

# ***Interactive comment on “Shoaling of internal solitary waves at the ASIAEX site in the South China Sea” by K. G. Lamb and A. Warn-Varnas***

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We thank the reviewers for there comments. Detailed responses are given below.

## Response to reviewer #1

### **Major points:**

1. May I suggest to highlight 'numerical simulation' in the title?

*This is a good idea. The title has been changed to "Two-dimensional numerical*

*C773*

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*simulations of shoaling internal solitary waves at the ASIAEX site in the South China Sea".*

2. The abstract: it is mostly about 'what has been done' in the work, not 'what has been found'. It would be nice if the authors could consider improving this.

*The abstract has been rewritten:*

*"The interaction of barotropic tides with Luzon Strait topography generates some of the world's largest internal solitary waves which eventually shoal and dissipate on the western side of the north South China Sea. Two-dimensional numerical simulations of the shoaling of a single internal solitary wave at the site of the Asian Seas International Acoustic Experiment have been undertaken in order to investigate the sensitivity of the shoaling process to the stratification and the underlying bathymetry, and to explore the influence of rotation. The bulk of the simulations are inviscid however exploratory simulations using a vertical eddy-viscosity confined to a near bottom layer, along with a no-slip boundary condition, suggest that viscous effects may become important in water shallower than about 200 m. A shoaling solitary wave fissions into several waves. At depths of 200-300 m the front of the leading waves become nearly parallel to the bottom and develop a very steep back as has been observed. The leading waves are followed by waves of elevation (pedestals) that are conjugate to the waves of depression ahead and behind them. Horizontal resolutions of at least 50 m are required to simulate these well. Wave breaking was found to occur behind the second or third of the leading solitary waves, never at the back of the leading wave. Comparisons of the shoaling of waves started at depths of 1000 and 3000 m show significant differences and the shoaling waves can be significantly non-adiabatic even at depths greater than 2000 m.*

*When waves reach a depth of 200 m their amplitudes can be more than 50% larger than the largest possible solitary wave at that depth. The shoaling behaviour is sensitive to the presence of small scale features in the bathymetry: a 200 m high bump at 700 m depth can result in the generation of many mode-two waves and of higher mode waves. Sensitivity to the stratification is considered by using three stratifications based on summer observations. They primarily differ in the depth of the thermocline. The generation of mode-two waves and the behaviour of the waves in shallow water is sensitive to this depth. Rotation affects the shoaling waves by reducing the amplitude of the leading waves via the radiation of long trailing inertia-gravity waves. The nonlinear-dispersive evolution of these inertia-gravity waves results in the formation of secondary mode-one wave packets. "*

3. P1166, L8-16: Please improve this paragraph; the first citation and the third citation have a similar story.

*Done. The paragraph now starts with:*

*“Liu et al (1998) demonstrated, with a two-layer Gardner equation model that includes cubic nonlinearity, that ISW depressions are transformed into a train of ISWs of elevation as they propagate over sloping topography into shallower water where the upper layer is thinner than the lower layer, as did Orr and Mignerey (2003) who based their simulations on observations from the ASIAEX site. Recently Grimshaw et al (2014) used the Ostrovsky equation to investigate the effects of rotation on the evolution of shoaling solitary waves. They too included a cubic nonlinear term. Their simulations were based on bathymetry and continuous stratifications observed in the South China Sea. They found that a significant consequence of rotation was the formation of*

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*a secondary trailing wave packet associated with nonlinear steepening of the radiated inertia gravity waves. ..."*

4. About rotation: are the authors aware of the recent work by Grimshaw et al. (2014)? They studied the combined effect of rotation and shoaling topography on the propagation of internal solitary waves in the South China Sea. A major finding is that the combined effect results in the formation of a secondary wave train after the leading wave passes by the shelf break. This secondary wave train, although being less pronounced, also appears in Fig. 18. The authors may want to discuss a bit around this. Grimshaw et al. (2014) also did some sensitivity runs which are also relevant to the topic of this paper.

