The Research on Relationships between Subdivision of Tidal Land Topographic Map and Projection: A Case Study of Investigation on Tidal Land Resources in Zhejiang Province

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ABSTRACT: The topographic map of tidal land which is the initial form of survey results of “Investigation on Tidal Land Resources in Zhejiang Province” will involve splicing of adjacent zone during formation, and there will be phenomenon of edge overlapped or separated which is thought to be related to error of survey or graphics. In this paper, the authors try to explain the actual result of zonal projection and map subdivision through explaining about analysis on projection and its distortion, the research on map subdivision and numbering, and the research on subdivision of tidal land topographic map. In addition, when you find the regularity of subdivision, you can estimate the distortion error of certain area of coastal tidal land in the map by its graph outline coordinate data.

Keywords: tidal land; topographic map; zonal projection; coordinate; map subdivision; map numbering

1 INTRODUCTION

The project of “Investigation on Tidal Land Resources in Zhejiang Province” has made a comprehensive and systematic investigation on tidal land resources in the whole province. It helps us to grasp the situation of tidal land resources accurately, which also provides us with data support for analyzing tidal land resources development laws and monitoring marine environment, and provides a basis for decision-making on ecological reclamation in the future.

This investigation has collected much data about tidal land, intertidal zone and remote sensing image based on support of basic control results by Zhejiang Administration of Surveying Mapping and Geoinformation. It includes some innovative technologies, such as analysis on multi-station tide data, positioning with network RTK technology, survey on tidal land by UAV and so on. It serves the status of tidal land resources, and the initial form of survey results is topographic map of tidal land. However, there would be some problems in the process of mapping. For instance, data from different zones, coordinate of graph outline from different zones and the large area of tidal land terrain are lack of comparably basic zonal topographic map due to zonal projection in coastal areas of the whole Zhejiang Province.

In this paper, we try to explain the relations between these problems around the definition of topographic map: Topographic map is a kind of common map which shows the positions and basic geographical elements of surface features and the elevation with contour [1], namely, surface features are converted from ellipsoidal surface to plane surface by projection and its distortion. It builds up the plane coordinate with vertical axis (X), horizontal axis (Y) and intercept of two axes as the origin of coordinate, in which X is projection of arc through the north and south poles of earth surface, and Y is projection of equator (parallel). It generates different zones when projected from ellipsoidal surface. Every map has its own number when subdivided by longitude difference and latitude difference in international rules, and as a result we can get the geodetic coordinates (latitude and longitude) of the map.

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2 ANALYSIS ON PROJECTION AND ITS DISTORTION

As the ellipsoidal surface of earth is an undevelopable curved surface, there would be distortion of length, area and angle which are all called distortion of topographic map projection when the earth surface is projected from ellipsoidal surface to plane surface. Whatever method of map projection from ellipsoidal surface to plane surface you choose, there will always be distortion and error inevitably when designing topographic map projection. Generally, there will be three kinds of distortion at the same time, but we can keep one of them without distortion in the case of special requirements [2]. Conformal Projection depends on area distortion to ensure that the angle is not distorted, such as nautical chart and current chart with Mercator Projection; Equidistant Projection is a projection with both angle and area unequally, whose distortion is between Conformal Projection and Equal Area Projection, and it is commonly used in thematic map and teaching map; Equal Area Projection depends on the increasing angle distortion to ensure that the area is not distorted, and it is commonly used in economic map and administrative map; Transverse Conformal Cylindrical Projection is also called “Gauss-Kruger Projection” for short, and it is commonly used in topographic map as the main projection in the results of this investigation.

2.1 Gauss-Kruger Projection

“Gauss-Kruger Projection” is a projection from ellipsoidal surface to plane surface with the method of Transverse Conformal Cylindrical Projection. Imagine that setting an elliptic cylinder on the earth ellipsoidal surface with a tangent meridian (this meridian is called central meridian), and then the central axis of the elliptic cylinder is located at the equator of the ellipsoid according to the requirements of the projection (such as projected lines of central meridian and equator are perpendicular to each other (Figure 1-A); the length of central meridian remains unchanged after projected; Conformal Projection is used) we project the intersection points of latitude and longitude lines within a certain range on to the surface of elliptic cylinder, then cut the plane of elliptic cylinder along the line from north pole to south pole and smooth it flat, finally we get the projected plane [2].

