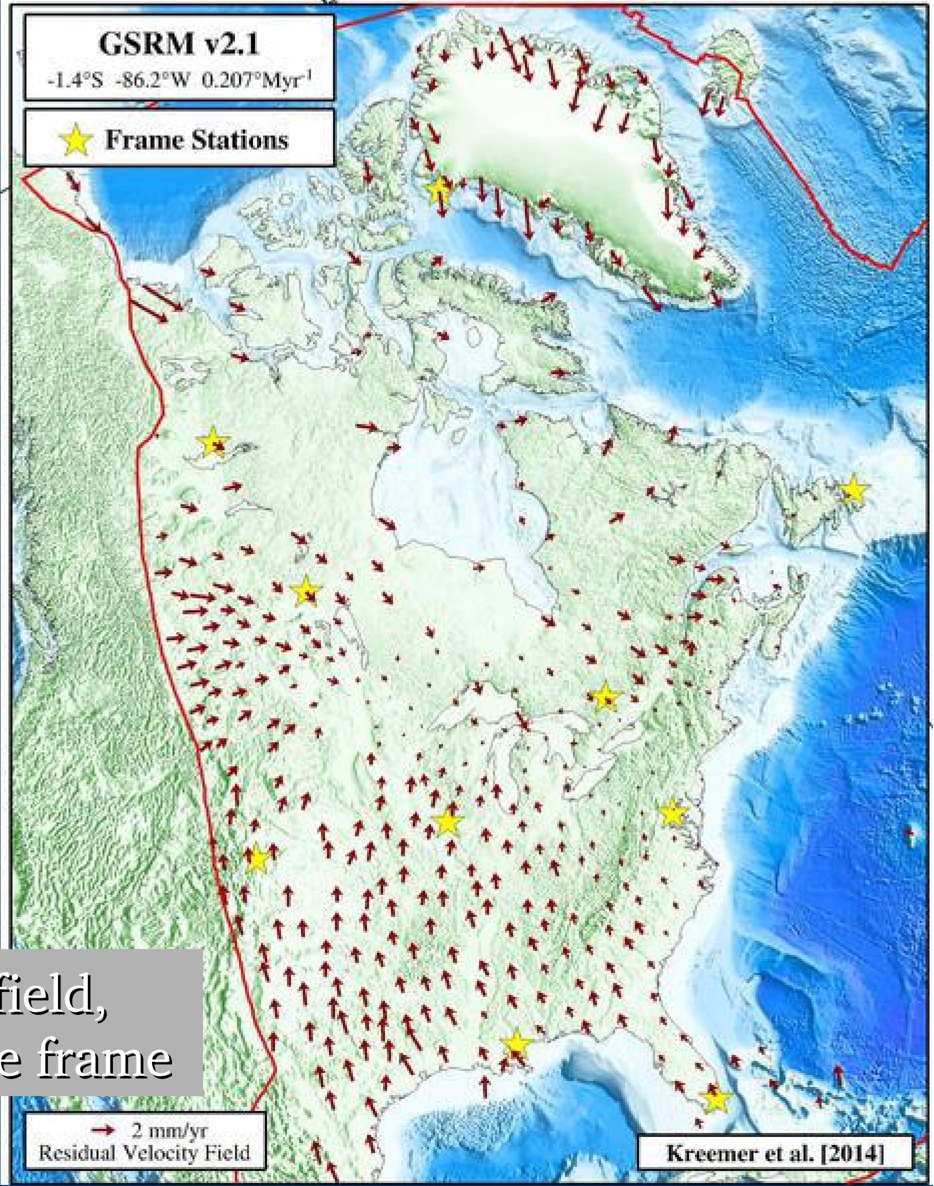
However, horizontal motions are subject to choice of reference frame

- No stable reference frame may exist if entire plate is affected
- Choice of frame should not rely on choice of GIA model

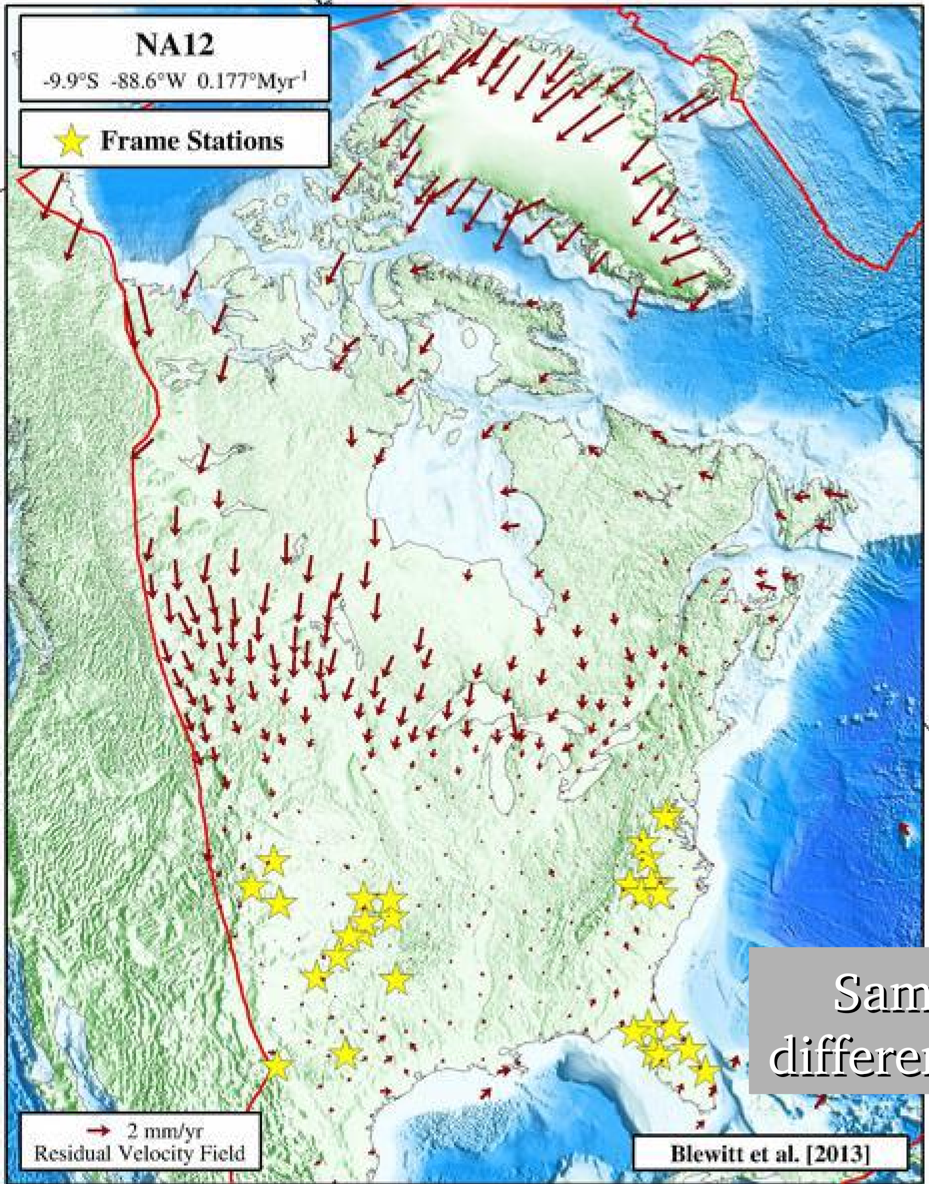
Horizontal strain rates may be more useful, because they are reference frame independent, however:

