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The political collapse of Chichén Itzá in climatic and cultural context

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ABSTRACT

Chichén Itzá dominated the political landscape of the northern Yucatán during the Terminal Classic Period (AD 800–1000). Chronological details of the rise and fall of this important polity are obscure because of the limited corpus of dated hieroglyphic records and by a restricted set of radiocarbon dates for the site. Here we compile and review these data and evaluate them within the context of political and climatic change in northern Yucatán at the end of the Classic period. The available data point to the end of elite activity at Chichén Itzá around AD 1000, a century after the collapse of Puuc Maya cities and other interior centers. Evidence supports a population shift in the eleventh century towards some coastal locations during a time associated with the end of monumental construction and art at Chichén Itzá. Our results suggest that regional political disintegration came in two waves. The first was the asynchronous collapse of multiple polities between AD 850 and 925 associated with a regional drying trend and punctuated by a series of multi-decadal droughts in the ninth and tenth centuries. The second wave was the political collapse at Chichén Itzá that coincides with the longest and most severe drought recorded in regional climate records between AD 1000 and 1100. This is a time that some scholars have characterized as a "dark age" across the northern Maya lowlands. Political developments during the Postclassic period (AD 1000–1517) correspond with a return to higher rainfall. These patterns support a strong relationship between political disintegration and climatic stress in the Maya lowlands. This research employs Bayesian radiocarbon models in conjunction with calendar dates on carved monuments and climate proxies to evaluate the rise and fall of Maya political centers and serves as an example of the impact of climate change on rainfall-dependent societies in Mesoamerica.

1. Introduction

The "Classic Maya collapse" has become one of the most cited examples of societal collapse in the ancient world. Popular conceptions idealize a complete disappearance of Classic Maya civilization. However, we know from archeological evidence that cultural continuities occurred and new forms of political and social organization emerged during the Postclassic period (AD 1000–1517). Archeological and palaeoclimatic evidence indicates that climate played an important role within cycles of population aggregation and political centralization in the Maya lowlands (Dahlin, 1990; Demarest et al., 2004; Dunning et al., 2012; Hodell et al., 1995, 2005; Iannone, 2014; Kennett et al., 2012; Turner and Sabloff, 2012). During the Classic period (AD 250–900/1000) polities developed and expanded during a period of high precipitation (Kennett et al., 2012). This contributed to more complex social and political hierarchies at the end of the Classic period (AD 600–800). Political disintegration occurred across the Maya lowlands between AD 750–1000, a period when multi-decadal droughts are recorded in multiple palaeoclimatic archives (Curtis et al., 1996; Hodell et al., 1995, 2005; Haug et al., 2003; Kennett et al., 2012; Medina-Elizalde et al., 2010; Webster et al., 2007). The end of monumental construction and dated hieroglyphic inscriptions on carved monuments across the diverse regions of the Maya lowlands suggests variability in the timing of the end of divine dynastic kingship (*k'uhul ajaw*; Ebert et al., 2014; Houston and Stuart, 1996). By AD 850, hieroglyphic texts with calendar dates sharply declined by over half in the southern lowlands (Kennett et al., 2012) where most centers were completely abandoned by the end of the Terminal Classic period (Santley, 1990).

Archeologists have long argued that there was significant social and political change in the transition from the Classic to Postclassic periods. These popular scenarios have suggested that as populations declined in the central and southern Maya lowlands, cities in the northern Maya lowlands experienced demographic and political growth at the end of the Classic period. Sites in the Puuc region flourished in the Late Classic, reaching their political apex during the Terminal Classic period. Chichén

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Itzá emerged as the dominant political capital during the Terminal Classic (AD 800–1000) and Early Postclassic periods (AD 1000–1250). The cultural florescence in the northern lowlands, isochronal with collapse in the south, has intrigued many archeologists (e.g., Dahlin, 2002), especially as archeological data indicate political and demographic persistence in the more arid northern lowlands during the interval of severe drought at the end of the Classic period. Recent re-evaluations of site and regional chronologies align the collapse of Chichén Itzá and northern sites more closely with the period of collapse in the southern lowlands (Andrews et al., 2003). However, these chronological models are primarily based on ceramic evidence and continue to be debated. Investigating the timing of the political collapse of Chichén Itzá and settlements in northern Yucatán is vital to understanding the impact of climate change on social and political systems in Mesoamerica. More importantly, variation in the timing of collapse in the northern Maya lowlands may shed light on social or political responses to climatic instability that may have enabled some polities to persist for longer in the midst of severe drought.

Archeological studies in the Maya lowlands are only beginning to investigate how populations responded to shifts in climate at the end of the Classic period (Chase and Scarborough, 2014; Iannone, 2014). Despite these efforts, detailed studies grounded by high-resolution chronologies that assess the demographic and political effects of individual drought episodes are lacking. In the absence of written records, some information about the effects of extended drought may be inferred from accounts of historic droughts during the Colonial Period in the northern Yucatán (Hoggarth et al., accepted for publication). Historic accounts describe episodic droughts from the sixteenth through nineteenth centuries, with agricultural failure, food shortage, famine, and high mortality recorded in multiple historical sources (Campos Goenaga, 2011; Escobar Ohmstede, 2004; Farriss, 1984; García Acosta et al., 2003; Restall, 1998). During colonial times, extended (multi-year) droughts contributed to agricultural failure and triggered population dispersal, with records describing indigenous populations migrating deep into the forest in search of food (Molina Hübbe, 1941:11–13). During the most severe drought in colonial Yucatán from AD 1765–1773, shortages of maize resulted in price increases with a high of 96 *reales*/*fanega* recorded in 1770, well above the more normal price of 2 *reales* (Hoggarth et al., accepted for publication). High mortality was noted in the towns of Tekanto and Ixil during the same episode (Bricker and Hill, 2009; Restall, 1998), likely due to increased susceptibility to disease that resulted from malnourishment. Because indigenous food production systems remained largely unchanged following the Spanish conquest, we can assume that multi-year droughts in the past also resulted in agricultural failure, potentially undermining political and economic structures (Kennett and Beach, 2013; Beach et al., 2015).

In this paper we explore the climatic and cultural context for the political collapse of Chichén Itzá. First, we consider the chronological association between multi-decadal droughts, recorded in climate records throughout the region, with evidence for the end of political activity across the northern Maya lowlands. We use calendar dates on carved monuments and lintels from across Yucatán in conjunction with radiocarbon date distributions from monumental contexts to clarify the timing of the end of monumental construction and large-scale political activities. Second, we explore the cultural context of regional political collapse by examining variation between the centers that collapsed during or shortly after extended droughts in comparison to those that persisted. Using these data, we assess the varied responses to extended drought associated with the "Classic Maya collapse" at Chichén Itzá.

2. Environmental and cultural background

2.1. Environmental diversity in the northern Maya lowlands

The northern Maya lowlands (Fig. 1) exhibit substantial diversity in elevation, environment, and climate (Chase et al., 2014; Dunning et al., 1998; Fedick, 2014). Groundwater is scarce across northern Yucatán, with populations accessing the water table through sinkholes (*cenotes*) and by storing rainwater in reservoirs (*aguadas*) and constructed underground cisterns (*chultunob*) (Luzzadder-Beach, 2000). Dunning et al. (1998) divided the northern Yucatán into 12 different adaptive regions. This has been recently expanded for the broader Maya lowlands to encompass at least 27 distinct environmental areas (Chase et al., 2014). Chichén Itzá is located in the northeast karst plain, characterized by elevations up to 25 m, variable soil cover up to 2 m in depth, and access to the water table through sinkholes, depressions, and *cenotes* (Chase et al., 2014; Dunning et al., 1998). The city was located centrally between the coast to the north and fertile agricultural zones to the west and east (Puuc and the Coba-Okop; Dunning et al., 1998:91–92; Chase et al., 2014:16–17, 23). The northwest karst plain exhibits some of the densest settlement recorded in the Maya lowlands (Dahlin, 2002:331; Hare et al., 2014; Kurjack, 1974), recorded in surveys at the sites of Chunchucmil (Dahlin et al., 2005; Hutson et al., 2008), Dzibilchaltun (Kurjack, 1974), Chichén Itzá and Ek Balam (Johnson, 2000; Houck, 2004). Access to the coastal zone, with its swamps, estuaries, and seasonally inundated savannas, may have contributed to high-density populations in these centers (Dahlin et al., 2005; Farrell et al., 1996). To the south, the Elevated Interior Region (EIR) includes the Puuc Hills and adjacent sub-regions, which have characteristically deeper soils (Dunning et al., 2012). Little evidence of intensive agricultural infrastructure has been recorded in the Puuc region. However, sites in this area were more dependent on artificial constructions such as *chultunob* and *aguadas* to store water (Barthel and Isendahl, 2013; Dunning et al., 2012; Isendahl, 2011). A small number of lakes are present in the Coba-Okop region. The northwest plains are also dotted with abundant sites (Garza Tarazona de González and Kurjack Bacso, 1980; Brown et al., 2006).

Precipitation increases in a gradient from west to east, with the northwest region of the Yucatán peninsula receiving an average of 500 mm of annual rainfall (Folan, 1983: Fig. 3; Sharer and Traxler, 2006 Fig. 1.6). An average of approximately 1200 mm is recorded for the northeast karst plain, while the east coast generally receives over 1500 mm (Deevey et al., 1980). The rainy season ranges from May to October, punctuated by the mid-summer drought in July and August (Magaña et al., 1999). Agricultural production, centered primarily on rain-fed maize cultivation, is vulnerable to severe and sustained droughts, but shorter drought survivability is attested to today and in historical records. Delays in the start of the rainy season may lead to lost crops and seed depletion. Freidel and Shaw (2000) have presented a strong case for food trade within Yucatán in response to variation in short term, minor droughts. Historical texts describe population dispersal to search for drought resistant food in historic times (Molina Hübbe, 1941:13). Furthermore, evidence suggests that more severe droughts impacted health and demography in colonial Yucatán. Even with centralized grain storage during the Colonial Period, Yucatán continued to suffer agricultural crises and famine until the Bourbon reforms allowing the importation of foreign grain in 1770 (Patch, 1993:204).

