Explaining the VLBI Estimated Degree-1 Load Variation Via Atmospheric, Oceanic, and Hydrological Mass Variations

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Overview

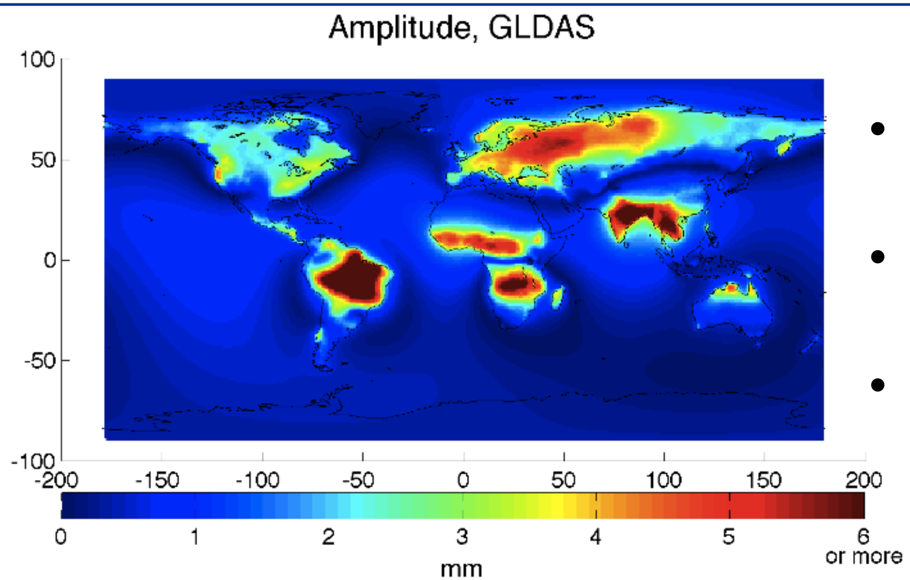
1. Hydrology Loading
2. Terrestrial Reference Frame Scale
3. Nontidal Ocean Loading
4. Loading Services at GSFC
5. Estimation of Degree-1 Deformation

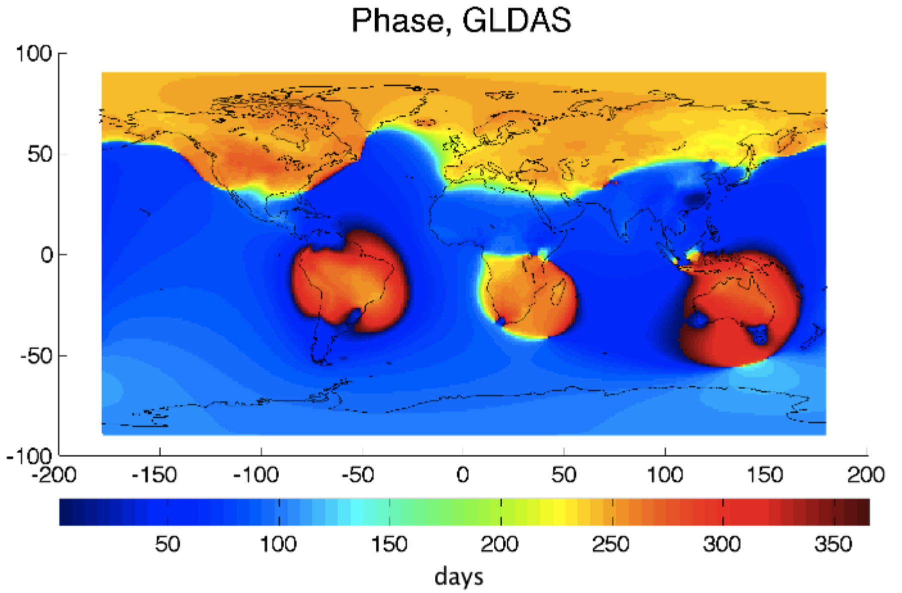
Hydrology Loading

Hydrology loading series calculation

- NASA GLDAS hydrology model (Rodell et al. 2004)
- Contributions from soil moisture, snow water, plant canopy surface water storage
- Used the 1°x1° monthly average model (1979-present)
- Site displacement loading computed by usual Green's function approach
- Vertical displacements are 3-10 mm; large annual signal

