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Interactive comment on "Historical reconstruction of ocean acidification in the Australian region" *by* A. Lenton et al.

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Response to Reviewers for Historical reconstruction of ocean acidification in the Australian region by Lenton et al. We would like to take the time to thanks the Reviewers for their efforts, which have improved the paper. Please find below a detailed response to each of the issues raised.

Anonymous Referee #1 Review of Lenton et al: Historical reconstruction of ocean acidification in the Australian region Lenton et al compile available data for ocean pCO2, SST, SSS and atmospheric CO2 to estimate the evolution of pH and aragonite saturation state on a higher spatial and temporal resolution than available before. They provide this data set to be applied to ecological applications and gain new insights on the magnitude of changes over the last 140 years. This study is a valid contribution to ocean acidification research, provides high resolution maps of pH and aragonite saturation state around Australia and gives estimates of their historical change. It will likely have many readers and be a very valuable reference for ecologists and physiologists working in this region. I recommend this manuscript for publication in Biogeosciences, after clarifying the methodological approach and providing further estimates on the uncertainty of the bold simplifications that the authors make. Some of the results need more discussion, see specific comments. The manuscript would also profit from another careful reading by the authors, as a number of typos are apparent and a rework of the maps in the figures is needed (see specific comments).

Specific comments: p. 8266 L 8-10: This sentence is unclear. My understanding from the text is that the authors use present day pCO2 from Sasse et al, together with constant (in time) salinity, the time-series of atmospheric CO2 and the time-series of sea surface temperature to calculate pH and aragonite saturation state as a 3D field (time-series of surface ocean around Australia). This 3D field can be used to look at the more recent part of it to produce the maps of present day pH/Omega and also to analyze the temporal evolution over the last 140 years. If this understanding is correct, it doesn't make any sense to say that "these predicted changes (are combined . . .) to reconstruct pH and Omega". It's one calculation for present and past together and it's not as the authors state here the case that the present is calculated first to predict the past. It's generally hard to understand from the abstract what the authors did. You should mention here which data goes into the calculation (not the specific data set, but time-series of SST, time-invariant salinity. . .)

Thank you, to better clarify what we have done, we have rewritten the abstract to highlight we use SST and climatological surface salinity and the atmospheric CO2 history to reconstruct the changes over the last 140 years.

The increase in atmospheric greenhouse gases over the last 200 years has caused an increase in ocean acidity levels. Documenting how the ocean has changed is critical for assessing how these changes could impact marine ecosystems and for the man-

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agement of marine resources. We use present day ocean carbon observations from shelf and offshore waters around Australia, combined with neural network mapping of CO2, sea surface temperature and salinity to estimate the current seasonal and regional distributions of carbonate chemistry (pH and aragonite saturation state). The changes in atmospheric CO2 and SST and climatological salinity are then used reconstruct pH and aragonite saturation state changes over the last 140 years (1870–2013). The comparison with data collected at Integrated Marine Observing System National Reference Station sites located on the shelf around Australia shows both the mean state and seasonality for the present day is well represented by our reconstruction, with the exception of sites such as the Great Barrier Reef. Our reconstruction predicts that since 1870 an average decrease in aragonite saturation state of 0.48 and of 0.09 in pH has occurred in response to increasing oceanic uptake of atmospheric COÂň2. Our reconstruction shows that seasonality is the dominant mode of variability, with only small interannual variability present. Large seasonal variability in pH and aragonite saturation state occur in Southwestern Australia driven by ocean dynamics (mixing) and in the Tasman Sea by seasonal warming (in the case of aragonite saturation state). The seasonal and historical changes in aragonite saturation state and pH have different spatial patterns and suggest that the biological responses to ocean acidification are likely to be non-uniform depending on the relative sensitivity of organisms to shifts in pH and saturation state. This new historical reconstruction provides an important to link to biological observations to help elucidate the consequences of ocean acidification.

p. 8268, l. 14-16: what about SOCAT data?

