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Global warming and tropical cyclone damage to housing in the Philippines

Miguel Esteban[1,5,*], Per Stromberg[2,6], Alexandros Gasparatos[3], Dexter Thompson-Pomeroy[4]

[1]Department of Civil and Environmental Engineering, Waseda University, 3-4-1 Ookubo, Shinjuku-ku, Tokyo 169-8555, Japan
[2]United Nations University, Institute of Advance Studies, 1-1-1 Minato Mirai, Nishi-ku, Yokohama 220-8502, Japan
[3]Biodiversity Institute, Oxford Martin School, Department of Zoology, Oxford University, Tinbergen Building, South Parks Rd., Oxford OX1 3PS, UK
[4]Columbia University, Columbia College, 6462 Lerner Hall, 2920 Broadway, New York, New York 10027, USA
[5]*Present address:* Graduate School of Frontier Sciences, The University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa City, Chiba, 277-8563, Japan
[6]*Present address:* Policy Analysis Unit, Swedish Environmental Protection Agency, Environmental Economics Unit, Vallhallavägen 195, 10648 Stockholm, Sweden

ABSTRACT: It is currently feared that the increase in surface sea temperature resulting from increasing levels of greenhouse gases (GHGs) in the atmosphere could result in higher tropical cyclone intensity in the future. Although the economic consequences have been studied for a number of developed countries, very little work has been done on developing countries. The present paper assesses the likely effects that increased typhoon intensity will have on damage to housing by the year 2085 in the Philippines, using a Monte Carlo simulation that magnifies the intensity of historical tropical cyclones between the years 1978 and 2008. The simulation shows that direct damage to housing could increase between 17 and 58%, depending on the adaptive capacity of each region in the Philippines and assuming the latter remains constant between now and 2085. The results clearly suggest the need to increase the resilience of local communities against the possible consequences of climate change.

KEY WORDS: Tropical cyclone · Climate change · Vulnerability · Philippines · Intensity increase · Housing damage

1. INTRODUCTION

Tropical cyclones can have devastating effects, especially in poor countries, such as the 1970 Bangladesh cyclone that claimed between 300 000 and 500 000 lives (Landsea et al. 2006). In the US, the 2005 hurricane Katrina caused major damage and left >1800 people dead, triggering a debate about whether such tragic events will occur more frequently in the future. More recently in 2007, Cyclone Sidr was one of the strongest cyclones ever recorded in the Bay of Bengal, causing huge damage when making landfall in Bangladesh. Sidr slammed the highly vulnerable low lying densely populated coastal areas of Bangladesh with heavy rain, winds of up to 215 km h^{-1}, and a significant storm surge (Shibayama et al. 2009).

However, the area most frequently affected by tropical cyclones is that of the north-western Pacific Ocean, accounting for approximately one-third of these phenomena (Imamura & Van To 1997). In 2006, typhoon Durian left 800 people dead in the Philippines alone (Munich Re 2007). Most recently the Philippine's National Disaster Coordination Council (NDCC) has reported at least 677 and 988 fatalities in 2008 and 2009 respectively, as a result of tropical cyclones. The damage to infrastructure (excluding

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*Email: esteban.fagan@gmail.com

private houses) and agriculture amounted to at least 20.2 billion (bn) pesos (~0.50 bn USD) in 2008 and 24.3 bn pesos (~0.57 bn USD) in 2009 (NDRRMC 2009). These direct damages constituted 1.11 (2008) and 1.23 % (2009) of the total GDP of the Philippines (NSO 2009).

The impact of tropical storms on the national economy can be even higher if damage to housing, loss of productivity and other indirect damage are taken into consideration. According to Munich Re (2009), between 1980 and 2008, 8 of the 10 costliest natural disasters in Asia were typhoons that hit Japan (though this may be due to an increase in insurance policies taken out).

It is feared that as a consequence of global warming, the frequency and intensity of tropical cyclones may increase due to the warming of the sea. This is supported by an analysis of the last 30 yr of satellite records of tropical cyclones (Webster et al. 2005). Elsner et al. (2008) found a significant upward trend for wind speed quantiles above the 70th percentile, when examining the upper quantiles of cyclone maximum wind speeds. However, the accuracy of satellite-based pattern recognition remains disputed (Landsea et al. 2006), and there remains significant debate about how rising greenhouse gases (GHGs) concentrations affect tropical cyclones (Mendelsohn et al. 2012)

To attempt to understand how tropical cyclones are likely to be altered by an increase in global temperatures, an ensemble of global climate models was used in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. This report shows that although there is general agreement that tropical cyclones are likely to increase in intensity, there is yet no broad consensus on the future frequency of these events (IPCC 2007).

