LONG-TERM ANALYSIS OF AIR TEMPERATURE TRENDS IN CENTRAL ASIA[1)]

With 8 figures and 5 tables

ERNST GIESE, IVO MOSSIG, DIEGO RYBSKI and ARMIN BUNDE

Keywords: Climate warming, time series analysis, Detrended Fluctuation Analysis (DFA), Central Asia
Klimaerwärmung, Langzeitkorrelationen, Detrended-Fluctuation-Analysis (DFA), Zentralasien

Zusammenfassung: Analyse langjähriger Zeitreihen der Lufttemperatur in Zentralasien

Verschiedene Phänomene wie die verstärkte Schrumpfung der Gletscher im Tien Schan und Pamir-Alaj-Gebirge deuten darauf hin, dass sich in der jüngeren Vergangenheit in Zentralasien eine Klimaerwärmung vollzogen hat. Deshalb wird gefragt, seit wann eine Klimaerwärmung eingetreten ist und mit welcher Intensität sie sich vollzogen hat. Insbesondere wird der Frage nachgegangen, ob die Klimaerwärmung der jüngeren Vergangenheit Ausdruck einer trendhaften oder zyklischen Entwicklung der Jahresmitteltemperaturen ist.

Zu diesem Zweck wurden auf der Basis von Monats- und Jahresmittelwerten der Lufttemperatur für ausgewählte Klimastationen, die in Zentralasien typische Standorte repräsentieren, Analysen langfristiger Zeitreihen durchgeführt. Eingesetzt wurden Verfahren der Regressions- und Korrelationsanalyse sowie Verfahren der „Detrended Fluctuation Analysis (DFA)", um in den Zeitreihen Langzeitkorrelationen und Trends zu identifizieren. Zur Quantifizierung auftretender Trends wurde eine Weiterentwicklung der DFA vorgenommen.

Summary: Different phenomena, as the enhanced shrinking of glaciers in the Tien Shan and Pamiro Alay, indicate that a climate warming has occurred in Central Asia in the recent past. Thus the questions are since when the climate warming has been taking place and what its intensity has been. A question, which is especially investigated, is whether climate warming in the recent past expresses a trend-like or cyclic development of annual temperature averages.

For this purpose analyses of long time series were performed, consisting of monthly and annual air temperature averages at selected climate stations representing typical locations in Central Asia. Applied were methods of the Regression and Correlation Analysis, in particular the Detrended Fluctuation Analysis (DFA), in order to identify long-term correlations and trends in the time series. For the purpose of quantification of occurring trends, the DFA was further extended.

1 Formulating the questions

Different phenomena, as the enhanced shrinking of glaciers in the Tien Shan and Pamiro Alay, the increase of runoff amounts of mountain rivers which are glacier-fed during the summer, as well as the fluctuation in the water levels of Central Asian lakes indicate that a climate warming has occurred in Central Asia in the recent past. In the following, this is to be examined using long near-surface air temperature.

It is noticeable that an obviously intensified melting process of the glaciers in the Tien Shan, Pamiro Alay and Dzhungarskiy Alatau has set in at the beginning of the 1970s, accompanied by an increased water runoff. Calculations of long-term mass balances exist for the Centralniy Tuyuksu Glacier in the Zailiyskiy Alatau (northern Tien Shan), the Kara Batkak Glacier in the Terskey Alatoo (central Tien Shan; Issyk Kul Basin) and Glacier No. 1 in the Borokhoro Shan (eastern Tien Shan) (cf. TURSUNOV 2002; HAGG 2003; DIKICH 2004). They suggest that a long-term glacier reduction, which has gained in intensity over the last 30 years, commenced in Central Asia with the beginning of the 20th century. This way it can be explained that the runoff amounts of rivers which are glacier-fed, as the Dzhuuksu or Chong Kyzylsu (fed by the Kara Batkak Glacier), have successively increased in summer months since the mid-1970s.

It is irrefutable that a general climate warming has occurred in Central Asia in the recent past. It is uncertain, though, whether this is due to a cyclic or a trend-like development of annual temperatures. As unclear is, at which point in time the climate warming has begun. Trend analyses, which were carried out, begin at different times and accordingly lead to different results.

AIZEN et al. (1997) performed trend calculations of annual averages and annual amounts of precipitation for 110 hydroclimatic measuring stations in the Tien Shan (including foothill areas) for the time between 1940 and 1991. They did not carry out the calculations based on the time series of individual climate stations, but on the basis of spatially aggregated time series, in order to reduce the strong high frequent fluctuations ('noise') within the time series. To this end the method of Thiessen was applied (cf. Diskyn 1970; Ward 1975). Taking into consideration the most important and effective circulation processes, as well as orographic factors (altitude and exposition) the Tien Shan was divided into four regions: a western, northern, central, and eastern region. Furthermore, a distinction of climate stations was made, depending on their altitude. On the basis of this, Aizen et al. (1997, 1397–1398) conclude that annual temperature averages in the Tien Shan in the time from 1940 to 1991 increased significantly, namely in average by 0.52 °C, i.e. by 1.0 °C per 100 years. With the exception of the northern Tien Shan region, the increase in air temperature is supposed to have happened with an almost equal intensity in all regions. For the northern region of the Tien Shan a weaker increase in temperature has been determined: above 2,000 m the increase is said to have been 0.8 °C, below 2,000 m only 0.6 °C (per 100 years).

Due to the considerable temperature fluctuations from one year to the next, the values of the calculated correlation coefficients are very small, with $r = 0.27$ to $r = 0.42$. Thus, a linear trend in the time series is not very significant, respectively overlain by cyclic noisy fluctuations. Only 7.5 to 17.7% of the variability in air temperatures within the time series can be traced back to a linear trend. And here the result is already embellished due to the spatial aggregation of the time series and the related building of average values (problem of ecological distortion).

An even graver result is achieved through the choice of the regression's starting and finishing point. It is factually unsubstantiated. Another way of defining it would lead to a different result (compare below). This is why Finaev (1999, 291), with an only slightly different time range, obtains a different result for the central region of the Pamir. There, the annual temperature averages in the time from 1929 to 1993 are supposed to have increased from 0.7 to 1.3 °C at the stations above 2,000 m and from 1.7 to 1.9 °C at the stations below 2,000 m (each per 100 years).

Romanovskiy (2002) has also performed an analysis of air temperature development in the Tien Shan. On the basis of 23 climate stations he has carried out trend calculations of monthly and annual temperature averages, with his trend calculations for the past 30 years, i.e. 1972–2001. With 1972, an extremely cold year was chosen, so that the values of the calculated trend coefficients are extremely high. Due to this, for example, unrealistically high trend coefficients of annual temperature averages of +4.3 to +5.1 °C per 100 years are calculated (also compare Romanovskiy a. Kuzmichenok 2005) (Tab. 1).

Based on the statements, a number of questions arise:

1.) As will be shown in the following, deferring the starting point and, correspondingly, the finishing point by only a few years will already lead to substantially divergent results. Thus, the result of trend calculations is fundamentally dependent on the starting and finishing points of the regression attempt. What remains is the questions regarding the choice of the trend analysis' time period.

2.) Furthermore, it has to be asked whether the implied linear development of annual temperature averages can be extrapolated for the following 20 or 30 years.

Table 1: Trend coefficients of annual temperature averages according to different authors and time periods in Central Asia

Trendkoeffizienten der Jahresmitteltemperaturen nach verschiedenen Autoren und Zeitabschnitten in Zentralasien

Author	Selected time period	Rise in temperature/ 100 years
Aizen et al. (1997)	1940–1991	+ 1.0 °C
Finaev (1999)	1929–1993	+ 0.7–1.3 °C (>2000m) + 1.7–1.9 °C (<2000m)
Romanovskiy (2002)	1972–2001	up to + 5.1 °C

---

[1] The article in hand was written in connection with works related to the research project "Water Scarcity, Water Use Conflicts and Water Management in the Arid Regions of Central Asia (Uzbekistan, Kazakhstan, Kyrgyzstan, Xinjiang/China)". Aim of the research project was to examine the reasons for and the consequences of the increasing water scarcity and deterioration of water quality in the arid regions of Central Asia. In this context, climate change plays an important role.

The analysis of the underlying data was made available to us by 'Kyrgyzhydromet' via the 'Institute of Water Problems and Hydropower', Kyrgyz Academy of Sciences in Bishkek (Dr. V. V. Romanovskiy, director of the laboratory) and by the 'Kazakh Research Institute of Environmental Monitoring and Climate (KazNIIMOSK)' in Almaty (Dr. M. Z. Burlibaev, Institute Director).

The four-year-long research project (May 2001–April 2005) was financed by the *Volkswagen-Stiftung* in connection with the support initiative "Between Europe and Orient-Middle Asia/Caucasus in the Focus of Science". We would like to express our sincerest thanks for the support we received.

Is it not more probable, according to the development of monthly and annual temperature averages so far, that the suggested trend-like development of air temperature is part of a long-term cyclic development?

Should formulations of this nature not be embedded in long-term development, in order to be able to assess short-term development?

3.) Moreover, it has to be asked whether temperature at the different climate stations behaves in a synchronous way or whether there are regional differences.

Against this background it is necessary to perform the time series analysis based on as long as possible records. Here, the following questions are to be investigated:

– When in the recent past did the climate warming in Central Asia begin?

