GLOBAL TERRAIN DATA ORGANIZATION AND COMPRESSION METHODS

LI Yi *, GONG Jianhua*

State Key Laboratory of Remote Sensing Science Institute of Remote Sensing Applications, CAS
3 Datun Road, Chaoyang District Beijing 100101, P.R. China

Commission V, WG V/4

KEY WORDS: Multi-resolution terrain model, Global terrain data, Improved SPIHT wavelet, Terrain simplification

ABSTRACT:

Terrain data is important data source in the 3D geographic visualization system. The key problem to browse global terrain data in network environment is to organize, transform and display data in a quick and efficient way. This paper introduces some of the key techniques in the global terrain visualization. The simplified global terrain data partition and organizing method is adopted. In order to reduce the size of datasets, the human-vision related improved SPHIT wavelet compression method is also introduced in this paper. The experiment shows that these technique solutions are effective to solve the problem in global terrain visualization in C/S mode.

1. INTRODUCTION

Since the digital Earth was first proposed by the USA former vice president Gore [1], the information technologies and collection of spatial data is developing very quickly. National Spatial Data Infrastructure (NSDI) and "digital earth" strongly desire the digital expression for a region, a nation, and even global area.

Virtual reality (VR) and GIS are important technologies for digital earth building and massive spatial information visualizing. Recently, as advancement in computer hardware and computer graphics, VR and VR-GIS get their great development, the traditional 2D GIS is promoted to Web and 3D GIS [2].

Global virtual terrain scene, which bears the weight of all kinds of spatial information and cultural information, is the basic framework of digital earth. A great number of 3D GIS prototype systems have been developed, which is widely applied in such areas as underground mine resource management, digital cities and digital ocean. In 1997, Lindstrom put forward a 3D digital earth prototype [3], which greatly contributed to the development of 3D virtual digital earth. EarthSystem developed by Keyhole Company of America in 2001 is so far an excellent web-based 3D information system [4]. ESRI Company released a multi-resolution global 3D data visualization model ArcGlobe in ArcGIS 9.0. This module allows users to visualize and analyze large amount of 3D data. And users can browse the earth in different scale smoothly. Stanford Research Institute International (SRI) developed a distributed terrain visualization system called Terravision. It is open source and it can manage and browse large amount of terrain and image data. Google earth can access the expanded Keyhole aerial image database and provide 3D virtual earth display and map search service. NASA developed global visualization system WorldWind which can display not only high quality of imagery data of the Earth, but also provided the imagery about Moon, Mars and so on.

Although some research has been made on browsing globe image and terrain data in net environment, some key problems such as effective organization and management of global large dataset, spatial data compression and simplification methods, data dispatch strategies and so on are still urged to be solved.

For the terrain data is important basic geographic data. It has widely applications and its data amount is very huge. This paper mainly focuses on the optimizing strategies for the browsing of terrain data in networking environment, such as the simplified global partition and organizing method of terrain data, and the improved SPHIT wavelet compression method to reduce the size of datasets, which is relevant with human-vision. The rest of the paper is organized as follows: In section 2 the global partition of terrain data and the storage and index method is introduced. In section 3, we introduce the improved SPIHT wavelet compression method to reduce the size of datasets, which is relevant with human-vision. The experimental results are shown in section 4. Some concluding remarks are given in section 5.

2. GLOBAL TERRAIN DATA PARTITION AND ORGANIZING METHODS

2.1 Existing partition and organizing method

The terrain surface distributed scope based on globe is very large compared to the visible scope which human eye can clearly observe the terrain surface. In order to make data dispatch more convenient and reduce the detail levels of terrain data. We need to do partitions to the earth surface. Nowadays the researchers around the world select many kinds of earth surface partition method according to different situations.

* LI Yi. li_yi81@126.com
* GONG Jianhua. jhgong@irsa.ac.cn

Discrete Global Grid (DGG) is an earth simulate grid that can be infinitely partitioned without shape transform. This discrete grid can simulate the earth surface when it is partitioned to a certain degree [5]. It has hierarchy and it is continuous in global area. So it is hopefully to solve the problems such as data fault, distortion and topology inconsistent which will happen when flat gird model is adopted in global multi-scale data management. It has become a new research hot point in the international GIS academe.

