

# Reference frames

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# Basic issues in reference frame realization

- Concept is to align the estimated site positions and possibly velocity to a set of well defined locations that have physical significance for the analysis being performed (e.g., PBO we align to a realization of the North America plate based on ITRF2008).
- GLORG is the module which does this and computes the covariance matrix of the aligned solution in the reference frame chosen.
- Transformation is often called an N-parameter Helmert transformation:
  - N=3 translation only (could also be just rotation)
  - N=6 translation and rotation
  - N=7 translation, rotation and scale
- In GLOBK analyses, you need to decide
  - How many parameters (3/6/7)
  - Sites to use to determine the parameters (sh\_gen\_stats)
  - Values of the positions/velocities of the reference frame sites
  - Weight to be given to heights in computing the transformation parameters (CND\_HGTV command; first two arguments for position and velocity).

# Choices of reference frame

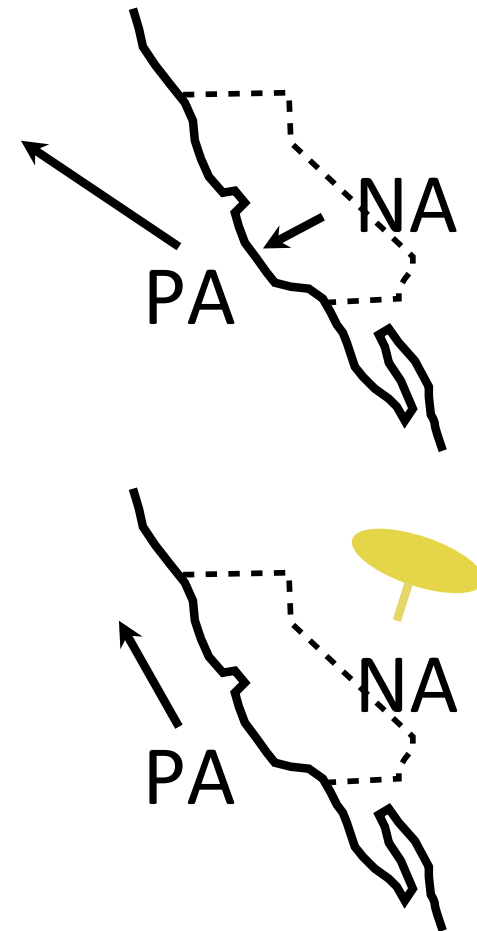
- Choose your reference frame based on your geophysical objectives
  - Velocities in ITRF are difficult to interpret visually from a geophysical perspective
    - Local surroundings of a volcano
    - One side of a fault
    - Upper plate of a subduction zone
- Major plate reference frame
  - Major plates are often chosen to conform with conventional perspectives of velocity solutions
  - Relative to Eurasia, Nubia, North America, South America, etc.
  - But don't feel restricted by this. Sometimes your geophysical discussion is best visualized relative to any stable boundary of a deforming region
- Regional reference frame
  - Central Valley of California, non-deforming part of Anatolia, smaller coherent regions, etc
- Local reference frame
  - Sites near but outside the influence of a volcano, geothermal field, etc.

# Ways to define a reference frame

- Create an apr-file for use by glorg
  1. Apply known rotation rate to apr-file (e.g. itr08\_comb.apr → itr08\_comb\_eura.apr)
  2. Zero velocity apr-file records (and iterate using sh\_exglk to create updated apr-file)
- Define set of sites (must be included in GAMIT processing or other H-file input to GLOBK) which define stable region
  3. `plate` in globk command file

# Examples

- Expressing velocities in ITRF is not very meaningful or useful when we want to look at the deformation at a plate boundary, e.g. the San Andreas Fault system
- Better to look at velocities with one side “fixed” so we can see what the other side is doing relative to it



# Reference frames in Geodetic Analyses

- Output from GAMIT
  - Loosely constrained solutions
  - Relative position well determined, “Absolute position” weakly defined
  - Need a procedure to express coordinates in a well defined reference frame
- Two aspects
  - Theoretical (e.g., rigid block, mantle-fixed, no-net-rotation of plates)
  - Realization through a set of coordinates and velocities
    - “finite constraints” : a priori sigmas on site coordinates
    - “generalized constraints” : minimize coordinate residuals while adjusting translation, rotation, and scale parameters
- Three considerations in data processing and analysis
  - Consistent with GPS orbits and EOP (NNR)
    - not an issue if network small or if orbits and EOP estimated
  - Physically meaningful frame in which to visualize site motions
  - Robust realization for velocities and/or time series