– With which intensity did the climate warming occur?

– Is the recent past's climate warming the result of a trend-like or of a cyclic development of annual temperature averages?

2 *Climate stations and data*

2.1 *Climate stations*

For the time series analysis only those climate stations were selected (cf. Tab. 2 and Fig. 1), for which long monthly averages of air temperature were available and accessible without discontinuities. At the same time they represent typical locations in Central Asia:

Table 2: Data basis of selected climate stations in Central Asia

Datenbasis ausgewählter Klimastationen in Zentralasien

No.	Climate station	Elev. in m	Topographical locations	Period of monthly temperature averages
	1) Lowland basin locations, regions of the northern foothills of the Tien Shan			
1	Kazalinsk	68	Estuary of the Syr Darya River into Aral Lake	1886–2001
2	Tashkent	478	Western foothills of the Tien Shan	1879–2001
3	Bishkek	771	Mountain foot region of the Kirgizskiy Range, northern slopes of the Tien Shan	1928–2000
4	Almaty	825	Mountain foot region of the Zailiyskiy Alatau, northern slopes of the Tien Shan	1879–2000
	2) Northern Tien Shan			
5	Baytik	1,590	Kirgizskiy Range, Ala Archa Valley, 20 km south of Bishkek	1915–2001
6	Novorossiyka	1,524	Chong Kemin Valley (right tributary of the Chu River), valley between Kungey Alatoo and Zailiyskiy Alatau	1931–2000
7	Tuya Ashu	3,120	Kirgizskiy Range, end of the valley Kara Balta, top of the pass, road Bishkek-Osh	1958–2002
	3) Issyk Kul Basin			
8	Balykshi (Rybache)	1,670	Western edge of the basin (relocated in 1957)	1931–2000
9	Cholpon Ata	1,620	North shore (relocated in 1971)	1929–2000
10	Krasnyy Oktyabr	1,645	North-eastern shore (closed in 1999)	1946–1998
11	Karakol (Przhevalsk)	1,718	Eastern edge of the basin (closed in 1997)	1879–1996
12	Pokrovka	1,740	South-eastern edge of the basin	1951–2001
13	Kara Batkak	3,415	Terskey Alatoo, glacier station, headwaters of the Chon Kyzyl Suu, south-eastern edge of the Issyk Kul Basin	1956–1999
	4) Central Tien Shan			
14	Suusamyr	2,091	Plateau between the Kirgizskiy Range, Suusamyr Too and Dzhumgal Too, Valley of the Suusamyr River	1937–2000
15	Naryn	2,045	Middle Naryn Valley	1882–2001
16	Tien Shan	3,614	Ara Bel Syrte between Terskey Alatoo and Ak Shyrak Massif, near Komtur goldmine (relocated in 1997)	1930–2001
	5) Western Tien Shan			
17	Zhalal Abad	971	Fergana Basin, eastern edge	1947–2000
18	Isfana	1,160	Fergana Basin, southern edge, Karasu Valley, northern slopes of Turkestan Range	1950–2000
19	Pacha Ata	1,529	Fergana Basin, western declivity of the Fergana Range, Padysha Ata Valley	1928–2000
	6) Southern Tien Shan			
20	Ak Say	3,135	Valley south of the At Bashy Range	1952–1997
21	Sary Tash	3,155	Alay Range, high altitude mountain valley, near Taldyk Pass, southern Tien Shan	1934–2000

Source of data: Kyrgyzhydromet, Bishkek (Dr. V. V. Romanovskiy) and KazNIIMOSK, Almaty (Dr. M. Zh. Burlibaev)

– central, lowland, arid basin locations (Kazalinsk);
– foothills of the Tien Shan (Almaty, Bishkek, Tashkent);
– intramontaneous valley and basin locations in the Tien Shan (Naryn Valley, Issyk Kul Basin; Fergana Basin):
– mountain and high mountain regions of different exposition in the Tien Shan, among others stations in the glacio-nival zone ≥ 3,000 m (Tien Shan Station 3,614 m, Kara Batkak 3,415 m, etc.).

2.2 *Data situation and reliability of data*

The data situation for a climatological time series analysis on the basis of monthly averages is not particularly favourable in Central Asia. Long records of the monthly air temperature average for the formerly Russian or soviet parts of Central Asia (Soviet Middle Asia) exist since 1846 only for a small number of climate stations (e.g. Kazalinsk), without discontinuities only since 1879/1880, more often yet since 1928/1931. In the Chinese parts of Central Asia (Autonomous Uigur Region Xinjiang) continuous measuring sequences of climatological data only begin in 1951/52.

Mainly political events as the Cultural Revolution in China from 1966 to 1976 and the collapse of the Soviet Union at the end of the 1980s have lead to extensive impairments with regard to data collection. Reasons for this are that measurements were interrupted or stopped, measuring stations were abandoned or relocated (e.g. the important high mountain station Tien Shan) and that measuring techniques changed so that some noticeable "inhomogenities" are to be found in the climatological time series. Therefore, only those records with relatively approved or reliable measured values were used. This is why the record of Tien Shan climate station, for which a continuous climatological record existed since 1930, had to be cancelled in 1997, when the station was relocated from its original position at the Ara Bel Syrte to the nearby "Comtur" goldmine on the edge of the Ak Shyrak Massif's glacier, after which the new measurements showed obvious and incorrigible inhomogenities when compared to the original one. These seem to be mainly based on the fact that the measuring technique was changed during relocation. Now, instead of conventional instruments (thermometer), automatic measuring instruments are used. In the meantime it has been realised that these are insufficiently protected against sun-rays so that measurements taken with the new instruments show extreme temperatures. As a consequence for Tien Shan station, this circumstance is said to have the effect that the measured monthly temperature averages are higher by up to 2 °C than the ones measured with conventional instruments (information by Prof. Podresov, Bishkek).

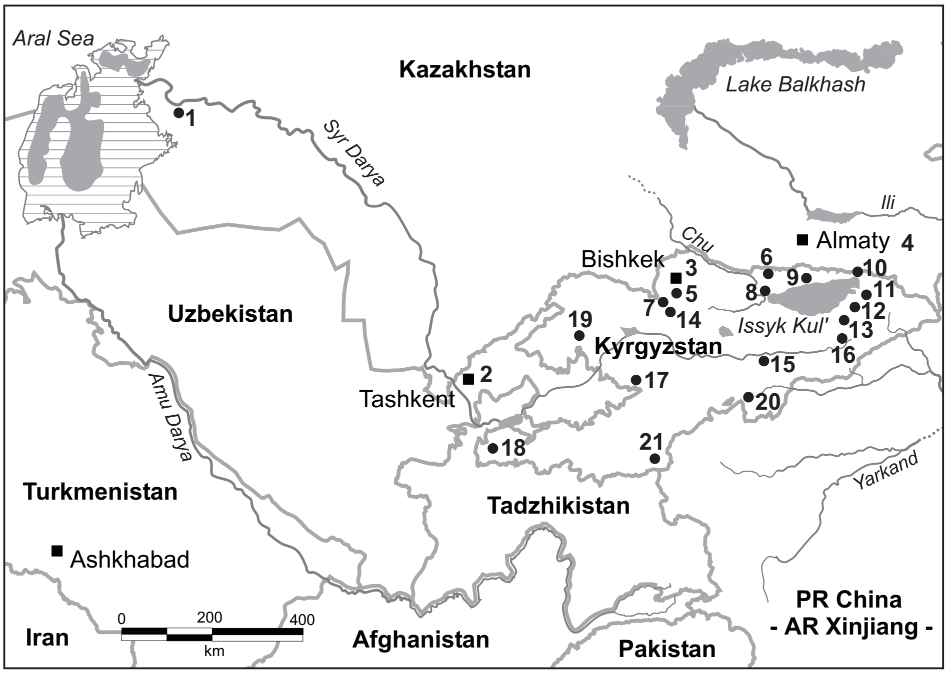


Fig. 1: Locations of selected climate stations in Central Asia

Standorte ausgewählter Klimastationen in Zentralasien

Table 3: Statistical values of air temperature records of selected climate stations in Central Asia 1970–2000
Statistische Kennwerte zur Lufttemperatur ausgewählter Klimastationen in Zentralasien 1970–2000

No.	Climate station	Elev. in m	Average air temperature 1970–2000, °C			
			Year	Standard deviation	January	July
	1) Lowland basin locations, regions of the northern foothills of the Tien Shan					
1	Kazalinsk	68	8.9	1.03	–9.9	27.2
2	Tashkent	478	14.4	0.67	0.9	27.8
3	Bishkek	771	10.9	0.76	–3.5	25.0
4	Almaty	825	9.5	0.75	–5.5	24.0
	2) Northern Tien Shan					
5	Baytik	1,590	6.6	0.58	–5.0	18.5
6	Novorossiyka	1,524	5.0	0.59	–9.3	17.1
7	Tuya Ashu (until 1998)	3,120	–3.6	0.81	–14.9	7.3
	3) Issyk Kul Basin					
8	Balykshi (Rybache)	1,670	7.8	0.55	–3.7	19.1
9	Cholpon Ata	1,620	8.2	0.47	–2.0	18.2
10	Krasnyy Oktjabr (bis 1998)	1,645	5.2	0.51	–8.2	16.4
11	Karakol (Przhevalsk) (bis 1996)	1,718	6.3	0.51	–6.3	17.5
12	Pokrovka	1,740	6.8	0.53	–4.8	17.4
13	Kara Batkak	3,415	–3.6	0.64	–13.5	5.5
	4) Central Tien Shan					
14	Suusamyr	2,091	–1.4	0.65	–21.7	14.0
15	Naryn	2,045	3.7	0.69	–15.2	17.6
16	Tien Shan (until 1996)	3,614	–7.6	0.47	–21.5	4.6
	5) Western Tien Shan					
17	Zhalal Abad	971	12.9	0.67	–2.6	26.2
18	Isfana	1,160	9.7	0.68	–2.9	22.1
19	Pacha Ata	1,529	8.0	0.65	–4.0	19.3
	6) Southern Tien Shan					
20	Ak Say (until 1998)	3,135	–7.2	0.85	–27.6	8.5
21	Sary Tash	3,155	–2.2	0.59	–16.2	10.1

Other stations were relocated as well, e.g. Cholpon Ata in the Issyk Kul Basin. In 1971 it was moved 10 km to the east of Kurskoe village and 2 km away from the northern shore of Lake Issyk Kul towards the mountains. A number of stations were closed. Among those was Karakol (Przhevalsk) station in the Issyk Kul Basin, for which climatological records are available from 1879 onwards. It was closed in 1997.

