os-2015-80 January 2, 2015
Continuous seiche in bays and harbors,
Park J., MacMahan J., Sweet W. and Kotun K.

Response to Reviewer #1.

> We are grateful to the reviewer for their careful and critical review of the manuscript. The revised manuscript incorporating their comments results in a more accurate description of the problem, provides additional context for the reader, and improves the clarity of the presentation. In particular, the reviewers additional citations refute the assertion in the original manuscript that continuous seiche had not been clearly recognized in the literature, and we thank the reviewer for lending their expertise in correcting this error.
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> Please note that the reviewers comments are listed below, with our responses indented under each comment.

General Comments

Looking at data from only two countries does not help in coming to 'global' conclusions. The authors do not seem to have made much effort to find any other data...

> It would be preferable to have data from all around the globe, not solely the Pacific basin. However, the suggested mechanism of tidally-forced shelf-resonances is not basin, country or tide gauge specific, and good agreement between the estimated and observed resonances across varying shelf domains suggests that the underlying physics are robust and independent of observation specifics or location.
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> Regarding other data, significant effort was expended to obtain and process the presented data. While it is always desirable to have a preponderance of data and results, when clear and consistent results are obtained as here, one needs to consider the trade off of time and effort balanced by competing demands for one's time and the potential of diminishing returns in supporting the primary hypothesis. A conundrum that we all face at one time or another.
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> This should be understood in the context that this work is a follow-on to work in Monterey Bay wherein continuous seiche has been recognized for some time and well characterized. Larry Breaker wondered whether a global mechanism for continuous seiche could be identified, motivating the present work. As mentioned below, we examined 6 additional bays/harbors and found the tidally-forced shelf-resonance at each one. So out of 7 basins we have examined, we found the mechanism in each one. This was not a trivial undertaking in terms of time and effort. One is then faced with a decision as described above. Will a coastal basin be identified where this is not the case? The answer must surely be yes. Yet given the positive results to a simple, but apparently not widely-known hypothesis, it seems reasonable to publish the findings.

There is also confusion in the text on whether 'continuous' or 'continuous-tidally forced' seiches are being discussed.

Thank you for this comment. We have modified the text to clarify the distinction.

The authors also make the claim that continuous seiching is a new observation (p. 2364) but that is not really true and I found the literature review inadequate and rather US-centric.

As mentioned above, we are grateful for the literature suggested by the reviewer which clearly refutes the assertion of continuous seiche as only recently recognized. The paper has been rewritten including additional references suggested by the reviewer providing a more accurate description of the problem.

The paper by Wijeratne et al. (p.2363) is misrepresented. The main points in that paper are that the seiches on the east coast of Sri Lanka vary over a fortnight but are strongest at neaps due to it taking a week for the internal tides to travel from the Andaman Sea. Those on the west coast have no fortnightly modulation but rather a diurnal one.

Thank you for this comment. Pertinent to our discussion we are interested in identifying recorded instances of continuous seiche, and their potential forcings. We believe that the observations in the original manuscript (pg 2363, 16-21) are justified in Wijeratne et al., so this is perhaps a matter of interpretation rather than misrepresentation.

Considering the first sentence: "Wijeratne et al. (2010) observed that seiches with periods from 17 to 120 min were continuous persistent throughout the year at Trincomalee and Colombo, Sri Lanka, finding a strong fortnightly periodicity of seiche amplitude at Trincomalee, but no discernible seasonal variability at Colombo." These are straightforward interpretations of the cited content, although it does seem a bit awkward and uninformative to discuss fortnightly periodicity and seasonal variability in the same sentence. The latter portion really serves no purpose to the argument or following discussions, and has been removed.

The second sentence reads: "The fortnightly modulations of seiche energy were attributed to forcing by astronomical tides, while the overall seiche generating mechanisms were thought to include diurnal weather, tides and currents." Here, we see the potential of a perceived inaccuracy as there is no distinction between astronomical tides and internal tides, of which the latter is primary issue/mechanism addressed by Wijeratne et al. We have changed this to remove any ambiguity.

It is notable that Wijeratne et al. not only provide evidence of continuous seiche, but also attributed the 74 minute seiche at Colombo and the 54 minute period at Galle to tidally-forced shelf resonances (section 3.1, pg 5). They then investigated seiche amplitude variations suggesting that diurnal modulations along Western Sri Lanka could be weather forced. This view is consistent with the one we are suggesting, that tidally-forced shelf resonances are a primary contributor to continuous coastal seiche, while internal waves (which clearly can be a primary forcing), weather and other forcings serve to modulate seiche amplitudes if they are

sustained by shelf-resonance. Based on this, we have rewritten this section highlighting the recognition of continuous seiche and tidal shelf-resonance by Wijeratne et al.

