The effect of changing stratification in the atmosphere in central zone of Eurasia according to vegetation data of Tien Shan mountains during 2002-2019

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Abstract. On the basis of long-term dynamics of the July's vegetation data (NDVI and VCI indices) for 31 ranges of the Tien Shan and Jungarian Alatau arid mountains located in the Eurasia center are found the atmosphere stratification change. The variability of Atlantic Ocean water vapor transport ability over Northern Tien Shan ranges to the Inner Tien Shan was detected. This phenomenon not related to the overall seasonal humidity but is obviously associated with atmosphere stratification regimes. The analyzed period consists of two eras from 2002-2008 and 2008-2019 years, which differ in the regime of accessibility of the Inner Tien Shan ranges for water vapor from Atlantic Ocean. The overall tendency of the changes in 2002-2019 is the increase in the availability ocean water vapor to the Inner Tien Shan ranges. Recorded changes may be due to global air temperature increases and atmospheric processes intensification.

1 Introduction

Atmospheric patterns transporting moisture from the Atlantic Ocean to the inlands of Eurasia are in complex interaction [1] with arid mountain ranges located in the center of the continent. Part of the ranges situated in the front edge of the dominating atmospheric transportation, capture the most of the moisture. Inner ranges, as a rule, are characterized by a significantly more arid climate [2]. Changes in atmospheric stratification affect the moisture conditions of the inner ranges of mountains land, which are expressed both in changes in snow deposite [3], and in vegetation condition [4,5]. As for vegetation cover, it is worthwhile noting the presence of two factors. The first one is in charge of absolute changes in the vegetation state. This is mainly due to the amount of water vapor transported and, partly, to temperature regimes. The second factor is traced by the relationship between vegetation state of the front and inner ranges. This ratio is related to the changes in the atmospheric stratification condition.

The ability of atmospheric flows to transport water vapor through mountain ranges cropping up along the way, in general, depends on width of the area [2]. This ability is stronger in the area of ascending branches of atmospheric circulation cells (Hadley and Ferrel cells), and weaker in the area of descending branches, respectively [6]. Climate changes, especially intra-continental ones, are almost completely controlled by atmospheric condition [7]. Atmospheric stratification regimes and its temporal variations are one of the most crucial parameters in the Earth's climate system. The ability to obtain information on variability of atmospheric stratification in the central zone of Eurasia from satellite monitoring of vegetation state of separate mountain ranges [4] and intermountain valleys [5] seems to be very relevant for understanding the tendency of the climate changes.

The state of natural vegetation cover is one of the indicators illustrating temperature and humidity conditions of underlying surface of the Earth. The central zone of Eurasia is distinguished by arid climate where the key parameter determining the vegetation state, is moisture conditions. Satellite observations using specific vegetation indices, of which NDVI [8] being the most popular, enable to obtain consistent sets of observations and use them to further determine current trends in changes of weather conditions at various spatial and temporal scales. Analysis of mountain range vegetation allows diagnose temperature and humidity conditions of underlying surface and their dependence on height above sea level and location inside the mountain lands [4].

The purpose of this study is to diagnose the changes in atmospheric stratification condition in the central zone of Eurasia in 2002-2019 based on data on vegetation state in 31 ranges of Tien-Shan and Dzungarian Alatau, located within 40^0-46^0 N latitude, 70^0-90^0 E longitude.

2 Research territory

The mountain ranges of Tien-Shan and Dzungarian Alatau adjoining to it on the north, are situated in the center of the Eurasian continent and occupy a territory of approximately 2500x600 km, Fig.1(a). The highest point of Tien-Shan is Pik Pobedy - 7439 m above sea level. Tien-Shan land consists of distinct ranges with characteristic heights of dominant peaks between 4000-6000 m. Geographers attribute the ranges to various groups, Fig.1(b). The main of which are Northern, Eastern, Western and the Inner (Central) Tien-Shan. The mountain ranges of the Northern Tien-Shan (Kyrgyz (No.6), Trans-Ili Alatau (No.7), Kungey Alatau (No.8) and Ketmen (No.9) (Fig.1(b)) are at the front (north-west) edge of this mountains and act as screens for the rest of the ranges, in particular, the Inner Tien-Shan, in relation to air masses, transporting water vapor from the Atlantic Ocean. The ranges of Tien-Shan significantly dry the overpassing atmospheric flows; therefore, one of the largest sand deserts of the world, Takla-Makan (1000x400 km), adjoins the Tien Shan on the south, with annual precipitation of less than 50 mm.