The arid environment in some parts of the northern Maya lowlands has implications for the social and economic effects of drought in the region. Climatic drying and multi-decadal droughts have been recorded from a variety of paleoenvironmental records in the Maya lowlands at the end of the Classic period (Curtis et al., 1996; Douglas et al., 2015; Haug et al., 2003; Hodell et al., 2005; Hodell et al., 1995; Kennett et al., 2012; Medina-Elizalde et al., 2010; Webster et al., 2007). Environmental records from lakes have yielded information about changes in vegetation, human activity (i.e., agriculture, burning), and climate change in the past. Evaporation/precipitation records based on oxygen isotopes ($\delta^{18}O$) of ostracods and gastropods in sediment cores from Lake Chichancanab and Lake Punta Laguna suggest increased aridity and lake salinity between AD 770 and 1100 (Curtis et al., 1996; Hodell et al., 2005; Hodell et al., 1995). Oxygen isotopes from a speleothem record at Tzabnah Cave in northern Yucatán showed dry intervals

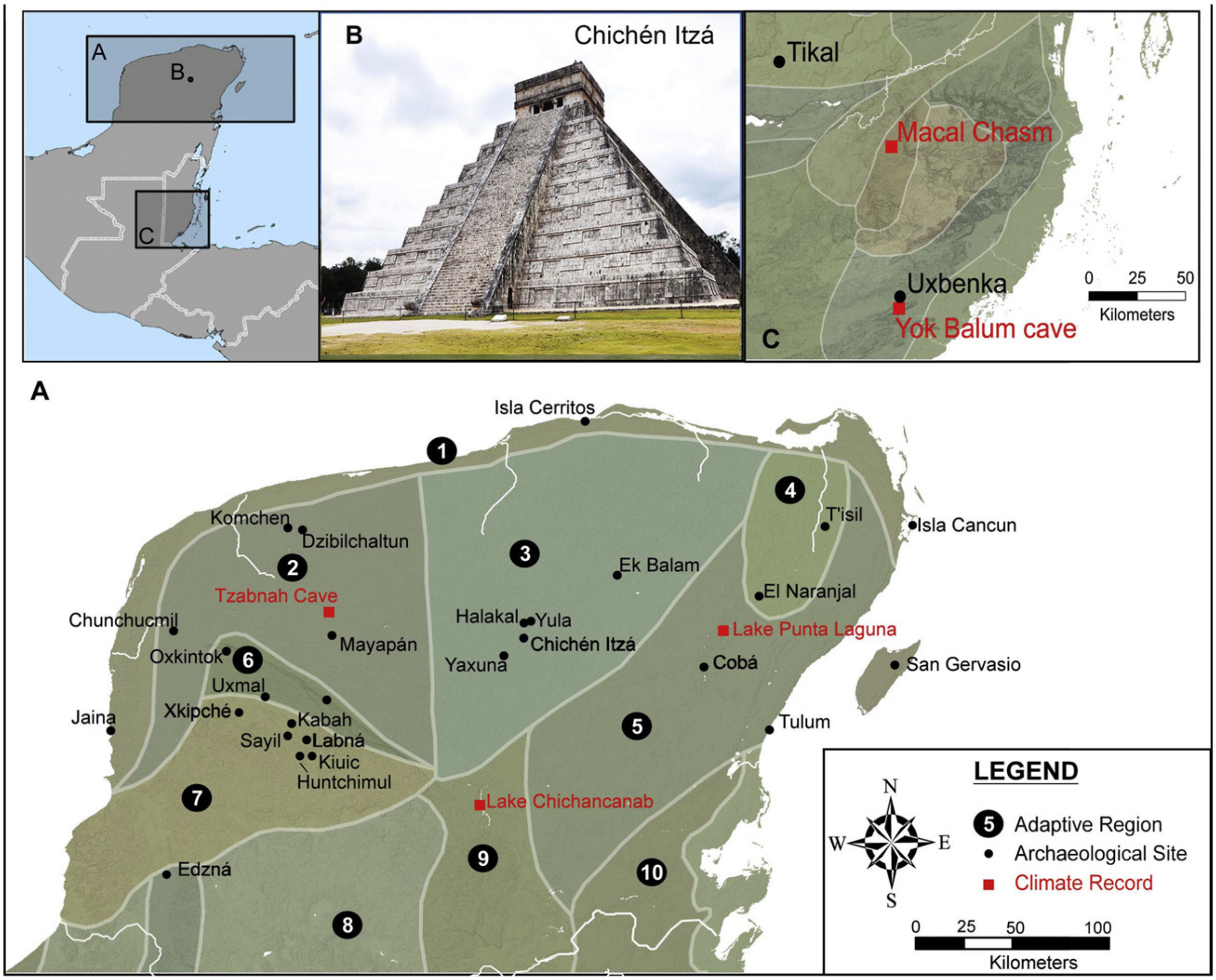

Fig. 1. Locations of archeological sites and paleoclimate archives mentioned in the text. White lines delimit environmental adaptive regions in the northern lowlands as specified by Dunning et al. (1998): 1) North Coast, 2) Northwest Karst Plain 3) Northeast Karst Plain, 4) Yalahau, 5) Coba-Okop, 6) Puuc–Santa Elena, 7) Puuc–Bolonchen Hills, 8) Central Hills, 9) Quintana Roo Depression, and 10) Uaymil. Also shown in the inset are adaptive regions in the central and southern lowlands, showing the locations of the Macal Chasm and Yok Balum cave.

between AD 810 and 938, with eight intervals of peak aridity between AD 806 and 935 (Medina-Elizalde et al., 2010). Climate proxy records from the southern lowlands show similar patterns as those from the northern lowlands. A period of increased precipitation from AD 858 to 890 is also evident in this record, a trend also identified in higher resolution climate records (e.g., Kennett et al., 2012).

2.2. Culture historical background

It was once thought that cultural developments in the northern Maya lowlands were initiated during the Late to Terminal Classic periods (AD 750–1000/1100) (Bey, 2006:16; Stanton, 2012). However, evidence for monumental and public architecture by the end of the Middle Preclassic Period (~600 BC) has been identified in northwest Yucatan (Anderson, 2012; after Peniche May, 2012), and at Yaxuna (Stanton and Ardren, 2005), Komchen (Andrews and Andrews, 1980), Kuluba (Barrero Rubio et al., 2003), Ek' Balam (Bey, 2006:27), west Mérida (Andrews and Robles Castellanos, 2004), Tipikal (Peraza Lope et al., 2002), and in the Puuc region at Kiuic (Gallareta Negrón et al., 2004) and Xocnaceh (Gallareta Negrón and Ringle, 2004). This research suggests that the region experienced comparable cycles of growth, collapse, and regeneration as is evident in the central and southern lowlands (Marcus, 1998, 2012).

Declines in monumental construction and occupation are noted at the end of the Late Preclassic and beginning of the Early Classic period (~AD 250) at some centers (e.g., Dzibilchaltun and Komchen, Andrews and Andrews, 1980). However, other urban centers emerged during this interval at Chunchucmil, Oxkintok, Yaxuna, Chac II, El Naranjal, Aké, and Izamal (Stanton, 2012). This period also featured new cultural developments such as the adoption of megalithic architectural styles across the region (Mathews and Maldonado Cárdenas, 1998). Recent evidence also indicates interaction between sites in northern Yucatán and more distant powerful cities. At Chac II, archeologists have suggested that architecture, artifacts, and burial practices indicate interaction and possibly colonization by populations from the urban center of Teotihuacan (Smyth and Rogart, 2004, but see Stanton, 2012; Braswell, 2012:15). The presence of central Mexican architectural styles and artifacts at some sites in the region suggests interaction in broader networks of culture and/or exchange (Braswell and Glascock, 2003).

Developments during the Late Classic period (~AD 600) included the political expansion of northern lowland cities including Edzná, Chunchucmil, Ek' Balam, Cobá, Itzamal, and Chichén Itzá (Ringle and Bey, 2012:387). Some of the highest density settlements are noted in the northwest (e.g. Dzibilchaltun and Chunchucmil). Ek' Balam has the largest number of hieroglyphic texts in the region (Grube and Krochock, 2007), featuring an emblem glyph and the highest title of rulership (*kaloomte'*) (Lacadena García-Gallo, 2004). Around the same time, populations and political complexity increased in the Puuc region, beginning around AD 750 and culminating at the end of the ninth century

(Carmean and Sabloff, 1996; Dunning and Kowalski, 1994; Isendahl et al., 2014). The region is well known for its Puuc-Maya style architecture, characterized by vaulted architecture, stone roofs, and geometric stone veneers featuring Chac masks. Uxmal emerged as the largest and most powerful urban center of the Puuc region during the ninth century (Dunning and Kowalski, 1994). Smaller centers such as Sayil, Kabáh, Xkipché, Nohpát, and Labna emerged earlier in the Late Classic (Isendahl et al., 2014; Ringle and Bey, 2012:387). Some scholars have suggested that Uxmal may have served as the central political capital of the region (Isendahl et al., 2014), while others suggest the region was organized within a system of city-states (Dunning and Kowalski, 1994). Puuc style architecture and ceramics also spread beyond the Puuc hills to much of the western portion of the state of Yucatán, as far as Kuluba (Garza Tarazona de González and Kurjack Bacso, 1980; Brown et al., 2006).

Chichén Itzá arose as the most influential political capital in the northern lowlands at the end of the Classic period (~AD 850) with carved monuments clustering between AD 869 and 890 (Grube and Krochock, 2007). This evidence, coupled with the spread of characteristic *Sotuta* ceramics at sites across portions of the eastern Yucatán (Andrews and Robles Castellanos, 1985), have been used to suggest that the expansion of Chichén Itzá's influence and power was based on military and territorial conquest (but see Stanton and Gallareta Negrón, 2001 and Manahan et al., 2012 for discussions on the ceramics). The earliest monumental buildings are concentrated in the southern area of Chichén Itzá (known as "Old Chichén") and are primarily constructed in Maya-Puuc architectural styles. The only long-count calendar date at the site comes from the Temple of the Initial Series that bears a date of AD 878. Architecture in the northern "New Chichen" area of the site is thought to have been constructed later in time and characterized by International/"Toltec" architectural styles. A calendar date at the High Priest's grave in this area is thought to date to AD 998 (Graña-Behrens et al., 1999). Some scholars suggest that the success and growth of the Itzá state may also be attributed to the adoption of shared council rulership (Schele and Friedel, 1990:348) rather than centralized authority of a single divine ruler (see Boot, 2005; Cobos, 2007; Ringle, 2004 for more recent interpretations). The polity also may have prospered through participation in interregional economic networks, importing large quantities of central Mexican obsidian and volcanic ash for pottery temper (Kepecs et al., 1994; Braswell and Glascock, 2003). The control of salt production also may have been influential in this growth (Kepecs, 2007), with Isla Cerritos possibly operating as the Itzá port (Andrews et al., 1988).

Despite extensive archeological research at Chichén Itzá, the exact timing of the rise and fall of this powerful state has been controversial. This debate centers on differing chronological models for the *Cehpech* and *Sotuta* ceramic complexes. Some (Brainerd, 1958; Smith, 1971) argued for sequential ceramic phases placing the initiation of the *Sotuta* complex around AD 1000 and the end of Chichén Itzá's domination around AD 1200. More recently, scholars (Anderson, 1998; Ball, 1979; Lincoln, 1986; Bey et al., 1998; Andrews et al., 2003) have proposed an earlier emergence with chronological overlap of these complexes. If accurate, this would suggest that the end of construction at Chichén Itzá occurred around AD 1000/1050 (Andrews et al., 2003). Few radiocarbon dates have been reported for the site, leaving this debate unresolved (see Volta and Braswell, 2014 and Cobos et al., 2014 for recent contributions to this debate). Archeological and historic evidence indicates that Chichén Itzá remained a prominent ritual and pilgrimage center after its collapse, well into the Colonial period (Restall, 1998; Roys, 1967:173).

More precise chronologies exist for other northern Maya sites during the Postclassic period. A radiocarbon chronology for the site of Mayapán supports the beginning of monumental construction at the Late Postclassic regional capital by AD 1150 (Peraza Lope et al., 2006). The culmination of Mayapán's power occurred with the establishment of a confederacy of provincial lords from across Yucatán. This form of shared rulership was governed by a council, but frequently dominated by the Cocom lineage head (Masson and Peraza Lope, 2014; Restall, 2001). Like at Chichén Itzá, warfare and militarism were prominent themes at Mayapán, detailed by its defensive walls and in ethnohistoric accounts (Kennett et al., 2016). The expansion of major settlements along the east coast of the peninsula, including at Tulum, San Gervasio, El Meco (Andrews and Robles Castellanos, 1986), Xelha, Tancah, and sites along the Belizean coast (e.g. Santa Rita Corozal, Chase and Chase, 1988) were likely related to the increasing importance of seaborne commercial trade during the Postclassic period (Masson and Rosenswig, 2005; McKillop, 1996; Sabloff, 2007:19–20; Sabloff and Rathje, 1975:74–77).

