STUDY OF ENVIRONMENTAL IMPACTS
OF
CLIMATE CHANGE OF ARAL SEA BASIN

A DISSERTATION

Submitted in partial fulfillment of the
requirements for the award of the degree
of
MASTER OF TECHNOLOGY
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By

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CANDIDATE'S DECLARATION

I hereby declare that the work, which is being presented in the dissertation entitled "**STUDY OF ENVIRONMENTAL IMPACTS OF CLIMATE CHANGE OF ARAL SEA BASIN**" submitted, in partial fulfilment of the requirements for award of the degree of **MASTER OF TECHNOLOGY** in **DEPARTMENT OF WATER RESOURCES DEVELOPMENT AND MANAGEMENT(CIVIL),** of Indian Institute of technology Roorkee, is an authentic record of my own work carried out for a period from July 2006 to June 2007 under the supervision of **Prof. Nayan Sharma**, Professor in the Department of Water Resources Development, Indian Institute of Technology Roorkee, Roorkee, India.

I have not submitted the matter in this dissertation for the award of any other degree.

Date: June29, 2007
Place: Roorkee

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This is to certify that the above-mentioned statement made by the candidate is correct to the best of our knowledge.

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ABSTRACT

Observed climate change (global warming) is directly related to greenhouse gas (GHG) concentration increase in atmosphere. Global warming rates, scales as well as its effect in some regions depend on global GHG emissions volume in atmosphere of the Earth in future.

In 1992 Intergovernmental Plane on Climate Change (IPCC) proposed 6 GHG emissions scenarios (IS92a, IS92b, IS92c, IS92d, IS92e, and IS92f). Scenario IS92a assumes that global population would increase up to 11.3 billion by 2100, economical growth would be 2.3-2.9% annually, and besides no attempts of restricting GHG emissions in atmosphere would be made. This is so called "business as usual" scenario. Scenarios IS92c и IS92d assume less quantity of emissions against scenarios IS92a и IS92b, and scenarios IS92e и IS92f – greater quantity due to difference in assessments of population increment, economical growth, use of various types of fuel and power sources. According to above mentioned scenarios there are the same number of global air temperature increase alternatives, moreover each variant has own uncertainty limits.

The most reliable tool for modeling physical processes, which define climatic changes, are three-dimensional numerical models of general circulation (GCM). Its advantage is that basing on conservation laws models, as much as possible, account physics of processes, which allow simulation and prediction of climate. However GCM has some constraints including horizontal resolution of models, which does not provide adequate regional climate simulation.

Great averaging on area, typical for global models, reduces amplitude of fluctuations of regional climatic characteristics.

Quality of air temperature changes simulation by climatic models in scale of hemispheres and continents is higher than for specific regions. Moreover, quality of regional climate change assessment depends on region location, its physical-geographical conditions, and used models.

While developing climate change scenarios on GCM basis it is necessary to take into account its different sensitivity. Regarding this climate sensitivity parameter is widely used, which is defined as global average air temperature variation by the surface

in state of balance, which occurs in response for CO_2 concentration doubling in atmosphere. This parameter values are in range 1.5-4.5°C.

In spite of significant uncertainties, GCM is successfully applied for global climate description in general and specific regions climate description as well. Results obtained on global models of general circulation of atmosphere and oceans are the most favorable basis for formation of climate change scenarios and regional vulnerability assessments.

When using global models results to assess regional climatic changes, it is necessary to take into account geographical features of certain regions, which are related to location relief, water objects, character of underlying surface etc. For this purpose «downscaling» methodic are used, by means of which climatic characteristics, given by models, are transformed to required for further use meteorological parameters with proper spatial and temporal resolution.

In given work regional climatic scenarios are built by method of statistical interpretation based on concept of "ideal forecast" described in (Spektorman, 2002) using gradual linear regression.

On the basis of analysis conducted for assessment of future changes of average climatic characteristics values of Uzbekistan and adjacent mountainous area following methodic is used:

- determination of statistical dependencies between climatic characteristics in local and global scales
- use of model global temperature assessments as future global climate forecasts for different IPCC emission scenarios.
- use of existing in series climatic characteristics of Uzbekistan quasi-cyclicities and tendencies to reduce uncertainty, correct scenarios and assessment of possible course of researched values.

Assessment of climatic conditions changes over Central Asia territory with account for available model assessments, regional analogous scenario and empirical-statistical approach show that we should expect some increase (from 0 to 20%) of total precipitation sums and temperature increase in all seasons of the year over Central Asia area, including flow formation zone, under realizing different GHG emission scenarios by 2030.

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ABBREVIATIONS

CCCM – Canadian Climatic Center Model

CFC – Chloral – Fluoric Carbon

ECMWF – European Center of Midterm Weather Forecast

GCM – General Circulation Model

GLAVGIDROMET/SANIGMI – General Hydro Meteorological Center, Uzbekistan

GHG – Green House Gas

GFDL – Model of US Laboratory of Geophysical Hydrodynamics

GISS – Model of US Goddard Institute

IPCCTG – IPCC Technical Guidelines

IPCC – Intergovernmental Panel on Climate Change

MAGICC – Model for the Assessment of Greenhouse-Gas Induced Climate Change

NCAR – US National Center of Atmospheric Events

RCM – Regional Climate Models (RCM)

SAR – Sodium Adsorption Ratio

SPI – Standardized Precipitation Index

SST – Sea Surface Temperatures

SCENGEN – Global and Regional SCENario GENerator

UKMO – UK Meteorological Bureau Model

CHAPTER 1

INTRODUCTION

1.1 General

As it is known, global climatic change is expected to impact on sustainable perspective development of the Aral Sea basin.

This impact is mainly directed to the volume of available water resources in the region.

Total water resources of the Aral Sea basin are 130-135 km^3. Nearly 10 km^3 of them are lost. Water intake accounts for about 90 % of general available water resources. After the average temperature has risen by 1 °C over the last 35 years and the volume of glaciers has reduced by 22 % for the same time, it is predicted by various scenarios that by 2020 water resources scarcity would have been rise as a result of evaporation increase and water resources decrease by from 6 to 20 km^3 every year (or by 5-15 % of total volume).

The estimates of the Aral Sea basin climate change impact significantly differ depending on methods, approaches and so on. Most of them are aimed to determine available water resources reduction.

In this situation it is important to show the means of demand shortening that can lead to reduction of pressure on water resources in the basin. Since agriculture is the biggest water consumer (about 85 %), it is important to evaluate irrigation demands for water taking into account temperature regime, arid climate, cropping structure, management at farm level and others to determine the means of water demands shortening.

1.2 Consequences and Risks, Interventions of Sustainable use of Water Resources

(a) Climate change in case of a 1-2 °C rise in temperature will lead to lower water content in rivers predominantly fed by snow, and in the longer run to a sharp reduction of runoff in rivers fed by both snow and glaciers.

(b) An air temperature rise of 1-2 °C will intensify the process of ice degradation. In 1957-180 glaciers in the Aral Sea river basins lost 115.5 km^3 of ice (approximately 104 km^3 of water), which constituted almost 20 per cent of the 1957 ice reserve. By 2000 another 14 per cent of the 1957 reserve was lost. By 2020 glaciers will lose at least another 10 per cent of their initial volume.

(c) A 3-4 °C rise in air temperature will result in the loss of all glaciers in the region. While in the initial period of the warming the melting of glaciers somehow compensates for a decrease in the runoff, it will be further followed by a disastrous fall in the river water content by 30 per cent and more.

(d) In case of a 3-4 °C rise in air temperature water resources may decrease by 40 per cent of their current amount.

(e) A decrease of regional water resources by one third will sharply reduce the irrigation capacity of the water management system and have a direct impact on irrigated farming. Even at present only 48-50 per cent of water intake reaches the fields due to bad irrigation systems, irrigation techniques and watering technologies. A rise in air temperature even by 1-2 °C will increase these losses (due to evaporation and filtration into the soil) by another 10 per cent.

(f) A shortage of water resources gave rise to the Aral Sea crisis. In the event of dryness further conservation and restoration of the Aral Sea will become unfeasible, at least with the help of the subcontinent's own water resources. Under the arising circumstances total water conservation in all economic sectors and especially in irrigated farming acquires utmost importance.

1.3 Nature of the Problem

In the water resources sector, technology, economics, and institutions interact to make water supply meet water demand. In managing water resource systems, water managers ask, "Can we modify the management of current systems to adapt to climate change?", "How might climate change impact the design of new water resource infrastructure?", and "Should climate change be included in our current planning?".

The water resources sector by its nature is very adaptive, on various time and spatial scales. Also, water managers have a wealth of knowledge and experience managing under changing hydrologic and socio-economic conditions. This experience places them in a good situation to be able to adapt the operation of their systems to a change in climate, if that change is not too great or too rapid.

1.4 Objectives of Study

The given thesis present results of studies of environmental impacts over Aral Sea Basin using different global and regional climatic scenarios and other empirical statistical methods.

The following questions have been studied during the thesis work:

1. Empirical-statistical method based on dependencies between global temperatures and regional climatic characteristics
2. Regional climate change scenarios building based on global climatic models outcomes
3. Assessment of future changes in air humidity
4. Assessment of water resources changes under probable climatic change

1.5 Organization of the Thesis

The Study is organized to achieve its objective in nine chapters.

Chapter – 1 is an Introduction. It gives general information about the situation in the Aral Sea basin due to Climate Change and its possible worldwide effects. Chapter – 2 is Literature Review, which deals several methodological backgrounds of methods used in the thesis. Chapter – 3 gives general information about study area. From Chapter 4 to Chapter 7 I tried in detail describe the work which is done to answer the above mentioned objectives of the thesis. Chapter – 8 Conclusions.

CHAPTER 2

LITERATURE REVIEW

2.1 General

Climate change is happening, and its impact on all of us is growing. Have you noticed storms and floods becoming more frequent around your area, or on television? Does it seem to be warmer in the winter, with less snow and more rain? Do we feel that spring is coming a little earlier each year, with flowers blooming or birds arriving before we expect them? These are all signs of accelerating climate change — or global warming, as it is sometimes known. If we don't take action to stop it, it is going to damage the world we live in, and alter the ways of life we now take for granted.

2.2 Human Influence on the Climate System

Human beings, like other living organisms, have always influenced their environment. It is only since the beginning of the Industrial Revolution, mid-18th century that the impact of human activities has begun to extend to a much larger scale, continental or even global. Human activities, in particular those involving the combustion of fossil fuels for industrial or domestic usage, and biomass burning, produce greenhouse gases and aerosols which affect the composition of the atmosphere. The emission of chlorofluorocarbons (CFCs) and other chlorine and bromine compounds has not only an impact on the radiative forcing, but has also led to the depletion of the stratospheric ozone layer. Land-use change, due to urbanization and human forestry and agricultural practices, affect the physical and biological properties of the Earth's surface.

2.2.1 The Enhanced Greenhouse Effect

The increased concentration of greenhouse gases in the atmosphere enhances the absorption and emission of infrared radiation. The atmosphere's opacity increases so that the altitude from which the Earth's radiation is effectively emitted into space becomes higher. Because the temperature is lower at higher altitudes, less energy is emitted, causing a positive radiative forcing.

2.2.2 The Effect of Aerosols

The effect of the increasing amount of aerosols on the radiative forcing is complex and not yet well known. The direct effect is the scattering of part of the incoming solar radiation back into space. This causes a negative radiative forcing which may partly, and locally even completely, offset the enhanced greenhouse effect. However, due to their short atmospheric lifetime, the radiative forcing is very inhomogeneous in space and in time. This complicates their effect on the highly non-linear climate system. Some aerosols, such as soot, absorb solar radiation directly, leading to local heating of the atmosphere, or absorb and emit infrared radiation, adding to the enhanced greenhouse effect.

Aerosols may also affect the number, density and size of cloud droplets. This may change the amount and optical properties of clouds, and hence their reflection and absorption. It may also have an impact on the formation of precipitation. These are potentially important indirect effects of aerosols, resulting probably in a negative radiative forcing of as yet very uncertain magnitude.

2.2.3 Land-use Change

The term "land-use change" refers to a change in the use or management of land. Such change may result from various human activities such as changes in agriculture and irrigation, deforestation, reforestation and afforestation, but also from urbanization or traffic. Land-use change results in changing the physical and biological properties of the land surface and thus the climate system.

2.2.4 Climate Response

The increase in greenhouse gas and aerosol concentrations in the atmosphere and also land-use change produces a radiative forcing or affects processes and feedbacks in the climate system. The response of the climate to these human-induced forcings is complicated by such feedbacks, by the strong non-linearity of many processes and by the fact that the various coupled components of the climate system have very different response times to perturbations. Qualitatively, an increase of atmospheric greenhouse gas concentrations leads to an average increase of the temperature of the surface-troposphere system. The response of the stratosphere is entirely different. The stratosphere is characterized by a radiative balance between absorption of solar radiation, mainly by ozone, and emission of infrared radiation mainly by carbon dioxide. An increase in the carbon dioxide concentration therefore leads to an increase of the emission and thus to a cooling of the stratosphere.

The only means available to quantify the non-linear climate response is by using numerical models of the climate system based on well-established physical, chemical and biological principles, possibly combined with empirical and statistical methods.

2.3 Aerosols.

Aerosols are tiny particles suspended in the air. Some occur naturally, originating from volcanoes, dust storms, forest and grassland fires, living vegetation, and sea spray. Human activities, such as the burning of fossil fuels and the alteration of natural surface cover, also generate aerosols. Averaged over the globe, aerosols made by human activities currently account for about 10 percent of the total amount of aerosols in our atmosphere. Most of that 10 percent is concentrated in the Northern Hemisphere, especially downwind of industrial sites, slash-and-burn agricultural regions, and overgrazed grasslands.

Scientists have much to learn about the way aerosols affect regional and global climate. We have yet to accurately quantify the relative impacts on climate of natural aerosols and those of human origin. Moreover, we do not know in what regions of the planet the amount of atmospheric aerosol is increasing, is diminishing, and is remaining roughly constant. Overall, we are even unsure whether aerosols are warming or cooling our planet.

Aerosols tend to cause cooling of the Earth's surface immediately below them. Because most aerosols reflect sunlight back into space, they have a "direct" cooling effect by reducing the amount of solar radiation that reaches the surface. The magnitude of this cooling effect depends on the size and composition of the aerosol particles, as well as the reflective properties of the underlying surface. It is thought that aerosol cooling may partially offset expected global warming that is attributed to increases in the amount of carbon dioxide from human activity.

Aerosols are also believed to have an "indirect" effect on climate by changing properties of clouds. Indeed, if there were no aerosols in the atmosphere, there would be no clouds. It is very difficult to form clouds without small aerosol particles acting as "seeds" to start the formation of cloud droplets. As aerosol concentration increases within a cloud, the water in the cloud gets spread over many more particles, each of which is correspondingly smaller. Smaller particles fall more slowly in the atmosphere and decrease the amount of rainfall. In this way, changing aerosols in the atmosphere can change the frequency of cloud occurrence, cloud thickness, and rainfall amounts.

If there are more aerosols, scientists expect more cloud drops to form. Since the total amount of condensed water in the cloud is not expected to change much, the average drop must become smaller. This has two consequences -- clouds with smaller drops reflect more sunlight and such clouds last longer, because it takes more time for small drops to coalesce into drops that are large enough to fall to the ground. Both effects increase the amount of sunlight that is reflected to space without reaching the surface.

2.4 Models of Ice Sheets

High resolution (20 km x 20 km horizontal grid), two- and three dimensional models of the polar ice sheets have been developed and used to assess the impact on global mean sea level of various idealized scenarios for temperature and precipitation changes over the ice sheets. AGCM output has also recently been used to drive a three-dimensional model of the East Antarctic ice sheet, but has not yet been used to assess the possible contribution of changes in mountain glaciers to future sea level rise. Output from high resolution ice sheet models can be used to develop simple relationships in which the contribution of ice sheet changes to future sea level is scaled with changes in global mean temperature (Houghton et al, 1997).

2.5 Scenarios and their Purpose.

Future greenhouse gas (GHG) emissions are the product of very complex dynamic systems, determined by driving forces such as demographic development, socio-economic development, and technological change. Their future evolution is highly uncertain. Scenarios are alternative images of how the future might unfold and are an appropriate tool with which to analyze how driving forces may influence future emission outcomes and to assess the associated uncertainties. They assist in climate change analysis, including climate modeling and the assessment of impacts, adaptation, and mitigation. The possibility that any single emissions path will occur as described in scenarios is highly uncertain (IPCC, 2000).

2.6 Using Climate Models

This assessment, of the likely changes to the hydrological cycle from global warming, is largely derived from published studies of the use of General Circulation Models (GCMs) coupled with smaller, catchment scale, hydrologic models.

GCMs are based on physical laws represented by mathematical equations that are solved on a three-dimensional grid over the globe. The solutions are obtained using high-powered supercomputers. Generally speaking, the greater the power of the supercomputer the finer the grid and/or the more complex the model that can be integrated forward in time to provide an estimate of the climate when greenhouse gas concentrations (for example) are increased according to some pre-specified scenario.

There are a number of major drawbacks in using these models.

The first relates to scenarios.

Any projection of future climate change is based on scenarios. These scenarios are idealizations of the rates at which greenhouse gases will be emitted in the future and there are, of course, widely varying estimates of just what these emission rates will be.

Secondly, when studying the impacts of changes in the hydrological cycle there is a scale mismatch between the GCMs, that might only have a grid point every 200 km or so, and the catchment scale hydrologic models, where the entire catchment might fit within three or less, grid points of the GCM.

Thirdly, there is a temporal scale issue. Generally, GCMs provide monthly mean data, whereas catchment scale models require hydrologic data (rainfall or stream flow) on daily or hourly time scales.

Nevertheless, the TAR WGII report summarizes the trends in precipitation due to global warming, as assessed from published reports of combined GCM/hydrologic model studies. According to these, there is likely to be:

(1) an increase in annual precipitation in high- and mid-latitudes and most equatorial regions;

(2) a general decrease of annual precipitation in the sub-tropics;

(3) small changes in annual precipitation, even by 2080, when compared with natural multi-decadal variability;

(4) increased frequency of heavy rainfall events as the world warms;

(5) a smaller proportion of precipitation may fall as snow (decreasing snow pack), thereby increasing winter run-off, but diminishing spring (snow-pack melt) run-off commensurately (R. K. Pachauri, 2002).

2.7 General Circulation Models (GCM)

GCMs are mathematical representations of atmosphere, ocean, ice cap, and land surface processes based on physical laws and physically-based empirical relationships. Such models have been used to examine the impact of increased greenhouse gas concentrations on future climate. GCMs estimate changes for dozens of meteorological variables for grid boxes that are typically 250 kilometers in width and 600 kilometers in length. Their resolution is therefore quite coarse. The most advanced GCMs couple atmosphere and ocean models and are referred to as coupled ocean- atmosphere GCMs; for an evaluation of coupled GCMs.

Two types of GCM runs can be useful for impact assessments. Almost all GCMs have been used to simulate both current ($1xCO_2$) and future ($2xCO_2$ or occasionally $4xCO_2$) climates. The difference between these simulated climates is a scenario of how climate may change with an effective doubling (or quadrupling) of atmospheric CO_2

concentrations. These are referred to as equilibrium experiments since both the current and future climates are assumed by modellers to be in equilibrium (i.e., stationary). GCMs used for equilibrium experiments generally have only a very simple representation of the oceans.

To be sure, climate is never in equilibrium. Greenhouse gas concentrations are not held constant, because of human activities or other reasons. The assumption of a stable climate makes it easier, however, for climate modellers to estimate the effect of increased greenhouse gases on climate and for impact assessors to examine potential impacts.

2.8 Regional Climate Models (RCM)

An alternative to downscaling using statistical techniques is the use of a regional climate models (RCM). These numerical models are similar to global climate models, but are of higher resolution and therefore contain a better representation of, for example, the underlying topography within the model domain and, depending on the model resolution, may also be able to resolve some of the atmospheric processes which are parameterized in a global climate model.

The general approach is to 'nest' an RCM within the 'driving' global climate model so that the high resolution model simulates the climate features and physical processes in much greater detail for a limited area of the globe, whilst drawing information about initial conditions, time-dependent lateral meteorological conditions and surface boundary conditions from the GCM. Most nesting techniques are one-way, i.e., there is no feedback from the RCM simulation to the driving GCM. The global model simulates the response of the global circulation to large-scale forcing, whilst the RCM accounts for sub-GCM grid scale forcings, such as complex topographical features and land cover in homogeneity, in a physically-based way and thus enhances the simulations of atmospheric and climatic variables at finer spatial scales. However, the RCM is susceptible to any systematic errors in the driving fields provided by the High frequency, i.e., 6 hourly, time-dependent GCM fields are required to provide the boundary conditions for the RCM; these are generally not routinely stored by global climate modelers, and so there needs to be careful coordination between the global and regional climate modeling groups in order to ensure that the appropriate data are available. Also, RCM simulations may be computationally demanding, depending on the domain size and resolution, and this has limited the length of many experiments.

2.9 MAGICC – Calculating Global Climate Change

MAGICC - Model for the Assessment of Greenhouse-gas Induced Climate Change – is a set of linked simple models that, collectively, fall in the genre of a Simple Climate Model as defined by. MAGICC is not a GCM, but it uses a series of reduced-form models to emulate the behavior of fully three-dimensional, dynamic GCMs. MAGICC calculates the annual-mean global surface air temperature and global-mean sea-level implications of emissions scenarios for greenhouse gases and sulphur dioxide. Users are able to choose which emissions scenarios to use, or to define their own, and also to alter a number of model parameters to explore uncertainty. The model has been widely used by the IPCC in their various assessments. MAGICC can be used on its own with no loss of function, but has also been designed to be used in conjunction with SCENGEN.

2.10 SCENGEN – Portraying Regional Climate Change

SCENGEN – a global and regional SCENario GENerator – is not a climate model; rather it is a simple database that contains the results of a large number of GCM experiments, as well as an observed global and four regional climate data sets. These various data fields are manipulated by SCENGEN, using the information about the rate and magnitude of global warming supplied by MAGICC and directed by the user's choice of important climate scenario characteristics. SCENGEN has been developed over a number of years to operate in conjunction with MAGICC, but can be used on its own in a more limited function. SCENGEN has not been officially used by the IPCC, but nearly all of the data sets used by SCENGEN – GCMs and observations – have been used or assessed in different IPCC assessments including the Third Assessment Report due to be published in 2001

2.11 Effect of Climate Change on Hydrologic Regime of Two Climatically Different Watersheds

Hydrologic modeling of the responses of two watersheds to climate change is presented. The watersheds are the Upper Campbell and the Illecillewaet watersheds located in British Columbia. The First is a maritime watershed located in the eastern slopes of the Vancouver Island Mountains; the second is located in the Selkirk Mountains in Eastern British Columbia. The Canadian Climate Centre General Circulation model has been used for the prediction of potential effects of climate change on meteorological parameters. In addition to the changes in the amounts of precipitation and temperature usually assumed in hydrologic climate change studies, other meteorological and climatic parameters also considered are the effect of climate on the spatial distribution of precipitation with elevation, as well as on cloud cover, glaciers, vegetation distribution, vegetation biomass production, and plant physiology. The result showed that the mean annual temperature in the two watersheds could increase by more than 3°C and the annual basin wide precipitation could increase 7.5 % in the Upper Campbell watershed and by about 17% in the Illecillewaet watershed. The higher temperatures changed some snowfall to rainfall and the extra precipitation was mainly in the form of rain. The increase of the CO_2 concentration caused stomata closure that reduced evapotranspiration. This effect was compensated by increased biomass in the Upper Campbell watershed, but not in the Illecillewaet watershed. These changes produced higher flows in winter and smaller flows in summer. The largest change in the hydrograph shape was in the Illecillewaet watershed where the mean annual maximum daily flow decreased by about 13% and its frequency was reduced. On the other hand, the mean annual runoff increased by 21%. In contrast, although the shape of the simulated annual hydrograph of the Upper Campbell watershed was not affected, magnitude and frequency of the annual maximum precipitation increased. Also, the mean annual runoff in the Upper Campbell watershed increased by 7.5%. These results indicate that different management procedures may be needed to minimize the effects of climate change on the water resources of the two climatically different watersheds and the regions that they represent (Loukas and Quick, 1996)

2.12 The Effects of Desiccation and Climatic Change on the Hydrology of the Aral Sea

Anthropogenic desiccation of the Aral Sea between 1960 and the mid-1990s resulted in a substantial modification of the land surface that changed air temperature in the surrounding region. During the desiccation interval, the net annual rate of precipitation minus evaporation (*P* – *E*) over the Aral Sea's surface became more negative by -15%, with the greatest changes occurring during the summer months. In addition, Aral Sea surface temperatures (SST) increased by up to 5°C in the spring and summer and decreased by up to 4°C in the fall and winter. A series of coupled regional climate–lake model experiments were completed to evaluate if the observed hydrologic changes are caused by desiccation or instead reflect larger-scale climatic variability or change, or some combination of both. If the $P - E$ changes are the result of desiccation, then a positive feedback exists that has amplified the anthropogenic perturbation to the hydrologic system.

