Determination of a local geoid for Deception Island

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Summary Deception Island (63ºS, 60ºW) is one of the few volcanoes in Antarctica showing active volcanism. Its last eruptions took place in 1842, 1967, 1969 and 1970, with unconfirmed ones in 1912 and 1917. To study the tectonics and volcanism in the area it is necessary to establish a local physical reference frame: a geoid. To determine this experimental geoid, ellipsoid and orthometric heights for several points were collected: geodetic heights were obtained from GPS observations whereas the orthometric ones were obtained from absolute gravimetric and levelling measurements. In order to calculate this surface, three different techniques have been applied: remove-restore, GPS/levelling and collocation methods.

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Introduction

Bransfield basin, between the South Shetland Islands and the Antarctic Peninsula, is an active extending marginal basin with a 500 km long spreading axis trending from NE to SW, between the parallels 60ºS and 63ºS. Deception Island (63ºS, 60ºW), located in the aforementioned basin, is the only volcano in the area showing active volcanism. Its last eruptions took place in 1842, 1967, 1969 and 1970, with unconfirmed ones in 1912 and 1917. During the period 1967-1970, the intense volcanic activity caused the destruction of the Chilean and British scientific bases, changed the island morphology and expelled a great amount of ashes that settled in the neighbouring islands (Smellie et al., 1988; Smellie et al., 2002; Vila 1992).

The presence of active volcanism in Deception Island and the existence of both superficial and deep seismicity make the tectonic situation of the area complex and one of the main goals of the geosciences studies. Therefore, the establishment of a proper geodetic reference frame, such as the geoid, acquires a high relevance.

An important application of the geoid to volcanic geodesy is the determination of vertical deformation models. Although horizontal components computed from GPS data are totally represented by ellipsoidal models, there is a lack of physical meaning of the ellipsoidal height as well as of accuracy when vertical deformation is being analysed. Consequently, not only a mathematical but also a physical reference system, allowing the study of the existing vertical deformation, is needed.

In addition, this surface could permit us to carry out real time levelling measurements by means of GPS receivers. In this area, this application would be quite interesting to measure vertical deformations in case of volcanic reactivation, which would be impossible and dangerous with classical levelling methods. Finally, global geoid models, such as OSU91A or EGM96, in volcanic areas with high geodynamic activity are so inaccurate that determining an experimental geoid model to improve the globally extrapolated models is essential.

Therefore, three different experimental geoid models for Deception Island, computed from GPS data, geometrical levelling and absolute gravimetric measurements, have been calculated. This mean sea level surface will be a very important reference frame to enhance our knowledge of the area and will allow us to improve the accuracy of the high degree geopotential models in this area of the Antarctica.

Data Acquisition

The acquisition of a complete set of data consisting of GPS observations, levelling data and gravimetric measurements has been necessary for the geoid computation.

REGID Geodetic Network

Due to the climate and the topographic conditions of the Island, the use of classical techniques of geodesy turns out to be useless. For this reason, GPS measurements seem to be more adequate since they are independent with regard to meteorological conditions and because they do not need any visual connection between the stations.

The design and establishment of the geodetic network, called REGID (figure 1), was planned according to the special characteristics of the zone. Deception Island is a horseshoe shape stratovolcano and it encloses an inner 16 km diameter bay, Port Foster, which is surrounded by a mountainous chain. So, the topographic conditions made the building of the stations restricted to areas near the coast (Berrocoso, 1997; Berrocoso et al. , 2006).

Regarding GPS data, although the REGID geodetic network has been surveyed from 1988, the data used in this study correspond to the 2002-03 Antarctic campaign, from November 2002 to February 2003. The equipment used consisted of TRIMBLE 4000SSE, 4000SSI, 4700, 4800 and 5700b receivers. Data were registered with a 15 s sampling rate and with an elevation mask of 10º. Furthermore, BERNESE v4.2 GPS Software (Beutler et al., 2001) was used to obtain a relative position of the network with respect to the reference station BEGC at the Spanish Base Gabriel de Castilla. In addition, IGS precise orbits and pole files were used, baselines were processed using QIF ambiguity resolution strategy and the tropospheric parameters were estimated from a Saastamoinen tropospheric model, as suggested for GPS data processing in Antarctic regions (Bouin and Vigny, 2000).