The first sentence of section 1 could maybe refer to Airy's study of the seiche at Malta which I think is often said to be the first seiche to be identified in the ocean rather than a lake.

Thank you for the suggestion. It is good to have additional context/reference for the reader, and we have added the citation as recommended.

2363, 19 – Colombo

Corrected.

2364, 18-22 - this is an amusing sentence. Have the authors never looked at tide gauge charts? If they had they would have seen that most of them have high frequency signals superimposed on the tide, that are most easily spotted at the turning points, through which a pencil line had to be drawn in the old days prior to being digitised for tidal analysis. In some ways electronic data loggers have been a backward step.

While the intention was not to induce amusement, it is always nice to bring a bit of levity and enjoyment to the reader! We suppose the question of whether we have looked at tide gauge charts is essentially rhetorical, intended to emphasize the reviewers amusement. Surely the reviewer is not suggesting that in general high frequency signals superimposed on the tide are seiche.

Regarding the opinion that in some ways electronic data loggers have been a backward step, we work with 'old-school' tide observers who hold the same opinion, however, the current state-of-the art in water level measurement and dissemination is rather remarkable, so several steps forward. An interesting discussion to be held under a different forum.

2365, 6 - as mentioned, I find 6 examples in only 2 countries a bit limited for making global conclusions.

As discussed above, we believe that good agreement between the estimated and observed resonances across the varying shelf domains (island and coastal) suggests that the underlying physics are robust and independent of observation specifics or location. Since such shelf conditions exist around the globe, it does not seem an unreasonable suggestion.

Additionally, subsequent to the initial review of the article we also have identified a shelf-resonance in Biscayne Bay of the northern Atlantic. In short, out of the 7 harbors/bays examined, we have found shelf-resonance seiche at each location. It would be folly to assert that such forcing is truly 'global' in the context of being found at every coastal location on the globe, but it is supportive that at every location we have examined, it has been observed. Further, the mechanism is compelling simple and ubiquitous, and, the energy analysis at Monterey suggests it to be the viable candidate at that location whereas internal waves are not.

17 - it would be good to say in the text here where (which countries) these bays are. Also in the figure 1 caption or the reader has to struggle with the lats and lons and his geographical memory.

We have clarified the locations.

2366, 14 - at Monterey and five other

Changed.

18 - I can see what is claimed at Kahului. But I can't for Honolulu - that is just green (zero) around 0.2 min through the plot. Maybe you mean about 0.8 min?

Thank you for the correction.

22 - 'A close examination'. Is the reader supposed to take this on trust? It is fundamental to a main claim of the paper. Are you referring to what comes much later in Figure 5? If so I would say so.

This is not the same as the amplitude-modulated modes in Figure 5. If one looks at the Kahului spectrogram at 2 minute periods, there is an distinct sine-wave modulation of the resonance periods (frequencies) versus time, e.g. the resonances themselves are frequency-modulated. Since this was not clear to the reviewer, we have changed the text to specifically exemplify the 2 minute mode.

In Figure 2 the 'vertical bands associated with increased energy'. I think I would say that does not mean more percentage of energy above and below the main band but rather a stronger band overall and then it is an artefact of the colouring.

Yes, the vertical bands are instances of increased overall energy, although not uniform increases across the spectrum as in the addition of white noise, but rather the canonical ocean wave spectrum under different sea states.

Also in Kahului, middle right of Figure 2 - the blue band at 0.2 min seems to have streaks that point to the bottom left. What are they?

These are temporospatial energy signatures of swell-events, as mentioned in section 3 Continuous Modes.

p2366 - it would good to know what the tidal range is at these 6 places and the tidal form factors.

We have added this information in the text and table 1.

2367, 12 - I would add ’identified in Figure 3’ after ’spectra’

Changed.

23-26 - there are many statements like this associating a peak in the spectra with some feature of the bay which you can’t possibly know for sure, without at least the use of a local model. Also p2369, 1 and many other places. And 2371, 6. 2372, 6.

If by a model the reviewer is referring to the basic physics of shallow-water wave propagation and wave resonance as outlined in lines 10-15, we agree. If the reviewer is suggesting that a numerical model is the only method to attribute observed water level resonances to spatial features of a bay or harbour, then we respectfully disagree. For example, in the United States the U. S. Army Corps of Engineers is responsible for harbor design, and has a long history of making such attributions based on observation and basic physical principles. For example, work from the early 1960's where numerical models are being vetted against observed modes that have been analytically attributed can be found here: http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=AD0684953

2368, 13 ’power spectra in Figure 3’

Added.

22 - affine? define?

We are referring to a mathematical affinity, a linear mapping between two states, which in this case is sensible in the discussion of dynamical (modal) behavior preservation. We believe that the typical OS reader is sufficiently mathematically erudite and familiar with the term.

