RESPONSE TO REVIEWERS

Note: The reviewer's original comments are indicated in black, and our responses are indicated in blue. Figures in the manuscript are numbered and labeled using Arabic numerals, e.g., Figure 1; those in the response to reviewers file are numbered and labeled using Arabic numerals with a prefix "R", e. g. Figure R1.

Reviewer #2

Summary and Recommendation:

This study examines data from high resolution numerical simulations, focusing on the northeastern South China Sea which experiences internal tides propagating from their generation site at the Luzon Straits. A short period of just under 3 spring-neap tidal cycles is considered, and the internal tide energy fluxes are compared between two periods 2 weeks apart, one of which includes an anticyclonic mesoscale eddy, while the other has no eddy. This comparison reveals that there is a net transfer of energy from the internal tides to the eddy (at least when only the first 3 modes are considered) and that the eddy facilitates topographic conversion from mode 1 to higher modes. The role of the eddy in refracting the internal tide energy flux is also considered, and in affecting changes in reflection at the continental slope. Overall, while this manuscript examines only one instance of internal tide/mesoscale eddy interaction, there are nonetheless many interesting results. However, I recommend some more effort to explain the causes of some of the behavior, and more connection made between the different changes identified.

Responses: We thank the reviewer very much for his/her constructive comments. These comments are valuable and helpful for improving our manuscript, and accordingly we have made extensive revisions to our manuscript to make our results convincing. Detailed corrections are listed below.

Significant suggestions:

1. Energy transfer from internal tide to eddy, v. inter-modal energy transfer.

From eqn 1, the authors have identified a net energy transfer from the internal tide to the eddy. However, it would be of interest to know whether this is manifest in an increase in eddy energy, or whether there a subsequent energy transfer from the eddy to higher internal tide modes. Can you separately diagnose the net mode-mode transfer, as in https://doi.org/10.1175/JPO-D-23-0045.1? Or can you track the eddy energy tendency - does the eddy energy in fact increase due to the internal tide energy transfer?

Responses: We understand the reviewer's concern. We examine the eddy kinetic energy (EKE) and its tendency along the eddy trajectory in Figure R1:

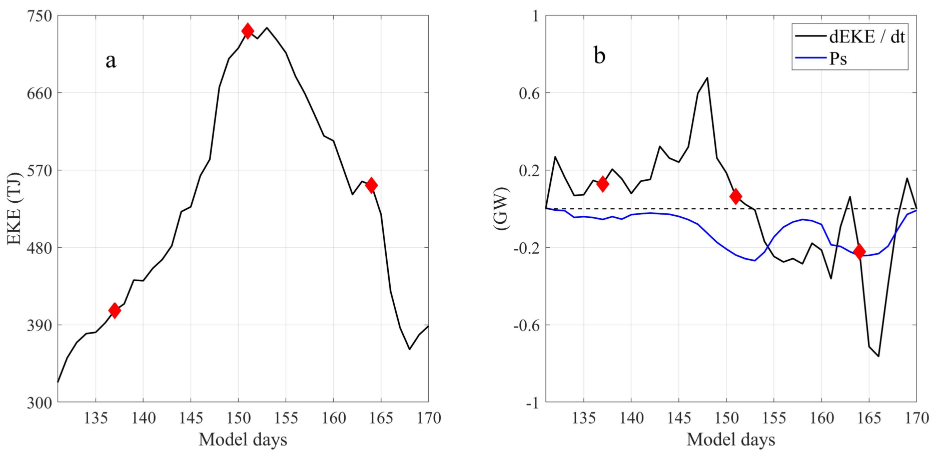

Figure R1 (a) The time variation of EKE, the red squares represent the days 137, 151, and 164. (b) The black line represents the tendency of EKE, and the blue line represents the change in shear production term (Ps). Note that negative Ps indicates energy transfer from internal wave field to eddy field.

