Review of the manuscript

Dynamics of the Mediterranean droughts from 850 to 2099 AD in the Community Earth System Model

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General comments

The authors investigate drought dynamics in a simulation with a comprehensive Earth System model during the last millennium and for a future GHG emissions scenario over the Mediterranean area. Their main results of the analysis of the climate simulation relate to a dominating influence of internal climate variability controlling drought in the pre-industrial times and hypothesize a stronger influence of external forcing factors, i.e. the increase in GHG concentrations for the historical period and even more pronounced for the GHG emission scenario.

The manuscript is well organized and written. In addition, the investigations include a comparison of different methods and what I really would like to emphasize, include the analysis of driving mechanisms controlling drought over the Mediterranean area, for instance related to large scale modes of atmospheric and coupled atmosphere-ocean dynamics. To my knowledge it's also the first study addressing drought dynamics specifically over the European Mediterranean area for the last millennium which makes it an important contribution for both, the modelling and the proxy community.

Below I listed a number of issues to improve the manuscript and to assess the model results in comparison with observational evidence.

Abstract

The abstract is brief and concise and summarizes the main conclusions of the study – maybe the authors can add some additional sentences on the uncertainties and limitations of the model-only study and include some basic statements on the suitability of the CCSM model to be used for drought studies over the Mediterranean realm.

1 Introduction

The authors should include a chapter on a more detailed description of the mean climatic characteristics of the Mediterranean area, especially during the winter half year when most of hydroclimatic variability plays a role. Moreover, it would be illustrative to elaborate in greater detail the spatial differences in hydroclimatic variability between the western and eastern Mediterranean area concerning the annual cycle (cf. references at the end of review by Dünkeloh and Jacobeit (2003), Luterbacher et al. (2006), Trigo et al. (1999), Peyron et al., (2017)).

A second point that might be also motivated in the introduction is why only a single model simulation with PMIP3-like forcings is investigated. Admittedly, the spatial resolution is one of the biggest advantages of the simulation, but also other simulations could have been addressed, especially when large-scale areal averages are analyzed. Authors should try to motivate why CCSM4 in this version is outstanding and suited for drought investigations over the Mediterranean area. (cf also Coats et al. (2015) for a model-only studies over North American droughts)

2.1 Description of the model and simulations

The CCSM model has a very high spatial resolution, but I was wondering why the vertical resolution is quite low, consisting of only 26 levels. A number of PMIP3 models use a lower spatial resolution but with a considerably higher vertical resolution. I mention this issue because it might have important implications for the atmospheric dynamics, controlling precipitation variability, both spatially and temporally, over the Mediterranean area. Hence, a realistic simulation of those processes is pivotal for a realistic simulation of drought (or non-drought) dynamics.

The authors mention the orbital forcing is set to 1990 AD conditions for the control simulation – I guess this also applies for the transient simulation. Which effects could this have when the orbital parameters are not varying concerning the radiation changes, especially during the summertime in the course of the last millennium ?

Also, as the Mediterranean area in the northern region has a very vulnerable vegetation cover that is also important for hydrological dynamics, some words on the reconstruction and potential changes in land cover over the area would be informative for the readership. Likewise, the authors mention the soil model consisting of 15 layers, which is quite extensive for a global Earth System model. As soil dynamics also play a central role in the investigations carried out at a later stage, authors should add some more information on the soil model and highlight its importance, especially over the Mediterranean area.

2.3 Drought definitions

As I mentioned previously, I like the approach addressing several drought-related and quantifying indices, as results might be dependent on the respective metric used. I missed however a comparison of the general hydrological cycle for present-day climate in comparison with observational and/or re-analysis data sets. I suggest to at least perform a validation for i) the winter season for precipitation spatially resolved over the Mediterranean area and ii) the annual cycle separated over the western and eastern and northern and southern Mediterranean (cf. links for data sources at the end of this review) in the 2nd half of the 20th century. This is important to test whether the model is capable to reproduce the main climatic features in important on investigations in the context of drought (cf. López-Moreno et al., (2009) for present-day situation).

