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Research Article

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Analysis of reference crop evapotranspiration and complexity in Liaoning Province

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ABSTRACT

In order to analyze reference crop evapotranspiration (ET_0) and its spatio-temporal variation of complexity in Liaoning Province and based on the daily meteorological data of 56 weather stations in Liaoning Province from 1954 to 2006, daily ET_0 was calculated by the Penman-Montieth formula and its complexity was calculated by the Lempel-Ziv algorithm. The results showed that: The average daily ET_0 was within the range of (2.380 ± 0.300) mm ,the maximum value 2.690mm achieved in 1965 and the minimum value 2.098mm achieved in 1954; average annual ET_0 was in a decreasing trend and the trend was at a rate of -0.017mm • 10a; the cumulative average value of all decades is negative except the 1960s,Liaoning Province spatial distribution of mean annual ET_0 rendered from the northwest to the southeast coast inland decreasing trend , and in addition to Zhangwu stations, Fuxin station , Fengcheng stations, Zhuanghe stations and King County station showed a significant upward trend , other sites mostly downward trend and 1/ 3 of the above sites showed a significant downward trend ; an increasing trend was observed from northwest to southeast coastal areas in 50a ET_0 complexity with higher complexity the southeast coastal areas and lower complexity northeast inland areas. First increase and then decrease trend were found in multi-year average yearly ET_0 complexity. In last 20 year, statistically significant decreasing trend was observed generally in Liaoning province. ET_0 complexity in liaoning province were significantly positive correlation with the temperature and wind speed, and relative humidity has significant positive correlation.

Key words: reference crop evapotranspiration; Lempel-Ziv; complexity; Penman-Monteith; trend analysis; Liaoning

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INTRODUCTION

Reference crop evapotranspiration (ET_0) is one of the standard reference crop potential evapotranspiration, refers to a hypothetical reference crop canopy evapotranspiration rate, assuming that crop height is 0.12m, a fixed foliage resistance is 70s • m-1, the reflection rate is 0.23, it's similar to transpiration and evaporation of green grass which has open surface, consistent height, exuberant growth and completely covers the ground and is not lack of water [1]. ET0 is an important basic parameter of estimating and forecasting crop water demand and farmland water management. It's one of the most important indicators to measure the ability of atmospheric evapotranspiration and estimate crop water requirements and production potential and regional wet and dry conditions. It plays an important role in the balance of the surface energy and water [2] and provides reliable support for agricultural science and rational use of water and irrigation. Therefore, estimating ET0 accurately has a great significance for water resource planning and management, scientific irrigation, agricultural drought monitoring and early warning.

In recent decades, warming became one of the several major global issues in this century, the research on global warming and its impact has become a multidisciplinary problem that need promote vigorously. Liaoning Province is located in the East Asian monsoon region who has the largest rate of change in the global environment and a

complex space environment and the variability on time. Liaoning Province is in the high latitudes of the northern hemisphere, it's a strong regional climate warming zone, drying trend is clearly becoming a serious problem of drought and water shortage situation is difficult to change. Therefore, in such an environment of gradual global warming and increasing dry, to understand spatial and temporal variation of ET_0 deeply plays a crucial role in understanding the interaction between the surface and the atmosphere, improving the management of water and land resources, drought detection and evaluation and rational development and utilization of water resources.

Complexity is a new interdisciplinary developed in the last ten years, it has been widely used in many fields, especially in nonlinear science [3-6], it has a small amount of calculation and no special sequence length requirements and it's easy to implement, so the research scholars in various fields study it more [7-9] .Its essence is constantly comparing whether a string is a substring of another string. If so, the complexity reminds the same, otherwise the increase in complexity. The larger one symbol time sequence complexity, the more the sequence of operation instructions to add, the more the new model, the faster a new model occurs at a rate, the weaker periodically, it indicates that the change of the data is disordered and complex. On the contrary, the more copy operation, the less new model, the slower the rate of emergence of new models, the stronger cyclical, it indicates that the data change is the regular [10]. However, in previous studies, the researches on ET0 complexity in domestic and foreign are still rare. In this view, on the basis of analyzing the change of ET0, the present study attempts to introduce complexity to ET0 study and researches the change of ET0 complexity. It's to understand temporal evolution and variation characteristics of ET0 complexity preliminarily and facilitate the scientific basis for a better understanding of the impact of climate change.

