2. The change in agroclimatic resources and their influence on agriculture

To analyze possible changes in agroclimatic resources as a result of climate change we have selected weather stations associated with agroclimatic groups and that characterize climatic conditions of particular planning zones:

Weather station	Planning zone
Urgench	Khorezm, Dashkhovuz, Lebap
Samarkand	Samarkand
Kattakurgan	Zarafshan, Samarkand
Navoiy	Navoiy
Bukhara	Bukhara, Akhal
Guzar	Kashakdarya, Mary
Termez	Surkhandarya, Vakhsh, Nizhne-Kafirnigan
Yangiyer	Golodnostepskiy, Yuzhno-Kazakhstna
Dzhizak	Dzhizak
Syrdarya	Syrdarya, Isfara, Khodzhent, Chakir
Ferghana	Namangan-Syrdarya, Andizhan, Yuzhno-Ferghana, Kampyr-Ravat, Severo-Ferghana

We made use of two regional climatic scenarios such as HadCM2 и ECHAM4 developed by using empirical-statistical method on a basis of relationships between values of average annual air temperature in case of greenhouse gas emissions under doubled CO_2 equivalent. Obtained data were compared with reference average long-term data. Forecast sees 0.3-2.0 ^{o}C increase of average annual temperatures in the region.

Scenarios of possible precipitation changes are based on expert evaluation. In-year precipitation is forecasted to be 105-120% of reference one.

Larger temperature changes (Annex, Tables 1-3, Fig. 2-6) are observed in northwest and utmost south parts of the region in Urgench and Termez weather stations (Khorezm, Surhandarya and Dashkhovuz planning zones). For central part higher increase of temperature is possible in Dzhizak and Syrdarya planning zones. Major temperature growth occurs in summer and winter. In general, average monthly temperature rises by 2 ^{o}C at a maximum.

Maximum temperature growth by 1,2-2,^{0}C is expected throughout the whole area in January and February. In central part 0,5-1^{0}C rise is expected in May. This can impact irrigation schedule. Autumn temperature will rise by 1-1,2^{0}C and 1,2-1,5^{0}C in central and southern parts, respectively. In the north temperature increase takes place till October that will change duration of growing season.

Maximum growth of precipitation is expected in mid-summer (Annex, Tables 4–6, Fig. 6–12). Maximum growth will amount to 80-110% in the north (by 10-15% in winter), while in central part it will amount to 40-80%. In the north increase in precipitation is expected one month earlier in summer. In winter precipitation is expected to increase by 10-20%, while in autumn it will grow by 15-30%. Absolute values of forecasted precipitation will be increased by 5-10 mm during January-April and August-December.

The climate warming and precipitation growth will result in changes in altitudinal and latitudinal climatic zones. Borders will move 150-200 m northward between dry tropical and temperate climate and 50-100 m between dry farming zone and dry lands with additional irrigation.

In general, regional agroclimatic resources will grow up.

Temperature rise is expected to result in prolonged growing season.

Sowing dates. Spring temperature growth rates and increase of soil moisture enables earlier spring sowings.

Table 1 gives dates of shifts in temperature through 3, 5, 10, 12, 15 ^{o}C, which are essential for sowing crops:

Cotton - higher than 10-12 ^{o}C

Gourds and melons - higher than 15 ^{o}C

Maize - higher than 10 ^{o}C

Alfalfa - higher than 5 ^{o}C

Grapes – higher than 5 ^{o}C

Rice - higher than 15 °C

Table 1 | Shift in air temperatures through given limits under current conditions (Reference) and under analog scenarios characterized by 1-2 °C rise of temperature

