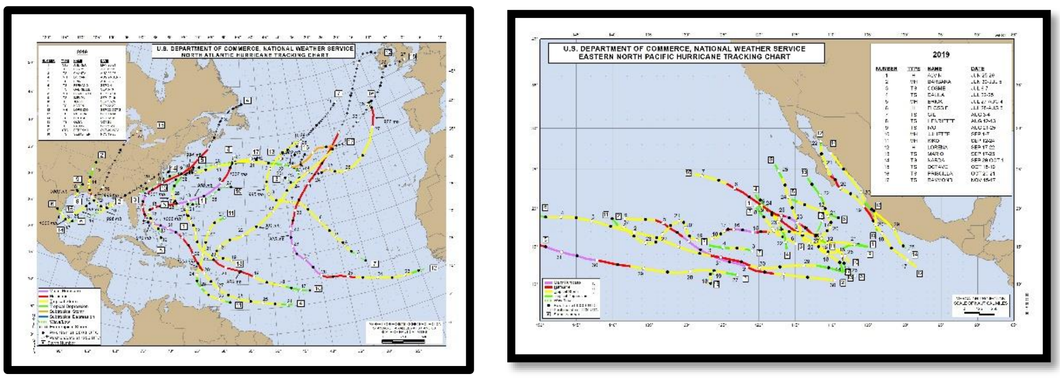
NATIONAL HURRICANE CENTER FORECAST VERIFICATION REPORT

2019 HURRICANE SEASON

John P. Cangialosi
National Hurricane Center

20 April 2020



2019 HURRICANE SEASON TRACK MAP OF THE ATLANTIC BASIN (LEFT) AND THE EASTERN NORTH PACIFIC BASIN (RIGHT).

ABSTRACT

There were 314 official forecasts issued during the 2019 Atlantic hurricane season, which is close to the long-term average number of forecasts. The mean NHC official track forecast errors in the Atlantic basin were a little above the previous 5-yr means for the short lead times, but below the means for the longer forecast times. A record for track accuracy was set at 120 h in 2019. Track forecast skill was slightly lower compared to 2018, but there has been a notable increase in track skill and decrease in error over the long term. The official track forecasts were slightly outperformed by the consensus models and EMXI at some time periods, and EMXI was the best-performing individual model overall. EGRI, AEMI, and CTCI were strong performers, while GFSI, HMNI, HWFI, and NVGI performed less well. The Government Performance and Results Act of 1993 (GPRA) track goal was missed.

Mean official intensity errors for the Atlantic basin in 2019 were similar to or lower than the 5-yr means for the short lead times, but the errors were well above the means at 96 and 120 h. Decay-SHIFOR errors in 2019 were also well above their means at 96 and 120 h, implying that the intensities of 2019's Atlantic basin tropical cyclones were challenging to predict at the long range forecast times. The official forecasts were quite skillful and beat all of the models from 12 to 48 h.

No records for intensity accuracy were set in 2019. Among the guidance, FSSE, IVCN, and HCCA were the best performers. CTCI and HWFI were also good performers, and CTCI was the best overall guidance at 120 h. LGEM and DSHP were fair performers early, but among the best models at 96 and 120 h. GFSI and EMXI had some skill in 2019, but these models were not competitive with the standard intensity models. The GPRA intensity goal was met.

There were 278 official forecasts issued in the eastern North Pacific basin in 2019, although only 62 of these verified at 120 h. This level of forecast activity was well below average and the lowest number of forecasts since 2011. The mean NHC official track forecast errors in the east Pacific basin were a little higher than the previous 5-yr means at most forecast times. No records for track accuracy were set in this basin in 2019. The official track forecasts were very skillful, but they were outperformed by HCCA, TVCE, and FSSE at some time periods. EMXI was the best individual model, and AEMI and EGRI were close behind. GFSI, HWFI, and HMNI were fair performers, but they were not competitive with the best models.

For intensity, the official forecast errors in the eastern North Pacific basin were lower than the 5-yr means for the short lead times, but notably higher than the means for the longer lead times. Conversely, Decay-SHIFOR errors were lower than their 5-yr means at all times, especially the longer lead times. No records for intensity accuracy were set. The official forecasts were close to the consensus models and were skillful through 72 h, but the official forecasts and the consensus aids did not have any skill at 96 and 120 h. DSHP was the best overall model, and it had the highest skill from 72 to 120 h. LGEM, GFSI, and EMXI had more skill than the official forecasts and consensus aids for the longer lead times.

An evaluation of track performance during the 2017-19 period in the Atlantic basin indicates that HCCA and TVCA were the best models, and EMXI was close behind. The official track forecasts for the 3-yr sample had skill that was quite close to the best aids throughout the forecast period. For intensity in the Atlantic basin, the official forecasts have performed quite well and had skill that was comparable to the best guidance, the consensus models. HWFI and LGEM were the best individual models.

A three-year evaluation from 2017-19 in the eastern North Pacific indicates that the official track forecasts were very skillful, and they had skill levels close to the consensus models. Regarding intensity, the official forecasts during the 3-yr sample performed as good as or better than the consensus models in that basin.

Quantitative probabilistic forecasts of tropical cyclogenesis are expressed in 48 and 120 h time frames in 10% increments and in terms of categories ("low", "medium", or "high"). In the Atlantic basin, results from 2019 indicate that the 48-h probabilistic forecasts were generally well calibrated, but a low bias (under-forecast) existed for the 120-h probabilistic forecasts in the low and high categories. In the eastern North Pacific basin, the 48-h and 120-h probabilistic forecasts were well calibrated at most probabilities.

TABLE OF CONTENTS

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, 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 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.

---

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.

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 and 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're 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, personal communication). 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 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

[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.

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. 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).

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

---

[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".

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.[9]

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 FSU "super-ensemble", for example, combines its individual components on the basis of past performance and attempts to correct for biases in those components (Williford et al. 2003). 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[10] on 12 March 2020 for the Atlantic basin, and on 6 February 2020 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 2019 verification and previews anticipated changes for 2020.

2. Atlantic Basin

a. 2019 season overview – Track

Figure 1 and Table 2 present the results of the NHC official track forecast verification for the 2019 season, along with results averaged for the previous 5-yr period, 2014-2018. In 2019, the NHC issued 314 Atlantic basin tropical cyclone forecasts[11], a number close to the long-term average of 322 (Fig. 2). Mean track errors ranged from 24 n mi at 12 h to 148 n mi at 120 h. The mean official track forecast errors in 2019 were slightly larger than the previous 5-yr means from

---

[9] The UKM and EMX models are only available through 120 h twice a day (at 0000 and 1200 UTC). Consequently, roughly half the interpolated forecasts from these models are 12 h old.

[10] In ATCF lingo, these are known as the "a decks" and "b decks", respectively.

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

12 to 48 h, but slightly smaller than the means at the longer forecast periods. The CLIPER errors for 2019 showed a similar pattern, being close to their longer-term means for the shorter lead times, but smaller than the long-term means from 72 to 120 h. A record for track accuracy was set at 120 h in 2019. The official track forecast vector biases were southward or southwestward (i.e., the official forecast tended to fall to the south or southwest of the verifying position), which increased with forecast time. Track forecast skill ranged from 46% at 12 h to 70% at 72 and 96 h (Table 2). The track errors in 2019 increased from the 2018 values at 24 and 48 h, but decreased from 72 to 120 h. Over the past 25 to 30 years, the 24−72-h track forecast errors have been reduced by 70 to 75% (Fig. 3a). Track forecast error reductions of about 60% have occurred over the past 15 years or so for the 96- and 120-h forecast periods. An evaluation of track skill indicates that the skill levels were slightly lower compared to 2018, but there has been a gradual increase in skill over the long term (Fig. 3b). 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.

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[12] verification for the official forecast along with a selection of early models for 2019. In order to maximize the sample size, a guidance model had 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 forecast 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 FSSE and TVCA, which had slightly lower errors than the official forecasts at most time periods. Among the individual models, EMXI was the best-performing aid, and it had similar or slightly higher skill than the official forecasts from 12 to 72 h. EGRI was the next best individual model, but it had less skill than the consensus aids, EMXI, and the official forecasts. AEMI and CTCI were strong performers as well, but GFSI, HMNI, HWFI, and NVGI were less competitive. In fact, the simple TABM had similar skill levels to GFSI/HMNI/HWFI from 12 to 72 h. An evaluation over the three years 2017-19 (Fig. 6) indicates that HCCA and TVCA were the best models, and 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 less skill than the official forecasts and the consensus aids for this sample. EGRI, GFSI, AEMI, and HWFI were fair performers and made up the next best models. NVGI performed less well.

[12] 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.

Vector biases of the guidance models for 2019 are given in Table 3b. The table shows that the official forecast had similar biases to the consensus aids, which all had a south or southwest bias. Although EMXI was very skillful in 2019, that model had a significant south-southwest bias at 96 and 120 h. Figure 7 shows a homogenous comparison of the 120-h biases of the official forecasts, GFSI, EXMI, and EGRI from 2017-19 in the Atlantic basin. It can be seen that mean biases (denoted by the red X) were generally small in most models, but NHC and GFSI had the least bias for that sample. EMXI had a slight slow and right bias and EGRI had a slow and left bias.

A separate homogeneous verification of the primary consensus models for 2019 is shown in Figure 8. The figure shows that FSSE was the most skillful model overall, except at 120 h. TVCA, TVDG, TVCX, and HCCA all had about comparable skill to one another and were the best aids at 120 h. GFEX had slightly less skill and AEMI was notably less skillful than the remainder of the guidance shown.

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 2019, the GPRA goal was 62 n mi and the verification for this measure was 74.7 n mi. It should be noted that Tropical Storm Sebastien late in the year was a big contribution to missing the GPRA goal. Without Sebastien, the average 48-h track error was 56.4 n mi.

b. 2019 season overview – Intensity

Figure 9 and Table 4 present the results of the NHC official intensity forecast verification for the 2019 season, along with results averaged for the preceding 5-yr period. Mean forecast errors in 2019 ranged from 5 kt at 12 h to 26 kt at 120 h. These errors were similar to or slightly lower than the 5-yr means from 12 to 72 h, but well above the mean at 120 h. No records for accuracy were set in 2019. The official forecasts had a slight low bias from 12 to 72 h, but a more notable low bias existed at 96 and 120 h. The Decay-SHIFOR5 errors had a similar pattern to the official forecasts and had substantially higher errors than their long-term means at 96 and 120 h, implying that the intensity of the season's storms was more challenging to predict at days 4 and 5. A closer inspection of the errors and biases indicate that some of the Hurricane Dorian intensity forecasts were far too low and were the primary contributions to the large bias and error at 120 h. Figure 10 indicates that the NHC official errors at 24-72 h held generally steady from 2018, but the 96 and 120 h errors increased significantly, again mostly due to the poor Dorian long-range intensity forecasts. Over the long-term, despite year-to-year variability, there has been a notable 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 5 to 10 years than they were in the 1990's and the first decade of the 2000's.

Table 5a presents a homogeneous verification for the official forecasts and the primary early intensity models for 2019. 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 from 12 to 48 h. The consensus models IVCN, HCCA, and FSSE were the best aids, and they outperformed the official forecasts at some of the longer forecast time periods. Among the individual models, CTCI was a strong performer and it was the best individual model from 48 to 96 h, and the best aid overall at 120 h. HMNI was a good performer early, but its skill trailed after

48 h. Conversely, HWFI's skill increased throughout the forecast period, but it had less skill than CTCI. DSHP and LGEM were less skillful than the dynamical models for the short lead times, but they were among the best models at 96 and 120 h. GFSI and EMXI had some skill in 2019, but these global models were not competitive with the regional hurricane or dynamical-statistical aids. An inspection of the intensity biases (Table 5b) indicates that all of the models had a low bias, especially at the longer forecast times, in 2019. The only models that had less bias than the official forecasts were CTCI at 96 and 120 h, and FSSE at several forecast times.

An evaluation over the three years 2017-19 (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 was the best individual model from 24 to 72 h and LGEM was best at the other forecast times. DSHP had slightly less skill than LGEM. GFSI had marginal skill and EMXI was generally not skillful.

The 48-h official intensity error, evaluated for all tropical cyclones, is another GPRA measure for the NHC. In 2019, the GPRA goal was 12 kt and the verification for this measure was 10.1 kt.

c. Verifications for individual storms

Forecast verifications for individual storms are given in Table 6. Of note are the unusually large track errors for Tropical Storm Sebastien at most verifying forecast lead times. The 48-h official forecasts during the first few days of Sebastien's existence were too fast in lifting the tropical storm northeastward, but forecasts issued on 22 November were far too slow. The typically reliable EMXI and GFSI models exhibited extremely large biases, with EMXI having a slow bias and GFSI taking Sebastien northeastward much too quickly. Conversely, the official track forecast errors were quite low for some of the stronger tropical cyclones, including Humberto and Lorenzo. Figure 13 shows an illustration of the official track errors stratified by storm.

With regards to intensity, Hurricane Dorian was one of the more challenging cyclones to predict in 2019. The official intensity forecast errors were higher than the 5-yr averages at all forecast times, and much higher than the means from 72 to 120 h. The NHC intensity forecasts suffered from a pronounced low bias during those long-range forecast times. 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=2019&basin=atl

3. Eastern North Pacific Basin

a. 2019 season overview – Track

The NHC track forecast verification for the 2019 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 278 forecasts issued for the eastern Pacific basin in 2019, which was the lowest number of forecasts in this basin since 2011, and well below the long-term mean (Fig. 16). Since many of the tropical cyclones in the basin were short-lived, only 62 of the forecasts verified at 120 h. Mean track errors ranged from 25 n mi at 12 h to 134 n mi at 120 h. These errors were a little higher than the 5-yr means at all forecast times, except at 120 h where the error was about the same as the 5-yr mean. The CLIPER errors were also a little higher than their 5-yr means from 12 to 36 h, but the errors from that model were a little lower than their 5-yr means for the 72-120 h period. No records for accuracy were set in this basin in 2019. The official track forecast vector biases were small through 96 h, but a more notable west-southwest bias existed at 120 h.

Figure 17 shows recent trends in track forecast accuracy and skill for the eastern North Pacific. Track errors have been dramatically reduced by about 70% for the 24 to 72 h forecasts since 1990, however, there has been little change in the errors during the past few years. At the 96 and 120 h forecast times, errors have dropped by about 60% since 2001, but like the short lead times, the error trends have been relatively flat during the past few years. Forecast skill in 2019 was lower than the 2018 values at all forecast times, and there appears to be little trend in track skill values during the past several years.

Table 8a presents a homogeneous verification for the official forecast and the early track models for 2019, with vector biases of the guidance models given in Table 8b. Skill comparisons of selected models are shown in Fig. 18. The official forecasts were very skillful and near the best models, the consensus aids. HCCA was the best aid, and it beat the official forecasts from 12 to 96 h. TVCA was the next best model, also beating the official forecasts from 12 to 72 h. FSSE was competitive with TVCE and HCCA early, edging out the official forecasts from 12 to 48 h, but its performance trailed the official forecasts and the best aids at forecast times beyond that. EMXI was the best individual model, and it had skill comparable to the consensus aids at 120 h, but its skill was lower than the official forecasts. EGRI and AEMI were next best, having skill values slightly lower than EMXI. GFSI, HMNI, and HWFI were fair performers, but they were not competitive with the best models. NVGI trailed and had skill that was comparable to the simple TAB models. An evaluation of the three years 2017-19 (Fig. 19) indicates that the official forecasts were very skillful, and they were near the performance of the consensus models. HCCA slightly bested the official forecasts in the short term, but it had about the same amount of skill as the official forecast for the longer lead times. Among the individual models, EMXI was the best performer from 12 to 72 h, but AEMI had slightly more skill at 96 and 120 h. GFSI and HWFI were close behind, but EGRI and CMCI performed less well. The official forecasts had smaller track biases than all of the models at 96 and 120 h in 2019. Among the models, EGRI had a significant west-northwest to northwest bias at 96 and 120 h, and GFSI had a large northeast bias at the same forecast time periods.

A separate verification of the primary consensus aids is given in Figure 20. The skill of the consensus models was tightly clustered, but HCCA, TVCX, and TVDG were the best aids from 12 to 96 h. AEMI was less skillful (about 10% lower skill) than the highest performers, and UEMI had slightly lower skill than AEMI.

b. 2019 season overview – Intensity

Figure 21 and Table 9 present the results of the NHC eastern North Pacific intensity forecast verification for the 2019 season, along with results averaged for the preceding 5-yr period. Mean forecast errors were 5 kt at 12 h and increased to 20 kt at 96 h. The errors were slightly lower than the 5-yr means from 12 to 48 h, but up to 28% higher than the 5-yr means from 72 to 120 h. The Decay-SHIFOR forecast errors were lower than their 5-yr means, especially at 96 and 120 h, where the 2019 errors were up to 47% smaller than normal. It is not common for there to be opposite trends in the NHC and Decay-SHIFOR errors, and further investigation is needed to explore the reasons why that occurred in 2019. No records for accuracy were set. A review of error and skill trends (Fig. 22) indicates that although there is considerable year-to-year variability in intensity errors, there has been a slight decrease in error over the past couple of decades at most forecast times. Forecast skill has changed little during the last several years, however. Intensity forecast biases were slightly high (over-forecast) from 12 to 72 h, and more notably high at 96 and 120 h.

Figure 23 and Table 10a present a homogeneous verification for the primary early intensity models for 2019. Forecast biases are given in Table 10b. The official forecasts were more skillful than all of the guidance at 12 h, but they generally followed the trend of the consensus models after that. The official forecast and the consensus aids were skillful through 72 h, but had no skill at 96 and 120 h. This appears to be partly associated with the low long lead-time Decay-SHIFOR errors. HWFI and HMNI had a fair amount of skill early, but their performance sunk significantly and the skill values turned sharply negative from 72 to 120 h. DSHP was generally the best guidance as it had about a constant level of 15-25% of skill over Decay-SHIFOR through the forecast period. LGEM was slightly less skillful that DSHP, but it also had skill through the period. Although GFSI and EMXI were marginally skillful, they both outperformed the official forecasts, the consensus aids, HMNI and HWFI at the longer forecast times. HWFI, HMNI, the official forecasts, and consensus models all had a high bias at 96 and 120 h, which was likely the reason for their poor performance at those time periods. DSHP had the least bias. An evaluation over the three years 2017-19 (Fig. 24) indicates a very different result than the 2019 sample. The official forecasts outperformed all of the guidance at 12 and 120 h, and they were competitive with the best aids, HCCA and IVCN, at the other forecast times. HWFI was the next best model, followed by DSHP and LGEM. GFSI had little skill while EMXI was not skillful.

c. Verifications for individual storms

Forecast verifications for individual storms are given for reference 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=2019&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. Beginning in 2007, forecasters subjectively assigned 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 period following the nominal TWO issuance time. In 2009, the NHC began producing in-house (non-public) experimental probabilistic tropical cyclone forecasts through 120 h, which became public in August of 2013. 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 2019 are given in Table 12 and illustrated in Figure 25. In the Atlantic basin, a total of 767 genesis forecasts were made. These 48-h forecasts were generally well calibrated, except for a slight low bias at the high probabilities. In the eastern Pacific, a total of 923 genesis forecasts were made. The forecasts in this basin were generally well calibrated, although a slight low bias existed at probabilities between 60 and 80%.

Verification of the 120-h outlook for the Atlantic and eastern North Pacific basins for 2019 are given in Table 13 and illustrated in Figure 26. In the Atlantic basin, the 120-h forecasts were not as well calibrated as the short term genesis forecasts as a low bias existed at the low and high probabilities. In the eastern North Pacific, the genesis forecasts were quite reliable and well calibrated, except for a slight low bias at 50% probability. 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 here suggest an intermediate level of forecaster confidence.

