Continentality in the Texas Coastal Zone

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ABSTRACT

An analysis is presented of continentality in the Texas coastal zone, based on standard climatological data from the existing National Weather Service network. In spite of prevailing onshore winds throughout the year, Texas coastal zone stations (Gulf of Mexico to 150 mi inland) exhibit a substantial degree of continentality by any of the usual definitions. Continentality by the Conrad definition ranged from approximately 25% in the Brownsville area to about 38% inland, with a mean value of approximately 33% for the 1941–70 period in the entire coastal zone.

Additionally, some measurements are presented of horizontal gradients of air temperature in summer and winter along a line perpendicular to the Gulf coast from near Port Aransas to near Sinton, Tex., approximately 30 mi inland. Mean daily temperature range and other statistical parameters for these stations underscored the continentality findings, and demonstrated substantial horizontal gradients of continentality in the immediate coastal zone, with a value of continentality of about 20% at the Port Aransas beach. Overwater values of continentality from summarized ship reports off the Texas coast were of the order of 18–20%.

1. Introduction

The degree to which land areas influence climate is expressed by the concept of *continentality*, first stated by Zenker in the 1890's (Hann, 1908; Conrad, 1946). Numerous modifications of the basic formula have been made, but all, including Zenker's original formulation, show the index of continentality for a given location to depend on the annual range of temperature and the latitude of the station. Inclusion of the latitude accounts for the observed increase of annual temperature range with latitude, and makes possible the comparison of continentality index values over large areas of the globe.

The empirical formula for continentality due to Conrad (1946) expresses the degree of land influence in an index

$$k=[1.7A/\sin(\phi+10°)]-14,$$

where A is the difference in mean temperature (°C) between the warmest and coldest months at the station and ϕ is latitude of the station. The two empirical constants were chosen in such a way as to make the index zero for the "most marine" location and 100 for the "most continental" among the stations studied. Conrad introduced the correction factor of 10° of latitude to avoid the difficulty of low-latitude determinations of continentality. Most distributions of continentality in the literature appear to utilize the Conrad formulation, although numerous modifications have been proposed by others (Gorczynski, 1920; Spitaler, 1922; Brunt, 1924; Johansson, 1931; Raunio, 1948; Hela, 1953).

Other techniques for the expression of continental and/or ocean effects have also been proposed: Kerner, 1905 (index of oceanicity); Dinies, 1932 (air mass climatology); Leighly, 1938 (extremes of annual temperature); Berg, 1940 (ratio of continental to maritime air masses); Calef, 1950 (interdiurnal variability of temperature extremes); Court, 1951 (temperature frequencies); Prescott and Collins, 1951 (lag of temperature behind insolation); Craddock, 1964 (interannual variability of monthly mean temperature); Bailey, 1968 (hourly temperatures related to annual range); Polowchak and Panofsky, 1968 (spectrum of daily temperatures).

The point is that continentality is not a simple concept, and a variety of schemes has been proposed to express the basic idea. In any case, a scale of continentality is useful in mapping the relative influence of land and water areas for the various climatological stations worldwide, giving numerical measures of the land (or water) effect.

Coastlines everywhere juxtapose continental and marine environments, accounting for such phenomena as the land/sea breeze. It is no surprise, therefore, to find that isopleths of continentality generally parallel the continental margins [e.g., Trewartha (1961) shown in Fig. 1]. However, it is clear from an examination of such distributions that continentality "spills over" to adjacent water areas, especially on the east (lee) coasts

