AUTHOR'S RESPONSES TO REFEREE 1

The manuscript 'Evaluation of an operational ocean model configuration at 1/12_ spatial resolution for the Indonesian seas – Part 2: Biogeochemistry' by Gutknecht et al. presents the marine biogeochemistry component of an high-resolution operational ocean model over the Indonesian seas. The authors conduct a thorough skill assessment of simulated biogeochemical fields from nutrients to the mesozooplankton against available satellite-derived product, climatologies and field measurements. The manuscript is overall well-written and demonstrates the good accuracy of this model configuration to replicate regional distribution of observed biogeochemical tracers. Nevertheless, I think this paper could be structured more efficiently and needs some clarification that have to be addressed first, and which prevent me of accepting this paper in its present form. Therefore, I recommend acceptance of this manuscript after some minor revisions.

We thank the reviewer for his thorough evaluation and constructive comments. We considered his suggestions carefully and provide a point-by-point reply below.

Major comments:

(1) While I acknowledge that several dataset employed in this study precludes to investigate interannual variability of some biogeochemical tracers, some of them can be used still (e.g., satellite-derived observations). Regarding the target of this operational configuration (up to monitor fisheries), assessing the interannual variability of the low trophic levels seems to be relevant.

Author's response:
We agree with the reviewer that a skillful representation of interannual variability of first trophic levels is of great relevance for this operational configuration. We added a description of climate modes in Section 2 Area of Study, and an assessment of interannual anomalies of chlorophyll-a for the period 2008-2014 in Section 5.3. The analysis points to the importance of modes of natural variability (e.g. ENSO, IOD) as drivers for interannual variability. The period (6 years) is, however, too short for a rigorous assessment of the role of these drivers.

In Section 2, we added:
"In addition to the seasonal variability driven by the Asia-Australia monsoon system, other forcing such as tides, the Madden-Julian Oscillation, Kelvin and Rossby waves affect the Indonesian seas and influence the marine ecosystems (Madden and Julian, 1994; Ffield and Gordon, 1996; Sprintall et al., 2000; Susanto et al., 2000, 2006). Indonesian seas are also greatly influenced by climate phenomena due to its position along the equator between Asia and Australia and between the Pacific and Indian oceans. Strength and timing of the seasonal monsoon are then affected by interannual phenomena that disturb atmospheric forcings and ocean currents. Indeed, a significant correlation between the Indonesian ThroughFlow (ITF) variability and the El Niño-Southern Oscillation (ENSO) phenomena in the western Pacific Ocean is assumed (e.g. Meyers, 1996; Murtugudde et al., 1998; Potemra et al., 1997), ENSO modulating rainfall and chlorophyll-a on inter-annual timescales (Susanto et al., 2001, 2006; Susanto and Marra, 2005). ENSO can be monitored using a Multivariate ENSO Index (MEI;

Wolter and Timlin, 1993, 1998; http://www.esrl.noaa.gov/psd/enso/mei/). Negative values of the MEI represent the cold ENSO phase (La Niña), while positive MEI values represent the warm ENSO phase (El Niño). In the eastern Indian Ocean, large anomalies off Sumatra and Java coasts can also be explained by the Indian Ocean Dipole (IOD) Mode monitored via the Dipole Mode Index (DMI; Saji et al., 1999). A strong positive index points to abnormally strong coastal upwelling and a large phytoplankton bloom near the Java Island (Meyers, 1996; Murtugudde et al., 1999). Sea level off Java-Sumatra modulates the ITF magnitude across the archipelago. Inside the archipelago, individual effect of each climate mode is often difficult to analyse as both events influence the ITF transport. Masumoto (2002) modelling study and Sprintall and Révelard (2014) using remotely sensed altimeter data, point out the significant impact of the Indian Ocean dynamics on the ITF transport variability across the Indonesian archipelago, likely to win out over Pacific Ocean dynamics."