5. Looking Ahead to 2020

a. Track Forecast Cone Sizes

The National Hurricane Center 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 2020 for the Atlantic and eastern North Pacific basins (based on error distributions for 2015-19) are given in Table 14. In the Atlantic basin, the cone circles will be largely unchanged from last year. In the eastern Pacific basin, the cone circles will be slightly larger (by up to 6%) from 36 to 72 h and slightly smaller at 120 h (by 5%). It should be noted that 60-h cone circles are now included, since NHC will be making operational forecasts at that forecast time, and are based on interpolation of the 48- and 72-h cone sizes.

b. Consensus Models

In 2008, NHC changed the nomenclature for many of its consensus models. The new system defines a set of consensus model identifiers that remain fixed from year to year. The specific members of these consensus models, however, 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 2020 is given in Table 15. The consensus models are unchanged from their compositions in 2019.

Acknowledgments

The author gratefully acknowledges Michael Brennan and Monica Bozeman of NHC, managers of the NHC forecast databases.

6. References

Aberson, S. D., 1998: Five-day tropical cyclone track forecasts in the North Atlantic basin. Wea. Forecasting, 13, 1005-1015.

Cangialosi. J.P., and C.W. Landsea, 2016: An examination of model and official National Hurricane Center tropical cyclone size forecasts. Wea. And Forecasting, 31, 1293-1300.

DeMaria, M., J. A. Knaff, and J. Kaplan, 2006: On the decay of tropical cyclone winds crossing narrow landmasses, J. Appl. Meteor., 45, 491-499.

Jarvinen, B. R., and C. J. Neumann, 1979: Statistical forecasts of tropical cyclone intensity for the North Atlantic basin. NOAA Tech. Memo. NWS NHC-10, 22 pp.

Knaff, J.A., M. DeMaria, B. Sampson, and J.M. Gross, 2003: Statistical, five-day tropical cyclone intensity forecasts derived from climatology and persistence. Wea. Forecasting, 18, 80-92.

Neumann, C. B., 1972: An alternate to the HURRAN (hurricane analog) tropical cyclone forecast system. NOAA Tech. Memo. NWS SR-62, 24 pp.

Williford, C.E., T. N. Krishnamurti, R. C. Torres, S. Cocke, Z. Christidis, and T. S. V. Kumar, 2003: Real-Time Multimodel Superensemble Forecasts of Atlantic Tropical Systems of 1999. Mon. Wea. Rev., 131, 1878-1894.

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
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

ID	Name/Description	Type	Timeliness (E/L)	Parameters forecast
TABS	Beta and advection model (shallow layer)	Single-layer trajectory	E	Trk
TABM	Beta and advection model (medium layer)	Single-layer trajectory	E	Trk
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
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

ID	Name/Description	Type	Timeliness (E/L)	Parameters forecast
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
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 HWFI EMXI CTCI	Consensus	E	Trk
TVCA	Average of at least two of GFSI EGRI HWFI EMXI CTCI	Consensus	E	Trk
TVCE	Average of at least two of GFSI EGRI HWFI EMXI CTCI	Consensus	E	Trk
TVCX	EMXI and average of at least two of GFSI EGRI HWFI EMXI CTCI	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 HWFI	Corrected consensus	E	Trk
HCCA	Weighted average of AEMI, GFSI, CTCI, DSHP, EGRI, EMNI, EMXI,HWFI, LGEM	Corrected consensus	E	Trk, Int

ID	Name/Description	Type	Timeliness (E/L)	Parameters forecast
ICON	Average of DSHP, LGEM, CTCI, and HWFI	Consensus	E	Int
IVDR	CTCI (double weight) HWFI (double weight) HMNI (double weight) GFSI DSHP LGEM	Consensus	E	Int
IVCN	Average of at least two of DSHP LGEM HWFI CTCI	Consensus	E	Int

Table 2. Homogenous comparison of official and CLIPER5 track forecast errors in the Atlantic basin in 2019 for all tropical cyclones. Averages for the previous 5-yr period are shown for comparison.

.

	Forecast Period (h)						
	12	24	36	48	72	96	120
2019 mean OFCL error (n mi)	24.7	40.8	58.0	74.7	88.4	115.4	148.3
2019 mean CLIPER5 error (n mi)	45.4	96.5	158.4	214.0	295.4	387.1	473.2
2019 mean OFCL skill relative to CLIPER5 (%)	45.6	57.7	63.4	65.0	70.1	70.2	68.7
2019 mean OFCL bias vector (°/n mi)	250/000	220/005	213/009	194/010	186/027	214/055	234/083
2019 number of cases	279	245	213	187	136	104	78
2014-2018 mean OFCL error (n mi)	24.1	36.3	48.1	63.2	98.2	139.0	183.3
2014-2018 mean CLIPER5 error (n mi)	45.2	98.1	158.0	220.7	341.4	444.0	525.9
2014-2018 mean OFCL skill relative to CLIPER5 (%)	46.7	63.0	69.6	71.4	71.2	68.7	65.1
2014-2018 mean OFCL bias vector (°/n mi)	006/002	345/003	333/004	325/004	322/003	296/006	264/030
2014-2018 number of cases	1308	1173	1044	919	709	544	428
2019 OFCL error relative to 2014-2018 mean (%)	2.5	12.4	20.6	18.2	-10.0	-17.0	-19.1
2019 CLIPER5 error relative to 2014-2018 mean (%)	0.4	-1.6	0.3	-3.0	-13.5	-12.8	-10.0

Table 3a. Homogenous comparison of Atlantic basin early track guidance model errors (n mi) for 2019. Errors smaller than the NHC official forecast are shown in boldface.

Model ID	Forecast Period (h)						
	12	24	36	48	72	96	120
OFCL	23.1	36.3	52.7	70.9	97.6	108.0	119.1
OCD5	39.1	80.4	138.2	197.0	314.4	414.8	514.9
GFSI	25.5	44.5	70.1	101.7	143.6	129.8	166.0
HMNI	27.0	47.5	72.0	104.1	145.1	147.2	177.9
HWFI	26.9	47.7	70.0	101.6	146.8	159.5	208.2
EMXI	23.4	**34.4**	**47.1**	**63.8**	100.9	121.7	142.5
EGRI	24.0	40.9	58.0	73.6	102.7	130.4	156.1
NVGI	29.7	46.0	63.8	82.0	132.7	156.4	195.1
CTCI	24.2	41.8	62.2	81.1	112.7	132.6	190.4
AEMI	26.1	42.6	62.0	82.0	115.1	136.1	180.1
FSSE	**21.5**	**33.8**	**48.2**	**63.3**	**83.3**	**105.6**	136.5
TVCA	**21.8**	**35.2**	**51.2**	**68.6**	98.5	**104.0**	123.1
HCCA	**22.6**	36.5	52.7	72.7	103.6	**102.8**	120.4
TABD	31.4	65.4	111.5	165.8	276.2	372.6	535.5
TABM	28.1	46.8	70.3	91.6	151.2	196.7	246.1
TABS	40.9	82.9	126.1	165.4	248.7	264.0	337.0
# Cases	134	121	108	100	79	58	43

Table 3b. Homogenous comparison of Atlantic basin early track guidance model bias vectors (º/n mi) for 2019.

	Forecast Period (h)						
Model ID	12	24	36	48	72	96	120
OFCL	216/003	216/002	222/003	009/001	180/024	217/038	240/042
OCD5	236/010	248/028	256/044	257/056	243/051	312/011	040/059
GFSI	218/001	234/001	047/004	053/015	108/029	185/015	030/020
HMNI	260/003	263/003	231/005	195/005	177/044	214/080	214/080
HWFI	039/003	039/006	019/006	036/010	170/021	231/068	238/084
EMXI	239/006	239/010	226/018	222/029	211/070	218/082	229/099
EGRI	146/003	112/008	087/013	078/023	109/037	115/031	103/033
NVGI	275/001	101/004	145/011	159/021	186/065	169/051	162/032
CTCI	145/001	125/002	127/003	090/007	140/023	169/031	131/042
AEMI	225/007	227/012	231/016	230/017	201/036	206/026	247/019
FSSE	191/002	182/003	209/005	196/002	182/023	216/024	251/026
TVCA	206/002	197/002	187/002	128/003	169/028	204/039	212/034
HCCA	178/004	169/004	151/004	111/006	171/024	224/043	246/039
TABD	093/009	082/036	078/068	076/107	087/187	094/220	093/334
TABM	207/005	156/009	141/014	139/022	145/048	091/069	067/103
TABS	252/019	241/042	236/066	230/094	219/143	194/098	196/095
# Cases	134	121	108	100	79	58	43

Table 4. Homogenous comparison of official and Decay-SHIFOR5 intensity forecast errors in the Atlantic basin for the 2019 season for all tropical cyclones. Averages for the previous 5-yr period are shown for comparison.

	Forecast Period (h)						
	12	24	36	48	72	96	120
2019 mean OFCL error (kt)	5.2	7.9	9.0	10.1	13.0	17.3	25.6
2019 mean Decay-SHIFOR5 error (kt)	7.0	11.3	14.9	17.9	22.4	30.7	37.6
2019 mean OFCL skill relative to Decay-SHIFOR5 (%)	25.7	30.1	39.6	43.6	42.0	43.6	31.9
2019 OFCL bias (kt)	0.2	-0.6	-1.3	-1.7	-3.2	-7.0	-17.2
2019 number of cases	279	245	213	187	136	104	78
2014-18 mean OFCL error (kt)	5.2	7.7	9.6	10.8	12.9	13.6	13.0
2014-18 mean Decay-SHIFOR5 error (kt)	6.8	10.7	13.9	16.8	20.2	20.8	21.6
2014-18 mean OFCL skill relative to Decay-SHIFOR5 (%)	23.5	28.0	30.9	35.7	36.1	34.6	39.8
2014-18 OFCL bias (kt)	-0.9	-1.2	-1.5	-2.0	-1.7	-1.2	-0.6
2014-18 number of cases	1308	1173	1044	919	709	544	428
2019 OFCL error relative to 2014-18 mean (%)	0.0	2.6	-6.3	-6.5	0.8	27.2	97.0
2019 Decay-SHIFOR5 error relative to 2014-18 mean (%)	2.9	5.6	7.2	6.5	10.9	47.6	74.1

Table 5a. Homogenous comparison of selected Atlantic basin early intensity guidance model errors (kt) for 2019. Errors smaller than the NHC official forecast are shown in boldface.

Model ID	Forecast Period (h)						
	12	24	36	48	72	96	120
OFCL	5.6	8.7	10.0	10.2	13.8	15.7	20.1
OCD5	7.4	11.9	15.7	17.8	22.9	31.3	37.4
HWFI	7.4	10.4	13.1	14.2	15.9	20.7	25.1
HMNI	7.2	10.2	12.3	13.7	20.3	25.8	29.1
CTCI	7.3	10.7	13.1	12.9	15.3	15.9	**17.4**
DSHP	7.1	10.8	13.2	14.5	17.6	19.2	28.6
LGEM	7.2	10.7	12.9	14.5	16.9	16.0	25.5
IVCN	6.5	9.1	10.8	11.3	**13.4**	**14.6**	21.1
FSSE	6.4	9.2	10.5	10.8	**12.8**	**14.5**	**18.3**
HCCA	6.2	9.1	10.4	10.5	**13.3**	16.2	**20.0**
GFSI	7.2	10.5	14.6	17.0	23.3	23.8	30.7
EMXI	8.1	10.9	14.0	16.2	20.9	23.7	29.2
# Cases	143	130	115	107	83	62	47

Table 5b. Homogenous comparison of selected Atlantic basin early intensity guidance model biases (kt) for 2019. Biases smaller than the NHC official forecast are shown in boldface.

	Forecast Period (h)						
Model ID	12	24	36	48	72	96	120
OFCL	-0.3	-0.6	-1.5	-2.2	-4.9	-5.2	-11.4
OCD5	-1.8	-2.5	-5.3	-7.0	-14.4	-21.6	-26.2
HWFI	-2.7	-3.2	-5.3	-7.1	-9.4	-11.2	-17.9
HMNI	-0.7	-2.4	-5.7	-9.5	-16.5	-19.8	-22.5
CTCI	-3.0	-4.1	-4.9	-4.9	-6.7	**-4.1**	**-1.3**
DSHP	-2.2	-3.0	-4.3	-4.5	-6.4	-8.2	-18.8
LGEM	-2.8	-4.0	-4.9	-5.2	-7.1	-9.4	-20.3
IVCN	-2.0	-3.1	-4.7	-5.9	-9.0	-10.2	-16.1
FSSE	-0.4	**-0.1**	**-0.3**	**-0.9**	**-2.4**	**-3.6**	**-8.4**
HCCA	-1.4	-1.9	-3.5	-4.2	-7.3	-8.4	-12.8
GFSI	-2.7	-4.3	-7.0	-9.4	-16.5	-20.8	-30.4
EMXI	-3.8	-5.8	-8.4	-10.9	-17.7	-21.5	-28.6
# Cases	143	130	115	107	83	62	47

Table 6. Official Atlantic track and intensity forecast verifications (OFCL) for 2019 by storm. CLIPER5 (CLP5) and 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: AL012019 ANDREA

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	2	18.2	18.2	2	0.0	0.0
012	1	18.7	54.2	1	5.0	8.0
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
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: AL022019 BARRY

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	16	8.5	8.5	16	2.8	2.8
012	16	13.3	22.7	16	2.8	3.9
024	14	21.6	39.8	14	2.9	4.9
036	12	30.4	64.9	12	3.8	7.6
048	10	41.1	92.4	10	3.0	10.4
072	6	70.6	136.4	6	5.0	4.0
096	2	75.0	128.7	2	7.5	3.5
120	0	-999.0	-999.0	0	-999.0	-999.0

Verification statistics for: AL032019 THREE

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	4	16.5	16.5	4	0.0	1.2
012	2	17.4	63.8	2	2.5	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
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: AL042019 CHANTAL

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	11	6.3	6.3	11	0.0	0.5
012	9	17.7	39.5	9	2.2	4.4
024	7	27.1	108.2	7	3.6	8.4
036	5	23.9	186.6	5	5.0	15.8
048	3	36.4	326.7	3	5.0	25.3
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: AL052019 DORIAN

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	57	4.2	4.4	57	2.7	2.9
012	55	14.3	28.0	55	6.6	8.7
024	53	27.0	67.8	53	10.7	15.3
036	51	38.9	116.8	51	13.1	21.7
048	49	49.5	164.1	49	14.3	25.4
072	45	70.6	269.4	45	17.8	30.4
096	41	109.4	386.3	41	25.7	45.0
120	37	159.7	471.2	37	38.9	54.1

Verification statistics for: AL062019 ERIN

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	11	10.6	10.6	11	0.5	0.5
012	9	43.4	60.7	9	3.9	4.4
024	7	61.6	136.6	7	2.9	8.7
036	5	89.4	213.8	5	3.0	13.2
048	3	104.3	253.3	3	10.0	20.3
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: AL072019 FERNAND

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	7	9.5	9.5	7	1.4	1.4
012	5	29.7	41.4	5	10.0	12.4
024	3	41.4	75.0	3	8.3	10.3
036	1	65.4	97.3	1	15.0	24.0
048	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: AL082019 GABRIELLE

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	27	9.6	10.0	27	0.9	0.9
012	25	28.3	63.1	25	4.4	4.8
024	23	42.8	144.0	23	6.5	7.7
036	21	60.1	233.7	21	6.9	8.2
048	19	78.8	314.8	19	7.4	9.2
072	15	112.5	353.0	15	10.3	9.7
096	11	160.4	452.4	11	7.3	8.0
120	7	184.5	472.5	7	10.0	7.6

Verification statistics for: AL092019 HUMBERTO

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	25	4.6	4.9	25	3.4	3.8
012	23	17.5	36.3	23	5.2	8.1
024	21	29.2	79.3	21	6.2	12.1
036	19	44.6	132.4	19	5.3	15.7
048	17	58.8	190.6	17	8.5	19.9
072	13	93.2	287.9	13	10.8	29.2
096	9	75.5	359.5	9	17.2	41.0
120	5	122.8	424.9	5	21.0	40.0

Verification statistics for: AL102019 JERRY

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	29	7.7	7.7	29	1.6	1.9
012	27	23.9	36.4	27	4.6	7.6
024	25	36.5	65.8	25	8.0	12.4
036	23	44.1	106.6	23	9.8	16.2
048	21	56.9	137.7	21	11.4	20.4
072	17	91.2	202.1	17	9.1	22.1
096	13	124.8	247.0	13	12.7	19.3
120	9	139.8	276.5	9	15.0	19.3

Verification statistics for: AL112019 IMELDA

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	3	3.7	9.4	3	1.7	3.3
012	3	12.7	48.2	3	1.7	2.0
024	3	24.7	74.1	3	3.3	2.7
036	1	52.2	149.7	1	0.0	2.0
048	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: AL122019 KAREN

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	22	13.5	13.5	22	0.9	1.1
012	20	29.3	45.7	20	4.2	5.7
024	18	41.5	91.8	18	4.7	10.0
036	16	47.3	158.3	16	6.9	11.7
048	14	54.7	258.1	14	8.6	15.0
072	10	84.1	493.1	10	10.0	15.5
096	6	218.8	786.3	6	12.5	17.8
120	2	330.0	1082.3	2	22.5	40.0

Verification statistics for: AL132019 LORENZO

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	38	9.8	10.1	38	2.4	2.4
012	36	19.0	32.9	36	7.6	11.1
024	34	25.2	67.2	34	10.7	15.4
036	32	34.0	111.9	32	8.6	15.4
048	30	45.2	150.9	30	8.7	16.3
072	26	68.2	244.5	26	12.7	21.9
096	22	90.5	364.4	22	11.6	23.8
120	18	102.0	521.6	18	11.4	23.7

Verification statistics for: AL142019 MELISSA

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	12	4.6	5.6	12	0.8	0.8
012	10	19.1	43.2	10	3.0	4.3
024	8	21.8	100.7	8	7.5	8.8
036	6	30.3	199.7	6	8.3	15.3
048	4	50.3	307.0	4	8.8	20.8
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: AL152019 FIFTEEN

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	6	17.9	17.9	6	0.0	0.0
012	4	38.6	52.2	4	2.5	1.8
024	2	40.2	58.0	2	7.5	5.5
036	0	-999.0	-999.0	0	-999.0	-999.0
048	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: AL162019 NESTOR

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	3	17.0	17.0	3	1.7	3.3
012	1	50.6	84.3	1	5.0	9.0
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
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: AL172019 OLGA

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	2	0.0	0.0	2	5.0	5.0
012	0	-999.0	-999.0	0	-999.0	-999.0
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
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: AL182019 PABLO

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	11	6.8	6.8	11	0.5	0.5
012	9	46.4	139.3	9	8.3	9.1
024	7	103.2	338.1	7	13.6	12.1
036	5	166.1	550.2	5	19.0	13.8
048	3	185.6	698.2	3	18.3	6.7
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: AL192019 REBEKAH

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	6	3.4	3.4	6	1.7	2.5
012	4	38.0	107.0	4	0.0	2.5
024	2	59.0	222.3	2	2.5	7.0
036	0	-999.0	-999.0	0	-999.0	-999.0
048	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: AL202019 SEBASTIEN

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	22	10.5	10.6	22	0.7	1.4
012	20	55.5	71.6	20	4.8	4.0
024	18	124.4	168.7	18	8.1	5.7
036	16	208.3	301.0	16	9.4	7.7
048	14	295.2	409.4	14	8.2	8.2
072	4	339.6	867.7	4	15.0	9.0
096	0	-999.0	-999.0	0	-999.0	-999.0
120	0	-999.0	-999.0	0	-999.0	-999.0

Table 7. Homogenous comparison of official and CLIPER5 track forecast errors in the eastern North Pacific basin in 2019 for all tropical cyclones. Averages for the previous 5-yr period are shown for comparison.

