Your Advisor Said, “Get the GPS Data and Plot it”

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Actual GPS Data

```
     2.11           OBSERVATION DATA    G (GPS)             RINEX VERSION / TYPE
teqc  2015Jun23     UNAVCO Archive Ops  20150701 01:44:30UTCPGM / RUN BY / DATE
Solaris x86 5.10|AMD64|cc SC5.8 -xarch=amd64|=+|=+          COMMENT
BIT 2 OF LLI FLAGS DATA COLLECTED UNDER A/S CONDITION       COMMENT
WIKR                                                        MARKER NAME
                                                            MARKER NUMBER
Glen Mattioli       UNAVCO                                  OBSERVER / AGENCY
4602203972          TRIMBLE NETRS       1.3-2               REC # / TYPE / VERS
0220368143          TRM29659.00     SCIT                    ANT # / TYPE
 -2489773.1435 -1384526.1041  5688747.8689                  APPROX POSITION XYZ
        0.0083        0.0000        0.0000                  ANTENNA: DELTA H/E/N
     1     1                                                WAVELENGTH FACT L1/2
     7    L1    L2    C1    P2    P1    S1    S2           # / TYPES OF OBSERV
    15.0000                                                 INTERVAL
    16                                                      LEAP SECONDS
input file: wikr201506300000a.tgd                           COMMENT
RINEX file created by UNAVCO GPS Archive.                   COMMENT
For more information contact archive@unavco.org             COMMENT
Monument ID: 22361                                          COMMENT
UNAVCO 4-char name:   WIKR                                  COMMENT
4-char name from Log or data file: WIKR                     COMMENT
Monument location: 63.55273 -150.92221 1188.7396            COMMENT
Visit ID: 111793                                            COMMENT
                                                            COMMENT
Wickersham_Dome_Kantishna_AK_2008_CGPS                      COMMENT
                                                            COMMENT
End of DB comments                                          COMMENT
 SNR is mapped to RINEX snr flag value [0-9]                COMMENT
  L1 & L2: min(max(int(snr_dBHz/6), 0), 9)                  COMMENT
  2015     6    30     0     0    0.0000000     GPS         TIME OF FIRST OBS
                                                            END OF HEADER
 15  6 30  0  0  0.0000000  0 11G03G31G23G29G12G10G06G14G25G24G02
  -4562196.281 6  -3411297.41043  24842319.313    24842312.879
        37.600          21.100
 -13867332.978 7 -10789914.60846  22703995.445    22703983.211
        47.600          36.800
  -1579648.135 6  -1117138.17143  25814542.711    25814531.824
        38.100          21.100
 -17449085.778 7 -13504056.95446  22286843.688    22286833.387
--More--(0%)
```

GPS Data are phase and pseudorange data that measure **distances to satellites**.

Positions are **estimated** from these measurements.

Velocities, displacements during earthquakes, etc are **estimated from the positions**.

GPS Data Products

- GPS Data vs. GPS Data Products
  - Orbits and clocks
  - Positions
- What are they?
- Where are they?
- What formats/etc are they in?
- Where can you find documentation for them?
- What do you need to know to use them?

Positions Depend on Products Used

- The position you estimate for a GPS site for a given day depends not only on the data, but also on what products and models are used in the estimation process:
  - Satellite orbits
  - Satellite clock biases or subnetwork/baseline definition
  - Elevation angle cutoff of the data, plus weighting
  - A multitude of calibration models
- The inversion is linearized about an a priori estimate, so your starting values can also matter.
- An example from my own solution system:

```
solve 15jun25DenaliSummit -orbfiletype pos -pcmodeltype
abs.atx -use_domes -use_azel -tropmap GMF -apriori_trop
GPT -elevmin 10 -oceanload tpxo7only_CM -strategy LOCALTIE
-subnet $SUBNETS/DenaliSummit.subnet -ambresol >&
15jun25DenaliSummit.daily
```

Some Important Processing Models

- Tropospheric delay (estimated)
  - Hopfield, Saastamoinen, Lanyi, Niell, **GMF, VMF1**
- Earth tides (well known)
  - Up to ~70 cm amplitude
- Ocean Tidal Loading
  - Response of solid earth to changing load of ocean tides
- Antenna Phase Center variations with elevation
  - Phase center is the point on the antenna that we actually measure distances to
  - It is an imaginary point in space, not a physical point

Models and Corrections Evolve with Time

- Many of the models used are adopted by community convention, and thus "standard"
- All of the models can be improved, and there has been steady improvement over the last 30 years.
  - Factor of ~30 improvement in GPS positioning accuracy from 1985 to 2015!
  - My expectation is that a further factor of 3-10 improvement will come in the next 10-15 years from improved modeling and multi-GNSS.

Consequences

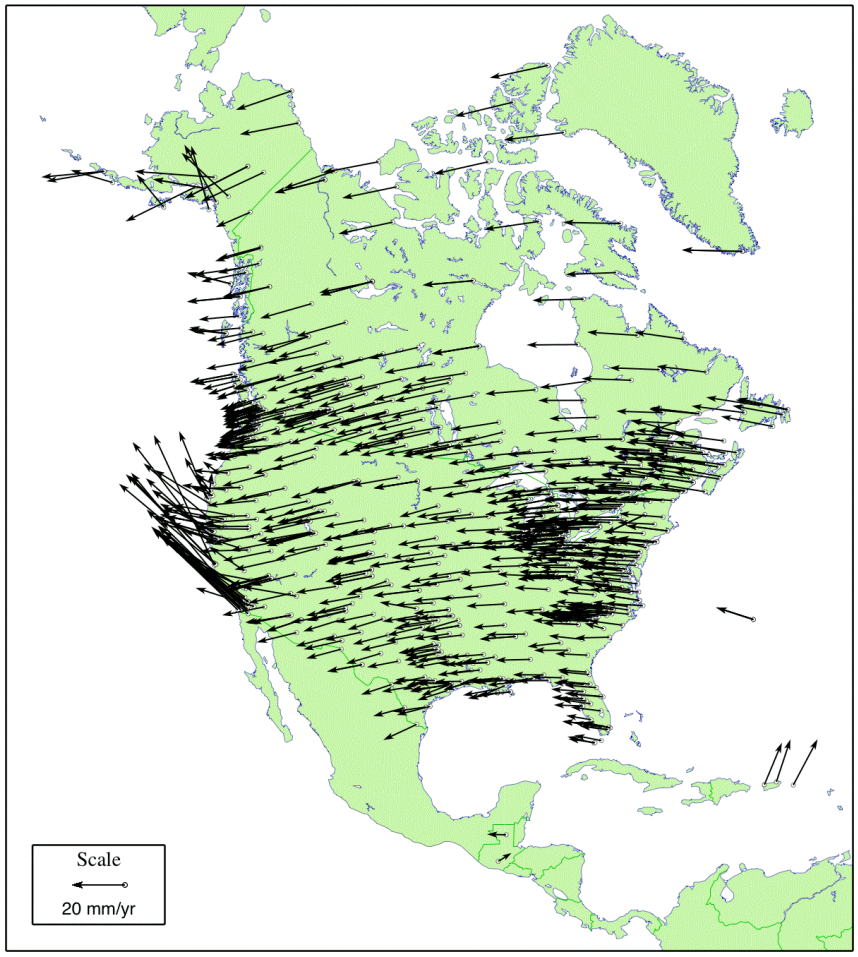
- Today's analysis of data for July 15, 2010 gives slightly different answers than we got 5 years ago for the same data.
- Velocity products are mostly consistent across sources, but time series are less so.
- All products are implicitly or explicitly versioned.
- All products will improve with the next release of a more consistent reference frame.
- Users need to know what went into deriving the products that they use, but most don't.