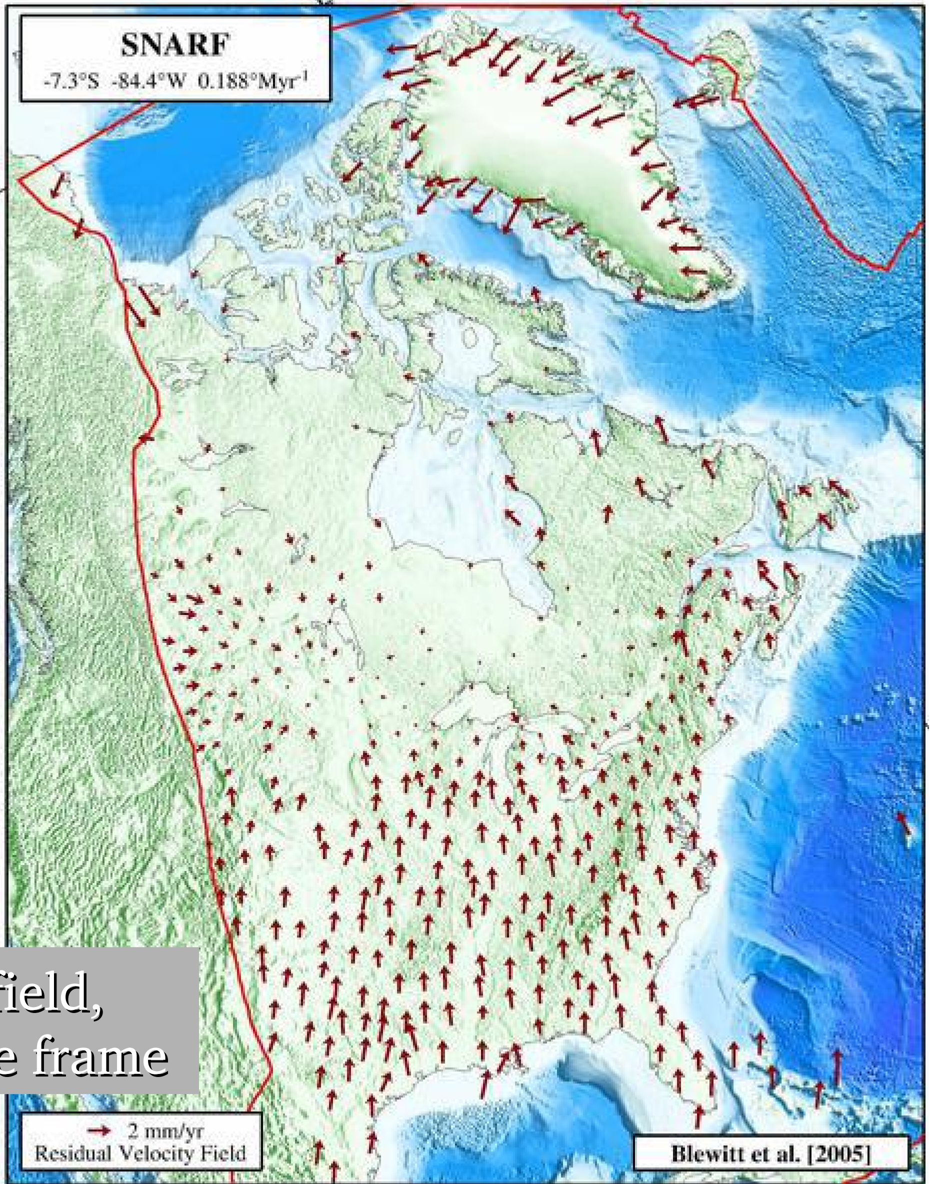
- Strain rates are at level at noise in data
- Strain rates are sensitive to outlier velocities
- Problem enhanced when station distance small





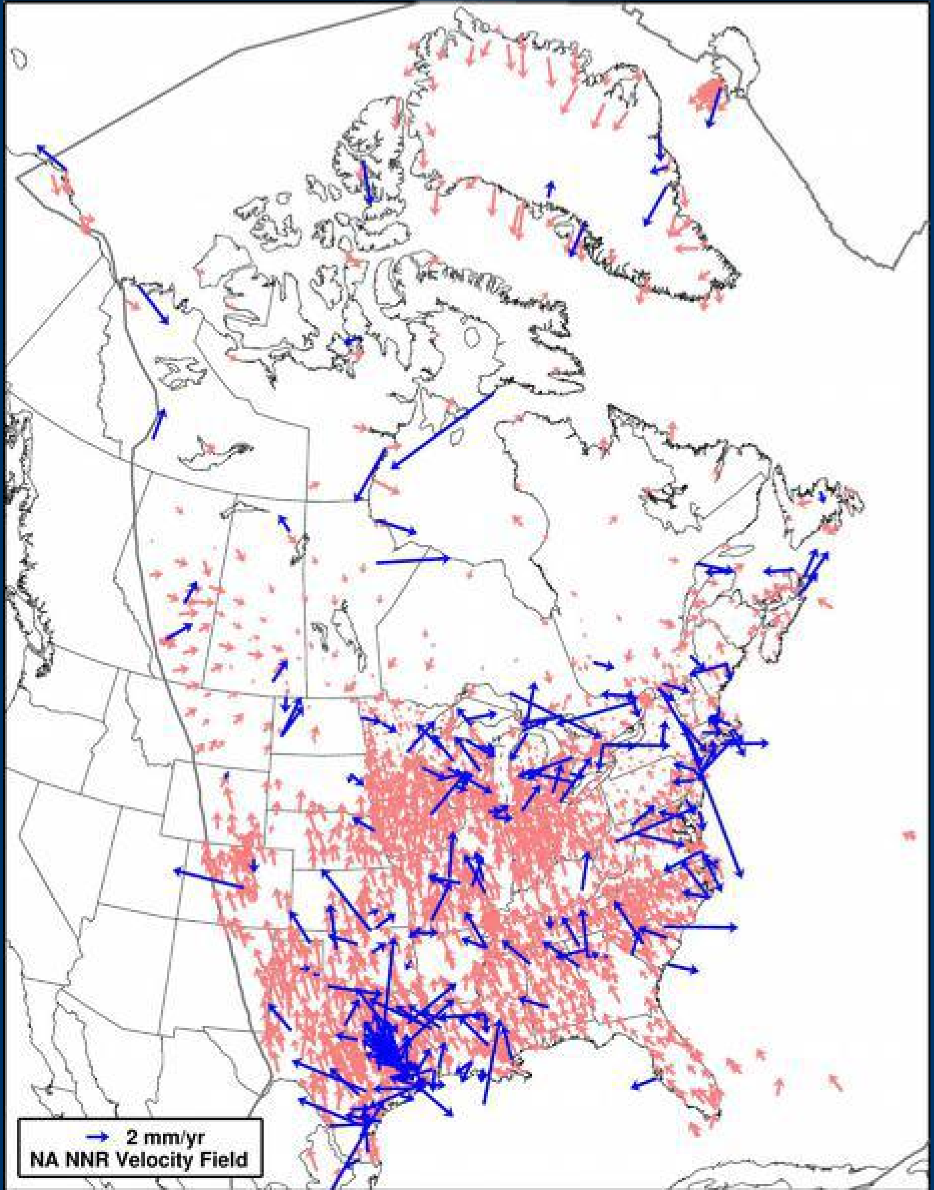
Same velocity field, different reference frame





