Comments on 2015 Science Panel Update to 2010 Report and 2012 Addendum

We highly commend the members of the Science Panel for volunteering their time and talents in public service to the people of North Carolina.

The 2015 Science Panel Update to 2010 Report and 2012 Addendum (referred to as SPU) presents two good approaches that use different assumptions to estimate sea level rises by 2045 at tide gauge locations in North Carolina (NC). One approach estimates rises by projecting empirical data measured by the NC tide gauges, which assumes the future reflects that past. The second approach uses sea level projections of the Intergovernmental Panel on Climate Change (IPCC 2013), which are based on IPCC global warming scenarios in which temperature rises more rapidly in the future than the past.

The SPU has two significant problems. Confidence intervals are incorrectly added and subtracted in the report, and it uses a value for global sea level rise that is appropriate for the period 1900 through 2009 but not for the periods of North Carolina tide gauge measurements, leading to projections not supported by the data.

Confidence intervals in SPU were incorrectly added and subtracted, producing errors in most tables. Averages are properly added and subtracted, but variances add for confidence intervals, meaning that confidence intervals are added in quadrature. For example (a ± c) – (b ± c) is not a - b ± 0 and (a ± c) + (b ± c) is not a + b ± 2c. In both cases the confidence interval is $\pm \sqrt{c^2 + c^2} = \pm \sqrt{2}$ c. The following website explains this: http://ipl.physics.harvard.edu/wp-uploads/2013/03/PS3_Error_Propagation_sp13.pdf. Note that IPCC (Church, et al, 2013) adds confidence intervals in quadrature for components of global sea level rise.

As an example of the errors caused by adding confidence intervals incorrectly, for Southport the SPU has (2.0 ± 0.41) - (1.7 ± 0.20) equal to 0.3 ± 0.21. However, the result should be 0.3 ± $\sqrt{(0.41)^2 + (0.2)^2}$ = 0.3 ± 0.46, making the range (- 0.16 to 0.76) rather than (0.09 to 0.51). Another example is in Table 8. The 2015 values for RCP2.6 and RCP8.5 are correctly given as both being about 2.4 ± 0.6 inches and the 2045 values as about 7.7 ± 2.1 inches and 8.7 ± 2.3 inches for RCP2.6 and RCP8.5 respectively. But when the 2015 values are subtracted from the 2045 values, the errors do not subtract, but add in quadrature, so the correct values are 5.3 ± 2.2 inches for RCP2 and 6.3 ± 2.4 inches for RCP8.5. Therefore, results should be 5.3 (3.1 to 7.5) for RCP2.6 and 6.3 (3.9 to 8.7) for RCP8.5 rather than 5.3 (3.9 to 6.8) and 6.3 (4.7 to 7.9) in SPU. The SPU should include a simple discussion and reference that explain how confidence intervals are added and subtracted.

It is not valid to use a global sea level rate of 1.7 ± 0.2 mm/yr over the periods of NC gauge measurements because this rate was determined for 1900 to 2009, whereas global rates during actual times of NC gauge measurements were sometimes much greater. SPU subtracts this unrepresentative low global rate along with subsidence from measured rates and calls the difference “oceanographic effects”. SPU then assumes these “oceanographic effects” continue unchanged for the next 30 years and adds them to IPCC scenarios, and this produces rises by 2045 that are not supported by the data.

The problem of using a global rate not representative of actual rates during periods of gauge measurements is readily seen for Duck and Oregon Inlet. The Duck gauge recorded from 1978 through 2013 and the Oregon Inlet gauge from 1977 through 2013. Satellite altimeters measured a global rise rate of 3.2 ± 0.4 mm/yr from 1993 through 2013 (University of Colorado, 2014). Therefore, for about 60% of the Duck and Oregon Inlet tide gauge records the global rise rate was substantially greater than 1.7 ± 0.2 mm/yr. It is important to realize that in addition to the linear rise of 1.7 mm/yr given in Church and White (2011), they have an acceleration term so the rise rate increases with time, and this is not considered in the SPU. The linear and acceleration terms determined by Church and White could be used to estimate rise rates during periods of NC gauge measurements. However, Church and White's approach underestimates the rise rate measured by satellite altimeters. Church and White use "synthetic data" generated by combining tide gauge data with Empirical Orthogonal Functions, whereas the satellite altimeter data are measured data. Therefore, the satellite altimeter data should be used for 1993 though 2013.

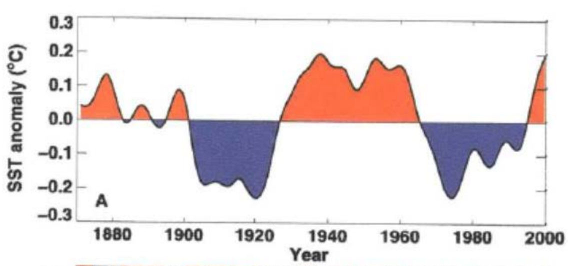
We can estimate the rate from 1978 to 2013 by taking a global rate of 1.9 ± 0.4 mm/yr for 1978 through 1992 (Church and White, 2011, have a global rate of 1.9 ± 0.4 mm/yr for 1961 through 2009, which is much more representative of the time period than the rate from 1900 through 2009) and a global rate of 3.2 mm ± 0.4 mm/yr from 1993 through 2013. Combining these rates gives a global rate from 1978 to 2013 of 2.66 ± 0.4 mm/yr (Ray and Douglas, 2011, show a global rise from 1978 to 2007 of about 2.5 mm/yr that when coupled with a rise from 2007 through 2013 of 3.2 mm/yr results in a similar global rate of 2.6 mm/yr from 1978 through 2013). With subsidence of - 1.49 ± 0.39 at Duck, this gives a relative sea level rise (global rate minus subsidence) of 4.15 ± 0.56 mm/yr (confidence intervals added in quadrature). This compares with the gauge recording of 4.57 ± 0.84 mm/yr over the same period. Note the two rates are within confidence intervals of each other. The same analysis for Oregon Inlet, results in an average global rate from 1977 to 2013 of 2.64 ± 0.4 mm/yr. With a subsidence of - 0.84 ± 0.65 mm/yr, this leads to a relative rise of 3.48 ± 0.76 mm/yr versus the recorded 3.65 ± 1.36 mm/yr. Again, calculated and measured rates are within confidence intervals.