Within the cultural history of the northern Maya lowlands, the persistence of Chichén Itzá and other northern polities in the wake of severe droughts between the ninth to eleventh centuries has posed a paradox for archeologists (Dahlin, 2002). Some recent chronological models (e.g. Andrews et al., 2003) bring the end of political activity at Chichén Itzá more in-line with the collapse of major polities in the southern lowlands at the end of the Classic period. Scholars have suggested that this question will only be resolved through additional AMS ^{14}C dating from stratigraphic contexts at Chichén Itzá and other major centers (Smith, 2011:47; Volta and Braswell, 2014). Securely dating the political collapse of Chichén Itzá is integral for understanding the relationship between shifts in climate and political disintegration, especially for identifying regional adaptations to climatic change.

3. Data and methods

Existing chronological evidence that may be used to understand the timing for the end of political activity at Chichén Itzá is limited. Until additional evidence is available, a focus on the regional and climatic context of these transformations may provide some clues as to their timing. Exploring regional patterns for large-scale ceremonial construction and art may also shed some light on how cultural changes at Chichén Itzá were related to broader patterns of regional political disintegration from AD 800–1150. Here we compile two regional datasets that we will use to explore the relationships between the breakdown of political systems across the region and severe drought.

3.1. Evaluating the climatic context

In order to evaluate the climatic context of the political collapse of Chichén Itzá and other northern lowland centers, we must identify chronological correlations between drought episodes and political or social transformations. The problem with using local climate proxy records from northern Yucatán to compare with archeological and historic datasets in the region lies in the resolution and precision of the climate records. Resolution refers to the time intervals that are represented between analyzed samples in the sedimentary or speleothem records. Higher resolution allows for a greater understanding of sub-annual climatic changes that may impact the growing season more negatively. Precision relates to the errors attached to radiocarbon or uranium series dates. Higher temporal precision constrains the chronometric distributions, allowing specific events to be fixed more accurately in time.

Early paleoclimate studies in the northern Maya lowlands (Hodell et al., 1995, 2005; Curtis et al., 1996) in the 1990s sparked a long-term discourse on the impact of drought on social and political change across the region. However, these studies produced relatively low-resolution records compared to more recent studies. The climate record from Lake Chichancanab (Hodell et al., 1995, 2005) has 5–20 year resolution with ~100 year radiocarbon error ranges. The proxy record from Lake Punta Laguna (Curtis et al., 1996) has 8-year resolution and 20–70 year radiocarbon year error ranges on average. Oxygen (δ^{18}O) isotopes of the Chaac speleothem from Tzabnah cave have an average resolution of 2.3 years across 1500 years, with annual resolution during the Terminal Classic period (Medina-Elizalde et al., 2010). Uranium-

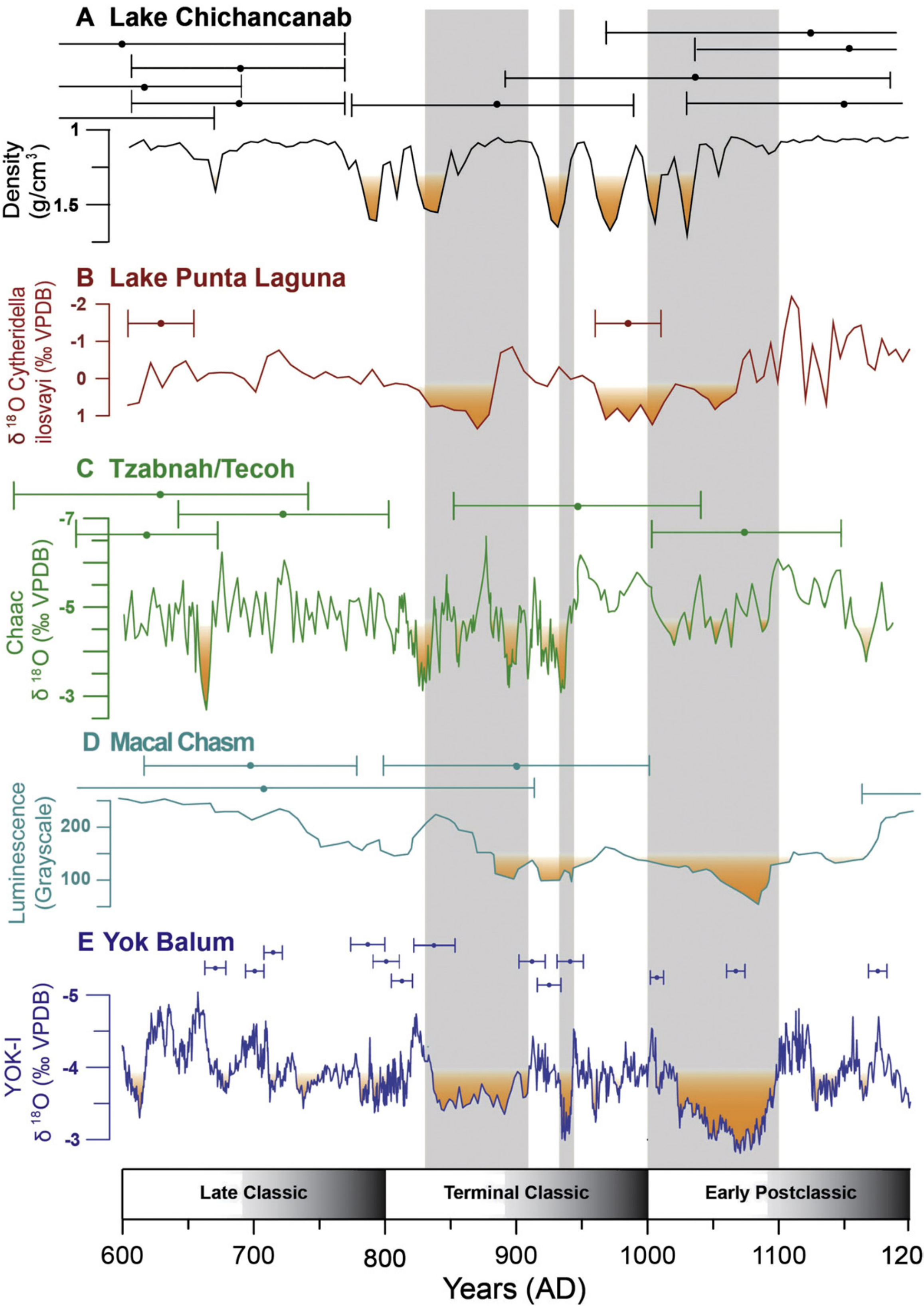

Fig. 2. Paleoclimate records from the northern Maya lowlands, including (A) Lake Chichancanab sediment density (Hodell et al., 2005), (B) Lake Punta Laguna ostracod (*Cytheridella ilosvayi*) $\delta^{18}O$ record (Curtis et al., 1996), and (C) Tzabnah Cave Chaac $\delta^{18}O$ speleothem record (Medina-Elizalde et al., 2010). These records are plotted against speleothem records from the southern lowlands showing the (D) Macal Chasm speleothem luminescence record (Webster et al., 2007) and the (E) Yok Balum (YOK-I) $\delta^{18}O$ record (Kennett et al., 2012). Uranium series and ^{14}C dates included for each record.

series dates for the Tzabnah record have attached errors of 7–60 yrs. The comparison of northern lowland paleoclimate records with climate proxies from other parts of the Maya area identifies congruent intervals of drought within the limits of dating errors of individual records (Fig. 2). Although the resolution and precision of paleoclimate records has recently increased, severe drought episodes (with dating precision considered) span the period between AD 725 and 1150 in the highest resolution and most precise proxy record from the northern lowlands (Medina-Elizalde et al., 2010). The broad time span of these climatic changes is not precise enough to allow for clear chronological associations between drought and the breakdown of political and social systems across the region to be identified.

The Yok Balum speleothem record has yielded the highest resolution paleoclimate data in the Maya lowlands to date (Kennett et al., 2012). Oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) isotopic measurements were taken in 0.1 mm increments, providing sub-annual resolution over the last two millennia. Over forty Uranium-series dates (5–10 year errors on average) provides high temporal precision. These data suggest a drying trend from AD 660–1100, showing a series of multi-decadal droughts from AD 820–915, ~AD 930, and an extended severe drought from AD 1020–1100 (Kennett et al., 2012). Despite the distant geographic location, strong temporal correlations have been noted for drought episodes recorded in the YOK-I record with severe droughts recorded historically in colonial Yucatán (Hoggarth et al., accepted for publication). Fig. 3 shows the close chronological correlation between severe droughts (3 years or longer) in colonial Yucatán with dry intervals in the Yok Balum proxy record. Although the Tzabnah Cave record is more proximate to Chichén Itzá and northern lowland centers, we argue that the resolution and dating errors are insufficient to make fine-grained interpretations to understand the cultural and climatic context of political collapse in the region. However, despite the distant location of the Yok Balum record in southern Belize, severe droughts recorded in historic texts from northern Yucatán between AD 1500 and 1800 show strong temporal correlations (within the limits of the dating uncertainties) with the YOK-I record. The correlation between droughts recorded in the Yok Balum record with distant climate records, as well as with historic records from northern Yucatán, suggests that multi-decadal droughts affected broad portions of the Maya lowlands and beyond. The northern and southern lowlands feature different ecologies and we would expect severe drought to impact these areas in different ways. However, periods of drought can be identified within the error ranges of lower resolution and less precisely dated records from across the Maya lowlands. This suggests that populations across the region would have to adjust and adapt to lower precipitation during intervals of severe drought. Classic droughts in the Maya lowlands are also paralleled in climate records from tree rings in central Mexico during