Same velocity field,
different reference frame

Data Selection



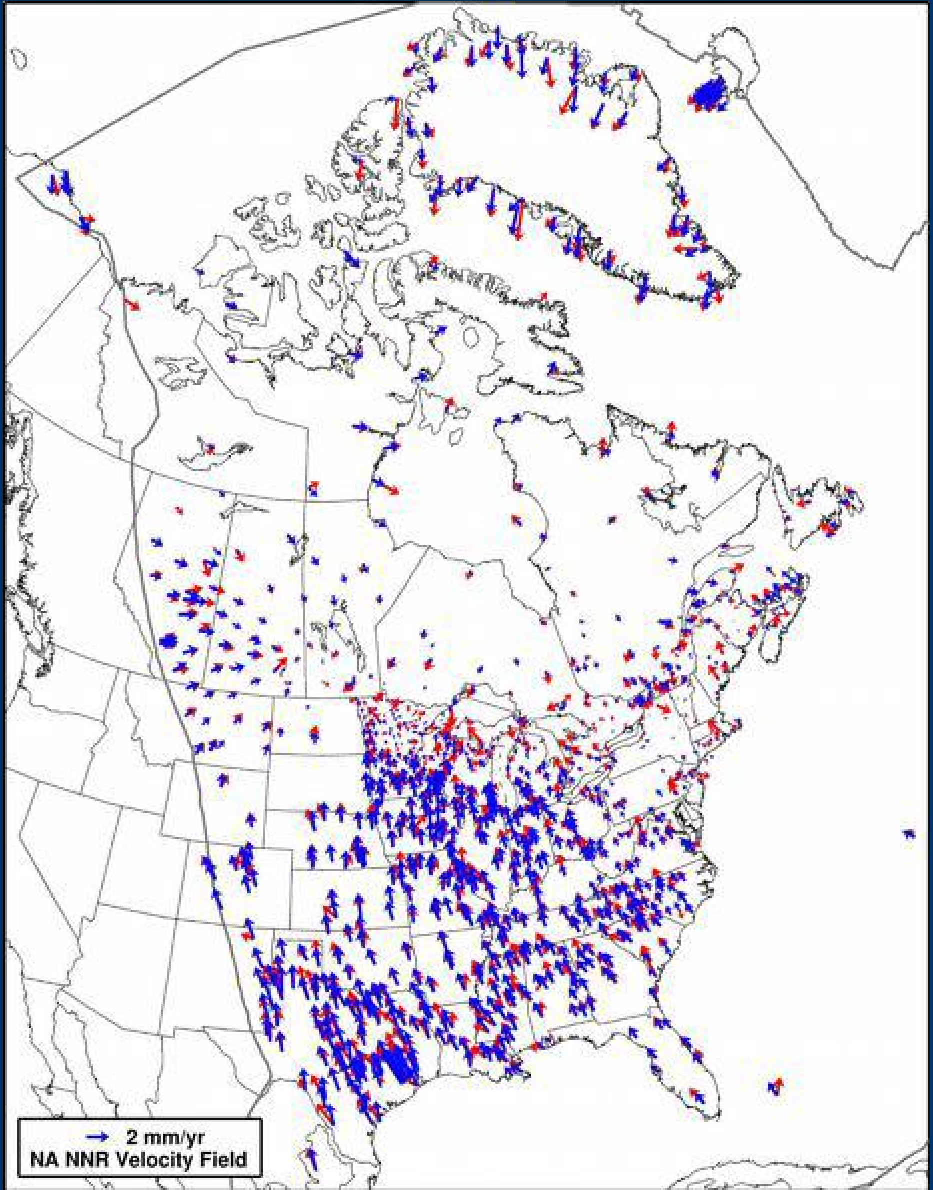
Velocities determined in IGS08 frame with MIDAS robust trend-estimator algorithm [*Blewitt et al.*, 2016]

Only time-series with >2.5 years of data → 2767 velocities

We added 17 CGPS velocities for Quebec [*Goudarzi et al.*, 2016] and 18 campaign velocities for Vestfirdir peninsula, Iceland [*Arnadottir et al.*, 2009]

Velocity outlier detection algorithm based on comparison of observed velocity with that predicted by the local velocity gradient derived from neighboring velocities (Left figure)→ 2531 velocities

Combined co-located velocities → 2194 velocities

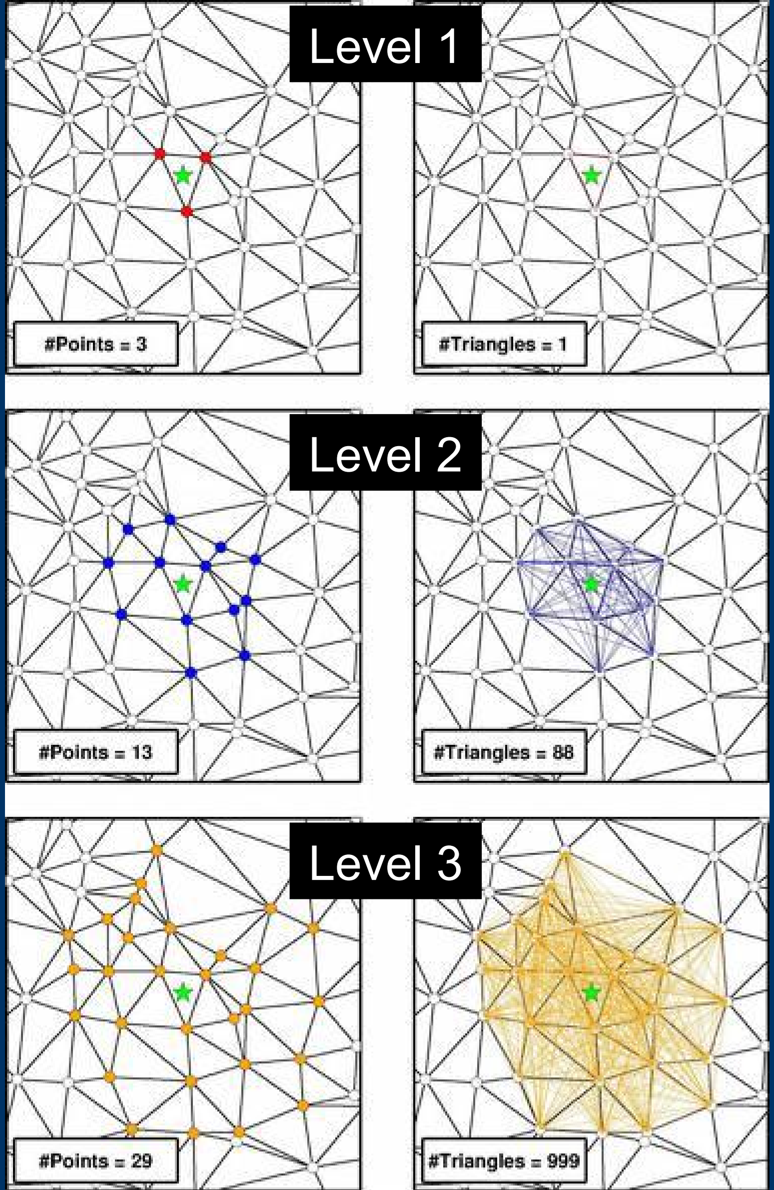


Data Selection

To further reduce the effect of outliers, each velocity is replaced by the median of the nearest neighbors using the “GPS Imaging” technique [*Hammond et al.*, 2016]

Each velocity is weighted based on distance.

