Research Article

Recognition of Changes in Air and Soil Temperatures at a Station Typical of China's Subtropical Monsoon Region (1961–2018)

Ming-jin Zhan^{1,2}, Lingjun Xia,¹ Longfei Zhan,² and Yuanhao Wang³

¹Jiangxi Provincial Eco-Meteorological Centre, Nanchang 330046, China

²Jiangxi Provincial Climate Centre, Nanchang 330046, China

³Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100029, China

Correspondence should be addressed to Yuanhao Wang; wyhsatan@126.com

Received 17 September 2019; Revised 28 October 2019; Accepted 14 November 2019; Published 1 December 2019

Academic Editor: Anthony R. Lupo

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Trends in soil temperature are important but rarely reported indicators of climate change. Based on daily air and soil temperatures (depth: 0, 20, 80, and 320 cm) recorded at the Nanchang Weather Station (1961–2018), this study investigated the variation trend, abrupt changes, and years of anomalous annual and seasonal mean air and soil temperatures. The differences and relationships between annual air and soil temperatures were also analyzed. The results showed close correlations between air temperature and soil temperature at different depths. Annual and seasonal mean air and soil temperatures mainly displayed significant trends of increase over the past 58 years, although the rise of the mean air temperature and the mean soil temperature was asymmetric. The rates of increase in air temperature and soil temperature (depth: 0, 20, and 80 cm) were most obvious in spring; the most significant increase in soil temperature at the depth of 320 cm was in summer. Mean soil temperature displayed a decreasing trend with increasing soil depth in both spring and summer. Air temperature was lower than the soil temperature at depths of 0 and 20 cm but higher than the soil temperature at depths of 80 and 320 cm in spring and summer. Mean ground temperature had a rising trend with increasing soil depth in autumn and winter. Air temperature was lower than the soil temperature at all depths in autumn and winter. Years with anomalously low air temperature and soil temperature at depths of 0, 20, 80, and 320 cm were relatively consistent in winter. Years with anomalous air and soil temperatures (depths: 0, 20, and 80 cm) were generally consistent; however, the relationship between air temperature and soil temperature at 320 cm depth was less consistent. The findings provide a basis for understanding and assessing climate change impact on terrestrial ecosystems.

1. Introduction

Increase in global mean surface temperature has been observed over recent centuries. The mean surface temperature around the world has risen by an average of 0.85°C (0.65–1.06°C) from 1880 to 2012. In the Northern Hemisphere, 1983–2012 might have been the warmest 30-year period of the previous 1400 years [1]. Under the effects of global warming, the mean surface temperature in China has shown a significant warming trend [2]. During 1909–2011, the regional temperature has increased by 0.9–1.5°C. In the past 50 years (1961–2011), the rate of increase in temperature has been 0.21–0.25°C/decade, which is greater than the global average [3].

Soil temperature is one of the factors that have an important impact in relation to climate change. Changes in soil temperature associated with climate warming could result in variation of terrain and hydrologic conditions, alteration of the distribution and growth rate of vegetation, enhancement of soil organic carbon decomposition, and increased emission of CO₂ from the soil to the atmosphere [4–8]. These effects could have significant consequences both locally and globally. However, because of the lack of observations with adequate spatial and/or temporal coverage, soil temperatures have not been analyzed as comprehensively as other climatic factors such as air temperature and precipitation. In the past century, the rate of warming of soil temperature in Ireland has reached 0.04–0.25°C/decade [9].

During 1958–2008, soil temperature showed a trend of increase of 0.26–0.30°C/decade in spring at approximately two-thirds of the monitoring stations in Canada [10]. Permafrost temperatures along a transect from north to south across Alaska generally warmed from the late 1980s to 1996. The magnitude of permafrost warming has been estimated in the range of 0.5–1.5°C [11]. In Russia, soil temperature at depths of 40–320 cm have increased by up to 9°C during winter, while air temperature has increased by approximately 4–6°C [12]. In Lhasa (Tibet), seasonal mean soil temperatures at depths below 40 cm have shown an even greater trend (0.43–0.66°C/decade) than air temperature [13]. Based on analysis of the long-term changes (1961–2010) in soil temperature at Guilin (southern China), Chen and Zhou [14] found that the annual variation of air temperature correlated very well with soil temperatures (below the depth of 80 cm). The rate of increase and the range of annual mean air temperature were reported as 0.184°C/decade and 0.8°C, respectively, i.e., higher than the changes of annual mean ground temperature at depths of 5–80 cm.

