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Progress in Natural Science 18 (2008) 1383–1393
Progress in Natural Science
www.elsevier.com/locate/pnsc

Interdecadal trend turning of global terrestrial temperature and precipitation during 1951–2002

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Received 28 January 2008; received in revised form 1 March 2008; accepted 2 June 2008

Abstract

A grid-by-grid counting of interdecadal trend turning (ITT) of annual mean surface air temperature (SAT) and total precipitation at 67,359 terrestrial grids in the period 1951–2002 is presented. An analysis of the last ITTs of SAT and total precipitation in the period, in the context of both occurrence time and linear trends after the breakpoint, indicates that a warming trend has become highly significant across most reagent of the world in the late 20th Century. Most terrestrial grids have recorded an ITT of total precipitation in either the 1970s or 1980s, and 45.7% of the terrestrial grids in the study have seen a decreasing trend in total annual precipitation after the breakpoint, with the remaining 54.3% having experienced an increasing trend. Basically, global terrestrial regions have experienced either an increasingly warm and dry climate or an increasingly warm and wet climate. An analysis of ITT of regional mean SAT and total precipitation in 22 regions shows that the Northern American continent has become increasingly warm and dry after the last interdecadal breakpoint. Meanwhile, the African continent has become increasingly warm and wet, with both Europe and most of Asia having the same trend. Southern South America and the West of Australia have experienced an opposite trend in climate, becoming increasingly cold and wet.

Keywords: Global terrene; Surface air temperature; Precipitation; Interdecadal trend turning

1. Introduction

As a result of global warming, climate change has had an increasing impact on the environment, water resources, industrial and agricultural activities, and human lives. Surface air temperature (SAT) and precipitation, in particular, are two key concerns. There have been numerous studies on understanding SAT and precipitation variations in different regions. For example, there have been studies on the intra- to multi-decadal variability of SAT and precipitation in the United States [1,2], SAT variations for the United States compared with variations around the world [3], SAT and precipitation variability in Europe [4–6], precipitation variability in South America [7–9], climate variations in China [10–12], and drought variability in West Africa, Asia, Australia, and around the world [13–18]. "*Climate Change 2007: the Physical Science Basis*" [19] reported by the Intergovernmental Panel on Climate Change (IPCC) has raised concerns over climate change. Based on the latest findings on SAT and precipitation variability, the report includes an undisputed statement on global climate warming: human activity is largely responsible for the warming. Observational data collected from 1850 to 2006 show that there was a warming process between the 1940s and 1960s and another warming process in the 1980s. Statistical analysis of global mean precipitation in the period 1900–2005 indicates an insignificant long-term variability trend, with a wet trend before the 1950s, a dry trend for the

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doi:10.1016/j.pnsc.2008.06.002

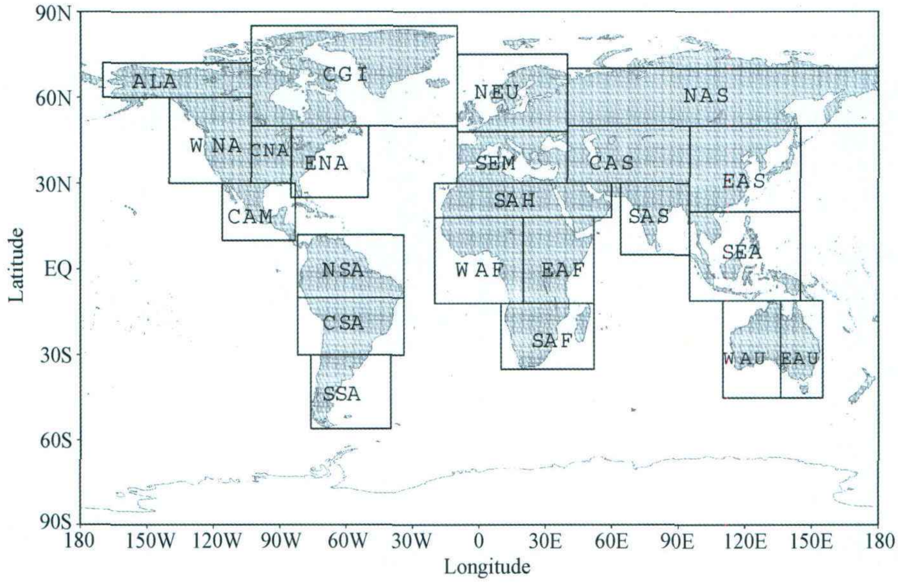

Fig. 1. Distribution of CRU data and associated regions.

