NATIONAL HURRICANE CENTER FORECAST VERIFICATION REPORT

2023 HURRICANE SEASON

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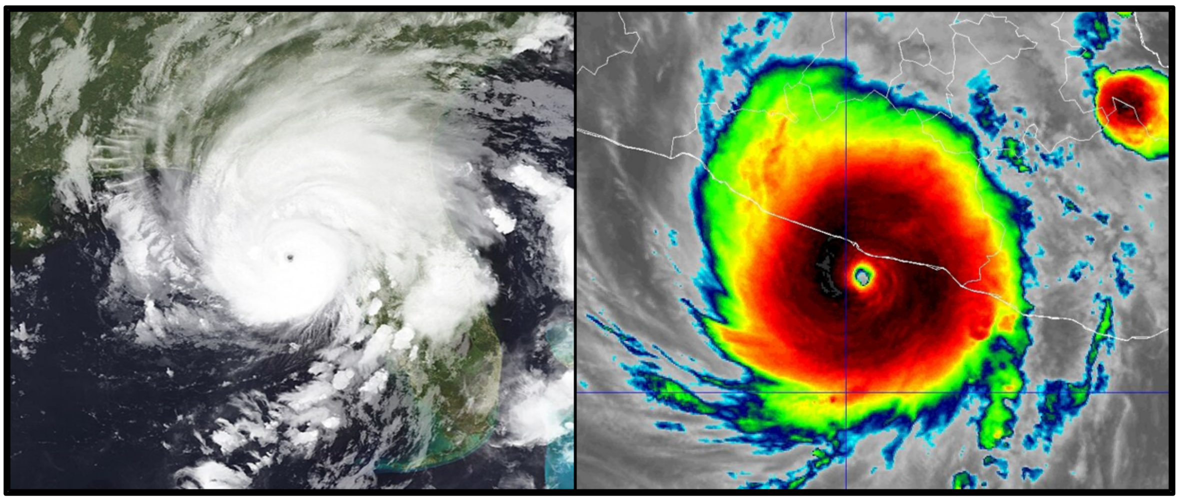

(LEFT) GOES-16 GEOCOLOR IMAGE OF HURRICANE IDALIA AT 0715 UTC 30 AUGUST 2023. (RIGHT) GOES-16 INFRARED SATELLITE IMAGERY OF CATEGORY 5 HURRICANE OTIS AT 0430 UTC 25 OCTOBER 2023, SHORTLY BEFORE IT MADE LANDFALL NEAR ACAPULCO, MEXICO. IMAGES COURTESY NOAA/NESDIS/STAR.

ABSTRACT

In total, 446 official forecasts were issued during the 2023 Atlantic hurricane season, which is well above the 30-year average number of forecasts and the highest level of tropical cyclone activity since 2020. The mean NHC official track forecast errors in the Atlantic basin were notably higher than their previous 5-yr means, especially at the longer lead times. In contrast, the CLIPER errors for 2023 were slightly lower than their 5-yr means There were no records for track accuracy set in 2023. Track forecast errors have decreased significantly over the long term, but there has been less improvement during the past several years. Errors increased in 2023 compared to the previous season. The official track forecasts were slightly outperformed by the consensus models at most time periods. EMXI performed well at the short lead times and HFBI was superior at long range. EGRI and AEMI were competitive with the best models while GFSI, HWFI, HMNI, CMCI,

CTCI and NVGI were less skillful. The Government Performance and Results Act of 1993 (GPRA) track goal was missed.

Mean official intensity errors for the Atlantic basin in 2023 were lower than the previous 5-yr means at all forecast times. Decay-SHIFOR errors in 2023 were significantly lower than their 5-yr means, implying that intensity of the season's storms was less challenging than normal to predict. The official forecasts beat all of the models at 96 and 120 h, and errors were near record lows at most forecast time periods. Although there is a considerable amount of year-to-year variability, the intensity forecast errors have been gradually decreasing over the past decade or so. Among the guidance, IVCN and HCCA were the best performers. HWFI was the best individual model for the short lead times while HMNI and HFBI were best for the longer lead times. GFSI was competitive with the best models, but EMXI had considerably less skill. The GPRA intensity goal was met.

There were 297 official forecasts issued in the eastern North Pacific basin in 2023, which is about 10% below the average level of seasonal forecast activity. The mean NHC official track forecast errors in the eastern North Pacific basin were slightly lower or comparable to the 5-yr means from 12 to 72 h, and greater than the 5-yr means at 96 and 120 h. The CLIPER errors were higher than their 5-yr means at all forecast times, indicating that the tracks of the season's storms were more challenging to predict than normal No records for track accuracy were set in 2023. Track forecast errors have considerably decreased over the long term, but the rate of improvement has slowed in recent years. The 2023 official track forecasts outperformed the individual models but were slightly bested by HCCA and FSSE at most forecast times. EMXI was the best-performing individual model from 12–60 h, and AEMI was the best individual model at 96 and 120 h. HFAI, HMNI, GFSI, and CTCI were also quite skillful, while EGRI and NVGI performed poorly.

The official intensity forecast errors in the eastern North Pacific basin were higher than the previous 5-yr means at most times. The Decay-SHIFOR errors were also larger than their 5-yr means at all lead times, which suggests that forecasting the intensity of the season's storms was more challenging than average. No records for intensity accuracy were set in 2023. While NHC intensity forecasts have improved over the past couple of decades, there remains considerable year-to-year variability. The 2023 official intensity forecasts were skillful and outperformed the individual models at most forecast times. The consensus aids NNIC and HCCA bested the official forecasts at a majority of lead times. HFAI was one of the best individual models for intensity, especially at longer lead times. GFSI and EMXI had considerably less skill than the rest of the intensity models.

An evaluation of track performance during the 2021–23 period in the Atlantic basin indicates that HCCA and TVCA were the best models. The official track forecasts for the 3-yr sample had skill that was quite close to the best aids throughout the forecast period. EMXI was the best individual model, but it had about 5% less skill than the consensus models and official forecasts. For intensity in the Atlantic basin, the official forecasts performed quite well and had skill that was comparable to the best guidance, the consensus models. HWFI and HMNI were generally the best individual models.

A three-year evaluation from 2021–23 in the eastern North Pacific basin indicates that the official track forecasts performed very well with skill levels among the best consensus models. Regarding intensity, the official forecasts during the 3-yr period generally performed comparably to the best models and consensus aids. Overall, HMNI was generally the best individual model and was competitive with the consensus aids at many forecast times.

Quantitative probabilistic forecasts of tropical cyclogenesis are expressed in 48- and 168-h time frames in 10% increments and in terms of categories (“low”, “medium”, or “high”). In the Atlantic basin, results from 2023 indicate that the probabilistic forecasts had a low bias for some of the low and medium 48- and 168-h probabilities. In the eastern North Pacific basin, a low bias existed for the higher probability 48-h forecasts and the lower probability 168-h forecasts.

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1. Introduction

For all operationally designated tropical or subtropical cyclones, or systems that could become tropical or subtropical cyclones and affect land within the next 48 h in the Atlantic and eastern North Pacific basins, the National Hurricane Center (NHC) issues an official forecast of the cyclone's center location and maximum 1-min surface wind speed. Forecasts are issued every 6 h, and contain projections valid 12, 24, 36, 48, 60, 72, 96, and 120 h after the forecast's nominal initial time (0000, 0600, 1200, or 1800 UTC)[1]. At the conclusion of the season, forecasts are evaluated by comparing the projected positions and intensities to the corresponding post-storm derived "best track" positions and intensities for each cyclone. A forecast is included in the verification only if the system is classified in the final best track as a tropical (or subtropical[2]) cyclone at both the forecast's initial time and at the projection's valid time. All other stages of development (e.g., tropical wave, [remnant] low, extratropical) are excluded[3]. For verification purposes, forecasts associated with special advisories do not supersede the original forecast issued for that synoptic time; rather, the original forecast is retained[4]. All verifications in this report include the depression stage.

It is important to distinguish between *forecast error* and *forecast skill*. Track forecast error, for example, is defined as the great-circle distance between a cyclone's forecast position and the best track position at the forecast verification time. Skill, on the other hand, represents a normalization of this forecast error against some standard or baseline. Expressed as a percentage improvement over the baseline, the skill of a forecast s_f is given by

$$s_f\,(\%) = 100 * (e_b - e_f) / e_b$$

where e_b is the error of the baseline model and e_f is the error of the forecast being evaluated. It is seen that skill is positive when the forecast error is smaller than the error from the baseline.

To assess the degree of skill in a set of track forecasts, the track forecast error can be compared with the error from CLIPER5, a climatology and persistence model that contains no information about the current state of the atmosphere (Neumann 1972, Aberson 1998)[5]. Errors from the CLIPER5 model are taken to represent a "no-skill" level of accuracy that is used as the baseline (e_b) for evaluating other forecasts[6]. If CLIPER5 errors are unusually low during a given season, for example, it indicates that the year's storms were inherently "easier" to forecast than

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1 The nominal initial time represents the beginning of the forecast process. The actual advisory package is not released until 3 h after the nominal initial time, i.e., at 0300, 0900, 1500, and 2100 UTC.

2 For the remainder of this report, the term "tropical cyclone" shall be understood to also include subtropical cyclones.

3 Possible classifications in the best track are: Tropical Depression, Tropical Storm, Hurricane, Subtropical Depression, Subtropical Storm, Extratropical, Disturbance, Wave, and Low.

4 Special advisories are issued whenever an unexpected significant change has occurred or when watches or warnings are to be issued between regularly scheduled advisories. The treatment of special advisories in forecast databases changed in 2005 to the current practice of retaining and verifying the original advisory forecast.

5 CLIPER5 and SHIFOR5 are 5-day versions of the original 3-day CLIPER and SHIFOR models.

6 To be sure, some "skill", or expertise, is required to properly initialize the CLIPER model.

normal or otherwise unusually well behaved. The current version of CLIPER5 is based on developmental data from 1931–2004 for the Atlantic and from 1949–2004 for the eastern Pacific.

Particularly useful skill standards are those that do not require operational products or inputs, and can therefore be easily applied retrospectively to historical data. CLIPER5 satisfies this condition, since it can be run using persistence predictors (e.g., the storm's current motion) that are based on either operational or best track inputs. The best-track version of CLIPER5, which yields substantially lower errors than its operational counterpart, is generally used to analyze lengthy historical records for which operational inputs are unavailable. It is more instructive (and fairer) to evaluate operational forecasts against operational skill benchmarks, and therefore the operational versions are used for the verifications discussed below.[7]

Forecast intensity error is defined as the absolute value of the difference between the forecast and best track intensity at the forecast verifying time. Skill in a set of intensity forecasts is assessed using Decay-SHIFOR5 (DSHIFOR5) as the baseline. The DSHIFOR5 forecast is obtained by initially running SHIFOR5, the climatology and persistence model for intensity that is analogous to the CLIPER5 model for track (Jarvinen and Neumann 1979, Knaff et al. 2003). The output from SHIFOR5 is then adjusted for land interaction by applying the decay rate of DeMaria et al. (2006). The application of the decay component requires a forecast track, which here is given by CLIPER5. The use of DSHIFOR5 as the intensity skill benchmark was introduced in 2006. On average, DSHIFOR5 errors are about 5–15% lower than SHIFOR5 in the Atlantic basin from 12–72 h, and about the same as SHIFOR5 at 96 and 120 h.

It has been argued that CLIPER5 and DSHIFOR5 should not be used for skill benchmarks, primarily on the grounds that they were not good measures of forecast difficulty. Particularly in the context of evaluating forecaster performance, it was recommended that a model consensus (see discussion below) be used as the baseline. However, an unpublished study by NHC has shown that on the seasonal time scales at least, CLIPER5 and DSHIFOR5 are indeed good predictors of official forecast error. For the period 1990–2009, CLIPER5 errors explained 67% of the variance in annual-average NHC official track forecast errors at 24 h. At 72 h, the explained variance was 40% and at 120 h the explained variance was 23%. For intensity, the relationship was even stronger: DSHIFOR5 explained between 50–69% of the variance in annual-average NHC official errors at all time periods. Given this, CLIPER5 and DSHIFOR5 appear to remain suitable, if imperfect, baselines for skill, in the context of examining forecast performance over the course of a season (or longer). However, they are probably less useful for interpreting forecast performance with smaller samples (e.g., for a single storm).

The trajectory-CLIPER (TCLP) model is an alternative to the CLIPER and SHIFOR models for providing baseline track and intensity forecasts (DeMaria et al 2022). The input to TCLP [Julian Day, initial latitude, longitude, maximum wind, and the time tendencies of position and intensity] is the same as for CLIPER/SHIFOR, but rather than using linear regression to predict the future latitude, longitude and maximum wind, a trajectory approach is used. For track, a

[7] On very rare occasions, operational CLIPER or SHIFOR runs are missing from forecast databases. To ensure a completely homogeneous verification, post-season retrospective runs of the skill benchmarks are made using operational inputs. Furthermore, if a forecaster makes multiple estimates of the storm's initial motion, location, etc., over the course of a forecast cycle, then these retrospective skill benchmarks may differ slightly from the operational CLIPER/SHIFOR runs that appear in the forecast database.

monthly climatology of observed storm motion vectors was developed from a 1982–2011 sample. The TCLP storm track is determined from a trajectory of the climatological motion vectors starting at the initial date and position of the storm. The climatological motion vector is modified by the current storm motion vector, where the influence of the current motion vector decreases with time during the forecast. A similar approach is taken for intensity, except that the intensity tendency is estimated from the logistic growth equation model (LGEM) with climatological input. Similar to track, the climatological intensity tendency is modified by the observed tendency, where the influence decreases with forecast time. The track used for the TCLP intensity forecast is the TCLP track forecast. When the storm track crosses land, the intensity is decreased at a climatological decay rate. A comparison of a 10-yr sample of TCLP errors with those from CLIPER5 and DSHIFOR5 shows that the average track and intensity errors of the two baselines are within 10% of each other at all forecast times out to five days for the Atlantic and eastern North Pacific. One advantage of TCLP over CLIPER5/DSHIFOR5 is that TCLP can be run to any desired forecast time.

NHC also issues forecasts of the size of tropical cyclones; these “wind radii” forecasts are estimates of the maximum extent of winds of various thresholds (34, 50, and 64 kt) expected in each of four quadrants surrounding the cyclone. Unfortunately, there is insufficient surface wind information to allow the forecaster to accurately analyze the size of a tropical cyclone’s wind field over much of the Atlantic and nearly all of the eastern Pacific. As a result, post-storm best track wind radii are likely to have errors so large as to render a verification of official radii forecasts unreliable and potentially misleading; consequently, no verifications of NHC wind radii are included in this report. In time, as our ability to measure the surface wind field in tropical cyclones improves, it may be possible to perform a meaningful verification of NHC wind radii forecasts (Cangialosi and Landsea 2016). In addition, there are currently some internal efforts at NHC to review wind radii climatology and verification for a subset of cases, and these results will be included in a separate report.

Numerous objective forecast aids (guidance models) are available to help the NHC in the preparation of official track and intensity forecasts. Guidance models are characterized as either *early* or *late*, depending on whether or not they are available to the forecaster during the forecast cycle. For example, consider the 1200 UTC (12Z) forecast cycle, which begins with the 12Z synoptic time and ends with the release of an official forecast at 15Z. The 12Z run of the National Weather Service Global Forecast System (GFS) model is not complete and available to the forecaster until about 16Z, or about an hour after the NHC forecast is released. Consequently, the 12Z GFS would be considered a late model since it could not be used to prepare the 12Z official forecast. This report focuses on the verification of early models.

Multi-layer dynamical models are generally, if not always, late models. Fortunately, a technique exists to take the most recent available run of a late model and adjust its forecast to apply to the current synoptic time and initial conditions. In the example above, forecast data for hours 6–126 from the previous (06Z) run of the GFS would be smoothed and then adjusted, or shifted, such that the 6-h forecast (valid at 12Z) would match the observed 12Z position and intensity of the tropical cyclone. The adjustment process creates an “early” version of the GFS model for the 12Z forecast cycle that is based on the most current available guidance. The adjusted versions of the late models are known, mostly for historical reasons, as *interpolated* models[8]. The adjustment algorithm is invoked as long as the most recent available late model is not more than 12 h old, e.g., a 00Z late model could be used to form an interpolated model for the subsequent 06Z or 12Z forecast cycles, but not for the subsequent 18Z cycle. Verification procedures here make no distinction between 6- and 12-h interpolated models.

A list of models is given in Table 1. In addition to their timeliness, models are characterized by their complexity or structure; this information is contained in the table for reference. Briefly, *dynamical* models forecast by solving the physical equations governing motions in the atmosphere. Dynamical models may treat the atmosphere either as a single layer (two-dimensional) or as having multiple layers (three-dimensional), and their domains may cover the entire globe or be limited to specific regions. The interpolated versions of dynamical model track and intensity forecasts are also sometimes referred to as dynamical models. *Statistical* models, in contrast, do not consider the characteristics of the current atmosphere explicitly but instead are based on historical relationships between storm behavior and various other parameters. *Statistical-dynamical* models are statistical in structure but use forecast parameters from dynamical models as predictors. *Consensus* models are not true forecast models *per se*, but are merely combinations of results from other models. One way to form a consensus is to simply average the results from a collection (or "ensemble") of models, but other, more complex techniques can also be used. The Hurricane Forecast Improvement Program Corrected Consensus Approach (HCCA), for example, combines its individual components on the basis of past performance and attempts to correct for biases in those components (Simon et al. 2018). A consensus model that considers past error characteristics can be described as a "weighted" or "corrected" consensus. Additional information about the guidance models used at the NHC can be found at http://www.nhc.noaa.gov/modelsummary.shtml.

The verifications described in this report are for all tropical cyclones in the Atlantic and eastern North Pacific basins. These statistics are based on forecast and best track data sets taken from the Automated Tropical Cyclone Forecast (ATCF) System on 11 April 2024 for the Atlantic basin, and on 14 March 2024 for the eastern North Pacific basin. Verifications for the Atlantic and eastern North Pacific basins are given in Sections 2 and 3 below, respectively. Section 4 discusses NHC's probabilistic genesis forecasts. Section 5 summarizes the key findings of the 2023 verification and previews anticipated changes for 2024.

[8] When the technique to create an early model from a late model was first developed, forecast output from the late models was available only at 12 h (or longer) intervals. In order to shift the late model's forecasts forward by 6 hours, it was necessary to first interpolate between the 12 h forecast values of the late model – hence the designation "interpolated".

2. Atlantic Basin

a. 2023 season overview – Track

Figure 1 and Table 2 present the results of the NHC official track forecast verification for the 2023 season, along with results averaged for the previous 5-yr period, 2018–2022. In 2023, the NHC issued 446 Atlantic basin tropical cyclone forecasts[9], a number notably above the latest 30-year mean (325) and the highest number of forecasts since 2020 (Fig. 2). Mean track errors ranged from 25 n mi at 12 h to 248 n mi at 120 h. The mean official track forecast errors in 2023 were above the 5-yr means at all times, and up to 44% larger at 120 h. In contrast, the CLIPER errors for 2023 were slightly lower than their 5-yr means, which typically indicates that the storms were a little less challenging to predict than average. No records for track accuracy were set in 2023. The official track forecast vector biases were small and north-northwestward at the short lead times, but a more notable north-northwest to north bias existed at 96 and 120 h (i.e., the official forecast tended to fall to the north/north-northwest of the verifying position). Track forecast skill ranged from 44% at 12 h to 66% at 36 h (Table 2). Over the past couple of decades, the 24−72-h track forecast errors have been reduced drastically by about 75% (Fig. 3a). Track forecast error reductions of about 60% have occurred over the past 20 years for the 96- and 120-h forecast periods. However, in 2023 there was a notable increase in track error, and overall improvements in track forecasting has slowed during the past several years. An evaluation of track skill indicates that there has been a gradual increase in skill over the long term (Fig. 3b), but skill did decrease some in 2023 and the trends appear relatively flat during the past several years. Figure 4 indicates that on average the NHC track errors decrease as the initial intensity of a cyclone increases, and that relationship holds true through the 120-h forecast period. It has been seen in multiple cases during the past few years that the NHC track errors are notably lower than average for major hurricanes, including Idalia and Lee in 2023.

Note that the mean official error in Figure 1 is not precisely zero at 0 h (the analysis time). This non-zero difference between the operational analysis of storm location and best track location, however, is not properly interpreted as "analysis error". The best track is a subjectively smoothed representation of the storm history over its lifetime, in which the short-term variations in position or intensity that cannot be resolved in a 6-hourly time series are deliberately removed. Thus, the location of a strong hurricane with a well-defined eye might be known with great accuracy at 1200 UTC, but the best track may indicate a location elsewhere by 5–10 miles or more if the precise location of the cyclone at 1200 UTC was unrepresentative. Operational analyses tend to follow the observed position of the storm more closely than the best track analyses, since it is more difficult to determine unrepresentative behavior in real time. Consequently, the t=0 "errors" shown in Figure 1 contain both true analysis error and representativeness error.

Table 3a presents a homogeneous[10] verification for the official forecast along with a selection of early models for 2023. In order to maximize the sample size, a guidance model had

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[9] This count does not include forecasts issued for systems later classified to have been something other than a tropical cyclone at the forecast time.

[10] Verifications comparing different forecast models are referred to as *homogeneous* if each model is verified over an identical set of forecast cycles. Only homogeneous model comparisons are presented in this report.

to be available at least two-thirds of the time at both 48 and 120 h to be included in this comparison. The performance of the official forecasts and the early track models in terms of skill are presented in Figure 5. The figure shows that the official forecasts were highly skillful, and near the best models throughout the forecast period. The best models were the consensus aids HCCA, TVCA, and FSSE, except at 120 h. Among the individual models, HFBI performed quite well from 72 to 120 h, beating all of the models and the official forecast at 120 h. EMXI was the best model for the shorter lead times from 12 to 72 h, besting the official forecasts at 60 and 72 h. EGRI and AEMI were the next best models, generally having slightly less skill than EMXI, HFBI, and the consensus models. The remainder of the models trailed, which includes GFSI, HWFI, HMNI, CTCI, and NVGI. An evaluation over the three years 2021–23 (Fig. 6) indicates that HCCA and TVCA were also the best models for this sample, with TVCA being superior at the longer lead times. The official forecasts had about the same skill levels as those models throughout the forecast period. EMXI was the best individual model, but it had about 5% lower skill than the official forecasts and consensus aids. GFSI, AEMI, EGRI, and HMNI all had about the same levels of skill as each other and were the next best models. CTCI, HWFI, and CMCI were slightly less skillful, while NVGI was not competitive.

Vector biases of the guidance models for 2023 are given in Table 3b. The table shows that the official forecast had similar biases to the consensus aids, which had a general northwest bias at most forecast times. EMXI had a significant west-southwest bias at 96 and 120 h, while GFSI had an even larger northeast bias at those forecast times. Figure 7 provides a comparison of track error and consistency, or how much the official forecast and models changed from cycle to cycle, around the 96-h forecast time period. It can be seen that for the 2021–23 sample the official forecasts had lower error and were more consistent than GFSI, EMXI, and EGRI.

A separate homogeneous verification of the primary consensus models for 2023 is shown in Figure 8. The figure shows that TVCA and TVCX were the most skillful models overall, but GFEX, FSSE, and HCCA had only slightly less skill. AEMI was notably less skillful through 72 h, but its skill levels were not far off from the best aids at 96 and 120 h.

Atlantic basin 48-h official track error, evaluated for all tropical cyclones, is a forecast measure tracked under the Government Performance and Results Act of 1993 (GPRA). In 2023, the GPRA goal was 53 n mi, and the verification for this measure was missed at 68.8 n mi. One storm, Philippe, had a large contribution to missing this target. See section 2c for more details.

b. 2023 season overview – Intensity

Figure 9 and Table 4 present the results of the NHC official intensity forecast verification for the 2023 season, along with results averaged for the preceding 5-yr period. Mean forecast errors in 2023 ranged from 4 kt at 12 h to 13 kt at 120 h. These errors were10–18% lower than the previous 5-yr means throughout the forecast period. Intensity forecast skill ranged from 21% at 12 h to 34% at 48 h. Although no records for accuracy were set in 2023, the intensity errors were near record lows at most forecast hours. The official forecasts had little bias at 12 and 24 h, but a slight high bias existed at the other forecast times. The Decay-SHIFOR5 errors were well below, 18–29% lower, than their 5-yr means, indicating that the season's storms were less challenging than normal to predict. Figure 10 indicates that the NHC official intensity errors changed little at most forecast hours over the past couple of years. Over the long-term, despite year-to-year variability, there has been a considerable decrease in error that began around 2010. It appears that the intensity predictions are gradually improving as the forecasts are generally more skillful in the past 10 years or so than they were in the 1990s and the first decade of the 2000s (Cangialosi et al. 2020), and progress has also been made in predicting rapid intensification (DeMaria et al. 2021).

Table 5a presents a homogeneous verification for the official forecasts and the primary early intensity models for 2023. Intensity biases are given in Table 5b, and forecast skill is presented in Figure 11. The official forecasts were quite skillful, and they beat all of the models at 96 and 120 h. The consensus models IVCN and HCCA were the best aids overall and outperformed the official forecasts from 24 to 72 h. Although the skill of the hurricane regional and statistical-dynamical models was fairly close, in general HWFI performed best for the short lead times and HMNI and HFBI for the longer lead times. DSHP and LGEM had large errors for the longer lead times, and in contrast, GFSI was competitive with the best individual models at 96 and 120 h. EMXI had little to no skill throughout the forecast period. An inspection of the intensity biases (Table 5b) indicates that most of the models had little biases, except for EMXI which had large low biases.

An evaluation over the three years 2021–23 (Fig. 12) indicates that the official forecasts have been consistently performing quite well, and had skill values close to the best aids IVCN and HCCA. For this sample, HWFI and HMNI were the best individual models at most forecast times. CTCI, DSHP, LGEM, and GFSI were fair performers, but they were generally not as skillful as HWFI and HMNI. EMXI was only skillful from 48 to 96 h and was not competitive with the remainder of the guidance.