Attempting to analyse the economic damage due to tropical cyclones is not an easy task. Generally speaking the damage can be divided into 2 components: (1) direct damage relating to the physical destruction, and (2) indirect damage due to the loss of productive time during the tropical cyclone passage. Hallegatte (2008) explains how the indirect costs include 'business interruption in the event aftermath, production losses during the reconstruction period, and service losses in the housing sector'. As tropical cyclones grow larger, the number of hours that a given area will be affected will increase in the future. Esteban et al. (2010) analysed the effect of downtime on port operations in Japan and concluded that additional investments would be required in Japanese port infrastructure to remove potential bottlenecks in the export of goods in the future. Hsiang (2010) also found that tropical cyclones can reduce the economic output of sectors such as agriculture, wholesale/retail/tourism and mining/utilities. Tropical cyclone-related housing damage can also be significant considering the increased economic output of the construction sector following years of strong tropical cyclones (Hsiang 2010).

Forecasting this direct damage is a quite difficult undertaking due to the non-linearity of wind damage, different storm lifetimes, and the rarity of large tropical cyclones (Nordhaus 2010). Nordhaus (2010) calculates that damage in the Atlantic coast of the United States rises with the 8th power of the maximum storm wind speed, although this seems high compared to what is calculated by other researchers. Pielke (2007) suggested that wind damage is proportional to the 3rd, 6th and 9th power of wind speed, in order to represent all the sets of probable possibilities. Hallegatte (2007) assessed hurricane damage on the east coast of the US, and found that a potential 10 % increase in intensity can cause a 54 % increase in the mean normalized economic losses. He used a damage function where the damage is related to the 3rd power of the wind speed and an extra parameter $\alpha(s)$ that measures the local vulnerability at each point s along the coast. Schmidt (2010) also analysed the economic damage in the US and concluded that economic losses in the year 2050 will be 11 % higher due to the intensification of storms. Mendelsohn et al. (2012) attempted to calculate the impact of climate change on global cyclone damage, and concluded that tropical cyclone damage is likely to double even without climate change. The damage increases in this case would be due to increasing income (Mendelsohn et al. 2012).

However, most of the studies regarding the economic effects of an — as yet — hypothetical increase in tropical cyclone intensity have focused on developed countries, ignoring the potentially far more devastating effects on developing countries.

This study applies some of the techniques mentioned above to the less studied case of the Philippines. Specifically the aim of this paper is to estimate how potential climate change-induced increases in tropical cyclone intensity can affect damages to housing.

2. METHODOLOGY AND ASSUMPTIONS

2.1. Model description

The majority of comparative studies undertaken in the field of natural hazards use the country/year dyad as the unit of analysis. However, the study of human-environment systems should include geo-physical variables. The use of gridded sub-national-level data that can account for spatial variation is highly desirable.

The economic impact of tropical cyclones in the Philippine depends on several factors such as the location of economic activity, number/intensity of storms affecting the region, the topography of the affected region and other socio-geographical attributes, such as land-use patterns. As all these factors vary geographically, the authors employ a disaggregated computational approach to measure the potential damage to housing caused by tropical cyclones under a climate change scenario for the year 2085.

For the case of direct damage to housing, the number of houses damaged is used as a proxy for the likely increase in housing damage potential in the future. Statistics for direct economic damage for the Philippines are scarce, and hence it is difficult to assess this damage in economic terms (see Section 2.7).

The methodology to calculate the geographical influence of the tropical cyclones is based on the work of Esteban et al. (2010), while the procedure to calculate housing damage is inspired by Hallegatte's (2007) procedure.

Initially the number of tropical cyclones that will be generated in the Asia-Pacific Basin for each month of the year is randomly determined based on historical probability distribution functions of the number of events in that particular month. This means that the tropical cyclones themselves are not randomly generated; instead, each one is picked at random from a set of 831 historical tracks.

Then the simulation randomly alters the strength and size of each tropical cyclone according to the expected future distribution of maximum wind speeds proposed by Knutson & Tuleya (2004) (see Section 2.5). This allows the determination of the number of hours that an area is expected to be affected by winds of certain strengths in the future. The results calculated are for year 2085, as the work of Knutson & Tuleya (2004) provides the expected distribution of maximum surface wind speeds for this year only. Although there are methods to randomly generate tropical cyclones (e.g. Hallegatte 2007), the computational demands of doing so are so great that attempting to then use a Monte Carlo simulation would result in a prohibitively long computational time. As a large number of historical tracks are available for the target region, and tropical cyclones generally follow the same general trajectories, by keeping the original historical tracks it is possible to obtain the desired simulations relatively quickly.