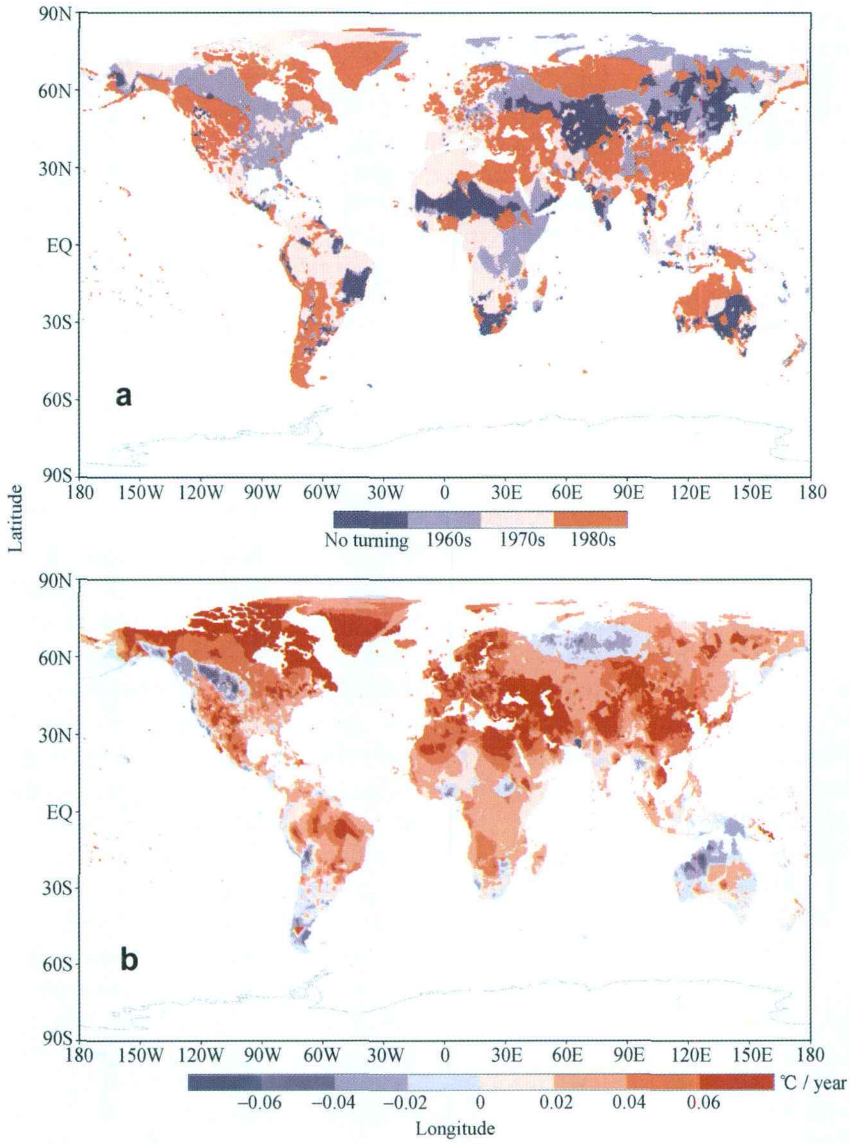

Fig. 2. Occurring time of the latest ITTs of annual mean SAT in 1951–2002 (a), and linear trends after the breakpoint (b).

1950s–1990s, and another wet trend after the 1990s. The report also presents an analysis of linear trend of annual mean SAT and total precipitation in different regions during 1901–2005 and 1979–2005, indicating somewhat different linear trends bearing regional signatures.

Analyzing the linear trend of time series is a methodology frequently used in climate change studies, allowing better understanding of a basic variability trend in a given period of time. As far as a climate series with a longer temporal scale is concerned, linear trend may not be able to depict all the fluctuations in climate change. The Fourth IPCC Assessment Report points out that not all variability in SAT and precipitation is linear. Such variability, more often than not, represents varied features at different time periods [19]. On the other hand, more and more published studies have shown that climate has noticeable interdecadal variability. Interdecadal climate variability is an important reference for interannual climate change and is also a disturbance in long-term climate change. Interdecadal climate variability has become a hot topic for climate change studies since the 1980s. It is also an important part of CLIVAR (Climate Variability and Predictability Experiment of the World Climate Research Program). In this context, a study of the changes in global SAT and precipitation in the past 50-odd years on an interdecadal time scale will elucidate the evolution and abrupt changes in the climate and is, therefore, of practical and scientific importance.

2. Data and methodology

This study used monthly precipitation and SAT data (spatial resolution of 0.5° × 0.5° and covering the period 1901–2002) provided by the University of East Anglia Climatic Research Unit (CRU) [20–23]. Only the annual total precipitation and mean SAT data for 1951–2002 have been included in the analysis in an attempt to make the final results more reliable. Meanwhile, mainly according to the definition in the Fourth IPCC Assessment Report [19], the entire terrestrial system (the Antarctic is not included) was divided into 22 regions (Fig. 1): (1) Alaska (ALA, 170°W–103°W, 60°N–72°N), (2) East Canada, Greenland, and Iceland (CGI, 103°W–10°W, 50°N–85°N), (3) Western North America (WNA, 140°W–103°W, 30°N–60°N), (4) Central North America (CNA, 103°W–85°W, 30°N–50°N), (5) Eastern North America (ENA, 85°W–50°W, 25°N–50°N), (6) Central North America (CAM, 116°W–83°W, 10°N–30°N), (7) Northern South America (82°W–34°W, 10°S–12°N), (8) Central South America (CSA, 82°W–34°W, 30°S–10°S), (9) Southern South America (76°W–40°W, 56°S–30°S), (10) Northern Europe (NEU, 10°W–40°E, 48°N–75°N), (11) Southern Europe and the Mediterranean (SEM, 10°W–40°E, 30°N–48°N), (12) the Sahara (20°W–60°E, 18°N–30°N), (13) West Africa (WAF, 20°W–20°E, 12°S–18°N), (14) East Africa (EAF, 10°E–52°E, 35°S–12°S), (15) South Africa (SAF, 85°W–50°W, 25°N–50°N), (16) Northern Asia (NAS, 40°E–180°, 50°N–70°N), (17) Central Asia (CAS, 40°E–95°E, 30°N–50°N), (18) East Asia (EAS, 95°E–145°E, 20°N–50°N), (19) South Asia (SAS, 64°E–95°E, 5°N–30°N), (20) Southeast Asia (SEA, 95°E–145°E, 11°S–20°N), (21) West Australia (WAU, 110°E–136°E, 45°S–11°S), and (22) East Australia (EAU, 136°E–155°E, 45°S–11°S). We determined annual time series of SAT

Table 1
Ratio of the number of grids with various ITT of SAT to the total number of grids in each region (%)

