

Oasis Innovation Hub for
Catastrophe and Climate
Extremes Risk Assessment

China Landfall Catalogue Description

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Executive summary

A new catalogue of typhoons making landfall in China based on the CMA best track data has been created. Parametric insurance relevant variables have been derived using the methodology described below. The catalogue contains the following variables at landfall:

Storm name, Landfall date, Location, Maximum wind speed (V_{\max}) in m/s, Minimum pressure (P_{\min}) in hPa, Radius of maximum winds (R_{\max}), in km, Radius of gale force winds (R_{18}) in km, radius of 26 m/s winds (R_{26}) in km, radius of 33 m/s winds (R_{33}) in km, Integrated Kinetic Energy (IKE) in $J \times 10^{12}$, Storm Precipitation Volume Rate within 500 km (P_{vol}) in $m^3/hr \times 10^8$.

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1 Background

Typhoons cause serious harm and enormous economic loss. Liu et al. (2014) estimate that in China alone a quarter of a billion people are affected by typhoons every year and the annual economic impact is of the order of 1-2% of GDP. It has been estimated that 2/3 of China GDP (the world's second largest economy) is exposed to tropical cyclone. The Asia Pacific is experiencing rapid economic growth with ever more risk exposure. The China market is liberalizing at the same time so that demand for insurance and risk assessment is also accelerating. Insurance and others needs access to new climate services to meet this demand. Parametric insurance is a type of insurance that does not indemnify the pure loss, but before the event agrees to make a payment upon the occurrence of a triggering event. The triggering event is often a catastrophic natural event which may ordinarily precipitate a loss or a series of losses.

Tropical cyclone catalogues are an essential baseline of climate information to build catastrophe models and parametric insurance. There is a need for such a catalogue to include new variables of land falling typhoons, which are currently not available, that cause of economic loss.

There was a need to identify those variables that most closely matched the economic damage. The first challenge is to identify the correct variables for a parametric insurance product. Firstly, the most widely chosen metric to define the intensity of typhoons is the maximum wind speed. There are specific challenges with using maximum wind speed. The maximum wind speed is not consistently reported. Depending on the agency it is reported as 1 minute, 2 minute, 10 minute average. The footprint of the maximum wind is very small fraction of the eye wall. For example, a wind speed of 50 m/s (Cat3 storm) sustained for 2 minutes (the China Meteorological Agency measure) covers perhaps only 3 km within an eye wall radius of 180 km or only 3%. It is therefore very difficult to measure and confirm directly. The current intensity estimate technique uses satellite image categories and matches the image pattern to the wind speed based on few historical in-situ observations in the Atlantic. We have also investigated the integrated kinetic energy (IKE) of the land falling storms by integrating the wind profile to a radius of 200 km from the storm centre. To obtain the wind profile we have applied the published Imperial College analytical lambda wind model. This methodology (and any other) requires information on the wind radius (for example the radius maximum wind). However, wind radii in the West Pacific have only very recently only become available routinely from the

