Reply to the Comments of Anonymous Referee#2 Posted on 26 March 2019

General Comment

- **Referee's General Comment**

Based a suite of atmospheric and oceanic datasets during the passage of TC Madi, Chowdhury et al. examined the upper ocean physical-biogeochemical response to the TC, mostly emphasized the effect of pre-existing cold core eddies underneath the TC. The topic of TC-ocean interaction in the BoB is interesting and important for TC forecasting. Generally, the effect of mesoscale eddy on TC-ocean interaction is well known at the present stage. Due the lack of in situ observations, studies on the Biogeochemical response to a TC is relatively less and this study may enrich our knowledge on the biogeochemical change induced by TC passage.

Author's Response

We thank the Reviewer#2 for reviewing the manuscript and for the comments.

- **Referee's General Comment**

In the manuscript, I find some conclusions are inaccurate or unclear with not sufficient evidences, especially on the effect of mesoscale eddies. Therefore, I suggest a major revision prior publication. I hope the following comments are useful when the authorsrevise their manuscript.

(1) How does cyclonic eddy (also OHC in line 143) affect TC translation speed? The authors only described the time series of translation speed and position of eddy, but did not clearly demonstrate the related mechanisms. The authors should supply more evidence to demonstrate how the eddy modulates steering flow and then affect TC translation speed.

Author's Response

To address the concern of the reviewer about the effect of mesoscale eddies and to demonstrate the role of eddies in modulating the translation speed of cyclone Madi we have used a two-prong approach. First, we calculated the time evolution maps of difference of SST of 5th December (pre-cyclone SST) from each day starting from 6th December to 14th December (See Figure A) to show the large SST cooling in the north (the location of cold core eddy), which led to the weakening of tropical cyclone Madi. Second, to quantify the role of eddy in reducing the speed of northward movement of tropical cyclone Madi in the region of eddy we have calculated the eddy feedback factor following Wu et al. (2007) which is presented in Figure B.

