July 28, 2015

Chairman Lamborn, Ranking Member Lowenthal, and members of the Committee:

I am John Englander, an oceanographer, independent consultant, and author of the book, *High Tide On Main Street: Rising Sea Level and the Coming Coastal Crisis.* (2nd Ed, 2013, The Science Bookshelf)

Thank you for inviting me to comment on the implementation of the Coastal Zone Management Act. Your oversight of that important legislation is a good opportunity to consider the profound changes in the coastline that are just beginning to occur and will almost certainly accelerate in the decades ahead. I believe that looking forward to new perspectives about our coastal zone management is a truly important role for your subcommittee and the Natural Resources Committee and deserves a high priority.

Throughout human civilization we have recognized the highly dynamic aspects of the broad coastal zone, particularly the varying tides and storms, and shoreline erosion or accretion. Yet, it was generally assumed that the base sea level was rather stable. That was a commonsense belief as the fundamental height of the ocean had changed little in all of recorded human history, going back some five or six thousand years.

Understanding of the ice age cycles, however, gives a critical perspective that is key to recognizing the new era we are now entering. Thus I would like to briefly explain the ice ages and the implications for future sea level change, as that will directly impact how we define and manage the coastal zone. Over long periods of time, centuries and millennia, the amount of ice and sea level vary inversely, in response to climate shifts, that is, long-term average temperature change.

With the natural cycles of glacial advance and retreat, sea level moves up and down roughly 300 to 400 feet, moving typical coastlines many miles inland or seaward. This phenomenon has been occurring in a regular pattern roughly every hundred thousand years (more precisely varying between 95 and 125 thousand years).

The most recent ice age extreme (Last Glacial Maximum) was some twenty thousand years ago. At that time ice sheets miles thick covered much of the northern hemisphere. Sea level was 390 feet lower than at present. As the ice melted, the sea rose for some fifteen thousand years when it stabilized at roughly the current height. That sea level change is shown in attached Exhibit A, illustrating how sea level rose since the last glacial maximum.

In Exhibit B, a chart of the last four hundred thousand years, that last glacial warming period is put in a larger perspective, looking at several full ice age cycles with the accompanying up and down of sea level. The red graph in the middle, shows global average temperature, and easily identifies four ice age cycles. The blue graph at the bottom shows the respective sea level. The green graph at the top, represents the carbon dioxide (CO_2) concentration.

At the last warm point in the cycle, 120,000 years ago, average global temperature was approximately the same as present and base sea level reached a height approximately twenty-five feet above the present. It is almost inevitable that our future sea level will eventually exceed that height. The key question of course is how long it will take to occur. The consensus thinking among scientists is that it will take centuries, though the evidence of increased melting in key locations continues to accumulate in recent years.

Over the last twenty-five years, the Intergovernmental Panel on Climate Change (IPCC) has published projections for SLR, though even they have rather consistently been on the low side. In Exhibit C, the 1990 projections are shown in blue with various spreads of possibility. The 2002 projections are shown in green, a little higher than the previous projection. Actual sea level is shown in gold, with a smoothed out trend line in red. While there is considerable variation, it is clear that even for the last decade or two, that official projections for sea level, underestimate the rise, more often than not.

The fact is that there is large uncertainty as to just how quickly the glaciers and ice sheets on land will melt. That depends on how warm the planet becomes, which in turn largely depends on the levels of the 'greenhouse gases' (GHG) and the unknown tipping points and feedback loops for the collapse of the ice.

Again referring to the three-part chart in Exhibit B, there is a long-term close correlation of sea level, average global temperature and carbon dioxide levels, with CO_2 being the GHG of greatest concern.

In that regard, I was very pleased to see the statement by your subcommittee featuring the support of alternative energy sources such as wind, solar, hydropower, biomass, and nuclear. They are most likely the key to reducing the growth of GHG and slowing the warming.

However, it needs to be noted that even if all GHG emissions were stopped today there is enough heat already stored in the ocean to guarantee sea level will rise for centuries. The rate of rise can be slowed but it can no longer be stopped in the foreseeable future.