Reference Frame

- The reference frame defines the coordinate system on a moving, deforming Earth
  - Origin and how it moves (geocenter)
  - Coordinate axis orientations
  - Definition of zero velocity, how coordinate axes rotate with time
    - ITRF maintains a no-net-rotation condition, which is geologically arbitrary
- Currently: ITRF2008 and progeny
- Soon: ITRF2014/2015
  - Next ITRF will include a seasonal positioning model

Plate Boundary Processes

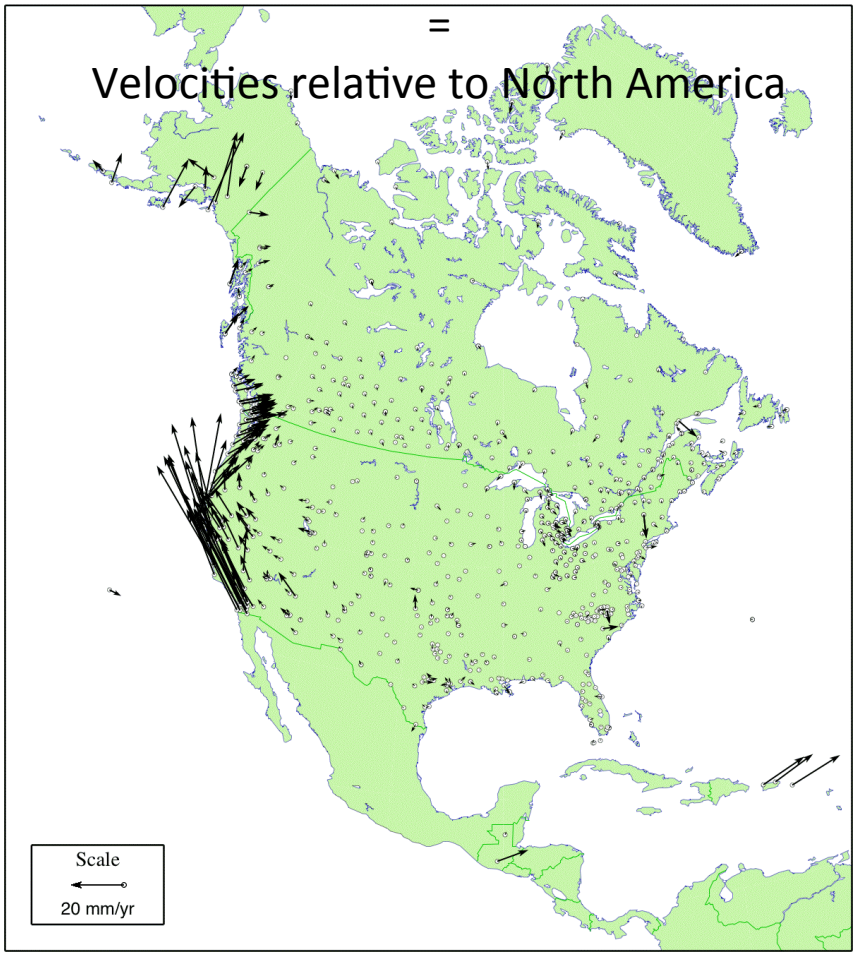
Velocities in ITRF



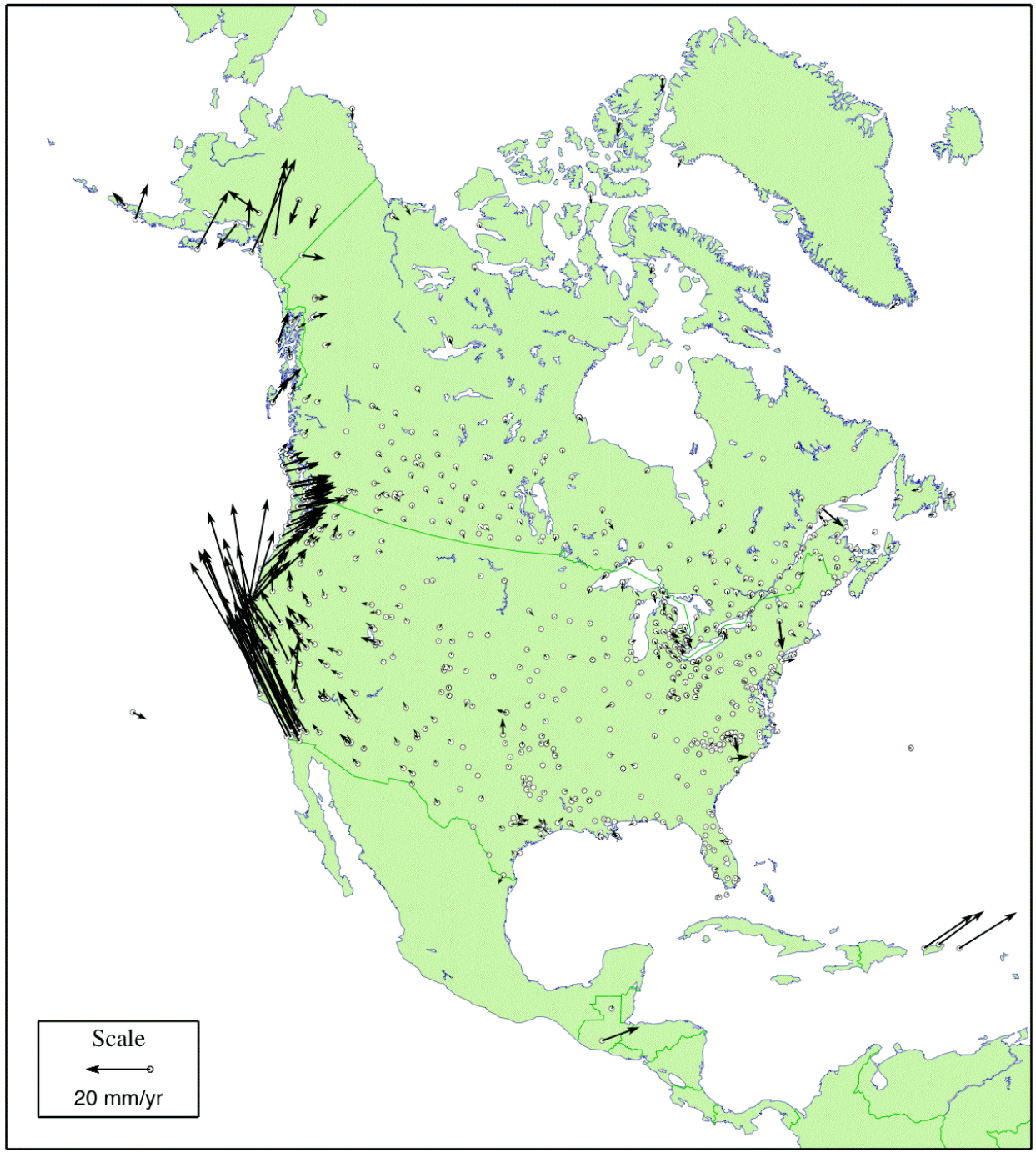
Subtract the rotation of the North American plate

=

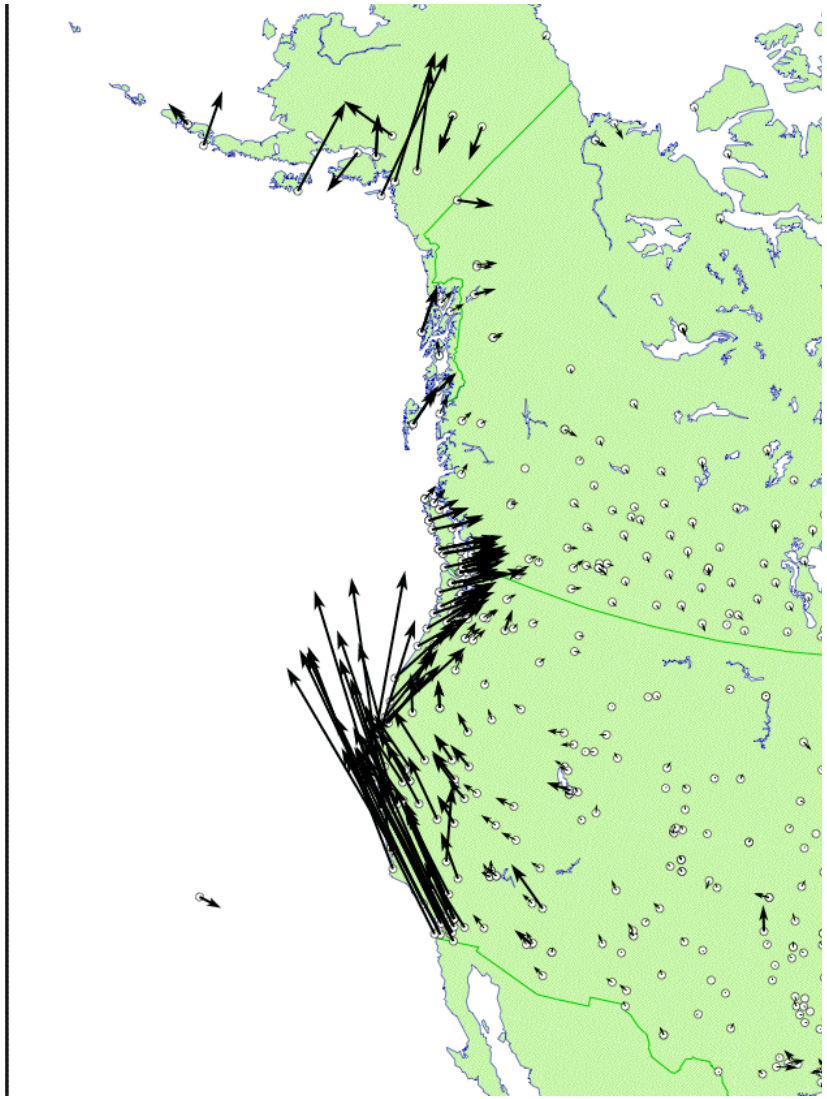
Velocities relative to North America



Mike Craymer, Geodetic Survey of Canada


Scale
20 mm/yr

Western North America



- Deformation of western North America results from a combination of:
  - Extension across Basin and Range
  - Shear on San Andreas fault system
  - Subduction strain in Cascadia and Alaska
  - Distributed deformation in N. Canada and Alaska

Sources of GPS Products

- IGS: International GNSS Service
- UNAVCO: Analysis for Plate Boundary Observatory and related data
- JPL: Time series and velocities of global and regional stations
- SOPAC: Global and other solutions, including their submission to the IGS
- GPS Explorer/READI: A NASA-funded consortium generating products for the western lower 48
- University of Nevada: A highly automated analysis of as much data as they can get their hands on (>13,000 stations!)

