Using GLDAS for computation of the land water loading signal

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Problem:

Development of an accurate model for computing site displacements caused by the land water mass loading.

Approach:

Convolution of the global time series of 2D field land water pressure variations with Green's function for elastic Earth.

Choice:

Field of the accumulated snow and soil moisture from

- GLDAS Noah model with $1^\circ \times 1^\circ \times 3^h$ resolution from 1979 through now.
- GLDAS Noah model with $0.25^\circ \times 0.25^\circ \times 3^h$ resolution from 2000 through now.

Validation Method:

Comparison with VLBI data

- Estimation of the global admittance
- Estimation of amplitude of annual position variations
- Comparison of baseline length repeatabilities

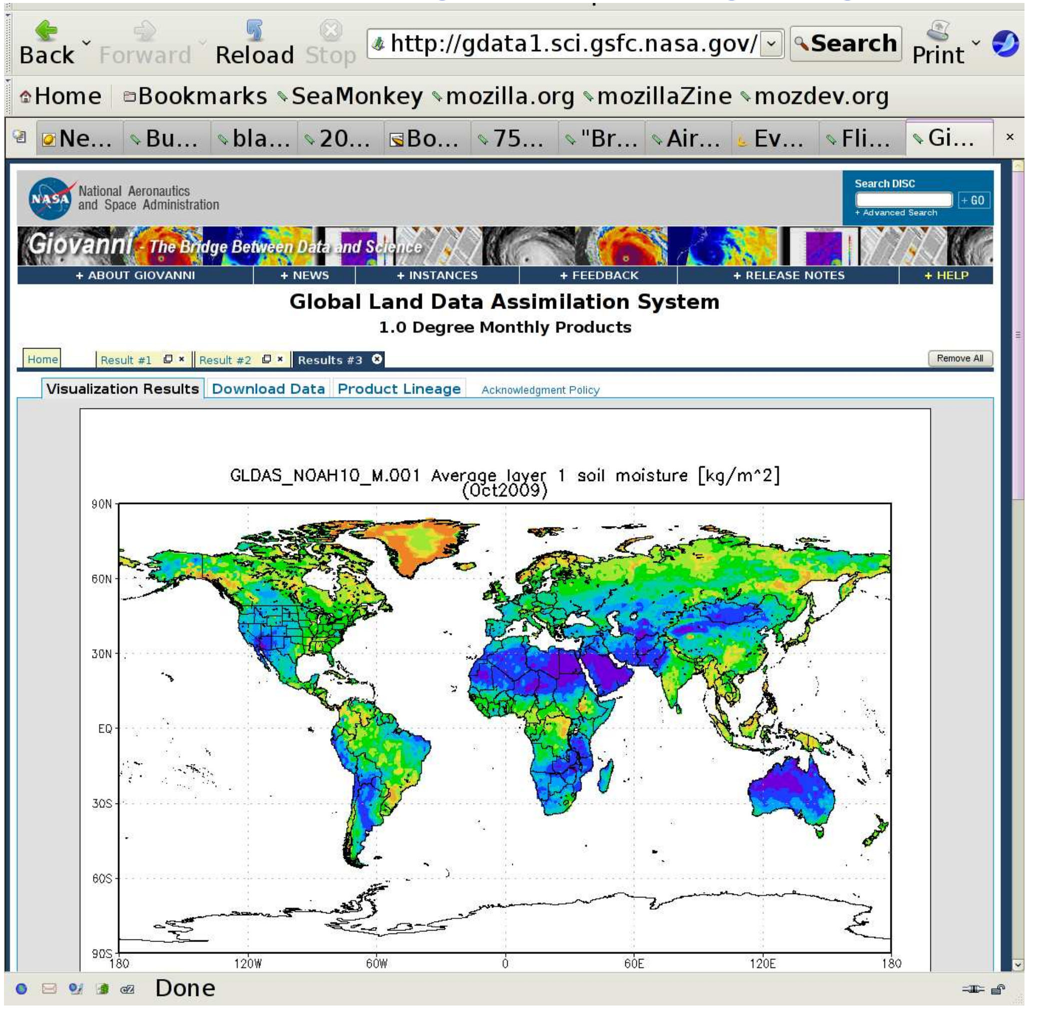
Land Water Model: GLDAS

- Land Surface Model: Noah
- Forcing: various analysis- and observation-based products
- Spatial resolution: $1^\circ \times 1^\circ$ and $0.25^\circ \times 0.25^\circ$
- Time resolution: 3^h.
- Time span: 1979–Present and 2000.02.24–Present.
- Output:
  - soil moisture content in range [0, 2] meter
  - accumulated snow water contents
  - and many others

