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A simple solution for georeferencing the Cassini map series of France

Keywords: Cassini map; France; georeference; GIS; historic maps

Summary: The Cassini map series of the 18th century France was geo-referred by other scientists several time. Their approach was to define as many control points (GCPs) as possible, to achieve an affordable fit to the modern cartographic products and coordinate systems, however this method claims a huge amount of work during the GCP selection.

Here we suggest a different solution. The sheets have their own grid system, which is supposed to be a Cassini projection grid, centered at the Observatory of Paris (origin of projection: $\phi=48^{\circ}50'10''$; $\lambda=2^{\circ}20'13.95''$ from Greenwich), which is based on a triangulation network (Ancienne Triangulation Française; ATF). Instead of an ellipsoid, a spheric base surface was used. Length of one degree along a meridian was set to 57,060 toises (cca. 111,213 meters), therefore the radius is 6,372,056 meters. Using the original and modern (WGS84) coordinates of the Paris Observatory, combined with the geoid undulation value of Paris, the datum shift coordinates from the ATF to the WGS84 are: $dX=+11986$ m; $dY=+439$ m; $dZ=-18438$ m.

Applying this GIS meta-data, just the four corners of each sheet can be applied as GCPs, and their grid coordinates are all indicated in toises (1 toise = 1.94906 meters). This geo-reference provides a good overview accuracy, which can be improved by the Bursa-Wolf type datum shift definition of the ATF, compiled using the original triangulation point list and the modern coordinates of these points.

Introduction

The Map of France by Cassini was one of the largest cartographic projects of the second part of the 18th century. Its result, the nice and picturesque series of 175 labeled and 7 auxiliary map sheets in 1:86400 scale is a unique data source, showing the geographical status of France around 1750. Its usage of the landscape historic analyses is traditional, just as examples, in the forest history (Dupuoy et al., 2007) and in coastline evolution analysis (Castaings et al., 2011). Such a cartographic product can be analyzed and incorporated to GIS applications in geo-referred form (Boutoura & Livieratos, 2006; Amoud, 2013; Cajthaml, 2011). As a result of the geo-reference, all pixels of the scanned maps or all vertices of the vectorized product have their own defined coordinates in a coordinate system, which is correctly defined in the GIS software environment. In the practice, this usually means that the geodetic datum (the base ellipsoid and its location/orientation) and the map projection (its type and projection parameters) are well defined (Timár & Molnár, 2013). If they are not known, it is also possible to seek ground control points (GCPs) to define the coordinates of all image elements in a commonly used coordinate

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system, albeit not the original one, used for drawing the map. Usually the UTM or the modern national grids (e.g. the NTF/Lambert zones for France) are used for defining the geolocation of the GCPs, besides their image (pixel) coordinates. We have to underline that using a different coordinate system always causes a systematic error, which can be up to 50-100 meters in horizontal accuracy for a map, showing an extent area of some ten kilometers.

However, the georeference of the Cassini map can be considered as a solved problem, using several (altogether up to 200 thousands) GCPs and the rubber-sheet model (White & Griffin, 1985). This method is discussed by Grosso (2010), Costes et al. (2012) and finally, with a detailed analysis, by Herrault et al. (2013). The resulted geo-referred map sheets and even the whole Cassini mosaic are publicly available at the David Rumsey Map Collection, both in GeoTIFF (for GIS packages) and KMZ (Google Earth) formats (Fig. 1). Here we provide another solution, which is based on the true, exact original coordinate system of the Cassini map system. After the coordinate system definition, all we have to know is the extents of the map sheets and the location of the projection center in the sheet system. These pieces of information are sufficient to carry out the whole georeferencing of the Cassini map in a few days, by just defining the image (pixel-) and projected coordinates of all four corners of all sheets.