2371, 6. What is a pier mode? Again these are plausible statements but you can’t know for sure.

A pier mode refers to a standing wave supported at one boundary by a pier structure extending into the water.

2372, 24-26 - so far you have considered just the 1-d dependence of a shelf mode and so its frequency. To write this sentence you must have an idea of its long-shelf dependence. What is it, in general terms? 2373, 1-4 ditto.

In general the along-shelf modulation is not something that we can consider without a numerical model, or a coherent set of along-shore water level observations. We were able to marginally address it at one location since we have a coherent set of measurements at Hawke and Poverty bays as discussed in section 4.9 Hawke and Poverty. Each coastal location can experience modulations of transverse shelf-waves by along-shore traveling modes (edge-

waves), and of course, variable bathymetry will induce along-shore spatial dependence, and there are certain to be other influences from internal waves, atmospherics etc.

2373, 10 - I don't understand 'shelf mode amplitudes'. There are several modes per site, there is not a unique frequency as I understand it (as you mention later for combining the metamodes), so presumably this is the amplitude of several modes combined or a band?

> We apologize for the confusion. As stated in the manuscript "Fig. 5 plots time series of the shelf-mode amplitudes from the spectrograms shown in Fig. 2". So these are amplitudes over time of the single shelf-mode at each of the stations. Modes other than the shelf-mode are not included. Referring to an excellent paper suggested by the reviewer: Woodworth et al. (JGR 2005 doi:10.1029/2004JC002648), our Figure 5 is the same metric as their Figure 5 "timeseries of seiche amplitude". Pertinent differences are that our amplitudes are determined by spectral analysis, that we present shelf-mode seiche specific to multiple stations, and that we have determined a modal decomposition of the timeseries of seiche amplitude. We have rewritten this to clarify the issue.

I think Figure 5 is very nice and I would stop there. There are clearly fortnightly dependencies which are the object of the paper. I have a problem with the metamode text and onwards with the energetics. I get the general ideas but it is a bit vague what you are doing and for someone unfamiliar with EMD, for example, it won't mean much. Anyway you say later you don't understand the metamodes properly yourself. I would drop the later tables and figures in the paper and the energetics discussion of Section 6, and maybe use them for writing a more theoretical report in the future.

> We would like to clarify that the fortnightly modes are viewed as supporting evidence for the hypothesis that tidally-forced shelf-resonances can be a primary driver of continuous seiche. Sufficient energy is a fundamental criteria for any source attribution hypothesis, and addresses a very simple question: does the proposed forcing mechanism contain sufficient energy to drive and sustain the observed resonances? For example, internal waves in Monterey Bay (which are quite energetic) had been proposed as a prospective driver of observed seiche, but a simple kinematic analysis shows that this is not possible (Park & Sweet, 2015).
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> Regarding the metamodes, as above, their fortnightly modulation provides compelling support for the primary hypothesis, and as far as we are aware, it is a novel concept in oceanographic analysis. We suggest that publication of this line of reasoning along with the questions it raises regarding metamode variability is consistent with scientific inquiry and may lead others to advance the state of knowledge. We therefore respectfully decline your suggestion to remove this material.

Section 7 - I think you will find many places where there is near-continuous seiching due to the ambient wind (the findings might not be published but that's a different issue). I would rewrite this to make it clearer you are looking at the tidal associations which are quite nice. Are any of the bays shallow enough to look at the change in frequency of the seiches with the tide? - Table 2 suggests not I guess.

> Please note that as suggested by Reviewer #2, this material now resides in a Discussion section. We have rewritten this material as noted to better relate the tidal hypothesis. Regarding the wind, as you point out it is difficult to conceive of it as a continuous forcing, rather a near-continuous one, and for that reason we do not consider it a candidate for continuous forcing.
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> Pertinent to the change in frequency, please recall the earlier discussion regarding the 2 minute mode at Kahului, these are exactly as the reviewer suggests, and as noted in the manuscript this has been verified at Monterey (Park and Sweet 2015).

Table 2. Monterey depths - why are 3 listed (harbour, bay and shelf?). Please make it clearer. Others also.

> Thank you for this clarification. Yes, the different depths correspond to representative values over the horizontal dimensions of the respective mode. We have clarified this in the text and the table.

Table 3 caption last line - I would add the estimates are from the nearest peaks in Figure 3. Should the frequency from Merian's formula be the same as for a shelf wave equation solution for a flat shelf?

> Yes, estimates of mode periods from the PSD's are directly from the observed peaks, as marked with triangles in Figure 2. As for an equivalence between Merian's and a wave equation solution, the boundary conditions of the latter will admit multiple solutions that match Merian's simplified geometry estimate.