Response to Dr D.J. Webb (Referee)

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The oceans and marginal seas around South-east Asia are unusual in that the diurnal tides are often much more significant than in the rest of the world's ocean. In this paper the tides of the Gulf of Thailand are investigated to see how resonances enhance the tides of the region. The main result is that the high diurnal tides are not due to a resonance of the Gulf of Thailand but that they are probably due to a quarter wave resonance of the South China Sea. The paper builds on the model study of Cui et al (2015) but also includes an analytic 1-D model which supports the quarter-wave hypothesis.
The paper is well written and easy to understand and although I have some serious criticisms of the work I would like to commend the authors on the standard of their discussion paper.

Reply: Dear Dr. Webb, we sincerely thank you for your careful reading of our manuscript and your constructive comments and suggestions, which are of great help in improving our study. We have addressed all these comments; our responses are given below.
In this response, your comments are copied in black, our replies are shown in red, and the following abbreviations are used:
R1 – Revision #1 - an updated manuscript, which will be submitted as a supplement to this response.

1. Abstract.
After reading the paper and that of Cui et al (2015) it seems obvious that it is the South China Sea which is responsible for the resonance. Thus changing the depth of the South China Sea changes the frequency of the resonance (fig 2) and the analytic resonance around 1 cy/day comes for the cos(beta_1 L_1) term in the equation on line 159. However, the abstract says that the resonant period of the Gulf of Thailand is itself close to 1 cycle/day - which is incorrect.
It would be more correct to say that the South China Sea and the surrounding sea together have a resonance around 1 cycle/day which is primarily due to the South China Sea having very close to a quarter wavelength standing wave at this frequency. Although the Gulf of Thailand does have a large amplitude response around 1 cycle per day the results indicate that this is just a passive response of the Gulf to the increased amplitude of the main South China Sea wave along the Gulf's southern boundary.
Reply: We agree with this comment and have added the following sentence in the abstract: "We find that the resonant frequency around 1 cycle per day in the main area of the South China Sea can be explained with the quarter-wavelength theory, and the large-amplitude response at this frequency in the Gulf of Thailand is basically a passive response of the gulf to the increased amplitude of the wave in the southern portion of the main area of the South China Sea".
2. Lines 19, 22, 24
It would help if the geographical features Taiwan Strait, Mindoro Strait, Balabac Strait and any others referred to in the text were included in figure 1.
Reply: These geographical names have been added to Fig. 1 as suggested.
3. Line 32
In some parts of the literature there is a tendency to refer to resonances in terms of their period. However because the angular velocity of resonances (or their frequencies) often form an arithmetic series corresponding 1/4, 3/4, 5/4, etc wavelengths I would recommend replacing periods here by angular velocities (or frequencies), possibly with the periods in brackets for those that need them.

Reply: This comment has been adopted. We have changed the units of period to those of frequency in R1.

4. Line 47-48

It is not that the resonant periods are related but that the two features are parts of the same resonance, the angular velocity of the resonance being determined primarily by the physical properties of the South China Sea.

Reply: We accept this point of view. Accordingly, these statements have been changed to "we investigate the reasons for the GOT to have a strong response around the frequency of one cycle per day and how the physical properties of the SCSB primarily determine the resonances of both the SCSB and the GOT".

5. Line 72: The Numerical Model

It is only in the code availability section that you say that you use the Princeton Ocean Model. I think this needs to be mentioned earlier in the paper as there are many types of ocean model of varying quality. The Princeton Model is well known and is usually acknowledged to be of good quality. However, it includes many options and parameters so, as in any other realistic model study, it is important to show that the version in use can realistically represent the actual tides in the region being studied. For this reason the paper needs an example of the model K1 (and/or O1) tides of the region and comparison with actual tidal observations either in the form of a chart or in the form of comparisons at key tide gauge positions. I realise that Cui et al (2015) did not do this, but if I had refereed their paper I would have made the same point.

Reply: We added the content of the numerical simulation of the tide K_1, and the results are compared with the tidal gauges. See the R1, Subsection 2.2.

You could also do with figures showing the flux of tidal energy for both the realistic K1 tidal forcing and with a constant amplitude on the boundary as in your test experiments, to show that the main influx of tidal energy is through the Luzon Strait. If you do not do this it is possible that your analytic model which is based on this assumption is not valid.

Reply: We calculated the tidal energy density of K_1 and 0.99 d^{-1}, and the results are shown in Figure 2b and 4b. See the R1 to be revised.

6. Line 72: Boundary Condition

More information is needed on the boundary of the model. The domain described in the text seems to be similar to Cui et al (2015) which makes me suspect you used the same code in the same configuration.

However, the other paper shows a southern boundary south of the Equator, whereas according to your text the present one is north of the Equator. Why the difference?

Reply: In Cui et al. (2015), the southern boundary is set at 2°S, but in this paper, the southern boundary moves northward to 1.5°N. This change in the southern open boundary does not influence the resonant frequencies but slightly improves the patterns of the amplitude gain and phase change.

