NOAA Technical Memorandum NWS NHC-12

MODIFICATION OF NMC ANALYSES AND PROGNOSES FOR USE IN STATISTICAL TROPICAL CYCLONE PREDICTION MODELS

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May 1979

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ABSTRACT. Several statistical models which provide operational guidance on the prediction of tropical cyclone motion in the Atlantic and Eastern Pacific basins use predictors derived from geopotential heights. These data are routinely acquired from National Meteorological Center (NMC) files stored in the computer system at Suitland, Maryland.

Following the installation of an operational spectral objective analysis scheme at NMC, performance of our statistical models which use geopotential heights as predictors became inconsistent. Other operational changes at NMC threatened delay or termination of an early analysis from which data were readily obtained. Therefore, an alternative source of height data was devised. Geopotential heights are generated from predicted and analyzed winds by use of a balance equation. Tests with two models (NHC72 and EPHC77) during 1978 showed that use of generated data rather than operational data generally resulted in smaller mean vector errors.

1. INTRODUCTION

Several statistical models developed at the National Hurricane Center (NHC) provide guidance on the prediction of tropical cyclone motion in the Atlantic and Eastern Pacific basins. Among these models, NHC67 (Miller et al., 1968), NHC72 (Neumann et al., 1972), NHC73 (Neumann and Lawrence, 1975) and EPHC77 (Leftwich and Neumann, 1977) include predictors derived from geopotential heights. These data are routinely acquired from National Meteorological Center (NMC) files stored in the computer system at Suitland, Maryland.

Beginning with the 1975 hurricane season, geopotential heights for our statistical models were obtained from NMC analyses produced by a spectral objective analysis technique (Bergman et al., 1974). Soon after the use of these analyses began, inconsistencies in performance of the objective statistical guidance models were noted. Because no changes had been made in the statistical models, studies were begun to identify any differences between the character of the spectral analyses and earlier developmental data which could cause a deterioration of the objective forecasts of tropical cyclone motion. One such study (Leftwich, 1977) documented differences in the representation of the storm vortex which led to inconsistencies in the steering of the cyclone by the large-scale environment. A further parallel study at NHC has identified large biases in the prognoses of the NMC 9-layer global model and the NMC 7-layer PE model in tropical regions. Because the spectral analyses change the first guesses provided by the 9-layer global model very little in data-void regions, these biases are transferred to the operational analyses. At 0600 and 1800 GMT predicted fields are used directly in the statistical models. Such biases produce artificial 24h height changes, the magnitude of which are used as predictors by the statistical models. Also, proposed operational schedule changes at NMC threatened to eliminate or delay an early (RADAT) hemispheric analysis traditionally used by the statistical models in preparation of guidance for scheduled advisories at either Miami or San Francisco.

A project was thus begun to develop a technique which would provide timely data at 0000 and 1200 GMT if the early NMC analyses were not available. Such a procedure should also incorporate information from the latest synoptic analysis. Thus, if biases in the heights could be reduced and the latest available information used, forecast errors of the statistical-synoptic models could be reduced.

The first option was to use 12h prognoses from the latest available run of either the NMC 7-layer primitive equation (PE) model or the NMC 9-layer global model, and then interpolate analyzed geopotential height values from the latest LFM initial analysis onto the portion of the large-scale (381 km) grid within the LFM region. An example of a 12h prognosis from the 9-layer global model is shown in Fig. 1. Discontinuities along the boundaries of the LFM analysis region south of 30° N were noted when interpolations were done (Fig. 2). Predicted geopotential heights from both of the above models were found to be consistently too low in the tropics. Therefore, a compromise method of obtaining data for our models was sought.

Examination of the daily operational NMC spectral analyses indicated that the wind fields were more conservative than the geopotential height fields. Alaka et al. (1967) showed that geopotential height fields could be successfully generated from winds in the vicinity of tropical cyclones by use of a balance equation. In this manner, an operational procedure has been developed which incorporates NMC prognoses and analyses to produce consistent geopotential height fields for use in our statistical-synoptic hurricane prediction models. The development and application of this procedure are discussed in the following sections.

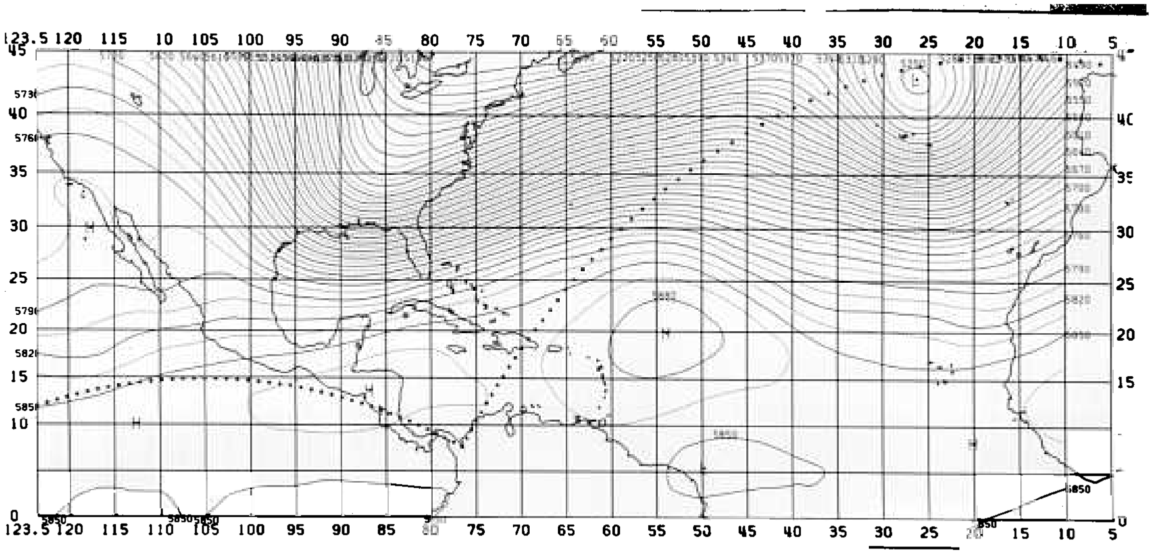

Figure 1. Twelve-hour predicted 500-mb height field from the NMC 9-layer global model valid at 0000 GMT 22 February 1978.