A new section (Section 5.3 Interannual variability) was added to the revised manuscript:
"Figures 7, 8 and 9 present interannual anomalies of surface chlorophyll-a concentrations between 2008 and 2014 for model output and MODIS ocean colour averaged over three regions: South China Sea, Banda Sea and Sunda area. Simulated fields and satellite derived chlorophyll-a are in good agreement in terms of amplitude and phasing, with temporal correlation coefficients of 0.56 for South China Sea and Banda sea and 0.87 for Sunda area. The model simulates a realistic temporal variability suggesting that processes regulating the seasonal as well as interannual variability of the Indonesian region are correctly reproduced. While the mean seasonal cycle of chlorophyll-a is driven by the strength and timing of the seasonal Asian monsoon, anomalies are driven by interannual climate modes, such as El Niño Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD).
IOD drives the chlorophyll-a interannual variability in the eastern tropical Indian ocean, with a correlation coefficient of 0.74 (Fig. 9). IOD index and anomalies of chlorophyll-a from satellite give a similar correlation coefficient of 0.7. A positive phase of IOD indicates negative SST anomaly in the south-eastern tropical Indian Ocean associated with zonal wind anomaly along the equator (Meyers, 1996). The abnormally strong coastal upwelling near the Java Island stimulates a larger phytoplankton bloom than usual (Murtugudde et al., 1999). On Banda Sea, no straightforward impact of ENSO or IOD reaches the first level of the food chain (Fig. 8). Inside the archipelago, both climate modes affect the ITF transport variability, and it is not trivial to separate the individual effect of each climate mode (Masumoto, 2002; Sprintall and Révelard, 2014). Same comment can be done for the South China sea (Fig. 7).
ENSO and IOD climate modes play a key role in the Indonesian region, but their impact on the marine ecosystem remain a complex study. The period of simulation is too short for a rigorous assessment of the role of these drivers. Direct relationship is evident only in the Indian part. But interannual anomalies of simulated chlorophyll-a compare well with satellite observations. This realistic variability suggests that interannual meteorological and ocean physical processes are captured by the model."

(2) It is unclear to me how the authors can evaluate the water masses transformation without showing any formation-transformation diagnostics. This is maybe a direct outcomes of the companion paper. If not, I recommend to use the terms ‘water mass hydrodynamics characteristics’ or equivalent which are presently shown and evaluated.

Author’s response:
Yes, diagnostics concerning water mass transformation are presented on the companion paper. We now clarify this point in the revised manuscript by adding a summary of the companion paper in the Introduction:
“The regional configuration of the ocean dynamics is fully described in Tranchant et al. (this volume, hereafter Part I). The physical model reproduces main processes occurring in this complex oceanic region. Ocean circulation and water mass transformation through the Indonesian Archipelago are close to observations. Eddy Kinetic Energy displays similar patterns to satellite estimates, tides being a dominant forcing in the area. The volume transport of the Indonesian ThroughFlow is comparable to INSTANT data. TS diagrams highlight the erosion of South and North Pacific subtropical waters while crossing the archipelago.”

(3) The authors point the influence of external inputs but they do not assess how accurate are the product employed to force PISCES. While I acknowledge that river inputs are difficult to assess, atmospheric inputs might be evaluate against air-borne measurements or available model outputs.

Author’s response:
All external inputs used to force PISCES are extensively described and discussed in the supplementary material of Aumont and Bopp (2006). In our paper, we emphasize the major role of river discharges in this region governed by the seasonal monsoon system. Rivers supply large quantities of nutrients to the ocean. We acknowledge the lack of data at the temporal and spatial resolution required to improve model forcing at the regional scale. In the conclusion section, we recommend the contracting organization of the INDO12BIO operational configuration to consider the importance of river discharge data in order to simulate realistic biogeochemical features along the coasts.

The revised manuscript (Section 3.3) was modified as follows:
“Three different sources are supplying nutrients to the ocean: atmospheric dust deposition, sediment mobilization, and rivers. Atmospheric deposition of iron comes from the climatological monthly dust deposition simulated by the model of Tegen and Fung (1995), and Si following Moore et al. (2002). Yearly river discharges are taken from the Global Erosion Model (GEM) of Ludwig et al. (1996) for DIC, and from Global News 2 climatology (Mayorga et al., 2010) for nutrients. A constant iron source from sediment reductive mobilization on continental margins is also considered. For more details on external supply of nutrients, please refer to the supplementary material of Aumont and Bopp (2006).”