Province, station	Option	Dates of shift through given limits in spring					Dates of shift in autumn		
		3°C	5°C	10°C	12°C	15°C	3°C	5°C	10°C
Nukus	Ref.	12.03	19.03	2.04	8.04	18.04	20.11	10.11	18.10
	1	12.03	18.03	30.03	4.04	12.04	27.11	16.11	24.10
Andizhan	Ref.	26.02	4.03	22.03	28.03	9.04	27.11	19.11	26.10
	1	9.02	1.03	14.03	24.03	5.04	2.12	15.11	5.10
Bukhara	Ref.	14.02	2.03	19.03	29.03	9.04	15.12	28.11	2.11
	1	28.01	25.3	13.03	24.03	3.04	26.12	5.12	9.11
Dzhizak	Ref.	20.02	4.03	21.03	11.04	12.04	16.12	1.12	22.11
	1	30.01	1.03	14.03	24.03	5.04	30.12	20.12	11.11
Karshi	Ref.	10.02	22.02	14.03	27.03	9.04	20.12	11.12	10.11
	1	10.01	30.01	9.03	18.03	3.04	31.12	23.12	17.11
Navoiy	Ref.	4.02	1.03	20.03	1.04	10.04	20.12	5.12	4.11
	1	28.01	24.02	12.03	25.03	6.04	30.12	20.12	10.11
Namangan	R Ref.	24.02	5.03	20.03	28.03	8.04	3.12	24.11	1.11
	1	6.02	27.02	22.03	23.03	4.04	6.12	28.11	7.11
Samarkand	Ref.	20.02	5.03	25.03	3.04	15.04	18.12	2.12	2.11
	1	2.02	28.02	15.03	28.03	10.04	27.12	18.12	11.11
Syrdarya	Ref.	26.02	5.03	24.03	2.04	12.04	2.12	20.11	28.10
	1	15.02	1.03	15.03	25.03	8.04	20.12	25.11	2.11
Denou	Ref.	-	8.02	10.03	18.03	5.04	-	23.12	19.11
	1	-	10.04	2.03	10.03	1.04	-	3.01	26.11
Tashkent	Ref.	15.02	5.03	21.03	1.04	12.04	17.12	18.12	2.11
	1	20.02	26.02	12.03	23.03	6.04	27.12	28.12	10.11
Ferghana	Ref.	25.02	3.03	22.03	1.04	12.04	16.12	22.11	29.11
	1	15.02	28.02	14.02	24.03	5.04	30.12	27.11	5.11
Urgench	Ref.	8.03	11.3	28.03	6.04	14.04	24.11	14.11	21.10
	1	5.03	9.03	26.03	1.04	10.04	30.11	20.11	28.10

Dates of shift through given temperatures in autumn indicate to the end of growing season. Due to temperature growth, the dates of shift through biologically optimal limits of the beginning and the end of growing season will change. Difference in dates of temperature shift through 10, 15, 20 °C in spring and autumn between 10% and 90% probability grows up by 15-30 days on average throughout the irrigated area.

Guiding by average long-term dates of sowing, without regard for climate change, will lead to reduction of crop yields since 5-10 days shift in sowing dates against optimal ones reduces crop yields by 10-20% on average. This relates to the fact that the most critical period of crop formation takes place under higher air temperatures (Fig.2).

