Luis A. Robles Macías*

The longitude of the Mediterranean throughout history: facts, myths and surprises

Keywords: History of longitude; cartographic errors; comparative studies of maps; tables of geographical coordinates; old maps of the Mediterranean

Summary: Our survey of pre-1750 cartographic works reveals a rich and complex evolution of the longitude of the Mediterranean (LongMed). While confirming several previously documented trends − e.g. the adoption of erroneous Ptolemaic longitudes by 15th and 16th-century European cartographers, or the striking accuracy of Arabic-language tables of coordinates−, we have observed accurate LongMed values largely unnoticed by historians in 16th-century maps and noted that widely diverging LongMed values coexisted up to 1750, sometimes even within the works of one same author. Our findings also dispute the important role traditionally attributed to astronomers in improving the accuracy of Mediterranean longitudes.

Objective and scope

The objective of this study is to reconstruct the chronological evolution of the accuracy and precision of one cartographic feature: the difference of longitude between the two extremities of the Mediterranean Sea (abbreviated LongMed henceforth). For that, the coordinates of Western and Eastern localities of the Mediterranean Sea have been measured on a large sample of cartographic works made or published before the mid 18th century. A voluntary effort has been made to include works of diverse types, i.e. not only maps but also globes, tables of coordinates and geography texts; and from as diverse geographic and cultural origins as possible. The only limitation on the type of works included in the sample is that it has to be possible to measure longitudes on them. This excludes the large majority of maps made before the 15th century, as they rarely display meridians or any other means by which longitudes can be ascertained. In particular most of the old maps of the Mediterranean *par excellence*, the "portolan charts", cannot be included in the database because, although they normally contain scales of distance, they show no indication of angular coordinates.

This article reviews earlier literature on the problem of the longitude of the Mediterranean, explains the methodology used in the study and outlines the main results obtained to date. New cartographic works will be added regularly to the database in the future to enable finer analysis of particular trends.

The problem of the longitude of the Mediterranean in historical literature

In our times, finding the difference of longitude between any two points of the surface of the Earth has become trivial because the cartographic coordinates of every point are easily accessible through a

* Independent scholar. 5684 Bay Street, apt 556. Emeryville, California, 94608 USA
[luis.a.robles.macias@gmail.com]

myriad of sources. It is thus easy to check that the difference of longitude between Punta de Tarifa (southernmost tip of Spain, and one of several arbitrary markers for the western end of the Mediterranean Sea) and Iskenderun (easternmost location of the Mediterranean) is exactly 41.78 degrees. However, in the not so distant past measuring differences of longitude was not a trivial task and cartographic works displayed different and often highly erroneous estimates of this value.

It is important to distinguish two related but different concepts: on one hand, the *difference of longitude* between two points is the angle formed by the planes containing their two meridians, and is almost always expressed in sexagesimal degrees; on the other hand, the *distance* between those same points is the length of the shortest path over the surface of the Earth that connects the two points, and is expressed in units like kilometers or miles. Knowledge of the distance between two points is not enough to compute their difference of longitude; one also needs to know the latitudes of the two points and the radius of the Earth to do that calculation. In this article, the term "longitude of the Mediterranean" (LongMed) will always mean the degrees and minutes that separate the Iberian Peninsula and Morocco from the Asian continent, and not the distance in kilometers or miles between such regions.

It is well known to historians of cartography that most maps produced up to around 1700 substantially overestimated LongMed. This fact may surprise given that ships from numerous civilizations have sailed across the Mediterranean Sea since the earliest recorded history, and that those same maps that show largely erroneous representations of the Mediterranean often present quite accurate longitudes for lands that only recently had come to the knowledge of Europeans, like the Americas or southern Africa. In the last three centuries several narratives have been put forward to explain such apparent paradox.

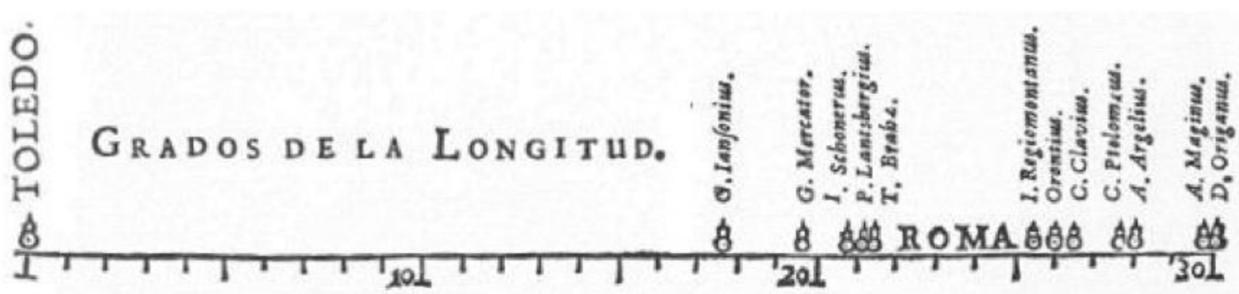


Figure 1: Graph showing different estimates of the degrees of longitude between Toledo and Rome compiled by Michael van Langren; version of 1644.

In the 16th and 17th centuries in Europe the accurate determination of longitude was a challenge that occupied academics, mariners, geographers and inventors. In the 1620's one Flemish cartographer, Michael van Langren, compiled the widely diverging estimates of longitude difference between Toledo and Rome (i.e. the western half of the Mediterranean) he observed in contemporary cartographic works. He had no way to tell which of them was the most accurate, and therefore no historical perspective on where the source of error could be; he nevertheless had the merit of creating the earliest known statistical data graph,[1] which is shown in Figure 1.

Less than one century later, French scientists were claiming victory over the determination of the lon-

[1] Friendly et al (2010).

gitude of the Mediterranean. Guillaume Delisle made an updated world map for the French crown with corrected coordinates and in a paper dated 1720 explained his sources and methods and provided what I think is the earliest historical perspective on the evolution of the error of LongMed. Delisle explains that the accurate astronomical observations of longitude made a few years earlier by two of his compatriots, Jean-Matthieu de Chazelles in the Eastern Mediterranean and Louis Feuillée in the Central Mediterranean, made him realize that nautical charts were much more reliable in their longitudes than the *cartes ordinaires*.[2] He therefore used these marine charts extensively to compile the latitudes and longitudes of the stretches of coast for which no astronomical observations were available, which were very numerous at his time, particularly in North Africa west of Tripoli and in the Iberian peninsula. Delisle praises specifically *le Portulan de Jacque Colomb*, which must be one of the nautical atlases published in Amsterdam by Jacob Colom, and that of *Vankeulen*, most likely the *Nieuwe Lichtende Zee-Fakkel* printed by Johannes van Keulen also in Amsterdam. However, none of the maps of the Mediterranean in these works displays meridians or scales of longitude. From Delisle's explanation it can thus be ascertained that he must have measured distances in leagues on the nautical charts between points of similar latitude and then computed their difference of longitude using some accurate estimate of the Earth's radius.

Delisle concluded that the difference in longitude between Gibraltar and Iskenderun was 41º30', compared it with the 56º that one could observe in the *cartes ordinaires* and reached the astonishing conclusion that the error of those maps in a sea "that has always been so familiar to us" was much higher than the error they showed in the difference in longitude between France and China.[3] Looking back to "the ancients" Delisle found that the geographical distances reported by Strabo were roughly correct, but did not mention Ptolemy's erroneous longitudes in his paper. Among modern attempts to correct the longitude of the Mediterranean he only cited Giovanni Riccioli's compilation of ancient and modern coordinates,[4] but he deemed it too superficial to be useful.

Five decades after Delisle, another famous French cartographer, Jean Baptiste d'Anville, gave a succinct account of the evolution of LongMed throughout history: Ptolemy had thought LongMed was equal to 62º whereas recent astronomical observations have shown it to be 42º; but, warned d'Anville, modern maps should not receive particular credit for this improvement because the shortened Mediterranean could already be found in Francesco Maria Levanto's *Specchio del Mare*, a nautical atlas published in 1664.[5] D'Anville thus followed Delisle's opinion according to which the main use of astronomical observations had been to corroborate that nautical charts were indeed an accurate cartographic source.

In 1784 John Blair wrote a more detailed historical account on the subject, building on Delisle's paper and completing it with other sources and studies. Blair stated that the exaggerated LongMed in old maps was due to an *amazing Mistake* made by Ptolemy, presumably due to dividing the correct distance in stades by an incorrect number of stades to a degree,[6] a hypothesis that was put forward by Pascal Gossellin a few years later in a seemingly independent and much more comprehensive way.[7]

[2] Delisle (1720: 366).
[3] ibidem, p. 368.
[4] Riccioli (1661).
[5] D'Anville (1769:157).
[6] Blair (1784:119-128).
[7] Gossellin (1790: 118-122).

That error, Blair went on, was perpetuated by every geographer and mapmaker down to the early 18th century, and it was corrected only thanks to astronomical observations made in the 17th century. Blair pointed that *one of the first attempts to rectify the Length of the Mediterranean, was made under the Auspices of Monsieur de Peiresk in 1635.*

This was Nicolas Claude Fabri, Lord of Peiresc a French astronomer who had "Observations made at Marseilles, Aleppo, and Grand Cairo, of an Eclipse of the Moon" on 27 August 1635. By this mean the difference of longitude between Marseilles and Aleppo *was found only to amount to 30º*, instead of the 45º previously assumed.[8] The second achievement he mentions is the maritime expedition sponsored by the French Academy of Sciences whereby de Chazelles sailed in 1696 *up the Levant to observe the Longitudes and Latitudes of Scanderoon [Iskenderun], Alexandria and Constantinople*. Chazelles applied the method of the eclipses of Jupiter's satellites, invented by Galileo Galilei in the early 17th century and first put into practice by Picard in 1671, to find out that Iskenderun laid 34º15' east of Paris, a very accurate value. These astronomical data allowed Guillaume Delisle to build a map of the Mediterranean Sea where the longitude between Gibraltar and Iskenderun was shortened to around 41º30'. Blair correctly pointed out that Delisle measured the longitude difference between Gibraltar and Paris from *Sea Charts* because it had not yet been astronomically determined in Delisle's time or even in his own.

Blair's narrative was echoed by two other British authors, Bell (1829:586) and Lardner (1833:14-19), both of which however left out the fact that Delisle had used nautical charts as sources. On the contrary, they emphasized astronomical observations as the only driving force for the improvement in cartographic accuracy. In Lardner's words, *the progress of geography towards mathematical correctness* had been due to *its alliance with the kindred science of astronomy*. Lardner lamented that Peiresc's astronomical data had been ignored by 17th-century mapmakers like Sanson and Coronelli, and praised Delisle for *the revolution, which he effected in geography*.

