RUSSIAN JOURNAL OF EARTH SCIENCES, VOL. 6, NO. 6, PAGES 457–460, DECEMBER 2004

Large magnetic anomalies over Russia revealed by balloon data

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Abstract. A stratospheric balloon flight at 30 km altitude measured the geomagnetic field intensity along a 6000 km track extending from Kamchatka to near the Ural Mountains. When the CM model was used to remove the main and external fields from the observed data, magnetic anomalies of several 100 nT amplitude and 250 to 750 km wavelength are observed. In the eastern part of the track these anomalies appear to be due to the bodies of up to 5 km depth and magnetizations of 0.12 SI (0.01 cgs).

1. Introduction

Magnetic measurements by stratospheric balloons provide wavelengths intermediate between those registered by aeromagnetic and satellite magnetic surveys. Aeromagnetic profiles provide information about anomalies whose shortest wavelength is comparable to the distance from the source, namely from few hundred meters to a few kilometers. Although aeromagnetic profiles also provide information about long wavelengths these long wavelengths are usually discarded in making aeromagnetic maps. Large geologic structures, with dimensions of a few hundred kilometers, cannot always be inferred from their shorter wavelength surface expression.

On the other hand present day lithospheric models of the geomagnetic field derived from satellite magnetic data at the altitude about 400 km do not have resolution to show magnetic features with wavelength shorter than about 1000 kilometers. These long wavelength anomalies are considered to be caused by the sources located in the deep crust and upper mantle both in continental and oceanic areas.

Stratospheric balloons which fly at the altitude of about 30 km: (a) register magnetic signal from the whole thickness of the earth's crust, (b) fill the gap between aeromagnetic and satellite magnetic data, (c) using vertical gradient measurements allow reliable separation of the external and internal components of the Earth's magnetic field, (d) provide long term coverage of hard to access areas, (e) allow identification of large and significant tectonic structures.

There have been relatively few geomagnetic field measurements at stratospheric altitudes. However, in recent years, there have been several stratospheric balloon flights by France [*Achache et al.,* 1991; *Cohen et al.,* 1986] and Japan [*Tohyama et al.,* 1992]. One of the longest and most successful of these, made by Russian scientists is reported here.

2. Balloon Magnetic Survey

In July 1996 the total intensity of the geomagnetic field was measured at an altitude of approximately 30 km by a balloon flight from Kamchatka (56.29°N, 159.75°E) on the east to the Caspian Sea covering the Sea of Okhotsk, the Central Siberian Platform, the West Siberian Plains and Urals Mountains (54.00°N, 50.5°E). This 6000 km traverse was made at latitude of about 55°N in 6 days (Figure 1). The measurements were made with a scalar proton precession magnetometer suspended 1 km below the gondola with accuracy about 0.2 nT. All readings were recorded each 8 minutes, providing a complete record of 990 readings. The altitude fluctuations were similar day by day for the whole flight. At 5 am local time the altitude rose from 27 km to a maximum average altitude about 33 km. It leveled off at a maximum altitude a few hours later. In the late afternoon it fell to the lower altitude again. Therefore for present purposes we will consider the altitude to be a constant 30 km. No attempt was made to adjust the magnetic readings for time variations of the geomagnetic field strength. A typical amplitude for the diurnal variation in the total field in

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Paper number TJE04162.
ISSN: 1681–1208 (online)

The online version of this paper was published 15 September 2004.
URL: http://rjes.wdcb.ru/v06/tje04162/tje04162.htm

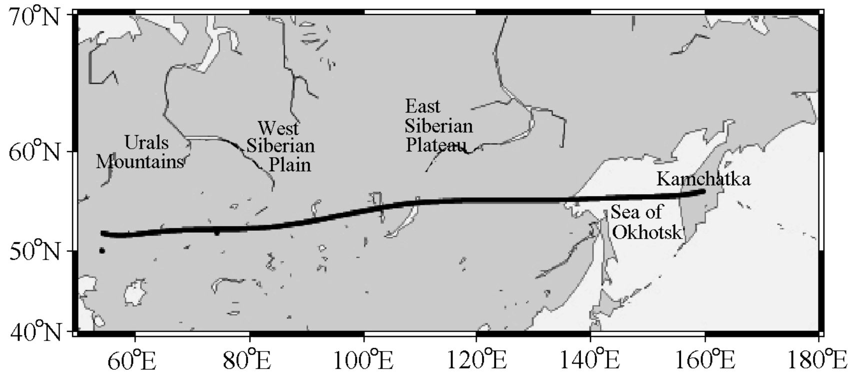

Figure 1. Balloon track over Russia.

1996 in the area surveyed by the balloon was about 50 nT as observed at Novosibirsk (Klyuchi) geomagnetic observatory located at 55°N, 82.9°E. Over a limited portion of the track a second proton precession magnetometer was suspended 1 km below the first magnetometer to provide measurements of the vertical geomagnetic field gradient. Results of gradient study are not discussed here.