EXPERIMENTAL SECTION

STUDY AREA

Liaoning Province is located in the northeastern region of southern China, it's an important junction between the Northeast economic zone and the Bohai Economic Zone in China. Geographic coordinates is in 118°53' to 125°46' east longitude and 38°43' to 43°26' north latitude , its land area is 145,900 km^2 accounting for 1.5% of China 's land area. Liaoning Province is located in the east coast of the Eurasian continent, mid-latitude regions, it has a temperate continental monsoon climate zone. The annual average temperature is between 7~11℃, the maximum temperature is 30℃, the lowest temperature is -30℃, the temperature is influnced by the monsoon climate and there are large differences among cities from southwest to northeast and descend from the plains to the mountains. The precipitation of Liaoning Province is the largest in Northeast areas and annual precipitation is between 600-1100mm.

The conventional observational data (temperatures, sunshine hours, relative humidity, average wind speed, etc.) of 56 weather stations in Liaoning Province from 1954 to 2006 was used in this research. The weather stations and meteorological elements data was aggregated statistically to obtain daily total radiation, maximum temperature, minimum temperature, average temperature, average relative humidity, average wind speed data. Study area and distribution of selected sites were shown in Figure 1.

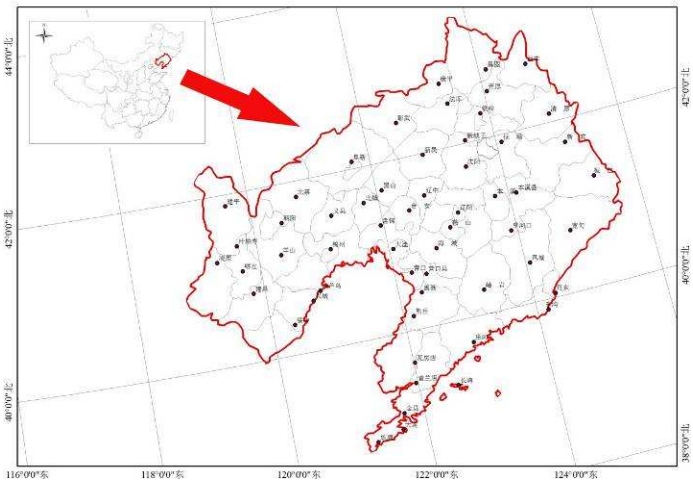

Fig. 1 Distribution map of meteorological site in Liaoning province

REFERENCE CROP EVAPOTRANSPIRATION

Penman-Monteith equation was based on energy balance equation and vapor diffusion theory. It considered not only the physiological characteristics of crops, but also the change of aerodynamic parameters with sufficient theoretical basis [11]. In 1990s, the UN FAO determined the Penman-Monteith equation as the standard method of calculating ET_0. The formula was [1] as follows:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (1)$$

Where, ET_0 is the reference crop evapotranspiration ($mm \cdot d^{-1}$); Δ is the slope of saturated vapor-pressure curve ($kPa \cdot ℃^{-1}$); Rn is the net radiation at crop the surface ($MJ \cdot m^{-2} \cdot d^{-1}$); G is the soil heat flux ($MJ \cdot m^{-2} \cdot d^{-1}$); e_S is saturation vapor pressure (kPa); e_a is actual vapor pressure (kPa); (e_s-e_a) is saturation vapor pressure deficit (kPa); γ is the psychometric constant ($kPa \cdot ℃^{-1}$); T is the mean daily air temperature at two meters height (℃); u_2 is the wind speed at two meters height ($m \cdot s^{-1}$).

LEMPEL-ZIV COMPLEXITY

Complexity was initially defined by the Kolmogorov [12] in 1965, it was characterized as a sequence of bits that could generate the minimum program of (0,1)and later the algorithm of complexity, which is applied in many fields, such as data compression [13], molecular biology [14], neural computation [15, 16] was given by Lempel and Ziv [13], known as Lempel-Ziv complexity (LZC).

