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Key Points:

- A 30-year climatology for 1991–2020 is considerably higher than that for 1981–2010 and is likely not representative of the full record
- Thirty-year North Atlantic climatologies have larger root mean squared hurricane prediction errors than 50-year climatologies
- The most representative climatology for 2021–2030 is likely 1971–2020 with an adjustment for short-lived named storms

Supporting Information:

Supporting Information may be found in the online version of this article.

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Optimal Climate Normals for North Atlantic Hurricane Activity

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Abstract Most climatologies use 30-year epochs that are updated at the start of each decade. They will shift from 1981–2010 to 1991–2020 in 2021. North Atlantic hurricane activity has large interdecadal variability that may lead to biases in a 30-year climatology. A previous inactive hurricane period included 1981–1990, while 2011–2020 is a part of the ongoing active era. As a result, the 1991–2020 normals are more active than the 1981–2010 normals, with the median accumulated cyclone energy increasing by ~40%. A 50-year epoch would be more likely to capture a full cycle of multidecadal variability, and this study demonstrates that 50-year climatologies have historically been better predictors of the subsequent decade's hurricane activity. This paper argues that the 1971–2020 climatology should, therefore, be the baseline for hurricane activity for the next decade with a possible adjustment for the non-climatic increase in observed short-lived tropical cyclones.

Plain Language Summary Climatologies are typically 30-year averages that are updated at the start of a new decade (e.g., in 2021, the 30-year average will be updated from 1981–2010 to 1991–2020). However, known changes in hurricane activity between decades are not typically well represented by a 30-year climatology. For example, 1981–1990 was a part of the last quiet period, but 2011–2020 is a part of the current active era. The 1991–2020 hurricane climatology is, therefore, much more active than 1981–2010. An integrated metric accounting for intensity, duration, and frequency of storms increases by 40% from the 1981–2010 to the 1991–2020 climatology. A 50-year climatology is more likely to include both active and quiet eras, which gives a better picture of "normal" hurricane activity. This study shows that the 50-year climatology has better predictive skill for seasonal hurricane activity than that of the standard 30-year average. New technology has also led to an increase in the number of short-lived tropical storms. The 50-year average for 1971–2020 with an adjustment for short-lived storms is likely to be the most representative climatology for the next decade.

1. Introduction

The National Oceanic and Atmospheric Administration (NOAA) uses the climatology of North Atlantic tropical cyclone activity to provide context for both their seasonal forecasts (e.g., NOAA CPC, 2020) and their annual State of the Climate reports (e.g., Bell et al., 2020). From 2001–2010, NOAA primarily used a 50-year climatology from 1951 to 2000 for both its seasonal averages and its classifications of above-normal, normal, and below-normal seasons (Bell et al., 2004; NOAA CPC, 2004), because North Atlantic tropical cyclone data became more reliable around 1950 (Landsea & Franklin, 2013).

Beginning with the 2011 season, the climatological period was changed to 1981–2010 (Bell et al., 2012). In their 2011 seasonal outlook (NOAA CPC, 2011), NOAA noted that the change from the 50-year period of 1951–2000 to the 30-year period of 1981–2010 was to account for higher levels of activity in the recent decades that "largely represent our ability to better identify relatively weak, short-lived systems that simply went unnoticed earlier in the record." Landsea et al. (2010) found that the number of storms lasting 2 days or less increased from around three per year in the late 20th century to around five per year in the early 2000s. This shift was driven primarily by new technologies, such as the Quick Scatterometer satellite (Brennan et al., 2009), and techniques to better distinguish between tropical and baroclinic systems such as the cyclone phase space diagram (Hart, 2003). The 1981–2010 period also conformed to the World Meteorological Organization (WMO) standard of 30-year climatologies for most climate variables (Arguez & Vose, 2010;

Table 1
Key Hurricane Season Statistics for Different Climatological Periods

	1951–2000	1981–2010	1991–2020	1971–2020
Mean named storms	10.6	12.1	14.4	12.5
Mean named storms >2 days	7.9	8.8	10.5	9.2
Mean hurricanes	5.9	6.4	7.2	6.4
Mean major hurricanes	2.2	2.7	3.2	2.6
Mean ACE	92.5	105.6	122.7	102.9
Median ACE	85.5	92.4	129.9	90.4
ACE 20th percentile	40.8	37.9	60.7	40.4
ACE 33rd percentile	68.4	71.7	75.4	67.6
ACE 67th percentile	103.9	124.4	152.5	130.8
ACE 75th percentile	121.1	161.0	173.8	139.7
ACE 80th percentile	136.9	168.4	177.3	152.4
71.4% of median ACE	61.1	66.0	92.7	64.6
120% of median ACE	102.6	110.9	155.8	108.5
165% of median ACE	141.1	152.4	214.3	149.2

Abbreviation: ACE, accumulated cyclone energy.

