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United States hurricane landfalls and damages: Can one-to five-year predictions beat climatology?

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This paper asks whether one- to five-year predictions of United States hurricane landfalls and damages improve upon a baseline expectation derived from the climatological record. The paper argues that the large diversity of available predictions means that some predictions will improve upon climatology, but for decades if not longer it will be impossible to know whether these improvements were due to chance or actual skill. A review of efforts to predict hurricane landfalls and damage on timescales of one to five years does not lend much optimism to such efforts in any case. For decision makers, the recommendation is to use climatology as a baseline expectation and to clearly identify hedges away from this baseline, in order to clearly distinguish empirical from non-empirical justifications for judgements of risk.

Keywords: economic damage; hurricanes; insurance; prediction; uncertainty

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1. Introduction

The answer to the question posed in the subtitle is, unfortunately, no. This paper explains why skilful prediction of US hurricane landfalls and damages is not possible in the short term, defined here as a time period of one to five years. A 'skilful' prediction is one that improves upon expectations derived from the statistics of the long-term historical record.

More precisely, this paper argues that the range of predictive methodologies available, and the corresponding diversity of predictions, mean that it is guaranteed that some prediction(s) will beat climatology, but it will be many decades if ever before we can know if that performance was due to chance or actual skill in the prediction methodology. On the timescales of decision making, decision makers must therefore proceed under irreducible uncertainties and fundamental ignorance. There may be many reasons for decision makers to hedge their judgements of risk in various directions, and there is ample science available to support virtually any hedging strategy. The paper concludes with a discussion of the implications of the lack of skilful prediction for decision making related to expectations of future storms and their impacts.

2. Methods and data

The methods employed in this paper are restricted to those that seek to identify strong signals using simple methods. This is for two reasons. First, strong signals identified using simple methods are most likely to have direct applications. There are countless studies that have sought to extract weak signals in messy hurricane data using complex methods, and such studies can indeed be of scientific value. However, for purposes of shaping expectations of hurricane behaviour on timescales of one to five years into the future, such studies are of little use if the signals identified

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are dependent upon methodological choices or if the signal is small when compared to uncertainties or variability.

At times, when one reads studies seeking to identify patterns or causality in geophysical time series, one may be tempted to invoke the old saw about how tortured data will inevitably confess. But at the same time there may indeed be scientifically meaningful signals in the data that complex methods are able to extract. Regardless, it seems straightforward that the more difficult it is to identify a signal in messy data the less practically useful is that knowledge. In practical terms, on timescales of decision making a signal that cannot be seen is indistinguishable from a signal that does not exist. Second, there are a number of studies that have sought to use complex methods to identify patterns and relationships in the US hurricane landfall record. Those studies will be referenced here, but not replicated.

The data on the economic losses from US landfalling hurricanes comes from Pielke et al. (2008), which sought to adjust historical losses as recorded by the US National Hurricane Center to estimate the damage that each historical storm would have produced had it made landfall in 2005. Pielke et al. (2008) presented two methods for adjusting past losses. The data used in this paper are based on the method first introduced in Pielke and Landsea (1998), and have been updated through the 2008 hurricane season.[1] The data used here do not include damage from storms that made landfall at less than hurricane strength, though such damage is considered in Pielke et al. (2008).

The data on landfalling hurricanes is from the National Oceanic and Atmospheric Administration's Hurricane Reanalysis Project.[2] Various other data used in the analyses presented below will be cited as they are used. Information on landfalling hurricanes is generally recognized as being more reliable as long as a century ago and earlier because large tropical cyclones would have been difficult to miss as the coastline was becoming increasingly populated. However, in the Pielke et al. (2008) dataset there are six storms prior to 1940 which made landfall at hurricane strength yet had no recorded damages. Logically, the chances that a landfalling storm was missed increases as one goes further back in time. However, the general convention is to assume that all landfalling hurricanes have been identified since 1900 (cf. Elsner and Jagger, 2006).

2.1. Landfall and damage records

Decision makers in a range of settings have considerable interest in the ability to anticipate hurricane landfalls in the USA and the losses associated with those impacts. Such expectations are key inputs to the pricing of homeowners' property insurance, the structure of complex financial transactions between global reinsurance firms and the movement of prices on commodities markets. Anticipation of hurricane landfalls can take the form of a prediction of a specific number of landfalls or the probability (risk) of landfalls. Judgements of risk are a form of prediction.

The US hurricane landfall record is shown in Figure 1 for the period 1851–2008 (reiterating that it is judged to be most accurate for the period since 1900, e.g. Landsea, 2007). The most important statistical feature of the record, since at least 1920, is its stationarity both in the number of storms making landfall (cf. Elsner and Bossack, 2001; Elsner et al., 2003; Nzerem et al., 2008; Smith, 2008) and also in the intensity of storms at landfall (Landsea, 2005). This means that the time series of landfalls has not shown any secular change although it has shown considerable variability. Thus, landfall statistics have been effectively modelled in various forms of a Poisson process (e.g. Elsner et al., 2003; Lu and Garrido, 2005). The damage record shows no trend since 1900 (Pielke et al., 2008). Average annual damage is USD11.3 billion (see Figure 2), and the median value is USD1.2 billion (updated to 2008 values); Pielke et al. (2008) provide a wide range of additional summary statistics and analysis of the normalized loss dataset.