*The authors were not aware of this paper at the time of submission. This reference has been added along with appropriate discussion. In the initial version of the paper figure 21c showed a mode-one solitary wave packet that was formed through rotational effects. We have replaced former figures 20 and 21 with new figures (figures 17 and 18) which clearly show the formation of secondary wave packets as reported by Grimshaw et al. We have also modified figure 15 (figure 18 in original manuscript) by adding a new panel comparing isopycnal heights at a later time for one case which clearly shows the secondary wave packet.*

*Part of the additions include the following sentences in section 3.6:*

*"The wave of elevation between  $x = 30$  and  $50$  km is larger in the rotating case (surface currents are twice as strong) and in the rotating case it subsequently steepens and forms a secondary packet of short waves (between  $x = 67$  to  $70$  km at  $t = 45$  h, Fig. 15c) which is not present in the non-rotating case. Such wave packets were reported by Grimshaw et al, (2014)."*

## Minor points:

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- P1164, L3: solitary ‘wave’ train.  
*Fixed.*
- P1164, L15: in situ ‘observations’?  
*Fixed.*
- P1167, L25: grammatical error.  
*Fixed.*
- P1169, L9–12: this should appear in the caption.  
*Sentences removed. Explanation in caption.*
- P1170, L27: is ‘approached’ they...  
*Fixed.*
- P1171, L18: ‘45.4’ m  
*Fixed.*
- P1171, L18: what are ‘Case 2 and 3’? Table 3 is not introduced before this.  
*Fixed. An introductory paragraph describing the table has been added. Tables 2 and 3 have been re-ordered.*
- P1174, L21: ‘too’ wide  
*Fixed.*
- P1174, L26: please explain a bit about ‘ $J=200$ ’.  
 *$J$  is the number of grid cells in the vertical. Mention of this is now made in section 2.1 where the model is introduced along with a comment about vertically varying resolution.*

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- P1180, L5: grammatical error.  
*Revised.*
- P1181, L12: steeper ‘than’  
*Fixed.*
- P1182, L23: the wave ‘has’ reached  
*Fixed.*
- P1184, L8: ‘e.g. t x=18’?  
*Fixed.*
- P1186, L16: consider case with an – specify which case?  
*Text has been modified.*
- P1186, L27: Incomplete sentence; informal in a paper.  
*Sentence modified.*
- P1187, L12: do the modeled characteristics of the second mode match those of observations (e.g., amplitude, location, etc.)? One may not expect a good agreement with such an idealized simulation, but it would be helpful to discuss it a bit.

*Only one mode-two wave was reported in the ASIAEX field program (see Lynch et al (2004)). Most of the observations of mode-two waves were obtained in the VANS/WISE field program which was conducted in 2005 and 2006 at a nearby location. These observations were from a mooring along the 350 m isobath and we do see them at this depth in the simulations. We have extended the discussion of the mode-two observations in section 4. It now reads*

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*“During the ASIAEX program only one mode-two wave was observed (Lynch et al, 2004). In a pilot program (Yang et al, 2004) observed a single mode-two wave in water 426 m deep. Yang et al (2009, 2010) analyzed mooring data obtained during the VANS/WISE program which was conducted in 2005 and 2006 in the vicinity of the ASIAEX field program. Data from a mooring deployed along the 350 m isobath was analyzed showed the occurrence of many mode-two waves. They appeared in two forms: convex mode-two waves in which there is a bulge in the thermocline with isotherms raised/lowered in the upper/lower part of the water column, and concave mode-two waves with isotherms displaced in the opposite directions. Convex mode-two waves were by far the most common. The mode-two waves trailed mode-one waves suggesting that they were generated via the adjustment of shoaling mode-one waves (Yanget al (2009). Stratification and seasonal variations played a role in generation of mode-two ISWs with mode-two waves more common in winter (Yanget al, 2009).*

*Our simulations also showed the formation of both convex and concave mode-two waves which evolved from the shoaling mode-one wave, as observed by Yang et al (2009, 2010). In the simulations they were present at the depths of the observed waves. Their presence and amplitude were sensitive to the stratification and to rotational effects. The shallow bump on bathymetry  $h_{15}$  led to the generation of a mode-two wave train and made the mode-two ISWs more prominent (see Fig. 13). The generation mechanisms of mode-two ISWs, their frequency of occurrence, and locations on the continental shelf require further study.”*

- P1189, L9: I think it is ‘northeastern’ South China Sea.

