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Astronomy, Architecture, and Landscape in the Olmec Area and Western Maya Lowlands: Implications for Understanding Regional Variability and Evolution of Orientation Patterns in Mesoamerica

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Abstract
In the area along the southern Gulf Coast in Mexico, a large number of previously unrecorded archaeological sites have recently been detected with the aid of lidar data, which also allowed us to determine the orientations of hundreds of structures and architectural assemblages, including many standardized complexes dated to the Early-to-Middle Formative transition. As revealed by our analyses, most orientations were based on astronomical and calendrical principles, occasionally combined with certain concepts of sacred geography. While the results of these analyses were presented in a recently published article, here we explore the potential of alignment data for addressing other questions of archaeological relevance. The distribution of particular building types and regional variations in alignment patterns in the study area suggest the existence of two somehow different cultural spheres, loosely corresponding to the areas conventionally called the Gulf Olmec region and the western Maya Lowlands. Examining pertinent evidence, we argue that it was in this area where some of the most prominent orientation groups materialized in later Mesoamerican architecture originated. We also attempt to reconstruct the paths of their diffusion, which are expected to contribute to understanding the dynamics of long-distance cultural interaction in Mesoamerica.

Resumen
Investigaciones recientes basadas en los datos de escaneo láser (lídar) detectaron una gran cantidad de sitios arqueológicos previamente no reportados en el área a lo largo de la costa sur del Golfo de México. Los datos lídar también nos permitieron determinar las orientaciones de un gran número de estructuras y grupos arquitectónicos, incluyendo muchos complejos estandarizados datados a la transición entre los periodos Preclásico Temprano y Medio. Nuestros análisis han revelado que las orientaciones fueron diseñadas, en su mayoría, a partir de principios astronómicos y calendáricos ocasionalmente combinados con algunos conceptos de geografía sagrada. Mientras que los resultados de estos análisis han sido presentados en un artículo publicado recientemente, aquí exploramos el potencial de los datos sobre los alineamientos para abordar otras cuestiones de relevancia arqueológica. La distribución de los edificios de ciertos tipos y las variaciones regionales en los patrones de orientación en el área de estudio sugieren la existencia de dos esferas culturales algo diferentes, que aproximadamente corresponden a las áreas convencionalmente designadas como la región olmeca del Golfo de México y las tierras bajas mayas occidentales. Examinando las evidencias pertinentes, argumentamos que fue ésta el área donde se originaron algunos de los grupos de orientación más comunes en épocas posteriores. Asimismo, intentamos reconstruir las trayectorias de su propagación, contribuyendo de esta manera a la comprensión de los procesos de interacción cultural a larga distancia en Mesoamérica.

Keywords: Mesoamerica; Maya; Olmec; archaeoastronomy; architecture; orientations; calendar; cultural history

Palabras clave: Mesoamérica; mayas; olmecas; arqueoastronomía; arquitectura; orientaciones; calendario; historia cultural

Recent archaeological research based on lidar datasets of different resolutions and covering an extensive area along the southern Gulf Coast (84,516 km^2) detected a large number of architectural complexes and mound groups. Among them are many standardized complexes dating to the Formative period and indicating that extensive monumental constructions were widespread centuries before previously thought and throughout the area connecting the Olmec core zone with the western Maya Lowlands (Inomata et al. 2020, 2021).

Our recently published analysis of orientations of both Formative and Classic period constructions in this area (Šprajc et al. 2023) revealed that they were based on the same astronomical and calendrical principles that dictated orientations in later Mesoamerican architecture. As shown by previous research in various Mesoamerican regions, the orientations of civic and ceremonial buildings in most cases recorded the sun's positions on the horizon on certain dates, which concentrate in four time-spans of the year and tend to be separated by multiples of 13 and 20 days. Since these were elementary periods of the 260-day calendrical cycle, in which a series of 20 day signs intermeshed with numbers from 1 to 13, these architectural orientations enabled the use of observational calendars that facilitated a proper scheduling of seasonal activities and the corresponding rituals. This anticipatory aspect of astronomical observations must have been of foremost importance because the rituals had to be prepared ahead of time. In general, the need for astronomical observations is understandable, considering that there was no intercalation system that would have maintained a permanent concordance of the 365-day calendrical year with the slightly longer tropical year. Nonetheless, the astronomically oriented structures cannot be interpreted as observatories serving practical needs only; since their primary functions were ceremonial, administrative, or residential, they must have had an important role in the activities related to the worldview and cosmologically substantiated political ideology (Aveni 2001; Aveni and Hartung 1986; Dowd and Milbrath 2015; Sánchez and Šprajc 2015; Šprajc 2001, 2018; Šprajc and Sánchez 2015; Šprajc et al. 2016).

Since a large number of sites detected on the lidar-derived relief model of the area along the southern Gulf Coast have clearly visible layouts, we were able to determine the orientations of 415 Formative and Classic complexes (Figure 1). Upon calculating their astronomical referents and analyzing their distributions, we identified several orientation groups, which had been previously recognized elsewhere in Mesoamerica. Considering a complex structure of dates marked by solar orientation groups, their independent origin in different regions is hardly conceivable; given the chronological priority of a number of monumental constructions exhibiting these orientations in the Gulf Coast area (see below), this was the most likely place of their origin, from where they later spread to other parts of Mesoamerica. In addition, the orientations of many architectural complexes built during the Early-to-Middle Formative transition represent the earliest evidence of the existence of the Mesoamerican 260-day calendrical cycle, predating the earliest reliable epigraphic records by almost a millennium. While the astronomical and calendrical significance of alignments was discussed in our previously published article (Šprajc et al. 2023), here we focus on other implications of our data. On one hand, they shed light on issues of cultural history. Both the distribution of particular building types and the alignment data suggest the existence of two different cultural traditions, which approximately correspond to the eastern and western half of the study area. The division was particularly pronounced in the Classic, but began to shape early in the Middle Formative period, roughly coinciding with the boundary between the areas generally referred to as the Gulf Olmec region and the western Maya Lowlands. On the other hand, our data bring us closer to understanding the evolution of orientation practices in Mesoamerica and their diffusion, which also reflects long-distance cultural interaction in particular periods.

Architectural Types and Orientation Groups

Among the 33,935 mound groups identified in the area, there are 478 standardized complexes dating to the Formative period (Inomata et al. 2021). They include extensive rectangular formations called the Middle Formative Usumacinta (MFU) and Veracruz Ceremonial (VC) complexes, which commonly incorporate an E-Group assemblage (composed of a pyramid and an elongated platform enclosing a plaza). The rectangular formations of MFU complexes are commonly delimited by multiple low