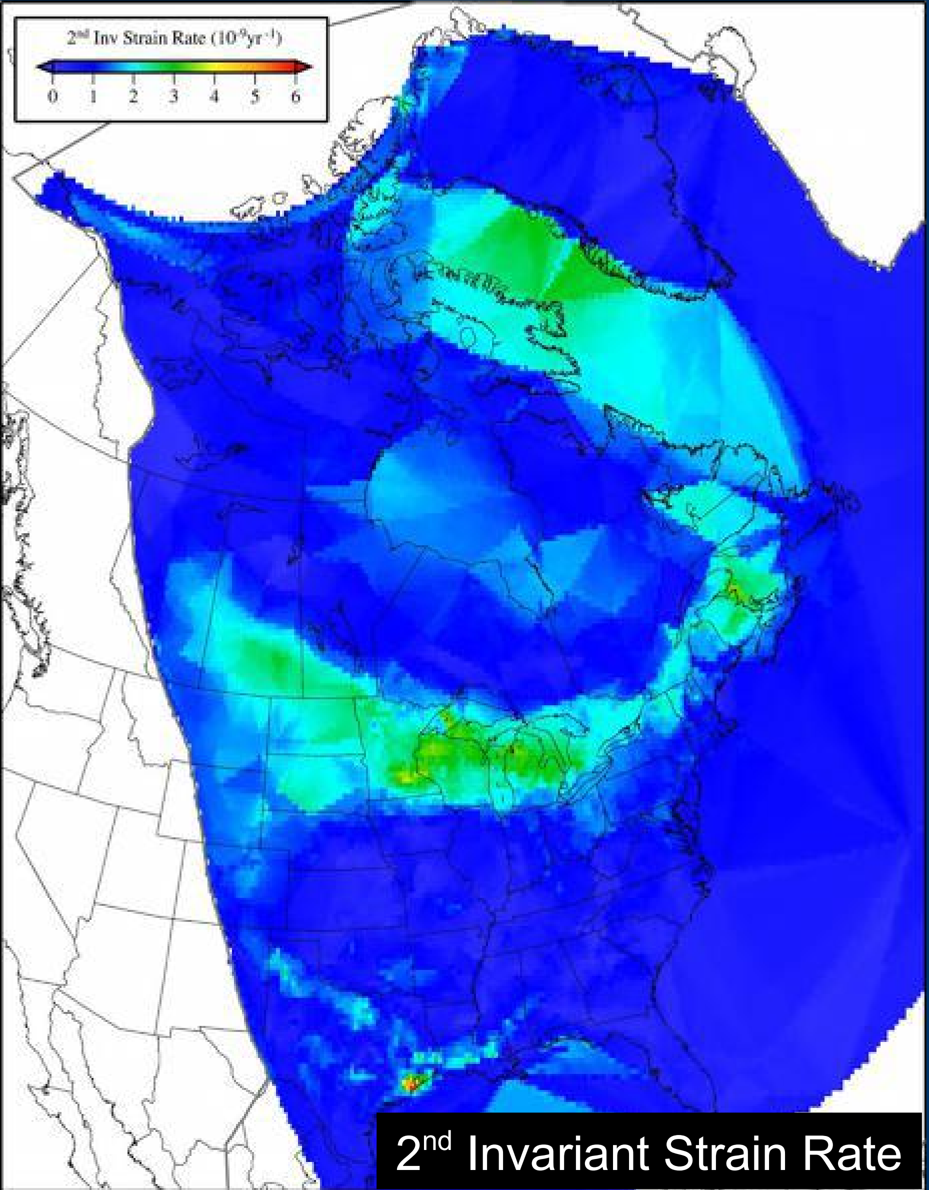
Technique is also applied to vertical velocities. For the horizontal velocities, a local rotation is first removed and then added back to the median.