WMO, 2017), and it was nearly perfectly split across a switch in 1995 from a quiet to an active era (Goldenberg et al., 2001).

Climatologies are typically updated at the start of each new decade, which means that NOAA will likely change to a new climatology for the 2021 hurricane season. This study examines potential choices for the new climate epoch, primarily either 30 years (1991–2020) or 50 years (1971–2020). Inspired in part by the optimal climate normal (OCN) methodology (Huang et al., 1996), we will show that a 50-year normal is more appropriate, even for those variables like named storms that have been significantly affected by changes in observing technologies. Like previously used climatologies, the 1971–2020 period also samples nearly equally between active and inactive eras.

2. Data

All data are obtained from the International Best Track Archive for Climate Stewardship (IBTrACS; Knapp et al., 2010; Schreck et al., 2014). IBTrACS compiles tropical cyclone best track data from agencies and sources around the globe. Only data from the National Hurricane Center (NHC) database (HURDAT2; Landsea & Franklin, 2013) are used here, except for 2020 where IBTrACS provides NHC's operational track advisory data as preliminary data. The 2020 data are, thus, subject to change following NHC's postseason best track analysis, but any changes should minimally impact our analysis. Atlantic tropical cyclone data are particularly sparse before 1878 when the US Army Signal Corps began tracking West Indian Hurricanes (Fernández-Partagás & Diaz, 1996). Following other studies discussing Atlantic tropical cyclone data quality (Landsea et al., 2010; Vecchi & Knutson, 2008, 2011), only data from 1878 onward are used here.

3. Classifying Seasons

Since around 2000, NOAA has primarily classified Atlantic hurricane seasons by their accumulated cyclone energy (ACE; Bell et al., 2000). ACE is the sum of squares of wind speeds from all subtropical storms, tropical storms, and hurricanes at 6-hour intervals. As such, ACE is an integrated metric that combines intensity, duration, and frequency of storms and approximates the kinetic energy generated by all named storms (≥34 kt) during the season. NOAA officially classifies seasons based on their ACE as a percentage of the median. Before 2011, seasons with ACE <75% of the 1951–2000 median were classified as below-normal, 75%–117% of the median were classified as near-normal, and >117% were classified as above-normal (NOAA CPC, 2010). The 75% and 117% values approximated the terciles of climatological ACE. In 2011, those values were changed to 71.4% and 120% of the 1981–2010 median (NOAA CPC, 2011). The revised values do not correspond with the terciles of the new climate epoch, but instead maintain the terciles from 1951 to 2000 (Table 1). In this way, historical years maintained their previous classifications of below/near/above normal, but it made those classifications harder to justify statistically.

Goldenberg et al. (2001) further defined hyperactive or extremely active seasons to exceed 150% of the 1951–2000 normal Net Tropical Cyclone (NTC) activity (Gray et al., 2000), which is another integrated metric of tropical cyclone activity. NTC correlates with ACE at 0.98 from 1951 to 2020. NOAA approximated this hyperactive season value as 152×10^4 kt^2 ACE, which was 175% of the 1951–2000 median (Bell et al., 2011) and 165% of the 1981–2010 median (Bell et al., 2020).

For greater consistency, we use actual tercile values for each climate epoch for determining below-/near-/above-normal seasons. We also use the 80th percentile for extremely active seasons. This percentile threshold is generally higher than the traditional 152×10^4 kt^2 but provides more consistent separation between active and extremely active periods. Finally, we propose using the 20th percentile for extremely inactive seasons.