# Frame definition with generalized constraints

- Applied in glorg: minimize residuals of reference sites while estimating translation, rotation, and/or scale (3 -7 parameters)

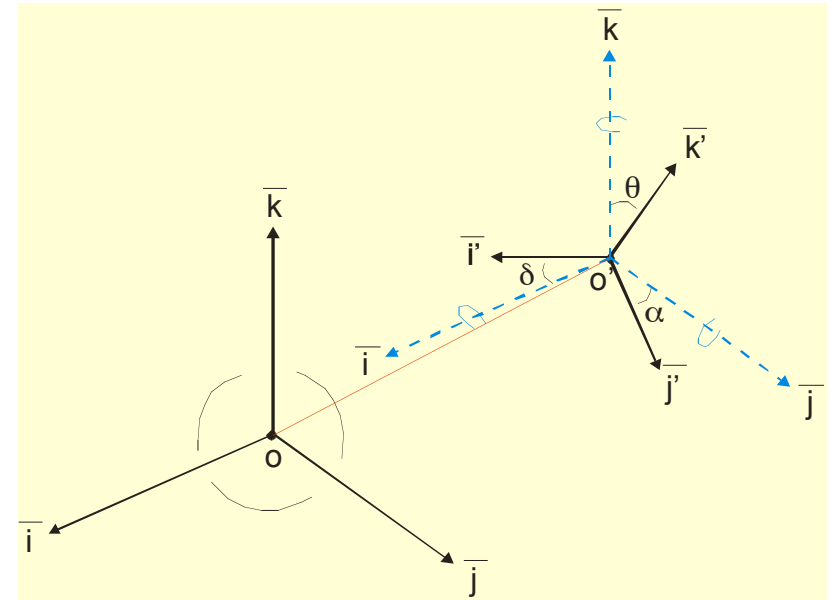
```
apr_file itr08.apr
```

```
pos_org xtran ytran ztran xrot yrot zrot
```

```
stab_site algo pie1 drao ...
```

```
cnd_hgtv 10 10 0.8 3.
```

```
stab_it 4 0.5 2.5
```



- All reference coordinates free to adjust (anomalies more apparent); outliers are iteratively removed by glorg
- Network can translate and rotate but not distort
- Works best with strong redundancy (number and [if rotation] geometry of coordinates exceeds number of parameters loading effects)

