Modeling Terrestrial Water Storage Variations with a Land Model

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Hypothesis:

1. Different representations of terrestrial hydrological processes in a land model for use in climate models may produce difference terrestrial water storage variations;

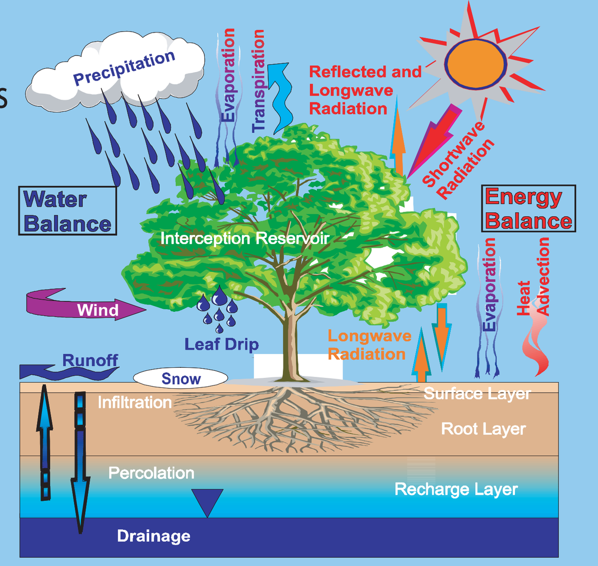
2. A land model can be improved through comparisons with the GRACE-derived terrestrial water storage variations;

3. Constrained by the GRACE-derived terrestrial water storage variation and runoff data, a land model forced by the observed precipitation data can produce more accurate evapotranspiration (ET).

Hydrological Processes in the NCAR Community Land Model (CLM)

The NCAR CLM has been developed to represent the terrestrial thermal and hydrological processes in the fully coupled Community Climate System Model (CCSM). The terrestrial hydrological processes in CLM include (Oleson et al., 2004):

> Interception of precipitation by the canopy
> Snow accumulation and ablation
> Infiltration and percolation of soil water
> Freezing and thawing of soil water
> Surface runoff and baseflow
> Evapotranspiration (ET)



Water storage variations in lakes and rivers are represented through variations of precipitation and evaporation over water surfaces, although the water storage of lakes and rivers is not explicitly included in the model. The soil depth is confined to 3.43 m. Thus the water storage variations induced by groundwater change are excluded in regions where groundwater is deep.

A Modified Version of CLM:

1. A Simple Topography-based Runoff Model (SIMTOP) (Niu et al., 2005)

Surface runoff: $Qs = \mathcal{P}\, F_{max} \exp(-0.5\, f\, Z_{wt})$

Baseflow: $Qb = Q_{max} \exp(-f\, Z_{wt})$

where $\mathcal{P}$ is precipitation, F_{max} is the maximum fractional saturated area, Z_{wt} is the depth to the water table, and Q_{max} is the maximum baseflow when the water table depth is at the ground surface. F_{max} is defined as the fraction of pixels with topographic index larger than the grid-cell–mean topographic index.

2. A More Permeable Frozen Soil Model (Niu and Yang, 2005)

a. Added the supercooled, liquid water (the liquid water that coexists with ice over a wide range of temperatures below the freezing point).

b. Enhanced infiltration and percolation rates under the assumption that a fractional permeable area exists because of the presence of macropores.

