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# Centennial-Scale Shifts in Storm Frequency Captured in Paleohurricane Records From The Bahamas Arise Predominantly From Random Variability

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**Key Points:**

- Pseudo records of past millennium hurricane activity closely replicate centennial-scale variability found in published sediment records
- Most of the centennial-scale signal captured in event-based paleohurricane records from The Bahamas is due to randomness not climate
- There is promise in using compilations of paleohurricane records to characterize hurricane activity and its drivers

**Supporting Information:**

- Supporting Information S1

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**Abstract** Event-based paleohurricane reconstructions of the last millennium indicate dramatic changes in the frequency of landfalling hurricanes on centennial timescales. It is difficult to assess whether the variability captured in these paleorecords is related to changing climate or randomness. We assess whether centennial-scale active and quiet intervals of intense hurricane activity occur in a set of synthetic storms run with boundary conditions from an earth system model simulation of the last millennium. We generate 1,000 pseudo sedimentary records for a site on South Andros Island using a Poisson random draw from this synthetic storm data set. We find that any single pseudo sedimentary record contains active and quiet intervals of hurricane activity. The 1,000-record ensemble average, which reflects the common signal of climate variability, does not. This suggests that the record of paleohurricane activity from The Bahamas reflects variability in hurricane frequency dominated by randomness and not variability in the climatic conditions.

**Plain Language Summary** Sedimentary records of past hurricane strike from coastal basins in The Bahamas indicate dramatic changes in hurricane frequency over the past millennium with century-scale periods of time with significantly different, and higher, levels of hurricane activity than has been observed during the last century. It is still unknown whether these anomalous hurricane patterns are a result of changes in climate or simply due to randomness. Here, we recreate these century scale patterns of hurricane activity for the past millennium using synthetic tropical cyclones and a model of how the passage of each storm is documented in a sediment record. We prove these patterns of activity are predominantly a result of randomness not climate changes. This work has important implications for future research into past millennium hurricanes. We cannot use single sediment records from The Bahamas to infer climate impacts on hurricane activity. Instead, we need to use regional or larger scale compilations of records to characterize hurricane activity and its drivers.

## 1. Introduction

With rising sea levels (Kopp et al., 2016; Woodruff et al., 2013) and projected increases in the frequency of intense tropical cyclones (TCs) (K. A. Emanuel, 2013; K. Emanuel et al., 2008; Korty et al., 2017; Sobel et al., 2016; Walsh et al., 2016), coastal communities are becoming more vulnerable to TC-induced inundation. Unfortunately, the models we use to predict TC activity in real time and into the future are typically validated using only the observational record. Specifically, with only 168 years of observations that suffer from biases (e.g., Knutson et al., 2019; C. W. Landsea & Franklin, 2013; C. W. Landsea et al., 2010; Vecchi & Knutson, 2008, 2011; Villarini et al., 2011), we cannot characterize the influence of climate variability on TC activity or elucidate TC-climate interactions during climatic states different from today. Natural archives of paleohurricane activity have been developed to extend the record of landfalling hurricanes back millennia, with these records exhibiting substantial variability in hurricane activity on centennial timescales. Very little work has been done to integrate paleohurricane records with existing TC models, and it is thus difficult to assess the underlying cause of this variability. Here, we integrate event-based paleohurricane records with a TC model run over the past millennium to assess the significance of centennial-scale variability in TC activity recorded in reconstructions from The Bahamas.

In the last few decades, there has been a growing number of high resolution sedimentary records of paleohurricane activity from coastal basins in the Atlantic (e.g., Donnelly et al., 2015; Lane et al., 2011; Schmitt et al., 2020; van Hengstum et al., 2016; E. J. Wallace et al., 2019). TCs generate strong winds, wave runup, and storm surge that displace and transport coarse grains into depositional environments where finer-grained sediments dominate (e.g., lagoons, marshes) (e.g., Oliva et al., 2017; D. J. Wallace et al., 2014). There, they form event beds, distinct layers of coarse material among the fine mud and/or peat. Documenting and dating event beds in sediment cores provides high resolution archives of TC activity at a location over thousands of years. In particular, collecting cores from blue holes in the Caribbean Sea have allowed for near-annual resolution records extending back over a thousand years (Schmitt et al., 2020; van Hengstum et al., 2014; E. J. Wallace et al., 2019; Winkler et al., 2020). While there is a myriad of different storm properties (e.g., intensity, track, and size) that could influence storm surge at a site, both modern event attribution in these sediment cores (Lane et al., 2011; E. J. Wallace et al., 2019; Winkler et al., 2020) and hydrodynamic modeling of large suites of synthetic TCs passing the sites (Lin et al., 2014) indicate that the vast majority of storms that leave deposits are above some intensity threshold (>Category 2 or 3) and passing proximal (within <100 km) to the site.

