The effect of temperature fields on soil and plant cover formation in arid ecosystems of the UvsNuur basin

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Abstract. Introduction of remote and automated methods into the practice of soil and ecological studies urges for development of the methodological basis for combined analyses of surface and satellite data. The aim of the study was to explore the possibility to identify and typologise the structural and functional borders of soil cover using temperature fields, obtained by combined analysis of the temperature time series obtained by field and remote temperature monitoring. The functional relationships that are expressed within geosystems as the flux of energy and matter are reflected in soil temperature regimes, hydrophysical soil properties and plant cover biological productivity, which were studied in the arid ecosystems of the UvsNuur depression in Tuva, Russia. The quantitative characteristic of the temperature fields of the psammophytic soils were obtained, and the effect of hydrothermal conditions and soil hydrophysical properties on above- and belowground phytomass stocks of the sand massif Zuger-Els revealed and discussed.

1. Introduction
Temperature regime is one of the most significant environmental factors that together with hydrological regime characterize the general energy level for soil and plant cover formation and functioning. A temperature field represents a combination of temperature data points within an area, which, based on the results of both domestic and foreign studies, is regarded as a leading factor in the structural and functional organization of soil and plant cover. The quantitative characteristics of temperature fields are widely used for forecasting soil properties and phytocenoses productivity as they closely correlate with environment characteristics and depend on soil formation factors. Most comprehensively the factors, determining soil properties in a specific point of an area under study, are accounted by the SCORPAN model. The latter represents a soil-predicting function, based on the assumption that a similar combination of soil forming factors, i.e. predictors, results in soils of similar genesis, whereas the borders between soil structures are determined by changes in soil cover differentiation factors [1, 2]. The obtained temperature field maps are sufficiently informative in relation to the energetic of soil formation processes and can be used to assess soil thermal conditions in poorly investigated areas.

2. Materials and Methods
The ecosystems of the aeolian accumulative plains in semi-fixed or mobile sands of the Zuger-Els, representing a part of the Borig-Del vast sand massif in Mongolia, were chosen as the study sites. The
Zuger-Els sand massif is a cluster in the State Nature Biosphere Reserve and UNESCO Nature Heritage of the UvsNuur basin. The prolonged shape of the massifs due to its alluvial origin by blowing the river terrace material “water-freed” after the erosion basis decreased. The Zuger-Els sands are separated from other geographical objects by a chain of residual hills, located along the border of the ancient valley, thus practically excluding any possibility of groundwater access to the sands from the freshwater Tere-Hol Lake and the Tes-Hem River. The borders of the sand massif are clearly displayed by the strips of the relatively closed steppe vegetation. Mobile sand areas covered by extremely scarce psammophytic vegetation, are located around the steps [3, 4]. The main diversity of the psammophytic plant communities at the eluvial (El) catena position was represented by *Leymus racemosus* (Lam.) Tzvelev – *Hedysarum fruticosum* (Pall.) and polydominant communities with *Stipa krylovii* (Roshev.), *Ephedra lomatolepis* (Shrenk). At the transit (Tr) position the main herbs and grasses species were represented by *Potentilla acaulis* L., *Artemisia tomentella* (Trautv), *Oxytropis tragacanthes* Fisch. ex DC., * Festuca valesiaca* Tzvel., *Stipa krylovii*, *Triticum desertorum* Fisch. ex Link, * Clestogenes squarrosa* (Trin) Keng. The accumulative (Ac) position was occupied by a phytocenoses with *Leymus racemosus* and *Stipa krylovii* prevailing and *Artemisia tomentella* also contributing. The catena complex was located in a typical for the Zuger-Els sands site, featuring a combination of specific geomorphological conditions, determining soil formation and phytocenoses productivity (figure 1).

![Figure 1](image_url). Location of the key study sites: (a) in the satellite image (N50°15’2.4”; E95°0,2’32.3”); (b) within the boundaries of the catena complex; (c) the general view of the Zuger-Els sand massif.

