<u>Response to Reviewer 1:</u>

General comments

The article presents novel numerical results describing the adjustment of a mode-2 ISW due to a background shear flow. The authors vary the center of the background shear and measure the amount of energy lost from the ISW. The authors attempt to demonstrate that this energy is radiated into three different types of waves: a leading mode-1 wave, an oscillating tail, and an amplitude-modulated wave packet. Comparison to the work of Shroyer et al. (2010) is made throughout.

The paper is well structured and contains new results that are applicable to a wide audience. However, substantial work is required to bring the paper up to an international standard. For example, there is missing literature review on mode-1 ISWs in back- ground currents and wave-mean flow interaction, various quantities are not carefully defined, and five cases do not suggest a fully developed study. Detailed suggestions and questions are below. I would like to see the article published, but the authors must address the following concerns.

Response:

Thank you very much for your constructive and helpful comments, which were extremely helpful in improving the manuscript. We have carefully read the comments and made substantial revisions accordingly as detailed in the following responses to specific questions. The NPG Language Editing service was contracted to review and polish the revised manuscript before submission. The main revisions are highlighted in the manuscript.

Question 1

There are no references to similar studies of mode-1 ISWs in shear flow. Comparisons to lower mode internal waves should be made to better position this article within the literature. Suggestions include: Stastna and Lamb (2002), and Lamb (2010).

Response:

In response to the reviewer's helpful comments, references related to mode-1 ISWs in shear flow have been added and discussed in the revision. Particularly, we have used the same method as that in *Lamb* (2010) to calculate the ISW energy in the presence of the background current. Some analysis methods in *Stastna and Lamb* (2002) are also used in the present study to investigate the variation of mode-2 wave properties in background shear current.

The related descriptions were added to the revision as follows (see also Page 2, Line 27 – Page 3, Line 4 in the main text):

"*The evolution of mode-1 ISWs in background shear current was extensively studied (Stastna and Lamb, 2002, Lamb, 2010, Grimshaw* et al.*, 2005, Fructus* et al.*, 2009). Lamb (2010) investigated the energetics of mode-1 ISWs in a background shear current, providing some methods commonly used to calculate the energy under that circumstance. Stastna and Lamb (2002) considered the effects of background current on mode-1 ISWs and discussed the properties of ISWs during the breaking process. In comparison, few works on mode-2 ISW in shear flow have been produced.*"

Question 2

Other than Shroyer et al. (2010), what other references exist for mode-2 ISWs in background currents? Are there none? That seems surprising.

Response:

Accordingly, the studies of mode-2 ISWs in the background current have been reviewed and summarized. Because of the difficulty to capture both the mode-2 waves and low-frequency background flows, to our knowledge, *Shroyer* et al. (2010)'s study is the sole one with the observational evidence based on which we can numerically examine the integrated evolution process of mode-2 ISWs in the background shear current.

The related descriptions were added to the revision as follows (see also Page 3, Lines

6 – 9 ; Page 3, Lines 19 – 21 in the main text):

"*Vlasenko* et al. *(2010) observed mode-2 ISW followed by mode-1 ISW in tidal flow in the South China Sea. Liu* et al. *(2013) investigated the generation and evolution of mode-2 ISW in the South China Sea and concluded that the mode-2 ISW might not propagate, evolve and persist for long time on the shelf.*"

"*Shroyer* et al. *(2010) is the sole one recording an integrated evolution process of mode-2 ISW in the background shear current, based on which we can numerically examine the modulation of mode-2 ISW in that circumstance.*"

Question 3

What predictions does theory make? Do the author's results match those of weakly nonlinear theory? It appears that KdV theory will apply and much can be learned by using standard techniques of KdV theory.

Response:

The initial properties of mode-2 ISW without the presence of a background shear current in our study is consistent with the prediction by KdV (Korteweg-de Vries) theory (Figure 1) (*Grimshaw* et al., 2007). As introduced by *Maderich* et al (2010), the weakly nonlinear KdV theory is suitable for slowly varying background conditions, but the intensive evolution process is not expected in the KdV framework, and as a result, a numerical modal approach is needed (*Grimshaw* et al., 2010; *Terletkska* et al., 2016; *Yuan* et al., 2018). The recent work by *Yuan* et al., (2018) observed the existence of a long mode-1 wave ahead of the mode-2 ISW during the evolution of mode-2 ISW over variable topography and found that this process cannot be characterized by KdV theory. Therefore, in the present study, we use the full-nonlinear and nonhydrostatic MITgcm model to examine the integrated evolution process of mode-2 ISW in the background shear current.

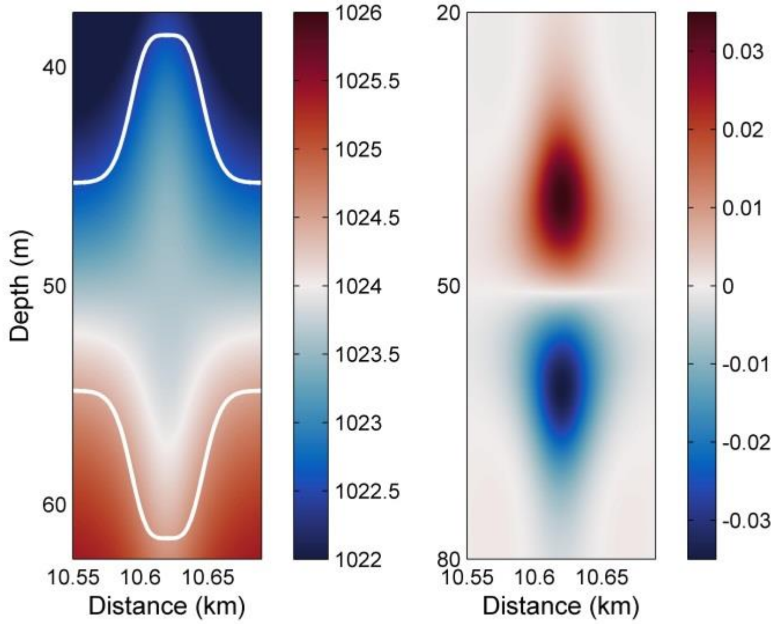

Figure 1. The characteristics of a single mode-2 ISW's (a) density field (1022 kg m^{-3} – 1026 kg m^{-3}) and (b) vorticity (-0.035 s^{-1} – 0.035 s^{-1}) in the absence of background shear current. The white lines in (a) demonstrate the theoretical solution of mode-2 ISW in KdV framework.

The related descriptions were added to the revision as follows (see also Page 2, Lines 19 – 23 in the main text):

"*Yuan* et al. *(2018) observed the existence of a long mode-1 wave ahead of mode-2 ISW during the evolution of mode-2 ISW over variable topography and found that this process cannot be characterized by KdV theory. The authors suggested using the MITgcm model, which can solve all modes to investigate the integrated evolution process of mode-2 ISWs in variable background conditions.*"

Question 4

Do five cases provide sufficient information to make generalized claims about ISWs in shear flow? For comparison, Maderich et al. (2017) ran 35 cases of collisions of internal waves.

