Analysis on regional difference of meteorological S&T innovation capability in China

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Abstract. This paper selects the relevant meteorological data in 2014-2017 of the seven regions of Chinese mainland divided in accordance with the administrative area to construct the index system of meteorological S&T innovation capability, and then by means of Entropy TOPSIS method to get the values of $C_i$ of the seven regions, and finally calculates the coefficient of variation of those $C_i$ values based on the analysis of the meteorological S&T innovation capability, the innovation environment, the innovation input and output to analyze the developmental differences across regions. The results of this research prove that from 2014 to 2017, the meteorological S&T innovation ability of South China, North China and East China was relatively strong, while that of other regions was relatively weak. Besides, the meteorological S&T innovation ability of each region fluctuated in different years, but by 2017, the differences in innovation ability of meteorological S&T among regions were narrowing.

1. Introduction

Technological innovation, an evolving concept, is a process to create new values by applying scientific discoveries and technological inventions to production systems [1]. And meteorological S&T is a very important part of the scientific and technological innovation system. For example, the accuracy of meteorological forecasting directly affects the national ability to prevent and mitigate natural disasters, to deal with climate changes and to develop and utilize climate resources, greatly concerning national economic and social security as well as people’s health and standard of living. Meanwhile, every major advancement in meteorological undertakings is inseparable from the great discoveries of science and technology. Therefore, the forecast accuracy of meteorology is closely related to the progress and development of meteorological S&T. Research on meteorological S&T innovation is of great importance.

In recent years, numerous researches on regional innovation ability have been done by scholars at home and abroad with two main research approaches. The first is to establish an index system for evaluating regional innovation ability, and then adopt suitable methods to measure innovation ability and finally analyze the regional differences in innovation ability. For instance, Zhao S L, et al (2013) used AHP to analyze the innovation activities of governments, colleges, research institutions and companies [2]. Sleuwaegen L, et al(2014) took advantage of data of 2007, 2009 and 2011 and the recursive structural equation model to analyze the regional innovation capabilities of 83 EU countries [3]. Chen J, et al (2017) collected data of various provinces in China from 2000 to 2014 to calculate the index of regional ecological innovation by constructing the index system and adopting projection,
and analyzed the ecological innovation abilities of 31 provinces [4]. Zhang Aili, et al(2016) established a panel clustering model specific to the unbalanced development of regional innovation capability in China, and deeply analyzed the development differences in innovation ability of three categorical regions [5]. Wu Dan, et al(2018) constructed the DEA-Malmquist index model to analyze the time and space differences in national S&T innovation ability between China and other 10 countries [6].

In the field of meteorological S&T innovation, quite a few Chinese scholars have also conducted relevant researches from the perspectives of its policies and countermeasures. On the whole, many researches on innovation ability and S&T innovation ability done by Chinese domestic and overseas scholars are involved in numerous fields except the meteorological field. The scanty papers themed on meteorological S&T are mostly based on policies and recommendations. There haven’t enough or none papers analyzing regional innovation ability on the basis of data. Hence, a series of in-depth studies should be done on the levels and differences of regional meteorological S&T innovation ability in China. What’s more, most of the previous studies on regional differences are from the view of 31 Chinese provinces, autonomous regions, and municipalities directly under the central government because the results of analyzing that of individual province, autonomous region and municipality are scattered and insufficient. As we all known, China can be divided into seven major regions according to the geographic administrative areas. As a consequence, this paper combines the connotation of meteorological S&T with the statistical data to construct an index system for meteorological S&T innovation capability, and then analyze the meteorological S&T innovation capability of these seven regions by means of Entropy TOPSIS method, and finally put forward some related suggestions for the results.

2. Index system and data resource
With reference to the global innovation index, national innovation ability, urban innovation capability and other evaluation indicators, combined with the connotation of meteorological S&T innovation ability, considering the availability of data, this paper constructs the index system of meteorological S&T innovation ability, and finally forms three secondary indexes and nine indexes of the third level, which comprehensively covers various kinds of indexes, such as, the research funding, scientific and technological talents, dissertations, achievements, awards, the data volume of meteorological data sharing services, and the number of projects undertaken by the per capita. The specific index system is shown in table 1.

| Grade I Index | Grade II Indexes | Grade III Indexes |
|--------------|------------------|-------------------|
| S&T Innovation Environment | The proportion of the number of meteorological professionals in total employment personnel | The proportion of the number of talents in or above master’s degree in total employment personnel |
| Meteorological S&T Innovation Ability | The data volume of meteorological data sharing services | Ratio of meteorological S&T funds in GDP |
| S&T Innovation Input | Annual growth rate of meteorological S&T funds | The amount of scientific research funds owing by meteorological professionals |
| S&T Innovation Output | The number of SCI papers published by professionals per capital | The number of projects taken by professionals per capital |
|                   |                   | The number of awards won by professionals per capital |

