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Refinements to Atlantic basin seasonal hurricane prediction from 1 December

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[1] Atlantic basin seasonal hurricane predictions have been issued by the Tropical Meteorology Project at Colorado State University since 1984, with early December forecasts being issued every year since early December 1991. These forecasts have yet to show real-time forecast skill, despite several statistical models that have shown considerable hindcast skill. In an effort to improve both hindcast skill and hopefully real-time forecast skill, a modified forecast scheme has been developed using data from 1950 to 2007. Predictors were selected based upon how much variance was explained over the 1950–1989 subperiod. These predictors were then required to explain similar amounts of variance over a latter subperiod from 1990 to 2007. Similar amounts of skill were demonstrated for each of the three predictors selected over the 1950–1989 period, the 1990–2007 period, and the full 1950–2007 period. In addition, significant correlations between individual predictors and physical features known to affect hurricanes during the following August–October (i.e., tropical Atlantic wind shear and sea level pressure changes, ENSO phase changes) were obtained. This scheme uses a new methodology where hindcasts were obtained using linear regression and then ranked to generate final hindcast values. Fifty-four percent of the variance was explained for seasonal Net Tropical Cyclone (NTC) activity over the 1950–2007 period. These hindcasts show considerable differences in landfalling U.S. tropical cyclones, especially for the Florida Peninsula and East Coast. Seven major hurricanes made Florida Peninsula and East Coast landfall during the top 15 largest NTC hindcasts compared with only two major hurricane landfalls in the bottom 15 smallest NTC hindcasts.

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1. Introduction

[2] Seasonal forecasts have been issued by the Tropical Meteorology Project (TMP) at Colorado State University (CSU), headed by William Gray, since 1984 [*Gray*, 1984a, 1984b]. These seasonal forecasts were originally issued in early June and updated in early August. Additional research in the late 1980s and early 1990s led to the development of an early December forecast [*Gray et al.*, 1992] that utilized West African rainfall and the quasi-biennial oscillation (QBO) as predictors. These predictors, when used in combination, explained about 50% of the cross-validated variance for the following year's hurricane season based on data from 1950 to 1990. However, these predictors did not show real-time forecast skill.

[3] More recently, *Klotzbach and Gray* [2004] developed a new December statistical hindcast scheme utilizing National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis data [*Kistler et al.*, 2001]. This newer prediction scheme utilized a total of six predictors and attempted to hindcast several forecast metrics including named storms, named storm days, major hurricanes, and Net Tropical Cyclone (NTC) activity [*Gray et al.*, 1994]. Although this scheme also showed considerable amounts of hindcast skill, it did not show real-time forecast skill from 2003 to 2007. Real-time predictions of NTC activity issued in early December have shown little correlation (r = 0.05) with observations over the period from 1992 to 2007.

[4] Additional revisions to the early December forecast scheme have recently been made. These revisions involve simplifying the statistical scheme and including more robust statistical tests for predictor significance, similar to what was done in *Klotzbach* [2007]. The remainder of the paper is structured as follows. Section 2 discusses the data that is used in the study. Section 3 describes the methodology utilized to obtain the predictors. Section 4 demonstrates the hindcast skill available when implementing the forecast scheme. Section 5 discusses the physical relationships between predictors and Atlantic basin hurricane activity, while section 6 examines the application of this prediction

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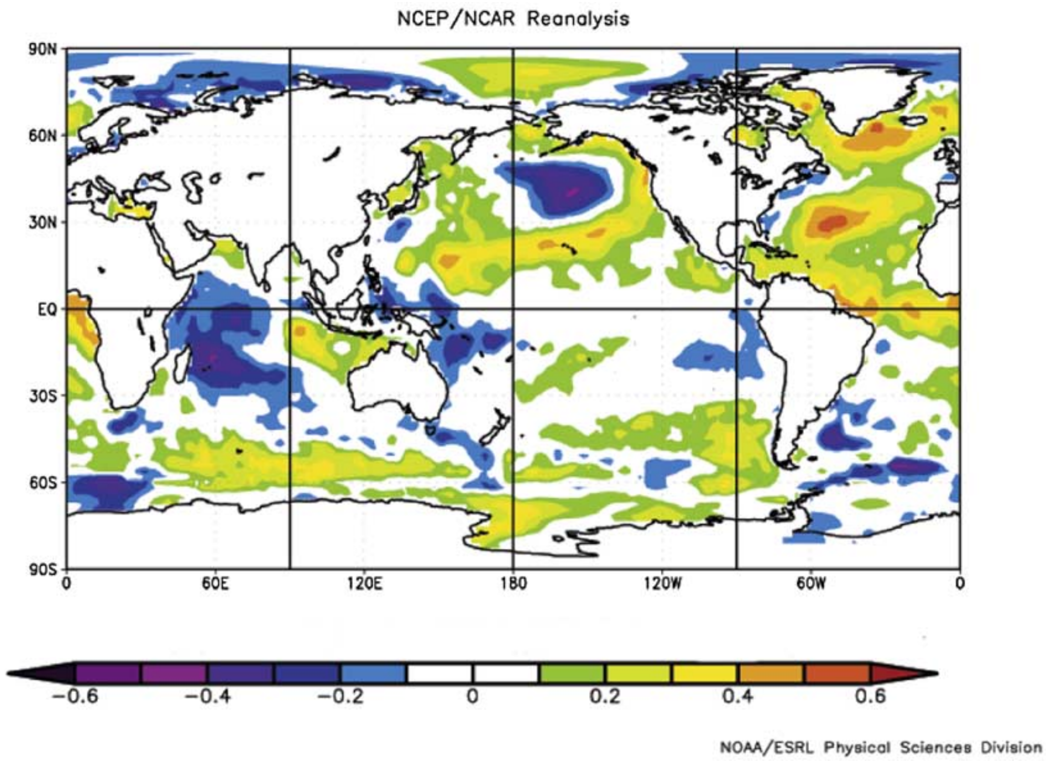

Figure 1. Linear correlation between October–November sea surface temperature and the following year's NTC activity over the period from 1950 to 1989.

scheme to United States landfalling hurricanes. Section 7 concludes and provides some ideas for future work.

