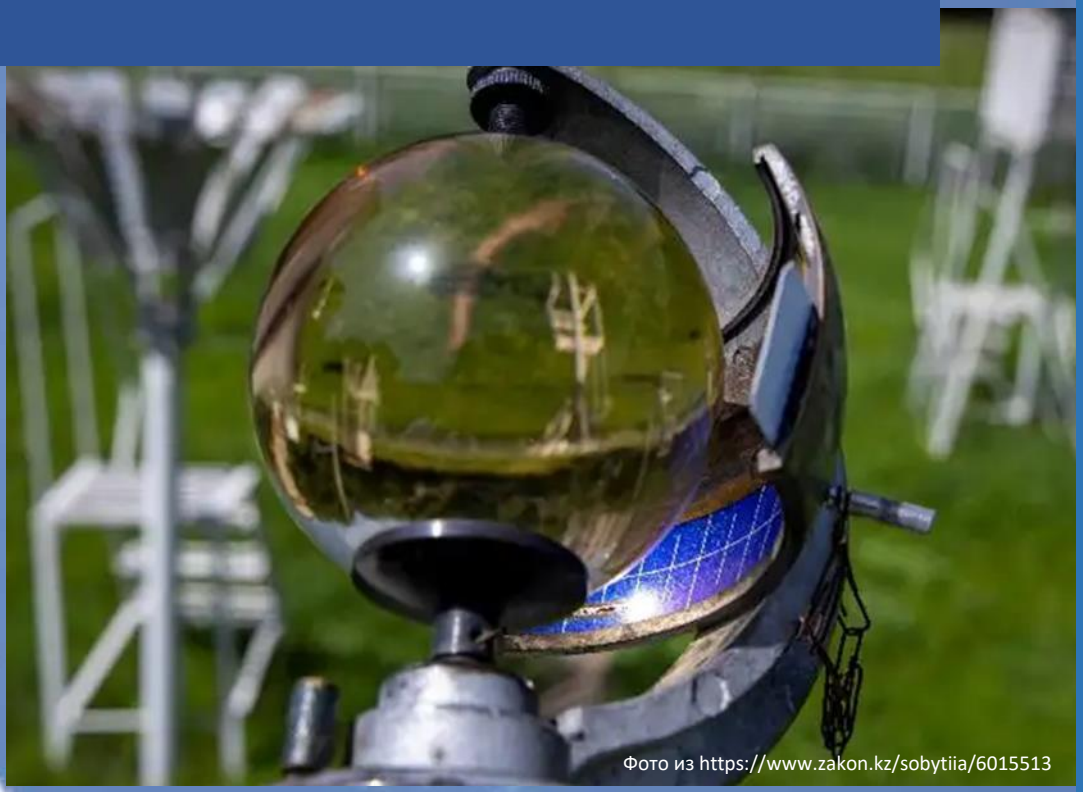
THE MINISTRY OF ECOLOGY AND NATURAL RESOURCES OF THE REPUBLIC OF KAZAKHSTAN

REPUBLICAN STATE ENTERPRISE KAZHYDROMET

SCIENTIFIC RESEARCH CENTER

ANNUAL BULLETIN OF THE DURATION OF SUNSHINE IN THE TERRITORY OF THE REPUBLIC OF KAZAKHSTAN FOR 2024



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ASTANA, 2025

CONTENT

BRIEF SUMMARY

Sunshine duration mode

- In 2024, sunshine hours in Kazakhstan ranged from approximately 1,980 to 3,120 hours per year. The highest hours were observed in the southern and western regions, while the lowest were in the north, east, and mountainous areas.
- Annual anomalies ranged from +744 to -347 hours: positive anomalies prevailed in the south and west, negative ones – in the north, east and in the mountains.
- Seasonal variations were characterized by partially positive anomalies in winter, maximum sunshine increases in spring, extreme values in the south in summer, and a moderate increase in autumn.

Number of cloudy and clear days

- In 2024, the number of cloudy days ranged from 50 to 150, and clear days from 17 to 119. The north and east of the country were characterized by cloudier weather, while the south and west had mostly clear days.
- The greatest number of cloudy days was observed in the northern and mountainous regions, and the minimum – in the southern and western plains.
- Clear days were prevalent in the south, especially in the plains and desert regions, and were rare in the north, east, and mountainous areas.

Satellite analysis of sunshine duration

- Satellite data were used to improve the detail of sunshine duration maps. The analysis revealed a general pattern: maximum insolation was observed in the south and southeast, while minimum insolation was observed in the north and mountainous regions. Satellite data provides a more detailed spatial distribution, while ground-based observations provide a more accurate estimate of absolute sunshine values.

INTRODUCTION

The Sun is the main source of energy for all natural processes on Earth. The energy coming from the planet's interior or from other stars is negligible compared to the Sun's. It is the Sun that determines the climate, weather, and much more on our planet.

Sunshine duration is the total time during which the sun's rays directly reach the Earth's surface and are not obscured by dense clouds.

In recent decades, the climate has undergone significant changes, and the dependence of various economic sectors on climate conditions has increased significantly. This has created an urgent need for more thorough and continuous monitoring of climate system components, providing reliable and timely information for decision-making in various fields.

Sunshine duration is a key climate indicator, playing a significant role in various areas of life and the economy, especially in agriculture, energy, and transport.

In the agricultural sector, sunlight determines photosynthesis, the length of the growing season, sowing dates, and crop yields, helping plan crops and select suitable crops. In the energy sector, sunlight duration influences the calculation of solar power plant capacity and efficiency, as well as the return on investment. In transportation, sunlight is important for visibility, road and airfield illumination, and the operation of solar charging systems. It also plays a role in healthcare, architecture, climate science, and tourism, making sunlight a vital resource for the economy and quality of life.

Sunshine duration data is essential for the efficient use of natural resources and the minimization of climate and economic risks. It helps optimize agriculture, increase the efficiency of solar energy, ensure transport safety, and improve conditions in urban development, healthcare, and tourism. Reliable information on sunlight is the foundation for sustainable development and informed decision-making in many areas of life and the economy.

This issue examines the characteristics of sunshine duration, its spatial distribution across Kazakhstan's regions, as well as seasonal differences and the dynamics of changes throughout the year. Data is provided to assess variations in sunshine in individual areas and identify characteristic seasonal patterns.

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1. DESCRIPTION OF SUNSHINE DURATION

Kazakhstan's location in temperate latitudes (40-55° N), along with low average cloud cover and especially low cloud cover, determines high solar radiation influx into its territory. The significant amount of light and insolation received by Kazakhstan are reflected in the quantitative characteristics of sunshine duration. Midday solar altitudes, which characterize the potential intensity of radiation and daylight hours, reach their highest values in the summer.

