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The Influence of Maritime Continent Deforestation on El Niño-Southern Oscillation: Insights from Idealized Modeling Experiments

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Abstract

During the past two decades, the Maritime Continent (MC) has experienced increased deforestation¹,². Using hundred-year long ensemble idealized deforestation experiments conducted with the fully-coupled Community Earth System Model (CESM) V1.2, here we show that the MC deforestation have a potential to alter the complexity (i.e., event-to-event differences) of the El Niño-Southern Oscillation (ENSO) in terms of its spatial pattern and temporal evolution. The deforestation model run increases the occurrences of Central Pacific El Niño and multi-year La Niña events compared to the control experiment. This change in ENSO complexity is caused by the strengthening effect of MC deforestation on subtropical ENSO dynamics. Conventional tropical ENSO dynamics influence ENSO occurrence and evolution through variations in the tropical Pacific thermocline and related tropical ocean-atmosphere interactions. However, subtropical ENSO dynamics govern the ENSO through coupling processes originated from the subtropical North Pacific. The MC deforestation in our idealized experiment accompanies an anomalous local overturning, which further alters the mean strength of the North Pacific subtropical high and strengthens subtropical ENSO dynamics. Therefore, MC deforestation has the potential to make the El Niño more complex and less predictable.
Land-use changes are occurring globally and can impact local and remote climates. Deforestation is one of the common land-use change, especially in tropical regions like the Maritime Continent (MC). Deforestation affects land properties and often reduces evapotranspiration, leading changes in surface heat fluxes and a warming of surface temperature. Deforestation can also alter surface albedo and roughness, impacting the radiation balance and reducing the aerodynamic flux exchanges. These local effects can further impact land-atmosphere interactions, such as the land-sea breeze. Modeling studies have shown that deforestation in the MC region can affect local climate and circulations, resulting in an increase in local upward motion, moisture convergence, and precipitation.

The impact of MC deforestation on local circulation can have further reach, leading to changes in regional or larger scale circulations and remote climate impacts. For instance, deforestation in the MC could contribute to precipitation decline over southern China by altering the tropical meridional circulation. MC deforestation can also lead to anomalous heating, which can then stimulate Rossby wave trains and result in remote impacts on extratropical climate, including a decline in the strength of Asia’s summer monsoon and warming in the Bering Sea. Moreover, the MC is situated near the joint ascending branches of the Hadley and Walker circulations, making it susceptible to altering the basin-scale atmosphere-ocean couplings that drive the El Niño-Southern Oscillation (ENSO). Prior studies have explored the potential interactions between MC deforestation and ENSO, but have mainly focused on how ENSO modifies the climate impacts of MC deforestation, rather than how deforestation affects ENSO. For example, some studies have found that El Niño amplifies the local impacts of MC deforestation. In this study, we aim to examine the potential impact of MC deforestation on changing the properties of ENSO.

The Walker circulation plays a crucial role in the generation and development of ENSO, as it regulates the interactions between the tropical atmosphere and ocean. These interactions refer to the interactions between surface wind, sea surface temperature (SST), and thermocline, as depicted by the Bjerknes feedback and charge-discharge process. The regional Hadley circulation in the Pacific descends over the northeastern Pacific and can also affect the ENSO generation and development through interactions between the subtropical Pacific ocean and atmosphere, as
described in the seasonal footprinting mechanism\textsuperscript{26,27}. The combination of tropical and subtropical components of ENSO dynamics can result in varying characteristics of ENSO events, creating its complexity\textsuperscript{27}. These characteristics include the type of event, such as Eastern Pacific (EP) or Central Pacific (CP)\textsuperscript{28}, and its temporal progression, which can be a single or multi-year event. The possible effects of MC deforestation on ENSO complexity through changes in the strengths of ENSO dynamics have not been previously explored and are the focus of the present study.

It should be noted that the goal of the present study is to explore the potential impacts that may be induced by MC deforestation on ENSO complexity, rather than identifying the impacts resulted from the existing deforestation. For this purpose, idealized deforestation experiments were performed in the study by replacing MC rainforests completely with C4 grass to maximize the deforestation impacts. Specifically, surface vegetation types over the MC (10°S–10°N and 90–150°E) were prescribed in the control run based on observation data\textsuperscript{29,30}, and were altered in the deforestation run by replacing broadleaf evergreen and deciduous trees with C4 grasses across the entire MC (Figure 1). The impact of deforestation on ENSO complexity was studied using the CESM1 model in a 400-year pair experiment (see Data and Method). The robustness of results was then examined with a six-member 100-year ensemble of the same experiment (Figure 2). The following results are based on the last 200-year of the 400-year pair experiments and the last 90-year of the 100-year ensemble pair experiments.