The climate stations' records of the Chinese part of Central Asia are affected by special changes and irregularities (AR Xinjiang). During the Cultural Revolution from 1966 to 1976 they were only run inadequately and inaccurately. Measurements were interrupted, not continued on a regular basis and sometimes only taken once each day (e.g. Xiehela and Shaliguilan stations).

The political change from soviet-influenced times (until 1961) to independent development in Xinjiang also had an influence on the measuring procedures of climate stations. Ürümqi's climate station, for example, was situated within the city on an elevation of 917.9 m. In November 1960 it was moved approx. 20 km from its original location to a site close to the airport, its elevation now is 653.6 m. In January 1976, after the end of the Cultural Revolution, it was relocated back into the city with the effect that the record is inconsistent. The inexplicable, unexpected break in the annual temperature averages from 5.1°C (1959) to 7.4°C (1961) is surely to be put down to these relocations. Reliable and also technologically consistent time series for Xinjiang are only available from the late 1970s onwards, i.e. only for the last 30 years. Furthermore, it has to be noted that the measurements in Xinjiang are conducted according to "Beijing time", i.e. removed by two hours as compared to "normal" time. Consequently, time series of climatological measuring stations in Central Asia's Chinese part are not considered in the following analysis.

Table 4: Trend coefficients of annual temperature averages of considered climate stations in Central Asia for different time periods
Trendkoeffizienten der Jahresmitteltemperaturen ausgewählter Klimastationen in Zentralasien für verschiedene Zeitabschnitte

No.	Climate station	Elev. in m	Trend coefficients 1934–2000	1950–2000	1970–2000	1972–2000
	1) Lowland basin locations, regions of the northern foothills of the Tien Shan					
1	Kazalinsk	68	0.020	0.031	0.041	0.048
2	Tashkent	478	0.028**	0.037**	0.031	0.042*
3	Bishkek	771	0.021	0.033*	0.034	0.042
4	Almaty	825	0.019	0.031*	0.039	0.046*
	2) Northern Tien Shan					
5	Baytik	1,590	0.006	0.010	0.007	0.012
6	Novorossiyka	1,524	0.010	0.016	0.017	0.024
7	Tuya Ashu (bis 1958–1998)	3,120	–	–	–0.013	–0.014
	3) Issyk Kul Basin					
8	Balykshi (Rybache)	1,670	0.024**	0.022**	0.026	0.034*
9	Cholpon Ata	1,620	0.030**	0.036**	0.019	0.013
10	Krasnyy Oktjabr (1946–1998)	1,645	–	0.019*	0.023	0.028
11	Karakol (Przhevalsk) (bis 1996)	1,718	0.024**	0.027**	0.023	0.027
12	Pokrovka (ab 1951)	1,740	–	0.018*	0.021	0.026
13	Kara Batkak (1956–1999)	3,415	–	–	–0.018	–0.026
	4) Central Tien Shan					
14	Suusamyr (ab 1937)	2,091	–	0.034**	0.004	0.006
15	Naryn	2,045	0.027*	0.042**	0.015	0.009
16	Tien Shan (bis 1996)	3,614	0.012	0.008	–0.007	–0.004
	5) Western Tien Shan					
17	Zhalal Abad (1947–2000)	971	–	0.026*	0.037*	0.048**
18	Isfana (ab 1950)	1,160	–	0.009	–0.003	0.009
19	Pacha Ata	1,529	0.009	0.015	0.014	0.024
	6) Southern Tien Shan					
20	Ak Say (1952–1997) [i]	3,135	–	–	–0.034	–0.042
21	Sary Tash [i]	3,155	0.024**	0.025*	0.014	0.018

*: Significance level 90%, **: Significance level 95%, ***: Significance level 99%

[i] Ak-Saj and Sary-Tash climate stations are located in high-lying mountain valleys and are exceptions

3 *Development of the annual averages*

In table 3, statistical values with regard to air temperature for the period from 1970 to 2000 have been assembled for the selected climate stations. The most obvious feature is the extreme continentality of Central Asia's climate. The difference between the warmest month (July) and the coldest (January) is 35 °C and more at some stations (e.g. Kazalinsk, Suusamyr, Ak Say). With increasing elevation the annual temperature averages decrease by an average of 0.6 °C/100m, with the stability index for this interrelation being very high with B = 86.1%.

Furthermore, what stands out is the large scattering of values around the average. The standard deviation of the annual averages from 1970 to 2000 fluctuates between σ = 0.47 °C (Tien Shan) and σ = 1.03 °C (Kazalinsk). The standard deviation of the annual values is important to evaluate a trend-like warming with conventional methods.

If, as in the present case, there are time series which oscillate to a high degree, a generalisation (schematisation) of the time series can be achieved by smooting (Gaussian low-pass filter). First of all, 7-year moving averages were calculated to suppress short periods (high frequencies) and emphasise longer periods such as 11 years and more (low frequencies).

As can be seen from the curve shapes in figures 2 and 3, the long-term development of annual temperature averages takes place in a more or less regular rhythm of up- and downswings. This was at least true until the beginning of the 1970s. If one follows the curve's up- and downswings and takes note of the level of relative minima and maxima, it seems as though the almost cyclic development since 1970/72 is replaced or overlain by a trend-like behaviour.

From the generalised curve shapes' depiction in figure 3 it can also be inferred that the curves run mostly synchronous. Cross correlations and phase synchronisation analyses (cf. Rybski et al. 2003; Rybski 2006) which were carried out, corroborate the fact of the curves' strong synchronicity. In order to ascertain whether a regular cyclicity does exist, Fourier analyses were performed. A regular cyclicity in the course of annual temperature averages cannot be ascertained by Fourier analyses, because the individual period lengths' calculated variance contributions are too low (Giese a. Mossig 2004, 23).

As was already pointed out in the introduction, the rhythmically fluctuating annual temperature averages since 1970/72 exceeds the previous maximum values (cf. Fig. 2). This course is evidently replaced or overlain by a trend-like development. If the development of annual temperature averages is depicted by means of 30-year moving averages, in order to especially suppress cycles with period of 17–30 years (20–24 years) as gathered from the curve shapes, it becomes evident that the trend-like increase of air temperature must already have set in before 1970/72. All the curve shapes of 30-year moving averages for different climate stations presented in figure 4 indicate that a positive linear trend of annual temperature averages started at the beginning of the 1930s, at the latest at the beginning of the 1950s.

To capture the increase of annual temperature averages and to distinguish different development phases from each other, all linear regression coefficients with variable beginning since 1890 and fixed end at 2000, have been calculated and depicted. This method clearly shows the influence individual times of initialisation have on the determined rise in temperature. This way distortions due to an 'unlucky' choice of time periods can be shown and avoided. As figure 5 reveals, the linear trend of b = 0.046 at Almaty station for the time period 1972–2000 is higher than the regression of b = 0.038 for 1971–2000. Per 100 years, this shift in the time of initialisation of only one year leads to a difference of 0.8 °C. If an earlier date is chosen as the regression's starting point, e.g. the initial year 1938, considerably weaker trend-like warming of b = 0.011 °C (or 1.1 °C/100 years) compared to the initial year 1972 is found.

