6D.2 SYNTHESIS OF US AND CARIBBEAN HURRICANE IMPACTS ON A WARMER GLOBE

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The future of humanity may well depend upon worldwide reduction of global greenhouse gas emissions. Because Tropical Cyclone (TC) landfalls are newsworthy and often tragic, environmental advocates cite increased human and economic impacts to support low-emission policies (e.g., Emanuel 2005, Webster et al. 2005). Skeptics argue that an unambiguous TC signal due to Anthropogenic Global Warming (AGW) has not yet emerged above large random variations. In this context it is essential to distinguish between political skepticism (or enthusiasm) that muddles the issue, and the scientific skepticism essential to nuanced understanding.

Thermodynamic arguments (e.g., Emanuel 1999) for increased Maximum Potential Intensity (MPI) as the sea warms are theoretically compelling and consistent with observations. By contrast, data issues may lead scientifically skeptical analysts to question pessimistic interpretations of some observational studies. Here, we seek clarity through in-situ statistics of hurricane occurrence and impacts.

Controversial "normalization" of continental-US hurricane damage for local population, individual wealth, and inflation yields sensibly zero 1900-2008 trend (Pielke et al 2008). A salient argument against this result is that stronger building codes and better forecasts reduce present-day damage. It is well documented that better forecasts have reduced US hurricane mortality by 90% compared with what would result with mid-20th Century practice (Willoughby 2012). The consensus among wind engineers is that Florida's present High Velocity Hurricane Zone building code would mitigate 50% of wind damage from a recurrence of 1992's Hurricane Andrew.

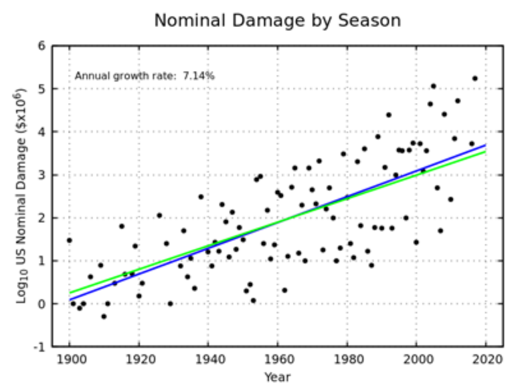

Fig. 1. Common log of US nominal hurricane damage (blue) and a line passing through the mean nominal seasonally aggregated damage, but with the same growth rate as US nominal GDP (green).

Nonetheless, much of 21st Century damage has resulted from storm surge and inland flooding rather than from wind, and "grandfathering" means that implementation of stronger building standards takes decades to make its way into the legacy housing stock.

Fitting an exponential trend line to 1900-2016 nominal (i.e., "then-year" with no inflation correction) US hurricane damage yields an annual growth rate essentially the same as that of US nominal Gross Domestic Product (Fig. 1). The statistical distributions of both normalized and detrended US damage are approximately log-normal—consistent with previous studies

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(Katz 2002, Willoughby 2012), but somewhat leptokurtic and negatively skewed. The logarithmic standard deviations represent factors of approximately ten times the geometric mean seasonal damage. These values mean that damage would have to double on century timescales for the increase to become statistically significant.

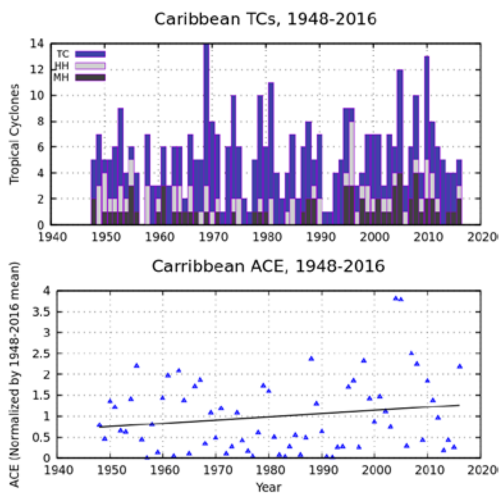

Fig. 2. Caribbean TC occurrence (top) and ACE (bottom) 1948-2016.