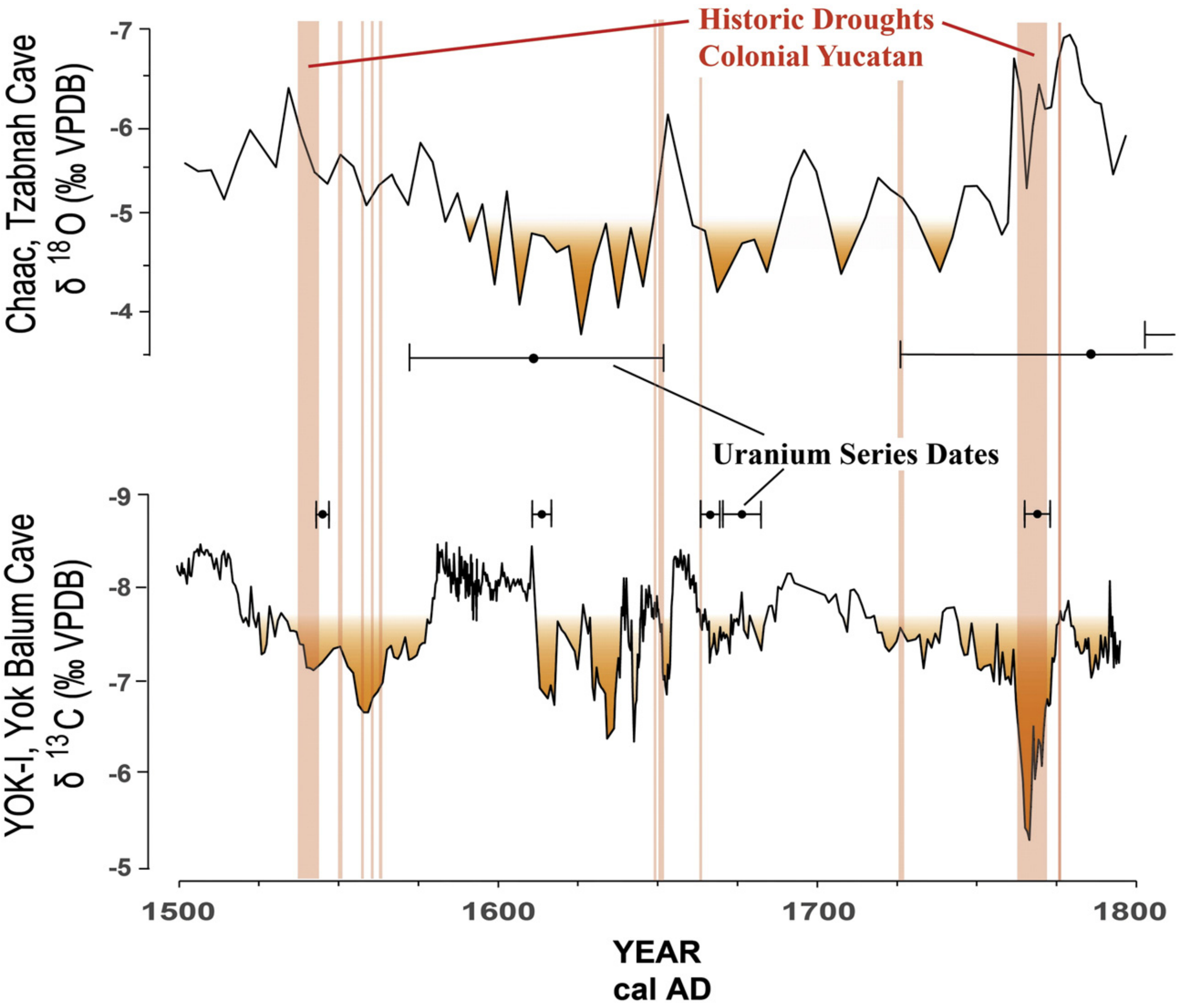

Fig. 3. Yok Balum (YOK-I) speleothem record plotted against the Chaac speleothem from Tzabnah Cave (Medina-Elizalde et al., 2010) and historic droughts (shaded in red) recorded in colonial Yucatán. The highly resolved and precisely dated nature of the YOK-I proxy record (Kennett et al., 2012) shows the close correspondence between the historic and paleoclimate records from the Yucatán peninsula with the Yok Balum speleothem record from southern Belize. These data suggest that severe droughts affected broad geographic areas of the Maya lowlands during the Colonial period, and likely earlier in time, and that this record can be applied to the northern lowlands.

the ninth century (Stahle et al., 2011). Based on these observations, we use the Yok Balum speleothem record to understand the climatic context for the collapse of political systems at Chichén Itzá and other northern lowland centers. We make the assumption that only severe (in intensity and/or duration) climatic changes would have impacted political systems of the greater region. These comparisons help to identify chronological associations between political centers that persisted and those that collapsed during individual drought episodes.

3.2. Evaluating the cultural context of collapse

Limited chronological data currently hinder a clear understanding of the timing of the disintegration of political systems at Chichén Itzá. In the absence of additional radiocarbon dates from stratified contexts, we examine political collapse in the broader regional context of the northern Maya lowlands relative to recorded multi-decadal droughts (Kennett et al., 2012). We compile radiocarbon and hieroglyphic dates from across northern Yucatan to estimate the timing of the end of monumental construction and political activity at Chichén Itzá and other political centers. Applying standards of chronometric hygiene to eliminate questionable dates, in conjunction with Bayesian chronological frameworks, allows for many of the large ^{14}C distributions to be constrained. Summed probabilities of radiocarbon dates are used to constrain intervals of monumental construction and dedication at individual sites across the broader region. These data are assessed in conjunction with hieroglyphic dates to identify congruent patterns between multiple lines of evidence that can help identify the end of political activity. Finally, we assess these data in relation to regional climate records to examine how political collapse temporally relates to broader shifts in climate. Understanding the temporal relationships between regional political disintegration and extended dry intervals may provide clues to how populations responded to climatic change.

3.2.1. Radiocarbon dates and summed probability distributions

Radiocarbon dates from sites across the northern lowlands were compiled from published sources for inclusion in the ^{14}C database. Associated information was recorded for each date, including the site name, sub-region, contextual information (specific stratigraphic and spatial relationships), type of material dated (charcoal, human remains, faunal remains, obsidian, ceramic, shell, mortar, stucco), lab number, whether the sample was dated via Accelerated Mass Spectrometer (AMS) or conventional ^{14}C dating, uncalibrated date and error ranges, 2-sigma calibrated distributions, and reference publication. All identified dates are included in this compilation, but a smaller set of dates from monumental contexts was used to constrain the chronology for each site.

Archeologists working in other geographic regions have developed a set of objective criteria for evaluating radiocarbon dates for building regional chronologies (Dean, 1978; Dunnell and Readhead, 1988; Fitzpatrick, 2006; Spriggs, 1989; also see Inomata et al., 2013, 2014) with the goal of removing nonsensical and undefendable radiocarbon dates (chronometric hygiene). Spriggs (1989) offered several standards by which he assessed the acceptability of radiocarbon dates in Southeast Asia. Some of these criteria present issues when applied to radiocarbon dates from the Maya lowlands, as in other regions (e.g. Caribbean, Fitzpatrick, 2006). This is due to the small number of radiocarbon dates, limited contexts, conflicting and/or controversial ceramic chronologies across the region, and the absence of contextual or chronometric data from the archeological literature at some sites. In assessing the usability of radiocarbon dates from across the Maya lowlands, we rely on the available literature and information to assess the reliability of dates, based on five criteria for either retaining or rejecting individual ^{14}C dates:

1) Material dated should not be from a long-lived species (unless clearly from an external growth ring).
2) The association with cultural remains cannot be ambiguous and the date should be supported by additional archeological evidence. Insufficient contextual information or not reporting uncalibrated dates yields ambiguous associations.
3) Dates from bone (human or faunal) and/or shell require additional pretreatment, purification, and assessment of reservoir effects or other environmental corrections.
4) Only radiocarbon dates with measurement precisions below 100 years (and preferably 60 years) should be used as larger errors contribute to “blurred probability distributions” that impede clear chronological distinctions (Kennett et al., 2008).
5) Dates derived from experimental techniques that have yielded questionable results in the region should be rejected until proven more reliable.

Over 250 ^{14}C dates were identified from the archeological literature of northern Yucatán (Appendix A). In cases where dated samples were re-run, or if additional a priori information were available, the original dates were retained in order to constrain the distributions (see Culleton et al., 2012). Dates that passed these criteria were retained for the analysis. For this study, we focused on dates from monumental contexts ($n = 102$ after the chronometric hygiene) as a proxy to gauge the political activity expressed through monumental construction and art. If any dates were derived from contexts in stratigraphic association, dates were modeled using the *Phase* or *Sequence* models in OxCal (Bronk Ramsey, 2009). In cases with dates from stratified contexts that did not pass the chronometric hygiene criteria, we assess the statistical fit between the date and associated samples.

Summed probability distributions have been used throughout archeology as a proxy for human activity (Buchanan et al., 2008; Collard et al., 2010a; Gamble et al., 2005; Gkiasta et al., 2003; Riede, 2009; Shennan and Edinborough, 2007). However, the application of this method to assess fluctuations in population has come under scrutiny (Ballenger and Mabry, 2011; Bamforth and Grund, 2012; Contreras and Meadows, 2014; Culleton, 2008; Kennett et al., 2008). Summed probability distributions have generally been used to assess trends in population levels at sites and across regions (Shennan, 2009), especially in North America (e.g., Buchanan et al., 2008; Kelly et al., 2013) and Europe (Armit et al., 2013; Collard et al., 2010b; Gkiasta et al., 2003; Hinz et al., 2012; Shennan, 2009; Shennan and Edinborough, 2007; van Andel et al., 2003). We do not use these distributions as a proxy for population. However, when dates are selected from specific contexts, such as from monumental construction episodes, we argue that this method yields an approximation of the initiation and cessation of political activity at a given center.

These methods are not often employed in the Maya region, as relative ceramic chronologies are typically the primary evidence used to understand sociopolitical change. However, summed probability distributions can be used effectively as a heuristic tool in conjunction with other datasets (e.g. Kennett et al., 2014). Williams (2012) lists four major limitations of the method: 1) intra-site sampling; 2) sample size influences results; 3) calibration effects; 4) taphonomic loss; and 5) comparison with other proxies.

Intra-site sampling issues plague all radiocarbon chronologies, as samples are often selected for dating in order to assess chronological relationships between strata or deposits, rather than to assess the entire occupational sequence. The assumption when using summed probability distributions is that dates are representative and associated with occupation and associated activities (Williams, 2012). In order to assess the chronology of the political collapse of Chichén Itzá and other competing polities in northern Yucatan, dates from contexts associated with monumental construction were selected (after the chronometric hygiene criteria described above) for inclusion in the summed probability distributions.

Summed probability distributions are also affected by the radiocarbon curve (Bamforth and Grund, 2012; Culleton, 2008), small sample size and/or data density (Contreras and Meadows, 2014; Hinz et al., 2012; Williams, 2012), and measurement precision (Contreras and

Meadows, 2014). To address these issues, the calibrated distributions were plotted against a histogram showing the number of calibrated 2-sigma ^{14}C dates binned in 25-year intervals. We identify important 'tipping points' that show positive or negative change in the proportion of radiocarbon dates with attached confidence intervals. Dates with analytical errors over 100 years were removed from the sample during the chronometric hygiene process, helping to minimize the effects of the latter issue (Culleton, 2008; Contreras and Meadows, 2014). Old wood-age offsets of long-lived species can also lead to earlier than expected dates from wooden lintels if the samples are not specifically taken from the exterior growth of the tree (see Kennett et al., 2002). We discuss these effects for determining the end of political activity at each site. General patterns may be identified through increases and declines in the probability density against the histogram of binned 2-sigma dates and used in conjunction with hieroglyphic dates from carved monuments and lintels as a secondary supporting source of chronological data.

3.2.2. Carved monuments and lintels with calendar dates

Hieroglyphic inscriptions on carved monuments and lintels bearing calendar dates have been compiled from across the Maya lowlands in the Maya Hieroglyphic Database (Macri and Looper 1991–2014, also see Munson and Macri, 2009; Kennett et al., 2012; Ebert et al., 2014). Using these sources, over 100 monuments with calendar dates were identified across the northern Maya lowlands. This information may be used to understand the chronological span of political activity that complements the radiocarbon data. Using multiple lines of chronometric data will aid in the identification of critical periods of political decline. As some sites feature only a single dated hieroglyphic inscription, any terminal calendar dates discussed in the text relate to sites where more than two separate hieroglyphic inscriptions featuring a calendar date has been identified (see Ebert et al., 2014).

