Journal of Environmental Management 198 (2017) 21–31

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Identify temporal trend of air temperature and its impact on forest stream flow in Lower Mississippi River Alluvial Valley using wavelet analysis

Ying Ouyang [a, *], Prem B. Parajuli [b], Yide Li [c], Theodor D. Leininger [d], Gary Feng [e]

[a] USDA Forest Service, Center for Bottomland Hardwoods Research, 775 Stone Blvd., Thompson Hall, Room 309, Mississippi State, MS, 39762, USA
[b] Department of Agricultural and Biological Engineering, Mississippi State University, Mississippi State, MS, 39762, USA
[c] Research Institute for Tropical Forestry, Chinese Academy of Forestry, Guangzhou, 510520, China
[d] USDA Forest Service, Center for Bottomland Hardwoods Research, 432 Stoneville Road, Stoneville, MS, 38776, USA
[e] USDA-ARS, Crop Science Research Laboratory, 810 Hwy 12 East, Mississippi State, MS, 39762, USA

ARTICLE INFO

Article history:
Received 21 February 2017
Received in revised form
5 May 2017
Accepted 6 May 2017

Keywords:
Air temperature
Climate change
LMRAV
Stream discharge
Wavelet analysis

ABSTRACT

Characterization of stream flow is essential to water resource management, water supply planning, environmental protection, and ecological restoration; while air temperature variation due to climate change can exacerbate stream flow and add instability to the flow. In this study, the wavelet analysis technique was employed to identify temporal trend of air temperature and its impact upon forest stream flows in Lower Mississippi River Alluvial Valley (LMRAV). Four surface water monitoring stations, which locate near the headwater areas with very few land use disturbances and the long-term data records (60–90 years) in the LMRAV, were selected to obtain stream discharge and air temperature data. The wavelet analysis showed that air temperature had an increasing temporal trend around its mean value during the past several decades in the LMRAV, whereas stream flow had a decreasing temporal trend around its average value at the same time period in the same region. Results of this study demonstrated that the climate in the LMRAV did get warmer as time elapsed and the streams were drier as a result of warmer air temperature. This study further revealed that the best way to estimate the temporal trends of air temperature and stream flow was to perform the wavelet transformation around their mean values.

Published by Elsevier Ltd.

1. Introduction

Air temperature and rainfall pattern variations due to climate change during the past several decades has been linked to changes in hydrologic processes, including changes in stream flow, soil moisture, and surface runoff; increases in air temperature and atmospheric water vapor content; variations in rainfall patterns and intensity; and reduction in snow cover due to ice melt (NRC, 2008). It has been reported that precipitation change has caused wetting in the Northern Hemisphere mid-latitudes, drying in the Northern Hemisphere subtropics and tropics, and moistening in the Southern Hemisphere subtropics and deep tropics in recent decades (Zhang et al., 2007; Bates et al., 2008). Heavy rainfall has increased over most areas, whereas the very dry land area has increased more than doubled globally since 1970s (Bates et al., 2008). There is sufficient scientific evidence that temperature has increased over the last 15–20 years in both air and water (IPCC, 2013) and air temperature in 2100 is expected to be 1.1–6.4 °C higher than that in 1900 (Tank et al., 2009). Each of the past three decades has been successively warmer than any previous decades based on instrumental records and the decade of the 2000s has been the warmest (Tank et al., 2009).

Estimate of stream flow is essential to water resource management, water supply planning, environmental protection, and ecological restoration; while stream flow is an important indicator of hydrological responses to climate change. Thus, climate change can have significant effects on stream flow (NRC, 2008; Pyke et al., 2008; Ouyang et al., 2015). Climate variability and change exacerbate stream flow and add the uncertainty and instability to the flow. To mitigate the likelihood of future climate impacts on stream flow, water resource managers must be able to assess potential risks and opportunities, and where appropriate, implement good practices to adapt for future climatic conditions.

* Corresponding author.
E-mail address: youyang@fs.fed.us (Y. Ouyang).

http://dx.doi.org/10.1016/j.jenvman.2017.05.014
0301-4797/Published by Elsevier Ltd.

Lower Mississippi River Alluvial Valley (LMRAV) is located in the floodplain of the Mississippi River starting at Cairo, Illinois and continuing to south through Missouri, Kentucky, Arkansas, Tennessee, Mississippi, and Louisiana (Fig. 1). In the frontier days, the LMRAV was considered as a water-rich region that supported a high standard of living and biodiversity. In the past several decades, this region has, however, experienced increasing water stress due to agricultural irrigation, climate change, land use conversion, and population increase (Shields et al., 2008; Ouyang, 2012, Ouyang et al., 2015; YMD, 2015). Extensive usages of ground and surface waters have led to overdrafts and declines in water resources in the LMRAV (Konikow, 2013), which are increasingly common and are more likely to become severe in the future (YMD, 2015). Although much attention has been given to estimate climate change impacts upon stream flows (Parajuli, 2010; Nazif and Karamouz, 2014; Tan et al., 2014), very few efforts have been devoted to assessing such impacts in the LMRAV. Kim et al. (2014) assessed impacts of bioenergy crops and climate change on hydrometeorology in the Yazoo

