Geographical Spatio-Temporal Hierarchical System and Digital Earth

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ABSTRACT Starting with the process of building the model of Regional Geosystem, the measures of geographical spatio-temporal changes—*spatial scale* and *frequentness of geographical event changing* were discussed. As a foundation of realizing integration of spatial data, Geographical Spatio-Temporal Hierarchical System (GSTHS), which is a dynamic representation pattern for spatio-temporal changes of geographical phenomena, was built. Finally, how to use GSTHS to design the user interface of Digital Earth was discussed.
KEYWORDS Digital Earth, GSTHS, Regional Geosystem, scale, frequentness, Spatial Field, Temporal Field

1. Introduction

The foundation of realizing Digital Earth [1] is integration of huge amount of spatial data with multi-source and multi-scale.There are two ways to integrate spatial data. One is called as the horizontal integration, which has been widely applied to current GISs technical platform; the other is vertical integration, which involves in the integration of spatial data with multi-source and multi-scale. As for the vertical integration with multi-source, there have been some mature technical methods that can be used and have already been combined with some Remote Sensing Image Processing Systems (RSIPSs). The vertical integration with multi-scale, however, is still in a research stage.

At present, the database models in GISs have been studied deeply, especially the entity-relational (E-R) model has been widely applied to the current database constructing. But how to describe the relationships among entities, it is still a problem now; although the objected-oriented method has been used to solve the problem, the relationships to be described are often simple and specific. The constructing of Digital Earth needs to study the general relationships among the components of Earth system, which disclose the spatial structure and dynamic mechanism of Earth system. Apparently, it needs multi-scale spatial data about the Earth to describe the general relationships. In order to realize a dynamic representation for spatio-temporal changes of the geographical phenomena that happen to the Earth, Geographical Spatio-Temporal Hierarchical System (GSTHS) should be set up based on the research on the general relationships. GSTHS is also a foundation for the vertical integration of spatial data with different scales.

Mr. Al Gore has pointed out that Digital Earth will include a "user interface"－Interface of visualization in three-dimension for browsing the Earth in multi-level resolutions. The designing of such a user interface refers to the GSTHS. The GSTHS can help Digital Earth to effectively achieve the dynamic monitor and modeling analysis of spatial events' changes at local, regional, national or global levels.

GSTHS should be developed through deeply researching on the essential methodology of geography. Geographical regionali-zation is regarded as a basic method to research into areal differentiation laws on the Earth surface. The application of regionalization will produce a hierarchical system of geographical regionalization. The hierarchical order of regionallized units is showed in table 1.

Geosystem, which consists of the different hierarchical subsystems, is a open system, there are the movement and transformation of material, energy and information not only in the inner of Geosystem but also between the Geosystem and its environment. What is emphasized in geography is that geographical regions as parts of geographical environment should be regarded as the beginning to study geographical environment. From this viewpoint, the geographical regions are direct objects studied by geography. A Geosystem of one region—Regional Geosystem should be set up in order to study systematically the geographical region. Regional Geosystem is the paradigm of researching into the Earth surface in modern geography[2], and is constructed based on the hierarchical system of geographical regionalization.

Table 1 The hierarchical series of geographical regionalization unit

High The hierarchical series of geographical regionalization unit	Geographic regionalization unit	Azonality unit	Continent Region Area Natural place	Complex
	Land type unit	Fundamen-tal unit	GSTHS Composite land type Complicated land type General land type Simple land type	
Low		Morpholo-gical unit	Land uint Land phase	Simple

Hierarchical structure is a concept on measure,

which is helpful to research into quantitative theory about nature. The structure theory of physical hierarchy includes the measure effect. If measure were not considered, unconditioned inference and unlimited extension would lead to theoretical fallacies[3]. Since Regional Geosystem is a hierarchical structural system, consequentially, it is also a measure concept, and includes measure effect on space and time, i.e., the *spatial scale* and the *frequentness of geographical event changing*. Therefore, the research on the process of building Regional Geosystem model will be helpful to promote the establishment of GSTHS.

Beginning with the research on the process of building Regional Geosystem model, the general relationships among the components of Earth system are discussed. On the basis of discussing the measures of geographical spatio-temporal changes—*spatial scale* and *frequentness of geographical event changing*, how to construct the GSTHS and how to use GSTHS to design a user interface of Digital Earth was discussed.

