Replies to Reviewer #1:

This is a very nice paper, which I enjoyed reading. The authors show that without Tibetan Plateau, ENSO variability is stronger, indicating that the Plateau in the real world reduces ENSO variability. Without the plateau, the thermocline is flatter, trades are weaker, and the convection center is located further to the east. These mean state condition render that the thermocline feedback and Ekman pumping feedback are stronger. These processes are analyzed thoroughly.

Overall, the paper is in a great shape and I hope that the authors can address these issues.

Response: Thank you very much for your comments. We have revised the manuscript carefully based on these suggestions. The followings are our point-to-point replies.

1. *These results are somewhat different from what I would have expected, based on an Indonesian Throughflow (ITF)-closure experiment (see Santoso et al. 2010, J. Climate, The Role of the Indonesian Throughflow on ENSO Dynamics in a Coupled Climate Model). Closing the ITF results in an El Niño-like climate state in the Pacific, which is similarly characterized by weakened trade winds and a flatter equatorial thermocline, but it leads to weaker ENSO variability. I wonder what happens to the ITF in the no Plateau experiment.*

Responses: Thank you very much for this suggestion. We have read Santoso et al.'s paper carefully. To see what has happened to the ITF in our NoTibet experiment, we calculated the volume transport across the red section in Fig. R1(a) as the ITF transport. It shows that the ITF transport in our Real simulation is around 15 Sv (Fig. R1b), which is similar to observed estimate (Wijffels et al., 2008). After removing the TP, the ITF is weakened substantially by more than 40% to only 8 Sv (Fig. R1b). Santoso et al. (2010) suggested that the equatorial Pacific zonal winds are highly correlated to the ITF transport and the correlation coeffecient is positive. In Fig. R1(c), we plot the time series of zonal wind stress averaged over the equatorial Pacific basin (120°E-90°W, -5°S-5°N) in the last 100 years. It shows that the equatorial Pacific zonal winds are weakened by 20% after the TP removal. Changes in zonal winds and ITF in NoTibet are qualitatively consistent with those in Santoso et al. (2010).

The mean climate change in NoTibet is similar to that in Santoso et al. (2010), that is, an El Niño-like climate state in the Pacific, which is characterized by weakened trade winds, a flatter equatorial thermocline, SST warming anomaly in central eastern Pacific, and thus reduced zonal temperature gradient along the equator. However, the responses of ENSO variability are different in these two studies. In Santoso et al. (2010), the amplitude of ENSO variability is decreased because of enhanced thermal damping feedback, weakened zonal advection feedback, Ekman pumping feedback, and thermocline feedback. The changes of the last three feedbacks are mainly attributed to decreased ocean sensitivity ($\beta_w,\ \beta_u$), weakened mean upwelling velocity $\overline{w}$, and weakened sensitivity of the response of the zonally averaged wind stress to ENSO SST anomaly (μ_a). In our results, ocean sensitivities ($\beta_w,\ \beta_u$) are **increased due to shallower mixed layer depth (MLD)**, accompanied by the eastward shift of atmospheric convection center, which is responsible for the enhanced ENSO variability in NoTibet.

The results of Santoso et al. (2010) and ours suggest that even though the equatorial Pacific is characterized by the same mean state change under different external forcing, say the weakened trade winds and a flattened equatorial thermocline, the ENSO variability may still exhibit different responses. The atmospheric convection scheme and MLD change are also important factors contributing to the properties of ENSO variability.

In this revision, we have added sentences in lines 450-454 as follows: "We also want to note that although the mean state change over equatorial Pacific is similar to an Indonesian Throughflow (ITF) closure experiment in Santoso et al. (2010), like the weakened trade winds and a flattening equatorial thermocline, the ENSO variability may still have different response. Changes in atmospheric convection scheme and ocean MLD are also important factors contributing to the properties of ENSO variability."

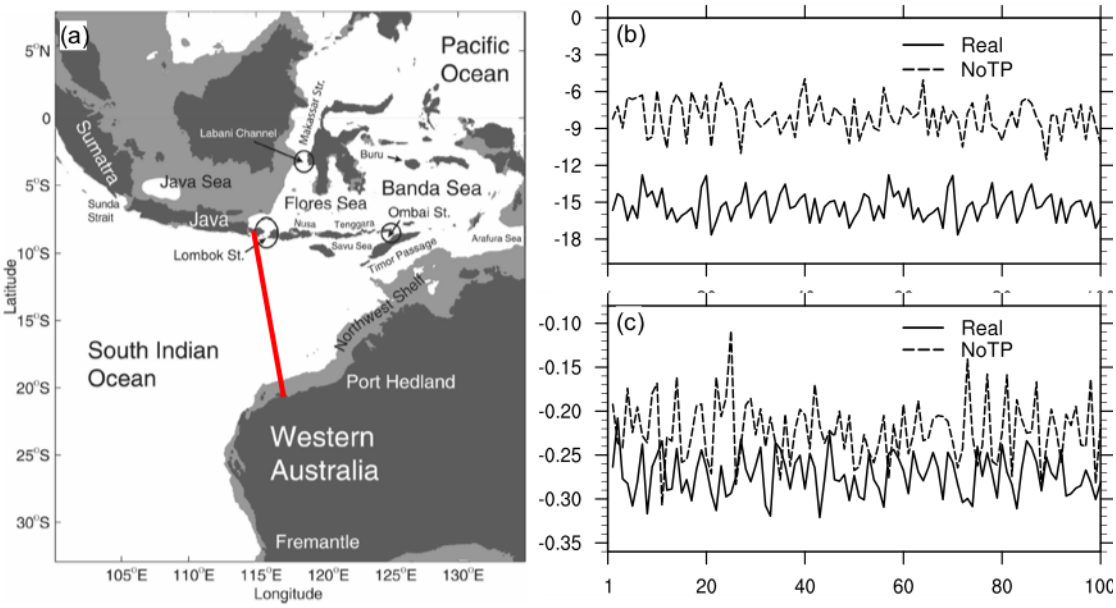

Fig. R1 (a) Geography of the study region, with names of the islands, straits, and seas discussed in Wijffels (2008). The red line represents the section that we use to calculate the ITF transport. (b) Time evolution of ITF transport across the section plotted in (a) (units: Sv, 1 Sv=$10^6 m^3/s$). (c) Time evolution of zonal wind stress averaged over the equatorial Pacific (120°E-90°W, -5°S-5°N) (units: dyn/cm^2). In (b) and (c), solid curve is for Real, and dashed curve for NoTibet.

