CALCULATING AND ANALYZING OF ECOSYSTEM SERVICE VALUE WITH BIG DATA BASED ON HIGH RESOLUTION LAND COVER INFORMATION

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ABSTRACT:

With the development of economics and society, the degradation of natural resources and environment is aggravated globally. The values of ecological environment and ecosystem service have been paid more and more attention popularly. However, the spatial-temporal changes in ecosystem service value (ESV) and their hotspots in China are not well understood. Chinese government has integrated the construction of ecological civilization into all aspects and processes of economic construction, political construction, culture construction and social construction, and clearly puts forward that we should establish the concept of natural value and natural capital, also natural ecosystem is valuable. During 2012 to 2021, an important project of China's First National Geographic Conditions Census and Continuously Monitoring had been completed by Chinese government. In this project, high resolution land cover product all over the country had been generated, and would be updated continuously every year. This achievement had received more and more attention, which brought the possibility of big data computing. A calculating method of land's ecosystem service value was proposed by using this achievement. The characters of data type, data time phase, and data structure for all the remote sensing information was analyzed. Based on this, a revised ecosystem service value assessment model was used for calculating. Combining the standard of terrestrial ecosystem in China and the equivalent value factor per unit ecosystem area, the specific calculating algorithm based on the big data was designed. Wuhan city, Hubei province, China was selected as the study area for validating the calculating method. The results showed that the total ecosystem service value in Wuhan city in 2015 was 9.42×10^{10} CNY, and the per capita ecosystem service value was 1.15×10^{4} CNY. Specially, water supplied the most ecosystem service value which accounted for 79.95%, followed by forest, grassland, farmland, and desert. The research shows that high-precision quantification and spatialization ecosystem service value can be calculated and obtained by using the high resolution land cover product obtained in the project of China's First National Geographic Conditions Census and Continuously Monitoring; the independent research and development software has solved the problem of software requirements, and the operational efficiency and performance can meet the calculating needs; the big data calculating algorithm has solved the problems of design and computation of structured and unstructured big data computing models; The results of this study will help to maintain the sustainable development of an area, and supporting more effective decision-making around the implementation of ecological conservation policies.

1. INTRODUCTION

Ecosystem services are of immeasurable value and are strongly connected to human health by preserving human productivity and quality of life, which also protects human well-being (Costanza, 2000). The importance of the ecosystem services has stimulated considerable interest in their conservation. Ever since 90’s of last century, after ecosystem services classification and monetary value of service value were proposed by Costanza (Costanza et al., 1997), the evaluating principles and methods of ecosystem service value had been clarified, the proposed algorithm had also been widely used in all kinds of ESV evaluation and had gotten some research achievements. ESV was an indicator of the ecosystem service value which could reflect the status quo of the ecosystem. Assessment of ESV was able to identify the spatial-temporal variations in ESV and assist investigator research on how ESV is affected by human living. At the same time, the quantitative evaluation model of ESV has also become a research hotspot in recent years (Li et al., 2014). The body of research on methods of estimating, mapping, and quantifying ecosystem services has grown exponentially (Fisher et al., 1997). Most research on the valuation of ecosystem services is focused on monetizing and estimating explicit ecosystem service value at a certain point in time (He et al., 2014). Xie G D, et al. evaluated ESV of 11 ecological service types provided in 2010 mainly used the method of unit area ecosystem value equivalent factor, based on the principle of labor value theory, and obtained various ESV’s total amount in China (Xie et al., 2015). Jiang C H, et al. modified Costanza’s model on two dimensions, which were the degree of vegetation flourishing and the effective time of vegetation providing ecological services. The ESV of Qinghai Lake basin in 2000 and 2012 were evaluated (Jiang et al., 2014). Li G Y, et al. took Yichun for example to carry out the ESV evaluation, and analyzed its relationship with the social and economic development (Li et al., 2018).