Many studies have investigated the variations of air and soil temperatures, but examination of the relationship between the changes of air temperature and soil temperature remains largely comparative. The question of whether there are regional differences between air and soil temperatures and the reasons for such differences remain unclear. This restricts accurate assessment of the impact of climate change on terrestrial ecosystems. In this study, the Nanchang Weather Station, located in a subtropical monsoon region of China that is sensitive to climate change, was adopted as the research object. The trends of variation of air temperature and soil temperature at four depths (0, 20, 80, and 320 cm) over the period 1960–2018 were investigated. The overall variation, abrupt changes, abnormal years of temperature, and the relationship between air and soil temperatures were analyzed. The research results will provide a scientific basis for improved understanding and assessment of the impact of climate change on terrestrial ecosystems.

2. Data and Methods

2.1. Study Area. The Nanchang National Weather Station (28°36'N, 115°55'E; elevation: 46.9 m) is located in the Poyang Lake Basin of the middle-lower reaches of the Yangtze River, China (Figure 1). The annual temperature at the Nanchang Weather Station is 18°C, and annual precipitation is approximately 1600 mm. The region has four distinct seasons: spring (March–May), summer (June–August), autumn (September–November), and winter (December–February). The main reason for choosing the Nanchang Weather Station as the research object is that the station has remained at the same location since 1960. Moreover, the time series data of both air temperature and soil temperatures at various depths recorded at the station are long and the data integrity is considered satisfactory (i.e., amount of missing data annually is <5%). In this study, the seasonal, interannual, and interdecadal variations of air temperature and soil temperatures (at depths of 0, 20, 80,

FIGURE 1: Location of the Nanchang National Weather Station, China.

and 320 cm) at the Nanchang Weather Station were analyzed.

2.2. Data Description. The records of both daily air temperature and soil temperature measured at the Nanchang Weather Station extend from January 1, 1960, to December 31, 2018. The amount of missing data during the 59-year period (i.e., <1%) is considered to have had little or no effect on the integrity of the research results.

2.3. Method

2.3.1. Test of Abrupt Change. An accumulative anomaly curve can be used to indicate a sudden change in temperature:

$$C(t) = \sum_{i=1}^t (X_i - \bar{X}), \quad (1)$$

where $C(t)$ is the accumulative anomaly of temperature, X_i is the value of the i -th year, and $\bar{X}$ is the mean value of the series. When the accumulative anomaly value $C(t)$ reaches the maximum, the corresponding t is the year of the turning point. To test whether the turning point meets the criterion of abrupt change, the signal-to-noise ratio (SNR) of the turning year is calculated:

$$\frac{S}{N} = \frac{|\bar{X}_1 - \bar{X}_2|}{S_1 + S_2}, \quad (2)$$

where S/N is the SNR of the turning year, $\overline{X}_1$ and $\overline{X}_2$ are the mean values of the stage before and the stage after the turning year, respectively, and S_1 and S_2 are the respective standard deviations of those two stages. When the value of S/N is >1.0 , the existence of an abrupt change is indicated [15, 16].

2.3.2. Anomaly and Standard Deviation. Climate anomalies are considered conditions in which anomalies of climatic elements reach a certain magnitude. The World Meteorological Organization believes that when an anomaly of a climatic element is more than double the standard deviation, the climatic element should be considered abnormal.

3. Results

3.1. Relationship between Annual Mean Air Temperature and Soil Temperature. Since 1960, both the annual mean air temperature and the annual mean soil temperature at different layers at the Nanchang Weather Station have been increasing. Over this period, the annual mean air temperature has remained lower than all the annual mean soil temperatures. The temperature difference between the air and the ground is positive. It is because the surface heating of the atmosphere is greater than the cooling effect, which means the transfer of heat to the atmosphere is dominant in Nanchang (Figure 2).

Based on data from 1960–2018, the correlation coefficient (R) of the linear relationship between the annual air temperature and the annual 0 cm soil temperature was determined as 0.914 ($P < 0.01$, Figure 3). The correlation coefficients between the annual air temperature and the annual soil temperature at the different layers studied (0, 20, 80, and 320 cm) in the past 58 years were all >0.700 , and they all passed the 0.01 significance test (Table 1). This finding indicates that the trends of air and soil temperatures have reasonable consistency.