*Yes. We were thinking of the western side of that region of the South China Sea. Text has been modified.*

- P1190, L28: as ‘they’ shoal into  
*Fixed.*
- P1191, L25: ‘120 m’  
*Fixed.*

### Tables/figures:

- Table 1: please explain the variables in the first row.  
*Done.*
- Table 2: the last sentence is incomplete.  
*Sentence has been revised.*
- Table 3: I do not see any ‘vn’ in the table. . . and delete one ‘for’ in the middle of the caption.  
*The  $\nu$  was meant to indicate cases for which sets of three runs were done with viscosity. Actual case numbers have an additional  $n$  to indicate the value of the viscosity. The caption has been modified to clarify this.*
- Fig. 1: please add information of isobaths and color bar.  
*Done.*
- Fig. 2: the grey lines in panels b and c are nearly invisible.  
*They have been darkened and thickened.*
- Fig. 3: please specify in the caption that panels a and b have different y-axis scales. I also found panel c not very readable and not necessary. Can the authors consider removing it?

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*We have removed panel (b) and kept panel (c). Plotting three panels in a single row stretches the plots vertically so they are more readable.*

- Fig. 5: please specify in the caption that the scale of y-axis in panels a and b is different.

*Done.*

- Fig. 9: please indicate in the figure the location of the mode-two wave.

*Done.*

- Fig. 10: 1) Line 4 in the caption: 100 m (dotted); 2) incomplete sentences in the caption; 3) the last sentence in the caption: if the curve of the higher vertical resolution results is indistinguishable from the solid curve, I don't think it necessary to actually overlie and describe this curve; 4) please add legend in the panels. I have to refer back to the caption very frequently during reading; 5) It seems that the information in the caption is inconsistent with that described in the text.

*This figure has been replaced and the caption rewritten. A new panel has been added including results from a simulation using 16 m resolution. Unfortunately we have not been able to redo all of the simulations at the higher resolution.*

- Fig. 12a: Is the magnitude of the y-axis correct?

*It should have been GJ/m, not MJ/m. Has been corrected.*

- Fig. 13: please try to enhance the readability this figure.

*We have changed the blue and green colours to improve readability and have added a legend.*

1. My primary criticism is they didn't really do enough when it comes to comparing the results to observations. The authors went to great lengths to accurately reproduce the bottom slope, topographic bumps, etc. of the SCS ASIAEX region, but then they never really got round to going back and comparing the model output with the actual field observations. There are many examples for instance in the IEEE ASIAEX special volume that show several of these features really well. Examples include the squaredoff waves, the broadening of the waves with decreasing water depth, the shape of the broad wave with the shallower slope on the leading edge and the extremely steep back side, even some examples of split waves whose spacing and timing looks similar to the simulated waves. The paper could be strengthened by referring to/comparing more specifically to some of those results. When it looks good, you might as well show it!

*We have added additional comparisons. In addition to the modified text regarding mode-two waves mentioned above we have*

*(a) Added the following text to section 4:*

*“Many of the observations from the ASIAEX program show waves that are broad, with a gently sloping front and steep back, in water of 120 and 85 m depth (Ramp et al (2004), Lynch et al (2004), Duda et al (2004)). These are often trailed by a small number of narrow waves of elevation and square shaped depressions as in our simulations. Figure 3 in (Duda et al, (2004)) shows the presence of waves of elevation in which the thermocline is raised above its rest height in a water depth of 85 m similar to the pedestals generated in out simulations. Ramp et al (2004) show several examples (e.g., 14:00-16:00 GMT on May 7, 15:00:16:00 GMT on May 9, their Figure 6) in which near bottom water is raised well into the water column in waves of elevation trailing a broad wave of depression in water of 120 m depth.*

