Using Air2water Model to Predict the Water Temperature of Fuxian Lake

Tingfang Jia and Yi Luo

Abstract

Lake surface water temperature (LSWT), known as the sentinel of climate change, is also a significant factor affecting the water ecological environment. The study found that the LSWT of global lakes increased at 0.03–0.04 °C/a, close to or exceeding the warming trend of temperature, resulting in serious water ecological problems. Therefore, it is urgent to understand the change trend of LSWT, so as to provide basis for relevant departments to formulate water policies. Air2water model only correlates the LSWT with the air temperature (AT), which can accurately capture historical long-term trends and inter-annual fluctuations. It could be used to monitor the lakes in answer to climate change. In this article, using the monthly average AT data of the Lake Fuxian basin in Yunnan Province from 1981 to 2020 and the MOD11A2 LSWT of Lake FuXian data from 2005 to 2018, the air2water model was used to predict the 40-year LSWT. The experimental results show that there is an alternating phenomenon of warm and cold cycles in the 40-year research interval, and the overall trend is increasing. The AT increases at approximately 0.0279 °C/a, using air2water Simulation LSWT at 0.0142 °C/a, but MOD11A2 LSWT increases at approximately 0.0337 °C/a. The reason may be that factors other than climate factors, such as human activities, are not considered.

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Keywords

Air2water model • Lake surface water temperature • Prediction • MOD11A2 • Air temperature

1 Introduction

Lakes have been called the climate change's sentinels and the lake water temperature, one of the main responses to climate change (Woolway & Merchant, 2017). It is very important to lake physics, chemistry and biodynamics (Williamson et al., 2009), and plays a crucial role in lake aquatic ecosystems (such as dissolved oxygen concentration, and fish growth.) (MacKay et al., 2009; Wetzel, 2001). LSWT refers to the water temperature in a lake ranging from 0 to 1 m (Sharma et al., 2015), which shows a rapid and direct response to climate forcing (O'Reilly et al., 2015), and it is known as a valuable index to evaluate the impact of climate change (Adrian et al., 2009). Moreover, because LSWT data are easier to obtain than other lake attributes, many scholars' studies on climate change focus on the long-term dynamic change trend of LSWT, especially for large lakes (Hampton et al., 2008).

Lakes contain about 87% of the fresh water on the earth's surface and are considered to be one of the most biodiversity ecosystems in the world. Long-term climate change causes a serious threat to lake ecosystems, especially the accelerated warming of average temperature in recent years (Kardol et al., 2018; Zheng et al., 2021). Research in recent decades has found that the LSWT of global lakes increased at 0.03–0.04 °C/a, close to or exceeding the warming trend of air temperature (AT) at 0.025 °C/a. The increase of LSWT has led to a series of eco-environmental problems, such as lake cyanobacteria outbreak and changes in biological community structure. (Kraemer et al., 2021). In addition, the study also found that there are huge spatial differences in the change trend of LSWT in many lakes around the world

B.-J. He et al. (eds.), *Climate Change and Environmental Sustainability*, Advances in Science, Technology & Innovation,
https://doi.org/10.1007/978-3-031-12015-2_4

(Mason et al., 2016; O'Reilly et al., 2015; Schneider & Hook, 2010) and so far as to the opposite trend was observed (Zhang et al., 2014). Consequently, it is essential to conduct a regional study on the dynamic change of LSWT, so as to better explain the interaction between climate change and local hydrological conditions, reveal the causes of LSWT change, and provide a basis for the formulation of water use and water treatment policies designated by relevant departments.