UNAVCO (PBO) Products

- Products page: http://pbo.unavco.org/data/gps
- PBO Time Series Viewer
- Velocity field
- Position time series
- Some other things (troposphere, etc)
- Products are based on daily solutions (all data for a given day). If you want kinematic/high rate solutions at sub-daily intervals, you need to go elsewhere or analyze them yourself.

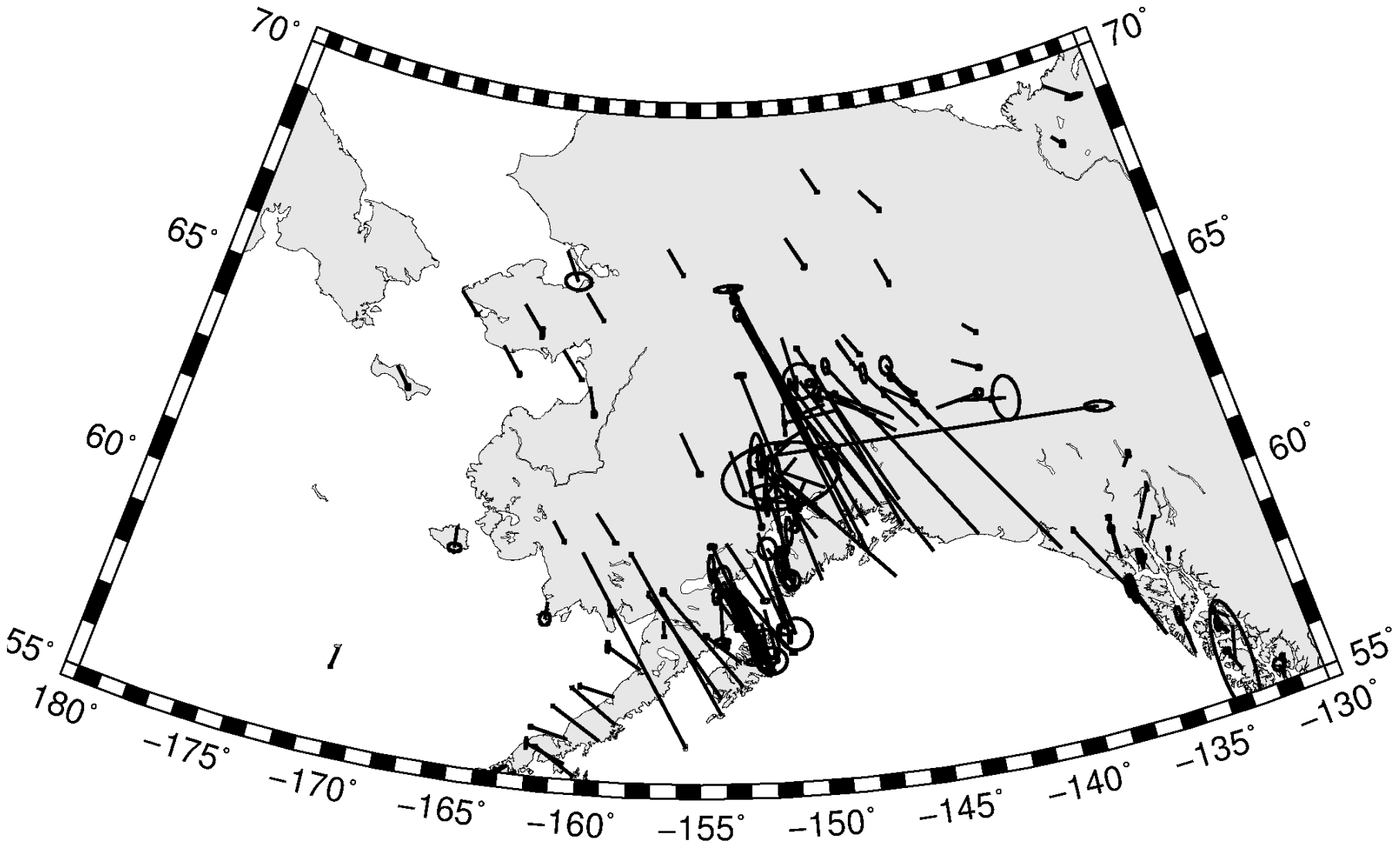
Velocities

- UNAVCO provides a velocity field based on the PBO data analysis
  - Somebody has to judge whether the motion of a site is really linear or not…
- Velocities are provided in multiple reference frames:
  - NAM08: North America-fixed (model by G. Blewitt)
  - IGS08: Updated GPS coordinate model consistent with ITRF2008
  - (obsolete) IGS05, SNARF

