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The studies of the Svalbard glacial surfaces albedo by an unmanned aerial vehicle.

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Abstract. Experiments related to the use of unmanned aerial vehicle (UAV) for assessing the albedo of Svalbard glaciers is described. Study area - Esmark Glacier (Isfjord Bay) and Aldegonda Glacier (Greenfjord Bay). The main purpose of the experiments is to estimate the surface albedo in the zone of the edge cracks of the outlet glacier (Esmark), where standard ground-based observations are impossible due to safety conditions, as well as to obtain spatial albedo estimates (Aldegonda) when satellite data cannot be used (overcast). The UAV (DJI Phantom 4 Pro) was retrofitted with a sensor that measures reflected solar radiation. The data on the incoming solar radiation at the surface level, measured by a similar sensor, were used to calculate the albedo. The albedo measurements were carried out along several profiles across the Aldegonda Glacier and along one profile above the Esmark Glacier, which was laid from a flat plateau (ice dome) through a zone of cracks to the open water surface of the fiord. For the first time, estimates of the surface albedo of the outlet glacier in the zone of edge cracks were obtained. Ground-based verification observations carried out on the Aldegonda glacier confirmed the results obtained by the UAV.

1. Introduction

Thermal balance observations carried out in natural conditions allow to evaluate the processes of interaction in the "*underlying surface - surface layer of the atmosphere*" system. Albedo is one of the most important elements of the surface heat balance, especially in the Arctic regions, where mechanisms of positive feedbacks cause "dramatic" changes in the conditions of the snow-ice surfaces (e.g. sea ice, glaciers). As a general rule, albedo values obtained at a point or a limited area of the surface cannot be extrapolated to the entire area of interest. That is why, special space ("*ground true*") surveys are carried out. Data on the albedo of snow-glaciers covers are also necessary for correct calculations of the melted layer of snow or ice during the ablation period. Together with the data of direct measurements (e.g. glaciological monitoring), these data make it possible to verify and improve the existing thermodynamic models of glaciers. What is even more important, it allows to evaluate the processes in the marginal zone of glaciers (zone of cracks), where any "*ground true*" observations are impossible. These zones absorb and reflect the incoming solar radiation with intensity different from the flat areas of a glacier. However, these processes are not taken into account in the classical thermodynamic models of glaciers sufficiently.

The UAV practice demonstrates their high efficiency in the research of hard-to-reach snow-ice surfaces areas, where standard "*ground true*" surveys are impossible for safety reasons. Such studies make it possible to obtain objective estimates of the spatial distribution of the albedo in the hard-to-reach areas and perform detailed mapping of similar areas mentioned above [1, 2, 3]. Previously, this could be done (and even then, only partially) during the long and laborious walking routes - profile or space surveys [4]. The studies of the albedo of the antarctic land-fast ice and the zone of cracks in the margin zone of the glacier dome in the area of the Russian "Progress" station were carried out within the framework of the 63rd Russian Antarctic Expedition [5]. Such study was done for the first time in domestic practice. The research was based on the use of an original portable measuring device (an analog-to-digital converter paired with a PaspberryPi microprocessor device) mounted on a UAV (DJI Mavic Pro). Finally, within the framework of the international expedition TransArktica-2019 on the RV "Akademik Treshnikov" (Russia), the high level spatial resolution estimates of the albedo and surface temperatures of arctic hummocks were obtained using an UAV, for the first time. Also, there were evaluated vertical turbulent fluxes of sensible heat from the windward and the leeward sides of the hummock ridge [6]. The main goal of this article is to demonstrate the original results related to obtaining albedo estimates for hard-to-reach areas of Svalbard snow-glacial surfaces.

2. Research locations

The main objects of our research were the glaciers of the Svalbard, located near the Russian Scientific Center in the settlement of Barentsburg. The first of them is the Aldegonda mountain-valley glacier, located on the western shore of the Greenfjord Bay, West Spitsbergen Island (see Figure 1a). The surface of the glacier is rather uniform, but there are several water streams extending from its top to the foot, as well as cracks located in its upper part. The second object, the Esmark glacier, is also a mountain-valley type, but its marginal part goes into the eponymous bay, meaning the glacier is an outlet (see Figure 1b). The marginal zone of the glacier is covered with numerous deep cracks and is absolutely inaccessible for standard "*ground true*" observations.

