Large-scale Vegetation Response and Feedback to Terrestrial Water Storage and Climate Variations

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GRACE terrestrial water storage (TWS) explains NDVI interannual variability better than precipitation

Precipitation is commonly used for investigating terrestrial ecosystem response to climate variability. Here, we show that GRACE TWS performs better than precipitation in explaining NDVI interannual variability (Figure 1) (Yang et al 2014).

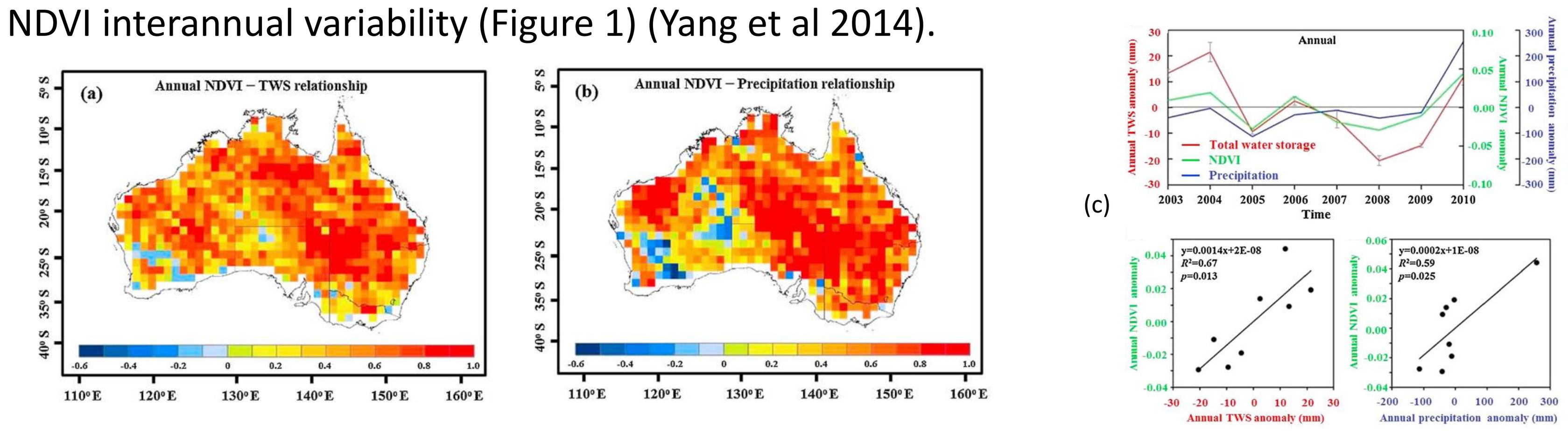


Figure 1 Person correlation coefficients for (a) NDVI-TWS, (b) NDVI-precipitation, and (c) the plots of continental integrated NDVI, TWS, and precipitation and their relations.

A continental scale TWS seesaw reported in Australia seems to be resulted from vegetation-soil moisture-climate interactions

A recent EOF analysis of GRACE and reconstructed TWS data reveals a continental scale TWS seesaw in Australia (Figure 2) (Chen et al. 2021). The TWS seesaw phenomenon is characterised by eastern Australia gaining water, while western Australia is losing water, and vice versa. Strong La Niña induced continent-wide wetting, resets this pattern, leaving each seesaw to last for 11± 5 years. It is found that the seesaw phenomenon disappears if the interval between two consecutive wetting episodes is too short or too long.

A concept of woody vegetation – soil moisture interactions in response to large interannual precipitation variability, seems to explain the TWS seesaws (Figure 3). During a dry interval when precipitation is lower than normal, vegetation cover deviates from its normal condition, becoming very poor and of high flammability, at the end when the wetting episode comes. After this wetting episode, the starting poor vegetation cover is more likely to gain moisture in subsequent years, i.e., a TWS-gaining seesaw phase, which supports vegetation recovery. At the end of this TWS-gaining phase when the next wetting episode comes, the better-than-normal vegetation helps the landscape to replenish its moisture storage. Here is where the problem roots. This sudden moisture supply makes the healthy vegetation cover grows even thicker in a very short period. This, now much-thicker-than normal, vegetation continuously depletes the moisture storage and degrades the vegetation cover in the subsequent years. This turns a previous TWS-gaining phase to now a losing phase.