	Forecast Period (h)						
	12	24	36	48	72	96	120
2019 mean OFCL error (n mi)	24.8	40.3	57.4	74.3	99.7	123.6	134.4
2019 mean CLIPER5 error (n mi)	40.4	78.9	116.0	148.7	199.3	234.2	273.3
2019 mean OFCL skill relative to CLIPER5 (%)	38.6	48.9	50.5	50.0	50.0	47.2	50.8
2019 mean OFCL bias vector (°/n mi)	342/001	314/001	225/003	232/006	261/008	258/007	257/024
2019 number of cases	245	211	180	155	116	86	62
2014-2018 mean OFCL error (n mi)	21.1	32.2	41.9	51.8	75.7	101.2	133.7
2014-2018 mean CLIPER5 error (n mi)	33.9	69.5	108.8	148.4	223.5	285.5	356.5
2014-2018 mean OFCL skill relative to CLIPER5 (%)	37.8	53.7	61.5	65.1	66.1	64.6	62.5
2014-2018 mean OFCL bias vector (°/n mi)	332/003	335/005	343/003	357/004	036/006	049/010	023/012
2014-2018 number of cases	1799	1619	1448	1294	1034	816	627
2019 OFCL error relative to 2014-2018 mean (%)	17.4	25.2	37.0	43.3	31.7	22.1	0.5
2019 CLIPER5 error relative to 2014-2018 mean (%)	19.7	13.5	6.6	0.2	-10.8	-18.0	-23.3

Table 8a. Homogenous comparison of eastern North Pacific basin early track guidance model errors (n mi) for 2019. Errors smaller than the NHC official forecast are shown in boldface.

Model ID	Forecast Period (h)						
	12	24	36	48	72	96	120
OFCL	22.2	35.3	49.2	63.1	86.9	104.1	114.7
OCD5	37.8	75.0	113.5	150.3	191.6	218.9	260.8
GFSI	25.9	40.1	57.2	78.1	124.9	161.9	188.3
HWFI	26.0	43.6	61.7	78.0	115.5	143.8	167.0
HMNI	25.8	41.3	59.5	78.6	121.0	157.6	183.5
EMXI	23.7	38.8	52.4	65.6	92.3	120.8	130.1
EGRI	24.7	40.6	55.3	69.4	92.7	121.7	177.5
NVGI	35.1	60.2	84.0	105.8	154.2	188.2	235.0
AEMI	24.7	39.7	55.9	70.9	101.9	124.6	148.6
FSSE	**21.6**	**33.0**	**46.8**	**60.6**	88.1	115.0	139.4
TVCE	**21.3**	**33.5**	**47.3**	**60.4**	**86.6**	107.0	121.8
HCCA	**20.8**	**31.5**	**43.7**	**55.8**	**80.0**	**102.7**	125.3
TABD	33.9	66.0	99.3	127.1	193.1	267.2	380.1
TABM	27.9	46.6	70.7	89.8	135.4	178.4	217.0
TABS	34.2	65.4	97.9	123.1	161.4	206.0	231.0
# Cases	148	131	116	100	78	59	44

Table 8b. Homogenous comparison of eastern North Pacific basin early track guidance model bias vectors (º/n mi) for 2019.

	Forecast Period (h)						
Model ID	12	24	36	48	72	96	120
OFCL	343/004	339/006	351/005	332/009	337/013	346/017	011/031
OCD5	276/003	247/008	233/007	293/016	334/052	328/071	349/111
GFSI	032/010	037/015	048/023	048/031	056/054	058/089	059/129
HWFI	052/004	071/009	069/014	062/019	075/045	072/073	080/079
HMNI	352/004	009/006	038/010	032/015	045/031	052/063	046/090
EMXI	309/009	291/013	280/014	276/019	265/037	255/063	264/066
EGRI	256/006	244/013	249/020	264/033	276/059	294/075	317/107
NVGI	325/013	302/022	290/029	292/038	318/049	344/068	009/095
AEMI	021/008	016/012	020/015	017/018	039/028	050/048	056/081
FSSE	342/005	007/002	093/004	078/002	102/006	087/022	074/053
TVCE	347/004	349/005	012/006	353/009	008/015	019/028	023/044
HCCA	000/003	006/002	072/003	018/003	035/009	032/022	046/047
TABD	060/005	088/017	093/039	092/063	083/132	074/214	069/327
TABM	351/009	010/015	033/023	041/030	052/053	060/079	064/142
TABS	005/017	014/034	017/049	005/058	340/067	310/060	305/032
# Cases	148	131	116	100	78	59	44

Table 9. Homogenous comparison of official and Decay-SHIFOR5 intensity forecast errors in the eastern North Pacific basin for the 2019 season for all tropical cyclones. Averages for the previous 5-yr period are shown for comparison.

	Forecast Period (h)						
	12	24	36	48	72	96	120
2019 mean OFCL error (kt)	5.2	9.1	11.1	13.3	18.1	19.7	18.4
2019 mean Decay-SHIFOR5 error (kt)	6.8	12.0	15.2	17.1	17.4	15.3	11.7
2019 mean OFCL skill relative to Decay-SHIFOR5 (%)	23.5	24.2	27.0	22.2	-4.0	-28.8	-57.3
2019 OFCL bias (kt)	0.6	0.6	0.9	2.0	5.1	9.9	11.0
2019 number of cases	245	211	180	155	116	86	62
2014-18 mean OFCL error (kt)	6.1	10.0	12.2	13.7	15.4	15.4	15.7
2014-18 mean Decay-SHIFOR5 error (kt)	7.9	13.2	16.8	19.2	21.8	22.8	22.1
2014-18 mean OFCL skill relative to Decay-SHIFOR5 (%)	22.8	24.2	27.4	28.6	29.4	32.4	29.0
2014-18 OFCL bias (kt)	-0.8	-1.3	-2.3	-3.3	-3.9	-4.2	-5.4
2014-18 number of cases	1799	1619	1448	1294	1034	816	627
2019 OFCL error relative to 2014-18 mean (%)	-14.8	-9.0	-9.0	-2.9	17.5	27.9	17.2
2019 Decay-SHIFOR5 error relative to 2014-18 mean (%)	-13.9	-9.0	-9.5	-10.9	-20.2	-32.9	-47.1

Table 10a. Homogenous comparison of eastern North Pacific basin early intensity guidance model errors (kt) for 2019. Errors smaller than the NHC official forecast are shown in boldface.

Model ID	Forecast Period (h)						
	12	24	36	48	72	96	120
OFCL	5.5	9.8	12.0	14.1	16.5	18.3	16.6
OCD5	7.1	12.5	16.3	18.7	17.8	**14.8**	**12.0**
HWFI	7.0	10.1	12.1	14.6	19.5	23.3	23.1
HMNI	7.3	11.1	14.1	17.1	21.0	22.0	19.6
DSHP	6.4	10.4	12.8	14.4	**14.6**	**11.1**	**9.1**
LGEM	6.8	11.2	14.0	15.7	**15.1**	**13.0**	**10.1**
IVCN	6.0	**9.2**	**11.3**	**13.2**	**14.7**	**15.2**	**15.0**
HCCA	6.0	**9.2**	**11.2**	**12.9**	**15.5**	**17.4**	**16.4**
FSSE	6.0	**9.4**	**11.7**	**13.8**	**15.8**	**16.2**	**16.0**
GFSI	7.5	11.8	14.7	16.2	16.8	**14.2**	**11.9**
EMXI	8.7	14.3	17.4	18.8	16.9	**12.9**	**11.3**
# Cases	171	151	133	112	86	66	48

Table 10b. Homogenous comparison of eastern North Pacific basin early intensity guidance model biases (kt) for 2019. Biases smaller than the NHC official forecast are shown in boldface.

	Forecast Period (h)						
Model ID	12	24	36	48	72	96	120
OFCL	1.0	1.0	1.2	2.4	5.6	9.5	9.9
OCD5	**-0.1**	-1.1	-3.7	-5.2	**-2.0**	**3.3**	**9.4**
HWFI	-2.8	-3.3	-3.0	**-1.0**	**4.6**	**8.8**	11.0
HMNI	**-0.5**	-1.4	-1.7	**-0.9**	**5.4**	10.6	**9.7**
DSHP	**0.1**	**-0.6**	-1.5	**-1.9**	**-1.6**	**-0.3**	**1.8**
LGEM	**-0.8**	-3.6	-6.5	-8.0	-7.1	**-6.5**	**-6.2**
IVCN	-1.0	-2.2	-3.1	-2.8	**0.8**	**3.3**	**3.7**
HCCA	**0.5**	**0.5**	**0.1**	**1.2**	**4.2**	**7.2**	**6.0**
FSSE	**0.8**	1.6	1.9	2.7	6.1	**9.1**	**9.2**
GFSI	-2.1	-4.1	-6.0	-5.9	**-3.2**	**-1.2**	**-0.6**
EMXI	-3.1	-5.9	-8.2	-9.6	-8.2	**-4.2**	**-1.3**
# Cases	171	151	133	112	86	66	48

Table 11. Official eastern North Pacific track and intensity forecast verifications (OFCL) for 2019 by storm. CLIPER5 (CLP5) and 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: EP012019 ALVIN

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	14	9.2	9.2	14	0.4	0.4
012	12	35.2	50.5	12	3.3	6.0
024	10	60.9	101.3	10	7.0	8.1
036	8	83.0	142.0	8	10.6	10.8
048	6	108.3	163.4	6	16.7	15.3
072	2	81.5	51.6	2	20.0	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: EP022019 BARBARA

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	22	3.4	3.1	22	0.7	0.7
012	20	10.1	23.5	20	6.0	6.8
024	18	13.9	52.1	18	10.8	14.7
036	16	15.6	84.8	16	14.7	22.6
048	14	21.6	122.2	14	17.1	28.0
072	10	40.9	188.9	10	12.5	28.7
096	6	76.8	263.2	6	10.8	18.7
120	2	151.1	166.0	2	25.0	7.5

Verification statistics for: EP032019 COSME

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	6	4.6	4.6	6	0.8	0.8
012	4	30.5	37.3	4	7.5	8.0
024	2	51.2	83.6	2	10.0	12.5
036	0	-999.0	-999.0	0	-999.0	-999.0
048	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: EP042019 FOUR

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	5	5.2	5.2	5	0.0	0.0
012	3	17.8	35.7	3	1.7	5.0
024	1	31.1	74.5	1	0.0	15.0
036	0	-999.0	-999.0	0	-999.0	-999.0
048	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: EP052019 DALILA

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	13	8.0	8.0	13	0.8	0.8
012	11	15.3	23.3	11	1.4	3.4
024	9	26.3	31.0	9	2.2	5.0
036	7	39.0	36.8	7	1.4	5.3
048	5	40.1	41.3	5	2.0	3.8
072	1	45.5	119.3	1	0.0	16.0
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: EP062019 ERICK

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	11	14.1	14.6	11	1.8	1.8
012	11	37.2	43.5	11	6.4	8.8
024	11	56.9	77.1	11	10.9	17.2
036	11	79.2	109.9	11	10.9	25.7
048	11	98.6	138.8	11	12.3	32.5
072	11	123.9	164.1	11	19.1	29.9
096	11	127.0	159.3	11	15.0	21.7
120	11	150.7	166.9	11	5.0	15.7

Verification statistics for: EP072019 FLOSSIE

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	22	8.3	8.3	22	0.5	0.5
012	22	20.1	36.7	22	4.3	4.8
024	22	31.1	67.6	22	8.4	7.4
036	22	38.6	93.3	22	10.7	9.0
048	22	51.1	116.6	22	14.8	9.7
072	22	77.6	162.0	22	23.6	12.7
096	18	84.8	222.8	18	32.5	16.1
120	14	80.5	285.0	14	37.9	17.2

Verification statistics for: EP082019 GIL

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	6	5.2	5.2	6	0.8	0.8
012	4	22.2	38.8	4	5.0	9.8
024	2	41.6	97.4	2	5.0	13.5
036	0	-999.0	-999.0	0	-999.0	-999.0
048	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: EP092019 HENRIETTE

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	6	4.1	4.1	6	1.7	1.7
012	4	16.1	15.7	4	2.5	4.2
024	2	26.8	25.6	2	2.5	6.0
036	0	-999.0	-999.0	0	-999.0	-999.0
048	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: EP102019 IVO

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	15	8.1	8.1	15	3.0	2.7
012	13	34.2	51.1	13	2.3	4.4
024	11	55.7	108.7	11	4.5	8.3
036	9	62.3	196.5	9	10.0	12.0
048	7	74.3	333.3	7	12.1	19.0
072	3	93.7	469.3	3	16.7	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: EP112019 JULIETTE

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	24	5.4	5.4	24	1.2	1.5
012	22	14.5	29.3	22	5.7	9.2
024	20	24.5	61.3	20	9.0	15.6
036	18	37.5	92.2	18	10.3	16.7
048	16	52.9	108.3	16	9.7	16.3
072	12	98.0	107.5	12	9.2	12.1
096	8	139.9	62.5	8	10.6	12.6
120	4	144.4	138.8	4	8.8	8.0

Verification statistics for: EP122019 AKONI

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	1	18.0	21.5	1	0.0	0.0
012	1	37.9	81.8	1	5.0	9.0
024	1	30.6	111.3	1	0.0	9.0
036	1	118.6	105.9	1	5.0	4.0
048	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: EP132019 KIKO

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	49	8.7	8.9	49	0.6	0.6
012	47	19.0	37.0	47	6.4	8.1
024	45	28.4	76.8	45	12.0	14.5
036	43	39.5	118.7	43	14.7	17.7
048	41	53.1	159.4	41	16.5	18.5
072	37	80.3	231.5	37	19.6	16.9
096	33	108.8	263.2	33	17.3	11.3
120	29	135.1	327.0	29	14.1	7.4

Verification statistics for: EP142019 MARIO

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	22	10.9	11.4	22	1.1	1.1
012	20	27.1	48.2	20	5.2	4.8
024	18	50.7	97.3	18	8.1	9.6
036	16	82.2	145.3	16	7.5	11.7
048	14	126.1	198.7	14	10.0	12.2
072	10	177.3	317.2	10	14.0	17.4
096	6	236.7	411.0	6	28.3	23.2
120	2	375.3	375.1	2	30.0	26.5

Verification statistics for: EP152019 LORENA

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	20	8.2	8.2	20	2.5	2.8
012	18	27.5	40.0	18	7.5	8.4
024	16	57.7	76.6	16	12.8	9.9
036	14	105.8	103.0	14	12.1	9.9
048	12	148.4	105.5	12	11.7	9.1
072	8	210.3	149.6	8	22.5	10.0
096	4	278.6	285.4	4	13.8	15.0
120	0	-999.0	-999.0	0	-999.0	-999.0

Verification statistics for: EP162019 NARDA

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	10	21.7	21.9	10	2.0	2.0
012	8	55.5	85.3	8	7.5	7.5
024	6	74.9	157.0	6	9.2	12.3
036	4	135.4	294.3	4	8.8	10.8
048	2	228.3	507.4	2	5.0	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

Verification statistics for: EP172019 SEVENTEEN

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	0	-999.0	-999.0	0	-999.0	-999.0
012	0	-999.0	-999.0	0	-999.0	-999.0
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
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: EP182019 OCTAVE

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	8	7.9	7.9	8	0.0	0.0
012	6	27.7	49.9	6	3.3	7.8
024	4	35.6	116.3	4	3.8	18.5
036	2	34.5	216.5	2	2.5	23.5
048	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: EP192019 PRISCILLA

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	4	11.2	11.2	4	2.5	2.5
012	2	28.5	69.1	2	5.0	8.0
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
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: EP202019 RAYMOND

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	11	5.9	5.9	11	0.9	0.9
012	10	41.8	58.4	10	6.0	5.2
024	8	75.7	107.9	8	7.5	9.9
036	6	100.9	97.3	6	7.5	13.2
048	4	107.9	92.8	4	7.5	19.5
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: EP212019 TWENTY-ONE

VT (h)	NT	OFCL	OCD5	NI	OFCL	OCD5
000	9	10.3	13.6	9	0.0	0.0
012	7	41.3	42.2	7	2.9	7.1
024	5	75.3	72.7	5	8.0	19.6
036	3	122.4	90.0	3	10.0	33.7
048	1	174.5	21.3	1	10.0	51.0
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 2019.

Atlantic Basin Genesis Forecast Reliability Table		
Forecast Likelihood (%)	**Verifying Genesis Occurrence Rate (%)**	**Number of Forecasts**
0	1	393
10	20	162
20	25	67
30	47	32
40	38	24
50	59	22
60	56	27
70	83	18
80	100	11
90	100	10
100	100	1

Table 12b. Verification of 48-h probabilistic genesis forecasts for the eastern North Pacific basin in 2019.

Eastern North Pacific Basin Genesis Forecast Reliability Table		
Forecast Likelihood (%)	**Verifying Genesis Occurrence Rate (%)**	**Number of Forecasts**
0	3	500
10	8	155
20	20	91
30	41	58
40	32	31
50	57	23
60	72	18
70	85	13
80	92	13
90	81	21
100	-	0

Table 13a. Verification of 120-h probabilistic genesis forecasts for the Atlantic basin in 2019.

Atlantic Basin Genesis Forecast Reliability Table		
Forecast Likelihood (%)	**Verifying Genesis Occurrence Rate (%)**	**Number of Forecasts**
0	20	70
10	19	260
20	43	145
30	78	72
40	35	49
50	38	47
60	51	41
70	60	30
80	100	21
90	100	31
100	100	1

Table 13b. Verification of 120-h probabilistic genesis forecasts for the eastern North Pacific basin in 2019.

Eastern North Pacific Basin Genesis Forecast Reliability Table		
Forecast Likelihood (%)	**Verifying Genesis Occurrence Rate (%)**	**Number of Forecasts**
0	5	160
10	12	173
20	26	144
30	35	132
40	41	70
50	69	80
60	52	25
70	79	42
80	87	39
90	88	58
100	-	0

Table 14. NHC forecast cone circle radii (n mi) for 2020. Change from 2019 values expressed in n mi and percent are given in parentheses.

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%)	25 (0: 0%)
24	41 (0: 0%)	38 (0: 0%)
36	55 (1: 2%)	51 (3: 6%)
48	69 (1: 2%)	65 (3: 5%)
72	103 (1: 1%)	91 (3: 3%)
96	151 (0: 0%)	115 (0: 0%)
120	196 (-2: -1%)	138 (7: -5%)

Table 15. Composition of NHC consensus models for 2020. It is intended that TVCA would be the primary consensus aids for the Atlantic basin and TVCE would be primary for the eastern Pacific.

NHC Consensus Model Definitions For 2020			
Model ID	**Parameter**	**Type**	**Members**
GFEX	Track	Fixed	GFSI EMXI
ICON	Intensity	Fixed	DSHP LGEM HWFI CTCI HMNI
TVCA**	Track	Variable	GFSI EGRI HWFI EMXI CTCI
TVCE	Track	Variable	GFSI EGRI HWFI EMXI CTCI HMNI EMNI
TVDG	Track	Variable	GFSI (double weight) EMXI (double weight) EGRI (double weight) CTCI HWFI
TVCX	Track	Variable	EMXI (double weight) GFSI EGRI HWFI
IVCN	Intensity	Variable	DSHP LGEM HWFI CTCI HMNI
IVDR	Intensity	Variable	CTCI (double weight) HWFI (double weight) HMNI (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 2019 (solid lines) and 2014-2018 (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 2019. 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 2017-19.

25. Reliability diagram for Atlantic (top) and eastern North Pacific (bottom) probabilistic tropical cyclogenesis 48-h forecasts for 2019. 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.