If global sea level rise rates are estimated for Beauford, Wilmington, and Southport using rates of 0.71 ± 0.4 mm/yr prior to 1935 and 1.84 ± 0.19 mm/yr from 1935 to 1961 (Church and White, 2006), 1.9 ± 0.4 mm/yr from 1961 to 1993 (Church and White, 2011), and 3.2 ± 0.4 mm/yr for 1993 through 2013 (University of Colorado, 2014); subtracting the vertical motions of Table 2 from these global rates result in relative sea level rise rates within confidence intervals of the measured rates in Table 1. For all five NC gauges, realistic global rates combined with subsidence yield relative sea level rates within confidence intervals of measured rates. Therefore, "oceanographic effects" must have relatively small magnitudes that are less than confidence intervals of measured rates.

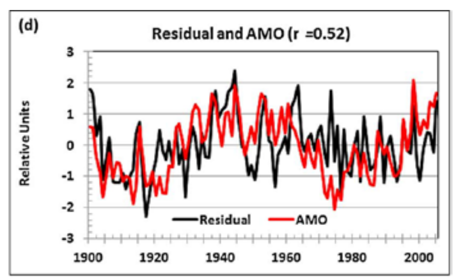
The above method of estimating global rise rates also applies to the gauges north and south of the NC gauges. Figure 5 of the SPU presents a figure from Ezer (2013) that is shown presumably to indicate there is a significant difference in sea level rise north of Cape Hatteras. The figure shows that the Norfolk (Sewell Point) gauge recorded the greatest sea level rise rate and acceleration of the gauges from Key West to Boston, and it is the nearest gauge north of the Duck and Oregon Inlet gauges. Using the same approach as for the NC gauges yields a global rate from 1927 through 2006 of 1.99 ± 0.33 mm/yr. Zervas (2013) shows a subsidence of - 2.61

± 0.11 mm/yr. Combining the calculated rate with subsidence yields 4.60 ± 0.33 mm/yr. Zervas shows the rise measured by the Norfolk tide gauge from 1927 through 2006 was 4.44 ± 0.27 mm/yr. The same approach applied to the Charleston gauge, the nearest long-term gauge south of NC, yields a global and subsidence relative rise of 3.14 ± 0.34 mm/yr versus the rate of 3.15 ± 0.25 mm/yr recorded by the Charleston tide gauge. As was the case for the five NC tide gauges, calculated rates for the Charleston and Norfolk gauges that are based on subsidence and realistic global sea level rates during periods of recording agree within confidence intervals of measured relative sea level rise rates. The average rise rate based on calculated global rates and subsidence for the five NC, Charleston, and Norfolk gauges is 3.15 ± 0.43 mm/yr, and this is in good agreement with the measured average rate for the seven gauges of 3.22 ± 0.55.

There certainly are oceanographic effects that affect sea level along the NC coast such as variations in the Atlantic Multidecadal Oscillation (AMO), North Atlantic Oscillation (NAO), and Gulf Stream as governed by the Atlantic Meridional Overturning Current (AMOC), and other factors. Indeed, Houston and Dean (2014) show that there are multi-decadal oscillations in the rate of sea level rise in every gauge recording in the world. Variations in the AMOC, AMO (see figures), and NAO can affect sea levels along the NC coast, but these variations will not remain constant over the next 30 years as is assumed in SPU ("oceanographic effects" are assumed in SPU to have a constant rate over 30 years when used with the IPCC scenarios). For example, it would not be valid to take falling sea levels on the Pacific Coast measured over the last 22 years by satellite altimeters (caused by an oscillation of the Pacific Decadal Oscillation – PDO), and project that sea level will fall on the Pacific Coast over the next 22 years. Indeed, Bromirski et al (2011) assert just the opposite will occur, the rise in sea level will be greater than the worldwide average along this coast for decades as the PDO reverses. AMO, NAO, and AMOC also have periodic reversals.



AMOC (Buckley, 2011)



AMO (Chylek et al, 2014)

SPU cites journal papers that indicate there has been acceleration in sea level rise in the mid-Atlantic area, but some of the papers also indicate the acceleration may well be a typical variation in decadal oscillations and not enduring. For example, Smeed et al (2014) say that evidence suggests that the decrease in the AMOC, "… represents decadal variability of the AMOC system rather than a response to climate change." Knopp (2013) says, "Consistent with the hypothesis that the regional 'hot spot' represents variability rather than the start of a trend, none of these indexes currently exceeds its range of historical variability. As the changes in these indices reflect the driving factors underlying the 'hot spot', the phenomenon may not prove to be enduring." Varying and non-enduring phenomenon cannot be assumed constant and projected into the future. In any case, magnitude of sea level change rates resulting from "oceanographic effects" are not apparent because relative sea level rates estimated from realistic global and subsidence rates agree within confidence intervals with measurements at all five NC gauge locations and gauges at Charleston and Norfolk.