Figure 1, which the caption calls the study area, shows only part of the model domain. Why is this? When I first read the introduction and saw this figure, I assumed that this included the model domain with say Luzon Strait as an open boundary and the regions you described as having negligible fluxes as closed boundaries. Your need to make the difference clearer earlier in the paper.

Reply: In R1, we have included an inset in the upper-left corner in Figure 1 showing the entire model domain, and the figure caption is revised as follows: "The South China Sea and its neighbouring area. The contours show the water depth distribution in metres. The blue line B is the mouth cross section of the Gulf of Thailand (GOT). The triangles represent the tidal gauge stations (the full names of these stations are given in Table 1). The inset in the upper-left corner shows the entire model domains (99-131°E, 1.5-42°N)".

You say that the northern and eastern boundaries as set well away from the South China Sea to limit the effect of the (fixed) boundary condition on the resonances of the South China Sea. However what about the boundaries to the south and east?

Reply: We add the following sentence: "The southern open boundary is set along a latitudinal section of 1.5 °N, which meets the southernmost tip of the Malay Peninsula".

6. Line 64 and 80-90: Real and complex variables

Analysis of waves and oscillating systems tends to be a lot neater and easier to understand when the physical wave is treated as the real part of a function of the type A(x) exp(-i omega t) where A is a complex number and 'i' is the complex i. Then your G and phi are just the amplitude and phase of a complex response function. The appendix would also be a lot shorter if you used complex variables whenever possible.

Reply: Since we use POM in the numerical computations, it is more direct and easier to understand to express the variables as usual functions of x, y and t in the sections on numerical modelling. In the section on theoretical model and in the appendix, we use complex variables as you suggested.

7. Lines 94-96

This is a bit of a mess and needs to be rewritten. From Cui at al. (2015) you know that there are resonant like features which affect both the Gulf of Thailand and the South China Sea. We know that if the Gulf of Thailand was removed, changing the depth of the South China Sea would affect its resonances. Thus what you are really doing here is to see how much changing these resonances affects the resonances of the combined system. (You could have also carried out runs with changed depths in the Gulf of Thailand - in fact I am surprised that you didn't).

What you are not doing here is finding out how the resonances of the South China Sea are affecting (i.e. changing the shape and frequency of) the localised resonances of the Gulf of Thailand.

Reply: According to your comment, we have carried out two additional experiments (numbered Exps. 4 and 5), in which the depths in the GOT are artificially multiplied by 1/2 and 2. The results are added to Table 2 and Figure 3 in R1.

8. Line 100- : The Results

The paper does not specify the geographical location used for figures 2a and 2b. The three SCSB peaks referred to in table 1 refer to the three main peaks of fig 2a. Changing the depth by a factor of 2 seems to change the frequencies by roughly sqrt(2), but this is not discussed.

Reply: (1) In the present study, we do not use specified locations to represent the area of concern; rather, we use the area-mean value of the top 20% amplitude gain to represent the amplitude gain of the corresponding area. This statement was given in the original manuscript and is retained in R1. For clarity, we added this statement to the captions of these figures in R1. (2) This is a good point; thank you. We added the following statement to R1: "It is worth noting that when the depths in the SCSB are artificially changed by factors of 1/2 and 2, the resonant frequencies are roughly changed by factors of $\sqrt{1/2}$ and $\sqrt{2}$, respectively. This indirectly indicates that the quarter-wavelength resonance theory is applicable to the SCS".

Exp 3 shows a second resonance near 1 cycle/day which also seems to have an effect in fig 2b. Changing the depth of the South China Sea will change the frequency of resonances but will not generate new ones. So what is this feature of the South China Sea affecting the Gulf of Thailand?

Reply: In Exp. 3, there is another weaker peak in the SCSB at the frequency of approximately 1.15 d^{-1}

(Figure 3a of R1). The peak frequency response may also have an effect on the GOT (plot for Exp. 3 in Figure 3b of R1), which results in a plateau peak of the GOT between 0.5 d^{-1} and 1.2 d^{-1}. We speculate that this is probably due to the fact that deepening the SCSB may result in a discontinuity of topographic data at the junction with the GOT. However, we are not sure of this speculation, and it is not included in R1.

In the case of fig 2b, representing the Gulf of Thailand response, there are indeed three main peaks matching the peaks in the South China sea plot - but there is also a lot else going on, especially in expt 1 and 2. What resonances are these?

Reply: The second peak of the GOT's response function at the frequency 0.45 d^{-1} is of some importance. We added the following statement to R1: "In addition, there is a weak response peak at the frequency 0.45 d^{-1} in the GOT (Exp. 1 in Figure 3b). Since the GOT has a length of 660 km and a mean depth of 36 m, the quarter-wavelength theory gives a resonant frequency of 0.61 d^{-1}. It seems that the peak at 0.45 d^{-1} is associated with the local regional resonance". Since in this part of study, we use real coastline and topography, which are irregular, the response function also contains some irregular fluctuations, which are difficult to explain.

