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Current Warming in Middle Asia and Atmospheric Circulation Change Development

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Authors' contributions

Authors YVP and BMK developed general idea and participated in the analysis. Author BMK carried out statistical calculations, trend analysis and wrote the first draft of the manuscript. Author APA managed the analyses of the study and managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

A study has been carried to determine the trends in atmospheric circulation forms in the beginning of the current warming in Middle Asia, on the basis of interannual changes of duration of synoptic processes in Middle Asia over the last 60 years. This study was conducted in Uzbekistan territory for a period over 100 years and series of temperature and annual precipitation measurements were recorded. In this study the methodology was employed based on statistical and trend analysis of time series, evaluation criteria of linear trends significance, and new indexes of circulation. It was also noticed that a notable increase in the average annual air temperature began in 60s of the last century in Uzbekistan. The warming is statistically significant. There was a slight increase in annual precipitation in the same period. Changes in air temperature and precipitation due to changes in the regional atmospheric circulation patterns. The length of the Northern and North-Western cold intrusions (meridional circulation form) has been decreasing, and the duration of Western intrusions (latitudinal circulation form) has not been changed virtually. Latitudinal transport of air masses has became predominant over Middle Asia from the middle 60s and index of circulation, representing

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ratio of the synoptic processes duration favorable for sedimentation, to the duration of anticyclonic processes was proposed. The value of this index has been decreased during the last 50 years, which had been associated with increased duration of anticyclonic processes not favorable for precipitation. However, rainfall has increased both in warm and cold half-year. A paradoxical situation appears, but it can be easily explained. Spektorman's researches confidently show that air masses which flow to Middle Asia for last 50 years became not only warmer but also wetter. The effect of air wetness rise in the process of precipitation is a subject of separate research. Besides, water vapor rise has become the main reason of intensification of greenhouse effect. According to the data of the World Bank emissions of carbon dioxide in Uzbekistan were many less than in many other countries. So, not carbon dioxide rise, but water vapor rise in atmosphere caused the warming of regional climate. Thus, the current warming in Uzbekistan is under the influence of one of the main climate-forming factors – circulation.

Keywords: Warming; trend; significance criteria; synoptic processes of middle Asia; atmospheric circulation; indexes of circulation.

1. INTRODUCTION

Over the past 115 years, climate scientists have distinguished three periods with different character in air temperature changes over time. The first period, covering the time period from the beginning of the century to the 1940s, has been characterized by intense temperature increase. The period from 40s to 70s has not been marked with significant change in average annual temperatures. There has been a new intensive increase in air temperature since 70s up to the present time. Recorded air temperature has shown the recent decades, and even in the recent years [1].

The main natural factors influencing on the Earth climate together are solar radiation, atmospheric circulation and the nature of the underlying surface. Much attention has been paid in the recent years to the so-called anthropogenic influence on climate formation processes. Identification of the role of each of these factors in the change of both global and regional climate is a very complex task. For this reason, it makes sense to consider the influence of individual factor on climate change within the limited physical-geographical region. Atmospheric circulation was chosen as such a factor as the most dynamic in time and space component of the climate system of the Earth. The general atmospheric circulation in hemispheric scale or the whole globe leads to latitudinal and meridional transport of matter and energy in atmosphere.

Modern principles of classification of atmospheric circulation forms in the Northern Hemisphere were laid by Wangenheim and Giers [2]. Extensive studies of the general atmospheric circulation have been built on the division of all synoptic processes into elementary synoptic processes (ESP) and their generalization in three forms: Western (*W*), Eastern (*E*) and Meridional (*C*) circulation. Detailed classification of synoptic processes in Middle Asia has been developed in 30s - 40s of the 20th century [3]. It has been refined and expanded in subsequent years [4]. Repeatability and duration of the separate synoptic processes are inextricably connected with one of the above circulation forms. Study of these characteristics in trending mode is an urgent problem in terms of development both long-term weather forecasting and climate prediction.

2. MATERIALS AND METHODS

Observational data of meteorological stations in Uzbekistan was used as a source material, as well as "Synoptic processes of Middle Asia calendars", published by Uzhydromet [5]. Daily 4-term data on the types of synoptic processes for the 12 months of the year from 1960 to 2012 of these calendars were chosen. The duration of each type was determined as a sum of the type terms for a single month and year.

