NOTES AND CORRESPONDENCE

Statistical Postprocessing of NOGAPS Tropical Cyclone Track Forecasts

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ABSTRACT

A statistical postprocessing technique is developed and tested to reduce the U.S. Navy global model (NOGAPS) track forecast errors for a sample of western North Pacific tropical cyclones during 1992–96. The key piece of information is the offset of the initial NOGAPS position relative to an updated (here best-track) position that will be known by 6 h after the synoptic times, which is when the NOGAPS forecast is actually available for use by the forecaster. In addition to the basic storm characteristics, the set of 24 predictors includes various segments in the 0–36-h NOGAPS forecast track as well as a 0–36-h backward extrapolation that is compared with the known recent track positions. As statistically significant regressions are only found for 12–36 h, the original 36-h to 72-h NOGAPS track segment is simply translated to the adjusted 36-h position. For the development sample, the adjusted NOGAPS track errors are reduced by about 51 n mi (95 km) at 12 h, 35 n mi (65 km) at 36 h, and 28 n mi (52 km) at 72 h. Independent tests with a 1997 western North Pacific sample, 1995–97 Atlantic sample, and 1996–97 eastern and central North Pacific sample of NOGAPS forecasts have similar improvements from the postprocessing technique. Thus, the technique appears to have a more general applicability to Northern Hemisphere tropical cyclones.

1. Introduction

Dynamical tropical cyclone (TC) track predictions have become the primary guidance at a number of forecast centers (Elsberry 1995). The global model analyses and forecasts have become more useful as the horizontal resolution has increased and synthetic TC observations have been introduced. For example, Goerss and Jeffries (1994) describe the impact of 13 pseudorawinsondes that are added to the U.S. Navy Operational Global Atmospheric Prediction System (NOGAPS) to depict the TC location, structure, and an adjustment to the environmental flow. Similarly, regional models such as the Geophysical Fluid Dynamics Laboratory model (Kurihara et al. 1993, 1995) have also become increasingly important guidance for the TC forecaster. These dynamical predictions have promise for TC track forecasting because they explicitly represent the TC structure differences and the nonlinear interaction between the vortex and the environment.

One of the difficulties with global models such as NOGAPS is the early portions of the track may be inconsistent with the recent motion of the TC, including beginning at an incorrect location. Even though the inclusion of synthetic TC observations such as in Goerss and Jeffries (1994) have reduced the ‘‘misplaced vortex problem’’ (Elsberry 1995), an offset of the initial TC position in the dynamical model from the actual position is still common. For western North Pacific TCs, the practice at the Joint Typhoon Warning Center (JTWC), Guam, has been to submit a request for objective guidance preparation based on an *extrapolated* position about 2.5 h prior to the 0000 UTC or 1200 UTC synoptic times, and this position was used as the center of the TC synthetic observations for the NOGAPS analysis. The NOGAPS data assimilation technique blends the TC synthetic observations with real observations and a 12-h NOGAPS forecast (Goerss and Jeffries 1994). Thus, the initial (0-h) NOGAPS vortex position will not generally agree with the extrapolated JTWC position, which later fixes may also indicate was not correct.

Another situation that leads to an inaccurate initial NOGAPS position is a major relocation of the TC, which tends to occur during the early stages when the center is not well defined. The JTWC may receive scatterometer or other information that leads them to relocate the initial position by 60 n mi (111 km) or more. Blending of the synthetic TC observations at this relocated position with the 12-h predicted vortex in the

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data assimilation technique may result in two separate vortices, or a single, elliptic vortex that is centered at some intermediate location. In addition to a center position offset, the initial predicted track may be quite erratic as an adjustment occurs.

Another important timing aspect of the 0000 UTC and 1200 UTC NOGAPS track predictions is that they are not received at Guam until 4–5 h after the synoptic time, and thus are not actually used until the 0600 UTC or 1800 UTC warning. Because new TC fix information has been received during the intervening period, especially if an extrapolated position had been submitted 2.5 h prior to the synoptic time, a much better TC center location is available. This continual updating of the past positions based on more recent knowledge of the TC position is part of the ‘‘working best-track’’ procedure at JTWC.

The objective of this postprocessing technique for NOGAPS is to make use of this new knowledge about the TC position at the 0000 UTC and 1200 UTC synoptic times to improve the accuracy of the NOGAPS track predictions at those times. This technique will attempt to adjust for a misplaced vortex in the NOGAPS initial conditions arising from an improper extrapolated position from JTWC, or from the blending of the synthetic TC observations and the 12-h forecast vortex in the data assimilation. When the NOGAPS initial position is close to the working best-track TC position, this offset adjustment will naturally be small.