It should help if the paper illustrated the amplitude and and phase of key resonances. The simplest solution would be to give the amplitude and phase of the solution when forced at the frequencies of the peaks in the response function. A better alternative would be to fit the (complex) response function R(x,w) at a set of w's around each of the resonance peaks to the equation A(x)/(w-w0) + B(x) + C(x)*(w-w0) Where A, B, C, w0 are complex, x is position, w is the (real) angular velocity of the forcing and w0 the estimated (complex) angular velocity of the resonance. A(x) would then be a better approximation to the amplitude and phase of the true resonance. Following the changes, the conclusions to this section need to be rewritten.

Reply: (1) According to this comment, we have added a figure on the distributions of amplitude gains and phase changes to R1 (as Figure 4a). (2) A(x)/(w-w0) + B(x) + C(x)*(w-w0) is a useful equation. Similar equations have been successfully applied to various sea areas to estimate resonant frequency and quality factor Q (e.g., Garrett and Munk, 1971, The age of the tide and the Q of the oceans, DSR; Sutherland et al., 2005, Tidal resonance in Juan de Fuca Strait and the Strait of Georgia, JPO). However, this or similar equations are generally used to fit the observed responses due to sparse sampling in terms of spectrum resolution. For example, in a semidiurnal band, only responses at frequencies of N_2, M_2, S_2 and K_2 are generally available. In the present study, the response functions are numerically generated. They are smooth and have fine resolution. Hence, fitting by the above equation would not yield significantly different results. The corresponding author (G. Fang) plans to use this equation in a future study.

9. Line 128

Semantics - the theory is 'applicable' to the Gulf of Thailand but does not explain the enhanced tides around 1 cycle day (although it might explain an enhancement if forced at 2 cycles/day).

Reply: Revised as suggested (the observation shows that semi-diurnal tides are small).

10. Lines 147-160

It would be best if most of this was kept in the appendix. All you really need is eqn 15 and the approximation when r*p_1/p_2 is small.

Reply: Most of the equations have been removed as suggested.

11. Lines 165-185.

I think this needs a little more thought. You should be able to show that the resonances near 0.5 and 2 cycles per day are resonances of the short channel (where cos(beta_2 L_2) is zero) and the one near 1 cycle per day is a resonance of the long channel (where cos(beta_1 L_1) is zero). Then friction reduces the amplitude of the shallow short channel resonances but has little effect on the amplitude of the long channel resonances except within the shallow channel.

Reply: According to your comment, we have added the following paragraph: "If we apply the quarter-wavelength resonance theory to channel 1, we can obtain resonant frequencies of 0.99 d^{-1}. If we apply the quarter-wavelength and three-quarter-wavelength resonance theories to channel 2 we can obtain resonant frequencies of 0.61 and 1.84 d^{-1}, respectively. Therefore, we can conclude that the major peaks around the frequency of 1.04 d^{-1} in Figure 6 are caused by resonance in channel 1. This indicates that channel 1 plays a determinative role in the two-channel system. Similarly, we can also conclude that the secondary and third peaks around the frequencies of 0.55 and 1.85 d^{-1} in Figure 6 are caused by resonances in channel 2, associated with the quarter-wavelength and three-quarter-wavelength resonances. Although the frequencies of the peaks shown in Figure 6 correspond well with those estimated based on the quarter-wavelength and three-quarter-wavelength theories, there are small discrepancies. This is due to the connection of the two channels. In fact, the resonant frequencies of the two-channel system also depend on the depth ratio of two channels, as shown in Eq. (14). In comparison to channel 2, the secondary, especially the third peak, in channel 1 is much more less significant. This can be explained as follows: The tidal incident wave from the channel 1 partially enters channel 2 across the steep topography at $x = 0$, and here, the rest of the wave is reflected. The reflected wave is superimposed with the incident wave, and tidal resonance occurs around the frequency of 1.04 d^{-1}. That is, the steep topography at $x = 0$ acts as a wall for channel 1, which causes the quarter-wavelength resonance to occur in the channel. Furthermore, the steep topography can also block most energy of the wave in channel 2 from entering channel 1. Therefore, the relatively large amplitudes in channel 2 at frequencies around 0.55 d^{-1} and 1.85 d^{-1} are not obvious in channel 1 under the action of friction".

12. Lines 189-195

I suppose my main point here is that the diurnal resonance affecting the Gulf of Thailand in not 'closely related' to that affecting the South China Sea. Instead it is exactly the same resonance.

Reply: Revised as suggested. The statement is changed to "Changing the water depths in the SCSB in our numerical experiments further shows that the resonance of the SCSB has a critical impact on the resonance of the GOT".

13. Appendix

This seems a bit long for the content. I suggest that you cut it down in size, trying to make it more elegant and leaving out some of the obvious steps.

Reply: We simplified the appendix as suggested. Nearly 2/3 of the equations have been removed.