Wijffels, S. E., G. Meyers, J. Godfrey, 2008: A 20-yr average of the Indonesian Throughflow: Regional currents and the inter-basin exchange. *J. Phys. Oceanogr.*, **38**:1965-1978.

2. *The other question I have is how the results reported vary from one 100 years to another 100 years. Given that 400 years are available, I hope the authors can provide an analysis. Do these changes and the associated mechanisms still hold? Further, do we see similar results in any of the 20 100-year period in the control experiment? What I am wondering is whether the result can be simply due to centennial variability?*

Responses: Thank you very much for these suggestions. We checked Fig. 2 and Figs.7-9 for the whole 400-year simulation. The standard deviations of SST anomaly (σ(SST)) for Real and NoTibet are about 0.60°C and 1.0°C, respectively (Fig. R2b); and the principle periods for Real and NoTibet are between 2 and 7 years (Fig. R2c) for the whole 400 years. We also checked the ENSO varibility in all of the 20 100-year periods in Real (figures not shown), and the ENSO properties are pretty much stable. The conclusions of 400-year data are the same as those in the last 100 years.

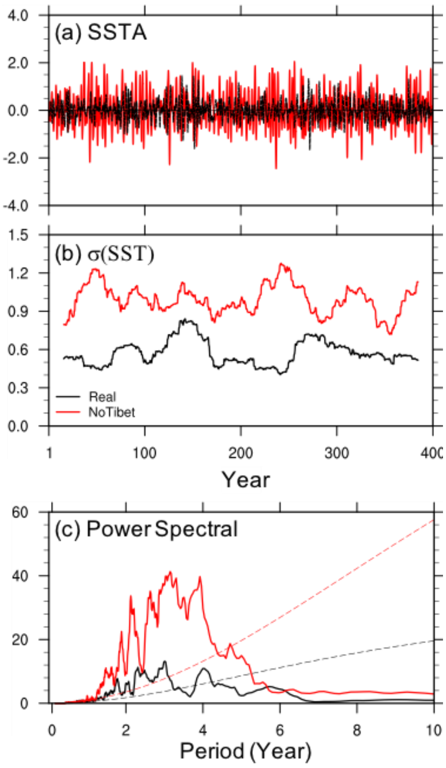

Fig. R2 Time series of (a) SST anomalies (SSTA; °C), (b) standard deviation of SSTA (σ(SST); °C) and (c) power spectrum of SSTA averaged in the Niño-3 region (150°-90°W, 5°S-5°N). Black (red) curve is for Real (NoTibet). The SSTA in (a) is smoothed with a 5-85 month band-pass filter. The σ(SST) in (b) is further smoothed with a sliding window of 31 years. In (c), the 95% confidence levels are plotted as dashed lines.

The vertical advection term ($-wT'T_z$) is the most important destabilizing factor for the SST variability in both Niño-3 and Niño-4 regions (Fig. R3). However, mechanisms for SST variability in the Niño-3 and Niño-4 regions are different. In the Niño-3 region (Fig. R4, left), both the thermocline (red curve) and Ekman pumping (blue curve) feedbacks are responsible for the enhanced ENSO variability, while in the Niño-4 region, only the Ekman pumping feedback (blue curve) is important (Fig. R4, right). Figures R3 and R4 are plotted for all 400 years.

We are confident that the ENSO variability changes and the corresponding mechanisms in response to the TP removal are robust, and are independent from the centennial variability.

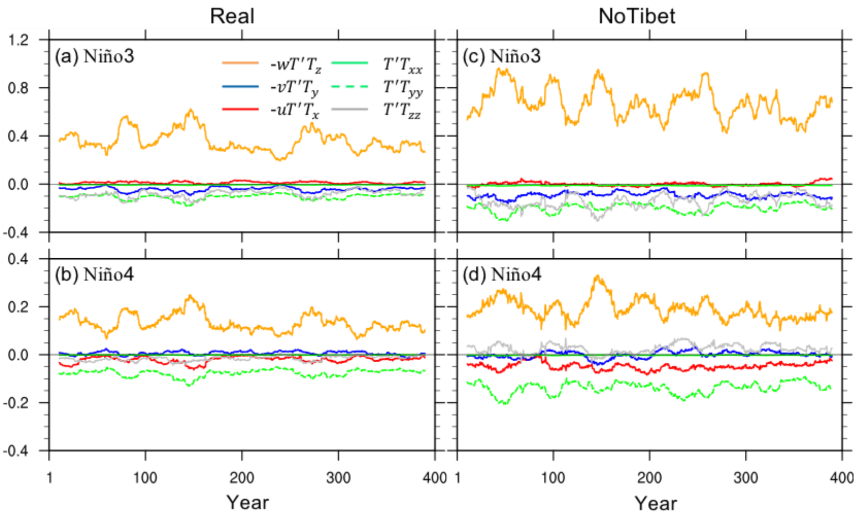

Fig. R3 Time evolutions of the terms in the temperature variance equation. (a) and (b) are for the Niño-3 and the Niño-4 regions in Real, respectively. (c) and (d) are similar to (a) and (b), respectively, except for NoTibet. A 21-year sliding window has been applied to each curve. The units of these terms are 10-6 °C^2/s. This figure is the same as Fig. 7, except for all 400 years.