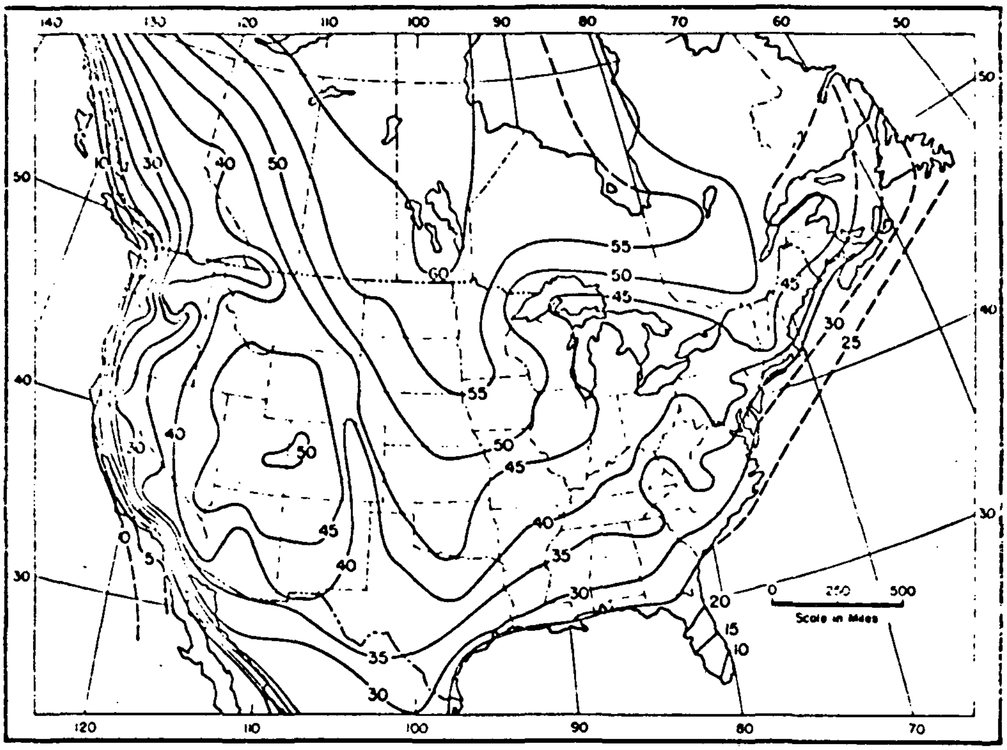

FIG. 1. Isopleths of equal continentality for Anglo-America, using V. Conrad's formula (Trewartha, 1961).

of continents in middle and high latitudes, and that such significant water bodies as the U.S. Great Lakes introduce a marine effect sufficient to distort the continentality isopleths. In North America, only the west (windward) coast exhibits continentality isopleths parallel to the coastline, as well as an index which approaches zero near the coast (see also MacKay and Cook, 1963). Such regional features of continentality distribution have prompted special studies on a smaller scale: Leighly, 1941 (U. S. Great Lakes); Fobes, 1954 (New England); D'Ooge, 1955 (western United States); DeBrichambaut and Wallén, 1963 (Near East); Kopec, 1965 (U. S. Great Lakes). A similar study is reported here for the Texas coastal zone.

2. Texas coastal zone study

a. *Continentality distribution*

Continentality by the Conrad (1946) formula was determined for 40 NOAA climatological stations in the Texas coastal zone for the standard period 1941–70, and for an additional 15 stations with near 30-year records.[1] Thus, 55 stations were utilized to yield continentality isopleths (Fig. 2) from the Gulf coast to approximately 150 mi inland.[2]

[1] Bracketed data plotted in Fig. 2 are for stations with 28 or 29 year records during 1941–70, or for stations with 30-year records overlapping 1941–70 by 26–29 years.

[2] "Miles" are statute miles.

The trend of the isopleths in Fig. 2 is nearly parallel to the Gulf coast; however, the upper Texas coast is more continental (~30%) than the lower coast (~25%), and there are other departures from the simple parallel mode suggested by the Trewartha distribution of Fig. 1. For instance, there is a tendency for smaller continentality to appear in the Rio Grande valley, compared to the continental (semi-arid) highlands just to the north. There is also a tendency for less continental air to appear in the region between Cotulla and San Antonio, and for the urban complex along an approximate Houston to Port Arthur axis to exhibit larger values of continentality than the surroundings. The mean value of the continentality index for the 55 stations for the 30-year period is 33.1%, with standard deviation of 3.2.

The continentality distribution shown in Fig. 2 must be considered preliminary, because no effort has been made to examine individual station exposures, nor to find other sources of error. There is no assurance that the 30-year period is a stable climatological period; indeed, a study of the data showed that 5-year means of continentality index generally increased slightly over the network during the 30-year period. It is difficult to tell whether this is a real increase in continentality in the Texas coastal zone, or merely an increase in urban effects around the existing climatological stations.