2. The Process of Building Regional Geosystem Model

noticed the significance of "Geosystem invariability" and its importance for analyzing Geosystem[4]. He proposed that the essential precondition to correctly understand the dynamic essence of Geosystem is the cognition for changeable and unchangeable basic units of Geosystem. Obviously, if we want to identify geographical laws from the regions, which are full of interactions among multiple geographical processes and has many affected factors with complicated relationships between each other, we should try to find out "entia" with "invariable" corresponding relations between space and process in geographical regions. The "entia" are the *land units*, which are the smallest spatial functional units resulted from landscape analysis. The unification of *research on the space and process* in modern geography is realized by the *land units*, which farthest assure the spatial "undivisiblity" and "homogenesis" of geographical processes that happen to them respectively. The *land units* are invariable basic units of Regional Geosystem and basic units to describe geographical landscape as well. Geographical landscapes are basic functional units in geographical regional analysis, therefore, they can be used as modules to assemble Regional Geosystem model according to time series of material and energy flows which happen to the region [2].Figure 1 shows how to build Regional Geosystem model.

According to figure 1, it is from foot to top to divide structural units with different hierarchical levels from geographical region to *land phases*. The *land phases* are the smallest *land units*, which possess fully unified geographical attributes and there already have been not any spatial meaning among them, they essentially act as the cartographic units.

Using different spatial scales to represent the structural units with different hierarchies, there is a relation as follows:

if Scale is regarded as spatial scale, then

Scale(for geographical region)< Scale(for geographical landscapes) < Scale(for land units) < Scale(for land phases)

Apparently, that dividing from foot to top discloses the changing of spatial scale during the process of building Regional Geosystem model.

Contrarily, it is from top to foot to construct spatial processes' models with different hierarchies from *land phases* to geographical region.

Using *frequentness* to describe the temporal change of spatial processes' models, there is a relation among the three kinds of spatial processes' models as follows:

If Frequentness^{-1} is represented as average temporal interval of geographical model running, then

Frequentness^{-1}(of Regional Geosystem model)> Frequent-ness^{-1}(of geographical landscapes' models)>Frequentness^{-1} (of land units ' models) >Frequentness^{-1} (of land phaces ' models)

Apparently, that constructing from top to foot discloses the temporal change during the process of building Regional Geosystem model.

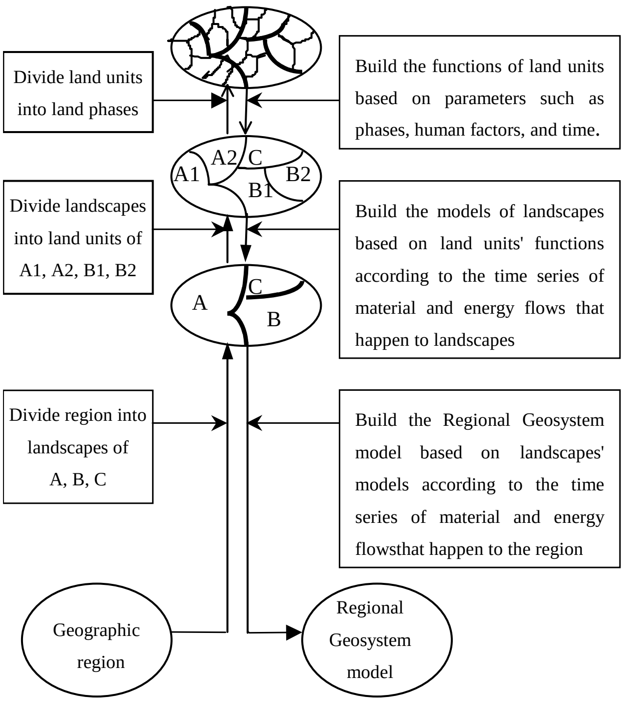

Fig. 1 Building Regional Geosystem model

3. The Measure of Geographical Space Changing—Spatial Scale

The research on geographical models is based on the geographical data with different spatial scales. The geographical data of a region with a certain scale, such as a geomorphic map with 1∶500000, represents not only the abstract and generalization of the regional spatial structure, but also the abstract and generalization of this regional functional mechanism under the specific scale. Such geographical data actually restricts the character of the geographical research what will be done on it. Therefore the geographical data with different spatial scales plays different model roles. Just in this sense, we consider that the spatial scale is a decisive factor to geographical research.