2 Study Area

Lake Fuxian, as shown in Fig. 1, is located 5 km south of ChengJiang and more than 70 km away from Kunming. It is a famous fresh water lake in China. The elevation of the lake is 1722.5 m; the lake area is 214.6 km^2; the deepest point is 158.5 m, and the average depth is 87.8 m. The water storage capacity of the lake is 20.62 billion cubic meters, accounting for 72.8% of the total water storage capacity of the nine lakes on the Yunnan Plateau and 9.16% of the total water storage capacity of the national freshwater lakes. The water quality of Lake Fuxian is Class I, a national first-class drinking water source, and is one of the natural lakes with the best water quality in China. In December 2013, the 2013 river and lake ecological environmental protection work organized by the Ministry of Finance and the Ministry of Environmental Protection was approved, and it was included in the national 15 key lakes support scope. It is particularly important to study the trend of water temperature changes in Lake Fuxian and to provide a basis of controlling and improving regional ecological environment.

3 Data Sources

3.1 AT Data

In this article, the air temperature (AT) data used are ERA5-Land monthly averaged data from 1981 to present (https://cds.climate.copernicus.eu/). It was generated by re-running the terrestrial portion of the ECMWF ERA5 climate reanalysis. Reanalysis combines model data with observations from around the world, using the laws of physics, to form a globally complete and consistent dataset. The reanalysis produced data going back decades, providing an accurate picture of past climates. This paper uses the 2 m temperature variable in the dataset.