Table 1. Index system of meteorological S&T innovation ability.
On account of the above index system, this paper selects the related data of 31 provinces, autonomous regions and municipalities directly under the central government in China for relevant analysis. And the data used in this study are derived from the China Meteorological Statistics Yearbook 2014-2017, China Statistical Yearbook and the 2017 Statistical Communiques on National Economic and Social Development of 31 provinces, autonomous regions and municipalities.

3. Theoretical model

TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution) was originally developed by C.L. Hwang and K. Yoon in 1981. Its basic principle is to sort by measuring the distance between the evaluation object and the optimal solution and the worst solution. If the evaluation object is closest to the optimal solution and farthest from the worst solution, it is the best; otherwise it is not optimal. In addition, adopting the TOPSIS method can make sure the chosen objects for research are obtained from statistical measurement data, avoiding the interference of subjective factors, and can objectively and comprehensively evaluate the chosen objects in the case of multiple indexes [7]. The basic steps are as follows:

1. Indicator evaluation: the comprehensive evaluation of m evaluation units and n indicators to construct decision matrix

   \[ A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mn} \end{bmatrix} m \times n \]  

2. Normalization: namely the dimensionless process of value A. Use the formula

   \[ b_{ij} = \frac{x_{ij} - \min x_i}{\max x_i - \min x_i} * 0.9 + 0.1 \]  

   to get

   \[ B = \begin{bmatrix} b_{11} & \cdots & b_{1n} \\ \vdots & \ddots & \vdots \\ b_{m1} & \cdots & b_{mn} \end{bmatrix} m \times n \]  

3. Giving weight with entropy weight method to each indicator, we can get the weight matrix \( W \), then the weighted normalization matrix \( T = WB \) is as follows

   \[ T = \begin{bmatrix} t_{11} & \cdots & t_{1n} \\ \vdots & \ddots & \vdots \\ t_{m1} & \cdots & t_{mn} \end{bmatrix} m \times n, \text{ where } t_{ij} = W_j b_{ij}, \ (i = 1,\ldots,m; j = 1,\ldots,n) \]  

4. Determining positive ideal solution \( T^+ \) and negative ideal solution \( T^- \)

   \[ T^+ = \{ t_{ij} | j = 1,\ldots,n \} = \{ \max t_{ij} | j = 1,\ldots,n \} \]  

   \[ T^- = \{ t_{ij} | j = 1,\ldots,n \} = \{ \min t_{ij} | j = 1,\ldots,n \} \]  

5. Calculate the distance between the evaluation units and positive ideal solution and negative ideal solution

   \[ D_i^+ = \sqrt{\sum_{j=1}^{n} (t_{ij} - t_{ij}^+)^2}, D_i^- = \sqrt{\sum_{j=1}^{n} (t_{ij} - t_{ij}^-)^2}, (i = 1,\ldots,m) \]  

6. Calculate the relative closeness degree between the evaluation units and the ideal solution

   \[ C_i = \frac{D_i^-}{D_i^+ + D_i^-} \ (i = 1,\ldots,m) \]  

The value of \( C_i \) is between \([0,1]\). The closer the value \( C_i \) of evaluation object is to 1, the closer it is to the optimal solution, which is at a higher level; the closer to 0, the farther it is to the optimal solution, which is at a lower level [6].

4. Empirical analysis

The mainland of China can be divided into seven major regions according to the geographical
administrative areas, namely, North China (Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia), Northeast China (Liaoning, Jilin, Heilongjiang), East China (Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shandong), Central China (Henan, Hubei, Hunan), South China (Guangdong, Guangxi, Hainan), Southwest China (Chongqing, Sichuan, Guizhou, Yunnan, Tibet), Northwest China (Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang). And we can calculate the values of $C_i$ of provinces, autonomous regions and municipalities by the way of Entropy TOPSIS method and average them to get the values of $C_i$ of the seven regions. With that, the values of $C_i$ of regional S&T innovation abilities, environment, input and output can also be calculated, and finally we can calculate the variation coefficient of $C_i$ for relevant analysis.

