On Some Aspects of Climate Change in Georgia

Teimuraz Davitashvili

***Abstract*—**In the present paper some hydrological specifications of Georgian water resources on the background of regional climate change are presented. Some results of extreme precipitation numerical calculations and Georgian's glaciers melting are given. The specific properties of regional climate warming process in the eastern Georgia is studied by statistical methods. Water resources alteration on the background of climate change is presented. The effect of the eastern Georgian climate change upon water resources is investigated.

***Keywords*—** Climate change, glaciers, precipitations, water resources.

I. Introduction

At present climate change problem is associated with a growing crisis in environment pollution, food production and health safety[1]. Indeed it became obvious that there is threaten on food production through increased precipitation, catastrophic flooding, growing desertification processes. Global climate change has impacted on durability of seasons too [2]. Namely in middle latitudes the summers became hotter, the winters colder, length of the spring has shortened with lower temperatures and only durations of the autumns have elongated with warm weather. These climate changes have affected on flora and fauna and especially on the plants of a particular regions of the earth having non homogenous topography and habitat [2]. Climate change is already occurring in the South Caucasus region where is a strong evidence of increasing trends in mean annual temperature with mean daily minimum temperature and mean daily maximum temperature [2,3]. This processes didn't pass also the territory of Georgia. Nowadays climate change on the territory of Georgia is evident at least on the background of the Georgian glaciers melting [2,4]. Glaciers are early indicators of ongoing climate change and change in glacier extent is an easily measured parameter, which provides an indirect, filtered signal of climate change [1,4]. For instance according to [5] yet the sensitivity of glaciers in the Everest region of Nepal to climate change is high too. On the other hand glaciers themselves play major roles in influencing regional and global climates. Also the glaciers are mainly fresh water storage resources too and in many countries as well as in Georgia millions of people depend on glaciers for drinking water, agriculture, and industry and power generation during key parts of the year [2,3,6]. Fluctuations of glaciers and ice caps in cold mountain areas have been systematically observed for more than a century in various parts of the world. During the last century, glaciers in the European Alps and the Caucasus Mountains have decreased to half their size, while in Africa only 8 percent of Mount Kenya's largest glacier remains [7]. If current trends continue, by the end of this century many of the world's mountain glaciers, will have vanished entirely [2,5]. In the present paper some hydrological specifications of Georgian water resources on the background of regional climate change are presented. Some results of Georgian's glaciers melting are given. The specific properties of regional climate warming process in the eastern Georgia is studied by statistical methods. The effect of the eastern Georgian climate change upon water resources is investigated.

This work was supported by the Shota Rustaveli National Science Foundation under Grant FR2017/FR17-548.

T. P. Davitashvili is with the I.Vekua Institute of Applied Mathematics of Iv. Javakhishvili Tbilisi State University, Tbilisi, CO 0186 Georgia (phone: +99532-218-6630; fax: +99532-218-6645; e-mail: teimuraz.davitashvili@tsu.ge).

II. Climate Change and Extrem Events Acceleration on the Territory of Georgia

Unfortunately for the last four decades have increased number of the extreme weather events on the territory of Georgia. For this period about three times have increased number of the natural hazards in comparison with the 60 years of the last century and as a consequence economic expenses have increased eight times (the economic expenses only for 2004 year reached 150 billion USD $) [2,3]. For the last four decades among the main natural disasters can be separated out increased number of the droughts, floods, landslides, storms, heavy showers on the territory of Georgia. Also there are evidence of extension of desertification processes in the some south and eastern regions of the territory of Georgia, reduction of numbers of glaciers in the Caucasus Mountains and volumes of the drinking waters in the eastern reservoirs [2,3]. Investigation dedicated to the question of intensity in formation of hazardous floods on the background of modern climate change on the territory of Eastern Georgia has been carried out for the period 1921-2015 years. Analysis of data of intensity hazardous floods has shown that in the East Georgia frequency of recurrence of hazardous floods for the period 1961-2015 in comparison with the period 1921-1960 has increased on 150% while extreme abundant precipitations has increased only on 12%. Especially for the last two decades there was increased number of the floods, landslides, heavy showers on the territory of Georgia. For instance an accident takes place on 13 06 2015 in capital city of Georgia Tbilisi. About for 2.5 hours there was heavy shower in Tbilisi and suburbs and as a consequence nearby to Tbilisi there occurred a heavy landslide which blocked the Vere River's canyon, formed a water-storage basin and the strong wave run across

the Vere River canyon and washed everything away until the square of Heroes in Tbilisi (see Fig.1).

Fig. 1 The Vere River's canyon after the flood

Unfortunately it was accompanied with sacrifices (20 persons passed away and half of all animals were suffocated in zoo). Namely Accident of such sizes from a flood didn't happen still in Tbilisi and increase the frequency of such kind accident is one of the evident indicators for regional climate changes.

