

Assessment of 3D hydrologic deformation using GRACE and GPS

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Paper G13A-08

G13A: Results of the Reprocessing of Space Geodetic Observations II



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Introduction

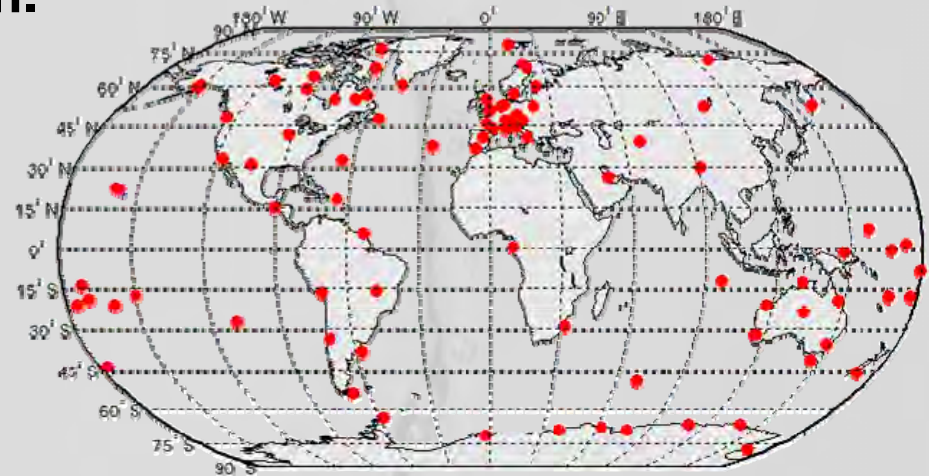
- Reprocessed GPS time series offer the potential to make a significant contribution to the study of changes in hydrology over the Earth.
- Historically hydrology at regional scales is notoriously difficult to measure – significant inroads have been made by GRACE.
- GPS is sensitive to the (3D) deformation that is induced by the time variable mass load of the water on the crust.
- **At what level will reprocessed GPS be of use for hydrology?**

Background

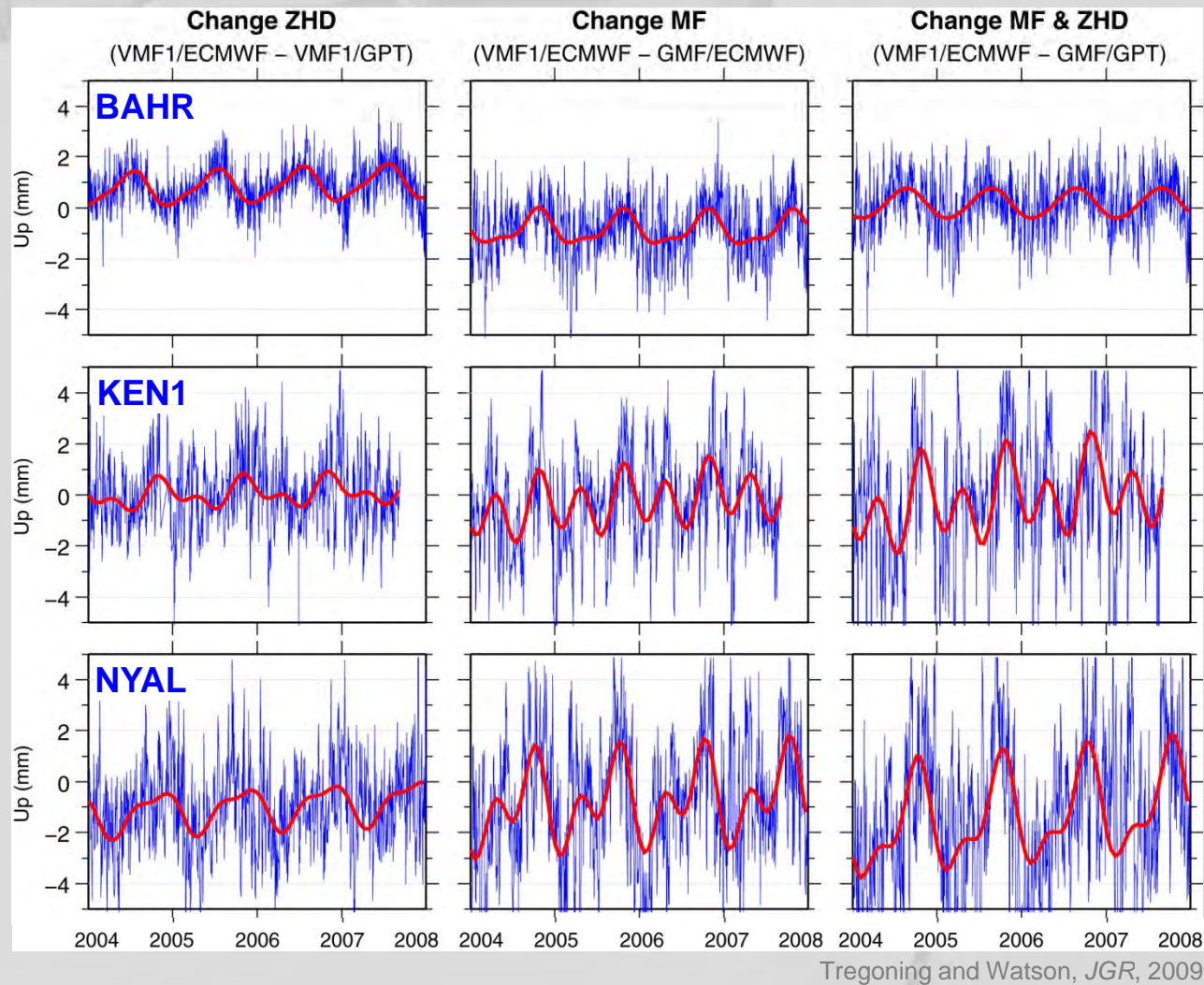
- The hydrological induced deformation signal is quasi-seasonal (solar), amplitudes up to ~10 mm (Up), ~1-2 mm (North/East).
- These low frequencies are notoriously challenging for GPS
 - » Propagation of mis-modelled high frequency signals (Penna et al *JGR*, 2007)
 - » Seasonal impact of apriori ZHD, mapping functions, ATML (Tregoning & Watson, *JGR*, 2009)
 - » Anomalous harmonics near frequencies of interest (Ray et al, *GPS Solns*, 2008)
 - » Multipath and geometry effects (King and Watson, *JGR*, 2009)
 - » ...
- We compare our reprocessed GPS time series against GRACE derived hydrological deformation.

Our GPS Reprocessing:

- We use updated solutions from Tregoning and Watson, *JGR*, 2009. GAMIT/GLOBK, ITRF2005, 2000-2009.
- Absolute pcvs, apriori ZHD: ECMWF, MF: VMF1, Tidal and non-tidal atmospheric pressure loading.
- Have compared processing in one global solution vs three global sub-nets, plus down weighting the height component by 10 and 100 during the frame realisation.
- Trends and offsets removed, only interested in quasi-cyclic signals across all coordinate components.



Improvements Observed...

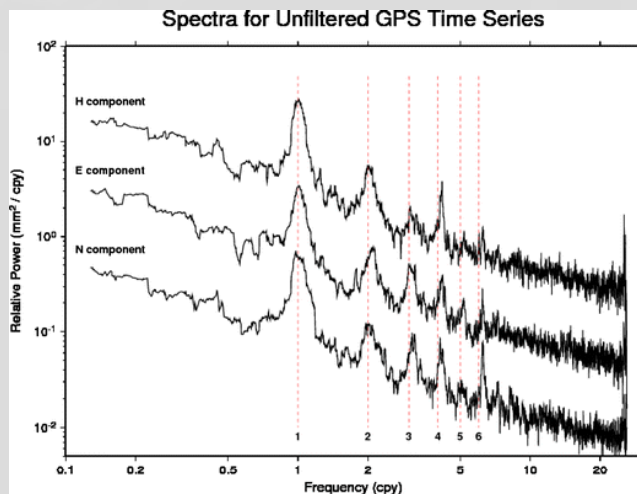


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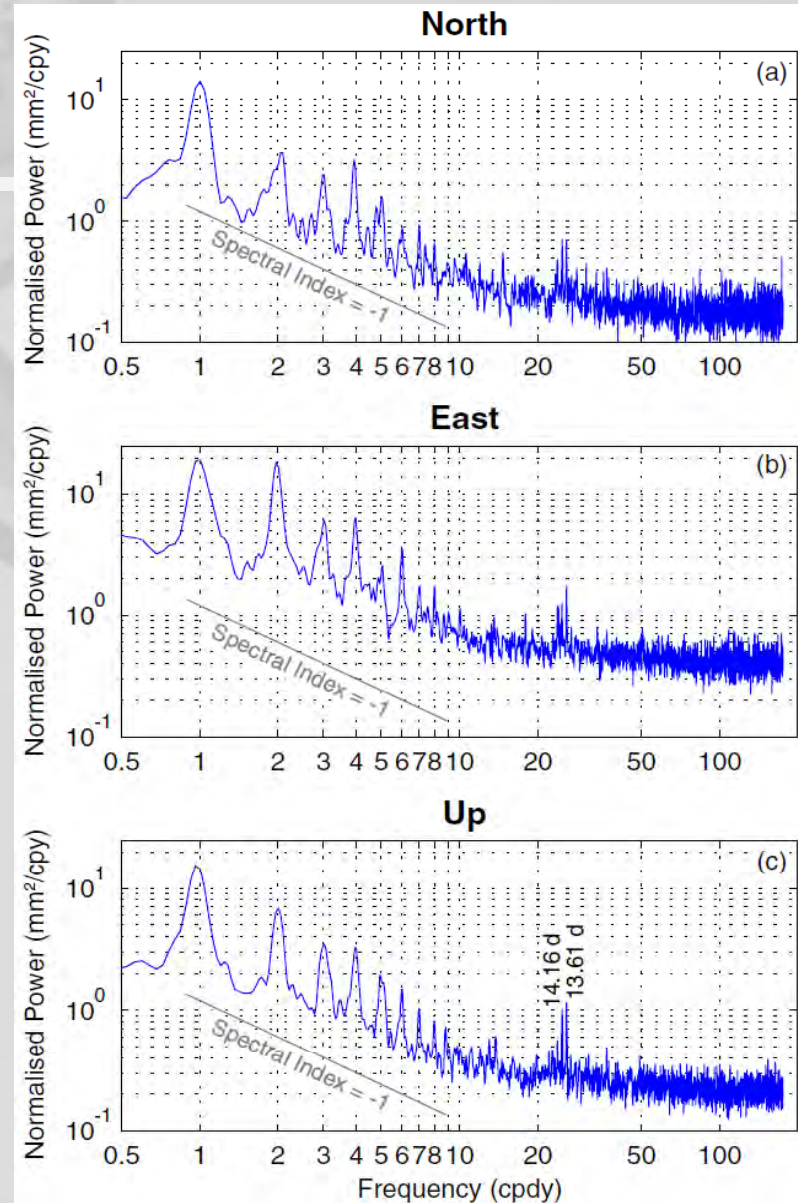


Draconitic Harmonics...



