Seven-Day Intensity and Intensity Spread Predictions for Atlantic Tropical Cyclones

HSIAO-CHUNG TSAI

Department of Water Resources and Environmental Engineering, Tamkang University, New Taipei City, Taiwan

RUSSELL L. ELSBERRY

Trauma, Health, Hazards Center, University of Colorado Colorado Springs, Colorado Springs, Colorado, and Department of Meteorology, Naval Postgraduate School, Monterey, California

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ABSTRACT

The extension of the Weighted Analog Intensity Atlantic (WAIA) prediction technique for Atlantic tropical cyclones (TCs) from 5 to 7 days revealed a need for two modifications. The first modification for the 7-day WAIA was to randomly select 70% of the TCs in the entire 2000–15 sample to be the training set and use the remaining 30% as the independent set. The second modification was to ensure that appropriate analogs were selected for ending storm situations such as landfall, postrecurvature, and nondevelopment or delayed intensification within the 7-day forecast interval. By simply constraining the analog selection such that the intensity at the last matching point with the target TC track does not exceed 50 kt (where 1 kt = 0.51 m s^{-1}), an increasing overforecast bias with forecast interval was almost eliminated in both the training set and the independent set. With these two analog selection modifications, the mean absolute errors, and the correlation coefficients of the 7-day WAIA intensities with the verifying intensities, are essentially constant from 5 to 7 days, which establishes this WAIA as a viable technique for 7-day intensity forecasts of Atlantic TCs.

1. Introduction

Tsai and Elsberry (2015b) developed a weighted analog technique called the Weighted Analog Intensity Atlantic (WAIA) for 5-day intensity and intensity spread predictions of Atlantic tropical cyclones (TCs) that is similar to the Tsai and Elsberry (2014) technique for western North Pacific TCs called the Weighted Analog Intensity Pacific (WAIP). These simple techniques are based on rankings of the 10 best historical track analogs to match the official track forecast and current intensity. A key step in the development of the WAIA and WAIP techniques has been a bias correction to eliminate an overforecast bias. The second key step has been a calibration of the original intensity spread among the 10 analogs to achieve a probability of detection of about 68% at all forecast intervals. Tsai and Elsberry (2015b) compared the WAIA mean absolute errors (MAEs), sample-mean biases, and geographic distributions of WAIA errors versus the four guidance products that are included in the intensity consensus (ICON) technique, and demonstrated the WAIA was more accurate than three of those four products in the 4- and 5-day forecast intervals.

The National Hurricane Center (NHC) has been considering an extension of their TC track forecasts from 5 to 7 days (C. Landsea, NHC, 2016, personal communication). Since the Joint Typhoon Warning Center (JTWC) is similarly exploring the capability to issue 7-day TC forecasts for the western North Pacific, Tsai and Elsberry (2015a) extended WAIP from 5 to 7 days. The key result was that the MAEs and the correlation coefficients of the WAIP forecast intensities with the verifying intensities essentially remain constant in the 5–7-day forecast interval. After calibration of the raw intensity spreads among the 10 historical analogs each 12 h, the uncertainty estimates about the WAIP intensity forecasts also do not increase during the 5–7-day forecast intervals. Tsai and Elsberry (2015a) concluded the 7-day WAIP will provide intensity and intensity spread predictions of western North Pacific TCs with a similar level of performance as for the 5-day WAIP.

Corresponding author e-mail: R. L. Elsberry, elsberryrl@comcast.net

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The objective of this study is to develop a 7-day WAIA for Atlantic TCs using the same approach as Tsai and Elsberry (2015a) used in the western North Pacific. Only a brief description of the methodology will be given in section 2 because this methodology has been described in detail in Tsai and Elsberry (2015b) for the 5-day WAIA, and the methodology and preliminary results for the 7-day WAIA are available in Tsai and Elsberry (2016). Here, the focus will be on two procedural modifications that were necessary to remove an overforecast bias to achieve smaller 7-day MAEs and more representative intensity spreads in the independent sample. It will be demonstrated in section 3 that after these modifications the 7-day WAIA intensity predictions of Atlantic TCs are essentially as accurate as the 5-day predictions, and the calibrated intensity spreads more accurately represent the uncertainty about those WAIA predictions.