The actual duration of sunshine is determined, in addition to astronomical factors, by cloud cover, which to a certain extent reflects the development of circulation processes. Large-scale circulation, as well as the influence of terrain, mean that cloud systems are most likely in the northern regions of the republic and in the extreme southeast, where mountains exert a significant influence. Accordingly, the average annual number of hours of sunshine, comparatively low in the north and in the foothills of the Trans-Ili Alatau (approximately 2,000 hours), reaches higher values in the south of Kazakhstan: Betpak-Dala - 2,936, Shymkent - 2,892 hours. Such high values are due to the peculiarities of cloud formation in the central and southern desert regions of the republic. The vast deserts of Central Asia and Kazakhstan, scorched by the sun, create conditions for the formation of intense convective air currents, as a result of which the level of condensation of water vapor rises significantly higher here than in other regions of Kazakhstan. As a result, convective cloud forms are located relatively high, and their development leads to the formation of thin cirrus clouds. Thus, it turns out that in the summer months, desert regions and southern Kazakhstan receive direct solar radiation for almost the entire daylight hours. The distribution of average aurora duration values does not at all follow the geographical distribution of the station. Thus, the Kostanay region (5.5 hours) has the same number of hours of aurora as the Almaty region (5.6 hours). In summer, southern stations, where daylight hours are significantly shorter compared to northern ones, are characterized by significantly longer duration of sunshine. The average maximum occurs in the desert areas of Betpak-Dala and the Turkestan region, where it is 12.6 hours per day. It should be noted that in most of the country, maximum sunshine occurs in the month of the summer solstice - June, less often in July. These areas also have the longest values of average aurora duration (7.9-8 hours). However, if we consider the sunshine duration gradations (at least 8, 6, or 4 hours per day), which is of interest for the rational placement of solar power installations that operate only during specific sunshine durations, some new opportunities emerge. Indeed, Kazakhstan has vast areas where sunshine lasts 8 hours or more for six consecutive months. With few exceptions, these areas are located south of the Atyrau-Betpak-Dala-Zaysan line. Sunshine duration at stations such as Betpak-Dala and Shymkent during the summer months is 83-96% of the potential. Therefore, these regions of Kazakhstan hold considerable potential for the development of solar power.

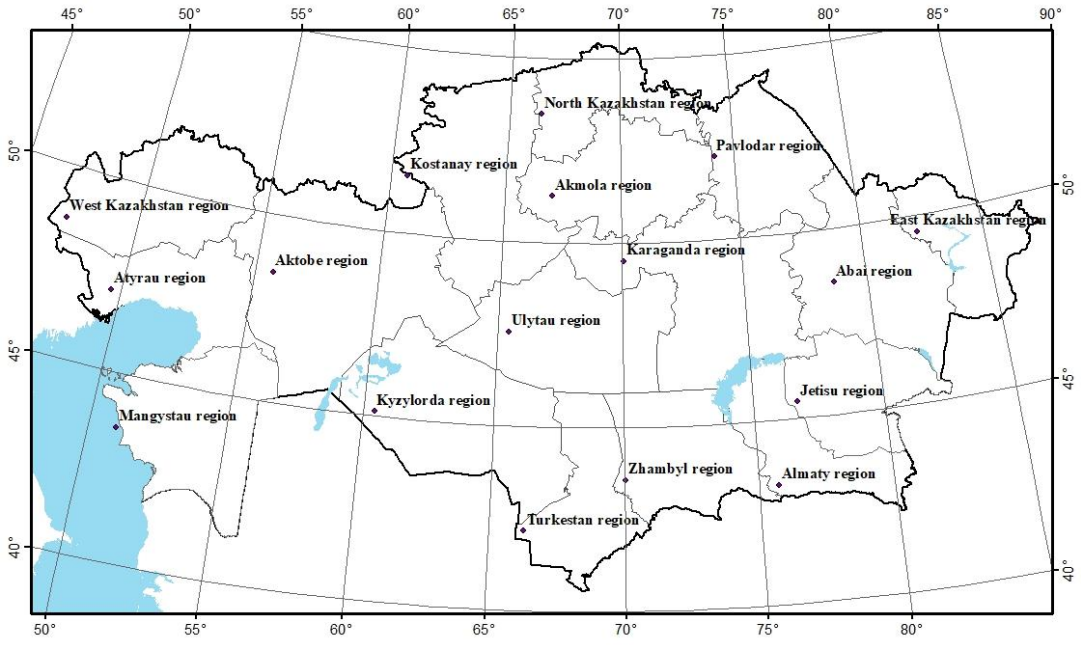
Number of clear and cloudy days. Clear and cloudy days are defined as days with a total cloudiness over all observation periods less than or greater than a certain critical value. These are most often days with clear or cloudy weather persisting 24 hours a day.

Number of clear days with overall cloud cover. In winter, the number of clear days with overall cloud cover is highest in eastern Kazakhstan, reaching 10-12 days per month. In western Kazakhstan, there are approximately 4-6 cloudless days during this period. Beginning in May, the greatest number of clear days is observed in the southern part of the republic. From July to September, this number reaches 20-25 days per month (even with overall cloud cover) . Even in October and November, the number of clear days in the south and southeast remains highest, reaching 15, then 10 days. Winter conditions here begin in December.

Number of cloudy days based on cloud cover. As follows from the clear day regime, the greatest number of cloudy days in winter is observed in western Kazakhstan – from 5 to 10 days per month. In the east, there are no more than 5-7 cloudy days in winter, and no more than 3 at the end of winter. The greatest number of cloudy days from May to October is observed in the north and east of Kazakhstan – up to 4-5 days. In the south, there are no more than 1-2 cloudy days in summer, and no more than one from June to September.

The annual number of clear days, measured by total cloud cover, reaches 160 in the south, while in the north it is only 40. The highest number of overcast days with low clouds occurs in the north—up to 60—and the lowest, however, not in the south, but in the Balkhash Depression—10 or less. Apparently, in the south, where there are 25-30 overcast days annually, advection processes of warm air masses are frequent in winter, causing fog and low, stratified clouds. The areas of Lake Balkhash are not affected by such processes, but they also do not lie in the path of cyclones, which pass either further south, in the foothills, or further north [1].

The administrative-territorial regions of Kazakhstan are shown on the map below.



Map of the administrative-territorial regions of the Republic of Kazakhstan

[1] Uteshev A. S. (ed.). Climate of Kazakhstan. – L.: Gidrometeoizdat, 1959. – 360 p.

2. MATERIALS AND METHODS OF RESEARCH

The term "sunshine" refers to the brightness of the solar disk exceeding the background diffuse glow of the sky, or, more readily visible to the naked eye, the appearance of shadows behind illuminated objects.