Nowadays the Discrete Global Grid is not mature. Instead many different solutions using inscribed polygon are adopted. Some are based on octahedron, such as the hierarchal structure model of global data, the continuous index model, the spatial data quality and hierarchal integrated model. Some are based on dodecahedron, such as the global DEM and image data compression model. Some are based on icosahedrons, such as global hierarchal data index model, the global navigation model and the global grid positioning system. Some are based on generic icosahedrons, such as global environment detection model [6].

But these solutions above have disadvantages. They organize and partition data regions on the basis of triangle unit. So the spatial operations should be carried out on the basis of triangle. For the geometry structure of triangle grid is complex, it doesn't have the confirmed orientation and symmetrical shape. So the spatial index is much complex and it is difficult to meet the demand of contiguity analysis, spatial query, data updating and visualization. Otherwise the data provided by data producing department is strictly partitioned according to longitude and latitude grid. It needs large mount of work to partition and organize data according to inscribed polygon.

2.2 The simplified partition and organizing method adopted

This paper adopts a simple earth partition method according to the demand of global terrain visualization.

Plate Carree projection is to directly map the longitude coordinate of the earth sphere to x axis and map the latitude coordinate of the earth sphere to y axis. This projection method results in the plane orthogonalization. The result of the projected sphere is a rectangle with the ratio of length and width 2:1. The demonstrative figure is Fig 1.

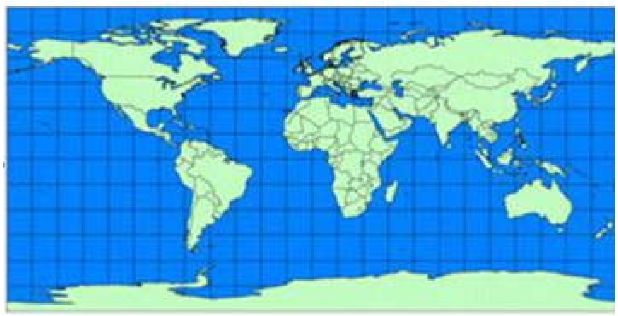


Figure 1. Plate Carree projection and geographic subdivisions of the globe

Although the Plate Carree projection and geographic subdivisions of the globe has distortions at the poles, it is more simple and familiar to us. And it can meet the demand of visualization for the two reasons below:
The first reason is that when we view earth from the space, the view point is far away from earth. So we can treat the earth sphere as a regular sphere and the elevation fluctuation of the earth's surface can be ignored. It is not necessary to display the coarsest terrain data on the earth surface. When the view point gets close to the earth, we only need to display a pseudo background sphere. When the view point is close enough to the earth surface, the elevation fluctuation need to be displayed. At this time the earth surface can be treated as an infinite flat surface. In this small scale the distortion along the longitude can be ignored.

The second reason is that when we browse the globe, most of the action still occurs at the middle latitudes where the majority of the world's population is concentrated. In these places the distortion is small and cannot affect our visual effect.

So in this paper Plate Carree projection and geographic subdivisions of the globe is adopted instead of polyhedral subdivisions. After the global surface is subdivided the pyramid model and linear quad tree are used to manage and organize DEM data.

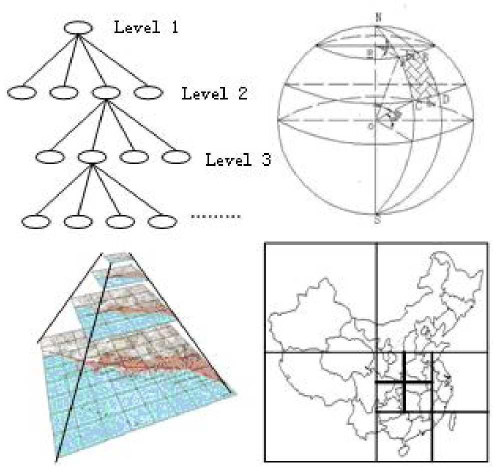


Figure 2. Quad tree partition and organizing method

Some of the important parameters need be introduced in linear quad tree and pyramid structure.

