On Feasibility to Detect Volcanoes Hidden under Ice of Antarctica via their "Gravitational Signal"

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***Abstract*—Many not yet discovered volcanoes may be hidden under thick layers of ice in Antarctica. Discovery of two volcanoes active under the ice (from seismic network), new gravitational field models with high resolution (like EIGEN 6C4) based also on gradiometry data from satellite GOCE and progress in mapping topography of bedrock (BEDMAP 2), mostly from remote sensing by satellites, has been inspiring to seek for hypothetic volcanoes hidden under ice of Antarctica by using these data sources. Our method is novel. We do not work with direct measurements like terrestrial gravity anomalies or airborne gradiometry, but with spherical harmonic expansion for the gravitational potential. This approach is not local, but regional and global, thus it has a lower resolution than the local data. We make use of analogy with the "gravitational signal" known for volcanoes and other structures in other parts of the Earth. We utilize various functionals and functions (not only ordinary gravity anomalies) of the disturbing geopotential (being represented by harmonic coefficients in expansion of the potential to spherical harmonic series, namely by EIGEN 6C4 to degree and order 2160). We claim that our method is promising for future successful search for subglacial volcanoes, having of course in hands also other than satellite data. Our present-day attempts to discover such volcanoes hardly can be of big success, because of low resolution (mainly) of the existing gravity data and (partly) due to a low resolution of even the best bedrock topography of Antarctica now available.**

Keywords- gravity field model EIGEN 6C4; Bedmap 2; functions of disturbing potential; volcano; Antarctica.

I. INTRODUCTION

Many not yet discovered volcanoes may be hidden under thick layers of ice of Antarctica. New gravity and topography data now available (see Section III) inspired us to try to detect such objects. We had experience with studies of other objects in other parts of the world [3][4] and we utilized it here. But, there are some problems specific to Antarctica. We had to answer the following questions. Are the best present-day available gravitational and topographic data of sufficient precision and resolution? How fast is an attenuation of the "gravitational signal" of a volcano with increasing depth under the ice?

We have not found any principal problem precluding a successful detection of large volcanoes under the ice. But, there is a practical obstacle in the low resolution of the gravity (mainly) and topography data (also), even coming from the best now available data sets, so practical examples of detected volcanoes are limited to a few cases in Queen Maud Land and near the Lake Vostok.

The attenuation of the signal under the ice for the gravity anomaly is not significant; the attenuation for the second radial derivative of the disturbing potential is negligible.

II. THEORY

Theory related to the present work in progress comes mainly from Pedersen and Rasmussen (1990) [1], Beiki and Pedersen (2010) [2] and from our previous research work [3][4].

III. DATA

Data are of two types of data of interest: gravitational and topographic, both with significant contribution to remote sensing methods. (1) The gravitational data are the harmonic geopotential coefficients (also known as Stokes parameters) in the spherical expansion of the disturbing gravitational potential into the spherical series. European Improved Gravity model of the Earth by New techniques (EIGEN 6C4, [5]) is expanded to degree and order 2190 in spherical harmonics. It corresponds to a resolution of 5x5 arc minutes, which is ~9 km half-wavelength on the Earth's surface. But the resolution in Antarctica is lower due to the fact that there we have solely satellite data (GRACE and GOCE) available in EIGEN 6C4. (2) The topography of the ground under ice (bedrock, base of the ice sheets) in Antarctica is known as BEDMAP 2 [6], being compiled from measurements of various kinds, with penetrating radars to the ground or water under the ice, with a resolution reaching 1x1 km in some areas of Antarctica and a few kilometres in the others. A combination of both sources is also possible, but a mutual independency of EIGEN 6C4 and BEDMAP 2 is lost.

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IV. COMPUTATIONS AND RESULTS

The gravity anomalies or disturbances, the Marussi tensor of the second derivatives, with the invariants and their ratios, the strike angle and with the virtual deformations are computed with our own software [7][8] in 5x5 arcmin grid everywhere where we need it. We learnt how the typical signal of volcanoes looks like outside Antarctica (e.g., [3][4]) and we now extrapolate to Antarctica under ice. We combine the gravitational data and the bedrock topography and seek for signal typical for a volcano simultaneously for more functionals or functions of the geopotential (examples in Figure 1 below). We indicate localities in the Gamburtsev Mountains, Queen Maud Land and other places (one example is in Figure 3) with candidates for volcanoes.