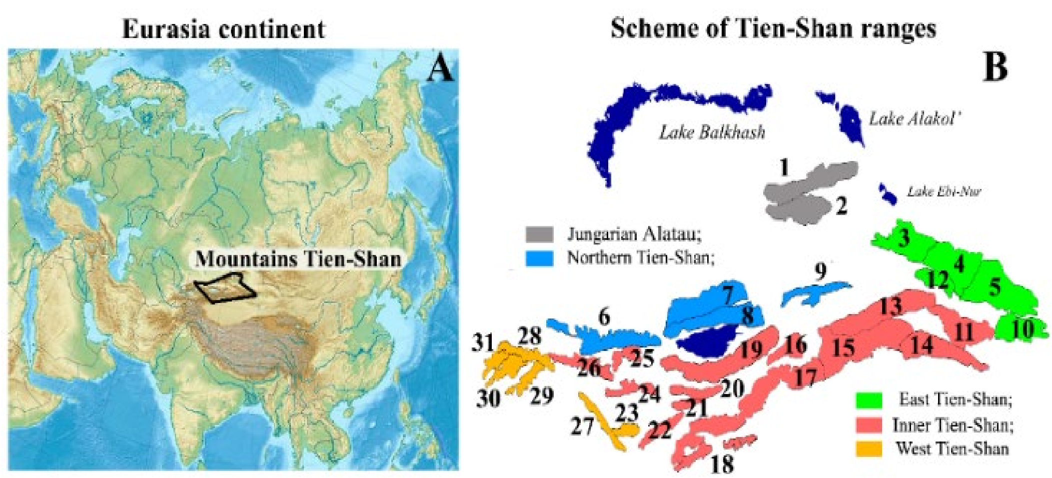

Fig.1. A - Disposition of mountains Tien-Shan in Eurasia continent; B- scheme of mountain ranges (1-31) used as objects for monitoring of the vegetation state.

3 Materials and methods

3.1 The satellite data

Temporally Smoothed NDVI, e-MODIS NDVI C6 product has been used in the study, which is publicly available on the website of Early Warning and Environmental Monitoring Program [http://earlywarning.usgs.gov] [9]. The U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center distributes satellite-derived vegetation products generated from the Collection 6 Moderate Resolution Imaging Spectroradiometer (MODIS) instrument flown aboard the Aqua satellite. These products respond to operational land monitoring applications requiring near-real time Normalized Difference Vegetation Index (NDVI) data for comparison against historical records. Real-time and historical NDVI products are composited in 10-day (decadal) intervals on a Geographic-mapping grid (Spheroid: WGS84). Archive depth is 18 years, from 2002 till present. e-MODIS NDVI C6 scene for Central Asia has the following dimensions (17407x13676 pix), with pixel size: x-direction: 0,002 (deg); y-direction: 0,002 (deg). The scene covers the territory within approximately 24-56°N latitude, 47-87° E longitude, including the Tien-Shan mountain system. The product features special spatial and temporal filters [9], which enables to minimize interfering effect of cloudiness. The seasonal characteristic of mountain vegetation was based on two scenes, decade 2 and 3 (decade 20 and 21). This period refers to the season maximum of mountain ridge vegetation observed in the second half of July.

3.2 Methods of satellite data processing

Intermountain plains separating of Tien-Shan lands are characterized by a semi-desert climate with low precipitation. Therefore, natural vegetation of Tien-Shan mountains represents an “island” of vegetation amid the mountain semi-deserts. Similar islands of vegetation, which are shaped due to the increased precipitation on mountain slopes, are easily mapped. Vegetation masks in 31 ranges of Tien-Shan and Dzungarian Alatau have been created using expert decoding, Fig.1(в). Vegetation masks include subalpine/alpine meadows and mountain forests. Description of the seasonal vegetation state was based on two scenes, decade 20 and 21 (July 10-31), from which a matrix of accumulated maximum values at each pixel position has been produced. As a characteristic of the year of vegetation masks of each of the analyzed ranges, the average NDVI value for the contour has been used.