The study area is located within the erzin dry steppe region of the south Altai Tuva-Hangai hollow-montane province of the steppe zone, mainly covered by Chestnut sandy loam and sandy soils with granite screees [5]. The sands are mostly fixed by sods, but vast areas are mobile. Such mobile sand areas are occupied by thin poorly developed meadow-chestnut and light-colored chestnut soils that drastically differ in the hydrophysical properties from zonal soils. Chestnut sandy soils as a specific systematic category were isolated in Tuva soil classification by V.A. Nosin in 1963 [5], describing the
properties of weakly fixed and highly mobile sands due to active deflation of hilly sand massifs. Later on much information about geomorphology, genesis and geocology of the sands was obtained. According to the principles of the substantive and genetic classification of soils [6], the Zuger-Els sands can be identified as psammozems and considered in the classification scheme along the following line: primary soil formation (stem), poorly developed soils (division), psammozems and humus-accumulating psammozems (type), typical O-C\textsuperscript{′}, podzolized W-\textsuperscript{Ce}-C\textsuperscript{′}, illuvial-ferric O-Cf-C\textsuperscript{′′} and pseudofibric O-Cff-C\textsuperscript{′′} (subtype).

The ground surface air and soil temperature monitoring was performed with the help of DS-1921G “Thermochron” data logger, taking into account the properties related to the genesis of climate types in the region. To register air temperature, the data loggers were placed at 2 m above the ground surface with no direct irradiation. Soil temperature was registered on soil surface and in soil genetic horizons. The temperature measurements were recorded at 4 hours increments. The obtained temperature records were used for estimating thermal resources and revealing their temporal trends [7].

To perform retrospective and statistical analyses and to visualize MODIS data we used software tools, developed by the Federal Research Center for Information and Computational Technologies (ICT, Novosibirsk, Russia). The software is based on new technology to access satellite data archives using PostgreSQL database management system (DBMS) with an additional module. The latter is intended for providing direct access to archived data files without the need for preliminary copying and file format transformation for the DBMS used [8]. The module provides transparent transformation of file archives with satellite images into virtual tables of the database, enabling SQL-inquiries into the data in file archives. The system can work with any spatial data formats without their preliminary reformatting and otherwise processing.

Soil physical, chemical and hydrophysical properties were determined by conventional techniques [9]. To evaluate productivity of phytocenoses, grown on the developing sandy soils, we determined the above- and belowground phytomass stocks following the methods recommended for grasslands [10]. At each study site three 10 m\textsuperscript{2} plots were chosen for geobotanical description. Within each plot quadrat (50·50 cm) subplots were chosen for clipping the aboveground phytomass at the ground surface level, whereas litter was manually collected from the surface. The standing dead phytomass (D) was separated from the green one (G), whereas the latter was also sorted into species. Litter (L) was washed from soil using sieves. At the centre of each subplot soil cores (10 cm\textsuperscript{3}) were collected from 0–10 and 10–20 cm depths to determine belowground phytomass. Soil cores were washed by decantation, and the obtained plant material was dried at 60 °C over 24 hours, and separated by sieving into large (> 2 mm), middle-sized (2.0-0.50 mm) and small (<0.5 mm) fractions, as well as into living (B) and dead (V) roots. Phytomass stocks are expressed in g/m\textsuperscript{2}. The names of the vascular plants are given in compliance with the Synopsis of the Siberian flora: Vascular plants, 2005 [11].

3. Results and Discussion

Temperature regime is one of the most significant environmental factors, determining the intensity energy- and mass exchange processes in soils. The arid ecosystems of the UvsNuur basin were developed under sharply continental climate with its low atmospheric precipitation and high thermal resources in summer. Spatial distribution of temperature fields of psammozems of the Zuger-Els sand massif, obtained by statistical analysis of the over-positioning of temperature fields and information content of soil cover contours with the ICT help, is shown in figure 2.

The mapping models allow visualizing the boundaries of the temperature fields of soil cover typologic units and can be used to reveal spatial and temporal gradients in thermal resources on large and local area scales. They also provide additional information about nature complexes, which formation and functioning occurs under ultra-high or low temperatures. Spatial differentiation of temperature fields, as well as day and night temperature fluctuations, could be clearly seen on the local scale.
Figure 2. Cartographic models of temperature fields for day and night temperatures (a) and statistical analysis over-positioning of temperature fields and information content of soil cover contours (b).

