15A.6 HURRICANE COST IS LARGELY CONTROLLED BY THE VERTICAL WIND SHEAR

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1. Introduction

Currently, there are several well-known metrics to infer the destructive potential of hurricanes. The accumulated cyclone energy (ACE) and power dissipation index (PDI) are good representatives of these measures, as they are able to consider the hurricane frequency, intensity and duration (Emanuel 2005; Bell et al. 2000). The important role of sea surface temperature (SST) in hurricane destructive potential has been identified using PDI and ACE (Emanuel 2005; Saunders and Lea 2008). However, the limitation of these metrics is that they do not take into account the spatial extent of the hurricane wind structure, namely, any size effects.

The size effect is crucial to understanding the hurricane destructive potential and cost. For instance, Hurricane Sandy's enormous size mainly explains its great economic loss. The vertical wind shear is one of the most important atmospheric variables affecting hurricane size and wind structure evolution (Maclay et al. 2008). However, it has been unclear whether the SST or vertical wind shear plays a more important role in the ultimate damage. To answer this question we need metrics of hurricane destructive potential that take into account the hurricane intensity and wind structure at the same time. To date it has not been possible to conduct such an analysis because it requires continuous historical profiles of near-surface wind speed from hurricane center to an outer storm limit.

To overcome this obstacle, we use a new analytical model ("the λ model", Wang et al. 2015) to reconstruct the hurricane historical wind profiles for 1988-2014. The λ model is highly effective because it requires no scaling parameters. It constructs a wind profile from only the minimum surface pressure, the latitude of hurricane center and one measure of wind radius. With the reconstructed wind profiles, we calculate three "integrated metrics": the integrated power dissipation (IPD), the integrated kinetic energy (IKE) and the integrated angular momentum (IAM). These metrics are based on the whole wind structure at landfall so the hurricane intensity and size effect are both considered at the same time.

2. Results

Fig. 1a shows that the IPD of individual hurricanes at landfall is well correlated with the adjusted hurricane cost. However, the IPD itself is only weakly related to hurricane intensity. Neither maximum wind speed at landfall nor PDI correlate as well with the hurricane cost as IPD does. There is also a good correlation between the hurricane cost and the other integrated metrics IKE (R^2=0.47, p<0.001) and IAM (R^2=0.42, p<0.001). For the intensity only driven metric ACE, the weak correlation (R^2=0.05, p=0.17) is similar to PDI.