The lack of trend in the landfall or damage record means that efforts to develop skilful

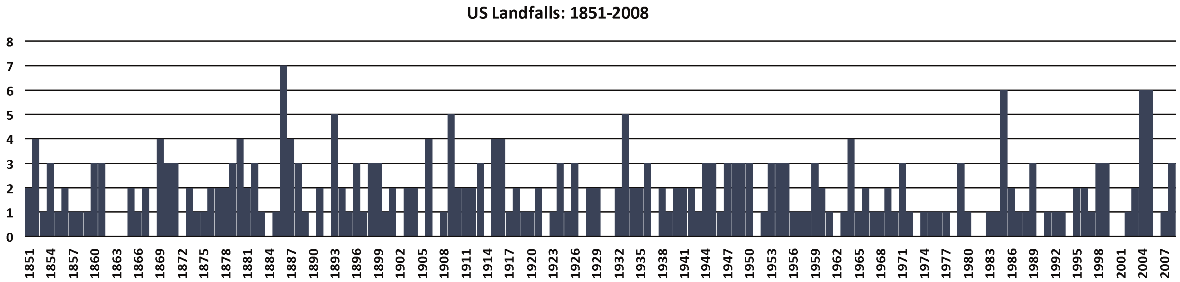

FIGURE 1 US hurricane landfalls, 1851–2008

predictions must necessarily be able to anticipate variability, as well as any future non-stationarities not evident in the historical record. If variability is to be anticipated then there must be relationships between those variables that can be accurately predicted and landfall frequency. Consequently, considerable scientific effort has been devoted to developing statistical and dynamic models of hurricane activity with the goal of offering skilful predictions of landfall and thus impact. The following section reviews this literature.

3. Efforts to make connections

An ability to anticipate hurricane landfalls reliably on short timescales, such as five years or less, would be of considerable value to decision makers. Unfortunately, despite notable advances

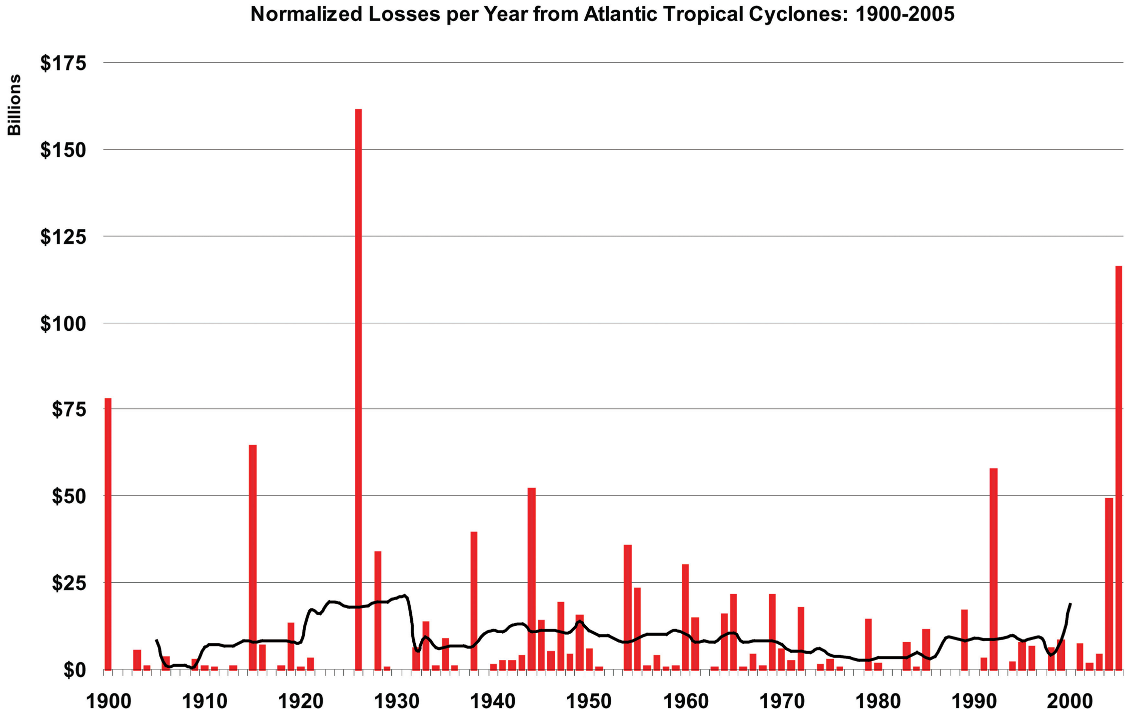

FIGURE 2 Normalized damages 1900–2005 for all landfalling tropical cyclones

Source: Reproduced from Pielke et al., 2008.

in scientific understanding as well as some indications of skilful in-sample explanatory power (i.e. retrodictions or hindcasts), no methodology has yet shown skilful out-of-sample predictions of US hurricane landfalls or damage, on timescales of one to five years, in the form of real-time forecasts provided to decision makers.