The first step to calculate the LZC is coarse processing sequence to obtain a sequence of the same length as the original sequence of symbols, there is now common binary value of the coarse-grained and coarse-grained multi-method [4, 17]. The formula was as follows:

$$C_{LZC} = \frac{c(n)\log_L n}{n} \quad (2)$$

DATA PROCESSING

Using Matlab programming, calculated daily ET_0 its complexity and statistics have in ET_0 values. Using ArcGIS spatial interpolation, analysis ET_0 interannual variability of spatial distribution. Using SPSS statistical software, using Pearson correlation analysis conducted mathematical statistical analysis and significance test.

RESULTS AND DISCUSSION

ET0 TIME VARIATION

ET_0 of each station was calculated according to the daily meteorological data of 56 stations in 53 years in Liaoning Province, then get the yearly average daily ET_0. Interannua trend l variation curves and linear line of yearly average daily ET_0 were shown in Figure 2. From Figure 2 that :the average daily ET_0 of Liaoning Province for 1954 to 2006 is 2.382 mm. The average daily ET_0 was within the range of (2.380 ± 0.300) mm ,the maximum value 2.690mm achieved in 1965 and the minimum value 2.098mm achieved in 1954; average annual ET_0 was in a decreasing trend and the trend was at a rate of -0.017mm • 10a;the conclusion was consistent with ET_0 in semi-arid and sub-humid areas studied by Guangheng Ni (2012) [12].

The cumulative average value of all decades were shown in Table 1. From Table 1 that: the cumulative average value of all decades is negative except the 1960s. The minimum value achieved in 1950s in Caohekou station, but the cumulative average value of all decades were little, and the mamximum value achieved in 1960s in Chaoyang station.

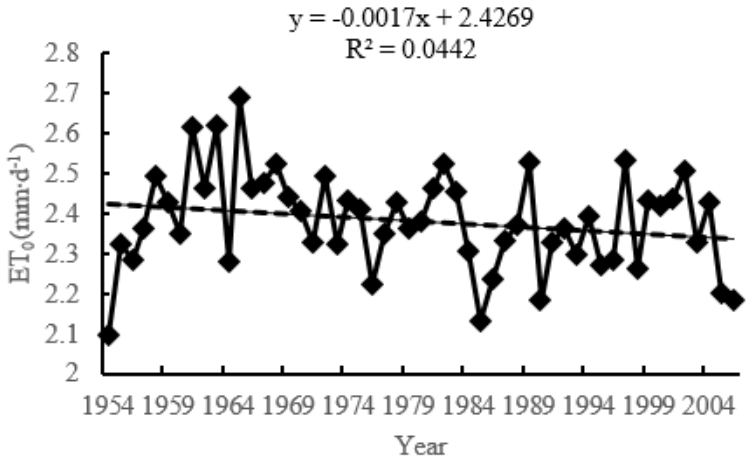

Fig.2 Annual variation of regional average ET_0

Tab.1 Decadal anomalies of regional average ET_0

Decade	Average /mm	Average ratew /%
1954-1959	-0.050	-2.111
1960-1969	0.111	4.640
1970-1979	-0.006	-0.269
1980-1989	-0.009	-0.373
1990-1999	-0.048	-2.019
2000-2006	-0.024	-1.016

SPATIAL DISTRIBUTION OF ET0 AND METEOROLOGICAL FACTORS

The mean annual ET_0 spatial distribution of Liaoning Province was shown in Figure 3. As can be seen from the figure, the average annual ET_0 in Liaoning Province from 1954 to 2006 was 635~1020mm, it was quite different each other. northwestern region of Liaoning Province was the maximum ET_0 zone (900~1020mm),it formed a high-value area as the core of Kangping-Heishan-Yebaishou, the mamximum value was 1016mm achieved in Chaoyang station. Kaiyuan-Xinchengzi-Dawa were relatively the small line of ET_0; ET_0 minimum zone (635-680mm) was in eastern area,it formed low areas at the edge of Xifeng-Fushun-Zhuanghe, the minimum value was 639mm achieved in in Caohekou station.

