Landscape and climatic conditions of the depressions of the southwestern part of the Baikal rift zone

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Abstract. The article presents data on continuous monitoring of the characteristics of the climate system with high spatial-temporal resolution. The study area is the Tunkinskaya rift system of depressions, in particular, the Tunkinskaya and the Mondinskaya depressions. Five cross sections characterizing the typical conditions of mountain-depression landscapes of the South Baikal region were selected. At each point of a cross section, a description of the landscape, laying of the soil section, its description, sampling for subsequent laboratory analyses to clarify the genesis and name were carried out. Meteorological parameters were monitored using stand-alone programmable thermographs. It was shown that the influence of individual and contrasting morphometric characteristics of depressions on the climate is reflected in the characteristics of the temperature and humidity regime as a whole, as well as in the features of the cold and warm period. There is a high spatial heterogeneity of temperatures and precipitation with a noticeable gradient between the peripheral and central parts of depressions. It is also shown that the territory is characterized by the high contrast of geological, geomorphological, phytocenotic and soil conditions, which creates a unique landscape diversity both between different depressions and within each depression.

1. Introduction

The study of climatic characteristics in orographically complex landscapes is associated with the need to take into account a large number of factors, such as the height and exposure of slopes, spatial heterogeneity of soil and vegetation, the structure of underlying rocks, the spread of permafrost, etc. As a result, when studying climate, in the mountain-depression relief, it is impossible to limit ourselves to generalizing the results of observations of climatic parameters in individual points without additional verification, additional quantitative estimates and a detailed analysis of the results.

The work on studying the climate and microclimate of the mountain-depression landscapes of Eastern Siberia and the adjacent territories was part of complex stationary and expeditionary studies, mainly from the beginning of the 1950s to the end of the 1970s. The vast majority of studies describe climate based on data from weather stations located mainly in the bottom of depressions. Many works present the results of field observations limited to the warm season.

Thus, at the moment there is a lack of up-to-date information on climate and climatic changes in mountainous regions, which substantially complicates the possibility of diagnosing and reconstructing the state of Siberian geosystems and analyzing their changes under the influence of natural and anthropogenic factors. The existing density of the network of weather stations does not allow to obtain
reliable information about the features of the regime of climatic elements in the conditions of dissected relief. Therefore, the collection and analysis of representative data characterizing the climatic regime of mountain-depression landscapes and the analysis of spatio-temporal climate variability taking into account global and regional changes is an urgent task of modern science.

To accumulate and fill in the missing data, the present work provides quantitative climatic and meteorological characteristics taking into account altitudinal zones, topography, soils, and underlying rocks using the example of intermontane depressions of the Tunkinskaya rift system (south-western part of the Baikal rift zone). The data presented were obtained in the process of continuous monitoring of the characteristics of the climate system with high spatial-temporal resolution.

2. Objects, data and methods
The Tunkinskaya rift system of depressions originates from the western extremity of the South Baikal Depression and extends westward in a sub-latitudinal direction. In the same direction, there is a gradual increase in heights. Thus, the absolute height of the bottom of the easternmost Bystrinskaya depression is 600-730 m, Torskaya – 660-800 m, Tunkinskaya – 700-900 m, Turanskaya – 840-1000 m, Khoytogolskaya – 900-1500 m, Mondinskaya – 1250-1600 m a.s.l. In the north, the system of depressions sharply delineated by steep Tunkinsky Goltsy Range with pronounced alpinotopic forms, in the south it is framed by a gently sloping plateau Khamar -Daban Range. The height of the ranges increases from 1000 m (in Bystrinskaya) to 3500 m (in Mondinskaya) [1]. Due to the significant altitude range, the patterns of vertical zonality in the study area are particularly pronounced. According to, the semi-humid sector of the mountains of Southern Siberia a characteristic altitude zones are formed here [2]. The range of altitudinal zones is represented by forest-steppe, forest (with subtaiga and mountain-taiga belts), and alpine belts. Depending on the height and exposure of the ridges, the manifestation of altitudinal zonation within the depression system is vary. The height of the upper and lower boundaries of the belts at Tunkinsk Goltsy Range southern exposure and more gentle Khamar -Daban Range northern exposure does not match. At the same time, differences in the vegetation composition of the dominant communities are observed at different macrospece within the same belt [3].

