Global Comparisons of GRACE with Water Storage Products

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1 - Annual Amplitudes

The following maps show the amplitude of an annual cycle fitted to GRACE level 2 data from CSR (release 4). Data from January 2003 until September 2006 are included. The fields have been post-processed using the filter described in [Swenson, et al 2006] to remove the "stripes" that otherwise require smoothing the data with large (half width > 500km) gaussians. The gravity fields are then converted to an equivalent thickness of water as in [Wahr, et al 1998].

By post-processing the GRACE data, hydrological signals with smaller scales can be resolved. For example, annual snowfall in the Canadian Rockies, the desert region of the southwestern United States and the rainy season in the southeastern United States are clearly visible. The Intertropical Convergence Zone in Africa shows up as two bands on either side of the equator, and Madagascar's signal is distinguishable from continental Africa's. Also visible are the monsoon seasons in northern Australia and southern Asia .

Figure 1 - Annual Amplitude Over North America (smoothed at 400 km)

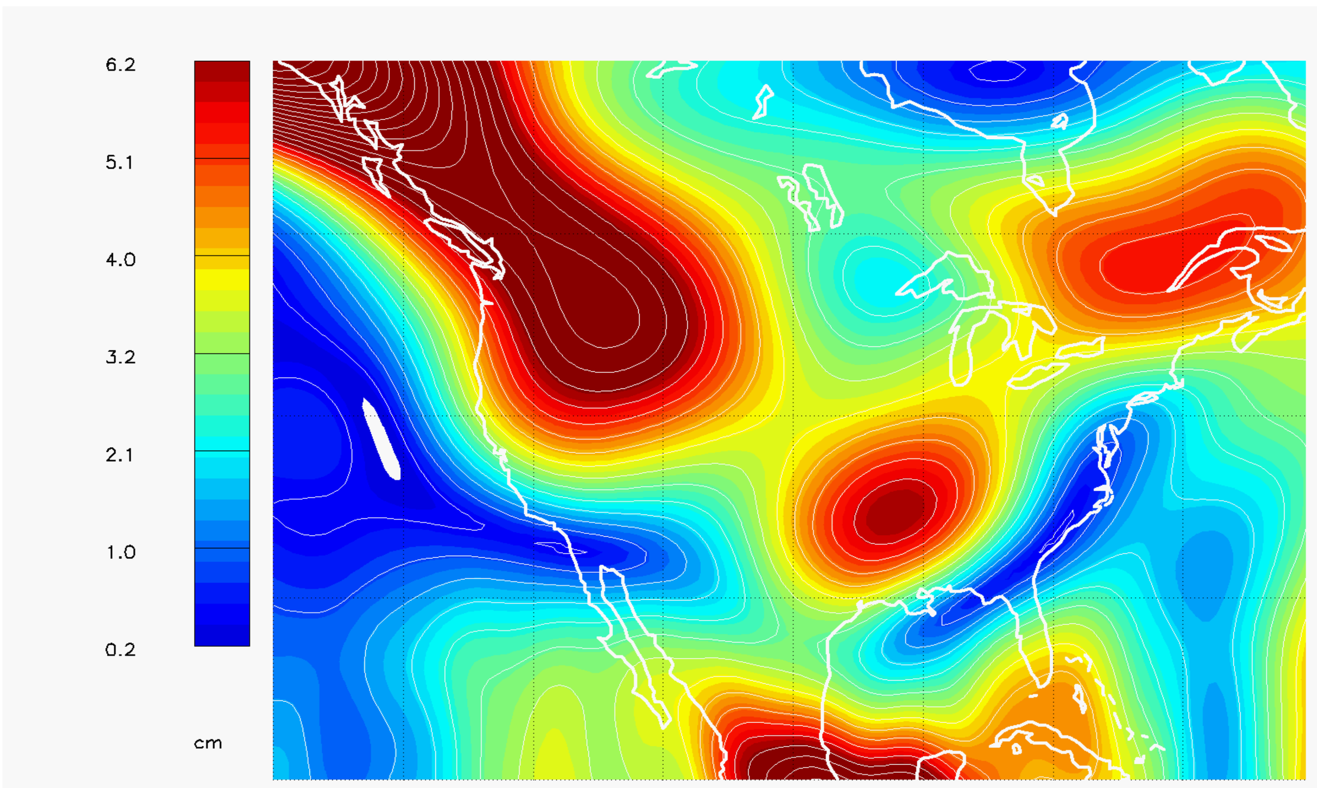


Figure 2 - Annual Amplitude Over Africa (smoothed at 350 km)