3.1. Landfall and North Atlantic Basin activity

Perhaps the most intuitive relationship to be explored is that between the total number of storms in the North Atlantic (NATL) and the number that make landfall. This relationship, however, is not straightforward. A simple correlation between the number of named storms (i.e. storms that reach tropical cyclone strength) and landfalling hurricanes is 0.46, explaining about 21 per cent of the variation in hurricane landfalls (for the period 1966–2008, which coincides with the satellite observational era; Landsea, 2007). Using only storms that reach hurricane strength in the correlation with landfalls offers a little improvement. Table 1 shows a range of simple correlations between basin activity, hurricane landfalls and damage.[3]

Logically, and as would be expected, correlations with damage improve as one moves to smaller subsets of the data, including intense hurricanes which historically have accounted for about 85 per cent of all damage (Pielke et al., 2008). The number of landfalling hurricanes shows a strong relationship with damage, explaining about half the variation and underscoring the importance of skilful landfall predictions. But at the same time, even a perfect prediction of the number of landfalling hurricanes leaves a considerable amount of uncertainty about damage, due to the nonlinear impacts of storms of different hurricane intensities, as well as the differential levels of population and development along the US coast.

TABLE 1 Correlations between various measures of activity, US landfalls and damage

	Hurricanes in basin	Landfalling hurricanes	Damage
Named storms in basin	0.87	0.46	0.27
Hurricanes in basin	*	0.52	0.42
Intense hurricanes in basin	*	0.58	0.45
Landfalling hurricanes	*	*	0.71

Note: Correlations with damage are computed as Spearman (rank) correlations. The time period of the analysis is 1966–2008, which coincides with the satellite observational era (Landsea, 2007).

Over decades it is clear that storm seasons with a greater number of named storms also have more landfalls and greater damage. From 1966 to 2008 hurricane seasons with 11 or more named storms (i.e. above the period average of 10.8 storms, which occurred in 23 of 43 years), there was an average of 2.1 US hurricane landfalls causing median damage of USD 2.3 billion. In seasons with 10 or fewer named storms (below the average of 10.8 storms, which occurred in 20 of 43 years) there was an average of 1.0 named storms causing median damage of USD640 million. However, the relationship between overall activity and landfalls is not nearly as pronounced in years with more than 11 named storms. The 13 years during the period 1966 to 2008 with 13 or more named storms had an average of 2.3 landfalling hurricanes, while the 10 years with 11 or 12 named storms had an average of 1.8 landfalling hurricanes. Each value falls well within the other's standard deviation, helping to explain why the overall number of named storms explains only a small portion of the variability in landfalls.

3.2. Landfall rates and proportion

Table 2 shows for three different periods – 1900–2008, 1951–2008 and 1979–2008 – the frequency of annual landfalls in the first and second half of each of the periods. A few curiosities stand out. The 54 years prior to 1954 saw 21 of 54 years (39 per cent) with zero or one landfall, whereas

TABLE 2 Number of years with indicated number of landfalls for three periods, each divided into halves

Hurricane landfalls	1900–1953	1954–2008	1951–1979	1980–2008	1979–1993	1994–2008
Zero	10	10	4	7	3	4
One	11	25	15	11	8	3
Two	17	7	3	4	1	3
Three	11	7	6	4	2	3
Four	3	0	0	0	0	0
Five	2	0	0	0	0	0
Six	0	3	0	3	1	2
Total years	54	54	29	29	15	15

the 54-year period 1954–2008 saw 35 years (65 per cent) with zero or one landfall. The 15-year period 1979–1993 saw four years with two or more landfalls, whereas the 15-year period 1994–2008 saw eight years with two or more landfalls. Damage from equal periods from 1901 to 2008 shows no evidence of secular changes in landfall numbers, overall damage or damage per landfall, as shown in Table 3 (cf. Pielke et al., 2008).

Efforts to anticipate future hurricane activity has primarily focused on developing seasonal predictions (i.e. for lead times of less than one year) of NATL basin activity, with yearly forecasts provided by teams from Colorado State University and the National Oceanic and Atmospheric Administration, along with a range of scientists, private firms and consultants offering their own predictions (for a review, see Camargo et al., 2007). Even though such forecasts are announced with much fanfare, widely reported on in the media and considered by many decision makers, they have thus far offered very little insight to the subsequent season's landfall or damages.

Nonetheless, the changing number of storms in the NATL basin since 1995 as compared to a much quieter period from 1970 to 1994 has led to a vigorous scientific debate over hurricane landfalls. The data record for named storms in the NATL basin, unlike the landfall record, does indicate statistical non-stationarity over the 20th century and the latter half of the 19th century. Specifically it shows a long-term increase in the overall number of storms, punctuated by periods of greater and lesser activity (e.g. Holland and Webster, 2007; see also Briggs, 2008). The data record has led to several competing interpretations to explain why the basin statistics would show an increase while the landfall statistics would not.