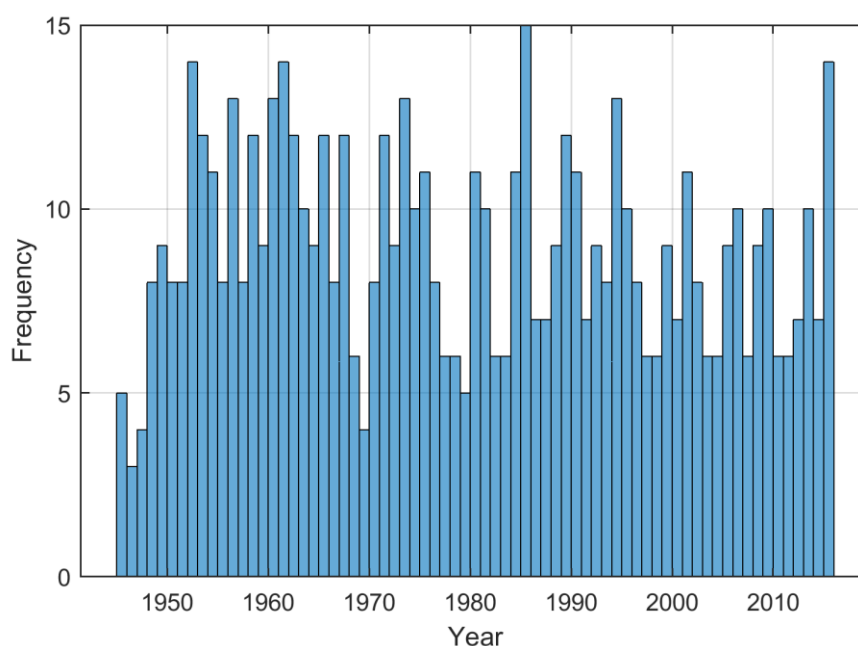
US Navy warning centre. It is more desirable and perhaps necessary to derive the integrated kinetic energy from the size information of the Chinese Meteorological Administration, but this is currently not done by them. This will limit the validation of the IKE variable against economic damage and inhibit a parametric product for China which will very likely need to be based on independent Chinese data.

Much damage is also caused by flooding. Similar to wind it is not obvious which rainfall variable is most likely to relate to damage. For example, one could consider the peak daily accumulation at a point or the integrated storm rainfall volume during land fall. We examined satellite data of rainfall at typhoon landfall. We established which rainfall variables is the most relevant to economic damage. The catalogue contains the integrated rainfall to 500 km radius from the centre during the landfall day as the rainfall volume rate at land fall.

2 Source Data

The landfall catalogue is based on the TC event set provided by the China Meteorological Administration (CMA) which was obtained from the International Best Track Archive for Climate Stewardship (IBTrACS) (Knapp et al., 2010), a world database by the NOAA National Climatic Data Center, which records TC data at 6-hour intervals and contains entries dating from 1945 to 2016. Data from other agencies are (such as the Joint Typhoon warning Centre) is available. However, after discussion with insurer and users it is clear that for political reasons only the CMA data set would be acceptable for parametric insurance. Furthermore only the CMA have access to very extensive weather stations in China which are essential to characterise the wind field at landfall. It is thus likely to form the most credible landfall catalogue. Dropsonde flight observations of typhoons by the Hong Kong Observatory over the South China Sea are also transmitted to CMA. **Error! Reference source not found.** shows the annual frequency of tropical cyclones making landfall on the Chinese coastline for the duration of the CMA record. Events in the first few years maybe under-reported and do not have associated intensity or minimum pressure values and have been excluded from the catalogue.

Figure 1. The annual frequency of China landfalling tropical cyclones in the Chinese Meteorological Administration (CMA) best track archive.