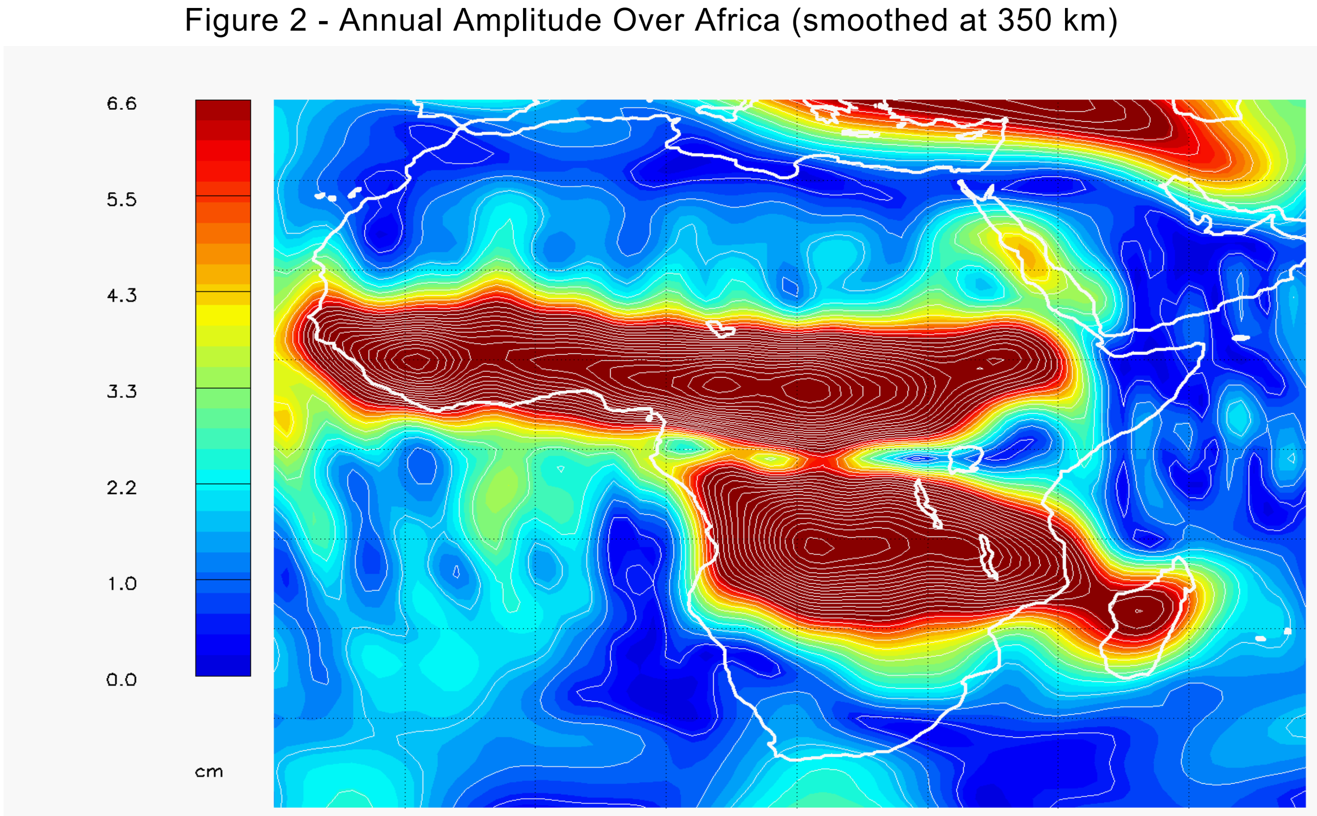


Figure 3 - Annual Amplitude Over Australia (smoothed at 350 km)