The effects of desiccation are examined by varying the simulated area, depth, and salinity of the Aral Sea in different model experiments. The simulated changes in SST resulting from desiccation are similar to the observed changes – both simulated and observed SSTs have increased during the spring and summer and have decreased during the fall and winter. The simulated changes in the annual cycle of $P - E$ resulting from desiccation are also similar to observed changes, but the simulated net annual decrease in $P - E$ is only -30% of the observed decrease. Warming has been observed across central Asia during the desiccation interval. The hydrologic response to this large-scale climatic variability or change was assessed by perturbing the meteorological boundary conditions (1.5°C cooling with constant relative humidity) but leaving the Aral Sea characteristics unchanged.

The simulated effects of warming do not closely match the observed changes on the monthly timescale—SST changes are positive and the $P - E$ changes are negative in all months. However, the annual change in $P - E$ is similar to the observed value. The simulated hydrologic response to the combined effects of desiccation and warming matches the observed SST and $P - E$ changes more closely than the response to each forcing alone. This result indicates that a combination of both desiccation and climatic change or variability has produced the observed hydrological changes – the primary effect of desiccation is to alter the annual cycle of SST and $P - E$ whereas warming has modified the hydrologic budget on the annual timescale (E Small et al, 2001)

2.13 Relationship Between the Indian Summer Monsoon and River Flow in the Aral Sea Basin

There is a significant contemporaneous relationship between summer runoff in the Amudarya and Zeravshan rivers and the intensity of the Indian summer monsoon. No such relationship exists for the Syrdarya.

This statistical relationship explains about 10% of the total runoff variability. This figure may seem rather small, but is not negligible when comparing it to other sources of discharge variability such as human interference in terms of water storage or irrigation. While the focus of this paper is a better understanding of the natural climate variability in Central Asia, it is conceivable that the link we describe can be applied in order to add further skill to seasonal forecasts of summer runoff.

It showed that the dominant physical link between Amudarya runoff and ISM intensity is not spillover precipitation due to the direct advancement of moist monsoon air masses into the Central Asian Mountains, but rather the response of tropospheric temperatures to changes in monsoon intensity. This warming effect has been attributed previously to the propagation of Rossby wave trains excited by condensational heating during monsoon rains. There are interesting differences between the regional impact of a Rossby wave response between winter and summer and between precipitation and runoff: The wintertime response over Central Southwest Asia to a tropically-induced Rossby wave packet appears to be a suppression of precipitation via thermally-forced subsidence. In the current summer analysis, the effect of the wave packet appears to be mainly via the associated temperature anomaly, and results in enhanced river flows.

It remains an issue of future research to investigate the monsoon-runoff relationship on other scales of space and time: Arguably, it is more important for smaller high-altitude river basins than for the Amudarya basin as a whole. Also, it would be instructive to find out if the intraseasonal variability in runoff can be linked to active and breaking periods of the Indian monsoon. Provided the relationship we showed to exist in present day climate has been a robust feature on temporal scales of centuries or millennia, it should be taken into consideration in studies of past climates concerned with, for instance, the evolution of the Aral Sea level or the extent of glaciation in the Central Asian Mountains (Schliemann et al, 2007).

CHAPTER 3

STUDY AREA

3.1 Location, Geomorphology, Landscape

The Aral Sea basin, which geographically coincides with almost the entire area of Central Asia, is located in the heart of the Euro-Asian continent. More specifically, the Aral Sea basin covers the whole territory of Tajikistan, Uzbekistan, the majority of Turkmenistan, three provinces of the Kyrgyz Republic (Osh, Jalalabad and Naryn), and the southern part of Kazakhstan (two provinces: Kyzyl-Orda and South Kazakh), and northern part of Afghanistan and Iran. For the purpose of this presentation, only the provinces of the first five countries within the Aral Sea Basin have been taken into consideration. This territory extends between longitudes 56° and 78° East, and latitudes 33° and 52° North, covering an area of about 1.549 million km^2, of which about 0.59 million km^2 are cultivable lands.

Table 3.1 Land resources in the Aral Sea basin

Country	Area of the country	Cultivable area	Cultivated area	Actually irrigated area
	ha	ha	ha	ha
Kazakhstan*	34 440 000	23 872 400	1 658 800	786 200
Kyrgyzstan*	12 490 000	1 257 400	595 000	422 000
Tajikistan	14 310 000	1 571 000	769 900	719 000
Turkmenistan	48 810 000	7 013 000	1 805 300	1 735 000
Uzbekistan	44 884 000	25 447 700	5 207 800	4 233 400
The Aral Sea basin	154 934 000	59 161 500	10 036 800	7 895 600
* only provinces in the Aral Sea basin are included				

The territory of the Aral Sea Basin can be divided into two main zones: the Turan plain and the mountain zone. The Kara Kum covers the western and the northwestern parts of the Aral Sea Basin within the Turan plain and Kyzyl Kum deserts. The eastern and south-eastern parts are situated in the high mountain area of the Tien Shan and Pamir ranges. The remaining part of the basin is composed of various types of alluvial and inter-mountain valleys, dry and semi-dry steppe. Different forms of relief in all the countries have created specific conditions, which are reflected by the interrelation between water, land and populated area within the region. About 90% of the territory of the Kyrgyz Republic and Tajikistan are occupied by mountains. This, on the one hand, creates for these two countries a "monopoly" on the formation of water within the basin and, on the other hand, a deficit of cultivable lands. The most important feature of the region is the number of oasis's (Fergana Valley, Khorezm, Tashaus, Mary, Zeravshan, Tashkent – Chimkent), which cover a small part of the overall area, but since ancient times have been the focus of human activity and population due to the presence of acceptable living conditions (water, precipitation, the best soils, etc).

The majority of the territory of Kazakhstan, Turkmenistan and Uzbekistan are covered by desert (more than 50%), and only less than 10% is represents by mountains. Such distribution of area has created a huge potential for the development of irrigation, which requires more water resources than those countries have available. This unequal allocation of water and land were seen in Soviet times as an opportunity to re-allocate the water resources for the development of newly irrigated area in lowland republics. However, in the current post Soviet period these circumstances have been transformed into a source of potential future conflicts.

3.2 Climate

The landlocked position of Central Asia within the Euro-Asian continent determines its sharply continental climate, with low and irregular precipitation. Large daily and seasonal temperature differences are characteristic of the region, with high solar radiation and relatively low humidity. Diverse terrain and altitude differences from 0 to 7,500 m above sea level lead to a great diversity of microclimate. Mountains are located in the east and southeast, which are the center for the formation of water and the origin of its flow. Although this area is often struck by humid winds, the mountains trap most of the moisture, leaving little precipitation for the other areas of the Aral Sea Basin.

The average July temperature on the lower elevations, in valley areas and desert, deviates from 26°C in the north to 30°C in the south, with maximum temperature up to 45-50°C. The average January temperature records are up to 0°C in the south to -8°C in the north with absolute minimum up to -38°C. The annual precipitation in the lowland and valleys is between 80-200 mm, concentrated in the winter and spring, while in the foothills precipitation is between 300-400 mm, and on the southern and south-western sides of the mountain ranges between 600-800 mm.

Climate in the region has specific zones of variation accordingly to geographic and geomorphologic conditions, which define the difference in water demands for irrigation. Big differences in air humidity in summer time between the old oasis's and newly irrigated area (50-60% and 20-30%) cause significantly larger water demands in former desert (now under irrigation) in comparison with oasis's. The second factor especially affecting agricultural production is the instability of spring weather, which deviates in temperature, precipitation and even late frosts (sometimes in the beginning of May) and hail (in June, which sometimes destroys emerging cotton plants and vegetables over big areas).

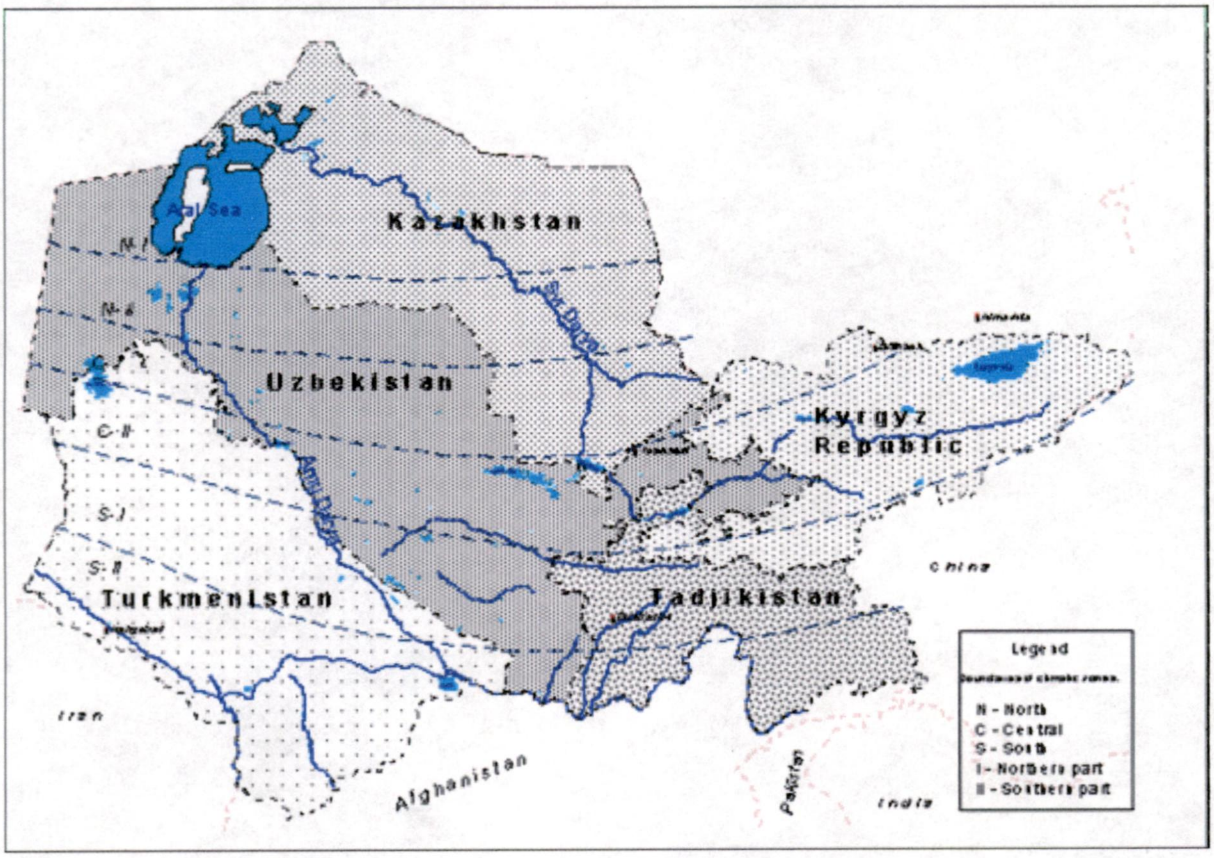


Figure 3.1 Scheme of the Climatic Zones in the Aral Sea basin

Table 3.2 Characteristics of the Climatic Zones

Climatic Zones	Evaporation, m^3/ha	Precipitation, m^3/ha	Average temperature, °C	
			January	July
N-I	400	500 ... >3000	- 7.39	27.61
N-II	600	500 ... >3000	- 4.58	28.27
C-I	1000	600 ... >3000	-0.94	29.0
C-II	1200	700 ... >3000	0.59	26.57
S-I	1400	900 ... >3000	2.86	29.21
S-II	1600	1000 ... >3000	2.29	29.5

3.3 Water resources of the Aral Sea basin

The water resources in the Aral Sea region consist of renewable surface and groundwater, as well as return water from anthropogenic use (wastewater and drainage water). There are two major river basins located in the Aral Sea Basin: the Syrdarya in the north, and the Amudarya in the south. The Zeravshan River, a former tributary of the Amudarya, has a position between these two major rivers.

3.3.1 Formation of the surface flow

A feature of the region is the division of its territory into three main zones of surface runoff: (a) the zone of flow formation (upper watersheds in the mountain areas),

(b) the zone of flow transit and its dissipation,

(c) the delta zones.

As a rule, there is not a significant level of anthropogenic changes in the zone of flow formation, but due to construction of big dams and water reservoirs on the border of this zone, the downstream run-off regime is changing significantly. Within the zone of flow transit and dissipation the run-off and the whole hydrological cycle are changing in consequence of interaction between rivers and territory. This interaction is characterizing by water withdrawal from river to the irrigated areas and the loading of return flow to the river with salt and agricultural chemicals.

In terms of water availability the Syrdarya is the second most important river in Central Asia but the largest in terms of length. From the Naryn headwaters its length is 3019 km, with a catchment area of 219 thousands km^2. Its headwaters lie in the Central (Interior) Tien-Shan Mountains. The river is known as the Syrdarya after the point where the Naryn joins with the Karadarya. The river has glacial and snow feeding, with a prevalence of the latter. The water regime is characterized by a spring-summer flood, which begins in April. The largest discharge is in June. About 75.2% of the Syrdarya run-off originates in the Kyrgyz Republic. The Syrdarya then flows across Uzbekistan and Tajikistan and discharges into the Aral Sea in Kazakhstan. About 15.2% of the flow of the Syrdarya is formed in Uzbekistan, about 6.9% in Kazakhstan, and about 2.7% in Tajikistan.

The Amudarya is the biggest river in Central Asia. Its length from the headwaters of the Pyandzh to the Aral Sea is 2540 km, with a catchment area of 309 thousands km^2. It is called Amudarya from the point where the Pyandzh joins with the Vaksh. Three large right tributaries (Kafirnigan, Surhandarya and Sherabad) and one left (Kunduz) flow into the Amudarya River within the middle reach. Further downstream towards the Aral Sea it has no tributaries. It is fed largely by water from melted snow, thus maximum discharges are observed in summer and minimum ones in January-February. Such availability of the flow within a year is very favorable to the use of the river water for irrigation. While crossing the plain, from Kerky to Nukus, the Amudarya loses the majority of its flow through evaporation, infiltration and withdrawal for irrigation. In terms of sediment the Amudarya carries the highest load of all the rivers in Central Asia and one of the highest levels in the world. The main flow of the Amudarya River originates on the territory of Tajikistan (about 74 %). The river then flows along the border between Afghanistan and Uzbekistan, across Turkmenistan territory and then again returns to Uzbekistan where it discharges into the Aral Sea. About 13.9% of Amudarya water is formed on Afghan territory and in Iran. About 8.5% of the Amudarya flow is formed in Uzbekistan.

The total mean annual flow of all rivers in the Aral Sea Basin is estimated as about 116 km^3. This amount comprises the flow of the Amudarya at 79.4 km^3/year and the Syrdarya at 36.6 km^3/year. In accordance with flow probabilities of 5% (high wet years) and 95% (dry years), the annual flow ranges from 109.9 to 58.6 km^3 for the Amudarya river, and from 51.1 to 23.6 km^3 for the Syrdarya river, respectively.

3.3.2 Surface water resources quality

Along the two rivers, the many intakes, which serve the major irrigation schemes, continuously reduce the volume of the remaining run-off in the rivers and inflow into the

Aral Sea. As flow has diminished, the quality of the remaining water has worsened because of the discharges of saline and polluted drain effluent from irrigated areas and the residues of agro-chemicals, which leach into the drainage systems and mix with the waters of the rivers. Besides this non-point source pollution from agriculture, consisting of salt and agro-chemical residues, there is also point-source pollution from industrial and municipal wastes, especially from metropolitan areas.

Table 3.3 Surface water resources in the Aral Sea basin (mean annual runoff, km^3/year)

Country	River Basin		Total Aral Sea Basin	
	Syrdarya	Amudarya	km^3	%
Kazakhstan	2.516	—	2.516	2.2
Kyrgyzstan	27.542	1.654	29.196	25.2
Tajikistan	1.005	58.732	59.737	51.5
Turkmenistan	—	1.405	1.405	1.2
Uzbekistan	5.562	6.791	12.353	10.6
Afghanistan and Iran	—	10.814	10.814	9.3
Total Aral Sea basin	36.625	79.396	116.021	100

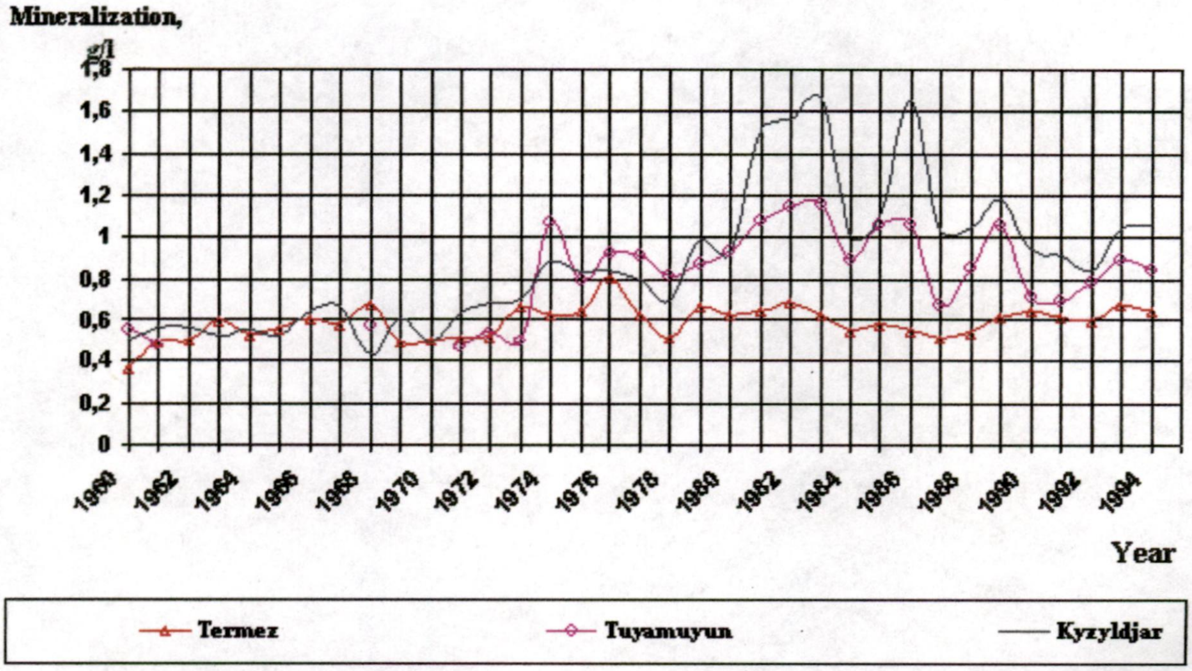
The trend of the river water quality with respect to salinity is negative. The salinity level increases in time and along the river, especially in the middle and lower reaches of the river. At the end of the 1960s the mineralization of water did not exceed 1.0 g/l, even in the lower reaches. Now it varies from 0.3-0.5 g/l in the upper reaches to 1.7-2.0 g/l in the lower reaches. The highest values occur in March and April in the upper reaches, and around May in the lower reaches. An explanation for these differences could be the leaching procedures on the irrigated areas. Apart from the salinity levels, given in g/l, the chemical composition of the river water determines its suitability for irrigation. The value often used to express the risk of developing alkalinity is the SAR (Sodium Adsorption Ratio), which is expressed in meq/l0.5. An analysis of available data showed that the SAR normally ranges from 0.5-7 meq/l0.5 at most gauging stations. These values indicate that, in general, the water is still suitable for irrigation. It is necessary to mention that during last few years the river water quality has stabilized due to reduction of effluent disposal.

During the years since independence from the Soviet Union there has been implemented a strict limitation of water allocation between the countries and increasing attention to ecological aspects. This has led to some improvement of water quality. It can be seen from the Figure 3.2 that water mineralization in the low reaches of the Amudarya has reduced and has not exceed the permitted limit (1.0 g/l).

3.3.3 Lakes and depressions

There are many natural lakes in the mountainous areas and ravines of Central Asia. The mountain lakes are of various origins. The majority of large lakes occupy basins which are the result of tectonic activity (Issuk-Kul, Song-Kel, Chetir-Kel, Karakul, and Sarichelek). Lakes originating from landslides due to earthquakes are the Sarez and Yashinkul in the Pamir mountains. Numerous lakes are of glacial origin; one of the largest is the Zorkul, located at 4125 m in the Eastern Pamir.

Figure 3.2 Variations of water mineralization along the Amudarya River



In the mountains, lakes are usually freshwater or slightly saline, depending on the quality of in-flowing water. The lake regime of the region requires further study.

The majority of lakes located in the lowlands owe their origin to the erosion-accumulation activity of rivers in an arid climate. Generally, lowland lakes are shallow with low shores and have heavy vegetation of reeds and rushes. They are often surrounded by saline soil (solonchak) and sand. Given enough precipitation, many of these lakes would turn into temporarily running waters, which would leave behind dry river beds over time. Lowland lakes may be either saline or freshwater. Initial assessments of freshwater reserves in mountain and lowland lakes suggest a volume of 60 km^3.

Due to the outflow of drainage waters to closed basins (no outlet); many human-induced lakes have come into existence. Most of these are shallow; however, Lake Sarikamish (at the lower reaches of the Amudarya) and Arnasay (at the middle reach of the Syrdarya) are the largest human-induced lakes in the region. Due to the limited capacity of the river channel of the Syrdarya below the Chardara reservoir (on the border between Kazakhstan and Uzbekistan), excess volumes of water are discharged into the Lake Arnasay during high water years. In the last few years, this practice has been common also in winter as a result of the energy releases from the Naryn-Syrdarya hydropower cascade. Estimates put the volume of water resources in human-induced lakes at 40 km^3. However, making use of these waters would require considerable pumping. Also, the waters are highly mineralized. The best future use of these waters may be for fishery and biodiversity conservation. (Interstate Coordination Water Commission, 2005)

CHAPTER 4

EMPIRICAL – STATISTICAL METHOD BASED ON DEPENDECIES BETWEEN GLOBAL TEMPERATURE AND REGIONAL CLIMATIC CHARACTERISTICS

4.1. Methodical Background

IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations with a Summary for Policy Makers and a Technical Summary (IPCCTG) (Carter et al, 1994) for assessment of climate changes effect in accordance with GHG emission scenarios offers to use system of models MAGICC (Model for Assessment of Greenhouse Gas Impact and Climate Change), within which framework information about regional structure of climate change is integrated. It is obtained on GCM with output of number of simple models, which allow defining global temperature response for given suppositions about potential GHG concentrations. MAGICC includes, according to IPCC materials, all presently available scientific knowledge, including data about payback of CO_2 enrichment as well as negative effects of sulfate aerosols and stratosphere ozone concentration reduction. In MAGICC scales of emissions are transformed to concentration parameters in atmosphere by means of gas behavior models, total radiation effect is calculated, which is introduced in simple climate model. This allows obtaining global assessments of average annual temperature. And although, as it is pointed in IPCCTG, one of serious MAGICC disadvantages is inability to account processes specific for one or other region, by means of this model the most plausible, on IPCC opinion, assessments of average annual global air temperature for six emission scenarios were obtained.

Initial data for climatic changes assessment over Uzbekistan and adjacent mountainous area were: global temperature changes on MAGICC under high climate sensitivity, given in IPCCTG and data of instrumental observations of air temperature and rainfalls on support stations.

Study of climate dynamics in Uzbekistan (I.S Kim, 1996) showed that thermal regime change in the republic proceeds analogously global changes. Important statistical dependence is determined between values of average annual air temperature over stations and rayons of Uzbekistan and adjacent mountainous area with global temperature (Nikulina and Spektorman, 1992). Correlation coefficients vary within from 0.56-0.58 in northern areas of Uzbekistan (Chimbay, Khiva) to 0.35-0.40 in southern areas (Denau, Guzar), i.e. statistical dependence significant at 1% level is noted. On data of mountain stations correlation coefficients turned out to be somewhat higher, but also statistically significant at 5% level.

At Fig. 4.1 comparison of observed global and regional trends is given. Warming of 30-ties and cooling of 60-ties can be clearly seen in temporal range of average annual air temperature changes over Uzbekistan.

With regard to above said to assess potential climate changes of Uzbekistan as response for processing global warming approach based on determination of statistical dependencies between observed climatic characteristics in local and global scales can be used.

Any anthropogenic impact on climate is reflected on background "noise" of natural climatic variability related both to internal fluctuations and external factors impact, such as change of solar intensity, orbital parameters of the Earth, volcanic eruption etc.

Studies conducted on forecast and analysis of available climate changes in Central Asia provided revealing of number of cyclical fluctuations in temporal series of air temperature (Muминova and Inagamova, 1995). In changes of average annual air temperature, average air temperature for cold and warm half-years on the background of existing trends to warming quasi 22-year cyclicity was found, i.e. cyclicity close to so called Hale's cycle of geomagnetic activity related to magnetic polarity of solar spots. Given cyclicity describes appropriately 24, 19 and 12% of initial series disperse. Account of natural cyclicities and tendencies will provide reduction of uncertainty of climate change assessments for the future.

On basis of analysis conducted for assessment of future changes of average climatic characteristics values of Uzbekistan and adjacent mountainous area following methodic is used:

- determination of statistical dependencies between climatic characteristics in local and global scales

- use of model global temperature assessments as future global climate forecasts for different IPCC emission scenarios.

- use of existing in series climatic characteristics of Uzbekistan quasi-cyclicities and tendencies to reduce uncertainty, correct scenarios and assessment of possible course of researched values.