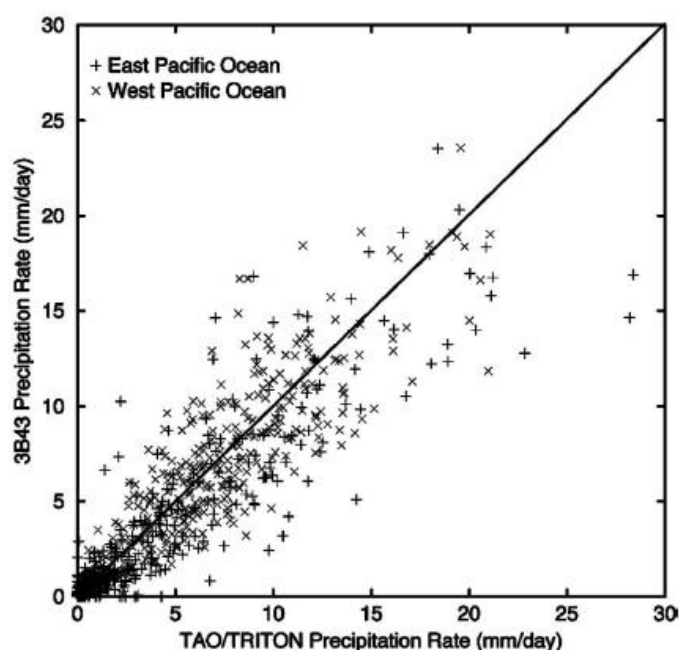


The TC track latitude and longitude were used to identify landfall events. The date and time, storm centre location, minimum pressure (p_{\min}) and intensity (V_{\max}) were recorded at timesteps corresponding to a TC making landfall. These entries form the basis of the catalogue. The storms appearing very early in the record, before 1949, do not have p_{\min} or V_{\max} values (or any other derived quantities) and have therefore been excluded. The radius of gale force wind (R_{18}) data which are not included in the IBTrACS archive were provided by the CMA directly (Feng et al., 2013). Data are available from 2001 onwards.

The rainfall data were obtained from The Tropical Rainfall Measuring Mission (TRMM) (Huffman et al., 2007) satellite product. The TRMM Multisatellite Precipitation Analysis (TMPA) provides a calibration-based sequential scheme for combining precipitation estimates from multiple satellites at fine spatial and temporal scales ($0.25^\circ \times 0.25^\circ$ and 3 hourly). TMPA is available both after and in real time, based on calibration by the TRMM Combined Instrument and TRMM Microwave Imager precipitation products, respectively. We used the after-real-time product which incorporates gauge data. The dataset covers the latitude band 50°N – 50°S for the period from 1998 to the delayed present. **Error! Reference source not found.** shows validation of the TRMM satellite product against gauge data from buoys in the east and west Pacific. It shows very little bias and relatively small scatter and hence offers a reliable estimate of precipitation rates.

We chose to use the volume rate (m^3/hr) within 500 km of the storm centre to represent storm precipitation, using the estimated storm location and time at landfall to extract this from the TRMM product.

Figure 2. Scattergram comparing TRMM research product precipitation estimates to values reported by single gauges located on TAO/TRITON buoys for the 7-yr period January 1998 to December 2004. All gridding is at $0.5^\circ \times 0.5^\circ$ monthly, values are expressed as mm day⁻¹, and the buoy reports are separated into west and east Pacific (west and east of the date line, shown as x's and +', respectively). Adapted from (Huffman et al., 2007)



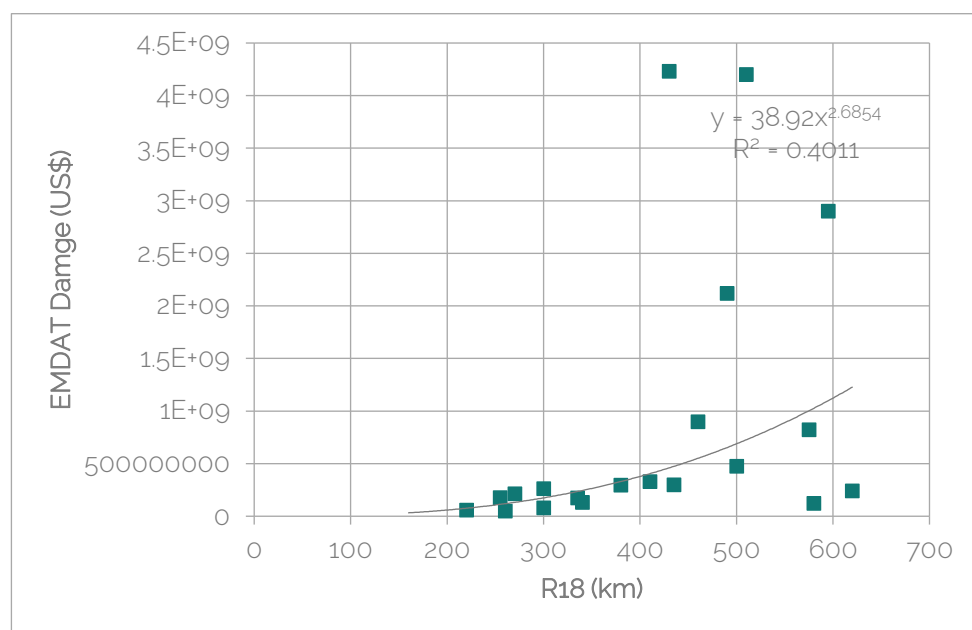
The data on economic losses and deaths were obtained from EM-DAT, an international disaster database developed by the Centre for Research on the Epidemiology of Disasters (CRED), Université catholique de Louvain.