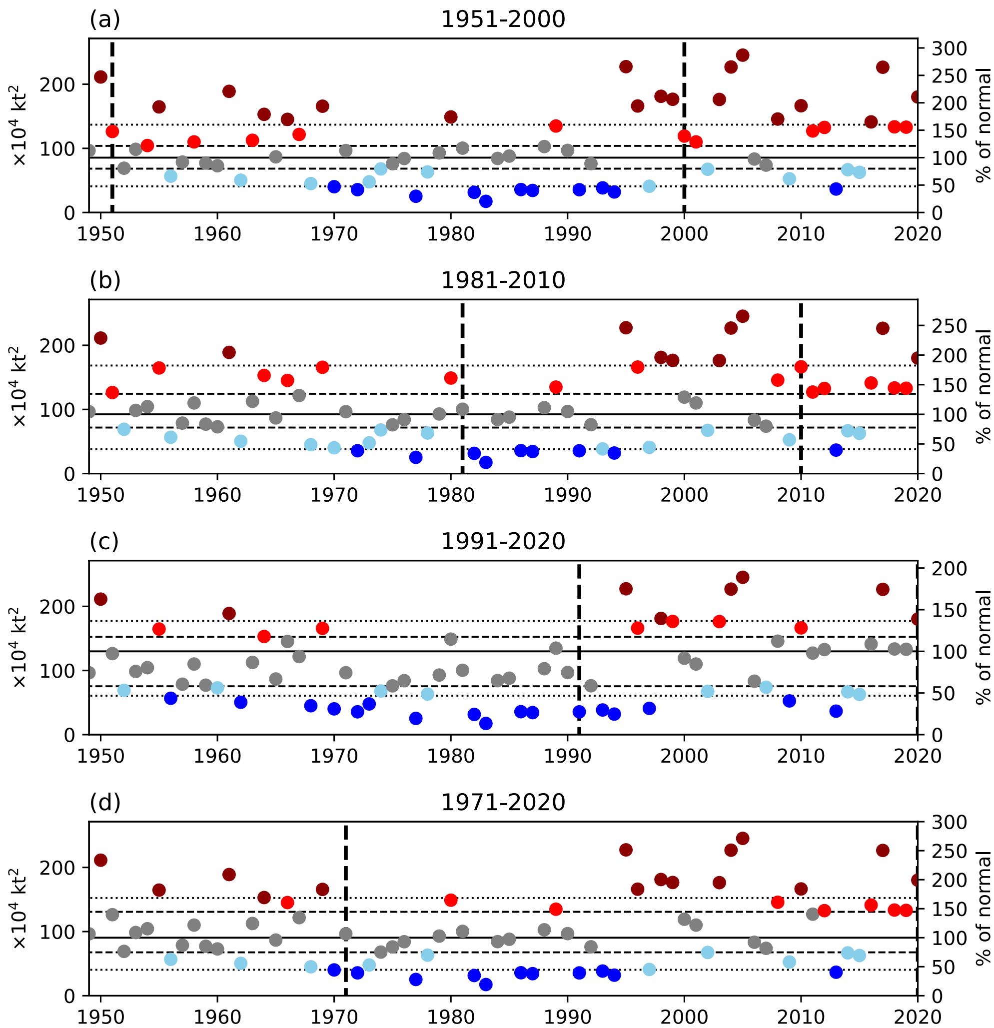

Figure 1. ACE by year relative to different climatological periods: (a) 1951–2000, (b) 1981–2010, (c) 1991–2020, and (d) 1971–2020 (periods outlined with vertical dashed lines). Solid horizontal lines represent the median for that climate period, the dashed horizontal lines denote terciles, and the dotted lines denote the 20th and 80th percentiles. Colors for the ACE values identify that a particular year would have been classified as extremely inactive (blue), inactive (light blue), near-normal (gray), active (red), or extremely active (dark red) using that climatological definition. ACE, accumulated cyclone energy.

4. Comparing Epochs

Figure 1 shows the time series of ACE using different climate epochs to classify individual seasons. The classifications are generally consistent between the two previous climatologies (1951–2000 and 1981–2010). The primary difference is that the 80th percentile is higher in the 1981–2010 climatology (Table 1) owing to the extremely active seasons in the early 2000s.

The North Atlantic was generally active from 1926 to 1969, inactive from 1970 to 1994, and then active again from 1995 to the present (Bell et al., 2020; Goldenberg et al., 2001; Knutson et al., 2019). Activity has been above, near, and below normal during all three of these eras, but extremely active seasons have occurred nearly exclusively during the active periods (with the exception of 1980, which just meets the 80th percentile for 1951–2000). Similarly, extremely inactive seasons occurred almost entirely in the inactive era (2013 being the lone exception). Even though the 1981–2010 epoch is only 30 years, it represents the longer-term climatology in part because it nearly perfectly straddles the inactive and active eras before and after 1995.