Modeled Terrestrial Water Storage Variations in Comparison with GRACE

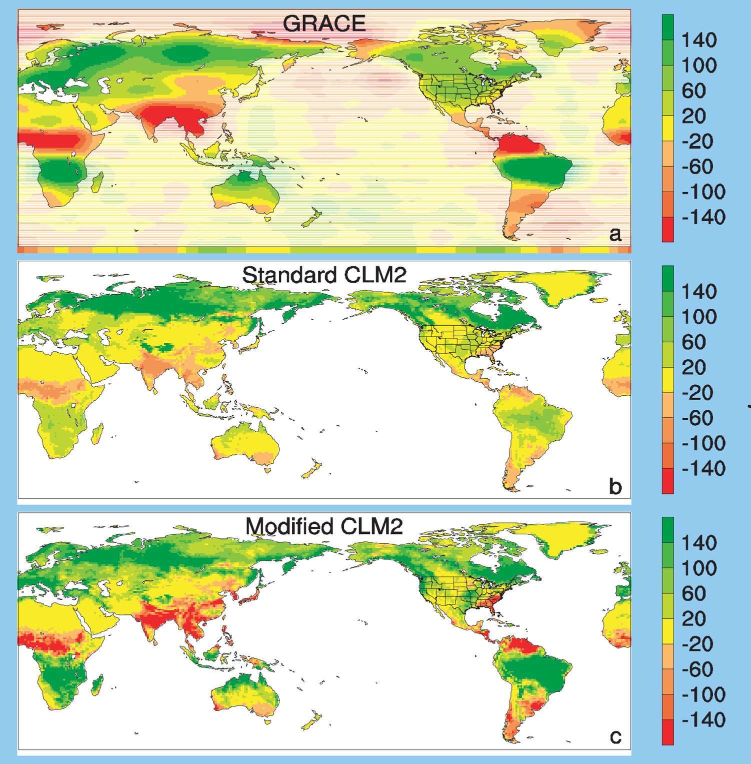


Figure 1. GRACE-derived water storage changes from August 2003 to April 2004 (2004APR-2003AUG) and simulations from the standard and modified CLM.

It shows a remarkably distinct patterns of water storage change in different climate zones, i.e., the cold, monsoon, and tropical rainforest regions. In clod regions, the positive changes result from the snow water and snowmelt water infiltrated into the soil in April 2004. The negative changes in monsoon regions result from the monsoon-season precipitation in August 2003. The positive changes in tropical regions are mainly due to the fact that August is in a dry season.

The Modified CLM compares more favorably with GRACE than the standard CLM.

The model is forced by the GLDAS observation-based surface hydrometeorological data (Rodell et al. 2004).

