Progress in understanding subsurface and surface water links using GRACE

J.T. Reager[1], M.J. Tourian[2], Heloisa Macedo[3], Ed Beighley[4], Joseph Lucey[5], N. Sneeuw[2], Jay Famiglietti[1], Cedric David[1]

[1] Jet Propulsion Laboratory, California Institute of Technology; [2]Univ. Stuttgart, [3] McGill University; [4] Northeastern University; [5] California State University, Los Angeles

2017 GRACE Science Team meeting

B.5: Hydrology

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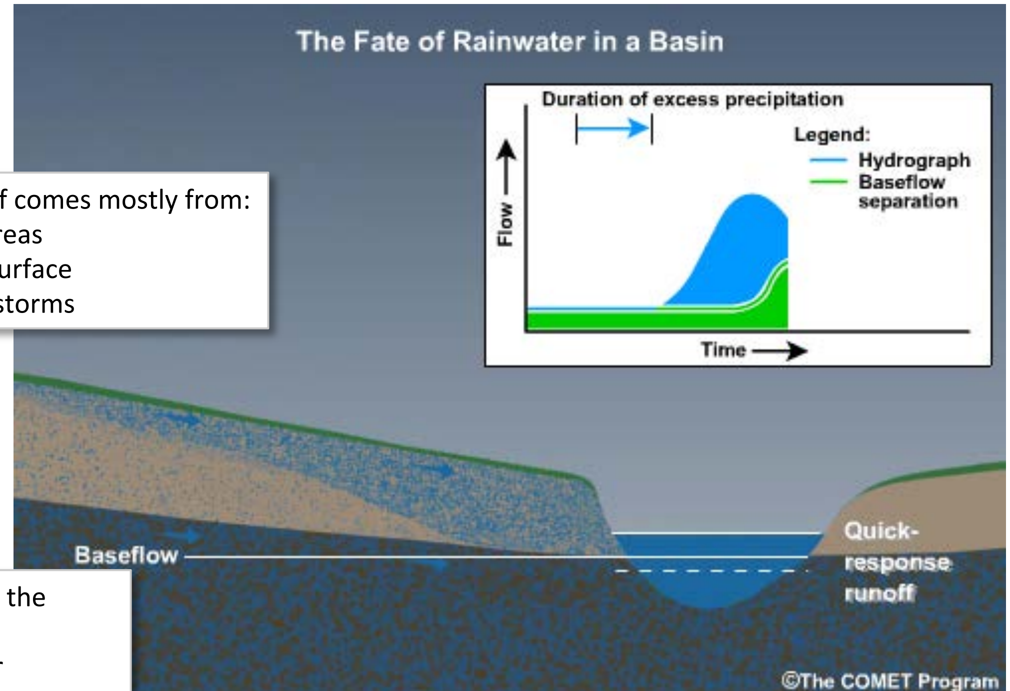
The basic concept: in most river basins, most of the time, runoff is generated by “baseflow”, or storage driven streamflow

- Long legacy of literature: e.g. Brutsaert and Nieber (1977), Kirchner (2009)
- This is a bit counterintuitive: It’s not surface runoff running into rivers, instead it is infiltration into the saturated water table rising to penetrate the river banks
- Because baseflow in rivers follows the regional water table, GRACE should have skill in predicting regional river runoff
- Several studies have explored the storage-discharge relationship: Riegger and Tourian, 2014; Reager et al (2015); Sproles et al. (2015)

Surface runoff comes mostly from:
- Urban areas
- Frozen surface
- Intense storms



Baseflow is the dominant contributor (60-90%)

Hornberger, G.M., J.P. Raffensperger, P.L. Wiberg, and K.N. Eshleman, *Elements of Physical Hydrology*.

Model runoff generation

- Some nice papers have started to look at hydrology in climate models, and why they do poorly
- The representation of accurate soil storage is important in runoff generation and in the representation of groundwater dynamics
- Getting the total drainable storage in the soil column is important to understand storage-runoff links

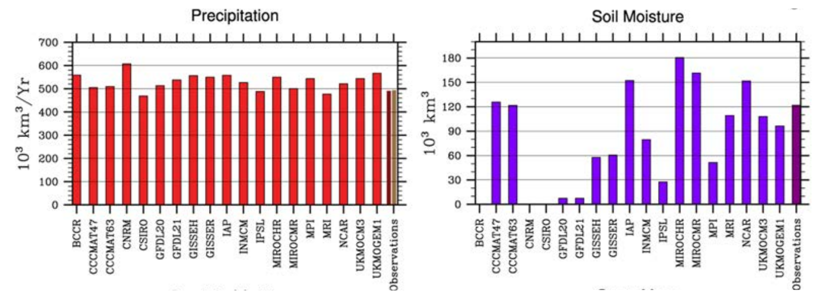
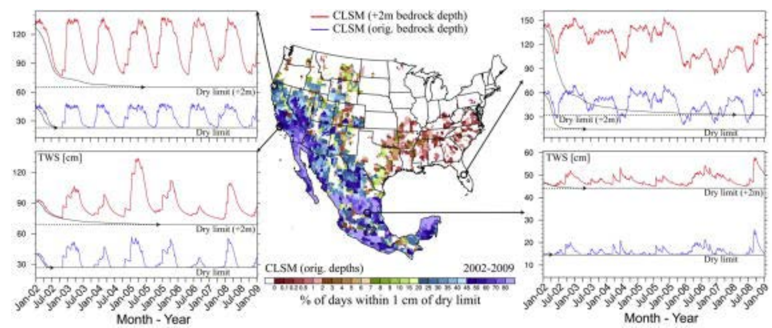
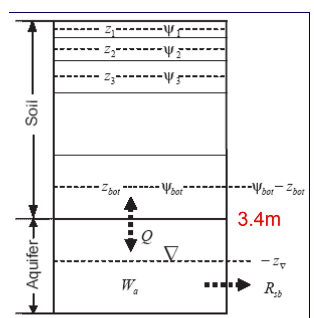


Figure 1: Time mean values of predicted precipitation (*left*) and soil moisture (*right*) from CMIP3 ensemble members in coupled climate simulations.