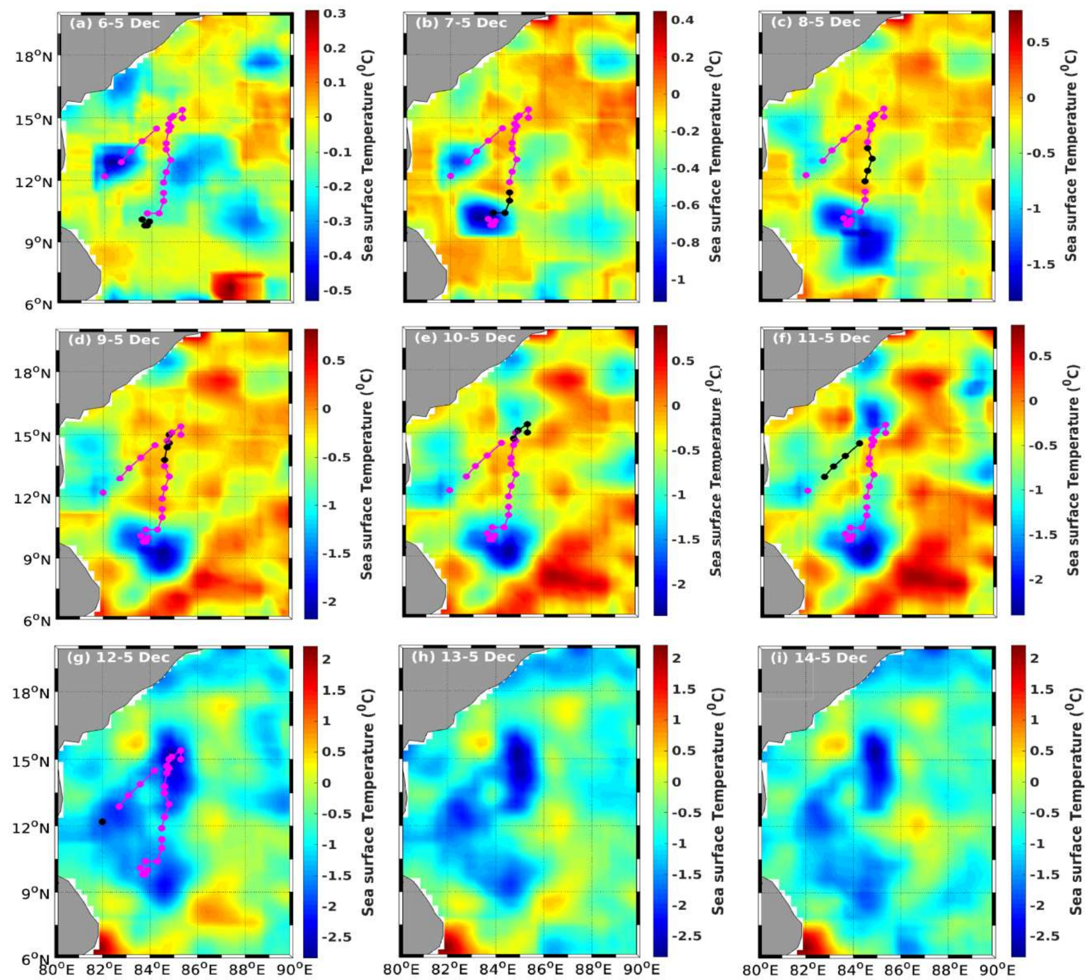

Figure A. Time evolution maps of difference of SST of 5th December (pre-cyclone SST) from each day starting from 6th December to 14th December.

The time evolution of difference in SST showed from 6th to 14th December showed a distinct cooling of 2 to2.5^{o}C in the region affected by the cyclone Madi. A comparison of these maps with Fig.3 of the manuscript clearly points that in the northern most region of the cyclone track, where there a cyclonic eddy was pre-existing; the cooling of SST was 2.5^{o}C, which was 0.5^{o}C colder than the rest of the region. The excess cooling of 0.5^{o}C noticed in the eddy region lends support to the notion that the slow translation speed led to the further cooling of SST, which contributed to the weakening of the cyclone from VSCS to SCS, through negative feedback.

Note also that after the passage of cyclone Madi, the SLA in the region of cyclonic eddy changed from -0.1 to -0.2 m. This SLA decrease of 10 cm is a combined 3-diminsional response of the cyclone Madi induced upward Ekman-pumping along with the cold core eddy induced eddy-pumping of subsurface waters.

To quantify the eddy's contribution to the intensity of the cyclone Madi we have calculated the eddy feedback factor F_{EDDY-T} following Wu et al., (2007) based on the following equation and presented in Fig.B

$$F_{EDDY-} = 0.38\ (SST_{Eddy}\text{-}26^{o}C)^{2.08}(SST\text{-}26^{o}C)^{-1.88}\ (ML_{Eddy})^{0.98}\ \text{x}\ (ML)^{-0.97}\ (\eta)^{0.22}\ (1\text{-}RH)^{-0.74}(\Gamma)^{0.45}\ (U_{H})^{-0.83}$$

The Table below gives the description of the parameter, its value and unit used for the computation of eddy feedback factor. The values for the SST, SST_{Eddy}, ML, ML_{Eddy}, and Γ were obtained from the Argo float data, while the translation speed were calculated from IMD data.

Table I. Value of the parameters, their unit and range used in the calculation of eddy feedback factor.

Parameter	**Unit**	**Range**
SST-26^{o}C	^{o}C	2.2-2.4
SST_{Eddy}-26^{o}C	^{o}C	1-1.2
Mixed layer Depth (Standard Ocean) (ML)	m	20
Mixed layer Depth (Eddy Ocean) (ML_{Eddy})	m	50
Storm size (η)	1	1
Relative Humidity (1-RH)	1	60-90%
Stratification below the Mixed layer (Γ)	$^{o}Cm^{-1}$	0.06
Translation speed (U_H)	ms^{-1}	1.63-5.41

The eddy feedback factor could be positive or negative; for example $F_{EDDY-} = +0.5$, indicatesan increase in the storm intensity by 50% due to the interaction with the warm ocean region, while a $F_{EDDY-} = -0.5$ indicates a decrease in storm intensity by 50% due to the interaction with cold ocean region (Wu et al., 2007).

The analysis showed that from 7th to 8th December when the system intensified from CS to VSCS and was passing through the warm patch associated with warm core eddy (see spatial maps of OHC at Fig.2 & positive SLA at Fig.3) the eddy feedback factor was positive and amounted to 59%. Thereafter, when the cyclone passed over the cold patch associated with cold core eddy during 9th and 10th December, the eddy feedback factor was negative and 69%. The figure below (Fig. C) pictorially represents the time evolution of the estimated central pressure (hpa) and maximum sustained surface wind (in knots) of the cyclone Madi along with eddy feedback factor.