The WMO standard for most climate variables is to produce 30-year normals that are updated every 10 years (Arguez & Vose, 2010; WMO, 2017). Following this standard, NOAA would transition from the 1981–2010 climatology to the one based on 1991–2020 for the 2021 hurricane season. While the previous epoch was split nearly evenly between the active and inactive eras, 26 of the 30 years from 1991 to 2020 occurred during the current active era. The 1981–1990 period averaged 72.6×10^4 kt^2 ACE, while the 2011–2020 period averaged 123.6×10^4 kt^2 ACE. As a result, the 1991–2020 median ACE is 40% higher than that from 1981 to 2010 (Table 1). The number of above-normal years from 1950 to 2020 would decrease from 25 with the current upper tercile from 1981 to 2010 to just 15 using the upper tercile of 1991–2020 (Figures 1b and 1c).

Interdecadal variability in Atlantic tropical cyclone activity is well documented, but its relative causes are still not well understood (Knutson et al., 2019; Sobel et al., 2016). Natural variability associated with the Atlantic multi-decadal oscillation and associated changes in the strength of the Atlantic Meridional Overturning Circulation has been proposed as one likely driver (Goldenberg et al., 2001; Klotzbach & Gray, 2008; Zhang et al., 2019). Anthropogenic greenhouse gases have also led to a warming trend in Atlantic sea surface temperatures (SSTs), which might drive a secular trend in increasing tropical cyclone activity (Knutson et al., 2019; Sobel et al., 2016). That trend also interacts with variations in anthropogenic aerosols (Booth et al., 2012; Villarini & Vecchi, 2012, 2013). The increase in these aerosols during the mid-20th century may have contributed to a cooling of Atlantic SST during that period. The subsequent decrease in aerosols following the enforcement of the Clean Air Act may have exacerbated the warming associated with greenhouse gases.

If the recent increase in tropical cyclone activity is secular, then the 1991–2020 normal could be appropriate for reflecting this "new normal." If, however, it is part of a larger multidecadal cycle, then a longer climatic period may be more representative of future possibilities. Regardless of whether the recent trend is secular, cyclical, or a combination of the two, we will show that interannual and interdecadal variability of tropical cyclone activity is too large to be captured by a traditional 30-year normal. Based on historical variability, a 50-year climatology is more appropriate. By coincidence, the new 50-year normal, 1971–2020, is also nearly perfectly bisected by the 1994–1995 transition between inactive and active periods, so most climatological values closely mirror that of the current 1981–2010 normals (Table 1). Figure 1d shows the ACE time series using our proposed quantile definitions for 1971–2020, and it is well aligned with the current definitions. Climatologies are typically updated every 10 years. Figure 2 shows how the median, terciles, and 80th percentile would have changed every 10 years using either a 10-year (top row), 30-year (middle row), or 50-year (bottom row) average. Seasons are then classified relative to what would have been the respective climatology at that time.

Ten years is assumed to be too short to reflect the true climatology, but it helps illustrate the variability. For example, the 1961–1970 ACE climatology was the second highest since 1950, and it would not have been representative of the subsequent start of the inactive era in the 1970s (Figure 2d). Named storms have increased precipitously in the recent decades. As a result, only three years would have been classified as below-normal since 1990 using the 10-year climatology, and only one of those (2014) would have been below-normal with a longer climatology. This trend is in part because microwave satellites and new operational practices have led to the naming of weaker and short-lived storms (Landsea et al., 2010). Counting only storms lasting longer than 2 days reduces this trend, but does not eliminate it, indicating that there is likely an increasing trend in named storms (Figure S1).

The 30-year climatologies are naturally more consistent with relatively small variations since the 1931–1960 climatology that would have been used in the 1960s. The most notable differences are in the ACE terciles and 80th percentiles. These ACE quantiles were steady or decreasing since 1941–1970 (1971–1980 climatological benchmark) until 1981–2010 when they all increased by more than 25×10^4 kt^2 with the inclusion of four extremely active years (2003, 2004, 2005, and 2010) where ACE was greater than 165×10^4 kt^2.

A 50-year climatology is more consistent through time. The key quantiles have remained nearly constant since 1921–1970 (used in the 1970s). The most notable changes were a decrease in the lower tercile of named storms starting with 1951–2000 and increases in the upper tercile and 80th percentile of ACE in the last two decades. However, these changes are still more muted than they would have been with shorter climatological periods.

