Responses to the comments received from Anonymous Referee #3 on os-2017-83

We thank the anonymous Referee#3 for the constructive comments on the manuscript. Our point-by-point responses are given in italic blue font following each comment.

Prakash et al. present a study about the effects of very strong storm on the ocean mixing and energy penetration in the water column. Study area is a single station in the Bay of Bengal. A 3D coupled is used for this.

Generally the study is well structured and provides and overview over dominant frequencies found in the models simulated kinetic energy and mixing characteristics. There are some points however, that prevent me from recommending publication in Ocean Science in its present form:

1) It becomes not clear to me what found the frequencies are related to. Are they specific for this special model used? Are they influenced by the frequency of coupling fluxes between ocean and atmosphere? The coupling time step is also not noted in the manuscript nor which fluxes/variables are exchanged. Or is a physical process possible behind the found frequencies. Could be worth to look at the atm. variable likewise to figure out similar frequencies.

The near-inertial frequencies are process and location (latitude) depended and not on the selection of model, model configuration or frequency of coupling fluxes between ocean and atmosphere. The frequency ranges of near-intertial oscillations (f) at the selected location and semidiurnal tidal constituent (M2) are now marked with two pairs of vertical lines in Figure 7 of the revised manuscript. The high energy of near-inertial oscillations (NIO) found in our study is generated due to the strong cyclonic winds. As suggested by the Referee, we have performed the power spectrum analysis on air-temperature and found similar frequencies. The figure is given below.

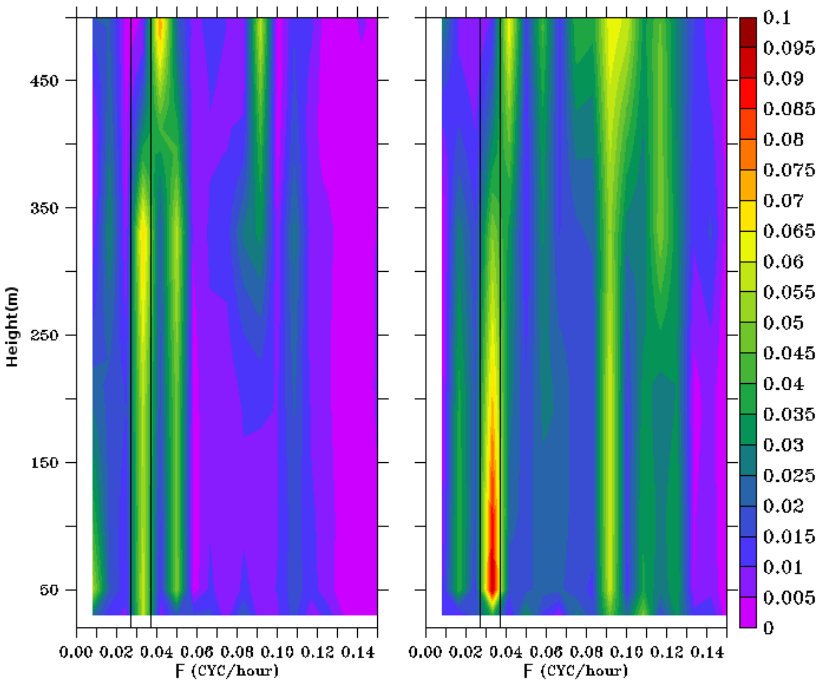

Figure: The power spectrum analysis (m^2s^{-1}) performed on the simulation period at the on-track (left panel) and off-track (right panel) locations.

In the revised manuscript, we have added an on-track location in addition to the existing off-track location (the two locations are shown in Figure 2 of the revised version) and results were compared for the kinetic energy. Similar NIO frequencies were found in air-temperature as that of oceanic currents. Further, the strength of NIO frequencies are stronger at the off-track location as compared to the on-track location both in the atmosphere and ocean. The power associated with NIO in the atmosphere (air-temperature) is about an order weaker than the oceanic NIO. As the aim of this paper is to estimate the kinetic energy propagation and mixing within the ocean, we have not attempted to analyse the energy distribution in the atmospheric column and, therefore, the air-temperature power spectrum figure is not being added to the manuscript.

The coupling time step (600 s) are now mentioned in lines 244-245 of the revised version. The fluxes/variables exchanged between the component atmosphere/ocean/wave models are now clearly mentioned in lines 169-181 of the revised version. A new figure (Figure 1) is included to show the variables exchanged between the model components.

2) The analysis of only one single station is not enough to draw wider robust conclusions. The usage of a 3D high resolution model, however, provides the possibility to extent and confirm the findings for whole domain and eventually further cluster the results according regional characteristics like water depth or hydrographic conditions (background stratification, salinity, river influenced region etc).

