RC2

Review of "Multi-scale EO-based agricultural drought monitoring system for operative irrigation networks management"

- This study proposes a methodology to assess drought conditions in two irrigation polygons of Italy based on different data sources obtained from satellite data. My opinion is that this manuscript should not be published because it is affected by several formal and methodological problems. The methodology is not well explained and justified and in general all the manuscript it is very difficult to follow. The use of different data sources of different origin makes difficult to know the connection between meteorological and agricultural droughts. The results are also presented in a very confuse way, with different plots in which it is not possible to obtain a clear message about the relationship between metrics and the evolution of the existing anomalies. Below I am providing specific comments that support my general assessment and my suggestion to reject this manuscript.

Answer: the methodology section will be rephrased to better explain all the steps in the analysis, also with the aid of a flow chart. The ADMOS indicator is computed assigning specific values reported in Fig.A, according to increasing drought conditions. The procedure is divided into four subsequent steps: 1) precipitation deficit, 2) soil moisture anomaly, 3) land surface temperature anomaly and 4) vegetation index anomaly. We believe the use of different data sources of different origin to be a major strength of this work. In fact, many studies on drought analyze the indicators using a single source of data, but as noted, the uncertainty of satellite information can be significant. Therefore, the possibility for the indicators to have an ample data pool, drawing from multiple data sources, strengthens the methodology developed in this work. Finally, we removed the "surplus of water" conditions (when SPI-1 was positive) in order to avoid confusion, as it did not took part in the calculation of the cumulated ADMOS.

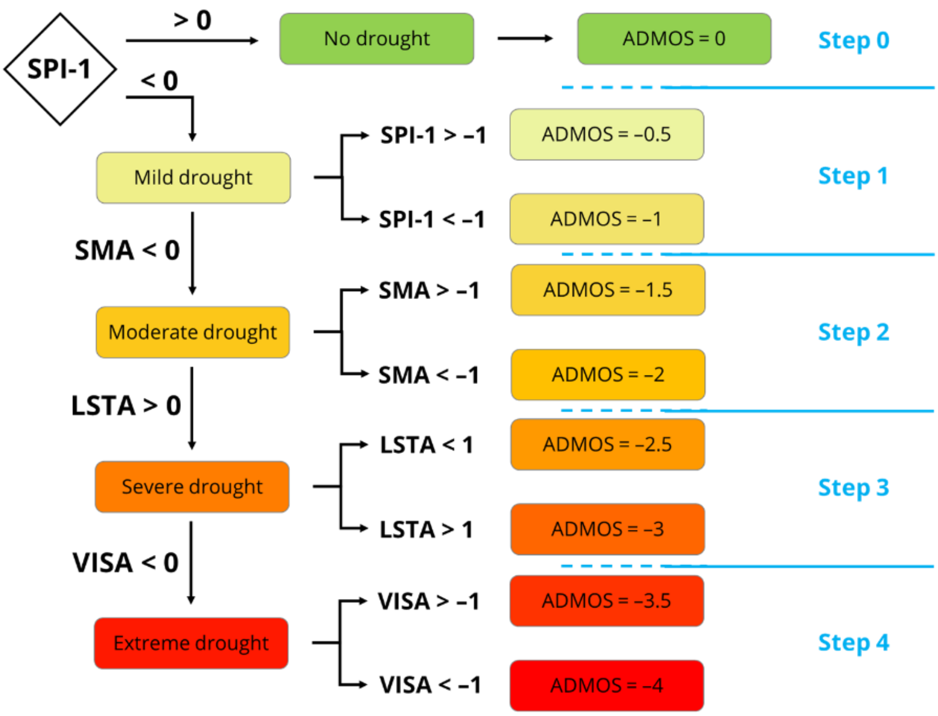


Fig.A Improved version of Fig.1 from the manuscript, detailing the ADMOS workflow/flowchart

- 9-14: Very confuse summary of the results. What is a cumulative drought monitoring system? A drought index can be cumulative, but I wonder what are the authors referring in relation to a drought monitoring system. It is not clear what kind of correlation the authors are referring.

Answer: We will improve the abstract in the revised version of the paper. We although believe that all the definitions are present in the paper, where for example it is explained how the time cumulative AMODS index is computed.

Here the new abstract: "Drought prediction is crucial especially where the rainfall regime is irregular and agriculture is mainly based on irrigated crops, such as in Mediterranean countries. In this work, the main objective is to develop an EO-based agricultural drought monitoring index (ADMIN) for the management operative irrigation networks. The ADMIN index considers different levels of drought conditions combining anomalies of rainfall, soil moisture, land surface temperature and vegetation indices. Multiple remote sensing data, which differ on sensing techniques, spatial and temporal resolutions and electromagnetic frequencies, are used and the uncertainty in anomalies computation derived from the use of multiple sources of remote sensing datasets is also discussed. The analyses have been performed over two Irrigation Consortia in Italy (the Chiese and Capitanata ones), which differ for climate, irrigation volumes and techniques, and crop types. The obtained results show an inverse dependency between the cumulated ADMIM and the irrigation volumes in the Capitanata area (which has on demand irrigation), whereas the dependency is much weaker in the Chiese Consortium (where irrigation is provided on a fixed basis, independently from the drought conditions). In both areas, the role of irrigation is critical to sustain production and preserve crop yields, which seem almost uncorrelated to ADMIN.

- 17: There are much better references to refer to drought characteristics and impacts. It seems that the authors have simply cited some papers related to drought... See e.g. IPCC AR6 Chapters 8 and 11 for a summary of drought complexity and implications.

Answer: thanks, but although some of the cited works could be more recent, or up to the point, we selected well-known (and highly-cited) works which describe why droughts are relevant. The selection of references could be a very subjective process. As an example of this, the paper cited first in Line 17, Wood et al. (2005) "summarizes and synthesizes the research carried out under the NOAA Drought Task Force (DTF), including an assessment of successes and remaining challenges in monitoring and prediction capabilities, as well as a perspective of the current understanding of North American droughts and key research gaps. [...] Results from the DTF papers indicate that key successes for drought monitoring include the application of modern land surface hydrological models that can be used for objective drought analysis, including extended retrospective forcing datasets to support hydrologic reanalyses, and the expansion of near-real-time satellite-based monitoring and analyses, particularly those describing vegetation and evapotranspiration". Nonetheless, we agree that some more accurate references could be added throughout the article and will revise this point for the final version of the manuscript.