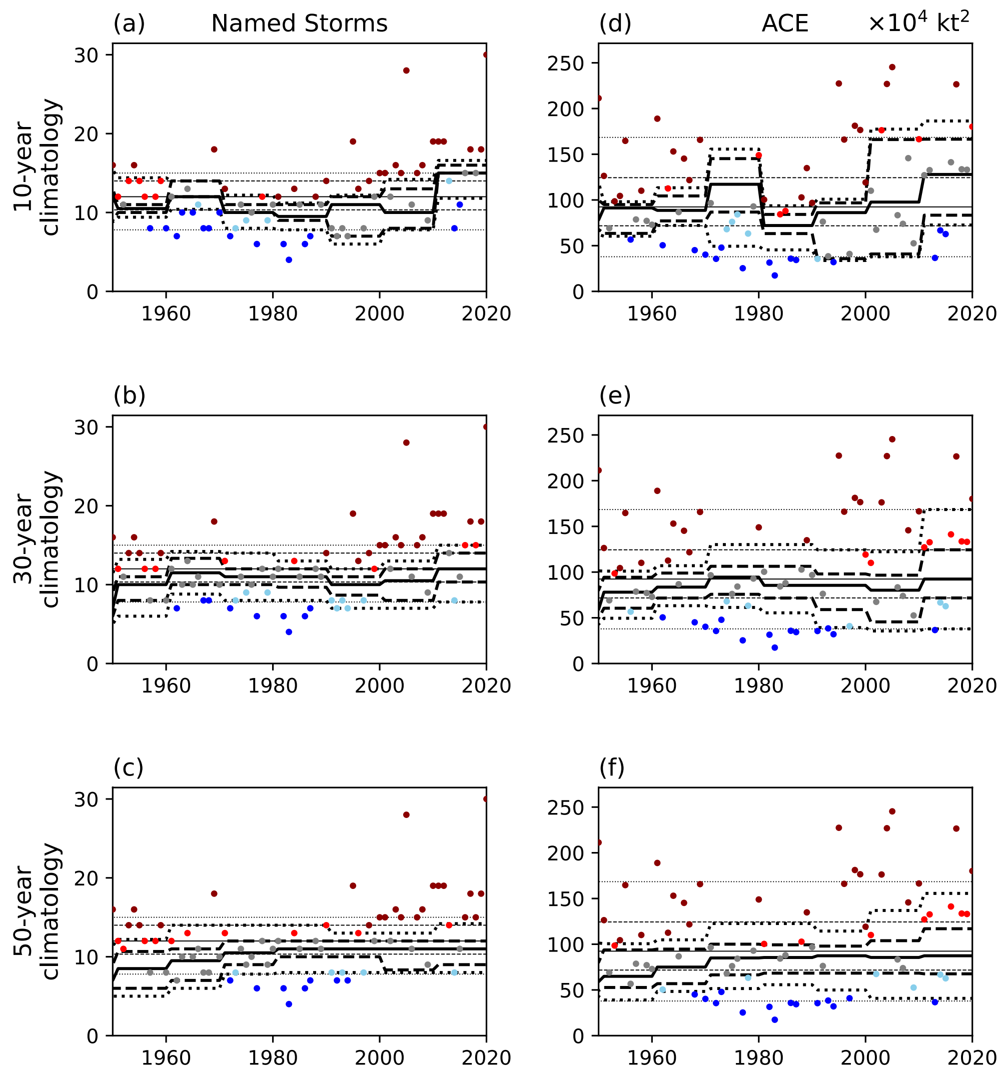

Figure 2. Time series of named storms (a-c) and ACE (d-f). Thick black lines denote the 20th (dotted), 33rd (dashed), 50th (solid), 67th (dashed), and 80th (dotted) percentiles using a 10-year (a, d), 30-year (b-e), and 50-year (c, f) climatology. Climatological values are updated every 10 years (e.g., 1951–1980 would be used for 1981–1990). The values for 1981–2010 are shown in thin black lines for reference. Each year is colored relative to its climatology using the same colors as Figure 1. ACE, accumulated cyclone energy.