- Pixel: the elevation point in block
- Block (ID): the data in every leaf node can be presented as block. The serial number of each leaf node begins from the left-bottom corner of the entire terrain data. The origin is at geographic coordinate (-180°,-90°). At the ID number increase from left to right, from bottom to top.
- Layer: Refers to the layer of quad tree. The top layer is defined as the 0 layer. This layer stores the original DEM data; the data resolution is the highest.

The Meta data of layer in the pyramid is as below

```
struct CVGEDemLayerInfo
{
    int XBlocksNum;
        //the Block number in x direction of current layer
    int YBlocksNum;
        // the Block number in y direction of current layer
```

```
    int BlockRow;
            //the row number of pixels in a Block
    int BlockColumn;
            //the column number of pixels in a Block
    double BlockSize;
            //the Block size (unit: degree)
    double BlockCellSize;
            //the resolution of pixels (unit: degree)
}
```

We can find that the relationship between the parameter of i+1 layer and i layer is as follows:

$XBlocksNum_{i+1} = 2*XBlocksNum_i$
$YBlocksNum_{i+1} = 2*YBlocksNum_i$
$BlockRow_{i+1} = BlockRow_i$
$BlockColumn_{i+1} = BlockColumn_i$
$BlockSize_{i+1} = BlockSize_i /2$
$BlockCellSize_{i+1} = BlockCellSize_i /2$

So every tile in the pyramid has the same number of pixels which helps to make the system running effective.

And we can get the RowID and ColumnID of block and pixel using the geographic coordinate (-180° <B<180° , -90° <L<90°):

$$xblock = (\text{int})\frac{B+180}{BlockSize_i}, \quad yblock = (\text{int})\frac{L+90}{BlockSize_i}$$
$$xpixel = (\text{int})\frac{B+180}{BlockCellSize_i} - xblock \times BlockRow_i$$
$$ypixel = (\text{int})\frac{L+90}{BlockCellSize_i} - yblock \times BlockColumn_i$$

Once the global quad tree is built, each cell in a layer corresponds to a certain longitude and latitude degree. If we need to add new data into it, we only need to update the node of quad tree; the structure of quad tree doesn't need to be modified. We can conclude that the tree structure has superiority in such aspects:

1) Data redundancy is greatly avoided
2) The visualization is simplified and the computer resource is saved.
3) All the data can be partitioned according to the longitude and latitude. So it can be easily accessed
4) It is good in expanding; you can add the higher resolution data as you want without the quad tree structure altered.

3. DEM COMPRESSION METHOD

The DEM data in global region has huge data amount, which brings great challenge to DEM storage, transmission and real-time rendering. Therefore how to compress and simplify DEM data is one of the key techniques.

At present the DEM compression method mainly includes converting grid structure to tin structure, entropy encode method, and mature image compression method [7].

Nowadays the wavelet transformation has been successfully adapted in the video and image compression. SPIHT encode method is the improved method based on EZW encode method. It can generate an embedded bit stream, and when receiving the bit stream it can break the received bit stream at any time for reconstruction. So it has good progressive transmission character.

This paper introduces an improved SPIHT encode method, it firstly evaluate the terrain surface complexity, and then calculate the bit rate of the encoding process according to the terrain surface complexity and terrain scale. So the terrain data in different complexity can be compressed effectively.

3.1 The relationship between wavelet compression and terrain surface complexity in visualization

The mathematic mechanism of DEM compression mainly includes the two points:

The first point is that the information of origin data exists big redundancy. For example the DEM data has elevation relativity in the adjacent grids. The information redundancy will generate extra coding. If we get rid of this redundant information the space take up by information will be reduced [8].

The second point is that DEM in very high precision is not necessary in some application area. For example in DEM visualization human eye is the information receiver, it cannot perceive the tiny hypsography. So in high compression ratio the decompressed DEM data still obtains satisfactory subjective quality.