Even if the initial NOGAPS position is not offset from the actual TC position, the initial track orientation occasionally departs significantly from a persistence (of past motion) track from the beginning of the NOGAPS prediction. If the storm actually continues to move in a similar track direction and speed as in the past 12–36 h, the erroneous NOGAPS track will have a significant angle relative to the persistence track. However, the forecasters may know that the initial NOGAPS track orientation is erroneous and desire a smoother blend with the persistence track based on the recent motion. Another objective of the postprocessing technique is to achieve a smoother transition between the early portion of NOGAPS track predictions and a persistence track.

If the initial TC vortex structure is too large, or the model physical process representations tend to grow the vortex size, a poleward bias in a dynamical track prediction may occur. For example, Nagata et al. (1998) indicates a change in the convective parameterization in the Japan Meteorological Agency global and regional models reduced the tendency for low-latitude TCs to drift poleward. Another potential cause of systematic error in the dynamical model is a poorly defined environmental flow in the region of the TC owing to sparse observations over the tropical oceans.

A technique for statistical postprocessing of the NOGAPS track predictions is developed to improve the accuracy and consistency of the guidance. Following earlier studies by Elsberry and Frill (1980) and Peak and Elsberry (1982), predictors are calculated that involve the direction and speed of the NOGAPS-predicted track and a backward extrapolation of that track. The statistical postprocessing technique is developed (section 2) for a sample of western North Pacific TCs during 1992–96, and is tested (section 3b) on a 1997 sample of TCs. Since these western North Pacific postprocessing equations also appear to improve the NOGAPS track predictions for an Atlantic sample (section 3c) and an eastern/central Pacific sample (section 3d), the technique appears to have applicability for Northern Hemisphere TCs.

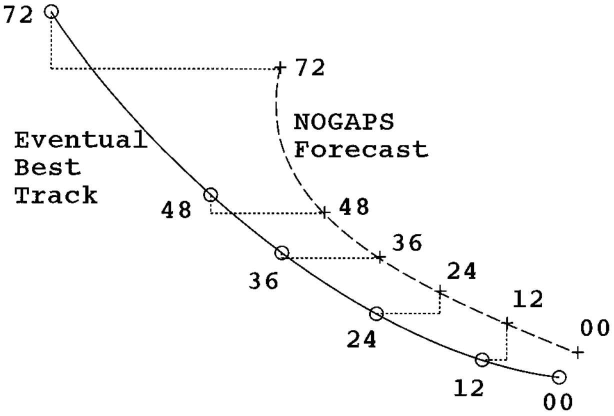

FIG. 1. Zonal and meridional predictands (dotted lines), which are the differences between the 12-, 24-, 36-, 48-, and 72-h NOGAPS forecast positions and the best-track positions determined from poststorm analysis.

2. Methodology

a. Predictands

The objective is to calculate a zonal and a meridional adjustment to the NOGAPS-predicted track positions at 12, 24, 36, 48, and 72 h to make them agree more closely with the best-track (poststorm analysis) positions (Fig. 1). Because the 60-h position is not archived, the predictands are the five zonal and five meridional distances from the best-track positions.

b. Predictors

As indicated in section 1, NOGAPS 0-h through 36-h forecast track segments expressed as zonal and meridional displacements (Fig. 2) are included as predictors (labeled ‘‘forward’’). These track segments distinguish between east–west and north–south oriented NOGAPS forecasts, for example, the north–south predictors tend to be selected for north–south regression equations. Only the 0-h through 36-h forecast track segments are required to be available as predictors, which increases the sample sizes. Similar results were obtained when a smaller sample with full 72-h NOGAPS tracks was utilized.

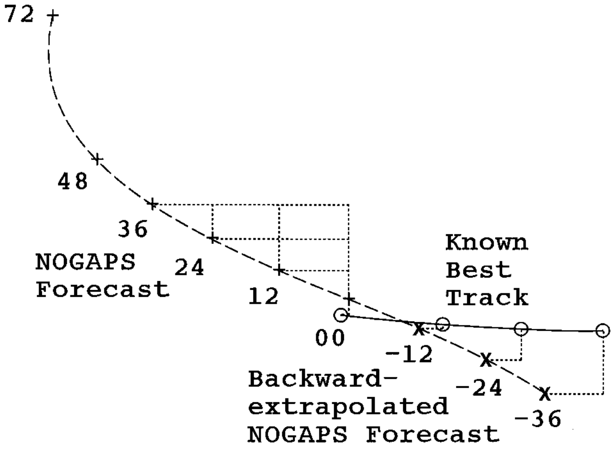

FIG. 2. Zonal and meridional predictors (dotted lines), which are the differences between the 0-h through 36-h NOGAPS forecast positions (dashed line), and initial (0 h) NOGAPS position offset relative to an updated (best-track) position, and differences between backward-extrapolated 12–36-h NOGAPS forecast positions and the known best-track positions.