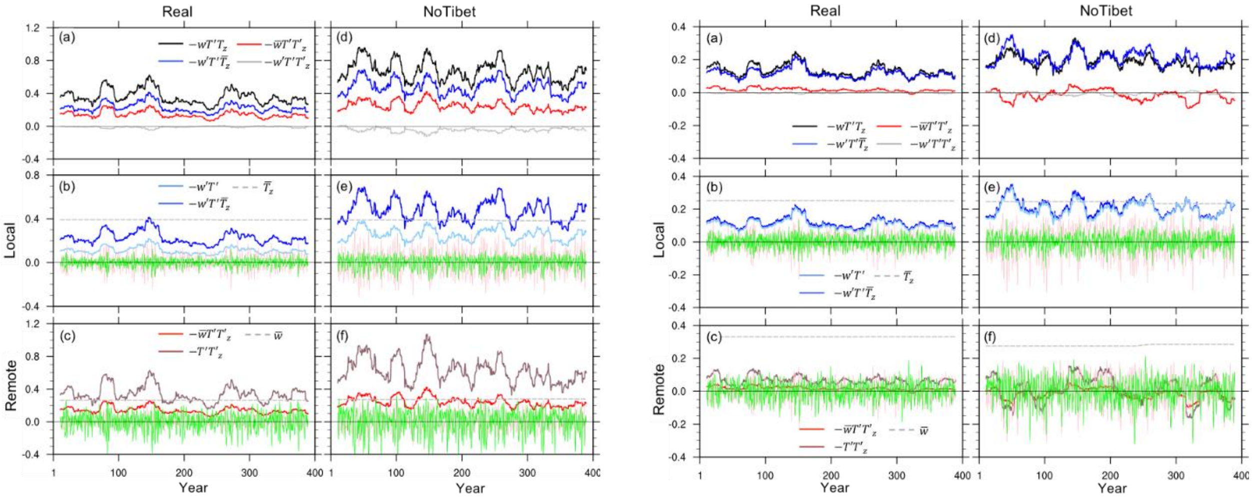

Fig. R4 Decomposition of the vertical temperature advection term averaged in (left) Niño-3 and (right) Niño-4 regions over the thermocline for Real and NoTibet. This figure is the same as Fig. 8, except for all 400 years.

Replies to Reviewer #2:

Tibet Plateau is clearly a prominent feature in the earth's topography, so is the ENSO variability in the climate system of the planet. Does the former play a role in the latter? The question is an interesting one, at least for those who believe that seeking knowledge for the sake of seeking knowledge, regardless its practical significance, is justified.

By doing a pair of experiments with a coupled GCM, Qin et al find that removing the Tibet Plateau energizes ENSO, so much so that the power of ENSO gets quadrupled (Fig.2). The authors then attempt to explain such a rather impressive change in such a global weather maker and a major source of inter-annual variability in the earth's climate system through the changes in the mean state. In particular, they note the changes in the zonal slope and the mean depth of the thermocline, which they further identify through an equation for the variance of the tropical SST as the main cause for the change in the level of ENSO activity.

In summary, this paper is on an interesting topic and has interesting findings. But the authors need to present more analyses to help the readers to understand the results reported here. Possible impacts on the results from clearly relevant model biases—such as the excessive cold-tongue, the westward shifting of ENSO, and the lack of asymmetry in the ENSO in the model---need to be discussed. The paper, lovely as it is now, needs major revision.

Response: Thank you very much for these comments. We have revised the manuscript carefully based on these suggestions. The followings are our point-to-point replies.

Major comments:

1. *Why does the thermocline become flatter and shallower? Or why the atmospheric circulation systems that go with these changes change the way they do in response to the removal of the Tibet plateau? The paper is short in addressing these questions. It is a coupled system and it is hard to disentangle all the involved parts in a clear "cause—effect" fashion. The reviewer acknowledge this difficulty, but finds that just showing the change in the surface winds and P-E over the tropical Pacific seems to be too thrift, given the potential importance of the findings. More information needs to be provided on the changes in the atmospheric circulation systems--in particular those who are known to play an important role in ENSO.*

Responses: Thank you very much for these suggestions. Actually, the effect of TP on global climate involves a series of work. In our previous studies (e.g., Yang et al., 2019; Wen and Yang, 2019), we carefully examined the responses of atmospheric circulation to the TP removal. That is why we do not include such analysis in this manuscript.

Removing the TP can lead to significant warming over the Eurasia continent due to the lapse-rate relationship, which contributes to the weakening of zonal Eurasia-Pacific thermal contrast and thus the weakening of trade winds (Su et al., 2018; Fig. 6 in Yang et al., 2019). Figure R5a shows the pattern change of atmospheric circulation. These figures are also shown in our previous works (Wen and Yang, 2019; Yang et al., 2019). The atmosphere changes have quasi-barotropic structures. There is a clear planetary wave structure in the North

Hemisphere, namely, an anomalous low-high-low pattern. Removing the TP induces cyclonic geopotential height anomalies to the north of the TP area and over the subpolar Atlantic, and anticyclonic anomalies to the south of the TP area and over the subpolar Pacific. Accompanied by anomalous high pressure over the North Pacific, there is an anomalous low pressure over the tropical Pacific, which contributes to the weakened trade winds.

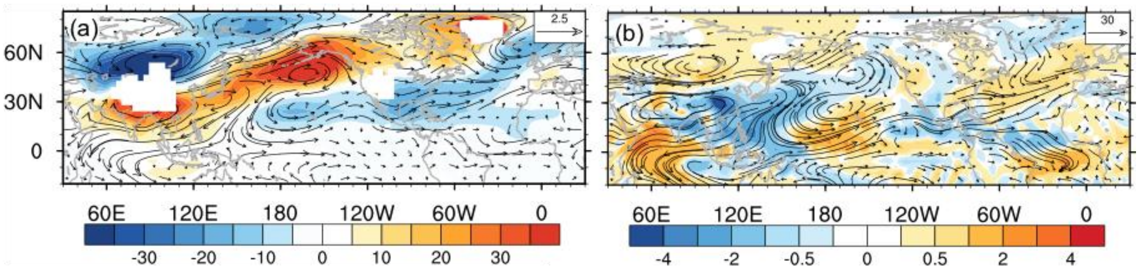

Fig. R5 Changes in (a) geopotential height (shading; m) and wind (vector; m/s) at 850 hPa, (b) vertically integrated moisture transport ($\rho_a \vec{v} q$; vectors; kg/m/s) and its convergence ($-\rho_a \nabla \cdot (\vec{v} q)$; shading; 10^{-5} kg/m^2/s) in NoTibet with respect to Real. Air density $\rho_a = 1.29\ kg/m^3$.