3. Aeromagnetic Survey

In 1979 the Ministry of Geology of the USSR issued aeromagnetic anomaly maps of geomagnetic field intensity (Z. A. Makarova, editor). These 18 maps were digitized by the US Naval Oceanographic Office and edited by Conoco. The digital data is deposited at the National Geophysical Data Center (NGDC). We analyzed digital aeromagnetic anomaly maps and came to conclusion that long wavelength anomalies were lost during compilation when local magnetic maps were consolidated into larger regional maps. The balloon track covers the easternmost of these aeromagnetic maps and over the central Sea of Okhotsk aeromagnetic data is missing (Figure 2).

Figure 2. Orthographic map showing balloon track (black line) and aeromagnetic map coverage (grey polygons).

4. Isolation of the Anomaly Field

Because of its altitude this survey is different from other geomagnetic field measurements and provides unique data. It does not show the short wavelength anomalies of near surface surveys but it does show wavelengths too short to be included in global models of the geomagnetic field. The track is the first over land which shows these intermediate wavelength anomalies which are common in oceanic areas. The track of the balloon passed near one of the highs on global maps of geomagnetic field intensity, but south of the region dominated by time varying field aligned currents. Geomagnetic field models show long wavelength anomalies which are thought due to the Earth's main with sources deep within the earth. The models also show shorter wavelength anomalies ($n > 14$ in spherical harmonic expansion series) which are thought to be due to crustal sources. CM3e is a magnetic reference model able to represent not only main and crustal magnetic fields but also the ionospheric and magnetospheric (primary and induced) fields. A distinct magnetic low near the eastern end of the track over the Sea of Okhotsk was observed.

Ravat et al. [2003] clearly showed the advantage of CM magnetic model [*Sabaka et al.*, 2002] relative to IGRF in the processing of aeromagnetic data in the central US (Kansas area). In the area of balloon track there are few ground magnetic observatories and, since ground magnetic observatory data is integrated into the models, there have been some difficulties with models here in the past. Total field

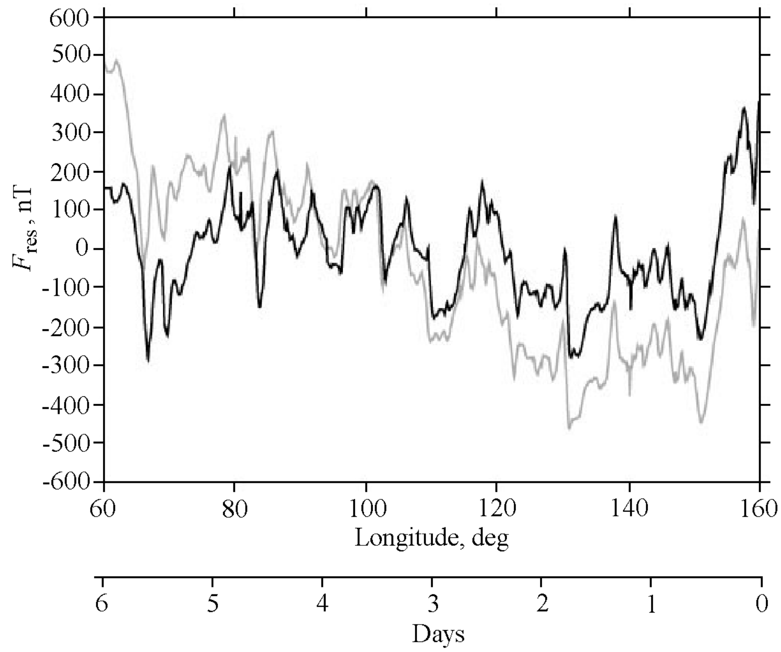

Figure 3. Magnetic profile with CM3e ($n < 15$) removed from observed data (grey line) and with CM3e ($n < 15$) and straight line fit removed from observed data (black line) versus longitude and time.

maps made from the IGRF show a maximum for this region in the northern hemisphere. Only the CM model (http://core2.gsfc.nasa.gov/CM/) compensate for magnetic disturbances, which are part of quiet daily variations. If one subtracts the main field components of CM3e ($n < 15$) from the observed data one obtains the profile shown in Figure 3. For illustrative purposes the data are also shown with a best fit straight line removed. The same magnetic profile over the balloon track and tectonic structures is shown in Figure 4. Anomalies of length 5 to 15 degrees of longitude (250 to 750 km) stand out.