Project the earth surface along a central meridian from west to east in every 3° or 6° (projection in a longitude of 3° is named as 3° zonal projection, the projection in a longitude of 6° is named as 6° zonal projection, and the projection in other values of longitude is named as arbitrary zonal projection), and the distortion is in proportion to the difference value of longitude. Take 3° zonal projection as an example: Project the earth surface in a longitude of 3° to the plane of elliptic cylinder and smooth it, after that we get the projected plane. The plane is combined with two gourd-shaped zones in 1.5°, and its central meridian and equator are perpendicular to each other without distortion. By analogy, we get 120 pieces of gourd-shaped zones with independent boundaries after 120 times projection around the equator, and each zone has its zone number: zone 1, 2…120 (Figure 1-C).

2.2 Simulated projection

It is much more straightforward to use watermelon cutting to simulate projection. Imagine that we set a glass cylinder on the watermelon, take both ends of the watermelon as south and north poles (Figure 2-A), then cut a gourd-shaped piece in 3° along watermelon stripes (Figure 2-B), remove the watermelon capsule and smooth it. Watermelon stripes symbolize the central meridian of earth (Figure 2-C), and the biggest loop perpendicular to watermelon stripes symbolizes the equatorial latitude of earth. The length of watermelon stripes close to the glass cylinder remains unchanged, just like the length of projected central meridian is the same as on the spot. But the rest of them all have distortion in length and width, and the distortion is getting larger when it gets away from the watermelon stripe which is closest to glass cylinder and when it comes closer to the biggest loop of watermelon (equator).

After the simulation we know that Gauss-Kruger Projection is similar to cut the earth into several pieces,
take 3° zonal projection as an example, and the earth surface is projected to 120 independent gourd-shaped pieces of plane. It is designed to make the distortion law same in each zone, and the error won’t be transferred from one zone to another. But after projection, the convergence angle in the central meridian is zero, and it increases in other meridians when getting closer to edge meridian.

As a result, splicing of adjacent zones would cause phenomenon of terrain overlapped or separated. We can see that the river network mosaic map of China in 30° zonal projection which is ten times as much as 3° zonal projection (Figure 3-1), and we assume that zone A is with its central meridian longitude 90°E and edge meridian longitude 105°E; zone B is with its central meridian longitude 120°E and edge meridian longitude 105°E and longitude 135°E, and the longitude 105°E is the splicing line of these two zones. After importing two maps of different zones into computer, you’ll find that there will be greater separation in splicing area (Figure 3-4) when it gets away from equator (latitude 0°), because after mosaic of two maps there are two virtual edge meridian respectively with their splicing point on the equator (latitude 0°), because after mosaic of two maps there are two virtual edge meridians which are different from each other. It is common to have serious errors there. It would cause a phenomenon of “coincidence at the top with overlapping at the bottom” or “coincidence at the bottom with separation at the top” if doing translation and mosaic. In addition, there would be the same phenomenon when transform in different coordinate systems, because different kinds of coordinate systems are based on different parameters of earth ellipsoid.

3 RECTANGULAR PLANE COORDINATE SYSTEM

The Rectangular Plane Coordinate System is also called as plane coordinate. We name the horizontal axis as X-axis and the vertical axis as Y-axis, which are named axes collectively, and their common origin O is named as the origin of coordinate [3]. It’s a mathematics coordinate system of counterclockwise direction. A rectangular plane coordinate system with meridian as its X-axis is Mapping Coordinate System. Mapping Coordinate System of our country is a rectangular plane coordinate system based on Gauss-Kruger Projection. They are mainly Beijing Coordinates System 1954, Xi’an Geodetic Coordinate System 1980 and China Geodetic Coordinate System 2000 [1]. They have different ellipsoid parameters of half long axis, half short axis and flattening, which are used for calculating the relationship between geographical coordinate system and rectangular plane coordinate system. They all use projected central meridian as its vertical axis (X-axis), projected equator as its horizontal axis (Y-axis), and intersection of two axes as its origin of coordinate in each zone. Vertical coordinate starts from equator as 0, the north of equator is positive and the south of equator is negative. Horizontal coordinate starts from central meridian, the east of central meridian is positive and the west of central meridian is negative. Quadrant increases with clockwise direction. China is located in the north of the east equator with latitude about 0-56° and covers
23 central meridians such as 72°, 75°...138° (in 3° zonal projection). In order to avoid use of inconvenience when horizontal axis (Y-axis) is negative, we remove the vertical axis 500km to the west as its starting axis. It also can be understood as the departure point of each central meridian in China is 500 km, not 0 km.