Data availability

From 1979 through present from Giovanni interface

http://disc.sci.gsfc.nasa.gov/giovanni



Loading computation:

1. Soil moisture and accumulated snow are converted to surface pressure
2. The average pressure field is computed
3. Area covered by glaciers are identified and marked
4. Loading Green's function are computed:

$$G_{\mathrm{R}}(\psi) = \frac{f\,a}{g_0^2} \sum_{n=0}^{+\infty} h_n^{'} P_n(\cos\psi)$$

5. Loading displacements induced by surface pressure variations $\Delta P(\vec{r}\,', t)$ for a station with of coordinates $\vec{r}$ is evaluated as:

$$\begin{aligned} u_r(\vec{r}, t) &= \iint \Delta P(\vec{r}\,', t)\, G_{\mathrm{R}}(\psi) \cos\phi'\, d\lambda'\, d\phi' \\ \vec{u}_h(\vec{r}, t) &= \iint \vec{q}(\vec{r}, \vec{r}\,')\, \Delta P(\vec{r}\,', t)\, G_h(\psi) \cos\phi'\, d\lambda'\, d\phi' \end{aligned}$$

   Integration is made over the land

3D loading displacements were computed:

- for 214 VLBI stations using $1^\circ \times 1^\circ$ GLDAS Noah model
- for 214 VLBI stations using $0.25^\circ \times 0.25^\circ$ GLDAS Noah model
- at $1^\circ \times 1^\circ$ grid using $1^\circ \times 1^\circ$ GLDAS Noah model
- at $1^\circ \times 1^\circ$ grid using $0.25^\circ \times 0.25^\circ$ GLDAS Noah model

For each cell a mean over 2001–2010 was computed and subtracted.

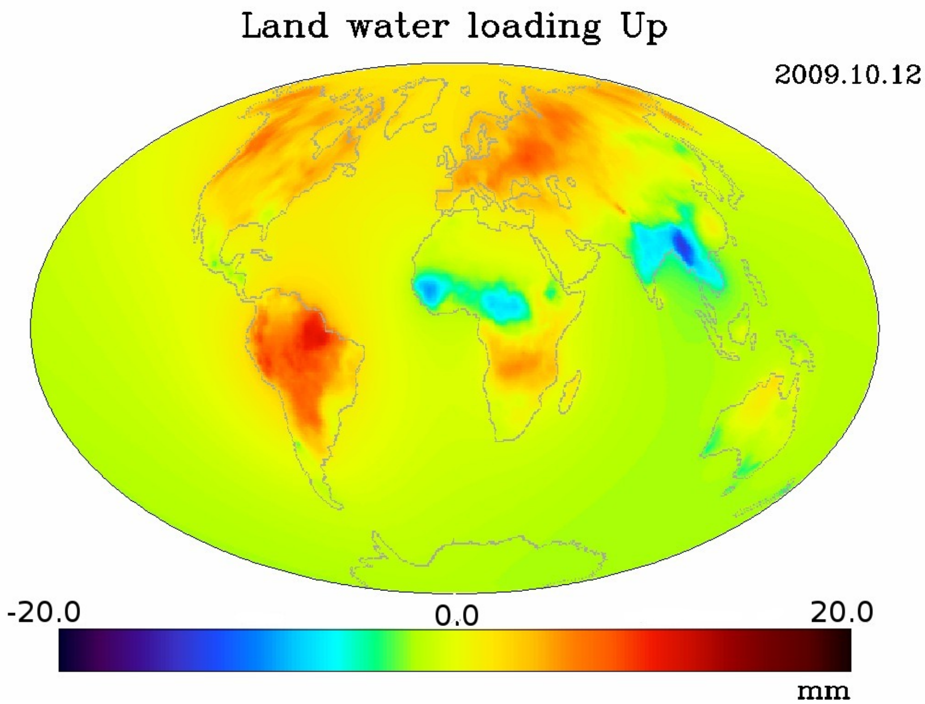
Areas that were under snow all year around were excluded.

When the grid $1^\circ \times 1^\circ$ of land water pressure was used for loading computation, the land-sea mask at grid $0.25^\circ \times 0.25^\circ$ was used.