The net result of the different behaviour of basin-wide activity and landfalling hurricanes is a decrease in the overall proportion of storms that make landfall, as shown in Figure 3, with a best fit linear trend. From at least 1950 there is no trend in the landfall proportion but considerable variation, ranging from 0 to about 55 per cent of named storms.

TABLE 3 Landfalling hurricanes, total normalized damage and damage per landfall for four equal periods

	1901–1927	1928–1954	1955–1981	1982–2008
Landfalling hurricanes	48	54	37	48
Total normalized damage (USD billion)	296	296	205	349
Damage per landfall (USD billion)	6.2	5.5	5.5	7.3

Note: The data shown in Table 3 above are sensitive to choice of interval, given that large damaging events lead to a large fraction of the damage for any particular period. However, the choice of comparison period does not alter the perspective of a long-term stationarity in landfall and damage statistics. For instance, the 54-year period 1901–1954 saw USD592 billion in normalized damage from 101 landfalls and the 54-year period 1954–2008 saw USD554 billion in normalized damage from 83 landfalls.

3.3. Spatial distribution of hurricane activity

One explanation for the different statistical behaviour of the basin and landfall data is that the increase observed in the overall basin activity is the result of changing observational practices rather than changes in storm activity. This line of argument posits, uncontroversially, that the number of landfalling storms is one of the most reliable hurricane time series. It then assumes, controversially, that the overall basin numbers are proportional to the number of landfalling

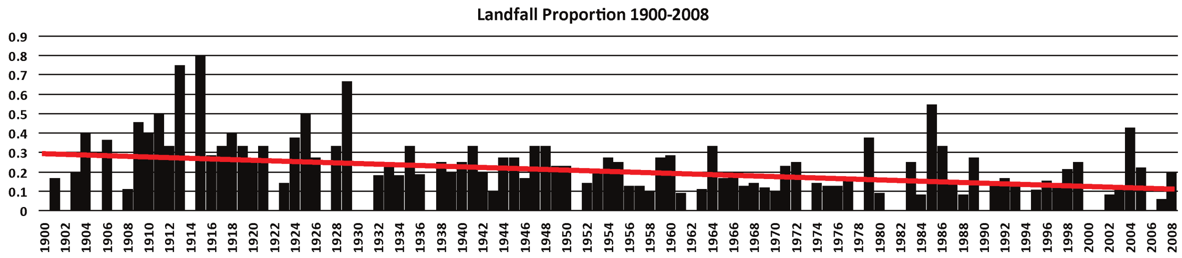

FIGURE 3 Proportion of named storms making landfall as hurricanes, 1900–2008

storms, and thus arrives at corrections which can be applied to the historical basin-wide data (examples of this line of argument can be found, for example, in Solow and Moore, 2002; Landsea, 2007).

A second line of argument is that the relatively small number of landfalls in the entire record leads to a meaningful chance that landfall numbers have indeed changed, based on the changes to overall basin activity, but that those changes cannot be detected at a statistically significant level. As Nzerem et al. (2008) argue, 'one cannot conclude from the lack of detectable change-points in the landfall series that this series isn't changing' (cf. Elsner et al., 2003). A similar line of argument was invoked by Emanuel (2005) in response to the observation that neither landfalls nor damage had increased since 1990 (Pielke, 2005). From the perspective of decision making, this argument is rather academic, as changes that cannot be detected can hardly be claimed to have much practical significance.

Both of these lines of argument miss an important factor in understanding the differential patterns seen in basin and landfall statistics, and that is the spatial distribution of trends in the NATL basin (see Pielke et al., 2008 for discussion). Specifically, if one looks at the increasing activity in the basin the increase has occurred in the easternmost part of the basin, far from land. The activity in areas where landfall takes place shows very similar trends to the landfall data. Figures 4a and 4b show these data.

Thus one need not invoke either the vagaries of chance or flawed data to explain the different statistics observed in the basin and for landfall. Instead, what needs to be explained is why the easternmost portion of the basin (i.e. the two most eastern quadrants in Figure 4b) has seen an increase in storm activity. This question will once again lead to thus-far unresolved questions about data quality and causality. However, because the activity in this part of the basin is not highly correlated with landfalls (Pielke and McIntyre, 2007), the debate is not particularly relevant to questions related to landfall prediction.

Because landfall proportions vary a great deal, even with a perfect prediction of basin activity, predictions of landfall will have limited skill. Thus, any prediction of landfall that assumes a constant landfall proportion (e.g. Coughlin et al., 2009) necessarily leads to a poor prediction of landfall activity. For instance, consider a prediction made starting in 2000 using data since 1950. If one compares a prediction of landfall based on simply the climatological average (from 1950 to the year before the predicted year) with a prediction using a perfect basin forecast assuming a constant landfall proportion (e.g. from 1950 to 1999, the average proportion was 15.6 per cent), the use of the perfect basin forecast method would improve upon climatology in only five of the subsequent nine years, indistinguishable from chance.[4] Because overall basin activity predictions are not perfect, this is the idealized best case scenario.

