Application of automatic thermographs (thermohygrographs) to microclimate monitoring

O V Vasilenko¹ and N N Voropay¹,²

¹ V B Sochava Institute of Geography SB RAS, Russia, Irkutsk
² Institute of Monitoring of Climatic and Ecological Systems SB RAS, Russia, Tomsk

oksna85@mail.ru, voropay_nn@mail.ru

Abstract. At V.B. Sochava Institute of Geography SB RAS work is carried out on studying the climate of landscapes in the Tunkinskaya depression. Thermographs and thermohygrographs, such as Hygrochron Temperature / Humidity Logger iButton (Maxim Integrated Inc., USA), are used for monitoring of air temperature and humidity. The application of DS1922 thermographs and DS1923 thermohygrographs to climate monitoring is promising and allows us to describe the features of temperature and humidity regimes correctly taking into account the properties and form of the underlying surface. The reliability of the observation data obtained by using the electronic loggers is confirmed by statistical methods. The differences in the time and average daily values of temperature and relative humidity obtained by the loggers and standard meteorological equipment in most cases do not exceed the instrumental error declared by the manufacturer. The data obtained with the help of DS1922 thermographs and DS1923 thermohygrographs can significantly supplement the available information on meteorological conditions in mountain areas.

1. Introduction

The climatic changes of recent decades have reached significant rates and scales. The global nature of the climate changes plays an important role in addressing many problems of sustainable development and is the subject of special consideration for scientists of various scientific disciplines. The observed changes in the climate system occur due to a number of natural and anthropogenic factors and can be predicted with the help of modern models of the general circulation of the atmosphere and the ocean. The influence of the climate forming factors in different regions is different. As a result, the temporal variability of the climate system is observed in a wide range of meteorological elements and has a complex spatial structure. In this regard, regional monitoring of climate components is an integral part of fundamental research on the global climate change.

At present, climate monitoring in Russia is carried out within the framework of the program «Global Climate Observing System» (GCOS) [1]. The GCOS performs measurements of numerous atmospheric parameters for solving a wide range of problems. The main components of the GCOS include a network of terrestrial meteorological, aerological, and radar observations; a system of marine and aerospace observations. The listed components of the GCOS have their advantages, as well as limitations, errors and inaccuracies. The density of the meteorological network is insufficient to study the regional climate, and the errors of various modern observation systems depend on the methods of measurement, the instruments used, the state of the atmosphere, and the time and conditions of the...
underlying surface. As a result, there is a need to expand the network for monitoring of meteorological elements, especially at the regional level, and to increase the involvement of alternative monitoring systems. These include data of satellite systems for observing the climate, mathematical modeling, as well as data from field observations using modern automatic measuring instruments.

2. Objects, data, and methods

Complex climatic studies using the modern observation systems have been successfully implemented at the Tunkinsky depression station of the V.B. Sochava Institute of Geography SB RAS. Within the framework of complex geographic studies, work is underway to identify spatial and temporal features of the distribution of climate components in mountain-depression landscapes and factors of their formation [2]. The study area lies within the southwestern part of the Baikal rift zone in the South Siberian physic-geographical region, and is represented by the Tunkinskaya branch of intermountain depressions.

The local conditions are imposed on the zonal features of the climate of this region due to a combination of high-mountainous terrain and relatively low intermountain depressions, latitudinal orientation of the main orographic elements, and regional peculiarities of the atmospheric circulation. In addition, the complex terrain and individual geomorphological conditions contribute to the formation of a unique microclimate of different landscapes of intermountain depressions of the Tunkinskaya branch, due to the interaction of the circulation and radiation factors and the properties of the underlying surface. Thus, as a result of the diversity of combinations of the local natural conditions, many patterns affect the formation of the mountain climate which, in turn, are insufficiently studied and require additional quantitative estimates. Estimates of the regime of the main elements of the climate of mountain-depression landscapes are based mainly on the results of observations of a fairly rare network of meteorological stations and posts. The meteorological stations according to which the analysis of climatic changes is performed are located in river valleys, on plains, and in open areas whose height does not exceed the average height of the basin bottom and do not give information on the climatic regime of the high-altitude relief forms. As a result, when studying the climate in the mountains it is not possible to generalize the results of observations of climatic parameters at individual points without additional verification, additional data, and detailed analysis.