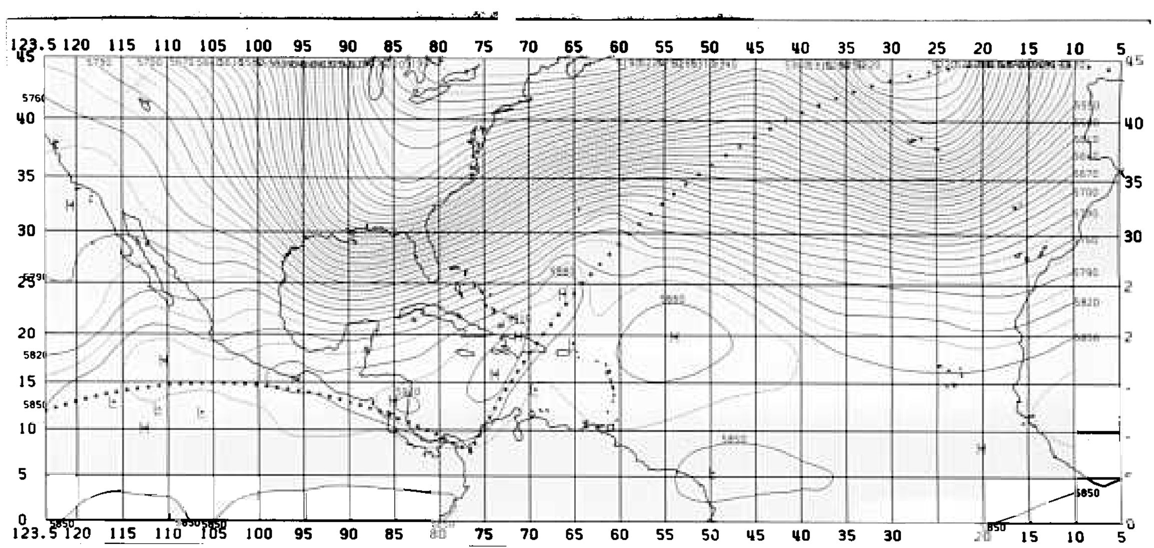

Figure 2. Same as Fig. 1, but with addition of heights interpolated from latest LFM initial analysis. Heavy dotted line is outer boundary of LFM analysis region.

2. THEORETICAL BACKGROUND

Charney (1963) scaled the well-known divergence equation

$$\frac{\partial D}{\partial t} + \underset{\sim}{v}\cdot\underset{\sim}{\nabla}D + \omega\cdot\frac{\partial D}{\partial p} + D^2 + \underset{\sim}{\nabla}\omega\cdot\frac{\partial \underset{\sim}{v}}{\partial p} - f\zeta + \beta u - 2J(u,v) + \nabla^2\Phi = 0 \quad (1)$$

for synoptic-scale motions in the tropics. By assuming that the rotational component of the wind is one order of magnitude greater than the divergent component, and substituting $\underset{\sim}{v} = \underset{\sim}{k} \times \underset{\sim}{\nabla}\Psi$ into (1), one obtains the following balance equation:

$$\nabla^2\Phi - f\nabla^2\Psi - \underset{\sim}{\nabla}\Psi\cdot\underset{\sim}{\nabla}f + 2\left(\frac{\partial^2\Psi}{\partial x\partial y}\right)^2 - 2\left(\frac{\partial^2\Psi}{\partial x^2}\frac{\partial^2\Psi}{\partial y^2}\right) = 0 \,. \quad (2)$$

Placing the Laplacian of geopotential on the left and utilizing the remaining terms as a forcing term on the right gives

$$\nabla^2\Phi = f\nabla^2\Psi + \underset{\sim}{\nabla}\Psi\cdot\underset{\sim}{\nabla}f - 2\left(\frac{\partial^2\Psi}{\partial x\partial y}\right)^2 + 2\left(\frac{\partial^2\Psi}{\partial x^2}\frac{\partial^2\Psi}{\partial y^2}\right) \,.$$

This equation can be solved for the geopotential, Φ, if a stream function field is known. Such a stream function field can be derived from an analyzed wind field by solution of

$$\nabla^2\Psi = \zeta \quad \text{where } \zeta = (\partial v/\partial x - \partial u/\partial y)$$

Solutions of (3) and (4) may be obtained by standard over-relaxation procedures. The domain used for this study was the 65 X 65 NMC 381-km hemispheric grid. In each case, appropriate boundary conditions are necessary. Several types of boundary conditions were tested. Boundary conditions from the operational barotropic tropical cyclone prediction model, SANBAR (Sanders et al., 1975), gave the most consistent results based on subjective comparisons with observed geopotential heights in the tropical regions of the Western Hemisphere. These boundary conditions, which maximize kinetic energy contained in the rotational component of the wind and make the wind component parallel to the boundaries geostrophic, are shown in Fig. 3.

3. OPERATIONAL PROCEDURES

The procedure by which geopotential heights are generated from operationally analyzed and predicted wind fields at 0000/1200 GMT is shown skematically in Fig. 4. Wind prognoses from the NMC 9-layer global model are obtained from files of the IBM 360/195 computer in Suitland. These predictions were selected because additional information is considered in the 6h cycle of the global model. Next, for every grid point within the LFM analysis region (Fig. 2), wind values are interpolated onto the large-scale grid from the latest initial analysis for the LFM model. Relative vorticity is computed from winds, and (4) is solved for a stream function field. Geostrophic stream function values are

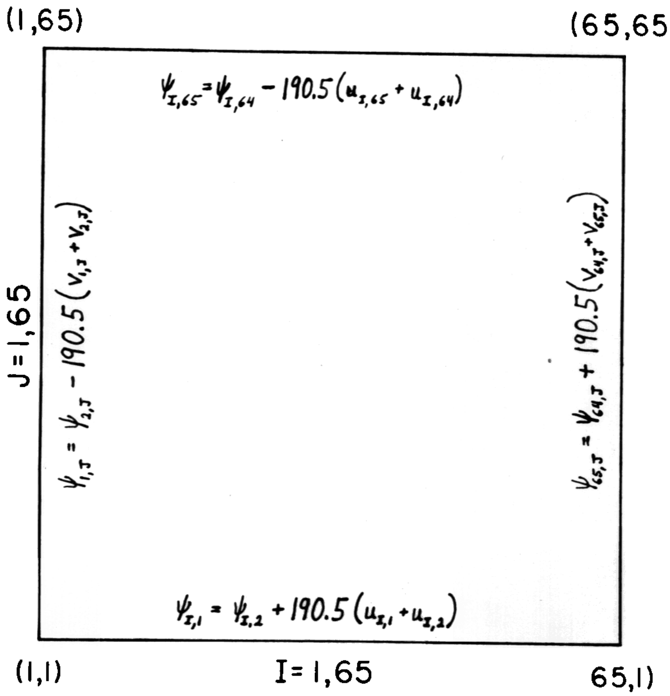

Figure 3. Boundary conditions used in relaxation procedure to obtain stream function fields.