5. Optimal Climate Normals

One of the primary roles of a climatology is to provide users with a baseline expectation for future activity. Huang et al. (1996) developed the optimal climate normal (OCN) methodology based on this expectation. They treated climatology as a 1-year forecast and defined the OCN as the climate period length that provided the largest anomaly correlation between these "forecasts" and observed values. We apply a similar methodology to the hurricane season climatology.

Huang et al. (1996) focused on 1-year forecasts, but climatologies are traditionally updated every 10 years. A reasonable expectation would be for the climatology to be consistent with the level of activity for the 10 years until the next update. Figure 3 examines how different climatology lengths would have performed through time with the primary metrics of seasonal activity. The climatological means were recalculated every year and used to predict the subsequent 10 years. For example, the 30-year value plotted for 1983 used a 1953–1982 mean to predict 1983–1992. We use mean instead of median for this analysis, because the

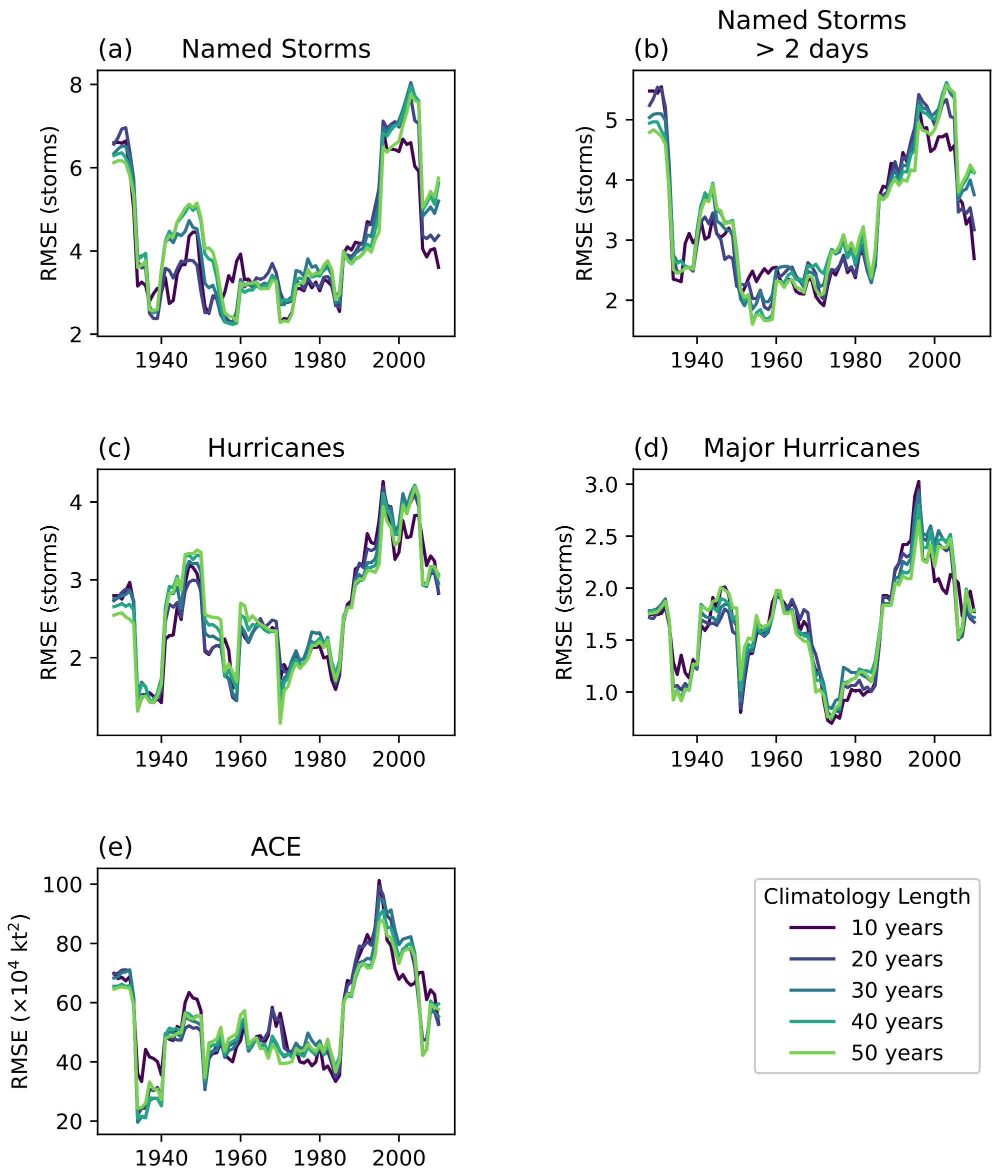

Figure 3. Time series of RMSE for climatologies of (a) named storms, (b) named storms lasting >2 days, (c) hurricanes, (d) major hurricanes, and (e) ACE updated every year and verified against the subsequent 10 years.

median may not change between verification periods. The RMSE values from those 10-year predictions are shown in Figure 3.

