NASA/TP—2009–215741

An Extended Forecast of the Frequencies of North Atlantic Basin Tropical Cyclone Activity for 2009

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March 2009

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LIST OF ACRONYMS, SYMBOLS, AND ABBREVIATIONS

10-yma	10-yr moving average
AT	Armagh Observatory temperature
CSU	Colorado State University
EN	El Niño
ERSST.v3	Extended Reconstructed Sea Surface Temperature, version 3
LN	La Niña
LP	lowest pressure (in mb)
<LP>	average lowest pressure (in mb)
NH	number of hurricanes
NMH	number of major (category 3 or higher) hurricanes
NOAA	National Oceanic and Atmospheric Administration
NTC	number of tropical cyclones
ONI	Oceanic Niño Index
PWS	peak wind speed (in kt)
<PWS>	average peak wind speed (in kt)
TP	Technical Publication
TSR	Tropical Storm Risk (team)
U.S.	United States

NOMENCLATURE

cl	confidence level
d	estimate of first difference (in 10-yma values)
Dur	duration (in months)
<*Dur*>	average duration (in months)
f	frequency
m	mean
<*max* ONI>	average maximum ONI value (in ºC)
$P(r)$	probability of *r* events occurring
r	number of events in Poisson distribution; coefficient of correlation
r^2	coefficient of determination
sd	standard deviation
se	standard error of estimate
X	variable of NTC, NH, or NMH

TECHNICAL PUBLICATION

AN EXTENDED FORECAST OF THE FREQUENCIES OF NORTH ATLANTIC BASIN TROPICAL CYCLONE ACTIVITY FOR 2009

1. INTRODUCTION

Each year, usually beginning in December prior to an upcoming hurricane season, which officially runs from June 1 through November 30, various groups project estimates for the number of tropical cyclones (NTC) (those with sustained winds of 34 kt or greater; to convert to mph, multiply by 1.151), number of hurricanes (NH) (those with sustained winds of 64 kt or greater), and number of major hurricanes (NMH) (those with sustained winds of 96 kt or greater) expected in the North Atlantic basin, these storms possibly affecting the highly populated regions along the Gulf coast and Atlantic seaboard from Texas to Maine in the United States (U.S.). The two groups giving extended forecasts in December include the Colorado State University (CSU) team and the Tropical Storm Risk (TSR) team (in the United Kingdom). As the season approaches and throughout the season, updates to their original forecasts are provided as well. The official forecast is given in May prior to the official start of the hurricane season by the National Oceanic and Atmospheric Administration (NOAA).

The purpose of this Technical Publication (TP) is to provide yet another early estimate of the expected tropical cyclone development in the North Atlantic basin for the 2009 hurricane season, one based on previous and continuing work performed at Marshall Space Flight Center over the past decade.[1–9] Additional material will follow in a subsequent TP closer to the official start of the 2009 hurricane season.

2. THE 2008 HURRICANE SEASON

For the 2008 hurricane season, the CSU team predicted 15 tropical cyclones forming in the North Atlantic basin, 8 becoming hurricanes and 4 becoming major (or intense) hurricanes. The TSR team predicted 10–19 tropical cyclones, 5–10 becoming hurricanes and 2–5 becoming major hurricanes. NOAA's official outlook called for 12–16 tropical cyclones, 6–9 hurricanes, and 2–5 major hurricanes. Presuming first differences in 10-yr moving averages (10-yma) of storm frequencies comparable to the post-1990 means (m) suggested that, perhaps as many as 16 tropical cyclones, 12 hurricanes, and 7 major hurricanes might have been expected in the North Atlantic basin during the 2008 hurricane season. Thus, all predictions leant toward increased activity above long-term averages in the North Atlantic basin during 2008. As it turned out, the predictions were fairly accurate. During the 2008 hurricane season, 16 tropical cyclones, including 8 hurricanes and 5 major hurricanes, formed in the North Atlantic basin, three striking the U.S. coastline with hurricane-strength winds.

Table 1 lists the 16 tropical cyclones that occurred in the 2008 North Atlantic basin hurricane season, giving their names, classification, occurrence dates, peak wind speeds (PWSs) (in kt) and lowest pressures (LP) (in mb). Comprehensive information for each tropical cyclone can be found at <http://www.nhc.noaa.gov/2008atlan.shtml> and at <http://typhoon.atmos.colostate.edu/forecasts>.[10,11]

From table 1, one determines that Gustav had the highest PWS (130 kt) and Ike had the lowest pressure (935 mb) during the 2008 North Atlantic basin hurricane season. The 16 storms had a combined average peak wind speed (<PWS>) of ≈77 kt and a combined average lowest pressure (<LP>) of ≈977 mb, both values indicative of strengthening when compared to similar values from the 2007 hurricane season (<PWS> = 66 kt and <LP> = 986 mb).

Table 1. The 2008 North Atlantic basin hurricane season summary.

Storm Name	Classification	Dates	PWS (kt)	LP (mb)
Arthur	TS	May 31–June 1	40	1,004
Bertha	MH	July 3–20	110	952
Cristobal	TS	July 19–23	55	998
Dolly	H	July 20–24	85	964
Edouard	TS	August 3–6	55	996
Fay	TS	August 15–24	55	986
Gustav	MH	August 25–September 2	130	941
Hanna	H	August 28–September 7	75	977
Ike	MH	September 1–14	125	935
Josephine	TS	September 2–6	55	994
Kyle	H	September 25–29	75	984
Laura	STS	September 29–October 1	50	993
Marco	TS	October 6–7	55	998
Nana	TS	October 12–14	35	1,004
Omar	MH	October 14–18	110	959
Paloma	MH	November 6–9	125	943

Classification:
H = Hurricane
MH = Major hurricane
STS = Subtropical storm
TS = Tropical storm

3. THE 2009 HURRICANE SEASON

3.1 Tropical Cyclone Frequencies (1950–2008)

Figure 1(a) displays NTC, (b) NH, and (c) NMH that formed in the North Atlantic basin during the interval 1950–2008, both in terms of yearly counts and 10-yma. Hence, during the interval 1950–2008, spanning 59 hurricane seasons, on average, there have been ≈11 tropical cyclones per year forming in the North Atlantic basin of which ≈6 became hurricanes and about 2 or 3 became major hurricanes. The yearly ranges span 4 to 28 for NTC, 2 to 15 for NH, and zero to 8 for NMH. Also shown are the standard deviations (*sd*) for the entire interval and the means (*m*) and standard deviations (*sd*) for the most recent interval, 1995–2008, an interval of enhanced activity. To the right of each panel are the observed frequency distributions, indicating that the primary modes are 8 and 11 for NTC, 4 and 6 for NH, and 2 for NMH. While the distributions for NTC and NH appear quite broad (possibly bi-modal), the distribution for NMH appears rather peaked, although all distributions are obviously rightward (or positively) skewed towards higher frequencies.

Noticeable in each is that the trend line; i.e., the 10-yma line, has increased above the long-term average, indicating that the present epoch (in particular, since 1995) is one of increased activity, especially as compared to the immediately preceding years; i.e., mid-1960s to mid-1990s). Since 1995, 12 of 14 yr have had NTC greater than its long-term mean, with only 1997 and 2006 having NTC falling below the mean, both years experiencing El Niño (EN) events during the hurricane season. Similarly, 10 of 14 yr have had NH and NMH exceeding their long-term averages.

Table 2 gives the mean, standard deviation, range, and sum for selected intervals of time for NTC, NH, and NMH, presuming two high-activity intervals (1950–1965 and 1995–2008) separated by one low-activity interval (1966–1994), the two combined high-activity intervals being about the same duration as the intermediate low-activity interval. Interestingly, the current high-activity interval (since 1995) has means larger than both the preceding high-activity (1950–1965) and low-activity (1966–1994) intervals. In fact, the difference in means is highly statistically significant when comparing the current high-activity interval with either previous interval for NTC, but is only statistically significant for NH and NMH when comparing the current high-activity interval with the immediately preceding low-activity interval. Also given are the mean, standard deviation, range, and sum for the combined high-activity intervals, which suggests that, on average, one should expect at least two or more NTC, NH, and NMH as compared to the low-activity interval.

3.2 Poisson Distributions

Because counts of tropical cyclones are computed for a given time interval; i.e., events per year, one can use the Poisson distribution[12] to determine the probability for a given number of events occurring during the year. The formula for the Poisson distribution may be written as

$$P(r) = (e^{-m} m^r)/r! \quad , \tag{1}$$

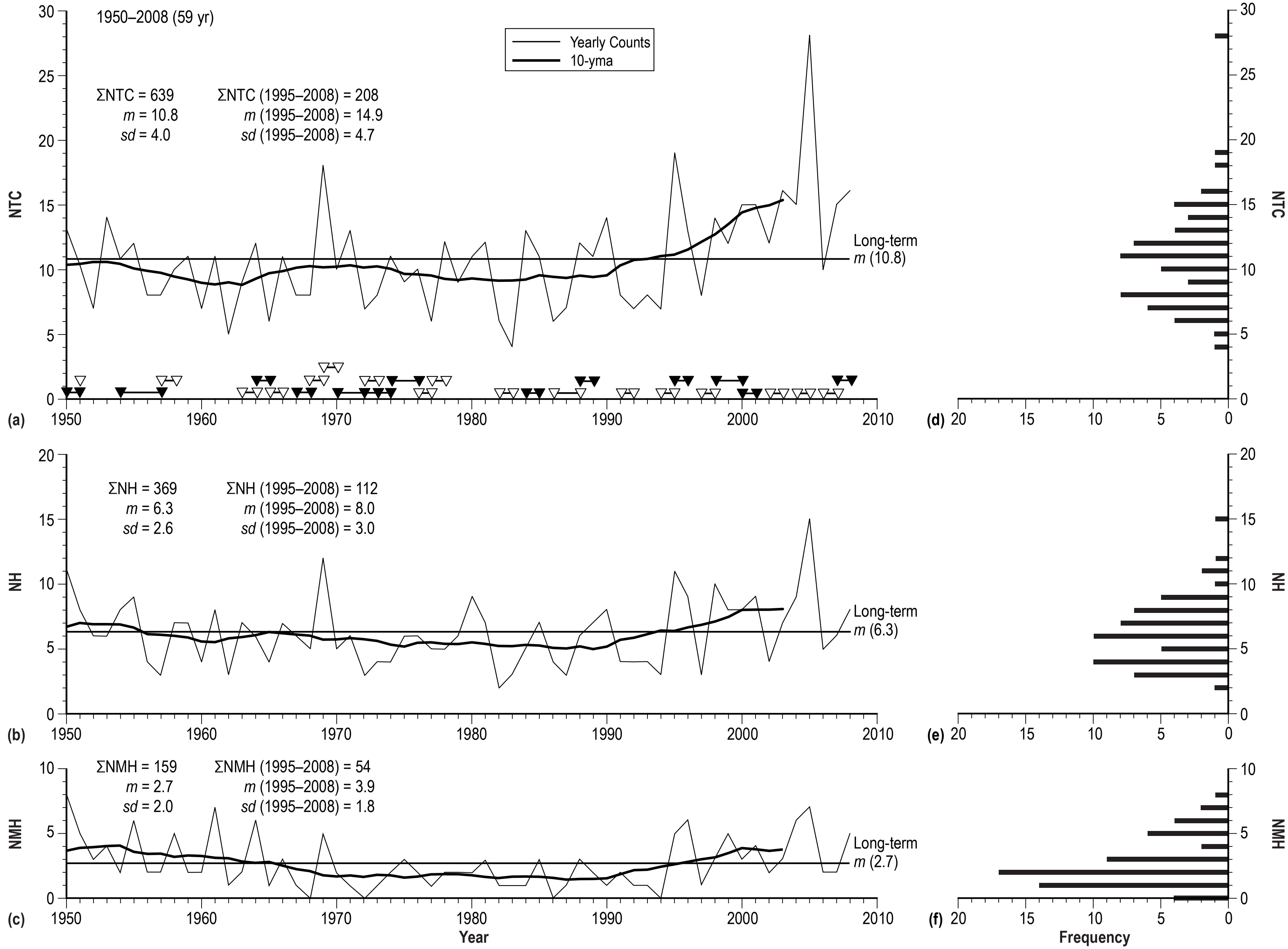

Figure 1. Yearly counts and distributions of North Atlantic basin (a) tropical cyclones, (b) hurricanes, and (c) major hurricanes, and (d)–(f) their frequencies, respectively.

Table 2. Means, standard deviations, ranges, and sums of NTC, NH, and NMH based on 1950–2008 statistics, assuming the existence of high- and low-activity intervals.

Interval:	1950–1965	1966–1994	1995–2008	Combined
Activity:	High	Low	High	High
NTC:				
m	9.63	9.55	14.86	12.07
sd	2.60	3.00	4.67	4.51
range	5–14	4–18	8–28	5–28
sum	154	277	208	362
NH:				
m	6.31	5.38	8.00	7.10
sd	2.27	2.09	3.04	2.75
range	3–11	2–12	3–15	3–15
sum	101	156	112	213
NMH:				
m	3.63	1.62	3.86	3.73
sd	2.25	1.15	1.83	2.03
range	1–8	0–5	1–7	1–8
sum	58	47	54	112

where r is the number of events per year (presuming a random distribution), $P(r)$ is the probability of r events occurring per year, and m is the mean number of events occurring per year.

Table 3 gives the probabilities using the Poisson distribution for NTC, NH, and NMH, presuming that each grouping is distributed randomly. In the table, f is the observed frequency for r during the overall interval 1950–2008. One finds that there is an 87.5% probability that NTC during any given year will always lie in the range of 6 to 15. There is only a 4.2% probability of having fewer than 6 events in a year and about an 8.2% probability of having 16 or more events in a year. For NH, there is an 84.4% probability of always having 3–9 events in a year, with only a 5% probability of having fewer than 3 events in a year and a 10.6% probability of having 10 or more events in a year. For NMH, there is a 79.6% probability of always having 1–4 events in a year, with only a 6.7% probability of having no events in a year and a 13.7% probability of having 5 or more events in a year.

