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# Objective identification of potentially damaging tropical cyclones over the Western North Pacific

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## Abstract

An impact-oriented objective windstorm identification algorithm (*WiTRACK*), originally developed and well established for studies on extra-tropical storms, is further developed to identify damage and loss related Tropical Cyclones (TC) over the Western North Pacific. Results based on JRA-55 reanalysis data reveal that *WiTRACK* is able to detect the majority of strong events with hit rates of about 77%/90%/98% for TCs of the three most severe categories. Using economic loss data for China, it is found that especially events with large losses are associated with a windstorm event identified by *WiTRACK*. Past loss events successfully tracked by *WiTRACK* are associated with substantially higher losses than those events, not identified by *WiTRACK*. Thus, even though less skilful than traditional detection schemes if evaluated for the totality of TC events, *WiTRACK* is a powerful tool to identify severe, damage and loss-related TC events which additionally benefits from its simplicity and minimal input data demands. The latter may allow to apply *WiTRACK* to datasets not meeting the data requirements of more complex TC detection schemes.

## 1. Introduction

Intense typhoons have large impact on economy and society of Eastern Asia as they are associated with strong winds and potentially high rainfall rates (Elliott *et al* 2015) as well as storm surges (Resio and Irish 2015). The impact of possible future changes of this natural hazard could be further amplified by changes in population densities of the affected regions. Thus, knowledge about potential changes of frequency and/or intensity of these damaging events under future climate conditions is crucial for adaptation and mitigation strategies. Objective algorithms have been successfully used to detect Tropical Cyclone (TC) events in gridded climate model data (e.g. Sugi *et al* 2009, Tory *et al* 2013a, Camargo 2013). These algorithms are valuable to analyze TCs in general, but are not designed to focus on severe TC events only, which are however the most important events due to their destructive nature. The aim of this study is to focus on damaging and loss related TC events. This is done by adapting *WiTRACK*—a scheme proven to be successful for objectively identifying damaging windstorms associated with extra-tropical cyclones (e.g. Leckebusch *et al* 2008, Nissen *et al* 2010, Osinski *et al* 2016, Pardowitz *et al* 2016)—for applicability to damaging TCs. The basic approach of this detection method is based on the assumption that infrastructure and building standards are usually adapted to the local wind climatology and damages typically occur for wind speeds beyond a threshold associated with a certain return period, that is a specific quantile of the local wind climatology. Thus, using wind speeds exceeding a local threshold as basic identification criterion for an extra-tropical windstorm feature tracking scheme allows to focus purely on potentially damage-related events.

Analogue to this, we assume that a local wind quantile threshold is useful for identifying damaging TCs, too. Besides the link to losses, the usage of such an approach is appealing as it is easily transferable to different

reanalyses or climate models (e.g. Befort *et al* 2015, Wild *et al* 2015, Befort *et al* 2016, Walz *et al* 2018, Befort *et al* 2019) given that it incorporates the model-specific wind speed climatology implicitly accounting for potential biases. This overcomes the need to use absolute thresholds for TC related windstorm detection and is one main difference to many TC detection algorithms (e.g. Sugi *et al* 2009, Tory *et al* 2013b, Camargo 2013, Walsh *et al* 2013, Horn *et al* 2014) which use different detection criteria/thresholds for e.g. wind speeds or relative vorticity (see table 1 in Walsh *et al* 2007 & Ullrich and Zarzycki 2017 their appendix B).

The application of the existing identification scheme—introduced by Leckebusch *et al* (2008) and further developed since then [see Kruschke 2015, for a thorough documentation]—to tropical windstorms consists of an adjustment to characteristics of TCs over the Western North Pacific (WNP) that is described in section 3.1. Tuning and validation of this adapted scheme is based on atmospheric reanalysis data, best track information, and loss data that is described in section 2 together with a description of those methods applied for validation. The validation results comparing climatologies of *WiTRACK* results and best track information are shown in section 3.2. Special emphasis is laid on testing *WiTRACK*'s performance discriminating between events in terms of their impact. Results in this respect are shown in section 3.3 while a summary and discussion is to be found in section 4. It should be kept in mind that the main target of this study is to develop an algorithm (*WiTRACK*) to successfully identify damage-related TCs in gridded climate data, which is also applicable to coarse resolved climate model simulations. Due to the minimal input data requirements compared to traditional TC detection schemes, *WiTRACK* could prove to be a valuable extension to the existing set of TC feature tracking schemes.