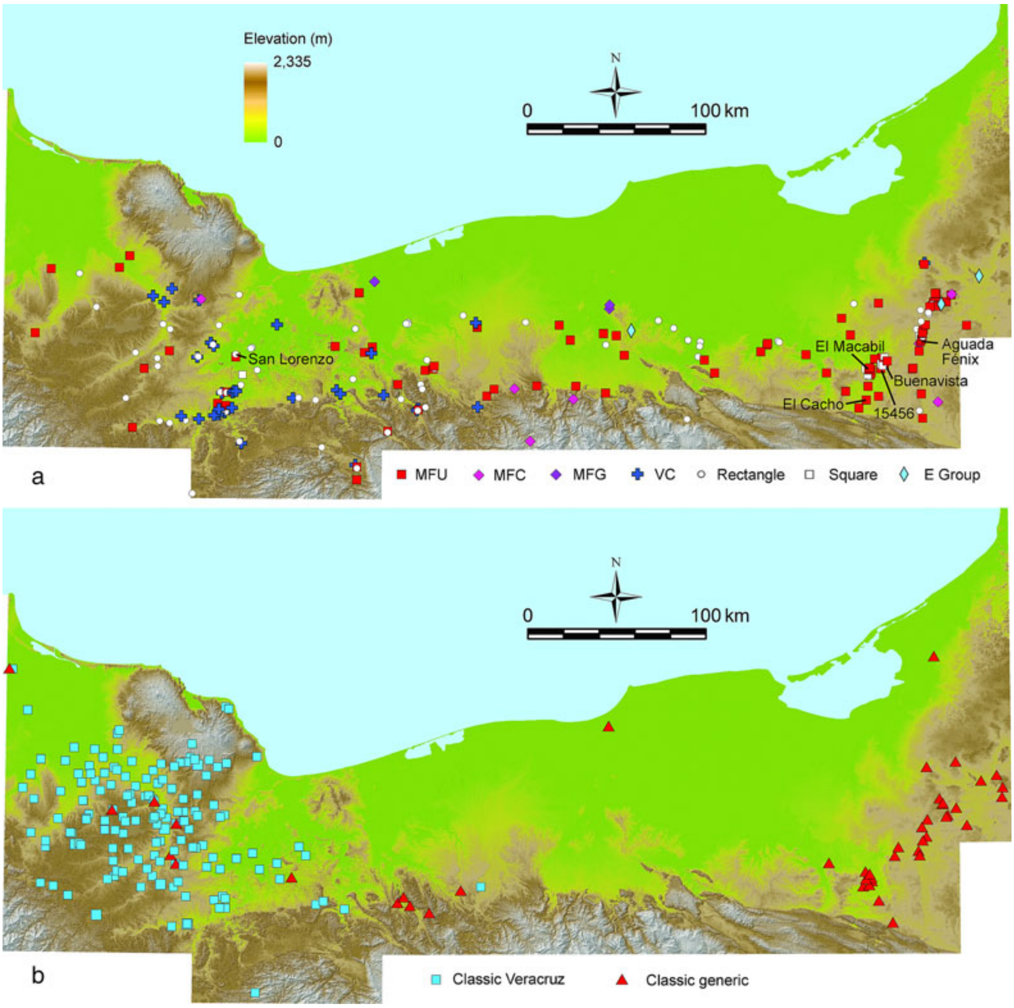

Figure 1. Map of the area with the location of Formative (a) and Classic period sites (b) included in the study. The symbols for E Groups only show stand-alone complexes; many more E Groups are integrated in larger complexes (MFUs, etc.). (Color online)

mounds, whereas those of the VC complexes typically have continuous linear mounds. In addition, VC complexes generally have a smaller rectangular projection delimited by linear mounds to the west of the E Group. Three excavated MFU complexes, Aguada Fénix, Buenavista, and La Carmelita, date to 1050–750 BC (Inomata et al. 2020, 2021). The initial construction of another MFU complex that we excavated can be dated loosely to the Middle Formative, but we did not obtain sufficient data to determine its precise date. Although the dates of VC complexes need to be examined through future excavations, their close similarity to MFU complexes implies that they are mostly contemporaneous. The results of salvage excavation and surface collection at El Marquesillo, Rancho La Estrella, Boca de Chalchijapan, and other sites suggest that the construction of some VC complexes may have started during the Early Formative period (Doering 2007; Hernández Jiménez 2012). The largest MFU site is Aguada Fénix; its main artificial plateau is 1400 m long, 400 m wide, and up to 15 m in height (Inomata et al. 2020).

Similar arrangements with an E Group, but without clear rectangular forms and often with taller pyramids and mounds, are the Middle Formative Chiapas (MFC) and Middle Formative Gulf (MFG) types. The standardized arrangements of these sites in the Gulf Olmec region and central and southern Chiapas, including La Venta and Chiapa de Corzo, have long been recognized (Clark and Hansen 2001; Lowe 1977). Scholars originally classified La Venta as an MFC site, but its tight linear arrangement of mounds contrasts with those of Chiapa de Corzo and other Chiapas sites that have more sparse placements of mounds. Inomata and colleagues (2021) created the MFG pattern as a sub type of the MFC pattern to include La Venta and similar sites. The chronology of La Venta has been a vexing problem (Pool 2007:159–160), but the settlement study of the La Venta area by Rust (2008) shows that most residential structures in the immediate vicinity of La Venta date between 800 and 400 BC (see the analysis of radiocarbon dates in Inomata et al. 2013). Although we need to consider the possibility that its ceremonial core was constructed earlier, it was probably not until 800 BC that La Venta became a powerful center with a large population. The MFC complexes of Chiapa de Corzo and Finca Acapulco were probably constructed before 800 BC, but this standardized form did not spread to other sites, such as Ocozocoautla, Mirador, and La Libertad until 800 or 700 BC (Clark 2016). We assume that most MFC and MFG complexes in our study area were occupied mainly between 800 and 400 BC (Ochoa and Hernández 1977). We should note that some MFC complexes in the Middle Usumacinta region survived longer. Excavations by Inomata and colleagues suggest that the MFC complex at El Tiradero was built mainly during the Terminal Formative period (100 BC–AD 250) and that of Rancho Zaragoza continued into the Terminal Formative after its initial construction in the Middle Formative.

Simpler assemblages are Rectangles, similar to MFUs but without an E Group, and Squares characterized by square spaces surrounded by linear mounds. We have not excavated those complexes, but their similarities to the MFU pattern suggest their contemporaneity.

After the apparent abandonment of these formal complexes, a number of later sites were established, many of them most likely during the Late Classic period (AD 600–1000). The Late Formative and Early Classic periods of this area are poorly understood, but various investigations, including excavations in the Middle Usumacinta region by Inomata and colleagues (2021), indicate that a substantial population did not return to many regions until the Late Classic (Killion and Urcid 2001; Symonds et al. 2002; Stoner and Stark 2023). The Classic Veracruz compounds (also called Long-Plaza Plan, Villa Alta Quadripartite Arrangement, Tipo 4, or Standard Plaza Plan) found in southern Veracruz have a standardized plan, with two parallel elongated structures flanking a plaza and a pyramid on one or two extremes (Borstein 2005; Daneels 1997; Killion and Urcid 2001; Symonds et al. 2002; Stoner and Stark 2023). Other Classic period sites exhibit diverse configurations; for the purposes of our analyses, we labeled them Classic generic.

Since the architectural complexes and individual buildings have roughly rectangular ground plans, or are composed of elements placed along perpendicular lines, one can assume that their orientations may have been functional in either north-south or east-west direction. Therefore, at every structure or compound, we tried to measure both types of alignments, but in several cases only north-south or east-west azimuths could be determined. In total, our data sample includes 365 north-south and 344 east-west azimuths, measured on 415 Formative and Classic period constructions (Šprajc et al. 2023: Table S1). Our analyses have shown that the orientations were astronomically functional predominantly, if not exclusively, in the east-west direction. We have identified several orientation groups, most of which refer to the sun's positions on the horizon on certain dates separated by calendrically significant intervals. In Figures 2 and 3, which show relative frequency distributions of declinations[1] and dates recorded on the eastern and western horizon by Formative and Classic structures, the orientation groups particularly relevant to the objectives of the present study are designated by numbers. Whereas Figure 4 shows frequency distribution of dates by architectural type, giving a sense of the underlying data, the graphs in Figures 2 and 3 were obtained using kernel density estimation (KDE). An advantage of this method over simple histograms is that the errors of individual alignments are taken into account. Depending on the resolution of lidar data from different sources (Inomata et al. 2020, 2021), possible errors were estimated and assigned to each alignment azimuth, and these errors were considered in calculating the corresponding declinations, dates, and intervals.[2] It should be noted that in most cases the estimated errors of azimuths do not exceed 1.5° (Šprajc et al. 2023:Table S1). In comparison with the large number of structures and architectural complexes in the area, our data sample is relatively small, because in many cases the alignments are poorly discernible or divergent, making it impossible to determine the intended direction with sufficient confidence.

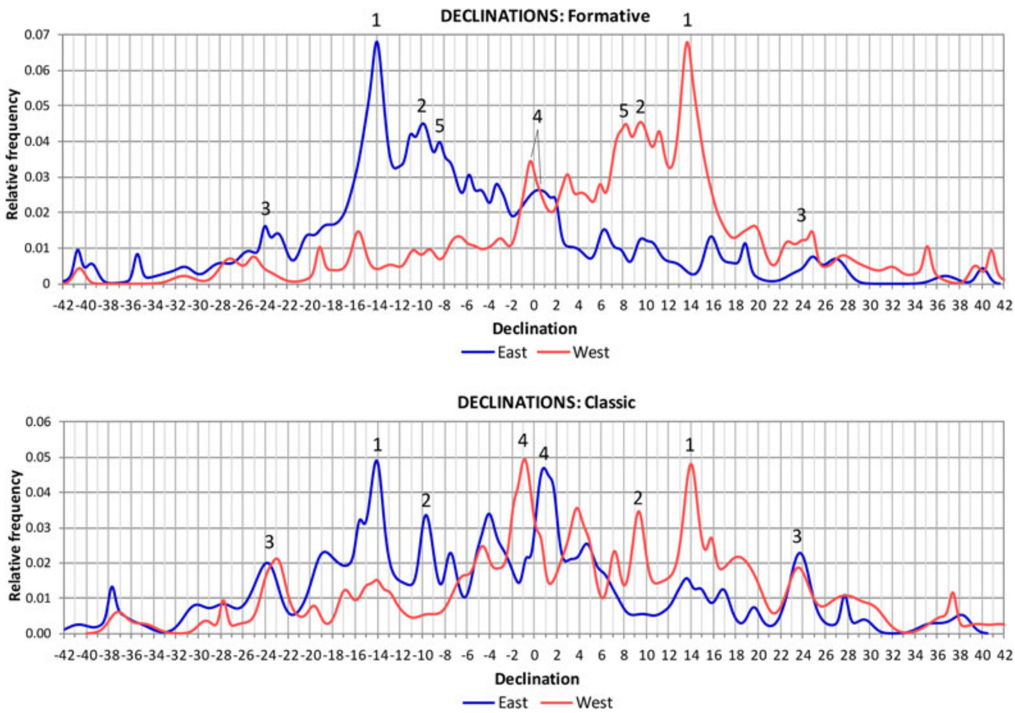

Figure 2. Relative frequency distribution of declinations corresponding to east-west azimuths by period. The orientation groups discussed in the text are designated by numbers. (Color online)