4.1. Regional meteorological S&T innovation ability

The measurement results of the meteorological S&T innovation ability are shown in Table 2.

| Regions            | 2014   | Ranking | 2015   | Ranking | 2016   | Ranking | 2017   | Ranking |
|--------------------|--------|---------|--------|---------|--------|---------|--------|---------|
| North China        | 0.2788 | 1       | 0.2287 | 5       | 0.2632 | 2       | 0.2761 | 1       |
| Northeast          | 0.2278 | 4       | 0.1414 | 7       | 0.2072 | 5       | 0.1940 | 6       |
| East China         | 0.2385 | 3       | 0.2620 | 2       | 0.2260 | 4       | 0.2166 | 3       |
| Central China      | 0.2179 | 5       | 0.1502 | 6       | 0.1211 | 7       | 0.1966 | 5       |
| South China        | 0.2489 | 2       | 0.2986 | 1       | 0.2837 | 1       | 0.2063 | 4       |
| Southwest          | 0.1727 | 6       | 0.2305 | 3       | 0.1622 | 6       | 0.2540 | 2       |
| Northwest          | 0.1649 | 7       | 0.2302 | 4       | 0.2402 | 3       | 0.1829 | 7       |

On account of the measurement results, the value of $C_i$ is used to describe the meteorological S&T capability of each region, which reflects their abilities on meteorological S&T. For example, in 2017, the $C_i$ value of meteorological S&T innovation ability in North China was 0.2761, ranking first; while the $C_i$ value in Northwest was 0.1829, ranking the last, which indicates the highest level of the meteorological S&T innovation ability in North China and lowest one in Northwest in 2017.

Based on the above results, it is easier to see that in terms of the time dimension, in 2014, meteorological S&T innovation ability was the strongest in North China and the weakest in Northwest. The strong ability of meteorological S&T innovation in Beijing and Tianjin was the main reason for North China ranking the first, which boosted the innovation capability of the entire region. However, except Shaanxi, the other provinces in the northwest region were all with weaker meteorological S&T innovation ability, especially Gansu in a countdown position all over the country. In 2015, the rankings of these regions changed slightly. Compared with that of 2014, the abilities in North China, Northeast China and Central China all decreased, while the capabilities in East China, South China, Southwest China and Northwest China all improved. Among which, the northwest region enjoyed the biggest increase in ability owing to the certain improvement of the abilities of meteorological S&T innovation in Gansu, Qinghai, Ningxia and Xinjiang, particularly the first two. In the meantime, the capabilities of various regions in North China have declined greatly, in particular, Tianjin. In 2016, the regional meteorological S&T innovation ability ranked in the following order: South China, North China, Northeast China, East China, Northwest China and Central China. South China was still continuing their leading position. But for Central China, the scores were continuously declining from 2014 to 2016. It was obvious to see the decreasing meteorological S&T innovation capabilities of Henan, Hubei and Hunan from the table. With the comparison of 2016, the $C_i$ value of the seven regions in 2017 were 0.0129, -0.0132, -0.0094, 0.0775, -0.0774, 0.0918, -0.0537. It could be easily seen that the largest increase in meteorological S&T innovation abilities was in Southwest, secondly in Central China; correspondingly, the largest declining in that was in Southwest China and then the Northwest China.
4.2. Regional meteorological S&T innovation environment

The measurement results of the meteorological S&T innovation environment are shown in table 3.

**Table 3.** The values of $C_i$ of meteorological S&T innovation environment of the seven regions in 2014-2017 and their rankings.

| Regions      | 2014  | Ranking | 2015  | Ranking | 2016  | Ranking | 2017  | Ranking |
|--------------|-------|---------|-------|---------|-------|---------|-------|---------|
| North China  | 0.2483| 3       | 0.2179| 2       | 0.2174| 3       | 0.2281| 1       |
| Northeast    | 0.2051| 4       | 0.1164| 6       | 0.2408| 2       | 0.1362| 6       |
| East China   | 0.2641| 2       | 0.2609| 1       | 0.2468| 1       | 0.2124| 2       |
| Central China| 0.1518| 6       | 0.1128| 7       | 0.1161| 5       | 0.1204| 7       |
| South China  | 0.2906| 1       | 0.2139| 3       | 0.2171| 4       | 0.1771| 4       |
| Southwest    | 0.1045| 7       | 0.1975| 4       | 0.0812| 7       | 0.2095| 3       |
| North China  | 0.2815| 5       | 0.1563| 5       | 0.1109| 6       | 0.1501| 5       |
| South China  | 0.2070| —       | 0.1940| —       | 0.1773| —       | 0.1847| —       |

Further, from 2014 to 2017, the $C_i$ values of S&T innovation environment in North China and East China were above the Chinese national average value, while that in Central China and Northwest China were below the average. North China and East China both ranked on the top list, indicating that relatively speaking, they were equipped with more meteorological professionals and talents in or above master’s degree, much data volume of meteorological data sharing services as well. Obviously, Central China and Northwest China performed rather worse on these aspects, especially in the latter, where the $C_i$ value of meteorological S&T innovation environment was much lower than the national average.