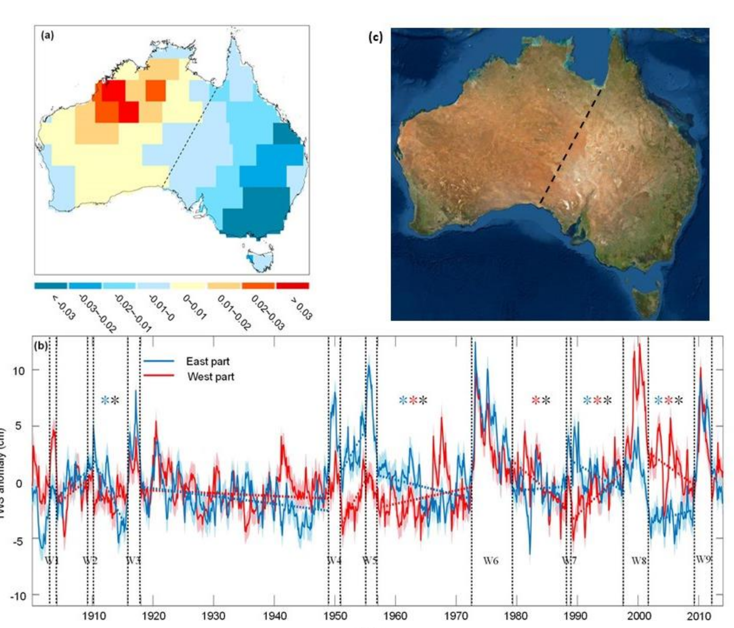


Figure 2 (a) Spatial coefficients of the second Empirical Orthogonal Function (EOF) mode of TWS variation in Australia indicating an east-west opposite pattern. (b) Regional average TWS anomaly of eastern and western Australia during 1901-2014. Blue (red) asterisk (*) indicates the trend of eastern (western) Australia is significant (α=0.05), and the black asterisk indicates the changes of regional average TWS anomaly between eastern and western Australia are significantly different. Four consecutive seesaw wetting and drying phases between the two parts are observed in the past five decades. (c) ArcGIS base image of the Australian continent.

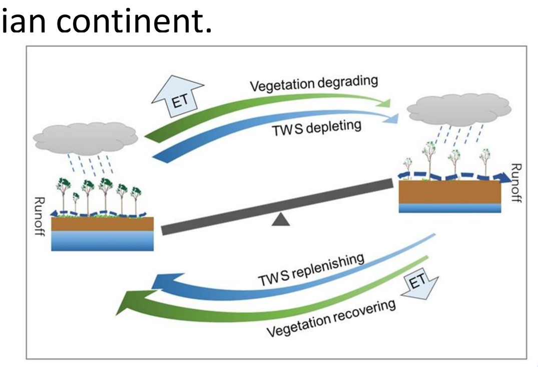


Figure 3 A schematic showing a possible mechanism of vegetation – soil moisture – climate interactions, explaining the observed TWS seesaws.

Which vegetation types are more likely involved in this feedback mechanism?

A non-linear Granger causality analysis was undertaken to investigate interactions between NDVI and TWS over Australia (Chen et al. 2022a). Bidirectional Granger causality relationship between TWS and NDVI is observed over half (58.4%) of the study area (Figure 4). The highest proportion of TWS-NDVI interactions is observed in grasslands, followed by shrublands, agricultural lands and savannas, and the lowest in forests.