In the revised manuscript, we have added an on-track location in addition to the existing off-track location (the two locations are shown in Figure 2 of the revised version) and results were compared (in Figures 6, 7, and 8 in the revised version). The analysis showed weaker NIO at the on-track location as compared to the off-track location. We have limited our analysis to the region influenced by the strong cyclonic winds that transfer the kinetic energy to the oceanic column.

A few studies have shown that the near-inertial energy rapidly decreases in the shallower depths towards the coast. The spatial distribution of near-inertial energy is primarily controlled by the boundary effect for inertial oscillations (Chen et al., 2017). The NIO energy found to decline with the decreasing depth and vanish in the coastal regions (Schahinger, 1988; Chen et al., 2017). Our 3-d coupled model simulations are performed for the period of a very severe cyclone Phailin. In the presence of strong cyclonic winds, impact of the differences in salinity (river influenced) on NIO as compared to a location under the storm would be difficult to access. Such a study would require a normal weather condition with uniform winds (idealistic winds) over the whole domain. However, this could be an interesting problem to be explored in the salt-stratified BoB in a future study.

3) No motivation for the selection of the abalysis station is given. Is it believed to be representative for a wider region? Why not take one along the main storm track shown in Fig.2 and another one further remote from the storm center. Or just anaylyze a section along the track and another outside the track.?

As suggested by the Referee, we have now added another location on the track of cyclone and compared results with the existing off-track location (the two locations are shown in Figure 2 of the revised version). However, the larger kinetic energy and mixing were found at the off-track location as compared to the on-track location. The selection of the off-track location was based on the maximum surface cooling observed at this location indicating strong mixing. The revised figures (Figures 6, 7, and 8 in the revised version) to show analysis at both the locations are included in the revised manuscript.

4) Validation. No attempt is made to demonstrate the ocean modells ability to reproduce generell hydrodynamic and hydrographic characteristics like simply surface SSS and SST. Where are the strengths and weaknesses of this model? When one aims to look at the energy cascade also the winds should be somehow assessed or at least showing the wind characteristics over the station(s) focused.

The performance of the coupled atmosphere-ocean model in simulating the oceanic parameters temperature, salinity, and currents during the Phailin is accessed in Prakash and Pant (2017). The strength of the coupled model is in simulating better oceanic and atmospheric features as compared to the stand-alone oceanic/atmospheric model. For example, the stand-alone WRF overestimates surface wind speed (comparison shown between coupled and stand-alone WRF against the buoy measurements in Figure 4 of the revised version). The stand-alone ocean model ROMS produces cold bias >-2.0 deg C (comparison shown in Figure 5 of the revised version). The better simulation of SST in coupled configuration resulted from the improvement in the wind speed and heat-fluxes.

As suggested, we have now included a panel showing the wind speed (in Figure 6 of the revised version) along with the profiles of temperature, u- and v-current, and barotropic/ baroclinic kinetic energy at both on-track and off-track locations.

5) No specific scientific or technical problem is addressed in this study. The manuscript aims at analyzing and quantify subsurface mixing and near inertial mixing. But why is this important and why can this only be done at this single station? Its difficult to see any broader implication in the manuscript at its present form but rather reads as an execise.

The study is first of its kind in the Bay of Bengal utilizing a 3-D coupled atmosphere-ocean-wave model to estimate the oceanic sub-surface mixing in the presence of near-inertial oscillations during a severe cyclone (mentioned in lines 12-14, 123-127 in the revised version). The study has important practical/societal implications. The proper representation of kinetic energy propagation and oceanic mixing have applications in improving the intensity prediction of cyclone, storm surge forecasting, and biological productivity (mentioned in lines 525-529 in the revised version). The analysis is now performed at two locations i.e. on-track and off-track, as suggested by the Referee.

Specific comments

line 27ff Introduction

The motivation of using a coupled atmosphere ocean model should be explained as this is by no means standard in regional modelling. What is here advantage over stand-alone components which justifies the more computer power required by coupled models. Refer other studies that used coupled models and summarize which improvements or problems they report. What is the added value you expect from a coupled model in you region?

A number of studies have used a coupled atmosphere-ocean model over a regional domain to address a variety of atmospheric/oceanic processes (Zambon et al., 2014; Warner et al., 2010). The regional coupled model is particularly useful in simulating atmospheric/oceanic conditions in storm conditions. There are several other regional studies (Warner et al., 2010, Ricchi et al., 2016, Nelson et al., 2014, Wu et al., 2016) for different storm cases and extreme events by utilizing the coupled atmosphere-ocean-wave model.