- 23: In irrigated lands water shortage can be relevant but in rainfed agricultural areas precipitation (but also temperature and atmospheric demand) play a very important role.

Answer: thanks, we will acknowledge this fact in the article.

- 25: Definitively this is not the best to refer to land atmosphere feedbacks and droughts. Again the citations are very poorly selected, which gives a very bad impression as it seems that references are only located randomly in the text to justify the use of references. About this topic, I would recommend to read Miralles DG, Gentine P, Seneviratne SI, Teuling AJ. 2019. Land–atmospheric feedbacks during droughts and heatwaves: state of the science and current challenges. Annals of the New York Academy of Sciences. Blackwell Publishing Inc., 1436(1): 19–35. ttps://doi.org/10.1111/nyas.13912.

Answer: thanks, we will add this work to the references.

- .25. It should be irrigated agriculture.

Answer: thanks we will add "irrigated" to agriculture

- .28. I would say better: "during the dry season in water limited regions". I would not refer to specific regions.

Answer: thanks we will rephrase it

- .29. One-sentence paragraph? I also find this very disconnected of the context. I suggest to remove this sentence as it does not provide any relevant message.

Answer: thanks, we remodulate this part.

- .35. Again poorly and non-suitable citations. Vicente-Serrano 2006 analyses spatial pattern of meteorological drought but there is nothing on this study on the dynamic of different types of drought. The authors should revisit all the citations of the manuscript. The poor and unsuitable citation approach is a solid formal argument to suggest the rejection of the manuscript.

Answer: thanks, for the observation, we already updated some of the references when answering to the reviewers' comments and will continue to do so for the final version of the manuscript.

- .40. Cite the WMO guidelines for SPI in which it is recommended as a reference drought index.

Answer: thanks, we will add this reference (https://library.wmo.int/doc_num.php?explnum_id=7768)

- .45. The SPEI is perfectly comparable in time and space (as the SPI) Also the Standard Palmer Drought Index is perfectly comparable spatially, so the argument of the authors is not correct. Why is the use of potential evapotranspiration a limitation? I would say that given atmospheric evaporative demand has a relevant influence on drought severity it should be an advantage.

Answer: thanks we agree on this, this line will be corrected in the revised version.

- 48-56: If remote sensing soil moisture is affected by so large uncertainties, what is the justification of its used? The low correlations found among soil moisture datasets presented below even justifies more my assessment.

Answer: Remote sensing products of soil moisture is a state-of-the-art variable, widely diffused in the scientific community and used for an incredibly large number of applications. Historically, SM data was obtained via insitu, point-wise sampling, using either fixed probes or during dedicated field campaigns (Joshi et al., 2016; Dorigo et al., 2011). However precise, this approach is still heavy in terms of required effort and resources (both in terms of time and economic costs) and provides only very locally information. This is an issue, as SM can heavily vary both in time and space because of heterogeneity in the meteorological and bio-geophysical drivers (Famiglietti et al., 2008), affecting the measures representativeness. Furthermore, the measurement density necessary for a meaningful upscaling of SM is itself a matter of discussion (Crow et al., 2012). Instead, remote sensing has eased the monitoring of SM over large areas and at reasonable spatial and temporal resolutions. An extensive review about numerous applications of remote sensing SM (notwithstanding their possible uncertainties) is provided by Babaeian et al. (2019). DIfferent applications show the potentiality of using and comparing SM products from different satellites for drought monitoring. AS Jessica Bhardwaj et al., 2022 who compared SMOS, SMAP and ASCAT, showing that ASCAT is a valuable dataset indicative of agrometeorological drought over Australia.

1. Famiglietti, J. S., Ryu, D. R., Berg, A. A., Rodell, M., & Jackson, T. J. (2008). Field observations of soil moisture variability across scales. *Water Resources Research*, 44, W01423. https://doi.org/10.1029/2006WR005804
2. Crow, W. T., Berg, A. A., Cosh, M. H., Loew, A., Mohanty, B. P., Panciera, R., de Rosnay, P., Ryu, D., & Walker, J. P. (2012). Upscaling sparse ground-based soil moisture observations for the validation of coarse-resolution satellite soil moisture products. *Reviews of Geophysics*, 50, 2011RG000372, L19406. https://doi.org/10.1029/2011RG000372
3. Babaeian, E., Sadeghi, M., Jones, S. B., Montzka, C., Vereecken, H., & Tuller, M. (2019). Ground, proximal, and satellite remote sensing of soil moisture. *Reviews of Geophysics*, 57, 530– 616. https://doi.org/10.1029/2018RG000618
4. Bhardwaj, J.; Kuleshov, Y.; Chua, Z.-W.; Watkins, A.B.; Choy, S.; Sun, Q. Evaluating Satellite Soil Moisture Datasets for Drought Monitoring in Australia and the South-West Pacific. Remote Sens. 2022, 14, 3971. https://doi.org/10.3390/rs14163971

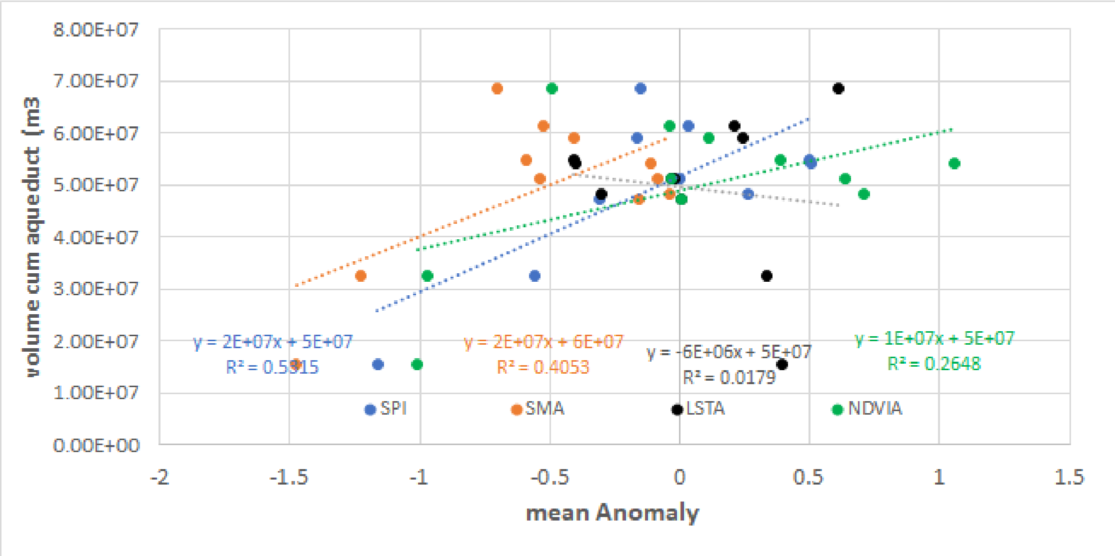
- .57. land surface temperature has been widely used. See e.g. TCI developed by Felix Kogan and the drought monitoring systems (and studies) that use it.

