

Recent developments in modeling atmospheric loading effects: Topography, reference pressure, and S1/S2

T. van Dam¹, J. Boehm², H. Spicakova², X. Collilieux³, J. Ray⁴, and Z. Altamimi³
¹FSTC, University of Luxembourg, Luxembourg; ²Vienna University of Technology,
Austria; ³IGN/LAREG and GRGS, France; ⁴NGS, NOAA, USA

Presented by Norman Teferle¹

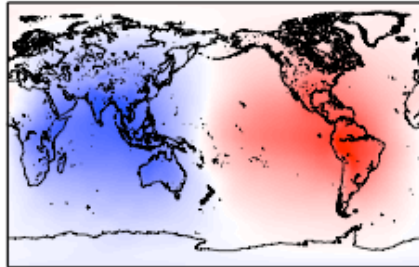
S1/S2 atmospheric pressure tides

- Global atmospheric products used to:
 - correct satellite altimetry data for sea surface height changes driven by surface pressure variability
 - compute atmospheric mass effects to correct satellite gravity data
 - compute surface displacements and estimate tropospheric delays for estimating coordinates from space geodetic techniques
- The source of global pressure fields are the analysis or reanalysis products from the meteorological centers, e.g. NCEP and ECMWF
- These products are known to contain signals associated with the atmospheric tides:
 - the diurnal S1(p)
 - the semidiurnal S2(p)
- These tides represent a substantial part of the sub-daily pressure variability in tropical latitudes

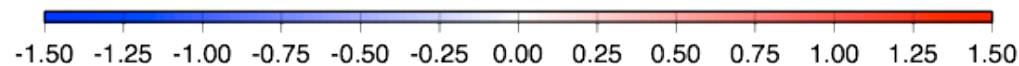
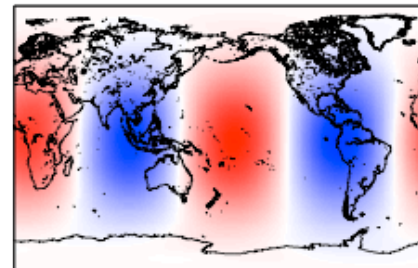
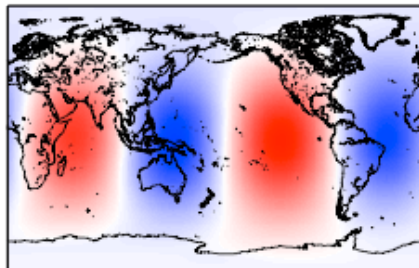
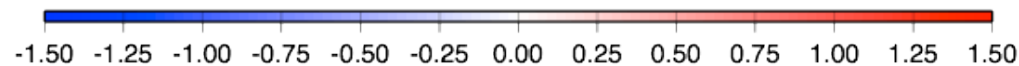
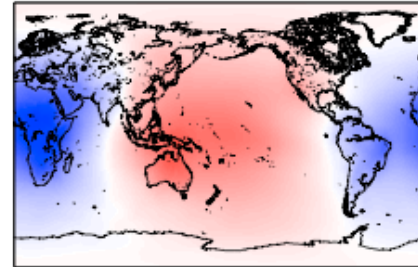
S1/S2

