# Mapping global water stress from GRACE satellite data

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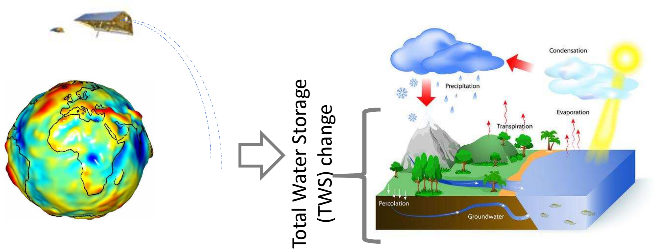
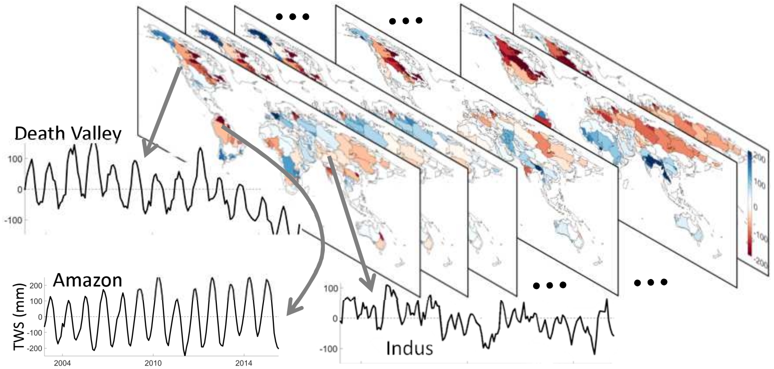
## GRACE satellite mission (2002—2017)




Illustrative fig: Gravity Recovery And Climate Experiment (GRACE) satellite mission provided a unique hydrological measurement: changes in the total water storage near the surface of the Earth.

## GRACE time-series




- Analyse catchments larger than 65,000 km$^2$ to obtain better accuracy[1, 2].
- Process level 02 GRACE fields → TWS change time series for 160 catchments.
- Use STL (Seasonal Trend decomposition using Loess) to decompose time-series into a seasonal and an inter-annual signal[3] (see the fig. below).
- Fit a line to the inter-annual signal to obtain linear trend.

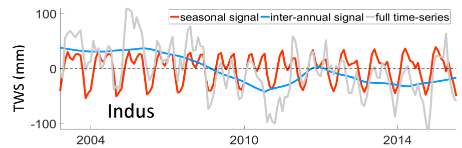



Fig. Decomposition of GRACE time-series using STL.

## Estimating natural variability!

We use inter-annual variability from the GLDAS model because:

1. It is 63 years long (1948—2010): will capture multi-decadal signals.
2. It uses observations to simulate TWS change, (not groundwater). Thus, it captures only natural variability but with subpar accuracy[8].
3. Accuracy can be improved by calibration: scale GLDAS with ratio between annual signal amplitude of GRACE and of GLDAS for the overlap period (2003--2010).

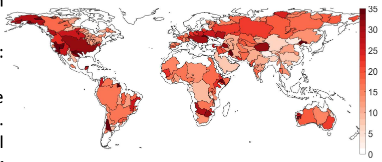
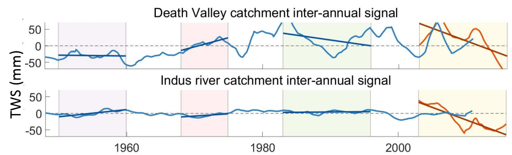


Fig. 1 standard deviation (mm) of inter-annual signal from the calibrated GLDAS model time-series.

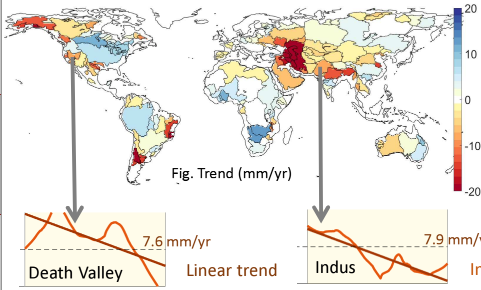
The natural variability varies markedly in space. How to use this information?

## Assessing severity of trends

- The hydrological natural variability can be multi-decadal and each catchment has a distinct natural variability[6, 7].
- GRACE time-series are short → trend will include: human intervention, natural variability, and signatures of anthropogenic climate change[6, 7].
- Inferences on water-storage stress from trend magnitude alone are misleading!
- For example, the Indus and the Death valley river catchments have similar trends, but distinct natural variability. The figure below illustrates that TWS change for the Death Valley is not unprecedented, while for the Indus it is exceptional.




## Interpreting global trend map from GRACE

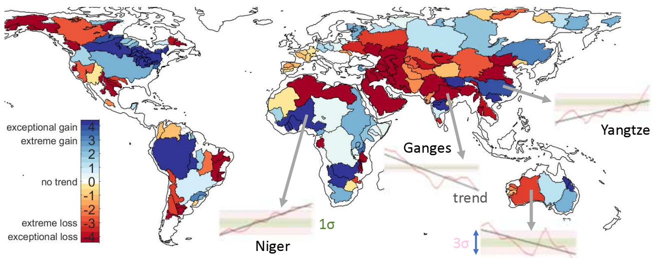



**Usual approach**

Magnitude of trend
↓
Severity of Water-storage stress[4, 5]
↓
Rank regions[4]

The Indus and the Death valley have similar trend. Does that mean they both experienced similar water-storage stress?