Around 65-70% of the precipitation in Middle Asia falls in the period from October to March inclusive. In mountainous areas these falls have solid phase predominantly, which contributes to their accumulation on glaciers. Therefore, the calendar year was divided into two equal periods: cold (October-March) and warm (April-September).

Calculation of the required characteristics was performed with use of standard statistical, trend and correlation analysis software. The ratio of the

trend increment to the standard deviation (σ) was chosen as a criterion for assessing the significance of linear trends in air temperature [6]:

$$\frac{\Delta Tr}{\sigma} = \frac{Tr(t_n) - Tr(t_t)}{\sigma}$$

where $Tr(t_n)$ and $Tr(t_t)$ – value of trends calculated according to equation of linear regression by the period from t_t to t_n.

The found data was compared with the research results of Middle Asian climatologists.

3. RESULTS AND DISCUSSION

Quantitative assessment of the climate change degree was made on the basis of a comparative analysis of the two major climatic parameters - temperature and precipitation.

The ratio of the trend increment of air temperature to its standard deviation indicates the importance of the change with respect to natural variability. Long-period observations of four stations in Uzbekistan located in different geographical conditions were used to analyze the changes in the mean annual temperature in the 20th century [7]. Urgench station is situated in oasis on the skirts of south-west of Kizilkum desert, Tashkent - in oasis foothills of the Tien Shan massif, Ferghana - in the south-eastern part of the vast basin valley, Termez - in south, the hottest part of the republic. Changes in average annual temperature in the last 22 years were analyzed according to the weather stations of Tashkent region (Table 1, Fig. 1).

Table 1. Characteristics of long term trends in average annual temperature changes by stations of Uzbekistan from 1900 to 2007

Station	Altitude elevation, m	Trend increment, ΔT (°C)	Standard deviation, σ	ΔT/ σ	K, %
Urgench	105	1,6	0,9	1,8	90
Tashkent	477	2,2	1,0	2,2	95
Ferghana	580	2,0	0,9	2,2	95
Termez	313	0,9	0,8	1,1	70
Angren*	942	0,7	1,2	1,7	90
Tuyabugiz*	404	0,6	1,2	2,0	93
Kamchik*	2145	0,6	1	1,7	90