To summarize, over periods less than a decade (perhaps even several decades), and certainly on the timescale of years, the total number of named storms offers little if any advantage over climatology for anticipating landfalling hurricanes. There are three main reasons for this conclusion. First, even though landfall proportions cannot be shown to have changed since at least

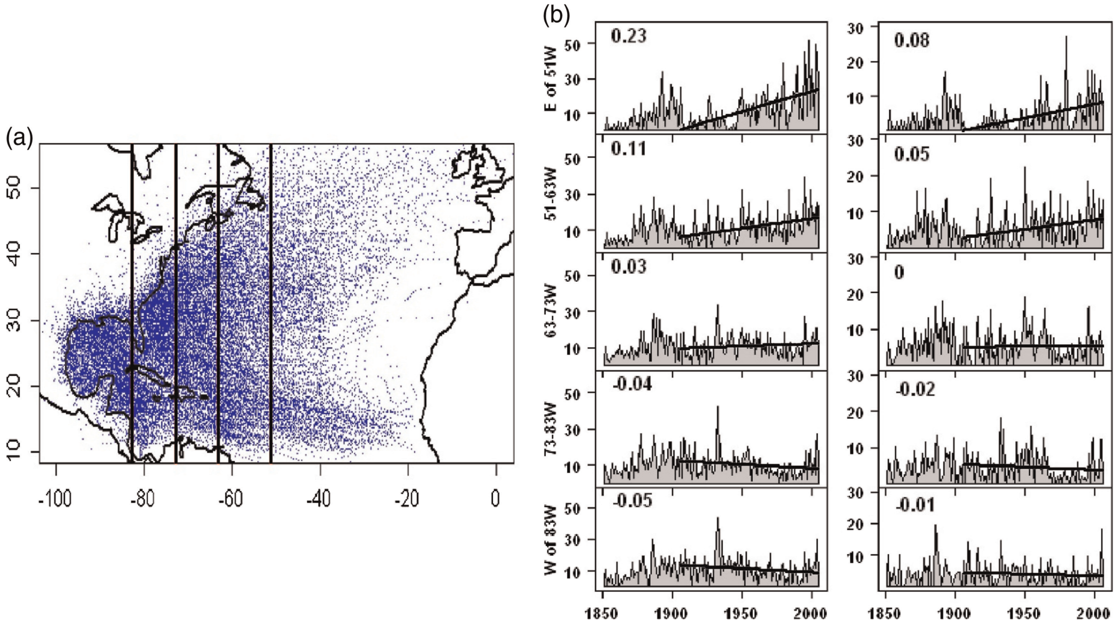

FIGURE 4 (a) NATL basin divided into five quintiles, each with an equal number of observations from the HURDAT dataset. (b) Measures of activity in each quartile: total number of storm days (left panel) and total number of hurricane days (right panel); trends are computed and shown (upper left, best fit line) from 1900

Source: Figures provided courtesy of S. McIntyre.

1950, the extremely large variability in this metric alone (see Figure 3) complicates any prediction of landfall based on first predicting the overall basin activity. Second, changes observed in the overall basin activity are not spatially uniform; increasing activity has occurred far from land. Finally, because the skill of existing seasonal predictions of basin activity is modest at best (e.g. Owens and Landsea, 2003), efforts to predict landfall rates on longer timescales based on NATL basin activity are unlikely to be forthcoming in the near term. Practically useful forecasts of landfall at timescales of one to five years will require the use of variables other than the number of storms in the basin.

3.4. El Niño: Southern Oscillation and landfall

Because there is no simple way either to predict overall basin activity or its annual relationship with landfalling hurricanes, scientists have looked for ways to explain the patterns of variability in storm activity. Many of such studies focus on NATL basin activity, but some also focus on landfalling hurricanes. The most well documented and strongest relationship is that between the El Niño-Southern Oscillation (ENSO, measured via the Southern Oscillation Index or temperatures of the equatorial Pacific Ocean) and storm landfalls.

Figure 5 shows the number of US hurricane landfalls in different states of ENSO from 1950 to 2007. Over this period there were fewer hurricane landfalls during El Niño years than during La Niña years.

Pielke and Landsea (1999) showed a relationship between ENSO and normalized damages (cf. Katz, 2002), and this relationship continues to hold through 2008 as shown in Table 4. Predictability of the state of ENSO shows skill only on timescales of less than a year, and even then the skill is not particularly large (Camargo et al., 2007). Thus, while ENSO has a significant