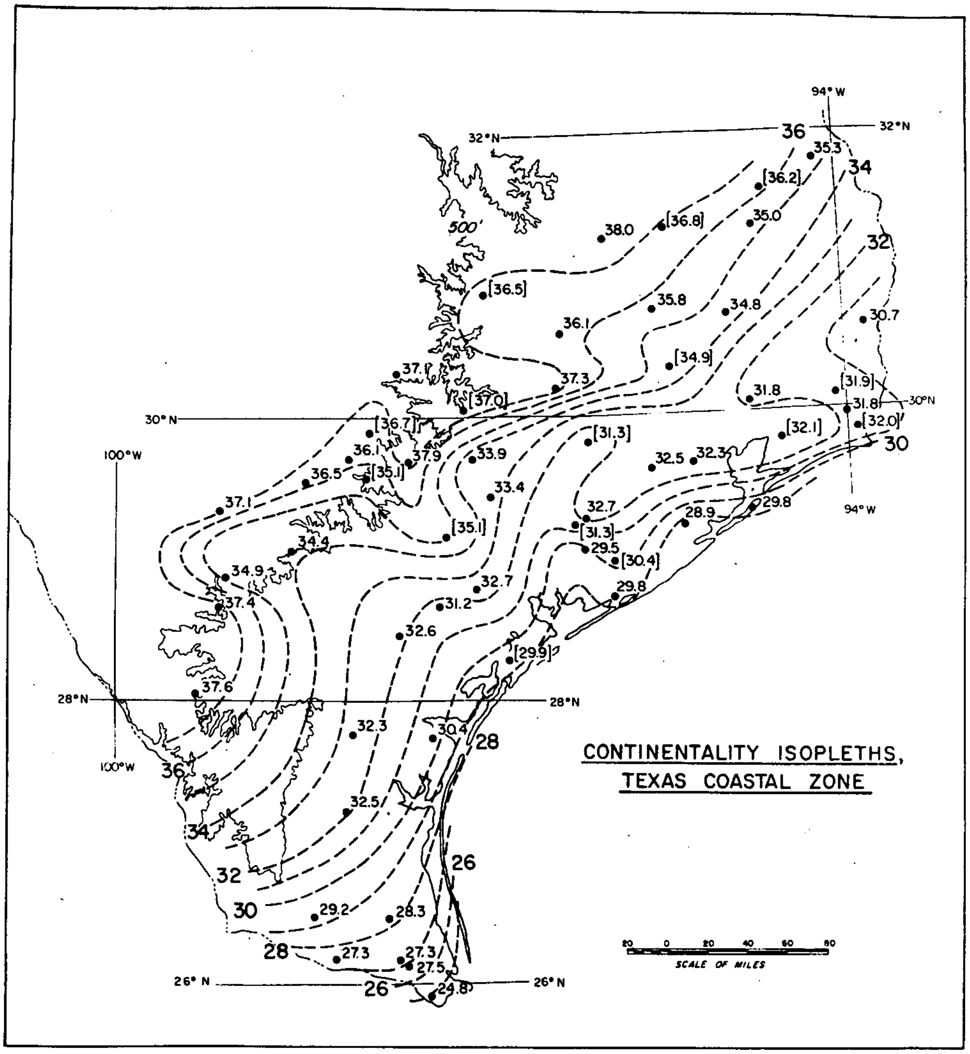

FIG. 2. Continentality isopleths, Texas coastal zone, Conrad definition, period 1941–70, 55 stations.

b. Field measurements

The small station density overland within 5–10 mi of the Gulf Coast (Jehn, 1974, pp. 7–10) does not permit a detailed examination of continentality by the Conrad formula or similar expressions which depend on mean annual temperature in the region where the largest gradients would be expected. In a study designed to monitor daily temperature range near the Texas coast, four hygrothermographs in standard instrument shelters were employed: one on the back beach on Mustang Island at Port Aransas, ~0.1 mi from the Gulf waterline; a second 1500 ft inland from the first at the University of Texas Marine Science Institute also on Mustang Island; a third[3] in Aransas Pass on the mainland, ~10 mi from the Gulf; and the fourth near the headquarters building of the Welder Wildlife Refuge northeast of Sinton, Tex., ~30 mi from the Gulf. The hygrothermographs were operated from 19 December 1974 to 25 January 1975, and from 6 June to 10 July 1975, representing a winter and a summer period. (Difficulty with the humidity elements left the temperatures as the only reliable data set during these two periods.) Hygrothermographs in standard shelters were chosen over other instrumentation so that comparison of the measurements with standard climatological data would be feasible.