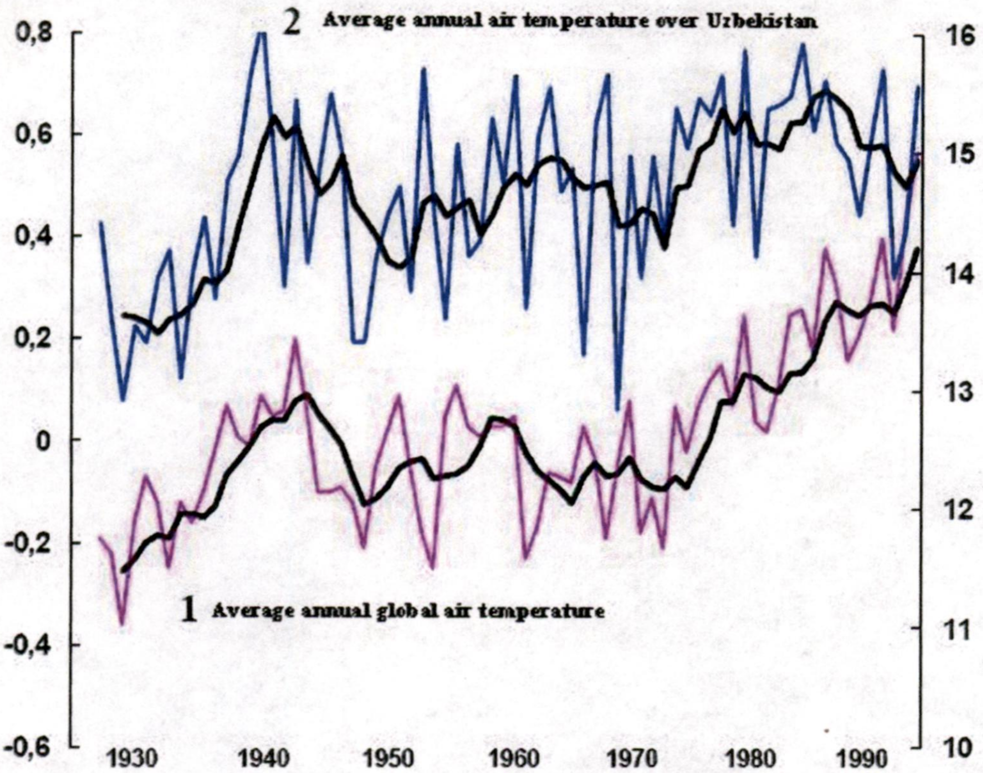


Fig. 4.1 | Changes of anomaly of average annual global air temperature (1) and average annual air temperature over Uzbekistan (2) stations

4.2. Assessment of Air Temperature Changes

Calculated according to proposed model assessments of temporal course of temperature changes on specific stations were integrated in groups according to values of changes themselves. By averaging for each season sets of values were obtained, which characterize model forecast of temperature changes within 2000-2002 years under assuming high climate sensitivity. Each set shown in Fig .4.2 characterizes physical-geographical regions according (Balashova et al, 1960).

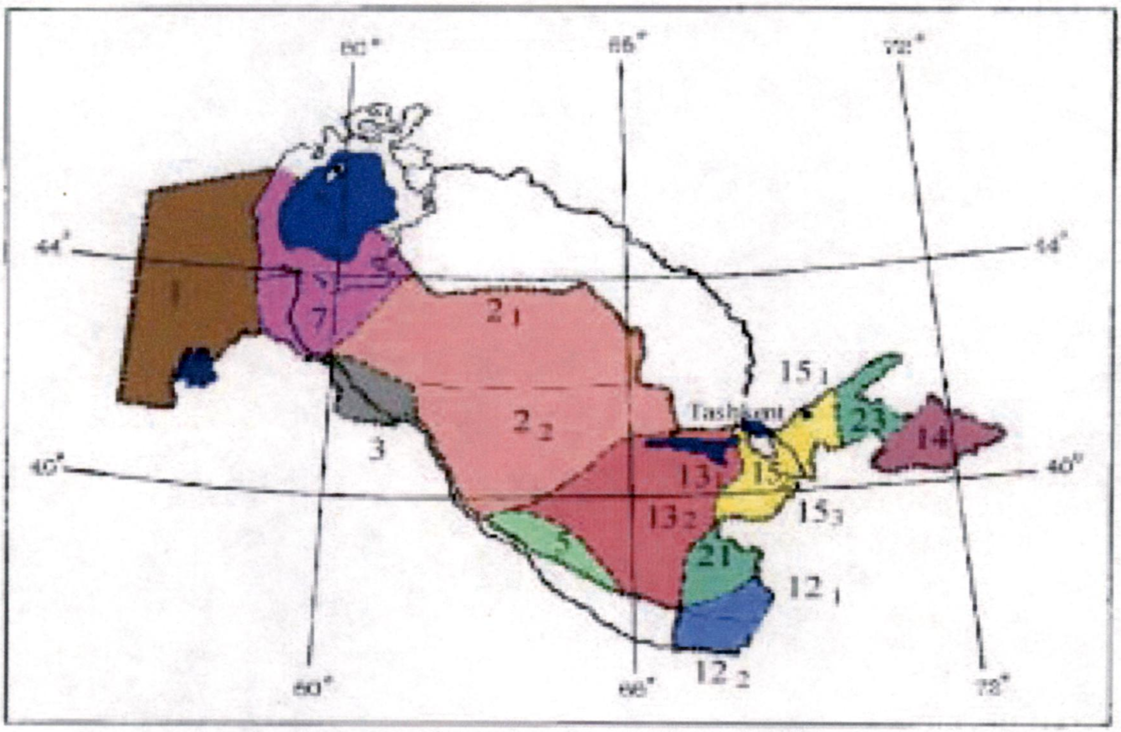


Fig. 4.2 | Location of climatic regions

After procedure of spatial-temporal averaging regional climatic scenarios for Uzbekistan were created. Twenty-year cyclicity under temperature change is significantly smoothed. Temporal course of average annual temperatures in accordance with emission scenarios IS92a and IS92b for various rayons of Uzbekistan is presented at Fig. 4.3.

In Tables 4.1 – 4.5 assessments of potential changes of average annual air temperature and average temperatures over seasons, obtained with assuming that above pointed GHG emission scenarios, integrated in couple: IS92c and IS92d (characterizes minimal emissions), IS92a and IS92b (characterizes medium emissions), IS92e and IS92f (characterizes maximal emissions) are given. In further integrated scenarios will be called cd, ab, and ef.

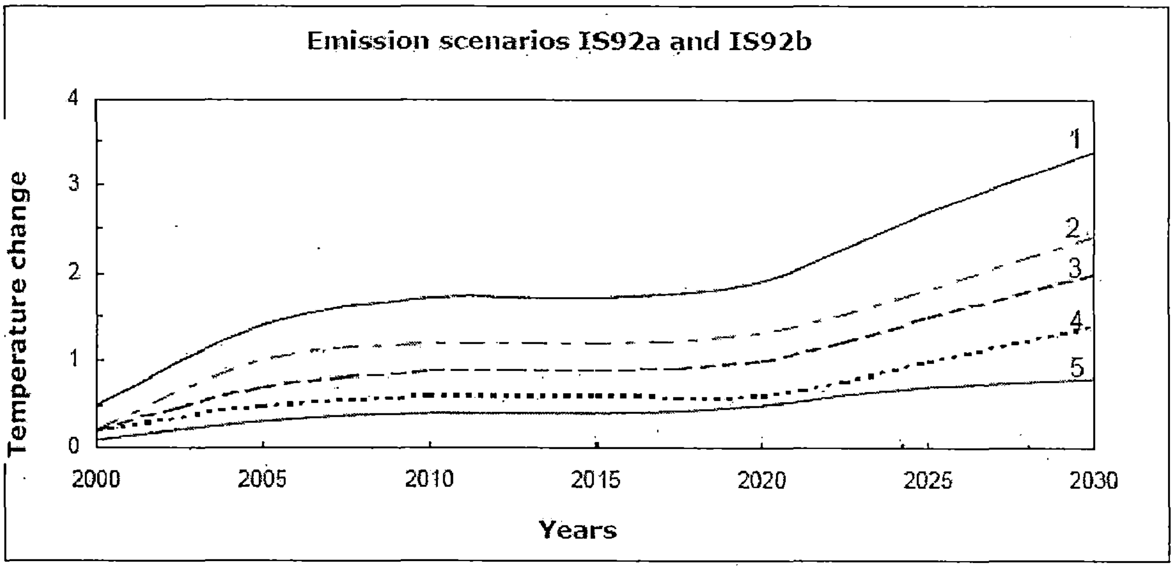


Fig. 4.3 | Assessments of potential changes of average annual air temperature anomalies for selected groups of regions

1 - climatic regions 1, 7; 2 - climatic regions 2, 3, 12, 13, 14 и 15;
3 - large depressions of Tyan-Shan and Pamir-Alay; 4 - climatic regions 5, 23;
5 - climatic regions 21 and Pamir

Outside Uzbekistan, in south mountain regions of Central Asia (Gorbunov's station, Karakul Lake, Khorog Lake), expected warming does not exceed in summer 0.5°C, in winter 1°C. In high mountain vast depressions of Tyan-Shan and Pamir-Alay (Naryn, Sary-Tash) in summer temperature reaches 1°C, in winter - 2°C. On average during the year warming values in given region do not exceed 1°C.

4.3. Assessment of precipitation changes

Atmosphere warming leads to its humidity increase and water vapor transportation increase to high latitudes. In result of CO_2 content increase all models give average global precipitation increase. On model assessments precipitation increases in high latitudes in winter, mostly precipitation increase covers middle latitudes as well. However some models for specific regions give even some decrease of precipitation.

Model assessments of regional precipitation changes for moment of CO_2 doubling are within -20% - +20% of control value. For many regions there is no even agreement in sign of model changes assessments. Under including in model aerosol impact calculations show less values of global rainfalls. Precipitation increase weakens in zone of Asian monsoon, because negative aerosol impact reduces contrasts of system ocean-land and weakens monsoon circulation as well.

As potential precipitation changes scenario in Central Asia in given paper expert assessment is used, based on numerous model calculations, available regional climatic tendencies in precipitation regime and above mentioned empirical-statistical method, which takes into account response of regional climate changes for proceeding global warming.

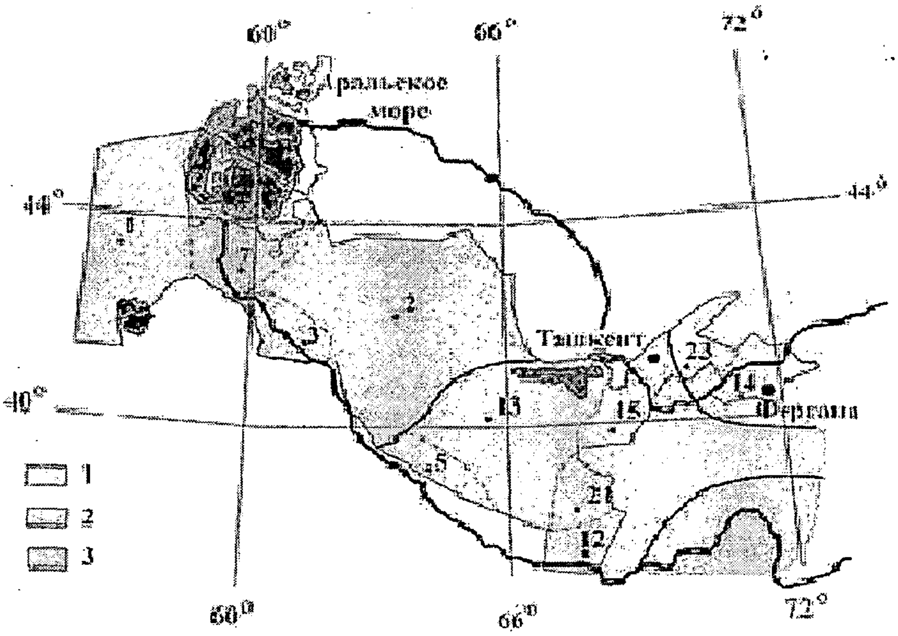


Fig. 4.4 | Variation (%) of total precipitation sums by 2030 in Uzbekistan and adjacent mountain area against 1961-1990 years

for emission scenarios cd: **1** - 100-105%; **2** - 105-110%; **3** - 110-115%;
for emission scenarios ab: **1** - 105-110%; **2** - 110-115%; **3** - 115-120%;
for emission scenarios ef: **1** - 110-115%; **2** - 115-120%; **3** - 120-125%.

To create precipitation regime scenario for Uzbekistan and adjacent mountain area linear trends are distinguished in temporal series of total precipitation sums over support stations, and assessments were calculated for its potential changes with account for response for global warming under realization of different GHG emission scenarios. Analysis of obtained result showed that linear tendencies extrapolated by 2030 correspond to designed precipitation values for emission scenarios IS92c and IS92d (cd) under assuming low climate sensitivity. Therefore values obtained by means of these two approaches are taken as minimal assessment values by 2030. When realizing rest emission scenarios additional precipitation increase is expected that corresponds to global model assessments. So these assessments of potential total precipitation sums regime changes of researched region for different GHG emission scenarios are given at Figure 4.4.

Given work presents amplification of climatic scenarios for stations located in flow use and formation zone. In Tables 4.6-4.9 potential changes of climatic characteristics (air temperature and precipitation) are given on stations in annual and seasonal temporal scales.

different GHG emission scenarios (IS92a -IS92f)

Number and name of climatic region	Administrative area	Basic period scenario	Regional climatic scenario II for 2015-2030 years			Regional climatic scenario I for 2020-2050 years		
			ab	cd	ef	ab	cd	ef
1. Ustyurt	Karakalpakstan	9.0	1.5	1.0	2.0	2.5	2.0	2.3
7. Priaralie	Karakalpakstan	10.0	2.5	2.0	3.0	3.0	2.1	3.6
2. Kyzyl Kum,	Navoy							
North (2_1)		11.8	1.0	1.0	1.5	1.7	1.4	2.5
Central (2_2)		13.8	2.0	1.0	2.0	1.2	0.8	1.2
3. Amudarya lower reaches	Khorezm	12.3	2.0	1.5	2.5	1.7	1.2	1.9
5. South-east Karakum	Bukhara	13.8	1.0	1.0	1.5	1.7	1.3	1.8
12. Upper -Amudarya	Surkhan-Darya							
South (12_2)		17.4	1.0	1.0	1.5	0.6	0.5	0.8
North (12_1)		16.8	1.0	1.0	1.5	1.2	1.0	2.3
13. Zerafshano-Kashkadarya								
Zeravshan (13_1)	Samarqand	13.8	1.5	1.0	2.0	1.8	1.1	2.1
Kashakadarya (13_2)	Kashakadarya	15.7	1.5	1.0	2.0	2.1	1.2	2.5
14. Fergana	Fergana Namangan Andizhan	13.3	1.5	1.0	2.0	2.8	2.2	2.9
15. Tashkent-Golodnostep	Tashkent							
Tashkent (15_1)		14.2	2.0	1.0	1.5	2.0	1.4	3.0
Golodnostep (15_2)	Jizak	14.4	1.0	1.0	1.5	1.2	1.0	1.8
Jizak (15_3)		13.0	1.0	1.0	1.5	1.2	1.0	1.8
21. South Tyan-Shan	Surkhan-Darya							
1000-2000 m b. s. l (21_1)		9.6	1.0	0.5	1.0	0.5	0.3	0.5
2100-3000 m b. s. l (21_2)		5.2	1.0	0.5	1.0	0.5	0.3	0.5
23. West Tyan-Shan	Tashkent							
1000-1500m b. s. l (23_1)		9.5	1.0	0.5	1.0	0.6	0.4	0.7
1600-2100m b. s. l (23_2)		2.8	1.0	0.5	1.0	0.9	0.6	1.1

Table 4.2 | Assessment of average winter air temperature changes (December-February) over climatic regions of Uzbekistan under realizing different GHG emission scenarios (IS92a -IS92f)

Number and name of climatic region	Administrative area	Basic period scenario	Regional climatic scenario II for 2015-2030 years			Regional climatic scenario I for 2020-2050 years		
			ab	cd	ef	ab	cd	ef
1. Ustyurt	Karakalpakstan	-6.3	1.5	1.0	2.0	2.0	1.6	2.6
7. Priaralie	Karakalpakstan	-4.3	2.0	1.5	2.5	2.8	2.2	3.6
2. Kyzyl Kum,	Navoy							
North (2_1)		-4.0	3.0	1.5	2.5	2.5	2.0	3.2
Central (2_2)		-0.7	2.5	2.0	2.5	2.7	2.1	3.5
4. Amudarya lower reaches	Khorezm	-1.5	2.0	1.5	2.5	2.5	2.0	3.2
6. South-east Karakum	Bukhara	2.8	2.0	1.5	2.5	1.9	1.5	2.4
12. Upper -Amudarya	Surkhan-Darya							
South (12_2)		5.6	1.0	1.0	1.5	0.9	0.7	1.2
North (12_1)		4.7	1.0	1.0	1.5	1.5	1.2	1.9
13. Zerafshano-Kashkadarya								
Zeravshan (13_1)	Samarqand	1.4	2.0	1.5	2.0	1.0	0.8	1.3
Kashakadarya (13_2)	Kashakadarya	3.7	2.0	1.5	2.5	1.2	1.0	1.6
14. Fergana	Fergana Namangan Andizhan	0.3	3.0	2.5	3.5	1.5	1.2	1.9
15. Tashkent-Golodnostep	Tashkent							
Tashkent (15_1)		1.8	2.5	2.0	3.0	1.7	1.4	2.2
Golodnostep (15_2)	Jizak	1.5	3.0	2.0	3.5	1.5	1.2	2.9
Jizak (15_3)		0.4	2.0	1.5	2.5	1.2	1.0	1.6
21. South Tyan-Shan	Surkhan-Darya							
1000-2000m b. s. l. (21_1)		-1.0	1.0	0.5	1.0	0.9	0.7	1.2
2100-3000m b. s. l. (21_2)		-4.5	1.0	0.5	1.0	0.3	0.2	0.4
23. West Tyan-Shan	Tashkent							
1000-1500m b. s. l. (23_1)		-2.2	1.5	0.5	2.0	0.6	0.5	0.8
1600-2100m b. s. l. (23_2)		-10.8	1.5	0.5	2.0	0.9	0.7	1.2

Table 4.3 | Assessment of average spring air temperature changes (March-May) over climatic regions of Uzbekistan under realizing different GHG emission scenarios (IS92a -IS92f)

Number and name of climatic region	Administrative area	Basic period scenario	Regional climatic scenario II for 2015-2030 years			Regional climatic scenario I for 2020-2050 years		
			ab	cd	ef	ab	cd	ef
1. Ustyurt	Karakalpakstan	9.8	1.0	1.0	1.5	1.0	0.8	1.3
7. Priaralie	Karakalpakstan	10.5	1.0	1.0	1.0	0.9	0.7	0.9
2. Kyzyl Kum,	Navoy							
North (2_1)		12.0	0.0	0.0	0.0	1.3	1.0	1.7
Central (2_2)		14.6	1.0	0.5	1.0	0.6	0.5	0.8
5. Amudarya lower reaches	Khorezm	14.0	0.5	0.5	1.0	0.2	0.1	0.1
7. South-east Karakum	Bukhara	16.5	1.0	0.5	1.0	0.2	0.1	0.1
12. Upper -Amudarya	Surkhan-Darya							
South (12_2)		18.0	0.5	0.0	0.5	0.5	0.5	0.6
North (12_1)		18.2	0.5	0.0	0.5	0.4	0.3	0.4
13. Zerafshano-Kashkadarya								
Zeravshan (13_1)	Samarqand	14.2	0.0	0.0	1.0	1.0	0.8	1.0
Kashakadarya (13_2)	Kashakadarya	16.4	1.0	0.5	2.0	1.4	1.1	1.8
14. Fergana	Fergana Namangan Andizhan	14.9	0.5	0.5	1.0	0.8	0.6	0.8
15. Tashkent-Golodnostep	Tashkent							
Tashkent (15_1)		14.5	1.0	0.5	1.5	0.4	0.3	0.4
Golodnostep (15_2)	Jizak	15.6	0.5	0.0	0.5	0.3	0.22	0.2
Jizak (15_3)		13.6	0.0	0.0	0.0	0.4	0.3	0.4
21. South Tyan-Shan	Surkhan-Darya							
1000-2000m b. s. l. (21_1)		8.0	0.5	0.0	0.5	0.6	0.5	0.6
2100-3000m b. s. l. (21_2)		4.0	0.5	0.0	0.5	0.2	0.3	0.4
23. West Tyan-Shan								
1000-1500m b. s. l. (23_1)	Tashkent	9.0	0.0	0.0	0.0	0.5	0.4	0.5
1600-2100m b. s. l. (23_2)		3.3	0.0	0.0	0.0	0.5	0.4	0.5

Table 4.4 | Assessment of average summer air temperature changes (July-August) over climatic regions of Uzbekistan under realizing different GHG emission scenarios (IS92a -IS92f)

Number and name of climatic region	Administrative area	Basic period scenario	Regional climatic scenario II for 2015-2030 years			Regional climatic scenario I for 2020-2050 years		
			ab	cd	ef	ab	cd	ef
1. Ustyurt	Karakalpakstan	25.0	2.0	1.5	2.5	1.8	1.0	1.5
7. Priaralie	Karakalpakstan	25.6	2.5	2.0	3.0	1.6	1.2	2.1
2. Kyzyl Kum,	Navoy							
North (2_1)		27.6	2.0	1.5	2.5	0.9	0.7	1.2
Central (2_2)		28.5	2.0	1.5	2.0	1.0	0.8	1.3
6. Amudarya lower reaches	Khorezm	26.8	1.5	1.0	2.0	0.7	0.6	0.9
8. South-east Karakum	Bukhara	27.9	0.5	0.5	0.5	0.3	0.2	0.4
12. Upper -Amudarya								
South (12_2)	Surkhan-Darya	28.5	2.0	1.5	2.5	0.2	0.1	0.3
North (12_1)		29.0	2.0	1.5	2.5	0.0	0.0	0.0
13. Zerafshano-Kashkadarya								
Zeravshan (13_1)	Samarqand	26.4	2.0	2.0	2.5	1.0	0.8	1.3
Kashakadarya (13_2)	Kashakadarya	28.3	1.5	1.0	2.0	0.8	0.6	1.0
14. Fergana	Fergana Namangan Andizhan	26.2	1.0	0.5	1.3	1.0	0.8	1.3
15. Tashkent-Golodnostep	Tashkent							
Tashkent (15_1)		26.0	2.0	1.5	2.5	0.8	0.6	1.0
Golodnostep (15_2)	Jizak	26.7	1.0	1.0	1.5	0.7	0.6	0.9
Jizak (15_3)		25.2	0.0	0.0	0.0	0.2	0.2	0.2
21. South Tyan-Shan	Surkhan-Darya							
1000-2000m b. s. l. (21_1)		22.0	1.0	0.5	1.0	0.2	0.1	0.3
2100-3000m b. s. l. (21_2)		16.0	1.0	0.5	1.0	0.2	0.1	0.3
23. West Tyan-Shan	Tashkent							
1000-1500m b. s. l. (23_1)		20.8	0.0	0.0	0.0	0.3	0.2	0.4
1600-2100m b. s. l. (23_2)		15.0	0.0	0.0	0.0	0.4	0.3	0.5

Table 4.5 | Assessment of average fall air temperature changes (September-November) over climatic regions of Uzbekistan under realizing different GHG emission scenarios (IS92a -IS92f)

Number and name of climatic region	Administrative area	Basic period scenario	Regional climatic scenario II for 2015-2030 years			Regional climatic scenario I for 2020-2050 years		
			ab	cd	ef	ab	cd	ef
1. Ustyurt	Karakalpakstan	9.0	1.5	1.0	2.0	1.5	1.2	2.0
7. Priaralie	Karakalpakstan	10.7	1.0	0.5	1.5	1.3	1.0	3.9
2. Kyzyl Kum,								
North (2_1)	Navoy	11.0	1.0	0.5	1.0	0.5	0.4	0.6
Central (2_2)		13.0	1.0	0.5	1.0	1.0	0.8	1.3
7. Amudarya lower reaches	Khorezm	17.8	1.5	1.0	1.5	1.2	1.0	1.6
9. South-east Karakum	Bukhara	14.7	1.0	0.5	1.0	1.4	1.1	1.8
12. Upper-Amudarya								
South (12_2)	Surkhan-Darya	16.1	0.5	0.5	1.0	0.6	0.5	0.8
North (12_1)		16.8	0.5	0.5	1.0	0.8	0.6	1.0
13. Zerafshano-Kashkadarya								
Zeravshan (13_1)	Samarqand	13.3	1.5	1.0	1.5	0.9	0.7	1.7
Kashakadarya (13_2)	Kashakadarya	15.2	1.0	1.5	1.5	2.2	1.7	2.8
14. Fergana	Fergana Namangan Andizhan	12.8	1.5	1.0	2.0	2.0	1.6	2.6
15. Tashkent-Golodnostep								
Tashkent (15_1)	Tashkent	13.6	2.0	0.5	2.0	1.9	1.5	2.5
Golodnostep (15_2)		13.7	1.0	1.0	1.0	1.1	0.9	1.4
Jizak (15_3)	Jizak	12.8	0.5	0.5	0.5	0.7	0.7	0.7
21. South Tyan-Shan	Surkhan-Darya							
1000-2000m b. s. l. (211)		10.0	1.0	1.0	1.0	1.1	0.9	1.4
2100-3000m b. s. l. (212)		6.0	1.0	1.0	1.0	0.6	0.5	0.8
23. West Tyan-Shan								
1000-1500m b. s. l. (231)	Tashkent	10.0	1.0	1.0	1.5	0.8	0.6	1.0
1600-2100m b. s. l. (232)		3.7	1.0	1.0	1.5	1.1	0.9	1.4