Waliser et al. (2010)



Houburg et al. (2014)



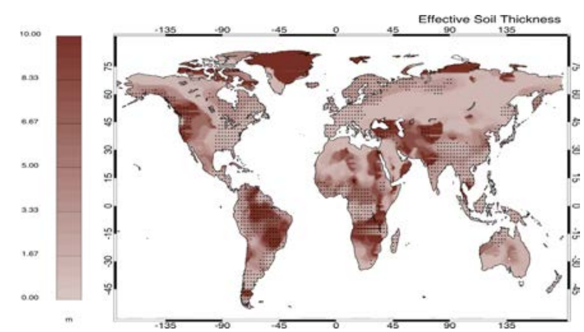
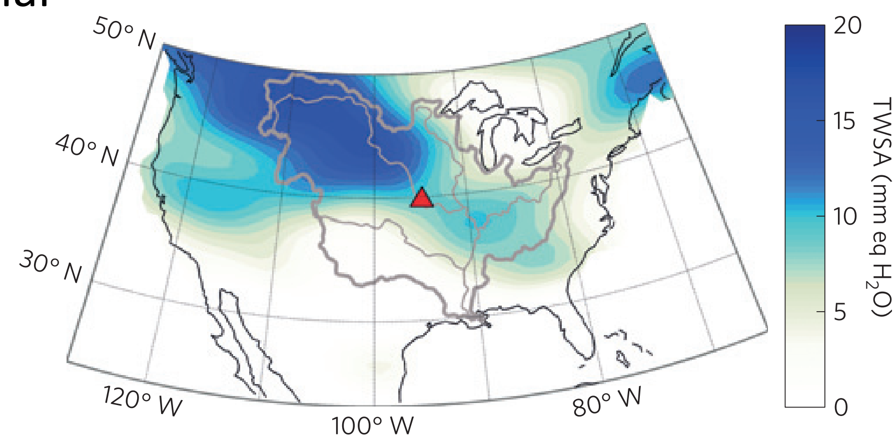


Figure 11. Optimal CLM soil thickness parameter (m). Value at each gridcell is taken from the ZBOT simulation giving the smallest rmsd between GRACE and CLM TWS.

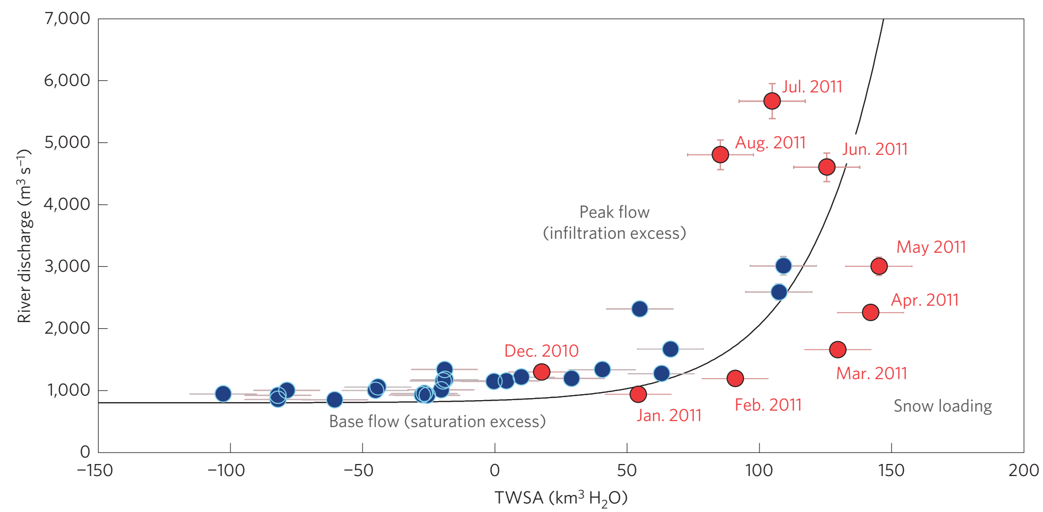
Swenson and Lawrence (2015)

Knowledge of storage-driven streamflow can offer value for prediction of flood potential

- Storage-streamflow curves establish a relationship between river discharge and basin-wide water storage
- These relationships are a bit different everywhere
- Basin-scale estimates of water storage can then be used to characterize regional "flood potential"
- i.e. if the ground is well saturated, how much rain is need to cause a flood?



This shows the map of GRACE water storage and the location of a stream gage on the Mississippi river.



This shows the exponential relationship between water storage and river discharge, during summer only (blue) and winter/summer transition (red)

Using GRACE observations to better understand storage-discharge relationships

1. A coupled analysis of GRACE-based land water storage and streamgage-based river discharge to apply a base flow recession approach for the first time using GRACE observations in the Mississippi River Basin

2. Mapping of the runoff generation process and the contributions of baseflow to streamflow, as well as estimating total water storage in the Amazon and Mississippi River Basins

3. A global assessment of the relationship between GRACE terrestrial water storage anomalies and surface water formation from radiometric remote sensing observations of surface water inundation extent.