**Results**

**Changes in mean state**

The mean state differences between the deforestation and control runs of the 200-year pair experiments indicate that MC deforestation leads to an increase in local land surface temperatures (Figure 3a) due to a decrease in evapotranspiration. The increased land surface temperature strengthens land-sea contrast, causing anomalous moisture convergence and upward air motions (Figure 3b), resulting in an increase in precipitation (Figure 3c). We notice from Figure 3b that the enhanced ascending motion over the MC is accompanied by an enhanced descent over the ocean to the north and east, forming an anomalous local overturning circulation pattern. The existence of the anomalous overturning is confirmed by a significant correlation (r=−0.52, p-value < 0.0001) between the yearly mean differences in ascending motion anomalies over the MC land (90-155°E, 10°S-10°N) and the descending motion anomalies over the ocean.
to the northeast of the MC (130-170°E, 7°S-4°N).

The deforestation-related overturning in the MC can lead to changes in the mean state over the subtropical North Pacific. The descending branch of the overturning circulation suppresses convection in the tropical western to central Pacific (Figure 3b), the resultant anomalous cooling of which can excite a Rossby wave train that propagate poleward through the upper-troposphere. The wave train propagates toward the northwestern Pacific, Bering Sea, Northern Canada, and then reflects southward to the west coast off the US-Mexico (Figure 3d). By examining the geopotential height anomalies at various level (200hPa, 500hPa, to the sea level) in Figure 3d-f, we found that a positive anomaly center with a barotropic structure, located over the western Bering Sea, extends into the lower troposphere and increases the sea level pressure (SLP) in the subtropical northeastern Pacific. The anomalous high pressure merges with another anomalous high in the northeastern Pacific resulting in a stronger subtropical Pacific High over the north Pacific (Figure 3f).

Yu et al. (2015) suggested that a stronger mean state of the subtropical Pacific high should lead to a more efficient seasonal footprinting mechanism (i.e., the subtropical component of the ENSO dynamics). Following Yu et al. (2015), we used the linear correlation coefficient between SST and 925hPa zonal wind anomalies to quantify the air-sea coupling strength and found that it had strengthened after the deforestation in the southern flank of the positive SLP anomaly over the northeastern Pacific (the marked area in Figure 4b). This suggests that MC deforestation can strengthen the subtropical ENSO dynamics, which is known to favor the production of the CP type of ENSO. Consistent with this, we found that the SST variance to increase significantly in the region extending from the northeastern subtropical Pacific to the tropical central-to-western Pacific in the deforestation run compared to the control run (Figure 4a). Since the subtropical ENSO dynamics is a crucial source of ENSO complexity, the impact of MC deforestation on ENSO complexity is explored next.

**Changes in ENSO complexity**

Previous studies have suggested that the subtropical ENSO dynamics tend to produce the CP type of ENSO, due to the influx of anomalous northeasterly trade winds into the tropical central Pacific, which leads to formation of ENSO SST anomalies. Previous studies have also suggested that the subtropical ENSO dynamics can lead to multi-year events. The CP ENSO caused by the subtropical ENSO
dynamics can excite atmospheric wavetrains propagating into the northeastern Pacific, reactivate the subtropical ENSO dynamics and producing another ENSO event of the same phase the following year\textsuperscript{33}. In contrast, the tropical ENSO dynamics tend to result in single-year events through a negative feedback to ENSO SST anomalies caused by ENSO-induced thermocline variations in the tropical Pacific\textsuperscript{27}. This feedback causes an El Niño event to be followed by a La Niña event and vice versa. Based on findings from those previous studies, we may expect to see an increased occurrence of CP-type and multi-year ENSO events (see Data and Method for the identification methods) in the deforestation run compared to the control run.