Sunshine duration is defined as the total time during which direct solar radiation exceeds 120 W m^{-2}. Physical sunshine duration is a temporal characteristic. Seconds or hours are used as units of measurement. For climatological purposes, terms such as "hours per day" or "number of hours of sunshine during the day" are used, as well as percentages to determine the "relative duration of sunshine during the day," which can be related to the maximum possible sunshine duration. A special device, a heliograph, is used to determine this, recording the moments when the sun's rays are strong enough to burn through a ribbon placed at the focus of a spherical glass lens.[2]

The heliograph consists of a cast-iron stand on which a glass sphere is mounted. A special tape is mounted at the sphere's focus, recording the duration of sunshine. The device is oriented according to the latitude of the location and the cardinal directions. The heliograph stands still, while the sun moves across the sky. Its rays, passing through the glass sphere, leave a black slit on the tape—a smoking trace of its movement across the sky from sunrise to sunset. If the sun shines all day without interruption, the number of hours of sunshine on clear days practically coincides with the duration of daylight. But if the sun is obscured for even ten minutes by rolling clouds, the burn on the heliograph tape is interrupted. The duration of sunshine varies depending on latitude and atmospheric circulation conditions. Changing air masses, and with them cloud cover and atmospheric transparency, sometimes bring the actual observed duration of sunshine closer to the value possible under ideal conditions, sometimes further from it.

The instrument is placed in an open area, away from trees, buildings, and other objects that could cast shadows during the day. The heliograph axis is oriented south (in the Northern Hemisphere), allowing for accurate tracking of the sun's movement across the sky. The instrument itself is securely mounted on a stable base to prevent movement and vibration. It is typically installed at a height of approximately one and a half meters above the ground. To obtain accurate data, the instrument's orientation and the condition of the recording tape are regularly checked.[3]

The analysis included data from 55 meteorological stations of the Kazhydromet network, where regular actinometric observations are carried out.

The initial data for preparing the sunshine duration analysis is a database that includes:

1) series of average monthly sunshine durations in hours, with 43 weather stations having data since 1977, 12 weather stations began observations in different periods.
2) series of the number of days with clear and cloudy days for 204 meteorological stations of the RSE Kazhydromet network.

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[2] Manual of Instruments and Methods of Observation. Volume I – Measurements of Meteorological Variables. Weather, Climate, Water. 2023 Edition – Geneva: WMO, 2023.

[3] Instructions for hydrometeorological stations and posts. Volume 3. Part I. Meteorological observations at stations. – L.: Gidrometeoizdat, 1985. – 280 p.

For each station, monthly sunshine duration anomalies—deviations from the norm— were calculated. The norms are based on long-term average sunshine duration values for the period 1991–2020.

Time series of anomalies of the considered values are averaged over the territory of Kazakhstan for 15 administrative-territorial regions, for the Zhetisu region and the Mangistau region for 2024 No observations of sunshine duration were made.

3. SUNSHINE DURATION MODE FEATURES

3.1 Duration of sunshine in Kazakhstan in 2024

The spatial distribution of sunshine duration in 2024 across Kazakhstan's regions ranged from 1,984 hours to 3,125 hours (Figure 3.1). The highest sunshine durations were recorded in the south of the country at the Turkestan weather stations in the Turkestan region (3,125 hours), the Aral Sea station in the Kyzylorda region (2,932 hours), and the Taipak station in the West Kazakhstan region (2,903 hours), which is associated with their drier climate.

The central, northwest and east regions of Kazakhstan showed average sunshine duration values ranging from 2400 to 2600 hours per year.

Minimum values The duration of sunshine was recorded at the meteorological stations of Shuyldak in the Turkestan region (1984 hours), Aktobe in the Aktobe region (2079 hours) and Pavlodar in the Pavlodar region (2181 hours), which indicates a relatively low solar activity, typical for the northern and foothill regions of the country.

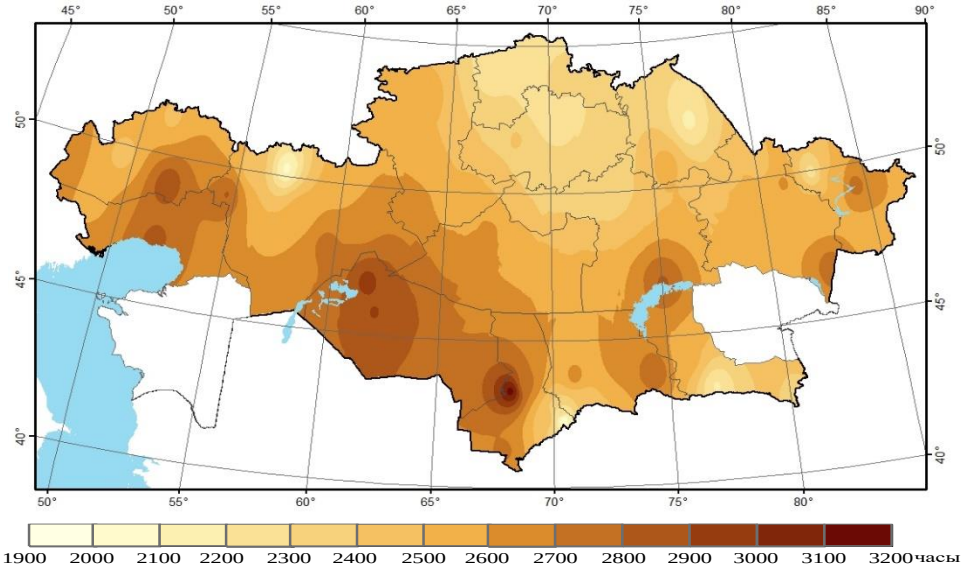

Figure 3.1 – Sunshine duration for 2024 (Areas without color indicate no monitoring data)

The annual total sunshine duration by region varied from 2,278 hours in Akmola region to 2,918 hours in Kyzylorda region (Table 3.1). Southern and western regions, such as Kyzylorda, Atyrau, and Zhambyl regions, receive more sunshine throughout the year than northern regions, such as Akmola and North Kazakhstan regions.

Summer Maximum Sunshine Duration were observed during the summer months – from May to August. In July, for example, in the Atyrau region, the duration of sunshine reached 397 hours.

In winter, especially in December and January, sunshine hours are significantly reduced due to shorter daylight hours and increased cloud cover. In December, the Akmola region experiences only 34 hours of sunshine.

Monthly data provide geographic and seasonal heterogeneity of solar radiation: the south and southwest of the country have high solar activity, while the north and northeast have lower activity.