The SPU should discuss how calculated rises as shown above agree within confidence intervals at all seven gauges, so additional factors other than subsidence should not be added to IPCC projected rises.

The error caused by using a rate of 1.7 ± 0.2 mm/yr at Duck from 1978 to 2013 and then having to postulate "oceanographic effects" that would remain constant for the next 30 year is easily shown. As shown earlier, there is a global sea level rise of 6.3 ± 2.4 in/yr for IPCC scenario RCP 8.5 (confidence intervals added incorrectly in Table 8). If we subtract the vertical motion of - 1.8 ± 0.5 in/yr at Duck, the relative sea level projection becomes 8.1 ± 2.5 in/yr (confidence intervals from adding in quadrature). The low, medium, and high values are therefore 5.6, 8.1, and 10.6 in/yr versus 7.3, 9.7, and 12.3 in/yr in Table 10.

Dropping the incorrect rate of 1.7 ± 0.2 mm/yr as representative of the global rate over the time of NC gauge measurements also simplifies results and makes them more understandable and transparent to non-technical readers. For example, one approach would just multiply measured rates by 30. The second approach would merely combine subsidence over 30 years with IPCC projections. These approaches are simple, understandable, and defensible; in contrast to the current approach in SPU 2015, which is easily criticized and, therefore, likely to be controversial.

Using three sentences to dismiss the possibility of deceleration may not satisfy critics. Satellite altimeters have made the best measurements of sea level rise in the past two decades because they measure over the globe rather than the limited locations of tide gauges and they do not have the problem of vertical land motions that tide gauges have. Satellite altimeter measurements show a decelerating sea level rise. Dean and Houston (2013) show that during the period of satellite altimeter measurements from 1993 to 2011, sea level had a deceleration of - 0.083 mm/yr^2 (deceleration also seen in Figure 5b of the SPU and Ezer, 2013, p. 5441). They analyzed all 456 tide gauges in the world with records from 1993 to 2011 and found a deceleration of - 0.041 mm/yr^2. The altimeter record (University of Colorado, 2014) analyzed from 1992.9595 through 2014.6508 still shows a deceleration of - 0.035 mm/yr^2. However, the record is relatively short and, as noted in Dean and Houston (2013), the deceleration may just be evidence of cyclic behavior - that is, caused by decadal variations. As noted earlier, uncertain and varying phenomena cannot be assumed to remain at current values and then be projected into the future.

With the Duck gauge as an example, projecting the current rate of rise at Duck for 30 years yields an average relative sea level rise of 137.1 ± 25.2 mm. Analysis of the altimeter record from 1992.9595 through 2014.6508 shows that the rise has the form $3.245x – 0.0176x^2$ with x equal to years of record. Over the next 30 years, this rise would produce a global rise of 81.5 ± 12 mm including the deceleration term. Subsidence would add 44.7 ± 11.7 mm/yr for a total of 126.2 ± 23.7 mm. This value is well within the confidence interval of the rise determined by projecting Duck rates without deceleration. Moreover, the difference in the two projections is only 10.9 mm, or 0.4 inches. Assuming the global deceleration for last 22 years will continue unchanged for the next 30 years is not justified, and its effect is small in any case.

Duck is shown in Table 4 to have a substantially greater vertical land motion than does Oregon Inlet, although the tide gauges are only about 30 miles apart. Since the Duck pier pilings are concrete, is it known whether the pier itself is sinking, so that it is not representative of land subsidence in the area? There are bench marks on the pier, in the parking lot, and along the pier access road, so the question can be settled if it has not been already. If settled, a sentence should note that there is not subsidence of the pier relative to land.

Additional comments on SPU 2015 are listed below by page section and page.

Executive Summary

We suggest a brief introductory paragraph in the Executive Summary. Something like:

"Two bases for quantifying global sea level change are reported in the scientific literature: (1) sea level as observed directly by tide gauges, and (2) volumetric changes including the best estimate of the average global subsidence of the sea floor (0.3 mm/yr) due to Glacial Isostatic Adjustment (GIA) as reported in the satellite altimeter measurements and calculations by Church and White (2006, 2011) and others. In this report, the first basis is used as the most relevant to those who will use the results."

We also suggest an expanded discussion of the above be included as an early section of the main text of the report. The 0.3 mm/yr is relevant to the SPU because IPCC projections include the GIA average global sea floor subsidence of 0.3 mm/yr. When IPCC projections are used to determine local relative rise projections, they are too large by 0.3 mm/yr because they include the effect of global sea floor subsidence. However, Zervas (2013) subtracted 1.7 mm/yr (includes the GIA value of 0.3 mm/yr) instead of 1.4 mm/yr to determine local subsidence. Therefore, subsidence values are too low by 0.3 mm/yr. The 0.3 mm/yr portions of IPCC projections and subsidence values offset, so IPCC and subsidence numbers are properly added (as done in the SPU) to determine relative sea level change at NC tide gauges.

Also, early in the main body of the report or alternatively as a table preceding the report there should be a description of terms and acronyms including: Relative Sea Rise (RSL), etc.