Figure R1a shows that the EKE increases firstly and then decreases, with its maximum value on day 151. This indicates that before day 151, the eddy continuously gains energy from other motions, and then gradually loses energy and dissipates afterwards. From Figure R1b, we can also find that the tendency of the EKE is positive before day 151, corresponding to its energy growth phase. Afterward, it becomes mainly negative, corresponding to its energy decay phase. During the whole period (40 days), most values of the shear production term (Ps) are negative, indicating that internal tides continuously transfer energy to the eddy field. It seems like there being a contradiction that both Ps and dEKE/dt are negative during the last 20 days. We think this may be due to other dynamic motions in the northern SCS such as Kuroshio intrusion, submesoscale motions and internal waves at various frequency bands, which contribute to variations in EKE along with SIT-to-eddy conversion discussed here accounting for a fraction of total energetics. It was also reported that EKE tendency in the northern SCS could involve advection effect by large-scale mean flow as well as barotropic/baroclinic instability processes (Liu et al., 2022, Figure R2).

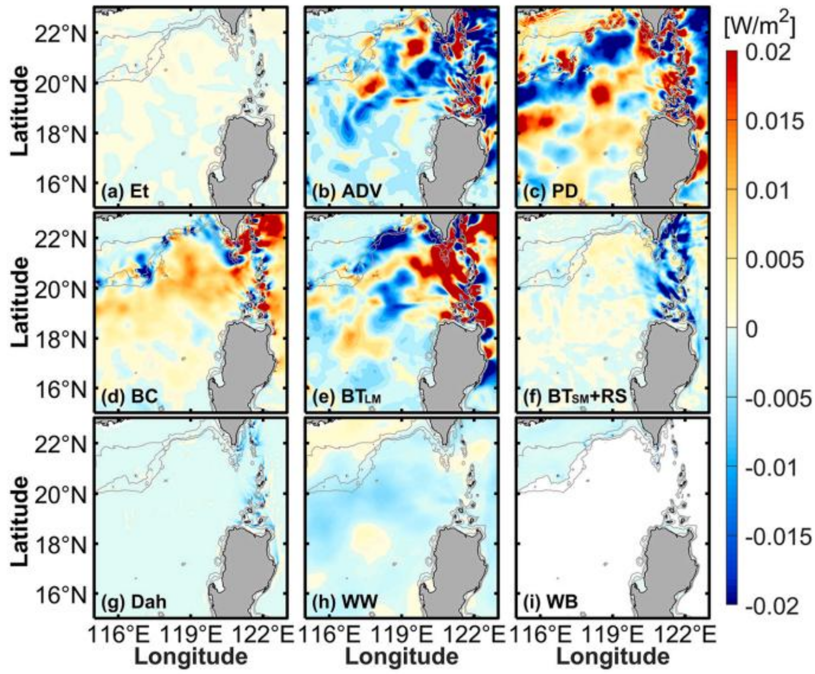

Figure R2 Cited from Liu et al. (2022). The tendency of EKE (Et), the advection of EKE by large-scale circulation (ADV), the perturbation pressure work divergence (PD), the energy conversion between EKE and eddy available potential energy through baroclinic instability (BC), the energy conversion between large-scale and mesoscale kinetic energy through barotropic instability (BT_{LM}), the energy conversion between mesoscale and s mesoscale kinetic energy through barotropic instability (BT_{SM} term), the interaction between mesoscale and submesoscale processes (RS term), the EKE dissipation caused by horizontal eddy viscosity (Dah term), the wind stress work (WW term), the friction work at the sea bottom (WB term).

Reference:

Liu, Y., Zhang, X., Sun, Z., Zhang, Z., Sasaki, H., Zhao, W., and Tian, J. (2022). Region-dependent eddy kinetic energy budget in the northeastern South China Sea revealed by submesoscale-permitting simulations. Journal of Marine Systems, 235, 103797.

2. Energy flux arrows

It would be very helpful to see arrows showing the energy flux in the figures 2a-c, 3a-c, and 4a-c. Which direction is the internal tide energy coming from? For example, is mode 1 predominantly coming from the Luzon Straits, while mode 3 is coming from the local continental slope, due to the topographic conversion from mode 1 to 3?