# Stabilization using a Global Set of Sites

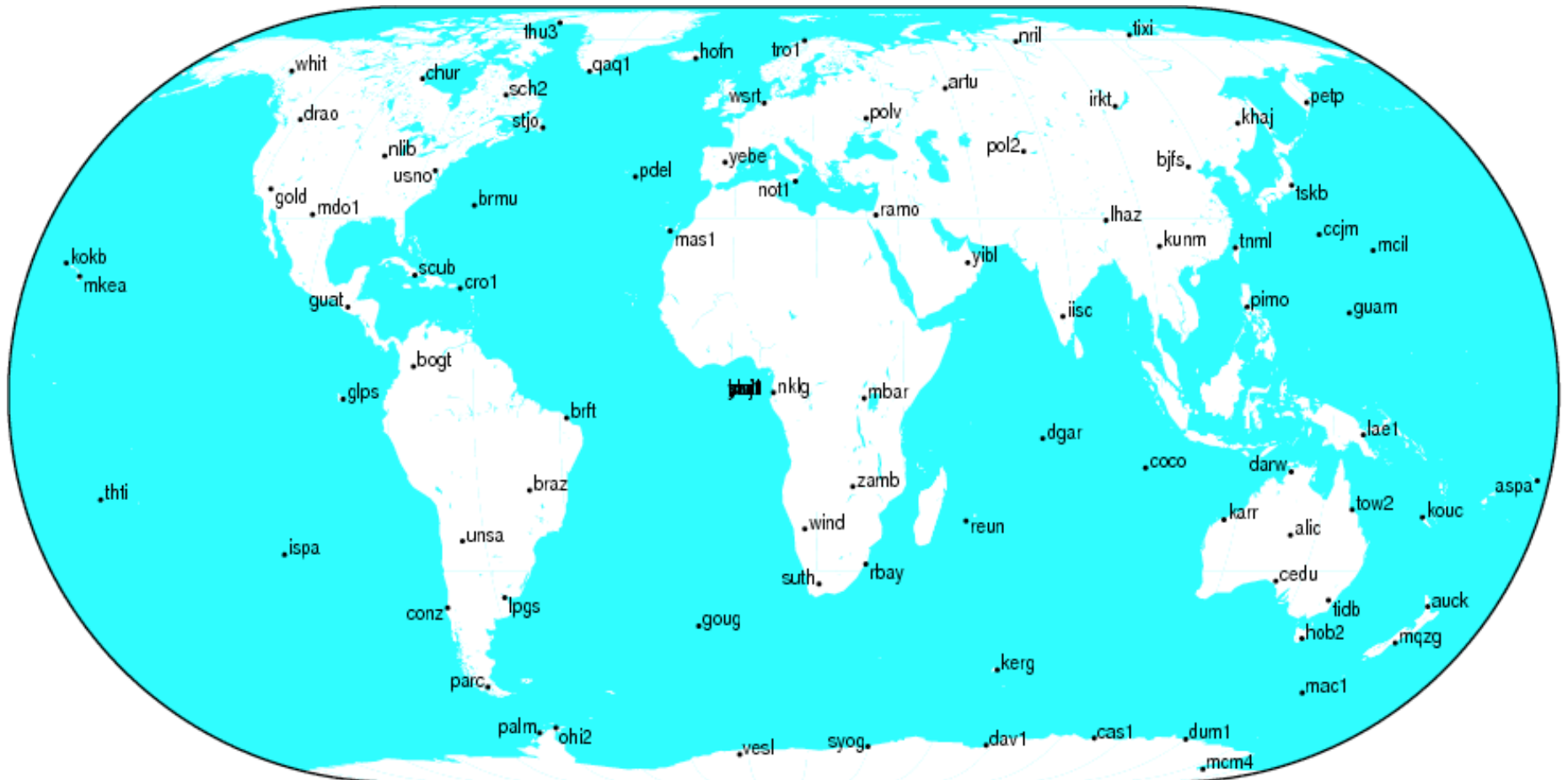
- Use 40 or more sites with good velocities determined in the ITRF2008 frame
- The `itr08_comb.apr` file, when used together with `itr08_comb.eq` to account consistently for instrumental changes over time, provides the widest choice of sites, 1992-2013.
- Combining your solution with the MIT or SOPAC global h-files offer access to over 100 sites without having to include them in your GAMIT processing.
  - You need just 4-6 common sites, which should be of high quality but need not be well known in ITRF2008 since these “tie” sites do not need to be in your frame-realization list.
- For global ITRF stabilization, you can use the hierarchical list `igb08_heirarchy.stab_site` in `gg/tables`
- Although a global frame may be a convenient way to do the stabilization, it is usually not necessary for regional studies.



# Stabilization using Regional or Local Sites

- If your area of study has a robust cGPS network (10 or more well-distributed sites) with accurate a priori velocities, then glorg stabilization is robust and little thought is involved (glorg will automatically discard the one or two sites which may be weak or inconsistent)
- If your region is short on cGPS stations with well-known coordinates, you will need to think carefully about the choice of sites to include in your solution and use the initial stabilization. A stabilization site should have
  - high quality data over the full span of your study
  - coordinates well-known in ITRF2008
  - Provide symmetric coverage around your study area (except that if the region is small enough, a translation-only stabilization may be possible and distribution is less important)