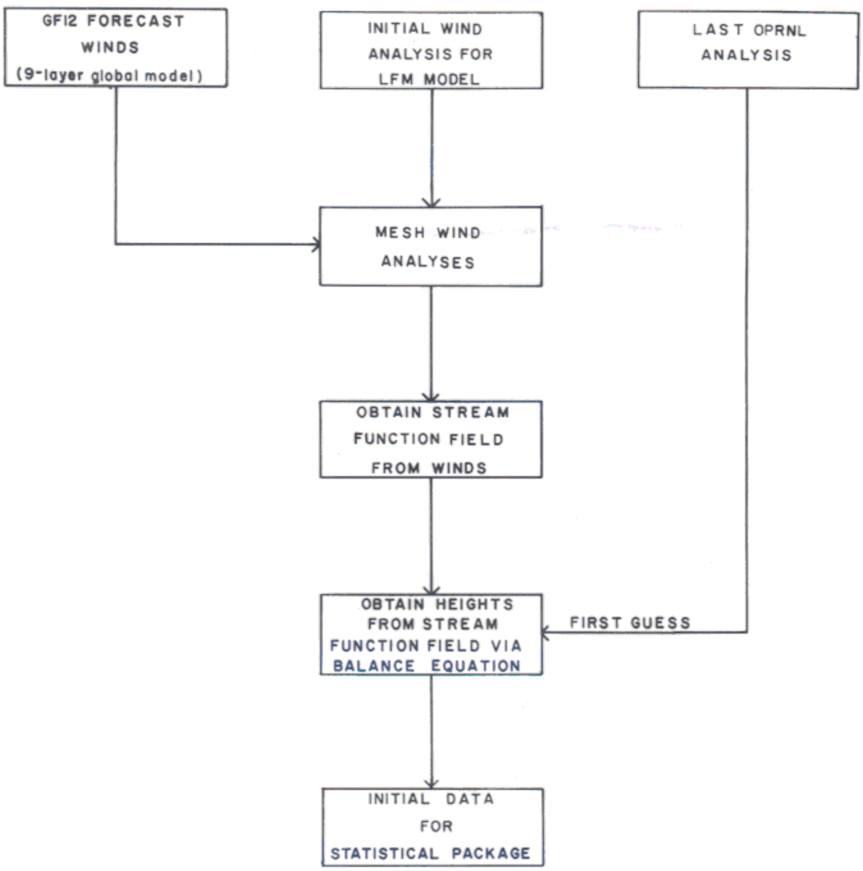

Figure 4. Balance equation procedure followed at 0000 and 1200 GMT.

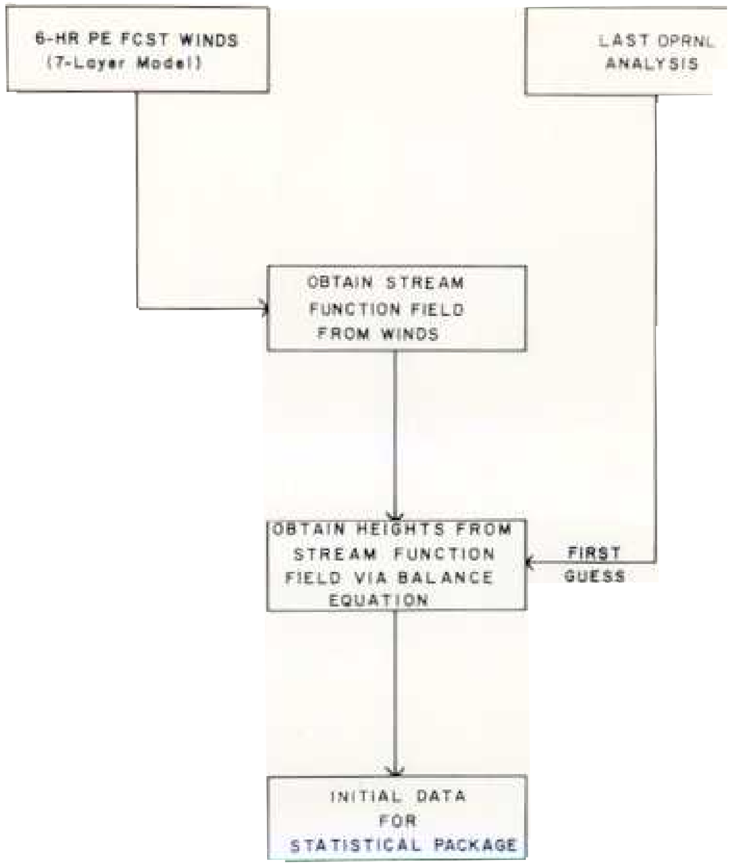

Figure 5. Same as Fig. 4, but for 0600 and 1800 GMT.

the first guess field. The resulting stream function field is then inverted to produce a geopotential field. The last operational spectral analysis is used as a first guess for the geopotential field. This procedure is followed at both 500- and 700-mb levels. At 1000 mb winds are not available, so predicted height values and height values interpolated from the LFM analysis region are used directly by the statistical-synoptic models.

A different procedure is used at 0600/1800 GMT. As shown skematically in Fig. 5, the 6h wind prognoses of the 7-layer PE model are used without the addition of interpolated values at 500 and 700 mb. Six-hour prognoses from the 9-layer global model are not available at these times. Again, the latest operational spectral analysis provides the first guess for the geopotential fields. At 1000 mb the 6h PE prognosis of geopotential heights is used without modification.

After each run of the balance equation procedure is completed, a standard 9-point smoother (Gerrity, 1976) is applied to the generated height fields. This is done to better portray the large-scale steering flow in the analyses used by the statistical models. All geopotential heights used for a given run of the statistical models are stored for future use in computation of 24h changes.