The 48-h official intensity error, evaluated for all tropical cyclones, is another GPRA measure for NHC. In 2023, the GPRA goal was 10 kt, and the verification for this measure was met at 8.4 kt.

c. Verifications for individual storms

Forecast verifications for individual storms are given in Table 6. Of note are the large track errors for Tropical Storm Philippe and Hurricane Nigel over the central portion of the basin. For Philippe, one reason for these high track errors was that the majority of NHC official predictions forecasted Philippe too far north and/or too fast relative to the ultimate track. This had to do with incorrectly forecasting Philippe's structure/intensity and how that affected its motion. In fact, these errors had a significant influence on the 2023 seasonal verification given that Philippe was one of the longer-lived tropical cyclones of the year. For Nigel, its long-term track was quite challenging to predict due to the complex steering pattern and timing of an approaching upper-level trough. Conversely, the official track forecast errors were quite low for Hurricanes Idalia and Lee, and were well below NHC's 5-yr means. Figure 13 shows an illustration of the official track errors stratified by storm.

With regards to intensity, Tropical Storm Jose was a challenging cyclone to predict, and NHC had particularly large intensity errors/low biases for that compact storm as it unexpectedly intensified. Conversely, excellent intensity forecasts were issued for Tropical Storm Cindy, Hurricane Don, and Hurricane Tammy. Figure 14 shows an illustration of the official intensity errors stratified by storm. Additional discussion on forecast performance for individual storms can be found in NHC Tropical Cyclone Reports available at http://www.nhc.noaa.gov/data/tcr/index.php?season=2023&basin=atl.

3. Eastern North Pacific Basin

a. 2023 season overview – Track

The NHC track forecast verification for the 2023 season in the eastern North Pacific, along with results averaged for the previous 5-yr period, is presented in Figure 15 and Table 7. There were 297 forecasts issued for the eastern North Pacific basin in 2023, which is about 10% below the latest 30-year mean for the basin (Fig. 16). The mean track errors ranged from 22 n mi at 12 h to 161 n mi at 120 h. These errors were slightly lower or comparable to the 5-yr means from 12 to 72 h, and greater than the 5-yr means at 96 and 120 h. The CLIPER errors were higher than their 5-yr means at all forecast times, indicating that the tracks of the season's storms were more challenging to predict than normal. Notably, the CLIPER errors at 96 and 120 h were 50–65% greater than their 5-yr means. No records for track accuracy were set in 2023. The official track forecast vector biases were generally small through 48 h, with a more pronounced east-southeast bias noted from 60–120 h.

Figure 17 shows recent trends in track forecast accuracy and skill for the eastern North Pacific. Over the past few years, track errors have been generally steady from 24 to 72 h. However, the long-term trends indicate that 24 to 72-h track errors have been reduced by about 60–70% since 1990. Similar to the Atlantic basin, this rate of improvement has slowed in recent years. At the 96- and 120-h forecast times, errors have dropped by 40–50% since 2001, but these decreasing error trends have flattened out over the past few years. Track forecast skill ticked upward at all forecast times in 2023, with the 48- to 120-h track forecasts over 70% more skillful than climatology-persistence. Forecast skill has notably increased since 1990 and is near all-time highs at several lead times, but the overall trend has levelled off in recent years.

Table 8a presents a homogeneous verification for the official track forecasts and the early track models for 2023, with vector biases of the guidance shown in Table 8b. Skill comparisons of the official forecast and selected models are shown in Fig. 18. The official forecasts were just as skillful as the most skillful guidance and outperformed all of the individual models through 96 h. The corrected consensus aids HCCA and FSSE were the best performing models overall, with slightly lower errors than the official forecasts at a majority of the forecast times. In terms of the individual models, EMXI was the best performer at shorter lead times (12–60 h), and AEMI was the best individual model at long range (96–120 h). Among the regional hurricane models, HFAI was the most skillful track guidance from 24–60 h, and HMNI was the best individual model at 72 h. HFBI had the largest errors at long range. The GFSI and CTCI were also quite skillful, while EGRI and NVGI were among the worst performing models. The official forecasts had similar directional biases to HCCA at all forecast times, and HMNI had the smallest biases of all the models.

Figure 19 shows an analysis of forecast skill over the past three seasons (2021–2023). The official forecasts compared well to the most skillful consensus models, and OFCL outperformed all of the individual models through 96 h. HCCA slightly bested OFCL at all forecast times, and FSSE and TVCE were among the top performers. EMXI was the most skillful individual model through 72 h. AEMI was the best individual model at 96 h and the top overall performer at 120 h. GFSI and CTCI were among the best individual models with increasing skill at longer lead times. HMNI, HWFI, and CMCI trailed the top models at most forecast times, while EGRI and NVGI were the worst track models for this sample. A separate verification of the primary consensus aids is given in Figure 20. HCCA and FSSE were the best aids at most forecast times, although the skill of the consensus models was tightly clustered. AEMI was less skillful than the consensus models through 72 h, but it was comparable to the best aids at 96 h and the most skillful model at 120 h. GFEX slightly trailed the rest of the consensus aids at longer lead times.

b. 2023 season overview – Intensity

Figure 21 and Table 9 present the NHC eastern North Pacific intensity forecast verification for the 2023 season, along with results averaged for the preceding 5-yr period. The mean intensity errors were higher than the 5-yr means at a majority of the forecast times (12–60 h and 120 h), with errors ranging from 7 kt at 12 h to 22 kt at 120 h. Notably, the official errors were 33% and 26% higher than the 5-yr means at 12 and 120 h, respectively. The Decay-SHIFOR forecast errors were larger than their 5-yr means at all lead times, which suggests the intensity of the season's storms was more difficult to forecast than normal. The official forecasts exhibited a low bias at all forecast periods, with 120-h intensity forecasts on average about 15 kt too low. No records for intensity accuracy were set in 2023. Figure 22 shows recent trends in intensity forecast accuracy and skill for the eastern North Pacific. While there has been a modest decrease in error over the past couple of decades at all forecast times, there remains considerable year-to-year variability. In 2023, NHC intensity forecasts were generally 25–40% more skillful than climatology-persistence.

Table 10a presents a homogeneous verification for the official intensity forecasts and the early intensity guidance for 2023, with forecast biases provided in Table 10b. Skill comparisons of the official forecast and selected models are shown in Fig. 23. The official forecasts were skillful at all forecast times and outperformed every individual model from 12–60 h. The corrected consensus aid HCCA was one of the top performers through 72 h, but its skill markedly dropped off at 96 and 120 h. NNIC was the best overall model at several forecast periods, and it was more skillful than the official forecasts at most lead times. One of the best individual models was HFAI, which had the lowest single-model errors from 36–96 h and was more skillful than the official forecasts from 72–120 h. LGEM was the best individual model at 12, 24, and 120 h. Several models (including FSSE and HCCA) were unskillful at 120 h, and EMXI had little to no skill throughout the forecast period. Every model had negative biases at all forecast times, likely a result of the numerous instances of rapid intensification that occurred during the 2023 season. DSHP had the smallest biases of all the models.

A three-year (2021–2023) evaluation of forecast skill is shown in Fig. 24. The official forecasts were at least 20% more skillful than climatology-persistence through 96 h and among the most skillful aids overall during this period. NNIC and IVCN were top performers, while HCCA and FSSE verified well through 72 h but showed declining skill at 96 and 120 h. HWFI and HMNI performed fairly well beyond 24 h, but were bested by LGEM at 96 and 120 h. The performance of DSHP and the global models (GFSI and EMXI) considerably lagged the rest of the guidance.

c. Verifications for individual storms

Figure 25 illustrates the official track errors stratified by storm in the eastern North Pacific basin. The errors for long-lived Hurricane Calvin were well below NHC's 5-yr means at all lead times. The short-term track forecast errors for a couple of hurricanes that struck Mexico (Hilary and Norma) were also below the 5-yr means. Conversely, larger track forecast errors were noted for a few storms that impacted land, including Hurricanes Lidia and Otis and Tropical Storm Pilar. In particular, the track errors for Pilar were much larger than NHC's 5-yr means at all forecast times, likely due to its unusual track offshore of Central America.

Figure 26 shows the official intensity errors stratified by storm. The largest intensity errors of the season occurred when Hurricane Otis unexpectedly underwent rapid intensification as it approached Acapulco, Mexico. Above-average intensity errors were noted for several other rapidly intensifying storms, including Hurricanes Dora and Jova. On the other hand, excellent intensity forecasts were issued for Hurricane Calvin, which rapidly intensified over the central portion of the eastern North Pacific.

Forecast verifications for individual storms are provided in Table 11. Additional discussion on forecast performance for individual storms can be found in NHC Tropical Cyclone Reports available at http://www.nhc.noaa.gov/data/tcr/index.php?season=2023&basin=epac.

4. Genesis Forecasts

The NHC routinely issues Tropical Weather Outlooks (TWOs) for both the Atlantic and eastern North Pacific basins. The TWOs are text products that discuss areas of disturbed weather and their potential for tropical cyclone development. Forecasters subjectively assign a probability of genesis (0 to 100%, in 10% increments) to each area of disturbed weather described in the TWO, where the assigned probabilities represented the forecaster's determination of the chance of tropical cyclone formation during the 48-h and 168-h periods following the nominal TWO issuance time. Note that the TWO was extended from 5 to 7 days in 2023. Verification is based on NHC best-track data, with the time of genesis defined to be the first tropical cyclone point appearing in the best track.

Verifications of the 48-h outlook for the Atlantic and eastern North Pacific basins for 2023 are given in Table 12 and illustrated in Figure 27. In the Atlantic basin (Table 12a), a total of 921 genesis forecasts were made. These 48-h forecasts were generally well calibrated, but had a slight low (under-forecast) bias for the medium (40–60%) probabilities. In the eastern Pacific (Table 12b), a total of 693 genesis forecasts were made. The forecasts in this basin were well calibrated for the low probabilities, but a pronounced low (under-forecast) bias is apparent for the 40–80% probabilities and a high (over-forecast) bias is seen for the 90% probability forecasts. It should be noted that a 3-yr verification of the 48-h genesis forecasts from 2021–23 (not shown) revealed that the biases in both the Atlantic and eastern North Pacific basins were muted for this larger sample.

The TWO was extended to 7 days in 2023. Verifications of the 168-h outlook for the Atlantic and eastern North Pacific basins for 2023 are given in Table 13 and illustrated in Figure 28. In the Atlantic basin (Table 13a), the 168-h forecasts had a low bias for the 10–50% probability ranges. In the eastern North Pacific (Table 13b), the genesis forecasts had a slight low bias at the low and medium probabilities, with the most pronounced low bias occurring for the 50% probability forecasts. The high probability forecasts were fairly well calibrated. The diagrams also show the refinement distribution, which indicates how often the forecasts deviated from (a perceived) climatology. Sharp peaks at climatology indicate low forecaster confidence, while maxima at the extremes indicate high confidence; the refinement distributions shown in all of the diagrams suggest an intermediate level of forecaster confidence. Figure 29 shows composites of all 7-day tropical cyclone genesis areas depicted in the Graphical TWO during the 2023 season.

5. Looking Ahead to 2024

a. Track Forecast Cone Sizes

The NHC track forecast cone depicts the probable track of the center of a tropical cyclone, and is formed by enclosing the area swept out by a set of circles along the forecast track (at 12, 24, 36 h, etc.). The size of each circle is set so that two-thirds of historical official forecast errors over the most-recent 5-yr sample fall within the circle. The circle radii defining the cones in 2024 for the Atlantic and eastern North Pacific basins (based on error distributions for 2019–23) are given in Table 14. In the Atlantic basin, the cone circles will be slightly larger (up to 8%) at most forecast times. In the eastern Pacific basin, the cone circles will be slightly larger through 48 h, slightly smaller at 60 h, and notably larger (up to 11%) at the longer lead times.

b. Consensus Models

The set of NHC consensus model identifiers remain fixed from year to year. However, the specific members of these consensus models will be determined at the beginning of each season and may vary from year to year.

Some consensus models require all of their member models to be available in order to compute the consensus (e.g., GFEX, ICON), while others are less restrictive, requiring only two or more members to be present (e.g., TVCA, IVCN). The terms “fixed” and “variable” can be used to describe these two approaches, respectively. In a variable consensus model, it is often the case that the 120-h forecast is based on a different set of members than the 12-h forecast. While this approach greatly increases availability, it does pose consistency issues for the forecaster.

The consensus model composition for 2024 is given in Table 15. The consensus models are unchanged from their compositions in 2023.

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List of Tables

Table 1. National Hurricane Center forecasts and models.

ID	Name/Description	Type	Timeliness (E/L)	Parameters forecast
OFCL	Official NHC forecast			Trk, Int
HFSA	Hurricane Analysis and Forecast System – A	Multi-layer regional dynamical	L	Trk, Int
HFSB	Hurricane Analysis and Forecast System – B	Multi-layer regional dynamical	L	Trk, Int
HWRF	Hurricane Weather and Research Forecasting Model	Multi-layer regional dynamical	L	Trk, Int
HMON	Hurricanes in a Multi-scale Ocean-coupled Non-hydrostatic model	Multi-layer regional dynamical	L	Trk, Int
GFSO	NWS/Global Forecast System (formerly Aviation)	Multi-layer global dynamical	L	Trk, Int
AEMN	GFS ensemble mean	Consensus	L	Trk, Int
UKM	United Kingdom Met Office model, automated tracker	Multi-layer global dynamical	L	Trk, Int
EGRR	United Kingdom Met Office model with subjective quality control applied to the tracker	Multi-layer global dynamical	L	Trk, Int
UEMN	UKMET ensemble mean	Consensus	L	Trk, Int
NVGM	Navy Global Environmental Model	Multi-layer global dynamical	L	Trk, Int
CMC	Environment Canada global model	Multi-level global dynamical	L	Trk, Int
NAM	NWS/NAM	Multi-level regional dynamical	L	Trk, Int
CTX	COAMPS-TC using GFS initial and boundary conditions	Multi-layer regional dynamical	L	Trk, Int
EMX	ECMWF global model	Multi-layer global dynamical	L	Trk, Int
EEMN	ECMWF ensemble mean	Consensus	L	Trk
TABS	Beta and advection model (shallow layer)	Single-layer trajectory	E	Trk
TABM	Beta and advection model (medium layer)	Single-layer trajectory	E	Trk

ID	Name/Description	Type	Timeliness (E/L)	Parameters forecast
TABD	Beta and advection model (deep layer)	Single-layer trajectory	E	Trk
CLP5	CLIPER5 (Climatology and Persistence model)	Statistical (baseline)	E	Trk
SHF5	SHIFOR5 (Climatology and Persistence model)	Statistical (baseline)	E	Int
DSF5	DSHIFOR5 (Climatology and Persistence model)	Statistical (baseline)	E	Int
OCD5	CLP5 (track) and DSF5 (intensity) models merged	Statistical (baseline)	E	Trk, Int
TCLP	Trajectory-CLIPER model	Statistical (baseline)	E	Trk, Int
SHIP	Statistical Hurricane Intensity Prediction Scheme (SHIPS)	Statistical-dynamical	E	Int
DSHP	SHIPS with inland decay	Statistical-dynamical	E	Int
OFCI	Previous cycle OFCL, adjusted	Interpolated	E	Trk, Int
HFAI	Previous cycle HAFS-A, adjusted	Interpolated-dynamical	E	Trk, Int
HFBI	Previous cycle HAFS-B, adjusted	Interpolated-dynamical	E	Trk, Int
HWFI	Previous cycle HWRF, adjusted	Interpolated-dynamical	E	Trk, Int
HMNI	Previous cycle HMON, adjusted	Interpolated-dynamical	E	Trk, Int
CTCI	Previous cycle CTCX, adjusted	Interpolated-dynamical	E	Trk, Int
GFSI	Previous cycle GFS, adjusted	Interpolated-dynamical	E	Trk, Int
UKMI	Previous cycle UKM, adjusted	Interpolated-dynamical	E	Trk, Int
EGRI	Previous cycle EGRR, adjusted	Interpolated-dynamical	E	Trk, Int
NVGI	Previous cycle NVGM, adjusted	Interpolated-dynamical	E	Trk, Int
EMXI	Previous cycle EMX, adjusted	Interpolated-dynamical	E	Trk, Int
CMCI	Previous cycle CMC, adjusted	Interpolated-dynamical	E	Trk, Int

ID	Name/Description	Type	Timeliness (E/L)	Parameters forecast
AEMI	Previous cycle AEMN, adjusted	Consensus	E	Trk, Int
UEMI	Previous cycle UEMN, adjusted	Consensus	E	Trk, Int
FSSE	FSU Super-ensemble	Corrected consensus	E	Trk, Int
GFEX	Average of GFSI and EMXI	Consensus	E	Trk
TVCN	Average of at least two of GFSI EGRI HFAI HFBI EMXI CTCI HWFI HMNI EMNI	Consensus	E	Trk
TVCA	Average of at least two of GFSI EGRI HFAI HFBI EMXI CTCI HWFI HMNI EMNI	Consensus	E	Trk
TVCE	Average of at least two of GFSI EGRI HFAI HFBI EMXI CTCI EMNI HWFI HMNI	Consensus	E	Trk
TVCX	EMXI and average of at least two of GFSI EGRI HFAI HFBI HWFI HMNI	Consensus	E	Trk
TVCC	Version of TVCN corrected for model biases	Corrected consensus	E	Trk
TVDG	GFSI (double weight) EMXI (double weight) EGRI (double weight) CTCI HFAI HFBI HWFI HMNI	Corrected consensus	E	Trk
HCCA (AL Trk)	Weighted average of AEMI CTCI EGRI EMNI EMXI GFSI HFAI HFBI HWFI UEMI	Corrected consensus	E	Trk
HCCA (EP Trk)	Weighted average of AEMI CEMI CTCI EGRI EMNI EMXI GFSI HFAI HFBI HWFI UEMI	Corrected Consensus	E	Trk
HCCA (AL Int)	Weighted average of CTCI DSHP EGRI EMXI GFSI HFAI HFBI HMNI HWFI LGEM	Corrected Consensus	E	Int
HCCA (EP Int)	Weighted average of CHPI CTCI DSHP EGRI EMXI GFSI HFAI HFBI HMNI HWFI LGEM	Corrected Consensus	E	Int
ICON	Average of DSHP LGEM HFAI HFBI CTCI HWFI HMNI	Consensus	E	Int

ID	Name/Description	Type	Timeliness (E/L)	Parameters forecast
IVDR	CTCI (double weight) HWFI (double weight) HMNI (double weight) HFAI (double weight) HFBI (double weight) GFSI DSHP LGEM	Consensus	E	Int
IVCN	Average of at least two of DSHP LGEM HFAI HFBI CTCI HWFI HMNI	Consensus	E	Int
NNIC	Average of at least two of HWFI GFSI DSHP LGEM	Corrected consensus	E	Int

Table 2. Homogenous comparison of official and CLIPER5 track forecast errors in the Atlantic basin in 2023 for all tropical cyclones. Averages for the previous 5-yr period are shown for comparison.

	Forecast Period (h)							
	12	24	36	48	60	72	96	120
2023 mean OFCL error (n mi)	24.5	38.5	52.2	68.8	88.8	111.0	169.2	248.1
2023 mean CLIPER5 error (n mi)	43.9	94.7	151.9	205.1	255.0	301.5	385.4	468.2
2023 mean OFCL skill relative to CLIPER5 (%)	44.2	59.2	65.6	65.2	65.0	63.2	56.1	47.0
2023 mean OFCL bias vector (°/n mi)	346/003	344/004	332/005	325/007	332/012	339/019	348/039	002/069
2023 number of cases	404	362	324	292	262	234	187	150
2018-2022 mean OFCL error (n mi)	23.8	35.7	47.8	61.4	76.1	90.5	125.7	172.1
2018-2022 mean CLIPER5 error (n mi)	46.4	99.2	157.4	215.0	254.9	321.2	405.1	486.6
2018-2022 mean OFCL skill relative to CLIPER5 (%)	48.7	64.0	69.6	71.4	70.1	71.8	69.0	64.6
2018-2022 mean OFCL bias vector (°/n mi)	356/002	316/003	299/003	301/004	026/005	310/003	185/006	195/012
2018-2022 number of cases	1742	1544	1363	1205	830	916	687	507
2023 OFCL error relative to 2018-2022 mean (%)	2.9	8.1	9.2	12.1	16.7	22.7	34.6	44.1
2023 CLIPER5 error relative to 2018-2022 mean (%)	-5.4	-4.5	-3.5	-4.6	0.0	-6.1	--4.9	-3.8

Table 3a. Homogenous comparison of Atlantic basin early track guidance model errors (n mi) for 2023. Errors smaller than the NHC official forecast are shown in bold-face.

Model ID	Forecast Period (h)							
	12	24	36	48	60	72	96	120
OFCL	22.1	35.5	49.4	66.5	87.1	115.4	170.5	252.4
OCD5	41.4	89.2	147.2	202.6	248.1	281.8	331.4	370.7
GFSI	24.9	44.1	63.3	82.2	108.9	144.9	212.8	296.0
EMXI	23.0	35.8	50.3	66.7	**84.2**	**109.0**	176.5	255.0
EGRI	25.0	40.3	56.7	78.8	103.0	131.9	182.2	262.3
CMCI	27.1	44.5	61.7	78.4	94.9	124.5	171.8	**245.5**
NVGI	30.4	52.9	77.9	104.3	131.8	162.9	236.4	359.7
HWFI	27.0	47.9	68.8	90.7	118.8	152.5	232.2	354.3
HMNI	25.7	42.6	59.9	77.4	97.6	130.7	209.5	316.1
HFAI	26.2	42.8	58.5	67.1	87.5	115.8	175.3	**247.6**
HFBI	26.3	43.0	58.2	71.0	88.1	**112.3**	**165.7**	**222.5**
CTCI	26.4	44.9	65.3	85.6	109.5	145.0	219.4	321.1
AEMI	24.5	41.3	59.8	78.0	99.4	127.3	185.4	262.6
TVCA	**22.0**	36.1	**49.0**	**62.7**	**80.0**	**106.4**	**163.4**	**233.4**
HCCA	**21.4**	**34.6**	**48.0**	**63.2**	**84.3**	**114.9**	178.2	279.2
FSSE	**21.5**	**35.3**	**48.9**	**63.6**	**82.3**	**109.6**	**170.0**	**247.1**
Forecasts	289	253	229	201	175	157	120	91

Table 3b. Homogenous comparison of Atlantic basin early track guidance model bias vectors (º/n mi) for 2023.

Model ID	Forecast Period (h)							
	12	24	36	48	60	72	96	120
OFCL	002/003	011/005	360/007	353/009	360/015	350/022	347/036	018/069
OCD5	320/004	356/006	005/009	022/020	025/041	022/063	021/104	010/160
GFSI	017/005	025/011	027/017	031/023	028/035	029/056	031/100	039/192
EMXI	335/005	313/005	300/008	276/012	260/016	252/030	245/057	230/070
EGRI	300/003	281/006	273/013	268/021	268/029	280/038	261/062	249/074
CMCI	304/009	298/015	292/021	287/025	285/029	297/030	306/035	325/037
NVGI	000/010	014/016	027/024	043/034	049/051	053/067	059/104	062/202
HWFI	030/006	048/011	053/015	054/019	046/027	037/040	029/081	042/182
HMNI	048/002	033/004	029/007	028/015	023/029	024/050	030/107	044/190
HFAI	030/004	033/003	051/002	048/007	033/010	025/021	017/034	041/067
HFBI	038/004	349/003	266/006	261/012	264/019	275/025	272/049	261/063
CTCI	040/004	055/009	051/012	048/017	036/029	028/041	018/053	044/093
AEMI	329/006	339/010	341/015	347/020	349/027	356/037	008/063	030/116
TVCA	008/003	014/005	005/005	000/007	001/012	000/022	001/036	034/066
HCCA	021/002	025/003	360/005	343/007	348/013	343/023	331/048	345/071
FSSE	019/004	039/007	043/008	041/009	022/013	007/026	007/047	038/087
Forecasts	289	253	229	201	175	157	120	91

Table 4. Homogenous comparison of official and Decay-SHIFOR5 intensity forecast errors in the Atlantic basin for the 2023 season for all tropical cyclones. Averages for the previous 5-yr period are shown for comparison.

	Forecast Period (h)							
	12	24	36	48	60	72	96	120
2023 mean OFCL error (kt)	4.4	6.4	7.5	8.4	9.4	10.4	11.4	12.7
2023 mean Decay-SHIFOR5 error (kt)	5.6	8.6	10.7	12.8	13.9	14.4	16.5	17.9
2023 mean OFCL skill relative to Decay-SHIFOR5 (%)	21.4	25.6	29.9	33.9	32.4	27.8	30.9	29.1
2023 OFCL bias (kt)	0.5	1.0	1.1	1.6	2.0	3.4	4.2	2.3
2023 number of cases	404	362	324	292	262	234	187	150
2018-22 mean OFCL error (kt)	5.1	7.6	8.9	10.1	10.7	11.5	13.3	15.5
2018-22 mean Decay-SHIFOR5 error (kt)	6.8	10.7	13.9	16.5	18.3	20.2	22.9	23.4
2018-22 mean OFCL skill relative to Decay-SHIFOR5 (%)	25.0	29.0	36.0	38.8	41.5	43.1	41.9	33.8
2018-22 OFCL bias (kt)	0.4	0.3	0.2	0.0	0.1	-0.3	-2.4	-6.4
2018-22 number of cases	1742	1544	1363	1205	830	916	687	507
2023 OFCL error relative to 2018-22 mean (%)	-13.7	-15.8	-15.7	-16.8	-12.1	-9.6	-14.3	-18.1
2023 Decay-SHIFOR5 error relative to 2018-22 mean (%)	-17.7	-19.6	-23.0	-23.0	-24.0	-28.7	-27.9	-23.5

Table 5a. Homogenous comparison of selected Atlantic basin early intensity guidance model errors (kt) for 2023. Errors smaller than the NHC official forecast are shown in boldface.