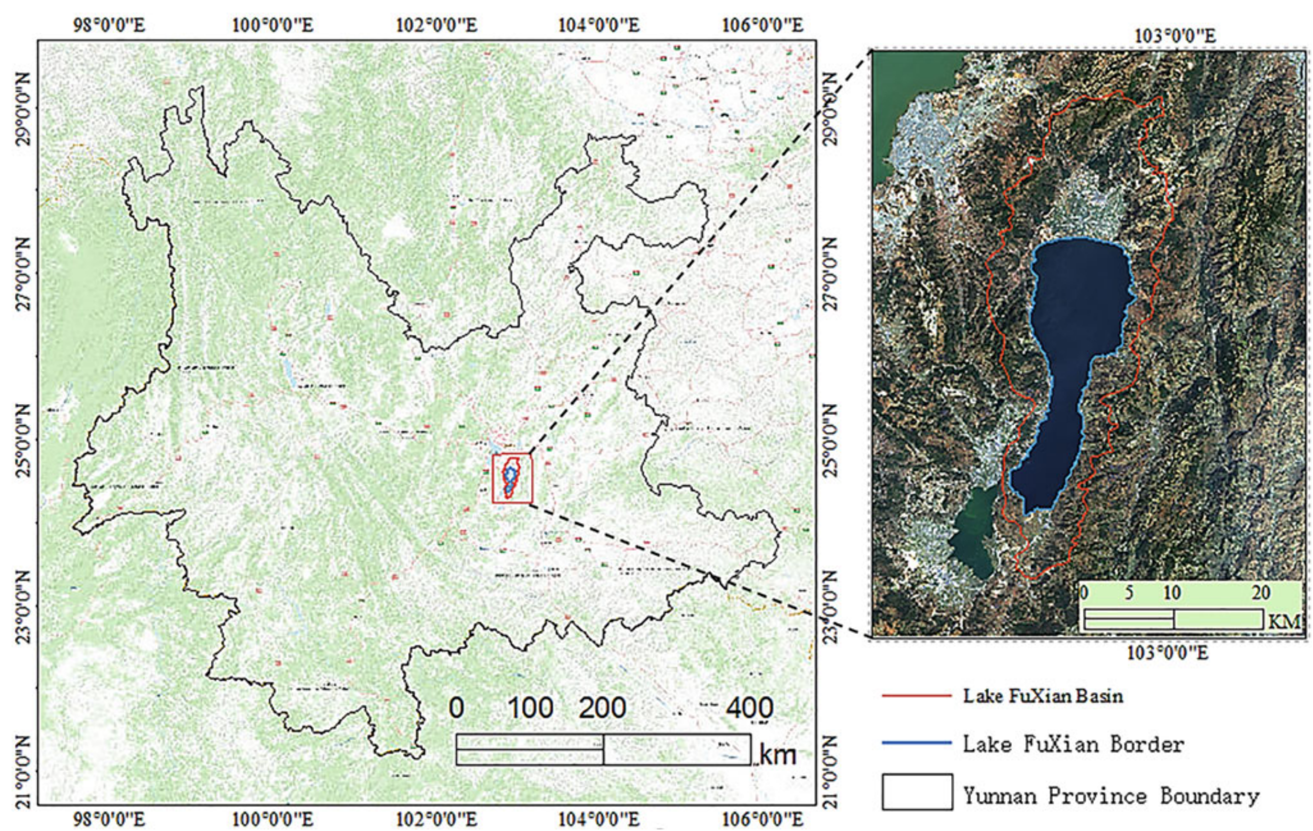

Fig. 1 Lake Fuxian

3.2 LSWT Data

Although the situ observation of LSWT has high accuracy, but most of these data are short-time, intermittent, and sparse local observation data. It is difficult to meet the requirements in spatial resolution and time resolution, and the accuracy of data can't be guaranteed. With the development of space RS technology, a variety of RS images can greatly overcome the limitations of in situ monitoring. Land surface temperature retrieve based on RS image provides the only possibility for global LSWT measurement. MODIS has high time resolution and free reception. It can obtain atmospheric, land, glacier, and hydrological information at the same time. It has a great application prospect in LSWT remote sensing monitoring. The water temperature data used in this article are based on the monthly average LSWT data from 2005 to 2018 based on MOD11A2 data. The MOD11A2 Level-3 MODIS land surface temperature (LST) and emissivity 8-day products are composed of the data from the daily 1-km LST product MOD11A2 is comprised of day (10:30) and night (22:30)' LST.

4 Air2water Model

Air2water is a hybrid model based on physics/statistics in which LSWT can be simulated and predicted only by knowing AT data (Piccolroaz, 2016). The model can accurately capture long-term trends and interannual fluctuations of historical or future LSWT and is suitable for longer time scales (from month to year) (Piccolroaz et al., 2013).

The air2water model has the form of ordinary differential equations, contains several parameters (different 4, 6, or 8 parameters), which illustrates the overall heat exchange with the atmosphere and the deep layer of the lake through a simplified relationship. Use AT and water temperature measurements for calibration. The calibration of the parameters allows one to estimate the influence of the main processes controlling the thermodynamics of the lake in a comprehensive manner and recognizes that the AT is the primary factor actuating the evolution of the system. As a matter of fact, under certain assumptions, changes in AT implicitly contain correct information about other main processes, so they are regarded as the only input variable in this method (Piccolroaz et al., 2013, 2015, 2017; Piccolroaz, 2016).

