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Chapter 9

Analysis for Soil Moisture in Jiangsu Province, China, Using GLDAS Data

Jingze Cai, Yuanzhi Zhang, Yu Li, Tingchen Jiang, X. San Liang, Xia Lu and Jin Yeu Tsou

Additional information is available at the end of the chapter

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Abstract

In this chapter, we present the analysis for the evolution characteristics of temperature, precipitation, and soil moisture. We choose a newly developed method that is based on the information flow (IF) concept to research the causality between annual mean temperature, precipitation, and soil moisture in Jiangsu province, China, from 1961 to 2011 by using the Global Land Data Assimilation System (GLDAS). The correlation and the causality of air temperature and precipitation on soil moisture were compared and discussed. The causality value of 0–10 cm layer is significantly different from zero, while the deeper, in comparison to the surface layer, is negligible. This result unambiguously shows the causality in the sense that the precipitation increase and the temperature decrease are causing the shallow soil moisture to increase. Temperature and all layers of soil moisture have a negative correlation, but precipitation inverses. Precipitation strongly has the greatest effects on soil moisture in the surface layer, though the rest layers are not obvious.

Keywords: soil moisture, GLDAS, evolution, information flow, Jiangsu province

1. Introduction

Nowadays, the global temperature is warming, so the weather changes became a hot topic today. Soil moisture plays a very key role in the process of climate evolution. It not only carries the responsibilities of energy and water exchange between land and atmosphere, but also takes part in charge of land-atmosphere interaction. Soil moisture and climate changes are connected, soil albedo, soil heat capacity, the transfer of heat into the atmosphere, and so on are affected by the change of soil moisture and thus indirectly affect climate change, but

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climate change will also re-act on the soil, and change its moisture content. For example, the heat capacity of the soil is small but the surface albedo is large, the transfer of heat into the atmosphere is not obvious in the area of small soil moisture; in different soil moisture area, the form of interaction is not the same [1, 2]. Because of the deep soil vertical direction, for the precipitation, soil moisture lags about 1–2 months. So, climate change is also restricted because of the soil moisture in the future [3]. In the same area, the evolution of soil moisture is mainly affected by the properties of soil, the strength of the light, the moisture of the air, the size of the wind speed, and so on. Particularly, the evolution of soil moisture is easy to be affected by temperature and precipitation [4]. Since the soil moisture plays a critical impact on the evolution of climate, soil moisture becomes the first consideration [5–8].

Affected by the length of the observation data and the influence of the area, the research of the climate evolution of the soil moisture in the area and the length of time is still very limited [4]. The numerical simulation is mature, and the study area and time scale are expanded. However, the correctness of numerical simulation is dependent on correct initial conditions [9]. Global Land Data Assimilation System (GLDAS) in order to overcome the scale difficulties and built up a global high-resolution land surface assimilation system, compared with other simulation products, GLDAS-driven data are more accurate and the simulation results are more reasonable. Currently, GLDAS supports a lot of research work with its unique advantages [10].

Currently, the applicability of GLDAS products has yet to be verified by the measured data [11, 12], but its distinct characteristics make many different works to be solved [13–15]. Some scholars reported that soil moisture change is active in the eastern China, the land-atmosphere interaction is very active, and the climate change is affected by the soil moisture greatly [16]. Coupled experiments have found strong coupling regions of soil moisture and precipitation: soil moisture in these regions is highly sensitive to precipitation [16]. Adding the soil moisture data assimilation not only improves the spatial distribution of rainfall and temperature in eastern China, but also makes the earth's surface temperature and rainfall simulation value be close to the observations [17]. Based on the observed data of soil moisture, some scholars studied the vertical evolution characteristics of soil moisture, and the relationship with precipitation [18], and the other scholars studied the relationship between soil moisture and climatic variation [19].