Wavelet method is effective in removing data spatial relativity. After wavelet transformation the data amount is the same. But the information energy is reallocated. Above 95% of energy centralize in the low frequency part; it describes the rough sketch of the terrain surface. Other high frequency parts describe the detailed component of the terrain surface. The principle of wavelet compression is to adopt approximate coefficient in low sampling rate and some approximate coefficient which we are interested to approach the origin terrain data. If we obtain more approximate coefficients, the distortion of decompressed data is low, but the compression ratio is low; if we obtain less approximate coefficients, the compression ratio is high, but the distortion of decompressed data is high. How to balance the compression ratio and the decompressed data quality is what we should research.

In the research we can find that when the DEM region is flat, the energy of the detailed component of the terrain surface is low, and we can adopt higher compression radio in the wavelet coding method with relative small distortion; and when the terrain surface is mountainous and fragmentized, if we adopt the same compression ratio as the flat region, the distortion will be huge.

So we can draw the conclusion that before the wavelet encoding we need to evaluate the terrain surface complexity and then decide what compression ratio to adopt.

3.2 The way to calculate terrain surface complexity in visualization

Evans described the terrain coarseness degree in 1998: coarseness and undulation of earth's surface reflects the degree of the terrain global undulation, local diversity and adjacent relativity in a special region.

The global undulation and local diversity can be seen as the coefficients of the high frequency parts in different scale. We can take the high frequency coefficients as a reference of the terrain surface complexity.

In the terrain visualization we can find that when the view point of the user grows higher, the terrain scale we saw will become bigger, and the terrain in the study region will become "flat". So we can conclude that the terrain surface complexity is relevant with the terrain scale, when the terrain scale become large the terrain surface "seems" to become flat.

Figure 3. The relation between flight height and terrain scale [Reddy 99]

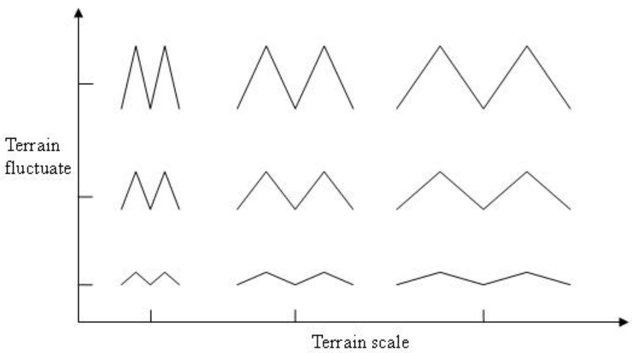


Figure 4. the relation between terrain surface complexity and terrain scale

We use (f_1^1, f_1^2, f_1^3,…, f_j^1, f_j^2, f_j^3,…, f_M^1, f_M^2, f_M^3) as a eigenvector to present the terrain surface complexity. M represents the maximum level number of wavelet decomposition. And f_j^1 , f_j^2 , f_j^3 represent the sum of coefficients in LHj, HLj, HHj. Then we adopt the formula to calculate terrain surface complexity:

$$R = \left\{ \sum_{j=1}^{M} \left[(f_j^1 + f_j^2 + f_j^3) / 2^j \right] \right\} / M$$

3.3 The improved SPIHT coding method adopted

Set Partitioning in Hierarchical Trees (SPIHT) compression algorithm is promoted by Said and Pearlman in 1996. It is an improved method of EZW. The data structures and coding blocks used by SPIHT are wavelet coefficients grouped into trees. SPIHT provides a progressive ordering of data that enables us to determine which data are most important to the DEM quality.

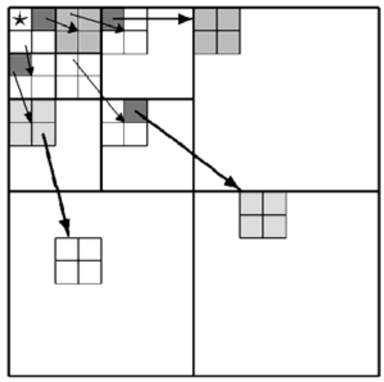


Figure 5. The zero-tree structure in SPIHT algorithm

In this paper we make some improvements on SPIHT algorithm according to terrain surface complexity, and adopt it as the compression method in this paper.

