*Journal of Georgian Geophysical Society,*
*Issue (A), Physics of Solid Earth, v.15a, 2011-2012, pp.67-87*

# Climate change in Georgia: Statistical and nonlinear dynamics predictions

**A. Amiranashvili [1], T. Matcharashvili [1,2], T. Chelidze [1,2]**

*1. M. Nodia Institute of Geophysics of I. Javakhishvili Tbilisi State University*
*2. European Centre "Geodynamical Hazard of High Dam", EUR-OPA*

*Abstract*

*The greenhouse effect (global warming) is one of the main hazards facing the whole planet. The climate forcing is due to rising concentration of greenhouse gases ($CO_2$, methane, water vapor): according to different assessments, the temperature will rise by 1.4-5.8$^0$C at the end of 21-th century. This can cause a lot of devastating effects and many of them will be impossible to prevent, which means that the humankind should find some way to adapt itself to global warming.*

*Georgia as a whole Caucasus is prone to many negative effects, connected with climate change: the mountain glaciers can melt and partially disappear, the sea level can rise, the vast areas of land can became deserts, water resources can be seriously affected.*

*Despite some earlier efforts, devoted to assessment of climate change in Georgia, the results are still ambiguous. In particular, the research carried out shows that during last decades the mean temperature in the Eastern Georgia is rising and in Western Georgia it is decreasing. These conclusions are debated and there is a need to re-consider them using new data and new methods of mathematical analysis of meteorological time series. For reliable assessments new modern methods of obtaining and analysis of climate data in the past, present and future is necessary to use.*

*Another problem is to ascertain whether this warming is exclusively the man-made effect or it is the result of natural cyclicity in the earth climate.*

*Specific objective is assessment of persistence and memory characteristics of regional air temperature variation in Georgia in the light of global climate change. For this purpose longest available temperature time series of Tbilisi meteorological station (since 1890) are analyzed. Similar time series on shorter time scales of 11 stations in the West and East Georgia will also be used as well as monthly mean temperature time series of 11 stations (1907-2006) in the West and East Georgia. As far as most incorrect conclusions about dynamical properties of complex dynamics are related to "data bleaching" procedures, in order to avoid destruction of original dynamics caused by linear filtering in the present research special noise reduction procedure of time series as well as multi scaling analysis based on CWT are used. Both mono- and multivariate reconstruction procedures of climate change dynamics are implemented. Additionally, temporally and spatially averaged daily and monthly mean air temperature time series are analyzed. Extent of persistence in mentioned time series is evaluated.*

## 1. Introduction: Global issues and South Caucasus

Most models of climate change are based on extrapolation of observed linear trends. At the same time, though global warming is well established, the question of persistence of trends on regional scales remains controversial. Indeed, climate change for specific region and specific time interval by definition includes more than the simple average of weather conditions. Either random events or long-term changes, or more often combinations of them, can bring about significant swings in a variety of climate indicators from one time period to the next. Therefore in order to achieve further understanding of dynamics of climate change and prevent related disasters, the character of stable peculiarities of analyzed dynamics should be investigated. Analysis of the character of long range correlations in climate time series or peculiarities of their inherent memory is motivated exactly by this goal. Such analysis carried out on different scales will help to understand and predict spatial and temporal features of regional climate change during general global warming.

According to Sylvén et al. (2008) "climate change has already started to have a significant impact on nature and people in the Southern Caucasus region – effects that will become even more severe in the future. This will create an extra burden on the development of societies in all the three countries of Armenia, Azerbaijan and Georgia, which still struggle to embark on a more sustainable path, including eradicating widespread poverty" (Table 1,2).

Table 1.The main environmental challenges related to climate change in Armenia, Azerbaijan and Georgia (Sylvén et al, 2008).

| Country | Environmental challenges |
|---|---|
| Armenia | Deforestation & illegal logging, Desertification, Use of solid fuels, Access to safe drinking water in rural areas, Management of Lake Sevan |
| Azerbaijan | Deforestation, Desertification and land degradation, Deteriorating air quality, Water shortage & insufficient water sanitation |
| Georgia | Land degradation (overgrazing, soil pollution and erosion), Illegal logging, Regional water shortage (particularly in eastern regions), Lack of access to safe drinking wate |

Table 2. Summary of reported economic losses linked to climate change in Southern Caucasus 1978-2007. The list should merely indicate the scale of the costs related to climate change in the region (modified from Sylvén et al, 2008).

| Country | Year | Events | Losses |
|---|---|---|---|
| Azerbaijan | July 1997 | Floods/erosion | 50 million USD |
| Azerbaijan | 2000-2007 | Floods and erosion (est. 70 mill/year) | 490 million USD |
| Georgia | May 2005 | Floods/erosion (low estimate) | 3 million USD |
| Georgia | 2000-2001 | Drought | 460 million USD |
| Armenia | 2000-2005 | Drought, frost, floods | 107 million USD |
| Armenia | Sept 2006 | Drought/forest fires | 9 million USD |

In (Harmeling, 2011) the climate risk index for 1990-2000 is presented for all countries of the world. Table 3 is a selection of data related to South Caucasus from above publication: according to it, Georgia has the largest values of losses per GDP in % and the highest rank (44), in comparison to Armenia and Azerbaijan.

Table 3. Climate Risk Index for 1990-2009 (Harmeling, S. GLOBAL CLIMATE RISK INDEX 2011) CRI = Climate Risk Index; GDP = gross domestic product; PPP = purchasing power parity; n/a = no data

| Index | Country | Overall CRI score | Death toll | | Death per 100,000 inhabitants | | Losses in million US$ PPP | | Losses per GDP in % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Total | Rank | Total | Rank | Total | Rank | Total | Rank |
| 136 | Armenia | 117.00 | 0 | 150 | 0.01 | 156 | 32.99 | 98 | 0.2 | 71 |
| 126 | Azerbaijan | 114.17 | 2 | 120 | 0.03 | 139 | 55.72 | 81 | 0.1 | 103 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| n/a | Ceorgia | n/a | 4 | 112 | 0.08 | 103 | 0.00 | n/a | 0.38 | 44 |

Still, despite grave assessments of Sylvén et al. (2008), according to numerous modeling results of Intergovernmental Panel on Climate Change (IPCC), Caucasus is the region of low or moderate magnitude of warming.

**2. Climate change history in the Western Caucasus (Georgia).**

The temperature measurements in Caucasus were first organized in Tbilisi (East Georgia) in 1844, namely, at the Tbilisi Geophysical Observatory. Thus we have here one of the longest temperature records; these data present average annual, as well as average seasonal temperature data. We tried linear, exponential, polynomial and 50 years average fittings to data. All of them reveal warming, which can be defined as $\Delta T = T_f - T_i$; here $T_f$ is the final and – $T_i$ initial temperature. According to linear and exponential fits of ΔT data, the temperature during 156 years raised by $1.20^0$C. These two fits do not show the change in the rate of warming, that is why polynomial and many-year average approximations seem to be more representative: the graph in Figs. 1 reveals trends in this long-term temperature record of average annual data: according to polynomial fit the 156 years $\Delta T = 1.4^0$C and for the last 50-years average $\Delta T = 1^0$C. Almost all this increment is obtained for the last 56 years, i.e. from 1950 to 2006.

The spatial distribution of ΔT in Georgia for 1906-1995 has been calculated in the frame of "Georgia's initial national communication under the United Nations Framework Convention on Climate Change" (1999). This study reveals the striking difference in the climate change trend between West and East Georgia (Fig. 2):

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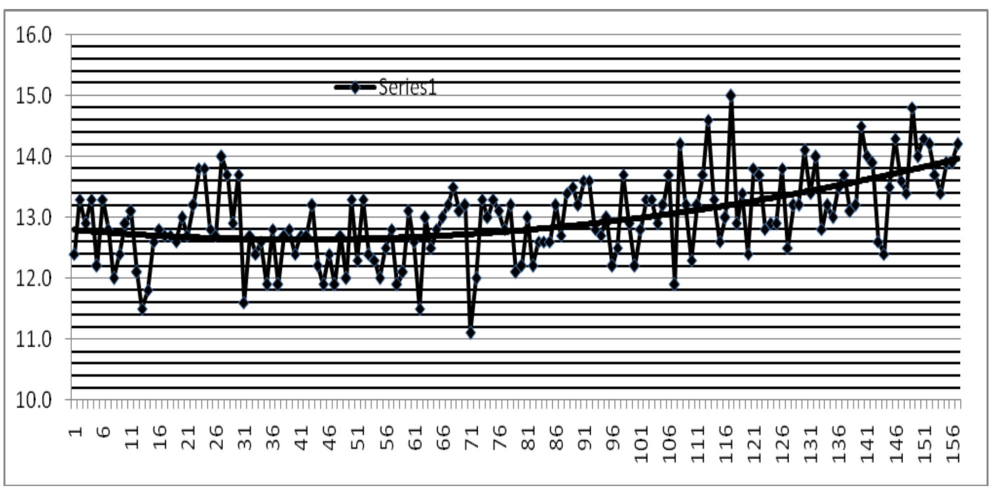


Fig. 1. Tbilisi temperature longest (156 years long) time series 1850-2006 (points) and the simplest fitting by second order polynomial (thick line)

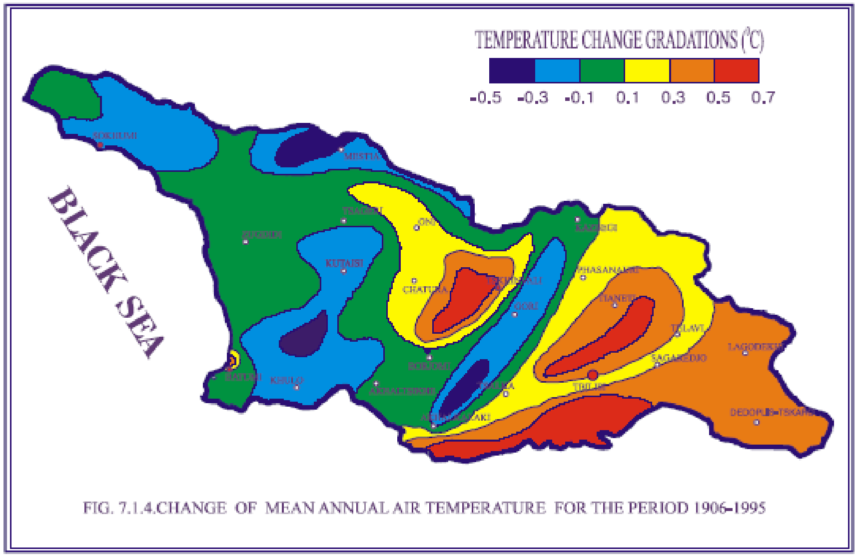


Fig. 2. Change of mean annual temperature in Georgia 1906-1995

More complicated statistical assessments were carried out using modern tools of statistics: autocorrelation, correlation fields, revealing periodicities, analysis of residuals etc. The estimation of difference between the investigated parameters was evaluated according to Student's criterion t with the level of significance not worse than 0.2. The results are shown below (Fig. 5, 6).