Table 3.1 – Duration of sunshine by month for 2024

Regions	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Year , hours**
Akmola region	70	121	160	176	215	265	230	157	185	135	90	34	**2278**
Aktobe region	101	150	160	265	309	294	337	319	298	135	115	59	**2543**
Almaty region	108	129	183	203	236	288	284	284	227	166	146	126	**2380**
Atyrau region	89	138	169	289	324	316	397	381	301	167	77	61	**2709**
Abay region	131	160	191	279	307	346	317	328	242	140	115	76	**2633**
East Kazakhstan region	127	148	171	272	284	330	299	318	222	129	98	80	**2478**
Zhambyl region	89	120	171	242	267	374	342	353	274	169	117	118	**2635**
West Kazakhstan region	73	147	160	256	352	314	377	355	311	146	72	51	**2612**
Karaganda region	108	149	180	249	268	346	305	291	269	151	117	71	**2503**
Ulytau region	149	203	280	266	372	307	301	276	132	104	94	136	**2620**
Kostanay region	95	165	203	238	298	342	302	270	288	156	124	64	**2542**
Kyzyloda region	135	154	203	318	303	386	373	362	298	147	137	102	**2918**
Pavlodar region	110	117	180	234	247	335	318	272	226	153	105	66	**2360**
North Kazakhstan region	68	145	191	214	279	312	287	226	245	166	108	40	**2279**
Turkestan region	92	118	140	232	256	356	352	345	254	160	132	118	**2554**

3.2 Sunshine duration anomalies

Sunshine duration anomalies in different regions of Kazakhstan showed significant spatial differences. Maximum anomalies reached + 744.4 hours and were recorded at the Novy Ushtogan weather station in Atyrau region. While the minimum values of anomalies were observed at the Ust-Kamenogorsk weather station in the East Kazakhstan region and the composition or - 347.5 hours (Figure 3.2).

Western and southern regions of Kazakhstan – weather stations such as Turkestan in the Turkestan region , Atyrau in the Atyrau region , Taipak and Chingirlau in the West Kazakhstan region - showed consistent positive anomalies in sunshine duration. Positive anomaly values ranged from +580 hours to +730 hours.

Negative sunshine duration anomalies were observed in the north and east of the country, as well as in the mountainous regions of the south, including the Zaysan weather stations in East Kazakhstan region, Semipalatinsk in Abay region, Shuyldak in Turkestan region, Burabay in Akmola region, and Balkhash in Karaganda region. Anomaly values here ranged from -170 hours to -300 hours.

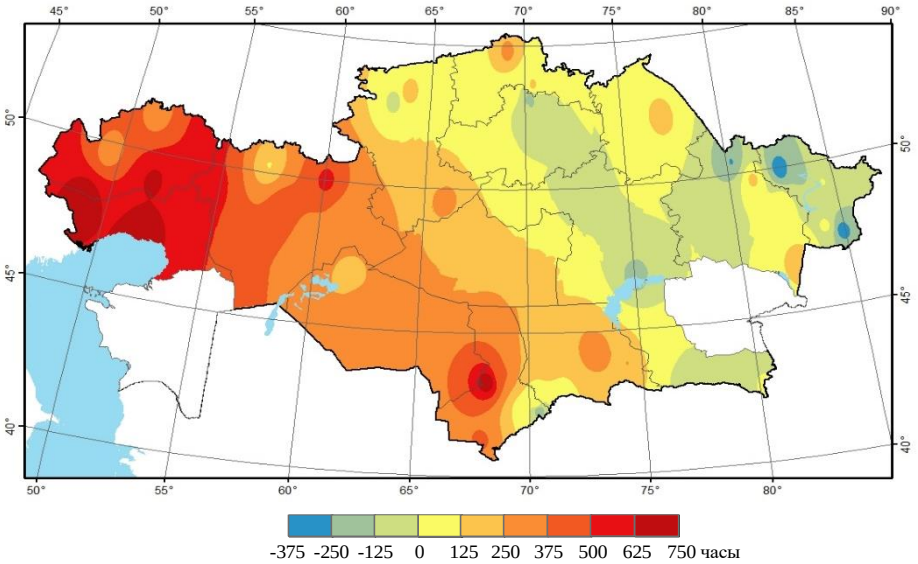

Figure 3.2 – Anomalies of average annual sunshine duration in 2024 (Areas without color indicate no monitoring data)

It should be noted that positive anomalies were observed in all seasons over most of the territory of the Republic of Kazakhstan, with negative anomalies observed only in a few locations (Figure 3.3)

In the winter period , positive anomalies were noted at the weather stations of Zaysan (+372.8 hours) in the East Kazakhstan region , Turkestan (+352.6 hours) in the Turkestan region and (Ulytau +350.9 hours) in the Ulytau region . Negative anomalies were recorded in the mountainous regions of the south and southeast of the country , and at the Kamenskoye Plateau weather stations (-35.6 hours) in Almaty region , Shuyldak in Turkestan region (-28.1 hours) and Kyrgyzsay in Almaty region (11.1 hours), which indicates a lack of sunlight in these areas .

Spring is characterized by the most consistent increase in sunshine hours across almost the entire country. Particularly high values were observed at weather stations in Ulytau (+707.1 hours) and the Ulytau and Zaysan regions . (+673.2 hours) in the East Kazakhstan region , Turkestan (+619.0 hours) in the Turkestan region . Negative anomalies at this time of year are noted only in individual meteorological stations , such as Shchuchinsk (-52.6 hours) in the Akmola region , Rudny (-44.3 hours) in the Kostanay region and Bayanauyl (-33.4 hours) in the Pavlodar region .

In summer, the southern and eastern regions continue to experience excess sunlight. Maximum positive anomalies include +918.8 hours in the Turkestan (Turkestan) region, +878.7 hours in the East Kazakhstan (Zaysan) region , and +818.5 hours in the Abay (Semipalatinsk) region. However, significant negative values were recorded in the northern part of the country : -159.6 hours in the Akmola (Shchuchinsk) region, -129.9 hours in the Kostanay (Rudny) region, and -118.4 hours in the East Kazakhstan (Seleznevka) region.

The autumn season again showed a general increase in insolation in the southern and western regions, at the Emba weather stations in the Aktobe region positive anomaly for silt composition +545.4 hours, Turkestan of the Turkestan region +521.3 hours, Shalkar of the Aktobe

region +481.6 hours. Negative deviations were observed at the Seleznevka weather stations in East Kazakhstan (-16.9 hours), Aidarly of Almaty (-12.8 hours) and the Aral Sea of Kyzylorda region (-8.6 hours).