2. Data

[5] Atlantic basin tropical cyclone statistics from 1950 to 2007 were calculated from the "best track" data set generated by the National Hurricane Center [*Jarvinen et al.*, 1984]. From the "best track" data set, an index of NTC activity was created. NTC was introduced by *Gray et al.* [1994] and is defined to be the following six parameters normalized by their 1950–2000 average values: named storms, named storm days, hurricanes, hurricane days, major hurricanes, and major hurricane days. By definition, a value of 100 NTC units is the average hurricane season from 1950 to 2000. NTC is the only metric predicted by this new forecast scheme, in an effort to develop a simpler scheme that utilizes fewer predictors than when multiple indices are forecast (i.e., named storms, hurricanes, major hurricane days, etc.).

[6] There is currently debate as to whether or not a small downward adjustment to the "best track" is needed in data prior to 1970 [*Landsea*, 1993, 2005; *Emanuel*, 2005]. The most recent consensus appears to be that a modest down-

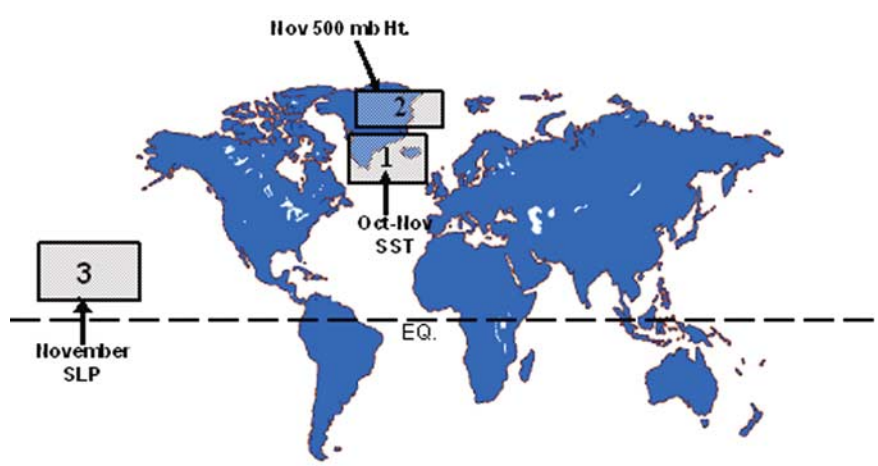

Figure 2. Location of predictors utilized in the new early December statistical forecast scheme.

Table 1. Listing of Predictors Selected for the Early December Forecast[a]

Predictor	Latitude–Longitude Region	1950–1989 Correlation	1990–2007 Correlation	1950–2007 Correlation
(1) October–November SST in the North Atlantic (+)	(55–65°N, 60–10°W)	0.48	0.56	0.55
(2) November 500-mb geopotential height in the far North Atlantic (+)	(67.5–85°N, 50°W–10°E)	0.52	0.48	0.51
(3) November SLP in the subtropical Northeast Pacific (+)	(7.5–22.5°N, 175–125°W)	0.33	0.53	0.36

[a]The sign of the predictor associated with above-normal tropical cyclone seasons is in parentheses. The correlation of predictors with NTC over the following periods (1950–1989, 1990–2007, and 1950–2007) is also provided.

ward adjustment is needed, that is, storms prior to 1970 in the "best track" should have reached 105 knots before being classified as major hurricanes (C. Landsea, 2008, personal communication). This downward adjustment prior to 1970 is included in calculations of the NTC activity metric.

[7] The National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis [*Kistler et al.*, 2001] was utilized to search for predictors. This reanalysis product provides global data on a 2.5° latitude by 2.5° longitude grid for a large number of parameters, including zonal wind, sea level pressure, sea surface temperature, velocity potential, and relative humidity. The reanalysis products are a combination of assimilated observations along with model-derived approximations.

3. Predictor Selection Methodology

[8] Predictors were selected from the NCEP/NCAR reanalysis using the Linear Correlations website available from the Climate Diagnostics Center (http://www.cdc.noaa.gov/Correlation/). First, a time series of Atlantic basin NTC was created for 1950–2007. Then, NCEP/NCAR reanalysis fields of sea level pressure, sea surface temperature and 500-mb geopotential height were correlated against the NTC index from 1950 to 1989, leaving out the 1990–2007 period as an additional data set to test hindcast skill. Correlations were investigated for both the combined October–November period and the individual month of November. Of the final three predictors selected, two utilized November data while the third predictor utilized October–November data. Figure 1 displays a linear correlation map between October–November sea surface temperature and the following year's NTC over the period from 1950 to 1989. Note the large areas of positive correlation in the North Atlantic.

[9] Areas selected as predictors correlated significantly at the 95% level ($r > |0.31|$) with NTC over the period from 1950 to 1989. Significance was determined by using a two-tailed Student's *t*-test and assuming that each hurricane season represents one degree of freedom. This assumption seems reasonable as the autocorrelation between one year's NTC and the following year's NTC is only 0.22. The areas selected had to be of fairly large spatial extent (at least 10° latitude by 15° longitude) in order to avoid selecting correlation "bulls-eyes" which sometimes exist in the NCEP/NCAR reanalysis. In order to remain in the predictor pool, several additional criteria had to be met. First, the correlation between the predictor and NTC had to remain significant at the 95% level ($r > |0.47|$) over the period from 1990 to 2007. Second, the predictor had to show significant correlations with physical features during the following August–October period that are known to effect Atlantic basin hurricane activity, such as alterations in wind shear patterns, sea level pressure patterns, and sea surface temperature patterns [*Gray*, 1984a, 1984b; *Knaff*, 1997; *Goldenberg et al.*, 2001]. Finally, when the predictors were added using stepwise regression, they had to add at least 3% additional variance explained for NTC over the three time periods of 1950–1989, 1990–2007, and 1950–2007.