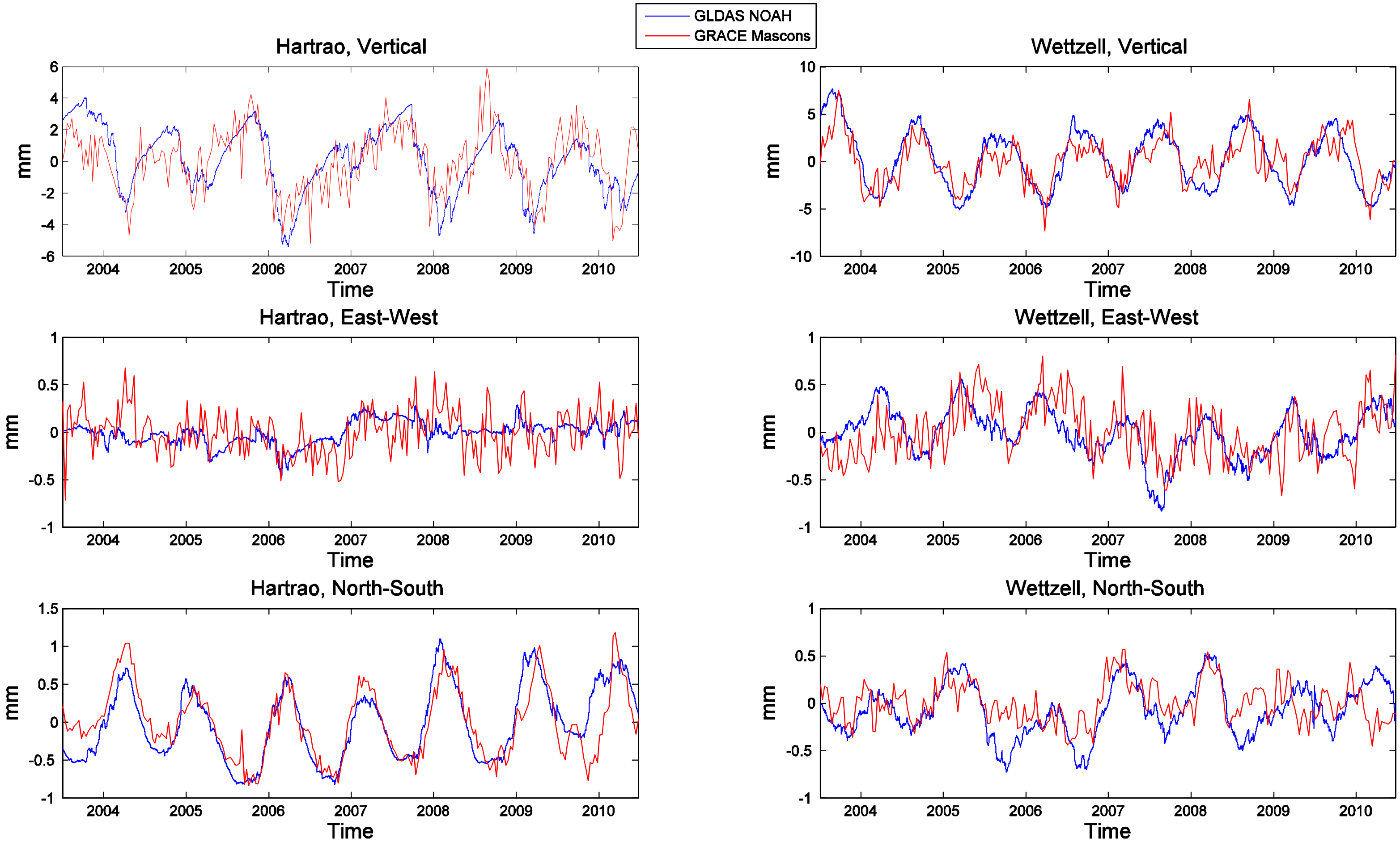
Hydrology Loading





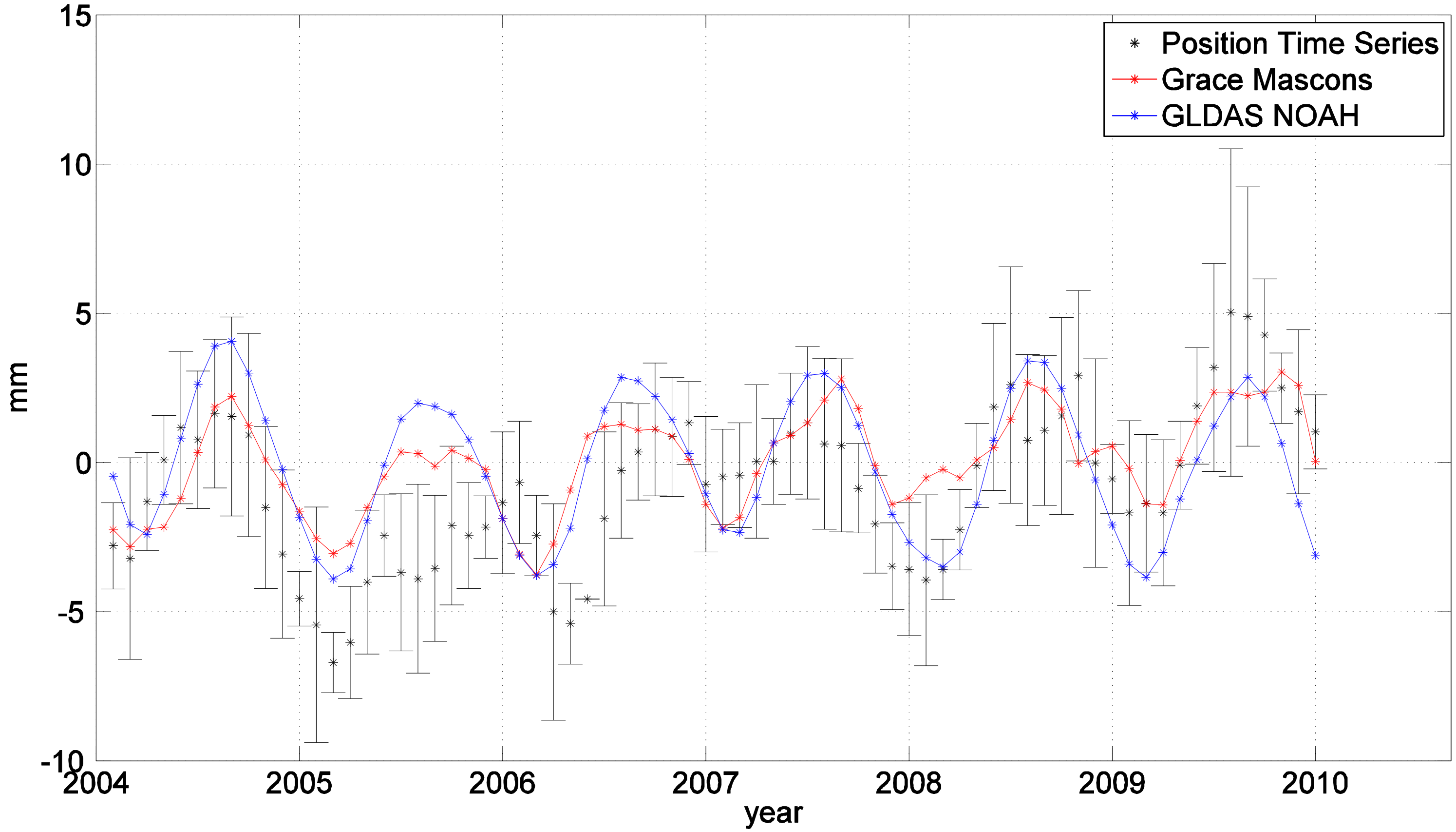
- Computed annual vertical amplitude of GLDAS loading signal
- Amplitudes from 0 to 10 mm (Amazon basin)
- Annual amplitudes for VLBI sites < 4.5 mm

