Review for Morales M.S., Carilla J., Grau H.R., Villalba, R. Multi-century lake area changes in high-elevation ecosystems of the Southern Altiplano, Clim. Past Discuss., 11, 1821–1855, 2015

Reviewer's comments in black
Authors responses and comments in blue

B. Luckman comments

At first glance this appears an excellent paper – It is a novel idea and a useful contribution to the regional picture with a well-developed tree-ring chronology and sophisticated analysis of the reconstruction that establishes strong links between the reconstruction, ENSO and possibly the PDO. The relationships are soundly grounded by the statistics but the difficult question is what has actually been reconstructed. The calibration statistics are strong but the data on which that calibration is based leave much to be desired, particularly as I assume there is likely considerable seasonal variation in lake area. I realize that the lake area data are scanty and those used are the best available but it is far from convincing that the average annual data for lake area used in the calibration are a good statistical approximation of the true value.

At the initial stage of our study the low number of images per year was our major concern developing this lake area reconstruction. However, we observed that an image from a particular date could well represent the lake area condition of the year. Although, that we couldn't capture all seasonal lake area variability, a pattern emerged, and is highly correlated with the annual tree-ring growth.

In order to validate the assumption that intra-annual variation was negligible and justified the use of the average annual data for lake area, we compared for each one of the nine lakes, the coefficient of variation at both, intra- and inter- annual time scale from 1975 to 2009 period. In all cases inter-annual variation was higher than intra-annual (see the supplement S2.1-9). Moreover, autocorrelation analyses were applied to determine persistence in the monthly and annual time series averaged for the nine lakes from 1975 to 2009 period. This analysis show strong 19 months persistence in the monthly series, while two years persistence was found in the annual series (see the supplement S3).

It may be possible to use the relationship between precipitation and lake area to justify these lake area figures as there is obviously a strong linkage and by calibrating precipitation –lake area relationship one could make inferences about changing lake area from a precipitation reconstruction. This would not change the properties, trends and patterns within the reconstruction and the relationships between the reconstruction and SSTs and might be a stronger, more statistically sound reconstruction.

Lakes have obvious advantages over rainfall series, for the following reasons: 1- there are no meteorological stations in the area. 2- Summer precipitation is of local convective type, without regional representation 3- Lake area integrates parameters that affect hydrological balance. Lake area is a direct measure of the accumulation and lost of water, including for example, the wind effects or radiation changes that are not taken into account in the instrumental measurements (or they do with complex models with difficult parameterization). Even when instrumental

precipitation data exist in the area, water balance estimation based only in precipitation should be worse than based on lakes.

Relationship between regional annual tree growth and a regional precipitation index from further north Altiplano ($r = 0.49$; $p < 0.003$) is much lower than the relation with regional lake area index ($r = 0.70$; $p < 0.0001$). Hence, the reconstruction model for precipitation would explain lower variances than those models for lake area.

The technique certainly shows promise but I would prefer to have seen a stronger calibration data set (or a better justification for using these data) before being convinced that a valid measure of annual lake area was being reconstructed. Lake area is clearly an important hydroclimatic variable in this environment and has significant ecological impacts in the Altiplano. Providing an estimate of these changes is a useful tool for examining climate impacts on these systems. However, one wonders whether approaching this problem using a precipitation or PDSI reconstruction would be equally useful or better that the lake area data used here.

As we response to the second comment, the lack of meteorological stations in the study area together with the convective type of the rainfall make precipitation records as no the best suitable data to be used for reconstruction in this study area.

Using PDSI records for reconstruction: Previous studies (Garreaud et al., 2009; Tencer et al., 2011) indicate the poor representation of climate variability by gridded products, such as PDSI, based on few or no high-altitude stations in remote areas with complex topographies, such as the Central Andes. Hence, the use of PDSI data could be even worse than precipitation.

Presenting the available data in the supplementary material indicates that the authors are aware of these limitations but I feel that they need to acknowledge this in the text and present a stronger rationale for using these data. The present section 2.3, though an accurate statement, glosses over these limitations and leads to several queries and assumptions about the data (and possibilities) that are clearly not the case based on the supplementary material (see my detailed comments below).

Page 1825, line 19, section 2.2 Lake area records
We incorporate the following paragraph to state why we decided to use the image records: "Good quality available images for the different years of the period 1975-2009, ranged from one to ten (dates of images are in the supplement, S1). Despite of the variable acquisition dates and number of the images, relative low intra-annual area variability was recorded for the nine lakes. A comparison between the coefficients of variation for each lake showed that inter-annual variability represented more than the double of the intra-annual variability (see the supplement, S2.1-9). Therefore, we assume that the monthly or seasonal variation was negligible in relation to the higher inter-annual lake area variation, and an area value from a particular image could well represent the mean lake area condition of the year. To further validate this assumption, autocorrelation analyses were performed to determine persistence in the monthly and annual time series averaged for the nine lakes from 1975 to 2009 period (see the supplement, S3). This analysis showed strong 19-month persistence in the monthly series, while two-year persistence was found in the annual series. AnClim program (Štěpánek, 2008) was used to perform this analysis."

Most of my other comments on the paper are largely corrections/ improvements of the English and a detailed list follows.

We appreciate very much the corrections/improvements of the grammatical and English language errors in the original manuscript. Most of them were corrected. Please, see detailed list.

Page   Line   comment
1822   4   have been shown

The abstract was substantially modified following D. Urrego's recommendation, and this sentence is not in the new version.

      5   hydrological ok
      8   in NWA ok
      10   of not from ok
      11   a regional? composite from how many sites?

A regional chronology composite from two sites, Vn Granada and Vn Uturunco.

      12   correlation

This word was eliminated from the new version of the abstract

      12   but you are dealing with a composite chronology?
Yes
      13   order here. Did you screen predictors before making the composite and then reconstruct

The abstract was substantially modified following D. Urrego's recommendation. Please, see the new version.

