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# Twenty-five years of Atlantic basin seasonal hurricane forecasts (1984–2008)

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[1] The Tropical Meteorology Project at Colorado State University, led by Dr. William Gray, has been issuing Atlantic basin seasonal hurricane forecasts in early June and early August since 1984. This paper examines the skill of these forecasts over the past twenty-five years (1984–2008) compared with climatology and a previous 3-year, 5-year and 10-year mean. Seasonal forecasts are shown to have smaller mean-squared errors than any of these metrics for most parameters, although improvements have been modest. The forecast models used by the Tropical Meteorology Project have changed over time, and the current early June and early August model's skill at hindcasting the past twenty-five years are investigated using cross-validation. Preliminary research indicates that using these new models may result in more significant skill improvements in future years. **Citation:** Klotzbach, P. J., and W. M. Gray (2009), Twenty-five years of Atlantic basin seasonal hurricane forecasts (1984–2008), *Geophys. Res. Lett.*, *36*, L09711, doi:10.1029/2009GL037580.

## 1. Introduction

[2] The Tropical Meteorology Project (TMP) at Colorado State University, led by Dr. William Gray, has been issuing Atlantic basin seasonal hurricane forecasts in early June and early August since 1984 [*Gray*, 1984]. These forecast models have developed and changed over time. They are now issued at four lead times (in early December, early April, early June and early August). Extensive discussion of the development of the statistical seasonal forecast models is available from *Klotzbach* [2007a]. To summarize, these forecast models are developed on "best track" data from the National Hurricane Center (NHC) [*Jarvinen et al.*, 1984] utilizing predictors selected from the NCEP/NCAR Reanalysis dataset [*Kistler et al.*, 2001].

[3] Early December and early April seasonal forecasts have only been issued since the early 1990s and have shown little real-time forecast skill [*Camargo et al.*, 2007]. This note focuses on the early June and early August forecasts. It expands upon the initial analysis done by *Owens and Landsea* [2003] of the 1984–2001 hurricane forecasts issued by the TMP and the analysis of *Saunders* [2006] who briefly examines the skill of several different seasonal forecast groups from 1984–2005 for named storms and hurricanes. This manuscript discusses the skill of the TMP's seasonal forecasts over the past twenty-five years (1984–2008). Section 2 discusses the data and methodology used to evaluate seasonal forecast skill, while section 3 examines the skill of the early June and early August seasonal forecasts from 1984–2008. Section 4 considers potential future improvements in skill using the current June and August models, while section 5 gives a summary and conclusion.

## 2. Data and Methodology

[4] The TMP has issued forecasts for named storms (a tropical or sub-tropical cyclone with maximum sustained winds of at least 34 knots), named storm days (four six-hour periods where a tropical or sub-tropical cyclone has winds of at least 34 knots), hurricanes (a tropical cyclone with maximum sustained winds of at least 64 knots) and hurricane days (four six-hour periods where a tropical cyclone has winds of at least 64 knots) at both the early June and early August lead time over the 1984–2008 period. We will investigate the skill of these four parameters at both lead times (eight total parameters). Major hurricanes, major hurricane days and Net Tropical Cyclone activity have only been predicted by the TMP since the early 1990s, so they will not be considered in this analysis. When evaluating the August lead time, only storms and storm days accumulated after 31 July will be considered. Forecasts will be verified against the National Hurricane Center's "best track" data [*Jarvinen et al.*, 1984]. Even though 1 August is two months into the hurricane season, about 90% of all hurricane activity occurs after that date (Figure 1).