2.2. Assumptions

The simulation model used in this paper draws significantly from the model developed by Esteban et al. (2010), which builds on a number of assumptions. Understanding these assumptions is crucial for appreciating the limitations of the present study.

(1) It is assumed that the tracks, frequency and seasonal distribution of tropical cyclones will not change in the future. It is possible that future increases in sea temperature could make the tropical cyclone season longer and/or increase the frequencies of these events. A number of studies on tropical cyclone frequency in warmer climate have been made, but the results of these are contradictory, and are still regarded as inconclusive as indicated by the 4th Assessment Report (IPCC 2007). A consensus statement from the 6th International Workshop on Tropical Cyclones of the World Meteorological Organisation (WMO 2006) states that 'although recent climate model simulations project a decrease or no change in global tropical cyclone numbers in a warmer climate there is low confidence in this projection' (p. 5). Thus, in the absence of any clear consensus on this point, the assumption of keeping the routes and frequencies the same can be seen as the default starting point of any simulation to determine economic risks. By relying on historical tropical cyclones the simulation model employed has no way to predict what future changes in global climate will have on typhoon routes or frequencies, and hence these follow closely the events of the last 20 yr.

(2) It is assumed that there is a general relationship between the maximum sustained wind speed and the size of the tropical cyclone. This point is not clearly established for the case of large typhoons (Knutson & Tuleya 2004), although Esteban et al. (2010) provide some statistical analysis to back this assumption.

(3) It is assumed that the topography and population distribution of the Philippines will not change dramatically in the future. This allows for the determination of the damage to housing in each location to be expressed as a percentage of the total houses, and allows the increase in potential damage to housing in each area to be calculated (assuming no increase in adaptive capacity in any region).

(4) It is assumed that regional changes in intensities of tropical cyclones will follow global averages. This is far from certain, as regional predictions are notoriously difficult (Knutson et al. 2010). However, it is not clear whether precise regional predictions will be available in the near future. In the absence of better results, keeping the intensity increase in the Philippines equal to that predicted for the world as a

whole appears sensible, considering that the Philippines is one of the countries most frequently affected by tropical cyclones.

(5) It is assumed that the likely onset of damage for tropical cyclones in the Philippines is a wind of ≥50 knots (kn). Below this value, damage will not be significant.

Esteban et al. (2010) explain how (in the context of these assumptions) the results of the model can be perceived as conservative, providing a relatively low estimate of the possible consequences of climate change-induced increases in tropical cyclone intensity. If the tropical cyclone season were to become longer, or the frequency of the storms increased, then this would most likely exacerbate the damage calculated in the present study.

2.3. Tropical cyclone data

Tropical cyclone data was obtained from the website of the Japan Meteorological Agency (http://www.jma.go.jp/jma/jma-eng/jma-center/rsmc-hp-pub-eg/besttrack.html), which provides best track data for tropical cyclones in the western North Pacific and South China Sea between 1951 and 2008. Prior to 1977 there is no satellite data available; hence it was only possible to use the historical tracks after this date. Nevertheless, the 30 yr of data used in the present study provided a total of 831 tracks of tropical cyclones, which cover the area well (Esteban et al. 2010). The data shows the dimensions and wind speed of each storm at different moments in time.

2.4. Simulation methodology

The Monte Carlo based methodology described by Esteban et al. (2010) was used as the basis to obtain the Expected Affected Time ($\hat{\vartheta}$) that an area is under the influence of wind of a certain strength in 1 future yr. The Expected Affected Time can be defined as the sum of each of the storm durations for a given wind period that takes place over 1 yr (ϑ) for all the simulation runs divided by the number of simulated runs (N):

$$\hat{\vartheta} = \frac{\sum_{1}^{N} \vartheta}{N} \tag{1}$$

The reason to use a Monte Carlo simulation is that each simulation run produces completely different results, and hence it is necessary to obtain an average of the expected result (Esteban et al. 2010). By using N = 5000 it is possible to obtain >99% accuracy (as compared to a N = 50 000 run).

The simulation starts by generating a random number of tropical cyclones for each month of the year from the probability distribution parameters given in Table 1. Esteban et al. (2010) obtained these values by analysing the number of storms in the western North Pacific and China Sea between 1971 and 2006, as published by the Japan Meteorological Agency. After the number of tropical cyclones in each month has been generated, the simulation then selects for each cyclone in the month one random historical cyclone track from the record of all the tropical cyclones between 1978 and 2008 (see Section 2.3).