These event-based paleohurricane reconstructions indicate that there have been dramatic changes in recorded hurricane activity over the past two millennia (e.g., Brandon et al., 2013; Bregy et al., 2018; Donnelly et al., 2015; Lane et al., 2011; E. J. Wallace et al., 2019; Winkler et al., 2020). In particular, these records capture multidecadal to centennial-scale periods with elevated frequency of hurricane strikes, "active intervals," followed by extended time periods of relative quiescence, "quiet intervals." Many studies have attributed these active and quiet intervals to changes in the large-scale climatic boundary conditions (e.g., the Intertropical Convergence Zone [Donnelly et al., 2015; van Hengstum et al., 2016], North Atlantic Subtropical High [Baldini et al., 2016; E. J. Wallace et al., 2019], El Nino Southern Oscillation [Donnelly & Woodruff, 2007]). However, these interpretations rely on the assumption that the signal captured in these records is dominated by climate.

In reality, there are likely two important contributors: 1) climate variability (the assumption) and 2) random clustering of events independent of climate. The first contributor encompasses large-scale and slowly varying climate factors (e.g., changes in Atlantic sea surface temperatures [K. Emanuel, 2008], vertical wind shear [Elsberry & Jeffries, 1996; Wong & Chan, 2004], vorticity [K. Emanuel, 2008]) that contribute to how many storms are forming and their tracks. The latter encompasses random factors like local weather (e.g., steering flow and moist processes) that affect whether a storm will pass close enough to a site or at high enough intensity to leave a deposit. While local weather is connected to climate, the highly chaotic nature of TC-local weather interactions (Lorenz, 1963; Sang et al., 2008; F. Zhang & Sippel, 2008; Y. Zhang et al., 2014) justifies our characterization of the influence of local weather as random within the context of paleohurricane research.

In this paper, we assess how much of the variability captured in Bahamian event-based paleohurricane records is due to large-scale climate variability. In particular, we focus on a blue hole site from a recently published paper on South Andros Island in The Bahamas (E. J. Wallace et al., 2019). We create 1,000 pseudo sedimentary records of paleohurricane activity at South Andros using an annual Poisson process-based draw (Woodruff et al., 2008) from an archive of synthetic storms consistent with modeled past millennium climate. Only storms meeting a prescribed threshold for deposit and a temporal resolution set by sedimentation rates at the site leave an event bed. We use these pseudo sediment records to rigorously determine the capacity of individual event-based paleohurricane records from the Caribbean to distinguish climate signal from noise. This work has critical implications for use of event-based paleohurricane records to infer climate impacts on intense hurricane activity.

## 2. Methods

### 2.1. Generating the Storm Data Set

We convert synthetic storm data into pseudo sediment records by mimicking the processes that affect whether a TC leaves an event bed in the blue hole on South Andros Island. Coarse sediment is only deposited in blue holes on South Andros Island during the close passage (<50 km radius away) of intense hurricanes (Category 3 and above) (E. J. Wallace et al., 2019). Such close-moving and intense hurricane strikes on the island are rare. From 1850 to 2014 CE, only two hurricanes left deposits in the blue holes.

To overcome this small numbers problem, we generate a database of 57,796 synthetic TCs—approximately 50 tropical depressions to Category 5 storms passing within 100 km of South Andros for each year between 850 and 2005 CE—using a statistical deterministic hurricane model (K. Emanuel et al., 2006, 2008). This higher resolution regional model produces its own TC climatology using the boundary conditions of a global climate model (GCM) in a technique known as downscaling. Here, we use the MPI-ESM (Max Planck Institute [MPI] Earth System Model) millennial simulation (850–1850 CE) and the historical simulation (1850–2005 CE) as the initial and boundary conditions for the TC model. We provide a brief overview of both the MPI-ESM-P model and TC downscaling method in supporting information. The genesis points, tracks, and intensities of these synthetic storms over the historical period (1850–2005 CE) broadly match those of observed storms (Figure S1).

