

## Reply to Comments on paper 'A review of droughts in the African continent: a geospatial and long-term perspective' by Masih et al. (Manuscript ID C760-765)

The authors are grateful to the two anonymous reviewers (reviewer # 1 and 2) for their valuable comments. The manuscript is substantially revised based on the comments. The comments are well received and highly appreciated. The section on causes of droughts is substantially enhanced by including findings from the studies indicated by the reviewers as well as by conducting review of more studies. Additional analysis is also conducted to support the findings on increasing geospatial extent of droughts in Africa (section 3.1). Minor corrections/revisions are also conducted considering the review comments. The replies and revisions are briefly described in the following report (directly after the original comments in blue colour). We explain it in the response given below in case we did not agree with a specific comment made by the reviewer. In addition to the response to the review comments given in this document, details on the revisions can be found in the revised manuscript. The revised manuscript is prepared using track changes mode to highlight the revisions conducted.

**Reviewer #1:** Manuscript: 'A review of droughts in the African continent: a geospatial and long-term perspective' by Masih et al. (Manuscript ID C760-765)

This manuscript presents a literature review of several aspects of droughts in Africa with a primary focus on the description of the main events and their related impacts. The manuscript is well organized and written. It presents a nice summary of the current status of droughts in Africa and makes useful suggestions for the future. On the other hand, I would expect that this kind of reviews provide a large scale picture that is not already evident or at least some connections between the topics should be presented. Sometimes the review of literature is too specific and makes it hard to follow the main argument, maybe the discussion of the generic aspects of the papers reviewed could be enhanced.

For instance in section 3.3 most of the time is dedicated to teleconnections between ENSO and little or nothing to shifts in ITCZ, monsoon, the Tropical Easterly Jet (TEJ) or the intertropical front (ITF). I think that this section that is called "causes of droughts" will be benefited with a broader discussion of physical processes that can led to droughts in Africa (Just to cite a few papers Janicot et al., 1998; Nicholson 2000, Rouault and Richard 2005). I know that no review is going to be complete, but if the authors want to keep a discussion on the causes of droughts its necessary a more in deep analysis. Therefore I think that this article can serve as a starting point of many future drought researches in the continent. While the manuscript is generally in a good shape, I do feel that the manuscript can be improved by addressing a few comments below.

Response: We highly appreciate the constructive comments and very useful suggestions made by the reviewer. We agree with all comments made by the reviewer and have addressed them in the revised manuscript. As indicated above, the section on causes of droughts is substantially revised by including findings from the studies indicated by the reviewer as well as by conducting review of more studies. Please see the revised section 3.3.

Page 2682 Line 25: droughts occur more frequently in Africa compared to the other continents? As it is I don't fully agree with this statement. The fact that droughts cause more impacts is because the societies there are more vulnerable but not necessary because droughts are more frequent. Please, rephrase or add any reference that can support this affirmation.

Response: Sentence rephrased.

Page 2683 L3: What is a mega-drought? A multi-year drought? Please define it briefly.

Response: Replaced with multi-year drought.

Page 2684 L15-19: This paragraph is vague and a bit confusing. There are statements related to an impact database (EM-DAT) and literature of the development of some drought related indicators. What is the clear message that the authors want to give here? I suggest being more specific here as is not clear if the authors want to refer to the development of the drought indicators or to the available datasets. Regarding to the information available at the moment there are specific continental drought monitoring and forecasting systems that deals with specific drought related information in real time as well as historical data: The African drought monitor: <http://hydrology.princeton.edu/adm> (Sheffield et al., 2013) and the DEWFORA African drought observatory <http://edo.jrc.ec.europa.eu/dewfora/> (Barbosa et al., 2013).

Response: Revised as suggested. The new paragraph reads as:

There are a growing number of continental and global data sets on drought. For instance, there are specific continental drought monitoring and forecasting systems that deal with specific drought related information in real time as well as historical data. The examples are the African drought monitor: <http://hydrology.princeton.edu/adm> (Sheffield et al., 2013) and the DEWFORA African drought observatory: <http://edo.jrc.ec.europa.eu/dewfora/> (Barbosa et al., 2013). Moreover, the EM-DAT data base (<http://www.emdat.be/database>) provides information on historic droughts recorded across the world along with their impacts. Significant advances have been made on the global scale estimation of various drought related indicators (e.g. Standardized Precipitation and Evaporation Index, SPEI) (Vicento-Serrano et al., 2010). Several remote sensing based data and products have been developed over time (e.g. Rojas et al., 2011; Sheffield et al., 2013). These efforts have resulted in significant increase in the scientific literature and data bases, which can facilitate continental scale analysis of droughts in terms of severity, spatial and temporal coverage.

Page 2684 L25: Causes of what? Aridity or droughts?

Response: Causes of droughts.

Page 2685 L15: What kind of variability are referring here? Spatial or temporal? This affirmation comes from Figure 1 or from the literature review?

Response: It is referred to spatial and temporal variability. Affirmation comes from Figure 1.