SOCAT data are not used in the reconstruction, to better explain the oceanic pCO2 used here please the response to next comment.

p. 8269, l. 17. As this is a crucial part of your method, you need to explain more about the method and the results of Sasse et al.

We now provide additional information on the methods and results of Sasse et al

(2013): Oceanic values of pCO2 were taken from an updated version of Sasse et al. (2013) that used a self-organising multiple linear output (SOMLO) approach to predict pCO2 values around Australia on a 1° x 1° degree grid each month for the nominal year of 2000. In brief, the SOMLO approach utilizes the global network of bottle-derived pCO2 and corresponding standard hydrographic parameters (SHP; temperature, salinity, dissolved oxygen and phosphate; N=17753) to first cluster the dataset into 49 neurons (or bins) based on similarities and homogeneity within the dataset. Principle component regressions were then derived between pCO2 and the SHP using data within each neuron. This can be thought of as a local-scale optimization, which follows the nonlinear clustering routine. To then predict pCO2 values for any set of SHP, a similarity measure is first used to establish which neuron best represents the SHP measurements, once established, pCO2 values are predicted using the regression parameters of that neuron. Independent testing by Sasse et al. (2013) reveals the SOMLO approach predicts open-ocean pCO2 values with a global uncertainty of 22.5 μatm (RMSE; N=17350), which decreases to 16.3 μatm (RMSE; N=859) within the Australia region. Monthly pCO2 climatologies presented in Sasse et al. (2013) were derived using the World Ocean Atlas (WOA) 2009 product (Antonov et al., 2010; Garcia et al., 2010a; Garcia et al., 2010b; Locarnini et al., 2010), which we update here via the WOA 2013 product (Garcia et al., 2014a, b; Locarnini et al., 2013; Zweng et al., 2013).

l. 20ff: If I understand correctly, the authors use Sasse et al ocean pCO2 and present day atm CO2 to calculate Delta pCO2. Then they use this Delta pCO2 together with the time-series of atmospheric pCO2 to calculate a time-series of ocean pCO2., i.e they assume that Delta pCO2 was constant over the last 140 years. This is a bold simplification and I'm skeptical that it holds, e.g. the temperature effect on pCO2 is not accounted for and air and sea are assumed to be in the same relative equilibrium instantly and always. In other words, it means that the ocean CO2 uptake was constant in the last 140 years, which is not the case (see e.g. Sitch et al. 2015, doi:10.5194/bg-12-653-2015, Figure 9c for a decreasing CO2 uptake around Australia between 1990 and

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2004). This needs to be addressed by the authors and estimates about the uncertainty of this assumption have to be made.

The reviewer are correct, in that the disequilibrium term is fixed over the last 140 years, certainly some of the changes is due to changes in the Revelle Factor which acts to reduce the amplitude of the disequilibrium term, which we account for in our analysis. However as the reviewer asserts more than ocean chemistry alone can affect the disequilibrium term, variability and change in circulation and biology impact oceanic pCO2 levels. To address the reviewer's comments we have expanded the discussion:

In this study we assumed that the seasonal air-sea disequilibrium (ΔpCO2) is seasonally time invariant i.e. no interannual variability, in the absence of longer-term observational datasets of oceanic pCO2. At present products the existing products of oceanic pCO2 fields that do exist e.g. (Landschützer et al., 2014) typically only extend back in time several decades reflecting the limit of historical observations. Consequently these products cannot be used to reconstruct long-term changes in ocean acidification.

