Subsatellite Systems of Remote Sounding of the Earth

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Abstract - The stratospheric balloon magnetic gradiometer system is developed and maintained at IZMIRAN already about 20 years. This system consists of three instrumental containers uniformly placed along a vertical 6 km line. System allows measuring parameters of the geomagnetic field along the whole flight trajectory. The GPS-receivers, located in each instrumental container, fix the flight coordinates. The developed launching technology, deployment in flight, assembly, data, transfer and processing, landing the containers with the equipment can be used for other similar problems of monitoring and sounding an environment. Useful flight weights of each instrumental container may be reaching 50 kg.

Keywords: stratospheric balloons, magnetic gradiometer system, Earth's crust magnetic structure.

1. INTRODUCTION

Many important parameters of an environment are expedient for measuring at lower altitudes, than satellite ones. The stratospheric balloons can be applied for such problems. Their flight altitudes cover the range from 20 to 50 km. At such altitudes there is steady zone airflow due to which the balloon flight trajectories can be of any direction, including the round-the-world ("boomerang") mode, i.e. when the balloon can return to an initial point by changing the flight altitudes. The modern technology allows executing continuous balloon flight within several years. Taking into account mentioned above and that the use of a balloon is commercial cheaper than any other carrier (satellite, airborne, ground borne or marine), it is possible to expect, in a future, significant extension of areas of its application, especially at remote sounding of the Earth.

2. REMOTE SOUNDING OF THE EARTH BY THE BALLOON GEOMAGNETIC GRADIOMETER DATA

Here we want to illustrate application of the stratospheric balloon for studying the anomaly geomagnetic field (AMF). The described system is developed and maintained at IZMIRAN already during about 20 years. Dimension-weight characteristics of the balloon, as well as the circumstance that the balloon drifts together with the air flow in a rarefied atmosphere, allow it to tow a suspension system oriented along the vertical line 6 km long and used as a gradiometer (Tsvetkov, 2002). The system was tested during few test and work flights, and the official permission to operate the gradiometer on board the balloon over the territory of Russia was received. Its operation in flight over the territories of other countries is to be agreed upon in the Ministry of Foreign Affairs (for example, the temporary permission was received from Ukraine and Kazakhstan).

With the appearance of GPS receivers, it has become possible to locate the balloon during its flight at an accuracy of a few meters. Various azimuths of the balloon motion, due to variations in the direction of the carrier air flow, allow the balloon to perform a detailed magnetic survey of large regions. The instability of the balloon flight altitude does not prevent a high-quality magnetic survey, because, if the data on the vertical gradient of the magnetic field are available, the field can be recalculated to any specified level within the altitude range 20-40 km.

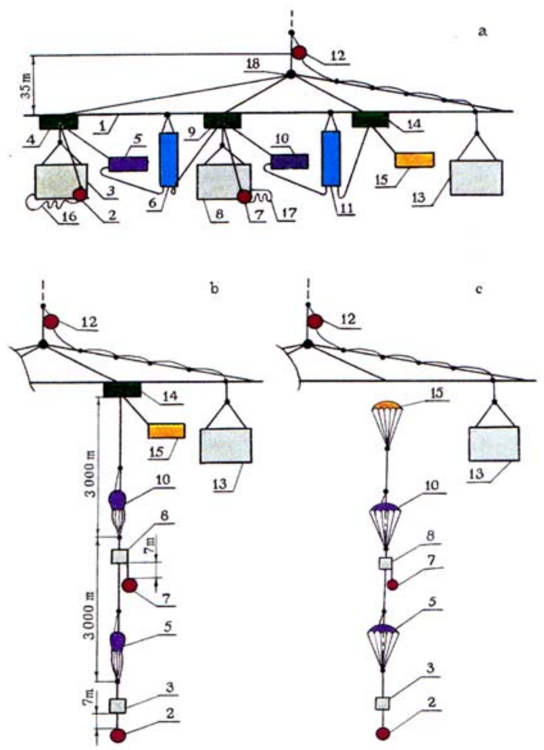

Figure 1. Scheme of balloon magnetic gradiometer in the starting (a), working (b) positions and at the finish stage (c) of flight