Table 4.6 | Norms and potential air temperature changes by 2030 (°C) in winter and summer over stations of mountain area for different emission scenarios

Station	Climatic scenarios							
	Winter				Summer			
	Norm	IS92ab	IS92cd	IS92ef	Norm	IS92ab	IS92cd	IS92ef
Pskem	-2.3	1.3	1.1	1.4	20.8	0.1	0.1	0.1
Charvak reservoir	-0.2	1.0	1.0	1.0	23.2	0.1	0.0	0.2
Tos River mouth	-2.9	1.4	1.1	1.5	18.1	0.1	0.0	0.3
Chatkal	-12.0	2.3	1.8	2.6	16.1	0.7	0.5	0.8
Naryn	-13.3	2.0	1.2	2.4	16.5	0.7	0.4	0.8
Sary -Tash	-15.1	1.1	0.7	1.3	8.9	0.3	0.1	0.4
Tyan -Shan	-20.2	0.5	0.4	0.6	3.6	0.8	0.5	1.0
Khaydarkan	-4.0	2.2	1.6	2.4	18.0	0.0	0.0	0.1
Khujand	1.1	2.0	1.5	2.2	27.1	0.6	0.5	0.6
Gorbunov's	-16.1	1.1	0.8	1.2	2.5	0.6	0.3	0.7
Khorog	-4.8	1.3	0.8	1.5	21.5	0.1	0.0	0.2
Karakul	-15.5	1.0	0.7	1.2	7.3	0.4	0.2	0.4

Table 4.7 | Norms and potential air temperature changes by 2030 (°C) in transit seasons over station of mountain area for different emission scenarios

Station	Climatic scenarios							
	Spring				Fall			
	Norm	IS92ab	IS92cd	IS92ef	Norm	IS92ab	IS92cd	IS92ef
Pskem	9.1	0.0	0.0	0.1	10.0	0.8	0.5	1.0
Charvak reservoir	11.5	0.4	-0.3	-0.5	12.1	1.0	0.7	1.3
Tos River mouth	8.2	-0.2	-0.1	-0.2	8.3	0.9	0.6	1.1
Chatkal	2.9	0.2	0.0	0.4	4.2	1.1	0.5	1.4
Naryn	5.7	0.7	0.3	0.9	5.1	0.8	0.6	1.2
Sary-Tash	-2.3	0.5	0.2	0.7	-1.4	1.0	0.3	1.1
Tyan-Shan	-6.8	0.0	-0.1	0.0	-6.9	0.8	0.5	1.0
Khaydarkan	6.6	0.0	-0.1	0.0	7.7	1.6	1.0	1.7
Khujand	15.4	-0.5	-0.4	-0.6	14.0	0.8	0.4	1.0
Gorbunov.s	-7.9	-0.1	-0.1	-0.1	-6.0	0.5	0.3	.6
Khorog	8.9	0.3	0.1	0.3	10.6	0.3	0.1	.5
Karakul	-3.9	0.3	0.2	0.4	-2.3	0.9	0.5	1.0

Table 4.8 | Potential changes of average annual air temperature by 2030 over mountain area stations for different emission scenarios

Station	Norm, mm	Climatic scenarios		
		IS92ab	IS92cd	IS92ef
Pskem	9.4	1.2	0.9	1.5
Charvak reservoir	11.6	0.9	0.6	1.1
Tos River mouth	7.9	0.7	0.5	0.8
Chatkal	2.7	1.3	0.9	1.5
Naryn	3.5	1.6	1.0	1.8
Sary-Tash	-2.4	1.3	0.8	1.5
Tyan-Shan	-7.6	0.3	0.1	0.3
Khaydarkan	7.1	1.1	0.7	1.3
Khujand	14.4	1.5	1.1	1.7
Gorbunov.s	-6.9	0.8	0.6	0.9
Khorog	9.0	0.8	0.5	0.9
Karakul	-3.6	0.8	0.5	0.9

Table 4.9 | Potential changes of total precipitation sums by 2030 (in % of norm) over mountain area stations for different emission scenarios

Station	Norm, mm	Climatic scenarios		
		IS92ab	IS92cd	IS92ef
Andizhan	252	114	116	117
Guzar	323	121	117	125
Pskem	823	109	107	111
Tos River mouth	715	119	112	123
Chatkal	437	105	103	108
Naryn	295	115	111	117
Khaydarkan	517	121	118	126
Sary-Tash	360	107	105	109
Khorog	268	119	114	124
Dekhauz	305	105	104	106
Iskanderkul	283	108	104	110
Gorbunov.s	1927	124	120	128

Assessment of climatic conditions changes over Central Asia territory with account for available model assessments, regional analogous scenario and empirical-statistical approach show that we should expect some increase (from 0 to 20%) of total precipitation sums and temperature increase in all seasons of the year over Central Asia area, including flow formation zone, under realizing different GHG emission scenarios by 2030.

CHAPTER 5

REGIONAL CLIMATE CHANGE SCENARIOS BUILDING BASED ON GLOBAL CLIMATIC MODELS OUTCOMES

5.1. Methodological Background

According to IPCC conclusion global climatic models of general atmosphere and ocean circulation outcomes present most appropriate base for regional scenarios building, which, in turn, serve as a basis for various regional assessments of vulnerability to climate changes. But information received from GCM, as a rule, has low spatial resolution (3 corresponds to 330 km on equator). Such low resolution is main limiting factor for its wide use. In this connection, problem of outcomes interpretation in different regional scales occurs.

One of the simplest ways to spatial detalization of GCM outcomes is interpolation of outcomes on denser spatial network with further imposing on climatic information of high resolution obtained from instrumental observations. Another approach is hydrodynamic models with high resolution for closed areas called regional climatic models. Another method is method of outcomes statistical interpretation. This method is used for assessment of climate changes impact on agriculture or forestry, water resources, etc. Often these methods are applicable only for specific geographic region. Regional climatic scenarios obtained on base of statistical interpretation suppose conservation of large and mezzo-scale statistical relations in the future.

In given work regional climatic scenarios are built by method of statistical interpretation based on concept of "ideal forecast" described in [Spektorman, 2002] using gradual linear regression.

5.2. Analysis of Existing Control Running of Global Climatic Models

Criterion for optimal model selection can serve numerical assessment of model capability to reproduce climate of basic period. For this purpose usually compare results of calculations on different models with real climate in grids of latitude-longitude network or interpolate GCM outcomes in coordinates of basic stations [Dolgih and Pilifosova, 1996]. Analysis of such comparison shows that some models within some seasons better reproduce field of temperature, other - field of precipitation, e.g. model capability depends on season and region localization.

We considered control running of some models for state of equilibrium (real climate reproduction under modern CO_2 concentration) [Spektorman and Nikulina, 1999]. Models outcome for general atmosphere and ocean circulation (data of US National Center of Atmospheric Events (NCAR).

Data bank contains results of air temperature near ground surface modeling (T, °C), precipitation (R, mm/day) in grids of regular network on earth surface for each month under modern CO_2 concentration ($1xCO_2$) and doubled one ($2xCO_2$).

Next models are being considered: CCCM – model of Canadian Climatic Center (spatial resolution - 2,22 on latitude and 3,75 on longitude, sensitivity to CO_2 doubling - 3,5°C); UKMO – model of Meteorological Bureau, UK (spatial resolution - 2,5 on latitude and 3,75 on longitude sensitivity to CO_2 doubling - 3,5°C); GFDL – model of US Laboratory of Geophysical Hydrodynamics (spatial resolution - 2,22 on latitude and 3,75 on longitude, sensitivity to CO_2 doubling - 4,0°C; GISS - model of US Goddard Institute (spatial resolution - 7,83 on latitude and 10,00 on longitude, sensitivity to CO_2 doubling - 4,2°C.

Comparison of results show that temperature regime of plane area is better modeled. In mountainous relief there are higher deviations from real data.

With regard for above mentioned stations were selected located within plane area, control running deviations from basic climatic data were calculated ($1xCO_2$) and interpolated in station coordinates. Analysis of results showed that in this case also modeled temperature differs from real one. Almost all models underestimate average monthly temperature (except summer).

Models CCCM and GFDL give highest deviations from real climate particularly in winter time.

Models UKMO и GISS results are more real. In Table 5.1 deviations from average temperature for Uzbekistan are presented.

Table 5.1 Average deviations of control modeled air temperature from basic climatic norm for plane area of Uzbekistan

Model	Season				Average Annual
	Winter	Spring	Summer	Autumn	
CCCM	-9.9	-6.6	0.5	-4.3	-5.1
UKMO	-3.5	-2.1	1.1	0.4	-1.0
GFDL	-9.5	-1.1	1.1	-2.0	-2.9
GISS	0.3	-2.8	-1.5	-0.9	-1.2

Analysis of modeling results for precipitation was carried out with regard for relief peculiarities. For this climatic data was averaged over plane and mountainous area.

Control modeled precipitation for the moment $1xCO_2$ was compared with climatic data of basic period and observation data in grids of network. Analysis shows that data interpolated from grids to station coordinates and observation data are in good compliance but for mountains this difference grows.

Control modeled values variations relatively climatic data are substantial. It is important to note that for stations in mountains inter-model variability for control running during spring months compiles with averaged climatic data. Modeled precipitation exceeds real climatic data.

In Table 5.2 modeled precipitation values and real climatic data over seasons of a year. Model GISS gives maximum precipitation. In winter it overestimated on average by 1.0 mm/day and in fall - by 0.5 mm/day. Models GFDL and UKMO describe precipitation more realistically for plane area. Good results were obtained under modeled and climatic data averaging over seasons.

Seasonal precipitation values computed based on foothill and mountain stations and climatic data for basic periods are also presented in table 10. It is necessary to note that for foothills and mountains high differences between modeled and real climatic data take place.

When describing climatic fields of precipitation with network grids substantial differences have place increasing in mountains.

UKMO and GFDL models give results closer to real data for plane area. Differences diminish while considering annual values. For mountains differences are less that allows using all models for precipitation prediction in mountains.

Table 5.2 Averaged over territory modeled precipitation values (mm/day) and real climatic data for basic period (model climate - data from network grids and observed data (station climate)

Model	Season				Average annual
	Winter	Spring	Summer	Autumn	
Plain					
CCCM	0.62	0.83	0.21	0.26	0.48
UKMO	0.73	0.41	0.00	0.31	0.36
GFDL	0.34	0.52	0.00	0.24	0.27
GISS	1.41	1.08	0.31	0.75	0.88
Model Climate	0.53	0.50	0.20	0.23	0.39
Station Climate	0.40	0.55	0.09	0.22	0.32
Foothills					
CCCM	1.12	2.13	0.41	0.48	1.04
UKMO	1.72	1.51	0.34	0.93	1.12
GFDL	0.41	1.12	0.64	0.43	0.65
GISS	2.50	1.71	0.62	1.14	1.49
Model Climate	0.83	1.18	0.46	0.40	0.71
Station Climate	1.33	1.46	0.08	0.53	0.85
Mountains					
CCCM	1.24	2.41	0.89	0.54	1.27
UKMO	2.08	2.46	0.87	1.62	1.51
GFDL	0.54	1.62	1.43	0.78	1.09
GISS	2.27	1.73	1.12	1.14	1.56
Model Climate	0.86	1.31	0.50	0.52	0.80
Station Climate	1.46	2.40	0.82	1.00	1.42

In conclusion the following can be said:

- model assessments of air temperature variations are underestimated;
- model assessments of precipitation is somewhat overestimated;
- temperature definition uncertainty is less for plane area compared with mountains;
- precipitation definition uncertainty is high for the regions with high natural precipitation variability especially for warm season of the year. Last conclusion is in compliance with precipitation field statistical structure in the Aral Sea basin. Coefficients of precipitation variations are highest for plane part of the basin and diminish in mountains. Thus, model scenarios uncertainty for precipitation is very high for the regions with high precipitation variability, particularly in dry season.

Range of regional climatic scenarios based on above described results has been built for CO_2 concentration doubling in Uzbekistan and adjacent mountains (Spektorman and Nikulina, 1999). Diapason of average annual temperature probable changes for models UKMO, GFDL and GISS amounts for 4,4-6,0°C for plane area and 3,4-5,2°C for mountains. Obtained values of expected temperature changes are overestimated due to sulfate aerosol effect not taken into account.

Models UKMO and GFDL give annual precipitation for plane area 90-116% from basic norm and 104-121% for mountains (UKMO, GFDL, GISS).

Scenarios developed for air temperature changes were used as extreme options while assessing environment and economic sectors vulnerability within UN Framework Convention (First National Report o the Republic of Uzbekistan within UN Framework Convention, 1999).

Analysis shows that single model of general circulation can't be selected, which describes Uzbekistan climate in best way. For more reliable assessment of probable climatic changes statistical interpretation of results is to be used.

5.3. Selection of Optimal GCM Outcomes for Regional Climatic Scenarios Building for Uzbekistan and Adjacent Mountainous Area

Given work task is to build regional climatic scenarios for the nearest future (by 2025) Described in sub-section 5.2 data are outcomes of models in state of equilibrium permitting obtain temperature and precipitation changes only for hypothetical moment of time when CO_2 concentration in the atmosphere is doubled ($2xCO_2$). Thus, these data can't be used for nearest future scenarios. For this models in state of transition are needed. These are more developed models of general atmosphere and ocean circulation allowing evaluation of climatic characteristics change with regard for gas emission (annual green house gas concentration increase).

Taking into account, that our objective is to build scenarios for the nearest future, we take average emission scenario (IS92a) called "business as usual" and average model sensitivity to gas concentration increase.

Analysis of literature and IPCC documentation (J.T. Houghton et al, 1995, and Feenstra et al, 1998) shows possibility to attract modern outcomes for the territory under consideration within system MAGICC/SCENGEN (Hulme et al, 2000). SCENGEN data base includes outcomes and permits to obtain changes of climatic characteristics in grids of network 5x5 (for period up to 2100 according to various emission scenarios using so called “simple climatic model” (Section 4.1).

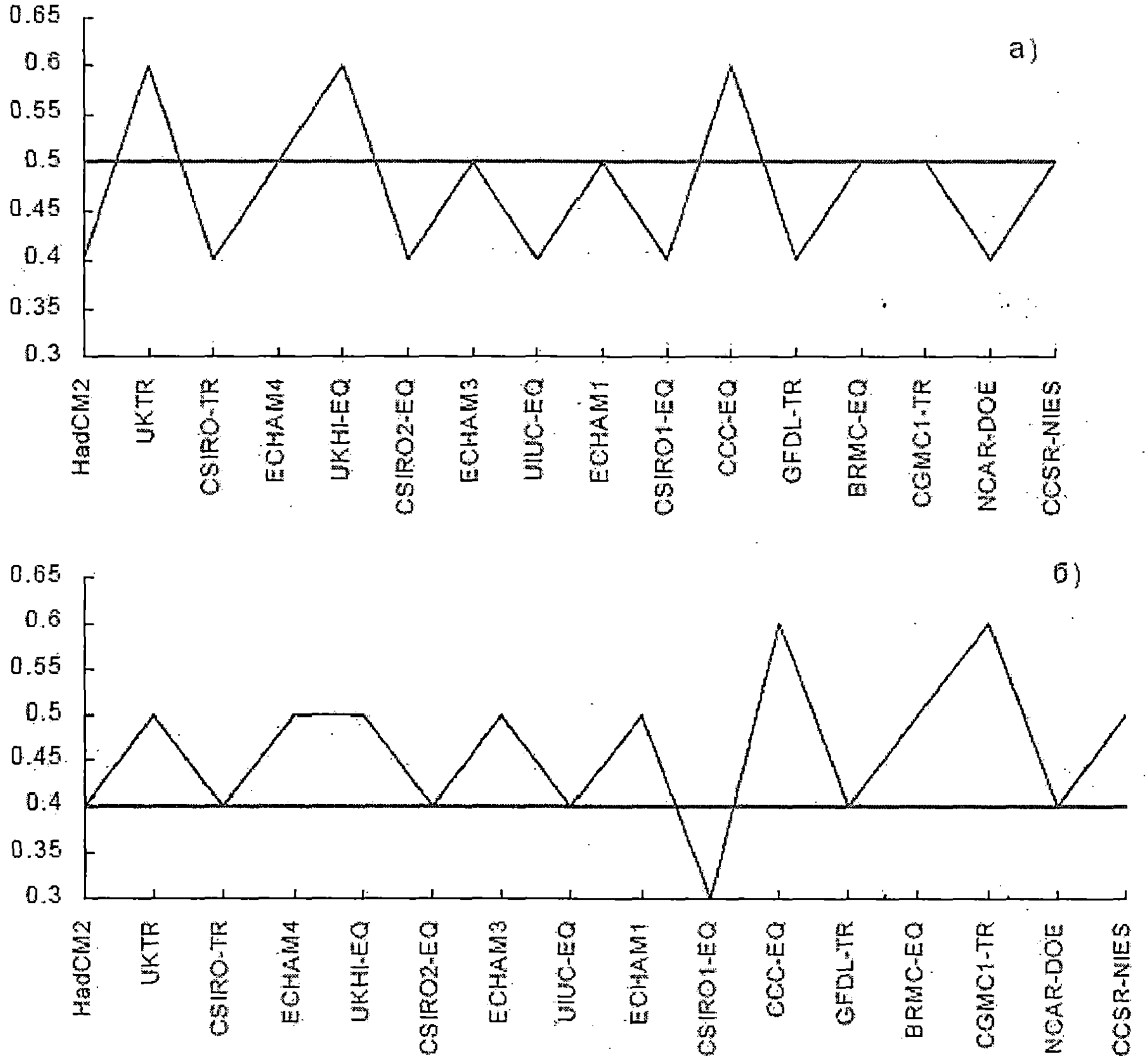


Fig. 5.1 | Comparison of deviations from basic norm according to various scenarios with actual anomalies of average annual air temperature (^{0}C) for 1991-2000

a - region with coordinates 40-45° latitude and 60-65° longitude

b - region with coordinates 35-40° latitude and 65-70° longitude;

straight line – observed actual values

Models for green house gas effect and climate changes (MAGICC). MAGICC is widely used by IPCC as well as system MAGICC/SCENGEN is permanently upgraded and disseminated within UN Convention. That's why outcomes collected in SCENGEN database are appropriate base for regional scenarios building.

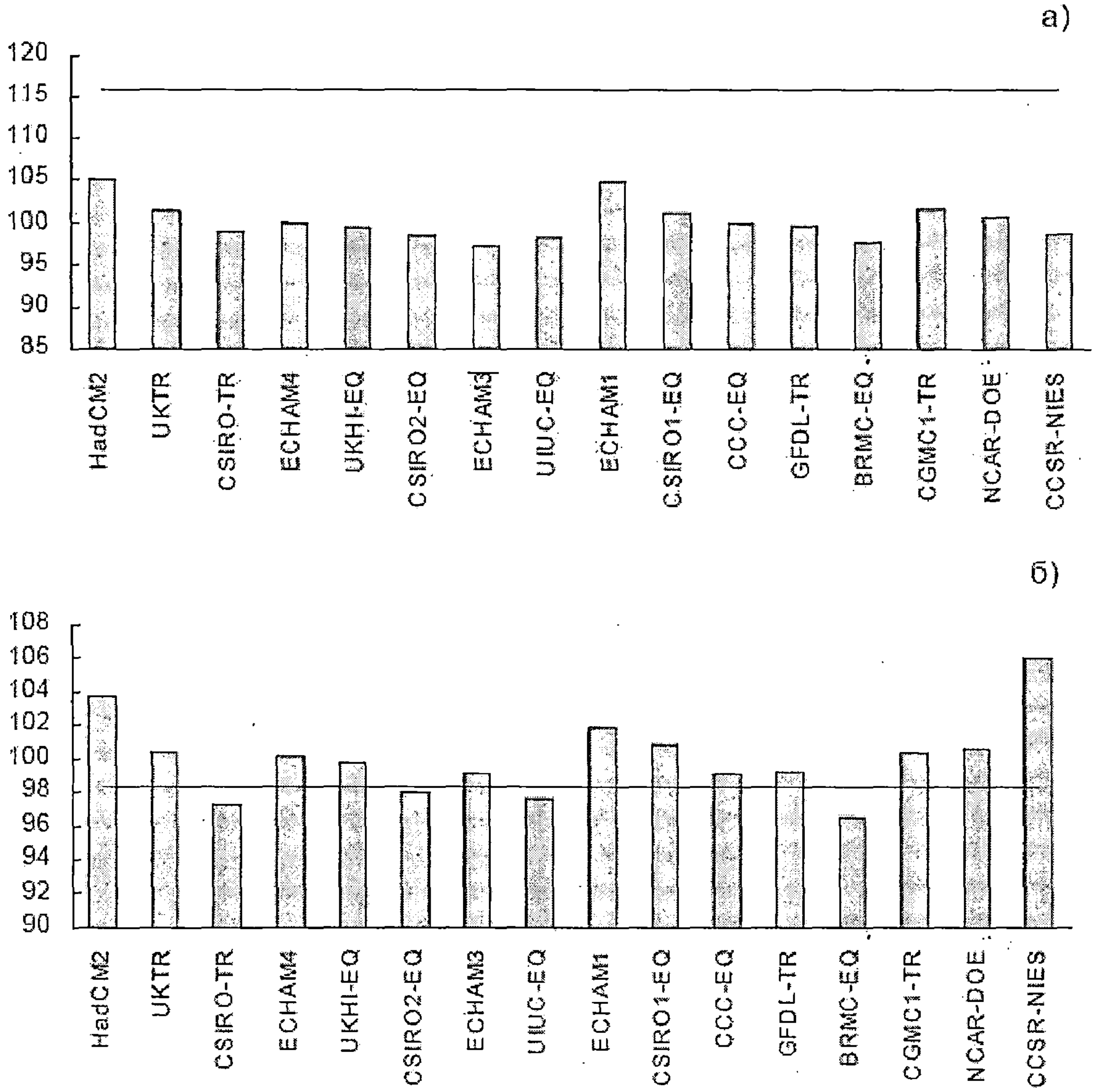


Fig. 5.2 | Comparison of precipitation sum % from basic norm with average annual temperature for 1991-2000

a - region with coordinates 40-45° latitude and 60-65° longitude

b - region with coordinates 35-40° latitude and 65-70° longitude;

straight line – observed actual values

It is necessary to analyze climatic models in SCENGEN database and select appropriate for regional scenarios building. For Central Asia model outcomes with resolution 5x5 using SCENGEN database can be obtained. To compare outcomes with observed climatic trends air temperature and precipitation anomalies were selected for central points of two regions with coordinates (between 40-45° and 60-65 °; 35-40 ° and 65-70 ° by 2000 (earliest scenario for 1986- 2015) and actual deviations from basic norm for 1991-2000 averaged in network scale 5x5, which are observed climatic trends.

It is necessary to note good compliance of model assessments and actual anomalies for a year as a whole Fig. 5.1.

The same coordination of precipitation scenarios with observed climatic trends is not found due to high spatial and temporal precipitation variability in the region. On Fig. 5.2 range of probable annual sum of precipitation in percent of 1961-1990 norms over different models under the same conditions for scenario building is shown.

Analysis of obtained scenarios for the earliest period for two regions of Uzbekistan and their comparison with observed climatic trends shows that it is difficult to give preference to any model but conclusion can be made: practically all models describe well observed temperature anomalies; calculated precipitation values were lower compared with actual ones.

It is necessary to underline that strict statistical analysis of precipitation data has not been made. There is high spatial and temporal precipitation variability. That's why statistical meaning of model assessments is lower compared with temperature (Houghton et al, 1995).

Based on IPCC documentations and analysis results, the following criterias were selected for optimal outcomes:

1. It is necessary to use the last available outcomes.
2. It is necessary to use data obtained in the state of equilibrium having the same resolution in horizontal direction and level number in the atmosphere and ocean.
3. It is necessary to take into account stratospheric sulfate aerosols effect because according to (IPCCTG) Central Asia is located within its maximum impact.

Let us consider climate change scenarios in grids of network 5x5 (selected from SCENGEN database by 2020 over 5 models meeting above criteria in points within Uzbekistan and adjacent mountainous area for precipitation (Fig. 5.3-5.5) and air temperature (Fig. 5.6-5.8).