→ *Here we cover three recent projects on these concepts*

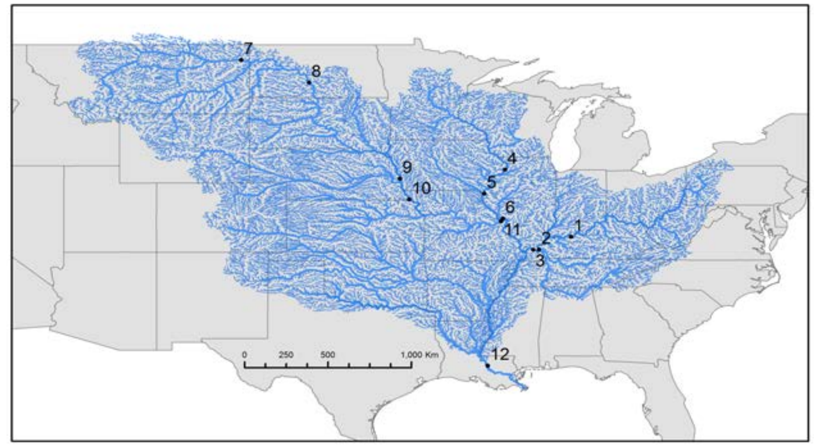
Macedo, E., Beighley, E., C. David and J.T. Reager (*GRL in review*)

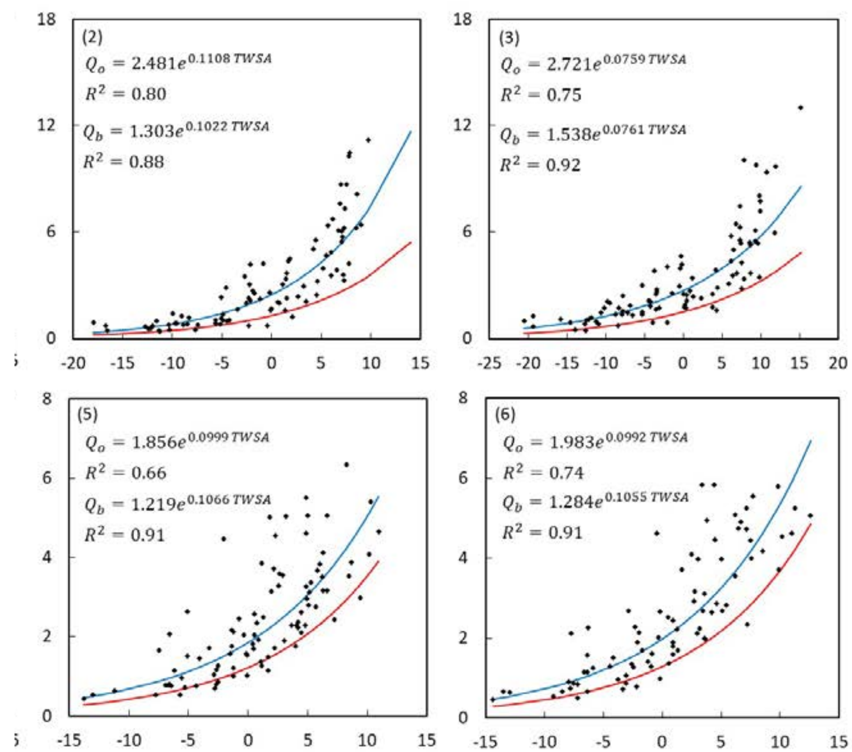
1) Base flow recession approach using GRACE observations in the Mississippi River Basin

Key points

- Developed storage-discharge relationships for 12 watersheds distributed throughout the Mississippi River Basin
- Non-linear regression analysis was used to establish a curve for baseflow
- Assumption that the lowest possible flow matching a given storage represents the baseflow or storage-driven portion of flow
- The mean fraction of baseflow in unfrozen streams was found to vary from 52 to 75%