In reality oceanic pCO2 will be impacted by changes in ocean dynamics and biological production. As primary production is very low around much of Australia (Condie and Dunn, 2006) (<0.2 mgm-3) it is unlikely that even a doubling of primary productivity in response to changes in nutrient supply could induce large changes in oceanic pCO2 around Australia. Consequently it is unlikely that variability in primary production plays a large role in modulating oceanic pCO2 levels. In response to changes in circulation only the variability in SST in the carbonate chemistry is accounted for in our reconstruction. While this variability maybe important at shorter-term timescales e.g. Sitch et al (2015) it is still not clear how important these changes are at decadal and longer timescales (Fay and McKinley, 2013). This highlights the need for products based on sustained long-term observations to better understand and characterize variability and change in ocean acidification.

l. 25-26: there should have been some measurements of ALK after the GLODAP data

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set was assembled. Please use and refer to some newer cruises as well.

The reviewer is correct there are measurements of ALK since GLODAP, however these remain quite sparse and of limited number, therefore this remains a correct statement. Therefore we have taken out the reference to GLODAP. At the same time we have recalculated of the alkalinity- salinity relationship incorporated all available cruises from GLODAP onwards. These are listed in an updated Table 1 and shown in an updated Figure 1

p. 8271, l. 2: please give more information on the method here. I checked in the Lenton et al 2012 paper and it's just one sentence, but makes it much easier to follow the paper if this is repeated here.

We have added the following to the text:

Our implementation of carbonate chemistry is derived from the OCMIP3 framework (O. Aumont, C. Le Quéré, and J. C. Orr, NOCES Project Interannual HOWTO, 2004, available at http://www. ipsl.jussieu.fr/OCMIP/).

l. 4-6: refer to Hauck and Völker, 2015 (doi: 10.1002/2015GL063070) where this is shown and/or to some of the earlier studies that suggest that this might be the case (Egleston et al., 2010, doi:10.1029/2008GB003407, Riebesell et al., 2009, doi:10.1073/pnas.0813291106; Pätsch & Lorkowski, 2013, DOI 10.4319/lom.2013.10.41.

We have added a reference to Hauck and Völker (2015)

l. 7ff. This correction is hard to follow, please explain more or illustrate with a figure. Can you validate this method somehow?

To make it clearer we have rewritten the text to say:

To correct for this, we first calculated the (detrended) seasonal anomaly of DIC in the period 1995-2006. We then added this seasonal cycle of DIC to the (deseasonalised)

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long-term DIC record (1870-2013). This allows us to reconstruct the historical DIC fields and the changes in the magnitude of the oceanic pCO2 in response to the Revelle Factor to be captured.

p. 8272, l. 17-19: Yongala is mentioned as being well and badly represented at the same time.

Thank you, we have removed the second reference to Yongala, which was in error.

p. 8273, l. 18: gradient from 8.1 to 8.14 does not seem to be strong to me. The latitudinal gradient in Omega appears stronger in Fig 5

We have removed the word strong – noting that the gradient is 60% of the total change since the preindustrial period and is significant as the uncertainty on pH was calculated to be 0.02.

l. 23ff: I'm confused by this small evaluation paragraph here by comparing to GLODAP which is not shown, whereas the Takahashi fields are shown and discussed later. Both parts of the evaluation should be placed in the same section.

We choose to keep this separate as it is only the Takahashi et al (2014) product that has both the mean state and the seasonal variability. To make it easier to follow we have changed heading 4.4 to be:

4.4 Comparison with Takahashi et al (2014) l. 27/8: explain the different effect of temperature on pH and Omega more and give reference for that. This is from equilibrium carbonate chemistry, and as such we have added a reference to the carbonate chemistry book of Zeebe and Wolf-Gladrow (2001)

p. 8274: l. 7: "The low seasonal variability suggests Omega > 3.5 in winter". Why don't you just check your reconstructed fields whether Omega goes below 3.5 in winter? Done, we have rewritten the sentence to be clearer saying that omega in the winter is above 3.5.

p. 8275: l. 24-27: what's the difference between (i) and (ii): both refer to the spatial interpolation?