According to the field studies, the thermal regime of chestnut soils and psammozems is determined by the average yearly air temperature of –1.9 °C; the average frost-free period of 169 days, and the accumulated temperature (>10 °C) sum of 2207°C·day (table 1).

Table 1. Yearly air and soil temperatures in the Zuger-Els sand massif in psammozem layers (temperature sumT°C·day/ days of period duration over which accumulated).

| Temperature regime characteristics | Air temperature | 0 | 10 | 20 | 50 |
|-----------------------------------|-----------------|---|----|----|----|
| Eluvial position, psammozem poorly developed (N50°17'20.6; E95°0.4'22.6) | yearly | -653.1 | 1420.5 | 1090.5 | 921.6 | 1010.1 |
| | >10° | 2207/125 | 3319/142 | 2985/139 | 2528/136 | 2510/135 |
| | >5° | 2407/151 | 3287/162 | 2903/165 | 2804/169 | 2721/165 |
| | >0° | 2461/169 | 3294/184 | 2907/183 | 2837/183 | 2774/185 |
| | <0° | -3114/172 | -1997/157 | -1935/157 | -1915/158 | -1764/156 |
| Average annual, °C | -1.9 | 4.2 | 3.4 | 2.7 | 3 |
| Transit position, humus-accumulating psammozem (N50°15'23.4; E95°0.2'32.3) | yearly | -653.1 | 794 | 579.5 | 658.6 | 882.8 |
| | >10° | 2207/125 | 2575/132 | 2400/133 | 2320/131 | 2226/128 |
| | >5° | 2407/151 | 2755/155 | 2522/150 | 2480/154 | 2448/158 |
| | >0° | 2461/169 | 2830/182 | 2603/179 | 2542/179 | 2496/179 |
| | <0° | -3114/172 | -2035/159 | -2024/162 | -1884/162 | -1613/162 |
| Average annual, °C | -1.9 | 2.3 | 1.7 | 1.9 | 2.6 |
| Accumulative position, psammozems ordinary (N50°19'12.6; E95°0.8'36.3) | yearly | -653.1 | 1416.7 | 1084.8 | 1059.3 | 963.2 |
| | >10° | 2207/125 | 3212/146 | 2788/139 | 2560/135 | 2257/129 |
| | >5° | 2407/151 | 3349/165 | 2965/164 | 2861/166 | 2483/159 |
| | >0° | 2461/169 | 3403/184 | 3016/186 | 2901/185 | 2547/187 |
| | <0° | -3114/172 | -1986/157 | -1934/155 | -1841/156 | -1584/154 |
| Average annual, °C | -1.9 | 4.2 | 3.2 | 3.1 | 2.8 |

Overall the correlation coefficient between the field and satellite data exceeded 0.8, confirming high information capacity of the satellite data for assessing temperature fields of soil cover typological units of the studied sand massif.
Temperature field formation and spatial differentiation on the local scale are directly related to thermal conductivity. One of the main characteristics of the latter is heat conductivity coefficient, determined by soil mineral matrix, organic matter accumulation, granulometry, bulk density and porosity. The high extent of grain sorting is the main characteristic feature of the Zuger-Els sand granulometry (table 2). Both along the mesorelief and soil depth profile the granulometric composition was dominated by fine grains (90–95%) with some silt and coarse sand contribution (1–3%). Small accumulation (up to 4%) of medium sand grains was found in the accumulative position. The mineral matrix composition of the Zuger-Els sands could be described as medium- and fine grainy one, well sorted and with low (2.0–2.5%) fine-sized grains’ content.