The overall patterns in Figure 3 are similar regardless of climatological period or variable. RMSE was high around 1930 and then generally flat until the mid-1980s when it rapidly increased. RMSE has since gone back down in recent years. The high values around 1930 were likely caused by incomplete data and the transition to the active era in the 1930s. Similarly, the increase in the mid-1980s likely relates to the transition to the current active era in 1995, which would have first appeared in the verification data in 1986. RMSE has decreased recently as more years in the current active era have been included in the climatologies.

The RMSE values tend to be lowest for the 10-year climatology because it responds more quickly to changes between active and inactive eras. However, that also means a more volatile climatology (Figures 2a and 2d). The RMSEs for the 30-, 40-, and 50-year climatologies are more consistent with one another. The longer the climatology, the less variable the RMSE values are. For example, all climatologies had higher RMSEs in the 1990s due to the active era shift, but the 50-year climatology RMSE was lower than the others. The 50-year

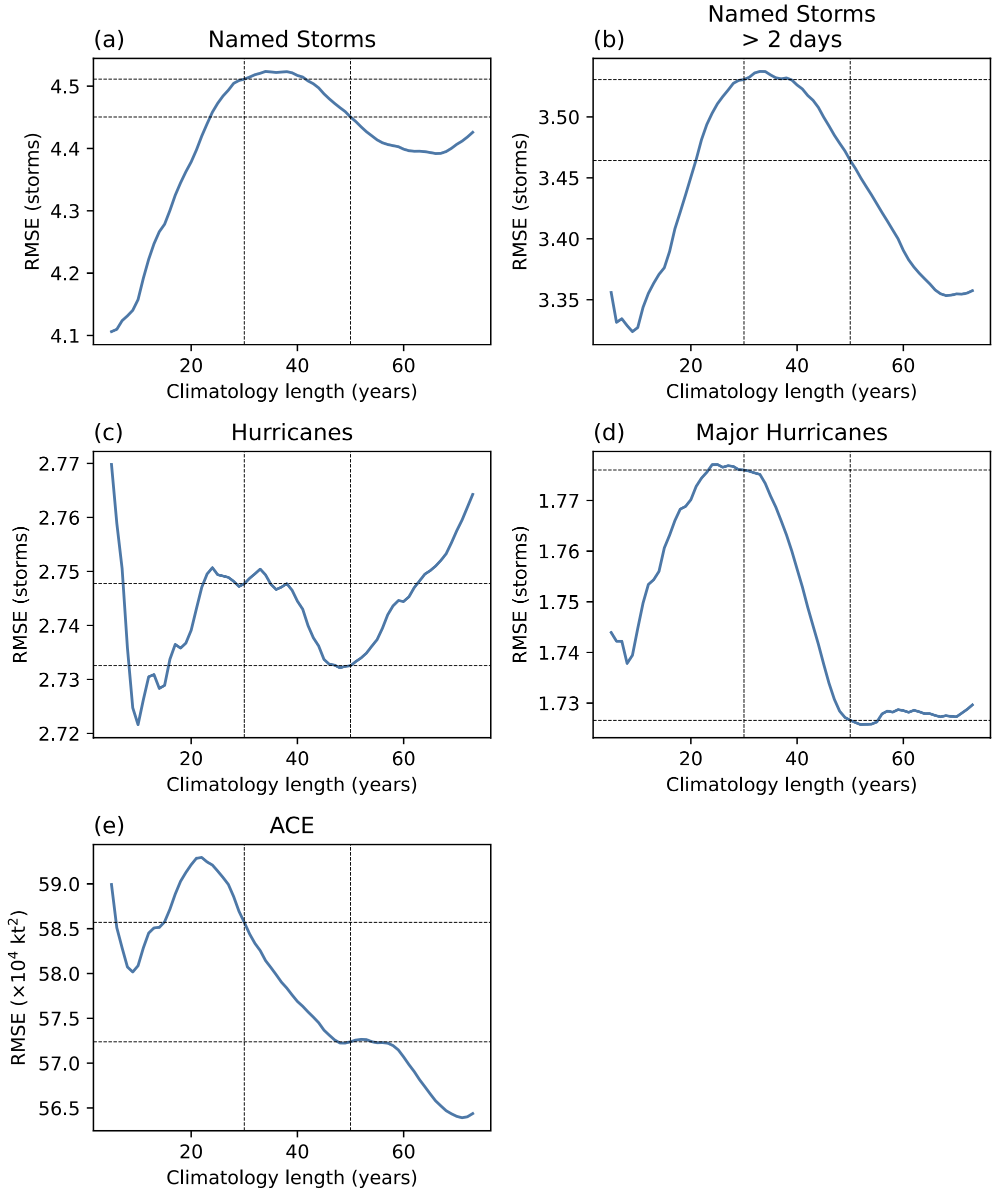

Figure 4. RMSE as a function of the number of years used for the climatology verified for 1951–2020 (a) named storms, (b) named storms lasting >2 days, (c) hurricanes, (d) major hurricanes, and (e) ACE. Dashed lines highlight the 30- and 50-year climatologies.

mean was long enough to contain data from the previous active era that would have been missed by shorter climatologies.

Figure 4 summarizes the RMSE results. As in Figure 3, the climatologies are calculated every year to predict the subsequent 10 years. The RMSE values are then averaged for all initial years, in addition to all 10 leads. The verification periods begin in 1951 to align with the previously used climate epoch (1951–2000) (Bell et al., 2004; NOAA CPC, 2004). The oldest climatology is therefore 1878–1950 (73 years), which is verified against 1951–1960.

The variations with climatology length are small for all five metrics. However, they have similar patterns, which indicate physical significance. They have a relative minimum around <10 years, a maximum around 20–40 years, and another minimum around >50 years. For all five metrics, the 30-year climatology has a higher RMSE than the 50-year climatology (dashed lines).