      17   what is the magnitude of seasonal fluctuations?

We add a new table in the supplement with average and range of lake area records at annual and inter-annual time scale. Also, we add new figures in Section 2 of the new version of the supplement, showing the monthly and annual magnitude of the fluctuations.

      22   delete comma ok
1823   4   in the lowest point of ok
      6   which consequently play ok
      8   do vertebrates nest?

We re-wrote this sentence as follow: "Bird and large vertebrate species depend upon the wetlands for grazing, nesting and water."

7-12   simplify into two sentences. This is an extreme environment with…. These conditions… ok

14   are not is ok

19   twenty-first ok

22   dynamics ok

25   levels recorded at gauging stations but this region lacks such instrumental data. ok

1824   2   delete assessed ok

3   P.t are small trees that grow … on …

We re-wrote this sentence as follow: "*P. tarapacana* is a small tree, ca 2-3m tall, and is the largest woody species that grows on the slope of the high volcanoes between 4200-5200 m."

4   near the lacustrine areas studied. ok

10   reorder. The main goal of our study was to use …. to develop ok

13   describe temporal fluctuations of lake area and ok

15   from the ok

18   factors, not forcing, variations in lake area? ok

We corrected the sentence as follow: "Finally, in order to identify the major climatic factors influencing variations in lake area, we compared the Vilama-Coruto lake reconstruction with indices of El Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO)."

19   with indices of ok

20   delete indexes ok

25   delete a ok

1825   2   the not a ok

4   delete the ok

6   reorder- P.t is a small tree, ca 2-3m tall, and is the largest… ok

7   delete The ok

8   Extreme ok

15   a table showing lake area sizes (and possible range of sizes) would be useful here.

Thanks for the comment. We agree with the reviewer that this information is important, so we add in the supplement a table (S4) showing lake area average of inter-annual fluctuation of the period 1975-2009, and the range at both, intra-annual (minimum and maximum records of the averaged months for the period 1975-2009) and the inter-annual (minimum and maximum records of the annual means for the period 1975-2009).

21   image not images ok

21   How did you standardize for seasonal variation in lake area in compiling these annual averages.

I did not standardize for seasonal variation. I averaged all available data for each year, then, I standardized for annual variation related to the period 1975-2009.

Also what is the relationship between lake area and pixel size- which determines the precision of your individual estimates. These procedures need to be defined in more detail as the representativeness of the calibration data is key to the reconstruction.

According with the reviewer, we add the following paragraph in page 1825, line 18:
"We calculated lake area based on the number of pixels and their sizes. Pixel size for Landsat MSS is 80 x 80m (0.0064 km2) and for Landsat TM is 30 x 30m (0.0009km2). For example in November 1978 Cerro Negro lake encompassed 316 pixels of Landsat MSS corresponding to 2.02 km2 (316 * 0.0064km2). In October 1988 the same lake, encompassed 2551 pixels of Landsat TM image, which is the same as saying 2.3 km2 (2551 * 0.0009 km2)."

This needs more data. The supplement shows several years in which the data are very sparse so perhaps some data on seasonal variability is needed. Possibly you could have done this on August variability which is the most complete record.

We agree with the reviewer about the scarce number of image per year, ranging from one to four since 1975 to 2004. However, one image would represent quite well the annual lake area condition. Please, see response to comment 1 and 4 and the analyses in section 2, 3 and 4 of the new version of the supplement.

Also you never give data on the area of the individual lakes reconstructed.

Please, see response to comment on page 1825, line 15.

      24   as Z scores ok
      25   to develop a regional mean ok
      26   except for 1983 when no image was available (but Supplementary shows no data for 1985 also).

Sorry, it was a mistake. The year 1985 have two images May-26 and Aug-30. We corrected and checked dates of images in S1 from the supplement.

      27   delete comma. ok
1826 1-2   How good is the relationship between precipitation and lake area? Could it also be used to estimate lake area for years prior to 1975 where there is a precipitation record-i.e. an independent verification of part of the reconstruction?

Please, see response 2 to reviewer's comment.
As we mention before, no precipitation data exist for the study area. However, following reviewer's comment, the correlation between lake area and precipitation records from further north meteorological stations (almost 400 km of distance from our study area) is relative low (r = 0.47; p < 0.02; Carilla et al. 2013) to be used for a reconstruction model.

      3   the supplement ok
      5   delete comma ok
      6   wetter north and east slopes? ok

7 on not in ok
10 contain at least 300 years of record ok
15 I assume this is perhaps October or November. This raises an interesting question as to whether you estimate lake area for a calendar year (Jan- Dec) or whether you used an equivalent of the Hydrological year (possibly July-June) - Having seen the data in the supplementary material I guess this doesn't matter.

It was no possible to detect a clear hydrological year in the diagrams of the averaged monthly lake area records (see S2.1-9 in the supplement). Maximum and minimum lake area values for the nine lakes did not showed a common occurrence pattern. This could be related in part to the high monthly persistence present in the lakes at intra-annual time scale (see S3 in the supplement). For other hand, correlations between tree-ring records and different combinations of mean annual lake area values (such as, several hydrological and calendar annual means) show highest for January to December.

19 correlation over what period

We add the period in the text

20 into not in ok
23 standardize not fit? ok
25 the signal free ok
1827 1 footnote bracket?
   5-9 and what were the results?

We add a reference to Table 1 in page 1827, line 5. Also, results were explained in section 3.1 Tree-ring chronology and reconstruction model

What is the EPS cutoff and Rbar values?

EPS and RBar characteristics were described in section 3.1 Tree-ring chronology and reconstruction model. Page 1830, line 17.

Should refer to Table 1 here? ok
9 used ok
11 of not on ok
12-15 you carried out several trials e.g. different seasonalizations of lake area, individual months perhaps or just one month (August?)?

