FREQUENCY OF HURRICANES IN NEWFOUNDLAND USING SEDIMENT CORES

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Abstract

The climate has a significant influence on tropical cyclone activity and it is still unclear how global climate change will impact these storms. Currently, the observational record of tropical cyclones is short and biased, giving little information on how these storms have changed over long periods of time. Using a sediment core from Holyrood Pond in Newfoundland, Canada, we reconstruct tropical cyclone activity over the past 8000 years. We track sediment signatures of storms by performing grain size analysis and show how storm frequency has changed over the Holocene. Newfoundland is currently in an inactive interval of tropical cyclones; however, this may change in the future and the understanding the risk associated with tropical cyclones is important. Compared to a site in Nova Scotia, Newfoundland storm activity has been more inactive over the observational period (1850-present). This difference may be due to the extent of these storms not reaching the northern latitudes of Newfoundland or a decrease in storm intensity as tropical cyclones travel further north.

1. Introduction

The climate has a major impact on the production of tropical cyclones. Global climate change has raised the question of whether warming oceans will result in an increase in hurricane frequency[1,2]. The rate and magnitude of tropical cyclones are important to study because the damage done by tropical cyclones greatly affects the topography of the coasts and affects humans living on the coasts[3]. For example, Hurricane Larry made landfall in Canada in September of 2021 and caused an estimated 25 million Canadian dollars in damage. Larry caused damage by increased wind speeds that caused trees to fall and resulted in nearly 61,000 people losing power in Newfoundland. Larry also caused five fatalities along the Atlantic Basin due to rip currents[4].

The history and future of hurricanes are not well understood because of short observational record of storms which only extends from 1850 CE to present. This short and biased record means there is no clear theory of how climate change affects the frequency of tropical cyclones[2]. The most reliable observational data on tropical cyclones is from satellites covering 1970 CE to present day[5]. Backbarrier ponds capture paleostorm records from overwash deposits that are left behind by storms. The depositional environment of a backbarrier pond is usually a low energy environment that is mostly made of silt sized grains, but when tropical cyclones occur, the high energy wave activity washes coarse grain material into the pond and can be used as a proxy for storm deposition[3].

By studying the overwash deposits in the Holyrood Pond sediment core, I reconstructed the storm frequency over approximately 8000 years.

2. Methods

2.1 Study Site

Holyrood Pond is a back barrier pond situated on the southeast end of Newfoundland Canada (Figure 1). The pond is approximately 69.6 m depth. The pond acts as a sink for coarse grained overwash deposits that occur during high energy events like tropical cyclones. The predominant sediment type in this low energy pond environment is silt sized particles. As storms make landfall near Holyrood Pond, high winds and waves suspend and transport coarse grain sediments into the pond and these sediments serve as a record of past tropical cyclones.

Eleven storms of various intensities have passed by this site over the last 160 years[6,7]. These storms either made direct landfall or passed by the site as at tropical storm or Category 1 strength with wind speeds of 60-75 knots (Figure 1).

2.2 Field Methods

Sediment cores were collected by a team of scientists from Woods Hole Oceanographic Institution (WHOI) in October 2021 in different locations in Holyrood Pond, including HOLY4-D2 (46.801ºN, 53.623ºW) (Figure 1). The pond was cored using a Rossfelder vibracore. We collected one long core (HOLY4 D2) that is 8.64 m in length using a three-inch aluminum barrel. We also collected one short surface drive 1.17 m in length that captures the sediment interface and includes recent storm layers, like Hurricane Larry in September of 2021.

2.3 Sediment Analysis

The cores were split, described at WHOI and sampled at Old Dominion University (ODU) over the Summer 2024. I sampled HOLY4-D2 at one-centimeter intervals over the total 8.64 m length of the core[8]. After collecting the wet samples, I weighed and then dried at 90ºC for a minimum of 8 hours to dry off any excess water. After weighing the dry sample, I combusted them in a muffle furnace at 550ºC for 5 hours to burn off organic matter in a process known as loss on ignition (LOI). After weighing the burned sample, I soaked the samples for 20 minutes and then wet sieved at 125 µm, which shows where coarse grain sand deposits can be found[9]. I then dried the sieved samples for 8 hours at 90ºC and weighed again to determine the coarse percent fraction.