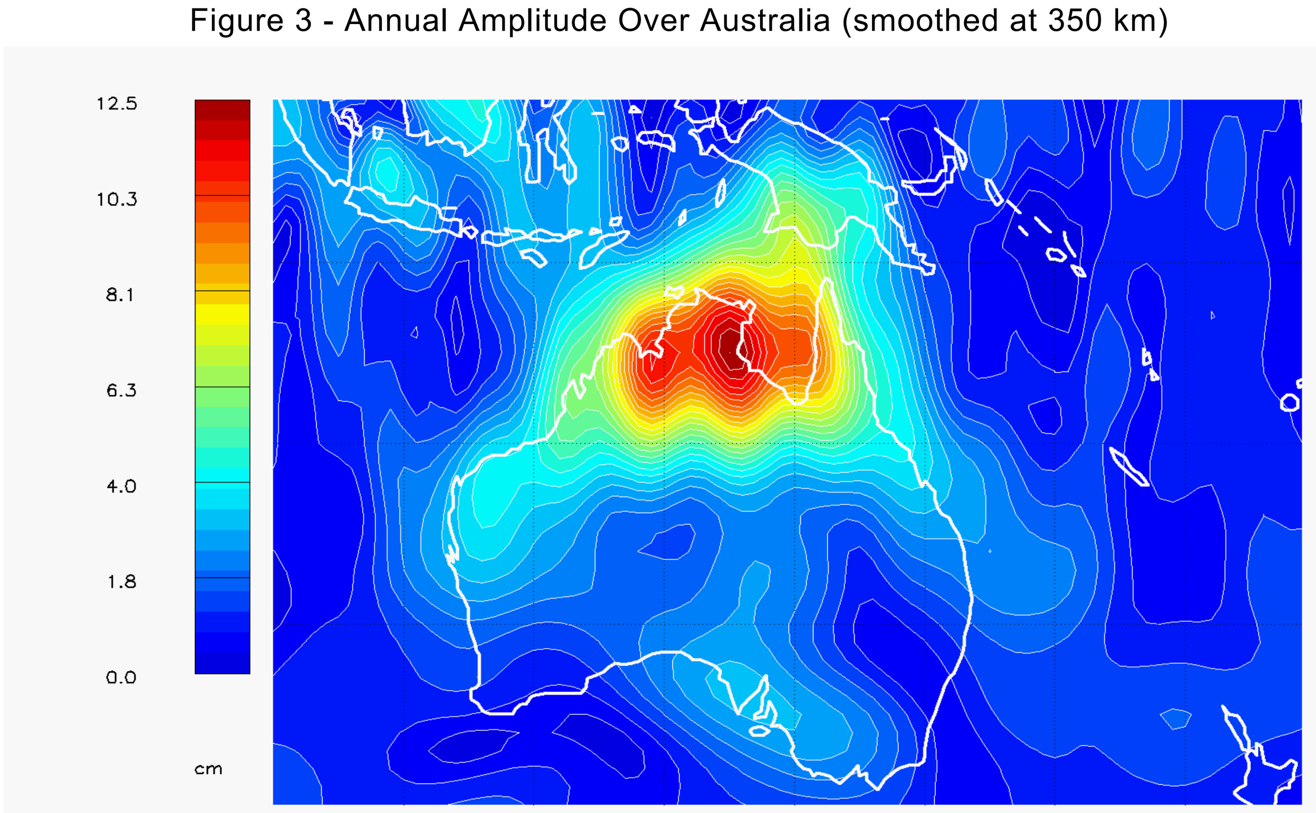
