Complex societies precede moralizing gods throughout world history

Harvey Whitehouse[1,14], Pieter François[1,2,14], Patrick E. Savage[1,3,14]*, Thomas E. Currie[4], Kevin C. Feeney[5], Enrico Cioni[6], Rosalind Purcell[6], Robert M. Ross[1,7, 8], Jennifer Larson[9], John Baines[10], Barend ter Haar[10], Alan Covey[11], Peter Turchin[12,13]

SUPPLEMENTARY INFORMATION

This section repeats some key information from the Supporting Information (SI) Appendix of ref. 8 (Turchin et al., 2018, "Quantitative historical analysis uncovers a single dimension of complexity that structures global variation in human social organization", *PNAS*). We present this information here in order to enable readers to understand key points of our approach as they relate to the present paper, our general methods, and the ways in which these methods were validated for measuring social complexity (SC).

Structure of Seshat: Global History Databank

Currently Seshat utilizes a sample of 30 locations across the globe, which were chosen in a stratified manner to provide even coverage to different world regions and to cover a broad range of societies at different levels of complexity. For each of the 30 global points we start at a period just before the Industrial Revolution (typically, 1800CE or 1900CE depending on the location) and go back in time to the Neolithic or equivalent period (subject to the limitation of data).

Unit of analysis: Our unit of analysis is a polity, an independent political unit that ranges in scale from villages (local communities) through simple and complex chiefdoms to states and empires. What distinguishes a polity from other human groupings and organizations is that it is politically independent of any overarching authority; it possesses sovereignty. See http://seshatdatabank.info/methods/codebook/ for further definitional details for this and other key terms.

Our dataset for this paper is made up 47,615 records (Supplementary Dataset) relating to social complexity, ritual, and religion.

[1] Centre for Anthropology and Mind, University of Oxford, Oxford OX2 6PE, UK
[2] St. Benet's Hall, Oxford OX1 3LN, UK
[3] Faculty of Environment and Information Studies, Keio University, Shonan Fujisawa Campus, Fujisawa, Kanagawa 252-0882, Japan
[4] Human Behaviour & Cultural Evolution Group, Department of Biosciences, University of Exeter, Cornwall TR10 9FE, UK
[5] School of Computer Science and Statistics, Trinity College Dublin, Dublin 2, Ireland
[6] Seshat: Global History Databank, Evolution Institute, San Antonio, FL 33576, USA
[7] ARC Centre of Excellence in Cognition and its Disorders and Department of Psychology, Royal Holloway, University of London, Surrey TW20 0EX, UK
[8] Department of Anthropology and Archaeology, University of Bristol, Bristol, BS8 1TH, UK
[9] Department of Modern & Classical Language Studies, Kent State University, Kent, OH 44242, USA
[10] Faculty of Oriental Studies, University of Oxford, Oxford OX2 6LU, UK
[11] Department of Anthropology, University of Texas Austin, Austin, TX 78712, USA
[12] Department of Ecology and Evolutionary Biology, University of Connecticut, CT 06269, USA
[13] Complexity Science Hub Vienna, 1080 Wien, Austria
[14] These authors contributed equally: Harvey Whitehouse, Pieter François, Patrick E. Savage
* e-mail: psavage@sfc.keio.ac.jp

Systematic sampling of past societies

Geographic sampling & Natural Geographic Areas (NGAs): To ensure that we collected data in a systematic manner we divided the world into ten major regions (see Figure SI1 and Table SI1 in ref. 8). Within each region we selected three natural geographic areas (NGAs) to act as our basic geographical sampling unit. An NGA is an area delimited by naturally occurring geographical features that are common places for human settlements to occur (for example, river basins, coastal plains, valleys, and islands). For data collection purposes each NGA is defined spatially by a boundary drawn on the world map (available at http://seshatdatabank.info/data). The extent of the NGAs does not change over time. The geographical features of NGAs themselves are not a current focus of investigation but rather act as our fixed points which determine which societies we collected data for.

Stratification for maximizing variation in socio-political organization: Within each world region we looked for NGAs that would allow us to cover as wide a range of forms of social organization as possible, which includes societies that are not traditionally thought of as complex ("small scale societies", "egalitarian tribes", "acephalous societies"). Within each world region we chose three NGAs, with one of each showing the following characteristics: 1) earliest developments of some kind of large-scale or centralized, stratified society that existing scholarship would refer to as a "complex society", 2) free of such "complex" societies until the modern or colonial period, and 3) intermediate in terms of the time that political centralization emerged. Because different world regions acquired centralized societies at different times there can be substantial variation across "early complexity" Note that these NGAs were selected and their selection criteria published[29] *before* collecting any data about moralizing gods or doctrinal rituals. It is of course possible that data from other polities in other NGAs could provide more information; however, we have no reason to suspect that the NGAs used in these analyses are unusual or unrepresentative in terms of the relationship between social complexity and religiosity. In the future we hope to collect data for many dozens more NGAs and these data will eventually be used to test the generality of our results, (see the Supplementary Discussion in the SI Appendix of ref. 8 for further discussion of sampling challenges and generality of findings).

Temporal sampling of polities: To populate the Databank, for each NGA we consulted the literature and chronologically listed all polities that were located in the NGA, or encompassed it. We chose a temporal sampling rate of one hundred years meaning that we only included polities that spanned a century mark (100CE, 200CE, etc.) and omitted any polities that only inhabited an NGA between these points (e.g. a polity that existed in an NGA between 401CE and 499CE, would not be included in the final dataset, but a polity that went 405CE to 501CE would be include as existing at 500CE). Our preliminary assessment of the data being collected indicated that a 100-year duration is short enough to capture meaningful changes in the social complexity of historical societies, but not too short to lead to oversampled data ("oversampling" results when the succeeding point in time contains the same information as the preceding one, thus not adding to the overall information content of the data set in terms of variability). Note that because our logistic regression analysis fits autoregressive terms, we explicitly capture temporal autocorrelations in our analysis. Thus, more frequently sampled time-series would simply result in higher autocorrelation coefficients and would not fundamentally affect our analysis.