Our 200-year pair experiments show that ENSO complexity changes in response to MC deforestation. The percentage of CP-type El Niño events increases from 33.3±8.0% in the control run to 51.4±8.7% in the deforestation run, while the percentage of EP-type El Niño events decreases from 66.7±8.0% in the control run to 48.6±8.7% in the deforestation run (Figure 5a and Supplementary Table 1). The percentages of EP and CP types does not change much for La Niña events. In both the control and deforestation runs, La Niña events are always dominated by the CP type. This is consistent with the ENSO research community’s general consensus that the existence of two types of ENSO spatial patterns (EP and CP) is more apparent for El Niño but not for La Niña\textsuperscript{34,35}. The observed La Niña events are known to be most of the CP type than the EP type. The cause of this El Niño-La Niña asymmetry is not yet fully understood, but one possible explanation is that the generation mechanism of La Niña is more related to the subtropical ENSO dynamics. Therefore, even with the strengthening of the subtropical ENSO dynamics due to MC deforestation, La Niña is dominated similarly by the CP type in both the control and deforestation runs.

However, in terms of ENSO evolution (single- and multi-year events), the change induced by MC deforestation is more evident for La Niña than for El Niño. The percentage of multi-year La Niña events increases from 73.7±7.5% in the control run to 85.7±6.2% in the deforestation run, while the percentage of single-year events decreases from 26.3±7.5% to 14.3±6.2% (Figure 5b and Supplementary Table 2). The percentage of single- and multi-year events for El Niño remain largely unchanged from the control to deforestation runs. The percentage of multi-year El Niño events increases from 41.0±8.0% to 48.6±8.7% after deforestation, while the percentage of single-year events decreases from 59.0±8.0% to 51.4±8.7%. These results are generally consistent with what we would expect from an intensification of the subtropical ENSO dynamics.
According to Fang and Yu (2020), La Niña is more capable than El Niño in re-activating the positive feedback of the subtropical ENSO dynamics to produce multi-year events. Hence, after MC deforestation strengthens the subtropical ENSO dynamics, its impact on the occurrence of multi-year events is stronger for La Niña than El Niño.

**Testing the robustness of MC deforestation's impact on ENSO Complexity with ensemble pair-experiments**

In order to determine the robustness of the impact of MC deforestation on ENSO complexity, we repeated all the analyses with the ensemble means of the six-member pair experiments. The mean state differences between the ensemble means of the control and deforestation runs (Figure 6) are similar to the results of the 200-year pair experiments (see Figures 3 and 4). The results from the ensemble experiments indicate that deforestation in the MC region can result in an increase in surface air temperature (Figure 6a) and precipitation (Figure 6c), as well as an abnormal local overturning circulation (Figure 6b). The local overturning circulation further stimulates a wave that travels into the northeastern Pacific (Figure 6d), leading to the strengthening of the subtropical Pacific High (Figure 6e). The strengthened subtropical ENSO dynamics, resulting from the enhanced subtropical height, lead to an increase of SST variance in the central tropical Pacific (Figure 6f). The changes in the complexity of ENSO in the ensemble are also consistent with the results of the 200-year idealized experiments. In regards to the spatial patterns of ENSO, the ensemble-mean percentages of CP-type (EP-type) El Niño and La Niña events both increase (decrease) following deforestation (Figure 7a and in Supplementary Table 3). The percentage of CP type El Niño increases from 38.1% in the control run to 43.4% in the deforestation, while the percentage of CP type La Niña increases from 60.0% in the control run to 63.2% in the deforestation.

In terms of the percentage change in each individual ensemble member, three (four) of the six members concur with the ensemble-mean results for El Niño (La Niña).

Although the percentage changes of the CP and EP types of La Niña following the MC deforestation are modest in the 200-year pair experiments, the changes are relatively larger in each ensemble pair experiments.

Regarding the evolution patterns of ENSO, both El Niño and La Niña events exhibit an increase in multi-year occurrences and a decrease in single-year occurrences after deforestation (Figure 7b and in Supplementary Table 4). The change is particularly
notable for La Niña events. The percentage of multi-year La Niña occurrences increases from 79.0% in the control run to 86.8% in the deforestation. Five of the six ensemble members concur with the ensemble-mean results. For El Niño events, the percentage of multi-year occurrences increases from 38.1% in the control run to 46.2% in the deforestation. Three of the six ensemble members display the same tendency of change as the ensemble mean.