Specific comments:

P 6670 L1 'D'evelopment

Author's response: Sorry, we corrected this typing error.

L10 coupled and 'on-line' are redonant.

Author's response: We feel that it is important to specify the mode of coupling, in this case "on-line", as PISCES can also be coupled to OPA/NEMO in a "off-line" mode. We are sorry if these words appear to be redundant.

L10 degradation is mentioned several times in the ms. I recommend the authors to explain a bit these terms if they are useful for the study or to remove them if they do not.

Author's response: Yes, you are right. On the revised manuscript we removed the term "degradation" as it is not usefull for the study.

L14 please reword this sentence because the papers focuses on the last 4 years of the simulation.

Author's response: As we now include interannual analysis in the revised version of the paper, we investigate the all years of the simulation expect the first one.
As a result, we modified the text in the abstract but also in Section 3.4:
- in the abstract: "The reference hindcast simulation covering the last 8 years (2007-2014) is evaluated against satellite, climatological and in-situ observations.".
- in Section 3.4: "For comparison with satellite products (chlorophyll-a, primary production), we presents annual mean for year 2011 as an example. For comparison with climatologies (zooplankton, nutrients, oxygen) and analysis of the seasonal cycle, we are using years 2010 to 2014. For interannual variability, we consider the whole length of simulation except the first year, so 2008 to 2014.".

L25 'water mass hydrodynamics and biogeochemical properties' ?
L26 vertical distribution of what ?

Author's response: We reformulate the this sentence in the abstract to:
"Vertical distribution of nutrient and oxygen is comparable to in-situ based datasets although slightly smoothed. Biogeochemical characteristics of North Pacific tropical waters entering in the archipelago are realistic. Hydrodynamics transformation of water masses across the Indonesian archipelago allows conserving nitrate and oxygen vertical distribution close to observations, in Banda Sea and at the exit of the archipelago."

P6671

L25 change ‘but propagate’ into ‘but also propagate’

Author’s response: We changed ‘but propagate’ into ‘but also propagate’

P6672

L7 Change ‘capacity’ into ‘capability’

Author’s response: We changed ‘capacity’ into ‘capability’

L9 Madec et al. 2008 shall be preferred regarding the NEMO model version

Author’s response: Yes, you are right, we changed the reference.

P6674

L26 please confirms that NEMO3.2 is used.

Author’s response: OPA/NEMO version 2.3 is used

P6675

L17 Do you refer to the standard PISCES set of parameters?

Author’s response: We used the standard PISCES set of parameters in its version 3.2, except for 2 parameters. Indeed, a sensitivity analysis focused on the half-saturation constant for phytoplankton growth. We tested each half-saturation constant of the model by dividing or multiplying the constant by a factor 2 as compared to the standard 3.2 namelist. We focussed on nanophytoplankton species as we aimed to decrease the chlorophyll-a concentrations in the open ocean. After all, an increase by a factor two of the half-saturation constant for NO_3, NH_4 and PO_4 assimilation (conc0 and concnnh4 parameters in the namelist) leads to slightly lower surface chlorophyll-*a* concentrations in the open ocean after some months of simulation. But after several years and monthly or annually averages, the impact is negligible, especially compared to the change of advection scheme (MUSCL vs QUICKEST-Zalezak). As discussed in the Discussions and Conclusions Section, the change in advection scheme impacts the biogeochemical tracer distribution to the first order. Ideally, we should have re-run the simulation with the standard PISCES namelist, but due to computing cost, this was not possible. It was decided to keep the 2 modifications. However, we chose not to detail this sensitivity study in the submitted paper due to its lack of significance.

P6676

L6 please expand the TOP acronym and explain its function. Is this another module coupled to PISCES ?