3.2. Interdecadal Changes of Air Temperature and Soil Temperatures. In the past 58 years, the air temperature has increased significantly at the Nanchang Weather Station ($P < 0.01$). The interdecadal mean air temperature in the 2010s, which was the warmest decade of the past 58 years, was 0.8°C higher than the annual mean air temperature during 1961–2018. The interdecadal mean air temperature in the 1960s, 1970s, and 1980s was 0.2, 0.5, and 0.5°C lower, respectively, than the annual mean air temperature. In the 1990s (2000s), it was equivalent to (0.6°C higher than) the annual mean air temperature (Table 2).

During 1961–2018, the air temperature increased by 1.0°C , although the rate of change varied between the different decades. From the 1960s to the 1970s, the air temperature dropped by 0.3°C ; in the 1970s and 1980s, the temperature remained largely unchanged, and after the 1990s, the temperature increased obviously. It has increased by 0.5°C from the 1980s to the 1990s. After the 2000s, the temperature has been increasing, rising by 0.6°C (0.2°C) from the 1990s to the 2000s (from the 2000s to the 2010s).

FIGURE 2: Changes of annual mean air and soil temperatures at the Nanchang Weather Station.

FIGURE 3: Relationship between annual mean air temperature and annual mean soil temperature at 0 cm depth at the Nanchang Weather Station.

TABLE 1: Relationship between annual mean air and soil temperatures.

Soil depth (cm)	Regression equation	Correlation coefficient
0	$y = 0.9787x + 2.5523$	0.914
20	$y = 0.748x + 6.181$	0.858
80	$y = 0.529x + 10.147$	0.798
320	$y = 0.4908x + 10.785$	0.700

Note. x : annual mean air temperature ($^\circ\text{C}$); y : annual mean soil temperature ($^\circ\text{C}$).

The soil temperatures at different layers have increased significantly since 1960 ($P < 0.01$), although the rates of change varied between the different decades. Soil temperatures exhibited a cooling trend from the 1960s to the 1970s, following which they remained stable from the 1970s to the 1980s. The mean soil temperatures were 0.2 – 0.5°C lower than the annual mean temperature over the 60-year period. Since the 1990s, the soil temperatures have risen rapidly. In the 2010s, the warmest decade, the soil temperatures were 0.5 – 0.6°C higher than the annual mean soil temperatures of

TABLE 2: Interdecadal mean air and soil temperatures, annual mean air and soil temperatures in the past 58 years, and the rate of climatic trend of annual mean temperatures ($^{\circ}\text{C}/\text{decade}$) at the Nanchang Weather Station.

Index	Interdecadal mean temperature ($^{\circ}\text{C}$)						Annual mean temperature ($^{\circ}\text{C}$)	Climatic trend rate ($^{\circ}\text{C}/\text{decade}$)
	1960s	1970s	1980s	1990s	2000s	2010s		
Air temperature	17.8	17.5	17.5	18.0	18.6	18.8	18.0	0.255
0 cm soil temperature	20.2	19.7	19.6	20.1	20.7	20.8	20.2	0.186
20 cm soil temperature	19.9	19.3	19.1	19.6	19.9	20.1	19.6	0.104
80 cm soil temperature	19.8	19.4	19.3	19.6	19.9	20.0	19.7	0.074
320 cm soil temperature	19.7	19.4	19.2	19.4	19.8	20.1	19.6	0.104

the different layers. Since 1960, the soil temperatures have increased by $0.2\text{--}0.6^{\circ}\text{C}$ at different depths.

In the past 58 years, the annual air temperature was 18.0°C , which is lower than the annual soil temperatures by $1.6\text{--}2.2^{\circ}\text{C}$. However, the rate of increase and the range of air temperatures were $0.255^{\circ}\text{C}/\text{decade}$ and 1.0°C , respectively, i.e., higher than all soil temperatures (equivalent rate of increase and range of $0.104\text{--}0.186^{\circ}\text{C}/\text{decade}$ and $0.2\text{--}0.6^{\circ}\text{C}$, respectively). Overall, the response of air temperature to the effects of global warming during the study period has been much faster and stronger than that of soil temperatures. It is evident that there has been asymmetry in the warming of air and soil temperatures.