The following sets can represent the corresponding tree representations:
O(i,j) is the set of coordinates of all offspring of node (i,j)
D(i,j) is the set of all coordinates that are descendants (all nodes that are below) of the node (i,j)
L(i,j) is the set of all coordinates that are descendants but not offspring of node (i,j)

The following are the lists that will be used to keep track of important pixels:

LIS: List of Insignificant Sets, this list is one that shows us that we are saving work by not accounting for all coordinates but just the relative ones.

LIP: List of Insignificant Pixels, this list keeps track of pixels to be evaluated

LSP: List of significant Pixels, this list keeps track of pixels already evaluated and need not be evaluated again.

A general procedure for the code is as follows:

1. Initialization: threshold $T=2^n$, $n = \left\lfloor \log_2(\max_{(i,j)}\{|C_{i,j}|\}) \right\rfloor$
LSP is empty; add starting root coordinates to LIP and LIS.

2. Sorting pass: (new n value)
① for entries in LIP: (Stop if the rest are all going to be insignificant)
- decide if it is significant and output the decision result
- if it is significant, move the coordinate to LSP and output sign of the coordinate
② for entries in LIS: (Stop if the rest are all going to be

insignificant)
IF THE ENTRY IN LIS REPRESENTS D(i,j) (every thing below node on tree)
- decide if there will be any more significant pixels further down the tree and output the decision result
- if it is significant, decide if all of its four children (O(i,j)) are significant and output decision results
*if significant, add it to LSP, and output sign
*if insignificant, add it to LIP
IF THE ENTRY IN LIS REPRESENTS L(i,j) (not children but all others)
- decide if there will be any more significant pixels in L(i,j) further down the tree and output the decision result
- if there will be one, add each child to LIS of type D(i,j) and remove it from LIS

3. Refinement Pass: (all values in LSP are now $2n \le |c_{i,j}|$)
For all pixels in LSP, output the nth most significant bit

4. Quantization-step Update: decrement n by 1 and do another pass at step 2.

In the procedure above, each judgement generates an output sign, and put it in the output bit stream. We can directly adjust the length of the output bit stream to control the compression ratio of terrain data. We use the formula below:

$$lTotalBits = nXDim \times nYDim \times BitRate$$

lTotalBits: The length of current output stream (unit: bit)
nXDim: the column number of the image pixels
nYDim: the row number of the image pixels
Bitrate: controls the compression ratio.

In this paper, bit rate is proportional to terrain surface complexity (R), and is inversely proportional to terrain scale.

So we add the step of terrain surface complexity calculation into the code procedure. The bit rate parameter direct ratios the terrain surface complexity (R). And the improved SPIHT coding method for DEM is as the figure below.

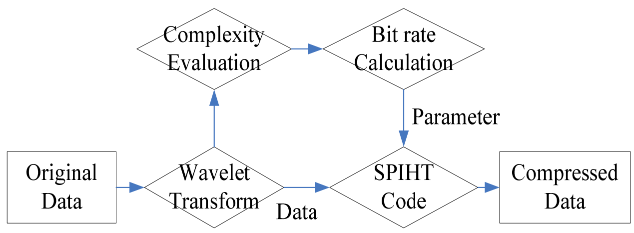


Figure 6. Improved SPIHT coding method for terrain compression

In the improved coding method, three levels of HAAR wavelet transform is adopted, then high frequency coefficients calculation and terrain complexity evaluation are proceeded. At last SPIHT code is carried through using the coefficients of the transformed data and bit rate generated in the complexity evaluation. The experiments of compression are in section 5.

4. EXPERIMENTAL RESULTS

In this section some experiments are carried out for the improved SPIHT compression method.

Three types of terrain data are used for experiment, which are in high undulation, middle undulation and low undulation areas.

And their compression results are shown in Figure 11. The x axis represents the bit rate adopted in the SPIHT encode. The higher the bit rate is, the lower the compression ratio is. And the y axis represents PNSR index after compressed. The higher PNSR is, the compressed data has finer fidelity .We can find that the low undulation area can also receive high PNSR using small bit rate, but the high undulation area need a big bit rate to receive satisfied compression quality.

