Reply to referee comment 2 of Clim. Past Discuss. 8, C119–C120, 2012 "Changes in the strength and width of the Hadley circulation since 1871" by Liu, J., M. Song, Y. Hu and X. Ren

We would like to thank the reviewer for the helpful comments on the paper. A point-by-point listing of our response to these comments follows.

The main comments pertains to the confidence the authors place on the 20CR reanalysis. The manuscript explains rightly that the 20CR reanalysis only assimilates surface observations. Its main advantage in comparison with other reanalysis is the long period covered. However, the 20Cr reanalysis are not free from problems and some recent publications have pointed out possible inhomogeneities due to the changing number of surface stations that are assimilated through the 20th century and that may give rise to spurious trends. For instance, the paper by Fergusson et al indicates that inhomogeneities in the 20CR data over the United States are quite likely present and recommend not to use data pre-1940 should be used to determine long-term trends. I think the authors should comment on the potential inhomogeneity in other areas more relevant for the Hadley Circulation and in which the density of stations is more scarce than in the United States
20 version 2 (20CR2), which provides the ïnˇA¸rst estimates of global tropospheric variability from 1871 to 2008 (Compo et al., 2011). Preliminary validations suggest that the 20CR2 depicts more realistic vertical structures of temperature trends in the tropics and subtropics, and probably suïnˇAˇ ers less from spurious trends than any previous re-analyses (see more detailed discussion of the key diïnˇAˇ erences between the 20CR2 and previous reanalyses, and the evaluations of the 20CR2 in Sect. 2).
see my comment above

The 20th century reanalysis version 2 (20CR2) is a new reanalysis that only assimilates surface pressure observations to constrain dynamics. Although the 20CR2 uses less observations than previous reanalysis, it can go back to the late 19th century and still produces meaningful results. We agree with the reviewer that the 20CR2 is not free from problems because of the changing number of surface pressure observations. The 20CR2 should definitely not be assumed to have the status of real observations, but it is useful as long as people are careful to take the caveats seriously, and be clear about the structural uncertainties. As we mentioned in the paper, the 20CR2 only became available to the scientific community in 2010, and its evaluation is in its early stages, which imposes some uncertainty in our results. However, an evaluation has demonstrated that the 20CR2 is generally in good agreement with two early ship-based upper-air data in 1906/07 and 1938/39

(Bronnimann et al., 2011). Also, the Global Historical Climatology Network (GHCN) data shows that the averaged surface temperature in the tropics and subtropics (30 ℃S-30 ℃N) has warmed by 0.045 ℃ for 1880-2008. Compared to the GHCN observations, the averaged near surface air temperature in the tropics and subtropics (30 ℃S-30 ℃N) of the 20CR2 shows comparable warming trend (0.052 ℃ for 1880-2008), and coherent variation (the correlation between the 20CR2 and GHCN is 0.96, 0.92 with the trend removed, > 99% significance). There is no apparent inhomogeneity in the 20CR2 as compared to the GHCN.

’25 between that pressure level and the top of the atmosphere. Note that the Hadley Circulation is a zonal-mean quantity, although there is considerable zonal asymmetry of the Hadley Circulation.’
This sentence sounds contradictory. If the Hadley Circulation is defined as a zonal mean quantity it cannot display zonal asymmetry

We changed the sentence to “Note that the Hadley Circulation is a zonal-mean quantity, which is also known as the mean meridional circulation.”

:10 Figure 2d shows the width of the Hadley Circulation, which is deïnˇA¸ned as the distance between the northern and southern edges of the Hadley Circulation. It appears that the width of the Hadley Circulation has not yet completed a cycle since 1871. SpeciïnˇA¸cally,’ I do not fully understand what ’complete a cycle’ means. There is no guarantee that the behavior of the Hadley Circulation has to be cyclical. So which is the ’cycle’ ?

As shown in Fig. 2d, the width of the Hadley Circulation shrunk by ~4-5 °in latitude from the 1870s to the mid-1920s, and then expanded gradually by ~4 °in latitude from the mid-1920s to the present. We therefore speculate the width of the Hadley Circulation might have not yet completed a cycle since 1871. We agree with the reviewer that there is no guarantee that the behavior of the width of the Hadley Circulation has to be cyclical. We now stated that “… we speculate that the width of the Hadley Circulation might have not completed a cycle since the 1870s, although there is no guarantee that the behavior of the width of the Hadley Circulation has to be cyclical.”

’come stronger and narrower. Moreover, the width of the Hadley Circulation has not ïnˇA¸nished a full life-cycle since the 1870s, which indicates the observed expansion in recent decades might be a reïnˇC´ ection of a long-period oscillation. To further conïnˇA¸rm the identiïnˇA¸ed secular variability, we perform a spectral analysis on the

time series of the width of the Hadley Circulation. The spectral analysis indicates that the width of’
The inclusion of new results in the conclusion section is misplaced, in my opinion.