This is a reasonable comment and we have now rewritten the text to say: ….likely reflects the coarser resolution of T14 the product than the reconstruction (4°x5° vs. 1°x1°) and the spatial interpolation required to generate T14

p. 8276, l. 17: 0.48 – is that the average number over all the area or the same at all locations. Describe how it was calculated.

This is the spatial mean change of the differences; to clarify we have added this to the text

l. 20-23: inconsistent, does the largest change occur "in northern Australian waters" or "in the Tasman sea and along the southern coast of Australia"? Don't you mean >0.6 (instead of <0.6)?

Thank you, yes this was in error, it should be > 0.6

l. 25: there is no figure 10.

Corrected

l. 25-26: show figure or describe gradient in Revelle factor, give numbers. Explain this sentence more.

We have added the following to the text:

This pattern of change around Australia is consistent with large-scale chemical buffering capacity of the ocean (Revelle factor) which increases from $\sim$ 9 at the equator to >11 at bottom of the study region e.g. Sabine et al. (2004).

l. 28: 0.09: – again, is that the average number over all the area or the same at all locations. Describe how it was calculated.

This is the spatial mean change of the differences; to clarify we have added this to the

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text: A net (spatial) mean decrease in pH of 0.09 is seen in the period 1990-2009 – 1889-1870

p. 8277, l. 5-6: does the gradient in temperature change, too? Else I would expect the temperature gradient to have an effect on pH but not necessarily on pH changes.

Yes the gradient changes, which is now illustrated in Figure 8.

p. 8279, l. 6-7, not only no interannual variability, but more importantly this implies that there is no trend of Delta pCO2 with increasing atmospheric CO2, which the authors need to discuss! This should not only be discussed with regard to seasonal versus interannual variability, but also with regard to the overall quality of the reconstruction. Present day values were evaluated against measurements at stations, but the past values cannot be evaluated, so this uncertainty is very important.

The reviewer is correct that by design that there is no trend in Delta pCOÂň2. We have removed the plot of the ratio of seasonal cycle to IAV at the suggestion of the reviewer, as we agree there is little value in this. We have now strengthened the discussion around the use of Delta pCO2, and touched upon the issues related to limited observations and long-term changes:

In this study we assumed that the seasonal air-sea disequilibrium (ΔpCO2) is seasonally time invariant i.e. no interannual variability, in the absence of longer-term observational datasets of oceanic pCO2. At present products the existing products of oceanic pCO2 fields that do exist e.g. (Landschützer et al., 2014) typically only extend back in time several decades reflecting the limit of historical observations. Consequently these products cannot be used to reconstruct long-term changes in ocean acidification.

In reality oceanic pCO2 will be impacted by changes in ocean dynamics and biological production. As primary production is very low around much of Australia (Condie and Dunn, 2006) (<0.2 mgm-3) it is unlikely that even a doubling of primary productivity in response to changes in nutrient supply could induce large changes in oceanic pCO2 around Australia. Consequently it is unlikely that variability in primary production plays a large role in modulating oceanic pCO2 levels. In response to changes in circulation only the variability in SST in the carbonate chemistry is accounted for in our reconstruction. While this variability maybe important at shorter-term timescales e.g. Sitch et al (2015) it is still not clear how important these changes are at decadal and longer timescales (Fay and McKinley, 2013). This highlights the need for products based on sustained long-term observations to better understand and characterize variability and change in ocean acidification.

l. 25-27: This effect needs to be discussed more. Can you give a rough estimate of the impact on pCO2, pH, Omega estimates?

In response to the second reviewer's comments we have changed the domain of the study to be up to 45S, rather than 50, which renders this comment redundant and hence it has been removed.

p. 8280, l. 11: climatology, do you refer to Takahashi or GLODAP (see comment above on putting these two evaluation bits in the same section)?

We have changed 'another' climatology to the climatology of Takahashi et al (2014)

l. 19: "marginal conditions": name Omega = 3.5

Added

Table 1/Figure 1: Is it not possible to cover a larger part of the Australian Seas by data (I'm surprised there is not more cruise data available)? What about cruises going to the south, the region south of 40âŮęS is only covered by the MAI station.