Analysis of air temperatures in the recent past in Tbilisi (Fig. 5) shows that after 1850-1906 period with cooling linear trend (section 1) there are permanent warming periods, 1907-1956 (section 2) and 1957-2006 (section 3). Temperature raised on average by 1$^0$C during the last 100 years.

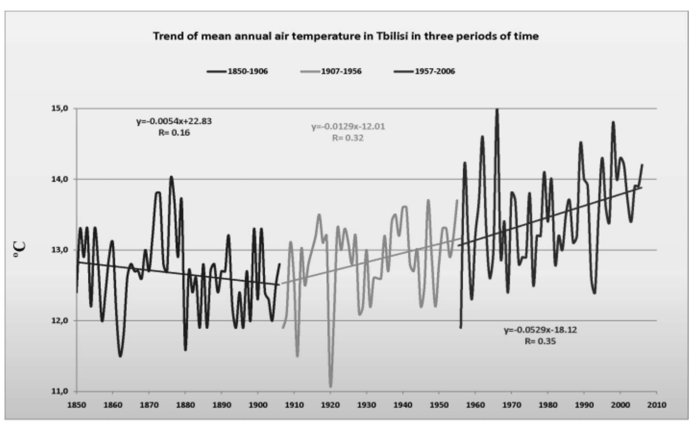


Fig. 5. Variability of mean annual air temperature in Tbilisi in 1850-1906 (section 1), 1907-1956 (section 2) and 1957-2006 (section 3) years with linear approximations

In Fig. 6 the difference between mean values of air temperature in Tbilisi in the period compared to 1907-1956 period. Significant differences (more than 0.1 degree C) are marked by dual shading (light and dark). It is evident that the largest differences, here - warming, are observed in cold months. The cold period months are in average twice warmer in the 1957-2006 compared to earlier 50 years.

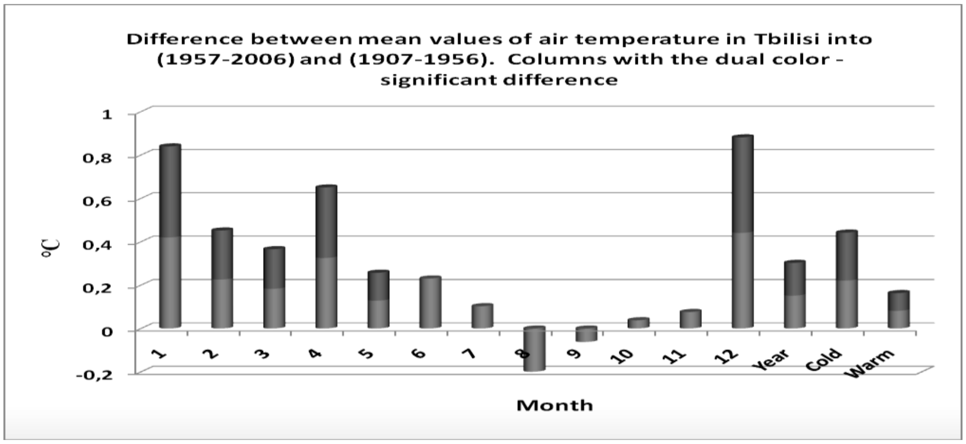


Fig. 6. Difference (dark parts) between mean values of air temperature in Tbilisi in (1957-2006) and (1907-1956). The last three columns – averages per year, per cold months and per warm months.

It is of fundamental importance to establish, is such warming the result of human industrial activity or there are some natural cycles of warming and cooling irrespective of man-made impact.

Last years in Georgia some proofs of earlier (pre-industrial) warm periods have been revealed. The monastery Betlemi dated to 10 cent. AD was cut in the rocks of the mountain Mkinvatsvery (Kazbek) at an altitude of 4200 m, where Christian priests lived at that time. Both pollen and non pollen palynomorphs were studied. The investigation showed that in $10^{th}$ cent. AD, in the environs of the ancient monastery there grew alpine and sub-alpine meadows with rich taxonomic composition. The monks have had domestic cattle and were engaged in beekeeping, which was possible only in conditions of warm climate (Kvavadze et al, 2011). At present it is impossible to live at these altitudes because of the severe climatic conditions. Mean annual temperature here is at present

$-6.1^0$. This points to existence of very warm periods in climate of Georgia even before industrial era.

The next substantial climate warming in the mountains of Georgia occurred from the end of the $13^{th}$ century AD to 14-15 century AD.This is indicated by the pollen data of investigation of the settlement "Navenakhari" (Kvavadze et al, 2009).

Comparison of these conclusions with global proxy reconstructions, show that mentioned periods indeed were warm (Chapman and Davis, 2010) and are defined as a Medieval Optimum, which according to Archer (2007) "took place about 800-1200 AD. This was a period of generally warm stable climate in Europe, coincident with a prolonged drought in the American southwest of sufficient intensity to spell the end of the Mayan civilization". In the same warm period Vikings settled in Greenland.

We can conclude that warm periods in South Caucasus/Georgia have been identified in earlier centuries, when anthropogenic impact was negligible.

In future for more reliable reconstruction of the past climate application of borehole geothermy method of reconstructing past temperatures up to 1000 year AD is necessary. Detailed variations of the surface temperature are evaluated from long-term highly resolved temperature measurements in boreholes: temperature variations slowly penetrate into the subground and can be measured hundreds or thousands of years after its occurrence. As the most part of heat comes from the Earth interior to the surface, the temperature profile would linearly increase with depth in case of constant temperature at the Earth surface, i.e for the stationary state. If the Earth surface is warming, than larger the warming, larger the deflection of temperature profile from the linear behavior; using mathematical inversion methods the past climate can be reconstructed up to 1000 years back. As a rule the linear trend is changed at the depth of the order of 150 m. Reduced temperatures are calculated by subtracting the background thermal regime from the measured temperatures. The deeper we measure temperature the more is the age of reconstructed surface temperature. There are good preconditions for application of geothermal method of reconstructing past temperatures up to 1000 year AD in Georgia and Caucasus. We have precise devices for temperature measurements in boreholes and good network of deep boreholes, which covers the whole region of Caucasus. Geothermal reconstruction of past temperatures seems to be a principal point for making decision on the existence of very warm periods in Georgia in 10th and 13th centuries AD, before industrial era.

Of course, the present warming also can be partly of natural origin, but the man-made positive feedback could significantly fasten natural process.

## 3. Assessments of future climate change in the World and Regions

Prediction of the future climate change is an extremely complicated problem (Palmer, 1998; Johns T. et al. 2003 and references in them). There are mainly two approaches to solution: i. creation of mathematical model, using system of equations, which define contribution of different factors to the Earth climate, namely positive and negative feedbacks. There are more than 20 such models, which are too complicated for analytical solution and are solved by special computer programs; ii. statistical analysis of existing climate data, including indirect data and prediction of future changes using this information.

The mentioned models of future warming are calculated for different scenarios, which prescribe different weights to above listed feedbacks. Fig. 6 illustrates warming rates for different emission scenarios developed by the Intergovernmental Panel on Climate Change (IPCC) for the period from 1900 to 2100 (http://www.ipcc.ch) and Table 3 shows assessments of temperature increase for 8 different models. In total, there are forty emission scenarios, and they are grouped into six scenario "families": A1B, A1FI, A1T, A2, B1 and B2. The lowest growth is expected for scenarios B1 and B2 and the highest growth for the cases A1F1 and A2.

Table 3.3. Temperature Increase 2000 to 2100 (°C)

| Model | Total | Land | Ocean |
|---|---|---|---|
| CCSR/NIES | 4.7 | 7.0 | 3.8 |
| CCCma | 4.0 | 5.0 | 3.6 |
| CSIRO | 3.8 | 4.9 | 3.4 |
| Hadley Centre | 3.7 | 5.5 | 3.0 |
| GFDL | 3.3 | 4.2 | 3.0 |
| MPI-M | 3.0 | 4.6 | 2.4 |
| NCAR PCM | 2.3 | 3.1 | 2.0 |
| NCAR CSM | 2.2 | 2.7 | 2.0 |

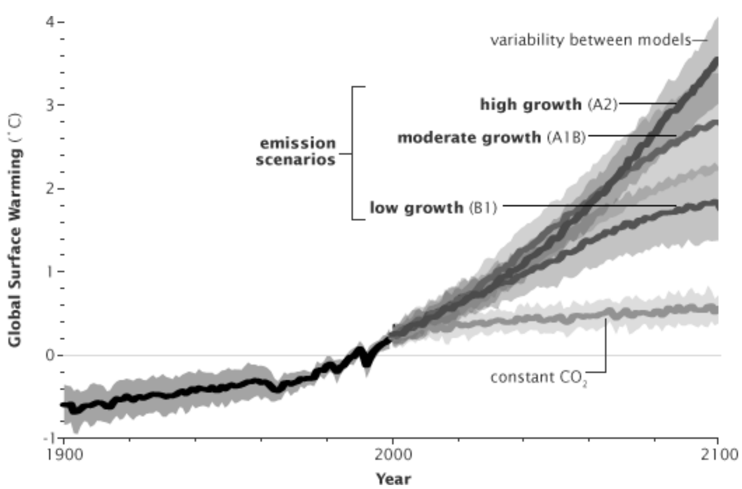

Fig. 3. Global warming simulations by the Intergovernmental Panel on Climate Change (IPCC). Earth will warm between two and six degrees Celsius over the next century, depending on how fast carbon dioxide emissions grow. Scenarios that assume that people will burn more and more fossil fuel provide

Both the climate and climate change vary from region to region. That is why besides global change (GCM) models covering scales of order of hundreds of km, development of regional climate change models (RCM) for processes covering scales from hundreds to several km is necessary (Brohanet al, 2006).