The research on the areal differentiation laws on the Earth surface is the fundamental task of physical geography. The areal differentiation laws can be divided into the fundamental and particular according to the spatial size controlled by them. The research on the fundamental laws of areal differentiation belongs to geographical "macroscopical" study, and furthermore the research on the particular laws of areal differentiation includes geographical "middlescopical" study and "microscopical" study. Table 2 shows the comparisons among three types of geographical research. From table 2, it can be seen that the geographical research possesses hierarchical character, one type of research should apply a suitable spatial scale.

4. The Measure of Geographical Time Changing —Frequentness

“Geography is a science which researches the complex relationships between human beings and geographical environment on space and time” (C. Harris, 1982). The geographical time is different from the time of sociology, history, physics, chemistry and so on. It is neither the same short as physical and chemical time, which may be a few hours, minutes or even shorter; nor the same as long as sociological and historical time, which may extend to the origin or far future of human society. Geographical time is a kind of "transect" cutting time measurement (“geographical time transect” for short); the transect has a certain thickness (periods) (R. Hart, 1959)[5].

Generally, Regional Geosystem consists of three subsystems with different hierarchical levels: human subsystem where human events mainly happen to, physical subsystem where physical events mainly take place and their combination — synthetic subsystem. During the running of physical subsystem, the scope of whether space affected or time continuance is generally larger than that during human subsystem running, and its form of expression is generally the slowly changing processes which happen to larger area. Such qualities of the physical subsystem control the characters of the physical events' occurrence, and make the range and frequentness of a physical event running become smaller. But, the physical event that breaks out suddenly, such as a natural disaster, is a exception, its scope is usually represented as a smaller area and a bursting process, and its range and frequentness are larger. During the running of human subsystem, the scope of whether space affected or time continuance is generally smaller than that during physical

Table 2. The comparisons among three types of geographical research

Research character	Research content	The scope of research object	The hierarchical level of structural unit of object	Spatial scale
Macroscopical	The latitudinal and non-latitudinal zonality	Continent	National	Greater than 1：500000
Middlescopical	The horizontal and altitudinal zonality	Region	Provincial	1：250000
Microscopical	Local morpho-feature and status change	Locality	County	Less than 1：50000

subsystem running, and its form of expression is generally the rapidly changing processes which happen to smaller area. Such qualities of the human subsystem control the characters of the human events' occurrence, and make the range and frequentness of human event running become larger. But, the human event that breaks out suddenly, such as a war, is a exception, its scope is usually represented as a larger area and a continual process, and its range and frequentness are smaller. The scope of synthetic subsystem is simultaneously affected by the two kinds of geographical systems above.

As discussed above, The frequentness of a physical event is smaller than that of a human event. Therefore, when some quantitative values on a physical or human geographical event need to be statistically calculated on a certain "geographical time transect", in general, the "thickness" of statistical time of the physical event is shorter compared with a human event. And even the "thickness" of some "geographical time transects" of some certain physical events, such as natural vegetation covering density and river cutting density, may be ignored, because of their long variation period. Conversely, the "thickness" of statistical time of the human event is generally longer, and even some certain human events perhaps need much more time in order to distinguish the temporarily fluctuation and specific trend.

Because the differences between the two kinds of frequentness lead to the change of "thickness" of two kinds of geographical events, the frequentness of geographical events changing can be taken as a measurement of the geographic time.

5. Build Geographical Spatio-Temporal Hierarchical System

In order to study the Geosystem, many kinds of conception models have been put forward, for examples, W. Weaver Model (1958)[6], S. Beer Model (1967)[7] , in which, S. Beer's "spatial resolution taper " is specially suitable for the research on Regional Geosystem.

S. Beer's Model asks to pay attention to the status of the studied objects in the hierarchical series when studying Geosystem. The status of spatial objects can help researchers to determine the spatial size, which is possibly involved when studying the objects, and what spatial scale should be applied. Furthermore, the status can help researchers to confirm the levels for the research on the geographical phenomena that happen to the objects, and the judging precision of the results. S. Beer's Model is a spatial hierarchical system based on geographical regionalization.