[5] To determine the skill of these seasonal forecasts, they will be compared against several "no-skill" metrics. The first metric is the 1950–2000 climatology as defined by the TMP which is 9.6 named storms, 49.1 named storm days, 5.9 hurricanes and 24.5 hurricane days. The other "no-skill" metrics are the previous three-year, five-year and ten-year mean. Mean absolute error (MAE) will be used as the skill metric, where MAE is defined to be:

$$\text{MAE} = |\text{Predicted Value} - \text{Observed Value}| \qquad (1)$$

[6] We use p-values calculated from a two-tailed Student's t-test to determine if the difference in MAE over the 25-year period are statistically significant between predicted values and the various "no-skill" metrics. We assume that each season represents an individual degree of freedom. We use MAE as the forecast metric of choice since it represents an easily understandable metric, that is, the average error of the forecast from observations over the period of record. Significance levels were also examined for mean squared error (MSE), and differences were not significant.

## 3. Early June and Early August Seasonal Forecast Skill

[7] Tables 1 and 2 display predicted versus observed named storms, named storm days, hurricanes and hurricane

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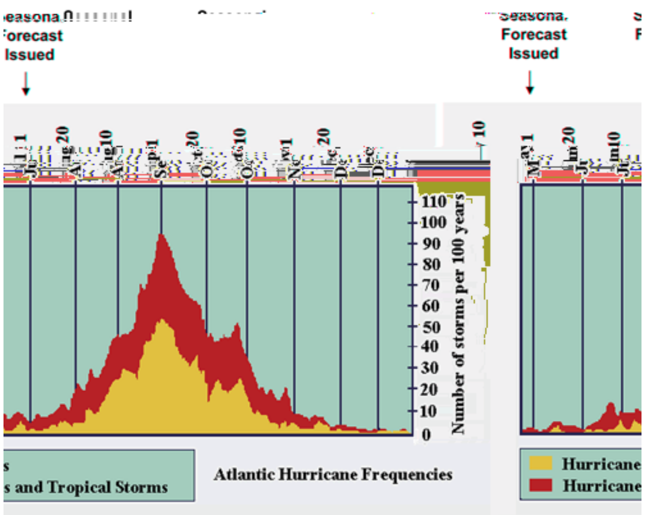


**Figure 1.** The climatological progression of the Atlantic basin hurricane season along with approximate dates of the Tropical Meteorology Project's June and August Atlantic basin seasonal hurricane forecast updates. Approximately 90% of all Atlantic basin hurricanes occur after 1 August. Figure adapted from the National Oceanic and Atmospheric Administration's figure located at http://www.nhc.noaa.gov/gifs/peakofseason.gif.

days in early June and early August, respectively. The statistical models upon which most of these forecasts were based was documented by *Gray et al.* [1994] for early June and by *Gray et al.* [1993] for early August. As mentioned before, the early August values include only storms forming after 1 August. The correlation between predictions and observations is also provided. All correlations are significant at the 95% level using a Student's t-test and assuming that each forecast year represents an individual degree of freedom. The reader may note that the correlation skill is higher for named storms than for hurricanes, which seems somewhat counter-intuitive, since named storms can be short-lived and are more frequently of sub-tropical origin than are hurricanes. This is largely due to the 2007 hurricane season. Even though it was about an average season for most parameters, it had a well above-average number of named storms (15). Since the TMP incorrectly predicted an active season, the named storm forecast looked quite good, although the forecast was much too high for other parameters. If 2007 had named storm activity more typical of an average hurricane season (e.g., 9–11 named storms), the correlation skill for named storms and hurricanes would be more comparable.

[8] We next investigate the skill of these real-time forecasts compared with various no-skill metrics discussed in the data section. Table 3 compares the mean absolute error (MAE) of the June and August forecasts with a climatological forecast, a previous three-year mean forecast, a previous five-year mean forecast and a previous ten-year mean forecast, respectively. Statistically significant differences in MAE, using a two-tailed Student's t-test, between real-time forecasts and no-skill forecasts are displayed in bold-face for the 95% level and underlined for the 90% level. In general, real-time forecasts have lower MAEs than do any of the no-skill forecasts, with statistically significant differences for several parameters.

