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Trends in total water storage over the eastern U.S., 2003-2012

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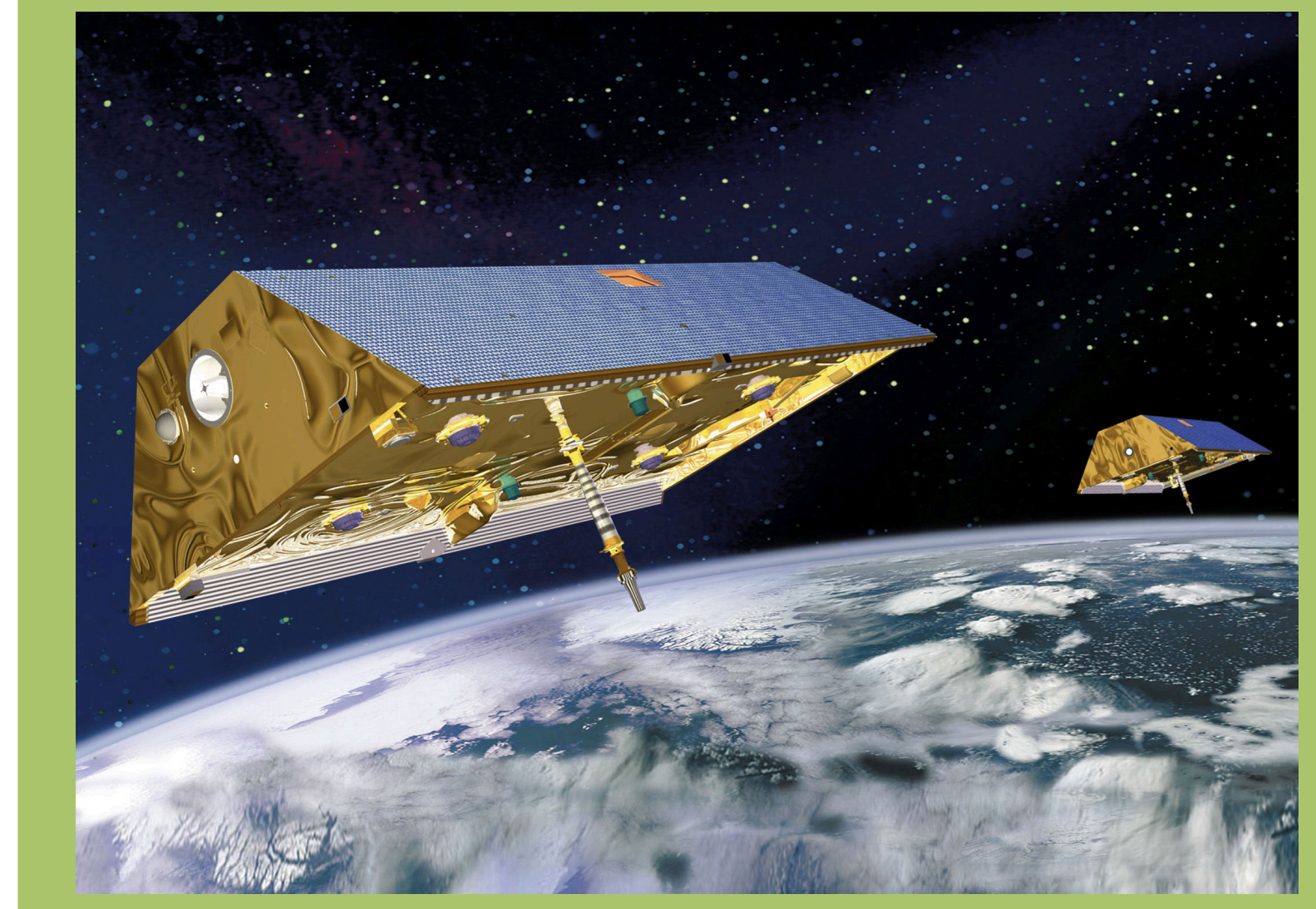
Motivation