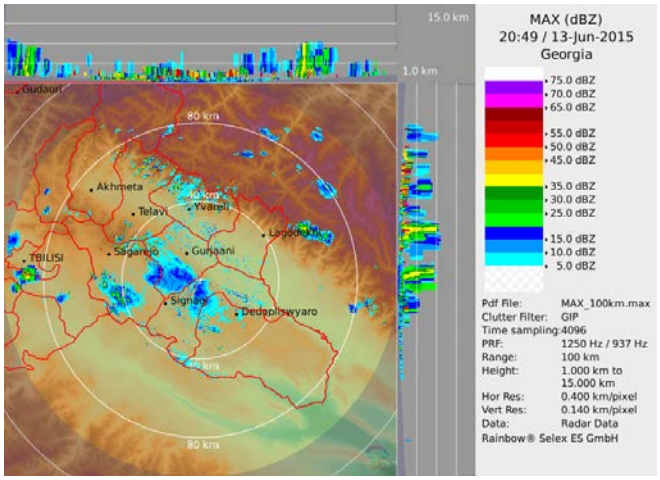

Fig.2 The reflecting power of cloudy system at 20:49 (13/06/2015) over the territory of eastern Georgia

Analysis of the basic data obtained by the weather C-band, dual polarized Doppler radar had shown that at 20:00 o'clock there was developed inner massive atmosphere processes in the form of atmosphere front which began increasing in activity above the village of Akhaldaba, about 20 km southwest of Tbilisi. Simultaneously at 20:49 above Tbilisi began development inner massive atmosphere processes too (see Fig.1) and at 22:00 o'clock its combination gave reinforced clods system with upper level 15 km, maximal reflection 66 dB and intensity of precipitations more than 100 mm/h (see Fig.2). During 1 hour capacity of cloud increased (especially in the village Tskneti) and after 24:00 o.clock it began weakening. For this time on all the territory of eastern Georgia was observed noerth-west direction wind. In Tbilisi at the 2km height its value was about 15m/s, while in neighbourhood area its value reached about 25-30 m/s.

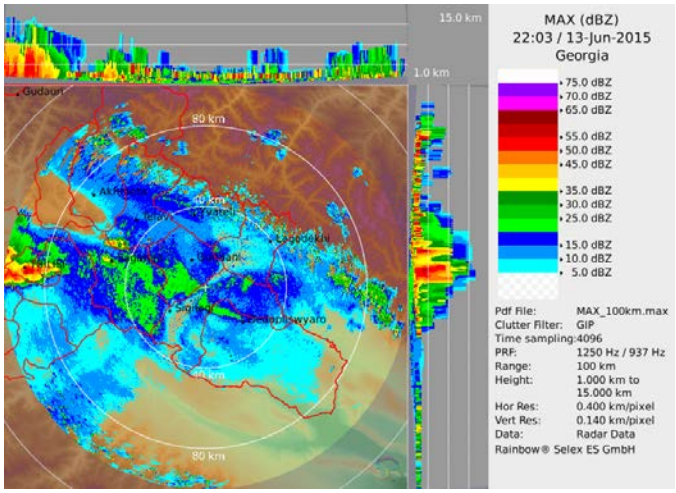

Fig.3 The reflecting power of cloudy system at 22:03 (13/06/2015) over the territory of eastern Georgia

Almost the same local scale, short term, severe, weather convective events took place on the 2nd of August, 21 of June and 23 of June 2016 in Tbilisi. For all these cases the fair weather suddenly changed by rough weather with a strong wind (about 35m/s). With the objective of providing risk management activities the regional WRF v.3.6.1 model's ability on summer time heavy showers prediction was studied. Three sets of nested domains with horizontal grid-point resolutions of 19.8, 6.6 and 2.2 km have been chosen to study local scale, short term, severe, weather convective events (precipitations) formation over the territory of eastern Georgia taking into consideration the Caucasus complex topography. Predicted accumulated total (24 h) precipitations were evaluated against the meteorological radar and radio zoned data.

Table 1. Five set of the WRF parameterization schemes used in this study.

WRF Physics	Set1	Set 2	Set 3	Set 4	Set 5
Micro physics	WSM 6	Thompson	Purdue Lin	Morrison 2-Moment	Goddard
Cumulus Parameterization	Kain-Fritsch	Betts-Miller Janjic	Kain-Fritsch	Grell-Devenyi ensemble	Kain-Fritsch
Surface Layer	MM5 Simil.	MM5 Simil.	MM5 Simil	(PX) Similarity	MM5 Similarit
Planet. Boundary Layer	YSU PBL	YSU PBL	YSU PBL	ACM2 PBL	YSU PBL
Land-Surface	Noah LSM	Noah LSM	Noah LSM	Noah LSM	Noah LSM
Atmospheric Radiat.	RRTM/Dudhia	RRTM/Dudhia	RRTM/Dudhia	RRTM/Dudhia	RRTM/ Dudhia

Results of numerical calculation showed that not one of the physical parameterization combinations presented in the

Table 1 were not able to model real deep, moist convection atmospheric event which took place on the 2nd of August, 21 of June, 23 of June 2016 and 13 June 2015 in Tbilisi.