Pages 2685 L25 to 2686 L9: Quite big change of argument here. In the previous paragraph the authors made a description of some generalities of precipitation regime in Africa and in this paragraph a review of the vulnerability is presented. This paragraph could fit better in the discussion presented in section 3.1 where the affirmation that semi-arid and sub-humid regions are more drought-prone and vulnerable and can be supported with tables 2 and 3.

Response: As suggested, paragraph is deleted from section 2.1 and moved to section 3.1.

Page 2686 L 20-22: Only one drought indicator is presented (SPEI) in the paper. At least a short discussion on the ability of other indicators to detect droughts in the continent should be necessary for a review paper.

Response: A short discussion on the ability of other indicators was added as suggested by the reviewer. The references are given indicating review articles on this specific topic. However, the focus of the paper is not on assessing the ability of different indicators to detect droughts in the continent. SPEI is widely used and is known to be highly correlated with other indicators (e.g: SPI, SRI). SPEI was chosen given the availability of long time series of data (more than 100 years).

Page 2687 L6-8: I don't see the need to define and restrict the definition of drought to only meteorological aspects in a review paper. It means that papers relating to agricultural, hydrological or socio-economic aspects of droughts were not included? I don't think that this is the case, however if this is the intention of the authors I would suggest to clearly state that the review is focused in meteorological aspects.

Response: We agree with the reviewer and have deleted these restricting sentences.

Page 2688 L 28-29 and Figures 2 and 3: It's not clear how Figures 2 and 3 can support the argument of the increase of drought severity and frequency. There are presented some cases and is hard to agree with this conclusion from there. How reliable are the datasets used to compute the SPEI in the first part of the twenty century?

Response: Comparing Figures 2 and 3, it can be seen that the most recent droughts (e.g. droughts (1972-73, 1983-84 and 1991-92) are more severe and also cover more area. To further clarify this point, more

analysis is conducted on time series data of SPEI and a Figure 4 was added which shows statistically significant increase on the area under droughts across the continent during 1901-2011. This is also confirmed by applying Spearman Rank test, which showed significant increasing trend in area under moderate, severe and extreme droughts in the African continent. Please see section 3.1.

Page 2691 L 1-2: What it means that the droughts were not anomalous? How the monsoon generated more severe and prolonged droughts? Please explain or rephrase.

Response: It meant that similarly severe droughts have also occurred in the past centuries. Sentence rephrased.

Page 2692 L3-4: The use of the word predicted in this context is not completely accurate. The results showed are a result of climate projections that represents the potential future evolution of the variables. Projections are distinguished from predictions as the first involve several assumptions (as future socioeconomic and technological developments) that may or may not be realised, and are therefore subject to significant uncertainty. Consider changing it with projected" or similar.

Response: Corrected as suggested.

Page 2692 L8-9: Consider rephrasing the first sentence of the section. It's not clear the message that come out from there.

Response: Sentence rephrased.

Page 2692, L15-19: The statements in these sentences are quite vague and are not adding substantial information. Consider deleting or rephrasing them.

Response: Sentence rephrased.

Page 2693 L 17-22: The main argument exposed here is the relationship between lower summer rainfall and changes in surface sea temperature in the Atlantic and Indic Ocean. Then the sentence that links El Niño events with deterioration of vegetation is hard to follow. Consider to elaborate more this point trying to link it with the Atlantic and Indian Oceans' arguments.

Response: As indicated above, this section is substantially revised and additional information is added.

Page 2694 L9: high frequency of what? Droughts? Vulnerability to droughts is not related with drought frequency but with the potential damage that a drought can give to a determined socio-economic system.

Response: Corrected as suggested.

Page 2695 L10-16: The structure of this paragraph can be improved.

Response: Done as suggested.

Page 2695 Last sentence: Even if I found the paper interesting, I don't see clearly how it can be used for long-term drought planning or as a guide for re-align policies, neither didn't I see any proposal to do so. This issues are particularly complex and aren't covered in this review. I recommend to delete this sentence or add substantial evidence in the paper that can support this affirmation.

Response: Sentence deleted.

**Reviewer #2:** Manuscript: 'A review of droughts in the African continent: a geospatial and long-term perspective' by Masih et al. (Manuscript ID C760-765)

Although evaluating a complex phenomenon such as droughts from the past, present and future at multiple spatial scales and across the entire continent may have merit, doing so in a single review article doesn't seem feasible. Perhaps limiting either the spatial or temporal scale of the scope of the article would make the topic more tractable. This would allow the authors to adequately cover the topic in an article of manageable length. As it stands, aspects of the article provide a discussion that is too brief to be useful.

Response: We appreciate the reviewer comments. We acknowledge that covering both spatial and temporal aspects of drought at the continental scale is an ambitious undertaking. However, we strongly consider that both spatial and temporal aspects are intertwined and should be dealt together. As indicated in the paper, separate studies exist, which cover either temporal or spatial aspect of droughts for one country/region. Our study made a significant contribution in systematically reviewing the available evidence on both aspects of droughts. We give a concise review of available studies in Table 2 and elaborate on the issues within the scope of this paper in Table 2 and rest of the manuscript. The revised manuscript is improved by addressing the specific comments provided by the reviewers and conducting some additional review and analysis.