Ray et al. *GPS Solutions*, 2008

1 dy \approx 351.4 days



Tregoning and Watson, *JGR*, 2009



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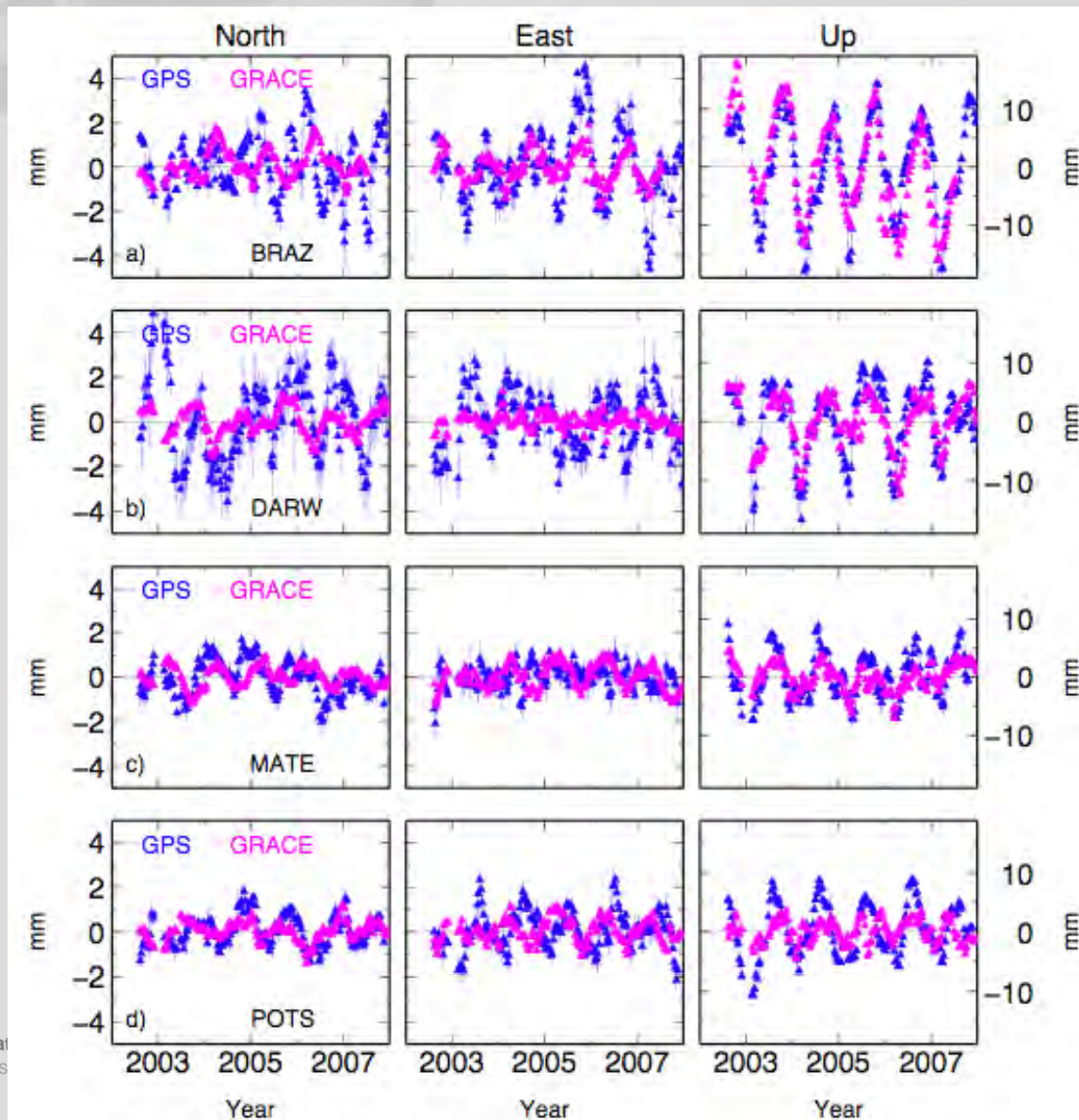
Our GRACE Processing:

1. We calculate changes in continental hydrology (equivalent water thickness) from GRACE.
 - » CSR RL04, GFZ RL04, monthly samples, filtering radii 500 and 1000 km
 - » CNES RL02, Ten day samples, no additional filtering
 - » Also extract EWT from WaterGap model (WGHM - Döll et al., 2003), filtered at 500 and 1000 km
2. Convolve surface loads with Green's functions to derive estimates of 3D elastic surface deformation at GPS site locations.



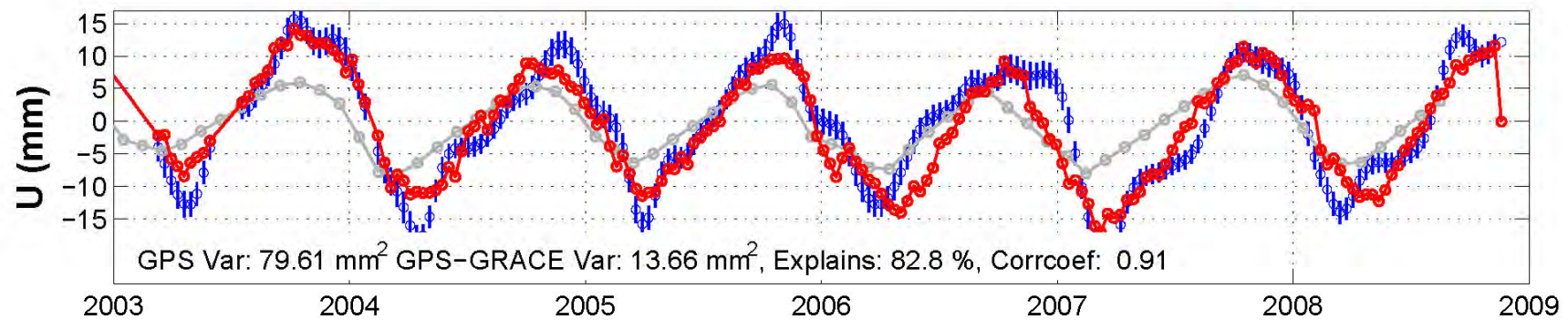
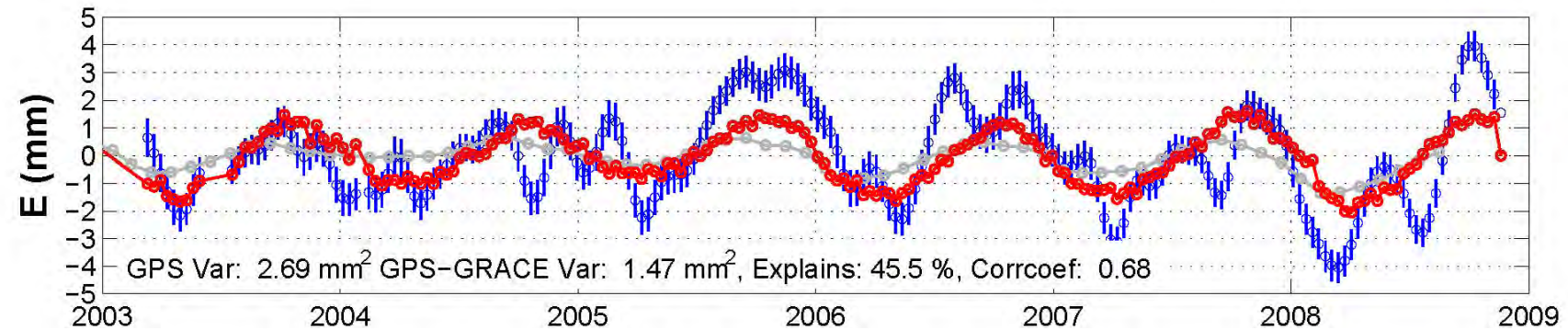
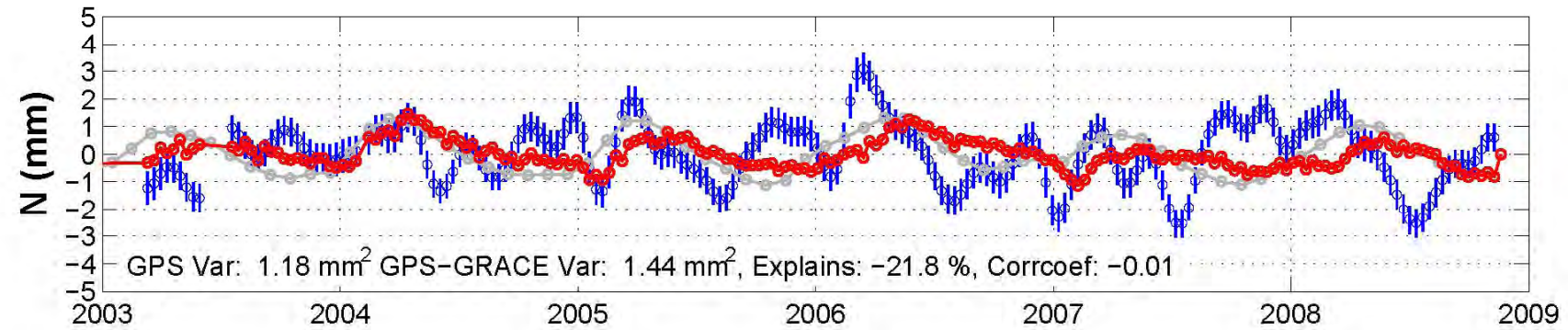
Some Examples...