The 200-year and ensemble pair experiments consistently demonstrate that MC deforestation has the potential to alter the complexity of ENSO in its spatial pattern and temporal evolution. Given that La Niña already tends to be of the CP and multi-year type, the strengthened subtropical ENSO dynamics caused by MC deforestation is likely to further enhance the dominance of these two specific patterns and evolution types. As a result, MC deforestation has the potential to further decrease the complexity of La Niña. However, MC deforestation is expected to shift the dominance of El Niño from the currently predominant EP-type or single-year towards a more frequent occurrence of the CP-type and multi-year. As a result, MC deforestation may result in an increase in El Niño complexity due to the amplification of stronger subtropical ENSO dynamics. The occurrence ratio of CP-type (51.4% in the 200-year pair experiments and 43.4% in the ensemble pair-experiments) and EP-type El Niño (48.6% in the 200-year pair experiments and 56.6% in the ensemble pair-experiments) is approximately equal in the deforestation runs, with a ratio close to 50% (Figure 5a and 7a). The ratio of occurrence of single-year and multi-year El Niño events is also near 50% in the deforestation simulations (Figure 5b and 7b), suggesting that predicting El Niño events might be more difficult in a world affected by MC deforestation.

Summary and Discussion

This study, using idealized experiment modeling, finds that MC deforestation has the potential to alter ENSO complexity by enhancing the importance and dominance of subtropical ENSO dynamics. The sequence of physical processes behind this impact is summarized in Figure 8. Deforestation accompanies an anomalous local overturning circulation over the Maritime Continent (step 1 in Figure 8), which triggers a wavetrain moving towards the North Pacific (step 2). This intensifies the background northeasterly winds over the northeastern Pacific, enhancing atmosphere-ocean interactions and the subtropical ENSO dynamics (step 3). As a result, significant changes are produced in the spatial pattern and temporal evolution of ENSO, with
stronger subtropical ENSO dynamics in the deforestation scenario compared to the control scenario. This leads to an increase in the frequency of CP-type El Niño and La Niña events (step 4) and the potential for more multi-year El Niño and La Niña events due to the CP-type ENSO events' ability to further stimulate the subtropical ENSO dynamics (step 5).

Some studies have indicated that the subtropical ENSO dynamics, which add complexity to ENSO, have gained greater significance in the 21st century\textsuperscript{32}. For example, multi-year La Niña events (such as the 2010-11-12, 2016-17-18, and 2020-21-22 events) appear to have become more frequent in the 21st century. Additionally, El Niño events have shifted from being single-year occurrences in the 20th century (e.g. 1982-83 and 1997-98 events) to being multi-year events (e.g. 2014-15-16 event). Previous studies have attributed the changing ENSO properties to global warming and decadal climate variability\textsuperscript{25,37,38}. Our study adds to this by suggesting that deforestation in the MC can also contribute to the growing complexity of ENSO by boosting the significance of subtropical ENSO dynamics. Further research is needed to investigate the effects of real-life deforestation in the Maritime Continent, not just idealized scenarios.

Although our deforestation experiments are idealized and not realistic, they demonstrate the possibility that deforestation in the MC could increase the complexity of El Niño, making El Niño events more complex and harder to predict. The current study relies solely on the CESM numerical climate model, and the results may be subject to model dependence. The impacts of deforestation on surface temperature are consistent across different models, however, the response of precipitation to MC deforestation is inconsistent across studies\textsuperscript{2,6,8,9,39,40}. The inconsistency is due to the competition between two opposing mechanisms (drying and warming effects) in response to MC deforestation. If the drying effects are stronger, then precipitation decreases following deforestation\textsuperscript{6,39,40}. On the other hand, if the warming effects predominate, precipitation increases due to deforestation\textsuperscript{2,8,9}. The simulated increase in precipitation from the impacts of MC deforestation in the CESM model was confirmed by a 50 km x 50 km regional climate model\textsuperscript{9}, indicating that the CESM model can give credible local and global responses to MC deforestation. Additionally, the increase in precipitation due to deforestation coincides with the upward trend in observed precipitation\textsuperscript{8}, although other factors such as global warming also contribute to the rising precipitation trend. Nevertheless, this study suggests that taking into account the
new subtropical ENSO dynamics\textsuperscript{25} may provide a deeper understanding of how deforestation in the Maritime Continent may impact ENSO complexity.