Along with the coarse percent data, I collected radiocarbon samples to determine chronological dates in the core (Figure 2). I extracted plant matter samples from the cores and sent them to National Ocean Sciences Accelerator Mass Spectrometry (NOSAMS) facility in Woods Hole, MA. Fifteen radiocarbon samples were sampled and thirteen were used to determine chronological dates throughout HOLY4. I excluded two dates that were outliers in the age date model, one that was too young and one that was too old. To construct an age model with the radiocarbon data, I used Bayesian accumulation histories for deposits (BACON) software v3.3 to create the age model[10] (Figure 3).

2.4 Event Identification

Event beds were identified using the coarse fraction data following the methods of Donnelly et al.[9] and Wallace et al.[8] to create a cutoff threshold for the coarse fraction data. To find the coarse anomaly, a 11-point moving average removed coarse fraction peaks over a certain threshold in the core. Events over the certain percent threshold were excluded to prevent spikes in coarse data skewing the data and excluding potential peaks. Three separate thresholds were used to determine the coarse anomaly because of the changing background grain size throughout HOLY4. In the first 345 cm, events over 15% coarse material were excluded. From 346 cm to 683 cm, events over 25% coarse material were excluded. Finally, in the last 124 cm of the core, events over 10% coarse material were excluded. After calculating coarse anomaly, we defined coarse grained event layers as coarse anomaly data that was greater than two standard deviations (95%) from the mean (Figure 4). The threshold for HOLY 4 is 17.29% coarse material.

Following the event identification, the event bed frequency was calculated using a 100-year moving window (Figure 5). This frequency data highlights when event layers were more or less frequent throughout time.

3. Results

3.1 Event Bed Description

The Holyrood Pond sediment core (HOLY4-D2) is an 8-meter-long core that contains predominantly fine-grained sediment with scattered coarse layers. Specific event beds could be identified by visual examination of sections of coarser grained sediment and organic matter. There is no evidence of bioturbation in the cores. The core is mostly a dark brown, silty sediment with areas of lighter and coarser sediment.

The sedimentation rate changed throughout the core. When determining the threshold for coarse anomaly, the grain size changes along with the sedimentation rate where the background sedimentation is coarser as the sedimentation rate increased. For the first 345 cm, the sedimentation rate is 0.12 cm/yr and results in a resolution of 8 years of time recorded per 1 cm sample. For 346 cm to 683 cm the sedimentation rate is 0.14 cm/yr and results in a resolution of 7 years of time per 1 cm sample. For 684 cm to 808 cm the sedimentation rate is 0.16 cm/yr and results in a resolution of 6 years of time per 1 cm sample. The core goes back 7900 years.

3.2 Changing Event Frequency

When determining the event frequency using the 100-year moving window, 20 event beds are identified. The average event frequency is 0.3 events per century. The event beds range from 4 cm to 31 cm in thickness.

The event frequency has changed throughout time (Figure 5), showing when Holyrood Pond tropical cyclone activity changed. Holyrood Pond shows increased activity from 8400 to 8300 year BP (year before present (BP) when present is defined as 1950), 6400 to 5900 year BP, 5650 to 5590 year BP, 4500 to 3500 year BP, and 2900 to 1500 year BP. In between these active intervals, periods of low activity occur. These quiet intervals occurred from 8300 to 6400 year BP, 5900 to 5650 year BP, 5590 to 4500 year BP, 3500 to 2900 year BP, and 1500 year BP to present.

4. Discussion

4.1 Event Attribution

Exploring event deposits in the HOLY4 core that date to the observational period (1850 to 2021) can identify the sensitivity of Holyrood Pond to storm induced overwash. The HOLY4 core was collected a month after Hurricane Larry hit Newfoundland in September 2021. Larry hit Newfoundland as a Category 1 hurricane and resulted in wind speeds of 70 knots.

However, the HOLY4 sediment core does not show any modern storms from the last 150 years including Hurricane Larry 2021. We argue that the most recent storms have not been powerful enough to generate overwash deposits in the Holyrood back barrier environment. The tropical cyclones over the past 150 years that have passed by or made direct landfall on Newfoundland all had intensities less than Hurricane Larry (Category 1 strength)[1]

4.2 Nova Scotia Site Comparison

We chose to compare our record to nearby records in Nova Scotia[11,12]. We chose this site because it has similar resolution, time covered and is in close proximity to Holyrood Pond. The Nova Scotia site is 700 km southwest of Holyrood Pond.

