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# Reaching the human scale: A spatial and temporal downscaling approach to the archaeological implications of paleoclimate data

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ABSTRACT

Assessing the implications of paleoclimatic and paleoenvironmental data at temporal and spatial scales that would have directly intersected with human decision-making and activity is a fundamental archaeological challenge. This paper addresses this challenge by presenting a spatial and temporal downscaling method that can provide quantitative high-spatio-temporal-resolution estimates of the local consequences of climatic change. Using a case study in Provence (France) we demonstrate that a centennial-scale Mediterranean-wide model of Holocene climate, in conjunction with modern geospatial and climate data, can be used to generate explicit and solidly-grounded monthly estimates of temperature, precipitation, and cloudiness at landscape scales and with annual resolution, enabling consideration of climate variability at human scales and meeting the data requirements of socioecological models focused on human activity. While the results are not reconstructions – that is, particular values are single realizations, consistent with the coarse-grained data but not individually empirically derived nor unique solutions – they provide a more suitable basis for assessing the human consequences of climate change than can coarse-grained data.



## 1. Introduction

Interpreting the consequences of environmental change for past peoples is a longstanding concern of archaeology, and often the 'hook' for paleoclimatic or paleoenvironmental studies as well. Developing explanatory links has remained a persistent challenge, however, and studies that are able to move beyond correlation to causation remain rare. Much of this difficulty results from the challenge of assessing the implications of paleoclimatic and paleoenvironmental data at temporal and spatial scales that would have been directly relevant to human decision-making and activity. We address this problem by developing a spatial and temporal downscaling method that can provide quantitative high-spatiotemporal-resolution estimates of the local consequences of climatic change. Using a case study in Provence we demonstrate that a centennial-scale Mediterranean-wide model of Holocene climate, in conjunction with modern geographic and climatic data, can be used to generate solidly-grounded monthly estimates of temperature, precipitation, and cloudiness at a 300 m spatial scale and with annual resolution. These results, it must be emphasized, are not reconstructions: they are single realizations consistent with coarse-grained data, but individual values are not directly empirically derived. Downscaling generates one set of values consistent with the coarse-grained input data, but the results are not unique solutions (Bierkens et al., 2000, p. 111; Wu and Li, 2006, p. 35). However, they provide a more suitable basis for assessing the human consequences of climate change than can coarse-grained data, as analyses of past human-environment interaction grounded in anthropological archaeology require high spatial and temporal resolution. Anthropological archaeological explanation relies on theoretical models of human behavior and decision-making that are necessarily grounded in human experience: spatial and temporal scales measured in hectares and years rather than regions and

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centuries.

In this paper we review these issues of scale and resolution in the study of past human-environment interactions before demonstrating how spatial and temporal downscaling has the potential to address the challenge of relating spatially and temporally coarse-grained paleoclimate data to fine-grained anthropologically-grounded explanations of past human behavior. We explore the application of spatial downscaling of paleoclimate data to provide high spatial resolution, and temporal downscaling to provide high temporal resolution. This combined approach enables consideration of landscape-scale spatial variability in past climates (vital in topographically diverse landscapes in which climate effects would not have been spatially uniform) as well as consideration of interannual variability. Such downscaling is a necessary tool for considering the human consequences of climate changes documented in spatial and temporal aggregate.

## 2. Scale and resolution in the study of past human-environment interactions

Description and analysis of past human-environment interactions, particularly over the long-term, comprises a fundamental goal of archaeology. This focus underlies several of the recently-articulated “grand challenges for archaeology” (Kintigh et al., 2014), and has been singled out in 21st century discussions of the discipline as central to archaeology's contribution to interdisciplinary efforts to understand past and present socio-environmental systems, as well as of pressing modern relevance (e.g., Van der Leeuw and Redman, 2002; Smith et al., 2012).

Analysis of long-term human-environment interactions promises improved understanding of both cultural and environmental trajectories, and provides a tool for examining the anthropogenic component of past and modern environment and climate. It is fundamental to ongoing debates over the Anthropocene, in which archaeologists, paleoenvironmental scientists, and geologists dispute the antiquity, character, and significance of that period (e.g., Braje, 2015; Crutzen and Steffen, 2003; Erlandson and Braje, 2013; Morrison, 2015; Ruddiman, 2013; Smith and Zeder, 2013; Zalasiewicz et al., 2015).