In 1834 Louis A. Sédillot published his father's posthumous translation of a 13th-century Arabic-language astronomical treatise by Abu'l-Hasan Ali Al-Marrakushi. It contained a table with the longitudes of 131 cities mostly in the Mediterranean region, which Sédillot later used to plot a map that he found out to be very accurate. He concluded that Abu'l-Hasan had a quite clear idea, for his time, of the length of the Mediterranean and seemed to have corrected Ptolemy's error.[9]

Another large set of medieval Mediterranean coordinates with values more accurate than those of Ptolemy's was published in the edition by Reinaud (1840) of Abu'l-Fida's geographical treatise. Joachim Lelewel (1852) analyzed those findings and others to produce a monumental study that included a comprehensive and insightful overview of the cartographic evolution of the Mediterranean basin. He deduced that *Arab astronomers* (the word *Arab* should be taken as shorthand for mostly Muslim men of diverse ethnic origins who wrote their works in Arabic between the 8th and the 15th centuries) had substantially reduced LongMed *in the times of Azarquiel* i.e. the 11th century,[10] but he criticized Arab *cartographers, who didn't extract any advantage from astronomical observations of longitude*.[11] Medieval portolan charts in the meantime, Lelewel pointed out, showed accurate Mediterranean coastlines and fulfilled their practical purpose without needing to indicate latitude or longi-

[8] ibidem, pp.130-132.
[9] Sédillot (1842:24-29).
[10] Lelewel (1852:lii of volume 1) (all translations into English are mine).
[11] ibidem, p.xxxv of volume 1.

tude.

The translation of Ptolemy's *Geography* into Latin in the 15th century was interpreted by Lelewel as an unfortunate event that *created an extreme perturbation in cartography* and took LongMed back to the erroneous value of the Alexandrian, particularly in maps printed by German authors.[12] At the same time, in 16th-century Spanish and Portuguese maps the Mediterranean basin *kept its nautical proportions preserved the precious fruit of previous works*.[13] Lelewel credited 16th-century Flemish cartographers, particularly Gerard Mercator, with having reduced LongMed to a more reasonable 53º,[14] while some 17th-century authors like Nicolas Sanson increased it to 56º. Then came *the Delisle and the gentlemen of the Académie Royale des Sciences to consummate the reform of continental geography* based on *astronomical observations... travelers accounts and topographic plans* but, Lelewel explained, *the march was slow* and *half a century passed before the correct size of 41º decidedly prevailed*.[15]

Oscar Peschel (1865: 654-655) drastically simplified Lelewel's conclusions on the evolution of LongMed in a mere two pages of his long book, stating that the difference of longitude between Iskenderun and Gibraltar had been reduced from Ptolemy's 62º to a less erroneous value of 52º by *the Arabs and the Dutch mapmakers*, and that the final reduction from 52º to the real value of 41º41' was then accomplished through astronomical observations by Chazelle in 1693 in the Eastern Mediterranean and by Feuillée in 1701-1702 in the Central Mediterranean region. Peschel therefore omitted the fact that LongMed was already close to its accurate values in some other *Arab works* as well as in some products of nautical cartography, as Lelewel had stressed. Peschel's narrative is similar to Bell's and Lardner's in its underlying theme of continuous progress towards improved accuracy, and similarly distinguishes two steps of improvement. It differs only in who should be credited for the first improvement step.

While Bell (1829:601) had minimized the role of medieval *Arab geographers* – claiming that they *all followed his [Ptolemy's] system, both in astronomy and geography, without any improvements in the method of ascertaining longitudes, or taking latitudes* and that their *astronomical observations are not very numerous, and are by no means entitled to the praise of accuracy* – Peschel put the *Arabs* on equal footing with Dutch mapmakers, which by the way Bell had failed to praise too. Peschel's simplistic historical scheme became popular while Lelewel's complex and increasingly outdated work quickly fell into oblivion.[16]

New findings in the second half of the 19th century enriched historians' knowledge of medieval astronomy, particularly the publication by Nallino (1896) of Al-Khwarizmi's table of coordinates, extracted from a world map presumably drawn in Baghdad under caliph al-Ma'mun. John K. Wright (1923) could therefore state that *in the ninth century, the astronomer Al-Khwarizmi had compiled geographical tables in which Ptolemy's estimate of the length of the [Mediterranean] sea was reduced from 62º to about 52º* and furthermore *it was understood by Moslem astronomers during and after the twelfth century of our era that the Mediterranean was about 42º long, not 62 as [Ptolemy] would have had it*. Wright however cautioned that these coordinates did not find practical application

[12] ibidem, pp.lxxxv-lxxxix of volume 1.
[13] ibidem, p.169 of volume 2.
[14] ibidem, pp.181-192 of volume 2.
[15] ibidem, pp.203-204 of volume 2.
[16] Giry (1875).

in geography in the Latin West because *the little interest that the men of the Latin West felt in the whole question of latitudes and longitudes was astronomical and astrological, not geographical* i.e. not for drawing maps even though such maps would have certainly been more accurate than contemporary maps. Wright did not comment on the possible relationship between the tables and Arabic geographical works.

More medieval tables of coordinates, mainly in Arabic, were discovered, systematically analyzed and published throughout the 20th century, in particular by the Kennedys.[17] In the 1990's Mercè Comes clarified the different meridians of reference used in those tables, and specifically discussed the issue of the longitude of the Mediterranean, comparing the coordinates of certain Mediterranean cities (Tangier, Toledo and Cordova in the West; Alexandria and Damascus in the East) in medieval Arabic coordinates with the values in Kepler's *Rudolphine Tables* of 1627 and in modern maps. She confirmed earlier authors' observation that Al-Khwarizmi had already reduced Ptolemy's error to a value comparable to that put forward by Kepler, and went on to realize that *in Al-Andalus, the astronomers (Al-Zayyat, Al-Marrakushi, Al-Maghribi) achieved a more precise adjustment of the size of the Mediterranean to its real size, calculating a value surprisingly correct*, very close to the modern one.[18]

The interpretation of the importance of these medieval *Arabic* or *Islamic* tables of coordinates became a controversial topic in the last decades of the 20th century. On one hand Gerald R. Tibbets[19] gave a very negative opinion on their value *(impossible to use in any scientific way, haphazard)* and only reluctantly accepted their potential geographic purpose as an unproven hypothesis for a few of them. He observed that *the tables may have been compiled from maps* but *no attempt to collate maps with tables has ever been found in the early period*, except perhaps *in the large sectional maps of al-Idrisi*. In a text that leaves me with doubts about Tibbets's correct understanding of the basic concepts of longitude and reference meridian, he stated that these tables were *unsystematic* because they used different reference meridians and that *the problem with most of the prime meridians is that they were situated in mythical places*.[20] On the specific subject of the longitude of the Mediterranean Tibbets acknowledged the reduction performed by Al-Khwarazmi but added that it *probably means very little and does not demonstrate a significant cartographic improvement of the Arabs over the Greeks*. He completely ignored the additional reduction of LongMed observed in later tables.

At the other extreme, Fuat Sezgin claimed the maximum importance for medieval Arabic cartography, of which tables of coordinates would have been an essential part. He stated that *the field of mathematical geography [...] experienced here [in the Arab-Islamic culture area] an uninterrupted process of development from the mid 8th century through into the 16th century. The degrees of longitude and latitude produced in the course of this process have continuously found expression in maps*.[21]

Sezgin gave great importance to the evolution of LongMed and computed the difference of longitude between Tangier and Iskenderun in numerous cartographic works up to 1700. He identified two steps of improvement in accuracy: first by the geographers of caliph al-Ma'mun in Baghdad in the 9th cen-

[17] Kennedy (1956) and Kennedy (1987).

[18] Comes (1995) and Comes (2000).

[19] Tibbets (1992a) covers the "early period" i.e. until around the 11th century and Tibbets (1992b) covers the period up to the 15th century.

[20] Tibbets (1992a:102-104).

[21] Sezgin (2005:xv-xxiv).

tury, who reduced the error from Ptolemy's ca. 20 degrees to ca. 10 degrees; and secondly by astronomical observations carried out later between Baghdad and Toledo, in Muslim-ruled Spain, which further reduced the Tangier-Iskenderun difference to around 44.5º, very close to its real value of 42.0º. Controversially, Sezgin added that up to the 18th century many of those European maps that were not based on Ptolemy – including medieval portolan charts – relied directly or indirectly for the longitude of the Mediterranean on one of the two improved Arab-Islamic models.

Sezgin's view of the evolution of LongMed is obviously at the antipodes of that given by Bell in the 19th-century. Sezing gives *the Arabs* all the credit, while Bell had completely neglected them. I would like to point out however that the two narratives are in fact very similar. They both assume that astronomers led the way by measuring coordinates and mapmakers followed suit. Both authors also paint a trend of continuous progress over time towards higher accuracy – only the dates and the protagonists are different.

The results of this study will show that the overall picture of the evolution of LongMed is much more complicated than that. Of all the authors I have reviewed, only Lelewel seems to have come close to grasping its actual complexity.

Methodology

The authors mentioned in the previous section computed LongMed as the difference of longitude between two particular locations at the Western and Eastern ends of the Mediterranean, typically Gibraltar or Tangiers in the West and Iskenderun or Alexandria in the East. However, there are two drawbacks to defining LongMed based on only two arbitrary localities:

- First, not even the best known localities appear in each one and all of the studied lists of coordinates or can be easily pinpointed in every map;
- Second, in some cartographic work the longitude of chosen few specific locations may be abnormally erroneous due to for example transcription mistakes so, if LongMed is computed based only on them, a very distorted value will be obtained.

Robust definition

I have preferred to develop a more robust definition of LongMed, using at least three – and normally many more – localities at each end. More specifically, for each of the pre-1750 cartographic works included in the database, I have calculated an average error E, and standard deviation σ, of the longitude of the Mediterranean in the following manner:

- First I have measured the longitudes of two sets of locations: one set on or near the Western shore of the Mediterranean and another set on the Eastern edge.
- I have then taken each member of the Western set Wm_i, and computed its difference of longitude with each of the members of the Eastern set Em_j.
- These observed differences $Wo_i – Eo_j$, have then been subtracted from the real differences of longitude for each couple $Wr_i – Er_j$, and a relative error thus calculated.
- Finally, for each cartographic work, the average E and the standard deviation σ of the individual errors have been computed using the formulae shown in Figure 2.

It should be noted that σ gives an indication of the underlying dispersion of the values of LongMed in each cartographic work and, contrary to other statistical measures like the standard error, does not decrease as the number of localities used to calculate the average increases:

- High σ means that a map is highly distorted in its shape, or that a list of coordinates contains aberrations due to copyist mistakes
- Low σ indicates that the analyzed cartographic work is internally consistent.

