Interactive comment on "How streamflow has changed across Australia since 1950's: evidence from the network of Hydrologic Reference Stations" by S. X. Zhang et al.

(Anonymous Referee #1, Received and published: 8 March 2016)

Authors' response to Referee #1

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Response to review referee #1: Many thanks for your time to review our manuscript. We highly appreciate your insightful and constructive comments which will help to improve the submitted manuscript. Please find our response below to your comments, questions and suggestions. The referee's comments are first recalled in *italics, blue colour font*, and then followed by our answer.

General comments

This article is well written overall and provides important results relevant to historical changes in Australian streamflows. It appears to be the first comprehensive analysis of streamflow trends and variability for Australia. It utilizes a newly available data set of minimally disturbed streamflow basins, which is critical for looking at climate driven changes. I don't see any major technical problems, however, more information is needed as it appears that catchments with different time periods are analysed together, this limits the comparability of catchments which is important for this type of trend/variability analysis. The results and discussion in places could be clarified, and better match the article figures. It's important to add at least a first cut at relating streamflow variability to large scale atmosphere/ocean patterns, particularly with the large number of step changes that were found.

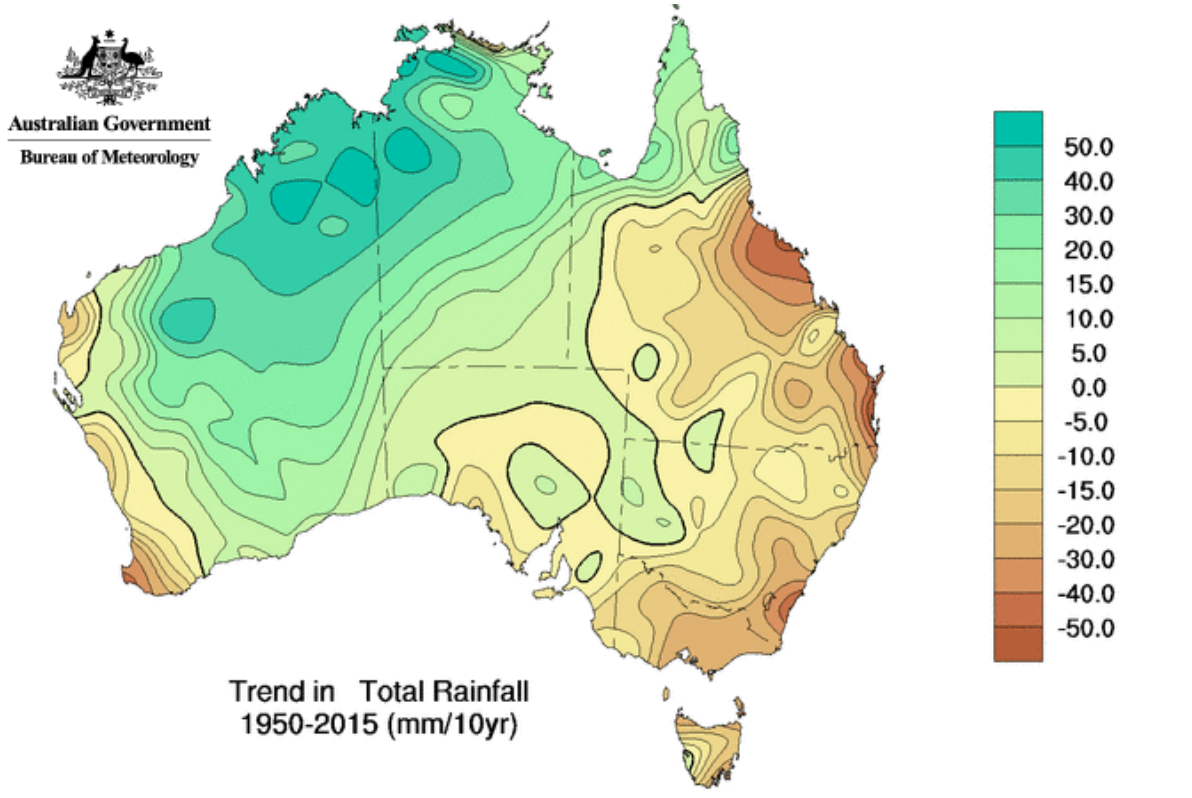
Answer

The authors would like to thank the referee for those positive evaluations of the manuscript and our work; and for the insightful comments on the data and method.