Notice that the zonal and meridional offsets of the initial position in the NOGAPS analysis from the actual TC position are also included as predictors. Unfortunately, the actual 0-h NOGAPS position has not been archived. Thus, the extrapolated position submitted by JTWC up to about 2.5 h prior to the synoptic times is used as a proxy. An alternative initial NOGAPS position extrapolated with a cubic spline from the 12-, 24-, and 36-h predicted positions did not change the results. In an operational application, the actual NOGAPS initial position would be available from the vortex tracker. As indicated in section 1, the crucial information is the offset of this initial NOGAPS position relative to an updated TC position from the working best track that will be available 6 h after synoptic time, which is when the NOGAPS track prediction is actually received and utilized at JTWC. As an approximation of this additional information, the postseason analysis position (so-called best track) will be used at 0 h, rather than, for example, the warning positions that are issued shortly after the 0000 UTC and 1200 UTC synoptic times.

As described in section 1, error sources such as model physics or a poor environmental analysis may lead to an incorrect NOGAPS track right from the beginning of the integration. To adjust for such erroneous tracks, Elsberry and Frill (1980) integrated a frictionless numerical model backward in time for 36 h to calculate displacements from the known past 12-, 24-, and 36-h TC positions. Peak and Elsberry (1982) simplified the procedure after noting the linearity of the backward and forward integrations of the model, and simply extrapolated the backward portion of the track. Thus, no additional integration of the model is required, and ‘‘backward predictors’’ may be defined as the zonal and meridional displacements of the backward extrapolated positions relative to the known past TC positions (Fig. 2). Notice that a NOGAPS track prediction along a persistence track will result in small backward predictor values and no adjustment is needed. However, if the NOGAPS-predicted track has a significant angle relative to the persistence track, the backward predictors will tend to adjust the initial portion of the NOGAPS track to be more along the persistence track. Although introducing a more persistent-type track via these backward predictors is effective when the NOGAPS-predicted track is erroneous, the enforcement of persistence motion may also degrade a correct forecast of an actual TC turn by projecting the track beyond the turning point.

In summary, 12 forward predictors are derived from zonal and meridional track segments connecting the 0-, 12-, 24-, and 36-h NOGAPS track forecast positions, the offset of the JTWC extrapolated position from the actual 0-h TC position provides 2 additional predictors, and 6 backward predictors are available from the zonal and meridional displacements of the 36-h backward extrapolated track relative to the known past positions. Finally, four additional predictors of the initial latitude, longitude, intensity, and Julian date (with zero on 15 February) are included to make a total of 24 predictors.

c. Database

Notice that in Fig. 2 the TC must have existed for at least 36 h and the NOGAPS-predicted track must extend to at least 36 h for the backward and forward predictions to be calculated. Although NOGAPS track forecasts are available in earlier years, the 12-h and 36-h positions were not archived prior to 1992. Consequently, these early NOGAPS forecasts could not be used for the statistical regression without the backward and forward predictors that require the 12-h and 36-h positions. The requirement that the NOGAPS track extend to at least 36 h is usually met, especially since June 1994 when the horizontal resolution was increased from T79 to T159.

A sample of 152 TCs during 1992–96 is available for developing the postprocessing technique. A lower intensity limit of 25 kt (12.5 m s^{-1}) is implied because this is the criterion to initiate a NOGAPS forecast. In general, track forecast errors are larger for weaker TCs than for the typhoon stage (Elsberry 1995). However, it is important to improve the NOGAPS track forecasts for these weaker TCs because JTWC must issue warnings if the intensity is 25 kt or more.