Table 4 gives the probabilities using the Poisson distribution for NTC, NH, and NMH, but now presuming that two activity modes (high and low) exist with each being distributed randomly about its corresponding mean. For the high-activity mode (which is the one now being experienced), there is a probability of ≈75.3% of always having NTC in the range of 8 to 15 per year, with only an 8.6% probability of having fewer than 8 events per year and a 16.1% probability of having 16 or more events per year. For NH, there is an 81.8% probability of always having 4–10 events per year, with only a 7.7% probability of having fewer than 4 events per year and 10.6% probability of having 11 or more events per year. For NMH, there is an 89.2% probability of always having 1–6 events per year, with only a 2.4% probability of having no events per year and an 8.4% probability of having 7 or more events per year. Because the trend lines are now above long-term averages for all categories

Table 3. Poisson distributions for NTC, NH, and NMH based on 1950–2008 statistics.

No. of Events	NTC ($m = 10.8$)		NH ($m = 6.3$)		NMH ($m = 2.7$)	
	f	$P(r)$	f	$P(r)$	f	$P(r)$
0	0	0.00002	0	0.00184	4	0.06721
1	0	0.00022	0	0.01157	14	0.18145
2	0	0.00119	1	0.03644	17	0.24496
3	0	0.00428	7	0.07653	9	0.22047
4	1	0.01156	10	0.12053	2	0.14882
5	1	0.02498	5	0.15187	6	0.08036
6	4	0.04496	10	0.15946	4	0.03616
7	6	0.06937	8	0.14352	2	0.01395
8	8	0.09365	7	0.11302	1	0.00471
9	3	0.11238	5	0.07911	0	0.00141
10	5	0.12137	1	0.04984	0	0.00038
11	8	0.11916	2	0.02855	0	0.00009
12	7	0.10724	1	0.01499	0	0.00002
13	4	0.08909	0	0.00726	0	0.00000
14	3	0.06873	0	0.00327		
15	4	0.04949	1	0.00137		
16	2	0.03340	0	0.00054		
17	0	0.02122	0	0.00020		
18	1	0.01273	0	0.00007		
19	1	0.00724	0	0.00002		
20	0	0.00391	0	0.00001		
21	0	0.00201	0	0.00000		
22	0	0.00099				
23	0	0.00046				
24	0	0.00021				
25	0	0.00009				
26	0	0.00004				
27	0	0.00001				
28	1	0.00001				
29	0	0.00000				

(NTC, NH, and NMH), one probably should expect yearly seasonal frequencies for the 2009 North Atlantic basin hurricane season to remain above average in number. (The reader is left to determine the preferred probabilities for the low-activity mode, a simple exercise.)

Table 4. Poisson distributions for NTC, NH, and NMH based on 1950–2008 statistics and assuming the existence of high- and low-activity intervals.

No. of Events	High-Activity Mode (1950–1965, 1995–2008)						Low-Activity Mode (1966–1994)					
	NTC (m=12.07)		NH (m=7.10)		NMH (m=3.73)		NTC (m=9.55)		NH (m=5.38)		NMH (m=1.62)	
	f	$P(r)$	f	$P(r)$	f	$P(r)$	f	$P(r)$	f	$P(r)$	f	$P(r)$
0	0	0.00001	0	0.00083	0	0.02399	0	0.00007	0	0.00461	4	0.19790
1	0	0.00007	0	0.00586	3	0.08949	0	0.00068	0	0.02479	11	0.32060
2	0	0.00042	0	0.02080	9	0.16690	0	0.00325	1	0.06669	8	0.25968
3	0	0.00168	3	0.04922	4	0.20752	0	0.01034	4	0.11959	5	0.14023
4	0	0.00507	4	0.08736	2	0.19351	1	0.02468	6	0.16085	0	0.05679
5	1	0.01223	1	0.12406	5	0.14436	0	0.04713	5	0.17307	1	0.01840
6	1	0.02460	4	0.14680	4	0.08974	3	0.07502	6	0.15519	0	0.00497
7	2	0.04242	4	0.14890	2	0.04782	4	0.10235	4	0.11927	0	0.00115
8	3	0.06400	6	0.13215	1	0.02230	5	0.12218	1	0.08021	0	0.00023
9	1	0.08584	4	0.10425	0	0.00924	2	0.12964	1	0.04795	0	0.00004
10	3	0.10360	1	0.07402	0	0.00345	2	0.12381	0	0.02580	0	0.00001
11	3	0.11368	2	0.04777	0	0.00117	5	0.10749	0	0.01262	0	0.00000
12	4	0.11434	0	0.02827	0	0.00036	3	0.08554	1	0.00566		
13	2	0.10616	0	0.01544	0	0.00010	2	0.06284	0	0.00234		
14	2	0.09153	0	0.00783	0	0.00003	1	0.04287	0	0.00090		
15	4	0.07365	1	0.00371	0	0.00001	0	0.02729	0	0.00032		
16	2	0.05556	0	0.00164	0	0.00000	0	0.01629	0	0.00011		
17	0	0.03945	0	0.00069			0	0.00915	0	0.00003		
18	0	0.02645	0	0.00027			1	0.00486	0	0.00001		
19	1	0.01680	0	0.00010			0	0.00244	0	0.00000		
20	0	0.01014	0	0.00004			0	0.00117				
21	0	0.00583	0	0.00001			0	0.00053				
22	0	0.00320	0	0.00000			0	0.00023				
23	0	0.00168					0	0.00010				
24	0	0.00084					0	0.00004				
25	0	0.00041					0	0.00001				
26	0	0.00019					0	0.00000				
27	0	0.00008										
28	1	0.00004										
29	0	0.00002										
30	0	0.00001										
31	0	0.00000										

3.3 The Effects of El Niño and La Niña

Across the bottom of figure 1(a) is a series of filled and unfilled triangles representing, respectively, the occurrences of La Niña (LN) (13 cold) and El Niño (EN) (17 warm) events as determined using the Oceanic Niño Index (ONI). The ONI is based on a 3-mo running means of version 3 of the extended reconstructed sea surface temperature (ERSST.v3 SST) anomalies in the Niño 3.4 region (located at 5º N. to 5º S. latitude and 120º W. to 170º W. longitude) based on the 1971–2000 base period, available at <http://www.cpc.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml>[13]. The ONI has become the de facto means of defining the occurrences of LN and EN events. When the ONI has at least a 5-mo continuous value of 5 ºC or warmer, an EN event is said to be occurring, while when the ONI has at least a 5-mo continuous value of –5 ºC or cooler, an LN event is said to be occurring. All other times are said to be representative of neutral conditions.

Table 5 lists the 13 LN and 17 EN events determined using ONI during the interval 1950–2008. The start and end times are given for each event, as well as the duration (in months, from beginning to end), the maximum negative or positive value of the ONI for the event, the event type, the strength of the event, and the sum of NTC, NH, and NMH that occurred during each event.

Table 6 summarizes event statistics. For example, during the interval of 1950–2008 (708 mo) 17 EN events were determined using ONI. These 17 events spanned some 167 mo or 23.6% of the interval 1950–2008 and, on average, each EN persisted ≈10 mo, having a maximum ONI value of 1.4 ºC. During the 17 EN events, 135 tropical cyclones occurred (21.1% of the total), including 73 hurricanes (19.8% of the total) and 26 major hurricanes (16.3% of the total), suggesting ≈8 tropical cyclones per event, with ≈4 becoming hurricanes and of these, about 1–2 becoming a major hurricane. In contrast, the 13 LN events spanned 191 mo or 27% of the interval 1950–2008 and, on average, each LN persisted about 15 mo, having a maximum ONI value of –1.4 ºC. During the 13 LN events, 176 tropical cyclones occurred (27.5% of the total), including 104 hurricanes (28.2% of the total) and 49 major hurricanes (30.8% of the total), suggesting about 13–14 tropical cyclones per event, with ≈8 becoming hurricanes and of these, ≈4 becoming major hurricanes. Thus, about half the time, the ONI reflected neutral conditions and about three-quarters of the time, the ONI reflected non-EN conditions. Clearly, when EN conditions prevail, there is a strong tendency for NTC, NH, and NMH to be reduced in number, as compared to when non-EN conditions prevail. It follows, then, that when EN conditions prevail, one probably should adjust slightly downward the expected frequency of tropical cyclones, hurricanes, and major hurricanes during a season, while when non-EN conditions prevail (especially, when LN conditions prevail) one probably should slightly augment the expected frequency of tropical cyclones, hurricanes, and major hurricanes during a season (independent of the activity mode).

Looking ahead to the 2009 North Atlantic basin hurricane season, then, clearly it is part of a long-going, high-activity phase (the current high-activity mode having already persisted for 14 yr, yet not expected to end for at least another decade or so) and dependent upon whether EN or non-EN conditions prevail during 2009, one should anticipate either slightly lower or higher, respectively, frequencies of tropical cyclones, hurricanes, and major hurricanes as compared to high-activity mode averages. Presently, NOAA's Climate Prediction Center[14] finds that neutral or LN conditions are expected at least for early 2009. If these non-EN conditions persist through the later half of the year, then one probability should expect continued increased activity during the 2009 hurricane season. Based on the current (1995–2008) high-activity mode average (14.9) and standard deviation (4.7), one projects $NTC = 14.9 \pm 8.3$ (the 90% prediction interval) for 2009, probably on the higher side if non-EN conditions prevail during the later half of the year or on the lower side if EN conditions should happen to develop. Statistically speaking, there is only about a 5% chance that

Table 5. Event listing of EN and LN, based on ONI using ERSST.v3.

Start	End	Duration (mo)	Max ONI (ºC)	Event Type	Strength	Sums NTC	NH	NMH
B01/1950	03/1951	>15	–1.7	LN	S	13	11	8
08/1951	12/1951	5	0.7	EN	W	9	7	4
04/1954	01/1957	34	–2.0	LN	S	31	21	10
04/1957	06/1958	15	1.7	EN	S	9	3	2
07/1963	01/1964	7	1.0	EN	M	9	7	2
04/1964	02/1965	11	–1.1	LN	M	12	6	6
06/1965	04/1966	11	1.6	EN	S	6	4	1
12/1967	04/1968	5	–0.8	LN	W	0	0	0
11/1968	06/1969	8	1.0	EN	M	0	0	0
09/1969	01/1970	5	0.7	EN	W	12	8	2
07/1970	01/1972	19	–1.4	LN	M	22	10	3
05/1972	03/1973	11	2.1	EN	S	7	3	0
05/1973	07/1974	15	–2.0	LN	S	10	4	1
09/1974	05/1976	21	–1.7	LN	M	15	8	3
09/1976	02/1977	6	0.8	EN	W	3	2	0
09/1977	02/1978	6	0.8	EN	W	6	4	0
05/1982	06/1983	14	2.3	EN	S	6	2	1
10/1984	09/1985	12	–1.1	LN	M	11	8	2
09/1986	02/1988	18	1.7	EN	S	10	5	1
05/1988	05/1989	13	–2.0	LN	S	12	6	3
05/1991	07/1992	15	1.8	EN	M	9	4	2
07/1994	03/1995	9	1.3	EN	M	7	3	0
09/1995	03/1996	7	–0.8	LN	W	7	5	3
05/1997	04/1998	12	2.5	EN	S	8	3	1
07/1998	06/2000	24	–1.7	LN	S	26	18	8
10/2000	02/2001	5	¬0.7	LN	W	4	1	0
05/2002	03/2003	11	1.5	EN	S	12	4	2
07/2004	02/2005	8	0.9	EN	W	15	9	6
08/2006	01/2007	6	1.2	EN	M	7	5	2
08/2007	05/2008	10	–1.5	LN	S	13	6	2

Notes:
B = Before
M = Moderate
S = Strong
W = Weak

more than 23 or fewer than 7 tropical cyclones should be expected in the North Atlantic basin in 2009. Similarly, $\mathrm{NH} = 8 \pm 5.3$ and $\mathrm{NMH} = 3.9 \pm 3.2$ for 2009 (both 90% prediction intervals), based on the statistics of the current 1995–2008 high-activity mode interval. The current status of EN/LN conditions can be found at <http://www.elnino.noaa.gov/>.[15]

Table 6. Statistical summary of EN and LN events.

Event	NE	TD (mo)	(%)	<*Dur*>	<*Max* ONI>	NTC				NH				NMH			
						Sum	(%)	ER	MR	Sum	(%)	ER	MR	Sum	(%)	ER	MR
EN	17	167	(23.6)	9.8	1.4	135	(21.1)	7.9	0.81	73	(19.8)	4.3	0.44	26	(16.3)	1.5	0.16
LN	13	191	(27.0)	14.7	–1.4	176	(27.5)	13.5	0.92	104	(28.2)	8.0	0.54	49	(30.8)	3.8	0.26

Notes:
(%) = Percent of total
ER = Event rate—number of NTC, NH, or NMH per number of events
MR = Monthly rate—number of NTC, NH, or NMH per total duration
NE = Number of events
TD = Total duration

The last EN was a moderate event that began in August 2006 and ended in January 2007. It was followed by an apparent strong LN that began in August 2007 and ended in May 2008. As noted above, non-EN conditions are now present and are expected to continue through at least early 2009. On average, the start of a new EN follows the end of an old EN by ≈32.2 mo (*sd* = 18.2 mo, range = 3–64 mo, median = 29.5 mo), based on the ONI listing of EN events (table 5). Counting January 2009, it has already been 24 mo since the end of the last EN, so it is not inconceivable that another EN could suddenly form during the 2009 Atlantic basin hurricane season, thus, making a precise prediction for the 2009 hurricane season somewhat difficult at this time.