Author's response: TOP is the component that allows the biogeochemical model PISCES to be coupled with NEMO-OPA ocean dynamics model. NEMO-TOP resolves the advection/diffusion equations of passive tracers as well as biogeochemical sources minus sinks if a biogeochemical model is activated, here PISCES.
We added a sentence in Section 3 to clarify what is TOP component:
"PISCES is coupled to NEMO-OPA via the TOP component that manages the advection/diffusion equations of passive tracers but also the sources and sinks terms due to biogeochemistry."

I think that merging the PISCES description with the 3.1 section could make the model setup clearer.

Author's response: For the revised version, we merged the NEMO and PISCES description with the Section 3.1 "The coupled model" to make the model setup clearer.

Few words on the Redfieldian assumption of PISCES provided in the ms can be also detailed here.

Author's response:
Redfieldian assumption of PISCES has been clarified in Section 3.1 of the revised version.
"Constant C/N/P Redfield ratios are supposed for all species. While internal Fe/C and Si/C ratios of phytoplankton are modelled as a function of the external availability of nutrients and thus variable, only C is prognostically modelled for zooplankton."

Please check the references of external inputs? (It seems to me that atmospheric dust deposition were derived from Tegen and Fung, (1995))

Author's response:
You are right, we corrected the references of external inputs; atmospheric dust deposition comes from the model of Tegen and Fung (1995).

P6677

Section 4: I suggest to re-order subsection with (1) INDOXMIX measurements which presents hydrodynamics properties, (2) nutrients and finally (3) ecosystems parameters.

Author's response: We reordered Section 4 as suggested.

L14 please indicate the exact period of the simulation

Author's response: We now clarify the exact period of the simulation in Section 3.4:
"The simulation started on January 3rd, 2007 and operates up to present day as the model currently delivers ocean forecasts. But for the present paper, we will analyse the simulation up to December 31, 2014."

L20 please provide the evolution of tracers' concentrations at various depth because 3D average generally masks drift. Please give few metrics to quantify the steady state of the tracers' concentrations.

Author's response:
The objective of Figure 1 is to demonstrate the model has a satisfying behaviour all along the simulation length, without drift due to mass conservation problems. To this end, tracers' concentrations over the whole 3D domain are presented. Strictly speaking, the model can not reach steady state as open boundary conditions and surface forcing come from global forecasting systems. Interannual variability, as well as temporal drift is introduced in the domain configuration.

We follow, however, the suggestion put forward by the reviewer and add the following figures to the supplementary material.

Figures A to F present the evolution of tracers' concentrations at various depths: surface, 0-100m, 100-600m and 600m-bottom, in order to detect abnormal drift with time. Please find as example the evolution of nutrients, chlorophyll-a and net primary production (NPP), but also the main stressors of marine ecosystems: sea surface temperature (SST) and oxygen concentrations. It can be seen that:

(1) Chlorophyll-a and NPP do not significantly drift over the time of the simulation (Figure A), with an averaged chlorophyll-a concentration about 0.51 mg Chl m^{-3} at the surface and 0.35 mg Chl m^{-3} between 0-100m and vertically integrated NPP about 58.9 mmol C m^{-2} d^{-1}.