Responses: We understand the reviewer's concern. As the reviewer suggested, we add arrows showing the SITs' energy fluxes to Figures 2-4. The Figures R3-R5 show that mode-1 SITs are generated from the Luzon Strait and propagate toward the northern SCS, the mode-2 SITs are similar to mode 1, which propagates mainly westward from the Luzon Strait. However, mode 3 is generated mainly near the continental slope in the northern SCS and propagates southward.

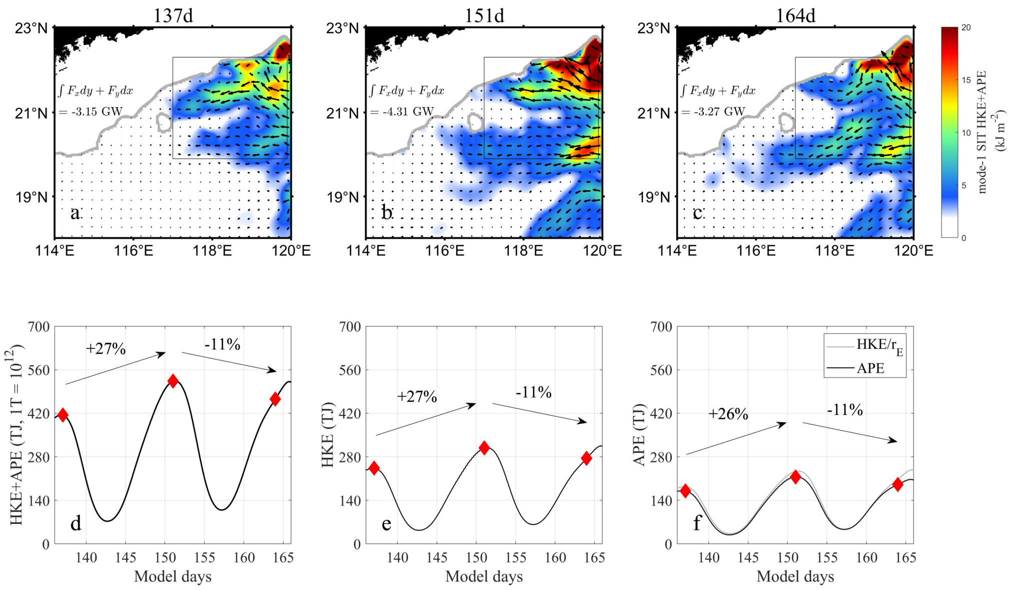

Figure R3 (a-c) Spatial distribution of mode-1 SIT energy on days 137, 151, and 164. Black arrows represent energy flux, and grey contours represent the depth of 250 m. (d-f) Time series of TE, HKE, and APE obtained from area integral over the region R2, with the red diamonds corresponding to days 137, 151, and 164, respectively. The grey curve in (f) is calculated using Eq. (2).