3.4 First-Differences in 10-Year Moving Average Frequencies

Previously, it was shown that the distribution of the year-to-year change; i.e., the first difference, in the 10-yma values of the frequencies can be used to forecast the expected frequencies for the following hurricane season.[9] Recall that the 10-yma is determined in the following way:

$$X_{\text{10-yma}}(0) = [X(–5) + X(5) + 2\Sigma X(i)]/20 \ , \tag{2}$$

where X is NTC, NH, or NMH; $X(–5)$ and $X(5)$ are values of X, respectively, 5 yr prior to and 5 yr after the year of interest ($X(0)$); and $\Sigma X(i)$ is the sum of $X(i)$ for the years i = –4, –3, –2, –1, 0, 1, 2, 3, and 4 yr bounding the year of interest. In equation (2), there are two unknowns: $X_{\text{10-yma}}(0)$ and $X(5)$. However, one can estimate the value of $X_{\text{10-yma}}(0)$ from the distribution of the year-to-year change in $X_{\text{10-yma}}$, as follows:

$$X_{\text{10-yma}}(0) = X_{\text{10-yma}}(–1) \pm d \ , \tag{3}$$

where d is the estimate of the first difference in $X_{\text{10-yma}}$, which usually equals ±0.1 or ±0.2. Hence, one can rewrite equation (2) solving for $X(5)$ as follows:

$$X(5) = 20[X_{\text{10-yma}}(–1) \pm d] – X(–5) – 2\Sigma X(i) \ . \tag{4}$$

Figure 2 displays the distributions of the first differences; i.e., $d = \Delta$10-yma of X: (a) NTC, (b) NH, and (c) NMH for 1950–2002. Noticeable is that the first differences vary little from year to year, usually being within ±0.2 units of zero. For NTC, d equals ±0.1 about 49% of the time and

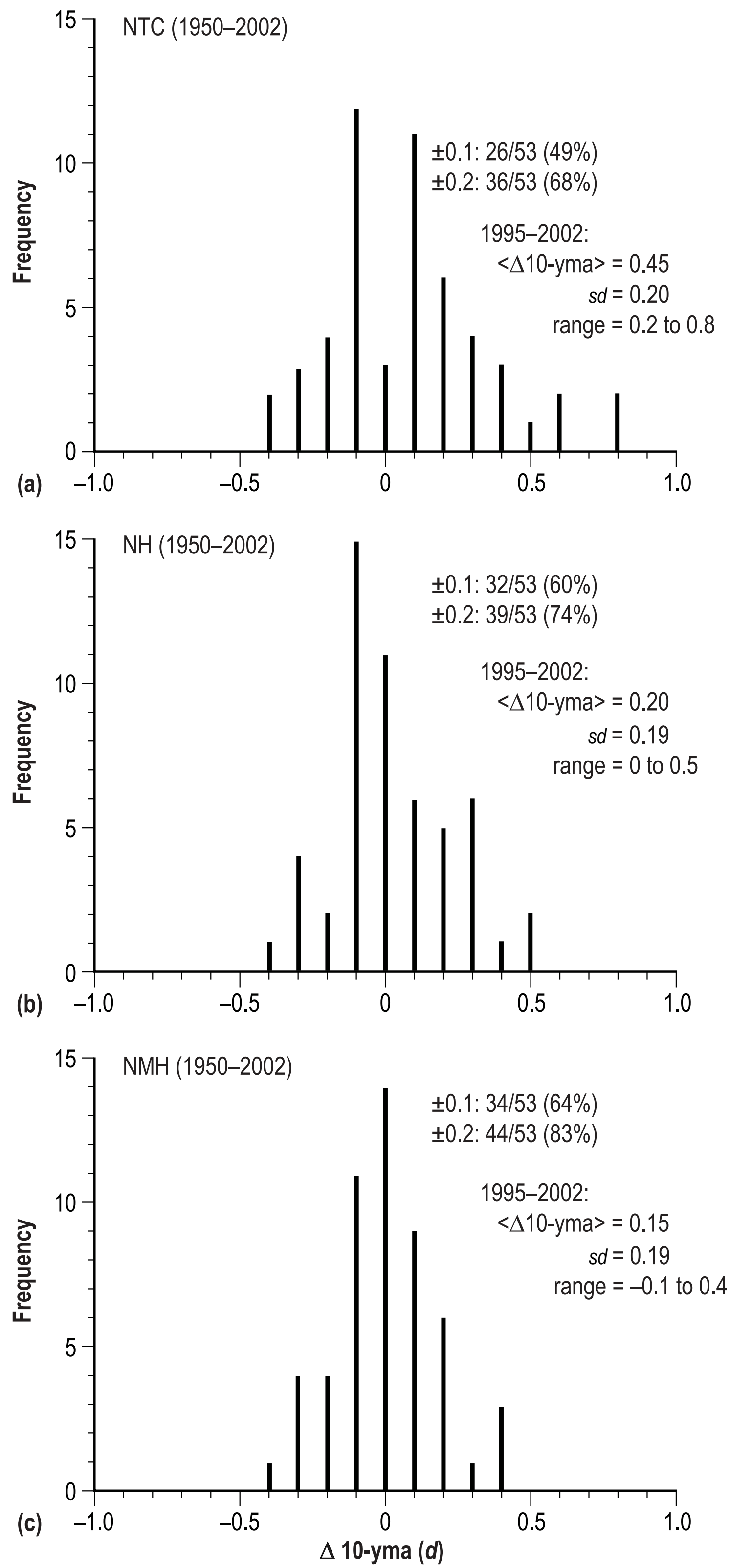

Figure 2. Distribution of first differences of 10-yma of North Atlantic basin (1950–2002) (a) tropical cyclones, (b) hurricanes, and (c) major hurricanes.

±0.2 about 68% of the time. For NH, the percentages are higher, and for NMH, they are higher still. Also shown in each panel are the average *d*, *sd*, and range determined for the current high-activity interval (1995–2002).

For NTC, from equation (4), $X(5)$ is NTC for 2009, $X(-5)$ is NTC for 1999 (=12), $\Sigma X(i)$ is the sum of NTC between 2000 and 2008 (=141), and $X_{10\text{-yma}}(-1)$ is the 10-yma of NTC for 2003 (=15.3). Hence, for 2009, NTC can be estimated to be about $12 \pm 20d$. If *d* equals zero, then NTC is 12 for 2009; if *d* equals ±0.1 (true about half the time), then NTC for 2009 will be about 10–14, and so forth. If, instead, one uses the average *d* for the current high-activity interval ($<d> = 0.45$), then NTC for 2009 could be as high as 21. Similarly, for 2009, NH and NMH can be estimated to be about $10 \pm 20d$ and $3 \pm 20d$, respectively, which translates to about 8–12 hurricanes and 1–5 major hurricanes, using $d = \pm 0.1$ (true more than half the time), or NH and NMH for 2009 could be as high as 14 and 6, respectively, using the average *d* for the current high-activity interval ($d = 0.20$ and 0.15, respectively).

3.5 The Role of Temperature and Decadal-Length Oscillation

Figure 3 shows the yearly and 10-yma variations in surface air temperature as measured by the Armagh Observatory located at Armagh, Northern Ireland (fig. 3(a) (AT)) and the yearly and 10-yma variations in ONI value (fig. 3(b)), both in degrees Celsius, for the interval 1950–2007. (The 2008 values are not yet available for AT and ONI at the time of writing.) The surface air temperature record as recorded at the Armagh Observatory has been found to serve as a viable proxy for representing global warming.[8,16–20] For the interval 1950–2007, AT averages ≈9.46 ºC. On the basis of the behavior of the 10-yma values of AT, an interval of cooler than average temperatures is inferred between about 1957 and 1990, with the lowest 10-yma value occurring about 1982 (9.05 ºC; the lowest yearly value measures 8.35 ºC in 1979). Since 1990, the 10-yma values of AT have been warmer than the mean, measuring 10.13 ºC in 2002. In terms of yearly temperatures, the temperature in 2007 averages 1.13 ºC warmer than the mean for 1950–2007. Armagh temperatures can be found at <http://climate.arm.ac.uk/scan.html> and <http://climate.arm.ac.uk/calibrated/airtemp/index.html>.[21,22]

The 10-yma values of ONI are negative prior to 1961 and again about 1969–1978. Since 1978, the 10-yma values have been positive, although they appear likely to become negative again very soon. During the first high-activity interval (1950–1965), four EN events, spanning a combined 38 mo, and three LN events, spanning a combined 60 mo, occurred, based on the ERSST.v3 listing. During the low-activity interval (1966–1994), nine EN events, spanning a combined 92 mo, and six LN events, spanning a combined 85 mo, occurred. During the current high-activity interval (1995–2008), four EN events, spanning a combined 37 mo, and four LN events, spanning a combined 46 mo, have occurred to date. Obviously, EN and LN events occur irrespective of whether the activity mode is one of high activity or low activity, although more LN months have occurred during the combined high-activity intervals than the low-activity interval and more EN months have occurred in the low-activity interval than the combined high-activity intervals. The overall behavior of the 10-yma of ONI seems to be the result of a quasi-periodic, decadal-length oscillation.

Table 7(a) gives the results of linear regression analyses correlating 10-yma values of NTC, NH, and NMH against 10-yma values of AT for the interval 1950–2002. Given are the inferred

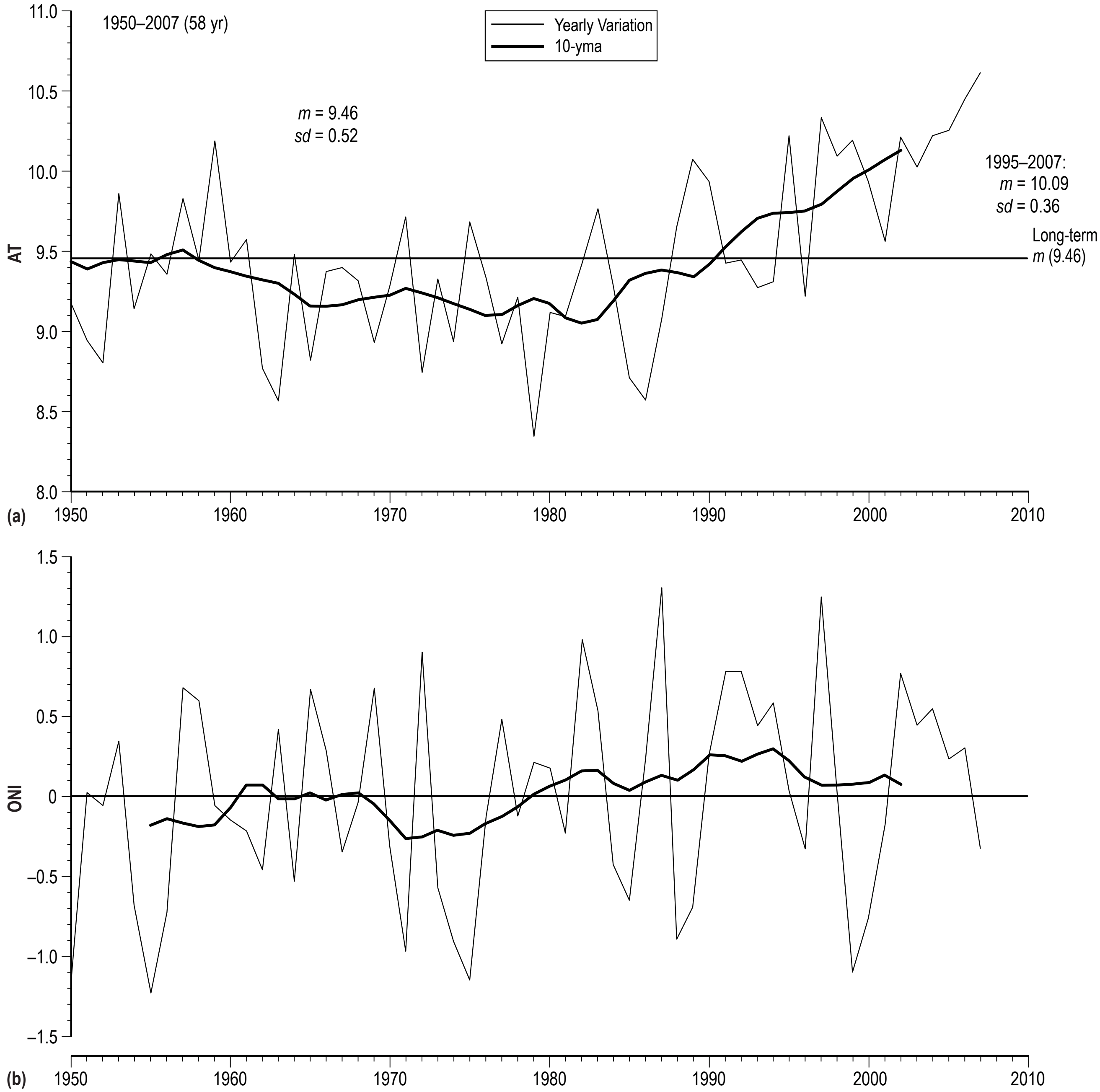

Figure 3. Surface air temperature yearly values from the (a) Armagh Observatory and sea-surface temperature anomaly yearly values using (b) ONI.

regression equation, the coefficient of correlation (*r*), the coefficient of determination (r^2) (which is a measure of the amount of variance explained by the inferred regression), the standard error of estimate (*se*), the confidence level (*cl*) (where those of $cl \geq 95\%$ are considered to be statistically important), and the mean (*m*) and *sd* of the 10-yma values of the fitted parameters; i.e., NTC, NH, and NMH. All inferred correlations are considered statistically important. In particular, the inferred regressions between NTC, NH, and NMH against AT are inferred to be highly statistically significant ($cl \geq 99\%$).

Table 7. Linear and bi-variate correlations based on 10-yma values: (a) Linear regression fits against AT, (b) linear regression fits against ONI, and (c) bi-variate fits against AT and ONI.

(a)	Correlation	*r*	*r*×*r*	*se*	*cl*	*m*	*sd*
NTC	–32.791 + 4.577AT	0.864	0.746	0.765	>99.9	10.242	1.501
NH	–15.162 + 2.245AT	0.829	0.687	0.434	>99.9	5.942	0.767
NMH	–14.314 + 1.775AT	0.665	0.442	0.570	>99.9	2.375	0.756
(b)	**Correlation**	***r***	***r*×*r***	***se***	***cl***	***m***	***sd***
NTC	10.215 + 2.010ONI	0.204	0.042	1.485	<90	10.242	1.501
NH	5.934 + 0.568ONI	0.113	0.013	0.771	<90	5.942	0.767
NMH	2.379 – 0.301ONI	–0.061	0.004	0.762	<90	2.375	0.756
(c)	**Correlation**	***r***	***r*×*r***	***se***			
NTC	–35.573 + 4.875AT – 1.449ONI	0.874	0.764	0.745			
NH	–17.465 + 2.491AT – 1.200ONI	0.858	0.736	0.403			
NMH	–17.822 + 2.151AT – 1.827ONI	0.747	0.559	0.513			

Table 7(b) gives the results of linear regression analyses correlating 10-yma values of the same parameters against 10-yma values of ONI for the interval 1955–2002. None of the inferred regressions are considered statistically important ($cl < 90\%$).