radial surface displacement in mm

Cosine



Sine

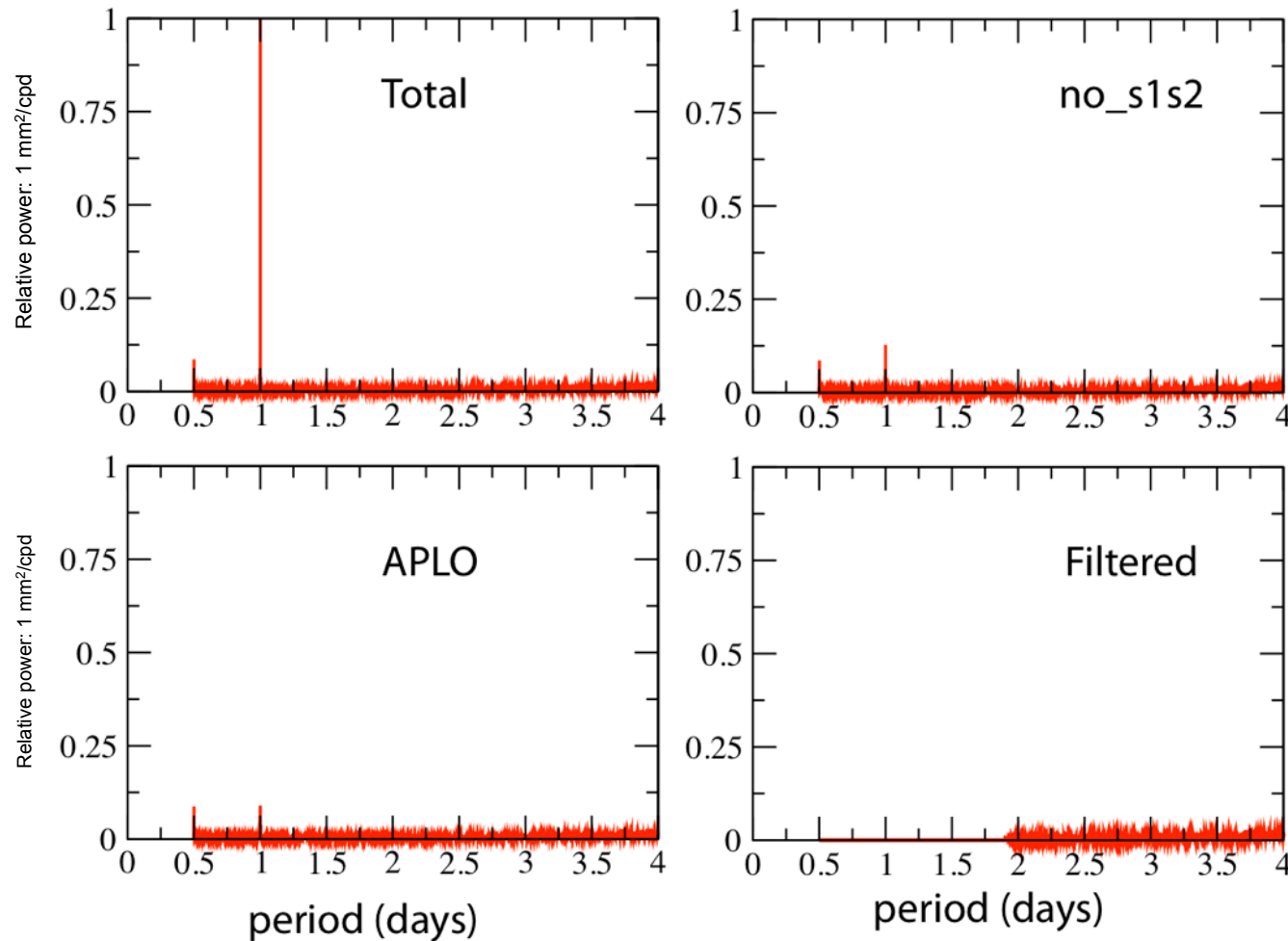


- S1/S2 loading model is generated using the S1/S2 pressure model of Ray and Ponte (*Annales Geophysicae*, 2003)
- Ocean is modeled as the solid Earth (no inverted barometer effect)
- Effects are largest at the equator

S1/S2

- the representation of the signals in the models is problematic
 - model deficiencies
 - data noise
 - 6-hour fields do not permit the proper resolution of the tides*
- Ponte and Ray (*GRL*, 2002) outlined a strategy for handling the tides
 - First remove the tides from the global surface pressure analyses
 - Petrov and Boy (*JGR*, 2004) - fit a mean, sine + cos for S1 and cos S2 to each grid point and remove it
 - using the technique of Van den Dool et al. (*JGR*, 1997)
 - or filtering
 - Then add a good S1/S2 tidal model back into the surface pressure data (Ray and Ponte, *Annales Geophysicae*, 2003)