Hydrology Loading



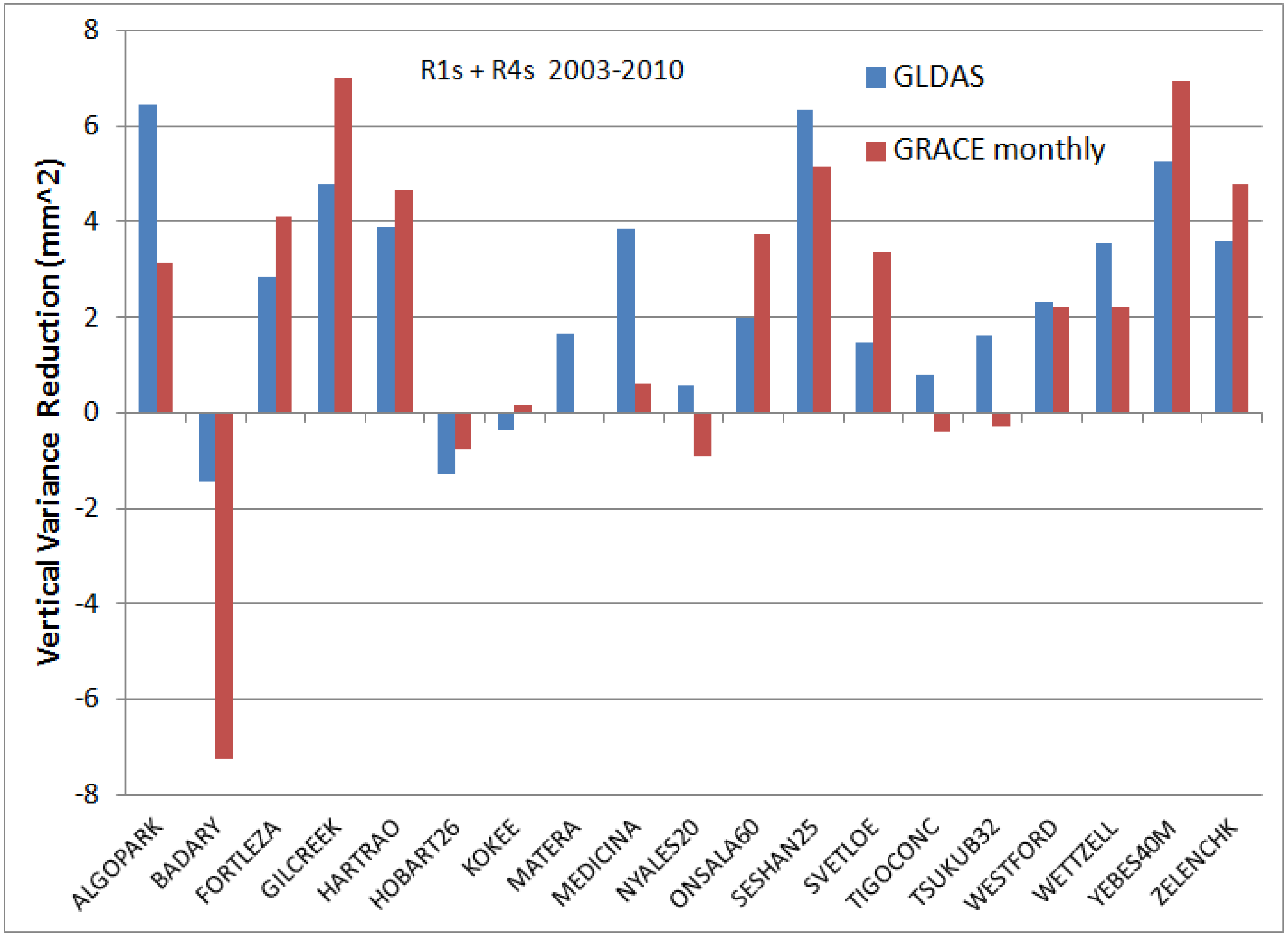
- VLBI sites: HartRAO (South Africa) and Wettzell (Germany)
- Reasonable agreement of 10-day GRACE mascon loading and GLDAS loading