3.3. Seasonal Changes in Air Temperature and Soil Temperatures.

In the past 58 years, the seasonal air temperature and soil temperatures have generally warmed, although the soil temperatures at depths of 0, 20, and 80 cm in summer and at the depth of 320 cm in winter show a slight decrease (Table 3).

In comparison with the annual mean air temperature during 1960–2018, the spring, summer, and autumn air temperatures in the 2010s increased by 0.9, 0.5, and 0.8°C , respectively. The 2010s was the warmest decade of the past 58 years, except during winter. The warmest winter during the study period was in the 2000s, when the mean temperature was 0.7°C higher than the 60-year average. From the 1960s to the 2010s, the average seasonal temperatures in spring, summer, autumn, and winter have increased by 1.5, 0.4, 0.9, and 1.0°C , respectively.

The interdecadal variations of soil temperatures in spring and autumn were similar to air temperature. The decade of warmest soil temperatures at all studied depths in spring and autumn was the 2010s, and the decade of warmest winter soil temperatures was the 2000s, i.e., the same as air temperature. The highest soil temperatures at depths of 0, 20, and 80 cm in summer were in the 1960s, while the highest soil temperature at the depth of 320 cm was in the 2010s.

The rate of increase in air temperature and soil temperatures at depths of 0, 20, and 80 cm was fastest in spring, i.e., 0.371 , 0.380 , 0.295 , and $0.202^{\circ}\text{C}/\text{decade}$, respectively. The fastest rate of increase of soil temperature at depth of 320 cm ($0.145^{\circ}\text{C}/\text{decade}$) was in summer.

In spring and summer, soil temperature decreases with increasing soil depth. In spring and summer, the air temperature was cooler than the soil temperatures at depths of 0 and 20 cm ($0.4\text{--}4.0^{\circ}\text{C}$) but warmer than the soil

temperatures at depths of 80 and 320 cm ($1.0\text{--}7.7^{\circ}\text{C}$). The rate of increase of air temperature was $0.371^{\circ}\text{C}/\text{decade}$ in spring, which was less than the rate of increase of soil temperature at depth of 0 cm ($0.380^{\circ}\text{C}/\text{decade}$) but greater than the rate of increase at other soil depths ($0.135\text{--}0.295^{\circ}\text{C}/\text{decade}$). The rate of increase of air temperature was $0.083^{\circ}\text{C}/\text{decade}$ in summer, which was greater than the rate of increase of soil temperature at depths of 0, 20, and 80 cm (-0.048 to $0.091^{\circ}\text{C}/\text{decade}$) but less than the rate of increase of soil temperature at depth of 320 cm ($0.145^{\circ}\text{C}/\text{decade}$). In autumn and winter, soil temperature increases with increasing soil depth. In autumn and winter, the air temperature was cooler than the soil temperatures at all depths ($0.7\text{--}11.9^{\circ}\text{C}$). The rate of increase of air temperature was $0.259^{\circ}\text{C}/\text{decade}$ in autumn and $0.273^{\circ}\text{C}/\text{decade}$ in winter, i.e., greater than the rate of increase of all soil temperatures (-0.072 to $0.240^{\circ}\text{C}/\text{decade}$). In general, in the past 58 years, the rate of increase of seasonal air temperature has been greater than the rate of increase of soil temperature at all depths except the 0 cm depth. It means the response of air temperature to the effects of global warming during the study period has been faster and stronger than that of soil temperatures.

3.4. Variation of the Difference between Air Temperature and Soil Temperatures.

Over the past 58 years, the differences between air temperature and the soil temperatures at different depths at the Nanchang Weather Station have shown a trend of decrease, mainly because the rate of warming of air temperature has been greater than that of soil (Figure 4). The difference between the soil temperature at 0 cm depth and the air temperature has remained relatively stable, although it has declined by 0.4°C since 1960. The difference between the soil temperature at 20 cm depth and the air temperature has had two significant periods of decline (the 1960s–1970s and the 1990s–2000s), and it has reduced by 0.8°C over the past 58 years. The difference between the soil temperature at 80 cm depth and the air temperature showed a trend similar to that at 20 cm depth, with a reduction over the study period of 0.9°C . The difference between the soil temperature at 320 cm depth and the air temperature remained relatively stable from the 1960s to the 1970s, although it has declined steadily since the 1980s. Overall, the temperature difference has decreased by 0.7°C since 1960. The rates of climatic trend between the air temperature and the soil temperatures at depths of 0, 20, and 320 cm range from -0.069 to $-0.181^{\circ}\text{C}/$

TABLE 3: Interdecadal seasonal mean air and soil temperatures ($^{\circ}\text{C}$), seasonal mean air and soil temperatures in the recent 58 years ($^{\circ}\text{C}$), and the rate of climatic trend of seasonal mean temperatures ($^{\circ}\text{C}/\text{decade}$) at the Nanchang Weather Station.