[9] For Atlantic basin seasonal hurricane forecasts, the no-skill metric that generally has the lowest MAEs of the four evaluated is the previous ten-year mean. This is in agreement with the World Meteorological Organization

**Table 1.** Early June Prediction Versus Observed Named Storms, Named Storm Days, Hurricanes and Hurricane Days Over the Period From 1984–2008[a]

| Year | Pred. NS | Obs. NS | Pred. NSD | Obs. NSD | Pred. H | Obs. H | Pred. HD | Obs. HD |
|---|---|---|---|---|---|---|---|---|
| 1984 | 10 | 13 | 45 | 63.25 | 7 | 5 | 30 | 18.25 |
| 1985 | 11 | 11 | 55 | 51.25 | 8 | 7 | 35 | 21.25 |
| 1986 | 8 | 6 | 35 | 23.25 | 4 | 4 | 15 | 10.50 |
| 1987 | 8 | 7 | 40 | 37.25 | 5 | 3 | 20 | 5.00 |
| 1988 | 11 | 12 | 50 | 46.75 | 7 | 5 | 30 | 21.25 |
| 1989 | 7 | 11 | 30 | 66.00 | 4 | 7 | 15 | 31.75 |
| 1990 | 11 | 14 | 55 | 72.25 | 7 | 8 | 30 | 26.75 |
| 1991 | 8 | 8 | 35 | 24.25 | 4 | 4 | 15 | 8.25 |
| 1992 | 8 | 7 | 35 | 40.25 | 4 | 4 | 15 | 16.00 |
| 1993 | 11 | 8 | 55 | 30.00 | 7 | 4 | 25 | 9.50 |
| 1994 | 9 | 7 | 35 | 28.75 | 5 | 3 | 15 | 7.25 |
| 1995 | 12 | 19 | 65 | 121.25 | 8 | 11 | 35 | 61.75 |
| 1996 | 10 | 13 | 45 | 79.00 | 6 | 9 | 20 | 45.00 |
| 1997 | 11 | 8 | 55 | 30.00 | 7 | 3 | 25 | 9.50 |
| 1998 | 10 | 14 | 50 | 88.00 | 6 | 10 | 25 | 48.50 |
| 1999 | 14 | 12 | 75 | 78.50 | 9 | 8 | 40 | 41.00 |
| 2000 | 12 | 15 | 65 | 71.50 | 8 | 8 | 35 | 32.75 |
| 2001 | 12 | 15 | 60 | 68.75 | 7 | 9 | 30 | 25.50 |
| 2002 | 11 | 12 | 55 | 57.00 | 6 | 4 | 25 | 10.75 |
| 2003 | 14 | 16 | 70 | 81.50 | 8 | 7 | 35 | 32.75 |
| 2004 | 14 | 15 | 60 | 93.00 | 8 | 9 | 35 | 45.50 |
| 2005 | 15 | 28 | 75 | 131.50 | 8 | 15 | 45 | 49.75 |
| 2006 | 17 | 10 | 85 | 52.75 | 9 | 5 | 45 | 21.25 |
| 2007 | 17 | 15 | 85 | 37.75 | 9 | 6 | 40 | 12.25 |
| 2008 | 15 | 16 | 80 | 84.75 | 8 | 8 | 40 | 29.50 |
| 1984–2008 Correlation | | 0.58 | | 0.45 | | 0.44 | | 0.44 |

[a]Correlations between forecasts and observations are also provided.

**Table 2.** Early August Prediction Versus Observed Named Storms, Named Storm Days, Hurricanes and Hurricane Days Over the Period From 1984–2008[a]