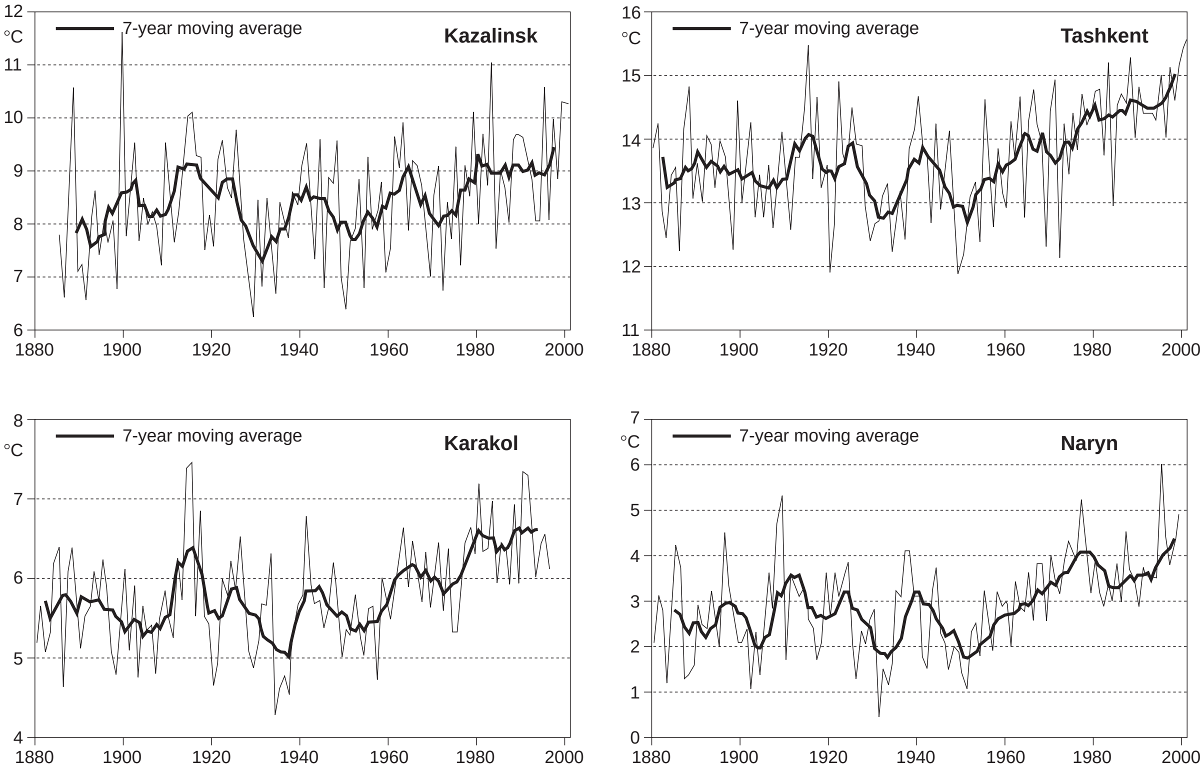
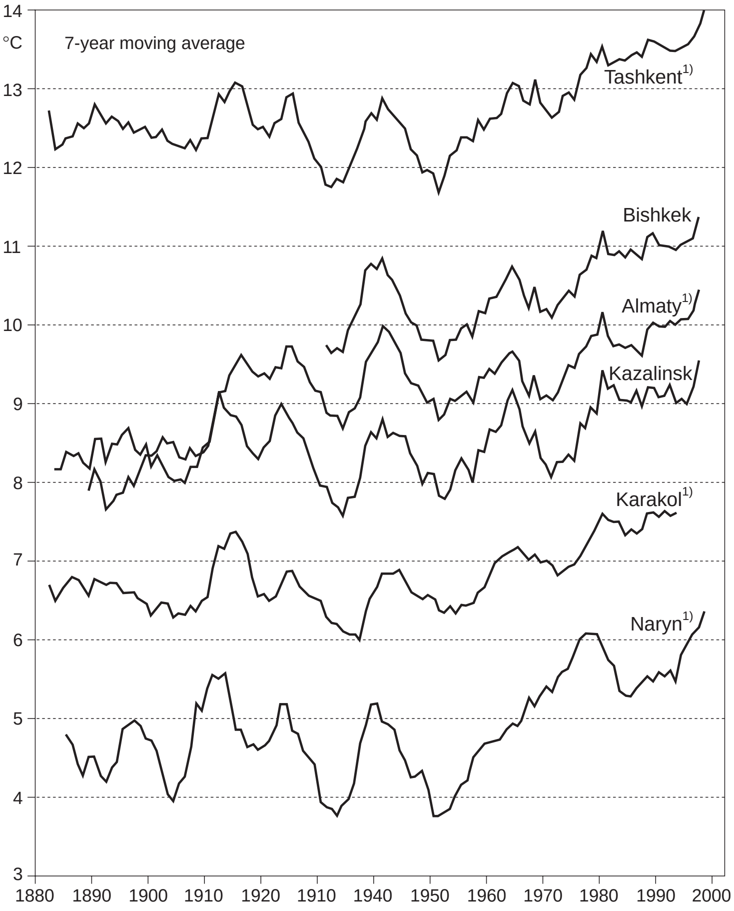


Fig. 2: Development of annual temperature averages at the stations Kazalinsk (1886–2000), Tashkent (1880–2001), Karakol (1880–1996) and Naryn (1882–2001)

Entwicklung der Jahresmitteltemperaturen der Stationen Kazalinsk (1886–2000), Taschkent (1880–2001), Karakol (1880–1996) und Naryn (1882–2001)

What, apart from the identification of selected extreme time periods for trend calculation, follows from the curve shape in figure 5 is that warming has not occurred evenly but has experienced an acceleration. Roughly three phases can be identified in which the regression coefficients reach a higher level: (a) initial year between 1890 and 1940; (b) initial year 1950–1965 and (c) initial year since 1970. As was already determined via the analysis of the moving averages, the cyclic fluctuation of the temperature is overlain by a linear rise in air temperature so that an increase appears in thrusts. These thrust start at the beginning of the 1930s, 1950s and 1970s. It has to be emphasised that the indication of a thrust-wise accelerated rise in air temperature over the last 70 years does in no way include the statement that such a development is also to be expected in the future. What is described here is only the course of the annual temperature averages of the recent past.

In table 4 the trend coefficients of annual temperature averages at climate stations were compiled for selected time periods of the development. In order to determine the statistic relevance of the regression coefficients, the often used trend/noise ratio T/R (Schönwiese 2000, 233f.; Schäfer 2001) was calculated. Significant trend values are marked in the table. It has to be remarked, though, that quantities of this nature are distorted due to autocorrelations (Rybski 2006). Thus the following passage (section 4) will introduce an alternative method for the determination of trends, which explicitly takes into account the effects of long-term correlations. The calculations depicted in table 4 allow to make the following statements:



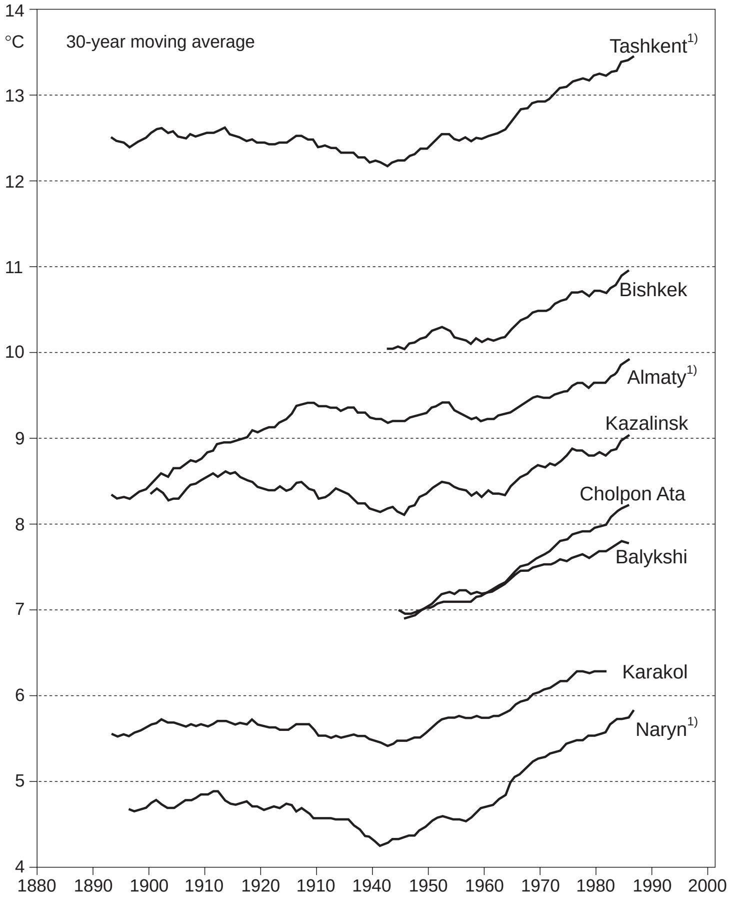
[1] Temperature records were shifted for better illustration: Tashkent -1°C, Almaty +4°C, Karakol +1°C, Naryn +2°C

Fig. 3: 7-year moving averages of annual temperatures at selected climate stations in Central Asia 1880–2000

Entwicklung der Jahresmitteltemperaturen ausgewählter Klimastationen in Zentralasien 1880–2000 (7-jähriges gleitendes Mittel)

1.) Over the last 50 years (1950–2000) a general rise in annual temperature averages has occurred throughout Central Asia. The most severe increases with coefficients between 0.031 and 0.037 are found at the climate stations in the lowland basins and foothills (per 100 years: Kazalinsk +3.1°C; Tashkent +3.7 °C; Bishkek +3.3 °C; Almaty +3.1 °C) as well as at a number of protected positioned climate stations in intramontaneous valley and basin locations (Naryn 2,045 m: +4.2 °C; Suusamyr 2,091 m: +3.4 °C; Cholpon-Ata 1,620 m: +3.6 °C) (cf. Tab. 4). If one compares the rise in air temperatures during this time with the rise in the average global air temperature, it can be seen that a distinctly stronger climate warming has occurred in Central Asia over the past 50 years (1950–2000). The increase in global temperature (cf. IPCC 2001) can be estimated at +0.94 °C (per 100 years) for the time period from 1950 to 2000.