## 2. Data & methods

The objective tracking algorithm is applied to the Japanese reanalysis products JRA55 Kobayashi *et al* (2015) for all months from 1979 until 2014 over the WNP region (90–180 °E; 0–70 °N). Here, 6 hourly wind speeds in 850 hPa in a horizontal resolution of 1.25° are used as input, which is a subtle difference to most existing *WiTRACK*-based studies using 10 meter wind speeds (e.g. Wild *et al* 2015, Befort *et al* 2016). This is motivated by the idea of developing a scheme also applicable to climate model simulations, for which wind speeds on 850 hPa are more widely available. Further changes to the standard configuration are presented in detail in section 3.1.

For the validation of tropical cyclone tracks as identified by the objective algorithm, the International Best Track Archive for Climate Stewardship (IBTrACS) version v03r8 (Knapp *et al* 2010) for the WNP is used. Some homogenization and pre-processing is applied to the raw data (see supporting information section S1 for details at [stacks.iop.org/ERC/2/031005/mmedia](https://stacks.iop.org/ERC/2/031005/mmedia)). This includes converting maximum sustained wind speeds to intensity classes (according to appendix 1-A in WMO 2015, see table S1 supporting information): Tropical Depression (TD), Tropical Storm (TS), Severe Tropical Storm (STS), Typhoon (TY), Very Strong Typhoon (VSTY), Violent Typhoon (VTY). Tracks identified by *WiTRACK* are matched to best tracks if fulfilling the following criteria: 1) a temporal overlap of at least 4 timesteps with a distance between both tracks below 400 km and 2) a mean distance of less than 1000 km.

To judge the performance of *WiTRACK* the hitrate (HR) to detect TCs as well as the False Alarm Ratio (FAR) are used, which are calculated the following:

$$\text{Hitrate (HR) [\%]} = \frac{\# \text{ of TCs detected}}{\# \text{ of observed TCs}} * 100$$

$$\text{False Alarm Ratio (FAR) [\%]} = \frac{\# \text{ of identified windstorms not matched}}{\# \text{ of windstorms detected}} * 100$$

Economic loss data for China for the period of 1999–2014, available from China's Yearbook of Meteorology (2000–2005) and the Annual Yearbook of Meteorological Disasters in China (2005–2016) is used CMA (2000–2005, 2005–2016), Chen *et al* (2018) for respective analyses in section 3.3. It should be noted that no adjustment has been performed on the loss database (e.g. taking into account inflation).

## 3. Results

### 3.1. Refinement of tracking algorithm for damaging tropical cyclones

This section describes the configuration developed in this study to identify damaging tropical cyclone windstorms using *WiTRACK*. Please refer to Leckebusch *et al* (2008) and Kruschke (2015) for more details regarding the basic principle of tracking windstorms using *WiTRACK* as well as a description of the latest developments. The general procedure to track a windstorm using *WiTRACK* is as following: In a first step, wind fields cohesively exceeding the local intensity threshold are identified for each time step of the input dataset. In a second step, wind fields smaller than a certain area are excluded to focus on meso- to synoptic-scale events. In a third step, the wind fields identified in each 6 hourly time step are tracked in time. Finally, all events that are

tracked for less than a minimum number of timesteps are removed. This selection completes focusing on highly organized storms, featuring certain size and lifetime.

To obtain a suitable configuration for this study, several adjustments to the standard configuration are necessary to account for the different characteristics of TC-related windstorms compared to extra-tropical cyclones (ETC) (see table S2 of the supporting information). Several sensitivity tests using JRA55 reanalysis data suggest the setup presented in table S2 (supporting information) to be suitable to detect TC related windstorm events. This includes using the local 98th percentile as intensity threshold, a minimum size of 130.000 km<sup>2</sup> and a minimum duration of eight six-hourly time steps.

The 98th percentile is the same intensity threshold that has been used for all existing *WiTRACK* studies focusing on ETC related windstorms. There, this threshold is motivated by its proven link to damages caused by ETC related windstorm events over Europe (Klawns and Ulbrich 2003). Sensitivity tests performed for the tropical WNP region in the course of the present study indicate not only the validity of our hypothesis that the general quantile approach with respect to the intensity threshold is transferable to the tropics (see section 4 for a discussion of this hypothesis) but also yield the very same quantile as for ETC-studies to provide the best results (not shown).

The minimum size of 130.000 km<sup>2</sup> is rather large for TC induced windstorm events and mainly motivated by the aim to develop a scheme applicable to coarse climate model data (with grid spacings of 200 km). Obviously, decreasing this value leads to a higher HR, however, it's also linked to a higher FAR. Overall, it is found that this minimum area threshold leads to large HRs (especially for strong TCs) together with a reasonable FAR (see section 3.2).

