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Emergence timescales for detection of anthropogenic climate change in US tropical cyclone loss data

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Abstract

Recent reviews have concluded that efforts to date have yet to detect or attribute an anthropogenic climate change influence on Atlantic tropical cyclone (of at least tropical storm strength) behaviour and concomitant damage. However, the possibility of identifying such influence in the future cannot be ruled out. Using projections of future tropical cyclone activity from a recent prominent study we estimate the time that it would take for anthropogenic signals to emerge in a time series of normalized US tropical cyclone losses. Depending on the global climate model(s) underpinning the projection, emergence timescales range between 120 and 550 years, reflecting a large uncertainty. It takes 260 years for an 18-model ensemble-based signal to emerge. Consequently, under the projections examined here, the detection or attribution of an anthropogenic signal in tropical cyclone loss data is extremely unlikely to occur over periods of several decades (and even longer). This caution extends more generally to global weather-related natural disaster losses.

Keywords: tropical cyclones, climate change, losses, disasters, United States

S Online supplementary data available from stacks.iop.org/ERL/6/014003/mmedia

1. Introduction

Increasing weather-related natural disaster losses have been well documented [1, 2]. Various changes (societal, building codes, etc) are known to influence the time series of disaster losses, and research to date has focused on determining whether an anthropogenic climate change signal is present after these changes have been accounted for by a process called loss normalization [3–5]. No insured or economic loss normalization study has yet been able to detect (much less attribute) an anthropogenic signal across a range of perils and locations around the world [5].

This study is concerned with the risk posed by US tropical cyclones (referred to as 'tropical storms' in the Atlantic when these tropical storm systems reach a maximum sustained wind speed of 63 kph), a peril that has significantly influenced global weather-related natural disaster losses (supplementary discussion and table S1 available at stacks.iop.org/ERL/6/014003/mmedia). Hurricanes—tropical cyclones with winds of 119 kph or greater—account for eight of the ten most costly inflation-adjusted insurance losses (2009 dollars) caused by weather-related hazards between 1970 and 2009 [1]. Not surprisingly the time series of US tropical cyclone damage has attracted special attention [3, 6–8].

That a residual trend, due to anthropogenic climate change or otherwise, has thus far not been detected in normalized US tropical cyclone damage should not be surprising as there has been no observed increase in hurricane frequency and intensity at landfall over the period for which normalization data is available [3, 9, 10]. Moreover, it has not yet been possible to detect anthropogenic signals in Atlantic Ocean basin records [9, 10]. Despite this, Knutson *et al* [10] conclude that a detectable and perhaps substantial anthropogenic influence

Table 1. Damage and storm changes by Saffir–Simpson category. Damage statistics are derived from the Pielke *et al* [3] normalized storm losses and projections are from Bender *et al* [11]. In our analysis we relied on the PL05 analysis of Pielke *et al* [3]. For two reasons the damage statistics differ from those of Pielke *et al* [3]: (i) theirs were based on the number of landfalls (a storm may make multiple landfalls) whereas ours are based on the number of landfalling storms. Ten storms with multiple landfalls were categorized according to their most intense crossing and their losses aggregated, and; (ii) we excluded zero and non-zero subtropical storm losses to ensure direct correspondence with tropical storm projected changes. The Saffir–Simpson category is the category at landfall for the damage statistics. From Bender M A, Knutson T R, Tuleya R E, Sirutis J J, Vecchi G A, Garner S T and Held I M 2010 Modeled impact of anthropogenic warming on the frequency of intense Atlantic hurricanes *Science* **327** 454–8. Reprinted with permission from AAAS.

	Storm loss frequency and damage distribution			Projected per cent changes over 80 years (warm versus control)				
Saffir–Simpson Storm Category	Count of loss events	Count per year	Per cent of total damage	CMIP3 ensemble	GFDL	MRI	MPI	HadCM3
Tropical	57	0.54	2.0	−13	+4	−16	−14	−14
1	44	0.42	5.0	−52	−40	−45	−48	−66
2	34	0.32	7.4	−17	−15	−28	−36	−53
3	53	0.50	35.6	−45	+9	−34	−51	−64
4	14	0.13	42.5	+83	+100	+72	+17	−56
5	3	0.03	7.4	+200	+400	+800	+100	0

on Atlantic tropical cyclone activity cannot be ruled out in the future. This raises an important question: if changes in storm characteristics in fact occur as projected, then on what timescale might we expect to detect these effects of those changes in damage data? The present study addresses this question.