2.5. Increase in tropical cyclone intensity by the year 2085

The assumptions regarding the increase in storm intensity in the year 2085 are derived from the work of Knutson & Tuleya (2004). These authors carried out simulations for a sea surface temperature change of between +0.8 to +2.4°C, which assume a linear +1% compounded annual increase in CO_2 concentrations over a period of 80 yr (up to the year 2085). This +1% annual increase means that CO_2 levels would reach 2.2 times the control value (that of 2004) by the year 2085. These authors acknowledge how other radiative forcing agents besides GHGs may have important effects on the global climate, but quantification of their past and possible future forcing remains even more unclear than for GHGs. Al-

Table 1. Probability distribution functions of number of tropical cyclones mo^{-1}

Month	Normal	SD
Jan	0.47	0.55
Feb	0.14	0.35
Mar	0.33	0.67
Apr	0.72	0.77
May	1.08	1.09
Jun	1.78	1.25
Jul	4.00	1.63
Aug	5.58	1.69
Sep	4.86	1.34
Oct	3.75	1.48
Nov	2.39	1.25
Dec	1.28	0.90

though these authors continuously refer to CO_2 and GHGs, it appears that they only actually considered CO_2 emissions in their model. Additionally, other factors such as vertical wind shear can also play a crucial role, although how to correctly apply this is at present still under discussion, so it was not included in the study of Knutson & Tuleya (2004).

A recent review by Knutson et al. (2010) highlighted the considerable uncertainties when estimating future increases in the intensity of tropical storms. The paper offered a wide range of such estimates, ranging between 2 and 11 % by 2100 (Knutson et al. 2010). This range does encompass the 6 % average increase described in Knutson & Tuleya (2004) for the year 2085 and which thus appears to be a reasonable value to assume in the present study.

Fig. 1 is used to derive a probability distribution function of the increase in intensity of tropical storms in the present study. From this probability distribution function the simulation draws a random value (i.e. an 'intensity multiplier'), which is then applied to the real historical tropical cyclone data to modify the tropical cyclone size. This way, although the tracks of the tropical cyclones do not deviate from that of the historical norm, their intensities and shapes can be made to change slightly (Esteban et al. 2010).

It should be noted that the wind speed distributions shown in Fig. 1 are not actually consistent with observed distributions of wind speed as they are based on Knutson & Tuleya (2004) simulations. Actual wind speed distribution is positively skewed. However, in order to be consistent it was better to use the control and 2085 results of Knutson & Tuleya (2004) rather than the actual (skewed) distribution of wind speed and the future (non-skewed) distributions provided by the same authors.

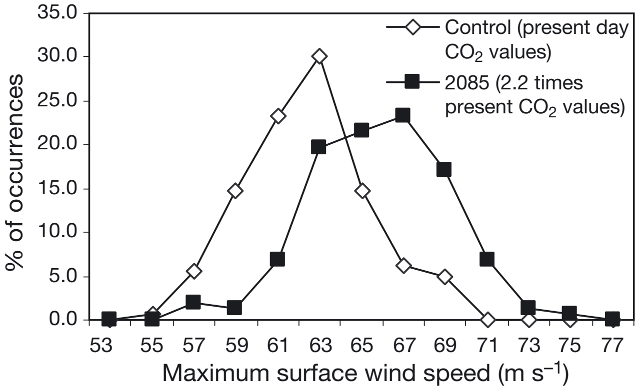

Fig. 1. Probability distribution functions for present and future typhoons. Source: (Knutson & Tuleya 2004)

2.6. Effect of maximum sustained wind speed on radius of tropical cyclone and simulation

The data of the Japan Meteorological Agency provides radii for sustained 50 kn winds at various time intervals. This data can be used to model the tropical cyclone as a circle representing the area that is affected by 50 kn winds or higher.

Esteban et al. (2010) carried out a historical analysis of all tropical cyclone data between 1978 and 2008 to show how there is a positive relationship between the maximum wind speed and the radius of a storm of the shape:

$$R = b_0 + b_1 W_{\max} + e \qquad (2)$$

where b_0 and b_1 are 2 parameters relating to the slope of the curve, R is the radius of 50 kn winds, $W_{\max}$ is the maximum sustained wind speed and e is the error. For the case of 50 kn winds, Esteban et al. (2010) performed a regression analysis of all storms in the Western Pacific, providing the following values for b_0 and b_1:

$$R_{50} = -81.345 + 2.099\ W_{\max} + e \qquad (R^2 = 0.59) \qquad (3)$$

Nevertheless, Esteban et al. (2010) propose that in order to investigate the sensitivity of the simulation, 2 different climate change scenarios should be investigated: Scenario A with $b_1 = 1$, and Scenario B with b_1 as shown in Eq. (3).

Any scenarios with a b_1 higher than that shown in Eq. (3) would result in the tropical cyclone becoming much bigger and would thus go against the conservative principle outlined in Esteban et al. (2010) and adopted in the present study.