Hydrology Loading

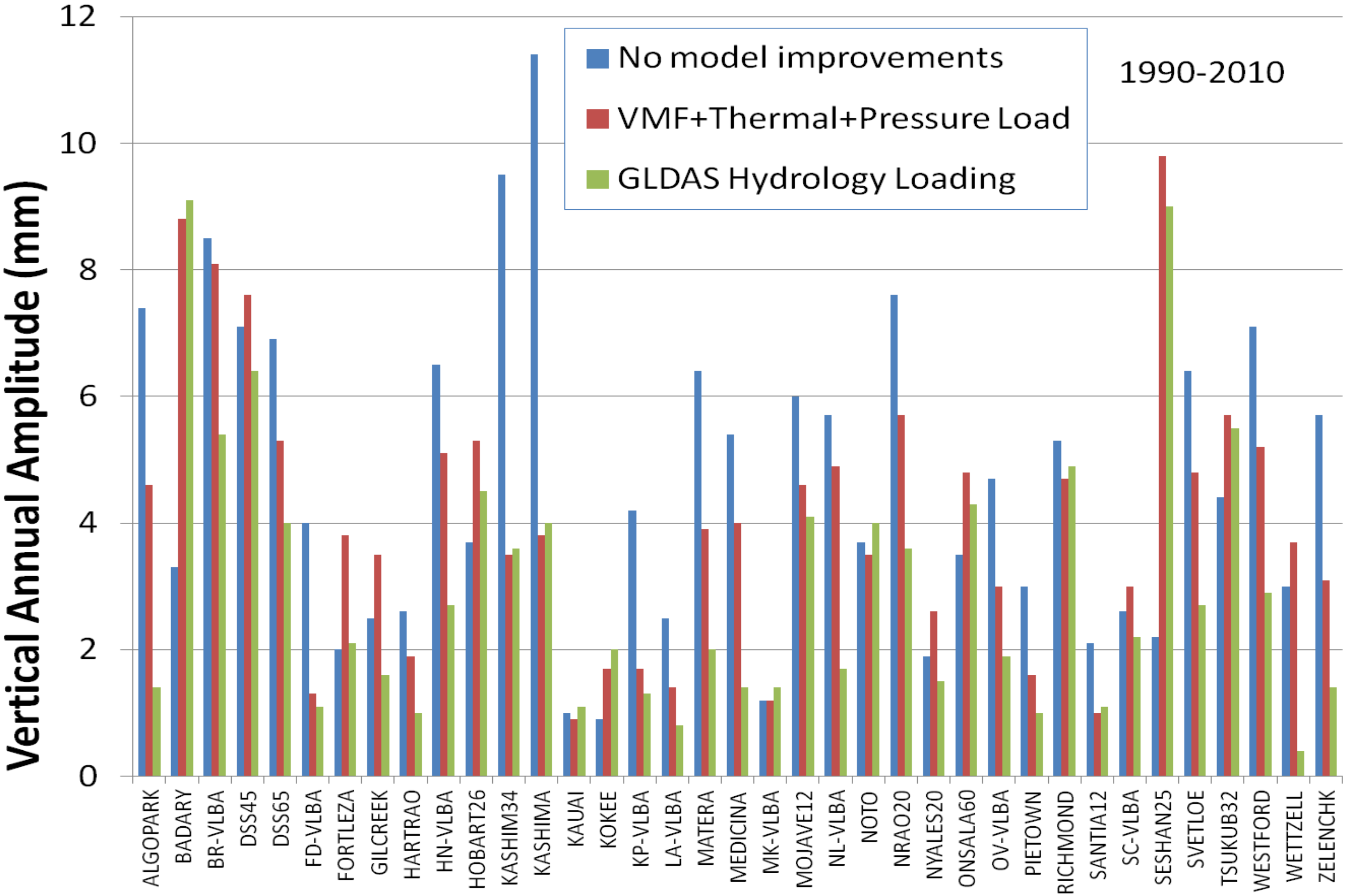


- Comparison of monthly average vertical VLBI position time series at Wettzell and the GLDAS and GRACE mascon loading series.
- Correlations between loading series and the VLBI series are 0.57(GLDAS) and 0.48(GRACE)

Hydrology Loading



- Analysis of VLBI operational weekly R1 and R4 network sessions 2003-2010
- Vertical variance is reduced with either the GLDAS or GRACE loading series



Vertical Annual Amplitude (mm)
12
10
8
6
4
2
0
No model improvements
VMF+Thermal+Pressure Load
GLDAS Hydrology Loading
1990-2010
ALGOPARK
BADARY
BR-VLBA
DSS45
DSS65
FD-VLBA
FORTLEZA
GILCREEK
HARTRAO
HN-VLBA
HOBART26
KASHIM34
KASHIMA
KAUAI
KOKEE
KP-VLBA
LA-VLBA
MATERA
MEDICINA
MK-VLBA
MOJAVE12
NL-VLBA
NOTO
NRAO20
NYALES20
ONSALA60
OV-VLBA
PIETOWN
RICHMOND
SANTIA12
SC-VLBA
SESHAN25
SVETLOE
TSUKUB32
WESTFORD
WETTZELL
ZELENCHK

Reference Frame Scale

	Annual (ppb)		Semi-annual (ppb)	
	cos	sin	cos	sin
Base case	-0.38	-0.37	0.05	0.20
+VMF1+Thermal Def	-0.16	-0.31		
+Atmospheric Load	-0.19	-0.33		
+Hydrologic Load	-0.06	-0.06	-0.01	0.08

Uncertainties = 0.02 ppb

- For the base case, the NMF mapping function was used and no pressure loading was applied
- The biggest reduction in annual amplitude is from hydrology loading