It was found that the performance achieved by the air2water model was fully comparable to that achieved by more complex process-based models (Piccolroaz, 2016), but process-based models require a large amount of input data, which are often very difficult to obtain. Piccolroaz et al. (2017) applied this model in different temperature datasets, and the research results show that the water temperature accuracy simulated by air2water model is very good regardless of the input dataset (root mean square error of monthly calculation ≤ 0.58 k) (Piccolroaz et al., 2017).

Using air2water model to predict LSWT, the series of observed AT data must be complete. To predict LSWT using the air2water model, the AT data column must be full daily resolution data. It can't have gaps or no data. If the AT data are incomplete, it can be filled with linear interpolation. Water temperature data can be discontinuous. If the water temperature data are not available, it needs to be filled with the value −999. The specific processing flow is shown in Fig. 2.

4.1 The Processing Steps for AT Data

- Since the downloaded temperature data format is.nc, you need to use the "Select by Dimensions" tool in the ArcGIS software for batch processing to obtain 480 AT image maps for each month from 1981 to 2020.
- Use ArcGIS software to extract the Lake Fuxian basin.
- Use the vector map of the Lake Fuxian basin as a mask to clip the images of step 1 to obtain monthly mean AT images of this basin. Use the average temperature of the basin rather than lake surface, taking into account the influence range of climatic factors.
- Write a Python script in the ArcGIS software to create a tool (named "raster mean tool") that can calculate the average value of all raster image pixels of a specified file type (such as .tif) under a given folder path. Calculate the average value of AT in this basin for each month from 1981 to 2020.