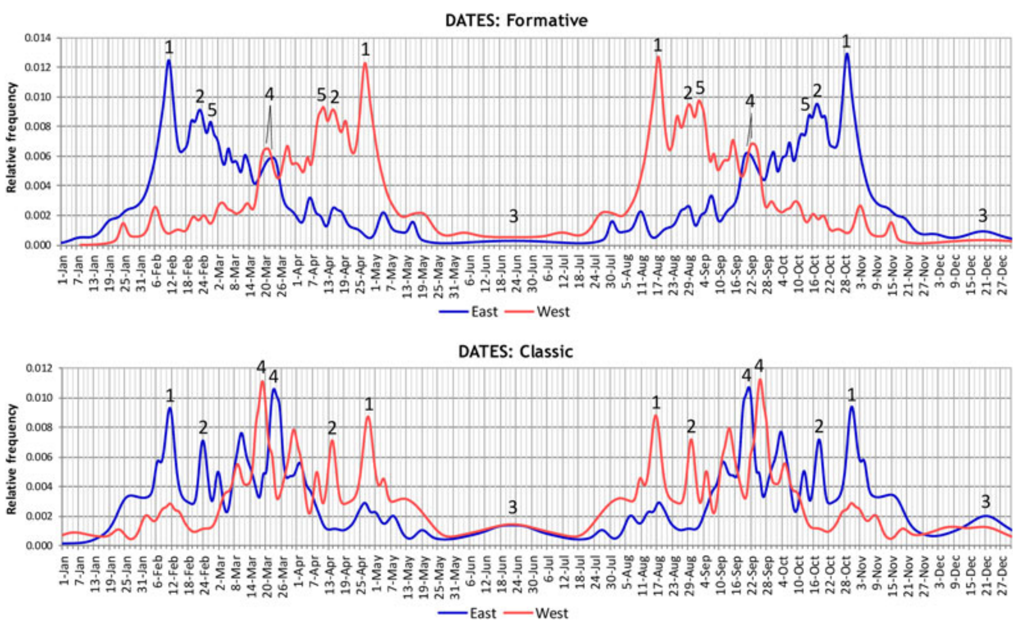

Figure 3. Relative frequency distribution of dates corresponding to declinations marked on the eastern and western horizon by period. The orientation groups discussed in the text are designated by numbers. (Color online)

The most widespread orientation group in the Formative was group 1, corresponding to sunrises on February 11 and October 29, separated by 260 days. The great majority of these orientations, which most clearly indicate the use of the 260-day calendar, are embedded in complexes most likely dating

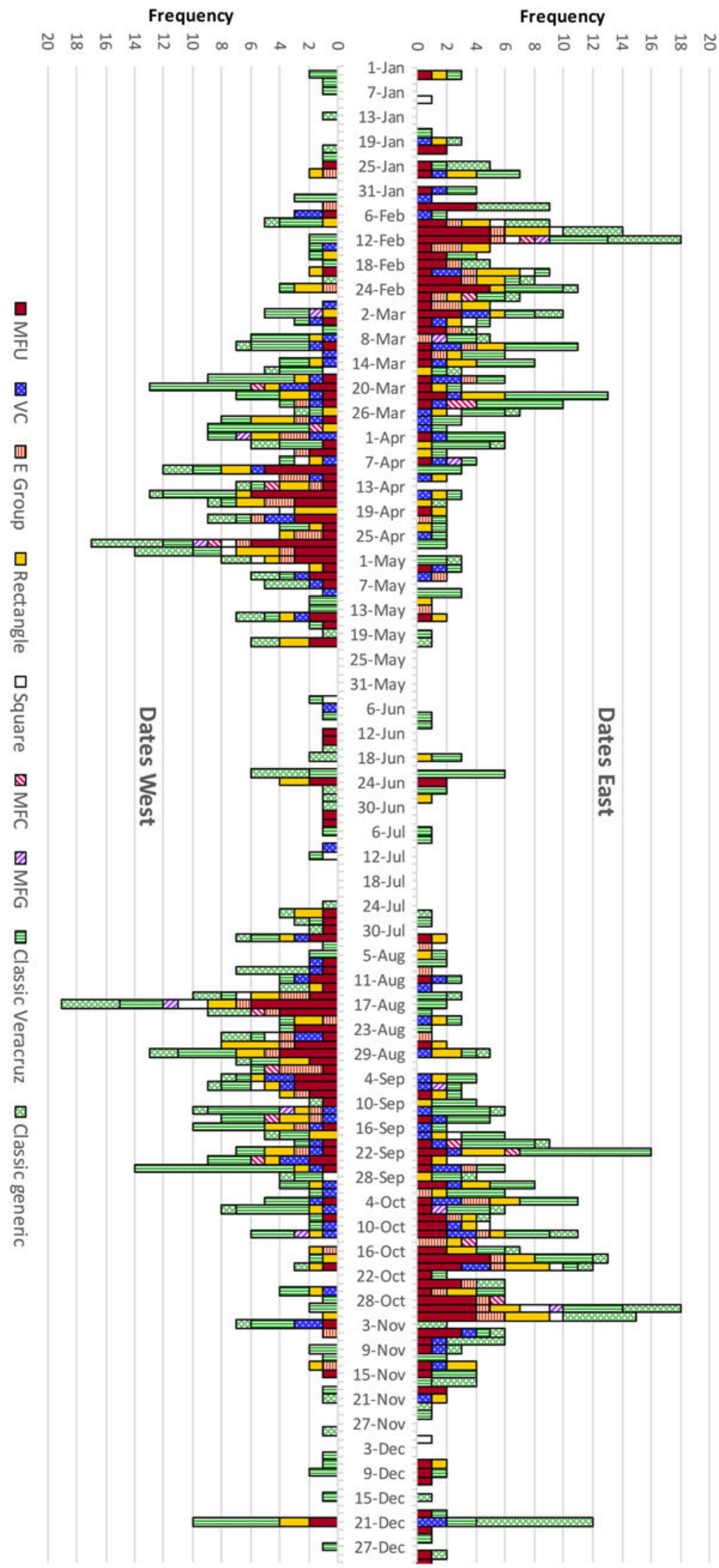

Figure 4. Frequency distribution of dates corresponding to declinations marked on the eastern and western horizon by structural type. (Color online)

to 1050–750 BC, if not earlier. Group 2, also common in the Formative, matches sunrises on October 17 and February 24, separated by 130 days. Both groups were prominent elsewhere in the later Lowland Maya architecture but were less popular in our study area during the Classic period. Groups 3 and 4, referring to the solstices and quarter days of the year, were frequent throughout the history of the area. The existence of solstitial alignments is better visible in Figure 2 (concentration of declinations around ±24°) than in Figure 3, because the errors in azimuth around solstitial directions correspond to large errors in days, resulting in extended curves around the solstitial dates (see also Figure 4). The solstices are naturally significant moments of the tropical year, marked by easily perceptible extremes of the sun's annual movement along the horizon, whereas the quarter days, falling one or two days after/before the spring/fall equinox, divide each half of the year delimited by the solstices in two equal parts. While there is no compelling evidence that the Mesoamericans were aware of the equinox (Šprajc 2023), the importance of the solstices and quarter days is attested by architectural orientations throughout Mesoamerica (Šprajc 2018).

Regional Patterns

Structural Types

The standardized architectural patterns, distributed continuously across the study area, indicate that its inhabitants had close interaction. Nonetheless, we see a slight difference between the eastern and western parts of the study area. While MFU complexes are spread across the area, the highest density is found in the Middle Usumacinta region in the east. VC complexes are confined to the western part. The division between the two regions became clearer during the Classic period as the density of sites in the central part declined: the Classic Veracruz complexes are only found in the western part, while other structural types (Classic generic) occur in greater numbers in the eastern part (Figure 1; Inomata et al. 2021: Figures 2a and 7a).

