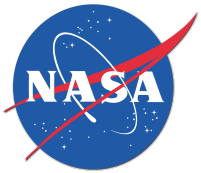

A new global mascon solution product

2013 GRACE Science Team Meeting, Austin, TX

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Recent publications related to GSFC mascons

- Luthcke, S.B., T.J. Sabaka, B.D. Loomis, A.A. Arendt, J.J. McCarthy, J. Camp (**2013**), Antarctica, Greenland and Gulf of Alaska land ice evolution from an iterated GRACE global mascon solution, J. Glac., Vol. 59, No. 216, 613-631, doi: 10.3189/2013jJoG12j147.

- Arendt, A., S. Luthcke, A. Gardner, S. O'Neel, D. Hill, G. Moholdt, W. Abdalati (**2013**), Analysis of a GRACE global mascon solution for Gulf of Alaska Glaciers, J. Glac., Vol. 59, No. 217, doi: 10.3189/2013JoG12J197.

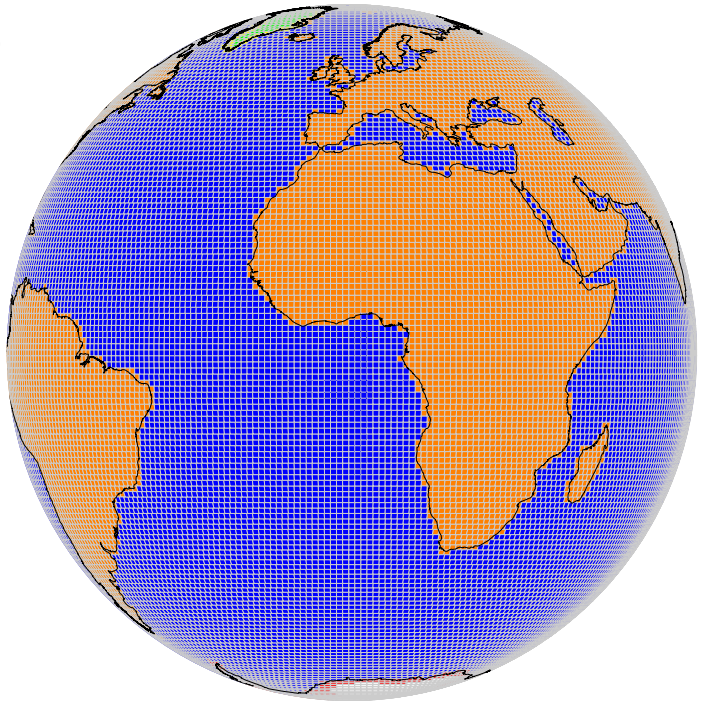
- Colgan, W., Luthcke, S., Abdalati, W., and Citterio, M.: Constraining GRACE-derived cryosphere-attributed signal to irregularly shaped ice-covered areas (**2013**), The Cryosphere Discuss., 7, 3417-3447, doi:10.5194/tcd-7-3417-2013.

- Loomis, B.D. and Luthcke, S.B., Optimized signal denoising and adaptive estimation of seasonal timing and mass balance from simulated GRACE-like regional mass variations (**2013**), Advances in Adaptive Data Analysis, In Review.

- Shepherd A, and many others (**2012**) A Reconciled Estimate of Ice-Sheet Mass Balance, SCIENCE, 338, 1183-1189.

GSFC global mascon product summary

- Recent paper: *Luthcke et al., Antarctica, Greenland and Gulf of Alaska land-ice evolution from an iterated GRACE global mascon solution, J. Glaciol. (2013)*
- 41,168 equal area 1-arc-degree mascons are directly estimated from GRACE KBRR L1B data with spatial and temporal exponential taper constraints applied; 10-day temporal resolution
- Spatial constraint: 100 km correlation distance
- Temporal constraint: 10-day correlation
- Most recent global solution has 7 separate constraint regions (mascons across constraint regions are uncorrelated):
  1. Greenland Ice Sheet > 2000 m
  2. Greenland Ice Sheet < 2000 m
  3. Antarctic Ice Sheet > 2000 m
  4. Antarctic Ice Sheet < 2000 m
  5. Gulf of Alaska glacier region
  6. Land (including all other ice regions)
  7. Ocean (including ice shelves)
- Solution is iterated to convergence