Thermographs and thermohygrographs Hygrochron Temperature / Humidity Logger iButton with the corporate designation DS1922 and DS1923-F5, respectively, were used to monitor the climatic characteristics at the local level taking into account the properties of the underlying surface, as well as the elements of the mountain-depression relief. Thermographs were installed at 58 model sites selected in the territory of the depression. The choice of the sites was carried out taking into account the characteristics of the relief and the altitudinal zonality of the intermountain depressions. Each key site has an individual landscape characteristic. The research sites are located in such a way that they cover the basic types of landscapes represented in the territory: goltys (bald mountains), mountain larch taiga, foothill Siberian pine-larch, meadow-mire and meadow-steppe landscapes, cryogenic meadow-lake-mire, and anthropogenic steppe-meadow landscapes of the bottom of the depression. Thus, the location of the key areas allows us to describe the features of the air temperature distribution in the depressions taking into account the characteristics of the landscape and relief elements. The measurements are carried out year-round since 2007 with an interval of 3 hours, synchronously with observations on the network of weather stations of the Russian hydrometeorological service “Roshydomet”.

The thermograph (thermohygraph) is a self-contained small-sized volatile electronic device for measuring temperature (temperature and relative humidity) of the environment and storing measurement data in its own memory with reference to real time. The range of recorded air temperature is from -40 to + 85°C. The discreteness of air temperature readings is 0.0625°C. The error in measuring the air temperature declared by the manufacturer is ± 0.5°C. The range of recorded values of relative air humidity is from 0 to 100%, the discreteness is 0.64%, and the measurement error declared by the manufacturer is ± 5% [3].
Electronic thermographs are widely used in the modern scientific research. The ability to measure temperature in different environments, storing a significant amount of information, the function of recording data at different frequencies and small dimensions make it possible to successfully use them for a variety of tasks of modern science [4-11, etc.]. In these studies, the parameters recorded by the registrar are not compared with the results of measurements of standard meteorological instruments, which casts doubt on the correctness of the findings.

To confirm the correct use of the thermograph (thermohygrograph) and the representativeness of the obtained data, we performed a comparative analysis of the air temperature and relative humidity series based on the observation results using the automatic equipment installed in a psychrometric box and a psychrometric pair at the Tunka meteorological station (Republic of Buryatia) during the observation period from October 2011 to June 2015. The number of observations for the air temperature comparison is 7910, and for the relative humidity, 1849. The thermograph and the thermohygrograph were programmed for meteorological measurements synchronously with the measurement of temperature and relative humidity of the air using standard meteorological instruments. The values of air temperature and relative humidity measured at the meteorological station are obtained from a set of data on the main meteorological parameters at Russian stations [12]. At meteorological stations of the Roshydromet network, air temperature measurements are carried out using a psychrometric thermometer, humidity measurements are carried out using a psychrometer when the air temperature is not lower than -10°C. With the help of psychrometric tables, the characteristics of humidity are determined (partial pressure of water vapor, absolute and relative humidity, mass fraction of water vapor, mixture ratio, dewpoint temperature, and pressure). At a lower temperature, the determination of the moisture characteristics is made according to the data of a dry thermometer and a hair hygrometer [13].

3. Results and discussion
As a result of a comparative evaluation of the measurement data of thermographs (thermohygrographs) and measurements carried out at a weather station, the following results were obtained.

The Kolmogorov-Smirnov test showed that the series of air temperature and relative humidity does not correspond to the law of normal distribution of characteristics (Figure 1).

![Figure 1. Distribution of temperature and relative humidity of air (measured data).](image-url)
thermometer it was 0.062 (p <0.01). When analyzing the relative air humidity series, these criteria were 0.098 and 0.076 (p <0.001), respectively. The results obtained significantly exceed the critical value of the criterion. Therefore, when comparing series nonparametric statistical methods should be used.