2.) The most significant rise in air temperatures commenced in 1970/72. For climate stations at lowland basin and foothill locations (Kazalinsk, Tashkent, Bishkek, Almaty), linear regression analyses performed for the time period from 1970 to 2000 show trend coefficients from 0.031 °C to 0.041 °C. If the regression is begun in the even colder year 1972 (absolute low) the trend coefficients rise to 0.042 °C and onwards to 0.048 °C. Here, it becomes evident, to which extent the result of a trend analysis is influenced by the choice of the initial year. Additionally, the trend/noise ratios, which have been calculated as a significance test, show that trends for such short periods are generally not significant and that linear regressions for a determination



[1] Temperature records were shifted for better illustration:
Tashkent -1°C, Almaty +4°C, Naryn +2°C

Fig. 4: 30-year moving averages of annual temperatures at selected climate stations in Central Asia 1880–2000

Entwicklung der Jahresmitteltemperaturen ausgewählter Klimastationen in Zentralasien 1880–2000 (30-jähriges gleitendes Mittel)

Table 5: Trend coefficients of Kazalinsk station's annual temperature averages with different ends

Trendkoeffizienten der Jahresmitteltemperatur der Station Kazalinsk nach verschiedenen Endzeitpunkten

Time range of the regression analysis	Trend coefficients (per 100 years)	Difference to 1998
1934–1998	+1.7 °C	–
–1999	+1.8 °C	+0.2 °C
–2000	+2.0 °C	+0.3 °C
1954–1998	+2.2 °C	–
–1999	+2.5 °C	+0.3 °C
–2000	+2.8 °C	+0.6 °C
1970–1998	+2.8 °C	–
–1999	+3.5 °C	+0.7 °C
–2000	+3.9 °C	+1.2 °C

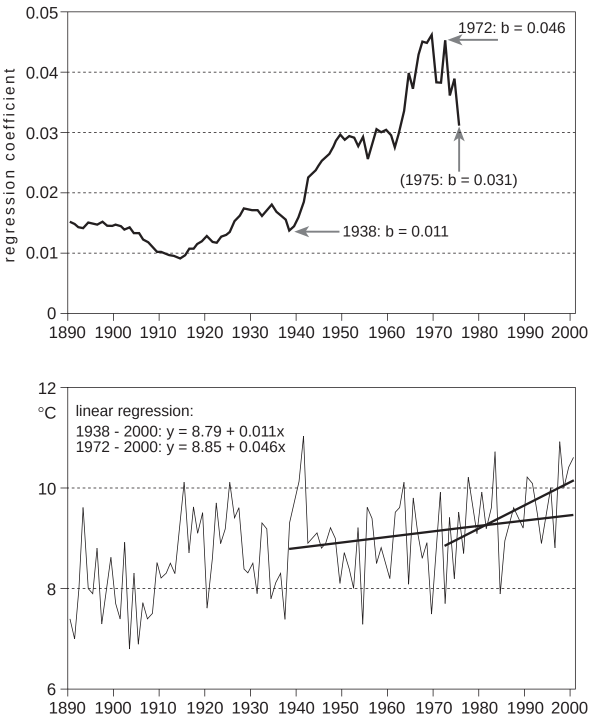


Fig. 5: Development of the linear regression coefficient b for the determination of the annual temperature average's rise at Almaty station up to the year 2000, against the initial year (regression coeff. of the year x – 2000)

Entwicklung der linearen Regressionskoeffizienten b zur Ermittlung des Anstiegs der Jahresmitteltemperatur der Station Almaty bis zum Jahr 2000 nach Anfangsjahren (Regressionskoeff. vom Jahr x – 2000)

of trends in annual temperature averages are only suitable for considerably longer periods starting in 1950 or 1934. Still, a significance level of 95% is only reached by seven of the 21 stations.

The choice of the trend analysis' end has an equal effect on the result (cf. Tab. 5).

Calculated trend coefficients should therefore be interpreted and evaluated with great care. Beginning and end of the trend analysis should always be well justified, extreme values at a time series' beginning or end are to be avoided. Despite the qualifying remarks it remains irrefutable that the climate warming in Central Asia is remarkably stronger than the global average.

4 *Linear trends or long-term correlations*

The enormous variation of calculated trend coefficients (cf. Tab. 4) cannot only be put down to local peculiarities of the different measuring stations or to unsuitably chosen time periods. Therefore, the fundamental question concerning the applied methods remains. Long-term processes and fluctuations are not considered by conventional regression analyses. Especially long-term correlations within the temperature time series, which cannot be quantified with conventional methods, call the results into question. Such long-term correlations can lead to considerable deviations of a time series from its mean and thus suggest an occasional trend, which in fact results from a long-term statistical coupling of the individual measured values (Kantelhardt et al. 2001; Eichner et al. 2003; Rybski et al. 2006). The previously determined seemingly cyclic fluctuations (cf. Fig. 2 and 3) are also to be found in long-term correlated sequences (cf. Fig. 6).

Panel (a) at the head of figure 6 shows generated time series without a trend, which does, though, contain long-term correlations of the strength which has been determined for the Karakol record. In panel (b) the same values are shown, but shuffled to remove long-term correlations, as these result from the specific arrangement of values. The distribution and standard deviation are not changed by shuffling the values.

It is apparent that the sequence of long-term correlations exhibits a much more pronounced mountain-valley structure than the lower sequence without long-term correlations. The discussed time series, which show a warming of the air temperature in Central Asia, could in the worst case correspond to detail (c) that was indicated in figure 6 (a). Therefore, the noted warming over the past decades, which was determined conventionally, possibly does not represent a trend in the sense of a lasting deviation from the average, but could be the result of long-term correlations within the time series or at least be superposed by the long-term correlation's effect. Without knowledge of the correlation's structure the deviations can easily be attributed to a trend.

In order to identify such long-term correlations in time series, the mathematical method of 'Detrended Fluctuation Analysis (DFA)', developed by PENG et al. (1994), is used. Detailed descriptions of the method and its possible applications can be found in PENG et al. (1994), KOSCIELNY-BUNDE et al. (1998), BUNDE and KANTELHARDT (2001), EICHNER et al. (2003), as well as in MOSSIG and RYBSKI (2005). The DFA method also allows one to assert whether a time series shows a trend or not (cf. KANTELHARDT et al. 2001). Still, such

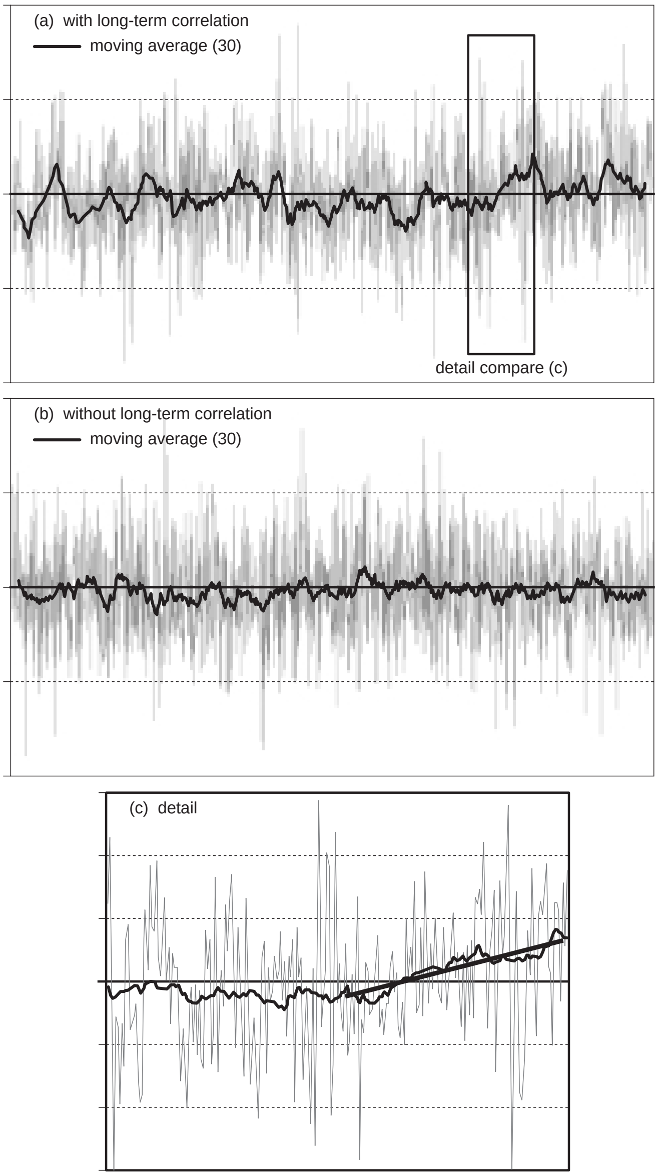


Fig. 6: (a) A generated long-term correlated sequence of numbers without trend. (b) The sequence of (a) after shuffling, by which the correlations have been destroyed. (c) Detail of (a) which seems to indicate trendy behaviour

a) Konstruierte langzeitkorrelierter Zahlenreihen ohne Trend. (b) Die Werte dieser Zahlenreihe (a) wurden durchmischt, um die Langzeitkorrelationen auszuschließen. (c) Ausschnitt aus (a) der einen scheinbar trendhaften Anstieg der Zahlenwerte suggeriert a trend may not be directly quantified by means of the Detrended Fluctuation Analysis and may thus not be compared with the results of conventional methods, nor be used for purposes of prognosis. The DFA can only show that a trend does probably appear in a data sequence, not however, how strong it is. Hence, further development was implemented extending DFA to quantify the strength of possible trends. This expanded method, though, does require intensive calculations so that the explanations will be exemplified for the Karakol climate station. Basic assumption for the new model was the commencement of a linear warming since 1950, which could be inferred from the previously introduced results of the conventional methods.