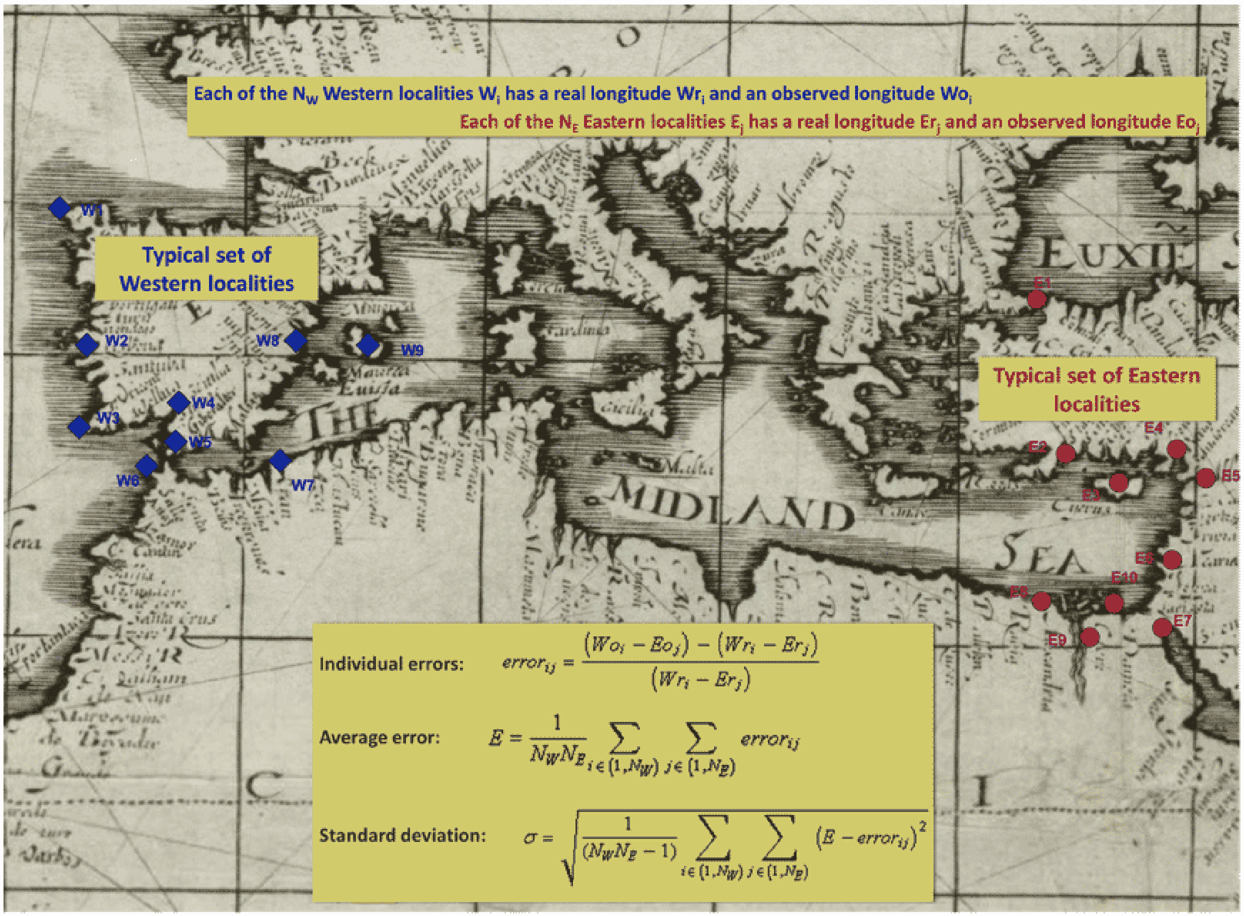


Figure 2: Examples of Western and Eastern localities chosen to calculate the average *(E)* and standard deviation *(σ)* of the error of LongMed by means of the indicated formulae. Background image shows Moxon's 1657 edition of Wright's world map.

It should be remarked that the Western and Eastern locations are not necessarily the same for all the studied cartographic works. This is not a problem because what is being analyzed in this study is the average longitude of the Mediterranean basin, not the difference of longitude between two specific cities. The terms *Western* and *Eastern* have been applied in a broad sense:

- Western locations have been chosen from the Iberian Peninsula, the Balearic Islands, and northern Morocco and Algeria.
- Eastern locations have been selected mainly from the *Levant* (today's Syria, Lebanon, Israel and the Palestinian territories), Egypt and Cyprus, plus several easy-to-identify coastal localities up to Istanbul.

Coordinates, globes and maps

The cartographic works considered in this study refer to three different types:
1) Lists of numerical coordinates;
2) Globes;
3) Maps.

Extracting relevant longitude values from the coordinates listed in tables and in geography texts is relatively straightforward. Most tables do not explicitly mention the position of the zero meridian that was assumed for their longitude values but fortunately that information is not necessary for this study because what is computed is the difference of longitude between pairs of locations, not the longitude of each individual place. One difficulty however is that for some place names listed in medieval works the equivalent actual location is not known, or not precisely. Another problem is the corruption suffered by the contents of manuscripts over time, some due to copyist mistakes and some due to the merging of coordinates from different tables without realizing that their longitudes were based on different reference meridians. I have followed the criterion of respecting the contents of the tables and texts as they have been handed to us by the scholars who edited them in the 19th and 20th centuries, not correcting copying errors or confusions of reference meridians beyond whatever corrections were made by the modern editors themselves.

In the case of globes I have been able to measure longitudes directly on the original for only one of them. In the other cases I have used some type of digital model. For example, for the Behaim Globe I made use of a digitally constructed high-resolution *plate-carrée* projection kindly provided by the Germanische Nationalmuseum and TU Wien.

For fully graduated maps, i.e. those that explicitly display meridians, I have measured longitudes by graphical interpolation between meridians, on paper copies or on digital reproductions. Some maps do not contain a complete grid of meridians and parallels but provide auxiliary means to compute longitudes, e.g. graduated equators. In those cases I have manually or digitally drawn meridians, making an assumption on the cartographic projection of the map. These maps have been labeled *debatable projection* in the database and visually distinguished from fully graduated maps in the charts of this article. As a reminder, this study does not include any map that absolutely lacks any indication of longitude or latitude, which is the case of all medieval nautical-style or 'portolan' charts of the Mediterranean with perhaps one sole exception.[22]

Attribute of dates

Another important methodological note regards how to attribute dates to each cartographic work. First of all, when a date is known only as a range, a year towards the middle of the range has been chosen so as to be able to plot the work on the graphs, e.g. the "15th century" date range attributed by the Biblioteca Nacional to the *Alfonsine Tables* in ms 4372 has been rendered as 1450 in the database. A subtler problem arises when the year in which the author compiled a table or drew a map is not the same as the date of the particular copy of the table or edition of the map that I have used to measure longitudes and calculate LongMed. In modern works the difference is often small, a matter of years or

[22] Lepore et al (2012).

a at most a few decades; but in medieval works several centuries may separate the original creation of a work from the extant copy used for this study. Which date should be given priority? I have decided to keep both in the database, listing for each work the "year of creation" as well as the "year of the observed copy" that I have actually used.
In the plots shown in the following pages, the vertical axis represents the error of LongMed and the horizontal axis the date of creation of the cartographic work. This provides a narrative from the cartographers' point of view, allowing for example to identify which earlier works a certain author may have known. I have prepared, but not included in this article for reasons of space, charts where the date plotted on the horizontal axis is that of the observed copy. This provides what we could call the public's point of view, helping us see which estimates of the longitude of the Mediterranean were in circulation at a given point in history.

Preliminary results

As of this writing the LongMed database includes values from:

- 124 maps,
- 36 textual lists of coordinates, and
- 6 globes.

The oldest items in it are the tables of coordinates compiled by Claudius Ptolemy in the 2nd century CE and the most recent one is J. M. Haas's map of Europe of 1743. The longest Mediterranean in the database is found in Myritius's world map of 1590 (average error = 67%, standard deviation = 9 percentage points; which will henceforth be abbreviated as 67% ± 9%), and the shortest one in the table of coordinates in Abraham Zacut and Diego de Torres's astrological treatise of 1487 (error = –16% ± 14%).
All of the sampled works are plotted in Figure 3. The general trends already identified by scholars since the 19th century can be observed, with nuances, but at the same time numerous intriguing outliers come to light.

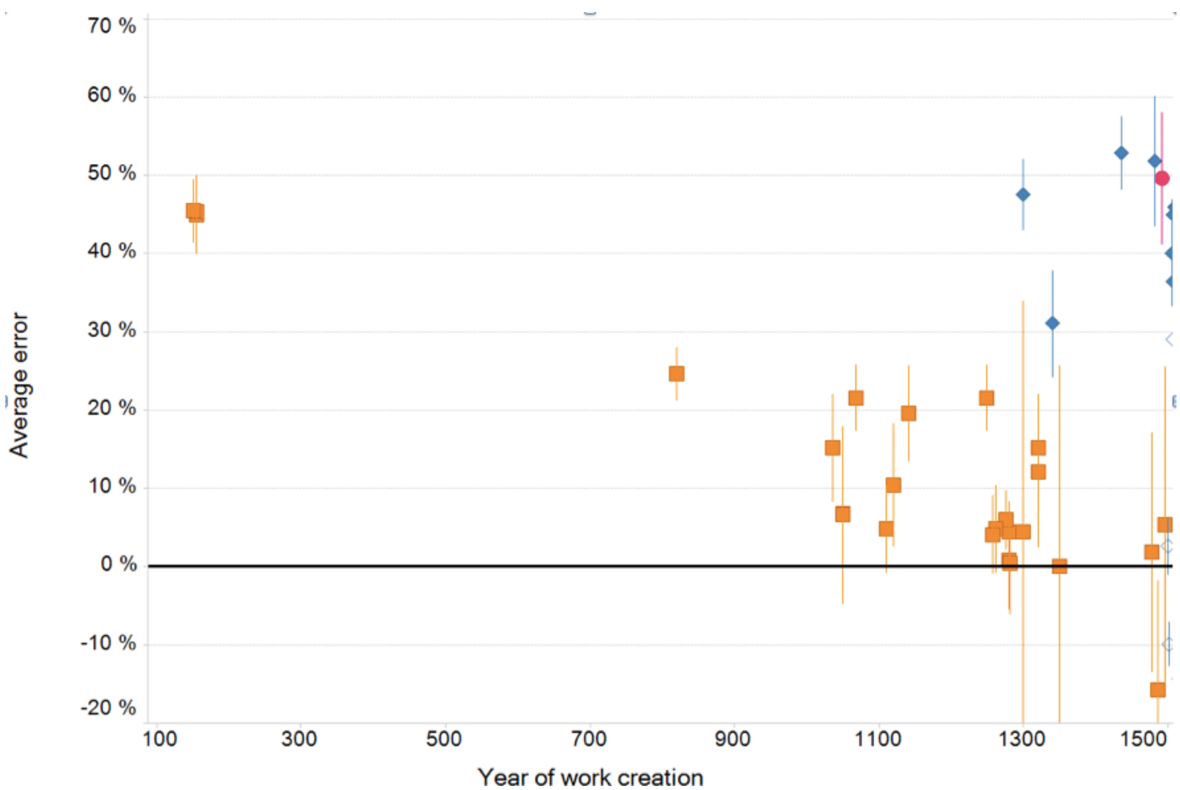
Ptolemy

Claudius Ptolemy is famous for having written a *Geography* in which the coordinates of several thousand locations of the entire known world are given in sexagesimal degrees, with longitudes counted from the meridian of the *Islands of the Blest* or *Fortunate Islands*. Ptolemy lived in the 2nd century CE but the oldest extant manuscripts of the *Geography* date from around 1300 CE.
It is worth noting that the last book of the *Geography*, Book 8, contains a second set of coordinates of 358 *noteworthy cities*, given in a completely different way: latitudes are expressed in terms of the duration of the longest day, whereas longitudes are reported as the difference in local time with respect to Alexandria, in hours. Its values are generally consistent with those of Books 2 – 7.
Furthermore, another work written by Ptolemy, entitled *Handy Tables*, contains a list of localities with coordinates expressed in sexagesimal degrees. Most of these place names are the same as those found in Book 8 of the *Geography* but every one of the numerous extant manuscripts shows variants,

additions and transcription mistakes.[23] The *Handy Tables* were a compendium of tables intended to make calculations easier for astrologers-astronomers (the two terms will be used interchangeably henceforth). Its earliest manuscripts, two copies from around 820 CE, are the oldest extant documents from which LongMed can be calculated. An older fragment of the *Handy Tables* in papyrus, from the beginning of the 3rd century CE, contains only a few localities and unfortunately no values from the extremities of the Mediterranean.