- Agreement between GPS and GRACE across N/E/U can be quite spectacular and in some cases quite poor.
- Horizontal components often indicate a phase difference (but not all the time).
- At what level are spurious signals biasing the GPS solution?



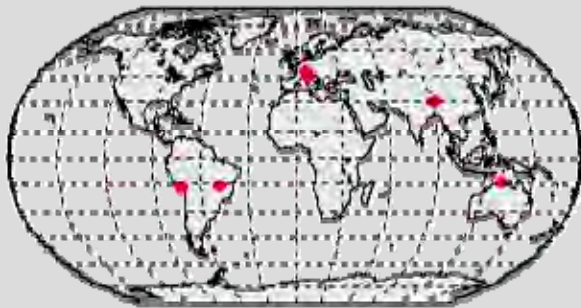
Site: BRAZ

GPS GRACE (CNESRL02) WGHM



Results...

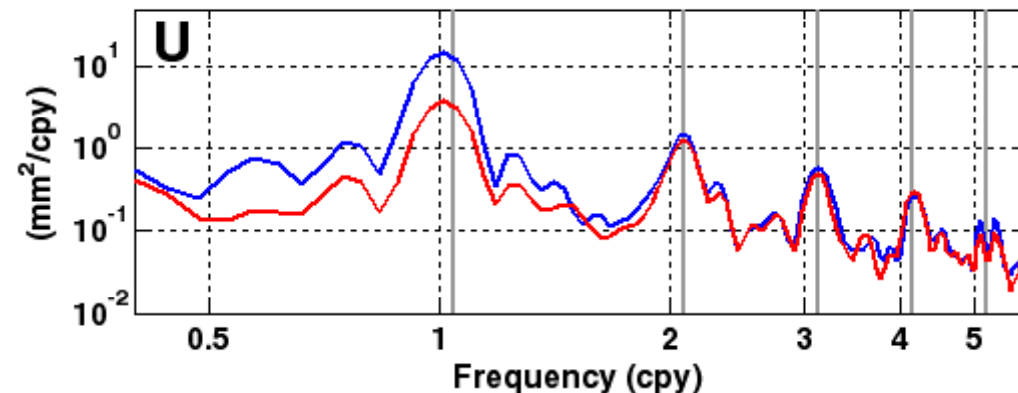
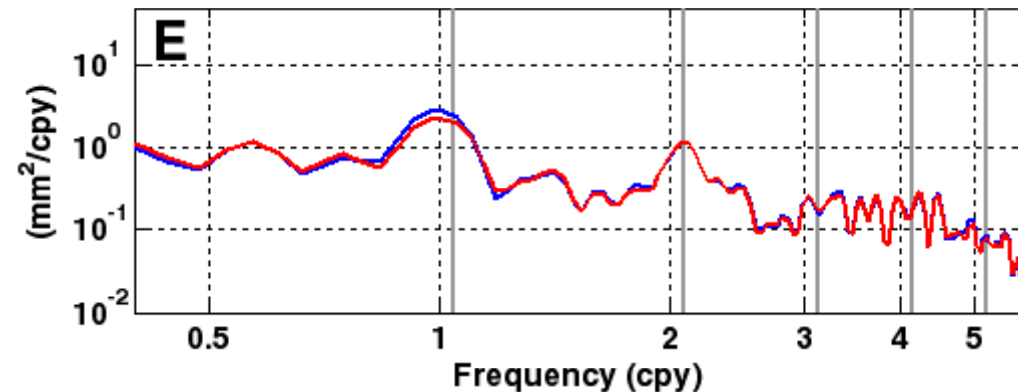
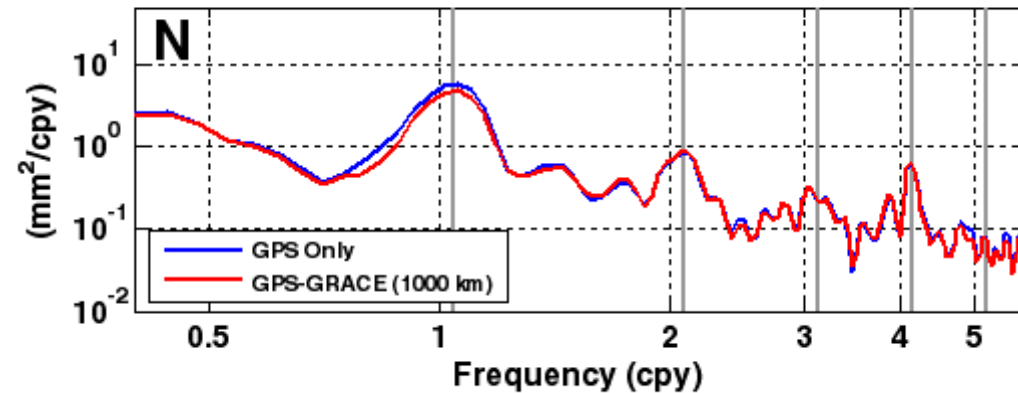
- First look at sites where GRACE and GPS have a correlation > 0.65 in the UP component.
- Stack lomb spectra of **GPS** and **GPS-GRACE** from these sites.



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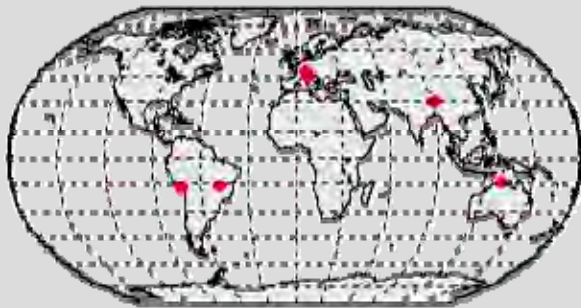
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Stacked Spectra (GRACE: CSR004)



Results...

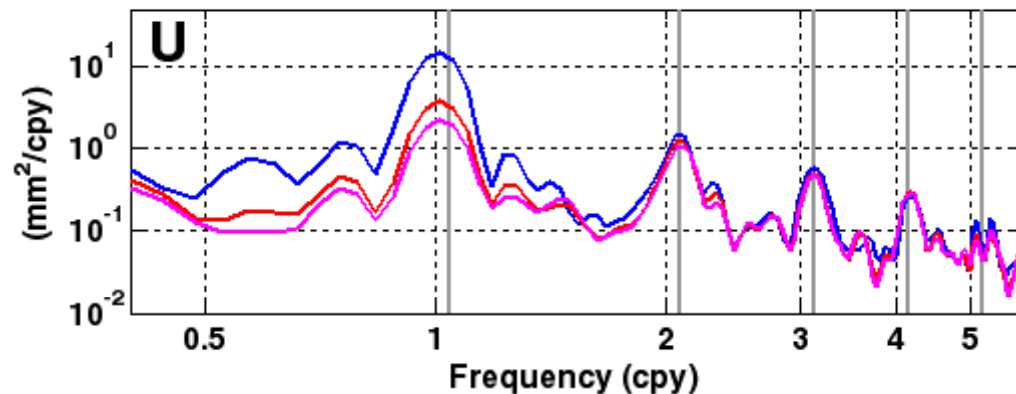
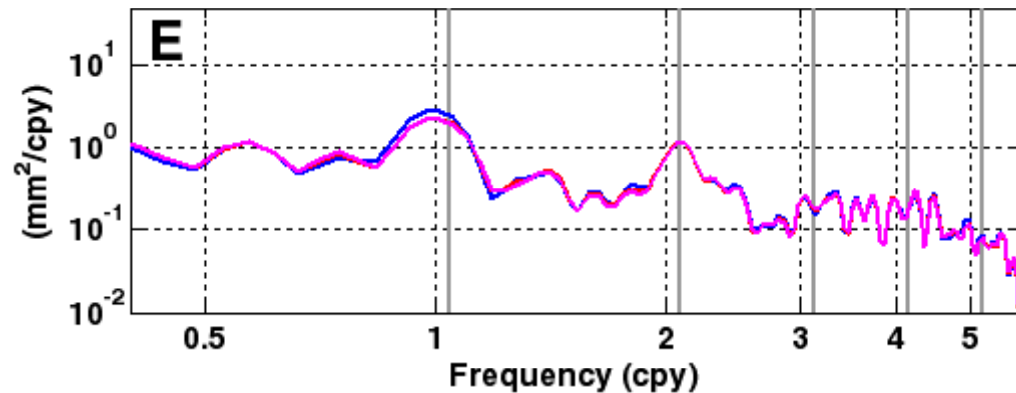
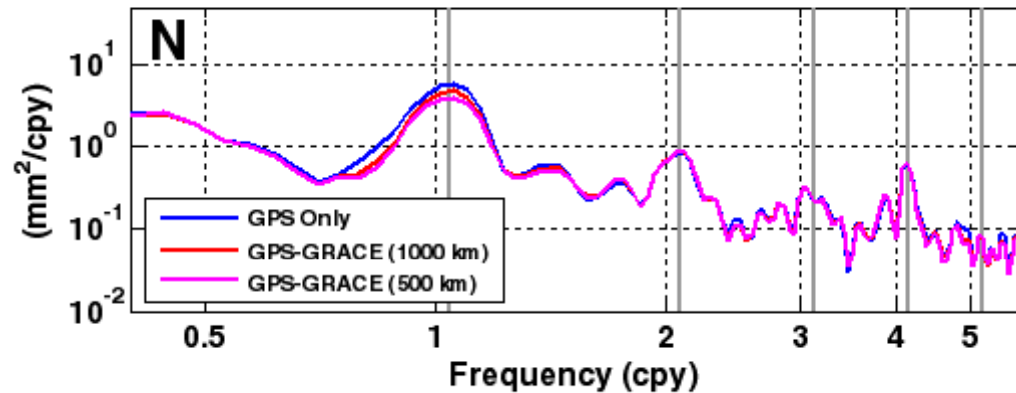
- Further improvement when using a shorter wavelength filter radius (500 vs 1000 km)