26. As described for Fig. 25, but for 120-h forecasts.

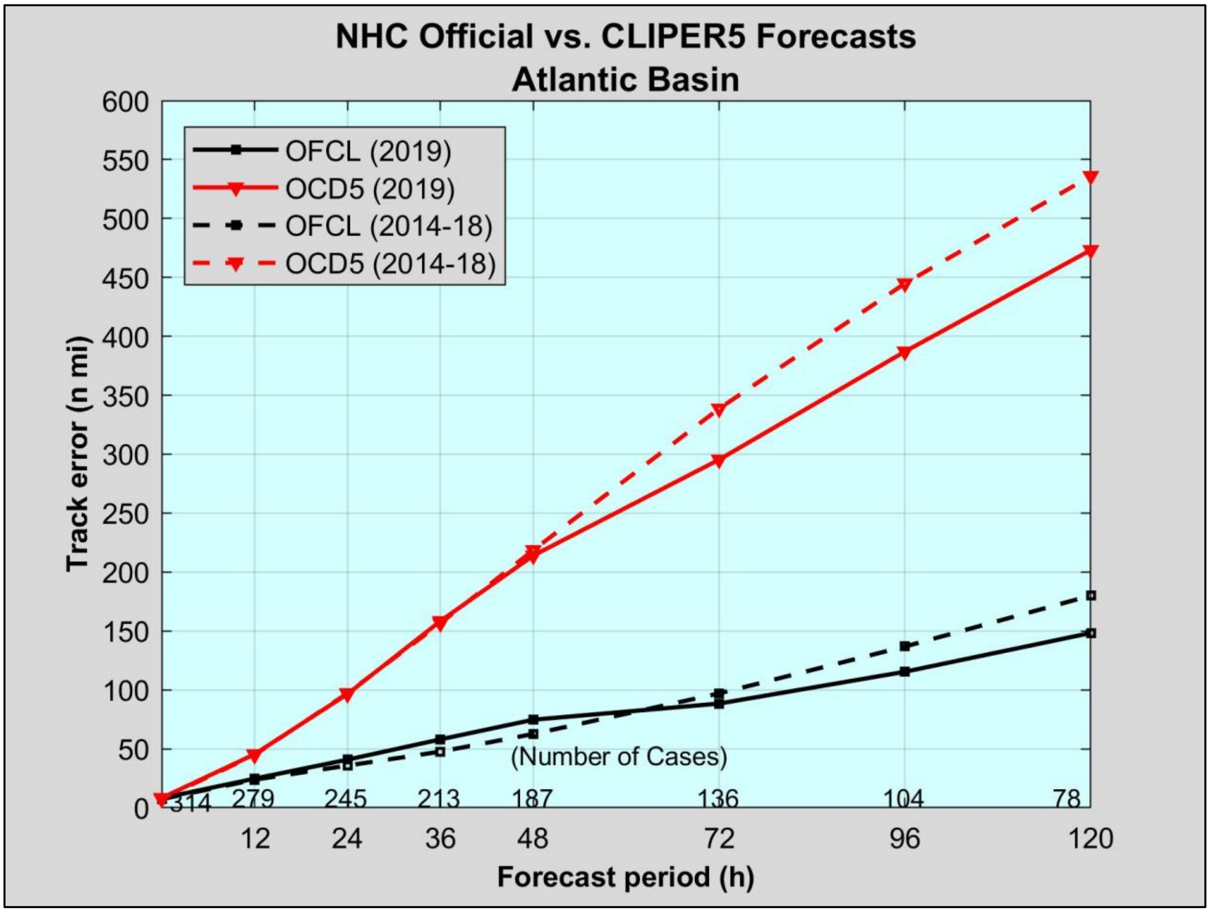


Figure 1. NHC official and CLIPER5 (OCD5) Atlantic basin average track errors for 2019 (solid lines) and 2014-2018 (dashed lines).

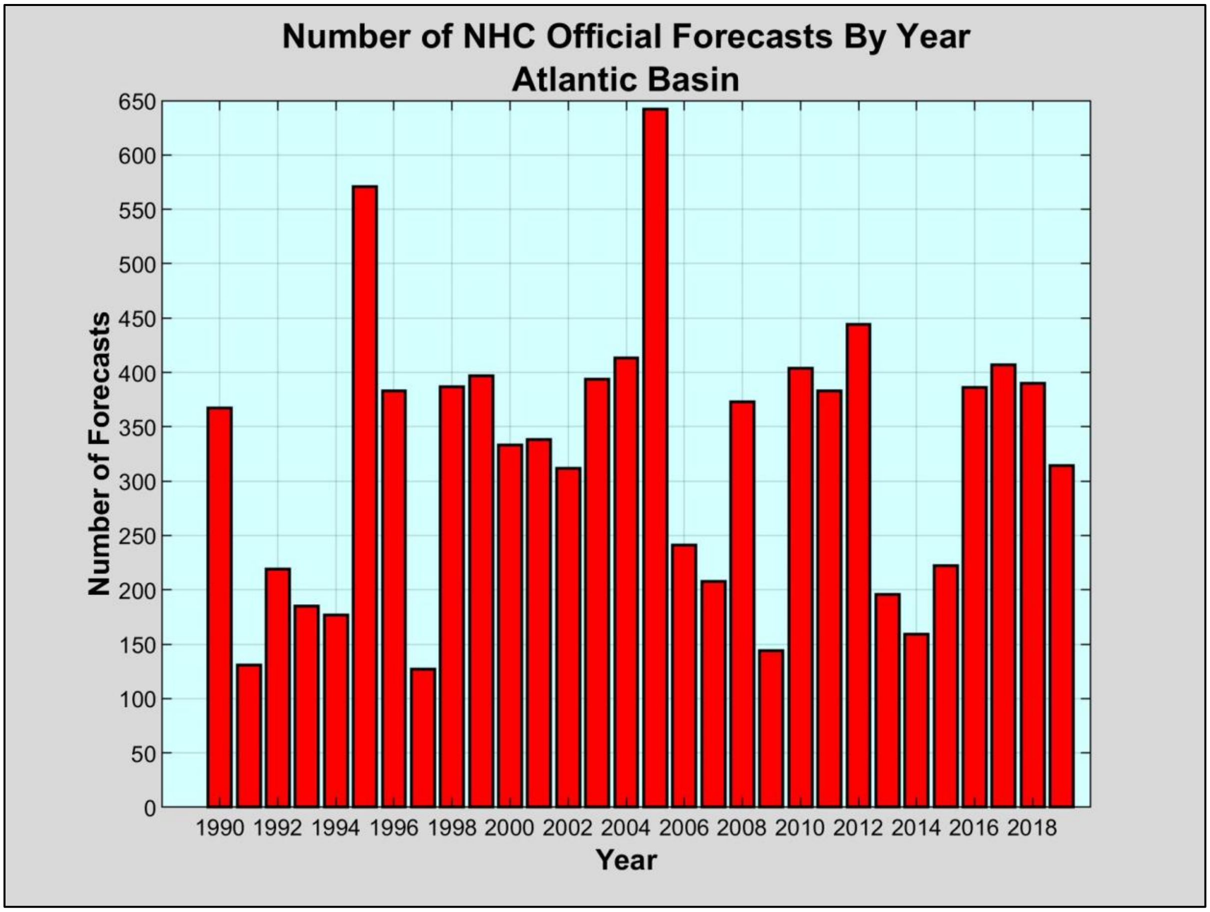
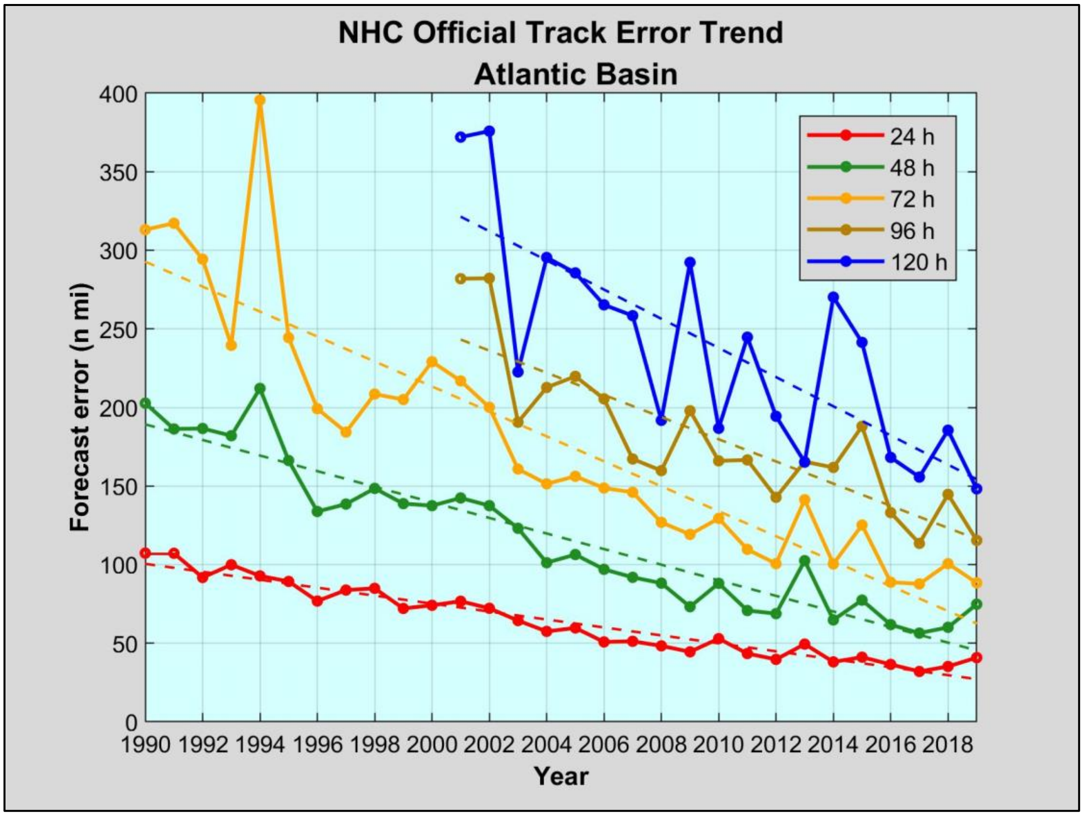


Figure 2. Number of NHC official forecasts for the Atlantic basin stratified by year.



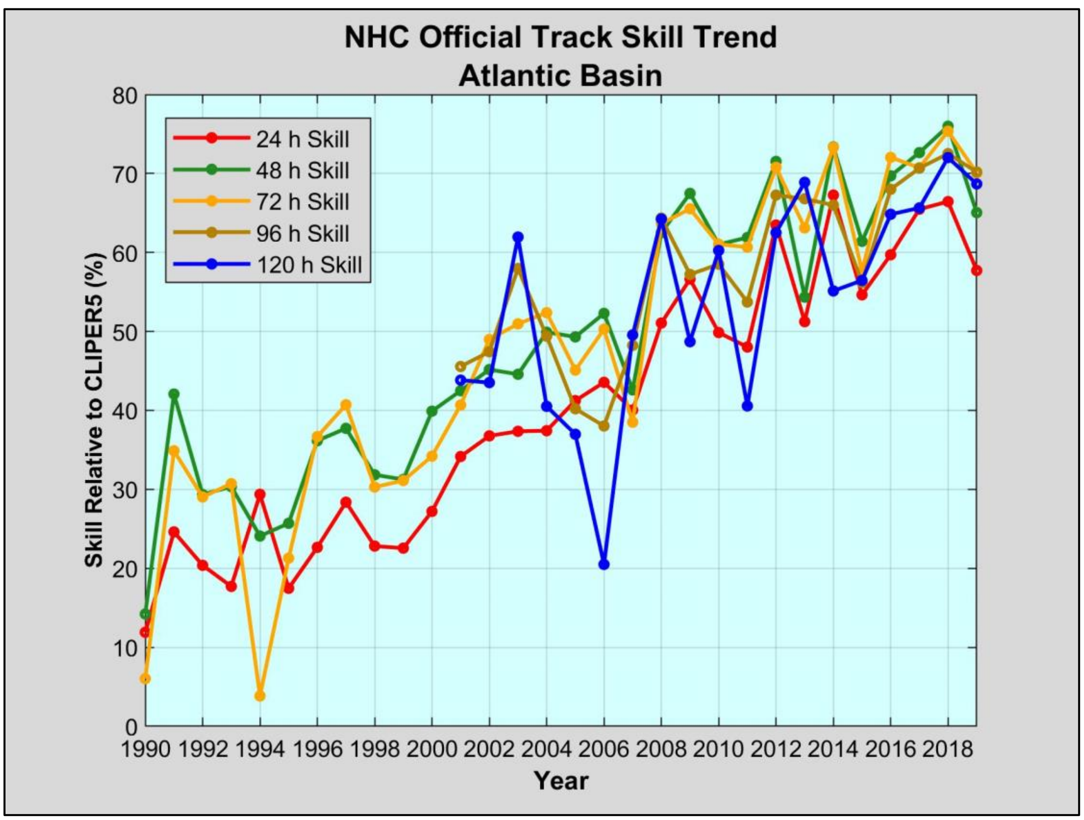


Figure 3. Recent trends in NHC official track forecast error (top) and skill (bottom) for the Atlantic basin.

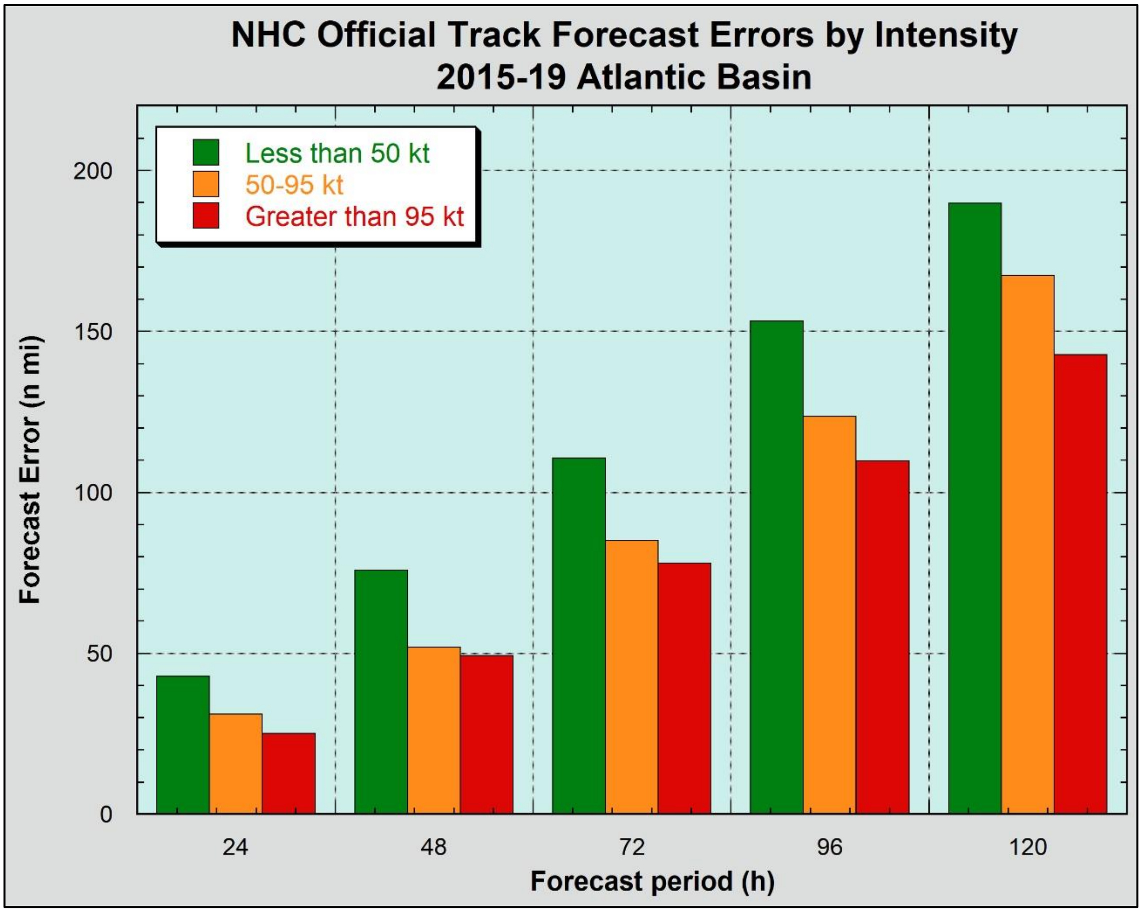


Figure 4. 2015-19 NHC official track forecast error binned by initial intensity for the Atlantic basin.

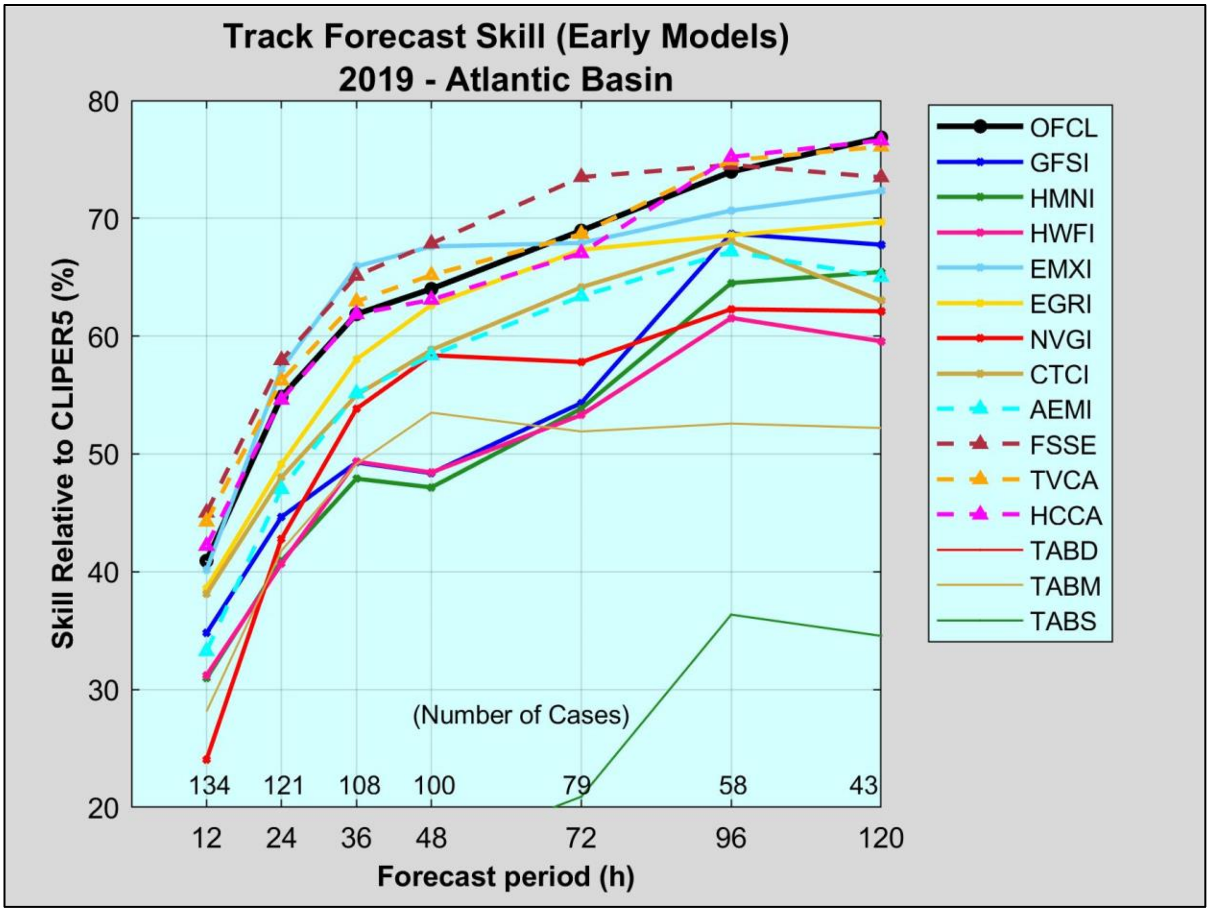


Figure 5. Homogenous comparison for selected Atlantic basin early track models for 2019. This verification includes only those models that were available at least 2/3 of the time (see text).