Answer: thanks, we will add this reference to the text to complement the work on LST (Kogan, F. N., 1997: Global Drought Watch from Space. Bull. Amer. Meteor. Soc., 78, 621–636, https://doi.org/10.1175/1520-0477(1997)078<0621:GDWFS>2.0.CO;2.)

1. www.nat-hazards-earth-syst-sci.net/12/3519/2012/ Nat. Hazards Earth Syst. Sci., 12, 3519–3531, 2012 3522 G. Sepulcre-Canto et al.: Development of a Combined Drought Indicator
2. Xiang Zhang, Nengcheng Chen, Jizhen Li, Zhihong Chen, Dev Niyogi, Multi-sensor integrated framework and index for agricultural drought monitoring, Remote Sensing of Environment, 188, 2017, 141-163, https://doi.org/10.1016/j.rse.2016.10.045.

- .71. The optimal solution is really to relate drought objective metrics with impacts and then select the most suited approach. For this purpose, empirical analysis that relates drought indices and impacts is needed.

Answer: we agree with you that such a comparison would be a valuable addition to the workflow of the whole paper. We will add these comparisons to the final version of the work but, in the meanwhile, we attach here some plots, conceptually similar to those in Figure.12 and 13, but featuring the single anomalies (average value in the crops season) instead of the ADMOS, over the Capitanata test case. The strength of ADMOS is particularly relevant when you compare the single anomalies with the cumulated irrigation volume, where you obtain a positive dependency (at higher SPI values you would expect to use lower irrigation water). Also, with SMA from remote sensing uncertainties in the correlation between SM dynamic and irrigation events. Moreover, comparing the determination coefficients (R2) with those from the figures in the manuscript, the correlation between cumulated volume from the aqueduct and single anomaly is everywhere weaker with respect to the ADMOS. This difference is even wider when considering all water inputs (aqueduct and natural rainfall), with the correlations falling below 0.20. Finally, when looking at the final yield (third figure, to be contrasted with fig.13 from the manuscript), a similar behaviour is observed if considering the ADMOS or single anomalies.


volume cum aqueduct (m3
mean Anomaly
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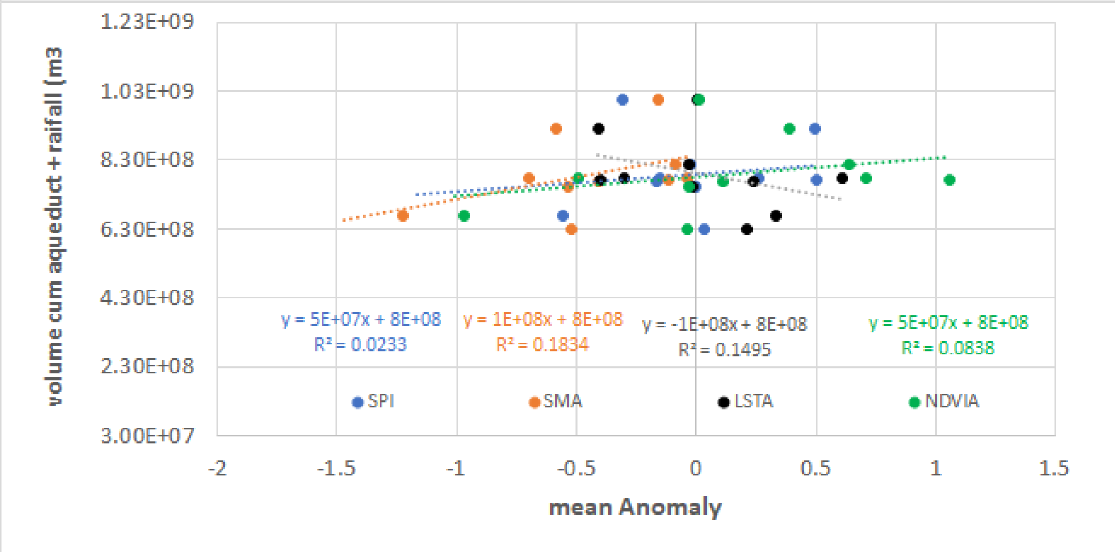
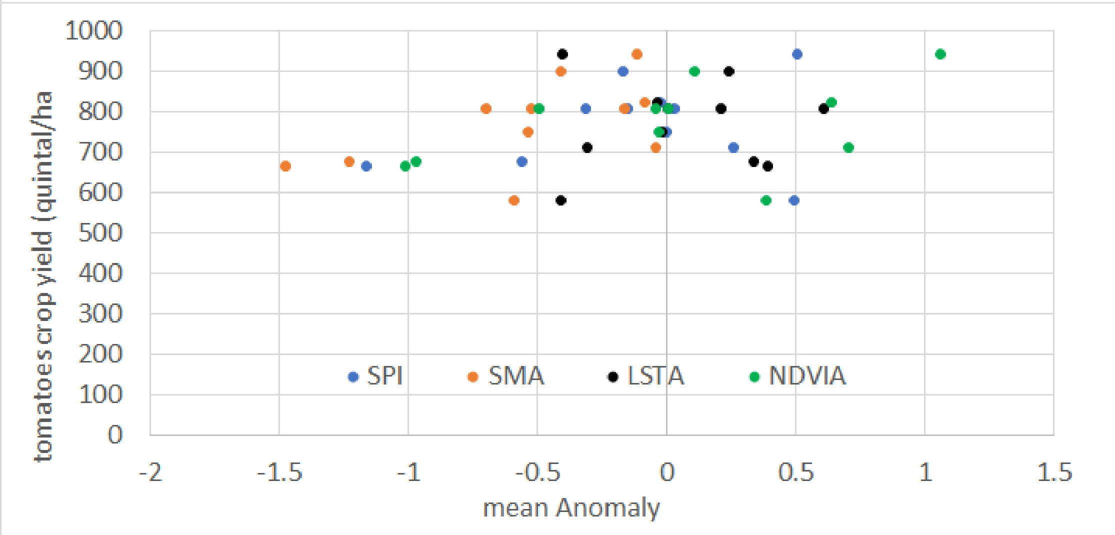
7.00E+07
6.00E+07
5.00E+07
4.00E+07
3.00E+07
2.00E+07
1.00E+07
0.00E+00
-2
-1.5
-1
-0.5
0
0.5
1
1.5
y = 2E+07x + 5E+07
R² = 0.5915
y = 2E+07x + 6E+07
R² = 0.4053
y = -6E+06x + 5E+07
R² = 0.0179
y = 1E+07x + 5E+07
R² = 0.2648
SPI
SMA
LSTA
NDVIA