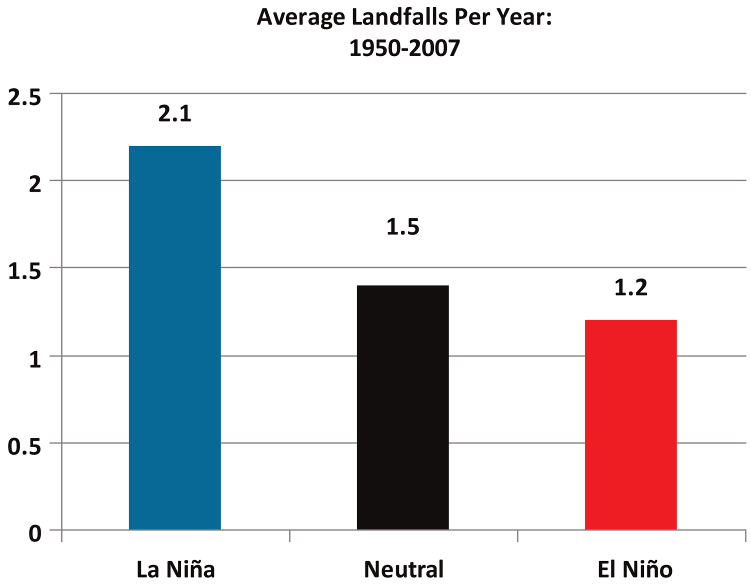

FIGURE 5 Average US landfalls by state of ENSO, 1950–2007. The SST data is from the NOAA Climate Prediction Center and is a three-month running mean for August, September and October of ERSST.v3 SST anomalies in the Niño 3.4 region (i.e. 5° N–5° S, 120°–170° W); available at www.cpc.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml. An El Niño year is defined by NOAA as an anomaly of 0.5°C or larger and a La Niña year is defined by an anomaly of −0.5°C or less. From 1950 to 2007 there were 18 La Niña years, 22 neutral years and 18 El Niño years

relationship with landfalls and damage, the ability to skilfully predict ENSO events more than a season or two in advance limits its use as a guide to landfalls and damages on a timescale of one to five years, leading scientists to explore other relationships.

3.5. Sea surface temperatures, climate oscillations, solar cycles and more

Scientists have published widely on the relationships of hurricane activity and sea surface temperatures (SSTs), Pacific Decadal Oscillation (PDO), North Atlantic Oscillation (NAO), Atlantic Multidecadal Oscillation (AMO), Atlantic Multidecadal Mode (AMM) and even more exotic relationships such as with the Quasibiennial Oscillation (QBO), Cold Tongue Index (CTI), African dust and rainfall, Asian and North American smog, sunspot activity and more. Some of this literature was reviewed by an international working group of the World Meteorological Organization (World Meteorological Organization, 2006; more recently, see Bogen et al., 2007).

TABLE 4 Replication of Table 2 in Pielke and Landsea (1999) using updated statistics on normalized damage and ENSO (including 2007)

	Median damage (USD billion)	Mean damage (USD billion)	Std dev (USD billion)
La Niña	6.6	9.2	10.5
Neutral	0.4	12.7	30.4
El Niño	0.4	7.7	14.5

Other studies have been developed by researchers at Florida State University, seeking to identify relationships of ENSO, NAO and AMO on landfalling storms and damage (e.g. Elsner and Jagger, 2006; Jagger et al., 2008). Elsner and Jagger (2008) find a relationship between the solar cycle and US hurricane counts, after accounting for SSTs, wind shear and steering currents.

Saunders and Lea (2005) use a metric of tropospheric winds to develop a model of landfalling activity, which its lead author characterized as 'the first to offer precision which is high enough to be practically useful' (Saunders, 2005).[5] The methodology was used subsequently in 2006–2008, resulting in a prediction issued each August for the current hurricane season, and in each case predicting landfall numbers to be above average. For these three years the number of landfalls was well below the historical mean in 2006 and 2007 and above average in 2008 (TSR, 2009). In stark contrast, Swanson (2008) suggests that the relationship between atmospheric winds and hurricane activity is in fact in the opposite direction, with the hurricanes perturbing the wind fields. Regardless of the direction of causality, there is no evidence that atmospheric winds can be predicted on timescales of a year or more.

The very public and sometimes acrimonious debate over climate change includes some who posit a straightforward relationship between increasing SSTs and increasing storm activity (e.g. Holland and Webster, 2007). If there is such a simple relationship, then increasing SSTs would be accompanied by increasing storm activity, landfalls and damage. Others have suggested a much more complicated relationship, even leading to suggestions of decreasing storm counts in the NATL (e.g. Emanuel et al., 2008; Knutson et al., 2008). Vecchi et al. (2008) show how different, legitimate views on the science lead to vastly different projections for future NATL activity. Presently, and indeed for the foreseeable future, debate over the effects of climate change on hurricane activity will remain contested (Pielke et al., 2005).

Risk Management Solutions (RMS) Ltd, a leading catastrophe modelling firm, has used a range of models coupled with expert elicitation to develop five-year forecasts of US hurricane landfall activity that it utilizes in its models used widely in the insurance and reinsurance industries (Lonfat et al., 2007; Jewson et al., 2009).[6] The RMS methodology resulted in an estimated 2.1 landfalling hurricanes and 0.9 landfalling intense hurricanes each year from 2006 to 2010. The actual values for 2006–2008 (i.e. the first three years of the forecast) are 1.3 hurricane landfalls and zero landfalling intense hurricanes per year. The long-term climatology would have suggested 1.5 hurricane landfalls and about 0.6 intense hurricane landfalls. To improve upon climatology for the five-year period of the forecast would require seven hurricane landfalls in 2009 and 2010, five of which are intense hurricanes.[7] The RMS estimates have been controversial because when incorporated into their catastrophe model as a 'short-term' outlook on activity, they lead directly to increased insurance rates, with corresponding financial benefits for many of the clients of RMS (see Hunter and Birnbaum, 2006).

