Links between GRACE water storage and NAO-EA-SCAND climate patterns in Iberia

Maria C. Neves[1,2*], Rui G. M. Neves[3,4]
[1] Universidade do Algarve, FCT, Campus de Gambelas, 8005-139, Faro, Portugal
[2] Instituto Dom Luiz (IDL), Universidade de Lisboa, 1749-016, Lisboa, Portugal
[3]Universidade Autónoma de Lisboa, DCEE, 1150-293, Lisboa, Portugal
[4]CICEE - Centro de Ciências Económicas e Empresariais, 1150-293, Lisboa, Portugal
* e-mail: mcneves@ualg.pt

Introduction

Groundwater drought develops as a smoothed and delayed response to persistent or frequent deficits in rainfall, or as result of a continued negative balance between recharge and extraction. Although not as accurate as in-situ observations, remote sensing has the advantage of providing near real-time and spatially continuous data. GRACE satellite data has been used to show evidence of groundwater depletion in aquifers all over the world (Rodel et al. 2018), and NASA currently generates weakly groundwater and soil moisture drought indicators based on GRACE-FO as part of the United States drought monitoring program. In Europe the Copernicus Global Drought Observatory also uses GRACE total water storage (TWS) anomalies as a proxy of groundwater drought. The use of GRACE satellite data for water resources management, particularly for groundwater systems in the Iberia Peninsula, looks promising (Neves et al. 2020), but its suitability to monitor drought requires further research.

On the other hand, large scale atmospheric circulation patterns also known as teleconnections control the interannual to interdecadal natural variability of the climate system. In the Iberian Peninsula, the North Atlantic oscillation (NAO), the East Atlantic (EA) and the Scandinavian (SCAND) patterns are the three main modes of variability driving winter precipitation, river flow and therefore surface and subsurface water storage. These patterns or modes of variability are characterized by indices which measure the strength of atmospheric pressure anomalies. Positive and negative phases of the indices, defined by values above or below given thresholds (e.g. NAO+ is defined for aggregates of winter month indices above 0.5), are generally associated with either wet or dry conditions. Previous studies have shown that wintertime NAO+ and EA- phases potentiate droughts in Iberia, the opposite occurring for NAO- and EA+ phases. However, few studies have recognized the importance of interactions amongst climate patterns and only recently did we become aware that their combinations or superpositions, as well as the temporal shifts in their synchronization, may lead to major anomalies in groundwater storage (Neves et al. 2019).

The purpose of the present study is to address the question: Do combined NAO-EA-SCAND phases also produce noticeable extremes in GRACE TWS observations? This question is relevant for two main reasons. First, GRACE offers a unique opportunity of fast and reliable large-scale monitorization of groundwater and can be used as an early warning system for groundwater drought or aquifer depletion. Second, the NAO-EA-SCAND indices provide a potential source of seasonal forecast since their wintertime value determines the availability of water in the following summer. Teleconnections may also be a source of long-term forecasting as they exert periodic controls on groundwater level and are linked to recurrent droughts.

Materials and methods

Monthly data from GRACE and GRACE-FO missions and ancillary datasets of precipitation, runoff and soil moisture were obtained from publicly available models and datasets (E-OBS, GLEAM, GRUN and ERA5) as referenced in Neves et al. (2020). The GRACE TWS anomalies in Iberia were downscaled using a multivariate regression model as proposed by Vishwakarma et al. (2021). The Standardized Groundwater Index (SGI) (Bloomfield and Marchant 2013) was then computed from GRACE TWS anomaly. The NAO, EA and SCAND climate indices were retrieved from the NOAA Climate Prediction Center. The links between TWS anomalies and the coupled phases of the climate indices has been evaluated using wavelet transform methods and singular spectral analysis as explained in Neves et al. (2019).