Why are the axes X and Y opposite in the mathematics coordinate system and the mapping coordinate system? We think that the axis which can be determined at first is the X axis. In mathematics coordinate system we have to determine the horizontal axis (X-axis) at first, then the vertical axis (Y-axis). But in mapping coordinate system we have to determine the true meridian at first, which is vertical axis, and then the equator is regarded as the horizontal axis. For instance, the area in this investigation covers two central meridians (zone 40 and zone 41), so we have to determine which zone the survey area belongs to. According to the principle of projection, we can find out which map has larger distortion by comparing the coordinate data of graph outline from each other, for example, the distortion of map with coordinate data that X=3130000 and Y=40612000 is larger than map with coordinate data that X=3413000 and Y=40510000. So the distortion is larger as being closer to the horizontal axis, and the distortion is smaller as being closer to the vertical axis (the departure point of each central meridian in China is 500km).

4 THE RESEARCH ON MAP SUBDIVISION AND NUMBERING

Map subdivision with projected earth plane is similar to cutting watermelon: First, cut the earth into north and south hemispheres along the equator, then project them on the plane, take the semi-circle where Zhejiang Province of China locates as an example to subdivide topographic map (Figure 4-A). According to the international regulation, there are rows named in Latin Alphabet (character code) A, B, C...V in every latitude of 4° from earth equator, and there are columns named in Arabic Numbers 1, 2, 3...60 in every longitude of 4°from the meridian of 180°. Each trapezoid frame surrounded by latitude and longitude is a

1:1000000 topographic map, and the map number is composed of row number (character code) and column number (digital code) where the map locates [4].

As shown in the map “H51” (Figure 4-B), the scale of the map is 1:1000000, and the row number “H” shows that this map is in the 8th row with its latitude 4°×8 = 32°, so the ordinate (X) of the trapezoid frame is in the range of 28° - 32°; column number “51” shows that this map is in the 51st column with its longitude 6°×51−180°=126°, so the abscissa (Y) of the trapezoid frame is in the range of 120°-126°.

According to the difference of 2° in latitude and 3° in longitude, we subdivide 1:1000000 scale map into 4 1:500000 scale maps. The numbers of the maps are respectively “H51B001001”, “H51B001002”, “H51B002001” and “H51B002002” (Figure 5-A). And the like we subdivide map into next level of scale. When the scale in the next level cannot be half splitted, we have to determine the scale. For instance, 1:100000 is the next map scale of 1:250000, and 1:10000 is the next map scale of 1:25000.

4.1 Interpretation of map number

Take the map “H51G051039” as an example: There are 5 sets of data in the map number, “H”, “51”, “G”, “051” and “039”. Row number “H” (8) and column number “51” show that the latitude of the map is in the range of 28°-32° and the longitude is in the range of 120°-126°. “G” means the scale of the map is 1:10000, “051” is the next level number of row number “H”, and “039” is the next level number of column number “51”.

Table 1. The codes of topographic maps with different scales.

<table>
<thead>
<tr>
<th>Scale</th>
<th>Code</th>
<th>Code</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:500000</td>
<td>B</td>
<td>C</td>
<td>D</td>
</tr>
<tr>
<td>1:250000</td>
<td>C</td>
<td>D</td>
<td>E</td>
</tr>
<tr>
<td>1:100000</td>
<td>D</td>
<td>E</td>
<td></td>
</tr>
<tr>
<td>1:50000</td>
<td>E</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

How is the map number “H51G051039” generated? We subdivide 1:1000000 map into 144 1:100000 maps according to the difference of 20° in latitude and 30° in longitude, the row numbers are 001-012 and, the
column numbers are 001-012 (Figure 5-B). Then subdivide map into 9216 1:10000 maps according to difference of 2’30” in latitude and 3’45” in longitude, the row numbers are 001-096 and the column numbers are 001-096. It must be pointed out that 1:100000 map is subdivided by 8 rows and 8 columns into 64 1:10000 maps (Figure 5-C). The map number H51G051039 is between row number 056-049 and column number 040-033 in 1:10000 map, the row number is 056÷8=007, and the column number is 040÷8=005 in 1:10000 map. The coordinates of southwest corner of the trapezoid frame are (X) 29°52’30” (Y) 122°22’30” (Figure 5-C). The map number, latitude and longitude can be calculated or graphically interpreted.