<u>* New constraint regions for hydrological basins can be easily added</u>

GSFC mascon solution

Gauss-Newton non-linear least squares

$$\text{GN iteration } k \begin{cases} \Delta\tilde{\mathbf{h}}_k &= \left(\mathrm{L}^{\mathrm{T}}\mathrm{A}^{\mathrm{T}}\mathrm{WAL} + \mu\mathrm{P}_{hh}\right)^{-1}\left(\mathrm{L}^{\mathrm{T}}\mathrm{A}^{\mathrm{T}}\mathrm{W}\mathbf{r} - \mu\mathrm{P}_{hh}\tilde{\mathbf{h}}_k\right) \\ \tilde{\mathbf{h}}_{k+1} &= \tilde{\mathbf{h}}_k + \Delta\tilde{\mathbf{h}}_k \end{cases}$$

$\tilde{\mathbf{h}}_{k+1} \equiv$ updated mascon state estimate
$\mathrm{L} \equiv$ partials of differential Stokes coefficients with respect to mascon equivalent water height
$\mathrm{A} \equiv$ partials of KBRR obs with respect to the differential Stokes coefficients
$\mathrm{W} \equiv$ data weight matrix; measurement noise and back-substituted arc parameters
$\mu \equiv$ damping parameter
$\mathrm{P}_{hh} \equiv$ mascon regularization matrix; exponential neighbor constraint
$\mathbf{r} \equiv$ KBRR residuals

… or written in the form of an anisotropic, non-symmetric filter that acts upon an unfiltered Stokes state to produce a filtered Stokes state … followed by a least-square collocation (LSC) prediction of the mascon state estimate from the filtered Stokes state estimate ….

$$\tilde{\mathbf{s}}_{k+1} = \mathrm{P}_{ss}^{-1}\left(\mathrm{N}^{-1} + \mathrm{P}_{ss}^{-1}\right)^{-1}\hat{\mathbf{s}}_{k+1}, \qquad \tilde{\mathbf{h}}_{k+1} = \mathrm{P}_{hs}^{-1}\mathrm{P}_{ss}\tilde{\mathbf{s}}_{k+1},$$

$$\begin{cases} \tilde{\mathbf{s}}_k &= \mathrm{L}\tilde{\mathbf{h}}_k \\ \Delta\hat{\mathbf{s}}_k &= \left(\mathrm{A}^{\mathrm{T}}\mathrm{WA}\right)^{-1}\mathrm{A}^{\mathrm{T}}\mathbf{r} \\ \hat{\mathbf{s}}_{k+1} &= \tilde{\mathbf{s}}_k + \Delta\hat{\mathbf{s}}_k \\ \tilde{\mathbf{h}}_{k+1} &= \mathrm{P}_{hh}^{-1}\mathrm{L}^{\mathrm{T}}\left[\mu\left(\mathrm{A}^{\mathrm{T}}\mathrm{WA}\right)^{-1} + \mathrm{LP}_{hh}^{-1}\mathrm{L}^{\mathrm{T}}\right]^{-1}\hat{\mathbf{s}}_{k+1} \end{cases}$$

$\tilde{\mathbf{s}}_{k+1} \equiv$ updated filtered Stokes state
$\hat{\mathbf{s}}_{k+1} \equiv$ updated unfiltered Stokes state
$\mathrm{P}_{ss}^{-1} \equiv$ Stokes signal auto covariance
$\mathrm{P}_{ss}^{-1} = \mathrm{LP}_{hh}^{-1}\mathrm{L}^{\mathrm{T}}$
$\mathrm{N}^{-1} \equiv$ Stokes noise covariance
$\mathrm{P}_{hs}^{-1} \equiv$ Stokes and mascon signal cross-covariance
$\mathrm{P}_{hs}^{-1} = \mathrm{P}_{hh}^{-1}\mathrm{L}^{\mathrm{T}}.$

GSFC global mascon product details (1 of 4)