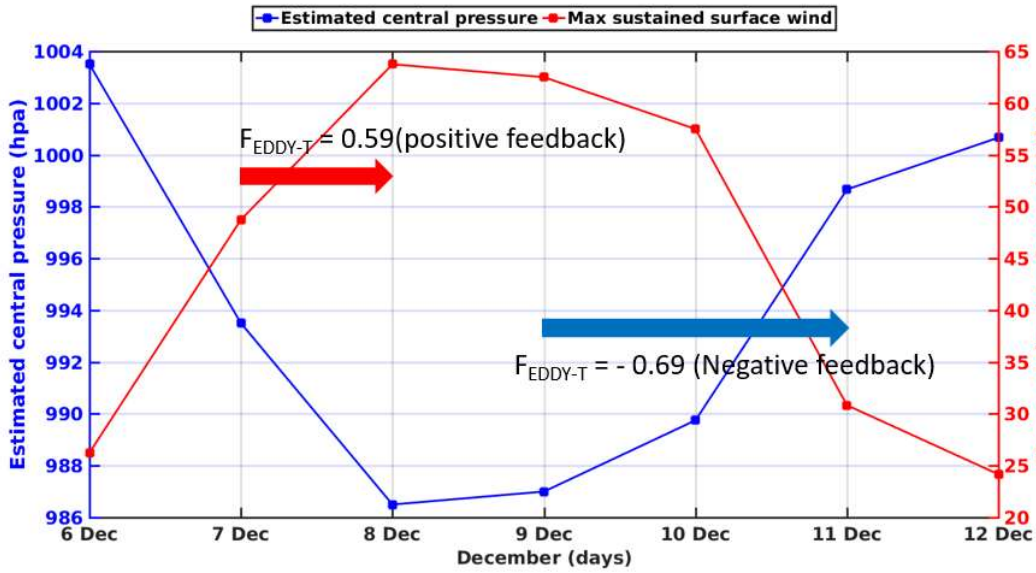

FIGURE B. Time evolution of the estimated central pressure (hpa) (blue solid line) and maximum sustained surface wind (knots) (red solid line) of the cyclone Madi. The red and blue horizontal solid arrows denote positive and negative eddy feedback factor respectively.

The present analysis quantifies the contribution of both warm and cold core eddies; when the cyclone Madi passed over the warm patch the system intensified from CS to VSCS and its translation speed increased (see Table 1), while when it passed over the cold patch from 9th to 10th the system slowed down and its northward movement was arrested as noted under the section 2.3.

A time-latitude plot of the OHC and TCHP with cyclone track superimposed on (Figure C) clearly shows that when the cyclone Madi reached its northern most position on 9th before its track reversal, it was moving over a region of small values of OHC as well as TCHP. We have already showed in the manuscript that these small values of OHC and TCHP were associated with cold-core cyclonic eddies.

Thus, based on the time evolution of (1) difference in SST showed from 6th to 14th December and (2) eddy feedback factor, our argument is that slow translation speed of Madi over cyclonic eddy can cause rapid weakening of tropical cyclone Madi when it stalled over a cyclonic eddy during 10th December. We infer that the 3-dimensional response of the cyclone Madi in terms of SST cooling was a significant factor in Madi's rapid weakening, as also suggested by the eddy feedback factor which showed that the contribution of cyclonic eddy in reducing the storm intensity was 69%.

We will include the above additional information with diagrams in the modified manuscript below line 184 of the previous version of the manuscript.