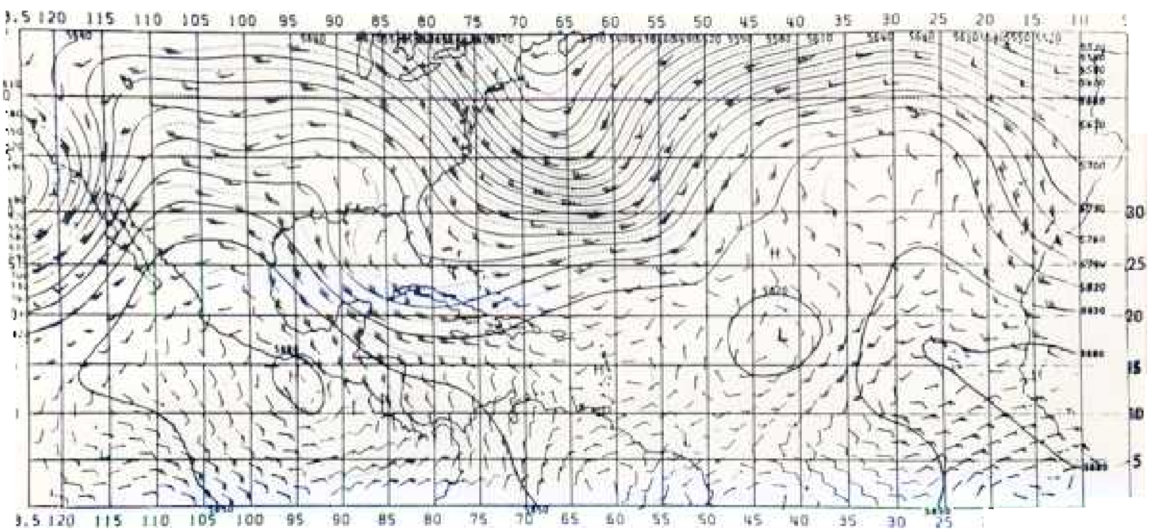

Figure 6. Operational NMC spectral analysis of 500-mb heights and winds for 1200 GMT 31 March 1978.

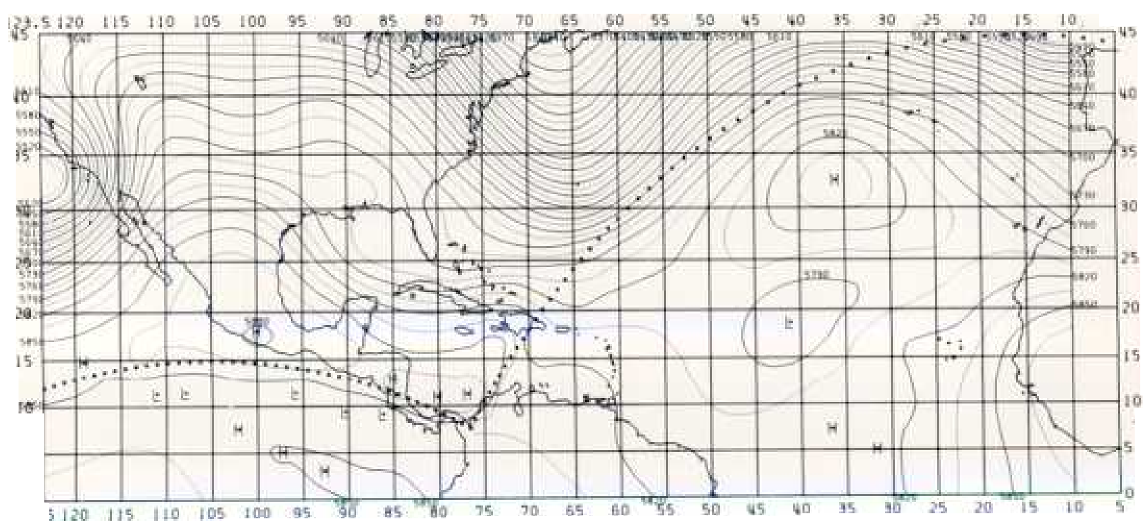

Figure 7. Same as Fig. 6, but with heights interpolated from latest LFM initial analysis. Heavy dotted line is outer boundary of LFM analysis region.

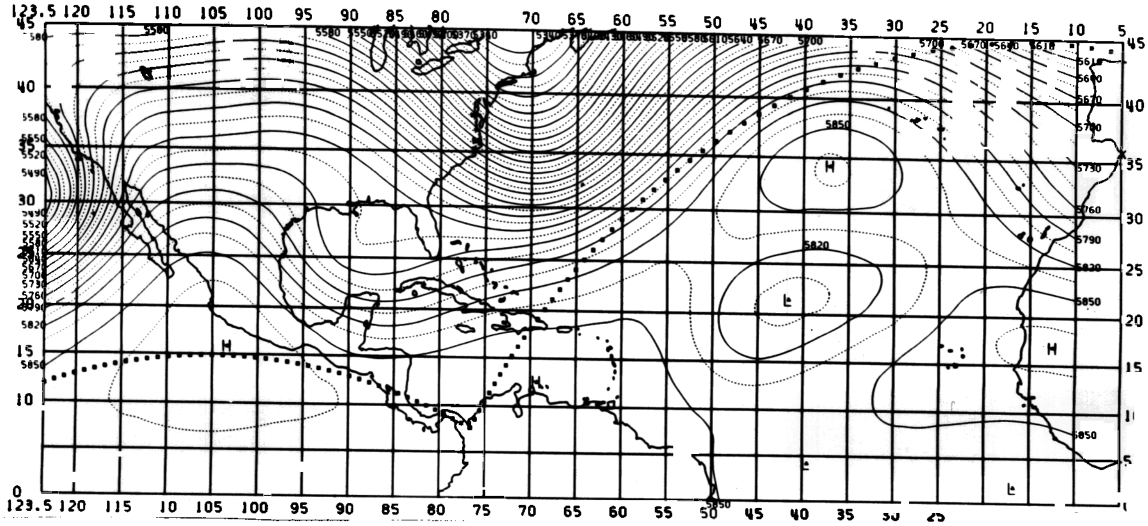

Figure 8. Generated 500-mb heights from balance equation procedure for 1200 GMT 31 March 1978.