V. CONCLUSION

Our method, based on combining gravity and topography data, is promising for future successful search (with new forthcoming data with higher resolution) for subglacial volcanoes and other objects hidden under the ice (or elsewhere, for example under the sand of the Sahara), having of course in hand also other than satellite data only. Our present-day attempts to discover such volcanoes hardly can be of big success, because of low resolution (mainly) of the existing gravity data and (partly) due to low resolution of the best bedrock topography of Antarctica now available. But we achieved some results, of those we present here one example to show how it works in the case of known volcanoes (Figure 2) and one case of predicted, hypothetical volcano (Figure 3).

ACKNOWLEDGEMENT

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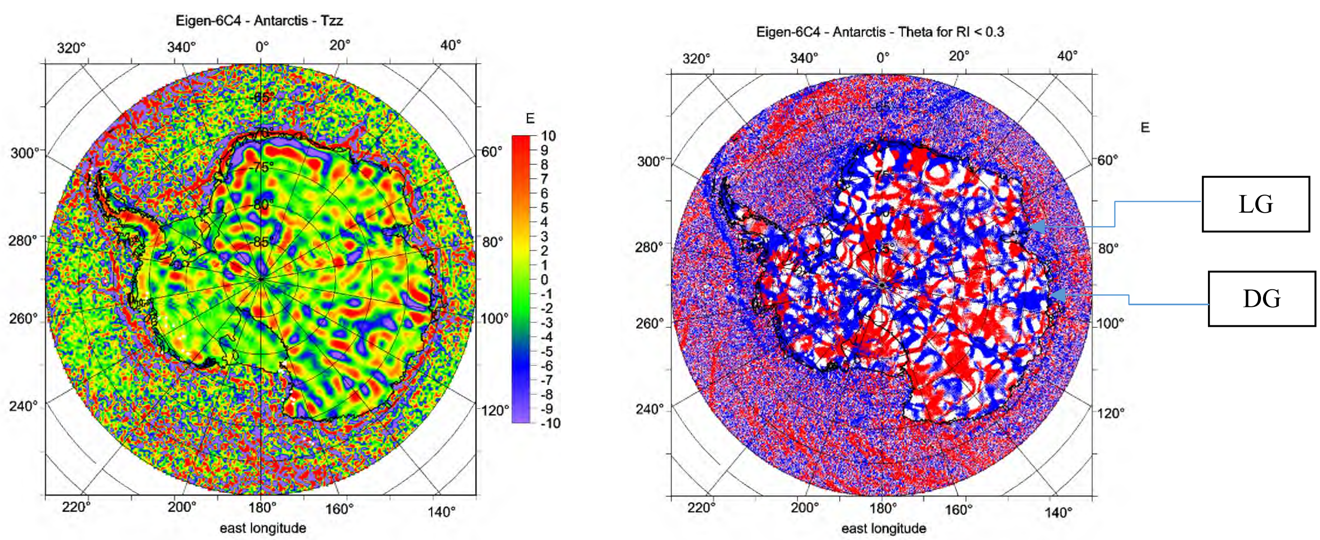

Figure 1. On the left: The radial component of the Marussi tensor (scale in Eötvös over Antarctica. On the right: The strike angle over Antarctica (in red its direction to the East, in blue to the West of the meridian). Lambert Glacier (LG), Dehmann Glacier (DG) shown by arrows.