The structure of Regional Geosystem has been mainly considered as its spatial distributing structure for a long time. But figure 1 shows that the Regional Geosystem model should be built on the base of spatio-temporal structure associating with the mechanism of the flows of material and energy. When a model of Regional Geosystem has been built in a geographical region, any of the "spatio-temporal structure levels" with different hierarchies in the model not only reflects the spatial distributing pattern of the geographical event that happen to one level in that region, but also discloses the geographical dynamic mechanism of the geographical event that happen to that level.

AS discussed above, the measure of Regional Geosystem is considered as spatial scale and frequentness, so the measure effect of Regional Geosystem should include two kinds: the *Spatial*

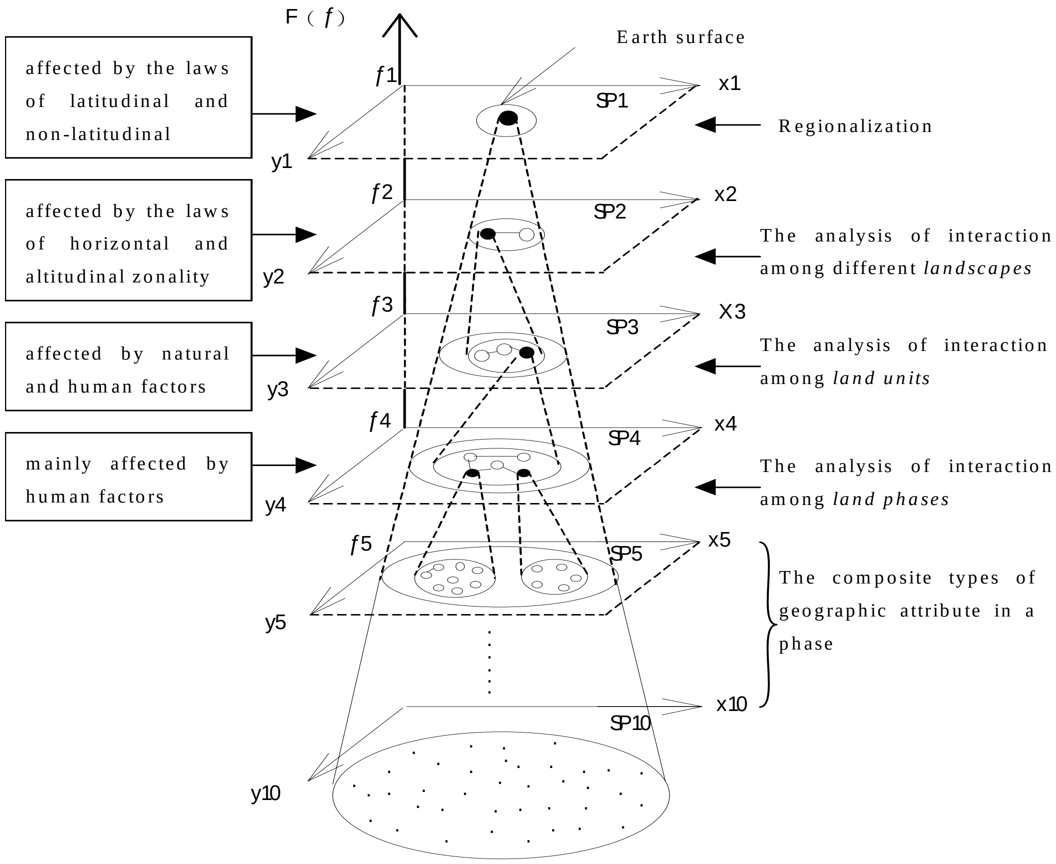

Fig. 3 Geographical Spatio-Temporal Hierarchical System

Field, and the *Temporal Field.* The *Spatial Field* is formed by the variation of spatial scales of different hierarchical levels in Regional Geosystem, that is S. Beer’s "spatial resolution taper". The *Temporal Field* is formed by the variation of frequentnesses of the geographical events that happen to each of the hierarchical levels in Regional Geosystem. *Spatial Field* reflects the spatial relationships of including and being included among structural units of different hierarchical levels in Regional Geosystem, while *Temporal Field* shows the relationships of control and feedback among geographical events that happen to each of the different hierarchical levels. Finally, *the Spatial Field and Temporal Field axis can construct Geographical Spatio-Temporal Hierarchical System* (figure 3).