The adjustment of the network was carried out in two stages: firstly, absolute geocentric coordinates for both BEGC and BEJC stations were obtained by the processing of the network data with the IGS station OHI2 at the Chilean Antarctic Base O'Higgins in the Antarctic Peninsula with respect to ITRF2000 reference frame, epoch 2000; secondly, the coordinates of the remaining stations at Deception Island, calculated with respect to the ITRF2000 as well, were processed from the coordinates previously obtained.

RENID Levelling Network

During the 2001-02 Antarctic campaign a levelling network, called RENID, was designed and built to establish a precise reference frame for real time monitoring of vertical deformations taking place in the island.

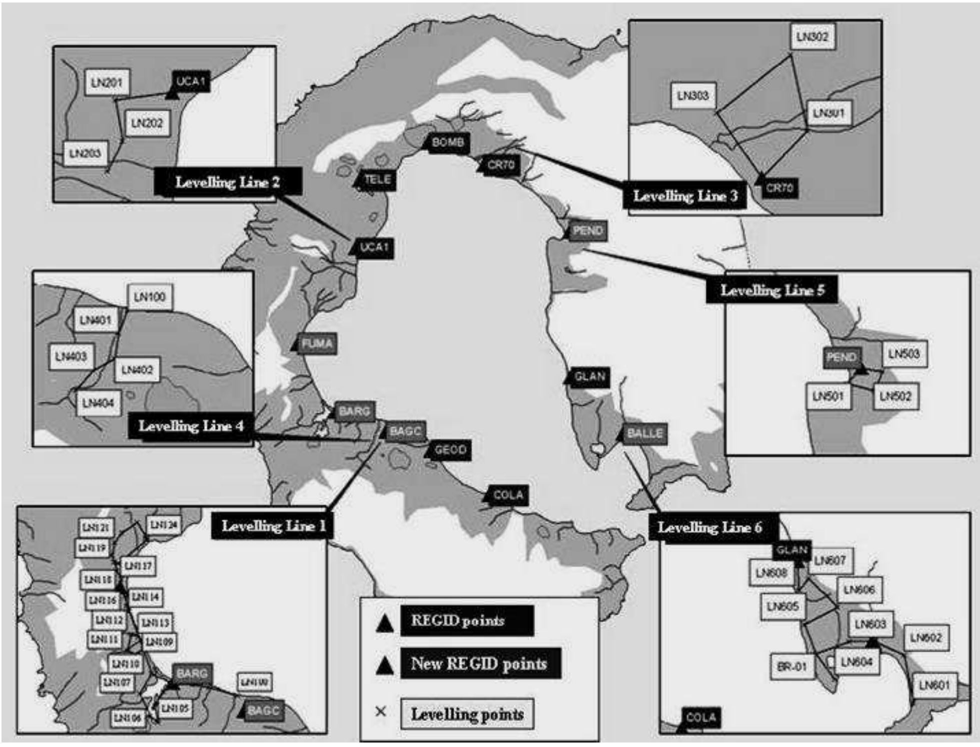

Figure 1. REGID and RENID networks

RENID levelling network, divided into six independent levelling lines, consists of fifty-seven benchmarks (Figure 1). The fundamental benchmark is LN000, in levelling line 4, which is located near the Spanish Antarctic Base Gabriel de Castilla. The orthometric height of LN000 was determined by a geometric levelling from the geodetic benchmark BARG at the Argentinean Antarctic Base, provided with orthometric height from 1991. Every line is connected to one of the REGID geodetic stations except levelling line 4, which is connected to the fundamental benchmark LN000.

Levelling surveys were carried out using a LeicaNA2 level, with σ=0.7 mm, during the 2001-02 and 2002-03 Antarctic campaigns whereas the connections among lines were done only during the second campaign, using a Wild T2000 theodolite and a DI5000 distancemeter. Every benchmark was GPS surveyed in 'fast-static' mode, keeping a base receiver at BEGC station.