To calculate LongMed for each one of these Ptolemaic sources I have used the recent digital edition by Stückelberger and Grasshoff (2006 – 2009), who reconstructed the most plausible values of each coordinate based on the oldest extant manuscripts. This methodology provides a reasonable estimate of the magnitude of LongMed error in Ptolemy's original work: 45% on average with 4% of 5% standard deviation. It doesn't tell us however how this value evolved in later manuscripts, if at all; such an investigation could be worthwhile.

[23] Stückelberger, Mittenhuber and Koch (2009:141-144).



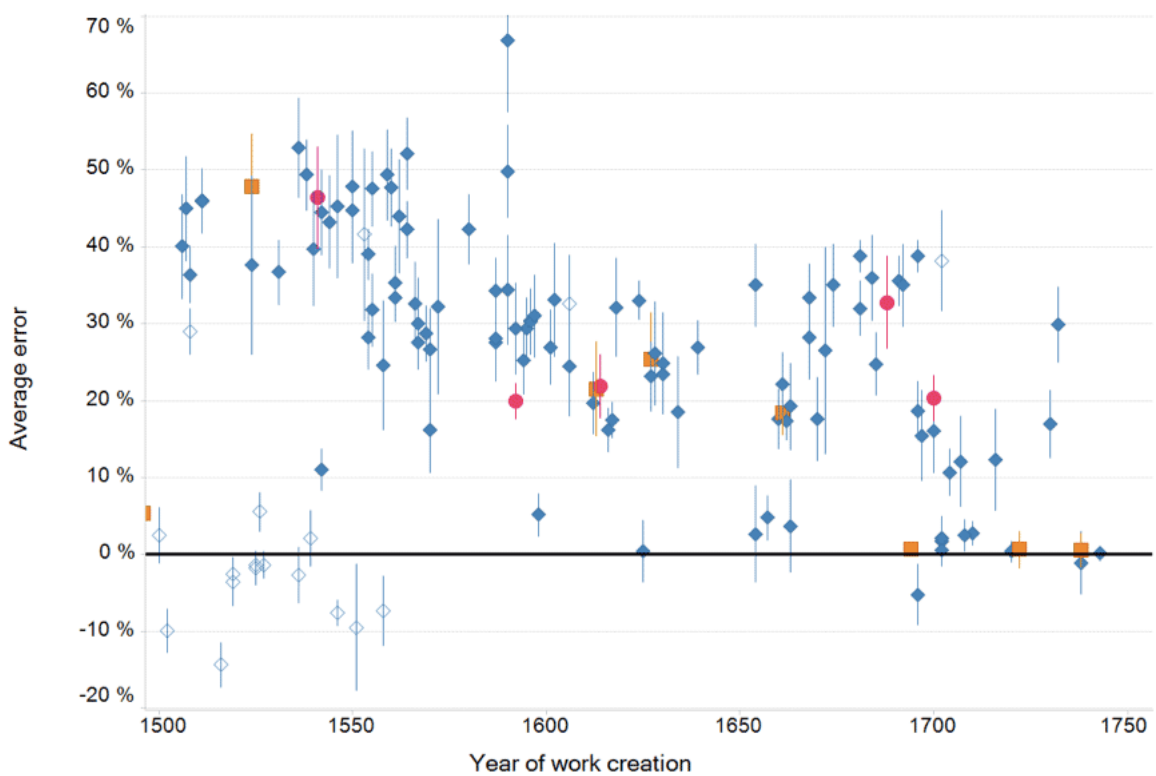


Figure 3: LongMed average error (dots) and standard deviation (error bars) vs year of creation of each cartographic work. Dot shapes and colors distinguish works by type: globes (pink circles), lists of coordinates (orange squares), graduated maps (filled blue diamonds) and maps with debatable projection (empty diamonds).

Greek title	Common English title	How longitudes are reported	Average error	Std. dev.
Mathematike Syntaxis	*Almagest*	Hour differences between only 4 cities	not possible to calculate LongMed	
Geographike Hyphegesis	*Geography*, Books 2 – 7	Sexagesimal degrees from Islands of the Blest	45%	5%
Geographike Hyphegesis	*Geography*, Book 8	Hours from Alexandria	45%	4%
Kanon poleon megalon in *Procheiroi Kanones*, or *Kanon*	*Table of Noteworthy Cities* in *Handy Tables*	Sexagesimal degrees from Islands of the Blest	45%	4%
Tetrabiblos, or *Apoteles-matiká*	*Tetrabiblos*	no coordinates, only verbal sketch of a world map	not possible to calculate LongMed	

Table 1: Claudius Ptolemy's works that contain geographical information. Note: to calculate LongMed from the long catalogue in Books 2 – 7 of the *Geography* I have used only a sample of localities.

Middle Ages

The earliest known reduction of Ptolemy's error, to 25% ± 3%, is found in Al-Khwarizmi's table of coordinates, created ca. 820 and extant in a manuscript dated 1037. Al-Khwarizmi was an astrologer-astronomer with no other known work about geography. Some details in the table contents reveal that it was compiled by measuring coordinates on some graduated map of the world. This suggests that the reduction of Ptolemy's error preceded Al-Khwarizmi and should be better attributed to the anonymous cartographers who made the map he used as source.

The next item in the database dates from around two centuries after Al-Khwarizmi. It is the table of 601 geographical coordinates contained in the great astronomical work written in Ghazna by Abu Rayhan Al-Biruni. From one of its multiple recensions I have calculated a LongMed error equal to 15% ± 7%. The sources of these coordinates are not known. Besides as astronomer, Al-Biruni was an active cartographer who drew several world maps, invented cartographic projections, measured the radius of the Earth and determined longitude differences by observation of lunar eclipses.[24]

Between the 11th and the 13th centuries, authors from Al-Andalus (i.e. the Muslim-ruled part of the Iberian Peninsula) and North Africa reported quite accurate coordinates of the Mediterranean. They are listed in Table 2. Some of these tables exist only in Latin or Hebrew translations and/or in manuscripts copied several centuries after the original, which often introduced transcription mistakes and complicates their study. One of the most remarkable is the table of 298 entries put together by Ishaq ibn al-Hasan al-Zayyat to include it in his *zij* (Arabic word for an astronomical handbook that typically includes a number of astronomical tables). Written around 1050, this is the earliest known independent table of coordinates made in Al-Andalus,[25] and also the first recorded use of a zero meridian located 7º30' to the west of Ptolemy's Fortunate Islands meridian.[26] In this table LongMed is more accurate than in any earlier work but suffers from a rather high standard deviation due to a couple of aberrant numbers, possibly corruptions due to scribal errors. Several later *zijes*, compiled by Al-Kammad, Al-Maghribi and Ibn al-Raqqam, contain even more accurate longitudes of the Mediterra-

[24] King (1999: 41-42).
[25] King (1999: 16).
[26] Comes (2000).

nean. The database also contains one work with a similarly accurate table of coordinates, the *Jami^c al-mabadi* by Abu'l-Hasan Ali al-Marrakushi, that is not a zij but a treatise on astronomical instruments.

Author	**Work**	**Date**	**Average error**	**Std. dev.**
Al-Khwarizmi	*Kitab surat al-ard*	ca. 820, extant ms dated 1037	25%	3%
Al-Biruni	*Qanun al-Mas^{c}udi*	composed 1030-40; numerous mss and recensions exist	15%	7%
Al-Zayyat	*zij* "185 ZAJ"	author died 1058, extant in undated ms	7%	10%
Al-Zayyat	*Dikr al-aqalim*	author died 1058, extant ms ca. 14th century	9%	12%
[Azarquiel] / G. de Cremona	*Toledan Tables*	11th century; extant in Latin mss 13th of 14th century	22%	4%
Abraham bar Hiyya	*Sefer ha-Ibbur*	original before 1124; Oxford ms ca. 1475; Paris ms 15-16th century[27]	10%	8%
[Azarquiel]	*Marseille Tables*	12th century, later than 1139	20%	6%
[Al-Kammad] / J. of Dunpno	*Tabula longitudinum ciuitatum et latitudinum earum*	author died 1195; translated into Latin 1262	5%	6%
Al-Marrakushi	*Jami^c al-mabadi…*	13th century, extant ms before 1410	4%	4%
Al-Maghribi	*zij* "300 TAJ"	compiled 1258, extant in ms copied 1394	4%	5%
Al-Maghribi	*zij* "350 MAG"	compiled 1276, extant in undated ms	6%	4%
Ibn al-Raqqam	*Al-Zij al-Shamil*	compiled 1279-80	1%	6%
Ibn al-Raqqam	*Al-Zij al-Mustawfi*	compiled after 1280	0%	6%

Table 2: Tables of geographical coordinates compiled between the 9th and 13th centuries. The names of untitled *zijes* follow the convention established by Kennedy (1987).

Some of the mentioned astronomers are known to have measured geographic latitudes themselves through astronomical observations but it is unclear whether they measured, estimated or simply copied longitudes; the only exception is al-Biruni, who is known to have measured at least some longitude differences. Different opinions exist on whether the tables of coordinates contained in astronomical manuals were ever used to plot maps or had anything today with cartography at all.

As was explained in the historical review section, Tibbets was very skeptical about it whereas Sezgin took it for granted. We have seen that at least in the case of al-Khwarizmi there is a clear relationship between the coordinates and a map but it is not that the map was based on astronomically-observed coordinates; on the contrary, the astronomer copied coordinates from a map in order to use them for his astronomical calculations.