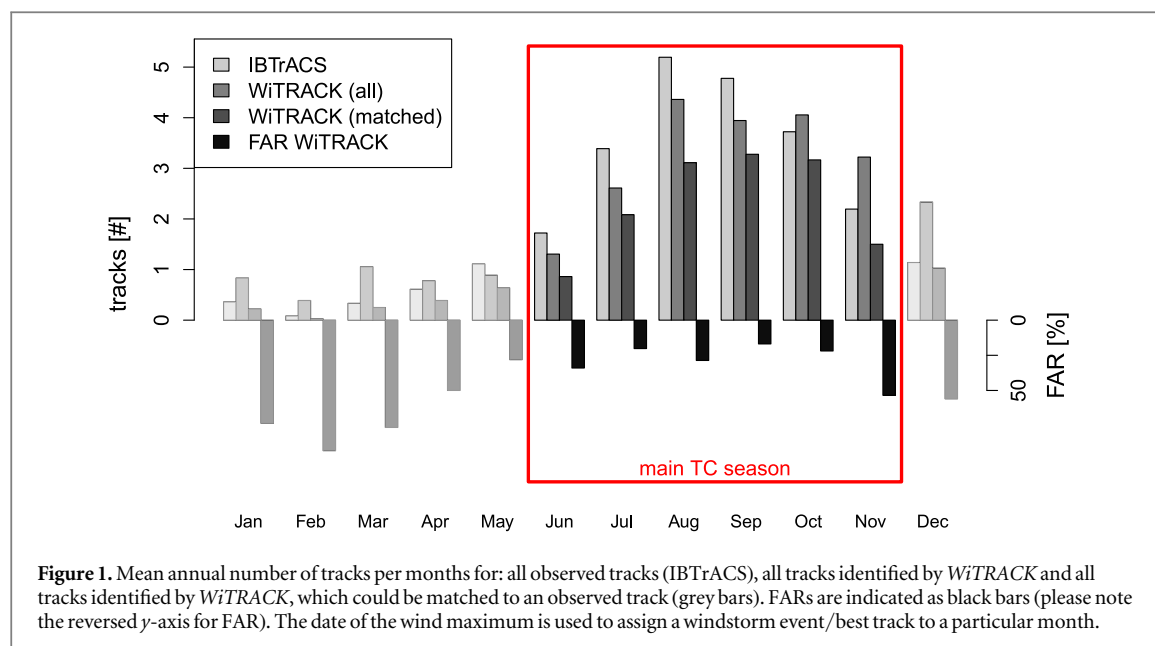
The sensitivity of the results to the minimum duration threshold has been tested, too. Overall, HR and FAR values increase for shorter minimum duration thresholds and vice versa decrease for longer minimum duration thresholds. The final choice of eight six-hourly timesteps is somehow arbitrary but using such a high thresholds guarantees to select only highly organized systems, which is generally the case for strong TC events.

Despite intensity, minimum area and duration thresholds, *WiTRACK* allows to change the value controlling the maximum translation velocity used for the tracking routine. It is found that a maximum distance of 500 km (per 6h-timestep) is sufficient to track TC windfields in tropical regions. In cases of extra-tropical transitions translation velocities and the spatial and temporal variability of wind speeds within storms featuring frontal systems typically increase. Initially developed for these regions, *WiTRACK* offers the possibility to allow for a storm-size dependent additional translation distance component accounting for such storm-internal relocation of maximum wind speeds. By means of sensitivity tests for a number of extra-tropical transitions the following configuration was found to yield best results for the target region of this study: a fixed maximum distance of 500 km is used south of 30 °N, whereas north of 30 °N an additional distance equal to one fifth of the wind field's maximum extent at the given time is allowed. The effect of using the size-dependent threshold for extra-tropical regions compared to using a fixed threshold of 500 km is illustrated for two re-curving TCs: Typhoon Tip and Typhoon Owen in 1979 (figure S1, supporting information).

As only wind speeds are used to detect windstorm events, the algorithm also identifies a large amount of windstorms associated with cyclones of extra-tropical nature for the region analyzed in this study. This makes sense, given the general aim of *WiTRACK* to identify potentially damaging windstorms independent of their meteorological nature. However, to focus on tropical storms in this study, we filter out most of these events by excluding windstorms which tracks are entirely north of 26 °N or east of 100 °E. Furthermore, it is found that *WiTRACK* identifies a large number of events close to the equator. Some of them might be associated with the Borneo vortex as well as with cold surge outbreaks during the winter monsoon. An example is the surge during mid of December 2006 with high winds over the Chinese Sea Tangang *et al* (2008), which is identified as a windstorm event by *WiTRACK*. Therefore, we require any windstorm identified by *WiTRACK* to exist at least for a part of its lifetime within the region of 10–26 °N and 100–180 °E to be further considered by our analyses. This geographical selection yields positive impact in terms of smaller FARs (not shown) while affecting only 2% of the observed TC events (see next section). We would like to emphasize, that this post processing procedure is not part of *WiTRACK* in general and is only necessary here to separate TCs from other types of storms. Apparently the area based selection criterion could be replaced by other methods to distinguish between TC and non-TC events, e.g. a warm core test. However, this would eliminate one major advantage of *WiTRACK* compared to other TC identification schemes which is the very low input data requirement.