The climate of the study area is formed as a result of the complex interaction of the lower atmosphere with a vast diversity in the surface structure. The radiation regime is characterized by an increased heat influx due to the prevalence of cloudy weather, large differences in the values of radiation and heat balances arising under the influence of the mountain-depression relief, a large difference in absolute heights and the vegetation type. In general, the climate is sharply continental, characterized by significant daily and annual temperature amplitudes, a small amount of annual precipitation. In the cold season, the Asian anticyclone dominates here, it corresponds to clear, calm, and frosty weather. The period with negative average daily temperatures begins in November and lasts about seven months. Winter is moderately severe, with little snow. Winter inversion of temperature is highly developed. The average temperature of the year is from -1.5 to -3.8°C. In summer, prevails cyclonic weather with moderately warm conditions. The sums of active temperatures range from 1200-1400°C in the Mondinskaya depression to 1500°C in the central part of the Torskaya and Tunkinskaya depressions. Continentality index vary from 61% in Mondy to 82% in Tunka. Permafrost is of an island character, its thickness is from few tens of meters to 100 m. Atmospheric humidification of the initial vegetation period is insufficient. High spatial heterogeneity of temperatures and precipitation is noted with a noticeable gradient between the peripheral and central parts of depressions. The annual rainfall in the study area is minimal throughout the East and Central Sayan and is 350–400 mm in the valleys, in Tunkinsky Goltsy – 500–600 mm, on the Khamar Daban slopes up to 1000 mm. In this case, the bulk of precipitation falls in the summer. The distribution of snow cover is very uneven. The height and density of the snow cover are affected by the ruggedness of the terrain and snow transport by strong westerly and northwesterly winds. In the center of depression, as a rule, the height of the snow cover does not exceed 0.5 m. Closer to the border of the forest – 1–1.5
The snow is loose here, on the slopes of the northern exposure it is more than on the southern ones. Snow thickens above the forest zone under the influence of wind [4].

Thus, the territory is characterized by a high contrast of geological, geomorphological, climatic, phytocenotic, and soil conditions, which creates a unique landscape diversity both between different depressions and within each individual one.

The most extensive in the area is the Tunkinskaya depression. It is characterized by the largest difference in altitude from 1300 to 2300 m between the bottom and surrounding ridges. In this regard, the presence of all altitudinal zones in depressions of the Tunkinskaya system is observed within its limits, while in other depressions one or another belt is absent. In Torskaya depression, due to the lower contrast of the relief and lower position above sea level, there is no alpine zone, and in Bystrinskaya depression, in addition to the alpine zone, the area of forest-steppe zone is also very limited. On the one hand, the high absolute elevations of the Mondinskaya depression caused the absence of dark coniferous cedar and subtaiga pine-larch-birch forests within the forest belt, and, on the other, the widest, high-altitude belt compared to other depressions of the Tunkinskaya system.

Soil-geomorphological cross sections were organized in the submeridional direction on the northern (Tunkinsky Goltsy Range) and southern (Khamar-Daban Range) sides of Mondinskaya and Tunkinskaya depressions. The latter also contains a profile in the sub-latitudinal direction from the Elovsky spur to mires at of the depression bottom (figure 1).

![Figure 1. Soil-geomorphological cross sections.](image)

Cross sections were laid taking into account the complex coverage of the soil and landscape diversity of the territory of the intermontane depression of the Tunkinskaya system. At each cross section, a description of the landscape, laying of the soil section, its description, sampling for subsequent laboratory analyses to clarify the genesis and name were carried out. Soil diagnostics were carried out according to the World Reference Base of soil resources [5]. To study the climatic characteristics, automatic thermographs were used [6]. Thermographs record the temperature and humidity all year round at a level of 2 m above the surface, in time step of 3 hours [7].