***4. On the future climate change in Georgia - new statistical assessments:***

In this part of work were used the data of the Hydrometeorological department of Georgia about the monthly average values of air temperature in 12 locations of Georgia (Table 1) for the period 1907-2006 (in Tbilisi 1850-2006 data are available). The data about monthly average values of Global Land, Global Land North Hemisphere and Zonal 24N-64N territories air temperature were used also for comparison [http://www.giss.nasa.gov].

The simplest prediction can be done by just extrapolation of time series: for example let us consider the extrapolation of 156 year Tbilisi temperature data (Fig. 4), which are best fitted by second order polynomial. The extrapolation display for the period 1850-2055 the increment $\Delta T = 2.4^0C$ with the most part of $\Delta T$ is in the last hundred years, from 1950 to 2050 and for the longer period 1850-2105, the increment $\Delta T = 4.4^0C$ with the most part of $\Delta T$ is in the last hundred fifty years, from 1950 to 2105.

It is interesting to note that this simplest extrapolation gives the assessment of temperature increment comparable with the predictions of the complicated mathematical models (Fig. 3).

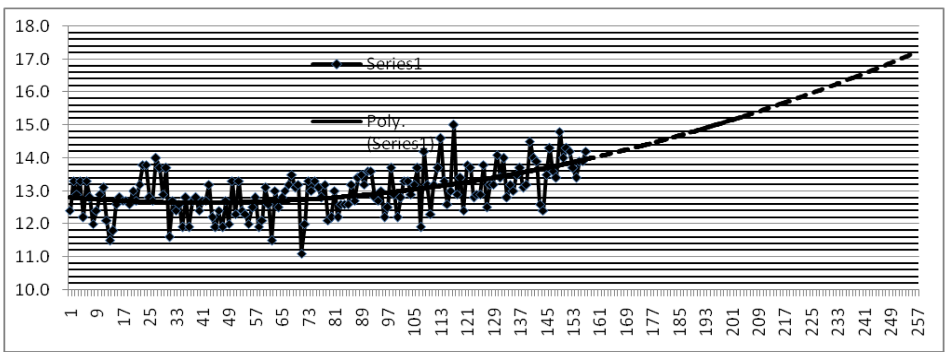


Fig. 4. Simple second order polynomial extrapolation of 156 year Tbilisi temperature data (see also Fig.3) to the year 2105.

*Expected Temperature Change to 2055- statistical assessments*

In this part we show results of (linear) statistical assessments of future trends in climate in Tbilisi (Fig. 7) and 12 locations in Georgia, marked on the map (Fig.2), using modern methods of statistical assessments: autocorrelation, correlation fields, revealing periodicities, analysis of residuals etc.

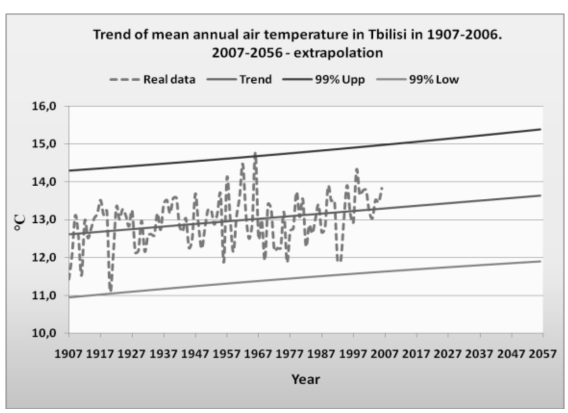

Fig 7. Trend and forecast of mean annual air temperature in Tbilisi using linear approximation. Upper and lower 99% limits are also shown.

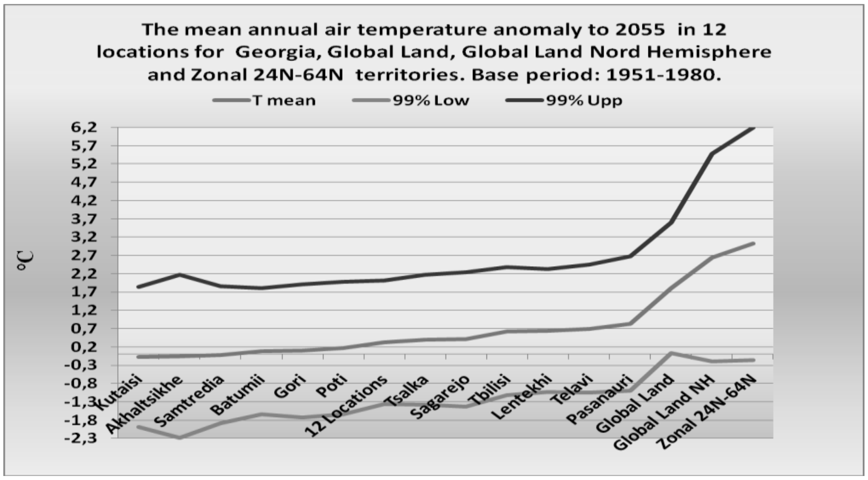


Fig. 8. The mean annual air temperature change prediction for 2055 in 12 locations for Georgia, Global Land, Global Land Nord Hemisphere and Zonal 24N-64N territories

In the correspondence with that indicated above to 2055 year the following values of the anomalies of mean air annual temperature (base period: 1951-1980) are expected for 12 Locations of Georgia (Fig. 8): Kutaisi: $-1.98 \le -0.07 \le 1.85$; Akhaltsikhe: $-2.29 \le -0.06 \le 2.17$; Samtredia: $-1.89 \le -0.01 \le 1.87$; Batumi: $-1.64 \le 0.08 \le 1.80$; Gori: $-1.72 \le 0.10 \le 1.92$; Poti: $-1.65 \le 0.17 \le 1.99$; : $-1.36 \le 0.33 \le 2.02$; Tsalka: $-1.38 \le 0.39 \le 2.17$; Sagarejo: $-1.43 \le 0.41 \le 2.25$; Tbilisi: $-1.11 \le 0.63 \le 2.38$; Lentekhi: $-1.04 \le 0.65 \le 2.33$; Telavi: $-1.05 \le 0.70 \le 2.45$; Pasanauri: $-0.99 \le 0.84 \le 2.67$. These values are less than predictions for the Global Land: $0.04 \le 1.81 \le 3.59$; Global Land NH: $-0.19 \le 2.64 \le 5.47$ and Zonal 24N-64N: $-0.15 \le 3.02 \le 6.20$, which is accordance with the IPCC assessments that Georgia is the zone of weak or moderate climate change.

Analysis reveals the existence of several periodic components in the air temperature time series.

As it follows from Fig. 9 periodic components, present in time series of mean annual air temperature for 12 stations of Georgia for real and residual data, are practically the same (20, 12.5, 9, 7.2 years etc.). Periodic components of mean annual global air temperature for real and residual data (Fig. 10) are similar for 20 years periodicity, but do not coincide (are shifted) for some ranges (11.5, 10 years etc.). We can only guess on the nature of these periodicities: as the temperature variations depend strongly on sun radiation, it seems reasonable to relate them to solar cycles, which are reflected in interplanetary magnetic field – IMF (Takalo, Mursula, 2002). For example, 20-22 years component can be related to 22-years long Hale cycle of solar magnetic field. There are also periodicities in IMF connected with well-known 10-12 year solar cycle and its first two harmonics, 5-6 and 2.5-3 years; some of temperature field periods are close to observed in the IMF: namely, 12.5, 5- 6.5 and 2.5-3 years periods in temperature field are close to 10-12, 5-6 and 2-3 years periodicities in IMF.

Multitude of periodic components in the spectra points to necessity of complexity (nonlinear dynamics) analysis of temperature time series, namely, analysis of scaling, fractal dimension etc, which will be presented in the final part of the paper.

