Fire and Storms – Part 2, Rev b

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1. Introduction

This was to be the second of two papers on (1) why wildfires are getting worse, and (2) why hurricanes are getting worse. The prior paper covered fires, and this will cover storms. Each paper will include recommendations as to what we can do to mitigate these disasters.

The prior paper in this series focused on wildfires because electric transmission and distribution (T&D) systems frequently provide an ignition source for those disasters, and also electric infrastructure in the burn-areas is destroyed by wildfires. While it is unlikely that electric T&D systems cause hurricanes, hurricanes result in major flooding (high-winds, etc.) so the electric infrastructure is also destroyed in areas ravaged by these storms.

Part 3 is information from late last year on verification of techniques used to measure Greenland and Antarctic Ice Sheets' melting. Meltwater runoff from these sheets is expected to become the major source of sea level rise within a few decades. The Part 3 paper shows that the scenario described in section 2.2 (below) appears to be increasingly likely to describe how future sea level rise will occur in our oceans.

Below is a link to the first and third papers.

https://www.energycentral.com/c/ec/fires-and-storms-%E2%80%93-part-1-rev-b

https://www.energycentral.com/c/ec/fire-and-storms-%E2%80%93-part-2-rev-b

2. Evidence and Explanations

In 2015 I came across a very long and very important paper written by team of leading climatologists. The team was led by Dr. James Hansen, one the most influential scientist in the last 30 years. This paper is referenced at the end of this paragraph.[1]

Two of the predictions made by this paper are:

- Sea level rise would occur much more rapidly than climatologists were then predicting (driven by rapid melting of the Antarctic and Greenland Ice Sheets).
- Atlantic hurricanes would intensify to superstorms (driven by a slowdown of the Atlantic Meridional Overturning Circulation, a.k.a. the Gulf Stream, and attendant effects)

[1] James Hansen, Makiko Sato, Paul Hearty, Reto Ruedy, Maxwell Kelley, Valerie Masson-Delmotte, Gary Russell, George Tselioudis, Junji Cao, Eric Rignot, Isabella Velicogna, Evgeniya Kandiano, Karina von Schuckmann, Pushker Kharecha, Allegra N. Legrande, Michael Bauer, Kwak-Wai Lo, "*Ice Melt, Sea Level Rise and Superstorms: Evidence from Paleoclimate Data, Climate Modeling, and Modern Observations that 2°C Global Warming is Highly Dangerous,* July 23, 2015, http://www.columbia.edu/~jeh1/2015/20150704_IceMelt.pdf

In the intervening years, most climatologists have grown to accept that these predictions are probably correct.

The two subsections below explore these two predictions and a following section explores how they interact with hurricanes.

2.1. Sea Level Rise

The sea-level is rising primarily due to a secondary effect and a tertiary effect of climate change. The secondary effect is the thermal expansion of sea water as it warms. The tertiary effect is the melting of glaciers and ice sheets (primarily the Antarctic and Greenland Ice Sheets) as they warm, providing run-off into the oceans thus increasing the level of the oceans.

The average sea-level has risen 8 to 9 inches since 1880. The source referenced at the end of this paragraph estimated that it will rise about another foot between now and 2040, and another 1 to 4 feet by 2100. There was a high level of confidence in the low number (1 foot) and a low level of confidence in the high number (4 feet).[2]

However, with little progress in fighting climate change a third scenario predicted by reference 1 comes into play and this could accelerate sea-level rise (next subsection).

2.2. Future Scenario from the Past

Much of modeling done in reference 1 focused on a period in the last interglacial period (italics are used for quotations from reference 1):

> *If the ocean continues to accumulate heat and increase melting of marine-terminating ice shelves of Antarctica and Greenland, a point will be reached at which it is impossible to avoid large scale ice sheet disintegration with sea level rise of at least several meters.*
>
> *We examine events late in the last interglacial period warmer than today, called [the] Eemian…*
>
> *While the Eemian is not an analog of future warming, it is useful for investigating climate feedbacks, the response of polar ice sheets to polar warming, and the interplay between ocean circulation and ice sheet melt.*

The Eemian period began about 130,000 years ago and ended about 115,000 years ago.[3] The interval that this document focuses on is during the warming phase of a specific Dansgaard–Oeschger Event that occurred approximately 120,000 years ago. Dansgaard–Oeschger events (often abbreviated D-O events) were rapid climate fluctuations that occurred 25 times during the Pleistocene period. D-O events each take the form of a rapid warming episode, typically in a matter of decades, each followed by gradual cooling over a longer period (typically centuries).

