Global Spatial Filtering (GSF) of GNSS Coordinates to Capture Small Transient Signals

Geoff Blewitt, Corné Kreemer, Jay Goldfarb, Hans-Peter Plag, and Bill Hammond

Nevada Bureau of Mines and Geology
University of Nevada, Reno

Funded by NSF EarthScope and NASA Earth Surface & Interior
Prelude: Recent PPP Improvements

ELKO Nevada: Up (m)

- Produced 2010
- PPP GIPSY 5.0
- Ambizap3
- IGS05 frame
- IERS 2003 models

- Produced 2012
- PPP GIPSY 6.1
- WLPB method
- IGS08 frame
- IERS 2010 models

- Derived from IGS08 solution
- Spatially filtered using 299 stations in North America
Introduction

- **GNSS Time Series are Spatially Correlated**
  - Geophysical signal of interest + Non-local systematic errors
  - Signal of interest can be over a limited distance scale
  - **Signal can be enhanced by filtering out non-local errors**

- **Cause of Non-Local Systematic Errors**
  - Satellite orbit + clocks + correlated errors in atmospheric delay
  - Geophysical signals of scale > scale of interest (e.g., loading)

- **Review of methods**
  - Double differencing by itself removes some non-local errors
  - Rius et al. [1995] computed non-local error by stacking geocentric radial coordinate time series within fixed radius about each station
  - Wdowinski et al. [1997] computed “Common Mode Error” (CME) by stacking 3-D residuals within a region (southern California)
Global Spatial Filtering (GSF): Concept and Approach

• Concept
  - Take Rius’ idea and apply it to 3-D daily coordinate residuals to a reference frame
  - Márquez-Azúa and DeMets [2003] applied this to a large region noting that it could be applied globally
  - But this requires stations have sufficient density at the scale of interest
  - Now the mean global neighbor distance is 140 km, most < 31 km
  - Now only 1% stations > 2000 km to nearest neighbor

• Approach
  - We design a continuous function rather than a hard cut-off radius
  - We test this on a network of 3,355 stations from 40-day sample in 2008
  - We assess effect of filter scale on reducing time series variance
Compute correction for site $i$ as weighted mean offset from frame for all 4,000 sites $j$

$$
\Delta x_i = \frac{\sum_j w_{ij}(x_j - x_j^{\text{frame}})}{\sum_j w_{ij}}
$$

How should we define $w_{ij}$?

(1) For filter scale $s$, weight should be a continuous function of $(r_{ij}/s)$
(2) Filter out the influence of far-field sites: $w(r/s \to \infty) \to 0$
(2) Filter out the influence of near-field sites: $w(r/s \to 0) \to 0$
(3) Stations should have most influence on $\Delta x_i$ at distance $r = s$

Design a weight function with these properties for thin ring of radius $r$

$$w_{\text{circle}}(r, s) = e^{- (r/s + s/r)}$$

Now, the weight for a point site should account for geometry ($N_{\text{stations}} \propto r$):

Therefore:

$$w_{ij}^{\text{site}}(s) = \frac{s}{r_{ij}} w_{\text{circle}}(r_{ij}, s) = \frac{s}{r_{ij}} e^{- (r_{ij}/s + s/r_{ij})}$$
Stacking Weight versus Distance

Global Spatial Filter Functions

- 900 km circle
- 300 km circle
- 900 km site
- 300 km site

Distance (km)

Relative Weight

Distance (km)
Results: Variance Reduction

3-D Position Variance
N=3,355 stations, 40-day test period

% Reduction

GSF Filter Scale

IGS05 Global 3000 km 900 km 300 km 90 km 30 km
Effectiveness of GSF
RMS repeatability of N=3,355 stations

- East
- North
- Vertical

Repeatability (mm)

- JPL orbits $\rightarrow$ IGS05
- Global Translation
- GSF Scale = 3000 km
- GSF Scale = 900 km
- GSF Scale = 300 km
- GSF Scale = 90 km
- GSF Scale = 30 km
Results: Time Series

2008-04-26 Mogul Nevada Mw5.0 Earthquake

Mw 5.0 earthquake
Results: Time Series

2008-04-26 Mogul Nevada Mw5.0 Earthquake: CONTROL (same scale)

- "IGS05"
- "GSF_3000km"
- "GSF_90km"

TNO North (mm)

Date (year)
Conclusions

- Global Spatial Filtering (GSF) can be implemented seamlessly with no pre-selected reference stations.
- Just a common global translation reduces repeatability 10% over the baseline case of IGS05. The GSF at $s = 3000 \text{ km}$ performs equally as well as a common translation.
- Up to 50% variance reduction is gained by GSF, improving as the scale $s = 3000 \text{ km} \rightarrow 900 \text{ km} \rightarrow 300 \text{ km} \rightarrow 90 \text{ km}$.
- At 300 km, RMS (E,N,V) = (1.0 mm, 1.1 mm, 3.7 mm)
  Reduction in variance = (63%, 52%, 52%)
  Reduction in RMS = (40%, 30%, 30%)
- Time series of $M_w$ 5.0 Mogul Earthquake of 2008-04-26 proves that GSF reduces non-earthquake artefacts in the time series.
Extending this Study

- This study was only over 40-day test period
  - Assumed no station motion model for frame
- Now testing GSF on secular reference frame over 16 yr
  - Stable North America frame based on IGS08: “NA12”
  - Defined by 299 stations meeting objective criteria
    - > 5 years of no steps using Goldfarb’s automatic detection method
    - cut on RMS scatter, and annual amplitude
  - No-net rotation for 30 stations meeting criteria
    - longitude > -105 degrees (east of Rio Grande Rift)
    - latitude < 41 degrees (south of post-glacial rebound)
    - vertical velocity < 0.8 mm/yr (stable sites)
  - Resulting RMS residual velocity is 0.2 mm/yr north, 0.3 mm/yr east
- GSF now being used to filter this frame for EarthScope studies