volume cum aqueduct + raifall (m3
mean Anomaly
1.23E+09
1.03E+09
8.30E+08
6.30E+08
4.30E+08
2.30E+08
3.00E+07
-2
-1.5
-1
-0.5
0
0.5
1
1.5
y = 5E+07x + 8E+08
R² = 0.0233
y = 1E+08x + 8E+08
R² = 0.1834
y = -1E+08x + 8E+08
R² = 0.1495
y = 5E+07x + 8E+08
R² = 0.0838
SPI
SMA
LSTA
NDVIA


tomatoes crop yield (quintal/ha
mean Anomaly
1000
900
800
700
600
500
400
300
200
100
0
-2
-1.5
-1
-0.5
0
0.5
1
1.5
SPI
SMA
LSTA
NDVIA

- .83. I wonder if the authors are proposing a drought monitoring system or a drought index. I believe that they are developing a drought index.

Answer: yes, we indeed are proposing a drought index, to be employed for monitoring of possible drought conditions.

- .91. A new drought index should be evaluated with impact data (e.g. crop damages and yields). The volumes of irrigation may be related to several other factors including water availability in reservoir storages, groundwater, etc.

Answer: thanks for the comment on which we agree. In fact, in Figure.13 we correlated the yearly measured total yield of the main types of crops in the two areas with the ADMOS yearly value. However, both areas are highly irrigated, so that no big differences are found in terms of crop yields in the different years. Therefore, it becomes important and significant to consider the impact of drought on irrigation volumes. We agree that availability also depends on groundwater and the filling availability of reserves, but this would be directly reflected in the volume of water which was effectively used for irrigation. This use also depends on the need for plants and therefore on the weather conditions. Thus, we think that correlating the ADMOS index with the effective water use for irrigation is an effective way of demonstrating that a particular season was drier than another. In Figure.12 a clear correlation is in fact observable.

- .105. Crop yield is also constrained by VPD anomalies sand increases in the atmospheric evaporative demand, particularly under low soil moisture conditions.
  .106. Increase in crop temperature can be also caused by decreased leaf stomatal conductance as consequence of increased VPD.

Answer: Crop yield of course is mainly constrained by soil water availability, VPD or air temperatures. All these aspects are indirectly taken into account by considering in the ADMOS index, the vegetation anomaly and the land surface temperature one, which directly show if crop is under stress (which could be due to water, temperature…).

- .115. Are the different variables following a normal distribution in order to apply this equation?

Answer: we believe that there has been a misunderstanding here. In this case, we are not making any assumption about the normality of the different variables, since we are not comparing them or processing them in any way. We are only determining the sign of the anomaly, i.e., whether the single values are below or above average. The procedure described in equation 1 is necessary only to provide a sign of the variability with respect to the average and to have an overall idea of the oscillations of the variables, each with respect to their mean. Numerous meteorological and drought-detection applications involving anomalies do not require any normality of the variables of interest, as for example done in Blenkinsop and Fowler (2007) and Phillips and McGregor (2001).

1. Blenkinsop, S. and Fowler, H.J. (2007), Changes in European drought characteristics projected by the PRUDENCE regional climate models. Int. J. Climatol., 27: 1595-1610. https://doi.org/10.1002/joc.1538
2. Phillips, I.D. and McGregor, G.R. (1998), The utility of a drought index for assessing the drought hazard in Devon and Cornwall, South West England. Met. Apps, 5: 359-372. https://doi.org/10.1017/S1350482798000899

- .117-120. It is confuse if the authors are using the monthly or daily scales.

Answer: we thank the reviewer for this question, which helps us to clarify this point that has been also raised by other reviewers. The anomalies are computed using the daily data (e.g. when available according to satellite acquisition time) and normalized according to the long-term mean daily values. The only index computed at monthly scale is the SPI-1 as for its definition related to 1 month anomaly. The index at this time scale might be useful in a on-demand irrigation scheme (as the Capitanata case study), to know the evolution of water availability as well as crops conditions and to infer the possible increase or decrease of irrigation water requests from the farmers allowing to better manage the water at Consortium scale at the same time scale of the operating water management system.

- .124. Figure 1 is confuse. It is not clear how the different indices are merged in order to generate the ADMOS. What is the criterion followed to select the thresholds?

Answer: the ADMOS is structured as a "point-system" index. Any time that one of the conditions detailed in the figure is verified, a point (or half point) is deducted. The half points were used to describe milder conditions, with the given anomaly (in absolute value) between 0 and 1, meaning that the value was different from the average, but still it was found within one standard deviation of the average. In joint response to another reviewer, an updated version of fig.1 has been developed (Fig.A), shown below.

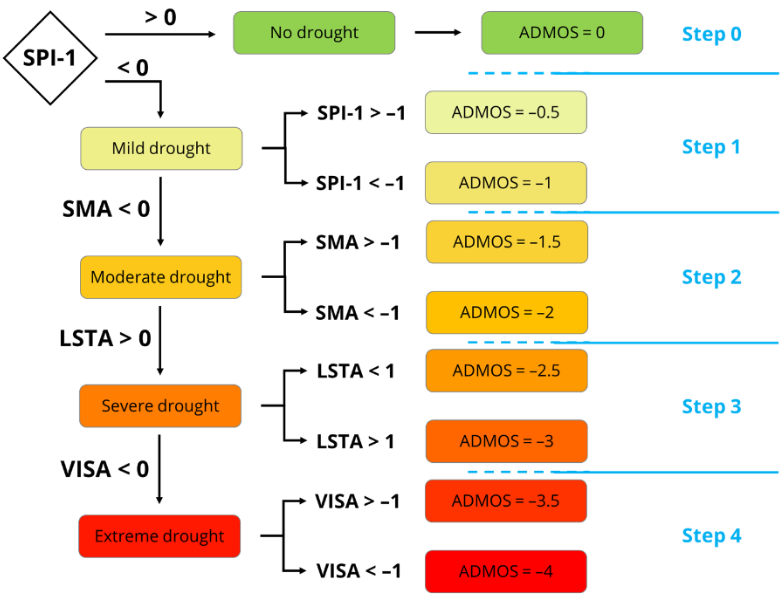


Fig.A Improved version of Fig.1 from the manuscript, detailing the ADMOS workflow/flowchart

- .130. Are equations 2 and 3 necessary? I do not think necessary to include the equation of the Pearson's r statistic.