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[2] USGCRP, 2017: Climate Science Special Report: Fourth National Climate Assessment, Volume I [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 470 pp, doi: 10.7930/J0J964J6. https://science2017.globalchange.gov/

[3] Wikipedia article on "Eemian", https://en.wikipedia.org/wiki/Eemian

The Eemian was chosen because it was the last period where earth's climate rapidly warmed from glacial conditions (4°C below the 1960 to 1990 average global temperature) through a period where the climate was much like it is today, to well above the current temperature (4°C above the 1960 to 1990 average global temperature).

The following is a scenario modeled by reference 1:

1. Approximately 130,000 years ago, radiation from the sun (insolation) peaked in the northern hemisphere. Insolation variability is caused by slow changes of the eccentricity of Earth's orbit, tilt of Earth's spin axis, and precession of the equinoxes, thus the day of a year at which Earth is closest to the Sun.

2. The peak insolation removed ice sheets from North America and Eurasia (from the prior ice age) over several thousand years and drove atmospheric CO_2 from 200 ppm up to ~285 ppm.

3. The warming caused by the increase in CO_2 resulted in extensive melting of Nordic sea ice (between Norway and Greenland).

4. The above melting created a cold freshened-water cap on the North Atlantic. This caused a stratification of the North Atlantic and forced the warm southern water to flow below the surface to the deep waters. Note that freshened sea water has a lower density than pure sea water and thus will stay on the surface. The stratification will push saltier water deeper, including the very salty Gulf Stream (salinity increase via evaporation).

5. The subsurface warm waters accelerated the melting of the Greenland Ice Sheet by warming the ice shelves for the outlet glaciers that buttress this ice sheet and slow its flow into the ocean.

6. The increasing North Atlantic stratification led to dilution of the Gulf Steam and a reduction or shutdown of the North Atlantic Deep Water formation which drives the Atlantic Meridional Overturning Circulation (AMOC, a.k.a. Gulf Stream). Approximately 118,000 years ago the proxies provide strong evidence of the shutdown or reduction of North Atlantic Deep Water formation.

7. The slowdown or shutdown in the AMOC created a warming of the South Atlantic Seas. Normally the AMOC transfers excess heat from the South Atlantic to the North Atlantic via the Gulf Stream.

8. The warming of the peak insolation had already created a freshening of the southern ocean around Antarctica through accelerated Antarctic Ice Sheet melting. This led to stratification of this ocean and a warming of the Antarctic ice sheet footings (similar to 4 and 5 above did for Greenland).

9. As the Antarctic Ice Sheet footings warmed, ice sheet disintegration accelerated.

10. The volume of water contributed to oceans from the disintegration of the Antarctic Ice Sheet is much greater that that from the Greenland Ice Sheet, so the oceans started to rise quickly.

11. There was rapid spiking of the sea-level several times during the late Eemian period. The ocean level peaked at approximately 20 meters above the level today (and the level when the Eemian climate was similar to todays), before it started to decline when the D-O Event entered its cold phase.

12. During the above scenario, the CO_2 level stayed very close to 285 ppm. The CO_2 level in 2019 is 410 ppm.

Another effect was seen from the above scenario. Strong evidence from Bermuda and the Bahamas show that superstorms came ashore there in the late Eemian. These storms came out of the northeast when the sea-level was at its highest. Thus the paleontological record of these events are preserved on land. These records show consistent wave heights of 20 meters above the then sea level, or 40 meters above current sea level. Enormous boulders (over 2,000 tons each) were lifted to near the peak wave height. Reference 1 stated:

> *Steeper pressure, temperature, and moisture gradients adjacent to warm tropical waters could presumably spawn larger and more frequent cyclonic storms in the North Atlantic than those seen today…Freshwater injection onto the North Atlantic and Southern Oceans causes increase of sea level pressure at middle latitudes and decrease at polar latitudes. These pressure changes have implications for the strength of prevailing winds and for severe weather.*

It should be noted that steps 4 and 5 of the above scenario are in progress, and regarding step 6, the AMOC has appears to have slowed down by about 15% in several studies.[4]

By examining the paleontological record the team that developed the climate model can use parts of this record as a proxy for future climate changes, and thus verify the accuracy of the model. However, it should be pointed out that the conditions in the late Eemian were different than those in the present and near-term future. This is mainly as a result of our rapidly rising atmospheric CO_2 verses the Eemian's relatively constant CO_2. Thus there will be no "cold phase" like the D-O events unless we (humanity) make it happen.