One of the problems with using calendar dates on carved monuments and lintels as the only proxy for political collapse lies in the nature of the texts themselves. Classic period hieroglyphic inscriptions in the central and southern lowlands often feature long count dates that allow the texts to be directly related to the Gregorian calendar (see Kennett et al., 2013). However, use of long-count calendar dates declined after AD 800 and most hieroglyphic texts in the northern lowlands were inscribed in short form (calendar round or *tun ajaw* format) (Thompson, 1937), leading to different interpretations of dates by epigraphers. Although the context and content of the monuments may lend additional information to fix these texts in time, these types of monuments cannot be equated the same absolute dates that may be assigned by long count dates. For this study, we use the interpretations with the most agreement among epigraphers, as identified in the Maya Hieroglyphic Database. Fewer carved inscriptions have been identified in the region than in the southern lowlands and scholars have suggested that these differences may be attributable to cultural or scribal traditions that were distinct from the south (Bey, 2006:18). However, texts at northern centers are often concerned with dedications (Krochock, 1988) and are often found on capstones or lintels in structures, some of which have been radiocarbon dated (e.g. at Chichén Itzá). The use of hieroglyphic and radiocarbon dates in conjunction allows for independent corroboration for assessing the end of political activity at northern lowland centers. This allows for the identification of sites that collapsed or persisted in the context of severe drought from the ninth to eleventh centuries. Identifying environmental, cultural, or economic attributes of polities that persisted may shed some light on adaptations and responses to shifts in climate that allowed populations to endure extended and severe droughts.

4. Results

The use of hieroglyphic dates from carved monuments and lintels in conjunction with existing ^{14}C dates from sites across the northern Maya lowlands provide evidence for the timing and nature of the collapse of regional polities that may be considered independently from debated ceramic chronologies (such as those at Chichén Itzá). Both lines of evidence show an apex in political activity between AD 700 and 900 (Fig. 4). Calendar dates on carved hieroglyphic inscriptions show two primary intervals of monumental dedication. The first and largest peak in inscriptions occurred from AD 650–775. Forty-four calendar dates are recorded at Puuc sites between AD 709 and 769 marking the beginning of the Puuc florescence. Summed probability distributions of radiocarbon dates show parallel trends that suggest a peak in monumental construction activity at Puuc sites beginning around AD 700. Ninety-four percent of all hieroglyphic dates originated in the Puuc region between AD 650 and 775. This period of hieroglyphic activity was followed by a 75% decline in texts over the following 50 years (in alignment with recorded ninth century droughts), with hieroglyphic dates identified at only two centers during this time. This decline also corresponds with the first carved inscription at Chichén Itzá at the Temple of the Hieroglyphic Jambs in AD 786 (Krochock, 1997). The number of sites bearing monuments or lintels with calendar dates remained fairly constant between AD 650 and 800.

A second peak in hieroglyphic inscriptions bearing calendar dates occurred from AD 850–925 (Fig. 4). This period of activity in carved inscriptions exhibits substantial differences from the distribution of seventh and eighth century carved monuments, with 75% of all calendar dates originating at Chichén Itzá between AD 850 and 875. Texts in the Puuc region declined during this interval of regional dominance by Chichén Itzá, only to rebound in the subsequent 25 years, with a proliferation of dated inscriptions at Uxmal at the beginning of the tenth century. Hieroglyphic and radiocarbon dates show complementary patterns that point to two waves of political collapse across the northern Maya lowlands. For the first wave of political collapse, we identify the asynchronous collapse of polities between AD 850 and 925 in the Puuc and interior regions. This time frame overlaps with the breakdown of political systems in the southern lowlands (Iannone, 2014). The second wave of political disintegration occurred around AD 1000 with evidence for the end of political activity at Chichén Itzá. These waves of political balkanization and decentralization show chronological correlations with severe droughts in the ninth and eleventh centuries but also reveal patterns of political activity that differs from the southern lowlands.

4.1. AD 850–925: ninth century droughts, Puuc collapse, and the rise of Chichén Itzá

Radiocarbon and calendar dates from across the northern Maya lowlands show evidence for the breakdown of political systems at many sites in the Puuc and other interior regions at the end of the ninth century and the beginning of the tenth century. This interval is associated with a series of multi-decadal droughts between AD 825 and 915 (Fig. 4). Several terminal calendar dates (the last hieroglyphic date recorded from a site with two or more dates) precede the most severe droughts in the ninth century. These occur in the Puuc region, first at Kayal in AD 744, at Xcalumkin in AD 769, and also at the important Classic Period center of Cobá in AD 781. The final calendar date from Dzibilchaltun, located in the northwest karst plain, is noted at AD 790. These patterns suggest that the last vestiges of political institutions and activities occurred may be comparable to some areas of the southern lowlands at the end of the ninth and the turn of the tenth century. This critical period of time also corresponds with up to a 69% decline in calendar dates from carved monuments and lintels across northern Yucatán between AD 750 and 800. However, no radiocarbon dates have been recorded for any of those sites, hindering our ability to assess whether the early end of the epigraphic record at these sites corresponds with an end of political activity or instead marked shifts in political influence across the region.

Summed probability distributions of radiocarbon dates from sites in the Puuc region may help to address some of these issues. Although no radiocarbon dates have been recorded at Xcalumkin, 57 dates were

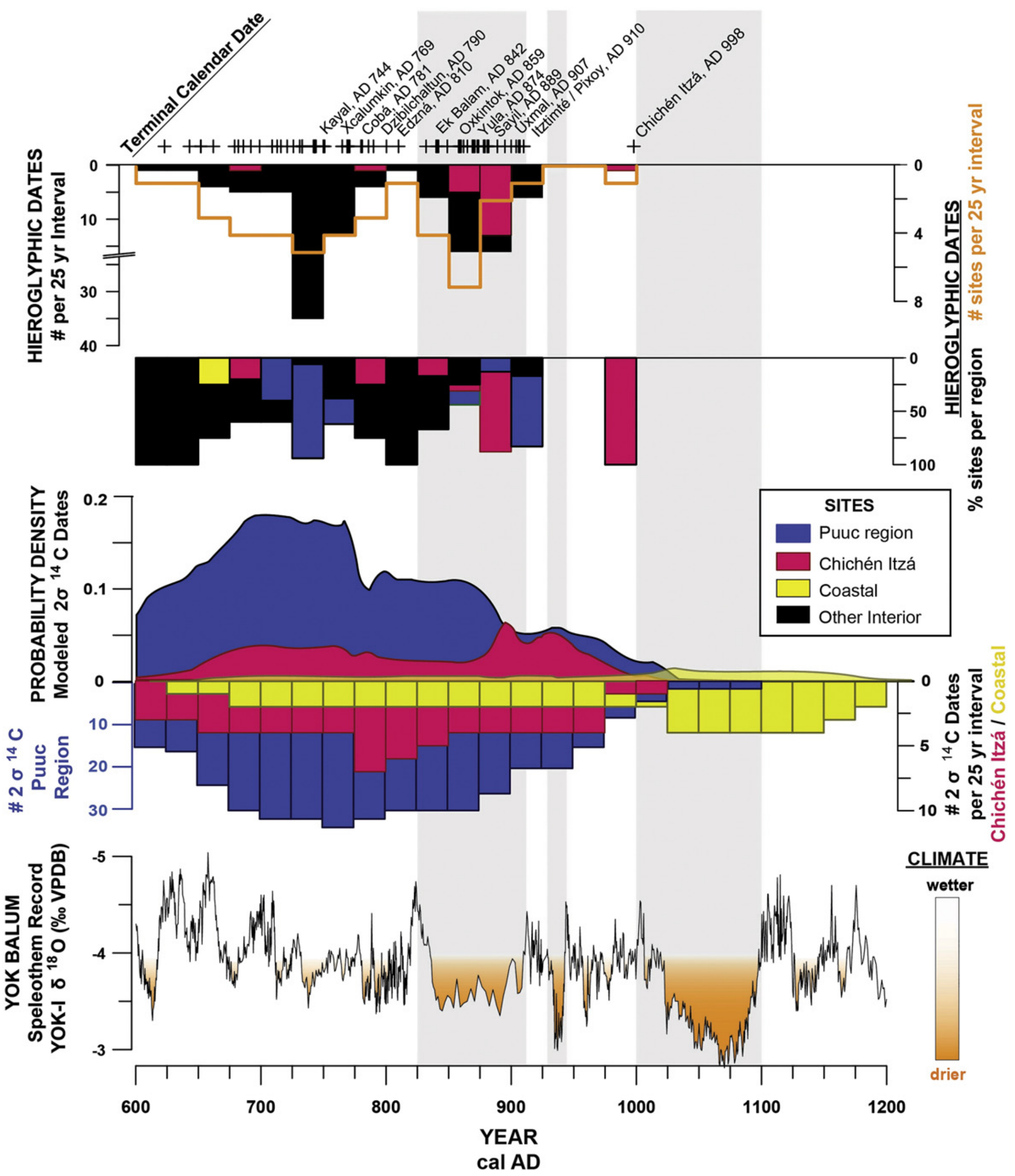

Fig. 4. Distributions of hieroglyphic dates in the northern Maya lowlands, summed probability distributions, and 2-sigma ^{14}C distribution histogram in 25-year bins. Distributions of hieroglyphic inscriptions from interior sites (black) are contrasted with those in the Puuc region (green), Chichén Itzá (red), and coastal region (yellow) to highlight patterns. The Yok Balum speleothem record shows the δ^{18}O isotopes from AD 600–1200, with periods of extended drought highlighted at AD 825–915, 930–945, and 1020–1100.

retained after the chronometric hygiene assessment from monumental contexts at Puuc sites[1] (Fig. 5). Those data show no declines in the distributions of radiocarbon dates that would suggest regional political collapse at sites in the Puuc region during that time. Rather, the interval between AD 700 and 875 show relative stability throughout this period. Congruent patterns are identified between terminal calendar dates and radiocarbon dates at Uxmal and Sayil and offer information to assess the timing for the end of political activity in the Puuc region. These data, supplemented with a larger corpus of radiocarbon dates from other Puuc sites, suggests that the Puuc region may have experienced two waves of political disintegration. The first wave occurred between AD 875–925, while the second occurred nearly a century later from AD 1000–1050.

A cluster of terminal calendar dates is noted from AD 842–910, corresponding to the latter half of the ninth century droughts. Hieroglyphic inscriptions bearing calendar dates declined by approximately 71% between AD 875 and 900 across northern Yucatán and were restricted to Uxmal during the period of growth noted for Chichén Itzá. During this same interval, radiocarbon distributions in the Puuc region declined by 28%[2], supporting the decline of political activity identified in

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[1] The small number of radiocarbon dates (and absence of hieroglyphic texts) from individual Puuc sites, including Xcoch, and Huntichimul (Fig. 5), preclude the use of these data to assess the interval of collapse without additional chronological data such as calendar dates. However, these ^{14}C dates are included in the Puuc summed probability distribution to examine broader political trends through time.

[2] The full result is 28.5% with an error of ± 14.5% at the 95% confidence interval.