We need to recognize that rise sea level rise is quite different than the temporary flooding from storms along the coast. The damaging wave action of storms is typically confined to the shoreline with storm surge affecting adjacent coastal waterways, all of which recedes in a very short time.

With rising sea level saltwater percolates through porous rock, getting into the fresh water table, flooding highly productive and ecologically sensitive marshlands, and extending up tidal rivers. Though not as dramatic as a severe storm, the affected area is far broader. As a result for each foot of vertical sea level rise the *average* shoreline is estimated to move inland roughly three hundred feet.

Given the importance of higher sea level to coastal facilities such as refineries, transfer terminals, wind farms, hydropower, ocean energy, and the infrastructure associated with traditional energy sources, I submit that this is a very important topic for consideration by your Committee.

There will be tremendous losses of assets, "write offs", as vast areas of land go underwater with increasing frequency during flood events, and eventually permanently. What is often overlooked is that there will also be tremendous opportunities for economic growth as we adapt to this new reality.

Now is the right time to see the future that is just over the horizon and will soon be at our shores – just like a tsunami racing invisibly across the sea at four hundred miles an hour, only becoming visible moments before impact. In this case I am using the tsunami as a metaphor for the relatively slow sea level rise.

But make no mistake the speed of the ice that is now melting on Greenland and Antarctica is happening at "warp speed' in geologic time. The pace of warming is tens or even a hundred times faster than at any known period in the last five hundred million years of geologic history.

Since this is without precedent in recorded human history and is often misunderstood, it may be worth reviewing the factors that contribute to sea level rise. Primarily it is the melting of ice on land, the glaciers and ice sheets, which can enter the ocean as icebergs (glacier fragments) or melt water. Another factor is the slight expansion of seawater as it warms. Such *thermal expansion* has been a major factor in the last century causing nearly four inches of global sea level increase, but that will almost certainly be overwhelmed by the ice melt in the coming century. (There are also other nuanced factors that can affect sea level, such as changing ocean currents and global mass redistribution, though I suspect those are beyond the scope of the subcommittee's inquiry.)

Certain locations vary considerably from the global average sea level change and warrant special attention even sooner. Over the last century, global average sea level has been approximately eight inches as shown in Exhibit D. However during the same period of time the New Orleans region has had approximately forty six inches of SLR, Norfolk thirty inches, Miami twelve, but Los Angles only four. Most of Alaska has had lower SLR in the same period. The differences are mostly due to land subsidence or uplift, which increases or reduces the global average sea level change. The point is that historical and future sea level change will not be the same everywhere and in fact will vary greatly.

The effects of sea level rise are often confused with storm surge, coastal erosion and the regular extreme high tide events, ('king tides'). Except for erosion, those other types of flooding are temporary, making it possible to rebuild and recover. Sea level rise is different in that it is essentially permanent, and will not recede for at least a thousand years.

I trust you will see that this insight has strong relevance for critical assets and infrastructure including ports, power plants, and military bases that have long durability and are difficult to elevate or relocate. Of course there will be an even broader effect on homeowners, businesses, communities, local and regional economies in the vulnerable low elevation coastal areas, where a majority of the US population resides.

I encourage this Subcommittee, the Committee on Natural Resources, and the Congress to revise and reauthorize the CZMA taking this seminal change in the land ocean boundary – the coastline -- into full consideration.

I would expect that your subcommittee is also interested in the changing Arctic given its potential role for energy exploration and shipping. Regardless of the associated concerns with those activities, it is worth noting that the melting of the polar ice cap has no effect on sea level, as it is floating sea ice. The disappearance of that perennial ice across the Arctic Ocean does however illustrate some key points. The fact that it will be essentially ice-free for increasing periods of time starting in some late September, almost certainly within the next decade or two, points to the profoundness of this new era. The sea around the North Pole has been frozen for roughly three million years.