4.2 The Processing Steps of MOD11A2 LSWT Data

- Use MRT tool to reproject MOD11A2 LSWT data.
- Use ArcGIS software to spatially interpolate the empty value area in the LSWT data.
- Synthesize the 8-day daytime and nighttime LSWTs data to obtain the monthly average images of the LSWT for each month from 2005 to 2018.
- The normalized difference water index (NDWI) is used in ENVI software to extract the boundary of Lake Fuxian.
- Use the vector map of the lake boundary as a mask to clip the image in step 3 to obtain the LSWT image of Lake Fuxian.
- Use "raster mean tool" to calculate the average value of LSWT of Lake Fuxian for each month from 2005 to 2018.

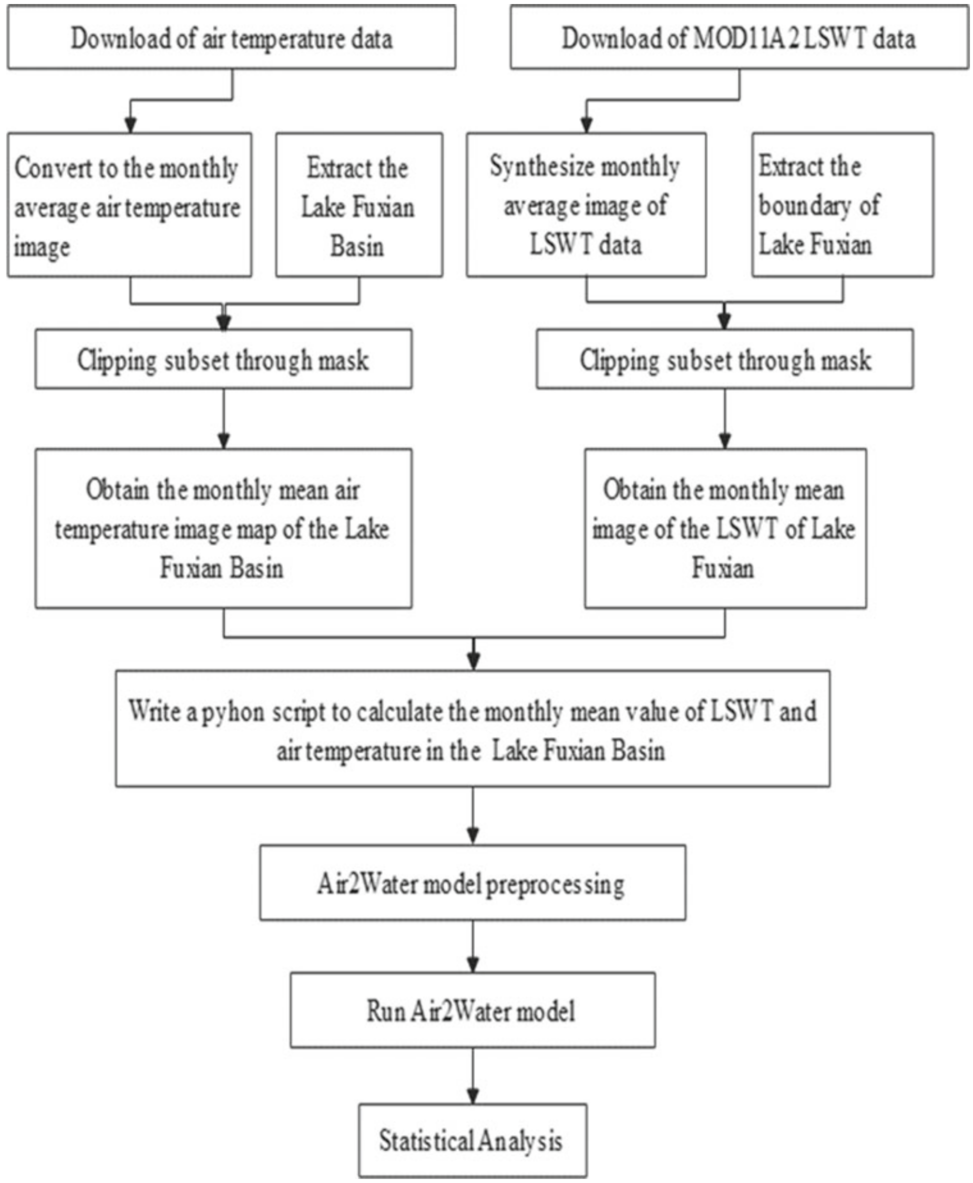

Fig. 2 LSWT predicts processing flow

4.3 Preprocessing of Air2water Model

This process requires running the parameter preprocessing script in MATLAB, inputting the average depth of Lake Fuxian, and estimating the reasonable variation range of the eight parameters in the model, as the Table 1.

4.4 Run Air2water Model

Use the AT data obtained in 4.1 and the LSWT temperature obtained in 4.2 as input data. In this article, considering 14 years of MOD11A2 LSWT data, the first 9 years' data were used for model calibration, and the data of the last 5 years were used for model validation.

5 Result

Figure 3a is a scatter plot of AT data, MOD11A2 LSWT data and simulated LSWT data by air2water from 2005 to 2018. It can be seen that the LSWT of Lake Fuxian with an average depth of 87.7 m exhibits obvious hysteresis cycle changes. The RMSE between MOD11A2 LSWT and Simulation LSWT is 0.916 °C, and the reason may be caused by the superposition of the error retrieved by MOD11A2 and the error of the air2water model itself. Figure 3b shows that there is an obvious linear correlation between MOD11A2 LSWT and Simulation LSWT.

Figure 4 is the month mean analysis line chart of AT data, MOD11A2 LSWT data, and air2water simulation

Table 1 Variation range of 8 parameters

Parameter	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8
Minimum value	−0.26758	0.00134	0.00227	1.00000	0.00000	0.00000	0.00000	0.00000
Maximum value	2.00000	0.07864	0.31115	20.89056	4.58118	1.00000	150.00000	0.50000