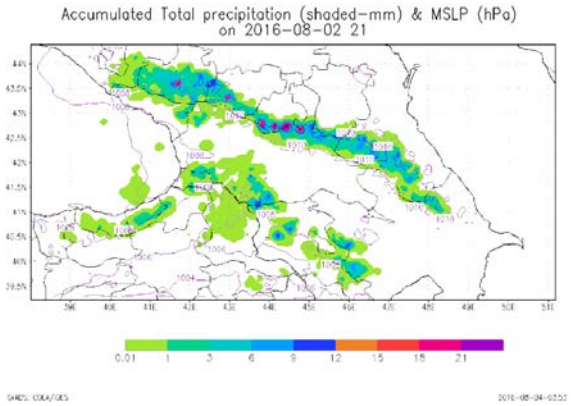

Fig.4 Map of the ATP for 02 August 2016 (21:00 local time) simulated by WRF Physics Options set1 on the nested domain with 6.6 km resolution.

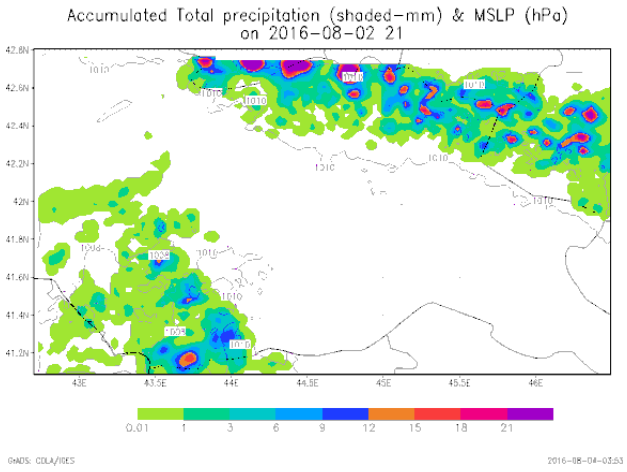

Fig.5 Map of the ATP for 02 August 2016 (21:00 local time) simulated by WRF Physics Options set1 on the nested domain with 2.2 km resolution.

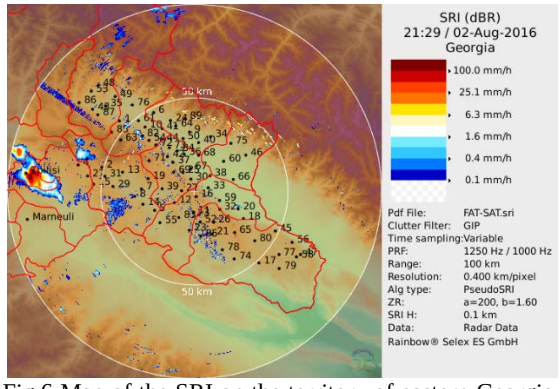

Fig.6 Map of the SRI on the territory of eastern Georgia obtained by weather radar's data at 21:29 on 2 August 2016.

Namely results of numerical calculations have shown that 24h predictions were not able to simulate properly the small-scale processes that bring to the development of deep convections. For example on the Fig.4 and Fig.5 are presented predicted fields of the ATP for 02 August 2016 (21:00 local time) on the nested domains with 6.6 km and 2.2km resolutions, respectively, which were simulated by WRF Physics Options set1 (it gave a better result than others). On the Fig.6 is presented Map of the accumulated total presipitations distribution obtained by weather radar, for 02 August 2016 (21:29 local time). Comparison of the Fig.4 and Fig.5 against the Fig.6 shows that the results of calculations are not in agreement with real situation which took place in Tbilisi and surroundings on 2 August 2016.

III. NATURAL DISASTER IN THE DARIALI GORGE

From the 2,100 glaciers that exist in the Caucasus today, approximately 630 are located within Georgia[8]. At present in modern glaciers of Georgia dominate the processes of the retreat and melting, sizes of large glaciers come apart into smaller ones, the volume and length of glaciers are reduced. According to the first catalogue of glaciers of Caucasus from 1850 the Caucasus glaciers over the territory of Georgia decreased by 231km^2[8]. As a result of glaciers melting appeared many negative forms of the relief, as circuses, frugally of the valley, exterminated relief and others. These forms of relief have formed dam lakes, which in most cases are located inwardly of glaciers. In total in Georgia counted about 16 such kinds of glaciers[9,10]. In Georgia glaciers play an important role in the surface and underground water basin formation and its balance regulation but sometimes owing to melting glaciers fall to the river gorges, create natural dams and latter its destruction leads to the catastrophic floods. A recent example of such phenomenon was a large-scale disaster that took place in May 17, 2014, in Dariali gorge of Kazbegi region. Namely Devdoraki glacier collapsed and taking into account its complex configuration(see Fig.7), dissipated in mudflow and further the accumulated debris flow material fall to the Tergi River and almost blocked the Tergi River pass, destroyed road, custom and hydropower station.