## A novel metric: Trend to Variability Ratio (TVR)




$\mathrm{TVR} = \frac{t*n}{\sigma}$, where $t$ is the trend from GRACE, $n$ is the length of GRACE time-series, $\sigma$ is the standard deviation of the natural-variability.

| Catchment name | Area (km$^2$) | TVR | Trend (mm/yr) |
|---|---|---|---|
| Colorado (Argentina) | 385601 | -3.0 | -18.7 |
| Tigris | 156857 | -11.4 | -18.1 |
| Karun | 65362 | -9.3 | -16.6 |
| Brahmaputra | 521828 | -27.5 | -14.2 |
| Sao Francisco | 627014 | -7.1 | -14.0 |
| Brazos | 106914 | -4.0 | -12.7 |
| Ganges | 906200 | -15.5 | -12.3 |
| Yukon | 819634 | -5.5 | -12.2 |
| Indus | 1122836 | -9.7 | -7.9 |
| Death Valley | 554060 | -2.7 | -7.6 |
| Saudi Arabia | 2398132 | -12.2 | -7.1 |
| Yellow River | 902468 | -4.8 | -4.2 |

## Physical interpretation

$$\mathrm{TVR} = \frac{\text{Total water expenditure}}{\text{allowed natural limit}},$$

TVR is a dimensionless quantity

A value in excess of ± 3 means unprecedented TWS change. A stronger negative TVR implies more severe water storage stress

Table: Comparing trend and TVR for some catchments. It shows us that the catchments with similar trends might be facing different level of water-storage trends.

## Conclusions

- Trends from short time-series, such as that from GRACE, are contaminated with natural variability.
- Comparing trends of different catchment is not justified because each catchment has its unique natural variability.
- We assess natural variability from a carefully calibrated hydrology model.
- We develop a novel metric, TVR, that provides a normalized measure of severity of water storage change by accounting for the historical natural variability.

### References

(1) Save, H., Bettadpur, S., and Tapley, B. D. ( 2016), High resolution CSR GRACE RL05 mascons, *J. Geophys. Res. Solid Earth*, 121, 7547–7569, doi:10.1002/2016JB013007. (2) Vishwakarma, B. D., Devaraju B. & Sneeuw N. (2018), What Is the Spatial Resolution of GRACE Satellite Products for Hydrology? *Remote Sensing* **10**, doi:10.3390/rs10060852. (3) Cleveland, R., Cleveland W., McRae J. & Terpenning I. (1990) STL: A Seasonal-Trend Decomposition Procedure Based on Loess (with Discussion). *Journal of Official Statistics* **6**, 3–73. (4) Famiglietti, J. S. (2014) The global groundwater crisis. *Nature Climate Change* **4**, 945–948, doi:10.1038/nclimate2425. (5) Rodell, M., Famiglietti J. S., Wiese D. N., Reager J. T., Beaudoing H. K., Landerer F. W. & Lo M.-H. (2018) Emerging trends in global freshwater availability. *Nature* **557**, 651 – 659, doi:10.1038/s41586-018-0123-1. (6) Eicker, A., Forootan E., Springer A., Longuevergne L. & Kusche J. (2016), Does GRACE see the terrestrial water cycle "intensifying"? *Journal of Geophysical Research-Atmospheres* **121**, 733-745, doi:10.1002/2015jd023808. (7) Latif, M. & Keenlyside N. S. (2011), A perspective on decadal climate variability and predictability. *Deep-Sea Research Part Ii-Topical Studies in Oceanography* **58**, 1880-1894, doi:10.1016/j.dsr2.2010.10.066. (8) Scanlon, B.R.; Zhang, Z.; Save, H.; Sun, A.Y.; Müller Schmied, H.; van Beek, L.P.H.; Wiese, D.N.; Wada, Y.; Long, D.; Reedy, R.C., (2018), Global models underestimate large decadal declining and rising water storage trends relative to GRACE satellite data. Proc. Natl. Acad. Sci. USA.

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Data availability: The GRACE spherical harmonic coefficients were downloaded from ftp://ftp.tugraz.at/outgoing/ITSG/GRACE/ITSG-Grace2016/monthly/monthly_n90. We have made use of $C_{20}$ and degree 1 spherical harmonic coefficients available at grace.jpl.nasa.gov, and catchment boundaries available at http://www.bafg.de/GRDC/EN/02srvcs/22gslrs/221MRB/riverbasinsnode.html. The GIA ICE-6GD model data was downloaded from http://www.atmosp.physics.utoronto.ca/~peltier/data.php. The hydrological model GLDAS Noah version 2 was downloaded from ldas.gsfc.nasa.gov/gldas/, which used the *Goddard Earth Sciences Data and Information Services Center*.