$$Q_b(S_i) = \min |Q_o(S_i)|, \; i = 1 \text{ to } n$$





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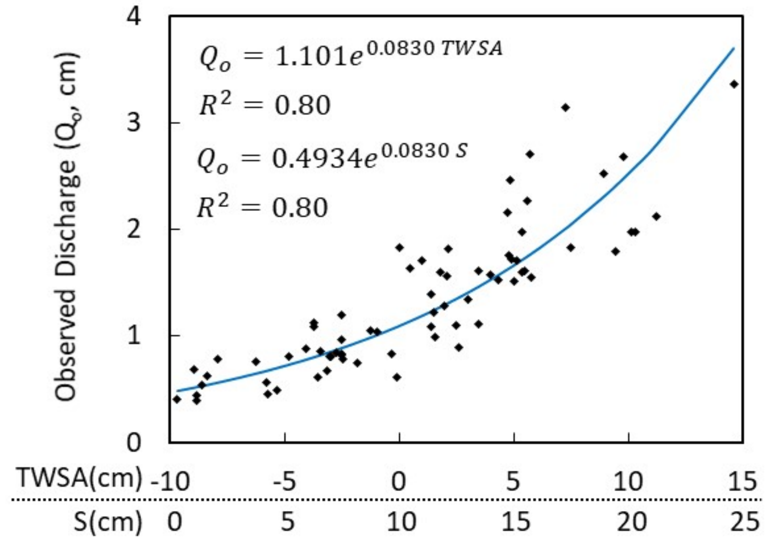
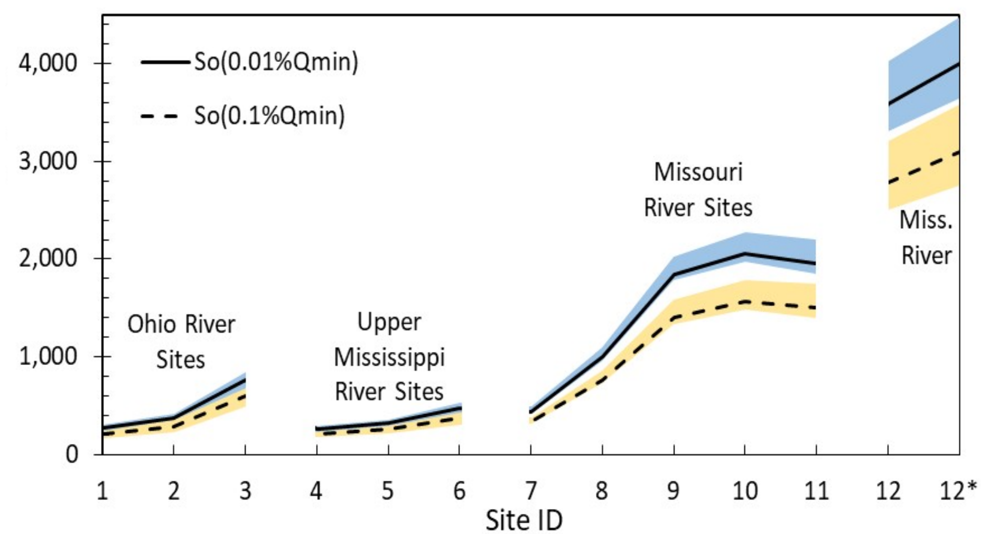
Macedo, E., Beighley, E., C. David and J.T. Reager (*GRL in review*)

1) Base flow recession approach using GRACE observations in the Mississippi River Basin

Key points

- As flow approaches zero, we can estimate the corresponding storage for zero flow
- This gives an indication of the approximate "total drainable storage" of the basin
- Estimates of maximum drainable water storage in the Mississippi River Basin of about **100-120 mm**
- This represents water in mean storage constantly, on average, required to drive runoff
- Eventually these relationships should be captured by models





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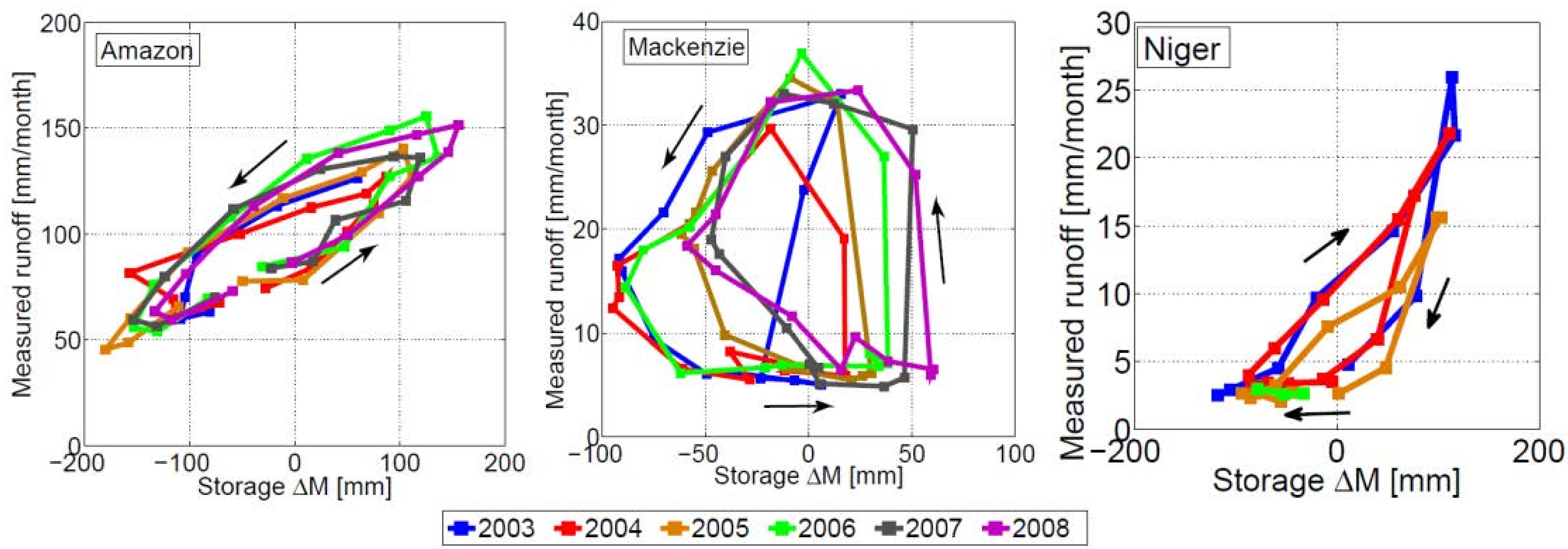
2. Estimating total drainable water storage in the Amazon River Basin