The variations in climatology and their RMSEs are a function not only of climate variability but also changes in observing networks and techniques. This is most apparent in the trend of the number of short-lived storms since 2000, which is largely driven by new microwave sensors (Landsea et al., 2010). The climatologies <10 years are particularly skillful for named storms (Figure 4a), but that is significantly reduced when storms lasting ≤2 days are removed (Figure 4b). Several studies (Landsea et al., 2010; Vecchi & Knutson, 2008, 2011) have also proposed adjustment factors to account for gaps in the early observational network. Similar to removing short-lived storms (Figure 4b), all of these adjustments reduce the RMSEs, with the effects being the largest for longer climatologies (Figure S2). The general trends are also similar with climatological medians rather than with the means (Figure S3), but the results are noisier because medians are more discrete and less likely to vary between verification windows.

6. Conclusions

The traditional 30-year climatology is not ideal for most metrics of Atlantic hurricane activity. A ~10-year climatology has the best predictive skill, but its volatility would be difficult to explain to users. Even a 30-year climatology can be dominated by one active (e.g., 1995–2020) or inactive (e.g., 1970–1994) era. A 50-year climatology is more likely to approximate one period of that multidecadal variability. Overall, a 50-year climatology generally has lower RMSE values and is more representative of the overall average Atlantic hurricane activity than a 30-year climatology. These findings may be of considerable significance given that most seasonal hurricane outlooks will be changing to a new climate epoch for verification and classification beginning with the 2021 hurricane season.

One justification for using the 30-year climatology for 1981–2010 is the recent increase in the number of short-lived named storms (e.g., named storms lasting ≤2 days) due to improved observing techniques. Landsea et al. (2010) estimated an increase from three of these storms per year to five during the first decade of the 2000s. That trend has continued with an average of 4.6 short-lived named storms per year from 2001–2020 including two storms that briefly attained hurricane strength. We recommend using the 50-year 1971–2020 average of 9.2 long-lived storms (>2 days; Table 1) and adding 4.6 to represent the current number of short-lived storms. That would result in a climatology of 13.8 total named storms per year. For all other North Atlantic hurricane season metrics, the raw 50-year mean should be representative.

Data Availability Statement

The data used in this manuscript are available from https://www.ncdc.noaa.gov/ibtracs/. The adjusted tropical cyclone counts used in the supplementary material were obtained from https://www.gfdl.noaa.gov/historical-atlantic-hurricane-and-tropical-storm-records/.

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