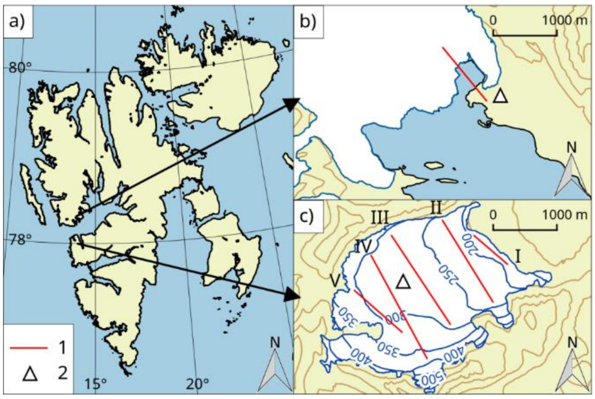

Figure 1 Location of the Esmark (b) and Aldegonda (c) glaciers on Svalbard (a)
1 - routes (profiles) of the UAV albedo surveys; 2 - position of ground observation points.

3. The methodology

An original portable device based on a PaspberryPi microprocessor (see Figure 2), a PiCamV2.0 camera and an LI-190SA photometer was designed and manufactured at the AARI for measurements using a UAV. The choice of these elements was associated with the flexibility of the Pi microprocessor architecture, the coincidence of the spectral coverage of the camera and the sensor (400-700 nm), as well as the typicality of the camera, which is a fairly common example of a good quality photographic recording device.

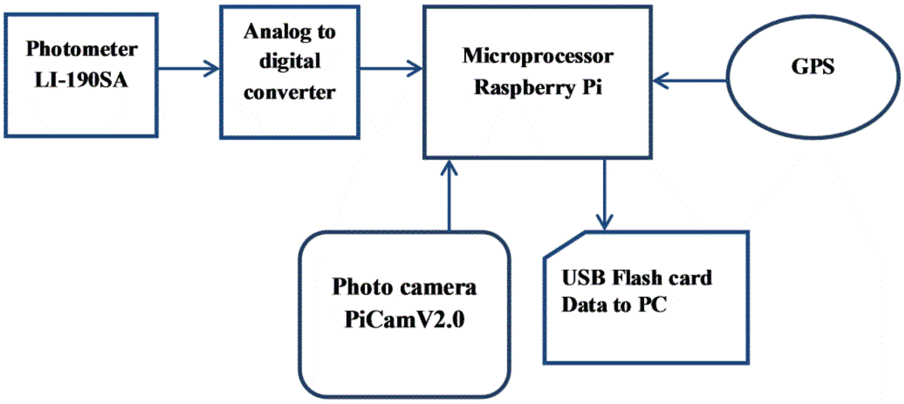

Figure 2 - Schematic diagram of the measuring unit based on the RaspberryPi microprocessor device

The device was made in a compact lightweight body and was intended for use on UAVs (model DJI Phantom 4 Pro). Autonomy was provided by a built-in rechargeable battery up to several hours of continuous operation. The built-in GPS / GLONASS receiver provided data on the spatial position of the UAV. Piloting was carried out in manual control mode, so that the UAV was constantly in the operator's line of sight. Data logging was performed in accordance with a specified time interval from 2 to 10 seconds. The device performed several actions simultaneously during working flights:
- registration of photometer readings (μmol/m²/sec);
- photographing the underlying surface with saving the image in the internal memory of the device;
- recording of parametric information (time, coordinates, image and exposure data).

Thus, "at the output" we received synchronous data on the reflective and exposure characteristics of the underlying surface. Photographic materials made it possible to exclude unrepresentative materials and provide a qualitative assessment of the morphometric characteristics of the filmed surface. The collected information was transmitted to a computer using a Wi-Fi connection. The analysis of the data obtained and the calculation of the surface albedo were carried out using licensed software.

The ground observation point with a special heat balance mast (HBM) was organized in the central part of the Aldegonda glacier to verify the data obtained using the UAV (model DJI Phantom 4 Pro). The HBM was equipped with radiation sensors to assess both incoming and reflected solar radiation. This was necessary in order to obtain representative estimates of the albedo at the surface level and compare it with the data obtained by the UAV. A similar ground-based measuring complex (HBM) was installed on the moraine in the vicinity of the Esmark glacier (see Figure. 1). We used LI-192SA low-response pyranometers (USA, *LICOR*), which record solar radiation in the range of 400-700 nm. A similar sensor (LI-190SA) was used in the UAV measuring device. Both sensors (LI-190SA and LI-192SA) recorded incoming and reflected solar radiation in the same spectral range and with the same resolution as the photo sensor of the measuring device camera. During the flights over glaciers, the UAV sometimes deviates from the horizontal position (roll, pitch, and yaw) due to changing wind loads (wind speed and direction). Unlike the built-in automatically stabilized UAV camera, the measuring device (LI-190SA sensor) is rigidly attached to the UAV body and this must be taken into account when taking measurements and data analysis. During each flight, a special file was created with complete flight telemetry - speed, altitude, tilt angles, data from onboard sensors, etc. When data processing we selected only the data collected during the horizontal position of the UAV and attachments. The error in calculating albedo values based on measurements of the incoming (HBM) and reflected solar radiation (UAV) did not exceed 5% in comparison with the data obtained at the ground observation point (HBM). On the Aldegonda glacier, the flight routes were planned along profiles oriented across the glacier from northwest to southeast, where the surface elevations were approximately the same above sea level (see Figure 1). Observations were made at a height of 20 m above the glacier surface. The flights were carried out at a speed of 5 m/s and a constant measurement interval of 5 seconds. Thus, the resolution along the flight profile (discreteness of the calculated albedo values) was 25 m. The albedo values calculated using the UAV reflected radiation data were interpolated to the nodes of a regular grid using the "*natural neighbor*" algorithm included in the standard set the "*gridding*" package of the Golden Software Surfer [7]. The algorithm uses a subset of the input data closest to the measurement point and applies a weighting method to them: each point in the subset has its own weight depending on the proximity of its location to the desired one. The key feature of this algorithm is that the interpolated values will always be within the range of the used primary data set which rules out the formation of false peaks or dips in the interpolation results. Thus, we managed to obtain the spatial distribution of albedo for a limited period of time under constant illumination conditions (sun height, cloudiness, horizontal visibility range, and other atmospheric conditions). The main area of the research at the Esmark glacier is the edge zone (zone of cracks) of the outlet glacier (see photo in Figure 3). The flights were carried out only along the profile from the dome area (a relatively flat area of the glacier surface) to the open water surface of the fjord.