Page 1. Ezer and Atkinson 2014 does not appear in the references.

Page 2. Fairbanks (1989) does not appear in the references.

Page 4. Table 1 has a percentage contribution to sea level rise from the Greenland and Antarctic ice sheets for the period from 1971 to 2010, but it is based on Table 13.1 of Church et al (2013), which does not have percentage contributions for these ice sheets for the period. SPU apparently assumes the numbers must add to 100%, but contributions are so uncertain that Church et al (2013) do not give percentages for either ice sheet. We suggest instead percentages be presented for the period shown in Table 13.1 from 1993 to 2010, because Greenland and Antarctic ice sheet contributions are given (it appears the total should be 2.94 rather than 2.8 mm/yr). In addition, the 1993 to 2010 rates give a better appreciation of current contributions to sea level rise. For example, “Land water storage”, which includes water impoundment and groundwater extraction, is shown in Table 1 to be only 6% of the contribution to sea level rise, whereas Table 13.1 has it contributing 13%, illustrating how important groundwater extraction has become to sea level rise.

Page 7.

Eggleston et al. 2013 should be Eggleston and Pope 2013.
The reference should be Engelhart et al. 2009 and not Englehart et al. 2009.

The acronym NCDENR appears without being defined as North Carolina Department of Environment and Natural Resources

Page 9.

Text says, “The present rate of GSL rise is 1.7 mm/yr (Church and White, 2011) …” Of course, this is not the present rate, but the average rate from 1900 to 2009. The present rate as measured by satellite altimeters from 1993 through the present is 3.2 mm/yr (University of Colorado, 2014).

Page 10.

Spanger-Siegfried et al. (2014) is a non-peer-reviewed internet article authored by an advocacy group. There are many non-peer-reviewed internet articles authored by skeptics of global warming and increased sea level rise that also could be cited, so we suggest dropping the reference. In addition, NOAA (June 2014) isn’t referenced although it focuses on nuisance flooding (Sea Level Rise and Nuisance Flood Frequency Changes around the United States, NOAA Technical Report NOS CO-OPS 073, http://tidesandcurrents.noaa.gov/publications/NOAA_Technical_Report_NOS_COOPS_073.pdf)

We recommend the reference to the 2014 National Climate Assessment (actual citation should be Melillo et al 2014 rather than Melillo 2014) be dropped because it has about a page of its 841 pages devoted to sea level rise. It has no original information, but bases its maximum projected sea level rise on the intermediate high listed in NOAA 2012. The NOAA report says the intermediate high is, “… based on an average of the high end of semi-empirical, global SLR projections.” IPCC 2013 (page 1140) said of semi-empirical modeling, “…there is no consensus in the scientific community about their reliability, and consequently low confidence in projections based on them.” A couple of authors of IPCC 2013 have used semi-empirical models and published papers, but they agreed with the IPCC statement that there is low confidence in projections based on semi-empirical modeling.

Pages 9-11.

The discussion of “oceanographic effects” is interesting, but as discussed earlier, the section should be eliminated or shortened with an emphasis on the effects having a magnitude less than confidence intervals and being oscillatory and likely non-enduring as pointed out by Smeed et al (2014) and Knopp (2013). As discussed earlier, the usefulness of Figure 5 is not apparent because subsidence combined with global rates equals measured rates within confidence intervals for the tide gauges from Charleston to Norfolk.

Page 12.

The acronym NWLON is never used.
Text says Yelverton and Hackney 1990, but references say Hackney, C.T. and G.F. Yelverton. 1990.

Page 23.

Sweet and Parker 2014 should be Sweet et al 2014.

Page 24.

The text says that, “One of the major sources of uncertainty in estimates of sea level rise even over a period as short as 30 years is introduced by our limited understanding of the rates of loss of the Greenland and West Antarctic ice shelves. The rates of melting and ice sheet loss into the sea are highly uncertain and could occur rapidly.” These sentences have an element of hyperbole. The IPCC numbers in Table AII 7.7 include uncertainties in loss of ice in Greenland and West Antarctica. In 2045, even for Scenario RCP 8.5, the upper confidence level is only 2.4 inches higher than the average and only part of this uncertainty is due to uncertainty in the loss of ice in Greenland and West Antarctica. There have been a number of media releases in 2014 emphasizing studies that indicate the West Antarctic ice sheet has started to collapse and the collapse is unstoppable. Joughin et al (2014) is the only one of these studies with a projected sea level rise rate resulting from this beginning collapse. They note that losses in the 21st century due to the beginning collapse of the West Antarctic ice sheet at the Thwaites glacier (which would eventually release other glaciers – in hundreds of years) will be less than 0.25 mm/yr with a more rapid rise of greater than 1 mm/yr within the range of 200 to 900 years from now. A rise of less than 0.25 mm/yr results in a rise over the next 30 years of less than 0.3 inches, and is largely accounted for in current IPCC projections.

The reference Boon, J. D., J. M. Brubaker, and D. R. Forrest (2010) is not found in the text.

Page 27.

The reference Horton, B.P., W.R. Peltier, S.J. Culver, R. Drummond, S.E. Engelhart, A.C. Kemp, D. Mallinson, E.R. Thieler, S.R. Riggs, D.V. Ames, and K.H. Thomson, 2009 does not appear in the text.

References cited in comments

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Ray, R.D. and Douglas, B.C., 2011. Experiments in reconstructing twentieth-century sea levels, *Progress in Oceanography*, 91, 496-515.

