Hydrol. Earth Syst. Sci. Discuss.,
doi:10.5194/hess-2016-258-AC1, 2016

Hydrology and Earth System Sciences Discussions

Interactive comment on "Reservoir storage and hydrologic responses to droughts in the Paraná River Basin, Southeast Brazil" *by* D. C. D. Melo et al.

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Received and published: 16 September 2016

General comments

On behalf of the co-authors, I would like to thank Dr. Fernando Fan for the positive feedback and valuable comments. Each comment was addressed and specific responses can be found in the following section. The original referee comments are in bold, followed by our response.

Specific comments

Page 2, lines 5-10: This paragraph is not clear. Why authors just give the name of GRACE satellite and do not talk about the others satellites whose measure

precipitation, evapotranspiration and etc..? And after authors are talking about TRMM without presenting it before. I suggest to improve it.

Response: We modified the sentence as follows. We include examples of remotely sensed precipitation and evapotranspiration; we also provide the meaning of TRMM before mentioning it in the following paragraph. "Increasing availability of remotely sensed (RS) anomalies in terrestrial total water storage (TWSA) data from the Gravity Recovery and Climate Experiment (GRACE) satellites, precipitation estimates from Tropical Rainfall Measuring Mission (TRMM), and evapotranspiration (ET) estimates from Moderate Resolution Imaging Spectroradiometer (MODIS) greatly enhances"

Page 3, lines 21-30: I missed the citation from other works that addressed the Parana basin in the literature review. I believe that the authors could include some researches mentioning that this basin is or has been studied by other researchers in other hydrology research. This will give more importance to the work, allowing to understand how this work fits within the existing studies on the basin

Response: Agreed. The revised manuscript includes references to previous studies in the study area as follows: "Previous hydrologic studies in this area include assessment of climate change impacts on water resources (Adam et al., 2015; Nóbrega et al., 2011), energy and hydrologic modelling (Camilloni et al., 2013; Ruhoff et al., 2013; Getirana et al., 2010), assessment of remotely sensed evapotranspiration (Ruhoff et al., 2013) and energy-based estimation of evapotranspiration (Ruhoff et al., 2012)."

Page 4, line 15: I was not able to identify clearly in which depth was considered for soil moisture using GLDAS, the GLDAS product that the author used contains soil moisture information for various bands (0-10cm, 10-40cm, rootzone, etc). Is it possible to make it more clear in the text?

Response: A more complete description of the GLDAS models is provided in the revised manuscript as follows:

“The number of vertical layers (VL) and respective depths (D) vary among LSMs: CLM (10 VL, $0 \leq D \leq 3.43$ m), Mosaic (3 VL, $0 \leq D \leq 3.5$ m), NOAH (4 VL, $0 \leq D \leq 2.0$ m) and VIC (3 VL, $0 \leq D \leq 2.0$ m). SM is the average layer soil moisture (ALSM) from individual LSMs. ALSM was obtained by depth-averaging the water amounts in specific soil layers ”

Page 4, lines 20-30: If possible I would suggest to transfer more information about SPI/SDI Drought indices from supplementary material to the main text. It would be interesting to give some more detail about the methodology for calculating the SPI/SDI or at least cite the original work that proposed methodology.

Response: We moved the following information related to SPI/SDI from Supplementary Material to the main text: “ SPI uses historical rainfall data to determine, at different timescales, the periods of positive and negative anomalies in rainfall based on the cumulative probability of rainfall occurrence over an area or at point (McKee et al., 1993) . . . For each water year, SDI is obtained for overlapping periods of 3, 6, 9 and 12 months based on cumulative streamflow data”

Page 5, lines 5-20: One of the study objectives was to identify the intensity, duration and extent of the droughts at the Parana watershed. It was clear what the periods of 2000 and 2014 had droughts and its duration and intensity (analyzing Figure 2). But for the spatial extent I think it could have been made a simple figure showing the spatial variation of the SDI/ SDI within the period of each drought, showing yet an outline of the area affected by the drought.

Response: The attached figure (Fig 1) was inserted in the manuscript. The following description and discussion about the figure was inserted in the Section 3.4.

“Streamflow data were used to calculate the Streamflow Drought Index and provide insights on linkages between meteorological and hydrological droughts (Fig. 6) for water years 2001 (WY 2001) and 2014 (WY 2014). In general, meteorological droughts resulted in hydrologic droughts, as indicated by the extreme low values of SDI where SPI

was negative (Fig. 6). However, some upstream reservoirs (highlighted with arrows) seem to have buffered the effects of the 2014 drought in the downstream reservoirs. Although SPI indicate a severe to extreme dry situation (SPI < -2) over those reservoirs, SDI increased from upstream (SDI < -2.50) to downstream (-2.5 < SDI < -2.0). This means that the river discharge deficit (hydrologic drought) caused by the meteorological drought was (modestly) attenuated by the upstream reservoirs. Comparison between WY 2001 and 2014 show the greater spatial extent of the most recent drought within the Parana basin (PB), which agrees with the rainfall anomaly in Fig. 3. Except for the south and central south of the PB, the extent of the hydrologic drought was more critical in WY 2014 than in WY 2001. For instance, the same sub-basin in the center of PB had, in WY 2001, $-1 \leq \text{SDI} \leq 0$, whereas, in WY 2014, $-2.7 \leq \text{SDI} \leq -2.0$.”