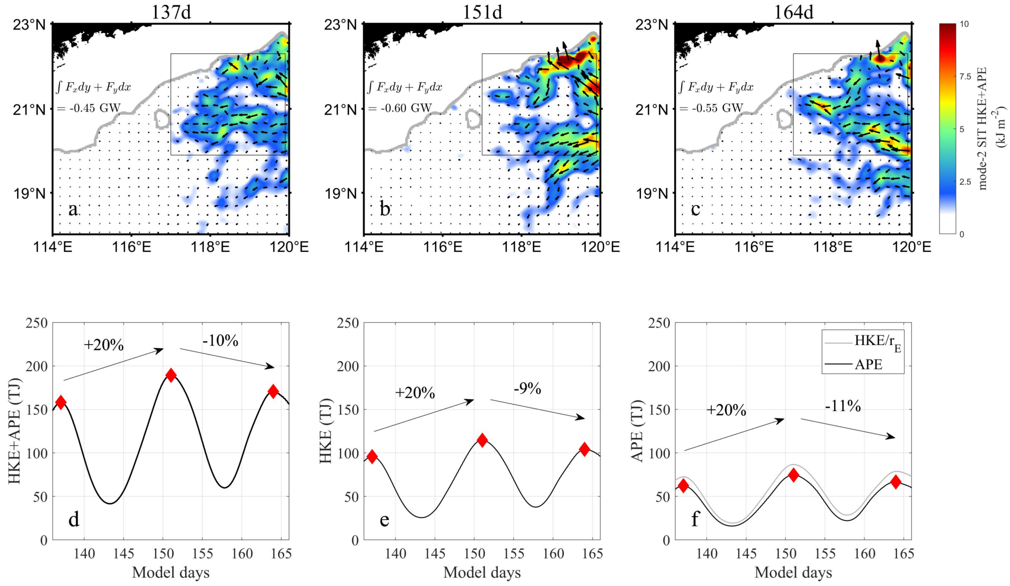

Figure R4 Same as Figure R3, but for mode-2 SIT.

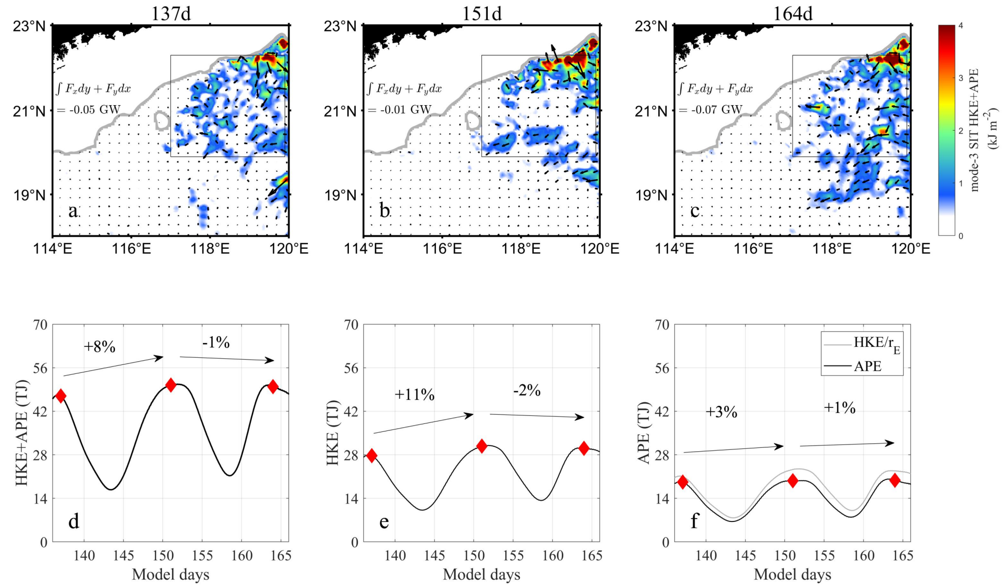

Figure R5 Same as Figure R3, but for mode-3 SIT.

3. How does the presence of the eddy contribute to the enhanced topographic scattering from mode 1 to higher modes?

Can we connect the enhanced topographic scattering in figures 5 and 6 to the influence of the eddy on the mode 1 propagation shown in figure 14? Does the redirection of the mode 1 toward the slope lead to the increase topographic energy conversion from mode 1 to higher modes?

Responses: We thank the reviewer for this valuable comment, which gives us ideas to explore the modal enhancement of the higher-mode SITs. The onshore energy flux for the first five modes crossing the red line in Figure R6 and Figure R7 are calculated by integrating flux values along the section (red line). For mode 1, the onshore flux is 3.19 GW and the offshore value is 1.06 GW on day 137, resulting in a reflection of 33%. On day 151, the onshore energy flux is 5.22 GW and the offshore value is 1.52 GW, with a reflection of 29%, decreasing by 4%. For mode 2, the onshore energy flux is 0.31 GW and offshore value is 0.10 GW on day 137, with a reflection of 32%. On day 151, the onshore energy flux is 0.70 GW and off shore value is 0.31 GW, with a reflection of 44%. The onshore energy flux for modes 3-5 on day 137 are 0.03 GW, 0.01 GW, and 0.01 GW, respectively, while the onshore values on day 151 changed to 0.08 GW, 0.02 GW, and 0.01 GW. As a result, we inferred that the increased higher modal SIT energy flux on the continental slope came from the mode-1 SIT (mode-1 SIT had a reduced reflection on day 151), which may be due to transmission of the mode-1 SIT as it passes the subcritical continental slope, transferring energy from the lower mode to the higher modes. It can be checked by Figure R7 that modes 3-5 have the remarkable energy flux vectors between the critical topography ($\gamma = 1$ magenta curve) and the 2000 m isobath. It is also reported that the low-modal internal tides passing through the subcritical continental slope topography are more susceptible to transmission (Hall et al, 2013; Wang et al., 2018 and 2019), consistent with our results.