[10] One predictor was removed from the pool of predictors after failing to meet the significance test over the period from 1990 to 2007. The predictor was an October–November sea level pressure measure in the area from 40 to 65°N, 160 to 130°W. The predictor correlated with NTC at −0.56 over the period from 1950 to 1989. However, over the period from 1990 to 2007, the predictor correlated with NTC at −0.22 (not significant at the 95% level), and it was removed from the predictor pool.

4. Results

[11] Figure 2 displays the locations of the predictors on a map. Only three predictors were utilized in this forecast scheme. It is believed that by regressing against only one index (NTC) and keeping the predictor pool small, the scheme will likely show more skill than some of the earlier schemes utilized by the TMP that had much larger predictor pools. The dangers of over-fitting a statistical scheme that utilizes only three predictors should be considerably reduced.

[12] Table 1 displays the locations and individual correlations between each of the three predictors and NTC over the developmental period from 1950 to 1989, the test period of 1990–2007, and the full period of 1950–2007. As mentioned in the methodology section, all predictors are significant at the 95% level over all three time periods.

Table 2. Stepwise Regression Technique Documenting the Increase in Variance Explained for NTC Over the Periods of 1950–1989, 1990–2007, and 1950–2007, Respectively[a]

Period	Predictor 1	Predictors 1 and 2	Predictors 1, 2, and 3
1950–1989	0.23	0.32	0.40
1990–2007	0.31	0.45	0.53
1950–2007	0.30	0.38	0.46

[a]Equations were developed over the 1950–1989 period. Predictor numbers are the same as listed in Table 1.

Table 3. Observed Seasonal NTC, Hindcast Seasonal NTC Using the Statistical Model, Final Hindcast Seasonal NTC Using the Rank Method, Hindcast Error Using the Statistical Model, Hindcast Error Using the Rank Method, and Error Using a Climatological Forecast (NTC = 100)[a]

Year	Observed NTC	Hindcast NTC	Hindcast NTC (Using Rank Method)	Hindcast Error	Hindcast Error (Using Rank Method)	Error Using Climatology
1950	230	155	192	75	38	130
1951	115	90	82	26	34	15
1952	93	121	124	−27	−31	−7
1953	116	154	188	−38	−73	16
1954	124	115	111	9	13	24
1955	188	134	129	55	59	88
1956	66	145	160	−79	−94	−34
1957	82	117	116	−35	−34	−18
1958	133	109	93	24	40	33
1959	94	114	106	−19	−11	−6
1960	92	133	129	−41	−37	−8
1961	211	188	200	23	11	111
1962	32	118	118	−86	−86	−68
1963	111	136	130	−25	−19	11
1964	160	85	80	75	80	60
1965	82	91	85	−9	−3	−18
1966	134	139	134	−5	0	34
1967	93	75	51	18	42	−7
1968	39	57	40	−17	−1	−61
1969	150	146	166	4	−16	50
1970	62	54	40	8	22	−38
1971	91	94	89	−3	2	−9
1972	27	72	46	−45	−19	−73
1973	50	77	52	−28	−2	−50
1974	72	87	82	−14	−9	−28
1975	89	90	83	−1	6	−11
1976	82	113	97	−31	−15	−18
1977	45	73	50	−29	−5	−55
1978	83	83	66	0	17	−17
1979	92	23	40	69	52	−8
1980	129	63	40	67	89	29
1981	109	115	109	−6	0	9
1982	35	84	74	−49	−39	−65
1983	31	15	40	16	−9	−69
1984	74	94	91	−20	−17	−26
1985	106	108	92	−2	14	6
1986	37	83	64	−46	−27	−63
1987	46	16	40	29	6	−54
1988	118	101	92	16	26	18
1989	130	145	150	−15	−20	30
1990	98	88	82	10	17	−2
1991	57	84	72	−27	−16	−43
1992	64	55	40	8	24	−36
1993	52	65	45	−13	7	−48
1994	35	80	57	−45	−22	−65
1995	222	108	93	114	129	122
1996	192	146	173	46	19	92
1997	51	82	62	−31	−11	−49
1998	166	183	200	−17	−34	66
1999	185	177	200	8	−15	85
2000	134	116	115	18	19	34
2001	129	136	133	−7	−4	29
2002	80	113	94	−33	−14	−20
2003	173	158	200	15	−27	73
2004	228	171	200	57	28	128
2005	273	147	185	126	88	173
2006	85	141	134	−56	−49	−15
2007	99	113	98	−14	1	−1
Average Error				|32|	|28|	|44|

[a]Hindcast values are derived from equations based on the 1950–2007 period.

[13] Table 2 displays the variance explained of these three predictors using stepwise regression over the period from 1950 to 1989 and applying those equations (developed from 1950 to 1989 using the stepwise regression technique) to the 1990–2007 period. Also, the variance explained over the full period using equations developed over 1950–1989 is listed. North Atlantic SST is added to the scheme first, followed by far North Atlantic 500-mb geopotential height and then subtropical Northeast Pacific sea level pressure. Note that the addition of each predictor adds considerable