### 2.2. Creating a Pseudo Sediment Record

Using our storm data set, we generate 1,000 pseudo sediment records for South Andros Island loosely following previously published methods (Woodruff et al., 2008). First, we generate records of storm occurrence at our site. To produce multiple synthetic records, each with a realistic number of storms from 850 to 2005 CE, we utilize a Poisson process-based (Bove et al., 1998; Elsner & Bossak, 2001) random draw. The probability ($P$) of $x$ number of storms occurring in a given year at South Andros is defined by:

$$P = \frac{\lambda^x e^{-\lambda}}{x!}$$

λ is the annual storm frequency determined by the ratio of the specified number of surviving storms (50) to the number of storms seeded for each year of the MPI simulation. In years from the MPI simulation where the large-scale climate conditions are favorable for storm development and subsequent tracking to South Andros, λ is greater and thus the probability of a larger $x$ is greater. λ is a fractional quantity, ranging from 0.06 to 0.55 storms/yr. The random draw produces an integer quantity $x$ of local hurricanes in a given year of a given record, such that the combination of deterministic and stochastic processes underlying local hurricane activity are captured. This random draw allows for more or fewer local hurricanes ($x$) than suggested by λ, while maintaining that the average $x$ across all 1,000 records is approximately equal to λ for each year. Once we have determined how many storms occur in a given year ($x$), we randomly select the $x$ storms from the 50 synthetic storms from that year. Thus, each of our 1,000 records of storm occurrence will have different numbers of and different actual storms occurring in a given year (Figure 1).

Using our records of storm occurrence, we apply the published criteria for event deposition at South Andros (E. J. Wallace et al., 2019) to each storm to determine whether that storm left a deposit (i.e., our pseudo sediment record). In particular, only >Category 3 hurricanes (max sustained wind speeds > 96 knots) that passed within 50 km of the site left a deposit in the South Andros blue hole record. However, cores collected from neighboring blue hole sites on South Andros indicate a different sensitivity, capturing some additional event beds (E. J. Wallace et al., 2019). Given the sensitivity differences between blue hole sites on South Andros, we decide to use a more conservative wider radius (100 km) for the purposes of this study that matches other blue hole environments in the Caribbean (i.e., Schmitt et al., 2020). In addition, we limit the number of storms recorded in pseudo sediment records based on the sedimentation rate at the site (∼1 cm/yr). Thus, if two or more storms with high enough intensity occur in a given year, only one deposit is created in the pseudo sediment record, since these separate storm layers would not be distinguishable in a sediment record. The final pseudo sediment record is just a binary outcome. In each year of the record, there will be either be a deposit or no deposit (Figure 1b). To analyze event frequency changes in these records on centennial time-scales, as is standard practice in event-based paleohurricane studies, we count up the number of events in a 100-year sliding window.