fully humid tropical

boreal

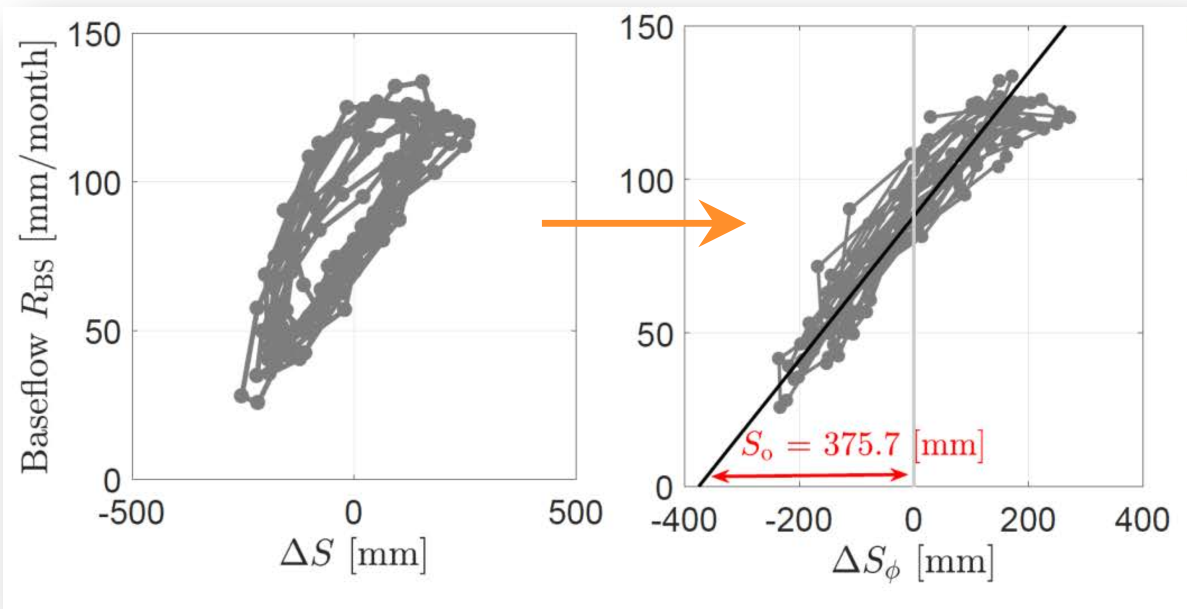
seasonally dry tropical

→ Some of this hysteresis is due to the travel time of water in the river network,

- especially for the Amazon, a huge basin, dominated by surface water and flooding

Riegger J and MJ Tourian (2014),
Characterization of runoff-storage relationships by satellite gravimetry and remote sensing, Water Resour. Res. 50, 3444–3466, doi:10.1002/ 2013WR013847

2. Estimating total drainable water storage in the Amazon River Basin



$\varphi \approx 0.52\ rad \Rightarrow \Delta t \approx 30\ d$

$S_0 = 375.7$ mm

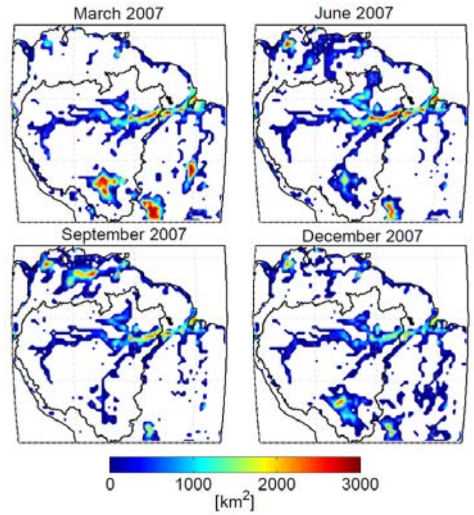
by Hilbert transform

- For this case, assumed all hysteresis due to a time lag for water to flow in the massive river network
- no curvature in the storage-discharge relationship
- This gives a low estimate of total drainable storage

2. Estimating total drainable water storage in the Amazon River Basin

Key points

- Storage-driven flow and total Amazon River flow are partitioned and modelled
- On average, 65% of the total drainable water of the Basin stored as surface water
- Amazon drainable water storage quantified observationally at 1766 km3
- Basin waters demonstrate an average 2-month residence time
- Assumption of linearity in storage-discharge needs further exploration