Due to the expanding human population (Vitousek et al., 1997), economic development and urban sprawl (Lambin et al., 2011), land cover and land change (Chen et al., 2014) have experienced enormous changes throughout the world during the last decades particularly from forests, savannas and other native landscapes to croplands, pasture-lands and built-up areas. The initiation of economic reforms in China in 1978 promoted rapid economic growth, urbanization and industrialization and transformed a population of 1.3 billion people from a largely agrarian society into an industrial economy (He et al., 2014). This rapid

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development had a significant influence on land use and cover changes and ESV changes (Liu et al., 2010).Recent literature has documented the negative effects (e.g., environmental pollution, soil erosion, natural disasters) on ecosystems that are associated with this rapid economic development (Diao et al., 2014, Liu et al., 2008). Relevant studies have focused on the dynamic changes in ESVs in China on regional, city or country scales (Fang et al., 2014, Xu et al., 2008, Li et al., 2010a, Li et al., 2007, Zhao et al., 2004).

The Millennium Ecosystem Assessment divided ecosystem services into 4 categories: provisioning services, regulating services, supporting services and culture services. And a number of second level types were divided based on these categories (Millennium Ecosystem Assessment, 2003). According to China's national conditions, Xie G D, et al. subdivided 11 second level types under the first level (Xie et al., 2015, Li et al., 2016). Based on the method of equivalent value per unit area, a national equivalent of the unit area's ecosystem service value was established (Xie et al., 2008).Remote sensing information is an important data source in the process of computing the ecosystem services value.

To improve human well-being and to change the deterioration of ecology and the environment, the Chinese government has implemented a number of national programs. By 2015, Chinese government had completed the project of China's First National Geographic Conditions Census, and had been updated continuously every year during 2016 to 2021. In this project, high resolution land cover product all over the country had been generated. High resolution land cover data all over China had been produced in the project based on remote sensing images better than 1 m spatial resolution. Besides, MODIS data has played an important role in resource, environment, and ecological aspects for its high temporal resolution and high spectral resolution.

A set of big data will be generated during the national land ESV calculation process, in order to solve the problem of big data calculating efficiency and performance, a method of big data calculating and analyzing of ESV was proposed based on multisource of remote sensing information, and a calculating software was developed to solve the big data computing challenges.

2. DATA DESCRIPTION

2.1 Land Cover Data

In the project of China's First National Geographic Conditions Census and Continuously Monitoring, high resolution land cover data was generated, which could reflect the natural and human geography spatial distribution. The natural resources of cultivated land, garden plot, forest land, grassland, water, and so on, were all obtained. 10 classes of level I were defined as the land cover classification system, which were cultivated land, garden plot, forest land, grassland, building construction, road, structure, artificial stack land, bare land and water; and 79 classes of level III were defined in detail (Leading Group Office of China's first National Geographic Conditions Census of the State Council, 2013).

The land cover product was vector spatial data format, and the total pattern quantity reached hundreds of millions. When it participated in calculation, for the convenience of calculation, the vector spatial data was rasterized, and the grid size was defined as 5m*5m, which could maintain the data's detail as much as possible.

The inputting data included rasterized land cover data (16 bit, signed integer), the land maximum enhanced vegetation index (EVI) data (16 bit, signed integer), the land Net Primary Productivity (NPP) data (32 bit, float), and the vegetation growing season data (32 bit, float). The outputting data and structure types included: provisioning services, regulating services, supporting services and culture services of individual ESV data, and the total ESV data, which were all 32 bit float. The amount of data of one edition reached 10 TB, and increased on this scale in the following monitoring year, which formed a scale of big data.

Based on the standard of "classification system of terrestrial ecosystems in China", the terrestrial ecosystems in China were divided into 6 classes of level I, which were farmland, forest, grassland, wetland, desert and water. The transformation and expression relationship of classification systems needed to be built during the calculation.

2.2 EVI Data

Considering of the spatial heterogeneity of the same ecosystem service, vegetation's flourishing degree and the time of vegetation provide effective ecological services in the ESV calculation, besides in order to reflect the earth's surface nature state in the same period with the unified time of project of China's First National Geographic Conditions Census, MODIS dataset was obtained (https://modis.gsfc.nasa.gov/) and used. EVI is improved by normalized vegetation index (NDVI). It is calculated from the red, blue and near-infrared bands. The standard MOD13Q1 product of MODIS dataset contains EVI dataset, which can reflect vegetation's growing status and seasonal and interannual variations features.