Table 7(c) gives the results of bi-variate regression analyses, based on both AT and ONI. The bi-variate analyses yield inferred regressions having slightly higher coefficients of correlation and are interesting in that they show that, given the occurrence of an EN event (warmer or positive-valued ONI), the expected frequencies are slightly reduced, while they are slightly enhanced given the occurrence of a LN event (cooler or negative-valued ONI). While true, it is obvious that the main determining factor is AT and not ONI.

Table 8(a)–(c) is likened to table 7(a)–(c), but now consider only the recent interval 1995–2002; i.e., the current high-activity interval. For table 8(a), all inferred regressions against AT are improved, with all being highly statistically significant. While table 8(b) shows that improvement occurs in inferred regressions against ONI, the inferred regressions remain statistically unimportant. Table 8(c) shows that all inferred bi-variate correlations are improved, although, obviously, as before, temperature undoubtedly is the main driver in the inferred regressions. It is apparent that if one has a good estimate for the 10-yma value, in particular, of AT for 2004, then one might be able to better predict the expected frequencies of tropical cyclones in the North Atlantic basin during the 2009 hurricane season.

As an example, 10-yma values of AT and ONI measured 10.13 and 0.07 °C, respectively, in 2002. Presuming that the 10-yma of AT for 2003 will be the same that occurred in 2002, one determines (from table 8(a)) the 10-yma of NTC for 2003 to be ≈15.3, which happens to agree exactly with its actual computed value. For NH, one determines the 10-yma of NH for 2003 to be ≈8.2, slightly higher than its actual computed value (=8.0), and for NMH one determines the 10-yma of NMH for 2003 to be ≈4.0, again, slightly higher than its actual computed value (=3.8). Using the bi-variate fits (table 8(c)) and presuming 10-yma values of AT and ONI being the same in 2003

Table 8. Linear and bi-variate correlations based on the 1995–2002 10-yma values: (a) Linear regression fits against AT, (b) linear regression fits against ONI, and (c) bi-variate fits against AT and ONI.

(a)	Correlation	*r*	*r*×*r*	*se*	*cl*	*m*	*sd*
NTC	–85.344 + 9.934AT	0.985	0.970	0.210	>99.9	13.113	1.482
NH	–34.314 + 4.201AT	0.963	0.928	0.230	>99.9	7.325	0.641
NMH	–27.401 + 3.098AT	0.929	0.863	0.143	>99.9	3.300	0.490
(b)	**Correlation**	***r***	***r*×*r***	***se***	***cl***	***m***	***sd***
NTC	14.666 – 15.157ONI	–0.535	0.286	1.353	<90	13.113	1.482
NH	8.018 – 6.762ONI	–0.552	0.305	0.578	<90	7.325	0.641
NMH	3.830 –5.170ONI	–0.552	0.305	0.441	<90	3.300	0.490
(c)	**Correlation**	***r***	***r*×*r***	***se***			
NTC	–80.860 + 9.508AT – 2.534ONI	0.988	0.976	0.270			
NH	–31.615 + 3.945AT – 1.526ONI	0.969	0.940	0.186			
NMH	–24.991 + 2.869AT – 1.362ONI	0.938	0.879	0.201			

as had occurred in 2002, one determines the 10-yma of NTC for 2003 to be ≈15.3, the 10-yma of NH for 2003 to be ≈8.2, and the 10-yma of NMH for 2003 to be ≈4.0, little different from using AT alone. Instead, using the average change in year-to-year 10-yma values for AT and ONI during the current high-activity interval; i.e., their first differences, equal to 0.06 and –0.02 ºC, thereby, inferring 10-yma values of AT and ONI for 2003 to be 10.19 and 0.05 ºC, respectively, one determines the 10-yma values for NTC, NH, and NMH for 2003 to be about 15.9, 8.5, and 4.2, respectively. The actual values for 2003 for the 10-yma of AT and ONI are not yet known, but should be lower than 10.16 ºC and –0.04 ºC, respectively, based on nearly complete monthly values for 2008 (needed are the monthly values for December for AT and November and December for ONI). Using these alternate values, one determines the 10-yma values for NTC, NH, and NMH for 2003 to be about 15.8, 8.5, and 4.2, considered to be upper limits. Presuming a December value of 5 ºC, based on the average December monthly means for 1950–2007, reduces the yearly average for 2008 to ≈9.87 ºC, which suggests that the 10-yma of AT for 2003 should be ≈10.14 ºC and that 10-yma values for NTC, NH, and NMH for 2003 might be about 15.7, 8.4, and 4.2, respectively, based on the preferred bi-variate fits.

Figure 4 shows the year-to-year change in the 10-yma values of AT and ONI. Changes of ±0.05 ºC tend to occur about two-thirds or more of the time, with the average change in the 10-yma values being about 0.06 ºC for AT, spanning 0.01 to 0.08 ºC, and about –0.02 ºC, spanning –0.10 to 0.04 ºC, for ONI in the current high-activity interval. Assuming that the change in year-to-year 10-yma values of AT and ONI will be about ±0.05 ºC and that the 10-yma values for 2003 will equal 10.14 and –0.04 ºC, respectively, for AT and ONI, one estimates the 10-yma values of AT and ONI for 2004 to be about 10.14 ± 0.05 ºC and –0.04 ± 0.05 ºC, suggesting the 10-yma value of NTC for 2004 to be about 15.7 ± 0.4. This value, however, is higher than that expected from the usual year-to-year 10-yma behavior of NTC (= 15.3 ± 0.1 or 15.3 ± 0.2) and, in fact, suggests an expected NTC for 2009 of about 18 ± 8, higher than that given the usual ± 0.1 or ± 0.2 change in year-to-year

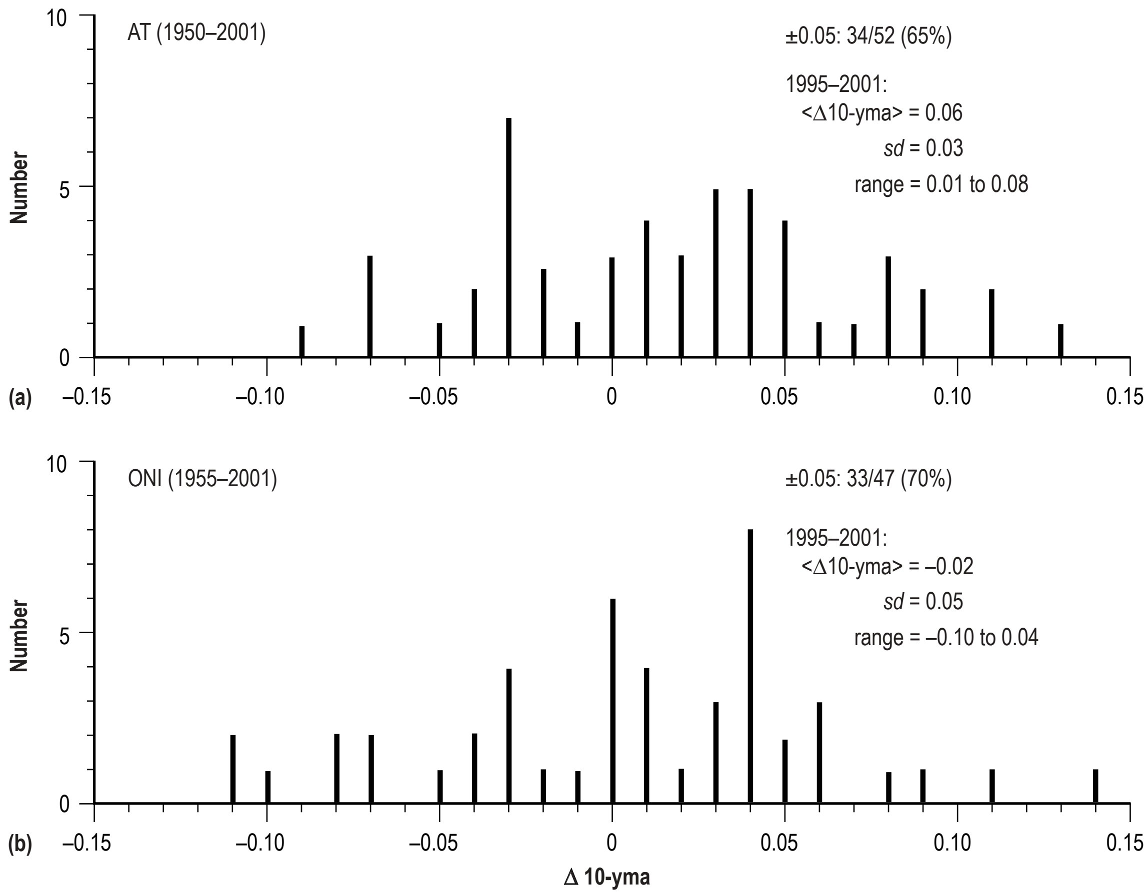

Figure 4. Temperature distribution first differences of 10-yma from the (a) Armagh Observatory and (b) ONI.

10-yma values of NTC, which suggests only 12 ± 2 or 12 ± 4, respectively, for NTC in 2009. Presuming that the inferred regressions are indeed valid, this may be an indication either that the expected 10-yma value of AT will not be as high as 10.14 ± 0.05 ºC or that the 2009 season might be considerably more active than one ordinarily might expect; i.e., it could be a statistical outlier with respect to using the usual first-difference values in estimating the frequencies for the upcoming hurricane season.

For NH and NMH in 2009, their expected frequencies are also of record size, as the following shows, if indeed the 10-yma of AT for 2004 is 10.14 ± 0.05 ºC and the year 2009 is not a statistical outlier with respect to the inferred bi-variate regressions for the current high-activity interval. For NH, one infers a 10-yma of about 8.4 ± 0.2 for 2004, which suggests an expected NH for 2009 to be about 18 ± 4. For NMH, one infers a 10-yma of about 4.2 ± 0.1 for 2004, which suggests an expected NMH for 2009 to be about 11 ± 2. For NH and NMH, these yearly numbers seem too high, since frequencies above 15 and 8 have never been experienced during the interval 1950–2008, differing markedly from their usual behaviors.

Figure 5 compares predicted and observed 10-yma values of the various parameters for the current high-activity interval, where the predicted values are based on the bi-variate fits given in table 8(c). The extrapolated predicted values for 2004 use 10-yma values for AT and ONI of 10.14 ± 0.0.5 ºC and –0.04 ± 0.0.5 ºC, respectively.

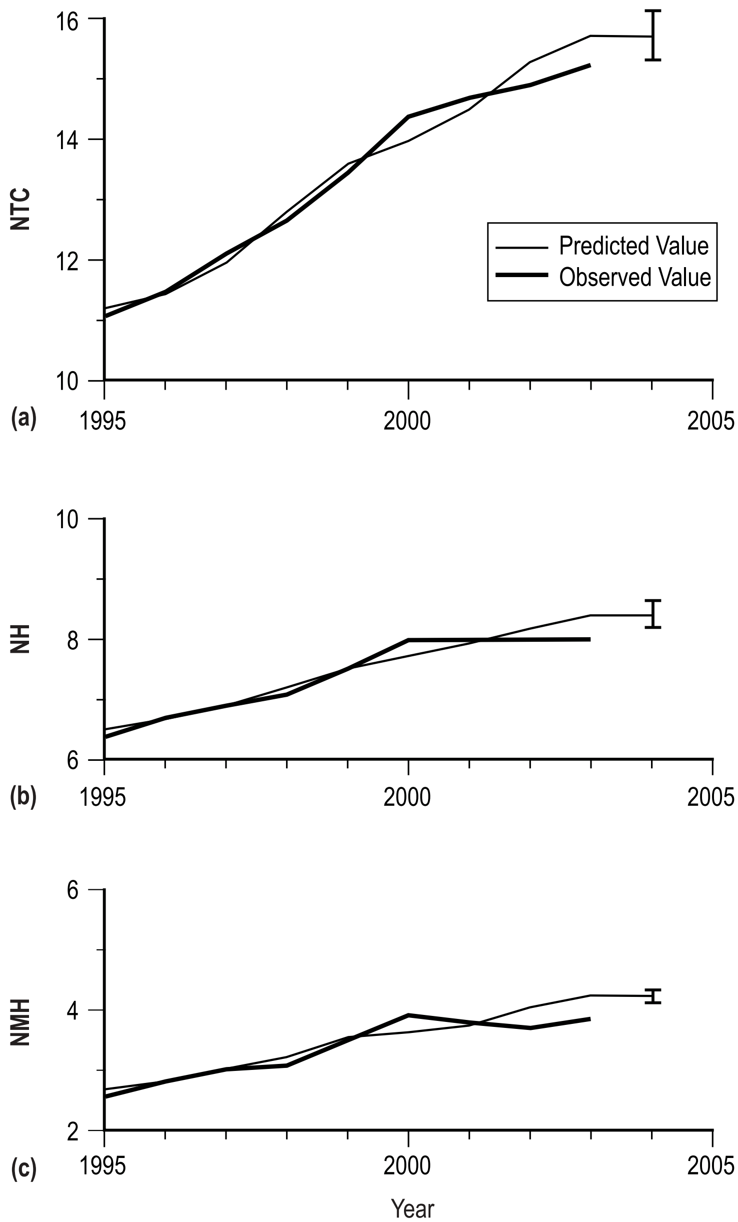

Figure 5. Comparison of predicted and observed 10-yma for (a) NTC, (b) NH, and (c) NMH.