Although a total of 1187 cases are available at 12 h, the verifying sample decreases to 1170, 1134, 988, and 761 at the 24-, 36-, 48-, and 72-h forecast intervals. These decreases occur because the TC may not have existed, or the 48-h or 72-h NOGAPS forecast may not have been available.

d. Regression equation development

The Efroymson (1960) stepwise regression technique is utilized, so the first predictor selected explains the

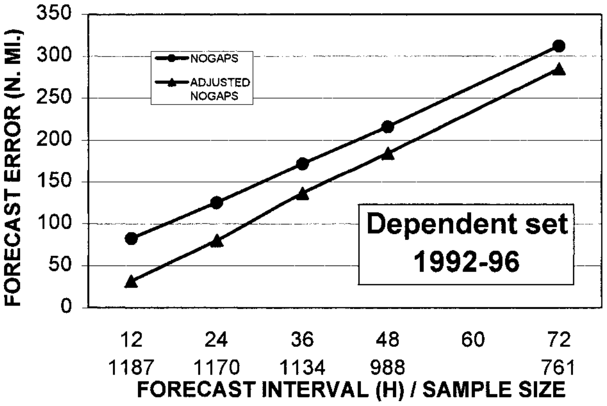

FIG. 3. Mean track errors for unadjusted (solid dots) and adjusted (triangles) NOGAPS forecasts for the development sample of 1992–96 western North Pacific TCs. Sample sizes are indicated along the abscissa.

largest amount of the variance in the predictand. Subsequent predictor selection is based on the highest partial correlation given the inclusion of the prior selected predictor. An option that allows removal of prior predictors after the entry of each new predictor should address the linearity aspect of these predictors, for example, the backward predictors at 12-h intervals if the past motion has been steady. This option is not exercised here because of the small number of predictors selected (see section 3a).

The regression equation development is for the entire (ALL) sample during 1992–96, because withholding an independent sample generated by setting aside every third case did not yield an improved track prediction at 48 h and 72 h. Initial sets of regression equations with a standard *f*-value default criterion for terminating predictor selection resulted in overfitting of the development sample by inclusion of too many predictors. For example, as many as 12 predictors may have been included although with removal of some predictors that became redundant. Subsequent tests are then made by limiting the number of steps in the regression equation development (see section 3a).

3. Results

a. Development sample

As indicated in section 2, the development sample is the entire 1992–96 sample of the NOGAPS forecasts of western North Pacific TCs that met the criteria of at least 36-h existence, initial and validation intensity of at least 25 kt, and at least a 36-h forecast track. The unadjusted NOGAPS track forecast errors increase almost linearly from 83 n mi (154 km) at 12 h to about 312 n mi (578 km) at 72 h (Fig. 3). Postprocessing of these NOGAPS forecasts with statistical regression equations using the predictors described in section 2b reduces the track errors over the entire 12- through 72-h interval. An immediate improvement of about 51 n mi (95 km) is achieved at 12 h, with progressively smaller improvements out to 72 h. However, only the improvements through 36 h are significant at 95% confidence. Thus, the 36-h through 72-h track segment of the unadjusted NOGAPs track has been appended to the adjusted 12-h through 36-h track. This simple translation of the 36–72-h track segment to begin at the adjusted 36-h position results in smaller errors, and more consistent tracks, than use of the 48- and 72-h regressions that are not statistically significant. The justification for appending the 36-h through 72-h track segment is that NOGAPS track forecasts in this interval are often useful even when the early tracks are misleading.

TABLE 1. Selection of predictors and explained variance (%) for the 12-h, 24-h, and 36-h zonal (*x*) and meridional (*y*) regression equations based on the 1992–96 development sample of NOGAPS track forecasts in the western North Pacific. The backward (back), offset, and forward (fwd) predictors are indicated.

12-h *x*	Explained variance		12-h *y*	Explained variance	
Predictor	Total	Additional	Predictor	Total	Additional
Back 12 *x*	35.4	35.4	Back 12 *y*	36.0	36.0
Offset 00 *x*	77.8	42.4	Offset 00 *y*	80.1	44.1
Back 36 *x*	85.1	7.3	Back 24 *y*	84.0	3.9

24-h *x*	Explained variance		24-h *y*	Explained variance	
Predictor	Total	Additional	Predictor	Total	Additional
Back 12 *x*	26.3	26.3	Back 24 *y*	25.5	25.5
Offset 00 *x*	52.8	26.4	Offset 00 *y*	48.0	22.5
Fwd 24–36 *x*	56.8	4.0	Back 36 *y*	55.1	7.1
Fwd 12–24 *x*	60.2	3.5	Back 12 *y*	58.0	2.9

