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

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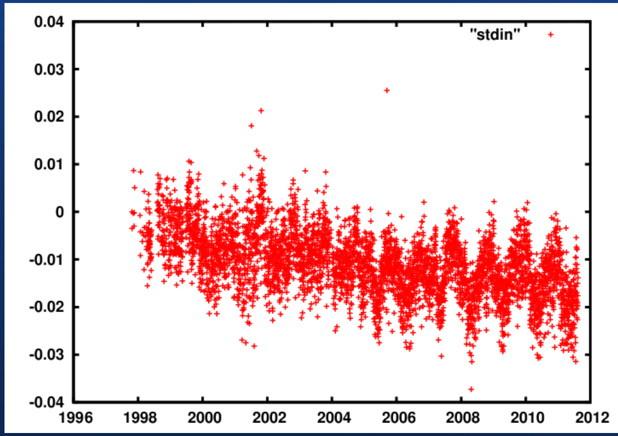
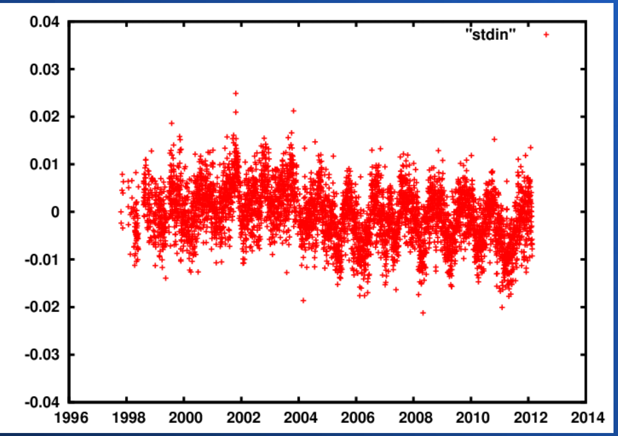
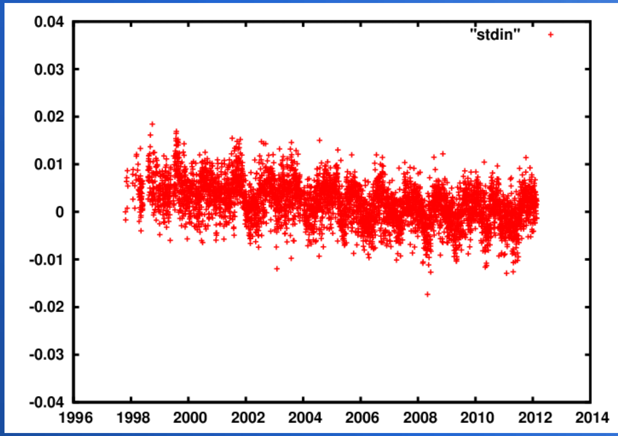
Prelude: Recent PPP Improvements
ELKO Nevada: Up (m)



- 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

GSF Method: Stacking Residuals

Compute correction for site i as weighted mean offset from frame for all 4,000 sites j

$$\Delta \mathbf{x}_i = \frac{\sum_j w_{ij} \left(\mathbf{x}_j - \mathbf{x}_j^{\mathbf{frame}} \right)}{\sum_j w_{ij}}$$

How should we define w_{ij}?