- Distributed data product is in HDF5 format (same as ICESat-1 & 2 and OIB)
- RL02 GSFC mascon products based on RL02 of the GRACE L1B data
- Parameter estimation: Simultaneous fit of bias, trend, acceleration, annual, semi-annual, and 161-d. The 161-d fit is removed from the delivered time series.
- Trend errors: Autocorrelation Eq. 3.10 from [Lee and Lund, 2004]
- 10-day errors: Mean Absolute Deviation (MAD) of the finest scale wavelet coefficients [Donoho and Johnstone, 1994]
- Filtered (noise removal) mascon time series: We apply the Wiener filter in the Fourier domain, where the estimated signal spectrum is the Fourier transform of the Gaussian smoothed time series, and the noise spectrum estimate is the MAD of the finest scale wavelet coefficients [Loomis and Luthcke, *in review*]
- Matlab functions to read the HDF5 files will be distributed with mascon solution data sets
- The forward modeled GLDAS, and ECMWF+MOG2D are available as separate HDF5 files. These models have been averaged spatially and temporally to match the global mascon solution.

GSFC global mascon product details (2 of 4)

- Government shutdown impacted final development, validation and product generation for RL02 v08, which will be current best product:
  - Release 2 L1B
  - Forward models: EIGEN-6C (d/o 200), ECMWF (3-hrly), MOG2D, GLDAS/NOAH (3-hrly, 0.25°, ice "masked out"), GOT4.8 tides (d/o 90), Pole and Solid Earth tides IERS2010, DE421
  - Fully Iterated

- What we are making available for the next few weeks while we complete v08, is our RL02 v04 so investigators can get experience with the products:
  - Release 2 L1B
  - Forward models: GGM02C (d/o 150), ECMWF (3-hrly), MOG2D, GLDAS/NOAH (3-hrly, 0.25°, ice "masked out"), GOT4.7 tides (d/o 70), Pole and Solid Earth tides IERS2003, DE403
  - NOT Iterated
  - This initial distribution only contains data through 2010

GSFC global mascon product details (3 of 4)

- The NASA GSFC distributed global mascon product will be in HDF5 format and is organized into the following groups:
  - **size**: Describes the size of the data sets in the subsequent groups
  - **time**: Defines the mascon time windows and center time for each "10-day" solution and includes a list of GRACE arcs applied to the solution
  - **mascon**: Defines the location, span, size, and constraint region of each mascon
  - **solution**: Time series solution for each mascon and parameter fits

- The **solution** group includes data sets with the following:
  - Time series solution for each mascon
  - Optimally filtered time series solution for each mascon
  - Multi-linear regression parameter fits for each mascon: bias, trend, acceleration, amplitude and phase of annual, semi-annual
  - Calibrated error for the 10-day solutions for each mascon
  - Calibrated trend error for each mascon

GSFC global mascon product details (4 of 4)

Excerpt from L3 HDF5 data format document:

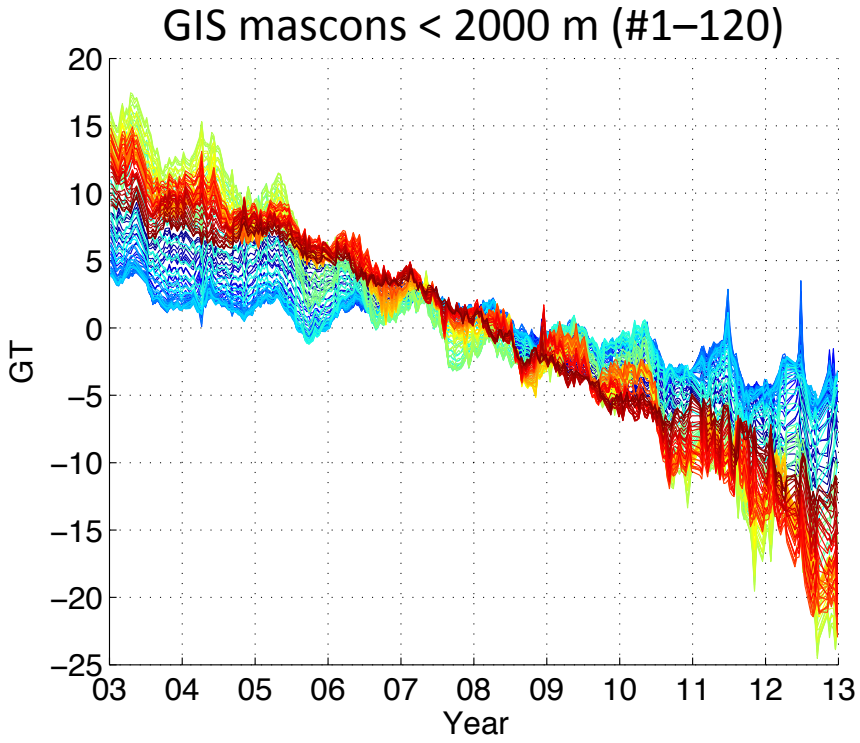
Group: /solution

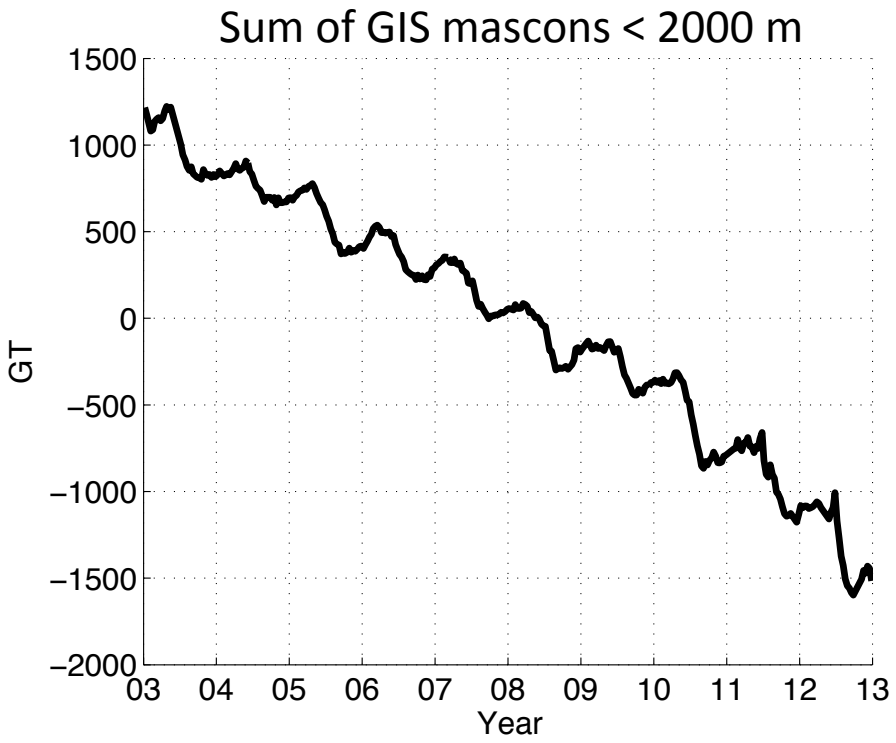
This group contains the time series of solutions (filtered and unfiltered) for each mascon and the best-fit parameters to each mascon time series over the data span defined by the dates in the fitspan dataset.

Dataset	Description	Size
values	Mascon solutions for each mascon location and time (cm w.e.)	N_mascon_times x N_mascons
values_filter1d	Filtered solutions for each mascon location and time (cm w.e.)	N_mascon_times x N_mascons
bias	Best-fit bias (cm w.e.)	N_mascons x 1
trend	Best-fit trend (cm w.e./yr)	N_mascons x 1
accel	Best-fit acceleration (cm w.e./yr^2)	N_mascons x 1
amp365d	Best-fit annual amplitude (cm w.e.)	N_mascons x 1
amp182d	Best-fit semi-annual amplitude (cm w.e.)	N_mascons x 1
phase365d	Best-fit annual phase (rad)	N_mascons x 1
phase182d	Best-fit bias (rad)	N_mascons x 1
err_10day	Estimated error of 10-day mascon solutions (cm w.e.)	N_mascons x 1
err_trend	Estimated error of mascon trends (cm w.e./yr)	N_mascons x 1
rms_est	RMS of estimated signal (cm w.e.)	N_mascons x 1
rms_resid	RMS of residual to fit (cm w.e.)	N_mascons x 1
fitspan	Time span of least-squares fit (YYYYMMDD)	2 x 1