For a steady state, the vertically integrated moisture transport divergence ($\nabla \cdot \vec{v} q$) of the entire atmosphere column is equivalent to the net freshwater flux across the ocean surface (Yang et al., 2015). In Fig. 4b of Wen and Yang (2019), also in Fig. R5b here, we plot the atmospheric moisture transport ($\vec{v} q$; vector) and convergence ($-\nabla \cdot \vec{v} q$; shading) to better illustrate the connection of freshwater flux between different regions, and the freshwater exchange between ocean and atmosphere. The atmospheric moisture convergence is plotted as positive (i.e., $-\nabla \cdot \vec{v} q > 0$), representing a loss of atmosphere freshwater to the ocean ($EMP < 0,\ i.e.,\ E < P$); the moisture divergence is plotted as negative, representing a loss of ocean freshwater to the atmosphere. It is clear that the water vapor is converged (i.e., freshening) in the central tropical Pacific, in response to the TP removal.

In this manuscript, we have rewritten the sentence in lines 183-186 as follows: "Removing the TP results in significant warming over Eurasia continent due to the lapse-rate relationship. The remarkable warming over the Eurasia continent contributes to the weakening of zonal Eurasia-Pacific thermal contrast, leading to the weakening of trade winds and zonal SST gradient in the tropical Pacific (Fig. 5a) (also seen Su et al., 2018; Yang et al., 2019; Wen and Yang, 2019)." Also the sentence in lines 201-202 as follows: "Removing the TP results in moisture convergence and thus freshwater gain in the central tropical Pacific (Fig. 5b) (also seen Fig. 4b in Wen and Yang, 2019)."

Wen, Q., and H. Yang, 2019: Investigating the role of the Tibetan Plateau in the formation of Pacific meridional overturning circulation. *J. Clim.*, **32**, doi: 10.1175/JCLI-D-19-0206.1.

Yang, H., X. Shen, J. Yao and Q. Wen, 2019: Portraying the impact of the Tibetan Plateau on global climate. *J. Clim.*, **32**, doi: 10.1175/JCLI-D-18-0734.1.

Su, B., D. Jiang, R. Zhang, P. Sepulchre, and G. Ramstein, 2018: Difference between the North Atlantic and Pacific meridional overturning circulation in response to the uplift of the Tibetan Plateau. *Climate of the Past*, **14**, 751.

2. *Also, have the authors done an experiment with just a mixed layer ocean? Does that usually help to understand the changes of a coupled phenomenon in response to an external perturbation?*

Responses: Thank you very much for your concern. We have done parallel Real and NoTibet experiments using slab-ocean configuration. The atmospheric circulation change over the tropical Pacific in a slab-ocean is very similar to that in the fully coupled simulation, including the weakened trade winds (Fig. R6) and anomalous water vapor convergence over the central tropical Pacific (Fig. R7). The temperature change over the tropical Pacific is also comparable in the fully coupled runs and slab-ocean runs (Fig. R8): warming in the eastern tropical Pacific and cooling in the western tropical Pacific. The consistence of slab-ocean results and fully coupled results suggest that the ocean process does not feedback much to the atmospheric circulation change. In other words, the TP affects the ocean circulation and buoyancy fields mainly via atmospheric processes. However, there is a significant difference in SAT (SST) response over (in) the North Pacific and North Atlantic between the fully coupled run and slab-ocean run (Fig. R8), which is due to the ocean meridional overturning circulation change (e.g., AMOC and PMOC). This was analyzed in details in our previous works (Wen and Yang, 2019; Yang and Wen, 2019).

The ENSO is, however, an atmosphere-ocean coupled variability. We must use the fully coupled model to analyze ENSO characteristics. After removing the TP, the atmospheric circulation change leads to a background climate shift. In association with these mean climate changes, the ENSO variability exhibits a much stronger amplitude in a world without the TP, in which the ocean processes play very important roles.

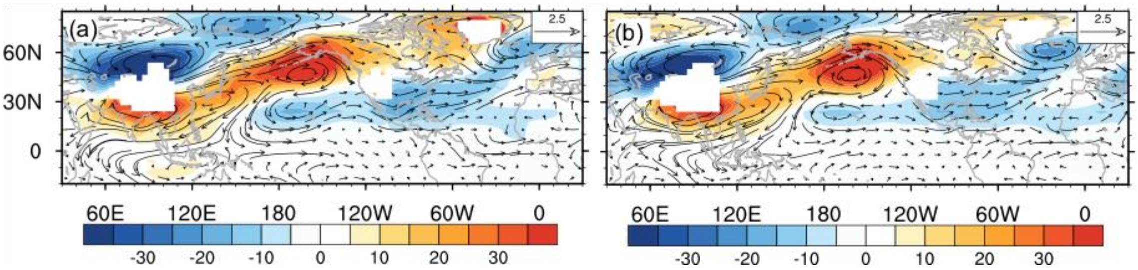

Fig. R6 Changes in geopotential height (shading; m) and wind (vector; m/s) at 850 hPa in **(a)** fully coupled simulation and **(b)** slab-ocean run.