Azimuths

Among the 344 east-west alignments that we have been able to determine, 110 (32%) are skewed north of east. This is a considerably higher share than in the rest of Mesoamerica, where the great majority of orientations exhibit the characteristic clockwise skew from cardinal directions (Aveni 2001; Šprajc 2018). In our study area, the counterclockwise skew was more common during the Classic and in the western part (Table 1 and Figure 5). Among the 184 Formative constructions in our data sample, 45 (24.5%) are skewed north of east, but the same deviation is exhibited by 65 (40.6%) of the 160 Classic structures. While the numbers of Formative constructions in the eastern and western parts of the area are similar, 37.2% of those located in the western half but only 11.1% of those in the eastern part are skewed north of east. Most of the Classic period structures are located in the western part; about a half of these are deviated north of east, whereas the same skew characterizes only one site in the eastern half.

The south-of-east/north-of-west skew of orientations, prevalent in Mesoamerica, can be attributed to the symbolism of world directions. The dates that the solar orientations with this deviation recorded on the eastern and western horizon fell mostly in the dry and wet seasons, respectively, and this is what the builders apparently wanted to achieve. There is evidence that the dry season was conceptually related to the eastern and the rainy season to the western part of the universe. Particularly revealing are the symbolism and directional associations of the sun, moon, and Venus, attested in prehispanic and early colonial iconography, written sources, and ethnographic survivals: the sun, presiding the east, was related to heat, fire, and drought, whereas the moon and Venus, primarily its evening manifestation, were associated with the west, as well as with water, maize, and fertility (Šprajc 2001:88–91, 2004, 2018:205, 228). If these concepts were responsible for south-of-east orientations, those skewed in the opposite direction might reflect a different belief system, perhaps one in which the fertility and related concepts were associated with the east, from where the rains regularly come in the Tropics. Recall that the alignments skewed north of east marked on the eastern horizon the dates falling mostly in the rainy season. However, since the north-of-east skew is nowhere patently dominant, it is also

Table 1. Numbers and Percentages of Deviations of East-West Alignments from Due East in the Eastern and Western Parts of the Study Area.

Formative Period Structures						
	Whole Area		West Half		East Half	
Skew	No.	%	No.	%	No.	%
North of East	45	24.5	35	37.2	10	11.1
South of East	139	75.5	59	62.8	80	88.9
Total	184	100.0	94	100.0	90	100.0
Classic Period Structures						
	Whole Area		West Half		East Half	
Skew	No.	%	No.	%	No.	%
North of East	65	40.6	64	50.4	1	3.0
South of East	95	59.4	63	49.6	32	97.0
Total	160	100.0	127	100.0	33	100.0
All Structures						
	Whole Area		West Half		East Half	
Skew	No.	%	No.	%	No.	%
North of East	110	32.0	99	44.8	11	8.9
South of East	234	68.0	122	55.2	112	91.1
Total	344	100.0	221	100.0	123	100.0

possible that, where both types of alignments occur, the symbolism of world directions had little role in orientation practices. As argued elsewhere, practical or observational motives cannot account for a preference for orientations skewed clockwise or counterclockwise from cardinal directions (Šprajc 2004).

Alignments to Mountaintops

While the astronomical basis of north-south alignments is improbable, some of them were likely dictated by topographic criteria. The azimuths of 28 structural alignments, considering their estimated errors, agree with the directions to hilltops on the local horizon. The intentionality of these correspondences is supported by the fact that in 21 architectural complexes with clearly elongated ground plans, the mountaintops are placed along their long axes (Table 2; Figure 6). Furthermore, orientations to prominent mountaintops are common in various parts of Mesoamerica and, given their number, are hardly coincidental (Sánchez and Šprajc 2015; Šprajc 2001, 2018; Šprajc and Sánchez 2015; Šprajc et al. 2016). Significantly, the alignments to horizon prominences on the eastern and western horizons, which could have served as foresights and thus facilitated observations, belong to common orientation groups (Šprajc et al. 2023). These cases indicate that important constructions were often located on carefully selected spots, conditioned by a combination of both astronomical and topographic criteria. In general, the relationship of architectural orientations with mountains can be accounted for by the latter's religious and ritual significance, particularly by their aquatic and fertility symbolism (Broda et al. 2001; Paulinyi 2014; Schaafsma and Taube 2006).

Among the cases detected, nine peaks are placed to the north, three to the south, six to the east, and 10 to the west (Table 2). While a greater number of hilltops lying to the west was likely conditioned by

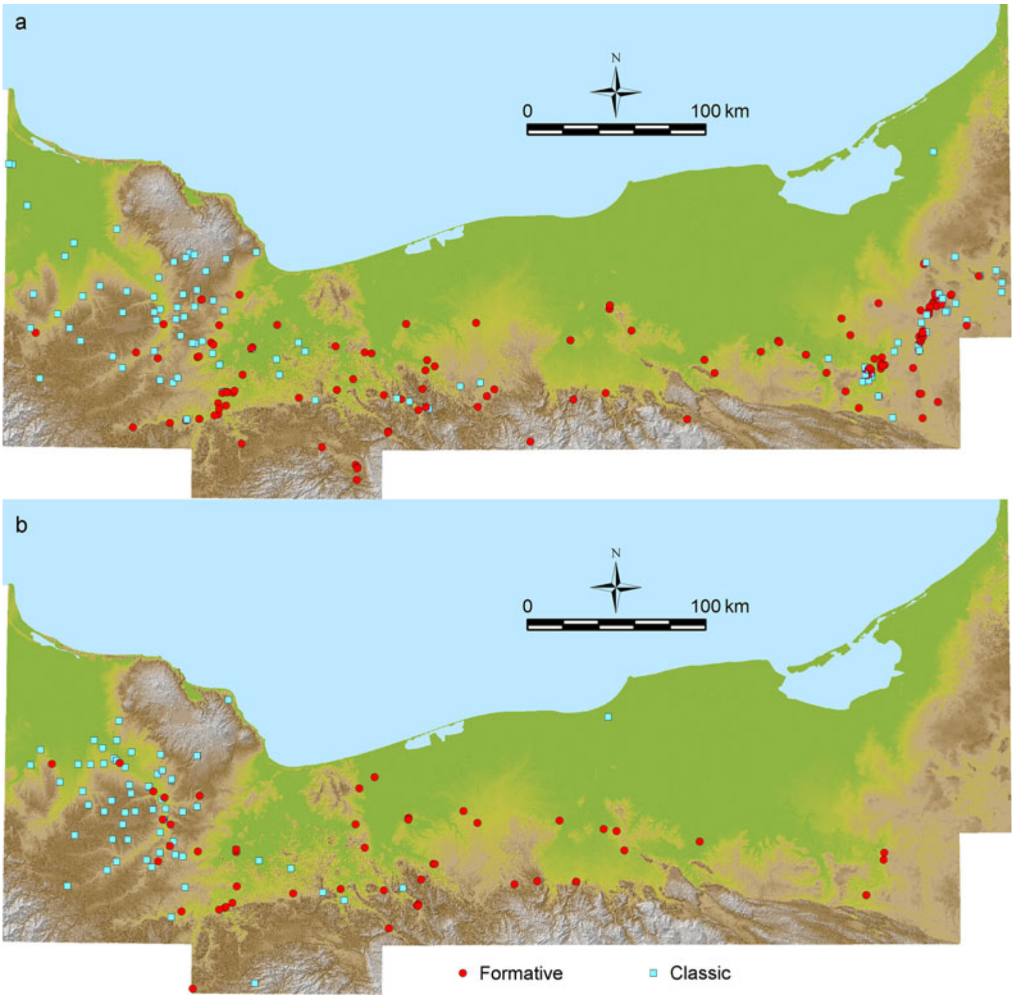

Figure 5. Distribution of south-of-east (a) and north-of-east orientations (b) of Formative and Classic structures. (Color online)

the lack of prominences in an easterly direction, the preference for the mountains on the northern horizon, also observed in central Mexico (Šprajc 2001), probably reflects a symbolic significance of north, because there is no lack of conspicuous horizon features in the area to the south. This fact conforms with Aveni and Hartung's (2000:63) observation that a prominent mountain can frequently be found to the north of a ceremonial center, and echoes the beliefs relating not only mountains but also the northern part of the universe to water and fertility (Corona Núnez 1957:35–38; Šprajc 1993:26–27; Thompson 1972:67; Wisdom 1940:393). In addition, the alignments to the summits in Sierra de los Tuxtlas may reflect the importance of this mountain range as a source of basalt for sculpted monuments. The concentration of alignments to mountains in the western part of the area and their scarcity in the eastern part (Figure 6) may be another evidence of different regional traditions, though another reason might be the lack of prominent mountains visible in the apparently preferred northerly direction from the sites in the eastern region.

Orientation Groups

Different regional traditions are also suggested by spatial distributions of constructions pertaining to a few prominent solar orientation groups. Figure 7 shows locations of the alignments that—considering their estimated errors—pertain to groups 1–4 (see above, and Figures 2 and 3). However, given their

Table 2. Data on Structural Alignments to Mountaintops.