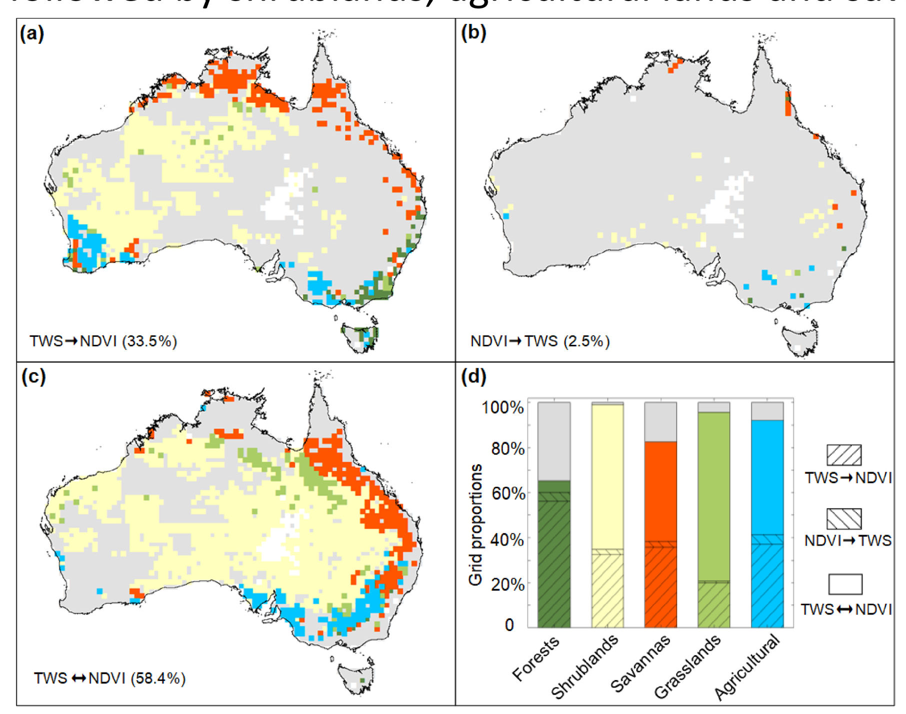


Figure 4 Unidirectional and bidirectional Granger causality relationships between TWS and NDVI during 1985–2015 revealed by the non-linear Granger causality test: (a) TWS unidirectional effects on NDVI; (b) NDVI unidirectional effects on TWS; (c) TWS-NDVI interactions, (d) the corresponding grid proportions for different vegetation types.

Where in Australia is vegetation more likely dependent on TWS?

The non-linear Granger causality analysis confirms that water is the dominant limiting factor for vegetation growth in Australia. NDVI in 62% of grid cells is dominantly driven by TWS (1985-2015) (Chen et al. 2022a).

The result also shows that the areal percentage in which temperature is the dominant driver for vegetation increased from 7.3% for 1985-1999 to 19.9% for 2000-2015 (Figure 5), suggesting climate warming in Australia has limited vegetation growth. This notion is supported by that the negative correlations between temperature and NDVI in the northern and eastern parts of Australia appear to be stronger in the period of 2000–2015 than that in 1985–1999.

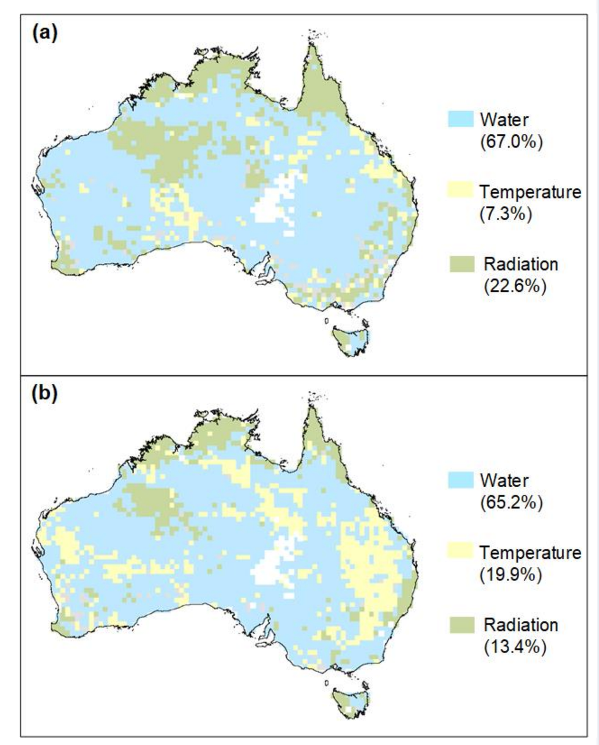


Figure 5 Spatial pattern of the largest non-linear Granger causality among three important climate drivers (water (TWS), temperature, radiation) for vegetation conditions during (a) 1985–1999 and (b) 2000–2015.