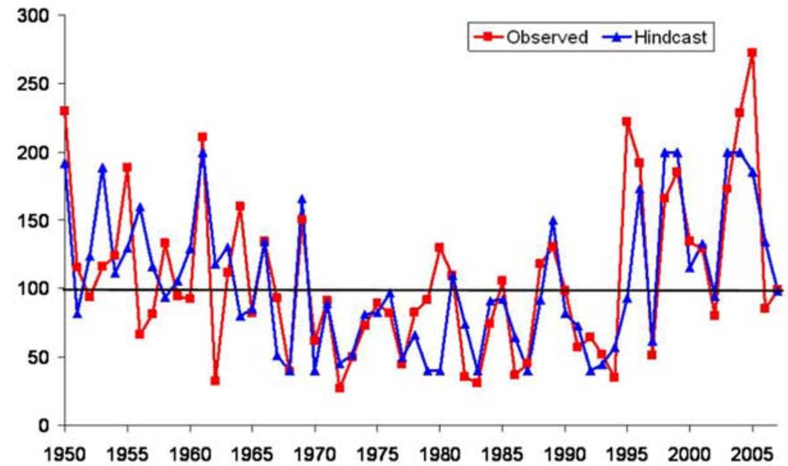

Figure 3. Rank hindcast NTC compared with observed NTC over the period from 1950 to 2007. The rank hindcasts explain 54% of the variance in observed NTC.

amounts of variance explained for each of the three periods examined. The hindcast scheme explains 40% of the variance over the dependent period from 1950 to 1989, while explaining 53% of the variance over the test period from 1990 to 2007. Over the full time period (1950–2007), the scheme explains 46% of the variance, using equations developed on 1950–1989.

[14] If equations are developed over the full forecast period from 1950 to 2007, variance explained for NTC increases slightly to 47%. The average error using the hindcasts is 32 NTC units compared with 44 NTC units using climatology. This reduction in average error is statistically significant at the 95% level using a two-tailed Student's *t*-test. The hindcasts are able to correctly predict an above- or below-average season (greater than or less than 100 NTC units) in 45 out of 58 years. It is remarkable that such a simple statistical scheme using only three predictors can explain such a large amount of variance in NTC 7 months before the start of the hurricane season. It is likely the interaction between large-scale modes such as El Niño-Southern Oscillation (ENSO) [*Rasmusson and Carpenter*, 1982], the Atlantic Multi-Decadal Oscillation (AMO) [*Goldenberg et al.*, 2001], and the Pacific Decadal Oscillation (PDO) [*Mantua et al.*, 1997] that provide the long-period memory that gives the model its hindcast skill.

[15] A new addition to this statistical forecast model when compared with earlier statistical forecast schemes used by the TMP is using a rank technique to adjust the statistical hindcasts. The ranking technique is generated by ranking all statistical hindcast values over the 1950–2007 period from 1 to 58. Then, actual observed NTC values for that ranking are assigned to a particular year. For example, 1953 ranked as the seventh largest hindcast value. The seventh largest observed value of NTC from 1950 to 2007 was 188, and therefore 1953 was assigned a final rank hindcast NTC value of 188. It should be noted that several observed values of NTC were either below 40 or above 200. However, especially at this early lead time, the confidence in the statistical scheme is not high enough to assign values greater than 200 or lower than 40. Table 3 summarizes hindcast values obtained using the statistical hindcast model along with the rank hindcast model. Comparisons to climatology are also provided. The average error using the rank hindcast technique is reduced to 28 NTC units (compared with 32 NTC units using the original statistical hindcasts), and the variance explained increases to 54% (compared with 47% using the original statistical hindcasts). The reduction in average error is not statistically significant using a two-tailed Student's *t*-test. The rank hindcasts correctly predict an above- or below-average season (greater than or less than 100 NTC units) in 44 out of 58 years (compared with 45 out of 58 years in the original statistical hindcasts).

[16] Figure 3 displays the final rank hindcasts versus observations for seasonal NTC from 1950 to 2007. Year-to-year variations in hindcast values are somewhat greater than using the original statistical model, in better agreement with actual observations. For example, the standard deviation in observed NTC is 58 units. The rank statistical hindcasts have a standard deviation of 50 NTC units compared with only 39 NTC units for the original statistical hindcasts. This new technique should help in better being able to predict large statistical outliers, given the non-normal distribution of annual NTC. For the remainder of

Table 4. Observed Seasonal NTC and Hindcast Seasonal NTC for the Top 10 Largest Hindcast Years

Year	Observed NTC	Hindcast NTC
1950	230	192
1953	116	188
1961	211	200
1969	150	166
1996	192	173
1998	166	200
1999	185	200
2003	173	200
2004	228	200
2005	273	185
Average	192	190

Table 5. Observed Seasonal NTC and Hindcast Seasonal NTC for the Bottom 10 Smallest Hindcast Years

Year	Observed NTC	Hindcast NTC
1968	39	40
1970	62	40
1972	27	46
1977	45	50
1979	92	40
1980	129	40
1983	31	40
1987	46	40
1992	64	40
1993	52	45
Average	59	42

the manuscript, when hindcasts are referred to, it is the final rank hindcast values unless otherwise noted.

[17] Table 4 displays the ten largest hindcast values compared with observations over the period from 1950 to 2007. All 10 years had above-average activity with nine out of the 10 years experiencing values of at least 150 NTC units.

[18] Table 5 displays the ten smallest hindcast values compared with observations over the period from 1950 to 2007. Nine out of 10 years had below-average activity, while eight out of 10 years experienced values of below 65 NTC units.

[19] One of the primary reasons why this forecast was developed was to provide a better real-time statistical model for seasonal NTC prediction in early December. Table 6 displays observed values of NTC from 1992 to 2007 along with actual real-time NTC forecast values and hindcast values from the new statistical scheme. One can clearly see the dramatic improvements that are made through implementation of the new hindcast scheme. Absolute forecast errors are reduced by approximately 55% when compared with either the real-time forecast or climatology. The new hindcast scheme's error is smaller than climatology in 14 out of 16 years and is smaller than the real-time forecast's error in 13 out of 16 years.

[20] The model was used in real-time prediction for the first time for the 2008 Atlantic basin hurricane season. The statistical model called for a somewhat above-average hurricane season of 127 NTC units.