Answer: we wanted to include all the equations and not give anything as known. Nevertheless, we will remove these equations in the new revised manuscript.

- .142. was affected? As the sentence refers to 2012 I think better use the past. Same 143.

Answer: thanks, we will correct these English issues in the new paper version.

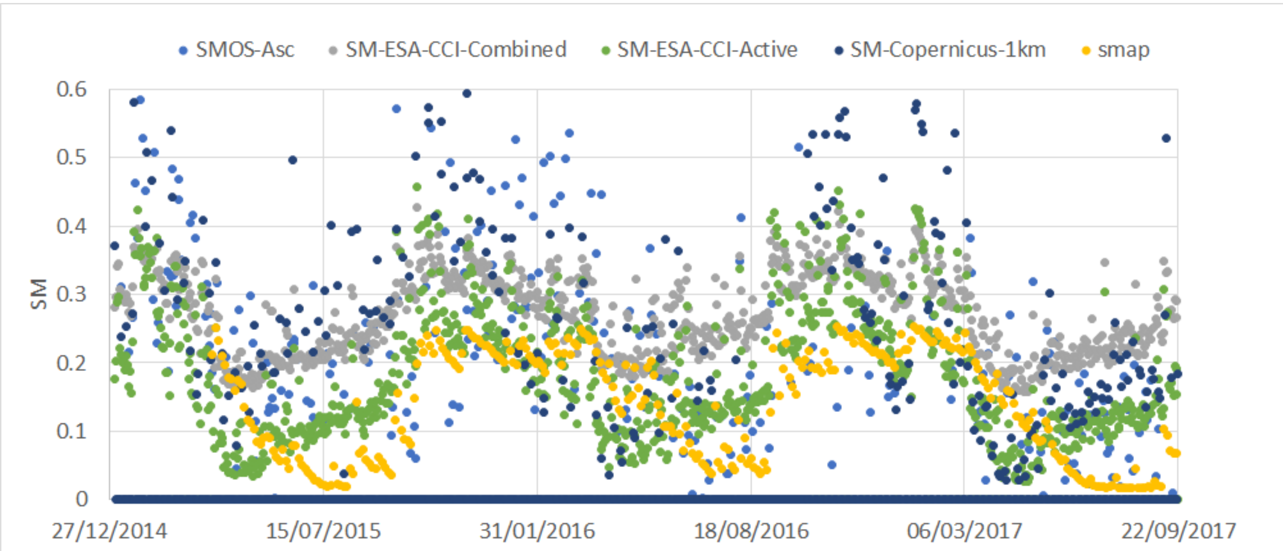
- .159. How robust is the calculation of SPI and the other drought indices based only on 20 years of data? e.g.in 168 in is indicated that 13 years of data are used. This will provide very uncertain indices. WMO recommends at least 30 years.

Answer: We agree on this. The SPI-1 index is computed using both ERA-5 data and ground stations network. The ERA-5 data are from 2000 to 2020, while the ground data are available for shorter time periods. So that the precipitation SPI-1 is calculated using both dataset and compared (section 3.1), showing a between the SPI series a RMSE of 0.33 mm and Pearson coefficient of 0.92 for the Capitanata Consortium, and similarly for the Chiese Consortium area with a RMSE of 0.52 mm and a r of 0.97. We will make this clearer in the text.

- Section 22.3. It is very confuse how all these soil moisture indices of different resolution and time span are used together. There is not explanation and justification of why these different soil moisture products are used and what is the advantage of using different datasets if they show low agreement.

Answer: soil moisture products from remote sensing are widely diffused in numerous kinds of applications and provide valuable information on spatial variability, especially over large areas (Babaeian et al., 2019). Nevertheless, as for other remote sensing products, some issues on uncertainties are present. Different works compare these soil moisture products: an example is offered by Cui et al. (2017), who tested SSM data from SMAP, SMOS, AMSR2 and ESA-CCI, among others, obtaining medium-to-high correlations with ground data (ranging from the 0.48 of AMSR2 to 0.89 of SMAP); another by El Hadjj et al. (2018), who compared SMOS, SMAP, ASCAT, and Sentinel-1 SSM products, also employing on-ground measurements and obtaining slightly better correlation results for SMAP (higher than 0.6) than ASCAT (around 0.5) and SMOS (lower than 0.5). A similar comparison was also performed by Paciolla et al. (2020), who contrasted each product with the precipitation occurred in each pixel, computed from ground stations. Medium-level correlations were found between the two, varying heavily from one dataset to the other.

In the image below, we compared the average SM values over the Capitanata consortium (plotted for simplicity only from 2015 to 2017), to provide an idea of the variability between the datasets. In general, all products are showing a similar dynamic, but with quite different values. SMOS and SMAP (L-band products) have similar shapes in the detecting the low SM periods. Another issue between the products is their consistency with water inputs (precipitation and artificial irrigation), as discussed in Paciolla et al. (2020).



Given this heterogeneity, we felt that choosing a single product and limiting out analysis to that product and that product would capture only partially the spectrum of possible values. Thus, we decided that employing the different products all together would lead to an increase in robustness for the whole ADMOS methodology.

1. Cui, C.; Xu, J.; Zeng, J.; Chen, K.-S.; Bai, X.; Lu, H.; Chen, Q.; Zhao, T. Soil Moisture Mapping from Satellites: An Intercomparison of SMAP, SMOS, FY3B, AMSR2, and ESA CCI over Two Dense Network Regions at Different Spatial Scales. Remote Sens. 2017, 10, 33
2. El Hajj, M.; Baghdadi, N.; Zribi, M.; Rodríguez-Fernández, N.J.; Wigneron, J.-P.; Al-Yaari, A.; Al Bitar, A.; Albergelb, C.; Albergel, C. Evaluation of SMOS, SMAP, ASCAT and Sentinel-1 Soil Moisture Products at Sites in Southwestern France. Remote Sens. 2018, 10, 569
3. Paciolla, Nicola, et al. "Irrigation and precipitation hydrological consistency with SMOS, SMAP, ESA-CCI, Copernicus SSM1km, and AMSR-2 remotely sensed soil moisture products." Remote Sensing 12.22 (2020): 3737.