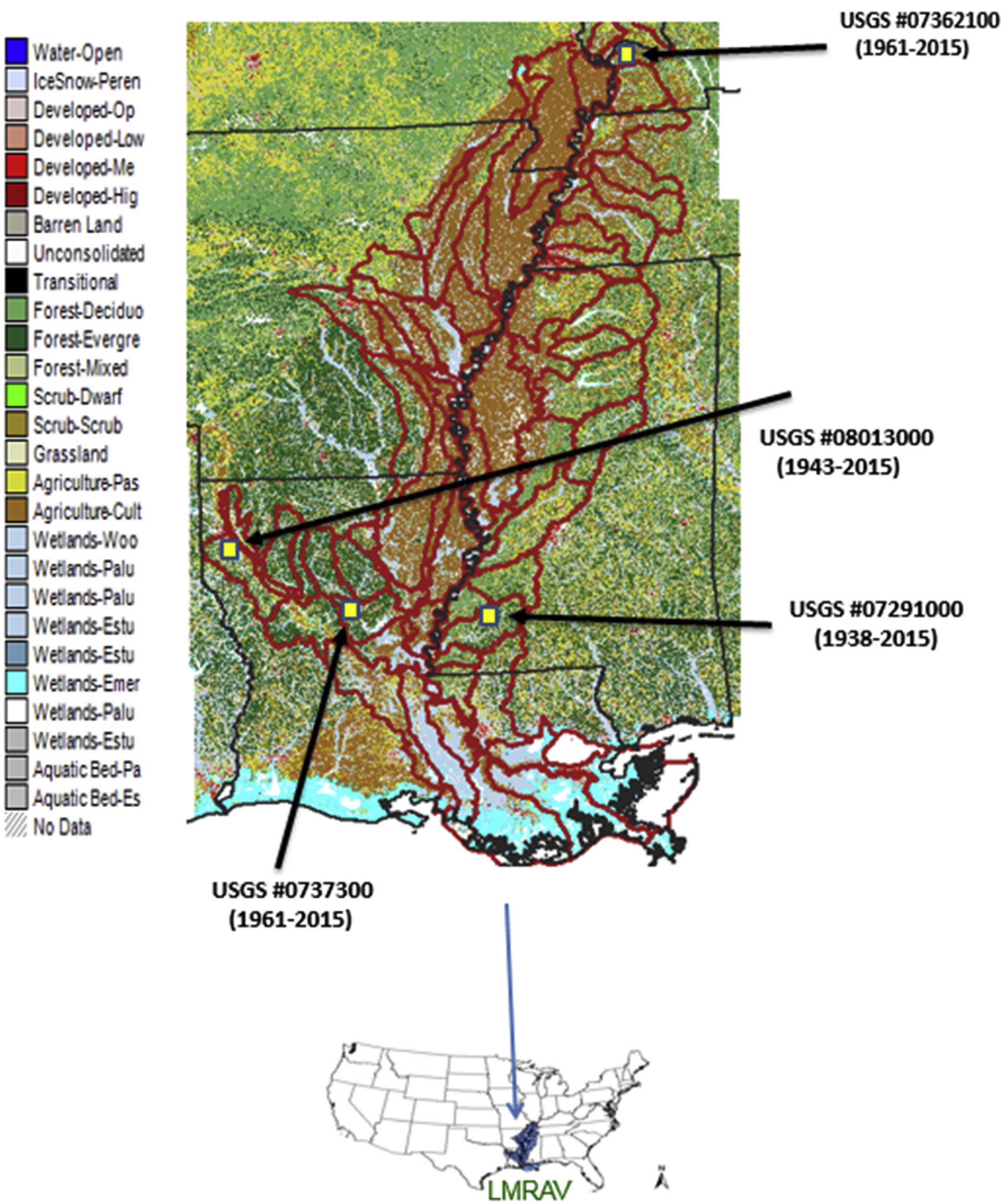

Fig. 1. Locations of Lower Mississippi River Alluvial Valley and the USGS surface water monitoring stations used in this study.

River Basin (YRB), Mississippi, which is a sub-basin within the LMRAV. These authors showed that climate change is likely to affect hydrometeorology more significantly than bioenergy crop production. Recently, Ouyang et al. (2015) estimated impacts of rainfall and air temperature variations due to future climate change upon hydrological characteristics in the YRB using BASINS-HSPF model. These authors found that monthly variations of water discharge, evaporative loss, and water outflow were primarily due to the monthly fluctuations of rainfall. A thorough literature search, however, has revealed that little effort has been devoted to identifying air temperature variation pattern due to climate change and its impact on stream flow in the LMRAV. With an increased understanding of the impacts of climate change upon water quantity and quality and their potential consequences to human consumption, terrestrial life, and forest ecosystem, there is a greater need to assess forest stream flow in watersheds in response to air temperature variation due to climate change. To this end, the wavelet analysis technique was employed to undertake this issue in this study.

The wavelet analysis technique, first coined by Grossman and Morlet (1984), has been extensively used in various fields including signal and image processing, meteorology, oceanography, hydrology, and water quality assessment (Grossman, 1985; Mallat, 1989; Daubechies, 1992; Labat, 2008; Maheswaran and Khosa, 2012; Nourani et al., 2014; Araghi et al., 2015). In essence, the wavelet transform (or analysis) technique is based on Fourier spectral analysis but with the adjustable frequency dependent window functions, generally called mother wavelets, to provide temporal and spatial resolution for non-stationary signals (Hwang et al., 2003). In recent years, wavelet analysis has been applied to estimate stream flows and river floods (Lim and Lye, 2004; Adamowski, 2008; Labat, 2008; Koirala et al., 2010). These studies have provided useful insights into the applications of wavelet analysis. A thorough literature search, however, revealed that insufficient efforts have been devoted to applying the wavelet analysis for assessment of climate change and its impacts upon hydrological processes, especially in the LMRAV.

The goal of this study was to apply the wavelet analysis technique to assess temporal variation of air temperature and its impact on forest stream flow using the LMRAV as a study site. The specific objectives were to: (1) identify temporal trends of air temperature; (2) estimate temporal variations of stream flows and their return periods; and (3) evaluate impacts of air temperature upon stream flows. Additionally, the approach on applying the wavelet analysis to achieve the aforementioned three objectives was discussed when appropriate.

2. Materials and methods

2.1. Study site and data acquisition

The watersheds selected in this study are located upstream of currently active U.S. Geological Survey (USGS) surface water monitoring stations, which are situated near the headwater areas of forest lands (Fig. 1) within the LMRAV. The headwater areas were selected because there are very few land use disturbances in these forest lands, which provide a unique opportunity for analyzing how the climate changes affect historic forest stream flows. Four USGS surface water monitoring stations, namely #07373000 in Big Creek at Pollock, LA, #07291000 in Homochitto, MS, #08013000 Calcasieu River near Glenmora, LA, and #07362100 in Smackover Creek near Smackover, AR, were selected in this study (Fig. 1). These stations are dominated by forestland use and have daily discharge data for the periods of records ranged from 60 to 90 years, and have very little or insignificant human disturbances based on our personal communications with the station managers. The discharge data are used to identify temporal patterns of stream flows as affected by climate change. To estimate the climate change for those four selected watersheds, we had also obtained the air temperature data from the nearby local weather stations from the US-EPA BASINS Meterological Database (http://www.epa.gov/exposure-assessment -models/basins-meterological-data).

2.2. Wavelet analysis

Mathematically, wavelet transform (or analysis) is a convolution of a signal with an analysis window (mother wavelet) shifted in time and dilated by a scale parameter. The continuous wavelet transform (CWT) of function $f \in L^2(\Re)$ is defined as the sum over all time of the real signal f(t) multiplied by the scaled (stretched or compressed), shifted versions of the wavelet function, ψ, as (Mallat, 1989):

$$WT_{a,b} = \int_{-\infty}^{\infty} f(t)\psi^*_{a,b}(t)dt \tag{1}$$

and

$$\psi_{a,b}(t) = \frac{1}{\sqrt{|a|}}\psi\left(\frac{t-b}{a}\right) \tag{2}$$

where a is the scale dilation parameter that determines the width of the wavelet, b is the translation parameter corresponding to the position of the wavelet, and * represents the complex conjugate. An elaborate review of wavelet analysis can be found elsewhere (Maheswaran and Khosa, 2012; Sang, 2013; Nourani et al., 2014).

There are several mother wavelet functions that can be used for stream flow analysis, including Haar wavelet, Daubechies wavelet, Symlet, Gaussian wavelet, Mexican Hat wavelet, and Morlet wavelet (Sang, 2013). However, selection of an appropriate wavelet function is a challenge and is largely dependent upon the problems at hand and the properties of wavelet functions (Maheswaran and Khosa, 2012). In this study, the Symlet and Mexican Hat functions were selected for analyzing air temperature and stream flow. The Symlets, also known as Daubechies' least-asymmetric wavelets, have the highest number of vanishing moments for a given support width and its associated scaling filters are near linear-phase filters (Nibhanupudi, 2003). These wavelets can be both orthogonal and biorthogonal and provide compact support (Maheswaran and Khosa, 2012). The Mexican Hat wavelet is the simple and commonly used wavelet function, which gives a “measure” of the second derivative of the analyzed signal (Liandrat and Moret-Bailly, 1990). The Mexican Hat wavelet has a real function (some wavelets are complex functions) and is easy to be implemented. All of the analyses were performed by MatLab v. R2015b (MathWorks, 2015) with its Wavelet Toolbox.