Season	Interdecadal	Mean air temperature	0 cm soil temperature	20 cm soil temperature	80 cm soil temperature	320 cm soil temperature
Spring	1960s	16.9	18.7	17.6	16.5	16.3
	1970s	16.5	18.0	17.0	16.1	16.1
	1980s	16.6	18.2	16.9	16.1	15.9
	1990s	17.1	18.8	17.6	16.5	16.2
	2000s	18.1	19.8	18.4	17.1	16.6
	2010s	18.4	20.0	18.6	17.2	16.8
	Annual	17.3	18.9	17.7	16.6	16.3
	Climatic trend rate	0.371	0.380	0.295	0.202	0.135
Summer	1960s	28.3	32.7	30.2	27.0	20.4
	1970s	28.0	32.0	29.7	26.8	20.3
	1980s	27.9	32.0	29.4	26.6	20.0
	1990s	27.8	31.7	29.2	26.5	20.2
	2000s	28.5	32.4	29.6	26.7	20.7
	2010s	28.7	32.2	29.7	26.8	21.1
	Annual	28.2	32.2	29.6	26.7	20.5
	Climatic trend rate	0.083	-0.088	-0.091	-0.048	0.145
Autumn	1960s	19.4	21.9	22.4	23.3	23.0
	1970s	18.8	21.1	21.6	22.8	22.7
	1980s	19.0	21.0	21.4	22.7	22.3
	1990s	19.6	21.9	22.0	23.1	22.5
	2000s	20.1	22.5	22.2	23.2	22.9
	2010s	20.3	22.5	22.4	23.3	23.3
	Annual	19.5	21.8	22.0	23.1	22.8
	Climatic trend rate	0.259	0.240	0.092	0.056	0.062
Winter	1960s	6.1	7.1	8.9	12.2	19.0
	1970s	6.5	7.4	8.8	12.1	18.8
	1980s	6.3	7.1	8.6	12.1	18.6
	1990s	7.3	7.9	9.3	12.4	18.9
	2000s	7.5	8.1	9.3	12.4	19.1
	2010s	7.1	7.6	8.9	12.2	18.0
	Annual	6.8	7.5	9.0	12.2	18.7
	Climatic trend rate	0.273	0.185	0.092	0.051	-0.072

FIGURE 4: Change of difference between annual mean soil temperature and air temperature at the Nanchang Weather Station.

TABLE 4: Interdecadal difference between mean soil temperature and air temperature, annual mean temperature difference in recent 58 years, and the rate of climatic trend of annual mean temperature difference at the Nanchang Weather Station.

Index	Interdecadal						Annual mean	Climatic trend rate
	1960s	1970s	1980s	1990s	2000s	2010s		
0 cm air	2.4	2.2	2.1	2.2	2.1	2.0	2.2	-0.069
20 cm air	2.1	1.8	1.7	1.6	1.3	1.3	1.6	-0.151
80 cm air	2.1	1.9	1.8	1.6	1.3	1.2	1.7	-0.181
320 cm air	1.9	1.9	1.8	1.5	1.2	1.2	1.6	-0.152

decade (Table 4). The rate of decrease of the temperature difference increases with increasing soil depth, i.e., the greater the depth of soil, the larger the reduction of the temperature difference.

3.5. Abrupt Change and Anomalous Characteristics of Air and Soil Temperatures. Based on equations (1) and (2), the years of abrupt change in air and soil temperatures were calculated. An abrupt change of annual mean air temperature occurred in 1997, while the abrupt change of spring air temperature occurred in 1996. Abrupt changes of summer and annual soil temperature at the depth of 320 cm occurred in 2005. Most annual and seasonal air and soil temperatures did not show abrupt changes; however, in general, the air and soil temperatures have changed from a relatively cold period to a comparatively warm period (Table 5).