North-South Alignments							
Site ID	Name	Type	Long Axis	Period	Aligned to Mountain	Azimuth (°)	Distance (km)
3	Ojo de Agua	Classic Veracruz minor	E-W	C	Volcán Santa Martha*	0.75	87.10
785	Rancho San Juan	Rectangle major	N-S	F	Volcán Santa Martha*	3.73	49.70
4365	Campo Burgoa	Classic Veracruz minor	N-S	C	Cerro el Vigía	343.94	37.20
8664		Classic Veracruz minor	N-S	C	Cerro Zempoaltépetl	217.35	111.75
9287	El Marquesillo	Classic Veracruz major	N-S	C	Volcán San Martín	0.72	59.56
9303		VC	N-S	F	Cerro el Vigía	330.15	50.52
9419	Laguna de los Cerros	Classic Veracruz major	N-S	C	?	359.29	28.20
9646		Rectangle major	N-S	F	Volcán Santa Martha*	353.49	83.49
9855		VC	N-S	F	Volcán Santa Martha*	5.53	61.40
10873		Classic Veracruz minor	N-S	C	Cerro Guiayem	218.91	54.60
19486		E Group		F	?	186.31	61.50
34103		Rectangle minor	N-S	F	?	31.11	6.80
East-West Alignments							
Site ID	Name	Type	Long Axis	Period	Aligned to Mountain	Azimuth (°)	Distance (km)
1	Ojo de Agua	Rectangle minor	E-W	F	Cerro Humo Grande	90.94	174.59
3	Ojo de Agua	Classic Veracruz minor	E-W	C	Cerro Humo Grande	270.97	173.40
110		Classic Veracruz minor	E-W	C	?	89.14	5.75
3079		Classic Veracruz minor	E-W	C	Cerro Mono Blanco	71.05	77.38
3448		Classic Veracruz major	E-W	C	Cerro Zizintépetl	271.45	134.40
5552	Los Azuzules	Classic Veracruz major	E-W	C	Pico de Orizaba	286.08	142.30
5571	Villa Nueva	Center minor		C	Pico de Orizaba	286.14	140.30
6037		Classic Veracruz major	N-S	C	?	273.70	17.20
9596		Classic Veracruz minor	E-W	C	Pico de Orizaba	299.32	249.19
10586	Medias Aguas	Classic Veracruz major	N-S	C	Cerro Guiayem	255.37	115.73
11551		Classic Veracruz minimal	E-W	C	?	289.60	0.61
11608		Rectangle minor	E-W	F	?	270.12	0.92
11732		Classic Veracruz minor	E-W	C	Cerro Guiayem	244.62	89.60
13946		Rectangle major	E-W	F	?	73.18	0.24
18767	Buenavista	MFU E Group		F	?	93.78	2.26
28657		MFU minor E Group		F	?	134.99	8.67

Notes: F: Formative, C: Classic. All angular values are in decimal degrees.
*Southern peak, highest for observer.

possible errors, some of these orientations may have targeted other dates; therefore, Figure 8 shows only the distributions of alignments with azimuth errors of less than 1°; solstitial alignments are not included in this figure, because they are unlikely to have had other referents. Here it should be noted that, while the peaks in Figure 3 correspond to sunrises on February 11 and October 29

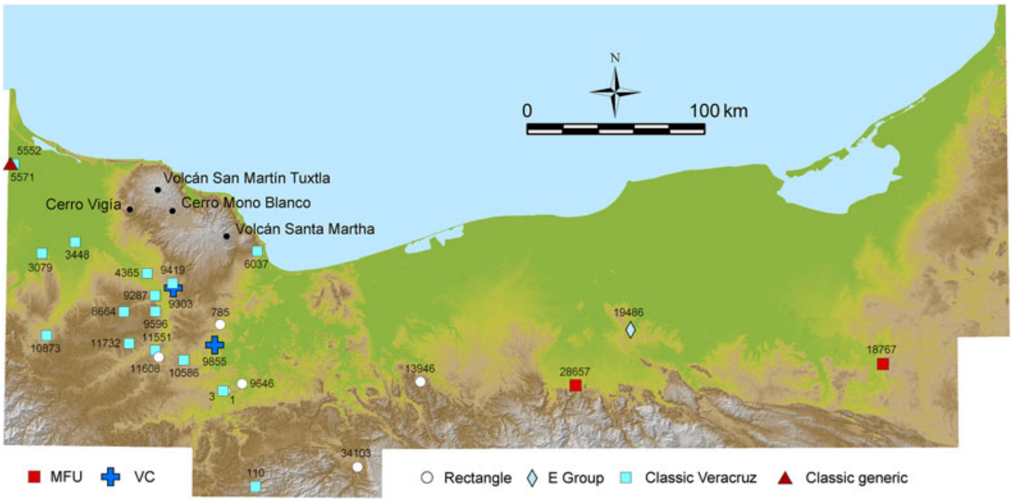

Figure 6. Location of structures aligned to mountaintops on the local horizon. (Color online)

(group 1) and on February 24 and October 17 (group 2), Figures 7 and 8 show locations of all compounds that can be related with these dates, including the few that are skewed north of east and therefore marked them on the western horizon.

Figures 7 and 8 show similar distributions. All these orientation groups existed since the early Middle Formative. Groups 1 and 2 apparently originated in the eastern part, where most of the Formative complexes with these alignments and of different types are concentrated. As Figure 1 shows, VC complexes are limited to the western half, and, accordingly, none of them belongs to either of the two groups. During the Classic, groups 1 and 2 were less popular; most of the Classic Veracruz complexes, which are all located in the western part of the area, recorded quarter days (group 4) and only a few pertain to groups 1 and 2. In contrast, many Classic period constructions of other types (Classic generic), which are concentrated in the eastern part (Figure 1), belong to group 1, but none of them recorded quarter days. This is particularly notable in Figure 9, which shows that the distributions of dates marked by Classic Veracruz compounds and by other types of structures from the same period are patently different. In the Formative, solstitial orientations appear only in the eastern part, probably because in the western section the solstices seem to have been marked by prominent mountaintops on the horizon (see below). These data, again, indicate the extent of two somehow different cultural spheres, which must have begun to shape during the Early-to-Middle Formative transition.

Origin and Spread of Orientation Patterns

Although the visibility of certain stars and asterisms in certain periods of the year and times of the night has been used for keeping track of the seasons by various societies, including the Mesoamerican, the simplest of the more precise methods devised for these purposes was the use of prominent horizon features as markers of the sun's positions in certain moments of the tropical year (Reyman 1975:213; Ruggles 2015:20). Research in different Mesoamerican regions revealed that, observing from important buildings at various sites, some prominent peaks on the local horizon correspond to the sun's positions on dates frequently recorded by architectural orientations (Šprajc 2001; Šprajc and Sánchez 2015:86–88; Šprajc et al. 2016:26–27). It is thus highly likely that many important buildings were not only oriented but also located on astronomical grounds, enabling the use of horizon calendars. These were likely the earliest form of precise observations of the sun's annual movement, but they were not completely abandoned when the astronomically significant directions became commonly incorporated into the built environment. Since sunrises or sunsets on certain dates can be marked by either natural features or human-made alignments, the architectural