Response:

Thank you for the constructive suggestion. Accordingly, several important factors were investigated to generalize our research in the literature, including the magnitude, thickness of shear layer, direction and symmetric offset of background shear current. The detailed configuration of the numerical simulation is given in Table 1.

Table 1. Summary of parameters of variable background shear currents. The depth and thickness of the pycnocline are denoted by z_0 and *h*. The thickness and depth of the shear layer are denoted by h_s and D_s. The magnitude of the shear current is denoted by U_d. The *Por* indicates the polarity of the background shear current, and "+" means the polarity-reversal shear current. The orientation of the background shear current is indicated by *Ori*, and "+" means an opposing shear current.

Case	z_0	h	h_s	D_s	U_d	Por	Ori
O1	50	10	3	40	0.22	(-)	(-)
O2	50	10	3	42.5	0.22	(-)	(-)
O3	50	10	3	45	0.22	(-)	(-)
O4	50	10	3	47.5	0.22	(-)	(-)
O5	50	10	3	50	0.22	(-)	(-)
O6	50	10	3	52.5	0.22	(-)	(-)
O7	50	10	3	55	0.22	(-)	(-)
O8	50	10	3	57.5	0.22	(-)	(-)
O9	50	10	3	60	0.22	(-)	(-)
H1	50	10	1.5	50	0.22	(-)	(-)
H2 (O5)	50	10	3	50	0.22	(-)	(-)
H3	50	10	4.5	50	0.22	(-)	(-)
H4	50	10	6	50	0.22	(-)	(-)
H5	50	10	7.5	50	0.22	(-)	(-)
U1	50	10	3	50	0.11	(-)	(-)
U2 (O5)	50	10	3	50	0.22	(-)	(-)
U3	50	10	3	50	0.33	(-)	(-)
U4	50	10	3	50	0.44	(-)	(-)

U5	50	10	3	50	0.55	(-)	(-)
D1	50	10	3	50	0.22	(-)	(+)
P1	50	10	3	50	0.22	(+)	(-)

The related descriptions were added to the revision as follows (see also Lines Page 3, Lines 26 – 30; Page 5, Lines 10 – 15 in the main text):

"*To reveal the sensitivity of the evolution of mode-2 ISWs to variable parameters of background shear currents, we introduced five sets of experiments (19 experiments in total) to generalize our research, including the magnitude, thickness of the shear layer, direction and symmetric offset of the background shear current.*"

"In the sensitive experiments, the magnitude of the shear current is denoted by U_d and defined as $|\Delta U|$. This value was varied from 0.5U_d to 2.5 U_d in the sensitivity test. Similarly, the thickness of the shear layer was varied from 0.5 h_s to 2.5 h_s. In cases D1 and P1, an opposing and polarity-reversal background shear currents were initialized for examination, respectively. We introduced an asymmetry parameter Δ to investigate the evolution of mode-2 ISWs in the offset background shear current (Carpenter et al., *2010).*"

Question 5

How were the values of the shear chosen? Were they chosen to match flow on the New Jersey shelf? What would happen if the shear was varied in terms of magnitude, or was oriented against the ISW (such that U1 and/or U2 were positive). What about shifting the shear upwards rather than down? What about hs compared to h? Please add some of these cases into the article. Further motivation for the values is required.

Response:

In the case O5, which was taken as a control experiment, the values of background shear current were chosen to match the observations in the New Jersey Shelf (*Shroyer* et al., 2010). The evolution process and calculated energy loss rate for the control experiment were in relative agreement with the field observations.

According to the reviewer's suggestions in questions 4 and 5, we have run more sensitive experiments in the revision (14 additional experiments in total). The main results include the following:

Orientation

The background shear current oriented against the mode-2 ISW only slightly affects the amplitude of the forward-propagating long wave and oscillating tail but significantly influences the amplitude of the amplitude-modulated wave packet. The opposing background shear current slightly increased the energy loss of mode-2 ISW during the modulation.

Magnitude of the shear

The amplitudes of the forward-propagating long wave and amplitude-modulated wave packet are positively proportional to the magnitude of the background shear current, but the oscillating tail is not very sensitive to the increasing magnitude of the background shear current (Figure 2 (a)). The energy losses of mode-2 ISW are also positively proportional to the magnitude of the background shear current (Figure 3 (a)).

Thickness of the shear layer

The amplitudes of all three shear-induced wave structures are negatively proportional to the thickness of the shear layer (Figure 2 (b)). The energy losses of mode-2 ISW are also negatively proportional to the thickness of the shear layer (Figure 3 (b)).

Offset upward

When the shear current is offset upward, the variation of the oscillating tail and amplitude-modulated wave packet in amplitude show similar trends to the downward offset cases (Figure 2 (c) and (d)), but the forward-propagating long wave is still insensitive to the offset direction of the shear current (Figure 2 (c) and (d)). The energy losses of mode-2 ISW are also negatively proportional to the asymmetry parameter Δ in both upward and downward conditions (Figure 3(c) and (d)).

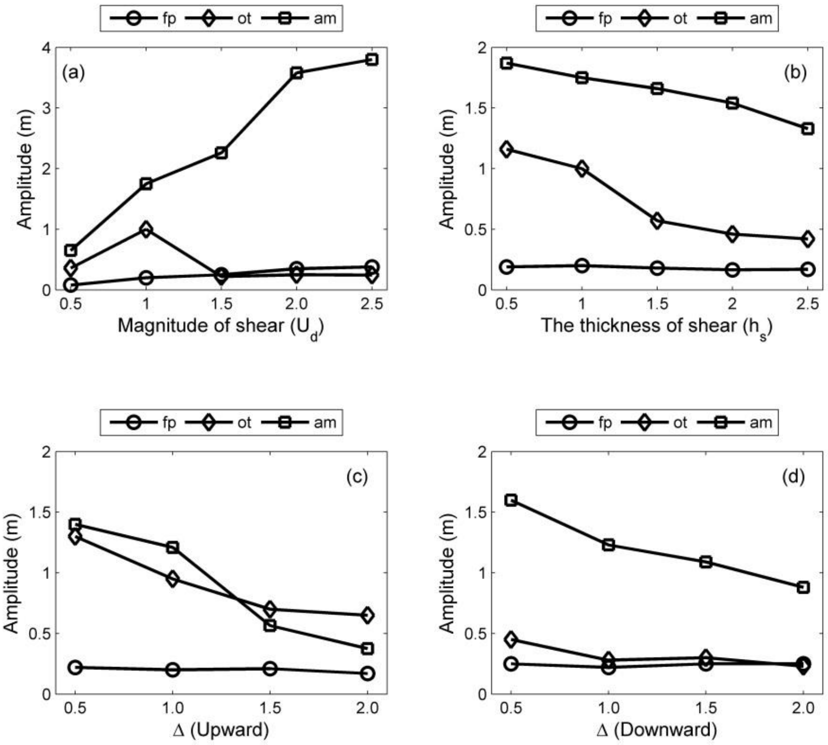

Figure 2. The summarized results of the amplitudes of the forward-propagating long wave (denoted by 'fp'), oscillating tail (denoted by 'ot') and amplitude-modulated wave packet (denoted by 'am') with the presence of (a) varied magnitude of shear currents at 40 T, (b) varied thickness of shear currents at 40 T, (c) upward offset background shear currents at 30 T and (d) downward offset background shear currents at 30 T.