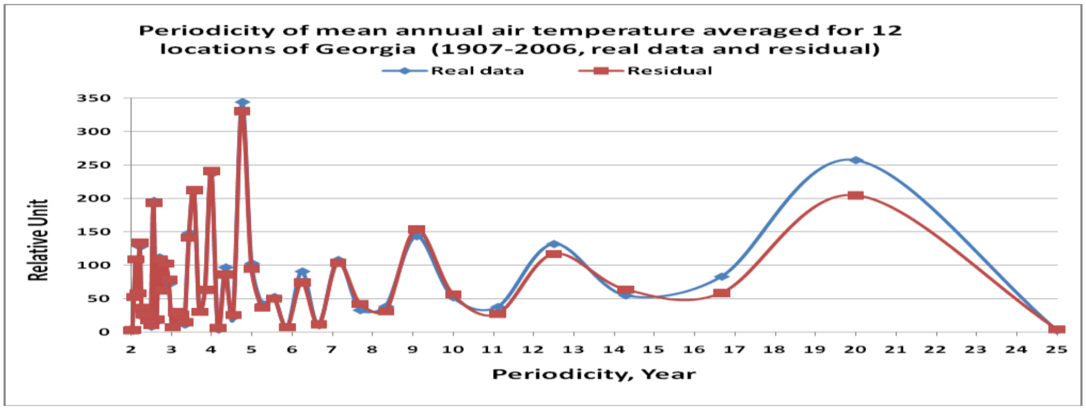


Fig. 9. Periodicities of mean annual air temperature averaged for 12 stations of Georgia (real data and residual)

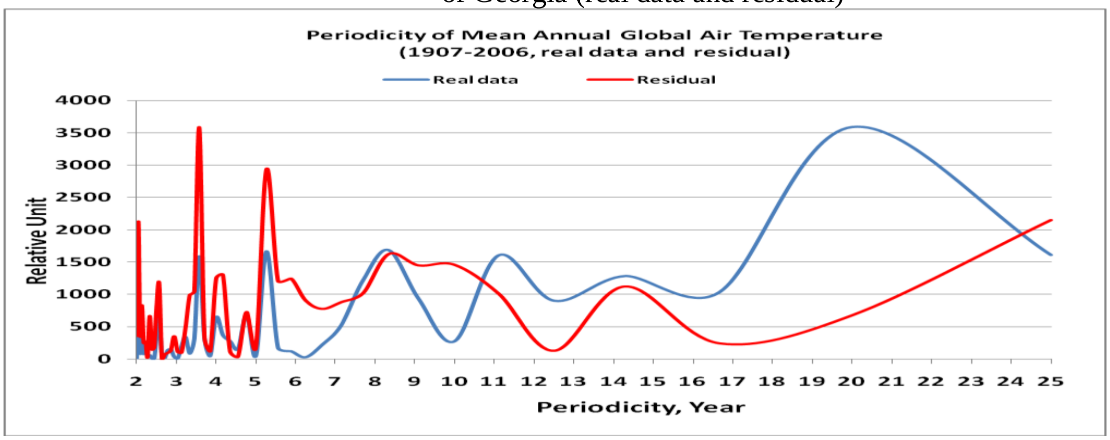


Fig. 10. Periodicities of mean annual global air temperature (real data and residual)

## 5. Past and Future Climate Change: nonlinear dynamics predictions, regional effects

Why is it necessary to use nonlinear dynamics tools for climate change studies? The matter is that atmospheric flows, an example of turbulent fluid flows exhibits signatures of nonlinear dynamics and chaos. They are characterized by self - similar fractal fluctuations of all space - time scales ranging from weather scale of days and month to climate scales tens and more years. Such types of dynamics of natural processes, when forming patterns have different character on different time and space scales, is too complex to be described by traditional (linear) statistical methods. Besides potential of scaling analysis, nonlinear dynamics reveals hidden nonlinear structures in sequences, which at the first glance seem to be random, in other words, reveal order in seemingly disordered data. As a rule such complex dynamics is difficult to be quantified. Fortunately in the last years new methods were developed, which allow to range quantitatively different levels of complexity allowing detection, identification and ordering from fully random (white noise) to more ordered types of systems behavior.

Thus used nonlinear dynamics tools give new important quantitative information on climate patterns – the degree of order in climatic time series, long-term correlations and their variation with space and time scales.

In this research in order to quantify scaling features in temperature data sets we used method of Detrended Fluctuation Analysis - DFA [Peng, et al. 1994, 1995] as well as Recurrence plots (RP) and Recurrence Quantitative Analysis (RQA).

According to DFA results presented as $F(n)$ vs. $n$ relation (Fig. 11) and DFA exponent $\alpha$ □ (Fig.12), for 30-35 day length time scale, mean air temperature data of Tbilisi and Kutaisi from 1936 to 2006 (DFA exponent $\alpha$ = 1.16 and 1.04 accordingly) indicates different scaling features for different time scales. Fluctuations for Kutaisi ($\alpha$ = 1.04) are $1/f$ noise ($\alpha$ = 1.0) type process while for Tbilisi ($\alpha$ = 1.16) dynamics of air temperature fluctuations is shifted to Brownian motion type ($\alpha$ = 1.5). It is interesting that fluctuations on the larger time scales from month to one year reveal clear persistent, long-range power law correlations ($\alpha$ > 1.5). Differences in dynamics of air temperature fluctuations is noticeable on one year time scale, where we see two crossovers on $F(n)$ vs. $n$ relation. For Kutaisi process is not clearly flicker noise ($\alpha$ = 1.27 ) but is far from to be regarded as close to Brownian motion as it is the case for air temperature fluctuations in Tbilisi ($\alpha$ = 1.42 ).

It is worth to mention here, that for time scales larger than one year process always looks as strongly antipersistent, i.e. at this time scales stability of observed trends is questionable and inversion of observed trends is a typical feature of dynamical process. Results of DFA analysis are presented in Figs. 2-4. From these data it follows that such patterns as persistent over larger than 1.5-2 year time scale heat (droughts) periods as well as persistent cold regimes are less probable in Georgia.

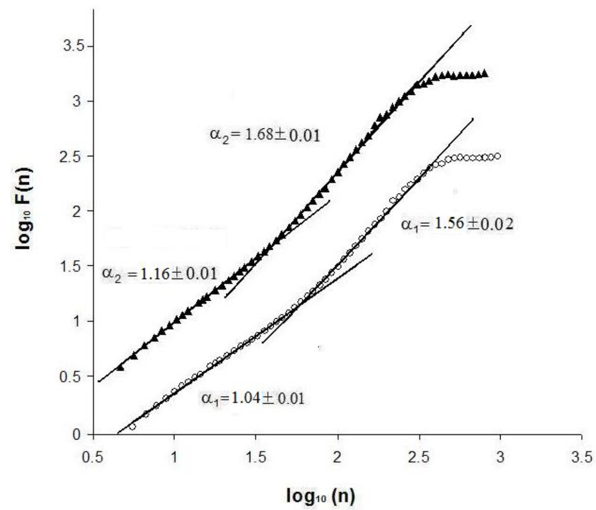


Fig.11. DFA analysis for daily mean temperature data Tbilisi 1936 -2006 (black triangles), Kutaisi 1936-2006 (white circles). 10 year windows one year step. Note crossovers at about 30-35 days and 350-370 days time scales.

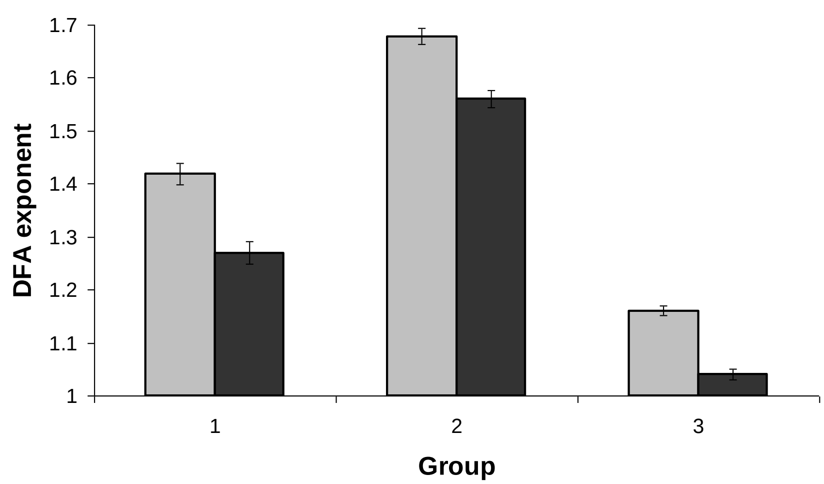

Fig. 12. Averaged DFA scaling exponents of daily mean temperature data Tbilisi 1936 -2006 (gray columns), Kutaisi 1936-2006 (dark columns). 3650 days windows 365 step. 1) one year time scale, 2) time scale from one month to one year, 3) one month time scale.

In Fig. 13 slopes of DFA vs. *n* relation are presented for daily mean temperature data from 1936 to 2006. Slopes are calculated for consecutive 10 year sliding windows with one year step. It follows from here that for both considered data sets scaling exponent is largest for time scales from one month to one year (upper pair of curves). Scaling exponent is smallest for one month time scale (lower pair of curves).

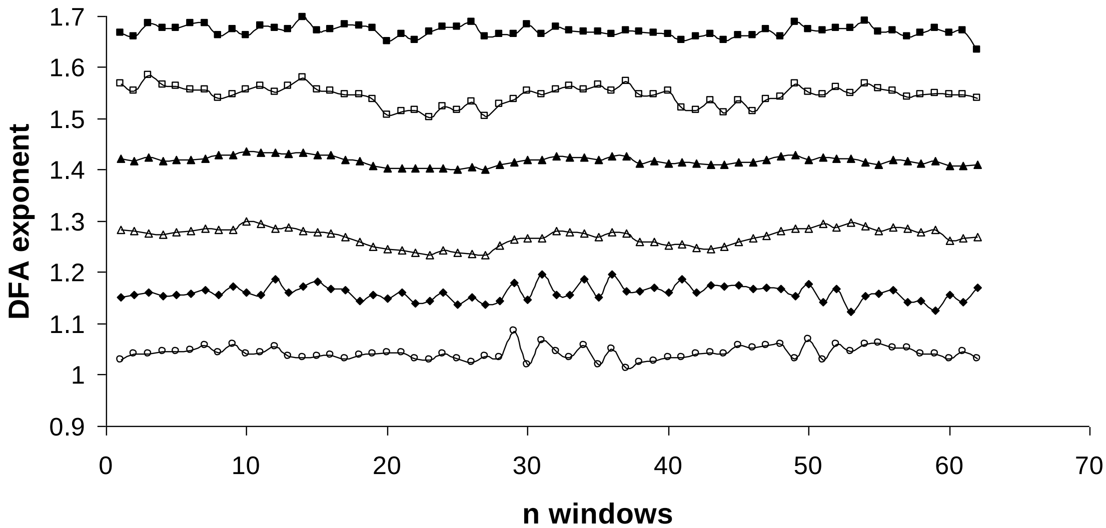


Fig. 13. Calculated for consecutive sliding windows (3650 days windows 365 step) DFA scaling exponents of daily mean temperature data Tbilisi 1936 -2006 (first, third, fifth curves from top), Kutaisi 1936-2006 (second, fourth, sixth curves from top). Dark and open squares, triangles and diamonds correspond to Tbilisi and Kutaisi data accordingly.