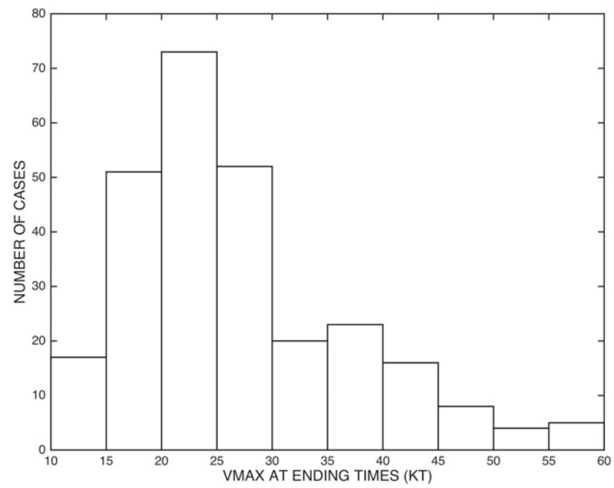

FIG. 1. Histogram of the intensity (V_{max}; kt) at the ending time of the Atlantic tropical cyclones during 2000–15 in the NHC best-track files.

2. Procedural modifications

The basic premise of WAIA is that the track of the TC is a primary determinant of the intensity on a time scale of 3–7 days or longer, and the spread among the 10 best historical analogs provides a measure of the range of the environmental influences that may be occurring along the track. As the life cycle stage of the TC is another important factor, only analogs in the NHC HURDAT2 dataset within ±30 days and with an initial intensity within ±15 kt (where 1 kt = 0.51 m s^{-1}) are considered. After ranking these analogs according to average track differences d_{track} and initial intensity differences d_{vo}, and then calculating a final ranking with equal weighting factors for d_{track} and d_{vo}, the 10 best analogs are selected to provide 10 intensity evolutions. The average track difference between the NHC track forecast and the candidate analog storm is calculated with a linearly increasing weighting factor of 1.0 at the initial time to 2.0 at and beyond 72 h for better matching of recurvature timing or landfall position and timing. In the calculation of the weighted analog intensity, an inverse weighting factor is utilized so the largest weights are given to the intensity evolutions of those analog tracks that most closely match the NHC track forecasts (except in this development phase the NHC best tracks are utilized).

The first modification of the methodology for the 7-day WAIA was prompted by the >10-kt overforecast biases for forecast intervals > 120 h and the fact that this large bias was somewhat different between the training set and the independent set, which for the 7-day WAIA were 2000–09 and 2010–15, respectively. Consequently, the bias correction each 12 h necessary to reduce this large overforecast bias to zero in the training set was not as effective when applied to the independent set. The first modification for the 7-day WAIA was therefore to randomly select 70% of the TCs in the entire 2000–15 sample to be the training set, and use the remaining 30% as the independent set. This sampling approach was successful in obtaining training and independent sets with similar overforecast biases with increasing forecast intervals, and thus allowed for the development of a bias correction that had consistent performance.