4.2 Calculating the difference of latitude and longitude

The difference of latitude and longitude of topographic maps with different scales.

<table>
<thead>
<tr>
<th>Scale</th>
<th>1:1000000</th>
<th>1:500000</th>
<th>1:250000</th>
<th>1:100000</th>
</tr>
</thead>
<tbody>
<tr>
<td>The difference of longitude</td>
<td>6°</td>
<td>3°</td>
<td>1°30’</td>
<td>30’</td>
</tr>
<tr>
<td>The difference of latitude</td>
<td>4°</td>
<td>2°</td>
<td>1°</td>
<td>20’</td>
</tr>
</tbody>
</table>

Maps of any scales are subdivided by 1:1000000 map in difference of latitude and longitude, and they have some regularity (Table 2). You can calculate the difference of latitude and longitude of the map if you remember row and column numbers of special scales such as 1:100000 and 1:10000, and you can get row and column numbers by multiple in other scales. For instance, the scale of 1:250000 is 4 times the size of 1:1000000, which means the row and column numbers are 4.

The difference of longitude=6°÷4=1.5°
The difference of latitude=4°÷4=1°
The row and column numbers are 12 in the scale of 1:100000 (in special):
The difference of longitude=6°÷12=30’
The difference of latitude=4°÷12=20’
The row and column numbers are 12x8 in the scale of 1:10000 (in special):
The difference of longitude=6°÷96=3’45”
The difference of latitude=4°÷96=2’30”

4.3 Conversion among the map number, latitude and longitude

Case 1:
Given information: The map number is H51G051039, the difference of longitude is 6° and, the difference of latitude is 4°.

Figure out the latitude and longitude of the southwest corner of graph outline in 1:100000 scale.
The longitude of the southwest corner= (51-30-1) × 6° =120°
The latitude of the southwest corner=32°-007×20’=29°40’

Case 2:
Given information: The map number is H51G051039, the difference of longitude is 30’ and the difference of latitude is 20’, the scale code is D (Table 1).

Figure out the map number and the latitude and longitude of the southwest corner of graph outline in 1:100000 scale.
Row number=051÷8=6.375 (carry the remainder) = 007
Column number=039÷8=4.875 (carry the remainder) = 005
The 1:100000 map number is H51D007005
The longitude of the southwest corner =120°+(005-1)×30’
=122°
The latitude of the southwest corner
=32°-007×20’=29°40’

Case 3:
Given information: The map number is H51G051039, the difference of longitude is 3’45” and, the difference of latitude is 2’30”.

Figure out the latitude and longitude of the southwest corner of graph outline in 1:10000 scale.
The longitude of the southwest corner
=120°+(039-1)×3’45”
=122°22’30”
The latitude of the southwest corner=32°-051×2’30”
=29°52’30”
5 SKETCH OF MAPPING PROCESS

As the investigation covers the whole coastal tidal land in Zhejiang Province, we divide the survey area into several pieces for different survey groups. The process is as follows: First of all, we get the elevation data from depth data corrected by tide data and generate 3D data files of underwater terrain in standard format by HHCH software, then we solve the relationships between geodetic coordinates, geographic coordinates and mathematics coordinates, and import data into computer with measured coastline, island line, symbol of reef, dry line, wharf line and any other data which would have an effect on water contour line; second, we set up the contour step, elevation range, data space and type of line; third, we build the triangle grid, generate underwater contour automatically, check and eliminate the exceptional elevation value, and then generate underwater contour again automatically; fourth, we adjust the generated contour with the real terrain and characteristics of underwater terrain, and make it smooth; finally, we splice adjacent zones together, insert terrain on land, and generate several zones of digital tidal land terrain of 1:10000 scale, then we enter the stage of map subdivision.