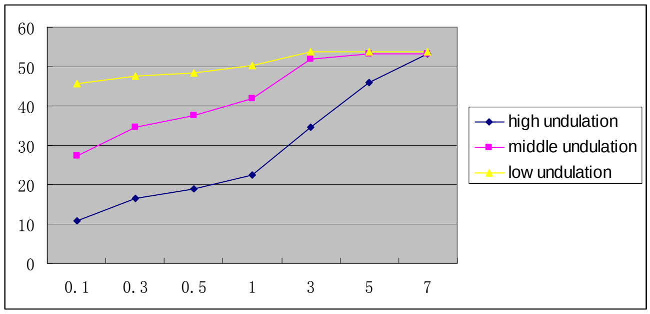
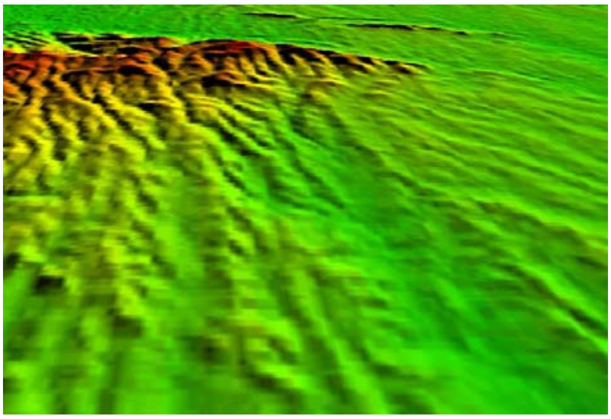


Figure 7. The relationship between PNSR and bit rate for three kinds of terrain area

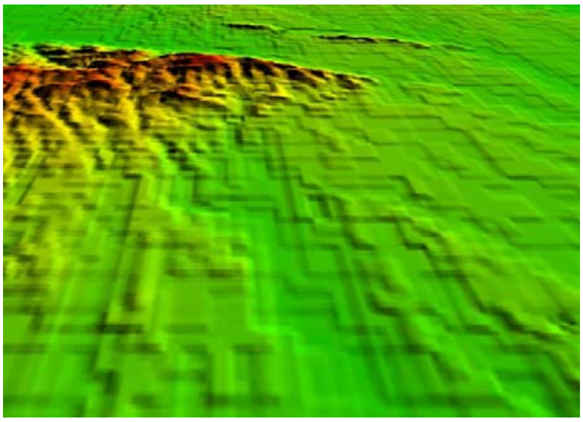
The compression results using the improved SPIHT coding method are shown in the figures below. In the flat area the bit rate calculated by the terrain surface complexity and terrain scale is 0.3, and we can find that when the bit rate adopts 0.3, the flat area can get an acceptable the compression result. (as shown in Figure 12).

In the mountainous area the bit rate calculated by the terrain surface complexity is 1.1, and the compression result is shown in Figure 13. But if we use the bit rate 0.3 to compress a mountainous area. The compressed terrain will degenerate severely.

We use the techniques adopted in this paper to realize global visualization The interface pictures of the global terrain visualization system are shown in Figure 14. We can find that these techniques can perform well.

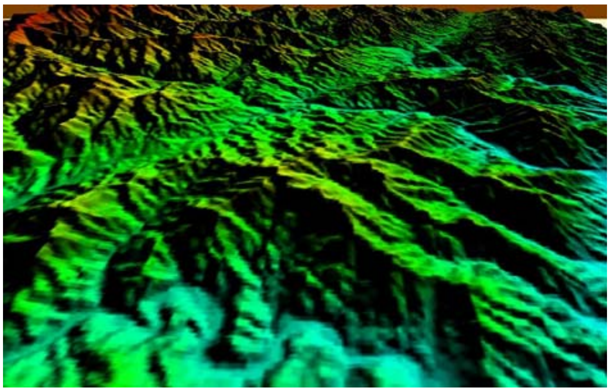


Original terrain

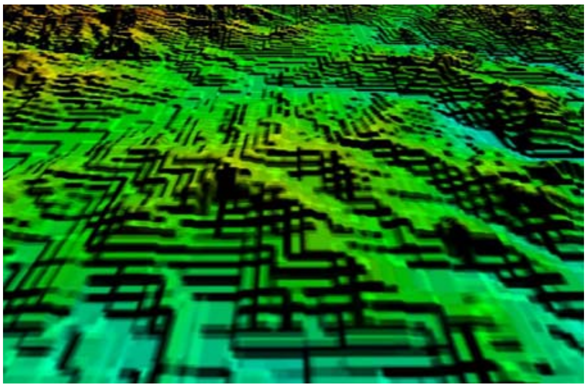


Compressed terrain (Bit Rate=0.3,PNSR=34.7)