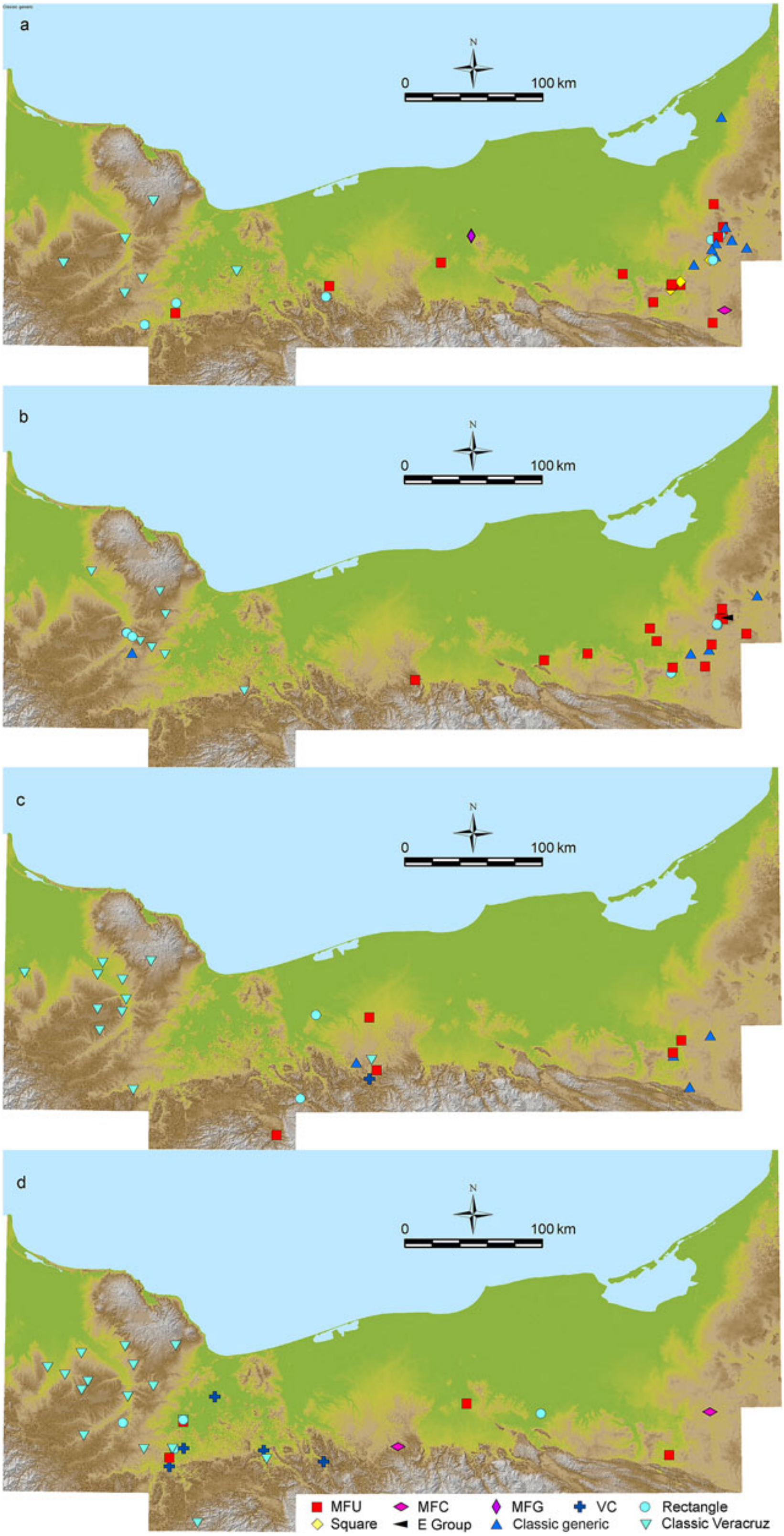

Figure 7. Spatial distribution of structures or complexes pertaining to orientation groups 1 (a), 2 (b), 3 (c), and 4 (d). (Color online)

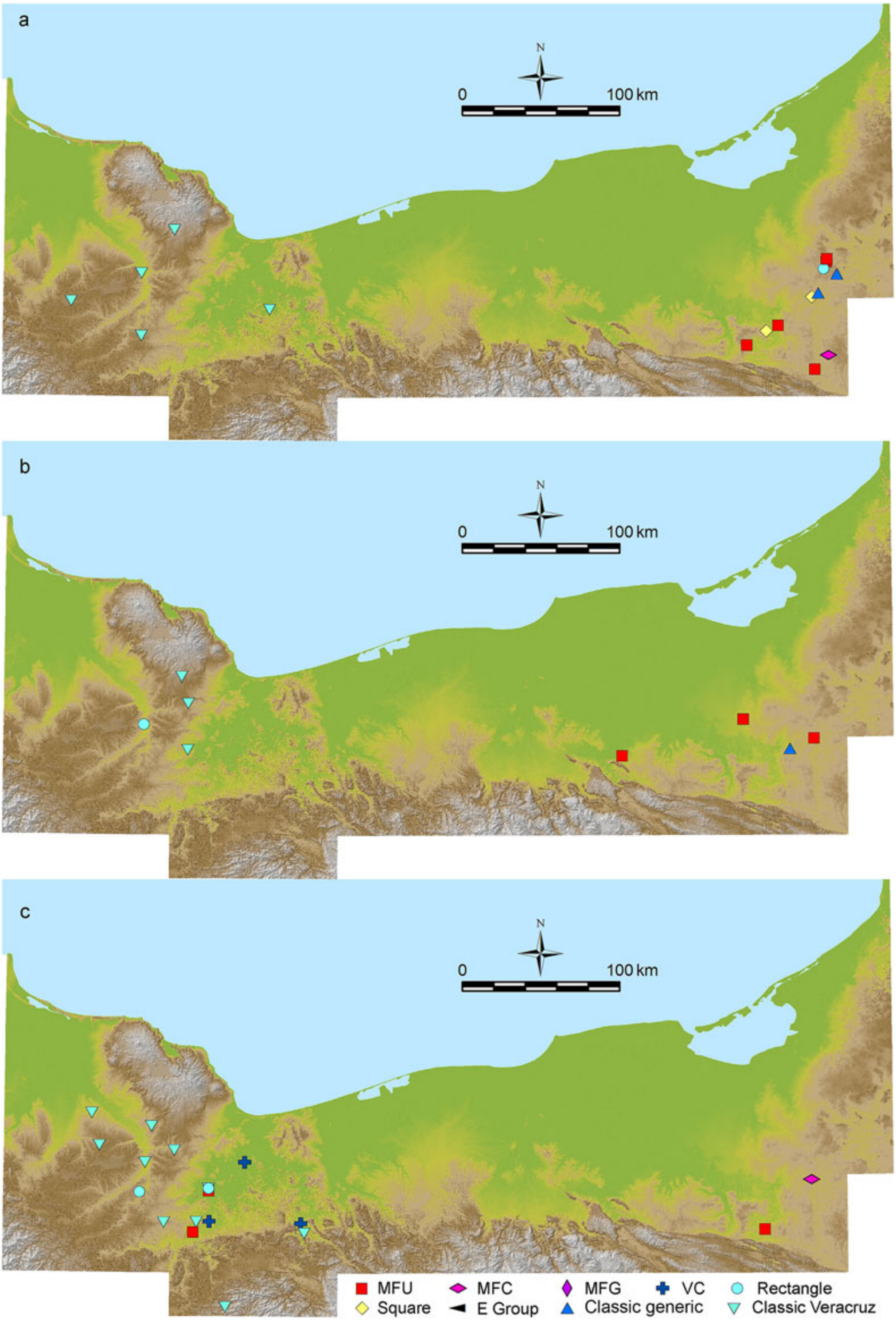

Figure 8. Spatial distribution of structures or complexes pertaining to orientation groups 1 (a), 2 (b), and 4 (c) and with azimuth errors of less than 1°. (Color online)

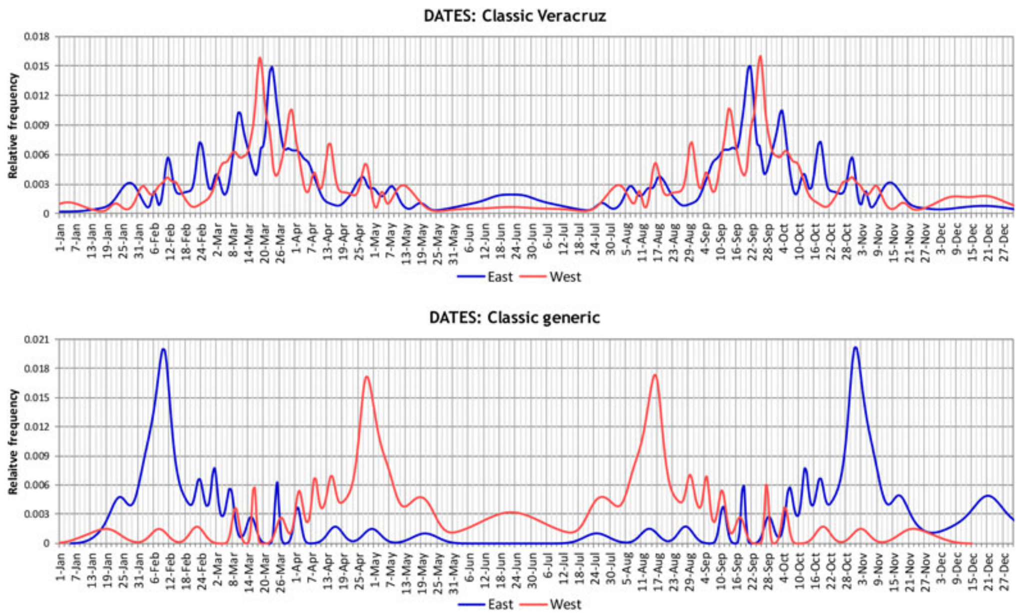

Figure 9. Relative frequency distribution of dates recorded by Classic Veracruz complexes and other types of Classic period constructions. (Color online)

orientations can be understood as artificial markers of horizon calendars. The structures aligned to summits on the eastern and western horizon, identified both in our study area and elsewhere in Mesoamerica, can be interpreted as reflecting a special, architecturally emphasized version of horizon calendars. Though a systematic study of the astronomical potential of horizon features visible from the sites in our area has not been done, some cases discussed below seem too significant to be fortuitous.