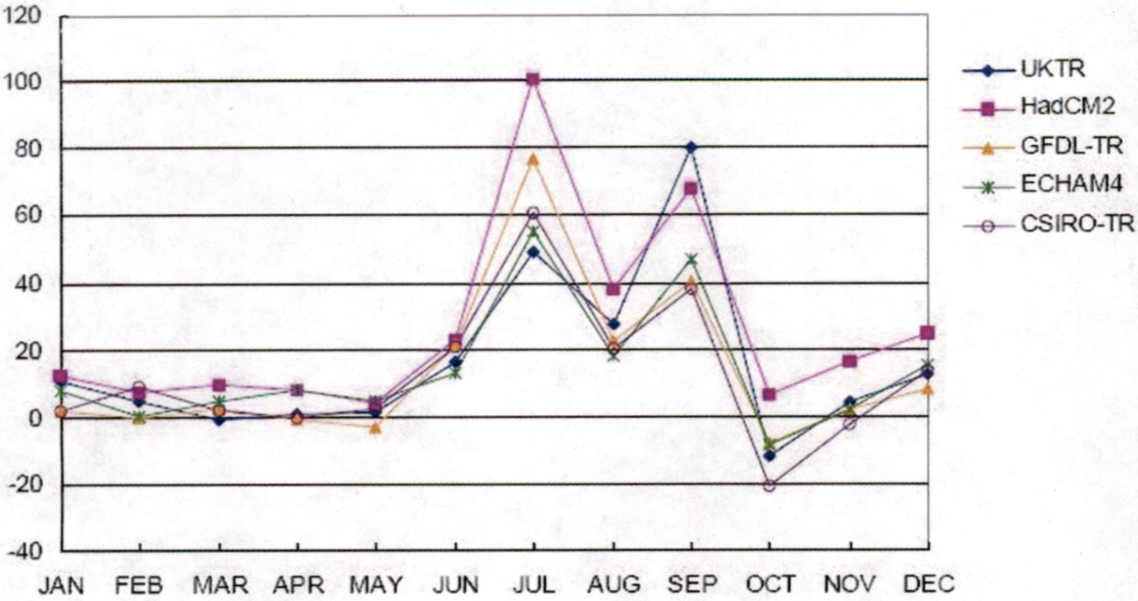


Fig. 5.3 | Expected monthly sum of precipitation (deviations from basic norm of 1961-1990) by 2020 for the region with coordinates 40-45 ° and 60-65 ° (plain)

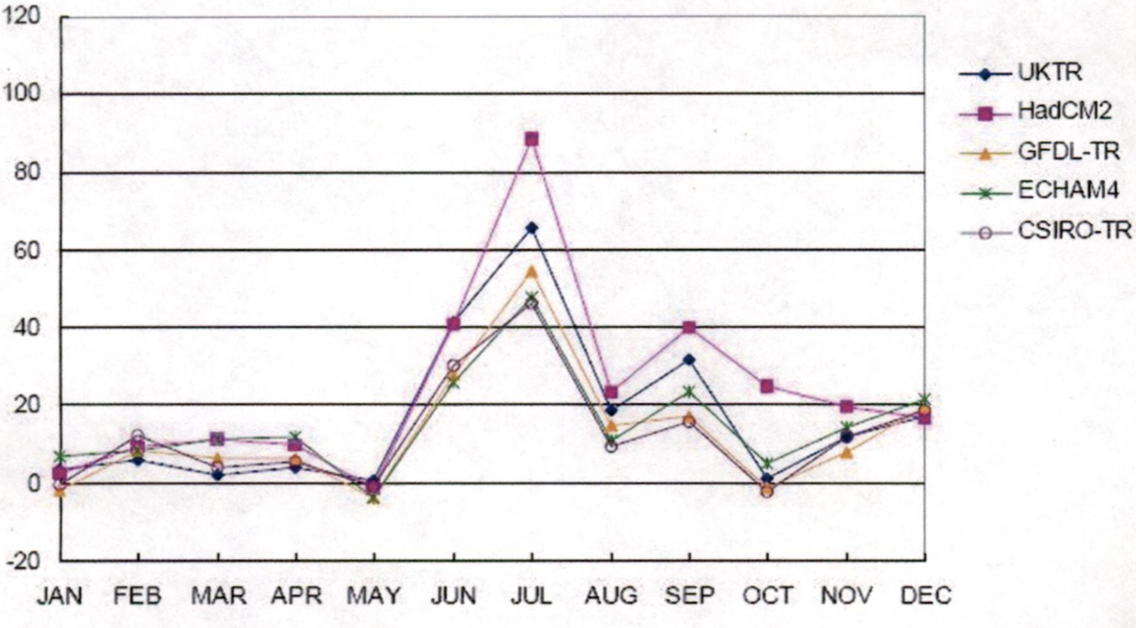


Fig. 5.4 | Expected monthly sum of precipitation (deviations from basic norm of 1961-1990) by 2020 for the region with coordinates 35-40° and 65-70° (mountains)

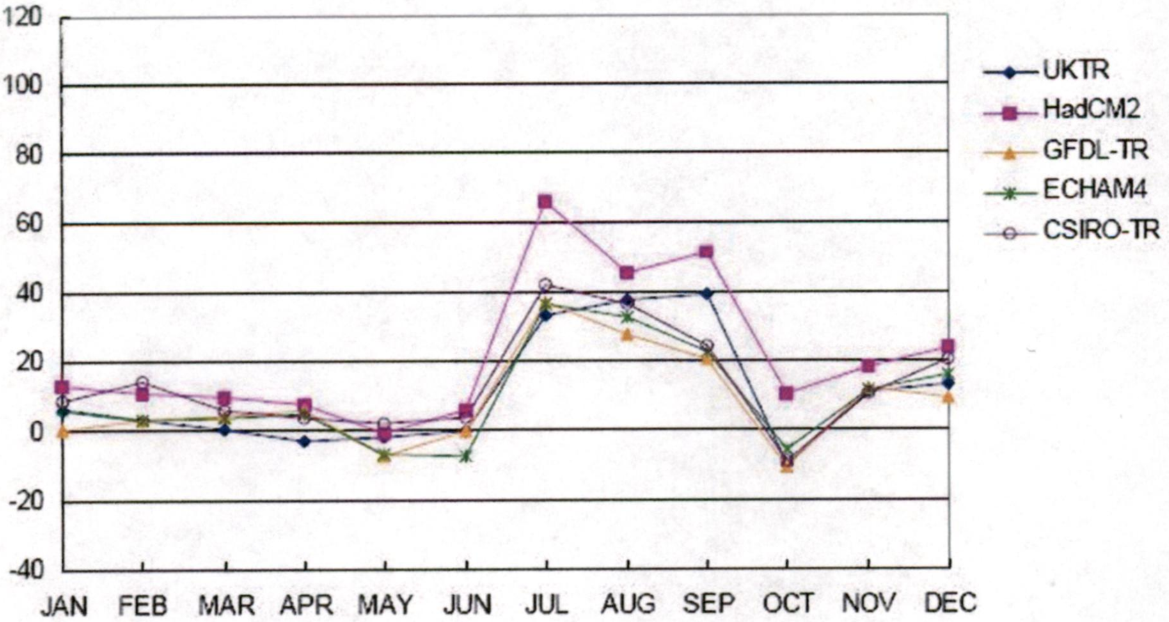


Fig. 5.5 | Expected monthly sum of precipitation (deviations from basic norm of 1961-1990) by 2020 for the region with coordinates 40-45° and 70-75° (mountains)

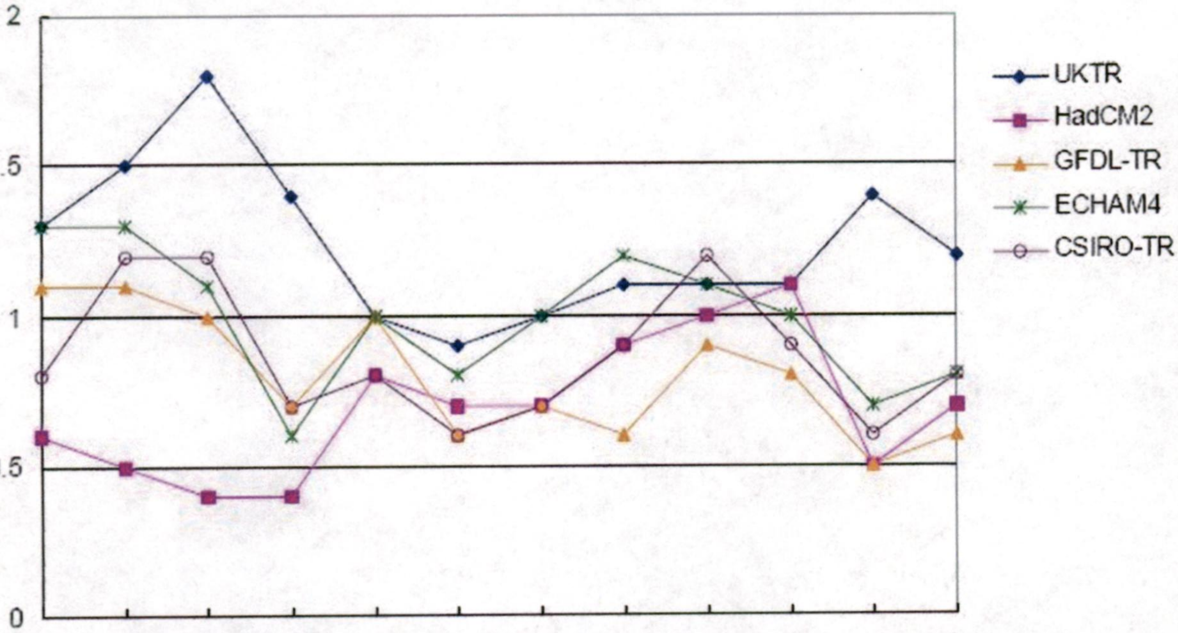


Fig. 5.6 | Expected average monthly temperature (deviations from basic norm 1961-1990) by 2020 for the region with coordinates 40-45° and 60-65° (plain)

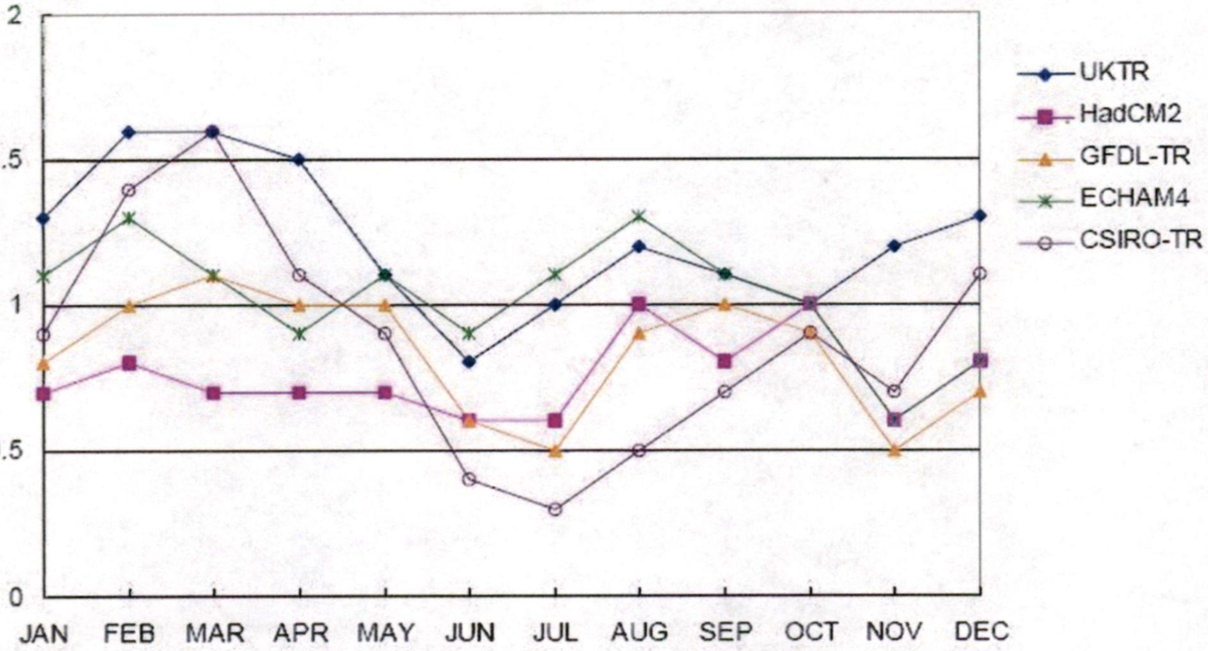


Fig. 5.7 | Expected average monthly temperature (deviations from basic norm of 1961-1990) by 2020 for the region with coordinates 35-40 ° and 65-70° (mountains)

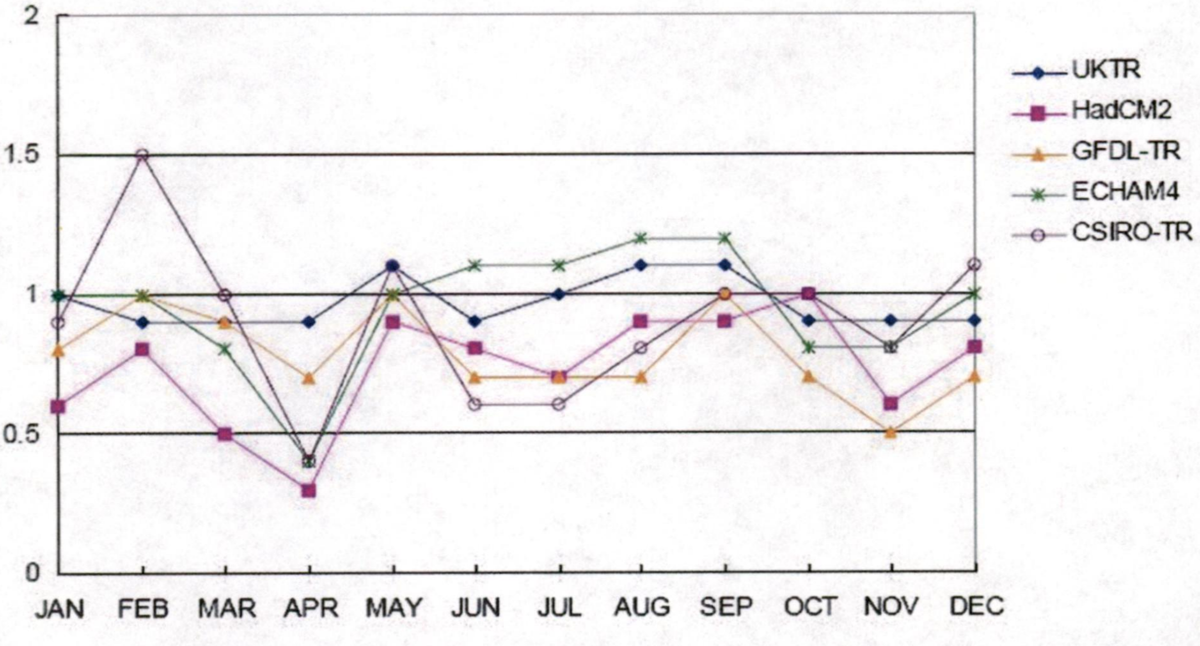


Fig. 5.8| Expected average monthly temperature (deviations from basic norm of 1961-1990) by 2020 for the region with coordinates 40-45° and 70-75° (plain)

Analysis of graphs shows that all selected GCM give agreed results. Taking into consideration existing uncertainty and necessity to reflect probable range of climatic changes, two models have been selected:

1) HadCM2 (UK, Hadley Centre);

2) ECHAM4 (Germany, Max Planck Institute).

Climatic model ECHAM4 is created based on the model of European Center of Midterm Weather Forecast (ECMWF) and parameterization developed in Hamburg allows to use this model for climate reproduction and prediction. This model of transition state includes 19 levels in the atmosphere and 11 in the ocean. According to this model data, global warming by 2071-2100 is expected to be 3°C and global precipitation should increase by 1.97% compared with norm of 1961-1990. Besides, softening effect of sulfate aerosols is taken into account.

Climatic model HadCM2 is a version of the model of UK Meteorological Office (UKMO). This is a model of transition state. It includes 19 levels in the atmosphere and 20 in the ocean. In accordance with HadCM2 model, global temperature increase by 2071-2100 will be 3.1°C and precipitation rise – 5.01% compared with norm of 1961-1990. Softening effect of sulfate aerosols is also taken into account.

5.4. Building Scenarios of Climate Changes in Uzbekistan Using Method of "Ideal Forecast" Concept's Statistical Interpretation

Method of GCM outcomes statistical interpretation based on "ideal forecast" concept was used. Main idea of "ideal forecast" is that statistical links are searched from diagnostic data and applied to GCM outcomes. Interpretation quality grows better with model perfection.

Archive of climatic anomalies of monthly resolution in grids of network is used as predictors. They are actual climatic parameters over stations within Uzbekistan and adjacent mountainous area.

Statistical interpretation methodology includes:

- Creation of archive in grids of network based on observation data (anomalies are averaged for vast territory and considered as ideal forecasts of selected GCM); for temperature formula (1) and for precipitation - formula (2) are used

$$\Delta T_m = \frac{1}{N}\sum_{i=1}^{N}\left(T_i - T_{cp}\right) \qquad (1)$$

$$R_m = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{100R_i}{R_{cp}}\right) \qquad (2)$$

- Building communication equations between averaged anomalies and station data;
- Utilization of built equations for calculation of scenario element over stations using model results in grids as predictors.

Such equations were built for all stations available in archive Table 5.3. To build multitude linear regression equation, method of predictors sifting was used. For each station climatic characteristic under consideration field of model outcomes in network grids was a vector-predictor.

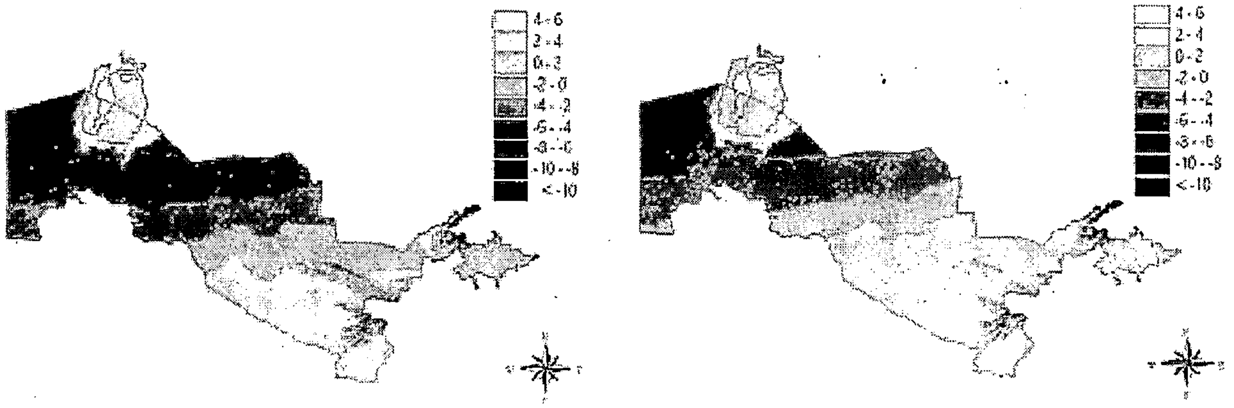
Given methodology allowed to obtain detailed over area scenarios and take into consideration regional peculiarities.

Below, as calculations illustration Fig. 5.9 modern basic January norms of average monthly air temperature and its change by 2050 according to scenario IS92a and sulfate aerosols effect (statistical interpretation of model ECHAM4 outcomes) are presented. On Fig. 5.9 temperature gradations shift to the north and new gradation (4-6°C) in southern regions of Uzbekistan appearance in case of selected scenario realization are shown.

Average monthly air temperatures over selected models (HadCM2 and ECHAM4) in anomalies and monthly sums of precipitation in percent of 1961-1990 norms are presented.

Table 5.3 | List of basic stations

Uzbekistan			Kyrgyzstan and Tajikistan	
1. Jaslik	18. Bukhara	35.Yangier	1.Karaкujur	10.Kulyab
2.Karakalpakia	19. Karakul	36.Tashkent	2.Krasny Oktyabr	11.Kurgan-Tyube
3.Chimbai	20. Ayakagitma	37.Tuyabuguz	3.Naryn	12.Khudjant
4.Kungrad	21.Karshi	38.Koкaral	4.Saritash	13.Gorbunov
5.Nukus	22.Guzar	39.Kaunchi	5.Talas	14.Khorog
6.Muinak	23.Dehkanabad	40.Dalverzin	6.Bishkek	
7.Urgench	24.Shahrisyabz	41.Syrdarya	7.Khaidarkan	
8.Khiva	25.Shurchi	42.Pskem	8.Cholpon-Ata	
9. Akbaital	26.Sherabad	43.Dukant	9.Chatkal	
10. Tamdi	27.Baysun	44.Oigaing		
11. Buzaubai	28.Denau	45.Koкand		
12. Mashikuduk	29.Termez	46.Feghana		
13. Jingeldi	30.Mingchukur	47.Fedchenko		
14. Samarkand	31.Jizak	48.Andizhan		
15. Kattakurgan	32.Gallyaaral	49.Namangan		
16. Navoy	33.Bogarnoye	50.Pap		
17. Nurata	34.Sanzar			



(a) (b)

Fig. 5.9 | Modern basic norm of average monthly air temperature in January (a) and its expected value by 2050 (b) in accordance with emission scenario IS92a and taking into account sulfate aerosol effect (statistical interpretation of ECHAM4 model outcomes)

Scenarios building for the nearest perspective have been made in accordance with average emission scenario (IS92a) and average model sensitivity to GHG concentration increase in the atmosphere. Calculated values are presented by 30-year average annual values by 2020, e.g. averaged diapason covers period of 2006-2035. Methodology of statistical interpretation allowed calculating expected changes for 50 stations of Uzbekistan, Tables 5.4-5.7 and some stations of adjacent area Tables 5.8-5.11

For summer months and stations where precipitation is practically not available link equations could not be built. Because of that, expected within scenario values have not been changed and correspond to basic norm 1961-1990 100%).

Thus, let us underline once more that task assigned in this work is to build regional climatic scenarios for the nearest future (by 2025). Described in sub-section 4.2 models data in equilibrium allow receive assessments of temperature and precipitation changes for hypothetical moment of CO_2 concentration doubling in atmosphere ($2xCO_2$), but we can't use it for scenario. For this purpose models of transition state are needed. Those are more developed models of general atmosphere and ocean circulation. They can serve for receiving climatic characteristics according to set scenario (assuming annual growth of green house gas concentration)

Taking into account, that our objective is scenarios building for nearest future, let us take average scenario of emission (IS92a) or "business as usual" scenario and average model sensitivity to green house gas concentration growth.

Analysis of different sources and IPCC documents shows possibility to use modern IAC outcomes for territory under consideration. We used system MAGICC/SCENGEN (Hulme et al, 2000). MAGICC is widely used by IAC and system MAGICC/SCENGEN is permanently upgraded and circulated within Program of National Message Support of UN Framework Convention. That's why IAC outcomes collected in SCENGEN database are the most appropriate base for regional scenarios building.

Taking into account existing uncertainty and necessity to reflect all range of changes when building regional scenarios, we have select for base two models:

1) HadCM2 (UK, Hadley Centre);

2) ECHAM4 (Germany, Max Planck Institute).

Using global models for assessment of the regional climatic changes it is necessary to take into account geographical peculiarities of the regions (relief, water bodies, ground surface, etc.). For this «downscaling» methodology is used (outcomes interpretation in network grids), by which climatic characteristics are transformed to necessary meteorological parameters with needed spatial and temporal resolution.

Scenarios building for nearest future is performed according to average scenario of emission (IS92a) and average sensitivity to green house gas concentration growth. Calculated values present 30-year average values by 2020 (within 2006 – 2035). Methodology of statistical interpretation based on concept of "ideal forecast" allowed calculate expected changes for 50 stations in Uzbekistan and some stations in adjacent mountains.

