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Calibration of the Tide Gauge at King Edward Point, South Georgia Island, South Atlantic Ocean

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Abstract

In 2008 a new pressure tide gauge with Global Sea Level Observing System Number 187 was installed at King Edward Point (KEP), South Georgia Island, South Atlantic Ocean. This installation was carried out as part of the Antarctic Circumpolar Current Levels by Altimetry and Island Measurements (ACCLAIM) programme. In 2013 the KEP Geodetic Observatory was established in support of various scientific applications including the monitoring of vertical land movements at KEP. Currently, the observatory consists of two state-of-the-art Global Navigation Satellite System (GNSS) stations with local benchmark networks. This ties all benchmarks and the tide gauge into the International Terrestrial Reference Frame 2008, and allows the establishment of a local height datum in a global height system through the use of a global gravitational model. In 2014 a tide board was added to the tide gauge, which, together with the GNSS and levelling observations, now enables a calibration of the tide gauge. This will make it possible to include the KEP tide gauge in the Permanent Service for Mean Sea Level (PSMSL) database.

In this study, we will present the results from the calibration of the tide gauge using the GNSS observations from the KEP Geodetic Observatory for the period from February 2013 to present, the levelling campaigns in 2013 and 2014, and geoid undulations derived from a seamless combination of the latest Gravity Observation Combination (GOCO) 05S and Earth Gravitational Model (EGM) 2008 models.

Introduction

During February 2013 and March 2014 the King Edward Point (KEP) Geodetic Observatory was established in South Georgia, South Atlantic Ocean (Figure 1) and additional surveys were carried out. With its remote location, South Georgia is one of few islands in the Southern Hemisphere, which can be employed to densify the global geodetic infrastructure and counteract the hemisphere imbalance in its observations (Figure 2).

The primary objective of the observatory is to measure crustal movements close to the tide gauge at KEP (Global Sea Level Observing System 187) and to provide a long-term vertical datum. It consists of two continuous GNSS stations KEPA (DOMES 42701M001) and KRSA (DOMES 42702M001) with local benchmark networks to geo-reference the tide gauge to the International Terrestrial Reference Frame (Figure 3). Noteworthy is that the Scientific Commitee of Antarctic Research (SCAR) established the campaign GPS station GRY1 near KEP research station and observed it for two days during 1998 [Dietrich et al., 2001].

As there is an incomplete understanding of the tectonics and potential glacio-isostatic adjustment of South Georgia and the associated continental shelf [e.g. Smalley, et al. 2007], the KEP Geodetic Observatory will also benefit studies on these regional processes (Figure 1). After the November 17, 2013 M_W 7.8 South Scotia Ridge earthquake, KEPA 1Hz data was applied to the seismological interpretation of the earthquake sequence [Ye et al., 2014]. Furthermore, the GNSS data can be applied to monitoring the ionosphere and the water vapour content of the troposphere [Teferle et al., 2014a].

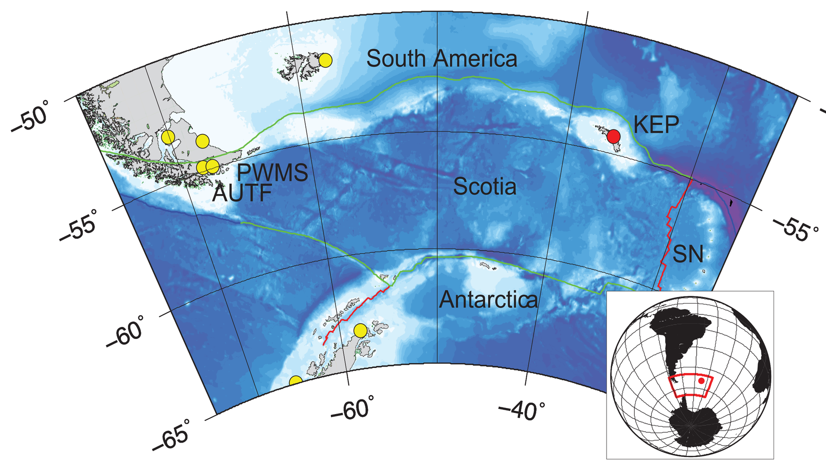

Figure 1: Location of King Edward Point (KEP) and tectonic plates in the South Atlantic Ocean (University of Texas at Austin): transforms/fracture zones (green), ridges (red) and trenches (blue); existing continuous GNSS stations (yellow circles) and KEP geodetic observatory (red circle); SN: the South Sandwich plate.

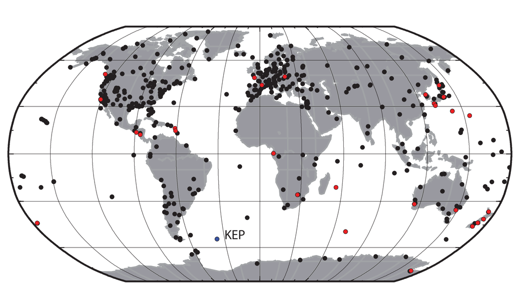

Figure 2: Global network of International GNSS Service (IGS) stations contributing to ITRF2008, (black dots), stations using a Trimble NetR9 receiver (red dots) and KEP.