For the air temperature series, the results of the Mann-Whitney test (U = 62317) and the variance analysis (Kruskal-Wallis test (H = 0.788)) indicate the absence of statistically significant (p <0.05) differences between the median values of the data series of the thermograph and the psychrometric thermometer. This allows us to conclude that two samples belong to the same general sample. In other words, the data of the thermograph (DS1922) and the psychrometric thermometer installed at the Tunka meteorological station reflect a single process due to one set of physical conditions.

The average difference between the data of the thermograph and those of the psychrometric thermometer is 0.2°C. The standard deviation of the difference is 0.4°C. During the entire observation period, the difference varies from -3.0 to 3.5°C. The difference in the data of the air temperature measured by the thermograph and the data of the psychrometric thermometer at the Tunka meteorological station during the year in 75% of the cases does not exceed the instrumental error (±0.5°C), and in 93% of cases ±1°C (Table 1, Figure 2a).

Table 1. The difference in air temperature data measured by thermograph and psychrometric thermometer at Tunka weather station (2012-2015).

| Temperature range (°C) | -45..-35 | -35..-25 | -25..-15 | -15..-5 | -5..+5 | +5..+15 | +15..+25 | +25..+35 | +35..+45 |
|------------------------|----------|----------|----------|---------|--------|---------|---------|---------|---------|
| Number of measurements | 153      | 814      | 1222     | 904     | 944    | 1092    | 744     | 130     | 6003    |
| Average (°C)           | 0.1      | 0.1      | 0.2      | 0.2     | 0.2    | 0.2     | 0.1     | 0.1     | 0.2     |
| Standard deviation (°C)| 0.4      | 0.5      | 0.5      | 0.5     | 0.4    | 0.4     | 0.4     | 0.4     | 0.4     |
| Maximum (°C)           | 1.8      | 3.1      | 3.2      | 3.2     | 2.5    | 3.5     | 2.0     | 1.1     | 3.5     |
| Minimum (°C)           | -1.0     | -1.9     | -2.6     | -2.7    | -2.9   | -2.1    | -2.8    | -1.3    | -3.0    |

The difference in the mean daily values according to the thermograph and the measurements of the psychrometric thermometer varies throughout the entire observation period from -0.6 to 0.8°C. When the observations are averaged to the daily scale, the difference in the data decreases to 0.2°C (Table 2). The errors of the average daily data measured by the thermograph are predominantly positive and do not exceed 0.4°C in 80% of the cases (Figure 2b). When analyzing the average daily temperatures, a systematic error in the thermograph readings of 0.2°C is revealed, upon elimination of which the
The difference between the thermograph and the psychrometric thermometer in 97% of cases does not exceed ± 0.4°C. This error is within the accuracy of measurement of the thermograph.

Table 2. Difference in the mean daily air temperature data measured by thermograph and psychrometric thermometer at Tunka weather station.

| Temperature range (°C) | -45..-35 | -35..-25 | -25..-15 | -15..-5 | -5..+15 | +15..+25 | +25..+35 | -45..+35 |
|------------------------|----------|----------|----------|---------|---------|---------|---------|---------|
| Number of measurements | 8        | 106      | 171      | 113     | 110     | 161     | 107     | 776     |
| Average (°C)           | 0.1      | 0.2      | 0.2      | 0.2     | 0.2     | 0.1     | 0.2     | 0.2     |
| Standard deviation (°C)| 0.2      | 0.2      | 0.2      | 0.2     | 0.1     | 0.2     | 0.1     | 0.2     |
| Maximum (°C)           | 0.3      | 0.5      | 0.6      | 0.8     | 0.6     | 0.8     | 0.7     | -0.2    |
| Minimum (°C)           | -0.3     | -0.6     | -0.5     | -0.4    | -0.3    | -0.2    | -0.2    | -0.6    |

The coefficient of correlation between the series of temperature measured by the psychrometric thermometer and the thermograph was 0.95 for the observed values and 0.96 for the average daily values.