For those periods when the NGA is divided up among a multitude of small-scale polities (e.g. independent villages, or small chiefdoms) it is not feasible to code each individual polity. In such instances we use the concept of "quasi-polity," which is defined as a cultural area with some degree of cultural homogeneity that is distinct from surrounding areas and approximately corresponds to an ethnological "culture" [32, 55, 56] or an archaeological sub-tradition[57]. We then collect data for each quasi-polity as a whole. This way we can integrate over (often patchy) data from different sites and different polities within the NGA to estimate what a "generic" polity was like. This approach is especially useful for societies known only archaeologically, for which polity boundaries cannot always be precisely specified.

Polities that nominally spanned more than one century mark were carved up into smaller century-level polities for analysis when data were available to do so. When such temporal resolution was impossible, our primary analysis treated the variables as being present from the beginning of the polity in which they appeared. Note that in such cases, subsequent centuries with from within the same polity whose codings would be identical to the first century of that polity were excluded from the PCA to avoid pseudoreplication. To ensure that this treatment of century-level sampling did not affect our results, we conducted robustness analyses by performing random bootstrap resampling of different centuries from within polities that crossed more than one century mark (see robustness analysis number 4 in this paper and p. 17 of the SI Appendix in ref. 8).

As an illustrative example, here is how we treated several representative polities that occupied the Upper Egypt NGA in this analysis:

a) Rashidun Caliphate (632-661CE). This polity was excluded because it did not cross either the 600CE or 700CE century marks. 76 such short polities that failed to cross a century mark were excluded across all 30 regions.
b) Umayadd Caliphate (662-749CE). This polity crossed only a single century mark at 700CE, and was thus analysed as it existed at 700CE.
c) Ottoman Empire (1517-1798CE; NB: Although the Ottoman Empire existed from the 13th to the 20th centuries, it only occupied Upper Egypt from the Ottoman conquest of 1517 until Napoleon's invasion in 1798CE). This polity crossed two century marks at 1600CE and 1700CE. Because historical data allowed us to capture information to distinguish changes between 1600CE and 1700CE, this polity was split into two unique polities, each of which were treated separately in the analysis as they existed at 1600CE and 1700CE, respectively.
d) Dynasty I (3100-2901BCE). This polity crossed two century marks: one at 3100BCE, and one at 3000BCE. Since historical and archaeological data did not allow us to capture information to distinguish changes between 3100BCE and 3000BCE, all values coded for this polity were coded as being present from 3100BCE, and the duplicate values at 3000BCE were excluded from the PCA. However, in the robustness analyses, random resampling of this polity meant that in some cases this polity would be treated as existing at 3100CE and in others it would be treated as existing at 3000CE.

Overall, our analysis was based on 414 unique societies for which unique data were available for a given region and century (median duration: 158 years). Our robustness analyses confirmed that uncertainty in temporal resolution did not affect our primary conclusion that complex societies precede moralizing gods throughout world history.

It is important to point out that our use of 100-year sampling of polities and quasi-polities is best understood as a means of sampling the vast literature on past human societies rather than trying to impose a rigid framework on the human past. Our data coding procedures enable us to capture changes in a particular variable within the lifetime of a polity and also allow us to capture variation within a polity or quasi-polity where there is such evidence. We are also able to flexibly incorporate multiple lines of evidence and uncertainty as we outline below. Our analyses demonstrate that one century is short enough to capture meaningful changes in the social complexity, rituals, and religion of historical societies, particularly with regard to our strong and robust evidence that complex societies precede moralizing gods. Of course if it is possible in the future to accurately code at higher sampling rates (e.g. 10-year or 50-year intervals) consistently throughout world history, this could provide better resolution in future studies. Our current approach of 100-year sampling is at least greatly superior to existing approaches that either rely on synchronic data without any temporal resolution at all[32] or use temporal sampling of 1,000-year windows.[57]

Data Collection

Identifying social complexity variables and creating complexity characteristic measures:

The following text summarizes the methods that were previously performed and described in detail in ref. 8.

Researchers from different disciplines have defined social complexity in different ways, each definition emphasizing different aspects, and with different measures being put forward to capture social complexity[58-65]. Our approach is inclusive in that we attempted to code a variety of aspects of what different disciplines understand by social complexity, and attempted to be as "theory neutral" as possible in determining the list of variables on which to collect information. In developing this list of variables we consulted a number of researchers recognized to be historical and archaeological experts on societies from a variety of regions and time periods, and who represent a variety of theoretical persuasions. In total, we identified c.70 variables relating to social complexity that could potentially be coded across different societies (see http://seshatdatabank.info/methods/codebook/). Through our data collection process we found that some of these variables were easier to capture than others, or had information that was more widely recorded. For our final analyses we used information on the 51 variables that could reliably be identified and coded. The nature of the historical and archaeological records means that information can be patchy, so we deliberately built some redundancy into our coding procedures meaning that different variables act as proxies for nine complexity characteristics.

It was not possible to code data for all variables for all polities (see below). For our final dataset we set a threshold that for a polity to be included 30% of the variables had to be coded (i.e. at least 16 of the 51 social complexity variables). This was to strike a balance between unnecessarily throwing away information by setting the threshold too high on the one hand, and including too many poorly covered polities that might create problems in the analysis stage on the other. We previously explored the effects of adjusting this threshold in robustness analyses[8] (see below).

Data Coding Approach

Having identified the polities and quasi-polities, and defined our variable codebook, data collection for the social complexity variables occurred in two phases. In Phase I, research assistants searched published articles and books on a particular polity (often with advice from a regional or polity expert on what sources were likely to be most useful) in order to find information about each variable and enter it into the databank. In Phase II, where possible, experts on the polity, academic historians or archaeologists, went over the data to check coding decisions made by RAs and help us fill the gaps. Experts also indicate when the value should be coded as "unknown." When two or more experts disagree about the value or there is ongoing debate in the literature, all choices are entered as alternatives. For quantitative variables whose values are known only approximately, coders are instructed to enter a likely range [min, max] that roughly corresponds to a 90 percent confidence interval (i.e. omitting possible, but unlikely or unrepresentative values).