Table 2. Granulometric composition of psammozems in the arid ecosystems of the Zuger-Els sand massif.

| Depth, cm | Loss HCl | 1-0.25 | 0.25-0.05 | 0.05-0.01 | 0.01-0.005 | 0.005-0.001 | <0.001 | <0.01 | >0.01 |
|-----------|----------|--------|------------|------------|-------------|-------------|--------|-------|-------|
| Eluvial position, psammozem poorly developed |
| 0-10  | 8.6 - | 90.1  | 0.1  | 0.2  | 0.8  | 0.2  | 1.2  | 98.8 |
| 10-20 | 7.4 - | 91.0  | 0.8  | 0.4  | 0.1  | 0.3  | 0.8  | 99.2 |
| 20-30 | 6.3 1.9 | 90.3  | 0.1  | 0.1  | 0.6  | 0.7  | 1.4  | 98.6 |
| 30-40 | 6.4 3.9 | 87.8  | 0.4  | 0.1  | 0.7  | 0.7  | 1.5  | 98.5 |
| 40-50 | 6.3 - | 93.2  | 0.1  | 0.2  | 0.1  | 0.1  | 0.4  | 99.6 |
| 50-60 | 6.4 - | 92.6  | 0.4  | 0.3  | 0.1  | 0.2  | 0.6  | 99.4 |
| 60-70 | 5.7 - | 92.5  | 0.7  | 0.4  | 0.1  | 0.6  | 1.1  | 98.9 |
| 70-80 | 4.7 - | 93.8  | 0.6  | 0.1  | 0.1  | 0.7  | 0.9  | 99.1 |
| 80-90 | 5.0 - | 92.3  | 1.0  | 0.7  | 0.2  | 0.8  | 1.7  | 98.3 |
| 90-100| 5.4 - | 92.7  | 0.2  | 0.6  | 0.5  | 0.6  | 1.7  | 98.3 |
| Transit position, humus-accumulating psammozem |
| 0-10  | 5.0 - | 92.1  | 0.2  | 0.9  | 0.5  | 1.3  | 2.7  | 97.3 |
| 10-20 | 5.9 - | 92.4  | 0.1  | 0.2  | 0.1  | 1.3  | 1.6  | 98.4 |
| 20-30 | 5.3 - | 90.7  | 2.5  | 0.7  | 0.1  | 0.7  | 1.5  | 98.5 |
| 30-40 | 5.8 - | 92.4  | 0.3  | 0.2  | 0.1  | 1.2  | 1.5  | 98.5 |
| 40-50 | 4.9 - | 94.0  | 0.5  | 0.1  | 0.1  | 0.4  | 0.6  | 99.4 |
| 50-60 | 5.4 - | 93.2  | 0.2  | 0.4  | 0.2  | 0.6  | 1.2  | 98.8 |
| 60-70 | 5.7 - | 92.3  | 0.5  | 0.3  | 0.4  | 0.8  | 1.5  | 98.5 |
| 70-80 | 5.3 - | 93.6  | 0.2  | 0.2  | 0.1  | 0.6  | 0.9  | 99.1 |
| 80-90 | 5.9 - | 93.0  | 0.1  | 0.1  | 0.3  | 0.6  | 1.0  | 99.0 |
| 90-100| 4.0 - | 95.1  | 0.1  | 0.3  | 0.1  | 0.4  | 0.8  | 99.2 |
| Accumulative position, psammozem ordinary |
| 0-10  | 4.8 0.7 | 93.2  | 0.6  | 0.4  | 0.2  | 0.1  | 0.7  | 99.3 |
| 10-20 | 6.6 - | 91.8  | 0.6  | 0.7  | 0.1  | 0.2  | 1.0  | 99.0 |
| 20-30 | 4.7 - | 93.0  | 0.6  | 0.9  | 0.5  | 0.3  | 1.7  | 98.3 |
| 30-40 | 4.6 - | 94.3  | 0.3  | 0.5  | 0.2  | 0.1  | 0.8  | 99.2 |
| 40-50 | 4.4 - | 93.9  | 0.6  | 0.4  | 0.5  | 0.2  | 1.1  | 98.9 |
| 50-60 | 6.1 - | 92.9  | 0.1  | 0.1  | 0.7  | 0.1  | 0.9  | 99.1 |
| 60-70 | 7.6 0.5 | 90.5  | 0.1  | 0.1  | 0.1  | 1.1  | 1.3  | 98.7 |
| 70-80 | 3.7 - | 94.8  | 0.2  | 0.1  | 0.5  | 0.7  | 1.3  | 98.7 |
| 80-90 | 4.4 1.1 | 92.9  | 0.5  | 0.1  | 0.8  | 0.2  | 1.1  | 98.9 |
| 90-100| 5.1 0.7 | 92.7  | 0.1  | 0.4  | 0.7  | 0.3  | 1.4  | 98.6 |