We expected that the close proximity of the Newfoundland and Nova Scotia sites would result in similar active intervals; however, there were some differences between reconstructions. Over the past 8000 years, there was some overlap in reconstructed storm activity, but the observational interval in each record diverged. The Nova Scotia site shows more storm activity for the last 1.7 ka while the Holyrood, Newfoundland site shows inactivity until 1.3 ka. This difference between Atlantic Canada sites suggests that each site is capturing different populations of storms. Perhaps storms turned after hitting the Nova Scotia site to the west and did not result in storm deposition at the Holyrood site. Additionally, the reduction in intensity as the storm reaches further north into Newfoundland may be a reason for the differences in activity. Typically, lower intensity storms do not cause enough storm surge to generate overwash deposits in the backbarrier.

4.3 Broader Implications

Studying the frequency and intensity of storms is important because it greatly affects humans living on the coasts and a better understanding of how these storms have changed overtime helps assess the risk to populations living on the coasts.

Our Holyrood Pond core shows that Newfoundland is in an inactive interval for storms during the modern interval (1850-present). This knowledge can help government agencies to quantify risks for Newfoundland. Over the past 8000 years, Newfoundland has seen periods of much higher storm activity, making current risk assessments biased too low. Modern coastal risk assessments use short observations of how tropical cyclones have changed over time. Our sediment reconstruction (HOLY4) allows us to extend storm observations back much further and show how tropical cyclone frequency has changed.

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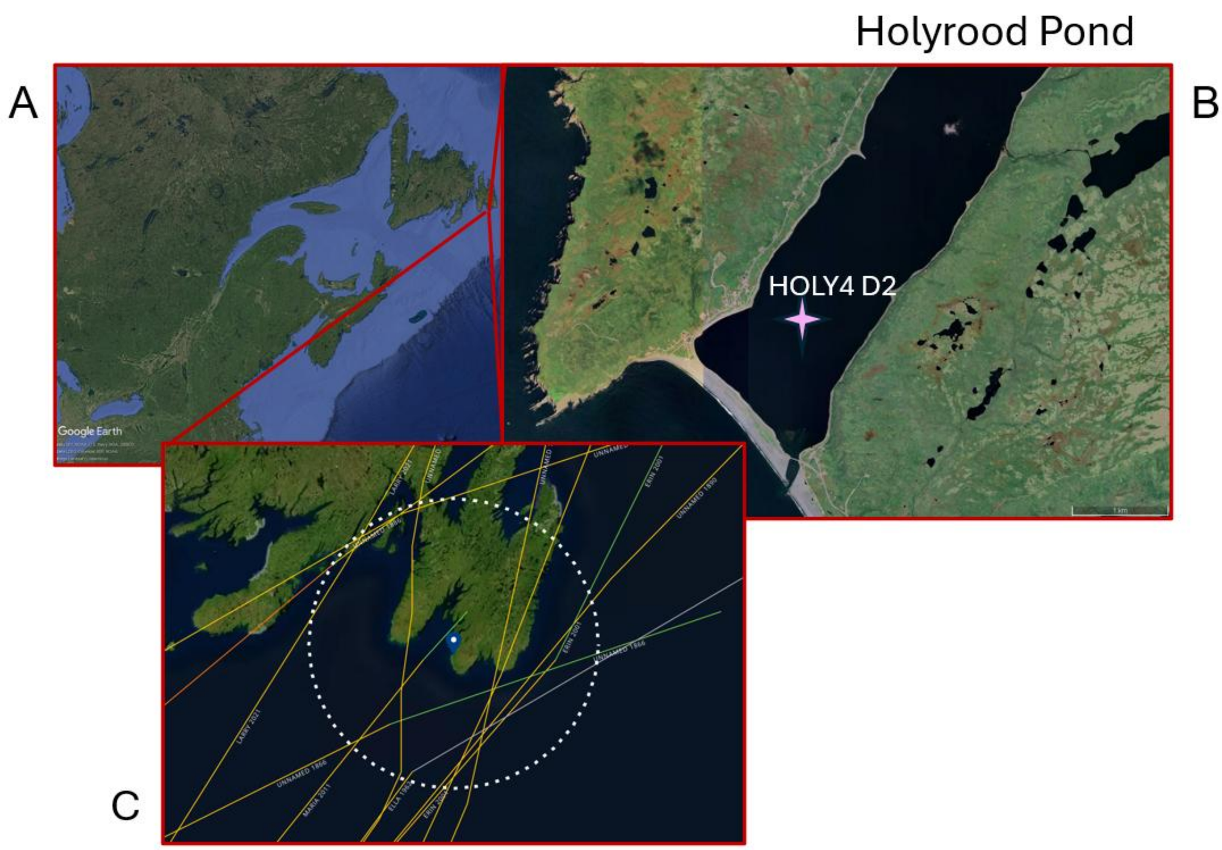

Figure 1. (a) Map of the Eastern Seaboard of North America. (b) Holyrood Pond (HOLY4-D2) location (46.801ºN, 53.623ºW). The location of the core (HOLY4-D2) is indicated by the pink star in (b). (c) Modern storm track[4]. (Modified by Google Earth, 2025).