4. SELECTED EXAMPLES OF GENERATED HEIGHTS

Fig. 6 is the operational spectral analysis of 500 mb winds and heights for 1200 GMT 31 March 1978. For comparison, the 12h prognosis of the 9-layer global model, modified over the LFM region, is presented in Fig. 7. Discontinuities are observed along the LFM boundary. These discontinuities have been successfully removed in the geopotential height field generated by balance equation procedure (Fig. 8). Large cross-contour wind flow existed in the eastern Atlantic in the operational analysis. Although cross-contour flow has been observed in the tropics, contours (e.g. 5850m) in Fig. 8 better represent the large-scale wind flow.

A comparison of generated height values with observed values at 500 mb was made for 1200 GMT 2 September 1978. At this time Hurricane Ella, located off the mid-Atlantic coast, posed a critical operational forecast requirement. The operational NMC spectral analysis is shown in Fig. 9. Observed height values are printed in bold figures for Kindley Naval Air Station, Bermuda, San Juan, Puerto Rico and Seawell, Barbados. Geopotential heights from the spectral analysis are too low for each of these stations. Generated values were also too low, but the differences from observed values were reduced by approximately 50%. The entire generated 500 mb field is shown in Fig. 10. Differences among these values are summarized in Table 1.

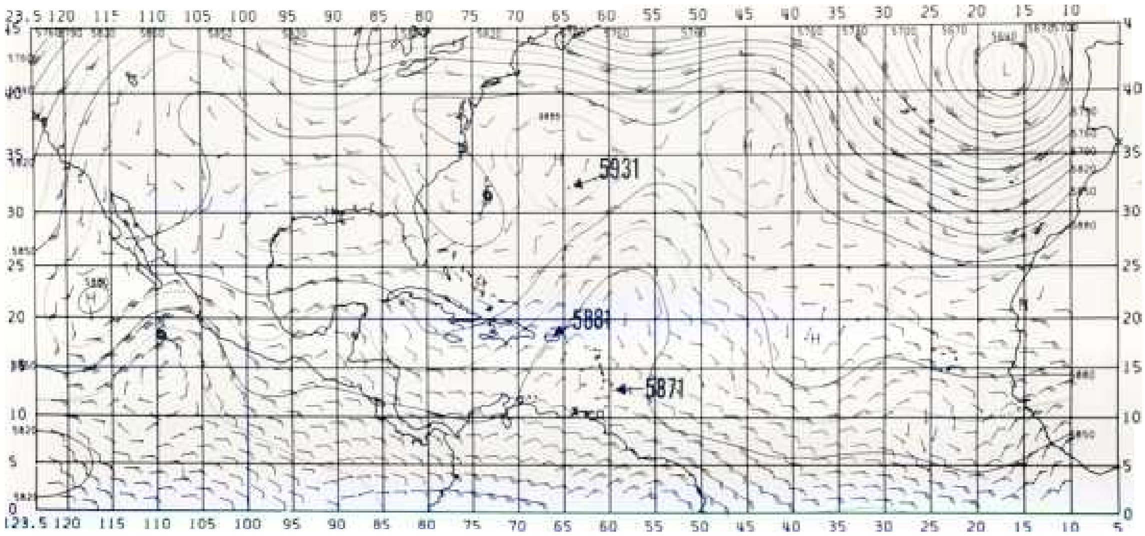

Figure 9. Same as Fig. 6, but for 1200 GMT 2 September 1978 Observed 500-mb heights at Bermuda, Puerto Rico and Barbados are shown in bold figures.

In addition to Ella in the Atlantic, Hurricane Norman was located in the Eastern Pacific. Of particular interest to us was the smoothing of the height fields by the balance equation procedure in the vicinity of both storms and in the vicinity of the inverted trough near the Lesser Antilles.

Because the operational NMC analysis for 1200 GMT produced heights that were lower than observed and this analysis became the first guess for the generated analysis at 0000 GMT following, the next generated heights were also lower than observed values. Even so, the balance equation procedure adjusted the first guess toward the observed values. This result suggests further consideration of using the last generated heights as the first guess for the next analysis rather than using the last operational spectral analysis.

5. FORECAST COMPARISONS FOR 1978

Two statistical-synoptic models were selected for comparisons of predictions for tropical cyclone cases from the 1978 Atlantic and Eastern Pacific seasons. These models are NHC72 (Atlantic) and EPHC77 (Eastern Pacific). Both models combine two separate forecasts - one from predictors based on climatology and persistence (CLPR) and the other from predictors derived from geopotential heights (SYNOP). In the NHC72 model geopotential heights and derived predictors for 500, 700 and 1000 mb are used. EPHC77 uses geopotential heights and changes for the 500 mb level only. The two separate forecasts are statistically weighted to produce a final forecast (FNL). Statistical weighting is different for the two models, but will not be discussed here. Effect of changing synoptic information is best seen in comparisons of SYNOP forecasts, before statistical weighting is done. Because different procedures were used at 0000/1200 GMT and 0600/1800 GMT, comparisons were made separately for each time.