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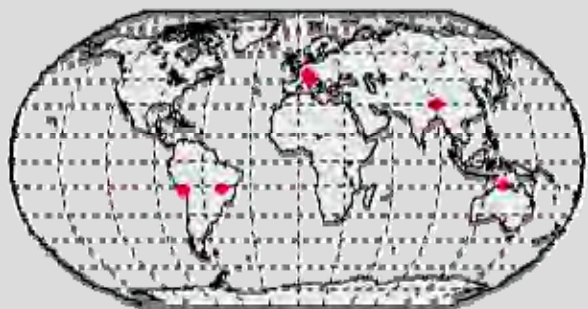
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Stacked Spectra (GRACE: CSR004)



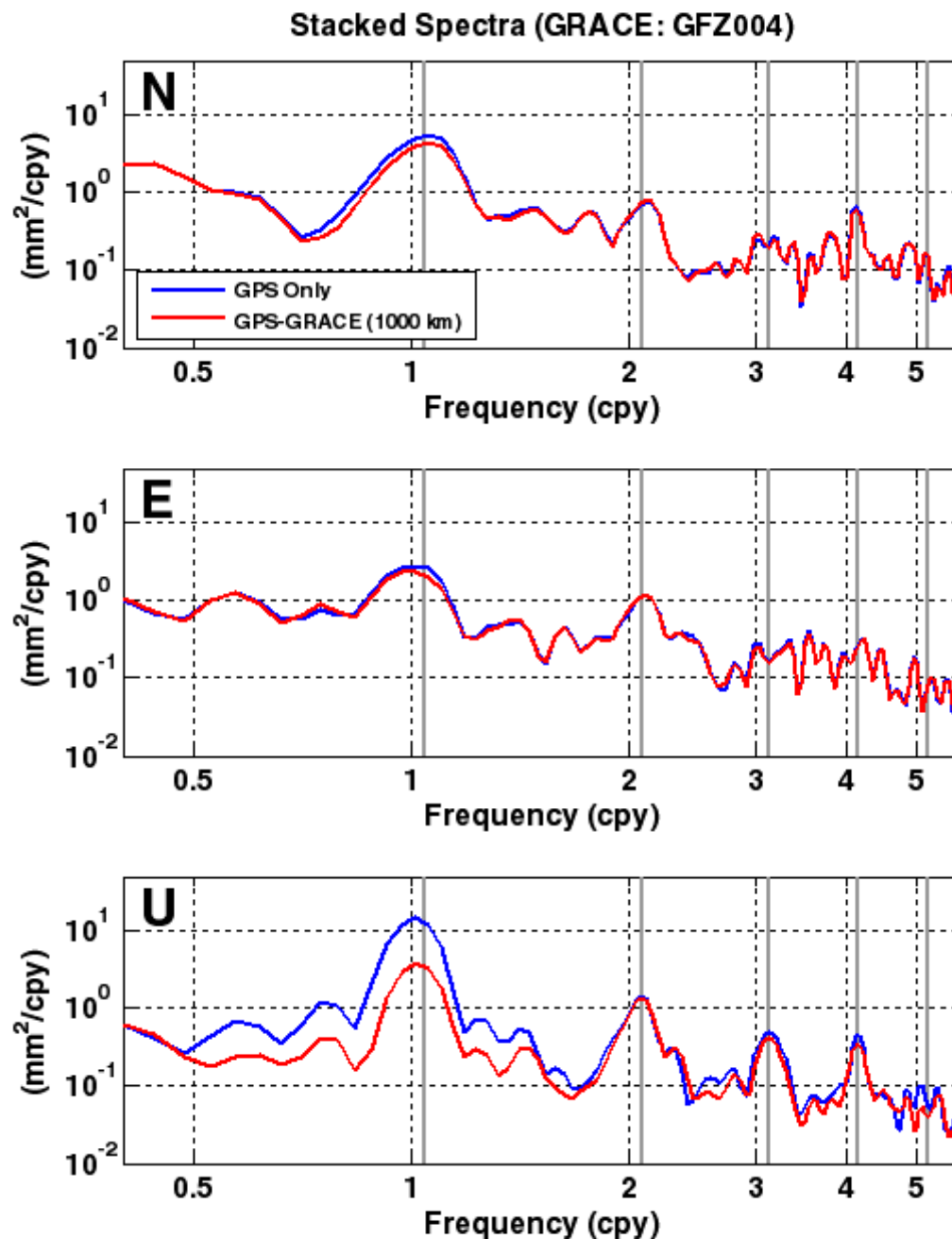
Results...

- Only small differences between CSR and GFZ solutions (note slightly different duration and number of samples).



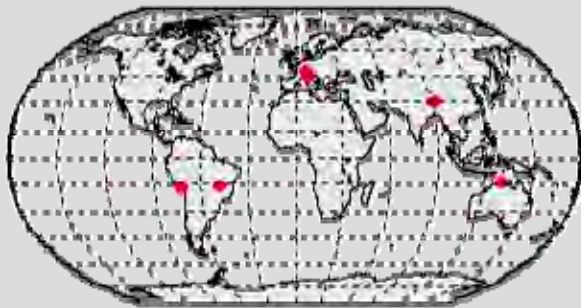
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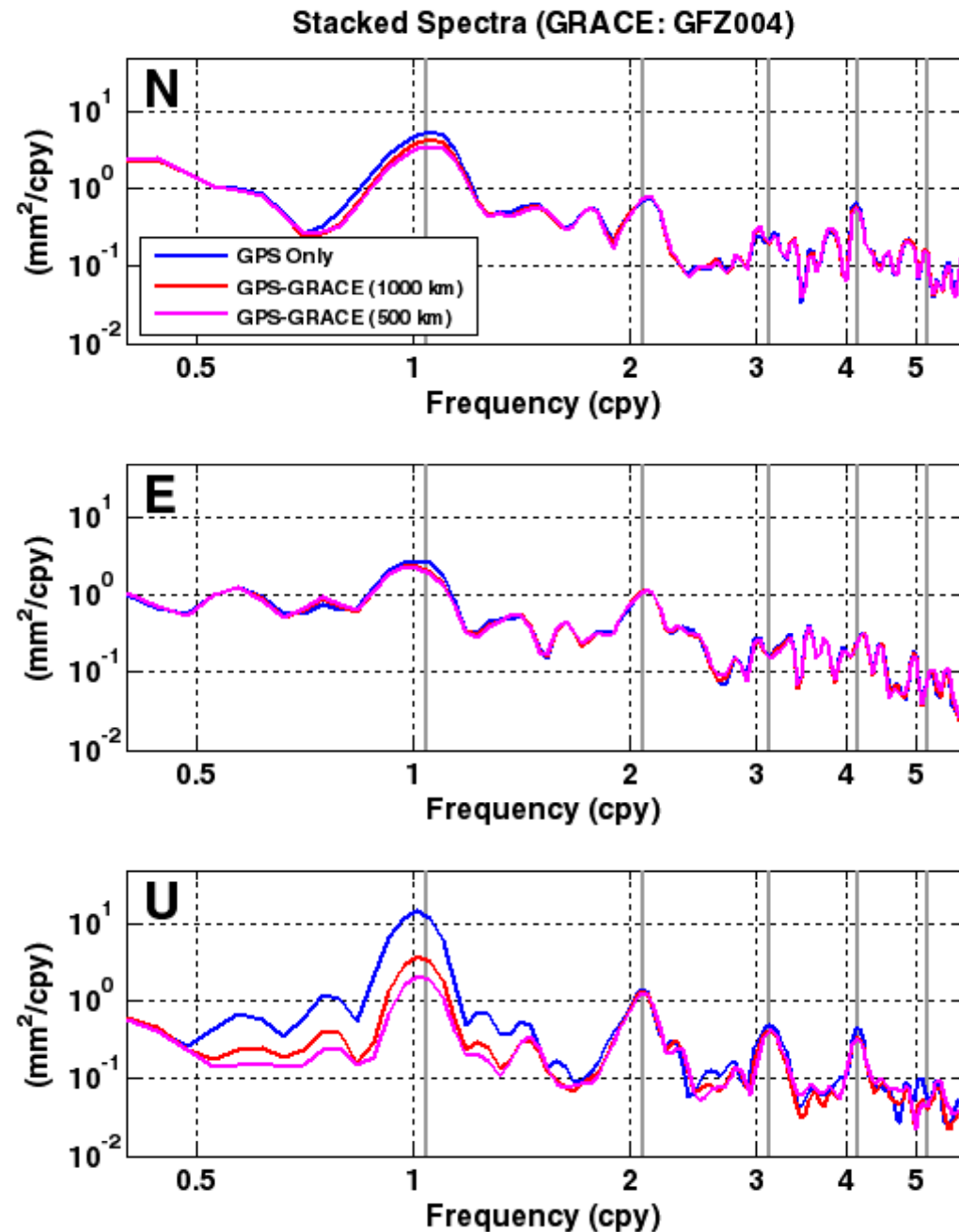
Results...

- Similar improvement when decreasing GRACE filtering radius.



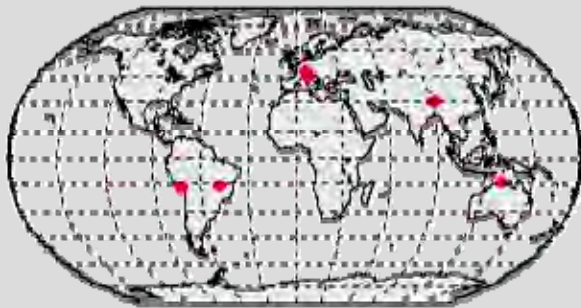
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Results...