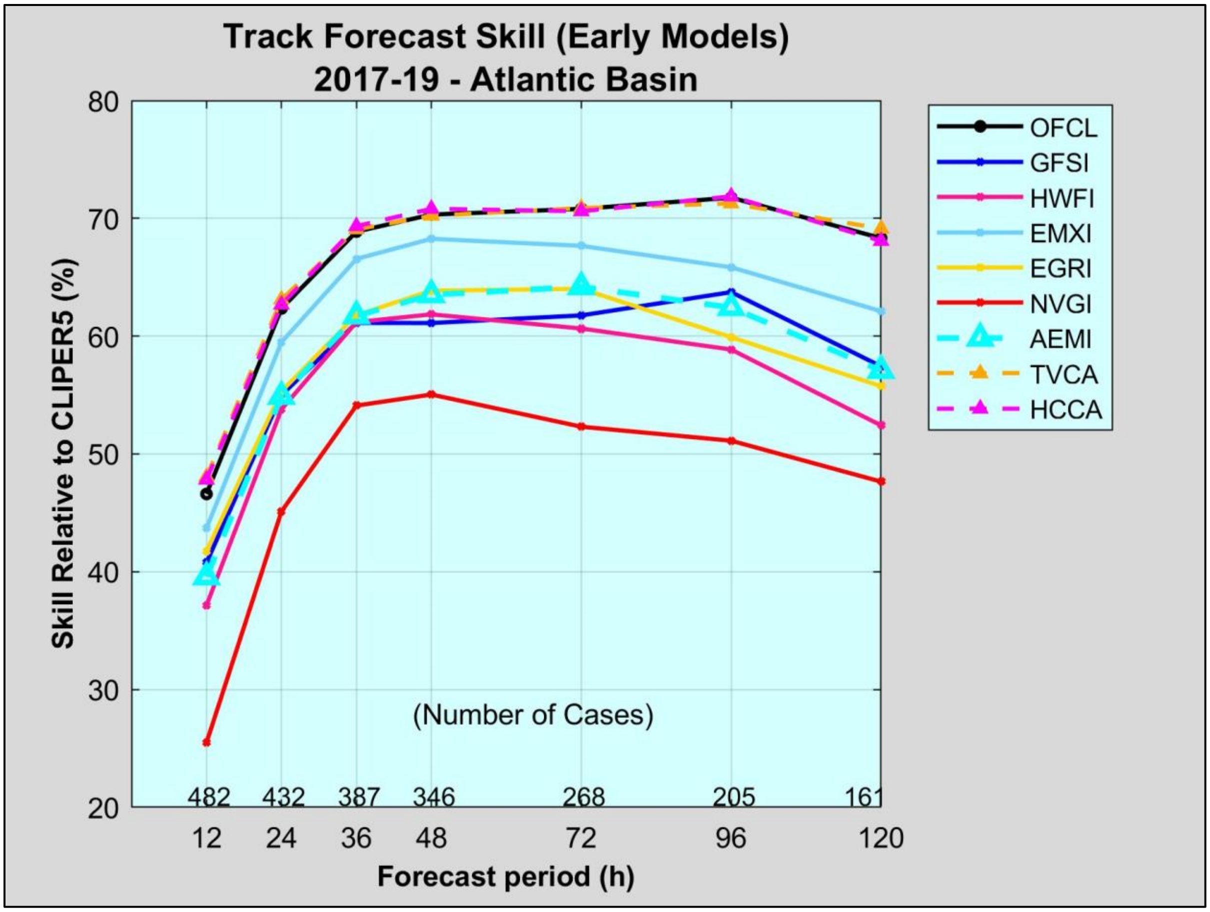


Figure 6. Homogenous comparison for selected Atlantic basin early track models for 2017-2019.

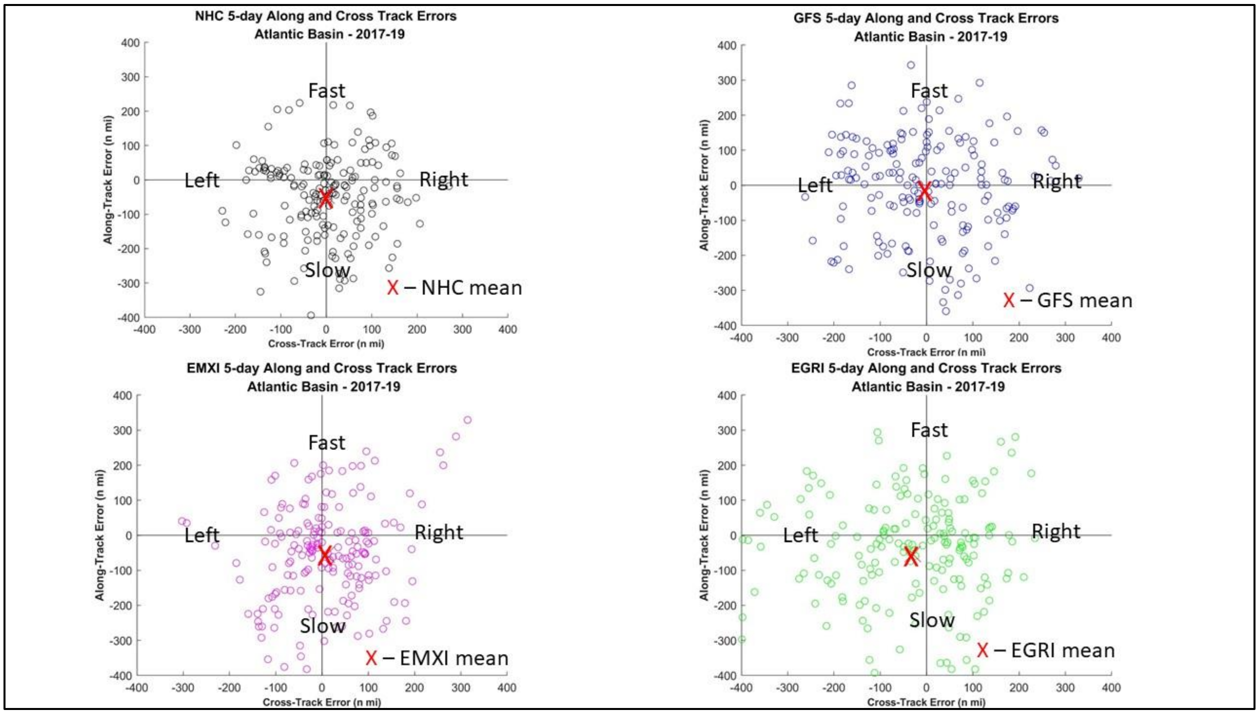


Figure 7. Homogenous comparison of OFCL, GFSI, EMXI, EGRI model track biases (n mi) at verifying 120-h forecasts for the Atlantic basin during the 2017-19 period. The red 'X' depicts the mean bias for each model.

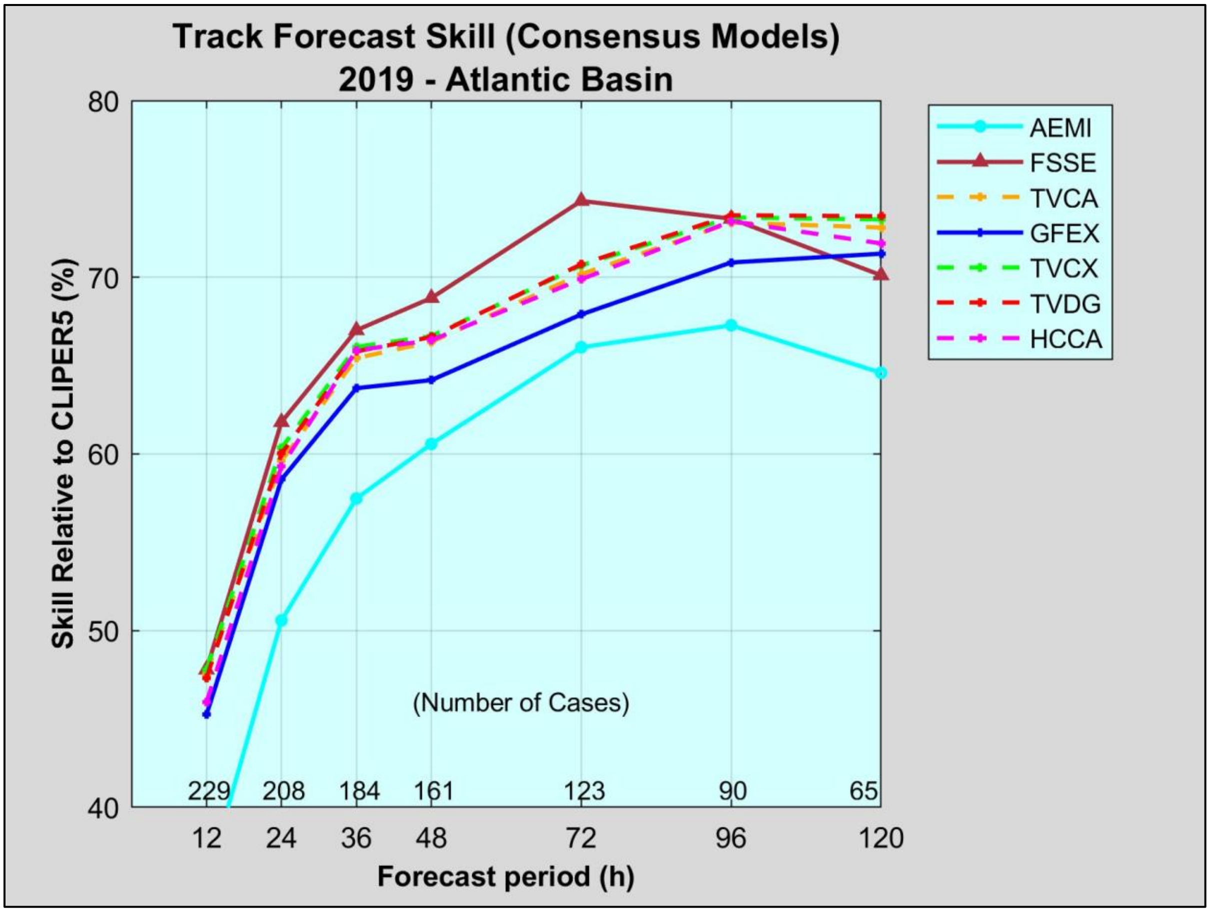


Figure 8. Homogenous comparison of the primary Atlantic basin track consensus models for 2019.

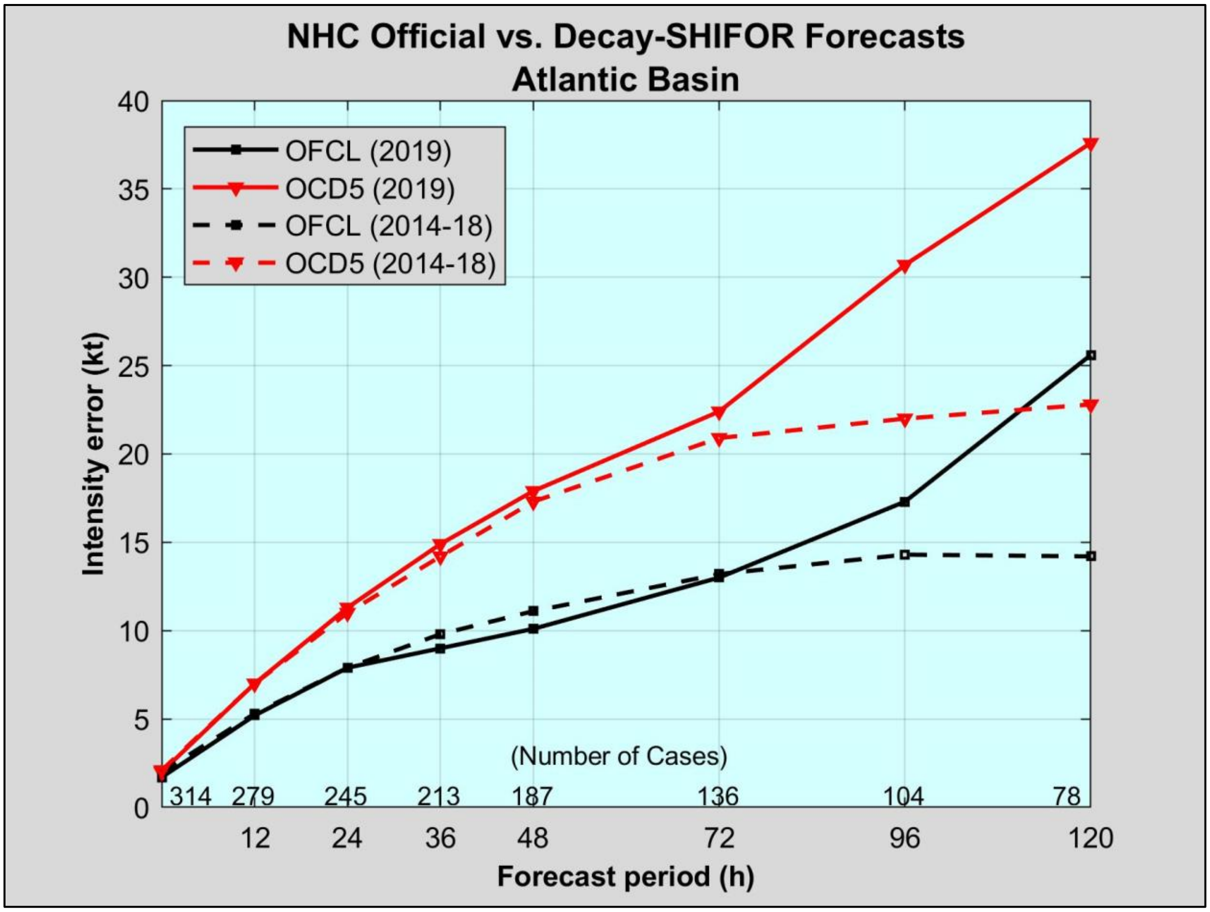
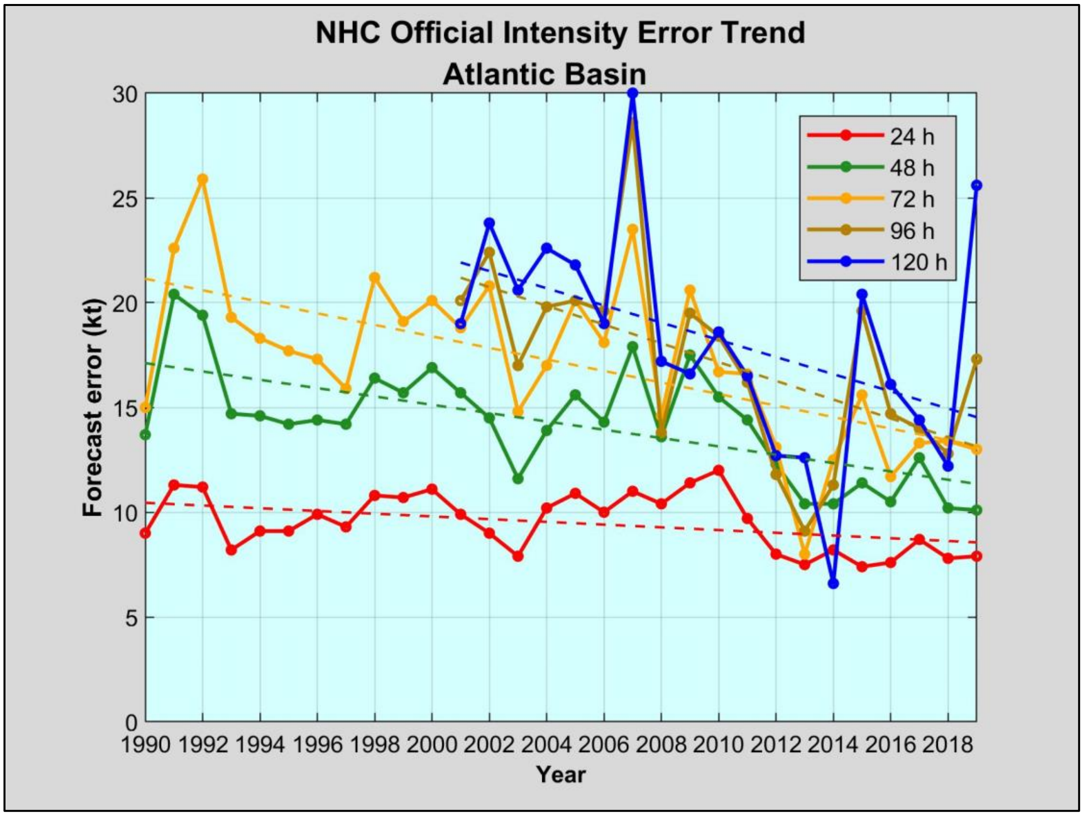


Figure 9. NHC official and Decay-SHIFOR5 (OCD5) Atlantic basin average intensity errors for 2019 (solid lines) and 2014-2018 (dashed lines).



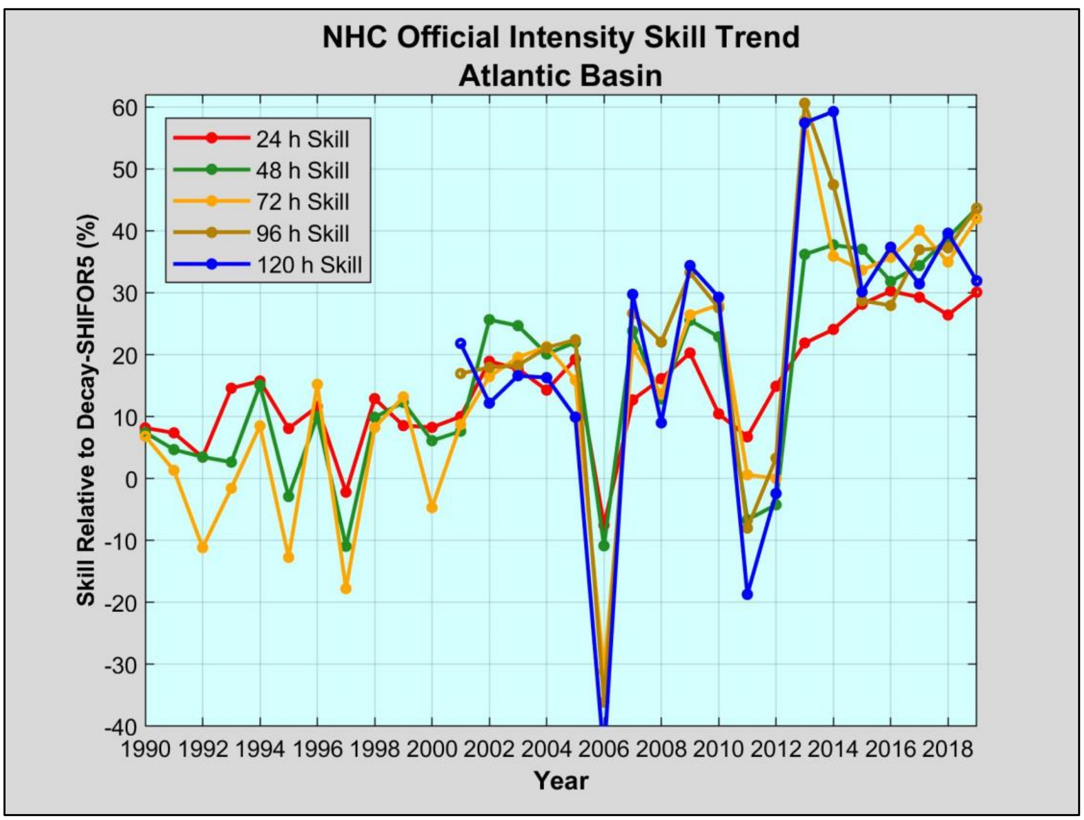


Figure 10. Recent trends in NHC official intensity forecast error (top) and skill (bottom) for the Atlantic basin.