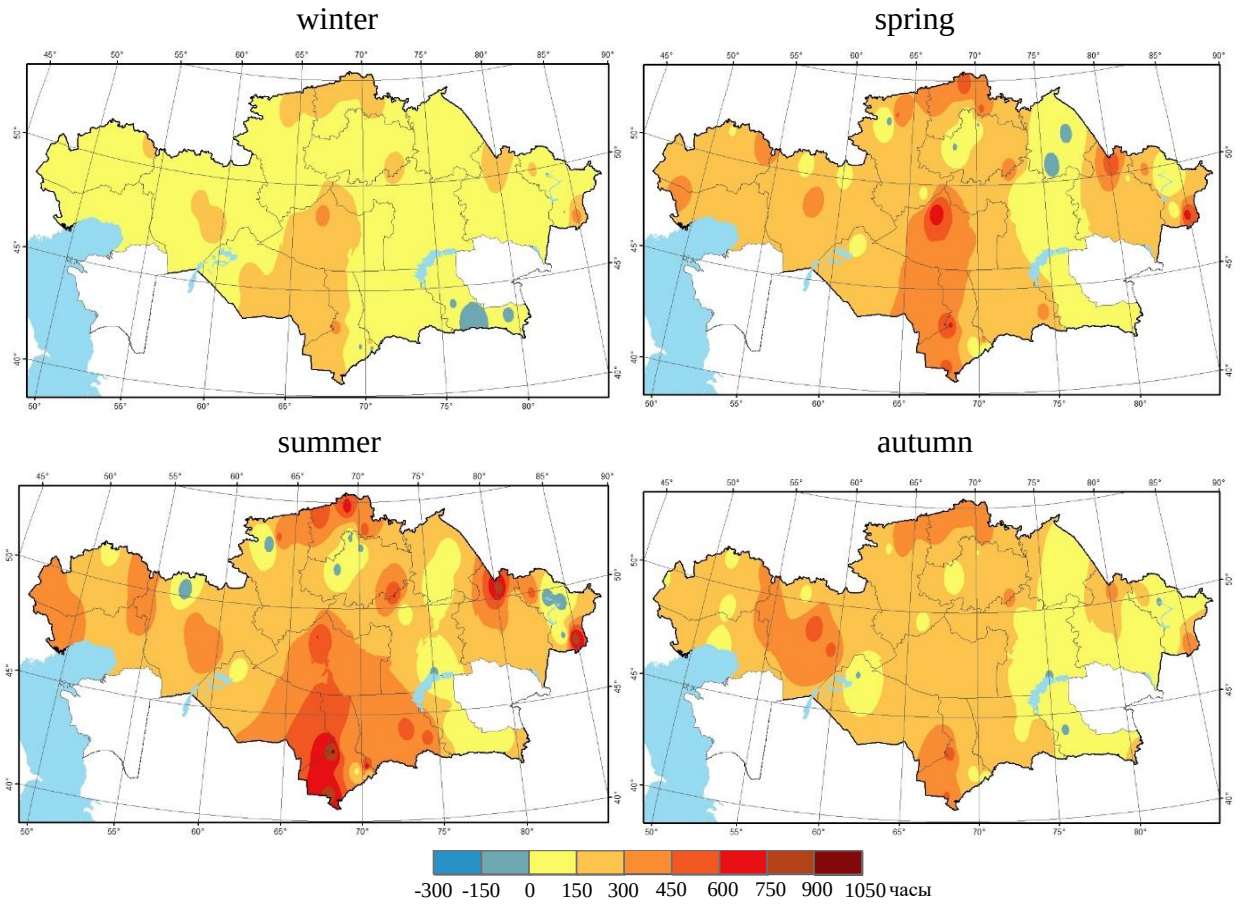

Figure 3.3 – Anomalies in sunshine duration by season for 2024. (Areas without color indicate no monitoring data)

During the winter period, sunshine duration anomalies in most regions of Kazakhstan are positive (Figure 3.4). The largest winter anomalies were observed in the Ulytau region (351.0 hours) and in the North Kazakhstan region (223.6 hours). At the same time, in Almaty (5.5 hours) and Pavlodar (21.9 hours) The areas showed minimal winter anomalies, which may indicate more cloud cover or less sunshine this season.

Spring anomalies increase significantly compared to winter. The highest values were observed in the Ulytau region (707.1 hours), North Kazakhstan (494.6 hours), and Turkestan (293.0 hours). Some regions, such as Pavlodar region, even had negative anomalies. (-26.5 hours).

Summer anomalies showed maximum values in most regions. Ulytau (602.1 hours), North Kazakhstan (598.8 hours), Turkestan (499.2 hours), and Zhambyl (419.3 hours) regions had particularly high values, reflecting intense sunshine during the summer months. Meanwhile, in some regions, such as Akmola (22.0 hours) and Pavlodar (79.4 hours), summer anomalies were comparatively low, which may be explained by local climate characteristics.

Autumn anomalies were generally lower than those in spring and summer, but still remained positive in most regions. The highest autumn values were recorded in North Kazakhstan (420.2 hours), Aktobe (317.2 hours), Turkestan (274.5 hours), and Kostanay (227.4 hours) regions. In a number of regions, such as Kyzylorda and Almaty regions, autumn anomalies were comparatively low—64.3 and 81.2 hours, respectively.