[3] Courtesy of Elgie Wingfield, Institute boat captain.

The diurnal variation of temperature at these four stations was examined for the summer and winter periods and compared with the daily range over the same periods at NWS reporting stations from Aransas Pass inland to Kenedy. The comparative data are summarized in Table 1.

The continental effect is striking, and is evidently concentrated in the first 30 mi or so from the Gulf of Mexico during the summer period, during which only one cold front passage was noted at Port Aransas

TABLE 1. Mean daily temperature range (°F) (MDR) from "Beach" Station to Kenedy, Tex.

	Summer period (6 June to 10 July 1975)							
	1 "Beach"	2 "Institute"	3 "Elgie"	Aransas Pass	4 "Welder"	Sinton	Beeville	Kenedy
Approximate distance from Gulf (mi)	0.1	0.4	10	10	30	30	60	80
MDR	4.3	7.5	12.5	13.9	17.6	19.0	18.8	20.6
	Winter period (19 December 1974 to 25 January 1975)							
	1 "Beach"	2 "Institute"	3 "Elgie"	Rockport	4 "Welder"	Sinton	Beeville	Kenedy
MDR	9.8	11.2	18.7	17.6	21.2	22.7	23.5	25.0

(11–12 June), although northeasterly winds were noted on other occasions as well. Similar results are noted for the winter period, except of course that the mean daily temperature range is larger, especially close to the coast, compared to the summer data.

While these data exhibit various degrees of continentality, the findings are not easily compared to the continentality distributions based on annual range of temperature. Bailey (1968) has examined the relationship of hourly temperatures to annual range, finding a useful correlation between annual range of temperature and the standard deviation of hourly temperatures around the annual mean for a large number of standard reporting stations (Fig. 3). The physical basis for this correlation suggests that there might be a shorter period validity applicable to the data available in the present study. Accordingly, temperatures were read from the hygrothermograph charts at 2 h intervals and tabulated for each station. Means and standard deviations were calculated for the winter and summer periods, with the results shown in Table 2.

The differences in arithmetic means for the four stations in one season are probably not significant, but in both winter and summer the increasing standard deviation with increasing distance from the Gulf is indicative of increased continentality.

Plotting the standard deviations shown in Table 2 versus the extreme range for the winter and summer periods for the four stations (Fig. 4) yields a relationship similar to that of Bailey (1968), suggesting that a fundamental correlation indeed exists between standard deviation of short interval temperatures and the range of temperatures during the period in question. It is not possible to interpret these results directly in terms of