### 3.2. Validation *WiTRACK* versus IBTrACS

The following results are achieved by matching observed best tracks and those tracks identified by *WiTRACK* in JRA55 using the final configuration. As discussed in sections 2 & 3.1, a post-processing is applied (for best tracks and tracks from *WiTRACK*) to remove events of extra-tropical nature. For consistency, this post-processing also applied to the best tracks (where the regional selection affects less than 2% of tracks). After this selection 887



observed TC tracks remain for comparison to *WiTRACK* events, of which about 20% are either classified Tropical Storm (TS, 22%), Severe Tropical Storm (STS, 21%), Typhoon (TY, 25%) or Very Strong Typhoon (VSTY, 23%). About 8% of all TCs are Violent Typhoons (VTY).

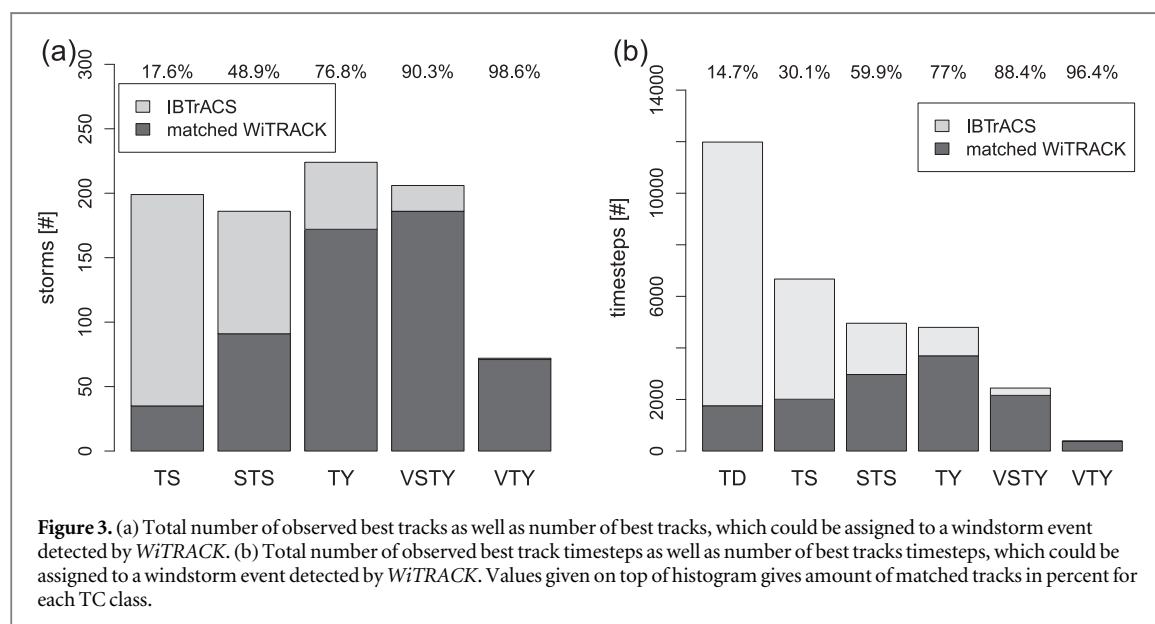
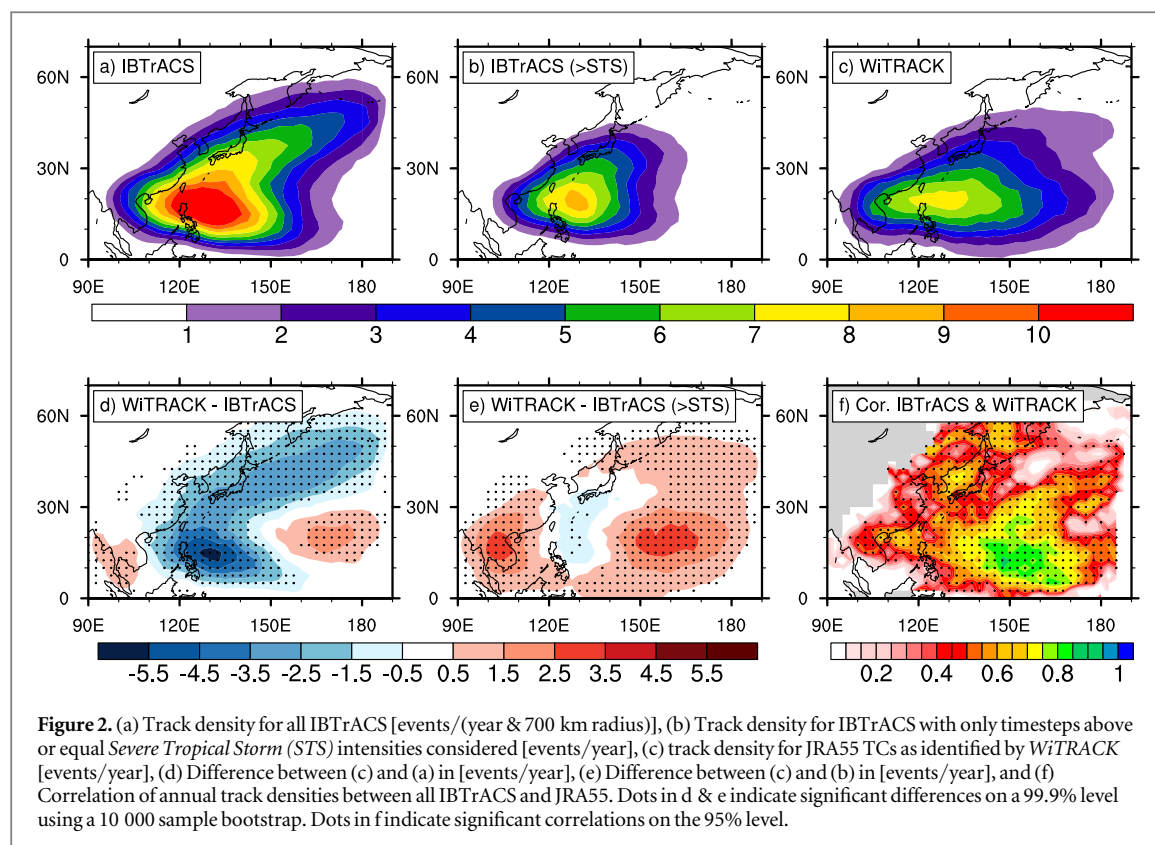
### 3.2.1. Overall hitrate/FAR & temporal/spatial variability