Taking into consideration that value of DFA exponent close to 1 means that investigated process is similar to white noise, it can be assumed, that daily temperature variation in Tbilisi is more regular comparing to Kutaisi for all considered time scales.

The variation of DFA exponents' values reveal some periodic features. In order to better visualize suggested quasi-periodicity in scaling features of analyzed data we used Savitzky Golay smoothing and filtering procedure for calculated DFA slope values for 3 different time scales – one year, one month to one year and one month (see e.g. Figs. 14,15,16).

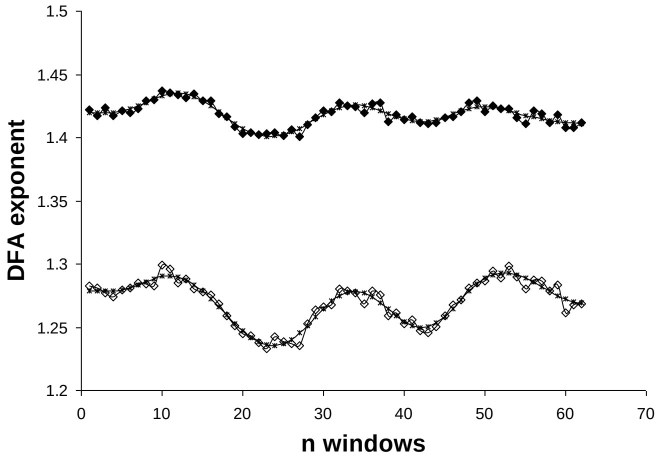


Fig. 14. Smoothed by Savitzky Golay filtering DFA scaling exponents for Tbilisi (top) and Kutaisi(bottom) mean daily temperature data, 1936-2006, One year time scale. Asterisks correspond to smoothed data.

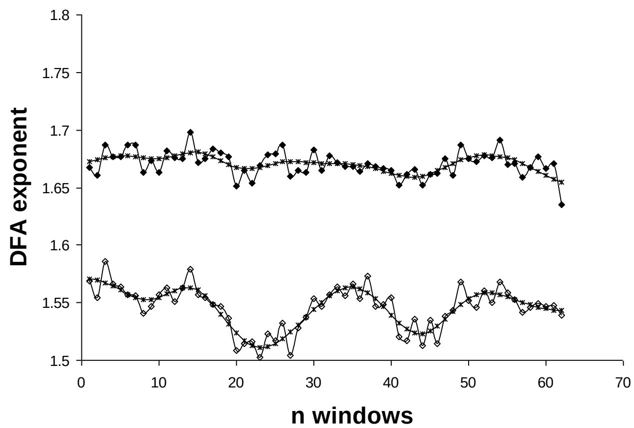


Fig. 15. Smoothed by Savitzky Golay filtering DFA scaling exponents for Tbilisi (top) and Kutaisi(bottom) mean daily temperature data, 1936-2006, Time scale from one month to one year. Asterisks correspond to smoothed data.

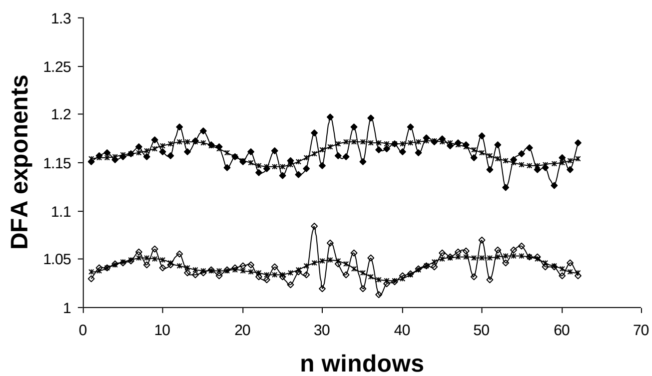


Fig. 16. Smoothed by Savitzky Golay filtering DFA scaling exponents for Tbilisi (top) and Kutaisi(bottom) mean daily temperature data, 1936-2006. One month time scale. Asterisks correspond to smoothed data.

We see from these results that scaling features of temperature data sets reveal periodic patterns but in different extent depending from time series and considered time scales. Namely about 24 year cycles are visible for longer (one year and one month to one year) time scales in DFA exponents of Kutaisi data sets while for one month time scale such periodic patters are questionable (Fig.5, 6). For Tbilisi data sets about 24 year periodic cycle is visible only for longest one year time scale.

As far as in period 1936-2006 Tbilisi data reveal quasiperiodic patterns only on one year time scale, in Fig. 17 we show DFA scaling exponents calculated for consecutive 10 year windows by one year step of longest available data sets from 1881-2006. In this Figure by asterisks Savitzky Golay smoothing is shown. According to our results quasiperiodic patterns are more characteristic for the last several decades of observation period.

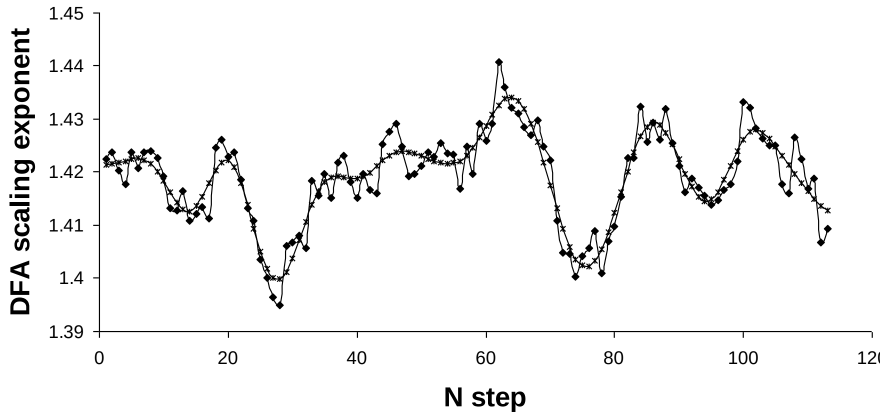


Fig. 17. DFA scaling exponents calculated for 1881-2006 Tbilisi daily temperature data, 10 year sliding windows one year step. Smoothed by Savitzky Golay filtering is shown by asterisks.

After documentation by DFA technique of differences in the scale depending long term correlation features of air temperature variation another methods: Recurrence plots (RP) and Recurrence Quantitative Analysis (RQA) were applied as a well recognized mean to detect and quantify recurring patterns (Marwan, 2003).

In addition to said above in methodology section RQA is a tool for qualitative and quantitative evaluation of nonlinear dynamical structure. It is sensitive and effective even for relatively short time series. Recurrence plots (Fig.18) shows much regular pattern for Tbilisi (East Georgia) in comparison to Kutaisi (West Georgia).

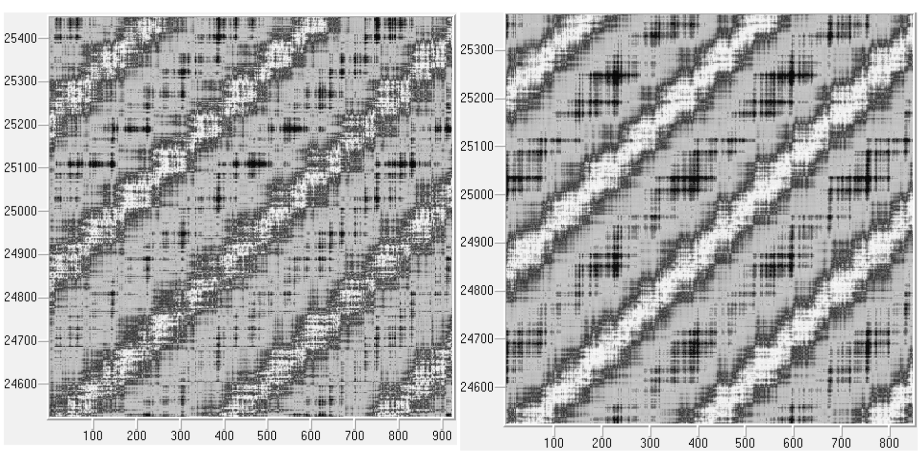

Fig. 18 . Recurrence plot of Kutaisi (left figure) and Tbilisi (right figure) daily mean temperatures data, 1936-2006.

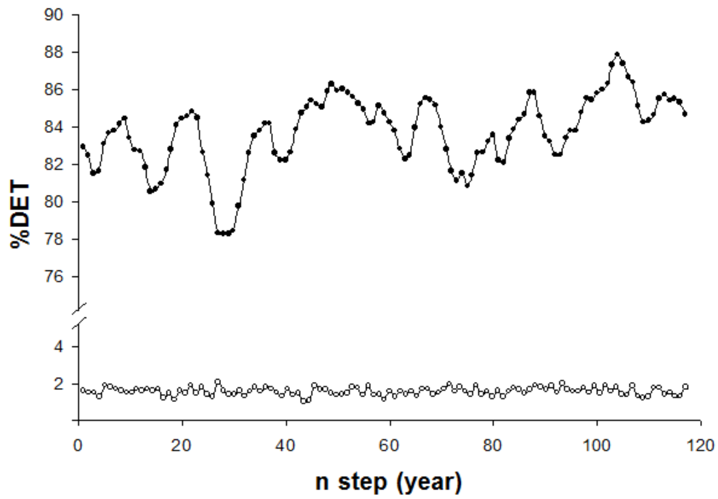


Fig. 5.19. Recurrence quantification analysis of daily mean temperature data Tbilisi 1981-2006, calculated for consecutive 5 year windows by one year step. Lower curve shows randomized time series.

