Responses to Reviews of manuscript "A near-global eddy-resolving OGCM for climate studies" (gmd-2016-17) by X. Zhang, P. R. Oke, M. Feng, M. A. Chamberlain, J. A. Church, D. Monselesan, C. Sun, R. J. Matear, A. Schiller and R. Fiedler.
(The reviewer's comments are in back and our responses are in blue)

We would like to thank all referees for their critical comments, which helped us to clarify and improve the manuscript significantly.

Given the comments, we feel it would be beneficial to first provide two general responses to clarify the motivation and intended application of our model, and the appropriateness of our modelling technique, before we address each reviewer's comments point by point.

General Responses:
#1. What is the motivation of our model experiment? The intended application?

High-resolution (1/10^o or finer) OGCMs are desired to study ocean's responses to climate change, since they can provide "eddy-resolving" (or "eddy-rich" to be strict) representation of physical processes, which are absent in coarse-resolution (~1^o) OGCMs. It's still challenging in ocean modelling to run eddy-resolving or eddy-rich global OGCMs over long periods (> 50 years). Further, it is anticipated that by resolving eddies the future impact of climate change on the ocean environment and marine biogeochemical cycles may differ from coarse resolution models that do not resolve eddies.

In this paper, we adapted an existing 1/10^o OGCM (OFAM3) and developed several strategies to carry out long period simulations. We demonstrated that after twenty years of spin-up from rest our historical experiment (1979-2014) can realistically represent ocean variability and change at 1/10^o resolution, driven by the JRA-55 Reanalysis surface forcing. In particular, we came up with a new and practical way to deal with model drift, through applying weak climatological restoring of temperature and salinity non-adaptively (i.e., independent of model states) in the deep ocean. In the historical experiment over 1979-2014, the weak restoring effectively helps maintain the deep-ocean close to the observed climatology, without contaminating the climate change signals of interest.

The strategies developed in our study should also in principle be applicable for other similar ocean modelling experiments, either basin set-up or global set-up.

In this study, we demonstrated a feasible way to deal with two long-existing and challenging issues in ocean modelling: 1. how to spin-up an eddy-rich ocean model? 2. how to control or minimize model drifts in order to study climate change signals? Dealing with these two issues are fundamental to any modelling efforts related to ocean climate change studies (such as ocean heat uptake). What we achieved with our modelling experiments should be a welcome contribution to the modelling community. An excellent simulation of ocean heat content change over 1979-2014 without data assimilation is a very nice achievement. In fact, it has already drawn attention from ocean temperature/heat reconstruction community who want to use our modelling result as a test bed to examine various mapping and reconstruction methodologies (Matt Palmer, personal communication, 2015).

However, we are very aware that our model set-up was not perfect, and an approach that address the root problem of model drift would be ideal. Specifically, we stated that our approach could be an efficient choice in the short term (refer to the next response), and suggested that more model development is needed to address above challenging issues.

Here we provide an example of **intended application**. Using the same configuration as described in this manuscript, we have carried out a further climate downscaling experiment ("future experiment") over 2006 to the end of 21st Century, driven by merged atmospheric forcing which combines the high-frequency part from JRA-55 reanalysis product with the long-term climate change part from the CMIP5 ensemble. Such experiment requires that the OGCM can be integrated over about 100 years and doesn't have larger drifts. Our model set-up satisfied this requirement very well, as we found in the recently-finished future experiment (please see our next General Response and refer to Fig. A - ocean heat content plot there). We are currently drafting a separate manuscript based on findings from the future climate experiment.

We have now revised the introduction to incorporate this general response.

#2. Whether flux correction techniques should be abandoned completely or utilized wisely?

Referees 1 & 3 had some concern about our usage of flux correction (or restoring). We discussed this point in the Discussion Section of the paper, and cited a recent example of using similar "correction" technique by Vecchi et al. (2014).