The vegetation cover of separate ranges Tien-Shan exhibits various numerical NDVI values and their multi-year variability. To bring all analyzed objects to comparable scale, NDVI values have been restated into the values of VCI (Vegetation Condition Index) [10,11]. In this respect, the modified version thereof has been applied [12], with three reference fixed values, where: 0 – multi-year low NDVI; 0,5 – arithmetic mean of a number of NDVI (2002-2019) samples; 1,0 – multi-year high NDVI. Additional fixation of the average value makes the comparisons of the conditions of separate ranges more accurate from the meteorological perspective, where the average value (norm) is one of the key concepts. For ease of presentation, VCI values, as a rule, are multiplied by 100, which forms a scale in the range of 0-100.

Transfer to the comparable vegetation state assessment scale enabled to diagnose the relevant variability of vegetation condition on different Tien-Shan ranges. For this purpose, for each season, a difference between [VCI_{range}] and [$VCI_{total\ mask}$] has been calculated. Time series (2002-2019) of these differences contain information about relevant changes in vegetation condition within different parts of the mountain lands, which, in turn, depends on the atmospheric stratification condition of this region.

4 Results

Changes in vegetation condition of the analyzed mountain ranges, in general, are represented in Fig.2. The conditions of relevant changes in vegetation of separate ranges, calculated across time series $[VCI_{range}]$-$[VCI_{total\ mask}]$ during the period of 2002-2019, are shown in Fig.3. To illustrate the trends of the relevant vegetation changes of the analyzed ranges, linear trend parameters have been used, in particular, the sign and value of the coefficient in the linear trend equation and the approximation confidence value (R^2).

Such approach enables to differentiate between the dynamics of differences in vegetation conditions of separate ranges of Tien-Shan and the regional vegetation state. The calculation results are shown for three time periods: 2002-2019; 2002-2008; 2009-2019. The legend on the presented map diagrams reflects the relationship between the values of the main parameters of the linear trend of $[VCI_{range}]$-$[VCI_{total\ mask}]$ time series. The legend is designed in such a way that more intense colors correspond to high R^2 values. At the same time, red color is attributed to those objects where there is a negative trend in the time series of the calculated VCI value, blue - to objects with a positive trend.

The relationship between the relative vegetation condition in Zailiisky Alatau and the general vegetation condition of the entire analyzed mountain range has also been assessed, Fig. 4.

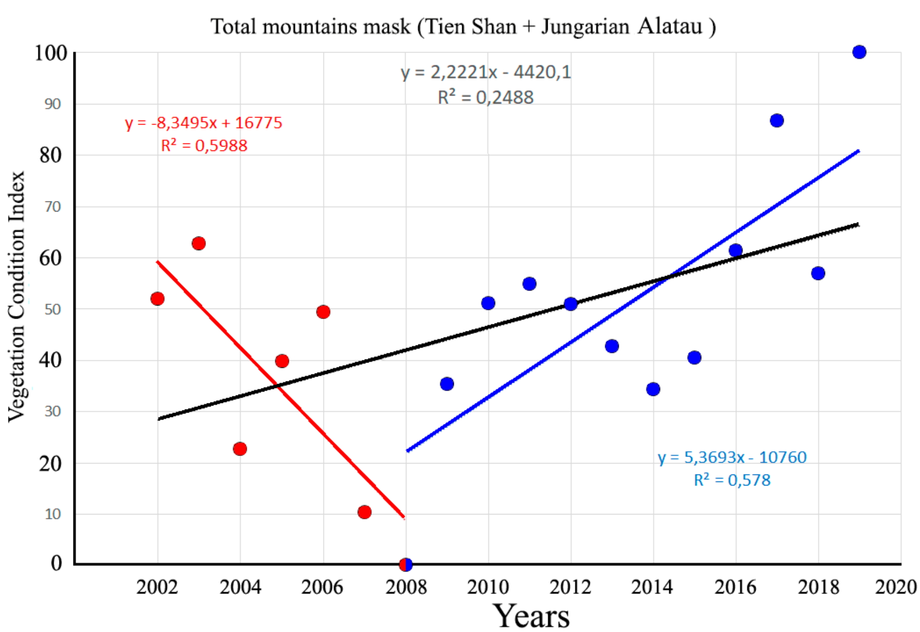

Fig. 2. Dynamics of VCI values for total mask which included all ranges (Tien Shan and Jungarian Alatau) during 2002-2019. Two time periods are highlighted in color: 2002-2008 (red); 2008-2019 (blue). The values of parameters of linear trend equations for the periods: 2002-2008 (red); 2008-2019 (blue); 2002-2019 (black); are given.