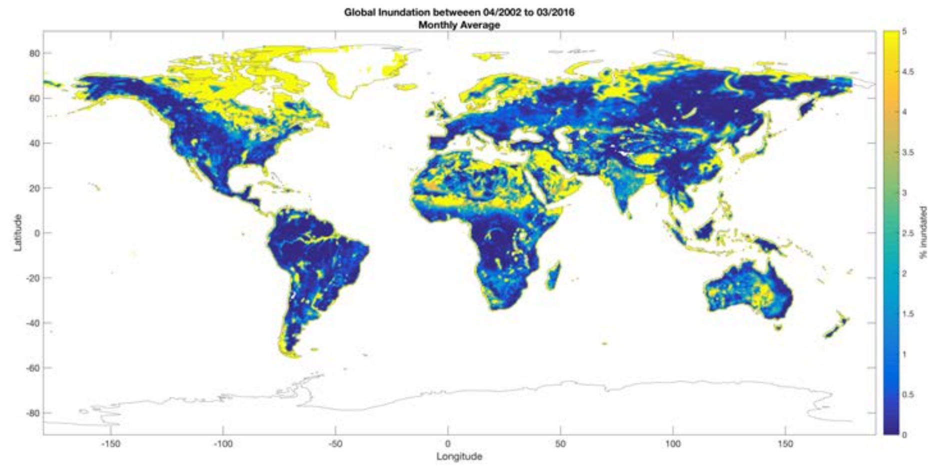


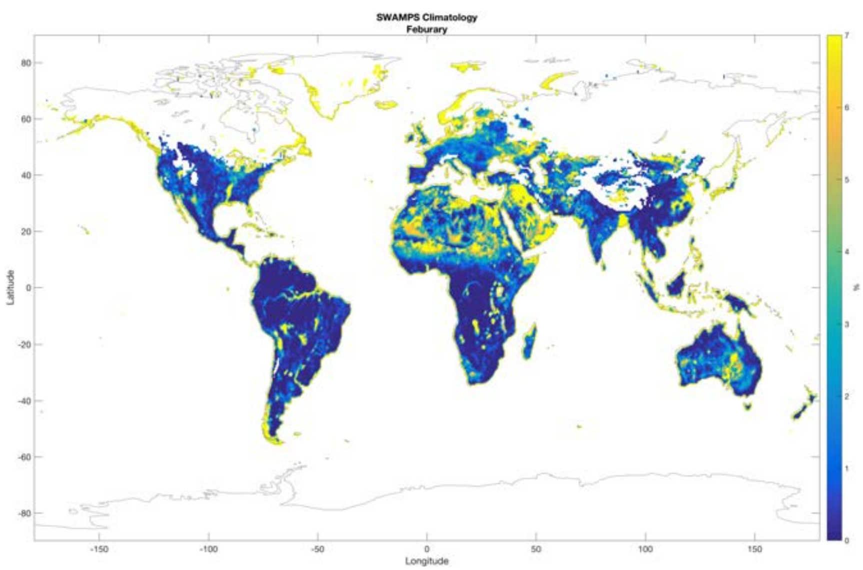
	performance		parameters			storage volume
Basin	corr	NSE	$\Delta\phi$ [day]	τ [month]	S_o [mm]	S_o×Area [km^3]
508	0.85	0.70	10	0.43±0.02	128±1	15±1
507	0.92	0.83	11	1.82±0.04	222±6	272±7
506	0.92	0.84	10	3.02±0.09	223±8	36±1
503	0.81	0.60	−31	1.78±0.08	299±14	83±4
505	0.94	0.85	44	5.10±0.21	349±17	127±7
504	0.84	0.67	−25	2.9±0.10	163±6	28±1
501	0.96	0.92	29	1.16±0.01	929±7	297±3
502	0.96	0.91	18	4.43±0.12	274±7	360±10
500	0.94	0.87	−5	1.55±0.03	883±17	654±12
Weighted average					391±11	$\sum$ 1840 ± 21
Amazon	0.94	0.88	30	4.27±0.11	375±10	1766±47
difference					16	74

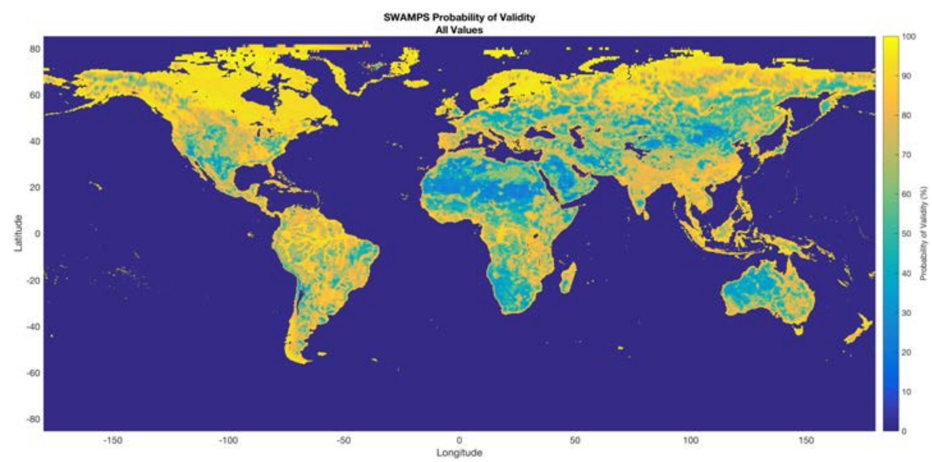
Lucey, Reager and Lopez (in prep)

3. Terrestrial water storage anomalies and surface water formation

- Surface Water Microwave Product Series (SWAMPS)
- % fractional surface inundation
- 0.25° x 0.25°, daily (original spatial/ temporal scale)
- Flood events can be observed through SWAMPS