A second issue here is the question why the authors do not present a spatially resolved analysis for their study region. The areal extent of their region is quite large and planetary wave train structures might affect the area at the same time with different impacts. For instance, a ridge structure over the western Mediterranean can be accompanied by a trough structure at the same time over the Eastern Mediterranean with profound differences related to the hydrological impacts. A consequence might be that in situations with non pan-Mediterranean droughts, those dipole structures between east/west and north/south are cancelled out and the respective areal averages only contain a residual component that is not related to atmospheric circulation dynamics. Maybe the authors could at least mention how the usage of areal average might affect their conclusions.

3.1 Quantification of droughts events over the Mediterranean: Selection of a drought index.

A general issue investigating droughts over semi-arid regions like the European-Mediterranean area with a pronounced annual cycle relates to the high (mulit-annual) temporal and spatial variability of the availability of water resources. Therefore, drought or periods with scarcity of water are an intrinsic part of the climatic conditions over those regions. Likewise, this also applies for the opposite case with strong torrential rains leading to flooding and disastrous destructions over the respective areas. I think those points should be mentioned here or earlier in the introduction to put the drought terminology into context, underpinning that dry conditions are an integral part of the climate over those areas. Other, non climatic factors, for instance related to geology in terms of limestone with a high potential to effectively store water during winter and release it during summer could be mentioned. In addition, human impacts with steadily increasing demand for water resources play an important role interfering with the direct climatic driven changes in drought dynamics.

3.3 Dynamics of multi-year droughts

I liked this part because it links the (regional) drought dynamics over the Mediterranean area with large scale modes of atmospheric (NAO) and atmosphere-ocean (ENSO) variability. However, especially in terms of ENSO I suggest to use a more objective test metric, because in my opinion the numbers are not really convincing for a robust inference which state of the ENSO precedes Mediterranean droughts. The authors should motivate their definition of a positive NAO / ENSO state that should considerable deviate from mean or neutral conditions. For instance, the threshold values of the SST anomaly over the tropical Pacific is set to ±0.5 K. Authors might use a metric based on percentiles of the according index-PDFs and investigate the situation separated into full period and drought prone years to test the robustness of the according conclusion. This could eventually also allow a quantitative differentiation in moderate/strong events for NAO and ENSO and their impacts on Euro-Mediterranean droughts.

3.4 Historical and Future conditions on droughts: 1850 to 2099 AD

The authors use a very strong GHG scenario – I wonder how results change in simulations with less pronounced increase in GHG. Moreover, how can changes in vegetation cover and/or human water consumption play into drought dynamics purely based on climatic considerations ?

In this context it is again important to ask about the consequences if the main controlling factors (e.g. atmospheric circulation, Trigo et al., (1999)) are not realistically simulated. Are the models really able to realistically mimic the (change) of atmospheric circulation over the past and the following years ? This is especially important, given the fact that Mediterranean precipitation is characterized by very short-lived and very intense precipitation events initiated by meso-scale circulation patterns (e.g. Genoa low) that might not be represented well enough in those models.

4 Conclusions

The conclusions are a good summary – what I think is important to add one or two chapters with more critical comments and insights on the limitations and uncertainties involved in the study (e.g.

only single model used, validation of atmospheric circulation dynamics, importance of non-climatic events for drought dynamics), and also the implications in the context of model-proxy comparisons.

Minor comments:

Figure caption: If possible, please add below the technical description of the Figure a short sentence what are the main contents of the Figures for a better overview for the reader on the main conclusion of the respective plot(s).

Figure 1: Please include latitudes and longitudes in the figure – why is the eastern Mediterranean region not completely included into the analysis ?

Additional data for comparison

https://crudata.uea.ac.uk/cru/data/hrg/

https://www.dwd.de/EN/ourservices/gpcc/gpcc.html

Additional references

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