We moved the spectral analysis from the conclusion section to the result and discussion section, and showed the plot of the spectral analysis (see Fig. 5).

’the width of the Hadley Circulation. The spectral analysis indicates that the width of the Hadley Circulation exhibits a clear secular peak indicative of centennial-scale variability that is distinct from the null hypothesis of a red-noise stochastic process, statistically signiïnˇA¸cant (>99 %, not shown).
Which red-noise null-hypothesis ? I guess the authors mean an autoregressive process of order one, but this is not clear. Why is this null-hypothesis realistic ? In any case, to infer a centennial-scale cycle from a 120-year long record is clearly adventurous. I guess that another null-hypothesis, for instance long-term memory processes would yield a different level of significance. The length of the records is just too short to infer any cyclic behavior at these long time scales.

We used a function in NCAR Command Language, which calculates the theoretical Markov spectrum and the lower and upper confidence curves using the lag 1 autocorrelation. The spectral analysis indicates that the width of the Hadley Circulation exhibits a clear secular peak indicative of centennial-scale variability that is distinct from the null hypothesis of a red-noise stochastic process, statistically significant (> 99%). However, the length of the records (138 years) does impose uncertainty of the inferred cyclic behavior. As mentioned in the paper, the position of the Intertropical Convergence Zone (ITCZ) is effectively a tracer of the horizontal scale of the Hadley cell (Hu et al., 2007). A growing paleoclimatic proxy evidence indicates centennial-scale oscillatory behavior of the position of the ITCZ for the past several millennia, i.e., the planktic foraminifer Globigerinoides sacculifer in Gulf of Mexico sediments shows distinct century-scale cyclicity of ITCZ (Poore et al., 2004). This provides another possible proof.

In Figure 5 the authors present a correlation analysis between some measures of the Hadley circulation and tropical temperatures, separately for a warm and a cold period. The wide scatter of the data points is evident, and I think that the authors should include the uncertainties in the regression lines. Also consider that these uncertainties are quite sensitive to assumptions about the normal distribution of data. For instance, in Fig 5, my visual impression is that the regression line for the warm period (red dots) is dominated by a high temperature outlier. It may be worth exploring how sensitive the regression line

is to trimming outliers. Since Fig 5 is being used to support claims about the relationship between the strength and width of the Hadley circulation on tropical temperature, I think it is important to have a robust handle on the uncertainties of these regressions.
This is related also to the correlations indicated in Table 1 and the trends shown in Fig 1. The level of significance or the width of the uncertainty ranges depends quite strongly on the null-hypothesis. For instance, I guess that the level of significance in Table has been estimated assuming as null-hypothesis uncorrelated white noise. However, tropical temperatures are clearly serially correlated and even display a quasi cyclic behavior related to ENSO. The authors should explain briefly how they have determined the level of significance.

Based on the reviewer's suggestion, we explored the sensitivity of the regressions to the high temperature outlier. Specifically, we repeated the regression analysis after removing the strength and width of the Hadley Circulation corresponding to the high temperature outlier for the warm period. The results show that the regressions with and without the high temperature outlier for the warm period are in good agreement (see below Table).

Regressions of the strength and width of the Hadley Circulation on the averaged 20CR2 surface air temperature in the tropics and subtropics for the warm period

	Original regressions (10^{10} kg/s per ℃)	Regressions after removing the high temperature outlier (10^{10} kg/s per ℃)
Strength (N)	**-0.88**	**-0.85**
Strength (S)	**1.28**	**1.29**
Width	**2.09**	**2.23**

Note: > 99% significance is in bold type

We used the t-statistic test for the correlations in Table 1 and trends in Figure 2, which assumes null-hypothesis uncorrelated white noise.

As suggested by the reviewer, tropical temperature is serially correlated and displays a quasi cyclic behavior related to ENSO. If the auto-correlation of tropical temperature is significant, then the degree of freedom, which is used in the calculation of level of significance, should be adjusted. Here, we adjusted the degree of freedom (df) by taking into account the autocorrelation of the averaged 20CR2 surface air temperature in the tropics and subtropics (30 ℃S-30 ℃N) following the method of Zwiers and Storch, 1995 (Taking serial correlation into account in tests of the mean, F. W. Zwiers and H. von Storch, J. Climate, 336-351).
Here, df = N*(1.0-acr(1))/(1.0+acr(1))

The results show that the level of significance with adjusted df for the both the cold and warm periods is reduced slightly as compared to those with original df (see below Table).

Level of significance of regressions of the strength and width of the Hadley Circulation on the averaged 20CR2 surface air temperature in the tropics and subtropics for the cold and warm periods

	Original df	Adjusted df
Strength (N)	67.452% (99.963%)	67.008% (99.810%)
Strength (S)	99.996% (100.000%)	99.988% (99.988%)
Width	13.433% (99.786%)	13.370% (99.401%)