In spring, the soil temperatures at depths of 20 and 80 cm were abnormally low in 1970. In 2007 and 2009, the soil temperature at 320 cm depth was abnormally high. In 2008, both the air temperature and the soil temperature at 0 cm depth were abnormally high. The air temperature and the soil temperatures at all depths were abnormally high in 2018. In summer, the air temperature and soil temperatures at depths of 0, 20, and 80 cm were abnormally low in 1999. The soil temperatures at the depths of 0, 20, and 80 cm were abnormally high in 1961, while the soil temperature at 320 cm depth was abnormally high in both 2008 and 2018. In 2013, the air temperature was abnormally high. In autumn, the air temperature and soil temperature at 0 cm depth were abnormally low in 1976 and 1981; the soil temperatures at depths of 20 and 80 cm were also abnormally low in 1981. Air temperature was abnormally high in 2014, and the soil temperature at the depth of 320 cm was abnormally high in both 2008 and 2009. In winter, air temperature and soil temperatures at all depths were abnormally (high) low in 2012 (2016). In terms of the annual mean, air temperature and soil temperature at the depth of 0 cm were abnormally high in 2007. Soil temperatures at depths of 20 and 80 cm (320 cm) were abnormally high in 2017 (2008, 2009, 2017, and 2018). Comparison revealed consistency between the years of abnormal air temperature and soil temperature at 0 cm depth. The years of abnormal seasonal temperature at depths of 0, 20, and 80 cm were also consistent, while the years of abnormal annual temperature differed. The soil temperature at depth of 320 cm was not consistent with other temperatures in abnormal years (Table 6).

TABLE 5: Abrupt change years of annual and seasonal mean air and soil temperatures at the Nanchang Weather Station.

Index	Spring	Summer	Autumn	Winter	Annual
Air temperature	1996	—	—	—	1997
0 cm temperature	—	—	—	—	—
20 cm temperature	—	—	—	—	—
80 cm temperature	—	—	—	—	—
320 cm temperature	—	2005	—	—	2005

Note. “—” indicates no abrupt change.

TABLE 6: Years of anomalous annual and seasonal mean air and soil temperatures at the Nanchang Weather Station.

Index	Spring	Summer	Autumn	Winter	Annual
Air temperature	2008, 2018 (+)	2013 (+), 1999 (—) 1961	2014 (+), 1976, 1981 (—)	2016 (+), 2012 (—) 2016	2007 (+)
0 cm temperature	2008, 2018 (+)	2013 (+), 1999 (—) 1961	1976, 1981 (—)	2016 (+), 2012 (—) 2016	2007 (+)
20 cm temperature	2018 (+), 1970 (—)	2013 (+), 1999 (—) 1961	1981 (—)	2016 (+), 2012 (—) 2016	2017 (+)
80 cm temperature	2018 (+), 1970 (—)	2013 (+), 1999 (—)	1981 (—)	2016 (+), 2012 (—)	2017 (+)
320 cm temperature	2007, 2009, 2017, 2018 (+)	2008, 2018 (+)	2008, 2009 (+)	2012 (—)	2008, 2009, 2017, 2018 (+)

Note. (+), abnormally high; (—), abnormally low.

4. Conclusions and Discussion

Over the past century, the global temperature has undergone significant change in terms of warming, and this change has shown an increasing trend in recent years because of the combined effects of human activities and natural factors [1, 17]. The effects of global warming affect not only air temperature but also precipitation patterns and soil temperature [18]. Soil temperature is one of the main factors affecting plant growth through control of biogeochemical

processes such as dissolved organic carbon export [19], length of growing season [20, 21], rates of mineralization [22, 23], nutrient assimilation by plants [24, 25], and plant productivity [26]. Under the background of global warming, it is very important to research the variation of soil temperature and its relationship with air temperature. Such work can provide theoretical support for the development of reasonable measures for the adaptation of agricultural practices to the effects of climate change. This study found that seasonal and annual air and soil temperatures at the study site have had significant upward trends over the past 58 years, consistent with previous research results [27–30]. However, this study also found that the rates and magnitudes of the warming of air and soil temperatures are inconsistent; i.e., there has been asymmetry in temperature rise. Existing research has indicated that the difference between soil temperatures and the air temperature in most of China is positive. In the arid regions of Northwest China, the temperature difference in autumn and winter show a decreasing trend, while in other seasons, the temperature difference shows an upward trend [31, 32]. In the humid regions of South China, the annual and seasonal temperature differences between air and soil temperatures show a decreasing trend [14]. In different regions, the abrupt change years and years of abnormal air and soil temperatures are also different. Therefore, the inconsistency found between the soil and air temperatures at the Nanchang Weather Station could lead to large errors when assessing the impact of climate change on terrestrial ecosystems using only air temperature data. As the Nanchang site is located in the subtropical monsoon region of China, further work will be required to determine whether the changes of the trends of soil and air temperatures observed in this study are exhibited in regions with other climate types.

