IMCES Geophysical Observatory for studies of surface-atmosphere interactions

E P Gordov, V Yu Bogomolov, E A Dyukarev, I G Okladnikov and S V Smirnov

Institute of Monitoring of Climatic and Ecological Systems SB RAS, Tomsk, Russia
E-mail: gordov@scert.ru

Abstract. This paper describes a geophysical observatory in use at the Institute of Monitoring of Climatic and Ecological Systems SB RAS and the data it provides. These data can be used for the development of new parameterizations in an active layer model. This model will allow us to reproduce the physical processes in the soil and on its surface and make a detailed description of the exchanges between the surface and the atmosphere. This, in turn, could significantly increase the reliability of regional weather forecasts, especially of extreme weather events. The anticipated improvement in regional meteorological forecasting, as well as in a variety of characteristics measured at the geophysical observatory and the supporting information infrastructure open up possibilities for novel practical applications. In particular, we plan to use the ongoing measurements and data obtained for agrometeorological applications in Western Siberia.

1. Introduction

A complete cycle of obtaining new knowledge in meteorology and climatology, as well as new opportunities for its applications, starts from measurements of meteorological characteristics. At the next step, researchers are trying to study relevant processes and create phenomenological models, which eventually lead to physical models providing mathematical description. The use of the models created allows one to determine the meteorological characteristics for some space domain and forecast their evolution in time. Joint use of observations and models forms a basis for monitoring and prognosis of regional meteorological characteristics and processes [1].

The development of novel instrumentation automatically measuring relevant characteristics and sending data obtained to a dedicated server, as well as the mature state of meteorological models and information-computational technologies, provide us with opportunities to add new features to the cycle mentioned above and significantly improve both models and relevant prognoses, thus leading to novel applications of the knowledge. Timely employment of local meteorological characteristics can be used to significantly enhance both the knowledge of the space distribution of the measured local values and their time evolution. Two types of approaches can be employed to reach these objectives. These are the data assimilation techniques widely used now in meteorological forecasting and fast bias correction procedures to correct biased regional climate models outputs [2]. As a result, systematic local measurements might lead to reliable calculations of high resolution spatial and temporal behavior of meteorological conditions, thus opening a way to novel applications in experimental areas like agriculture.

In this paper, we first describe the state of the art of a Geophysical Observatory (GO) created at the Institute of Monitoring of Climatic and Ecological Systems (IMCES) SB RAS near the city of Tomsk and equipped with well-established standard meteorological instruments, as well as with modern measuring devices developed at IMCES. Then some results of a research of atmospheric and surface processes performed by using the ongoing GO observations will be presented. Finally, we discuss the use of knowledge gained in the development of new parameterizations for meteorological and climatic models, as well as approaches to enhancing the reliability of the current and predicted meteorological characteristics calculated with a high spatial resolution for West Siberia region.
2. The IMCES Geophysical Observatory

2.1. General Description

The geophysical Observatory (GO) is located at the premises of IMCES (coordinates: 56°28′32″ N, 85°03′17″ E, the altitude elevation is 167 m, the zero point elevation of the barometer is 188.4 m). The GO infrastructure is located in the territory and in the buildings of IMCES SB RAS in Akademgorodok, in the south-eastern suburban area of Tomsk. The observatory has two main observation sites, several laboratory rooms with measuring and recording equipment and instrumentation for office processing of field research data. It has been working since 2007.

Currently, instrumental and visual meteorological, aerological, spectrophotometric, atmospheric electric, aerosol spectrometric, and gas analytical observations are being performed at the observatory. The observation modes are either continuous or periodic, depending on their type and tasks being solved.

The main ground-based meteorological observations, including atmospheric-soil, actinometric, and atmospheric-electric ones, are carried out using an automated meteorological information-measuring system (AMIMS) with high temporal resolution (continuous measurements with half or minute averaging). Visual hourly meteorological observations provide information on the cloud cover, the state of the atmosphere, and the underlying surface and weather patterns.

Using an automated meteorological information-measuring complex (AMIMC) based on spatially separated ultrasonic automatic meteorological stations (AMSs), gradient high-frequency (up to 80 Hz) measurements are carried out at heights of up to 30 m (it is planned to increase them to 40 m), providing information on both the basic meteorological values and the characteristics of atmospheric turbulence in the surface layer, including heat, moisture, and momentum fluxes with a high temporal resolution.