| Year | Pred. NS | Obs. NS | Pred. NSD | Obs. NSD | Pred. H | Obs. H | Pred. HD | Obs. HD |
|---|---|---|---|---|---|---|---|---|
| 1984 | 10 | 13 | 45 | 63.25 | 7 | 5 | 30 | 18.25 |
| 1985 | 10 | 9 | 50 | 45.75 | 7 | 6 | 30 | 20.75 |
| 1986 | 7 | 4 | 25 | 18 | 4 | 3 | 10 | 9.50 |
| 1987 | 7 | 7 | 35 | 37.25 | 4 | 3 | 15 | 5.00 |
| 1988 | 11 | 12 | 50 | 46.75 | 7 | 5 | 30 | 21.25 |
| 1989 | 9 | 8 | 35 | 61 | 4 | 7 | 15 | 31.75 |
| 1990 | 11 | 12 | 50 | 65.5 | 6 | 7 | 25 | 24.50 |
| 1991 | 7 | 7 | 30 | 22.5 | 3 | 4 | 10 | 8.25 |
| 1992 | 8 | 6 | 35 | 38.75 | 4 | 4 | 15 | 16.00 |
| 1993 | 10 | 7 | 50 | 29 | 6 | 4 | 25 | 9.50 |
| 1994 | 7 | 6 | 30 | 26.75 | 4 | 3 | 12 | 7.25 |
| 1995 | 16 | 14 | 65 | 107.25 | 9 | 10 | 30 | 61.00 |
| 1996 | 11 | 10 | 50 | 65 | 7 | 7 | 25 | 38.50 |
| 1997 | 11 | 3 | 45 | 16.75 | 6 | 1 | 20 | 7.25 |
| 1998 | 10 | 13 | 50 | 85 | 6 | 10 | 25 | 48.50 |
| 1999 | 14 | 11 | 75 | 74 | 9 | 8 | 40 | 41.00 |
| 2000 | 11 | 15 | 55 | 71.5 | 7 | 8 | 30 | 32.75 |
| 2001 | 12 | 14 | 60 | 66.75 | 7 | 9 | 30 | 25.50 |
| 2002 | 9 | 11 | 35 | 55.25 | 4 | 4 | 12 | 10.75 |
| 2003 | 14 | 12 | 60 | 63.75 | 8 | 5 | 23 | 30.75 |
| 2004 | 13 | 15 | 55 | 93 | 7 | 9 | 30 | 45.50 |
| 2005 | 13 | 21 | 67 | 102.5 | 8 | 12 | 44 | 38.50 |
| 2006 | 13 | 7 | 69.5 | 45.5 | 7 | 5 | 35 | 21.25 |
| 2007 | 13 | 12 | 73.75 | 34.75 | 8 | 6 | 35 | 12.25 |
| 2008 | 13 | 12 | 64 | 59 | 7 | 6 | 36.25 | 20.75 |
| 1984–2008 Correlation | | 0.60 | | 0.54 | | 0.58 | | 0.51 |

[a]Correlations between forecasts and observations are also provided. Only activity after 1 August is counted in this analysis.

which uses the previous ten-year mean as its no-skill metric for seasonal forecasts [*World Meteorological Organization*, 2002].

[10] These results illustrate that seasonal forecasts issued in early June and early August have shown some promise at providing skillful information as to the likely levels of activity to occur in the upcoming hurricane season. However, the modest improvements over no-skill forecasts argue that there is still considerable work that needs to be done in improving these forecasts. The next section investigates the potential skill that forecasts over this same time period could have utilizing the current statistical schemes developed recently by the TMP.

## 4. Potential Seasonal Forecast Skill Improvements

[11] The statistical forecast models that the TMP uses as its basis for seasonal forecasts have been revised and updated throughout the years. Current statistical models utilized in the early June and early August forecast schemes are detailed by *Klotzbach and Gray* [2008] and *Klotzbach* [2007b]. We have attempted to make sure that we have strong physical relationships between each of the predictors selected in the new forecast scheme and atmospheric/oceanic features known to impact Atlantic basin tropical cyclones. For example, it has been well documented that active hurricane seasons have a warmer than normal tropical Atlantic [e.g., *Goldenberg et al.*, 2001; *Saunders and Lea*, 2008], lower than normal sea level pressure [*Knaff*, 1997] and reduced levels of vertical wind shear [*Gray*, 1984]. Figure 2 shows a linear correlation plot between one of our early June predictors (a measure of April–May sub-tropical Atlantic SST between 20–50°N and 15–30°W and May sub-tropical Atlantic SLP between 10–35°N and 10–40°W, details available from *Klotzbach and Gray* [2008]) and August–October sea surface temperature, sea level pressure, 200 mb zonal wind and 925 mb zonal wind, respectively, as derived from the NCEP/NCAR reanalysis. Note that the predictor is correlated with an anomalous warm tropical Atlantic, anomalous low sea level pressure in the