Out of the 887 observed tracks, about 63% can be matched to at least one windstorm event identified by *WiTRACK*. This hitrate for the observed TC events is complemented by an overall false alarm ratio (FAR) of about 36% (see section 3.2.2 and 4 for a discussion of this performance). The FAR value shows a high seasonality as revealed by comparing the seasonal cycle from all observed and identified (by *WiTRACK*) TC events (figure 1). In general, the climatological seasonal cycle is well captured, with small FAR values throughout the main TC season (about 30%). However, too many windstorms are identified during the winter season, with FARs above 80%. This can be explained by the fact that only wind speeds are used to identify windstorm events plus a pre-selection of tracks based on their region of appearance. No additional information, which would allow to separate a TC from a non-TC are used as e.g. a warm core test (Bengtsson *et al* 2007). Beside a good agreement w.r.t. the seasonal cycle, the temporal variability of observed TCs on interannual time scales is well represented by *WiTRACK* with a correlation of about 0.7 (figure S3, supporting information).

Spatial patterns of track densities (calculated according to Befort *et al* 2016) are similar between TC windstorms identified in JRA55 and IBTrACS, even though with mostly fewer events detected by *WiTRACK* (figure 2). The IBTrACS' main centre of activity south of Taiwan is also present for windstorms identified by *WiTRACK*, however the observed southeast-northwesterly tilt of this centre is not represented by the windstorms detected in JRA55 (compare figures 2(a) & (c), difference plotted in figure 2(d)). Also the number TCs re-curving towards Japan and the Northeast is underestimated by *WiTRACK*. The generally smaller number of events detected by *WiTRACK* is explained by a low HR for weaker TC events (as will be shown later in section 3.2.2). If calculating the track densities for IBTrACS considering only timesteps equal or above Severe Tropical Storm (STS, maximum winds  $\geq 48$  kn) intensity, a different track density pattern is found with no prominent tilting of the main centre of activity south of Taiwan and a drop of re-curving TCs (see figure 2(b)). This pattern resembles the one obtained by *WiTRACK* (see figure 2(e)). Temporal correlations between annual track densities of all observed best tracks and those identified by *WiTRACK* show moderate to high agreement for most parts of Eastern Asia (figure 2(f)) with values around 0.41 (median over all considered grid points; interquartile range 0.20–0.58).