"The design of combining adaptive relaxation of temperature and salinity during the spin-up and non-adaptive relaxation during historical experiment is novel, though its underlying idea has known to the modelling community, mostly applied to air-sea fluxes. For example, surface flux correction was once a common practice for coupled climate models (e.g., Sausen et al. 1988), e.g., helped to represent ENSO variability better (Roeckner et al. 1996), but it became less common in recent years. Nonetheless, Vecchi et al. (2014) recently rejuvenated such method to correct systematic ocean biases through flux correction and achieved better performance in tropical cyclones forecasting."

Vecchi et al. of NOAA/GFDL is not the only group who are still applying correction in their model experiment. Magnusson et al. (2013) of ECMWF found that for their seasonal and decadal forecast, flux-correction method gives better forecasting results than the full initialisation and anomaly initialisation methods. In particular, they argued that flux-correction has its own advantage and should not be taken off the table from a pragmatic point of view. Mojib Latif's group at GEOMAR uses various flux-corrections in their experiments with the Kiel Climate Model (e.g., Ding et al. 2015; personal communication with. M. Latif). Ding et al. (2015) found only a flux-corrected model experiment can capture the equatorial Atlantic interannual variability reasonably well, while uncorrected experiment cannot.

Based on the fact that some leading centres are still using this technique, what we have achieved with our model experiment should not be regarded as a "serious step backwards", but rather a practical application of existing idea/methodology.

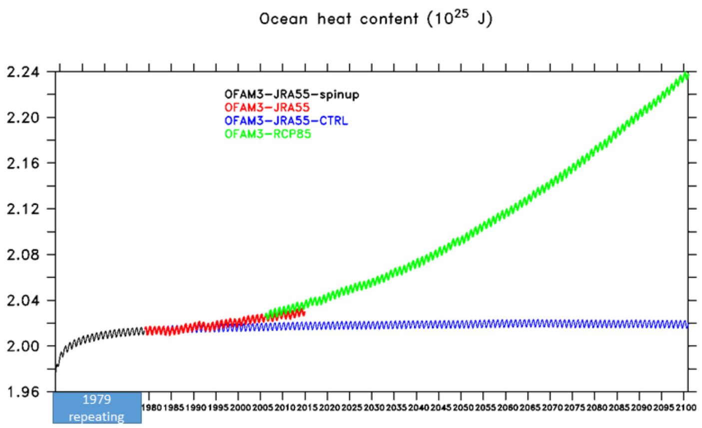

Figure A. Global ocean heat content (10^{25} Joule) of the model simulations for spin-up (black), historical (red), future (green) and control (blue) experiments. Spin-up and historical experiments were described in this manuscript. With the same configuration as the historical experiment, the future experiment is initialized from the ocean state at the end of 2005 of the historical experiment, and is driven by climate change forcing derived from

CMIP5 models. The control experiment, initialized from the final state of the spin-up experiment, is integrated with repeated year 1979 forcing and non-adaptive relaxation.

As mentioned in the Discussion Section, using the same configuration as described in this manuscript, we run a further experiment to downscale ocean climate changes from 2006 to the end of 21st century. We also run a parallel control experiment from 1979 to the end of 21st century, which has repeated 1979 year forcing and non-adaptive relaxation, to quantify any residual drift. Figure A shows the ocean heat content (OHC) from all four experiments (spin-up, historical, future and control). The lack of a discernable trend in the OHC from the control experiment (with repeated forcing, non-adaptive restoring in the deep ocean) demonstrates that our experimental design was successful.

We have now added more information about using "correction" in the introduction, and cited recent relevant publications.

References:

Ding, H., Greatbatch, R. J., Latif, M., and Park, W.: The impact of sea surface temperature bias on equatorial Atlantic interannual variability in partially coupled model experiments, Geophys. Res. Lett., 42, 5540–5546, doi:10.1002/2015GL064799, 2015

Magnusson, L., Alonso-Balmaseda, M., Corti, S., Molteni, F., and Stockdale, T.: Evaluation of forecast strategies for seasonal and decadal forecasts in presence of systematic model errors. Clim. Dyn., 41, 2393-2409, 2013.