In this chapter, we used the data of GLDAS to analyze the evolution characteristics of soil moisture, focusing on the evolution characteristics of soil moisture and assessing the effects and differences between temperature and precipitation in different seasons from 1961 to 2011 in Jiangsu province, China. As soil moisture is an important reference of climate change, the evaluation of dry and wet climate conditions is significant not only to meteorology, but also to the natural environment, farming cultivation, and so on.

2. Materials and methods

The study area is located in the central part of China's east coast, the lower reaches of the Yangtze River and the Huaie River in Jiangsu province, China (30–35°N and 116–121°E). The east of Jiangsu is Yellow Sea. The annual runoff is between 150 and 400 mm in Jiangsu province, while there is more precipitation in the south than in the north. The average temperature was

between 12 and 16°C in Jiangsu province, China, rising from northeast to southwest. Jiangsu belongs to the transitional climate of the temperate zone to the subtropics, with mild climate, moderate rainfall, four distinct seasons. The Huaihe River and irrigation canal in north Jiangsu are considered as the boundary, always belongs to the humid warm temperate zone, north subhumid monsoon climate, the south of a subtropical humid monsoon climate.

GLDAS currently offers two versions of the dataset, namely GLDAS-1 and GLDAS-2; the former version provides CLM, Noah, MOS and 1 × 1° resolution land surface air pressure, air temperature, wind speed, rainfall, evaporation rate, snow rate, and soil moisture data since 1979 generated by VIC model as well as the resolution of the global 0.25 × 0.25° datasets since 2000 generated by Noah model [20]; GLDAS-2 provides datasets from 1948 to 2010 generated by Noah, in which resolution is 0.25 × 0.25° and 1 × 1° [21]. The time resolution of GLDAS-1 and GLDAS-2 both producing meteorological elements is 3 h, which is the basis for composing monthly scale data. In this chapter, we choose four layers' soil moisture data from GLDAS-2.0 and observed data of temperature and precipitation. The flow chart is shown in **Figure 1**.

In the chapter, we use information flow (IF) and Mann-Kendall test to investigate the change in soil moisture.

We choose a newly proven mathematical method [22–24], which is able to evaluate variable causal relation between time series, to distinguish quantitatively the causality between the driving and feedback factor. This new mathematical method is based on the information flow. The new formula is inferred from first principles, rather than an empirical formula, so the property of causality is guaranteed. It also clearly shows the differences between correlation and causality. In the linear limit, the maximum likelihood estimator of the causality from X2 to X1, (units: nats per unit time) is:

$$T_{2\to1} = \frac{C_{11}C_{12}C_{2,d1} - c_{12}^2 C_{1,d1}}{c_{11}^2 c_{22} - c_{11}c_{12}^2} \tag{1}$$

where C_{ij} is the sample covariance between X_i and X_j (i, j = 1, 2), and $C_{i,dj}$ is the covariance between X_i and $[X_j(t + k\Delta t) - X_j(t)]/(k\Delta t)$, with Δt being the time step and $k \geq 1$ some integer. Ideally, when $T2 \to 1$ is nonzero, then X2 is causal to X1 and vice versa. In practice, it usually cannot be precisely zero, and a statistical significance test should be performed [22]; in the present study, the computed causality is significant at the 95% level. A corollary of the above formula is that causation implies correlation, but correlation does not imply causation. For

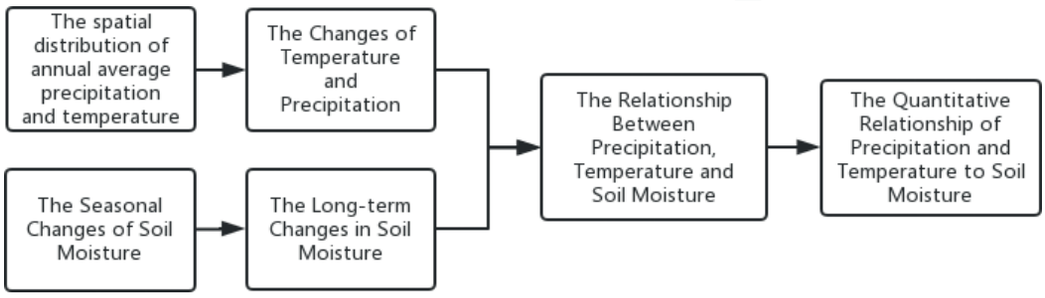


Figure 1. The flow chart of the analysis for the evolution characteristics of temperature, precipitation, and soil moisture in Jiangsu province.

details about the derivation and applications (in climate science and financial economics), see Liang [23–25] among others.