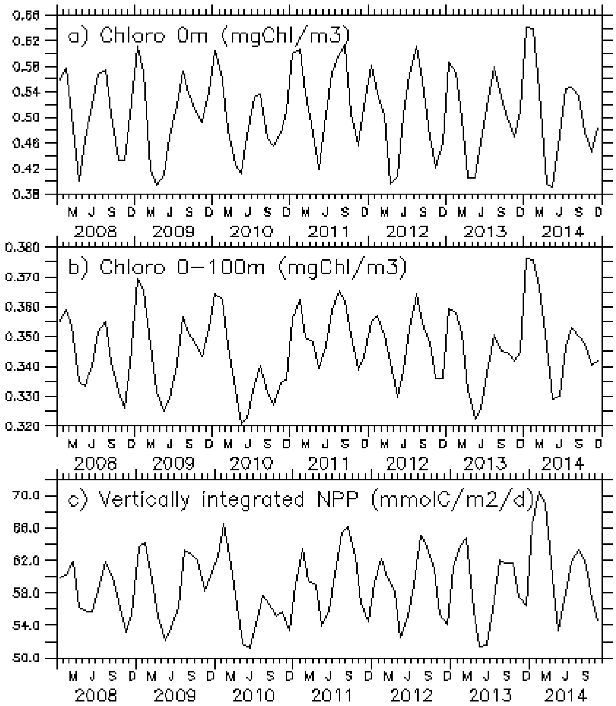

Figure A: Temporal evolution of chlorophyll-a concentrations at the surface (a) and in the first 100m depths (b) and vertically integrated NPP (c), averaged over the whole INDO12BIO domain.

(2) Nutrients do not present a clear trend, but display a vertical adjustment in course of simulation (Figures B, C, D and E; please note different scales on ordinate axes). Nitrogen and Phosphate are

almost stable in the upper 100m. They slightly decrease at depth (600-to bottom) during the first years of simulation and then increase the following years. Dissolved Si increases in the top 600m and decreases below. Conversely, dissolved Fe decreases in the 100 to 600m depth interval and increases below.

(3) Dissolved oxygen does not present a clear trend in the first 100m (Figures B and C). However, over the whole 3D domain, a mean drift of -0.006 ml O_2 l^{-1} yr^{-1} is simulated by the model. The strongest negative trends are mainly located in the top 200m, in the archipelago (South China Sea, Banda Sea, and semi-enclosed areas), but also in the open ocean (not shown). Some areas also exhibit positive trends. The strongest are found in the Pacific and Indian parts of the model domain and are mainly situated between 300 and 1500m depth (not shown). Again a negative oxygen trend is simulated below. As for nutrients, the model reorganizes the vertical distribution of oxygen during the simulation.

(4) The simulated time series of SST (Figure F) is compared to the Reynolds product based on remotely sensed SST data. The positive bias is discussed in Tranchant et al. (this volume). Here, we are more interested by the phasing and the temporal trend between simulated and observed SST. Temporal variations are realistically simulated by the model, with an excellent correlation between the two time series (r = 0.94). Simulated monthly averaged SST presents a positive trend of +0.023°C yr^{-1}. Monthly averaged Reynolds SST indicates a positive trend of +0.032°C yr^{-1}.

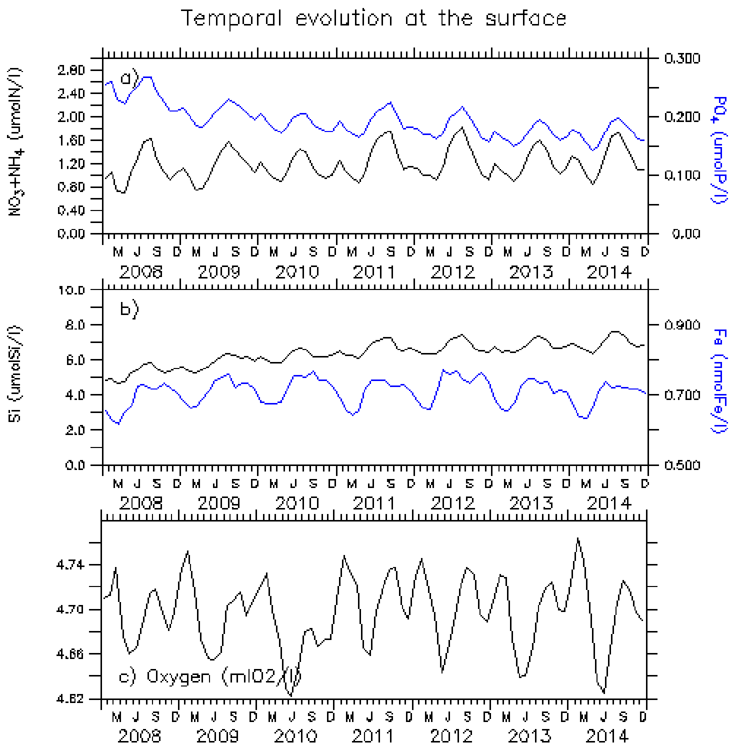

Figure B: Temporal evolution of nutrient (nitrate+ammonium, phosphate, Dissolved Si, and Dissolved Fe) and oxygen content at the surface, averaged over the whole INDO12BIO domain.