Table 5.4 | Change of average monthly air temperature according to model ECHAM4 by 2020 (deviation from basic norm, 50 stations in Uzbekistan)

Station number	Months											
	1	2	3	4	5	6	7	8	9	10	11	12
1	1.6	1.5	0.9	0.4	0.9	0.4	0.8	1.2	1.0	0.6	0.4	0.4
2	1.5	1.5	0.6	0.4	1.0	0.4	0.8	0.9	1.0	0.7	0.4	0.4
3	1.5	1.4	0.8	0.5	0.9	0.4	0.6	0.8	1.0	0.9	0.4	0.4
4	1.4	1.5	0.7	0.3	0.7	0.4	0.5	1.0	0.9	0.7	0.4	0.4
5	1.4	1.4	0.7	0.4	0.7	0.4	0.9	0.9	1.2	1.0	0.4	0.4
6	1.4	1.3	1.1	0.3	1.0	0.4	0.5	0.8	1.1	1.1	0.4	0.6
7	1.5	1.7	0.6	0.5	0.9	0.4	0.9	1.1	1.0	0.9	0.4	0.4
8	1.5	1.5	0.6	0.6	0.9	0.5	0.8	1.1	1.2	0.8	0.4	0.5
9	1.6	2.0	0.9	0.6	1.1	0.6	0.6	1.5	1.3	0.9	0.4	0.7
10	1.4	1.9	0.6	0.5	1.0	0.7	1.1	1.2	1.1	0.9	0.4	0.8
11	1.7	1.9	0.6	0.5	1.1	0.7	1.2	1.3	1.2	1.0	0.4	0.5
12	1.6	2.0	0.6	0.4	1.3	0.9	1.1	1.3	1.6	0.9	0.4	0.7
13	1.6	2.0	0.6	0.6	1.1	0.9	1.4	1.5	1.5	1.0	0.4	0.7
14	1.6	1.7	0.6	0.4	0.8	0.5	0.7	1.0	1.2	1.0	0.4	0.8
15	1.5	1.8	0.6	0.4	1.0	0.7	0.9	1.1	0.9	1.0	0.4	0.8
16	1.8	1.6	0.6	0.5	0.9	0.7	1.1	1.0	1.0	0.9	0.4	0.7
17	1.7	1.9	0.8	0.4	1.1	1.1	0.9	1.1	1.2	0.9	0.4	0.9
18	1.6	1.6	0.7	0.6	0.7	0.6	0.8	0.9	0.7	0.8	0.4	0.8
19	1.5	1.7	0.6	0.5	1.0	0.7	1.4	1.6	1.2	0.7	0.4	0.8
20	1.6	1.9	0.6	0.5	1.5	1.0	1.1	1.3	1.5	1.1	0.4	0.9
21	1.5	1.5	0.5	0.2	1.0	0.6	1.2	1.6	1.5	1.0	0.6	0.8
22	1.3	1.4	0.7	0.2	1.2	0.9	0.8	1.0	1.3	1.1	0.6	0.9
23	1.4	1.4	0.5	0.4	0.9	1.0	0.9	1.2	1.4	0.9	0.6	1.0
24	1.4	1.5	0.6	0.3	0.9	1.0	1.0	1.3	1.3	0.9	0.5	0.8
25	1.2	1.4	0.8	0.4	0.8	0.8	0.7	1.0	0.6	0.8	0.4	0.9
26	1.1	1.2	0.6	0.3	1.0	1.0	0.8	1.0	1.2	0.7	0.6	0.9
27	1.4	1.4	0.8	0.3	1.0	0.9	1.4	1.1	1.4	1.0	0.6	1.0
28	1.1	1.4	0.5	0.3	0.8	0.9	0.8	1.0	0.8	0.5	0.4	0.8
29	1.1	1.3	0.6	0.3	0.8	0.9	1.0	1.5	1.5	0.5	0.6	0.8
30	0.9	1.3	0.8	0.4	1.3	1.3	1.7	1.7	1.8	1.2	0.5	0.8
31	1.6	1.9	0.6	0.6	1.1	0.6	1.2	1.0	1.1	1.1	0.5	0.9
32	1.7	1.9	0.6	0.5	1.1	0.5	1.0	1.1	1.2	0.9	0.5	0.8
33	1.7	1.8	0.6	0.5	0.7	0.9	0.8	1.1	1.1	0.7	0.3	0.6
34	1.6	1.9	0.7	0.6	1.0	0.9	0.9	1.2	1.2	1.1	0.5	0.9
35	1.5	1.9	0.7	0.5	0.7	1.1	1.2	1.3	1.4	1.3	0.4	0.6
36	1.6	1.7	0.6	0.5	1.0	0.7	0.7	1.1	0.9	0.8	0.6	0.7
37	1.7	2.0	0.6	0.5	0.8	0.5	0.6	0.9	0.6	0.7	0.3	0.7
38	1.7	2.0	0.6	0.5	1.1	0.5	0.7	1.0	0.8	0.8	0.5	0.7
39	1.7	1.9	0.6	0.5	0.9	0.7	0.7	0.7	0.8	0.7	0.5	0.9
40	1.7	2.0	0.6	0.5	1.0	0.6	0.6	1.0	0.6	0.5	0.5	0.9
41	1.7	2.0	0.6	0.5	1.0	0.5	0.6	0.8	0.8	0.6	0.4	0.8
42	1.2	1.4	0.7	0.6	0.9	0.9	1.4	1.4	1.4	1.2	0.4	0.7
43	1.1	1.3	0.8	0.6	0.9	1.2	1.3	1.3	1.7	1.4	0.9	0.6
44	0.9	1.3	0.8	0.9	1.4	1.0	1.5	1.4	1.6	0.8	0.4	0.7
45	1.4	1.8	0.6	0.6	0.8	0.7	1.0	1.1	0.7	0.7	0.3	0.9
46	1.4	1.6	0.6	0.5	0.8	0.6	0.7	0.7	0.7	0.7	0.3	0.8
47	1.6	1.8	0.6	0.6	0.7	0.8	0.6	0.7	0.9	0.7	0.3	0.7
48	1.5	1.6	0.7	0.5	1.1	0.8	0.8	1.0	0.8	0.9	0.3	0.5
49	1.5	1.8	0.7	0.6	0.8	0.8	0.6	1.0	0.9	0.9	0.5	0.5
50	1.5	1.6	0.7	0.6	0.8	0.6	0.7	0.9	1.0	0.9	0.5	0.8

Table 5.5 | Change of average monthly air temperature according to model HadCM2 by 2020 (deviation from basic norm, 50 stations in Uzbekistan)

Station number	Months											
	1	2	3	4	5	6	7	8	9	10	11	12
1	0.7	0.6	0.2	0.2	0.6	0.4	0.4	0.9	0.9	0.8	0.3	0.4
2	0.6	0.4	0.2	0.2	0.7	0.4	0.4	0.7	0.9	0.8	0.3	0.4
3	0.7	0.6	0.2	0.2	0.7	0.4	0.4	0.6	0.8	1.0	0.3	0.4
4	0.6	0.7	0.2	0.2	0.5	0.4	0.4	0.7	0.8	0.8	0.3	0.4
5	0.6	0.6	0.2	0.2	0.5	0.4	0.5	0.6	1.0	1.1	0.3	0.4
6	0.6	0.5	0.3	0.2	0.7	0.4	0.4	0.6	0.8	1.2	0.3	0.4
7	0.8	0.8	0.2	0.3	0.6	0.4	0.6	0.9	0.9	1.1	0.3	0.4
8	0.8	0.8	0.2	0.4	0.8	0.4	0.5	0.9	1.0	1.0	0.3	0.4
9	0.8	0.8	0.2	0.4	0.8	0.5	0.4	1.1	1.0	1.1	0.3	0.5
10	0.7	0.8	0.2	0.3	0.7	0.6	0.7	0.9	1.0	1.0	0.3	0.6
11	0.9	0.8	0.2	0.4	0.9	0.6	0.8	0.9	1.0	1.1	0.3	0.4
12	0.9	0.8	0.2	0.2	1.0	0.7	0.6	0.9	1.3	1.0	0.3	0.6
13	0.9	0.8	0.2	0.4	0.9	0.7	0.9	1.1	1.3	1.1	0.3	0.6
14	0.9	0.8	0.2	0.3	0.6	0.4	0.4	0.8	0.9	1.1	0.3	0.6
15	0.9	0.8	0.2	0.3	0.8	0.5	0.6	0.8	0.6	1.1	0.3	0.6
16	0.9	0.8	0.2	0.3	0.7	0.6	0.6	0.8	0.8	1.1	0.3	0.6
17	0.9	0.8	0.3	0.3	0.9	0.8	0.5	0.8	0.9	1.0	0.3	0.8
18	0.9	0.8	0.2	0.4	0.6	0.4	0.5	0.6	0.6	0.9	0.3	0.7
19	0.9	0.8	0.2	0.4	0.8	0.6	1.0	1.2	0.9	0.8	0.3	0.7
20	0.9	0.8	0.2	0.4	1.2	0.7	0.7	1.0	1.2	1.3	0.3	0.7
21	0.9	1.1	0.3	0.2	0.9	0.5	0.7	1.2	1.2	1.1	0.4	0.7
22	0.8	1.0	0.3	0.2	1.1	0.7	0.5	0.7	1.0	1.3	0.3	0.7
23	0.9	1.1	0.3	0.3	0.8	0.7	0.5	0.9	1.0	1.0	0.3	0.8
24	0.9	1.1	0.3	0.2	0.8	0.7	0.5	0.9	1.0	1.0	0.3	0.7
25	0.8	1.1	0.5	0.3	0.7	0.5	0.4	0.8	0.5	0.9	0.3	0.7
26	0.7	1.0	0.3	0.2	1.0	0.7	0.6	0.8	0.9	0.9	0.4	0.7
27	0.9	1.1	0.4	0.2	0.9	0.6	0.9	0.8	1.2	1.3	0.5	0.8
28	0.7	1.1	0.3	0.2	0.7	0.6	0.5	0.7	0.6	0.7	0.3	0.6
29	0.7	1.1	0.3	0.2	0.7	0.7	0.7	1.2	1.2	0.8	0.4	0.6
30	0.6	1.1	0.5	0.3	1.1	0.9	1.0	1.3	1.3	1.4	0.4	0.7
31	1.0	1.2	0.4	0.5	0.9	0.5	0.9	0.9	0.9	1.2	0.3	0.8
32	1.1	1.2	0.4	0.4	0.7	0.3	0.7	0.9	1.0	1.0	0.3	0.7
33	1.1	1.2	0.4	0.4	0.5	0.6	0.5	0.9	0.9	0.8	0.3	0.6
34	1.0	1.2	0.4	0.4	0.8	0.7	0.5	0.9	0.9	1.2	0.3	0.8
35	1.0	1.2	0.4	0.4	0.5	0.8	0.7	1.0	1.1	1.4	0.3	0.6
36	1.0	1.1	0.4	0.4	0.6	0.5	0.3	0.8	0.7	0.9	0.3	0.6
37	1.0	1.2	0.4	0.4	0.5	0.3	0.3	0.6	0.4	0.9	0.3	0.6
38	1.1	1.2	0.4	0.4	0.8	0.3	0.6	0.9	0.7	0.8	0.3	0.6
39	1.0	1.2	0.4	0.4	0.6	0.5	0.5	0.5	0.7	0.8	0.3	0.8
40	1.1	1.2	0.4	0.4	0.8	0.4	0.4	0.7	0.4	0.7	0.3	0.8
41	1.1	1.2	0.4	0.4	0.7	0.4	0.3	0.6	0.6	0.7	0.3	0.7
42	0.8	0.9	0.4	0.4	0.6	0.6	0.8	1.0	1.1	1.2	0.3	0.7
43	0.7	1.1	0.4	0.5	0.6	0.8	0.7	1.0	1.2	1.5	0.7	0.6
44	0.6	0.9	0.5	0.7	1.0	0.5	0.9	1.1	1.2	0.7	0.3	0.6
45	0.9	1.1	0.4	0.4	0.5	0.4	0.5	0.9	0.6	0.7	0.3	0.8
46	0.9	0.9	0.4	0.4	0.5	0.4	0.4	0.5	0.6	0.8	0.3	0.7
47	1.0	1.1	0.4	0.5	0.4	0.5	0.3	0.5	0.8	0.8	0.3	0.7
48	1.0	0.9	0.4	0.4	0.8	0.5	0.5	0.7	0.6	1.1	0.3	0.5
49	1.0	1.1	0.4	0.5	0.6	0.5	0.3	0.7	0.7	0.9	0.4	0.5
50	0.9	0.9	0.4	0.5	0.5	0.4	0.4	0.7	0.7	1.0	0.4	0.7

Table 5.6 | Change of precipitation on model ECHAM4 by 2020 (ratio to basic norm %, 50 stations in Uzbekistan)

Station number	Months											
	1	2	3	4	5	6	7	8	9	10	11	12
1	116	128	92	99	100	125	162	117	128	95	85	108
2	108	109	92	103	105	111	131	144	125	119	96	107
3	93	104	98	87	101	126	116	105	133	92	80	97
4	105	112	99	88	101	128	137	93	186	96	87	114
5	97	111	109	92	101	118	136	100	147	91	83	98
6	97	119	89	84	99	115	135	61	116	90	88	106
7	115	124	112	101	106	151	184	100	122	80	104	116
8	114	122	121	100	111	176	158	92	123	83	108	107
9	114	106	115	95	93	125	113	174	112	89	93	114
10	108	99	120	108	105	159	152	100	103	98	111	127
11	106	111	119	102	93	87	128	100	127	80	95	107
12	112	106	115	112	106	130	95	100	106	93	100	124
13	115	109	113	105	101	149	144	100	107	95	101	129
14	102	123	114	112	95	153	141	100	117	94	121	117
15	107	124	121	118	102	151	108	100	121	97	119	127
16	104	111	111	122	104	204	128	100	100	97	109	128
17	105	111	122	116	103	130	137	100	143	95	117	129
18	108	113	115	117	109	100	120	100	100	91	105	132
19	103	111	112	118	105	140	100	100	100	97	103	133
20	109	112	118	113	95	221	103	130	100	102	102	118
21	109	120	120	126	104	102	100	100	91	91	126	120
22	106	114	116	114	93	144	100	100	112	90	129	118
23	104	121	115	113	104	109	100	100	100	96	130	117
24	106	117	120	115	100	147	128	100	110	94	125	118
25	101	113	112	115	115	100	100	100	100	100	121	130
26	104	118	115	109	102	100	100	100	100	99	134	125
27	105	115	117	115	105	177	103	93	104	100	131	117
28	103	116	115	120	108	223	100	100	100	97	120	124
29	102	109	107	106	102	100	100	100	100	100	129	129
30	106	113	110	108	107	131	105	100	97	89	124	117
31	105	115	117	106	93	122	156	129	117	95	130	124
32	102	109	122	108	92	147	141	123	126	94	134	116
33	94	100	109	108	85	87	106	120	91	98	113	100
34	101	115	121	110	93	135	166	102	137	99	125	116
35	103	114	112	106	96	96	130	114	99	92	128	112
36	103	106	123	105	92	142	196	192	121	90	117	114
37	103	112	117	106	90	190	166	100	107	91	128	126
38	102	112	115	106	85	94	128	100	111	91	127	130
39	104	110	118	105	93	128	178	100	130	90	121	122
40	102	111	115	106	91	76	153	118	114	94	126	122
41	103	114	121	109	95	88	144	100	102	91	122	125
42	105	107	116	104	93	101	138	134	117	90	109	114
43	103	109	114	107	92	120	138	160	119	90	120	122
44	103	108	117	104	92	99	143	140	108	91	122	117
45	118	123	117	107	84	115	141	109	110	86	134	132

46	113	110	108	102	87	100	136	121	98	95	147	131
47	111	114	114	106	91	109	127	168	94	93	146	127
48	112	115	117	106	94	110	158	166	104	95	149	131
49	115	123	115	107	92	120	135	134	158	93	143	135
50	114	121	111	107	86	108	136	115	146	87	141	131

Table 5.7 | Change of precipitation on model HadCM2 by 2020 (ratio to basic norm %, 50 stations in Uzbekistan)

Station number	Months											
	1	2	3	4	5	6	7	8	9	10	11	12
1	118	96	103	102	131	185	148	124	94	89	104	118
2	116	95	108	105	110	154	152	125	117	99	103	116
3	111	105	88	103	130	164	123	138	96	91	106	111
4	118	107	91	102	136	167	128	185	102	96	116	118
5	118	117	93	99	126	171	120	153	98	95	106	118
6	118	94	86	104	121	143	102	124	89	96	105	118
7	118	119	101	105	136	220	100	140	92	122	125	118
8	118	121	101	113	136	217	136	143	97	125	118	118
9	112	118	96	91	136	135	152	127	103	105	121	112
10	102	121	108	107	136	188	100	122	114	124	130	102
11	118	121	100	92	92	165	100	151	97	107	115	118
12	108	117	108	111	134	122	100	142	107	108	124	108
13	118	120	102	100	136	188	100	127	114	109	132	118
14	118	118	111	98	136	189	100	143	112	128	117	118
15	118	121	116	103	136	137	100	141	116	126	126	118
16	112	112	118	104	136	220	100	100	115	116	124	112
17	115	121	112	103	136	195	100	177	113	123	128	115
18	118	116	113	114	100	145	100	100	106	111	127	118
19	115	114	113	105	136	100	100	100	111	110	131	115
20	116	121	109	95	136	119	152	100	115	110	116	116
21	121	120	121	105	98	100	100	100	104	131	118	121
22	115	118	111	95	138	100	100	134	103	131	117	115
23	121	115	110	106	114	100	100	100	111	131	116	121
24	120	123	112	103	155	171	100	130	107	131	118	120
25	113	111	116	109	100	100	100	100	120	126	122	113
26	120	113	108	109	100	100	100	100	120	131	116	120
27	116	117	113	107	155	121	83	119	115	131	113	116
28	117	114	120	109	155	100	100	100	118	126	118	117
29	110	107	105	106	100	100	100	100	125	131	121	110
30	114	113	107	109	144	167	100	112	105	130	117	114
31	121	121	107	100	116	183	129	153	115	130	129	121
32	116	121	107	100	116	183	141	143	115	130	120	116
33	99	113	107	92	89	133	126	89	106	110	94	99
34	116	121	108	96	116	183	129	149	119	130	120	116
35	119	116	107	99	112	179	120	123	109	130	117	119
36	115	121	107	97	116	183	160	149	107	123	122	115
37	118	121	108	97	116	183	100	134	109	130	131	118
38	119	120	107	92	106	183	100	137	109	130	134	119

39	117	121	106	101	116	183	100	156	108	128	126	117
40	116	121	108	97	88	183	140	145	114	130	127	116
41	120	121	109	104	104	183	100	126	108	129	129	120
42	115	121	108	99	116	158	145	146	102	114	121	115
43	117	121	110	97	116	168	160	149	105	127	129	117
44	117	121	108	97	115	171	150	130	105	130	125	117
45	122	119	112	91	116	153	121	138	109	130	136	122
46	112	111	107	94	116	167	139	123	119	130	134	112
47	118	119	110	100	116	148	160	115	118	130	131	118
48	122	121	110	103	116	183	160	130	121	130	135	122
49	122	121	110	97	116	155	160	167	117	130	136	122
50	122	117	110	94	116	166	125	167	110	130	136	122

Table 5.8 | Changes of average monthly air temperature on model ECHAM4 2020 (deviations from basic norm, stations of Tajikistan and Kyrgyzstan)

Station number	Months											
	1	2	3	4	5	6	7	8	9	10	11	12
1	0.9	1.0	0.9	0.6	0.9	0.7	1.0	0.8	1.1	1.1	0.8	0.8
2	0.7	0.7	0.6	0.5	0.7	0.6	0.8	0.9	0.6	0.8	0.7	1.0
3	1.5	1.8	0.9	0.6	1.1	1.1	0.9	0.8	0.8	1.0	0.9	0.9
4	0.8	0.9	0.9	1.0	0.7	1.1	1.0	1.1	1.2	1.2	0.9	0.8
5	1.2	1.8	1.0	0.6	1.3	1.0	0.9	1.2	0.7	1.0	0.9	1.0
6	1.5	1.4	1.0	0.6	1.4	1.3	1.0	1.0	1.3	0.9	0.9	1.2
7	1.1	1.2	1.0	0.6	0.9	1.3	1.3	1.3	1.3	1.1	0.7	1.0
8	0.9	0.7	0.6	0.5	0.9	0.6	0.6	0.7	0.6	0.7	0.5	0.7
9	0.9	1.3	1.7	1.4	0.9	1.0	1.4	1.5	1.2	0.9	0.9	0.9
10	1.0	1.2	0.8	0.4	1.1	1.2	0.7	0.9	1.1	0.8	0.7	1.0
11	1.2	1.0	0.8	0.4	1.1	0.9	0.6	0.8	0.6	0.6	0.7	0.8
12	1.3	1.5	0.9	0.6	1.3	0.9	0.8	0.8	1.0	0.7	0.7	1.1
13	0.8	0.8	0.6	0.5	0.9	1.1	1.1	1.3	1.4	1.0	0.8	0.6
14	1.4	1.5	1.2	0.6	1.2	1.1	1.2	1.0	1.0	0.9	0.8	1.4

Table 5.9 | Changes of average monthly air temperature on model HadCM2 by 2020 (deviations from basic norm, stations of Tajikistan and Kyrgyzstan)

Station number	Months											
	1	2	3	4	5	6	7	8	9	10	11	12
1	0.5	0.7	0.6	0.4	0.5	0.5	0.6	0.6	0.7	1.0	0.7	0.7
2	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.7	0.4	0.9	0.5	0.8
3	1.0	0.6	0.6	0.6	0.6	0.6	0.6	0.7	0.5	1.1	0.4	1.0
4	0.6	0.7	0.7	0.7	0.4	0.7	0.6	0.8	0.8	1.1	0.9	0.6
5	0.7	1.0	0.6	0.4	0.9	0.7	0.5	0.8	0.6	1.1	0.8	1.0
6	0.8	0.7	0.5	0.5	1.0	0.9	0.6	0.8	1.0	0.9	0.8	1.2
7	0.7	0.9	0.7	0.5	0.6	0.9	0.7	1.0	0.9	1.2	0.6	0.9
8	0.6	0.4	0.4	0.4	0.6	0.5	0.3	0.5	0.4	0.7	0.5	0.6
9	0.6	0.8	1.0	1.1	0.5	0.7	0.9	1.1	0.9	0.9	0.9	1.0
10	0.6	1.0	0.5	0.3	0.9	0.8	0.4	0.7	0.7	0.9	0.5	0.8

11	0.7	0.8	0.5	0.3	0.9	0.6	0.4	0.6	0.5	0.8	0.5	0.6
12	0.7	0.9	0.5	0.5	0.9	0.6	0.4	0.6	0.8	0.8	0.6	1.0
13	0.5	0.6	0.4	0.3	0.5	0.7	0.6	0.9	0.8	0.9	0.7	0.5
14	0.7	0.9	0.8	0.5	0.8	0.5	0.7	0.7	0.7	0.8	0.7	0.9

Table 5.10 | Changes of precipitation on model ECHAM4 by 2020 (deviations from basic norm, stations of Tajikistan and Kyrgyzstan)

Station number	Months											
	1	2	3	4	5	6	7	8	9	10	11	12
1	110	105	109	105	100	103	106	107	111	99	104	105
2	106	95	102	103	103	104	105	103	102	100	102	101
3	110	109	108	105	99	96	117	110	118	107	109	107
4	107	106	104	102	98	105	112	110	103	102	108	121
5	107	97	101	106	93	97	121	123	119	97	106	111
6	104	98	104	103	94	93	118	110	119	97	102	103
7	105	102	109	103	95	94	127	126	118	96	111	116
8	106	101	100	104	102	102	101	107	108	103	103	128
9	105	105	105	101	95	89	131	124	121	94	108	115
10	105	108	109	109	94	110	125	100	132	103	111	116
11	106	110	112	108	94	142	100	100	100	103	113	118
12	107	104	110	100	99	83	135	123	124	95	109	117
13	105	103	104	105	99	110	121	109	106	96	108	116
14	109	109	114	103	92	122	157	100	112	101	119	119

Table 5.11 | Changes of average monthly air temperature on model HadCM2 by 2020 (deviations from basic norm, stations of Tajikistan and Kyrgyzstan)

Station number	Months											
	1	2	3	4	5	6	7	8	9	10	11	12
1	109	110	105	99	105	112	110	116	104	106	112	109
2	105	108	105	102	107	111	108	108	104	103	110	105
3	112	111	107	100	101	132	115	128	118	112	114	112
4	107	106	105	98	111	125	115	108	112	112	118	107
5	107	104	107	99	108	169	136	141	108	110	121	107
6	104	108	105	99	100	155	115	134	108	105	113	104
7	107	112	106	100	108	159	136	136	110	115	120	107
8	106	103	103	100	103	105	111	119	116	110	133	106
9	114	113	106	100	96	149	134	146	111	114	126	114
10	109	109	107	98	130	166	100	154	120	114	110	109
11	110	110	107	99	155	100	100	100	124	115	108	110
12	108	112	104	100	102	163	136	154	113	114	121	108
13	107	107	107	100	118	137	111	119	111	111	116	107
14	111	116	106	100	140	196	100	142	130	123	115	111

CHAPTER 6

ASSESSMENT OF FUTURE CHANGES IN AIR HUMIDITY

6.1. Observed humidity trends

Humidity deficit is a difference between saturation vapor pressure and actual vapor pressure under given temperature. 6 stations were selected to describe man's impact on humidity regime. These stations characterize the following areas: Nukus station-irrigated Amudarya downstream; Tamdy station - central Kyzyl Kum; Tashkent station-sub mountain zone where urbanization influence is stronger; Dzhizak station - Golodnaya steppe, with irrigated area extended intensively over last decades; and, Chimbay and Muynak stations - Priaralie (besides, Muynak is the former near-shore station).

Autumn changes in average humidity deficit (data of these stations) are shown in Fig. 6.1. Though Nukus station is located not far from irrigated schemes, its humidity deficit trends are similar to those observed at Tamdy station. Long-term trends are not observed for winter and spring, while there is a tendency to deficit increase in summer and autumn. Humidity deficit tends to increase almost in all seasons at Tashkent station, and Dzhizak station records anthropogenic decrease of humidity deficit. Humidity deficit trends are practically unequivocal in Priaralie - as the sea depletes, humidity deficit grows in all seasons and amplitude of fluctuations increases. It is even visible that homogeneity of observational series breaches. This is connected with the regression of the Aral Sea.