**Table 3.** Mean Absolute Errors Between Observations and Real-Time Forecasts From 1984–2008, Between Observations and the 1950–2000 Climatology, Between Observations and the Previous Three-Year Mean, Between Observations and the Previous Five-Year Mean and Between Observations and the Previous Ten-Year Mean[a]

| Forecast Parameter | Real-Time Forecast | Climatology | Previous 3-Year Mean | Previous 5-Year Mean | Previous 10-Year Mean |
|---|---|---|---|---|---|
| June NS | 2.9 | **4.1** | **3.7** | 3.2 | 3.3 |
| June NSD | 20.0 | 23.4 | **24.5** | 21.8 | 20.8 |
| June H | 2.0 | 2.4 | 2.6 | 2.3 | 2.2 |
| June HD | 11.9 | 13.0 | 14.5 | 12.6 | 11.8 |
| August NS | 2.4 | **3.5** | **3.4** | **3.0** | **3.1** |
| August NSD | 16.9 | 21.7 | **22.5** | **20.3** | 20.1 |
| August H | 1.7 | 2.1 | **2.6** | 2.2 | 2.1 |
| August HD | 10.1 | 12.0 | **13.6** | 11.9 | 11.4 |

[a]MAEs, mean absolute errors, are calculated for both early June and early August predictions for named storms (NS), named storm days (NSD), hurricanes (H) and hurricane days (HD). Only activity after 1 August is counted in the early August analysis. Statistically significant differences in MAE, using a two-tailed Student's t-test, between real-time forecasts and no-skill forecasts are displayed in bold-face for the 95% level and underlined for the 90% level.