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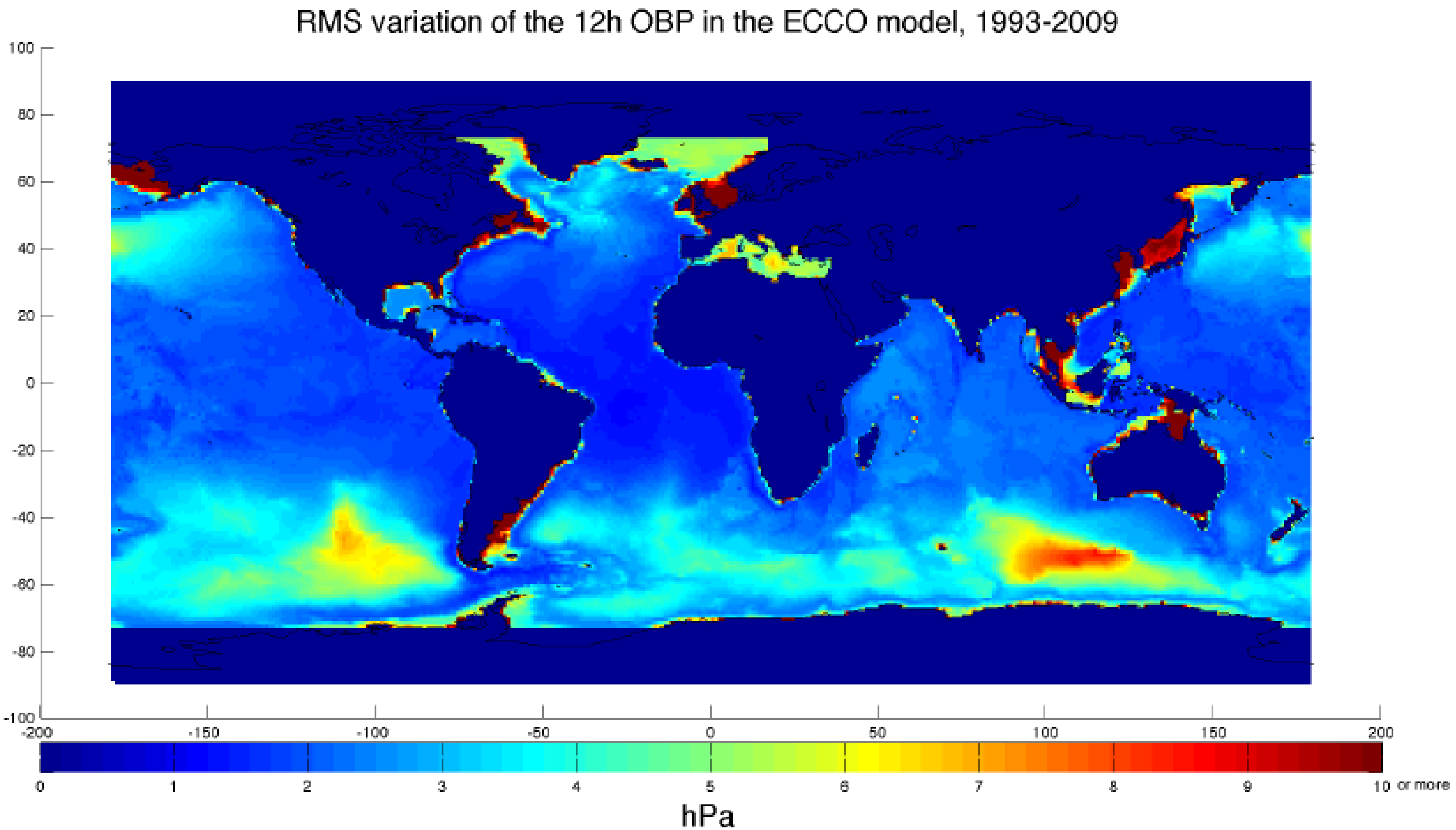
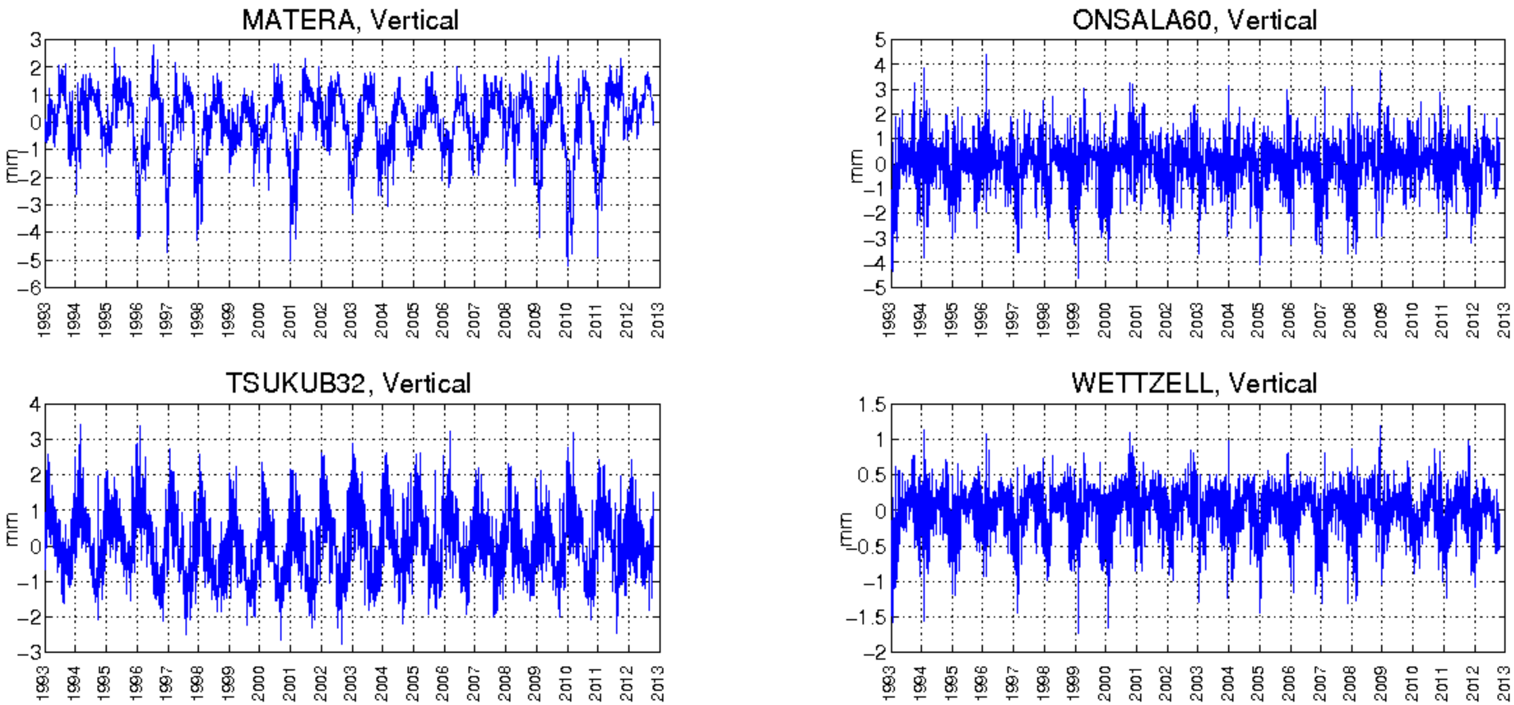
Nontidal Ocean Loading Calculation