When analyzing the series of observations of the relative air humidity, a systematic error is detected in the data recorded by the thermohygrograph. For the observed values it was 6%, and for the average daily values 8% (Figure 3a, 3b). Taking into account the additive correction for this error in the series of relative humidity obtained using electronic recorders and standard meteorological instruments, there are no statistically significant differences between the median values and the variance of both observed and mean daily values (Mann-Whitney test, Kruskal-Wallis test). The Spearman rank correlation coefficient between the series is 0.96 for both samples.

Figure 3. Distribution of the differences between urgent (a) and average daily (b) air humidity data measured by thermohygrograph (DS1923) and psychrometer at Tunka weather station.

The error of relative humidity registration declared by the manufacturer, with a 2-byte retention of the results, is ± 5% at measurements in the temperature range of −20 ... +85°C. At air temperature below 20°C, relative humidity measurements are not stopped, but the thermohygrograph reading is higher than the hygrometer data. On average, the deviation is 12%, while mainly (in 94% of cases) deviations are higher than the registration error, and in 55% of cases they are in the range of 10-15%.

As shown above, the thermohygrograph slightly overestimates the relative humidity readings. At temperature above −20°C, 93% of the measurements fall within the range of −5 ... +15% according to
the urgent observations, and 100% according to the average daily data. After introducing a correction for the systematic error, it was found that in the range of deviations of ±5% (registration error) 68% of the results of the urgent observations and 86% of the average daily values fall within the study period. In this case in the range of ±10%, 98 and 100% were found, respectively (Table 3).

### Table 3. Difference in the mean daily air temperature data measured by thermograph and psychrometric thermometer at Tunka weather station.

| Temperature range (°C) | Number of readings | Range of humidity (f, %) | Before correction | After correction |
|------------------------|--------------------|-------------------------|-------------------|-----------------|
|                        |                    |                         | Mean deviation     | Min (f, %) | Max (f, %) | Min (f, %) | Max (f, %) |
| -40 / -20              | 2                  | 0-20                    | 19                 | 18        | 20        | 11         | 10         | 12         |
|                        |                    | 21-40                   |                    |           |           |            |            |            |
|                        | 239                | 41-60                   | 12                 | -25       | 22        | 4          | -33        | 14         |
|                        | 407                | 61-80                   | 12                 | -16       | 19        | 4          | -24        | 11         |
| -20 / 0                | 4                  | 0-20                    | 12                 | 1         | 17        | 4          | -7         | 9          |
|                        |                    | 21-40                   |                    |           |           |            |            |            |
|                        | 90                 | 41-60                   | 10                 | -2        | 29        | 2          | -10        | 21         |
|                        | 283                | 61-80                   | 9                  | -6        | 21        | 1          | -14        | 13         |
|                        | 297                | 81-100                  | 4                  | -5        | 14        | -4         | -13        | -6         |
| 0 / +20                | 10                 | 0-20                    | 8                  | -3        | 15        | 0          | -11        | 7          |
|                        |                    | 21-40                   |                    |           |           |            |            |            |
|                        | 100                | 41-60                   | 8                  | -7        | 26        | 0          | -15        | 18         |
|                        | 150                | 61-80                   | 5                  | -13       | 17        | -3         | -21        | 9          |
|                        | 102                | 81-100                  | 0                  | -22       | 12        | -8         | -30        | 4          |
| +20 / +40              | 10                 | 0-20                    | 6                  | 0         | 12        | -2         | -8         | 4          |
|                        |                    | 21-40                   |                    |           |           |            |            |            |
|                        | 29                 | 41-60                   | 4                  | -2        | 15        | -4         | -10        | 7          |
|                        | 3                  | 61-80                   | -1                 | -3        | 1         | -9         | -11        | -7         |
|                        | 1                  | 81-100                  | 4                  | 4         | 4         | -4         | -4         | -4         |

As a result of a joint analysis of the data of automatic measurements of the air temperature at the sites located in the Tunkinskaya depression and the landscape map, schemes of the spatial distribution of the mean monthly temperature were obtained. The territory is represented by landscapes of nine types. According to the measurement data within each landscape type, the average air temperature for each month of observations was calculated. The obtained values were extrapolated to the entire area of the landscape section. The spatial distribution of the air temperature of the coldest (January) and warmest (July) months is considered in detail (Figure 4) [14].