Remote sensing of the vertical distribution (VD) of the wind speed and direction, as well as atmospheric turbulence characteristics in the atmospheric boundary layer (ABL) is carried out automatically with preset time intervals using a Doppler sodar (a meteorological wind profiler). The information is provided with high spatial resolution (up to 10 m) at heights of up to 1 km.

Spectrophotometric observations provide data on the total ozone content (TOC), the characteristics of ultraviolet radiation (UV), cloud cover, spectral transparency of the atmosphere (spectral aerosol optical depth, AOD), and the atmospheric moisture content. UV and TOC measurements are performed using multichannel medium resolution filter radiometers in manual (hourly) and automatic (continuous with minute averaging) modes. The AOD and moisture content are measured automatically every minute using a multi-channel solar photometer under direct solar radiation. Registration of the sky state is made automatically with a preset time interval using a panoramic sky scanner based on a high-resolution digital camera.

Spectral measurements of the surface aerosol particulate number and light scattering coefficients are performed using a set of aerosol spectrometers and a nephelometer in the periodic mode with a specified time interval.

Gas analysis of radon, carbon dioxide, and water vapor surface concentrations is carried out by automatic gas analyzers by air sampling at ground levels, 2 and 10 m, or from accumulation chambers and wells (for estimating gas emissions from the soil) at specified time intervals. Physicochemical studies of air and water samples collected during field expeditions are carried out in the observatory using chromatographs.

All-year chamber measurements of carbon dioxide fluxes using an automated soil CO₂ flux system LI-8100a allow one to estimate the carbon balance of the urban grassland. A model of net ecosystem exchange (NEE) was suggested to study the influence of different environmental factors. The model uses air temperature, incoming photosynthetically active radiation, vapor pressure deficit, and leaf area index as the explanatory factors for gross primary production, heterotrophic and autotrophic respiration. Observation results obtained at two sites (bare and vegetated soil) allow one to calculate the temperature sensitivity for soil and plant respiration. The total annual NEE is 163.5 g C
Growing plants accumulate 522.7 g C m$^{-2}$ in total, but the net annual release of CO$_2$ is higher (686.2 g C m$^{-2}$). The ecosystem being studied is a source of carbon according to modeling and observation results [3].

The observational data acquisition and storage in the GO is hierarchical. Raw data are recorded in the measuring instruments, databases of information-measuring systems and complexes, and an electronic journal of weather observers. Then the data are transferred to the database of the integrated information-computational system of IMCES SB RAS, where they undergo quality assessment, archiving, visualization in graphical and digital forms for the users.

Currently the GO regularly transmits measurement data on total ozone concentration and UV radiation to the State Geophysical Observatory, the Central Aerological Observatory, and the PEEX In-Situ Atmospheric-Ecosystem Collaborating Stations Network in the Russian Federation. It should be added that the GO is also used for education and research works of pupils, students, and postgraduates.

2.2. Radiation measurements with a high resolution

The radiation measurements are performed by a multifilter radiometer NILU-UV-6T [4] and a pyranometer Keep & Zonen CM11 [5] on a roof observation platform with 1-min resolution. The radiometer measures UV radiation at 305, 312, 320, 340, and 380 nm (FWHM=10 nm) and PAR. The measurement accuracy is less than 10%. The data processing software calculates the daily average and maximum dose rates and integrated daily doses of UV-A, UV-B, PAR, CIE-, and CLW-weighted irradiance [6–9]. The software also provides cloud cover assessment (spectral transmittance of cloudiness) and total ozone column.

The pyranometer CM11 measures global radiation in the range of 305–2800 nm. The measurement accuracy is 2–3 %.

![Figure 1](image.png)

**Figure 1.** Long-term observations of CIE-weighted irradiance, long-term observations of CLW-weighted irradiance.
Figure 2. Long-term observations of UV-A irradiance, long-term observations of UV-B irradiance.

Figure 3. Current measurements of global radiation, long-term observations of total ozone.

Long-term (2006–2018) observations of incoming short-wave solar radiation carried out with a high temporal resolution, total ozone and cloudiness in Tomsk (Western Siberia) led to the following results:

- time series of UV-A/B irradiance have significant negative linear trends and the slope of UV-A trend is the greatest one;
- trend of the linear PAR is insignificant;
- diminishing of the total ozone concentration over Tomsk region stopped and, thus, observed negative linear UV trends can be associated with the total ozone stabilization;
- the influence of cloudiness on radiation fluxes is stronger in the UVI range than in the entire UV range;
- variations of the global radiation and PAR induced by clouds are up to 30 %, for UV radiation they are up to 10 %, and Ci, Ac, and Cu clouds have a maximum impact;
- dense cloudiness (As, Ns, Sc, Cb) and overcast completely attenuate radiation fluxes in the UVI range.
2.3. Measurements of surface and soil characteristics

