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.

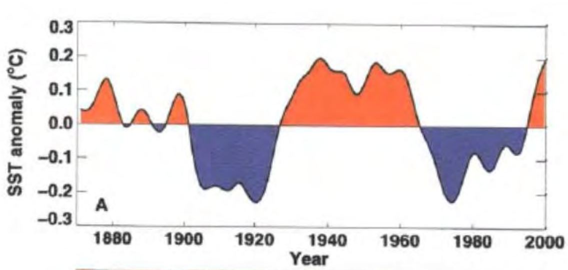
We can estimate the rate from 1978 to 2013 by taking a global rate of 1.9 ± 0.4 mm/yr for 1978 through 1992 (Church and White, 2011, have a global rate of 1.9 ± 0.4 mm/yr for 1961 through 2009, which is much more representative of the time period than the rate from 1900 through 2009) and a global rate 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.

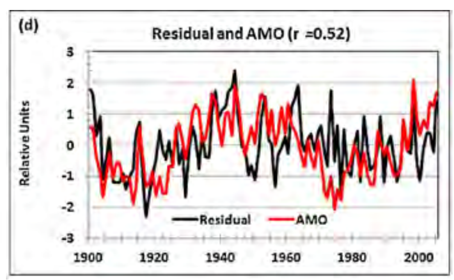
The above method of estimating global rise rates also applies to the gauges north and south of the NC gauges. Figure 5 of the SPU presents a figure from Ezer (2013) that is shown presumably to indicate there is a significant difference in sea level rise north of Cape Hatteras. The figure shows that the 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

Bromirski, P.D.; Miller, A.J.; Flick, R.E., and Auad, G., 2011. Dynamical suppression of sea level rise along the Pacific Coast of North America: Indications for imminent acceleration. *Journal of Geophysical Research–Climate*, 116, C7, doi: 10.1029/2010JC006759.

Buckley, M.W., 2011, Decadal variability of the Atlantic Meridional Overturning Circulation, Dissertation, Massachusetts Institute of Technology. http://dspace.mit.edu/handle/1721.1/68891#files-area.

Church, J.A. and White, N.J., 2006. 20th century acceleration in global sea-level rise. *Geophysical Research Letter*s, 33, L01602, doi:10.1029/2005GL024826.

Chylek, P., Klett, J.S., Lesins, G., Dubey, M.K. Hengartner, N., 2014. The Atlantic Multidecadal Oscillation as a dominant factor of oceanic influence on climate, *Geophysical Research Lette*rs, 1689-1697, 10.1002/2014GL059274. http://onlinelibrary.wiley.com/doi/10.1002/2014GL059274/pdf

Dean, R.G. and J.R. Houston, 2013. "Recent sea level trends and accelerations: Comparison of tide gauges and satellite altimeters," Coastal Engineering, 75, 4

Joughin, I., Smith, B.E., and Medley, B., 2014. Marine Ice Sheet Collapse Potentially Under Way for the Thwaites Glacier Basin, West Antarctica, *Science*, 344, 735-738.

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/