4. DISCUSSION AND SUMMARY

Table 9 summarizes the yearly and 10-yma values for NTC, NH, NMH, AT, and ONI for the interval 1950–2008 used in the previous analyses. Also included are the number of EN and LN months during the years, based on ONI values using ERSST.v3, and the names and month of first occurrence (in parentheses) of those North Atlantic basin hurricanes having PWS equal to 140 kt or higher. The two storms having the highest PWS are Camille (1969) and Allen (1980), both having peak wind speeds equal to 165 kt and both being named in the month of August. The storm of lowest pressure is Wilma, being named in October 2005 and having LP equal to 882 mb.

Table 9. Summary of yearly and 10-yma values for NTC, NH, NMH, AT, and ONI (1950–2008).

	Yearly Values					10-yma Values								
Year	NTC	NH	NMH	AT	ONI	NTC	NH	NMH	AT	ONI	NLNM	NNM	NENM	Comment
1950	13	11	8	9.17	–1.14	10.4	6.7	3.7	9.43	–	12	0	0	Dog (08)
1951	10	8	5	8.95	0.02	10.5	7.0	3.9	9.39	–	3	4	5	Easy (09)
1952	7	6	3	8.81	–0.06	10.6	6.9	3.9	9.43	–	0	12	0	
1953	14	6	4	9.87	0.34	10.6	6.9	4.0	9.45	–	0	12	0	
1954	11	8	2	9.15	–0.68	10.5	6.9	4.0	9.44	–	9	3	0	
1955	12	9	6	9.49	–1.23	10.1	6.6	3.6	9.44	–0.18	12	0	0	Janet (09)
1956	8	4	2	9.37	–0.73	9.9	6.2	3.4	9.49	–0.14	12	0	0	
1957	8	3	2	9.83	0.68	9.8	6.1	3.4	9.52	–0.17	12	9		
1958	10	7	5	9.45	0.60	9.5	6.0	3.2	9.45	–0.19	0	6	6	Cleo (08)
1959	11	7	2	10.20	–0.06	9.3	5.9	3.3	9.40	–0.18	0	12	0	
1960	7	4	2	9.44	–0.15	9.0	5.6	3.3	9.38	–0.07	0	12	0	Donna (08); Ethel (09)
1961	11	8	7	9.58	–0.22	8.9	5.5	3.1	9.35	0.07	0	12	0	Carla (09); Hattie (10)
1962	5	3	1	8.76	–0.46	9.0	5.8	3.1	9.33	0.07	0	12	0	
1963	9	7	2	8.57	0.42	8.9	5.9	2.8	9.30	–0.01	0	6	6	
1964	12	6	6	9.49	–0.53	9.2	6.0	2.7	9.23	–0.01	9	2	1	
1965	6	4	1	8.82	0.67	9.7	6.3	2.8	9.16	0.02	2	3	7	
1966	11	7	3	9.38	0.28	9.9	6.2	2.5	9.16	–0.02	0	8	4	
1967	8	6	1	9.40	–0.35	10.1	6.1	2.2	9.17	0.01	1	11	0	Beulah (09)
1968	8	5	0	9.32	–0.04	10.2	6.0	2.1	9.20	0.02	4	6	2	
1969	18	12	5	8.93	0.68	10.1	5.7	1.8	9.21	–0.05	0	2	10	Camille (08)
1970	10	5	2	9.28	–0.32	10.2	5.7	1.7	9.23	–0.16	6	5	1	
1971	13	6	1	9.72	–0.97	10.3	5.8	1.8	9.27	–0.27	12	0	0	Edith (09)
1972	7	3	0	8.74	0.90	10.1	5.7	1.7	9.24	–0.25	1	3	8	
1973	8	4	1	9.33	–0.58	10.2	5.6	1.8	9.21	–0.21	8	1	3	
1974	11	4	2	8.94	–0.91	10.0	5.3	1.8	9.18	–0.24	12	0	0	
1975	9	6	3	9.69	–1.15	9.6	5.2	1.6	9.14	–0.23	12	0	0	

Table 9. Summary of yearly and 10-yma values for NTC, NH, NMH, AT, and ONI (1950–2008) (Continued).

Year	Yearly Values					10-yma Values					NLNM	NNM	NENM	Comment
	NTC	NH	NMH	AT	ONI	NTC	NH	NMH	AT	ONI				
1976	10	6	2	9.33	–0.13	9.6	5.5	1.7	9.10	–0.17	5	3	4	
1977	6	5	1	8.92	0.48	9.5	5.5	1.9	9.11	–0.13	0	6	6	
1978	12	5	2	9.21	–0.12	9.2	5.4	1.9	9.16	–0.07	0	10	2	
1979	9	6	2	8.35	0.21	9.1	5.4	1.9	9.20	0.01	0	12	0	David (08)
1980	11	9	2	9.11	0.18	9.3	5.5	1.8	9.17	0.06	0	12	0	Allen (08)
1981	12	7	3	9.09	–0.23	9.2	5.4	1.7	9.08	0.10	0	12	0	
1982	6	2	1	9.43	0.98	9.1	5.2	1.6	9.05	0.16	0	4	8	
1983	4	3	1	9.77	0.53	9.1	5.2	1.7	9.08	0.16	0	6	6	
1984	13	5	1	9.29	–0.43	9.2	5.3	1.7	9.19	0.08	3	9	0	
1985	11	7	3	8.70	–0.65	9.5	5.3	1.7	9.32	0.04	9	3	0	
1986	6	4	0	8.57	0.23	9.4	5.1	1.6	9.37	0.09	0	8	4	
1987	7	3	1	9.07	1.30	9.3	5.0	1.5	9.39	0.13	0	0	12	
1988	12	6	3	9.65	–0.89	9.5	5.2	1.5	9.37	0.12	8	2	2	Gilbert (09)
1989	11	7	2	10.07	–0.70	9.4	5.1	1.5	9.34	0.16	5	7	0	Hugo (09)
1990	14	8	1	9.93	0.26	9.5	5.2	1.5	9.42	0.25	0	12	0	
1991	8	4	2	9.42	0.78	10.3	5.7	1.9	9.53	0.25	0	4	8	
1992	7	4	1	9.45	0.78	10.7	5.9	2.2	9.62	0.22	0	5	7	Andrew (08)
1993	8	4	1	9.27	0.44	10.8	6.1	2.2	9.71	0.26	0	12	0	
1994	7	3	0	9.32	0.58	11.0	6.4	2.4	9.74	0.29	0	6	6	
1995	19	11	5	10.22	0.03	11.1	6.4	2.6	9.74	0.22	4	5	3	
1996	13	9	6	9.22	–0.33	11.5	6.7	2.8	9.75	0.12	3	9	0	
1997	8	3	1	10.32	1.24	12.1	6.9	3.0	9.79	0.07	0	4	8	
1998	14	10	3	10.09	0.02	12.7	7.1	3.1	9.87	0.07	6	2	4	Mitch (10)
1999	12	8	5	10.18	–1.10	13.5	7.5	3.5	9.95	0.07	12	0	0	
2000	15	8	3	9.93	–0.77	14.4	8.0	3.9	10.00	0.08	9	3	0	
2001	15	9	4	9.57	–0.18	14.7	8.0	3.8	10.06	0.12	2	10	0	
2002	12	4	2	10.20	0.76	14.9	8.0	3.7	10.13	0.07	0	4	8	
2003	16	7	3	10.02	0.44	15.3	8.0	3.8			0	9	3	Isabel (09)
2004	15	9	6	10.21	0.54						0	6	6	Ivan (09)
2005	28	15	7	10.24	0.23						0	10	2	Emily (07); Katrina (08); Rita (09); Wilma (10)
2006	10	5	2	10.43	0.29						0	7	5	
2007	15	6	2	10.59	–0.34						5	6	1	Dean (08); Felix (09)
2008	16	8	5								5	7	0	

Table 10 gives the monthly record of AT, NTC, NH, NMH, and ONI for the interval January 1950 through December 2008. Also included are the start and end months and strength of EN and LN events, based on ONI using ERSST.v3, and the names of storms having PWS equal to 140 kt or higher. January 1978 marks the lone month/year having the earliest occurring storm, an unnamed

Table 10. Monthly values of AT, NTC, NH, NMH, and ONI (1950–2008).

Year	Month	AT	NTC	NH	NMH	ONI	Comments
1950	01	5.89	0	0	0	–1.7	LN(S) peak?
	02	4.87	0	0	0	–1.5	LN(S)
	03	7.94	0	0	0	–1.4	LN(M)
	04	7.36	0	0	0	–1.4	LN(M)
	05	11.39	0	0	0	–1.3	LN(M)
	06	19.52	0	0	0	–1.2	LN(M)
	07	15.04	0	0	0	–0.9	LN(W)
	08	14.50	4	4	4	–0.8	LN(W); Dog (160)
	09	11.98	3	3	2	–0.8	LN(W)
	10	9.52	6	4	2	–0.8	LN(W)
	11	4.85	0	0	0	–0.9	LN(W)
	12	1.70	0	0	0	–1.0	LN(M)
1951	01	4.09	0	0	0	–1.1	LN(M)
	02	3.21	0	0	0	–0.9	LN(W)
	03	4.51	0	0	0	–0.7	LN(W) end
	04	6.82	0	0	0	–0.4	
	05	9.33	1	1	1	–0.2	
	06	13.26	0	0	0	0.1	
	07	15.23	0	0	0	0.3	
	08	14.16	3	2	2	0.5	EN(W) start
	09	13.37	3	2	2	0.6	EN(W); Easy (140)
	10	10.48	3	3	0	0.7	EN(W) peak
	11	7.58	0	0	0	0.7	EN(W) peak
	12	5.43	0	0	0	0.6	EN(W) end
1952	01	2.44	0	0	0	0.3	
	02	4.26	1	0	0	0.2	
	03	6.89	0	0	0	0.1	
	04	9.26	0	0	0	0.1	
	05	12.10	0	0	0	0.0	
	06	13.03	0	0	0	–0.2	
	07	15.64	0	0	0	–0.3	
	08	14.73	2	2	1	–0.3	
	09	10.25	2	2	1	–0.1	
	10	9.06	2	2	1	–0.2	
	11	4.60	0	0	0	–0.2	
	12	3.56	0	0	0	–0.1	
1953	01	4.86	0	0	0	0.1	
	02	5.84	0	0	0	0.3	
	03	5.73	0	0	0	0.4	
	04	6.69	0	0	0	0.4	
	05	12.73	1	0	0	0.5	
	06	13.65	0	0	0	0.4	
	07	14.68	0	0	0	0.4	
	08	14.91	3	2	1	0.4	

Table 10. Monthly values of AT, NTC, NH, NMH, and ONI (1950–2008) (Continued).

Year	Month	AT	NTC	NH	NMH	ONI	Comments
1953	09	13.98	4	3	3	0.4	
	10	10.15	4	1	0	0.3	
	11	8.08	1	0	0	0.3	
	12	7.17	1	0	0	0.2	
1954	01	4.49	0	0	0	0.3	
	02	4.28	0	0	0	0.2	
	03	6.24	0	0	0	–0.2	
	04	7.99	0	0	0	–0.6	LN(W) start
	05	10.81	0	0	0	–0.8	LN(W)
	06	12.71	1	1	0	–0.8	LN(W)
	07	13.63	1	0	0	–0.8	LN(W)
	08	13.64	2	2	0	–1.1	LN(M)
	09	11.71	4	3	1	–1.2	LN(M) peak 1
	10	10.95	1	1	1	–1.1	LN(M)
	11	6.44	1	0	0	–1.1	LN(M)
	12	6.99	1	1	0	–1.0	LN(M)
1955	01	3.23	0	0	0	–1.0	LN(M)
	02	1.97	0	0	0	–0.9	LN(W)
	03	4.42	0	0	0	–0.9	LN(W)
	04	9.80	0	0	0	–1.0	LN(M)
	05	9.85	0	0	0	–1.1	LN(M)
	06	12.98	0	0	0	–1.0	LN(M)
	07	16.81	1	0	0	–1.0	LN(M)
	08	17.32	4	3	2	–1.0	LN(M)
	09	14.13	5	5	3	–1.4	LN(M); Janet (150)
	10	9.23	2	1	1	–1.8	LN(S)
	11	8.08	0	0	0	–2.0	LN(S) peak 2
	12	6.09	0	0	0	–1.7	LN(S)
1956	01	3.97	0	0	0	–1.2	LN(M)
	02	2.63	0	0	0	–0.7	LN(W)
	03	7.33	0	0	0	–0.6	LN(W)
	04	8.05	0	0	0	–0.6	LN(W)
	05	11.79	0	0	0	–0.5	LN(W)
	06	13.03	1	0	0	–0.5	LN(W)
	07	15.13	1	1	0	–0.6	LN(W)
	08	13.21	1	1	1	–0.8	LN(W)
	09	13.34	4	1	0	–0.8	LN(W)
	10	9.86	0	0	0	–0.9	LN(W)
	11	7.46	1	1	1	–0.8	LN(W)
	12	6.73	0	0	0	–0.7	LN(W)
1957	01	5.35	0	0	0	–0.5	LN(W) end
	02	5.34	0	0	0	–0.1	
	03	9.51	0	0	0	0.3	
	04	8.81	0	0	0	0.6	EN(W) start

Table 10. Monthly values of AT, NTC, NH, NMH, and ONI (1950–2008) (Continued).