36-h *x*	Explained variance		36-h *y*	Explained variance	
Predictor	Total	Additional	Predictor	Total	Additional
Back 12 *x*	20.5	20.5	Back 24 *y*	17.8	17.8
Offset 00 *x*	39.3	18.8	Offset 00 *y*	35.7	17.9

In addition to smaller mean forecast track errors (Fig. 3) from the postprocessing, more consistent forecasts result from the adjustments. Whereas the standard deviations of the unadjusted NOGAPS 12-, 24-, and 36-h errors are 58 n mi (107 km), 86 n mi (159 km), and 118 n mi (219 km), the postprocessing reduces these standard deviations to 24 n mi (44 km), 56 n mi (104 km), and 97 n mi (180 km), respectively. Notice that the spread of the adjusted 24-h NOGAPS forecasts is as small as the unadjusted 12-h NOGAPS forecasts. Although progressively smaller standard deviations are achieved at longer forecast intervals, even the adjusted 72-h NOGAPS forecasts have slightly smaller standard deviations (about 9 n mi or 17 km).

The selection of predictors in the regression equations (Table 1) reveals how the improvement in adjusted NO-

GAPS track forecasts is achieved. In each zonal (*x*) or meridional (*y*) adjustment, the first and second predictors selected are the corresponding backward 12-h (or 24-h) *x* or *y* predictor and the corresponding offset of the *x* or *y* JTWC extrapolated position that is used for the TC synthetic observations in NOGAPS relative to the actual best-track position. Almost all of the explained variance is achieved from just these first two predictors selected, with a reduction from about 85% explained variance at 12 h to about 60% at 24 h, and about 36% at 36 h. Although about 30% (20%) explained variance is achieved for the 48-h (72-h) regressions, these equations led to track error reductions that are not statistically significant in the development sample, and thus are not used. The third predictor in the 12-h equations (Table 1) is again a backward predictor. This is also true for the third and fourth predictors in the 24-h meridional equation. Only the 24-h zonal equation includes forward NOGAPS track segments. Notice that these third and fourth predictors (when selected) add much less explained variance. In most of these equations, selection of another predictor would have added less than 1% variance. The decision to stop predictor selection after the number of steps indicated in Table 1 is made based on the minimum 12-, 24-, and 36-h track errors for equation sets ranging between one and eight steps. Even though the individual zonal and/or meridional predictands would have been fit more closely with additional steps, this selection criterion of minimum (combined) track error is applied.

It is clear from Table 1 that the initial position offset, and the reorientation of the forecast track direction based on the backward extrapolation of the NOGAPS forecast track at 12 h and either 24 h or 36 h, are the primary inputs for improving the performance. Thus, knowledge of a mislocation of the initial NOGAPS position, or a departure of the initial NOGAPS-predicted direction and speed relative to a persistence-type forecast track based on known recent positions, may be exploited to improve the NOGAPS short-term forecast performance.

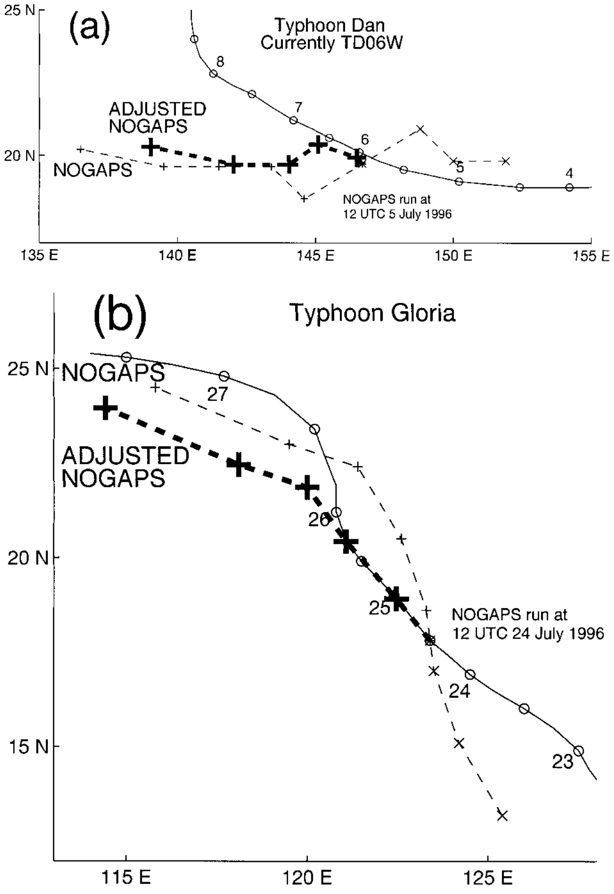

FIG. 4. Examples of best tracks (solid, with open dots each 12 h with dates adjacent to 0000 UTC positions) and unadjusted NOGAPS forecasts (light dashed, crosses at 12-h intervals to 72 h omitting 60 h) with backward-extrapolated positions at −12, −24, and −36 h, and adjusted NOGAPS forecasts (heavy, dashed with crosses at 12-h intervals to 72 h omitting 60 h) for (a) TY Dan at 1200 UTC 5 July 1996 and (b) TY Gloria at 1200 UTC 24 July 1996.