5. Physical Relationships Between Predictors and Atlantic Basin Hurricane Activity

[21] One of the primary reasons why some of the TMP's earlier statistical forecast models have failed in real-time forecasting is likely due to a lack of rigorous statistical tests and inadequate understanding of the physical relationships between individual predictors and Atlantic hurricane activity. In the previous section, the more rigorous statistical tests that were conducted in order to verify the legitimacy of individual predictors were demonstrated. In this section, individual predictors and their likely physical relationships with Atlantic basin hurricane activity are discussed. Some analysis of predictors 2 and 3 was included in *Klotzbach and Gray* [2004]. In this manuscript, a discussion of predictor 1 and some additional new physical insights into predictors 2 and 3 are provided. In addition, correlation maps between individual predictors and August–October sea surface temperature, sea level pressure, 200-mb zonal wind, and 925-mb zonal wind are provided. These maps illustrate the fact that these predictors are likely physically tied to features that are known to effect Atlantic basin hurricane activity.

[22] Predictor 1. October–November SST in the North Atlantic (55°–65°N, 60–10°W) (+).

[23] Warm North Atlantic sea surface temperatures in the fall are indicative of an active phase of the Atlantic Multidecadal Oscillation (AMO) and a strong Atlantic thermohaline circulation [*Goldenberg et al.*, 2001]. There tends to be a fairly strong autocorrelation between North Atlantic SSTs in this region during the late fall and SSTs during the following August–October period as seen in Figure 4a. An active AMO is associated with anomalously low vertical wind shear, anomalously warm tropical Atlantic

Table 6. Observed NTC, Real-Time NTC Prediction, New Statistical Model NTC Hindcast, Real-Time Forecast Error, New Model Hindcast Error, and Error Using Climatology Over the Period That December Forecasts Have Been Issued (1992–2007)[a]

Year	Observed NTC	Real-Time NTC Prediction	New Model NTC Hindcast	Real-Time Error	New Model Hindcast Error	Error Using Climatology
1992	65	61	40	4	25	−35
1993	52	117	45	−65	7	−48
1994	35	110	57	−75	−22	−65
1995	222	140	93	82	129	122
1996	192	85	173	107	19	92
1997	52	110	62	−58	−10	−48
1998	169	90	200	79	−31	69
1999	182	160	200	22	−18	82
2000	130	125	115	5	15	30
2001	134	90	133	44	1	34
2002	82	140	94	−58	−12	−18
2003	174	140	200	34	−26	74
2004	229	125	200	104	29	129
2005	277	115	185	162	92	177
2006	85	195	134	−110	−49	−15
2007	99	140	98	−41	1	−1
Average Error				|66|	|30|	|65|

[a]The new model-derived hindcast errors improve upon climatology or real-time forecast errors by approximately 55%.

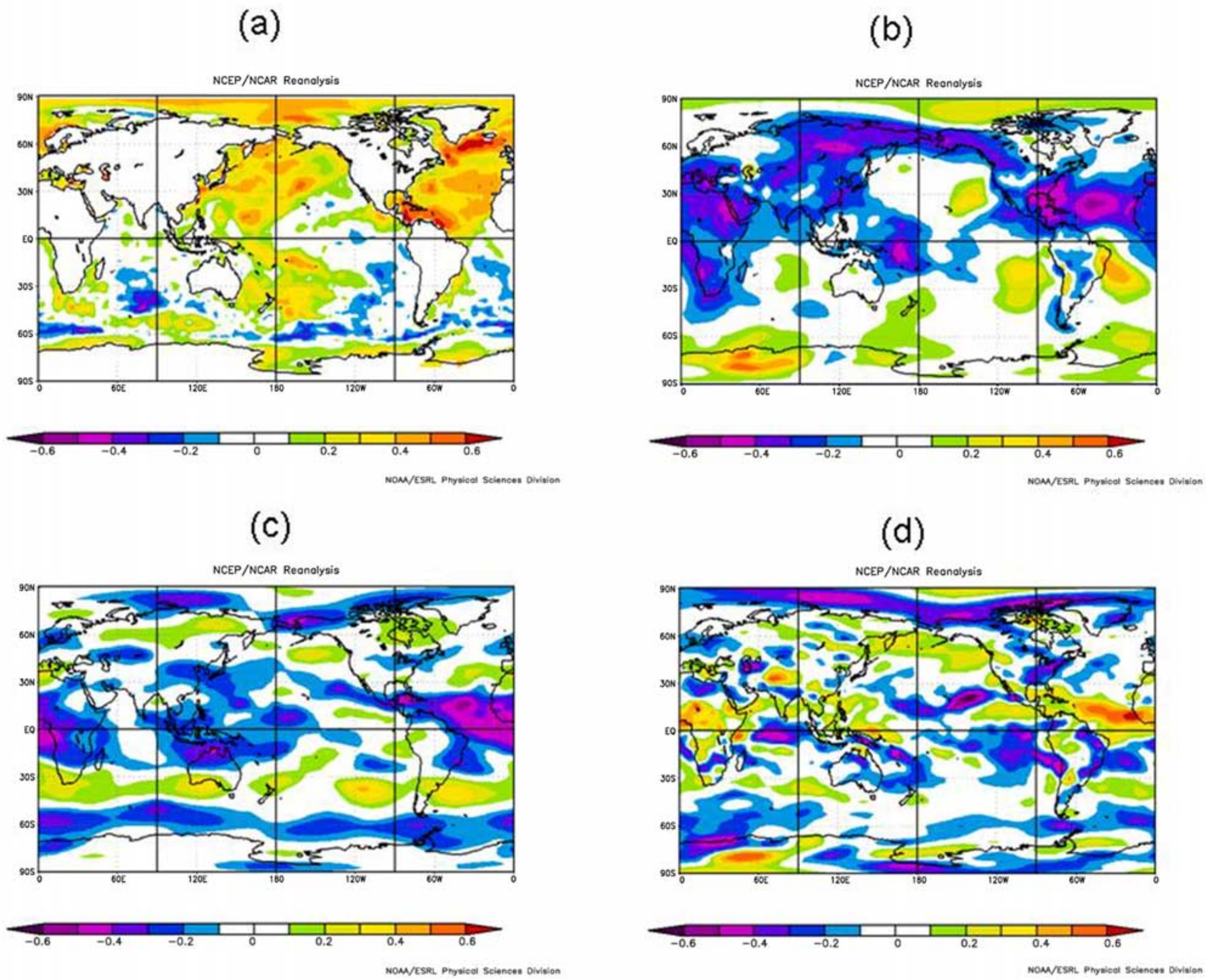

Figure 4. Linear correlation between October–November SST in the North Atlantic (Predictor 1) and the following year's August–October sea surface temperature (Figure 4a), August–October sea level pressure (Figure 4b), August–October 200-mb zonal wind (Figure 4c), and August–October 925-mb zonal wind (Figure 4d).