Mann-Kendall (MK) method is a nonparametric statistical test method. Nonparametric test method is also called distribution test, which not only do not need a sample to follow a certain distribution, but also is not affected by the interference of a few outliers [26–27].

The formula is expressed as:

$$Z_c = \begin{cases} \dfrac{S-1}{\sqrt{\mathrm{var}(S)}}, & S > 0 \\ 0, & S = 0 \\ \dfrac{S+1}{\sqrt{\mathrm{var}(S)}}, & S < 0 \end{cases} \tag{2}$$

If the Z_c value is greater than zero, this means an increasing trend, the reverse is the tendency to decrease.

$$S = \sum_{i=1}^{n-1} \sum_{k=i+1}^{n} \mathrm{sgn}(x_k - x_i) \tag{3}$$

where x_k and x_i are the annual values in years k and i, and $k > i$, respectively.

$$\mathrm{sgn}(\theta) = \begin{cases} 1, & \theta > 0 \\ 0, & \theta = 0 \\ -1, & \theta < 0 \end{cases} \tag{4}$$

$$\mathrm{var}[S] = \left[n(n-1)(2n+5) - \sum_{t} t(t-1)(2t+5) \right] \Big/ 18 \tag{5}$$

in which t_i denotes the number of ties to extent i. The summation term in the numerator is used only if the data series contains tied values.

$$\beta = Median \left(\frac{x_i - x_j}{i-j} \right), \quad \forall j < i \tag{6}$$

$1 < j < i < n$, beta denotes slope; if beta is greater than zero, this represents rise, the reverse is decrease, the numerical value indicates the significance of the trend.

3. Results and discussion

3.1. Characteristics of climate change in Jiangsu province, China

3.1.1. The changes of temperature and precipitation

The Jiangsu province area roughly tends to warming and dry from 1961 to 2011, as shown in **Table 1**. Analyzing the observation data of rainfall and temperature evolution trend in Jiangsu

area, we can know that temperature in Jiangsu is warming, because of the large trend coefficient and passing the confidence level of 99%, while the precipitation presents the decreasing trend, in which trend coefficient is small, and fails to pass the confidence test. These results show that in recent years, Jiangsu province became warming and slightly drier.

The annual average precipitation in the south of the Yangtze river is more than in north of the Yangtze river, the value gets 10.8%. During 1961–2011, the precipitation in the south of the Yangtze river is increasing but in the north of the Yangtze river is not exactly the same. From 1985 to 1995, precipitation is reduced in the south of the Yangtze river. From microcosmic view, increase or decrease amplitude is significant in the south of the Yangtze river. The precipitation is relatively stable in the north of the Yangtze river. Interannual variability is quite different from 1971 to 2000 but gradually close in recent years.

From the perspective of the interannual relationship of extremely warm days, the threshold below (above) some station in Jiangsu has an extreme low temperature (high temperature) day, then counting extreme low temperature (high temperature) days from year to year. According to the statistical results, increasing amplitude of warm day is less than the decreasing amplitude of cold day; increasing amplitude of warm night is less than the decreasing amplitude of cold night. The phenomenon of warm days and warm nights is obvious. Overall, under the background of global warming, temperature is increasing in Jiangsu province and extreme low temperature events are reducing, but extreme high temperature events are rising.