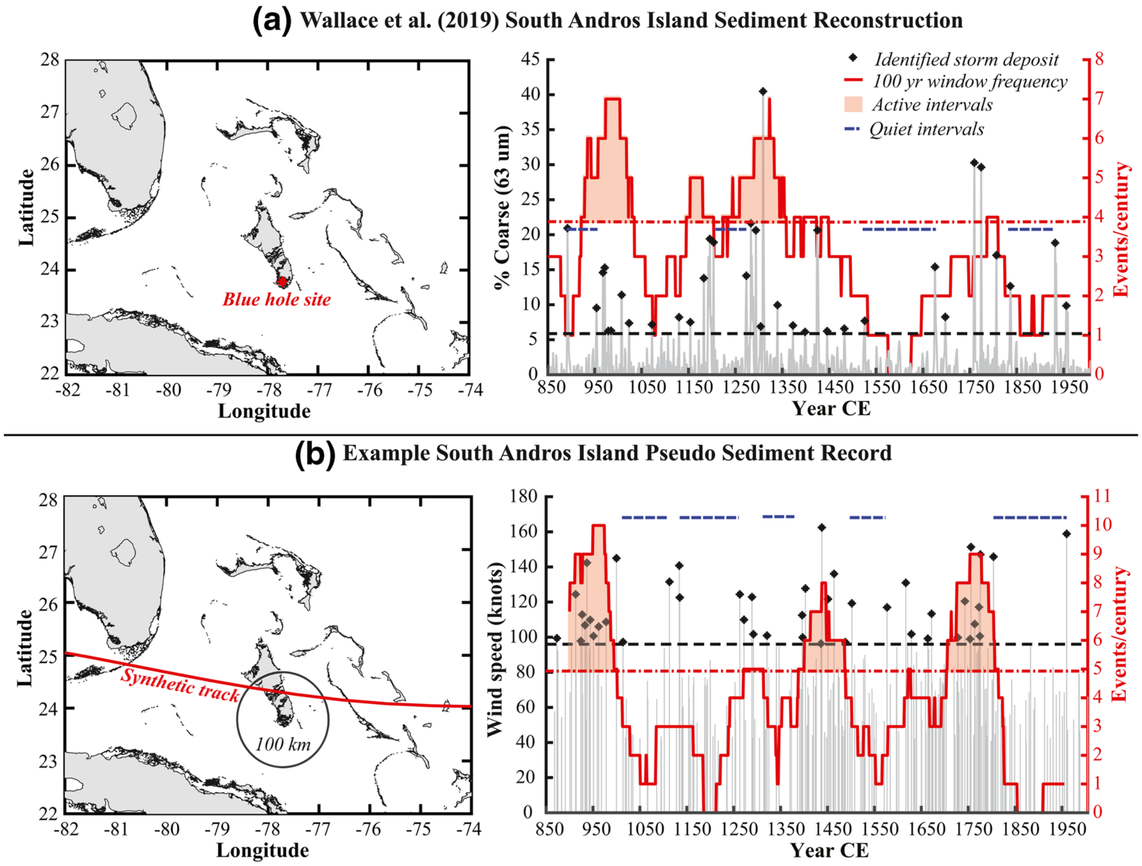


**Figure 1.** (a) Paleohurricane site and sediment reconstruction from the AM4 blue hole (23.78°N, 77.72°W) on South Andros Island (E. J. Wallace et al., 2019). Coarse anomaly data (gray) as a function of time with the event bed threshold (black dashed line). Event beds are denoted as black diamonds. (b) An example synthetic storm track passing within a 100 km radius circle of AM4 and an example pseudo sediment record. All storms were generated using a downscaling model (K. Emanuel et al., 2006, 2008) from 850 to 2005 CE. Gray bars indicate maximum radial winds upon closest passage to AM4 of each synthetic storm selected. Black diamonds indicate storms that left a deposit in the pseudo record by exceeding the >Category 3 intensity threshold (black dashed line). The 100-year event frequency is plotted in red [note: different vertical scales in (a) and (b)]. Dashed red lines indicate the active interval threshold. Extended periods of time when the 100-year event frequency is above this threshold are active intervals (red highlights). Quiet intervals (blue dashed lines) are 50-year gaps between events.

### 2.3. Defining Active and Quiet Intervals in the Pseudo Sediment Records

We determine active and quiet intervals in our pseudo sediment records using established methods (Donnelly et al., 2015; Lane et al., 2011; E. J. Wallace et al., 2019; Winkler et al., 2020) for comparison with the number observed in the South Andros sediment record (Figure S2). Active intervals are defined as consecutive years when the 100-year window event frequency is above an upper confidence limit encompassing the expected random variability of hurricane strikes at a site. We calculate this expected frequency for all pseudo records from South Andros using the average frequency of events in the record. Specifically, an average of 43.7 storms leave deposits in the 1,000 pseudo records from 850 to 2005 CE, resulting in an expected frequency of 3.78 events/century. Assuming that event deposition follows a Poisson process with the rate of 3.78 events/century, we compute an upper 90% confidence interval (4.9 events/century) (Ulm, 1990). Quiet intervals are defined as 50-year periods or more where no events are recorded in a pseudo record (Figure 1).

Typically, sediment proxy records contain both multidecadal (20–50 consecutive years above threshold) and centennial-scale (100 consecutive years above threshold) active intervals. To compare with the South Andros reconstruction, we calculate an average number and 2 sigma range of both the shorter timescale (multidecadal) and longer timescale (centennial) active intervals as well as the quiet intervals in our 1,000 pseudo sediment records (Figure S2).