sea surface temperatures and anomalously low sea level pressures during August–October (Figure 4). These anomalously low values of vertical wind shear are generated by a weakening of the Tropical Upper Tropospheric Trough (TUTT) in the central Atlantic. When this occurs, upper-level westerlies and low-level easterlies are reduced, thereby reducing vertical wind shear.

[24] Predictor 2. November 500-mb geopotential height in the far North Atlantic (+) (67.5–85°N, 50°W–10°E).

[25] Predictor 2 correlates at −0.73 with November values of the Arctic Oscillation (AO) [*Thompson and Wallace*, 1998] and at −0.55 with November values of the North Atlantic Oscillation (NAO) [*Barnston and Livezey*, 1987]. Negative AO and NAO values imply more blocking or ridging in the central Atlantic and an associated reduction in the strength of the westerlies. In addition, a negative NAO is associated with a weaker Azores High, resulting in weaker trade winds and positive SST anomalies in the tropical Atlantic [*Marshall et al.*, 2001]. These anomalies are clearly evident during the following August–October period (Figure 5). Other following summer-early fall features that are directly correlated with this predictor are low sea level pressure in the Caribbean and easterly anomalies at 200 mb, resulting in weaker vertical wind shear (Figure 5). Both of these are also hurricane-enhancing factors.

[26] Predictor 3. November SLP in the subtropical Northeast Pacific (+) (7.5–22.5°N, 175–125°W).

[27] High pressure in the subtropical Northeast Pacific tends to appear during the fall and winter prior to a La Niña event [*Larkin and Harrison*, 2002]. High pressure forces stronger trade winds in the East Pacific which encourages mixing and increases upwelling, helping to initiate La Niña conditions. Also, these stronger trades likely help keep cool conditions in the tropical Pacific into the upcoming hurricane season, by inhibiting the recharge

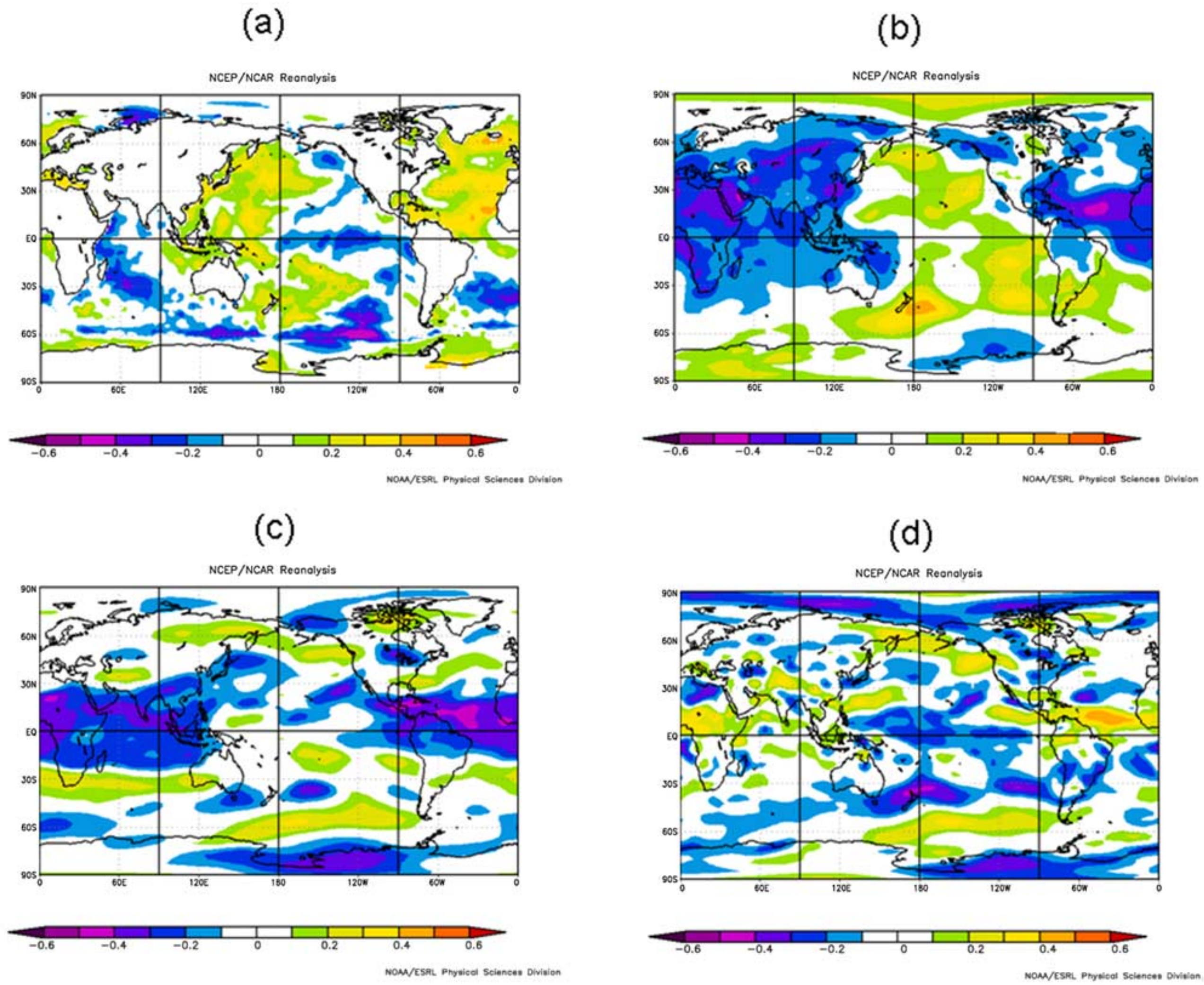

Figure 5. Linear correlation between November 500-mb geopotential height in the far North Atlantic (Predictor 2) and the following year's August–October sea surface temperature (Figure 5a), August–October sea level pressure (Figure 5b), August–October 200-mb zonal wind (Figure 5c), and August–October 925-mb zonal wind (Figure 5d).