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

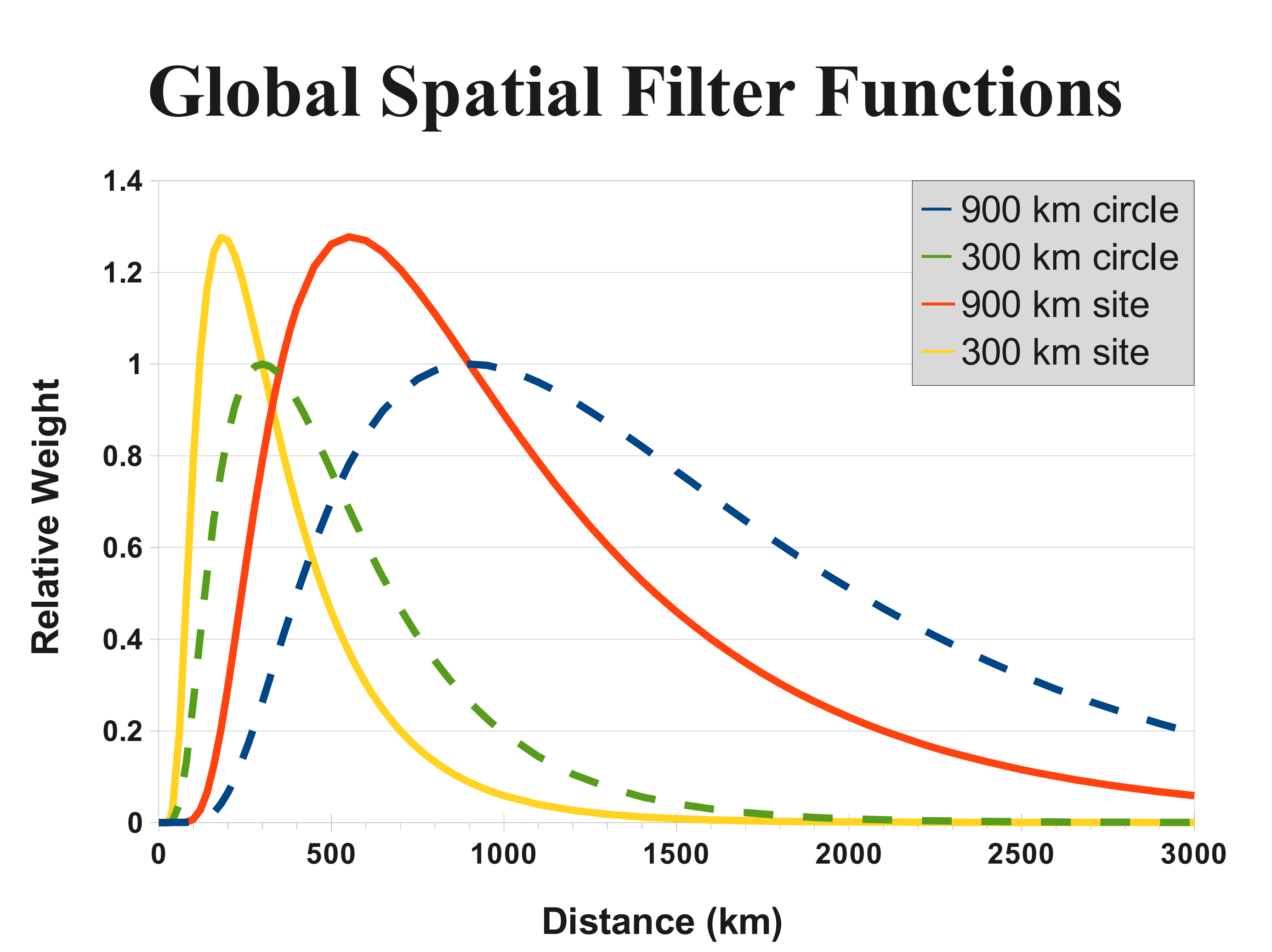
Design a weight function with these properties for thin ring of radius r

