Assessment of groundwater storage derived from IPCC models, and projections for the next 50 years

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I. Goals

- It has been demonstrated that GRACE* anomaly data can be used as a proxy for water storage.
- Our goal in this work is to use GRACE to validate IPCC model output, and thus examine future water storage trends.
- We started with an analysis of the Mississippi (MS) river basin, since its large footprint encompasses many model grid points.
- Our eventual goal is to examine the CA water basins.
- We have compared GRACE data to soil moisture, since the total water storage (TWS) value in the mid-latitudes is dominated by soil moisture.
- *GRACE: Gravity Recovery and Climate Experiment (NASA and DLR). GRACE has twin satellites that orbit Earth and measure monthly changes in Earth's gravity field.

II. Methods

- In this project we compare GRACE TWS anomaly observations to soil moisture fields simulated by several IPCC models. The A2 scenario is assumed for all runs reported here, and comparisons can be made for individual river basins. Here we report on comparisons for the MS river basin.
- A river basin shapefile is used to determine the boundary of a model's soil moisture grid points to be selected for averaging within the river basin (bold grey line in Fig 2a,c for MS basin).
- We computed GRACE anomaly TWS data averaged across the MS basin for the period 2002-2009 in order to see the observed intra- and inter-annual variations. These are shown in Fig 1, along with the composite for the period (bold, dashed line).
- The composited monthly average from four models (Table 1) is then computed and compared to the composited monthly average GRACE data, and the correlation (*r*) is calculated. Figure 2b shows the comparisons for the four models. For these four IPCC A2 simulations, $r \geq 0.9$, indicating that the annual cycle of soil moisture is simulated reasonably well by the models.
- Soil moisture distributions averaged over the last decade of each 100-year simulation are then compared to those for the first decade to look for long term trends in distributions (Fig 2c; "cold" colors represent drying).
- We also looked at trends in soil moisture averaged across the MS basin for each 100-year simulation (Fig 2d). The UKMO Had CM3 and GISS models show small drying trends over the century; the MIROC model shows a strong drying trend over the century (discussed further in V), with the last decade statistically different from the first (95% CL).
- These analyses will next be applied to the Western US river basins, e.g., the San Joaquin basin in central California. Expected problems include the narrow basin footprint *vs.* IPCC grid resolution. We plan to examine downscaled data for small western basins.

Table 1. Models used for comparison with GRACE, with model sensitivity and grid resolution.

Model	Sensitivity (°C)	Grid Resolution	
		Latitude (°)	Longitude (°)
UKMO Had Gem1	4.4	1.250	1.875
Miroc 3.2 (Med res)	4.0	~2.79	~2.81
UKMO Had CM3	3.3	2.50	3.75
GISS ER	2.7	4.00	5.00

IV. Results

(a) Modeled soil moisture averaged over same time as GRACE observation period

(b) Correlation between GRACE and modeled soil moisture monthly average

(c) Difference plot of modeled soil moisture - last decade minus first decade

(d) Time series of modeled soil moisture with trend analysis to 95% confidence level