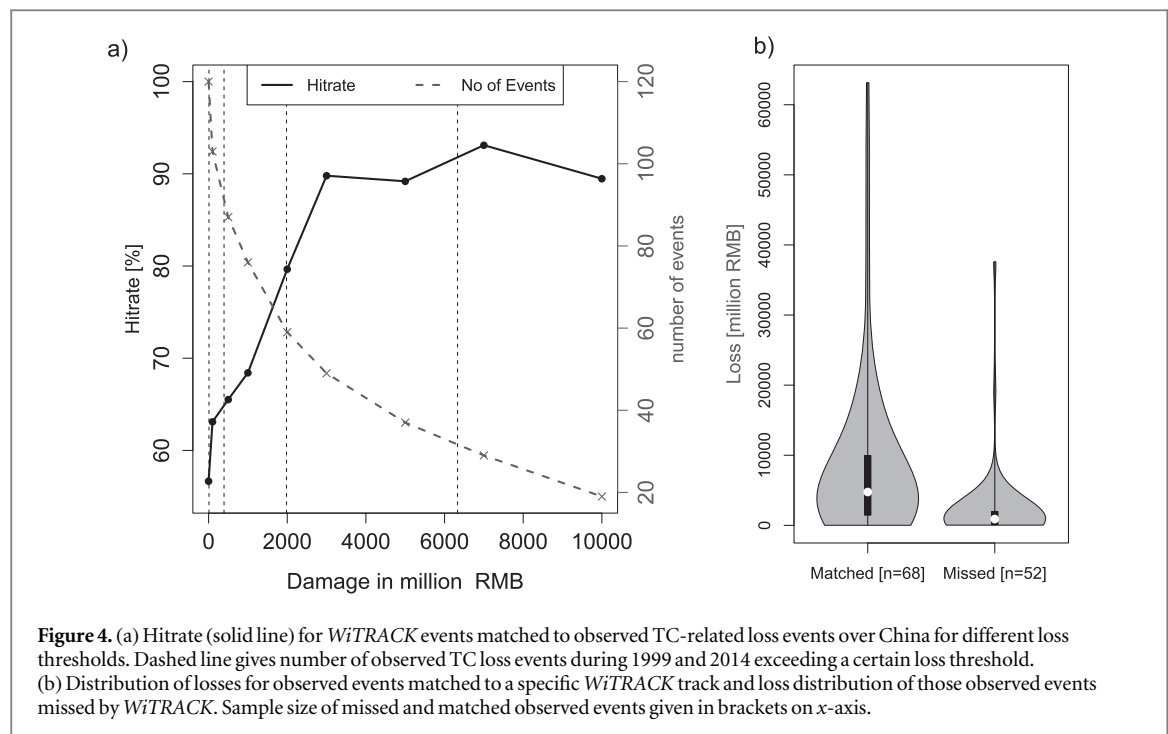
### 3.2.2. Hitrate $\sim$ TC intensity

At first glance, overall HR/FAR do not seem very impressive. However, most analyses presented in section 3.2.1 include all observed TC events (weak and strong). As stated, this study aims to develop an algorithm targeted on damage-related TC events, which are generally characterized by strong winds. As indicated already from the spatial analysis in section 3.2.1 (figure 2), differentiating with (maximum) intensity of the best tracks might be useful for understanding the above-mentioned discrepancies.



It is found that relative amount of matched best tracks increases with the maximum intensity itself (figure 3(a)), featuring a HR of about 77% for Typhoons (TY), about 90% for Very Strong Typhoons (VSTY) and over 98% for Violent Typhoons (VTY). Thus, the low hitrate is mostly due to less intense TCs (TD, TS, STS). This result is expected as the identification of windstorm events is based solely on wind speeds and their exceedance of the 98th percentile and less intense tropical cyclones are defined by lower wind speeds. The tracks identified by WITRACK associated with 12 major observed TCs exceeding 115 knots in maximum sustained wind speeds are shown in figure S2 (supporting information). The overall result for this subset is that WITRACK is very well capable of identifying and tracking these extreme events. The only major event (VTY class) not identified by WITRACK in its present configuration is Typhoon Saomai in 2006, for which the area of wind speeds exceeding the 98th percentile was too small for many timesteps. Typhoon Saomai can be identified by WITRACK if decreasing the minimum area threshold to 70.000 km<sup>2</sup>, however, such a low threshold would not





be applicable to climate models anymore which is the goal of the *WiTRACK* configuration as presented in this study.

Tracks identified by *WiTRACK* are generally shifted towards the right (relative to translation direction) compared to the best track. This is expected (and known from ETCs) as higher wind speeds are usually found in this sector (on the Northern Hemisphere) due to the addition of translational and rotational velocity of the system.

The hitrates presented so far are calculated based on matched observed and tracked overall events. Thus, a windstorm event lasting much shorter than the observed TC would increase the hitrate even if most of the observed TC timesteps could not be assigned to an identified windstorm event. To overcome this, hitrates are additionally calculated for the individual timesteps of observed TCs (figure 3(b)). As expected hitrates increase with the intensity of the TC at the specific timestep, with a hitrate about 81% for all timesteps with TC intensity above or equal Typhoon class. This suggests that the developing and decaying stages of Typhoon events are usually not associated with a *WiTRACK* event. These results are supported by the fact that the duration of observed TCs is on average twice as long as for the matched windstorm(s).