University of Colorado, 2014. 2014_rel5: Global Mean Sea Level Time Series (seasonal signals removed). http://sealevel.colorado.edu/

Reply to comments by Houston and Dean

We first extend our appreciation to our reviewers for their time and careful consideration of this report and methodology. Two issues that impact the calculation of the range of future sea level rise projections are the primary focus of the review comments. They are 1) how the confidence interval or range of projections for each component is treated mathematically as elements are combined in the methodology and 2) the assessment of local effects and how these are used in combination with the IPCC projections. The Panel has considered these comments and a synthesis of our discussions are provided below. The additional comments were more editorial in nature and will be considered in our revised draft in March.

1) The Panel discussed possible inclusion of 'quadrature' in assessing limits or ranges of estimates in our November meeting and is revisiting our proposed methodology based on the reviewers' comments. Because of the expression of range of estimates in the Table ll.7.7 of Annex ll: Climate System Scenario Tables is not a confidence interval, we have asked for additional review from statistics at NC State on our methodology and will not have their input until later this month. At that time we plan to update our calculations and will communicate with the reviewers on the outcome.

2) The reviewers note that the length of record for the gauge at Duck is not consistent with the time period used to establish a global SLR of 1.7 mm/yr and conclude that therefore the computed local effect at Duck is in error. Further, they suggest an alternative computation which would result in a conclusion that the local effect can be explained by the local VLM (vertical land motion) only.

The Panel recognizes the issues with respect to length of record of the tide gauges and the time period of the record relative to assessment of global sea level rise and in the November meeting considered using different rates for different gages. The primary tide gauge that has spurred this discussion is the Duck gauge. The time frame of operation of this gauge and the Oregon Inlet gauge are the shortest in North Carolina, spanning the late 1970s to present time frame (data through the end of 2013 were employed for the report). The panel spent considerable time discussing the issue of the different time periods of measurement for each of the gauges including an analysis offered by Tom Jarrett that could simulate the extension of the time series at Duck in order to be more consistent with the time frame for the use of 1.7 mm/yr. As a result of this discussion the Panel recommended that the time series issue should be dealt with as a special project outside the work of the Panel.

In response to the reviewers' comments we offer the following discussion. The time frame of operation of the Duck gauge coincides with a measured increase in the rates of sea level rise along the mid-Atlantic region (consistent with the reviewers' analysis). The question at hand is whether this measured increase reflects a global increase or is local. In addition, if local, will the effect persist for the 30 year response period requested by the CRC or is it other (i.e., cyclic or not persisting). In our draft, the Panel made the assumption that the local effect was separate from the global and would persist into the future. This assumption is clearly stated and the numbers reflect that approach. The Panel felt that it was responsible to acknowledge the possibility that local effects including oceanographic factors could persist and to bring this information to the attention those making management decisions. After discussion in the January meeting, the Panel decided to keep this analysis in the report.

Because it is an assumption and we recognize it as such, we can compute and present the alternative formulation (considering the IPCC projections in combination with the VLM numbers) in order to communicate the magnitude of the difference in the projections by making this assumption. Using VLM directly eliminates the step of assuming a global sea level rise rate in the proposed methodology. Using the updated 2013 VLM values as computed by Zervas essentially reduces the local effects at Duck and Oregon Inlet 1-2 inches in the 30 year projection since these gauges have the shorter temporal records and are located north of Cape Hatteras where the increase in the mid-Atlantic rates has been observed. Projections for the Beaufort gauge remain the same and Wilmington and Southport differ by less than 1 inch. (see table below). Note, the magnitude of the high and the low of the local effect and the difference may change when procedures for error analysis are finalized.

Station	Local Effects			VLM Effects			Difference		
	Relative Sea Level Rise by 2045, inches			Relative Sea Level Rise by 2045, inches			Relative Sea Level Rise by 2045, inches		
	Mean	**High**	**Low**	**Mean**	**High**	**Low**	**Mean**	**High**	**Low**
Duck	3.4	4.2	2.6	1.8	2.2	1.3	-1.6	-2.0	-1.3
Oregon Inlet Marina	2.3	3.7	0.9	1.0	1.8	0.2	-1.3	-1.9	-0.7
Beaufort	1.2	1.4	1.0	1.2	1.4	1.0	0.0	0.0	0.0
Wilmington	0.4	0.6	0.2	0.5	0.7	0.2	0.1	0.1	0.0
Southport	0.4	0.6	0.1	0.6	0.8	0.4	0.2	0.2	0.3

The issue of the impact of the length of record and time period of the record of the tide gauges on the computations (including VLM) is important as the state considers how to use the information and our recommendation for further analysis will likely remain in the report.

The Science Panel has not adequately addressed our comments on the Science Panel Update (SPU), and, therefore, in its present form the SPU is not publishable as we expected in a referred journal. The Panel did not rebut our criticisms of assumptions underlying one of its key approaches. Instead it merely said the assumptions were clearly stated. However, these assumptions were not justified in the SPU or in a rebuttal of our criticisms. Assumptions must be clearly justified, not merely clearly stated.

The Panel's one action that was responsive was to indicate it would include in one part of a table sea level rises based on the standard approach of adding IPCC projections and vertical ground. We recommended this approach because local and global data presented in the SPU provided no evidence of a persistent local effect other than ground motion that would cause an extra increase in sea level rise on the NC coast over the next 30 years.