**Data from 1991 to 2012*

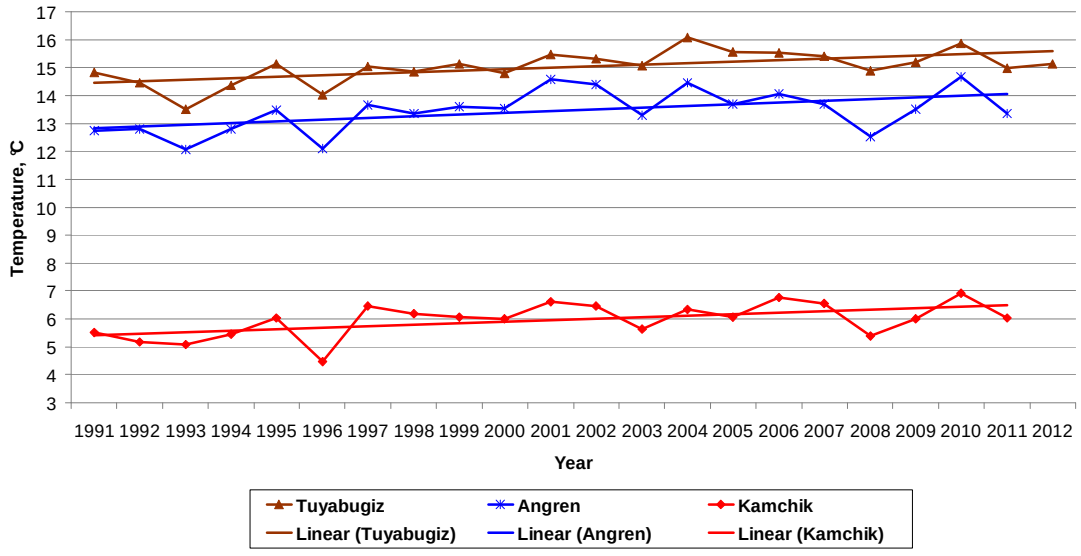

Fig. 1. Interannual average air annual temperature change

The results of the researches of the Uzbek climatologists show the significant warming in Uzbekistan, which began in 60s of the 20th century. But the most intense took place in the late 20th - early 21th century. At the same time significant average annual temperature changes at all stations is over its natural variability. However, the warming process proceeded non-uniformly in the country. The greatest warming has been observed in large industrial centers (Tashkent, Ferghana), where the increase in the average annual temperature was 2.0 - 2.2℃. This warming, apparently, is due to additional effect of urbanization. The smallest warming has been observed in the southern regions (Termez). Warming has also affected overall increase of the average minimum and maximum air temperatures [7].

Analysis of Standardized Precipitation Index series (amount of precipitation as a % of average long-term) in the cold and warm half of a year and a whole year of long-period stations has showed that there is a slight tendency to fall increase, or its lack at separate stations. In general, change in annual precipitation in the late 20th century - early 21th relative to the base period of 1961-1990 increased by an average of 6-12% on flat land areas and up to 6% - on foothill and mountain [8].

However, according to our data interannual variations in annual fall for the stations of Tashkent oasis has shown great variability of distribution for the last 22 years (Fig. 2). Thus, the difference in the amount of precipitation in 1993 and 1995 reached 700 mm. But, significant trend of change in annual precipitation during this period was not observed. Accordingly the coefficient of significance of linear trend of precipitation quantity is close to zero. Comparison of annual precipitation for the periods of 1976-2005 and 1991-2012 showed that in the last period there was an increase of the average annual rainfall relative to the period 1976-2005 at most stations. The greatest increase in precipitation was observed at Pskem (46.1 mm), Sukok (43.2 mm) and Kamchik (57.4 mm) stations. Comparison of fall for the cold and warm half of a year showed that the increase in annual precipitation was due to their increase in the cold half of a year.

Thus, the warming in Uzbekistan can be confidently declared as an accomplished fact. The root cause of this warming was figured out in this research.

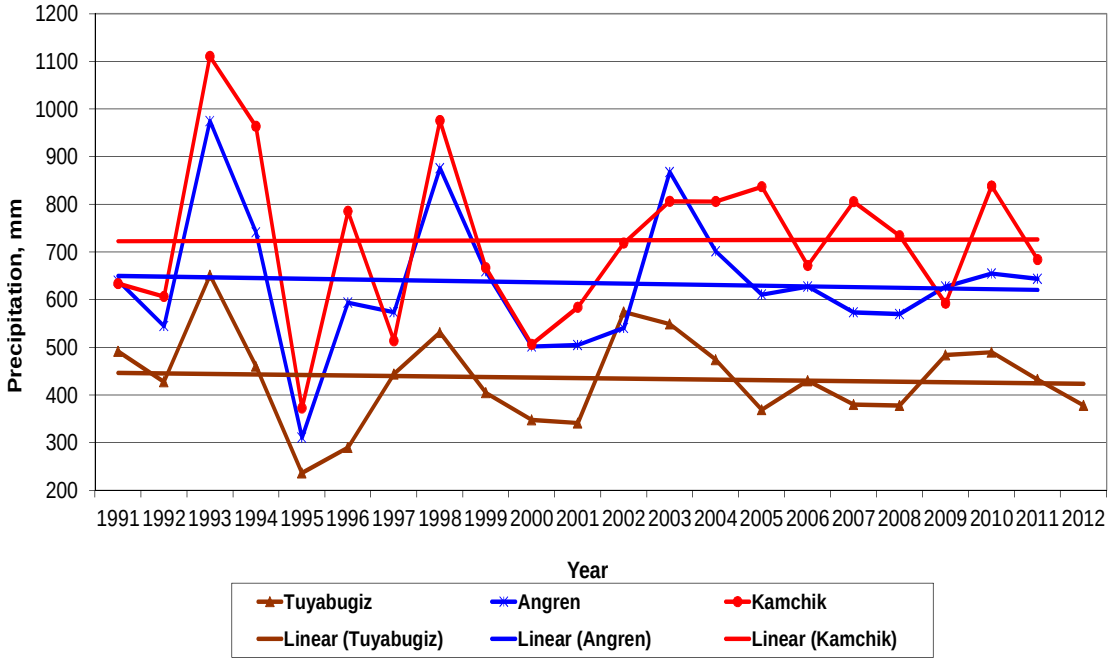

Fig. 2. Interannual annual precipitation change

From a dynamic point of view, the weather and climate of Middle Asia is determined by the regional atmospheric circulation over Middle Asia, which is part of the General atmospheric circulation. All the natural synoptic processes in Middle Asia can be divided into the following types:

1 – South Caspian cyclone;
2 – Murgab cyclone;
3 – Upper Amu Darya cyclone;
4 – Wide outflow of a warm air;
5 – North-Western cold invasion;
6 – North cold invasion;
7 – Wave action at cold front;
8 – Stationary cyclone over Middle Asia;
9 – South-Western anticyclone periphery;
9a – South-Eastern anticyclone periphery;
9b – South anticyclone periphery;
10 – Western invasion;
11 – Summer thermal depression;
12 – Low gradient elevated pressure pole;
13 – Low gradient decreased pressure pole;
14 – Western cyclone;
15 – Deriving cyclone.

Table 2. Characteristics of long-term trends in the average annual duration of synoptic processes types in Middle Asia from 1961 to 2012

Invasion type	Season	Linear trend equation	Trend increment, ΔL (daily)	Standard deviation, σ	ΔL/σ	K, %
North-Western	warm	y = -0.4737x + 953.87	25	9.82	2.54	98
cold invasion	cold	y = -0.3687x + 744.25	19.5	8.54	2.28	97
Northern cold	warm	y = -0.373x + 748.55	13.5	7.91	1.7	90
invasion	cold	y = -0.1477x + 296.7	7	3.99	1.75	91
Western cold	warm	y = -0.2678x + 565.16	17.5	10.33	1.69	90
invasion	cold	y = -0.0084x + 40.593	0	9.47	0	0

Research of Kim [2] has shown that the development of North-Western and Northern cold invasions in Middle Asia is most favorable when the meridional circulation form (*C*). *W* form is more favourable for the Western cold invasions. Therefore, change of the length of the above invasions can be used as an indicator of one circulation form to another change in Middle Asia.

New dimensionless parameter - index of circulation was used to assess changes of the circulation forms in the study period:

$$I_1 = \frac{W - C}{W}$$

where, *W* – total duration of the Western invasions; *C* – total duration of the Northern and North-Western invasions.

Table 2 above shows that there is a negative trend in the duration of each of the three synoptic types. The trend of Western invasion for the cold half of a year is almost not expressed. It should be noted that all trends have a high degree of significance.

Fig. 3 presents a graph of the annual values of index of circulation trend during the study period. The figure shows that there has been increase in the length of the Western invasions. Since the early 70s of the last century their number has become more than total duration of the North and North-Western cold invasions. According to the researches of Spektorman the average annual temperature in Uzbekistan has begun to increase since the 60s of the last century [7].

It is proposed to use the following index of circulation to quantitative assessment of the sediment-forming synoptic processes types duration changes:

$$I_2 = \frac{P - D}{P}$$

where, *P* – total annual duration of precipitation forming synoptic processes, which include synoptic processes 1, 2, 3, 5, 6, 7, 8, 10, 14 and 15, *D* – total annual duration of anticyclonic synoptic processes types (4, 9, 9a, 9b, 12, 13), in which precipitation is unlikely.

It is obvious that in case of a negative value of I_2, the number of anticyclonic processes exceeds the number of all the others that belong to wet forming.

Long term variations of this index are presented in Fig. 4 above. As it can be seen from the figure the index shows a strong trend of decreasing.