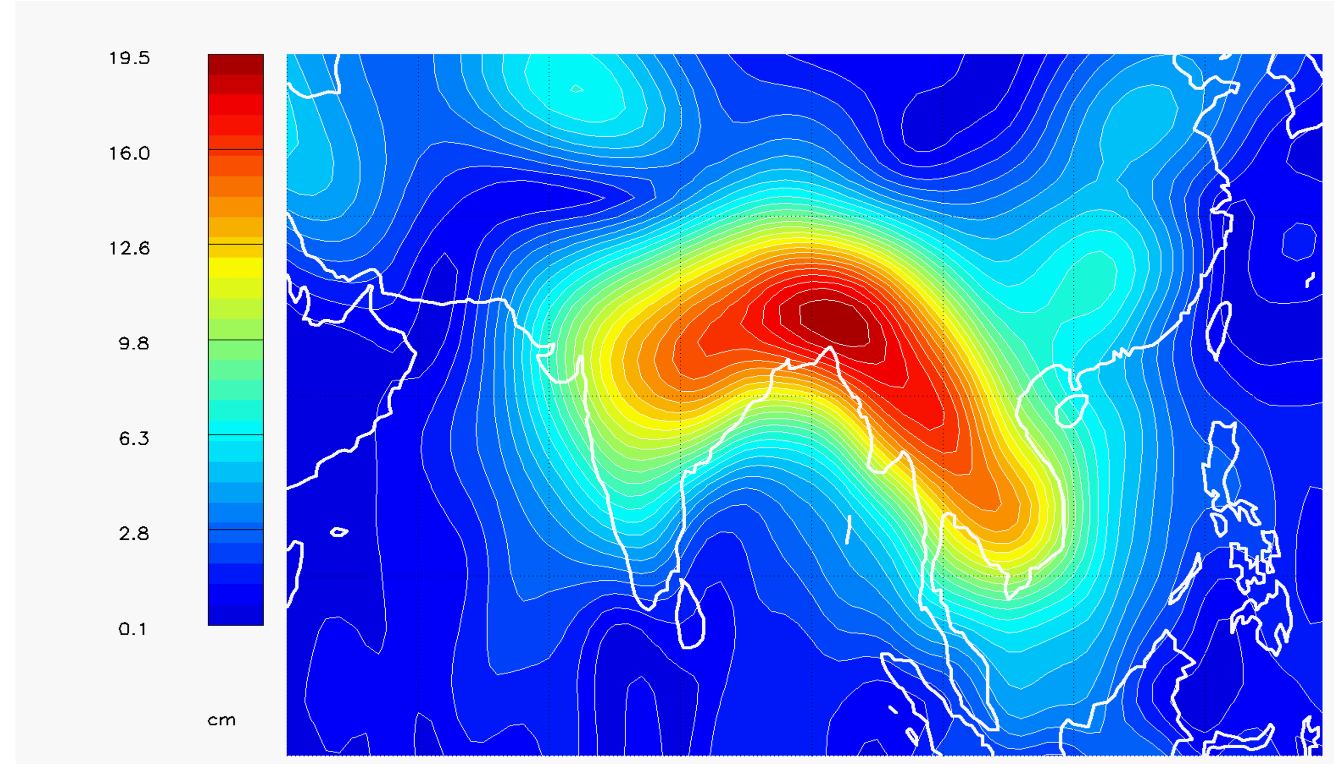