2.7. Estimation of direct damage

The impact of maximum wind speeds on damage is non-linear with physical damage increasing sharply with maximum winds. However, not all storms have the same duration. Also the period over which the wind is exerted is important. As a result, damage is likely to happen only after a certain threshold (non-linear failure mode) is reached, which only happens in a few storms.

For the case of the Philippines, which is a highly mountainous country, the amount of precipitation also plays a vital role, as much of the damage is due to flooding and landslides. Although the computation of precipitation is not possible using the model discussed in this section, there generally is a relationship between the size of the storm and the amount of precipitation due to it.

To ascertain the relationship between high winds and housing damage, a total of 22 typhoons and tropical storms that affected the Philippines were analysed for the period 2003–2008. The data used was collected by the National Disaster Coordinating Council of the Philippines, which issues the 'SitRep' NDCC Reports after each major storm. These reports include damage data for each region in the country such as the number of casualties, affected people, damaged and destroyed houses and losses in infrastructure and agriculture. Unfortunately the data available before 2003 is not of sufficient quality for the purposes of the present study, so only the period 2003–2008 was analysed.

In the present study the damage to each of the 17 regions of the Philippines was assumed to be proportional to the number of hours that each region was affected by 50 kn winds and the number of people affected by them. Based on that, the number of hours that each province was affected by 50 kn winds was calculated for each of the 22 storms considered in this study. Then the number of people affected for each of the 17 regions was added up from the provincial results.

The justification behind targeting 50 kn winds is that this is the threshold for severe wind damage such as broken branches, uprooted trees, blown over construction signs and barricades, and the peeling of poorly attached asphalt shingles off roofs (Ahrens 2011). In other words, winds below this threshold do not cause any significant damage, aside from that to poorly constructed structures (Ahrens 2011).

The methodology used here contrasts with that used by other authors who relate damage to the maximum wind speed (e.g. Schmidt 2010). Maximum wind speed is only exerted in a comparatively small area at the centre of the storm. However, damage does not only occur at the centre of the tropical cyclone, but extends to other regions, sometimes spanning to half the size of the Philippines for some storms. Nevertheless, using the number of hours that each province is affected by 50 kn winds will indirectly take into account the effect of maximum wind speeds, as a storm that produces high maximum central wind speeds will typically have a large size. Due to its idealised circular shape, the areas touched by the centre of the storm will be affected longer by 50 kn winds, and hence the effect of maximum wind speed on damage can be indirectly modelled.

In order to understand the effect of tropical cyclones on a given population it is crucial to have additional information such as the local geography, the geographical distribution of the population, the level of socioeconomic development and the resilience of the region against tropical storms. Yusuf & Herminia (2009) calculated the adaptive capacities of various countries in the Asia-Pacific and defined adaptive capacity (A_c) as the degree to which adjustments in practices, processes or structures can moderate or offset potential damage (or take advantage of opportunities) from climate change. This can be expressed as:

$$A_c = f\ (\text{socioeconomic factors, technology, infrastructure}) \quad (4)$$

In the present study, the 17 regions of the Philippines were grouped into 5 'super-regions', according to their location and A_c. Subsequently one regression per region was applied in order to identify the damage function of wind on housing. The authors assumed that the A_c varies across regions, but that it is rather constant across time in the short run represented in this study.

3. RESULTS

Fig. 2 shows the relationship between the number of hours that a certain area was affected by 50 kn winds and the damage to buildings. This graph suggests that there is indeed such a relationship. However, this relationship is different for each area, due to differences in the A_c and geography. The relationship between the number of buildings affected by each storm and the strength of the storm can be expressed as:

$$D_b = a_1 T_{50} + e \quad (5)$$

where D_b is the number of buildings affected (destroyed or damaged) per 1000 inhabitants, a_1 is the slope of the trendlines shown in Table 2, T_{50} is the number of hours a region is affected by 50 kn winds or higher, and e is the error.

These relationships can be used to estimate potential increases in housing damage in the Philippines by 2085 due to climate change-induced increases in cyclone intensity, assuming that there are no changes in population, infrastructure and quality of housing construction.