2.3 Equivalents data

The data of equivalents of per unit area of ecosystem is a kind of survey and statistical data. The standard value equivalent of ecosystem service function is the annual average value equivalent of all kinds of ecosystem service functions on unit area of different types of ecosystems, which reflects the annual average value of different ecosystems and their ecosystem services in the whole country. In the ESV calculation, the equivalents data defined by Xie G D, Li G Y, et al. were quoted as the standard value equivalent of ecosystem service, which includes provisioning services, regulating services, supporting services and culture services of farmland, forest, grass land, wetland, desert and water (Xie et al., 2015, Li et al., 2016).

3. METHOD

3.1 Calculating Method

The calculating method was proposed based on previous studies. The purpose of leading EVI, NPP and vegetation growing season data into calculation was to modify the ESV to reflect the spatial heterogeneity of the same ecosystem service more accurately. On the basis of multi-source remote sensing information and equivalents of ESV supplied by per unit area of ecosystem, the 4 individual ESV of provisioning services, regulating services, supporting services and culture services for every grid were calculated; also the total ESV was calculated. The formulas for calculating the ESV of every grid were as follows.

$$\mathrm{V_{ig}} = \mathrm{S_i} \times \mathrm{m\_G} \times \mathrm{H_n} \times \frac{\mathrm{m\_NPP_i}}{\mathrm{m\_NPP'}} \tag{1}$$

$$\mathrm{V_{it}} = \mathrm{S_i} \times \mathrm{m\_T} \times \mathrm{H_n} \times \frac{\mathrm{m\_GS_i}}{\mathrm{m\_GS'}} \times \frac{\mathrm{m\_EVI_i}}{\mathrm{m\_EVI'}} \tag{2}$$

$$\mathrm{V_{iz}} = \mathrm{S_i} \times \mathrm{m\_Z} \times \mathrm{H_n} \times \frac{\mathrm{m\_EVI_i}}{\mathrm{m\_EVI'}} \tag{3}$$

$$\mathrm{V_{iw}} = \mathrm{S_i} \times \mathrm{m\_W} \times \mathrm{H_n} \times \frac{\mathrm{m\_GS_i}}{\mathrm{m\_GS'}} \tag{4}$$

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where S_i stands for the grid's area; m_G, m_T, m_Z, m_W stand for the equivalents of provisioning service value, regulating service value, supporting service value and culture service value respectively; H_n stands for the economic value of the equivalents of ESV supplied by per unit area of ecosystem; m_NPP_i stands for the NPP of the specific land cover types of farmland, forest and grassland; m_NPP′ stands for the average NPP of the specific land cover types of farmland, forest and grassland; m_EVI_i stands for the EVI of the specific land cover types of farmland, forest and grassland; m_EVI′ stands for the average EVI of the specific land cover types of farmland, forest and grassland; m_GS_i stands for the vegetation growing season of the specific land cover types of farmland, forest and grassland; m_GS′ stands for the average vegetation growing season of the specific land cover types of farmland, forest and grassland.

The formula for calculating the total ESV of every grid:

$$V_i = V_{ig} + V_{it} + V_{iz} + V_{iw} \tag{5}$$

where V_i stands for the total ESV of grid i; V_{ig}, V_{it}, V_{iz}, V_{iw} stand for the provisioning service value, regulating service value, supporting service value and culture service value respectively.

3.2 Big Data Computing Model

As mentioned above, big data would be formed during the calculation. So computing model needs to ensure that the big data's inputting and reading are correct, computing memory doesn't overflow, the calculated results of 4 individual ESV and the total ESV can be output simultaneously for same calculation unit, and the batch process is normally running.

Considering the commercial software is difficult to meet the computing demand, ESV assessment software was independent researched and developed based on the theory of raster spatial analysis, which realized the functions of organization structure, function distribution, data interface (Li et al., 2008), operation and error handling, and so on. This software had solved the technical problems of the land ESV calculation process, and improved the data calculation speed, efficiency and quality. Computing model of big data had solved several important technical issues, including ensuring the computing performance, batch processing to improve computing efficiency and solving the problem of integrated inputting and simultaneous outputting for the multi-source data in same calculation unit.