### 3.3. Economic losses ~ *WiTRACK*

In section 3.2.2 it is shown that *WiTRACK* performs better for TC events of higher intensity. However, losses are not exclusively determined by absolute wind speeds, e.g. as shown by Zhai and Jiang (2014). Based on Chinese loss data from 1999 until 2014 we additionally analyze in how far *WiTRACK* is able to detect loss-related events. Based on this data, we find that the minimum distance of a best track of a Chinese loss-event to the coastline of China does not exceed 250 km. Thus, for the following analysis, a *WiTRACK* is matched to an observed loss event if its minimum distance to the coastline is not greater than 250 km either (additionally to the general conditions used for matching presented in section 2). Figure 4(a) shows the percentage of loss related TCs over China matched to a *WiTRACK* exceeding different loss thresholds. About 55% of all loss related events can be matched to a *WiTRACK* windstorm. This percentage increases to around 90% or above for loss events above 3000 million RMB (approx. 440 million US\$, equivalent to the 60th percentile of all loss events). This shows that those events not detected by *WiTRACK* are mainly related to smaller losses, which is further supported by comparing the loss-distributions of loss events, which are missed or matched by *WiTRACK* (figure 4(b)). The median loss-event matched to a *WiTRACK* windstorm is associated with about 5 times higher losses than the median loss-event not matched to a *WiTRACK* windstorm.

This confirms that *WiTRACK* is a powerful tool to identify tropical cyclones that are potentially related to substantial economic loss, discriminating against such events that are less likely to be related to significant loss.

## 4. Summary & discussion

In this study an existing scheme to detect potentially damaging ETC related windstorm events—*WiTRACK*—is transferred to identify damage-prone tropical cyclone events over the Western North Pacific. This is done by applying the objective windstorm identification algorithm to JRA55 6 hourly wind speeds in 850 hPa. The choice of using JRA-55 is motivated by a previous study showing that this reanalysis dataset is best for TCs (Murakami 2014). It is found that too many events during the boreal winter are detected by *WiTRACK* which are mostly of extra-tropical nature. This is expected as windstorms are identified based on local wind speeds only, not taking any other characteristics of TCs, e.g. a warm core, into account (as done by other TC detection algorithms, e.g. Bengtsson *et al* 2007). Most of these events can be excluded easily by simple geographical filtering of the tracking results (done in this study by excluding all tracks solely identified outside the region 100–180 °E and 10–26 °N).

For validation purposes, best tracks from the IBTrACS archive are compared to the *WiTRACK* results. The performance of *WiTRACK* is measured by calculating hitrates (HR) for different intensity classes as well as the false alarm ratio (FAR). Overall, 63% of all observed TC events can be associated with at least one windstorm event identified by *WiTRACK*. This low percentage is mostly due to missing comparably weak TCs such as Tropical Storms and Severe Tropical Storms, for which hitrates are about 18% and 49%, respectively. *WiTRACK*'s ability to detect weaker TC events could be altered by e.g. lowering the wind intensity threshold. However, these low hit rates of for less intense TCs are desired as the intention is to develop a scheme solely focusing on damaging TC events, which are usually associated with severe TC events. The ability of *WiTRACK* to identify strong TC events is proven by hitrates of about 85% for observed TC events with a maximum intensity equal or above Typhoon class. The FAR of *WiTRACK* reveals a value of about 36%, which is mostly due to the detection of too many events during December to May. However, the seasonal cycle is well captured by *WiTRACK* as well as the interannual variability with a correlation of about 0.7 for annual TC numbers. Furthermore, a good agreement (in terms of correlation coefficients) of the spatial distribution of *WiTRACK* windstorms and observed TCs over the WNP is found.