Regression analysis was performed to test the suitability of the proposed equations (1 regression per region). The results suggest a link between the amount of time (expressed in h) that the wind speed is >50 kn, and housing damage. The R^2 values are 0.56, 0.24, 0.21 and 0.48 for the 4 regions, and are statistically

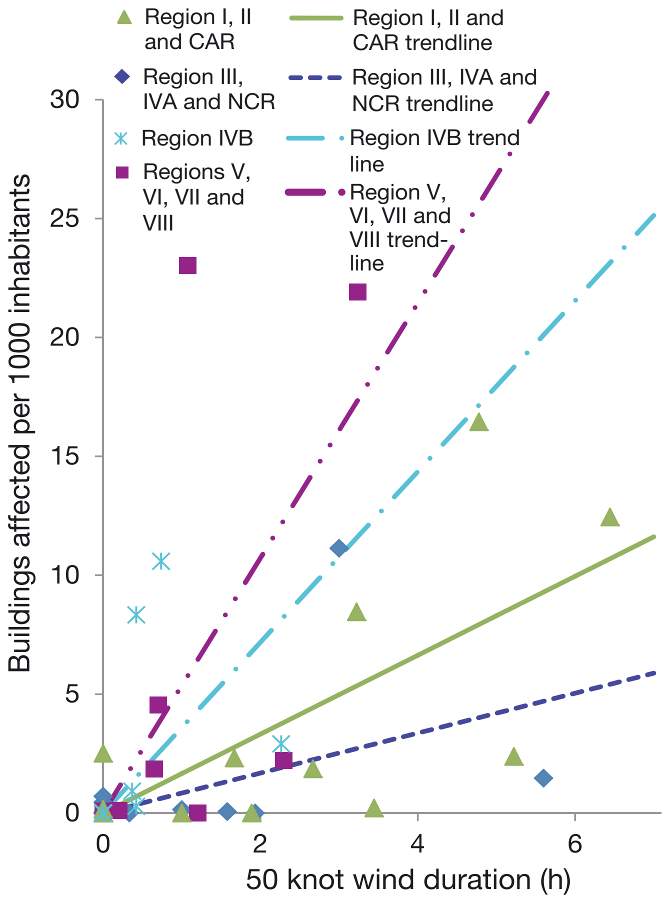

Fig. 2. Effect of duration of high winds (50 kn) on the number of damaged buildings

significant at the 5% level or lower for all 4 regions (Table 2). The R^2 value of 0.56 obtained for regions I, II and CAR is relatively high when compared to other similar studies (e.g. Schmidt 2010). On the other hand, R^2 of 0.40 is modest. Therefore, our results for Regions I, II and CAR, and Regions V, VI, VII and VIII are reasonably robust, while for the other regions should be interpreted with caution. However, it must be stressed that deriving the wind damage functions for tropical storms is a difficult endeavor for which it is difficult to obtain precise data.

One interesting observation is how damage appears to be relatively well approximated by a linear relationship. This does not mean that the damage function is actually linear, which would go against the conclusions reached by other authors as explained in Sections 1 and 2.7. Rather, it appears that comparatively little data is available for the stronger storms (which would start to show the non-linear nature of damage). This results in an underestimation of damage; hence, our results can be deemed conservative (see Section 2.2).

Table 2 contains the expected percentage increases in housing damage for the two climate change scenarios. The results suggest that direct damage from future tropical cyclones on housing could increase quite significantly in the Philippines if climate change effects are factored in. In 2 out of the 5 macro-regions, there could be an increase of up to 58% in housing damage over what can currently be expected based on historical trends. Fig. 3 shows the Expected Time that each group of regions will be affected by 50 kn winds and the subsequent increases in housing damage for each scenario.

In the worst affected areas (Regions V, VI, VII and VIII), future damage can be can be as high as 30 (Scenario A) to 36 (Scenario B) houses per 1000 inhabitants (up from 25 damaged houses for the Control Scenario). However, these results should be treated with caution, as the damage functions used in this study (Fig. 2) were obtained after the analysis of only 6 yr of data. Considering that the most damaging typhoons occurred prior to the time series we used in the current analysis, our results represent a lower-bound estimate of future damage.

Table 2. Summary of parameters determining disaster damage. Parentheses: p-values, *p = 0.01, **p = 0.05, ***p = 0.1. Ac: adaptive capacity, a1: slope of trendlines, N/A: not available

Regions	A_c	a_1	Constant	95% CI to a_1	95% CI to constant	R^2	Increase in damage to houses (%)	
							Scenario A	Scenario B
I, II, CAR[a]	0.45–0.55	1.66 (<0.01)	−0.17 (0.84)	0.96 to 2.36	−1.91 to 1.56	0.56***	18	37
III, IV-A, NCR[b]	0.6–0.72	0.84 (0.03)	0.13 (0.81)	0.11 to 1.57	−0.97 to 1.22	0.24**	28	58
IV-B[c]	0.61	2.59 (0.04)	0.58 (0.36)	0.21 to 4.96	−0.71 to 1.87	0.21**	29	58
V, VI, VII, VIII[d]	0.32–0.45	5.36 (<0.01)	0.17 (0.89)	2.70 to 8.03	−2.39 to 2.72	0.48***	21	47
IX, X, XI, XII, ARMM[e]	0.36–0.45	N/A	N/A	N/A	N/A	N/A	N/A	N/A