The lowest values of the monthly air temperature in January were recorded in the landscapes of the central part of the depression. This is the type of cryogenic meadow-lake-mire (-27.6°C), foothill sub-taiga pine (-25.5°C), meadow-steppe of the Irkut River valley (-24.8°C), and anthropogenic steppe-meadow of the basin bottoms (-22.7°C). On the slope of southern exposure (the Tunkinsky Goltsy ridge), the average monthly January temperature is -19.4°C in the foothills (the type of foothill Siberian pine-larch), to the middle of the slope it rises to -14.3°C (mountain pine-larch taiga with Siberian pine), and in the goltsovye belt it decreases to -15.7°C. On the slope of northern exposure (the Khamar-Daban range), the average monthly January temperature in the lower part of the slope is -16.8°C (mountain larch taiga), it rises to -15.8°C in the middle part of the slope (mountain dark coniferous taiga of high plains). The influence of the landscape conditions on the slopes on the average monthly air temperature values in January is poorly expressed, and the air temperature distribution along the slope is due to the presence of powerful temperature inversions.
The distribution of the monthly average air temperature of the depression in July is more uniform than in January. The difference between the warmest and the coldest types of landscape is 7.5°C, and not taking into account the goltsy belt of the Tunkinskoe Goltsy Ridge it is 3°C.

The landscapes of the central part of the depression are warmer (16.9 - 17.2°C). Unlike the distribution of the average monthly air temperature in January, the difference between the air values for various landscape types at the bottom of the hollow is insignificant (0.3°C). A small difference in the monthly average air temperature at forest and open landscapes in the central part of the basin may be indicative of a smoothing of the influence of the underlying surface type on the transition from daily to monthly average temperature values in summer. On the Khamar-Daban Range (northern slope), the average monthly temperature in July in the lower part of the slope is 15.3 °C (mountain larch taiga) and decreases to 14.8 °C in the middle part of the slope (mountain dark coniferous taiga of high plains). On the Tunkinskoe Goltsy Ridge, the monthly average July temperature is 15.8°C in the foothills (foothill Siberian pine-larch), then to the middle of the slope it drops to 13.9°C (mountain pine-larch taiga with Siberian pine), and in the goltsy belt it decreases to 9.6°C.

![Figure 4. Spatial distribution of monthly average air temperature (°C) within different types of landscapes of Tunkinskaya depression. Tunkinsky Goltsy ridge landscapes: 1 – goltsy, 2 – mountain pine-larch taiga with Siberian pine, 3 – foothill Siberian pine-larch, landscapes of the central part of depression: 4 – foothill sub-taiga pine, 5 – cryogenic meadow-lake-mire, 6 – meadow-steppe of Irkut River valley, 7 – anthropogenic steppe-meadow of the bottom of depression, landscapes of Khamar-Daban range: 8 – mountain larch taiga, 9 – mountain dark coniferous taiga of high plains.](image)

The reliability of the obtained air temperature fields was estimated by comparing them with the measurements at the observation sites during the year. The validity of the cartographic material is confirmed by a linear relationship with high correlation coefficients (0.98) between the air temperature measurements at the observation sites and the average monthly values on the maps. The average absolute air temperature difference calculated from the observation data and displayed on maps for all sites and months is 0.33°C. During the year the error value varies from -1.3°C to 1.3°C and does not depend on the season. The difference between the measured monthly average temperatures at individual sites and the temperature fields presented on the map during the year in 96.5% of cases does not exceed ±1°C and in 87% of cases, ±0.5°C.

Mapping and analysis of the monthly average air temperature of the surface layer of various landscapes of the Tunkinskaya depression showed that the temperature regime of the landscapes in summer and winter differ. In winter, the landscapes of the central part are characterized by the lowest
air temperature values, and the landscapes of the slopes of ridges are the highest, which is due to the presence of winter temperature inversions; in summer the reverse picture is observed.