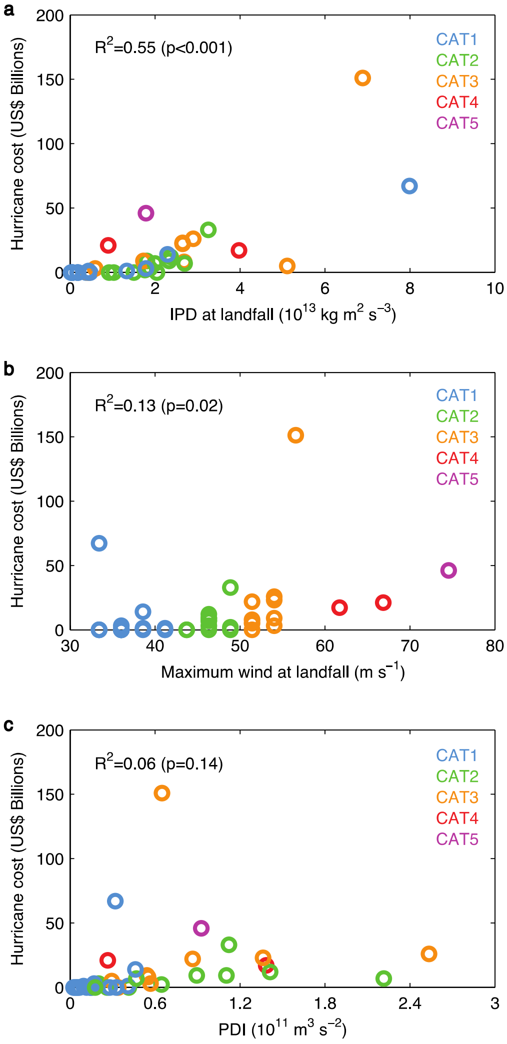

***Figure 1**. Comparison between the hurricane cost and metrics of hurricane destructive potential. (a) IPD at landfall. (b) Maximum wind speed at landfall. (c) PDI. The metrics are deduced from 40 US landfalling hurricanes for 1988-2014. The IPD at landfall of a hurricane is the sum of IPD from all the landfalls it makes, whereas the maximum wind speed is the maximum value of maximum wind speeds at landfalls. The markers are classified into 1-5 categories (CAT) according to the Saffir-Simpson Hurricane Scale.*

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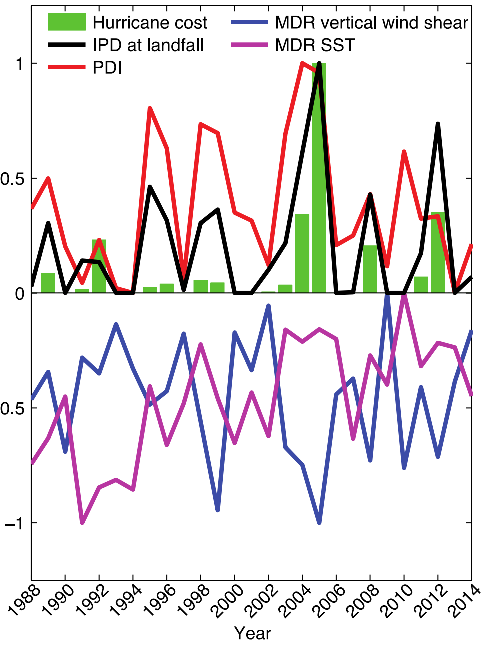

***Figure 2**. Variability of annually accumulated IPD, PDI, hurricane cost and MDR (20^{o}W-60^{o}W, 6^{o}N-18^{o}N) SST and vertical wind shear for August–October mean. The annually accumulated IPD is computed with 40 US landfalling hurricanes at landfall and the annually accumulated PDI is calculated with 187 hurricanes for 1988-2014. All the variables are normalized. For ease of comparison, a constant offset, -1, has been added to the normalized vertical wind shear and SST.*

We next compare the annually accumulated IPD at landfall to the annually accumulated PDI of all hurricanes for 1988-2014. To explain the long-term changes in IPD and PDI, we also show the annual variations in SST and vertical wind shear within the main development region of hurricanes (MDR, 20^{o}W-60^{o}W, 6^{o}N-18^{o}N). As shown in Fig. 2, the SST is somewhat positively related to IPD (R^2=0.14, p=0.05), but the vertical wind shear shows a remarkably stronger anti-correlation (R^2=0.42, $p<0.001$).

In terms of hurricane cost shown in Fig. 2, the R^2 between the annually accumulated IPD and cost is 0.71 ($p<0.001$) whereas the R^2 between the annually accumulated PDI and cost is 0.26 (p=0.004). Since the annually accumulated IPD shows good correlations with both long-term hurricane cost and environmental factors, it is plausible to establish a link between the cost and SST or vertical wind shear in the MDR directly. It is surprising that the annual hurricane cost is largely controlled by the vertical wind shear in the MDR (R^2=0.32, p=0.002). In contrast, the correlation between the cost and SST is much weaker and more uncertain (R^2=0.10, p=0.12).

Figure 3 displays the sensitivity of the annually accumulated hurricane cost and five hurricane destructive potential metrics (IPD, IKE, IAM, PDI and ACE) to the SST and vertical wind shear in the MDR. The sensitivity to SST in the MDR is 222%/^{o}C (for cost), 155%/^{o}C (for IPD), 150%/^{o}C (for IKE), 146%/^{o}C (for IAM), 103%/^{o}C (for PDI) and 101%/^{o}C (for ACE). On the other hand, decreasing the vertical wind shear in the MDR by 1.0 m s^{-1} is linked to the increase in hurricane cost of 126%, IPD of 86%, IKE of 83 %, IAM of 81%, PDI of 46% and ACE of 41%.