- no fraction

The light granulometry of sands resulted in low soil humus content (0.8–2.5%), low cation exchange and water holding capacities, as well as high water permeability, infiltration rate and hydrologic conductivity, fluctuating somewhat at the eluvial and transit positions. Fine grain and coarse sand grains were also found to fluctuate at the same positions (1–2%). The accumulative
position had increased (up to 4%) medium sand content. The mineral substrate of the Zuger-Els sand massif was found to be represented by medium and fine grains, very well sorted, with low content of fine grains (2.0–2.5%). The light soil texture resulted in low (0.8–2.5%) humus content, low cation exchange and water holding capacities, as well as high water permeability, infiltration rate and hydrologic conductivity.

Soil profile and mineral bedrock structure are characterized by bulk density and porosity. Depending on the primary components and their compaction, the bulk density of sands can vary broadly. The uniform granulometry of spherical grains can be loosely (47.6%) cubically or more densely (25.9%) hexagonally packed. The highest bulk density of 1.5–1.6 g/cm\(^3\) was found in aeolian sands with >50% of fine grains, packed at maximal density (figure 3).

The recent aeolian depositions the bulk density was found to lower (1.3–1.5 g/cm\(^3\)). The bulk density closely correlates with substrate total porosity, which in the studied Zuger-Els psammozem ranged from 40 to 50%. Aeration porosity (Paer) in soil layers with loosely compacted granulometric fractions was found to be rather high (12–15%). In more densely compacted and moist layers Paer decreased sharply (2–4%), in compacted sand layers resulting in a small Paer volume, indispensable for sustaining normal gas exchange and active aerobic processes.

![Figure 3. Physicochemical properties of psammozem of the Zuger-Els sand massif. Soils: 1 – poorly developed psammozem, 2 – humus-accumulating psammozem, and 3 – ordinary psammozem.](image)

Porous space structure significantly affects the quantitative parameters, characterizing soil water status and content. Hydrophysical soil properties directly influence formation of aeolian relief, as wetter sands are less mobile, whereas the plants, which are also one of the main relief-forming factors, more actively colonize and grow in sites with better soil and hydrological conditions. When soil water content exceeds the minimal, i.e. field, water-holding capacity (FC) due to heavy rainfall, the entire porosity volume in psammozem become filled almost to its maximum; exceeding the latter, water rapidly flows laterally or downwards the soil profile. Normally, under natural conditions psammozem contain no more than 40% water (of the total soil volume), corresponding to MWC, and 1.5% under maximal hygroscopic moisture (HM). Due to the temperature gradient in the surface sand layer, water flows towards the spots with lower temperature, therefore the aeration zone develops a layer with permanent wilting point water content (PWP), i.e. with water unavailable to plants, which in our study accounted for 0.7–1.3% of soil volume (figure 4).

The plant available, i.e. productive, water content (AW) is of practical importance for soil water balance. The AW, commonly accumulating in soil layers below the aeration zone, was estimated to range from 20 to 40% in the studied psammozems.
Heat availability and hydrophysical soil properties directly affect plant community development and productivity. Estimates of phytomass stocks and production are the main characteristics of landscape structure and functioning. The studied soil profiles had horizons with lesser bulk density, but increased AWC; and even small changes in hydrothermal conditions were shown to seriously affect plant species composition and productivity of phytocenoses.

**Figure 4.** Water-physical properties of psammozem of the Zuger-Els sand massif. Soils: 1 – poorly developed psammozem, 2 – humus-accumulating psammozem, and 3 – ordinary psammozem. Abbreviations used: FC – field water-holding capacity. HM – maximal gyroscopic moisture, PWP – permanent wilting point, and AW – readily available water content.

