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Interactive comment on "Limited impact of El Niño – Southern Oscillation on the methane cycle" *by* Hinrich Schaefer et al.

Hinrich Schaefer et al.

h.schaefer@niwa.co.nz

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We thank Zhen Zhang for the time taken to evaluate our study and for the helpful comments and suggestions. Below we address each criticism individually. Please note that some points were brought up by several referees and commenters; please see our other responses for additional information and changes to the manuscript. Referees' comments are bracketed as follows: <>. Our response is in regular font. Quotes from the manuscript are in quotation marks.

<I found the title is a bit misleading as it sounds like ENSO has limited impacts on CH4 sources and sinks, which is not supported by previous studies.>

We have clarified the goal and scope of the study in the introduction. We have also

changed the title following suggestions from this comment and other referees. Relevant changes to the title and manuscript are as follows:

Title: "Limited impact of El Niño – Southern Oscillation on variability and growth rate of atmospheric methane"

Abstract: "Here, we test the impact of ENSO on atmospheric CH4 in a correlation analysis."

Abstract: "It is possible that other processes obscure the ENSO signal, which itself indicates a minor influence of the latter on global CH4 emissions."

Introduction: "We conduct correlation analyses between ENSO variability and [CH4], as well as δ13CH4 records to quantify how much ENSO anomalies in emissions and sinks affect atmospheric CH4. Specifically, we explore how much of the year-to-year variability in methane levels can be attributed to ENSO and how large the ENSO-CH4 signal is in dependence of latitude."

Conclusions: "Further identification of these processes is necessary to inform climate change mitigation policies and climate projections."

<-The response of CH4 concentration to natural CH4 sources could be weak during weak/moderate ENSO events and the methane sources from anthropogenic activities could be dominating.>

The goal of our study is to find out whether the cumulative effect of ENSO events on the methane cycle is strong enough to drive observed trends in atmospheric methane (see response above). This does indeed mean that other processes may dominate. In fact, this is the main finding of the paper and has been discussed explicitly in the original submission, e.g., in Section 5.3.7., which is titled "Role of other methane cycle processes" and in the conclusions. Relevant passages include: "...or other processes in the CH4-cycle obscure the ENSO impacts."; "ENSO could affect CH4 emissions from tropical wetlands and biomass burning as predicted by Hodson et al. (2011) and van der Werf et al. (2006), respectively, but the resulting isotopic signal is overwhelmed by other components of the CH4 cycle. Such influences could be other sources (particularly anthropogenic ones), variability in atmospheric transport or changes in CH4 sink processes."; and "Our results do not rule out that ENSO influences CH4 emissions from wetlands and biomass burning through temperature, enhanced precipitation or droughts in key regions, but any such impacts are overwhelmed by OH-dynamics or other source and sink processes."

<Also, the general assumption of lower CH4 during El Ninos seems to be controversial to the observations in some El Nino event (e.g. 1997/98).>

The focus of our study is if the impact of ENSO on atmospheric CH4 is persistent throughout our records. Working with general assumption of lower CH4 during El Ninos, consistent with the findings in the latest paper authored by the commenter, is therefore a valid approach. The variance in expression between different ENSO events is discussed in the original submission, section 5.3.4. concluding with the sentence: "Depending on the strength and geographical expression of the climate anomaly, ENSO may thus cause regional or global emission anomalies that are opposite to the expected pattern."

<I feel it would be very helpful if the authors could add an additional analysis to maximize the signals by focusing on strong ENSO events.>

Attribution of signals to specific ENSO events is better approached with different methods and data sets than used in our study. Several recent publications on this topic are cited in the original submission, e.g., Pandey et al. (2017). It is also not the question we are trying to answer. Strong events may cause larger signals, but they are also rarer and more sporadic, so that their impact on our time series is limited. This is discussed in section 5.3.3. Another point on this suggestion is that the commenter's last publication identifies only four strong El Ninos, two of which occur before the start of our tropical δ13CH4 and HCN records. It is impossible to find general patterns with such a

small sample size. We therefore prefer to maintain the scope of our study. Please note that the original submission already provided the following finding on strong El Ninos and their impact on the correlations:

"The full BHD record for 1992-2016 gives very similar results as the 1998-2016 subset used for comparison with the other stations (as discussed above). However, the shorter subset for 1998-2014 produces larger Pearson r2-values (0.26 for running means and SOI), and for 2001-2014 we find Pearson r2-values up to 0.38 (growth rate correlated to EMI). These shorter data sets omit the strong El Niño events of 1998 and/or 2015-16, which could have been expected to have a strong influence on methane emissions and consequently δ13CH4."