The measurement subsystem includes (1) a programmable microcontroller ATMEGA1280 that collects measurement data from sensors, sequentially polls through a 1-Wire digital interface, stores them in non-volatile Flash memory (AT45DB321, 4 Mb or 90,000 measurements), and transfers them to the server according to a schedule via a Wi-Fi network or FT232RL USB interface, (2) a power supply containing a network converter and a battery, and (3) digital and analog measuring converters (sensors):
- sensors of air temperature DS18B20 and air relative humidity HIH5031 (in a radiation shield at 2-m height above the surface);
- liquid and solid precipitation sensor Davis 7852M (at 2-m height);
- soil temperature probe with DS18B20 temperature sensors (depth levels: 0, 2, 5, 10, 15, 20, 30, 40, 60, 80, 100, 120, 160, 200, 240, 280, 320, 400, 450, and 500 cm);
- single soil temperature sensors DS18B20 in the soil section (depth levels 0, 2, 5, 10, 15, 20, 30, 40, 60, 80 and 100 cm) and in soil cores (depth levels: 20, 40, 60, 120, 160, 240, and 320 cm);
- Vaisala soil temperature sensors DTS12G1 (depth levels: 0, 10, and 20 cm);
- snow temperature probe with DS18B20 temperature sensors (levels from 0 to 120 cm in increments of 5 cm; in-house development);
- ultrasonic snow depth sensor MB7389;
- sensor of electrical conductivity of snow cover (in-house development);
- atmospheric pressure sensor MPL3115A2.

The technical characteristics of the main sensors are given in Table 1.

The controller is located in a protecting box (Ingress Protection Code IP65), which has thermal insulation, which allows the controller to operate without additional heating in the temperature range from –50 to + 50 °C. Measurements can be performed at intervals of 2 s or more depending on the task. The measurement period is currently 10 minutes. Solid precipitation in the precipitation meter is pre-melted. The software allows one to remotely operate the controller, set the order (periodicity) of reading measurement data, plot measurement results, and export data into “csv” text format.

The number of soil and snow temperature sensors and their installation depths are stipulated by the need to obtain high-quality information on the distribution and variability of temperature in the soil layer and snow cover with high spatial and temporal resolution, which is required for modeling heat-mass transfer processes in the soil, heat transfer between the underlying surface and the atmosphere. In particular, the placement of several sensors at the same depth is caused by the need to ensure representativeness of data on soil and snow temperature obtained by temperature probes of a specific design, which are used in field studies of the soil and peat temperatures in different landscapes.

| Parameter                                         | Value                                      |
|---------------------------------------------------|--------------------------------------------|
| Range and accuracy of air/soil/snow temperature sensor | –55…+50°C, ±0.1°C                          |
| Range and accuracy of air humidity sensor          | 0…100 %, ±3.5 %                           |
| Range and accuracy of liquid precipitation sensor   | 0…1000 mm/hr, ±5 %                         |

Measurements of meteorological values are carried out in an automatic mode, independent of external power, with a high time resolution. The acquisition, operational storage, and transmission of measurement data is carried out both via wired and wireless communication channels to the observatory database.

As an example, Figure 4 shows some measurement results obtained using a modernized AMIIS. The temporal variations of air temperature (T_a), precipitation amount (P) for 10-minute intervals, and
soil temperature (Ts) on the surface (Ts0) and depths from 5 to 500 cm for the period from March to August 2019 are shown. Despite significant fluctuations of the air temperature, the temperature of the surface and upper soil layers under the snow cover (until April 13, 2019) changed slightly. The snow depth in March 2019 reached 90 cm, and the soil froze to a depth of 15 cm only. After quick snow melting and short but intense thaw, the soil thawed completely. In summer, the temperature fluctuations on the surface and in the upper layers of the soil actually repeat the air temperature fluctuations. With depth, the amplitude of diurnal temperature fluctuations decreases significantly and deeper than 40 cm the diurnal course of the soil temperature does not exist. The annual course of soil temperature can be traced at all depths. The maximum values of soil temperature at a depth of 80 cm were observed in August, at a depth of 160 cm in September, and deeper the temperature will increase until December.

Figure 4. Variations of air temperature, precipitation amount, and soil temperature at the surface and depths for March - August 2019 according to measurements on the ground observation site of GO.

