1 Response to Reviewer #2's comments

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General comments

The authors discuss the causal effects of climate modes on past and future (global) evaporation using an ensemble of simulations. With a (relatively) simple metric the authors show whether changes in (land or ocean) evaporation are likely to be caused by climate modes. The authors have done an impressive literature study, which backs up their own data-rich analysis. The main conclusion is basically that individual climate modes have effects all over the globe. The potential of this paper lies in using such a wealth of data (causal effects of different climate modes on global evaporation and its consistency across an ensemble of climate model simulations). In the end, most of the results are presented separately (per climate mode). I would advise to synthesize all causal effects of different climate modes in one global figure, where the authors could show in which regions (past or future) which climate mode is dominant. The text abundantly mentions which areas are influenced most by which climate mode, but visualizing this in a figure would give a much better overview in my opinion.

Response: We thank Reviewer Jasper Denissen for helpful comments. In this document, the responses to the Reviewer's comments are provided below in **blue text**. The Reviewer's comments are shown in **black text**.

We added Figure 7 as a summary for the dominance of individual climate modes on regional evaporation as below. We chose to only show the regions with p value less than 0.25, (i.e., climate modes are unlikely to have no causal effects on evaporation (Stocker et al., 2013)).

We also added the corresponding text to Discussions section:

"The dominance of an individual climate modes on evaporation is summarized in Figure 7 for historical and future periods. Figure 7 shows the regions where the lowest probability for the absence of Granger causality between climate modes and evaporation is less than 0.25 (i.e., climate modes are unlikely to have no causal effects on evaporation). This result indicates the important role of ENSO on global evaporation."