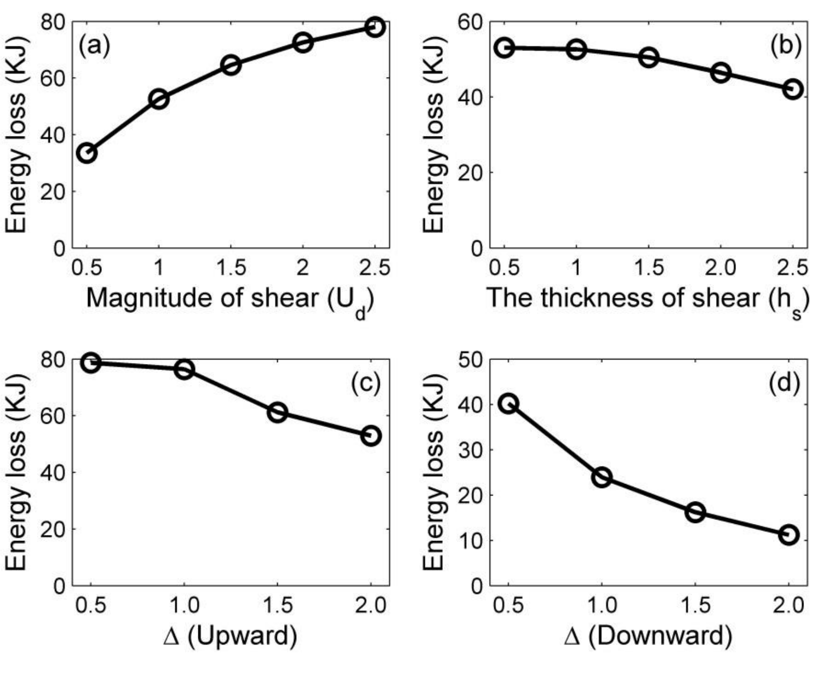

Figure 3. The summarized results of the energy loss of the mode-2 ISW at 30 T with the presence of (a) varied magnitude of shear currents, (b) varied thickness of shear currents, (c) upward offset background shear currents and (d) downward offset background shear currents.

The related descriptions were added to the revision as follows (see also Page 4， Lines 23 – 24; Page 11, Line 17 – Page 12, Line 5; Page 12, Lines 13- 21; Page 12 Line 22 – Page 13, Line 4; Page 15, Lines 1 – 6; Page 15, Lines 9 – 18; Page 15, Line 27 – Page 16, Line 3; Page 21, Lines 16 – 27 in the main text):

"*The choice of background density stratification in all experiments and the shear current in the control experiment (case O5) followed the field observation over the New Jersey Shelf (Shroyer* et al.*, 2010).*"

"*In case D1, the background shear current oriented against the mode-2 ISW. The general pattern of the forward-propagating long wave, oscillating tail and amplitude-modulated wave packet were similar to those in the control experiment. In this opposing case D1, the amplitude of the forward-propagating long wave and oscillating tail were not significantly affected. For the mode-2 ISW, its amplitude also remains nearly unchanged between the following (controlled experiment) and opposing cases, while the amplitude-modulated wave packet's amplitude* decreased *from 1.85 m (control experiment) to 1.09 m in the opposing case. These results suggest that only the amplitude-modulated wave packet is sensitive to the orientation of the background shear current.* "

"*The magnitude of the background shear current was varied from 0.5 U_d to 2.5 U_d from case U1 to case U5 to study its influence on the evolution of the mode-2 ISW. The increasing magnitude of the background shear current leads to smaller amplitudes of the mode-2 ISW in both upper and lower parts . In the larger magnitude case, the amplitude-modulated wave packet and forward-propagating long wave were significantly strengthened, and their amplitudes reached 3.75 m and 0.38 m (case U5), respectively. In contrast, a larger magnitude didn't make the amplitude of the* *oscillating tail continue to increase. In the larger magnitude case, the oscillating tail was unable to be clearly observed. Its amplitude becomes smaller (0.25 m) than that of the forward-propagating long wave (0.38 m). In summary, all three shear-induced waves are sensitive to the magnitude of the shear current."*

"*The thickness of the shear layer h_s was also varied to investigate its effect on the modulation of mode-2 ISW (cases H1 to H5). In comparison with the control experiment, the forward-propagating long wave's amplitude decreased with larger h_s, reaching 0.17 m in case H5 with 2.5 h_s. The amplitude-modulated wave packet and oscillating tail both decrease to 1.33 m and 0.42 m in amplitude in larger h_s (case H5), respectively, while the mode-2 ISW's amplitude reaches 7.95 m. This result shows that the background shear current with smaller h_s could only moderately deform the mode-2 ISW. As a result, all three shear-induced wave structures are sensitive to the variation in the thickness of the shear layer.*"

"*When the shear current is offset in the upward direction ($\Delta < 0$), the asymmetry of the mode-2 ISW during the modulation became clearer. The amplitude of the oscillating tail and amplitude-modulated wave packet both decreased when the shear current was offset upward, showing a symmetric variation trend with respect to the downward offset condition. For the forward-propagating long wave, its amplitude oscillates by approximately 0.2 m, suggesting the insensitive nature of the long wave to the upward offset shear current.*"

"*The amplitudes of the forward-propagating long wave, oscillating tail and amplitude-modulated wave packet in varied background shear currents are summarized. The amplitude of the forward-propagating long wave and amplitude-modulated wave packet are positively proportional to the magnitude of the background shear current, but the oscillating tail is insensitive to the higher magnitude of background shear current (Fig. 9 (a)). The amplitudes of the oscillating tails and amplitude-modulated wave packet are inversely proportional to the thickness* *of the shear layer, and the forward-propagating long wave decreased slightly in amplitude with increasing* h_s *(Fig. 9 (b)). To reveal the effects of the Δ on those shear-induced wave structures, a comparison of different cases from Δ = 0 (case O5) to Δ = 2 (case O9) was given.*"

"*A similar variation trend could be found in the upward offset cases (Fig. 10 (c)). The amplitudes of the oscillating tail and amplitude-modulated wave packet decreased monotonically as the shear current offset upward. The forward-propagating long wave was barely affected by Δ and remained constant at approximately 0.2 m in all offset cases.*"