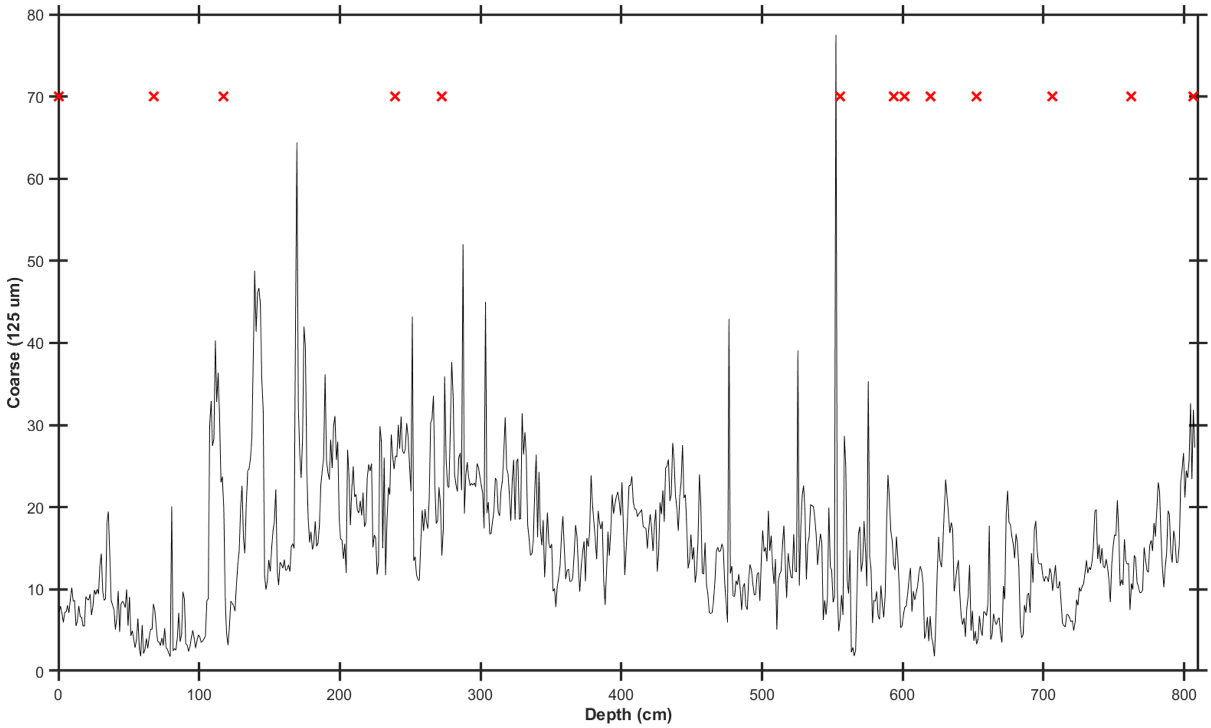

Figure 2: Percent coarse fraction (>125 μm) versus depth in core (black). The red marks are the location of ^{14}C samples plotted above the coarse fraction plot. Event beds are shown as a large, but brief peak.