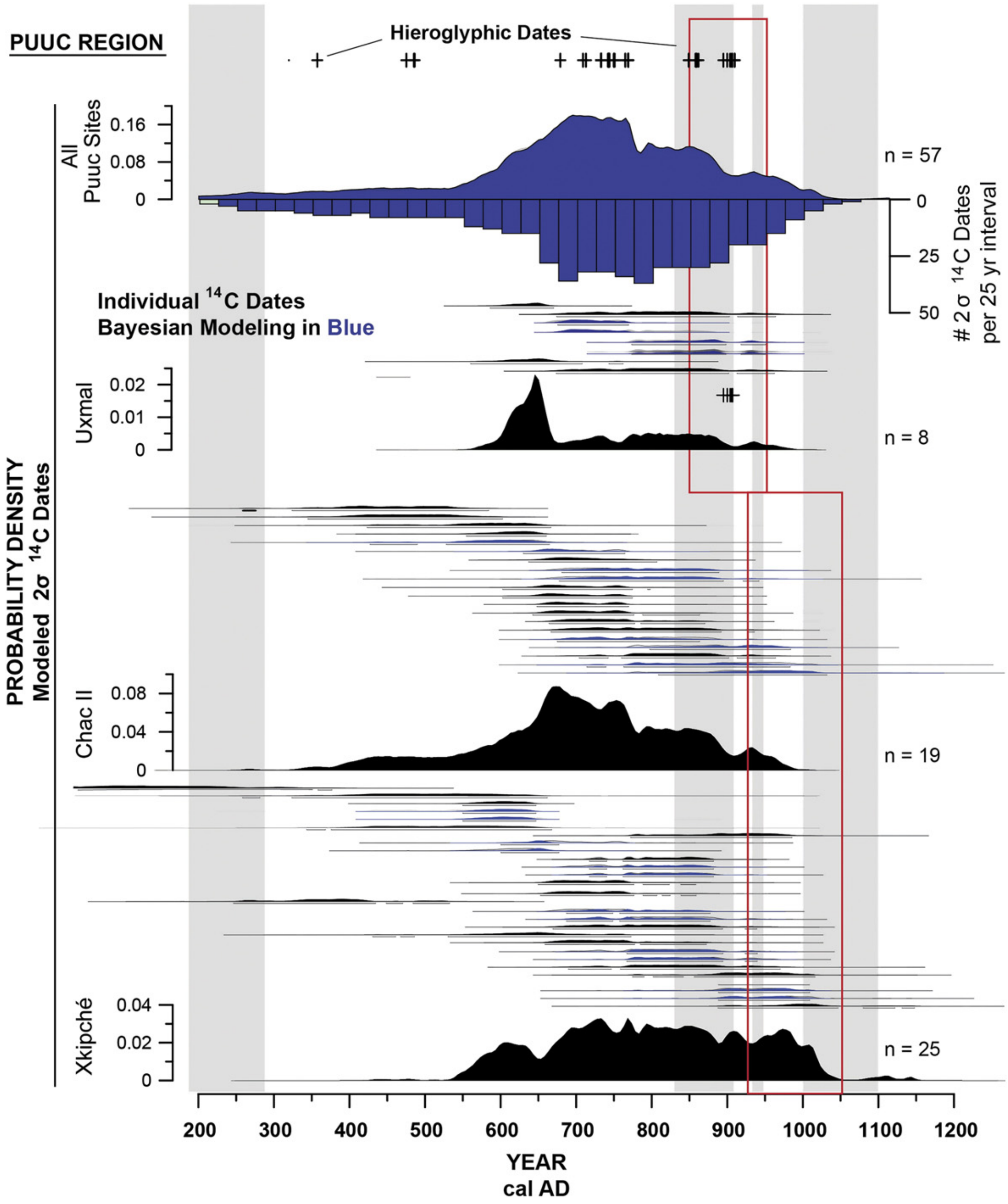

Fig. 5. Summed probability of all modeled and unmodeled dates from Puuc sites after the chronometric hygiene, shown with a histogram of radiocarbon dates in 25-year bins. Modeled and unmodeled dates at individual sites in the Puuc region also shown with the summed probability distributions, revealing two episodes of political collapse in the Puuc region.

hieroglyphic texts. Kowalski (2006; Dunning and Kowalski, 1994:90) argues that the period between AD 895–907, which is prominently featured in the epigraphic record of Uxmal, may represent an alliance between Uxmal and Chichén Itzá prior to Uxmal's fall by the middle of the tenth century. Although the radiocarbon data cannot validate the nature of the relationship between those centers, it does support the end of political activity at Uxmal in the first half of the tenth century (but see Cobos et al., 2014:59–63). The epigraphic record at Uxmal ends at AD 907 and the final texts in the Puuc region date to AD 910 at Pixoy and Itzimte. One radiocarbon date (Erl-1317) from Building A1, room 5 at Uxmal does not align with other ^{14}C or hieroglyphic dates. It is possible that this date represents the replacement of a lintel at a later date and, regardless, it is unclear whether or not these activities took place in the context of continued monumental construction or later occupational activity. If accurate, it would bring the fall of Uxmal to around the time of the collapse of Chichén Itzá. The identification of *Sotuta* ceramics in excavations in the ceremonial center (summarized in Ringle, 2012:198) may support either interpretation. However, as the Nunnery Complex features some elements of International style architecture, this might suggest that the end of political activity at the site was concurrent with Chichén Itzá (see Cobos et al., 2014 for an expanded discussion) and dates to the first half of the eleventh century. Only one radiocarbon date from Sayil remains after the chronometric hygiene, dating between cal AD 660–950. Although the radiocarbon data is restricted, the terminal calendar date at the site at AD 889 suggests the political collapse of that site at the end of the ninth century. Several dates from Xcoch also fall within this interval. The growth in political influence at Chichén Itzá is noted by an increase of 31% of calendar dates on carved monuments and lintels at that site between AD 850 and 875 (Fig. 5).

Calendar dates on hieroglyphic inscriptions increased further in the following 25 years, with 88% of all inscribed calendar dates in the northern lowlands focused at Chichén Itzá between AD 875 and 900. These data show evidence for increased political and economic power at northern centers throughout the ninth century in the midst of severe droughts. Less is known about Chichén Itzá's power and influence during the tenth century. No hieroglyphic inscriptions are identified for a period of over 100 years at Chichén Itzá following the cluster of inscriptions at the end of the ninth century. The final inscription recorded at the center is associated with the High Priest's Grave and thought to date to AD 998 (Graña-Behrens et al., 1999). Although the nature of political activity in the tenth century at Chichén Itzá remains unclear, radiocarbon data sheds some light on monumental construction in the different sectors of the center. These dates provide clues regarding the timing of the end of monumental construction and political activity in the center.

Although the radiocarbon data are limited, the recent publication of new dates from stratigraphic excavations at the Great Terrace (Braswell and Peniche May, 2012; Volta and Braswell, 2014) offers new opportunities to understand the history of monumental construction at Chichén Itzá and begin to assess the chronology of the political collapse. To begin this process, ^{14}C dates were grouped by area of the site, between the southern area known as "Old Chichen" and in the northern area known as "New Chichen" (see Volta and Braswell, 2014: Fig. 13.3). These areas roughly reflect architectural styles that are thought to temporally represent earlier Maya architecture versus those in the later International style (Cobos, 2003; Volta and Braswell, 2014). The four ^{14}C dates from "Old Chichen" come from lintels in the Casa Colorado and Monjas Complexes (Hubbs et al., 1960; Chandler et al., 1963). We modeled these dates using the latest calendar date from the lintels in the Casa Colorada and Monjas complex (AD 871) as a *terminus ante quem* to constrain the dates (Fig. 6), since we assume that the trees from which the lintels were carved must pre-date the dedication date of the complex (see Appendix B for the Bayesian chronological model). This model constrains the summed probability distribution of dates from "Old Chichen" to cal AD 605–845, consistent in age with Puuc Maya centers. If the outer portion of the wood were removed in the carving process (see Kennett et al., 2013; Satterthwaite and Ralph, 1960), we would expect that the age of the trees to be near or slightly later than the end of the radiocarbon distributions. The end of this interval largely corresponds with the beginning of the epigraphic record at Chichén Itzá in AD 832 and corroborates political expansion in the second half of the ninth century. Radiocarbon dates from lintels and charcoal from excavations in "New Chichen" also help to assess the timing for the end of monumental construction at the site. The temporal overlap between "Old Chichen" and "New Chichen" sectors of the site suggest the second expansion and proliferation of political power at Chichén Itzá occurred during a shorter interval of more stable rainfall in the tenth century.

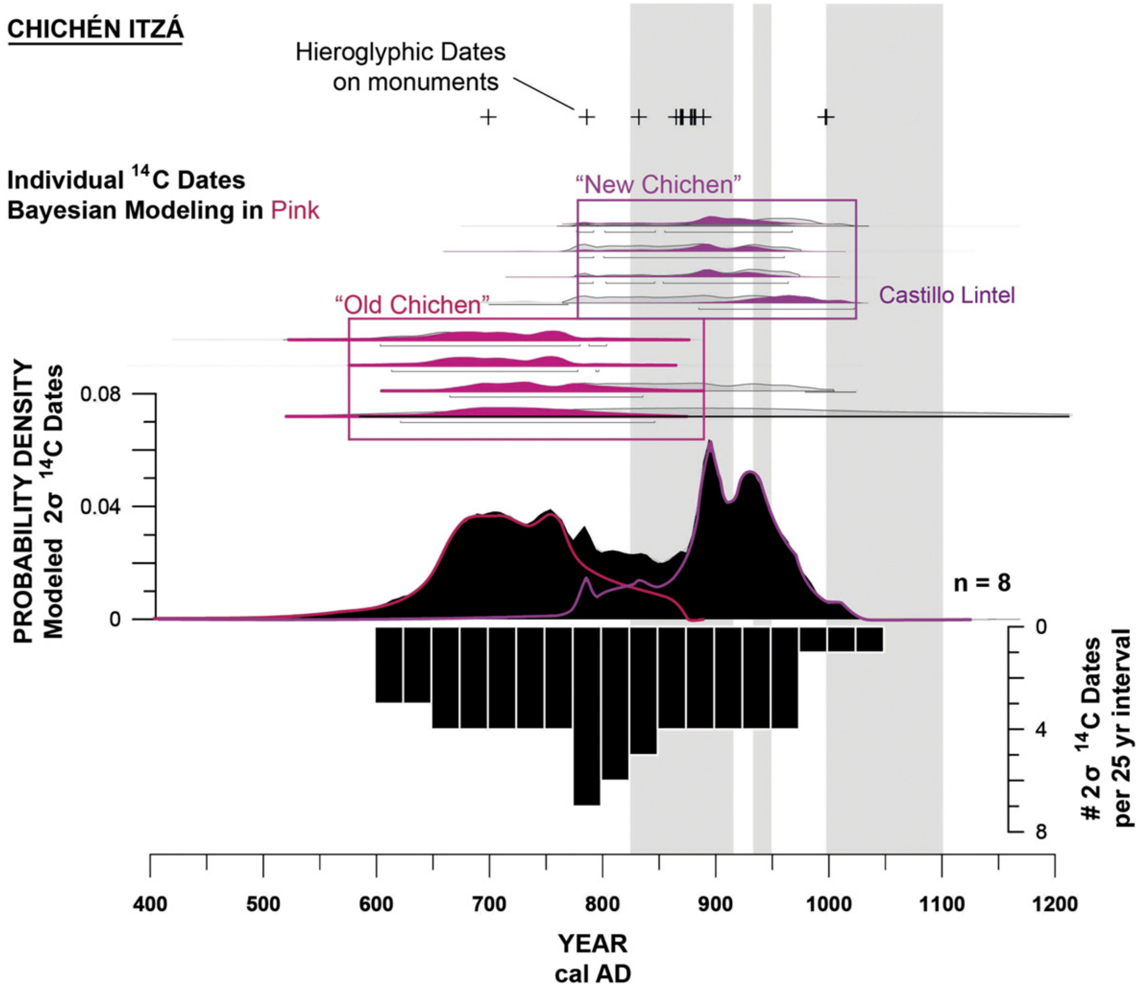

Fig. 6. Summed probability distributions of eight radiocarbon dates at Chichén Itzá that passed the chronometric hygiene criteria, plotted against individual ^{14}C dates shown with modeled Bayesian distributions in red, and hieroglyphic calendar dates on monuments. Gray shaded intervals show multi-decadal droughts in the Yok Balum climate record.