Time	No breakpoint		1960s		1970s		1980s	
Trend	<0	>0	<0	>0	<0	>0	<0	>0
ALA	0.00	4.03	0.00	43.28	0.00	36.01	13.13	3.54
CGI	0.00	0.00	0.00	16.01	0.03	30.07	2.23	51.67
WNA	0.00	3.63	0.00	11.00	0.04	20.89	42.78	21.67
CNA	0.00	0.00	0.00	55.28	0.00	27.01	12.08	5.62
ENA	0.00	0.16	0.00	62.73	0.00	20.24	4.66	12.21
CAM	0.00	4.84	0.00	14.83	0.10	59.03	13.12	8.07
NSA	0.00	8.07	0.11	2.98	0.04	74.88	5.67	8.25
CSA	0.00	19.99	1.54	2.23	0.45	37.76	13.15	24.89
SSA	0.00	9.25	1.80	3.61	4.55	5.64	58.15	17.01
NEU	0.00	5.08	0.00	29.27	0.00	23.34	0.29	42.02
SAM	0.00	0.20	0.00	1.54	0.00	57.25	0.04	40.97
SAH	0.00	12.39	0.47	10.38	0.44	42.83	0.03	33.47
WAF	0.00	30.88	0.00	9.33	0.00	47.44	9.33	3.00
EAF	0.00	12.08	0.00	56.48	0.16	20.19	7.29	3.79
SAF	0.00	19.02	0.00	10.24	0.00	51.10	14.42	5.21
NAS	0.00	22.97	0.00	31.77	0.00	11.26	25.97	8.03
CAS	0.00	27.61	0.00	8.20	0.00	19.31	0.07	44.81
EAS	0.00	12.24	0.00	16.72	0.00	16.29	0.55	54.20
SAS	0.00	14.56	0.00	20.95	0.00	27.60	11.73	25.16
SEA	0.00	9.75	0.00	15.97	0.00	39.66	24.22	10.40
WAU	0.00	13.37	0.00	0.19	11.73	9.71	57.06	7.94
EAU	0.00	44.98	0.00	0.41	15.60	4.55	22.32	12.14

and total precipitation for each region in an attempt to facilitate discussion of trend changes in these regions.

Tomé and Miranda [24] developed a piecewise linear fitting model (PLFIM) to determine breakpoints in climate change. The model uses a least-squares approach to compute the best continuous set of straight lines that fit a given time series, subject to a number of constraints on the minimum distance between breakpoints and on the minimum trend change at each breakpoint. The approach uses a number of combinations for computing the piecewise linear trends of each combination of time segments in a given time series, and judges whether a breakpoint occurs using the two above constraints. The model also allows an optimized combination that meets trend turning conditions using the methodology of statistical analysis, with which one can test trend turnings and linear trends of each time segment in a given time series. Using this approach, we previously analyzed interdecadal trend turning (ITT) of the climate in mainland China and obtained useful results [25]. This paper reports a detailed analysis of ITT for global terrestrial SAT and precipitation in the past 50-odd years, using the same model. Two conditions were preset to judge the occurrence of ITT: (1) the positive/negative signs of linear trends of two continuous time segments are different and (2) the time span between the two breakpoints is not less than 15 years.

3. Spatial distribution of the ITT of SAT

We examined interdecadal trend breakpoints of annual mean SAT in 67,359 terrestrial grids for 1951–2002. We also analyzed the linear trends in and after the last ITT.

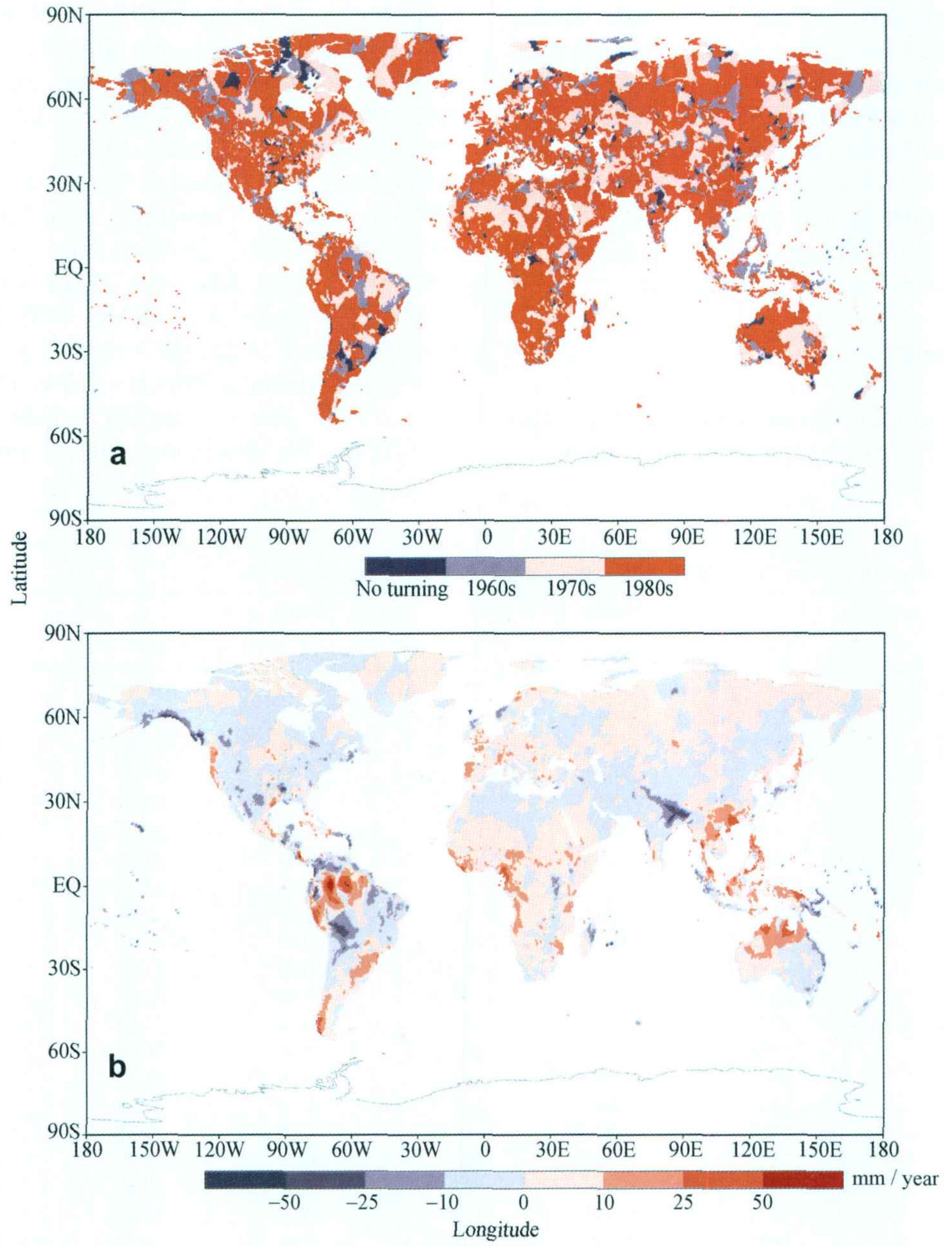

Fig. 3. Occurring time of the latest ITT of annual total precipitation in 1951–2002 (a), and linear trends after the breakpoint (b).