Biruni was at the same time an astronomer and a cartographer so he is likely to have actively used tables of coordinates to draw maps but we have no proof. At this point it is important to point out that geographical coordinates appear in other Arabic-language medieval works, besides *zijes*: descriptive geographical books, which indicate numerical coordinates for each city or region they mention. Two such books have been included in the database because they contain values from the two extremities of the Mediterranean: the *Dikr al-aqalim* by al-Zayyat, and the *Taqwim al-buldan* by Abu'l-Fida. The

[27] Personal communication from Ilana Wartenberg.

purpose of these works is clearly geographic, nothing to do with astrology, and the coordinates are useful to the reader only if he/she is capable of plotting them, at least mentally, so as to locate cities with respect to each other. Their relationship with cartography is therefore quite probable, in my opinion.

It should be noted that the newer, increasingly accurate determinations of longitudes did not necessarily replace the older values, which kept on being transmitted throughout the entire Middle Ages. For example Mediterranean coordinates similar to those transcribed by Al-Khwarizmi were used by Ibn al-Zarqali (called Azarquiel in Latin) in 11th century Muslim Spain for his *Toledan Tables*, which in turn enjoyed great popularity both in Arabic and in Latin translations up to at least the 14th century. In parallel, Ptolemy's coordinates kept on being copied in Greek and Arabic versions of his *Geography* and his *Handy Tables*; the latter being called the *Zij Batlamiyus*.[28]

This coexistence of old and new values probably explains why Abu'l-Fida, writing in the early 14th century, was not certain of which of his coordinate sources was most trustworthy and thus felt the need to provide several values of longitude for each locality.[29] To add to the confusion, longitudes from different tables were merged by later authors without realizing that they were based on different reference meridians. This is the reason why several tables of coordinates from the 14th and 15th centuries show extremely high standard deviations.

16th century

In the first half of the 16th century, LongMed ranged between 35% and 55% in most European cartographic works. These values are of course Ptolemaic in origin but the substantial difference between the two ends of the range suggests that several opinions on the true value of LongMed coexisted at that time even within the circles most influenced by Ptolemy.

In the second half of the century the predominant trend shifted towards a somewhat shorter Mediterranean, with 25 – 30% error. Such a reduced LongMed first appeared in print in Mercator's map of Europe of 1554 (error = 28% ± 4%), which showed a significant reduction with respect to the same author's earlier works. Mercator's new value was quickly adopted by other commercially successful mapmakers like Abraham Ortelius. Lelewel's intuition about the key role of Mercator [30] was therefore correct, which is remarkable because Mercator's 1554 map of Europe was discovered only in 1889,[31] decades after Lelewel published his book.

[28] Tibbets (1992a: 96).
[29] Lelewel (1852: liii).
[30] Lelewel (1852: 181-192).
[31] Ortroy (1892).

Author	Work	Date	Average error	Std. dev.
Gerard Mercator	World map on two cordiform hemispheres	1538	49%	5%
Gerard Mercator	Globe	1541	46%	7%
Gerard Mercator	***Europa* (1st edition)**	**1554**	**28%**	**4%**
Gerard Mercator	Rectangular world map	1569	29%	4%
Gerard Mercator	*Europa* (2nd edition)	1572	28%	4%
Rumold Mercator	World map on two circular hemispheres	1587	28%	5%
Rumold Mercator	*Europa* in *Atlas*	1595	29%	4%

Table 3: LongMed error in cartographic works published by Gerard Mercator and his son Rumold, in chronological order. The 1554 map of Europe is highlighted in bold typeface.

There are, however, several maps and one globe that show substantially lower values of LongMed than the predominant 16th-century trend. These outliers have been highlighted in Figure 4 and will be described briefly in the next paragraphs.

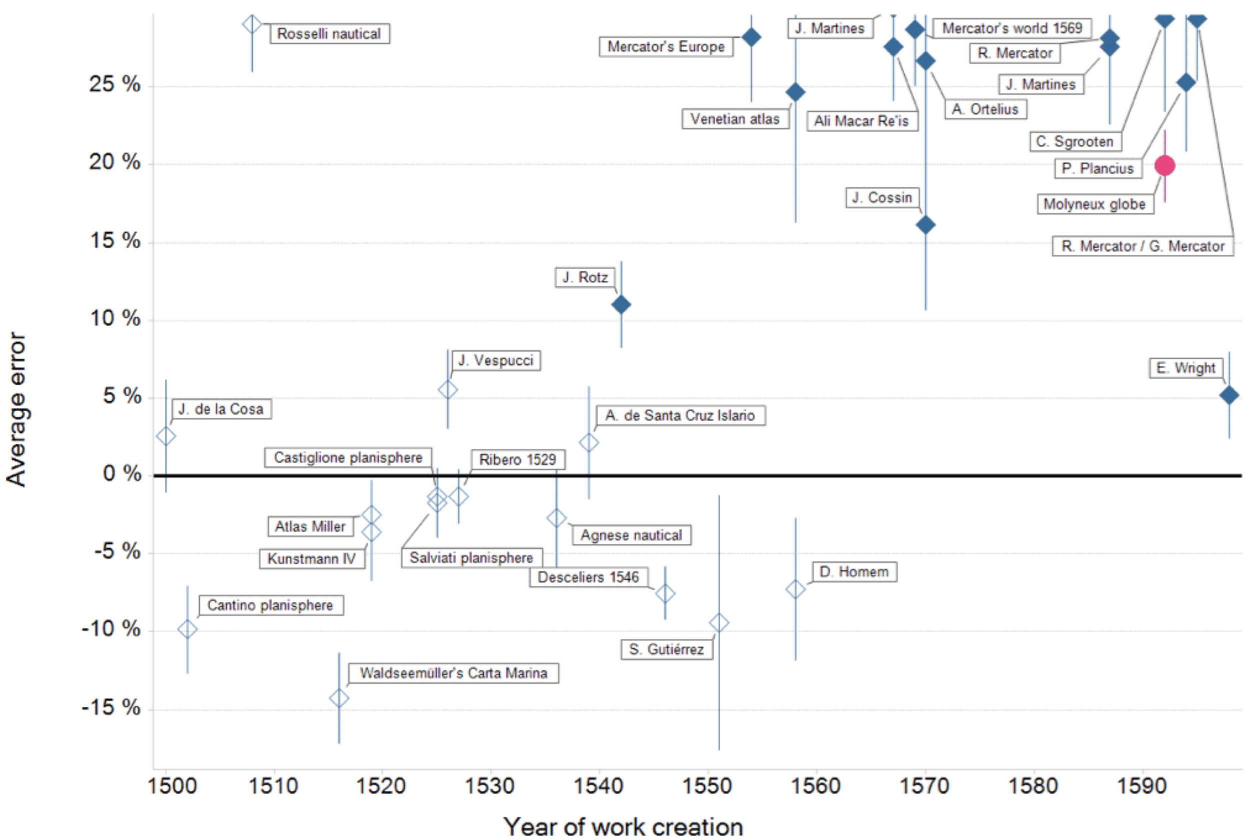


Figure 4: Sixteenth-century cartographic works showing LongMed error lower than 30%. Symbols distinguish works by type: globes (pink circles), graduated maps (filled blue diamonds) and maps without a complete grid of meridians (empty diamonds).

Jean Rotz was a cartographer and navigator from Dieppe, France, who emigrated to England and in 1542 presented a manuscript atlas entitled *Boke of Idrography* to king Henry VIII. This atlas, now preserved at the British Library, contains a world map on two circular hemispheres drawn in globular projection, with a neatly delineated grid of meridians and parallels. In it the Mediterranean shows a longitudinal error of 11% ± 3%, therefore substantially more accurate than what Mercator would estimate twelve years later. Jean Rotz's map is remarkable but is not an isolated exception because there is at least one other example of an unusually short Mediterranean among 16th-century works from the Norman school of cartography: the sinusoidal world map drawn by Jean Cossin in 1570, which has an only slightly higher LongMed error of 16% ± 5%.

One very remarkable outlier from the end of the 16th century, with an unusually short Mediterranean basin and no doubts about its cartographic projection, is the anonymous world map contained in Richard Haklyut's book *Principal Navigations,* published in 1598 – 1600. Likely the work of Edward Wright, this map in Mercator's projection shows a LongMed error of just 5% ± 3%. Wright himself with the 1610 edition of his *Certaine Errors* published a second version of the map.[32]

Figure 5: Detail of Jean Rotz's world map in the *Boke of Idrography*. Meridians are spaced at 10-degree intervals.

Numerous other charts from the 16th century show shorter Mediterranean longitudes than Mercator's or even than Rotz's. Most of them are manuscript; only Waldseemüller's *Carta marina* is printed, among those included in this study's database. These maps are mostly drawn in "nautical style", almost always showing wind roses and latitude scales. Some of them display one horizontal scale of longitude and a few vertical meridians, but none has a complete grid of meridians. Therefore if one wants to compute their LongMed some assumptions need to be made regarding the underlying cartographic projection.

For calculation purposes, I have supposed that meridians are vertical straight lines in all of them. In those that lack longitude scales I have had to make one additional assumption on how to space meridians. In Table 4 are listed the assumptions and the resulting values of LongMed, which as can be seen are all quite accurate except for the case of Rosselli's map.

I would like to emphasize that it is not fully certain that each and every one of these charts, particularly the earliest ones, was deliberately drawn by its author based on a projection with vertical meridians.[33] It is not sure either that numerical values of longitude were actually used to plot localities on all of them; distances and rhumbs may have been used in lieu of angular coordinates for at least

[32] Parsons and Morris (1939).

[33] Among others, Snyder (1993: 5-8) supported this interpretation for at least some of these maps whereas Gaspar (2007) rejected it.

some places. On the other hand, it is clear that at least some of the users of these maps believed them to have been drawn in some kind of cylindrical projection, as exemplified by the orthogonal grid of meridians and parallels that Johannes Schöner drew by hand on his copy of Waldseemüller's *Carta marina*. These charts may therefore have transmitted the apparent values of LongMed listed in Table 4 even if their authors were not necessarily aware of or in agreement with those values.