Famiglietti and Rodell (2013) argued that between 2003 and 2012, total water storage from the Gravity Recovery and Climate Experiment (Box 1) has increased by 1-3 cm/year in the Midwestern U.S. and decreased by 1-3 cm/year in the southeastern U.S. They attributed the decrease to increased groundwater pumping for irrigation. The magnitudes of these trends, however, are much higher than magnitudes in groundwater storage trends from 1988-2007 derived by Brutsaert (2010) using baseflow recession analysis (Box 2). We hypothesize that the observed trends are related more strongly to soil moisture than to the subsurface.

Box 1: Gravity Recovery And Climate Experiment (GRACE)

Main Concept: Changes in gravity can be mapped from space. These changes are due to changes in total water storage.



Credit: NASA
http://gracetellus.jpl.nasa.gov/

GRACE, a joint project between U.S. and German space agencies (NASA and DLR, respectively) is a constellation of two satellites flying on the same orbit around Earth. Because of variations in the Earth's gravity field, the relative speed of the two satellites varies. By measuring the distance between the two satellites, it is possible to map changes in the Earth's gravity in time and space. These variations in gravity are due to variations in mass. On short time scales, the movement of water is the primary cause of changes the Earth's gravity field. As such, GRACE measures changes in total water storage.

What is total water storage change?

$$\Delta S_{total} = \Delta S_{surface} + \Delta S_{soil} + \Delta S_{groundwater}$$

Total water storage change (ΔS_{total}) over land includes changes in surface water storage ($\Delta S_{surface}$), such as in lakes, reservoirs, wetlands, river floodplains, and snow; changes in soil moisture storage (ΔS_{soil}), and changes in groundwater storage ($\Delta S_{groundwater}$). We use liquid water equivalent (water mass converted to cm liquid water) averaged over 3 versions from GRCTellus RL05.DSTvSCS1401 (available at http://grace.jpl.nasa.gov/data/gracemonthlymassgridsland/).

Box 2: Baseflow Recession Analysis

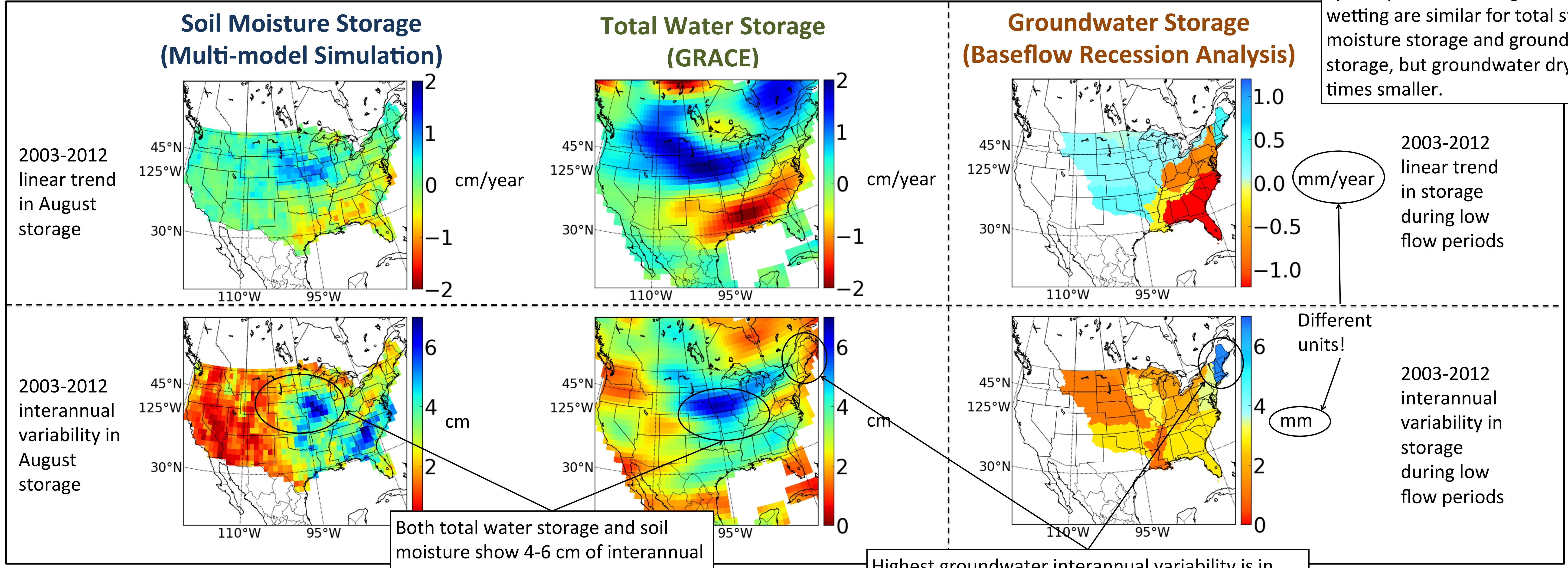
Main Concept: Streamflow during drought or low-flow periods is driven by groundwater stored in upstream aquifers; therefore low flows can be used to assess groundwater storage.