Year	Month	AT	NTC	NH	NMH	ONI	Comments
1957	05	10.65	0	0	0	0.7	EN(W)
	06	14.22	2	1	1	0.9	EN(W)
	07	15.12	0	0	0	0.9	EN(W)
	08	14.65	1	0	0	0.9	EN(W)
	09	11.90	4	2	1	0.9	EN(W)
	10	10.18	1	0	0	0.9	EN(W)
	11	6.72	0	0	0	1.2	EN(M)
	12	5.58	0	0	0	1.5	EN(S)
1958	01	4.36	0	0	0	1.7	EN(S) peak
	02	5.31	0	0	0	1.5	EN(S)
	03	4.28	0	0	0	1.1	EN(M)
	04	8.04	0	0	0	0.7	EN(W)
	05	10.09	0	0	0	0.5	EN(W)
	06	13.26	1	0	0	0.5	EN(W) end
	07	15.36	0	0	0	0.4	
	08	14.83	4	3	3	0.2	Cleo (140)
	09	14.63	4	3	2	0.0	
	10	10.74	1	1	0	0.0	
	11	7.97	0	0	0	0.2	
	12	4.54	0	0	0	0.4	
1959	01	2.32	0	0	0	0.4	
	02	5.76	0	0	0	0.5	
	03	7.86	0	0	0	0.4	
	04	8.84	0	0	0	0.2	
	05	12.25	1	0	0	0.1	
	06	14.56	2	1	0	–0.2	
	07	16.10	2	2	0	–0.4	
	08	16.18	1	0	0	–0.5	
	09	14.00	3	3	2	–0.4	
	10	12.32	2	1	0	–0.3	
	11	6.79	0	0	0	–0.2	
	12	5.48	0	0	0	–0.3	
1960	01	4.32	0	0	0	–0.3	
	02	3.81	0	0	0	–0.3	
	03	6.79	0	0	0	–0.3	
	04	9.53	0	0	0	–0.1	
	05	12.84	0	0	0	–0.1	
	06	15.05	1	0	0	–0.1	
	07	14.59	2	1	0	0.0	
	08	14.26	2	2	1	0.0	Donna (140)
	09	12.55	2	1	1	0.0	Ethel (140)
	10	9.86	0	0	0	–0.2	
	11	6.79	0	0	0	–0.2	
	12	2.89	0	0	0	–0.2	

Table 10. Monthly values of AT, NTC, NH, NMH, and ONI (1950–2008) (Continued).

Year	Month	AT	NTC	NH	NMH	ONI	Comments
1961	01	3.86	0	0	0	–0.1	
	02	7.49	0	0	0	–0.2	
	03	9.19	0	0	0	–0.2	
	04	9.22	0	0	0	–0.1	
	05	10.77	0	0	0	0.1	
	06	13.50	0	0	0	0.2	
	07	13.97	1	1	1	0.1	
	08	14.36	0	0	0	–0.3	
	09	13.50	6	5	5	–0.6	Carla (150)
	10	10.05	2	1	1	–0.6	Hattie (140)
	11	6.34	2	1	0	–0.5	
	12	2.72	0	0	0	–0.4	
1962	01	4.43	0	0	0	–0.5	
	02	5.30	0	0	0	–0.5	
	03	3.67	0	0	0	–0.4	
	04	7.99	0	0	0	–0.5	
	05	10.25	0	0	0	–0.4	
	06	12.95	0	0	0	–0.3	
	07	13.92	0	0	0	–0.2	
	08	13.84	2	1	0	–0.3	
	09	11.78	1	0	0	–0.4	
	10	10.55	2	2	1	–0.6	
	11	6.22	0	0	0	–0.7	
	12	4.28	0	0	0	–0.7	
1963	01	–0.17	0	0	0	–0.6	
	02	1.27	0	0	0	–0.3	
	03	6.83	0	0	0	0.0	
	04	8.36	0	0	0	0.1	
	05	9.94	0	0	0	0.1	
	06	13.98	0	0	0	0.3	
	07	14.31	0	0	0	0.7	EN(W) start
	08	13.99	2	2	1	0.9	EN(W)
	09	12.50	5	4	1	0.9	EN(W)
	10	11.02	2	1	0	0.9	EN(W)
	11	7.13	0	0	0	1.0	EN(M) peak
	12	3.65	0	0	0	1.0	EN(M) peak
1964	01	5.45	0	0	0	0.9	EN(W) end
	02	5.18	0	0	0	0.4	
	03	5.40	0	0	0	0.0	
	04	8.99	0	0	0	–0.5	LN(W) start
	05	12.38	0	0	0	–0.7	LN(W)
	06	13.35	1	0	0	–0.7	LN(W)
	07	15.19	1	0	0	–0.7	LN(W)
	08	14.62	3	1	1	–0.8	LN(W)
	09	13.49	5	4	4	–1.0	LN(M)

Table 10. Monthly values of AT, NTC, NH, NMH, and ONI (1950–2008) (Continued).

Year	Month	AT	NTC	NH	NMH	ONI	Comments
1964	10	9.58	1	1	1	–1.1	LN(M) peak
	11	6.93	1	0	0	–1.1	LN(M) peak
	12	3.85	0	0	0	–1.0	LN(M)
1965	01	3.10	0	0	0	–0.8	LN(W)
	02	3.77	0	0	0	–0.5	LN(W) end
	03	5.90	0	0	0	–0.2	
	04	8.41	0	0	0	0.0	
	05	11.44	0	0	0	0.3	
	06	14.09	1	0	0	0.7	EN(W) start
	07	13.39	0	0	0	1.0	EN(M)
	08	14.03	2	2	1	1.3	EN(M)
	09	11.79	2	1	0	1.5	EN(S)
	10	10.87	1	1	0	1.6	EN(S) peak
	11	4.54	0	0	0	1.6	EN(S) peak
	12	4.52	0	0	0	1.5	EN(S)
1966	01	4.04	0	0	0	1.2	EN(M)
	02	5.65	0	0	0	1.1	EN(M)
	03	7.80	0	0	0	0.8	EN(W)
	04	6.99	0	0	0	0.5	EN(W) end
	05	11.14	0	0	0	0.3	
	06	15.09	1	1	1	0.2	
	07	14.62	4	3	0	0.2	
	08	13.88	1	1	1	0.0	
	09	13.93	4	1	1	–0.2	
	10	9.16	0	0	0	–0.2	
	11	4.93	1	1	0	–0.3	
	12	5.33	0	0	0	–0.3	
1967	01	5.04	0	0	0	–0.4	
	02	5.65	0	0	0	–0.5	
	03	6.76	0	0	0	–0.6	
	04	8.86	0	0	0	–0.5	
	05	9.60	0	0	0	–0.2	
	06	13.77	0	0	0	0.0	
	07	15.39	0	0	0	0.0	
	08	14.60	1	1	0	–0.2	
	09	13.08	4	3	1	–0.4	Beulah (140)
	10	9.50	3	2	0	–0.5	
	11	5.89	0	0	0	–0.4	
	12	4.64	0	0	0	–0.5	LN(W) start
1968	01	5.27	0	0	0	–0.7	LN(W)
	02	2.31	0	0	0	–0.8	LN(W) peak
	03	6.41	0	0	0	–0.8	LN(W) peak
	04	7.90	0	0	0	–0.7	LN(W) end
	05	9.46	0	0	0	–0.4	
	06	14.35	3	2	0	0.0	

Table 10. Monthly values of AT, NTC, NH, NMH, and ONI (1950–2008) (Continued).

Year	Month	AT	NTC	NH	NMH	ONI	Comments
1968	07	14.58	0	0	0	0.3	
	08	15.26	1	1	0	0.3	
	09	13.04	3	1	0	0.3	
	10	12.22	1	1	0	0.4	
	11	6.83	0	0	0	0.7	EN(W) start
	12	4.21	0	0	0	0.9	EN(W)
1969	01	4.71	0	0	0	1.0	EN(M) peak
	02	1.19	0	0	0	1.0	EN(M) peak
	03	3.89	0	0	0	0.9	EN(W)
	04	7.54	0	0	0	0.8	EN(W)
	05	10.73	0	0	0	0.6	EN(W)
	06	13.31	0	0	0	0.5	EN(W) end
	07	15.88	1	0	0	0.4	
	08	15.48	5	4	3	0.4	Camille (165)
	09	13.30	6	4	2	0.6	EN(W) start
	10	12.66	5	3	0	0.7	EN(W) peak
	11	4.21	1	1	0	0.7	EN(W) peak
	12	4.26	0	0	0	0.6	EN(W)
1970	01	3.75	0	0	0	0.5	EN(W) end
	02	2.82	0	0	0	0.3	
	03	4.87	0	0	0	0.2	
	04	7.04	0	0	0	0.1	
	05	12.66	1	1	0	0.0	
	06	15.82	0	0	0	–0.3	
	07	14.16	1	0	0	–0.6	LN(W) start
	08	15.38	3	1	1	–0.7	LN(W)
	09	13.29	3	1	1	–0.7	LN(W)
	10	10.43	2	2	0	–0.7	LN(W)
	11	6.71	0	0	0	–0.8	LN(W)
	12	4.52	0	0	0	–1.1	LN(M)
1971	01	4.97	0	0	0	–1.3	LN(M)
	02	5.58	0	0	0	–1.4	LN(M) peak
	03	5.89	0	0	0	–1.2	LN(M)
	04	8.01	0	0	0	–0.9	LN(W)
	05	11.00	0	0	0	–0.8	LN(W)
	06	12.06	0	0	0	–0.8	LN(W)
	07	15.86	1	0	0	–0.8	LN(W)
	08	14.58	4	2	0	–0.8	LN(W)
	09	13.93	6	4	1	–0.8	LN(W); Edith (140)
	10	11.51	1	0	0	–0.9	LN(W)
	11	6.62	1	0	0	–1.0	LN(M)
	12	6.64	0	0	0	–0.9	LN(W)
1972	01	3.62	0	0	0	–0.7	LN(W) end
	02	4.35	0	0	0	–0.3	
	03	5.83	0	0	0	0.0	

Table 10. Monthly values of AT, NTC, NH, NMH, and ONI (1950–2008) (Continued).

Year	Month	AT	NTC	NH	NMH	ONI	Comments
1972	04	8.41	0	0	0	0.3	
	05	10.02	1	0	0	0.6	EN(W) start
	06	11.18	1	1	0	0.8	EN(W)
	07	15.06	0	0	0	1.1	EN(M)
	08	13.53	2	1	0	1.4	EN(M)
	09	11.48	2	1	0	1.6	EN(S)
	10	10.14	0	0	0	1.8	EN(S)
	11	5.48	1	0	0	2.1	EN(S) peak
	12	5.73	0	0	0	2.1	EN(S) peak
1973	01	5.25	0	0	0	1.8	EN(S)
	02	4.29	0	0	0	1.2	EN(M)
	03	6.28	0	0	0	0.5	EN(W) end
	04	7.29	0	0	0	0.0	
	05	10.70	0	0	0	–0.5	LN(W) start
	06	14.41	0	0	0	–0.8	LN(W)
	07	15.28	2	1	0	–1.0	LN(M)
	08	15.33	2	1	0	–1.2	LN(M)
	09	13.25	2	1	1	–1.4	LN(M)
	10	8.89	2	1	0	–1.7	LN(S)
	11	5.97	0	0	0	–1.9	LN(S)
	12	4.97	0	0	0	–2.0	LN(S) peak
1974	01	6.06	0	0	0	–1.8	LN(S)
	02	5.15	0	0	0	–1.6	LN(S)
	03	5.63	0	0	0	–1.2	LN(M)
	04	8.45	0	0	0	–1.1	LN(M)
	05	10.30	0	0	0	–0.9	LN(W)
	06	12.64	1	0	0	–0.7	LN(W)
	07	13.90	1	0	0	–0.5	LN(W) end
	08	14.45	4	2	2	–0.4	
	09	10.94	4	2	0	–0.5	LN(W) start
	10	7.53	1	0	0	–0.7	LN(W)
	11	5.23	0	0	0	–0.8	LN(W)
	12	6.99	0	0	0	–0.7	LN(W)
1975	01	5.90	0	0	0	–0.6	LN(W)
	02	5.22	0	0	0	–0.6	LN(W)
	03	5.07	0	0	0	–0.7	LN(W)
	04	8.67	0	0	0	–0.8	LN(W)
	05	10.09	0	0	0	–0.9	LN(W)
	06	14.03	1	0	0	–1.1	LN(M)
	07	16.29	1	1	0	–1.3	LN(M)
	08	16.78	2	2	1	–1.3	LN(M)
	09	12.09	3	3	2	–1.5	LN(S)
	10	10.49	1	0	0	–1.6	LN(S)
	11	6.32	0	0	0	–1.7	LN(S) peak
	12	5.42	1	0	0	–1.7	LN(S) peak

Table 10. Monthly values of AT, NTC, NH, NMH, and ONI (1950–2008) (Continued).

Year	Month	AT	NTC	NH	NMH	ONI	Comments
1976	01	5.49	0	0	0	–1.6	LN(S)
	02	4.84	0	0	0	–1.2	LN(M)
	03	5.55	0	0	0	–0.9	LN(W)
	04	8.69	0	0	0	–0.6	LN(W)
	05	10.70	1	0	0	–0.5	LN(W) end
	06	15.69	0	0	0	–0.2	
	07	16.45	1	0	0	0.1	
	08	16.33	5	4	2	0.3	
	09	12.24	2	1	0	0.6	EN(W) start
	10	8.83	1	1	0	0.8	EN(W) peak
	11	5.47	0	0	0	0.8	EN(W) peak
	12	1.77	0	0	0	0.8	EN(W) peak
1977	01	2.31	0	0	0	0.6	EN(W)
	02	4.08	0	0	0	0.5	EN(W) end
	03	6.85	0	0	0	0.3	
	04	7.26	0	0	0	0.2	
	05	9.92	0	0	0	0.2	
	06	12.40	0	0	0	0.4	
	07	15.99	0	0	0	0.4	
	08	14.45	1	1	1	0.4	Anita (150)
	09	12.27	3	3	0	0.5	EN(W) start
	10	11.41	2	1	0	0.7	EN(W)
	11	4.11	0	0	0	0.8	EN(W) peak
	12	6.00	0	0	0	0.8	EN(W) peak
1978	01	3.22	1	0	0	0.8	EN(W) peak
	02	3.12	0	0	0	0.5	EN(W) end
	03	6.15	0	0	0	0.0	
	04	6.75	0	0	0	–0.3	
	05	11.72	0	0	0	–0.4	
	06	12.90	0	0	0	–0.3	
	07	14.41	1	0	0	–0.3	
	08	14.52	4	2	1	–0.4	
	09	13.51	3	2	1	–0.4	
	10	11.83	3	1	0	–0.3	
	11	8.16	0	0	0	–0.2	
	12	4.26	0	0	0	–0.1	
1979	01	0.77	0	0	0	–0.1	
	02	2.35	0	0	0	0.0	
	03	4.21	0	0	0	0.1	
	04	7.22	0	0	0	0.2	
	05	8.92	0	0	0	0.1	
	06	13.58	1	0	0	0.0	
	07	15.33	2	1	0	0.1	
	08	13.92	3	2	2	0.2	David (150)
	09	12.31	2	2	0	0.3	

Table 10. Monthly values of AT, NTC, NH, NMH, and ONI (1950–2008) (Continued).