4. DISCUSSION

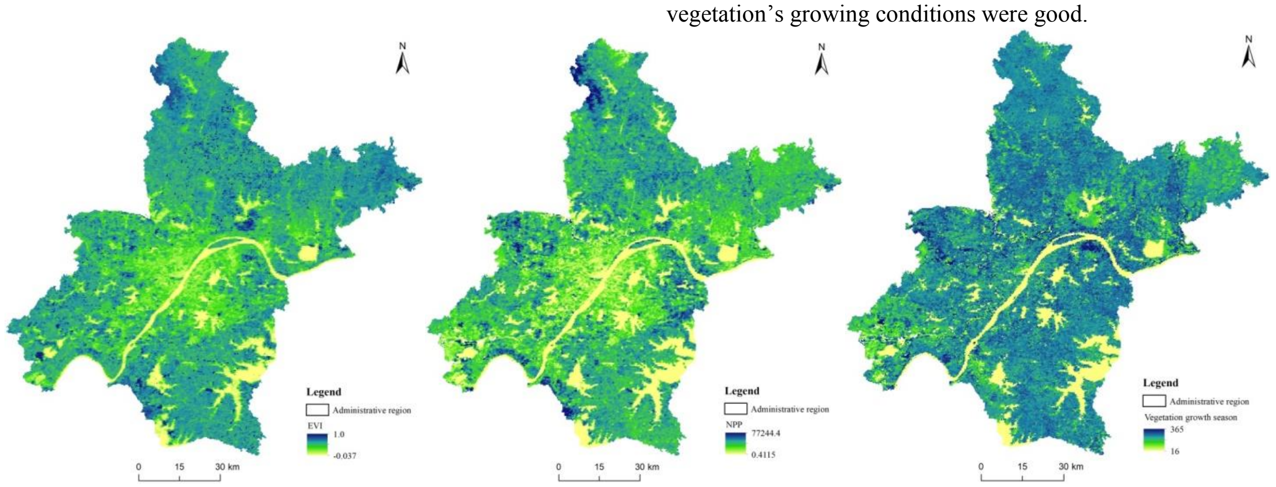
4.1 Study Area

Wuhan city locates in the east of Hubei province, China between 113°41′ and 115°05′ E longitude and 29°58′ - 31°22′ N latitude. According to the administrative divisions of the People's Republic of China 2015, Wuhan city's area is 8483 km^2, and the population is 8.21 million (Ministry of Civil Affairs of the People's Republic of China, 2015). Wuhan city is located in the mid latitude region, which is the subtropical monsoon climate region. With the wide distribution of river system and abundant rainfall, the water resource is very abundant. 13 districts locate in Wuhan city, which are Jiangan district, Jianghan district, Qiaokou district, Hanyang district, Wuchang district, Qingshan district, Hongshan district, Dongxihu district, Hannan district, Caidian district, Jiangxia district, Huangpi district, and Xinzhou district, as shown in Figure 1.

Figure 1. Study area

4.2 EVI, NPP and Growing Season

The MODIS data had been pre-processed, ant the vegetation's maximum EVI, NPP and growing season spatial pattern in the study area in 2015 are shown in Figure 2, which are clipped from the national range. The maximum EVI value in the study area was at a high level, the maximum NPP value reached 77244.4 g.C/m^2, and the value range of vegetation growing season was from 16 to 365. The data indicated that the vegetation's growing conditions were good.



(**a**) EVI (**b**) NPP (**c**) Vegetation growing season

Figure 2. Spatial patterns of vegetation's EVI, NPP and growing season

4.3 Calculating Result

Big data calculating was carried out based on the evaluation method of ESV, and the result of study area is shown in Figure 3.