"*The polarity and the direction of the background shear current have minor effect on the energy loss of mode-2 ISWs. The energy loss of the mode-2 ISW was positively proportional to the magnitude of shear current, but reverse proportional to the thickness of shear layer (Fig. 14 (a) and (b)). For case U5, 78.04 KJ* m^{-1} *energy loss in 30 T, ~53% of total energy of mode-2 ISW and the averaged energy loss rate was 13* Wm^{-1}*, indicating the magnitude of shear could significantly increase the energy loss of mode-2 ISW. in contrast, for case H5, 42.05 KJ* m^{-1} *energy loss in 30 T, ~29% of total energy of mode-2 ISW and the averaged energy loss rate was 7W* m^{-1}*, showing that a larger thickness of shear has opposite effect on the energy loss of mode-2 ISW. In the offset background shear currents, the energy loss of mode-2 ISW monotonically decreased with an increasing Δ, showing a symmetric trend in both upward and downward offset cases (Fig. 14 (c) and (d)). Therefore, the energy losses of mode-2 ISWs are sensitive to the magnitude, thickness and offset extent, but insensitive to the polarity and direction of background shear current.*"

Question 6

How was the background shear introduced? Was it continuously increased over a short duration of time or instantaneously turned on? What was numerically done to add the shear? The first paragraph of section 2.3 does not make it clear that the ISW was generated without the presence of the background shear. Please correct this.

Response:

The initialization of the mode-2 ISW in section 2.3 has been refined accordingly. The background shear current was instantaneously turned on after the appearance of a stable mode-2 ISW in the absence of a background shear current. Then, the velocity field of the background shear current was superimposed on the model.

The related descriptions were added to the revision as follows (see also Page 7, Lines 3 – 4, Page 7 Lines 14 – 15 in the main text):

"*A rank-ordered mode-2 ISW train was generated by the "lock-release" method without background current.*"

"*At 6000 s after the initialization of numerical model, the velocity field of the background shear current was superimposed on the model.*"

Question 7

Page 7, line 4. How was the amplitude of the wave calculated? Much of section 3 discusses the change in amplitude or compares different amplitudes, but it is unclear where this came from. L is also not defined in the text.

Response:

The definitions and calculations of the amplitude have been clarified accordingly, and the definition of *L* has been added in the manuscript.

The related descriptions were added to the revision as follows (see also Page 7, Lines 10 – 14 in the main text):

"*The amplitudes of shear-induced waves were defined as maximum isopycnal displacement (Stastna and Lamb, 2002). The amplitude A of mode-2 ISWs was defined as the maximum displacement of the upper and lower isopycnals, which are equal in* *the initial state (Terletska* et al.*, 2016). The wavelength L was defined as the width of the wave at half of the amplitude of the mode-2 ISW in the initial state.*"

Question 8

What is the difference between the oscillating tail and the amplitude-modulated wave packet? To me they look identical. What are their defining features? How did you distinguish between them?

Response:

Detailed definitions of the oscillating tail and amplitude-modulated wave packet have been added in the revision. The related figures have been improved to clearly demonstrate their differences. The amplitude-modulated wave packet appeared at the end of oscillating tail as steady-state envelopes *(Terletska* et al., 2016), and it could be clearly observed at the end of the oscillating tail (Figure 4). The amplitude-modulated wave packet (Figure 5) was defined as a pulsating wave packet propagated with a steady-state envelope, inside which the waves oscillate freely with different amplitudes (*Terletska* et al., 2016).

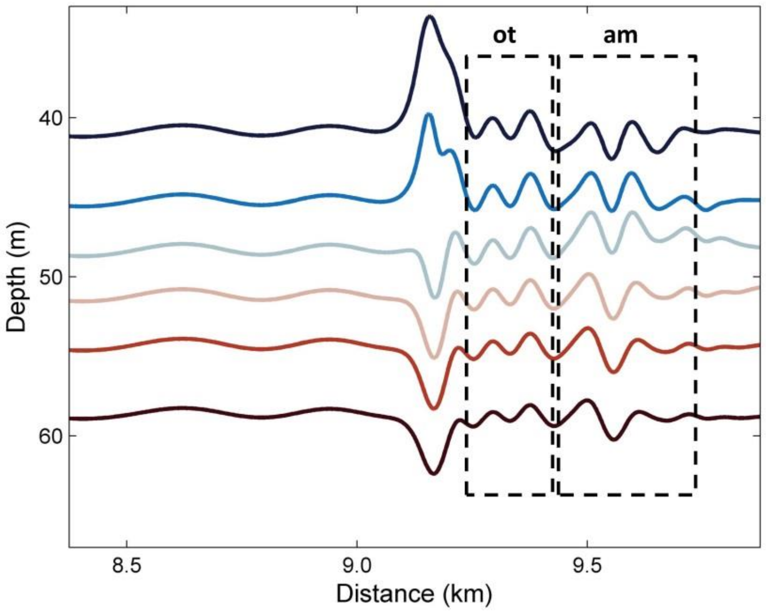

Figure 4: The evolution process of mode-2 ISW in case O5 at 14 T, where the 'ot' and 'am' denoted the oscillating tail and amplitude-modulated wave packet, respectively (see also FIigure 4(d) in the manuscript).

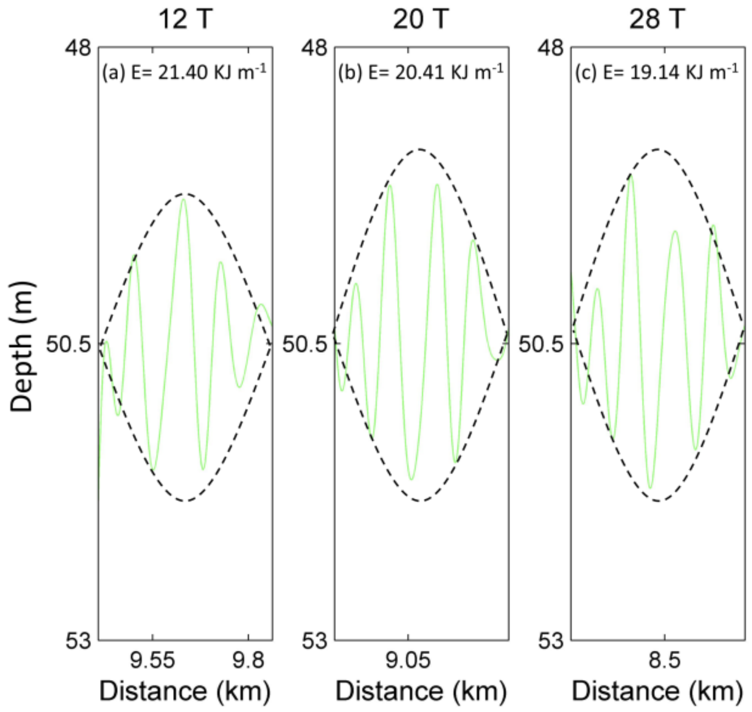

Figure 5. The envelopes of the amplitude-modulated wave packet in the case O5 (Δ = 0) at (a) 12 T, (b) 20 T and (c) 28 T, where the mean density isopycnal of upper and lower layer (green line) are plotted.