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

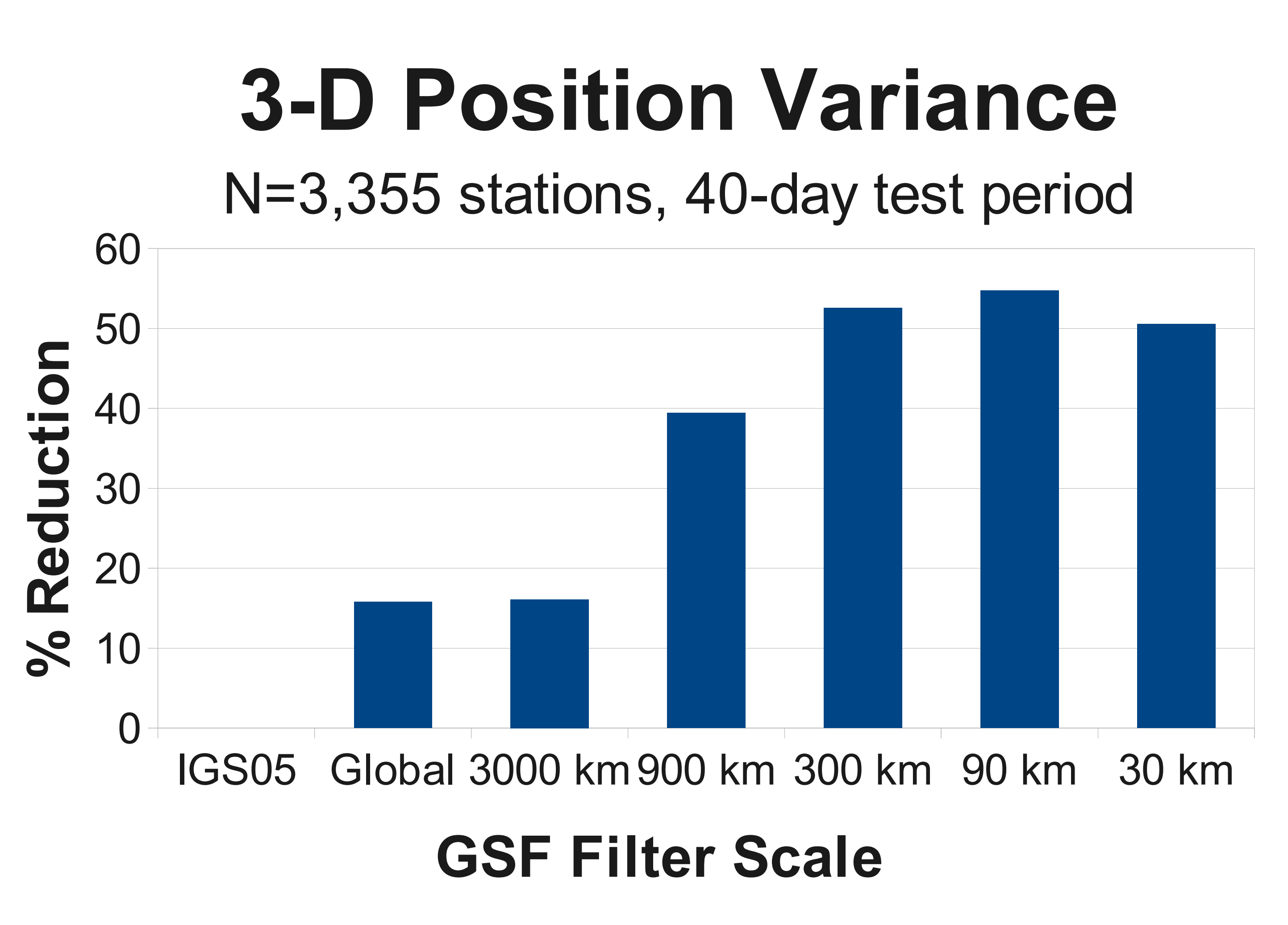
Now, the weight for a point site should account for geometry $\left(N_{\text{stations}} \propto r \right)$:
Therefore:

$$w_{ij}^{\text{site}}\left(s \right) = \frac{s}{r_{ij}} w^{\text{circle}}\left(r_{ij}, s \right) = \frac{s}{r_{ij}} e^{-\left(r_{ij}/s + s/r_{ij} \right)}$$