3. Results and discussion

3.1 Profile description I
Profile I is located in the northern part of the Tunkinskaya depression. It has a total length of 9 km and originates in the alpine zone of the southern macro slope of the Tunkinsky Goltsy Range at an absolute
height of 2150 m. The average annual soil temperature at a depth of 40 cm is -2.7°C, the average monthly maximum of the soil temperature is noted in July (9.9°C), the minimum in February is -15.8°C. The number of days with a temperature steadily exceeding 0°C reaches 160. The average value for the period with positive soil temperatures is 6.1°C, for the period with negative values is -10.2°C. The soil cover is represented by Nudilithic Leptosols, Lithic Leptosols, and Someriumbic Leptosols.

At an altitude of 1900 m, a sub-belt of subalpine Folic Leptosols and Lithic Leptosols lies in a narrow strip. The average annual air temperature at an altitude of 1900 m is about -3.2°C, maximum (9.9°C) is in August, minimum (-17.9°C) is in February. The frost-free period lasts 172 days; the average temperature of the warm period is 8.5°C. The period with negative air temperature reaches 192 days, the average air temperature over the specified period is -8.7°C. The average annual soil temperature at a depth of 40 cm is -1.2°C. The maximum average monthly soil temperature at an altitude of 1900 m was observed in July (13.5°C), the minimum – in January (-14.5°C). The number of days with positive values of soil temperature is 160, the average temperature for a period with a positive soil temperature is 6.8°C, for the period with negative temperature is -8.6°C.

The forest belt begins from 1700 m. The average annual air temperature at the site is -1.4°C, the average monthly maximum (12.1°C) observes in August, minimum (-16.6°C) – in February. The duration of the frost-free period is 163 days, the average air temperature of the frost-free period is 8.2°C. The period with negative temperature reaches 200 days with an average air temperature of -9°C. Soil formation here occurs on steep slopes, the tilt angles of which can reach 45° and change places in steep. Depending on the parent rocks, within its limits, Folic Entic Podzols can be found under pine-larch and larch forests on acidic rocks, Rendzic Leptosols under larch-birch bean-cereal-mixed-grass forests on carbonate (limestones, marbles).

At an altitude of 1400 m, the average annual temperature of the soil, at a depth of 40 cm, remains positive (1.4°C). In February, the average monthly soil temperature reaches a minimum (-4.2°C). The maximum was recorded in August at 9.2°C. The period with a temperature steadily exceeding 0°C lasts for 190 days. Below narrow strips are cedar-larch forbs and lingonberries on Folic Leptosols and Folic Entic Podzols. Due to powerful temperature inversions during the winter period, the average annual temperature in the belt of cedar-larch forbs and lingonberries is positive (1.0°C) [8]. The duration of the frost-free period is 200 days, the average air temperature of the frost-free period is 11.5°C. The maximum value of the average monthly air temperature falls on August (14.9°C). The cold period lasts for 165 days, the average temperature of the cold period reaches -8.5°C. The minimum average monthly air temperature was recorded in February (-14.5°C.)

At the foot of the Tunkinsky Goltsy Range (altitude 1080 m) at the site of a sharp profile fracture and transition to the piedmont part of the vegetation is represented by a mesoxerophilous pine-grass forest with larch and undergrowth from the cotoneaster and middle meadowsweet on Entic Podzols and Someriumbic Leptosols. Here, in the characteristics of the microclimate, a powerful influence of prolonged inversions of air temperature is also traced. The average annual air temperature remains positive (1.2°C), the period with the average daily temperature steadily exceeding 0°C lasts 202 days. The average air temperature, in this case, reaches 9.5°C. The maximum air temperature is shifted to July (15.4°C). The cold period is reduced to 163 days, with an average air temperature of -9.3°C. The average monthly minimum of air temperature is shifted to January (-14.1°C).