3. Use of measured data for the development of new parameterizations

A further step in understanding the physical processes is to perform mathematical and numerical simulations using the available measurement data for the particular area. At present, the data of measurements performed at the GO are used in the development of a new block of the active land layer for the climatic model of INM RAS [10]. The active layer model includes a multilayer (23 levels) soil model that describes the transfer of heat, liquid moisture taking into account its freezing / thawing, and water vapor [11], as well as a multilayer heat transfer scheme in snow cover. Calculation of the surface and subsurface runoff, as well as the influence of vegetation on the soil water balance, is carried out according to the parameterizations used in the ECHAM3 model (The ECHAM3 atmospheric general circulation model, 1992). The current version of the active layer model of INM RAS-MSU considers that a land surface cell may contain the following surface types: vegetation, open soil, snow, and inland waters. The proportion of snowless surface occupied by vegetation, inland waters, and open soil is prescribed according to [12].
Detailed measurements of the thermal and radiation balance on the surface, as well as the thermal regime in the soil carried out at the GO, will be used to validate and verify the model of the active land layer for specific soil types. In particular, this will make it possible to determine the contribution of specific parameterizations included in the model of the active land layer, which significantly affect the calculated moisture and soil temperature. These parameterizations, which are some approximations obtained from physical considerations and empirical data, are then used to calculate important soil characteristics, such as thermal conductivity (Johansen, O. et. All). In this case, the calculated values can give results significantly different from the measurement data (Figure 5).

![Figure 5. Soil temperature at different depths according to observations at Meteorological Observatory and model calculations.](image)

The results of detailed measurements will allow us to find limits of applicability of the parameterizations and determine the possibility of using them for various types of mineral soils. Modeling of processes in the soil should make it possible to determine the coefficients through quantities that depend on a number of moisture, density, and temperature factors. Knowledge of these dependences will allow one not only to reproduce all physical processes occurring in the soil and on its surface, but will allow a more detailed description of exchanges between the surface and the atmosphere. Of course, the latter is significant for climate modeling, but these processes are even more important for mesoscale meteorological modeling. A correct description of exchanges between the surface and the atmosphere will significantly increase the reliability of regional weather forecasts, especially forecasting of extreme weather events.

4. Planned use of GO data for practical applications
The anticipated improvement of regional meteorological prognoses, as well as a variety of characteristics measured at the GO and a mature level of the supporting information infrastructure, opens up opportunities for novel practical applications. In particular, we plan to use the GO ongoing measurements and data obtained for agrometeorological applications in West Siberia.
Indeed, the climatic and meteorological conditions, especially extreme hydrothermal phenomena, significantly affect the productivity of the agricultural sector. The traditional calculation of agrometeorological characteristics on the basis of data measured at Roshydromet weather stations does not provide the spatial resolution necessary for agricultural producers and does not provide them with predictive characteristics. Plain expansion of the measurement network, rapid transfer of data, and their analysis also cannot provide a consumer with the required information. To solve this problem, we propose using the Web GIS Climate previously developed for climate applications (http://climate.scert.ru) [13, 14, 15]. To do this, its functionality will be expanded with new algorithms for calculating agrometeorological characteristics, and the transition to quasi-operational data analysis will be completed.

It is planned that a high-speed data stream (selected meteorological characteristics) from the GO and several autonomous weather stations deployed by an agricultural producer will be obtained in the real-time mode by a dedicated server, pre-processed, and stored in an intermediate data storage. At the same time, every 24 hours the results of predictive mesoscale meteorological modeling of high resolution will be transferred to the same dedicated server. They will undergo a quick bias correction procedure and then stored in a high-performance data archive of the web-GIS Climate. Later, these data will be used by the web-GIS Climate for quick calculation of corresponding agrometeorological characteristics and production of digital maps of agrometeorological risks for a region of interest. As a result, such an approach will provide, in a quasi-operational mode, accurate agrometeorological characteristics and their forecasts with the spatial resolution required by stakeholders. It might also lead to the development of digital intelligent farming and land management systems.

5. Conclusions
The above description was given to illustrate the use of data measuring at the GO at the different steps of knowledge and applications. The use of measured data allows one to understand the physical processes of surface-atmosphere interaction and eventually could lead to more reliable results of climatic and meteorological modeling. The GO ongoing measurements and data obtained, as well as the anticipated information, open up possibilities for novel applications, like the above-described agrometeorological applications in Western Siberia.

It should be added that the variety of characteristics measured at the GO and the present mature level of the supporting information infrastructure of the GO provide a potential that can be widely used in national and international research cooperation.

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