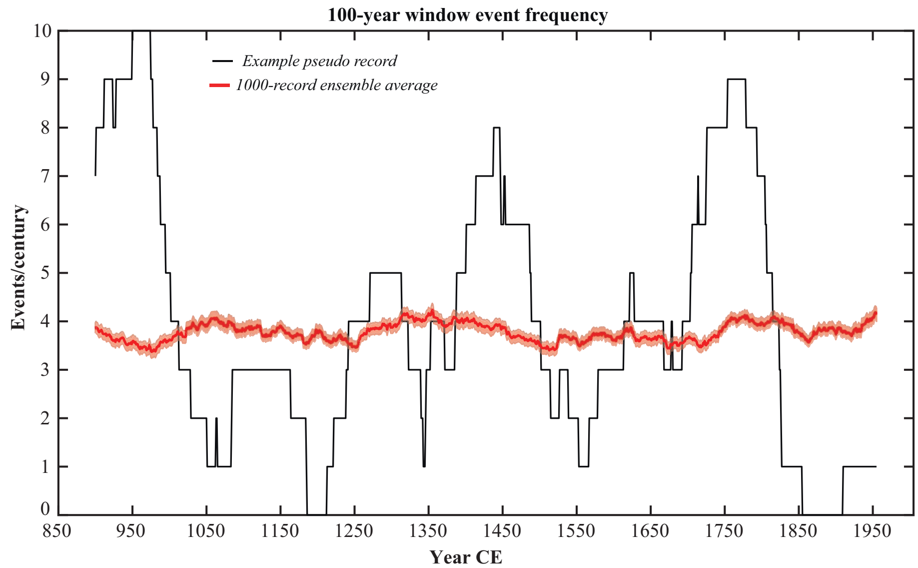


**Figure 2.** 100-year window event frequency from 850 to 2005 CE for an example pseudo sediment record (same as Figure 1b) created for South Andros Island (black). The 1,000-record ensemble average (climate signal) is shown in red. The 95% confidence intervals (red shading) for the climate signal were calculated using the values from 100 different sets of 1,000 pseudo sediment records.

### 2.4. Defining the Climate Signal and Quantifying the Signal-to-Noise Ratio (SNR)

We average the 1,000 different 100-year window event frequencies for the pseudo-sediment records together to get a representation of the underlying centennial-scale climate signal of hurricane strikes at our site (Figure 2). The climate SNR between single pseudo sediment records and the climate signal is calculated as the value of the 1,000-member ensemble average in each year divided by the standard deviation of the 1,000 members for that year. The expected Poisson noise in the ensemble average is defined by:

$$\text{Noise} = \frac{\sqrt{N}}{\sqrt{x}}$$

$N$ is the mean value of the $x$-member ensemble average (3.78 events/century).

## 3. Results

### 3.1. Comparing Pseudo Records to South Andros Reconstruction

All of the pseudo sediment records show dramatic changes in hurricane activity over the past millennium, much like we find in the actual reconstruction (Figure 1). On average, the 100-year window event frequency for a single pseudo sediment record varies from 1 to 8 events/century. Across the 1,000 pseudo records, we observe on average 1.2 ± 1.8 centennial-scale active intervals and 2.9 ± 3.5 multidecadal-scale active intervals. Often directly following these active intervals, we see quiet periods. We record on average 6.2 ± 3.3 quiet periods over the past millennium. In general, pseudo sediment records contain similar numbers of events as the South Andros reconstruction as well as a similar number and length of active and quiet intervals (Figure S2).

### 3.2. Climate SNR in Pseudo Records

By using a Poisson process-based random draw from the ~50 synthetic storms for each year, we are generating 1,000 different scenarios of storm occurrence all consistent with the climate conditions that occurred in that year, but also accounting for randomness. Averaging the 1,000 pseudo sediment records together quantifies the climate signal. We find that this ensemble average (our climate signal) has much less variability than any single record (Figure 2), with a range of 3.4–4.2 events/century. Although subdued, the variability in the 1,000-member ensemble average is outside the expected Poisson noise of ∼0.06 events/century. Ensemble averages with fewer members correlate significantly with the 1,000-member defined climate signal (25 members – $r = 0.4$; 100 members – $r = 0.7$) at the 95% confidence level (supporting information, Figure S3).