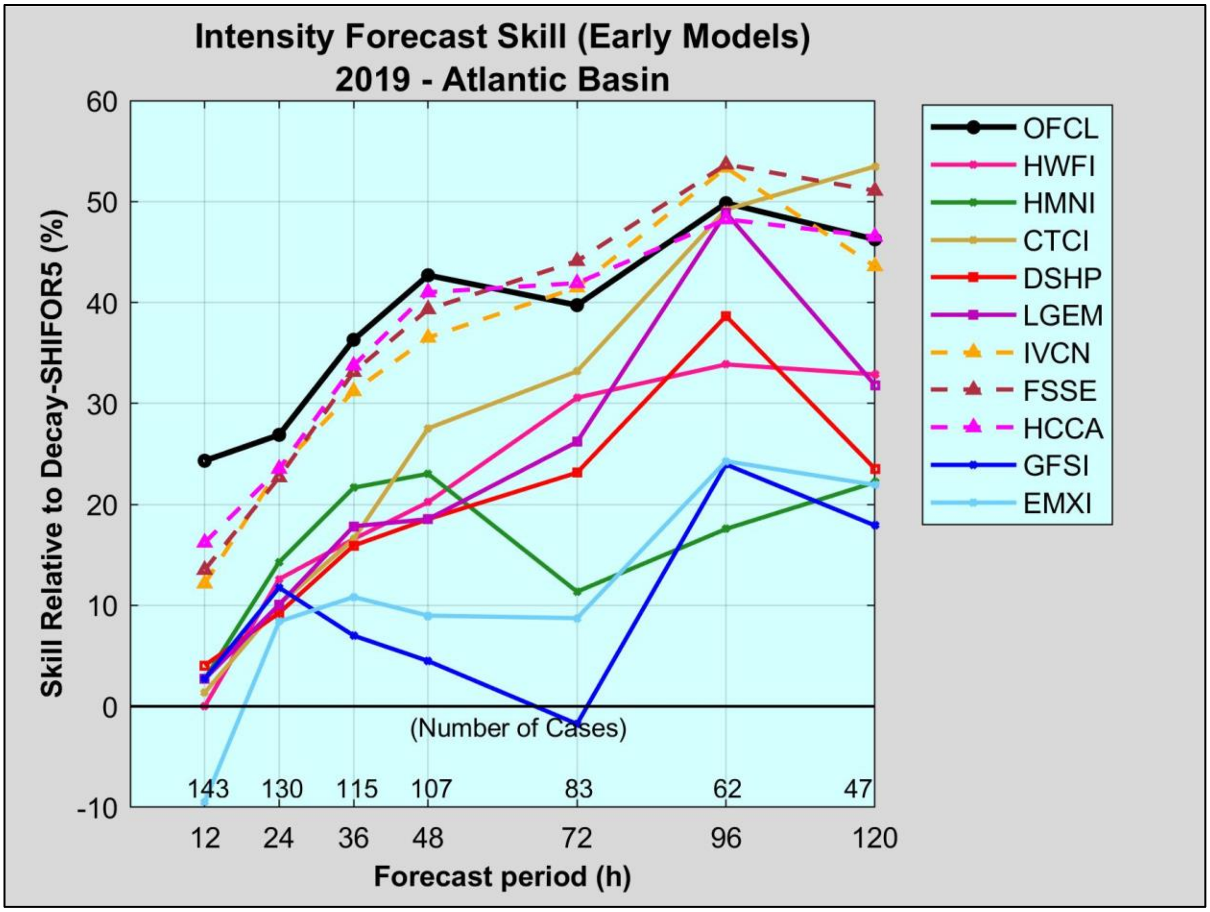


Figure 11. Homogenous comparison for selected Atlantic basin early intensity guidance models for 2019.

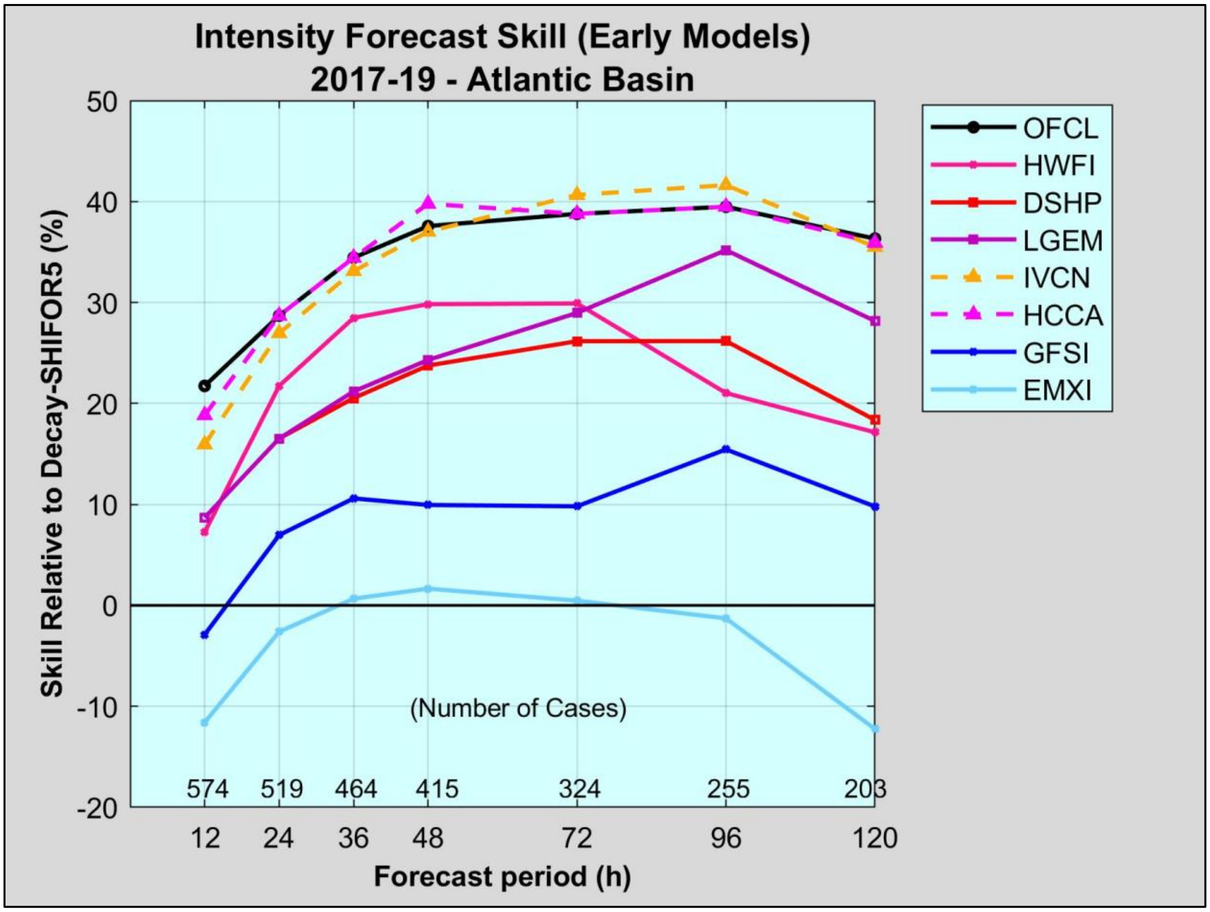


Figure 12. Homogenous comparison for selected Atlantic basin early intensity guidance models for 2017-2019.

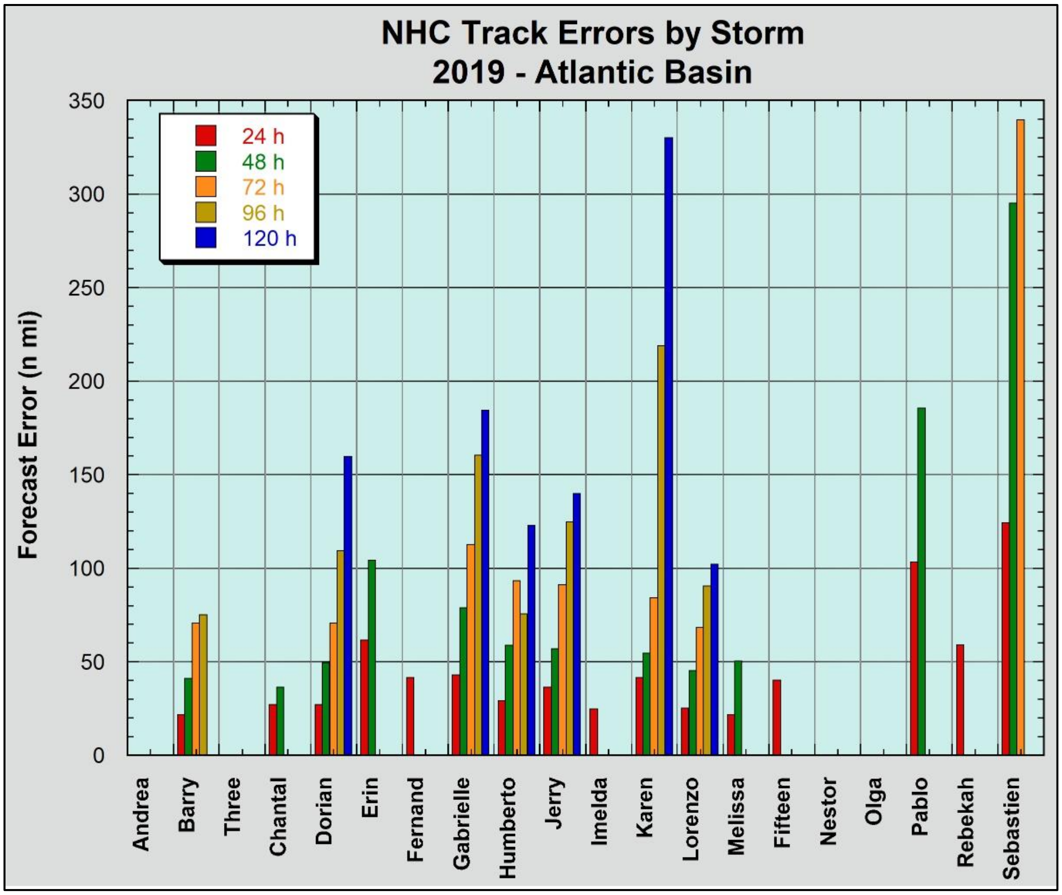


Figure 13. 2019 NHC official track errors by tropical cyclone.

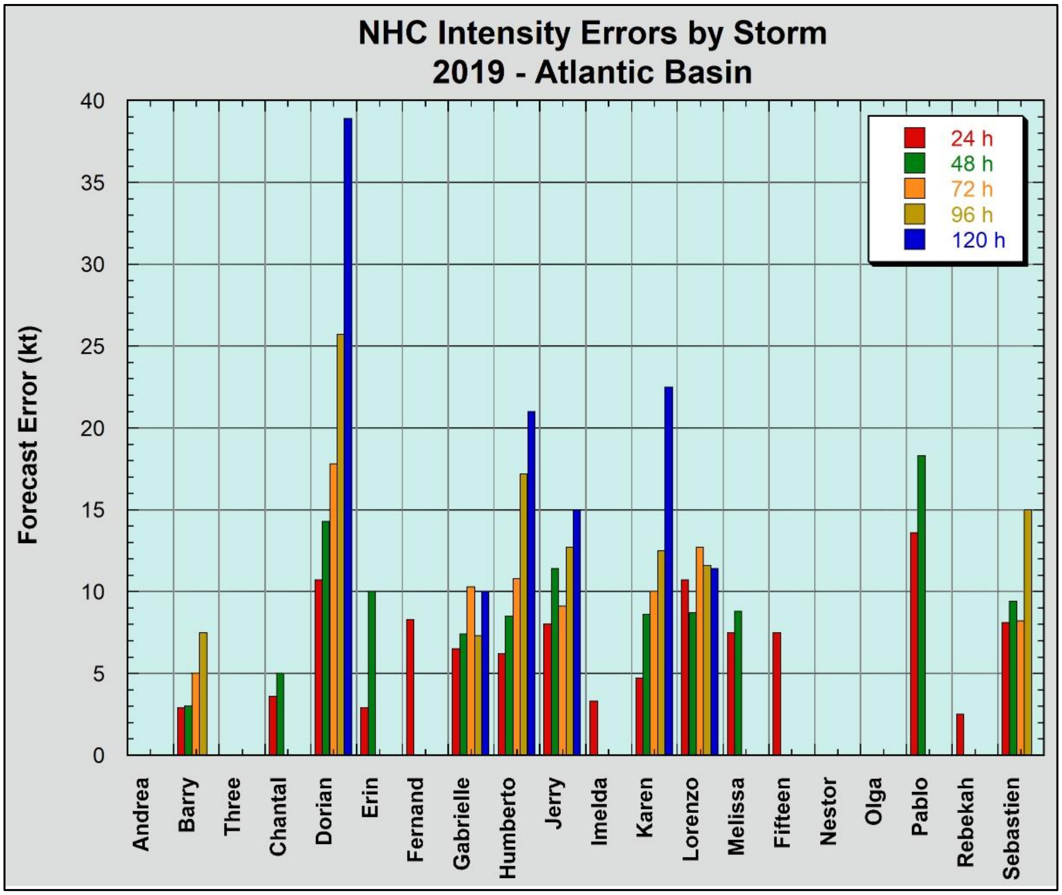


Figure 14. 2019 NHC official intensity errors by tropical cyclone.

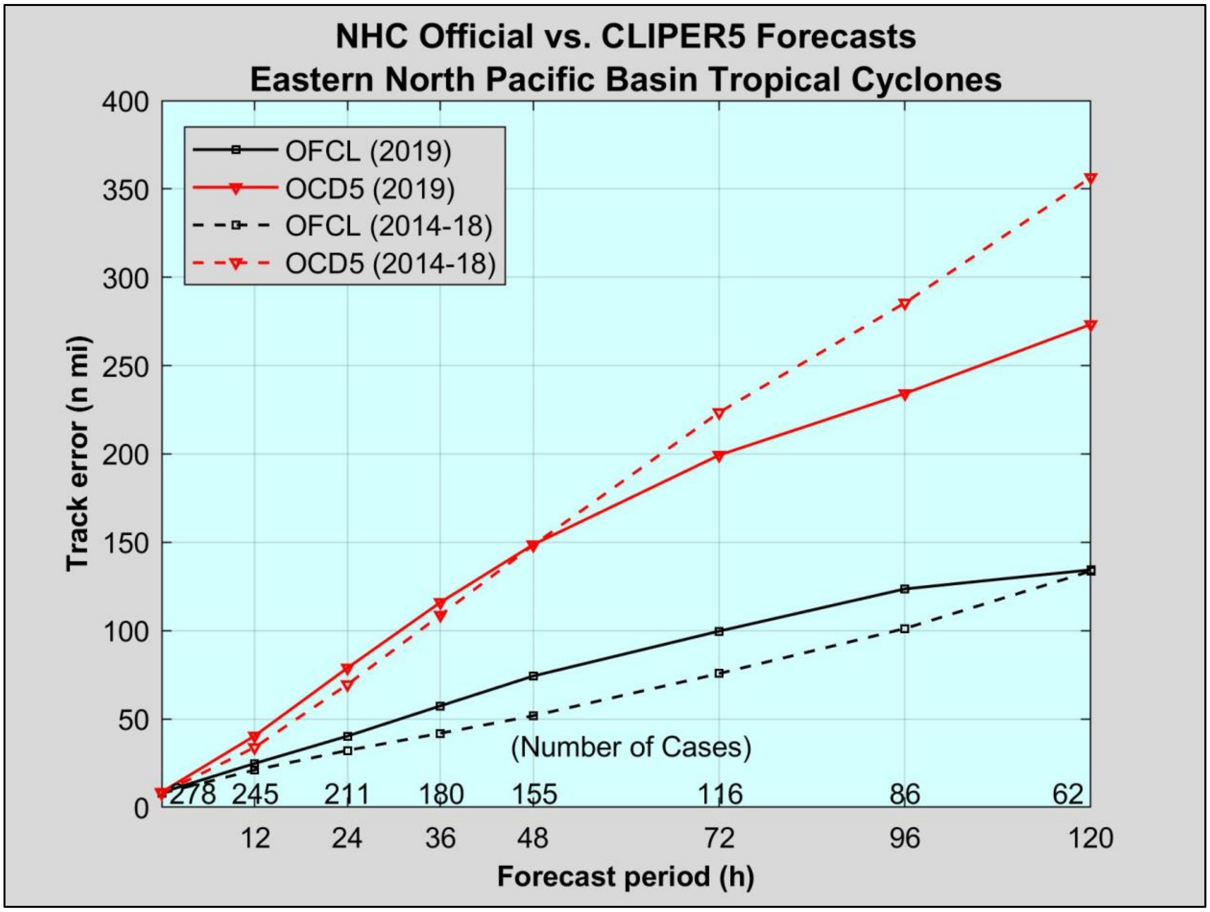


Figure 15. NHC official and CLIPER5 (OCD5) eastern North Pacific basin average track errors for 2019 (solid lines) and 2014-2018 (dashed lines).

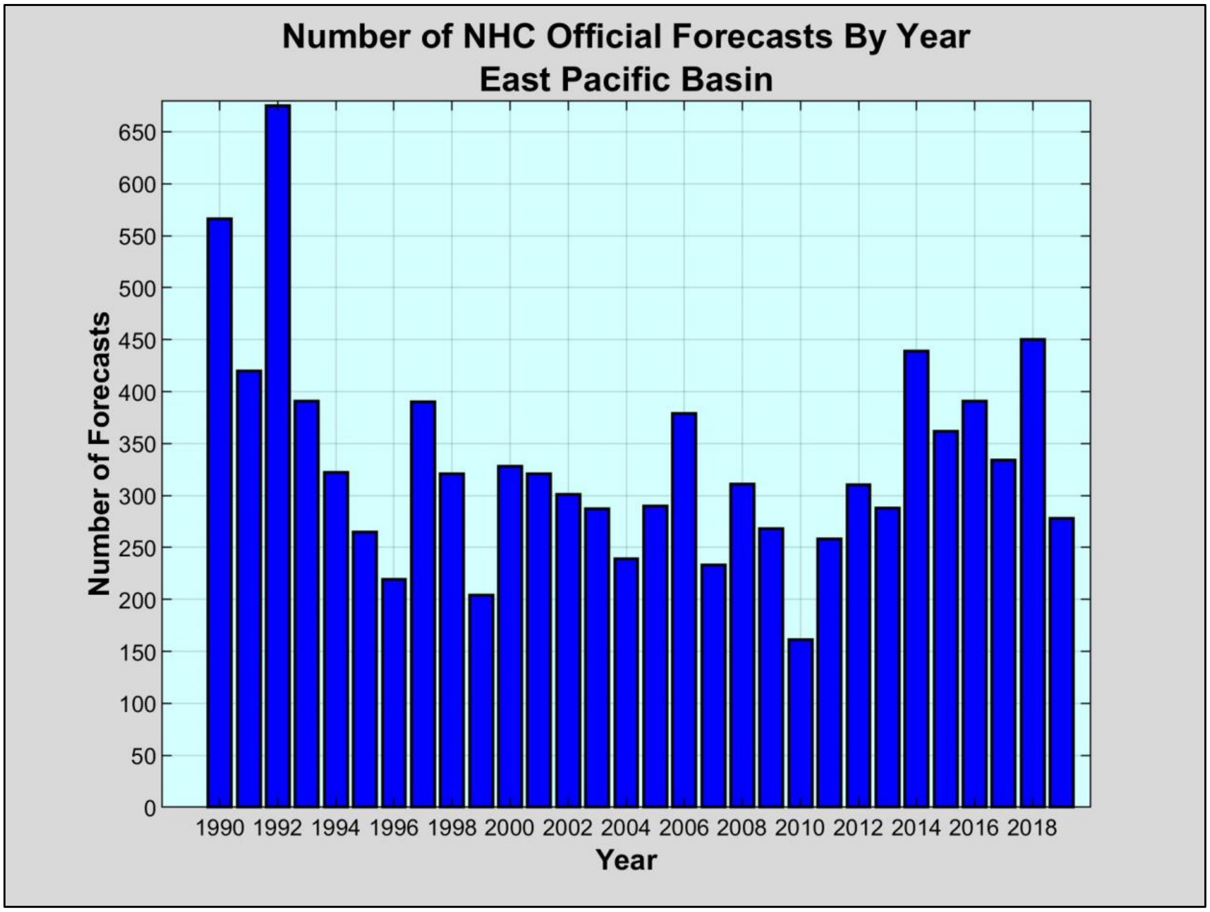


Figure 16. Number of NHC official forecasts for the eastern North Pacific basin stratified by year.