The coding procedure used in our databank has a number of features designed to address issues relating to the nature of historical and archaeological information. First, there is the value of the coded variable. For a numerical variable the value can be either a point estimate, or a range approximating the 90-percent confidence interval. Binary variables can take the following values: present, absent, inferred present, inferred absent, and unknown (a numerical variable can also be coded as unknown). "Inferred" presence or absence indicates some degree of uncertainty: when direct evidence of presence (for example) is lacking, but the expert can confidently infer it. For example, if iron smelting has been attested both for the period preceding the one that is coded, and for the subsequent period, we code it as "inferred present" even though there is no direct evidence for it (assuming there are no indications that this technology was lost and then regained). To incorporate this uncertainty into our analyses an inferred present coding is given a value of 0.9 (rather than 1) and inferred absent is given a value of 0.1 (rather than 0). We previously explored the effect of treating inferred codings identically to non-inferred codings (i.e. using 1 and 0 rather than 0.9 and 0.1) and found our results robust to these assumptions[8].

Binary variables can also have temporal uncertainty associated with them. For example, if we know that iron smelting appeared in the NGA at some point between 300CE and 600CE, we code period previous to 300CE as absent, the period following 600CE as present, and the period between 300CE and 600CE as effectively "either absent, or present".

As mentioned above, Seshat also reflects disagreements among the experts. When two or more experts propose different values for the same variable, all are entered. These values can also contain uncertainty. For example, a Seshat record may state that the population of a particular polity at 300BCE was either between 30,000 and 40,000 people (according to Expert I) or between 60,000 and 120,000 (according to Expert II).

Table S1 | Breakdown of Supplementary Dataset data analysed by type of coding uncertainty

Variable type	Number of Seshat records analysed in this paper	As percentage of data analysed
Unambiguous (e.g., "present", "absent", "daily", numeric)	35,647	74.9%
"Inferred"	7,565	15.9%
"Unknown" (missing data)	2,642	5.5%
Numeric range (e.g., 500-600)	1,255	2.6%
"Disputed" (expert disagreement)	506	1.1%
Total	**47,615**	**100%**

The second important part of a Seshat record is a narrative explaining why this particular variable was coded in this particular way. Typically, this narrative is first written by an RA, who may quote the relevant text from a reference (usually an academic book or article). The narrative is then checked and edited by experts as needed. Subsequent experts can add to it and disagree with previously recorded estimates.

The third part of a Seshat record is the references to publications or other databases. As of June 2018, Seshat included references from 2,137 unique sources. As not all the knowledge that can be brought to bear on these issues is necessarily in the literature a reference can also be attributed to an expert with knowledge of the polity. In such cases the expert makes a judgment on the coding themselves and provides a justification.

We expect that Seshat records will evolve as more experts are involved in checking them, and as new insights or evidence are produced by academic historians and archaeologists. As such changes occur, they do not simply overwrite the previous information; instead, the Databank stores these changes so that the evolution of any record can be examined at any later time. This feature of Seshat Databank ensures continuity and accumulation of knowledge. It also identifies gaps in our knowledge, where a lack of evidence prevents us from being certain about features of societies in the past.

Data Availability

All data reported in this paper (i.e. the full set of 414 polities from 30 NGAs with codings, detailed justifications and references for the social complexity, religion and ritual variables) are available open access at http://seshatdatabank.info/data. Researchers can also download updated and expanded versions of the databank from http://seshatdatabank.info/datasets/ as text files suitable for analysis and reuse.

The raw data and code specifically used in this analysis are available online at http://github.com/pesavage/moralizing-gods.

Statistical Analysis

Multiple Imputation (MI): Dealing with Missing Data, Uncertainty, and Expert Disagreement

Because of the fragmentary nature of the information that is available about past societies, it was not possible to reliably code all variables for all polities (~6% of data points could not be reliably coded due to lack of evidence). It is important that such cases are recorded as unknown rather than attempting to make guesses about these values based on limited knowledge[66] as this more accurately reflects our current understanding (or lack thereof) of past societies. Such missing data, however, present a challenge for the statistical analyses. Simply omitting rows in the data matrix that contain missing values is undesirable as it risks 1) throwing away valuable information from data points that could be coded, and 2) leading to biased estimates as some time periods and regions of the world are better attested than others.

To deal with missing values, as well as incorporate uncertainty and expert disagreement into our analyses, we use a technique known as multiple imputation[43], which involves replacing missing entries with plausible values that are sampled in probabilistic manner. This approach results in valid statistical inferences that properly reflect the uncertainty caused by missing values[67]. Multiple imputation procedures can vary depending on the type of variable and the type of data coding issue faced.

Expert disagreement. In cases where experts disagree, each alternative coding has the same probability of being selected. Thus, if there are two conflicting codings presented by different experts and if we create 20 imputed sets, each alternative will be used 10 times on average.

Uncertainty. Values that are coded with a confidence interval are sampled from a Gaussian distribution, with mean and variance that are estimated assuming that the interval covers 90% of the probability. For example, if a value of [1,000–2,000] was entered for the polity population variable, we would draw values from a normal distribution centered on 1,500 with an SD of 304. It is worth noting that this procedure means that, in 10% of cases, the value entered into the imputed set will be outside the data interval coded in Seshat. For categorical or binary variables, we sample coded values in proportion to the number of categories that are presented as plausible. For example, if our degree of knowledge does not allow us to tell whether a certain feature was present or absent at a particular time, then the imputed datasets will contain "present" for roughly one-half of the imputed sets and absent for roughly one-half of the sets.

Missing data. For missing data, we impute values as follows. Suppose that, for some polity, we have a missing value for variable A and coded values for variables B–H. We select a subset of cases from the full dataset, in which all values of A–H variables have values and build a regression model for A. Not all predictors B–H may be relevant to predicting A, and thus, the first step is selecting which of the predictors should enter the model (information on model selection is given below). After the optimal model is identified, we estimate its parameters. Then, we go back to the polity (where variable A is missing) and use the known values of predictor variables for this polity to calculate the expected value of A using the estimated regression coefficients. However, we do not simply substitute the missing value with the expected one (because as explained above, this is known to result in biased estimates). Instead, we sample from the posterior distribution characterizing the prediction of the regression model (in practice, we randomly sample the regression residual and add it to the expected value). We applied the same approach to each missing value in the dataset, yielding an imputed dataset without gaps. The overall imputation procedure was repeated 20 times, yielding 20 imputed sets that were used in the analyses.

Robustness checks

The PCA and multiple imputation procedures have previously been subject to extensive assumption checks and robustness checks to assess whether the results are dependent on various different modelling assumptions.[8] Overall the following descriptions demonstrate that our social complexity data are highly robust to the assumptions of the PCA and multiple imputation analyses.