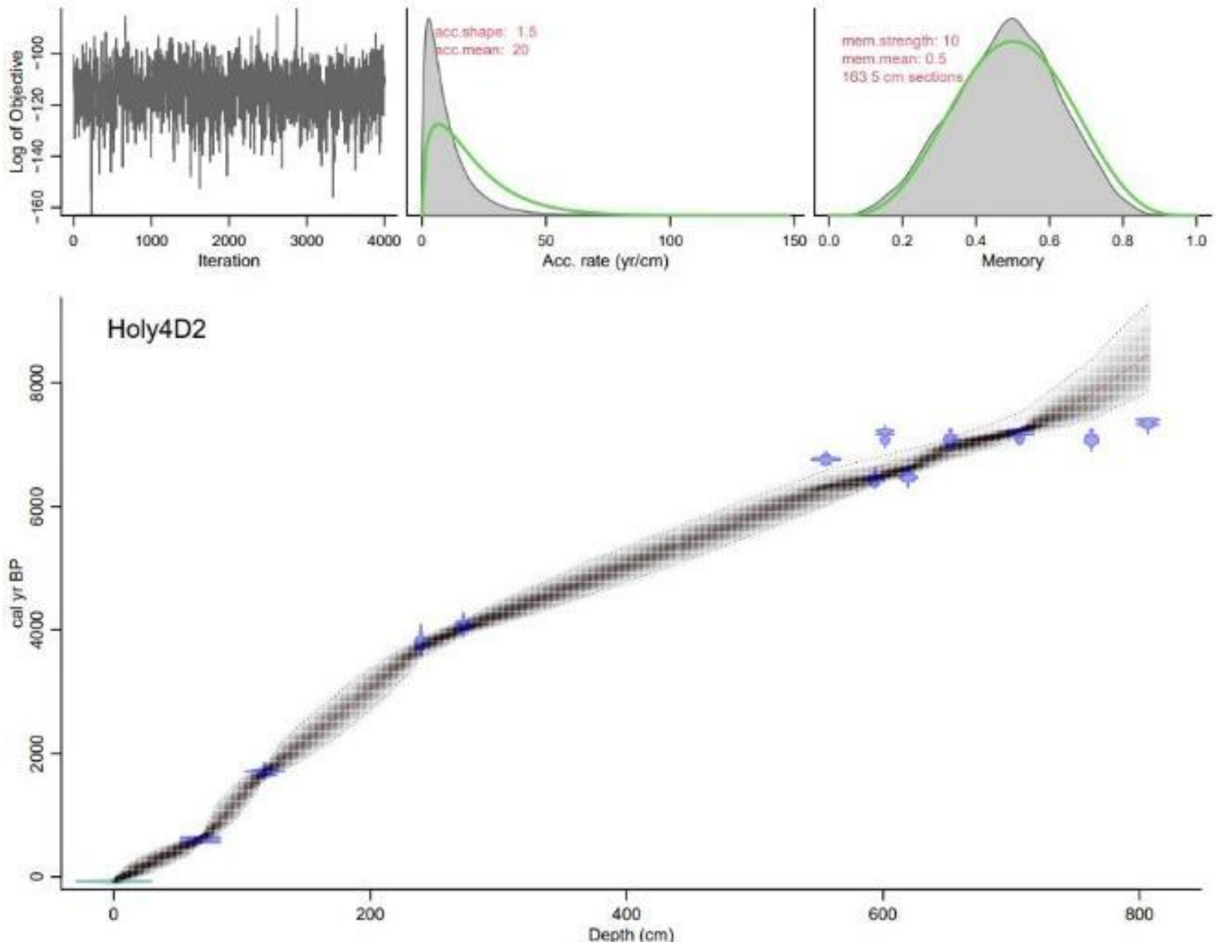

Figure 3: Age model derived from radiocarbon dates (blue). 95% confidence bounds are shaded in gray around the age model. This figure was generated using BACON v3.3 age modeling software[9]. BACON is a Bayesian accumulation history for deposits.