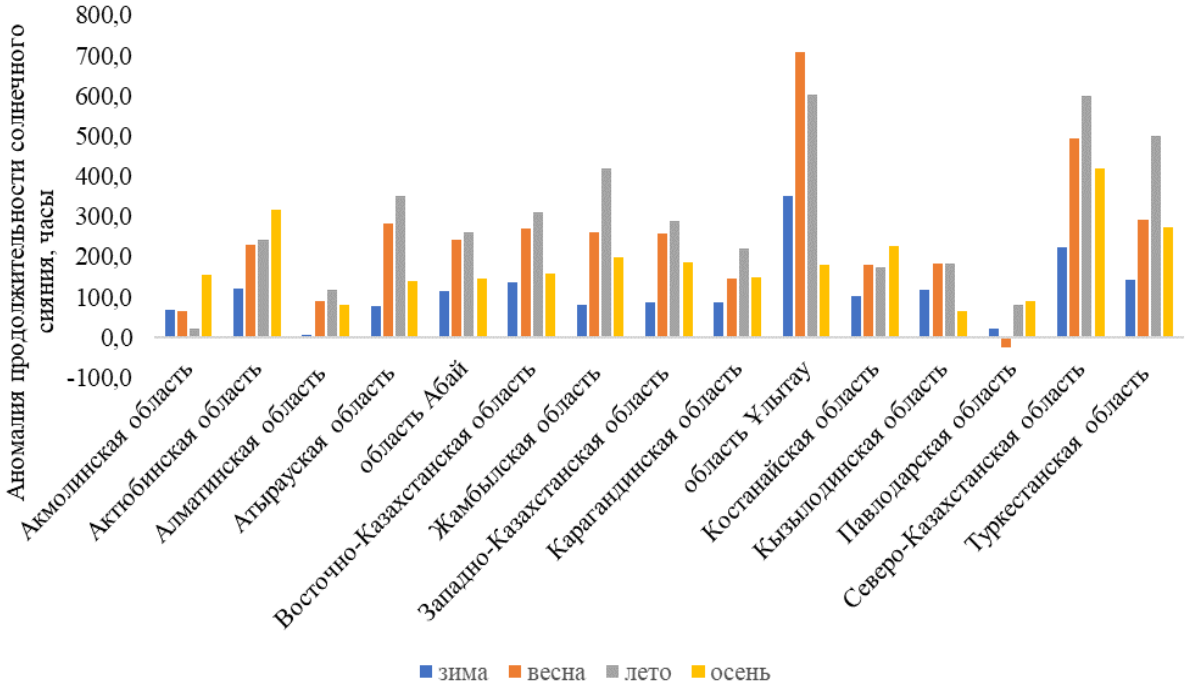

Figure 3.4 – Seasonal indicators of sunshine duration anomaly by region for 2024

3.3 Number of sunny and cloudy days

The number of sunny and cloudy days is an important climatic characteristic, reflecting the level of sunlight and the degree of cloudiness throughout the year. The number of clear and cloudy days affects the photosynthetic activity of plants, the duration and comfort of daylight, as well as the efficiency of solar installations.

The spatial distribution of sunny and cloudy days by total cloud cover across the Republic of Kazakhstan is presented in map form. Values are presented as the number of days per year.

An overcast day is defined as a day with overcast skies during daylight hours (Figure 3.5). The highest number of overcast days, measured by total cloud cover, is observed in the North Kazakhstan, Akmola, and Pavlodar regions. The number of overcast days per year ranges from 80 to 150. In the central part of the country, the number of clear days ranges from 60 to 90. In the southern and eastern regions of the country, the number of overcast days per year ranges from 50 to 70.

The maximum number of cloudy days in 2024 was recorded at the Shokpar weather station in the Zhambyl region: 206 days. The number of cloudy days decreases from north to south and from west to east, with the exception of elevated areas, where the number of cloudy days also

increases. Mountainous regions are most susceptible to cloud formation due to the upwelling of moist air and its cooling at altitude. Humid regions with bodies of water, dense vegetation, or frequent precipitation favor cloud formation, meaning a greater number of cloudy days. days . The fewest cloudy days were observed at the Kapchagay weather station in the Almaty region , with only 14 cloudy days.

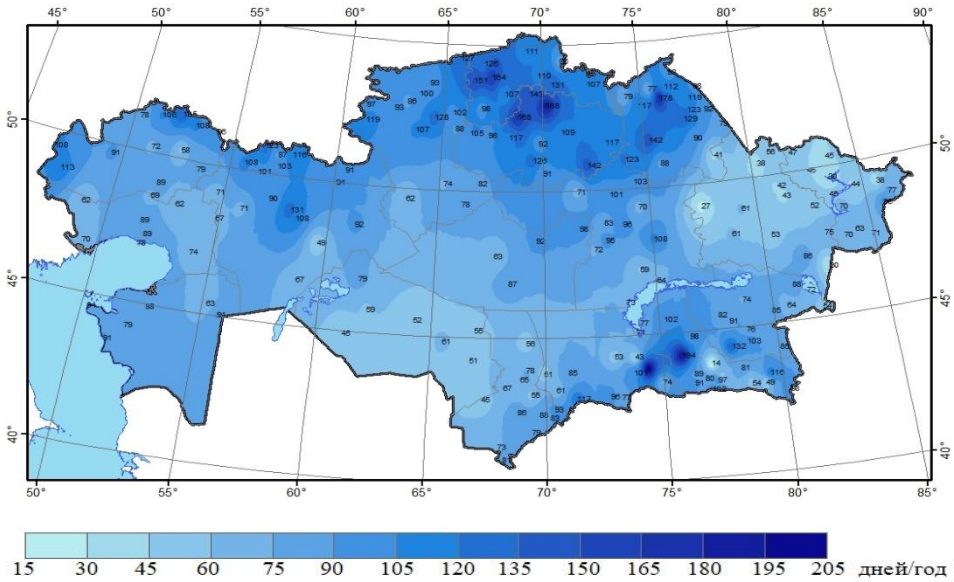

Figure 3.5 – Number of cloudy days in 2024

A clear day is defined as a day during which the weather was mostly clear, without significant clouds.

The number of clear days, measured by total cloud cover, is significantly higher in the southern and western regions of the country, particularly in the Turkestan and Kyzylorda regions. These regions experience between 60 and 110 clear days. Flat and desert areas are characterized by the least cloud cover due to the dry climate. In the northern and eastern regions, the number of clear days ranges from 25 to 80. In central Kazakhstan, the number of clear days ranges from 40 to 70.

The maximum number of clear days (119) was recorded at the Kyzylkum meteorological station in the Turkestan region (Figure 3.6). The minimum number of clear days was recorded in the North Kazakhstan and Almaty regions, at the Sergeevka and Aydarly meteorological stations, where the number of clear days was only 17.