In figure 3, F(f) is *Temporal Field* axis; $SP_{1,2,3\cdots\cdots10}$ are Spatial Planes which apply suitable spatial scales to represent the structural units of different hierarchical levels; small hollow or solid circles on spatial planes represent the structural units of different hierarchical levels. On the spatial planes of SP_2、SP_3 and SP_4, short lines represent interactions among different structural units, and all short lines on one spatial plane represent geographical dynamic mechanism of geographical event that happen to that spatial plane. From foot to top along *Temporal Field* axis, the values of frequentness and spatial scale vary from large too small. Here f_1、f_2、f_3 and f_4 compose the *Temporal Field* of Regional Geosystem, and SP_1、SP_2、SP_3……SP_{10} together compose the *Spatial Field* of Regional Geosystem.

On SP_1, the studied geographical region is divided from the Earth surface, as a part of the Earth surface, the region must be affected by the laws of latitudinal and non-latitudinal zonality. On SP_2, a region is divided into the different landscapes, which are controlled by the laws of horizontal and altitudinal zonality. On SP_3, a geographical landscape is divided into the different land units, which are affected by not only the natural but also the human factors. On SP_4, a land unit is divided into the land phases, which are mainly affected by human factors. From SP_5, the GSTHS steps into a stage of geographical attribute combination, on the spatial plains in that stage, there isn't conception of geographical event's process.