Figure 4 - Annual Amplitude Over Southern Asia (smoothed at 400 km)



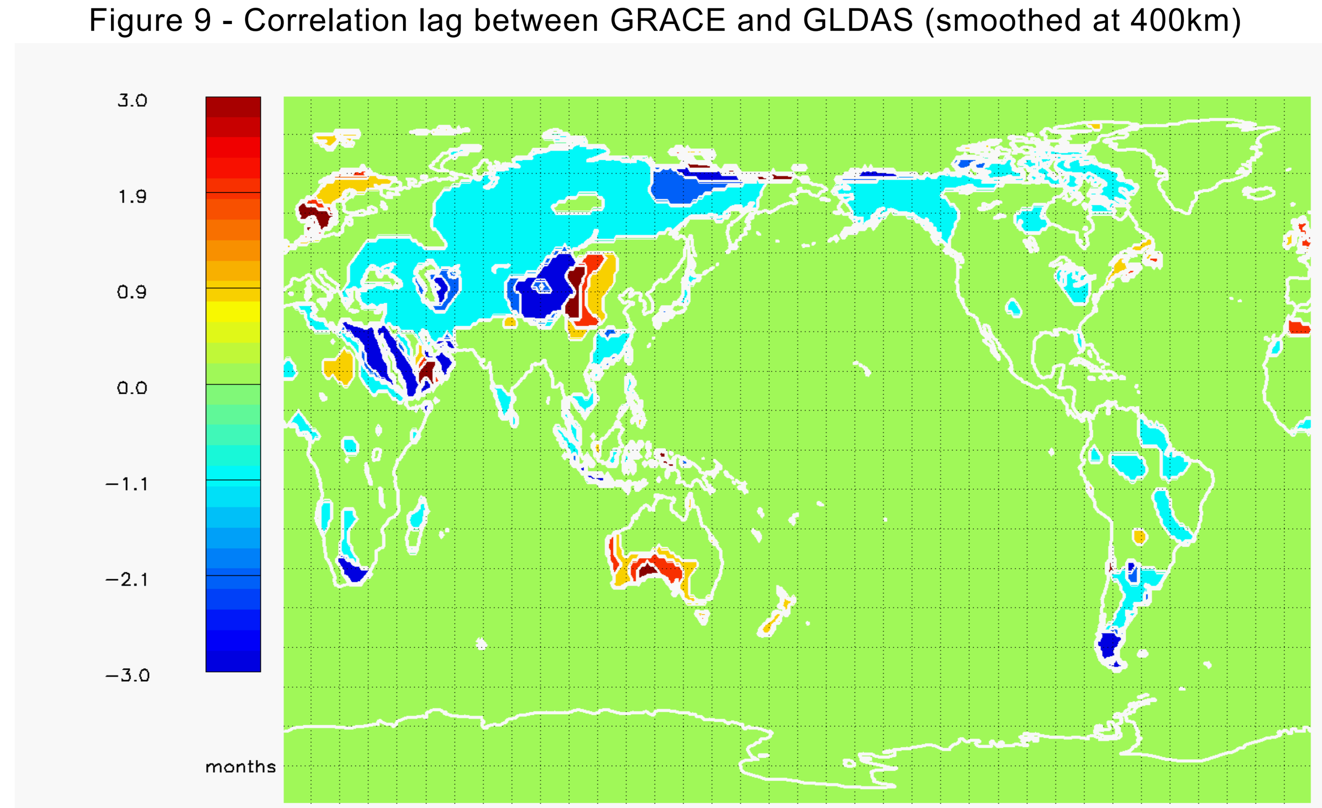
3 - Cross-Correlation Analysis

After examining time series from several river basins, a pattern emerged: the hydrology signal from GLDAS tends to peak before GRACE does. In order to examine the time lag between GRACE and GLDAS on a global scale, the cross-correlation of the two time series was computed using the following equation:

$$CrossCorrelation(lag) = \frac{1}{N}\sum_{i=1}^{N} GRACE(t_i + lag) * GLDAS(t_i)$$

The factor in front of the summation corrects for the fact that as the lag is varied, the number of months that line up changes. The lag was varied in integer steps between -3 and +3, and the value of lag which maximized the cross-correlation at each point is plotted below. Because there is no GLDAS signal over the oceans, they have been masked out.

Figure 9 - Correlation lag between GRACE and GLDAS (smoothed at 400km)



In most regions, the phase lag is either 0 (indicating that GRACE and GLDAS peak at the same time) or -1 (indicating that GLDAS peaks 1 month before GRACE). Positive phase lags occur predominantly in arid regions where the signal to noise ratio of GRACE is low and also along coasts where ocean signals leak into GRACE, so these phase lags are probably not physically meaningful.

There are several possible explanations for this phase lag:

(1) It is known that the NOAH land surface model melts snow prematurely, which could contribute to GLDAS leading GRACE in regions with significant snowfall.

(2) GLDAS/NOAH lacks a groundwater component, and consequently tends to underestimate water residence times.

(3) GLDAS/NOAH does not include a river routing scheme, so that water is lost from the model as soon as it runs off into a river. In reality, the fact that water takes a finite time to reach the ocean means that water in rivers continues to contribute to the GRACE signal until it leaves the continent.

2 - River Basin Time Series

Most time variability in GRACE is attributed to hydrological processes. Therefore, comparisons between hydrology models and GRACE provide independent confirmation of both the model's and GRACE's accuracy. We chose to compare GRACE to the Global Land Data Assimilation System (GLDAS), which drives land surface water models such as NOAH using meteorological observations. To conserve global water mass, the GLDAS product has been modified by adding a spatially uniform signal to the oceans at every time step.

Shown below are CSR GRACE and GLDAS time series averaged over various river basins. A basin function which takes the value 1 inside the basin and 0 outside is convolved with a gaussian of half-width 300km to produce the averaging function. GRACE and GLDAS are then spatially averaged over the globe using this averaging function to obtain two time series. The error bars are constructed by fitting and removing a secular trend, annual cycle, and a semi-annual cycle to each set of GRACE harmonics, then taking the rms of the resulting residual time series. These residual rms values are then multiplied by 1.15 because the same fitting procedure applied to random data decreases the rms by 15%. These scaled rms values are then convolved with the smoothed averaging kernel according to the method described in [Wahr, et al 2006] to produce 1 sigma error bars.

Figure 5 - GRACE (black) and GLDAS (orange) over the Mississippi River Basin

Agreement is good in the Mississippi- GLDAS generally lies within the error bars, and both time series peak at the same time.