Attached is revised Figure showing the additional cruises used in this study, please also see the table included earlier.

Figures 3+4: Increase fontsize of axes labels.

Unfortunately this is not possible, as we are keen to keep the high spatial resolution of time axes, thereby allowing us to identify the times associated with particular events e.g. Cyclone Yasi. If we were to make these larger this would not be possible.

Figure 5+6+7+9: the figures are not readable, increase fontsize of all axes labels and tick marks. I'd recommend to use red for low pH and low Omega values. Use the same color scale for Figures 5 and 6. The regional differences between pH and Omega could be elaborated more in the text.

The figures have been improved and the colour bar enlarged, the color scales are the same for Figures 5 & 6 – however we have not changed the color palette at present we feel that the regional differences in pH and aragonite saturation are well described in the text.

Figure 7: the overlain temperature is even harder to read. It would be much easier to grasp if another map would show temperature.

We have followed the reviewers suggestion and added a separate figure for the changes in SST and associated IAV in Figure 8.

Figure 8: plot critical value (3.5) as dashed line.

Done

All remaining technical comments have been addressed.

Anonymous Referee #2 Received and published: 31 July 2015

This paper deals with a comprehensive view of ocean acidification in surface waters over the coastal and open zones around Australia in high resolution; presented are reconstructed maps or trends of the mean state, seasonal variability, interannual variability, and long-term trends of aragonite saturation level and pH. These are the fundamental information that we need as a basis of assessing the impact of the ocean acidification on marine ecosystem and its services. However, these mappings and reproductions are still highly challenging, given that the measurements of CO2 system variables are still limited in space and time. Authors tackled this by combing a new relationship between salinity and alkalinity for this region with climatological pCO2 maps they produced previously. The method and interpretations appears quite robust, but in some points they are unclear or questionable. Uncertainties and caveats need to be stated more explicitly so that the method and results presented here can serve for better assessments in the future. In summary, I recommend publication after a rather substantial revision based on the comments given below.

Specific comments:

- Page 8269, lines 16-19: The product of pCO2 fields given by Sasse et al (2013) is a key for this work from which the fields of aragonite saturation state and pH were derived. Explain the method and data sources of its updated version in more detail, and describe the uncertainty in the estimates.

The products of Sasse et al has now been described in additional detail in the text: Oceanic values of pCO2 were taken from an updated version of Sasse et al. (2013) that used a self-organising multiple linear output (SOMLO) approach to predict pCO2 values around Australia on a 1° x 1° degree grid each month for the nominal year of 2000. In brief, the SOMLO approach utilizes the global network of bottle-derived pCO2 and corresponding standard hydrographic parameters (SHP; temperature, salinity, dissolved oxygen and phosphate; N=17753) to first cluster the dataset into 49 neurons (or bins) based on similarities and homogeneity within the dataset. Principle component regressions were then derived between pCO2 and the SHP using data within each neuron. This can be thought of as a local-scale optimization which follows the nonlinear clustering routine. To then predict pCO2 values for any set of SHP, a similarity measure is first used to establish which neuron best represents the SHP measurements, once established, pCO2 values are predicted using the regression parameters of that neuron. Independent testing by Sasse et al. (2013) reveals the SOMLO approach predicts open-ocean pCO2 values with a global uncertainty of 22.5 μatm (RMSE; N=17350), which decreases to 16.3 μatm (RMSE; N=859) within the Australia region. Monthly pCO2 climatologies presented in Sasse et al. (2013) were derived using the World Ocean Atlas (WOA) 2009 product (Antonov et al., 2010; Garcia et al., 2010a; Garcia et al., 2010b; Locarnini et al., 2010), which we update here via the WOA 2013 product (Garcia et al., 2014a, b; Locarnini et al., 2013; Zweng et al., 2013).