We analyzed the longest available for Tbilisi data sets of daily mean temperatures (1881-2006) from the same point of view. Results presented in Fig. 5.19 show noticeable changes in the extent of regularity for analyzed period. We see prevalence of 10-20 year cycles in %DET variation except period about 1920 to 1950, when these cycles are questionable. Curve shown in the bottom of Fig. 5.19 corresponds to shuffled original data when internal dynamical structure was intentionally destroyed. Presented results indicate that the shuffled series lost all recurrence features manifested in original time series; no type of deterministic structure or extent of regularity is presented.

It is worth to mention that RQA%DET characteristic for all analyzed daily mean temperature data sets from several stations either in the West or East Georgia clearly show presence of increasing trend in the last decades. This points that in spite of differences found between East and West Georgian temperature variations generally the extent of regularity increased to the end of analyzed time period.

After analysis of existing past experimental (instrumental) data we proceed to assessment of possible future scenario of daily mean temperature variation based on concepts of nonlinear time series analysis. For this purpose we used local linear prediction scheme in the phase space. This procedure is inherently linear though is performed in the reconstructed phase space of nonlinear dynamical system and ensures acceptable compromise between quality of forecast and necessary computing resources for complex process.

Exactly we divided original measured time series in two parts to validate prediction model. In Fig. 5.20, we observe weak positive trend (0.11% of adjusted coefficient of multiple determination) in the second half of 1936-2006 Tbilisi daily mean temperature data. Forecasted from the first part of original data reveals almost the same weak trend (compare Figs. 5.20 and 5.21). As far as prediction results in principle coincide with existing data we calculate 10 year forecasting for Tbilisi based on longest available data (Fig. 5. 22 14). We see from this Figure weak but still increasing trend in forecasted daily mean temperature values for the next 10 year.

It is also important to mention that forecasted data also reveal increase in extent of order in the temperature daily variation similar to the actual data sets (see e.g. Fig. 5.23 15).

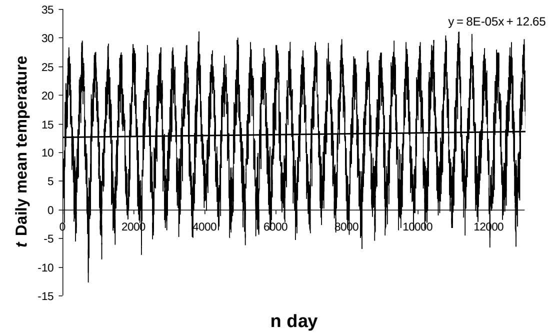


Fig. 5.20 12. Weak positive trend in the second half of Tbilisi mean daily temperature data from 1936 to 2006.

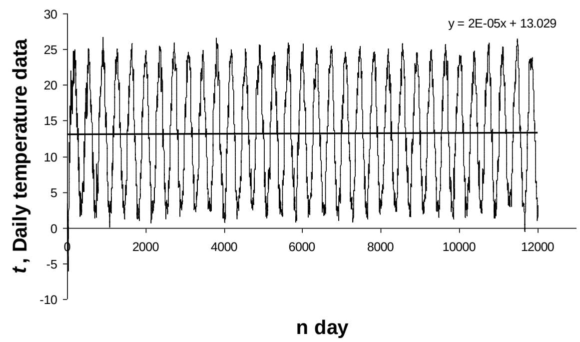


Fig. 5.21 13. Weak positive trend in the forecasted daily temperature (35 year forecast) from the first part of (70 year length data measured in Tbilisi from 1936 to 2006) of the whole time series.

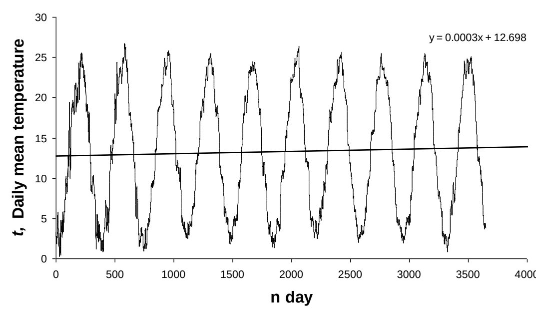


Fig. 5.22 14. Weak positive trend in the forecasted for 10 year Tbilisi daily mean temperatures data sets. Forecast was made based on Tbilisi mean daily temperature time series from 1881 to 2006.

According to our results forecasted data show different rates for different locations, but still all of them manifest increase in mean temperature values: e.g. for Tbilisi (predicted using1936-2006 data) forecasted increase in the next 10 years is about 0.2% (from 13.10 to 13.12 degree, $\Delta T = 0.02^0C$), for Batumi forecasted increase is about 4% (14.50 to 15.15 degree, $\Delta T = 0.65^0C$), for Pasanauri forecasted increase is about 4% (from 7.83 to 8.14 degree, $\Delta T = 0.31^0C$), for Poti - 4% (from 14.20 to 14.77 degree, $\Delta T = 0.57^0C$), for Samtredia - about 4% (from 14.50 to 15.06, $\Delta T = 0.56^0C$), for Kutaisi - about 7% (from 14.66 to 15.72 degree, $\Delta T = 1.06^0C$). Such differences may be caused by the quality of used data sets. Anyway for all locations increase in mean daily temperature values was forecasted.

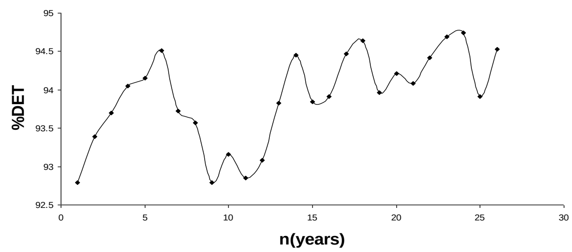


Fig. 5.23 15. RQA %DET values forecast for 1971-1998 calculated from the first part (1936-1970) of Tbilisi mean daily temperature data from 1936 to 2006 period.

Next in order to ensure that our results are not caused by influence of different noises we have carried out procedure, similar to above analysis on denoised original sets. We deliberately have avoided using of standard linear filtering procedures in order to preserve as possible closeness to original dynamical structure of temperature data sets. We performed nonlinear noise reduction procedure in reconstructed phase space of nonlinear dynamical system. As an example in Fig. 5.24 16. denoised and noise part of original data is presented.

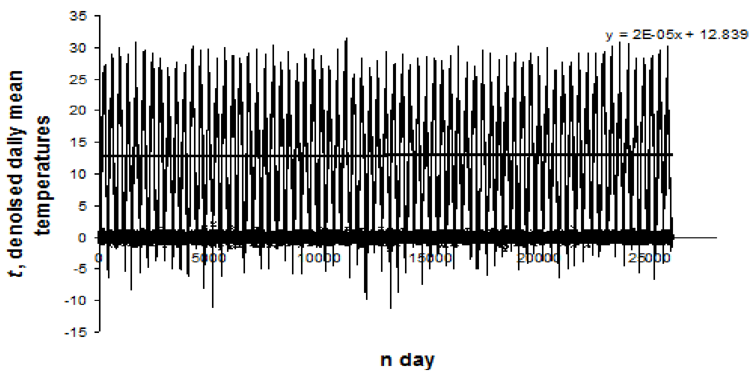


Fig. 5. 24  16. Denoised Tbilisi 1936-2006 daily mean temperature data sets, below is shown the reduced noise contribution to original data.

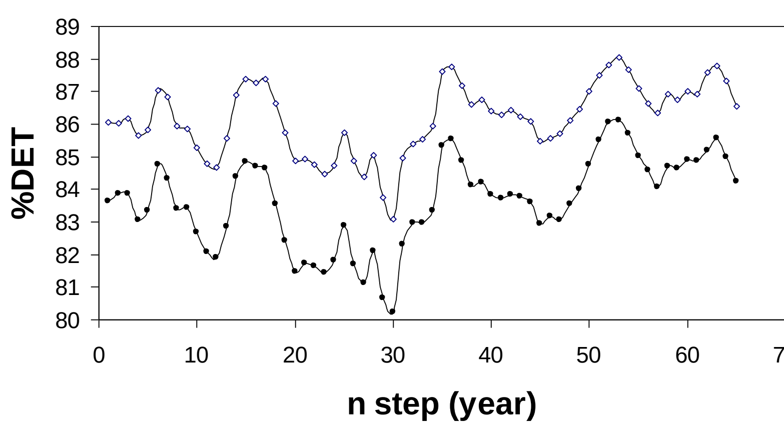


Fig. 5.25 17. RQA %DET of original (dark circles) and denoised (open circles) Tbilisi 1936-2006 daily mean temperature data sets.

As it follows from our results, denoising does not lead to qualitative changes in our results (Fig. 5.25 17). At the same time found variations in ordering are quantitatively more obvious in denoised time series, which is quite logical.

From our results it follows that dynamics of daily mean temperature variation is time and space scale depending process and this particular property can not be analyzed without application of modern tools of complexity theory. In the Eastern part of country dynamics of temperature variation is noticeably regular comparing to the West Georgia. These changes definitely are of local origin. At the same time there are large scale spatio-temporal influences, which cause similar patterns of variation in the extent of regularity in both parts of country.

We also conclude that increase of temperature can be predicted in both parts of Country and this process is not affected by different noises contained in existing data sets.