The motivation for a second modification of the methodology for the 7-day WAIA was several examples of poor performance by the 7-day WAIP provided by Tsai and Elsberry (2015a). An important contributor to this poor WAIP performance involved situations in which a sufficient number of appropriate analogs were not available in the JTWC historical database. Examples provided by Tsai and Elsberry (2015a) included tracks in the South China Sea that may be short lived if the TC makes landfall, or long lived if the TC track includes a sharp turn to the north and thus has a delayed landfall along the east coast of China. An analogous situation in the Atlantic region would be a TC in the western Caribbean or Gulf of Mexico that might have an early landfall. Other examples of poor WAIP performance noted by Tsai and Elsberry (2015a) were "ending storm" situations due to landfall or recurvature prior to 7 days, or perhaps the storm remained over the ocean without developing within 7 days. Tsai and Elsberry (2015a) also provided an example of a tropical depression that persisted for many days without intensifying in an area of the western North Pacific where

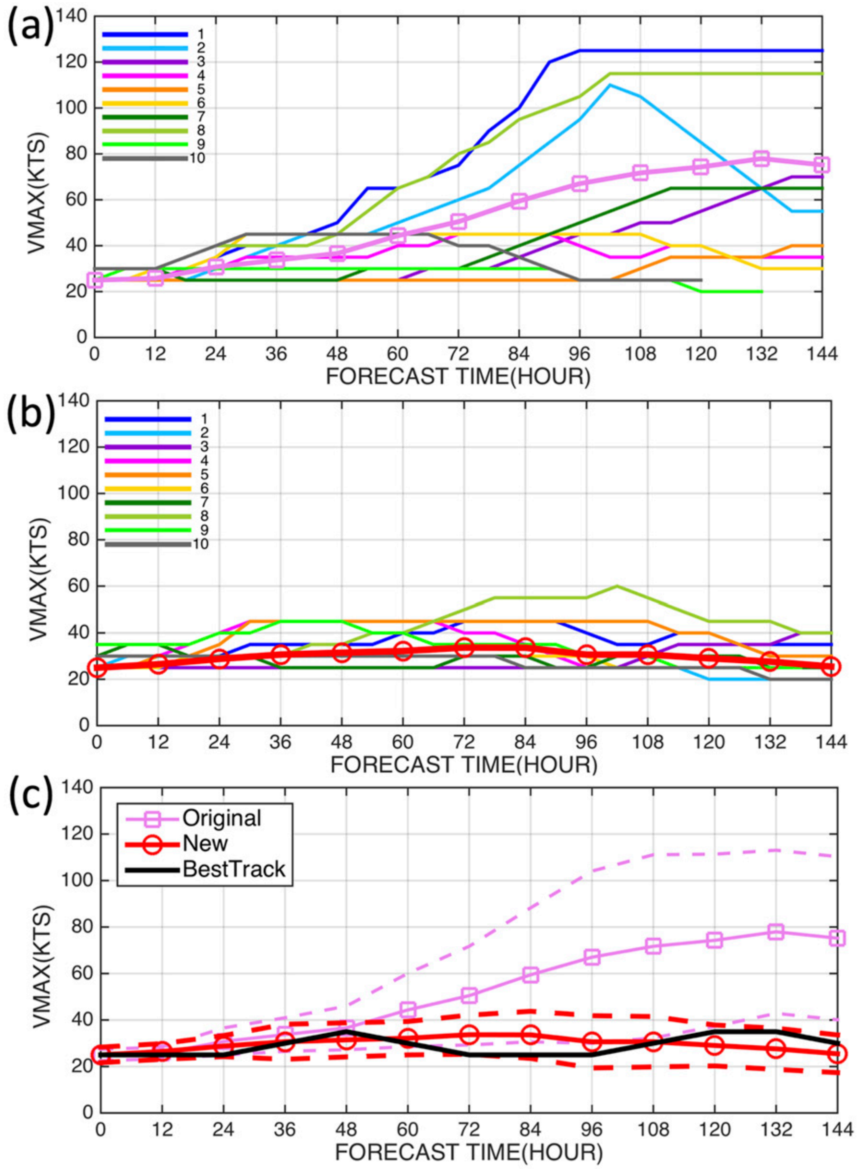

Fig. 2. Intensity (kt) evolutions for 10 ranked historical analogs (color lines at top left) based on the (a) original analog selection and (b) new analog selection techniques with the thick purple and red lines, respectively, indicating the WAIA intensity forecast for AL022009 from 1200 UTC 10 Aug 2009 and ending after only 144 h. (c) Comparison of the original and new WAIA intensity forecasts from (a) and (b) and their corresponding intensity spread predictions (dashed purple and red lines, respectively) with the verifying intensities (solid black line).

the majority of the analogs did intensify. An analogous situation in the Atlantic region is whether (or when) an African easterly wave will develop in the eastern Atlantic or farther west over warmer water, and an example will be shown later.