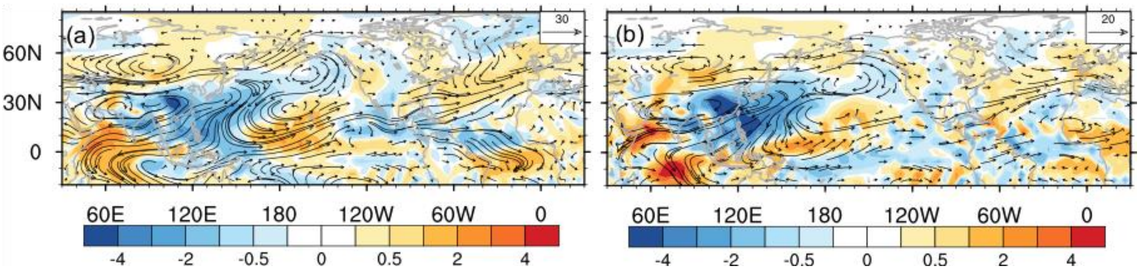

Fig. R7 Changes in vertically integrated moisture transport ($\rho_a \vec{v} q$; vectors, kg/m/s) and its convergence ($-\rho_a \nabla \cdot (\vec{v} q)$; shading; 10^{-5} kg/m^2/s) in **(a)** fully coupled simulation and **(b)** slab-ocean run. Air density $\rho_a = 1.29\ kg/m^3$.

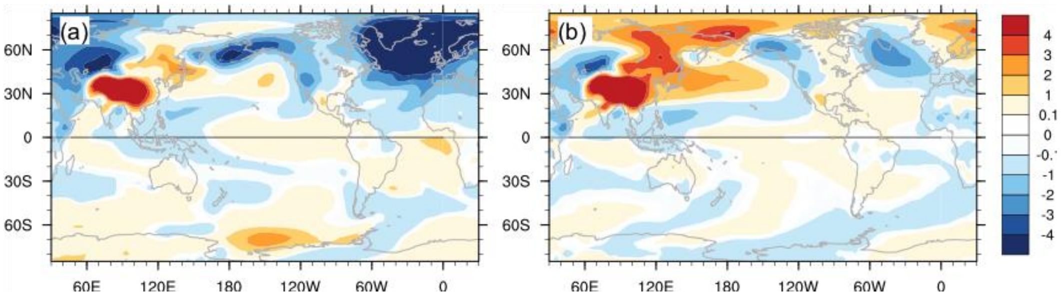

Fig. R8 Changes in surface air temperature (°C) in **(a)** fully coupled simulation and **(b)** slab-ocean run.

Yang, H., and Q. Wen, 2019: Investigating the role of the Tibetan Plateau in the formation of Atlantic meridional overturning circulation. *J. Clim.*, **32**, doi: 10.1175/JCLI-D-19-0205.1.

3. *What has become typical in studies using a coupled GCM is to simply ignore the possible impact from the biases in the model on their findings. But not all the readers share the optimism that these biases do not matter. As the authors have noted themselves in Fig. 3, the model used has a biased ENSO. The spatial pattern of the SST variance in the model differs significantly from that in the observations. The authors did not show the histogram of the Nino3 SSTA side by side with the simulated one, but judging from what are in Fig. 4, ENSO in the model is clearly more symmetric than that in observations. To what a degree these biases may affect the impressive sensitivity the authors have found here? Some discussion in this aspect seems to be warranted.*

Responses: Thank you very much for these comments. In Fig. 3, the spatial pattern of the SST variance in the model does show some differences from the observations, which is also found in Vega-Westhoff and Sriver (2017). However, in terms of ENSO period and amplitude, the model is doing a reasonably good job when compared with the observations (Figs. 2-3).

The impact of model bias and resolution on the results is always a big concern for this type of research. The model bias of CESM with respect to observations has been examined comprehensively in previous studies (https://journals.ametsoc.org/topic/ccsm4-cesm1). In our previous work (Yang et al. 2019), we examined model bias carefully. First, we compared the meridional overturning circulation (MOC) in the Atlantic and Pacific in our CESM control simulation with that from ECCO-v4 ocean reanalysis (Forget et al., 2015). They are mostly consistent (figures not shown). Second, the meridional heat transport calculated from CESM control simulation is in an excellent agreement with that based on observations (Trenberth and Caron, 2001; Yang et al., 2015). Third, the mean SST pattern from CESM control simulation is generally in good agreement with that from ERSST-v4 (Huang et al., 2015) (Fig. R9). The SST bias in CESM is also clear. For example, the cold bias in the North Pacific and North Atlantic is significant (Fig. R9c), when compared with the observations (Fig. R9b). The lower SST in the North Atlantic may lead to a stronger AMOC than in the reality. The SST in the tropical Pacific is colder than the observation by 1-2°C (Fig. R9), particularly in the warm-pool region, which may lead to a weaker Walker circulation in the tropics (Guilyardi et al., 2009).

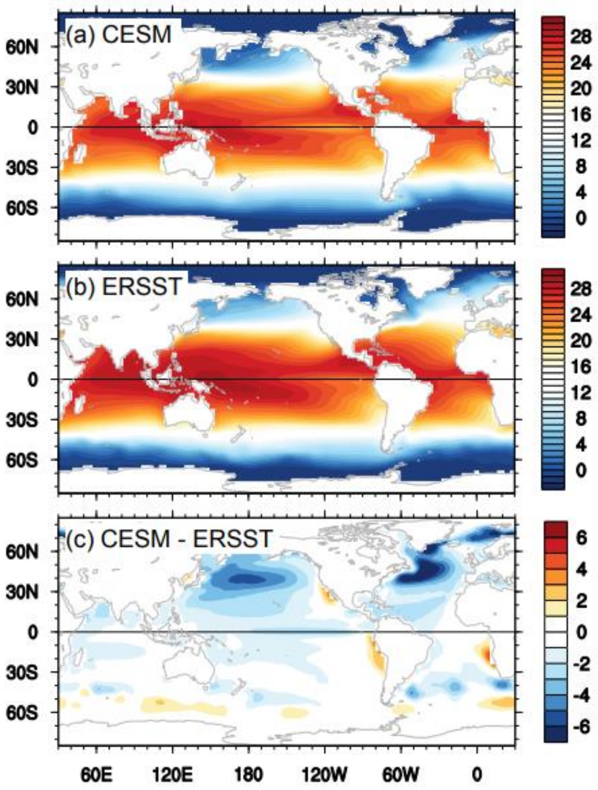

Fig. R9 Spatial patterns of mean SST (°C) from (a) CESM control run and (b) ERSST-v4 averaged between 1980 and 2018. After Huang et al. (2015). (c) is the SST bias of CESM model, with respect to ERSST.