Thus, humidity deficit is very climate-sensible indicator of drought. If local man's impact is absent, this indicator fixes tendencies to increased aridity in autumn-summer period.

Evaporativity. Evaporativity behavior in particular seasons was estimated by N.N.Ivanov's formula with L.A. Molchanov's adjustments for conditions of Uzbekistan (Spektorman and Nikulina, 1998; Applied statistics guidebook, 1989)

$$E_m = 0{,}00144\ (25 + T)^2 \cdot (100 - a), \qquad (1)$$

Where *T* - is average monthly temperature, *a* - is average monthly relative humidity. Calculation of actual evaporation is specific and very complex problem (Spektorman, 2002). However, value calculated by formula (1) is an objective test for assessing potential evaporation trends in given meteorological conditions.

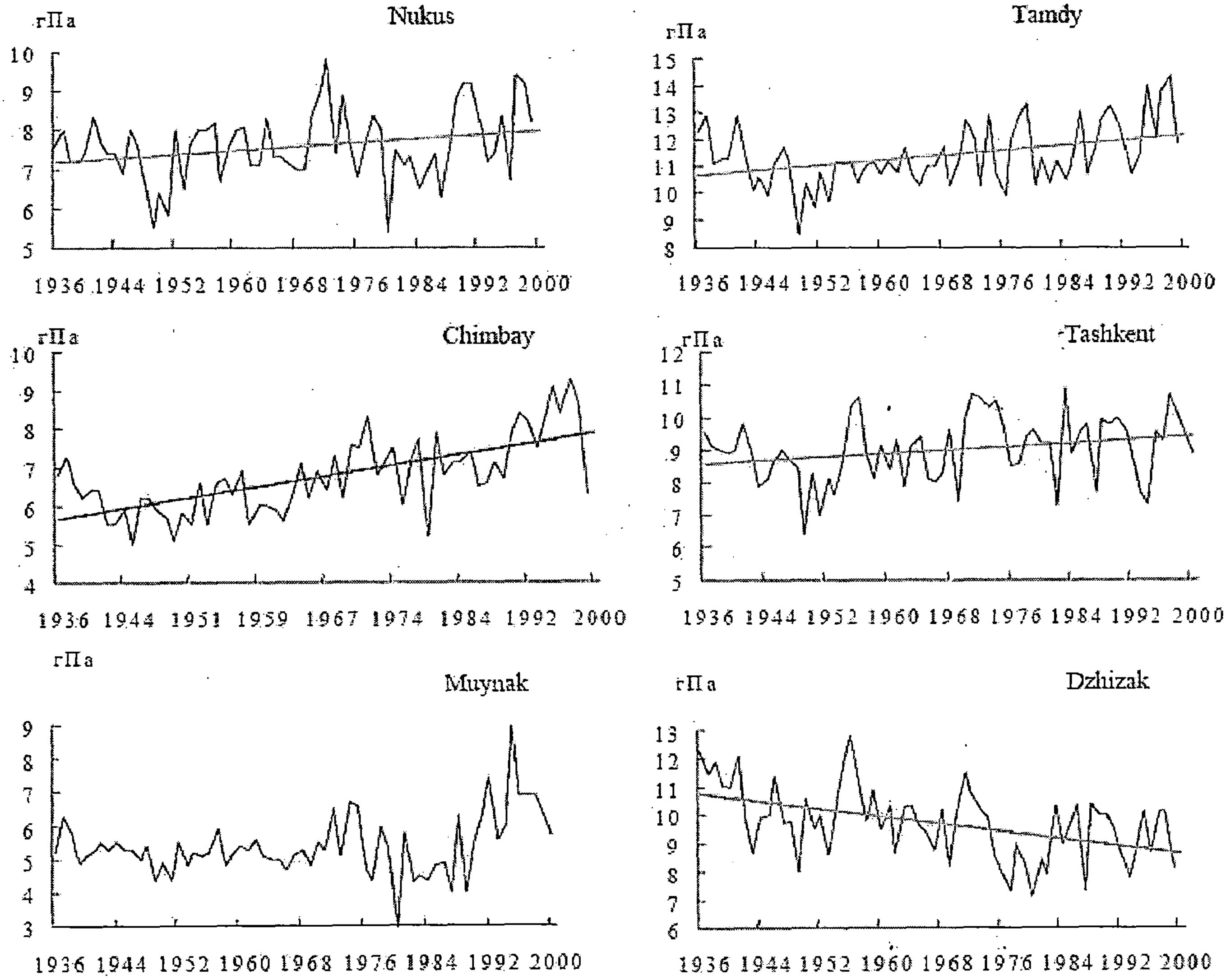
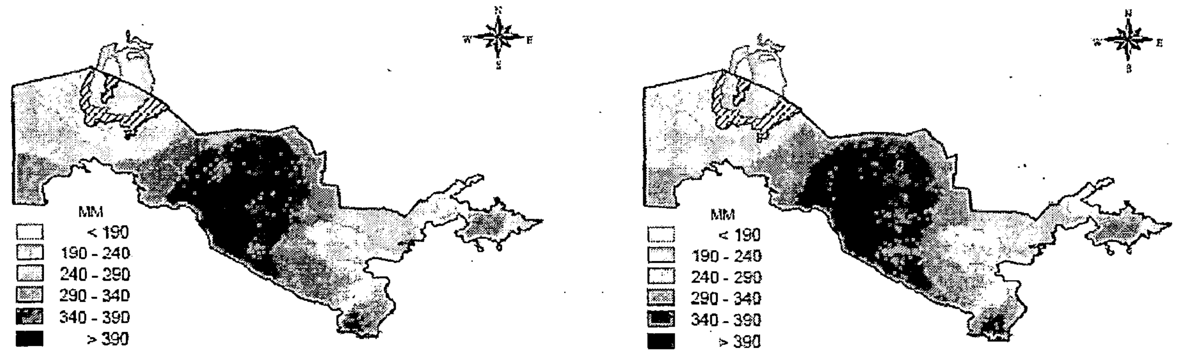
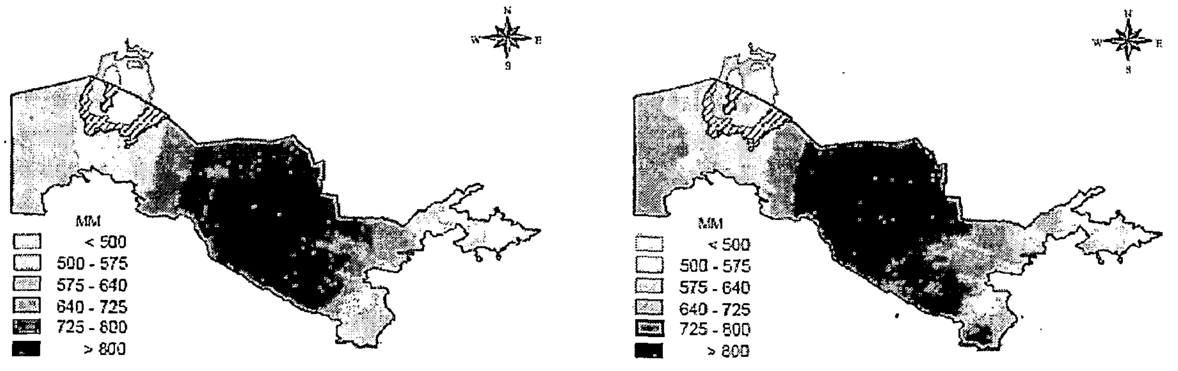


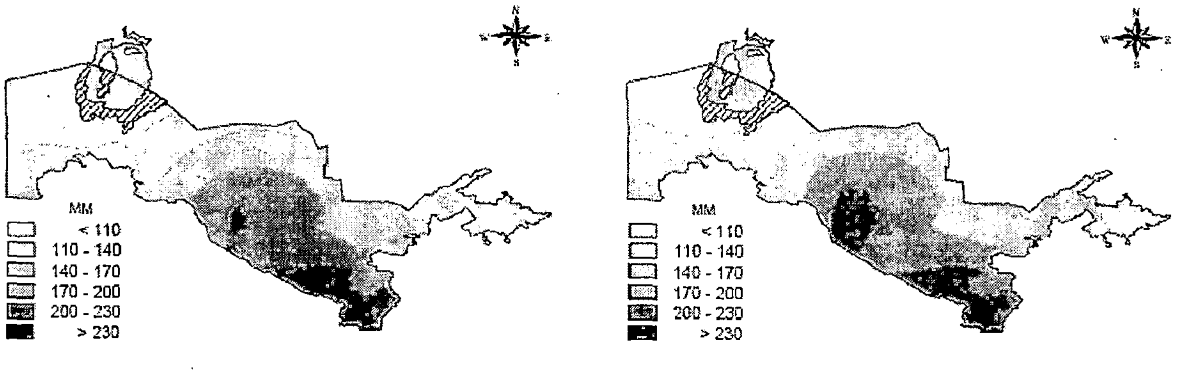
Fig. 6.1 | Changes of average autumn humidity deficit by weather stations located in Uzbekistan



1940-1969 Spring 1970-1999



1940-1969 Summer 1970-1999



1940-1969 Autumn 1970-1999

Fig. 6.2 | Evaporation values computed for various 30-years period

The minor difference between evaporation values computed for various 30-years periods is observed in spring. In summer an increased evaporativity is observed during 1970-1999. Besides Priaralie, evaporativity increases over the whole plane area in the republic, including Fergana Valley and Valleys of Surkhandarya and Kashkadarya. Only in Golodnaya Steppe evaporativity decreases under influence of human-induced changes Fig. 6.2. Area, which is characterized by maximum seasonal evaporativity during current 30-years period, has covered essential plane zone of Uzbekistan. Trends observed in summer are particularly important since they make major contribution to annual total. Autumn is also characterized by the increase of in posse evaporation.

6.2. Experiment on humidity estimation under climatic scenario

On a basis of "ideal forecast" conception an attempt was made to develop scenario of absolute specific humidity changes based on relationships with average monthly air temperatures.

Computation of prospective changes in air humidity under scenario conditions was based on regression equations formulated on a basis of actual data. Table 6.1 gives cumulative correlation coefficients for particular stations in Uzbekistan. Given correlation coefficients indicate to the close relationships during winter and spring months. This allows us to obtain reliable estimations of air humidity changes on a basis of average monthly temperatures.

Table 6.1 | Cumulative correlation coefficients (R_{svod}) used under inclusion of three predictors in the equation of regression to compute water vapor pressure (absolute specific humidity)

Station	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
Zhaslyk	0.89	0.86	0.76	0.37	0.42	0.37	0.39	0.46	0.36	0.68	0.73	0.85
Chimbay	0.88	0.88	0.80	0.58	0.43	0.43	0.24	0.38	0.63	0.71	0.67	0.92
Akbaytal	0.81	0.85	0.66	0.32	0.31	0.52	0.55	0.44	0.45	0.53	0.69	0.86
Tamdy	0.79	0.87	0.59	0.46	0.47	0.39	0.30	0.49	0.36	0.53	0.72	0.79
Samarkand	0.73	0.89	0.57	0.63	0.68	0.12	0.26	0.79	0.15	0.5	0.42	0.72
Karakul'	0.84	0.89	0.69	0.41	0.48	0.34	0.48	0.49	0.36	0.56	0.71	0.8
Dzhizak	0.84	0.91	0.71	0.51	0.57	0.53	0.58	0.55	0.44	0.47	0.41	0.78
Tashkent	0.79	0.84	0.67	0.67	0.63	0.30	0.39	0.62	0.42	0.54	0.65	0.83
Pskem	0.33	0.73	0.66	0.68	0.45	0.32	0.46	0.33	0.38	0.58	0.66	0.73
Ferghana	0.72	0.86	0.57	0.65	0.77	0.46	0.29	0.67	0.55	0.62	0.62	0.79

It should be noted that, in spite of temperature, air humidity for continental regions depends mainly on general atmospheric circulation pattern. In summer and autumn, when there is no outside humidity inflow, which is characteristic of Uzbekistan, relationship between temperature and absolute specific humidity becomes weaker but considerable inverse relationship arises between temperature and relative humidity Table 6.2 (Scientific-applied guidebook on climate, 1989).

Table 6.2 | Coefficients of correlation between average monthly temperatures and relative humidity by weather stations

Station	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
Chimbay	0,04	-0,1	-0,57	-0,63	-0,70	-0,79	-0,82	-0,8	-0,72	-0,58	-0,34	-0,06
Tamdy	-0,28	-0,25	-0,50	-0,54	-0,57	-0,57	-0,62	-0,55	-0,55	-0,61	-0,4	-0,28
Tashkent	-0,59	-0,57	-0,67	-0,73	-0,80	-0,83	-0,83	-0,78	-0,85	-0,78	-0,64	-0,57
Ferghana	-0,33	-0,38	-0,71	-0,72	-0,79	-0,79	-0,8	-0,8	-0,83	-0,76	-0,57	-0,39
Samarkand	-0,57	-0,49	-0,71	-0,73	-0,76	-0,80	-0,84	-0,77	-0,81	-0,81	-0,67	-0,62
Termez	-0,64	-0,65	-0,73	-0,82	-0,81	-0,81	-0,82	-0,79	-0,84	-0,82	-0,64	-0,64

Obtained results indicate to a need for further developmental works on estimation of humidity parameters under climate change. Additional complexity during estimation of humidity changes in Uzbekistan is caused by various local manmade impacts (depletion of the Aral Sea, presence of irrigation systems and irrigated schemes, appearance of artificial lakes). It is necessary to continue with study and estimation of humidity changes subject to local man's impact that breaches homogeneity of humidity observational series.

Developed regression equation methods allow us to provide preliminary estimation of humidity changes under climatic scenario. For practical purposes as a scenario of relative humidity for short-term the values averaged over last decade may be used, as an analogue of future climate warming Table 6.3. Sequence of stations corresponds to the list given in section 5.4, Table 5.3.

Table 6.3 | Average values of relative humidity (%) over 1991-2000 by 50 stations in Uzbekistan

Station	Month											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1	87	85	78	57	53	44	42	40	48	59	79	88
2	78	74	67	51	47	40	36	37	41	51	69	77
3	71	67	59	47	45	42	41	44	48	53	63	71
4	80	76	72	59	56	47	43	46	54	59	70	78
5	79	72	61	49	49	46	48	48	51	54	69	79
6	84	81	75	64	61	54	53	50	58	62	75	83
7	80	73	64	52	49	45	47	50	53	58	72	80
8	84	78	66	54	51	45	46	49	52	57	73	83
9	79	72	58	42	39	30	29	30	33	44	66	79
10	72	68	56	43	37	29	24	24	28	36	59	71
11	55	52	45	39	35	31	29	31	35	38	45	54
12	80	75	63	50	40	31	27	27	31	46	68	79
13	71	64	53	47	39	33	32	33	37	43	64	68
14	76	75	72	62	57	45	41	41	47	58	68	73
15	83	81	77	67	59	47	42	42	50	60	76	84
16	80	76	69	57	51	40	36	39	48	57	68	75
17	78	75	69	59	53	40	35	37	46	60	72	76
18	81	74	65	53	45	37	37	39	43	53	67	79
19	78	72	62	50	44	36	35	36	42	52	67	77
20	82	76	63	47	38	27	25	23	28	41	67	79
21	78	75	70	61	53	39	36	37	43	52	67	78
22	79	78	77	69	57	45	41	42	47	60	73	80
23	67	67	66	57	50	35	29	28	32	42	54	60
24	72	70	68	62	56	41	37	39	47	56	65	71
25	79	75	75	68	62	53	52	56	60	65	73	76
26	69	65	64	53	42	32	34	36	40	47	57	63
27	63	63	63	58	55	49	45	45	52	56	58	60
28	67	64	64	58	53	45	45	48	50	56	63	65
29	76	70	70	58	46	36	34	37	44	54	67	75
30	63	67	71	66	60	46	41	39	45	55	60	60
31	72	71	68	61	56	46	44	45	50	60	69	71
32	79	78	72	63	56	44	43	46	50	60	73	79
33	83	81	75	67	63	49	41	41	46	59	75	81
34	79	79	76	65	60	43	34	34	40	53	70	78
35	72	73	76	72	69	60	51	47	53	60	66	69
36	73	68	63	59	58	48	44	44	49	59	69	72
37	81	76	68	60	56	45	44	45	48	57	71	80
38	87	84	76	69	65	56	58	63	65	69	79	86
39	85	80	71	63	59	49	47	50	54	63	76	85
40	80	76	73	65	60	50	51	57	61	69	77	80
41	88	83	76	70	65	58	59	62	64	72	82	88
42	69	68	67	60	62	54	47	39	41	53	65	70

43	57	61	68	62	61	49	43	39	42	50	56	56
44	72	72	75	72	65	61	57	49	49	59	69	71
45	83	76	64	54	48	42	39	39	44	58	72	83
46	80	75	67	60	56	49	47	49	53	64	74	82
47	85	79	70	62	58	51	54	59	61	68	79	86
48	87	81	72	64	58	51	52	56	62	69	80	88
49	79	72	67	61	54	47	48	53	56	62	74	83
50	82	76	68	61	59	52	56	58	63	68	75	84

CHAPTER 7

ASSESSMENT OF WATER RESOURCES CHANGES UNDER PROBABLE CLIMATIC CHANGES

7.1 General

Water resources play very important role in development of arid and semi-arid zones and their socio-economic well-being. Uzbekistan is major water consumer in Central-Asian region. Agrarian sector development on base of irrigated farming and other water uses have decisive meaning for Uzbekistan economy development.

Under uneven water resources distribution and their scarcity assessment of water resources and their changes under climatic factors is very topical.

Impact of probable climate changes on region's river mode can be evaluated using flow formation rather complete and reliable models of certain frequency and accuracy.

Flow formation model for mountainous rivers developed by SANIGMI allows taking into account main flow formation regularities and evaluating climatic changes impact on river flow, snow cover, glaciers within separate river basins (Agaltseva and Borovikova, 1999 and Agaltseva and Pak, 1998).

Set of models includes model of snow cover formation in the mountains, model of glacier flow and model of snow, glacier and rain transformation into flow. It takes into account major regional peculiarities of flow formation zone located in high mountains of Tyan-Shan. and Pamir-Alai.

For set of models practical use automated information system has been created. Numerical experiments are carried out with series of meteorological scenarios to assess model response to meteorological elements impact (their values and temporal distribution). To evaluate climatic impact on water resources flow formation zones of large and small rivers were selected having different types of recharge within Amudarya and Syrdarya basin: Pskem, Chatkal, Akhangaran, and inflow to Charvak reservoir, Kurshab, Tar, Yassy, Karakulja in Syrdarya basin and Vakhsh and Zeravshan in

Amudarya basin. Vakhsh River has glacier-snow recharge and Akhangaran River has snow-rain recharge.

As to climatic scenarios, documents of IPCC show that methods of reliable forecast of troposphere and climate as a whole temperature change are not yet available. All proposed assessments present options of climatic system response to green house effect, which are called "climatic scenarios"

Prediction of future earth climate change as a whole and for separate regions is not a goal of climatic scenarios. Climatic scenarios are developed for evaluation of potential vulnerability of regional ecosystems and socio-economic sectors and reaction strategy development. Because climatic scenarios are accompanied by high uncertainty, it is expedient to use several climate change scenarios for vulnerability assessment.

For physical processes modeling determining global climate, three-dimensional numerical models of general atmosphere circulation (AGCM) are considered as the most reliable tool. Presently, there are at least 20 AGCM, which can potentially provide agreed and physically plausible assessments of global climate changes (Perziger, 1999 and Chub, 2000)

Recent combined climatic models "atmosphere-ocean" development permits use them for evaluation of future climate and quantitatively evaluate impact of green house gases concentration increase in the atmosphere. Such models are being developed in leading climatic centers and IPCC recommends use these results for the regional climatic scenarios building.

According to IPCC suggested scenarios (IS92a, IS92b, IS92c, IS92d, IS92e, and IS92f), there is the same number of global air temperature increase options. Each option has own uncertainty limits.

In conditions of Uzbekistan for each scenario of emission and each season set of values has been obtained determining model forecast of temperature changes since 2000 till 2030. Because of small difference in effect on temperature scenarios "a" and "b", "c" and "d", "e" and "f" were united in pairs. As to probable precipitation change, only annual sum of precipitation for different scenarios in mountainous territories at 2030 were obtained.

Results of calculations presented in Table 7.1 permit to assume that in case of considered scenarios realization at 2030, significant changes of water resources are not expected. In Amudarya basin their reduction by 2-4% and in Syrdarya basin their increase by 3-4% are probable.

Table 7.1| Norms and probable river flow changes in Central-Asian region by 2030 under various climatic scenarios

River	Q	Q norm	Q % of norm for various climatic scenarios		
			IS92ab	IS92cd	IS92ef
Akhangaran	Q veg Q an	33,8 20,9	103 106	102 103	106 109
Chatkal	Q veg Q an	179 112	103 105	102 103	105 106
Pskem	Q veg Q an	118 73,5	98 99	98 99	95 98
Inflow to Charvak reservoir	Q veg Q an	297 185	98 100	98 99	93 97
Vakhsh	Q veg Q an	944 547	97 97	94 94	98 98

Taking into account high scenarios uncertainty in precipitation (annual sum of precipitation without distribution between the seasons is given in scenario); it is expedient to make calculations without regard for precipitation. Results of such calculations are presented in Table 7.2. They show trend of flow maintenance at existing level and even its small reduction.

Table 7.2 | Norms and probable river vegetation flow changes in Central-Asian region by 2030 under various climatic scenarios

River	Q	Q norm	Q % of norm for various climatic scenarios		
			IS92ab(t)	IS92cd(t)	IS92ef(t)
Akhangaran	Q veg Q an	33,8 20,9	96 99	97 99	94 98
Chatkal	Q veg Q an	179 112	97 99	98 99	92 97
Pskem	Q veg Q an	118 73,5	98 99	98 99	95 98
Inflow to Charvak reservoir	Q veg Q an	297 185	98 100	98 99	93 97
Vakhsh	Q veg Q an	944 547	97 97	94 94	98 98

7.2 Climatic scenarios use based on models of general atmosphere circulation

Anthropogenic climate changes can be accepted as scenarios obtained through equilibrium models of general atmosphere circulation under CO_2 concentration doubling. Model GFDL is developed in Geophysical Laboratory of Fluid Dynamics (USA), model GISS - in Goddard Institute of Space Research (USA), and model UKMO - In Meteorological Agency in UK, model CCCM - in Canadian Climatic Center.

Results of air temperature near the earth surface, precipitation and radiation computation corresponding to current CO_2 concentration are control running and show model capability to produce real climate. Under CO_2 concentration doubling computations relate to state of equilibrium and assess climate changes occurring under CO_2 concentration doubling (it is possible by 2050-2075) (Chub et al, 1999).

Model scenarios of seasonal precipitation changes in percent of 1951-1980 basic norms for Uzbekistan and adjacent mountainous territory under CO_2 concentration doubling are shown on Fig. 7.1.

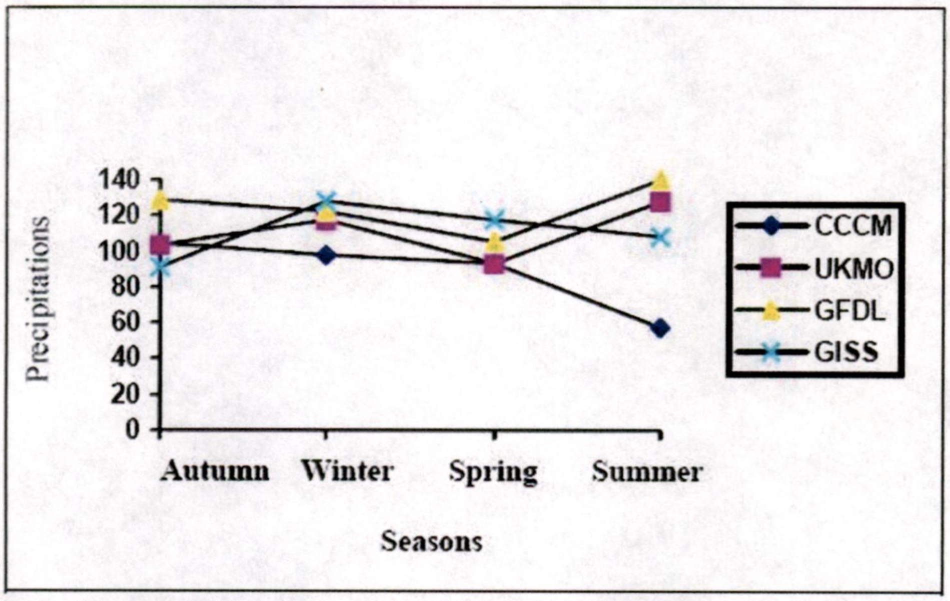


Fig. 7.1 | Model scenarios of probable precipitation changes in percent of 1951-1980 basic norm for Uzbekistan and adjacent mountainous territory CO_2 concentration doubling

In Table 7.3 results of surface water resources changes under various climatic scenarios are given. Model CCCM gives maximum discrepancies with real climate in control running and presents the strictest scenario giving maximum climate aridization.

According to this model, under CO_2 concentration doubling significant average annual temperature increase is probable; precipitation in mountain and foothills will be 95-98%.Vegetation flow will reduce by 40-50% on small rivers and by 15-20% on large ones.