Section 3.3 (Causes of Drought) is, in places, inadequate in its representation of the literature. The description of the causes of drought in each region focuses primarily on ENSO, and largely ignores - or notes as an aside - other influencing factors. In East Africa and Southern Africa, for example, inadequate consideration is given to the influence of the Indian Ocean or the Walker circulation (Funk et al., 2008; Park and Funk 2011). Neither is there any discussion of the influence of the Atlantic Ocean and the Atlantic Multidecadal Oscillation for this region (Giannini et al., 2013). The description of causes of drought for Northwest Africa is virtually nonexistent. Northwest Africa should either be removed from this study, or this section needs to be substantially expanded.

Response: This section is substantially revised. Other drought influencing factors were added. All references indicated by the reviewer 1 and reviewer 2 are examined and found very useful. Additionally more studies are examined and included to improve this section. Please see section 3.3.

The conclusion that droughts will continue to become more frequent in the future based on comparisons of the four most intense droughts of the first half of the 20th century vs. the second half is not adequately supported. Without a physical mechanism, the difference is neither clear nor distinguishable between a one-time shift in climate and a continuing trend. Although the authors reference Giannini et al. (2008), this discussion should be emphasized (i.e. reference Fig. 1 from Giannini et al.). Choosing only four events for their figure leaves the reader wondering why only four were chosen and whether the relationship of increasing drying holds true across severities of

drought as defined by intensity and frequency. The chosen diagram, for instance, tells the reader nothing about the evolution of the frequency of middle-intensity droughts across the continent. Droughts of the recent past are often listed as evidence of the increasing intensity of drought. Due to possible observation bias, listing droughts of the recent past is not sufficient to demonstrate that droughts have become more frequent (i.e. recent droughts have been well recorded while the more distant past is less well documented).

Response: This point is clarified and supported by additional analysis. A figure is added showing trend in SPEI over the period 1901-2011. A trend analysis is also conducted using Spearman test, which shows significant increasing trend on the area of the African continent under moderate, severe and extreme droughts. The drought events shown in the Figures 2 and 3 are carefully chosen based on the fact that these events are reported in most of the studies as severe droughts. Furthermore, as indicated in the paper, several specific studies show increasing trend in the droughts. Please see section 3.1.

The discussion of future droughts across the African continent seems muddled. The majority of the evidence - and of the description in the text - speaks to the difficulty of simulating droughts in GCMs, but the authors then conclude that despite the many complexities and limitations that droughts will almost certainly be "widespread and extreme" in the future. This seems to be implying that droughts will certainly intensify in the future, which is unsupported by the evidence provided. If this is not the case, it should be clarified. Additionally, it is unclear if this conclusion applies to the entire continent uniformly or whether different regions will experience differing patterns of drought in the future.

Response: As noted in the paper, we make this argument on intensification of droughts based on study of Dai (2013) and the conclusion is clearly stated for central and southern Africa. We do mention that for other regions, like Sahel, available studies do not agree on this issue. In our opinion, the key message on this subject is clear. Readers can refer to the given studies for further details.

Page 2685 lines 0-10: The authors note several ways that others have divided the continent into regions, but do not explicitly state how they will do so for this study.

Response: Information is added.

Page 2688 lines 27-28: Given the limited temporal coverage for most countries, as noted in lines 9-11 of the same page, is the EM-DAT data reliable for diagnosing this?

Response: We do acknowledge this limitation in our paper. But together with other evidence, EM-DAT data also substantiate the point.

Page 2688 lines 28-29: refers to the three most intense droughts in the text but the actual figures show four droughts from each time period. What is the justification for the number of droughts chosen, and does this relationship hold true across a greater number of droughts?

Response: Corrected. As noted before, these droughts are most widely referred in literature as the most significant events. This point is added in the text in section 3.3.

Page 2689 lines 6-9: clarify this sentence, I'm not sure I understand it completely (i.e. which areas are vulnerable, and why is that information relevant to the frequency?)

Response: Revised.

Page 2689 lines 11-13: provide references for multi-year droughts in the Sahel being more common, and being less common in East Africa.

Response: Done as suggested.

Page 2689 lines 23-28: it seems unnecessary to list out all of the regions indicated as vulnerable. A figure could be useful, but the information in text form is cumbersome.

Response: The list is deleted. The reader can refer to the given reference Rojas et al. (2009) for further information.

Page 2692, L8-15: A mass-citation of studies is inappropriate. Please separate the references into more specific citations so as to be useful for the reader. For example, they could be separated based on those looking at natural phenomenon only, those that sought to identify anthropogenic causes and those that did both.

Response: The references were separated based on natural and anthropogenic phenomenon.

Page 2695 lines 10-20: Line 18 seems to imply increasing frequency and severity of droughts, which contradicts the uncertainty expressed in line 10. Please clarify.

Response: As noted in the paper, the conclusion drawn in line 18 is based on the evidence available from the past (e.g. 1900-2013 and few centuries before). On the other hand line 10 speaks on the uncertainty in the projections made by using GCMs, though for some regions these are also quite convincing (e.g. for central and southern Africa most likely to face increased frequency and severity of droughts).