Fig. 2(a) and (b) shows the occurrence time of ITT in annual mean SAT in each terrestrial grid, and associated linear trends after the breakpoint. It is apparent that in the past 52 years, some regions did not have an ITT in SAT, with a linear warming trend seen mainly in Northern and Central Asia, West Africa, Central South America, and East Australia. These regions account for 12.6% of the global terrestrial grids in the study. At the same time, a range of regions, including the Central, Eastern, and Northwestern parts of North America, East Africa, and Northern Asia, registered an earlier ITT of SAT in the 1960s, mainly featuring a warming trend after the breakpoint. These regions account for 21.6% of the total grids in the study. In addition, 13.5% of the grids had a cooling trend after the interdecadal breakpoint in the 1980s; the grids are mainly in Western North America (42.8% of the grids in the region), Southern South America (58.2% of the grids in the region), Northwestern part of North Asia (26.0% of the grids in the region), and West Australia (57.1% of the grids in the region). The regions corresponding to the remaining grids (51.5% of the global terrestrial grids in the study) witnessed an ITT of annual mean SAT in either the 1970s or the 1980s, with a warming trend after the breakpoint. In the past 50-odd years, the grids for which there were basically no ITT in the SAT indicated a warming trend, and 85.7% of grids in this study showed a warming trend after breakpoints. It is apparent that global warming became highly significant in the global terrestrial system in the late 20th Century. The numbers of grids with different ITT patterns (grouped according to the time of the breakpoint and trend after the breakpoint) as a proportion of the total number of grids are given in Table 1 (an underlined number indicates the largest portion of ITT in a region).

4. Spatial distribution of the ITT of precipitation

We also studied ITT of total annual precipitation for 1951–2002 by examining 67,359 terrestrial grids. Fig. 3(a) shows the occurrence time of the last interdecadal breakpoint of precipitation in each terrestrial grid. Most terrestrial grids registered an ITT in either the 1970s or the 1980s; and 25.7% of the terrestrial grids saw such changes in the 1970s and 62.5% in the 1980s. The linear trend after the breakpoint (Fig. 3(b)) indicates that a decrease in precipitation (45.7% of the terrestrial grids) was mostly seen in North America, Central South America, East Europe, the Sahara, Central and South Asia, Northeastern East Asia, and East Australia. Along with SAT variability (Fig. 2), a warming and increasingly dry trend appeared in most grids in the past 20 or 30 years. The remaining 54.3% of the terrestrial grids experienced an ascending trend of precipitation after the last breakpoint, and this was most noticeable in Northern South America, some parts of the West African coast, South China, Southeast Asia, and Northwestern Australia. In the same manner, SAT variability has seen warmer and wetter conditions for most grids in Northern South America, South China, and Southeast Asia. Northwestern Australia is a special case with most grids enjoying a decrease in SAT and an increase in precipitation. Table 2 presents the ratios of grids with different ITT patterns to the total number of grids in each region (an underlined number indicates the largest portion of ITT in a region).

Table 2
Ratio of grids with various ITT of precipitation to the total number of grids in each region (%)

Time	No breakpoint		1960s		1970s		1980s	
Trend	<0	>0	<0	>0	<0	>0	<0	>0
ALA	0.82	4.37	10.11	8.73	2.43	9.37	<u>52.31</u>	11.87
CGI	0.01	5.74	2.46	4.69	23.19	2.23	27.29	<u>34.38</u>
WNA	0.21	0.18	9.25	0.64	13.59	4.09	<u>58.40</u>	13.63
CNA	0.00	6.11	1.94	3.40	10.76	12.50	<u>37.22</u>	28.06
ENA	0.08	1.21	6.52	1.13	<u>43.93</u>	6.52	26.39	14.24
CAM	2.12	0.30	6.96	1.72	13.62	5.95	<u>35.92</u>	33.40
NSA	0.07	0.18	4.83	11.09	27.44	2.51	16.47	<u>37.40</u>
CSA	0.40	3.84	4.09	6.15	17.89	6.80	<u>46.42</u>	14.41
SSA	0.16	8.78	0.39	12.85	8.23	2.43	11.91	<u>55.25</u>
NEU	0.00	4.06	1.08	3.21	5.83	20.12	<u>36.38</u>	29.30
SEM	1.15	0.83	3.79	1.58	13.75	4.23	22.76	<u>51.92</u>
SAH	0.32	0.17	1.31	5.29	13.38	24.02	<u>35.10</u>	20.41
WAF	0.89	0.12	0.20	0.65	1.95	23.78	3.53	<u>68.87</u>
EAF	1.68	0.07	4.39	0.92	3.66	18.08	7.82	<u>63.38</u>
SAF	0.56	0.52	1.27	1.83	19.96	4.27	9.72	<u>61.86</u>
NAS	0.66	0.79	4.08	6.48	7.94	18.61	15.75	<u>45.69</u>
CAS	0.52	1.29	3.92	2.40	18.84	16.45	<u>44.95</u>	11.63
EAS	2.76	0.32	5.05	6.32	7.21	14.90	31.24	<u>32.19</u>
SAS	5.34	0.33	4.81	3.10	22.79	6.06	<u>40.84</u>	16.73
SEA	0.54	0.11	1.98	19.61	7.50	11.84	12.75	<u>45.66</u>
WAU	0.13	4.67	1.83	3.28	9.84	11.10	1.39	<u>67.78</u>
EAU	2.71	0.07	0.68	4.68	<u>47.22</u>	0.54	21.10	23.00

5. ITTs of regional SAT and precipitation

We analyzed ITTs of SAT and precipitation in the 22 regions for 1951–2002 (Figs. 4–9) to understand climate changes in different regions in the last 50-odd years.