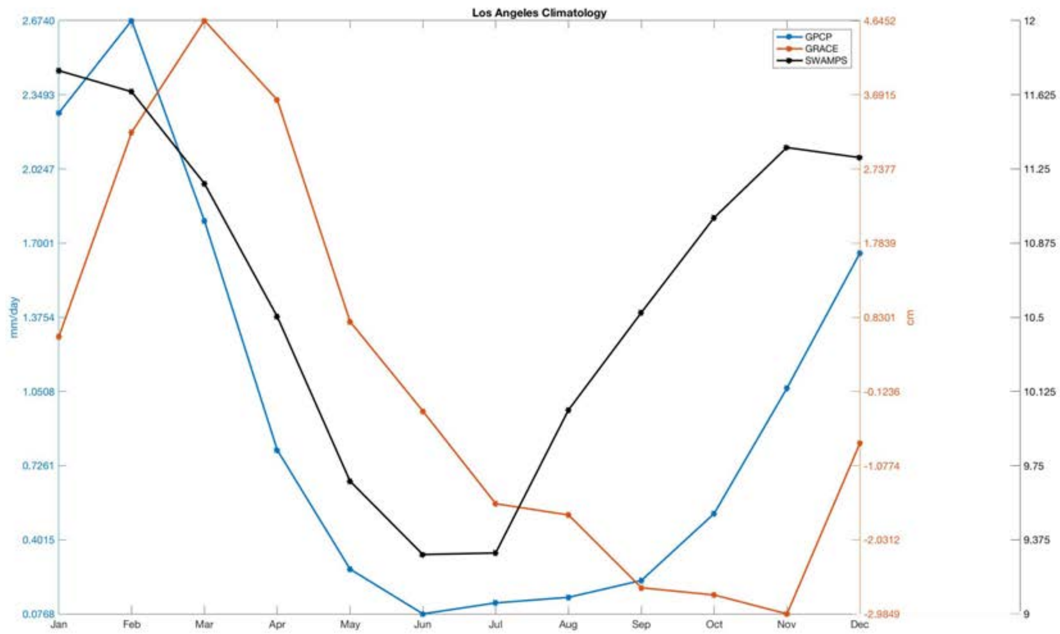


Lucey, Reager and Lopez (in prep)

3. Terrestrial water storage anomalies and surface water formation

Climatology

- Long-term monthly average of observations (i.e. Grab all January values and average)
- Provides general relationship
- Robust regressions

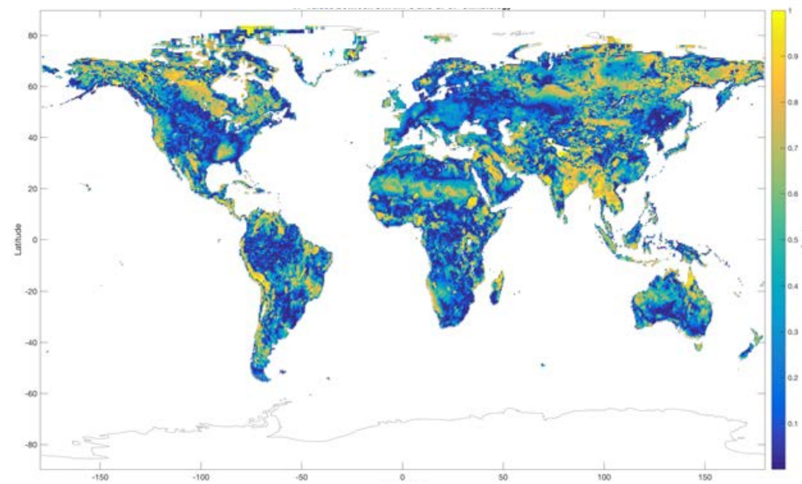


Lucey, Reager and Lopez (in prep)

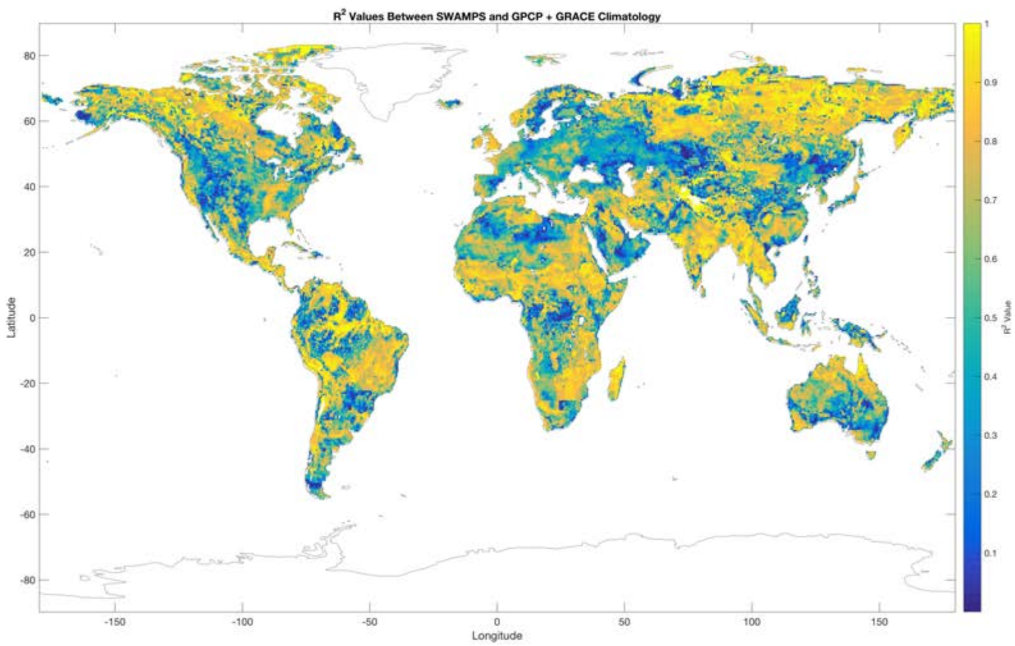
3. Terrestrial water storage anomalies and surface water formation

- How well this linear model explains the response variable
- Significant improvement with multi-linear regression
- Gives a mapping of where storage drives runoff on average, where GRACE is most useful in flood prediction