GSFC mascon product examples

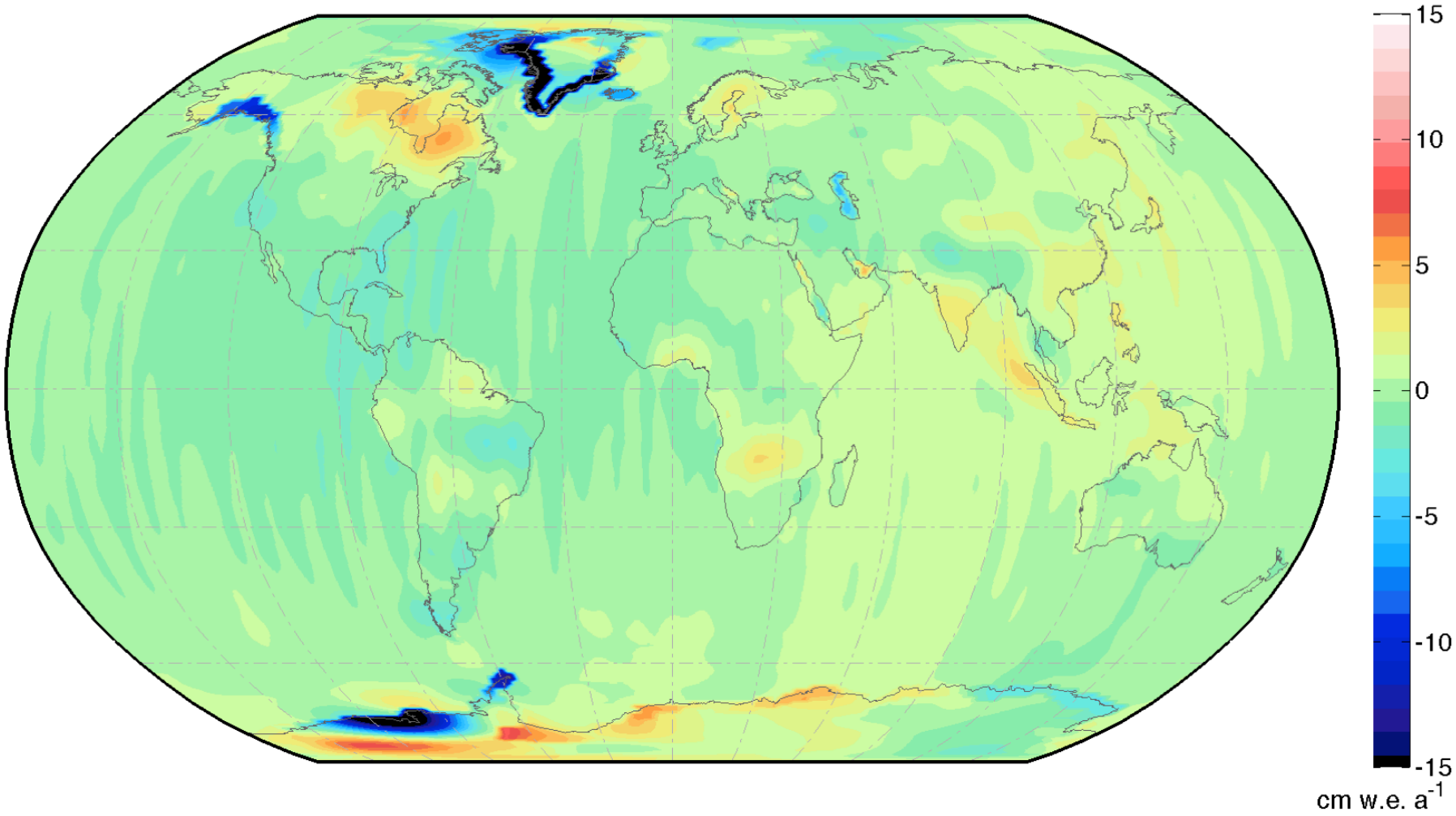
The **mascon** group contains the area of each mascon, so the time series of each mascon from the **solution** group is easily converted from cm w.e. to GT and then summed for any designated region (e.g. GIS elevation < 2000 m):