Model ID	Forecast Period (h)							
	12	24	36	48	60	72	96	120
OFCL	4.8	6.5	7.5	8.7	9.6	10.2	11.6	12.9
OCD5	5.9	9.0	11.0	13.1	13.6	13.2	15.6	18.6
HWFI	6.0	7.2	8.7	9.5	10.5	12.0	16.2	21.7
HMNI	5.6	7.7	9.1	9.7	10.7	11.1	13.2	17.6
HFAI	6.1	8.2	10.1	11.6	12.9	13.5	15.9	17.2
HFBI	6.2	7.7	9.5	10.8	11.4	12.8	13.8	14.9
CTCI	5.9	8.2	9.8	11.3	12.2	12.3	13.6	16.6
DSHP	5.4	7.7	9.1	10.4	11.6	13.1	17.0	21.8
LGEM	5.6	7.4	9.0	10.2	11.8	13.2	17.4	20.1
IVCN	4.8	**6.0**	**7.1**	**8.2**	**9.0**	**9.8**	11.9	14.2
HCCA	4.8	**5.9**	**7.3**	8.7	**9.3**	**9.8**	12.3	15.0
FSSE	**4.7**	**5.9**	**7.4**	8.8	10.1	11.2	16.0	18.7
GFSI	6.0	8.0	9.6	10.8	11.7	12.2	13.9	15.0
EMXI	6.1	8.7	11.1	13.0	14.6	15.5	17.3	19.2
NNIC	5.3	7.3	9.3	10.4	12.4	12.7	16.8	16.4
Forecasts	326	294	264	236	211	188	146	115

Table 5b. Homogenous comparison of selected Atlantic basin early intensity guidance model biases (kt) for 2023. Biases smaller than the NHC official forecast are shown in boldface.

Model ID	Forecast Period (h)							
	12	24	36	48	60	72	96	120
OFCL	0.9	1.8	2.0	2.4	2.8	4.1	4.1	2.7
OCD5	**0.1**	**0.8**	**0.2**	**-0.3**	**-1.3**	**-1.6**	-4.3	-5.6
HWFI	-2.1	**-1.6**	**-0.5**	**0.4**	**2.3**	5.2	9.0	11.6
HMNI	-0.8	**-1.2**	-2.0	**-1.7**	**-0.7**	**0.4**	**1.2**	**1.3**
HFAI	-1.2	**-0.4**	**0.8**	**2.1**	3.8	6.1	9.8	10.6
HFBI	**-0.6**	**-0.9**	**0.5**	**0.1**	**0.9**	**2.4**	4.2	3.8
CTCI	**-0.6**	**-0.9**	**-0.4**	**1.1**	**2.5**	**4.0**	**3.9**	3.4
DSHP	**0.4**	1.8	2.1	2.7	4.1	6.1	7.6	10.1
LGEM	**-0.2**	**-0.3**	**-0.4**	**0.0**	**0.7**	**1.9**	**2.0**	**1.9**
IVCN	**-0.3**	**-0.1**	**0.2**	**1.1**	**2.3**	4.1	5.7	6.0
HCCA	**0.5**	**1.3**	**1.8**	**2.1**	3.0	4.4	6.4	6.8
FSSE	**0.1**	**1.3**	**1.6**	**2.3**	3.2	4.7	8.7	9.6
GFSI	-1.2	-1.7	-2.1	**-2.0**	**-1.7**	**-0.6**	**-0.5**	**-2.3**
EMXI	-2.4	-4.1	-6.4	-8.9	-10.8	-11.8	-14.5	-16.0
NNIC	1.3	3.0	4.0	5.6	7.4	7.4	11.1	8.5
Forecasts	326	294	264	236	211	188	146	115

Table 6. Official Atlantic track and intensity forecast verifications (OFCL) for 2023 by storm. CLIPER5 (CLP5) and Decay-SHIFOR5 (SHF5) forecast errors are given for comparison and indicated collectively as OCD5. The number of track and intensity forecasts are given by NT and NI, respectively. Units for track and intensity errors are n mi and kt, respectively.

Verification statistics for: AL022023 ARLENE

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	7	4.1	4.1	7	2.1	2.1
012	5	26.5	60.6	5	2.0	3.8
024	3	40.8	151.1	3	1.7	2.3
036	1	34.8	381.7	1	0.0	0.0
048	0	-999.0	-999.0	0	-999.0	-999.0
060	0	-999.0	-999.0	0	-999.0	-999.0
072	0	-999.0	-999.0	0	-999.0	-999.0
096	0	-999.0	-999.0	0	-999.0	-999.0
120	0	-999.0	-999.0	0	-999.0	-999.0

Verification statistics for: AL032023 BRET

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	21	8.8	8.8	21	0.0	0.0
012	19	21.8	26.8	19	2.9	4.0
024	17	33.9	62.9	17	3.8	7.1
036	15	43.9	104.0	15	4.0	11.1
048	13	57.1	168.7	13	4.2	14.2
060	11	65.8	203.7	11	4.1	13.1
072	9	84.4	235.1	9	5.0	10.9
096	5	176.2	288.9	5	14.0	11.2
120	1	330.6	412.0	1	25.0	17.0

Verification statistics for: AL042023 CINDY

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	16	15.1	15.1	16	0.3	0.3
012	14	24.0	39.3	14	1.8	4.8
024	12	39.7	82.7	12	2.5	7.2
036	10	58.8	150.9	10	2.0	10.4
048	8	79.5	208.2	8	2.5	11.5
060	6	110.9	281.8	6	4.2	12.0
072	4	136.5	329.2	4	5.0	5.5
096	0	-999.0	-999.0	0	-999.0	-999.0
120	0	-999.0	-999.0	0	-999.0	-999.0

Verification statistics for: AL052023 DON

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	40	4.1	4.2	40	1.0	1.4
012	38	16.3	46.3	38	2.9	4.8
024	36	24.6	114.8	36	3.9	6.1
036	34	34.4	198.6	34	4.7	7.2
048	32	48.8	282.6	32	6.1	9.4
060	30	64.5	366.1	30	7.2	10.6
072	28	71.5	456.6	28	6.2	12.7
096	24	70.2	665.4	24	5.0	19.6
120	20	59.9	826.8	20	8.2	9.1

Verification statistics for: AL062023 GERT

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	24	9.7	9.7	24	0.8	1.0
012	20	31.1	54.3	20	3.8	3.8
024	14	51.7	120.6	14	6.1	5.6
036	9	76.8	202.1	9	10.0	7.3
048	6	108.6	243.5	6	11.7	9.8
060	3	103.4	181.7	3	13.3	5.7
072	1	118.5	150.0	1	20.0	7.0
096	0	-999.0	-999.0	0	-999.0	-999.0
120	0	-999.0	-999.0	0	-999.0	-999.0

Verification statistics for: AL072023 EMILY

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	3	1.9	1.9	3	0.0	0.0
012	1	5.6	34.4	1	5.0	12.0
024	0	-999.0	-999.0	0	-999.0	-999.0
036	0	-999.0	-999.0	0	-999.0	-999.0
048	0	-999.0	-999.0	0	-999.0	-999.0
060	0	-999.0	-999.0	0	-999.0	-999.0
072	0	-999.0	-999.0	0	-999.0	-999.0
096	0	-999.0	-999.0	0	-999.0	-999.0
120	0	-999.0	-999.0	0	-999.0	-999.0

Verification statistics for: AL082023 FRANKLIN

000	48	9.1	9.1	48	0.7	0.7
012	46	25.8	50.2	46	6.5	6.7
024	44	40.3	106.5	44	9.0	11.5
036	42	51.4	169.8	42	9.2	15.6
048	40	70.8	240.0	40	8.9	16.3
060	38	97.5	307.9	38	8.3	18.4
072	36	130.2	373.9	36	8.9	22.4
096	32	179.9	476.3	32	10.3	30.2
120	28	292.1	512.2	28	14.1	32.1

Verification statistics for: AL092023 HAROLD

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	7	14.4	14.4	7	2.1	2.9
012	5	34.4	61.6	5	3.0	5.0
024	3	41.0	157.3	3	1.7	6.7
036	1	24.6	265.3	1	0.0	14.0
048	0	-999.0	-999.0	0	-999.0	-999.0
060	0	-999.0	-999.0	0	-999.0	-999.0
072	0	-999.0	-999.0	0	-999.0	-999.0
096	0	-999.0	-999.0	0	-999.0	-999.0
120	0	-999.0	-999.0	0	-999.0	-999.0

Verification statistics for: AL102023 IDALIA

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	19	2.9	2.9	19	1.1	1.1
012	17	23.8	50.0	17	6.5	8.2
024	15	38.7	99.8	15	8.0	12.1
036	13	51.8	165.8	13	6.2	13.4
048	11	56.9	249.7	11	6.4	20.6
060	9	61.7	334.0	9	9.4	27.7
072	7	46.1	409.6	7	14.3	31.0
096	3	58.4	515.6	3	8.3	12.0
120	0	-999.0	-999.0	0	-999.0	-999.0

Verification statistics for: AL112023 JOSE

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	14	8.2	8.2	14	3.6	3.6
012	12	30.7	52.8	12	8.8	6.3
024	10	39.6	103.6	10	13.5	8.0
036	8	63.7	157.3	8	16.2	6.6
048	5	70.2	124.6	5	20.0	5.2
060	2	68.4	53.2	2	25.0	7.0
072	1	20.6	108.1	1	25.0	1.0
096	0	-999.0	-999.0	0	-999.0	-999.0
120	0	-999.0	-999.0	0	-999.0	-999.0

Verification statistics for: AL122023 KATIA

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	11	12.2	12.2	11	1.8	1.8
012	9	28.8	52.4	9	4.4	8.2
024	7	42.8	107.8	7	8.6	14.4
036	5	50.0	110.2	5	7.0	11.6
048	3	62.7	116.6	3	3.3	6.7
060	1	73.4	96.9	1	0.0	11.0
072	0	-999.0	-999.0	0	-999.0	-999.0
096	0	-999.0	-999.0	0	-999.0	-999.0
120	0	-999.0	-999.0	0	-999.0	-999.0

Verification statistics for: AL132023 LEE

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	43	3.8	4.1	43	1.2	1.3
012	41	12.8	23.8	41	8.0	9.2
024	39	14.2	50.1	39	12.7	14.3
036	37	17.5	82.5	37	16.4	16.5
048	35	23.3	113.4	35	18.3	18.0
060	33	33.4	149.2	33	19.2	17.2
072	31	47.3	180.6	31	18.7	12.6
096	27	88.9	232.0	27	19.1	11.6
120	23	134.2	291.4	23	18.0	11.7

Verification statistics for: AL142023 MARGOT

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	38	7.5	7.5	38	0.8	0.8
012	36	19.4	40.4	36	3.1	4.5
024	34	30.8	95.2	34	3.7	5.5
036	32	45.2	160.8	32	5.0	7.0
048	30	61.3	222.3	30	7.0	8.9
060	28	82.3	257.4	28	7.3	9.6
072	26	107.5	287.9	26	7.5	10.3
096	22	157.5	299.4	22	5.9	8.0
120	18	173.3	284.8	18	6.7	11.1

Verification statistics for: AL152023 NIGEL

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	27	9.9	9.9	27	0.4	0.6
012	25	18.1	50.2	25	4.6	3.8
024	23	31.4	114.2	23	8.5	6.6
036	21	45.3	188.3	21	8.6	9.3
048	19	58.9	250.1	19	8.2	11.4
060	17	81.9	302.8	17	8.5	14.2
072	15	110.8	320.4	15	12.7	16.3
096	11	211.6	345.1	11	10.9	20.4
120	7	435.2	492.8	7	12.1	15.9

Verification statistics for: AL162023 OPHELIA

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	5	2.9	2.9	5	1.0	1.0
012	3	32.8	46.6	3	1.7	4.7
024	1	18.8	122.9	1	5.0	31.0
036	0	-999.0	-999.0	0	-999.0	-999.0
048	0	-999.0	-999.0	0	-999.0	-999.0
060	0	-999.0	-999.0	0	-999.0	-999.0
072	0	-999.0	-999.0	0	-999.0	-999.0
096	0	-999.0	-999.0	0	-999.0	-999.0
120	0	-999.0	-999.0	0	-999.0	-999.0

Verification statistics for: AL172023 PHILIPPE

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	52	10.9	11.0	52	1.2	1.2
012	50	36.5	42.0	50	2.9	4.2
024	48	66.3	80.4	48	3.6	5.9
036	46	94.6	127.8	46	4.8	8.2
048	44	126.9	172.8	44	6.4	11.2
060	42	163.8	221.4	42	9.0	12.3
072	40	206.9	275.2	40	12.2	13.5
096	36	308.7	380.6	36	17.4	15.9
120	32	411.3	502.0	32	17.7	24.9

Verification statistics for: AL182023 RINA

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	13	6.2	6.2	13	1.5	1.5
012	11	29.5	52.1	11	3.2	4.1
024	9	53.8	101.7	9	2.2	7.6
036	7	90.2	151.1	7	1.4	10.6
048	5	154.9	201.5	5	5.0	15.0
060	3	219.3	183.6	3	8.3	16.3
072	1	253.1	343.7	1	10.0	18.0
096	0	-999.0	-999.0	0	-999.0	-999.0
120	0	-999.0	-999.0	0	-999.0	-999.0

Verification statistics for: AL192023 SEAN

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	18	7.8	7.8	18	1.1	1.1
012	16	29.0	34.1	16	3.4	5.2
024	14	52.1	73.1	14	3.6	9.6
036	12	67.7	103.7	12	2.9	10.4
048	10	79.9	107.3	10	1.5	14.3
060	8	82.9	107.9	8	4.4	16.0
072	6	72.1	128.1	6	5.0	19.2
096	2	93.7	263.9	2	5.0	28.5
120	0	-999.0	-999.0	0	-999.0	-999.0

Verification statistics for: AL202023 TAMMY

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	37	4.7	4.9	37	0.5	0.7
012	35	26.4	51.8	35	4.1	5.8
024	33	37.6	114.4	33	6.2	8.9
036	31	42.5	177.0	31	8.2	10.4
048	31	50.9	230.5	31	8.4	11.1
060	31	70.0	272.4	31	8.1	10.9
072	29	91.0	266.4	29	8.4	9.9
096	25	146.4	279.8	25	7.2	8.4
120	21	242.7	362.1	21	6.7	9.8

Table 7. Homogenous comparison of official and CLIPER5 track forecast errors in the eastern North Pacific basin in 2023 for all tropical cyclones. Averages for the previous 5-yr period are shown for comparison.

	Forecast Period (h)							
	12	24	36	48	60	72	96	120
2023 mean OFCL error (n mi)	21.9	33.3	42.7	52.8	64.7	79.3	115.8	160.6
2023 mean CLIPER5 error (n mi)	38.5	78.3	127.9	181.4	241.8	313.3	474.4	621.0
2023 mean OFCL skill relative to CLIPER5 (%)	43.1	57.5	66.6	70.9	73.2	74.7	75.6	74.1
2023 mean OFCL bias vector (°/n mi)	327/002	101/000	127/005	122/012	116/021	115/032	114/045	101/054
2023 number of cases	265	234	204	176	150	129	93	66
2018-2022 mean OFCL error (n mi)	22.1	34.0	45.4	56.0	70.9	78.7	100.5	117.8
2018-2022 mean CLIPER5 error (n mi)	36.7	73.4	114.0	156.9	193.2	244.5	317.0	376.0
2018-2022 mean OFCL skill relative to CLIPER5 (%)	39.8	53.7	60.2	64.3	63.3	67.8	68.3	68.7
2018-2022 mean OFCL bias vector (°/n mi)	284/001	178/002	173/004	165/006	168/011	147/008	105/009	056/014
2018-2022 number of cases	1468	1280	1112	958	558	709	508	362
2023 OFCL error relative to 2018-2022 mean (%)	-0.9	-2.1	-5.9	-5.7	-8.7	0.8	15.2	36.3
2023 CLIPER5 error relative to 2018-2022 mean (%)	4.9	6.7	12.2	15.6	25.2	28.1	49.7	65.2

Table 8a. Homogenous comparison of eastern North Pacific basin early track guidance model errors (n mi) for 2023. Errors smaller than the NHC official forecast are shown in boldface.

Model ID	Forecast Period (h)							
	12	24	36	48	60	72	96	120
OFCL	20.2	31.4	40.5	50.9	64.8	78.8	123.9	171.2
OCD5	35.6	74.3	127.4	189.3	255.2	330.5	530.6	675.8
GFSI	23.0	38.0	51.6	66.9	86.5	102.6	142.4	186.2
EMXI	21.7	33.6	44.2	57.9	77.2	101.1	150.8	208.7
EGRI	25.0	44.2	65.5	88.2	112.4	141.5	193.6	237.7
CMCI	26.4	45.2	63.0	79.4	97.4	118.0	179.6	234.8
NVGI	28.9	47.8	67.2	90.4	116.5	145.5	189.7	227.8
HWFI	24.5	39.6	55.3	70.1	86.9	103.8	149.6	201.8
HMNI	24.0	39.9	54.3	65.9	78.1	90.0	128.3	186.4
HFAI	24.4	36.7	48.3	60.6	77.4	93.4	143.6	**162.9**
HFBI	24.2	37.8	49.3	66.2	83.4	104.5	181.6	241.1
CTCI	25.2	40.9	54.5	70.7	86.3	101.4	132.2	**165.4**
AEMI	23.2	38.3	52.4	66.2	80.9	94.8	125.8	**144.2**
TVCE	20.6	32.5	42.7	53.2	66.5	79.6	**120.8**	**164.2**
HCCA	20.6	**30.7**	**38.5**	**49.5**	**64.0**	80.1	**120.4**	**161.3**
FSSE	20.5	31.8	**40.4**	**47.9**	**59.5**	**69.7**	**117.7**	**164.2**
Forecasts	197	169	154	134	115	97	62	37

Table 8b. Homogenous comparison of eastern North Pacific basin early track guidance model bias vectors (º/n mi) for 2023.

	Forecast Period (h)							
	12	24	36	48	60	72	96	120
OFCL	316/001	143/000	145/007	123/013	113/023	108/033	095/053	088/049
OCD5	033/002	044/009	055/022	055/044	061/087	061/141	057/316	056/472
GFSI	073/002	086/008	104/015	093/024	090/037	087/049	085/074	076/076
EMXI	286/005	255/007	211/010	181/014	156/022	144/032	106/058	090/081
EGRI	274/010	266/021	256/035	253/048	249/063	248/082	268/114	272/171
CMCI	190/004	164/011	160/022	148/033	133/046	122/062	098/116	092/153
NVGI	320/009	330/016	342/023	000/035	013/054	019/084	017/140	015/189
HWFI	355/002	282/002	213/007	184/012	168/017	162/021	153/034	158/049
HMNI	330/005	323/009	320/010	327/011	349/011	009/011	076/009	114/011
HFAI	082/004	097/007	121/012	115/020	102/034	095/049	084/099	081/117
HFBI	075/002	120/004	134/010	115/021	100/038	093/063	082/152	083/210
CTCI	052/005	064/011	080/014	079/024	082/038	083/053	100/076	099/077
AEMI	100/003	106/007	126/015	115/021	112/033	111/042	100/060	091/052
TVCE	331/002	304/001	182/004	148/008	122/015	113/023	094/047	089/055
HCCA	090/000	125/003	136/009	125/018	114/030	108/046	094/080	093/076
FSSE	296/002	089/000	140/006	119/012	115/020	119/030	111/047	107/048
Forecasts	197	169	154	134	115	97	62	37

Table 9. Homogenous comparison of official and Decay-SHIFOR5 intensity forecast errors in the eastern North Pacific basin for the 2023 season for all tropical cyclones. Averages for the previous 5-yr period are shown for comparison.

	Forecast Period (h)							
	12	24	36	48	60	72	96	120
2023 mean OFCL error (kt)	7.2	10.5	12.8	14.6	15.3	13.6	16.2	22.2
2023 mean Decay-SHIFOR5 error (kt)	9.8	15.8	19.7	22.8	24.3	23.4	23.4	30.3
2023 mean OFCL skill relative to Decay-SHIFOR5 (%)	26.5	33.5	35.0	36.0	37.0	41.9	30.8	26.7
2023 OFCL bias (kt)	-0.8	-2.7	-4.5	-5.6	-5.8	-4.7	-6.9	-14.8
2023 number of cases	265	234	204	176	150	129	93	66
2018-22 mean OFCL error (kt)	5.4	8.9	11.0	12.8	14.3	15.8	17.0	17.6
2018-22 mean Decay-SHIFOR5 error (kt)	6.9	12.1	15.9	18.6	18.7	21.0	22.3	22.1
2018-22 mean OFCL skill relative to Decay-SHIFOR5 (%)	21.7	26.4	30.8	31.2	23.5	24.8	23.8	20.4
2018-22 OFCL bias (kt)	0.7	1.0	1.2	1.4	2.8	1.2	0.3	-3.0
2018-22 number of cases	1468	1280	1112	958	558	709	508	362
2023 OFCL error relative to 2018-22 mean (%)	33.3	18.0	16.4	14.1	7.0	-13.9	-4.7	26.1
2023 Decay-SHIFOR5 error relative to 2018-22 mean (%)	42.0	30.6	23.9	22.6	29.9	11.4	4.9	37.1

Table 10a. Homogenous comparison of eastern North Pacific basin early intensity guidance model errors (kt) for 2023. Errors smaller than the NHC official forecast are shown in boldface.

Model ID	Forecast Period (h)							
	12	24	36	48	60	72	96	120
OFCL	7.8	10.7	12.8	14.3	14.1	13.4	17.6	24.8
OCD5	10.5	16.6	20.1	22.9	23.3	22.7	25.4	33.6
HWFI	10.3	14.4	17.0	18.8	19.0	17.6	21.6	28.3
HMNI	9.5	13.5	16.0	18.4	19.2	18.4	23.4	30.8
HFAI	9.7	14.0	15.5	16.1	14.8	**12.1**	**17.2**	**24.5**
HFBI	9.4	13.8	15.7	16.4	16.8	15.5	19.3	29.5
CTCI	9.4	14.4	17.2	18.6	18.0	17.3	22.6	33.1
DSHP	9.3	13.4	16.2	18.0	18.8	19.2	21.2	**22.8**
LGEM	9.1	13.1	15.6	17.6	18.3	17.9	**17.2**	**19.8**
IVCN	8.6	12.1	14.3	15.7	15.1	13.5	17.7	**24.7**
HCCA	7.8	**10.4**	**12.6**	**14.2**	**13.2**	**11.5**	22.0	34.7
FSSE	8.1	11.2	14.0	15.8	15.3	14.5	24.1	36.2
GFSI	10.7	16.4	19.8	22.0	21.4	19.6	23.7	35.1
EMXI	11.8	18.2	22.7	24.8	23.7	21.4	26.0	37.1
NNIC	8.4	11.3	**12.3**	**13.8**	**12.6**	**13.0**	**14.3**	**18.9**
Forecasts	214	188	167	146	126	107	72	46

Table 10b. Homogenous comparison of eastern North Pacific basin early intensity guidance model biases (kt) for 2023. Biases smaller than the NHC official forecast are shown in boldface.

Model ID	Forecast Period (h)							
	12	24	36	48	60	72	96	120
OFCL	-0.6	-2.4	-3.8	-4.8	-4.0	-3.3	-8.5	-17.4
OCD5	-1.6	-2.4	**-3.7**	-5.0	-6.0	-7.5	-15.6	-27.1
HWFI	-7.1	-10.4	-11.9	-12.4	-12.0	-11.9	-17.9	-27.1
HMNI	-4.9	-9.3	-12.0	-13.9	-14.8	-15.7	-21.8	-30.8
HFAI	-4.9	-7.9	-9.9	-10.7	-8.5	-6.1	-9.2	**-14.2**
HFBI	-3.1	-5.6	-9.5	-12.8	-11.5	-9.8	-16.0	-25.0
CTCI	-5.7	-10.5	-12.1	-13.1	-13.6	-13.9	-20.3	-30.2
DSHP	-1.7	-3.1	**-3.5**	**-3.4**	**-2.5**	**-2.1**	**-5.7**	**-13.5**
LGEM	-2.6	-6.1	-7.4	-7.5	-6.6	-6.0	-9.5	**-14.1**
IVCN	-4.0	-7.2	-9.1	-10.3	-9.6	-9.0	-14.0	-22.1
HCCA	-2.8	-6.0	-7.6	-8.7	-7.8	-5.9	-14.1	-24.9
FSSE	-3.1	-6.2	-8.7	-10.5	-10.0	-10.2	-18.8	-34.2
GFSI	-4.9	-9.0	-11.6	-13.5	-13.5	-13.2	-17.8	-30.5
EMXI	-5.7	-10.1	-12.7	-14.2	-14.4	-14.3	-21.7	-33.7
NNIC	-1.0	-2.5	-4.0	**-4.5**	-4.7	**-2.9**	-9.4	**-14.6**
Forecasts	214	188	167	146	126	107	72	46

Table 11. Official eastern North Pacific track and intensity forecast verifications (OFCL) for 2023 by storm. CLIPER5 (CLP5) and Decay-SHIFOR5 (SHF5) forecast errors are given for comparison and indicated collectively as OCD5. The number of track and intensity forecasts are given by NT and NI, respectively. Units for track and intensity errors are n mi and kt, respectively.