5 Discussion

Atmospheric flows transporting water vapor from the Atlantic Ocean to the center of the continent are under the influence of various factors, and their seasonal characteristics are quite variable. This leads to year-to-year changes in temperature and moisture conditions that reflects in vegetation state of Tien-Shan and Dzungarian Alatau ranges. The main weather factor affecting the mountain vegetation state in July is moisture (air humidity, amount of precipitations). Humid years alternate with dry years, but at the same time, noticeable persistence is recorded in multi-year perspective. During the period of 2002-2008 there was recorded a deterioration in vegetation condition, Fig.2. Then, from 2008 to 2019, vegetation state has improved, Fig.2. Relative vegetation condition of separate ranges during the period of 2002-2008 had a clear structure, Fig.3. The front edge of Tien-Shan, attributed to the Northern Tien-Shan (ranges No. 6-9), where there is more intense precipitation, showed much stronger deterioration than other ranges. For the period of 2008-2019, mild stratification of the territory is characteristic, with the exception of two ranges of the Inner Tien-Shan: Kungey Alatau (No. 19) and the Borokhotan ridge (No. 13), which have demonstrated marked

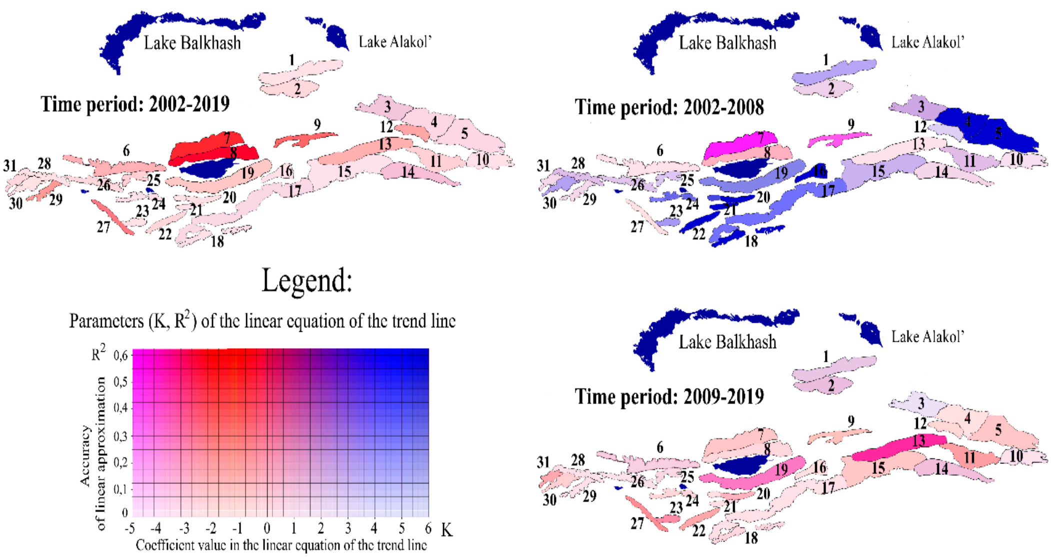

Fig. 3. The schemes of Tien-Shan and Jungarian Alatau mountain ranges, which colored by linear trend parameters (the coefficient [K] of the trend equation and the confidence value of the linear approximation [R^2]) are presented. The time series ($VCI_{range} - VCI_{total\_mask}$) during 2002-2019 served as the basis for this analytical procedure. The characteristics of three time periods: 2002-2019; 2002-2008; 2009-2019; are shown.