A tentative reconstruction of the evolution and spread of orientation patterns in Mesoamerica was offered in a previous study (Šprajc 2018), but requires some amendments in the light of new data, particularly in relation to early developments. Since the earliest architectural orientations known so far in Mesoamerica are located in the southern Gulf Coast area, it seems very likely that the orientation practices evidenced elsewhere in later periods, particularly those materialized in solar orientations that reflect complex observational schemes, had their origin in that region during the Early-to-Middle Formative transition. Our data about the distribution and chronology of structures (Table 1, Figure 5) suggest that the south-of-east skew, prevalent throughout Mesoamerica (Aveni 2001; Šprajc 2018), originated in the eastern part of our study area. In the Maya Lowlands, the principle of orienting structures south of east was practically mandatory from the Middle Formative on, with exceptions being relatively common only in eastern Petén and western Belize (Sánchez and Šprajc 2015; Šprajc 2021). The north-of-east deviations, while they nowhere predominate, appear in greater numbers also in central and northern Veracruz, in Oaxaca, and in northern and western Mesoamerica (Šprajc and Sánchez 2015; Šprajc et al. 2016). Their origin seems to have been in the western part of our study area, where such an orientation characterizes San Lorenzo, the earliest known monumental site, and where this trend became particularly pronounced during the Classic period (Table 1). Admittedly, these proposals might require modification if comparably early or earlier structures are eventually found elsewhere.

The available data suggest that the earliest astronomical alignments in Mesoamerica recorded the solstices and quarter days, in agreement with the natural significance of these dates: if the solstices, marked by the easily perceivable extremes of the solar annual movement along the horizon, served for halving the seasonal year, the next step in timekeeping was likely the determination of midpoints in time in each of these halves (Šprajc 2018:231–232). At San Lorenzo, the central part of the main plateau, with remains of a Formative Rectangle and a Classic Veracruz compound, as well as the

MFU complex to the south (Inomata et al. 2021:Figure 4a), are oriented to quarter-day sunrises. As established by previous research (Šprajc and Sánchez 2015:76), observing from the site core at the beginning of the site's occupation in the mid-second millennium BC, the sun at December solstice set behind the northern edge of the elongated and relatively level ridge of Mt. Zempoaltépetl in Oaxaca, which is still the most sacred place for the local Mixe calendar specialists and is regularly ascended during the ceremonies held around the solstices (Rojas 2022:198). The same quarter-day orientation is embedded in the core area of Laguna de los Cerros, from where Citlaltépetl volcano (Pico de Orizaba) marked June solstice sunsets. This site reached its apogee during the Late Classic, when a prominent Classic Veracruz complex was built. However, the analogous situation at San Lorenzo suggests that the late complex and urban layout may well have adopted the orientation of the early settlement, which was founded around 1400 BC, possibly by a relative of a San Lorenzo ruler (Borstein 2001; Cyphers 2008:335, 2012:92–93). Although there is no firm evidence that Classic Veracruz compounds had Formative antecedents, such a possibility is at least suggested by Complex A of La Venta, composed of two parallel elongated mounds running in a north-south direction and delimiting a courtyard with a pyramidal mound at each of its ends (Diehl 1981:77–78).

Such combinations of solstitial and quarter-day alignments are also found at later Formative sites. The main structural compound of Río Viejo, Oaxaca, is oriented to a prominent mountain marking the June solstice sunset, while the quarter-day sunrises occur over a summit on the eastern horizon (Šprajc and Sánchez 2015). Similarly, observing from the circular pyramid at Cuicuilco in central Mexico, where the altars of the early phases are aligned to the summer solstice sunrises, Mt. Papayo marks sunrises on the quarter-days (Šprajc 2001). Solstitial and quarter-day orientations are relatively rare in early architecture of the Maya Lowlands (Sánchez and Šprajc 2015; Šprajc 2018), probably because the area witnessed substantial colonization only after ~1000 BC, when other orientation groups, originating in the area under study, became more popular.

While some MFU sites, with 20 rectangular edge platforms that may allude to the calendrical significance of number 20, exhibit close similarities with the layout of the large rectangular complex on the main plateau of San Lorenzo, the latter has no E Group, which is often contained in the MFU and the morphologically related VC, MFC, and MFG complexes. Different regional traditions are also reflected in the fact that at Laguna de los Cerros and San Lorenzo, the solstices are marked by prominent mountains, while at Chiapa de Corzo, south of our study area, the solstitial direction is embedded in a MFC complex and its E Group (Šprajc and Sánchez 2015). Archaeological data from Chiapa de Corzo indicate migrations or influences from the Pacific coastal region to the south, where solstitial orientations were common since the early Middle Formative (Aveni and Hartung 2000; Bachand 2013:19–20). It seems significant that it is only in the eastern part of our study area, lying north of Chiapa de Corzo, where Formative solstitial orientations are found (Figure 7c), whereas in the western part the solstices seem to have been marked by mountaintops on the horizon. Aside from San Lorenzo and Laguna de los Cerros, a few other sites have a rather obvious solstitial marker on the horizon.

The MFC pattern and the E Group configuration probably originated along the Pacific coast. The earliest mound-construction tradition is found in the area, and the site of Ojo de Agua dating to 1200–1000 BC exhibits a spatial pattern that appears to have been a prototype of the E Group and MFC formation (Hodgson et al. 2010; see discussion in Inomata 2017). The rectangular form of the MFU pattern appears to have been established originally at San Lorenzo (Inomata et al. 2021). These observations suggest that the MFU and other similar patterns developed as a mix of traditions originating from San Lorenzo and the Pacific coast with local innovations, which included more diversified orientations.

Occurrences of the early orientation groups that we have identified were previously documented in different parts of Mesoamerica, although particular regions are characterized by specific, locally developed alignment patterns. The orientations marking February 11 and October 29 (group 1) belong to the most widespread alignment group in the Maya Lowlands and common also elsewhere, particularly in central Mexico. The data available before this study suggested that these orientations originated in the central Maya Lowlands, where they appeared no later than the second century BC (Sánchez and Šprajc 2015:78–79, 220; Šprajc et al. 2009). Given the evidence discussed here, however, their origin was much earlier and very likely in the eastern part of the southern Gulf Coast lowlands (Figures 7 and 8). They spread to central Mexico relatively late, because the earliest known building with this orientation is the Sun Pyramid of Teotihuacan (Šprajc 2001, 2018:234). The Late Formative Maya ceramic pieces have been found at various localities of Teotihuacan, indicating particularly intense relations with the central Petén (Cañas Ortiz 2014; Clayton 2005). Since no examples of this orientation group antedating the Classic period have so far been found in the area between the southern Gulf Coast lowlands and central Mexico (Oaxaca, Puebla, and central Veracruz), its appearance in Teotihuacan may have been a result of more direct transmission of the concept from the Maya Lowlands.

The Ciudadela of Teotihuacan adopted a different orientation, matching sunsets on May 3 and August 11, separated by 100 (= 5 × 20) days, but these dates were also recorded by some earlier central Mexican structures dated to the Late and Terminal Formative (Šprajc 2000, 2001). Observing from the main pyramid of La Venta, the setting sun on these dates aligned with the summit of the Santa Martha volcano (Šprajc and Sánchez 2015). Therefore, in agreement with diverse archaeological data indicating diffusion of cultural elements from La Venta to Veracruz, as well as connections with Teotihuacan (Nichols 2016:18, 26; Stark 1999:212; Stark and Heller 1991), it was proposed that these alignments spread from La Venta to central Mexico via central Veracruz, where not only Classic period compounds of Los Azuzules and Villa Nueva but also some Late and Terminal Formative structures of Cerro de las Mesas were aligned to the Citlaltépetl volcano (Pico de Orizaba), which marked sunsets on May 3 and August 11 (Šprajc 2018:233–234). Such a scenario is still likely, but in the light of our new data it should be added that this orientation group, even though not particularly prominent, appeared along the southern Gulf Coast before the apogee of La Venta, during the early Middle Formative period (Šprajc et al. 2023:Text S4, Table S7).

The orientations of group 2 (February 24 and October 17) spread to the rest of the Maya Lowlands by the Early Classic, but apparently did not gain much popularity elsewhere in Mesoamerica. Group 5, marking sunsets on April 11 and September 1, separated by 143 (= 11 × 13) days (Figure 3), became common on the Yucatán Peninsula by the Late Formative, but a preferred target of several Formative E Groups in the central lowlands were sunrises on March 2 and October 10, also separated by 143 days (Šprajc 2021); one of them is the E Group at Ceibal, with its earliest stage dated to around 950 BC (Inomata et al. 2017). For three complexes in our study area (MFU with E Group 12950, VC 13443, and Rectangle minor 11832; Šprajc et al. 2023:Table S1), these dates are the only possible among the conceivably significant referents. To judge by their types, these complexes are from the early Middle Formative, but in the absence of more accurate chronological data it remains unknown where these orientations first appeared.