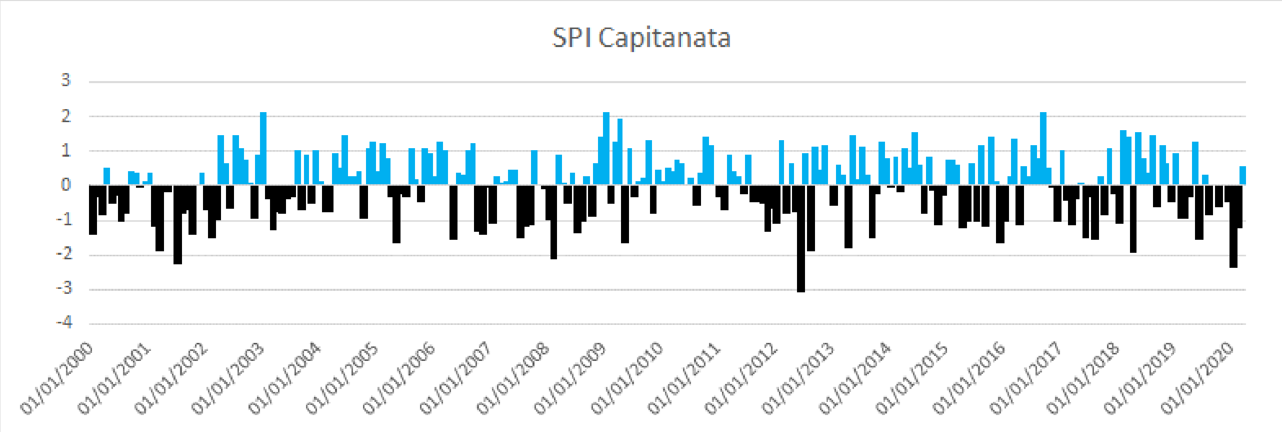
- .214. Why thermal bands are resampled to 100 meters?

Answer: the original LANDSAT8 data are collected directly at 100m, but we resampled them at 30 m to be consistent with the other datasets.

- Figure 3. It is impossible to identify the drought periods according to the SPI based on this plot. I would suggest to be replaced all the plots by time series.
- Figure 4. Same that for precipitation. I do not think it is possible to compare these different datasets based on these plots. The statistics that compare the datasets suggest strong uncertainties and difficulties for comparison. I do not think that the authors are providing realiable combination of the different datasets and, in addition, validation is not provided.
- Same comments are valid for surface temperature and vegetation indices. My impression is that authors have used all the information they have found by different sources, but they have not considered any coherent approach to analyse drought severity, to validate the different products and to stablish uncertainties associated to the datasets. In addition, the information is not showed in a coherent way and it is very difficult to determine the evolution of the anomalies in the different metrics and also to establish comparisons.
- 549: But the remote sensing information is not used in a coherent way considering a careful validation. Several datasets are put together considering different time periods and I cannot find a coherent message by so confuse merging.

Answer: Thanks for the comments, we respond here to the group of the last three comments on a similar topic.

Regarding the plots by time series, we believe that the simple time series plots increase the confusion in the reading and interpretation of data, so that we chose the kind of plot present in the paper on purpose. Below we provided some time series plots of the single variables and, as you can see, it is difficult to detect any seasonality in the values across the different years. The whole thing results poorly comprehensible, whereas in our original plots you can easily compare the values for a given month/period across the different years, for the SPI and the other variables.