Results and concluding remarks

The analysis of GRACE TWS time-series was performed over the five larger rivers basins in Iberia (Douro, Tagus, Guadiana, Guadalquivir and Ebro). The results showed distinct seasonal and annual water storage characteristics over these river basins. Overall, TWS showed a downward trend between 2003 and 2022 over all regions. The temporal evolution of SGI also exhibited specific characteristics over each river basin, but an overall common feature is that droughts became more frequent in recent years. Good correlations between time-series of TWS anomalies and climate indices confirms the influence of teleconnections in each of the river basins.

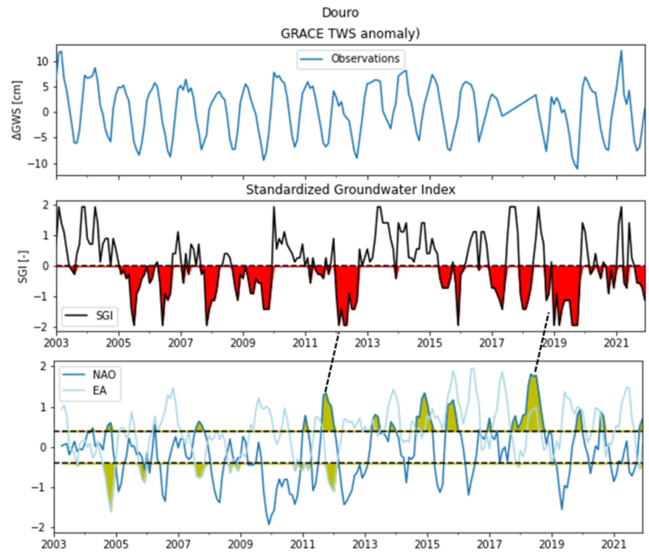

Figure 1. Example of the relationships between GRACE TWS anomaly in the Douro basin, episodes of groundwater drought denoted by negative values of SGI and the positive and negative phases of NAO and EA. Major droughts occurred for combined NAO+EA- phases in 2012 and 2018.

Specific phase combinations enhance the possibility of extreme hydrologic events particularly droughts (NAO+ EA–) as shown in Figure 1 for the Douro Basin. In response to the initial research question posed in the introduction, extremes in GRACE TWS can indeed be linked with combined phases of climate patterns. Although extremely challenging the prospective forecasting of climate pattens, months or even one year ahead, can be used to improve the design and implementation of management measures such as adaptive planning and flexible water allocation to reduce the impact of future droughts.

Acknowledgments: The authors would like to acknowledge the financial support of Fundação para a Ciência e a Tecnologia (FCT), I.P./MCTES, through national funds (PIDDAC) –UIDB/50019/2020

References

Bloomfield JP, Marchant BP (2013) Analysis of groundwater drought building on the standardised precipitation index approach. Hydrol. Earth Syst. Sci. 17: 4769–4787. https://doi.org/10.5194/hess-17-4769-2013

Neves, MC, Jerez S, Trigo R (2019) The response of piezometric levels in Portugal to NAO, EA, and SCAND climate patterns. J. Hydrol. 568: 1105–1117. https://doi. org/10.1016/j.jhydrol.2018.11.054

Neves, MC, Nunes LM, Monteiro JP (2020) Evaluation of GRACE data for water resource management in Iberia: a case study of groundwater storage monitoring in the Algarve region. J. Hydrol. Reg. Stud. 32: 107734. https://doi.org/10.1016/j. ejrh.2020.100734

Rodell, M, Famiglietti JS, Wiese DN, Reager JT, Beaudoing HK, Landerer FW, Lo MH (2018) Emerging trends in global freshwater availability. Nature 557: 651–659. https://doi.org/10.1038/s41586-018-0123-1

Vishwakarma, BD, Zhang J, Sneeuw N (2021) Downscaling GRACE Total Water Storage Change using Partial Least Squares Regression. Sci Data 8: 95. https://doi.org/10.1038/s41597-021-00862-6