Observation data always show the positive skewness of ENSO, which is explained by nonlinear interactions (Burgers and Stephenson, 1999; An and Jin, 2004). However, like most GCMs, the CESM model exhibits a linear ENSO, with SST skewness near zero in the tropical Pacific (van Oldenborgh et al., 2005). That means the nonlinear term is underestimated in the CESM model, which is also verified by the temperature variability equation, in which the nonlinear term is nearly zero (Fig. 7). The main nonlinear processes relevant to the ENSO include atmospheric convection, evaporation, wind response to SST anomalies, zonal advection, and thermocline-surface coupling (Guilyardi 2006, 2009). These terms, in turn, may also affect the local term and remote term in the temperature variance equation (section 4). Since the nonlinear effect is negligible in this model, the effect of the linear terms, includes the local and remote term may be exaggerated in this study. Please also refer our reply to question 5 about ENSO skewness.

In addition, since there are two centers of SST variability in the tropical Pacific, we discuss the mechanisms in section 4 separately for these two regions to avoid missing some processes related to ENSO variability change.

In this revision, we added "The lack of asymmetry of ENSO variability may be due to the underestimation of nonlinear interactions (An and Jin, 2004) or the stronger cold tongue of simulated mean SST in the CESM model compared to observations (Sun et al., 2013)" in lines 171-174.

We also add some discussion in section 5: "The impact of model bias on the results in this work is of another concern. Unlike observations, the CESM model exhibit a linear ENSO, with SST skewness near zero in the tropical Pacific. This bias may come from the weak non-linear interactions, e.g., atmospheric convection, evaporation, wind response to SST anomalies, zonal advection and thermocline-surface coupling (Guilyardi et al., 2009), which, in turn, may affect the local term and remote term in the temperature variability equation." (Lines 455-459).

Burgers, G. and D. B Stephenson, 1999: The Normality of El Niño. *Geophys. Res. Let.*, **26**, 1027-1030.

An, S. I. and F. F. Jin, 2004: Nonlinearity and asymmetry of ENSO. *J. Clim.*, **17**, 2399-2412.

Guilyardi, E., 2006: El Niño–mean state seasonal cycle interactions in a multimodel ensemble. *Climate Dyn.*, **26**, 329–348.

——, A. Wittenberg, A. Fedorov, et al., 2009: Understanding El Niño in ocean–atmosphere general circulation models: Progress and challenges. *Bulletin of the American Meteorological Society*, **90**, 325-340.

van Oldenborgh, G. J., Philip, S. and Collins, M., 2005: El Niño in a changing climate: a multi-model study. *Ocean Science*, **1**, 81-95.

4. *Speaking on more technical issues, I have noted in Fig. 1 that the changes in topography from the control experiment (Real) to the experiment without the Tibet Plateau (NoTibet) involves more than just flattening out Tibet Plateau. The entire Eurasia continent east to 60E is flattened out. Maybe that is how Tibet Plateau is defined in this particular context, but some who are not yet get updated on the new world geography may like to see the authors to have the region that Tibet plateau covers defined for their purpose here.*

Responses: Thank you very much for this suggestion. In this revision, we added "Note that the TP area defined in this study is 23°-80°N, 63°E-180°." in line 122.

As you pointed out, the region defined in this manuscript also includes the Mongolian Plateau (MP). Some studies found that the MP, despite its smaller size, exerts a great influence on the wintertime subtropical westerly jet (Shi et al., 2015; White et al., 2017), and plays a significant role in strengthening the East Asian winter monsoon (Sha et al., 2015). For the summer monsoon circulation over the Euro-Asian region, these authors all stated that the TP plays a much more important role.

We also performed a simulation in which we only removed the area of the Tibetan Plateau (60°-140°E, 20°-45°N; No_Regional_TP) (Fig. R10). The results are nearly unchanged from those in NoTibet. The σ(SST) in No_regional_TP is roughly of the same magnitude as that in NoTibet (Fig. R11). The tropical SST anomaly shows much bigger oscillation after the TP removal (Fig. R11). Also, the mean ocean climate change is very close to that shown in our manuscripts, that is, weakened trade winds, SST warming in the central-eastern Pacific and SST cooling in the western Pacific, more freshwater gain in the central tropical Pacific, shallower mixed layer depth in the central tropical Pacific, and flattened thermocline (Fig. R12). In addition, we examined the atmospheric circulation change in No_Regional_TP (Fig. R13). We found that the atmospheric circulation changes over the tropical oceans are nearly identical in NoTibet and No_Regional_TP. The difference exists in high latitudes. **Our work also confirms that the TP plays a more important role in tropical climate change.**

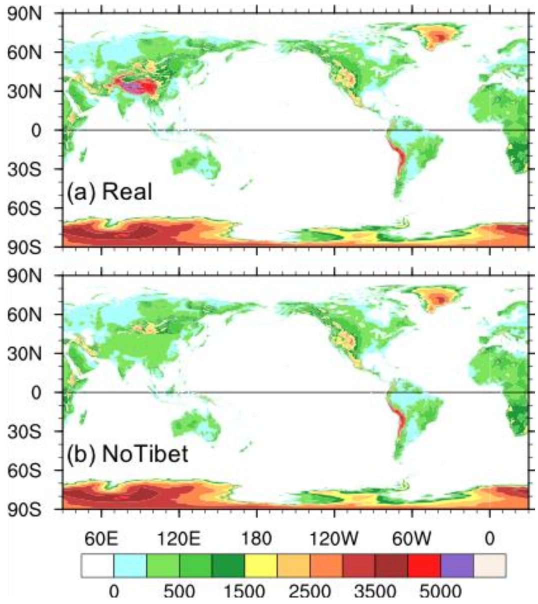

Fig. R10 Topography configuration in coupled model experiments. (a) is for the control simulation with realistic topography (Real), and (b) is for the experiment without the regional Tibetan Plateau (No_Regional_TP; 60 °E-140 °E, 20 °N-45 °N) . Units: m.