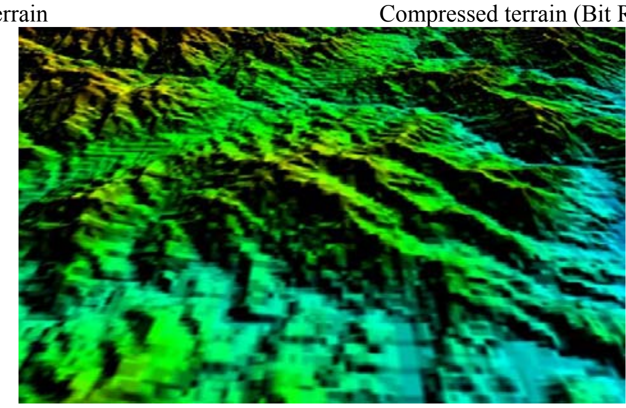
Figure 8. Flat area



Original terrain

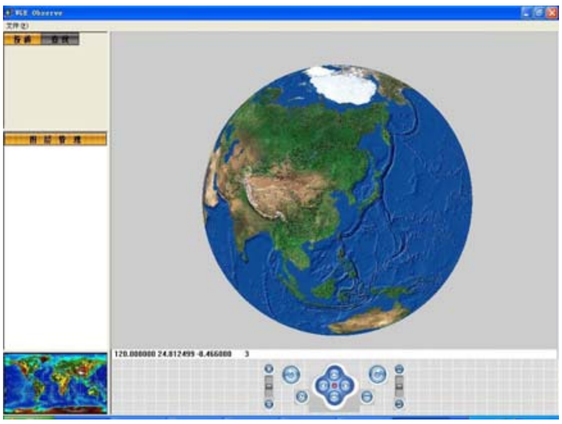


Compressed terrain (Bit Rate=0.3, PNSR=16.4)



Compressed terrain (Bit Rate=1.1, PNSR=22.38)

Figure 9. Mountainous area



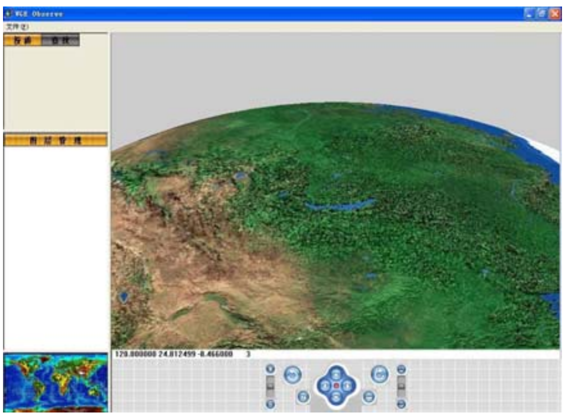


Figure 10. The global interface

5. CONCLUSIONS

In the geographic visualization visual fidelity and system efficiency are always in a dilemma. In the situation which our computer resource is limited what we should research is how to balance the visual fidelity and system efficiency.

This paper makes some probing research on this problem. And some of the key techniques in the global terrain visualization are introduced. For example, the simplified global terrain data partition and organizing method, and the improved SPHIT wavelet compression method considering the terrain surface complexity.

In the following work more deep research should be done on more available methods to calculate terrain surface complexity and better evaluation of visualization demand.

ACKNOWLEDGEMENTS

This research is partially supported by the Key Knowledge Innovative Sub-Project of Chinese Academy of Sciences (Kzcx2-yw-126-01), National High-tech R&D Program (863 Program) (2006AA12Z204), and National Basic Research Program of China, 973 Program, No. 2007CB714402.

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