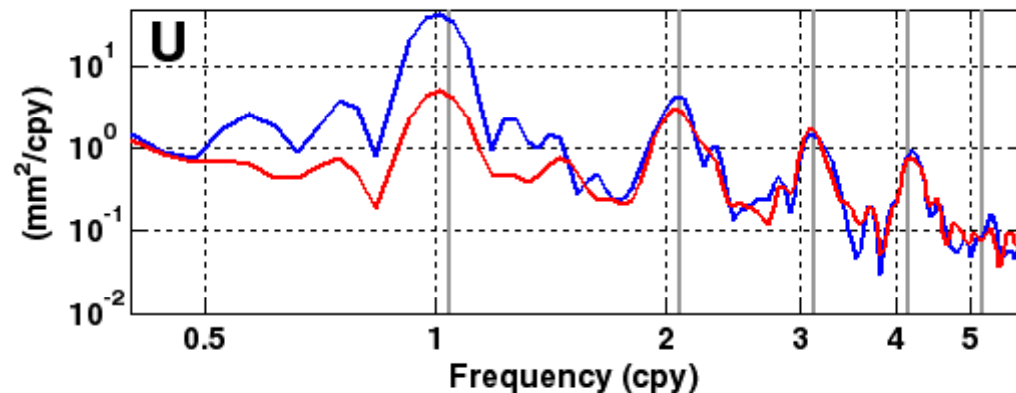
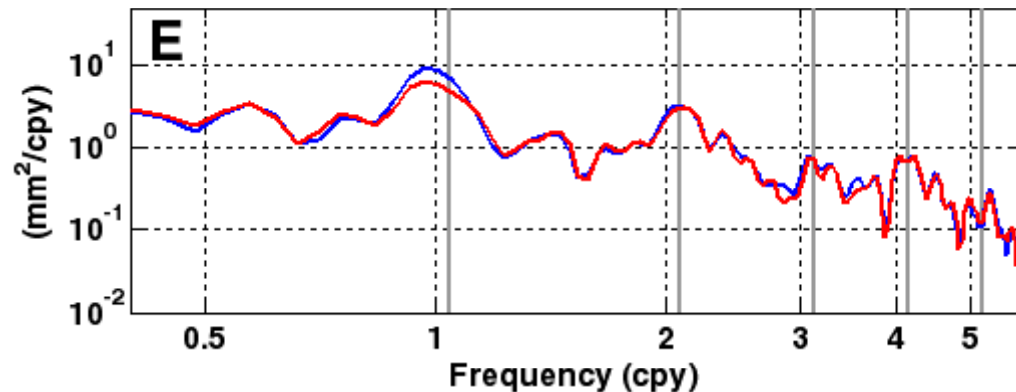
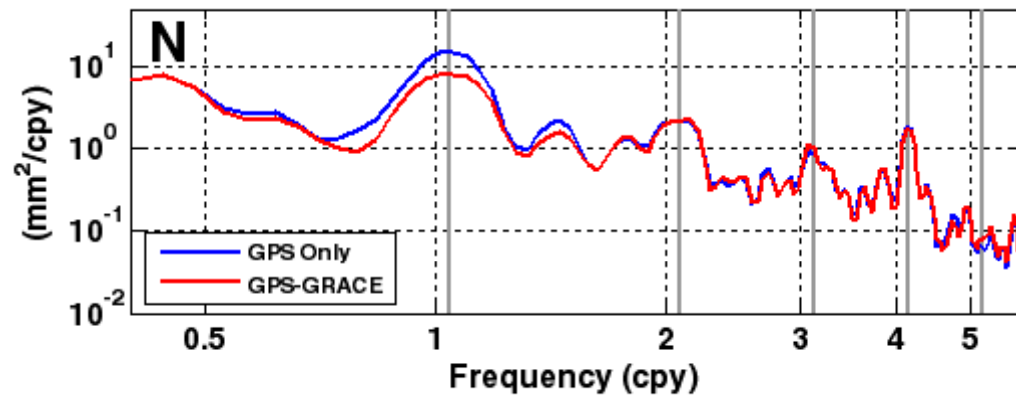
- Similar results for CNES02 (note sampling frequency is much higher hence change in baseline variance).
- Even from just six sites, residual energy in GPS-GRACE appears centred on harmonics of the draconitic year ($\sim 351.4\text{d}$) as per grey lines.



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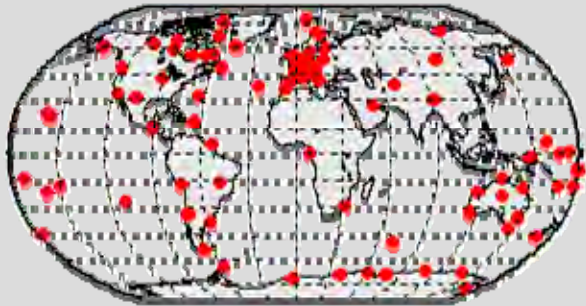
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Stacked Spectra (GRACE: CNES02)



Results...

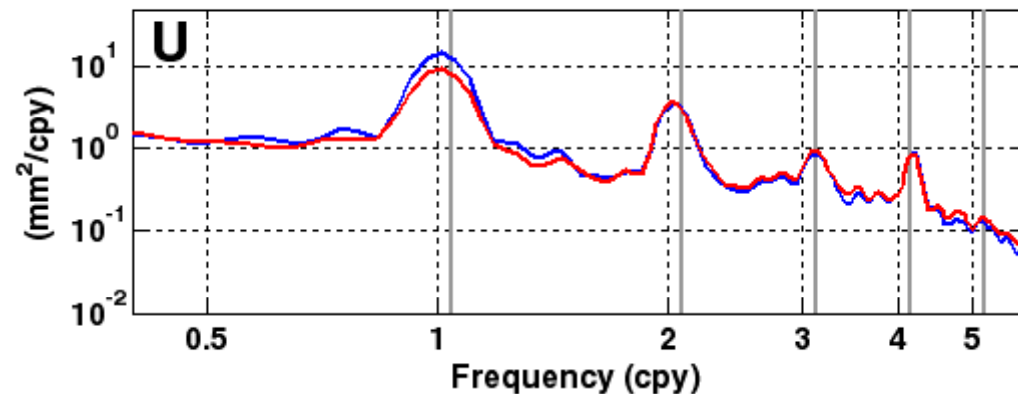
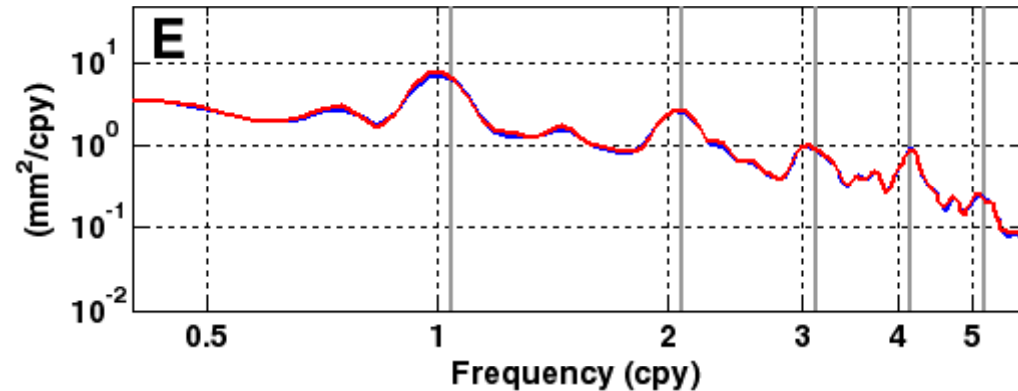
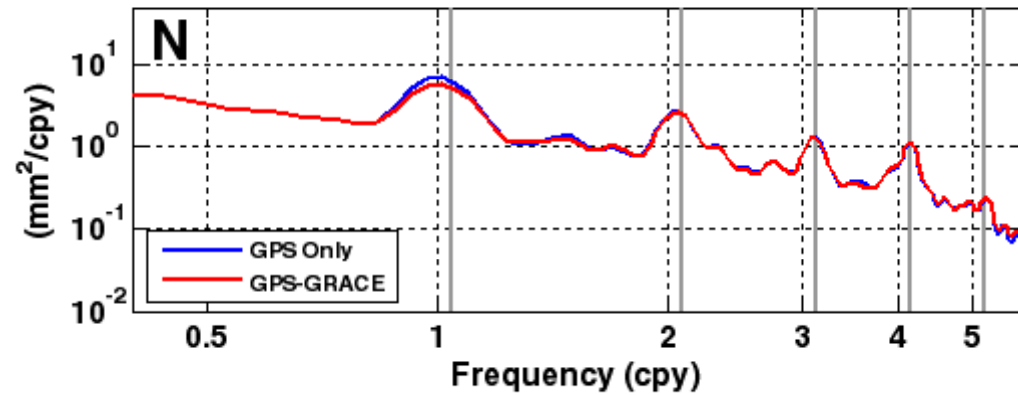
- Stacking all sites highlights the prevalence of the draconitic harmonics across all coordinate components.



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Stacked Spectra (GRACE: CNES02)



Recap...

- At the sites where we expect a hydrology signal, using GRACE enables a reduction in variance of GPS time series at quasi-annual periods.
- Using reprocessed GPS, GRACE can explain up to ~80% of the variance in Up, and up to ~60% in North and East at some sites.
- The residual signal seems dominated by GPS error at harmonics of the draconitic year, rather than GRACE error.

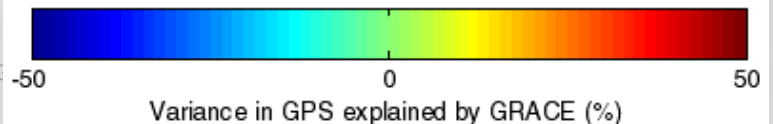
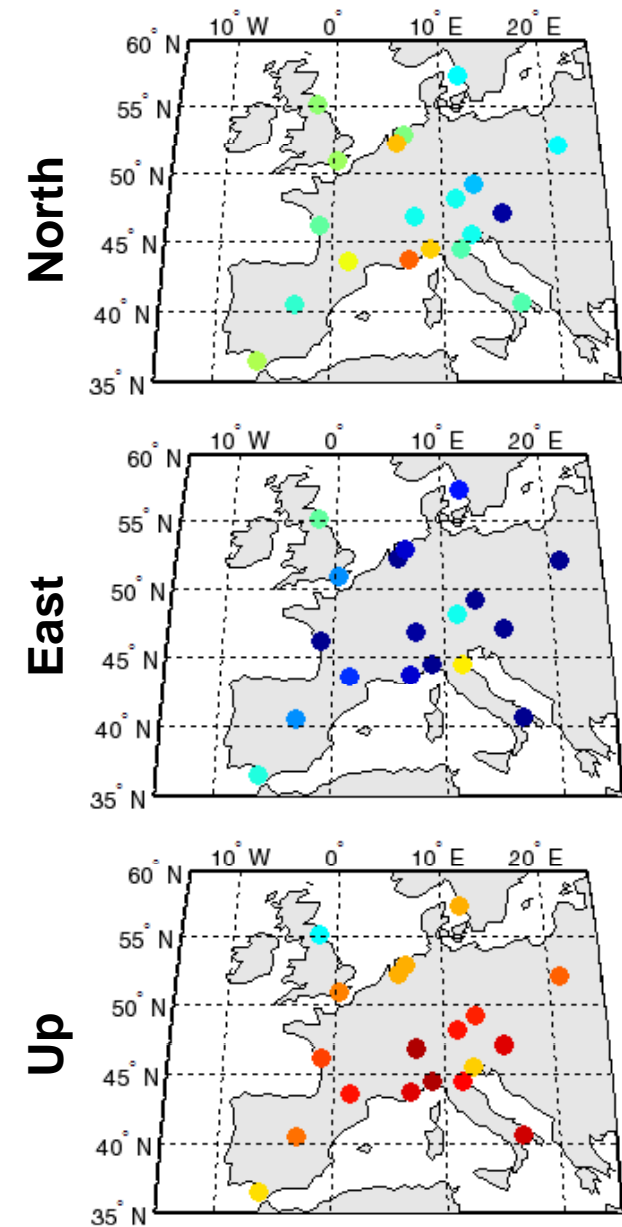
Over Europe...