The annual average precipitation in the south of the Yangtze river is more than in north of the Yangtze river, the value gets 10.8%. During 1961–2011, the precipitation in the south of the Yangtze river is increasing but in the north of the Yangtze river is not exactly the same. From 1985 to 1995, precipitation is reduced in the south of the Yangtze river. In general, the trends are the same. From microcosmic view, amplitude is significant in the south of the Yangtze river with significant increase or decrease. The precipitation is relatively stable in the north of the Yangtze river. Interannual variability is quite different from 1971 to 2000 but gradually close in recent years.

3.1.2. The long-term changes in soil moisture

Characteristics of the soil moisture anomaly in Jiangsu are consistent; the biggest soil moisture change rate is located in Jiangsu, which means Jiangsu is a soil moisture-sensitive area. This area is located in China's north and south climate transition zone, the climate change rate is large, land-atmosphere interaction is very active, so soil moisture anomalies are relatively prominent. Shallow soil moisture in Jiangsu has obvious interannual variability features and

Category	Value Z_c	Slope
Precipitation	−1.01	−0.03
Temperature	5.48***	0.03

Note: *** represents passed 99% significance testing.

Table 1. Mann-Kendall test of temperature and precipitation change trends.

unobvious trend to dry, but there is an obvious trend to dry in the deep soil moisture since 1988. Although the interannual features of deep and shallow soil moisture have some differences in individual years, such as deep and shallow soil moisture anomalies are a reverse phase in 1989. Soil moisture in Jiangsu does not have an obvious trend for a long time, soil moisture has a 2–4 years cycle change before 1985, but the later cycle change is 6–8 years.

3.2. The relationship between precipitation, temperature, and soil moisture

Soil moisture plays a leading role on seasonal time scale of land-atmosphere interaction, partial wet soil can lead to more precipitation. The soil moisture as an important physical parameter of land surface process accumulates the surface hydrological processes, which is also the main process of solid earth, material life, biochemistry cycle, and so on. Through affecting the surface albedo, heat capacity, land surface vegetation growth status, sensible heat flux, latent heat flux, radiation flux and momentum flux, soil moisture can cause climate change.

Temperature and precipitation are key factors that result in the change of soil moisture, precipitation change is the main factor that affects soil moisture change, but the rise of the temperature will result in higher vapor pressure and evaporation, which increases evapotranspiration and decreases soil moisture. Using the theory of information flow in the time series of precipitation, temperature, and soil moisture in Jiangsu province found that there is a positive correlation between soil moisture and precipitation, and a negative correlation between soil moisture and temperature, but in different depth layer, the relationship is significant difference. However, previous researches about the impact of precipitation and temperature to soil moisture are mostly using the observation data in the local scale and short time scare, and just using simple mathematical correlation analysis. Under the background of global soil moisture significant changes, it is necessary to analyze long-term change trend of the impact of temperature and precipitation to soil moisture by using quantitative analysis. Therefore, the theory of information flow is used in this chapter to analyze the relationship between temperature, precipitation, and soil moisture, which can deepen our understanding of soil moisture change in the long time series and the mechanisms between temperature, precipitation, and soil moisture, take effective ways to inhibit the deterioration of soil moisture, improve soil condition, reasonably utilize climate resources, adjust the agricultural ecological layout, and provide a scientific reference actively respond to climate change.

Comparing the correlation and causality between temperature, precipitation, and soil moisture in Jiangsu province, it is obvious that every layer of soil moisture and precipitation has a positive correlation but temperature has negative correlation. The correlation between increasing precipitation or rising temperature and changing soil moisture alone is not necessarily to prove that the changing soil moisture is caused by the increasing precipitation or rising temperature. So we use information flow (IF) to analyze the precipitation, temperature, and soil moisture covering the period from 1961 to 2011 (51 years). We calculate the information flow (IF) in nat (natural unit of information) per unit time [nat/ut] from the 51 annual time series of precipitation and temperature to soil moisture.