The second modification for the 7-day WAIA was to ensure that appropriate analogs were selected for ending storms due to landfall, postrecurvature, or nondevelopment or delayed intensification within the 7-day forecast interval. The modification is to simply add a constraint in the analog selection such that the intensity at the last matching point at the end of the target TC track cannot exceed 50 kt. Thus, if the NHC forecast track (here the best track) is shorter than 7 days, then an analog will not be selected if the intensity of that analog is 50 kt or higher at the forecast interval time corresponding to the ending time of the NHC track. Another condition is that there must be at least three analogs that

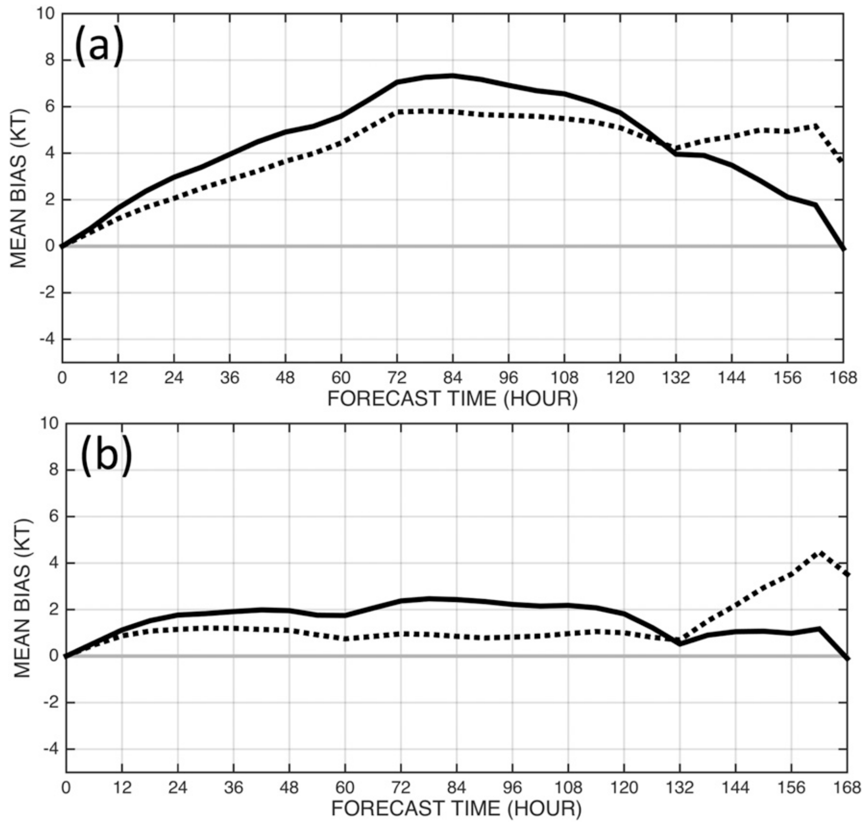

FIG. 3. Mean intensity bias (kt) of the training set (dashed lines) and the independent set (solid lines) for the (a) original and (b) new modified versions of the analog selections for the 7-day WAIA.

meet all selection conditions for a WAIA prediction to be made.