[a] North Philippines; [b] NCR: National Capital Region (Manila); [c] Islands, west Philippines; [d] Islands, east and central Philippines; [e] Not normally affected by typhoons, as it is too close to equator

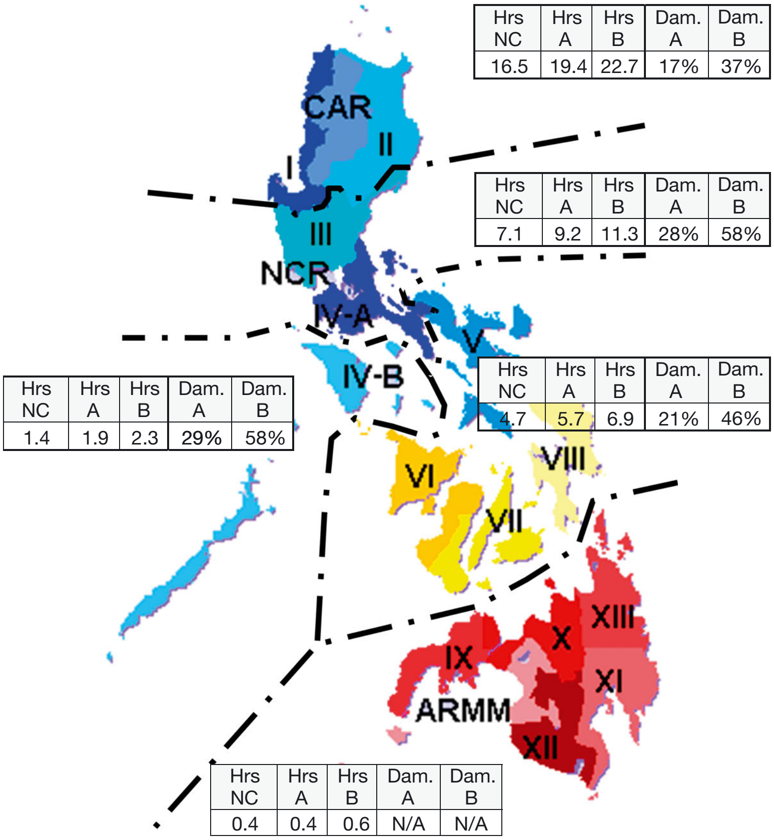

Fig. 3. Average number of hours that each group of regions is affected by 50 knot winds, and increases in housing damages. Hours (Hrs) in scenarios NC (control), A and B. Increase in housing damage (Dam.): % for Scenarios A and B. Color differentiates administrative areas

4. DISCUSSION

There is now broad scientific evidence that climate change could dramatically affect human economic systems. The Stern Report (Stern 2006) claims that 'the overall costs and risks of climate change will be equivalent to losing at least 5% of global GDP each year, now and forever. If a wider range of risks and impacts is taken into account, the estimates of damage could rise to 20% of GDP or more'[1].

The results of the present simulation are an attempt to move from the highly aggregated approach followed in the Stern Report into a more detailed assessment of one specific climate change-related hazard in a particular country.

When compared to the other Asia-Pacific countries that are most severely affected by tropical storms (i.e. Japan, China, Taiwan and South Korea), the Philippines have by far the lowest GDP per capita. In 2008, per capita income in the country amounted to 1,845 USD which was ~1.8, 9.2, 10.4 and 20.8 times lower than that of China, Taiwan, South Korea and Japan respectively (IMF 2009). Considering the decreasing marginal utility of income, it is expected that even moderate income losses due to tropical storms are more significant to the average citizen of the Philippines when compared to the wealthier neighbouring countries (Layard et al. 2008).

At the same time the Philippines have by far the highest fertility rate of any of the other tropical cyclone-prone countries in the region. With an estimated fertility rate of 3.11 children per woman for the period 2005-2010, the Philippines is the only country in this group that actually surpasses the world average and will experience a significant population increase by 2050 (UN-DESA 2010). This means that in the future, and in comparison to the other countries in the region, proportionally more Filipinos will be prone to extreme wind events.

The results overall suggest that damage will increase in the north of the country, which is historically the worst affected region by tropical cyclones[2]. Our simulations suggest that in some regions housing damage can increase by 58% depending on the climate scenario used (see Table 2). Clearly this is a very simple prescription considering the ongoing conflicts in the south, which make this proposition difficult. The above illustrate the complex challenges that policy-makers face when assessing the various benefits and problems of different climate change adaptation strategies.