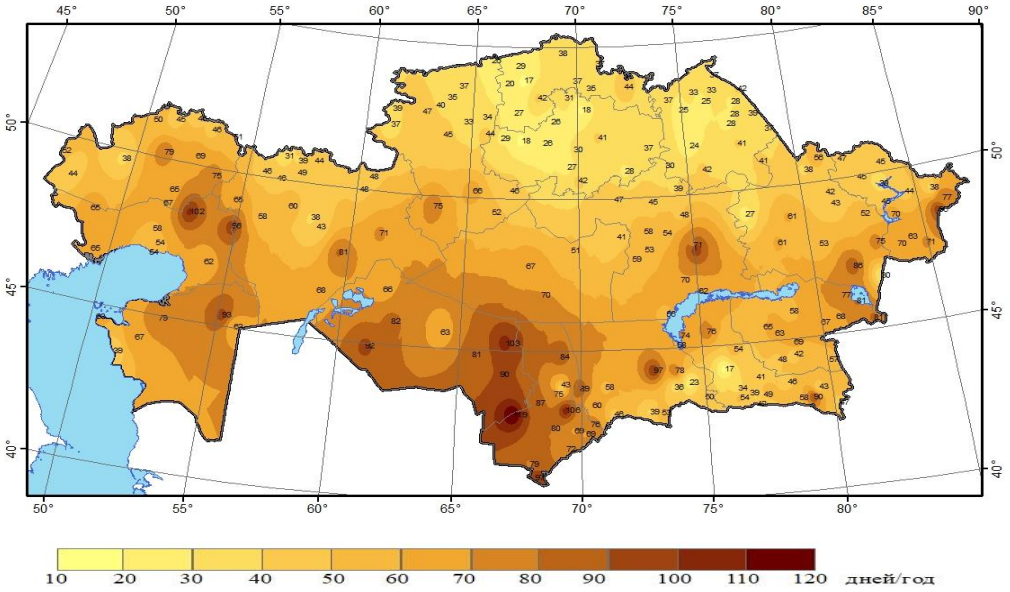

Figure 3.6 – Number of clear days in 2024

4. ESTIMATION OF SUNSHINE DURATION BASED ON SATELLITE DATA

The ground-based sunshine duration measurement network in Kazakhstan is extremely limited. There are only slightly more than 50 measurement points, which is insufficient to accurately map this parameter for the 2.7 million square kilometers of the Republic's territory. Mathematical methods for extrapolating point measurements assume that the conversion of a limited set of point measurements to a regular data grid (map base) is based on simple functional relationships. Typically, the assumption of linear laws is used for extrapolation. This approach is poorly suited to mapping weather and climate parameters over large areas with limited ground-based data. Extreme deviations in the mapped parameter in zones between existing ground-based point measurements cannot be reconstructed. As a result, to detect and map a local outlier, it must be recorded by at least one station in the ground-based data network.

Unfortunately, the ground-based network of meteorological stations recording sunshine duration in Kazakhstan is too sparse, and a direct solution to this problem is neither currently nor in the future. The only way to improve the reliability and detail of sunshine duration mapping is to use additional information, preferably gridded data with an acceptable period. The most obvious option is satellite data.

Sunshine duration is significantly dependent on cloud cover. Satellites easily detect cloud cover during optical sensing. The presence of cloud cover significantly alters the spectral characteristics of the underlying surface. A distinctive feature of satellite data is the instantaneous nature of the information. A satellite scene represents the state of the spectral characteristics of the underlying surface at the moment of the orbital platform's flyby. Furthermore, the physical meanings of the time of sunshine at a given point on the Earth's surface and the cloud cover of that point as observed by a satellite are not identical. In the former case, this is the time during which the direction toward the Sun is unobstructed by cloud cover. Moreover, the angle of the Sun's elevation and direction toward it changes regularly throughout the day, from sunrise in the east to sunset in the west. Satellites detect the presence of cloud cover in the direction from a point on the Earth's surface to the satellite. These angles are determined by the flyby time and the direction of the orbital platform's trajectory. In general, these angles are not related to the Sun's position in the sky.

Thus, satellite data on cloud cover characteristics are only indirectly related to solar shine duration. A strength of satellite data is their format, which is a regular data grid. The best-known and standard satellite product describing cloud cover status is the " Cloud " product . Fraction " from NASA (Figure 4.1).

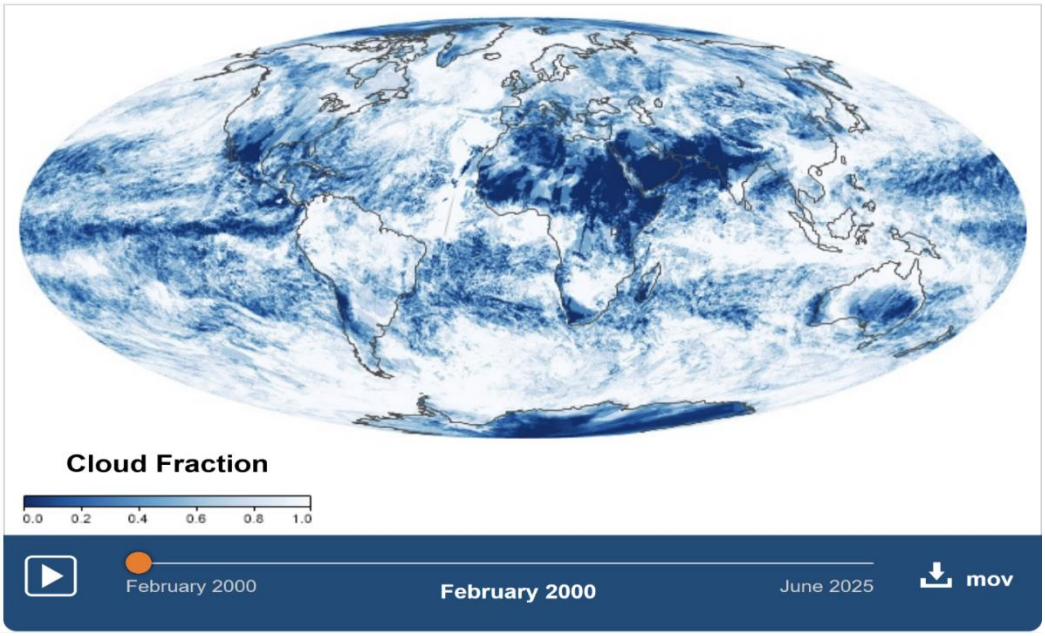

Figure 4.1 – Example of a global Cloud map Fraction[4]

This product displays the proportion of cloud cover over a given spatial-temporal sample. It is constructed using data from the Aqua and Terra satellites (MODIS scanner) with a spatial resolution of 1.0 to 0.1 degrees (Figure 4.2).

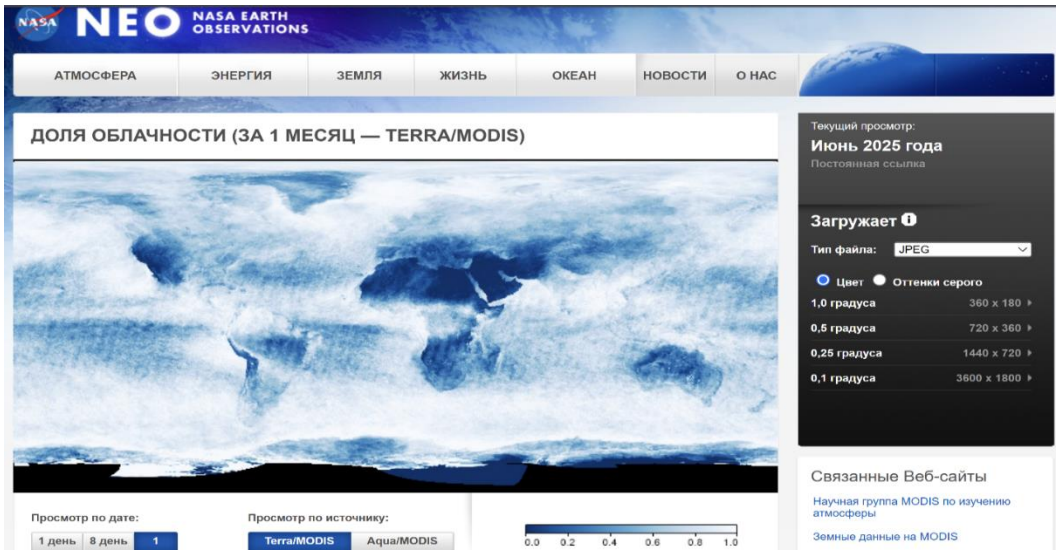

Figure 4.2 – Example of an average monthly Cloud product Fraction (June 2025) from the resource[5]