Although much has been learned about tropical cyclones and various modes of climate, none has thus far resulted in knowledge that has been shown to provide skilful predictions of out-of-sample (i.e. in real time) US landfalls or damage on timescales of one to five years (cf. Karen Clark and Company, 2008). One reason for this is that the track record of such forecasts is not long. However, the experience that is available to date does not suggest optimism. Even so, those who may differ with the conclusions reached here can support their view by issuing predictions shown to be skilful on timescales of one to five years, and sustain accurate enough performance over time to show skill. But demonstrating such skill will probably impossible for at least several decades, and the next section explains why this is so.

4. The impossibility of demonstrating skilful predictive capabilities in the near term, or how the guaranteed winner scam meets the hot hand fallacy

Upon seeing efforts to establish relationships between various climate variables and NATL hurricane activity one is tempted to quote John von Neumann who said of fitting relationships with various parameters, 'with four parameters I can fit an elephant, and with five I can make him wiggle his trunk' (as related in Dyson, 2004). Indeed, my own research shows a correlation of

0.33 between the total score in the UK Football Association's (FA's) annual Cup Championship game and the subsequent hurricane season's damage, without even controlling for SSTs, ENSO or the Premier League tables. Years in which the FA Cup championship game has a total of three or more goals have an average of 1.8 landfalling hurricanes and USD11.7 billion in damage, whereas championships with a total of one or two goals have had an average of only 1.3 storms and USD6.7 billion in damage.

I am sure that no one would believe that there is a causal relationship between FA Cup championship game scores and US hurricane landfalls, yet the existence of a spurious relationship should provide a reason for caution when interpreting far more plausible relationships. Two simple dynamics associated with interpreting predictions help to explain why fundamental uncertainties in hurricane landfalls will inevitably persist.

The first of these dynamics is what might be called the 'guaranteed winner scam'. It works like this: select 65,536 people and tell them that you have developed a methodology that allows for 100 per cent accurate prediction of the winner of next weekend's big football game. You split the group of 65,536 into equal halves and send one half a guaranteed prediction of victory for one team, and the other half a guaranteed win on the other team. You have ensured that your prediction will be viewed as correct by 32,768 people. Each week you can proceed in this fashion. By the time eight weeks have gone by there will be 256 people anxiously waiting for your next week's selection because you have demonstrated remarkable predictive capabilities, having provided them with eight perfect picks. Presumably they will now be ready to pay a handsome price for the predictions you offer in week nine.

Now instead of predictions of football match winners, think of real-time predictions of hurricane landfall and activity. The diversity of available predictions exceeds the range of observed landfall behaviour. Consider, for example, Jewson et al. (2009) which presents a suite of 20 different models that lead to predictions of 2007–2012 landfall activity to be from more than 8 per cent below the 1900–2006 mean to 43 per cent above that mean, with 18 values falling in between. Over the next five years it is virtually certain that one or more of these models will have provided a prediction that will be more accurate than the long-term historical baseline (i.e. will be skilful). A broader review of the literature beyond this one paper would show an even wider range of predictions. The user of these predictions has no way of knowing whether the skill was the result of true predictive skill or just chance, given a very wide range of available predictions. And because the scientific community is constantly introducing new methods of prediction the 'guaranteed winner scam' can go on forever with little hope for certainty.[8]

Complicating the issue is the 'hot hand fallacy' which was coined to describe how people misinterpret random sequences, based on how they view the tendency of basketball players to be 'streak shooters' or have the 'hot hand' (Gilovich et al., 1985). The 'hot hand fallacy' holds that the probability in a random process of a 'hit' (i.e. a made basket or a successful hurricane landfall forecast) is higher after a 'hit' than the baseline probability.[9] In other words, people often see patterns in random signals that they then use, incorrectly, to ascribe information about the future.

The 'hot hand fallacy' can manifest itself in several ways with respect to hurricane landfall forecasts. First, the wide range of available predictions essentially spanning the range of possibilities means that some predictions for the next years will be shown to have been skilful. Even if the skill is the result of the comprehensive randomness of the 'guaranteed winner scam' there will be a tendency for people to gravitate to that particular predictive methodology for future forecasts. Second, a defining feature of climatology is persistence, suggesting that nature does sometimes have a 'hot hand'. However, this too can lead one astray. Consider that following the record number of landfalls and damage of 2004 and 2005, global hurricane activity dropped to extremely low levels (Maue, 2009). Distinguishing between a true 'hot hand' and a 'winner's scam' can only occur over a period substantially longer than the timescales of prediction.

As a result of these dynamics, robust predictive skill can be shown only over the fairly long term, offering real-time predictions and carefully evaluating their performance. The necessary time period is many decades. Judgements of skilful predictive methodologies on shorter timescales must be based on guesswork or other factors beyond empirical information on predictive performance.

5. Conclusion: What is a decision maker to do?

This paper has argued that efforts to develop skilful predictions of landfalling hurricanes or damage on timescales of one to five years have shown no success. It has further argued that, given the diversity of predictions now available on these timescales, inevitably some will appear skilful in coming years. However, despite the tendency to view these predictions as actually skilful, a much longer perspective than the timescale of the predictions will be needed to robustly evaluate their performance. This sets up a frustrating situation where decision making must be made under conditions of irreducible uncertainty and ignorance.

