A SYSTEMATIC BIAS IN THE AVIATION MODEL'S FORECAST OF THE ATLANTIC TUTT: IMPLICATIONS FOR TROPICAL CYCLONE FORECASTING

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1. INTRODUCTION

In the science of tropical cyclone (TC) forecasting, three key components – genesis, intensification, and often movement – are dependent upon an accurate assessment of current and future upper tropospheric (200 mb) winds. Therefore knowing the strength and location of the summertime Tropical Upper Tropospheric Trough (TUTT; Sadler 1976), which is located in the Mid-Atlantic Ocean and extends through the Caribbean Sea to the Gulf of Mexico, are crucial pieces of information for the TC forecaster.

TUTTs inhibit the formation of TCs by allowing large amounts of vertical wind shear (VWS) to be positioned directly over the prestorm disturbance. VWS can be quantified in the following manner:

$$\mathrm{VWS} = \sqrt{(u_{200} - u_{850})^2 + (v_{200} - v_{850})^2} \quad (1)$$

where u and v are the zonal and meridional wind components at each grid point for the 200 and 850 mb levels. According to Eq. (1), westerly flow at 200 mb superimposed over easterly tradewind flow at 850 mb gives high VWS values. Therefore, VWS south of a TUTT axis is usually large. Equation (1) also indicates that a large difference in wind magnitude between these two levels leads to large VWS. A tropical disturbance in a deep tropospheric easterly flow has a better chance of development if u_{850} and u_{200} are similar in magnitude, since this condition yields low VWS values. Values of VWS ≥ 10 ms^{-1} are generally considered to be great enough to inhibit TC genesis by advecting upper level moisture and temperature anomalies away from the low-level disturbance center (Zehr 1992).

This paper is a summary of the article by Fitzpatrick et al. (1995). The aim of this summary is to examine the forecasting skill of the National Meteorological Center's Aviation (AVN) model, with respect to the North Atlantic 200 mb flow and the associated TUTT, relative to the forecasting skill of persistenace and climatology.

2. METHODOLOGY AND RESULTS

In 1993 AVN analyses and forecast fields for the 48 h forecast for 850 and 200 mb were analyzed from August through late September. A total of 63 cases that contained the analyses, forecast fields, and their verification were available.

It was found that the upper tropospheric forecast flow fields in the vicinity of the climatological position of the TUTT were biased toward stronger easterlies than what verified. The low-level forecast flow fields were, in general, observed to have very little systematic bias. Therefore, errors in the vertical wind shear (VWS) are dominated by the errors at 200 mb.

Shear values were calculated from the AVN for the initial time period and the 48 h prediction fields by using Eq. (1). An example of the 48 h AVN forecast errors (observed minus forecasted VWS) is shown in Fig. 1 for 00 UTC 3 September when a TUTT existed. A wide region near the Caribbean Sea experienced 8 ms^{-1} or greater error in the forecast VWS field. The locations of large positive errors correspond extremely well with the regions of observed westerly winds south of the TUTT axis. The errors represent a general tendency of the AVN to unrealistically weaken the TUTT in the 48 h forecast, and errors typically were on the order of 10 ms^{-1}.

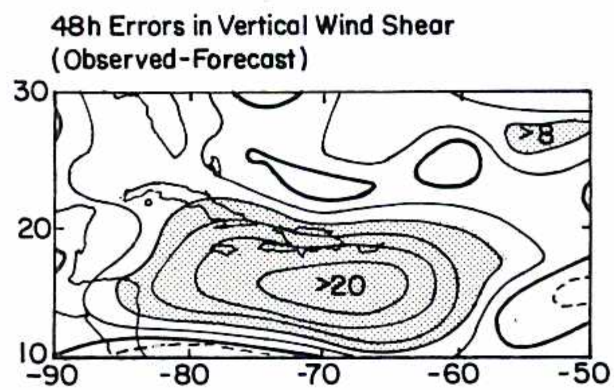

Figure 1: VWS errors (ms^{-1}) for a strong TUTT case associated with the AVN 48 h forecast that verifies on 00 UTC 3 September 1993. Errors > 8 ms^{-1} are shaded. Contour intervals are 4 ms^{-1}. Bold line is 0 ms^{-1}.