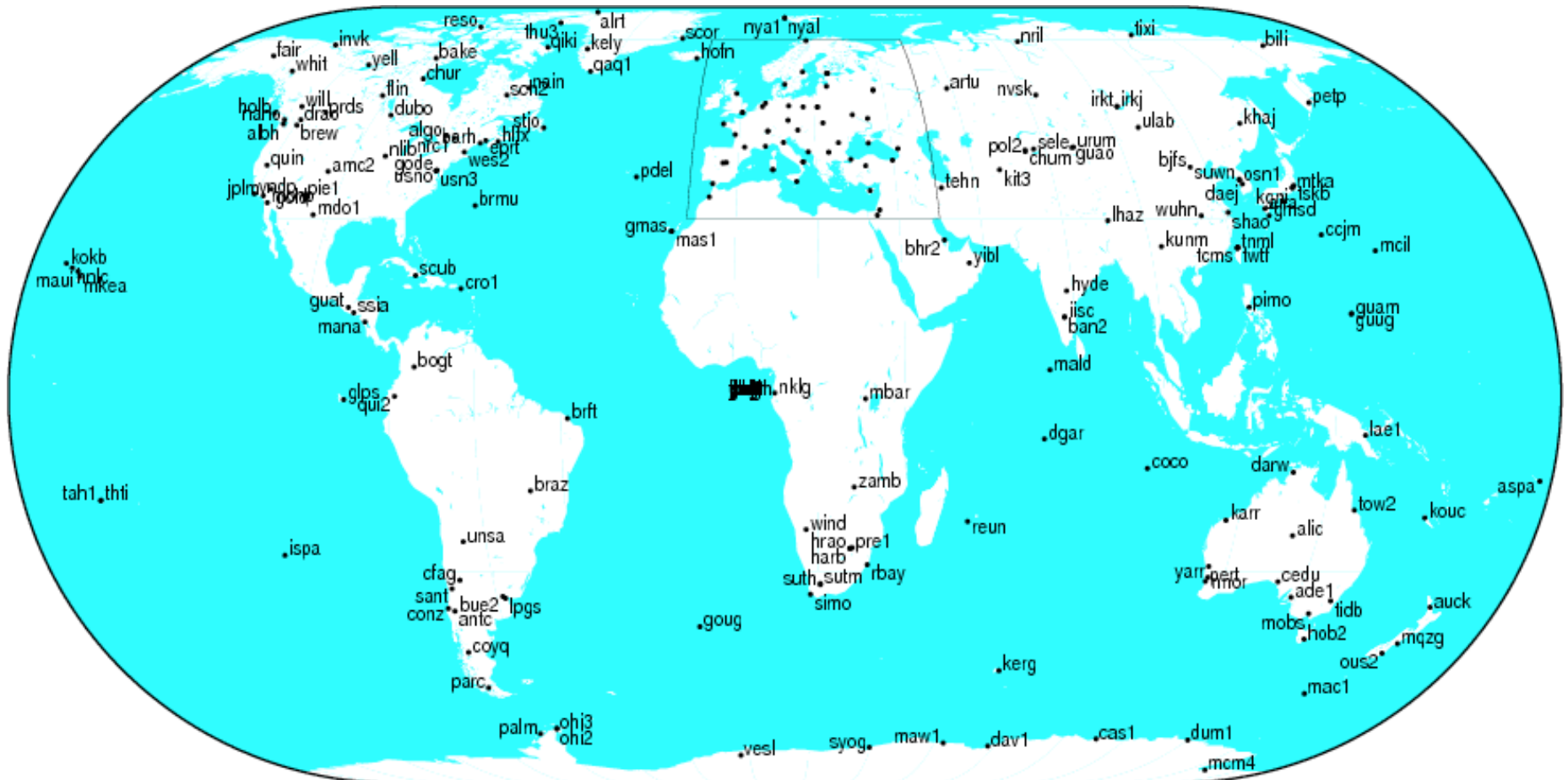
# IGS (IGb08) reference frame core network



SM 2013 Jul 09 18:48:14

[http://igscb.jpl.nasa.gov/network/refframe\\_core.html](http://igscb.jpl.nasa.gov/network/refframe_core.html)