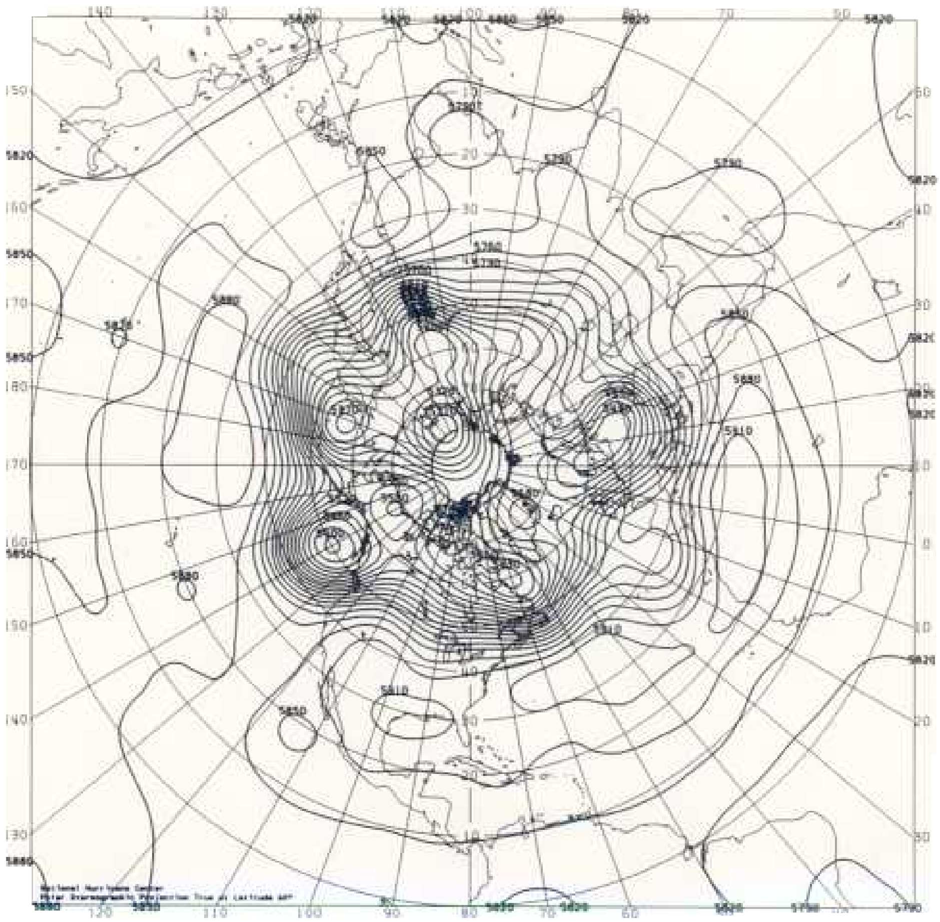

Figure 10. Northern Hemisphere 500-mb height field generated by the balance equation procedure for 1200 GMT 2 September 1978.

Table 1. Values of 500-mb heights at 1200 GMT 2 September 1978 for Kindley, Bermuda, San Juan, Puerto Rico and Seawell, Barbados from NMC operational spectral analysis (OP), generated heights (BZ), and observed heights (OB).

Station	OP	BZ	OB
Kindley	5900	5915	5931
San Juan	5850	5870	5881
Seawell	5845	5855	5871

Fig. 11a depicts mean vector errors for operational and experimental (generated heights) SYNOP forecasts of EPHC77 for all cases in the 1978 Eastern Pacific sample. As in all comparisons, the percentage change in forecast errors, D, is given by

$$D = 100 \cdot (BZ-OP) / OP \qquad (5)$$

where BZ and OP are the experimental and operational mean vector errors, respectively. Values of D represent the net effect of replacing currently used synoptic information with generated geopotential heights. For all cases, decreases were observed in the mean vector errors for each of the three forecast periods. When only SYNOP forecasts for 0000/1200 GMT are considered (Fig. 11b) introduction of generated data produced larger decreases in mean vector errors than for all cases combined. A decrease of 12% occurred in the 72h forecast period. As shown by Fig. 11c, little change from the operational forecasts was seen for the 0600/1800 GMT cases.

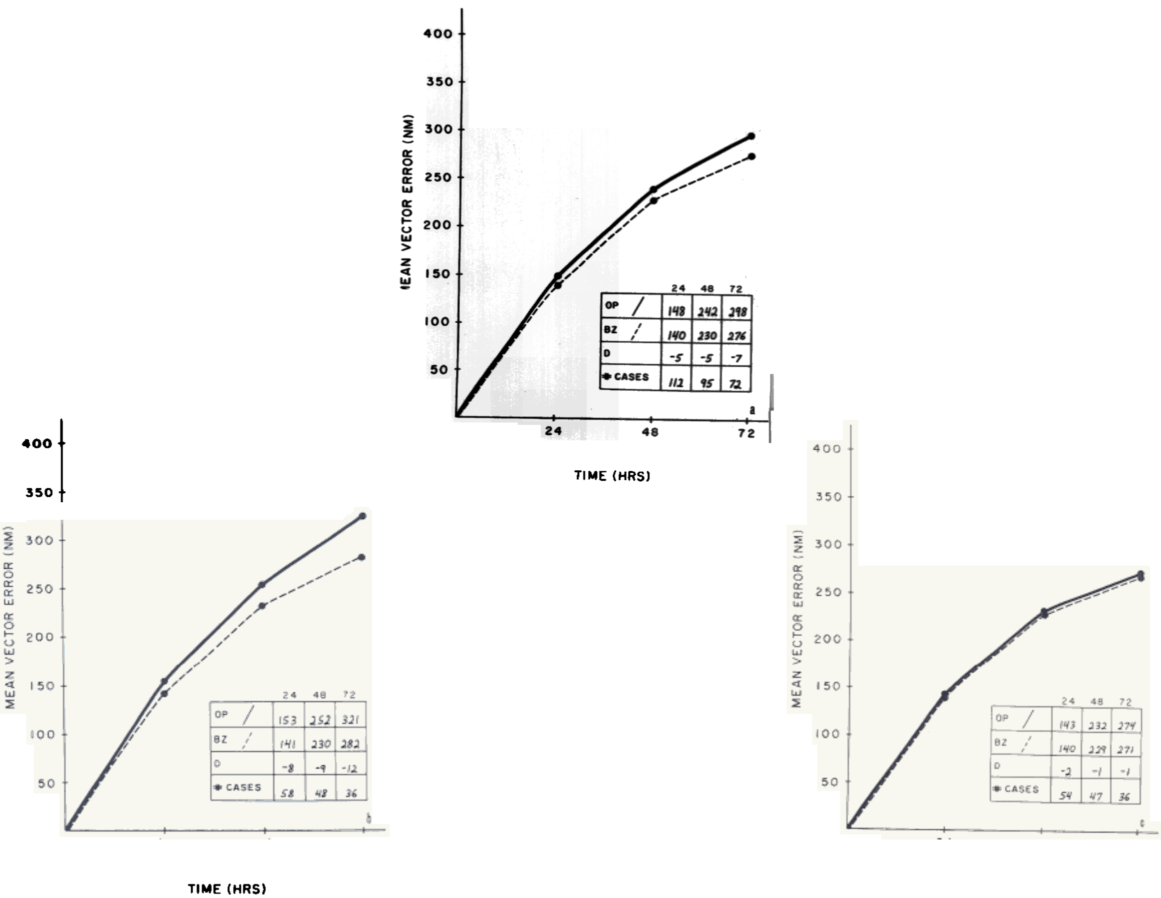

Figure 11. Comparisons of mean vector errors of SYNOP forecasts of EPHC77 model for (a) all cases, (b) 0000 and 1200 GMT only, and (C) 0600 and 1800 GMT only.