*In our simulations we start with a single solitary wave in deep water. The shoaling wave fissions into several waves, with at least two well separated solitary waves having been formed by depths of 600–700 m for both bathymetries, with the waves separating at greater depth for bathymetry  $h_0$  which has the more gentle slope. For the steeper bathymetry the waves have reached shallower water before completely separating. In contrast, Lynch et al (2004) and Ramp et al (2004) report that large solitary waves at a depth of 350 m have split into two by the time they reach a depth of 200 m."*

(b) Added the following text to section 3.7:

*"For stratification  $\bar{\rho}_2$  (Fig. 17b) the pycnocline is above the mid-depth on the shelf and solitary waves of depression persist. In this case it can be seen that the leading depression has a steep front (at approximately  $x = 86$  km), in contrast to the other cases. Ultimately a broad square-shaped solitary wave of depression will form. Ramp et al (2004) observed waves of depression at 120 m depth during times when the internal tide had raised the thermocline above the mid-depth (their Figure 6, 18:00 GMT May 13 to 06:00 GMT May 14), some of which have the appearance of broad waves of depression (e.g., between 23:00 and 02:00)."*

2. On a similar but not quite the same note, I think it's not quite clear what, if anything, the shoaling has to do with a-waves vs. b-waves. These waves are described in the introduction, and then one might be led to believe that it is the described shoaling mechanism that creates the a-wave packets. Actually, it's not, because the a-waves already exist as very clear packets in the deep basin (2500 m water depth) and do not require a shoaling mechanism to create them, they are already there. That's not to say the work is not relevant: Both large b-waves (which are generally solitary) and the leading wave in a type a-packet (usually

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the biggest ones) are observed to split and form additional waves as the waves shoal. This only happens for the largest waves generated near the spring tide, but it does happen.

*We did not mean to imply that shoaling creates the a-waves and b-waves and we chose to consider the shoaling of a single solitary wave rather than a packet of waves. Text has been modified by adding*

*“The formation of these wave packets is tied to the generation of the waves in Luzon Strait (Alford et al, (2010), Buijsman et al, 2010)).”*

3. Finally, can the authors comment any more on the wave energetics? Is energy conserved, i.e., the energy in the original specified wave equals the sum of the energy in the split-out waves? If not, where is the energy coming from?

*The following text has been added to the first part of section 3 (before section 3.1):*

*Theoretically energy is conserved as waves shoal if viscosity and diffusion is ignored, however in the simulations the total energy (kinetic plus available potential energy) changes due to numerical error. It can increase slightly in deep water due to numerical diffusion thickening the pycnocline. For case 2 the wave field at  $t = 42$  h (see Figure 4c) contains 96% of the initial energy, with 90% of the initial energy contained in the wave field on the gently sloping part of the shelf slope ( $x > 90$  km). The leading two solitary waves contain 50% and 16% of the initial energy. At  $t = 50$  h the leading depression contains 42% of the initial energy with 7% of the initial energy now residing in the pedestal between the two leading solitary waves. At  $t = 58$  h only 84% of the initial energy remains. The leading two waves of depression contain 19.9%*

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and 10.9% of the initial wave energy while the pedestal between them has 10.5% of the initial energy.

For Case 3 at  $t = 29$  h (Figures 7(c) and 8) the energy in the full wave field is 98.8% of the original energy. The leading wave has about 36% of the original energy, vs 50% for Case 2. The second solitary wave is not cleanly separated from the trailing waves so a precise estimation of its energy is not possible however about 17% of the wave energy lies between 31 and 35 km. Approximately 15% of the wave energy is in reflected waves to the left of the bump ( $x < -15$  km).

Additional comments on energy include:

Section 3.4 (effect of bumps):

*"The bump also results in a reduction in wave amplitude, with the leading three waves containing 60% and 71% of the initial wave energy for cases Cases 4 and 4nb. "*

Section 3.5:

*"At the early times shown (panels a, c, e) the leading wave contains 36%, 53% and 75% of the initial wave energy showing a striking increase with the initial wave amplitude."*

Smaller stuff:

4. The title should include something to suggest that these are simulations and not observations

*This is a good idea. The title has been changed to "Two-dimensional numerical simulations of shoaling internal solitary waves at the ASIAEX site in the South China Sea".*

5. Bottom page 2 and top of page 3: Even Zhou and Alford now admit this is wrong! Subsequent work including their own shows it's the eastward flow in the strait that pops off the big ones.