The coupled atmosphere-ocean model found to improve the intensity of cyclonic storm when compared to the uncoupled model over different oceanic regions (Warner et al., 2010; Zambon et al., 2014; Srinivas et al., 2016; Wu et al., 2016). Zambon et al. (2014) compared *the simulations from the coupled atmosphere-ocean and uncoupled models and reported significant improvement in the intensity of storm in the coupled case as compared to the uncoupled case. The uncoupled atmospheric model produced large ocean-atmosphere enthalpy fluxes and stronger winds in the cyclone (Srinivas et al., 2016). When the atmospheric model WRF was allowed interactions with the ocean model, the SST found to be more realistic as compared to warm bias in the stand-alone WRF (Warner et al., 2010). Wu et al. (2016) demonstrated the advantage of using a coupled model over the uncoupled model in better simulation of typhoon Megi's intensity. These points are now included in lines 57-67 of the revised version.*

In our region, there are marked improvements in the wind speed in the atmospheric model and SST in the oceanic model component in the coupled configuration as compared to the stand-alone atmospheric model and stand-alone ocean model (Figures 4 and 5 in the revised version). The mean sea level pressure was lower and surface wind speed was higher in the stand-alone model as compared to the coupled model, which was close to the buoy (BD09) measurements (Figure 4 in revised version). The overestimated wind speed in the stand-alone atmospheric model give rise to the larger heat loss by ocean in the stand-alone ocean model resulting into the cold SST bias (Figure 5 in revised version). The improvement in the surface wind speed in coupled configuration is due to the better representation of sea surface roughness and heat-fluxes.

line 76: biological primary productivity is a flux rather not a concentration. I would remove ”concentration” in this sentence. Chlorophyll on the other hand is a concentration.

This paragraph on the biological productivity has been deleted in the revised manuscript as per suggestions from another Referee.

Line 120 – 130.
Here a number very specific parameterization schemes for the atmospheric model are named. Why where these chosen and not others? Are there more options available in this mode? If yes explain why you chosed the ones you explicitly named. Can it be expected that they have impact on the result?

The specific parameterization schemes used in this study are based on the sensitivity experiments of the parameterization schemes in the same atmospheric model WRF by ourselves and others (Osuri et al., 2012). There are other parameterization schemes available in the model but over our region, the selected schemes performed better. Similar parameterization schemes were used in the coupled atmosphere-ocean model by Glenn et al. (2016), Zambon et al. (2014), Warner et al. (2010).

134 – 155: Please tell the reader which variables or fluxes are communicated between the ocean-atmosphere-wave models and which is the coupling time step?

The coupling time step (600 s) are now mentioned in lines 244-245 of the revised version. The fluxes/variables exchanged between the component atmosphere/ocean/wave models are now clearly mentioned in lines 169-181 of the revised version. A new figure (Figure 1) is included to show the variables exchanged between the model components.

192 – 201
The validation is by far not sufficient here. The track is obviously ok. But no validation for wind is provided which would likewise influence SST and thermocline depth level. It would be also helpful to judge the general performance of the ocean model for temperature and salinity therby taking account also in situ measurements not only satellite data. Apparently

the model exists at least since 2005. Has there ever been a validation undertaken for the ocean model showing general characteristics of the thermocline etc?

A validation of wind at the buoy BD09 location is now provided in Figure 4 of the revised version. For comparison, the stand-alone atmospheric model and coupled model simulated winds are plotted together with the buoy measurements. The general performance of the ocean model in coupled configuration for the Phailin cyclone has been thoroughly discussed in our published article (Prakash and Pant, 2017). The similar model has been found capable in simulating realistic oceanic features in various storm conditions (Warner et al., 2010, Nelson et al., 2014, Wu et al., 2016, Zambon et al., 2014).

What is figure 3 showing? snapshots, daily averages?
Magnitude of cooling: how large is it? Corresponds your single analysis site with the maximum cooling seen in Fig. 3?
The SST values shown in Figure 3 (Figure 5 in revised version) are daily averages. Figure caption is modified to reflect this. In the daily-average plot (Figure 3 of old version), the magnitude of cooling was up to -2.5 °C but in the hourly time series plot (Figure 4a in old version; Figure 6 in revised version) up to -3.5°C maximum cooling was observed.

203 – 215
Its no surprise the isotherms are deepening during a storm. What information do you want to give by chosing a 23C isotherm at a single place? Are other processes more important when considering other isotherms?

The thermocline, defined as the depth of maximum temperature gradient, is usually referred to a location dependent isotherm depth (Kessler, 1990; Wang et al, 2000). Over the BoB region, the depth of 23ºC isotherm (D23) found to be an appropriate representative depth of the thermocline (Girishkumar et al., 2013). These points are now mentioned in lines 339-342 of the revised version.

line 228:
That's intressting. Is it possible to make a more general statement that the baroclinic component is higher than the barotropic here ? how is it in the center of the storm/ in peripherals of the storm?