Water Storage Variations in Cold Regions

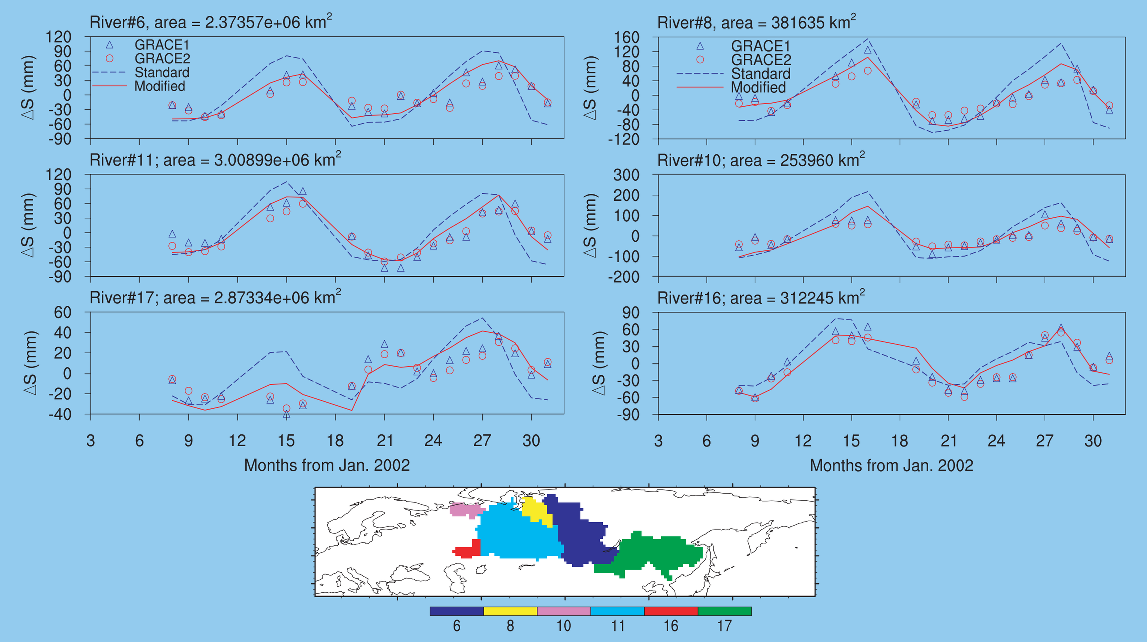


Figure 2. Water storage variations of three large river basins and three small river basins in cold regions.

The GRACE data are from Chen et al. (2004) and Seo and Wilson (2005).

Water Storage Variations in Monsoon Regions

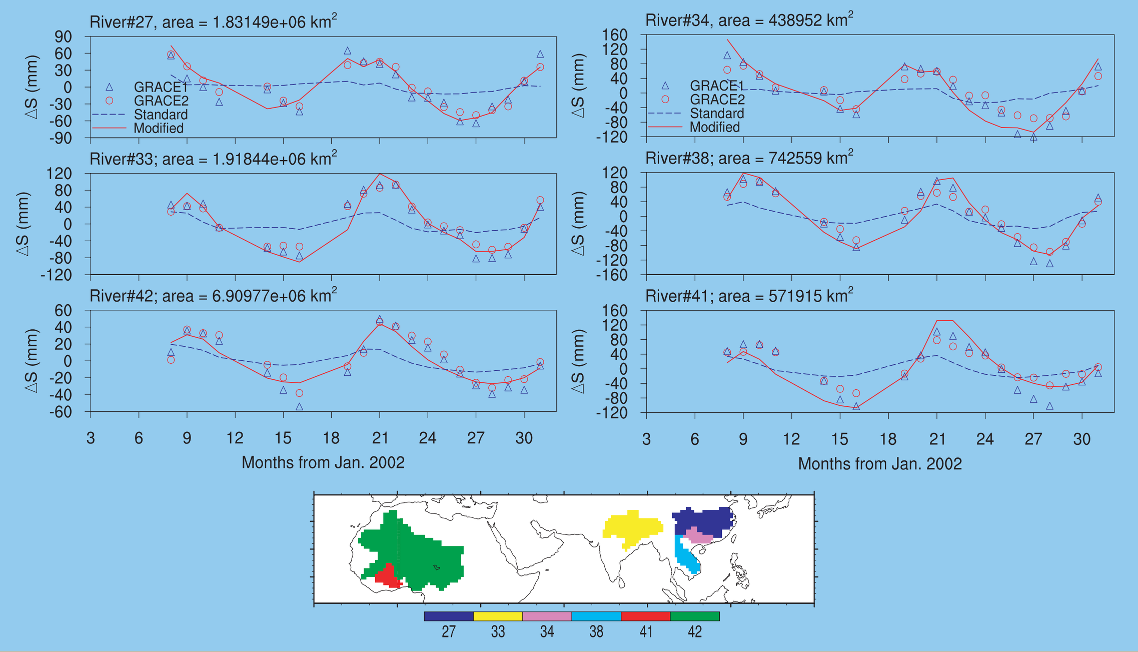


Figure 3. Water storage variations of three large river basins and three small river basins in monsoon regions.