Table 1 documents the 48 h AVN model errors found at specific locations throughout the entire two month time period under analysis. All four locations show an underestimation of the VWS during the two month period for all cases. When stratified by 200 mb westerly and easterly wind cases at the verification time (48 h), it becomes apparent that the easterly bias is strongest when westerly winds (typically associated with a TUTT to the north) were observed. When moderate (< 10 ms^{-1}) westerlies were observed at 48 h, this bias is on the order of 5 ms^{-1}. Furthermore, when strong (≥ 10 ms^{-1}) westerlies were observed at 48 h, the underestimation in the VWS is on the order of 10 ms^{-1}. This implies that there is a consistent tendency for the AVN to unrealistically diminish all westerly momentum, even for westerly winds with substantial strength, in the tropics. However, when 200 mb easterly winds occurred at 48 h, the errors are small.

For an additional perspective, the 48 h forecast VWS errors are plotted in terms of 5 ms^{-1} classes for easterly, westerly, and strong westerly wind regimes at the 48 h verification time (Fig. 2). As expected, when easterly winds were observed, the AVN errors are semi-Gaussian. However, west winds experience a positive error bias and, in fact, very few errors are negative. For strong westerlies the bias is strongly positive.

To examine these errors in more detail, the AVN shear values were stratified by winds observed at model initialization and by winds observed at the 48 h verification time (Table 2). From this tabulation, it is clear that the AVN suffers a tendency to weaken or eliminate 200 mb westerly winds and/or to introduce 200 mb easterly winds in the Caribbean Sea. For example, the VWS errors are highest when: 1) west winds were observed to increase with time, 2) east winds became westerly with time, or 3) west winds were observed to be steady-state. This indicates the AVN model's inability to generate, maintain, or build westerlies associated with a steady-state or growing TUTT. In contrast, for the cases when: 1) easterlies were observed throughout the forecast period, 2) west winds weakened with time, or 3) west winds became easterly with time, the VWS forecast errors are small. This probably also reflects the model's bias toward generating 200 mb easterlies in most cases.

While identifying such a bias provides useful information, the forecaster is left with a dilemma – how does one predict the 200 mb flow in the future for a tropical westerly wind regime? One approach is to assume that the TUTT is approximately a steady–state system, and use persistence. Another approach is to utilize climatology. Both procedures are further investigated.

Climatological data were provided by the Climate Analysis Center's Global Tropical Climate Diagnostics for the years 1979 to 1988 (prepared by Muthuvel Chelliah at the National Center for Atmospheric Research). This ten–year VWS climatology is interpolated to the four individual locations for the following time periods: 1) 8/10 – 8/20, 2) 8/21 – 9/9, 3) 9/10 – 9/20, and 4) 9/21 – 9/30. For this ten-year climatology, westerlies exist in all four time frames at 200 mb (not shown).

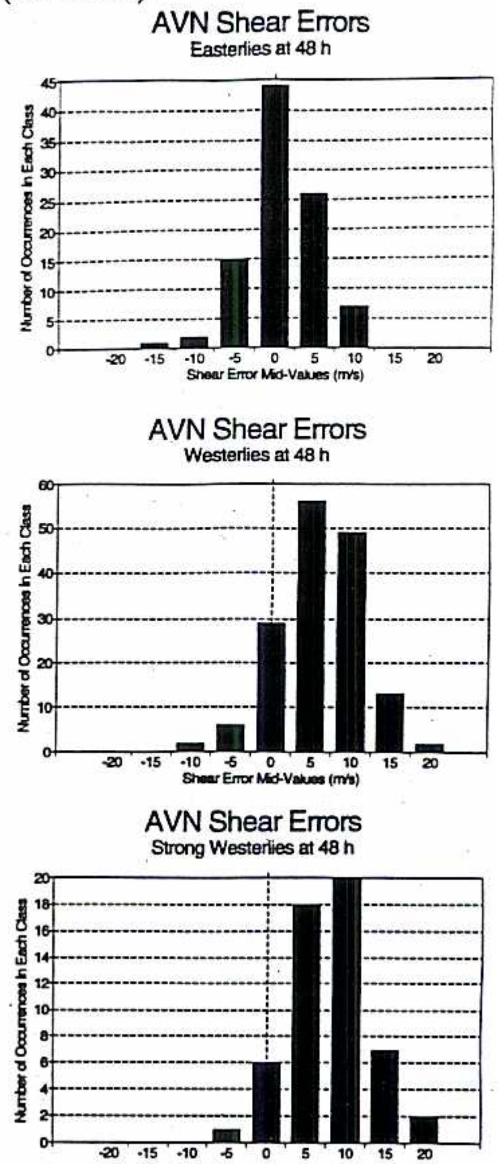

Figure 2: AVN 48 h forecast VWS errors plotted in terms of 5 ms^{-1} classes for easterly, all westerly, and strong westerly wind regimes (≥ 10 ms^{-1}) observed at the 48 h verification time.