In order to compare the expanded method of DFA with the conventional result of regression, all regression values of Karakol station for different initial years of a beginning warming in the 1950s were calculated with different final years. Trend values vary between 2.4 °C per 100 years for the regression of 1955–1996 and 2.9 °C for the time window 1950–1994. The trend value of 2.7 °C listed in table 4, which was calculated due to the regression of 1950–1996, can thus be used as a plausible comparative value for the new method, which was not influenced to an extreme degree by an unsuitable beginning or finishing point.

4.1 Results of the Detrended Fluctuation Analysis (DFA)

The basic idea of fluctuation analysis is that a series' cumulated sums dislocates the further, the stronger its statistical dependencies (autocorrelations) between the original values are. First of all the series to be examined is subtracted by its mean, which may also be cyclic, e.g.

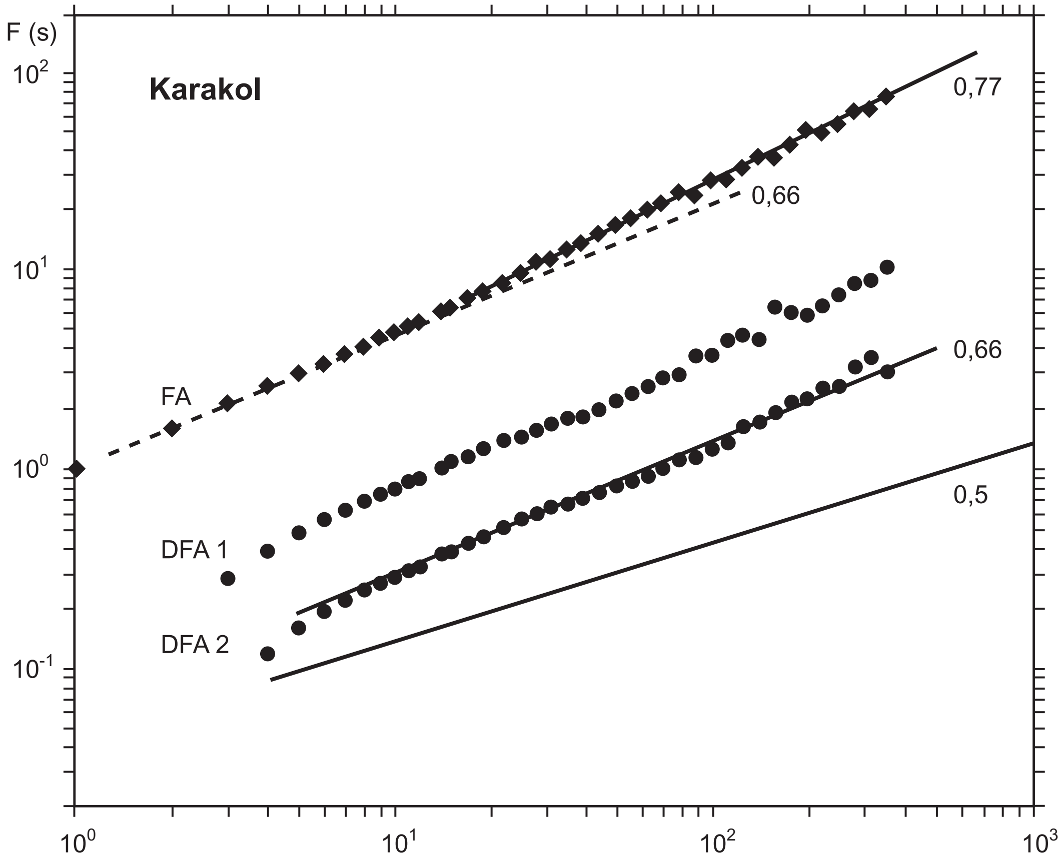


Fig. 7: Fluctuation functions of FA, DFA1 and DFA2 of the deseasoned temperature record (monthly values) of Karakol station

Fluktuationsfunktionen FA, DFA1 und DFA2 der saisonbereinigten Temperaturreihe (Monatswerte) der Station Karakol the seasonal cycle. From this, the cumulated series is constructed by adding values in succession so that for example the tenth value is given by the sum of the first ten values and so on. Following a one-dimensional random walk (cf. BUNDE a. HAVLIN 1994, 12ff.) the cumulated series' root-mean-square displacement, after a certain number of steps s (also called scale), behaves proportional to the root of steps (exponent 1/2), if the original values are independent from each other (not correlated). If, though, correlations occur in the values of the investigated series, then the displacement of the cumulated series is considerably larger. This can be explained through the fact that successively larger values followed by larger ones or smaller values followed by smaller ones are added up, and that neighbouring large and small values compensate each other less frequently. The so called fluctuation function F(s) (cf. KOSCIELNY-BUNDE et al. 1998) is calculated from this so called profile, the cumulated series. Then, in the case of long-term correlations (characterised by a power-law decaying auto-correlation function), there is a fluctuation function which does not increase with an exponent 1/2, but with a larger exponent. This way, the correlation structure can be quantified. The advantage of the DFA is that long-term correlations can be determined, even if the random fluctuations are overlain with a trend. For this, the already mentioned cumulated series is divided into windows of size s, in which local regressions are performed. The residual component then forms the fluctuation function, which is now independent from underlying trends of certain polynomial order. One of the method's advantages is that through the variable length of intervals, in which the trends are systematically eliminated, short-term changes as well as long-term trends are considered (and eliminated). This leads to the additional advantage that the DFA's results are not affected by unsuitable beginning or finishing points.

The linear regressions of fluctuation functions in logarithmic representation provide the fluctuation exponent α. If $\alpha > 1/2$, the time series is influenced by long-term correlations and it can be said: the bigger α, the stronger the effect of long-term correlations. Thus the following exponents are relevant for interpretations:

$\alpha \cong 0.5$	the time series is uncorrelated
$0.5 < \alpha < 1$	the time series' values are long-term correlated.

The time series analysis of air temperature at Karakol stations by DFA are based on monthly averages from 1879–1996 (all in all 1,416 data points). Figure 7 shows the corresponding graph for the determination of fluctuation exponent α, which matches the slope of the fluctuation function F(s) in the double-logarithmic plot (cf. MOSSIG a. RYBSKI 2005; RYBSKI 2006). Besides DFA1, the almost parallel DFA2 is also depicted, in whose case not linear regression (DFA1) but parabolic regression are used for the systematic elimination of trends in the time intervals of variable length within the record. In the cases of DFA1 and DFA2 for the Karakol station, the fluctuation function F(s) shows a slope of $\alpha = 0.66$ for larger time scales (at the latest from $s = 10^1$, i.e. as of a period of 10 months).

The determined exponents correspond to the results of earlier studies (cf. KOSCIELNY-BUNDE et al. 1998; EICHNER et al. 2003), which, on a global scale, hint to an almost universal occurrence of the fluctuation exponents around $\alpha = 0.65$ in the case of long air temperature records at continental sites. Among others, this regularity was used as a criterion to evaluate global climate models (cf. GOVINDAN et al. 2002; VJUSHIN et al. 2004).

The first result to be noted is that the time series of the average monthly temperature at Karakol station does actually include long-term correlations. Thus the determined warming of air temperature also depends on the time series' internal correlation structure. The trend value, which was determined with conventional methods and which does not take into account the effect of long-term correlations, is probably overestimated or the trend's significance is overestimated.

In addition, above DFA1 and DFA2, the fluctuation function of the conventional FA is shown in figure 7. In the case of FA, trends are not eliminated and appear as larger slopes. From the non-detrending FA's slope it can be seen that there has to be a trend besides the long-term correlations within Karakol station's temperature time series (cf. KANTELHARDT et al. 2001). This can be clearly recognized when looking at the FA's steepening curve shape (transition from $\alpha = 0.66$ to $\alpha = 0.77$ interval lengths $s = 10^1$). This break shows that the temperature fluctuations F(s) on large time scales increase excessively, which, in the end, can most probably be attributed to a trend.

All in all, the determined increase of air temperature at Karakol station is obviously based on both, the long-term correlation's effect, as well as a trend, i.e. a systematic change within the measured values. There still remains the problem that the respective influence of these two components cannot be separated with the DFA. It is unclear to which extent the rise in temperatures at Karakol can be put down to a lasting warming trend and how strongly, on the other hand, the long-term correlations' effect acts. Due to this question the DFA method was systematically used on specially constructed random sequences, in order to be able to estimate the influence of occurring trends.