I recall my first expedition in 1985 diving under the polar ice cap, when we had to drill through ten feet of ice. That *multi-year ice* is almost gone. Now we just have thin ice that builds up and then melts each year. That thin ice, or lack of ice, has very different energy characteristics, which has a huge impact on the planet's weather.

The changes to the Arctic are truly profound and raise new issues. As I am sure you have considered there is the opening of sea routes, the challenge of treacherous waters for our Navy and Coast Guard to operate, and new areas of shoreline rapidly eroding as the coastline is exposed by the disappearing ice and melting permafrost.

Your subcommittee has the opportunity to mark a place in our nation's history by recognizing and planning ahead for the dynamic changes in store for our coastal zone. Sea level will almost certainly reach the upper limit cited in the 2014 *National Climate Assessment* regardless of exactly when it occurs. That report explicitly said they had a 90% confidence that SLR this century would be between upper and lower bounds of 8 inches and 6.6 feet. It is difficult to quantify the collapse rate of the *West Antarctic marine glaciers*, due to the phenomenon of "tipping points", which defy accurate modeling until they can be observed in detail.

That challenge leads to an inadvertent conservative or low figure, not because of a lack of risk, but rather due to the inability to put a precise number on it. With other phenomena where we have had prior experience such as earthquakes, tornedos, and hurricanes we plan for low probability high-risk events. In the case of sea level rise, the worst-case scenarios for this century now exceed ten feet, yet hardly anyone is putting that scenario in their range of planning.

A key point in that National Climate Assessment that is often overlooked is that they acknowledge a one-in-ten chance that it will not be within those bounds. In risk terms, a ten percent chance is huge. In fact a risk assessment is exactly how we should be considering the effect of rising sea level on the coastline and our management thereof.

We are already seeing the destructive effects of sea level rise today. Just to cite a few examples: In Miami Beach, they recently installed $15 million of pumps to keep salt water off the streets that now occurs every 28 days with the full-moon high tide. It is just the first phase of a $400 million plan that they admit has limitations as sea level continues to rise. In Hampton Roads, both military and private locations are seeing steadily worsening flooding, a combination of higher global sea level, a slowing of the Gulf Stream, and subsidence.

From the Carolina banks to Cape Cod, coastal changes are noticeable from year-to-year. Along San Francisco's seven-mile Embarcadero well inside the Bay, saltwater now comes over the seawall onto the street with increasing frequency. I could cite examples from Annapolis, Boston, Seattle, and the Gulf Coast or dozens of others. These are manifestations of rising sea level already increasing the problem of storm impacts and abnormal high tides. It will continue to get worse.

In the longer term, mid-century and beyond, rising sea level will dramatically change the coastal zone, probably beyond what most of us can imagine, within the lifetimes of our children and grandchildren. We can ignore reality and leave future Americans to suffer the consequences.

Or we can see the future in front of us and plan for intelligent adaptation. Recent evidence from Antarctica makes clear that the melting forces are well ahead of nearly all the models and projections, similar to the way that the melting of the polar ice cap is far ahead of the models. Those who understand the dynamics of glacial collapse and the uncertainty of specific projections, appreciate that the models will almost certainly continue to underestimate the rate of their collapse, and the sea level rise that will directly result.

To close my remarks, the sea does not care what we think or want, or what laws we pass. Throughout history the ocean has taught man humility. We ignore its power at our peril. Along with crisis, there is opportunity. There can be tremendous innovation and adaptation in the coming decades as we anticipate and change our coastal oriented society and economies. But getting a good return on investment requires that we see where things are headed.

I often cite the Dutch as an example of how it is possible to do bold engineering, but also to illustrate the potential trap of inadequate design. Many have seen pictures of the amazing gates at Rotterdam harbor, the *Maeslantkering*. Designed in the 1980's with construction finished in the early 90's, it is a key part of their innovative coastal defense system. The cost was almost a billion dollars. It was designed for a one-in-ten thousand-year storm, and the worst historical downstream flooding from the three rivers that merge there.