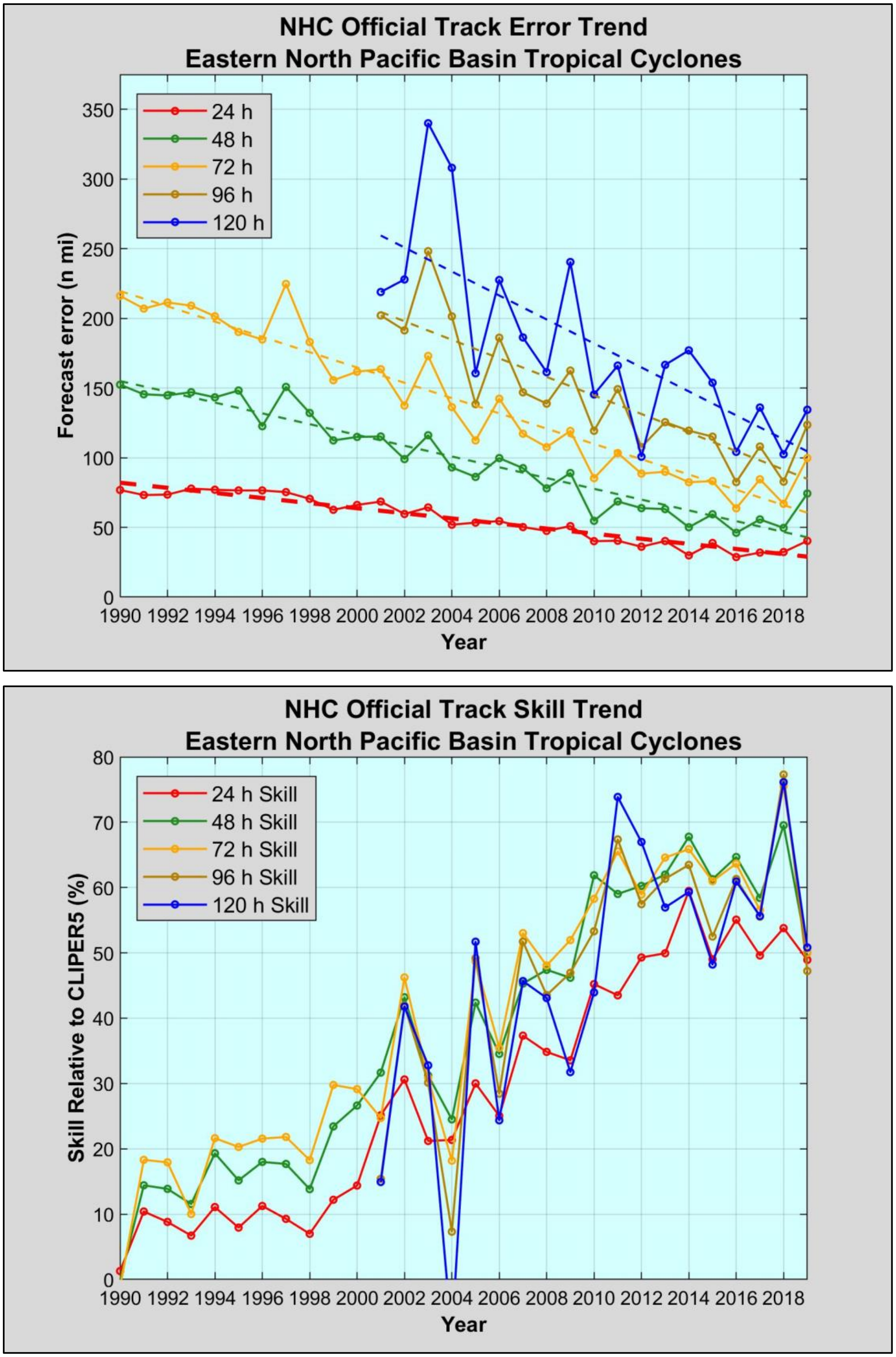


Figure 17. Recent trends in NHC official track forecast error (top) and skill (bottom) for the eastern North Pacific basin.

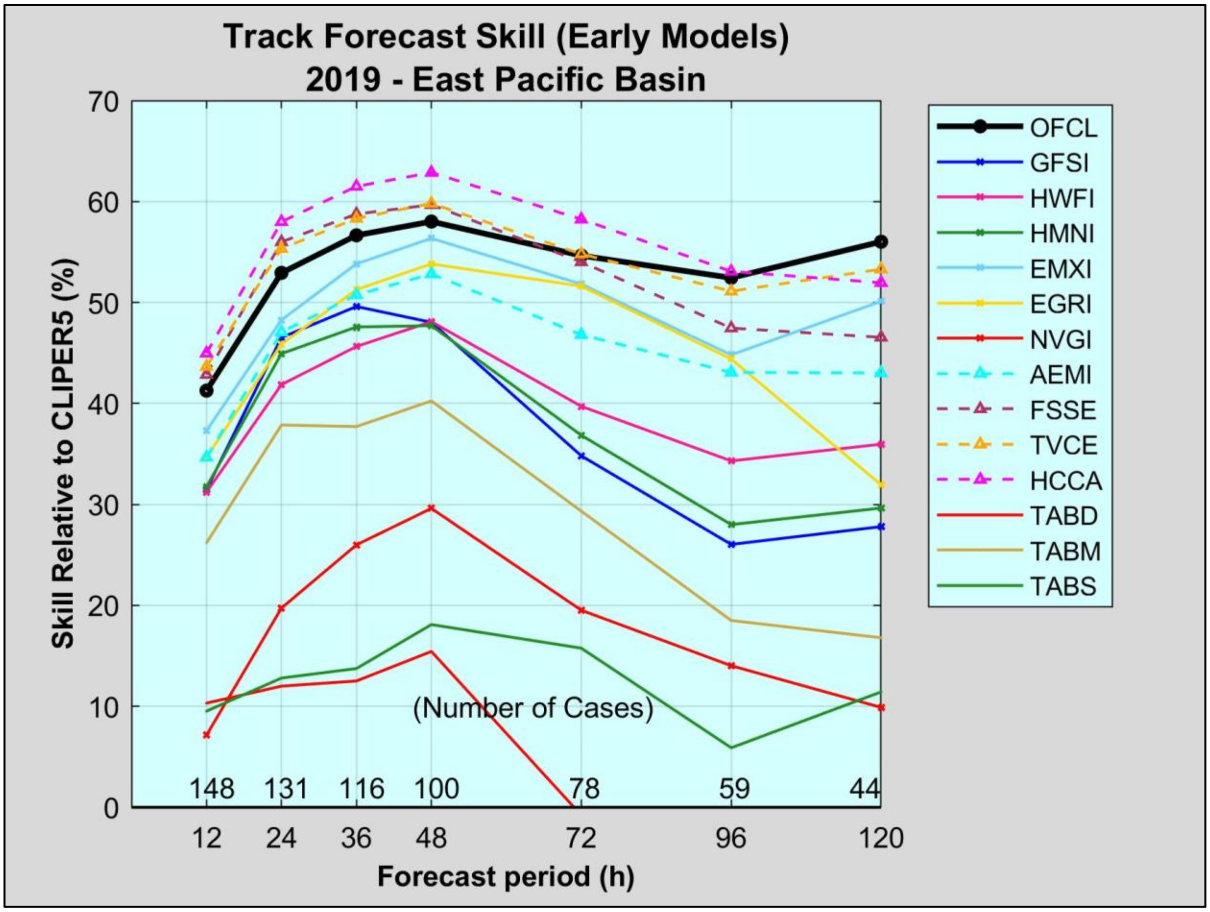


Figure 18. Homogenous comparison for selected eastern North Pacific early track models for 2019. This verification includes only those models that were available at least 2/3 of the time (see text).

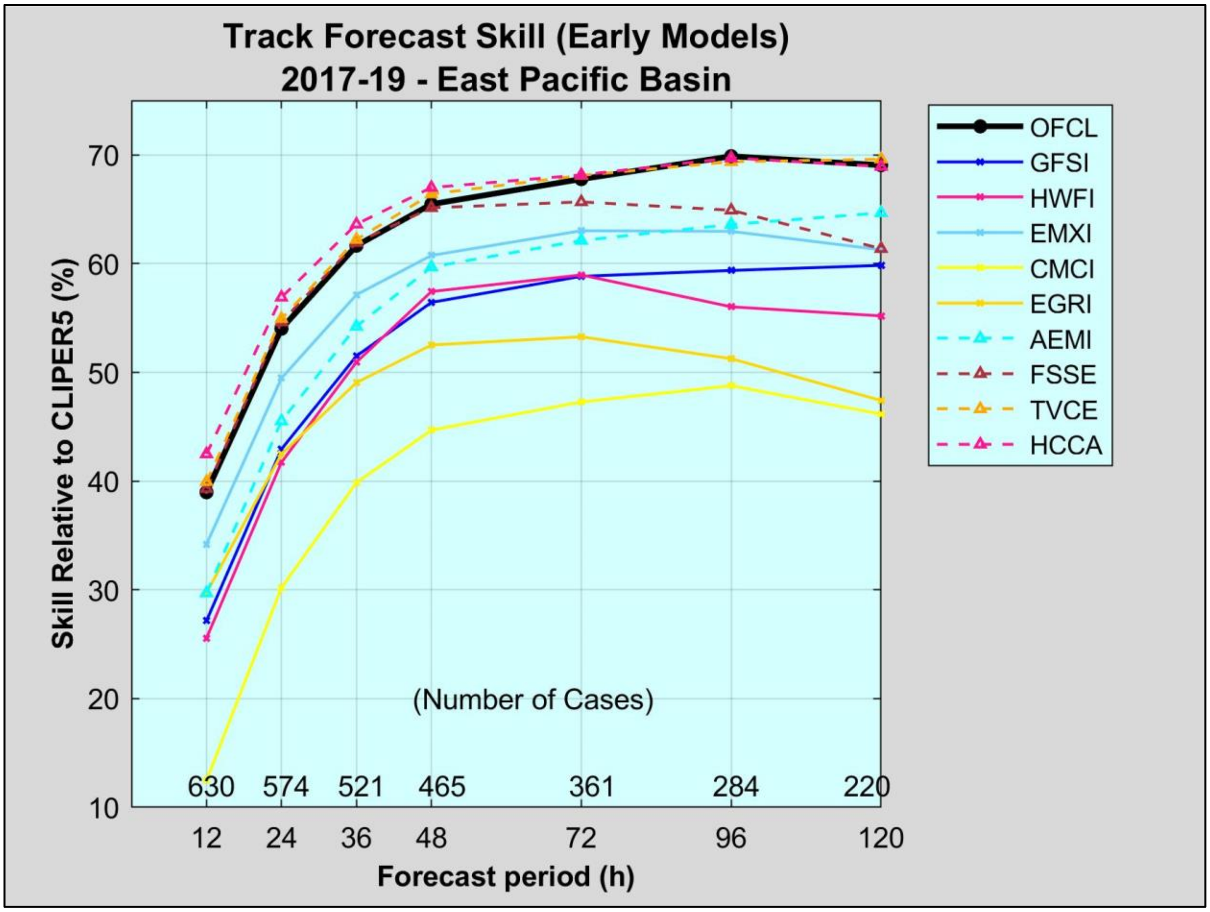


Figure 19. Homogenous comparison for selected eastern North Pacific basin early track models for 2017-2019.

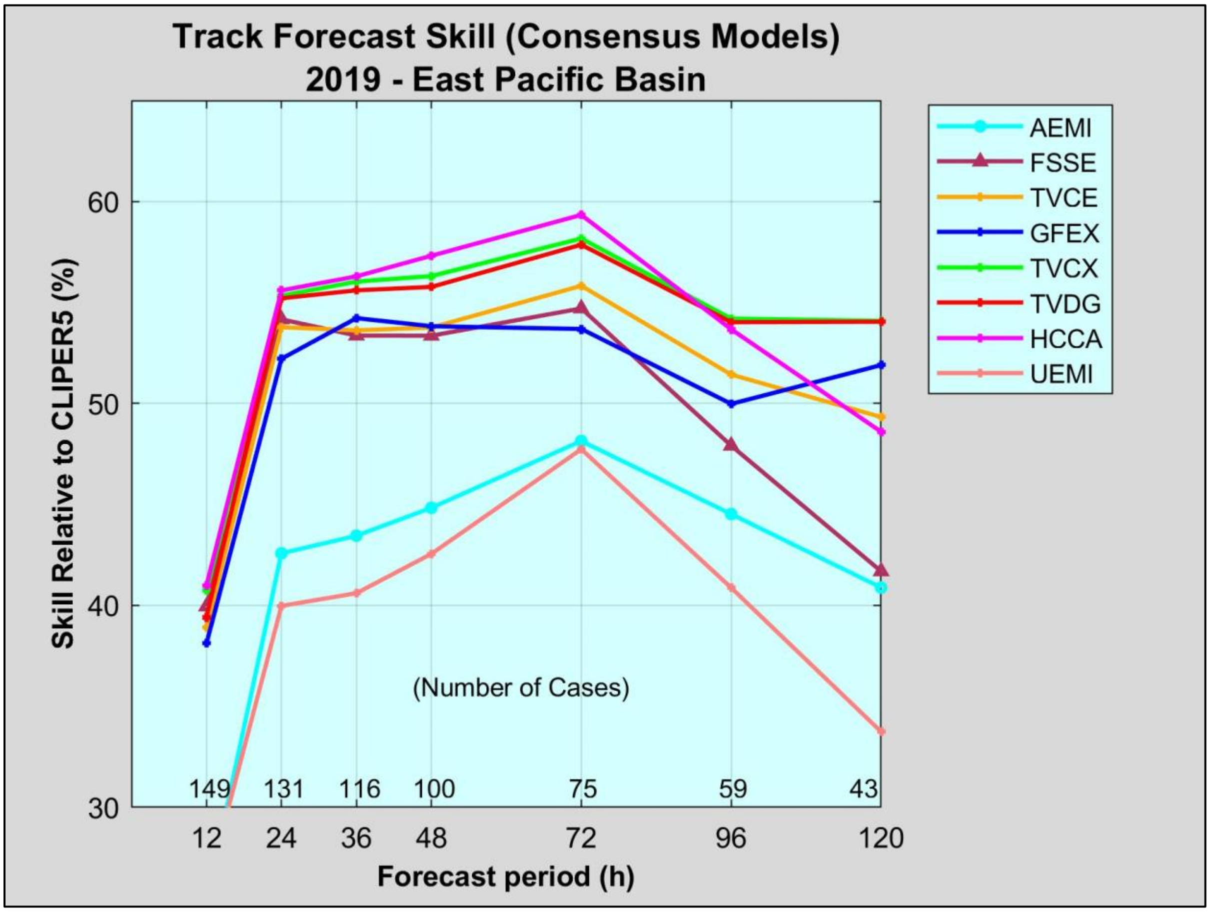


Figure 20. Homogenous comparison of the primary eastern North Pacific basin track consensus models for 2019.

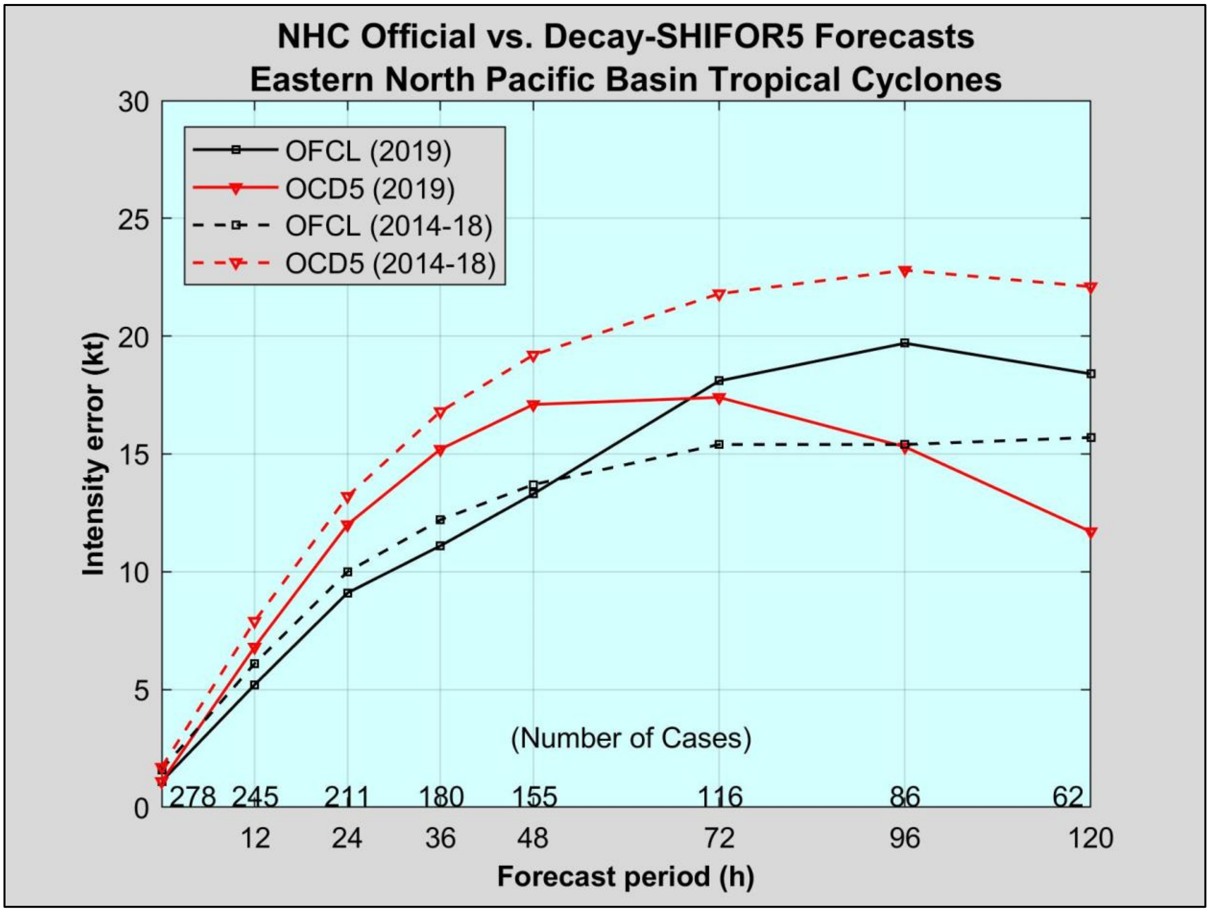


Figure 21. NHC official and Decay-SHIFOR5 (OCD5) eastern North Pacific basin average intensity errors for 2019 (solid lines) and 2014-2018 (dashed lines).

