142 On the Use of the Dvorak Current Intensity as a Climate Data Record in the Western North Pacific

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1. INTRODUCTION

Trends in tropical cyclone (TC) intensities across the western North Pacific (WP) basin have recently been examined by Webster et al. (2005), Emanuel (2005), Klotzbach (2006), Wu et al. (2006), Kamahori et al. (2009), Nakazawa et al. (2009), and others. According to Webster et al. (2005), for the period 1990-2004 there has been an increase in the number of category 4 and 5 storms on the Saffir-Simpson Hurricane Wind Scale (SSHWS, Simpson 1974). Emanuel (2005) states that peak wind speeds have increased by over 50% in the WP basin since 1949. Both these articles, and others, have used historical maximum sustained wind speed data from the Joint Typhoon Warning Center (JTWC, Chu et al. 2002) to obtain results. Meanwhile, Wu et al. (2006) used historical maximum sustained wind speed data from the Tokyo Regional Specialized Meteorological Centre (RSMC). The Tokyo RSMC (also referred to as the Japan Meteorological Agency, JMA) is the agency that the World Meteorological Organization (WMO) has deemed as the official source of tropical cyclone information in the WP. However, there are other sources of data in the WP, including the Hong Kong Observatory (HKO) and the China Meteorological Administration's (CMA) Shanghai Typhoon Institute. The largest difference between each of these four sources is the typhoon tracking practices, which include different wind speed averaging periods in use at each agency and affects how wind speeds are recorded in the best track data. Given that the aforementioned articles have examined TCs using maximum sustained wind (MSW) data, how is it that they have obtained varying results?

Given the availability of satellite coverage in each basin and the paucity of in situ observations (few surface observations, no aircraft reconnaissance, etc.), the Dvorak (1984) satellite-intensity estimation technique is the primary method for determining the intensity of tropical cyclones. The technique results in a satellite-derived intensity category (T-number), which is converted to current intensity (CI) using procedural rules that limit the daily change in intensity. Thereafter, the CI is mapped to a corresponding MSW (Velden et al. 2006). In the WP basin, the Dvorak technique became the only available method to estimate a cyclones intensity after the end of routine aircraft reconnaissance in 1987 (Nakazawa and Hoshino 2009).

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CI has been used by different agencies in different ways to map to a MSW. In particular in the WP are the differences between the Dvorak and Koba et al. (1991) mapping tables, highlighting the importance of recognizing a 1-min versus 10-min mapped MSW.

In a recent article by Knapp and Kruk (2010), an examination of the interagency differences in MSW revealed that large differences exist in the WP for the same storm. For example, maximum sustained winds from JMA, CMA, and HKO tend to be lower than the JTWC while a majority of the MSW's between CMA and HKO agree to within 10kt of JMA. Despite these differences, Knapp and Kruk (2010) stated that such differences may be reconcilable. As the MSW values are related linearly, they deduced that it may possible to compare wind speeds from one agency to another via a linear correction. Since procedures are in place at many agencies that specify adjustments to the result of the Dvorak technique, it follows that a reversal of the wind speed conversion procedures can be done to re-derive the original Dvorak intensity. Furthermore, Knapp and Kruk (2010) stated that an analysis of trends in tropical cyclone intensity using CI is more steadfast and less uncertain than using the MSW, owing to varying wind speed conversion factors in use amongst the agencies. The CI is the fundamental measurement for comparison between agencies since the same technique is applied globally. The mapping to MSW from CI is meaningless if the CI-numbers are different between the agencies. Nakazawa (2009) pioneered the comparisons between JMA and JTWC using operational CI data and found that the JTWC estimates tended to be higher than JMA, which was attributed to a faster intensification or slower weakening rates by the JTWC.

The goal of this paper is to introduce the CI-space analysis technique and demonstrate CI as a climate data record. Unfortunately, CI is not yet routinely archived as part of the historical best track record. However, Levinson et al. (2010) indicated that all agencies currently use the Dvorak (1984) technique to determine the intensity of tropical cyclones in their respective basins. Levinson et al. (2010) also documented that each agency converts the satellite intensity estimates from Dvorak to their agency-specific wind averaging period (1-min., 10-min., etc.). Therefore, if historical conversion factors are known, it is possible to "back out" this conversion to re-derive CI. As historical conversion factors are documented by Knapp and Kruk (2010), this backing-out technique can be applied globally to all basins starting in 1985.

The next section describes the source of the best track wind speed data and the methodology behind the CI derivation technique and it is followed by an exploration of the utility of this technique in the WP basin and as a climate data record. Finally, a discussion of the results concludes the article.

2. DATA and METHODS

Historical MSW data for the western North Pacific was obtained from the International Best Track Archive for Climate Stewardship (IBTrACS, Knapp et al. 2010). The IBTrACS dataset is a global repository for tropical cyclone best track data and includes data for the WP basin from CMA, HKO, JTWC, and JMA. Tropical cyclone best track data are combined in IBTrACS to facilitate inter-comparisons by collocating reports in time and space (Kruk et al. 2010).

For each storm having reports from more than one agency, each agency's originally reported position, maximum sustained wind speed and minimum central pressure are available in IBTrACS.