The studied catena complex did not show any difference in above- and belowground phytomass stocks between different catena positions; however, each of the studied phytocenoses displayed specific features, related to heat availability and hydrological regime (table 3–8). Notably, the composition of dominant species assemblages, making the main contribution into the green phytomass stock, differed between different catena positions. Practically half (44.6%) of the green phytomass stock at the eluvial position was produced by *Leymus racemosus* with 40% of projective cover, which can be considered rather high for plant communities growing on sandy soils, and specifically on the poorly developed psammolozems studied (table 3).

**Table 3.** Species composition and the aboveground green and dead phytomass stocks of the *Hedysarum-Leymus* community on the poorly developed psammozem at the catena eluvial position

| No. | Species composition          | Projective coverage, % | Green phytomass (G), g/m² | Green phytomass (G), % in total phytomass stock |
|-----|------------------------------|------------------------|----------------------------|-----------------------------------------------|
| 1   | *Leymus racemosus*           | 40                     | 51.9                       | 44.6                                         |
| 2   | *Hedysarum fruticosum*       | 20                     | 22.2                       | 19.3                                         |
| 3   | *Artemisia tomentella*       | 10                     | 14.4                       | 12.4                                         |
| 4   | *Gypsophila paniculata*      | 10                     | 12.3                       | 10.5                                         |
| 5   | *Orostachys spinosa*         | 10                     | 7.7                        | 6.6                                          |
| 6   | *Agropyron desertorum*       | 10                     | 7.2                        | 6.2                                          |
| 7   | *Salsola tragus*             | 10                     | 0.6                        | 0.05                                         |
| 8   | *Parmelia vagans*            | 10                     | 0.1                        | 0.0                                          |

Total green fractions (G), g/m² 116.3
Standing dead phytomass (D), g/m² 19.7
Litter (L), g/m² 7.2
Total aboveground phytomass (G+D+L), g/m² 143.2
Rather high (19.3%) contribution into green phytomass stock was made by *Hedysarum fruticosum*; the shares of other species ranging 6–10%. The aboveground phytomass stock was composed mainly of the green phytomass (81.2%), with standing dead phytomass and litter accounting for 13.7 and 5.0%, respectively. Belowground phytomass stock was significantly higher than the aboveground one, being composed mainly by big (>2.0 mm in diameter) living and dead roots in 0–10 cm layer (table 4). The latter fractions accounted for 46.7 and 35.3% of the total phytomass, respectively. With soil depth the belowground phytomass stocks decreased, comprising 17% in the 10–20 cm layer. Total belowground phytomass in the 0–20 cm layer was estimated as 2634 g/m².

| Living (B) and dead (V) | Living (B) and dead (V) belowground phytomass, g | Living (B) and dead (V) belowground phytomass, g/m² |
|-------------------------|-----------------------------------------------|-----------------------------------------------|
|                         | B | V | B+V | B | V | B+V |
| >2.0 cm                 | 9.6 | 3.0 | 12.6 | 961 | 301 | 1262 |
| 2.0–0.5 cm              | 0.8 | 2.4 | 3.2 | 80 | 240 | 320 |
| <0.5 cm                 | 1.9 | 3.9 | 5.8 | 191 | 390 | 581 |
| Total                   | 12.3 | 9.3 | 21.6 | 1232 | 931 | 2163 |
| 10–20 cm                | 0.8 | 0.8 | 1.7 | 83 | 83 | 166 |
| >2.0 cm                 | 0.4 | 0.9 | 1.3 | 38 | 89 | 127 |
| 2.0–0.5 cm              | 0.4 | 1.3 | 1.8 | 46 | 132 | 178 |
| <0.5 cm                 | 1.7 | 3.5 | 4.7 | 167 | 348 | 471 |
| Total                   | 1428 | 447 | 579 | 2634 |  |

The phytocenoses at the catena transit position was dominated by *Potentilla acaulis*, *Artemisia tomentella* and *Oxytropis tragacanthoides* (table 5).