A group of closely-related world maps of this type is particularly worthy of attention because of their extremely accurate and precise values of LongMed: the Salviati planisphere, the Castiglioni planisphere and the *Carta universal*... signed by Diego Ribero and preserved in Vatican, all drawn in Spain in the 1520's.[34]

Author / work	Date	Location	Assumptions on meridian spacing	Average error	Std. dev.
J. de la Cosa, World map	1500	Andalusia	I assume distance 'Cancro' – Equator equals 23.5º of longitude	3%	4%
Cantino planisphere	c. 1502	Portugal	I assume distance Tropics – Equator equals 23.5º of longitude	-10%	3%
F. Rosselli, World map	1508	Venice	I assume meridian spacing equal to parallel spacing per latitude scale	29%	3%
M. Waldseemüller, *Carta marina*	1516	Lorraine	Meridian grid hand-drawn by J. Schöner	-14%	3%
Mediterranean map in *Atlas Miller*	c. 1519	Portugal	Scale of longitude in west part of the map; I extend it to the whole map	-2.5%	2.2%
Kunstmann IV, World map	c. 1519	Portugal / Andalusia?	Equator has unnumbered marks that I assume represent one degree	-4%	3%
Castiglione planisphere	1525	Andalusia?	Graduated equator	-1.3%	1.7%
Salviati planisphere	c. 1525	Andalusia?	Equator has unnumbered marks that I assume represent ten degrees	-1.7%	2.2%
J. Vespucci, World map	1526	Andalusia	Graduated equator	6%	3%
D. Ribero, *Carta universal* (preserved in Vatican)	1529	Andalusia	Graduated equator	-1.3%	1.7%
B. Agnese, map of the Western hemisphere	1536 – 1564	Venice	Graduated equator	-3%	4%
A. de Santa Cruz, Mediterranean map in *Islario*	c. 1539	Andalusia	Scale of longitude at parallel 13ºN	2%	4%
P. Desceliers, World map	1546	Normandy	Scale of longitude at southern edge	-7.5%	1.7%
S. Gutiérrez, *Carta general*	1551	Andalusia	Graduated equator	-9%	8%
D. Homem, World map in *Queen Mary Atlas*	1558	England	Scales of longitude at northern and southern edges	-7%	5%

Table 4: Apparent LongMed error in a sample of 16th-century nautical-style maps lacking a complete grid of meridians. For all maps I have assumed vertical equidistant meridians in order to compute LongMed.

[34] Sánchez (2013: 180-188 and 194-210).

All these maps show average errors below 2% in absolute value and standard deviations around 2%, provided that the meridians are assumed to be represented as equidistant vertical lines. In this case the assumption is, in my opinion, highly valid due to four features that these maps share:

i) one important meridian – the line of demarcation between Spain and Portugal in the Atlantic – is drawn as a vertical line;

ii) at least two scales of latitude are drawn as vertical lines as well;

iii) the equator is graduated in longitude with evenly spaced marks that are distant from each other the same length as the equivalent amount of degrees on the latitude scale, and

iv) the overall rectangular shape of the maps does not suggest any bending of meridians, as opposed to for example oval world maps.

Similar Mediterranean coastlines are observed in two other planispheres made in Seville and preserved in Weimar, dated 1527 and 1529, which I have however not included in the database due to lack of images with high enough resolution to measure coordinates. These world maps are exceptional not only for their highly accurate LongMed but also because they are the earliest extant nautical-style maps in which Mediterranean latitudes are substantially correct too.[35]

Figure 6: Detail of a facsimile of Diego Ribero's 1529 world map preserved in Vatican (courtesy of the Library of Congress).

The results shown for Rotz, Coussin, Wright and the nautical-style charts raise a number of questions:

- Why did each of these mapmakers draw the Mediterranean in his own particular way rather than follow the majority trend of the time?
- Was it a deliberate choice on their part?
- How much were they influenced by other cartographic works?
- By which ones precisely?

[35] Astengo (1995: 215-16).

Answering these questions is beyond the scope of this work but I will nevertheless provide some information on the motives and sources of two of these cartographers: Diego Ribero and Edward Wright.

Ribero, cosmographer of the Casa de la Contratación, inserted a legend about the shape of the Mediterranean in his 1529 world map preserved in Vatican (also found in the 1527 and 1529 maps preserved in Weimar). I transcribe the legend here and provide a translation into English:

Diego Ribero

"Nota q[ue] el levante que comunmente llamamos lo que se contiene dende el estrecho de gibraltar adentro ba / asentado & puesto por altura dello por dicho de personas q[ue] en alguas partes del an estado y tomado el sol / & en lo demas sigo alos cosmographos que particularmente ablaron dela latetud d[e] algunos lugares & / los grados delongetud en el no pueden corresponder alas partes con que median enla equinoccial / por la minoridad d[e]los paralelos porque en la berdad del cayro almar Roxo o dende Damasco o iheru / salen al mar persico ay muy poco camino & aquy se haze mucho por Razon dela menoridad delos pa / ralelos como tengo dicho demanera que tuve por menor Inconveniente esto q[ue] no desproporcio / nar el mar & tierra de levante d[e] como ya esta usado & conçebido enla mente..."

Translation (Robles)

Note that the Levant, as we commonly call what is contained inwards from the Strait of Gibraltar [i.e. the Mediterranean Sea], is drawn according to its height [i.e. latitude] based on the reports of people who have been to some parts of it and taken the Sun [i.e. measured latitudes by means of astronomical observations]; for the rest I follow the cosmographers who particularly spoke about the latitude of some places. And in it the degrees of longitude cannot correspond to the parts with which they are measured on the equinoctial [line] due to the shortening of the parallels, because in fact from Cairo to the Red Sea or from Damascus or Jerusalem to the Persian Gulf there is a very short distance and here [i.e. on the map] it becomes a long one due to the shortening of the parallels as I have said; and so I found this [option] less inconvenient than disproportioning the sea and land of the Levant from what is already usual and conceived in the mind..."

Ribero vaguely describes his sources for latitude data and does not mention any source for his apparently accurate longitudes. Paradoxically he warns the reader that the longitudinal distances in the Mediterranean cannot match the corresponding number of degrees measured on the equator, as I have assumed, due to a cartographical artifact: the incorrect rendering of the "*minoridad de los paralelos*" i.e. the convergence of meridians. Ribero thus posits that in the map the Mediterranean appears shorter than it really is.

Based on his words, Ribero cannot be credited with having actively researched the true value of LongMed and represented it on a map; on the contrary, he seems to have believed that the apparent value of LongMed one could deduce from this map assuming vertical meridians was incorrectly low. Curiously Ribero did not dare to correct the shape of the Mediterranean because, he says, it was already considered 'usual' in his time. To me this indicates that he must have copied that shape from some earlier cartographer.

Edward Wright was a scholar at the University of Cambridge who had an interest in navigation. In 1589 he joined the English naval raid against Spanish and Portuguese shipping around the Azores islands. Back in Britain he joined as mathematician the team that produced the globes published by

Emery Molyneux in 1592.[36] Molyneux's terrestrial globe, the first one ever made in England, has a LongMed error of 20% ± 2%, which is more correct than Mercator's but still substantially higher than that of Wright's later map. Therefore it cannot have been Wright's source for the Mediterranean.
A cartouche on the globe lists some of Molyneux's sources: Spanish and Portuguese nautical charts for the Americas and the East Indies, and English geographers for Northern regions. Other areas like Africa, where Molyneux had no special information from English or Spanish sources, seem to have been copied from Jacob van Langren's 1589 globe,[37] which I haven't been able to measure. In any case, some new information obtained after 1592 must have pushed Wright to shorten the Mediterranean in his 1598 map further than on the globe. Parsons and Morris (1939) stated that "Wright transferred the facts and details from Molyneux's globe to his own chart, and [John] Davis and Hakluyt assisted in recording the latest discoveries." The navigator John Davis had met Wright in the Azores in 1589 and in 1596 and 1597 took part in English attacks against respectively Cadiz and the Azores.
Did Davis bring back from those expeditions some captured Spanish or Portuguese map with short LongMed that Wright then used as source for his world map? A way to confirm or rule out this hypothesis could be to analyze in detail the Mediterranean toponyms and coastal outlines on Wright's maps.

17th century

In the 17th century most of the values of LongMed proposed in the previous century remained in use simultaneously, creating the cartographic confusion that would be denounced by Michael van Langren, among others. The LongMed values favored by Mercator and Ortelius were adopted by authors like Hondius (1630, 25% ± 7%) and Visscher (1639-1652, 27% ± 3%) whereas French mapmaker Nicolas Sanson stuck to a more Ptolemy-like proportion (1654, 35% ± 5%). Willem Blaeu opted for a somewhat shorter Mediterranean in his *Europa recens* (1617, 18% ± 2%), while quite accurate LongMed values were found in one of Jean Guérard's planispheres (1625, 0.5% ± 4%), in several maps made by the Colom family (e.g. 1654, 3% ± 6%) and in an updated edition of Wright's planisphere (Moxon 1657, 5% ± 3%).
The Norman cartographer Jean Guérard is a curious case because a few years after his map with an accurate Mediterranean he drew another planisphere with a substantially more erroneous LongMed (1634, 19% ± 7%). Why he decided to switch to a more erroneous value, I don't know. Guérard is not, by the way, the only author to have used two contradictory values of LongMed in his maps. Battista Agnese and Alonso de Santa Cruz both employed even more widely differing values in their works in the 16th century: accurate, or at least apparently accurate, LongMed in their nautical-style charts and highly erroneous, Ptolemy-like values in world maps drawn with full grids of meridians.
It is also instructive to observe the evolution of Mediterranean longitudes in the tables of coordinates used by European astronomers of this period. From purely Ptolemaic models with high LongMed errors (e.g. Apian 1524, 48% ± 7%), Kepler's *Rudolphine Tables* reduced the error to 25% ± 6% in 1627 and then Riccioli to 18% ± 3% in 1661. However, in the two cases maps had been produced with similarly increased accuracies decades before respectively Kepler and Riccioli published the ta-

[36] Wallis (1951).
[37] Wallis (1955).

bles.

This challenges the narrative established by some 19th and 20th-century authors according to which astronomers would have led the way in improving the accuracy of the Mediterranean longitude, and mapmakers followed suit. On the contrary, the compiled data tends to support a parallel, independent development of astronomical tables of coordinates and mapmaking in the 17th century, or perhaps even the use by astronomers of coordinate values taken from maps in the same manner as Al-Khwarizmi did in the 9th century.

Around 1700 the French started to produce works with accurate and precise values of LongMed, as already explained in the review section of this article. This new paradigm seems to have spread quickly, as almost all European maps registered in the database showed correctly sized Mediterranean seas within only a few decades.

Some outliers persisted nevertheless, like Nicolas de Fer's *L'Europe* of 1716 (12% ± 7%). Furthermore the first maps printed in the Ottoman Empire, in I. Müteferrika's editions of the *Tarih-i Hind-i Garbi* (1730) and the *Cihannüma* (1732), show rather high errors (17% ± 4% and 30% ± 5% respectively) that attest that the diffusion of the new LongMed values was not so swift beyond Western Europe.