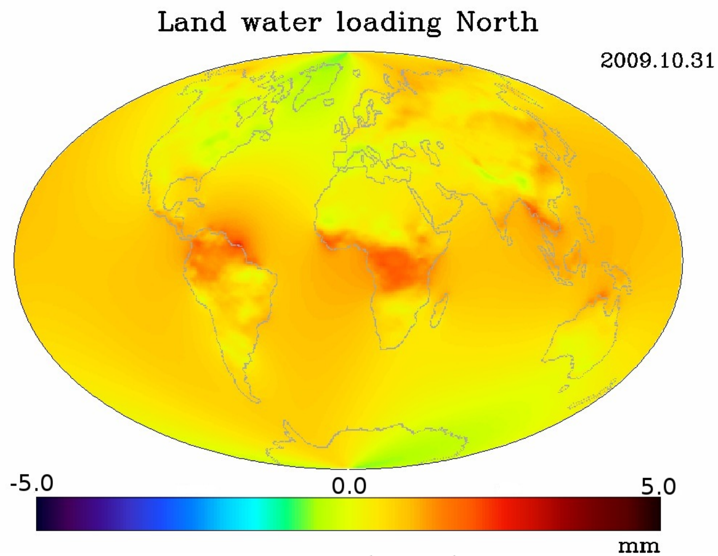
Accuracy of computation: 1%.

Displacements caused by land water loading:

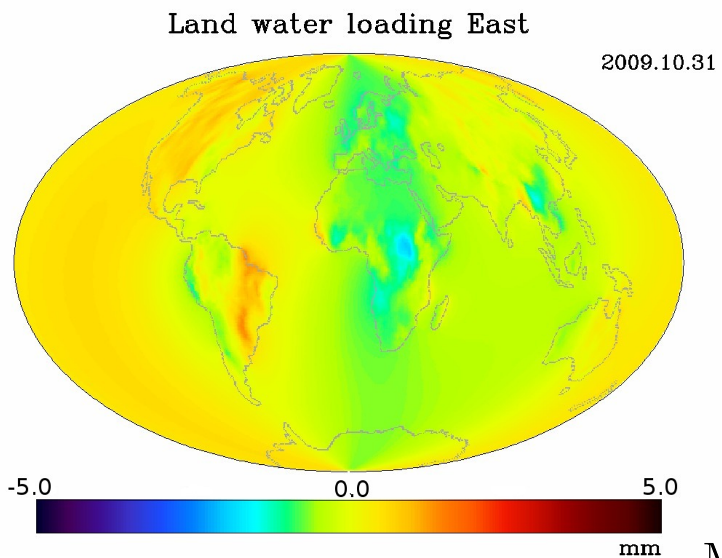
Vertical displ.



North displ.



East displ.



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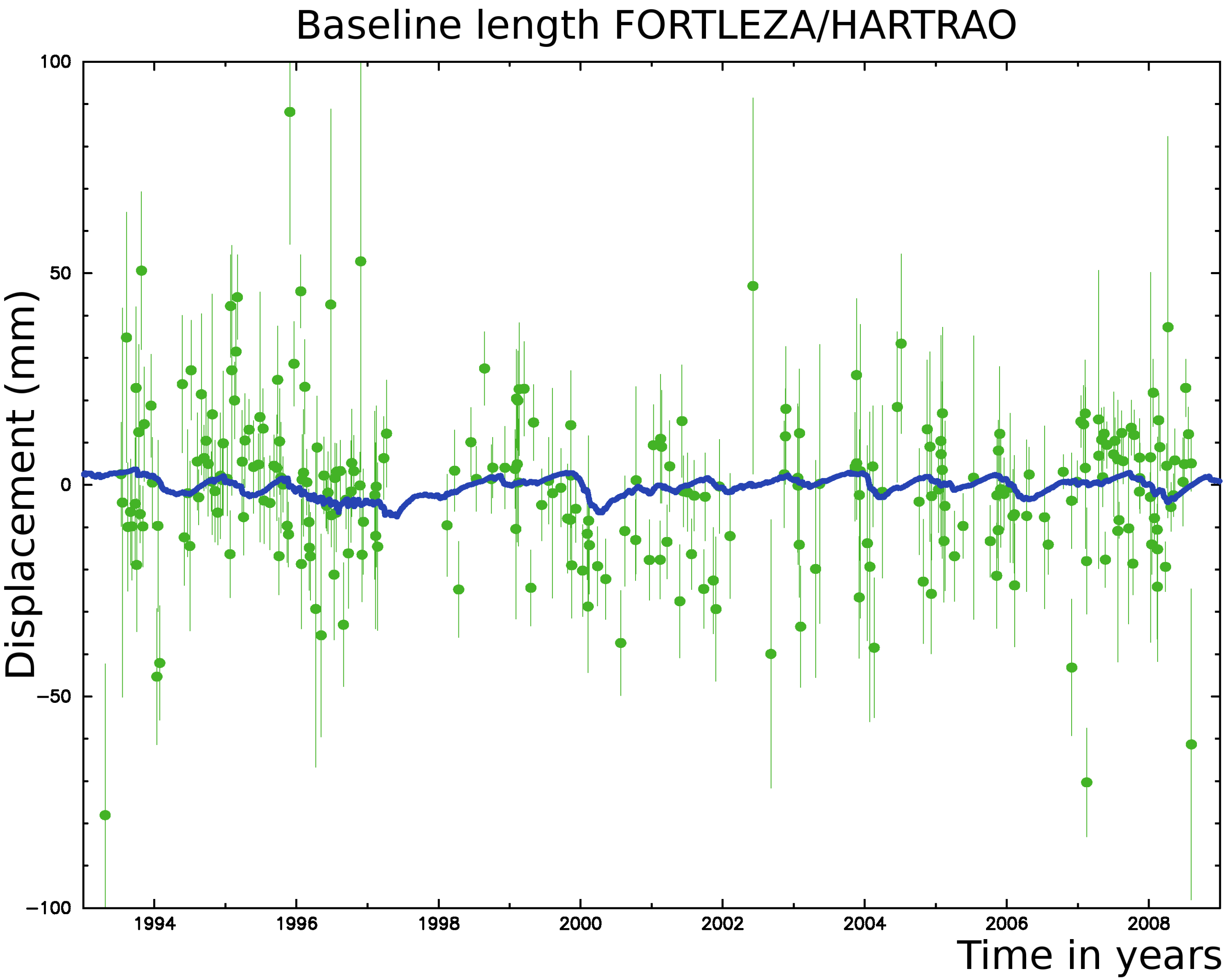
Validation using VLBI