For NHC72, mean vector errors for all SYNOP forecasts showed decreases in all time periods (Fig. 12a) when generated heights were used. Again, largest decreases occurred for the 0000/1200 GMT sample. Percentage decreases of 13 and 11 were observed for the 48 and 72h periods, respectively (Fig. 12b). Generated heights produced inconsistent changes in errors for the 0600/1800 GMT sample. As shown in Fig. 12c, although a 17% decrease is seen for 24 hours, a 2% increase was observed at 48 hours, then a 6% decrease at 72 hours.

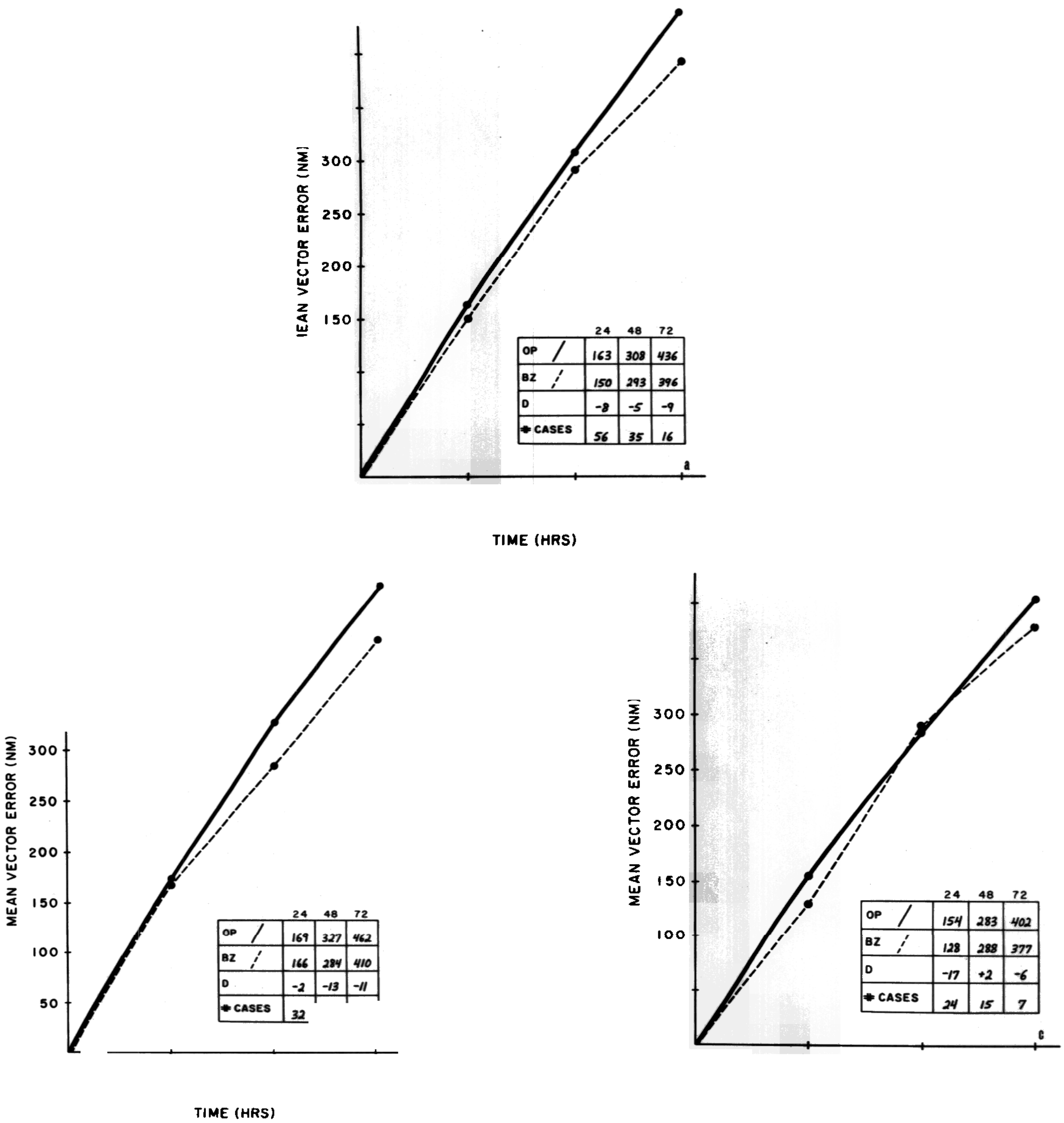

Figure 12. Same as Fig. 11, but for NHC72 model

These results suggest potential changes in mean vector errors if effects of changing the synoptic information were transferred completely to the FNL forecasts. The question to be asked at this point is whether implementation of the balance equation procedure without modification of the existing statistical models will improve the operational statistical-synoptic guidance. This question may be approached by similar considerations of the FNL forecasts.

In all cases for both models magnitudes of mean vector errors for FNL forecasts are less than for corresponding SYNOP forecasts. This indicates that the statistical weighting with the CLPR forecasts indeed improves the forecasts. Variations in the statistical weighting from storm to storm obscure the exact portion of the changes in the SYNOP forecasts that is reflected in each FNL forecast. No separation of these effects, as may be accomplished by such methods as rescreening of predictors, will be discussed at this time.

Decreases were observed in the FNL forecasts for all cases combined for EPHC77, but smaller percentages than in the SYNOP forecasts for the same time periods (Fig. 13a). As shown in Fig. 13b, largest changes were still in the 0000/1200 GMT cases. Mean vector errors increased slightly at 48 and 72 hours for the 0600/1800 GMT cases (Fig. 13c).

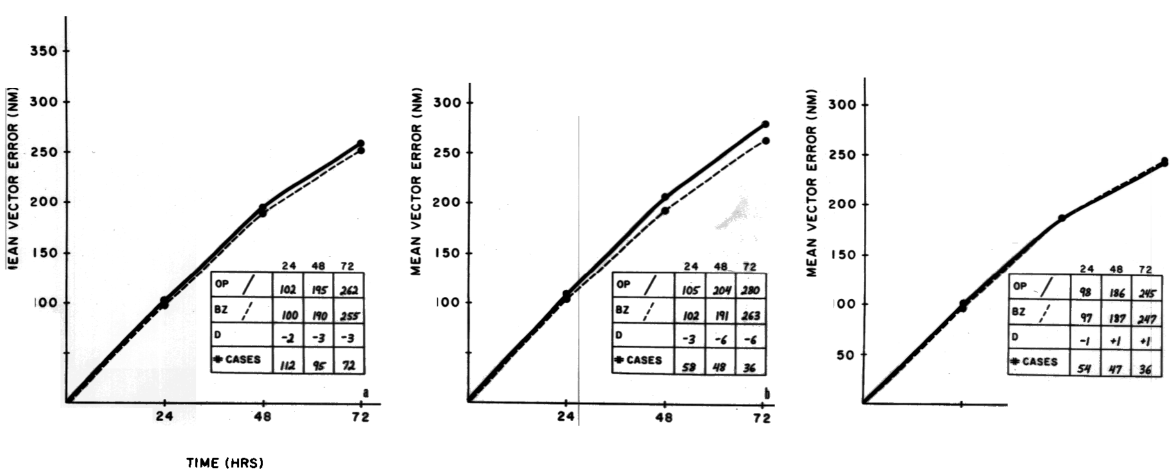

Figure 13. Same as Fig. 11, but for FNL forecasts of EPHC77 model.