- JPL ECCO ocean model
- Used 12-hour ocean bottom pressure since 1993
- Oceanic volume (not mass) conserving
- Site displacement loading computed by usual Green's function approach
- Vertical displacements are largest near the coast; large annual signal; rms variation VLBI sites: 0.11-1.67 mm

Nontidal Ocean Loading

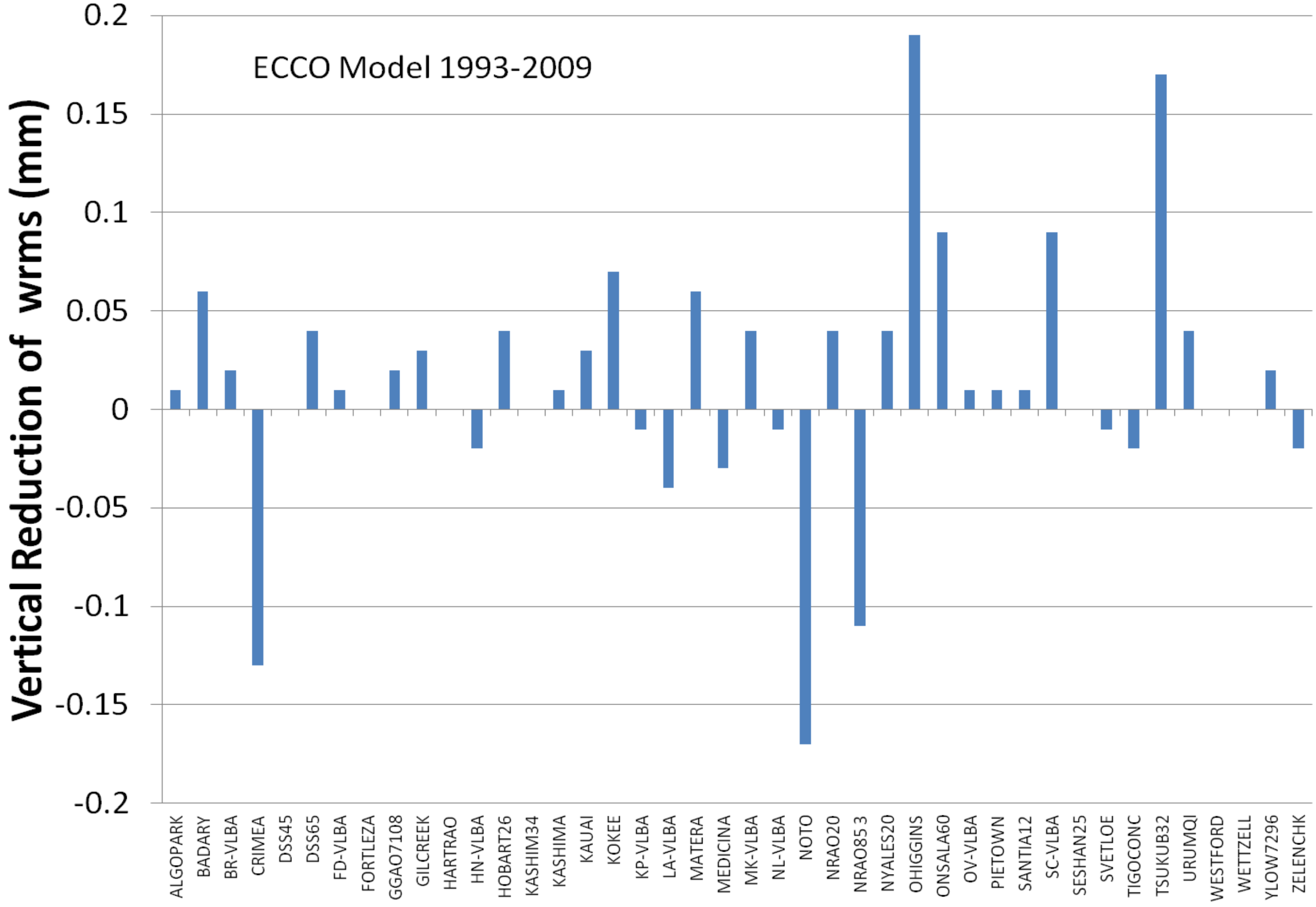


Nontidal Ocean Loading

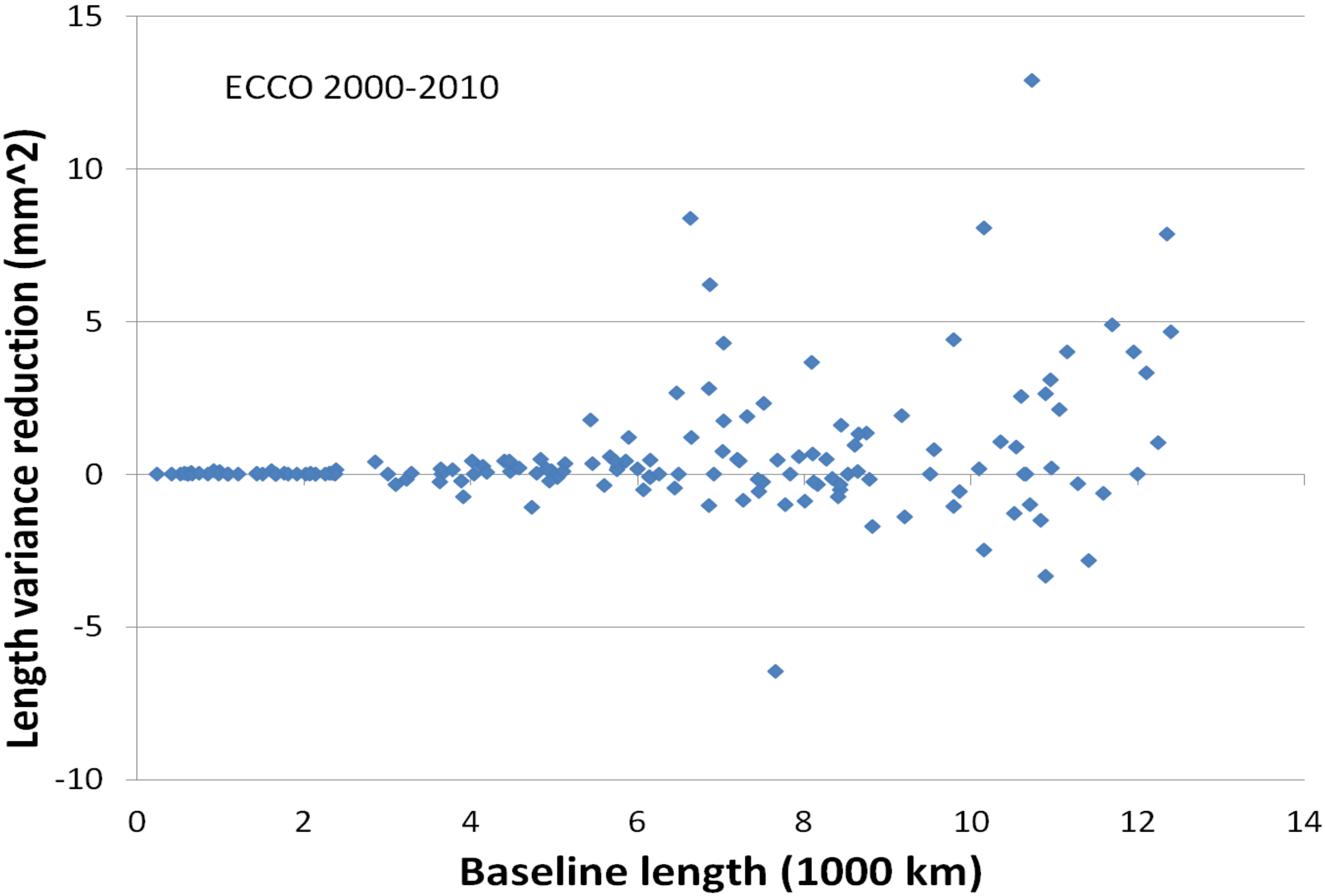


- Typical vertical loading series at VLBI sites:
  Coastal sites: Matera (Italy) rms 1.18 mm, Onsala (Sweden) rms 0.85 mm,
  Tsukuba(Japan) rms 0.89 mm