and discharge of the warm pool during the winter and spring months. Figure 6 displays linear correlations between predictor 3 and the following August–October's values of sea surface temperature, sea level pressure, 200-mb zonal wind, and 925-mb zonal wind. Note the large area of negative correlations for SST in the tropical Pacific indicative of La Niña. Cool ENSO conditions are associated with reduced vertical wind shear across the tropical Atlantic and especially in the Caribbean [*Gray*, 1984b; *Klotzbach*, 2007].

6. Early December NTC Hindcasts and U.S. Landfalling Tropical Cyclones

[28] The TMP has been issuing landfall probability forecasts since August 1998. The primary justification for issuing these forecasts is that on a statistical basis, more active tropical cyclone seasons have more landfalling storms than do inactive tropical cyclone seasons. If seasonal forecasts are developed that have statistical skill at forecasting tropical cyclone seasons, there should also be skill in issuing landfall probability forecasts, as discussed in *Klotzbach* [2007]. For this newly developed December scheme, considerable differences exist between seasons with high NTC hindcasts compared with low NTC hindcasts. Table 7 displays the ratios for landfalling named storms, hurricanes, and major hurricanes for the Gulf Coast, the Florida Peninsula and East Coast, and the entire United States coastline for the top 10 versus bottom 10 and the top 15 versus bottom 15 NTC hindcasts from early December.

[29] In keeping with discussions in *Klotzbach and Gray* [2004] and *Klotzbach* [2007], the strongest ratios are found for storms making landfall along the Florida Peninsula and East Coast. For example, the top 15/bottom 15 NTC landfall ratios are 36 to 17 for named storms, 19 to 8 for hurricanes, and 7 to 2 for major hurricanes. Figure 7 displays the tracks of the major hurricanes making landfall

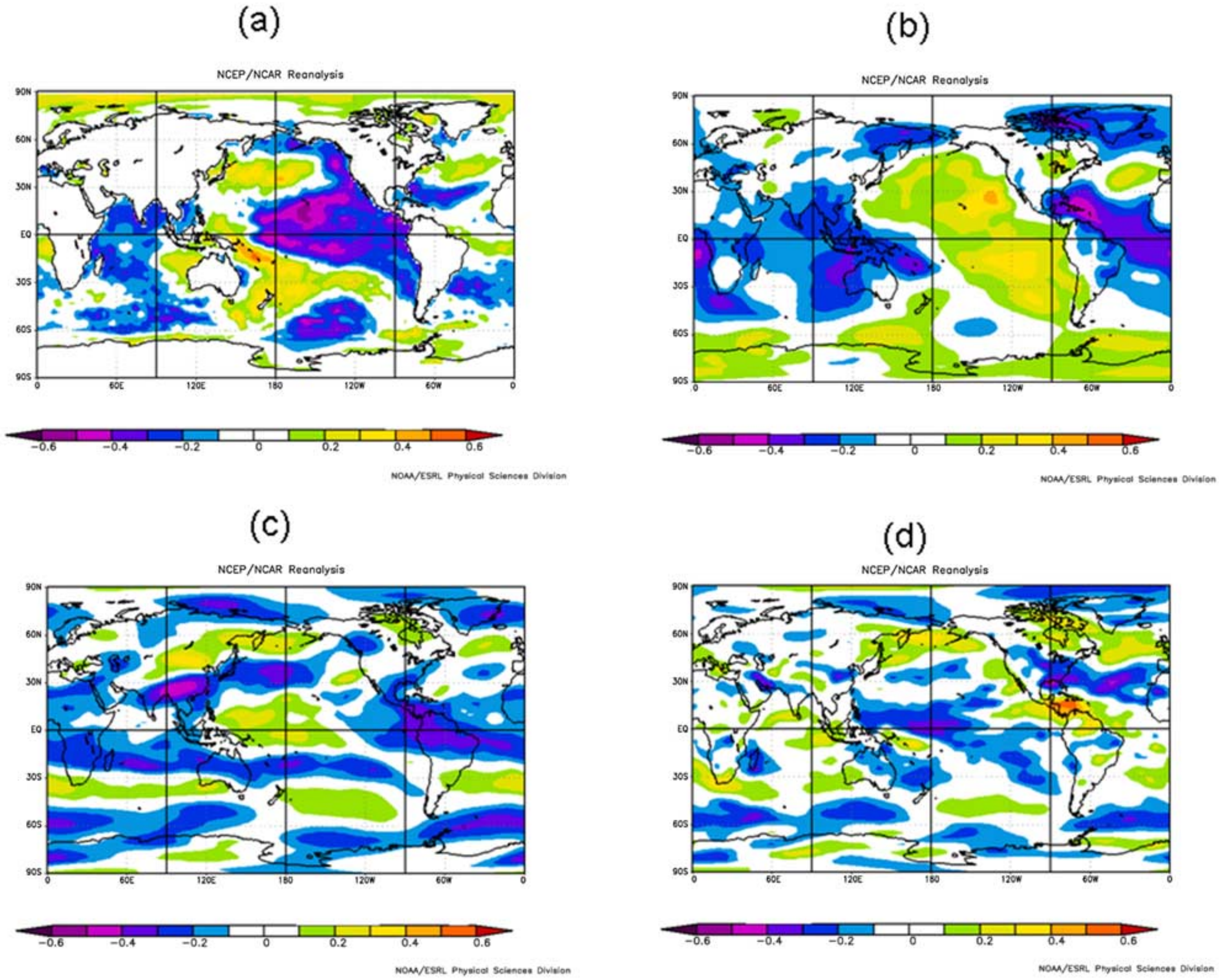

Figure 6. Linear correlation between November SLP in the subtropical Northeast Pacific (Predictor 3) and the following year's August–October sea surface temperature (Figure 6a), August–October sea level pressure (Figure 6b), August–October 200-mb zonal wind (Figure 6c), and August–October 925-mb zonal wind (Figure 6d).