A histogram of the intensities (V_{max}) in 5-kt intervals at the ending times of TCs in the NHC best-track files during 2000–15 is presented in Fig. 1. While 193 of these ending V_{max} values are between 15 and 30 kt, 67 of these TCs ended with 35 kt $\leq V_{max} \leq$ 50 kt, and only 9 ($\sim$3.4%) TCs had ending intensities greater than the 50-kt threshold for analog selection in this second modification to WAIA. Given the intensity distribution in Fig. 1, and with the WAIA condition that the initial intensity difference must be <20 kt, application of the condition excluding analogs with intensities exceeding 50 kt at the ending time will be effective in constraining the WAIA predictions to be well below 50 kt.

The new selection criterion is illustrated in Fig. 2 for the AL022009 TC track from 1200 UTC 10 August 2008 that ended after only 144 h (6 days). This midseason TC track began just southwest of the Cape Verde Islands and extended westward almost to the eastern Caribbean (not shown) without developing beyond 35 kt. With the original analog selection criteria, the 10 historical analogs included nondevelopers, late developers, and three TCs that had peak intensities > 100 kt (Fig. 2a). Indeed, analog 1, which best matched the track and initial intensity, reached an intensity of 125 kt at t = 96 h and maintained this intensity through 144 h. With this large spread among the analog intensity evolutions, the WAIA forecast was "down the middle" with a peak intensity of 80 kt at 132 h (Fig. 2a, pink line). Imposing the new selection criterion that no analog intensity should exceed 50 kt at the ending time, a different set of 10 historical analogs was selected (Fig. 2b). Again, the WAIA is down the middle, but now the peak intensity is about 35 kt (red line).

A comparison of these two WAIA intensity and intensity spread forecasts is given in Fig. 2c. The important results are that the WAIA forecast with the new selection criterion has very small errors, and the verifying intensities lie within the small intensity spread about that WAIA forecast. By contrast, the WAIA forecast with the original analog selection criteria has increasingly larger intensity forecast errors after t = 60 h with magnitudes exceeding 40 kt at t = 108 h and again at t = 132 h. Even though the intensity spreads are very large for the original version, the verifying intensities lie