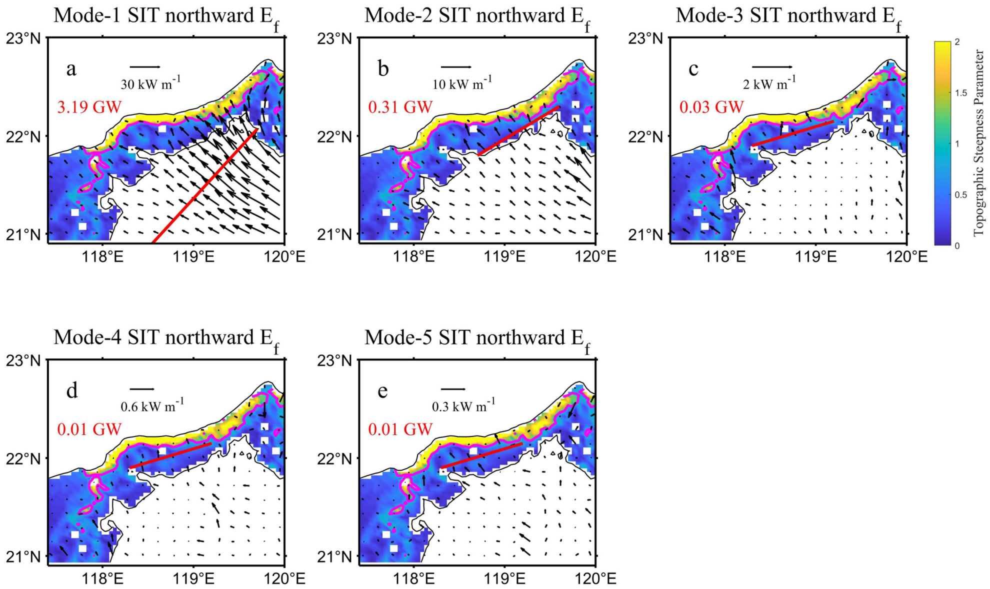

Figure R6 Spatial distribution of the northward component (incident wave) of the energy flux (arrows) for the first five SITs modes on day 137, superimposed on the contour map of topographic steepness parameters from 250 to 2000 m, with magenta contour for $\gamma = 1$. The red values in the upper left are calculated by integrating energy flux along the section (red line).