The correlation of precipitation and soil moisture shows a declining with the rising of soil depth from 0.563 in the surface layer to 0.242 in the 100–200 cm layer. This result unambiguously shows precipitation has the greatest effects in the surface layer, though the rest layers are not obvious. The main reason of these results is that water in 0–10 cm layer comes from atmosphere, whereas the water in deep layer is from hydrosphere, like osmosis. Each soil (0–10 cm, 10–40 cm, 40–100 cm, and 100–200 cm), the correlation coefficient of soil moisture and temperature is 0.112, 0.458, 0.433, and 0.591, respectively. This shows that, in addition to 0–10 cm layer, the rest layers' temperature has a larger impact the deeper the soil layer.

We calculate the information flow (IF) in nat (natural unit of information) per unit time (nat/ut) from the 51 years' annual time series of temperature and precipitation to soil moisture. The values in **Tables 2** and **3** clearly confirm that the temperature, precipitation, and soil moisture have a causal relationship. Specifically, the variation of precipitation and temperature is the main driver of the 0–10 cm soil. Obviously, the value of 0–10 cm layer is significantly different from zero, while the deeper, in comparison to the 0–10 cm layer, is negligible. This result unambiguously shows the causality in the sense that the precipitation increase and the temperature decrease are causing the 0–10 cm soil moisture increase significantly. Jiangsu is located in the subtropical and warm temperate transition zone with mild climate, four distinct seasons, significant monsoon and other typical climate characteristics. **Table 4** indicates that when the temperature stabilizes more than 10°C, the correlation is positive with soil moisture in each layer and the temperature stabilizes less than 10°C, the correlation is negative. When the temperature stabilizes between 22 and 10°C, the temperature and precipitation with soil moisture in each layer has a strong correlation, and when the temperature stabilizes more than 22°C, only the shallow soil with temperature and precipitation has a strong positive correlation but a minimum correlation in 40–100 cm layer. When the temperature stabilizes less than 10°C, precipitation with soil moisture has a strong negative correlation and a weak correlation between soil moisture and temperature.

3.3. Discussion

To study the effects of climate change or predict the climate changes, soil moisture is worth to be considered, but the lack of soil moisture observation data, the various soil moisture

	Correlation and causality		
Soil layer	Correlation	Temperature→Soil moisture	Soil moisture→Temperature
0–10 cm	−0.112	0.513 ± 0.019	−0.479 ± 0.021
10–40 cm	−0.458	0.299 ± 0.019	−0.276 ± 0.017
40–100 cm	−0.433	0.179 ± 0.010	−0.177 ± 0.009
100–200 cm	−0.591	0.197 ± 0.010	−0.196 ± 0.010

The chosen unit time step is ut = 1 year.

Table 2. Correlation and causality between temperature and soil moisture in Jiangsu province.

	Correlation and causality		
Soil layer	Correlation	Precipitation→Soil moisture	Soil moisture→Precipitation
0–10 cm	0.563	0.853 ± 0.138	-0.499 ± 0.029
10–40 cm	0.400	0.366 ± 0.068	-0.357 ± 0.019
40–100 cm	0.341	0.199 ± 0.052	-0.194 ± 0.011
100–200 cm	0.242	0.219 ± 0.025	-0.209 ± 0.012
The chosen unit time step is ut = 1 year.			

Table 3. Correlation and causality between precipitation and soil moisture in Jiangsu province.

Category	Regression coefficient	0–10 cm	10–40 cm	40–100 cm	100–200 cm
Spring	Temperature	0.99	0.79	0.99	0.95
	Precipitation	0.99	0.68	0.98	0.98
Summer	Temperature	0.74	0.62	0.29	0.40
	Precipitation	0.66	0.54	0.19	0.31
Autumn	Temperature	0.99	0.99	0.99	0.99
	Precipitation	0.99	0.99	0.99	0.98
Winter	Temperature	−0.13	0.06	−0.07	−0.14
	Precipitation	−0.91	−0.81	−0.88	−0.91

Table 4. Regression coefficients of temperature, precipitation, and soil depth in different seasons.

simulation data and uncertain output limit the pace of research. Combining the observation data and simulated data can make up the shortfall of them. With the evolution of pattern, the development of simulation data will infinite close to the observation data. In the following research, we will continue to explore GLDAS data accuracy and the scope of application.