Yes, we used every singular months, different seasonalities, calendar (Jan-Dec) and hydrological years (Jul-Jun, Aug-Jul, Nov-Oct). The highest correlation was obtained using the mean January-December record.

14 found ok

15 et seq. this section needs clarification. Were the two lags used in the final reconstruction? Are they T+1 and T-1? How does leave out one work with lagged predictors?

Predictors used for the lake area reconstruction were the tree-ring chronology and just one lag (t+1). We corrected and clarified in the manuscript: page 1827, line 21.

21-24   invert sentence - The leave out …… was used to….. ok
26   as not us ok

1828   4-8   where do you provide the results of these statistical tests? Reference to Figure 2 needed?

We provide the results of this analysis in Figure 2 and section 3.1 Tree-ring chronology and reconstruction model. We add a reference to Fig. 2 in page 1827, line 23 of the section 2.4 lake area reconstruction.

12   delete /

Thanks, originally it was the letter l not /

13   Fig 3 perhaps? Possibly delete this ref to keep figure refs in order. ok
15   reference to Table 2? ok
16   within rather than along? ok
25   dates of extreme events. ok

1829   3-4   reorder. The influence of Pacific sea surface temperatures (?) on lake area fluctuations in the V-C area was estimated by examining the …
ok
5   averaged annual what? SSTs?

Yes, sea surface temperatures. We corrected in page 1829, line 5

11   delete The ok
14   spectral? ok
15   spectrum or spectra? spectra

1830   3   the or their

We replaced "the" by "their"

5   indices ok
7   the SSA ok
13   the regional chronology ok
14   tree-ring width or just ringwidth?

We replaced "tree ring width" by "ring-width".

14   As previously demonstrated (…. ok

24   to capture ok

1831   3   Fig 2. Figures should be cited consecutively so this should be Fig 3 if you have cited a Figure 2 previously

It is Fig. 2, the reconstruction model.

12   Fig 3b or 2b

It is Fig. 2b

15   figure number

It is Fig. 3

19   16th.? The 15th

The year 1503 is the beginning of 16th not 15th century

21   spans most of the 16th century (1504-…. ok
24   high lake area ok

1832   1   were ok
3   encompasses ok
6   begins in the 1930s ok
8-9   During this 30 year period 1987 was the only year to exceed the long-term historical mean area.

Following reviewer's recommendation, the sentence "Over this 30-year interval, the lake area during the year 1987 slightly surpassed the long-term historical mean" was replaced by the "During this 30 year period 1987 was the only year to exceed the long-term historical mean area."

11   A different …. changes in lake area

Corrections were incorporated

13   periods of lowest lake area ok
15   The period 1983-2007 is has the smallest 25 year mean and is substantially lower than …..

We replaced the sentence "In terms of 25 year moving averages, the period from 1983 to 2007 ranks at the top among the five lowest events." By "In terms of 25 year moving averages the period 1983-2007 is has the smallest 25 year mean and is substantially lower than the other four lowest events."

20   delete the sentence similar patterns

      21   1857 are similarly the lowest and highest 50 year periods in this 600 year record (Table 2).

      23   these results

      24-26   the fluctuations have been the lowest or the actual lake areas?

      27   delete this sentence?

      28   Changes in the occurrence rate…. (Fig 4)

1833   1-6 The recurrence interval of extreme events (<20% of the mean area) was between 4-7 years in the 15th -18th century and between 7-15 years in the nineteenth century. It has steadily increased from ca 6 in the 1930s to 2 in recent years.

      10   significantly negatively correlated ok
      17   at an inter-…. ok
1834 1   at a time ok
      3   shows ok
      5   of the nineteenth ok
      6   year ok

8	over or throughout not along ok
8	delete around? ok
10	the 16th, the 15th etc.
17	by not at ok
19	showing that both records have large…. ok
1835 2	why is the citation to Carilla here?

Because the use of satellite-derived lake area records as a measured of water balance, was also explored in Carilla's paper.

To clarify we modified the following paragraph:
"The use of satellite-derived lake area records as a measured of water balance, resulted…"
        by
"Consistent with the results obtained by Carilla et al. (2013), the use of satellite-derived lake area records as a measured of water balance, resulted …"

        7 it may be higher but is the lake area reconstruction founded on a stronger calibration data set than the precipitation records? What is the correlation between these two records? Do they share the same chronology predictors?

The number of years used for the lake area reconstruction model was n=34 while for precipitation reconstruction was n=45. Therefore, precipitation calibration data were better than lake area data set. However, the lack of precipitation data in the study area, make lake area satellite records of greater value.
Precipitation reconstruction is based on 7 tree-ring chronologies distributed over the Altiplano, while lake area reconstruction is based on 2 tree-ring chronologies from the southern part of the Altiplano. Both reconstructions share one tree-ring chronology, so they are not totally independent records. However, when we replace the shared chronology from the precipitation reconstruction looking for the independences between both reconstructions we find very similar results. This is because there is a strong spatial correlation in tree growth throughout the Altiplano (see Table 4 from Soliz et al. 2009).

Correlations matrix between the 14 residual tree-ring chronologies over the common period 1890–1999.
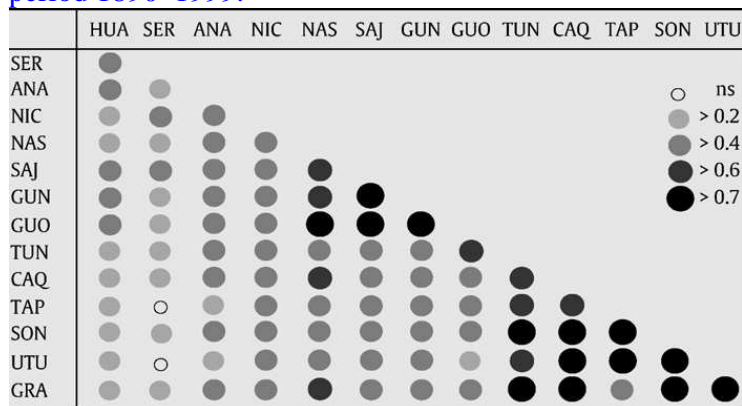
Sites are arranged from north (left) to south (right) along the X-axis. All correlations

>0.2 are statistically significant at the 99% confidence level except TAP versus HUA and CAQ versus SER, which are significant at 95% confidence level. ns = not significant.

