Toth and Aronson Response to Reviewer #1

1. The authors stated a hypothesis that changes in ENSO activity around 4.2 ka triggered coral reef shutdown for about 2500 years (roughly between 4.1 and 1.6ka) in the Eastern Pacific. The hypothesis involved some hot topics including the late Holocene ENSO, 4.2 ka event and reef coral bleaching and mortality, therefore it sounds very interesting, but the authors did not provide direct evidences to support their hypothesis. Apart from the hypothesis itself, the authors did not provide any new information.

Our aim in this review paper is to present the hypothesis that ENSO could have played a role in the 4.2 ka event and outline a framework for how this hypothesis could be tested using records from coral reefs in the tropical Pacific. It was not our goal to provide new data or information, but rather to review the existing literature in the context of our hypothesis. We reworded the end of our introduction to clarify this point:

Whereas the majority of the records of the 4.2-ka event have come from terrestrial environments, the contemporary impacts of ENSO are often felt most keenly in marine ecosystems. Understanding whether and how marine ecosystems responded to climatic changes around 4.2 ka is, therefore, critical to deciphering the ultimate drivers of the 4.2-ka event. Here, we explore the hypothesis that ENSO played a role in the 4.2 ka event by reviewing paleoecological and paleoceanographic records from marine environments in the tropical Pacific. We focus on the long-term collapse of coral-reef development in the tropical eastern Pacific (TEP) to evaluate the role of which does appear to be related to changes in ENSO in the 4.2-ka event. The conclude that the relationship between ENSO and the 4.2 ka event warrants further study and outline a conception framework for future studies to investigate the linkages between these climatic phenomena using records from coral-reef environments in the tropical Pacific.

2. The basis of the authors' hypothesis is the mentioned "hiatus", i.e. the vertical accretion ceased from ~4100 to 1600 cal BP (totally 2500 years) in their reef cores. On one hand, the authors did not show the detailed information about their cores, such as the reef type (fringing reef, atoll, barrier reef), the spatial distribution and the lengths of the cores. On the other hand, the authors did not tell us whether the reef also ceased the development laterally. Most likely, their reef changed development orientation from vertical to lateral, because of sea level oscillations. If so, such change or the 2500-year hiatus should be controlled by sea level oscillation, rather than the 4.2 ka climate and the related ENSO activities. In this case, their hypothesis is wrong.

We have clarified that all the reefs in Pacific Panamá are fringing reefs (there are no barrier reefs in the eastern Pacific and atolls are uncommon). Detailed information about the cores is provided in previous publications and we now include a reference to where that information can be found. The reasons why sea-level variability is unlikely to have caused the hiatus have been discussed in previous publication. We have added the following sentence to point out those studies:

The fact that the the shutdown in reef accretion occurred in both the Gulf of Panamá and the Gulf of Chiriquí excludes upwelling and outbreaks of Acanthaster as drivers: upwelling is weak or absent in the Gulf of Chiriquí, and Acanthaster is absent from the Gulf of Panamá. Other possible factors, including changes in relative sea level, tectonics, and bioerosion, cannot explain the observed patterns either (Toth et al., 2012, 2015a).

We did add some additional information about the depths where the cores were collected and where the hiatus occurred; however, the sea-level history of the eastern Pacific is unclear so we are unable to convert those data to paleodepths. Nonetheless, the broad range of depths over which the hiatus occurs (~1.6 m) suggests that lateral accretion was also limited at the onset of the hiatus in reef accretion. The description of the core records now reads:
Our push-cores from three fringing Panamanian reefs, which spanned across a gradient of upwelling and water depths (-0.8 to -4.1 m relative to mean sea level), and which we dated with radiocarbon and uranium-series techniques, showed that vertical accretion essentially ceased from ~4100 to 1600 cal BP (Fig. 2; calibrated calendar years before 1950; Toth et al., 2012). There is no evidence that the reefs shifted to lateral reef accretion at this time, as the reefs were growing in a broad range of depth environments (~1.6 m across the cores included in Toth et al. [2012]) at the time of shutdown. The hiatus in growth lasted approximately 2500 years, meaning the reefs were in a phase of negligible growth for as much as 40% of their history (Toth et al., 2012). Detailed core logs are provided in Toth et al. (2012, 2013).

3. Modern observations have suggested that the large-scale coral bleaching and mortality were mostly associated with strong El Niño events, which exert high levels of thermal stress to the corals. This study, however, suggested the attenuated ENSO variability and the La Niña conditions in the 4.2-ka event had suppressed coral populations, and leaded to the shutdown of the reef accretion. The logic seems inconsistent with the modern observations.
Our reconstructions suggest that enhanced La Niña likely provided the initial trigger for reef shutdown in Pacific Panamá; however, we hypothesized higher ENSO variability* overall *(i.e., both La Niña and El Niño) suppressed reef development in the eastern Pacific for the next 2500 years. We added some text to clarify this point in the prospectus.