Water Storage Variations in Tropical Regions

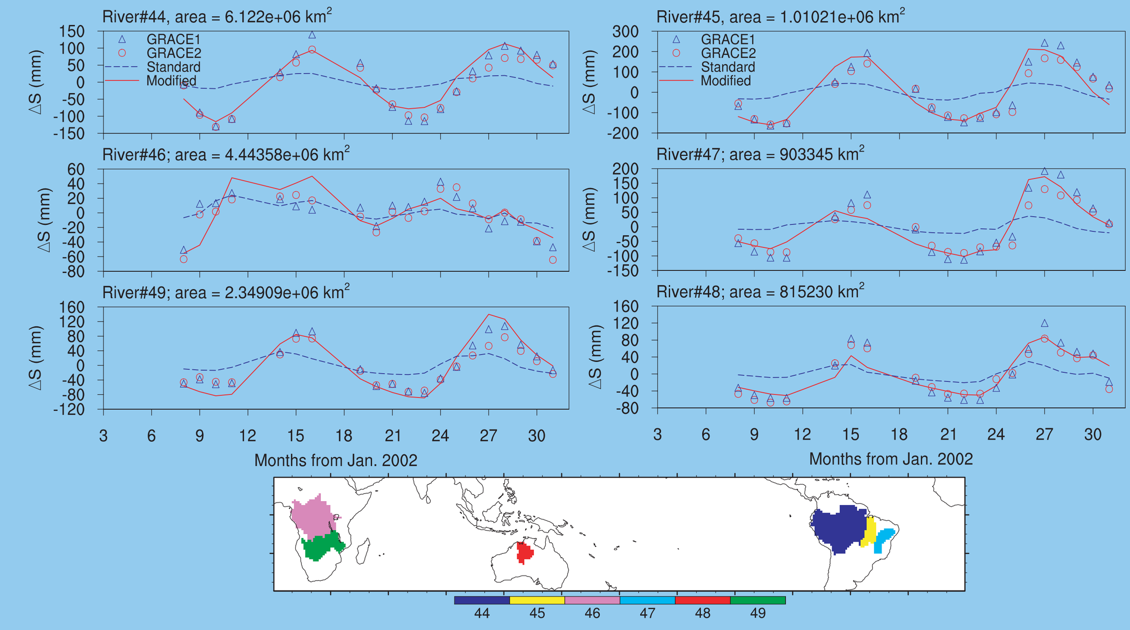


Figure 4. Water storage variations of three large river basins and three small river basins in tropical regions.

Modeled Evapotranspiration (ET) Constrained by Water Storage Variations of GRACE in the Amazon River Basin

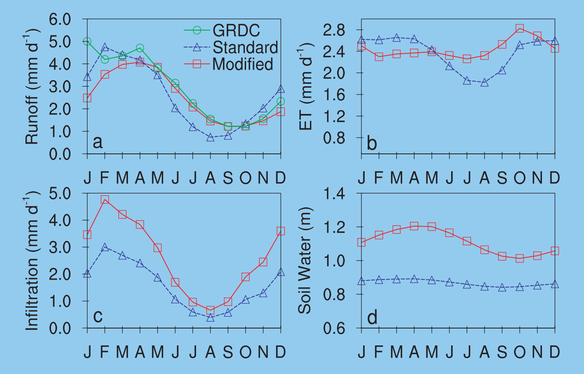


Figure 4. Three-averaged (a) runoff, (b) ET, (c) infiltration, (d) total soil water in the 3.43 m deep soil with the modified CLM and the standard CLM.

The modified CLM that produces more accurate runoff and water storage variations results in a favorable change in ET, whihc shows a weaker annual cycle than the standard CLM. The Amazon ET is energy-limited and thus in phase of net radiation instead of precipitation (Shuttleworth, 1988)

Conclusions

The GRACE-derived terrestrial water storage change provides us with a new constraint for developing land models because it offers insights into the processes that control the terrestrial water storage variability.

The modified CLM with a new treatment of runoff and frozen soil processes performs much better in simulating the seasonal variability of terrestrial water storage in global river basins of various spatial scales above 200,000 square km.

By simulating more accurate water storage change and runoff, the modified CLM produces a favorable change in the modeled ET in the Amazon River basin in that it has a weaker annual cycle than does the standard CLM .

References

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