9-10   is there literature justification for this statement?

According with reviewer we include two references (Mason et al. 1994; Morales et al. 2004) and we clarified the statement as follow:

At the sampling sites, precipitation explains high percentage of the total radial growth variance, but also summer temperatures which increase evapotranspiration and reduced soil water supply, affect tree growth variability (Morales et al. 2004). In the same way, the areal extent and depth of water in lakes respond to changes in precipitation and evaporation integrated over the lakes and their catchment basins (Mason et al. 1994). Both, tree-growth and lake area integrate changes in climatic parameters including precipitation, temperature, radiation and wind speed. As a consequence, a closer association is expected between tree growth and lake extents than tree growth and singular parameters such as precipitation or temperature.

Would PDSI be comparable to the Lake area parameter or are the data for PDSI lacking?

PDSI could be comparable to the lake area parameter because integrate precipitation and temperature. However, instrumental records used to calculate PDSI are very scarce and from stations located outside of the study area that not represent very well the hydrological balance of the study site.

12   how are these specific intervals defined?

We used the Rodionov analysis explained in method section page 1828 - line 10

17   how independent are the precipitation PDSI and lake area reconstructions. Are the same chronologies involved?

No *P. tarapacana* chronologies are included in the PDSI reconstruction, but precipitation and lake area reconstruction are not totally independent because they share one tree-ring chronology. Please, see response to the comment of page 1835, line 7

19   are assumed to be associated?

In Carilla et al. (2013), lakes areas were positively (negatively) correlated with precipitation (temperature). Therefore, we demonstrated that these records were associated.

21   isotope records ok
29   separated by ok
1836   1   own=? Individualistic or individual characteristics?

We change "own" by "individualistic"

Is the proxy record from the silver mines at Potosi any use for comparison?

Thanks for the comment. The historical document based precipitation reconstruction from Potosí was related to the lake area reconstruction.
We add an statistical analysis in the supplement (S7) and the following paragraph in the main manuscript page 1835, line 26
"These dry years where also identified in other high resolution precipitation reconstruction based on historical documents from the silver mines from Potosi (southern Bolivia) across the period 1585-1807 (Gioda and Prieto, 1999). The annual dry events of the historical series and lake area reductions were consistently related at inter-annual variations during the common period (see statistical analysis in the Supplement; S7)."

    4   what vegetation index?

This paragraph referred to our previous study (Carilla et al. 2013). To avoid confusion we add the reference "Carilla et al. 2013" in page 1836, line 5.

    8-10   combine these two sentences .. reconstruction indicates that… is exceptional over the 1407-2007 period.   ok
    11   and the driest 25 and 50 year intervals occur in…… ok
    14-18   delete first sentence and run on from the paragraph above?

Thanks, but we let the original paragraph.

    16   that changes from a recurrence interval of …. ok
    20   what is oxygen isotopic rate δ18O?

We corrected and changed the following sentence:
"… been recorded in oxygen isotopic rate $\delta^{18}O$ from Quelccaya (Thompson et al., 2006) and Pumacocha (Bird et al., 2011)."
        By
"…been identified in $\delta^{18}O$ isotope records in the ice core from Quelccaya (Thompson et al., 2006) and sediment core from Pumacocha (Bird et al., 2011)."

    23   seem ok
    26   increasing temperatures or increasing trend of temperatures? ok
1837 13   analysis reveals or analyses reveal? ok
    15   delete all ok
    16   indices ok
    17   throughout not along ok
    20   period analysed ok
    21   The ….strong during the ok
    25   present evidence for ok
    26   from 1700? ok
    28 et seq. simplify- The main oscillatory modes between … and …..-are similar though negatively related, over the xxx-yyy period

According with the reviewer, we simplify the paragraph:

"When we compared the main oscillation modes of variability between the lake- area reconstruction and the instrumental PDO and N3.4 SSTs indexes over the common period, negative relationships were evident at multi-decadal, decadal and inter-annual mode of variability, highlighting the Pacific influence over most modes of variability in Coruto-Vilama lake areas."
By
"The main oscillatory modes between the lake-area reconstruction and the instrumental PDO and N3.4 SSTs indices are similar though negatively related over the 1900-2007 and 1872-2007 periods, respectively."

      29   indices ok
1838 1-10   and what are the relationships with precipitation which is also strongly correlated with SSTs?

As we mentioned before, correlation between lake area and precipitation records from further north meteorological stations (almost 400 km of distance from our study area) is relative low (r = 0.47; p < 0.02; Carilla et al. 2013).

      18   appear ok
      20   period analysed ok
      24   Does it also show the earlier shift ca 1947?

We did not identify the earlier shift (ca. 1947) in the lake area reconstruction. However, above average lake area condition was recorded since 1944 to 1958. This relative humid condition follows an extreme lake area reduction lasting consecutively 8-yr (1935-1942).

      25   evidence ok
      26   from not since? ok
      28   has not have ok
1839   3   have been documented ok
      7   that the PDO   ok
      10   has persisted since 1999. ok
      13   I find it surprising that there is little comparative analysis with precipitation or ENSO reconstructions for the adjacent region based on the same species and possibly some of the same chronologies. How different is the lake area reconstruction from the precipitation reconstruction. This is not to take away from the lake area reconstruction but are the conclusions about ENSO and PDO any different from those previously identified through precipitation-related reconstructions?