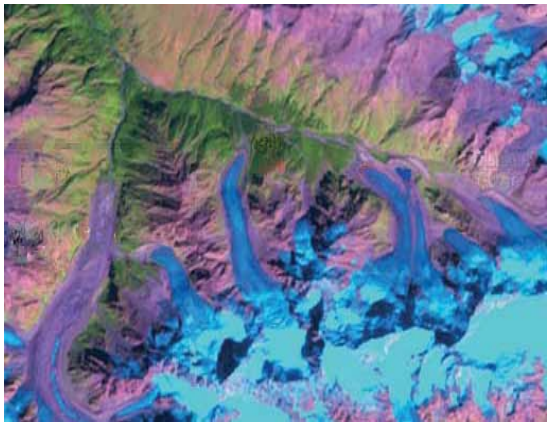

Fig.7 The Devdoraki glacier collapse

Unfortunately the natural disaster in the Dariali gorge, has killed several people and left others missing. The disaster also damaged a section of the road formerly known as the Georgian-Russian Military Road which connected Georgia with Russia. According to the state security and crisis management council, several people have been trapped in the Dariali hydropower plant's derivation tunnel, where construction works were underway when the landslide hit. Another accident happened very soon after this accident, on August 20, 2014. Owing to heavy rains having place on August 20, 2014 and due to the large debris of the Devdoraki glacier fell down and big amount of clastic flow material accumulated on the slopes of the mountain fell to the Tergi River and partially blocked the river bed once again destroyed existing infrastructure: road, custom, almost finished hydropower station[11]. Unfortunately such kind of events are frequent in Georgia for the last period of time which indicates that climate change process in progress on the territory of Georgia.

IV.ANTICIPATED CHANGES OF CLIMATE PARAMETERS BY PRECIS MODELING

For the last two decades meteorological observation stations in Georgia have reduced from 86 to 12 owing to hard economical situation. So for better understanding climate change process the soil surface and meteorological processes that lead to desertification, glaciers meltind, acceleration of the extreme events e.c. it is necessary to use new satellite technology, techniques and reliable mathematical models. For prediction of the possible changes of climate elements on the territory of Georgia until 2050, were used: the Regional Climate Model PREdicting Climate for Impact Studies (PRECIS) (with a resolution of 25 km x 25 km) and the statistical software MAGICC/SCENGEN [12]. The results of calculations based on the PRECIS model have showen that It is expected a 5% decrease in overall precipitation on the territory of Georgia by 2050, with strong inter-seasonal variability. On the territory of Georgia in overall decreased precipitation and increased temperature will reduce the runoffs of Georgian rivers and cause problems in water supply. These problems will be more vulnerably in Eastern Georgia Rivers with high water demand (such as Iori). Also it is expected that the process of climate change differently affects various regions of Georgia. on the territory of Eastern Georgia (especially in Dedoplstskaro Region) is expecting an average 7% decrease in precipitation with a 30% decrease in the summer. This will cause an increase the frequencies of drought and a 5-6% decrease in annual run-off at 2050 in the river Iori, which is the most vulnerable. On the territory of Western Georgia and the coastal zone have just activated storm frequencies, floods, runoff and sedimentation in rivers due to increasing of temperature gradients, showers and glacier's melting. At present on the coastal zone of Georgia is observed a 4% decrease in annual precipitation, but numerical calculations have shown that the seasonal winter precipitation (snow) will increase by 14%. How it is expected this will a 5-10% increase in river runoff in the spring in the Rivers Rioni and Tskhenistskali and thus a strong negative effect on the flood frequency and the occurrence of landslides is forecasted. From 1925 the Black Sea level has already raised by 0.7 m, and the Black Sea has captured the sea-shore of 3.5 km width. The Black Sea level will rise of 20-30 cm is expected in 2050 in the delta of the River Rioni (Reports to the CPUTWIL,2008)[2,3,12-14].

V.GLACIERS MELTING ON THE TERRITORY OF GEORGIA

According to the first catalogue of glaciers of Caucasus contemporary process of glaciers retreat began from "Fernau" stage in 1850[15], when total area of the Caucasus glaciers decreased by 333km^2 , and made 1997 km^2. According to the new catalogue of glaciers total area of the Caucasus glaciers decreased by 511km^2 and in the northern regions of the Caucasus the area of the glaciers decreased more considerable and its exceeds almost twice the decreased of glaciers areas on the southern slopes of the Caucasus[8]. For this period total area of the Caucasus glaciers over the territory of Georgia decreased by 231km^2[16]. The global climate change has affected the Georgian glaciers too. Nowadays in modern glaciers of Georgia dominate the processes of retreat and melting, sizes of large glaciers come apart into smaller ones, the volume and length of glaciers are reduced mainly by climate change. Investigations performed for the West Georgia have shown that for the period 1961-1999 in the extreme hot and cold months, glacial flow has reduced on 2-15% which has been conditioned by increasing of abundant snowing in winters and frequently cloudiness, in the north of Western Georgia [17].For the same period of time glacial flow has increased on 14-23%, with comparison of 1931-1960 in the Eastern Georgia which was stipulated by reduction of snow fall and precipitations in the extreme hot and cold months, arising of recurrent of extreme hot months and melting of glaciers. As a result of glaciers melting appeared many negative forms of the relief, as circuses, frugally of the valley, exterminated relief and others[4,6,9]. These forms of relief have formed dam lakes, which in most cases are located inwardly of glaciers. In total in Georgia counted about 16 such kinds of glaciers. According to [4]contemporary process of glaciers retreat began from "Fernau" stage in 1850, when total area of the Caucasus glaciers decreased by 333km^2 , and made 1997 km^2. According to the new catalogue of glaciers total area of the Caucasus glaciers decreased by 511km^2 [8].For this period total area of the Caucasus glaciers over the territory of Georgia decreased by 231km^2 [17].