4.1.1. AD 1000–1050: eleventh century mega-drought and the fall of Chichén Itzá

After the chronometric hygiene assessment, eight radiocarbon dates were retained from monumental contexts at Chichén Itzá, with four dates (Volta and Braswell, 2014:Table 13.2) associated with the later constructions on the Great Terrace (Fig. 6). In order to assess when the Great Terrace of "New Chichen" was constructed, we modeled dates passing the chronometric hygiene criteria in a *Sequence* that assumes that Stage IV from Braswell and colleagues' (Braswell and Peniche May, 2012; Volta and Braswell, 2014) Great Terrace excavations chronologically preceded the cut date for a lintel from the Castillo.[3] This chronological model produces a summed probability distribution between cal AD 775–970 for the construction of Stage IV of the Great Terrace and cal AD 880–1025 for the Castillo lintel[4] (see Appendix B for details on modeling the dates in OxCal). As mentioned previously, this estimate is likely conservative if the outer portion of the lintel was removed in the carving process. Based on this modeled sequence, we estimate that the final construction of the Castillo, and possibly other International style structures in the "New Chichen" sector of the site, to date between cal AD 900 and 1050. The correspondence between the final carved monument date aligns well with these data, and suggests some of the final large-scale political activities at the site occurred after cal AD 1000.

A concurrent wave of political collapse in the Puuc region appears to have occurred at Chac II and Xkipché at around the same time as at Chichén Itzá (Fig. 5). As no hieroglyphic inscriptions with calendar dates have been identified for either site, we rely on the radiocarbon evidence to assess the timing of collapse of those polities. Nineteen dates from monumental contexts at Chac II and 25 dates from Xkipché were retained using the chronometric criteria. Additional information about stratigraphic relationships reported with the radiocarbon dates allowed us to model the age of monumental construction (Smyth, 1998; Smyth and Rogart, 2004; Vallo, 2003) more effectively. These analyses yield summed probability distributions between cal AD 400 and 1000 at Chac II and cal AD 550–1050 at Xkipché. These data suggest that the chronology of political collapse at Xkipché and Chac II differed from many centers in the Puuc region. First and second-rank urban centers such as Uxmal and Sayil experienced political disintegration in the first half of the tenth century. However, lower-rank settlements such as Chac II and Xkipché may have flourished after the end of Uxmal's influence.

The number of radiocarbon dates from Puuc sites declined approximately 50%[5] from cal AD 950 to 975, suggesting that the end of monumental construction and political activity of some lower-level Puuc centers occurred within a century of the final political activities at Chichén Itzá (after AD 1000). This correspondence is striking, as Chichén Itzá, Chac II, and Xkipché went into decline within the context of the most severe drought of the Yok Balum climate record.

Evidence for increased monumental construction at coastal sites can be identified during this second wave of political collapse of interior portions of the northern Yucatán during the first half of the eleventh century. A total of 12 radiocarbon dates were recorded from across the north and eastern coast of Yucatán from Isla Cerritos, San Gervasio, Isla Cancun, and Tulum. After applying the chronometric hygiene criteria, only 6 dates were retained from Isla Cerritos and Tulum (Fig. 7). Three samples from Isla Cerritos derive from stratigraphic levels in Structure 8 (TP12). We used this contextual information to constrain the radiocarbon distributions. We modeled these dates in a *Sequence* that places Beta-14083 (level 7) chronologically earlier than Beta-14082 (level 4). The Bayesian model constrained the latter two dates between cal AD 980–1215 (see Appendix B for the chronological model). There were two samples that came from level 7 of Structure 13 at Isla Cerritos. Of these dates, Beta-14085 was thought too late for its context, in contrast with Teledyne I-14244 from the same level (Andrews et al., 1988; Gallareta Negrón, 1989). The resulting summed probability distribution of radiocarbon dates from Isla Cerritos and Tulum spans between cal AD 650–1250.

The shift from interior settlements to those along rivers, lakes, and coastal regions during the Postclassic period (~AD 1000/1100–1511) has been noted by a number of scholars (Masson, 2000; Santley et al., 1986; Turner and Sabloff, 2012:13908). Although the radiocarbon assays from coastal sites are limited, these data demonstrate this shift towards the coast, with an increase in the radiocarbon distributions at Isla Cerritos and Tulum in the interval between cal AD 1025–1050. These trends are chronologically correlated with the worst drought recorded in the Yok Balum record, which suggest that polities along the coast were more resilient in the face of drought. This may be due to these populations' access to marine resources and greater connectivity with long-distance economic and political networks. These results parallel many of the findings of previous studies. Although the coastal areas would have offered more stable food resources, it was not the only area fostering resilience (at least in occupation and large-scale political activity). Sites along freshwater drainages towards the coasts, lagoons, rivers, and those with *cenotes* and *aguadas* may also have been preferred areas for occupation. Evidence for the survival of populations at smaller sites during the 11th century has been noted for well-watered areas such as in northern Belize (Masson, 2000; Masson and Rosenswig, 2005; Pendergast, 1986) and in the Petén Lakes region (Rice and Rice, 2009). At Caye Coco in northern Belize, ceramics and radiocarbon dates suggest that Chichén Itzá influenced ceramics disappeared at some sites across the Maya lowlands during the eleventh century (Masson and Rosenswig, 2005, see Chase, 1982 and Walker, 1990 for identification of the ceramics). The radiocarbon and epigraphic record from Chichén Itzá and the other areas of the northern and central lowlands indicates a decline in large-scale construction with a congruent shift in occupation to more stable resource zones during the eleventh century.

4.1.2. AD 1150–1300: The emergence and growth of the late Postclassic capital at Mayapán

Radiocarbon dates from Mayapán comprise the entirety of evidence for understanding political developments following the eleventh century. Monuments at Mayapán are exclusively inscribed in the *tun ajaw* calendar format, which makes direct correlations with the Gregorian calendar uncertain. However, Masson and colleagues (Peraza Lope et al., 2006; Masson and Peraza Lope, 2014:59,80) place three important stelae at AD 1185, 1244, and 1285. They suggest that the two former dates are associated with founding events that were associated with cycles in the ritual calendar. Radiocarbon dates from Mayapán offer support for the increase in political activity during this time. We identified 41 radiocarbon dates from various projects that have focused their research at the site (Peraza Lope et al., 2006: Table 1; de Vries et al., 1958:136). In order to assess the development and decline of political activity at the site, we explore the radiocarbon dates exclusively from monumental contexts. After the chronometric hygiene assessment, 31 radiocarbon dates were retained from monumental contexts at Mayapán (Appendix A). Several dates, such as GrN-451, A-12783, and A-13861 were rejected for their large errors (>100 yrs). In addition, dates from several monumental contexts (such as GrN-450, A-12796, and A-12792) yielded modern or ambiguous temporal distributions that may be associated with recent activities or disturbance.

Although some evidence has been identified for early occupation at Mayapán, these data suggest that the population was small and monumental construction likely began by the middle of the twelfth century (Peraza Lope et al., 2006:157–160). In terms of political activity, there

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[3] Beta-295908 (Stage V, Great Terrace) shows poor agreement (A = 5.9%; A'c = 60.0% General Outlier Model, Bronk Ramsey, 2009) when the date is placed in a Sequence after Stage IV and prior to the Castillo lintel. This supports Volta and Braswell's (2012) rejection of the date.

[4] Although our methods and software (OxCal) differed from those of Volta and Braswell (2014:380–383), the Bayesian model yields the same result for the "New Chichen" dates.

[5] This estimate is 50% ± 20.5% at the 95% confidence interval.

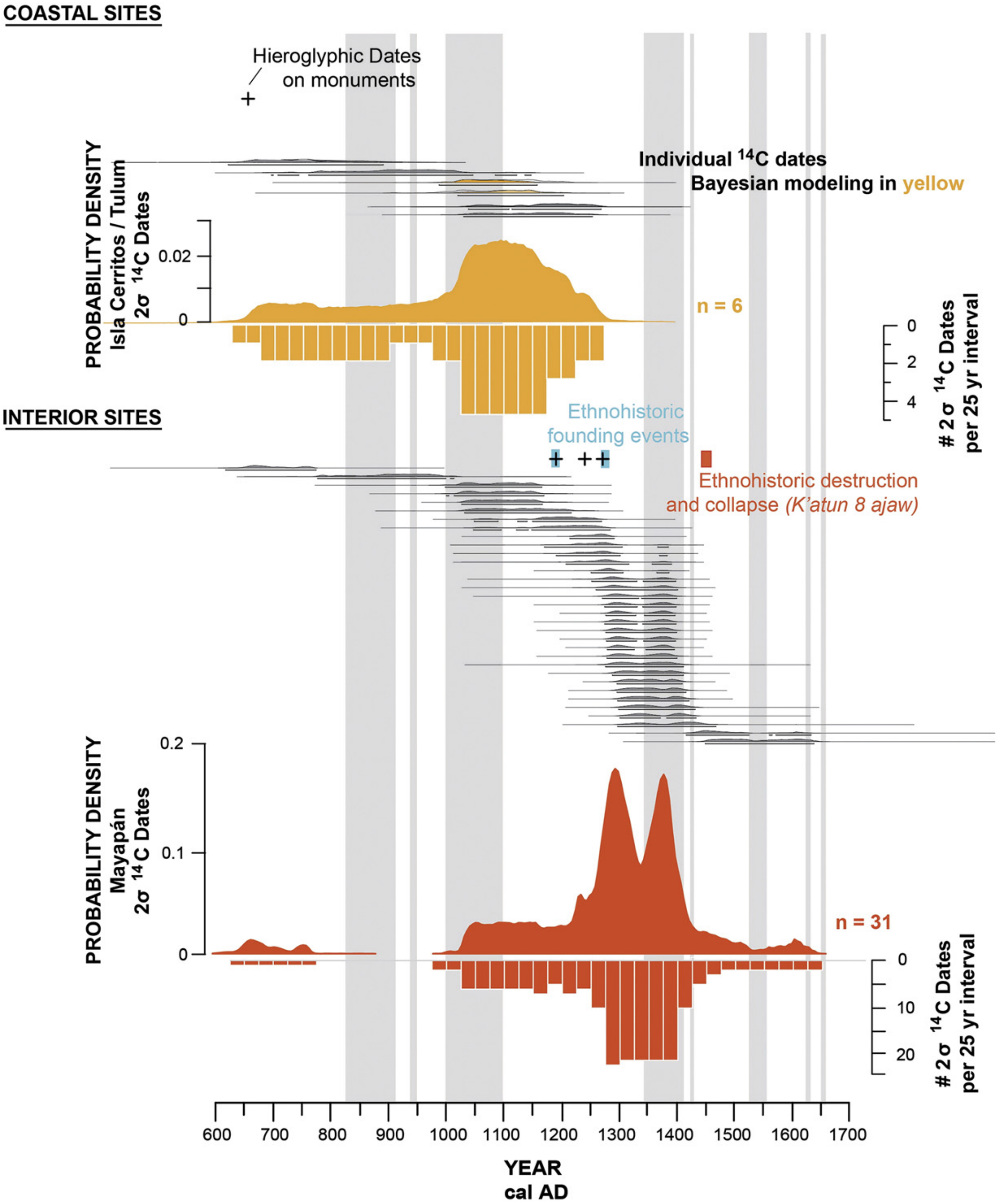

Fig. 7. Summed probability distributions, with individual modeled and unmodeled ^{14}C dates from Isla Cerritos, Tulum and Mayapán showing the interval of political activity at coastal sites and the emergence of Mayapán as a regional center.

is a correspondence between calendar dates and associated ethnohistoric foundation events with an increase in the probability density of radiocarbon dates from monumental contexts. This would suggest an increase in political activities and construction during the latter half of the thirteenth century. Similarly, a decline of 73%[6] of radiocarbon distributions from 1400 to 1425 indicates a substantial decline in political activity. This evidence for political decline is paralleled in ethnohistoric accounts of the destruction and collapse of the Mayapán state in *K'atun* 8 *ajaw* from 1441 to 1461. These data suggest that political activity at Mayapán may have been in decline as early as the turn of the fifteenth century. This period has been characterized as being fraught with political turmoil and violence (Masson and Peraza Lope, 2014:536–537). While political factions described for Mayapán's political structure may explain the downturn in the site's fortune, it is notable that an extended dry interval is recorded from around AD 1350–1400. Even if drought did not play a role in Mayapán's demise, it is important to point out the regional capital developed during a return to stable environmental conditions following the eleventh century severe and

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[6] Taking into consideration the sample size, these data show a decline of 73% ± 20% at the 95% confidence level.

protracted drought. This suggests that cycles of political centralization and balkanization are at least loosely tied to broad climatic patterns.