4. Conclusions

By analyzing the evolution of soil moisture in Jiangsu province, China, a few conclusions have been summarized.

There are some differences in the decadal variability of average temperature on both sides of the Yangtze river, the average temperature in the south of the Yangtze river is higher than in the north of the Yangtze river, but the temperature is rising in whole Jiangsu. The temperature rose slightly in the early period but increased obviously in the later period. The average annual precipitation is generally more in the south of the Yangtze river than in the north of the

Yangtze River, the gap between the two is bigger from 1971 to 2000. In recent years, the gap is gradually close.

By using information flow, we can know that the causality value of shallow layer is significantly different from zero, while the deeper, in comparison to the shallow layer, is negligible. This result unambiguously shows the causality in the sense that the precipitation increase and the temperature decrease are causing the shallow soil moisture increase. Soil moisture in the surface layer is more affected by precipitation in four seasons from 1961 to 2011, but precipitation has a same regularity. The variation of precipitation lags soil moisture (10–40 cm, 40–100 cm, and 100–200 cm) about 1–3 months. Deeper soil has a certain memory function for climatic evolutionary process, which can accumulate lots of data about the surface hydrological processes. In line with the data analysis, soil moisture indicates a falling trend from 1961 to 2011, while interannual change is obviously different, which shows that Jiangsu province may have future drought conditions.

Temperature and precipitation have some relationships between different layers of soil moisture. When the temperature stabilizes between 22 and 10°C, the temperature and precipitation with soil moisture in each layer have a strong correlation. Once when temperature rose, only the shallow soil has a strong positive correlation with temperature and precipitation, the minimum correlation is in 40–100 cm layer. When the temperature dropped, precipitation with soil moisture has a strong negative correlation and a weak correlation between soil moisture and temperature.

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Conflicts of interest

The authors declare no conflict of interest.

Author contributions

Jingze Cai and Yuanzhi Zhang conceived and designed the experiments, performed the experiments, analyzed the data, and wrote the chapter; Yu Li and Xia Lu improved the data analysis; Tingchen Jiang, X. San Liang, and Jinyeu Tsou contributed reagents/materials/analysis tools.

Author details

Jingze Cai[1], Yuanzhi Zhang[1,2]*, Yu Li[3], Tingchen Jiang[4], X. San Liang[1], Xia Lu[4] and Jin Yeu Tsou[2]

*Address all correspondence to: yuanzhizhang@cuhk.edu.hk

1 School of Marine Sciences, Nanjing University of Information Science and Technology, Nanjing, China

2 Center for Housing Innovations, Chinese University of Hong Kong, Shatin, Hong Kong

3 Faculty of Information Science, Beijing University of Technology, Beijing, China

4 Faculty of Surveying and Mapping, Huaihai Institute of Technology, Lianyungang, China

References

[1] Zhang Q, Wang S, Wei G. A study on parameterization of local land-surface physical processes on the GOBI of Northwest China. Chinese Journal of Geophysics. 2003;**46**: 616-623

[2] Guan XD, Huang JP, Guo N. Variability of soil moisture and its relationship with surface albedo and soil thermal parameters over the Loess Plateau. Advances in Atmospheric Sciences. 2009;**26**:692-700

[3] Zhu Q, Lan H, Shen T. Numerical study of the influence of soil moisture and surface albedo on climate of north part of China. Acta Meteorologica Sinica. 1996;**54**:493-500

[4] Cai J, Zhang Y, Li Y, Liang XS, Jiang T. Analyzing the characteristics of soil moisture using GLDAS data: A case study in eastern China. Applied Sciences. 2017;**7**(6):566

[5] Ma Z, Wei H, Fu C. Progress in the research on the relationship between soil moisture and climate change. Advances in Earth Science. 1999;**14**:300-303

[6] Li B, Wen X, Wang L, Yan P. Tendency of soil moisture in spring of Heilongjiang province in recent 30 years. Journal of Arid Meteorology. 2011;**29**:289-296