4.3. Regional meteorological S&T innovation input and output

The measurement results of the meteorological S&T innovation input and output are respectively shown in table 4 & 5.

**Table 4.** The values of $C_i$ of meteorological S&T innovation input of the seven regions in 2014-2017 and their rankings.

| Regions     | 2014  | Ranking | 2015  | Ranking | 2016  | Ranking | 2017  | Ranking |
|-------------|-------|---------|-------|---------|-------|---------|-------|---------|
| North China | 0.2153| 4       | 0.1959| 5       | 0.2601| 2       | 0.1932| 2       |
| Northeast   | 0.1722| 7       | 0.1081| 7       | 0.0989| 6       | 0.0918| 6       |
| East China  | 0.2418| 3       | 0.2023| 4       | 0.1589| 4       | 0.1453| 5       |
| Central China| 0.2077| 5       | 0.1660| 6       | 0.0784| 7       | 0.0886| 7       |
| South China | 0.2628| 2       | 0.3001| 2       | 0.2331| 3       | 0.1581| 3       |
| Southwest   | 0.2813| 1       | 0.2411| 3       | 0.1519| 5       | 0.2514| 1       |
| North China | 0.1864| 6       | 0.3704| 1       | 0.3007| 1       | 0.1497| 4       |
| South China | 0.2270| —       | 0.2315| —       | 0.1905| —       | 0.1614| —       |
Table 5. The values of $C_i$ of meteorological S&T innovation output of the seven regions in 2014-2017 and their rankings.

| Regions        | 2014     | 2015   | 2016    | 2017     | 2017     |
|----------------|----------|--------|---------|----------|----------|
| North China    | 0.3079   | 0.2422 | 0.2856  | 0.3587   | 1        |
| Northeast      | 0.2192   | 0.1670 | 0.1993  | 0.2487   | 3        |
| East China     | 0.1863   | 0.2756 | 0.2171  | 0.2439   | 4        |
| Central China  | 0.2346   | 0.1555 | 0.1359  | 0.2858   | 2        |
| South China    | 0.1948   | 0.3548 | 0.3668  | 0.2304   | 5        |
| Southwest      | 0.1082   | 0.1674 | 0.1963  | 0.2001   | 7        |
| Northwest      | 0.1330   | 0.1279 | 0.2181  | 0.2073   | 6        |
| Average Nationwide | 0.1934  | 0.2145 | 0.2299  | 0.2526   | —        |

When it comes to Southwest China, its investment level of meteorological S&T innovation had been declining until 2016, however, its output level of that had been rising, which showed its meteorological S&T innovation efficiency was continuously increasing before 2016. But in 2017, more investment but no increase in output indicated that its efficiency of meteorological S&T innovation declined compared to the previous years. As far as East China is concerned, the continuous reduction of investment in 2014-2017 as well as the obvious fluctuation in output proved its efficiency instability of meteorological S&T innovation. In terms of South China, there had been taking a great downward trend of investment on meteorological S&T innovation since 2015, while its corresponding output had not changed much but fell sharply in 2017. The decline might be caused by the decline of the investment. The exact reason for that might be the significant reduction of funds in meteorological S&T invested by Shanghai, Jiangsu and Zhejiang in 2017 in the comparison of the previous years, leading to the much decrease of investment of the whole region, which in turn had affected the output of meteorological S&T innovation. With regard to the northwest region, its investment on meteorological S&T innovation had fallen the most since 2015 but with its output increasing year by year, which proved its efficiency of that was constantly improving. For North China, it experienced the increase in 2016 and then the decrease in investment as well as the continuous increase in output, reflecting that its meteorological S&T innovation efficiency has also increased to some extent.

4.4 Differences analysis of the regional meteorological S&T

The coefficient of variation of $C_i$ values in each region from 2014 to 2017 was calculated so as to measure the change trend of differences in meteorological S&T innovation capability, environment, input and output. The calculation results are shown in Table 6.