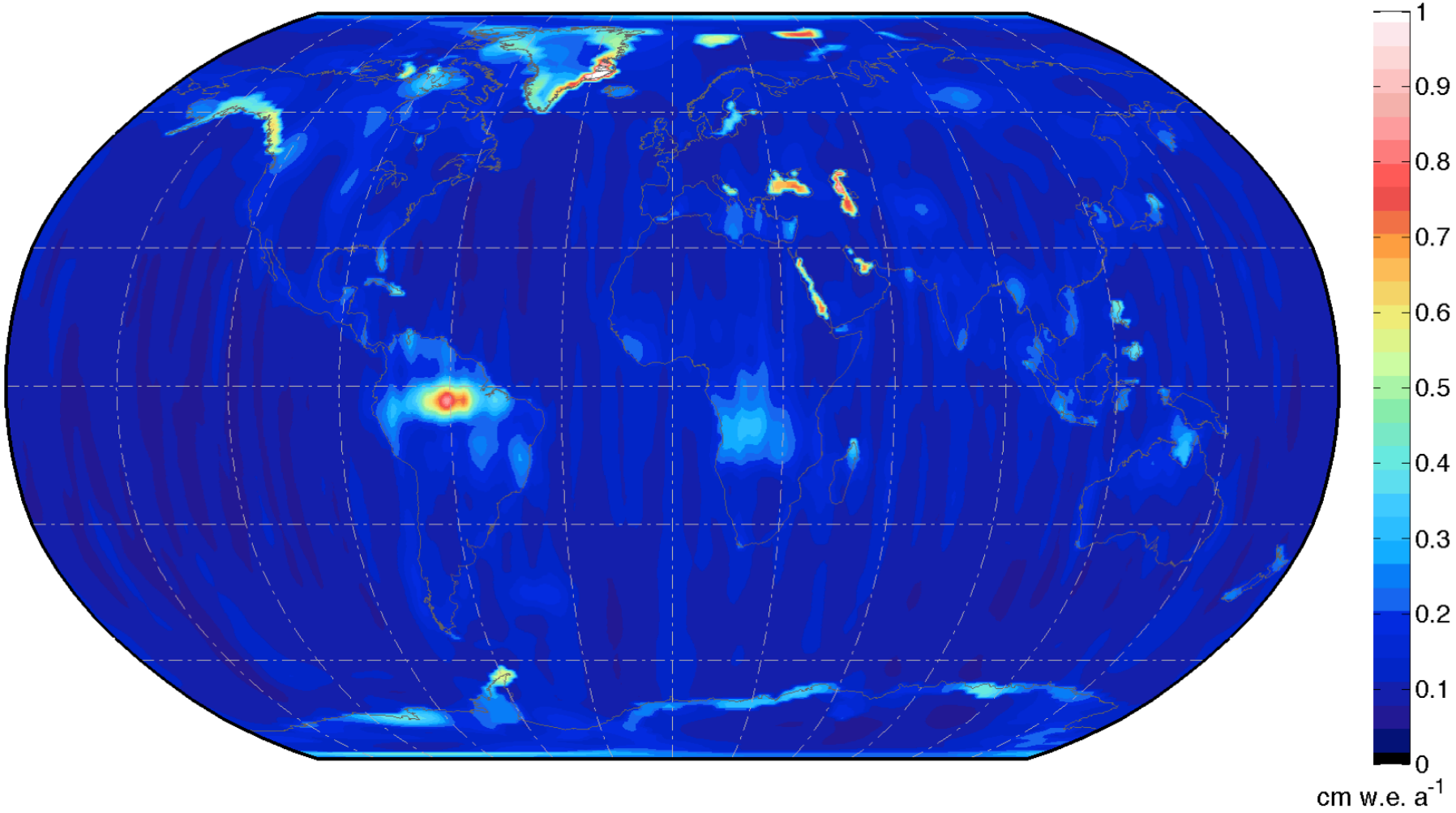
GSFC mascon product examples

v04 trend (2003.01.01 – 2012.12.31)