On the foothill inclined plain adjacent to the Tunkinsky Goltsy Range, the specifics of the soil cover and landscapes as a whole lies in the polychronic, caused by the periodic activation of water and mudstone mudflows [9]. The territory of the foothill inclined plain is represented by gently sloping sections from 1.5 to 5°. Its length is 4.5 km. In the upper part at an altitude of 1000-800 m at the point of profile fracture, a subtaiga belt with a birch-pine-cedar shrub-herb-mossy forest Folic Entic Podzols and Entic Podzols stretches in a narrow strip. In this strip, much more precipitation falls along the ridge than the lower parts of the depression. There are practically no early summer periods of drought. This is probably since the directions of the ranges almost coincide with the direction of movement of the western air masses that bring precipitation, and a small angle of the rain shadow falls on the lower parts of the southern slopes of the Tunkinsky Goltsy Range.
Below the cedar forests fall out of the vegetation; there is a change to more xerophytic pine and birch-pine forests. Among them, there are derivative birch forests and forest meadows, in places significantly steppe. The profile crosses areas of fallow soils located west of the Tagarkhai village. They spontaneously overgrow with pine from the nearest forest border.

Below 800–750 m a.s.l., a transition occurs to the mire-lake complex at the depression bottom, where the soil cover is represented by Histic Gleysols under peaty schmidtosocherny meadows. Gleyic Phaeozems soils are confined to hummocky bubbly sedge meadows with oppressed birch.

### 3.2 Profile description II

Profile II has a total length of 9 km. It originates in abs. height of 1405 m on the northern macro slope of the Khamar-Daban Range in the mountain taiga belt. Here under sparse larch-cedar, lingon-green-moss forests with dwarf birch shrubs and rhododendron, Folic Turbic Cryosols are formed. Woody vegetation is oppressed, the height of the trees does not exceed 20 m, the lower dry branches are covered with epiphytic lichens. The average annual air temperature here is ~0.54°C, the average monthly minimum (~20.1°C) is shifted to January. The maximum was recorded in July (15.2°C). The period with an air temperature steadily exceeding 0°C lasts for 205 days. The average temperature of the frost-free period is 8.0°C. The period with air temperature below 0°C lasts for 160 days, the average temperature of the cold period is -14.7°C.

At an altitude of 1200 m under the birch-cedar-lingon-cowberry-sphagnum forest, the soil cover is represented by the Histic Cryosols. At an altitude of 800-1000 m in areas where soil-forming rocks are characterized by medium loam granulometric composition as a result of long-term preservation of seasonal permafrost, small-leaved grass forests with an admixture of spruce on Folic Reductacaquic Cryosols are widespread. On southern exposures, Albic Stagnic Luvisols are found in gullies and saddles. In well-drained positions with lighter (sandy and light loamy) granular composition at this height, derivatives of birch-aspen and pine-birch-lingonberry forests on Folic Cambisols and Folic Entic Podzols are common.

Below 800 m, a forest-steppe belt begins, covering the lower parts of foothill inclined plains and terrace levels of the Irkut River. Natural soils here are represented by Entic Podzols and Cambisols under birch-pine forests or Stagnic Phaeozems under meadow and meadow-steppe communities. The landscapes of this part of the basin are strongly transformed by agricultural activity and represented by pastures and fallow soils, on which processes of natural restoration of vegetation are currently taking place. Mostly, pine-birch and birch-pine forests overgrow. The average annual air temperature is 0.2°C. The minimum average monthly air temperature falls on February (~16.5°C), the maximum observed in July (15.9°C). The period with an air temperature steadily exceeding 0°C increases to 213 days. The average temperature of the warm period is 9.5°C. Accordingly, the cold period lasts 152 days, the average temperature rises to -12.2°C.

### 3.3 Profile description III

Profile III originates on the western macro slope of the Elovsky spur, which is the right side of the Tunkinskaya depression and has a length of 10 km. At an altitude of 990 m in the subtaiga subbelt, the natural soil cover is represented by Albic Luvisols on medium and light loamy weathering products of basalts under birch-aspen-lingon-mixed grass forest. On lighter-grained rocks under pine-birch shrub-and-grass forests Folic Cambisols and Folic Entic Podzols.