Page 1835, line 26 in the section 4. Discussion and concluding remarks.
Following reviewer's comment we add more comparative analysis between our lake reconstruction and other proxies records for the region and adjacent regions.

These dry years where also identified in other high resolution precipitation reconstruction based on historical documents from the silver mines from Potosi (southern Bolivia) across the period 1585-1807 (Gioda and Prieto, 1999). The annual dry events of the historical series and lake area reductions were consistently related at inter-annual variations during the common period (see statistical analysis in the supplement; S7).

19th century showed the highest lake area records of the reconstruction, consistent with the most important wet period identified in the precipitation reconstruction from the Altiplano (Morales et al., 2012). Also, others low resolution environmental proxies such as the peat-accumulating wetland from Cº Tuzgle in the dry Puna, Argentina (Schittek et al., 2015) and packrat middens in the Andean precordillera from the northern Atacama Desert, Chile (Mujica et al., 2014), highlight the large pluvial period of the 19th century.

Page 1839, line14. Also we add a paragraph incorporating the main findings about ENSO and PDO related with our lake area reconstruction and how this study complement other studies discussing the regional manifestations of PDO and ENSO.

"In the present study, common cycles and periodicities were identified between lake area and ENSO (at inter-annual/decadal oscillation modes) and PDO (at multi-decadal oscillation mode). These results allow to identified ENSO and PDO frequency, amplitudes and associated teleconnection patterns. These findings were consistent to those recorded for the ENSO related precipitation reconstruction from the Altiplano (Morales et al. 2012), while no previous analyzes were made about the PDO influence on the reconstructed precipitation. Since most palaeo-reconstructions of ENSO devoid of tropical/subtropical records (Li et al., 2013), our lake-area reconstruction provides valuable information about ENSO and also PDO evolution during the past 600 years and should be considered as a key input in further high-resolution reconstructions of these hemispheric forcing."

	16	provided ok
	26	where the water ok
	29	project ok
1840	1	presently or present-day not actually ok

3 don't your results indicate that the last 20-30 years have actually exceeded prior natural variability? Isn't this the value of the present reconstruction?

Our results indicate that the last 3 decades were the driest of the period 1407-2007, but we did not say that this value exceed prior natural variability.

	6-8	possibly but the key will remain the availability of good present day lake data for calibration studies. ok
	18	his help ok
	19	his ok
	20	routine ok
1841	4	April , 1993, 330-… ok
	10	Proc. Not P.? ok
1842	9	glaciers or a glacier? a glacier.
	20-4	shorten the citation?

1844 11 16°S ok
1847 is the lowest 25 yr. minimum area correct? Yes
1848 Fig 1 green stars difficult to see

We increased green stars size in the new version of the Fig. 1

Is Vn. Uturunco the name of the lake, mountain and the chronology site?

Vn Uturunco and Granada, are the names of the chronologies and mountains

1849 I find it easier to have the identification of the parts of the diagram BEFORE the description i.e. Figure 2. (a) Observed, etc.

Thanks for the suggestion; we changed identifications of the panels in the figures

1850 The horizontal orange lines are the means of the periods, not the regime shifts. The regime shifts are difficult to see and could maybe be identified by vertical Arrows above the figure and dates.

Following reviewer suggestion; we incorporated arrows and date to identify the regime shifts. Also we change the caption of the figure as follow:

"Fig. 3. Annual (January-December) Vilama-Coruto lake area reconstruction for the period AD 1407–2007. Annual lake area expressed as Z-score of the 1975–2007 lake area mean area. The 35-yr smoothing-spline curve highlights the multi-decadal variability. Significant (95% c.l.) regime shifts (blue arrows) and the mean of periods (orange horizontal line) detected by the Rodionov (2004) method (window length=25 yr). Dates of the regime shifts are shown in the figure. Uncertainties of the reconstruction are shown by the light green band (±1 RMSE)."

1851 Figure 4 caption Changing probability of extreme low values (<20th percentile) from …….. Caption should indicate how this is smoothed

Following reviewer's comment we changed the caption
Fig. 4. Occurrence rate of extreme lake area decrease (lake area values under percentile 20) along the reconstruction time span (1407-2007) in the Vilama-Coruto region.
        By
Fig. 4. Changing probability of extreme low values (<20th percentile) of the Vilama-Coruto lake area reconstruction from 1407 to 2007. A Kernel smoothing method was used with a bandwidth of 50 years. The shaded represent 95% confidence interval based on 1000 bootstrap simulations.

1853 See comment on labelling components as in Fig 2. Panel last line of caption ok
1854 (SSA) of reconstructed lake areas (dates) ok
1855 (SSA) over the 1870-2010 interval. ok

Supplement
Line 1 LANDSAT ok

These data are very sparse only 5/35 years have 8-10 months of data, 27 have 1-3 months of data (15 with 2) and two (1983 and 1985) have none. The record from 1982-1985 has only two months of data. On a monthly basis 20 years have August, 14 have May and 10 have December. This would make it very difficult to see (or correct for) any seasonal pattern. The authors indicate they averaged monthly values to get a yearly average area (and estimated 1983- no mention of 1985). It is difficult to see how, apart possibly for 2005-2009, one could get a reasonable estimate of the annual average.

One would imagine that there would be quite a large seasonal variation in lake area in this environment. If this is the case how can one get a reasonable estimate of annual average area from one or two months of data, especially when the months for which data are available vary from year to year- unless, of course, there is little seasonal variation in lake area? Can some information be provided to assuage these concerns?

Please, see response to the first comment.

How well do these "annual averages "correspond with appropriate precipitation records.

Please, see response to the second comment.