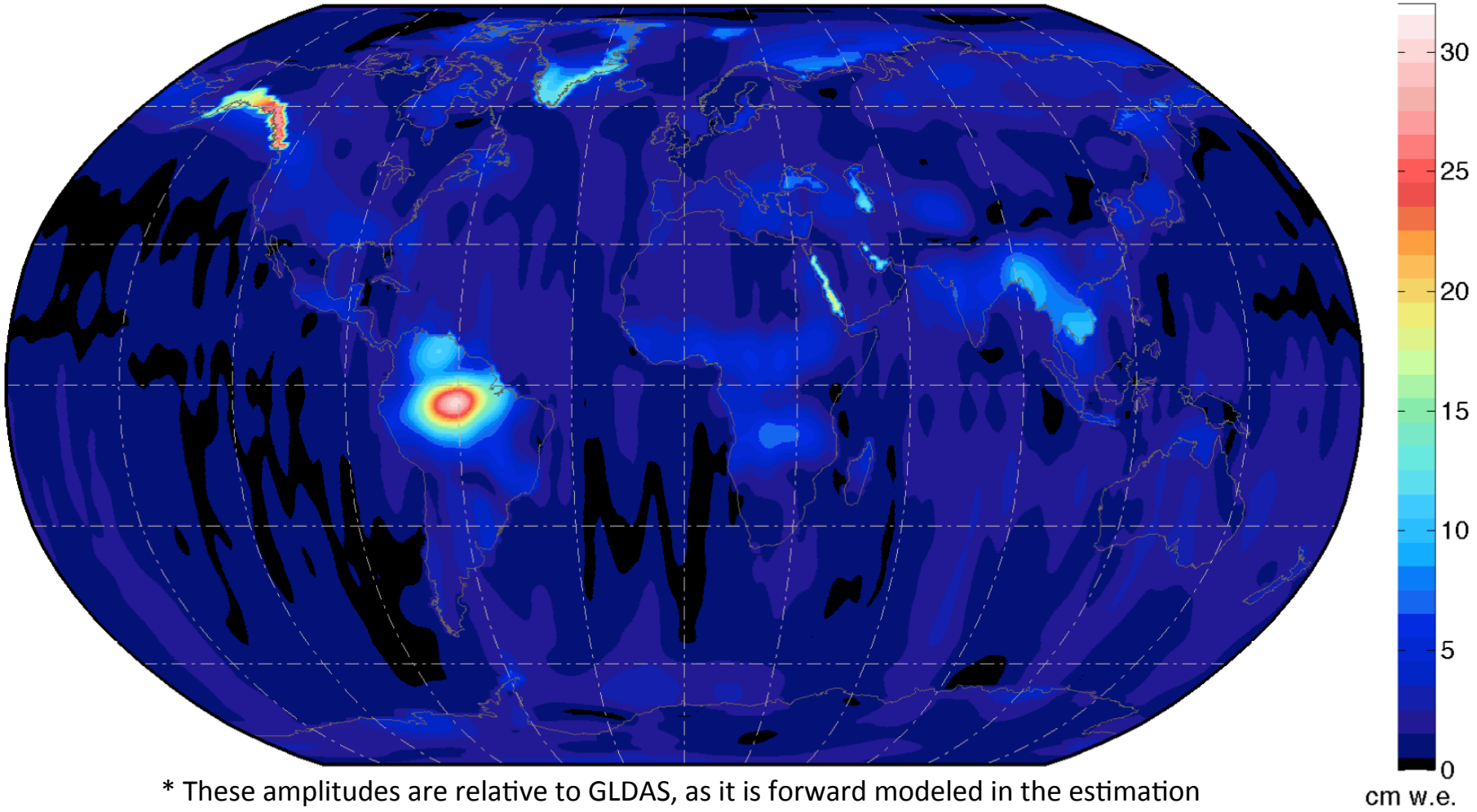
GSFC mascon product examples

v04 trend error (2003.01.01 – 2012.12.31)