For assessment, monitoring and modeling rapid change of high-mountain environments requires the application of modern Remote Sensing Technologies and GIS systems [6,18,19]. Unfortunately use of such kind of technologies for investigation monitoring of climate change impacts on glaciers alteration over the territory Georgia started only recently. Below is presented an expression which allows to get correlation between alteration of an average atmosphere temperature and value of respective altitude of glaciers [16].

$$T_i = T_o + K \cdot \left(H_i - H_o\right), \qquad (1)$$

where H_0, Hi and T_0 ,Ti are values of respective altitude of glaciers and temperature at the initial and investigated moments of time, respectively. K is parameter value of which is defined for each glacier individually.

(1) was examined for the several glaciers (Devdodaraki,Gergeti e.c.) and obtained results have been compared with the data of high mountain meteorological station Kazbegi located at the altitude snow line (3650m). For instance the value of parameter K for the glacier Gergeti was equal to 0.0062^0C per one meter. Results of calculations have shown that difference between calculated and real observed values was about 1.4-2%. So (1) could be used for the assessment of glaciers vulnerability to the expected climate change. The IPCC estimates that "the rapid melting of Caucasus' glaciers will continue, possibly to an extent where hardly any glaciers will be left at the end of the 21st century"[1]. It is also expected that in eastern Georgia risk temperature increases of above 2°C is high [20,21]. For example let us examine once again the glacier Gergeti using contemporary data of high mountain meteorological station Kazbegi. So accept H_0=3670, and suppose that T_i-T_0= 2°C, than according to (1) will get H_i=3992.It means that the glacier Gergeti will disappeared, no rivers flows during the warm and dry periods. This will have a significant negative impact on agriculture and water availability.

Modelling of the glaciers fluctuation has primary importance in knowledge and in the prediction of water resources in Georgia. Although each glacier has its own geometry and dynamic behavior numerical modelling is good means to understand the behavior of particular glacier flows [21]. The importance of glacier fluctuation has been recognized since the end of the 19^{th} century [21,22,23]. Namely glacier fluctuations (melting) is acting on the human activities in the constructions and functioning of hydropower stations, runoff for irrigation purposes, contribute significantly to sea-level fluctuations on the century time scale[24,25] and as a consequence on the land surface changeability, on negative profits of world fresh water-supply and on local, regional and global climate change [26].

It must be noted that the main factor in glacier melting is the long term meteorological conditions. Mainly glacier long-term fluctuation is determined by influence of the air temperature, atmosphere solid precipitations and the overall glacier volume [27]. In order to study the glacier mass balance change it is necessary to know the current volume of the glacier that is definition of its bed and surface topography which is not a trivial task even having data from remote sensing, airborne surveying techniques (for surface topography), radio-echo-sounding(with ground penetrating radar) and other techniques (for the bed topography) [28]. In order to overcome this lack of data there are suggested some methods to simply estimate the ice volume based on the glacier surface area and an area-volume relation [29]. Chen and Ohmura [29], proposed (for a glacier in a steady state) a scaling relationships between glacier's volume V and surface area S which has the following form: $[V] = 28.5 [S]^{1.357}$. Such relationship supports to use remote sensing, radio-echo-sounding and other techniques for definition of glacier's volume if it is known surface area. If one assumes that the volume-area relationship always holds, one can use it to deduce the area as the volume decreases [30,31]. On the basis of these methods, in [23] have been found that the glacier mass will loss over the next 70 years by 15 to 20%. The same we have done for the some Caucasus glaciers. For example it have been found that the Devdoraki glacier's mass will loss over the next 50 years by 35 to 45%.