2. Data and methods

In a recent study, Bender *et al* [11] estimated it would take 60 years for a projected increase in frequency of category 4 and 5 Atlantic hurricanes to emerge as a signal in a time series of category 4 and 5 hurricanes. This result was derived from an ensemble mean of 18 global climate change projections—the 18 models were from the World Climate Research Programme coupled model intercomparison project 3 (CMIP3) and used the Intergovernmental Panel on Climate Change (IPCC) A1B emissions scenario. Using a regional model of the atmosphere and a high-resolution hurricane model, Bender *et al* [11] projected an 81% increase in the frequency of category 4 and 5 hurricanes in 80 years, or roughly a +1% linear trend per year. The 60-year emergence timescale for this trend was based on bootstrap re-sampling using category 4 and 5 annual hurricane counts between 1944 and 2008.

We modify the Bender *et al* [11] emergence timescale methodology and apply their model-based projections of the per cent change in the number of Atlantic storms in each Saffir–Simpson (SS) category to the annual frequency of economic losses due to each category (table 1). We use the storm loss list from Pielke *et al* [3] with two exceptions: the subtropical storm loss and an incorrectly classified tropical storm loss (actually subtropical) in 1974 were removed. The resulting list is then a catalogue of mainland US landfalling Atlantic storms (tropical storm to category 5) (see supplementary discussion for further detail, available at stacks.iop.org/ERL/6/014003/mmedia).

In addition to the 18 CMIP3 model ensemble mean, we also analyse the four projections of Bender *et al* [11] for Atlantic storm activity in the context of anthropogenic climate change from four of the individual CMIP3 global models (table 1)—Geophysical Fluid Dynamics Laboratory GFDL-CM2.1; Japanese Meteorological Research Institute MRI-CGCM; Max Planck Institute MPI-ECHAM5, and the Hadley Centre UK Meteorological Office UKMO-HadCM3. Frequency projections from the individual models result from the same downscaling methodology as that applied to the 18-model ensemble [11]. The variability in projected storm activity between global models is due to differences in wind shear, potential intensity and other environmental factors (see Bender *et al* [11] for further detail).

To estimate the time it takes for each of the five anthropogenic signals (hereafter referred to as CMIP3, GFDL, MRI, MPI and HadCM3) to emerge in storm losses we first construct an arbitrary length synthetic loss time series. We do this by modelling the number of storm losses in each category in each year of the time series using a Poisson distribution (supplementary discussion and table S3 available at stacks.iop.org/ERL/6/014003/mmedia). (The Poisson parameter [12] is the average storm count per year for each SS category.) Our use of a Poisson distribution gives a signal emergence time in hurricane behaviour similar to that estimated in Bender *et al* [11] (see supplementary discussion available at stacks.iop.org/ERL/6/014003/mmedia).

Storm losses are sampled (with replacement) from the Pielke *et al* [3] normalized direct economic storm losses (1900–2005) and aggregated annually. In successive years the projected per cent changes in SS storm category are applied to loss frequencies on an annual basis assuming a linear trend. We then calculate the gradient of the least-squares line fitted to the synthetic loss time series and repeat this process many times (10 000 iterations) for each length tested. If there is a sufficiently small number ($<5\%$) of positive (i.e. when testing for a negative trend) or negative (i.e. when testing for a positive trend) gradients the signal is deemed to have emerged and the earliest end year of the synthetic loss time series in which this threshold is met is referred to as the emergence timescale ($p = 0.05$) (following Bender *et al* [11], see figure 1 and table 2, plus supplementary discussion for further detail available at stacks.iop.org/ERL/6/014003/mmedia).