3. Results and discussion

3.1. General description of stream discharge and air temperature data

Daily changes in stream discharge for the four USGS stations selected in this study are shown in Fig. 2. This figure showed a typical characteristic of stream flow with peaks varied from year to year and location to location. The mean, minimum, and maximum discharges ranged, respectively, from 1.83 to 22.13 m^3/s, from 0.00 to 0.11 m^3/s, and 285.99–999.55 m^3/s among the four stations (Table 1). These discrepancies occurred because of the differences in hydrogeology and climate conditions among the stations.

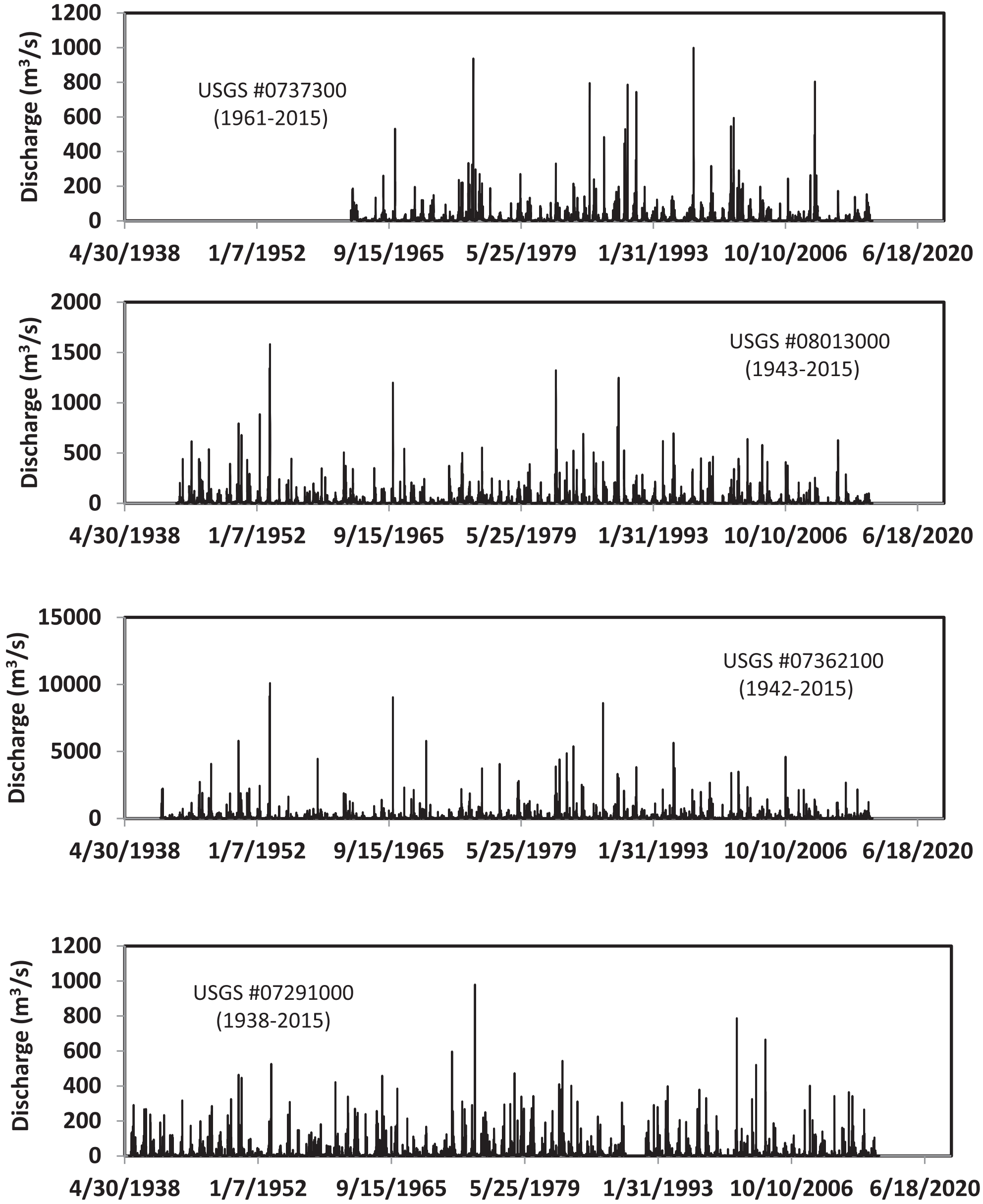

Fig. 2. Daily discharges for the four USGS stations selected in this study.

Table 1
Descriptive statistics of stream discharge and air temperature for the four USGS stations used in this study.

Parameter	USGS #07291000		USGS #07362100		USGS #07373000		USGS #08013000	
	Discharge (m^3/s)	Air temperature (°C)	Discharge (m^3/s)	Air temperature (°C)	Discharge (m^3/s)	Air temperature (°C)	Discharge (m^3/s)	Air temperature (°C)
Mean	7.28	18.82	11.78	13.73	1.83	18.26	22.13	18.61
Standard Error	0.15	0.04	0.23	0.06	0.05	0.05	0.39	0.05
Median	2.27	20.11	2.52	14.78	0.85	19.44	4.84	19.89
Mode	1.42	27.11	0.34	24.22	0.51	26.89	0.99	27.17
Standard Deviation	24.48	7.65	31.93	9.89	6.36	8.00	54.42	7.72
Sample Variance	599.44	58.45	1019.57	97.80	40.45	64.04	2961.69	59.55
Kurtosis	273.51	−0.60	228.57	−0.78	720.81	−0.75	174.22	−0.68
Skewness	13.15	−0.56	11.59	−0.37	22.13	−0.47	9.99	−0.52
Range	979.42	42.72	999.55	54.78	285.88	43.83	1582.44	44.00
Minimum	0.31	−10.67	0.00	−20.61	0.11	−10.50	0.42	−9.67
Maximum	979.73	32.06	999.55	34.17	285.99	33.33	1582.86	34.33
Sum	199643.71	549806.61	228395.53	406278.00	35447.52	433582.28	429023.98	414551.28
Count	27414	29220	19383	29585	19383	23741	19383	22280
Confidence Level (95.0%)	0.29	0.09	0.45	0.11	0.09	0.10	0.77	0.10