S1/S2: PSD for height time series BRAZ

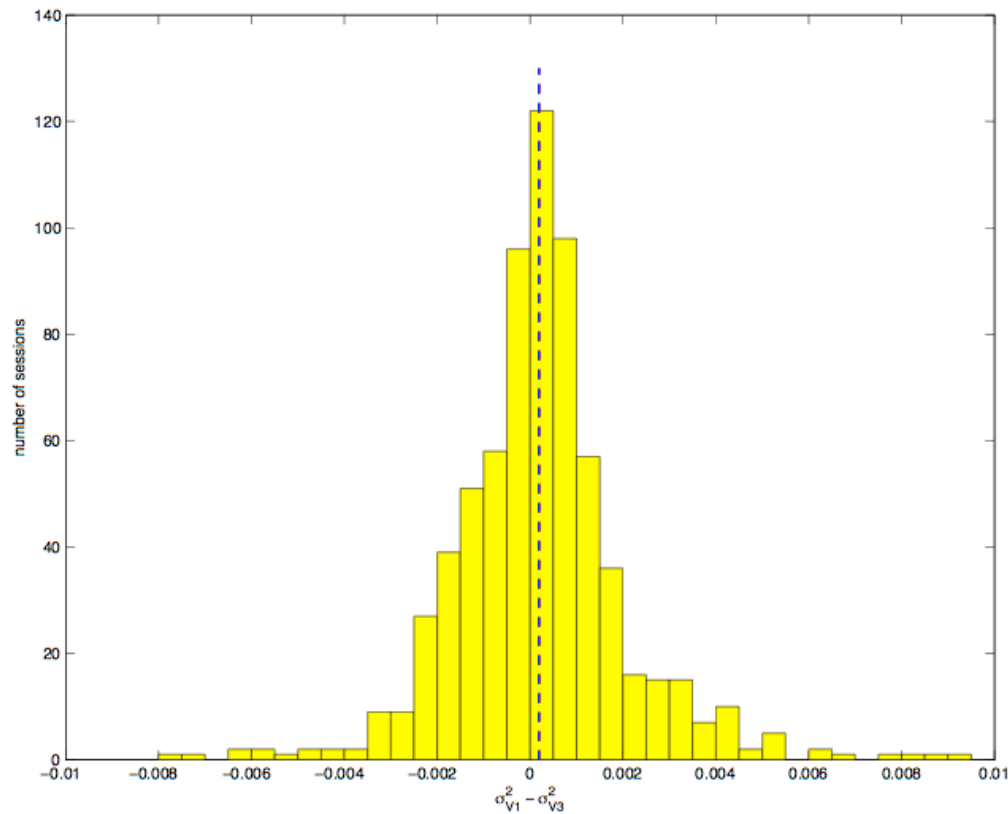


- Using the technique of Van den Dool et al. (*JGR*, 1997) and Petrov and Boy (*JGR*, 2004) does not remove all of the signal at the one and two cycles/day

S1/S2

- we tested the S1/S2 model with VLBI and SLR data processing (to do the test correctly with GPS you'd also have to apply the model at the orbit determination level)
- IERS Workshop on Conventions, September 2007; Boehm and Tesmer, S1/S2 Atmospheric loading in VLBI Analysis
 - Global solution
 - 2880 sessions; 4×10^6 observations
 - $wrms = \sqrt{v^T P v / P}$
 - no S1/S2 - S1/S2 (van Dam) mean diff. = 0.00008 ps improvement; median diff. = 0.00020 ps
- IERS workshop on Conventions, September 2007; Ries, S1/S2 Atmospheric pressure loading in SLR analysis
 - 6 months of SLR data used: January - June 2007
 - 0.0-0.9 mm² reduction in variance

S1/S2



- Most recent test with VLBI
 - 693 sessions; 1242629 observations
 - 24 hour sessions from 2002 to 2008
 - NNR/NNT on VTRF2008
- Improvement is 200 ppm versus the case when no corrections are applied