4. Conclusions
The use of DS1922 thermographs and DS1923 thermohygrographs is promising and allows us to correctly describe the features of temperature and humidity regimes taking into account the properties and form of the underlying surface. The reliability of the observation series obtained by using the electronic recorders is confirmed by statistical methods. The differences in the time and daily values of temperature and relative humidity obtained by the loggers and standard meteorological devices in most cases do not exceed the instrumental error declared by the manufacturer. The data obtained with the help of DS1922 thermographs and DS1923 thermohygrographs can significantly supplement the available information on meteorological conditions in mountain-depression areas.

The use of data of field observations in combination with landscape maps makes it possible to correctly (with an accuracy of 0.5°C) describe distributions of monthly air temperatures in the mountain-hollow landscapes of south-western Pribaikalie. The temperature regimes of landscapes in summer and winter periods are different: the maximum contrasts between average monthly air temperatures are most pronounced in the cold period. In January, the difference between the warmest and the coldest types of landscape is 13°C, and the landscapes of the central part of the basin have the lowest values. In summer, the temperature difference between the warmest and coldest types of the terrain does not exceed 7.5°C, and the landscapes of the central part of the depression are the warmest.

Acknowledgments
This work was performed under IG SB RAS research project 0347-2016-003.

References
[1] Evaluation report on climate change and its consequences on the territory of the Russian Federation: Climate change 2008 (Moscow: Roshydromet) p 277
[2] Vasilenko O V and Voropay N N 2015 Features of formation of the climate of the depressions of the southwestern Baikal region Izvestiya RAS, Geographic series 2 104-11
[3] Scientific and Technical Laboratory «Electronic Instruments» [Electronic resource] - Access mode: http://www.thermochron.ru (reference date: 20 April 2007)
[4] Konstantinov P Ya 2011 Use of automatic recording devices (loggers) for temperature monitoring of permafrost soils Cryosphere of the Earth 1 23-32
[5] Korkin S E 2012 Monitoring studies of rock temperature to obtain background indices of the territory of the natural park «Siberian Uvaly» Bulletin of the Tyumen State University 7 69-75
[6] Korkin S E 2014 Soil temperature in the landscapes of the «Siberian Uvaly» Izvestiya of the Samara Scientific Center of the Russian Academy of Sciences 16 1209-13
[7] Shmakin A B, Osokin N I, Sosnovsky A V, Zazovskaya E P and Borzenkova A V 2013 Effect of snow cover on freezing and thawing of soil in Western Spitsbergen Ice and Snow 4 52-9
[8] Litvinov N A 2013 Body temperature and microclimatic habitat conditions of two species of round-headed animals in the Northern Caspian Region Bulletin of the Perm State Humanitarian Pedagogical Universit: Series of Physics and Mathematics and Natural Sciences 1 19-26
[9] Vorobyeva I V 2014 Ecological functions of humic substances of soils in the south of Central Siberia Proc. of the VI All-Russian Scientific Conference with international participation Humic substances in the biosphere 10-3
[10] Osokin N I and Sosnovsky A V 2014 Experimental studies of the coefficient of effective thermal conductivity of the snow cover in Western Spitsbergen Ice and Snow 3 50-8
[11] Pereladov M V, Sidorov L K, Botnev D A, Vagin A V, Khokhlov A V and Iskhakov A A 2015 Integrated research of the coastal waters of the northern Kuril Islands in August-September 2015 Proc. of RFRIFO 158 190-3

[12] Bulygina O N, Veselov V M, Razuvaev V N and Aleksandrova T M Description of the array of urgent data on the main meteorological parameters at Russian stations Certificate of state registration of the database 2014620549 http://meteo.ru/data/163-basic-parameters#description of the mass-data

[13] Manuals for Hydrometeorological Stations and Posts 1969 3(1) (Leningrad: Hydrometeo Pub.) p 308

[14] Vasilyenko O V, Istromina E A and Voropay N N 2017 Mapping of the air temperature field of the Tunka depression on a landscape basis Geography and natural resources 2 182-9