<-For C13-CH4, the authors assume that a detectable change in C13-CH4 during ENSO should be observed if ENSO has significant impacts on wetland and biomass burning given that the suppression of wetland and enhanced biomass burning act in the same direction on C13-CH4. I wonder if this signal can be detected without removing noises from other factors like atmospheric transport, local OH, and other biogenic sources which are also influenced by climate conditions (e.g. landfills and agricultural sources, which have similar C13-signature as wetlands and also respond to changing rainfall and temperature).>

This comment goes back to the one above on interfering signals from other processes (see response above). While the individual arguments are all correct, they do not invalidate our point from the original submission: "If ENSO is invoked as a main cause of recent trends in [CH4] and δ13CH4 this should be manifested in sizeable correlations." We have added a note in the introduction regarding the commenter's point that some anthropogenic sources could reinforce the wetland anomalies: Introduction: "Several anthropogenic sources are subject to the same ENSO forcing and are expected to vary in concert with wetlands (e.g., rice agriculture, possibly livestock)."

<In addition, the growth of wetland CH4 emissions during El Ninos is more complex

than previous thoughts, Zhang et al., (2018) suggest that wetland CH4 emissions were suppressed at the early stage of El Nino but the wetland CH4 growth rate is in the rising phase at the later stage of El Ninos.>

It is unclear how much mixing and transport would smooth out the evolving signal from an El Nino event in our atmospheric records. Nevertheless, the sequence has the potential to cause patterns in monthly growth rates (strong positive anomalies) that are in contradiction with the general pattern of reduced overall emissions. We have noted this in sections 5.2. and 5.3.4.:

"The highest values are from (detrended) growth rates, which can be more indicative of dynamics within an ENSO event, rather than its overall emissions impact (Zhang et al., 2018)."

"Zhang et al., (2018) report an evolving response of wetland emissions to El Niños, where an initial reduction due to decreased wetland extend is counteracted by increased microbial activity under higher temperatures during the later stages of the event."

<Given that the peak of CH4 growth for wetland and biomass burning occur differently, this could weaken the net impact on the C13-CH4 signal.>

This was explicitly stated in the original submission (Section 5.3.1.): "It is possible that biomass burning and wetland CH4 production have different response times to ENSO forcing, which would weaken their cumulative impact on ïĄď13CH4."

<- Zhang et al., (2018) suggests that wetland CH4 emission could have a step increase of $\sim$9 Tg CH4/yr for the period of 2007-2014 compared to 2000-2006. Could this affect some of the authors' conclusions?>

The finding indeed affects certain conclusions, although with the caveat that Melton et al. (2014) show that different wetland models show a large range in modelled emissions and do not necessarily agree in the simulated trends. Agreement of the model

ensemble would be needed for a robust conclusion. We have added the following passages:

Section 5.3.6.: "Other wetland variability may have contributed to the rise (Zhang et al., 2018); given the range in wetland model output (Melton et al., 2014) this stands to be confirmed by ensemble runs."

Section 6.: "Our results do not rule out that wetland production is a contributor to the post-2007 [CH4]-rise if driven by environmental controls other than ENSO. This is suggested by a modelled increase in wetland CH4 production between the periods 2000-2006 and 2006-2014, although with the limited confidence of a single wetland emissions model (Zhang et al., 2018)."

Please note that we have added additional passages - or amended existing ones - informed by the study of Zhang et al. (2018) with regards to various points:

Section 5.3.2.: "One explanation for the lower combined wetland-pyrogenic δ13CH4 signal is low sensitivity of wetland CH4 production to ENSO events. This is consistent with r2-values of 0.12-0.26 between modelled wetland methane emissions (using different climate data sets as drivers) and MEI as reported by Zhang et al., (2018)."

Section 5.3.3.: "Previous findings that modelled tropical (Zhu et al., 2015) and global (Zhang et al., 2018) wetland CH4 emissions can explain at most 25% and 14%, respectively, of the variation in atmospheric methane growth rates therefore agree with our results that ENSO exerts only a minor control on atmospheric CH4." (note that the previous version read ". . . ENSO exerts only a minor control on global CH4 emissions")

Section 5.3.4.: (Zhang et al., 2018) report an evolving response of wetland emissions to El Niños, where an initial reduction due to decreased wetland extend is counteracted by increased microbial activity under higher temperatures during the later stages of the event. A complex response of wetland CH4 production is not only seen in models, however. Conclusions: "There is evidence for additional methane emissions from agriculture (Wolf et al., 2017) . . ."

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