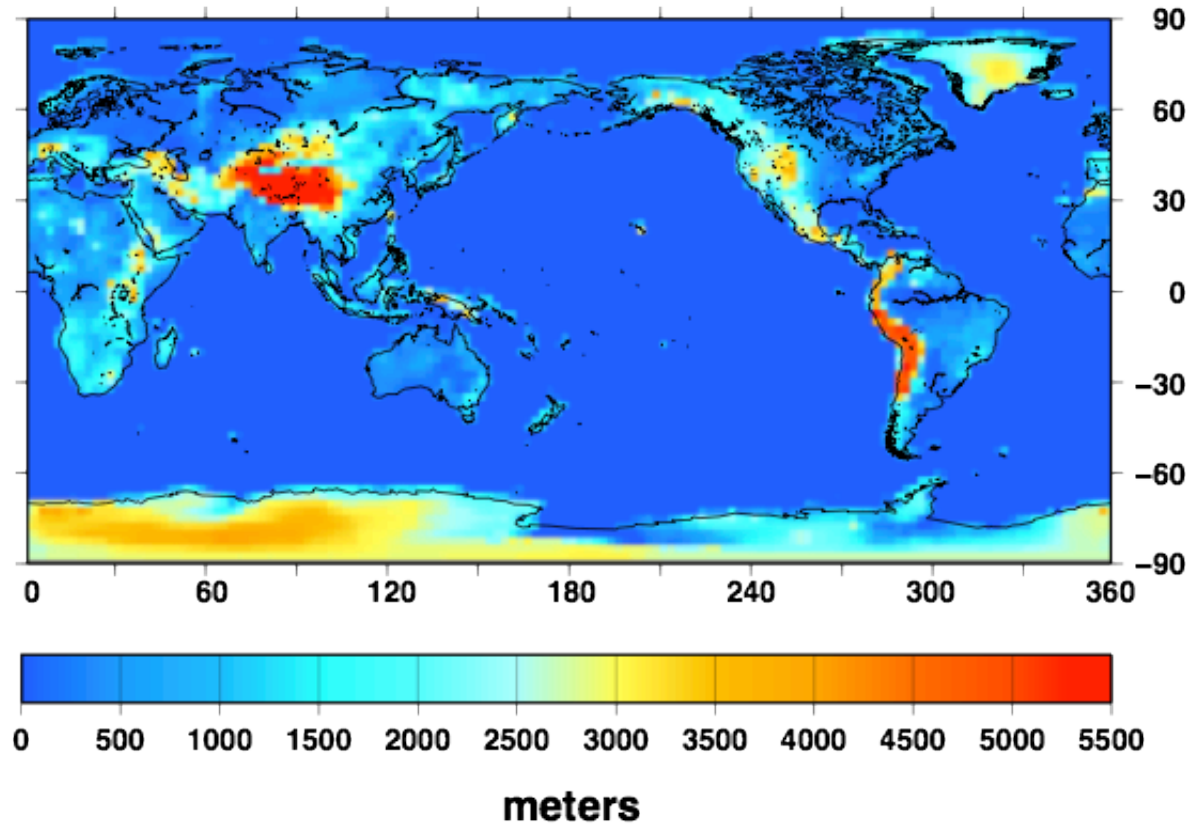
S1/S2 Conclusion

- The Ponte and Ray (2002) tidal model has been shown to reduce the residuals on VLBI and SLR data processing
 - as an aside, the model by van Dam did slightly better than the model by Petrov and Boy
 - BUT both derived from Ponte and Ray (2002) so it is unclear what the problem is
- We recommend that the S1/S2 model be incorporated into the GPS data processing software as is done with the ocean tidal models

topographic pressure loading

- Global pressure products used to estimate surface loading effects are provided at a limited resolution
- The pressure is assumed to have a constant value of the minimum grid size
- If the topography in the grid cell exhibits large variability, then because the atmosphere is in hydrostatic equilibrium the surface pressure within the cell will vary significantly over the area of the grid cell
- The implication of this fact is that estimates of loading effects derived for stations in regions of high topographic variability will be insufficient
- Paper in press in JGR: *Topographically Induced Height Errors in Predicted Atmospheric Loading Effects*, T. van Dam, Z. Altamimi, X. Collilieux, and J. Ray

topographic pressure loading



- Maximum topographic change in 2.5 degree grid units using 10' topography data
- Maximums can easily reach up to 2000 meters but larger changes are possible
- 2000 meters in topography represents a change of 200 mbars
- if the load were only distributed over a radius of 0.2 degrees (20 km) the surface would depress by 4 mm.

topographic pressure loading

- To investigate the effects of unmodeled topography, we generate two surface pressure data sets
 - NCEP_{FINE} = Reanalysis 2.5° x 2.5° => 0.125° x 0.125°
 - NCEP_{TOPO} => NCEP Reanalysis converted to hydrostatic pressure using standard lapse rate for temperature in the atmosphere