Cross validation of multiple imputation procedure

For the multiple imputation to be a worthwhile procedure, we need to ascertain that the stochastic regression approach for predicting missing values actually yields better estimates than, for example, simply using the mean of the variable. To do this, we used a statistical technique known as k-fold cross-validation[68]. This is done by quantifying how well we can predict the value of a particular feature of a particular society based on known information about the values of other features in that society and the observed relationships between the known and the unknown variables in other societies. Cross-validation results indicate that regression models can predict all variables much better than the mean (Table 1 and Table SI2 in ref. 8), with overall predictability ($\rho 2$) varying between 0.53 and 0.84. Different world regions are also well predicted by the relationships between variables observed in other world regions. A general result of the cross-validation analysis is that it confirms that there is enough information within the dataset to allow internal prediction, which is the basis for the method of multiple imputation. We now turn to the results of multiple imputation for principal component analysis.

Assessing potential for bias in multiple imputation procedure

We assessed whether the multiple imputation method used in this study could have introduced bias into our results. The first thing to point out is that analyses on cases that are fully coded (and therefore did not have missing data imputed) did not result in parameter estimates or overall findings that were substantially different from our analyses that involved multiple imputation: PC1 explained ~77% of the variance in the main analyses with 30% missing data, but in the dataset with no missing values the proportion explained by PC1 was still 71%. We also created 100 "artificial" data sets that had the same pattern of missing values as the overall data set. The artificial data set was then subjected to the multiple imputation procedure. The "true" value of proportion of variance explained by PC1 in the full dataset was 0.706. Comparing this to the artificial data sets we find estimating PC1 resulted in a mean of 0.685 and a mode of 0.695 (range: 0.635 - 0.725; Figure SI9 ref. 8). These results indicate that overall the MI procedure works very well for the goals of our study and has not created a bias that is driving our results and conclusions.

Robustness analyses for Principal Component Analysis (PCA)

PCA was used to investigate the internal correlation structure characterizing the nine measures of social complexity calculated from the 51 variables as described above. Note that PCA cannot be appropriately performed using only the 51 raw variables because many of these are binary presence/absence variables and PCA requires continuous variables. Furthermore, there is a great deal of missing data due to the nature of the archaeological and historical that make comparisons at this level more challenging; this is why such binary variables are aggregated into the "complexity characteristics" described above. In our analyses only a single principal component, PC1, had an eigenvalue greater than 1 (see Table SI4 in ref. 8). Across 20 imputed data sets PC1 explains on average 77% of the variance in the complexity characteristics data, and the variation between imputed datasets is very low (95%CI = 0.4%). We conducted extensive validation of this analysis in ref. 8 (summarized below), all of which supported the idea that different aspects of social organization have co-evolved in predictable ways, and that the first principle component from this analysis (PC1) is a valid and useful proxy for measuring social complexity.

Adjusting the data inclusion threshold

In previous analyses we tested the effects of using different inclusion thresholds (our chosen default value being 30%). We tested the effects of performing PCA on datasets using 10%, 50% and 100% (i.e. only cases with complete codings) coverage thresholds (in the latter case multiple imputation was not required to impute missing values). Adjusting the inclusion threshold had little effect on the proportion of variance explained by PC1: 10% cutoff – n=418, r^2=0.76; 50% cutoff - n=409, r^2=0.77; 100% - n=205, r^2=0.71). Our results are therefore robust both to different levels of missing data and to the multiple imputation procedure used to impute missing data.

Accounting for sampling biases

In our main dataset some NGAs have a greater coverage than others due to differences in the timing of the beginnings of agriculture in different regions, the level of research effort that has previously gone in to studying different regions of the world. The fact that we are analyzing time series data and the possible historical connections between different regions (either due to shared ancestry or various forms of later contact) can lead to potential autocorrelation in our data over space and time. Our stratified sampling approach was designed to offset the largest or most obvious of these potential biases, but there remains the possibility that parameter estimates from our results may be affected by such issues. We were not able to completely control for these factors in our PCA (for example, there is no widely accepted global cultural phylogeny to allow us to perform phylogenetic PCA). However, to examine our robustness to these issues, we used bootstrap resampling to create random sub-samples that lead to more balanced datasets and examined whether this affected our results. We did this in two ways: 1) Our analysis treats individual polities that span multiple centuries into separate polities for each century. Therefore, for any given polity that spanned multiple century marks, we resampled to produce only one entry per polity. 2) To ensure even geographical coverage, we resampled 10 polities per world NGA. If our main results are due to an overrepresentation of certain NGAs we would expect to see a large drop in the percentage of variance explained by PC1 in these robustness analyses. Sampling of one entry per polity had almost no effect on the proportion of variance explained by PC1 (n=285, r^2=0.79), and resampling of 10 polities per NGA only resulted in a relatively small drop in the proportion of variance explained by PC1 (n=300, r^2=0.69).
In the current analyses examining the potential correlation between religious features and social complexity, autocorrelations due to spatial structure, temporal structure, and shared cultural history are all explicitly estimated and controlled for in our regression model.

Effects of variable choice

To assess whether our results are dependent on the particular variables combination of variables included in the analyses we ran two further sets of robustness analyses: 1) we included only one population variable (polity population) and all the other non-population complexity characteristics; 2) we included only one population variable and removed one of the non-scale complexity characteristics (CC8: "texts"). This allowed us to assess whether: 1) inclusion of several population variables leads to an overestimate of the importance of PC1; 2) whether the inclusion of a particular non-scale variable, which could be argued to be more relevant to certain cultural traditions, was biasing our results. These additional analyses again had little impact on our findings: including only one population variable returned a single principal component that explains 78.7% (±0.4%) of the variance, while also removing "texts" returns a single principal component that explains 77.7% (±0.4%) of the variance (see tables SI6, SI7, and SI Appendix from ref. 8 for further discussion).
Overall, these robustness analyses suggest that our main findings are robust to the specific choices we have adopted for our analysis.