| No. | Species composition | Projective coverage, % | Green phytomass (G), g/m² | Green phytomass (G), % in total phytomass stock |
|-----|---------------------|------------------------|---------------------------|-----------------------------------------------|
| 1   | *Potentilla acaulis* | 40                     | 37.7                      | 30.1                                          |
| 2   | *Artemisia tomentella* | 30                    | 33.1                      | 26.4                                          |
| 3   | *Oxytropis tragacanthoides* | 30              | 19.5                      | 15.5                                          |
| 4   | *Stipa krylovii*     | 10                     | 12.4                      | 9.9                                           |
| 5   | *Festuca valesiaca*  | 10                     | 5.3                       | 4.2                                           |
| 6   | *Cleistogenes svarrossa* | 10                     | 3.1                       | 2.5                                           |
| 7   | *Caragana pygmaea*   | 10                     | 5.2                       | 4.1                                           |
| 8   | *Parmelia vagans*    | 10                     | 1.5                       | 1.2                                           |
| 9   | *Agropyron desertorum* | 10                 | 2.7                       | 2.5                                           |

Total green fractions (G), g/m²: 125.5
Standing dead phytomass (D), g/m²: 4.2
Litter (L), g/m²: 2.3
Total aboveground phytomass (G+D+L), g/m²: 132.0
Shifts in dominant species affected phytomass content in phytocenoses. Alongside with high green phytomass (95%) low dead phytomass (2–4%) was found, as such species produced little of those fractions. Belowground phytomass, similarly to the phytocenoses described above, drastically exceeded the aboveground phytomass stock and was produced mostly as big living roots (50%) in the 0–10 cm layer (table 6). Total belowground phytomass stock in 0–20 cm layer was estimated as 2634 g/m². Heat availability for the phytocenosis apparently facilitated high belowground phytomass production.

Table 6. Living (B) and dead (V) belowground phytomass stocks of the Potentilla-Artemisia community on the humus-accumulating psammozem at the catena transit position.

| Living (B) and dead (V) roots, mm | Living (B) and dead (V) belowground phytomass, g | Living (B) and dead (V) belowground phytomass, g/m² |
|---------------------------------|-----------------------------------------------|-----------------------------------------------|
|                                 | B     | V     | B+V  | B     | V     | B+V  |
| >2.0                           | 15.9  | 5.6   | 21.5 | 1587  | 557   | 2144 |
| 2.0–0.5                        | 1.2   | 2.6   | 3.8  | 122   | 259   | 381  |
| <0.5                           | 0.9   | 2.3   | 3.2  | 91    | 230   | 321  |
| Total                          | 18.0  | 10.5  | 28.5 | 1800  | 1046  | 2846 |
|                                 |       |       |      |       |       |      |
|                                 | B     | V     | B+V  | B     | V     | B+V  |
| >2.0                           | 0.3   | 0.6   | 0.9  | 32    | 61    | 93   |
| 2.0–0.5                        | 0.2   | 1.2   | 1.4  | 21    | 123   | 144  |
| <0.5                           | 0.4   | 0.8   | 1.2  | 36    | 76    | 112  |
| Total                          | 0.9   | 2.6   | 3.5  | 89    | 260   | 349  |
|                                 |       |       |      |       |       |      |
|                                 | B     | V     | B+V  | B     | V     | B+V  |
| >2.0                           |       |       |      |       |       |      |
| 2.0–0.5                        |       |       |      |       |       |      |
| <0.5                           |       |       |      |       |       |      |
| Total                          |       |       |      |       |       | 3205 |

The herbs and grasses community at the accumulative position was dominated by Leymus racemosus, contributing the most (52.4%) into the total aboveground phytomass stock (table 7).

Table 7. Species composition and the aboveground green and dead phytomass stocks of the herbs and grasses community on the ordinary psammozem at the catena accumulative position.

| No. | Species composition | Projective coverage, % | Green phytomass (G), g/m² | Green phytomass (G), % in total phytomass stock |
|-----|---------------------|------------------------|----------------------------|-----------------------------------------------|
| 1   | Leymus racemosus    | 40                     | 73.5                       | 52.4                                         |
| 2   | Stipa krylovii      | 30                     | 16.8                       | 12.0                                         |
| 3   | Artemisia tomentella| 30                     | 10.7                       | 7.6                                          |
| 4   | Potentilla acaulis. | 10                     | 2.8                        | 2.0                                          |
| 5   | Caragana pygmaea    | 10                     | 3.1                        | 2.2                                          |
| 6   | Parmelia vagans     | 10                     | 1.5                        | 1.1                                          |
| 7   | Agropyron desertorum| 10                     | 0.6                        | 0.4                                          |
| 8   | Ephedra lomatolepis | 10                     | 0.3                        | 0.2                                          |
| Total|                     |                        | 109.1                      |                                               |