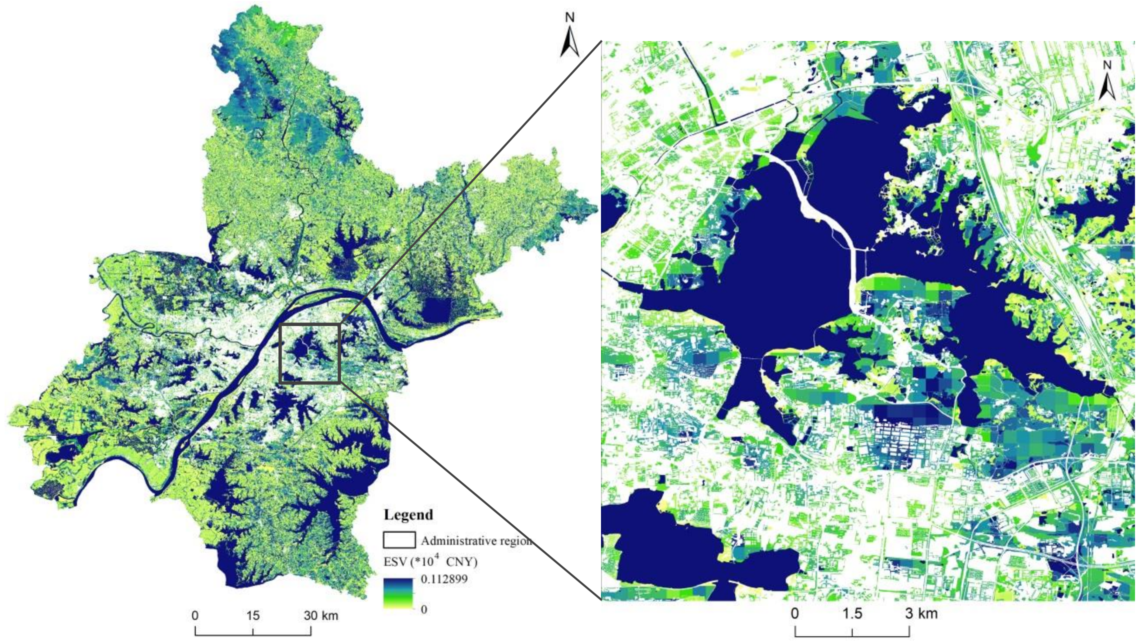


Figure 3. Spatial patterns of ESV and local enlargement (5m*5m grid)

Based on numerical statistics and analysis, the total ESV, provisioning service value, regulating service value, supporting service value, and culture service value from the view of ecosystem service types ware obtained as shown in Table 1.

Administrative division	Population ($\times10^4$)	Area (km^2)	Total values ($\times10^8$ CNY)	Per capita ($\times10^4$ CNY)	Unit area ($\times10^4$ CNY /hm^2)	Provisioning value ($\times10^8$ CNY)	Regulating value ($\times10^8$ CNY)	Supporting value ($\times10^8$ CNY)	Culture value ($\times10^8$ CNY)
Jiangan district	69	64	5.85	0.08	9.15	0.42	5.02	0.28	0.13
Jianghan district	48	33	0.70	0.01	2.11	0.05	0.58	0.04	0.02
Qiaokou district	53	46	1.13	0.02	2.46	0.08	0.95	0.07	0.03
Hanyang district	53	108	11.31	0.21	10.47	0.82	9.80	0.47	0.21
Wuchang district	114	81	13.62	0.12	16.82	1.00	11.90	0.48	0.25
Qingshan district	45	45	3.24	0.07	7.20	0.23	2.78	0.16	0.07
Hongshan district	78	509	72.91	0.93	14.32	5.34	62.59	3.58	1.40
Dongxihu district	27	439	52.35	1.94	11.92	4.06	44.17	3.11	1.01
Hannan district	11	288	34.34	3.12	11.92	2.84	28.95	1.93	0.61
Caidian district	47	1094	123.31	2.62	11.27	8.87	104.81	7.28	2.36
Jiangxia district	70	2015	275.02	3.93	13.65	19.35	234.99	15.25	5.42
Huangpi district	111	2261	186.29	1.68	8.24	11.84	153.42	16.61	4.43
Xinzhou district	95	1500	161.86	1.70	10.79	11.80	136.16	10.69	3.21
Wuhan city	821	8483	941.93	1.15	11.10	66.71	796.13	59.95	19.15

Table 1. Statistical analysis results of ESV from the view of ecosystem service types

The statistical analysis results from the view of terrestrial ecosystems types, which included total ESV, farmland service value, forest service value, grassland service value, desert service value, and water service value respectively, were shown in Table 2.