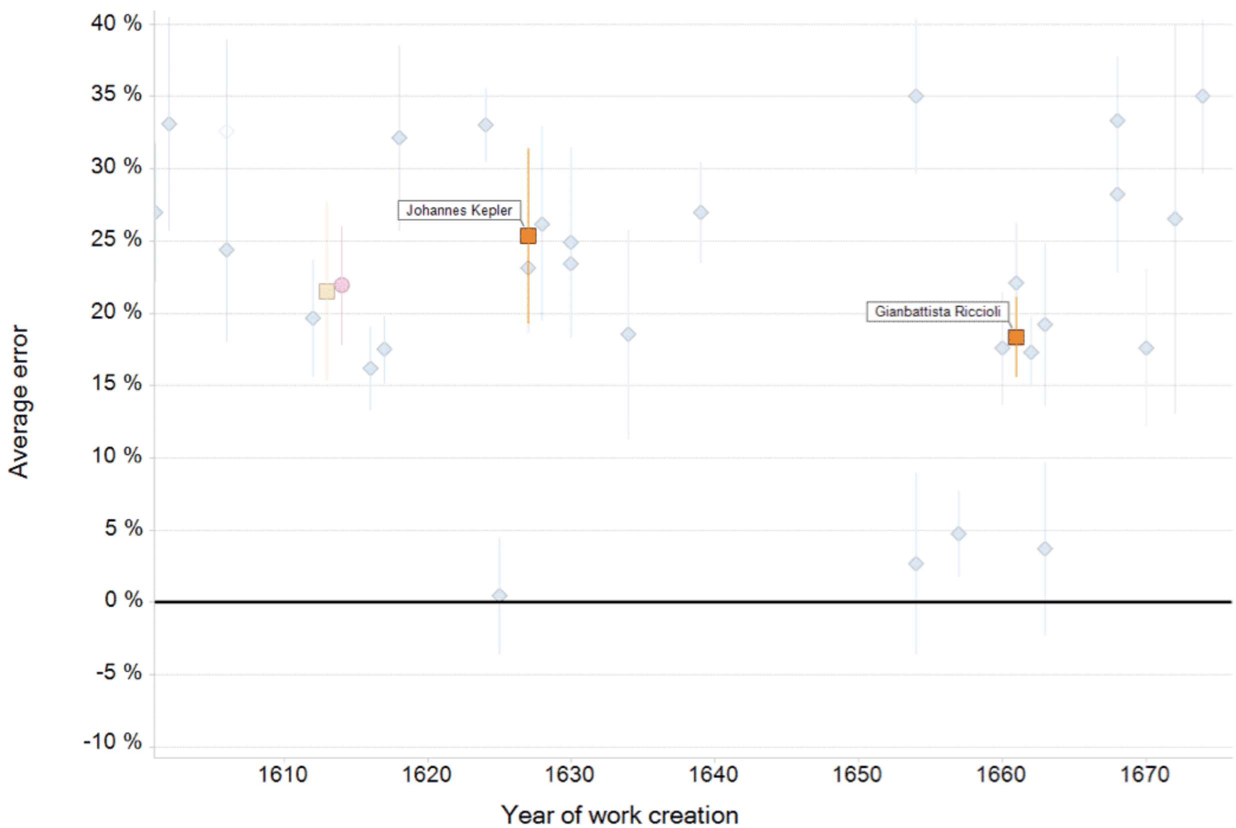


Figure 7: Kepler's and Riccioli's tables of coordinates are highlighted. As can be seen, numerous other cartographic works showed similar values of LongMed decades before each of those two tables were published.

Geographical variability

In general, the database reveals that the evolution of LongMed varied significantly across geographical and linguistic regions. This is hardly surprising given that *scientific knowledge is local in origin* and *constructed at specific sites through the engagements of particular scientists with particular skills, materials, tools, theories and techniques*.[38] For reasons of space, I have to leave the analysis of those local evolutions for future articles. Figures 8a and 8b nevertheless provide a preview of the evolution of LongMed in four different geographic areas.

[38] Turnbull (1996:6).

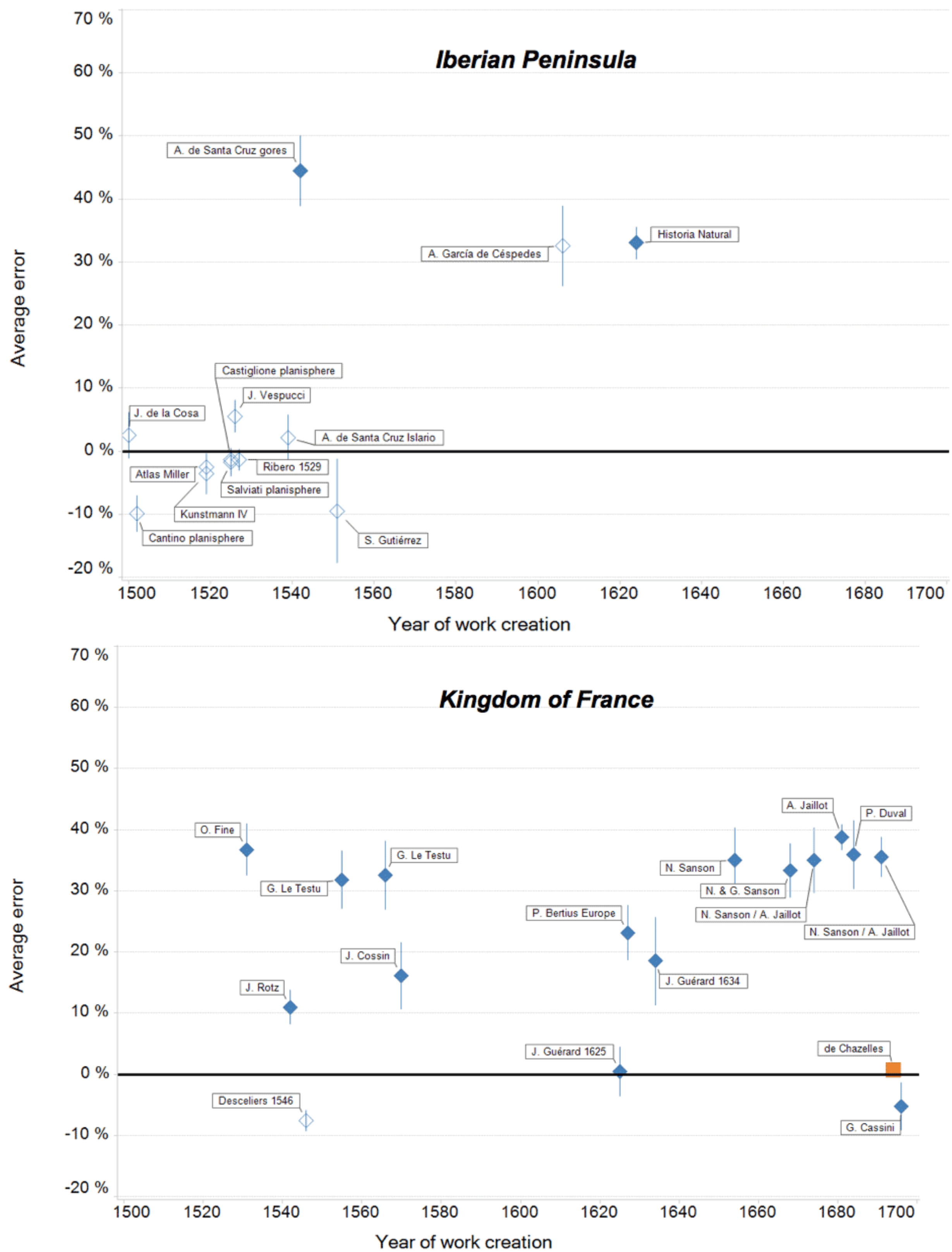


Figure 8a: LongMed error between 1500 and 1700 in the Iberian Peninsula (above) and the Kingdom of France (below).

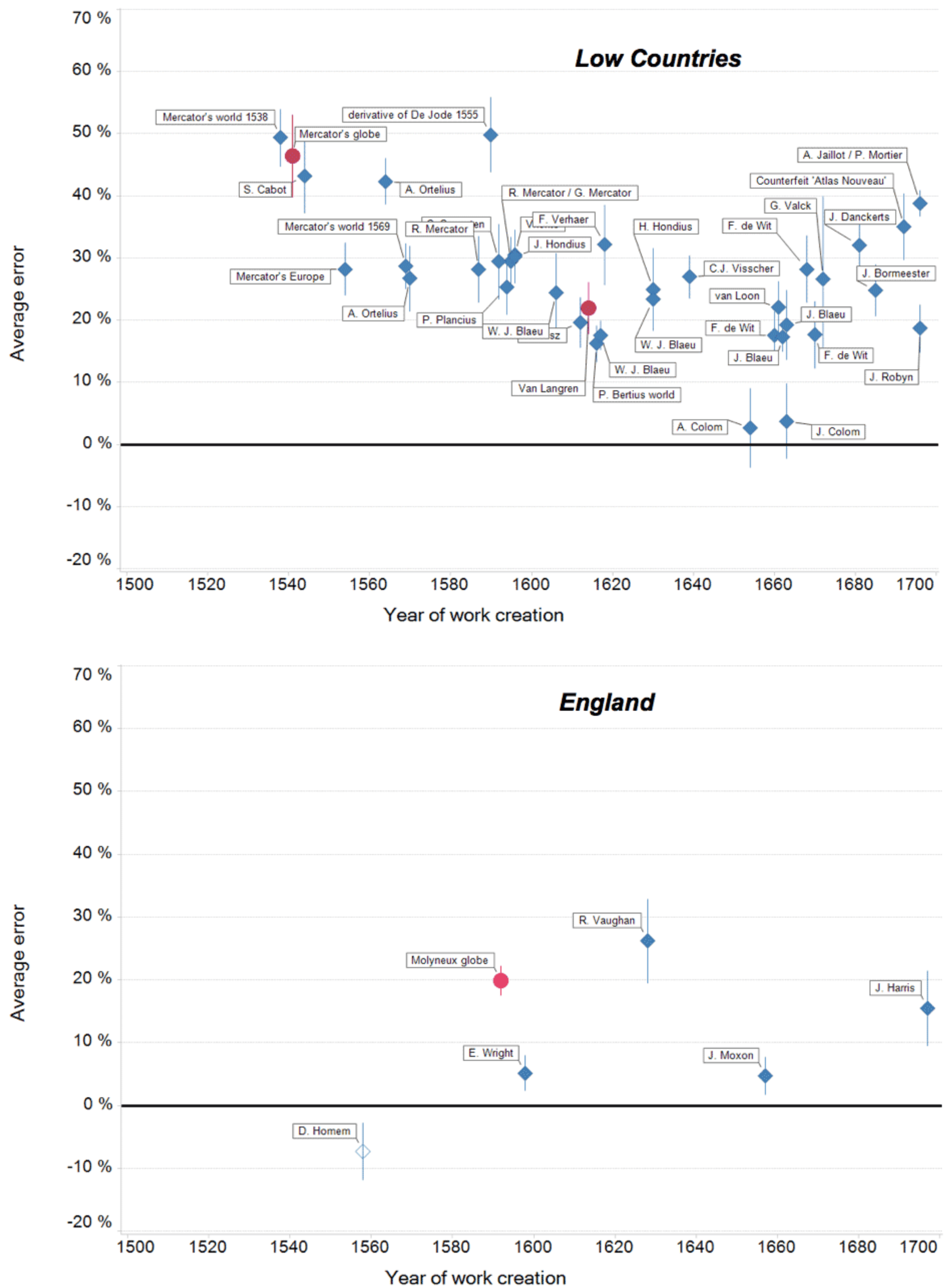


Figure 8b: LongMed error between 1500 and 1700 in the Low Countries (above) and England (below).