2.3. Evidence from the Present

The following information is from a recent paper published in Science.[5] I have provided a link in the reference below, but access is limited (I was able to access it because I'm an AAAS member).

This report modeled the 2017 Hurricane Season. This season was very active with six major Atlantic hurricanes. The mean number of these storms was 2.7 during the period 1979–2017. Among these storms, Hurricanes Harvey, Irma, and Maria made landfall over the Gulf Coast and the Caribbean causing substantial damage.

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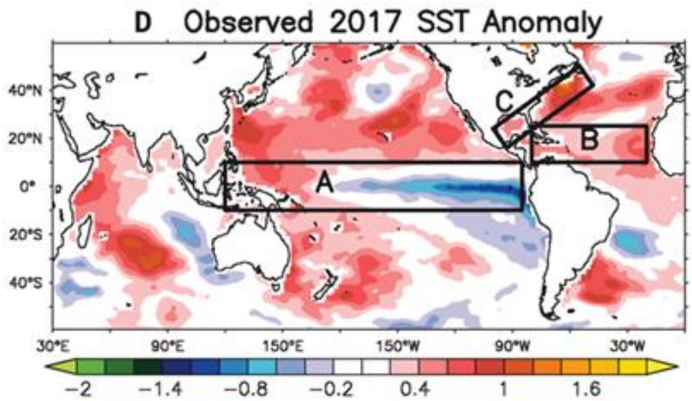
[4] Benoit Thibodeau, Christelle Not, Jiang Hu, Andreas Schmittner, David Noone, Clay Tabor, Jiaxu Zhang, Zhengyu Liu, American Geophysical Union (AGU), Geophisical Research Letters, " Last Century Warming Over the Canadian Atlantic Shelves Linked to Weak Atlantic Meridional Overturning Circulation", https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2018GL080083

[5] H. Murakami, E. Levin, T. L. Delworth, R. Gudgel, P.C. Hsu, Science, "Dominant effect of relative tropical Atlantic warming on major hurricane occurrence", 16 November, 2018, http://science.sciencemag.org/content/362/6416/794?rss=1

The team in the reference modeled the 2017 Hurricane Season using NOAA's Geophysical Fluid Dynamics Laboratory HiFLOR climate model[6]. Earlier simulations had demonstrated that HiFLOR can accurately simulate year-to-year variations in major hurricane frequencies. The model run for this paper used a July to November period. Two potential influences were investigated: (1) El Niño / La Niña (a.k.a. El Niño-Southern Oscillation or ENSO) global sea temperature and atmosphere cycle and (2) sea surface temperature rise. During 2017, ENSO was in a developing moderate La Niña. The Niño3.4 index was 0.4 standard deviations below normal. The sea surface temperature was 1.5 standard deviations above normal in the main Atlantic hurricane developing region (Region B in the map below).



Multiple model runs were used with multiple variations of ENSO and sea surface temperature in both the Atlantic and Pacific. The only variation that strongly affected the number of major hurricanes was the sea surface temperature. The actual (high) sea surface temperatures for 2017 correctly resulted in 6 major hurricanes. Using the average sea surface temperatures for the period 1980–2017 resulted in only 3 major hurricanes.

The authors of this paper studied the effect of various ENSO conditions on major hurricane frequency, and found them minimal in comparison to the effect of sea surface temperature increases. They felt that other natural oscillations, specifically the Atlantic Multidecadal Oscillation, and the Atlantic Meridional Mode may have some impact (see below). Prior studies have shown a relationship between these (and ENSO) and major hurricane population. Note that both of these oscillations affect sea surface temperatures.

The Atlantic Multidecadal Oscillation (AMO): is an oscillation in an ocean current affecting the North Atlantic Ocean, in particular its sea surface temperature. The period of oscillation is 50 to 70 years.

The Atlantic Meridional Mode (AMM): A key component of the AMM is a positive feedback between the ocean and atmosphere. During a positive phase of the AMM, sea surface temperatures (SSTs) become warmer than normal in the tropical North Atlantic and cooler than normal in the tropical South Atlantic. Surface air pressure responds to the SST anomalies, becoming higher than normal over the anomalously cold SSTs and lower than normal over anomalously warm SSTs. Anomalous surface winds flow from

[6] Geophysical Fluid Dynamics Laboratory, High-resolution Climate Modeling, https://www.gfdl.noaa.gov/high-resolution-climate-modeling/

the cold to the warm hemisphere, strengthening the mean southeasterly trade winds in the South Atlantic and weakening the northeasterly trade winds in the North Atlantic. The surface wind anomalies thus provide a positive feedback onto the initial SST anomalies by forcing changes in wind-induced evaporative cooling of the ocean.[7]

ENSO: El Niño is an oscillation of Pacific Ocean temperatures and currents. The Southern Oscillation is the corresponding oscillation of atmospheric temperatures and currents. Together these are El Niño / Southern Oscillation, or simply ENSO.