So what might a decision maker concerned about hurricane landfalls or damage over the next one to five years actually do?

The recommendation here is to start with the historical data as a starting point for judging the likelihood of future events and their impacts. Figure 6 shows the frequency of landfalling hurricanes per year for the period 1851–2008 (other time periods are shown in Table 2, and decision makers may wish to use a record that starts in 1900 for data quality reasons). Similarly, Figure 7 shows the same data but for running five-year periods from 1851 to 2008.

A decision maker may have reasons to hedge his or her views of these distributions in one way or another, and (s)he will certainly be able to find a scientific justification for whatever hedge (s)he prefers (see Murphy, 1978). However, it is important to recognize that any decision to adjust expectations away from those in the historical record represents a hedge. Reasons for hedging might include risk aversion or risk-seeking behaviour, a gut feeling, trust in a subset of the expert community, a need to justify decisions made for other reasons and so on. But at present, there is no single, shared *scientific* justification for altering expectations away from the historical record. There are instead many scientific justifications pointing in different directions.

Starting with the historical record allows for a clear and unambiguous identification of hedging strategies and justifications for them. An ability to distinguish between judgements that can be made based on empirical analysis and those that are based on speculation or selectivity is an important factor in using science in decision making. Such a distinction can also help to identify the role that financial or other

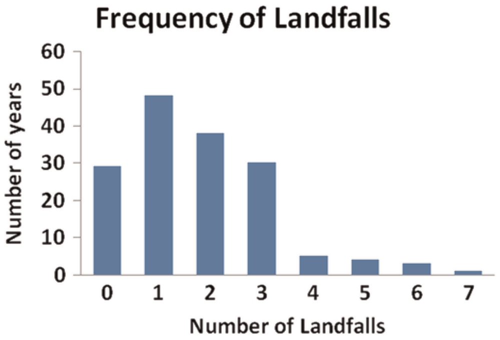

FIGURE 6 Histogram of annual number of landfalls, 1851–2008

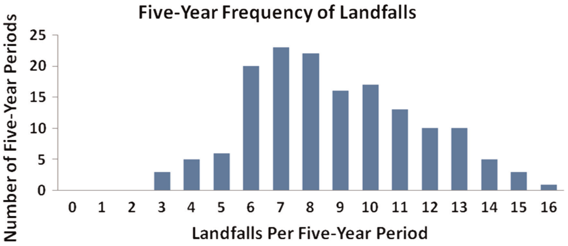

FIGURE 7 Histogram of running five-year number of landfalls, 1851–2008

interests play in the choice of relevant science in a particular decision process.

Given that the climate system is known to be non-stationary on various timescales, there are of course good reasons to expect that uncertainties may be larger than the variability observed in the past, given that the climate system can assume modes of behaviour not observed over the past century and a half. Each decision maker should carefully evaluate how *unknown unknowns* might influence their judgements. In addition to decision making under conditions of uncertainty, decision makers need also to make judgements under conditions of ignorance, where uncertainties cannot be known with certainty.

Decision makers will continue to make bets on the future and, just like in a casino, some bets will prove winners and some will be losers. But over the long term those who do the best in the business of decision making related to hurricane landfalls and their impacts will be those who best match their decisions to what can and cannot be known about the uncertain future. And such wisdom starts with understanding the historical record and why the scientific community cannot produce skilful forecasts of future landfalls and damage for the foreseeable future.

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Notes

1. The choice of dataset does not influence the results presented here, as the two methods lead to very similar results. The data used here express losses in constant 2008 US dollars, under the assumption that loss potentials plus inflation have increased by 4 per cent per year since 2005, leading to a 12.5 per cent increase in the normalized data from the 2005 baseline. 2006 had no hurricane landfalls, and thus no damage. 2007 had one landfall, with USD500 million in damage (see Blake, 2007). 2008 had three hurricane landfalls with an estimated USD16.6 billion in total losses, made by doubling the estimates of onshore insured losses provided by the Insurance Services Office for Louisiana and Texas in the third quarter of 2008 (see Insurance Services Office, 2008).
2. See www.aoml.noaa.gov/hrd/hurdat/Data_Storm.html.
3. All correlations with damage are expressed using the rank (Spearman) correlation.
4. This conclusion is identical using data from 1966, the start of the geostationary satellite era.
5. A team of researchers at Colorado State University has also issued landfall forecasts in recent years (see CSU, 2009).
6. This author participated in the 2008 elicitation process.
7. Because RMS issues a new five-year forecast each year, they are now in the interesting situation where the most recent five-year forecast is inconsistent with the one issued from 2006–2010 as they imply different rates of occurrence for the period of overlap.
8. What if the nature of relationships and processes in the global atmosphere is non-stationary on timescales less than that required to demonstrate skill with certainty? See Pielke (2009) for a discussion.
9. The ‘gambler’s fallacy’ is also relevant here. It posits that the odds of a miss are higher after a run of ‘hits’.

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