Basic solution setup:

- All data from 1980.04.13 through 2010.07.26 (7.0 million data points) 48 frequently observed stations.
- Ocean and atmospheric pressure loadings applied.
- Path delay in atmosphere computed by direct integration of propagation equations using refractivity 4D field from MERRA.
- Estimation of positions, linear velocities, and harmonic site position variations at 4 frequencies (Sa, Ssa, S_1, S_2) for 48 stations, non-linear motion for 19 sites, source positions, EOP, and nuisance parameters.

First Look:

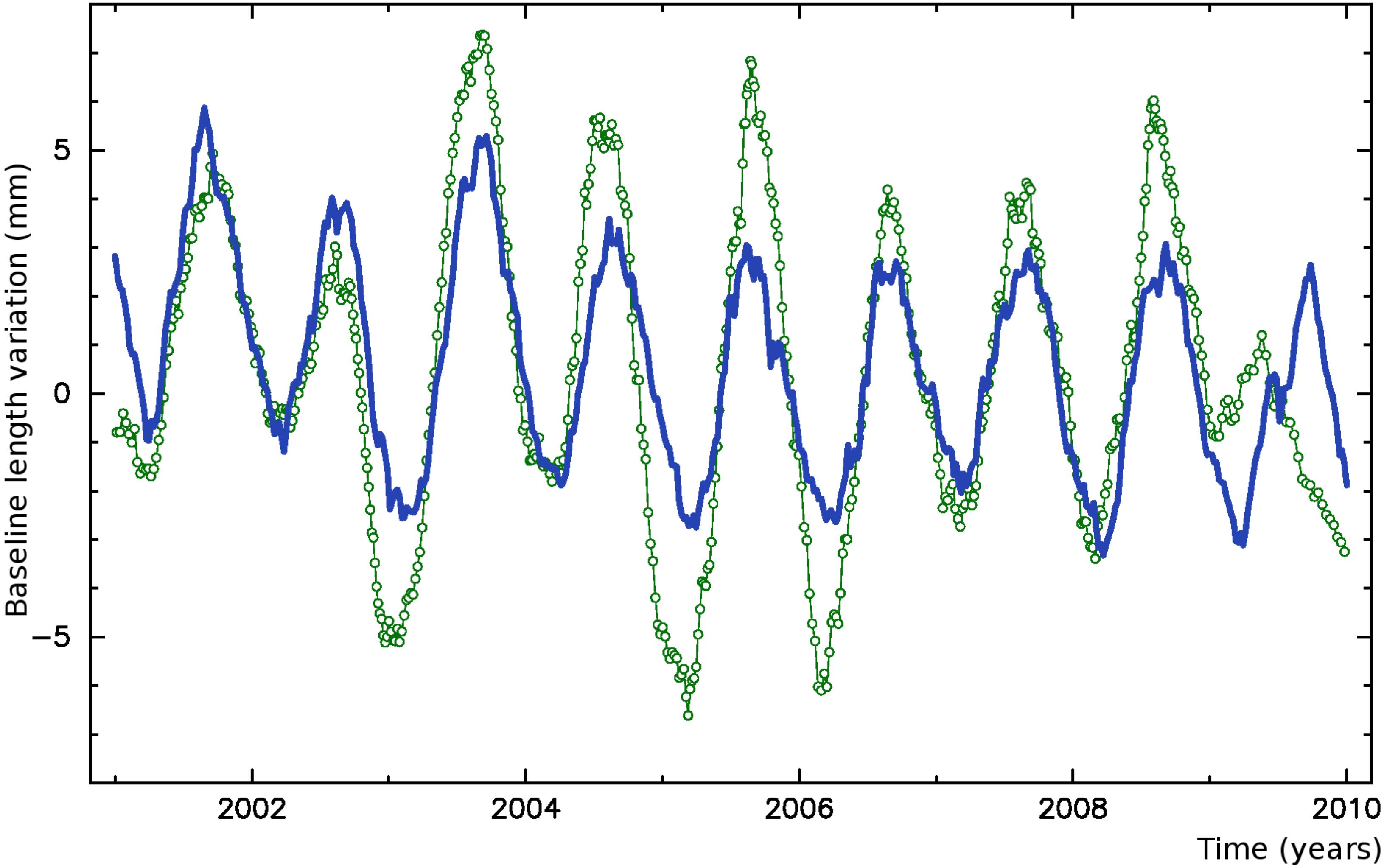


Observed baseline length (daily estimate)
land water loading

Second Look:

Baseline length Westford/Wettzell.

Observed baseline length (after smoothing) and model **land water loading**.



Validation technique:

- **Estimation of global admittance factors:**

  Represent the model $M(t)$ as a product $a \cdot M(t)$

  Fit a directly using the observations (not time series of site positions!)

  Expectation of the LSQ estimate of the admittance factor, $E(\hat{A})$, is

  $$E(\hat{a}) = \rho_{ml} \frac{\sigma_l}{\sigma_m} \qquad \text{if } \mathrm{Cov}(\epsilon, l) = 0$$

  - a = 1 : The model is perfect. The model signal is completely retrieved from data
  - a = 0.5: Only 1/2 of the model signal found in data.
  - a < 0.5: Model has a flaw. Applying the model degrades fit.
  - a = 0 : The model is inadequate. No model signal is found in data.

- **Evaluation of harmonic site position variations:**

  Reduction of the amplitudes of estimates of harmonic site position variations at annual and semi-annual frequencies is expected.

- **Evaluation of baseline length repeatabilities**

  Baseline length repeatability: the wrms after fitting a secular motion model in baseline lengths series.

  Repeatability metric: $\sqrt{A^2 + (B \cdot L)^2}$

Global admittance:

$1^\circ \times 1^\circ$ grid

Before 2000.02.24

Up	**0.19**	$\pm$ 0.02
East	**0.42**	$\pm$ 0.04
North	**0.58**	$\pm$ 0.04

After 2000.02.24

Up	**0.65**	$\pm$ 0.02
East	**0.38**	$\pm$ 0.05
North	**0.53**	$\pm$ 0.05

1980.04.13 — 2010.07.26

Up	0.54	$\pm$ 0.02
East	0.40	$\pm$ 0.04
North	0.75	$\pm$ 0.04

After 2000.0 with Sa filtered out

Up	0.84	$\pm$ 0.03
East	0.57	$\pm$ 0.06
North	0.42	$\pm$ 0.06

$0.25^\circ \times 0.25^\circ$ grid

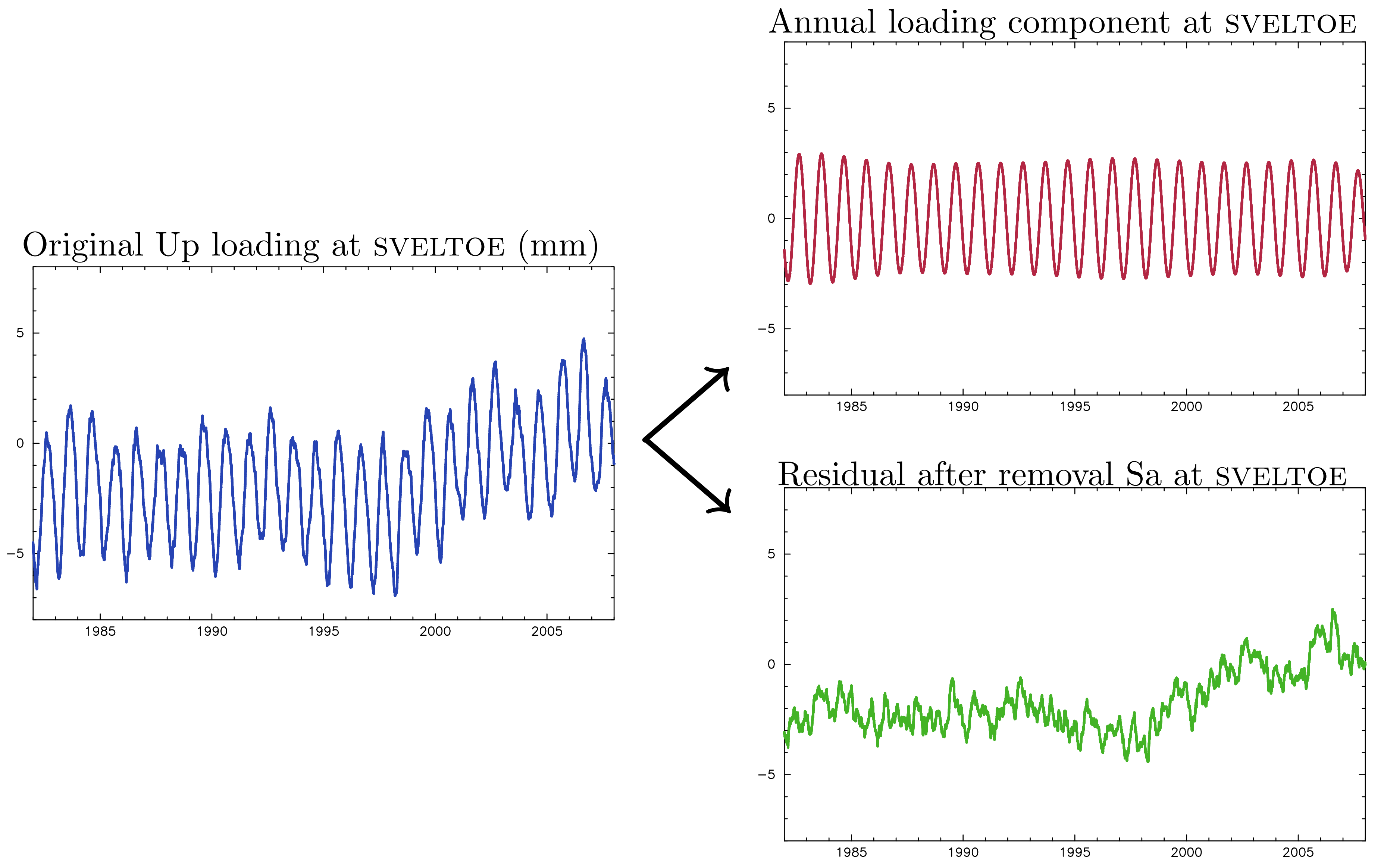
After 2000.02.24

Up	0.67	$\pm$ 0.02
East	0.54	$\pm$ 0.05
North	0.59	$\pm$ 0.05

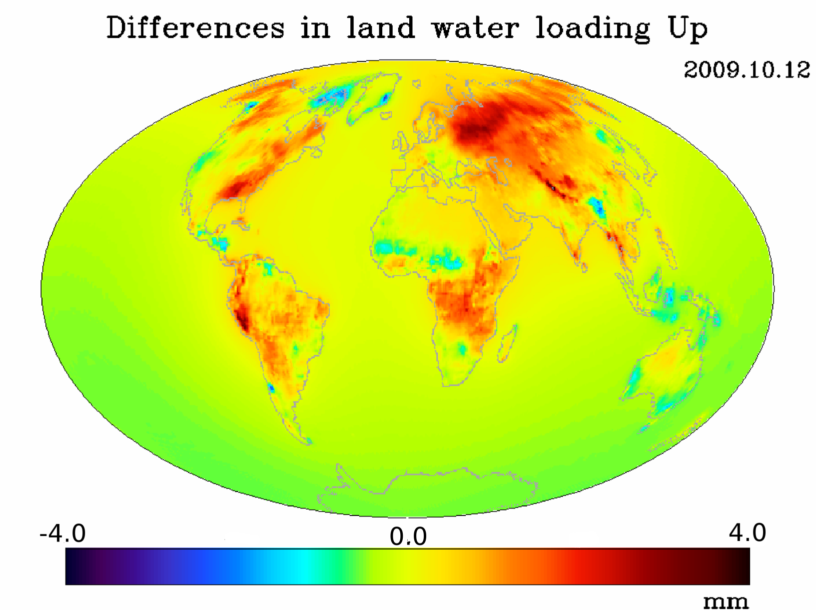
After 2000.0 with Sa filtered out

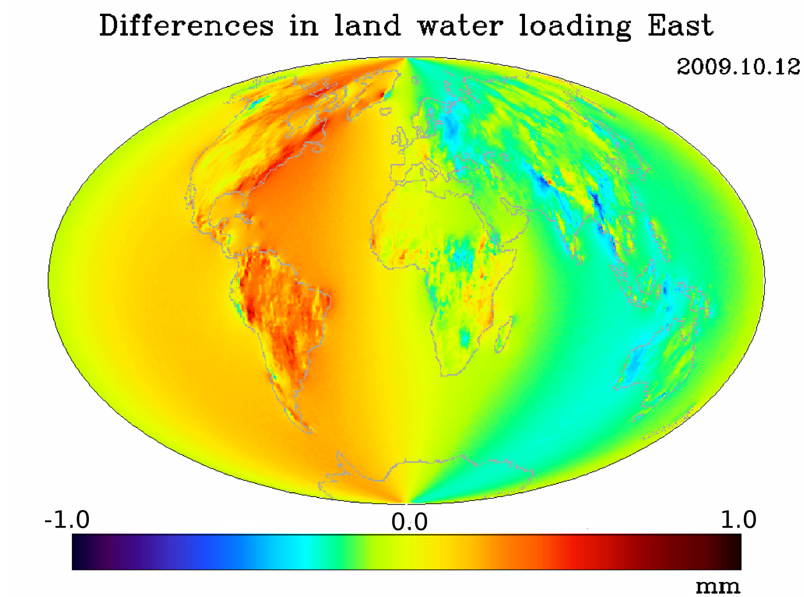
Up	**0.91**	$\pm$ 0.03
East	**0.83**	$\pm$ 0.06
North	**0.52**	$\pm$ 0.06