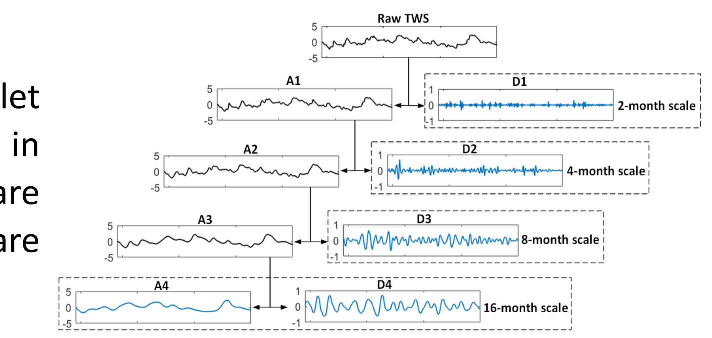
Relevant publications

- Chen, A., Guan, H., Batelaan, O. (2022a). Non-linear interactions between vegetation and terrestrial water storage in Australia. Journal of Hydrology, 613. DOI: 10.1016/j.jhydrol.2022.128336.
- Chen, A., Guan, H. and Batelaan, O. (2022b). Spatially differentiated effects of local moisture deficit and increased global temperature on hot extreme occurrences. Journal of Hydrology. https://doi.org/10.1016/j.jhydrol.2022.128720.
- Chen, A., Guan, H., Batelaan O. (2021) Seesaw terrestrial wetting and drying between eastern and western Australia. Earth's Future. DOI: 10.1029/2020EF001893
- Chen, A., Guan, H., Batelaan, O., Zhang, X. & He, X. (2019). Global soil moisture-air temperature coupling based on GRACE-derived terrestrial water storage, Journal of Geophysical Research: Atmospheres, 124, 14, p. 7786-7796.
- Long, X., Guan, H., Sinclair, R., Batelaan, O., Facelli, J.M., Andrew, R., et al. (2019). Response of vegetation cover to climate variability in protected and grazed arid rangelands of South Australia. Journal of Arid Environments, 161 pp. 64-71.
- Andrew, R., Guan, H. and Batelaan, O. (2017a). Estimation of GRACE water storage components by temporal decomposition. Journal of Hydrology, 552 pp. 341-350.
- Andrew, R., Guan, H. and Batelaan, O. (2017b). Large-scale vegetation responses to terrestrial moisture storage changes. Hydrology and Earth System Sciences, 21 pp. 4469-4478
- Yang, Y., Long, D., Guan, H., Scanlon, B., Simmons, C., Jiang, L., et al. (2014). GRACE satellite observed hydrological controls on interannual and seasonal variability in surface greenness over Mainland Australia. Journal of Geophysical Research: Biogeosciences, 119(12) pp. 2245-2260.
- Wang, H., Guan, H., Gutierrez-Jurado, H. and Simmons, C. (2014). Examination of water budget using satellite products over Australia. Journal of Hydrology, 511 pp. 546-554.

Wavelet decomposed TWS can improve its usefulness for investigating land-atmosphere interactions

Terrestrial water storage lumps water in surface water bodies, biomass and root zone, deep vadose zone, and aquifers. For vegetation, only those that can be assessed by roots matter. Given that different components of TWS have different dynamic patterns, it is possible to separate them (Figures 6 &7) Andrew et al. 2017a). Applications of decomposed TWS time series are demonstrated in Figure 8 for vegetation (Andrew et al. 2017b), and in Figure 9 for hot extreme occurrence (Chen et al. 2022b).

Figure 6 The structure of a discrete wavelet decomposition (an example from a grid cell in Australia (30.5 S, 130.5 E)). A1, A2, A3, A4 are approximate components, and D1, D2, D3, D4 are detail components. Raw TWS=D1+D2+ D3+D4+A4.