Verification statistics for: EP012023 ADRIAN

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	19	6.3	6.3	19	0.5	0.8
012	17	20.8	27.9	17	3.8	7.0
024	15	34.9	53.0	15	7.3	12.9
036	13	47.8	76.1	13	7.7	15.6
048	11	71.5	112.2	11	5.9	15.3
060	9	92.3	164.7	9	7.2	16.9
072	7	106.3	224.1	7	6.4	18.7
096	3	126.8	446.4	3	6.7	10.0
120	0	-999.0	-999.0	0	-999.0	-999.0

Verification statistics for: EP022023 BEATRIZ

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	9	8.3	8.3	9	6.7	6.7
012	7	18.7	26.5	7	9.3	14.9
024	5	26.0	61.7	5	11.0	18.4
036	3	32.2	87.8	3	15.0	14.3
048	1	42.0	109.6	1	0.0	2.0
060	0	-999.0	-999.0	0	-999.0	-999.0
072	0	-999.0	-999.0	0	-999.0	-999.0
096	0	-999.0	-999.0	0	-999.0	-999.0
120	0	-999.0	-999.0	0	-999.0	-999.0

Verification statistics for: EP032023 CALVIN

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	23	6.9	6.9	23	2.4	2.4
012	23	16.2	28.4	23	6.5	9.4
024	23	20.8	54.6	23	7.8	12.7
036	23	24.8	90.3	23	7.8	14.4
048	23	28.1	131.7	23	11.1	18.3
060	22	37.6	174.3	22	11.1	19.7
072	20	45.6	212.2	20	9.0	18.1
096	16	63.4	305.3	16	6.6	17.4
120	12	70.8	409.0	12	6.2	12.8

Verification statistics for: EP042023 FOUR

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	3	11.8	11.8	3	0.0	0.0
012	1	39.1	88.7	1	0.0	3.0
024	0	-999.0	-999.0	0	-999.0	-999.0
036	0	-999.0	-999.0	0	-999.0	-999.0
048	0	-999.0	-999.0	0	-999.0	-999.0
060	0	-999.0	-999.0	0	-999.0	-999.0
072	0	-999.0	-999.0	0	-999.0	-999.0
096	0	-999.0	-999.0	0	-999.0	-999.0
120	0	-999.0	-999.0	0	-999.0	-999.0

Verification statistics for: EP052023 DORA

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	24	1.9	1.9	24	0.6	0.6
012	24	15.0	26.2	24	9.0	12.7
024	24	23.3	64.4	24	13.1	20.7
036	24	32.0	121.5	24	16.5	26.9
048	24	41.2	186.1	24	21.2	34.3
060	24	52.1	258.5	24	23.8	38.9
072	24	65.4	343.5	24	25.6	44.4
096	24	90.4	541.6	24	31.7	50.0
120	24	122.2	750.6	24	38.5	55.6

Verification statistics for: EP062023 EUGENE

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	8	13.2	13.2	8	0.6	0.6
012	6	9.1	43.4	6	10.0	11.8
024	4	20.9	126.3	4	11.2	16.2
036	2	43.0	222.9	2	2.5	9.5
048	0	-999.0	-999.0	0	-999.0	-999.0
060	0	-999.0	-999.0	0	-999.0	-999.0
072	0	-999.0	-999.0	0	-999.0	-999.0
096	0	-999.0	-999.0	0	-999.0	-999.0
120	0	-999.0	-999.0	0	-999.0	-999.0

Verification statistics for: EP072023 FERNANDA

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	18	7.7	7.7	18	0.6	0.6
012	16	17.1	33.6	16	10.0	12.6
024	14	28.4	67.7	14	15.7	25.1
036	12	35.7	93.6	12	17.1	33.2
048	10	40.2	97.9	10	17.5	37.2
060	8	40.0	94.7	8	15.6	34.5
072	6	41.6	107.0	6	15.8	24.5
096	2	60.7	210.4	2	7.5	11.0
120	0	-999.0	-999.0	0	-999.0	-999.0

Verification statistics for: EP082023 GREG

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	2	4.2	4.2	2	0.0	0.0
012	2	12.7	33.4	2	0.0	2.0
024	2	27.6	72.8	2	0.0	2.5
036	2	44.0	107.3	2	0.0	4.5
048	2	54.1	123.2	2	2.5	6.5
060	2	71.0	153.1	2	5.0	18.5
072	2	71.6	170.9	2	2.5	21.5
096	0	-999.0	-999.0	0	-999.0	-999.0
120	0	-999.0	-999.0	0	-999.0	-999.0

Verification statistics for: EP092023 HILARY

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	18	10.6	10.6	18	4.4	4.4
012	16	20.1	44.3	16	11.9	14.5
024	14	25.4	101.6	14	15.4	21.7
036	12	29.2	175.7	12	18.8	28.3
048	10	40.5	254.3	10	19.5	31.2
060	8	57.0	328.8	8	18.8	31.9
072	6	85.8	408.6	6	23.3	23.0
096	2	149.4	604.4	2	22.5	9.5
120	0	-999.0	-999.0	0	-999.0	-999.0

Verification statistics for: EP102023 IRWIN

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	10	7.5	8.1	10	0.5	0.5
012	8	25.4	37.8	8	3.1	3.0
024	6	46.2	46.3	6	5.0	3.7
036	4	75.4	58.6	4	5.0	4.0
048	2	108.9	101.8	2	2.5	1.5
060	0	-999.0	-999.0	0	-999.0	-999.0
072	0	-999.0	-999.0	0	-999.0	-999.0
096	0	-999.0	-999.0	0	-999.0	-999.0
120	0	-999.0	-999.0	0	-999.0	-999.0

Verification statistics for: EP112023 JOVA

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	22	5.7	5.7	22	0.5	0.5
012	20	19.7	33.5	20	9.0	10.7
024	18	30.0	62.2	18	17.8	20.7
036	16	39.8	94.8	16	25.9	30.0
048	14	48.9	137.1	14	32.1	37.5
060	12	64.0	205.9	12	32.1	39.2
072	10	80.4	281.2	10	26.0	34.8
096	6	86.1	370.2	6	24.2	15.8
120	2	73.6	408.2	2	25.0	17.5

Verification statistics for: EP122023 TWELVE

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	5	3.6	3.6	5	3.0	3.0
012	5	29.3	58.8	5	4.0	3.2
024	5	64.3	123.0	5	6.0	4.0
036	4	107.4	223.1	4	7.5	2.8
048	2	155.9	352.7	2	5.0	2.0
060	0	-999.0	-999.0	0	-999.0	-999.0
072	0	-999.0	-999.0	0	-999.0	-999.0
096	0	-999.0	-999.0	0	-999.0	-999.0
120	0	-999.0	-999.0	0	-999.0	-999.0

Verification statistics for: EP132023 KENNETH

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	12	20.4	20.4	12	0.4	0.4
012	10	39.3	63.7	10	2.5	4.5
024	8	48.8	104.9	8	6.2	9.1
036	6	49.2	155.1	6	5.8	13.3
048	4	50.7	204.4	4	6.2	15.8
060	2	43.7	199.7	2	5.0	22.5
072	0	-999.0	-999.0	0	-999.0	-999.0
096	0	-999.0	-999.0	0	-999.0	-999.0
120	0	-999.0	-999.0	0	-999.0	-999.0

Verification statistics for: EP142023 FOURTEEN

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	5	18.5	19.7	5	0.0	0.0
012	3	44.2	46.3	3	5.0	5.0
024	1	29.6	34.1	1	10.0	10.0
036	0	-999.0	-999.0	0	-999.0	-999.0
048	0	-999.0	-999.0	0	-999.0	-999.0
060	0	-999.0	-999.0	0	-999.0	-999.0
072	0	-999.0	-999.0	0	-999.0	-999.0
096	0	-999.0	-999.0	0	-999.0	-999.0
120	0	-999.0	-999.0	0	-999.0	-999.0

Verification statistics for: EP152023 LIDIA

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	33	8.7	8.8	33	0.6	0.6
012	31	23.5	44.3	31	5.3	8.2
024	29	35.7	95.4	29	6.4	11.0
036	27	39.8	149.3	27	7.8	12.1
048	25	45.2	204.9	25	7.2	11.9
060	23	48.8	256.9	23	9.3	11.3
072	21	52.3	308.4	21	9.3	11.9
096	17	101.5	384.0	17	11.5	14.6
120	13	201.4	469.6	13	16.9	21.6

Verification statistics for: EP162023 MAX

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	6	11.3	11.3	6	3.3	3.3
012	4	23.0	42.4	4	8.8	13.8
024	2	49.0	110.1	2	10.0	14.0
036	0	-999.0	-999.0	0	-999.0	-999.0
048	0	-999.0	-999.0	0	-999.0	-999.0
060	0	-999.0	-999.0	0	-999.0	-999.0
072	0	-999.0	-999.0	0	-999.0	-999.0
096	0	-999.0	-999.0	0	-999.0	-999.0
120	0	-999.0	-999.0	0	-999.0	-999.0

Verification statistics for: EP172023 NORMA

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	23	5.7	6.1	23	0.9	0.9
012	21	21.7	41.0	21	9.5	12.7
024	19	31.7	76.1	19	10.8	18.2
036	17	38.1	113.1	17	12.6	17.9
048	15	43.4	131.0	15	13.0	15.5
060	13	51.1	138.5	13	11.2	21.2
072	11	64.1	155.2	11	8.6	18.6
096	7	118.5	304.3	7	17.9	8.0
120	3	126.7	598.0	3	36.7	7.0

Verification statistics for: EP182023 OTIS

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	14	8.2	8.2	14	2.5	2.9
012	12	30.2	30.9	12	16.2	20.8
024	10	60.2	49.4	10	29.5	29.9
036	8	95.3	64.2	8	39.4	32.2
048	6	135.5	86.9	6	51.7	30.0
060	4	196.3	124.8	4	60.0	41.5
072	2	297.7	208.5	2	22.5	25.0
096	0	-999.0	-999.0	0	-999.0	-999.0
120	0	-999.0	-999.0	0	-999.0	-999.0

Verification statistics for: EP192023 PILAR

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	32	8.2	9.0	32	1.4	1.4
012	30	24.4	46.2	30	3.8	5.9
024	28	39.9	111.8	28	5.4	13.3
036	26	51.8	203.6	26	6.9	20.0
048	24	75.2	318.7	24	7.3	24.4
060	22	109.1	449.2	22	5.5	15.0
072	20	144.6	575.5	20	3.8	13.9
096	16	232.2	762.5	16	6.2	14.3
120	12	306.0	779.2	12	7.1	14.5

Verification statistics for: EP202023 RAMON

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	11	12.5	12.5	11	1.4	1.4
012	9	26.6	45.0	9	4.4	4.0
024	7	28.5	65.8	7	4.3	4.1
036	5	40.6	123.5	5	6.0	6.4
048	3	34.7	137.3	3	6.7	5.7
060	1	43.6	91.5	1	15.0	9.0
072	0	-999.0	-999.0	0	-999.0	-999.0
096	0	-999.0	-999.0	0	-999.0	-999.0
120	0	-999.0	-999.0	0	-999.0	-999.0

Table 12a. Verification of 48-h probabilistic genesis forecasts for the Atlantic basin in 2023.

Atlantic Basin Genesis Forecast Reliability Table		
Forecast Likelihood (%)	**Verifying Genesis Occurrence Rate (%)**	**Number of Forecasts**
0	0	432
10	15	151
20	12	99
30	21	63
40	49	51
50	61	23
60	77	30
70	67	42
80	100	8
90	100	13
100	-	0

Table 12b. Verification of 48-h probabilistic genesis forecasts for the eastern North Pacific basin in 2023.

Eastern North Pacific Basin Genesis Forecast Reliability Table		
Forecast Likelihood (%)	**Verifying Genesis Occurrence Rate (%)**	**Number of Forecasts**
0	0	332
10	5	77
20	24	79
30	35	49
40	58	24
50	59	27
60	87	31
70	92	26
80	90	21
90	71	28
100	–	–

Table 13a. Verification of 168-h probabilistic genesis forecasts for the Atlantic basin in 2023.

Atlantic Basin Genesis Forecast Reliability Table		
Forecast Likelihood (%)	**Verifying Genesis Occurrence Rate (%)**	**Number of Forecasts**
0	2	43
10	25	289
20	47	118
30	59	104
40	60	58
50	64	70
60	64	56
70	65	91
80	94	49
90	100	31
100	100	3

Table 13b. Verification of 168-h probabilistic genesis forecasts for the eastern North Pacific basin in 2023.

Eastern North Pacific Basin Genesis Forecast Reliability Table		
Forecast Likelihood (%)	**Verifying Genesis Occurrence Rate (%)**	**Number of Forecasts**
0	0	11
10	26	129
20	29	135
30	38	74
40	58	33
50	73	26
60	64	33
70	76	59
80	92	99
90	88	93
100	100	2

Table 14. NHC forecast cone circle radii (n mi) for 2024. Change from 2023 values expressed in n mi and percent are given in parentheses.

2024 Track Forecast Cone Two-Thirds Probability Circles (n mi)		
Forecast Period (h)	**Atlantic Basin**	**Eastern North Pacific Basin**
3	16 (0: 0%)	16 (0: 0%)
12	26 (0: 0%)	26 (1: 4%)
24	41 (2: 5%)	39 (1: 3%)
36	55 (2: 4%)	53 (2: 4%)
48	70 (3: 4%)	65 (2: 3%)
60	88 (7: 8%)	76 (-2: -3%)
72	102 (3: 3%)	92 (6: 7%)
96	151 (6: 4%)	119 (9: 8%)
120	220 (15: 7%)	152 (15: 11%)

Table 15. Composition of NHC consensus models for 2024.

NHC Consensus Model Definitions For 2024			
Model ID	**Parameter**	**Type**	**Members**
GFEX	Track	Fixed	GFSI EMXI
ICON	Intensity	Fixed	DSHP LGEM HFAI HFBI CTCI HWFI HMNI
TVCA**	Track	Variable	GFSI EGRI HFAI HFBI EMXI CTCI HWFI HMNI EMNI
TVCE	Track	Variable	GFSI EGRI HFAI HFBI EMXI CTCI EMNI HWFI HMNI
TVDG	Track	Variable	GFSI (double weight) EMXI (double weight) EGRI (double weight) CTCI HFAI HFBI HWFI HMNI
TVCX	Track	Variable	EMXI (double weight) GFSI EGRI HFAI HFBI HWFI HMNI
IVCN	Intensity	Variable	DSHP LGEM HFAI HFBI CTCI HWFI HMNI
IVDR	Intensity	Variable	CTCI (double weight) HWFI (double weight) HMNI (double weight) HFAI (double weight) HFBI (double weight) GFSI DSHP LGEM

** TVCN will continue to be computed and will have the same composition as TVCA. GPCE circles will continue to be based on TVCN.

List of Figures

21. NHC official and Decay-SHIFOR5 (OCD5) eastern North Pacific basin average intensity errors for 2023 (solid lines) and 2018–2022 (dashed lines).

22. Recent trends in NHC official intensity forecast error (top) and skill (bottom) for the eastern North Pacific basin.

23. Homogenous comparison for selected eastern North Pacific basin early intensity guidance models for 2023. This verification includes only those models that were available at least 2/3 of the time (see text).

24. Homogenous comparison for selected eastern North Pacific basin early intensity guidance models for 2021–23.

25. 2023 NHC eastern North Pacific official track errors by tropical cyclone at 24, 48, 72, 96 and 120 h.

26. 2023 NHC eastern North Pacific official intensity errors by tropical cyclone at 24, 48, 72, 96 and 120 h.

27. Reliability diagram for Atlantic (top) and eastern North Pacific (bottom) probabilistic tropical cyclogenesis 48-h forecasts for 2023. The solid lines indicate the relationship between the forecasts and verifying genesis percentages, with perfect reliability indicated by the thin diagonal black line. The dashed lines indicate how the forecasts were distributed among the possible forecast values.

28. As described for Fig. 27, but for 168-h forecasts.

29. Composites of 7-day tropical cyclone genesis areas depicted in NHC's Tropical Weather Outlooks for the Atlantic and East Pacific basins during the 2023 season.

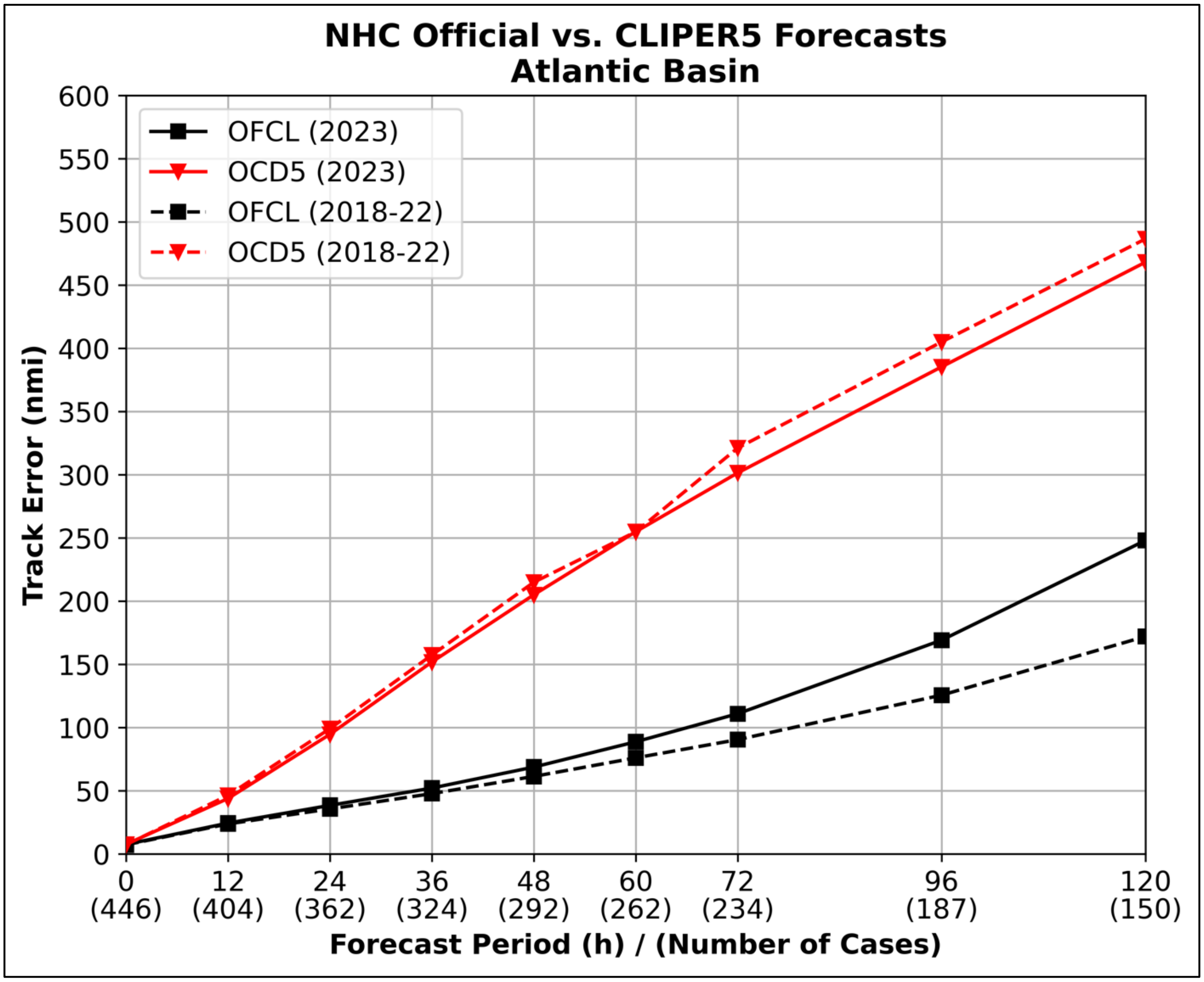


Figure 1. NHC official and CLIPER5 (OCD5) Atlantic basin average track errors for 2023 (solid lines) and 2018–2022 (dashed lines).

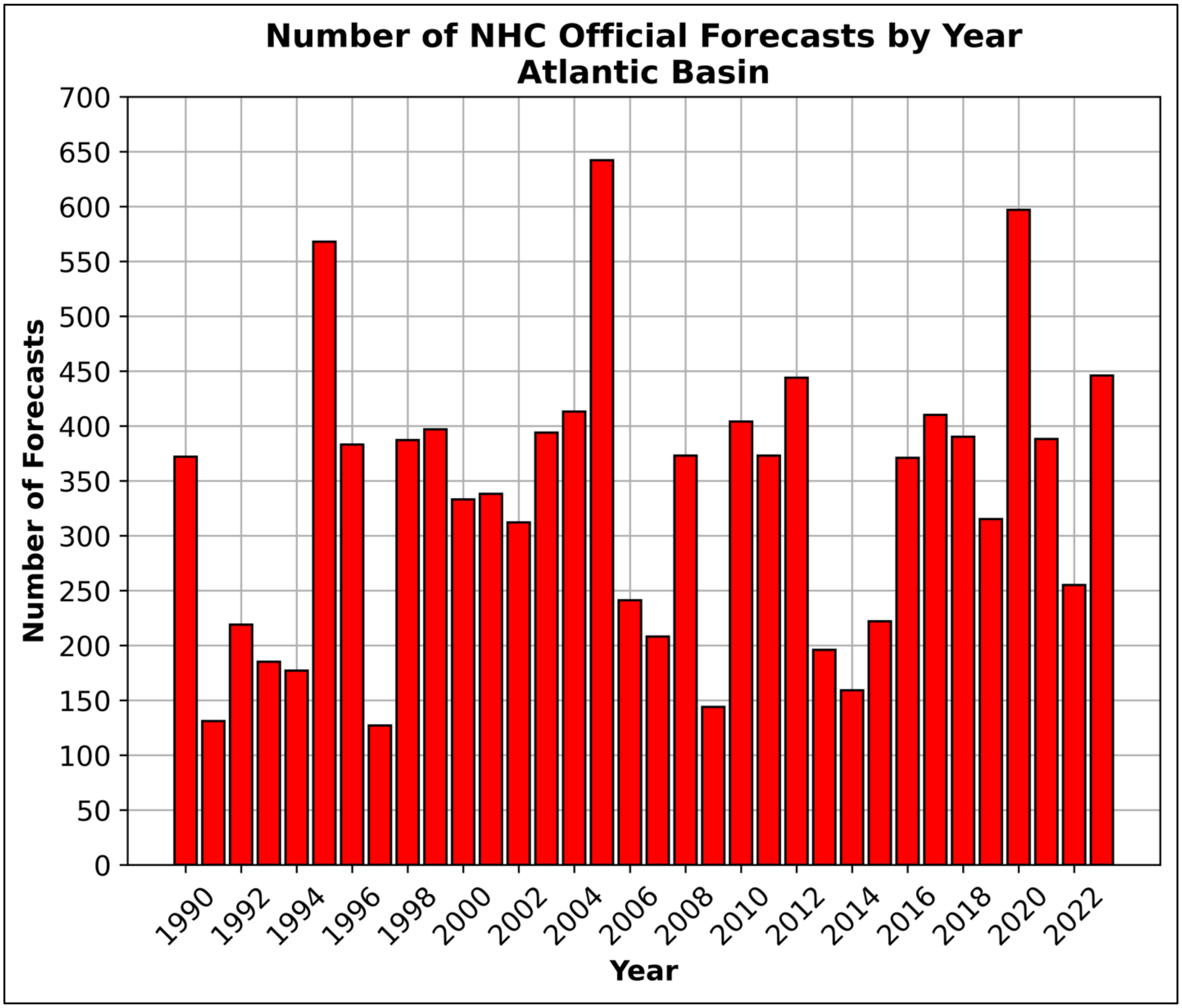
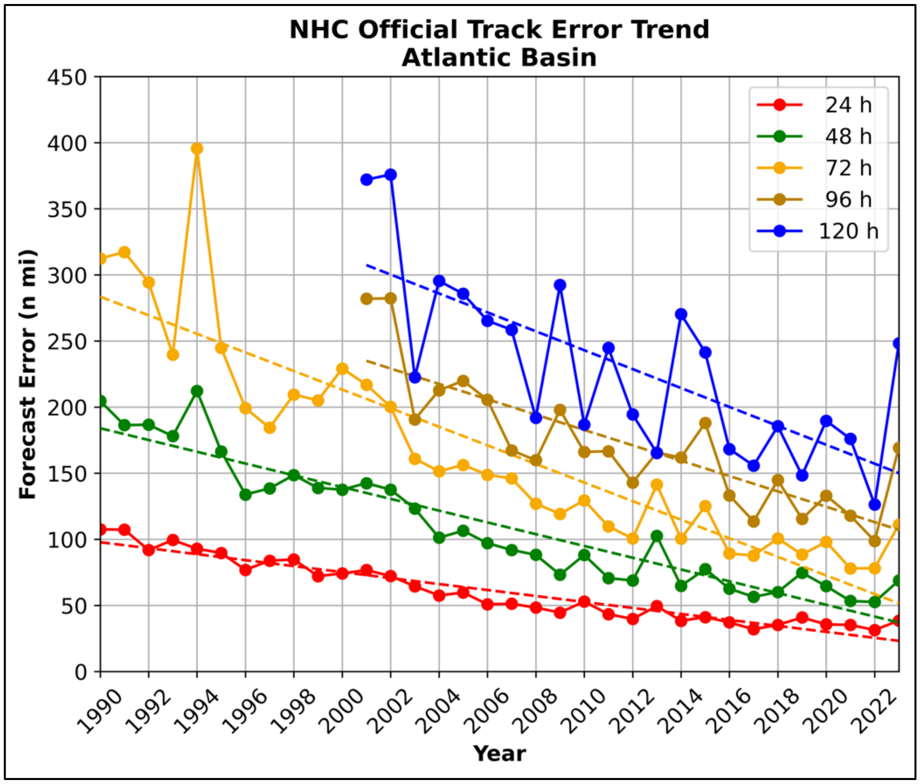


Figure 2. Number of NHC official forecasts for the Atlantic basin stratified by year from 1990–2023.