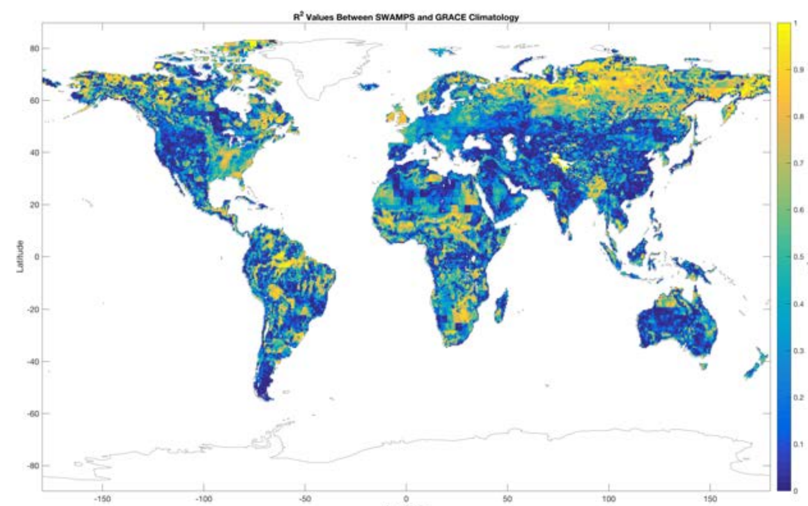
R^2 for SWAMPS and GPCP Climatology



R^2 for SWAMPS and GPCP+Grace Climatology



R^2 for SWAMPS and GRACE Climatology

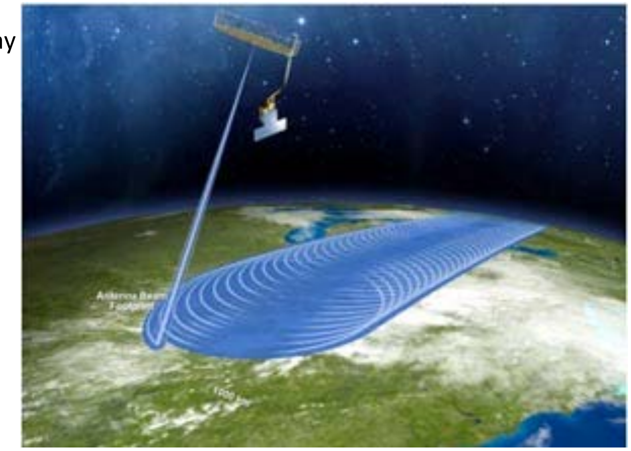


Future: Column soil moisture and runoff generation processes

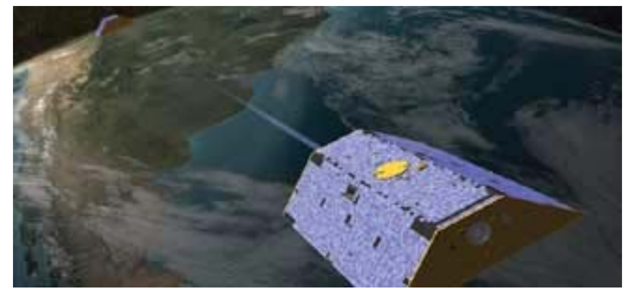
With GRACE-FO and SWOT together:

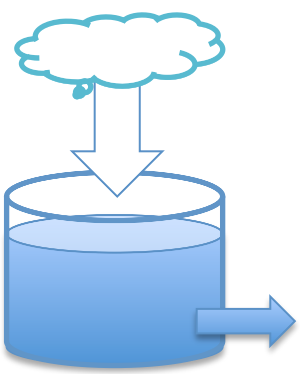
- We can see storage and discharge at more places than gages alone
- Introduces the ability to spatially resolve these relationhips
- Will improve model performance, runoff generation, flood prediction and the terrestrial water balance

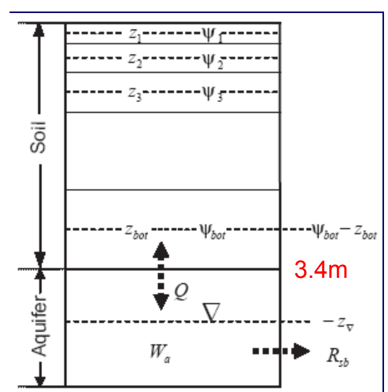
36km, 8-day

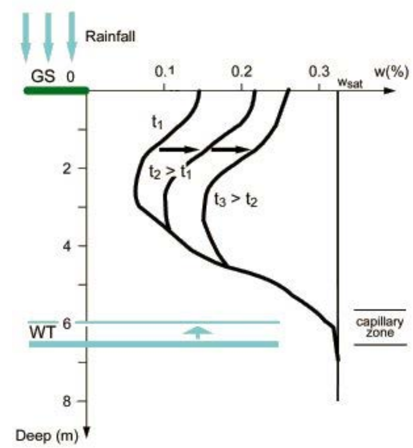


50km (scaled), 30-day









Summary

- Saturation of soils and more groundwater leads to runoff generation called 'baseflow' – GRACE is really the only way to get insight here

- Linking terrestrial water storage to independent river runoff observations may provide a means to better understand runoff generation processes for models

- Continuing work needs to be done in demonstrating the use of GRACE observations in estimating the Total Drainable Water Storage for different regions

- Eventually models can use these relationships as a reference data set to tune runoff generation processes and better predict extremes.

Questions : john.reager@jpl.nasa.gov