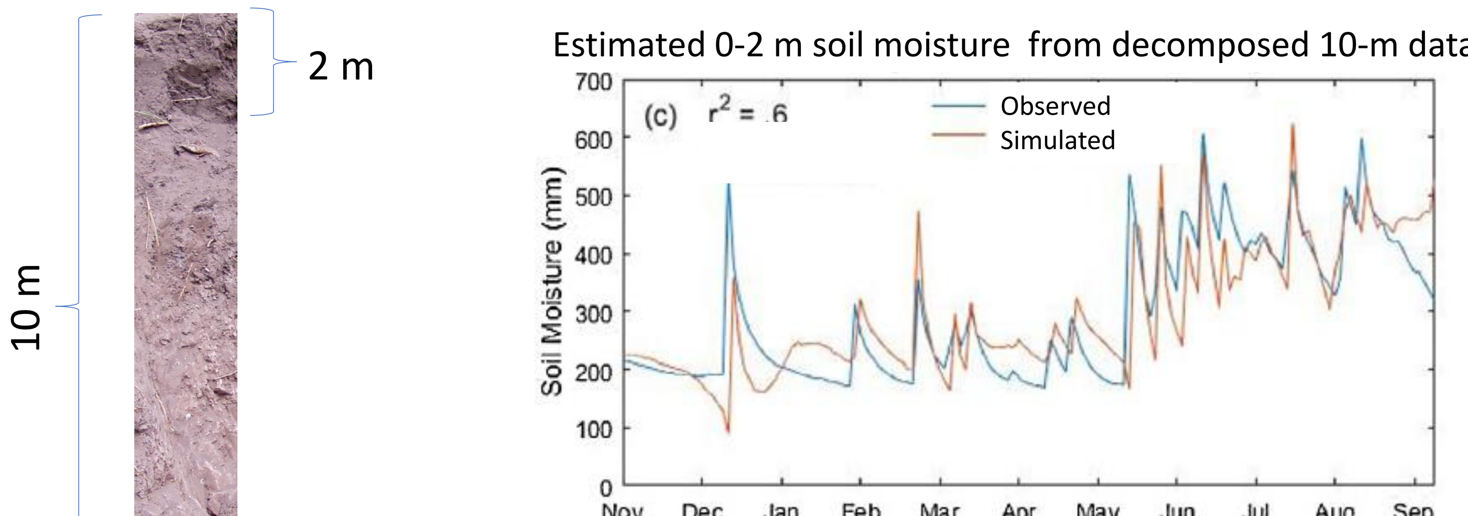


Figure 7 Multiple linear regression estimated top 2-m soil water storage based on wavelet decomposed 10-m soil water storage time series.