SPI Capitanata
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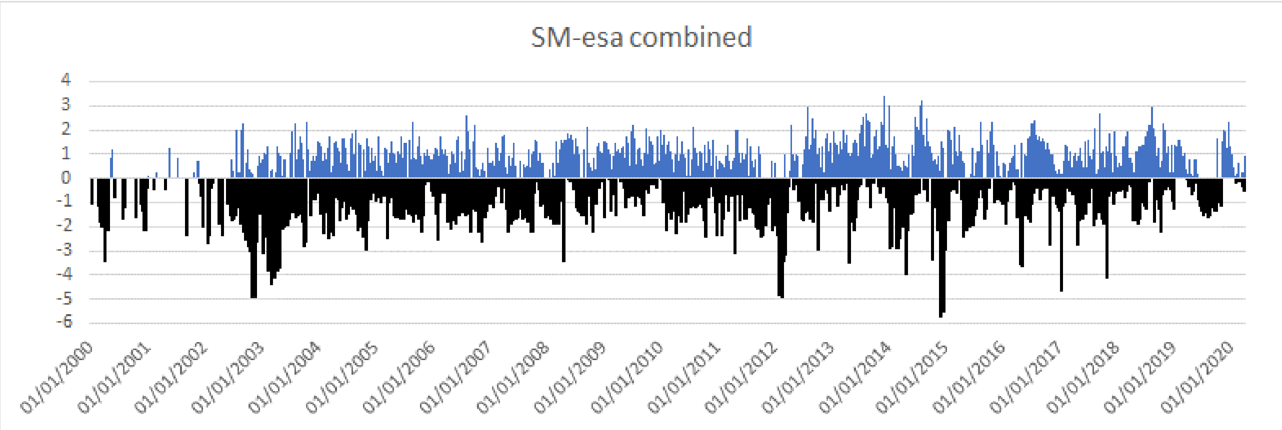
SM-esa combined
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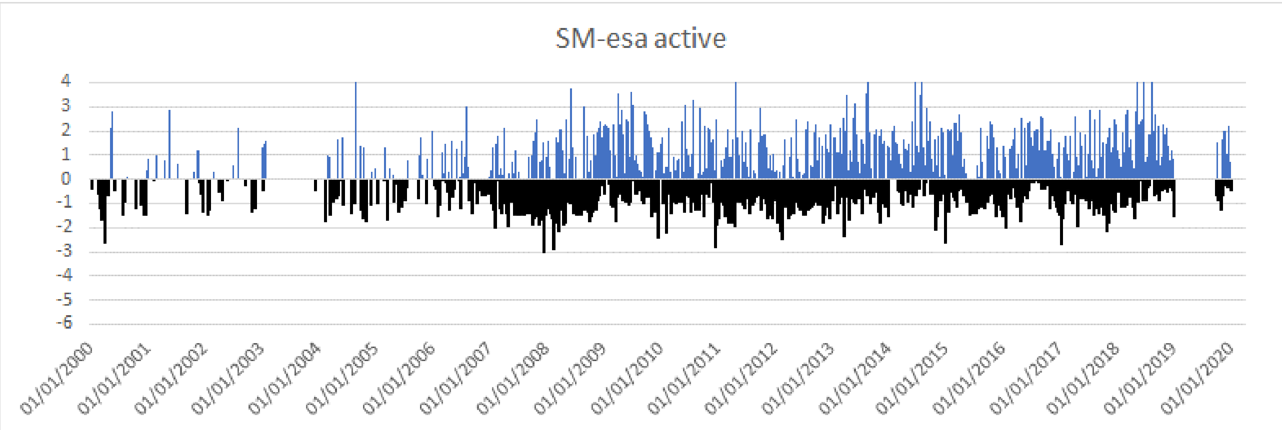
SM-esa active
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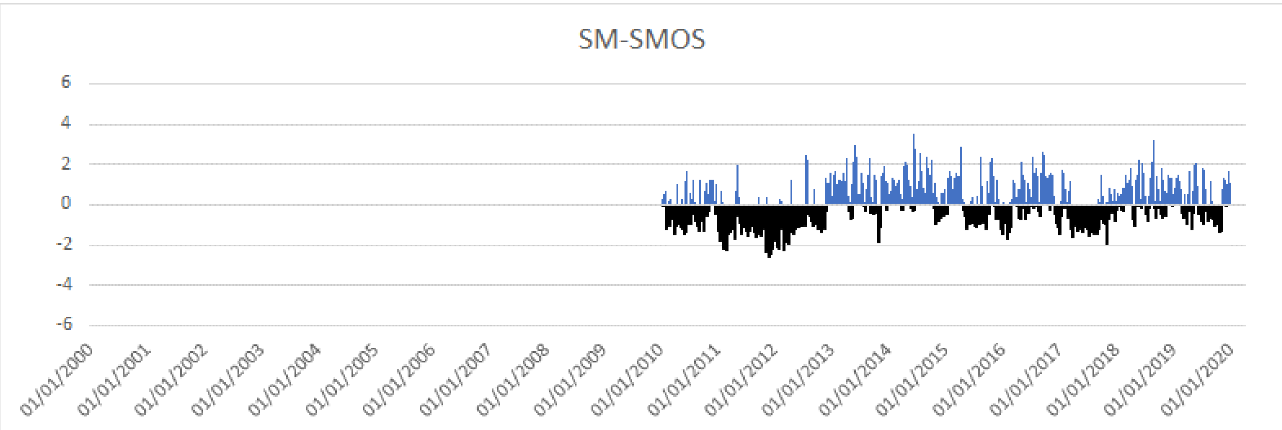
SM-SMOS
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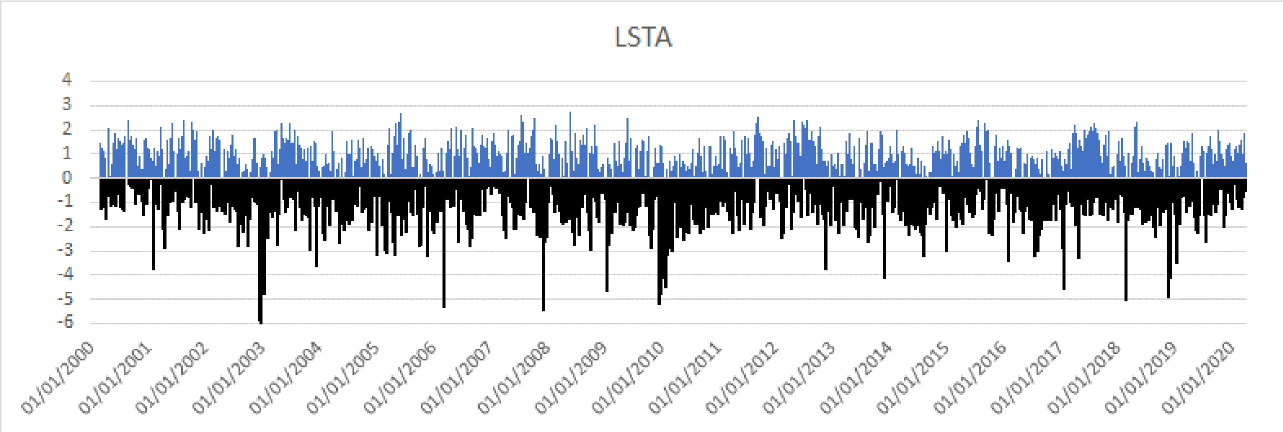
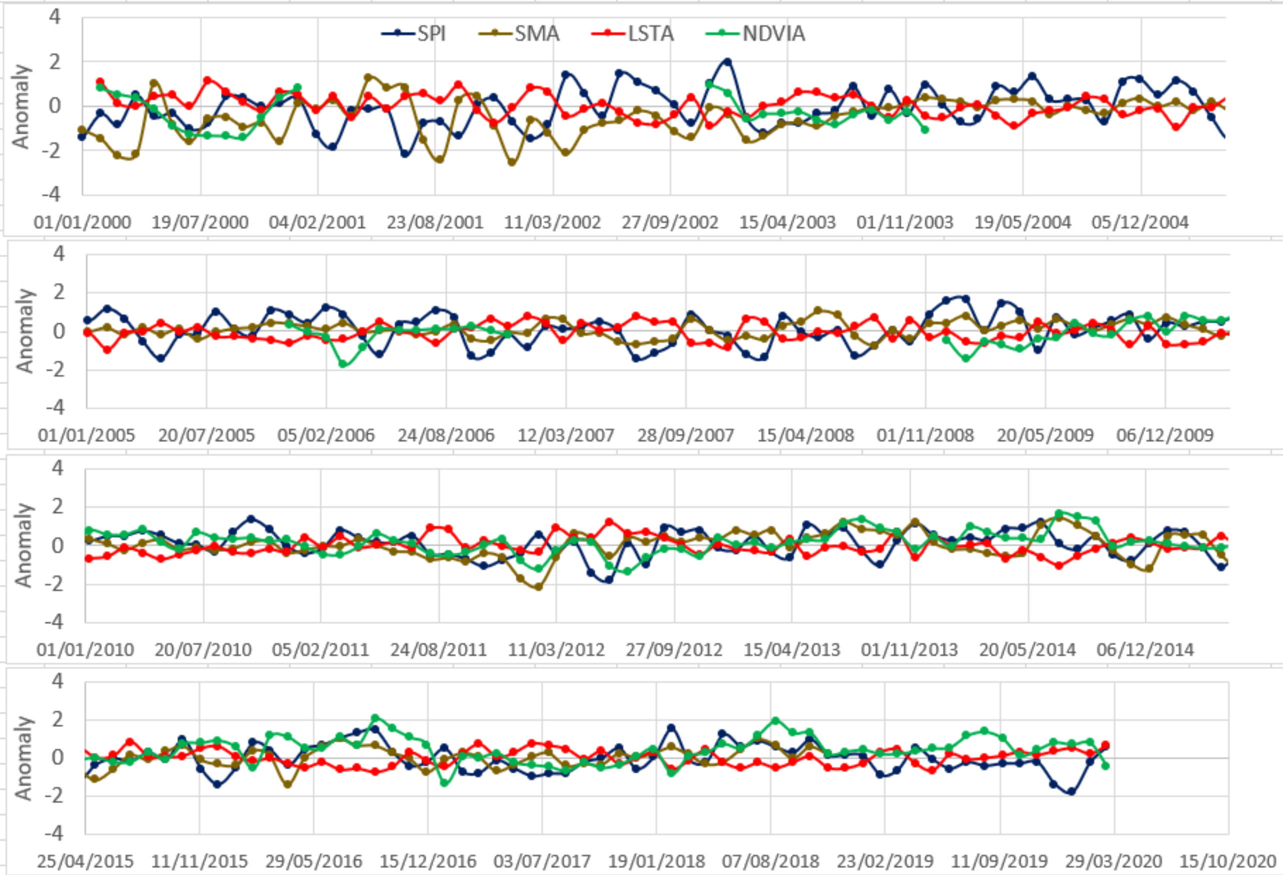