The Panel did not address our comments relating to adding and subtracting errors. The approach used in the SPU is embarrassingly incorrect, and the Panel should have simply admitted so and made corrections. It is good the Panel will be seeking help from NC State. However, it is important to provide NC State with correct information. For example, the Panel's response says, "…the expression of range of estimates in the Table ll.7.7 of Annex ll: Climate System Scenario Tables is not a confidence interval." This is incorrect. Table II.7.7 of Annex II uses the term "likely range" and says to go to Section 13.5.1 of "Sea Level Change" of IPCC (2013) to see what this means. On page 1184 of Section 13.5.1 (entitled "Confidence in Likely Ranges and Bounds"), it says "The AR5 5 to 95% process-based model range is interpreted as a likely range". The IPCC numbers all have 95% confidence intervals.

Even if the Panel was not sure about the IPCC numbers, it should have been clear that the NOAA sea level rise rates, vertical land motion, and global rates from Church and White (2011) all had confidence intervals, so it is inexplicable that the Panel did not agree with our comments and correct the SPU. The NOAA (2014) sea level rise rates have confidence intervals as can be seen in Table ES1 of the SPU report itself, which has the caption, "Sea level rise over 30 years at existing published rates of sea level rise (NOAA 2014). Magnitude of rise was determined by multiplying the rate ± the 95% confidence interval…" VLM numbers from Zervas (2013) have confidence intervals as noted in the following from Zervas, "Table 1 lists the published relative NOAA sea level trend for each station (along with the 95% Confidence Interval of the trend) and the estimated rate of VLM (along with the 95% Confidence Interval) using the methodology described above." The projections of Church and White (2011) have standard deviation confidence intervals.

Had the errors been simple average errors rather than confidence intervals, the absolute value of the errors would have had to have been added regardless of whether the means were added or subtracted. In any case, the approach used in the SPU is glaringly incorrect. The website below explains how to add and subtract both simple average errors and confidence intervals. http://www.rit.edu/cos/uphysics/uncertainties/Uncertaintiespart2.html.

The Panel's response says, "The reviewers note that the length of record for the gauge at Duck is not consistent with the time period used to establish a global SLR of 1.7 mm/yr and conclude that therefore the computed local effect at Duck is in error." Actually, this comment holds for all the NC gauges with the lack of consistency being greater the shorter the record. The SPU approach results in spurious "local effects" for all gauges with the spurious effects being about equally large at Oregon Inlet and Duck. We noted in our review that it was not valid to use a global sea level rate of 1.7 mm/yr over the periods of NC gauge measurements because this rate was determined for 1900 to 2009, whereas global rates during actual times of NC gauge measurements were all greater, and sometimes much greater. We showed for all the NC gauges and for the Norfolk and Charleston gauges that if a simple approach is used to estimate realistic global sea level rates, when these rates are added to vertical motion rates, the results match measured data within confidence intervals for every gauge - that is, there are no residuals for any of the gauges. The SPU only obtains residuals that it calls "local effects" because 1.7 mm/yr is lower than the actual global sea level rise rates during the periods of tide gauge measurements. No one would claim that the global rise in sea level was 1.7 mm/yr from 1977 (Oregon Inlet gauge) or 1978 (Duck gauge) to 2013, when satellite altimeters (and tide gauges within confidence intervals) say the rise from late 1992 to 2013 was 3.2 mm/yr. We do not know yet if the increase in global sea level rise from the early 1990s to today is an enduring increase or a multidecadal variation. However, there is no doubt from measurements that it occurred and the global sea level rate from 1977 or 1978 to 2013 was a good deal greater than 1.7 mm/yr. The SPU did not justify using the incorrect global rise of 1.7 mm/yr during gauge measurements, but just "assumed" it was true and as a result obtained spurious local effects. If realistic values for global rates during periods of gauge measurements are used, these residuals all disappear (within confidence intervals of measurements). The Panel's response provided no rebuttal of our demonstration that the global sea level rate it used over the periods of NC gauge measurements was incorrect and led to its spurious "local effects".

We also showed in our comments that even if there had been local effects, the SPU's own references, which it uses to justify projecting the effects forward, do not support projecting varying and non-enduring phenomena forward. We noted that Smeed et al (2014) say that evidence suggests that the decrease in the AMOC, "… represents decadal variability of the AMOC system rather than a response to climate change." We noted that Knopp (2013) says, "Consistent with the hypothesis that the regional 'hot spot' represents variability rather than the start of a trend, none of these indexes currently exceeds its range of historical variability. As the changes in these indices reflect the driving factors underlying the 'hot spot', the phenomenon may not prove to be enduring." Eber (2013) says, "The results suggest that global SLR is accelerating in recent years but that this acceleration is a combination of long-term trends and multidecadal variations." IPCC (2013) projections include acceleration and are the best source for determining the long-term global trend that Eber noted. "Multidecadal variations" that Eber noted north of Cape Hatteras are oscillatory, and even if they were significant today in NC, they would have different values in 30 years, and could even have phases that reduce sea level rise somewhat. We also provided a classic case of why a multidecadal variation on the Pacific Coast of the US, which has resulted in an actual fall in sea level over more than 20 years, cannot be projected forward at present values. As we noted in our review, "Varying and non-enduring phenomenon cannot be assumed constant and projected into the future." The Panel provides no rebuttal of our criticism and no justification for carrying forward a varying and non-enduring effect, even if it were shown to exist.