Percentage of other dominants (Stipa krylovii, Artemisia tomentella) in the total aboveground phytomass and dead phytomass was much lower (12.0 and 7.6%). The main part of the belowground
phytomass, similarly to other catena positions, was concentrated in the 0–10 cm soil layer because of the B fraction (58.2%) with less significant (10%) contribution from the V fraction (table 8).

Table 8. Living (B) and dead (V) belowground phytomass stocks of the herbs and grasses community on the ordinary psammozem at the catena accumulative position

| Living (B) and dead (V) roots, mm | Living (B) and dead (V) belowground phytomass, g | Living (B) and dead (V) belowground phytomass, g/m² |
|---------------------------------|-----------------------------------------------|-----------------------------------------------|
|                                 | B                                             | V                                             | B                                             | V                                             |
| 0–10 cm                         | 13.7                                          | 2.4                                           | 16.1                                          | 1369                                          | 241                                           | 1610                                          |
| >2.0                            | 0.4                                           | 1.3                                           | 1.7                                           | 38                                            | 128                                           | 168                                           |
| 2.0–0.5                         | 0.2                                           | 2.3                                           | 2.5                                           | 23                                            | 230                                           | 253                                           |
| <0.5                            | 14.3                                          | 6.0                                           | 20.3                                          | 1430                                          | 599                                           | 2029                                          |
| Total                           | 0.7                                           | 0.2                                           | 0.9                                           | 71                                            | 23                                            | 94                                            |
| 10–20 cm                        | 0.2                                           | 1.2                                           | 1.4                                           | 21                                            | 123                                           | 144                                           |
| >2.0                            | 0.2                                           | 0.6                                           | 0.8                                           | 24                                            | 59                                            | 82                                            |
| 2.0–0.5                         | 1.1                                           | 2.3                                           | 3.1                                           | 114                                           | 228                                           | 320                                           |
| Total                           | 1.1                                           | 2.3                                           | 3.1                                           | 114                                           | 228                                           | 320                                           |
| 0–20 cm                         |                                               |                                               |                                               |                                               |                                               |                                               |
| >2.0                            |                                               |                                               |                                               |                                               |                                               | 1704                                          |
| 2.0–0.5                         |                                               |                                               |                                               |                                               |                                               | 312                                           |
| <0.5                            |                                               |                                               |                                               |                                               |                                               | 335                                           |
| Total                           |                                               |                                               |                                               |                                               |                                               | 2351                                          |

The 0–10 cm layer was found to contain 320 g/m² of B+V, accounting for 14% of the total belowground phytomass stock. In the 0–20 cm layer the amount of B+V was estimated as 320 g/m².

4. Conclusion
Cartographic models of temperature fields, obtained as a result of combined analysis of field and satellite data, were shown to be rather informative about the energetics of the soil formation processes and can be used for assessing hydrothermal conditions in the arid ecosystems of the Zuger-Els sand massif. Quantitative characteristics of the psammozem temperature fields, soil physicochemical and hydrophysical properties and thermal supply during the period of biological activity had crucial effect on above- and belowground phytomass production of plant communities, growing in mesolandscapes at catena hypsometric positions. The soil temperature regime affects to a larger extent belowground phytomass stock. Optimal conditions for heat availability to plants at transit catena position facilitate accumulation of living and dead belowground roots, thus supplying plant material belowground for soil organic matter formation. Functional relationships, which within the geosystems are expressed as matter and energy fluxes, in the UvsNuur arid ecosystems can be studied using temperature regime, soil water-physical properties and plant biological production as proxies.

Acknowledgements
The study was carried out according to the state assignment of Institute of Soil Science and Agrochemistry of Siberian Branch of the Russian academy of sciences with financial support from the Ministry of Science and Higher Education of the Russian Federation.

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