*Text has been modified.*

6. Figure 18: (b,c) should be (b,d)

*Figure has been changed and caption has been modified.*

### Response to reviewer #3

1. This study presents a series of 2D, nonhydrostatic model experiments of shoaling internal waves with various amplitudes, model resolutions, 2D bathymetries, rotation, stratification, and viscosity. The simulations are of high resolution of 33 m and 400 layers and show impressive and detailed structure. Novel results are the comparison of the simulations with adiabatic shoaling waves computed using the DJL equation. Can the authors explain what causes the differences between the DJL and numerical model solutions?

*The differences between the DJL and numerical solutions are a consequence of the depth changing sufficiently rapidly that the shoaling waves do not have time to adjust to the changing depth, i.e., the time scale for adjusting towards a DJL solution is longer than the time scale over which the depth changes. This is mentioned in the opening paragraph in section 3.2. We have mentioned this in the summary paragraph of that section.*

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2. The paper feels a little long with its 23 figures, and many of the texts accompanying the figures are too descriptive with too much detail. Maybe reduce the text and omit Figures 3a, 4, and 11 (merge with 2), and 21 (merge with 20 and consider one density?).

*The number of figures has been reduced to 19. We have removed one of the panels from figure 3, merged former figures 2 and 11 and eliminated figure 4. In addition legends and colourbars have been added to many figures. Former figures 22 and 23 have been merged by adding the vertical viscosity profile function  $f(z)$  as an extra panel in Figure 23 (now figure 19). Former Figures 20 and 21 have been replaced with new figures comparing the wave fields for all three stratifications with and without rotation at a single time. Former figures 14 and 15 have been merged by showing results at four different times instead of at six different times (new figure 12).*

3. My main criticism is that the justification for this paper is lacking in the introduction. Why is this paper relevant? What does it add to the existing literature that is missing? Including some questions/objectives may improve the focus of this paper. Moreover, it is not always clear why the sensitivity experiments were performed. Maybe mention these reasons in the first lines of each new section? (why use different density profiles? why use different initial depths? why use different viscosities?) The readability is further improved if a brief summary is added at the bottom of each experiment section with the “take-home message”. This extra text can be offset by omitting some of the descriptive details.

*Further motivation has been added to the introduction:*

*“The large internal solitary waves that shoal onto the Chinese Continental shelf are highly energetic features that have implications for biological productivity and sediment transport (Wang et al 2007, Reeder et al 2011). (St. Laurent 2008) concluded that these waves drive one*

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*of the most dissipative coastal regions of the world's oceans. Thus it is important to understand their shoaling dynamics. While ISWs often appear as packets we have chosen to consider the evolution of a single ISW for simplicity. In this first study we also ignore the important effects of background tidal currents which will modify the shoaling behaviour by introducing time varying currents and stratification. Instead we focus on exploring the sensitivity of the evolution of a single shoaling ISWs for a range of wave amplitudes to the underlying bathymetry, small changes in stratification and the effects of rotation. These simulations are based on observations from the ASIAEX experimental site (Orr and Mignerey, 2003; Duda et al, 2004; Ramp et al, 2004)."*

*Motivations for some of the sensitivity studies (sections 3.3 (different depths) and 3.7 (different stratifications)) have been added along with some summary take home messages (first part of section 3, section 3.3). We have also provided more motivation for the simulations with viscosity (end of first paragraph of section 3.8):*

*(a) End of introductory part of section 3 (before section 3.1):*

*In summary, the steep slope between depths of 2250 and 750 m for bathymetry  $h_{15}$  results in significant reflection of incident wave energy. The leading solitary wave in shallow water contains less energy than for the case using bathymetry  $h_0$  which has a gentler slope. For bathymetry  $h_{15}$  two large leading solitary waves are formed in shallow water which are trailed by a train of small amplitude mode-one and higher mode waves that are generated by the interaction of the shoaling wave with the bump. For bathymetry  $h_0$  there are 3–4 solitary waves and the leading solitary wave has about 50% more energy than that in the other case. No trailing mode-one wave train or higher mode waves are evident. When the*