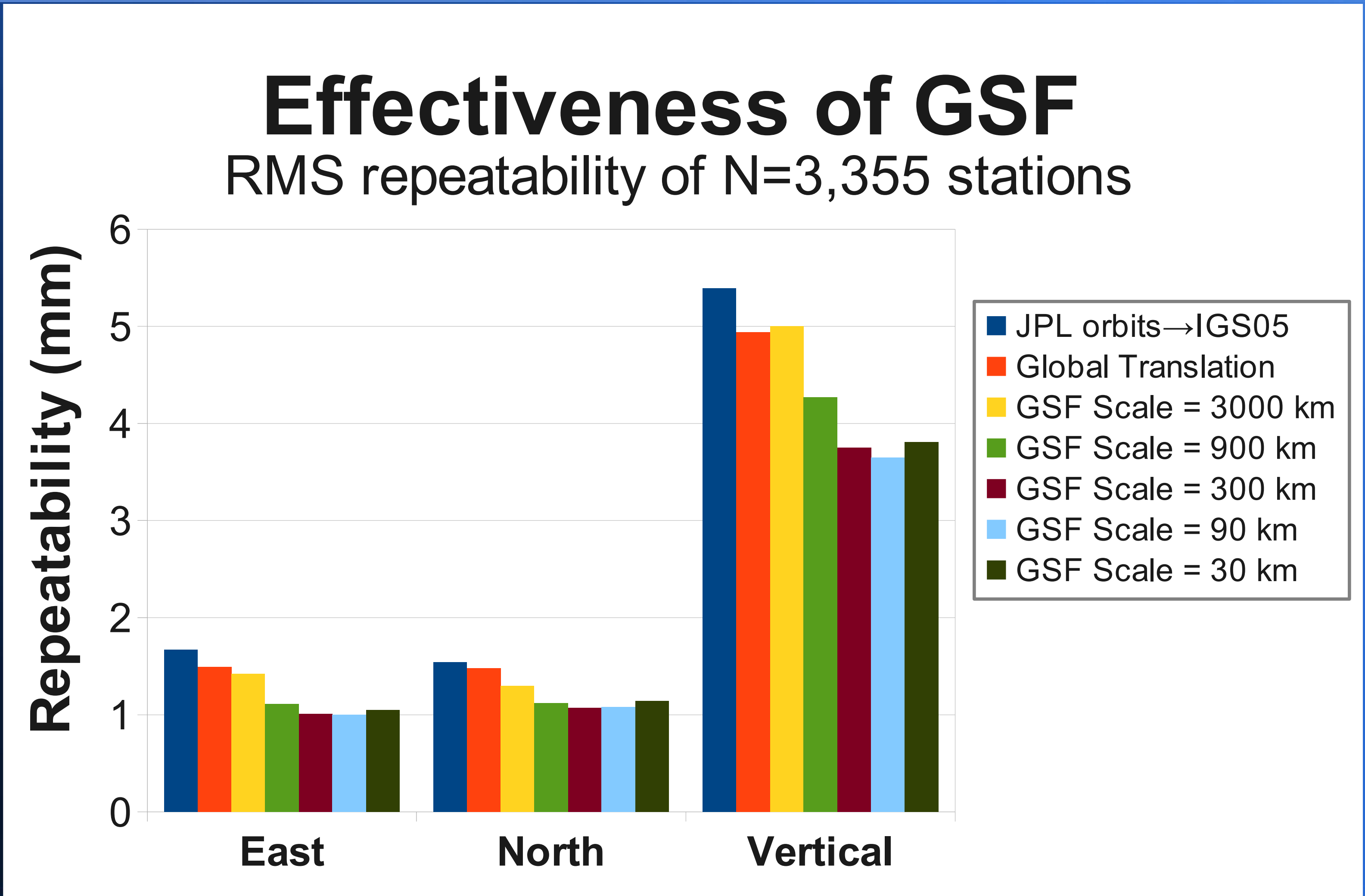
Stacking Weight versus Distance



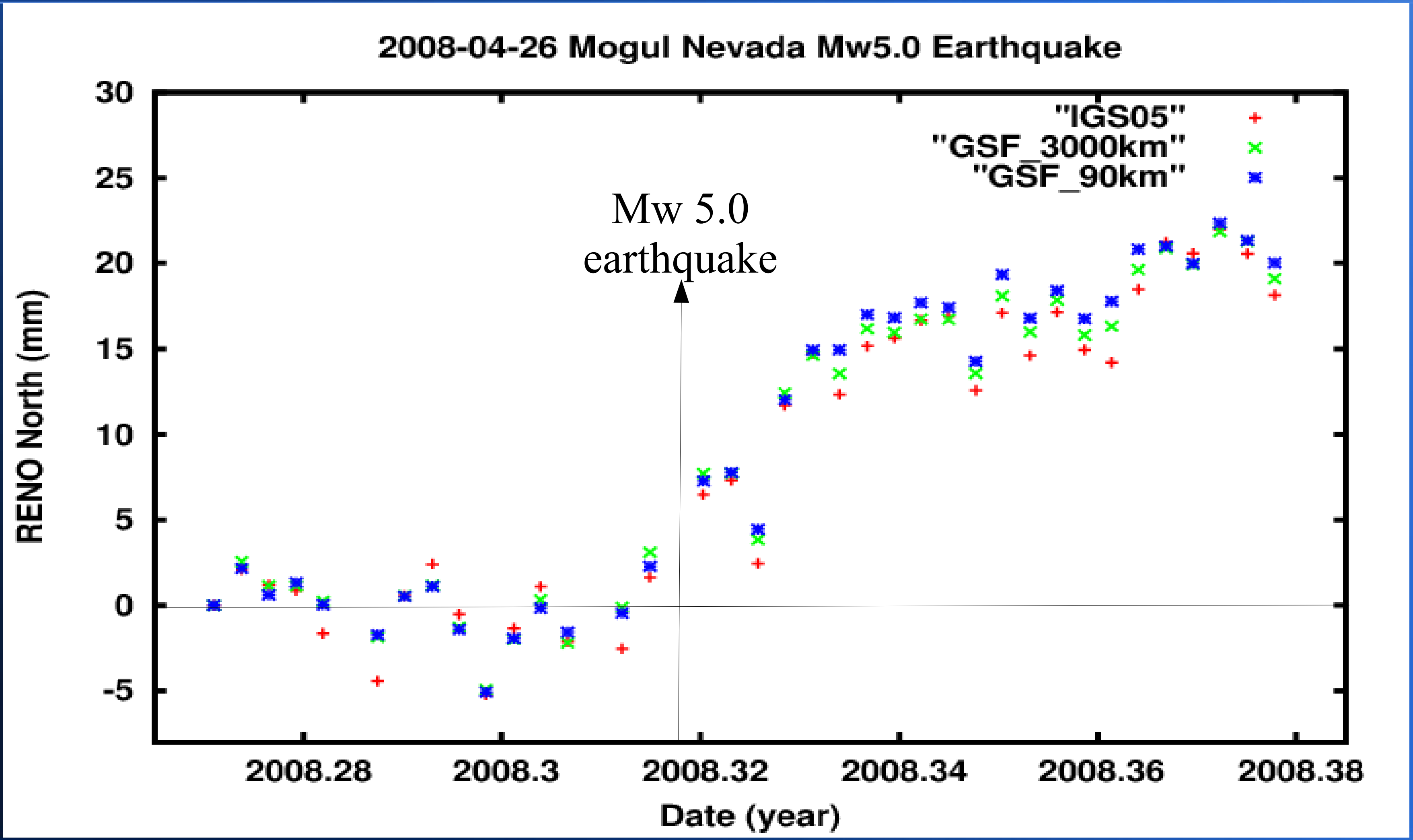
Results: Variance Reduction



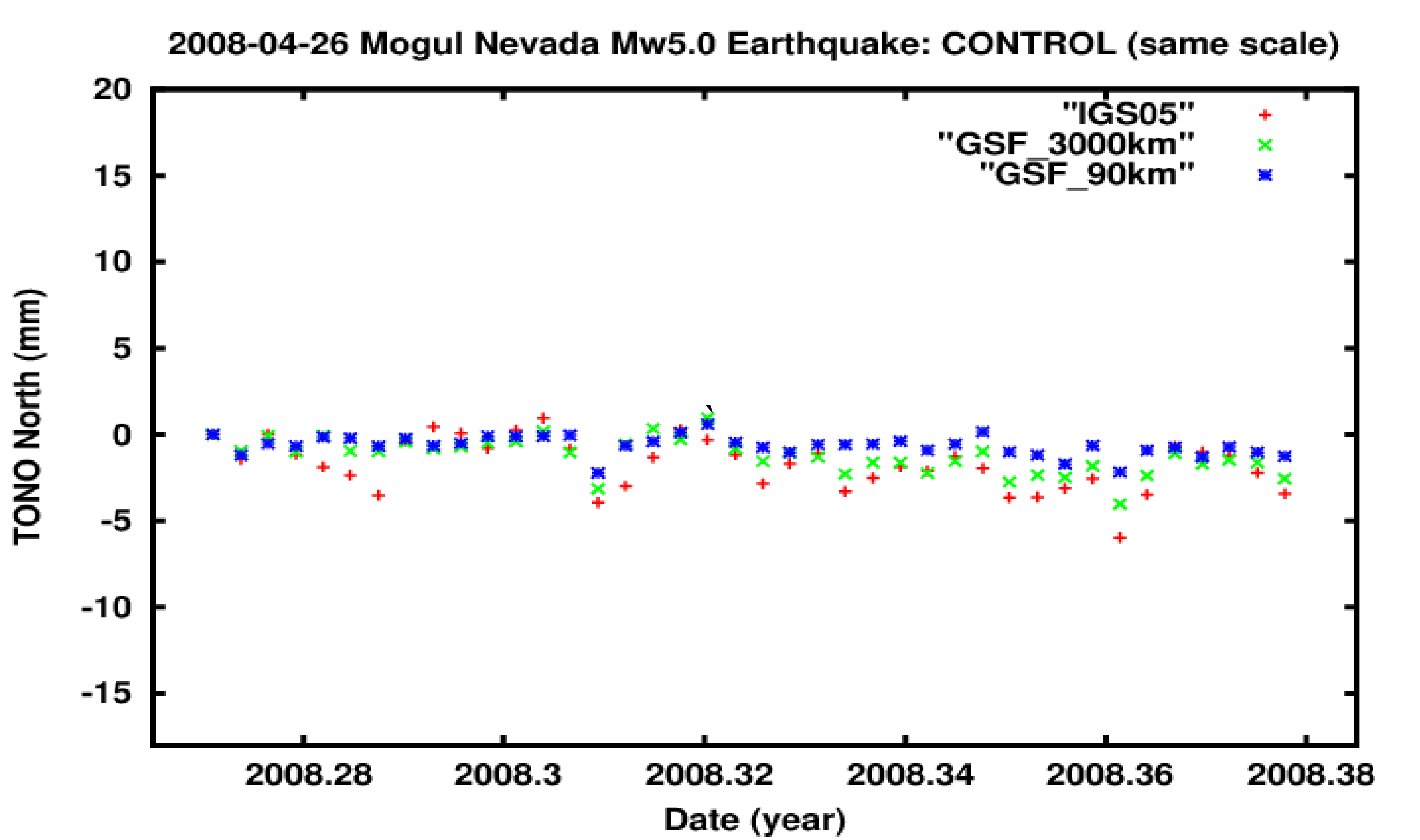
Results: Repeatability



Results: Time Series



Results: Time Series



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 km performs equally as well as a common translation.
- Up to **50% variance reduction** is gained by GSF, improving as the scale *s* = 3000 km → 900 km →300 km→90 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