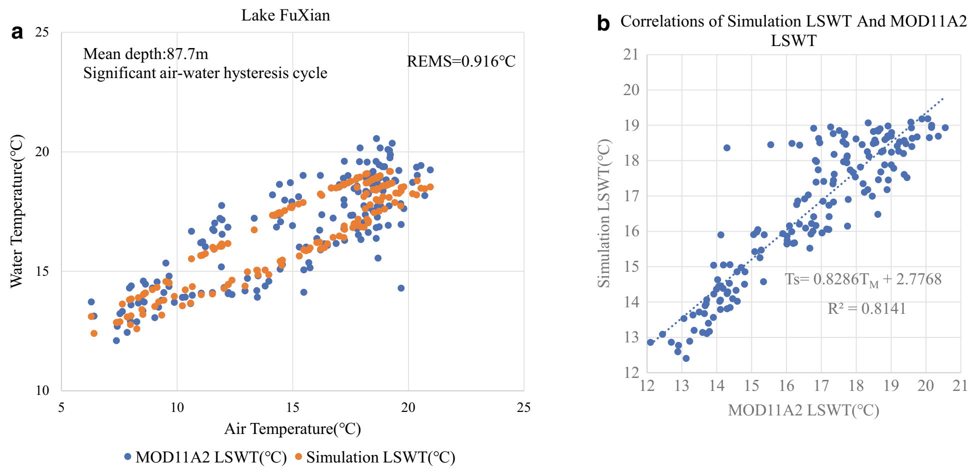

Fig. 3 Scatter plot of Simulation LSWT data, MOD11A2 LSWT data, and AT data

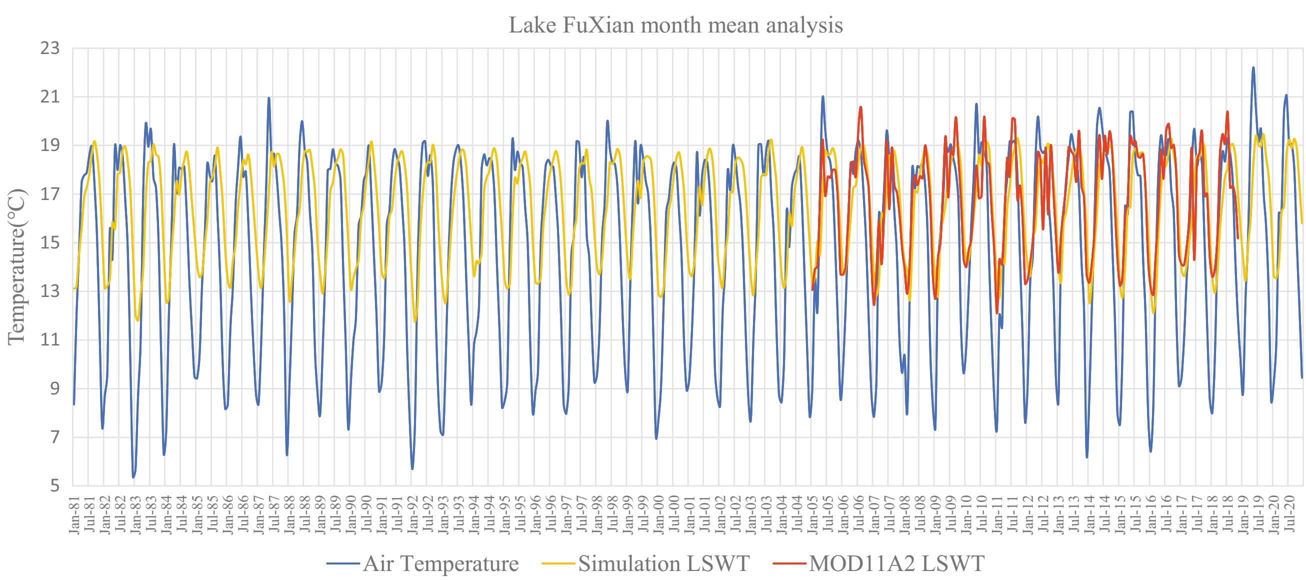

Fig. 4 Month mean analysis line chart of simulation LSWT data, MOD11A2 LSWT data, and AT data

LSWT data from 1981 to 2020. It can also be seen that LSWT and AT have significant hysteresis cycle. The figure shows that the low temperature value generally lasts relatively short in December or January each year, and the high temperature value generally lasts from May to September each year and lasts longer. Compared with AT, LSWT has obvious lag, which is related to large and deep lakes with large thermal inertia.

Figure 5 shows a line chart of the annual average analysis of AT data, MOD11A2 LSWT data, and air2water simulated LSWT data from 1981 to 2020. It can be seen from this figure that warm years and cold years alternate in this 40-year interval, and the overall trend is increasing. The AT is increasing by about 0.0279 °C/a and the air2water Simulation LSWT is increasing by 0.0142 °C/a. The MOD11A2 LSWT grows at a rate of approximately 0.0337 °C/a.