Figure 3 - Area of work on the Esmark glacier.

Taking into account the changing height of the glacier surface above sea level (from 30 m in the outlet part to 150 m in the plateau area), the UAV flights were performed at different altitude depending on the glacier section, but not less than 50 m from its surface. In both cases (objects of research), the interval of data acquisition from the HBM was synchronized with the interval of data logging and image by the UAV.

4. Results

The marginal zone is a characteristic feature of the Svalbard outlet glaciers. There are discontinuities of the glacier cover, the formations of deep faults oriented mostly across the direction of the glacier movement along the valley, (i.e. parallel to its front) are observed in such areas. Deep cracks should determine a different nature of the reflect solar radiation from the glacier surface, which should affect the albedo values of such surface areas, from our point of view. For example, we recorded a decrease in the surface albedo in the zone of deep cracks formed by the snow-ice cover failures over subsurface water streams in the area of the antarctic "Progress" station by the UAV [5]. We expected to obtain similar results at the Esmark glacier. Figure 4 shows the profile of the albedo values, calculated using the measured reflected solar radiation data (UAV) and the incoming solar radiation measured at the ground observation point near the glacier (HBM).

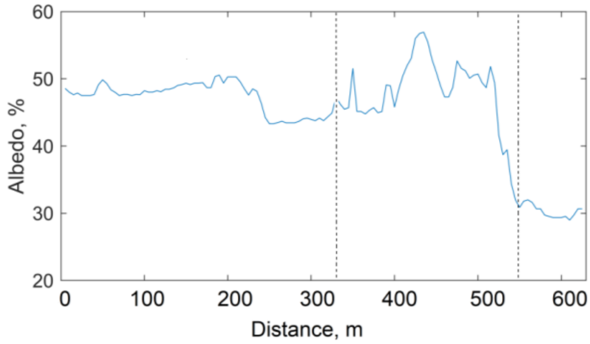

Figure 4 Albedo values along the UAV flight profile over the marginal zone.

The actual zone of cracks is limited by dotted lines (see photo in Figure 3). As follows from the figure, the albedo of the sea surface (adjacent to the ice barrier of the fjord water) is approximately 30%, which significantly exceeds the average albedo of sea waters. This can be explained by the large amount of fine and grated ice on the surface of the fjord waters, which is formed as a result of the constant spalling (collapse) of fragments of the ice barrier (see photo in Figure 5a). The albedo values are characterized by significant variability directly in the edge zone of the glacier (zone of cracks). The average albedo values in the area immediately adjacent to the flat surface of the dome (see photo in Figure 5b) do not exceed 50%. Directly in the zone of cracks (see photo in Figure 5c), the albedo varies from 30 to 58%. This circumstance may be due to the increasing slope of the glacier surface directly in the edge zone, in comparison with the relatively horizontal sections adjacent to the dome. Taking into account the height of the sun, the angles of incidence of sunlight (direct solar radiation) can reach 90 degrees on such areas of the glacier surface. In such cases, the reflection is minimal and the albedo decreases. On the other hand, the incidence of sunlight on the vertical walls of deep cracks can lead to multiple re-reflection of the incident ray, including into the depth of the crack. This should lead to a decrease in the reflected radiation and be the reason for a decrease in the albedo values. Also, the marginal zone is characterized by the alternation of sunlit and shaded areas of the glacier surface. This can also explain the decrease in the surface albedo, all other things being equal.