Go to the UNAVCO Website

- http://pbo.unavco.org/data/gps

Plot the PBO velocities



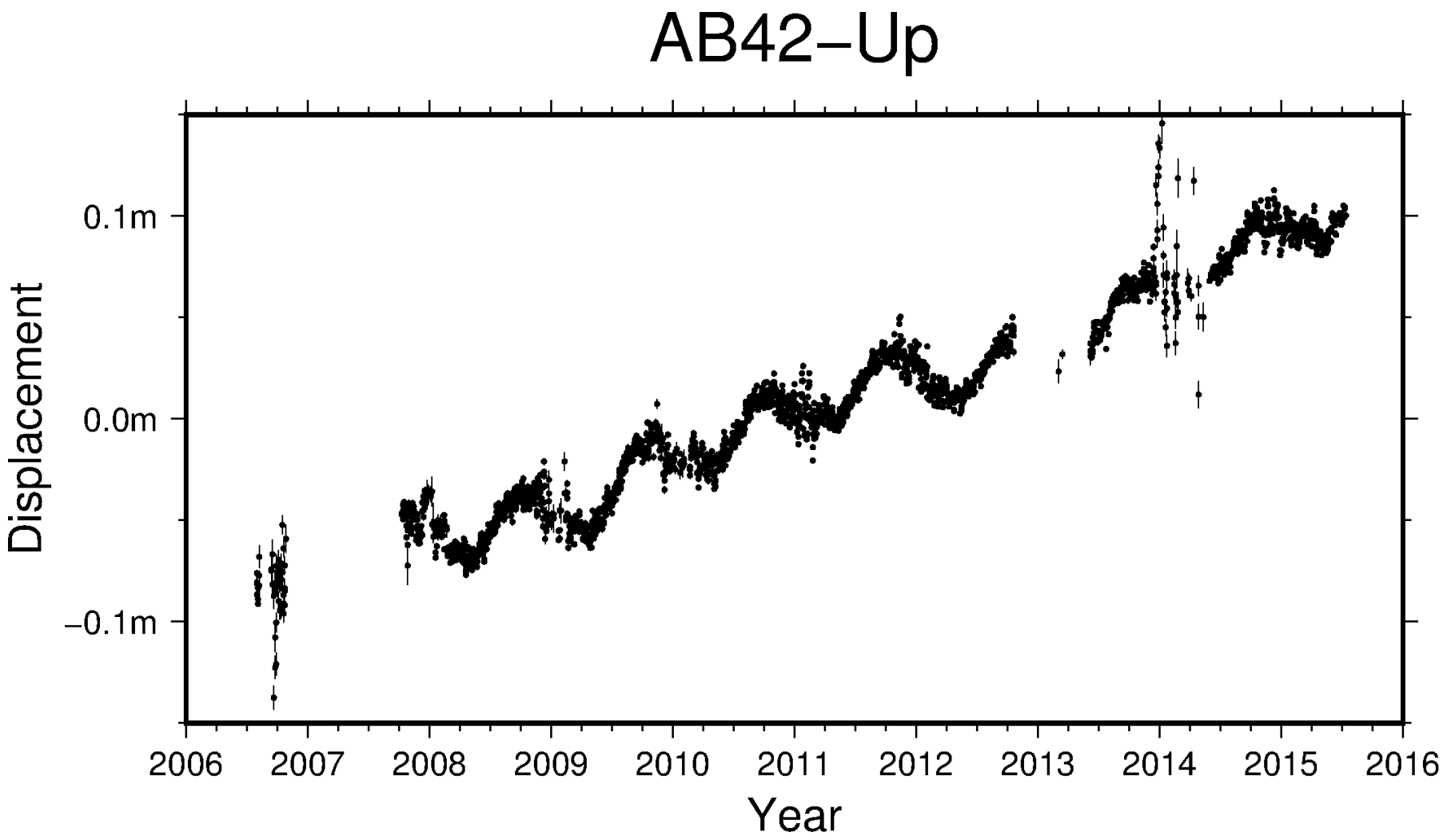
Position Time Series

- Stored on a site by site basis
- Multiple solutions: NMT, CWU, PBO combined
- Versions with different products
  - pbo.final_nam08: Final orbits only
  - pbo.rapid_nam08Rapid orbits only
  - pbo.nam08: Final orbits where available, otherwise rapid
- Two different formats, .pos and .csv