https://doi.org/10.1051/e3sconf/202014903004

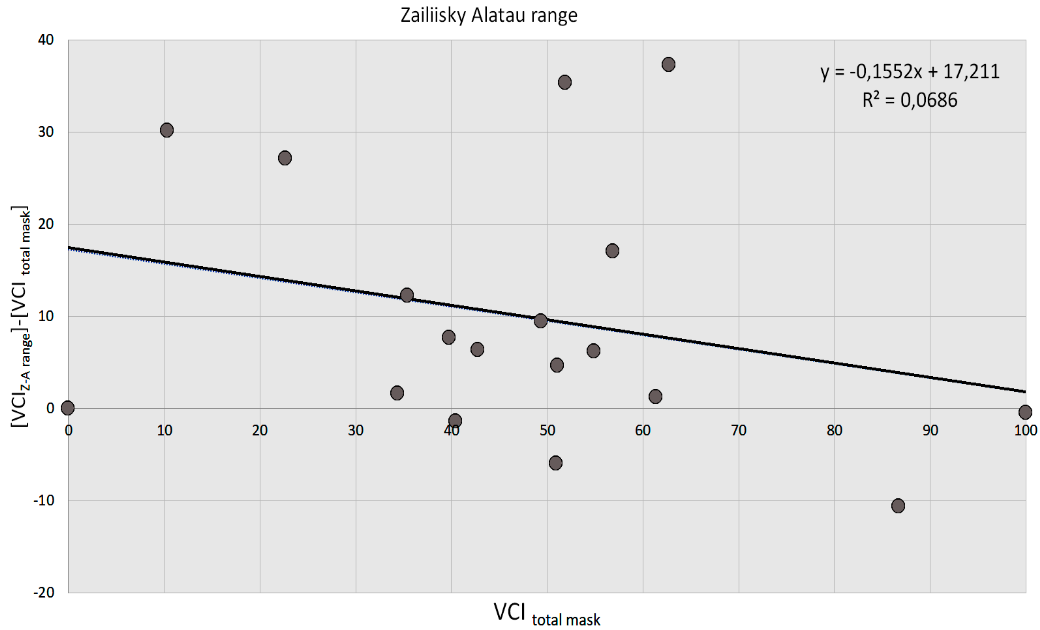

Fig. 4. The relation the July's vegetation state of all mountain ranges (VCI $_{\text{total mask}}$) against the differences between July's vegetation state of the Zailiisky Alatau range (VCI $_{\text{Z-A range}}$) and all ranges (VCI $_{\text{total mask}}$) during 2002-2019 years.

deterioration in vegetation condition, Fig.3. the entire monitoring period of 2002-2019 in total had a tendency to relative deterioration in vegetation condition of the Northern Tien-Shan ranges, Fig. 3. The foundation for this effect has been laid in 2002-2008.

The results obtained show that of the Northern Tien-Shan ranges are distinguished into a separate group showing relative deterioration in vegetation state. Whereby no clear relationship between the degree of relative deterioration in vegetation condition of the Northern Tien-Shan ranges, for instance, Zailiiskiy Alatau (No. 7) and vegetation conditions of the entire analyzed region, Fig.4, has been observed. I.e. the ability of atmospheric patterns to transport water vapor to the Inner Tien-Shan is not related with the overall seasonal moisture.

The ability of atmospheric patterns to transport water vapor through of the Northern Tien-Shan ranges is determined by atmospheric stratification conditions. The reasons of multi-year changes in the characteristics of these conditions remain unknown. It is possible that this phenomenon is related to the changes in the width of global atmospheric circulation cells (Ferrel, Hadley) because of its reaction to changes in the energy balance of the Earth.

6 Conclusion

The analysis of NDVI and VCI vegetation indices in 31 ranges of Tien-Shan and Dzungarian Alatau during the period of 2002-2019 has shown that there exists change in the ability of atmospheric flows to transport water vapor from the Atlantic Ocean towards the center of Eurasia to the ranges of the Inner Tien-Shan. This ability varies at various monitoring periods. Time span of 2002-2019 can be conditionally represented as consisting of two stages. The first, the period of 2002-2008, which is characterized by a marked increase in the availability of water vapor transported towards the ranges of the Inner Tien-Shan. The second, the period of 2008-2019, with a stable pattern that does not have clear trends. The general tendency of the analyzed period shows an increase in the share of water vapor transported by atmospheric processes to the Inner Tien-Shan. The recorded effect is obviously associated with the changes in atmospheric stratification in the center zone of Eurasia, which, in turn, is a consequence of the reaction of global atmospheric circulation to the Earth's climate changes.

Acknowledgment

This work was financially supported by Ministry of Education and Sciences of Kazakhstan, grant AP05134241.

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