  Inland site: Wettzell (Germany) rms 0.31 mm
- RMS variation is much smaller than VLBI residual vertical RMS

Nontidal Ocean Loading

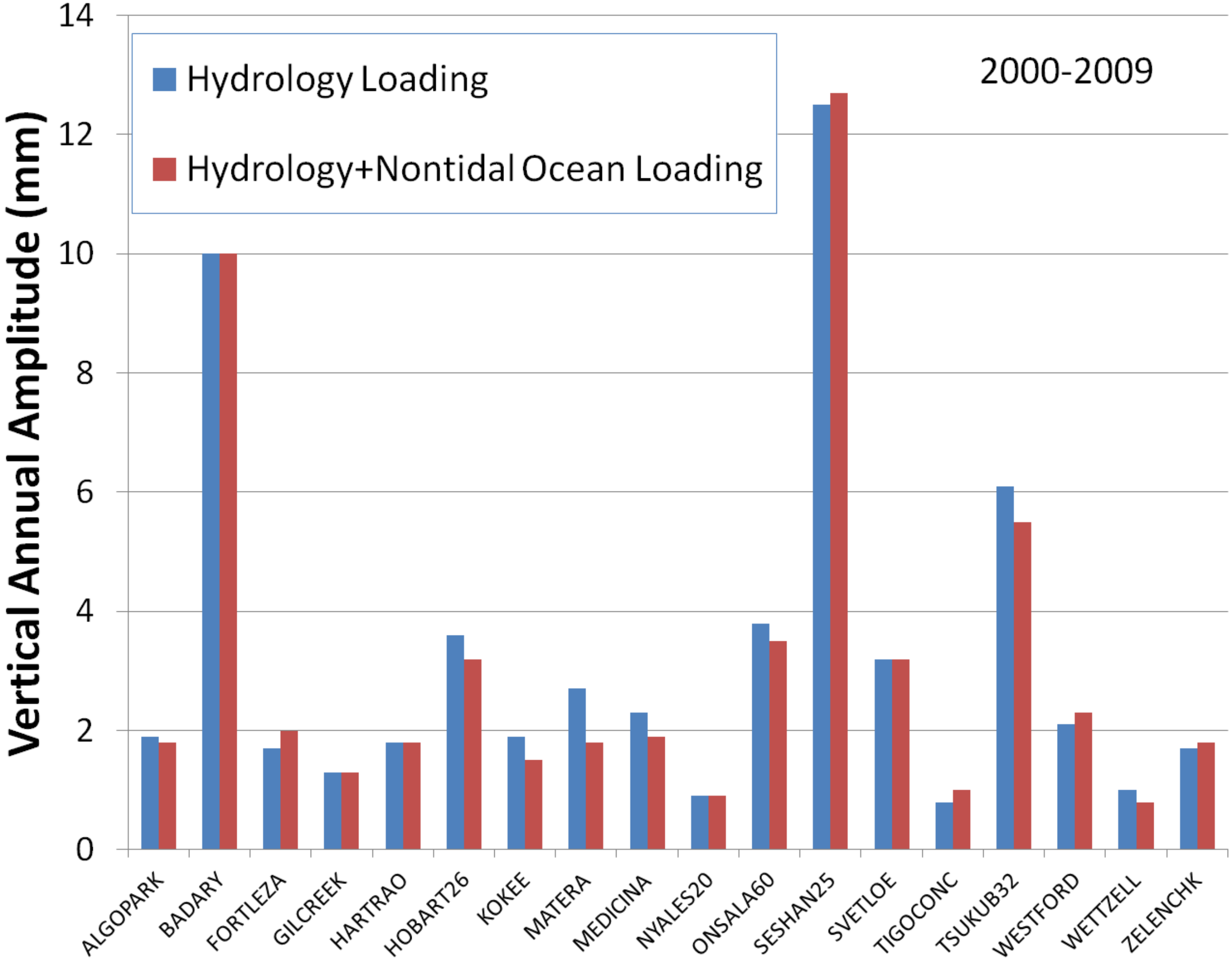


Nontidal Ocean Loading



Nontidal Ocean Loading

R1+R4 operational networks



Loading Services at GSFC

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Hydrology Loading

- GLDAS NOAH model since 1979, updated when data is available
- Monthly series for 170 VLBI stations
- 1x1 degree gridded map with loading series for each lattice point
- http://lacerta.gsfc.nasa.gov/hydlo/