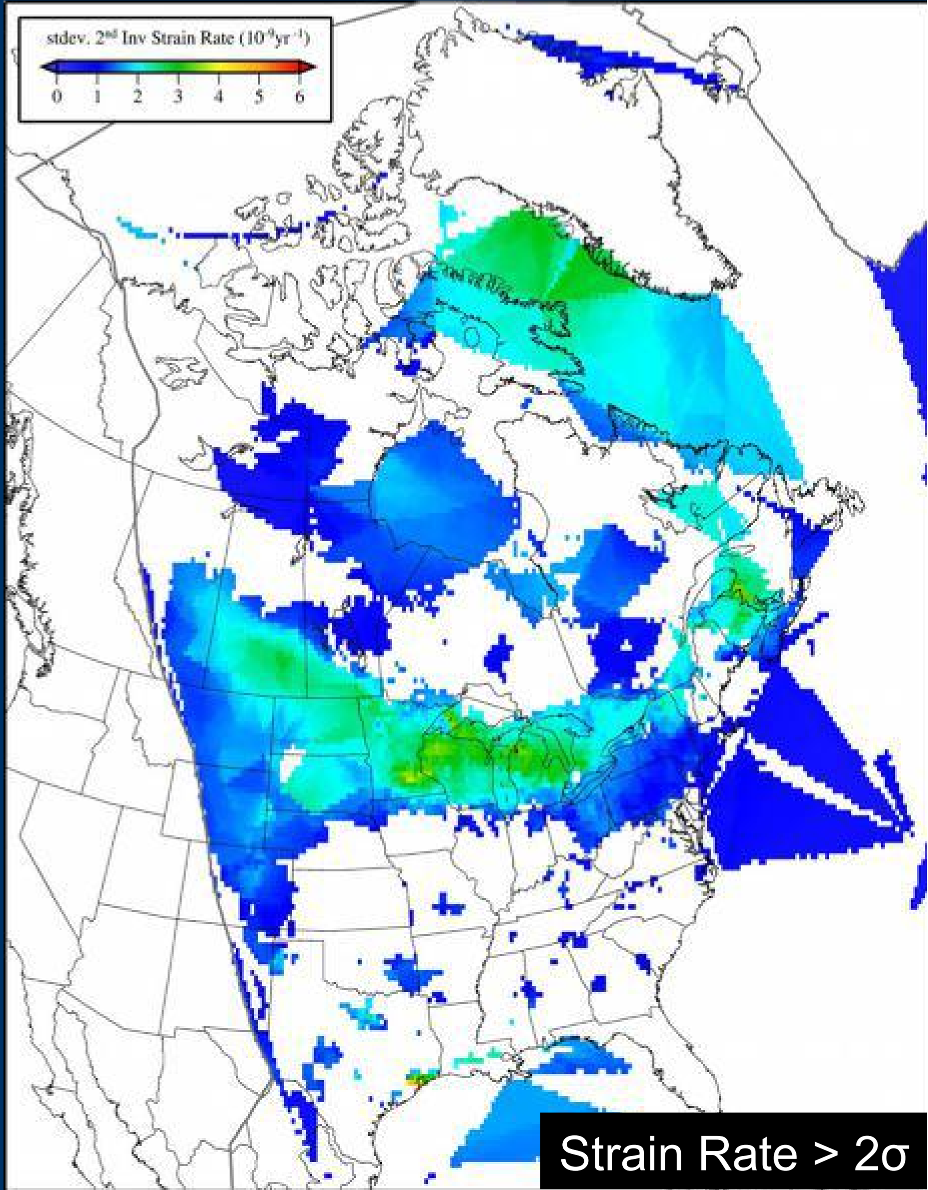


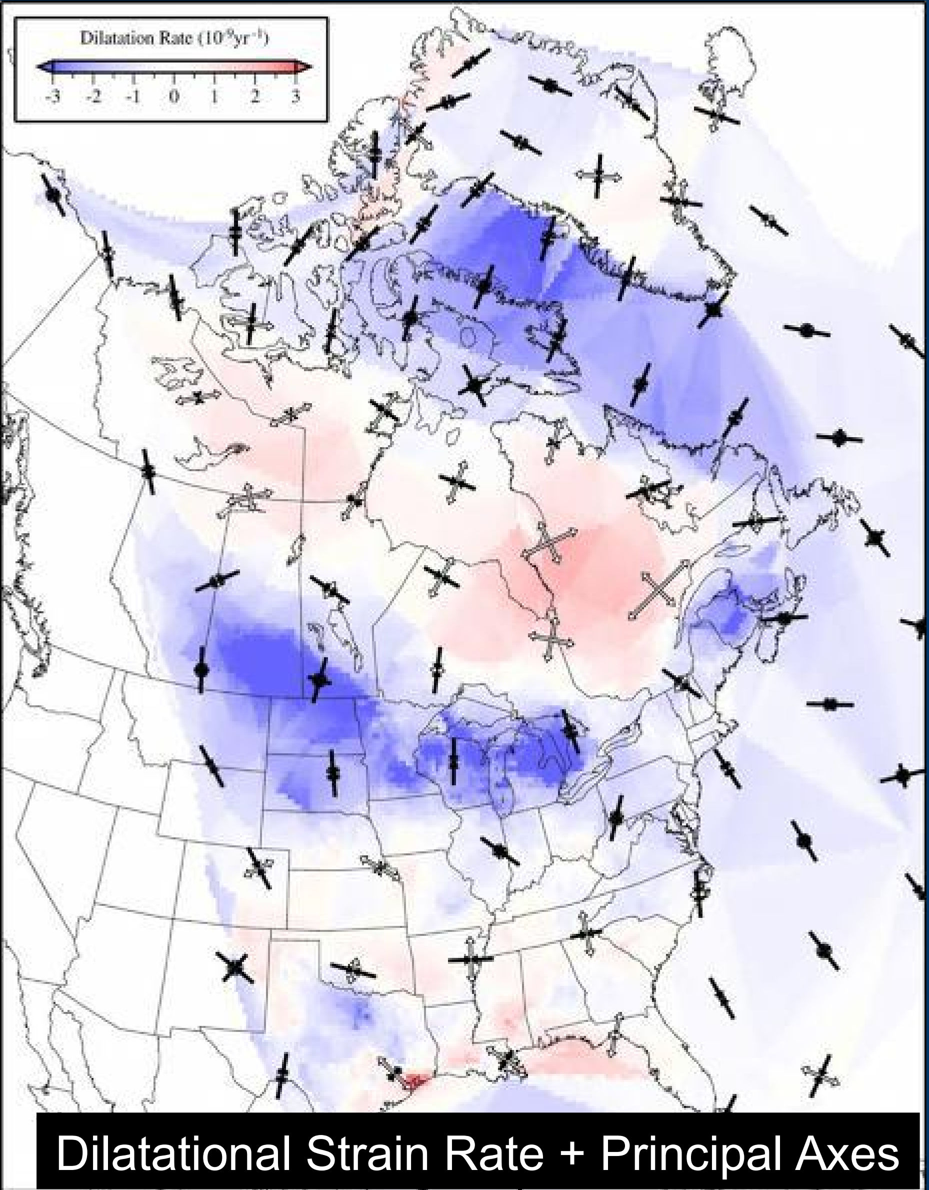
MELD Algorithm

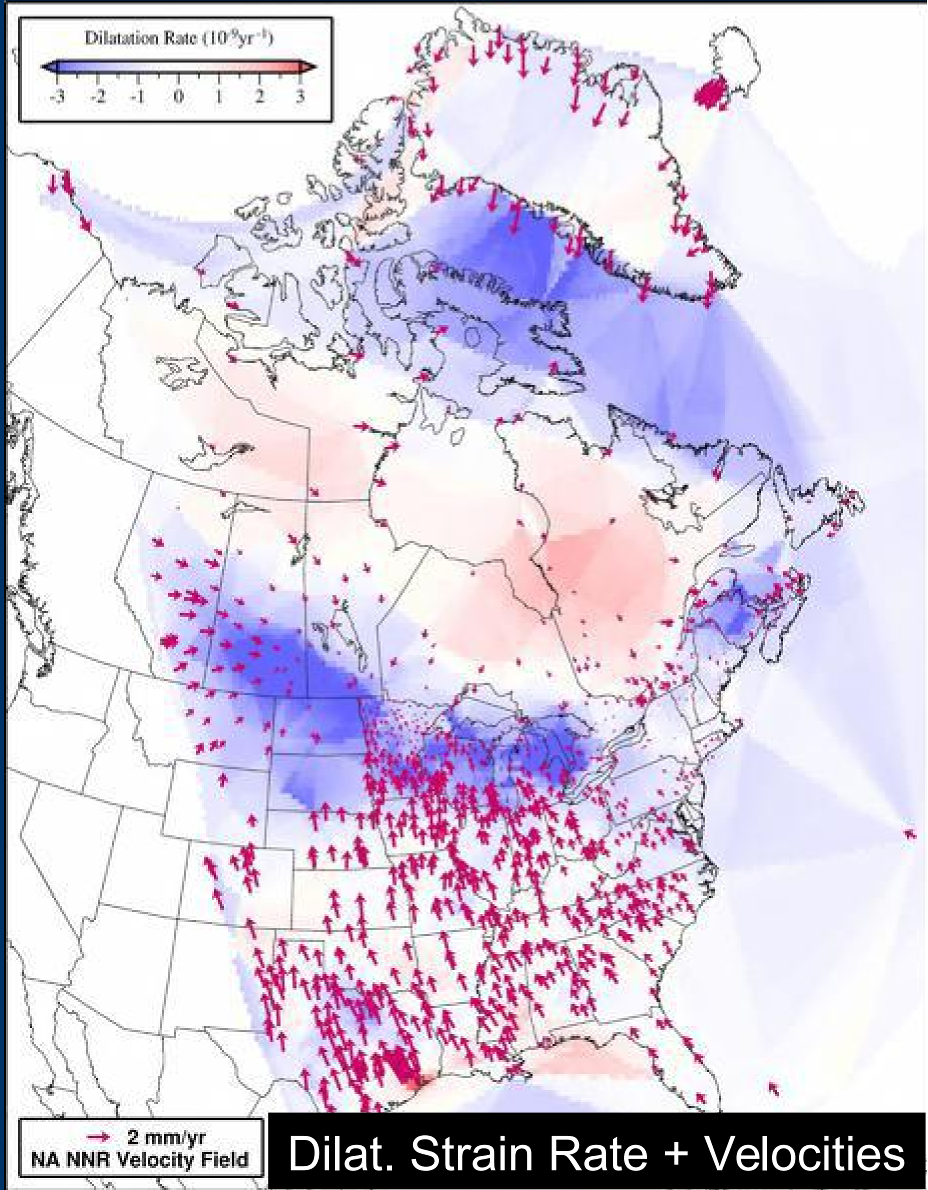
MELD: Median Estimate of Local Deformation

1. Delaunay triangulation of data points
2. Find triangle in which eval. pt. resides
   This would allow strain rate estimate based on three most-local velocities ('Level 1')
3. Level 2 considers all additional data points one level away from Level 1.
4. Create all possible triangles of those points.
5. Exclude small and 'skinny' triangles.
6. First consider only triangles that encompass eval. pt. If N_{min}=100 is not reached, also consider triangles that don't encompass point.
7. Go to Level 3 if N_{min} is still not reached, etc.
8. Take median value of strain and rotation rate components