3. Results

Anthropogenically driven changes in damage potential over 80 years are estimated by weighting the per cent of total damage by SS category with the corresponding projected per

Table 2. Emergence timescale, change in damage potential and the simulated mean change in damage after 80 years and at the emergence timescale. Simulated values (10 000 iterations) refer to the per cent change in damage between the mean damage calculated from the least-squares lines and the average annual damage calculated over the 106 year normalized historical record. In estimating values beyond 80 years, we linearly extrapolate the projections in table 1. Emergence timescales are rounded to the nearest 10 years.

		Change in damage potential (%)		Simulated mean change in damage (%)	
	Emergence timescale (years)	After 80 years	At emergence timescale	After 80 years	At emergence timescale
CMIP3 ensemble	260	+30	+94	+30	+106
GFDL	150	+72	+135	+71	+138
MRI	150	+73	+137	+74	+138
MPI	550	−9	−62	−9	+41
HadCM3	120	−54	−81	−54	−82

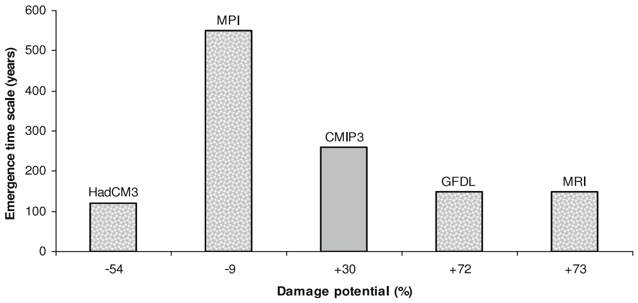

Figure 1. Emergence timescale of anthropogenic signals in normalized damage versus the per cent change in damage potential after 80 years. Damage potentials vary from those in Bender *et al* [11] due to the use of different damage statistics, as presented in table 1. Emergence timescales are rounded to the nearest 10 years.

cent changes in frequency (table 1). The results are shown in figure 1 and table 2. The CMIP3 ensemble change in damage potential is +30% with the contribution from the increase in more intense events dominating that from the decrease in less intense events. The same holds true for the GFDL and MRI models while the reverse is true for the MPI model. A negative change in damage potential for the HadCM3 model (figure 1 and table 2) is obvious as it projects a decrease or zero change in frequency across all SS categories (table 1).

The absolute change in damage potential is roughly related to the emergence timescale of anthropogenic signals in normalized losses. The MPI model has the smallest absolute change in damage potential (9%) and it takes 550 years, the largest of those tested, for a signal to emerge (figure 1 and table 2). On the other hand, the MRI signal has the equal second fastest emergence timescale at 150 years despite the model having the largest absolute change in damage potential (73%). The HadCM3 signal emerges the fastest (120 years) and we estimate the emergence timescale of the CMIP3 ensemble signal to be 260 years (figure 1 and table 2). Other factors that influence the emergence timescale beyond the absolute change in damage potential include the sign of the projections (there is less variability in simulated storm numbers as the annual frequency decreases); the consistency of the sign throughout SS categories and the magnitude of projections.

A closer examination of the MPI signal emergence demonstrates the interplay of some of these factors. The MPI model change in damage potential and simulated mean change in damage are negative (−9%) after 80 years (table 2) as is the simulated mean gradient (least-squares estimate). At the emergence timescale, however, the simulated mean change in damage and mean gradient (least-squares estimate) are both positive. It takes approximately 280 years for the simulated mean gradient to change sign: the percentage of positive gradients does not fall below 5% at any time during the first 280 years and it is not for a number of years after the SS category 1, 2 and 3 frequencies have become zero (supplementary table S4 available at stacks.iop.org/ERL/6/014003/mmedia) that the signal emerges.