in the top 15 and bottom 15 NTC hindcasts for the Florida Peninsula and East Coast.

7. Conclusions and Future Work

[30] There exists significant hindcast skill in predicting the following year's NTC activity parameter by early December (7 months prior to the start of the hurricane season). A simple statistical scheme utilizing three predictors is able to explain over 50% of the variance in NTC over the period from 1950 to 2007. Predictors were selected based on their skill over the period from 1950 to 1989, while the 1990–2007 was set aside for additional testing of model skill. Physical relationships between individual pre-

Table 7. Number and Ratio of Landfalling Named Storms, Hurricanes, and Major Hurricanes for the US, the East Coast (EC), and the Gulf Coast (GC) for the Top 10 and Bottom 10 and the Top 15 and Bottom 15 NTC Hindcast Years From Early December Over the Period From 1950 to 2007

Hindcast Landfall Occurrences	US NS	US H	US IH	EC NS	EC H	EC IH	GC NS	GC H	GC IH
Top 10	53	29	13	30	17	6	23	12	7
Bottom 10	29	15	7	13	7	2	16	8	5
Ratio	1.8	1.9	1.9	2.3	2.4	3.0	1.4	1.5	1.4
Top 15	67	35	14	36	19	7	31	16	7
Bottom 15	39	19	8	17	8	2	22	11	6
Ratio	1.7	1.8	1.8	2.1	2.4	3.5	1.4	1.5	1.2

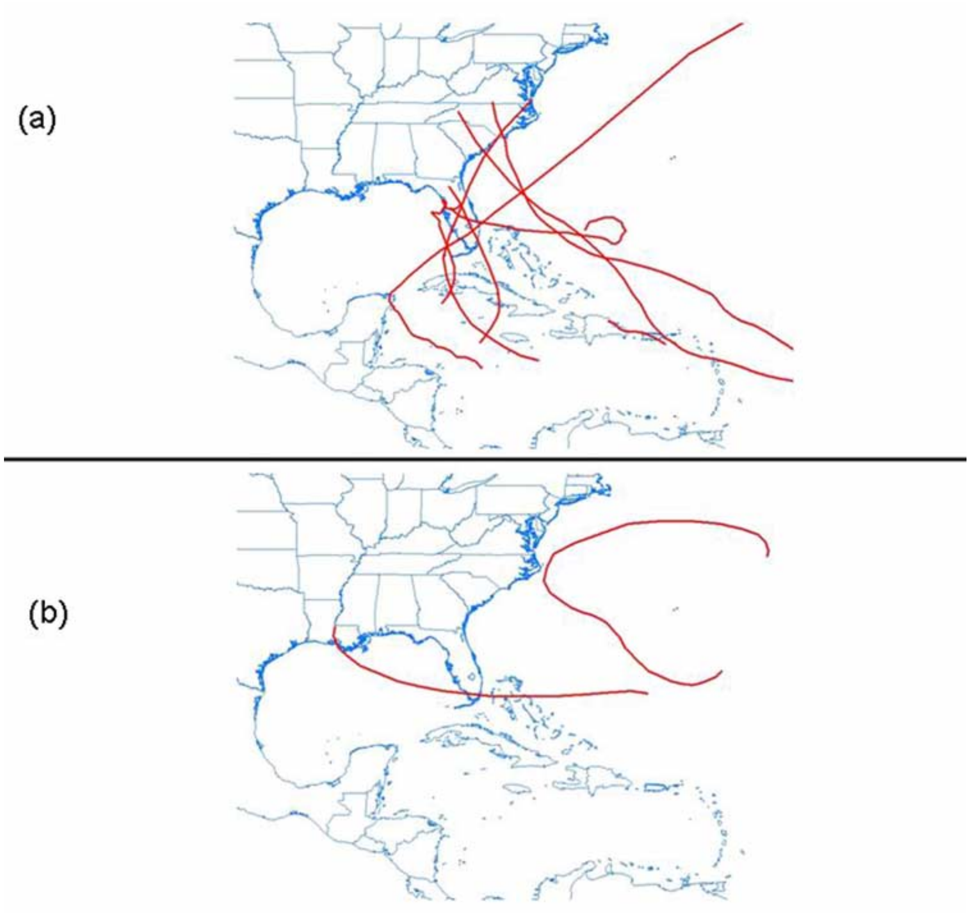

Figure 7. Tracks of major hurricanes making Florida Peninsula and East Coast landfall for the top 15 NTC hindcasts (Figure 7a) and bottom 15 NTC hindcasts (Figure 7b). Seven major hurricanes made landfall in the top 15 NTC hindcasts compared with two major hurricanes in the bottom 15 NTC hindcasts.

dictors and the following year's hurricane season were discussed. NTC hindcasts were also shown to exhibit significant relationships with U.S. landfalling hurricanes, especially along the Florida Peninsula and East Coast.

[31] Over the next few months, I intend to revise the early April and early June statistical schemes using a similar methodology to what has been done with the early December scheme. A combination of rigorous statistical tests and improved physical intuition will likely lead to enhanced real-time forecasting skill.

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