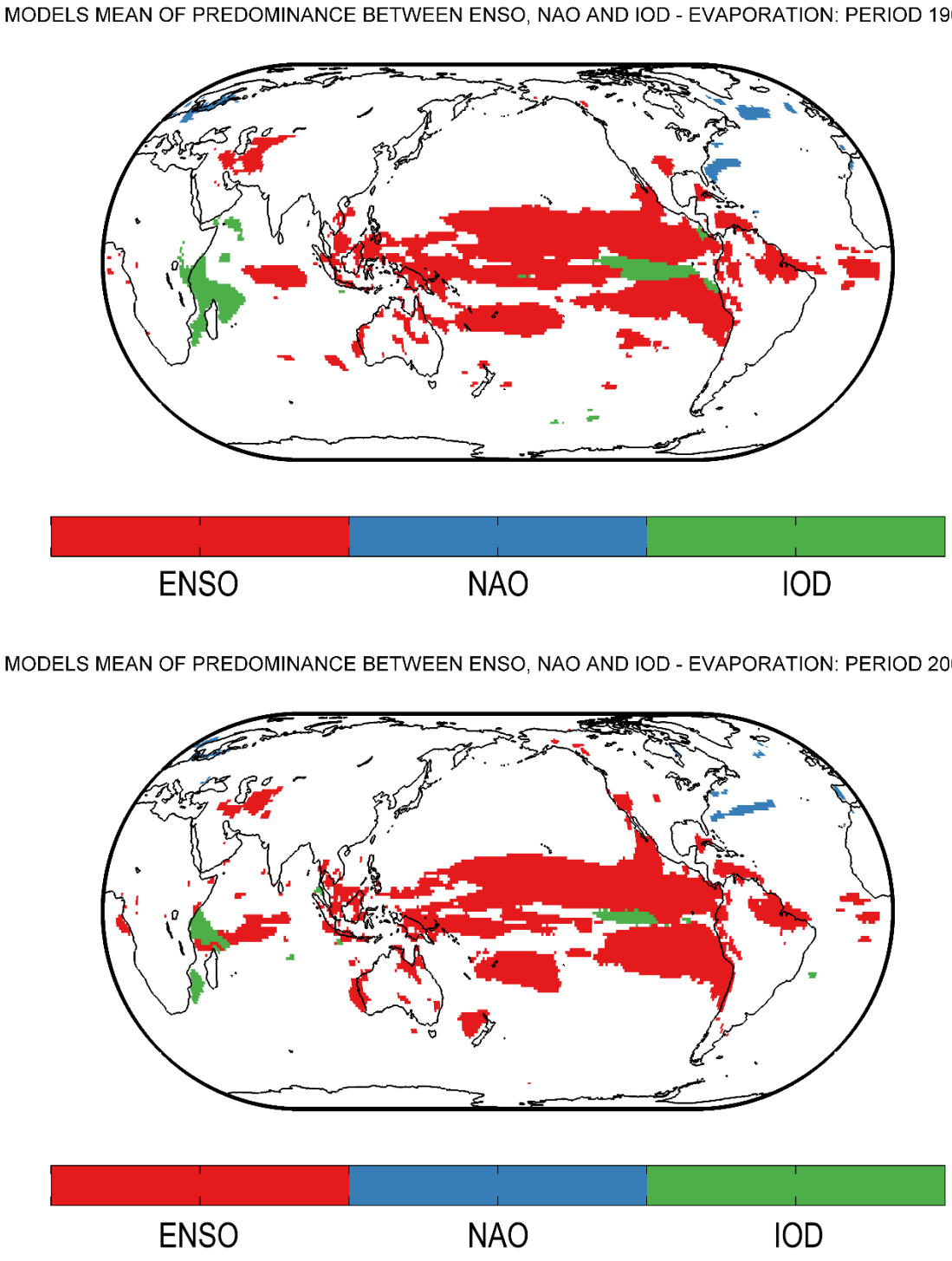

Figure 1. The predominance of single climate mode on regional evaporation for periods 1906-2000 (a) and 2006-2100 (b). The predominance of a climate mode at a grid point is defined when the lowest *p* value of all climate modes (see also Figures 1, 2 and 3) at the given grid point is less than 0.25 (i.e., climate modes are unlikely to have no causal effects on evaporation). The predominance of ENSO, NAO and the IOD on evaporation are shown in red, blue and green shades, respectively. ENSO = El Niño–Southern Oscillation. NAO = North Atlantic Oscillation. IOD = Indian Ocean Dipole.

Specific comments

• Line 43: "Besides, evaluating the models' consistency in reproducing the impacts of internal climate variability on evaporation is important for understanding the difference between models". I do think this is important, but hardly mentioned in the paper. This could be emphasized more (in the abstract/conclusions?).

Response: We thank the Reviewer for raising this point. We discussed the consistency of model simulations in Section 3. For example: "There is high agreement between models (indicated by stippling in Figure 1) in simulating ENSO-evaporation connection of these regions. Specifically, high agreement of climate models in teleconnection between ENSO and tropical oceans evaporation implies that models can simulate the impacts of ENSO on evaporation."

and

"In historical simulations (Figure 2a), the IOD impacts might reach as far as the Southern Ocean (region close to 150°W to 120°W; 45°S to 60°S) where there is high agreement between models."

and

"NAO mainly contributes to change in evaporation of the North Atlantic European sector where high agreement between models is found (see Figure S7 for additional details)."

We added the following sentence to the Abstract and Conclusions as your suggestion:

"There is high agreement between models in simulating the effects of climate modes on evaporation of these regions."

• Line 54-55: Why are the starting/ending years 'roughly' and not exactly...?

Response: Most models have exactly starting/ending years of 1850/2005 for historical simulation and starting/ending years of 2006/2100 for future simulation. Several models have different starting/ending years. For example, model MIROC5 has the ending year of 2012 in historical simulation. We think it is more correct to use the word 'roughly'.

• Line 59: From which climate model does 'rlilpl' come? Why only one member?

Response: All models have the simulation r1i1p1. Using one ensemble member per model is a simple way to guarantee the "one model, one vote" rule (Knutti et al., 2010). Here we use 15 different models for the analysis, this common approach is widely used and helps to reduce the uncertainties. We added the following text to Section 2.1 to clarify this point:
"As we use 15 different models for our analysis, the uncertainties related to the effects of climate modes on evaporation are reduced. The results based on multi-model mean were shown to be better and more reliable than single model results (Weigel et al., 2010)."

• Line 61-62: "Most of climate models do not provide separately the data of evaporation from canopy (i.e. transpiration) and water evaporation from soil (i.e. evaporation)." What does this mean for this research? I miss a connecting sentence here. Maybe append something like: "which complicates attributing changes in evaporation to canopy or soil related processes."

Response: We thank the Reviewer for this suggestion. We rewrote this sentence as follows:
"Most of the climate models do not provide separately the data of evaporation from canopy (i.e. transpiration) and water evaporation from soil (i.e. evaporation) which complicates attributing changes in evaporation to canopy or soil related processes. Hence, the term 'evaporation' used in this study is referred to both transpiration and evaporation."