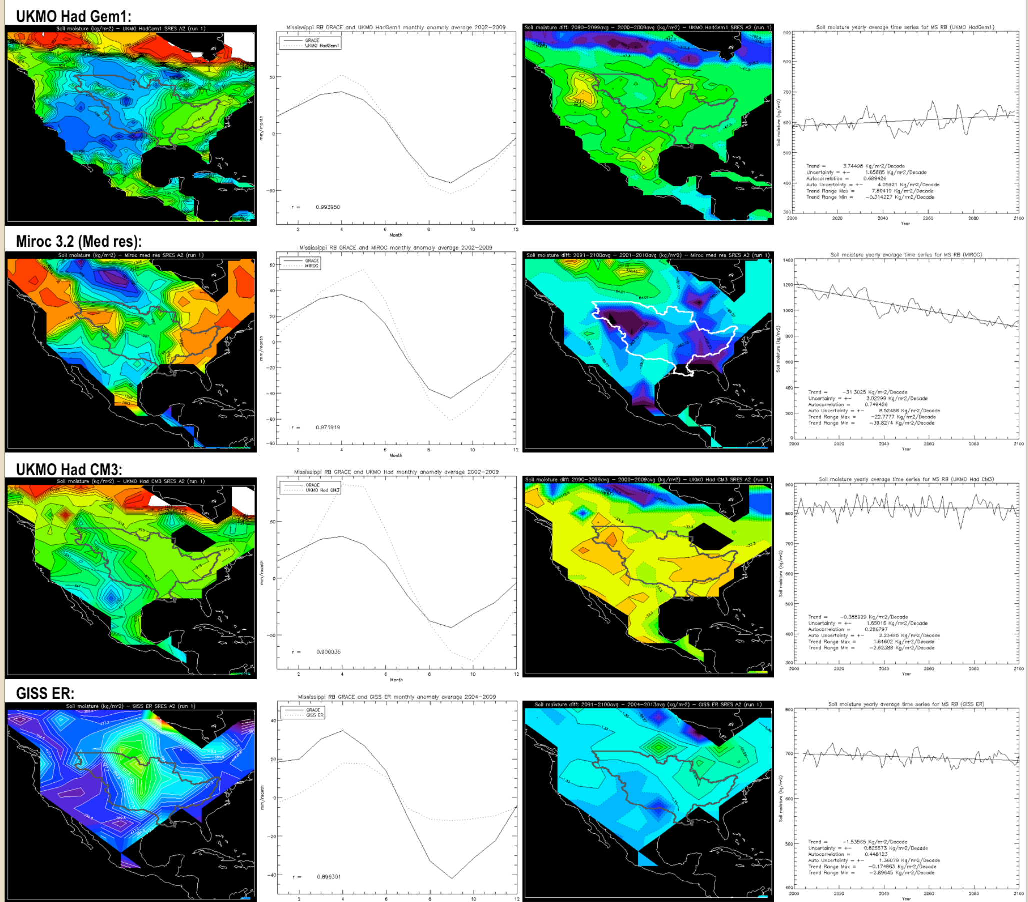

Figure 2. (Above, from left) (a) Contour plot of modeled soil moisture averaged over same time as GRACE observations, with Mississippi river basin outlined; (b) plot showing composite of modeled soil moisture anomaly and GRACE TWS anomaly (mm/month) with correlation between them; (c) contoured difference plot between first and last decade of modeled soil moisture; (d) time series of modeled soil moisture data with trend analysis to 95% confidence level.

Table 2. (Right) Models used for comparison with GRACE, with model correlation (*r*) to GRACE data, trend and uncertainty (accounting for autocorrelation) of modeled soil moisture to year 2100, and mean difference and uncertainty between last decade and first decade of modeled soil moisture.

Model	GRACE r	Trend	Uncertainty	Mean Diff.	Uncertainty
UKMO Had Gem1	0.99395	3.74	4.06	44.77	10.65
Miroc 3.2 (Med res)	0.971919	-31.3	0.749	-272.97	13.83
UKMO Had CM3	0.900035	-0.39	2.23	-6.83	14.08
GISS ER	0.896301	-1.54	1.36	-4.39	4.92
Trend in kg/m²/decade					
Blue shading indicates statistical significance at 95% confidence level					

III. GRACE Observations

- GRACE TWS anomaly data are analyzed for the MS river basin from May 2002 through November 2009 (Fig 1).
- GRACE data are interpolated to same time resolution as models used for comparison.

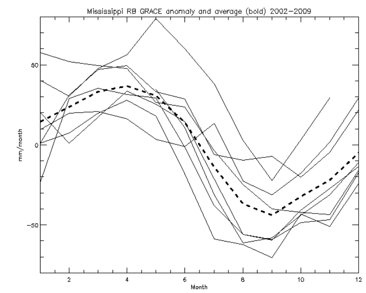

Figure 1. Annual cycles of monthly-averaged GRACE TWS anomaly data for Mississippi river basin over the period 2002-2009; composite shown by bold dashed line.

V. Conclusions

- The UKMO Had Gem1 does not have a statistically significant trend in soil moisture for the MS basin under the SRES A2 scenario, but the first and last decades are statistically different. This model is also the most sensitive and has the highest resolution of the four models analyzed.
- The MIROC 3.2 (Med res) model has a statistically significant downward trend in soil moisture averaged across the MS basin under the SRES A2 scenario, and the first and last decades are statistically different.
- The UKMO Had CM3 model does not show any statistically significant trends in soil moisture under the SRES A2 scenario. Fig 2c suggests a weak drying trend in the upper plains states.
- The GISS ER model shows a small but statistically significant drying trend in soil moisture under the SRES A2 scenario, although the magnitude is much lower than in the MIROC model. However, the first and last decades of the GISS ER model are not statistically different from one another.

VI. Future Research

- Perform same analysis on all available IPCC models with A2 scenario and archived soil moisture (prefer non-bucket models).
- Perform same analysis on all available IPCC models with different scenarios, and also examine ensembles.
- Examine model differences in soil moisture initial values and spatial distributions.
- Use downscaled data to analyze CA river basin trends.

VII. Contact Information

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