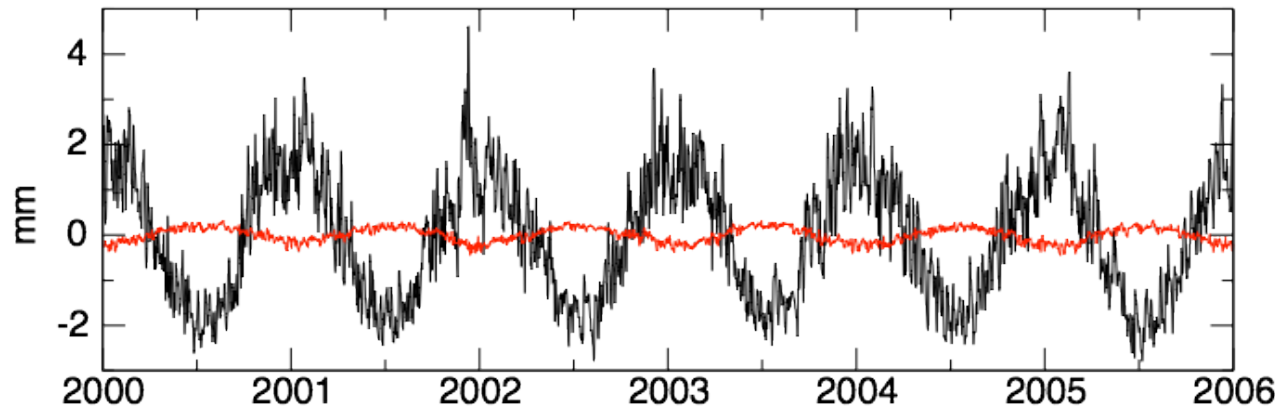
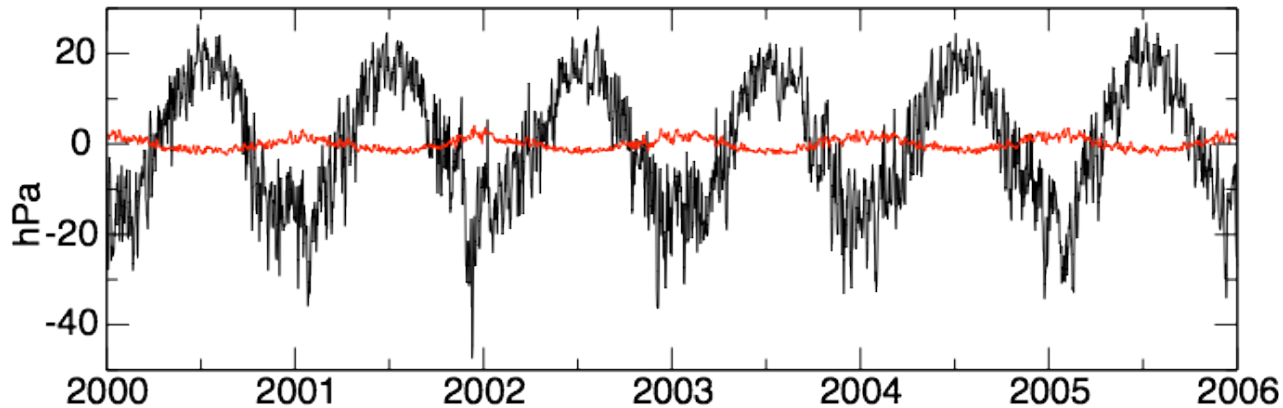
$$p(z) = p_o \left[\frac{T_o - \Gamma z}{T_o} \right]^{\frac{g}{R\Gamma}}$$

- $p(z)$ = pressure at elevation
- p_o = pressure in the original 2.5° x 2.5° grid
- Γ = lapse rate = $-dT/dz = 0.006499^\circ \text{ K/m}$
- z = geopotential height (which is related to geometric height)
- g = acceleration of gravity = 9.80665 m/s^2 (a constant if z is the geopotential height)
- R = gas constant