The related descriptions were added to the revision as follows (see also Page 10, Lines 6 – 11, Page 10, Lines 19 – 21 in the main text):

"*It also caused the asymmetrical distribution of the vorticity in the horizontal, which is associated with the generation of forward-propagating long waves and the amplitude-modulated wave packet (Fig. 4 (b)), and the latter was defined as a pulsating wave packet (Clarke* et al.*, 2000). The pulsating wave packet propagated with a steady-state envelope, inside which the waves oscillate freely with different amplitudes (Terletska* et al.*, 2016).*"

"*The oscillating tail caused by the shear was visible between the mode-2 ISW and the amplitude-modulated wave packet (Fig. 5 (d)) at 14 T after the initialization of the background shear current, and it was a radiated mode-1 oscillatory disturbance trailing mode-2 ISW (Stamp and Jacka, 1995).*"

Question 9

Page 9, lines 9-16. How does the complexity of the vorticity field imply higher energy transfer? How do you know that the energy in the radiating waves does not arise from the background mean flow? Have the authors read the literature on wave-mean flow interaction? This seems highly pertinent and must be included in the article. Lastly, how does larger amplitude imply a higher energy? Are the authors assuming linearity? Is this applicable here? The use of the term applied (or implying) in these sentences is not justified, and begs further quantification. (See also lines 18-21 on page 11).

Response:

Thank you for your suggestion. The vague description of the relationship between the complexity of vorticity and the energy transfer has been revised. The linear relation between energy and amplitude is inappropriate here, and it has been improved accordingly.

We reviewed some classic works on wave-mean flow interaction. As introduced by *Grimshaw* (1984), the energy of radiating waves is generally exchanged with the mean flow. Therefore, we compared the energy loss of mode-2 ISWs with the total energy of radiating waves and found they were nearly the same in quantity. This finding means that the energy from the background mean flow makes a relatively small contribution to the radiating waves. To reveal the energy transfer process in wave-mean flow interactions require a detailed analysis, but this is beyond the main scope of present study, which focused on the evolution of mode-2 ISWs in the background shear current. A comment has been added to the manuscript that notes the importance of wave-flow interaction investigations in the near future.

The related descriptions were added to the revision as follows (see also Page 10, Lines 11 – 18; Page 15, Lines 6 – 8; Page 27, Lines 21 – 26 in the main text):

"*To the aft of the ISW, the shear induced by the background currents lead to the deformation of the vortex dipole, and an increasing complexity of the vorticity field implied an intensive adjustment occurred. As illustrated in Fig. 5 (c), 10 T after the initialization of the background shear current, the vorticity of the mode-2 ISW is* *redistributed to adapt to the background condition. In this process, which is related to the generation of an amplitude-modulated wave packet and a forward-propagating long wave, the vortex of the ISW shrank. The forward-propagating long wave and amplitude-modulated wave packet can be seen in Fig. 5 (c) with amplitudes of 0.25 m and 1.8 m respectively, and the latter was clearly observed at the rear of the mode-2 ISW.*"

"*The small amplitude of the oscillating tail and amplitude-modulated wave packet indicate that the modulation could be weaker when Δ increased, and the weakening of the oscillating tail makes the amplitude-modulated wave packet more visible.*"

"*The presence of background shear current generally caused the energy exchange between waves and mean flow (Grimshaw, 1984). We compared the energy loss of mode-2 ISW with the total energy of radiating wave and found that they were nearly the same in quantity. It means the energy from the background mean flow makes a relatively small contribution to the radiating waves. This avenue represents a possible direction for further investigation of the wave-mean flow interaction in complicated flow fields.*"

Question 10

In connection to the previous comment, section 3.4 makes many of the same assumptions about how energy and wave amplitude are related. But this relation is unclear and non-trivial.

Response:

The descriptions in section 3.4 have been improved accordingly. We have also optimized the structure of the manuscript to include the relationship between the amplitudes of shear-induced waves with different parameters of background shear currents, and the energy analysis has been moved to the following sections.

The related descriptions were added to the revision as follows (see also Page 15, Lines 17 – 26 in the main text):

"*The modulation caused by background shear currents was weakened as the Δ increased, corresponding to the decreased amplitude of the amplitude-modulated wave packet and oscillating tail. The amplitude-modulated wave packet has the highest amplitude among all cases compared to those of the other two wave forms. The amplitude of the amplitude-modulated wave packet decreased from 1.8 to 1 m monotonically, and the amplitudes of the oscillating tails decreased from 0.85 to 0.25 m between the case O5 (Δ = 0) and the case O7 (Δ = 1) but remained stable between the case O7 (Δ = 1) and case O9 (Δ = 2), indicating that the amplitude-modulated wave packet were more sensitive to the Δ than the oscillating tail. As expected, the ratio between the amplitude of modulated wave packet and oscillating tails increased from 2.1 in the case O5 to 4 in the case O9, so the amplitude-modulated wave packet became more distinct in case O9.*"

Question 11

Page 9, lines 20-22. The consequent in the following conditional sentence does not following from the antecedent. "Based on the vorticity field shown in Fig. 6 (d), the generation of the oscillating tail and the forward-propagating long wave was continuously sustained by the energy of the ISW". A single snapshot does not indicate anything about the continuous evolution of the radiating waves. I suggest adding a Hovmoller (space-time) plot to show the time varying nature of the waves. However, this is only possible if sufficient time resolution is available.

Response:

Thank you for your suggestion. A Hovmöller plot has been made to illustrate the time-varying nature of the evolution process of the mode-2 ISW (Figure 6). The oscillating tail and forward-propagating long wave could be found to evolve continuously. Related descriptions have been added to the manuscript.

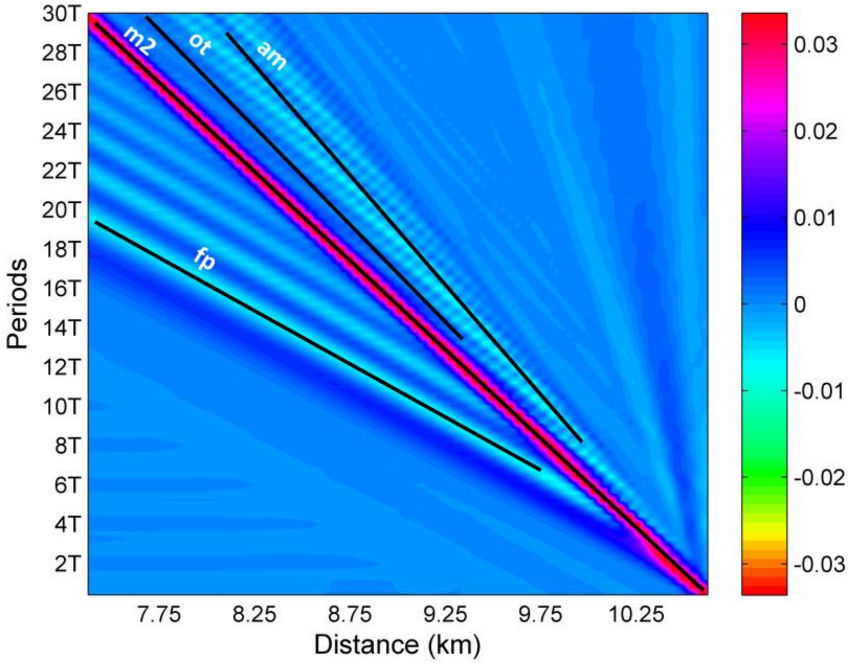

Figure 6. Hovmöller plot of horizontal velocity without background shear current at the surface. The mode-2 ISW, forward-propagating long wave, oscillating tail and amplitude-modulated wave packet are denoted by 'm2', 'fp', 'ot' and 'am', respectively. The color bar ranges from -0.034 to 0.034 m/s.