Plus they added an allowance for one foot of sea level rise, as that was the worst they considered possible when it was designed. Now they recognize that will soon be inadequate. If they had been able to foresee the possibility of five to ten feet of SLR back in the 1980's they admit they would have designed the barrier with greater height for longer effectiveness and a better ROI – return on investment.

Our coastline is largely unchanged since the founding of the United States, a nation founded in recognition of truth and science. Our founders specifically recognized that the world of man and nature was dynamic and would need to adapt accordingly.

Our changing coastline, a significant feature of the United States, is an appropriate place to implement that attitude, respecting the collaborative relationship between the Federal government and the States. From my perspective the CZMA seems like the right forum to have that discussion about public policy. The sea is rising and the shoreline is shifting. We have time to adapt, but no time to waste.

Thank you again for the opportunity to testify. I would be pleased to answer questions.

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Exhibits on separate pages below

Exhibit A

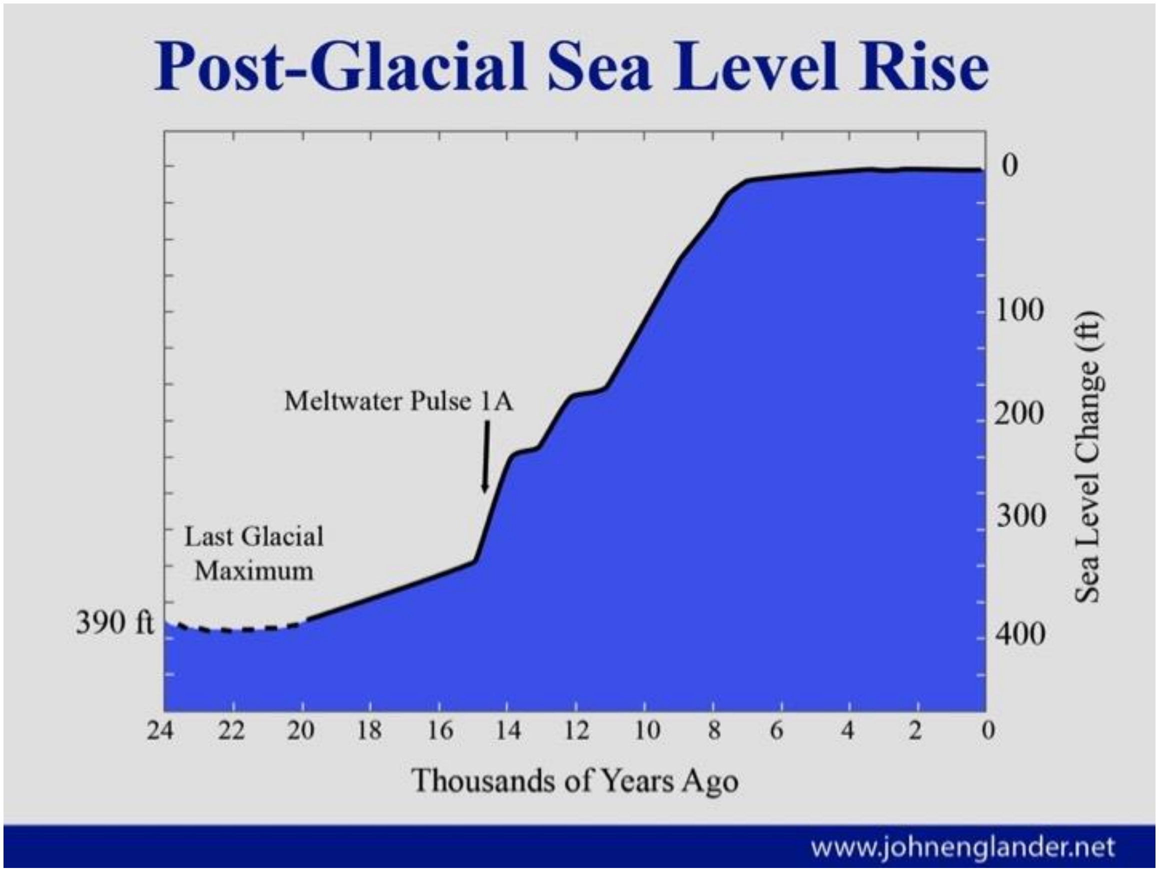
Post-Glacial Sea Level Rise
Meltwater Pulse 1A
Last Glacial Maximum
390 ft
0
100
200
300
400
Sea Level Change (ft)
24
22
20
18
16
14
12
10
8
6
4
2
0
Thousands of Years Ago
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Exhibit B