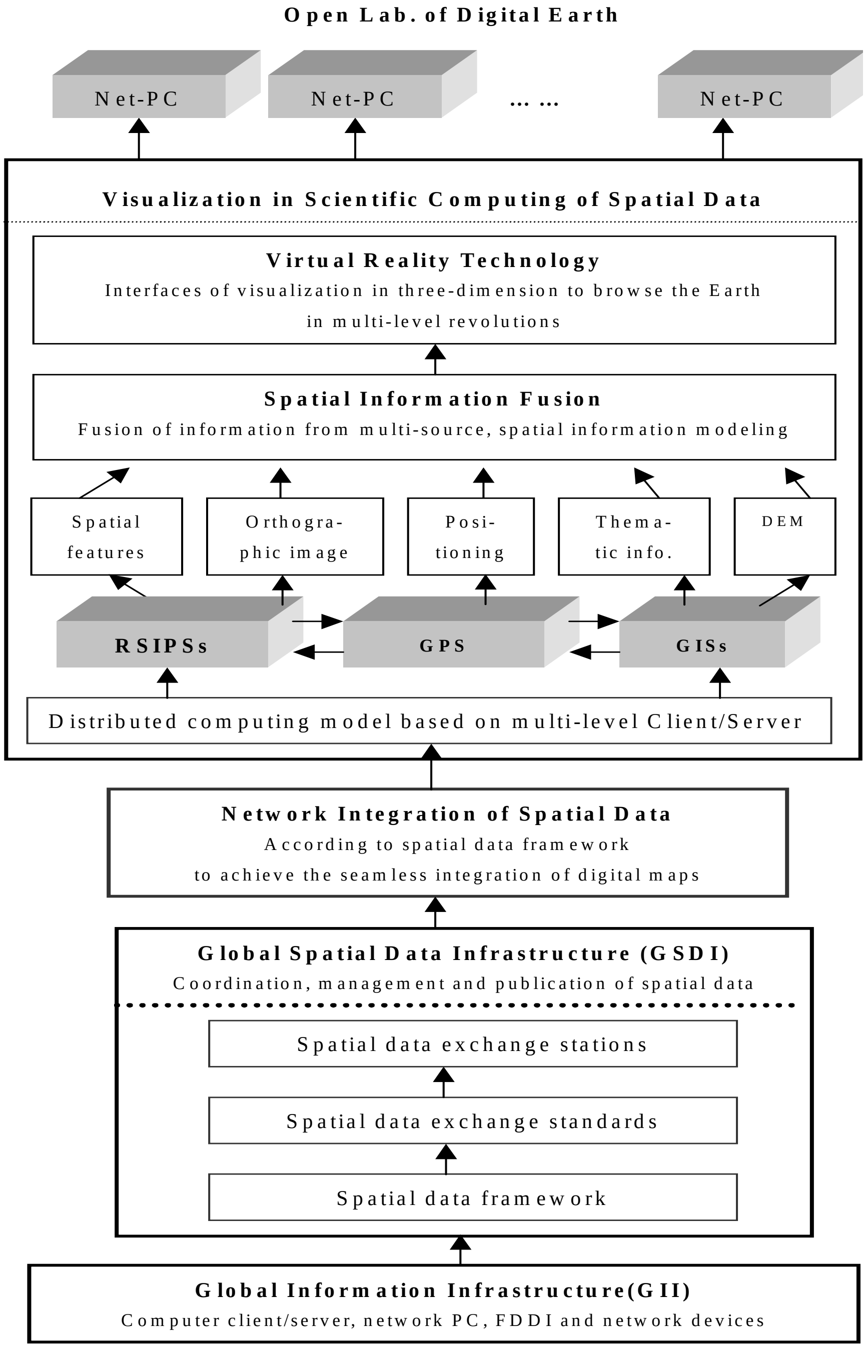

Figure 4. The structural system of Digital Earth

6. Using GSTHS to Dynamically Describe the Geographical Phenomena

Showed as figure 3, on SP_1, SP_2, the geographical events are mainly affected by the natural power. But on SP_3, not only the natural but also the human factors will affect the land units, so the land units are the ideal spatial measure for geographical research on the "man-land relationship".

According to the analysis above, it can be seen that the geographical research on Regional Geosystem supported by GSTHS has a hierarchical character. From the SP_5 to the lowest level SP_{10}, it is the stage to manipulate the geographical attribute data. From SP_4 to the highest level SP_1, it is the stage to carry out the research on geographical region. In addition, the hierarchical character of geographical research restricts the scope of the problem that can be solved by every spatial plane, and also brings up a standard of the precision assessing for research result given by every spatial plane. On SP_2, it can directly provide scientific basis for establishing provincial fundamental construction programming and some important indexes in the development of agricultural production by the research on the interactions among different landscapes. On SP_3, it can directly provide an overall production and construction programming for counties. On SP_4, the research on the land phases has more important significance, because it can directly provide the production programming of agriculture, forest, pasture, sideline and fishery, and farm fundamental construction programming for all villages and towns.

The GSTHS provides a dynamical representation model about the spatio-temporal changing of geographical phenomena for building Digital Earth. According to "the spatial resolution taper" of the GSTHS, any region on the Earth surface can be represented spatially as a group of structural unit series with different hierarchical levels, i.e., geographical region—geographical landscapes—land units—land phases—the combining types of geographic attributes. That series represent the vertically integrated relationships of including and being included spatially among geographical entities, and provide a organizing framework for designing the user interface of Digital Earth in order to browse spatial data under different spatial scales.

According to Temporal Field axis of the GSTHS, any geographical event on the Earth surface can be represented as a series of geographical processes with different hierarchical levels, i.e., geographical event—the spatial processes that happen to geographical landscapes—the spatial processes that happen to land units—the spatial functions that happen to land units. The series discover the relationships of controlling and being controlled of the geographical processes that occur on time series, and provide mechanism for Digital Earth to simulate the occurrence of geographical events.

7.Conclusion

The realization of Digital Earth needs four basic conditions at least: the first is *Global Information Infrastructure* (GII); the second is *Global Spatial Data Infrastructure* (GSDI); the third is *Netwsork Integration of Spatial Data*; the forth is *Visualization in Scientific Computing of Spatial Data*. The figure 4 shows the structural system of Digital Earth. As showed by Figure 4, apart from GII and GSDI, the foundation for realizing Digital Earth is the integration of huge amount of spatial data with multi-source and multi-scale.

From Figure 4, it can be seen that the realization of Digital Earth will ultimately provide a "data warehouse" that will have stored huge amount of Earth spatial data for human to study and protect her own beautiful home— the Earth. The *user interface* of Digital Earth will provide a means for human to enter the huge "data warehouse". The GSTHS provides a organizing framework of spatial data for *user interface* to realize the function of browsing spatial data under different spatial scales, and also provides mechanism for Digital Earth to simulate the occurrence of geographical processes. The research on the GSTHS belongs to the

application fundamental theory of geo-information science, its establishment will greatly promote the research on the integration of spatial data with different scales and the virtual study on the geographical events that happen on the Earth surface.

Digital Earth is constructed on the basis of the modern information technology such as the computer technology, communication technology, spatial technology and etc., so it is the integrator of many modern information technologies; and also its ultimate establishment must have the support of the fundamental theory of geo-information science. Undoubtedly, the research on Digital Earth will bring an information economic age of technological innovation for the fields being related with geoscience.

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