Skewness is a measure of the lack of symmetry and a dataset is symmetric if it looks the same to the left and right from the center point. Table 1 showed that the stream flows from all stations had large skewness in the following order: USGS #07373000 (22.13) > USGS #07291000 (13.15) > USGS #07362100 (11.59) > USGS #08013000 (9.99). Kurtosis is a measure of whether the data are peaked or flat relative to a normal distribution. A dataset with high kurtosis tend to have a distinct peak near the mean, decline rather rapidly, and has a heavy tail, whereas a dataset with low kurtosis tends to have a flat top near the mean rather than a sharp peak. Overall, high kurtosis was observed for stream flows from all of the four stations and they were in the same order as for

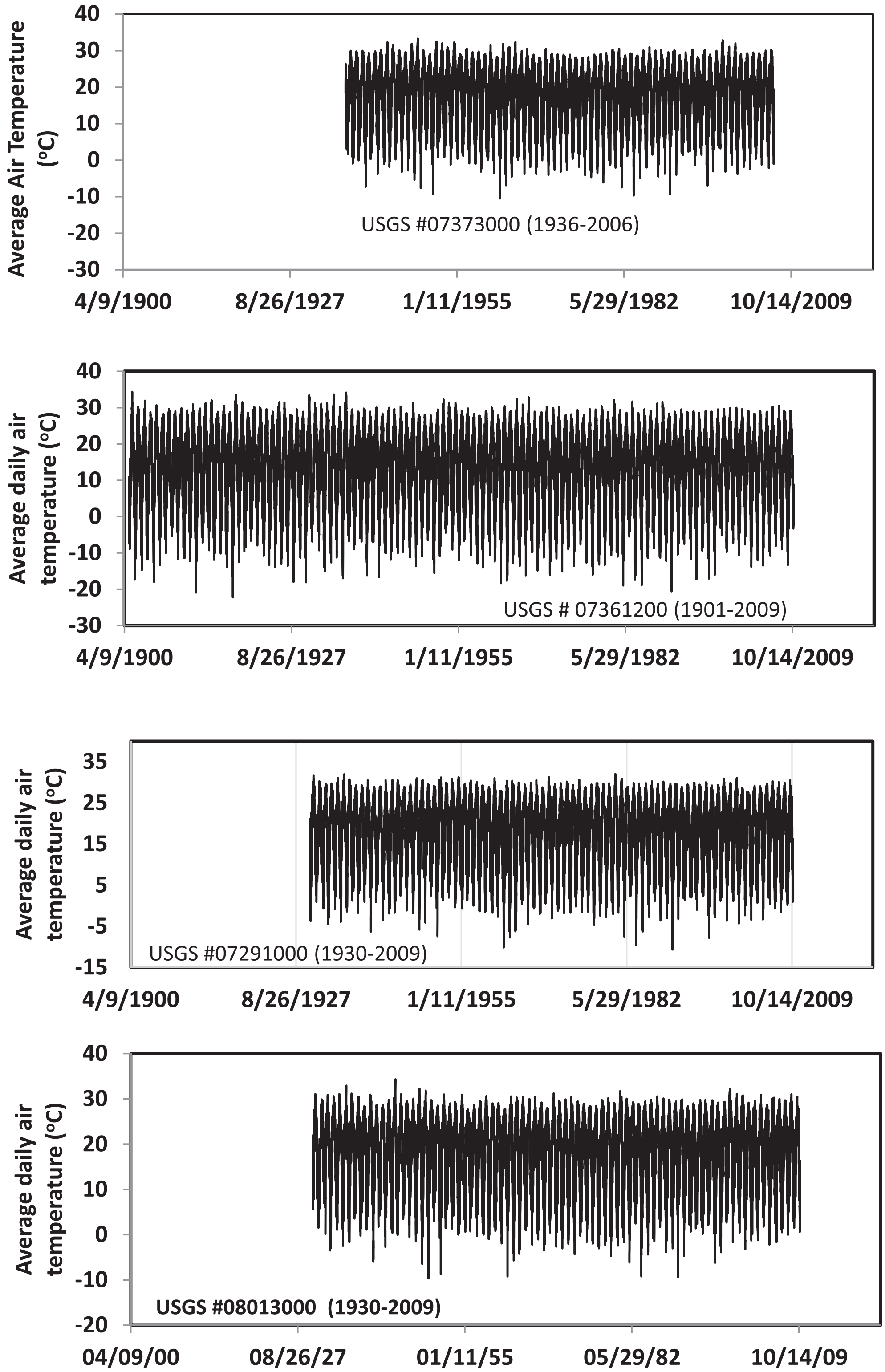

Fig. 3. Daily average air temperature for the four USGS stations used in this study.

the case of skewness (Table 1): USGS #07373000 (720.81) > USGS #07291000 (273.51) > USGS #07362100 (228.57) > USGS #08013000 (174.22). Results indicated that stream flows from these watersheds were highly dynamic and non-linear.

Analogues to the case of stream flow, daily changes in air temperature for the four stations showed a typical pattern with temperature variations from time to time and location to location (Fig. 3). The mean, minimum, and maximum daily air temperature ranged, respectively, from 13.73 to 18.82 °C, from −20.61 to −9.67 °C, and from 34.33 to 32.06 °C among the four stations (Table 1). These differences occurred due to the difference in geographical locations. Unlike the case of stream flow, only slight differences in skewness and kurtosis were observed for air temperature among the four stations (Table 1). Results revealed that the temporal variations of air temperature through the years were more symmetric than that of stream flow in the LMRAV.

Although the above findings provided very good graphical views and descriptive statistics on stream flow and air temperature for the watersheds selected in this study, they could not answer the flow questions: Did the climate change impacts on stream flows in