Based on daily temperature data, this study analyzed the variation of seasonal and annual temperature, probability distribution of temperature in different climatic states, relationship between air and soil temperatures, difference between soil and air temperatures, and abrupt changes and abnormal years. The main conclusions derived are as follows:

- (1) The relationships between the air temperature and soil temperature at each of the studied depths over the past 58 years all showed good correlation and a significant upward trend. The annual air temperature was lower than the soil temperature by 1.6–2.2°C, but both the rate (0.255°C/decade) and the range (1.0°C) of warming of the air temperature were larger than those of soil temperature at all depths. Under the background of global warming, the change of air temperature has been faster and more intense than soil temperature. The rate of increase of air and soil temperatures has been asymmetric.
- (2) Annual and seasonal air and soil temperatures have mostly increased over the study period. However, soil temperatures at depths of 0, 20, and 80 cm in summer and at 320 cm depth in winter showed slight decreasing trends. Air temperature and soil

temperatures at depths of 0, 20, and 80 cm had the highest warming rates in spring, while soil temperature at 320 cm depth had the highest warming rate in summer. The rate of increase of air temperature and soil temperature at depths of 0, 20, and 80 cm were most obvious in spring, i.e., rates of 0.371, 0.380, 0.295, and 0.202°C/decade, respectively. The rate of increase of soil temperature at 320 cm depth (0.145°C/decade) was most obvious in summer. In both spring and summer, the soil temperature decreases with increasing depth. The air temperature is lower than the soil temperature at depths of 0 and 20 cm but higher than the soil temperature at depths of 80 and 320 cm. In autumn and winter, the soil temperature increases with increasing depth, and the air temperature is lower than the soil temperature at each depth.

- (3) Over time, the differences between the air temperature and soil temperatures at different depths decreased, reducing by 0.4–0.9°C. The rates of the climatic trend of the differences between the air temperature and soil temperatures were between –0.069 and –0.181°C/decade, and the rate of reduction increased with increasing soil depth.
- (4) Generally, the air and soil temperatures have changed from a relatively cold period to a comparatively warm period. The time series of most annual and seasonal air and soil temperatures did not show any sudden changes. Abrupt changes of the annual air temperature and soil temperature at 320 cm depth occurred in 1997 and 2005, respectively. Air temperature in spring and soil temperature at 320 cm depth in summer showed abrupt changes in 1996 and 2005, respectively.
- (5) Seasonally, the years of anomalous air temperature and soil temperatures at depths of 0, 20, and 80 cm were consistent, but they were inconsistent with soil temperature at 320 cm depth in winter 2012. Annually, the air temperature and soil temperature at 0 cm depth were anomalously high in 2007, whereas the soil temperatures at depths of 20 and 80 cm were anomalously high in 2017. In 2008, 2009, 2017, and 2018, the soil temperature at 320 cm depth was anomalously high.

Data Availability

The daily air temperature data and soil temperature data at depths of 0, 20, 80 and 320 cm (1960–2018) used to support the findings of this study were accessed from <http://data.cma.cn/> under account and therefore cannot be made freely available. All other data are available from the authors upon reasonable request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

This study was supported by the Jiangxi Meteorological Bureau and Jiangxi Eco-Meteorological Center and a bilateral cooperation project between the Natural Science Foundation of China and the Pakistan Science Foundation (41661144027). The CMA Climate Change Science Fund (CCSF (201722 and 201810)) provides a policy-oriented training course for PhD students. The authors are thankful for the support of the High-Level Talent Recruitment Program of the Nanjing University of Information Science and Technology (NUIST). The authors thank James Buxton MSc from Liwen Bianji, Edanz Group China (<http://www.liwenbianji.cn/ac>), for editing the English text of this manuscript.

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