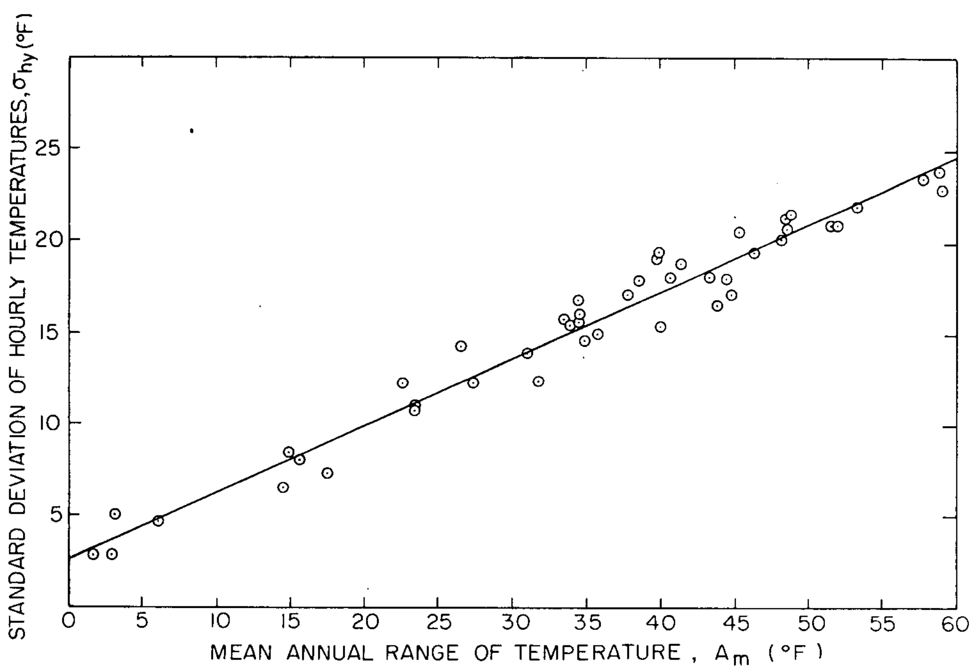

FIG. 3. Standard deviation of hourly temperatures vs mean annual range of temperature (after Bailey, 1968).

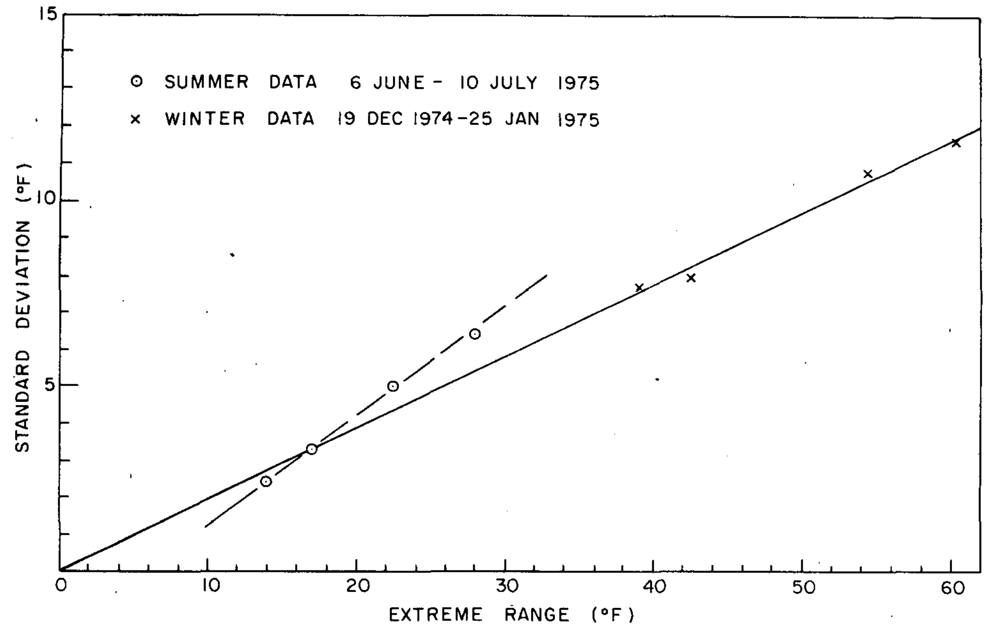

FIG. 4. Standard deviation of 2 h temperatures vs extreme range, Texas coastal zone field measurements, 1974–75.

continentality based on annual range. However, the stations within 30 mi of the Gulf of Mexico in Table 2 could be interpreted[4] as having a standard deviation of hourly temperatures for the year of the order of 12°F. Bailey's analysis indicates that the annual range of temperature corresponding to this standard deviation is approximately 25°F. An annual temperature range of this magnitude at the latitude of Port Aransas would yield a continentality index (Conrad) of close to 25%, a value somewhat less than the extrapolated value in Fig. 2. Data from a single year (1974–75) can hardly be compared with a long-period record, but the order of magnitude of this continentality index along the coastal bend seems reasonable. Judging by the smaller standard deviations exhibited much closer to the coast in Table 2, it would appear that the continentality index at "Beach" for 1974–75 could be on the order of 20%.