• Line 65: "…, CMIP5 data is useful…" Why is the data useful? Because of the abundance of data based on climate models with slightly different assumptions?

Response: The CMIP data is useful as they help to better understand past and future climate change, not only because the abundance of data. In fact, all models are not correct and climate models still have great uncertainties. Hence, using the results from multi models are important to reduce these uncertainties.
We rewrote this sentence as follows to clarify this point:
"However, CMIP5 data is useful for better understanding of past and future climate and provides additional understanding about the connections between major climate modes and global evaporation."
We also mentioned the usefulness of climate model simulations in the Introduction as follows:

"As long term and reliable evaporation data is lacking (e.g., Hegerl et al., 2015; Miralles et al., 2016), climate model simulations provide additional opportunity to examine the impacts of main climate modes on global evaporation."

• Line 73-74: Why focus on the tropical Pacific, tropical Indian and North Atlantic Oceans with the mentioned climate modes? Please motivate why these (and related climate modes) are in focus.

Response: We added the following sentence to the Methods section to clarify this point:
"These climate modes are the main sources of global climate variability at interannual timecales (e.g., Abram et al., 2003; Hurrell et al., 2003; McPhaden et al., 2006)."

• Line 79: Please elaborate on what the order of the causal model means.

Response: We rewrote this sentence as follows to clarify the meaning of the order:
"…$p \geq 1$ is the order (or the number of lagged time series) of the causal model…"

• Line 90: What is it that makes the applied techniques necessarily robust?

Response: We think the applied techniques (i.e., Granger causality test) are well established for detecting causal effects. We rewrote the Methods section as follows to clarify this point:
"We apply test of Granger causality for the predictive model described in equation (1). Specifically, in order to assess the causal influence from Y to X, we compute the probability of the null hypothesis for an absence of Granger causality from Y to X. The model shown in equation (1) is defined as a complete predictive model where all variables (i.e., past data of evaporation and climate indices) are used to estimate evaporation. The null model of no causal effects from given climate mode (i.e., variable Y) to evaporation is defined by removing the terms related to Y (i.e., by setting $\beta_i = 0\ with\ i = 1, \dots, p$) in equation (1). The complete model and the null model are then compared by using the following indicator:

$$L_{Y \to X} = n(\log\left|\Omega_{p,\beta_i=0}\right| - \log\left|\Omega_p\right|)$$

where $|\Omega_p|$ is the determinant of the covariance matrix of the noise residual, and n is the length of the data time series. We test the significance of the complete model by comparing the $L_{Y \to X}$

indicator against a χ_p^2 null distribution. This test results in a probability for no causal effect of the considered variable Y on evaporation."

• Line 100-102: "Specifically, high agreement of climate models in teleconnection between ENSO and tropical ocean evaporation implies that models can simulate the impacts of ENSO on evaporation." Why does a high agreement between models necessarily signal a capability to simulate impacts of ENSO on evaporation?

Response: We thank the Reviewer for raising this point. The map of ENSO-evaporation connection presented here (Figures 1 and S1) confirm the results obtained previously (e.g., ENSO influence on evaporation of Australia and Amazonia where there is high consistency between models as shown in Figure 1 and S1). Thus, we think this result show the capability of the models. However, there is uncertainty in some other regions.

We removed this sentence to avoid confusing the readers.

• Line 105: Why focus on two significance levels and not just on one? If two significance levels are necessary, please indicate why.

Response: The purpose of using two significance levels is only for visualisation. In Figures 2 and 3, the region with 5% significance level is too small (e.g., for the effects of NAO and the IOD) and we think it would be useful to provide additional information with 10% significance level. In some cases, different significance levels should be used to show different level of uncertainty (e.g., Stocker et al., 2013).

• Line 145: Figure S3 and S4 do not show seasonal responses of evaporation to the IOD. Do you mean Figure S5 and S6?

Response: We thank the reviewer for pointing this out. We corrected to Figure S5 and S6 for the seasonal responses of evaporation to the IOD.

• Line 170: The differences in Fig. 4 do not imply unique combinations: a difference of -.1 can result from Granger causalities 0 and .1 or .9 and 1. I would advise to test whether the difference is significant or not.

Response: We agree with the reviewer that these differences do not imply unique combinations. However, we note these values are original and are true values. Figure 4 is only the additional result of Figures 1, 2 and 3 which show the multi-model mean map of probability for no Granger causal impact from individual climate mode to global evaporation. The results described in Figures 1, 2 and 3 are tested for significance.