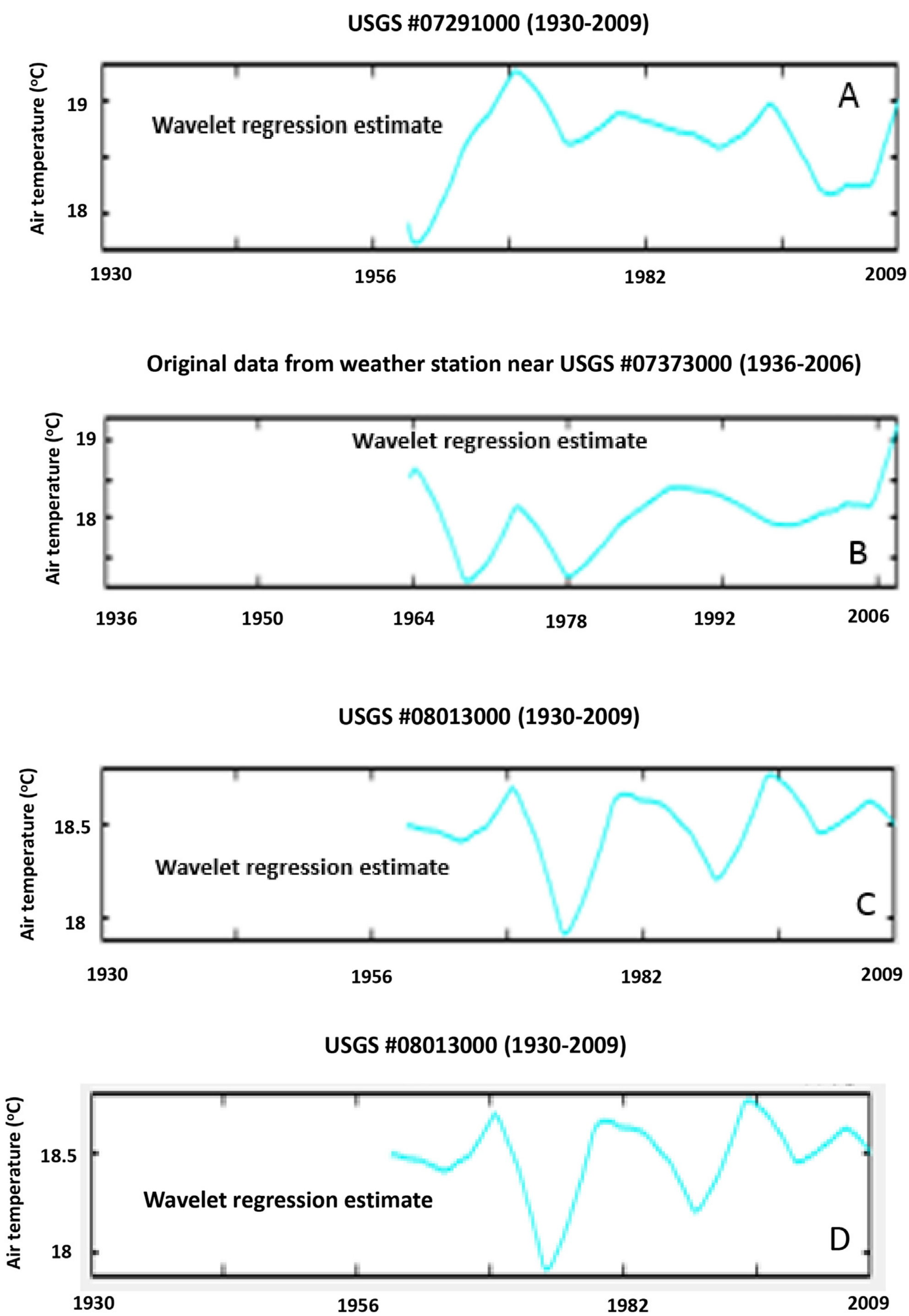

Fig. 4. Wavelet analysis of daily air temperature trends for the four USGS Stations.

the LMRAV? If so, how did such a change affect the forest stream flows in this region? For this reason, the wavelet analysis technique was employed to answer these questions as presented in the following sections.

3.2. Temporal trend of air temperature

Air temperature is one of the most important indicators for estimating climate change. However, a graphical view of daily air temperature changes (Fig. 3) provided little to no information on their temporal trends during the past several decades in the LMRAV. In contrast, with the application of wavelet transformation, such temporal trends were clearly identified as shown in Fig. 4. This figure was constructed through de-noise using wavelet regression estimation with the Symlet function at Level 5. Level 5 was chosen for decomposition (de-noise) because this level can estimate the air temperature trends around their mean values. The mean air temperatures were 18.82 °C for USGS #07291000, 13.73 °C for USGS #07362100, 18.26 °C for USGS #07373000, and 18.61 °C USGS #08013000 (Table 1). Mean air temperature variations are a good indicator for assessing climate change.

Fig. 4A shows the wavelet regression estimate of daily air

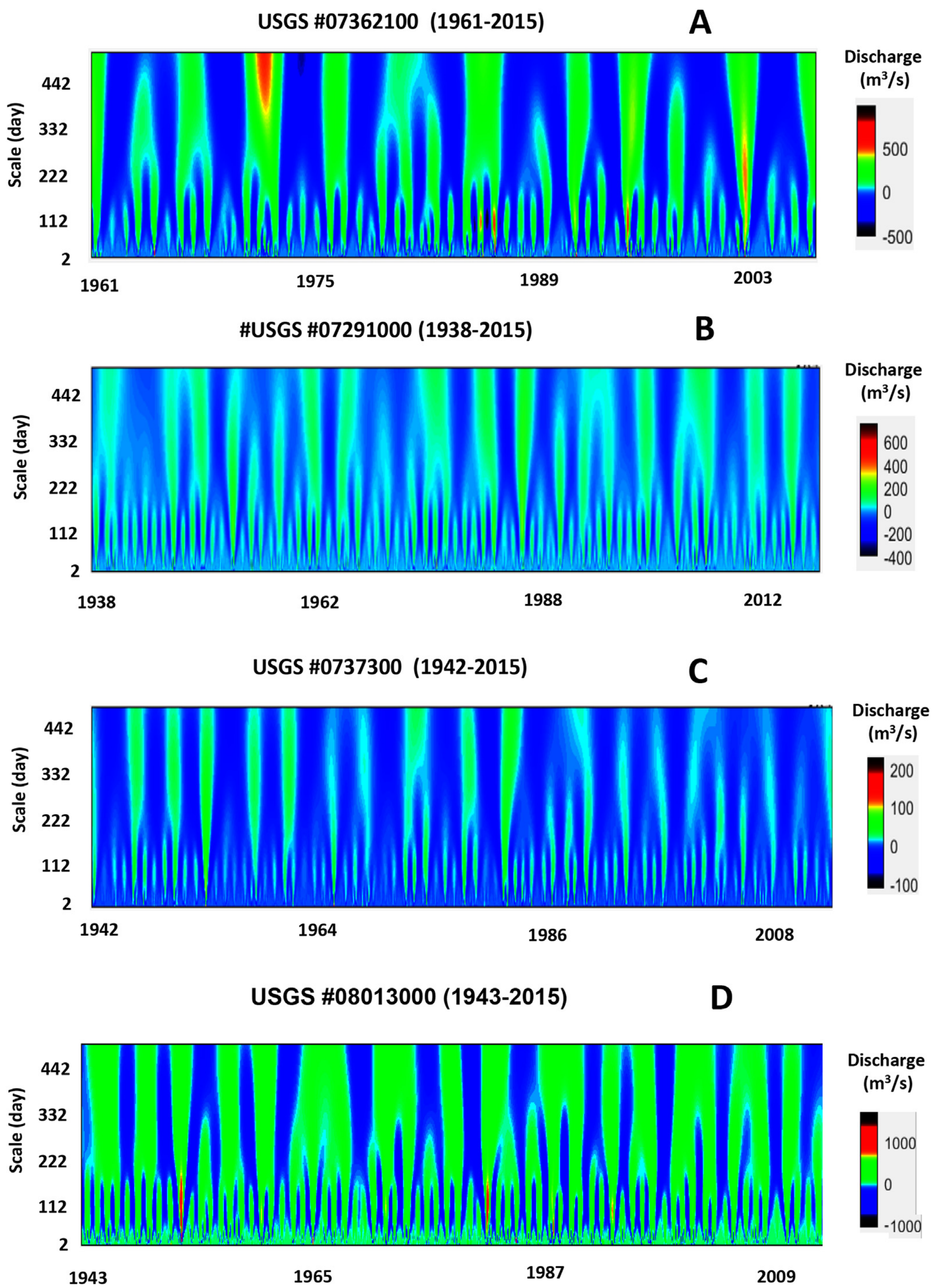

Fig. 5. Wavelet scale-grams of daily stream flows for the four USGS stations.

temperature near the USGS station #07291000 from 1930 to 2009 (79 years). This estimate was obtained through wavelet de-noised and filtration with Symlet function using the original measured data shown in Fig. 3. Result showed that the air temperature fluctuated around its mean value (18.82 °C) with an increase trend from 1956 to 2009. Similar results were obtained for the rest of three USGS stations (Fig. 4B–D). That is, the air temperature around the mean values for the rest of the three stations had an increased trend during the last several decades. Results demonstrated that on average the climate in the LMRAV did get warmer as time elapsed. The warmer climate in the LMRB is a prerequisite for assessing climate change impacts on forest stream flows.