Comparing the variability in each of the 1,000 individual records (containing the climate signal and randomness) to the climate signal, we find a SNR of 2. Thus, only 68% of the individual records would give you a value in a given year within two events/century of actual climate signal. While each of the pseudo sediment records contain active and quiet intervals of hurricane activity, the timing of these intervals are very different from record to record. Thus, when we average the 1,000 different records together, the SNR is low (Figure 2). This low SNR suggests that there is too much noise to use a single reconstruction from South Andros to infer climate impacts on hurricane activity. Instead, hurricane activity in a single reconstruction, even on centennial timescales, is dominated by random variations in intense hurricane strikes.

To test the underlying cause of dramatic centennial-scale variability in the individual pseudo sediment records, we create a second set of pseudo sediment records using a pure Poisson process (i.e., without hurricane or climate model data) (supporting information). Any single record created using this pure Poisson process contains centennial-scale variations like the reconstruction (Figure S4). Finding similar centennial-scale variability in a single record dictated purely by randomness further confirms that random clustering of intense hurricane strikes creates most of the signal observed in a single reconstruction.

## 4. A Coherent Signal Across Sites in The Bahamas

While significantly dampened compared to a single record, the ensemble average does contain an underlying centennial-scale climate signal (Figure 2). We see more hurricanes from 1015 to 1115 CE, 1270 to 1450 CE, and 1750 to 1850 CE and fewer hurricanes from approximately 915 to 1015 CE and 1460 to 1740 CE. We investigate whether this climate signal extends to other islands in The Bahamas. This is motivated by recent efforts to collect paleohurricane records from blue holes throughout the Caribbean region to better constrain regional and basin-scale hurricane activity. Using the same random draw methods from independent sets of randomly seeded synthetic storms forced by the same MPI climate model output, we create 1,000 pseudo sediment records for two other sites in the northern Caribbean where paleohurricane reconstructions from blue holes have been collected: Long Island, The Bahamas, and Caicos Island. Long Island is situated ∼250 km to the southeast of South Andros and Caicos Island is ∼650 km to the southeast of South Andros. Long Island is only ∼380 km away from Caicos Island (Figure 3). The ensemble averages (climate signals) for these other two sites also show centennial-scale variations in hurricane activity over the past millennium. The climate signals for the sites that are less than 400 km apart (Long Island and South Andros; Long Island and Caicos) correlate significantly with each other at the 95% confidence level ($r = 0.32$; $r = 0.36$, respectively). However, the common climate signals degrade for Caicos Island and South Andros Island ($r = -0.05$), which are further apart (Figure 3).

Importantly, the pseudo sediment records for each site in the analysis above were produced from independent sets of synthetic storms, yet we still observe a similar climate signal across neighboring sites (i.e., South Andros and Long Island). Nevertheless, it is clear from this exploratory work that the climate signal can degrade between sites as close as 650 km apart (i.e., South Andros and Caicos). Together these results suggest that there is promise in trying to compile reconstructions from sites that are close enough to experience the same climate signal but far enough apart to sample different storms. Compiling paleohurricane reconstructions together into regional or basin-scale estimates of hurricane activity is important for placing modern Atlantic hurricane activity into a longer term context and for regional preparedness and planning. Previous work shows that an Atlantic basin-integrated reconstruction formed from compiling regional paleohurricane records together is statistically consistent with a completely independent model of TC activity driven by proxy reconstructions of past climate (Mann et al., 2009). However, as the field of paleotempestology expands toward compiling new and old paleohurricane reconstructions together, it is important to understand how much of the changes we observe in hurricane activity in these records and