**Data and Method**

*The CESM1 model.*

The CESM1 model is a comprehensive earth system model that integrates component models for the atmosphere (Community Atmosphere Model version 5 (CAM5)\textsuperscript{41}), land (Community Land Model version 4 (CLM4)\textsuperscript{30,42}), ocean (Parallel Ocean Program, version 2 (POP2)\textsuperscript{43}), sea ice (Los Alamos Sea Ice Model (CICE)\textsuperscript{44}), and river (River Transport Model (RTM)\textsuperscript{42}). The version of CESM used in this study is 1.2 and was obtained from the National Center for Atmospheric Research (NCAR). The horizontal resolution for CAM5 and CLM4 is 0.9° latitude x 1.25° longitude, for POP2 and CICE it is 1° x 1°, and for RTM it is 0.5° x 0.5°. CAM5 has 30 vertical levels while POP2 has 60. We used the B \_\_2000\_CAM5 compset of the CESM1 model, which features all components coupled with the CESM coupler version 7. The compset represents the monthly climatology well-mixed greenhouse gas concentrations (CO\textsubscript{2}, CH\textsubscript{4}, N\textsubscript{2}O, etc.), aerosol distributions, and solar intensity are prescribed under present-day scenarios (the year 2000). For more information, visit https://www2.cesm.ucar.edu/models/cesm1.2/.

*Deforestation pair experiments*

We conducted idealized experiments using the NCAR CESM1.2 fully coupled model, which consisted of one 200-year pair experiment and six 90-year ensemble pair experiments, as shown in Figure 2's schematic plot. The 200-year pair experiment was a cold start simulation and ran for 400 years. The first 200 years were for spin-up, and the data from the last 200 years were used in the study (as indicated by the green shading period in Figure 2). The control run continued until 800 years, and the data from the end of this 800-year simulation was used to launch another six ensemble members. We created small perturbations among members by using different daily initial conditions to drive them\textsuperscript{45,46}. First, we launched a paired experiment for 10 years as a spin-up using the end of the 800-year simulation. Then, we produced daily restart files from the end of year 10, specifically the daily initial conditions from 0811-01-01 to 0811-01-06 for both the control and deforestation experiments. Finally, we used these daily restart files to launch six ensemble paired members, each lasting 100 years (designated as members 1-6). For the six members, we only analyzed the last 90 years of data (as indicated by the orange shading period in Figure 2). By comparing the paired control and
deforestation runs, we aimed to understand the remote impacts of MC deforestation and its effects on ENSO complexity. In the control runs, the default Plant Functional Types (PFT) were used in the CLM4 (as seen in the left column of Figure 1). In the deforestation runs, we modified the PFT dataset by replacing all the broadleaf evergreen and deciduous trees in the MC region (10°S-10°N and 90-150°E, indicated by black dashed boxes) with C4 grasses (as seen in the right column of Figure 1). We chose to use C4 grasses as the land surface type after deforestation because they are the main vegetation type in oil palm plantations, which are expanding in the MC.47

**ENSO definitions**

ENSO events: The December-January-February (DJF) cold tongue index (CTI) was used to identify ENSO events. It was defined as the mean of the SSTAs averaged between 6°S-6°N and 180°-90°W. The seasonal cycle and trend were removed, and a three-month running mean was applied. In the 200-year idealized experiments, an El Niño (La Niña) event was identified when the index exceeded 0.64°C (-0.64°C), which corresponds to 0.7 standard deviations in the control run. We used the same criteria for identifying ENSO events in the deforestation run, as the mean SST was similar to the control run (not shown). The same method was applied in the other six pairs of simulations. However, each pair had its own criteria ranging from 0.66°C to 0.8°C.

Classification of single-year and multi-year ENSO events: An ENSO event was classified as a single-year event if the CTI value in the following DJF changed sign, from positive CTI at year 0 (CTI0) to negative CTI at year 1 (CTI1), or from negative CTI0 to positive CTI1. If the sign of the CTI did not change, the event was classified as a multi-year event (i.e., from positive CTI0 to positive CTI1).

Classification of EP- and CP-type ENSO events: The type (EP or CP) of an ENSO event was determined based on the sign of the difference between the NIÑO3 (SSTA averaged in the area between 5°S-5°N and 150°-90°W) and NIÑO4 (SSTA averaged in the area between 5°S-5°N and 160°E-150°W) indices. Only the first year of each event was considered for multi-year ENSO events. An ENSO event was classified as EP-type if the difference was positive and as CP-type if the difference was negative.