[4] Bailey (1968) noted a relationship among dispersions about the mean such that the sum of the variance of hourly temperatures about the monthly mean (σ_{hm}^2) and the variance of the monthly mean temperature about the annual mean (σ_{my}^2) equals the variance of the hourly mean about the annual mean (σ_{hy}^2). In the present case, σ_{hm} is approximated by the standard deviations shown in Table 2; σ_{my} can be determined from climatological data for such stations as Rockport and Sinton to be in the order of 10°F. Thus, σ_{hy} for "Elgie" and "Welder" must be in the order of 13°F, giving an annual range (A_m) of the order of 28°F (Fig. 3), and a continentality index of the order of 30%, in agreement with the isopleths of Fig. 2. Since σ_{hm} for "Beach" and "Institute" are smaller than those for Elgie and Welder, σ_{hm}^2 for the year can be estimated to be in the order of 35. If σ_{my}^2 is taken to be about 100, σ_{hy} will be of the order of 12°F.

c. Overwater values

Suitable temperature data from overwater locations are unavailable in the sense of long records at a single location. However, weather observations are made routinely (and with a fair-weather bias) by ships which operate in the Gulf. The National Climatic Center, under the direction of the U. S. Naval Weather Service Command (1975), has summarized meteorological observations for overwater locations in a series of publications. The data so summarized for limited overwater areas are applied to the "centroid" of the area. The location for summarized ship reports in the extreme western Gulf of Mexico (Area 29, Corpus Christi) is 27.5°N, 95.8°W, and the primary period of record is 1952–71. Utilizing the frequency distributions of temperatures at the synoptic hours for ships in this area for the period of record yields the following data: 1) mean

TABLE 2. Statistical summary of 2 h winter and summer temperatures (°F).

	1 "Beach"	2 "Institute"	3 "Elgie"	4 "Welder"
Winter data [19 December 1974 to 25 January 1975 (372 cases)]				
Arithmetic mean	57.41	58.14	56.55	56.73
Standard deviation	7.68	7.96	10.82	11.65
Summer data [6 June to 10 July 1975 (316 cases)]				
Arithmetic mean	83.30	82.69	82.00	81.99
Standard deviation	2.43	3.30	5.01	6.42

temperature of the warmest month (August), 83.9°F; 2) mean temperature of the coldest month (January), 63.5°F; 3) annual range of temperature, 20.4°F. The calculation of continentality index (Conrad) gives $k=17.6\%$, a not unreasonable overwater value for the coastal waters approximately 80 mi off the Texas Coast. A similar calculation for the Galveston area (Area 28, at 28.3°N, 93.2°W) gives $k=20.0\%$. This is in general agreement with the previous finding of larger values of continentality along the upper Texas coast, compared to the lower coast. Moreover, these over water values of continentality seem to fit reasonably with the barrier island value of 20% estimated for the coastal bend near Port Aransas.

3. Summary and conclusions

A preliminary distribution of continentality index by the Conrad definition has been exhibited for the Texas coastal zone, based on climatological data for the period 1941–70. Additionally, detailed field measurements of surface air temperature from the Gulf beach at Port Aransas inland to near Sinton in a summer and a winter period have been used to demonstrate relatively large horizontal gradients of continentality index in the Texas coastal bend. Finally, estimates of continentality index over water have been made from available surface air temperatures made on ships over the period 1952–71. Internal consistency is exhibited by these various continentality values.

Continentality by any definition is but one of many parameters used to characterize the climate of a given area. It is clear from this study that detailed distributions of climatic variables will be needed to characterize climatic resources of the Texas coastal zone, especially in the region closest to the coastline, including bays and estuaries and the adjacent Gulf, where very few data exist. Resource catalogs of the Texas coastal zone such as those of Fisher *et al.* (1972) and Fruh *et al.* (1972, 1973) are deficient in their listing of climatic resources as a consequence of dependence on existing climatological stations. Data needs can be met in part by studies such as the one described here. A better long-term solution would be the establishment of additional climatological stations close to the coast. A good starting point would be to establish a standard climatological reporting station at the Port Aransas Laboratory of the UT Marine Science Institute, and the simultaneous placement of an automatic weather station (AMOS) on one of the oil or gas platforms just offshore. The data from these two stations would serve present operational needs of the Corpus Christi forecast district, and would be the nucleus of additional studies of the transitional climates of the Texas coastal zone.

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My wife Peggy has been a capable research assistant in much of the field work. J. C. Evans assisted with the initial study, psychrometer transects by automobile from Port Aransas to ~20 mi inland, 15–16 August 1974. Larry Powers helped with chart changing and in other ways. Dr. L. Drawe maintained records at the Welder Station. Leif B. Svensson assisted with the literature search. W. Randall Poteet made most of the continentality calculations. Sue Sweeney typed the manuscript.

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