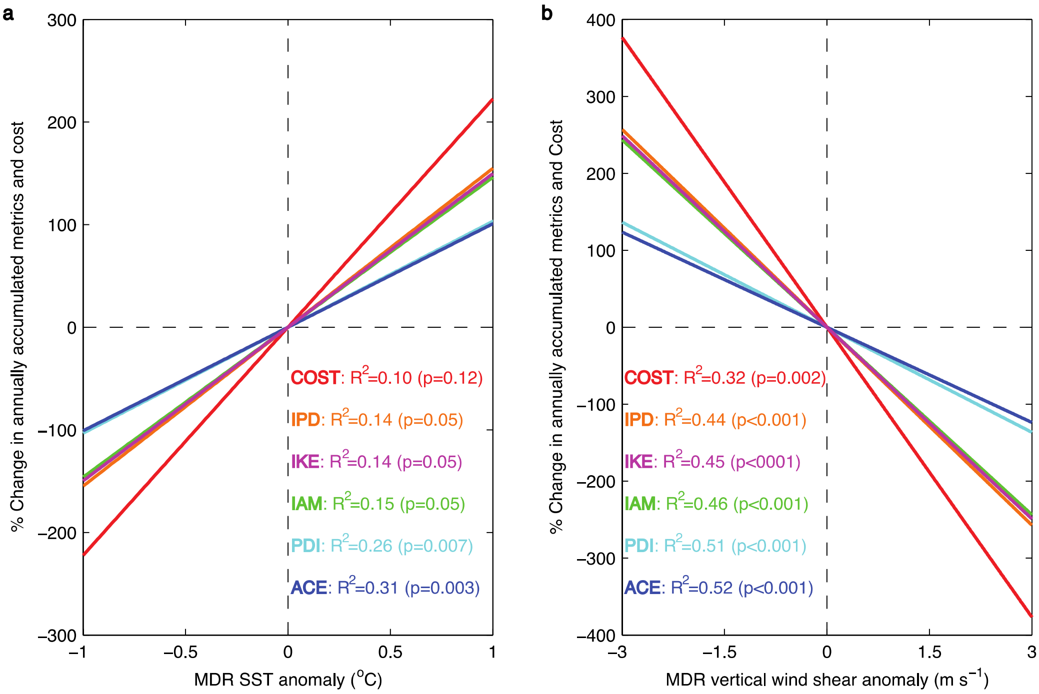

***Figure 3**. Sensitivity of the annual hurricane cost and metrics of hurricane destructive potential to August-October SST and vertical wind shear in the MDR. The SST and vertical wind shear anomalies are relative to the 1988-2014 mean in the MDR. The percentage changes in the metrics and hurricane cost are also relative to 1988-2014 mean.*

3. Discussion and Conclusions

Our results show that the wind structure at landfall is crucial to the destructive potential of individual hurricanes, rather than just the intensity or the duration. The financial damage is clearly dependent on the exposure, but by considering the wind structure at landfall, the total exposure is more implicitly taken into account than can be done with a single point intensity measure. The maximum wind speed at the landfall location is a relatively much weaker measure of the footprint, exposure and hence total damage.

For the long-term variability, compared to the SST in the MDR, the vertical wind shear always shows a much stronger correlation (and less uncertainty) with the hurricane cost and all metrics. These results suggest that the vertical wind shear in the MDR is the dominant factor that controls these metrics of annual hurricane destructive potential and therefore also the annual hurricane cost in the US.

The physical explanation in this strong connection between the wind shear and damage likely lies in the evolution of hurricane wind structure and their final size. The hurricane size can be significantly influenced by the size and intensity of the initial (Chan and Chan 2014, 2015). A large and strong initial vortex cannot be generated under strong vertical wind shear in the MDR because it inhibits genesis and subsequent intensification (Kossin et al. 2014). When the initial vortex is larger it encourages horizontal angular momentum flux into the hurricane to drive its growth (Wang et al. 2015; Chan and Chan 2015, 2014, 2013). This explains the remote link of the vertical wind shear in the MDR and the annually accumulated IPD, IKE and IAM at US landfall.

Acknowledgments

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