Up: Agreement is much improved c.f. non-reprocessed GPS time series

North: Agreement is mixed but mostly poor

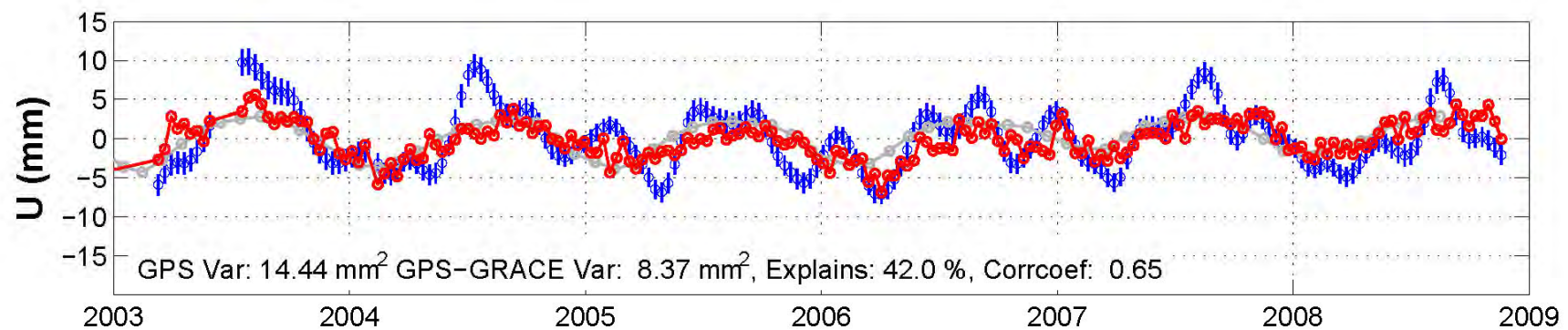
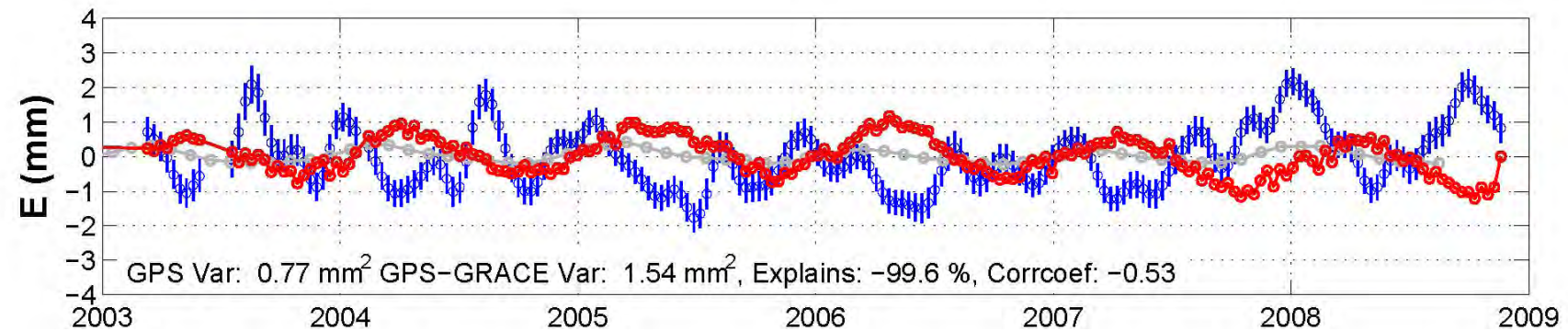
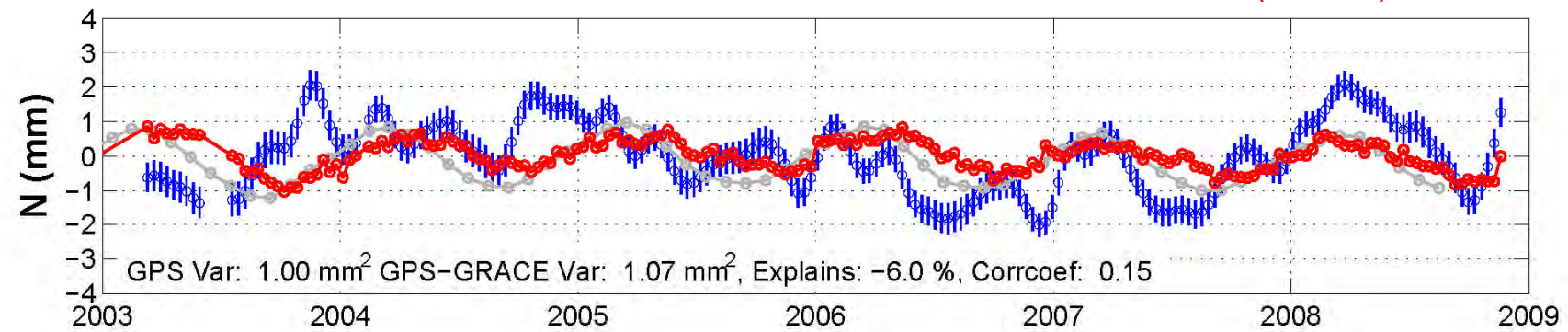
East: Agreement is v.poor (-)ve correlation

- The hydrology signal in N/E over these areas has an amplitude of ~1 mm. This is at the level of the spurious signals in the GPS time series.
- Real hydrology + spurious signals in E = a signal out of phase with GRACE?



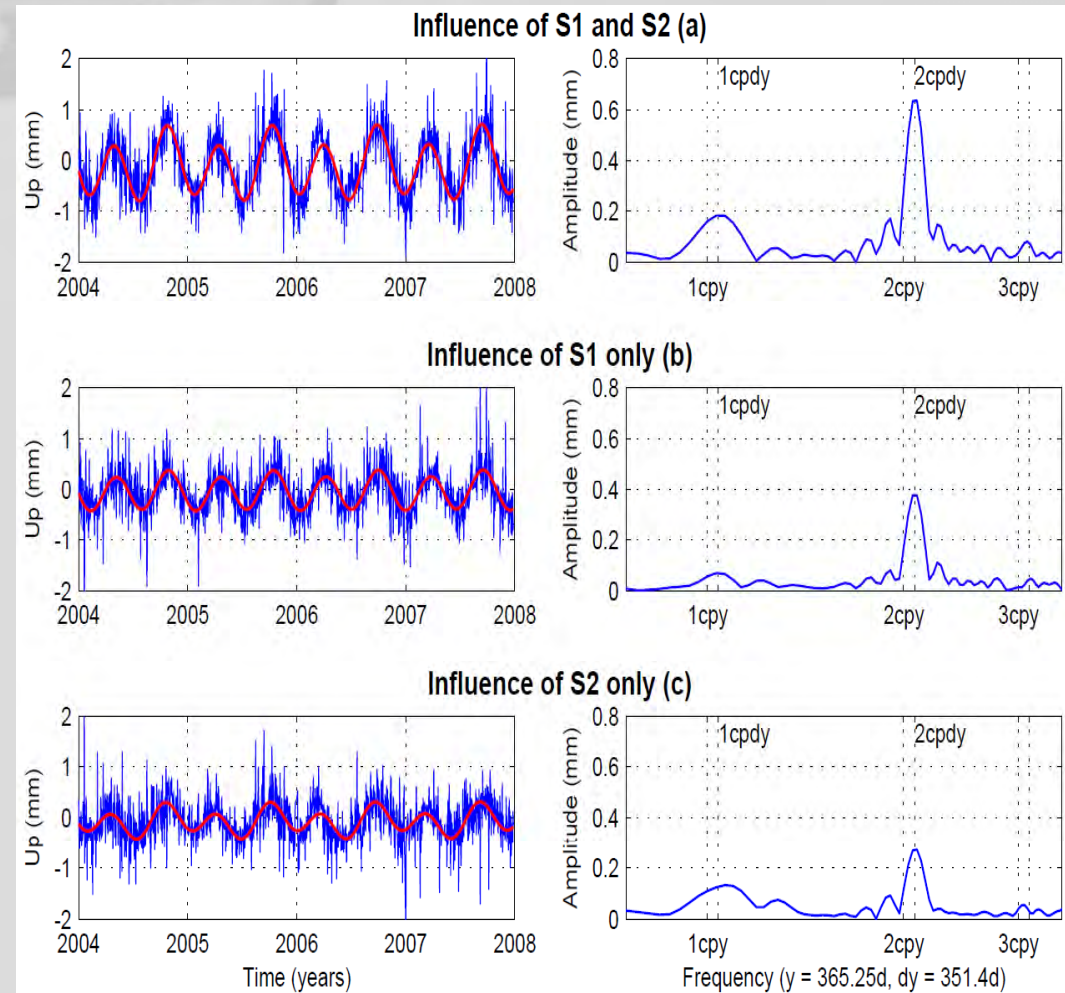
Site: MATE

GPS GRACE (CNESRL02) WGHM



Drivers for GPS Error...