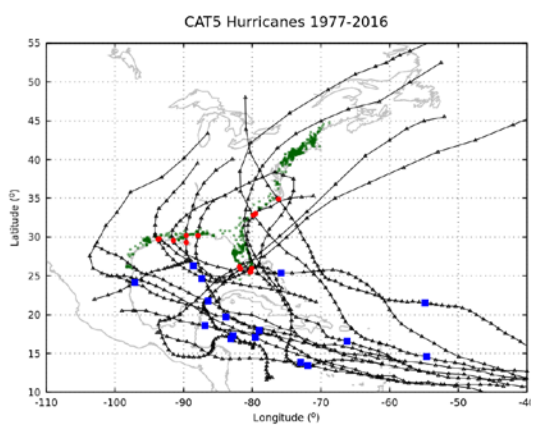

Fig. 3. Atlantic basin category 5 hurricane, 1977-2016. Triangles indicate 6-hourly positions, blue squares indicate lifetime maximum intensities, green squares are US coastal cities > 100K population and red circles indicate US landfalls.

From 1900-2016, there was a small, not statistically significant, decrease of Accumulated Cyclone Energy (ACE) for US landfalling hurricanes. This result contrasts with the reported substantial basin-wide increase of numbers and intensities (e.g., Elsner et al. 2008), which can plausibly be attributed to improved observations of the remote North Atlantic. Nonetheless, a Caribbean domain exhibits a statistically significant increase of major hurricanes and a not-yet-significant increase of ACE, which may become significant when 2017 data are included (Fig. 2). Historically, this domain has been heavily traveled

N	Mode	Name	YR	ST	Damage	V_mx	V_lf
1	C	Great_Miami	1926	FL	213060	130	125
2	F	Galveston	1900	TX	142370	125	120
3	F	Harvey	2017	TX	110103	113	113
4	F	Galveston	1915	TX	103440	125	115
5	F	Katrina	2005	LA	91130	150	110
6	W	Andrew	1992	FL	76410	150	145
7	C	Pinar_del_Rio	1944	FL	66550	125	90
8	F	Donna	1960	FL	61730	125	105
9	F	Sandy	2012	NY	54660	100	70
10	F	Lake_Okeechobee	1928	FL	54600	140	125
11	F	New_England	1938	NY	54160	140	105
12	C	Irma	2017	FL	44041	155	113
13	W	Wilma	2005	FL	31020	160	105
14	F	Hazel	1954	SC	30370	75	75
15	F	Diane	1955	NY	27820	90	60
16	F	Camille	1969	LA	26070	150	150
17	W	Charley	2004	FL	26040	130	130
18	F	Ike	2008	TX	24400	125	95
19	C	Hugo	1989	SC	23890	140	120
20	F	Ivan	2004	AL	22320	145	105

Fig 4. The 20 most destructive US hurricanes, 1900-2017. Cyan shading indicates cyclones where flooding was the most destructive geophysical element, and yellow shading around the year indicates inactive AMO phase.

by shipping, received priority for aircraft reconnaissance, and the analyzed time interval was chosen to avoid aliasing of the Atlantic Multidecadal Oscillation (Goldenberg et al. 2001) into the trend.   Moreover it is in the high ocean heat contents (e.g., Mainelli et al. 2008) *of the Caribbean domain where one would* expect the MPI response due to warming seas to be most pronounced. Hurricane Maria's devastating impact in Puerto Rico is consistent with this interpretation.

Atlantic Basin category 5 hurricanes in the (Fig. 3) fall into two classes. Those that made US landfall as category 5 hurricanes (the 1935 Labor Day Storm, Camille and Andrew) all intensified rapidly in the hours just before US landfall. A different pattern emerges from examination of the 19 Atlantic category 5 hurricanes since 1977. Except for Andrew, 18 of them intensified rapidly over the Caribbean or the Gulf of Mexico loop current, often undergoing multiple eyewall replacements that increased their overall size. Of these, 12 then weakened by an average of two Saffir-Simpson categories before US landfall as major, but not extreme hurricanes. Only 6 missed the continental US entirely. Similarly, the 20 most destructive hurricanes (Fig. 4) had weakened by an average of 21 kt by US landfall. Hurricane Irma of 2017 fit this pattern, as did Matthew of 2016, Post-Tropical Storm Sandy of 2012, and Katrina, Rita and Wilma of 2005.

This pattern suggests a nuanced interpretation of the evolving threat on a warming Earth. While there is no reason to expect the danger of US category 5 landfalls to diminish, it is reasonable to imagine that increases in Caribbean major hurricanes will result in both more windstorm disasters in the islands and more flooding disasters caused by formerly extreme, but currently weakening, Caribbean TCs that bring heavy rainfall and raise devastating storm surge on US shores. If this speculation stands the test of time, the Caribbean will experience more Marias and the continental US will experience more Harveys.

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