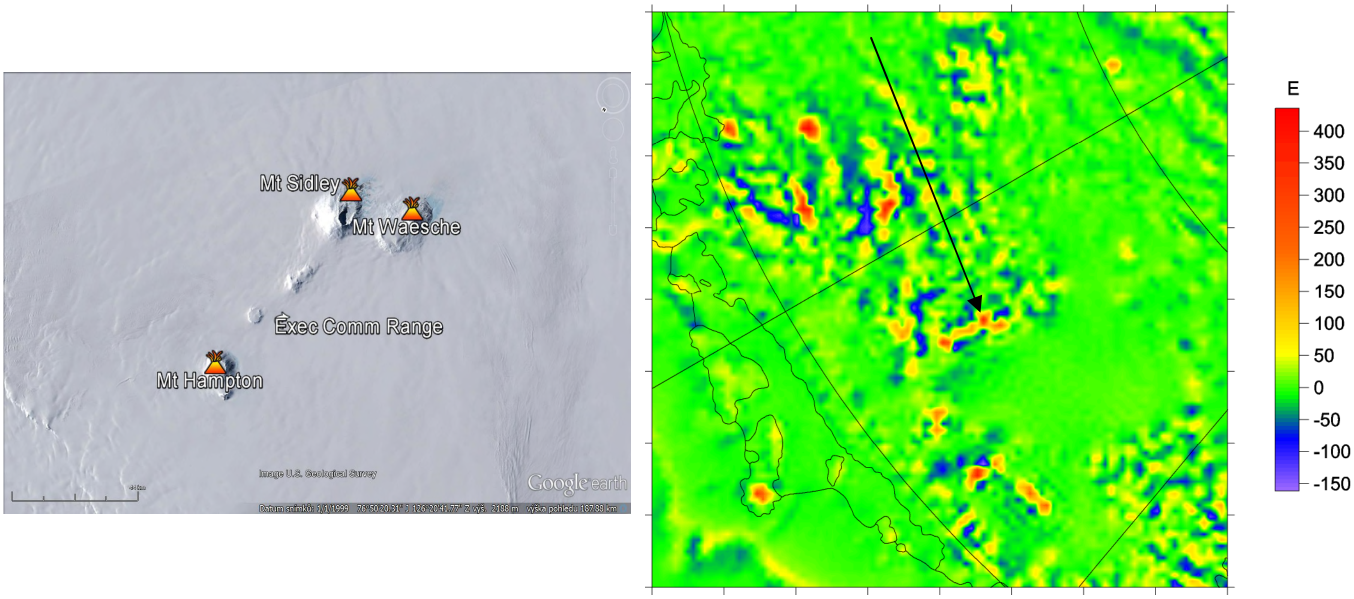

Figure 2. On the left: Topography of the area of Mt Sidley, the highest, dormant volcano in Antarctica, and the Executive Committee Range of Marie Byrd Land, from © Google Earth, example of known volcanoes, visible on the surface. On the right: The second radial component of the disturbing potential from a combination of the EIGEN 6C4 and BEDMAP 2. The arrow shows Mt Sidley.

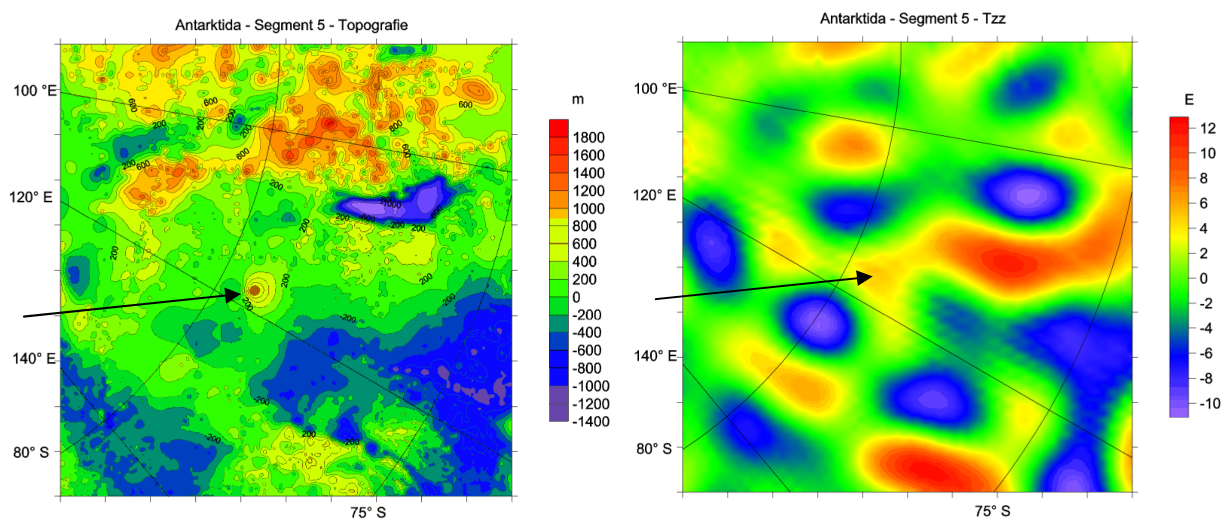

Figure 3. One example of our new results. On the left: Bedrock topography according to the BEDMAP 2 model (scale in metres) near the lake Vostok (large blue oblong depression with a depth to 1000 m, hidden under about 3 km of the ice) with suspicious cone-shaped object nearby (isolated mountain in a plain terrain, with a relative height difference of about 1200 m). On the right: The second radial derivatives of the disturbing geopotential (scale in Eötvös) according to the EIGEN 6C4 gravity field model for the same territory.

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