An example of a drastic postprocessing adjustment is given in Fig. 4a. Notice the initial position (asterisk) is the extrapolated JTWC position, which is offset well to the west of the best-track position at 1200 UTC 5 July 1996. Furthermore, the erratic southwestward 0–12-h segment differs considerably from the westward prior track. The backward-extrapolated position at −12 h near 21°N, 149°E is a considerable distance from the actual TC position at 0000 UTC 5 July at 19°N, 150°E. Similarly, the −24 h and −36 h backward-extrapolated positions are well to the west of the corresponding TC positions at 1200 UTC and 0000 UTC 4 July, respectively. The postprocessing technique has very successfully adjusted the 12-h NOGAPS forecast position to just south of the verifying position. Similarly, the adjusted 24-h position is just to the southwest of the verifying position. Whereas the adjusted 36-h position is an improvement over the unadjusted NOGAPS position, it is well to the south of the verifying position. Since the original 36- to 72-h NOGAPS track segment is simply appended to this erroneous 36-h adjusted position, the adjusted 48- and 72-h positions are along a westward track parallel to the unadjusted NOGAPS track. Although the offset and reorientation effects of the postprocessing technique have reduced the 48- and 72-h errors, the technique does not adjust for a missed poleward turn in the NOGAPS forecast.

A more subtle case with only a small initial position offset and a small NOGAPS-predicted track bias to the right is shown in Fig. 4b. Comparison of the backward-extrapolated positions with the past 36-h positions would appear to require a counterclockwise rotation of the NOGAPS track. Such a rotation is made in the adjusted NOGAPS positions. While leading to a large (small) improvement in the 12-h (24-h) position, the excellent unadjusted NOGAPS positions at 36- and 48-h are slightly degraded.

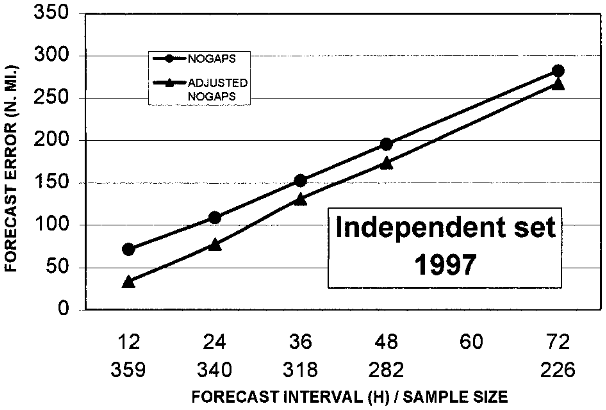

FIG. 5. Mean track errors as in Fig. 3, except for the 1997 independent sample from the western North Pacific.

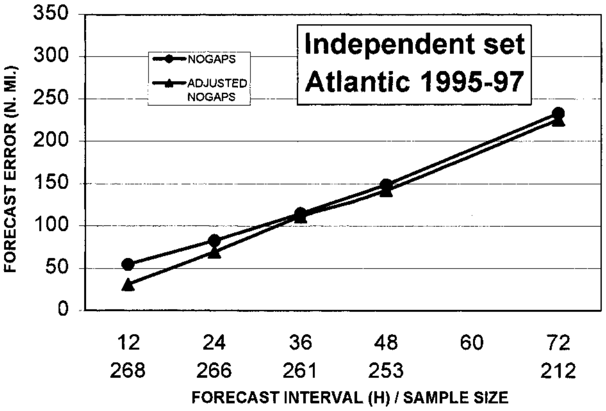

FIG. 6. Mean track errors as in Fig. 3, except for a validation sample of 1995–97 Atlantic tropical cyclones.