5. Discussion

Severe droughts are well documented across the northern and southern Maya lowlands from the ninth to eleventh centuries (Curtis et al., 1996; Douglas et al. 2015; Hodell et al., 2005; Hodell et al., 1995; Kennett et al., 2012; Medina-Elizalde et al., 2010; Webster et al., 2007). These episodes are chronologically associated with the period of political collapse and societal disruption at the end of the Classic period. Numerous studies have noted that cities in the northern Maya lowlands, characterized by lower annual rainfall and fewer freshwater bodies of water (e.g., lakes and rivers), persisted and even flourished after AD 850 when political disintegration and abandonment occurred in the south. In 2002, Bruce Dahlin suggested that the drier conditions in the north, coupled with rich resource zones and integration within expansive exchange networks, served as adaptive advantages for northern lowland populations that allowed for the growth of some centers (e.g. Chichén Itzá). He suggested that these and other adaptations (such as increased militarism) explain the paradox in the archeological and climate records. However, more precise chronological evidence was needed to fully explore these issues.

In this study, hieroglyphic and radiocarbon dates from across the northern Maya lowlands identified two waves of political disintegration at the end of the Classic period. The first occurred between AD 850 and 950 throughout the interior and Puuc regions, including at Uxmal. These changes are chronologically associated with a series of multi-decadal droughts during the ninth and the beginning of the tenth centuries. The second wave of political collapse is highlighted at Chichén Itzá between AD 1000 and 1100. Puuc centers, such as Xkipché and Chac II, also appear to have persisted in the face of drought into the ninth and early tenth centuries. The end of political activity at those centers aligns with the chronological evidence at Chichén Itzá and coincides with the longest and most severe drought recorded in the regional climate records between AD 1000 and 1100. In the midst of the political collapse of Chichén Itzá, settlements along the northern coast of Yucatán experienced growth marked by continued monumental construction. Evidence for activity is also noted at some sites, including residential activity at Xuenkal and ritual activity at Balankanche Cave (Appendix A).

The persistence of Chichén Itzá and some Puuc centers to the beginning of the eleventh century cannot be accounted for solely on the basis of environmental differences. Populations at Chichén Itzá had continuous access to water through the large *cenotes* at the site. In contrast, populations in the Puuc region principally relied on cisterns (*chultunob*) and *aguadas* for storing water from seasonal rains. However, water was more accessible in some parts of the Puuc region, including near Chac II, as Stephens (1843) recorded local populations journeying more than 5 km underground within the Gruta de Chac to obtain water. However, no literature mentions the presence of land features that would have allowed populations to access the water table at or near Xkipché. In addition, the site of Xcoch, with access to water within the Gruta Xcoch did not persist for as long as Chac II. Smyth et al. (2010) suggest that the large *aguadas* may have diverted surface water from draining into the cave and limited access to water during drought intervals. These data suggest that consistent access to the underground water table was not a deciding factor for persistence and that other factors may have influenced the longevity of occupation and construction at Xkipché. Furthermore, it is unlikely that *cenotes* or underground access to water lessened the effects of drought on agricultural production. However, some common attributes may be identified for the persisting centers. Archeological evidence, including artifact types and styles, sources of lithic materials, or architecture indicate that these centers participated in broad economic or political networks across Mesoamerica (Braswell and Glascock, 2003; Kepecs et al., 1994). Chichén Itzá appears to have adopted strategies for dealing with climatic drying. Interregional interaction may account for these differences. Control of salt production along the coast may have provided valuable exchange goods that allowed for participation in interregional networks of exchange (Kepecs, 2003). The presence of central Mexican obsidian and trade goods from across Mesoamerica at Xkipché suggest integration within the Itzá economy (Braswell et al., 2011).

The growth of Chichén Itzá in the midst of episodic multi-decadal droughts during the ninth and tenth centuries may be associated with cultural and political adaptations. The shift in architecture and material culture, from Puuc to International styles, indicates that the polity may have adapted to losses in agricultural or economic production through participation in interregional networks of exchange. Evidence of increased militarism in the epigraphic record at Chichén Itzá may also suggest territorial expansion focused on increasing access to limited resources. Freidel and colleagues (Freidel and Shaw, 2000; Freidel and Reilly, 2010) argued that surplus maize was exchanged and converted into durable goods to deal with periodic shortages. Furthermore, Masson and Freidel (2012) argued that food may have been exchanged within higher rainfall zones within the traditional 150–175 km distances for overland transport, and even greater distances using watercraft. These adaptations may have mitigated smaller, shorter droughts, and expanded the procurement of goods and materials from areas with available resources.

Braswell (2012) argues that shifts in construction and population towards the coasts in the northern lowlands offer evidence that sea-borne trade and participation in broader economic networks may have served as an adaption to changing environmental conditions. Our results offer evidence of this marked shift towards the coast. In addition, the chronological evidence indicates that interior cities that persisted into the late tenth and early eleventh centuries were integrated within the Itza economy, marked by the dominance of central Mexican obsidian and other trade goods from across Mesoamerica. Radiocarbon evidence indicates that monumental construction at Mayapán began in the mid-twelfth century (Peraza Lope et al., 2006). These data, along with available hieroglyphic and radiocarbon dates from Chichén Itzá, suggests that monumental construction and political activity in the interior of the Yucatan peninsula was greatly reduced between AD 1025 and 1100. The congruence of the climate records during this interval is striking and suggest that the worst drought in over 2000 years may have restricted the mobilization of labor for large-scale monumental construction. We argue this was likely the result of severe socioeconomic drought impacting food production, as experienced during the “Great Famine” between AD 1765 and 1773 in and around Mérida (Hoggarth et al., accepted for publication). As the eleventh century droughts appear far more severe and protracted than the eighteenth century drought in the Yok Balum record, we suspect that the migration and mortality recorded during the Colonial period may have also affected eleventh century populations.

6. Conclusions

Greater emphasis has been placed on studying the complex relationships between climate, environment and cultural dimensions of social change in Mesoamerica (Beach et al., 2015; Chase and Scarborough, 2014; Hodell et al., 2000; Iannone, 2014; Kennett et al., 2012; Kennett and Marwan, 2015; Luzzadder-Beach et al., 2012; Neff et al., 2006; Stahle et al., 2011). These studies are integral because they offer the opportunity to explore variability in cultural responses and adaptations within and between diverse ecosystems and geographic regions. The impact of humans on the environment during the transition to the Anthropocene makes archeological and historical studies on climate change relevant today (Erlandson and Braje, 2014). Archeological and historic case studies provide integral sources of time depth to understand how climate change will affect populations in the future (Riede, 2014). Examining the impacts of climate on complex, rainfall-dependent, agricultural societies such as the ancient Maya offers the potential to understand how global shifts in climate will affect modern populations. These studies are especially relevant for populations in Mesoamerica and Central America or those reliant on similar systems of food production (Kennett and Beach, 2013; Beach et al., 2015).

These methods offer new ways to explore human-environment interactions at sites across the Maya lowlands where ceramic chronologies have been debated (e.g., Hoggarth et al., 2014). Using these independent methods to evaluate chronological patterns of social change allowed for periods of monumental construction and political activity to be identified in the northern Maya lowlands. Pursuing multiple lines of evidence, we identified congruencies between hieroglyphic and radiocarbon datasets to understand the regional and climatic context of the political collapse of Chichén Itzá and other centers in northern Yucatán. We identified two intervals of political disintegration across the northern Maya lowlands. The first corresponded to a period of political collapse at centers in the Puuc and other interior regions from AD 850–925. The expansion and florescence of Puuc centers was identified by an increase in the summed probability distributions of radiocarbon dates and hieroglyphic texts dating between AD 750 and 910. Like many other political centers in northern Yucatán, evidence for political disruption and the end of the dedication of carved monuments and monumental construction is noted around the turn of the tenth century. However, Chichén Itzá endured this interval of societal disruption, with evidence for renewed political activities identified for the latter half of the tenth century. This interval corresponds with a period of increased rainfall in the Yok Balum record and may suggest that broad climatic trends influenced the ability of polities to expand through increased production and availability of food and other resources. Chichén Itzá's militaristic and territorial expansion may have also served as social responses to acquire increasingly limited resources as populations expanded.

The second interval of political collapse occurred around AD 1000 and featured the end of monumental construction and hieroglyphic inscriptions at some Puuc centers and at Chichén Itzá around AD 1025–1050. The available data limits our ability to definitively pinpoint the end of International style construction at Chichén Itzá. However, the Castillo lintel was one of the last additions to this structure and we suspect that other construction episodes in the "New Chichen" sector of the site also date to the first half of the eleventh century. The end of the epigraphic record at AD 998 is consistent with this interpretation. The temporal correlation between the political collapse of Chichén Itzá and the longest and most severe drought in the Yok Balum record suggests that the severity of eleventh century droughts affected even well adapted populations and political systems. An interval of revival is noted at coastal centers around AD 1000. As migration and dispersal is recorded for historic records in colonial Yucatán, populations may have relocated across the landscape to areas with accessible water and resources. Coastal locations, in addition to those along lakes, rivers, and lagoons, offered marine resources that were only minimally affected by meteorological or agricultural drought. The development of the Late Postclassic capital at Mayapán came after the worst drought of the past 2000 years, during a period when precipitation returned to normal levels. Coastal sites continued to surge and prosper in the wake of Mayapán's collapse until the arrival of the Spanish (Masson and Peraza Lope, 2014), similar to the period after the fall of Chichén Itzá.

Results from this study indicate that environmental variability was not the sole determinant of cultural and political adaptations to intervals of severe drought. Evidence in the northern Maya lowlands suggests that the most successful polities, such as Chichén Itzá, expanded their networks of political and economic interaction to increase access to declining resources in the face of drought at the end of the Classic period. Increased chronological precision and archeological studies focused on the effects and responses of populations to climate change in the Maya lowlands and across Mesoamerica contribute to our understanding of these complex issues.

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