In this study, the period of record is 1985-2008, which is consistent with Knapp and Kruk (2010) and follows the recommendation of Chu et al. (2002) who stated that the JTWC best track data are suitable for quantitative analysis after 1985. In addition, going much earlier is generally pre-Dvorak (1984), and there is as of yet no guarantee that the Dvorak enhanced infrared technique was used at any given agency prior to 1985.

Procedures at some agencies specify adjustments to the result of the Dvorak (1984) technique. Agencies convert the 1-min Dvorak wind speeds (MSW_1) to another wind speed averaging period with a multiplicative factor. Wu et al. (2006) report that 0.9 is used at HKO to convert MSW_1 to MSW_{10}. However, while Yu et al (2007) do not explicitly state the procedures at CMA to convert to a 2-min MSW, they do use 0.871 when comparing to JTWC wind speeds. At JMA, instead of a scaling factor, they use a separate mapping of CI to MSW_{10} based on Koba et al. (1991).

According to Knapp and Kruk (2010), one can derive the Dvorak-equivalent current intensity, CI_E, for each best track point in a storm using mapping tables in operation at the time and then re-estimate the equivalent wind speed (MSW_E) based on another table. For example, one might back out the CI reported by JMA then determine a Dvorak-equivalent maximum sustained wind speed. Theoretically, this wind speed should be comparable to the MSW from JTWC because it uses the Dvorak technique (Chu et al., 2002).

Since best track data from JMA follows a 10-min sustained wind as derived from the Koba et al. (1991) relationship, wind speeds from JMA were converted to CI_E using linear interpolation of the Koba et al. (1991) intensity mapping and were compared to CI obtained from the operational dataset at the JMA (not shown) during 1987-2006. That CI_E obtained from MSW_{10} fits extremely well with the CI from the operational dataset archived by the JMA; 65.7% of the differences between the CI_E and CI are within ±0.5, 89.1% are within ±1.0 CI, and 97.6% are within ±1.5 CI. The distribution between the two parameters is consistent with JTWC (1974) which found 74% and 91% within ±0.5 and ±1.0 CI, respectively, between CI and CI derived from JTWC best track data. According to Guard (2004), a difference of 0.5 is considered operationally "acceptable", while differences that exceed 1.5 CI are "unacceptable." The high rate of matching between the operational CI and those obtained through inverting the Koba technique indicates that CI_E is representative of the raw data and the technique can be applied to other agencies.

In the following, the CI_E from all agencies are intercompared. In deriving CI_E, MSW_{10} from CMA and HKO are converted to MSW_1 by reversing the operational conversions at each agency. MSW_1 are then converted to CI_E by interpolating the Dvorak table.

3. CI as a CLIMATE DATA RECORD

Cumulative distribution function (CDF) plots for the CI_E were generated for each agency in the WP (not shown). An analysis of the upper distribution of the CDF plots indicates that nearly all agencies have a 90^{th} percentile threshold between 5.0 and 5.5 (90 to 102 kt on the Dvorak scale). The distribution of the 95^{th} percentile reveals similar continuity amongst the agencies, with a spread between 5.75 and 6.25 (109 to 121 kt). Differences of 0.5 CI can easily result from interpretation of satellite imagery. For example, it can be the difference between analysts in their interpretation of the distance of the arc length of the log spiral band. Thus, for the most intense storms, nearly all agencies agree on the intensity of the tropical cyclone to within "interpretable" differences. Even at the high-end of the distribution, all agencies are in good agreement and the annual interagency differences vary minimally for the most intense storms.

A more robust comparison between the agencies is shown in Figure 1, where the reported MSW from each agency is plotted in the first column and the MSW_E as mapped from the CI_E to the Dvorak intensity table is shown in the second column. The red line is the slope of the regression between the agencies. Similar to the results from Knapp and Kruk (2010), there is large disparity in the wind reports in the WP basin, especially when comparing against the JTWC (column 1), as the linear slope differs from a true one-to-one relationship (except for CMA and HKO as already discussed). Note, however, that when the comparison is done using the reversal of the CI_E (column 2), the agreement between all agencies is dramatically improved. Between JTWC and JMA, the slope increases from 0.62 to 0.97 (and the statistical noise increases from 7 to 12 kt). For the comparison between JTWC and CMA, the slope increases from 0.73 to 0.86, and the statistical noise increases from 8 to 9 kt. Meanwhile, the slope decreases between JMA and CMA from 1.13 to 0.85, though the noise increases from 6 to 9 kt. The increase in the noise values may be attributable to the increasing distribution of the winds across a larger range in wind speed, such that even the most intense storms are captured by working in CI-space (e.g., JMA v. CMA or JMA v. HKO). It is thus shown that the differences between the agencies in MSW are reconcilable through a linear-relationship when using CI as the baseline for the analysis and strongly argues in favor of archiving CI as part of the best track record.