Go to the UNAVCO Website

- ftp://data-out.unavco.org/pub/products/position/AB42/

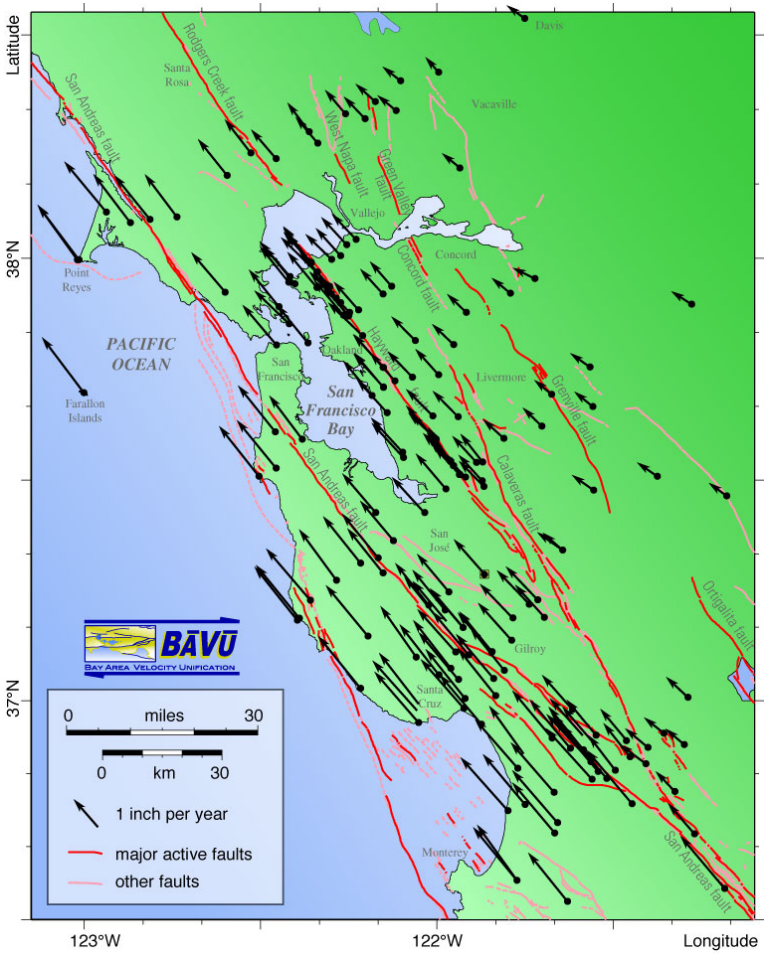
Plot a PBO Time Series

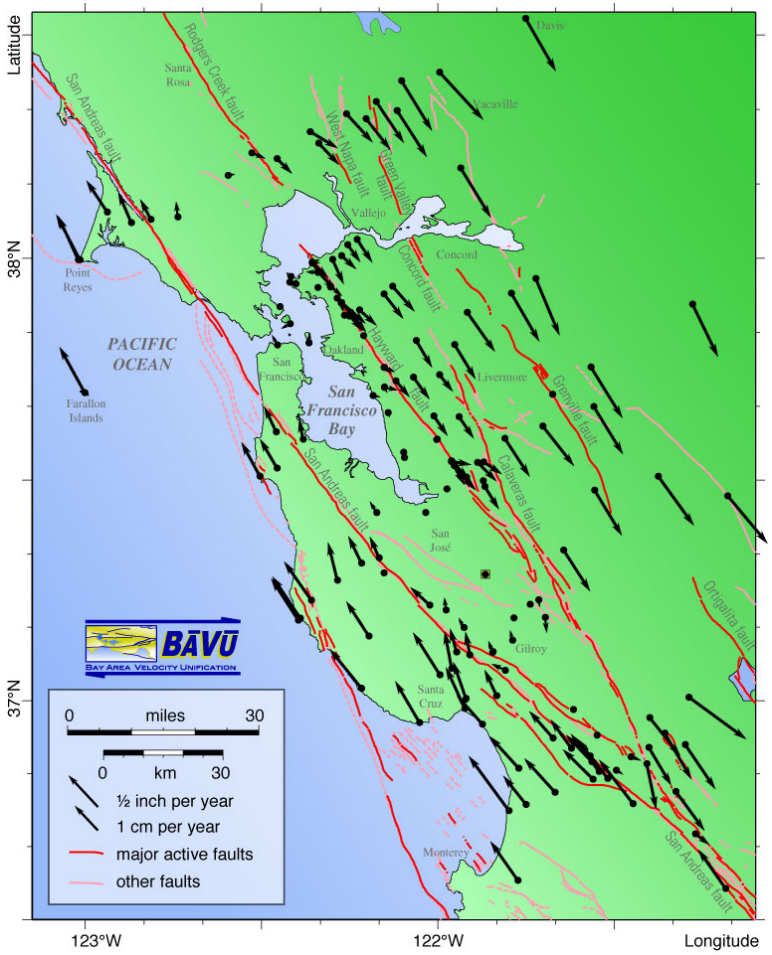


Interpreting the Velocities

- Sometimes GPS velocities have simple and easy interpretations related to long-term tectonics
- But usually not in detail. Differences include:
  - Elastic deformation from locked faults
  - Postseismic deformation following large earthquakes
  - Transient deformation (slow slip events)
  - Volcanic, GIA, etc…

SF Bay Area


Latitude
38°N
37°N
123°W
122°W
Longitude
Rodgers Creek fault
San Andreas fault
West Napa fault
Green Valley fault
Concord fault
Hayward fault
Calaveras fault
Greenville fault
Ortigalita fault
Santa Rosa
Davis
Vacaville
Vallejo
Concord
Point Reyes
PACIFIC OCEAN
Farallon Islands
Oakland
San Francisco
San Francisco Bay
Livermore
San José
Gilroy
Santa Cruz
Monterey
BAVU
Bay Area Velocity Unification
0 miles 30
0 km 30
1 inch per year
major active faults
other faults


Latitude
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Rodgers Creek fault
San Andreas fault
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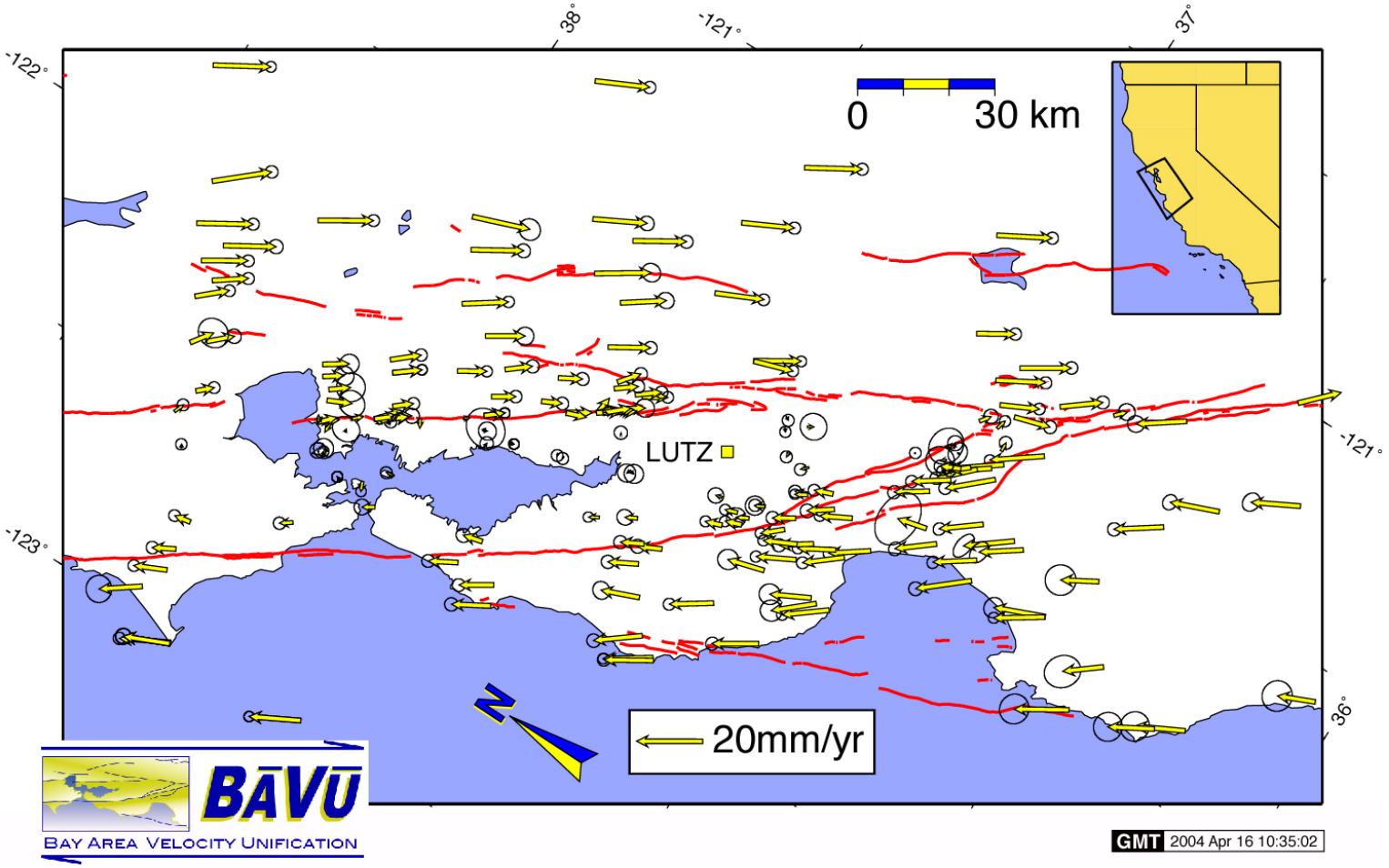
PACIFIC OCEAN
Farallon Islands
Oakland
San Francisco
San Francisco Bay
Livermore
San José
Gilroy
Santa Cruz
Monterey
BAVU
Bay Area Velocity Unification
0 miles 30
0 km 30
½ inch per year
1 cm per year
major active faults
other faults