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APPENDIX

Table S2 | Details of the earliest evidence for moralizing gods, doctrinal rituals, and writing for the 30 regions in Extended Data Table 1

	Moralizing gods		**Doctrinal rituals**		**Writing**	
Modern country name	**Polity name (approximate dates)**	**Description**	**Polity name (approximate dates)**	**Description**	**Polity name (approximate dates)**	**Description**
Egypt	Dynasty II (2900-2700BCE)	The sun god (later known as *Ra*) created and governs the cosmos, judging fate in the afterlife based on how well one followed the code of *maat* ("what is right"; e.g. protecting the weak, no cheating/theft)[69,70]. *Maat* was mythologized as the daughter of the sun god.	Naqada III (3300-3100BCE)	Widespread standardized ritual elite burials[71].	Naqada III (3300-3100BCE)	The earliest hieroglyphic writing was found in tomb U-J at the Abytos Cemetary[72].
Iran	Dynasty of Akkad (2250-2090BCE)	The all-seeing sun god, *Shamash*, punished the unjust for lying, theft, etc[73].	Susa I (4300-3800BCE)	Sealings show ceremonies with hierarchical relations among participants with principal figures flanked by smaller attendants[74].	Susa II (3800-3100BCE)	Proto-Elamite adopted Sumerian cuneiform c. 3200BCE[75].
Turkey	Old Kingdom of Hatti (1650-1500BCE)	The Hittites practiced "an extreme form of polytheism" in which various gods punished oath-breaking, theft, etc[76].	Central Anatolia Early Chalcolithic (6000-5500BCE)	Widespread standardization and routinization of ritual practices (e.g. burial, house burning, wall plastering) at Çatalhöyük[77].	Central Anatolia Middle Bronze Age (2000-1700BCE)	Old Assyrian dialect of Akkadian[78].
China (Henan)	Western Zhou Dynasty (1040-770BCE)	The supreme ruler god, *Di/Tian*, and other gods and ancestor spirits punished those who violated oaths[79].	Erlitou (1850-1600BCE)	Widespread standardized ceremonial vessels for ancestor-worship rituals[80].	Shang Dynasty (1250-1120BCE)	Oracle bone script[81].

Pakistan	Achaemenid Empire (550-330BCE)	*Ahura Mazda* created and governs the cosmos, rewarding and punishing behavior (e.g. lying, theft) in the afterlife[82].	Mature Harappan (2500-2100BCE)	"Priest-King" stone sculpture suggests standardized religious hierarchy[83].	Mature Harappan (2500-2100BCE)	Indus/Harappan script[83].
Uzbekistan	Achaemenid Empire (520-330BCE)	See above re: Ahura Mazda. Note that this region was occupied by the Achaemenid Empire slightly later than the previous.	Achaemenid Empire (520-330BCE)	Religious hierarchy with Achaemenid King as representative of *Ahura Mazda* on earth overseeing *Mobats* (upper *magi*) and *Herbats* (lower *magi*)[84].	Achaemenid Empire (520-330BCE)	Aramaic script[85].
Italy	Early Roman Republic (510BCE-270BCE)	Roman gods punished oath-breaking and other violations of *fides* (faith/trust)[86].	Roman Kingdom (720-510BCE)	Vestal virgins made daily sacrifices to Vesta[87].	Roman Kingdom (720-510BCE)	Western Greek alphabet introduced[88].
India (Karnataka)	Mauryan Empire (300-200BCE)	Various good and bad deeds (e.g. religious alms; lying) determine the conditions of one's rebirth through karmic retribution[89].	Southern Indian Neolithic (3000-1200BCE)	Widespread standardized rituals involving burning mounds of cow dung into ash[90].	Mauryan Empire (300-200BCE)	The edicts of Ashoka were inscribed in Brahmi and Kharosthi[91].
France	La Tène Gaul C2-D (170-30BCE)	Celtic gods punished oath-breakers[92].	La Tène Gaul C2-D (170-30BCE)	Religious hierarchy with Supreme Druid overseeing Druids and apprentices[93].	La Tène Gaul B2-C1 (320-170BCE)	Celtic coins were inscribed in Greek[94].
Cambodia	Early Funan (220-540CE)	See above re: Karmic retribution.	Early Funan (220-540CE)	Doctrinal Hindu and Buddhist rituals (e.g. daily prayer) introduced[95,96].	Early Funan (220-540CE)	Sanskrit and Brahmi introduced[97].
Mongolia	Rouran Khaganate (300-550CE)	See above re: Karmic retribution.	Rouran Khaganate (300-550CE)	Doctrinal Buddhist rituals (e.g. daily prayer) introduced[98].	Xiongnu Imperial Confederation (210-60BCE)	Chinese partially introduced[99].

Yemen	Himyarite Kingdom (380-530CE)	God created and governs the cosmos, rewarding/punishing various forms of prosocial behavior, including honesty and sharing resources[100].	Himyarite Kingdom (380-530CE)	Twice daily communal prayer[101].	Himyarite Kingdom (380-530CE)	Various scripts, including Arabic[102].
Japan	Asuka period (540-710CE)	See above re: Karmic retribution.	Yayoi Period (300BCE-250CE)	Daily domestic rituals involving clay bell figurines[103, 104].	Kofun Period (250-540CE)	Chinese introduced via Korea[105].
Indonesia (Java)	Medang Kingdom (730-1020CE)	See above re: Karmic retribution.	Medang Kingdom (730-1020CE)	Doctrinal Hindu and Buddhist rituals (e.g. daily prayer) introduced[95,106].	Medang Kingdom (730-1020CE)	Sanskrit introduced[107].
Iceland	Icelandic Commonwealth (930-1260CE)	Norse gods punished oath-breakers[18,108].	Icelandic Commonwealth (930-1260CE)	Doctrinal Christian rituals (e.g. weekly mass) introduced[109,110].	Icelandic Commonwealth (930-1260CE)	Norse runes; Latin introduced with Christianity[110].
Mali	Wagadu Late Period (1100-1200CE)	*Allah* created and governs the cosmos. At the resurrection (*Hashr*), *Allah* will send individuals to hell (*Jahannam*) or paradise (*Cannat*) after final judgment (*Hisab*) of their behavior (e.g. cheating, theft)[111].	Wagadu Middle Period (1000-1070CE)	Religious hierarchy with Wagadu King overseeing sorcerers and heads of clans who were responsible for performing rituals[112,113].	Wagadu Late Period (1100-1200CE)	Classic Arabic of the Koran[114].
Ghana	Pre-Ashanti period (1500-1700CE)	*Onyankopon* created and governs the cosmos, allowing only those Akan who follow *obra* (good conduct; e.g. reciprocity, mutual aid) to join the *Nana* (ancestors) in the afterlife[114].	Pre-Ashanti period (1500-1700CE)	Religious hierarchy with high priests serving the king (*omanhene*) and lower priests serving minor shrines and local communities[115].	Ashanti Empire (1700-1900CE)	Roman script introduced by European missionaries[116].
Indonesia (Kalimantan)	Pre-Brooke Raj period	Maintenance of *adat* (harmonious relations) among Iban is	Pre-Brooke Raj period	Daily *piring* (ritual food offering)[118].	[Pre-Brooke Raj period	None until introduced by Christian missionaries[119].