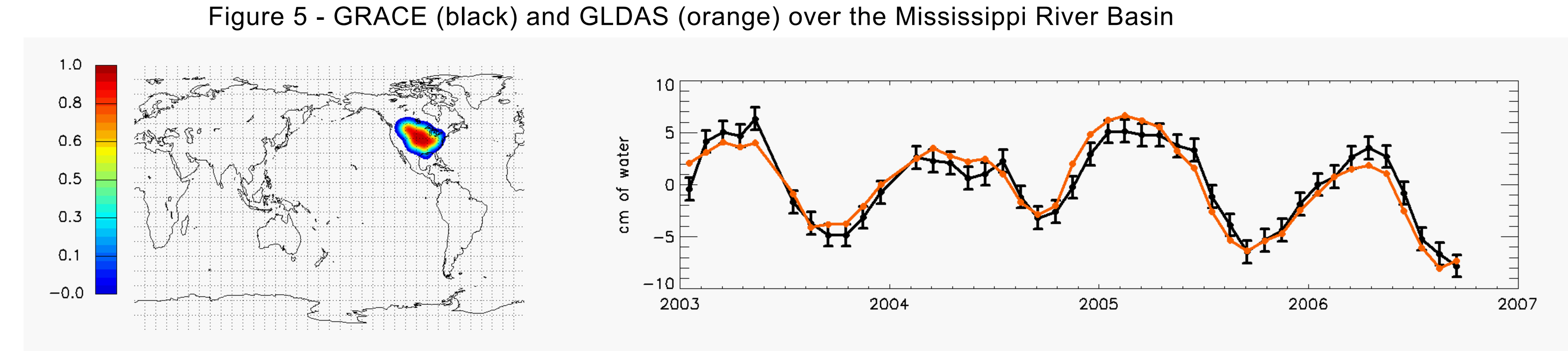


Figure 6 - GRACE (black) and GLDAS (orange) over the Tocantins River Basin

In the Tocantins basin, the amplitude of GLDAS is slightly smaller than GRACE, and GLDAS lags behind GRACE by one month.

This lag time could be due to the fact that the water storage model ignores water as soon as it enters rivers, but the gravity signal from that water remains until the water leaves the basin.

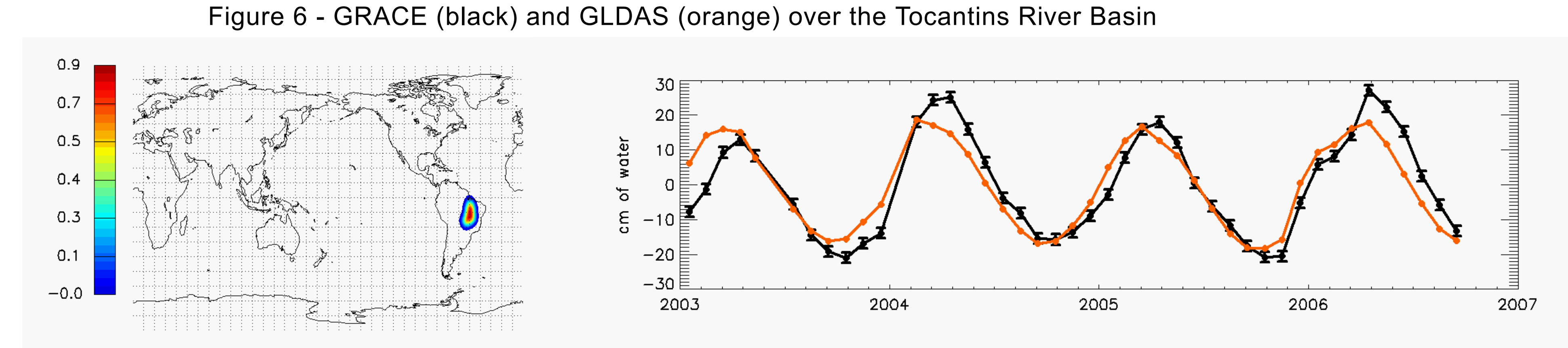


Figure 7 - GRACE (black) and GLDAS (orange) over the Yenisey River Basin

The Yenisey also exhibits the phase lag seen in the Tocantins.