topographic pressure loading

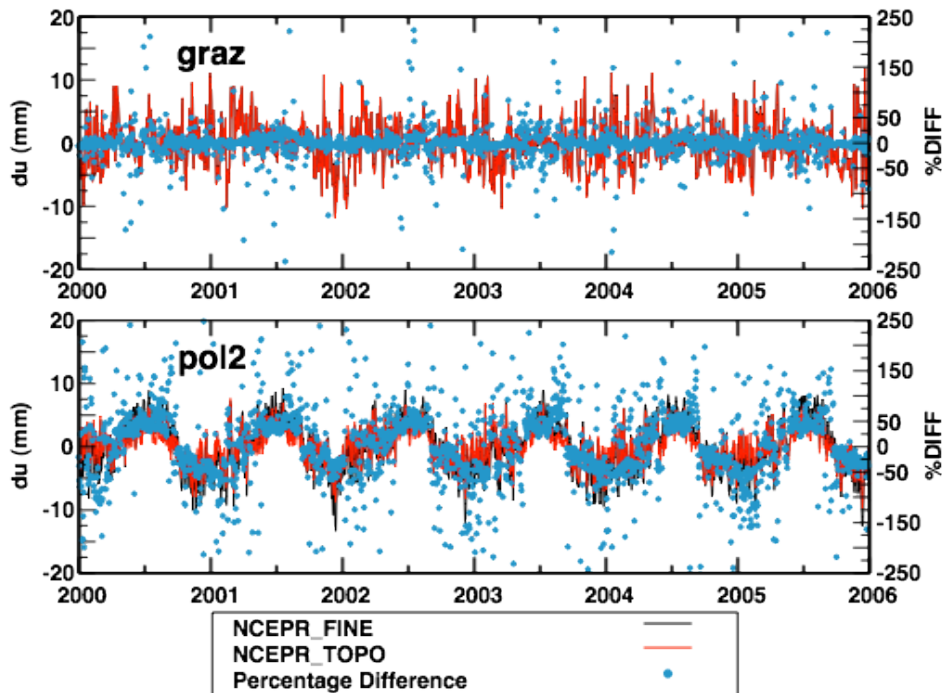
- Ocean mask is $0.125^\circ \times 0.125^\circ$
- Modified inverted barometer in both cases $\Rightarrow p_{ocean} = \frac{\int \Delta p dS}{A}$
- Δp is the change in pressure over each $0.125^\circ \times 0.125^\circ$ grid cell in the ocean
- Note: it is important that we compare the NCEP_{FINE} with the NCEP_{TOPO}.
- If we compared NCEP_{TOPO} with the $2.5^\circ \times 2.5^\circ$ reanalysis data, we could not separate ocean mask effects from topography effects

topographic pressure loading



- difference between $NCEP_{FINE}$ and $NCEP_{TOPO}$ for pol2, Bishkek Kyrgyzstan (black) and graz, Graz, Austria (red)
- the annual signal is expected (derived in the paper)

topographic pressure loading



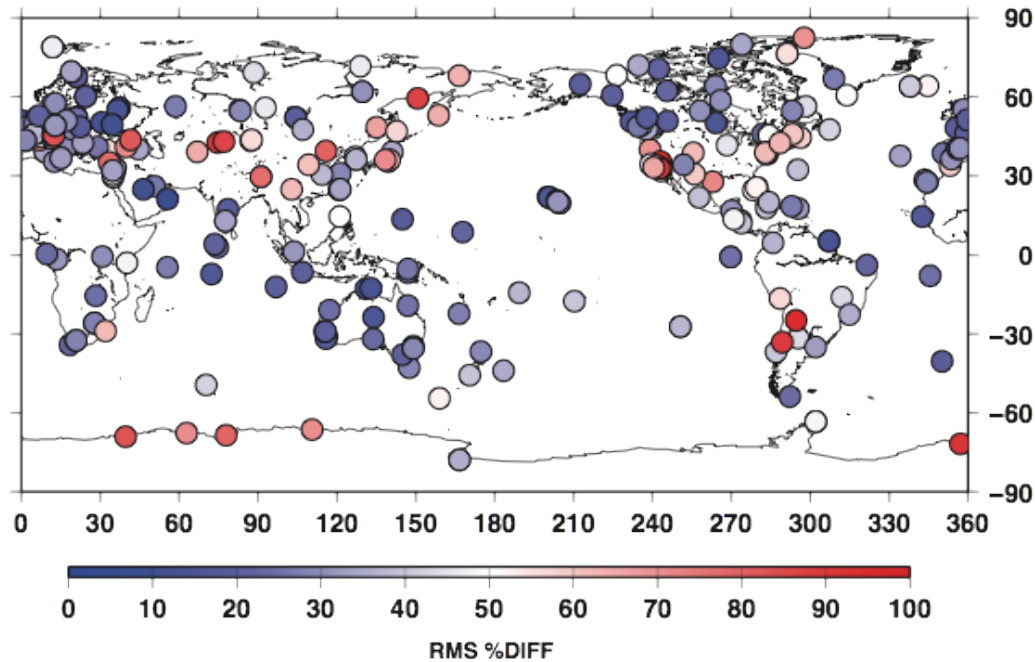
NCEP_{FINE} have a mean error of 15%

NCEP_{FINE} have a mean error of 43%

- Let's assume the NCEP_{TOPO} are truth; Now determine the errors that one would make using NCEP_{FINE}
- Compute the percentage error as:

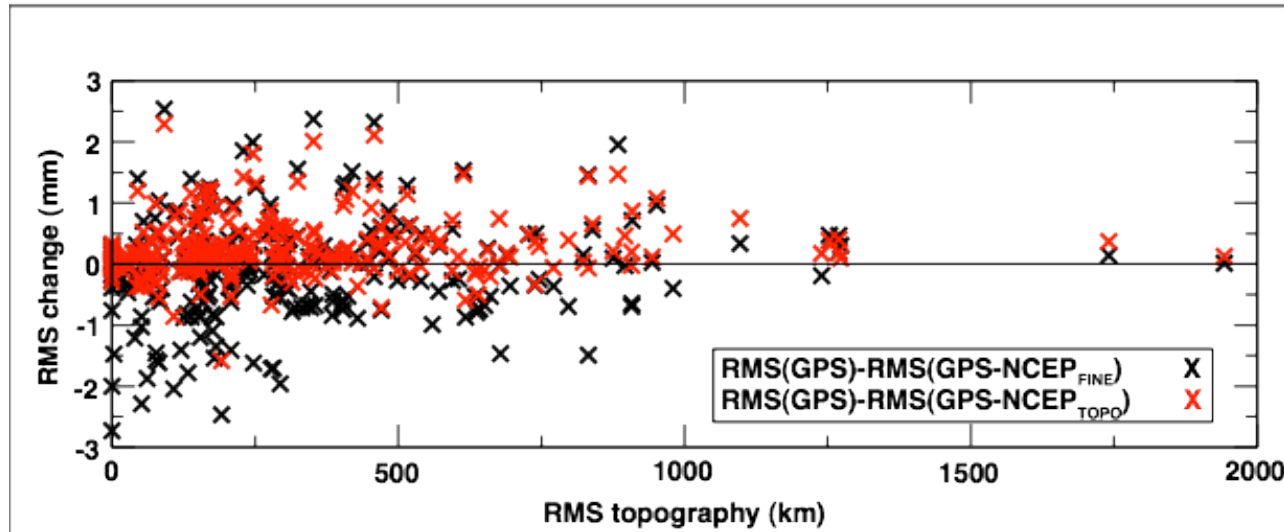
$$100 \times \frac{NCEP_{TOPO} - NCEP_{FINE}}{NCEP_{FINE}}$$

topographic pressure loading



- %Diff for a global set of stations
- %Diff is often less than 40% indicating relative agreement between the models
- 55% of the stations have %Diff greater than 60%

topographic pressure loading



- RMS(GPS) - RMS(GPS-NCEP_{FINE}) in black
- RMS(GPS) - RMS(GPS-NCEP_{TOPO}) in red

- Compare the models with ITRF2005 residuals for 312 weeks of data and 246 stations
- NCEP_{FINE} reduced the RMS in 48% of the cases; NCEP_{TOPO} reduced the RMS in 74% of the cases
- RMS change as a function of topographic variability
- X's above improvement; X's below worsened
- More red X's above => better model for removing the pressure loading effect

Conclusions: topographic pressure loading

- We determined the pressure effect
 - using pressure on a reference surface defined by the analysis center
 - using pressure on a reference surface with highly variable topography
- On a day to day basis, the differences are quite small except in regions of high topographic variability
- Annual signals in the heights from the two methods can be significant
- Comparison with ITRF residual heights indicates that $NCEP_{TOPO}$ does better than $NCEP_{FINE}$ in reducing the scatter on the height coordinates
 - But there are some instances where the neither model reduces the scatter on the height coordinates

reference pressure

- to determine effects due to time variable changes in pressure, we usually remove a reference pressure
- J.-P. Boy, P. Gegout, T. van Dam, APLO all use a long term mean as the reference pressure
 - consistent with the model used, e.g. NCEP or ECMWF
 - However, at a very low level they are inconsistent with one another
- A reference pressure model has been released by TUV
 - 'Memo: A method for the definition of global reference pressure', H. Schuh, M. Schindelegger, D.D. Wijaya, J. Boehm and D. Salstein, (June 21, 2010)
 - http://ggosatm.hg.tuwien.ac.at/LOADING/REFPRES/global_reference_pressure_memo.pdf
 - just released so that we have not had time to look into the effects of using a reference pressure different from the means we normally use