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*waves arrive on the shelf large pedestals form which are conjugate to the flow in the leading depression. These waves are much larger than the largest possible solitary wave for the ambient background conditions.*

(b) Section 3.3:

*Intro:*

*For reasons of numerical efficiency it is tempting to truncate the bathymetry and start waves from depths of, say, 1000 m. Here we briefly explore the implications of doing so.*

*Summary:*

*Truncating the deep water depth to 1000 m significantly modifies the fissioning processes resulting in fewer waves, reducing the relative amplitude of the second solitary wave and increasing the distance between the two leading waves.*

(c) Section 3.7: Intro:

*The stratification at the ASIAEX site varied over the course of the field program. Here we consider the sensitivity of the shoaling behaviour to various in stratification over the course of the program. The major difference in our stratifications is the depth of the thermocline which also acts as a proxy for the raising and lowering of the thermocline in response to the internal tides in the region which are not included in our simulations. Ramp et al (2004) report on the influence of the internal tides on the wave forms in shallow water.*

(d) In section 3.8 we have changed the intro to

*In the real world shoaling waves are subject to a no-slip bottom boundary conditions and the effects of boundary layer instabilities*

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*as well as diffusion and dissipation related to other physical processes, in particular tidal currents. In order to point out the potential implications of these processes some simulations were done with vertical eddy viscosity/diffusivity of the form*

*and at the end of the introductory paragraph we have added*

*The functional form of the eddy viscosity/diffusivity is ad-hoc. We take the point of view that physically what is important is a mechanism to create boundary layer separation and vortex shedding off the boundary and we do this in a simple way while confining the viscosity/diffusivity to a region close to the bottom boundary. We consider three different values of  $K$  to illustrate of the sensitivity of the results to its value.*

*After listing the three viscosity values we have added “The latter is possibly unrealistically large.”*

4. The figures do not have titles describing experiment cases and times of snapshots, as well as colorbars, legends, transect labels (e.g. Figure 6), etc. It is tiring for the reader to go back and forth between the caption and the figure. I suggest making all figures easier to read by including these things.

*Most of the figures have been modified to include legends and colourbars. We have also added depth values along the upper axis in some of the line plots (e.g., the resolution tests).*

5. P1164, l25. Z&A ref year is 2006!

*Corrected.*

6. P1166, l1. Buijsman and others (see Alford et al 2011) found that westward currents were not the cause of the a and b waves. Simulations indicate eastward currents.

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*Text corrected.*

7. P1166, I4. Typo? “. . .sloping front have”

*Fixed.*

8. P1166, I8. Correct English? “KdV extended . . .”

*Correct as is.*

9. P1168. L19-I5. Omit this detailed description on the bathymetry?

*We have retained the detail as we think it useful to include information on the bathymetric slopes.*

10. P1170. Section 2.4. Is this discussion on alpha relevant for the rest of the paper?  
Maybe omit?

*This section has been shortened a bit by removing the details about the cubic coefficient  $\alpha_1$ . The discussion of alpha is relevant in so far as it predicts whether or not waves of elevation or depression are formed on the shelf.*

11. P1170, I27. “approachED”?

*Fixed.*

12. P1172, I3. “Feature”. At what km? Mark in figure?

*km given in text.*

13. P1172, I7. Same for “pedestal”. At what km? Mark in figure?

*Location given in text.*

14. P1172, I16-18. Propagating used twice in one sentence.

*We think this sentence is OK as is.*

15. P1172, I25. “stronger currents THAN”.

*Fixed.*

16. P1173, I6. How did you “calculate” ISWs?

*Solutions of the DJL equation modified to include background currents (Stastna & Lamb, 2002) were calculated. Text has been modified and references to DJL equation with background currents have been added.*

17. P1174. Section 3.1 and Figure 10d. It seems that there is a large difference in shallow water between  $DX=50$  and 33 m. I wonder if the model simulation has converged with a resolution of 33 m? Can you do a test for  $DX=15$  m, or at least make a statement about the model convergence in this section?

