Ocean Sci. Discuss., 12, C130–C134, 2015
www.ocean-sci-discuss.net/12/C130/2015/

Ocean Science
Discussions
Open Access

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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Received and published: 23 April 2015

We thank the reviewer for their very detailed reading of the manuscript and for their suggestions for improvement. In the following we sketch how we plan to eventually revise this manuscript to address these suggestions.

General comments:

Uncertainties of the atmospheric forcing in the conclusion: We are aware that the resolution of the NCEP atmospheric used in the STORM simulation is not ideal. However, if the focus of the study lies on the decadal variability of upwelling, we have to use this product. Even with this implication in the modelling settings, this simulation consumed

a large proportion of computing resources on a supercomuter dedicated to only climate studies. Our study is of course not the last word, and it was not intended to be. Simulations in the future will undoubtedly include high resolution atmospheric forcing from reanalysis or free-running coupled models, but our study is nevertheless a step forward to understand the low-frequency variability of upwelling. If those simulations in the future reveal clear differences to the STORM simulation, this will show that a high-resolution atmospheric forcing is critical for the low-frequency variations, but before this conclusion can be reached, a benchmark with low-resolution forcing is needed. The manuscript is candid about the possible limitations of NCEP in this regard, so the reader of the manuscript cannot be mislead. In addition, a recent paper (Wang et al. 2015) has analyzed projected changes in upwelling using CMIP5 simulations, all of them with atmospheric resolutions of the order of NCEP - some a bit finer, some a bit coarser. We thus think there is a added value in this study. We will discuss the caveats associated with the atmospheric forcing even more clearly in a revised version.

Definition of South Benguela region: Defining the region more closely restricted to the coast (15-30S) does not change the temporal variations of the index. The correlation between this new index and the one used in the original manuscript in the December-February is 0.9, and both indices can barely be distinguished in a plot. We will add a sentence indicating the lack of sensitivity to the choice of geographical box in the model.

Not enough innovative results: This is a first analysis of upwelling in a global high-resolution ocean simulations over several decades. Even if there will be a high coupled model in the future, this results can be used to compare and conclude if a high resolution of the ocean alone provide a good assumption of the upwelling.

Specific comments:

HadISST for validation: This data set has only a horizontal resolution of 1 degree, but it covers a long period. The AVHRR data set has a much finer resolution but spans a

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shorter period of 25 years. The initial submission presents a comparison of the model results with both data sets, so that we are not certain what the comment of the reviewer really means.

SLP regions: The analysis of the SLP gradient has been done with slightly different regions too, confirming the results presented in the initial manuscript. The regions cover in general the core of the continental low and subtropical high.

Forcing of STORM and gridded observational data: The STORM simulation was forced with gridded data (NCEP version 1). It is unclear to us what this comment refers to.

Model description about spatial scales of forcing, air-sea interface: We will include a more detailed description of the model and especially how the boundary conditions are implemented. Furthermore, we will explain with more detail if the air-sea interactions are handled in the model, with regard to the relatively coarse resolution of the atmospheric driver NCEP.

Usual assumption of serial correlated and normally distributed regression residuals: We will explain better what we meant in the manuscript. The series of upwelling in North Benguela clearly display decadal variability, so that the test of significance of a linear trend is not correct using the usual assumptions of uncorrelated regression residuals. This is why we additionally used another, more sophisticated, method, based on Monte Carlo re-sampling of the original series and phase randomization to preserve the auto-correlation structure. Using this method, the estimated linear trend is no longer statistically significant. Visually, it is also clear that a linear trend is not statistically different from zero.

Validation of ocean dynamics: It would be great having the possibility to compare the ocean dynamics in more detail with observations, but unfortunately to our knowledge no observations of currents, velocity- based upwelling indices or wind observations spanning several decades are available for this region.

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Cold bias: how much due to NCEP. The issue of SST bias in climate models is being vigorously investigated, since it is pervasive across many climate models and may be related to the global climate sensitivity as well. The reason is not clear, as it has been recently reviewed by Richter (2015). Both atmospheric and oceanic processes may be involved: stratiform clouds in the boundary layer, too weak winds, and remote oceanic influence from the Tropics. Although the origin of the bias may have an influence on the decadal variability of upwelling, we think that to clarify this point in this study is clearly beyond the scope of the manuscript.

Correlations between SST and upwelling index: how much seasonal: The correlations are calculated using seasonal means and separately for each season. Thus the seasonal cycle cannot affect the correlation, which represents the consistency of the decadal and interannual variations.

South Benguela DJF nearly significant trend, but not seen in fig. 6: We regret that we did not clearly explain our point. We argue that the trend is not significant when properly assessed. This is why no trend can be visually identified in Fig 6.

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 (flux into the ocean). We wanted to be precise and indicate that we consider the momentum flux as positive when entering the ocean in the positive u and v directions, but it seems that we have caused more confusion. This point has now been more clear.

Wind stress coarse resolution should be discussed: Like mentioned in point 1, NCEP is the only available data set covering a period long enough to analyse decadal variability in this region. We will discuss in more detail the possible effects and uncertainties evoked by the using NCEP.

Not strictly significant: The significance is determined as explained in point 8. Statisti-

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cal 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 version is not misleading on this, and we feel that some readers my find it useful.

Differences between ERA-Interim and NCEP: The results of the SLP gradient analysis of NCEP and ERA-Interim agree quite well. The only difference is the statistical significance when correlating the gradient with the upwelling index. Again, the significance depends on the strength of the correlation and on the sample size. ERA-Interim covers only 32 years, whereas NCEP spans twice that period. Thus, there is no contradiction if the correlation is approximately the same but it is not significant in the ERA dataset. This illustrates the previous point on statistical significance and physical relevance. Sometimes, statistical significance depends on the computer resources at hand: a longer simulations can render a statistically insignificant results into a statistically significant one.

Interactive comment on Ocean Sci. Discuss., 12, 403, 2015.