VI. WATER RESOURCES ALTERATION ON THE BACKGROUND OF CLIMATE CHANGE

Climate change of Georgia is characterized with strongly expressed regional peculiarities. There are observed as warming as well cooling processes on the territory of Georgia. Namely statistical treatment of data of average climate temperature of 1905-2005 years has shown simultaneously sharp process of warming in Eastern Georgia and climate cooling in Western Georgia. There are also exposed the micro regions, where the average climate temperature does not change according to time. The mentioned changeability of the climate on the whole territory of Georgia corresponds to the picture of global climate change [32-34]. As on the whole territory of Western Georgia takes place the climate cooling process, it was necessary to find out such constantly acting thermal and advective-dynamic sources, which caused climate cooling in Western Georgia. We have found that the Black Sea, the Caucasus and Surami Range, which bisects the territory of Georgia into west and east sides, significantly influence on local climatic cooling conditions in Western Georgia[35-36]. The Main Caucasian Mountains barrier protects Georgia from cold air intrusions from the north, while the influence of cool, moist air from the Black Sea and specific circulation processes conduce to high precipitation rates and cooling process especially on the territory of Western Georgia[35-36]. The climate in Georgia alters through parallel from subtropical at the Black Sea coast to the arid continental in Eastern Georgia. Precipitation decreases from west to east and mountains generally receive higher amounts than low-lying areas. The absolute maximum annual rainfall is 4100 mm around the Mt. Mtirala in south-west Georgia (Adjara region), whilst the rainfall in east-south Georgia varies between 150 and 800 mm per year. Georgia's arid and semiarid regions are especially sensitive to desertification. These include the south-eastern part of Georgia – the districts of Shida Kartli, Sighnaghi, Sagarejo, Dedoplistskaro and especially Shirakhi region. In these regions droughts are frequency in winter and in summer [20]. Droughts in Georgia are characterized by special extra conditions of the weather, with high temperature, low humidity and absence of atmospheric precipitations for a long period of time, i. e. when a daily norm of atmospheric precipitations are less than 1mm. Genesis of droughts is determined by numerous natural phenomenon, but on the territory of Georgia atmosphere currents play an great importance. Namely when air currents are invading from the east, or south-east regions, they bring dry air masses on the territory of Georgia. Namely during the influence of the Asia Depression, the currents of summer thermal cyclone are extending from the south-east and as a result dry and hot air masses are formed over the territory of Georgia. Minimum

temperature of the lowland dos not fall below +20° C , and a daily maximum exceeds +38° C. Recurrence of the influence is the highs in July (25,1%). The main formation factors of water flows strongly depend on the anomalies of the air temperature. Investigations carried out for the dry region of Georgia (low Kartli) have shown that during positive and negative anomalies of temperature were observed significant changes of water balances for the period 1931-1999 [17]. Namely for positive anomalies of the temperature the mean value of annual precipitations has reduced on 29%, summary evaporation has been increased on 27% and water flow decreased on 69% in Lower Kartli. For the last five years there were three times (2010, 2012, 2014) reiterated (recurrence) catastrophic droughts on the territory on Georgia which had stipulated to an aggravate process of desertification in the eastern dry regions of Georgia. Unfortunately the catastrophic droughts on 2006, 2010, and 2012 years which take place in the south and south-east territories of Georgia had not studied properly and as a result the economic expenditure of all productivity of internal gross efficiency of Georgia made 6%. Statistical data of observations for the last century have shown that catastrophic droughts on the territory of Georgia had repeated one time in each ten years while for the last ten years it take place four times. The last indicates that increment of droughts by all appearances has reduced volume of water resources on the territory of Georgia and taking into account that 80% of electricity is coming from hydro powers so not only energetic crisis but scarcity of drinking water supplies will appearance in the dry regions of Georgia very soon. During the droughts there are reduction of precipitations and volumes of the surface water basins but even for this hard situations dry regions of Georgia are rich by underground waters resources which needs increase activity in exploration drilling for social security and logistical support of population.

VII. Conclusion

At present impact of global climate change on the territory of Georgia is evident at least on the background of the Caucasus glaciers melting which during the last century have decreased to half their size. Glaciers are early indicators of ongoing global and regional climate change. Knowledge of the Caucasus glaciers fluctuation (melting) is an extremely necessary tool for planning hydro-electric stations and water reservoir, for development tourism and agriculture, for provision of population with drinking water and for prediction of water supplies in more arid regions of Georgia. Otherwise, activity of anthropogenic factors has resulted in decreasing of the mowing, arable, unused lands, water resources, shrubs and forests, owing to increasing of the production and building. Transformation of one type structural unit into another one has resulted in local climate change and its directly or indirectly impacts on different components of water resources on the territory of Georgia. Climate change process has already started in Georgia and its impact on environment is more than ever evidence for last two decades. At present climate change in Georgia generally is characterized by, the increasing average annual temperatures and frequency of shower precipitations, melting glaciers and sea level rise, redistribution of river flows and decreasing snowfall. Also for the last two decades there are observed more frequent extreme events which are characterized with flooding, landslides, forest fires. and erosion of soils with significant economic losses and human casualties as a result. It is important to note that glaciers melting much more has observed over the eastern regions, then western areas of Georgian Main Caucasus Ridges. It is obvious that the main factors of Georgian glaciers melting are Great Caucasus Ridges location, direction, height, atmosphere circulation processes and main climate determine parameters such are atmosphere temperature and precipitation. But also this variation was stipulated by difference of degree of glaciers shading, surface pollution, frequent of cloudiness, summer down pouring and etc. Glacier mass loss leads to reduction of water resources as stored in glaciers and to changes in dry-season river flows. These processes have consequences for drinking water supply, irrigation, hydropower production, industrial water use, fishery, water quality, etc. Nowadays there are several attempts to find out reliable methods for prediction these natural hazard events for short or long time periods. We tried to present some aspects of these problems for the territory of Georgia.