Below 800 m, the interpenetration of the forest-steppe belt and the subtaiga sub-belt is observed, which significantly complicates the identification of clear boundaries between them. In the upper and middle parts of the piedmont inclined plane in the range of abs. heights of 750-800 m are widespread Entic Podzols, formed on loose (gravel-pebble with sand and sandy loamy) alluvial-proluvial drift cones under pine and birch-pine shrub-lingon-mixed grass forest. The relationship between the tree and grass layers in these ecosystems is largely determined by anthropogenic factors [3]. A significant part of the land is represented by fallow lands of different times, the age of which varies from 25-30-year to 150-year and older. The proximity of settlements leads to increased anthropogenic pressure on the soil -
grazing and haying, which prevents spontaneous reforestation on the one hand and contributes to the formation of steppe plant communities on the other. More arid conditions of soil formation on the lower parts of foothill inclined and alluvial plains contribute to the warming, which is due to a regular decrease in atmospheric moisture in the direction from the mountainous framing to the depression part.

The climatic characteristics of profile III as a whole have a more uniform spatial structure and characterize the climate of the central part of the depression. The average annual air temperature -1.2°C, the average monthly maximum falls in July and varies from 15.8 to 17.5°C, the minimum is shifted to January reaching the average monthly values from -23.5 to -24.7°C. The duration of the period with an average daily air temperature steadily exceeding 0°C lasts 178-201 days. The average air temperature during the warm period in the central part of the basin is from 8.5 to 12.7°C. The period with negative air temperature in the central part of the Tunkinskaya depression at all observation sites occurs synchronously and lasts for 216-135 days. The average temperature of the cold period ranges from -7.5 to -16°C.

3.4 Profile description IV
Profile IV originates in the alpine zone on the southern macro slope of the Tunkinsky Goltsy Range on the abs. 2315 m high in the Mondinskaya depression. Its length is 7 km. The territory is characterized by low values of average annual air temperature (3.7°C), with average monthly minimums in February (-20.5°C) and maximums in July (10.8 °C). The average annual soil temperature at a depth of 40 cm is -3.2°C. The number of days with positive soil temperature is 156 days, the average temperature of this period is 8.1°C, the period with negative soil temperature lasts for 209 days, with an average temperature of -12.8°C. Nudilithic Leptosols, Lithic Leptosols, and Someriumbric Leptosols are formed here under the rocky dryad tundra. Below is a belt of subalpine woodlands. Here, the average annual air temperature reaches its minimum values of -4.6°C, the minimum is also noted in February (-22.1°C), and the maximum in July (9.2°C). The average annual soil temperature at a depth of 40 cm is -3.5°C. The period with soil positive temperature lasts for 165 days, the average temperature of the period is 5.6°C.

At an altitude of 2150 m, they are represented by sedge-drylad larch forests with rhododendron shrubs, and from 2080 m to 2000 m a narrow strip of cedar woodlands is anemone- lingonberry, moss-lichen on the Protosodic Lithic Leptosols. Among larch woodlands, sedge meadows with willow shrubs (1940 m a.s.l.) are found. The soil cover here is represented by Someriumbric Leptosols. Below of 1700 m begins the forest belt. Someriumbric Leptosols and Histic Leptosols are formed under a larch sedge-mixed grass forest (height 1690 m). With a decrease in height, average annual air temperatures increase from -3.2°C at an altitude of 2150 m to -1.5°C at a site with altitude 1690 m. The minimum average monthly air temperature is shifted to January and averages of -17.7°C, the maximum is observed in July (11.2°C). At an altitude of 1690 m, the average annual temperature of the soil is -1.8°C. The period with a positive temperature of the soil is 170 days, the average temperature of the period is 1.6°C.