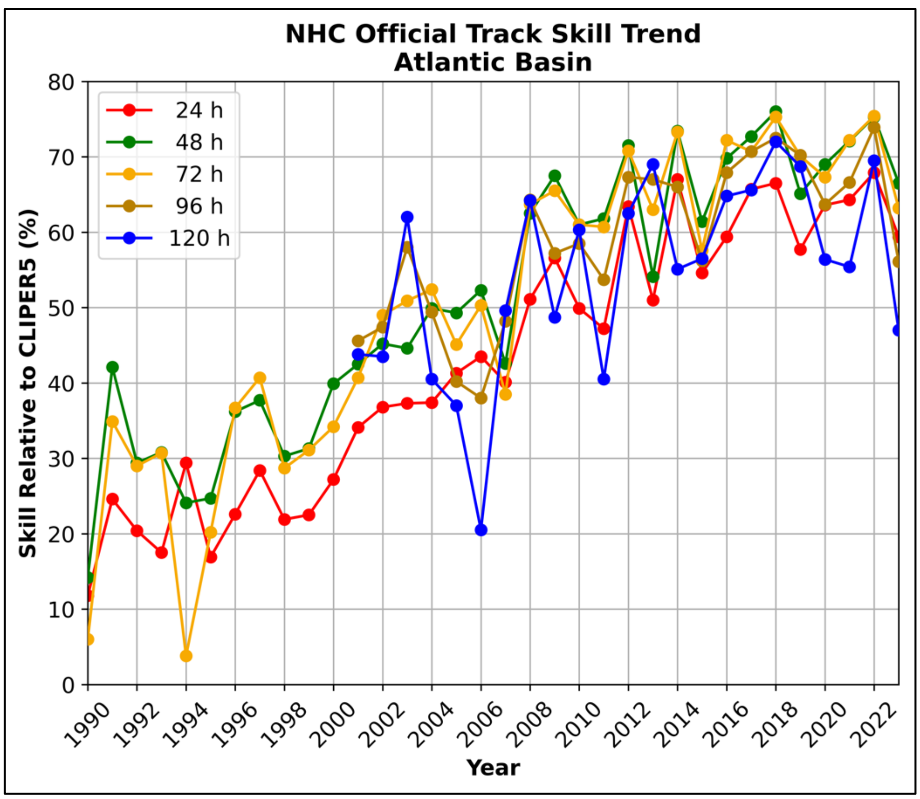


Figure 3. Recent trends in NHC official track forecast error (top) and skill (bottom) for the Atlantic basin.

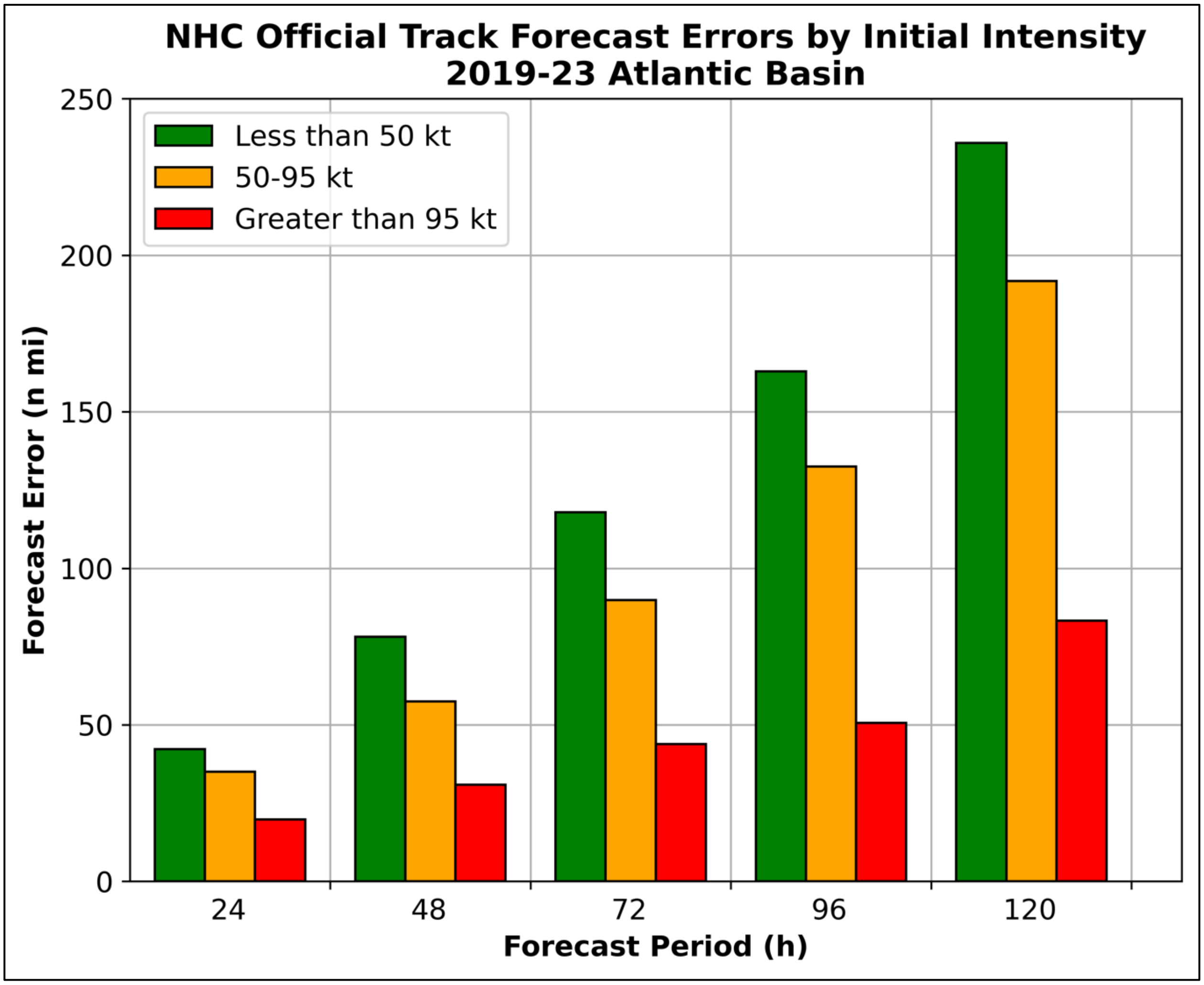


Figure 4. 2019–23 NHC official track forecast error binned by initial intensity for the Atlantic basin.

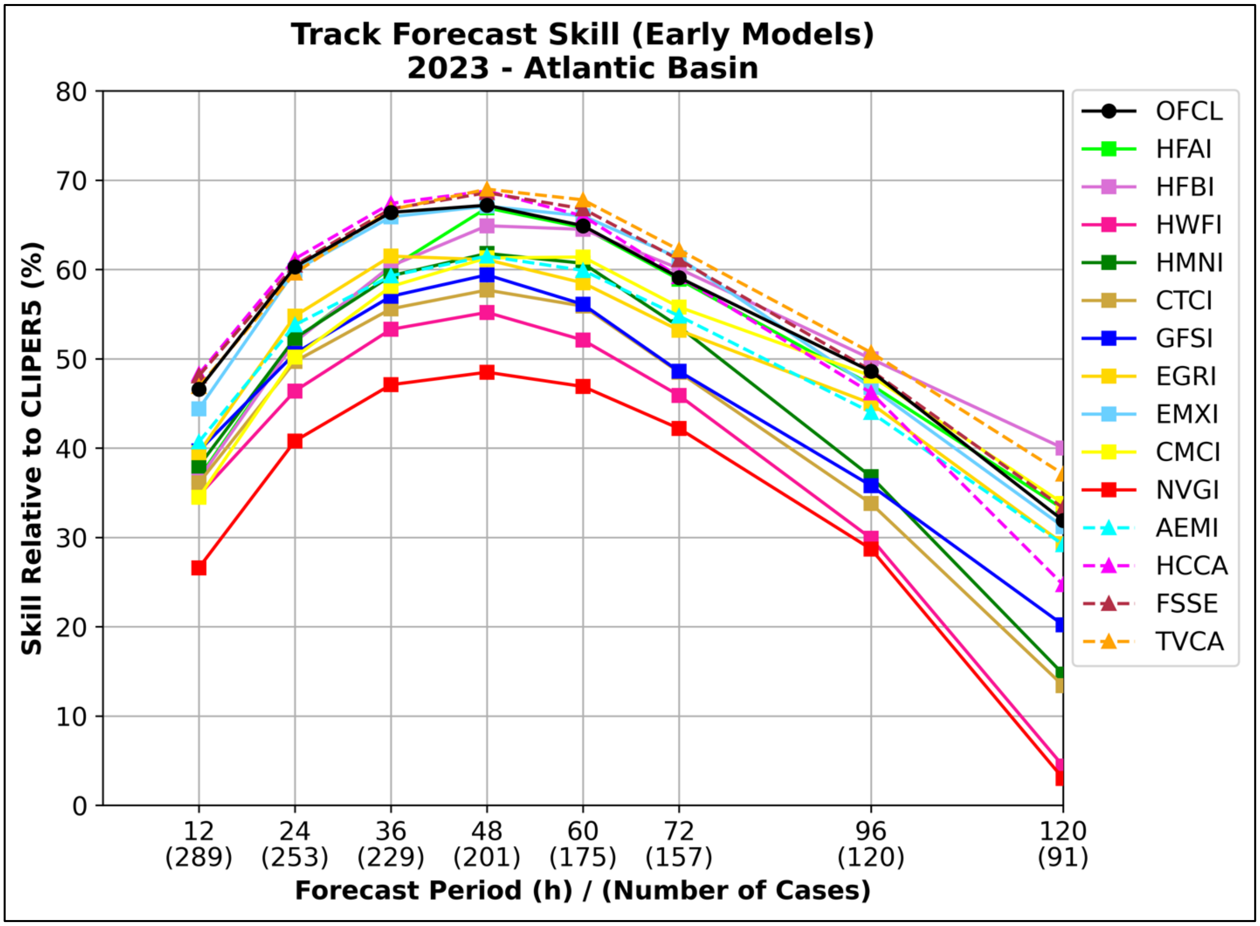


Figure 5. Homogenous comparison for selected Atlantic basin early track models for 2023. This verification includes only those models that were available at least 2/3 of the time (see text).

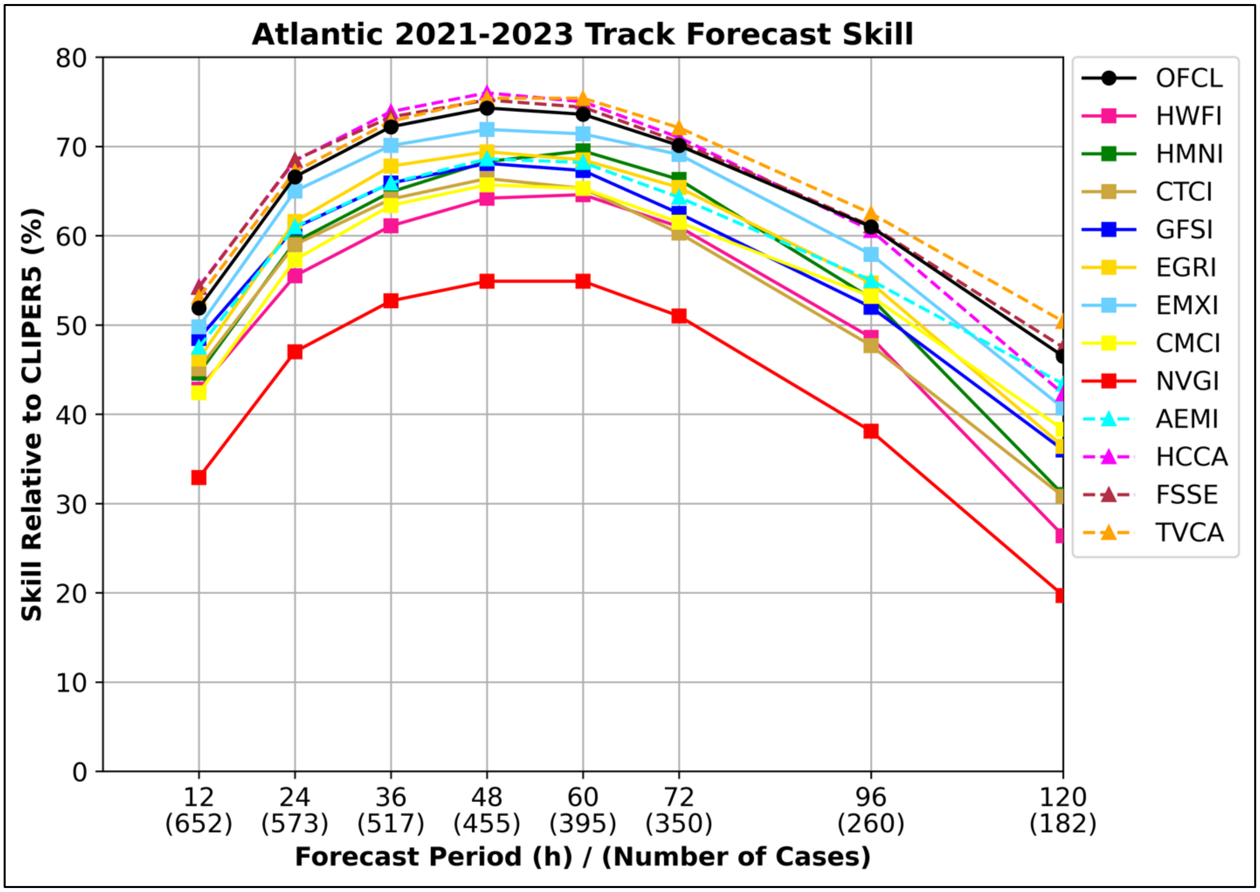


Figure 6. Homogenous comparison for selected Atlantic basin early track models for 2021–2023.

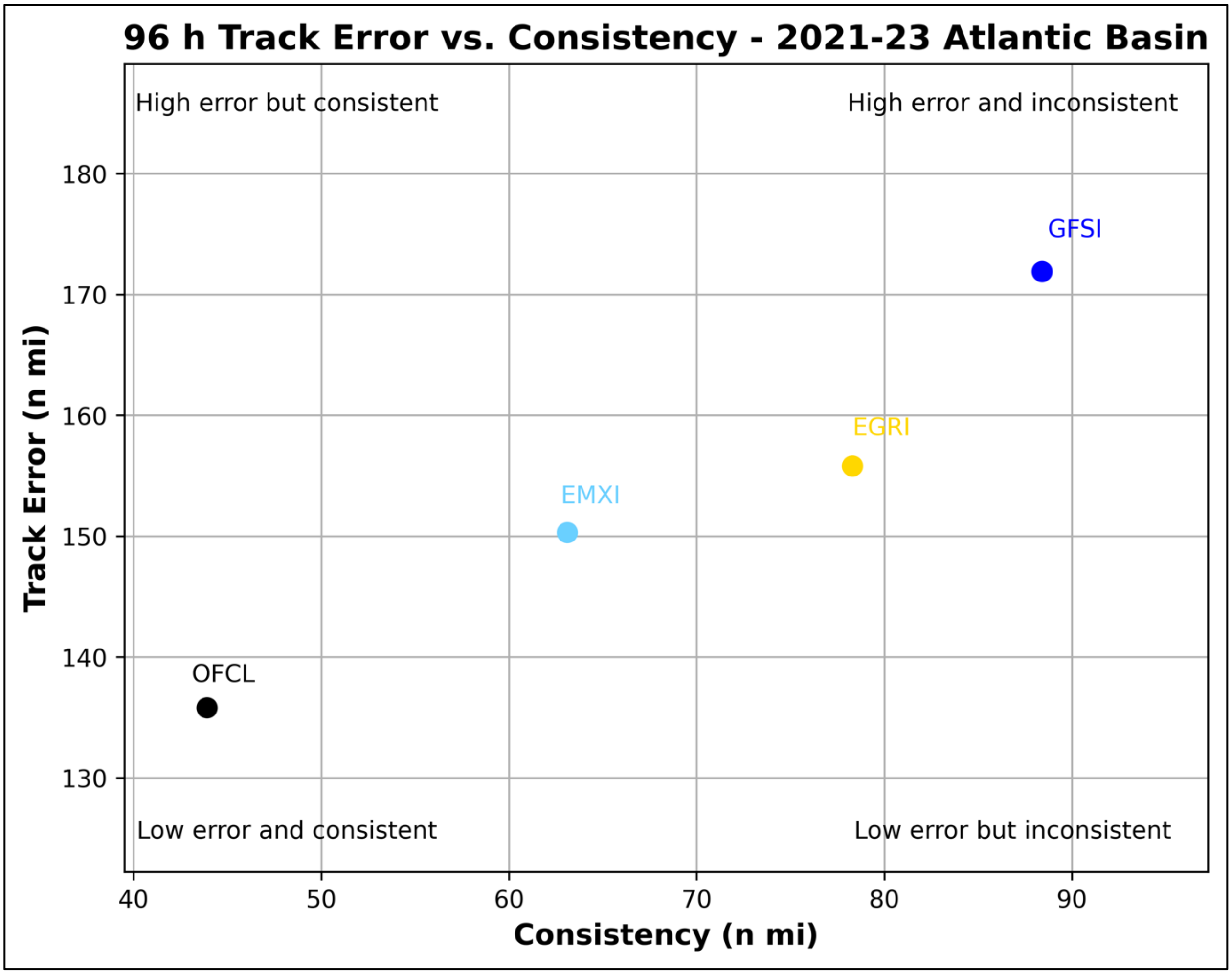


Figure 7. Track error vs. consistency around the 96-h forecast period in the Atlantic basin of GFSI, EMXI, EGRI, and OFCL (NHC) from 2021–23.

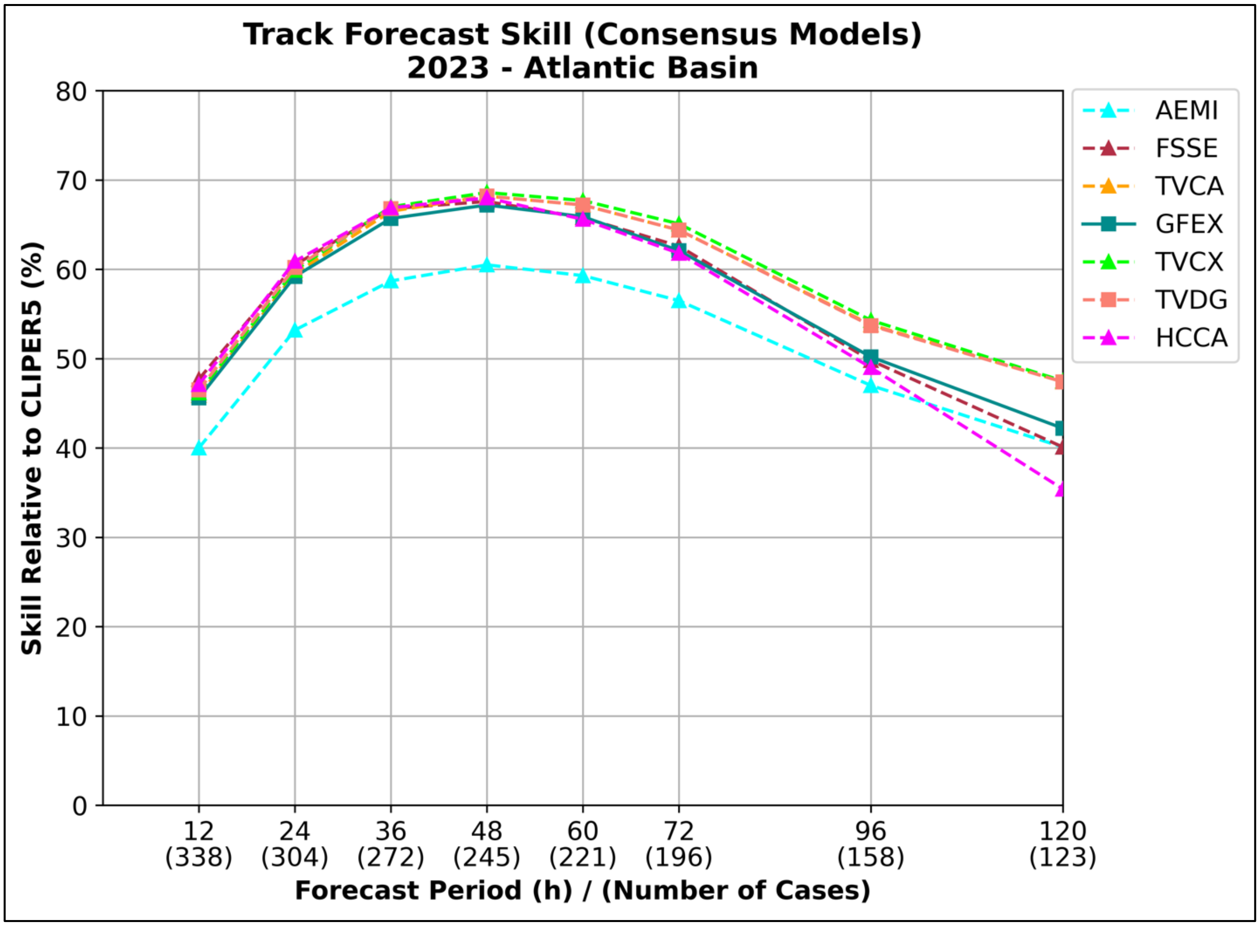


Figure 8. Homogenous comparison of the primary Atlantic basin track consensus models for 2023.

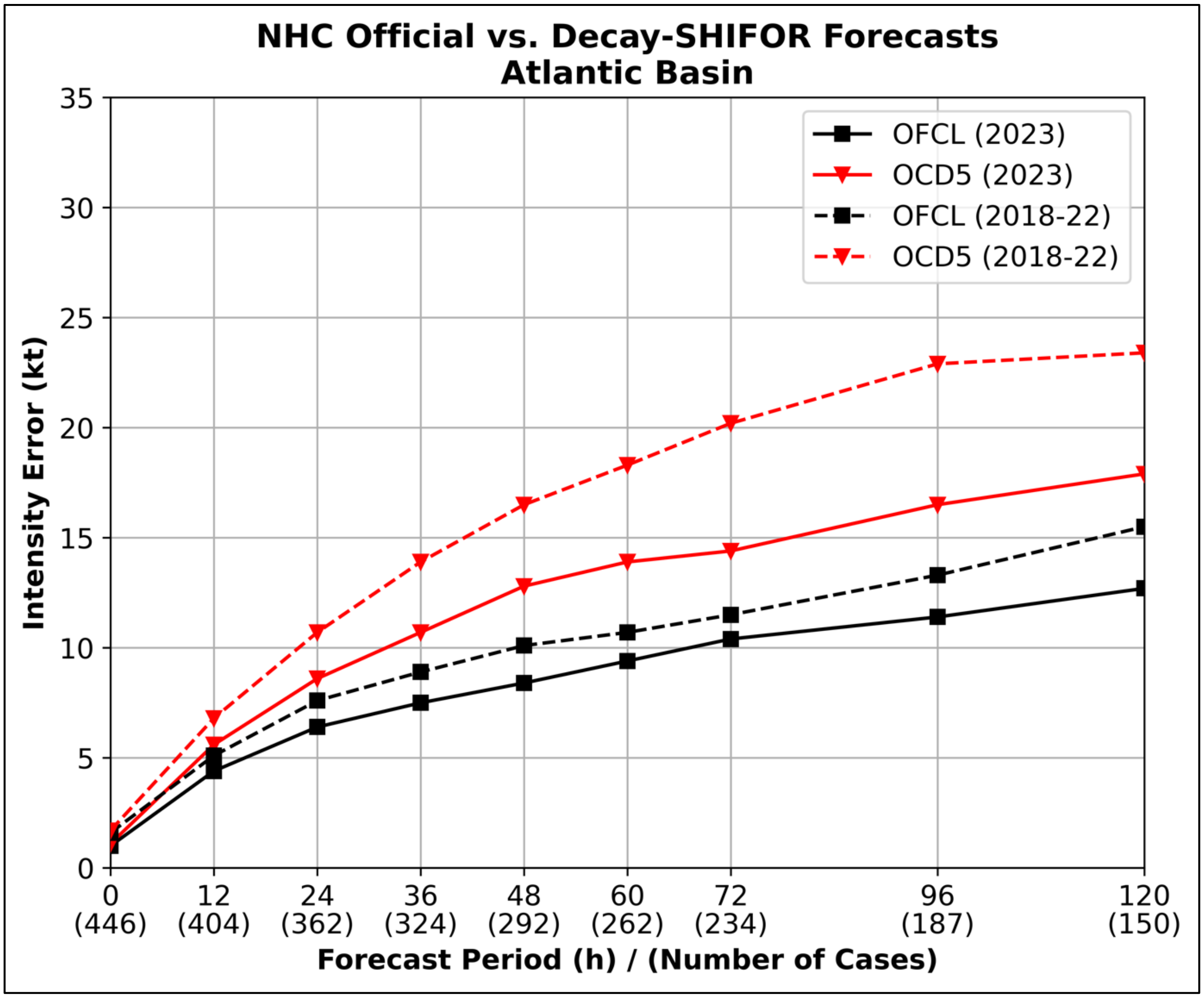
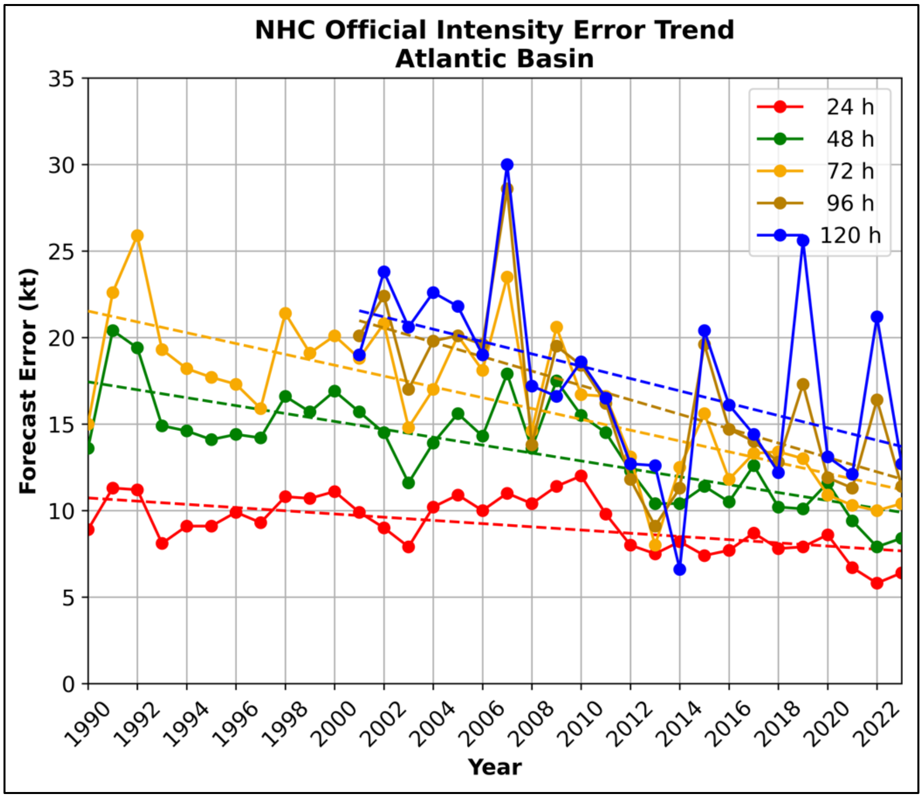


Figure 9. NHC official and Decay-SHIFOR5 (OCD5) Atlantic basin average intensity errors for 2023 (solid lines) and 2018–2022 (dashed lines).