REGRID Gravimetric Network

REGRID gravimetric network was established during the 2002-03 Antarctic campaign from REGID and RENID networks. In addition, another gravimetric point at Livingston Island, GBEJC, was included in the network.The fundamental gravimetric point in the island was GBEGC, in the vicinity of the Spanish Antarctic Base Gabriel de Castilla. Gravimetric measurements were obtained by using a Lacoste & Romberg D-203 gravimeter. Also, a gravimetric link among GBEGC in Deception Island, GBEJC in Livingston Island and APPA gravimetric point in Punta Arenas (Chile) was made. Usual tides, height and drift corrections were applied to the whole set of gravimetric data.

Complementary observations

In addition to GPS observations, the stations of the REGID network have been linked to the RENID ones by geometric levelling, in such a way that these stations are provided with levelling measurements with respect to the main benchmark LN000. In the same way, every levelling benchmark was positioned in 'fast-static' mode, keeping one base receiver at BEGC station. Therefore, taking into account that the gravimetric network was established from REGID and RENID networks, REGRID is provided not only with absolute gravity values, but also with geodetic coordinates and levelling measurements.

To spread out the observations to the outer area of the Island and to make the measurement set denser, 44 secondary points were also established. So, GPS observations, levelling and gravimetric measurements were also obtained for these marks; every point was positioned by 'fast-static' mode, using a TRIMBLE 5700 dual frequency receiver and levelling tasks were carried out using a WILD T2000 total station with a DI5000 distancemeter.

Applied methods

Three different methods have been considered to obtain the geoid height: remove-restore, collocation and GPS/levelling methods; GPS and gravimetric data are needed when using the two first techniques whereas levelling data are also needed with the last one.

Remove-restore is based on the resolution of the Stokes´ integral by breaking down the frequency spectrum of the gravity anomaly, Δg, and geoid height, N, into three different bands of frequency: low (MOD), high (DTM) and medium (MED) components. Then, FFT is used as an integration method.

Like the previous algorithm, in collocation method a partition of the spectrum is also made, but the values of the geoid height are now obtained through the covariance matrix, where Δg_{FA} denotes the free-air anomaly, $S(\psi)$ the Stokes´ Function, n the measurement error and s_1, s_2 the errors due to the model used in the observation and computational points respectively (Figure 2):

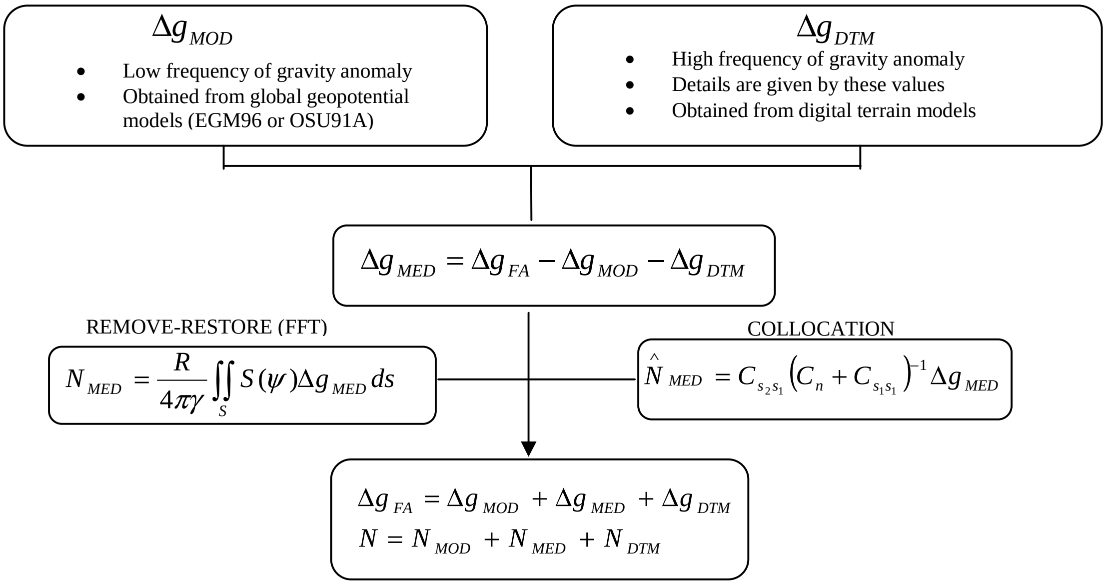

Figure 2. Remove-restore and collocation methods

Finally, GPS/levelling method considers a set of points around the island where absolute gravity, g_k, levelling measurements, n_{P_k}, and ellipsoid coordinates are known. By means of the orthometric height of a particular point, such as BARG, we are able to obtain the orthometric heights in the remaining points P_j by using the attached scheme:

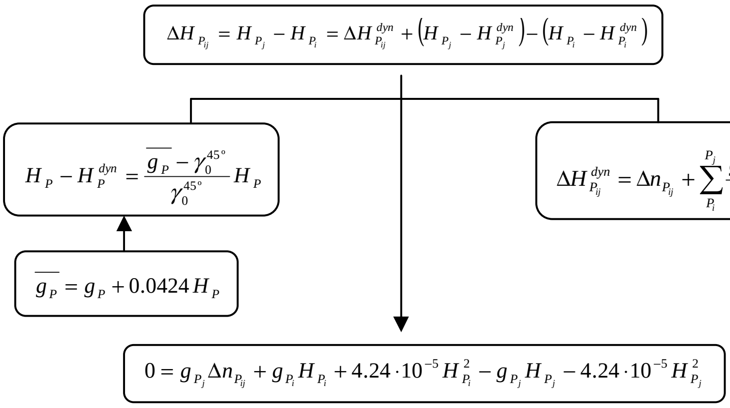

Figure 3. GPS/levelling method

where H_P^{dyn} is the dynamic height at P, $\gamma_0^{45°}$ the mean normal gravity at latitude 45º and δn_k the levelling height between two consecutive points of the levelling line considered. So, to calculate the geoid, we only have to take into account the well-known formula h=H+N, where h, H and N are the ellipsoidal, orthometric and geoid heights respectively.

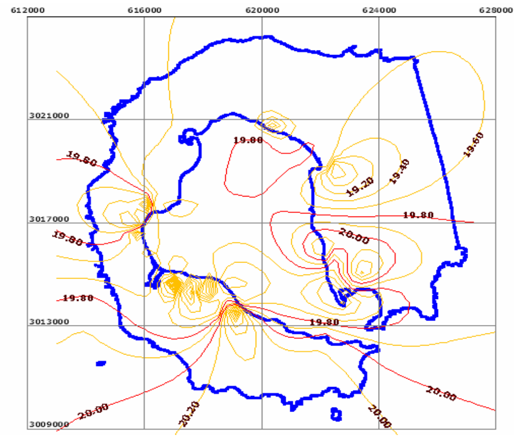

Figure 4. Geoid height maps from the application of the GPS/levelling method.

Results and conclusions

By comparing the derived geoid heights to those geoid heights from global geopotential models, we obtain the correction factor for the area of Deception Island. In fact, GPS/levelling and collocation techniques provide more details than remove-restore method when compared with global geopotential models (Table 1).

With regard to computational cost, remove-restore method has a higher cost than GPS/ levelling and collocation methods not only due to the use of Global Geopotential Models but also because of the methods of numerical integration. Moreover, remove-restore and collocation methods only need GPS and gravimetric measurements whereas GPS/levelling method also needs levelling data which are really difficult to obtain in areas like Deception Island.

Table 1 Comparison between local and global geoid models

	REMOVE-RESTORE RMS (m)	GPS/LEVELLING RMS (m)	COLLOCATION RMS (m)
OSU91A	0.0503	0.3922	0.4248
EGM96	0.1738	0.4547	0.3798

Although the GPS/levelling method is quite simple and accurate, the required measurements make data acquisition hard and complicated. The remarkable point of the local geoid obtained by means of this algorithm is the high level of detail which is reached by the combination of levelling and gravimetric data, accuracy needed in order to control the state of the volcano and its deformation.

It must be pointed out that this experimental geoid should be improved by adding data from the outer area of the island. In particular, marine gravimetric measurements should be added.

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