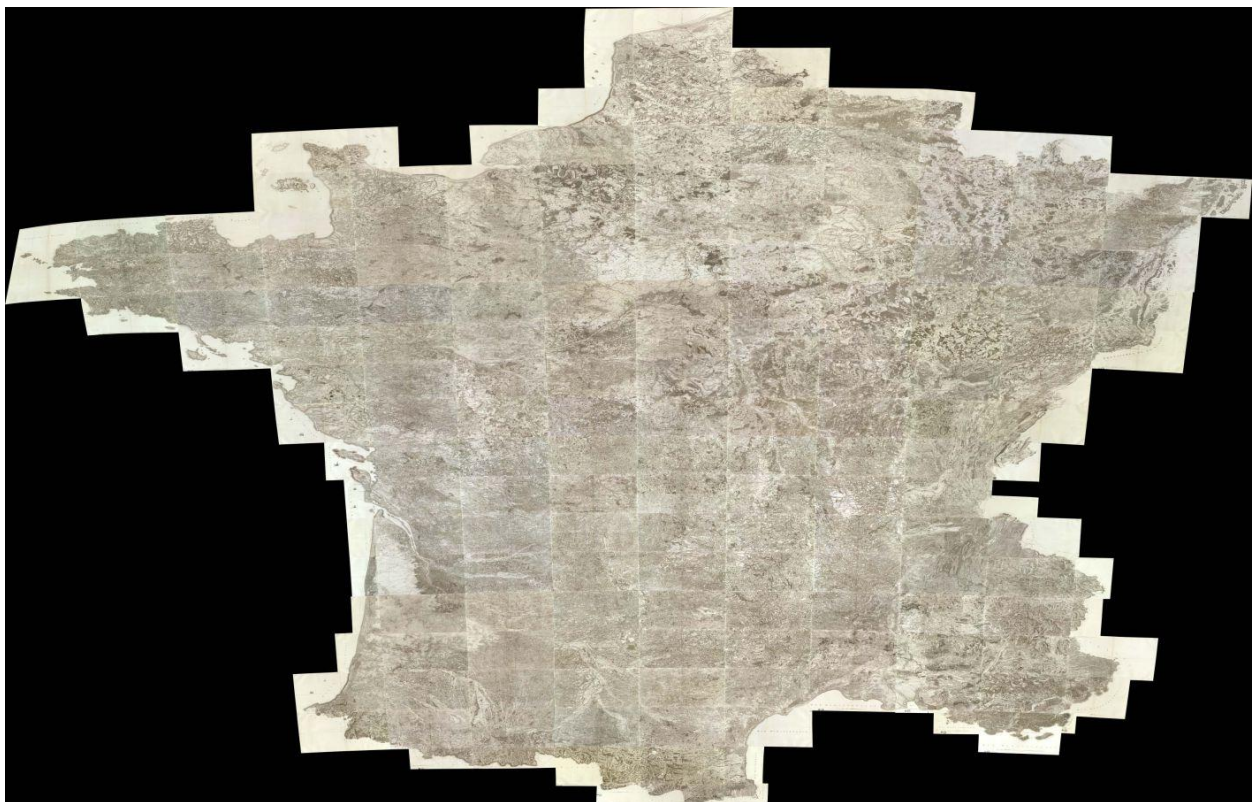


Figure 1. The georeferenced mosaic of the 1:86400 Cassini sheets at the David Rumsey Map Collection; a result of defining of several tens of thousands control points.

The native coordinate system of the Cassini map

The map projection of these sheets are obviously the one, which is called 'Cassini projection' afterwards of the project, defined by César-François Cassini de Thury in 1745, for spherical base surface. Later, it was extended to ellipsoidal base surfaces by the German mathematician Johann Georg von Soldner, therefore this projection of referred to as 'Cassini-Soldner projection' in GIS

packages. In short, the spherical version is called 'Cassini' while the ellipsoidal one is the 'Soldner' or 'Cassini-Soldner' projection. For the discussed maps, the base surface is a sphere, however we shall choose the Cassini-Soldner option with a spherical datum.

The three-dimensional position of this sphere was defined by a geodetic basepoint set, which is now referred to as Ancienne Triangulation Française (ATF), however at the time of its creation it was called 'les principaux triangles qui servent de fondement à la description géométrique de la France' (the principal triangles acting as the basis of the geometric description of France; Cassini & Maraldi, 1744). For the present study, it is a big luck that the map appendix of this latter work contains all of the information items, needed for defining both the ATF and the parameters of the used Cassini projection (Fig. 2); the radius of the base sphere and the latitude of the Paris Observatory (the projection center).



Figure 2. Description of the used sphere base surface and the projection of geodetic origin of the Cassini mappation.

The base surface is described as follows: 'en supposant la terre sphérique et la grandeur du Degré moyen en France de 57600 toises' (the spherical Earth is supposed and one degree [along the meridian] distance is 57600 toises. As one toise is 1.94906 meters, toises, one degree distance is cca. 111,213 meters, therefore the radius is 6,372,056 meters. It is also given, that the origin is the pole of the Paris Observatory, with the latitude of 48d 50m 10s. The longitudes of the triangulation points are given from the meridian of the Paris observatory, without indication of the eastern or western position from it. According to Mugnier (2001), the longitude difference between Paris and Greenwich, used for the ATF was 2d 20m 13.95s. This latitude-longitude pair can be used for the necessary parameters of the Cassini projection in any GIS software (latitude and longitude of the origin), while the false eastings and false northings can be simply set to zero.