5. Magnetic Modeling of Balloon Lithospheric Anomalies

To understand what crustal bodies might cause the anomalies observed by the balloon, we used a forward modeling technique. Since we have only a one-dimensional survey, rather than an area survey we used a 2D modeling technique [*Heirtzler et al.,* 1964]. This assumes that the anomalies are linear for a length equal to about the height of the survey (30 km). The Russian aeromagnetic survey in other parts

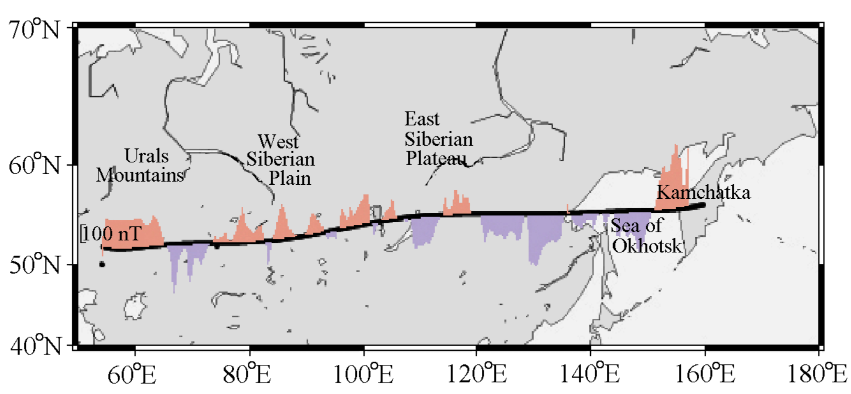

Figure 4. Magnetic anomalies over the balloon track.

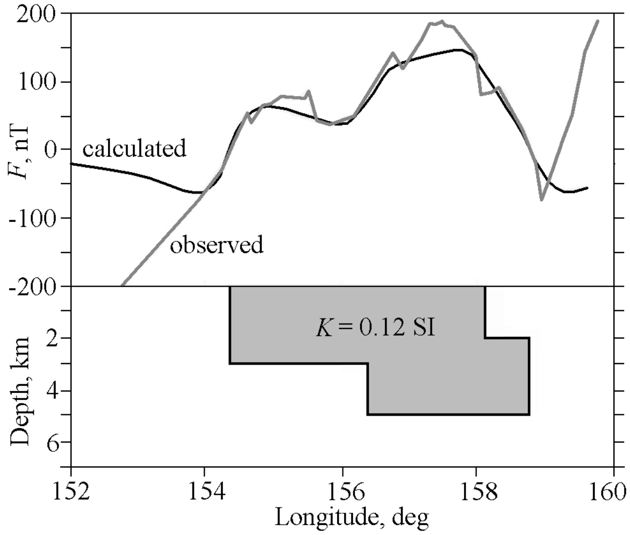

Figure 5. Observed and calculated magnetic anomalies for bodies whose cross sections are shown. The bodies are assumed to be two dimensional, striking north-south with a susceptibility 0.12 SI (∼0.01 CGS).

of Siberia suggests that this may be approximately true. For this model study we chose the large amplitude anomaly on the eastern end of the track covering western Kamchatka and the Sea of Okhotsk. Figure 5 shows the observed anomaly (measured anomaly minus main field from CM3e) and the calculated anomaly for the body shown. This body has a deep root of about 5 km and a strong magnetization of 0.12 SI (0.01 cgs). The topographic data show the deep root is under the western side of Kamchatka and the root to be less deep under the eastern side of the Sea of Okhotsk. In this calculation we assumed the body to strike north-south, the magnetization to be induced and the inducing field direction to be like that of the present geomagnetic field.

A preliminary checks on 2D models for other anomalies along the profile show that there are other deep rooted bodies of high magnetization. A correlation with major tectonic or structural features in Siberia is planned.

6. Conclusions

Magnetic measurements on a stratospheric balloon flight shows that there are many magnetic bodies with dimensions of 250 to 750 km in Siberia. Bodies of this size cannot be identified with present satellite geomagnetic field models and have not been identified from surface surveys

Acknowledgments. This project was supported by NASA Headquarters code Y, and Russian Academy of Sciences (IZMIRAN).

References

Achache, J., and C. Yves, and G. Unal (1991), The French Program of Circumterrestrial Magnetic Surveys Using Stratospheric Balloons, *EOS Transactions of the American Geophsyical Union, 72,* 97–101.

Cohen, Y., M. Menvielle, and J. L. LeMouel (1986), Magnetic Measurements aboard a Stratospheric Balloon, *Phys. Earth Planet. Inter., 44,* 348–357.

Heirtzler, J. R, G. Peter, M. Talwani, and E. G. Zurflueh (1964), Magnetic Anomalies Caused by Two-Dimensional Structures: Their Computation by Digital Computers and Their Interpretation, *Technical Report,* no. 6, CU-6-62, Nonr-Geology,Columbia University.

Ravat, D., T. G. Hildenbrand, and W. Roest (2003), New Way of Processing near-surface Magnetic Data: *The Utility of the Comprehensive Model of the Magnetic Field, 22*(8), 784–785, The Leading Edge.

Sabaka, T. J., N. Olsen and R. A. Langel (2002), A Comprehensive Model of the Quiet- Time near-Earth Magnetic Field: Phase 3, *Geophys. J. Int., 151,* 32–68.

Tohyama, F. Y, and T. Takahashi (1992), Observation of the Geomagnetic Field by Polar Patrol Balloon, *Journal Solar Terrestrial Environmental Research in Japan, 16,* 60.

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(Received 9 September 2004)