4.2 Application of the DFA for the estimation of trends

The basic idea on which the further development of the DFA for the quantification of trends is based (for a detailed description see Rybski a. Bunde 2007), involves the generation of long-term correlated random sequences (i.e. without trends) (cf. Makse et al. 1996), which, with regard to their correlation structure, match the behaviour of the instrumental record of the Karakol station. In the case of such random sequences without trend the same mean fluctuation exponent α describes both, the DFA of different orders and the non-detrending FA.

In the next step, to simulate the warming, successive linear trends are added to these random sequences beginning at that time which corresponds to the year 1950. The stronger the added trend is, the steeper rises the FA in comparison with the DFA, whose average slope remains constant $\alpha = 0.66$ due to its detrending properties (cf. Rybski 2006). This way the added trend can be increased until the FA's average slope of the generated random numbers plus trend matches the picture obtained for the record of Karakol station, whose FA slope was $\alpha = 0.77$.

As the determined fluctuation functions of these random sequences never exactly form a certain FA-slope but are scattered around an average exponent, it is necessary to construct and statistically analyse a large number of these artificial random sequences. In this case, 5,000 such sequences, used to estimate the trend within the measured values of Karakol station, were constructed and evaluated with DFA to achieve statisti-

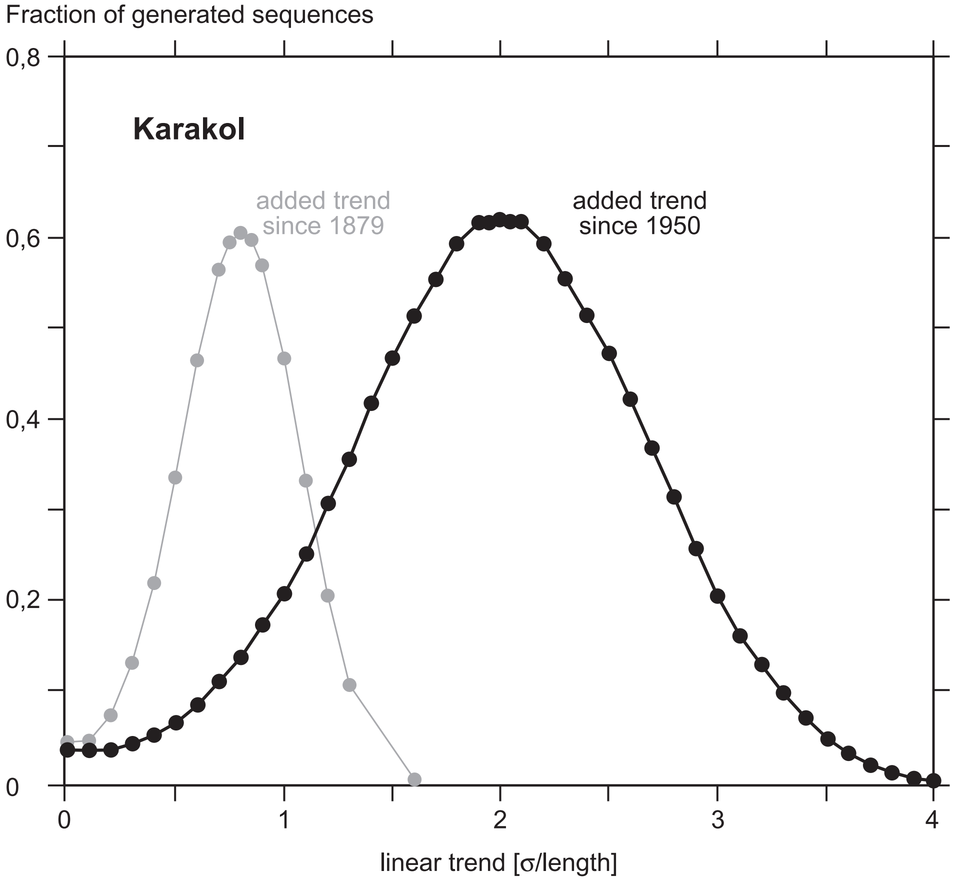


Fig. 8: Fraction of simulated random sequences, which provide comparable exponents, as does the temperature series of Karakol, for the FA as well as for the DFA, depending on the strength of an added trend since 1950 (Karakol: $\alpha_{DFA2} = 0.66 \pm 0.05$; $\alpha_{FA} = 0.77 \pm 0.05$)

Anteil der simulierten Zufallszahlenreihen, die in Abhängigkeit von der Stärke eines ab 1950 hinzugefügten Trends sowohl für die FA als auch die DFA vergleichbare Exponenten liefern wie die Temperaturreihe von Karakol (Karakol: $\alpha_{DFA2} = 0.66 \pm 0.05$; $\alpha_{FA} = 0.77 \pm 0.05$)

cally robust results. The results of this method are summarized in figure 8.

As a unit for the added trend since 1950 the standard deviation α of the instrumental record, divided by its length, is chosen. Therefore, the value 1 on the x-axis indicates that the modelled trend-like increase in the warming phase since 1950 is of the strength 1σ / (record length).

In figure 8, the closest point to the origin (0 σ/length) corresponds to the case without trend since 1950. These random sequences can as well mirror the structure for Karakol, which was determined with the (D)FA. It is very unlikely, though, that this corresponds to the real situation at Karakol, as without added trend only 5% of the analysed 5,000 random sequences possess the characteristics of the measured record at Karakol. The second point in figure 8 therefore signifies how many of the analysed time series possess the slope of FA and DFA2 at Karakol station, if a trend of 0.1 σ/length is added from 1950 onwards etc. In more than 60% of the cases a trend of 2 σ/length is the most likely. Still, with a strength between 1.9–2.1 σ/length, the values for added trends since 1950 lead to similarly high probabilities in the distribution curve as does this peak value. Correspondingly, a span for the trend value thereby determined should be named. If the unit "standard deviation/record length" is calculated back into months and °C, this corresponds to a warming by +0.022 °C–0.025 °C per year for an assumed warming period from 1950 onwards. Per 100 years, the trend-like warming thereby corresponds to 2.2–2.5 °C. The warming by 2.7 °C per 100 years, which has been established with conventional methods (without consideration of the long-term correlation), is therefore apparently slightly overestimated.

It has to be remarked that the DFA-based estimation of the warming since 1950, as well as the regression analyses, which observe the period since 1950, assume the hypothesis that a previously stationary record is changed at a single point. This is a simplification whose limitations have to be worked off successively, e.g. by calculating a smooth transition into a phase of warming.

Sources for possible smaller errors and deviations with regard to the presented DFA-based method for the determination of warming trends within the analysed record can originate in the assumption of a normal distribution of the generated comparative sequences. The determination of the fluctuation exponent α can also be afflicted by uncertainties. Furthermore, it is unclear whether short-term correlations within the measured record have an influence on the DFA-based trend determination method.

5 Results

It can be inferred from the generalised curve (cf. Fig. 2 and 3) that the development of the annual temperature averages runs in a more or less regular rhythm of up- and downswings. Cross correlation and phase synchronisation analyses which were carried out point to a strong synchronicity of the curve shapes. However, the result of performed Fourier analyses shows that the annual temperature averages do not follow a regular cyclicity.

A trend-like increase in air temperature overlies the cyclic fluctuations of annual temperature averages since the beginning of the 1930s, at the latest since the beginning of the 1950s. The most pronounced rise in annual temperature averages over the past 50 years (1950–2000) has been recorded by climate stations located in lowland basins and foothills in intramontaneous valley and basin locations. In the first case, calculated regression coefficients lay between 0.031 and 0.037, thereby pointing to a rise in air temperatures by 3.1 °C to 3.7 °C per 100 years. In the second case there is even an increase of 3.4 °C to 4.2 °C. If the rise in air temperatures during this time is compared to the increase of the air temperature's global average (+0.94 °C), a noticeable warming of the climate has been taking place in Central Asia over the past 50 years (1950–2000).

The superposition of cyclic and trend-like developments has resulted in the fact that the warming has not occurred steadily but in a thrust-like fashion. Three thrusts can be distinguished. They started at the beginning of the 1930s, 1950s and 1970s. Due to them, the thrust-like rise of annual temperature averages experienced an acceleration. The strongest and longest rise in air temperatures started in 1970/72. Linear regression analyses carried out for the period 1970–2000 supply trend coefficients of 3.1 °C to 4.1 °C (per 100 years) for the climate stations in lowland basin and foothill locations (Kazalinsk, Tashkent, Bishkek, Almaty). If the regression is begun in the even colder year 1972 (absolute minimum), the trend coefficients increase to 4.2 °C and up to 4.8 °C. Here it becomes obvious how much the result of a trend analysis is influenced by the choice of the initial year and the subsequent choice of the finishing year.

These trend coefficients, determined in the conventional way, do not take into account long-term correlations, though. To work out their effect, the time series analysis was continued with the help of the Detrended Fluctuation Analysis (DFA), based on the example of Karakol station. This way it was determined that the record of air temperature (monthly values) shows a trend as well as long-term correlations, which overlie each other. The different exponents of the trend-eliminating DFA compared to the non-detrending FA was used to quantify the strength of the identified trends. For this purpose, long-term correlated random sequences without trend were generated, which correspond to Karakol station's temperature record, with respective to the correlation behaviour (DFA2). Via the successive addition of trends in these generated random sequences from the point in time which corresponds to 1950, an estimation of trend values can be carried out by way of comparing the exponents of the FA. The warming at Karakol station was estimated to 2.2–2.5 °C, per 100 years. According to the conventional regression analysis (trend value: 2.7 °C, per 100 years) the warming is therefore slightly overestimated, due to the long-term correlations which have not been taken into account, but differ only in a justifiable order of magnitude.