The related descriptions were added to the revision as follows (see also Page 11, Lines 1 - 3; Page 11, Lines 5 – 8 in the main text):

"*A Hovmöller plot (Fig. 7) of horizontal velocity without the background shear current at the surface was plotted (Lamb* et al.*, 2014). The forward-propagating long wave, oscillating tail and amplitude-modulated wave packet were found to propagate persistently.*"

"*Based on the vorticity field (Fig. 6 (d)) and the time-space varying nature (Fig. x), the generation of the oscillating tail and forward-propagating long wave was continuously sustained by the energy of the ISW. Therefore, they have the potential to drain the energy from an ISW over a long time scale.*"

Question 12

Page 13. How are x_l and x_r defined? The authors say they are the boundaries of the integration region, but don't specify where they come from. They are critical to the discussion of the size of the wave, and the choice of definition will have a large impact in the energy values.

Response:

The definitions of x_l and x_r have been clarified. x_l and x_r are denoted the as the left and right boundaries, respectively, where the available potential energy flux equals zero (*Lamb*, 2010).

The related descriptions were added to the revision as follows (see also Page 17 Lines 6 - 8 in the main text):

"x_r *and* x_l *are the boundary locations of the integration region, and x satisfies* $x_l \leq x \leq x_r$*. During the calculation of the wave energy,* x_r *and* x_l *are denoted as the left and right boundaries, respectively, where the available potential energy flux equals zero (Lamb, 2010)*"

Question 13

Page 20, lines 9-11. What waves are transient to the introduction of the shear, and what are persistent? Much of this article seems to consist of the initial adjustment when the background shear is introduced. What is the long time behavior of the mode-2 wave in the presence of shear? On another note, what can be said about the generation of a mode-2 ISW while shear is present?

Response:

The amplitude-modulated wave packet, oscillating tail and forward-propagating long wave were observed to be persistent (Figure 6). The forward-propagating long wave and oscillating tail are generated persistently due to the continuous energy input from mode-2 ISW (Figure 6). The amplitude-modulated wave packet is generated transiently because it no longer receives energy from the mode-2 ISW after it propagates away.

As for the long-term behaviour, the mode-2 ISW could adjust itself to adapt to new background conditions if there exists a stable solution for the mode-2 ISW. In contrast, the energy of mode-2 ISW would radiate away if no stable solution for the mode-2 ISW is allowed in that circumstance. This dynamic also indicates that the mode-2 ISW could generate in an appropriate background shear current where a stable solution exists. A detailed discussion has been added in the manuscript.

The related descriptions were added to the revision as follows (see also Page 26 Lines 5 – 14 in the main text):

"*As for the long-term behaviour, the mode-2 ISW could adjust itself to adapt to new background conditions and experience a dramatic transformation with disintegration into a wave train (Grimshaw* et al.*, 2010, Yuan* et al.*, 2018). In our simulation, the mode-2 ISW was observed to adjust itself to the new background condition with a shear current. The high energy loss rate is in agreement with the observation by Shroyer* et al. *(2010). However, the mode-2 ISW might not be able to survive for long time in situ because the background conditions in real ocean could be more complex and vary with time, leading to a background condition where a stable solution of mode-2 ISW does not exist. It is also possible that the mode-2 ISW could generate in an appropriate background shear current if a stable solution exists in that condition.*"

Specific comments

Question 1

Page 3, lines 12-14. Are there references?

Response:

Related references have been cited.

Question 2

Page 4, what evidence do you have that your solution is numerically convergent or accurate? Did you conduct grid refinement strategies? How were the viscosity parameters chosen? What motivation do you have for them?

Response:

The total energy of simulation domain has been integrated, and we found that it was convergent and stable. The initial mode-2 ISW in the absence of a background shear current was also in agreement with the KdV theory (Figure 1).

Second, no grid refinement strategies were applied. A high resolution was introduced to assure that the modulation of the mode-2 ISW in the background shear current could be clearly observed. The time-step of the simulation was set 0.4 s to satisfy the *Courant-Friedrichs-Lewy* condition.

The choice of viscosity was set following previous studies with similar field scales (*Grisouard et al.*, 2010, *Xie et al.*, 2015). The choice of viscosity aims to avoid breaking and ensure the model can run smoothly (*Guo* and *Chen*, 2012, *Yuan* et al., 2018).

Question 3

Page 4, line 19. Please write the equation for delta out explicitly.

Response:

The equation for Δ has been added.

The related descriptions were added to the revision as follows (see also Page 5, Lines 15 – 18 in the main text):

"*The asymmetry parameter Δ (Carpenter* et al.*, 2010) is defined as follows:*

$$\Delta = \frac{D_S - z_0}{h/2}$$

where D_S denotes the depth of shear centre and h denotes the thickness of pycnocline."

Question 4

Figure 1. Please define the cases in the main body of the article and not in the figure caption.

Response:

A detailed introduction of experiments has been added in the revision.

The related descriptions were added to the revision as follows (see also Lines Page 5, Lines 18 – 20 in the main text):

"*The Δ was varie*d *from -2 to 2 (case O1 to case O9) to investigate the evolution of the mode-2 ISW in the offset background shear current.*"

Question 5

h_{mix} and l_{mix} are not defined in the text. Just in the caption for figure 3.

Response:

The definitions have been added.

The related descriptions were added to the revision as follows (see also Page 7, Lines 5 – 7 in the main text):

"*Figure 3 demonstrates the configurations of the simulation domains. A mixed region was set to be symmetric around the centerline of the pycnocline at the right end, and its length* l_{mix} *and height* h_{mix} *were 375 m and 25 m, respectively.*"

Question 6

Is a lock-release of this form applicable on a field scale?

Response:

The mode-2 ISW generated by 'lock-release' method in our simulation remains stable and demonstrates a symmetric nature in agreement with the theory (Figure 1) and consistent with the observations (*Shoryer* et al., 2010).

Question 7

The colormap used in figures 4, 6, 8 is not good. Please change to something symmetric about a reference value. I suggest colormap 'balance' from Thyng et al. 2016. A matlab package is available for download.

Response:

We appreciate that constructive suggestion from the reviewer. We have applied the 'balance' colormap in the related figures accordingly.

Question 8

What is being plotted in figure 4a? Is it temperature? Please make clear.