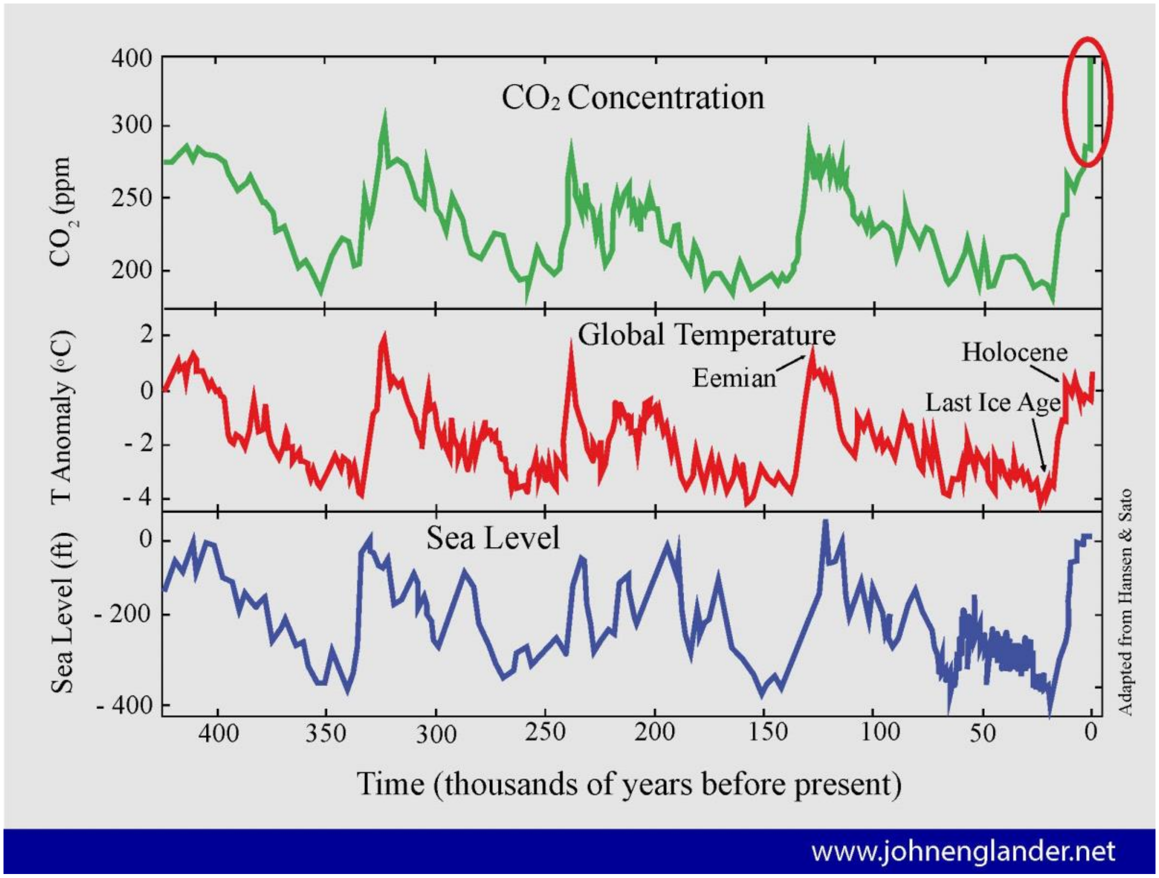
CO2 Concentration
CO2 (ppm)
400
300
250
200
Global Temperature
T Anomaly (°C)
2
0
- 2
- 4
Eemian
Holocene
Last Ice Age
Sea Level
Sea Level (ft)
0
- 200
- 400
400
350
300
250
200
150
100
50
0
Time (thousands of years before present)
Adapted from Hansen & Sato
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Exhibit C