The MPI signal is the only signal that emerges earlier (540 years) if sub-periods are also examined—the number of negative gradients falling below 5% between years 80 and 543 (see supplementary discussion for further detail, available at stacks.iop.org/ERL/6/014003/mmedia). When simulating beyond the 80-year extent of frequency projections, we assume the same linear rate of change from the first 80 years. If the annual frequency in any SS category reaches zero before the emergence timescale (supplementary table S4 available at stacks.iop.org/ERL/6/014003/mmedia), it is held at zero beyond that point, regardless of physical reality. As is to be expected, there is generally good agreement between the change in damage potential and simulated mean change in damage (table 2).

4. Discussion

Our study is based upon a number of other assumptions. In using projections from Bender *et al* [11] we consider only climate projections from the IPCC Fourth Assessment Report (AR4) A1B emissions scenario and we accept the limitations of all models. Moreover we also adopt the Bender *et al* [11] assumption that the frequency and intensity of landfalling storms are representative of Atlantic basin activity. Our study ignores future rising sea-levels and related adaptation efforts, both of which will be important for damage arising from storm surge, as well as any future changes in tropical cyclone rainfall. With respect to these issues, we note that the historical damage record compiled by the US National Hurricane Center generally does not include losses associated with rainfall-induced flooding [6].

While there are inevitable uncertainties in the loss record, the fact that normalized damage reflects the El Niño-Southern Oscillation (ENSO) cycle [13] and trends in landfall frequency and intensity [3] in geophysical data gives cause for confidence that the time series is of sufficient quality for our purposes. However our simulation approach does not preserve the ENSO influence or that of others such as the Atlantic Multi-decadal Oscillation. By modelling event loss frequency as a Poisson distribution we also ignore any of the clustering between SS categories prevalent in the annual loss records.

Our analysis assumes that any future changes in building codes, land-use planning and other risk reduction and climate adaptation strategies are addressed in future normalization such that the normalized losses remain unbiased. A bias would make signal detection more difficult but will only occur if these factors are not accounted for in future normalization. We use losses normalized to year 2005 values to estimate emergence timescales but our results are independent of values at this year. If we normalize losses to values at any year throughout the synthetic loss time series the same emergence timescales are obtained (see supplementary discussion for further detail, available at stacks.iop.org/ERL/6/014003/mmedia).

5. Conclusions

This study has investigated the impact of the Bender *et al* [11] Atlantic storm projections on US tropical cyclone economic losses. The emergence timescale of these anthropogenic climate change signals in normalized losses was found to be between 120 and 550 years. The 18-model ensemble-based signal emerges in 260 years.

This result confirms the general agreement that it is far more efficient to seek to detect anthropogenic signals in geophysical data directly rather than in loss data [14]. It also has implications for the emergence timescale of anthropogenic signals in global weather-related natural disaster losses given these losses are highly correlated with US tropical cyclone losses (supplementary discussion and table S1 available at stacks.iop.org/ERL/6/014003/mmedia). Our results suggest that the emergence timescales are likely to be even longer than those determined for US tropical cyclone losses given that different perils will have different sensitivities to future anthropogenic climate change and may even change in different directions. We note that US tropical cyclone losses may become increasingly less correlated with global weather-related records as the loss potentials of developing countries in particular continue to rise rapidly, irrespective of future changes in climate [15]. This means that the relationship between the signal emergence time in US tropical cyclone losses and global losses may weaken over time.

Based on the results from our emergence timescale analysis we urge extreme caution in attributing short term trends (i.e., over many decades and longer) in normalized US tropical cyclone losses to anthropogenic climate change. The same conclusion applies to global weather-related natural disaster losses at least in the near future. Not only is short term variability not ‘climate change’ (which the IPCC defines on timescales of 30–50 years or longer), but anthropogenic climate change signals are very unlikely to emerge in US tropical cyclone losses at timescales of less than a century under the projections examined here.

Our results argue very strongly against using abnormally large losses from individual Atlantic hurricanes or seasons as either evidence of anthropogenic climate change or to justify actions on greenhouse gas emissions. There are far better justifications for action on greenhouse gases. Policy making related to climate necessarily must occur under uncertainty and ignorance. Our analysis indicates that such conditions will persist on timescales longer than those of decision making, strengthening the case for expanding disaster risk reduction in climate adaptation policy [15].

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