3.5 Profile description V
Profile V originates on the northern macro slope of the Mondinskaya depression (Khamar-Daban Range) in the alpine zone at 2000 m a.s.l. The vegetation is represented by a rocky cereal-sedge tundra with dwarf birch, willow, rhododendron, and Dasiphora on Folic Turbic Gleyic Cryosols. There is a single depressed undersized larch. At an altitude of 1880 m on the northwestern slope, under the larch rhododendron forest, Histic Gleyic Cryosols form. At the foot of the Khamar-Daban Range at an altitude of 1630 m on a flat surface of the slope, the vegetation is represented by birch-larch - moss forests. Soil cover is represented by Folic Albic Podzols. Cambisols are formed in the lower part of the foothill inclined plain (1390 m) on the northeastern slope under birch-larch steppe forests. On the terrace of the Irkut River at. 1270 m under the steppe with spaced out larch formed Arenic Fluvisols.
The average annual air temperature on the slope decreases with height, the effect of temperature inversions is practically not observed here. Thus, at 2000 m a.s.l., the average annual temperature is -3.4°C and increases with a decrease in altitude to -1.5°C (1403 m). The minimum average monthly air temperature was observed in January (-22.5°C), the maximum in July (12.5°C). The average annual soil temperature is -2.5°C. The period with soil temperature steadily exceeding 0°C does not exceed 145 days, the average temperature of the period is about 4°C.

4. Conclusion
The combination of increased moisture and a warmer microclimate on the southern slope of the Tunkinsky Goltsy Range created favorable conditions for the development of birch-larch and larch-pine-birch grass forests with rich undergrowth, typical of the more western regions of Siberia. According to the weather station Arshan, located in the foothill region of the Tunkinsky Goltsy Range in winter, air temperature here is 3-6°C higher than in the central part of the depression, and 2-4°C lower in the summer months. This difference becomes less noticeable only in the off-season and is about 0.1°C. The average annual air temperature in the weather station Arshan is -1.4°C, the average January temperature is -19.9°C, July temperature is 16°C. At the same time, the minimum temperatures in January drop to -42°C, the maximum in July rise to 36°C. A characteristic feature of the winter period is the temperature inversions that occur after a sharp decrease in air temperature in the surface layer. Inversions are observed over the entire length of the slope and are observed throughout the year, reaching maximum characteristics (vertical gradient - 13°C/100 m, duration 8.5 days) in the cold season, at night [11].

The distribution of air temperature characteristics (average, max., min.) on the northern slope of the Tunkinskaya depression is more affected by altitude (average annual air temperatures decrease from 2.6 to 1.4°C) and the presence / absence of vegetation (forested areas are characterized by lower temperature amplitudes) The temperature regime of the soil depends on more factors than the temperature regime of air. Along with the influence of altitudinal zonation and vegetation, it is necessary to take into account soil characteristics (type, particle size distribution, humidity, etc.). Unlike air temperature, the maximum and minimum annual temperatures in the soil at 40 cm depth are observed not in July and January, but in August and February, respectively. With increasing site height, annual extrema decrease in absolute value, and therefore the annual amplitude of soil temperature also decreases from 27.0°C (820 m a.s.l.) to 2.5°C (1400 m a.s.l.). The main factor of such differences in temperature is the change with the height of the ground vegetation cover - from the old fallow to the larch-cedar forest with dwarf birch, rhododendron and lingonberry-sphagnum moss in the upper part of the slope. The dense sphagnum moss cover (up to 35-40 cm high) is a heat insulator that prevents both heating and cooling of the soil. Unlike open areas, in these cases there are no daily temperature fluctuations, and the maximum and minimum in the annual course of soil temperature can last for several days [12].

In a more closed, highly located and smaller area of the Mondinskaya depression, the warm period begins at a later date and is characterized by lower values of the average air temperature and other microclimate characteristics. The influence of the basin relief on climatic characteristics is more evident in the cold season, when a powerful Siberian anticyclone is established over the territory. In general, there is a high spatial heterogeneity of temperatures and precipitation with a noticeable gradient between the peripheral and central parts of the depressions.

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