3 Methodology

3.1 Size

Currently, there are several well-known metrics to infer the destructive potential of hurricanes, e.g., Saffir-Simpson Hurricane Scale and hurricane strength (Simpson and Saffir, 1974; Weatherford et al., 1988). The accumulated cyclone energy (ACE) and power dissipation index (PDI) have been widely used as indicators of destructive potential (Bell et al., 2000; Emanuel, 2005), as they are able to consider the hurricane frequency, intensity and duration. 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. For example, Figure 3 shows a strong relationship between the radius of gale force winds, R18 and the EMDAT damage data. We therefore include various measures of the wind-profile of cyclones in the catalogue.

Figure 3. EMDATA damage data against R18 with a fitted power law model.



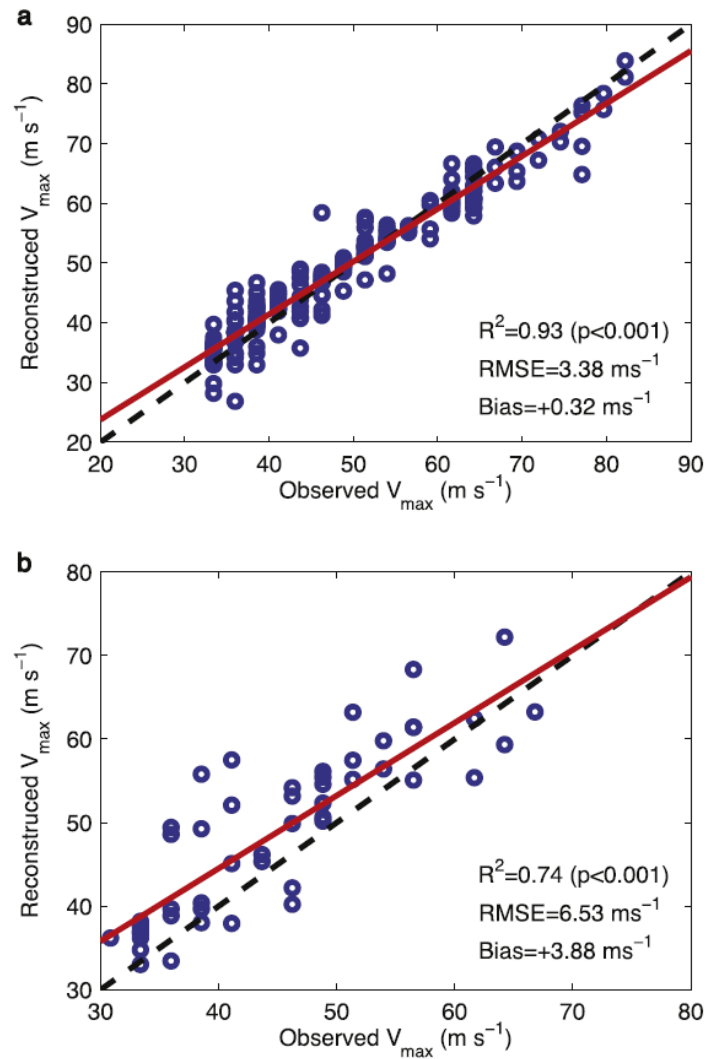
Information about the full radial profile of wind speed is not available in the best track record and typically, for the most recent events, only Rmax or R18 is available. Therefore an analytical model allowing calculation of the full profile is desirable. We used the Imperial College lambda model (Wang et al., 2015) as formulated in (Wang and Toumi, 2016):