- Solar diurnal (S1) and semi-diurnal (S2) changes in atmospheric pressure deform the crust. (Ferland & Ray, 2002)
- S1 and S2 propagate with high admittance to ~ 351 d and $\sim 351/2$ d (1 cpy and 2 cpy).
- Multipath... (Ferland & Watson, 2009)
- Orbis...
- ...



Tregoning and Watson, JGR, 2009



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Conclusions...

1. Hydrology from GRACE can describe an improved amount of variance when using reprocessed GPS time series.
2. Shorter filter wavelengths on GRACE products produce the better fit (500 vs 1000 km, not further optimised in this study).
3. GRACE is not without error, BUT, the dominant signal in the difference between GPS and GRACE appears to be GPS related and exists at harmonics of the draconitic year.
4. In many areas, the quasi-seasonal / draconitic GPS error is now of comparable magnitude to the hydrology signal (~ <1mm in N/E, ~ <4mm in Up).
5. Until we understand these spurious signals, it will be difficult to further understand hydrology using reprocessed GPS time series.

The End

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Spares...



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Inferring displacement from GRACE

Surface loading is defined in terms of the equivalent water thickness (EWT) as inferred from the GRACE spherical harmonic solutions' time series, using the formulation of Wahr et al. (1998).

For the CSR and GFZ times series (level three from Uni. Of Colorado):

- Spherical harmonic solutions destriped using the methodology of Swenson & Wahr (2006);
- Data smoothed using 500 & 1000 km Gaussian filters (Wahr et al. 1998);
- $C_{2,0}$ in the original solutions replaced by values from Satellite Laser Ranging (SLR);
- $C_{1,0}$, $C_{1,1}$ and $S_{1,1}$ added based on method of Swenson et al. (2008);
- Use of release RL04, solutions expanded until degree/order 70, with a time mean (static field) removed.

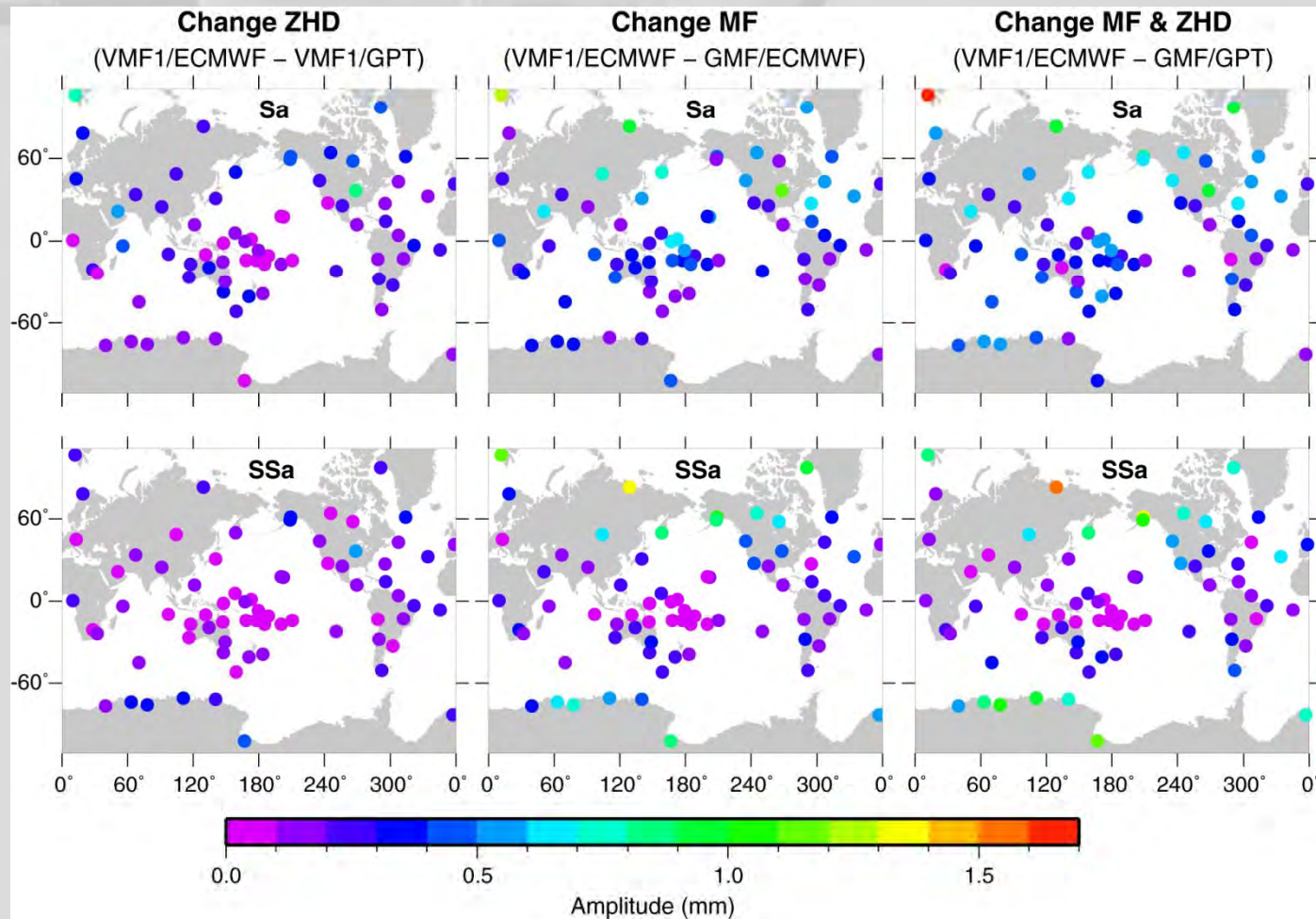
For the CNES solutions:

- An average is found for each harmonic component and removed from the coefficients;
- Degree 1 terms modified with values derived using the method of Munakane (2007);
- The degree $C_{2,0}$ largely from SLR data.

WaterGAP Global Hydrological Model (WGHM)

- 0.5° grid, global except for Greenland and Antarctica (Döll et al., 2003).
- Considers major hydrological processes:
 - Snow accumulation and melting.
 - Evapotranspiration.
 - Runoff generation.
 - Lateral transport of water.
- Modelling time step is 1 day.
- Lateral water transport accounts for storage capacity of groundwater, lakes, wetlands and rivers.
- River discharge has been tuned against time series from 724 globally distributed river gauge stations.
- Number of datasets used (e.g. soil map of the world, global drainage direction map).
- Displacement inferred for three cases:
 - Unfiltered
 - 500 km Gaussian filter applied
 - 1000 km Gaussian filter applied

Recent Improvements...



Tregoning and Watson, *JGR*, 2009

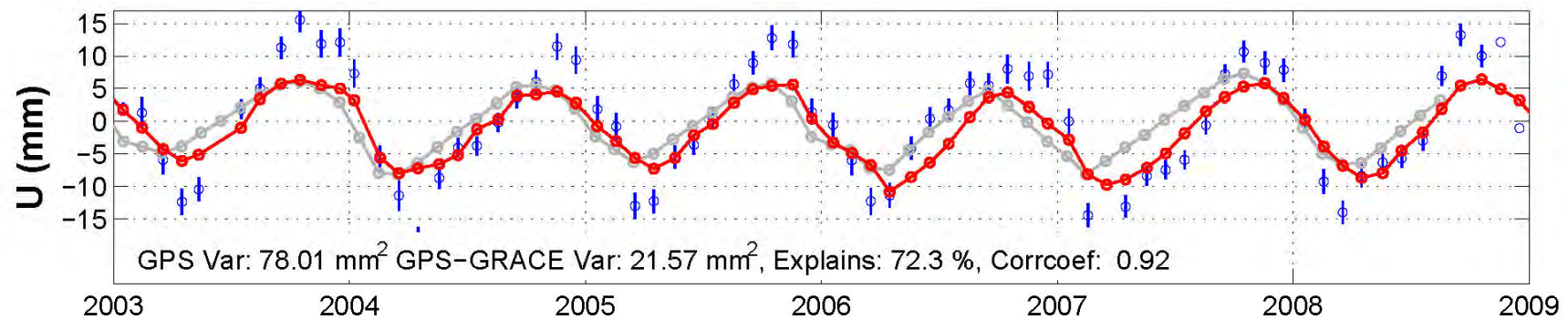
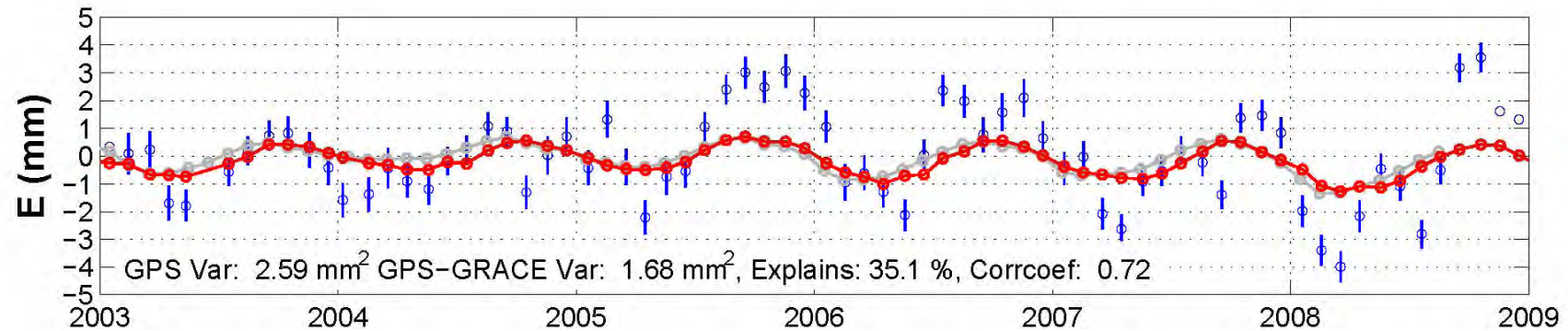
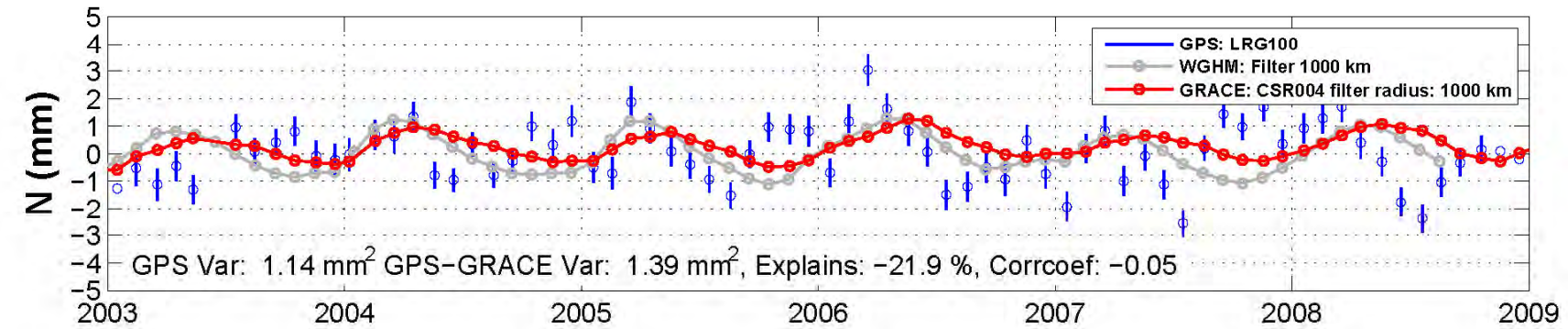