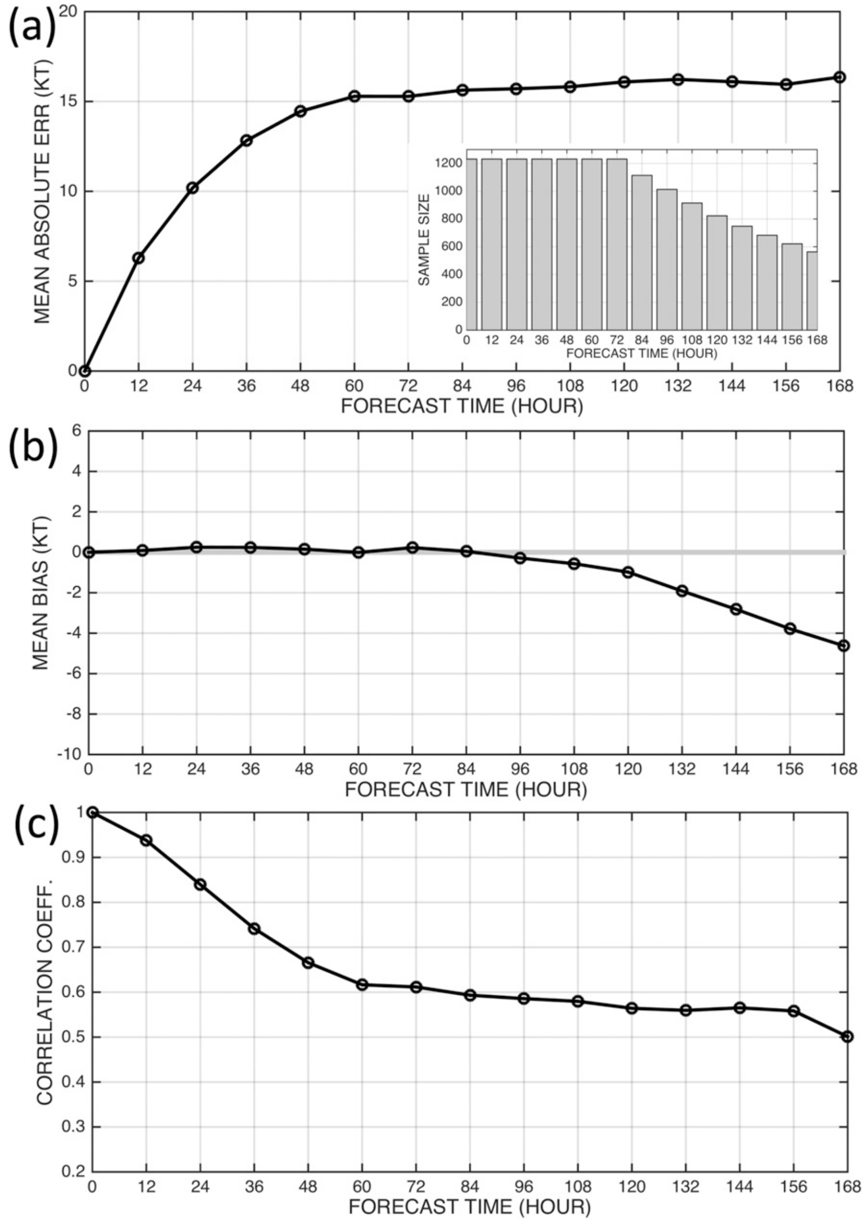

FIG. 4. (a) MAEs (kt), (b) mean biases (kt), and (c) correlation coefficients for the 7-day WAIA hindcast independent sample after a bias correction is also applied. The sample sizes are shown in the inset in (a).

outside the intensity spread at these two forecast intervals. In summary, these ending storm cases may result in large overforecasts that are successfully reduced by the new analog selection criteria.

The impacts of these two modifications in the selection of analogs for the 7-day WAIA are illustrated by comparisons of the mean biases for the original version training set and independent set in Fig. 3a and then the mean biases for the new analog selection version training set and independent set in Fig. 3b. Although there are large overforecast biases in both the original version training set and independent set, the general shapes of these biases are more similar when the 70%/30% definitions of the training and independent sets are applied (Fig. 3a) rather than the 2000–09 and 2010–15 definitions (not shown). The key result is that the new constraint on the analog selections for ending TCs has virtually eliminated the overforecast bias in both the training set and the independent set (Fig. 3b). That is, the mean bias in the new version of the training set is about 1 kt from