$$V = \sqrt{\frac{2(p_{env} - p_{min})}{\rho}} \times \sqrt{\frac{2\lambda^2}{r^2} \left(1 - e^{-\frac{r^2}{2\lambda^2}}\right) - e^{-\frac{r^2}{2\lambda^2}} - \frac{1}{2}fr}$$

where V is the wind speed at radius r , f is the Coriolis parameter, p_{env} is the environmental pressure and p_{min} is the minimum pressure. Figure 4 demonstrates that the lambda model effectively recreates V_{max} from V_{26} for Atlantic hurricanes at both their lifetime maximum intensity and at landfall giving confidence that the model successfully represents the full wind profile.

Figure 4. Comparison between the reconstructed and observed V_{max} by using the λ model and R26. The largest maximum wind speed of the reconstructed wind profiles in four quadrants is regarded as the reconstructed V_{max} . (a) Comparison between the reconstructed and observed V_{max} at the time of highest intensity of 183 hurricanes for 1988–2014. (b) As in (a), but for 56 landfalls made by 40 US landfalling hurricanes. The solid red line is the linear least squares fit of the

reconstructed V_{max} , and the black dashed line represents the perfect reconstruction ($y=x$).



The full radial profile of wind speed can therefore be generated providing at least V_{max} or p_{min} , and R_{max} or R_{18} are known, allowing the calculation of the shape parameter, λ . This model then provides us with the desired values for R_{max} , R_{33} , R_{26} and R_{18} .

Where size data are unavailable in the record an estimate of R_{max} was calculated using the method proposed originally in (Knaff and Zehr, 2007) which was reformulated as

$$R_{max} = 66785 - 176.92 * V_{max} + 1061.9 * (\phi - 25),$$

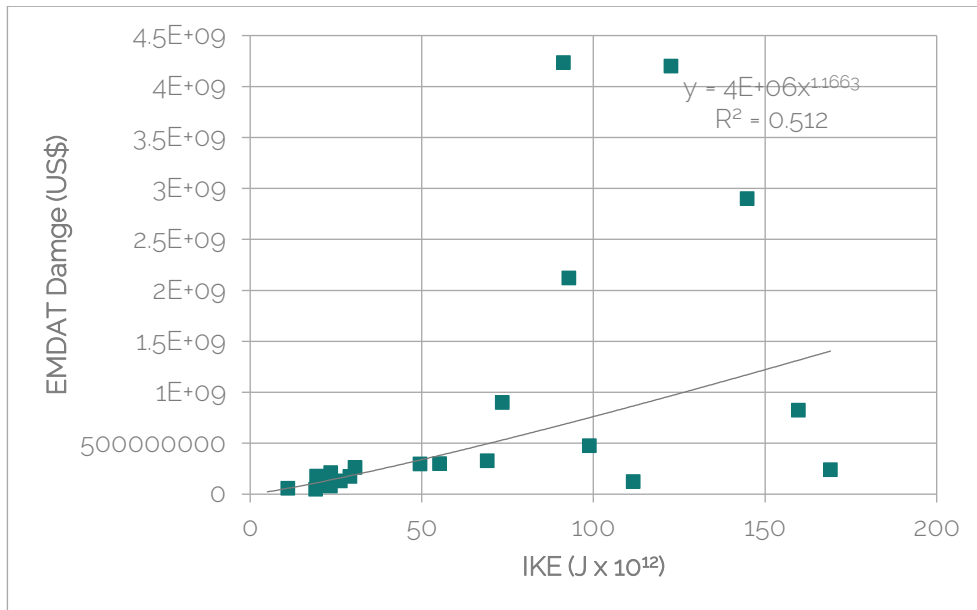
by (Wang and Toumi, 2018) which exploits the observed dependence of R_{max} on V_{max} and latitude, ϕ .