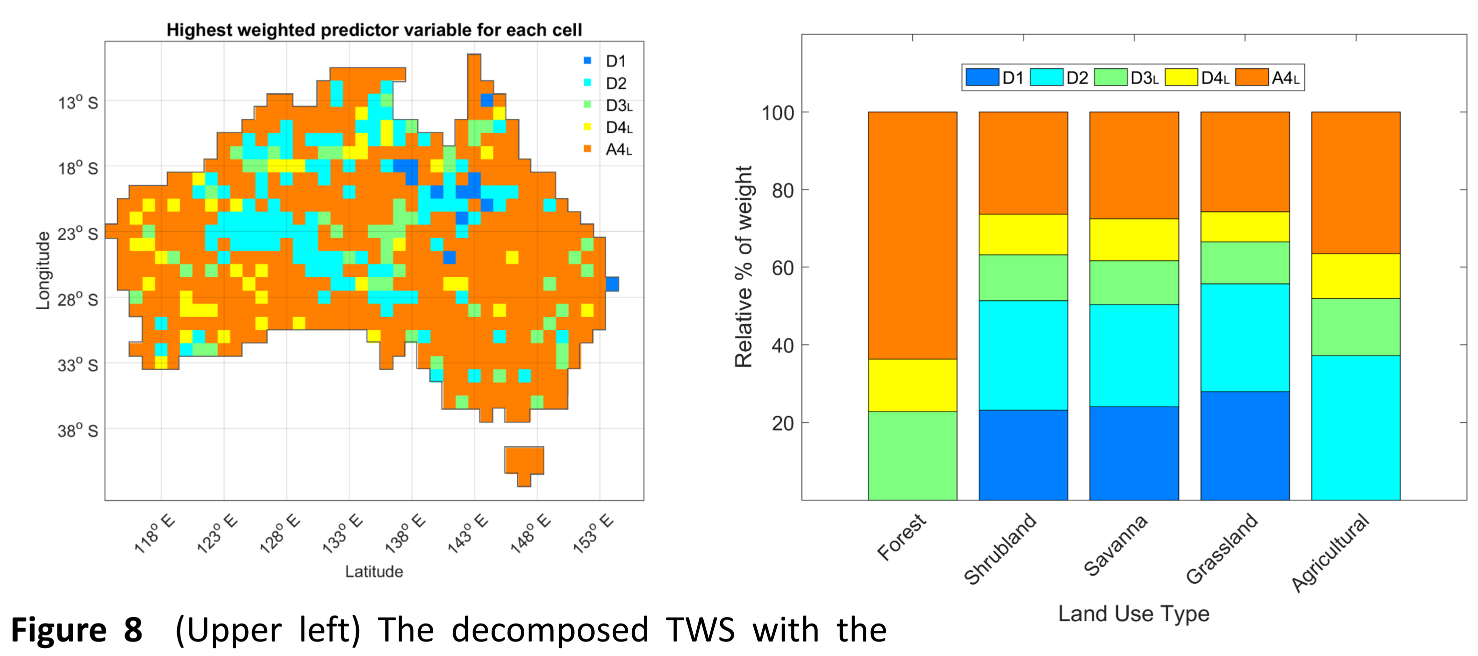


Figure 8 (Upper left) The decomposed TWS with the highest relative weight in the regression for each cell across Australia. A4 is more dominant, however D2 is prominent in distinct areas throughout central Australia. (Upper right) The relative weight of each decomposed TWS* for each land use type, showing that forests are A4L dominated, while shrublands, savannas and grasslands are very similar with relative equal weights of D1, D2 and A4L (Andrew et al. 2017b).

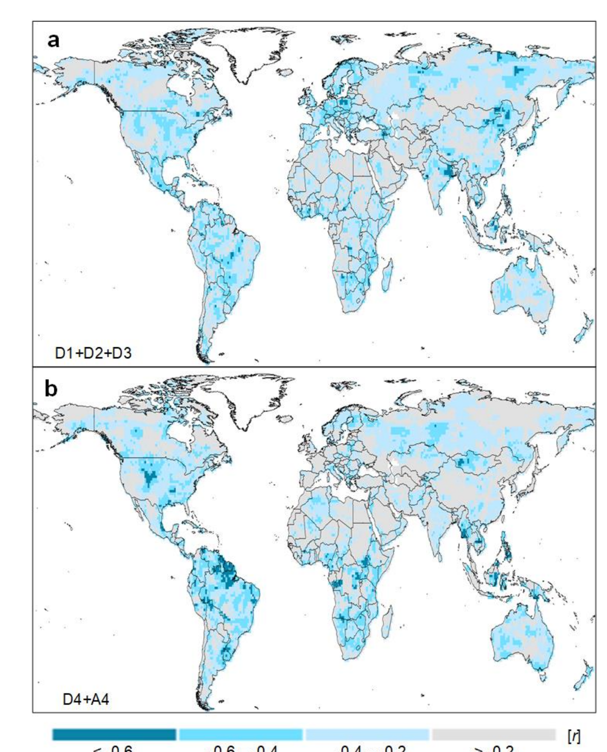


Figure 9 Correlation between number of hot days in the hottest months and TWS wavelet decomposition levels (1985–2015) (a) dominant in shallow soil moisture (D1, D2 and D3, only the maximum r value is shown), and (b) those dominant in deep soil moisture (D4 and A4, only the maximum r value is shown) (Chen et al. 2022b).

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