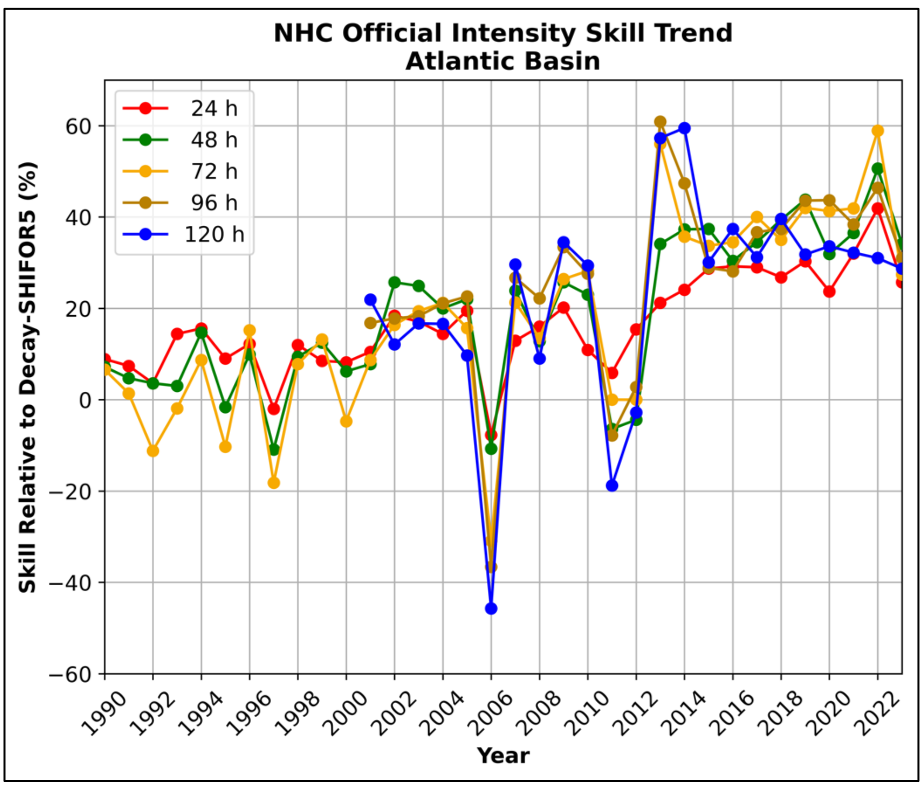


Figure 10. Recent trends in NHC official intensity forecast error (top) and skill (bottom) for the Atlantic basin.

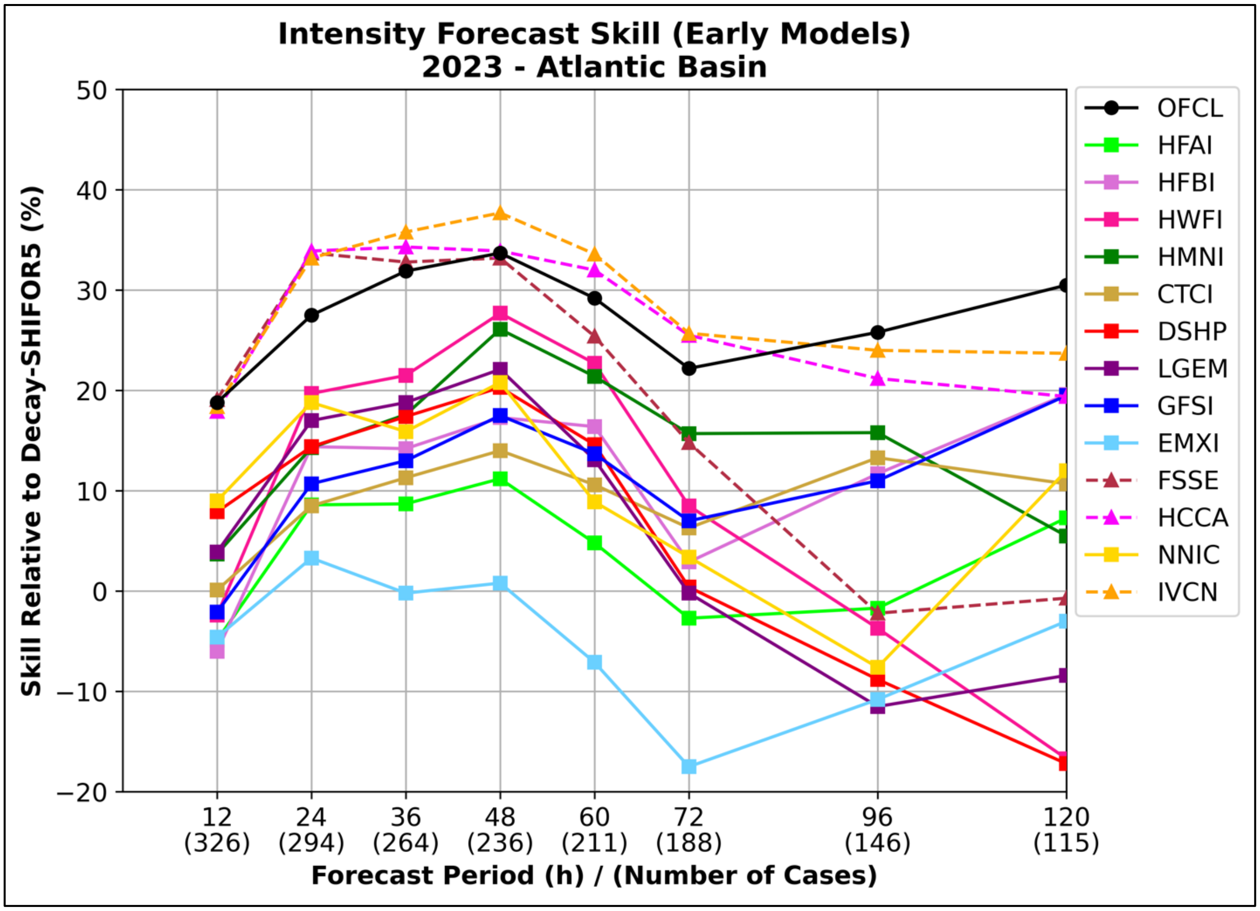


Figure 11. Homogenous comparison for selected Atlantic basin early intensity guidance models for 2023.

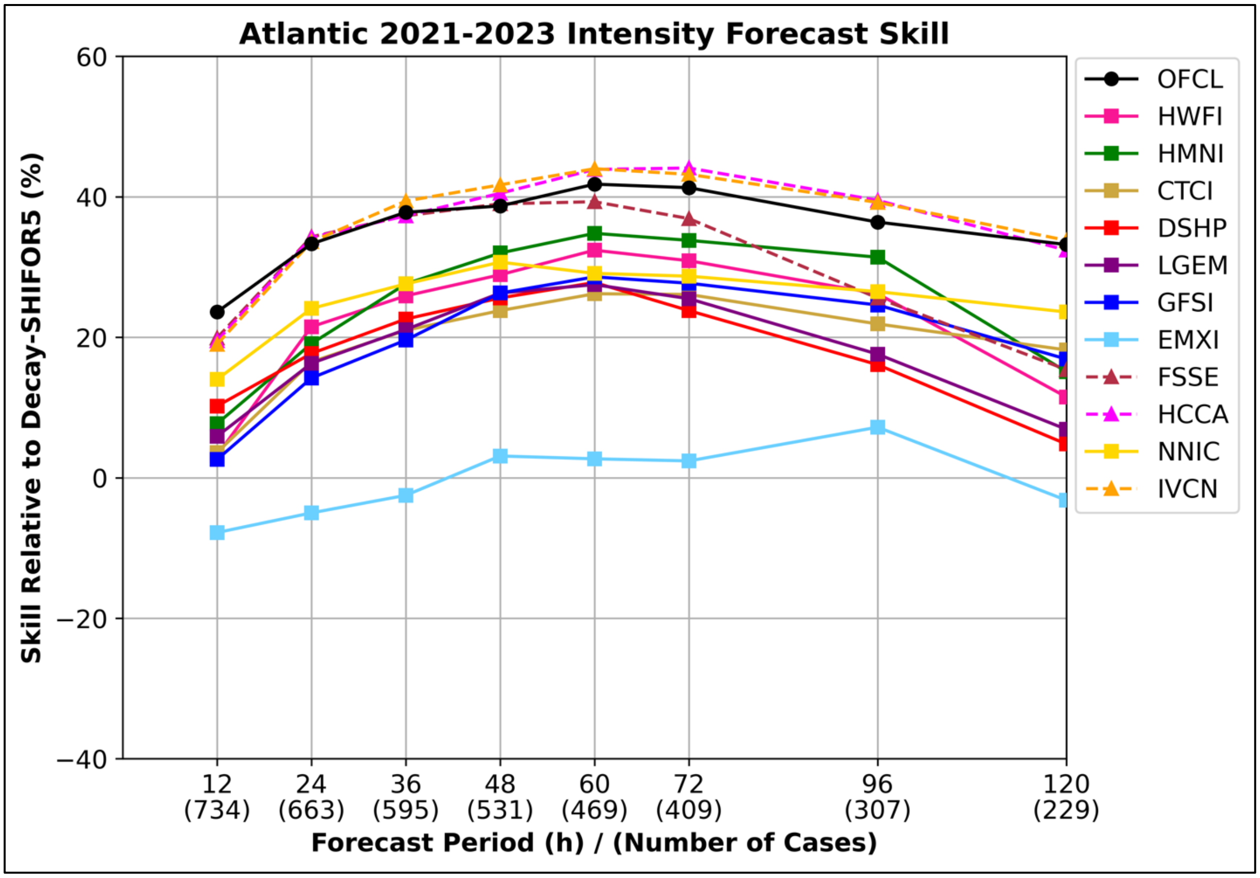


Figure 12. Homogenous comparison for selected Atlantic basin early intensity guidance models for 2021–2023.

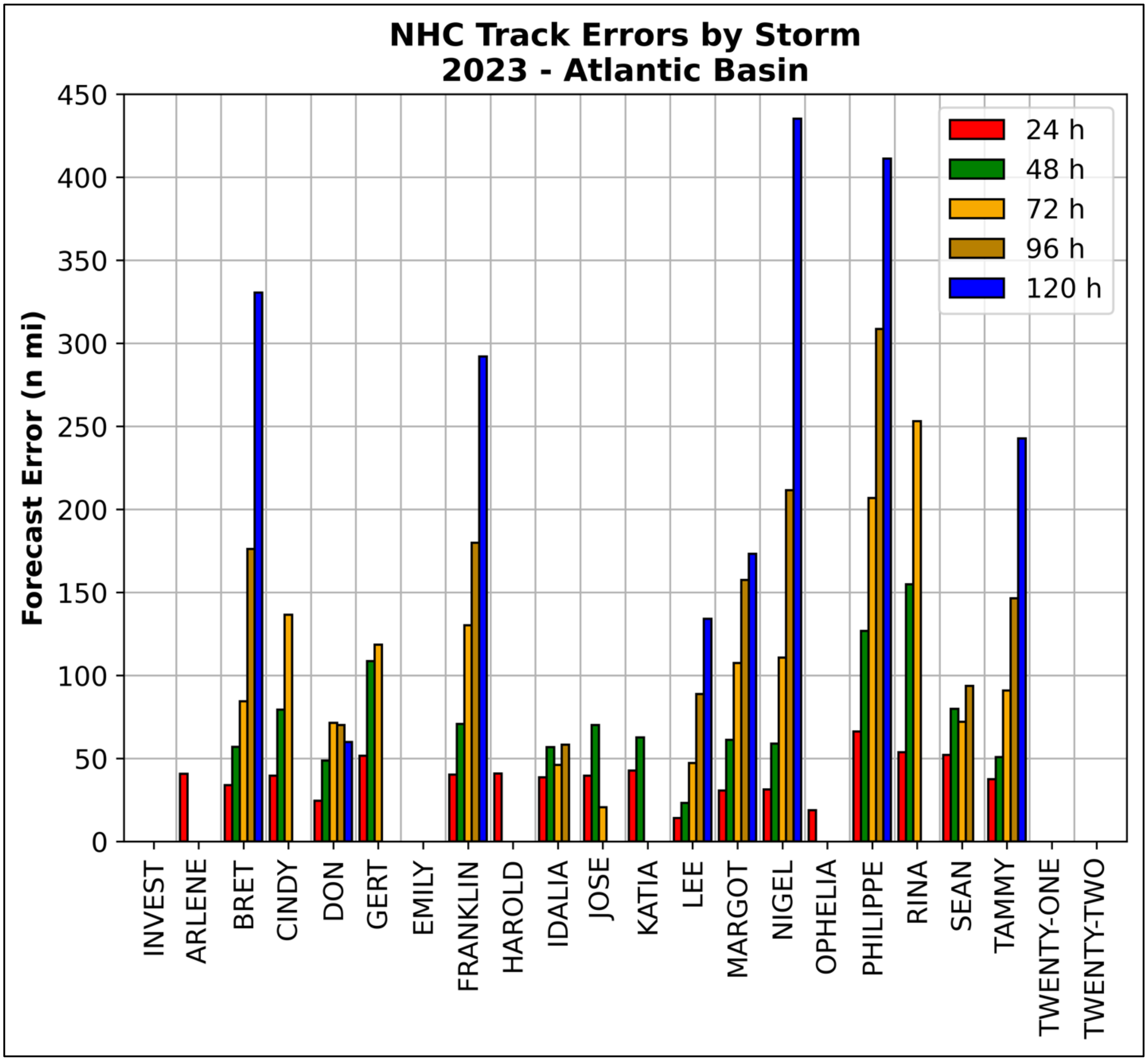


Figure 13. 2023 NHC official track errors by tropical cyclone at 24, 48, 72, 96 and 120 h.

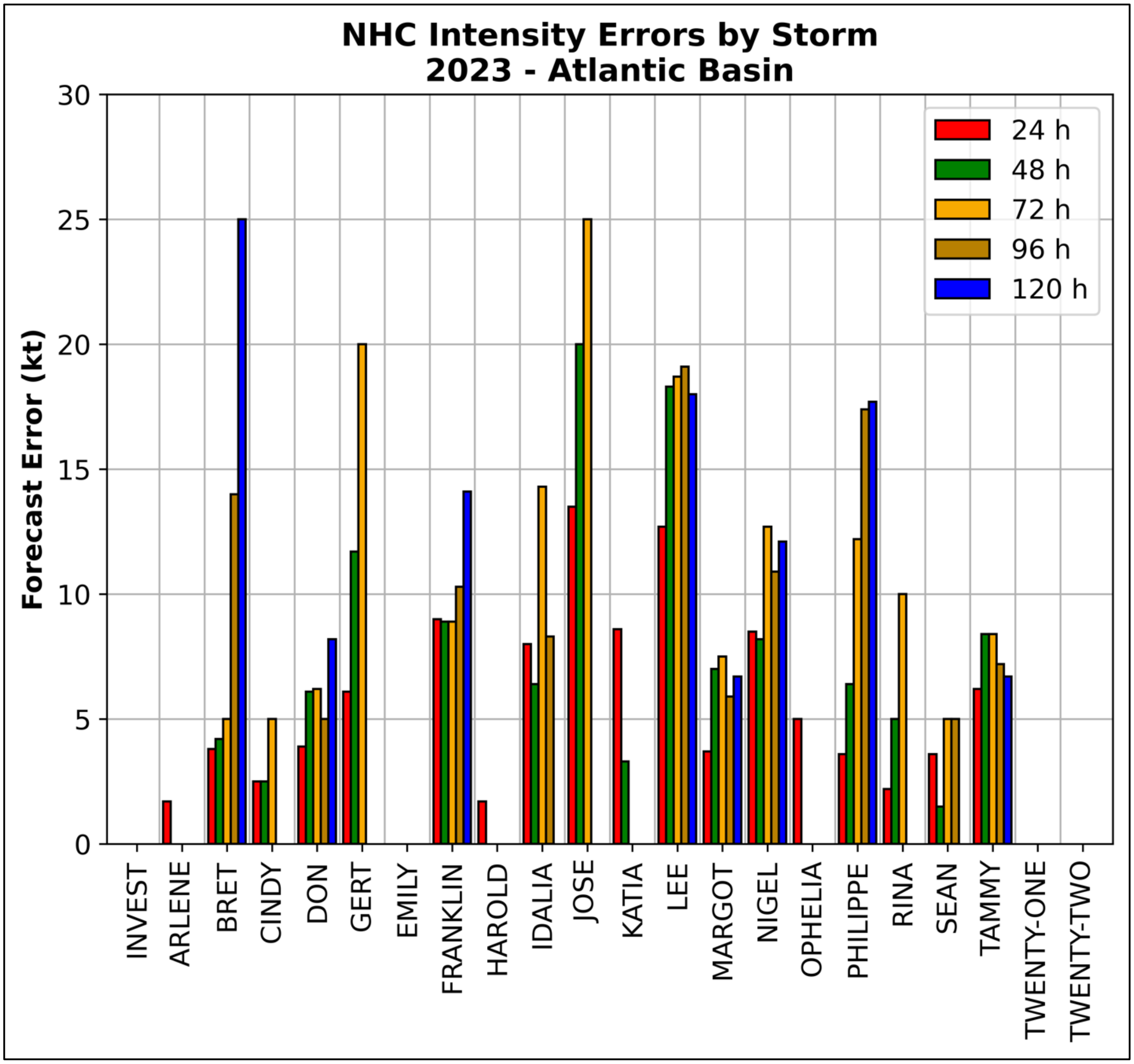


Figure 14. 2023 NHC official intensity errors by tropical cyclone at 24, 48, 72, 96 and 120 h.

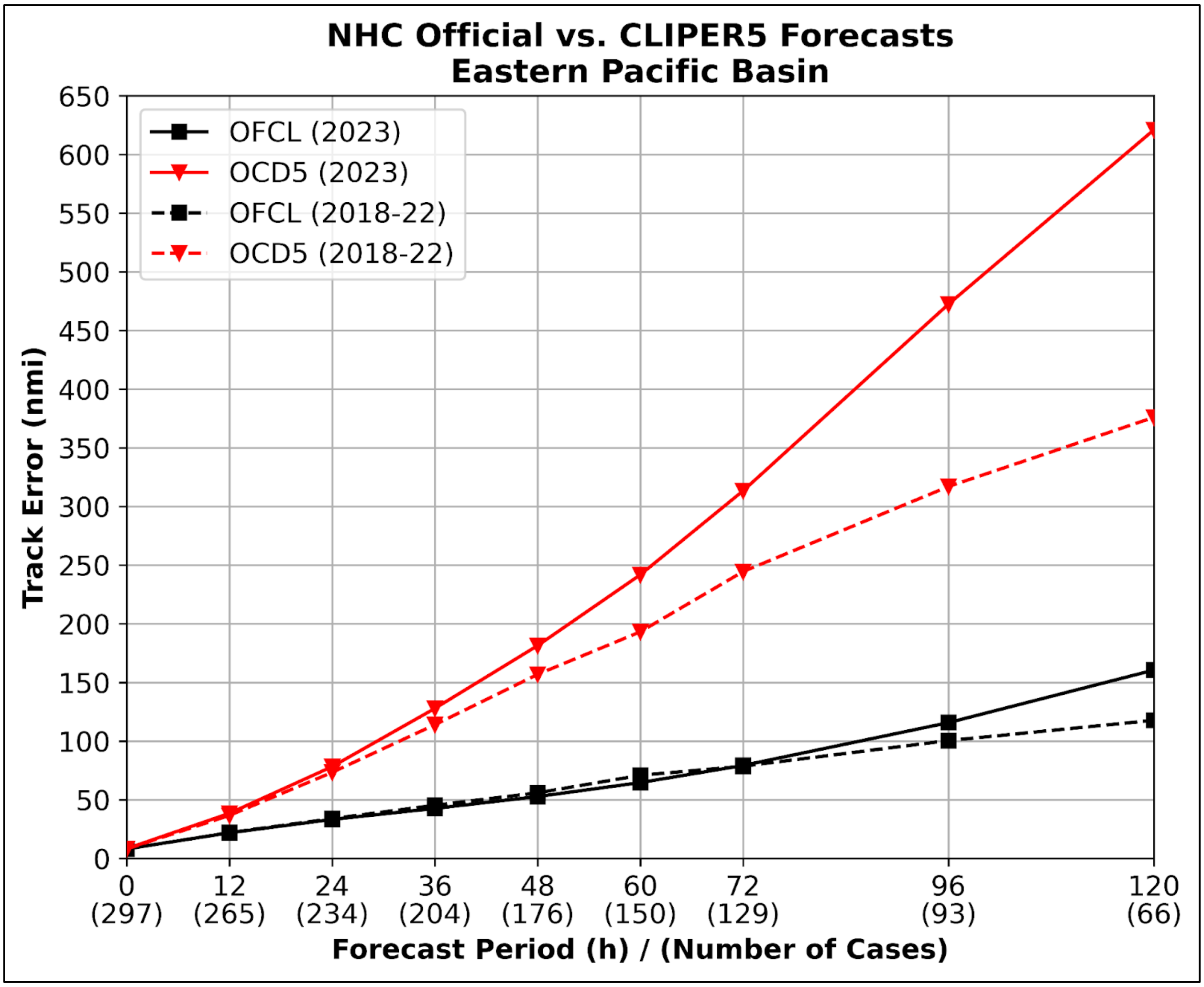


Figure 15. NHC official and CLIPER5 (OCD5) eastern North Pacific basin average track errors for 2023 (solid lines) and 2018–2022 (dashed lines).

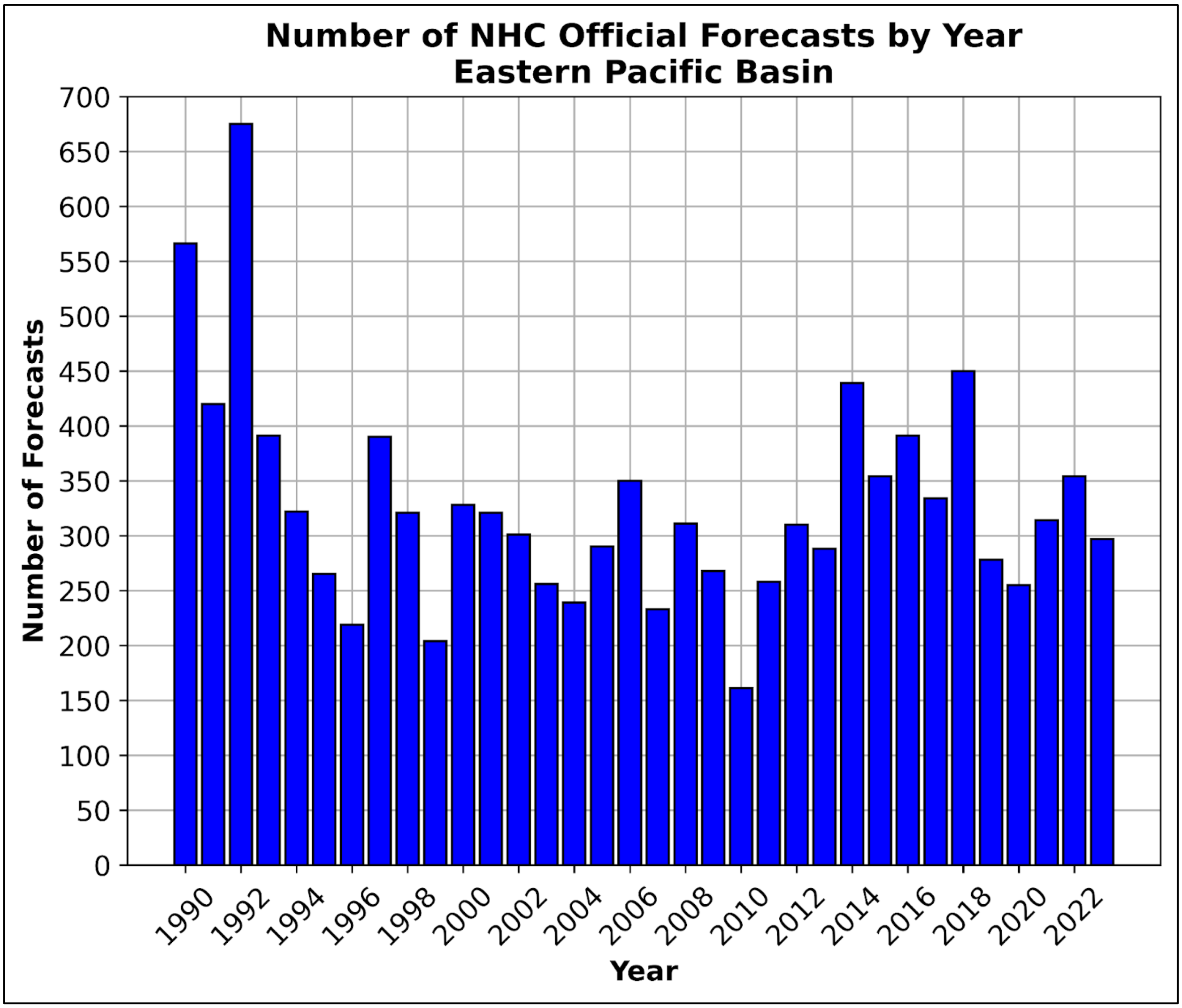
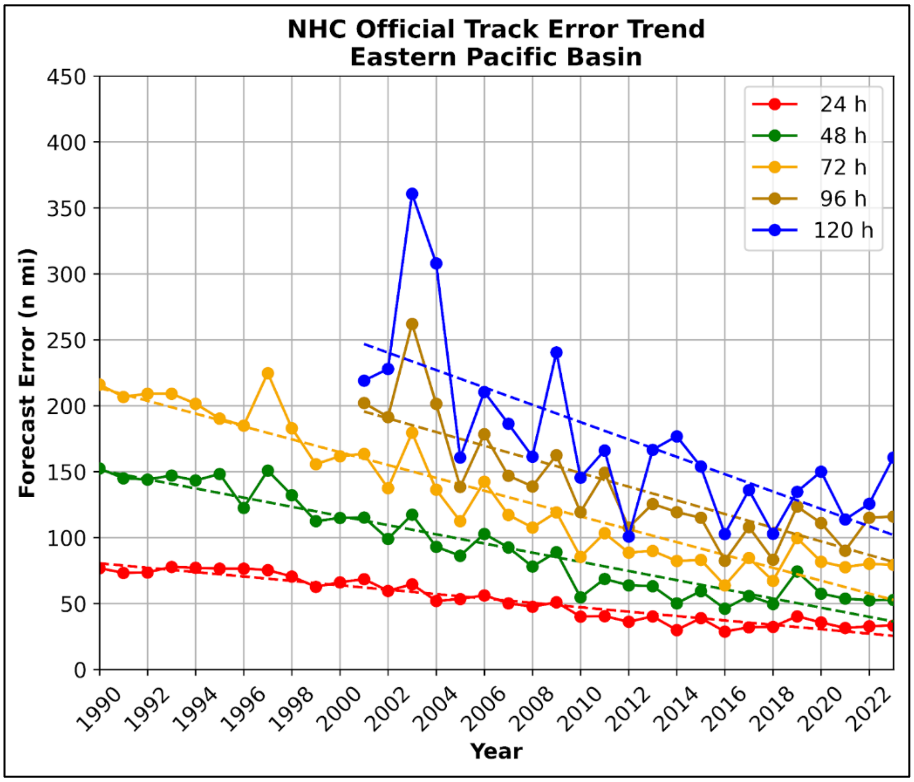


Figure 16. Number of NHC official forecasts for the eastern North Pacific basin stratified by year from 1990–2023.