Response:

Figure 4a shows the density field of mode-2 ISW. The caption has been modified.

Question 9

Text in figures 5, 6, etc. is too small and the resolution needs to be increased.

Response:

Revised accordingly.

Question 10

Put color bars on all vorticity plots.

Response:

Added.

Question 11

Page 10, lines 2-3. I do not see how the following sentence arises from the statement just prior to it, "Thus, the energy loss of the ISW caused by forward-propagating long waves occurs earlier than oscillating tail." I don't see how the forward-propagating wave happens earlier.

Response:

This sentence has been improved in the revision. As shown in the Hovmöller plot (Figure 6), the forward-propagating long wave and amplitude-modulated wave packet generated simultaneously. The oscillating tail appeared after the amplitude-modulated wave packet propagated away from the mode-2 ISW, indicating that the energy loss caused by oscillating tail happened later than forward-propagating long wave.

The related descriptions were added to the revision as follows (see also Page 11, Lines 8 – 11 in the main text):

"*It should be noted that the forward-propagating long wave and amplitude-modulated wave packet generated simultaneously, while the oscillating tail appeared after the amplitude-modulated wave packet propagated away from the mode-2 ISW. Thus, the energy loss of the ISW caused by forward-propagating long waves occurs earlier than the oscillating tail.*"

Question 12

Figure 8. What is BLIW? Define this somewhere.

Response:

The word 'BLIW' was changed to 'amplitude-modulated wave packet', which is more easily understood.

Question 13

Page 11, line 16. Do the authors have any physical reason why "the forward-propagating long wave may not be affected by delta"?

Response:

As suggested by reviewer, we carried out sufficient experiments to further investigate the forward-propagating long wave that was generated by the collapse of mixing induced by shear instability. The results show that the amplitude of the forward-propagating long wave is proportional to the magnitude of the shear current, indicating that the forward-propagating long wave was affected by the strength of shear. Δ denoted the offset extent of background shear current, and the strength of shear remains unchanged when Δ varied. Therefore, the variation in Δ has no effect on the forward-propagating long wave.

The related descriptions were added to the revision as follows (see also Page 24, Lines 11 – 15 in the main text):

"*The results in section 3.8 show that the amplitude of the forward-propagating long wave is proportional to the magnitude of the shear current, indicating that the forward-propagating long wave was affected by the strength of shear. Δ denotes the offset extent of the background shear current, and the strength of the shear remains unchanged when Δ varied. Therefore, the forward-propagating long wave was insensitive to variation in Δ.*"

Question 14

Page 13, the vertical integrals can be written as $\int_{-H}^{0}$ rather than $\int_{-H(x)}^{0}$ since the bottom topography is flat.

Response:

Accepted.

Question 15

Page 13, at what time did the initial mode-2 ISW contain 146.2 KJm^{-1}? Just before the introduction of the shear?

Response:

Yes. The description of initial energy has been improved.

The related descriptions were added to the revision as follows (see also Page 17, Lines 10 – 11 in the main text):

"*The total energy of the initial mode-2 ISW just before the introduction of the shear calculated by the above expressions was 146.2 KJ* m^{-1}"

Question 16

Page 13, Define EOF and give a brief overview of its applicability here. Why is it applicable while normal mode decomposition is not?

Response:

A brief overview of EOF has been added. The normal mode decomposition is not suitable since the flow field in our simulations appears to be highly nonlinear in nature (*Venayagamoorthy* and *Fringer*, 2007).

The related descriptions were added to the revision as follows (see also Page 17 Line 23 – Page 18, Line 2 in the main text):

"*The EOF (empirical orthogonal function) method was applied to the modal decomposition. EOF is commonly used for mode decomposition and space-time-distributed datasets examination in oceanography (Venayagamoorthy and Fringer, 2007). The normal mode decomposition is not suitable for the analysis of forward-propagating long waves, amplitude-modulated wave packets or oscillating tails since the flow field in our simulations appears to be highly nonlinear in nature (Venayagamoorthy and Fringer, 2007)*"

Question 17

Can you explain the periodicity of figure 10 b? Why is it a function of distance and not time? What about the long time behaviour (when the wave approaches x = 0)?

Response:

We revised Figure 10 to give the variation with a function of time (Figure 7). The periodicity was caused by the superimposition of the energy of the mode-1 oscillating tail and the trailing mode-2 energy. These features trailed the mode-2 ISW with different wavelengths and therefore exhibited periodicity. The long-term behaviour of wave structure can be viewed in the response to major question 13.

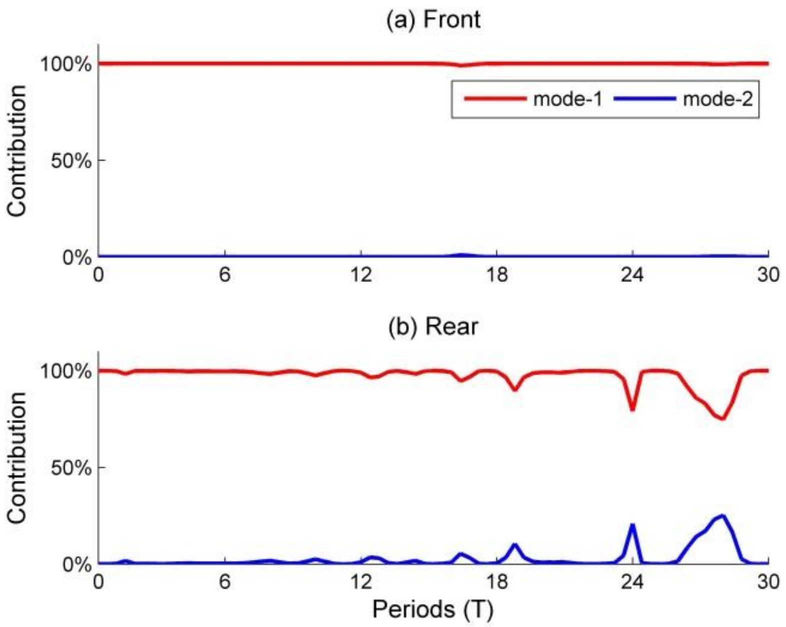

Figure 7. Percent contributions of mode-1 and mode-2 to the total kinetic energy in case (Δ = 0) from 0 to 30 T at the (a) front and (b) rear of the mode-2 ISW.

Question 18

What are the breakdowns of the energy flux in terms of KEf , APEf , and W? What happens before t = 6T?

Response:

The breakdowns of the energy flux have been plotted accordingly (Figure 8), and we also refined Figure 11 in the previous manuscript to show the energy flux before 6 T.

The pressure perturbation energy flux dominates the energy flux both in the front and rear, and this phenomenon accords with *Lamb* and *Nguyen* (2009). Before 6 T, the mode-2 ISW deformed due to the shear effect, and the forward-propagating long wave and amplitude-modulated wave packet were not generated completely yet.