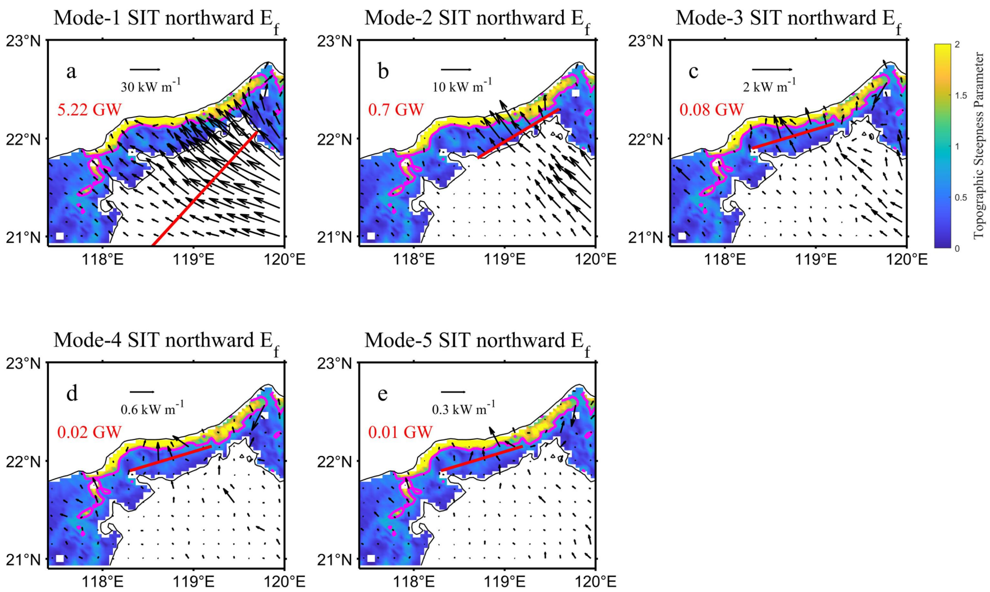

Figure R7 Same as Figure R6, but for day 151.

References:

Hall, R. A., Huthnance, J. M., and Williams, R. G. (2013). Internal wave reflection on shelf slopes with depth-varying stratification. Journal of Physical Oceanography, 43(2), 248-258.

Wang, S., Chen, X., Li, Q., Wang, J., Meng, J., and Zhao, M. (2018). Scattering of low-mode internal tides at different shaped continental shelves. Continental Shelf Research, 169, 17-24.

Wang, S., Chen, X., Wang, J., Li, Q., Meng, J., and Xu Y. (2019). Scattering of low-mode internal tides at a continental shelf. Journal of Physical Oceanography, 49(2), 453-468.

4. Reflection at continental slope - mode 1

In section 3.2.1 the impact of the eddy on the reflection of mode 2 is examined. However, mode 1 is not mentioned here - why not? It would be interesting to know whether the increased topographic conversion from mode 1 to higher modes in the presence of the eddy also leads to reduced reflection of mode 1.

Responses: We thank the reviewer for the valuable suggestion. As the reviewer suggested, we applied the decomposition method of incident and reflected waves to mode-1 SIT and got the map of energy flux in Figure R8. This figure shows that the energy reflection also occurs in the first mode as the mode 1 SIT passes over the continental slope. The reflection of mode 1 influenced by eddy on day 151 is slightly smaller than that without eddy influence on day 137, implying that mesoscale eddy contributes to the reduced reflection of mode 1 SIT. Meanwhile, this suggests that the energy of mode-1 SIT is partially involved in the generation of the higher-mode SITs.