	(1650-1840CE)	rewarded/punished broadly (e.g. good/poor harvest, sickness)[117].	(1650-1840CE)		(1650-1840CE)]	
USA (Hawaii)	Kamehameha's Kingdom (1780-1820CE)	*'Aumakua* (family ancestor spirits) enforce good behavior among their descendants (e.g. helping others, refraining from harm)[120].	Kamehameha's Kingdom (1780-1820CE)	Daily offerings to the god *Lono* and the *'aumakua* (family ancestor spirits)[121].	[Kamehameha's Kingdom (1780-1820CE)]	None until introduced by Christian missionaries[122].
Micronesia (Chuuk)	Pre-German period (1770-1890CE)	*Önulap* created and governs the cosmos, but does not personally intervene. However, the Chuuk sky god *Oororofich* was "angered by theft and other antisocial behavior"[123].	Pre-German period (1770-1890CE)	Weekly breadfruit fertility ceremony[124].	[Pre-German period (1770-1890CE)]	None until introduced by Christian missionaries and Japanese colonial government[125].
Russia (Yakutsk)	[Pre-Russian period (1400-1640CE)]	The Sakha sky god, *Tangara,* and other spirits brought misfortune to those who disrespected the gods through failure to observe proper rituals/taboos, but did not enforce fairness/reciprocity/loyalty among humans[126].	[Pre-Russian period (1400-1640CE)]	No doctrinal rituals, only imagistic (non-standardized, infrequent) rituals (e.g. shamanic healing rituals, initiation rituals)[127].	[Pre-Russian period (1400-1640CE)]	None until introduced by Christian missionaries[127].
India (Garo)	[Pre-British period (1770-1870CE)]	"One treats the [Garo] spirits and gods with respect and circumspection because they can cause sickness and crop failure, but they do not send these as punishment for immoral behavior."[128]	[Pre-British period (1770-1870CE)]	No doctrinal rituals, only imagistic rituals (e.g. sacrificial rituals following births and deaths)[129].	[Pre-British period (1770-1870CE)]	None until introduced by Christian missionaries[130].
China (Yunnan)	[Late Qing period (1700-1900CE)]	Hmong *kuei* (gods/spirits/ancestors) reward and punish adherence to sacrificial rituals/taboos, but one's fate in the afterlife is determined based on circumstances of death (e.g. violent deaths result in return as an	[Late Qing period (1700-1900CE)]	No doctrinal rituals, only imagistic shamanic rituals (e.g. healing rituals, mortuary rituals)[132].	[Late Qing period (1700-1900CE)]	None until 20th c. Pollard script[133].

		evil *kuei*) rather than moral conduct[131].				
Papua New Guinea (Oro)	[Pre-British period (1730-1880CE)]	"there were ritual prohibitions against [Orokaiva] going near certain volcanic craters, lest the demi-god *Sumbiripa* became angry, and spirits living in the countryside were believed to occasionally attack people, but the "reason" for *Sumbiripa*'s anger and the spirits' attack seem to stem more from transgressions against the gods than against other humans."[134]	[Pre-British period (1730-1880CE)]	No doctrinal rituals, only imagistic rituals (e.g. initiation rituals, healing rituals)[135].	[Pre-British period (1730-1880CE)]	None until introduced by Christian missionaries[136].
USA (Finger Lakes)	[Pre-British period (1570-1710CE)]	"Accusation of witchcraft was an essential social control mechanism among Iroquoian groups, but it is not witches doing the social control, rather it is the fear that deviant behavior will lead to an accusation of being a witch that provides the mechanism for self-discipline."[137]	[Pre-British period (1570-1710CE)]	No doctrinal rituals, only imagistic rituals (e.g. healing rituals, funerary rituals)[138,139].	[Pre-British period (1570-1710CE)]	None until introduced by Christian missionaries[140].
USA (Cahokia)	[Illinois Confederacy (1640-1720CE)]	The Illinois performed rituals (e.g. for warfare, shamanistic healing) to gain favour of supernatural agents, but punishment for social violations was carried out directly by humans[141,142].	Emergent Mississippian period (900-1050CE)	Religious hierarchy headed by ruler-priests[143].	[Illinois Confederacy (1640-1720CE)]	None until introduced by Christian missionaries.
Mexico (Missouri)	[Monte Alban V period (900-1520CE)]	Zapotec priests performed ritual sacrifices and offerings to ancestor cults, but no evidence of supernatural punishment for transgressions against humans[144].	Monte Albán II period (100BCE-200CE)	Religious hierarchy involving standardized arrangement of primary and secondary temples[145].	Rosario phase (700-500BCE)	Glyphs inscribed on a stone slab at San José Mogote[146].

Colombia (Sierra Nevada de Santa Marta)	[Pre-Spanish period (1530-1830CE)]	The Universal Mother, the Sun, and Totemic animals control the cosmos and punish Tairona for failure to perform correct rituals, but not for violations of interpersonal morality[147].	[Pre-Spanish period (1530-1830CE)]	No doctrinal rituals, only imagistic shamanic rituals (e.g. initiation rituals, funerary rituals)[148].	[Pre-Spanish period (1530-1830CE)]	None until introduced by colonial Spanish[149].
Ecuador (Lowland Andes)	[Pre-Ecuador period (1050-1520CE)]	Ritual purification and body painting was performed to protect against spirits/witches, but "There are no gods who play ethical or moral roles in the Jivaro [Shuar] pantheon"[150].	[Pre-Ecuador period (1050-1520CE)]	No doctrinal rituals, only imagistic shamanic rituals (e.g. initiation rituals, mortuary rituals)[151].	[Pre-Ecuador period (1050-1520CE)]	None until introduced by Christian missionaries[152].
Peru	[Inca Empire (1400-1530CE)]	Inca supernatural agents meted out "terrible punishment", but this was not for transgressions against humans but failures to properly revere the gods or the Inca ruler (who was himself believed to possess supernatural powers)[153–155].	Killke period (1250-1400CE)	Religious hierarchy with priests at principal temple overseeing local level state priests[156].	[Inca Empire (1400-1530CE)]	None until introduced by colonial Spanish, although quipu (knotted string constructions) were previously used to encode numerical information information[157-160].