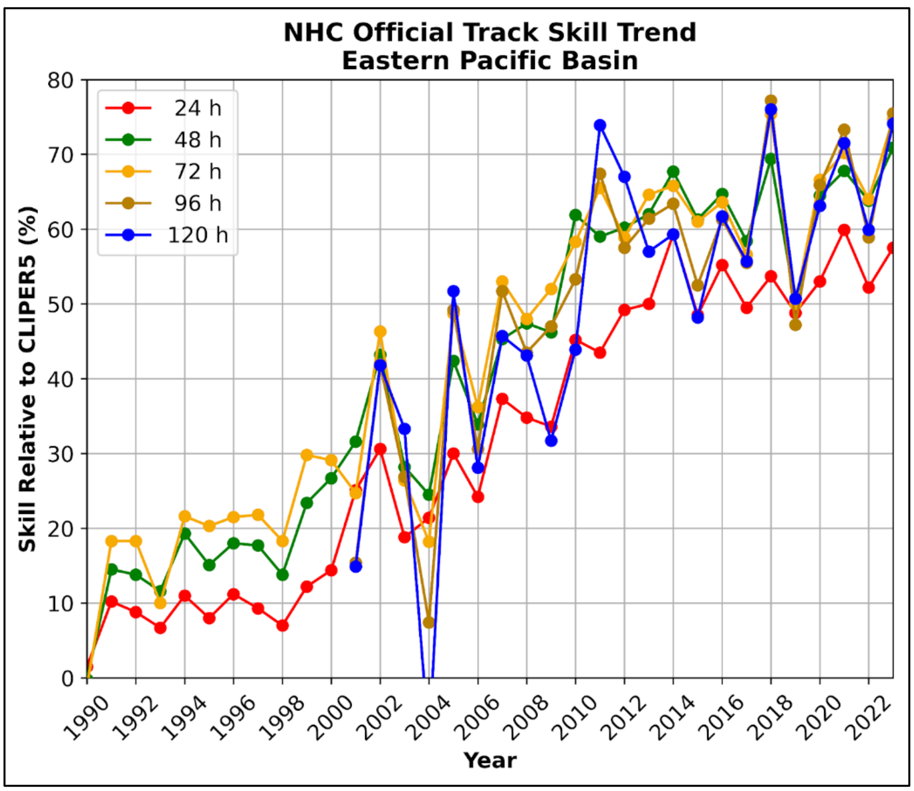


Figure 17. Recent trends in NHC official track forecast error (top) and skill (bottom) for the eastern North Pacific basin.

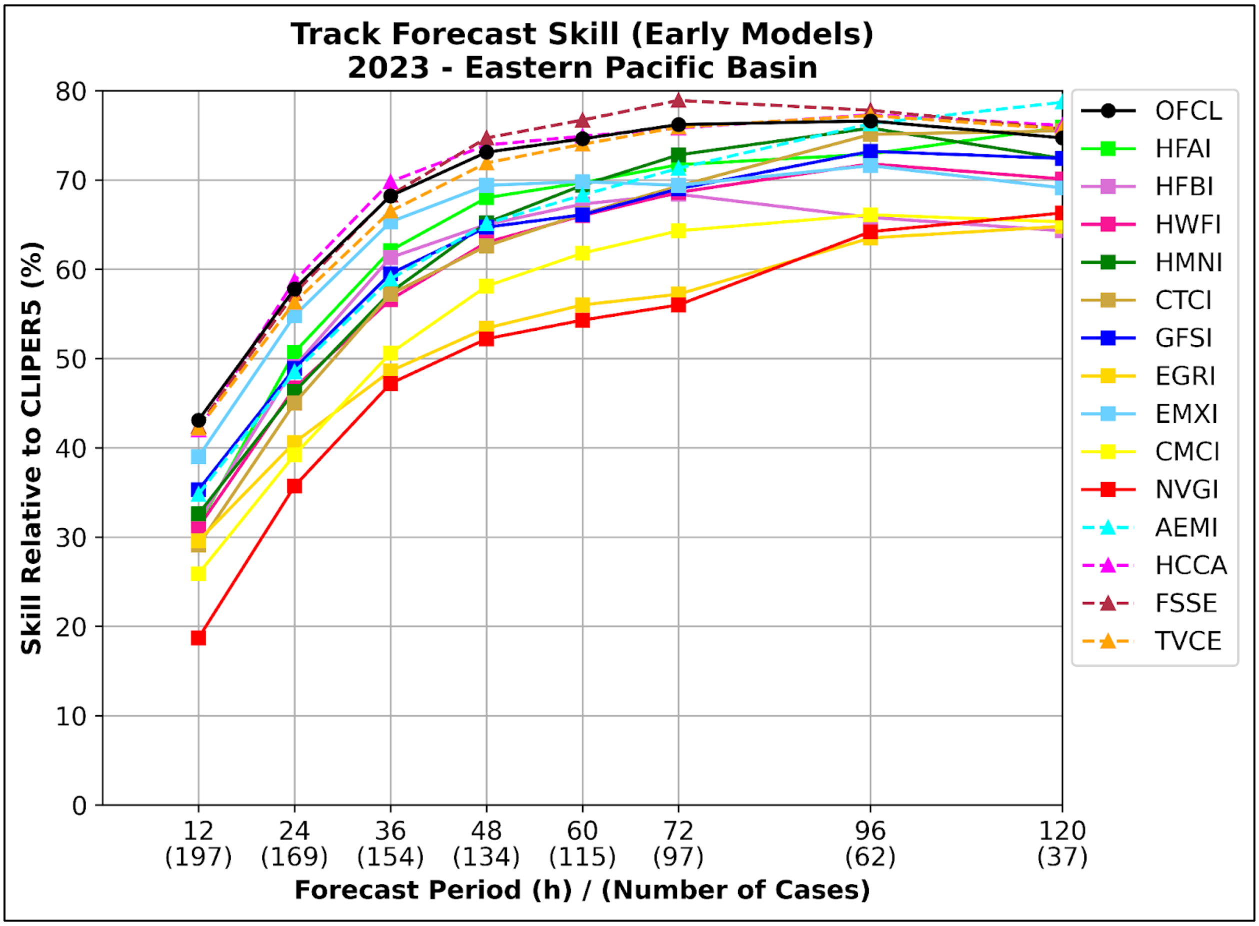


Figure 18. Homogenous comparison for selected eastern North Pacific early track models for 2023. This verification includes only those models that were available at least 2/3 of the time (see text).

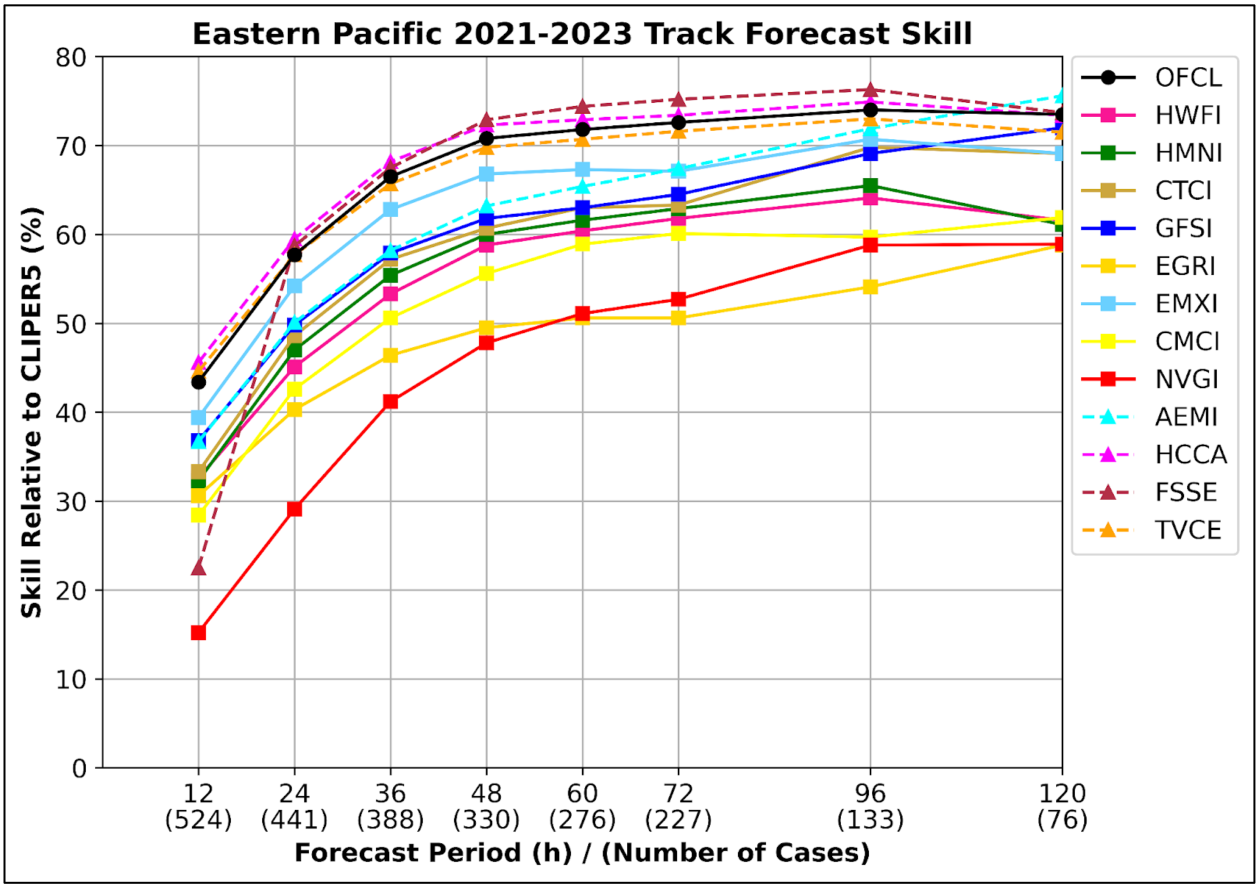


Figure 19. Homogenous comparison of track forecast skill for selected eastern North Pacific basin early models for 2021–2023.

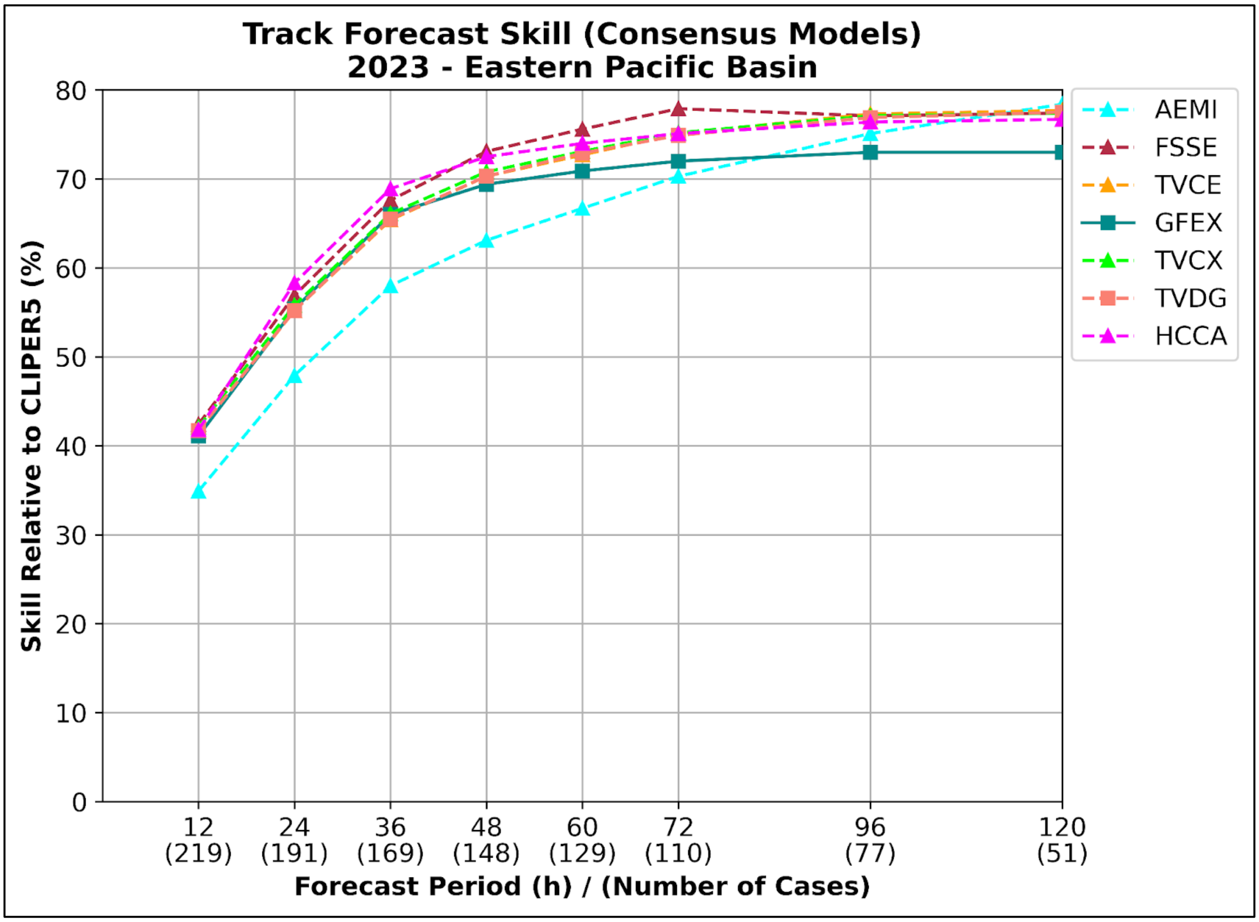


Figure 20. Homogenous comparison of the primary eastern North Pacific basin track consensus models for 2023.

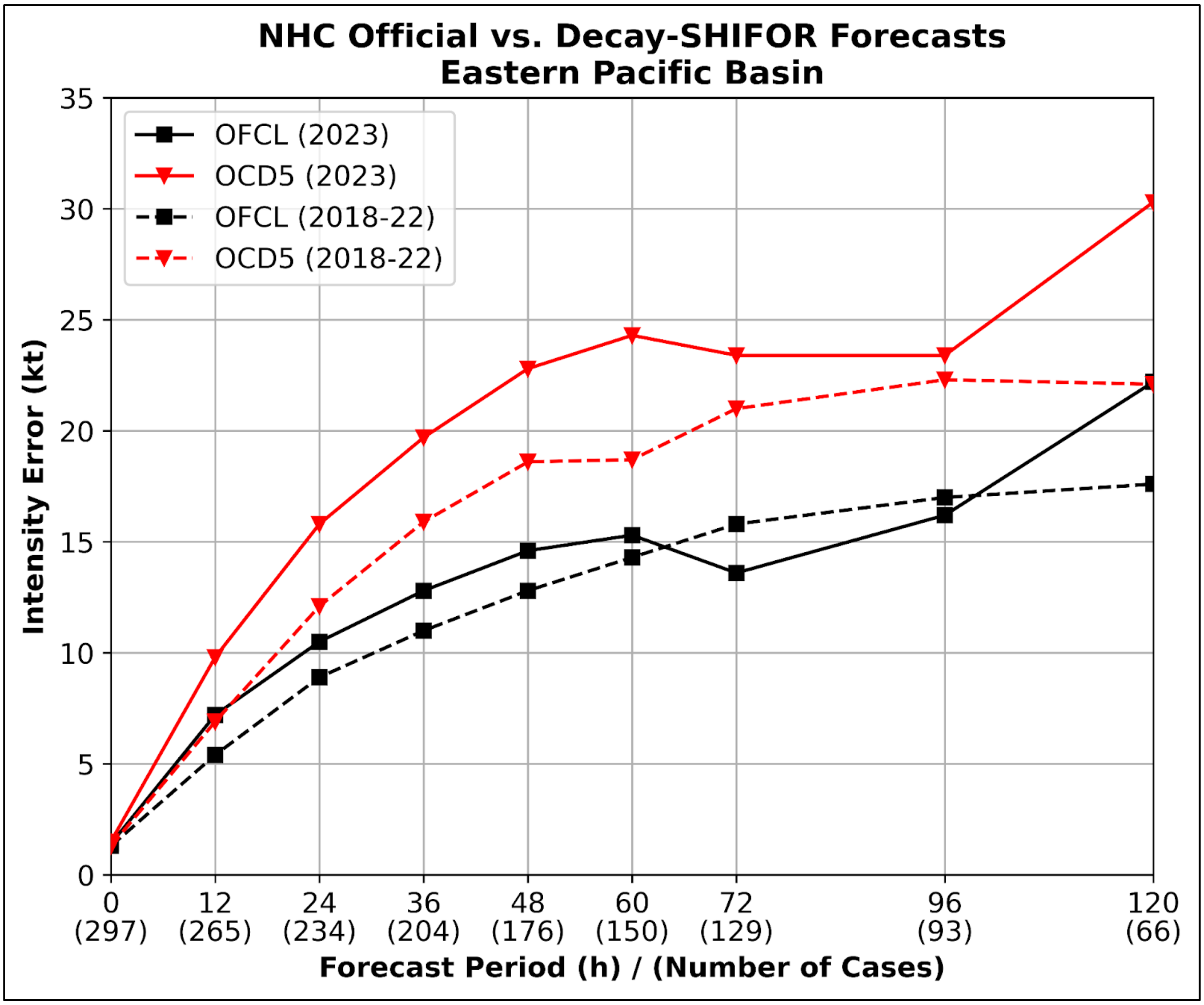


Figure 21. NHC official and Decay-SHIFOR5 (OCD5) eastern North Pacific basin average intensity errors for 2023 (solid lines) and 2018–2022 (dashed lines).

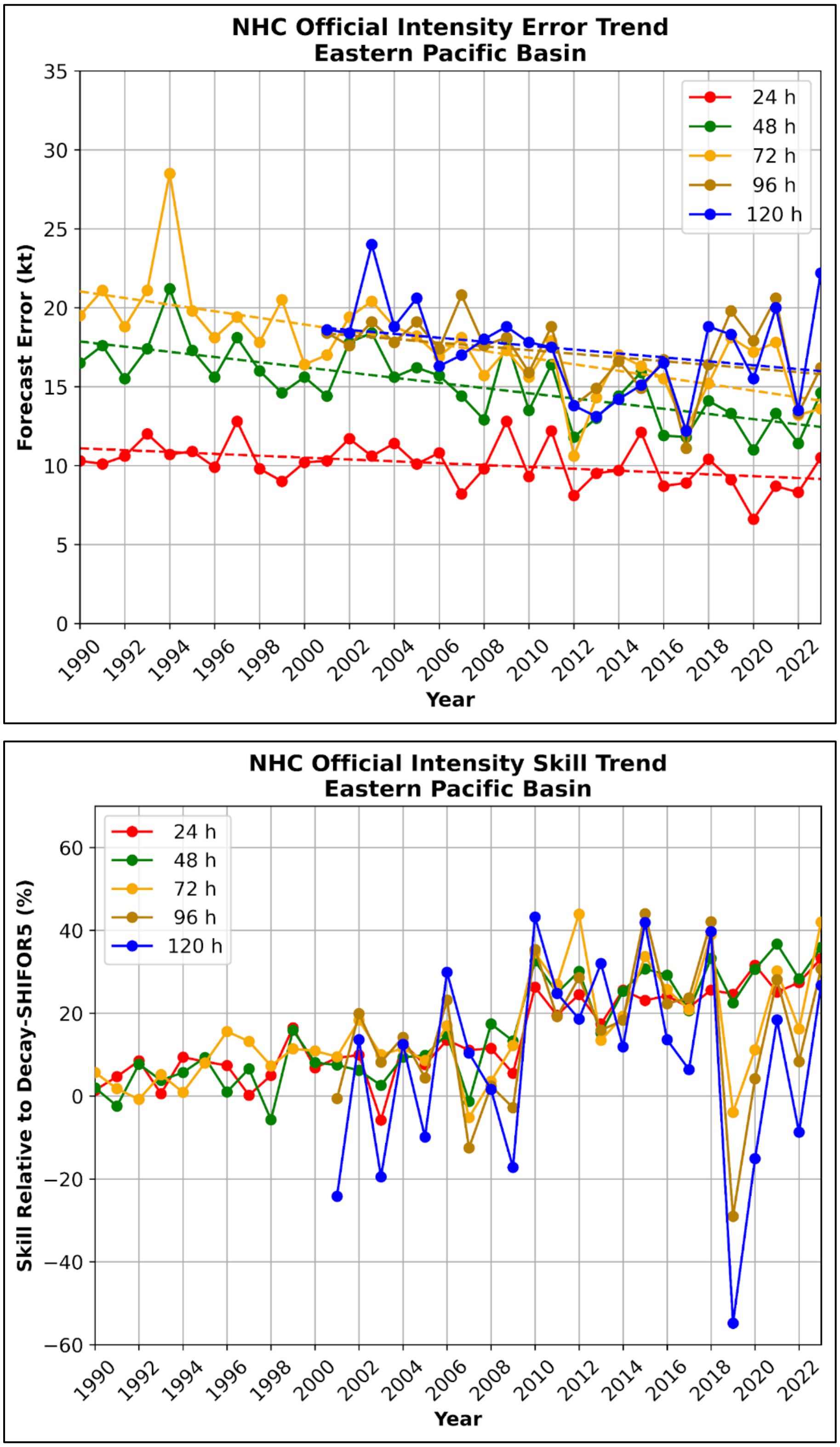


Figure 22. Recent trends in NHC official intensity forecast error (top) and skill (bottom) for the eastern North Pacific basin.

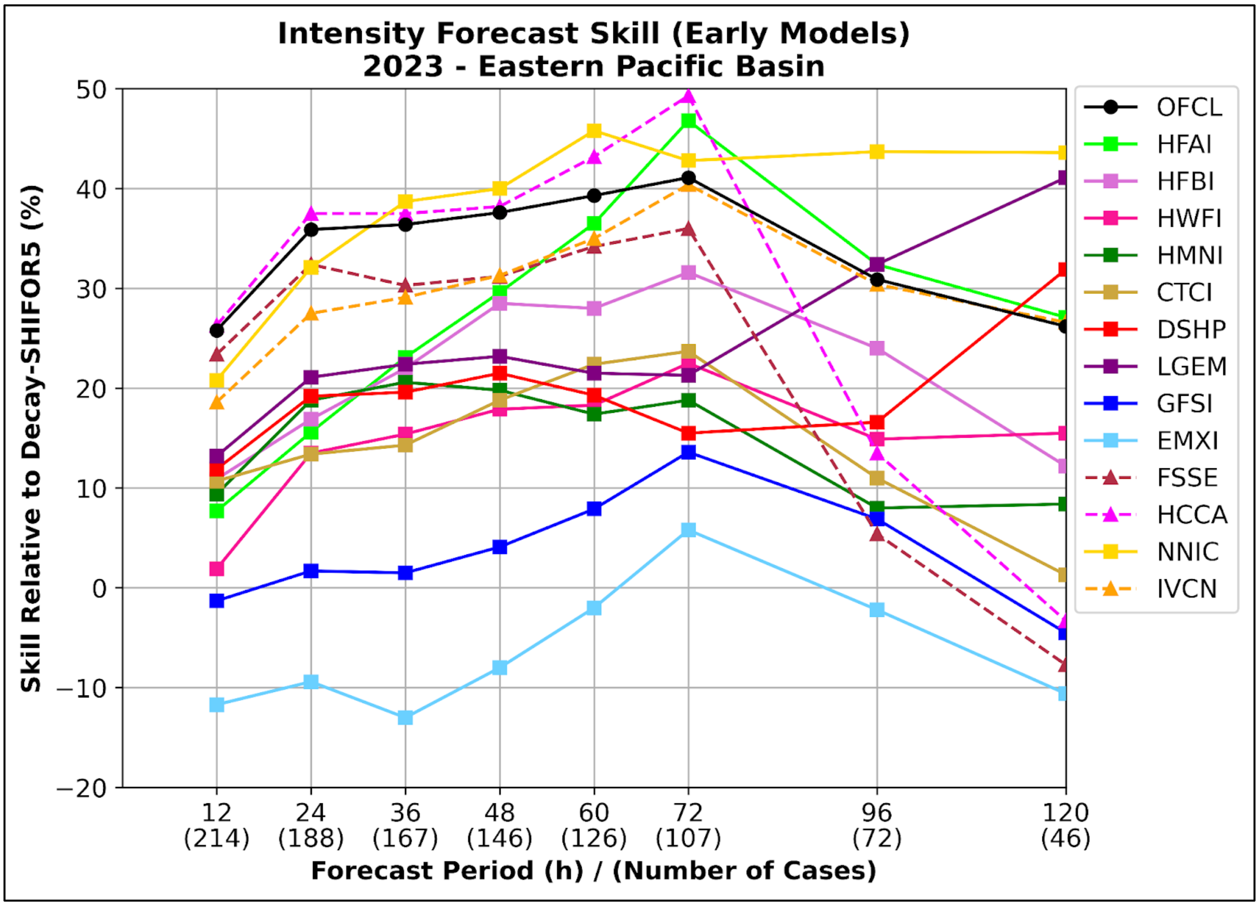


Figure 23. Homogenous comparison for selected eastern North Pacific basin early intensity guidance models for 2023.