In its response, the Panel justifies using a 1.7 mm/yr rate and assuming the resulting local effects persist unchanged for 30 years because it says they are "clearly stated" assumptions. However, the Panel cannot justify assumptions that are not supported by evidence by merely saying the assumptions are clearly stated. Incorrect assumptions lead to incorrect outcomes regardless of how clearly the incorrect assumptions are stated.

The Panel did not even comment on our question as to whether the Duck pier might be sinking relative to land.

We had numerous comments on the last four pages of our review of the SPU, and none of these comments were addressed by the Panel. It only said it would "consider" the comments. Considering comments and addressing them are not the same.

An adequate response would have sent the latest version of the draft report and provided real responses to our comments. The Panel would have addressed our comments by rebutting our criticisms and justifying its assumptions or agreeing with us and changing its approach. Instead it basically ignored the comments, providing no rebuttals and keeping assumptions that it does not justify.

We recommend that the Panel adequately address our comments even with the pressing time constraints. It can easily remove the approach in the SPU that it has not been able to justify, making the SPU simple, understandable, and defensible. We would happy to review another version of the SPU to determine if it is publishable.

Reply to comments by Houston and Dean from January 17th

1) *Calculation of confidence intervals.*

The reviewers were correct in pointing out that the propagation of error in the estimates should be added in quadrature. Therefore, the 30 year change in sea level for RCP 2.6 and RCP 8.5 is 5.3 (3.1 to 7.6) inches and 6.3 (3.8 to 8.8) inches, respectively. This has also been incorporated into the projections including VLM (see No. 2).

2) *Estimation of local effects and use of 1.7 ± 0.2 mm/yr for global sea level rise.*

The panel appreciates the detailed review comments related to global and local sea level rates and their computation. The Panel met on March 13, 2015 and has agreed to adopt the approach of combining the IPCC projections with VLM estimates from Zervas. The revised projections presented in the table below have also been combined considering quadrature error propagation as discussed above.

RCP 2.6 + VLM				
	Mean	**Low**	**High**	**95% CI**
Duck	7.1	4.8	9.4	2.3
OI	6.3	3.9	8.7	2.4
Beaufort	6.5	4.2	8.7	2.3
Wilmington	5.8	3.5	8.0	2.3
Southport	5.9	3.7	8.2	2.3
RCP 8.5 + VLM				
	Mean	**Low**	**High**	**95% CI**
Duck	8.1	5.5	10.6	2.5
OI	7.3	4.7	9.9	2.6
Beaufort	7.5	5.0	10.0	2.5
Wilmington	6.8	4.3	9.3	2.5
Southport	6.9	4.4	9.4	2.5

Note that the VLM and IPCC confidence intervals were added in quadrature.

3) *Since the Duck pier pilings are concrete, is it known whether the pier itself is sinking, so that it is not representative of land subsidence in the area?*

As part of NOAA's maintenance program, they routinely (once or twice a year) run a new level from the land-based benchmarks to the gauge. These data show that the pier has not settled.

4) *Using three sentences to dismiss the possibility of deceleration may not satisfy critics.*

We have changed the structure and revised these sections to separate Potential Decrease in Sea Level Rise (now section 5.2) from Potential Increase in Sea Level Rise (now section 5.3). We have revised Section 5.2 based on the comments as follows:

5.2 Potential Decrease in Sea Level Rise

The Science Panel examined the scientific research regarding deceleration of sea level rise, meaning a rate lower than existing published global rates of sea level rise, over the next 30 years. There have been many efforts to detect acceleration or deceleration in the past sea level record. AR5 (Rhein et al. 2013) discusses these studies and concludes, as have others (Houston and Dean 2011, 2013; Houston 2013, Chambers et al. 2012), that strong multi-decadal variations in the tide gauge record make it difficult to detect whether there is a long term acceleration or deceleration using record lengths less than 60 years (see also Section 3.2). While researchers using both tide data and altimetry data have reported analyses that observe deceleration in sea level records (e.g., Houston and Dean 2011, 2013; Ezer 2013), the signal is small and indicative of cyclic or multi-decadal variations. Houston (2013) summarizes the existing studies and concludes that the range of acceleration in the existing record is from -0.01 to 0.01 mm/yr2, or just ±0.18 inches over 30 years, so not a significant factor. There is therefore no justification to apply a global deceleration factor to existing gauge rate projections for the next 30 years.

5) *We suggest a brief introductory paragraph in the Executive Summary and an expanded discussion of GIA in the body of the report.*

A brief note on GIA has been added to the body of the report. However, we have not modified the Executive Summary to include comments on GIA because we are not emphasizing this factor as a result in itself but rather as a contributor to the results.

Section 3.1 Vertical Land Motion (VLM)

This phenomenon also causes some ocean basins to be subsiding as mantle material moves from under the oceans into previously glaciated regions on land.

In addition a reference to satellite data has been added to **Section 8 Recommendations for Updating the Report**:

Continued monitoring of global and regional sea levels using satellite data will improve as the record length is extended, and these data should be reviewed for consideration in future reports. This will also provide the opportunity to examine coincident time frames with varying data sources (i.e., satellite altimetry and tide gauges).

7) *There should be a description of terms and acronyms including Relative Sea Rise (RSL), etc.*

After the Table of Contents a section describing Terms and Acronyms has been added.