Overall it was shown that the internal correlation structure of a record has to be considered when determining temperature trends, as the trend tests can be influenced by long-term correlations. The method of trend estimation under consideration of long-term correlations requires complex algorithms. As outlook, the results obtained for the Karakol station have to be put in a general framework by applying the method to further climate stations in order to substantiate these first findings in hand.

References

Aizen, V.; Aizen, E.; Melack, J. M. a. Dozier, J. (1997): Climatic and hydrologic changes in the Tien Shan, Central Asia. In: Journal of Climate 10 (6), 1393–1404.

Bunde, A. a. Havlin, S. (1994): A brief introduction to fractal geometry. In: Bunde, A. a. Havlin, S. (eds.): Fractals in science. Berlin, Heidelberg, New York, 1–25.

Bunde, A. a. Kantelhardt, J. W. (2001): Langzeitkorrelationen in der Natur: von Klima, Erbgut und Herzrhythmus. In: Physikalische Blätter 57, 49–54.

Dikich, A. N. (2004): Gletscherwasserressourcen im Issyk-Kul'-Becken (Kirgistan). Gegenwärtiger und zukünftiger Zustand. Zentrum für internationale Entwicklungs- und Umweltforschung der Universität Gießen, Discussion Papers 19. Giessen.

Diskyn, M. N. (1970): On the computer evaluation of Thiessen weights. In: Journal of Hydrology 11, 69–78.

Eichner, J. F.; Koscielny-Bunde, E.; Bunde, A.; Havlin, S. a. Schellnhuber, H.-J. (2003): Power-law persistence and trends in the atmosphere: a detailed study of long temperature records. In: Physical Review E 68.

Finaev, A. (1999): Climatic changes in the mountain glacier area of Pamir. In: Wettlaufer, J. S.; Dash, J. G. a. Untersteiner, N. (eds.): Ice physics and the natural environment. NATO ASI Series 156, 289–295.

Giese, E. a. Mossig, I. (2004): Klimawandel in Zentralasien. Zentrum für internationale Entwicklungs- und Umweltforschung der Universität Gießen, Discussion Papers 17. Giessen.

Govindan, R. B.; Vyushin, D.; Bunde, A.; Brenner, S.; Havlin, S. a. Schellnhuber, H.-J. (2002): Global climate models violate scaling of the observed atmospheric variability. In: Physical Review Letters 89 (2).

Hagg, W. (2003): Auswirkungen von Gletscherschwund auf die Wasserspende hochalpiner Gebiete, Vergleich Alpen – Zentralasien. Diss. München.

IPCC (2001): The scientific basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge.

Kantelhardt, J. W.; Koscielny-Bunde, E.; Rego, H. H. A.; Havlin, S. a. Bunde, A. (2001): Detecting long-range correlations with detrended fluctuation analysis. In: Physica A 295, 441–454.

Koscielny-Bunde, E.; Bunde, A.; Havlin, S.; Roman, H. E.; Goldreich, Y. a. Schnellnhuber, H.-J. (1998): Indication of a universal persistence law govering atmospheric variability. In: Physical Review Letters 81, 729–732.

Makse, H. A.; Havlin, S.; Schwartz, M. a. Stanley, H. E. (1996): Method for generating long-range correlations for large systems. In: Physical Review E 53 (5), 5445–5449.

Mossig, I. a. Rybski, D. (2005): Die Erwärmung bodennaher Luftschichten in Zentralasien. Zur Problematik der Bestimmung von Trends und Langzeitkorrelationen. Zentrum für internationale Entwicklungs- und Umweltforschung der Universität Gießen, Discussion Papers 26. Giessen.

Peng, C.-K.; Buldyrev, S. V.; Havlin, S.; Simons, M.; Stanley, H. E. a. Goldberger, A. L. (1994): Mosaic organization of DNA nucleotides. In: Physical Review E 49, 1685–1689.

Romanovskiy, V. V. (2002): Sovremennye izmeneniya klimata na Tien Shan. Bishkek.

Romanovskiy, V. V. a. Kuzmichenok, V. A. (2005): Ursachen und Auswirkungen der Seespiegelschwankungen des Issyk-Kul' in jüngerer Zeit. Zentrum für internationale Entwicklungs- und Umweltforschung der Universität Gießen, Discussion Papers 22. Giessen.

Rybski, D. (2006): Untersuchung von Korrelationen, Trends und synchronem Verhalten in Klimazeitreihen. Diss. Giessen.

Rybski, D. a. Bunde, A. (2007): Methods of trend detection in long-term correlated records. In: Physica A (preprint).

Rybski, D.; Havlin, S. a. Bunde, A. (2003): Phase synchronization in temperature and precipitation records. In: Physica A 320, 601–610.

Rybski, D.; Bunde, A.; Havlin, S. a. Storch, H. von (2006):

Long-term persistence in climate and the detection problem. In: Geophysical Research Letters 33 (6), L06718.

SCHÄFER, D. (2001): Rezente Klimaänderungen in China? Ein Vergleich mit globalen Trends. In: Geographische Rundschau 53 (10), 42–47.

SCHÖNWIESE, C. D. (2000^3): Praktische Statistik für Meteorologen und Geowissenschaftler. Berlin, Stuttgart.

TURSUNOV, A. A. (2002): Ot Arala do Lobnura: Gidrologiya besstochnych bassejnov Centralnoy Azii. Almaty.

VJUSHIN, D.; ZHIDKOV, S.; HAVLIN, S.; BUNDE, A. a. BRENNER, S. (2004): Volcanic forcing improves Atmoshere-Ocean Coupled General Circulation Model scaling performance. In: Geophysical Research Letters 31.

WARD, R. C. (1975): Principles of hydrology. London.

BUCHBESPRECHUNGEN

BÖHNER, JÜRGEN; MCCLOY, KEITH RAYMOND and STROBL, JOSEF (eds.): SAGA – Analysis and Modelling Applications. 130 S. und zahlr. Abb. und Tab. Göttinger Geographische Abhandlungen 115. Verlag Erich Goltze, Göttingen 2006

Das große Potenzial von Open-Source-Software in Forschung und Lehre wird auch an deutschen Hochschulen zunehmend erkannt. Diese Anwendungen sind frei verfügbar und von Nutzern nach individuellen Anforderungen direkt erweiterbar. Mit der Entwicklung und Bereitstellung des Geographischen Informationssystems (GIS) SAGA (System for Automated Geoscientific Analyses) leistet ein Konsortium aus deutschen, dänischen und österreichischen Wissenschaftler/innen einen Beitrag in diesem wachsenden Feld.

Im vorliegenden Band der Göttinger Geographischen Abhandlungen bieten die Entwickler/innen und einige Anwender/innen des SAGA-Paketes Einblicke in dessen Funktionsweise und in Anwendungsmöglichkeiten. Ein Teil der Aufsätze befasst sich mit technischen Aspekten der Software. So finden sich Beiträge zur Geschichte und zum grundlegenden Aufbau des Programmpaketes, zu den Erweiterungsmöglichkeiten um Module für bestimmte wissenschaftliche Anwendungen sowie zu Teilen der verwendeten Algorithmik.

Eine zweite Gruppe von Beiträgen präsentiert Anwendungsbeispiele für die noch recht neue Software. Diese decken klassische Einsatzgebiete für GI-Systeme in verschiedenen Bereichen der physischen Geographie ab. So finden sich Aufsätze zur pedologischen Modellierung, zur Abschätzung von Naturgefahren wie Steinschlag und Massenverlagerungen und Beispiele aus der Hydrologie. Diese Beiträge sind nicht als Anleitungen zum Einsatz von SAGA zu verstehen, geben aber einen guten Einblick in das Potenzial der Software.

Insgesamt spannt dieser Band einen interessanten Bogen von technischen zu angewandten Aspekten geographischer Informationssysteme, wobei am Beispiel SAGA die Möglichkeiten freier Software in diesem Bereich eindrucksvoll herausgestellt werden. Dennoch wäre eine klarere Struktur, z.B. im Sinne einer deutlich erkennbaren Zweigliederung in einen einführend-technischen und einen inhaltlichen Teil, für potenzielle SAGA-Anwender/innen wünschenswert gewesen. Auch die Berücksichtigung einiger Beiträge aus dem humangeographischen Bereich wäre der allgemeinen Zugänglichkeit zuträglich gewesen. Und während der Einsatz der englischen Sprache mit Sicherheit die Sichtbarkeit im internationalen Rahmen verbessert, hätte den zumeist von deutschsprachigen Autor/innen verfassten Texten zuweilen eine sprachliche Überarbeitung gut getan.

Trotz dieser Einschränkungen ist diese Zusammenstellung ein wertvoller und wichtiger Beitrag, der anschaulich zeigt, dass freie Software zu Recht ihren Platz in der modernen geographischen Forschung beansprucht. Auch wenn dieser Band nur physisch-geographische Anwendungsbeispiele enthält, sei die Lektüre Geograph/innen aller Fachrichtungen empfohlen. Dem SAGA-Paket wiederum sei eine lange Zukunft sowie ein breiter und aktiver Nutzerkreis gewünscht.

JAN CERMAK