4. Table 1 shows the time range of the beginnings of the hiatus are wide (from 5 to 3.8 ka BP), m and it is not strictly around ~4.2 ka BP, which suggests the reef hiatus was not related to the ~4.2 ka event.
This is an interesting comment. The age-range for the start of the hiatus arises for several reasons. First is the uncertainty around dates in the cores. Second is the very-real possibility that coral branch-fragments were missing of the exact ages to delimit the actual start of the hiatus. Regarding the latter point, if 4200-year-old branch-fragments in excellent taphonomic condition, which denote rapid population growth, are missing from the particular spot where we cored in Panamá, or where someone else sampled in another locality, then the estimated start-time of the hiatus will be artificially early. If, on the other hand, the oldest fragments from during the actual hiatus are missing from that particular spot, our estimate of the start-time will be artificially late. A third point worth noting is that we do not yet fully comprehend how the 4.2-ka event was manifested on Pacific reefs and how it interacted with changes in relative sea level. These points are now articulated in the first paragraph of Section 5 of the paper:
however, falls or stillstands in relative sea-level in the western Pacific after the middle Holocene likely also contributed to stalled late-Holocene reef growth in many locations (e.g., Dechnik et al., 2018), potentially making it more difficult to discern the impacts of climatic variability and also potentially introducing variability into the start-times of hiatuses in reef accretion. Other possible causes of variations in the start-times listed in Table 1 include the artifactual absence of

coral material of particular ages in particular samples and the uncertainty associated with the dating techniques.

5. Based on the high ΔR and the low Sr/Ca-SST (Fig. 2), the authors suggested that strong upwelling occurred in ~3.8-3.6 ka BP and partially attributed the hiatus to the upwelling. However, the variations of the ΔR and the Sr/Ca-SST are not always in phase, particularly for the last millennium. Could the authors clarify the relationship between the upwelling and the SST?

We do not attribute the hiatus to upwelling, as the hiatus also occurred in the non-upwelling Gulf of Chiriquí. Instead, we use our record of upwelling to infer broader-scale changes in climate at this time, as upwelling is intensified during La Niña and suppressed during El Niño. The late Holocene changes in upwelling and SST provide further support for our argument about the changes in ENSO that may have allowed reef development to resume ~1600 years ago. We have added the following sentences to emphasize this point:

Our records suggest that upwelling was more moderate after the hiatus (Fig. 2A), which would indicate that there were fewer or less extreme La Niña events at this time. Furthermore, because the climate remained relatively cool after the hiatus (Fig. 2B), it is likely that the influence of El Niño events had also decreased.

6. It is well known that ENSO variability has been closely linked with the strength of Easter Asian Summer monsoon throughout the Holocene. The Asian stalagmites, which recorded the evolution history of East Asian Summer monsoon with precise dating controls, documented the 4.2 ka events lasting only hundreds of years. However, the authors claimed that there existed a 2500-year shut down of vertical reef accretion in the tropical Eastern Pacific beginning 4.2 ka, and tied to increased variability of ENSO.

This issue is addressed in the following sentence in Section 4:

Whereas the 4.2-ka event was manifested as an abrupt, short-lived climatic event in many locations, the large-scale climatic and ecosystem responses to the event may have been more gradual and more protracted.

7. If the hypothesis is correct, the ENSO plays a role in climate change at 4.2 ka. What are the ultimate causes driving ENSO variability?

The ultimate causes of ENSO variability are still being debated, as we discuss in the final paragraph of Section 4.

8. The Asian monsoon is generally suppressed during El Nino events and enhanced during La Nina events. According to the Figure 3, during the hiatus period, the tropical ocean experienced different ENSO modes, but the climate in Asian monsoon areas experienced a dry period during the 4.2 ka event. How to explain it?

We agree that most of the records of the 4.2 ka event reflect El Niño-like, as we discuss in the second paragraph of Section 4; however, we also point out in the following paragraph that some records indicate that more La Niña-like conditions followed this period. We added a reference that makes this suggestion in relation to the east Asian monsoon:

Similarly, whereas a number of records indicate a weaker East Asian Monsoon around 4.2 ka, indicative of an El Niño-like climate (Straubwasser et al., 2003), there is also evidence that some regions of southern Asia became wetter after 4.2 ka (reviewed in Wu and Liu, 2004).

9. Tectonic activity is also a possible cause to result in the stagnate of coral reef accretion vertically.
Please see our response to Comment 2.