3.2 Integrated Kinetic Energy

While both the intensity and structure of the cyclone are considered indicators of potential damage, we need metrics of hurricane destructive potential that take into account the hurricane intensity and wind structure at the same time. The importance of taking into account the wind structure as well as intensity has been highlighted before and although there have been case studies, to date, a comprehensive analysis has been difficult, because it requires continuous historical profiles of near-surface wind speed from hurricane centre to an outer storm limit. Using traditionally available data (V_{max} , P_{min} , R_{max}) this has not been possible. The lambda model described above allows us to overcome this obstacle, by reconstructing the historical wind profiles of all the landfalling cyclones.

Integrated kinetic energy (IKE) has been proposed as an indicator of cyclone destructive potential, and is typically computed from the surface wind field by integrating the 10-m-level kinetic energy per unit volume over portions of the storm domain volume (V) containing sustained surface winds above gale force strength. Previous results suggest that the IKE captures the physical link to both the surge and the total scale of wind damage (Wang and Toumi, 2016). As the hurricane damage mainly happens within 6–12 h after landfall, it is understandable that this metric integrated at landfall performs better than both the power dissipation index (PDI) and accumulated cyclone energy (ACE) throughout the lifetime and maximum wind speed at landfall. Figure 5 shows how storm damage scales with IKE at landfall and the data have been fitted with a power law model exhibiting slightly super-linear behaviour. Considering no exposure information is considered, the coefficient of determination of 0.51 IKE is a good indicator of destructive potential.

Figure 5. Showing Damage associated with a landfall event against the integrated kinetic energy at landfall.



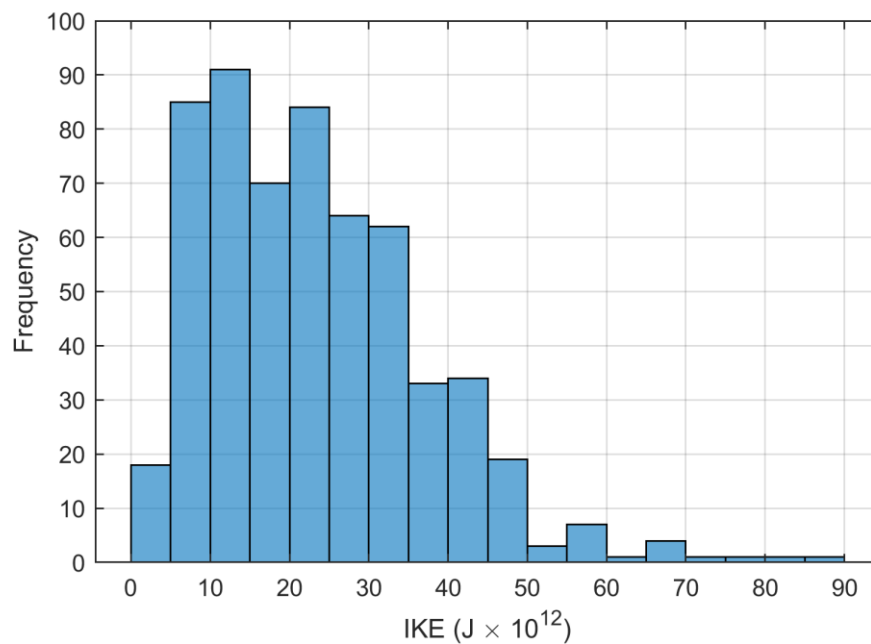
The integrated kinetic energy (IKE) (Powell and Reinhold, 2007) is obtained by integrating the kinetic energy using the wind speed profile given by the lambda model described above:

$$IKE = \int_D \frac{1}{2} \rho V^2 dD,$$

where D is the integral volume 1 m in the vertical with at least gale force wind.