El Niño is an irregularly periodic change caused by variations in sea surface temperatures over the tropical eastern Pacific Ocean that affects much of the tropics and subtropics. The warming phase is known as El Niño and the cooling phase as La Niña.

The atmospheric changes during the different phases of the Southern Oscillation are complex and global in their range. These are best explained by an article from the NOAA Earth Systems Research Laboratory linked below.

http://www.esrl.noaa.gov/psd/enso/enso.description.html

3. Sea Level Rise and Major Hurricane Interactions

The following factors affect the flooding that might be expected with hurricanes:

3.1. Tides

The residents and infrastructure-owners in a given area could be lucky or unlucky depending on whether a hurricane's storm surge is decreased or increased by the tide level in a given area at the time of the surge.

The author took half of the difference between high water and low water, which should give a conservative estimate of the lessening or contribution of the tide (below or above the mean seal level) Using the 2019 predicted tide tables for various locations on the East Coast during the normal hurricane season,[8]

The following levels were found.

- Kings Point, NY (Long Island) – 3 to 4 feet
- Baltimore, MD – less than a foot
- Sewell's Point, VA – 1 to 1.5 feet
- Wilmington, NC – 2 to 2.5 feet
- Charleston, SC – 2.5 to 3 feet
- Fernandina Beach, FL (Near Jacksonville) – 3 to 3.5 feet

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[7] Gregory Foltz, Renellys Perez, NOAA, Atlantic Oceanographic and Meteorological Laboratory, Tropical Atlantic Variability, Atlantic Meridional Mode, http://www.aoml.noaa.gov/phod/research/tav/tcv/amm/index.php

[8] U.S. Department of Commerce, Tide Tables 2019, High and Low Water Predictions, East Coast of North and South America, https://tidesandcurrents.noaa.gov/tidetables/2019/ectt2019FullBook.pdf

- Miami, FL – 1 to 1.5 feet

The tidal variations along the Gulf Coast per the above source and criteria are typically less than a foot.

3.2. Storm Surge

Predicting the storm surge for a given area and a given storm strength is a complex process, but NOAA's National Hurricane Center has produced interactive storm surge prediction maps and these can be accessed through the link below. The predicted ranges are from less than 3 feet to greater than 9 feet.

https://www.nhc.noaa.gov/nationalsurge/

3.3. Flooding Rains

The following hurricanes from the 2017 and 2018 season had exceptional flooding rains. It will be assumed that these are indicative of future major storms. It should be noted that these seasons had two very slow moving hurricanes (Harvey, 2017, and Florence, 2018) which are the worst case for flooding rains.

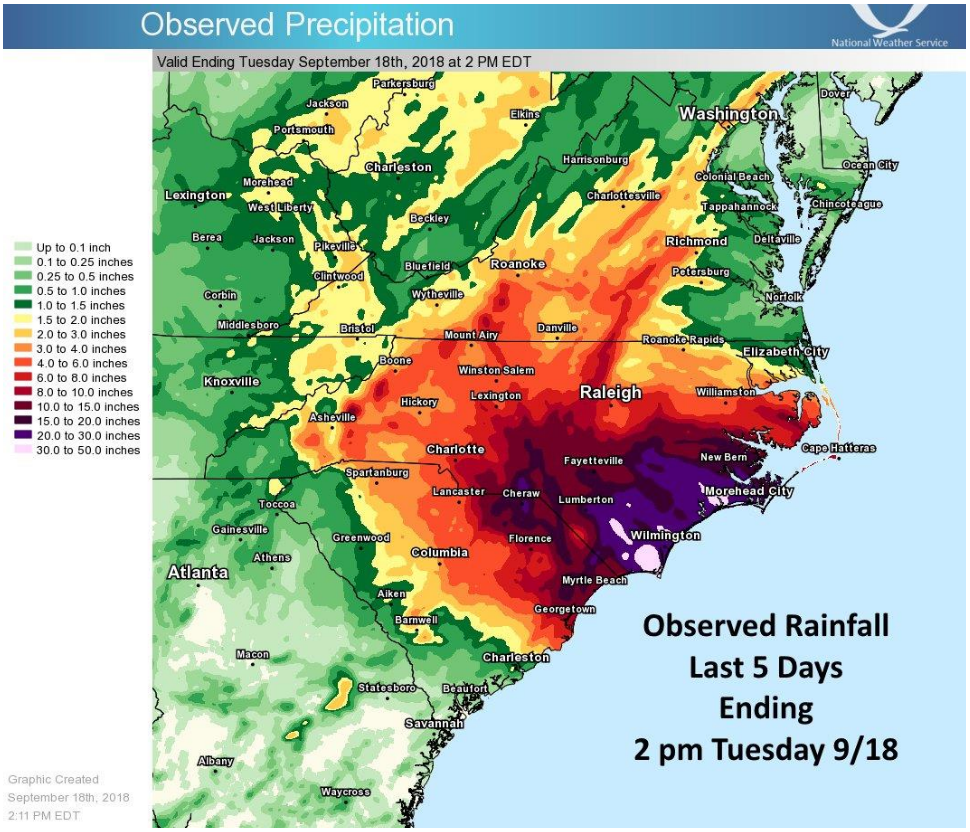
The hurricane's name and some text regarding the flooding rains follow:

- **Harvey (2017):** *is tied with 2005's Hurricane Katrina as the costliest tropical cyclone on record, inflicting $125 billion in damage, primarily from catastrophic rainfall-triggered flooding in the Houston metropolitan area … In a four-day period, many areas received more than 40 inches of rain as the system slowly meandered over eastern Texas and adjacent waters, causing unprecedented flooding. With peak accumulations of 60.58 in, in Nederland, Texas, Harvey was the wettest tropical cyclone on record in the United States.*[9]

- **Hurricane Irma (2017):** *was the costliest storm in the history of the U.S. state of Florida (Approx. $50 Billion)… Precipitation was generally heavy to the east of the storm's path, peaking at 21.66 inches in Fort Pierce.*[10]

- **Hurricane Florence (2018):** *was a powerful and long-lived Cape Verde hurricane (forms near the Cape Verde Islands off the west coast of Africa) that caused severe damage in the Carolinas in September 2018, primarily as a result of freshwater flooding. Florence dropped a maximum total of 35.93 inches (913 mm) of rain in Elizabethtown, North Carolina, becoming the wettest tropical cyclone recorded in the Carolinas, and also the eighth-wettest overall in the contiguous United States.*[11] (See image below).

[9] Wikipedia Article on Hurricane Harvey, https://en.wikipedia.org/wiki/Hurricane_Harvey
[10] Wikipedia Article on Hurricane Irma, https://en.wikipedia.org/wiki/Hurricane_Irma
[11] Wikipedia Article on Hurricane Florence, https://en.wikipedia.org/wiki/Hurricane_Florence



Credit for image: US National Weather Service Eastern Region Headquarters.

3.4. Combined Impacts

As a hurricane's outer bands start making landfall, the runoff slowly starts entering the coastal system of rivers and streams. With slow moving storms, this can cause localized flooding even before damaging winds impact coastal areas. When the storm-surge initially impacts the coast, it blocks the mouth of these rivers and streams, increasing flooding. Hurricanes with high storm surges can use the rivers and streams to push floods inland, further worsening flooding. High rain amounts quickly saturate the soil and attempt to run off, using roadways and other natural paths and blocking first-responders. Weakened tree root systems from extended flooding will make the trees more vulnerable to high winds and cause damage to infrastructure by falling and floating trees. Worse-case is floating trees and other debris damming waterways, preventing drainage and worsening flooding.

4. Mitigation

The steps below are minimal but necessary mitigation. Even if someone with a really effective magic wand waved it and instantly stopped all greenhouse gas emissions, the world is simply too huge, and there are too many environmental changes in Mother Nature's pipelines. The sea levels will continue to rise with increasing speed and storms will continue to intensify for many centuries, if not millennia.

- Governments and other environmental advocates should continue to purchase infrastructure on all low-lying areas near ocean coasts, condemn these and return the properties to natural wetlands and flood-plains (New Jersey, California and probably other states are already doing this).

- Utilities near ocean coasts should harden all of their infrastructure to withstand probable hurricanes.
- Large, capital-intensive facilities on low-lying ground near ocean coasts should create long-term plans to harden infrastructure in the short term (decades) and abandon and retreat in the long-term.
- Federal government should make disaster-aid contingent on the above actions being completed with reasonable speed.

Also, some governments are already moving to net-zero greenhouse gas emissions with reasonable speed. Eventually the pain from climate change effects such as described in this and the prior paper will become so great that all will fall into line (or be forced to by the majority).