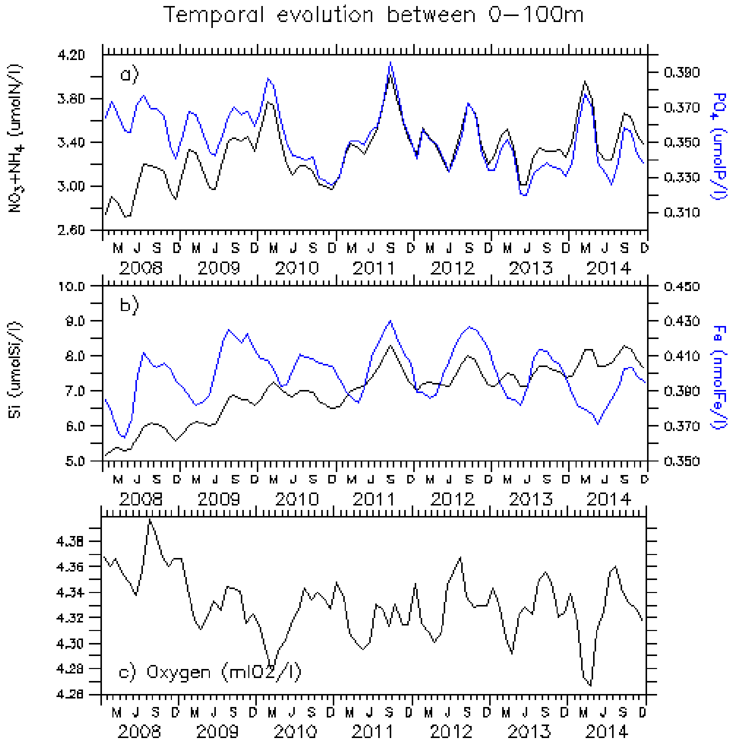

Figure C: Temporal evolution of nutrient (nitrate+ammonium, phosphate, Dissolved Si, and Dissolved Fe) and oxygen content in the first 100m depths, averaged over the whole INDO12BIO domain.

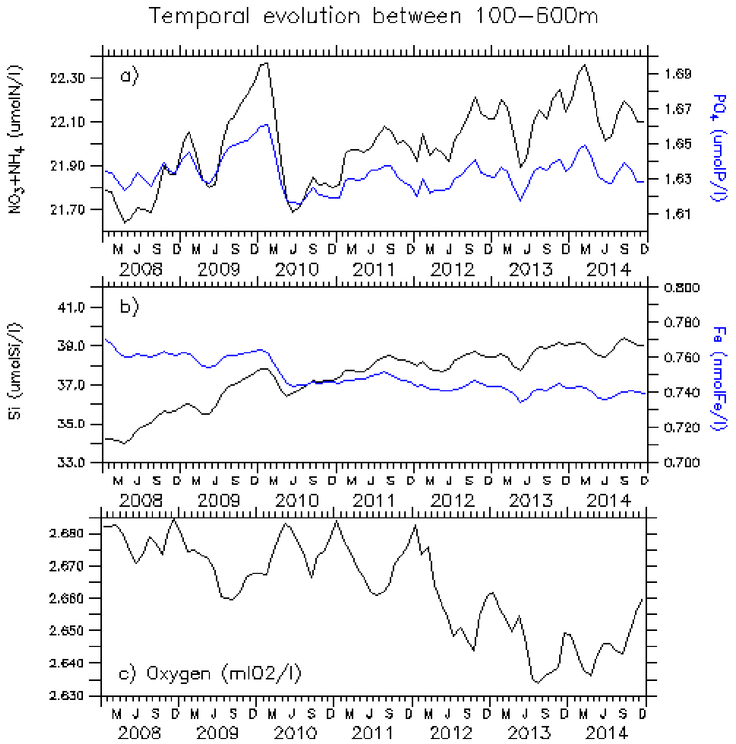

Figure D: Temporal evolution of nutrient (nitrate+ammonium, phosphate, Dissolved Si, and Dissolved Fe) and oxygen content between 100 and 600m depths, averaged over the whole INDO12BIO domain.