Conclusion and way forward

The evolution of the longitude of the Mediterranean (LongMed) has been surveyed in 166 cartographic works from Antiquity up to the mid 18th century. The picture that emerges is richer and more complex than what can be found in most historical narratives. Some of the trends already identified by earlier historians of cartography are corroborated in this study, for example the increasing accuracy of medieval Arabic-language tables of coordinates or the widespread use of erroneous Ptolemaic longitudes in 16th-century Europe.

Some outliers have however been found that show accurate LongMed values at times when most cartographic works were very incorrect and, on the contrary, some maps show substantial LongMed errors decades after the true value had been astronomically determined and published. Diverse and mutually contradictory values of LongMed have been observed to coexist from the High Middle Ages up to well into the 18th century; such confusion was recognized at different epochs by, among others, Abu'l-Fida and Michael van Langren. Differences in the way that LongMed evolved are noticeable across geographical and linguistic regions, and contradictory values are sometimes found even within the works of a same author.

The results of this study also challenge the narrative put forward by some 19th and 20th-century scholars according to whom astronomers would have led the way in improving the accuracy of the Mediterranean, and mapmakers followed suit. On the contrary, all the surveyed European tables of coordinates from the 16th and 17th centuries contain LongMed estimates similar to those already found in earlier maps and globes.

Some of the findings of this study open avenues for further research, e.g.:

- What relationship is there, if any, between the quite accurate Mediterranean coordinates of Arabic-language tables and contemporary maps?
- How were Iberian cartographers of the first half of the 16th century able to draw such an accurate Mediterranean, and why did their successors seemingly abandon it? Which were Jean Rotz's, Edward Wright's and Jean Guérard's sources for their relatively correct values of LongMed? How was the knowledge of the true dimensions of the Mediterranean, as determined by the French Academy of Sciences, received in different countries and cultures?

In parallel to those future investigations, more maps, globes and lists of coordinates should be added to the database so as to document the main trends more comprehensively and to identify other outliers of interest. A higher number of data points is definitely needed to perform finer analyses, like studying the evolution of LongMed in specific geographical or cultural regions. The readers are kindly encouraged to suggest additional cartographic works that should be included in the database, which will be posted online in free access.

Acknowledgements

I am very grateful to Julio Samsó for his cordial advice and for having given me access to numerous medieval lists of coordinates I could not have obtained otherwise. I also thank Jean-Charles Ducène, Leif Isaksen, Ilana Wartenberg and Chet van Duzer for their kind help. Thanks are also due to the anonymous reviewers for their constructive comments and suggestions.

References

Astengo, C. (1995). L'asse del Mediterraneo nella cartografia nautica dei secoli XVI e XVII. *Studi e Ricerche di Geografia*, XVIII (2), 213-237.

Bell, J. (1829). Supplement by the Editor. In C. Rollin, *The history of the arts and sciences of the ancients*. Glasgow & Edinburgh: Blackie, Fullarton & Co. and A.Fullarton & Co., 566- 617.

Blair, J. (1784). *The history of the rise and progress of geography*. London: T. Cadell and W. Ginger. http://books.google.com/books?id=fFgmAAAAMAAJ

Comes, M. (2000). Islamic Geographical Coordinates: al-Andalus' contribution to the correct measurement of the size of the Mediterranean. In *Science in Islamic Civilization. Studies and Sources on the History of Science*. Istanbul: Research Centre for Islamic History, Art and Culture, 123-138.

Comes, M. (1995). Las tablas de coordenadas geográficas y el tamaño del Mediterráneo según los astrónomos andalusíes. In *Al-Andalus: el legado científico*, Fundación El Legado Andalusí, 22-37

D'Anville, J.-B. B. (1769) *Traité des Mesures itinéraires anciennes et modernes*, Paris. Reprinted in M. de Manne (ed.), *Oeuvres de d' Anville*, Paris: Imprimerie Royale, 1834, 82-246.
http://books.google.com/books?id=gXIHPni3GEAC

Delisle l'Ainé, G. (1720). Détermination géographique de la situation et de l'étendue des différentes parties de la terre. In *Histoire de l'Académie Royale des Sciences Année MDCCXX*, Paris : Imprimierie Royale, 1722, 365-384 http://archive.org/stream/histoiredelacad20laca#page/364/mode/2up

Friendly M., Valero-Mora, P. and Ibáñez Ulargui, J. (2010). The First (Known) Statistical Graph: Michael Florent van Langren and the "Secret" of Longitude. *The American Statistician* 64 (2): 185–191. http://www.datavis.ca/papers/vita/Friendly-etal2010langren.html

Gaspar, J. (2007). The Myth of the Square Chart. *e-Perimetron*, 2 (2): 66-79.
http://www.e-perimetron.org/Vol_2_2/Gaspar.pdf

Giry, A. (1875). Exposition internationale de Géographie à Paris. *La Revue scientifique*, 16:.301-305. http://books.google.com/books?id=Zx4gAQAAMAAJ&pg=PA301

Gossellin, P.-F-J. (1790). *Géographie des grecs analysée; ou Les systèmes d'Ératosthènes, de Strabon et de Ptolémée comparés entre eux et avec nos connoissances modernes*. Paris: Imprimérie de Didot l'aîné. http://gallica.bnf.fr/ark:/12148/bpt6k55438586.pdf

Kennedy, E.S. (1956). A Survey of Islamic Astronomical Tables. *Transactions of the American Philosophical Society*, 46: 123-177.

Kennedy, E.S. and Kennedy, H. (1987). *Geographical coordinates of localities from Islamic sources*. Frankfurt am Main: Institut für Geschichte der Arabisch-Islamischen Wissenschaften an der Johann Wolfgang Goethe-Universität.

King, D.A. (1999). *World Maps for Finding the Direction and Distance of Mecca: Examples of Innovation and Tradition in Islamic Science*. Leiden: Brill.

Lepore, F., Piccardi, M., Pranzini, E. (2012). The autumn of mediaeval portolan charts. Cartometric issues. *e-Perimetron* 7 (1): 16–27. http://www.e-perimetron.org/Vol_7_1/Lepore%20et%20al.pdf

Lardner, D. (1833). *The history of maritime and inland discovery*, vol. III, book V. London: Longman, Rees, Orme, Brown & Greene. http://books.google.com/books?id=-oaRjzUr9ysC

Lelewel, J. (1852). *Géographie du Moyen Âge*. Bruxelles. Volume 1 (http://archive.org/stream/gographiedumoy01lele#page/n7/mode/2up) and volume 2 (https://archive.org/stream/gographiedumoy02lele#page/n7/mode/2up)

Nallino, C. A. (1896). Al-Huwarizmi e il suo rifacimento della Geografia di Tolomeo. *Atti della R. Accademia dei Lincei 1894 Serie Quinta*, II: 4–53. http://www.archive.org/stream/memorieatti02accauoft#page/n9/mode/2up

Parsons, E.J.S. and Morris, W.F. (1939). Edward Wright and his work. *Imago Mundi*, 3(1), 61-71.

Peschel, O. (1865). *Geschichte der Erdkunde*, Geschichte der Wissenschaften in Deutschland 4. München: Bayerische Akademie der Wissenschaften. http://books.google.com/books?id=66kBAAAAYAAJ

Reinaud, J.T. and de Slane (1840). *Géographie d'Abulféda. Texte arabe publié d'après les manuscrits de Paris et de Leyde*. Paris: Imprimerie Royale. http://archive.org/details/gographiedabou00abal

Riccioli, G. B. (1661). *Geographiæ et hydrographiæ reformatæ libri duodecim*. Bologna. http://books.google.com/books?id=AkI_1g-eg48C

Sánchez, A. (2013). *La espada, la cruz y el Padrón: Soberanía, fe y representación cartográfica en el mundo ibérico bajo la Monarquía Hispánica, 1503-1598.* Madrid: CSIC

Sédillot J.J. (1834). *Traité des instruments astronomiques des arabes composé au treizième siècle par Aboul Hhassan Ali, de Maroc.* Paris: Imprimérie Royale. http://archive.org/details/traitdesinstru01marruoft

Sezgin, F. (2005). *Mathematical Geography and Cartography in Islam and their Continuation in the Occident*, 3 vols., Geschichte des Arabischen Schrifttums. Frankfurt am Main: Institut für Geschichte der Arabisch-Islamischen Wissenschaften an der Johann Wolfgang Goethe-Universität.

Snyder, J. P. (1993). *Flattening the Earth: Two Thousand Years of Map Projections*. Chicago and London: The University of Chicago Press.

Stückelberger, A. and Grasshoff , G. (2006 - 2009). *Klaudios Ptolemaios Handbuch der Geographie : griechisch-deutsch*, 3 vols. and CD-ROM. Basel: Schwabe Verlag.

Stückelberger, A., Mittenhuber, F. and Koch, L. (2009). Kanon bedeutender Städte, in *Klaudios Ptolemaios Handbuch der Geographie : griechisch-deutsch*, vol. 3, 134-215. Basel: Schwabe Verlag

Tibbetts, G.R. (1992a). The Beginnings of a Cartographic Tradition. In *The History of Cartography*, Volume 2, Book 1, 90-107. Chicago: University of Chicago Press. http://www.press.uchicago.edu/books/HOC/HOC_V2_B1/HOC_VOLUME2_Book1_chapter4.pdf

Tibbetts, G.R. (1992b). Later Cartographic Developments. In *The History of Cartography*, Volume 2, Book 1, 137-155. Chicago: University of Chicago Press. http://www.press.uchicago.edu/books/HOC/HOC_V2_B1/HOC_VOLUME2_Book1_chapter6.pdf

Turnbull, D. (1996). Cartography and science in early modern Europe: Mapping the construction of knowledge spaces. *Imago Mundi*, *48*(1), 5-24.

Ortroy, F. van. (1892). L'oeuvre géographique de Mercator. *Revue des questions scientifiques*, 507-571. http://www.vliz.be/imisdocs/publications/224281.pdf

Wallis, H. M. (1951). The First English Globe: A Recent Discovery. *The Geographical Journal*, 117 (3), 275-290.

Wallis, H. M. (1955). Further Light on the Molyneux Globes. *The Geographical Journal*, 121 (3), 304-311.

Wright, J.K. (1923). Notes on the knowledge of latitudes and longitudes in the middle ages. *Isis*, 5, 75-98 http://archive.org/stream/isisacad05acaduoft#page/74/mode/2up