The key point is that both drastic and more subtle initial TC position offsets and track orientations appear to be handled reasonably well at short forecast intervals, and small improvements (occasionally small degradations) are made at longer forecast intervals. However, postprocessing of NOGAPS track forecasts with the present set of predictors (section 2b) cannot adjust for major track errors when the NOGAPS forecast ‘‘busts.’’

b. Validation with an independent western North Pacific dataset

A valid criticism of the regression test in section 3a is that it is performed on subsets of the development sample. As discussed in section 2d, withholding an independent test set was not possible because all available cases during 1992–96 had to be utilized in an attempt to achieve improved performance at 72 h. An independent dataset is now available for testing from the NOGAPS forecasts during the 1997 season.

A number of improvements have been made to the NOGAPS model during the 1992–96 period of this study and the accuracy of the TC track predictions has improved (e.g., Goerss 1997). Thus, it is not surprising that the unadjusted NOGAPS track forecast errors for the 1997 season (Fig. 5) are smaller than in the 1992–96 development sample for the ALL regression equations (Fig. 3). Notice that the unadjusted NOGAPS mean 72-h track forecast errors are only about 282 n mi (523 km) compared to about 312 n mi (578 km) during 1992–96.

It is noteworthy that NOGAPS track forecast improvements throughout the 12–72-h interval are obtained for the 1997 season (Fig. 5) using the ALL regression equation set derived from a 1992–96 period in which the NOGAPS errors were somewhat larger. Improvements relative to the mean unadjusted NOGAPS forecast errors range from 38 n mi (53%) at 12 h, 22 n mi (14%) at 36 h, and 15 n mi (5%) at 72 h. Reductions in the standard deviations of the adjusted NOGAPS forecast errors compared to the unadjusted NOGAPS errors are again found (not shown). Although it clearly would be advantageous to recalculate the regression equations at the end of each typhoon season to take advantage of a larger sample size, the forecast improvement achieved in this independent 1997 sample would suggest a rederivation is not absolutely necessary.

c. Validation with an Atlantic dataset

Given the success with an independent sample from the western North Pacific, a test is performed with a sample of NOGAPS forecasts for Atlantic TCs. The justification for such a test is that the initial position offset and track orientation problem is common in other TC basins. In addition, the systematic track biases due to NOGAPS physical process representations should be similar throughout the Northern Hemisphere.

A sample of NOGAPS forecasts for Atlantic TCs during 1995–97 was available for this test. This is a period during which the NOGAPS was known to perform well (R. Jeffries 1998, personal communication). Indeed, the unadjusted NOGAPS 72-h track forecast error (Fig. 6) is only 234 n mi (434 km), which is even smaller than the 1997 western North Pacific sample in Fig. 5. One reason for these smaller errors throughout the 12- to 72-h forecast interval is that only one of the 268 cases in the Atlantic sample had an initial intensity of 25 kt, whereas 141 cases of the 1187 cases in the western North Pacific sample had an initial intensity of 25 kt. It is well known that named TCs are positioned more accurately than tropical depressions, and that NOGAPS (and other dynamical models) provides more accurate forecasts for named TCs (Elsberry 1995).

Even given that the postprocessing equations were developed in a different basin, and for a somewhat different period, the adjusted NOGAPS track forecasts in the Atlantic are again consistently improved throughout the 12- to 72-h forecast interval (Fig. 6). On a percentage basis (43%, 3%, and 3% at 12, 36, and 72 h),

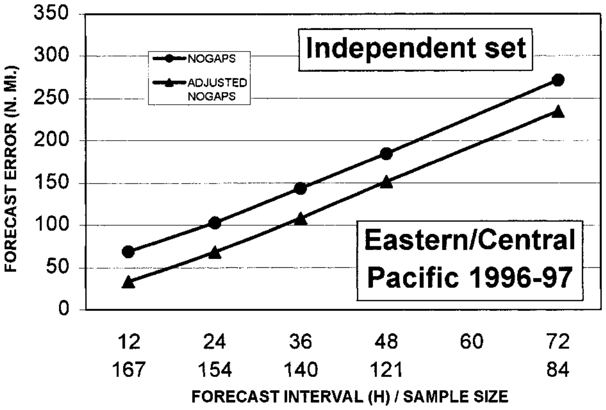

FIG. 7. Mean track errors as in Fig. 3, except for a validation sample of NOGAPS forecasts of 1996–97 eastern and central North Pacific tropical cyclones.