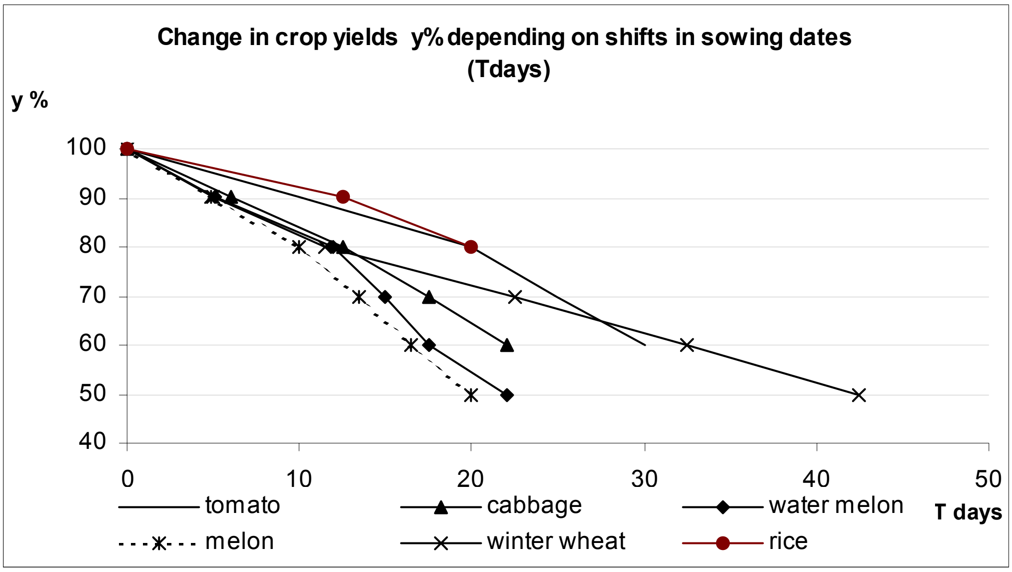

Fig. 2 | Influence of shift in sowing dates against optimal ones on crop yields

Crop development. Influence of agrometeorological conditions on rates of crop development is estimated by duration of crop phenological phases. We observe successive change of development phases, the development being irreversible. If due to external factors any phase does not take place in plant organism, the next phase will not begin even under optimal conditions.

The main factor influencing the rate of development is thermal conditions which are characterized by average daily air temperature.

For crop passing period between phases i and i+1 and for beginning phase i+1 a specific for this phase sum of average daily temperatures T^c_{i+1} is required, moreover T^c_{i+1} and threshold development temperatures are biological constants of given crop variety and do not depend largely on temperature fluctuations within a phase.

It follows from the above-mentioned that if fix dates of the beginning of the next phase i+1 T^c_{i+1} to an accuracy of 24 hours, then,

$$Ti+1 = ti + \delta i+1$$

where δi+1 is duration between phases i and i+1, which is found from the following:

$$F = \left| T^c_{i+1} - \sum_{l=1}^{\delta_i+1} T_l \right| \to \min_{\{\delta_{i+1}\}} ,$$

where, depending on calculation method, one or another average daily temperature (more than 0; 5 or 10°C relative to changing in ontogenesis thresholds, etc.) is used.

Table 2 gives total effective temperatures necessary for passing every next biological phase for main crop varieties in the region.

Calculation of cumulative values of effective temperatures allows us to determine duration of every crop development phase. Weather station Dzhizak, where considerable changes in climatic parameters are observed, was selected to demonstrate data analysis. As an example we show calculation of cumulative values of effective temperature (more than 10 ^{0}C), which was done for early-ripening, mid-season, and late-ripening varieties of cotton. Phenological phase is changed by another one when necessary total effective temperature is reached (Table 2).

Table 2 | Total effective temperatures for vegetation phases under sufficient soil moisture

1. Cotton (total effective temperatures more than 10^o)

Variety	Sowing - sprouting	Sprouting - budding	Budding-flowering	Flowering– opening of 1st cotton bolls	Sowing - opening of 1st cotton bolls
Fast-ripening	95	400	480	760	1735
Mid-season	100	425	500	850	1875
Late-ripening	100	480	530	1050	2160

2. Melon – water melon (more than 15^o)

Variety	Sowing-sprouting	Sprouting - flowering	Flowering-ripening	Ripening- last harvesting
Fast-ripening	50	290	500	190
Mid-season	70	340	660	170
Late-ripening	80	380	780	190

3. Maize (more than 10^o)

Variety	Sowing-sprouting	Sprouting – panicle emergence	Milky ripeness	Waxy ripeness
Mid-season	80	890	1300	1560
Late-ripening	80	1210	1670	1880

4. Alfalfa (more than 5^o)

Variety	Before budding	Before flowering	Before the first cutting
Mid-season	390	550	580
Late-ripening	410	650	730

5. Grapes (more than 5^o)

Variety	Swelling of buds	Start of flowering	Start of ripening
Mid-season	120	710	1520
Late-ripening	130	730	1920

6. Rice (more than 15^o)

Variety	Sowing - sprouting	Sprouting - tillering	Tillering - earring	Earing – waxy ripeness
Fast-ripening	210	480	400	210
Mid-season	270	620	640	250
Late-ripening	350	770	1920	280

Sowing-sprouting period

The period starts with the date of sowing. This date was determined on a basis of date of shift to given air temperature (10-12 ^{0}C). The sowing date shifts by 2 days against reference date.