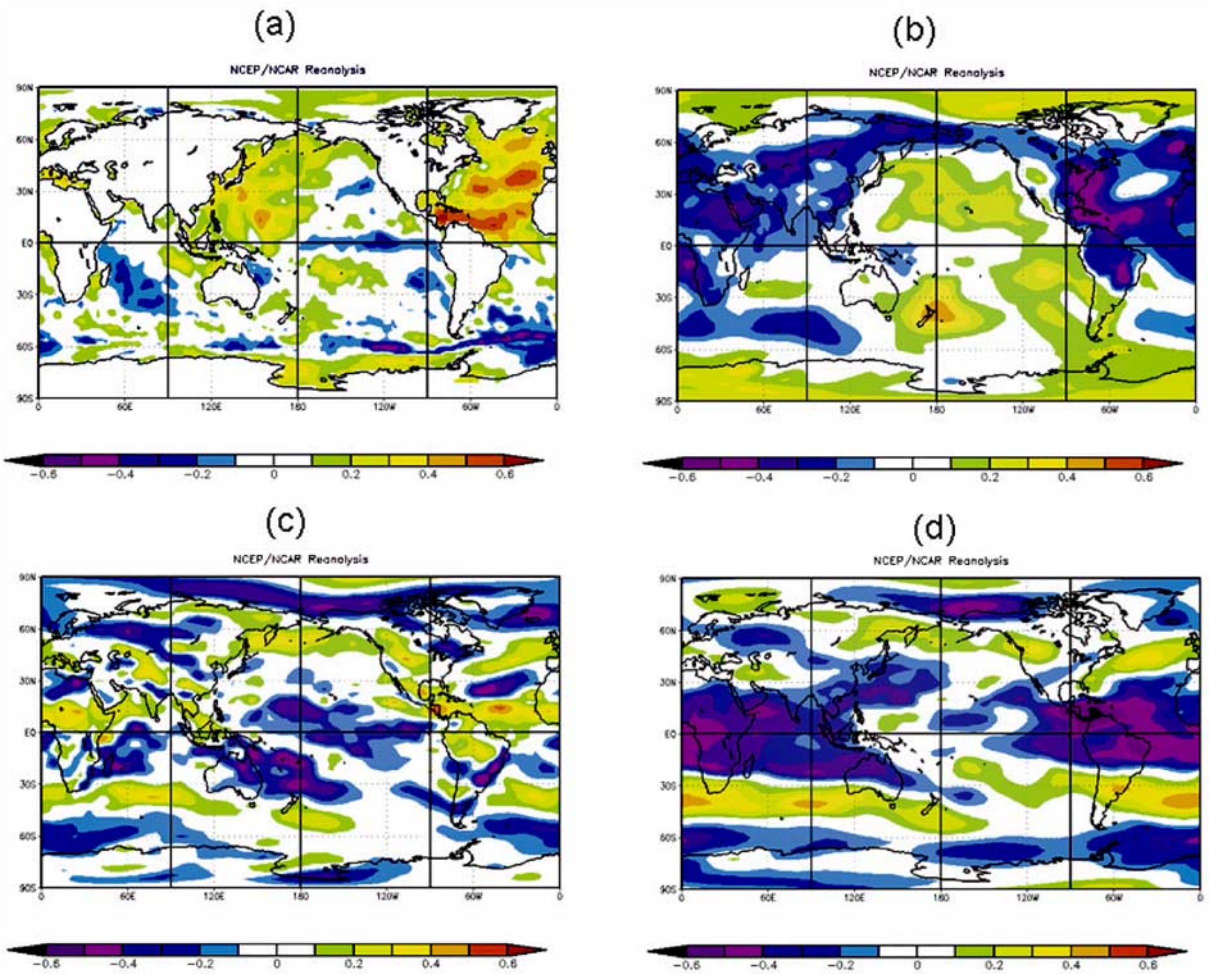


**Figure 2.** Linear correlations between the subtropical Atlantic index (April–May sub-tropical Atlantic SST between 20–50°N and 15–30°W and May sub-tropical Atlantic SLP between 10–35°N and 10–40°W) and (a) August–October sea surface temperature, (b) August–October sea level pressure, (c) August–October 925 mb zonal wind and (d) August–October 200 mb zonal wind. All four of these parameter deviations are known to be favorable for enhanced hurricane activity.

**Table 4.** Mean Absolute Errors Between Early June and Early August Cross-Validated Hindcasts and Observations From 1984–2008, Between Observations and the 1950–2000 Climatology, Between Observations and the Previous Three-Year Mean, Between Observations and the Previous Five-Year Mean and Between Observations and the Previous Ten-Year Mean[a]

| Forecast Parameter | Current Model Hindcast | Climatology | Previous 3-Year Mean | Previous 5-Year Mean | Previous 10-Year Mean |
|---|---|---|---|---|---|
| June NS | 2.6 | **4.1** | 3.7 | 3.2 | 3.3 |
| June NSD | 12.8 | **23.4** | **24.5** | **21.8** | **20.8** |
| June H | 1.5 | **2.4** | **2.6** | **2.3** | **2.2** |
| June HD | 7.4 | **13.0** | **14.5** | **12.6** | **11.8** |
| August NS | 2.4 | **3.5** | 3.4 | 3.0 | 3.1 |
| August NSD | 12.4 | **20.4** | **21.8** | **19.6** | **19.0** |
| August H | 1.3 | **2.1** | **2.6** | **2.2** | **2.1** |
| August HD | 6.3 | **12.0** | **13.6** | **11.9** | **11.4** |

[a]MAEs, mean absolute errors, are calculated for both early June and early August predictions for named storms (NS), named storm days (NSD), hurricanes (H) and hurricane days (HD). Only activity after 1 August is counted in the early August analysis. Statistically significant differences in MAE, using a two-tailed Student's t-test, between cross-validated hindcasts and no-skill forecasts are displayed in bold-face for the 95% level and underlined for the 90% level.

tropical Atlantic, anomalous easterly flow at 200 mb and anomalous westerly flow at 925 mb. These anomalous flows result in reduced vertical wind shear over the tropical Atlantic.