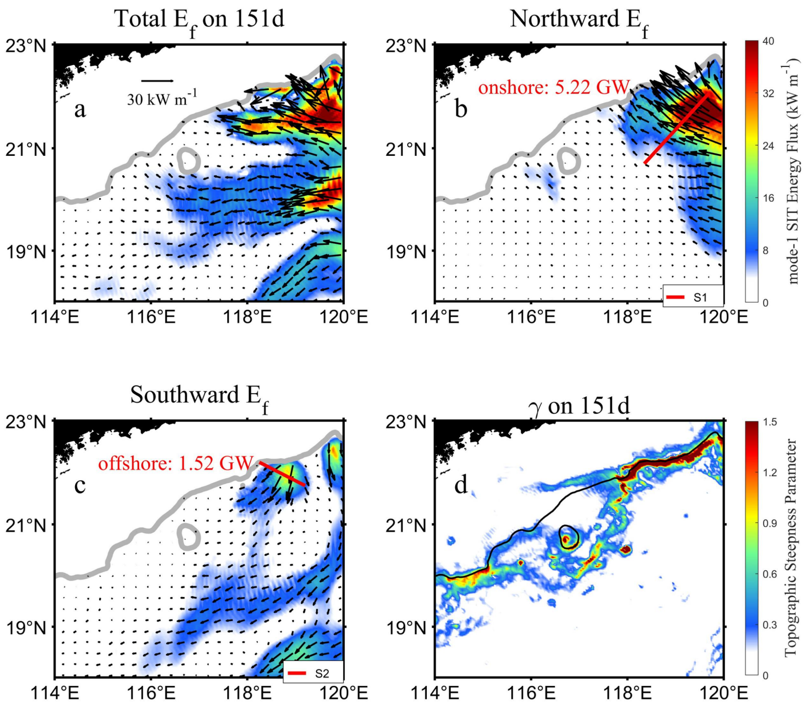

Figure R8 The energy flux of mode-1 SIT on day 151 in (a), (b), and (c) for total, northward, and southward, respectively. The energy fluxes integrated along sections S1 and S2 are labelled as onshore and offshore values, respectively. The topographic steepness parameter for SIT on day 151 is presented in (d).

5. Reasons for enhanced reflection of mode 2

While the authors have shown that the eddy leads to enhanced reflection of mode 2 at the slope, I don't see much explanation of this change - how does the eddy influence this enhanced reflection? Is it due to the refraction of the internal tide toward the slope? Or is it due to the changes in stratification structure induced by the eddy influencing the slope criticality?

Responses: We are sorry for this information gap. We show the rose diagram and topographic steepness parameter of the mode-2 SIT energy flux in Figure R9.

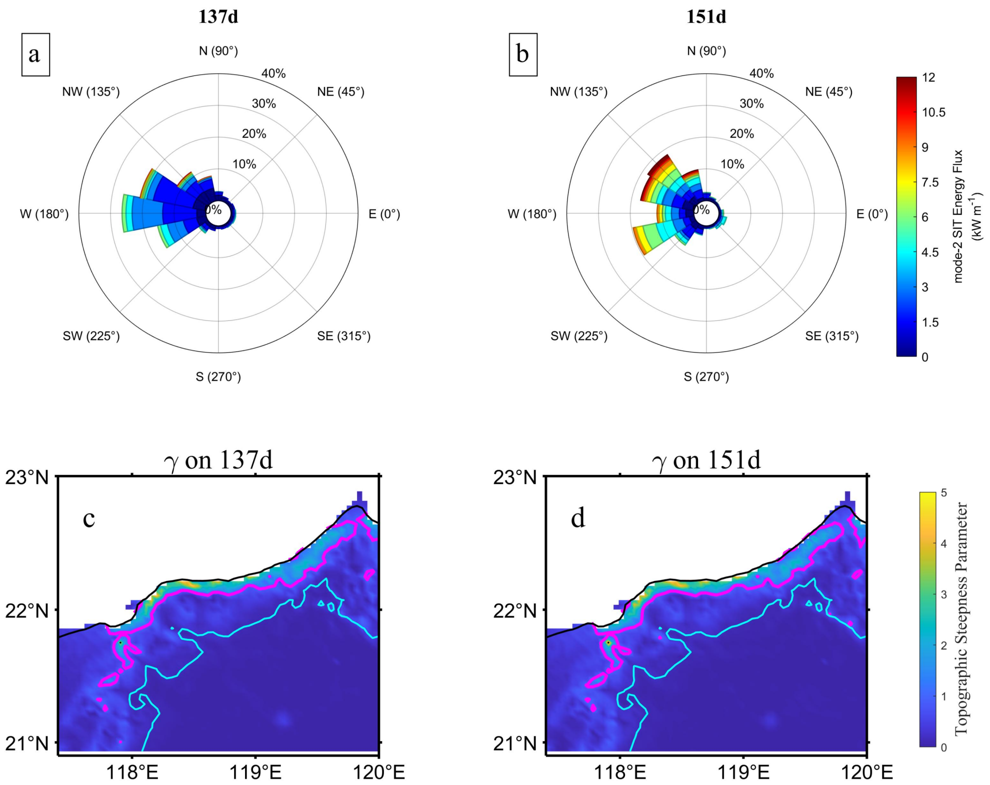

Figure R9 (a-b) The rose diagrams for the mode-2 SIT on days 137 and 151, respectively, the selected calculated region is (119-120° E, 19.9-22.3° N). (c-d) The topographic steepness parameter for days 137 and 151, respectively, magenta line for $\gamma = 1$ and cyan line for the 2000 m isobath.