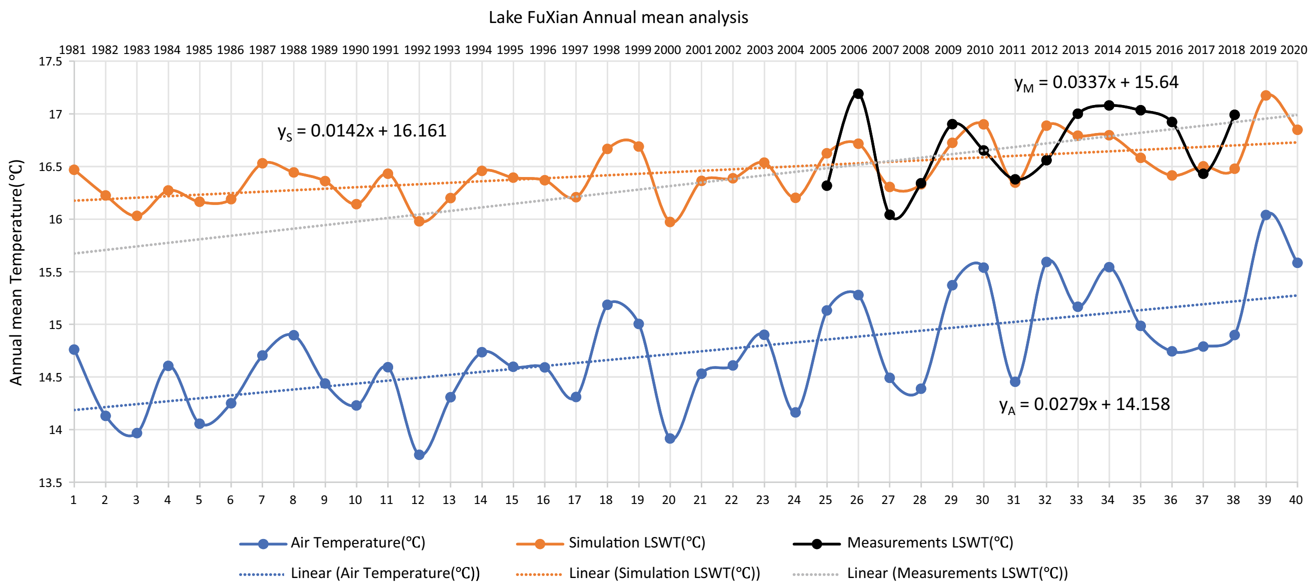

Fig. 5 Annual mean analysis line chart of simulation LSWT data, MOD11A2 LSWT data, and AT data