Decreases in mean vector errors occurred for all samples of FNL forecasts from the NHC72 model. As shown in Fig. 14a, the largest percentage decrease for all cases combined was seen in 72-hour forecasts (8%). Comparable results were obtained when cases were categorized by time (Figs. 14b and 14c). Additional comparisons for the NHC72 model are desirable because of the smallness of the sample available during the 1978 season.

These results indicate that improvement can be made in the overall mean vector errors in the current NHC72 and EPHC77 models by replacing currently used synoptic information with data generated by the devised balance equation procedure. It is suggested that greater improvement would be seen in the NHC72 model than in the EPHC77 model. Also, inclusion of data from the initial LFM analysis aids the performance of these models.

6. SUMMARY AND CONCLUSIONS

A procedure has been developed to generate geopotential heights at 500 and 700 mb for use in statistical-synoptic tropical cyclone prediction models. Geopotential heights are obtained from predicted and analyzed winds by use of a derived balance equation.

Such generated heights reduced biases previously observed in the NMC spectral analyses. Generated large-scale height patterns better portrayed a steering relationship between wind and height than the operational analyses. For cases from the 1978 Atlantic and Eastern Pacific tropical cyclone seasons, predictions made with the NHC72 and EPHC77 models using generated heights generally gave lower mean vector errors than operational forecasts. Best results were at 0000/1200 GMT when information from the initial LFM wind analyses was incorporated into the balance equation procedure. It is concluded that this procedure can be run successfully on an operational basis and lead to improved guidance from these two statistical synoptic models.

7. ACKNOWLEDGMENTS

The author acknowledges the helpful discussion of Mr. Charles J. Neumann, Chief, NHC Research and Development Unit.

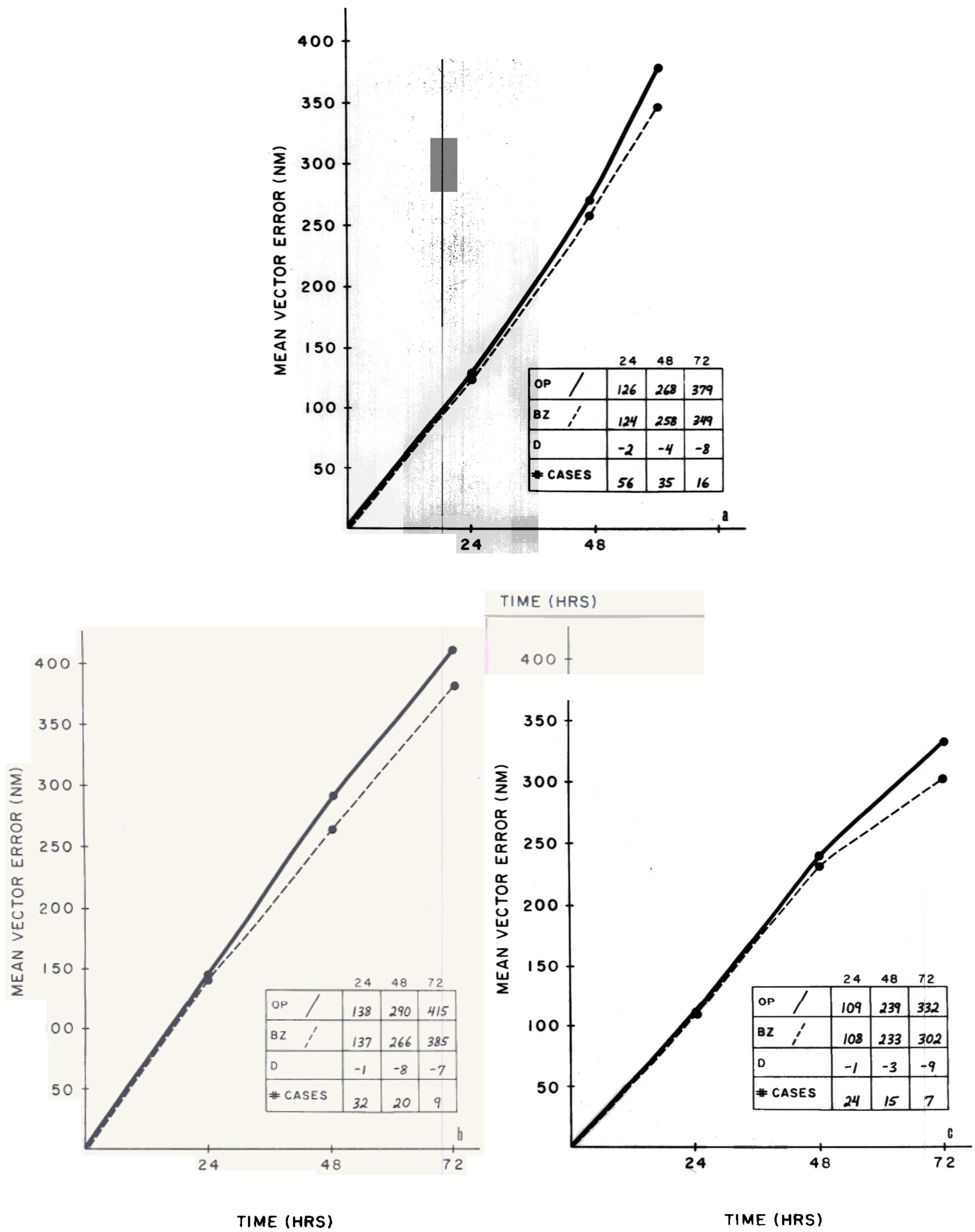

Figure 14. Same as Fig. 11, but for FNL forecasts of NHC72 model.

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