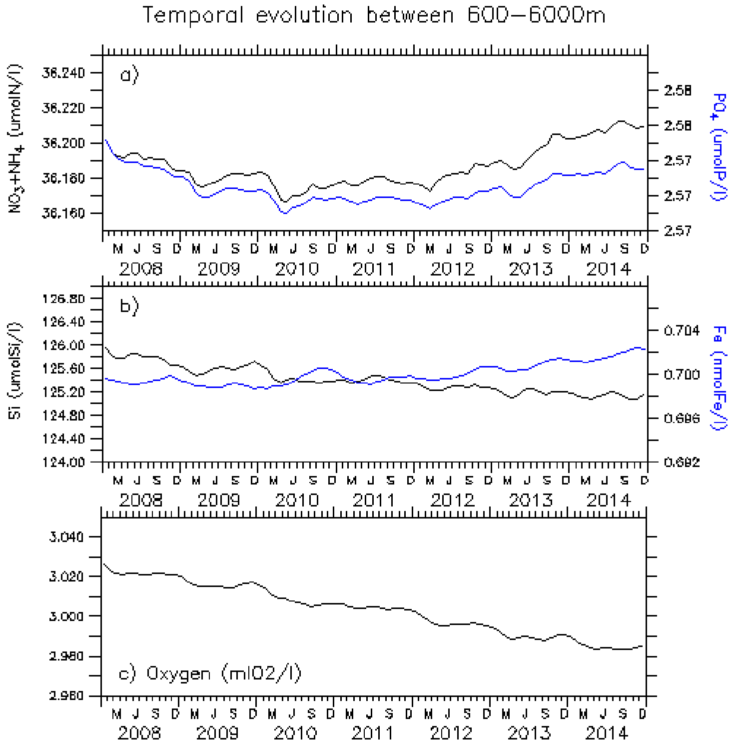

Figure E: Temporal evolution of nutrient (nitrate+ammonium, phosphate, Dissolved Si, and Dissolved Fe) and oxygen content at depth (between 600 and 6000m depths), averaged over the whole INDO12BIO domain.

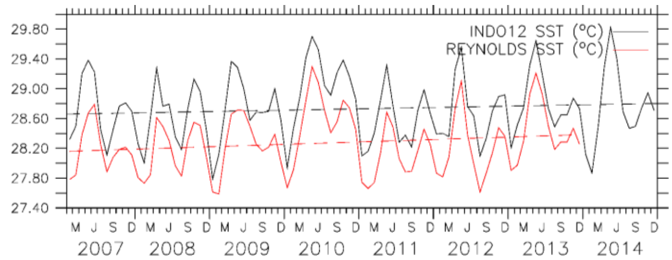

Figure F: Temporal evolution of Sea Surface Temperature over the whole domain (solid line) and associated trend (dashed line), computed from INDO12BIO monthly outputs (black) and from Reynolds satellite product (red).

To conclude, the model tends towards a "steady state", in terms of numerical equilibrium. There is no loss of material (temperature, carbon, oxygen, …) due to numerical deviation. For the physical part, a realistic temporal trend is simulated in SST as compared to satellite data. For biogeochemistry, chlorophyll-a and NPP are almost stable during the time of the simulation, while nutrients and oxygen need a longer-term vertical adjustment.

However, it is not straightforward to conclude on a potential drift of the model as the simulation is too short to estimate accurate temporal trends, and the region has very few data to compare with. This is why we did not include these plots to the main section of revised version, but decided to add them to the supplementary material. However, in the revised version, we now include the interannual variability of chlorophyll-a.

P6679

Section 4.2 : please refer to Henson et al. (2010) which used several satellite-derived algorithm to compute phytoplankton production. This paper is of interest for this study since it discuss the uncertainty of the CbPM algorithm compared to the others.

