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Interactive comment on "Decadal variability and trends of the Benguela Upwelling System as simulated in a high-resolution ocean simulation" *by* N. Tim et al.

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We thank the reviewer for the very detailed reading of this (and previous) manuscripts and for all constructive suggestions. In the following, we sketch how we plan to eventually revise this manuscript to address these suggestions.

General comments:

oceanic drivers: (oceanic conditions strongly influence upwelling), meridional SSH gradient between equator and pole (should be discussed in Discussion): We have calculated the gradient the meridional gradient of SSH in the STORM simulation as follows: SSH(10N-10S, 50W-30E) minus SSH(30S-40S, 50W-30E). This gradient is, as the re-

viewer suspected, negatively correlated with the Benguela upwelling. The correlation with North Benguela upwelling is significant with a coefficient of -0.42. The correlation with South Benguela upwelling is not significant with a coefficient of -0.17. This gradient has in JJA and DJF a positive but not significant long term trend in the simulation. The sign of the trend, as the reviewer suggested, would oppose any positive trend in upwelling by an onshore transport (Colas et al. 2008), and thus it could theoretically contribute to mask the long-term trend in upwelling caused by anthropogenic forcing. We will include these results in the manuscript.

validation of NCEP: We will include a validation of NCEP by plotting the climatology of the alongshore wind stress, the wind stress curl and SLP. This variables show a realistic pattern for the South Atlantic Ocean and the Benguela region. More problematic is the validation of the long-term trends of NCEP winds, due to the lack of in-situ observations in this area. The results of the STORM simulation are admittedly conditional on the quality of the NCEP forcing, but unfortunately there are no clear alternatives for the study of the long-term variability. Probably, a more comprehensive validation should involve a comparison with other reanalysis products, like 20CR. As we wrote in our response to reviewer #2, our study has to be viewed as a first analysis of upwelling decadal variability based on the instruments at hand.

bias NCEP-QuickSCAT: Because the STORM simulation is driven by NCEP, including a validation of NCEP by comparing it to QuickSCAT would not be helpful in interpreting the results.

trends in upwelling-favourable winds: We will include the estimated trends in upwelling-favourable winds. The trends over the whole simulation period are small and not significant. Neither the upwelling, nor its drivers the upwelling-favourable winds and the SLP gradient show significant trends (except SLP gradient in MAM). This does agree with the findings of Narayan et al 2010 who did not find a significant trend in upwelling-favourable wind of ERA40. Our results, however, disagree with the positive trends in COADS and NCEP. Nevertheless, the trends in the sea surface temperature derived

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from HadISST mentioned by Narayan et al. 2010 strongly depend on the analysed period. The trends of upwelling shown by Narayan based on sediment records are dominated by multidecadal variability rather by a long-term trend, although analysing only the last 30 years would probably lead to a positive trend in upwelling-favourable winds. We will discuss and compare the results obtained by Narayan and our study in the new version.

Specific comments:

difference between central and eastern Pacific El Niño: The Multivariate ENSO Index includes the sea-surface temperature in the Tropical Pacific and the atmospheric response to ENSO events. The different flavours of ENSO are reflected in the evolution of the MEI within each ENSO event, but in the end the atmosphere is reacting to the SST in the Tropical Pacific, independently of weather a particular ENSO event is categorised into one of the ENSO-flavours. Thus we do not see much gain in stratifying the MI index according to the different ENSO-flavours as we are only interested in investigating the influence of the Tropical Pacific on Benguela Upwelling

Tab 1: This table Includes the periods used in this study, and not the periods for which the data sets have been last updated. The STORM simulation does not run until presently, but ends in 2011.

ERA-Interim: Has a resolution of T255, which corresponds to 80km, approx. 0.70 degree at the equator.