The effectiveness of these schemes are examined in Table 3, in which the average errors now are stratified by winds observed at the initialization time. For this two–month period, both climatology and persistence experience smaller VWS errors than the AVN for all stratifications. When all cases are considered, average persistence errors are approximately zero, implying that this procedure introduces no forecast bias. When sub-divided by different wind stratifications, the errors are smallest in magnitude compared to the other two predictive procedures (though it is the same as climatology for weak westerlies) except for observed easterlies at initialization. This implies that 200

Table 1: Relative errors (ms^{-1}) for the 48 h forecasted VWS from the AVN model for selected locations and the overall average during August and September 1993. Positive values indicate more VWS was observed than forecasted. The type of observed winds (west, east, west < 10 ms^{-1} and west ≥ 10 ms^{-1}) refer to the 200 mb wind flow at the particular location at the verification time 48 h ($t = 48$). Number of cases are in parenthesis.

Category	15°N, 80°W	15°N, 70°W	20°N, 65°W	12.5°N, 60°W	Avg
All Cases ($t = 48$)	5.7 (63)	6.1 (63)	2.2 (63)	2.0 (63)	4.0 (252)
West ($t = 48$)	7.7 (37)	7.4 (43)	3.5 (47)	4.6 (30)	5.8 (157)
East ($t = 48$)	2.8 (26)	3.4 (20)	−1.6 (16)	−0.4 (33)	1.1 (95)
West < 10 ms^{-1} ($t = 48$)	7.3 (26)	5.2 (30)	2.6 (24)	3.5 (23)	4.7 (103)
West ≥ 10 ms^{-1} ($t = 48$)	8.6 (11)	12.5 (13)	4.5 (23)	8.3 (7)	7.8 (54)

Table 2: Average relative forecast errors (in ms^{-1}) for the 48 h VWS from the AVN model during August and September 1993 stratified by winds observed at initialization ($t = 0$) and 48 h later ($t = 48$). Number of cases are in parenthesis. Due to missing wind observations coinciding with model initialization, there are 4 fewer total cases (248) than in Table 1.

Category	East ($t = 48$)	West < 10 ms^{-1} ($t = 48$)	West ≥ 10 ms^{-1} ($t = 48$)
East ($t = 0$)	1.4 (51)	5.8 (37)	8.8 (6)
West < 10 ms^{-1} ($t = 0$)	1.3 (33)	5.0 (44)	7.2 (25)
West ≥ 10 ms^{-1} ($t = 0$)	−2.3 (8)	2.3 (21)	8.1 (23)

mb easterlies often did not persist for two consecutive days during August and September 1993.

Using climatology as a forecast inherently yields almost no forecast bias for a case with an initial easterly wind, since 200 mb westerlies exist in the climatology. Apparently, this procedure nudges the forecast back to a normal 200 mb westerly wind regime. This tendency is also apparent for the weak westerly stratification, since climatological winds are < 10 ms^{-1}.

Table 3: Average relative forecast errors (in ms^{-1}) for the 48 h VWS of all wind stratifications at model initialization ($t = 0$) using the AVN prognostic field, persistence, and climatology. The number of cases are the same as Table 2.

Category	AVN	Persistence	Climatology
All Cases ($t = 0$)	4.0	−0.1	1.3
West ($t = 0$)	4.3	−1.9	2.1
East ($t = 0$)	3.6	2.9	0.1
West < 10 ms^{-1} ($t = 0$)	4.3	−1.2	1.2
West ≥ 10 ms^{-1} ($t = 0$)	4.2	−3.2	3.8

In summary, it is recommended that the forecaster use persistence and/or climatology near the Caribbean Sea during the hurricane season to forecast 48 h VWS and 200 mb winds. For 200 mb east winds, climatology is the suggested predictor. For westerly winds < 10 ms^{-1}, half climatology and half persistence is advised. For westerly winds ≥ 10 ms^{-1}, persistence is suggested. Until this bias in the AVN is successfully reduced, it is desirable that the Atlantic basin TC forecaster be aware of this systematic error and make subjective changes in his/her forecasts.

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