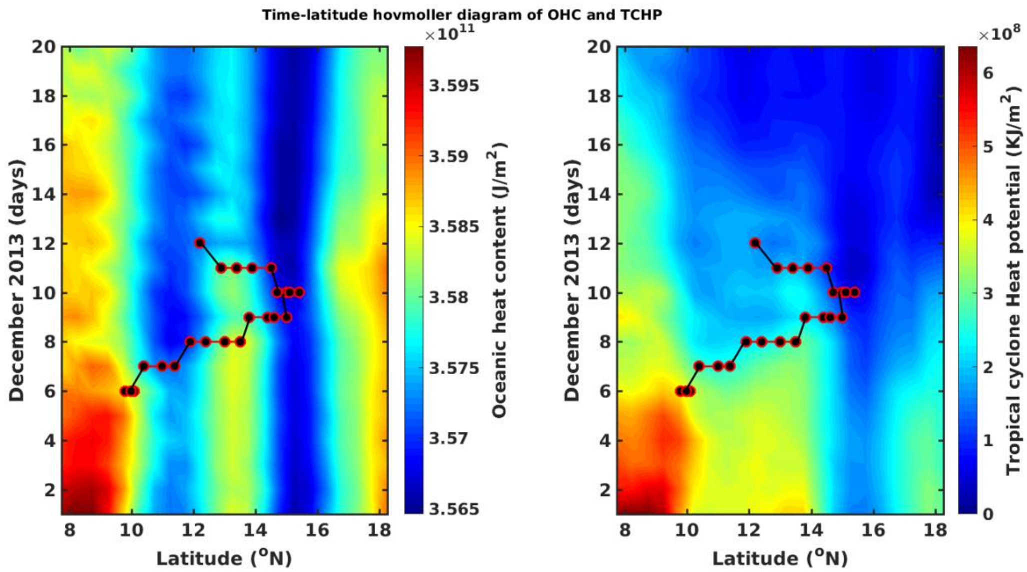

FIGURE C. Time-latitude plot of (left panel) oceanic heat content (J/m^2) and (right panel) tropical cyclone heat potential (KJ/m^2) with cyclone track superposed on it.

- **Referee's General Comment**

(2) On the effect of mesoscale eddy on TC intensity change. The authors just describedthe movement of TC Madi and relative position with respect to the eddies and thenconcluded the intensity change of Madi was dominated by the eddies. I do know theauthors show OHC change during the TC passage, but actually the key (oceanic)factor controlling TC intensity change is SST. At least, the time series of SST like figures 2-4 should be given to substantiate the eddy effect. Furthermore, the slow TCtranslation speed may induce large SST cooling and contribute to the weakening ofMadi.

Author's Response

We thank the reviewer for the suggestion and based on the suggestion we prepared the time evolution of SST maps (FIGURE D). We found that presenting the time evolution maps of difference of SST of 5th December (pre-cyclone SST) from each day starting from 6th December to 14th December, presented in Figure A under the "Author's Response to previous question, is more effective to bring out clearly the SST cooling . We also showed there that the translation speed of the tropical cyclone Madi reduced during 9th and 10th when the system was passing through the region of cold core cyclonic eddy. The excess cooling of 0.5^{o}C noticed in the eddy region lends support to the notion that the slow translation speed led to the further cooling of SST, which contributed to the weakening of the cyclone from VSCS to SCS.