## Conclusions

- There are many gaps in the climate change studies in Georgia, which call for action.
- Palaeo-biological investigations show that there were periods of very warm climate in Georgia (X-XI and XII-XIV centuries) before starting of strong anthropogenic impact.
- For quantitative reconstruction of the past climate the borehole geothermy should be applied.
- The existing instrumental temperature data are from 1850 in Tbilisi and from 1880 in 12 meteorological stations in Georgia. These data were used in analysis of trends and for climate forecast. The detail digital data bases covering the whole observation period (1850-2010) are absent.
- New statistical calculations of the climate regime in Georgia confirm earlier results on the difference in the climate patterns in the Western and Eastern parts of the country. The statistical calculations of temperatures for 2055 on the base of data for 1950-2006 period show that the maximal (local) increment of the average annual temperature is of the order of $0.7^0$C (settlement Pasanauri, East Georgia), when in the West Georgia the increment is close to zero or negative. This is less than global assessments for the land. It should be noted that the 99% confidence region for increment of the annual temperature in Georgia spans from approximately $+2^0$C to $-2^0$C.
- Common statistical analysis indicates to weak auto-correlation and at the same time reveals several periodicities both in original and detrended time series.
- Extrapolation of the observed temperature trends by statistical methods predict mainly continuation of warming in the East Georgia and cooling or negligible change in the West with predominant warming in the cool periods.
- Nonlinear analysis of temperature data, namely Detrended Fluctuation Analysis (DFA) shows that time series exhibit several time scales with different dynamical characteristics. The long-range correlation features of air temperature fluctuations in Tbilisi and Kutaisi are different. According to another method - Recurrence Quantitative Analysis (RQA) temperature time series are more ordered in the East compared to West Georgia. These differences in the degree of regularity are definitely of local origin.
- The ordering strength of temperature time series vary in time revealing existence in some periods of low-dimensional processes close enough to multi-scale quasi-periodicity, occurring simultaneously in West and East Georgia. We suppose that besides local peculiarities leading to different levels of ordering in both West and East Georgia, there are some global factors leading to similar type of time-dependent dynamics in the both parts of country. Physical mechanism of such regular time-dependence is not clear: our guess is that as the temperature variations depend strongly on sun radiation, it seems reasonable to relate them to solar cycles, which are reflected in interplanetary magnetic field cycles: 20-22 years component in temperature variations can be related to 22-years long Hale cycle of solar magnetic field. Besides, 12.5, 5- 6.5 and 2.5-3 years periods in temperature field are close to 10-12, 5-6 and 2-3 years periodicities in IMF.
- For time scales larger than one year process always looks as strongly antipersistent, i.e. at this time scales stability of observed trends is questionable and inversion of observed trends is a typical feature of dynamical process
- Using nonlinear methods small increase of temperature can be predicted in both parts of Georgia for the next 10 years and this process is not affected by different noises contained in existing data sets.

➢ Taking into account significant differences in climate patterns in the West and East Georgia, for reliable climate change prediction detail regional model should be developed.

**Acknowledgements**

Authors acknowledge financial support of Open Partial Agreement on Major Disasters at the Council of Europe (EUR-OPA)

**References**

[1] Amiranashvili A., Amiranashvili V., Gzirishvili T., Kharchilava J., Tavartkiladze K. - Modern Climate Change in Georgia. Radiatively Active Small Atmospheric Admixtures, Institute of Geophysics, Monograph, Transactions of M.Nodia Institute of Geophysics of Georgian Academy of Sciences, ISSN 1512-1135, vol. LIX, 2005, pp.,1-128.

[2] Amiranashvili A., Chikhladze V., Kartvelishvili L. – Expected Change of Average Semi-Annual and Annual Values of Air Temperature and Precipitation in Tbilisi, Journal of the Georgian Geophysical Society, Issue B, Physics of Atmosphere, Ocean and Space Plasma, ISSN 1512-1127, vol. 13B, Tbilisi, 2009, pp. 50 – 54.

[3] Amiranashvili A., Kartvelishvili L., Khurodze T. – Application on Some Statistic Methods for the Prognostication of Long-Term Air Temperature Changes (Tbilisi Case), Basic Paradigms in Science and Technology Development for the 21st Century, Trans. of the Int. Conf Dedicated to the 90th Anniversary of Georgian Technical University, September 19-21, Tbilisi, 2012, vol. 2, pp. 331-338 (in Russian).

[4] Amiranashvili A., Matcharashvili T., Melikadze G., Chelidze T. - On the Climate Change in Georgia in the Past, at Present and in the Future: What Should be Done for Filling the Gaps – Abstract of 7th Ann. Int. Conf. of REC Caucasus “Climate Change Adaptation – Challenge and Opportunity for Caucasus”, November 10-11, Tbilisi, 2011, pp. 29-30.

[5] Archer, D. Global Warming. Blackwell. 2007.

[6] Begalishvili N., Tavartkiladze K., Vachnadze J. - Modern Climate Change in Georgia. Century change of moisture content of atmosphere and its influence on moisture turn, Monograph, Institute of Hydrometeorology of Georgia, Tbilisi, ISBN 9928-885-9-8, 2007, 123 p., (in Russian).

[7] Brohan, P., J. J. Kennedy, I. Harris, S. F. B. Tett and P. D. Jones (2006), Uncertainty estimates in regional and global observed temperature changes: A new data set from 1850, *J. Geophys.Res., 111,* D12106, doi:10.1029/2005JD006548.

[8] Budagashvili T., Karchava J., Gunia G., Intskirveli L., Kuchava T., Gurgenidze M., Amiranashvili A., Chikhladze T. - Inventory of Greenhouse Gas Emissions and Sinks. Georgia’s Initial National Communication on Under the United Nations Framework Convection on Climate Change, Project GEO/96/G31, Tbilisi, 1999,137 p.

[9] Chapman, D. and Davis, M. 2010. Climate Change: Past, Present, and Future. *Eos Transactions*, AGU. Vol. 91, No. 37.

[10] Dubrova T.A. - Statistical methods of forecasting in economy, the Moscow international institute of the econometrics, computer science, finance and right, M., 2003, 50 p., (in Russian).

[11] Eckmann, J. P., Kamphorst, S. O., Ruelle, D., (1987). Recurrence Plots of Dynamical Systems, Europhysics Letters, 4, 973-977.

[12] First National Communication of the Republic of Armenia under the United Nations Framework Convention on Climate Change”, October 1998.

[13] Forster E., Ronz B. - Methods of correlations and regressions analysis, M., “Finance and Statistics”, 1983, 304 p., (in Russian).

[14] GINC - Georgia’s initial national communication under the United Nations Framework Convention on Climate Change, Tbilisi, 1999.

[15] Gobejishvili, R . Glaciers of Georgia, Metsniereba Publ. House, Tbilisi. 1989 (in Russian).

[16] Hansen, J., R. Ruedy, M. Sato, M. Imhoff, W. Lawrence,D. Easterling, T. Peterson, and T. Karl (2001), A closer look at United States and global surface temperature change, *J. Geophys. Res., 106*(D20), 23,947–23,963.

[17] Harmeling, S. Global Climate Risk Index 2011. Germanwatch e.V. 2010.
[18] "Human Development Report 2007/2008, Fighting climate change – human solidarity in a divided world", UNDP 2007.
[19] Initial Nation Communication of Azerbaijan Republic under the United Nations Framework Convention on Climate Change, Baku 2000.
[20] Jacob, D. Regional Climate Models. In: Encyclopedia of Complexity and System Science. Springer, 2009, pp. 7591-7602
Johns T. et al. 2003. Anthropogenic climate change for 1860 to 2100 simulated with the HadCM3 model under updated emissions scenarios. Climate Dynamics. 20: 583–612, DOI 10.1007/s00382-002-0296-y.
Kantelhardt, J. W., S. A. Zschiegner, A. Bunde, S. Havlin, E. Koscielny-Bunde, and H. E. Stanley (2002),
[21] Multifractal detrended fluctuation analysis of nonstationary time series, Physica A. 316, 87-114.
Kendall M.G. - Time-series. Moscow, 1-200, 1981, (in Russian).
Kobisheva N., Narovlianski G. - Climatological processing of the meteorological information, Leningrad, Gidrometeoizdat, 1978, 294 p., (in Russian).
[22] Kvavadze, E., Licheli, V. 2009.The palaeocologyandeconomics of Atskuri in Medieval period. Bulletin of the Georgian National Museum ,Natural Sciences and Prehistory Section # 1, 68-76,
[23] Kvavadze, E., Licheli, V., Margvelashvili, P. 2011. Climatic optima in the mountains of Georgia during Middle Age: results of palynological investigation of Navenakhari settlement and Betlemi monastery. INQUA 18-th Congress, Bern, Switzerland, http://www.inqua2011.ch/
[24] Marwan, N., (2003). Encounters With Neighbours Current Developments Of Concepts Based On Recurrence Plots And Their Applications (PhD Thesis, University of Potsdam).
[25] Maslin, M., Randalls, S. (Eds) 2011. Future Climate Change. Routledge.
[26] National Aeronautics and Space Administration, http://www.giss.nasa.gov/
[27] Palmer, T. N. Nonlinear Dynamics and Climate Change: Rossby's Legacy. Bulletin of the American Meteorological Society , 1998, 1411-1423.
[28] Peng, C.K., Buldyrev, S.V., Havlin, S., Simmons, M., Stanley, H.E., Goldberger, A.L., (1994). Mosaic organization of DNA nucleotides, Phys. Rev. E 49, 1685.
[29] Peng, C.K., Havlin, S., Stanley, H.E., Goldberger, A.L., (1995). Quantification of scaling exponents and cross over phenomena in nonstationary heartbeat time series, Chaos, 5. 82–87.
[30] Review of the World Climate Research Programme (WCRP). (2009). Paris, International Council for Science. 40 pp. Available at www.icsu.org
[31] Riebeek, H. 2011. Global Warming. http://earthobservatory.nasa.gov/Features/GlobalWarming/
[32] Rodriguez, E., J. C. Echeverria, and J. Alvarez-Ramirez (2007), Detrended fluctuation analysis of heart intrabeat dynamics, Physica A: Statistical Mechanics and its Applications. 384, 2, 429-438.
[33] Shvangiradze M., Beritashvili B., Kutaladze N. – Revealed and predicted climate change in Georgia and its impact on economy and natural ecosystemsıo Papers of the Int. Conference International Year of the Planet Earth "Climate, Natural Resources, Disasters in the South Caucasus", Trans. of the Institute of Hydrometeorology, vol. No 115, ISSN 1512-0902, Tbilisi, 18 – 19 November, 2008, pp. 76 – 80 (in Russian).
[34] Sylvén, .M, Reinvang, R., Andersone-Lilley, Ž. Climate Change in Southern Caucasus: Impacts on nature, people and society. WWF Norway- WWF Caucasus Programme. July, 2008
[35] Stokes, C.R., Gurney, S.D., Shahgedanova, M. and Popovnin, V. Late 20th century changes in glacier extent in the Caucasus Mountains, Russia/Georgia », Journal of Glaciology (52): 99-109, 2006.
[36] Taghieyeva, U. "Problems of forecasting: The key natural hydrometeorological phenomena affects ecological safety of the South Caucasus in the context of Azerbaijan", National Hydrometeorological Department, Republic of Azerbaijan, 2006.
[37] Takalo, J., Mursula, K. 2002. Annual and solar rotation periodicities in IMF components. Geophys. Res. Letters. 29, DOI 10.1029/2002GL014658
[38] Tavartkiladze K., Elizbarashvili E., Mumladze D., Vachnadze J. – Empirical model of ground air temperature field change in Georgia, Monograph, Tbilisi, 1999, 128 p., (in Georgian).
[39] Tavartkiladze K., Shengelia I. – Modern Climate Change in Georgia. Variability of radiation regime in Georgia, Monograph, "Metsniereba", Tbilisi, 1999, 150 p., (in Georgian).