Although the possibility of stronger future tropical cyclones has been evoked to make the case for action on climate/energy policy (climate change mitigation), Pielke (2007) argues that policy action should also focus on reducing vulnerabilities, at least in the short term. Pielke (2007) estimates that to reduce potential future global tropical cyclone damage, a 10% reduction in GHG emissions by 2050 will be far less effective than taking adaptation measures (i.e.

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[1] http://www.hm-treasury.gov.uk/d/CLOSED_SHORT_executive_summary.pdf

[2] The south of the country is also sometimes hit by strong weather events, such as tropical storm Washi in December 2011, which caused devastating damage to the island of Mindanao.

reducing the vulnerability of people and property) by between 5:1 and 22:1, depending on the assumptions taken. Although the nature of this research is highly idealized, it indicates how small reductions in vulnerability could have almost the same effect as if GHG concentrations were immediately stabilized at 2006 levels.

The present study must be interpreted as an indicative assessment of the likely consequences (housing damage) of an increase in tropical cyclone intensity due to climate change. The model presented forms an important tool to investigate potential changes in tropical cyclone intensity. However like any climate model, it contains hypotheses about how the climate system works, and can yield fairly different results depending on these assumptions.

The model employed in the present research uses the results provided by Knutson & Tuleya (2004) to alter the strength of historical tropical cyclones, and as a result cannot take into account possible changes in tropical cyclone paths. There are also large uncertainties about future changes in tropical cyclone intensity, as highlighted in Pielke (2007), who reports how 9 leading scholars on tropical cyclones and climate change research give very different answers (ranging from 0 to 36%) about the magnitude of tropical cyclone intensity increases by 2100. Furthermore the forward translation speed of a typhoon is also an important factor that might change in the future, though at present there is not a very good understanding of this phenomenon. Keeping the speed of typhoons constant (as our model does) appears sensible in the absence of better data, but also represents a limitation of the current method. Also, the present model reproduces the number of storms that occur during each month, but does not do it temporally. Each storm is given a number, but not a period of the month when it takes place. Hence, the effect that ≥2 consecutive storms can have on an area cannot be reproduced. This can have a significant effect. For example if an area is hit in rapid succession by 2 tropical storms, it could experience a dramatic increase in direct and indirect damages. This effect was witnessed in November 2004, when the Philippines was hit by 4 consecutive storms. In this case the damage recorded was exacerbated with each storm. The reports from the NDCC highlight that each consecutive storm caused more damage than what would have been typical. In this situation it is difficult for the NDCC to accurately report the damage due to each storm and the final figure for the last storm is likely to include damage that was also caused earlier. Thus damage figures in these situations should be viewed with caution. This effect also partly explains some of the scattering in the direct damage data that was used to derive the wind damage functions (see Fig. 2).

Furthermore, the direct damage of extreme wind effects is far more complex to quantify than was outlined in the present study. For example, the present model only encompasses one aspect of direct damage, that on housing. Infrastructure, agriculture and human casualties are also reported in the NDCC reports, though their interpretation (and simulation) is far more problematic, not the least because they are given in monetary terms (infrastructure and agriculture), and it is not clear how they were derived. For a more detailed assessment of the direct damages of tropical storms in the Philippines, more years of damage data would be needed. In this sense the present results should be viewed as preliminary.

Finally, our calculations also assume that the adaptive capacity for each area of the Philippines will remain unaltered, which is clearly unrealistic, as increases in wealth and adaptation measures are expected to increase adaptive capacity. In this sense, the present study highlights the need for an improvement in adaptation measures to improve resilience against this potential increase in tropical cyclone intensity.

5. CONCLUSIONS

The present study calculates the possible effect that climate change will have on tropical cyclone intensity and how this will affect housing damage in the Philippines. To estimate climate change-induced increases in tropical cyclone intensity for 2085, the methodology of Esteban et al. (2010) was used, which in turn uses the estimates of typhoon intensity increases of Knutson & Tuleya (2004) as assumptions.

Considering the difficulty in putting a precise monetary figure to increases in direct damage, the present research uses housing damage as a proxy. It is thus estimated that potential damage might increase significantly in the future, up to 58% in certain regions by 2085, assuming no changes in adaptive capacity. These results build on essentially 3 estimations: storm size, damage functions and projected increase in storm intensity. These 3 uncertainties add to each other and should be considered when interpreting the results. Due to the nature of the assumptions made, these results are likely to be lower bound estimates, and hence can be deemed conservative.

The adaptive capacity of each region is crucial to the amount of damage likely to be experienced in the future. Developing adaptive capacity against tropical storms across the country (including the less severely hit southern areas) would reduce housing damage, or the effects of such damage, and would bring benefits even without an increase in tropical cyclone intensity.

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