We note that additional information is added to the Methods section as follows to clarify the significance test:

"We apply test of Granger causality for the predictive model described in equation (1). Specifically, in order to assess the causal influence from Y to X, we compute the probability of the null hypothesis for an absence of Granger causality from Y to X. The model shown in equation (1) is defined as a complete predictive model where all variables (i.e., past data of evaporation and climate indices) are used to estimate evaporation. The null model of no causal effects from given climate mode (i.e., variable Y) to evaporation is defined by removing the terms related to Y (i.e., by setting $\beta_i = 0 \; with \; i = 1, \dots, p$) in equation (1). The complete model and the null model are then compared by using the following indicator:

$$L_{Y \to X} = n(\log\left|\Omega_{p,\beta_i=0}\right| - \log\left|\Omega_p\right|)$$

where $|\Omega_p|$ is the determinant of the covariance matrix of the noise residual, and n is the length of the data time series. We test the significance of the complete model by comparing the $L_{Y \to X}$ indicator against a χ^2_p null distribution. This test results in a probability for no causal effect of the considered variable Y on evaporation."

• Line 185-194: Are these results or do these belong in the discussion section?

Response: Yes, we think these sentences discuss the connection between the present study and previous ones (Martens et al., 2018; Miralles et al., 2013).

• Line 209: In Figure 5, panels a and b can be combined, just as panels c and d to be able to be able to visually compare a bit better. The authors could even think of combining all the panels together, to see be able to compare easily between land and ocean, past and future (there are only 12 bars).

Response: We thank the reviewer for this advice. We replaced Figure 5 by a new Figure as follows:

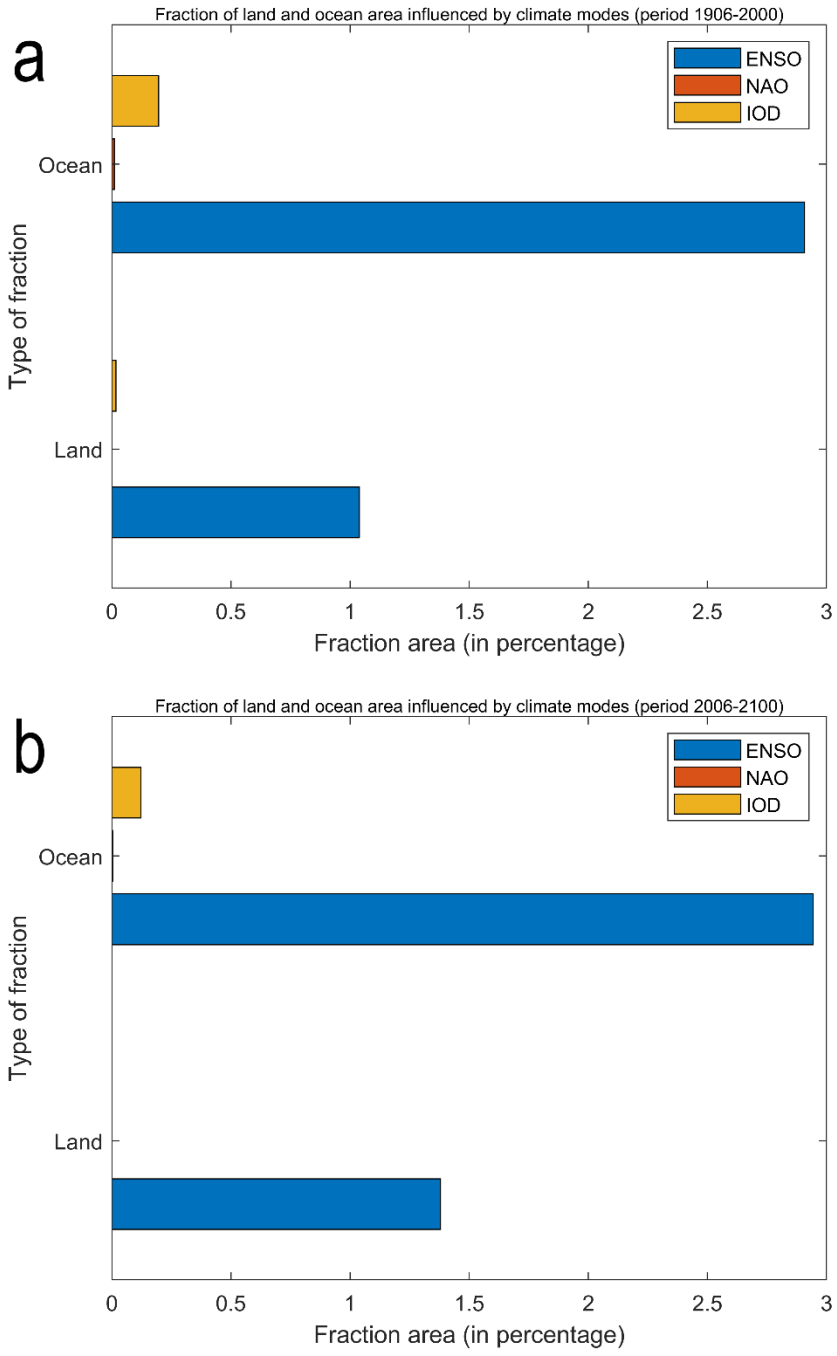

Figure 2. Fraction of Earth surface for land and ocean with probability for the absence of Granger causality between climate modes and evaporation less than 0.1 (i.e., p value < 0.1). The results are shown for the influence of individual climate mode on annual mean evaporation for periods 1906-2000 (a) and 2006-2100 (b). Fraction areas influenced by ENSO, NAO and IOD are shown in blue, red and yellow bars, respectively. Several fraction areas are close to zero. ENSO = El Niño–Southern Oscillation. NAO = North Atlantic Oscillation. IOD = Indian Ocean Dipole.

• Line 217-220: What is the added value of Figure S10 (showing Figure 5 with p 0.25)? The conclusion remains the same and inferences of this figure aren't mentioned.

Response: At standard significance level of 5%, the fraction areas for NAO and IOD are low and close to zero. We think it is important to provide additional information to show that NAO and the IOD still have the causal effects on evaporation at higher significance level. We also think this Figure S10 makes it easier to compare the effects of NAO and the IOD.

We added the following text to the Discussions Section:

"Figure S10 indicates that the land and ocean area influenced by the IOD is slightly higher compared to NAO."

• Line 231: Same comment as for Figure 4: I would advise to test whether the means are significantly different or not.

Response: We thank the Reviewer for pointing this out. Figure 6 is only additional result of Figures 1, 2 and 3 which show the multi-model mean map of probability for no Granger causal impact from individual climate mode to global evaporation. The results described in Figures 1, 2 and 3 are tested for significance.

• Line 231-232: "Specifically, the fraction area of Earth surface showing lower probability of ENSO effects for 2006-2100 period is approximately 52.9% (Figure 6a)." I highly doubt this conclusion. The authors should first assess whether the differences are significant or not and after that determine reassess the overall ENSO effects. 52.9% is just slightly higher than just assigning an de(in)crease of ENSO effects randomly (50%). This also goes for following similar conclusions.

Response: The differences shown here are original and true values because all the p-values are the results of Granger causality test for all climate models. The value 52.9% is not a random number but it is an original value and it shows the fact that ENSO causal effects on global evaporation are slightly different between the two periods 1906-2000 and 2006-2100 (See also Figure 1). Figure 6 is only an additional result of Figures 1, 2 and 3 which show the multi-model mean map of probability for no Granger causal impact from individual climate mode to global evaporation. The results described in Figures 1, 2 and 3 are tested for significance.

Technical corrections

• Line 40: "… between individual climate mode**s**"

Response: We corrected as your suggestion.

• Line 56: "Using other data periods with similar length**s** (i.e., 95 years) **do** not alter…"

Response: We corrected this sentence as follows:
"Using other data periods with similar lengths (i.e., 95 years) do not alter the results and conclusions."

• Line 61: "Most of **the** climate models…"

Response: We corrected as your suggestion.

• Line 158: "…of NAO impact**s**…"

Response: We corrected as your suggestion.

• Line 187: "…in agreement with previous studie**s**…"

Response: Here we only cite one study.

• Line 198: "in **the** Australian continent…"

Response: We corrected as your suggestion.

• Line 229-230: "…for **the** future period 2006-2100 and **the** historical period 1906-2000…"

Response: We corrected as your suggestion.

• Line 264: "…for a short term…"

Response: We corrected as your suggestion.

2 References

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