It should be noted that the approach used to identify the temporal trend of air temperature is somewhat novel since this approach had not yet been reported in the literature. More specifically, one may use different wavelet functions at different transformation levels (e.g., d_1 to d_8) with different air temperature ranges to obtain a fluctuated and inconsistent air temperature trend as time elapsed. Our study found that a best way to obtain a consistent temporal trend of air temperature was to perform the wavelet transformation around the mean air temperature. Mean air temperature variations through the years are considered as a good

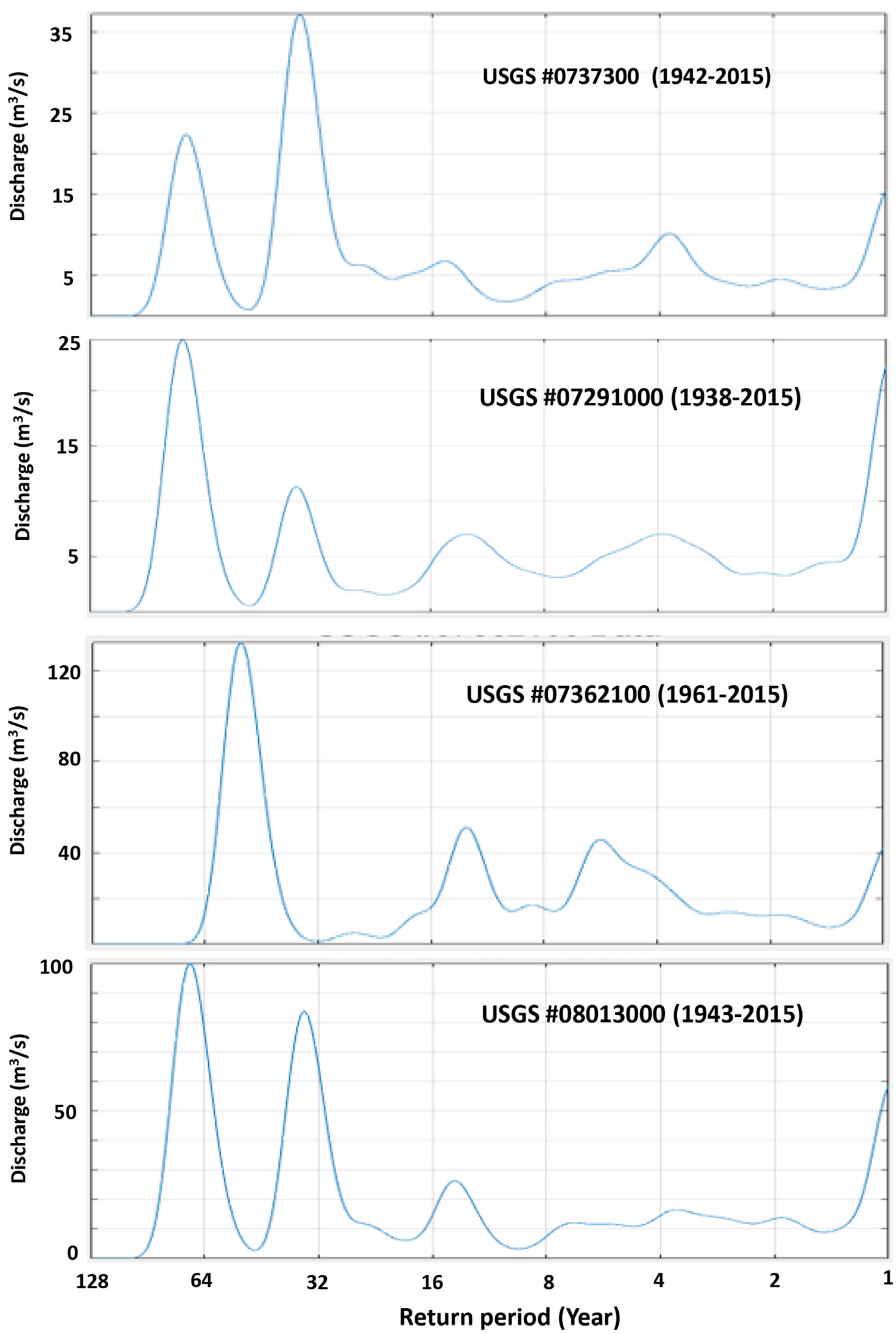

Fig. 6. Wavelet spectral analysis of stream flow returning periods for the four USGS stations.

variable for climate change assessment.

3.3. Temporal variation of stream flow

Temporal variations of stream discharge for the four USGS stations are shown in Fig. 5. This figure was constructed using the Mexican Hat wavelet transformation of stream discharges based on time scale. The contours on the figure are the wavelet coefficients, representing the extent and magnitude of the discharges. For Station #07362100, the frequency of stream discharge at a rate of 250 m^3/s occurred every 112 days in almost every year, while only about four occurrences of stream discharge at the same rate (250 m^3/s) were found for the time scale ranged from 222 to 442 days in every 14 years (Fig. 5A). In addition, a hot spot (at high discharge rate of above 500 m^3/s) was identified at a time scale around 442 days in 1970. Results revealed that the stream flow with a rate of 250 m^3/s in this watershed could occur every 112 days for most of the years. This finding could be difficult to deduce by using other traditional methods and it is important to water resource managers for estimating river water quantity and establishing water supply planning.