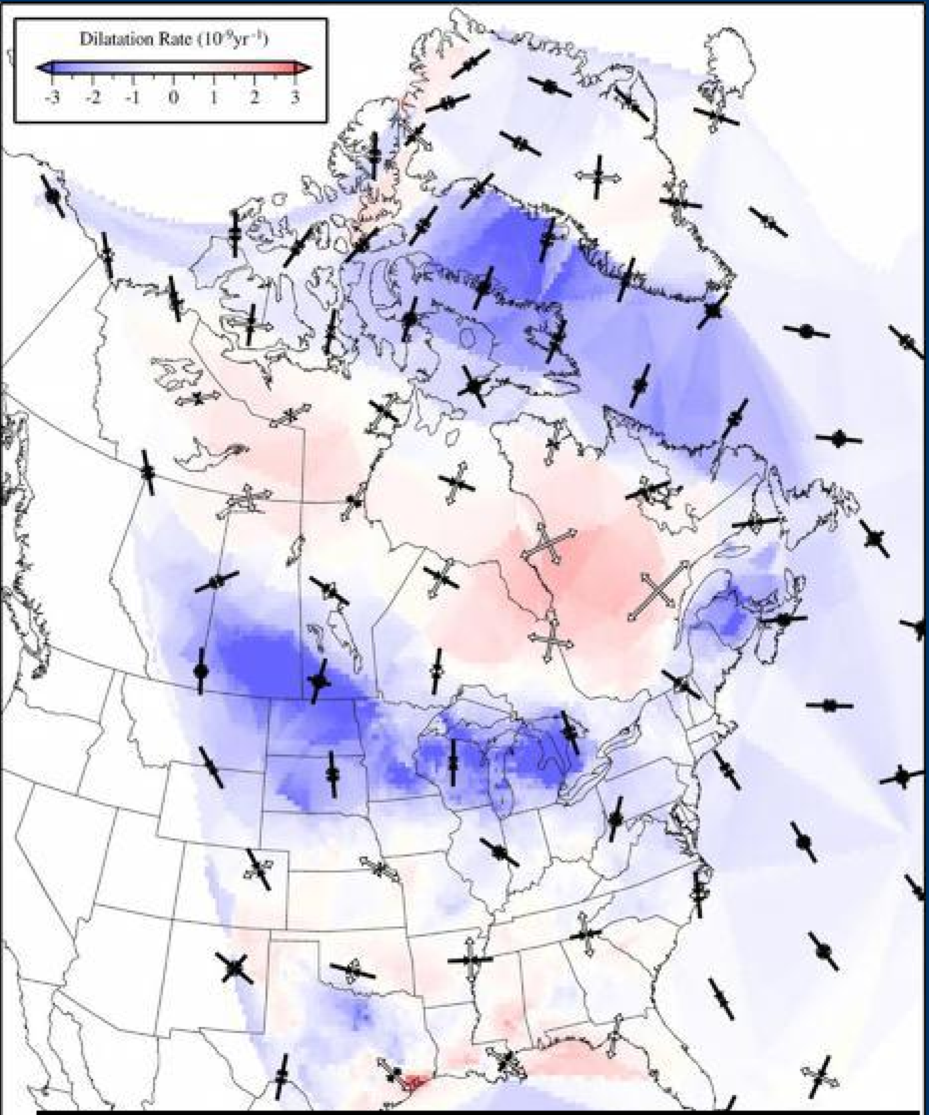

2nd Inv Strain Rate (10⁻⁹yr⁻¹)
0 1 2 3 4 5 6
2nd Invariant Strain Rate


stdev. 2nd Inv Strain Rate (10⁻⁹yr⁻¹)
0 1 2 3 4 5 6
Strain Rate > 2σ


Dilatation Rate (10⁻⁹yr⁻¹)
-3 -2 -1 0 1 2 3
Dilatational Strain Rate + Principal Axes


Dilatation Rate (10⁻⁹yr⁻¹)
-3 -2 -1 0 1 2 3
2 mm/yr
NA NNR Velocity Field
Dilat. Strain Rate + Velocities

Strain Rate Model



Dilatational Strain Rate + Principal Axes

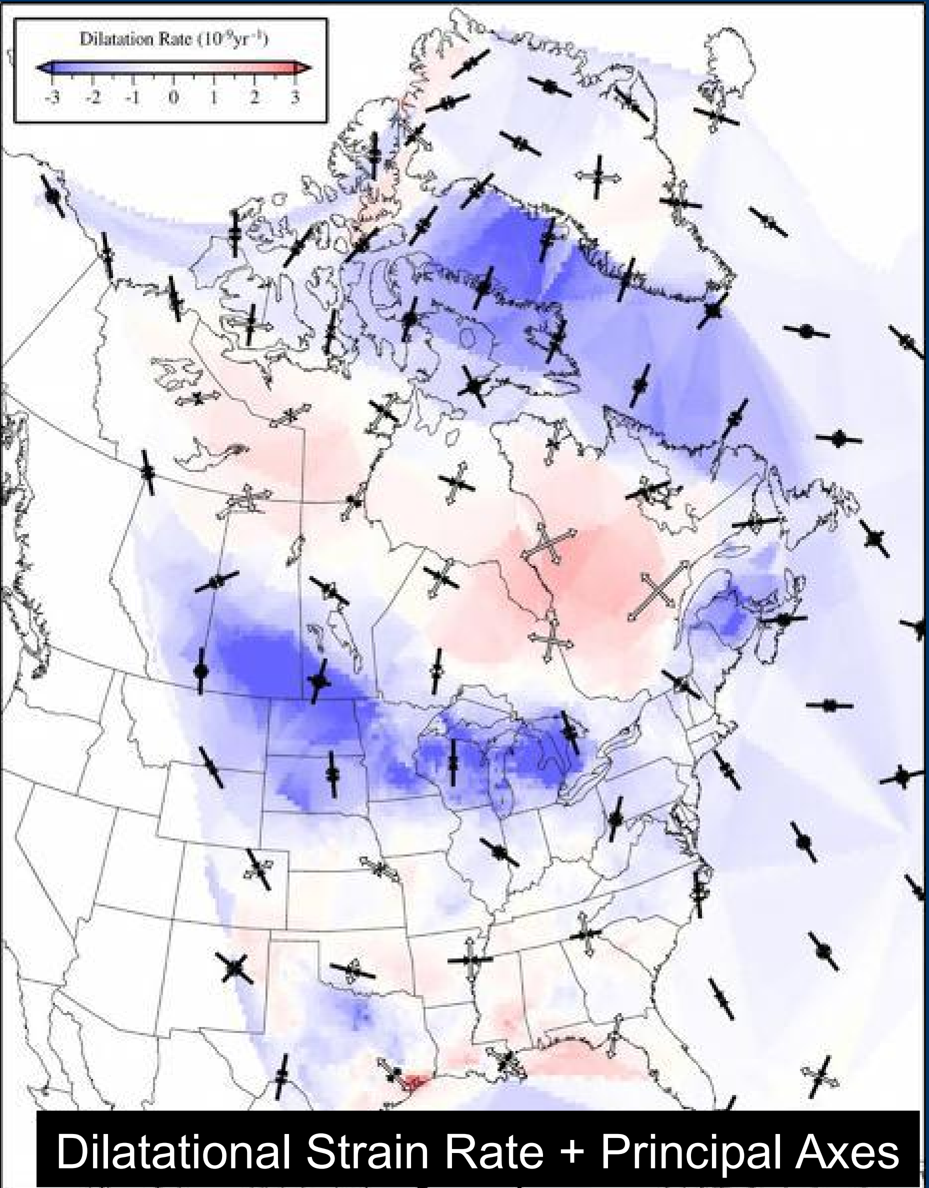
Two centers of positive dilatation (i.e., extension) east and west of Hudson Bay.