Unfavorable situation can occur in case of climate changes development in accordance with model UKMO. In this case surface resources can reduce by 15-20%.

According to scenario GFDL average annual precipitation will increase by 24% and water resources can increase by 5-10% that coincides with scenario GISS.

Analysis showed that under climatic scenarios CCCM and UKMO evaporation from basin surface can increase by 20-22% as well as under scenarios GFDL and GISS - by 10 -15% of norm. Spring flood will be shifted by one month. For rivers of snow-rain recharge peak flow can occur in April. In result of warming share of rain will increase.

On Fig. 7.2 - 7.3. Akhangaran and Kugart rivers' hydrographs are presented as an example. Peak flow shift is evident on these hydrographs. It should be taken into account that modeling results are not predictive. These are computations of river low under different climatic scenarios, which are being further developed.

Table 7.3 | Surface water resources changes in river basins of Central Asia under anthropogenic climate changes within the model of general atmosphere circulation

River	Q	Q norm	Surface water resources change, %			
			GFDL	GISS	UKMO	CCCM
Akhangaran	Qveg	33,8	+1	-4	+8	-41
	Qan	20,9	+12	+12	+20	-16
Chatkal	Qveg	179	+8	-3	-4	-27
	Qan	112	+11	+7	+3	-11
Pskem	Qveg	118	+18	+13	-3	-9
	Qan	73,5	+13	+12	+2	-4
Inflow to Charvak reservoir	Qveg	297	+11	+3	-2	-17
	Qan	185	+12	+9	+3	-7
Vakhsh	Qveg	944	+16	0	-11	-27
	Qan	547	+12	+1	-7	-12
Kugart	Qveg	28,6	-7	-12	-29	-48
	Qan	18,4.	+2	+4	-11	-27
Zeravshan	Qveg	257	+6	-4	-19	-30
	Qan	158	+10	+5	-3	-15

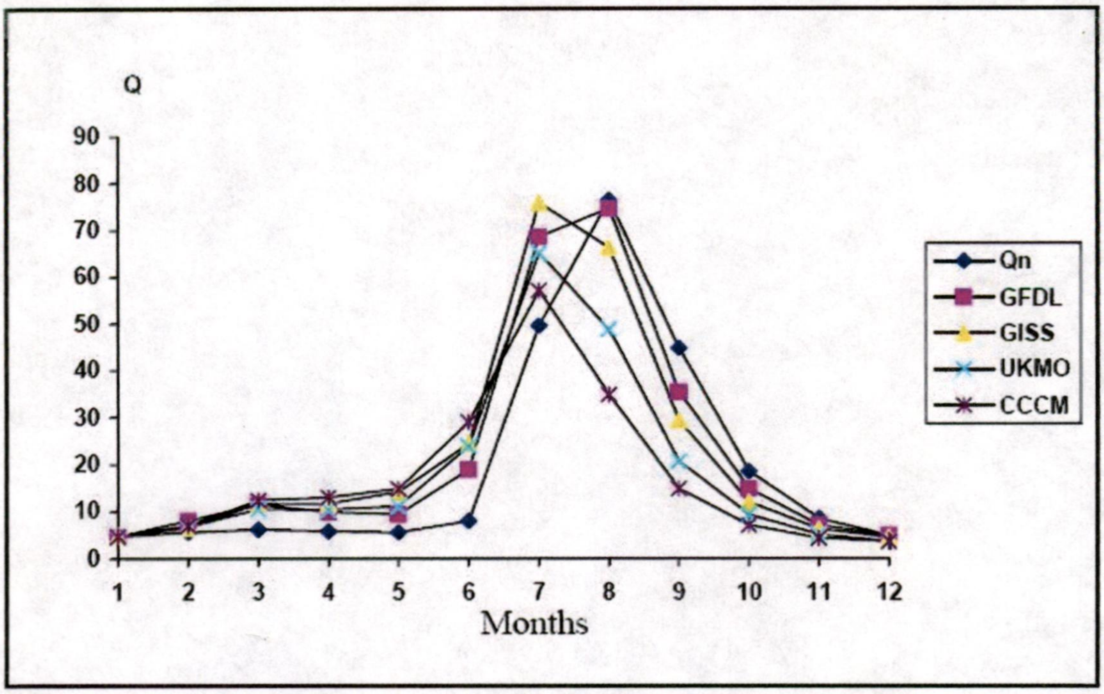


Fig. 7.2. | Hydrographs of Akhangaran river flow under climatic scenarios based on general atmosphere circulation

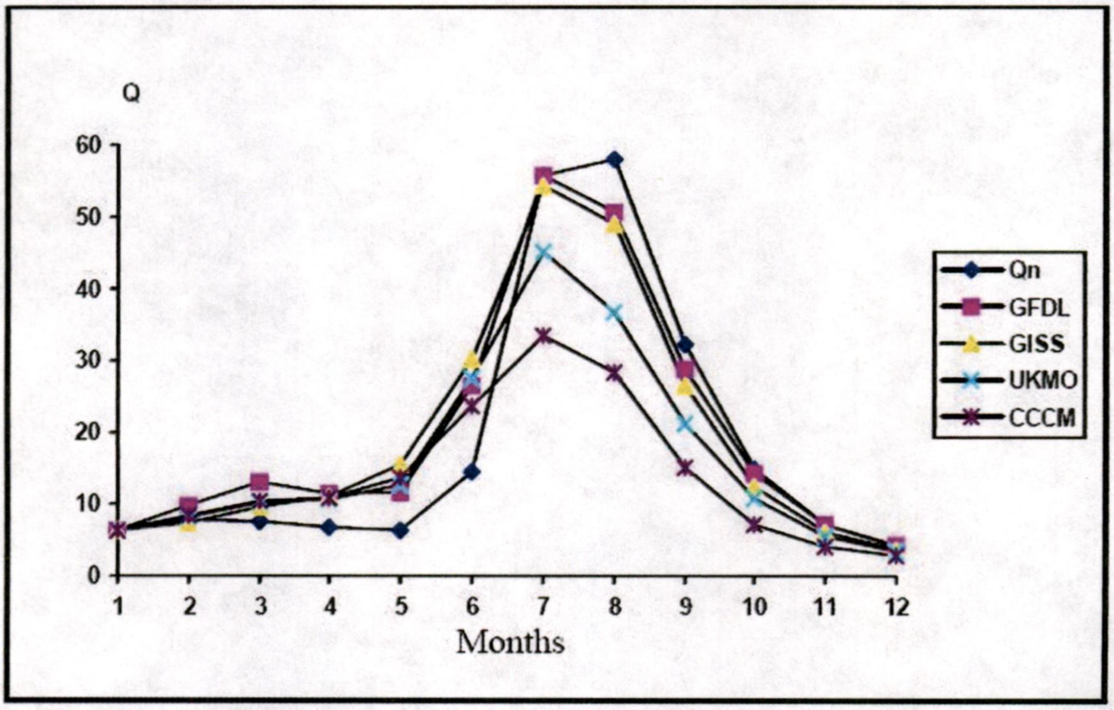


Fig. 7.3. | Hydrographs of Kugart River flow under climatic scenarios based on general atmosphere circulation

Since goal is to build regional climatic scenarios for the nearest future, transition models ECHAM4 and HadCM2 described in Chapter – 4 were used.

Table 7.4 shows vegetation flow changes computed under transition and regional scenarios realization are presented.

Computations on mathematical model of mountainous rivers flow formation under above scenarios realization allow to assume that within range of climatic parameters under consideration during 20-30 years water resources change will not be significant. But under climate warming average vegetation water discharge reduction will be observed. Probable flow changes will be within +3 to – 2...7%.

Table 7.4 | Norms and probable vegetation flow changes in the rivers of Central-Asian region by 2025 under various climatic scenarios

River	Q	Q norm	**Q % of norm for different climatic scenarios**		
			ECHAM4	**HadCM2**	**IS92ab(t)**
Chatkal	Qveg.	212	92	97	88
Pskem	Qveg.	126	99	103	105
Inflow to Charvak reservoir	Qveg.	338	94	99	94
Vakhsh Inflow to Nurek reservoir	Qveg.	984	93	95	93
Zeravshan	Qveg.	258	99	97	93
Karakulja	Qveg.	39,1	97	97	99
Yassy	Qveg.	39,8	96	96	99
Kurshab	Qveg.	26,7	96	98	99
Tar	Qveg.	76,9	96	99	101
Inflow to Andijan reservoir (sum of 4)	Qveg.	182,5	96	98	100
Inflow to Toktogul reservoir	Qveg.	595	590	586	581

7.3. Evaluation of river watershed sensitivity to natural and anthropogenic changes of climatic parameters

Region rivers differently response to climate warming because of their different sources of recharge. Snow recharge rivers flow decreases faster with temperature increase. Rivers with glacier recharge are more inert. At the same time, along with glaciers degradation more active flow reduction will occur.

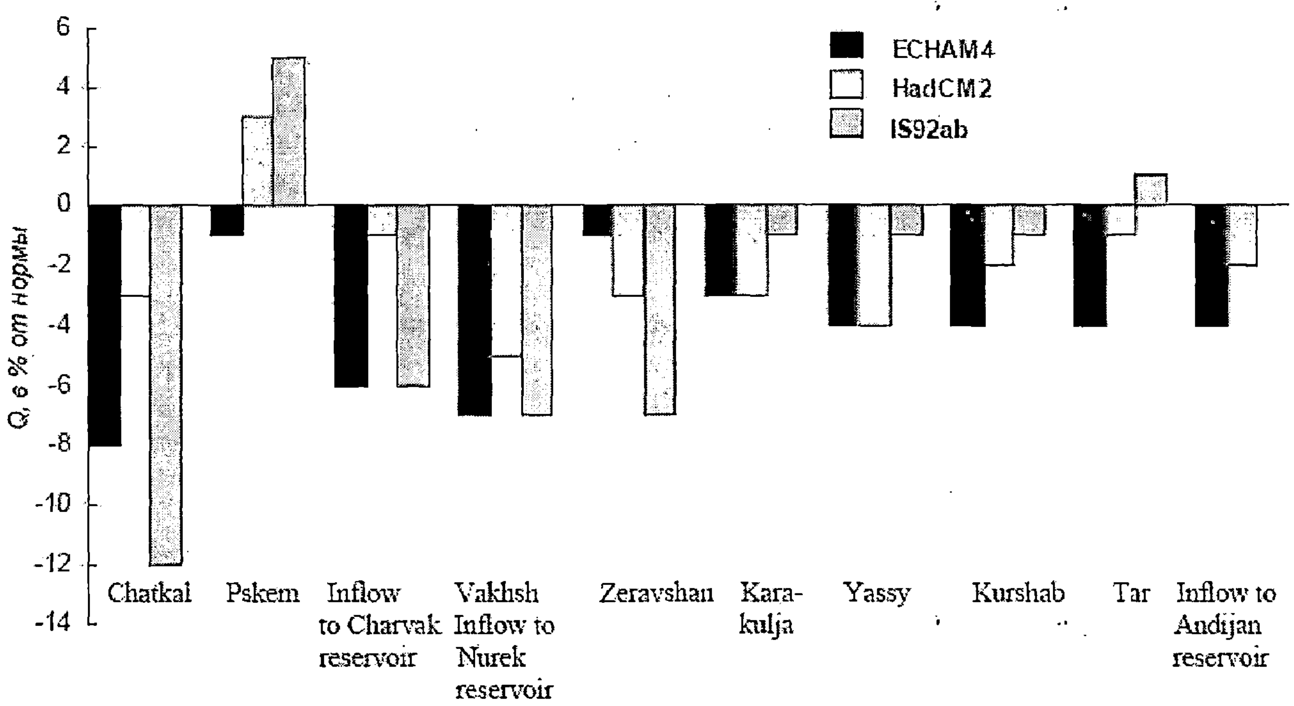


Fig. 7.4 | Evaluation of river watersheds sensitivity under various climatic scenarios

On Fig. 7.4 some rivers-indicators flow changes under “transition” and regional climatic scenarios are presented. Inflow to Charvak reservoir (Syrdarya basin) and Nurek reservoir (Amudarya basin) is presented on Fig. 7.5 as an example of integral characteristic.

In Table 7.5 Amudarya and Syrdarya flow integral assessment based on numerical experiments with basins-indicators under “transition” and regional climatic scenarios is given.

Results show that significant river flow reduction will not occur. Flow fluctuation increase between different years can be expected.

It can be assumed that period up to 2025 will be interrupted by dry years similarly to the last decade. Complex hydro meteorological situation of 2000 can serve as analogue. Dryness of this year is caused by low precipitation in flow formation period and high air temperature. To verify models basing on precipitation and air temperature, Chatkal and Pskem rivers hydrograph for 2000 has been compute.

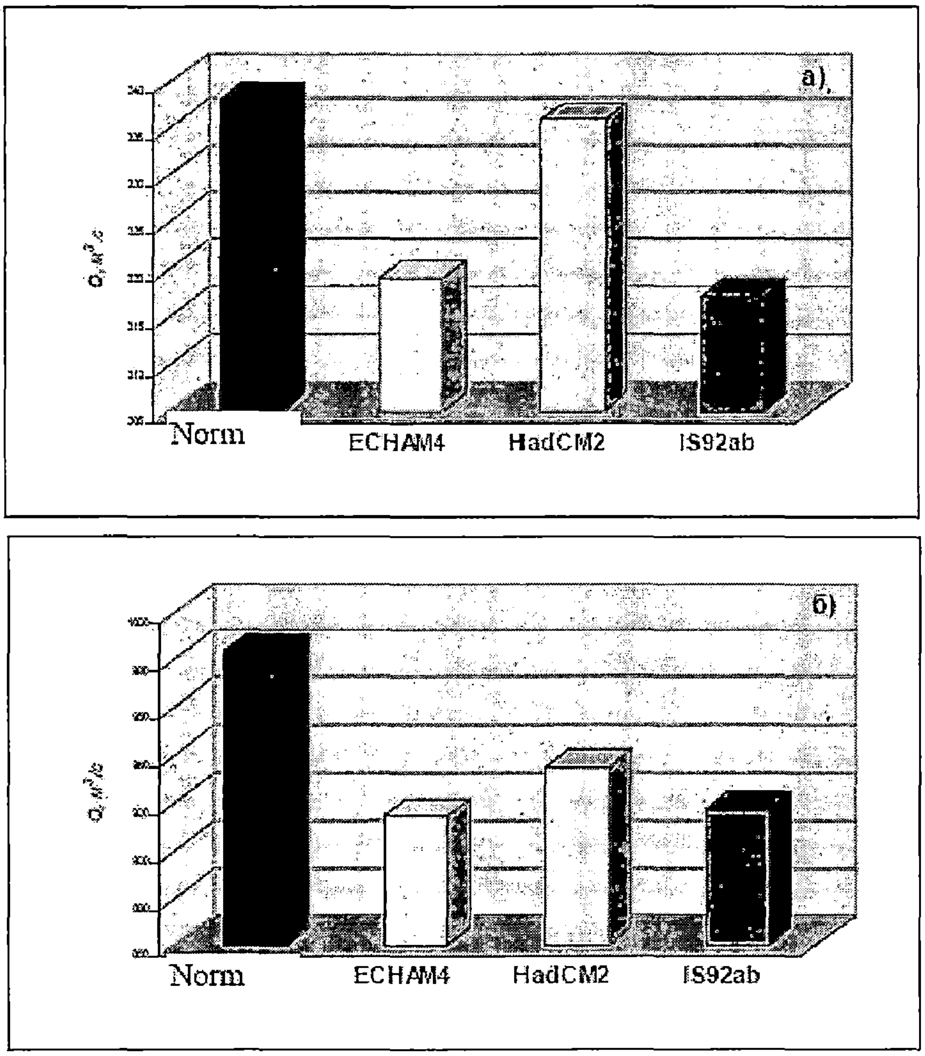


Fig. 7.5 | Changes of inflow to Charvak (a) and Nurek (b) reservoirs under various climatic scenarios

Table 7.5 Expected water resources change in main rivers of the Aral Sea basin under various climatic scenarios (% of basic norm)

River	Basic nom (km3/year)	Climatic scenarios		
		ECHAM4	HadCM2	IS92ab
SyrDarya	37,9	-2	-1	-2
AmuDarya	78,5	-3	-3	-4

On Fig. 7.6 actual and computed hydrographs are presented compared with average annual values.

According to GLAVGIDROMET data, average annual air temperature in Uzbekistan in 2000 was higher compared with climatic norm. This year like 1941 was the warmest for all observation period. Analysis of annual precipitation changes shows that 2000 was very dry.

Similar situation can lead to extremely dry years when significant flow reduction is possible.

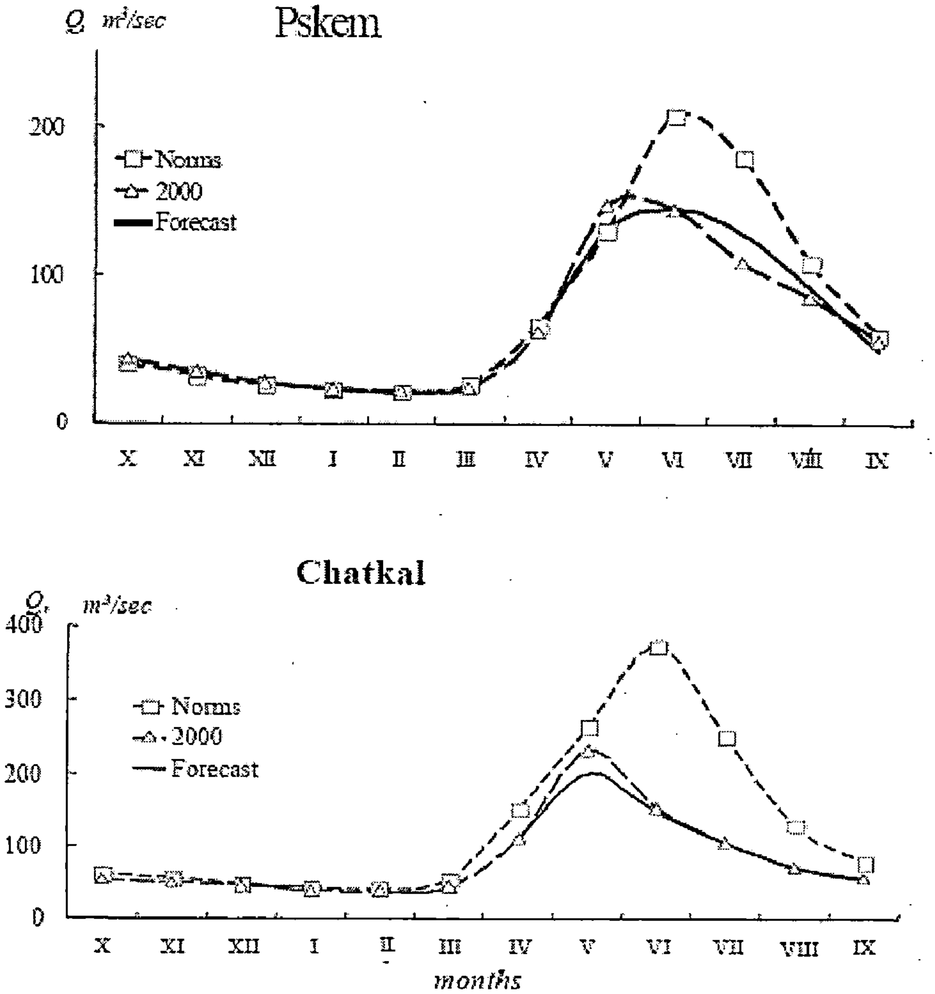


Fig. 7.6 | Actual and predicted hydrographs compared with average annual values

1 - Pskem; 2 – Chatkal

7.4 Glaciers and climatic changes

Presently, glaciers shrinking are under consideration. What is the cause: green house effect or climatic cycles?

According to V.M. Kotlyakov, during the last 420 thousand years there were 4 climatic cycles. Cold periods were longer than warm ones. Because of different causes temperature sharply reduced and fell with difference up to 10°C. Even during the last millennium temperature fluctuations amounted for 1.5-1.0°C. VII, XVI, XX centuries were warm as well as XIII-XV and XVII-XIX centuries were cold. Present warming does not come beyond natural fluctuations in spite of higher green house concentration (Chub and Ososkova, 1999).

Glaciers located in the mountains are main source and long-term reserve of fresh water. But ice stock is not stable. Presently, glaciers retirement is observed: small glaciers disappear and large ones are being broken. Glacier shrinking leads to snow melt flow reduction.

Observations in various glacier regions showed that flow reduces slower than glacier area. Actual area of glacier grows due to its separation.

Different researches note incompliance between snow melt increase and glacier area reduction. Scientists have found that "long-term flow changes linked with glaciers degradation are shadowed by snow melt increase in dry years: glacier area decreases and flow increases"

Glaciers differently response to air temperature increases. Calculations performed for summer temperature change by 0.5°C and 1°C and annual precipitation by 20% showed that temperature change by 1°C leads to change of firn ice border change on 120.140 m. The same effect gives precipitation reduction by 20%.

These characteristics effect on glacier area is more complicated. Maybe it depends on precipitation distribution and relief structure. These factors change much for various basins and lead to different results.

For instance, temperature increase by 0.5°C leads to glacier area in Sokh and Isfara basin reduction by 8%, in Margilandaya, Kashkadarya and Oihangs basin by 30%. Temperature increase by 1°C reduces glacier area twice. It worth to remind that long-term temperature change influence is difficult to find.

If to consider glacier evolution during last 50 years and compare data on glacier morphometry in USSR Catalogue (1965-1982) with ground observations and aerospace images, some glaciers show stationary state and even increase (liner size increase, .dead tongue. animation). For main mass of glaciers signs of reduction are typical: glaciers with area less than 1 km^2 disappear, large glaciers are broken into small ones, morena area glacier and pollution increase.

Glacier response to climatic parameters (temperature, precipitation) changes has inert character: lag depends on area (0-10 years).

It is necessary to note following peculiarities of glacier flow:

Firstly, its share depends on snow amount during preceding winter and winter ablation. In low snow years glaciers are spent for flow compensating lack of snow melt and rain.

Secondly, glacier flow reaches maximum in July-August when other water sources (seasonal snow and rain) are exhausted.

If big glaciers are located in flow formation zone and glacier recharge exceeds 5-10% of total annual inflow, calculation without regard for glacier flow leads to big discrepancies in mountainous river flow modeling. For that model of glacier flow formation is included in a set of models because it computers total flow from glaciers including snow melt, ice and firn.

For description and calculation of total melt water all glaciers within region under consideration are considered as single ice area. Dependant of basin size within this area several rayons are excreted uniting multitude of similar glaciers. Mathematical and physical statistical models of snow and ice accumulation and melting within annual cycle are taken as a methodological base.

It is evident that river basin frozenness depends on relief and climatic conditions. It is known that for high mountains firn line is integral climatic indicator. Accuracy of frozenness assessment is determined by climatic scenarios reliability.

Frozenness response to climatic changes assessment was performed for Ghissar-Alai based on methodology described in Chub and Ososkova, 1999. Since in all scenarios temperature increase is assumed, all combinations of temperature (0, 1, 2, 3°C) and precipitation (-50%, 0%, 50%, 100%) changes were taken. Results showed that option is optimal when temperature is unchanged and precipitation is doubled. In this case firn line height reduces by 0.5km that will lead to sharp increase of glacier area and flow.

Option is the most unfavorable when precipitation decreases twice and temperature increases by 3°C: firn line goes up by 700 m; frozenness area reduces by 86%, glacier flow - by 96%.

Obtained results show that climatic conditions change under temperature increase by 1-2°C will lead to river flow reduction of both types of recharge.

Temperature increase by 1-2°C will accelerate glacier degradation process. For 1957-1980 glaciers within the Aral Sea basin lost 115.5 km3 of ice (near 104 km3 of water) that constitutes almost 20% of ice stock by 1957. By 2000 losses amounted for 14% of 1957 stock. By 2020-2025 glaciers will loose 10% more from initial volume.

Calculations of glacier flow done under “transition” scenarios (ICHAM, HADSM) showed that under those scenarios glacier flow reduction (3-5%) will occur by 2025 because under frozenness area reduction melting will occur at expense of melting layer increase.

CHAPTER 8

CONCLUSIONS

1. Results of calculation based on “transition” scenarios show that there will not be significant river flow change in the nearest future though some its reduction (2-6%) can be expected due to global temperature rise.

2. Due to climate aridization snow melt share will reduce by 5-10% (change of seasonal snow border, 2-4 weeks lag in snow cover melting).

3. Precipitation can increase by 7-10% that also negatively impacts snow stock. With precipitation increase soil erosion, mudflow and turbidity increase are probable.

4. Assessment of climatic conditions changes over Central Asia territory with account for available model assessments, regional analogous scenario and empirical-statistical approach show that we should expect some increase (from 0 to 20%) of total precipitation sums and temperature increase in all seasons of the year over Central Asia area, including flow formation zone, under realizing different GHG emission scenarios by 2030.

5. Obtained results show that climatic conditions change under temperature increase by 1-2°C will lead to river flow reduction of both types of recharge.

6. Temperature increase by 1-2°C will accelerate glacier degradation process.

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