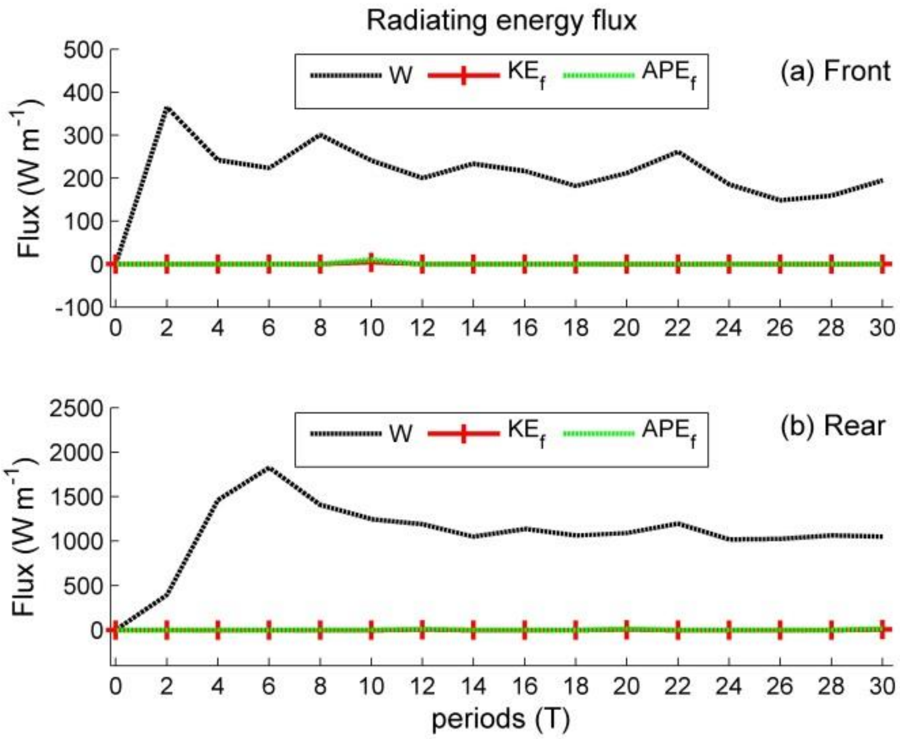

Figure 8. The breakdowns of the energy flux in terms of *W*, KE_f, and APE_f.

The related descriptions were added to the revision as follows (see also Page 20, Lines 4 – 7 in the main text):

"*The pressure perturbation generally make the largest instantaneous contributions to the total energy flux (Lamb and Nguyen, 2009; Venayagamoorthy and Fringer, 2005). For an ISW, the pressure perturbation term could be dominant (Lamb 2007). Since we focused on the energy loss of the mode-2 ISW, a total energy flux was analysed in the following paragraph.* "

Question 19

Page 15, lines 11-13. I'm still not convinced that the following is true: "the high radiating flux before 12 T indicates the generation process of the amplitude modulated wave packet and that the relative low radiating energy flux above 12 T is caused by the generation of an oscillating tail." The authors have yet to clearly show that the amplitude-modulated wave packet is short lived while the oscillating tail is persistent.

Response:

We plotted the energy flux in the rear of the mode-2 ISW induced by amplitude-modulated wave packet and oscillating tail, respectively (Figure 9). The amplitude-modulated wave packet has a relative high energy flux during the early stage of modulation, and an oscillating tail with a small energy flux appeared after 12 T.

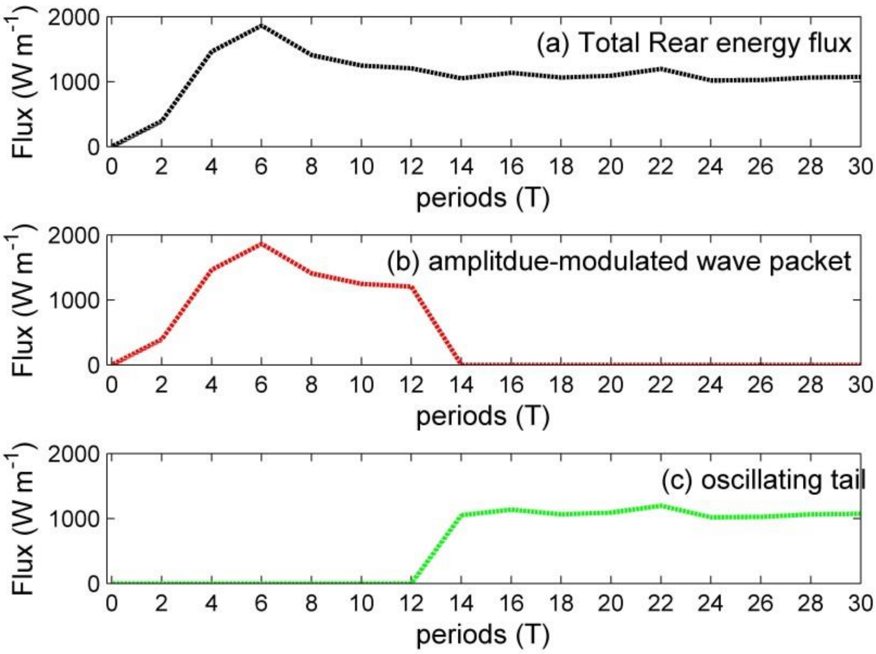

Figure 9. The total energy flux in the rear of the mode-2 ISW and the energy fluxes induced by the amplitude-modulated wave packet and oscillating tail.

Question 20

Page 16, line 13. It appears that the authors haven't been rigorous enough about how the energy is transferred. Why use the word 'suggests'?

Response:

This sentence has been refined accordingly.

The related descriptions were revised as follows (see also Page 21, Lines 6 – 8 in the main text):

"*Combining the results of the energy flux in front and rear of the mode-2 ISW (Fig. 13), thus, in the early stage of modulation, the amplitude-modulated wave packet could make a larger contribution to the energy transfer process.*"

Question 21

Table 2. Should the units be KW m^{-1}?

Response:

The units of energy loss rates were W m^{-1}, and it was in consistent with the observations (10 W m^{-1}) of *Shoyer* et al., (2010)

Question 22

Page 17, line 8. which observations where compared? and where? Were there more than the Shroyer et al. (2010) paper?

Response:

The initial expression has been improved. The wavelength and amplitude of the mode-2 ISW were chosen to match the observations in the New Jersey Shelf (*Shroyer* et al., 2010).

The related descriptions were added to the revision as follows (see also Page 22, Lines 6 – 7 in the main text):

"*In the simulation of the present study, the wavelengths and amplitudes of the mode-2 ISWs were selected to be comparable to the observation of Shroyer* et al. *(2010) on the New Jersey Shelf.*"

Question 23

Figure 15. What field is being plotted? Density? Which isopycnal is being plotted?

Response:

The isopycnal of mean density was plotted, and the caption has been improved.

Question 24

The text at times is missing articles (such as ‘the’) and the tense is sometimes mixed up. Please review for grammar.

Response:

We have checked and improved the expressions of the manuscript. The NPG Language Editing service was contracted to review and polish the revised manuscript before the submission.

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