For locations without precolonial concepts of moralizing gods, doctrinal rituals, or writing, dates in brackets represent the latest polity analyzed. Religious systems imposed/adopted after the beginning of colonial periods are not included.

Table S3 | Full logistic regression results for Extended Data Table 3.1 (Doctrinal ritual defined via religious hierarchy or ritual frequency).

Parameter	Coefficient estimate (± SE)	z-value	*P* [Pr(>|z|)]
(Intercept)	-4.9 ± 0.4	-11.1	<.001
Time (100-year lag)	4.7 ± 0.6	7.6	<.001
Social complexity (SC)	6.6 ± 0.9	7.5	<.001
Geographical proximity	-1.4 ± 1.2	-1.2	.23
Language phylogeny	-1.5 ± 3.7	-0.4	.68
Time (200-year lag)	0.2 ± 0.6	0.2	.81

The model includes parameters for social complexity and for geographical, temporal, and cultural relationships, ordered by absolute z-value (see Methods for details).

Table S4 | Full logistic regression results for Extended Data Table 3.2 (Doctrinal ritual defined via religious hierarchy only).

Parameter	Coefficient estimate (± SE)	z-value	*P* [Pr(>|z|)]
(Intercept)	-4.4 ± 0.4	-12.0	<.001
Time (100-year lag)	4.3 ± 0.4	9.5	<.001
Social complexity (SC)	5.2 ± 0.7	7.9	<.001
Geographical proximity	-1.3 ± 1.0	-1.3	.19
Language phylogeny	-2.6 ± 2.9	-0.9	.36
Time (200-year lag)	-0.1 ± 0.4	-0.1	.91

The model includes parameters for social complexity and for geographical, temporal, and cultural relationships, ordered by absolute z-value (see Methods for details).

Table S5 | Full logistic regression results for Extended Data Table 3.3 (Doctrinal ritual defined via ritual frequency only)

Parameter	Coefficient estimate (± SE)	z-value	*P* [Pr(>|z|)]
(Intercept)	-4.9 ± 0.4	-11.2	<.001
Time (100-year lag)	4.4 ± 0.5	8.3	<.001
Social complexity (SC)	4.3 ± 0.7	6.2	<.001
Language phylogeny	5.1 ± 3.0	1.7	.09
Geographical proximity	-0.3 ± 0.7	-0.4	.68
Time (200-year lag)	0.0 ± 0.5	-0.1	.94

The model includes parameters for social complexity and for geographical, temporal, and cultural relationships, ordered by absolute z-value (see Methods for details).

Table S6 | Full logistic regression results for Extended Data Table 4.1 (Excluding religious hierarchy)

Parameter	Coefficient estimate (± SE)	z-value	*P* [Pr(>|z|)]
(Intercept)	-7.9 ± 0.9	-8.7	<.001
Social complexity (SC)	9.5 ± 1.4	6.8	<.001
Time (100-year lag)	3.7 ± 0.7	5.5	<.001
Language phylogeny	11.8 ± 5.5	2.1	.03
Geographical proximity	-2.5 ± 1.2	-2.0	.05
Time (200-year lag)	0.9 ± 0.7	1.3	.18

The model includes parameters for social complexity and for geographical, temporal, and cultural relationships, ordered by absolute z-value (see Methods for details).

Table S7 | Full logistic regression results for Extended Data Table 4.2a (Scale SC variables only)

Parameter	Coefficient estimate (± SE)	z-value	*P* [Pr(>|z|)]
(Intercept)	-9.6 ± 1.1	-8.8	<.001
Social complexity (SC)	11.8 ± 1.7	7.1	<.001
Time (100-year lag)	3.8 ± 0.6	6.0	<.001
Language phylogeny	10.5 ± 5.5	1.9	.06
Time (200-year lag)	1.1 ± 0.6	1.8	.08
Geographical proximity	-1.5 ± 1.3	-1.3	.21

The model includes parameters for social complexity and for geographical, temporal, and cultural relationships, ordered by absolute z-value (see Methods for details).

Table S8 | Full logistic regression results for Extended Data Table 4.2b (Non-scale SC variables only)

Parameter	Coefficient estimate (± SE)	z-value	*P* [Pr(>|z|)]
(Intercept)	-6.7 ± 0.8	-8.7	<.001
Social complexity (SC)	7.4 ± 1.1	6.5	<.001
Time (100-year lag)	3.7 ± 0.7	5.6	<.001
Language phylogeny	12.1 ± 5.4	2.2	.03
Geographical proximity	-2.4 ± 1.2	-2.0	.05
Time (200-year lag)	1.0 ± 0.7	1.6	.11

The model includes parameters for social complexity and for geographical, temporal, and cultural relationships, ordered by absolute z-value (see Methods for details).

Table S9 | Full logistic regression results for Extended Data Table 4.3 (Moralizing High Gods [MHG] only)

Parameter	Coefficient estimate (± SE)	z-value	*P* [Pr(>|z|)]
(Intercept)	-6.8 ± 0.8	-8.4	<.001
Time (100-year lag)	4.1 ± 0.5	7.5	<.001
Social complexity (SC)	5.7 ± 1.0	5.5	<.001
Language phylogeny	8.3 ± 4.2	2.0	.05
Geographical proximity	-0.8 ± 1.0	-0.8	.43
Time (200-year lag)	0.36 ± 0.5	0.7	.51

The model includes parameters for social complexity and for geographical, temporal, and cultural relationships, ordered by absolute z-value (see Methods for details).