Nontidal Ocean Loading

- JPL ECCO model since 1993, updated when data is available
- 12-hour resolution series for 170 VLBI stations
- 1x1 degree gridded map will be generated in future
- http://lacerta.gsfc.nasa.gov/oclo/

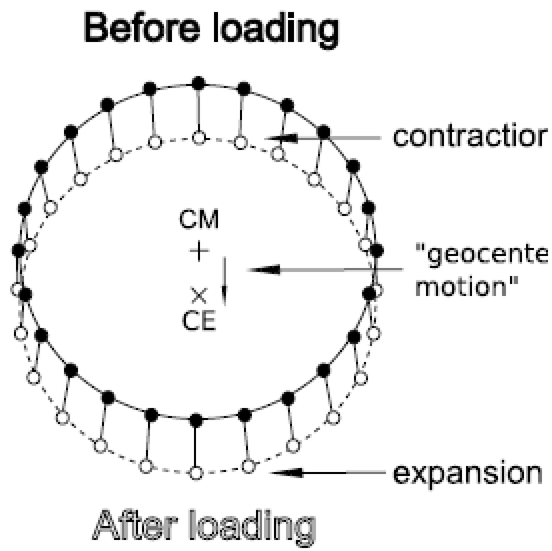
Atmospheric Pressure Loading

- Maintain Petrov-Boy series
- NCEP Reanalysis since 1979, updated when data is available
- 6-hour series for 824 VLBI+GPS+SLR sites
- 2.5x2.5 degree gridded map with loading series for each lattice point
- http://lacerta.gsfc.nasa.gov/aplo_eph/

Degree-1 Loading

Blewitt et al. (2001), Trupin et al. (1992): Surface mass load transport =>
1) Displacement of the geocenter
2) Deg-1 deformation of the Earth's surface

Lavallee and Blewitt (2002): Correlation between VLBI baseline length measurements and deg-1 deformation determined from GPS



From Lavallee, 2006

- VLBI is not directly sensitive to the geocenter since it is not a satellite technique
- Indirectly sensitive via deg-1 deformation

Degree-1 Loading

Displacement of CM relative to CE:

CM=center of mass solid Earth+load
CE=center of mass solid Earth

$$\Delta\mathbf{r}_{\mathbf{CM}} = \frac{\mathrm{M_L}\Delta\mathbf{r}_{\mathbf{L}}}{\mathrm{M_E}} = \frac{\mathbf{m}}{\mathrm{M_E}} \qquad \mathbf{m} \equiv M_L \Delta\boldsymbol{r}_{\boldsymbol{L}}$$

M_L = transported load mass $\Delta\boldsymbol{r}_{\boldsymbol{L}}$ = center of mass of M_L in CE

Load moment vector $\mathbf{m}$ ~ deg-1 coefficients of the surface mass density

$$\mathbf{m} = \frac{4\pi R^3}{3}(\sigma_{11c}, \sigma_{11s}, \sigma_{10c})$$

Deg-1 displacement in CF (center of figure frame) is

$$\Delta\boldsymbol{s} = \mathbf{G}^{\mathrm{T}}\mathrm{diag}[\mathrm{h}'_1, \mathrm{l}'_1, \mathrm{l}'_1\,]\mathbf{G}\,\frac{\mathbf{m}}{\mathrm{M_E}}$$

G is topocentric -> geocentric rotation
$\mathrm{h}'_1, \mathrm{l}'_1$ are deg-1 Love numbers in CF

Estimate **m** from VLBI data.   Infer geocenter motion $\Delta\mathbf{r}_{\mathbf{CM}}$.

Geocenter Annual Motion

	X		Y		Z	
	Amp (mm)	Phase (day)	Amp (mm)	Phase (day)	Amp (mm)	Phase (day)
VLBI 1985-2002	4.3±0.8	10±12	5.0±0.8	202±10	5.5±0.8	70±9
VLBI 1985-2010	9±0.6	36±9	5.5±0.6	230±8	6.5±0.6	76±7
SLR 1993-2002 Moore & Wang (2003)	3.5±0.6	26±10	4.3±0.6	303±8	4.6±0.6	33±7
SLR 2002-2010 Cheng et al. (2010)	3.2±0.4	31±5	2.6±0.4	305±5	4.3±0.3	31±5

- VLBI estimates subject to aliasing from higher spherical harmonics
- VLBI global coverage is lacking especially in the southern hemisphere
- Remaining unmodeled annual variation in VLBI

Summary

- Annual site displacement amplitudes are reduced with the VMF1 mapping functions + thermal deformation model + loading corrections

- Application of hydrology loading and nontidal ocean loading reduce the residual site position scatter

- Applying the loading corrections + thermal deformation + VMF1 reduces the annual amplitude of the VLBI reference frame scale from 0.54 ppb to 0.08 ppb

- Estimation of the degree-1 components of surface deformation from VLBI data imply geocenter annual amplitudes that are generally too large compared to those determined from SLR

- In future work we will try to limit aliasing of higher degree terms into the VLBI estimates by applying displacements (deg>1) derived from GRACE or geophysical models (ocean,hydrology, atmosphere)