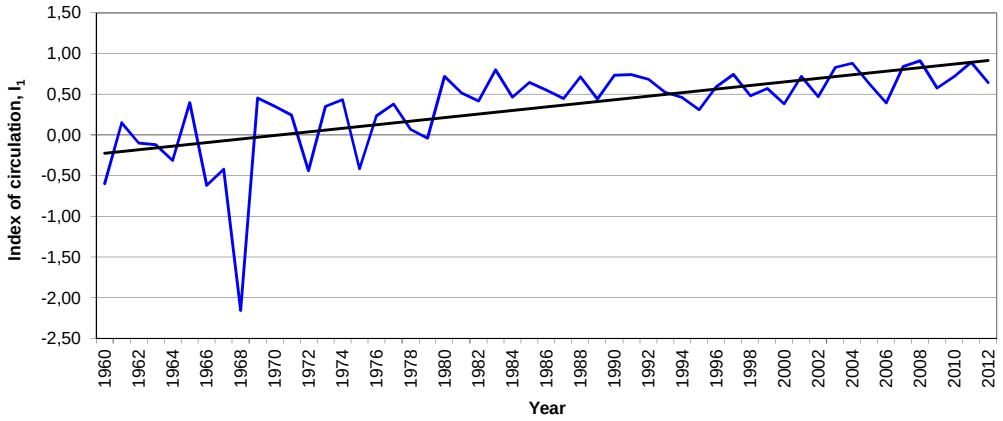

Fig. 3. Interannual change of index of circulation I_1

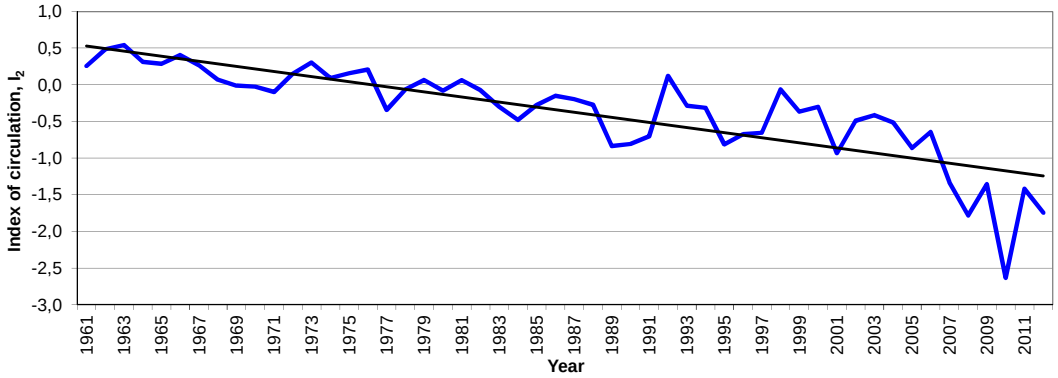

Fig. 4. Interannual change of index of circulation I_2

Thus, the air temperature increase is due mainly to the decrease of the North-Western and Northern cold invasions duration. Increase in precipitation cannot be explained only by the increase in the duration of the Western invasion in the cold half-year.

4. CONCLUSION

Keeping in view of the results and discussion, following data are noticed apart from the significant increase in average annual air temperature began in 60s of the last century in Uzbekistan and more conclusions were drawn:

a) The warming is statistically significant. There was a slight increase in annual precipitation in the same period. Changes in air temperature and precipitation were observed due to changes in the regional atmospheric circulation patterns. The length of the Northern and North-Western cold intrusions (meridional circulation form) has been decreasing and the duration of Western intrusions (latitudinal circulation form) has not been changed virtually. Latitudinal transport of air masses has become predominant over Middle Asia from the middle 60s.

b) Index of circulation, representing ratio of the synoptic processes duration favorable for sedimentation, to the length of anticyclonic processes was proposed. The value of this index has been decreased during the last 50 years, which had been associated with increased duration of anticyclonic processes not favorable for precipitation. However, rainfall has increased both in warm and cold half-year.

c) A paradoxical situation appears, but it can be easily explained. Spektorman's (2006, 2009) researches confidently show that air masses which flow to Middle Asia for last 50 years became not only warmer but also

wetter. The effect of air wetness rise in the process of precipitation is a subject of separate research.

d) Besides, water vapor rise has become the main reason of intensification of greenhouse effect. According to the data of the World Bank (2010) emissions of carbon dioxide in Uzbekistan were many less than in many other countries [9]. It indicates that there is no carbon dioxide rise, but water vapor rise in atmosphere is predominant due to the warming of regional climate.

The findings clearly prove that the main cause of the regional warming is changing of the shape of the atmospheric circulation in the Northern hemisphere: namely *W* type became predominant. Thus, regional warming in Middle Asia has been under the influence of one of the main climate-forming factors – circulation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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