[40] Tavartkiladze K., Begalishvili N., Kharchilava J., Mumladze D., Amiranashvili A., Vachnadze J., Shengelia I., Amiranashvili V. – Contemporary climate change in Georgia. Regime of some climate parameters and their variability, Monograph, Tbilisi, ISBN 99928-885-4-7, 2006, 177 p., (in Georgian).
[41] Tavartkiladze K., Amiranashvili A. – Expected changes of air temperature in Tbilisi city, Papers of the Int. Conference International Year of the Planet Earth "Climate. Natural Resources. Disasters in the South Caucasus", Trans. of the Institute of Hydrometeorology, vol. No 115, ISSN 1512-0902, Tbilisi, 18 – 19 November, 2008, pp. 57 – 65 (in Russian).
[42] Webber, C. L., Zbilut, J. P., (1994). Dynamical assessment of physiological systems and states using recurrence plot strategies. Journal of Applied Physiology, 76, 965-973.

(Received in final form 20 December 2012)

# Изменение климата в Грузии: статистическое и нелинейно-динамическое прогнозирование

**А. Амиранашвили, Т.Мачарашвили, Т.Челидзе**

**Резюме**

Парниковый эффект (глобальное потепление) - одна из главных опасностей, стоящей в целом перед планетой. Воздействие на климат происходит из-за роста концентрации парниковых газов ($CO_2$, метан, водяной пар): согласно различным оценкам, в конце 21-го столетия температура повысится на 1.4-5.8 °С. Это может привести ко многим разрушительным эффектам, многие из которых невозможно будет предотвратить, что означает, что человечество должно найти способы адаптации к глобальному потеплению.

Грузия, как в целом и Кавказ, подвергается многим отрицательным эффектам, связанным с изменением климата: полное или частичное таяние горных ледников, повышение уровня моря, опустынивание обширных территорий, серьезное воздействие на водные ресурсы.

Несморя на то, что многие предыдущие работы были посвящены оценке изменения климата в Грузии, результаты все еще неоднозначны. В частности, выполненные исследования показали, что в течение последних десятилетий температура воздуха в Восточной Грузии в среднем повышается, а в Западной Грузии - уменьшается. Эти выводы обсуждены и показано, что необходимо их переосмыслить с учетом использования новых данных и современных методов математического анализа рядов метеорологических наблюдений. Для более надежных оценок необходимо использовать современные методы получения и анализа данных о климате в прошлом, настоящем и будущем.

Другая проблема состоит в том, чтобы установить, является ли указанное потепление исключительно искусственным эффектом, или это результат естественной цикличности в климате Земли.

Особая цель - оценка постоянства и характеристик памяти регионального изменения температуры воздуха в Грузии на фоне глобального изменения климата. Для этой цели проанализирован имеющийся в наличии самый длинный температурный ряд для метеорологической станции Тбилиси (с 1890 г.). Подобные более короткие временные ряды годовых и месячных температур воздуха для 11 станций на Западе и Востоке Грузии также были использованы (1907-2006).

Так как наиболее ошибочные заключения относительно динамических свойств сложной динамики связаны с процедурой "отбеливания данных", в целях предотвращения разрушения первоначальной динамики, вызванной линейным просачиванием, была использована существующая исследовательская специальная шумовая процедура сокращения ряда времен, так же, как и методика многомерного анализа масштабирования, основанного на CWT. Осуществлены как моно,- так и мультивариантные процедуры реконструкции динамики изменения климата. Проведен также анализ пространственно-временных характеристик средних дневных и месячных значений временных рядов температуры воздуха. Оценена степень постоянства в упомянутых временных рядах.

# კლიმატის ცვლილება საქართველოში: სტატისტიკური და არაწრფივ-დინამიკური პროგნოზირება

ა. ამირანაშვილი, თ. მაჭარაშვილი, თ. ჭელიძე

რეზიუმე

სათბურის ეფექტი (გლობალური დათბობა) – ერთერთი იმ საშიშროებათაგანია, რომელიც დგას პლანეტის წინაშე. კლიმატზე ზემოქმედება ხდება სათბური გაზების ($CO_2$, მეთანი, წყლის ორთქლი) კონცენტრაციის ზრდის გამო: სხვადასხვა შეფასებებით 21-ე საუკუნის ბოლოს ტემპერატურა გაიზრდება 1.4-5.8 °C. ამან შეიძლება მიგვიყვანოს მრავალ დამანგრეველ ეფექტამდე, რომელთა შორის ბევრის თავიდან აცილება შეუძლებელი იქნება, რაც იმას ნიშნავს, რომ კაცობრიობამ უნდა მოძებნოს გლობალურ დათბობასთან ადაპტაციის საშუალებები.

საქართველო, როგორც მთლიანად კავკასია, ასევე განიცდის ისეთ მრავალ ეფექტის ზემოქმედებას, რომელიც დაკავშირებულია კლიმატის ცვლილებასთან: მთის მყინვარების სრული ან ნაწილობრივი დნობა, ზღვის დონის მომატება, დიდი ფართობების გაუდაბნოება, სერიოზული ზემოქმედება წყლის რესურსებზე.

იმის მიუხედავად, რომ არაერთი ადრინდელი ნაშრომი იყო მიძღვნილი კლიმატის ცვლილებასთან საქართველოში, შედეგები მაინც არაცალსახაა. კერძოდ, გამოკვლევებმა აჩვენა, რომ ბოლო რამდენიმე ათწლეულში ჰაერის ტემპერატურა აღმოსავლეთ საქართველოში საშუალოდ მატულობს, ხოლო დასავლეთ საქართველოში – კლებულობს. ეს დასკვნები განხილულია და ნაჩვენებია, რომ საჭიროა მათი ხელახალი გააზრება ახალი მონაცემებისა და მეტეოროლოგიური მონაცემების რიგების ანალიზის თანამედროვე მათემატიკური მეთოდების გამოყენების გათვალისწინებით. უფრო საიმედო შეფასებებისათვის საჭიროა გამოყენებული იქნას კლიმატზე წარსულში, ამჟამად და მომავალში მონაცემების მიღებისა და ანალიზის თანამედროვე მეთოდები.

სხვა პრობლემა იმაში მდგომარეობს, რომ საჭიროა დადგენილ იქნას, არის თუ არა აღნიშნული დათბობა მხოლოდ ხელოვნური ეფექტი, თუ ის შედეგია ბუნებრივი ციკლურობისა დედამიწის კლიმატში.

განსაკუთრებული მიზანია – საქართველოში ჰაერის ტემპერატურის რეგიონალური ცვლილების მეხსიერების მუდმივობა და მახასიათებლები კლიმატის გლობალური ცვლილების ფონზე. ამისათვის გაანალიზებულია არსებული ყველაზე გრძელი ტემპერატურული მწკრივი თბილისის მეტეოროლოგიური სადგურისათვის (1890 წლიდან). ამგვარი შედარებით მოკლე დროითი მწკრივები წლიური და თვიური ჰაერის ტემპერატურისათვის აღმოსავლეთ და დასავლეთ საქართველოს 11 სადგურზე ასევე იქნა გამოყენებული (1907-2006 წწ.)

რადგან ყველაზე არასწორი დაკვნები რთული დინამიკის დინამიკური თვისებების მიმართ დაკავშირებულია “მონაცემების გათეთრების” პროცედურასთან, პირველადი დინამიკის დანგრევის თავიდან ასაცილებლად, რომელიც გამოწვეულია წრფივი გაჟონვით, გამოყენებული იქნა არსებული დროითი რიგების შემოკლების სპეციალური კვლევითი ხმაურის პროცედურა ისევე, როგორც მასშტაბირების მრავალგანზომილებიანი ანალიზის მეთოდიკა, დაფუძნებული CWT –ზე. განხორციელებულია როგორც მონო, - ასევე კლიმატის ცვლილების დინამიკის მულტივარიანტული პროცედურები. ჩატარებულია აგრეთვე ჰაერის ტემპერატურის საშუალო დღიური და თვიური მნიშვნელობების დროითი რიგების მახასიათებლების სივრცულ-დროითი ანალიზი. შეფასებულია აღნიშნული დროითი რიგების მუდმივობის ხარისხი.