Because of the significant snowfall in this basin, another possible explanation for the time lag in this case is that GLDAS/NOAH is known to melt snow too early. Also, GLDAS/NOAH doesn't include a groundwater component, so any melted snow that doesn't get absorbed into the soil doesn't show up in the model.

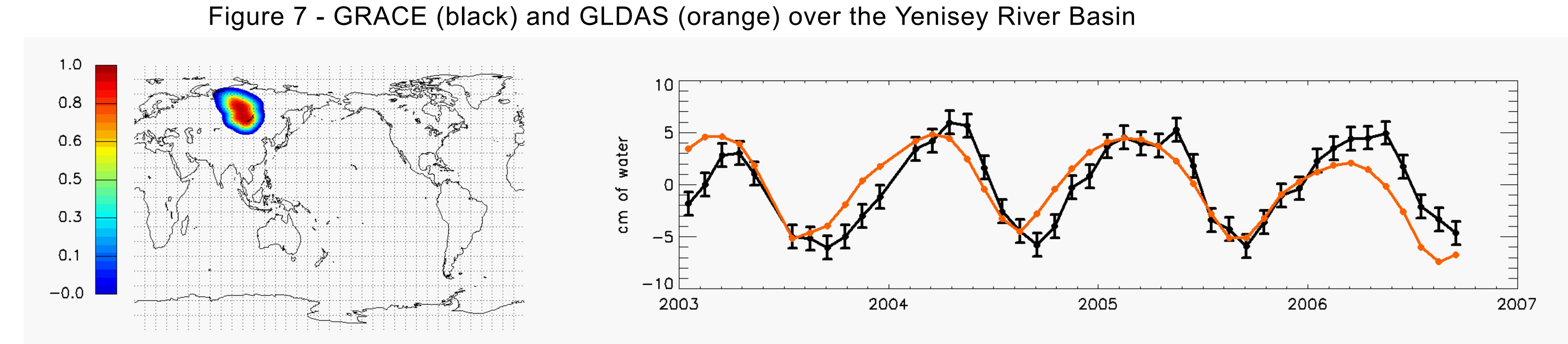
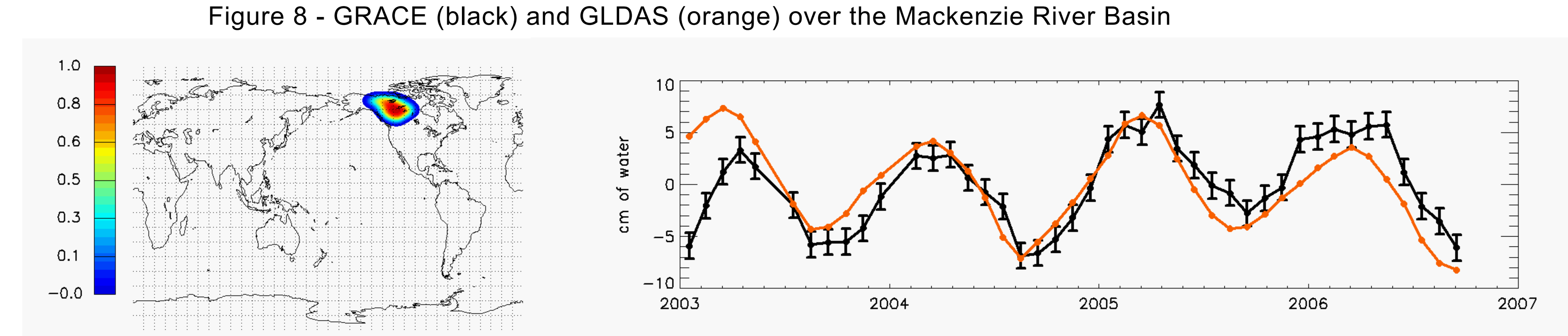


Figure 8 - GRACE (black) and GLDAS (orange) over the Mackenzie River Basin

The phase lag is also observed in the Mackenzie basin, along with a secular trend due to post-glacial rebound.



4 - Summary

- The destriping procedure described in Swenson, et al 2006 produces high resolution fields, allowing smaller scale features to be resolved.
- Agreement between GRACE and GLDAS is generally good- GLDAS lies within or near the 1 sigma error bars around GRACE in most regions.
- GRACE generally lags GLDAS by 1 month. This could be due to GLDAS/NOAH melting snow early and lack of a groundwater component and a river routing scheme in the water storage model underlying GLDAS.

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