Fig. 4 presents the results of ITTs in the six regions of North America. It is apparent that both ALA and ENA registered a breakpoint as early as 1965, corresponding to a change from decreasing to increasing temperatures, and two changes in precipitation corresponding to a change

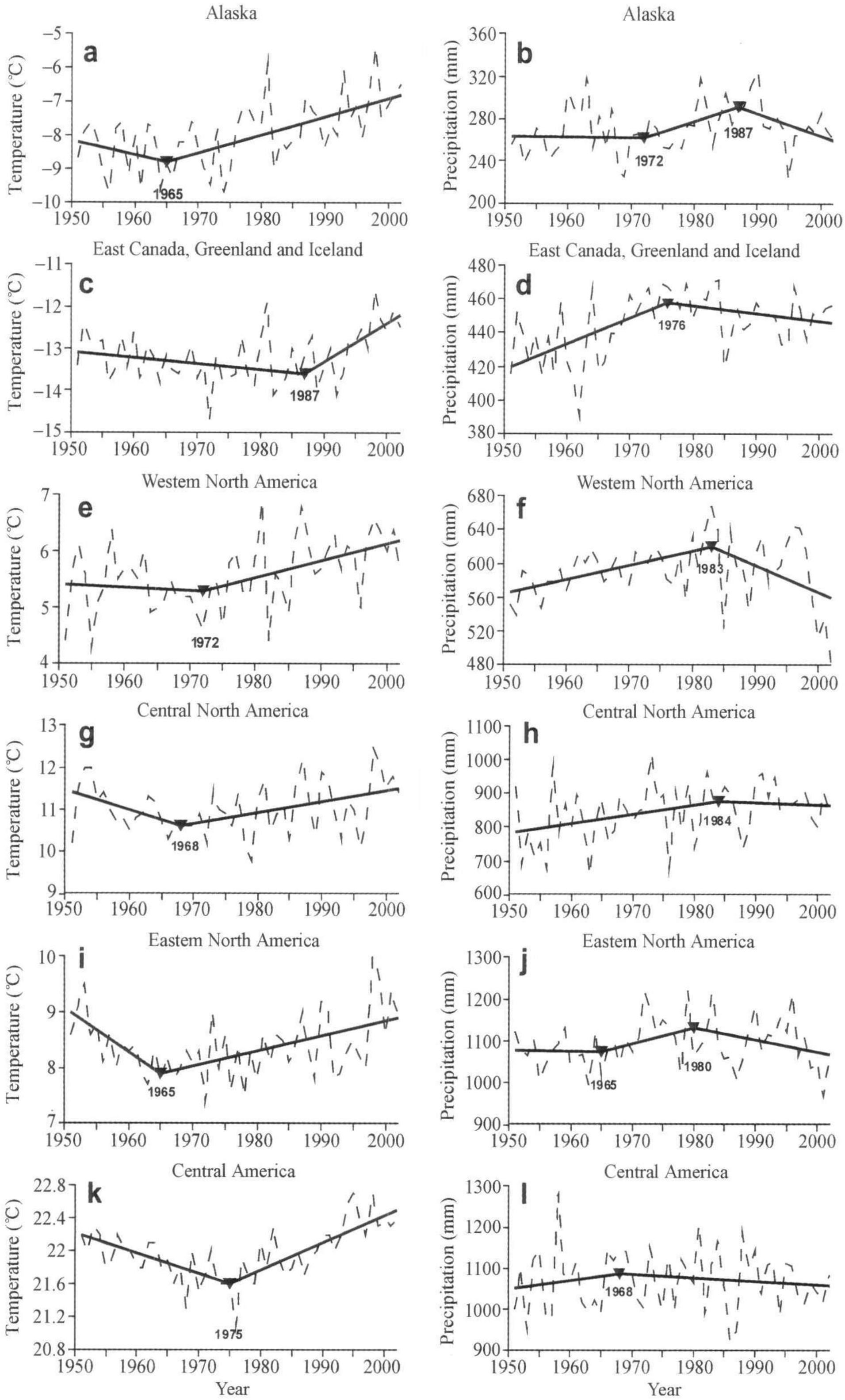

Fig. 4. ITTs of SAT (a, c, e, g, i, and k) and precipitation (b, d, f, h, j, and l) in each region of North America during 1951–2002. Dotted lines represent annual variations, solid show the lines linear trend, and inverted triangles and numbers indicate breakpoints.