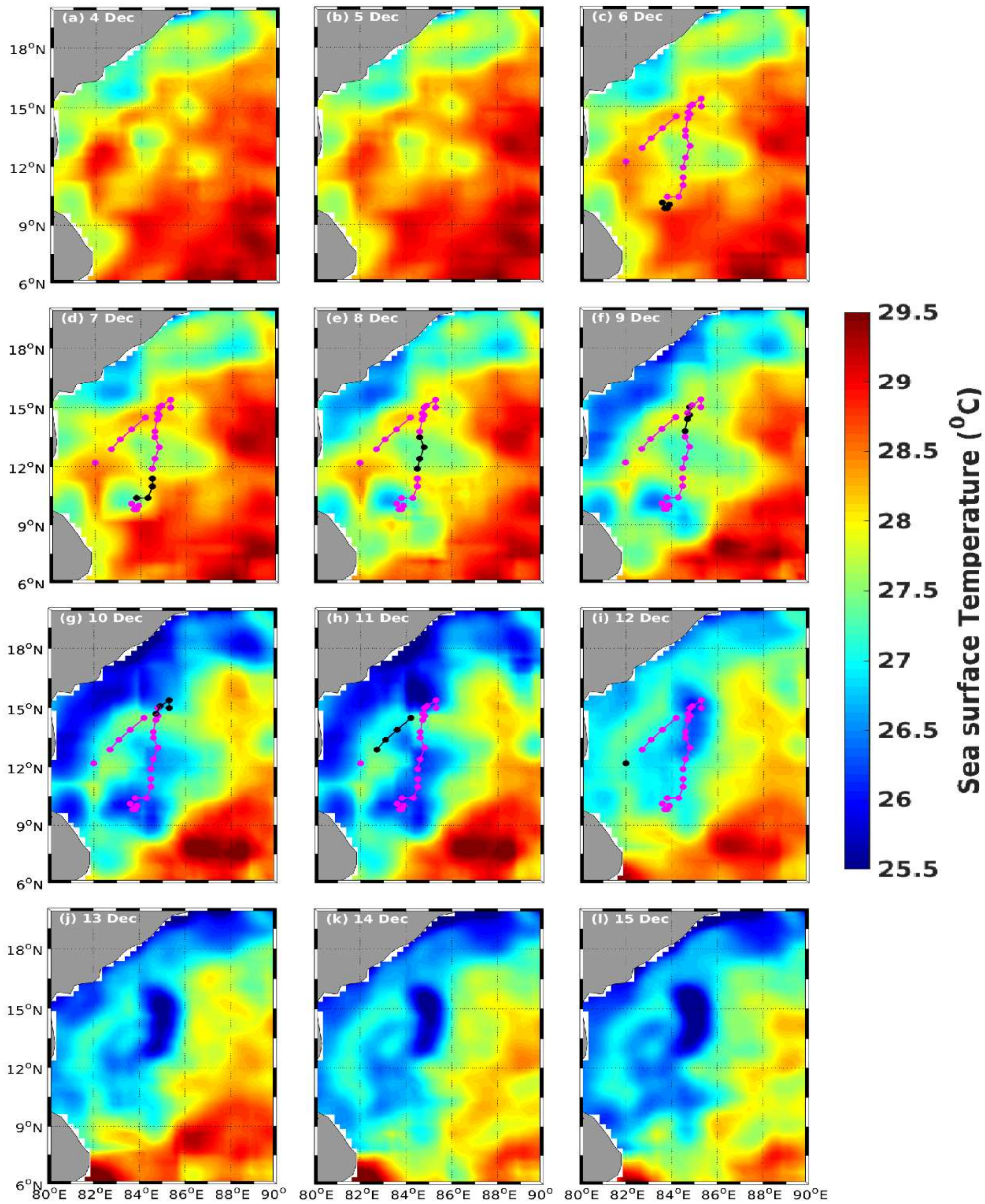

Figure D. Time evolution of Sea surface temperature (°C) from 4th to 15th December 2013 superimposed with track of cyclone indicated by black (current position) and magenta (entire track) colours.

- **Referee's General Comment**

(3) On the mechanism of SST and biogeochemical response. The authors concluded that the SST cooling and Cha increase was due to eddy-pumping of subsurface waters. However, there were clear subsurface temperature increase and Cha decrease in the thermocline in Fig. 11, indicating a non-negligible role of diapycnal mixing. This was

also consistent with results from many previous studies, i.e., the SST change was mainly due to diapycnal mixing (Price 1981).

Author's Response

We agree with the reviewer that diapycnal mixing is an important mechanism that redistributes the vertical properties of within the Ocean. The occurrence of subsurface temperature increase of 0.2 to 0.3°C is discussed under section 3.4 of the manuscript. This is associated with mild thermal inversion, which is commonly observed in Bay of Bengal in this time. As per the suggestion of the reviewer we will include the role of diapycnal mixing in the modified manuscript after line 261.

- **Referee's Specific Comment**

(1) line 67: the Unisys Weather does not give TC track information right now. Actually, the TC track information of Unisys Weather is originated from the Joint Typhoon Warning Center.

Author's Response

Thank you for point out this. We will modify and include this in the modified manuscript.

- **Referee's Specific Comment**

(2) line 80: The temperature profiles should be indicated to calculate OHC.

Author's Response

We clarify that we have not calculated the upper oceanic heat content (OHC), but the data has been taken from climate forecast system reanalysis (CFSR) of National Centre for Environmental Prediction (NCEP) climate forecast system (CFS) version 2 (http://www.ncep.noaa.gov) (Saha et a., (2014).The oceanic temperature data used for the calculation OHC as per equation 3 is from the ocean model GFDL MOM version 4 which is configured for the global ocean. The horizontal grid resolution of the OHC data in our study domain is 0.5 x 0.5 degree latitude by longitude. The value of Cp for a sea water salinity of 35 and temperature in the range of 30to 0oC is 4.0 kJ kg-1 K-1 (kindly note that the value given in the manuscript is 3.87 is not correct and we will rectify it by replace it with 4.0). We will include this and modify the line 80.