# IGS (IGb08) reference frame network

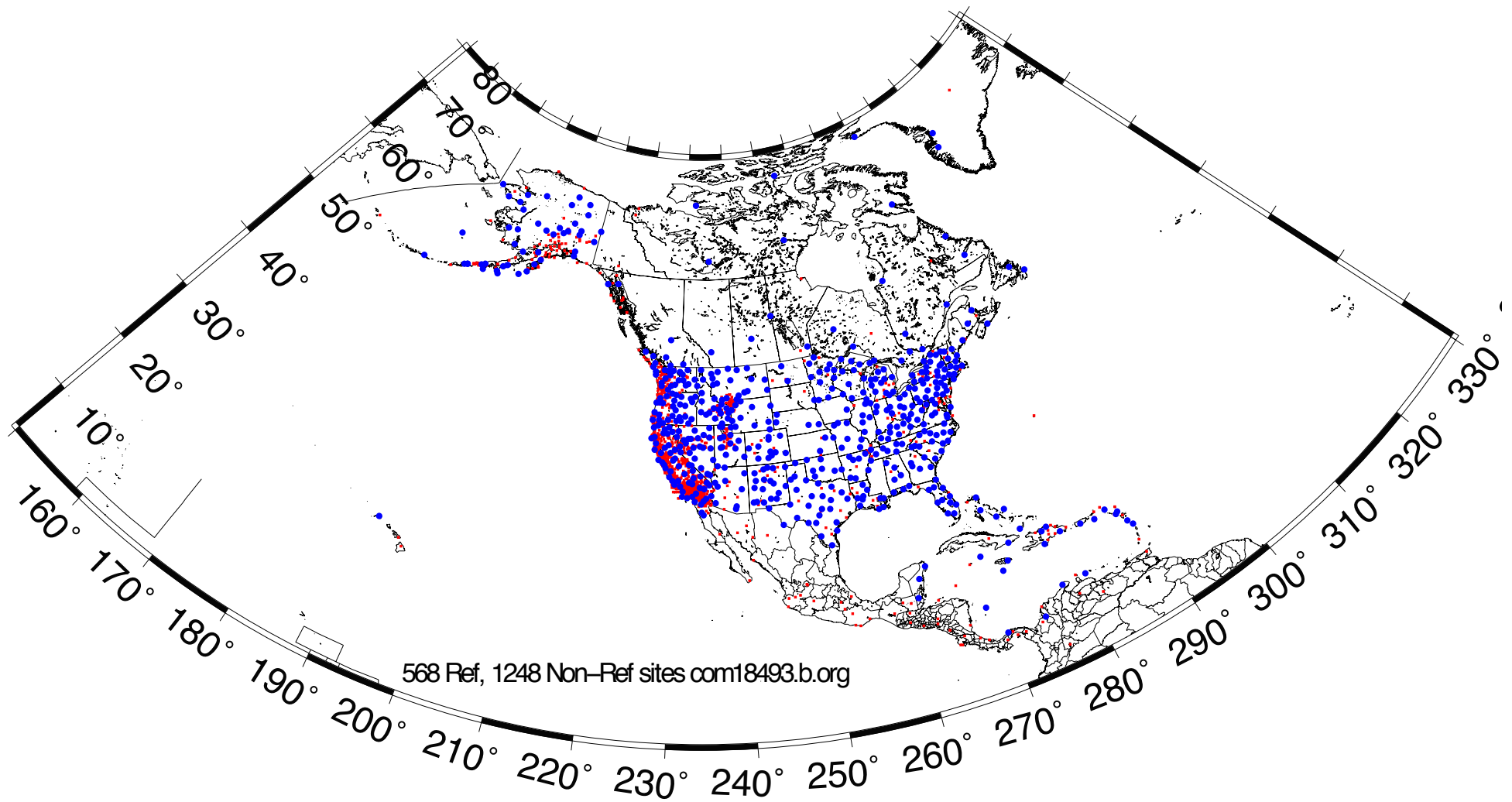


SM 2013 Jul 09 18:48:07

<http://igsceb.jpl.nasa.gov/network/refframe.html>

# Frame realization sites for PBO

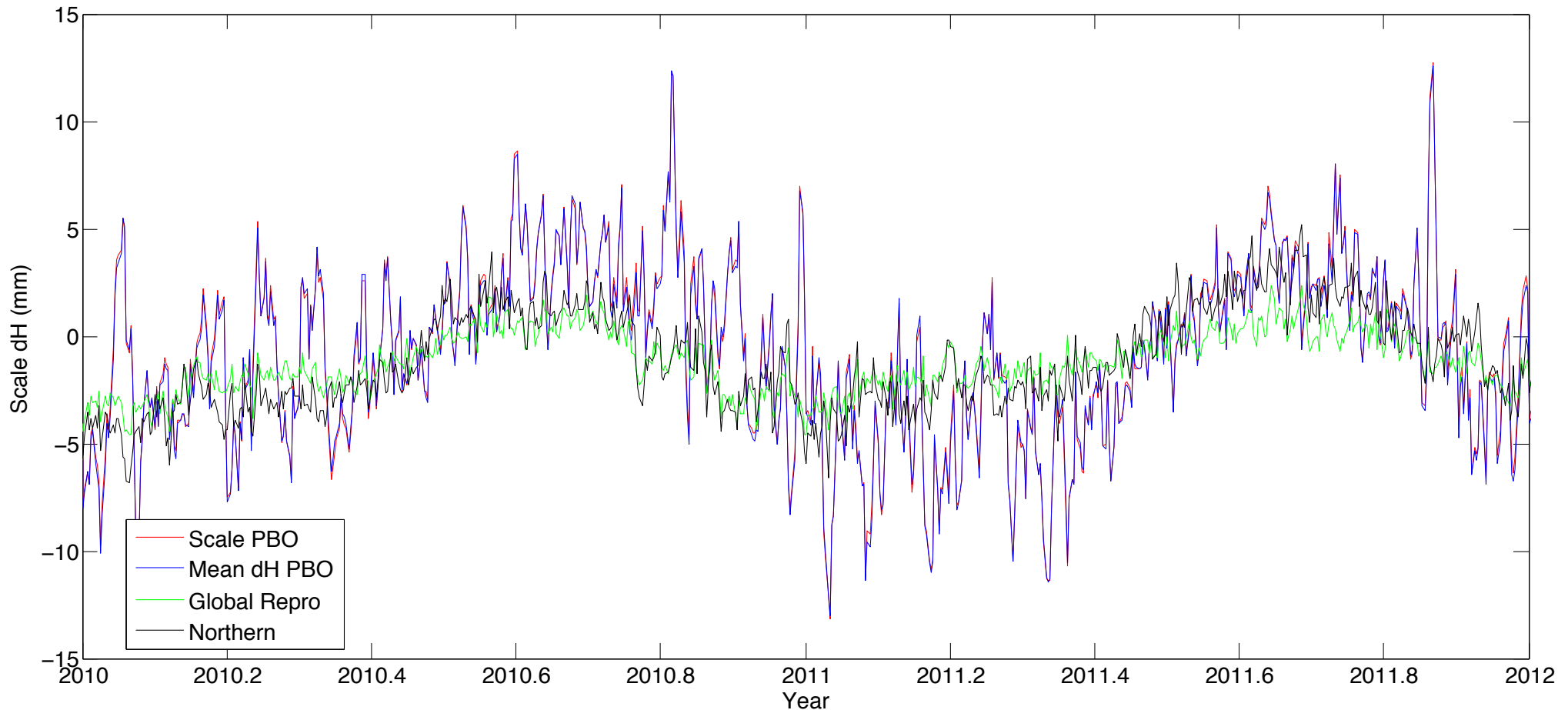
- PBO used an hierarchical list based on 500km site spacing (sh\_gen\_stat stabrad option). (Blue dots)



# Issues with Estimating Scale

- Many GPS analyses, automatically include scale when aligning reference frames. Since the Earth is almost spherical, scale changes are directly proportional to the average height difference between the reference site coordinates and their a priori values.
- When comparing and analyzing height changes, how scale is treated directly effects the results. Aspects of this issue are discussed in a white paper that should be available shortly from the GAGE analysis documentation at UNAVCO.
- Scale estimates are related the mean height differences over the reference sites. Should this be removed or not is an open question.
- Scale estimates on next slide show magnitude of effect for the PBO network.

# PBO network scale estimates



PBO network estimates compared to global estimates converted to average height differences (6317 km Earth). Spikes in winter are often due to Alaskan sites.

# Use of Global binary H-files

- Include global h-files ... or not ? For post-2000 data not needed for orbits
- Advantages
  - Access to a large number of sites for frame definition
  - Can (should) allow adjustment to orbits and EOP
  - Eases computational burden
- Disadvantages
  - Must use (mostly) the same models as the global processing
  - Orbits implied by the global data worse than IGSF. Once-per-revolution radiation model parameters (loose in global h-files) should be treated carefully.
  - Some bad data may be included in global h-files (can remove)
  - Greater data storage burden
- MIT hfiles available at [ftp://everest.mit.edu/pub/MIT\\_GLL/HYY](ftp://everest.mit.edu/pub/MIT_GLL/HYY)  
When using MIT files, add apr\_svant all F F F to globk command file to fix the satellite antenna offsets

# Velocities and Time Series

- The criteria for stabilization are different for velocity solutions and time series
- Velocity solutions:
  - Physical reference is important
  - Not so sensitive to station dropout (solution holds the frame together)
- Time series:
  - Physical reference is not important
  - Sensitive to station dropout
  - Best representation of the statistics of the velocity solution is stabilization using ALL the well-determined sites from the velocity solution, now in a common frame