Surprisingly scanning the Figure 2 indicates that the residual values have little correlation with the number of months on which the annual average is based.

The residuals of the regression models indicate that annual value based on the averaged months are not significantly autocorrelated at inter-annual time scale.

What would happen if you calibrated on the 20 years of August data and estimated (or calibrated estimated annual vs. August total?

Correlation between the tree ring chronology and August lake area records is highly significant (r=0.71; p>0.0001; n=20) and slightly higher than the correlation with the mean annual lake area record (r=0.696; p<0.0001; n=34). However, the calibration of the model August records will be based on N=20 against N=34 of the actual model.

Having said this, regardless of the calibration, the analysis of the changes over time, trends, periodicities, etc., in the reconstruction are real and clearly reflect changes in the ringwidth series on which the reconstruction is based. One wonders whether it would be better to reconstruct precipitation from this tree- ring record which could be more strongly calibrated because there is clearly a good relationship with the SST data. Using the satellite data to monitor lake changes and calibrate these against tree rings is a great idea but I would really have to know what the lake data used in the calibration actually represent.

It also would be useful either in the text or supplement to have an indication of the area of the lakes studied i.e. the average size and perhaps extreme annual values.

Please, see response to comment of page 1825, line 15.

D. Urrego commnets

The paper presents a calibrated lake level reconstruction from southwest Bolivia and northwest Argentina. The reconstruction of lake level changes over the past 600 years is of outstanding resolution and worthy of publication. The paper also includes high quality and meticulous data analysis and statistical treatment that enhance the value of the dataset. Discussion is somewhat weak and leaves the climatic interpretation somewhat underdeveloped. For instance, what is the most likely climatic mechanism responsible for the links between the reconstructed changes in lake surface areas in the region of interest and ENSO and PDO? On the format side of things, careful proof reading is needed, as the paper contains quite a few typos, plural/singular inconsistencies, missing words, and tense inconsistencies.

In summary, the data and statistical manipulation are remarkable, however the discussion could be largely strengthened and the description of the methodology could also be made more clear. My recommendation is that the paper be considered for publication in the Climate of the Past after incorporating major revisions. I provide more specific comments below.

Many thanks for the revision and the improvement of the manuscript. Following reviewer's recommendation many aspects were modified. Please, see responses to the specific comments.

Specific comments:
Title should be modified to capture the interest of the readership of the journal who are mostly interested in past climate change. The term 'ecosystems' seems inappropriate here. As phrased it reads as if the lake area changes happen in the ecosystems, instead of in the lake.

Following reviewer comment, we modified the title as follow:
Multi-century lake area changes in the Southern Altiplano: A tree-ring based reconstruction

R- Abstract should highlight the main findings: In my opinion, the main findings are the decrease in lake levels in the 20th century compared to the past 600 years, and the link between this and SST in the tropical and subtropical Pacific (ENSO, PDO).
The last sentence of the abstract should be stronger and should relate to the implications of the reconstructed climate changes. What do these findings mean in light of current global warming and IPCC predictions of increase aridity in this region?

The abstract was substantially modified: following reviewer's comment we highlight the main findings and eliminate some method aspects. Also, we link better our findings with model projections of decrease precipitation for 21st century.

This is the new version of the abstract:

Abstract. Size fluctuations in endorheic lakes in northwestern Argentina (NWA) and southwestern Bolivia (SWB) are very sensitive to basin hydrological balances, and consequently, very vulnerable to deleterious effects from climatic changes. The management of these water resources and their biodiversity requires a comprehensive knowledge of their natural variability

over multiple time scales. In this study, we present a multi-century reconstruction of past lake-area fluctuations in NWA and SWB. The evidence used to develop and validate this reconstruction includes satellite images and a century-long tree-ring record from *P. tarapacana*. Inter-annual fluctuations in lake area of nine lakes were quantified based on Landsat satellite images over the interval 1975 to 2009. A regional *P. tarapacana* tree-ring chronology, composite from two sampling sites, was used as predictors in a regression model to reconstruct the mean annual (January-December) lake area from the nine lakes. The reconstruction model captures 60% of the total variance in lake-area fluctuations and shows adequate levels of cross-validation. This high-resolution reconstruction covers the past 601 yr and characterized the occurrence of annual to multi-decadal lake area fluctuations and its main oscillation modes of variability. Our reconstruction points out that the late twenty century decrease in lake area was exceptional over the period 1407–2007; a persistent negative trend in lake area is clear in the reconstruction and consistent with glacier retreat and other climate proxies from the Altiplano and the tropical Andes. Since the mid 1970s, the Vilama-Coruto lake system recorded an accelerated decrease in area consistent with an increasing recurrence of extremely small lake-area events. Throughout the 601 yr, the reconstruction provides valuable information about spatial and temporal stabilities of the relationships between changes in lake area, ENSO, and PDO, highlighting the Pacific influence over most modes of lake area variability. Global and regional climate models for the Altiplano project a marked reduction in precipitation to the end of the 21st century, exacerbating presently dry conditions. These results provide a baseline for the historical range of variability in lake fluctuations and thus should be considered for the management of biodiversity and water resources in the Central Andes during the next decades.

R- While the quantitative data analyses presented in the paper are outstanding and very robust, the description of the approach in the methodology is difficult to follow. Please add a flow chart showing the different steps involved in the data analyses. This is important because it is likely to improve the reproducibility of the methodology.

Traditionally most common methods in dendroclimatology were used in this study, which have been widely discussed in elsewhere. However following reviewer advice, we add few paragraphs to clarify the methods section as follow:

Section 2.2 Lake record.
Page 1825, line 18
"We calculated lake area based on the number of pixels and their sizes. Pixel size for Landsat MSS is 80 x 80m (0.0064 km2) and for Landsat TM is 30 x 30m (0.0009km2). For example in November 1978 Cerro Negro lake encompassed 316 pixels of Landsat MSS corresponding to 2.02 km2 (316 * 0.0064km2). In October 1988 the same lake, encompassed 2551 pixels of Landsat TM image, which is the same as saying 2.3 km2 (2551 * 0.0009 km2)."