The vertical gradient of magnetic anomalies is the most sensitive parameter characterizing the bedding depth of the AMF source. Alternative attempts of other researchers to create an aircraft carrying a high-sensitivity magnetic

gradiometer for the measurement of magnetic gradients have not been success (Nelson, 1992). This problem can be solved, if the gradiometer base oriented along the vertical line is increased, for example, to 6 km, which can be realized only with the balloon.
The gradiometer consists of three instrumentation containers with the scientific equipment, GPS receivers, and devices for the transmission of data through the satellite channel of the Globalstar system. The layout of the gradiometer on the balloon (using the magnetic gradiometer as an example) in different position is presented in Fig.1. In the starting position (upper part of Fig.1), the gradiometer is in the folded state, and its dimensions are minimized in such a manner that they remain within the overall dimensions of the standard suspension of the balloon. The carrier 6 km rope is stacked in two magazines (3 km in each magazine). The magazine consists of two kapron clothes (length ~ 18 м and width ~ 1м of each cloth), superimposed one on another and sowed together along their short side on cells. A carrier rope sequentially is packed in these cells so that it could be extracted from them completely. The cloth is contracted into a roll. The process of deployment can be traced in Fig.1 (here are: 1 – balloon suspension girder; 2, 7, 12 – magnetic field sensors; 3, 8, 13 – container with magnetometers; 4 – pyrolock, ensuring beginning of process of descent of container 3 and a magnetic field sensor 2; 5, 10 – bracket parachutes; 6, 11 – rope-magazines; 9 – pyrolock, ensuring beginning of process of descent of container 8 and magnetic field sensor 7; 14 – pyrolock, ensuring division of system at landing; 15 – saving parachute; 16, 17 – convolution with cable-rope to magnetic field sensors 2 and 7; 18 – starting lock).

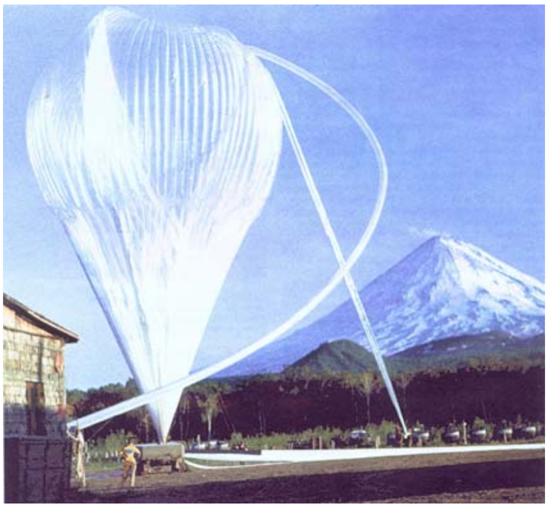

Figure 2. Stratospheric balloon launch, Kamchatka, Russia, 1998

At the balloon altitude of 3 km from the Earth's surface on a command acting from barometrical relay, works pyrotechnic lock 4, the instrumental container 3 with the sensor 2 of magnetic fields begin to fall and pull out from the chamber the parachute 5. The lifting rope under action of weight of the container 3 begins to extract from magazine 6. At releasing of the parachute 5 motion of the container 3 with the sensor 2 are decelerated. At the extraction of the whole rope from magazine 6 a container 3 with the sensor 2 hang on a rope fixed on pyrotechnical lock 9. Reaching a 6 km altitude, works pyrotechnical lock 9 and the process of deployment is renewed already for a carrier rope packed in the magazine 11, and happens similarly previous. At the extraction of the whole rope from magazine 11, the process of deployment of gradiometer is completed. The gradiometer gains a working condition (Fig. 1b). Thus, the instrument containers are separated one by one from a stratospheric balloon basket at unfolding of gradiometer. These containers stay united with the basket in consecutive order along a vertical carrying rope 6 km in extent. Such system of deployment of gradiometer, as has shown experience, works without a hitch. Fig. 1c shows the finish stage of gradiometer flight (the landing). The gradiometer operates using the natural orientation of measuring base along the direction of the gravity force. Therefore, variations in the wind velocity with altitude may cause substantial deflections of the lower sensor from vertical (with respect to the position of the upper sensor). For the warm season, this deflection does not exceed 25 m per each kilometer of the length of measuring base.