After performing the analysis over the on-track location (centre of the storm) in addition to the existing off-track location, we can infer that the kinetic energy associated with the baroclinic component found to be much higher than the barotropic component of current in the centre as well as off-track location in the Phailin (Figure 6 of the revised version). Please notice that barotropic currents plotted with a multiplication factor of 10^2 to plot both baroclinic and barotropic current components in the same scale (this multiplication factor is mentioned in figure caption).

line 241:
Figure 5 show maximun spectral power in frequency band between roughly 0.03 and 0.04 cycles per hour. Please make more clear which frequencies you attribute to tidal forcings and inertial mixing.

The frequencies attributed to the near-inertial oscillations and tidal forcing are now clearly marked with f and M2, respectively in Figure 7 of the revise version.

244:
When tidal oscillation were absent at the whole vertical section shown in Fig. 5 how can these oscillation then dominate at the surface (sentence line 240)?

The sentence has been elaborated and modified to make it clear (lines 400-406 in the revised version).

250-251:
Is it meant that NIO dominates the mixing at 14 m depth when windstress would be absent?
We meant that NIO dominates the mixing at 14 m depth in presence of local wind stress that dominated the mixing compared to any other process. Other processes include the background flows, the presence of eddies, variations in sea surface height, non-linear wave-wave and wave-current interactions (Guan et al., 2014; Park and Watts, 2005). The sentence has been modified in lines 411-415 in the revised version.

252 – 268 (Figure6, Fig. 7):
Here higher order statistics is applied. Which frequency has the input data? The scale in Figure 6 goes until 60 periods/hour, so you need a minimum of 60 seconds in the output frequency of the model, right? Also, Figure 6 show the percentage at 40m depth but the text discusses it at 14 m.
We regret this mistake in the unit. We have now corrected the unit as Period (days) in Figure 9 of the revised version. The frequency of the input data is 60 min. The typo mistake of 40 m is corrected as 14 m in figure caption.

Using filter techniques a number of values for the baroclinic current strengths and kinetic energy are given. The temporal evolution of these parameters is proven to be related to the storm activity. But what else can we learn from that.

The filter techniques used to estimate the strength of near-inertial oscillations (NIO) in the frequency range of 0.028 to 0.038 cycles h-1 at the selected locations. The analysis was helpful to understand the downward propagation of kinetic energy and decay of NIO with the increasing depth. We realized that profiles of filteres baroclinic meridional (Vf) and zonal (Uf) currents based on the filter technique was not adding any new information to the paper. Therefore, we have now replaced the Figure 7 (old version) with Figure 8 (in revised version). The figure description has been modified accordingly in lines 416-428 in revised version.

Figure 6 contains no white dashed line as mentioned in the text. All this seems not be surprising, so are there more general implications from these singels events analyzed at a single location? This reads more like an exercise.
There was no white dashed line in the figure and its mention in the text and figure caption has been deleted. The analysis is now performed at two locations- one at the on-track and another at the off-track location.

line 311ff Conclusion
The conclusions lists all the above mentioned phenomena which might be intressting but no attempt is made to put the results in wider context or to draw more general implications for the community. Can corresponding frequencies also be found in atmospheric variables like air temperature, heat fluxes etc? This could be an argument for using coupled models.

The study has important practical/societal implications. The proper representation of kinetic energy propagation and oceanic mixing have applications in improving the intensity prediction of cyclone, storm surge forecasting, and biological productivity (mentioned in lines 525-529 in the revised version). As suggested by the Referee, we have performed the power spectrum analysis on air-temperature and found similar frequencies. The figure is given above with its description.

No attempt is undertaken to further interpret the found frequencies. Are they model specific i.e. dependent parametrizations, numerical schemes etc or can they be explained physics? And how robust are they when only one anaysis station is used? What is the roles of NIO compared to other processes of vertical mixing especially if you analyze them more on the shelff with shallow water depths?

The near-inertial frequencies are process and location (latitude) depended and not on the selection of model, model configuration, parameterization, or numerical schemes used in the coupled model. The high energy of near-inertial oscillations (NIO) found in our study is generated due to the strong cyclonic winds. Now, the analysis has been performed at two locations- on-track and off-track in the cyclone Phailin. Through the filter technique analysis, we have shown (in Figures 7 and 8 in the revised version) that NIO were the dominant frequency signals in presence of cyclone-induced local wind stress that dominated the vertical mixing in our study period during a cyclone. Our analysis was limited to the locations under the influence of strong cyclonic winds that would lead to strong mixing and associated cooling. However, a few studies have shown that the near-inertial energy rapidly decreases in the shallower depths towards the coast. The spatial distribution of near-inertial energy is primarily controlled by the boundary effect for inertial oscillations (Chen et al., 2017). The NIO energy found to decline with the decreasing depth and vanish in the coastal regions (Schahinger, 1988; Chen et al., 2017), mentioned in lines 96-99 of the revised version.

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