Page 1825, line 19
"Good quality available images for the different years of the period 1975-2009, ranged from one to ten (dates of images are in Supplement, S1). Despite of the variable acquisition dates and number of the images, relative low intra-annual area variability was recorded for the nine lakes (see lake area range in Supplement, S2). A comparison between the coefficients of variation for

each lake, showed that inter-annual variability represent more than the double of the intra-annual variability (see Supplement, S3.1-9). Therefore, we assume that the monthly or seasonal variation was negligible in relation to the higher inter-annual lake area variation, and an area value from a particular image could well represent the mean lake area condition of the year. To further validate this assumption, autocorrelation analyses were applied to determine persistence in the monthly and annual time series averaged for the nine lakes from 1975 to 2009 period (see Supplement, S4). This analysis show strong 19 months persistence in the monthly series, while two years persistence was found in the annual series. This analysis was performed using the AnClim program (Štěpánek, 2008)."

Section 2.4. Lake area reconstruction.
Page 1827, line 21
We rephrase the next paragraph:
"Two lags (t, t-1) were considered as candidate predictors of annual lake area in a stepwise multiple regression (Weisberg, 1985). To validate the model, we used the "leave-one-out" cross-validation procedure (Michaelsen, 1987; Meko and Baisan, 2001)."
as follow:
"The chronology at year t and a lag (t+1) were considered as candidate predictors of annual lake area in a stepwise multiple regression (Weisberg, 1985). The "leave-one-out" cross-validation procedure (Michaelsen, 1987; Meko and Baisan, 2001) was used to validate the model (Fig. 2)."

R- Please justify why non-overlapping averages over 5, 25 and 50 years are worth calculating with this dataset? If the purpose of the paper is to identify the signal of ENSO or PDO, it does not seem appropriate to take the high-resolution data (annual) and average them. For instance, what longer term climatic variability do you intend to identify with a 50 year average?

Since the reconstruction, precipitation, temperature and Pacific sea surface temperatures, exhibits considerable natural variability from inter-annual to multi-decadal timescales, a non-overlapping averages over different periods represents a simple way to identified intensity and duration of events (droughts or wets). A drought (wet) was simply defined as a year or a set of consecutive years below (above) the long-term mean. This method is normally used in dendroclimate reconstruction.

R- Please add the composite chronology from P. tarapacana mentioned in P 1830 L 20-25 as a Figure in the Supplementary Information.

The regional chronology was added to the supplement (S7).

R- In the Results section, subsection 3.1 you mention that the reconstruction accounts for 60% of the total variability in lake level changes. Someone could argue that consistency below 90% is not good enough. Where does this 60% threshold come from or what is it based on? R2, p-values? Please justify.

We agree with the reviewer that this percentage of explained variance could be relative low for someone. However, it is well accepted for dendroclimatology community that a robust reconstruction model has to be higher than 40%, but also is relative to the study area, species and

time span of the regression model. In South America hydroclimatic reconstructions explained variance range between 32% and 55% (Boninsegna et al. 2009). This explained variance percentage is obtained from the R_{adj}^2 adjusted for loss of degrees-of-freedom (Draper and Smith, 1981). Page 1831, line 4-5.

R- The discussion presents several interesting statements but falls short at piecing the climatic history together. Please elaborate/clarify the following ideas:

1. Tree rings and surface areas of lakes in arid environments (P 1835, L 7-10). This sentence needs rephrasing, it is not clear what is meant

Following reviewer's comment we completed and rephrased the paragraph as follow:

At the sampling sites, precipitation explains high percentage of the total radial growth variance, but also summer temperatures which increase evapotranspiration and reduced soil water supply, affect tree growth variability (Morales et al. 2004). In the same way, the areal extent and depth of water in lakes respond to changes in precipitation and evaporation integrated over the lakes and their catchment basins (Mason et al. 1994). Both, tree-growth and lake area integrate changes in climatic parameters including precipitation, temperature, radiation and wind speed. As a consequence, a closer association is expected between tree growth and lake extents than tree growth and singular parameters such as precipitation or temperature.

2. Correspondence with Altiplano records (P 1835, L 15-19). What is the linking climatic mechanism?

The three hydroclimatic reconstructions are close related because express changes in water balance and water availability, that are directly linking with variation in precipitation and also evaporation. The climatic mechanism over this region was described in several previous studies such as Lenters and Cook, 1997; Vuille et al., 2000; Garreaud and Aceituno, 2001; Bradley et al., 2003; Garreaud et al., 2009.
To explain in a very synthetic way, the main moisture source for the Altiplano is the easterly influx from the Amazon Basin. However, wet or dry episodes are related to changes in the mean zonal wind, largely modulated by Pacific Ocean surface temperature.

Page 1825, line 11. We add the following paragraph describing briefly the precipitation regime over the Altiplano:
Summer precipitation variability is related to local orography and with changes of the upper troposphere zonal wind, which in turn favor or block the ingression of wet easterly flow transporting humid air masses from the Amazon basin (Vuille et al., 2000; Garreaud and Aceituno, 2001; Bradley et al., 2003; Garreaud et al., 2003).

3. What is the atmospheric –low or high-pressure system – that links observed changes between Andean glaciers and the reconstruction presented here? (P 1836, L 24-27)

Since glacier and lakes express water balance, related with precipitation and temperature, both systems in the Central Andes show similar behavior. Decrease in precipitation and a warming trend are causing glacier retraction and decrease in lake extends.