Block Model



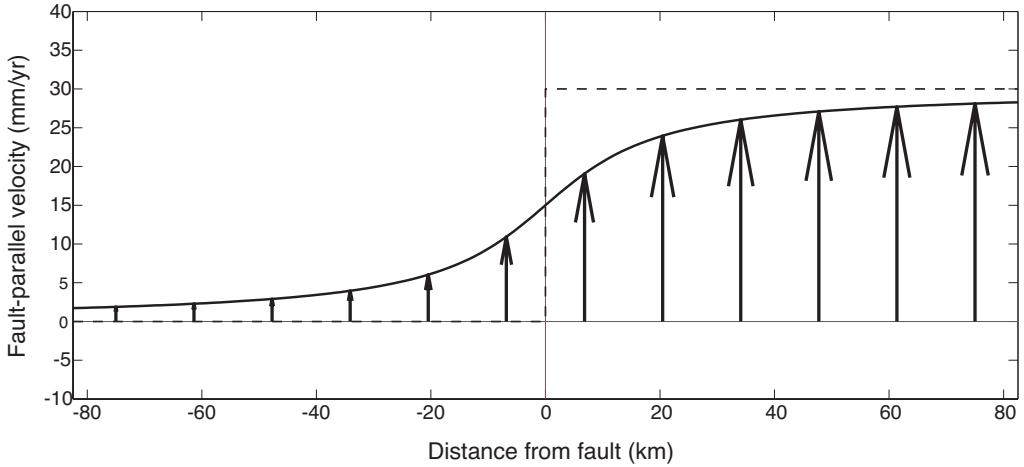
d'Alessio et al. (2005, JGR), doi: 10.1029/2004JB003496

Modeling Elastic Deformation

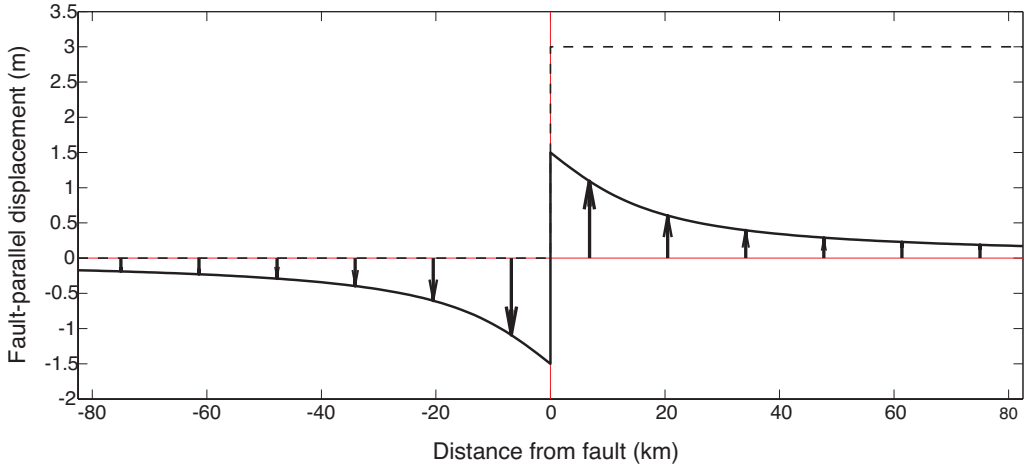
- We can model effect of locked faults using **elastic dislocation** theory with an elastic **half-space**
  - There are simple analytical expressions for 2D
  - There are standard computer codes for 3D
  - The same codes work for earthquake (coseismic) deformation
- A simple approach is to represent motions by a combination of rigid block motion and "backslip" to cancel the motion on the shallow fault (Savage and Burford, 1973)
- Backslip represents the ***slip deficit*** of the shallow fault