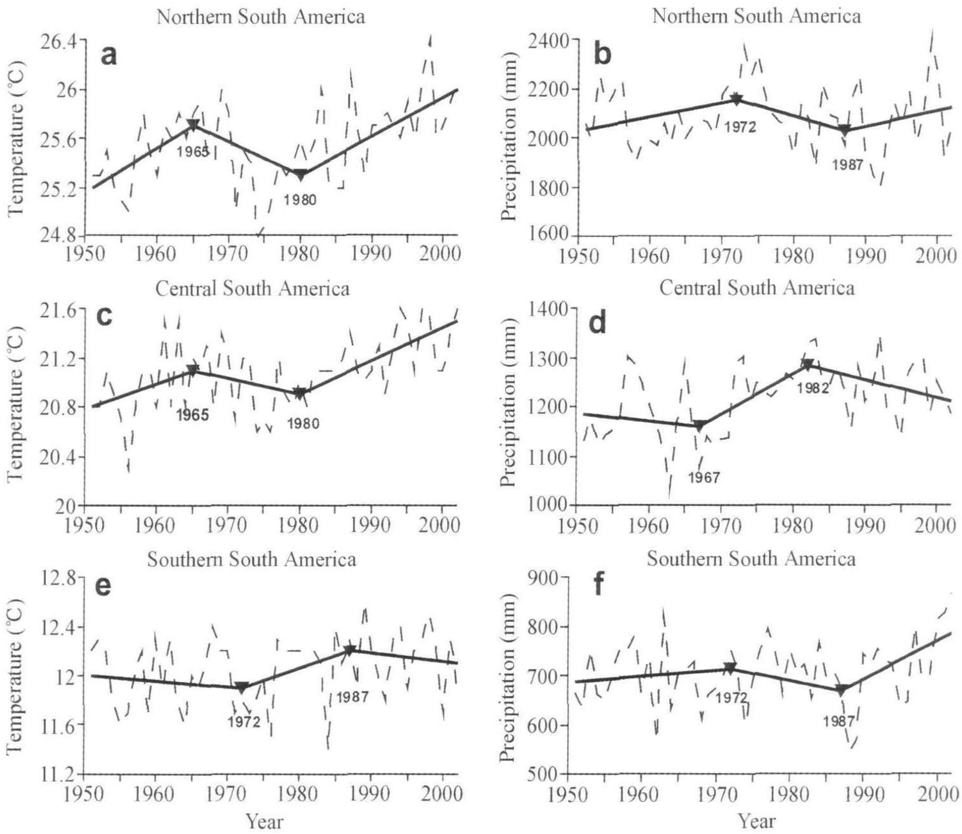

Fig. 5. ITTs of SAT (a, c, and e) and precipitation (b, d, and f) in each region of South America during 1951–2002. Dotted lines represent annual variations, solid lines show the linear trend, and inverted triangles and numbers indicate breakpoints.

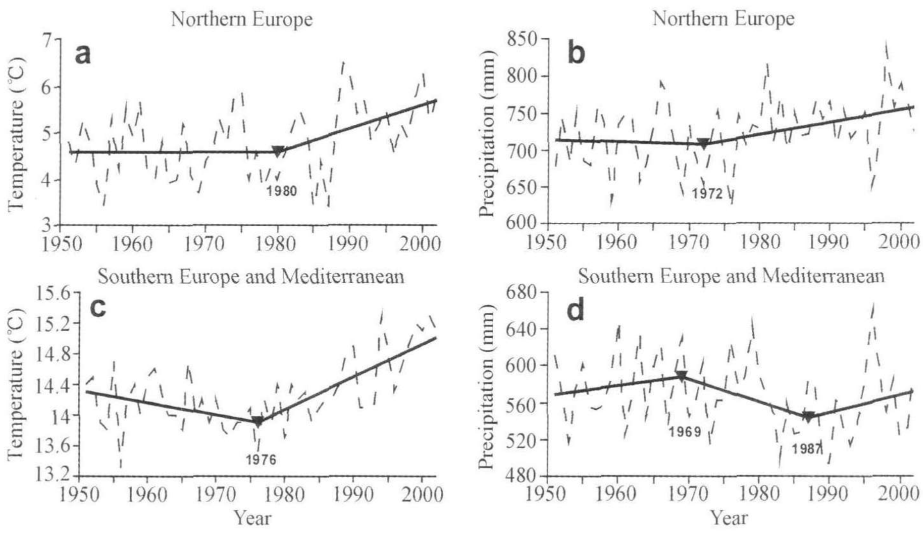

Fig. 6. ITTs of SAT (a and c) and precipitation (b and d) in each region of Europe during 1951–2002. Dotted lines represent annual variations, solid lines show linear trends, and inverted triangles and numbers indicate breakpoints.

from increasingly wet to increasingly dry climates in both 1987 and 1980. ENA and ALA became warmer and drier in the early and late 1980s, respectively. CAM had an ITT from decreasing to increasing temperatures in 1975 and an ITT from an increasingly wet to an increasingly dry climate in 1968, establishing a warmer and drier climate after the mid-1970s. The other three regions witnessed an ITT of SAT from decreasing to increasing temperatures and an ITT of precipitation from an increasingly wet to an increasingly dry climate, establishing a warmer and drier climate after the breakpoint. Overall, North America developed a noticeably warming and increasingly dry climatic trend.

The three regions in South America had different patterns for ITT. For example, NSA and CSA shared two ITTs of SAT, with the last ITT being from decreasing to increasing