Page 10, lines 25-30: In the conclusions authors shows a summary of results and em- phasize as conclusions of the research the importance of integrating remote sensing, modelling and monitoring data and that the analysis highlights the importance of reser- voir location. I think those statements are indeed true. But I also think they are kind of trivial, and they are not necessarily innovative conclusions of this single research. I suggest the authors to remove those conclusions (or shorten) and add a conclusion with inverted reasoning: how these results can be useful for the analyzed system? What they mean going for future management of water resources in the basin? How can we evolve with these used techniques for practical or more research purposes?

Response: We agree that they may not sound innovative but they summarize what we did in this study. However, we added a more practical conclusion and replaced the term “comprehensive” with “preliminary, as shown in this new paragraph to discuss the proposed question:

“A preliminary understanding of drought propagation, i. e. how meteorological drought culminates in hydrologic drought, was presented here. Our analysis indicates that socio- economic droughts (failure to supply water, electricity, etc) in the PB are subject to a natural cascade of effects (rainfall deficits > soils moisture decrease > run-off reduction > reservoir depletion) that are related to antecedent soil moisture conditions and dam operations. An important practical measure is to continuously monitor meteorological indices, such as SPI. Based on such indices, it may be possible to anticipate and reduce drought impacts by means of public campaigns to alert the population about the potential drought and to encourage reduction in water and electricity consumption. The lag time between meteorological droughts and hydrologic responses results in time for some actions to be taken to reduce drought impacts, such as modifying dam operations. Given the spatial variability of droughts and the interconnected electric grid in Brazil, another possible measure is to reduce hydroelectric generation in a region potentially affected by an imminent drought and, temporarily, increase electricity generation in other regions. Given the uncertainties in the modelling process adopted by ONS to manage hydroelectric generation, dam operators can profit from radar-based real-time rainfall measurements or remotely-sensed near-real-time rainfall estimates. The difficulty of gathering station data for short timescales emphasizes the importance of remote sensing rainfall for reservoir operations. Finally, land surface models can be used in addition to the rainfall-runoff models currently used by ONS, to project hydrologic responses by inputting weather forecast data."

Pages 9 and 10: At the discussions or conclusions I also miss a paragraph, a scheme, a flowchart or something else highlighting the comprehensive understanding of the linkages between meteorological and hydrological droughts for future management proposed in the study objectives. Who are them? Is it possible to make them more clear?

Response: This was addressed in the paragraph above, inserted in the revised version.

Technical corrections

Page 3, line 7: Please keep verbs tenses consistent. In this case, in the past

Response: Done

Page 5, lines 23-25: I suggest to rewritten this paragraph to avoid the triple "The Grace . . ."

Response: Agreed. Those sentences were rephrased as follows:

"The GRACE satellite data provide valuable information on the regional extent of drought impacts on total water storage (TWS), despite its coarse spatial resolution (100,000–200,000 km^2 (Fig. 4). TWS data from GRACE do not include the 2001 drought because the GRACE monitoring period extends from 2002 to present. Analysis of GRACE data indicate greater depletion in TWS (≈ -60 to $\approx -90\,\mathrm{mm\,yr^{-1}}$ between Apr 2011 and Apr 2015) in Southeastern Brazil, which corresponds to the northeast part of PB. ″

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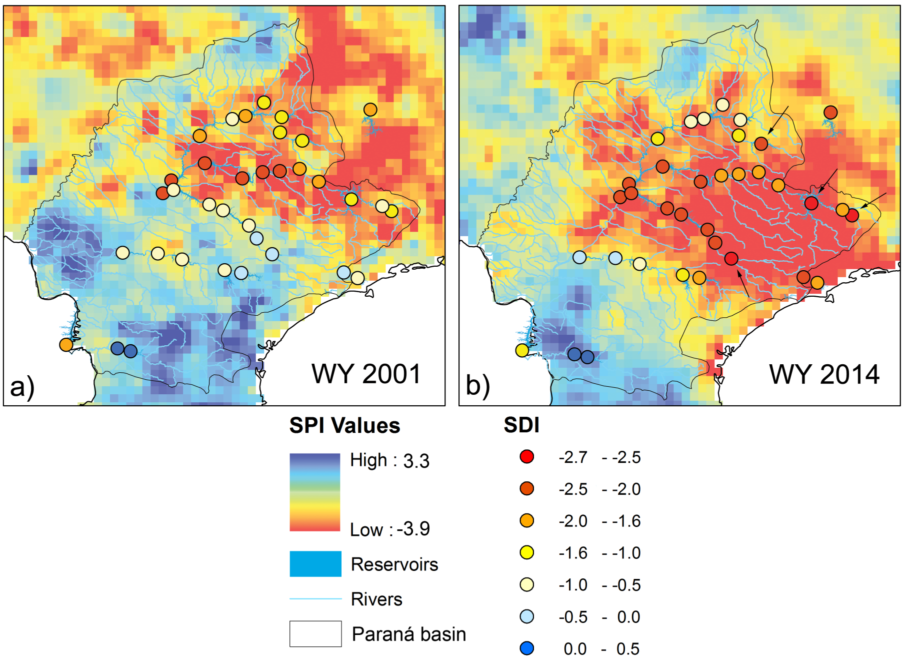

Fig. 1. Spatial variation of the Standardized Precipitation Index (SPI) and Streamflow Index (SDI) in the period of two droughts.