4. SUMMARY

Analysis of tropical cyclone intensity is complicated by how different agencies report maximum sustained winds. The common denominator amongst agencies, however, is the universal reliance on the Dvorak enhanced IR technique. In much of the world, satellite is in fact the only data sue to the paucity of in situ observations over open ocean (island and buoy reports are sparse) or aircraft reconnaissance outside the North Atlantic basin. Taking advantage of the commonality, we have converted agency best track intensities back to a equivalent-Dvorak current intensity, CI_E to analyze time series in CI space rather than in MSW.

Analysis in CI space showed that the four agencies warning and providing best track data for the Western Pacific Ocean – HKO, JMA, CMA and JTWC – had significant agreement in the distribution of the strongest storms. The 90th percentile of CI_E had a range of 5.0 to 5.25 and the 95th percentile ranged 5.75 to 6.25, a range of only 6 and 12 kt respectively.

It is encouraging to note that for the most intense storms in the WP, the CI-numbers are nearly identical amongst the agencies. While the corresponding MSW may differ owing to operational procedures and differences in wind speed conversion factors, the satellite-based intensity estimation is more consistent. This demonstrates that working with CI (or CI_E), rather is more robust and less subjective than with reported MSW. Furthermore, it strongly argues in favor of arching CI as part of the best track record.

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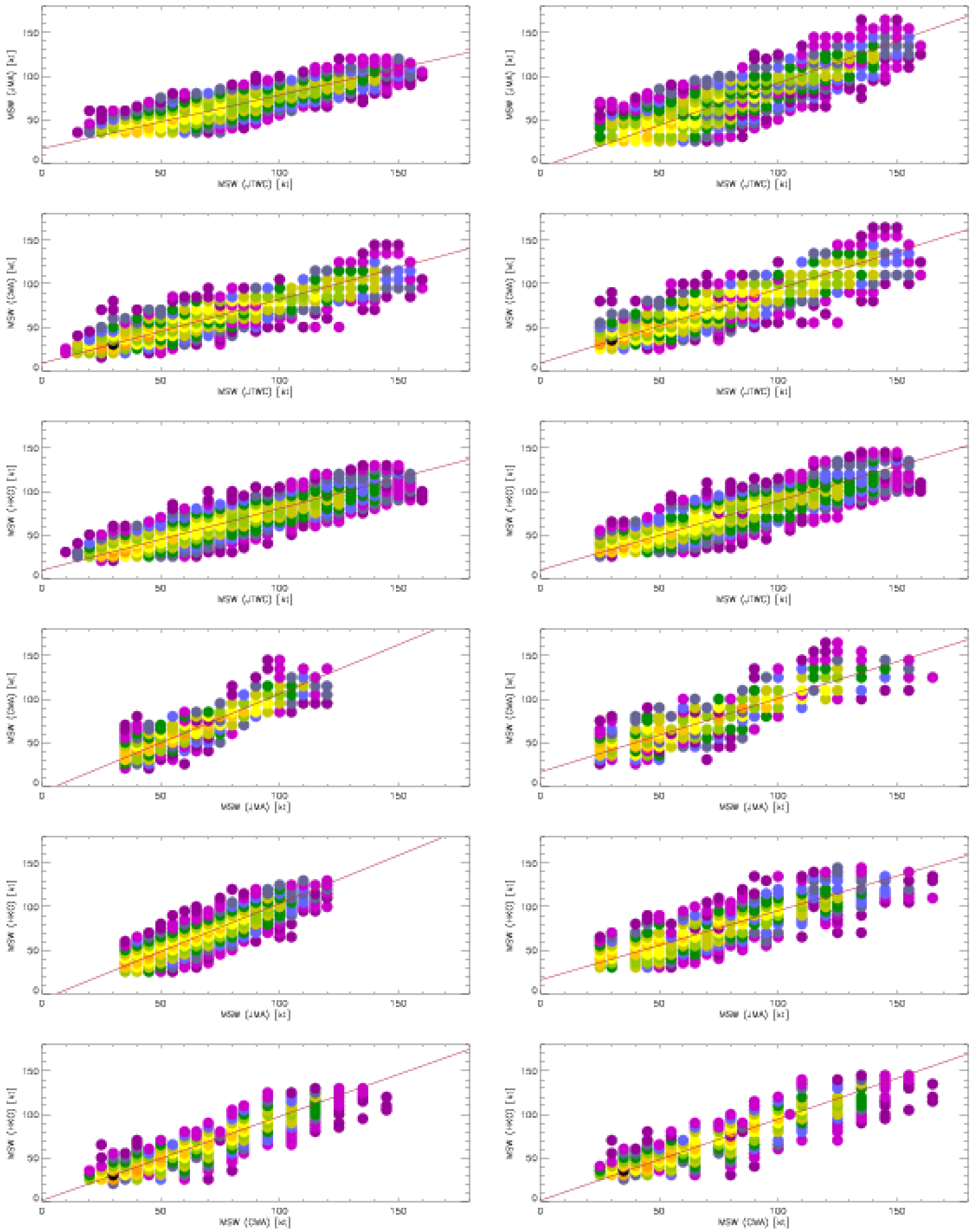

Figure 1. A comparison between the reported MSW (column 1), and the equivalent-MSW (column 2) as re-derived from the CI_E. Red line denotes the slope of the linear regression and colored circles denote the number of occurrences at each point.