For the first question in general comments: catchments with different time periods are analysed together. Firstly, we checked the statistics of data availability of all 222 stations, with minimum 30 years data, average 48 years data, and 86% stations longer than 40 years data. Most of the stations have observations starting in 1970s. One intention of this study is to look at the long term changes in Australian streamflow, therefore the full length of observations of all stations are used in the analysis. If the data is truncated to have a consistent time periods over the continent, this means only 30 years data to be used, and for some stations half of data length will be cut which will limits an holistic examination of the historic records. Secondly, the data length of every station was not exactly the same over the continent, but for the stations within the same region, the data lengths were in more consistent time periods. And data in most of stations (86%) has very similar time period. These make the comparisons on a fairly consistent base.

Lastly, the primary purpose of the work is to provide long-term trends of streamflow data of Australia rivers with observation data as much as available. This helps to provide long-term high-quality daily flow observations data of Australian rivers for a broad range of users and researchers. We might be able to try the continental scale analysis within a common period as the next project activity.

For the second question in general comments: relating streamflow variability to large scale atmosphere/ocean patterns. We agree to this point. Though a thorough analysis of the relationship between streamflow and climate indices is out of scope of this study, we have added relevant literatures on climate, and include a discussion to relate the flow changes with main climate indices. To show an example for that: adding a trend map of rainfall for discussion. The Figure below gives an example showing an updated summary of long-term rainfall trends (1950-2015). Changes in precipitation or other climate variables impact on the rainfall-runoff process directly, and indirectly causing changes in flora, relief and soil erosion. The identified trend patterns in annual total streamflow are spatially consistent with trends in annual total rainfall as shown in this Figure, where most of eastern and south-western Australia has experienced substantial rainfall declines since 1950; while north-western Australia has become wetter over this period. This similarity implies that hydrological variability is closely related with changes in rainfall patterns.



(source: http://www.bom.gov.au/climate/change/index.shtml#tabs=Tracker&tracker=trend-maps&tQ%5Bmap%5D=rain&tQ%5Barea%5D=aus&tQ%5Bseason%5D=0112&tQ%5Bperiod%5D=1950)

Specific comments

Line 109, Was there a criteria for the Hydrologic Reference Stations for extensive basin water use or groundwater pumping? This could be hard to quantify, but is important, especially for low flows and in dry areas.

Answer

Yes, whether there is water use diversion or not, is important especially for low flow or dry areas. There was a criterion regarding this: line 109 "unregulated catchments with minimal land use change". Catchments with extensive basin water use or groundwater pumping were filtered and not included in HRS catchments, based on the local knowledge of the basin, stakeholder consultation and land use change analysis. For more information on the station selection process and involvement of stakeholders in prioritising the stations list, users can refer to the HRS web site at http://www.bom.gov.au/water/hrs/guidelines.shtml .

Line 109, Was any consideration given for catchments with substantial overlap in area (nested basins). Basins with substantial overlap would not offer independent information for an analysis.

Answer

Overlapping in area has been considered. We have checked all HRS stations thoroughly, only at a few locations there are nested basins: 3 in Queensland, 2 in North Territory and 1 in New South Wales. 5 of them have less than 10% area overlapping (which can be considered as independent) and only 1 has 50%. The influence to overall analysis is marginal.

Line 133, It's stated that "the primary data used in this study" are from the HRS network.
Does this mean that stations outside the HRS network were used? This is problematic, if this is the case for this analysis.

Answer

All data used are from the HRS network. We have edited this sentence by removing "primary", and have "all data used" instead.

Line 145, Could use more specifics on how well the model did for filling in data gaps; "perform well" is quite vague.

Answer

We agree and have specifide the model performance in this part, with the statistics of NSE results: Median = 0.74; mean 0.72; STDEV =0.12

Line 159, I don't recall any discussion of the data collection agency/agencies. Were they collected by the same agency? If not, do they meet the same standards for inclusion in the HRS? If not, how do you assure consistency across regions when analysing trends or variability? Have collection methods remained constant over time? This should be addressed. If not consistent over time, monotonic trends or step changes could be biased.

Answer

Water data is collected across Australia by many organisations, utilities and regulators in different states and territories, often to meet the requirements of their own documented procedures and sometimes with reference to Australian or international standards or guidelines. The Bureau's role as the national water information provider, has been working collaboratively with the water industry to develop and promote water information standards and guidelines to collate, interpret and access nationally consistent data. All data included in the HRS database are compiled, quality-checked by the Bureau, and therefore are consistent nationally and over the time. Bureau has developed a set of standard data quality code and

references guides on how it relates to different agencies quality code. This will be addressed in the manuscript.