- Page 8270, line 8 (Eq(1)): In the southern rim of the region (40S-50S), the alkalinity –salinity relationship of Eq(1) appears to give significantly smaller values of surface alkalinity than those from previous studies (Lee et al., Geophys. Res. Lett, 33, L19605, doi:10.1029/2006GL027207, 2006; Takatani et al., J. Geophys. Res., Oceans, 119, doi:10.1002/2013JC009739. 2014). The difference may reach to 30 umol/kg, resulting in the large differences in aragonite saturation state and pH. I suggest authors to incorporate the data of total alkalinity from 40S-50S taken at Repeat Hydrography Sections SR03 and I09S, and reevaluate Eq(1). High-quality data of total alkalinity around Australia are also available from sections I05, P21, and P06 (http://cdiac.ornl.gov/oceans/RepeatSections/). Surface alkalinity data from TF5, the main data source of analysis for Eq(1) (Table 1 and Figure 3), are not available from the website indicated in the footnote of Table 1. Correct the quotation.

We have taken the reviewers comment and calculated the alkalinity-salinity relationship with significantly more data. We have also removed the NRS data from this relationship to allow the comparison of the reconstruction with the NRS to be fully independent. The reviewers are indeed correct there are some very large errors in the area south of 45S. Once we had recalculated the alkalinity-salinity relationship we saw that clearly that the alkalinity –salinity relationship, calculated north and south of 45S were quite different. Consequently we have only considered data north of 45S in the study domain. This means we have made a very small adjustment to alkalinity-salinity relationship, which is now:

TA (umol/kg) = (Salinity-35)* (64.0 +/- 0.2) + 2270.0+/-0.1

The additional data is given in an updated Table 1 and an updated Figure 1

- Page 8272, lines 8-22, and Figure 4: Compare also the reconstructed pH with values calculated from observations. The sensitivity to temperature change shall be quite different between aragonite saturation state and pH. The time-series plots of pH also help to understand the phase of seasonal variation. The uncertainties in the reconstructed aragonite saturation state and pH as derived from the uncertainties in the reconstructed pCO2 and TA should be also given.

We have now compared the reconstructed values of pH and aragonite saturation with values of pH and aragonite saturation calculated from cruises in the Table above with the exception of cruises from Transfuture 5 and SS201004. This allows us to calculate the uncertainty as the residual mean standard error (RMSE) of the pH and aragonite as 0.02 for pH and 0.1 respectively

In the text we now state:

To assess the uncertainty in the reconstructed ocean acidification values, we compared these with the values calculated from individual cruises, this allowed us to estimate the uncertainty (as the root mean squared error) to be 0.02 and 0.1 in pH and aragonite saturation state respectively.

Page 8273, lines 25-28: I suspect the interpretation here. The distribution of aragonite saturation state and pH are also set by the large-scale variation of DIC. I presume that a relatively low pH in the tropical region is driven by warmer temperature. On the other hand, the decrease of pH south of Australia is driven by the elevation of DIC/TA increase, although this tendency may have been biased because of the underestimation of TA by Eq (1).

The reviewer is indeed correct this result is biased by the data south of 45S, which have now been removed (see above comments).

Page 8274, lines 16-19: I don't understand this sentence. I guess the seasonal variation in DIC should be also taken into account. It appears to me that the seasonal

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variations of pH and aragonite saturation state along the east coast of Australia and in the Tasman Sea are controlled by the interplay between DIC/TA and SST.

We have rewritten the sentence to be clearer and it now says:

That the large seasonal variability in aragonite saturation state is not associated with large seasonal variability in pH along the East Coast of Australia and in the Tasman Sea, suggests that the dominant driver of seasonality variability is SST rather than ocean dynamics, as evident in other regions.