Year	Month	AT	NTC	NH	NMH	ONI	Comments
1979	10	10.68	1	1	0	0.5	
	11	6.59	0	0	0	0.5	
	12	4.41	0	0	0	0.6	
1980	01	2.50	0	0	0	0.5	
	02	5.17	0	0	0	0.4	
	03	4.77	0	0	0	0.3	
	04	9.09	0	0	0	0.2	
	05	11.34	0	0	0	0.3	
	06	12.97	0	0	0	0.3	
	07	13.84	0	0	0	0.2	
	08	15.13	3	3	1	0.0	Allen (165)
	09	13.96	5	3	1	–0.1	
	10	8.69	1	1	0	0.0	
	11	6.69	2	2	0	0.0	
	12	5.19	0	0	0	0.0	
1981	01	5.29	0	0	0	–0.2	
	02	4.31	0	0	0	–0.4	
	03	7.52	0	0	0	–0.4	
	04	8.40	0	0	0	–0.3	
	05	10.91	1	0	0	–0.2	
	06	12.91	1	0	0	–0.3	
	07	14.79	0	0	0	–0.3	
	08	16.16	2	1	0	–0.3	
	09	13.63	5	5	3	–0.2	
	10	6.97	1	0	0	–0.1	
	11	7.09	2	1	0	–0.1	
	12	1.55	0	0	0	0.0	
1982	01	3.57	0	0	0	0.0	
	02	5.17	0	0	0	0.1	
	03	6.23	0	0	0	0.2	
	04	9.40	0	0	0	0.4	
	05	10.94	0	0	0	0.7	EN(W) start
	06	14.51	2	1	0	0.7	EN(W)
	07	15.96	0	0	0	0.8	EN(W)
	08	14.80	1	0	0	1.0	EN(M)
	09	13.04	2	1	1	1.5	EN(S)
	10	9.43	1	0	0	1.9	EN(S)
	11	6.10	0	0	0	2.2	EN(S)
	12	4.09	0	0	0	2.3	EN(S) peak
1983	01	5.67	0	0	0	2.3	EN(S) peak
	02	2.89	0	0	0	2.1	EN(S)
	03	7.12	0	0	0	1.6	EN(S)
	04	6.29	0	0	0	1.3	EN(M)
	05	10.02	0	0	0	1.0	EN(M)
	06	13.59	0	0	0	0.7	EN(W) end

Table 10. Monthly values of AT, NTC, NH, NMH, and ONI (1950–2008) (Continued).

Year	Month	AT	NTC	NH	NMH	ONI	Comments
1983	07	18.04	0	0	0	0.3	
	08	17.04	2	2	1	–0.1	
	09	12.95	2	1	0	–0.5	
	10	9.91	0	0	0	–0.7	
	11	7.21	0	0	0	–0.9	
	12	6.50	0	0	0	–0.7	
1984	01	2.52	0	0	0	–0.4	
	02	4.50	0	0	0	–0.2	
	03	5.11	0	0	0	–0.2	
	04	8.65	0	0	0	–0.3	
	05	10.08	0	0	0	–0.4	
	06	14.61	0	0	0	–0.4	
	07	16.13	0	0	0	–0.3	
	08	16.49	4	0	0	–0.2	
	09	12.42	6	2	1	–0.2	
	10	9.83	1	1	0	–0.6	LN(W) start
	11	5.89	1	1	0	–0.9	LN(W)
	12	5.29	1	1	0	–1.1	LN(M) peak
1985	01	0.62	0	0	0	–1.0	LN(M)
	02	3.81	0	0	0	–0.9	LN(W)
	03	4.99	0	0	0	–0.8	LN(W)
	04	8.84	0	0	0	–0.8	LN(W)
	05	10.40	0	0	0	–0.8	LN(W)
	06	12.49	0	0	0	–0.6	LN(W)
	07	15.10	2	1	0	–0.6	LN(W)
	08	13.57	3	3	1	–0.5	LN(W)
	09	13.99	3	1	1	–0.6	LN(W) end
	10	9.14	2	1	0	–0.4	
	11	3.97	1	1	1	–0.4	
	12	6.01	0	0	0	–0.4	
1986	01	3.61	0	0	0	–0.5	
	02	1.00	0	0	0	–0.5	
	03	5.71	0	0	0	–0.3	
	04	5.82	0	0	0	–0.2	
	05	10.46	0	0	0	–0.1	
	06	14.37	2	1	0	0.0	
	07	14.81	0	0	0	0.2	
	08	12.36	1	1	0	0.4	
	09	11.62	2	1	0	0.6	EN(W) start
	10	10.43	0	0	0	0.9	EN(W)
	11	7.11	1	1	0	1.0	EN(M)
	12	5.58	0	0	0	1.2	EN(M)
1987	01	3.08	0	0	0	1.2	EN(M)
	02	4.23	0	0	0	1.3	EN(M)
	03	5.09	0	0	0	1.2	EN(M)

Table 10. Monthly values of AT, NTC, NH, NMH, and ONI (1950–2008) (Continued).

Year	Month	AT	NTC	NH	NMH	ONI	Comments
1987	04	9.62	0	0	0	1.1	EN(M)
	05	10.64	0	0	0	1.0	EN(M)
	06	11.98	0	0	0	1.2	EN(M)
	07	15.94	0	0	0	1.5	EN(S)
	08	15.06	3	1	0	1.7	EN(S) peak
	09	12.45	3	1	1	1.6	EN(S)
	10	8.45	1	1	0	1.5	EN(S)
	11	6.74	0	0	0	1.2	EN(M)
	12	5.58	0	0	0	1.1	EN(M)
1988	01	4.51	0	0	0	0.7	EN(W)
	02	4.90	0	0	0	0.5	EN(W) end
	03	6.69	0	0	0	0.1	
	04	8.89	0	0	0	–0.3	
	05	11.10	0	0	0	–0.9	LN(W) start
	06	14.81	0	0	0	–1.3	LN(M)
	07	14.12	0	0	0	–1.4	LN(M)
	08	14.48	3	0	0	–1.2	LN(M)
	09	12.76	7	4	2	–1.3	LN(M); Gilbert (160)
	10	9.86	1	1	1	–1.6	LN(S)
	11	5.93	1	1	0	–2.0	LN(S) peak
	12	7.84	0	0	0	–2.0	LN(S) peak
1989	01	7.08	0	0	0	–1.8	LN(S)
	02	5.91	0	0	0	–1.6	LN(S)
	03	6.85	0	0	0	–1.2	LN(M)
	04	6.57	0	0	0	–0.9	LN(W)
	05	12.11	0	0	0	–0.7	LN(W) end
	06	14.23	1	0	0	–0.4	
	07	18.24	2	1	0	–0.4	
	08	15.15	4	4	1	–0.4	
	09	12.95	2	1	1	–0.4	Hugo (140)
	10	11.26	1	1	0	–0.3	
	11	6.64	1	0	0	–0.2	
	12	3.90	0	0	0	–0.1	
1990	01	6.22	0	0	0	0.1	
	02	5.73	0	0	0	0.1	
	03	8.42	0	0	0	0.3	
	04	7.98	0	0	0	0.3	
	05	12.42	0	0	0	0.2	
	06	13.04	0	0	0	0.2	
	07	15.85	2	1	0	0.3	
	08	16.11	6	2	1	0.3	
	09	12.04	2	2	0	0.3	
	10	10.88	4	3	0	0.3	
	11	6.38	0	0	0	0.3	
	12	4.16	0	0	0	0.4	

Table 10. Monthly values of AT, NTC, NH, NMH, and ONI (1950–2008) (Continued).

Year	Month	AT	NTC	NH	NMH	ONI	Comments
1991	01	3.47	0	0	0	0.4	
	02	3.0	0	0	0	00.4	
	03	7.31	0	0	0	0.3	
	04	7.92	0	0	0	0.3	
	05	11.24	0	0	0	0.6	EN(W) start
	06	11.87	0	0	0	0.8	EN(W)
	07	16.39	1	0	0	1.0	EN(M)
	08	16.05	1	1	1	0.9	EN(W)
	09	13.74	3	1	1	0.9	EN(W)
	10	9.45	3	2	0	0.9	EN(W)
	11	6.46	0	0	0	1.3	EN(M)
	12	6.21	0	0	0	1.6	EN(S)
1992	01	4.86	0	0	0	1.8	EN(S) peak
	02	5.97	0	0	0	1.7	EN(S)
	03	7.55	0	0	0	1.5	EN(S)
	04	8.14	1	0	0	1.4	EN(M)
	05	12.27	0	0	0	1.2	EN(M)
	06	15.03	0	0	0	0.9	EN(W)
	07	15.13	0	0	0	0.5	EN(W) end
	08	13.82	1	1	1	0.2	Andrew (150)
	09	11.73	4	2	0	–0.1	
	10	7.55	1	1	0	–0.1	
	11	7.09	0	0	0	0.1	
	12	4.26	0	0	0	0.3	
1993	01	5.92	0	0	0	0.4	
	02	6.63	0	0	0	0.4	
	03	6.60	0	0	0	0.5	
	04	9.19	0	0	0	0.7	
	05	10.53	0	0	0	0.7	
	06	14.13	1	0	0	0.7	
	07	14.32	0	0	0	0.4	
	08	13.88	4	1	1	0.3	
	09	12.05	3	3	0	0.3	
	10	7.71	0	0	0	0.3	
	11	5.39	0	0	0	0.3	
	12	4.87	0	0	0	0.3	
1994	01	4.85	0	0	0	0.2	
	02	3.01	0	0	0	0.2	
	03	6.86	0	0	0	0.2	
	04	7.58	0	0	0	0.3	
	05	9.85	0	0	0	0.4	
	06	12.86	0	0	0	0.4	
	07	15.71	1	0	0	0.5	EN(W) start
	08	14.11	2	1	0	0.5	EN(W)
	09	12.10	2	0	0	0.7	EN(W)

Table 10. Monthly values of AT, NTC, NH, NMH, and ONI (1950–2008) (Continued).

Year	Month	AT	NTC	NH	NMH	ONI	Comments
1994	10	10.06	0	0	0	0.9	EN(W)
	11	9.56	2	2	0	1.3	EN(M) peak
	12	6.04	0	0	0	1.3	EN(M) peak
1995	01	4.76	0	0	0	1.2	EN(M)
	02	6.0	0	0	0	00.9	EN(W)
	03	5.42	0	0	0	0.6	EN(W) end
	04	8.98	0	0	0	0.3	
	05	10.92	0	0	0	0.2	
	06	14.21	1	1	0	0.1	
	07	17.05	4	1	0	–0.1	
	08	18.24	7	4	2	–0.2	
	09	13.21	3	3	2	–0.5	LN(W) start
	10	12.36	4	2	1	–0.6	LN(W)
	11	8.16	0	0	0	–0.8	LN(W) peak
	12	3.40	0	0	0	–0.8	LN(W) peak
1996	01	6.19	0	0	0	–0.8	LN(W) peak
	02	3.58	0	0	0	–0.7	LN(W)
	03	5.40	0	0	0	–0.5	LN(W) end
	04	8.84	0	0	0	–0.3	
	05	8.88	0	0	0	–0.2	
	06	13.66	1	0	0	–0.2	
	07	15.25	2	2	1	–0.1	
	08	14.78	4	3	2	–0.2	
	09	13.39	2	2	2	–0.1	
	10	11.17	3	1	1	–0.2	
	11	5.70	1	1	0	–0.3	
	12	3.87	0	0	0	–0.4	
1997	01	4.49	0	0	0	–0.4	
	02	6.26	0	0	0	–0.3	
	03	8.12	0	0	0	–0.1	
	04	9.34	0	0	0	0.3	
	05	11.23	0	0	0	0.8	EN(W) start
	06	12.80	1	0	0	1.3	EN(M)
	07	15.68	4	2	0	1.7	EN(S)
	08	17.09	0	0	0	2.0	EN(S)
	09	13.09	1	1	1	2.2	EN(S)
	10	10.58	2	0	0	2.4	EN(S)
	11	8.89	0	0	0	2.5	EN(S) peak
	12	6.35	0	0	0	2.5	EN(S) peak
1998	01	4.94	0	0	0	2.3	EN(S)
	02	8.33	0	0	0	2.0	EN(S)
	03	8.06	0	0	0	1.4	EN(M)
	04	7.45	0	0	0	1.1	EN(M) end
	05	11.99	0	0	0	0.4	
	06	13.10	0	0	0	–0.1	

Table 10. Monthly values of AT, NTC, NH, NMH, and ONI (1950–2008) (Continued).

Year	Month	AT	NTC	NH	NMH	ONI	Comments
1998	07	14.56	1	0	0	–0.7	LN(W) start
	08	15.30	4	3	1	–1.0	LN(M)
	09	13.86	6	4	1	–1.1	LN(M)
	10	10.16	2	2	1	–1.2	LN(M); Mitch (155)
	11	7.05	1	1	0	–1.4	LN(M)
	12	6.30	0	0	0	–1.5	LN(S) peak 1
1999	01	5.02	0	0	0	–1.5	LN(S) peak 1
	02	5.79	0	0	0	–1.2	LN(M)
	03	7.33	0	0	0	–0.9	LN(W)
	04	9.54	0	0	0	–0.8	LN(W)
	05	12.06	0	0	0	–0.8	LN(W)
	06	12.87	1	0	0	–0.8	LN(W)
	07	16.54	0	0	0	–0.9	LN(W)
	08	15.36	4	3	2	–1.0	LN(M)
	09	14.48	3	2	2	–1.0	LN(M)
	10	10.78	3	2	0	–1.2	LN(M)
	11	7.77	1	1	1	–1.4	LN(M)
	12	4.61	0	0	0	–1.7	LN(S) peak 2
2000	01	5.21	0	0	0	–1.7	LN(S) peak 2
	02	6.28	0	0	0	–1.4	LN(M)
	03	7.89	0	0	0	–1.0	LN(M)
	04	7.15	0	0	0	–0.8	LN(W)
	05	11.61	0	0	0	–0.6	LN(W)
	06	14.03	0	0	0	–0.6	LN(W) end
	07	15.54	0	0	0	–0.4	
	08	16.03	4	2	1	–0.4	
	09	14.14	7	5	2	–0.4	
	10	9.94	4	1	0	–0.5	LN(W) start
	11	6.27	0	0	0	–0.7	LN(W) peak
	12	5.09	0	0	0	–0.7	LN(W) peak
2001	01	3.07	0	0	0	–0.7	LN(W) peak
	02	4.63	0	0	0	–0.5	LN(W) end
	03	5.05	0	0	0	–0.4	
	04	7.75	0	0	0	–0.3	
	05	12.49	0	0	0	–0.1	
	06	13.24	1	0	0	0.1	
	07	15.27	0	0	0	0.1	
	08	15.45	3	0	0	0.0	
	09	13.39	4	4	2	0.0	
	10	12.41	4	2	1	–0.1	
	11	8.09	3	3	1	–0.1	
	12	4.09	0	0	0	–0.2	
2002	01	6.82	0	0	0	–0.1	
	02	6.41	0	0	0	0.1	
	03	7.71	0	0	0	0.2	

Table 10. Monthly values of AT, NTC, NH, NMH, and ONI (1950–2008) (Continued).