GSFC mascon product examples

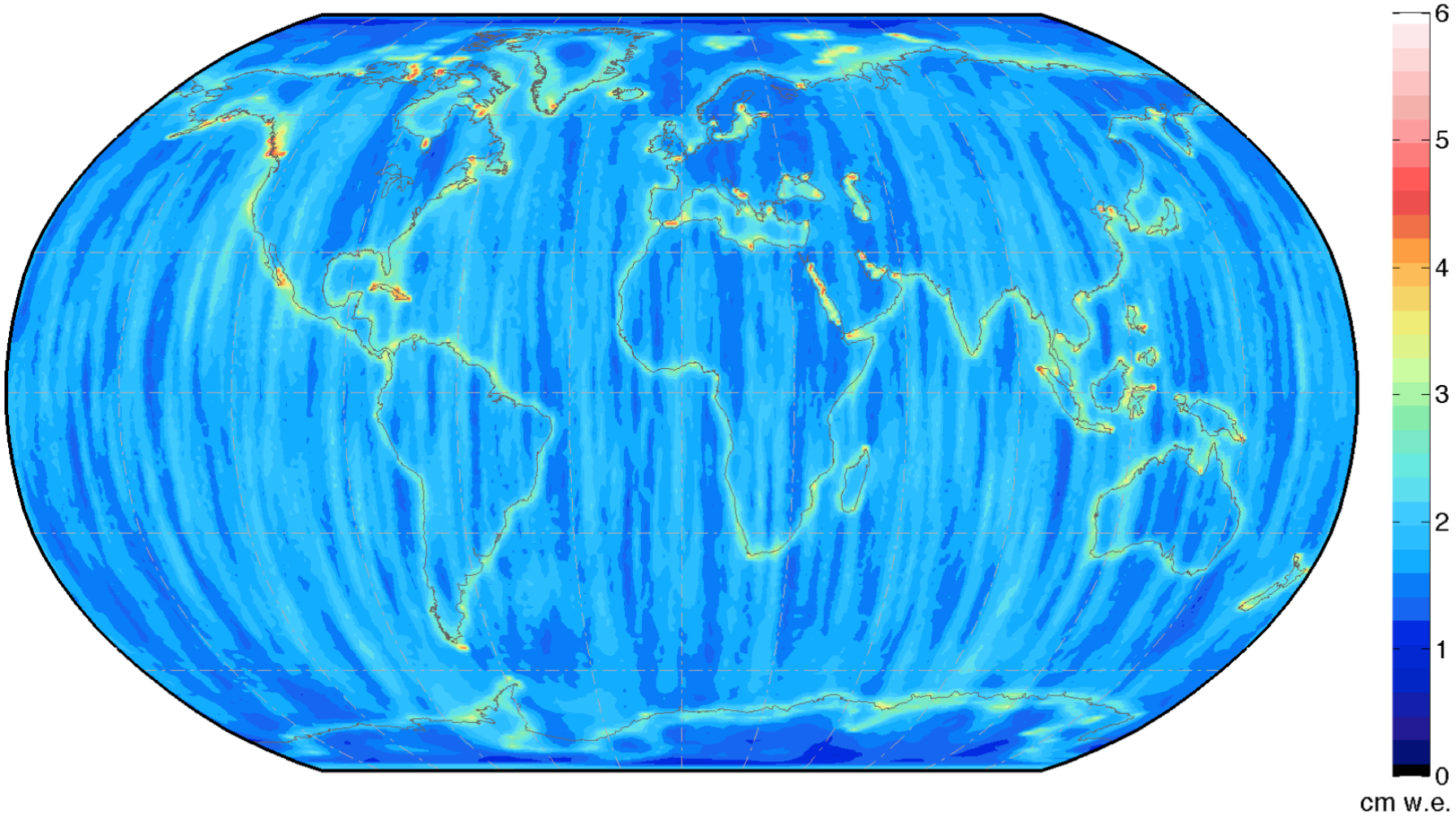
v04 annual amplitude* (2003.01.01 – 2012.12.31)



* These amplitudes are relative to GLDAS, as it is forward modeled in the estimation

GSFC mascon product examples

v04 10-day error (2003.01.01 – 2012.12.31)



GSFC global mascon product access

RL02 v04 interim product can be downloaded from the following location.
In the future the data sets will be distributed via PODAAC.

To have the link below e-mailed to you, please send request to Scott:
Scott.B.Luthcke@nasa.gov

Center Network Environment Project

"Excellence in Networking"

WebDrive Upload Completed Successfully

You have 30 days from 10-22-2013 to download the file(s) from the following URL:

https://webdrive.gsfc.nasa.gov/longauth/600/scott.b.luthcke/SJBkjoC

Please use the following to login:

username = gsfc_mascon_rl02_v04_Apr03-Nov10
password = gsfc_mascon_rl02_v04_Apr03-Nov10

Thank you for using WebDrive