[12] These forecast models hindcast Net Tropical Cyclone (NTC) activity [*Gray et al.*, 1994], which is defined to be the following six parameters normalized by their clima-

**Table 5.** Percentage Improvement in MAE Between Real-Time Forecasts and Cross-Validated Hindcasts Compared With Climatology Over the Period From 1984–2008

| Forecast Parameter | 1984–2008 Real-Time Forecasts | 1984–2008 Cross-Validated Hindcasts |
|---|---|---|
| June NS | 29 | 37 |
| June NSD | 15 | 45 |
| June H | 17 | 38 |
| June HD | 8 | 43 |
| August NS | 31 | 31 |
| August NSD | 22 | 43 |
| August H | 19 | 38 |
| August HD | 16 | 48 |

**Table 6.** Correlation Between Observations and 1984–2008 Real-Time Forecasts Along With the Correlation Between Observations and 1984–2008 Cross-Validated Hindcasts Using the Most Recent Statistical Models

| Forecast Parameter | 1984–2008 Real-Time Forecast Correlation | 1984–2008 Cross-Validated Hindcast Correlation |
|---|---|---|
| June NS | 0.58 | 0.71 |
| June NSD | 0.45 | 0.83 |
| June H | 0.45 | 0.78 |
| June HD | 0.44 | 0.81 |
| August NS | 0.60 | 0.64 |
| August NSD | 0.54 | 0.84 |
| August H | 0.58 | 0.82 |
| August HD | 0.51 | 0.83 |

tological average values: named storms, named storm days, hurricanes, hurricane days, major hurricanes and major hurricane days. By definition, an NTC of 100 is an average hurricane season. In general, a drop-one cross-validation approach is considered an upper bound on future forecast skill [*Gray et al.*, 1994]. We utilize equations based on this approach to evaluate hindcasts issued over the 1984–2008 time period in early June and early August.

[13] Table 4 compares the MAE of the June and August cross-validated hindcasts, using the most recent statistical models, with a climatological forecast, a previous three-year mean forecast, a previous five-year mean forecast and a previous ten-year mean forecast, respectively. Statistically significant differences in MAE, using a two-tailed Student's t-test, between real-time forecasts and no-skill forecasts are displayed in bold-face for the 95% level and underlined for the 90% level. In general, hindcasts utilizing the new early June and early August schemes show statistically significant lower MAEs than do any of the no-skill forecasts, indicating the potential for improved skill of seasonal forecasts in the future. In general, MAE values for cross-validated hindcasts show the least improvement over no-skill forecasts for named storms, which is to be expected, since the new seasonal forecast models are built off the Net Tropical Cyclone (NTC) parameter which weighs more intense tropical cyclones more heavily. Correlations are also higher between cross-validated hindcasts and observations than they were for real-time forecasts and observations. Table 5 summarizes the percentage improvement in MAE between real-time forecasts and cross-validated hindcasts compared with climatology, while Table 6 displays correlations between observations and real-time forecasts along with correlations between observations and cross-validated hindcasts.

## 5. Conclusions

[14] Seasonal forecasts issued in early June and early August over the period from 1984–2008 have shown modest skill improvement over several no-skill metrics. Newly-developed forecast models in early June and early August indicate that increased skill in future years may be possible, especially with an increased emphasis on strong physical relationships between predictors and August–October atmospheric/oceanic features. There is an inherent curiosity amongst the general public for any quantitative information about how active the upcoming season is likely to be, and we show in this manuscript that this is possible. These models will likely continue to be modified and improved in the years ahead as additional data and improved physical insights become available.

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