Acknowledgment

Thanks to Dr. N.Kutaladze, Dr. Z.Modebadze, Mrs. I. Samkharadze and Mr. G.Mikuchadze for their efforts in configuration, developing WRF v.3.6 and PRECIS models for the Caucasus region and executing a series of calculations. The computer time for this study was provided by the Georgian Research and Education National Association GE-01-GRENA under the leadership of Dr.R.Kvatadze.

References

[1] IPCC, 2007. Climate Change 2007: Synthesis Report. Pachauri, R.K. and A. Reisinger (eds.), Contribution of Working Groups I, II and III to the Fourth Assessment. Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland. 104 pp.

[2] M. I. Westphal, M. Mehtiyev M. Shvangiradze V. Tonoyan, 2011, Regional Climate Change Impacts Study for the South Caucasus Region, p.63.

[3] *Second National Communication to the United Nations Framework Convention on Climate Change*; Ministry of Environment Protection and Natural Resources, Republic of Georgia. 2009, www.unfccc.int, p.240

[4] C. Huggel, W. Haeberli, A.Kääb, E. Ayros, , and Portocarrero, C., 2003, Assessment of glacier hazards and glacier runoff for different climate scenarios based on remote sensing data: a case study for a hydropower plant in the Peruvian Andes. EARSel eProceedings, 2, pp.22-33.

[5] J. M. Shea, W. W. Immerzeel, P. Wagnon, C. Vincent, and S. Bajracharya, Modelling glacier change in the Everest region, Nepal Himalaya, The Cryosphere, 9, 1105-1128, 2015

[6] K. Andreas, C.Huggel, L.Fischer, 2006, Remote Sensing Technologies for Monitoring Climate Change Impacts on Glacier- and Permafrost-Related Hazards, 2006ECI Conference on Geohazards,Lillehammer,Norway, pp.67-78

[7] R. J. Braithwaite, O. B. Olesen, Calculation of glacier ablation from air temperature, West Greenland *In J. Oerlemans (Ed.),*

Glacier Fluctuations and Climatic Change, Kluwer Academic Publisher, 1989, pp.124-135

[8] Catalogue of Glaciers of USSR., Vol.8,9. Leningrad,1965-1977(in Russian)

[9] Gorgijanidze S., Tsintsadze N., 2007, Geography of dam lakes created by the glaciers stepping back, Transactions of the Hydrometeorological Institute, V.111, p. 43-49 (Georgian)

[10] Huggel, C., Kääb, A., and Salzmann, N. (2004). GIS-based modeling of glacial hazards and their interactions using Landsat TM and Ikonos imagery. Norwegian Journal of Geography, 58, pp.61-73.

[11] G.Kordzakhia, L.Shengelia, G.Tvauri, M.Dzadzamia, The Research of Devdoraki Glacier Based on Satellite Remote Sensing Data and Devdoraki Glacier Blockage Analysis in Historical Context, Report of ICAE 7-10 May, 2015, Tbilisi-Batumi, pp.56-65

[12] N.Kutaladze, L.Kartvelishvili, G.Kordzakhia, N. Shavishvili L.Megrelidze,2005. Reccurence ofextreme temperature events inGeorgia on background of climate change. Bullit. of GeorgianAcademy of sciences 171, N3, pp.489-480.

[13] X.Zhang, E.Aguilar, S.Sensoy, H.Melkonyan, U. Tagiyeva, N. Ahmed, N.Kutaladze and all, 2005: Trends in Middle East climate extreme indices from 1950 to 2003, Journal of Geophisical Researchs, V. 110, D22104, 12 PP., doi:10.1029/2005JD006181

[14] T.Matchatashvili, N.,Kutaladze. P.Japaridze , L.Megrelidze, D.Mikautadze 2006. Trends and long Range correlation in Daily Temperature Records in Georgia. Bullit. of Georgian Academy of sciences 173, N1, pp.95-98.

[15] E.T.Podozersky, Catalogue of Glaciers, 1911(in Russian).

[16] G.Svanidze, V.Tsomaia, 1999, Assessment of vulnerability of Georgian glaciers to expected climate change, Georgian National Bulletin of the UNFCCC, No 8(E), pp. 52-60

[17] Tsomaia V., Meskhia R.,2007, The dynamic of glacial flow in Georgia according to the modern climate change conditions, Transactions of the Hydrometeorological Institute, V.111, p. 26-29 (Georgian)

[18] C.Huggel, W.Haeberli, A. Kääb, E. Ayros, C.Portocarrero, 2003, Assessment of glacier hazards and glacier runoff for different climate scenarios based on remote sensing data: a case study for a hydropower plant in the Peruvian Andes. EARSel eProceedings, 2, pp.22-33.