Average long-term, reference option			
Start of growing season 03.04 End of growing season 29.10			
Phenological phase /Variety	Fast-ripening	Mid-season	Late-ripening
I. Sowing-sprouting	19	20	20
II. Sprouting-budding	43	43	47
III. Budding-flowering	28	29	30
IV. Flowering-opening of the first bolls.	42	48	64

Model HadCM4			
Start of growing season 01.04. End of growing season 31.10			
Phenological phase /Variety	Fast-ripening	Mid-season	Late-ripening
I. Sowing-sprouting	15	16	16
II. Sprouting-budding	41	43	47
III. Budding-flowering	29	30	30
IV. Flowering-opening of the first bolls.	40	45	57

Model Echam-4			
Start of growing season 01.04 End of growing season 31.10			
Phenological phase /Variety	Fast-ripening	Mid-season	Late-ripening
I. Sowing-sprouting	15	16	16
II. Sprouting-budding	40	42	46
III. Budding-flowering	29	30	30
IV. Flowering-opening of the first bolls.	39	44	56

Temperature rise in early spring reduces the sowing-sprouting period by four days. This will provide even sprouting. It is known that prolonged situation of seeds in soil leads to uneven sprouting and requires additional sowing or re-sowing. If duration of sowing-sprouting is 20-25 days, conditions for sprouting may be considered as satisfactory; 14-19 days, good; and, less than 14 days, very good.

Duration of sowing-sprouting period depends on available soil water. Fig. 3 shows relationship between period duration and air temperature/soil moisture.

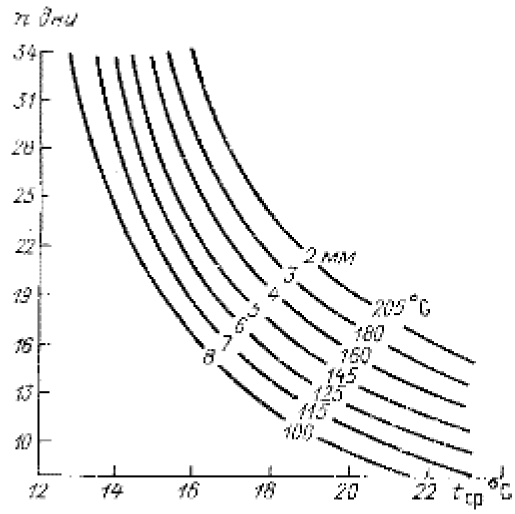

Fig. 3 | Relationship between sowing-sprouting and water- and heat- availability (Muminov, 1991)

In case of moisture shortage heat resources may not be fully used for plant development. Crops are sown in natural moisture conditions on less than 30% of area. Forecasted increase of precipitation will not change situation considerably. According to data from weather station Dzhizak amount of precipitation will rise by 24-26 mm during January-March. Under actual average evaporation from water surface of 0.3 mm, obtained additional amount of moisture will be lost through evaporation. Recharge irrigation is required to provide soil moisture at a level of 70% of FC during the period of sowing. Optimal date of recharge irrigation will depend on climatic and, to a large degree, on soil conditions, and may be calculated using daily balance method.

Sprouting-budding period is reduced by 1-2 days. Optimal for this period average monthly temperature of -21^{0}C is forecasted. However, rise in average daily temperature to 28-29^{0}C, showery rain, hail, and strong wind may lead to decrease of yields.