*We did not mean to suggest the simulations had converged. We have done an additional simulation using a horizontal resolution of 16 m and a new panel has been added to the figure comparing results from different resolutions. A comment about convergence has been added to the text. The results have converged well up to about the time the leading waves reach a depth of 140 m. For the 16 m resolution case the back of the leading depression is steeper but better resolved than in the 33 m resolution case (7–8 grid points vs 4–5). After breaking commences they become quite different in detail. The front part of the leading depression is the same but the steep backs drift apart in the two cases. At  $t = 42$  h (time of last panel in original version of the paper) the steep back of the leading depression in the 33 m resolution case lags that in the 50 m case by a bit more than 600 m and leads that in the 16 m resolution case by a bit more than 400 m. That is, as the resolution increases the leading depression increases in length and there is more energy in the leading depression. This could be a consequence of numerical dissipation which increases as the resolution decreases. It is clear that results have not converged even at a resolution of 16 m.*

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18. P1177. Section 3.2. It is not explained in this section what causes the deviation between the DJL solutions and the simulations. Is it the nonlinear advection terms in the momentum equation? Wave breaking? How does the supercriticality (=slope angle over beam angle) of the slope affect these differences? Do the simulations become exactly the same as the DJL simulations when a subcritical slope is used (that would be a fun experiment)? The criticality of the slope is nowhere discussed in the paper and its relevance for the simulations and evolution of the solitary wave (see Klymak et al 2011, JPO)?

*As pointed out above, the deviation is a consequence of the short time scale over which the shoaling waves experience a depth change vs the time scale for it to adjust to its new depth. We do not know what terms are responsible but it is not a consequence of wave breaking as wave breaking does not occur until depths of less than 200 m are reached. The concept of subcritical or supercritical slopes is normally applied to waves with a well defined frequency (e.g., the internal tide, as done by Klymak et al). For a shoaling solitary wave the flow along the bottom experiences a single short downward flow followed by a single short upward flow. We estimated a frequency  $\omega = ck$  where  $c$  is the estimated propagation speed of the solitary wave and  $k = 2\pi/\lambda$  where  $\lambda$  was taken as four times the length of the front half of the wave, defined as the distance from the crest to the point where the surface current was 5% of its peak value. Using this frequency we estimate that the slope is always subcritical and that along much of the slope  $\omega^2$  is less than  $N^2$ . The closest the slope comes to being critical (apart from a very narrow region when  $N^2 - \omega^2$  changes sign) is above the left side of the bump for bathymetry  $h_{15}$  where the ray slopes are estimated to be 4, 3 and 2 times the bathymetric slope. This of course is sensitive to the choice of the wave width which determines the frequency  $\omega$ . We think this approach to predicting fissioning and/or wave breaking is best left for a more detailed study.*

19. P1177, I12. Typo: “long small amplitude shelf”?

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added a comma after “long”

20. P1178, I10. “energy increases”. Is this energy increase for the same wave as it shoals? Where is this energy coming from? This somewhat contrasts with the statement on I20. Please explain/rewrite.

*These statements are not for shoaling waves. The DJL equation is solved for a specified APE. As the water depth decreases the total energy of the solitary waves for fixed APE increases at first because the kinetic energy of the waves increases (i.e., the ratio KE/APE increases). There is a water depth at which the kinetic, and hence total, energy has its maximum value. As the water depth decreases beyond that point the total energy of solitary waves for fixed APE decreases. We have modified the first sentence (now the start of a paragraph) to read “As the water depth decreases from 3000 m with the APE fixed the total wave energy increases due to the increasing KE/APE ratio, .....”.*

21. P1180, I6. “increase more slowly” What causes this difference?

*We do not know why the currents would adjust more slowly than the amplitude does.*

22. p1186, section 3.7. What is the relevance of this section to the reader? Why not use summer and winter stratifications? Remove/shorten this section?

*The stratification observed in the summer does exhibit some variability and our goal was to explore the sensitivity of the shoaling behaviour to this variability. Clearly large differences would be expected if a winter stratification was used. We have replaced the figures used to illustrate this variability and modified the text accordingly. See in particular the introduction to section 3.7 quoted above.*

23. P1190. I28. Typo? “as THE shoal”

*Fixed.*

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