North Benguela same latitudes like South Benguela: The land grid-cells included in the definition of the geographical box are of course ignored in the calculation of the upwelling indices. A regular rectangular geographical box is easier to communicate to the reader.

show in the plots only significant correlations: There are reasonable arguments, both physical and statistical, to show the full correlation pattern. A counter example from the

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statistical point of view is the following: 100 coins are tested by counting the number of heads and tails in 50 draws. All coins have displayed 27 times heads. Taken individually, this number is not statistically significant. However, the fact that all coins report more than 25 heads is statistically very significant. Reporting only the statistically significant coins (none) would be misleading. Form the physical point of view, there are instances where the line of zero correlation (therefore the most insignificant value) is the most important. For instance, when calculating correlation with the SLP field, the zero isoline - usually the isoline where the spatial gradient in correlation is strongest - indicates the strongest correlation with the geostrophic wind. Both examples indicate that the spatial structure of the correlation field as a whole, and not only the grid-cells that display a significant correlation, may provide important information.

downward wind stress: Wind stress is the flux of momentum, and as such it has a sign that is subjective. For instance, the NCEP reanalysis consider the momentum flux that leaves the atmosphere in the positive u and v directions as negative. An ocean model usually defines this very same flux as positive. We wanted to be precise and indicate that we consider the momentum flux as positive when entering the ocean in the usual u and v directions, but it seems that we have caused more confusion. This point will be made more clear.

cross-spectral analysis of up_wvelo and MEI: The spectral analysis of ENSO has been presented many times in the literature. It would be repetitive to include it here. It is well known that ENSO frequency band is 3 to 5 years. The cross-spectral analysis would be meaningful if we expected a lag of several years in the response to ENSO, but since this response will be mediated by the atmosphere, such a lag is very unlikely.

vertical black lines showing the uncertainty in the spectra, significance of spectral, red noise: Those vertical lines in the spectra show the standard classical estimation of uncertainty ranges, as described in statistical text books (see e.g. Jenkins, Spectral Analysis and its Application, 1968; Storch and Zwiers, Statistical Analysis in Climate Research, 2000). The suggestion proposed by the reviewer - namely to test the spec-

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tral peaks against what would be expected from a red-noise process, has been more recently used in climate research. Although it may provide useful guide lines about the possible significance of the peaks, it is formally incorrect. The autoregressive model, either its order and/or the value of its parameters, has to be estimated from the very same data that are going to be tested. This formally invalidates the test. The so called 'Mexican hat paradox', a section in the book Storch and Zwiers cited previously (section 6.4), is devoted to illustrate the misuse of the very same observations in the design of the null hypothesis of the test and in the test itself. A further point against the use of a background stochastic processes as null hypothesis is that a test against red noise is only vaguely determined. Other null hypothesis could also be prescribed, like ARMA process or a fractional integrated process, instead of a more simple autoregressive processes. Actually, climate time series are usually better approximated by process that are much more complex than autoregressive processes. This type of tests could be applied only when there are a priori theoretical reasons (independent of the observed the series) to prefer a particular stochastic processes as a null-hypothesis.

spectral analysis (how is significance determined?; sentence is vague and useless?) 'In both regions the spectra show some enhanced variability that is not strictly statistically significant, but which are nevertheless documented here as it supports some of the results of the correlation analysis and as it can be useful for future analysis with longer simulations. ': The significance is determined as explained in the response to referee #2. Statistical significance depends on two factors: the strength of the signal and the sample size. For instance, the spectral peaks that are not significant in a 50-year simulations may become significant in a 100-year simulation if physically the signal strength remains the same. In the future, longer high resolution simulation may be performed where the question of the ENSO influence on Benguela upwelling may be investigated. This influence is also part of Bakun's hypothesis in its most recent form. So there is a point in presenting the results of the spectral analysis, with the possible relationships to ENSO and other climate modes in mind, even though in the 50-year simulation they might not be statistically significant. The text of the initial ver-

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sion clearly reflects this caveat, and we feel that some readers my find this analysis useful.

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