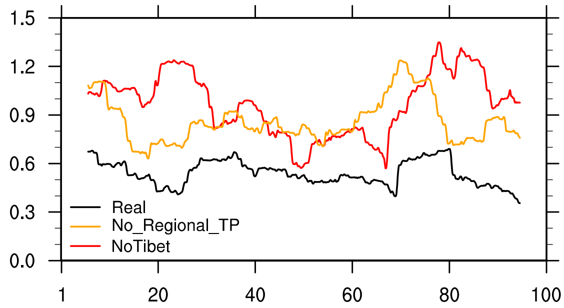

Fig. R11 Time series of standard deviation of SST anomalies (σ(SST); °C) averaged in the Niño-3 region (150°-90°W, 5°S-5°N). The σ(SST) field is smoothed with a sliding window of 11 years. Black line is for Real simulation, red is for NoTibet and orange is for No_Regional_TP.

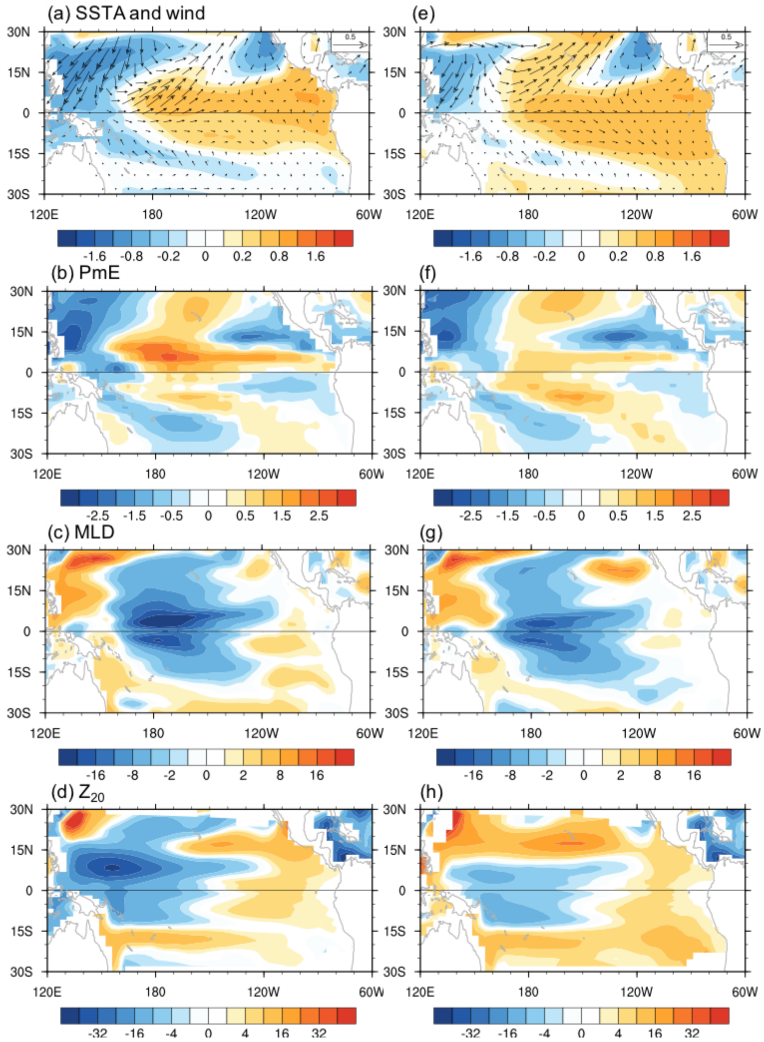

Fig. R12 Quasi-equilibrium changes in the mean tropical climate, including (a): SST (°C) and surface wind stress (dyn/cm^2), (b): precipitation minus evaporation (PmE; 10-5 kg/m2/s), (c): mixed layer depth (m), and (d): thermocline depth (m) in NoTibet. (e-h) are the same as (a-d), except for No_Regional_TP.