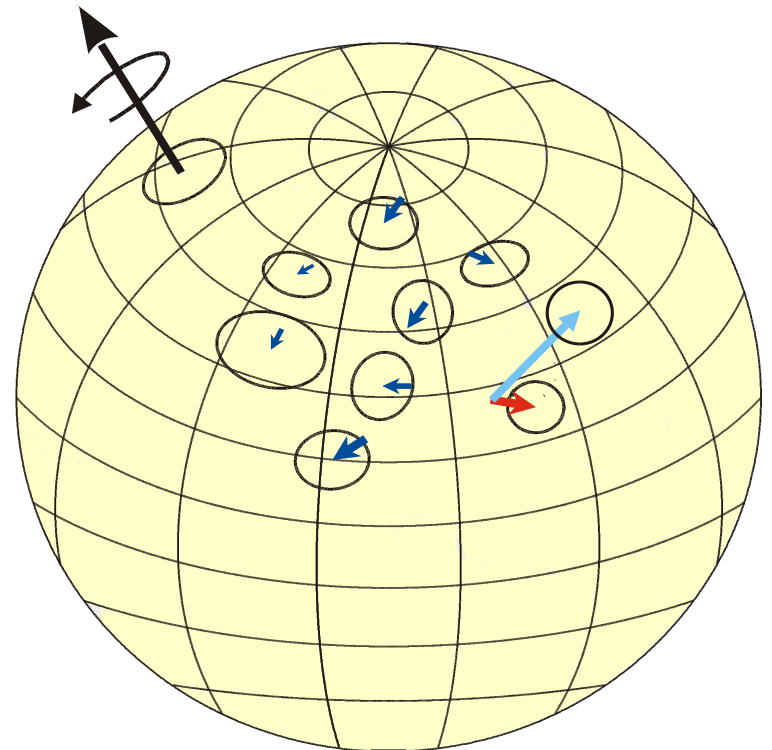
# Referencing to a horizontal block ('plate')

Applied in glorg: first stabilize in the usual way with respect to a reference set of coordinates and velocities (e.g. ITRF-NNR), then define one or more 'rigid' blocks

```
apr_file itr08.apr
pos_org xtran ytran ztran xrot yrot zrot
stab_site algo pie1 nlib drao gold sni1 mkea chat
cnd_hgtv 10 10 0.8 3.
plate noam algo pie1 nlib
plate pcfc sni1 mkea chat
```

After stabilization, glorg will estimate a rotation vector ('Euler pole') for each plate with respect to the frame of the full stabilization set and print the relative poles between each set of plates

Use sh\_org2vel to extract the velocities of all sites with respect to each plate



# Rules for Stabilization of Time Series

- Small-extent network: translation-only in glorg, must constrain EOP in globk
- Large-extent network: translation+rotation, must keep EOP loose in globk;
- if scale estimated in glorg, it must estimate scale in globk
- 1st pass for editing:
  - “Adequate” stab\_site list of stations with accurate a priori coordinates and velocities and available most days
  - Keep in mind deficiencies in the list
- Final pass for presentation / assessment / statistics
  - Robust stab\_site list of all/most stations in network, with coordinates and velocities determined from the final velocity solution
- System is often iterated (velocity field solution, generate time series, editing and statistics of time series; re-generate velocity field).

# GLOBK Reporting of models

- When binary h-files from GAMIT h-files are used (as opposed to SINEX files), GLOBK and GLIST can report models used. Can be critical when combining with MIT h-files.

```
GPS System Information : Time GPST Frame J2000 Precession
IAU76 Radiation model BERNE Nutation IAU00 Gravity EGR08
EarthRad NCLE1 AntThrust ANTBK
```

```
MODELS Used in Analysis: SD-WOB | SD-UT1 | IERS10 | E-
Tide | K1-Tide | PoleTide| OC-Load | MPT2010 | OceanPT |
```

```
LOAD Models Used : NCEP CM USED |
```

```
ATM Delay Models Used : UFL | GP25 | VMF1 | VMF1
| 2nd Order Ion | GMAP | IGRF11 |
```

These lines are wrapped.

# Summary

- Atmospheric delay treatment and issues
  - VMF1 approach (used gridded assimilation meteorological data) is probably best but does require large and regularly updated (if near real-time) grid files
- Loading
  - Not standard yet in IGS processing. Again needs large grid files. Models used in GAMIT can be removed in GLOBK.
- Reference frame realization: Vertical effects
  - Treatment of scale estimates and impact on height estimates should be carefully considered when heights are of interest.