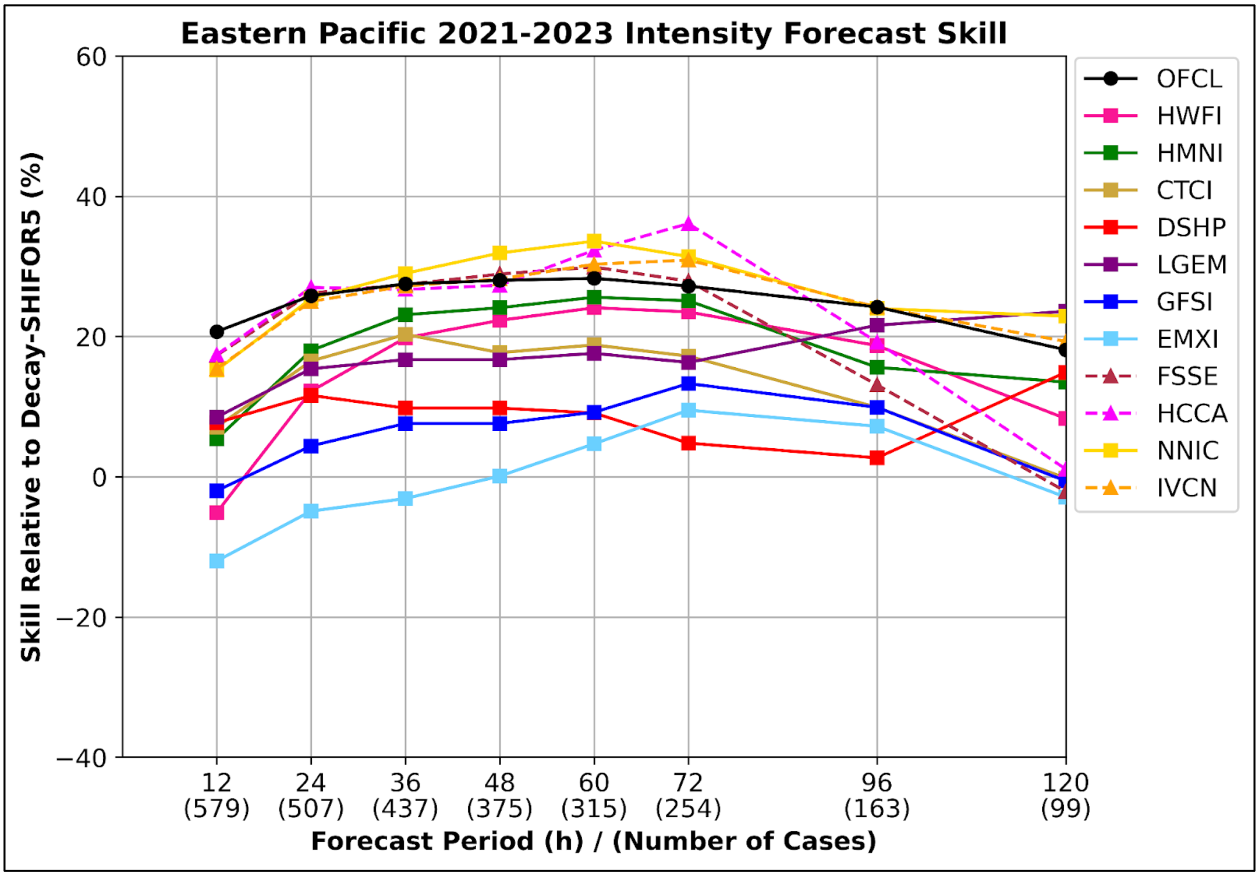


Figure 24. Homogenous comparison of forecast intensity skill for selected eastern North Pacific basin early guidance models for 2021–2023.

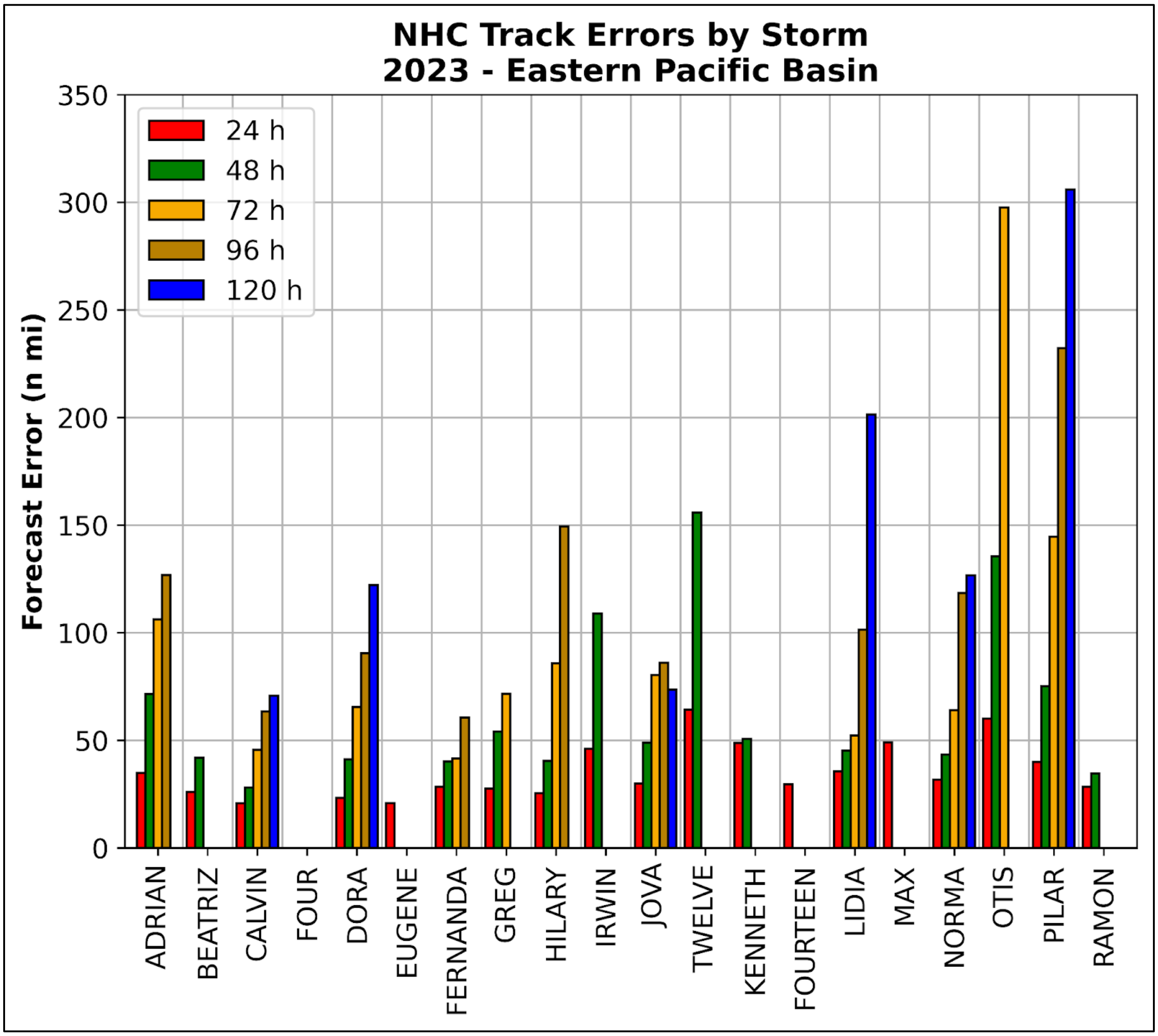


Figure 25. 2023 NHC eastern North Pacific official track errors by tropical cyclone at 24, 48, 72, 96, and 120 h.

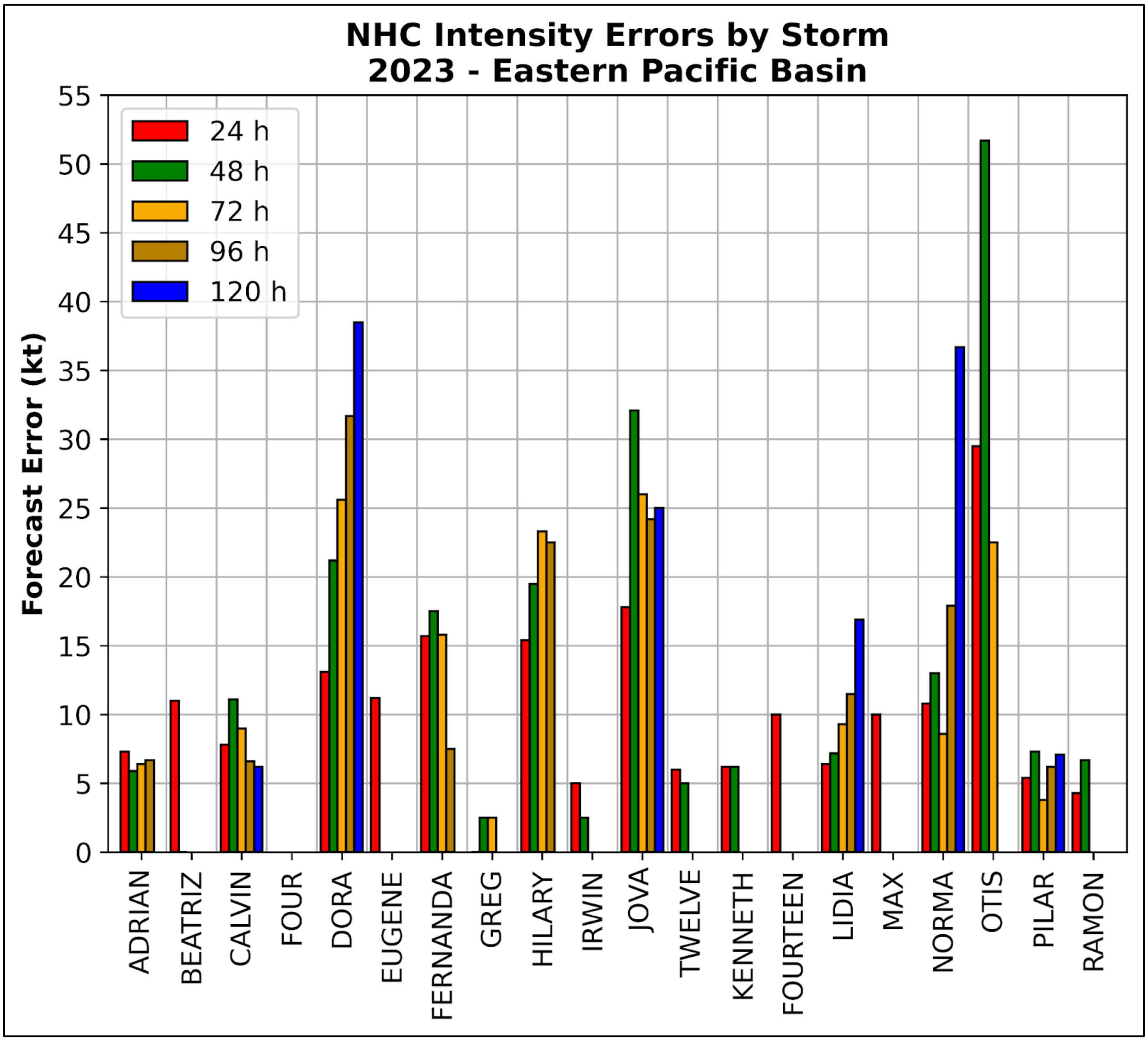
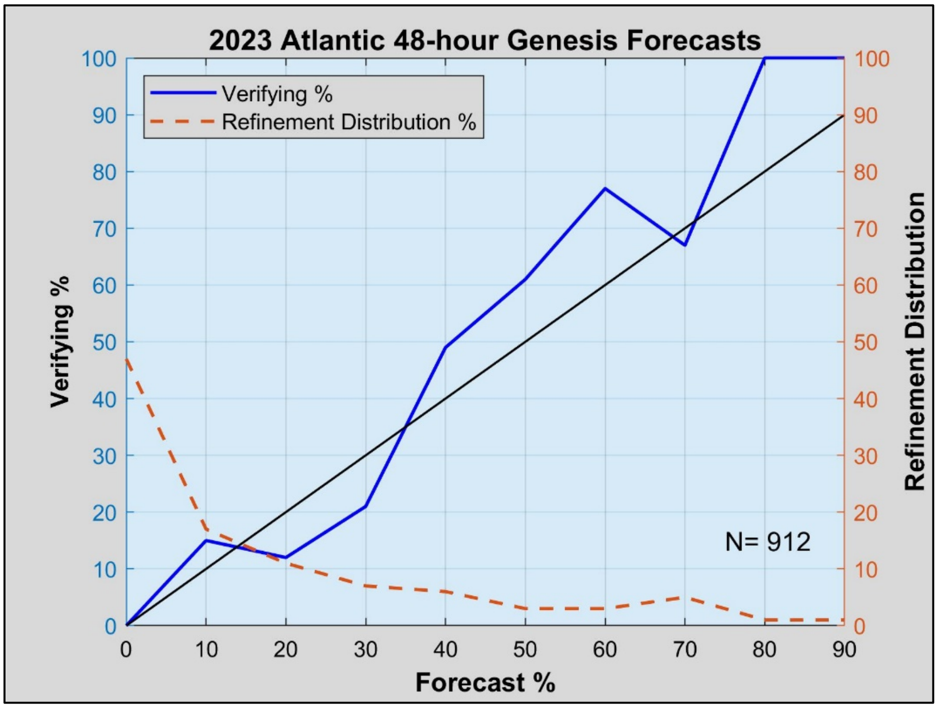


Figure 26. 2023 NHC eastern North Pacific official intensity errors by tropical cyclone at 24, 48, 72, 96, and 120 h.



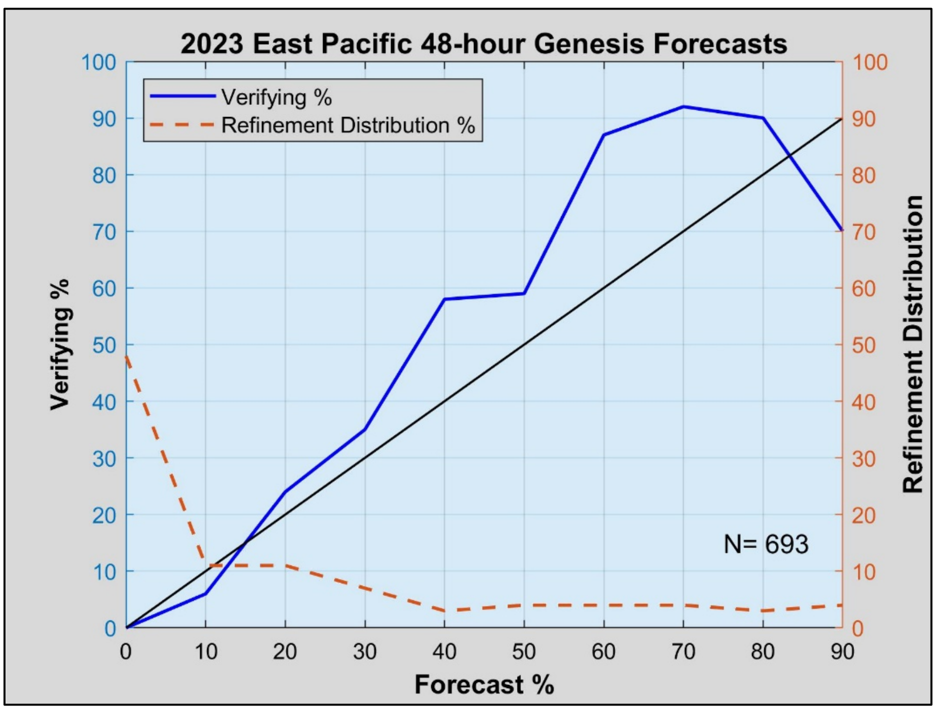
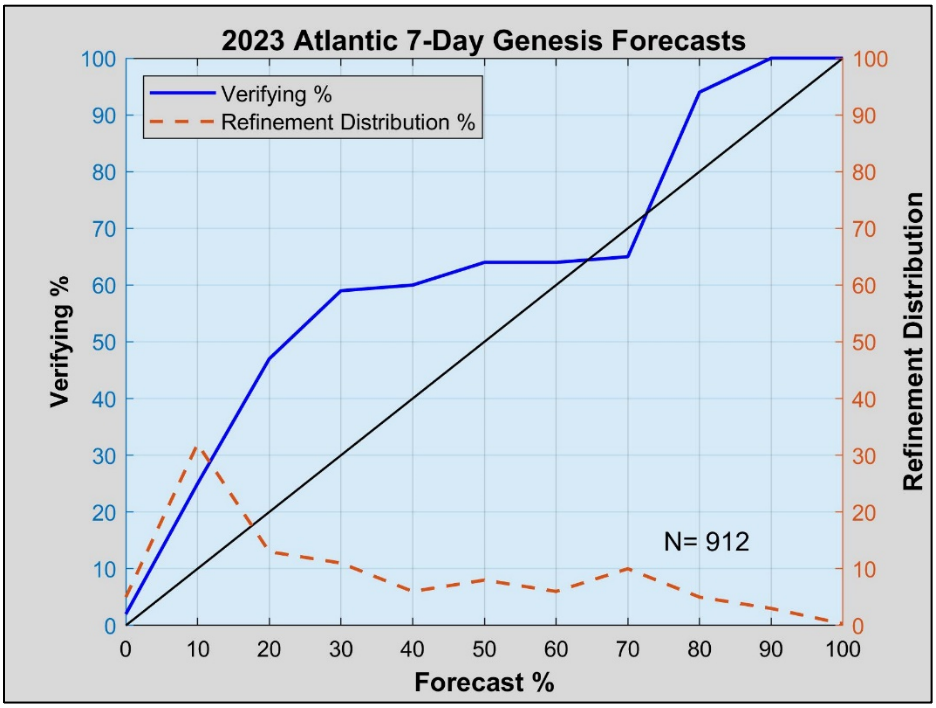


Figure 27. Reliability diagram for Atlantic (top) and eastern North Pacific (bottom) probabilistic tropical cyclogenesis 48-h forecasts for 2023. The solid lines indicate the relationship between the forecasts and verifying genesis percentages, with perfect reliability indicated by the thin diagonal black line. The dashed lines indicate how the forecasts were distributed among the possible forecast values.



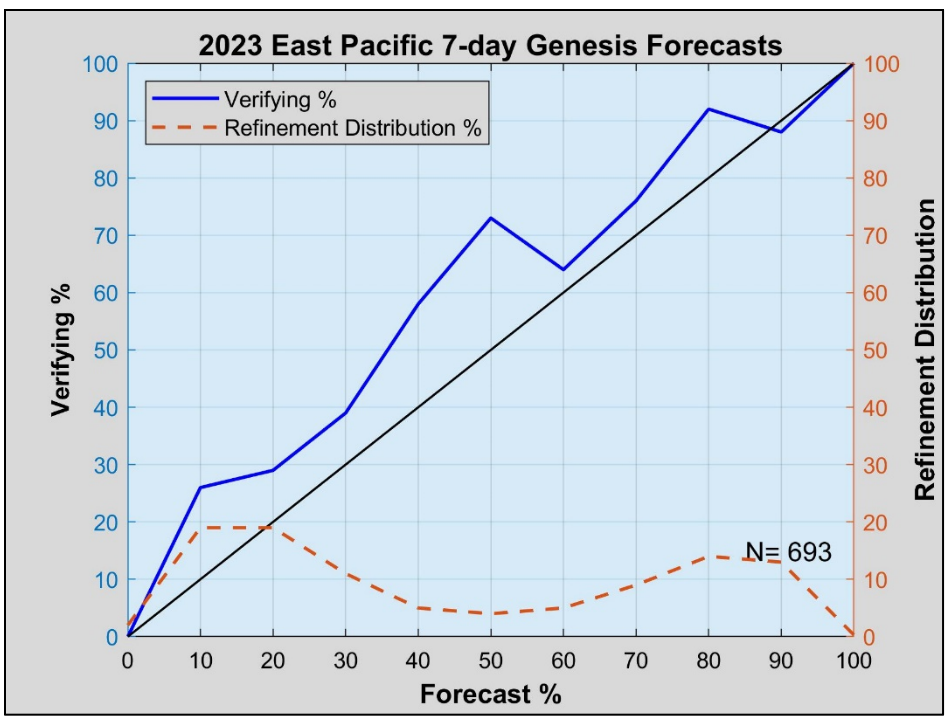


Figure 28. As described for Fig. 27, except for 168-h forecasts.

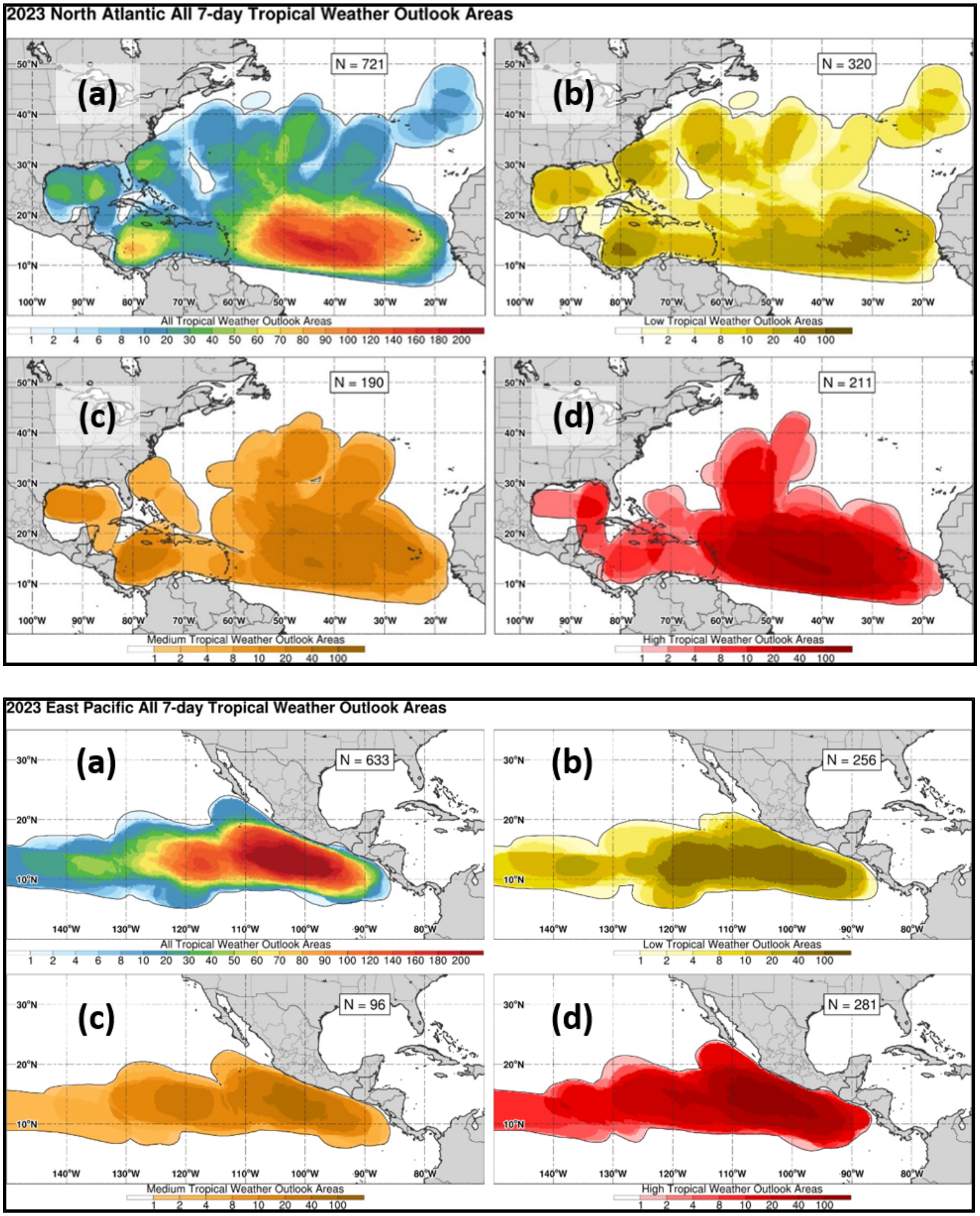


Figure 29. Composites of 7-day tropical cyclone genesis areas depicted in NHC's Tropical Weather Outlooks for the Atlantic and East Pacific basins during the 2023 season for (a) all probabilistic genesis categories, (b) low (<40% category), (c) medium (40–60%) category, and (d) high (> 60% category).