Year	Month	AT	NTC	NH	NMH	ONI	Comments
2002	04	8.93	0	0	0	0.4	
	05	11.37	0	0	0	0.6	EN(W) start
	06	13.53	0	0	0	0.8	EN(W)
	07	14.55	1	0	0	0.9	EN(W)
	08	15.81	3	0	0	0.9	EN(W)
	09	13.82	8	4	2	1.1	EN(M)
	10	9.37	0	0	0	1.3	EN(M)
	11	8.74	0	0	0	1.5	EN(S) peak
	12	5.38	0	0	0	1.4	EN(M)
2003	01	4.60	0	0	0	1.2	EN(M)
	02	4.68	0	0	0	0.9	EN(W)
	03	7.22	0	0	0	0.5	EN(W) end
	04	9.69	1	0	0	0.1	
	05	11.03	0	0	0	–0.1	
	06	14.30	1	0	0	0.0	
	07	16.44	2	2	0	0.3	
	08	16.41	3	2	1	0.4	
	09	13.67	5	3	2	0.5	Isabel (145)
	10	9.03	2	0	0	0.5	
	11	7.91	0	0	0	0.6	
	12	5.30	2	0	0	0.4	
2004	01	5.38	0	0	0	0.4	
	02	4.98	0	0	0	0.2	
	03	6.95	0	0	0	0.2	
	04	9.17	0	0	0	0.2	
	05	11.71	0	0	0	0.3	
	06	15.06	0	0	0	0.4	
	07	14.78	0	0	0	0.7	EN(W) start
	08	16.38	8	5	3	0.8	EN(W)
	09	14.02	4	4	3	0.9	EN(W) peak; Ivan (145)
	10	9.12	2	0	0	0.8	EN(W)
	11	8.55	1	0	0	0.8	EN(W)
	12	6.42	0	0	0	0.8	EN(W)
2005	01	6.3	0	0	0	0.6	EN(W)
	02	5.1	0	0	0	0.5	EN(W) end
	03	7.8	0	0	0	0.4	
	04	8.4	0	0	0	0.5	
	05	10.6	0	0	0	0.5	
	06	14.8	2	0	0	0.5	
	07	15.9	5	3	2	0.5	Emily (140)
	08	15.5	5	2	1	0.3	Katrina (150)
	09	14.5	5	5	2	0.2	Rita (155)
	10	11.8	7	4	2	–0.1	Wilma (160)
	11	6.4	3	1	0	–0.4	
	12	5.8	1	0	0	–0.8	

Table 10. Monthly values of AT, NTC, NH, NMH, and ONI (1950–2008) (Continued).

Year	Month	AT	NTC	NH	NMH	ONI	Comments
2006	01	5.1	0	0	0	–0.8	
	02	4.8	0	0	0	–0.6	
	03	5.8	0	0	0	–0.3	
	04	8.3	0	0	0	–0.1	
	05	11.3	0	0	0	0.2	
	06	15.4	1	0	0	0.3	
	07	18.0	2	0	0	0.4	
	08	15.5	3	1	0	0.5	EN(W) start
	09	15.0	4	4	2	0.7	EN(W)
	10	12.1	0	0	0	0.9	EN(W)
	11	7.4	0	0	0	1.2	EN(M) peak
	12	6.4	0	0	0	1.1	EN(M)
2007	01	6.5	0	0	0	0.8	EN(W) end
	02	5.8	0	0	0	0.4	
	03	6.9	0	0	0	0.1	
	04	11.2	0	0	0	–0.1	
	05	11.7	1	0	0	0.0	
	06	14.5	1	0	0	–0.1	
	07	14.8	1	0	0	–0.2	
	08	15.2	2	1	1	–0.5	LN(W) start; Dean (145)
	09	13.7	8	4	1	–0.8	LN(W); Felix (145)
	10	11.7	1	1	0	–1.1	LN(M)
	11	8.8	0	0	0	–1.2	LN(M)
	12	6.3	1	0	0	–1.4	LN(M)
2008	01	6.0	0	0	0	–1.5	LN(S)
	02	6.0	0	0	0	–1.4	LN(M)
	03	6.2	0	0	0	–1.1	LN(M)
	04	8.4	0	0	0	–0.7	LN(W)
	05	13.2	1	0	0	–0.5	LN(W) end
	06	13.8	0	0	0	–0.4	
	07	15.8	3	2	1	–0.1	
	08	15.5	4	2	1	0.0	
	09	12.7	4	2	1	0.0	
	10	9.0	3	1	1	–0.1	
	11	6.8	1	1	1		
	12		0	0	0		

Notes:

- Armagh temperatures are calibrated through December 2004; values are provisional beginning January 2005.
- ONI values are determined from the 3-mo running mean of ERSST.v3 SST anaomalies in the Nino 3.4 region based on the 1971–2000 base period, where EN/southern oscillation conditions (W=weak, M=moderate, S=strong) are defined when the threshold is met for a minimum of five consecutive months.
- Negative ONI means cooler and positive ONI means warmer.
- Counts refer to the month of onset (when sustained winds exceeded 34 kt).
- For the 1950–2005 timeframe, data were extracted from reference 23.
  For 2006 and 2007, data were extracted from year-end season reports (best track tables, including data only when tropical cyclone is described as tropical storm or hurricane).

subtropical storm forming on January 19, while several years have had storms forming in December, including 1953, 1954, 1984, 2003, 2005, and 2007. The most prolific month/years (those having 7 or more tropical cyclones being named in a single month) include September 1988 (7 named storms, including Gilbert), August 1995 (7 named storms), September 2000 (7 named storms), September 2002 (8 named storms), August 2004 (8 named storms), October 2005 (7 named storms, including Wilma), and September 2007 (8 named storms, including Felix). In 2008, the months of August and September each provided the most named storms (4 each, including Gustav in August and Ike in September) and the last tropical cyclone was named in November (Paloma).

Table 11 gives the monthly counts of NTC, NH, and NMH for 1950–2008 by ONI condition (EN, LN, and neutral) and in total. Noticeable is that tropical cyclones have occurred in all months of the year except March, with the bulk occurring in August–October (77.3%). Similarly, the bulk of all hurricanes and major hurricanes have occurred in August–October (83.5% and 91.8%, respectively). No hurricanes or major hurricanes have been seen in January–April and only two hurricanes (no major hurricanes) have been seen in December. When El Niño is present, major hurricanes have occurred only in the months of July (1 event) and August–September (25 events). When La Niña is present, major hurricanes have occurred exclusively in August–November (49 events). When neutral conditions prevail, major hurricanes have occurred throughout the hurricane season, May–November (159 events, about half in September alone).

Table 11. Monthly counts of NTC, NH, and NMH based on ONI condition (1950–2008).

	NTC				NH				NMH			
Month	EN	LN	Neutral	Total	EN	LN	Neutral	Total	EN	LN	Neutral	Total
January	1	0	0	1	0	0	0	0	0	0	0	0
February	0	0	1	1	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0	0	0	0
April	1	0	1	2	0	0	0	0	0	0	0	0
May	1	2	6	9	0	0	2	2	0	0	1	1
June	8	6	21	35	3	1	6	10	1	0	1	2
July	7	13	37	57	2	4	20	26	0	0	5	5
August	31	41	96	168	16	27	58	101	8	15	32	55
September	56	69	94	219	35	45	66	146	17	24	34	75
October	24	33	50	107	13	20	28	61	0	8	8	16
November	6	8	18	32	4	5	12	21	0	2	3	5
December	0	4	4	8	0	2	0	2	0	0	0	0
Total	135	176	328	639	73	104	192	369	26	49	84	159

As previously noted, the two groups giving early forecasts for the upcoming 2009 North Atlantic basin hurricane season in December 2008 include the CSU team and the TSR team. The initial CSU December estimate[24] for the 2009 hurricane season is for 14 tropical cyclones, including 7 hurricanes and 3 major hurricanes, while the initial TSR December estimate[25] for the 2009 hurricane season is for 14.8 ± 4.3 tropical cyclones, including 7.7 ± 2.8 hurricanes and 3.5 ± 1.8 major (or intense) hurricanes, or about 10–19 tropical cyclones, 5–11 hurricanes, and 2–5 major hurricanes to be expected for the 2009 North Atlantic basin hurricane season. Thus, both groups anticipate continued above-average activity in the upcoming season, very similar to the 1995–2008 averages for NTC, NH, and NMH (equal to 14.9, 8.0, and 3.9, respectively).

Recall from table 4 that the peak probability for NTC in the presumed high-activity mode based on Poisson statistics is 12 ($P(12) = 11.4\%$), with the central 50% being about 9–14 ($P(9–14) = 51.2\%$), and there is only a 13.8% chance of having fewer than 9 tropical cyclones and a 23.4% chance of having more than 14 tropical cyclones during the season. For NH and NMH, their peak probabilities, presuming the high-activity mode, are 7 ($P(7) = 14.9\%$) and 3 ($P(3) = 20.8\%$), respectively, with central 50% intervals being about 5–8 ($P(5–8) = 55.2\%$) for NH, and 2–4 ($P(2–4) = 56.8\%$) for NMH. There is only a 16.4% chance of having fewer than 5 hurricanes and a 28% chance of having more than 8 hurricanes during the season, and there is only an 11.3% chance of having fewer than 2 major hurricanes and a 31.9% chance of having more than 4 major hurricanes during the season.

Instead, based on the statistics of the current high-activity interval (1995–2008), one finds the central 50% intervals to be about 12–18 for NTC, 6–10 for NH, and 3–5 for NMH, presuming a normal distribution for each. The 90% prediction intervals are about 7–23 for NTC, 3–13 for NH, and 1–7 for NMH, suggesting only a 5% chance of having fewer than 7 or more than 23 tropical cyclones during the season, fewer than 3 or more than 13 hurricanes during the season, and either none or more than 7 major hurricanes during the season.

When EN-like conditions prevail, one anticipates a slight reduction in the anticipated seasonal frequencies of NTC, NH, and NMH, while when non-EN-like conditions prevail (especially, when LN-like conditions prevail), one anticipates a slight increase in the anticipated seasonal frequencies. It has been more than 24 mo since the last EN event ended (January 2007) and because EN events recur, on average, ≈32 mo after their previous end date, it is not inconceivable that another EN event could begin during the 2009 hurricane season. However, because the latest NOAA EN/LN forecast[26] is for continued neutral-to-LN conditions prevailing throughout 2009, with about half of the forecasts calling for another LN event, one anticipates continued above-average frequencies for the upcoming 2009 hurricanes season; i.e., ≥11 tropical cyclones, ≥6 hurricanes, and ≥3 major hurricanes.

Based on the usual behaviors of their first differences in 10-yma values; i.e., $d = \pm 0.1$, ≈50% or more of the time, one anticipates NTC = 10–14, NH = 8–12, and NMH = 1–5 for the 2009 hurricane season. However, if global warming is now the principal driver for anticipating the frequencies of tropical cyclones during the current high-activity interval, as suggested by the highly statistically significant inferred linear regression and bi-variate regression fits, then the anticipated seasonal frequencies for the 2009 hurricane season might be considerably higher than average. Presuming the 10-yma value for AT and ONI to be 10.14 ± 0.05 °C and -0.04 ± 0.05 °C, respectively, for 2004, one expects seasonal frequencies for the 2009 hurricane season could be about 18 ± 8 for NTC, 18 ± 4 for NH, and 11 ± 2 for NMH, with the latter two frequencies being of near-record to record size.

In summary, the 2009 North Atlantic basin hurricane season is expected to be one that will be of higher activity than long-term averages, suggesting continuation of the high-activity mode that has been in vogue since 1995. Furthermore, the season could be one of near-record to record size, especially, if global warming is now the principal driver for generating tropical cyclones.

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14. ABSTRACT
An extended forecast of the frequencies for the 2009 North Atlantic basin hurricane season is presented. Continued increased activity during the 2009 season with numbers of tropical cyclones, hurricanes, and major hurricanes exceeding long-term averages are indicated. Poisson statistics for the combined high-activity intervals (1950–1965 and 1995–2008) give the central 50% intervals to be 9–14, 5–8, and 2–4, respectively, for the number of tropical cyclones, hurricanes, and major hurricanes, with a 23.4% chance of exceeding 14 tropical cyclones, a 28% chance of exceeding 8 hurricanes, and a 31.9% chance of exceeding 4 major hurricanes. Based strictly on the statistics of the current high-activity interval (1995–2008), the central 50% intervals for the numbers of tropical cyclones, hurricanes, and major hurricanes are 12–18, 6–10, and 3–5, respectively, with only a 5% chance of exceeding 23, 13, or 7 storms, respectively. Also examined are the first differences in 10-yr moving averages and the effects of global warming and decadal-length oscillations on the frequencies of occurrence for North Atlantic basin tropical cyclones. In particular, temperature now appears to be the principal driver of increased activity and storm strength during the current high-activity interval, with near-record values possible during the 2009 season.

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