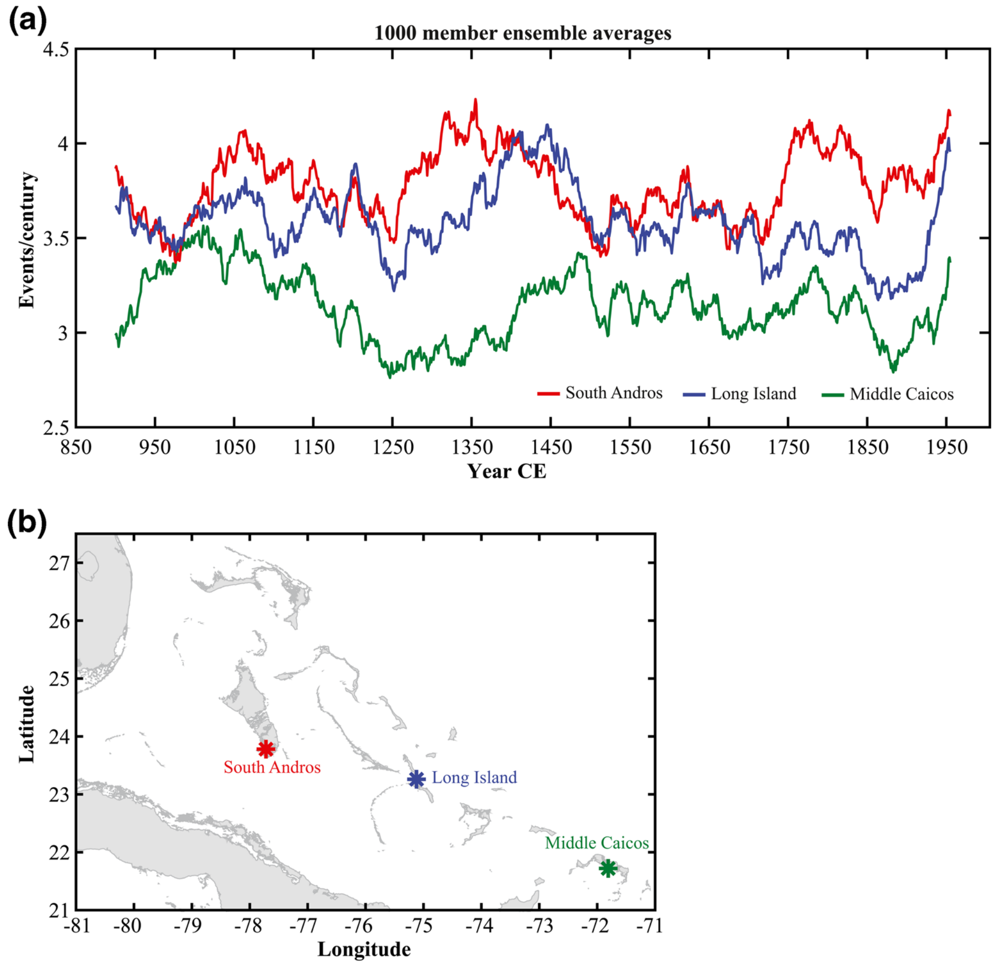


**Figure 3.** (a) The 1,000-member ensemble averages of the 100-year event frequency of pseudo sediment records created from synthetic storms passing within 100 km of South Andros (red), Long Island (blue), and Middle Caicos (green). (b) Map of blue hole sites on South Andros (23.78°N, 77.72°W), Long Island (23.26°N, 75.11°W), and Middle Caicos (21.72°N, 71.81°W).

compilations of these records are driven by climate. Thus, future work exploring the best ways to compile paleohurricane records together to maximize climate signal and quantify regional and basin-scale hurricane activity is needed.

## 5. Implications for Paleohurricane Research

The results presented herein have the potential to transform the way we understand paleohurricane research. Interpretation of paleohurricane records often relies on an assumption that the signal in each record is directly related to climate variability and change. In this study, we find that this is not true for any individual event-based record of paleohurricane activity from the Caribbean. These records suffer from a significant sampling bias; each site samples only a small subset of storms moving through the Caribbean. Whether a storm passes close to a site and at high enough intensity to leave an event bed is driven more by random variability (i.e., local weather) than by climate.

Previous work from the Bahamas (van Hengstum et al., 2014, 2016; E. J. Wallace et al., 2019; Winkler et al., 2020) and Belize (Schmitt et al., 2020) have used a single paleohurricane record to make claims about the climatic drivers of Atlantic and Bahamian hurricane activity over the past few thousand years. The sampling bias explored in this work means that each of these sites alone should not be used in this context.

In short, we need to exercise caution in making climate interpretations or inferring regional to basin-scale hurricane activity from a single record.