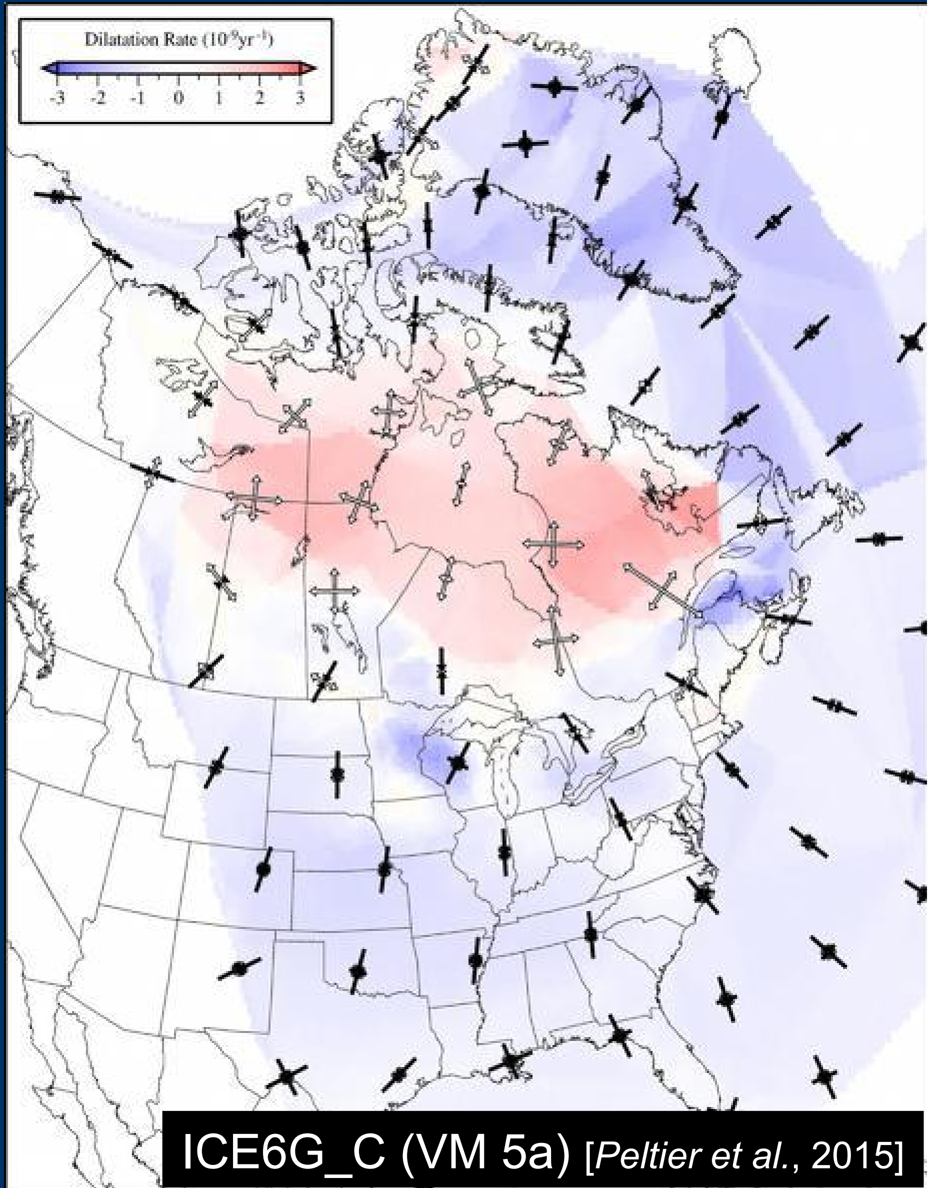
Extension mostly bi-axial

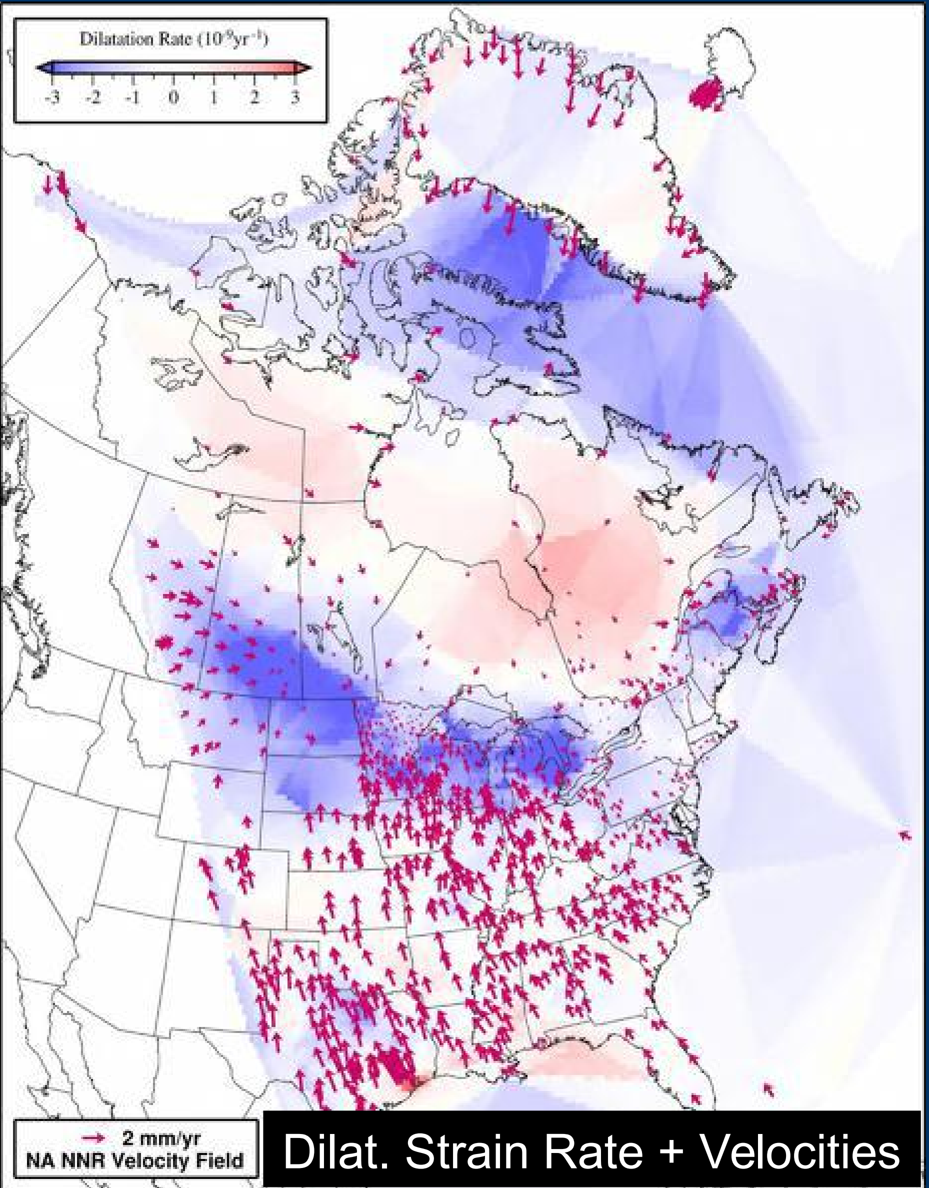
Negative dilatation (i.e., contraction) in belt from Canadian Great Plains, to Great Lakes, New England, and Davis Strait/Baffin Bay