Line 173, Why isn't Qmin (for 1-day, 7-day or similar) analyzed? These low flows are typically important for water managers and ecological flows.

Answer

Thanks for suggesting that. Qmin was not included in the current work, but it's a good idea and it can be considered in the future.

Line 186, Does the Median Crossing and Rank Difference test consider the possibility of long-term persistence? If not, an important type of autocorrelation is being ignored.

Answer

Yes these 2 tests (Median crossing & Rank difference) consider the long-term persistence as well (Kundzewicz and Robson, 2000). Autocorrelation checking was part of the randomness test, so it was not missed in this analysis.

Line 192, it doesn't appear that consistent periods of record were used for the various trend/step change tests in the article. This limits the comparability of results between catchments. Please provide more information. Authors should consider doing tests for selected periods and only including sites with mostly complete data for those periods.
Multiple periods could be used, such as a 30 year period up to the present and a 50 year period up to the present. I don't recall a mention of what the last water year in this analysis is. This is important.

Answer

The first part of this comment is addressed above in general comments. For the second question, the data used in this study are up to end of 2014, so the last water year is 2014. We have added this in the text accordingly.

Line 194, Why not use the non-parametric Sen slope instead of least squares regression.
Regression is sensitive to non-normality and outliers. Skewed distributions and outliers were noted previously in the article.

Answer

Many thanks for this suggestion. We agree completely as the non-parametric Sen slope is more appropriate method for this data set than the least square regression method which is parametric. We have followed the advice to apply the non-parametric Sen slope instead of LSR, and update the results in Table 2. The following are the references for non-parametric slope estimator: Sen, Pranab Kumar (1968, Journal of the American Statistical Association 63: 1379–1389), Theil, H. (1950), which were added to the paper. The Sen slope method was not in the current system, however, it will be considered in the next HRS web portal upgrade.

Line 251, The first sentence that summarizes trends seems inconsistent with the second sentence. Please reword.

Answer

The two sentences of this paragraph are rephrased to make the idea clearly, in this way: "Patterns of trends were noted in the different flow regimes. Moving through the flow variables from low (Q10), to median (Q50), to high (Q90), and onto maximum (Qmax), an increasing number of stations were found with no trends, combined with decreasing number for non-random series. "

Line 261, I think of trends as being one type of non-stationarity.

Answer

We agree that trend or step change is one type of non-stationarity. Text is reworded in such a way that trend and step-change come under ‘ non-stationarity’.

Line 261, Not clear what this paragraph is getting at, suggest expanding or contracting it.

Answer

We tried to address the question broadly, what could be the reasons behind the observed flow changes, as an introducing paragraph for the following sections of trend and step changes. Possible reasons are: (i) changes in rainfall resulted in changes in streamflow – rainfall-runoff process has changed; (ii) distribution of rainfall within the year, (iii) changes in unconfined groundwater level, particularly in the streamzone, changes in threshold, (iv) probable changes in evapotranspiration process due to though no significant changes in landuse/landcover.

This paragraph has been rephrased accordingly, such as “Detecting the trend and non-stationarity in a hydrologic time series may help us to understand the possible links between hydrological processes and global environment changes. Many of the streamflow time series in this dataset exhibit trends or step-changes in the mean or median. Abrupt changes and trends in the hydrologic time series could be indicators of hydrologic non-stationarity or long-term gradual changes in the rainfall-runoff transformation processes.”

Line 267, Need quick summary of trend methods.

Answer

A quick summary of trend methods was added here, to support the results statement.

Line 271, Suggest rewording, this statement seems incorrect. All stations showing significant trends are in the south (depending on how you define south) and all increasing trends are in the north.

Answer

We have reworded the sentence, such as “all stations showing decreasing trends (35% of stations) are in the southern part of Australia and all stations showing increasing trends (4% of stations) in the northern part”.

Line 274. Why not test the importance of the last decade on trends? This could be done by repeating analyses but removing the last decade. This would be easy or hard, depending on how automated the trend testing is.

Answer

This will be interesting to look at, but it is not within the scope of the present paper. We would prefer to keep the current trend testing results, and put the suggestion as future research work.

Line 275, Need Murray-Darling labeled on the figures and also the major regions of Australia (boundaries already in place for the major regions) for readers not from Australia.

Answer

Figure 1, 5, 6 have been modified, with the basin code (from I to XII) marked for each region, and readers can refer the basin names to Table1.

Line 280, Did you do trends in baseflow or baseflow index? The former is described in the methods and the latter is labeled in Table 2. The interpretation of these is obviously different.