This list is referred to by page number in the review

Pg 1 *Ezer and Atkinson 2014 does not appear in the references.*

The reference below has been added to the list of references:

Ezer, T. and L.P. Atkinson, 2014. Accelerated flooding along the U. S. East Coast: On the impact of sea level rise, tides, storms, the Gulf Stream and the North Atlantic Oscillations. Earth's Future, 2(8), 362-382, doi:10.1002/2014EF000252

Pg 2 *Fairbanks (1989) does not appear in the references.*

The reference below has been added to the list of references:

Fairbanks, R.G., 1989. A 17,000 year glacio-eustatic sea level record: influence of glacial melting rates on the Younger Dryas event and deep ocean circulation. Nature, 342, 637-642.

Pg 4. *Table*

Suggested edits to table using 1993-2010 timeframe have been made.

Pg 7 *Eggleston et al. 2013 should be Eggleston and Pope 2013 and the acronym NCDENR appears without being defined as North Carolina Department of Environment and Natural Resource*

Changes made to revise to Eggleston and Pope 2013 and acronym has been replaced with "NC Department of Environment and Natural Resources"

Pg 9 *Text says, "The present rate of GSL rise is 1.7 mm/yr (Church and White, 2011) …" Of course, this is not the present rate, but the average rate from 1900 to 2009. The present rate as measured by satellite altimeters from 1993 through the present is 3.2 mm/yr (University of Colorado, 2014).*

The sentence is changed to "….the global sea level rise average rate from 1900 to 2009…"

Pg 10 *Spanger-Siegfried et al. (2014) is a non-peer-reviewed internet article authored by an advocacy group…. We suggest dropping the sentence*

This sentence was deleted and Spanger-Siegfried removed from references.

Pg 9-11 *oceanographic effects*

Figure 5 and references to it have been removed and conclusion has been added that:

At this stage, it is unknown whether oceanographic effects on RSL will persist into the future; however, this is an important area of current oceanographic research which should be followed closely in future sea level rise assessment reports.

Panel feels this discussion is important to bring forward and an area of research that should be followed closely.

Pg 12 *a) The acronym NWLON is never used. B) Text says Yelverton and Hackney 1990, but references say Hackney, C.T. and G.F. Yelverton. 1990.*

Acronym NWLON has been removed.

Citation has been corrected to Hackney and Yelverton 1990

Pg 23 *Sweet and Parker 2014 should be Sweet et al 2014.*

This has been corrected and an additional citation of Sweet and Park 2014 has been added.

Pg 24 *The text says that, "One of the major sources of uncertainty in estimates of sea level rise even over a period as short as 30 years is introduced by our limited understanding of the rates of loss of the Greenland and West Antarctic ice shelves. The rates of melting and ice sheet loss into the sea are highly uncertain and could occur rapidly." These sentences have an element of hyperbole.*

The paragraph has been rephrased as:

The short 30-year period also allows increased confidence in the forecast, relative to a 60 or 100 year forecast during which more rapid climate change is expected. One of the major sources of uncertainty in estimates of sea level rise is the behavior of ice sheets. However, the IPCC states that only the collapse of marine-based sectors of the Antarctic ice sheet, if initiated, could cause global mean sea level to rise substantially about the likely predicted range during the 21st century (Church et al. 2013). As research evolves with more data and our understanding of these phenomena improves, forecasts will be updated. This is one of the many reasons that the Panel recommends updating this report every five years.

Pg 27 *The reference Horton, B.P., W.R. Peltier, S.J. Culver, R. Drummond, S.E. Engelhart, A.C. Kemp, D. Mallinson, E.R. Thieler, S.R. Riggs, D.V. Ames, and K.H. Thomson, 2009 does not appear in the text.*

Citation of this reference has been added to p. 6.

The Science Panel's reply to comments that Professor Bob Dean and I made was thorough and quite responsive.

I highly commend Science Panel members for the many hours they spent and expertise they contributed in developing the Science Panel Update (SPU). Their task was difficult, but they successfully adhered to a tight schedule to produce the SPU on time and in accordance with NC General Assembly Session Law 2012-202. The State of North Carolina is indebted to them for their voluntary service and the fine product they produced. Special recognition must be given to Professor Margery Overton for her leadership as Chair of the SPU. The State also is very much indebted to Mr Frank Gorham, Chairman, Coastal Resource Commission, who set up a process that stayed on schedule and faithfully followed a peer review process.

Projecting future sea level rise is a difficult task, given that there are many uncertainties in everything from local ground motions to local oceanographic processes to global sea level change. The SPU presents two basic approaches to project sea level change over the next 30 years in North Carolina. First, it takes empirical data of relative sea level rise rates (that include ground motions) at five NC gauges and projects the rates into the future. Second, it takes the 2013 projections of global sea level rise made by the Intergovernmental Panel on Climate Change (IPCC) and adds local ground motion determined by Zervas (2014). The first approach provides an estimate of relative sea level rise at the NC gauges if the rise in the future is the same as in the past. The second approach provides an estimate of relative sea level rise if climate projections made by the IPCC occur. These two approaches cover the likely range of sea level rise over the next 30 years.

I believe the SPU is a good contribution to the scientific literature and agree with SPU recommendations for further research and a five-year update. I recommend the highlights of the SPU be submitted to a peer-reviewed journal for publication. Many states and local communities would be interested in the approach.

I discussed the SPU with Professor Bob Dean up to three days before his death, including the conversation Professor Overton and I had about the planned SPU response to our comments. He would have agreed with all of my comments above.

James R. Houston
Director Emeritus
Engineer Research and Development Center
Corps of Engineers

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