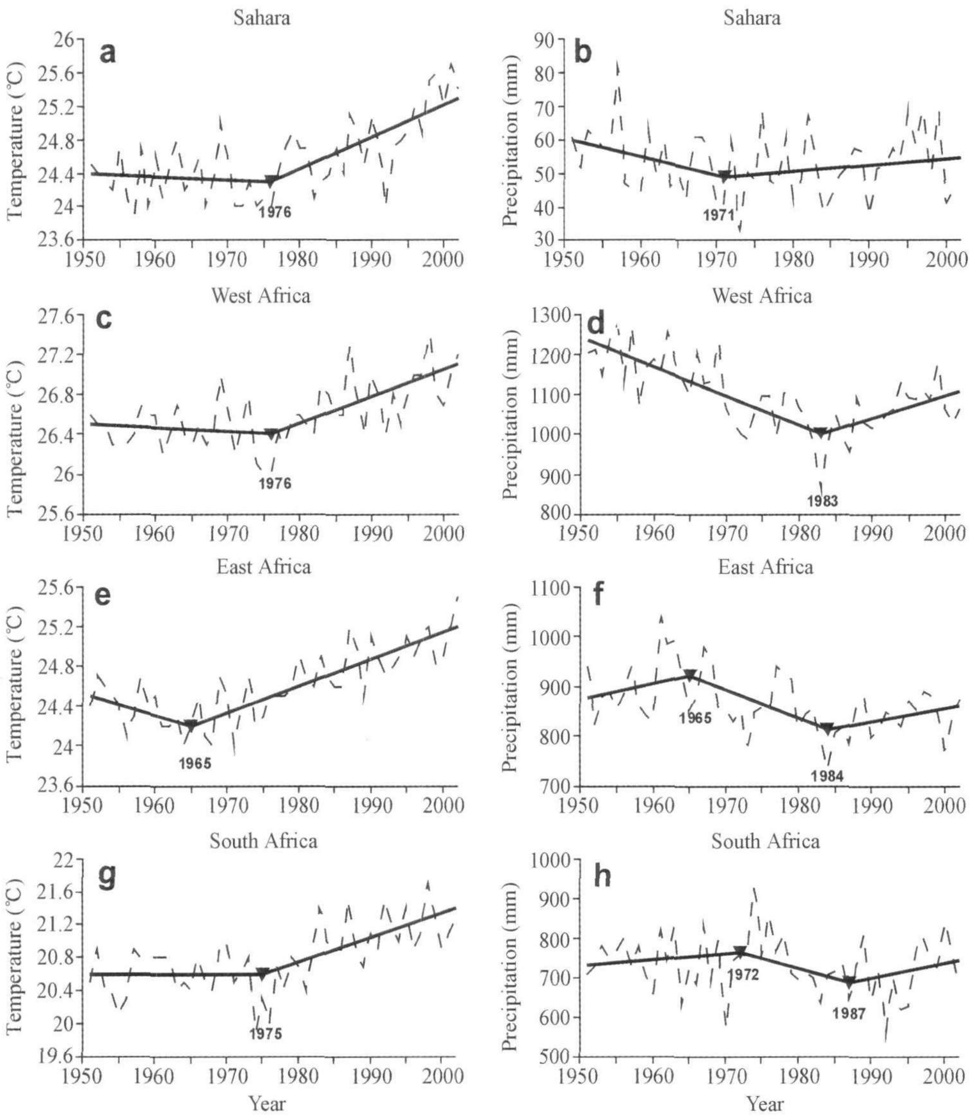

Fig. 7. ITTs of SAT (a, c, e, and g) and precipitation (b, d, f, and h) in each region of Africa during 1951–2002. Dotted lines represent annual variations, solid lines show linear trends, and inverted triangles and numbers indicate breakpoints.

temperatures in 1980. In the context of precipitation, NSA and SSA shared a trend, with the last ITT taking place in 1987, from an increasingly dry to an increasingly wet climate, establishing a warm and wet climate in the 1980s. CSA had an ITT towards decreasing precipitation in 1982, establishing a warm and dry climate trend. SSA experienced a change in its temperature trend in 1987 towards decreasing temperature, and has had an increasingly cold and wet climate since the late 1980s (Fig. 5).

In Europe (Fig. 6), NEU had two ITTs of annual mean SAT and total precipitation in 1980 and 1972, marking for an increasingly warm and wet climate since the early 1980s. SEM had only one ITT for SAT, in 1976, though it had two changes of the precipitation trend in 1969 and 1987. SEM became wetter after 1987, resulting in an increasingly warm and wet climate since the late 1980s.

Africa saw only one ITT of SAT in the period 1951–2002, with an ascending trend after the breakpoint. EAF recorded an ITT of SAT as early as in 1965, with the other three regions having the same ITT in the 1970s. Africa is quite different in the regional distribution of precipitation. For example, SAH began changing in 1971 from having decreasing precipitation to slightly increasing precipitation. WAF saw a change in precipitation in 1983 with an ascending trend. Both EAF and SAF had two ITTs towards increasing precipitation in the past 50-odd years, with the last breakpoints in 1984 and 1987, respectively. Overall, the African continent has experienced a warmer and wetter climate (Fig. 7).

In Asia, NAS, SAS, and SEA registered an ITT of SAT in the period 1951–2002, with their breakpoints for a warmer climate occurring between the 1960s and 1970s. Meanwhile, both CAS and EAS saw two ITTs of SAT with an ascending trend before the 1960s, an ITT towards decreasing temperatures from the mid-1960s to the early 1980s, and a noticeable warming trend after the early 1980s. NAS and SEA shared the same change in annual total precipitation from decreasing precipitation before 1987 to increasing precipitation. EAS had an ITT around 1978, also towards an increasing trend. Both CAS and SAS expe-