Reproductive period. The period consists of three sub-periods: budding-flowering, flowering-opening of the first bolls, opening of the first bolls-ripening. Agrometeorological assessment for this period is based on quantitative indices that link cotton development rates with heat availability factors. Considerable influence of heat availability for plants on development rates occurs mainly since the beginning of flowering phase. Duration of a period from flowering till opening of the first bolls has decreased by 1 day for fast-ripening varieties and by 1-2 days for mid-season ones. The largest period reduction (by 7-8 days) is observed for late-ripening varieties.

By data from weather station Dzhizak and due to climate change, cotton development period from sowing till opening of the first bolls is expected to decrease by 7-9 days for fast-ripening varieties; 6-8 days, mid-season; and, 11-13 days, late-ripening ones (Fig.4).

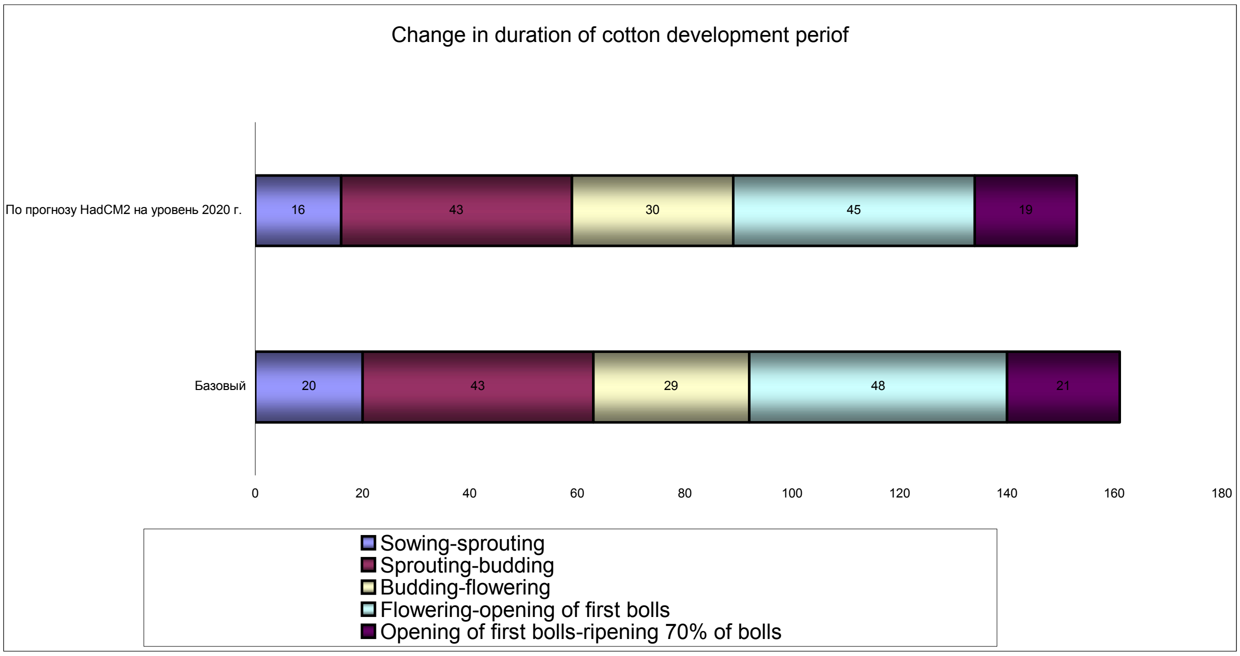

Fig. 4 | Decrease in duration of cotton phenological phases under climate change

Harvesting. Ripening of 70% out of a number of bolls formed by the opening of first bolls takes place under total positive daily temperatures of more than 400 ^{0}C for fast-ripening varieties; 500 ^{0}C, for mid-season varieties.

In simulations of phenological phases the first fast-ripening cotton bolls start to open on 21 August in reference option and on 15 August in scenario Had. The period, which is necessary for ripening of 70% of bolls, is computed on a basis of total average monthly temperatures and dates for harvesting are 11 September and 3 September, respectively. Dates of full ripening are 14 September and 19 September, respectively. Similarly, forecasts for mid-season and late-ripening cotton varieties can be made.