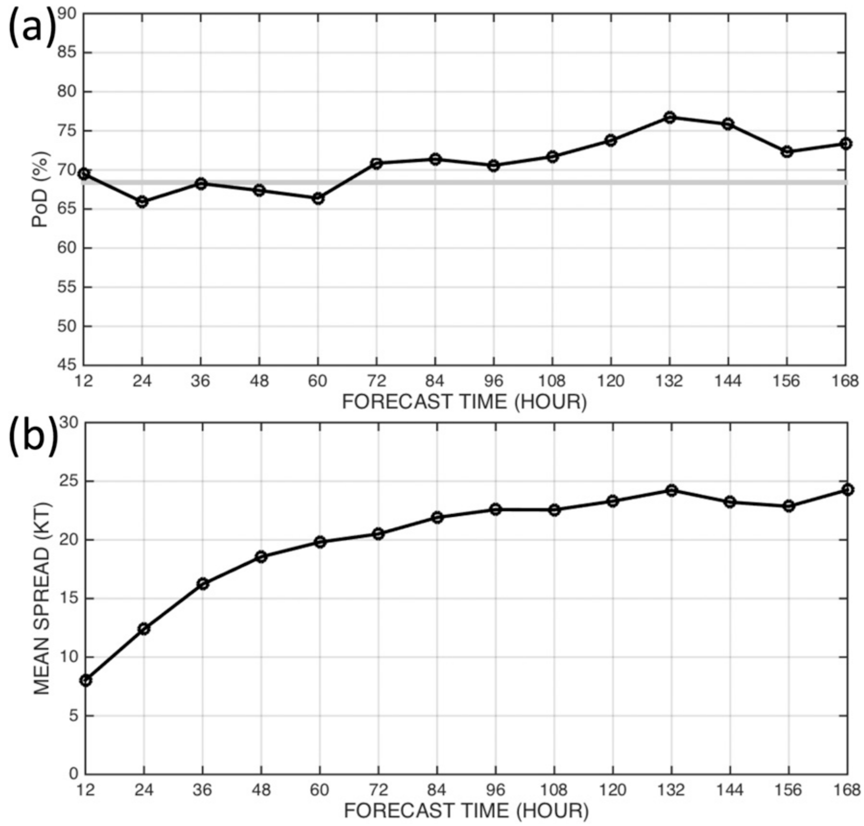

FIG. 5. As in Fig. 4, but for (a) POD (%), and (b) mean spread (kt).

12 through 132 h and then increases to about 4 kt during the last 12 h. Although the mean biases for the independent set are about 2 kt through about 120 h, the mean biases range from 0 to 1 kt between 120 and 168 h.

It is emphasized that this reduction in mean biases is not due to a bias correction. Rather, simply making two modifications to the analog selection conditions has almost eliminated the overforecast biases in both the new versions of the training set and the independent set. Indeed, these two modifications have practically eliminated the need for a bias correction in the 7-day WAIA. Conversely, one can infer that it was the lack of accounting for the ending storm situations that had contributed to the increasingly large overforecast bias in the original version of the 7-day WAIA.

3. Performance evaluation for modified 7-day WAIA

The MAEs for the independent set of 7-day WAIA hindcasts (Fig. 4a, with NHC best tracks as input) are very similar to the MAEs for the 5-day WAIA through 120 h (Tsai and Elsberry 2015b). The key result here is that these MAEs do not further increase between 120 and 168 h. Recall that the mean biases even without a bias correction (Fig. 3b) have been reduced to between 0 and +1 kt. Now with a bias correction (Fig. 4b), the mean biases for the independent sample are near zero from 12 to 96 h, and only gradually amplify to −4 kt at 168 h. The correlation coefficients of these WAIA hindcasts with the verifying intensities decrease rapidly to 0.60 at 60 h, and then only slowly decrease to 0.56 at 156 h before falling to 0.50 at 168 h. Thus, the 7-day WAIA will provide intensity predictions of Atlantic TCs with a level of performance similar to that of our 5-day WAIA.

Although not discussed in section 2, an improvement in the analog selection also has an impact on the probability of detection (POD; Fig. 5a) and the mean intensity spread (Fig. 5b). The objective of the calibration of the raw intensity spreads among the 10 best historical analogs is to achieve 68% of the WAIA hindcasts falling within the WAIA intensity spread. Except for some overdetermined PODs in the 120–144-h forecast intervals, these 7-day WAIA hindcasts for the independent sample are quite successful (Fig. 5a). Another key result is that the mean intensity spreads are essentially constant in the 120–168-h range (Fig. 5b) and yet include about 68% of the verifying intensities.

In summary, two modifications to the original WAIA analog selection methodology have practically eliminated a large overforecast bias that existed when the WAIA was extended from 5 to 7 days. Since the MAEs, correlation coefficients, and mean intensity spreads are almost constant from 120 to 168 h, this WAIA is a viable technique for 7-day intensity and intensity spread predictions, and now addresses difficult situations of ending storms such as landfall, recurvature, or delayed intensification or decay over the open ocean. In the future, this approach of constraining the analog selections to meet special conditions of the target storm will be extended to apply constraints on analog selection for formation time, rapid intensification, and bimodal or bifurcation situations.

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