The distribution of calculated IKE values for all cyclone featured in the catalogue is shown in Figure 6. It shows IKE is a positively skewed, approximately log-normally distributed variable with broad peak between 10 and 30 J x 10¹² and maximum values of around 90 J x 10¹².

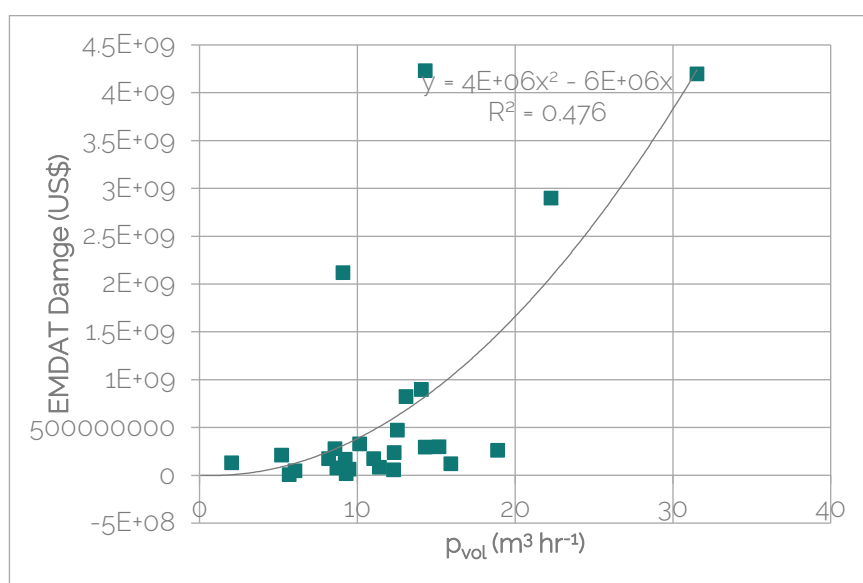
Figure 6. Histogram of IKE values in the catalogue.



3.3 Precipitation

Precipitation leading to flooding is known to contribute significantly to storm damage and is another variable not available in previously existing storm catalogues. Figure 7 shows the strong relationship between storm damage and landfall precipitation rate with a quadratic model giving an R^2 value of 0.47.

Figure 7. Storm damage against landfall precipitation volume rate.