However, such analysis continues to be challenged by problems of spatial and temporal scale and resolution (cf. Contreras, 2017). The problem is not unique to archaeology, but central also to modern discussions of climate change: what are the local consequences of global climate? In analytical terms, how can we move from global summary data to local characterizations that enable consideration of the human consequences of climate change? Moreover, as the global effects of local behaviors can also be significant for large-scale modeling, the inverse problem is also an important focus: in order to estimate the aggregate global impact of local behaviors, those behaviors must themselves be modeled, taking into account how diverse actors respond to local conditions.

The need to reconcile contrasting scales and resolutions results partly from evidentiary constraints, and partly from contrasting foci and explanatory mechanisms of archaeology on the one hand and paleoclimatic and paleoenvironmental science on the other. Paleoclimatic and paleoenvironmental science often strives to achieve regional and long-term relevance, resulting in coarser (regional and centennial) scales of analysis. In contrast, archaeological explanation relies fundamentally on anthropological models of behavior – i.e., understandings of human activity that are grounded in decision-making at local and annual scales. As a result, linking analyses that focus on distinct scales, with varying resolutions, is vital to relating archaeological and paleoclimatic and paleoenvironmental data, and has been the focus of both practical and theoretical consideration in archaeology (e.g., Stein, 1993; Lock and Molyneaux, 2006; Robb and Pauketat, 2013; Kintigh and Ingram, 2018). Nevertheless, analysis (and even description) of human-environment interaction remains difficult at best with coarse-grained data, and must confront basic questions of scale and resolution: In space, what do regional-scale data mean for landscape-scale experience, and in time, what do centennial-scale data mean for annual or seasonal experience?

This problem is endemic to applications of regional modeling to archaeological explanation (cf. Brayshaw et al., 2011, p. 28): even when they succeed in revealing interesting patterning, coarse-grained models can suggest broad correlations but require finer-grained analyses if explanatory linking mechanisms are to be pursued. High-resolution empirical data might be ideal, but it is (given the character of paleoclimatic, paleoenvironmental, and archaeological archives) rare and spatially and temporally uneven. In their absence, when only a limited number of observations for a broad area with varied topography may be available from recorded and/or modeled data, it is possible to take modern data from that area and, presuming the climate-geography relationships to have remained relatively constant over time, reconstruct realistically spatially variable climate data. Similarly, modern (recorded) interannual variability can serve as the basis for realistically modeling temporal variability in climate variables. Spatial and temporal downscaling thus offer a way of mobilizing uneven data to explore potential linking mechanisms between climate variables and human behavior, and ultimately a way of developing arguments that move from correlation to explanation.

### 2.1. Downscaling

Downscaling addresses the problem of deriving small-scale values from large-scale aggregates (Bierkens et al., 2000, pp. 111–118; Wilby et al., 2004; Wu and Li, 2006, pp. 34–36). The principle is that any summary value is by its definition a product of a number of possible individual values that even when not precisely known can be probabilistically estimated. We focus here on statistical downscaling of low-resolution climatic data to enable generation of climate variables at the landscape scale. This is based on applying relationships between high-resolution and low-resolution fields, calibrated based on time periods where both exist, to the target low-resolution field.

The climate-modeling community has explored downscaling of climate data, stimulated by the desire to address regional impacts of climate change in scenarios where global climate models (GCMs) are the primary data source (cf. Fowler et al., 2007; Wilby et al., 2004). The focus has primarily been on future impacts, but the paleoclimate community (e.g., Korhonen et al., 2014; Levavasseur et al., 2011; Vrac et al., 2007) has also begun to explore the potential of downscaling methods as means of examining regional or implications of global models of past climate. Geographically-based downscaling (e.g., Joly et al., 2010; Martin et al., 2013; Vrac et al., 2007) is one means of dealing with spatially heterogeneous landscapes, and is particularly valuable for applications to past climates, as geographic variables are generally stable over archaeological timescales, whereas regional climate relationships to GCMs may have been significantly different in the past (cf. Vrac et al., 2007, p. 670).

Geographically-based methods that have been applied to paleoclimatological data are based on the calibration of potentially non-linear relationships between the target high-resolution variable and its low-resolution version, where the latter is complemented by high-resolution geographical variables (topography, distance to sea, etc.; see Vrac et al., 2007). The most appropriate calibration technique is generally recognized to be a generalized additive model (GAM) (Hastie and Tibshirani, 1990) or a multinominial