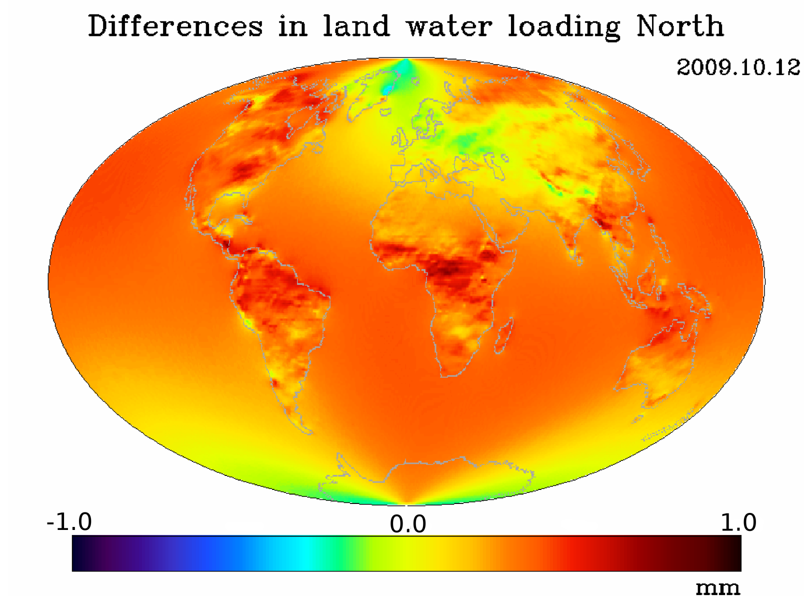
Filtering annual constituent out



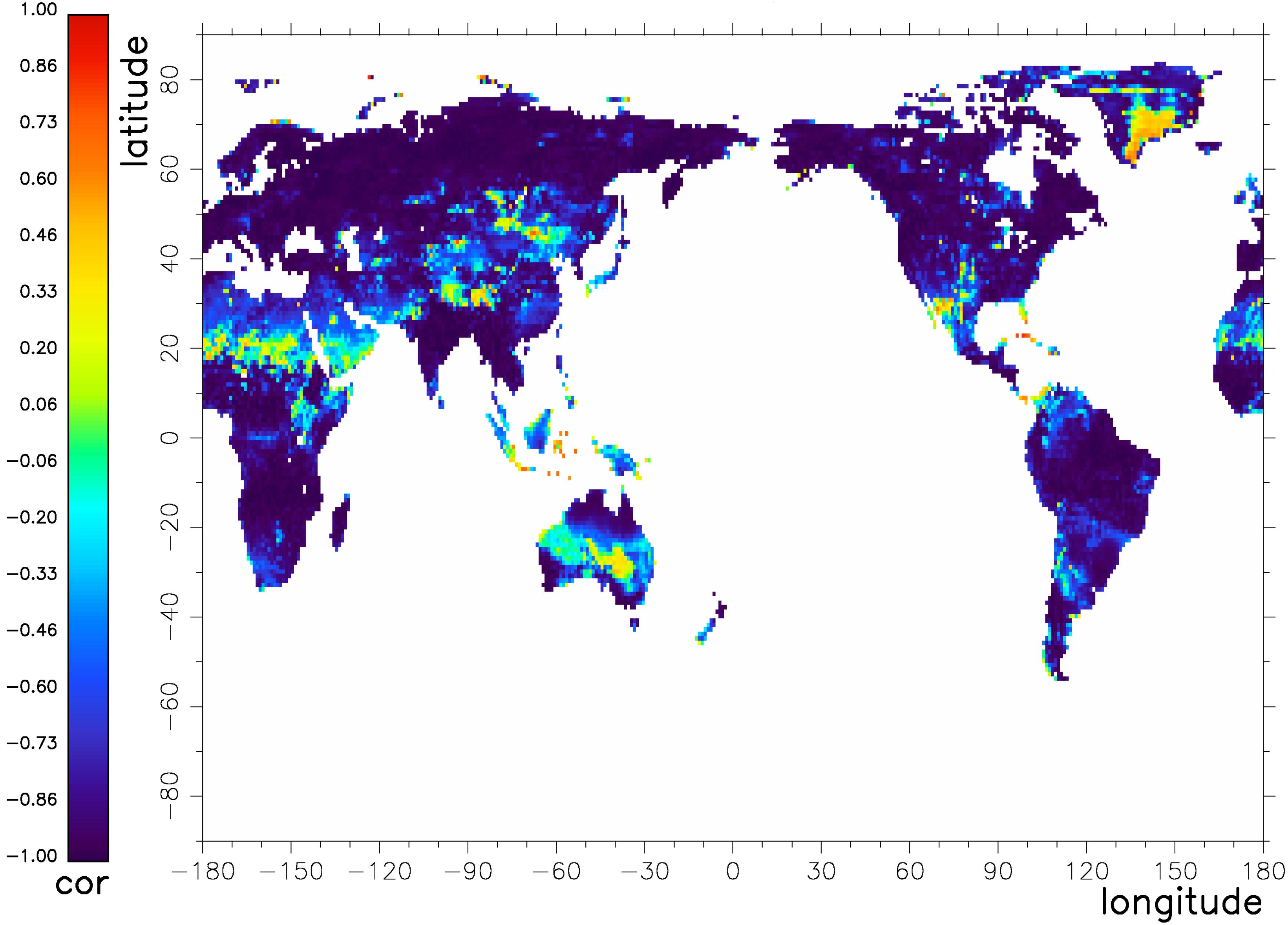
Differences in loading displacements computed using Noah model at $0.25^\circ \times 0.25^\circ$ and $1^\circ \times 1^\circ$ grids.







Correlation between Up land water loading and land water surface pressure



Reduction of annual site position variations

Harmonic	Reference solution χ^2_{ndf}(ver)	χ^2_{ndf}(hor)	With land water loading χ^2_{ndf}(ver)	χ^2_{ndf}(hor)
Sa	**19.6**	**11.9**	**10.3**	**8.5**
Ssa	4.4	2.9	4.2	2.9

Baseline length repeatability test

Without land water loading:

$\sqrt{A^2 + (B \cdot L)^2}$: $A = 3.37\,\text{mm}, \;\; B = 1.11^{-9}$

With land water loading:

$$A = 3.11\,\text{mm}, \;\; B = 1.08^{-9}$$

Conclusions:

- **91%** of anharmonic vertical loading signal from GLDAS Noah model **was found in VLBI data** after 2000.0
- Loading from GLDAS Noah model **prior 2000 fits poorly VLBI data**
- Loading from GLDAS from the Noah model with $\mathbf{0.25^\circ \times 0.25^\circ}$ **resolution better fits** VLBI data then from the $1^\circ \times 1^\circ$ resolution
- **Amplitudes of the residual annual position variations are reduced by 20–40%** after applying land loading model
- Reduction of baseline length repeatability is insignificant
- **Radioastronomy observations of radiogalaxies allow to discriminate soil moisture models**

Plans:

GLDAS team has plans to compute ground water component