Table 6. Regional differences analysis on meteorological S&T innovation: the coefficient of variation of $C_i$ values in each region from 2014 to 2017.

|                     | 2014     | 2015     | 2016     | 2017     |
|---------------------|----------|----------|----------|----------|
| Meteorological S&T Innovation Ability | 0.1841   | 0.2575   | 0.2652   | 0.1575   |
| Meteorological S&T Innovation Environment | 0.3249   | 0.3050   | 0.3985   | 0.2375   |
| Meteorological S&T Innovation Input    | 0.1782   | 0.3851   | 0.4562   | 0.3681   |
| Meteorological S&T Innovation Output   | 0.3348   | 0.3818   | 0.3207   | 0.2146   |
Figure 1. Regional Differences Analysis on Meteorological S&T Innovation: The Coefficient of Variation of $C_i$ Values in Each Region from 2014 to 2017.

It can be seen from table 6 that there existed an increase in the coefficient of variation of meteorological S&T capacity from 2014 to 2015, showing the regional differences in meteorological S&T innovation capabilities in various regions increased in 2015. By 2016, the coefficient of variation further increased but with small increasing range, which indicated the further expansion of regional differences in meteorological S&T innovation abilities among these seven regions. However, in 2017, the coefficient of variation reached the minimum of the research range to prove the differences of the meteorological S&T innovation abilities of the seven regions were narrowing down to the smallest one in recent years.

It is observed from figure 1, that the meteorological S&T innovation environment differences of the seven regions had shrunk in 2015 when compared with that in 2014, but suddenly increased in 2016, and reached the minimum in 2017. The reason is that $C_i$ values of meteorological S&T innovation environment of each region were relatively concentrated in 2017 with fewer changes of that in North China and Central China than previous years, some decrease in East China, South China and Northeast China and certain increase in Northwest and Southwest China, which leads to the small degree of dispersion of $C_i$ values in various regions, showing that the differences of meteorological S&T innovation environments in various regions are gradually decreasing, further explaining the tendency to balance of the environment differences. Meanwhile, it can be found that the differences in input and output of meteorological S&T innovation in various regions in 2017 were also decreasing, too.

5. Conclusions and suggestions
We can clearly see via the above analysis that among the seven regions divided by the China’s geographic administrative areas, from 2014 to 2017, the meteorological S&T innovation ability of North China are all higher than the Chinese national average, while that of Central China were lower than the national average. Intuitively, in 2014-2017, changes of the innovation ability are relatively small for East China but highly fluctuated for Central China. We can infer from the $C_i$ coefficient of variation that the continuous narrowing of the differences in meteorological S&T innovation capabilities among the seven regions means their tendency to be in a balanced development for meteorological S&T innovation ability. In the meantime, East China and North China ranks in the forefront and Central China and Northwest China are logging behind in S&T innovation environment. With regard to the meteorological S&T innovation efficiency, Northeast China takes the last but Central China takes the top. There has certain volatility in meteorological S&T innovation efficiency in various regions.

From the above empirical analysis of the meteorological S&T innovation capabilities of the seven regions, we can know that they are distinctly different from each other in this aspect with configuration to be further improved in S&T innovation resources. However, it should be noted that the resource endowments vary from place to place, and whether S&T innovation capabilities can be
fully developed requires further discussion. But the regional meteorological S&T innovation capabilities can be coordinately developed. The specific strategies are as followed: First, establish inter-regional financing mechanisms to narrow regional differences. Areas with strong meteorological S&T innovation abilities, such as South China and East China, should try to maintain their advantages of resource endowments to reduce fluctuations. At the same time, they should also build good interaction mechanisms with areas with lower resource endowments to realize sharing and interaction of resources and technologies so as to narrow regional gaps and achieve the comprehensive improvement of meteorological S&T innovation capabilities, such as, firstly, constructing a number of cross-regional, large-scale, multidisciplinary research projects, or large-scale key research infrastructures to effectively reduce costs, mitigate risks, accelerate technology diffusion and expand external resource input to improve overall energy efficiency; and secondly, strengthening the input on meteorological innovation and technology, especially on basic research and development funds. The breakthroughs and innovations of core technology are derived from the continuous investment in basic research [8]. The development of meteorological S&T is more inseparable from the research of basic science. Hence, we should attach greater emphasis to the investment in applied basic research, and strive to narrow the gap between major core technology and international advanced levels, and provide strong support for the construction of meteorological powers. And the third is to pay more attention to the opening and cooperation of scientific and technological innovation. Technological innovations today present new characteristics-more international and collaborative. All people are likely to benefit from the comprehensive innovation. In conclusion, China should learn the experiences from home and abroad, inside and outside the industry to increase the sharing level of meteorological data in a further way, enhance the construction of the infrastructure platform of meteorological S&T and promote the opening and sharing of meteorological S&T resources.

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