- **Referee's Specific Comment**

(3) line 123-124: Most people may be not familiar with the classification of intensity ofIMD. Please give the range of wind speed of different IMD categories or use the morepopularSaffir-Simpson scale.

Author's Response

As suggested by the reviewer we will provide the range of wind speed by adding a new column in Table 1

- **Referee's Specific Comment**

(4) line 149 & 150: Compared with the huge OHC of the ocean, the heat uptake by a TC was very small. The decrease of local OHC may be subject to the advection of TC induced strong currents.

Author's Response

We agree with the reviewer. We will add a couple of sentences to include this aspect after line 150.

- **Referee's Specific Comment**

(5) line 189 & 200: To examine the effect of vertical wind shear on TC, people mostly average the vertical wind shear azimuthally around the TC center, not the spatial map as in Fig. 5. Relatively, vertical wind shear of 10-15 m/s is not small and may compromise TC intensification.

Author's Response

We have calculated the vertical wind shear based on following formula (Balaji et al., 2018, Evan & Camergo 2011)

Vertical wind shear = $\sqrt{(U_{200hP} - U_{850hP})^2 + (V_{200hP} \quad V_{850h})^2}$

Winds at 850 and 200 hpa were used for the calculation of wind shear (Saha et al., 2014) (http://www.ncep.noaa.gov) by determining the difference in the magnitude of the vertical wind velocity between 200 and 850 hpa.

Vertical shear is one of the parameters that are examined to see if the atmosphere could support the formation of a cyclone. For example, a low vertical wind shear is usually congenial for cyclogenesis. Hence, we have used the time evolution of this parameter to assess the suitability of the atmosphere in the formation of cyclone Madi.

We will include the above information and modify the lines 87-88.

We agree that the wind shear of 10-15 m/s is not a small value and hence may impact the further development of cyclone. **We will include the following matter and modify lines 198-199.**

Where the cyclone Madi was formed the observed shear value was 5m/s, which is very low and represented a favourable condition for cyclogenesis. Subsequently, when the tropical cyclone Madi attains its maximum intensity, the shear value was between 5-10m/s. On 10th December when the intensity of Madi reduced from VSCS to SCS it was moving towards a region where shear was very high 10-15m/s. This relatively high value of shear is not congenial for the further development of the tropical cyclone.

Hence, the slow translation speed of Madi over cyclonic eddy can cause rapid weakening of tropical cyclone Madi when it stalled over a cyclonic eddy during 10th December. We infer that the 3-dimensional response of the cyclone Madi in terms of SST cooling was a significant factor in Madi's rapid weakening, as also suggested by the eddy feedback factor which showed that the contribution of cyclonic eddy in reducing the storm intensity was 69%. Further, the relatively strong vertical wind shear would add to negate the strengthening and further northward movement of cyclone.

Technical corrections Suggested by the Referee

(1) line 25: "occurred" should be "ever reported"

Author's response

We will correct it to "ever reported"

(2) line 153: delete the first "it"

Author's response

We will delete

(3) line 339: delete the second "and"

Author's response

We will delete the second "and" in line 339

(4) Line 875-883: The line number overlaying the figure legend is confusing.

Author's response

Thank you for the suggestion. We will rectify this.

References

Balaji M., Chakraborty, A., &Mandal, M. Changes in tropical cyclone activity in north Indian Ocean during satellite era (1981–2014), Int. J. Climatol. 2018;1–19

Evan, A.T &Camargo, S.J. (2011) A climatology of Arabian Sea cyclonic storms, J Clim 24:140-158, DOI: 10.1175/2010JCLI3611.1

Price, J.F., (1981). Upper Ocean Response to a Hurricane, J. Phys. Oceanography 11. 153-175.

Wu, C.-C., Lee, C-Y., &Lin,I.-I.(2007).The effect of the ocean eddy on tropical cyclone intensity, J. of the Atmospheric Sciences, 64, 3562-3578, DOI: 10.1175/JAS4051.1