If the GPS receivers (in each instrumentation container) are used in such a flight, it will be possible to know the spatial position of each container and its deviations from the vertical line passing through the upper container and introduce the corresponding corrections into the measured data. In the case of measurements of vertical geomagnetic gradients and their increments along the vertical line, such corrections are introduced quite accurately. Photo (Fig. 2) shows the real stratospheric balloon launch with gradiometer on a board, Kamchatka, Russia, 1998.

Changes in the flight altitude depending on the solar radiation and underlying surface type are characteristic of the balloon. This instability of the balloon flight altitude does not prevent a high-quality magnetic survey, because, with the available data on the geomagnetic field vertical gradient, it is possible to convert the field to any specified level within the altitude range of 20-40 km (Tsvetkov, 2004). It is well known that the quality of interpretation of the crystal magnetic field depends on the quality of solution of the problem of dividing field into parts in accordance with their physical sources. The problem of recognition of the crystal magnetic field can be reliably solved in the field of gradients (Tsvetkov, 1997).
Below we will calculate the depths of sources using the characteristics of AMF decay. For this purpose, field changes

Table 1. Dependence of the induction of magnetic anomaly field on the survey altitude

Survey altitudes, km	Field values, nT	
	for the first anomaly	for the second anomaly
0	500	600
20	105	140
30	65	90
40	44	63

with increasing upward distance from the sources were approximated by the exponential function. In a rather narrow altitude range, e.g., 20-40 km, the exponent of the field decay with altitude can be taken constant. In this case, depths of sources of individual magnetic anomalies can be determined if a magnetic field is known at a series of altitudes. The same magnetic anomalies of Transbaikalia, for which the magnetic field were recalculated in the altitude range of 20-40 km, have been taken as experimental data. The magnetized rocks concentrated in the large block represented the source of these anomalies, whose vertical and horizontal dimensions were comparable with the distance of a balloon from the Earth's surface. The maximal values of the fields of the considered magnetic anomalies (obtained above for altitudes of 20, 30, and 40 km) and of the same anomalies (at altitude 0) taken from the map (Makarova, 1977) are given in Table 1.

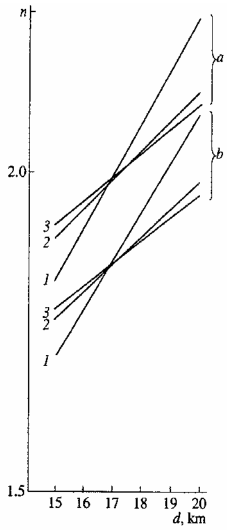

Fig.3. Decay coefficients of (a) the first and (b) the second anomalies for altitudes of (1) 0-20 km, (2) 20-30 km and (3) 30-40 km on the source depth

The calculations have been performed using formula:

$$Y = k / h^n$$

where k is the coefficient depending on magnetization and shape of the anomaly source; h is the distance to the source magnetic center ($h = H + d$; here H is the survey altitude above the Earth's surface, and d is the depth of the source magnetic center); and n is the parameter characterizing the field decay rate with increasing distance from the source. Since k = const for each anomaly, we have:

$$Y_1 h_1^{n_1} = Y_2 h_2^{n_2} = Y_3 h_3^{n_3} = Y_4 h_4^{n_4} .$$

Assuming that n = const within the ranges of altitudes 0-20, 20-30, and 30-40 km for each magnetic anomaly, we determine the depths at which the field decay exponent is constant. The numerical computations indicate that the calculated depths of the magnetic center are 16-17 km for both anomalies.

Fig. 3 illustrates the dependence of coefficient n on source depths (d). It is evident that the angle of intersection between the linear dependences increases with increasing difference between altitudes to which the fields have been recalculated. For example, the intersection angle for lines 2 and 3 is insignificant. This indicates that the accuracy of geomagnetic field measurements at different altitudes should be very high. The required accuracy can be obtained only if magnetic measurements are simultaneously performed on one balloon but at different altitudes. In this case, the recalculated field values become close to real values with increasing spacing of a gradiometer.

3. CONCLUSIONS

The example described the use balloon sounding of the Earth's crust magnetic structure - an extraction of magnetic anomalies, determination of a depth of bedding of magneto active rocks. The developed launching technology, deployment in flight, assembly, data transfer and processing, landing the containers with the equipment can be used for other similar problems of monitoring and sounding an environment. Useful flight weights each instrumental container may be reach 50 kg.

4. ACKNOWLEDGEMENTS

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