Interseismic vs. Coseismic

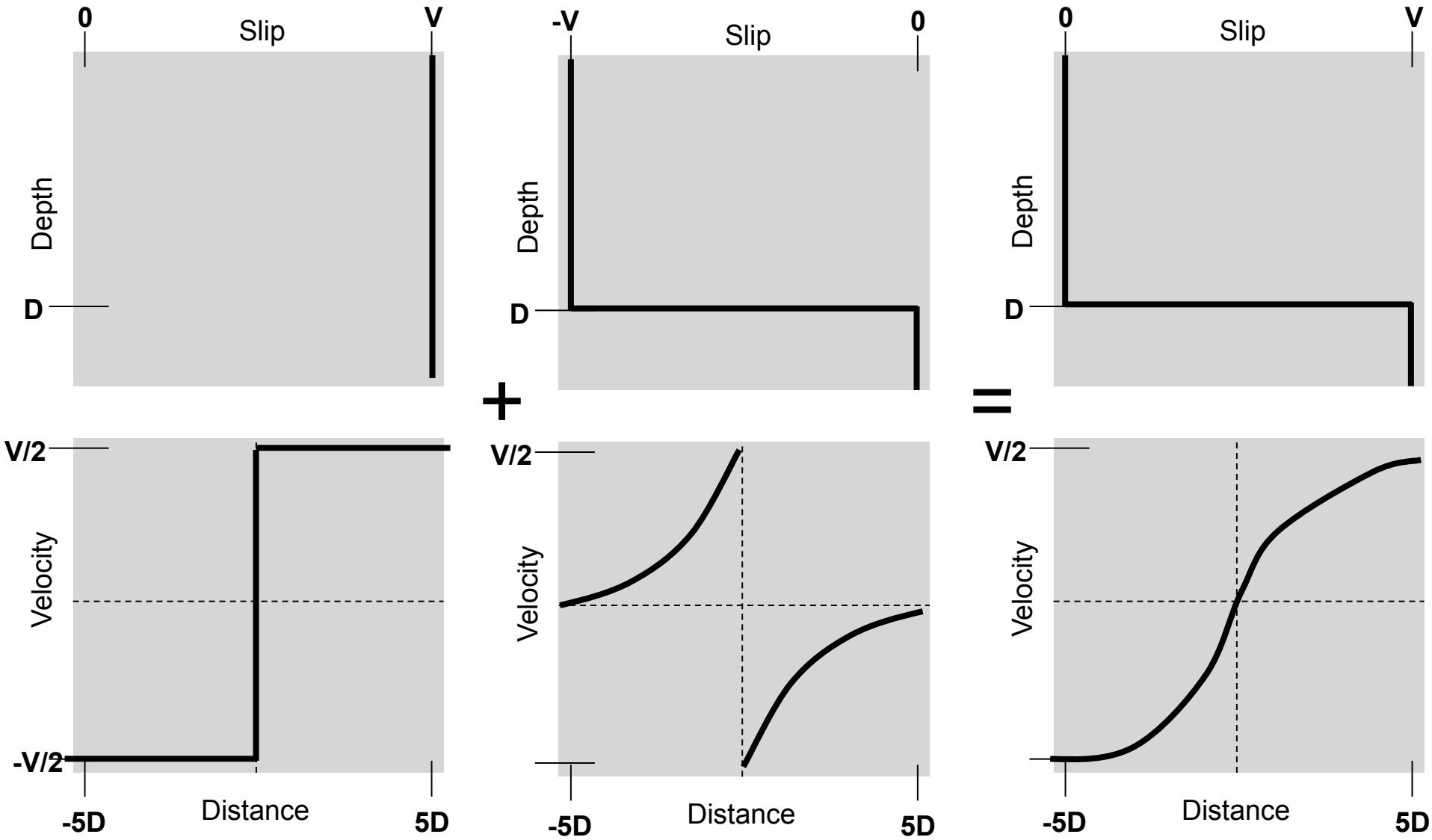
Interseismic
Between earthquakes



Coseismic
During earthquake



Calculate by Superposition



2D Strike Slip Fault

$$V(x) = \frac{S}{\pi} \operatorname{atan}\left[\frac{(x - x_f)}{D}\right]$$

Savage and Burford (1973)

V(x) = fault-parallel velocity at position x

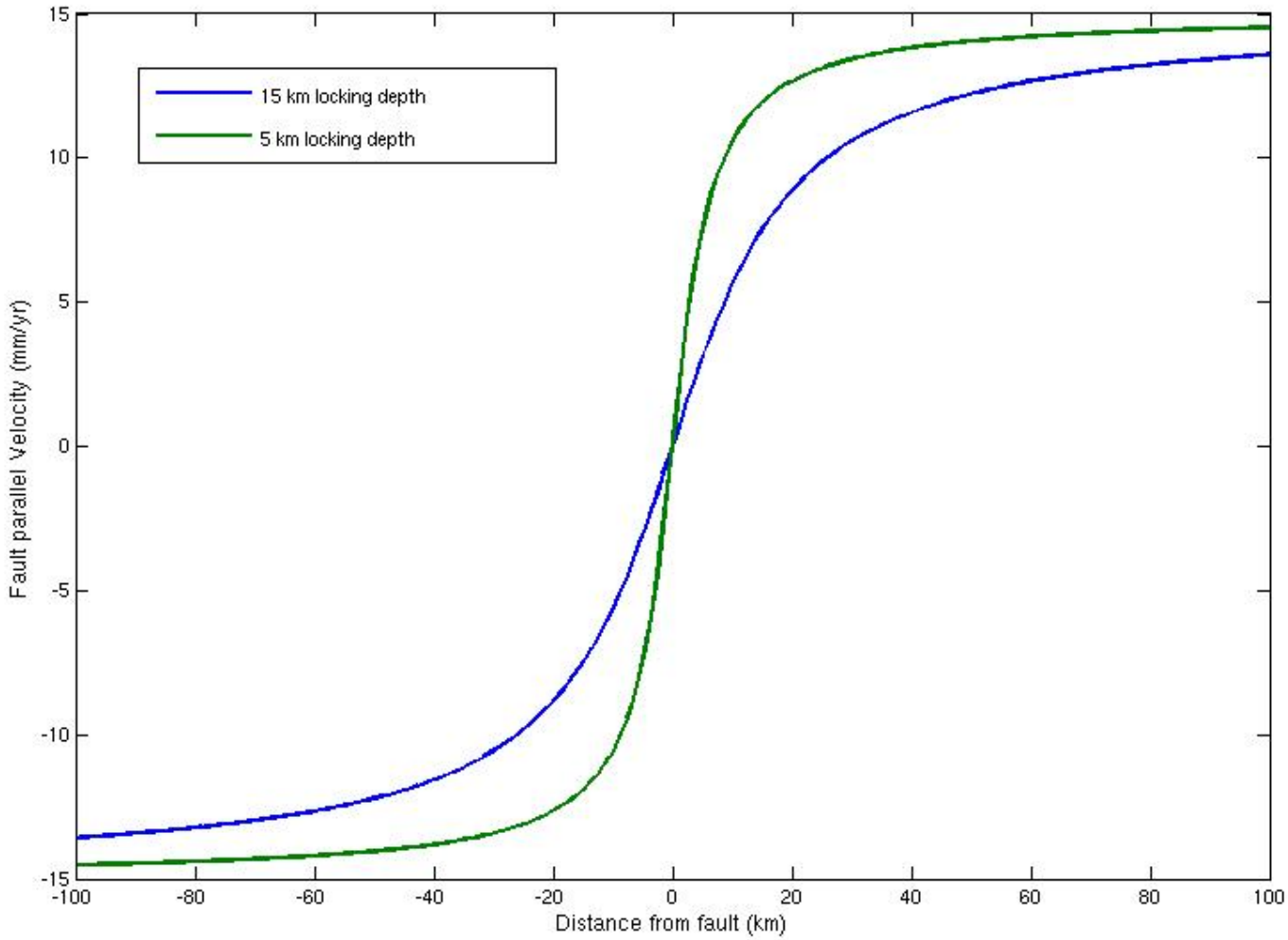
S = long-term slip rate

D = locking depth

x = perpendicular distance of site from fault

x_f = position of fault

In this formulation, a site on the fault has zero velocity – the reference frame is fault-centered

For a far-field reference frame, add or subtract S/2

Changing the Locking Depth