**Monte Carlo Method**

The 200-year idealized experiments utilized the Monte Carlo resampling method to determine the possible range of occurrence rates for single-year, multi-year, EP-type, and CP-type ENSO events. This was achieved by randomly sampling a hundred years
from the experiment data, repeating the process a thousand times. The mean and spread
for each ENSO type was then calculated based on the results from the thousand
iterations of resampling.

Data availability

The data used in this study, including restart and initial files, can be obtained by
contacting Ting-Hui Lee at lth313836@gmail.com. All the data processing, figures, and
tables code can be downloaded in the Zenodo (https://zenodo.org/record/7623476#.Y-
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Contributions

J.Y.Y and M.H.L conceived the study. T.H.L and M.H.L designed the experiments.
T.H.L conducted the simulations and performed data analysis. All authors contributed
to the interpretation of our results.

Competing interests

The authors declare no competing financial interests.


7. Feng, N. Understanding the climatic impacts of land use and land cover change over southeast Asia Maritime Continent using numerical model and satellite observations. (University of Alabama in Huntsville, 2016) Available at: https://louis.uah.edu/uah-dissertations/88.


Figure 1

Plant functional types (present in percentage) for broadleaf evergreen trees (top), broadleaf deciduous trees (middle), and C4 grasses (bottom) prescribed in the CESM CLM4 for the control run (left) and deforestation run (right). The area affected by deforestation is denoted by black dashed boxes and extends from 10°S to 10°N and from 90° to 150°E.
Figure 2

Schematic illustration of the conducted experiments. The horizontal lines indicate the simulation duration for each run, while the vertical lines represent the starting time for each run. Green and orange shading indicate the 200-year idealized simulations and ensemble members, respectively, which are the periods used for data analysis. CTL represents the control runs, and DEF represents the deforestation runs.
Figure 3

Mean differences between 200-Year deforestation and control runs. This figure displays the mean state differences between the 200-year deforestation and control runs, including (a) surface temperature (in °C), (b) omega velocity (in Pa/s) integrated from 1000 hPa to 100 hPa with mass weighting, (c) precipitation (in mm/day), (d-e) wind (in m/s) and geopotential height (HGT, in m) at 200 and 500 hPa respectively, (f) 925 hPa wind (in m/s) and sea level pressure (SLP, in Pa). The stippled areas indicate areas where the differences are statistically significant at a 95% confidence level, determined using a Student’s t-test.
Figure 4

a) Difference in the standard deviation of sea surface temperature (in °C) between the 200-year deforestation and control run. Stippled areas indicate differences that are significant at a 90% confidence level, as determined by an f-test. b) Difference in the correlation between sea surface temperature and zonal wind between the 200-year deforestation and control run.
Figure 5

The percentages of different types of ENSO events in the 200-year simulations. Panel a) displays the occurrence of tropical eastern Pacific (EP) and central Pacific (CP) type ENSO events, while panel b) shows the proportion of single-year (SY) and multi-year (MY) ENSO events. The left two bars correspond to El Niño, while the right two bars correspond to La Niña. The color coding shows EP-type or SY ENSO events in black and CP-type or MY ENSO events in red. The detailed percentages can be found in the Supplementary Table 1 and 2.
Mean state differences between the ensemble deforestation and control runs. a) depicts the difference in surface temperature (in °C). b) shows the difference in omega velocity (in Pa/s), which is integrated from 1000hPa to 100hPa with mass weighting. c) represents the difference in precipitation (in mm/day). d) displays the differences in wind (in m/s) and geopotential height (HGT, in m) at 200hPa. e) illustrates the differences in 925hPa wind (in m/s) and sea level pressure (SLP, in Pa). f) shows the difference in the standard deviation of sea surface temperature (in °C). The stippled areas in a) to e) indicate the regions where the differences are significant at 95% confidence level as determined by a Student's t-test. The stippled areas in f) indicate regions where the differences are significant at 90% confidence level as determined by an f-test.
Figure 7

Same as Figure 5, but for the results of the six-member ensemble experiments. The percentages can also be found in Supplementary Table 3 and 4.
Figure 8

A series of significant physical processes are depicted to demonstrate the impact of MC deforestation on atmospheric circulations and background states (1-3), ENSO dynamics in the subtropical region (3), SST variability during ENSO events (3), and the complexity of ENSO (4-5). The color shading in the figure represents the variance differences in SST between the deforestation and control runs (identical to Figure 4a).

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- 15530supp35326rq0cvyconvrt.pdf