$$\frac{dS_{groundwater}}{dt} = K\frac{dy}{dt}$$

Brutsaert (2008) showed that groundwater storage ($S_{groundwater}$) in riparian aquifers upstream of any point along a river can be estimated as a linear function of low flows (y=flow per unit of catchment area). In the equation to the left, K is the characteristic basin drainage time scale.

Here, we extended estimates of the trend in groundwater storage over time ($dS_{groundwater}/dt$) from Brutsaert (2010) to overlap the period of GRACE observations (2003-2012). In this case, y was calculated using the 7-day low-flow average for each year.

Results



Spatial patterns of long-term drying and wetting are similar for total storage, soil moisture storage and groundwater storage, but groundwater drying is ~10 times smaller.

Both total water storage and soil moisture show 4-6 cm of interannual variability in the midwest and southeast, with less on the west coast.

Highest groundwater interannual variability is in New England, where total water storage variability is low. In general on a year-to-year basis, the total water storage is more variable where groundwater storage is less variable.

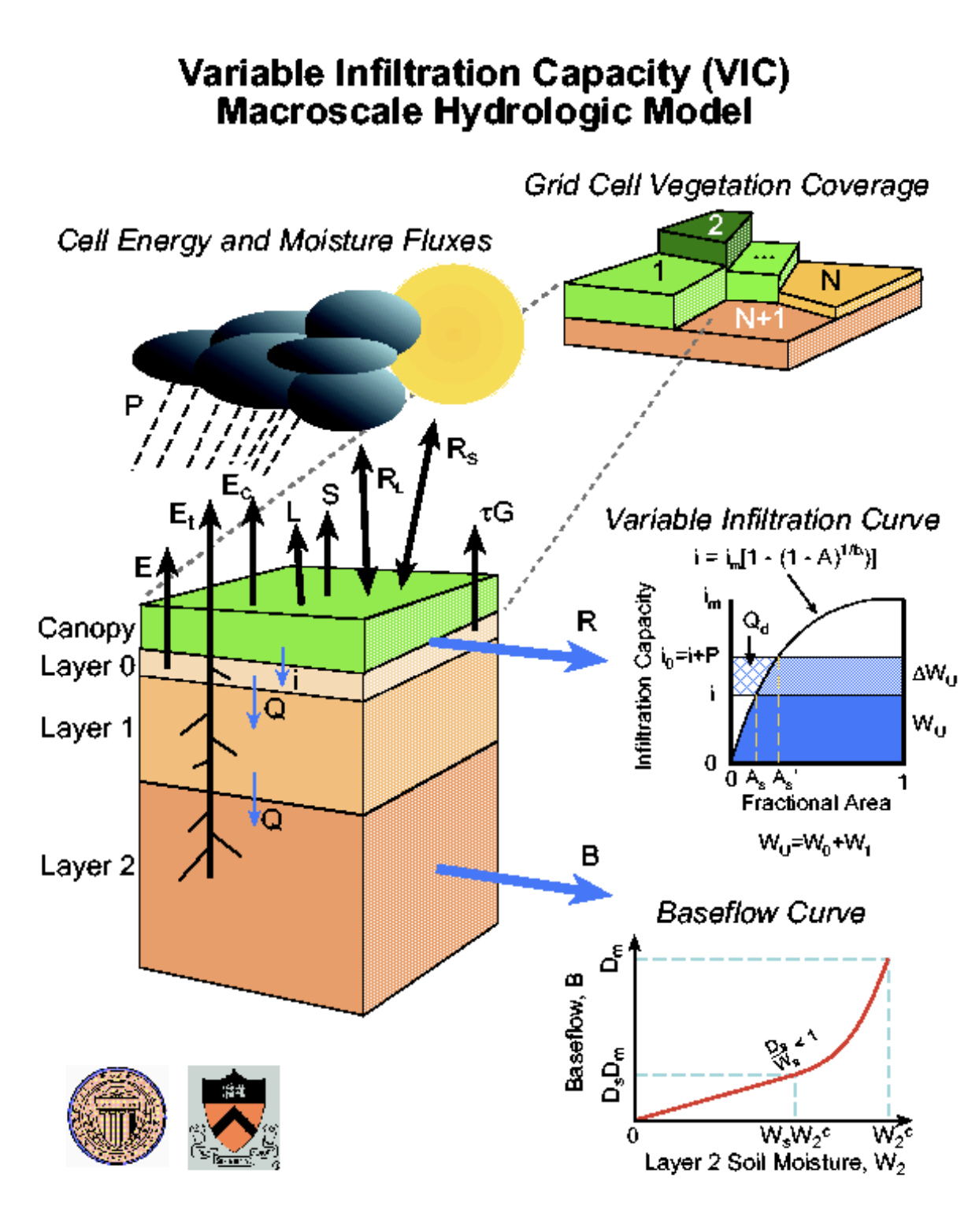
Box 3: Multi-Model Soil Moisture Simulations

Main Concept: Land Surface Models simulate the physical processes of the hydrologic cycle. Because soil moisture is difficult to measure, realistic models are one of the best ways to estimate historical soil moisture over large areas.