Answer

Thank you for pointing out this. The trend test was applied to baseflow, not baseflow index. In Table 2, baseflow index was listed there (calculated by the ratio of baseflow to total flow), and the trend results of baseflow was indicated at the top right corner.

Line 302, Why aren't the numerous step change decreases from the 1970s in southeastern Australia (Figure 6) mentioned?

Answer

Discussion is added, in section 4, sub-section about "step change", to address the step change decreases from the 1970s in south-eastern Australia.

Line 306, Rainfall changes, whether they are monotonic trends or step changes would force streamflow changes. Please clarify.

Answer

More discussions were added here for relating rainfall changes with flow trends, as addressed above in general comments.

Line 307, Please state what percentage of sites in different regions had significant Mann-Kendall trends, step changes, or both, and comment on whether, for the latter, this implies that Mann-Kendall significant trends were due to step changes.

Answer

We have added a quick summary of result statistics for trends and step changes for different regions.

Line 329, Why mention only winter trends for southern Australia, all seasons seem to have significant downward trends, with autumn having fewer than the others. Please clarify.

Answer

More discussion was added here to cover more aspects of seasonal changes.

Line 358, Specify what parts of Australia these are here for non-Australians (to avoid people having to look for this earlier in the article).

Answer

Texts were revised to specify what parts of Australia. Also Figure 1, 5, 6 were modified with the basin code, to make it more clear where the discussion is about (it's addressed above in Line 275 question).

Line 361, Rainfall deficiency "observed all over the continent" is not consistent with streamflow increases in the north.

Answer

This sentence was rephrased accordingly.

Line 362, The accuracy of the statement on drought conditions depends on what type of drought you're referring to (meteorological, hydrological, soil moisture, etc.). This statement isn't correct if it refers to rainfall deficiencies, as those drive streamflow (not the reverse). **Answer**

Accuracy of statement on drought was added, with referring to literature on the severe drought in southeast Australia 1997-2009 (SEACI, 2011, The Millennium Drought and 2010/11 Floods; Ummenhofer et.al, 2009).

Line 368, need reference after "decade."

Answer

Reference was added: decade means for the years 1997–2009 inclusive. SEACI, 2011, The Millennium Drought and 2010/11 Floods, http://www.seaci.org/publications/documents/SEACI-2Reports/SEACI2_Factsheet2of4_WEB_110714.pdf.

Line 370. It would be very useful, in helping to interpret trends (especially with the large number of step changes) to look at the relation between streamflow statistics and major atmosphere/ocean patterns. A thorough analysis I can understand being beyond the scope of the article, but a first cut I think is reasonable and important. For example, you could correlate the interannual variability of streamflow statistics to major atmosphere/ocean indices. I'm not familiar with which ones are important for Australia, but ones that are known or suspected to be important to rainfall or streamflows could be tested. These could be relatively easy and may provide valuable information for interpreting the step changes. The discussion could also focus on the timing of known changes (what year) for indices that are important to Australian hydrology and compare those to the years that catchments showed step changes.

Answer

This is already addressed above in general comments, more discussion were added for this point.

Line 396, It seems like the text describing trends for different regions doesn't match Figure 5. Rather than "Northern Territory and north-west of Western Australia, shouldn't it be "northern part of Northern Territory"? There's only one weak trend in northern Western Australia.

Answer

We have modified the text to be more specifically describing the locations, such as "In Northern Territory there was an increasing trend in annual streamflow (QT) while there was no significant trend visible in the northern region of Queensland. However, in south-eastern Queensland there was a significant decreasing trend. Most of the gauging stations in New South Wales, Victoria, south-east South Australia, south-west Western Australia, and north-west Tasmania showed a significant decreasing trend in annual streamflow. In South Tasmania, central Australia, most of the stations showed no significant trend in annual streamflow. "

Line 401, Catchments in the southeast of S. Australia have significant downward trends in Figure 5.

Answer

We have included it in the text.

Line 413, Both areas have a mix of step changes in the 1990s and 1970s in Figure 6.
General comment on figures: the trend symbols are too small in Figures 5-8.
Technical corrections and typos

Answer

We have added this comment in the paragraph, and improve the figure quality (enlarge the symbol, size of graph, and improve the resolution).

Line 396, incorrect figure reference.

Answer

It's been corrected as "Figure 1". Thanks for pointing it out.

Figure 5 caption, change "decrease" to "decreasing"

Answer

We have changed the caption accordingly.

Thank you again for your valuable comments!