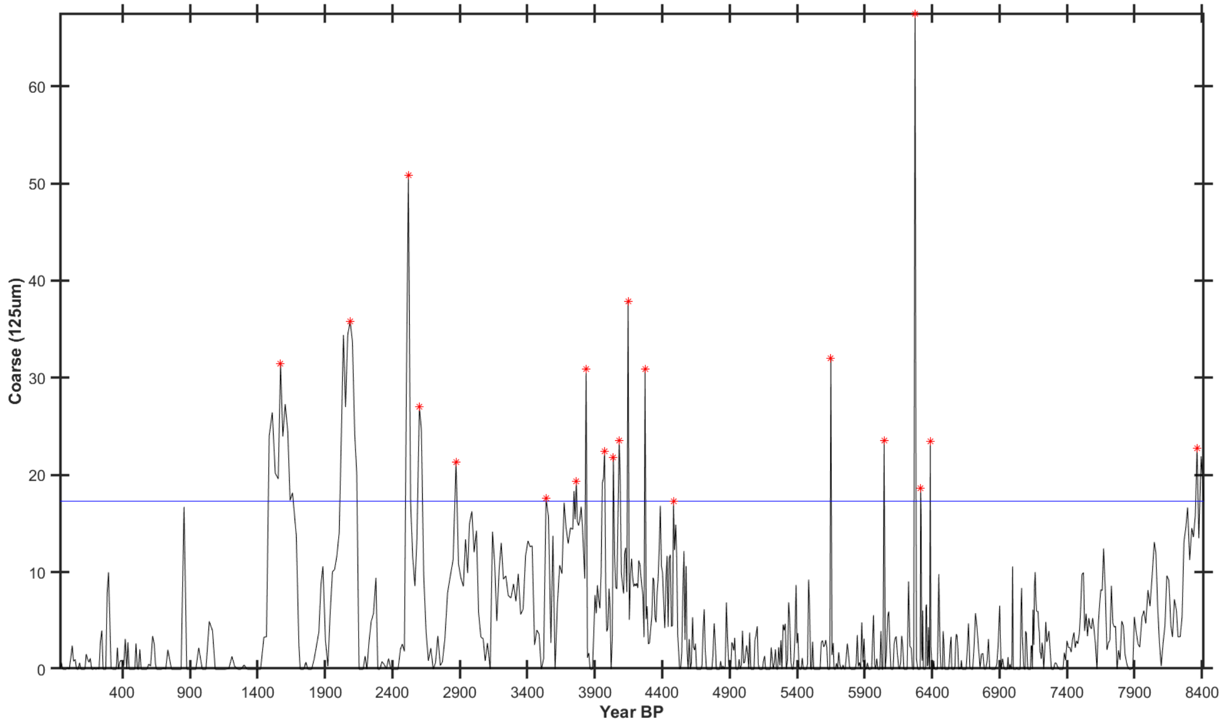

Figure 4: Coarse anomaly plot (solid black line) for HOLY4-D2 as a function of time. 95% statistical event cutoff of 17.29% coarse material is shown in a solid blue line. Events are showing with a red star.

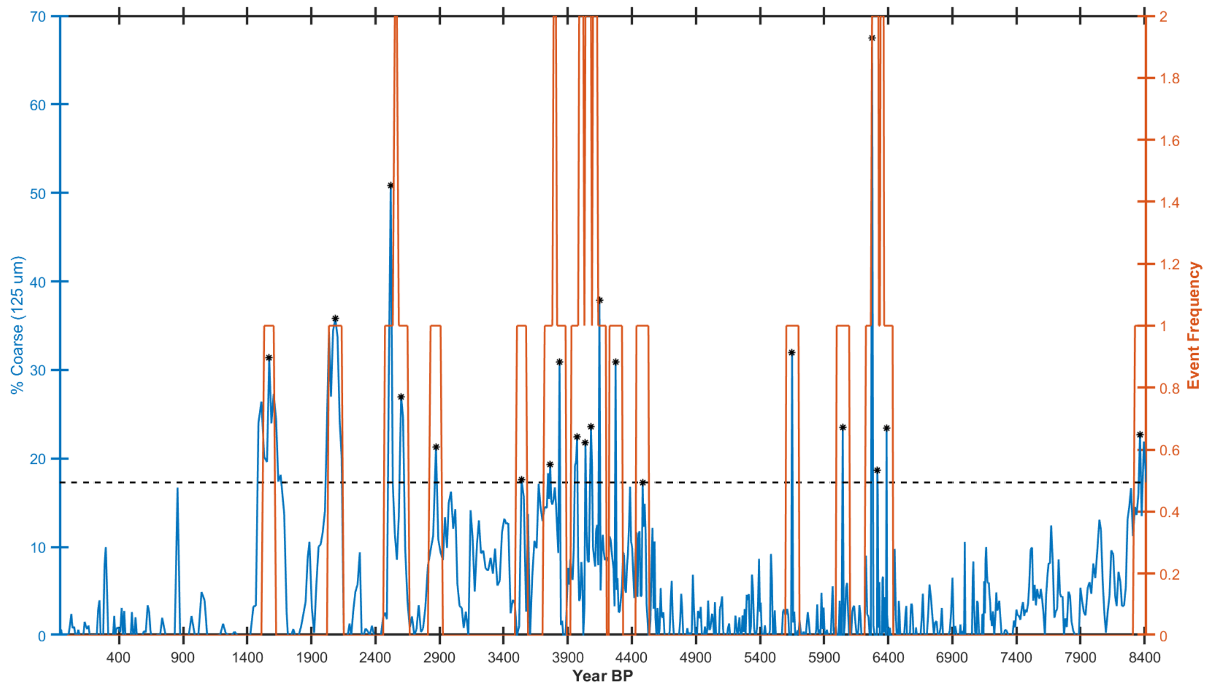

Figure 5: The coarse anomaly (blue) as a function of time for HOLY4-D2. The 100-year moving window event frequency (orange). The dashed line indicates the event bed threshold of 17.29% coarse material.

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