As part of the UW Surface Water Monitor (Wang et al., 2009; Wood et al., 2008; http://www.hydro.washington.edu/forecast/monitor/index.shtml), historical soil moisture conditions were simulated using 5 models:

- VIC (Variable Infiltration Capacity) v. 4.0.6
- Noah (National Centers for Environmental Prediction/ Oregon State University/Air Force/Hydrologic Research Lab) v. 2.8
- SAC (Sacramento/Snow-17)
- CLM (Community Land Model) v. 3.5
- CATCHMENT model

These models differ in how they calculate snow, soil, runoff generation, etc. Because each model generally performs better in certain conditions, we use the multi-model average to minimize the uncertainty associated with model error. The schematic for VIC is shown at right as an example.



Credit: http://www.hydro.washington.edu/Lettenmaier/Models/VIC/Overview/ModelOverview.shtml

Conclusions

- Trends in multimodel soil moisture more closely match the total water storage trend observed by GRACE than the trends in groundwater storage derived from baseflow recession, which are orders of magnitude smaller. This suggests that drying in the southeast between 2003-2012 is due more to drying in the near-surface than enhanced pumping.
- Results suggest that soil moisture, rather than groundwater, variability accounts for a large proportion of interannual variability in the GRACE signal.
- On-going work looking at water levels in wells suggests that the groundwater storage trends may be larger for non-riparian aquifers than shown here; however, our results still indicate that soil moisture plays an important role in the long-term drying.

References

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