This work also offers an explanation for why recent event-based paleohurricane records from neighboring islands in the Caribbean observe different patterns of hurricane activity (E. J. Wallace et al., 2019; Winkler et al., 2020). They are each capturing a small subset of storms that pass through the Caribbean and the variability in each record is dominated by randomness. It is currently unclear whether this sampling issue applies to all paleohurricane sites in the Atlantic. During the hurricane season (June to November), sea surface temperatures in the Caribbean are generally warm enough for the development and maintenance of hurricanes (Locarnini et al., 2013). Variability in local hurricane activity is thus likely to be dominated by the tracking of hurricanes after development. Given the lack of climate signal in Caribbean records, we can infer that hurricane tracks are driven by local-to-regional weather rather than by climate.

At paleohurricane sites in temperate locales (e.g., Boldt et al., 2010; Brandon et al., 2013; Bregy et al., 2018; Donnelly et al., 2015; Lane et al., 2011), however, climate is less favorable to hurricane growth and survival. Instead, shifts in large-scale climate like the Atlantic Multidecadal Variability, the Intertropical Convergence Zone, or the North Atlantic Subtropical High could create more or less favorable conditions for the development of hurricanes that will eventually reach the U.S. East and Gulf Coasts. If this is the case, we might expect a stronger climate signal in paleohurricane records from these regions. In general, paleohurricane reconstructions from the U.S. East Coast (Boldt et al., 2010; Donnelly et al., 2015) and Gulf Coast (Brandon et al., 2013; Bregy et al., 2018; Lane et al., 2011; Rodysill et al., 2020) tend to have more reproducible patterns in centennial-scale variability from site to site than records from The Bahamas. Future work simulating past millennium storms for North American and Caribbean coastlines is needed to determine if this sampling bias extends to subtropical paleohurricane sites.

Ultimately, this study is the first to highlight the value in integrating TC models with existing paleohurricane reconstructions. Unfortunately, our results are limited to a single GCM (MPI-ESM-P), largely due to the lack of daily wind data (required for the TC model simulations) archived for last millennium simulations from other GCMs. Given intermodel differences in the simulation of large-scale climate variability during the last millennium (e.g., Coats, Cook, et al., 2015; Coats, Smerdon, et al., 2015), there is likely a larger climate signal in other models. Future studies using an ensemble of different models are needed to characterize the true magnitude of the climate signal at paleohurricane sites. Doing this will require that high temporal resolution outputs are archived even for long model simulations like those of the past millennium.

Even with a multimodel ensemble of past millennium hurricanes, model-based results will not capture some properties of past millennium hurricanes at paleohurricane sites. This is because the real-world and simulated climate of the past millennium both result from a combination of internal variability, which will follow different trajectories, and common externally forced processes. Likewise, the simulation of these processes suffers from biases inherent to the modeling of the earth system and from uncertainties regarding the character and imposition of the external forcing. Many GCM simulations disagree with proxy reconstructions and instrumental data about the timing, amount, and spatial extent of surface temperature changes over the past millennium (e.g., Brohan et al., 2012; Fernandez-Donado et al., 2013; PAGES 2k-PMIP3 group, 2015).

In addition, we make simplifying assumptions of real-world processes in the creation of our pseudo-sediment records. These include using a uniform sedimentation rate of 1 cm/yr for all the sites and assuming a site sensitivity dictated only by storm intensity and proximity of storm passage. While these simplifying assumptions are reasonable, there are often small differences in sedimentation rate within cores and across sites, and it is likely that other storm properties (e.g., translational velocity, track orientation, and size) play a role in event deposition (Lin et al., 2014). Site geometry, in particular, likely plays a larger role in event deposition for island sites like The Bahamas where storms can pass from many different directions. Despite these inherent and methodological uncertainties, we expect the results of our analyses to be largely conservative—if we conclude that there is a significant climate sampling issue using simplifying assumptions, this issue will likely worsen using more site-specific assumptions. To address these uncertainties directly, we need more hydrodynamic modeling in blue hole systems to explore the storm characteristics that are most important for generating coarse sediment transport on carbonate platforms.

This work highlights the promise in compiling reconstructions from neighboring sites together to maximize the climate signal and to better characterize regional to basin-scale hurricane activity. Future studies exploring the best ways to compile reconstructions from the Caribbean, and elsewhere, are needed. Here, we have shown that integrating TC model and proxy data together is a critical step toward this goal.

## Data Availability Statement

The synthetic storms and MATLAB scripts for processing are available on the WHOI Coastal Systems Group (https://web.whoi.edu/coastal-group/data/) website.

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