Similar frequency pattern with different discharge rates were obtained for other three USGS stations. That is, the discharge rates occurred every 112 days in almost every year were 200 m^3/s for Station #07291000, 50 m^3/s for Station #07373000, and 500 m^3/s for Station #08013000. It is apparent that the stream discharge

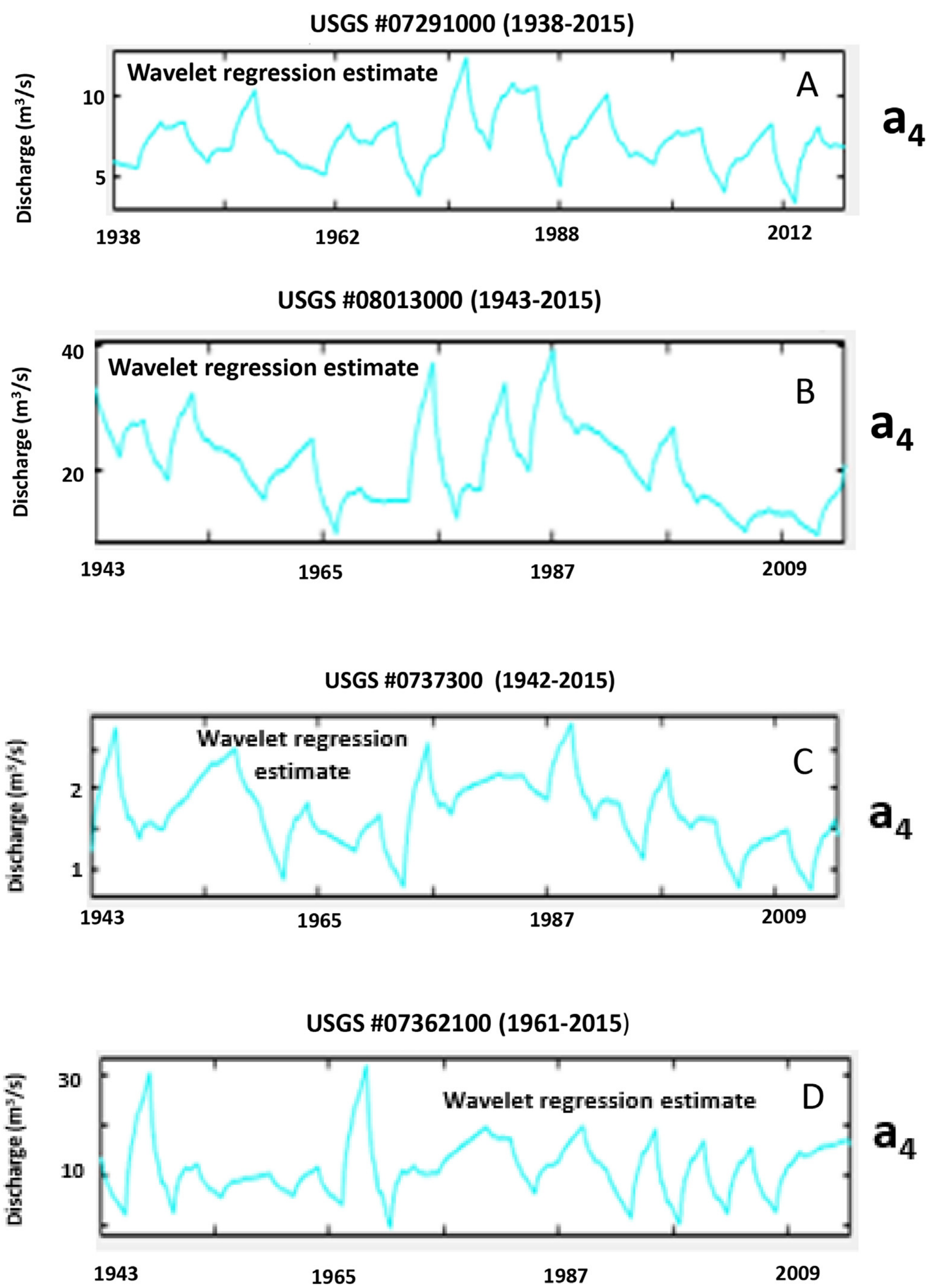

Fig. 7. Wavelet analysis of stream flow trends for four USGS Stations.

rates occurred every 112 days in almost every year among the four stations were in the following order: Station #08013000 > Station #07362100 > Station #07291000 > Station #07373000, which had the same order as the average discharges among the stations (Table 1).

Return periods of stream discharge for the four stations during the past several decades are shown in Fig. 6. Results from this figure were obtained using wavelet spectral analysis. The stream discharge rates returned in every one year were 10, 23, 40, and 57 m^3/s, respectively, for Stations #0737300, #07291000, #07362100, and #08013000. The discrepancy in discharge rates at the one-year returning period among the stations was proportional to the mean discharges among the stations. In other words, the higher the mean discharge rate was, the higher the returning discharge rate at a one-year returning period would be. However, this was not true for a multiple-year returning period. For example, the discharge rate was about 9 m^3/s for #0737300 for a 4-year returning period but was 7.5 m^3/s for #07291000 for the same returning period although the average discharge was higher for #07291000 than for #0737300. An exact reason for this phenomenon remains to be investigated.

3.4. Impact of climate change on stream flow

Impact of climate change on stream flow in the LMRAV during the last several decades was estimated through investigating the temporal trends of stream discharge in response to those of air temperature. Our hypothesis is that as the air temperature increases with time, the LMRAV become warmer and the streams become drier, which is primarily a result of climate change impact because the four stations chosen in this study are from headwater forest lands with little human and natural disturbances. Temporal trends of stream discharge for the four stations were shown in Fig. 7. This figure was constructed through de-noise (filtration) using wavelet regression estimation with the Symlet function at Level 4 (a_4). Level 4 was used for decomposition (de-noise) because this level estimated the trends of stream discharge around their average values. The average stream discharges were 7.28 m^3/s for USGS #07291000, 11.78 m^3/s for USGS #07362100, 1.83 m^3/s for USGS #07373000, and 22.13 m^3/s USGS #08013000 (Table 1). Variations of average stream discharge through the years were used to estimate the stream flow status due to climate change in this study.

Changes in daily stream discharges around their average value at Station #07291000 from 1938 to 2015 were shown in Fig. 7A. In general, the daily stream discharges around the average value decreased as time elapsed, especially from 1974 to 2015. Such a decrease in stream discharge corresponded well to the increase in air temperature around its mean value (Fig. 4A). Result indicated that a warmer air temperature during the past several decades could be one of the factors for a drier stream in this watershed. Similar results were found for the other three stations used in this study (Fig. 7B–D). In other words, the increases in air temperatures around their mean values had a negative correlation to the decreases in stream discharges around their average values. Results further confirmed that stream flows in the LMRAV were affected by climate change due to warmer air temperature.

Analogues to the case for identifying the temporal trend of air temperature, we also found that a best way to estimate the temporal trend of stream flow was to perform the wavelet transformation around the average stream discharge. This approach is important when applying wavelet analysis to identify the temporal trends of air temperature and stream flow. Further study is warrant to applying the same approach for identifying temporal trends for other climate and hydrological variables.

4. Summary

Wavelet analysis technique has been applied to assess climate change and its impact on forest stream flows. Four USGS surface water monitoring stations in the LMRAV were selected to obtain discharge and air temperature data for the analysis. These stations are situated near the headwater areas of forest lands and were selected because they have a long-term discharge data ranged from 60 to 90 years with very few land use disturbances, which provide a unique opportunity for analyzing how the climate change affects the historic forest stream flows.

Although the descriptive statistical analysis provided some useful information on stream flow and air temperature, it could not tell if the climate change occurred in the LMRAV and how this change affects stream flow. However, with the application of wavelet analysis, an increasing temporal trend of air temperature around its mean value was detected for the past several decades in this region. Results demonstrated that the climate in the LMRAV did get warmer as time elapsed.