Author's response: Yes, we are aware that CbPM gives results substantially different from the other algorithms. We now clarify this point in the revised version. But we are keen to present the dispersion between satellite-based algorithms, and more particularly in this region where uncertainties concerning satellite optical measurements can be great due to river discharges and shallow water depths that disturb the signal.

We added the following sentence to the revised manuscript (Section 4.4): "Henson et al. (2010) point the uncertainty of the CbPM algorithm, giving results substantially different from the other algorithms."

L14 please give a reference for MAREDAT.

Author's response: Sorry, we added the reference to MAREDAT atlas:
Buitenhuis, E. T., Vogt, M., Moriarty, R., Bednaršek, N., Doney, S. C., Leblanc, K., Le Quéré, C., Luo, Y.-W., O'Brien, C., O'Brien, T., Peloquin, J., Schiebel, R., and Swan, C.: MAREDAT: towards a world atlas of MARine Ecosystem DATa, Earth Syst. Sci. Data, 5, 227-239, doi:10.5194/essd-5-227-2013, 2013.

P6680

L4 Please explain. In PISCES, phytoplankton growth is limited by the various nutrients concentration (e.g., Laufkötter et al., 2015). Therefore, nitrate and phosphate should be decoupled in the model.

Author's response:
Yes, growth rate of phytoplankton is limited by the external availability in N, P, Si and Fe. Stoichiometry of C/N/P is fixed in PISCES. So nitrate+ ammonium and phosphate are not independent nutrients. We clarified this point in Section 3.1.
For the Indonesian configuration, we only present nitrate, and dissolved Si distributions in the submitted paper, as phosphate gives similar results to nitrate.

Section 5: Here also, I suggest to re-order the subsection by presenting (1) annual mean state nutrients and ecosystem parameters and (2) seasonal to interannual variability of some biogeochemical fields (if Chl and NPP have reached a steady steate before 2010). According to Gierach et al. (2012), the 2009-2010 ENSO event has implications on the biological fields.

Author's response: As suggested, we reordered the Section 5 in 5.1 Annual mean state; 5.2 Mean seasonal cycle; 5.3 Interannual variability; 5.4 INDOMIX cruise.
Yes ENSO event and also IOD phenomena have implications on the biological fields. It is now discussed in Section 5.3 Interannual variability.

P6686,

L17 please detail what water mass transformation means.

Author's response: We reformulated the sentence in Section 6 to:
"Biogeochemical characteristics of North Pacific tropical waters entering in the archipelago are set by the open boundary. Hydrodynamics transformation of water masses across the Indonesian archipelago are simulated satisfyingly. As a result, nitrate and oxygen vertical distributions match observations in Banda Sea and at the exit of the archipelago."

References:

Gierach, M. M., Lee, T., Turk, D. and McPhaden, M. J.: Biological response to the 1997-98 and 2009-10 El Niño events in the equatorial Pacific Ocean, Geophys. Res. Lett., 39(10), L10602, doi:10.1029/2012GL051103, 2012.

Henson, S. A., Sarmiento, J. L., Dunne, J. P., Bopp, L., Lima, I., Doney, S. C., John, J. and Beaulieu, C.: Detection of anthropogenic climate change in satellite records of ocean chlorophyll and productivity, Biogeosciences, 7(2), 621–640, doi:10.5194/bg-7-621-2010, 2010.

Laufkötter, C., Vogt, M., Gruber, N., Aita-Noguchi, M., Aumont, O., Bopp, L., Buitenhuis, E., Doney, S. C., Dunne, J., Hashioka, T., Hauck, J., Hirata, T., John, J., Le Quéré, C., Lima, I. D., Nakano, H., Séférian, R., Totterdell, I., Vichi, M. and Völker, C.: Drivers and uncertainties of future global marine primary production in marine ecosystem models, Biogeosciences Discuss., 12(4), 3731–3824, 2015.

Tegen, I. and Fung, I.: Contribution to the Atmospheric Mineral Aerosol Load From Land-Surface Modification, J Geophys Res-Atmos, 100, 18707–18726, 1995.