Above-mentioned analysis of cotton development, based on data from weather station Dzhizak, may be considered as an example that reflects general trends. The climate warming will change sowing dates and reduce periods of ripening for all crops.

Early harvesting of cotton will allow us to gather in guza-paya and to sow wheat not in cotton rows but in specially prepared soil in recommended dates: the second ten-days of September for the beginning and September 10 for completing sowing in northern provinces. Similarly, the third ten-days of September and October 20 in other provinces.

Crop yields. Increase in temperature and in carbon dioxide concentration is to impact positively crop growth and development.

The modified A.N.Polevoy's semiempirical model was used for forecasting yields. Evaluation of crop productivity and agrometeorological conditions of yield formation under given climatic scenarios is based on computing dynamics of crop biomass formation, including its productive part. At the same time, the process of yield formation is considered as the final stage in the set of physiological processes, intensity of which depends on biological characteristics of plants, changing (according to scenarios) external factors, and relationships between the processes themselves. Dynamic productivity model consists of photosynthesis block, respiration block, and growth block, thus enabling modification of the blocks depending on greenhouse gas concentrations. Input parameters are maximum air temperature, average air temperature, sunshine hours, precipitation, plant information, growing-season details, and site latitude. After finishing and modifications made in some formulas of the dynamic-statistical model for cotton and grains, the model has been run and produced 3-12% growth of cotton yields under optimal water supply.

CROPWAT computation of cotton water consumption (Annex, Table 7) shows that total evapotranspiration in climate scenarios grows up compared to reference option.

However, water use per unit product tends to grow down.

Under climate change grain yields are expected to increase by 7-15%.

Rice is particularly susceptible to more than 32 ^{0}C increase in temperature, and in case of temperature and CO_2 rise 10% reduction in rice yields may be expected.

Similar rise in temperature and carbon dioxide will stimulate increase in alfalfa harvest and productivity.

The climate change will create favorable conditions for early vegetables because of decreased possibility of spring frosts.

Table 3 gives the results of yield forecasting for provinces. Crop yield in reference option is determined as the average for the last 5 years.

Table 3 | Crop yields (centner/ha) depending on 1-2°C changes in air temperature

Province	Cotton		Rice		Maize	
	Reference	Forecast	Reference		Reference	Forecast
Karakalpakstan	14,1	15,5	19,9	17,9	10,7	12,0
Andizhan	30,0	33,0	37,1	33,4	54,4	60,9
Bukhara	28,4	31,2	27,1	24,4	35,2	39,4
Kashkadarya	21,5	23,7			17,6	19,7
Namangan	25,0	27,5	20,9	18,8	41,2	46,1
Samarkand	22,7	24,9	21,6	19,5	29,1	32,6
Surhandarya	27,0	29,7	25,3	22,8	36,9	41,3
Khorezm	26,5	29,1	40,5	36,4	37,6	42,1
Ferghana	26,3	28,9	31,4	28,2	35,6	39,8
Tashkent	23,7	26,0	33,4	30,1	29,9	33,4
Syrdarya	14,4	15,9	22,9	20,6	30,8	34,4
Dzhizak	15,7	17,3	15,1	13,6	19,9	22,3
Navoy	25,6	28,1	15,4	13,8	19,3	21,6

Forecasted climate change potentially will exert positive influence on plants. However, realization of this potential is possible when plants are provided with nutrients, water, insect protection, etc. Figure 13 (Annex) shows a family of relationships between yields of particular crops and water and heat availability. It can be seen that higher yields require that both these factors be supplied; shortage of any of these factors would restrict yields.

A negative consequence of the climate change is increment of days with critical for plants higher temperatures. The tables (Annex, Tables 8–10) contain results of forecasting potential critical temperature frequency and relevant negative consequences on plant development and yield.

Particularly hazard effect of these stress conditions occurs under low water supply.