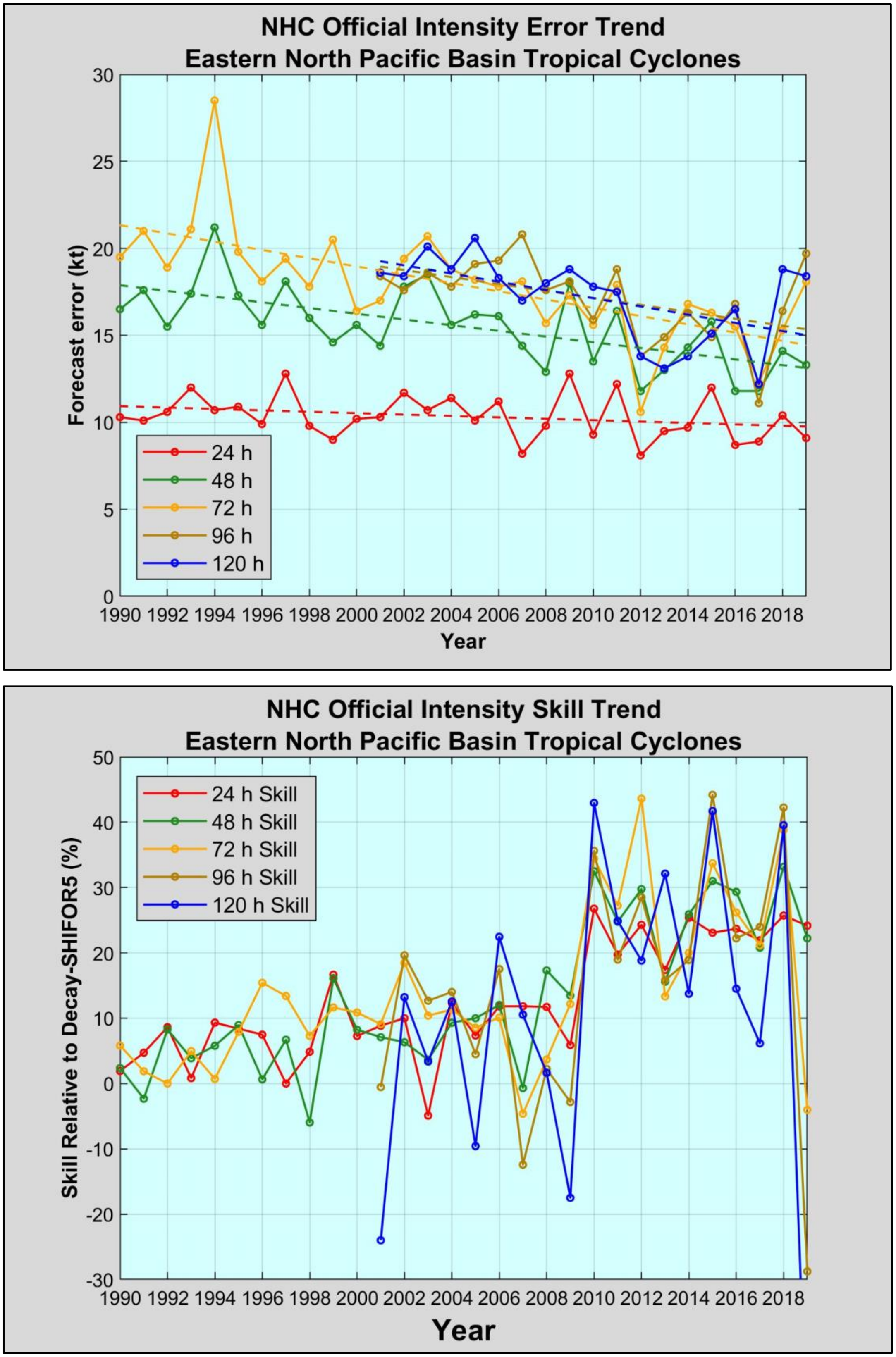


Figure 22. Recent trends in NHC official intensity forecast error (top) and skill (bottom) for the eastern North Pacific basin.

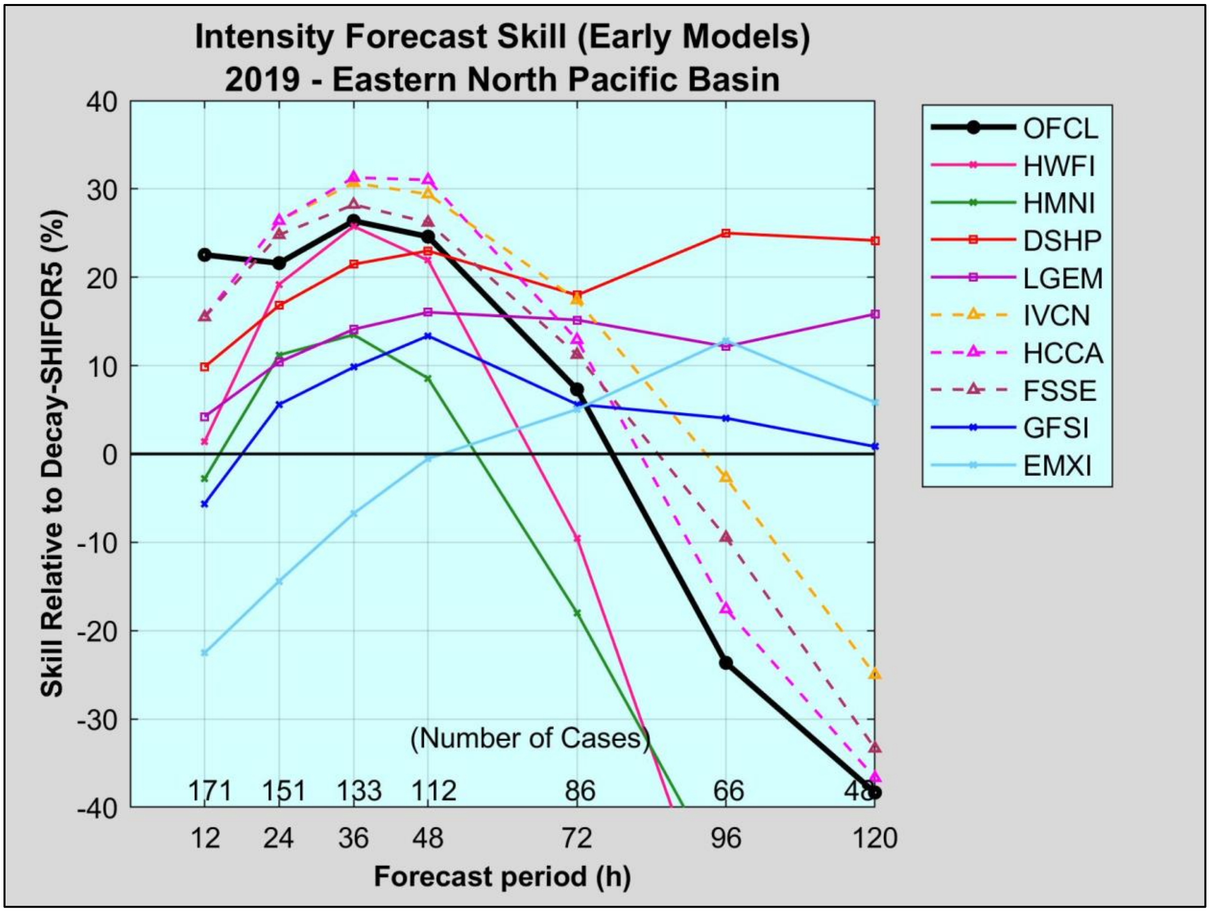


Figure 23. Homogenous comparison for selected eastern North Pacific basin early intensity guidance models for 2019.

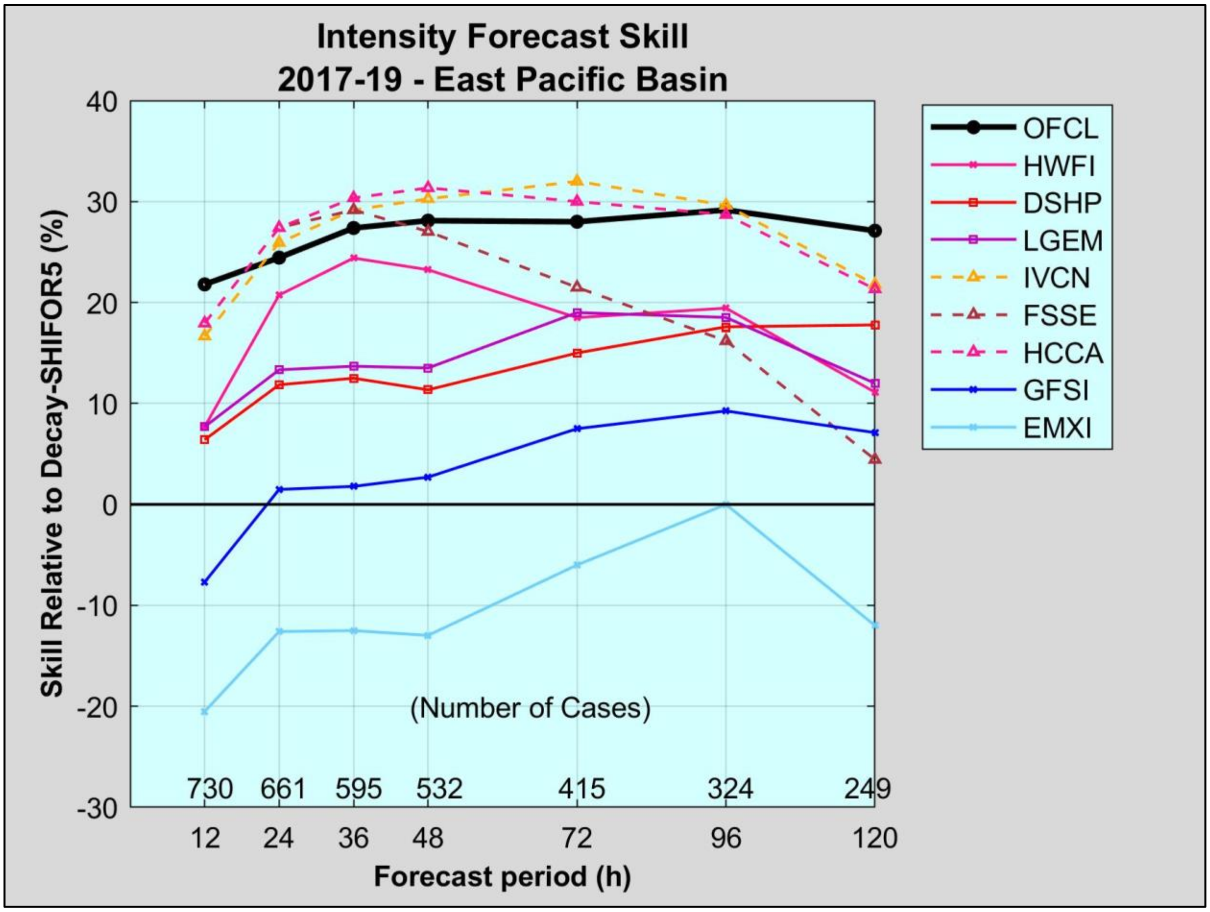
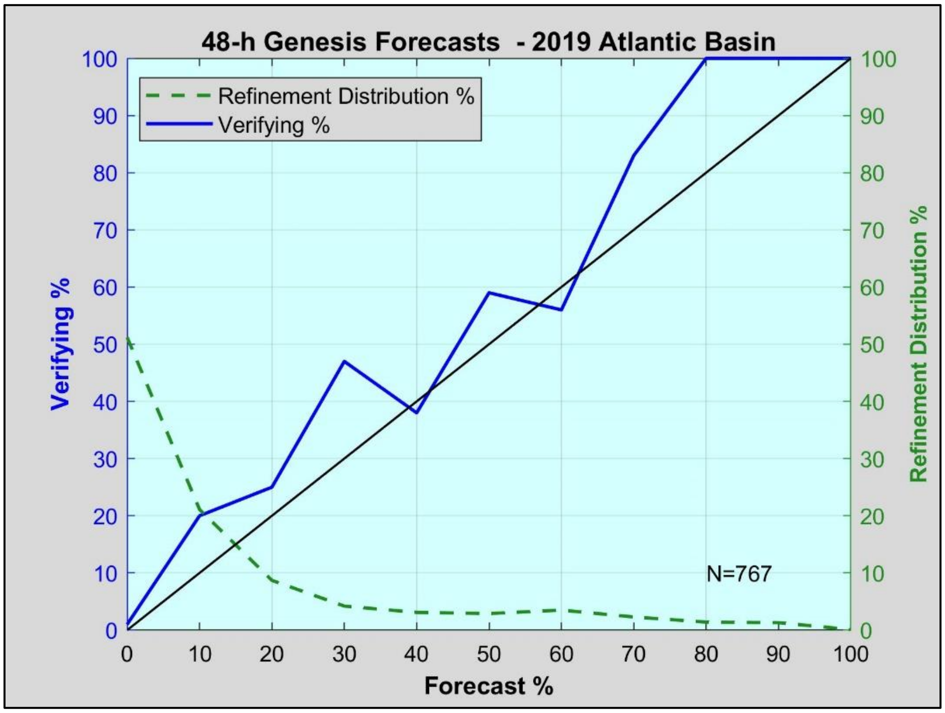


Figure 24. Homogenous comparison for selected eastern North Pacific basin early intensity guidance models for 2017-2019.



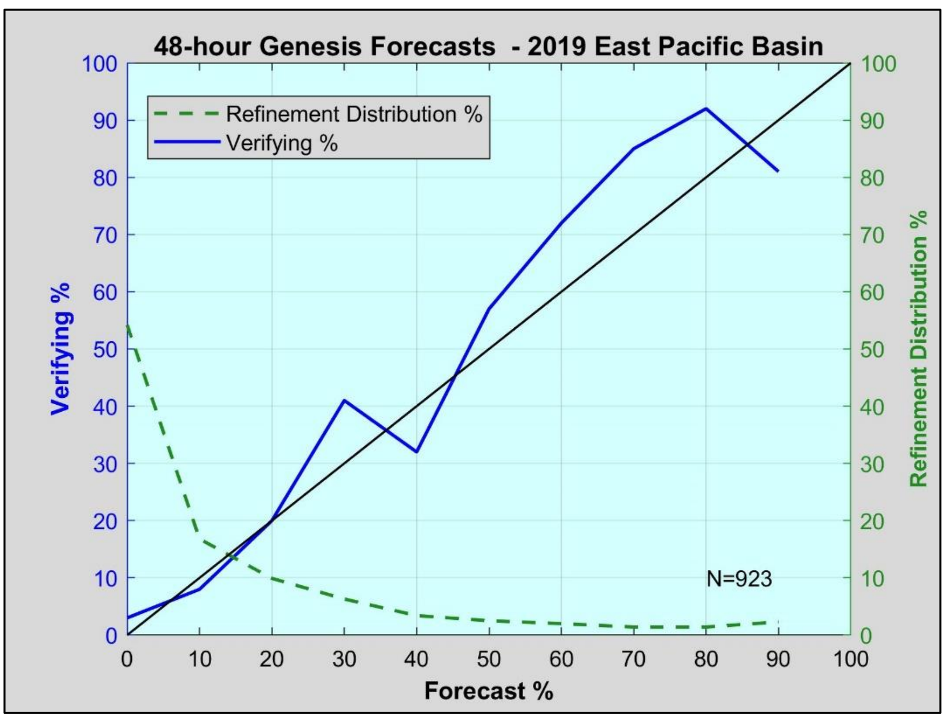
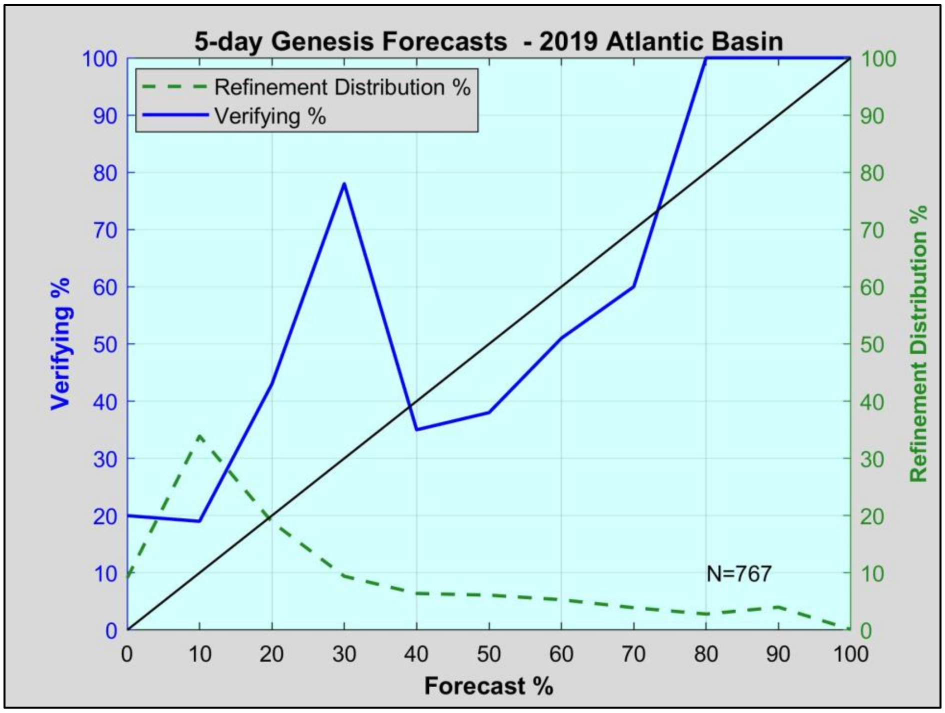


Figure 25. Reliability diagram for Atlantic (top) and eastern North Pacific (bottom) probabilistic tropical cyclogenesis 48-h forecasts for 2019. The solid lines indicate the relationship between the forecasts and verifying genesis percentages, with perfect reliability indicated by the thin diagonal black line. The dashed lines indicate how the forecasts were distributed among the possible forecast values.



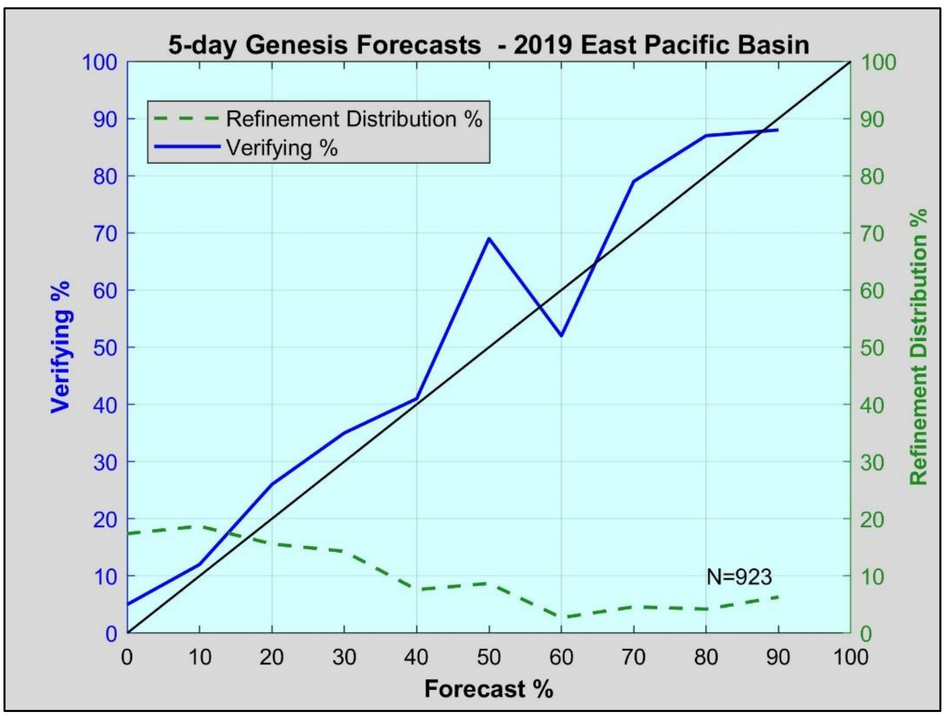


Figure 26. As described for Fig. 25, except for 120-h forecasts.