The Middle and Late Formative orientations in Oaxaca differ notably from those in our study area; remarkably, the two regions with divergent early orientation trends overlap with two distinct ceramic style provinces advocated by Flannery and Marcus (2000:9–10, Figure 3). However, a connection of the southern Gulf Coast region with Oaxaca is suggested by Structure 19 on Mound 1 of San José Mogote, oriented to a mountaintop on the eastern horizon and to sunsets on March 31 and September 12, which delimit a 200-day interval. The early stages of this structure date to between 900 and 600 BC (Flannery and Marcus 2015). The orientations of this group, subsequently appearing at Monte Albán and in Middle Formative Chalcatzingo in central Mexico (Šprajc 2001; Šprajc and Sánchez 2015), are attested along the southern Gulf Coast, where they might be earlier (Šprajc et al. 2023: Text S4), as well as in several E Groups in the central Maya Lowlands, some of them dating to the Middle Formative period (Inomata et al. 2018; Šprajc 2021). Their widespread distribution can be accounted for by long-distance contacts, but the lack of more reliable chronological data makes the place and time of their origin uncertain.

While the orientations in most of the Maya Lowlands refer almost exclusively to the sun, the northeast coast of the Yucatán Peninsula is distinguished by the presence of an alignment group most likely related to a star or asterism, as well as by the largest concentration of orientations to the major lunar extremes, which occur only sporadically elsewhere in Mesoamerica (González-García and Šprajc 2016; Sánchez and Šprajc 2015:59–69; Sánchez et al. 2016; Šprajc 2016, 2018). Alignments of both groups are also common in the southern Gulf Coast area (Šprajc et al. 2023). Since some archaeological and historical data suggest that the two regions were connected through trade and shared the worship of the Maya goddess Ixchel, associated with the moon (Sabloff and Rathje 1975:24–26; Scholes and Roys 1968:33, 57, 77, 395), these facts might explain the similarities in orientation patterns. The most likely place of origin of these alignments was the Gulf Coast area, where they appear in the early Middle Formative and from where their diffusion may have followed maritime routes, perhaps related to the early colonization of the Yucatán Peninsula. However, given a distinct orientation trend in the upper Usumacinta basin, where some alignments of both groups were also identified (Sánchez and Šprajc 2015:59–65, 219–220, Tables 4 and 6), they may have spread there along the Usumacinta River; the importance of this route in trade networks is attested in later periods (Scholes and Roys 1968:33).

Yet another orientation group we have identified in the study area corresponds to the major extremes of Venus as evening star. The orientations targeting these phenomena, though not very common, are known from different parts of Mesoamerica (Aveni 2001; Sánchez and Šprajc 2015; Šprajc 1993, 2001, 2018), but the earliest examples are found along the Gulf Coast (Šprajc et al. 2023:Text S2, Figures S4 and S5, Table S4).

Our alignment data, representing the earliest evidence of astronomical practices in Mesoamerica, also provide novel information concerning the time-depth of the intimately related 260-day calendrical count. The earliest unequivocal epigraphic evidence of its use was found in Late Formative mural paintings at the central lowland Maya site of San Bartolo, Guatemala, dated to 300–200 BC, whereas the hypotheses that this cycle originated during the Middle or even Early Formative period were based on ambiguous or unreliable data (Justeson et al. 1985:33–34; Rice 2017; Stuart et al. 2022). The orientations we have analyzed constitute the only currently available material evidence that brings us closer to answering the question of when this cycle first appeared: since the orientations marking dates separated by multiples of 13 or 20 days would have only made sense in combination with the formal calendrical system, particularly the 260-day count, and given the dating of early complexes with these alignments, we can now safely conclude that this cycle was in use by ∼1050 BC, centuries earlier than it was first attested by written records (Inomata et al. 2020; 2021; Šprajc et al. 2023). As long as no evidence to the contrary is found, the area along the southern Gulf Coast remains the most likely place of its origin. Malmström (1973) hypothesized that the 260-day count originated at Izapa, which lies on the latitude where solar zenith passages occurring on April 30 and August 13 are separated by 260 days. However, the apogee of Izapa corresponds to the Late Formative period, with its early construction phases dating to around 850 BC (Rosenswig et al. 2013). While there was substantial earlier occupation in the area (Clark and Pye 2000; Hodgson et al. 2010), the orientations of Formative sites along the Pacific coast, including Izapa, refer to the sun's positions at the solstices (Aveni and Hartung 2000; Lowe et al. 1982) and thus offer no evidence of the 260-day count.

Concluding Remarks

In various ancient societies, astronomical and cosmological concepts had an important role in landscape formation and conceptualization and were frequently expressed in the astronomically based alignments materialized in architecture and urban patterns. As exemplified by a number of studies, archaeoastronomical investigations of this aspect of spatial order offer important insights into extinct cognitive worlds, which are difficult or impossible to grasp from other types of archaeological data. Furthermore, the architectural orientations and other alignments documented in the archaeological record are attributes of material vestiges (Iwaniszewski 2015:321) and can thus be useful for addressing other questions of archaeological relevance. Regional interaction and broader sociopolitical processes can be reconstructed from various types of archaeological evidence, but the potential of alignment studies for solving these issues has been largely underestimated. Traditionally, archaeologists have been very careful to record architectural details, the dimensions and layout of structures, but their orientations have received much less attention.

Our alignment data indicate that the lowlands along the southern Gulf Coast were the primary stage for the initial development of the astronomically oriented monumental architecture and the

Mesoamerican calendrical system. They also suggest the existence of two somehow different regional sets of concepts and practices that began to shape during the transition from the Early to Middle Formative period. Although these patterns loosely correspond to the areas conventionally called the Gulf Olmec region and the western Maya Lowlands, we should also note that there is no simple relationship between cultural complexes and ethnic identities. The south-of-east skew of orientations soon diffused eastward, becoming a characteristic that dominated architectural orientations throughout the Maya Lowlands up to the Spanish conquest. While the same trend prevails also elsewhere in Mesoamerica, the north-of-east orientations are relatively common in some regions. They also have early origins, probably in the western part of our study area, where this skew is exhibited by San Lorenzo, the earliest monumental site, as well as by many later structures. Since the same dates can be marked by the sun's positions on either the eastern or western horizon, practical or observational motives cannot explain the preferences for north-of-east or south-of-east orientations. It is not impossible that regional variations in the distribution of the prominent orientation groups reflect some differences in environmental conditions or primary subsistence activities, which may have required different seasonal scheduling. However, considering that the same orientation groups are found in other, environmentally different parts of Mesoamerica, but none of them correlates preferentially with a specific natural setting, the variations in orientation trends were most likely conditioned by the development of culturally idiosyncratic conceptual schemes and ritual schedules.

The evidence we have discussed sheds light on the origin and diffusion of architectural orientation patterns that can be included among the characteristically Mesoamerican cultural traits. On one hand, these data reinforce some previously formulated hypotheses based on different types of evidence. On the other, they reflect the development of regional traditions and some long-distance contacts that have not been clearly attested by previously available archaeological data. It is not impossible that the alignments to the sun's solstitial extremes, which are visually striking moments of the year, appeared independently in different regions (as indeed they did in other parts of the world). However, it is utterly unlikely that the alignments allowing the use of complex observational calendars composed of the same dates, even if found in widely separated parts of Mesoamerica, would have been a result of independent local inventions. Therefore, it can be safely concluded that they appeared as a consequence of diffusion of the same or similar underlying concepts. Our data, representing material correlates of specific elements of worldview, do not allow a deeper insight into the mechanisms of this diffusion. However, the results of this study, exemplifying the utility of information of this type for addressing issues of cultural history, are expected to stimulate the search for further evidence that may clarify the economic, social, or political aspects of the processes involved.

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Competing Interests. The authors declare none.

Notes

1. The declination expresses angular distance from the celestial equator to the north and south and depends on the azimuth of the alignment (horizontal angle measured clockwise from the north), geographic latitude of the observer, and the horizon altitude corrected for atmospheric refraction.
2. For KDE analyses, we used the Gaussian kernel, with a normal distribution centered on the nominal value and with a standard deviation (bandwidth) equal to the error assigned to each value. All normal distributions (kernels) were then summed up and plotted. Since the errors assigned to several similar values tend to cancel out, the most prominent peaks of the resulting curves are expected to closely correspond to the values targeted by particular orientation groups (for details, see González-García and Šprajc 2016; Šprajc et al. 2023).

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