(a) (b) (c)

Figure 5 Typical surface types of the Esmark glacier:
(a) – see water surface; (b) – flat area (dome); (c) – crack zone.

The use of the UAV made it possible to estimate the albedo of a significant part of the surface of the Aldegonda glacier, spending no more than one hour on flights along the profiles (see Figure 1). In the framework of standard ground-based observations, this requires at least a day, which is associated with limited routes for safe movement along the glacier [4]. The spatial distribution of albedo was obtained for various weather conditions and the state of the glacier surface. One UAV flight was carried out in the complete absence of snow on the surface (the snow melted), the second - after a short snowfall. In both cases, cloudy conditions did not allow using the capabilities of high spatial resolution satellites in the visible range (Landsat or Sentinel). The results are shown in figure 6.

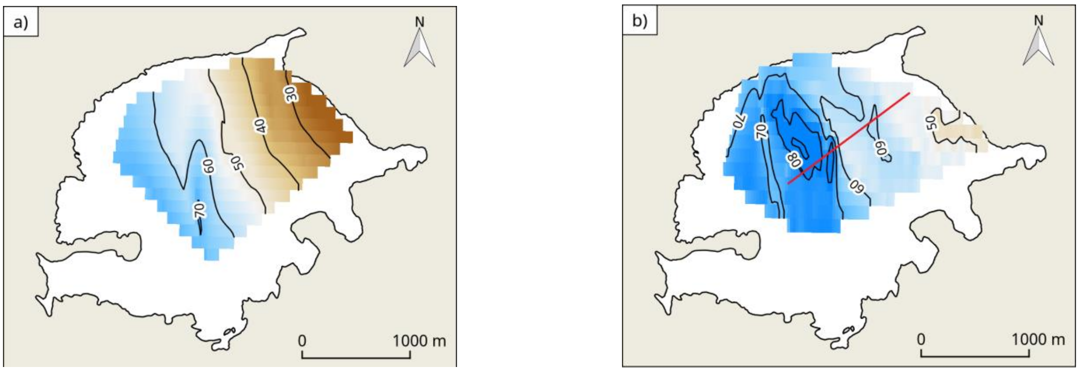

Figure 6 Distribution of the albedo before (a) and after snowfall (b), red line – the route of ground observations.

We compared ground observations made along the profile ("*ground true*" measurements) with the data obtained by UAV for the data verification. The results are shown in Figure 7.

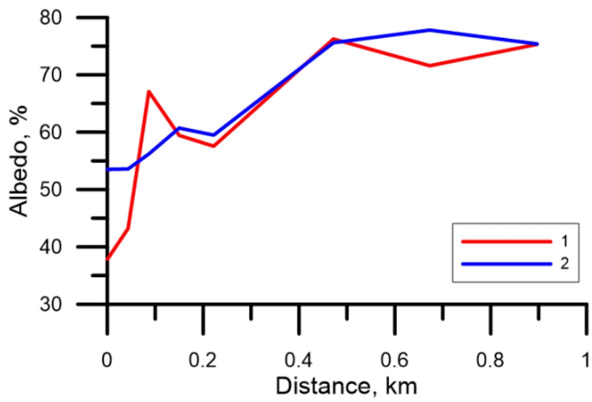

Figure 7 The albedo of the glacier surface obtained by "*ground true*" measurements (1) and UAV (2).

As follows from the figure, the profile obtained by UAV is smoother than the profile drawn from the ground-based observations. This phenomenon can be explained by the difference of measuring technique. When measuring the reflected radiation from a certain altitude (UAV), the signal is formed by a larger area comparing with the one during the ground measurements. This leads to the well-known "*smoothing*" of the morphometric characteristics and color features of the glacier surface during this period of the year. The surface itself can have numerous features such as firn, fresh snow, melt water on the surface, pollution by rock particles, etc. Another possible reason is the use of interpolated values to build a profile by UAV. The main trend is an increase in albedo with height. It is clearly visible in both approaches, while the absolute values coincide, especially in the central part of the profile.

5. Conclusions

Field experiments carried out over the Svalbard glaciers have shown the high efficiency of using UAV for assessing the albedo of the underlying surface. For the first time, it was possible to estimate the albedo in the marginal zone of the cracks of the outlet type glacier (Esmark Glacier, Isfjord Bay). Such measurements cannot be performed by standard methods and means. The estimates obtained will make it possible to more correctly calculate the heat balance of the glacier surface in such a dynamic zone, which will undoubtedly contribute to an objective assessment of the mass balance of the glacier as a whole. Areal surveys of the Aldegonda Glacier (Greenfjord Bay) made it possible to obtain estimates of the albedo of its surface for various snow and surface conditions. The use of UAVs makes it possible to estimate short-term changes in the albedo of the underlying surface, which is impossible when using satellite images due to the discreteness of flights and cloud conditions.

6. Acknowledgments

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