Page 8276, lines 6 - Page 8277, lines 6; Historical changes: This method assumes constant delta-pCO2 over the time period of 1870-2013 (P9269, L20-24). When combining this assumption with the atmospheric CO2 record, this will give the upper limit of DIC increase and thereby the upper limits of aragonite saturation state decrease and pH decrease associated with the atmospheric CO2 rise. In the western South Pacific, this assumption has been only weakly constrained by the observations over the past a few decades (Takahashi et al., Deep-Sea Research II, 56, 554-577 (2009); Inoue et al., Tellus, 51B, 830-848 (1999)). In addition, changes in ocean circulation and mixing potentially have a large impact on these trends. These caveats should be addressed in the text.

It is true that we make the assumption that the delta pCO2 is fixed in time, to address the issues raised by both reviewers we have revised the discussion to say:

In this study we assumed that the seasonal air-sea disequilibrium (ΔpCO2) is seasonally time invariant i.e. no interannual variability, in the absence of longer-term observational datasets of oceanic pCO2. At present products the existing products of oceanic pCO2 fields that do exist e.g. (Landschützer et al., 2014) typically only extend back in time several decades reflecting the limit of historical observations. Consequently these products can not be used to reconstruct long-term changes in ocean acidification.

In reality oceanic pCO2 will be impacted by changes in ocean dynamics and biological production. As primary production is very low around much of Australia (Condie and Dunn, 2006) (<0.2 mgm-3) it is unlikely that even a doubling of primary productivity in response to changes in nutrient supply could induce large changes in oceanic pCO2 around Australia. Consequently it is unlikely that variability in primary production plays a large role in modulating oceanic pCO2 levels. In response to changes in circulation only the variability in SST in the carbonate chemistry is accounted for in our reconstruction. While this variability maybe important at shorter-term timescales e.g. Sitch et al (2015) it is still not clear how important these changes are at decadal and longer timescales (Fay and McKinley, 2013). This highlights the need for products based on sustained long-term observations to better understand and characterize variability and change in ocean acidification.

Page 8277, lines 7 - Page 8278, lines 9; Interannual variability: In reality, IAV of aragonite saturation state and that of pH have been controlled by the IAVs of DIC and TA as well as those of temperature and salinity. However, if I understood the method correctly, the IAV presented in Figs. 7 and 8 is in principle the IAV of the thermodynamic effect of SST on aragonite saturation state and pH at isochemical condition (climatological DIC + climatological S + climatological TA) and does not represent the effect of IAVs of DIC and TA. Does it make sense to compare the IAV of just SST's thermodynamic effect with the seasonal variations shown in Fig.5? The amplitude of seasonal variation of DIC has not been shown in this paper, but Lee (Limnol. oceanogr., 46, 1287-1297, 2001) suggested that it ranges from 15 umol/kg in the northern to 50 umol/kg in the southern Australian waters. This implies that IAV of DIC is also significant.

We agree and state clearly in the paper that our analysis is somewhat limited by not having the IAV in DIC, we agree with the reviewer that the comparison of seasonal to IAV is not that meaningful around all of Australia and we have removed this figure and adjusted the text accordingly.

All minor comments have been addressed.

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Updated Figures and Tables

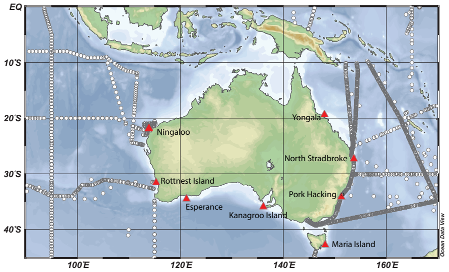

Figure 1 Locations (circles) of the concomitant measurements of alkalinity and salinity used to develop a new salinity-alkalinity relationship for the Australian Region, the cruises are listed in Table 1. Overlain on this plot (red triangles) are the locations of IMOS National Reference Stations (NRS) used in this study.

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Fig. 1.

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