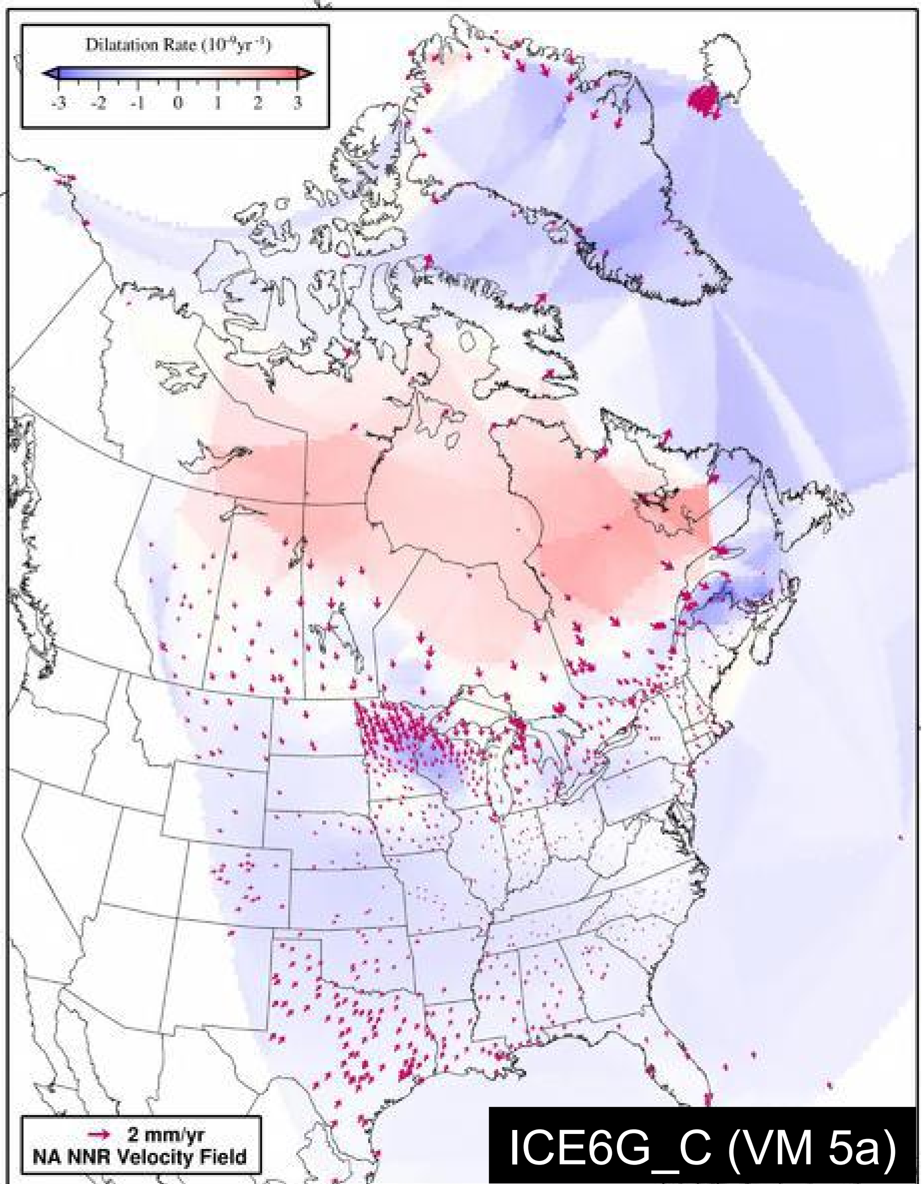
Contraction direction there is orthogonal to belt; i.e., radial to former ice sheet

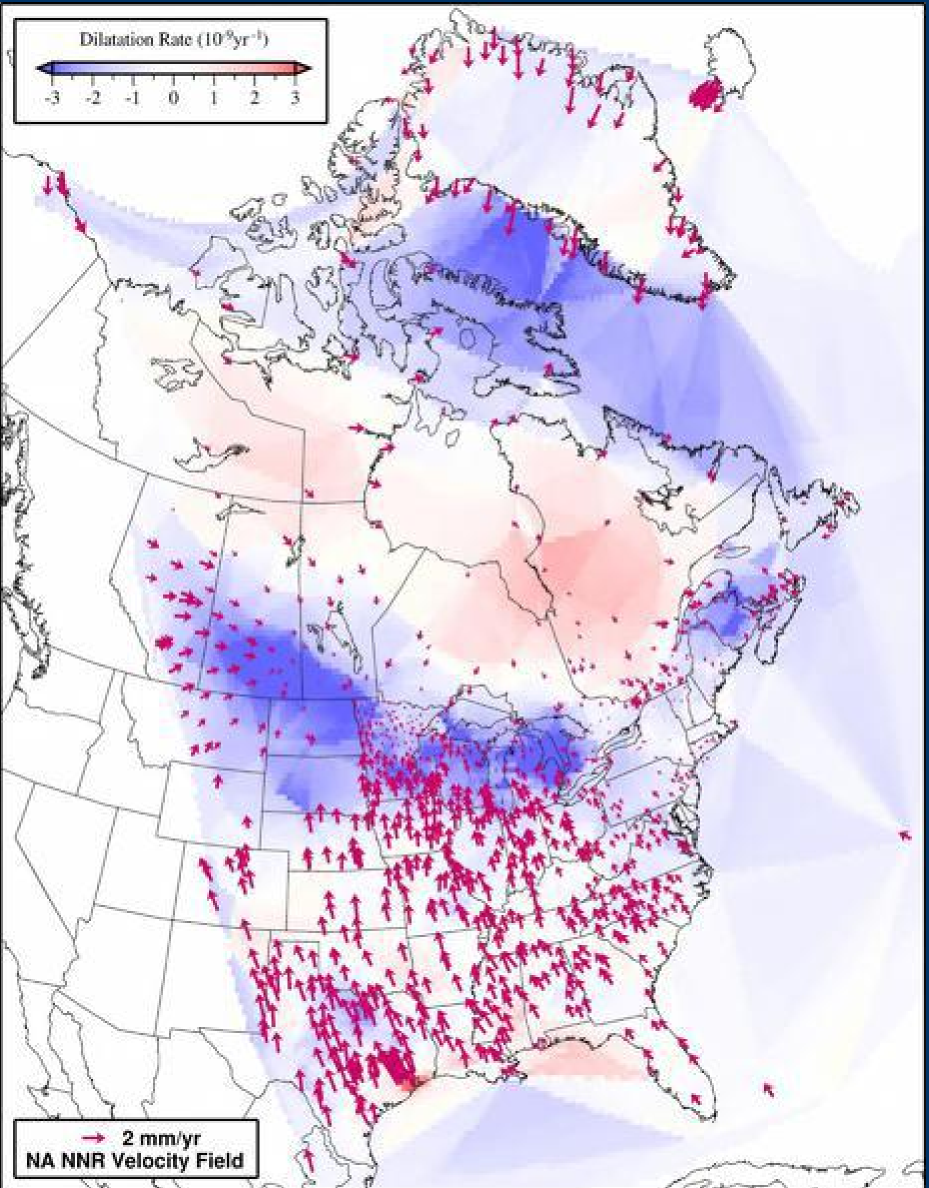
Positive dilation along Gulf Coast with extension direction towards Gulf


Dilatation Rate ($10^{-9}yr^{-1}$)
-3 -2 -1 0 1 2 3
Dilatational Strain Rate + Principal Axes


Dilatation Rate ($10^{-9}yr^{-1}$)
-3 -2 -1 0 1 2 3
ICE6G_C (VM 5a) [*Peltier et al.*, 2015]


Dilatation Rate (10⁻⁹yr⁻¹)
-3 -2 -1 0 1 2 3
2 mm/yr
NA NNR Velocity Field
Dilat. Strain Rate + Velocities


Dilatation Rate (10⁻⁹yr⁻¹)
-3 -2 -1 0 1 2 3
2 mm/yr
NA NNR Velocity Field
ICE6G_C (VM 5a)



Summary

1. We present a new strain rate model for intraplate North America

2. The strain rate field is determined by a new median-based algorithm that's designed for low straining areas and robust against outlier data

3. Result is dominated by contractional strain rates in a belt around the former ice-sheet and extensional strain rates underneath ice-sheet

4. Far-field intraplate velocities are ~2 mm/yr towards former ice-sheet

5. Strain rate pattern and magnitude are largely consistent with those for ICE6G_C (VM5a), but some significant differences exist as well