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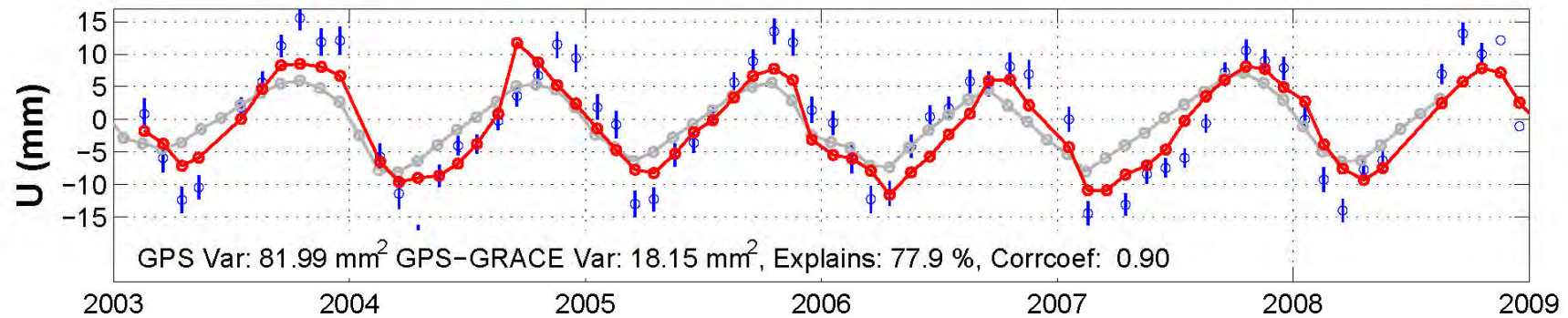
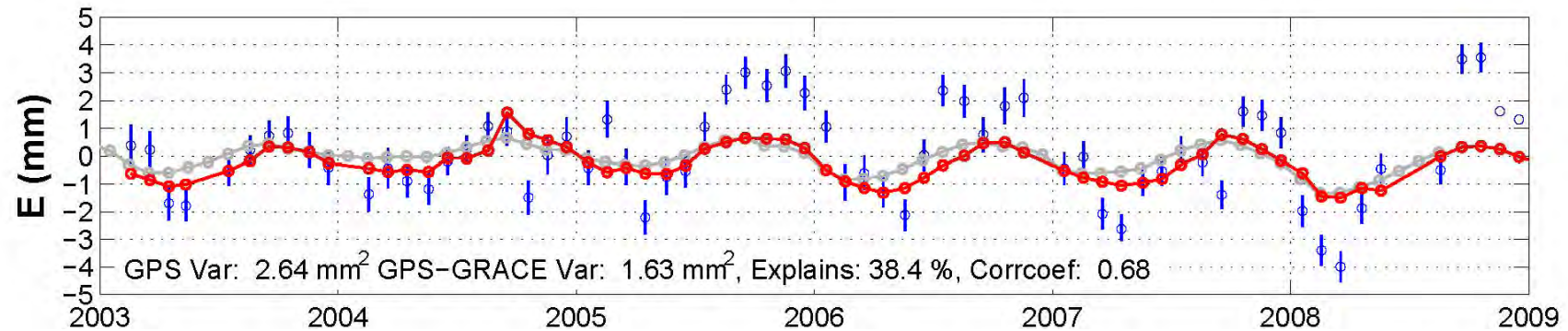
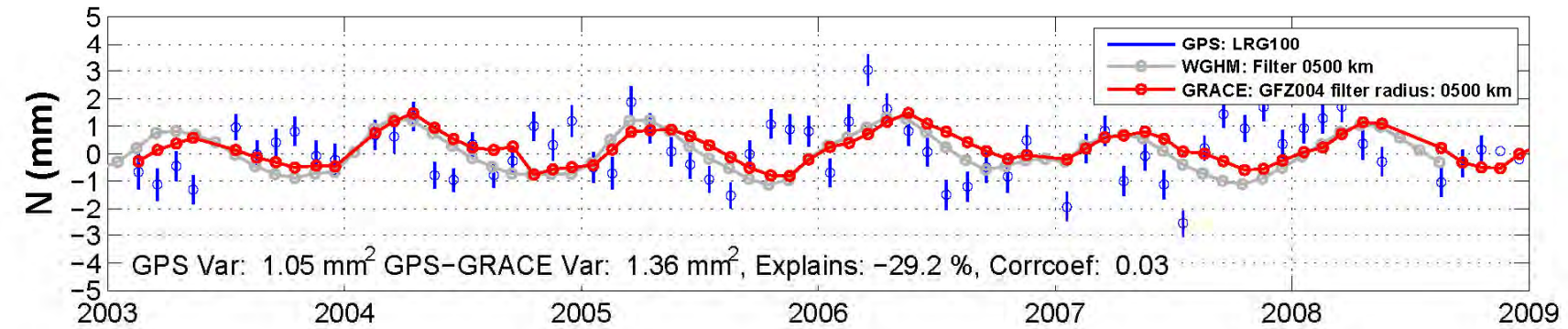
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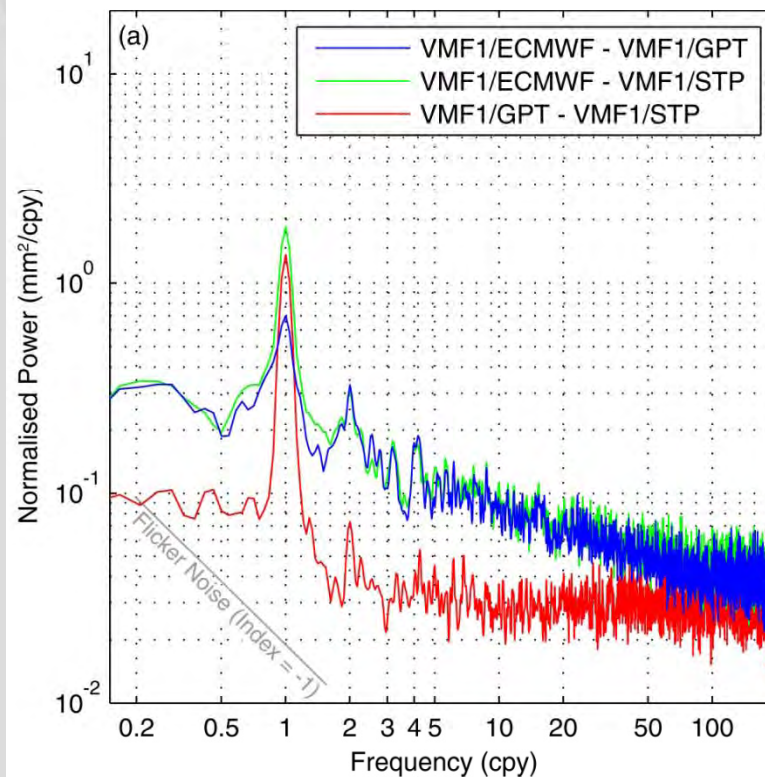


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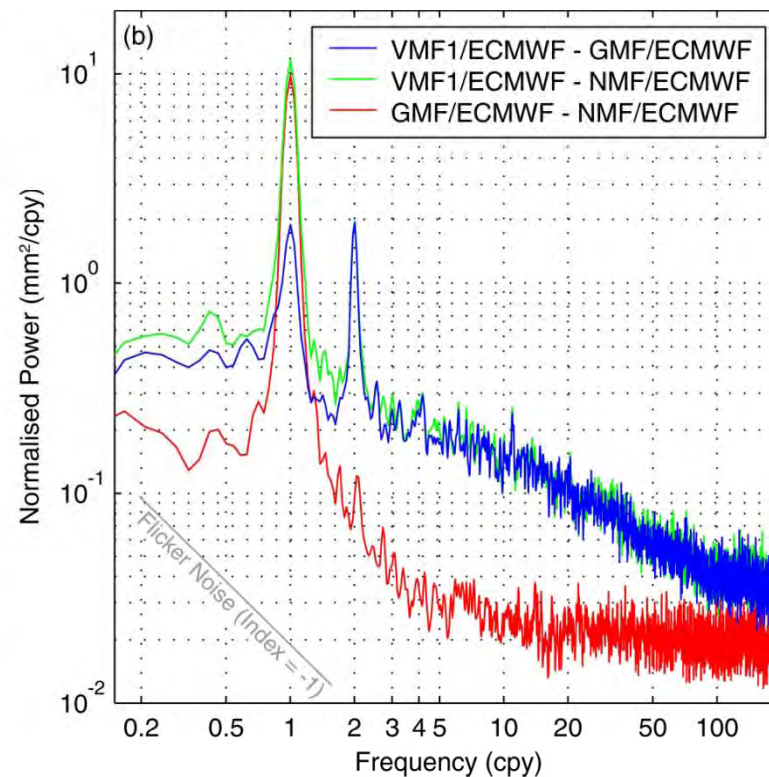


Improvements observed...

Tregoning and Watson, *JGR*, 2009



Changing a priori ZHD



Changing Mapping Function



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