Table S10 | Full logistic regression results for Extended Data Table 4.6a (Social complexity measured by polity population only)

Parameter	Coefficient estimate (± SE)	z-value	*P* [Pr(>|z|)]
(Intercept)	-10.7 ± 1.3	-8.4	<.001
Social complexity	13.4 ± 2.0	6.8	<.001
Time (100-year lag)	3.9 ± 0.7	6.0	<.001
Language phylogeny	11.1 ± 5.5	2.0	.04
Time (200-year lag)	1.0 ± 0.7	1.5	.13
Geographical proximity	-1.5 ± 1.2	-1.2	.22

The model includes parameters for social complexity and for geographical, temporal, and cultural relationships, ordered by absolute z-value (see Methods for details).

Table S11 | Full logistic regression results for Extended Data Table 4.6b (Social complexity measured by polity territory only)

Parameter	Coefficient estimate (± SE)	z-value	*P* [Pr(>|z|)]
(Intercept)	-8.8 ± 1.0	-8.8	<.001
Social complexity	10.3 ± 1.6	6.4	<.001
Time (100-year lag)	4.2 ± 0.6	6.5	<.001
Time (200-year lag)	1.5 ± 0.6	2.3	.02
Language phylogeny	12.3 ± 5.8	2.1	.03
Geographical proximity	-1.5 ± 1.2	-1.2	.22

The model includes parameters for social complexity and for geographical, temporal, and cultural relationships, ordered by absolute z-value (see Methods for details).

Table S12 | Full logistic regression results for Extended Data Table 4.6c (Social complexity measured by capital population only)

Parameter	Coefficient estimate (± SE)	z-value	*P* [Pr(>|z|)]
(Intercept)	-9.7 ± 1.1	-8.5	<.001
Time (100-year lag)	3.9 ± 0.6	6.3	<.001
Social complexity	10.9 ± 1.7	6.3	<.001
Time (200-year lag)	1.5 ± 0.6	2.4	.02
Language phylogeny	8.7 ± 5.7	1.5	.13
Geographical proximity	-0.03 ± 1.2	-0.02	.98

The model includes parameters for social complexity and for geographical, temporal, and cultural relationships, ordered by absolute z-value (see Methods for details).

Table S13 | Full logistic regression results for Extended Data Table 4.6d (Social complexity measured by hierarchical complexity only)

Parameter	Coefficient estimate (± SE)	z-value	*P* [Pr(>|z|)]
(Intercept)	-9.3 ± 1.1	-8.7	<.001
Social complexity	15.5 ± 2.3	6.9	<.001
Time (100-year lag)	3.9 ± 0.6	6.2	<.001
Time (200-year lag)	1.4 ± 0.6	2.2	.03
Language phylogeny	9.0 ± 5.3	1.7	.09
Geographical proximity	-1.0 ± 1.2	-0.9	.39

The model includes parameters for social complexity and for geographical, temporal, and cultural relationships, ordered by absolute z-value (see Methods for details).

Table S14 | Full logistic regression results for Extended Data Table 4.6e (Social complexity measured by government only)

Parameter	Coefficient estimate (± SE)	z-value	*P* [Pr(>|z|)]
(Intercept)	-4.8 ± 0.5	-10.7	<.001
Time (100-year lag)	4.0 ± 0.6	6.6	<.001
Social complexity	4.1 ± 0.7	5.5	<.001
Language phylogeny	13.6 ± 5.6	2.4	.02
Time (200-year lag)	1.3 ± 0.6	2.2	.03
Geographical proximity	-1.0 ± 1.1	-0.9	.36

The model includes parameters for social complexity and for geographical, temporal, and cultural relationships, ordered by absolute z-value (see Methods for details).

Table S15 | Full logistic regression results for Extended Data Table 4.6f (Social complexity measured by infrastructure only)

Parameter	Coefficient estimate (± SE)	z-value	*P* [Pr(>|z|)]
(Intercept)	-5.5 ± 0.6	-9.8	<.001
Time (100-year lag)	3.9 ± 0.6	6.5	<.001
Social complexity	4.4 ± 0.8	5.4	<.001
Time (200-year lag)	1.7 ± 0.6	2.9	.004
Language phylogeny	9.7 ± 5.4	1.8	.07
Geographical proximity	-0.8 ± 1.2	-0.7	.48

The model includes parameters for social complexity and for geographical, temporal, and cultural relationships, ordered by absolute z-value (see Methods for details).

Table S16 | Full logistic regression results for Extended Data Table 4.6g (Social complexity measured by information systems only)

Parameter	Coefficient estimate (± SE)	z-value	*P* [Pr(>|z|)]
(Intercept)	-5.7 ± 0.6	-8.8	<.001
Time (100-year lag)	3.8 ± 0.6	6.0	<.001
Social complexity	4.8 ± 0.8	5.9	<.001
Time (200-year lag)	1.4 ± 0.6	2.3	.02
Language phylogeny	9.2 ± 4.8	1.9	.06
Geographical proximity	-0.8 ± 1.1	-0.8	.45

The model includes parameters for social complexity and for geographical, temporal, and cultural relationships, ordered by absolute z-value (see Methods for details).

Table S17 | Full logistic regression results for Extended Data Table 4.6h (Social complexity measured by texts only)

Parameter	Coefficient estimate (± SE)	z-value	*P* [Pr(>|z|)]
(Intercept)	-5.2 ± 0.5	-9.6	<.001
Social complexity	5.0 ± 0.8	6.4	<.001
Time (100-year lag)	3.5 ± 0.6	5.6	<.001
Language phylogeny	12.7 ± 5.6	2.3	.02
Time (200-year lag)	1.4 ± 0.6	2.3	.02
Geographical proximity	-1.5 ± 1.1	-1.3	.19

The model includes parameters for social complexity and for geographical, temporal, and cultural relationships, ordered by absolute z-value (see Methods for details).

Table S18 | Full logistic regression results for Extended Data Table 4.6i (Social complexity measured by money only)

Parameter	Coefficient estimate (± SE)	z-value	*P* [Pr(>|z|)]
(Intercept)	-6.0 ± 0.6	-10.2	<.001
Social complexity	7.0 ± 1.1	6.6	<.001
Time (100-year lag)	4.2 ± 0.7	6.3	<.001
Time (200-year lag)	1.1 ± 0.7	1.7	.09
Geographical proximity	-0.9 ± 1.3	-0.7	.47
Language phylogeny	2.3 ± 4.9	0.5	.64

The model includes parameters for social complexity and for geographical, temporal, and cultural relationships, ordered by absolute z-value (see Methods for details).