In contrast, a decreasing temporal trend of stream discharge around its mean value was detected for the past several decades in the LMRAV. The decrease in stream flow corresponded well to the increase in air temperature during the same time period. Results confirmed that stream flows in the LMRAV were affected by climate change due to a warmer air temperature.

A best way to estimate the temporal trends of air temperature and stream flow was to perform the wavelet transformation around their mean values. Further study is therefore warrant to applying the same approach to identify temporal trends for other climate and hydrological variables.

Acknowledgement

The study was supported by USDA-NIFA-AFRI competitive grant program (Project # 67020-21407).

References

Adamowski, J., 2008. River flow forecasting using wavelet and cross-wavelet transform models. Hydrol. Proc. 22, 4877–4891.
Araghi, A., Baygi, M.M., Adamowski, J., Malardb, J., Nalley, D., Hasheminia, S.M., 2015. Using wavelet transforms to estimate surface temperature trends and dominant periodicities in Iran based on gridded reanalysis data. Atmos. Res. 155, 52–72.
Bates, B.C., Kundzewicz, Z.W., Wu, S., Palutikof, J.P., 2008. Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change. IPCC Secretariat, Geneva, p. 210.
Daubechies, I., 1992. Ten Lectures on Wavelets. Society for Industrial and Applied Mathematics, Philadelphia, Pennsylvania, p. 61.
Grossman, A., 1985. Wavelet transform and edge detection. In: Blanchard, Ph, Streit, L., Hazewinkel, M. (Eds.), Stochastic Processes in Physics and Engineering. Reidel, Dordrecht.
Grossman, A., Morlet, J., 1984. Decomposition of hardy functions into square integrable wavelets of constant shape. SIAM J. Math. Anal. 15, 723–736.
Hwang, P.A., Huang, N.E., Wang, D.W., 2003. A note on analyzing nonlinear and nonstationary ocean wave data. Appl. Ocean. Res. 25, 187–193.
IPCC, 2013. Climate Change 2013: the Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the International Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. https://www.ipcc.ch/report/ar5/wg1/.
Kim, H.K., Parajuli, P.B., To, F., 2014. Assessing impacts of bioenergy crops and climate change on hydrometeorology in the Yazoo River Basin, Mississippi. Agric. For. Meteorol. 169, 61–73.
Koirala, S.K., Gentry, R.W., Mulholland, P.J., Perfect, E., Schwartz, J.S., 2010. Time and frequency domain analyses of high-frequency hydrologic and chloride data in an east Tennessee watershed. J. Hydrol. 387, 256–264.
Konikow, L.F., 2013. Groundwater Depletion in the United States (1900–2008). U.S. Geological Survey Scientific Investigations Report 2013–5079, p. 63. Available at. http://pubs.usgs.gov/sir/2013/5079.
Labat, D., 2008. Wavelet analysis of the annual discharge records of the world's largest rivers. Adv. Water Res. 31, 109–117.
Liandrat, J., Moret-Bailly, F., 1990. The wavelet transform: some applications to fluid dynamics and turbulence. Eur. J. Mech. B, Fluids 9, 1–19.

Lim, Y.H., Lye, L.M., 2004. Wavelet Analysis of tide-affected low streamflows series. J. Data Sci. 2, 149–163.
Maheswaran, R., Khosa, R., 2012. Comparative study of different wavelets for hydrologic forecasting. Comput. Geosci. 46, 284–295.
Mallat, S., 1989. A theory formultiresolution signal decomposition: the wavelet representation. IEEE Trans. Pattern Analy. Mach. Intellig 11, 674–683.
MathWorks, 2015. Wavelet Toolbox: User's Guide (R2015b). Accessed February 15, 2016 from. http://www.mathworks.com/help/wavelet/index.html.
Nazif, S., Karamouz, M., 2014. Evaluation of climate change impacts on streamflow to a multiple reservoir system using a data-based mechanistic model. J. Water Clim. Change 5, 610–624.
Nibhanupudi, S., 2003. Signal Denoising Using Wavelets. PhD Thesis. University of Cincinnati.
Nourani, V., Baghanam, A.H., Adamowski, J., Kisi, O., 2014. Applications of hybrid wavelet-artificial intelligence models in hydrology: a review. J. Hydrol. 514, 358–377.
NRC, 2008. Hydrologic Effects of a Changing Forest Landscape. National Research Council of the National Academies. The National Academies Press, Washington DC, USA, p. 168.
Ouyang, Y., 2012. A potential approach for low flow selection in water resource supply and management. J. Hydrol. 454–455, 56–63.
Ouyang, Y., Zhang, J.E., Li, Y.D., Parajuli, P.B., Feng, G., 2015. Impacts of rainfall and air temperature variations due to climate change upon hydrological characteristics: a case study. J. Water Clim. Change. http://dx.doi.org/10.2166/wcc.2015.101.
Parajuli, P.B., 2010. Assessing sensitivity of hydrologic responses to climate change from forested watershed in Mississippi. Hydrol. Proc. 24, 3785–3797.
Pyke, C.R., Najjar, R.G., Adams, M.B., Breitburg, D., Kemp, M., Hershner, C., Howarth, R., Mulholland, M., Paolisso, M., Secor, D., Sellner, K., Wardrop, D., Wood, R., 2008. Climate Change and the Chesapeake Bay: State-of-the-science Review and Recommendations. A Report from the Chesapeake Bay Program Science and Technical Advisory Committee (STAC), Annapolis, MD, p. 59.
Sang, Y.F., 2013. A review on the applications of wavelet transform in hydrology time series analysis. Atmos. Res. 122, 8–15.
Shields Jr., F.D., Cooper, C.M., Testa III, S., Ursic, M.E., 2008. Nutrient Transport in the Yazoo River Basin, Research Report 60. US Dept. Of Agriculture Agricultural Research Service National Sedimentation Laboratory, Oxford, Mississippi, USA. http://www.ars.usda.gov/SP2UserFiles/person/5120/NSLReport60.pdf.
Tan, M.L., Ficklin, D.L., Ibrahim, A.L., Yusop, Z., 2014. Impacts and uncertainties of climate change on streamflow of the Johor River Basin, Malaysia using a CMIP5 general circulation model ensemble. J. Water Clim. Change 5, 676–695.
Tank, A.M.G., Zwiers, F.W., Zhang, X., 2009. Guidelines on Analysis of Extremes in a Changing Climate in Support of Informed Decisions for Adaptation. Climate Data and Monitoring, WCDMP-No. 72, World Meteorological Organization, WMO-TD No. 1500.
YMD (Yazoo Mississippi Delta Joint Water Management District), 2015. Groundwater monitoring, a primary YMD activity for 25 years. http://myemail.constantcontact.com/YMD-Joint-Water-Management-District-May-21–2015.html?soid=1120967545567 &aid= AuOD6KeG9Sc. E-Newsletters, May 12, 2015.
Zhang, X., Zwiers, F.W., Hegerl, G.C., Lambert, F.H., Gillett, N.P., Solomon, S., Stott, P.A., Nozawa, T., 2007. Detection of human influence on twentieth-century precipitation trends. Nature 448, 461–465.