[7] Wang L, Wen J, Wei Z, Hu Z. Soil moisture over the west of Northwest China and its response to climate. Plateau Meteorology. 2008;**27**:1257-1266

[8] Chen S, Guo Y, Zheng Y, Wang J. Impact of precipitation on soil moisture in Gansu arid agricultural regions. Journal of Desert Research. 2012;**32**:155-162

[9] Liu S, Lin H, Hu F, Liang F, Wang J, Liu H. Numerical simulation of evapotranspiration mechanism over soil-vegetation-atmosphere system. Journal of Arid Meteorology. 2004; **22**:1-10

[10] Tapley B, Bettadpur S, Ries J. GRACE measurements of mass variability in the earth system. Science. 2004;**305**:503-505

[11] Long D, Scanlon B, Longuevergne L, Sun A, Fernando D, Save H. GRACE satellite monitoring of large depletion in water storage in response to the 2011 drought in Texas. Geophysical Research Letters. 2013;**40**:3395-3401

[12] Long D, Shen Y, Sun A, Hong Y, Longuevergne L, Yang Y, et al. Drought and flood monitoring for a large karst plateau in Southwest China using extended GRACE data. Remote Sensing of Environment. 2014;**155**:145-160

[13] Reichle R, Koster R, Liu P, Mahanama S, Njoku E, Owe M. Comparison and assimilation of global soil moisture retrievals from the advanced microwave scanning radiometer (AMSR) for the earth observing system (AMSR-E) and the scanning multichannel micro-wave radiometer (SMMR). Journal of Geophysical Research-Atmospheres. 2007;**112**:D09108. DOI: 10.1029/2006JD008033

[14] Niu G, Yang Z, Dickinson R. Development of a simple groundwater model for use in climate models and evaluation with gravity recovery and climate experiment data. Journal of Geophysical Research-Atmospheres. 2007;**112**:277-287

[15] Quintana P, Moigne P, Durand Y. Analysis of near-surface atmospheric variables: Validation of the SAFRAN analysis over France. Journal of Applied Meteorology and Climatology. 2008;**47**:92-107

[16] Koster D, Dirmeyer P, Guo Z. Regions of strong coupling between soil moisture and precipitation. Science. 2004;**305**:1138-1140

[17] Hu M, Ding H, Liao F. An improvement on summer regional climate simulation over East China: Importance of data assimilation of soil moisture. Chinese Science Bulletin. 2009;**54**: 2388-2394

[18] Zhang X, Wu X, He J. Vertical character of soil moisture in China. Acta Geographica Sinica. 2004;**62**:60

[19] Ma Z, Wei H, Fu C. Relationship between regional soil moisture variation and climatic variability over East China. Acta Geographica Sinica. 2000;**58**:284-286

[20] Rui H. Readme Document for Global Land Data Assimilation System Version 1 (GLDAS-1) [EB/OL]. 2014. http://disc.Sci.gsfc.nasa.gov/services/grads-gds/gldas

[21] Rui H. Readme Document for Global Land Data Assimilation System Version 2 (GLDAS-2) products [EB/OL]. 2014. http://disc.Sci.gsfc.nasa.gov/services/grads-gds/gldas

[22] Vaid BH, Liang XS. An abrupt change in tropospheric temperature gradient and moisture transport over East Asia in the late 1990s. Atmosphere-Ocean. 2018;**1**:1-9

[23] Liang XS. Unraveling the cause-effect relation between time series. Physical Review E. 2014;**90**:052150

[24] Liang XS. Normalizing the causality between time series. Physical Review E. 2015;**92**: 022126

[25] Liang XS. Information flow and causality as rigorous notions ab initio. Physical Review E. 2016;**94**:052201

[26] Mann B. Non-parametric tests against trend. Econometrica. 1945;**13**:163-171

[27] Kendall G. Rank Correlation Methods. 4th ed. Vol. 4. London, UK: Charles Griffin; 1975. p. 202

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