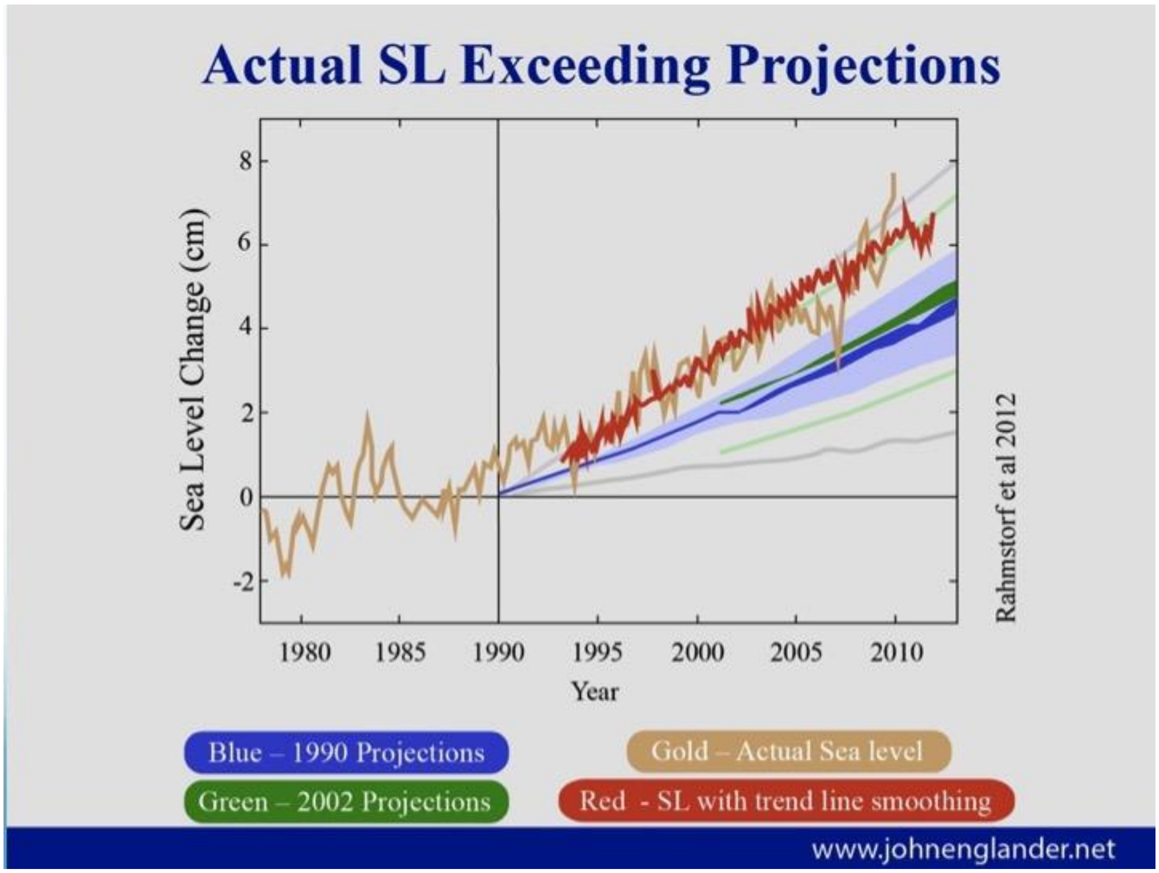
Actual SL Exceeding Projections
Sea Level Change (cm)
8
6
4
2
0
-2
1980
1985
1990
1995
2000
2005
2010
Year
Rahmstorf et al 2012
Blue – 1990 Projections
Gold – Actual Sea level
Green – 2002 Projections
Red - SL with trend line smoothing
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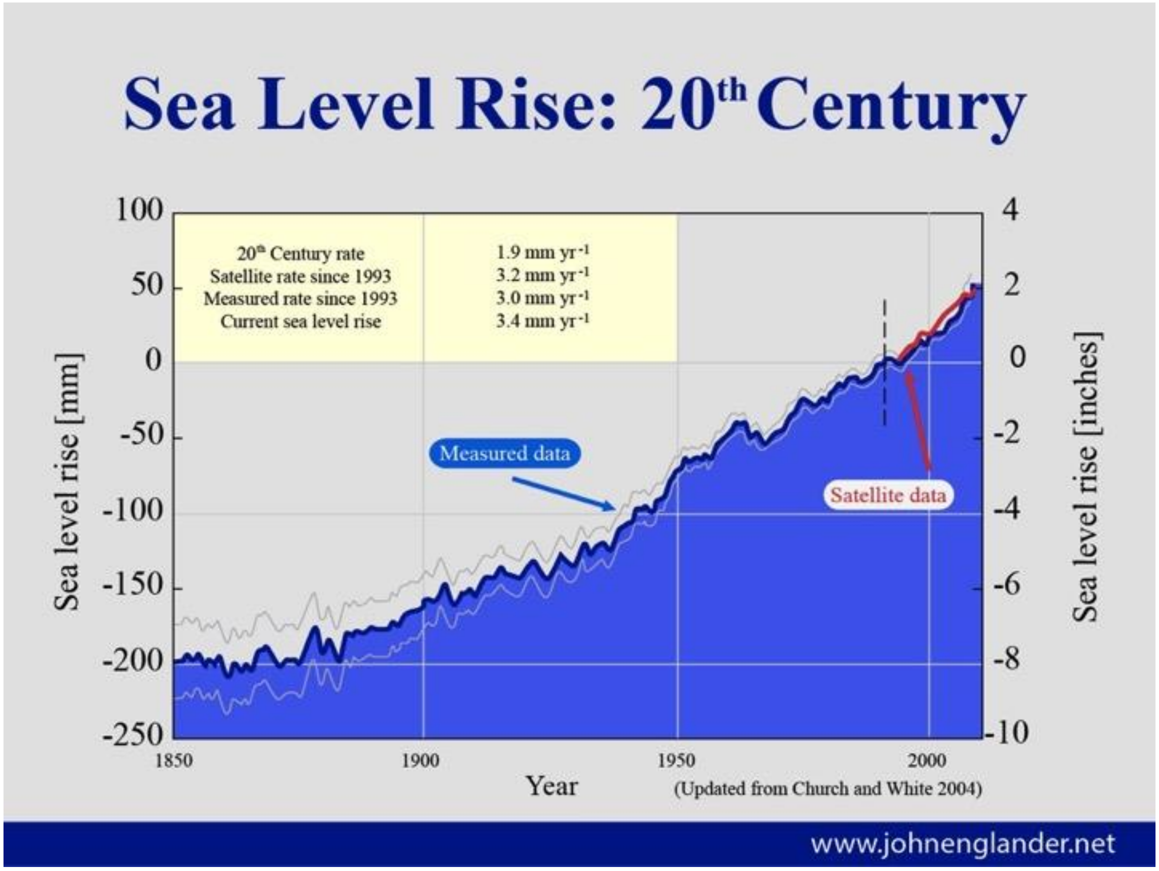
Exhibit D


Sea Level Rise: 20th Century
20th Century rate
Satellite rate since 1993
Measured rate since 1993
Current sea level rise
1.9 mm yr-1
3.2 mm yr-1
3.0 mm yr-1
3.4 mm yr-1
Measured data
Satellite data
Sea level rise [mm]
Sea level rise [inches]
100
50
0
-50
-100
-150
-200
-250
4
2
0
-2
-4
-6
-8
-10
1850
1900
1950
2000
Year
(Updated from Church and White 2004)
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