Also, we have to derive at least the abridging Molodensky-type datum shift parameters for the ATF sphere to realize its spatial position. Using the abovementioned old coordinates of the Paris

observatory and its modern ones in WGS84, as well as the geoid undulation value of Paris we obtain the following parameters for the ATF to WGS84 datum transformation:

$$dX=+11986 \text{ m}; dY=+439 \text{ m}; dZ=-18438 \text{ m}.$$

Note that the relatively high dX and dZ values are the consequences of the spheric shape. We can define the native coordinate system by all of these parameters then we can proceed to GCP definition for the 187 sheets.

Control points for geo-referencing the Cassini sheets

The terrain covered by each Cassini sheet is 40,000 by 25,000 toises (77,962 * 48,727 meters). The grid (projected) coordinates are indicated at the sheet boundaries in toises, so after selecting a corner point by computer mouse, we can easily give the projected coordinates of the corner. All in all, for all 175+7 sheets, 728 GCPs are needed to be defined. Moreover, these GCPs can be picked up semi- or full automatically (Rus et al., 2010), there is no need to seek identical points of the terrain in the old and new maps.

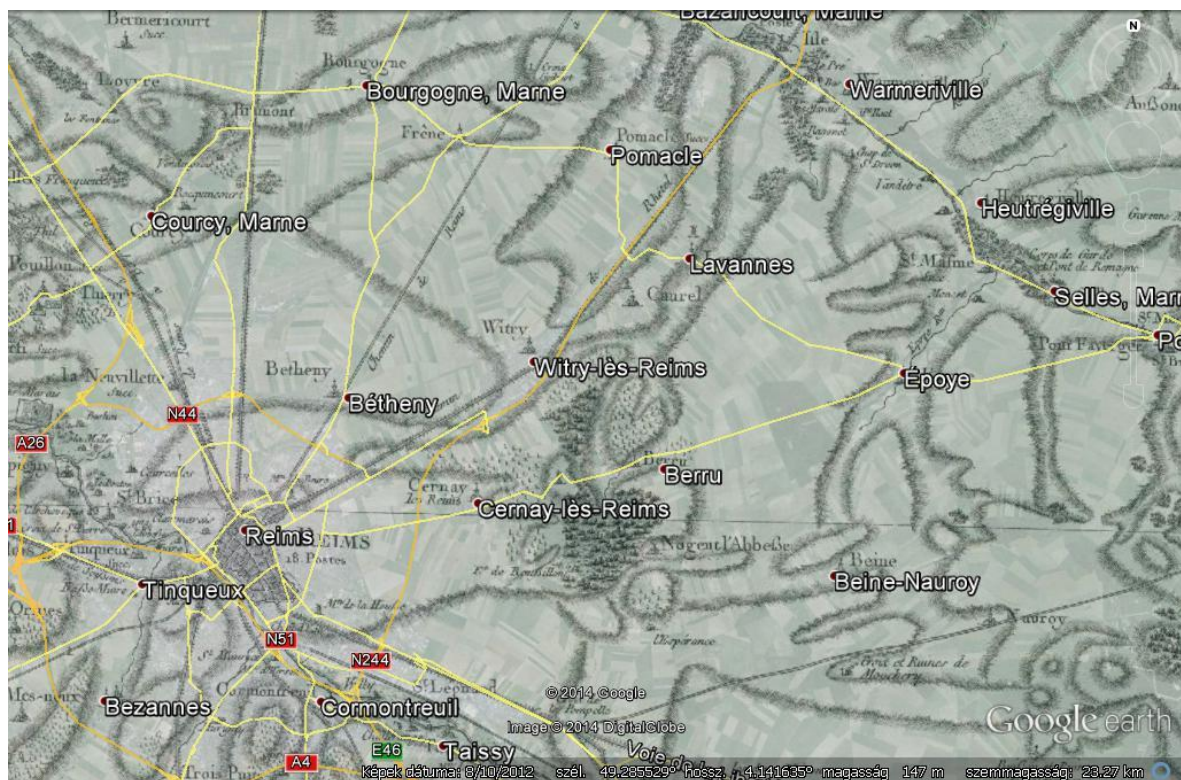


Figure 3: Result of the simple geo-reference of the Cassini sheets around Reims, NE France on the Google Earth basis.

Results of the geo-reference and possible improvements

The accuracy of this simple georeferencing method is surprising. Even very far from the projection origin, the horizontal errors are no more than a few hundred meters (Figs. 3 & 4).



Figure 4: Result of the simple geo-reference of the Cassini sheets around Le Verger, W France on the Google Earth basis.

According to the results, the method is fully capable to build a mosaic for overview and coarse location purposes. Further improvement can be made by use a Bursa-Wolf type datum description, as Cassini & Maraldi (1744) published the coordinates of several terrain objects, whose modern coordinates are also available. Of course, a correction grid can be also compiled and applied, however this would need a lot of control points – and, as it was mentioned in the Introduction, with a large sum of control points, the problem is already solved (Grosso, 2010; Costes et al., 2012; Herrault et al., 2013).

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