[19] C.Huggel, A.Kääb, N. Salzmann, 2004, GIS-based modeling of glacial hazards and their interactions using Landsat TM and Ikonos imagery. Norwegian Journal of Geography, 58, pp.61-73.

[20] M.Sylvén, R.Reinvang, Z. Andersone, 2008, WWF overview report, Climate Change in Southern Caucasus: Impacts on nature, people and society, p.35

[21] Shahgedanova M., Hagg W., Hassell d., Stokes C.R. and V. Popovin, Climate Change, Glacier Retreat, and Water Availability in the Caucasus Region, *In Book Threats to Global Water Security*, Editors: J. Anthony A. Jones, Trahel G. Vardanian, Christina Hakopian ,Publisher Springer Netherlands, 2009, pp. 131-140.

[22] J.Oerlemans, , A flowline model for Nigardsbreen, Norway: Projection of future glacier length based on dynamic calibration with the historic record, *Annals of Glaciology*, 24, 1997, pp. 382-389.

[23] R. S. W. Van de Wal, M. Wild, Modelling the response of glaciers to climate change by applying vloume-area scaling in combination with a high resolution GCM, *Climate Dynamics* 18(3-4), 2001, Dec. pp.359–366.

[24] A.Dyurgerow, S. Meier, Mass balance of mountain and subpolar glaciers: A new global assessment for 1961– 1990, *Arct. Alp. Res.*, 29, 1997a, pp.379–391.

[25] Z.Zuo, J.Oerlemans, Numerical modelling of the historic front variation and the future behaviour of the Pasterze glacier. *Ann Glaciol* 24, 1997, pp.234-241.

[26] J.Oerlemans, B.Anderson, A. Hubbard, Ph.Huybrechts, T.Johannesson, W.H.Knap, M.Schmeits, A.P.,Stroeven, R.S.W. Van de Wal, V. Wallinga, Z. Zuo, Modelling the response of glaciers to climate warming, *Climate Dynamics* .14, 1998, pp.267-274.

[27] Ch.Schneeberger, Glaciers And Climate Change: A Numerical Model Study, *Diss. ETH No. 14743*, A dissertation submitted to the SWISS FEDERAL INSTITUTE OF TECHNOLOGY ZURICH

[28] L.Shengelia, G.Kordzakhia, G.Tvauri, T.Davitashvili, N.Begalishvili, Possibilities of the use of remote sensing technologies for the estimation of modern climate change impact on the Caucasus glaciers, *Georgian National Academ y of Sciences, Monthly Scientific-Reviewed Magazine, "Science and Technologies"*, Vol.4-6, 2012, pp. 25-30.

[29] J.Chen, A. Ohmura, Estimation of Alpine glacier water resources and their change since 1870s. In H. Lang and A. Musy (Eds.), Hydrology in Mountainous Regions I, Volume 193, 1990, pp. 172–135. IAHS.

[30] M. F.Meier, D. B. Bahr, 1996: Counting glaciers: Use of scaling methods to estimate the number and size distribution of the glaciers of the world In S. C. Colbeck (Ed.), Glaciers, Ice Sheets and Volcanoes: a Tribute to Mark F. Meier, Hanover, New Hampshire, pp. 89–94. CRREL Special Report 96-27: U. S. Army.

[31] R. J.Braithwaite, O. B. Olesen, Calculation of glacier ablation from air temperature, West Greenland *In J. Oerlemans (Ed.), Glacier Fluctuations and Climatic Change*, Kluwer Academic Publisher, 1989, pp.124-135

[32] K.Ya. Kondratyev, I. Galindo, *Contemporary stage of civilization development and its perspectives*, Univ. of Colima Press, 2002.

[33] S. Levitus ,J.L. Antonov, J. Wang, "Anthropogenic warming of Earth's climate system " *Science*, vol. 292, N 5515, 2001, pp. 267-270.

[34] "Summary of Analytical Report by IPCC" *Bulletin of WMO*, vol.1, No. 1., 1991.

[35] T.Davitashvili, Z.Khvedelidze, A.Khantadze, K.Tavartkiladze, I.Samkharadze, "Investigation of Some Climate Singularities on the territory of Georgia by Mathematical Modeling",- *Transactions of the Institute of Hydrometeorology* Vol.115, 2008, pp. 7-19.

[36] T. Davitashvili, A.Khantadze, On climate, desertification and water pollution problems for the territory of Georgia" Netherlands: Springer-Verlag, ,2008 ,pp.453-469.

[37] T. Davitashvili, A. Khantadze, Kh. Sharikadze. "Influence of Non-linear Heat sources on Climate Change". *Reforts ofVIAM*. Vol.17. N3, 2002, pp.21-29.