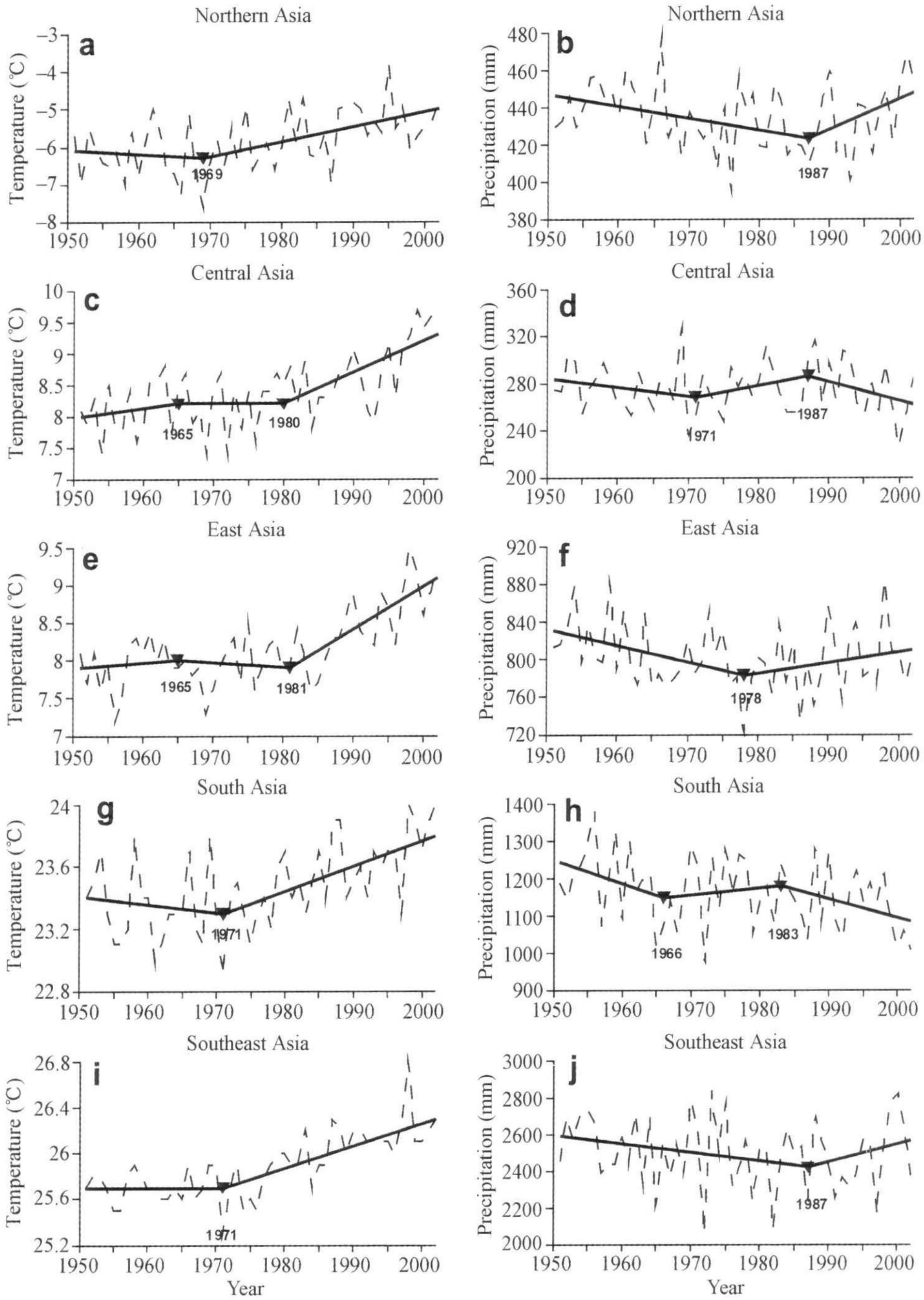

Fig. 8. ITTs of SAT (a, c, e, g, and i) and precipitation (b, d, f, h, and j) in each region of Asia during 1951–2002. Dotted lines represent annual variations, solid lines show linear trends, and inverted triangles and numbers indicate breakpoints.

rienced two ITTs of precipitation, with the last ITTs in 1987 and 1983, respectively. Both regions have established increasingly warm and dry climates since 1980s.

Fig. 9 shows ITTs of SAT and precipitation in West and East Australia. West Australia changed from being increasingly warm to increasingly cold and from increasing dry to increasingly wet in 1987. West Australia has recorded an increasingly cold and wet climate since 1987. East Australia had no ITT of SAT in 1951–2002, having a linear warming trend, although there was an ITT of precipitation from increasingly wet to increasingly dry in 1974. East Australia has maintained an increasingly warm and dry climate since the mid-1970s.

6. Conclusions and discussion

A grid-by-grid examination of ITTs of annual mean SAT and total precipitation for the 67,359 grid points in 1951–2002 and an analysis of the latest ITTs of SAT and precipitation in the period, in the context of both occurrence time of a breakpoint and the linear trend afterwards, have indicated that grids that have not had an ITT of annual mean SAT and have a warming trend, and grids that have had a warming trend after an ITT of SAT account for up 85.7% of the terrestrial grids in the study. As a result, the warming trend has become highly significant in the global terrestrial system in the late 20th Cen-

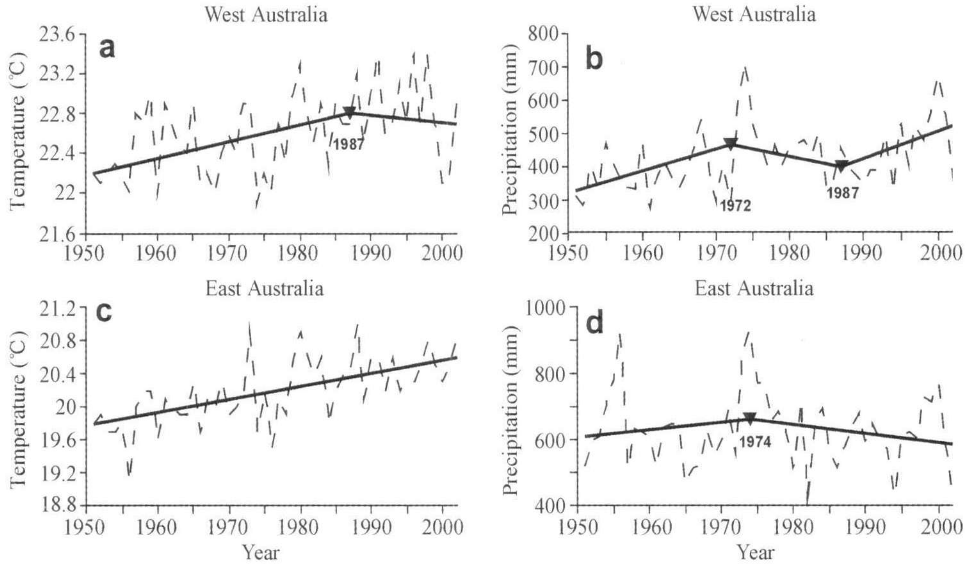

Fig. 9. ITTs of SAT (a and c) and precipitation (b and d) in each region of Australia during 1951–2002. Dotted lines represent annual variations, solid lines show linear trends, and inverted triangles and numbers indicate breakpoints.

tury. Most terrestrial grids had an ITT of precipitation in either the 1970s or 1980s. Of these, the grids with an ITT in the 1970s accounted for 25.7% of all terrestrial grids, and the grids with an ITT in the 1980s accounted for 62.5%. Following the breakpoint, 45.7% of the terrestrial grids have had a decreasing trend in annual precipitation, with the remaining 54.3% having an increasing trend after the last ITT. Global terrestrial regions have basically become increasingly warm and dry or increasingly warm and wet.

An analysis of ITTs of regional mean SAT and precipitation in the 22 regions shows North America has become increasingly warm and dry after the last ITT. CSA, CAS, SAS, and EAU also share the same climate trend. In Africa, four regions established increasingly warm and wet trends after the last ITT. NSA, NAS, EAS, and SEA in Europe moved towards warmer and wetter climates, with most of Asia having the same trend. Both SSA and WAU moved towards colder and wetter climates after the last ITT.

Acknowledgements

This work was jointly supported by National Natural Science Foundation of China (Grant No. 90502003) and International Sci-Tech Cooperative Project funded by the Ministry of Science and Technology of China (Grant No. 2007DFB20210). The authors thank A.R. Tomé from the University of Lisbon for providing FORTRAN source codes of the Piecewise Linear Fitting Model (PLFIM) used in the study.

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