For detailed about the climatic mechanism affecting glaciers over the Central Andes see Vuille, M., Francou, B., Wagnon, P., Juen, I., Kaser, G., Mark, B., and Bradley, R.: Climate change and tropical Andean glaciers: Past, present and future, Earth-Sci Rev., 89, 79–96, 2008.

4. Longest interval with reduced lake levels recorded in the second half of the 20th century (P 1839, L 10-14). What is the climatic mechanism proposed for this observed change?

A study by Trenberth et al. (2014) demonstrated that the PDO switched to a negative phase (La Niña-like pattern) around 1999, coincident with a pause (hiatus) in the sustained increase in global mean surface temperatures (Trenberth et al., 2014). However, this hiatus is evident at coastal and lower elevation temperatures while at higher elevation locations warming trend still continue.

Also, in the early 21st century a strengthening of the upper-tropospheric Westerlies leading to decreased precipitation over Central Andes was identified (Neukom et al. 2015). Therefore, the dominance of Westerlies together with the warming trend over Central Andes may thus explain much of the recent dramatic lake area decrease.

Following reviewer's comment we modified the paragraph as follow

However, we note that the downward trend in Coruto-Vilama lake areas have persisted since the year 1999. This suggests that, in addition to PDO, different forcings may have contributed to the persistence of dry conditions in our study region for the past decade. A dominance of the upper-tropospheric Westerlies during second half of 20th and early 21st centuries, leading to decreased precipitation by blocking the moisture easterly flow from the Amazon basin (Neukom et al. 2015), together with a continuous warming trend of the upper troposphere over the Central Andes (Vuille et al. 2015) may thus explain much of the recent dramatic lake area decrease. Furthermore, an anomalous ENSO activity in the late 20th century (Li et al. 2013) would even strengthen the negative relationship between Westerlies and precipitation, with the consequence intensification of drier conditions.

5. How is this new reconstruction complementing other studies discussing the regional manifestations of PDO and ENSO? This is one of the most important findings of the paper but the idea is only introduced but very poorly discussed.

Page 1839, line14 Following reviewer's recommendation we add the following paragraph incorporating the main findings about ENSO and PDO related with our lake area reconstruction and how this study complement other studies discussing the regional manifestations of PDO and ENSO.

"In the present study, common cycles and periodicities were identified between lake area and ENSO (at inter-annual/decadal oscillation modes) and PDO (at multi-decadal oscillation mode). These results allow to identified ENSO and PDO frequency, amplitudes and associated teleconnection patterns. These findings were consistent to those recorded for the ENSO related

precipitation reconstruction from the Altiplano (Morales et al. 2012), while no previous analyzes were made about the PDO influence on the reconstructed precipitation. Since most palaeo-reconstructions of ENSO devoid of tropical/subtropical records (Li et al., 2013), our lake-area reconstruction provides valuable information about ENSO and also PDO evolution during the past 600 years and should be considered as a key input in further high-resolution reconstructions of these hemispheric forcing."

6. The last paragraph of the discussion is somewhat weak. As stated, it sounds as if the aim of the paper was to produce a reconstruction, instead of shedding light on the climatic mechanisms responsible for the observed changes.

We agree with the Reviewer that this is an important issue to explore. However, it is beyond the scope of this contribution. The main purpose of this study is to use P. tarapacana ring-width records and Landsat images to develop a high-resolution multi-century reconstruction of past fluctuations in lake area from the Vilama-Coruto region in Northwest Argentina (NWA) and Southwest Bolivia (SWB). Composite maps to elucidate the influence of zonal wind and other climate forcings on the Altiplano will be included in a future contribution specifically dealing with climate influences on the tree-ring and other proxy hydroclimatic reconstructions from the region.

Minor comments Please define the term 'endorreic' for the non-specialist readers P 1824, L 5. Please add a reference to the first sentence in this paragraph.

We repleaced 'endorreic' by a more useful word 'endorheic' that is related to interior drainage basin.

At the end of this paragraph, do you mean to reconstruct lake level fluctuations and moisture balance? Please tweak P 1824, L 15.

We reconstructed lake area fluctuations, that is a direct estimation of water balance.

Please add comma after word " periodicities" P 1826, top paragraph,

Thanks, comma was added

please add "the" before "supplement" P 1825, L 5.

Ok

Please clarify sentence on "trend distortion in index series" P 1829, L 5.

Please, see reference Melvin, 2004 for clarification about "trend distortion"

First sentence, is this annual averaged precipitation or temperature?

It is Sea Surface Temperatures. We corrected in page 1829, line 5

Please clarify P 1831, L19-20. Please consider rephrasing. . . "The fifteenth century high lake level stand was characterized. . ."

Thanks for the comment. We replace the sentence "This fifteenth century was characterized by high inter-annual variance…" by "The fifteenth century high lake level stand was characterized by high inter-annual variance…"

P 1834, L 3, Consider replacing "show" with "showed" to keep the paragraph in the same tense

We replaced the word "show" by "showed"

Table 2.
Please modify Figure caption: As phrased it sounds like the numbers are moving averages but they seem to be z-scores of annual lake area. Z-scores and anomalies are presumably not the same thing, please verify terminology. Is rank 1 more important than 5? Please clarify this in the on.

Thanks for the comment. We eliminate the word "moving" from the caption.
We agree with the reviewer that anomalies is not the same than z-score. The numbers are the means of the z-score of annual lake area, so we eliminate the word "anomalies in the caption.

We Modified the caption of table 2 as follow:
"Table 2. Lowest and highest non-overlapping averages of the reconstructed (1407–2007) lake area fluctuations for the Vilama-Coruto lake system. Annual lake area expressed as Z-score of the 1975–2007 lake area mean. Ranks 1–5 correspond to the five most extreme reconstructed lake area years or set of consecutive years." Rank 1 represents the most important minimum (maximum) lake area record.

Figure 1. Please make markers larger so they are more visible

Thanks. We increased green starts and markers.