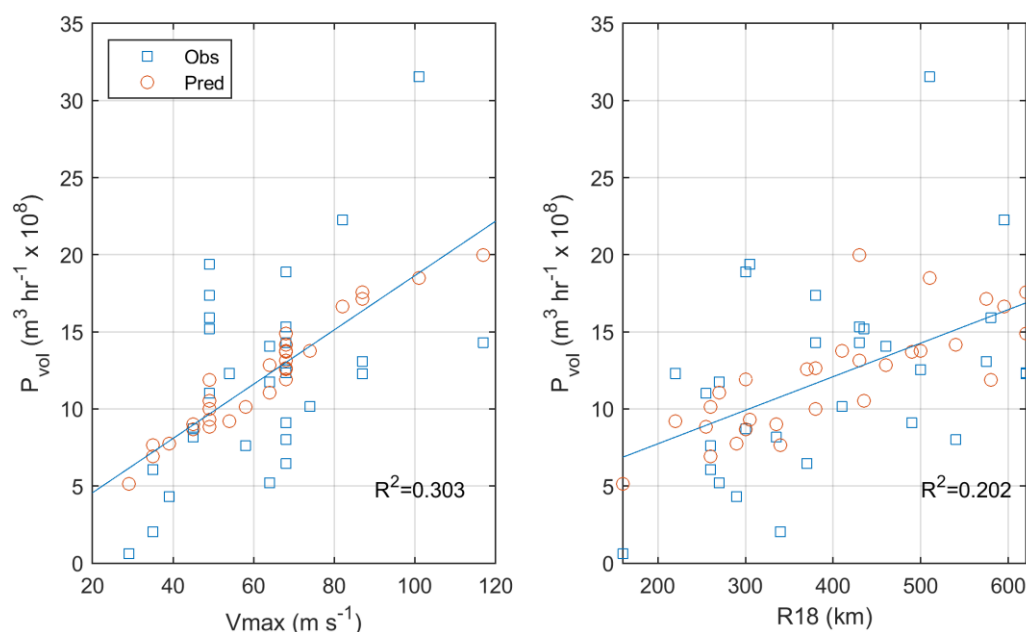


As TRMM rainfall volume data is only available from 1998 a method was devised to estimate precipitation for earlier storms. A search across available predictors revealed V_{max} and R_{18} to be strongly correlated with storm precipitation volume rates derived from TRMM. A predictive model was obtained through multiple linear regression giving the formula

$$P_{vol} = 0.1399V_{max} + 0.0094R_{18} - 0.4118 ,$$

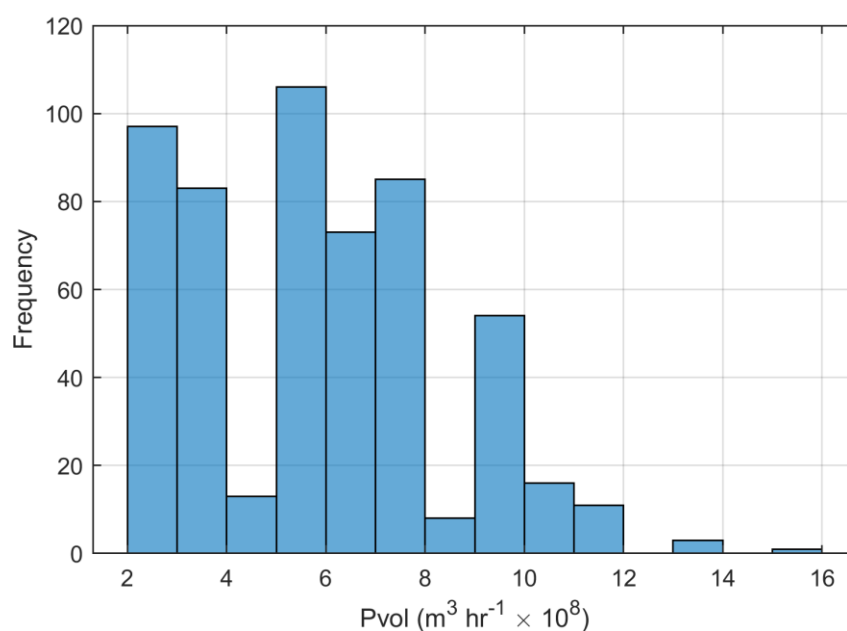
where P_{vol} is the rain volume rate within 500 km of the storm centre in units of $m^3/hr \times 10^8$. Figure 8 shows the observed and predicted values of P_{vol} against V_{max} and R_{18} .

Figure 8. The observed (blue squares) and model predicted (orange circles) precipitation for TCs with precipitation data available against Vmax and R18.



The above model was used to provide a storm landfall precipitation rate for each entry in the catalogue. The distribution of the catalogued values are shown in **Error! Reference source not found.** with values ranging from 2 to $16 \times 10^8 m^3 hr^{-1}$ and a mean of $6 \times 10^8 m^3 hr^{-1}$.

Figure 9. Histogram of landfall precipitation volume rates in the catalogue.



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Inspirational quotes

Oasis Innovation Hub for Catastrophe and Climate Extremes Risk Assessment Project (H2020_Insurance) is an EU-funded project aiming to innovate a new open source standard for risk assessment, improve climate modelling, damage assessment techniques and accuracy of models as well as operationalise an e-Market for hazard data and climate services: www.oasishub.co. The overarching goal is support the understanding of climate risks by the (re) insurance sector and wider society. This will help decrease the gap between insured and uninsured losses caused by climatic hazards.'