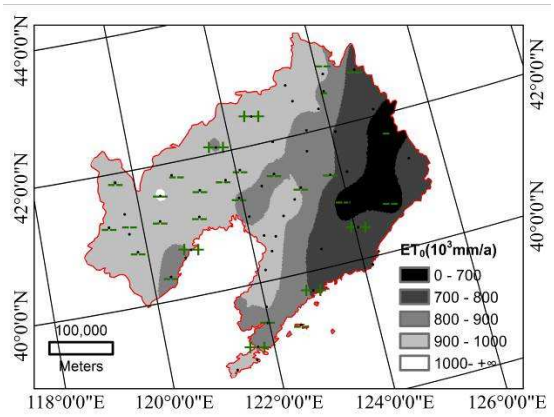

Fig.3 Spatial distribution of multi-year average ET0

Overall, Liaoning Province spatial distribution of mean annual ET_0 rendered from the northwest to the southeast coast inland decreasing trend , and in addition to Zhangwu stations, Fuxin station , Fengcheng stations, Zhuanghe stations and King County station showed a significant upward trend , other sites mostly downward trend and 1/ 3 of the above sites showed a significant downward trend.

ET0 COMPLEXITY VARIATION

The average annual ET_0 complexity distribution of Liaoning Province was shown in Figure 4.The figure shows that ,

on the whole , mean annual spatial distribution of ET_0 complexity were quite different each other and showed increasing trend from the northwest to the southeast coast inland. where the maximum value area of the province. Mean annual ET_0 complexity of Dandong station , Donggou station , Zhuanghe station were greater than 0.60, the minimum value areas were the Northeast and northwest inlands.Changes of ET_0 complexity did not directly affect the generation of ET_0, but the greater the complexity ET_0 was , the more random ET_0 changed , and the less regular namely; And vice versa. Significant differences of spatial distribution of the ET_0 complexity indicated that ET_0 randomness of different regions in Liaoning Province was different and there were big differences in ET_0 predictability.

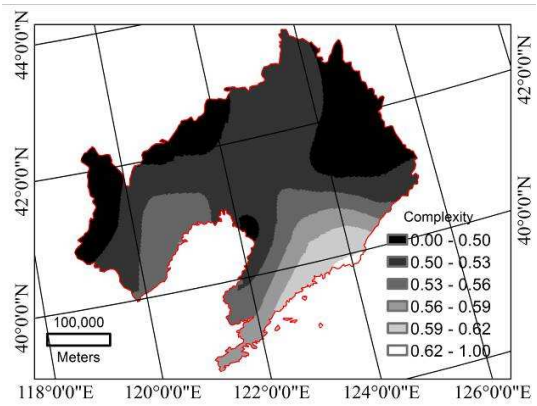

Fig. 4 Spatial distribution of Annual ET0 complexity in Liaoning province

CONCLUSION

(1) The average daily ET_0 was within the range of (2.380±0.300) mm ,the maximum value 2.690mm achieved in 1965 and the minimum value 2.098mm achieved in 1954; average annual ET_0 was in a decreasing trend and the trend was at a rate of -0.017mm•10a; the cumulative average value of all decades was negative except the 1960s;

(2) Liaoning Province spatial distribution of mean annual ET_0 rendered from the northwest to the southeast coast inland decreasing trend , in addition, Zhangwu stations, Fuxin station , Fengcheng stations, Zhuanghe stations and JinXian station showed a significant upward trend, other stations mostly downward trend and 1/3 of the above stations showed a significant downward trend;

(3) An increasing trend was observed from northwest to southeast coastal areas in 50a ET_0 complexity with higher complexity in the southeast coastal areas and the lower complexity in northeast inland areas.

There was a generally downward trend of the mean ET_0 from 1954 to 2006 in Liaoning Province, which was consistent with ET_0 of Taizi River Basin researched by Li Lu[18] and ET0 of 9 stations in northeast researched by Nan jifu [19]. There is a close correlation between ET0 and climate change, while the complex topography of Liaoning Province also impact ET0, this study was studied only from the point of climate change, if it combined topography and meteorological factors to analysis ET0 of spatial and temporal variations in Liaoning Province, it can understand the variation in Liaoning Province and characteristics of ET0 more clearly [20]. It was still the initial exploratory stage in the study of ET0 complexity, and it was not perfect in many aspects. There was only a qualitative analysis of the correlation between meteorological factors and ET0 complexity, and there were too fewer stations in this study, the conclusion was still rough. If finer spatial and temporal evolution of its ET_0 complexity factors were studied, it also need to increase the density of the stations and further research.

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