From Figure R9(a-b), it can be clearly seen that the eddy has a significant impact on the propagation direction of the mode-2 SIT. On day 137, the mode-2 SIT mainly propagates toward west (180°) and west-northwest (157.5°). It is generally parallel to the critical topography (magenta curve) with a nearly east-west orientation around 119°E. Therefore, the topographic reflection was suppressed due to the angle of the incident waves on day 137. In contrast, on day 151, the mode-2 SIT is deflected by eddy towards the continental slope, and its propagation direction changes to northwest (135°) and west-northwest (157.5°). The angle between its propagation direction and critical topography (magenta curve) increases, which facilitates the reflection of mode-2 SIT. By comparing the topographic steepness parameters on days 137 and

151 (Figure R9c-d), we find that their differences are slight (the magenta curves in these two panels are almost identical), suggesting that the increase in reflection is due to the change of incident angle caused by refraction of the mode-2 SIT due to eddy. We added the related text to the revision.

Minor comments:

6. Abstract, line 13-14: The rate at which energy is transferred from the internal tide to the eddy is given here. To know how significant this is, what is this transfer rate as a percentage of the incoming energy flux integrated over the eddy diameter/height?

Responses: We understand the reviewer's concern. Seen from Figure R3b-R5b, it is found that the internal tidal energy of the first three modes in the region R2 is 4.92 GW, and the energy transferred from SIT to eddy in this region is approximately 0.33 GW, leading a transfer rate of 7%. However, the SIT in the region R2 varies with time significantly. For example, the internal tidal energy of first three modes is 3.65 GW on day 137, we worried that using a transfer rate may not be universal.

7. Introduction, line 25: delete "and so on", since it does not provide any additional information.

Responses: We thank the reviewer. We made this revision.

8. Line 33: More correctly, it is not the dissipation which affects the overturning circulation, but rather the mixing that may be induced by the loss of energy from internal tides.

Responses: We are sorry for this confusion. Yes, the circulation could be shaped by the mixing which could transform the water masses and modulate density distribution. In the revision, we made this correction.

9. Line 37: "a hotspot" - a hotspot of what?

Responses: We would like to refer to a hotspot of studying multiscale dynamical motions.

10. Line 41-42: If transfer of energy from the mesoscale eddy to the internal wave field induces a viscous effect, this would be a viscous effect on the eddy circulation, not on the internal wave field (which increases in energy in this statement). So it's doubtful that an eddy viscosity can be used to parameterize this effect in an internal tide prediction model.

Responses: The reviewer is right. We removed this paragraph for improving the readability of the whole manuscript.

11. Line 51 and elsewhere: Change "inner-modal redistribution" to "inter-modal redistribution" (it is a redistribution between modes).

Responses: We understand the reviewer's concern and make this revision.

12. Figure 7, caption: Change "but for the advection term of the velocity component.." to "but for the velocity component of the advection term..."

Responses: We thank the reviewer. We made this revision.

13. Figure 8, caption: Change "but for the advection term of the pressure component.." to "but for the pressure component of the advection term.."

Responses: We thank the reviewer. We made this revision.

14. Lines 317-325: There is some repetition here. For example line 322-323 closely repeats line 317-318.

Responses: We thank the reviewer. We removed repetitions and merged some sentences in the revised manuscript.

15. Line 334-335, and elsewhere: "near-filed" and "far-filed" should be "near-field" and "far-field".

Responses: We are sorry for this typo, the word has been corrected.

16. P18, lines 362-368: Too much space is given here to showing that the stratification changes alone have little impact on the ray propagation. I think you could combine figures 13 and 14 and focus on discussing the more significant impact of the eddy flow field.

Responses: We understand the reviewer's concern. As the reviewer suggested, the manuscript was revised with focusing on the analysis of eddy flow field.