6 THE RESEARCH ON SUBDIVISION OF TIDAL LAND TOPOGRAPHIC MAP

The boundary between two central meridians (120°, 123°) in Zhejiang Province is 121°30', which goes through Haihuang Mountain in Cixi, Qiangjiao in the west of Xiangshan Harbour, inspection department in Sanmen Bay, the entrance of Taizhou Bay, Shiqiao in Wenling and Pishan Island from north to south. The latitude and longitude of graph outline are calculated according to the parameters of CGCS2000 and the difference of latitude in each central meridian zone, and they are displayed on the screen. Each loop through 4 points is the inner line of graph, then grid of kilometers is added (Figure 6). Till now we get the inner grid for topographic map subdivision in geodetic coordinate system (zone 40 and zone 41).

6.1 New-built standardized map

We just have to save the basic information in the ObjectARX topographic map file because the survey area of this investigation is coastal tidal land without names, and the map title is replaced by map number which is the only code without reuse in the world. We only have to point out the place we need when working, then by calculating map number from coordinate the software will generate a map file including coordinate system, elevation system, time, scale, identification, confidentiality classification, etc., which will be shown in the map (Figure 7). \[5\]

![Figure 7. The new-built standardized map](image)

6.2 Validation on map number

In order to avoid error in a certain link affecting the calculation results, we have to validate the correctness of map number when standardized map has been built. The most direct way is to use coordinate of any point to calculate the map number where the point locates, and it’s applied to calculate map number of any scales. Its principle is to figure out the total quantity of rows in map of certain scale by the difference of latitude in 1:1000000 map divided by the difference of latitude in a certain scale map, namely to figure out the quantity of rows from the start to the end, and then figure out the quantity of rows from the end to this certain point. The remainder of the point latitude divided by 4° is the row distance from the end to the point, and then we calculate the column number: The remainder of the longitude of the point divided by the difference of longitude in 1:1000000 map is the location of 1:1000000 map, and the column number is the value of the remainder divided by the difference of longitude in certain scale map and plus 1.

**Case 4:**
Given information: The latitude and longitude of a certain point in the map are 29°52'30" and 122°22'30".
Figure out the map number of 1:10000 scale.
The row number of 1:1000000 map = \(29°52'30''\div4°\) =7+1= 8 (H)
The column number of 1:1000000 map
=122° 22’30”÷6°
=20+31= 51
The row number of 1:10000 map
=4°÷2’30”=29°52’30”÷4°÷2’30”
=96(14400+150)÷45(6750+150) =051
The column number of 1:10000 map
=122°22’30”÷6°÷3’45”+1
=38(8550÷225)+1=039
So the map number where the point locates is “H51G051039”.

6.3 Checking the tidal land topographic map
We need to gather all the subdivided maps from different working groups together and check them. The method is to insert all the maps into the inner grid line of graph (Figure 6) one by one, and then check the edge matching of points, lines and data symbols.

7 CONCLUSIONS

Above all, there is much causality between topographic map and projection and subdivision with certain concealment. First, maps of any scales are subdivided by 1:1000000 map in the difference of latitude and longitude. If you find out the regularity of subdivision, the map number, latitude and longitude can be calculated or graphically interpreted. During the defense against the typhoon “Haikui” in 2012, we can get the information of map number with any scales and basic topographic map soon by inputting a group of latitude and longitude data in the software, so as to improve the work efficiency significantly. Second, we can estimate the distortion of the map by a group of coordinate data. For example, the distortion of the map with coordinate data \(X=3130000, Y=40612000\) is larger than that of the map with coordinate data \(X=3413000, Y=40510000\). We can also determine that a group of coordinate data is located either in the west or east side of the central meridian, and estimate the latitude and longitude because 1° approximately equals to 30 meters. Third, the splicing of adjacent zones would cause phenomenon of terrain overlapped or separated, because zonal projection makes the distortion law same in each zone; the error won’t transfer from one zone to another, the distortion error of projection from curved surface to plane surface increases when getting closer to edge meridian, and the convergence angle increases in adjacent zones. It’s not the error of survey or graphics.

REFERENCES