To simplify the situation, annual data for 2024 were compared. Ground-based data on the time of sunshine at ground points and average annual values of Cloud Fraction (Aqua). Monthly average Cloud values were used in the calculations. Fraction , which were averaged to the annual

[4] https://www.earthobservatory.nasa.gov/global-maps/MODAL2_M_CLD_FR
[5] https://neo.gsfc.nasa.gov/view.php?datasetId=MODAL2_M_CLD_FR&date=2025-06-01

mean level. The degree of applicability of the satellite product under consideration in the task of refining sunshine time maps can be assessed by the characteristics of the empirical relationship (calibration curve) between the parameters under consideration (Figure 4.3) .

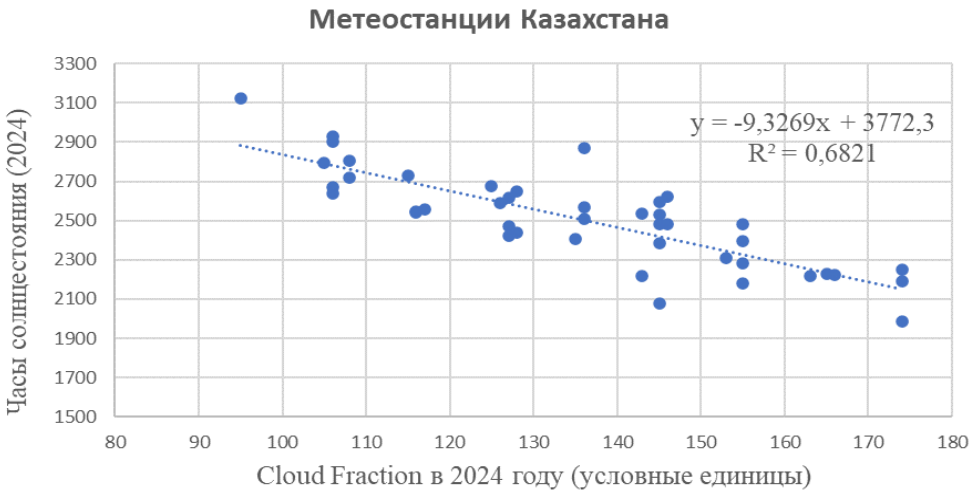

Figure 4.3 – Calibration curve between ground-based and satellite data. Satellite data of cloud cover fraction of ground-based measurement points versus the sunshine time recorded at them for 2024

The reliability of the linear approximation for the calibration curve (R2 = 0.6821) is quite high. There is no doubt about the presence of a reliable relationship between these parameters. However, a linear approximation equation with this level of reliability cannot be applied to all pixels of a regular matrix as a functional dependence. The random, noisy component is quite large. Constructing a regular matrix of the Cloud Fraction parameter for its use in mapping the annual level of sunshine in Kazakhstan required some coarsening. To suppress the noisy component, Gaussian blurring (a method of coarsening an image using a Gaussian function) was used, followed by data clustering for additional coarsening within a fixed number of units. The resulting regular Cloud matrix Fraction was used to approximate ground- based solar duration data for 2024 and to construct the corresponding map (Figure 4.4) .

This map shows the spatial distribution of sunshine across Kazakhstan, where lighter shades indicate longer sunshine durations, and darker shades indicate shorter ones. According to satellite data, the longest sunshine durations were observed in the southern and southeastern regions of the country — in the Kyzylorda, Turkestan , Zhambyl, and Zhetisu regions, as well as in certain areas of the East Kazakhstan and Abay regions . Lower values are typical for the northern and northeastern regions of the country . – North Kazakhstan, Akmola, Palodar regions and in the north of the Abay region .

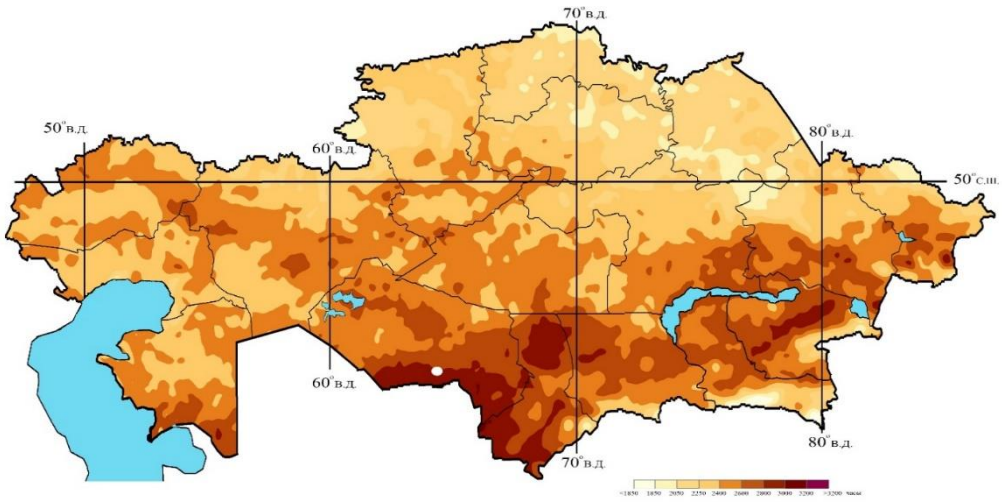

Figure 4.4 – Map of the duration of solar radiance in 2024. Constructed using ground-based and satellite data (Cloud Fraction / NASA , resolution 0.1 degrees)

Compared to a map constructed from ground-based observations (Figure 3.1), this map shows a general agreement in the spatial distribution of sunshine: both satellite and ground-based data indicate a predominance of sunny weather in the southern regions, as well as relatively low values in the northern and mountainous areas.

However, some discrepancies can be noted. Satellite data (Figure 4.4) show somewhat more pronounced contrasts between regions and, as a rule, slightly underestimate values compared to ground-based measurements, especially in the western regions. This may be due to the specific interpretation of cloudiness in satellite products (Cloud Fraction), as well as differences in temporal resolution and calculation methodology.

Thus, both maps demonstrate similar patterns of sunshine distribution across Kazakhstan in 2024, confirming the reliability of the obtained results. Satellite data provides a more detailed spatial picture, while ground-based data provides a more accurate estimate of absolute sunshine duration.

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