Administrative division	Total values ($\times10^8$ CNY)	Farmland ($\times10^8$ CNY)	Forest ($\times10^8$ CNY)	Grassland ($\times10^8$ CNY)	Desert ($\times10^8$ CNY)	Water ($\times10^8$ CNY)
Jiangan district	5.85	0.02	0.48	0.27	0.00	5.08
Jianghan district	0.70	0.00	0.12	0.03	0.00	0.55
Qiaokou district	1.13	0.00	0.17	0.06	0.00	0.90
Hanyang district	11.31	0.04	0.51	0.32	0.00	10.44
Wuchang district	13.62	0.00	0.50	0.07	0.00	13.05
Qingshan district	3.24	0.00	0.28	0.09	0.00	2.87
Hongshan district	72.91	0.87	5.63	2.57	0.01	63.83
Dongxihu district	52.35	2.07	3.84	3.16	0.00	43.28
Hannan district	34.34	1.54	1.48	1.80	0.00	29.52
Caidian district	123.31	4.09	10.49	5.52	0.02	103.19
Jiangxia district	275.02	8.1	29.59	4.68	0.02	232.63
Huangpi district	186.29	10.1	40.75	16.18	0.02	119.24
Xinzhou district	161.86	6.64	17.18	9.52	0.05	128.47
Wuhan city	941.93	33.47	111.02	44.27	0.12	753.05

Table 2. Statistical analysis results of ESV from the view of terrestrial ecosystems types

According to Table 1, the total ESV value in Wuhan in 2015 was 9.42×10^{10} CNY, and the ESV value of unit area was 1.11×10^5 CNY /hm^2. In the 13 districts, Wuchang district's ESV of unit area was the highest, reached 1.68×10^5 CNY /hm^2, the largest contributor is water, accounted for 95.81% of the total; and the lowest area was Jianghan district, only 2.11×10^4 CNY /hm^2.

According to Table 1, from the view of ecosystem service types, regulating service value was the highest, reached 7.96×10^{10} CNY, accounted for 84.52% of the total ESV; followed by provisioning service value of 7.08% of the total ESV. The individual ESV took on the sequential characteristics of regulating service value, provisioning service value, supporting service value and culture service value.

According to Table 2, from the view of terrestrial ecosystems types, water ESV was the highest, reached 7.53×10^{10} CNY, accounted for 79.95% of the total ESV, this had a lot to do with the large area of water in Wuhan city; followed by forest ESV of 1.11×10^{10} CNY. The individual ESV took on the sequential characteristics of water, forest, grassland, farmland and desert.

Furtherly, according to Table 1, per capita amount of ESV in Wuhan city was 1.15×10^4 CNY; and according to the statistical data, the GDP was 1.09×10^{11} CNY in 2015, and per capita GDP was 1.33×10^5 CNY. The ratio of per capita GDP and per capita ESV was 1:0.09. The results showed that the value of ecosystem services in the study area was relative poorer than the social and economic value, which indicated that the local government need to pay more attention to the protection of the ecological environment while developing the social economy.

4.4 Calculating Efficiency

The processing efficiency is important for scientific computing algorithm for big data computing. Only when the processing efficiency reaches a certain level, the computation results can be obtained in finite time.

The independent developed calculating software had solved the big data computing challenges by using block algorithm for single big data and batching cycle processing algorithm for the whole big data. The area of Wuhan city is 8483 km^2, inputting data quantity is 11.3 GB, it took 34 minutes for data calculating by using single computer, and the computer's memory occupancy was about 258MB (computer system is Windows 7, 64 bit operation system, 32 GB memory, 1.9 GHz processor). Besides, the whole national terrestrial ESV was calculated in 6 days by using 5 computers and multi-thread practically, which could meet the computing needs.

5. CONCLUSIONS

Establishing and improving the value realization mechanism of ecological products is an important measure for Chinese people to implement the thought of ecological civilization, and is of great significance to promote the comprehensive green transformation of economic and social development.

With the development of remote sensing technology, many kinds of ESV calculation methods have been researched and been widely used in practical research. This work attempts to calculate the value of ecosystem services and do some basic work for the quantification of ecosystem service value and method system construction. The results show that it is meaningful.

Taking the opportunity of the results of China's First National Geographic Conditions Census and Continuously Monitoring, this paper uses the land cover results obtained from high-resolution remote sensing images to calculate the national high-precision ecosystem service value quantitative value, which provides a good case reference for the calculation of ecosystem service value.

At the same time, facing the problems of the current commercial software, which is limited in heterogeneous data input, difficult to realize batch processing mode in the calculation process, difficult to customize and output the calculation results, and cannot meet the needs of big data computing, it solves a series of related technical problems through independent research and development of software, so as to lay the foundation for big data computing. It also lays a foundation for the calculation of the follow-up update of continuously monitoring results.

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