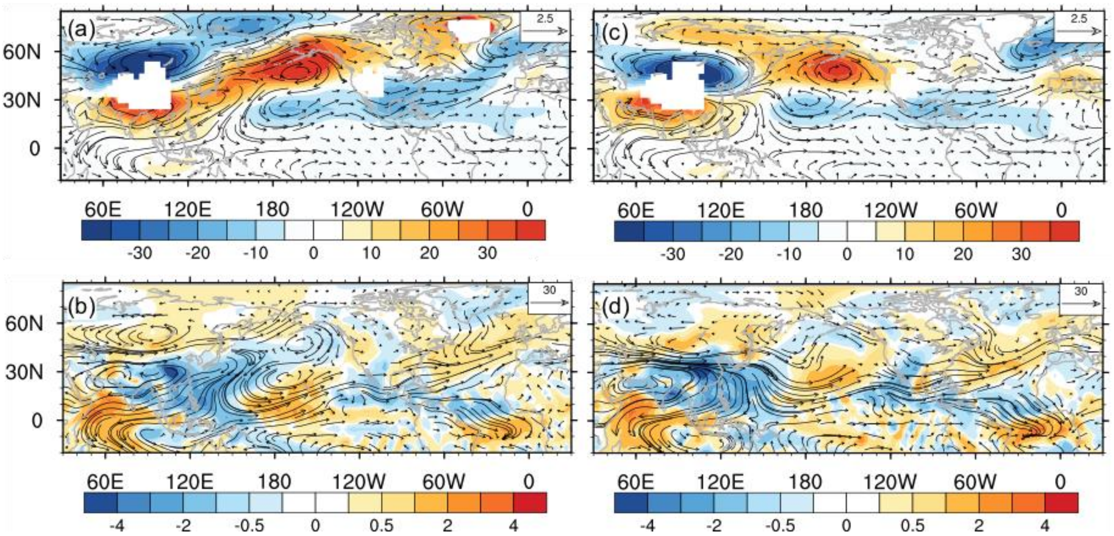

Fig. R13 Quasi-equilibrium changes in (a) geopotential height (shading; m) and wind (vector; m/s) at 850 hPa and (b) vertically integrated moisture transport ($\rho_a \vec{v} q$; vectors; kg/m/s) and its convergence ($-\rho_a \nabla \cdot (\vec{v} q)$; shading; 10^{-5} kg/m^2/s) in NoTibet. (c-d) are the same as (a-b), except for No_Regional_TP.

Sha, Y., Z. Shi, X. Liu, and Z. An, 2015: Distinct impacts of the Mongolian and Tibetan Plateaus on the evolution of the East Asian monsoon. *J. Geophys. Res.*, **120**, 4764–4782, doi:10.1002/2014JD022880.

Shi, Z., X. Liu, Y. Liu, Y. Sha, and T. Xu, 2015: Impact of Mongolian Plateau versus 759 Tibetan Plateau on the westerly jet over North Pacific Ocean. *Climate Dyn.*, **44**, 3067–3076, doi:10.1007/s00382-014-2217-2.

White, R. H., D. S., Battisti, and G. H. Roe, 2017: Mongolian mountains matter most: impacts of the latitude and height of Asian orography on Pacific wintertime atmosphere circulation. *J. Clim.*, **30**, 4065-4082.

5. *Possible impacts on the results from clearly relevant model biases—such as the excessive cold-tongue, the westward shifting of ENSO, and the lack of asymmetry in the ENSO in the model---need to be discussed.*

Responses: Thank you very much for these suggestions. Please also refer to our replies to Question 3. The model bias of CESM with respect to the observations has been examined comprehensively in previous studies (https://journals.ametsoc.org/topic/ccsm4-cesm1), including surface temperature (Chen et al., 2017); Atlantic meridional overturning circulation, sea-ice extent (Gent et al., 2011), ENSO and Pacific Decadal Variability (Deser et al., 2012). In general, the CESM can simulate good mean climate and internal variability. However, the CESM model, like most current models, is certainly not perfect. We discussed briefly the model bias in the discussion section.

The mean SST pattern from CESM control run is generally in good agreement with that from ERSST-v4 (Huang et al., 2015) (Fig. R9, and also Fig. 14 in Yang et al., 2019). The SST bias in CESM is also clear; for example, the warm pool in the western tropical Pacific is weaker and the cold tongue in the eastern tropical Pacific is stronger (Fig. R9a), when compared to the observations (Fig. R9b). The excessive cold-tongue is a common feature in GCMs (Reichler and Kim, 2008; Guilyardi, 2009). These recurrent biases will lead to increased cooling via oceanic upwelling, mixing, and latent heat flux to the atmosphere (Guilyardi, 2009), which will affect the ENSO variability via oceanic and atmospheric processes.

In addition, Sun et al. (2013) found a positive correlation between the magnitude of the bias in simulated warm-pool size and the magnitude of the bias in simulated ENSO asymmetry. These findings suggest that the excessive cold tongue may lead to the lack of asymmetry in the ENSO in CESM. As expected, CESM cannot reproduce the asymmetry in the ENSO. There is no skewness of El Niño and La Niña events (Fig. 4). Previous studies attributed the ENSO asymmetry to nonlinear oceanic processes (Jin et al., 2003; Su et al., 2010), nonlinear dependence of atmospheric deep convection (Hoerling et al., 1997), zonal shift of surface wind anomalies during warm and cold events (Kang and Kug, 2002), and climate over the Indian Ocean (Okumura and Deser, 2010). Thus, the asymmetry of El Niño and La Niña involves nonlinear processes in both ocean and atmosphere, which will also affect climate sensitivity and thus ENSO behavior.

The westward extent of simulated ENSO variability is another discrepancy in CESM model (Figs. 3a and e). This phenomenon may have resulted from the unrealistic westward displacement and enhancement of the equatorial trade winds in the western Pacific, which is also a systematic bias among many CMIP5 models (Taschetto et al., 2014). Studies by Ham and Kug (2012) and by Kug et al. (2012) showed that the location of ENSO events in climate models is sensitive to the atmospheric response, in particular to the location of convection, to the underlying SST anomaly patterns. Bellenger et al. (2013) also demonstrated that convection parameterization in climate models can strongly affect the seasonal phase locking of ENSO. Thus, the bias of atmpsheric convection scheme in CESM may also affect the sensitivity of ocean surface wind stress anomaly to SST perturbation, and thus ENSO amplitude.

In this revision, the discussion of model biases has been added to section 5 in lines 466-476: "In addition, the mean SST pattern from CESM (Fig. 14 in Yang et al., 2019) shows an excessive cold-tongue in the eastern tropical Pacific compared with observation. This bias will lead to enhanced cooling via oceanic upwelling, mixing, and latent heat flux to the atmosphere (Guilyardi, 2009). In addition, the excessive cold-tongue may also leads to the lack of asymmetry of ENSO variability (Sun et al., 2013). The westward extent of simulated ENSO variability is another problem in CESM model (Figs. 3a and e), which is also a systematic bias among many CMIP5 models (Taschetto et al., 2014). This may be due to the westward displacement of the equatorial trade wind in the western Pacific. The bias of atmospheric convection scheme in CESM may also affect the sensitivity of surface wind stress to SST perturbation, and thus the ENSO amptitude."

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