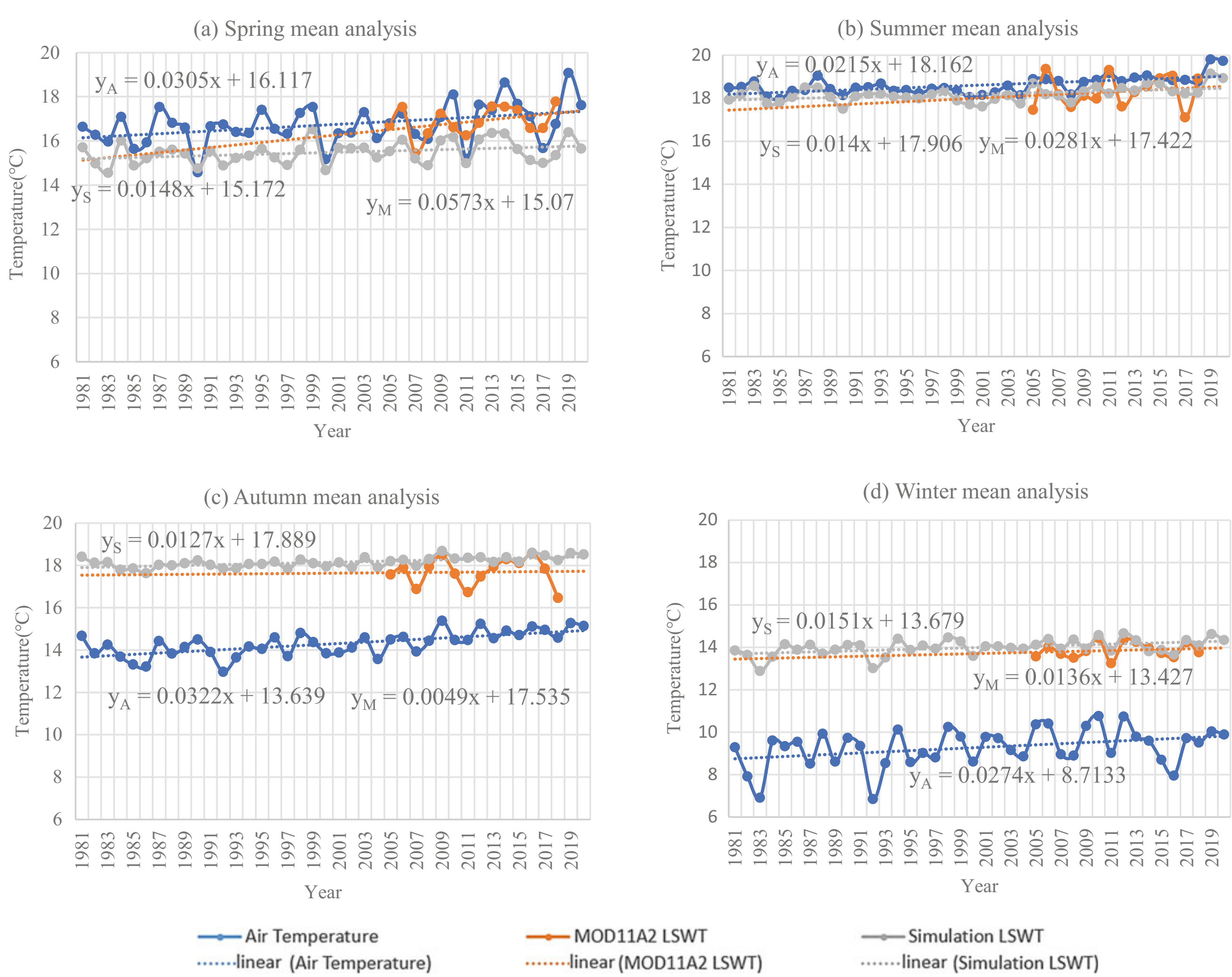

Fig. 6 Season mean analysis Line chart of Simulation LSWT data, MOD11A2 LSWT data and AT data

Figure 6 is a line chart analyzed by season. It can be seen from the figure that the highest growth rate of MOD11A2 LSWT in spring in this region is 0.0573 °C/a, and the change rate of AT is relatively high at 0.0305 °C/a; the highest growth rate of AT in autumn is 0.0322 °C/a, while the growth rate of MOD11A2 LSWT is the lowest; the growth rate of Simulation LSWT in each season is basically the same; the temperature difference between AT and LSWT in spring and summer is small, while the temperature difference between autumn and winter is the large. The minimum temperature difference between AT and LSWT in summer is less than 0.6 °C, and the maximum temperature difference in winter is more than 4 °C.

6 Conclusion

Air2water is a simple tool that can promote scholars without modeling or physics background to use the model to quickly simulate and predict the changes of LSWT. Using the air2water model to predict the Lake Fuxian LSWT, it can be seen that LSWT has been on the rise for nearly half a century. The increased rate of MOD11A2 LSWT is significantly higher than that of AT, especially higher than that of air2water Simulation LSWT. The reason may be caused by the superposition of the error retrieved by MOD11A2 and the error of air2water model itself. The error of MOD11A2 data mainly comes from the error of retrieval model, and the lack of data caused by problems such as cloud coverage. The main reason for the error of air2water model is that it does not consider factors other than climate factors, such as land use classification, increase and distribution of impervious surface area, population distribution, and economic development. Due to time reasons, this article uses the monthly average value of AT to simulate LSWT. If you use shorter time scale daily AT data to simulate, the effect may be better. Later, work will add in situ data to verify the predicted LSWT and MOD11A2 LSWT data and further analyze and study the factors that affect the LSWT increase, hoping to improve the lake ecology provide a basis for governance.

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