A comparison of *WiTRACK*'s performance to existing Tropical Cyclone detection schemes proves difficult. This is due to several factors: 1) existing literature focusing on the application of these schemes to reanalysis data and a comparison to observational data are rare (as already mentioned by Zarzycki and Ullrich 2017), 2) there are considerable discrepancies in the representation of Tropical Cyclones between different reanalysis datasets (Hodges *et al* 2017) and 3) previous studies don't use the same metrics to measure the performance of the respective detection algorithm. However, keeping these caveats in mind, existing studies are used to understand how results from *WiTRACK* compare to other multi-parameter detection schemes. The study by Murakami (2014) focused on the ability of a vorticity based algorithm to detect TCs in different reanalysis datasets and how these results compare to observational data. The hitrate is about 63% for all observed TCs (for JRA55), together with a global false alarm rate of about 25% (with a smaller FAR of about ~18% over the WNP). Slightly higher skill is found for the TempestExtremes detection scheme applied to JRA55 reanalysis data, which is likely to be related to comprehensive tuning (Zarzycki and Ullrich 2017). Here, hitrates are about 79.2% with a false alarm rate of 15.6%. For the Northern Hemisphere hitrates are about 80% and FAR about 29% for the scheme used by Hodges *et al* (2017) (see their table 2). Another TC detection scheme applied to ERA-Interim shows an overall hitrate over the WNP of 90% together with a FAR of 22% (Tory *et al* 2013b; their table 5). Similar results using ERA-Interim with yet another scheme (Okubo-Weiss-Zeta) have been found by Bell *et al* (2018), with hitrates of about 76% over the Northern Hemisphere. Hitrates found for *WiTRACK* over the WNP of about 63% together with an FAR of about 36% appear to be only slightly less skilful than those found for other multi-parameter detection schemes. However, caution is necessary when comparing results for different reanalyses as shown by Hodges *et al* (2017), who applied the same tracking algorithm to several different reanalyses datasets, which revealed large difference in how TCs are represented among those datasets. However, even though the performance in detecting TC events heavily depends on the scheme itself, most studies suggest that hitrates increase for stronger TC events, which is in line with results presented here for *WiTRACK*. Furthermore, results for stronger TCs might be more comparable between different reanalysis datasets as differences among these datasets tend to decrease with TC intensity (Hodges *et al* 2017; their table 3).

As described, studies applying multiple different tracking schemes to reanalysis datasets, which include a thorough comparison to observations are sparse. However, substantially more work has been published applying different algorithms to gridded datasets, as e.g. climate model output. These studies show that the detected number of TC events is quite sensitive to the tracking scheme used. Murakami (2014) found that the annual mean TC number for the scheme by Walsh *et al* (2007) is 39.6, whereas it is about 83.9 for the scheme by Murakami and Sugi (2010) and about 92.3 for the scheme by Strachan *et al* (2013) (all for JRA55; see Murakami 2014; their table 1c). However, the scheme by Murakami and Sugi (2010) has been optimised to



detect annual TC numbers in the range from 83 to 84 (see Murakami 2014; section 2.3 for more details). Similarly, huge differences are found between two algorithms used in Bell *et al* (2019) (see their table 2) and also between three algorithms used in Horn *et al* (2014) (see their table 2). Giving these large differences for mean annual numbers, TC numbers detected by *WiTRACK* are certainly within the range of other objective TC identification schemes.

Overall, *WiTRACK* applied to JRA55 reanalysis appears to be slightly less skilful than other TC detection methods in terms of hit rates and false alarm rates. However, it should be kept in mind that *WiTRACK* is especially designed to detect intense TCs, for which hit rates are reasonable high (above 90% for the two most extreme TC categories). The higher performance of traditional TC detection algorithms comes at the prize of much larger input data requirements (usually 3-dimensional wind, temperature and partly humidity data) compared to *WiTRACK*, which uses 2-dimensional wind speed data only. In line with the *WiTRACK* performance being better for more intense storms, it is found that those events, successfully identified by *WiTRACK* tend to be associated with substantially larger economic loss. Furthermore, the probability to detect observed loss-related events increases with their total loss amounts. Despite these encouraging results for a comparably simple scheme, a certain number of loss events are not identified by *WiTRACK* in its current configuration. This might be due to different reasons, three of them should be mentioned here: (i) The *WiTRACK* configuration presented in this paper features a very high threshold regarding the minimum size of the windfield to be directly applicable for usually coarse resolution CMIP5/6 climate model output, certainly missing some smaller observed events. (ii) TC related losses are not entirely determined by wind speeds but are also associated with precipitation, storm surges as well as size of the TC system itself (Le 2000, Zhai and Jiang 2014, Park *et al* 2016), (iii) A general limitation of the *WiTRACK* approach is the lack of a comprehensive analysis regarding the suitability of the 98th percentile as an intensity threshold for loss-prone wind speeds in the tropics. Testing the latter requires for reliable long-term, high-resolution loss and wind speed data for different tropical regions, which unfortunately hasn't been available for this study. However, results shown in this paper indicate that the implicit usage of such a local percentile based threshold yields useful results regarding damage-related TCs.

Based on the above results it is concluded that (even though its level of skill is slightly lower compared to traditional TC identification schemes) *WiTRACK* is a powerful tool to analyse strong damage-related TC events over the WNP. The main advantage to other TC detection schemes lies in its simplicity and the minimal input data requirements. This allows identifying severe TC events also in datasets with insufficient data available (which hinders the application of usual TC schemes). Further analysis should analyse in how far this approach can be transferred to other basins, e.g. the North Atlantic. Based on the result of the current study, a logical next step is the application of the *WiTRACK* scheme for TCs over the WNP-region in climate model output, such as provided by the CMIP5 and CMIP6 models.

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