the improvements are not as large as in the western North Pacific development sample (61%, 21%, 9%) or the 1997 independent sample (53%, 14%, 5%). The better initial positions for Atlantic tropical cyclones, and considering the more intense TCs in the Atlantic sample, probably account for the smaller improvements. Nevertheless, an improvement in the NOGAPS short-term track guidance, which is when a TC watch would be issued, is highly desirable. Furthermore, the standard deviations of the adjusted NOGAPS track forecast errors are reduced relative to the unadjusted forecasts, although not as large as in the development sample. Thus, both the accuracy and consistency of the NOGAPS track forecasts for Atlantic TCs could be improved by this postprocessing technique.

d. Validation with an eastern/central North Pacific dataset

For similar reasons as given in section 3c, it was decided to test whether the western North Pacific postprocessing technique could be applied to NOGAPS track forecasts in the eastern and central North Pacific. The available sample is considerably smaller as it includes only eastern Pacific TCs 8–12 during 1996 and 1–19 during 1997, and TCs 2 and 5 during 1997 in the central Pacific. Only 11 of the 167 cases were for TCs with an intensity of 25 kt.

Although TCs in the eastern Pacific are considered to be less difficult to forecast (Elsberry 1995), the NOGAPS (and other dynamical models) do not have as much skill as in the Atlantic. For this sample (Fig. 7), the unadjusted NOGAPS 72-h track forecast errors average 272 n mi (504 km) versus 312 n mi (578 km) in the western North Pacific development sample. As in the Atlantic test (Fig. 6), the adjusted NOGAPS track forecasts are consistently improved throughout the 12- to 72-h intervals. On a percentage basis, the improvements are 52%, 24%, and 14% at 12, 36, and 72 h, which is comparable at 12 h and better at longer intervals than the 1997 western Pacific independent sample. Similar reductions in the standard deviations of the adjusted NOGAPS forecast errors are found as in the Atlantic sample.

4. Summary

A simple postprocessing technique to improve the NOGAPS tropical cyclone track forecasts in the western North Pacific has been developed. The primary objective is to improve the early track errors that arise from an offset in the initial position in the NOGAPS analysis relative to an updated position that will be known 6 h after the 0000 UTC or 1200 UTC synoptic times, when the forecasters first make use of the NOGAPS track predictions. Early track direction discrepancies relative to a persistence of past motion orientation that may arise from an incorrect analysis or a model systematic bias may also be corrected by the postprocessing technique. In addition to the initial position offset, forward predictors are derived from the NOGAPS 0–36-h forecast zonal and meridional displacements. The first-selected predictors are the zonal and meridional distances between backward-extrapolated NOGAPS track forecasts at 12, 24, and 36 h and the corresponding past positions, which are useful in reorienting the forecast track direction to be more aligned with the persistence track motion vector. The development sample is the entire 1992–96 sample of NOGAPS forecasts of western North Pacific TCs that meet the criteria of at least 36-h existence, initial and validation intensity of at least 25 kt, and at least a 36-h forecast track.

For the development sample, the adjusted NOGAPS track errors are reduced by about 51 n mi (95 km) at 12 h, 35 n mi (65 km) at 36 h, and 28 n mi (52 km) at 72 h. Reductions in the standard deviations of the adjusted NOGAPS track errors are also achieved, such that the spread of the 24-h adjusted NOGAPS errors is about equal to the 12-h unadjusted NOGAPS error spread.

Validations with three independent datasets illustrate the likely usefulness of the postprocessing technique throughout the Northern Hemisphere. Application to the 1997 western North Pacific TCs results in improvements relative to the unadjusted NOGAPS forecast errors of 53% at 12 h, 14% at 36 h, and 5% at 72 h. Corresponding percentage improvements for a 1995–97 sample of NOGAPS forecasts of Atlantic TCs are 43%, 3%, and 3%. In the eastern/central North Pacific, the corresponding percentage improvements in mean adjusted NOGAPS track errors are 52%, 24%, and 14%. Thus, the postprocessing regression equations developed for a western North Pacific sample of tropical cyclones during 1992–96 have a more general applicability.

Whereas this postprocessing equation set only applies to the NOGAPS track forecasts, the problems associated with initial position offsets and initial track directions that depart from a persistence track vector are common to other global models. These problems arise even if synthetic TC observations are applied to improve the initial vortex position, structure, and motion in the global models. The technique should be even more applicable to the European Centre for Medium-Range Forecasts of TC motion, for which the initial position offset is more evident since no synthetic TC observations are applied in that model. It is hoped that an operational application of this postprocessing technique will result in improved dynamical track predictions, especially in the 12- to 36-h range when watches and warnings are issued for landfalling TCs.

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