Regarding SM, as replied also to other comments, soil moisture products from remote sensing are widely diffused in numerous kinds of applications and provide valuable information on spatial variability, especially over large areas (Babaeian et al., 2019). Also given the heterogeneity and uncertainty of SM products from remote sensing, we felt that choosing the different products all together would lead to an increase in robustness for the whole ADMOS methodology.

Figures 4, 6, 7 and 8 allow the comparison among RS sources, providing a way to understand the possible uncertainties and differences that are present among the various sources of information.

However, we agree that, for the comparison of the different anomalies, we could add a single time plot series with monthly aggregated values. Below we provide an example for the Capitanata dataset, where the SPI negative anomaly of July-August 2011 is followed by a high negative SMAI in August-September and followed by a positive LSTA. Similarly in the summer of 2012, where negative SPI and SMAI are followed by positive LSTA and negative NDVIA. The one for Chiese will also be added in the revised version of the manuscript.



Precisely because these SM data may have uncertainties, but at the same time are widely used, the robustness of the presented approach is based on a combined use of these data. In Table.2 all the products are intercompared, providing evidence of the uncertainty of the different datasets.

If with Validation you mean the validation of remote sensing products we can argue that we did not developed own products but we used already available and validated ones. Moreover, when comparing local sparse ground data with remote sensing ones, the scale and representativeness of both data need to be considered. Instead if for validation you mean of the entire index, to reinforce the strength of the methodology each single anomaly is now correlated with the irrigation volume and crop yield (as shown in one of the previous comments).

- Figures 9 and 10: Based on the uncertainties in the datasets and methods indicated above, the uncertainty in the results described based on these figures are very strong. It is not possible to infer on which dataset (e.g. soil moisture, surface temperature and vegetation index) this plot is generated.

Answer: Thanks for the comment, which helps us to correct this oversight in specifying the dataset used for Figure.9 and 10. Actually, in fact, the datasets on which the different drought conditions are based will be specified: SPI ERA-5, SMA ESA-CCI combined, LSTA and NDVIA MODIS.

- .445. I cannot identify how the different products are combined in order to generate the ADMOS and it is very confuse the use of different data products at the same time and in an independent way.

Answer: as described in the methodology section, each product is analysed in terms of anomaly and, if the conditions detailed in Figure 1 are met, the corresponding ADMOS level is assigned to each day. We developed a more clear version of fig.1 to better convey its message (fig.A here below).

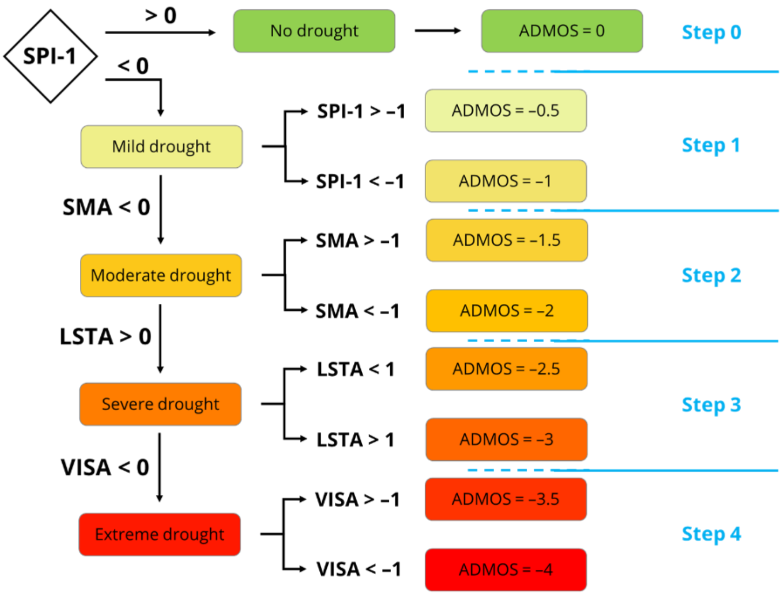


Fig.A Improved version of Fig.1 from the manuscript, detailing the ADMOS workflow/flowchart

- .545: I agree that different indices are compared, but this is not done in this study. There is not validation of different metrics and selection of most suitable according to empirical information.

Answer: As replied also to the previous comment, we agree with you that such a comparison would be a valuable addition to the workflow of the whole paper. We will add these comparisons to the final version of the work.