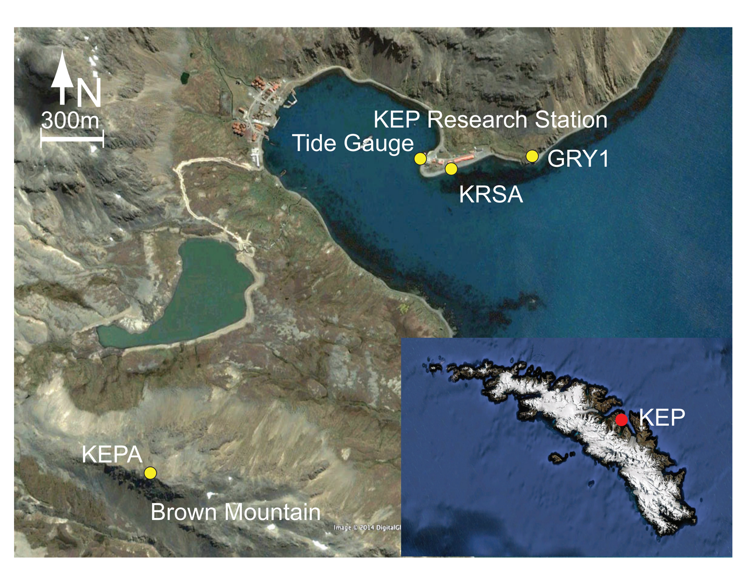

Figure 3: Map of surroundings of KEP Research Station. Locations of KEPA and KRSA continuous, and GRY1 SCAR campaign GNSS stations, and of the tide gauge. Imagery from Google Earth.

GNSS Installations

KEPA, the primary GNSS station, is located on the highest point of Brown Mountain (320 m), which lies southwest of KEP (Figure 3). This ensures a clear horizon for the GNSS measurements in the extremely mountainous (up to 3000 m) surroundings. The antenna and 1-m mast are bolted onto a rock outcrop (Figure 4a) with an aluminium pipe frame housing the auxiliary equipment and enclosures approximately 30 m away (Figure4b).

KRSA, the secondary station, is located at KEP Research Station close to the tide gauge and other sensors (the geomagnetic and seismological stations - not shown) (Figure 3). Its purpose is to monitor relative motions between KEPA and the research station which is located on gravel deposits. Being located at sea level KRSA suffers from large sky obstructions to the northeast from Mt Duse (670 m). The antenna is mounted on a 1.5-m mast, which it bolted onto a 1-m concrete pillar (Figures 5a and 5b). Although the pillar is purpose-built, it sits on 1x1 m concrete foundations which has supported other instrumentation in the past and has therefore been assumed to be “as stable as it gets”, considering the lack of bedrock. The receiver and electronics are housed in a Pelican case directly at the station. Further details on both GNSS stations are in Table 1.

Figure 4: a) KEPA GNSS antenna on 1-m mast with view northeast towards KEP Research Station and Mt Duse; b) KEPA aluminium pipe frame with electronics and auxiliary equipment.

Figure 5: a) KRSA GNSS antenna on 1.5-m mast, concrete pillar and equipment case with view southwest towards Brown Mountain; d) KRSA station with view northeast towards Mt Duse.

	KEPA (DOMES 42701M001)	KRSA (DOMES 42702M001)
GNSS Equipment	Trimble NetR9 Trimble Choke Ring TRM59800.00 SCIS Robot antenna calibration by NGS, USA	Trimble NetR9 Trimble Choke Ring TRM59800.00 SCIS Robot antenna calibration by Geo++, Germany
GNSS Data/Archive	1s and 15s GPS, GLONASS, Galileo and BDS daily download, Unavco Inc., TIGA	1s and 15s GPS, GLONASS, Galileo and BDS hourly download, University of Luxembourg
Power System	12V DC from 2 solar panels with 80 Watts 20x deep-cycle lead-gel batteries	27 V DC from mains power at research station RCV internal battery is used as UPS
Communications	Intuicom EB-1 900 MHz Ethernet radio bridge Uptime: 5 hours on/off VSAT communication link @ KEP	Phoenix Contact DSL/Ethernet link Uptime: permanent VSAT communication link @ KEP
Weather Sensor	Vaisala WXT-520 weather station (dedicated)	KEP Automatic Weather Station

Table 1: Equipment details for continuous GNSS stations KEPA and KRSA.

Earth Gravity Model Preliminary Results

The inclusion of Gravity Recovery and Climate Experiment (GRACE) observations in the Earth Gravitational Model 2008 (EGM2008) [Pavlis et al., 2012], has significantly improved its accuracy compared to its precessor EGM96. The satellite mission Gravity Field and Steady-sate Ocean Circulation Explorer (GOCE) has since contributed further to our knowledge of the Earth’s gravity field to an unrivalled precision on a global scale. Pail et al. [2010] have made the first attempt in combining satellite-only gravity field models by incorporating the initial data from GOCE and GRACE and resolved the harmonic coefficients up to degree and order 224 (GOCO01S). Here we use the recently released model GOCO05S [Meyer-Gürr et al., 2015] and spectrally combined it with the EGM2008 model using a Butterworth filter (Figure 6). A geoid combination of low-pass filtered GOCO05S and high-pass filtered EGM2008 models provides better estimates in areas of insufficient gravity coverage. The improvement in the higher order spherical harmonics from this approach can be seen in Figure 7. Table 2 compares the ellipsoidal and Geoid heights for KEPA and KRSA. It can be seen that the Geoid heights from the Combined model are approximately 24cm lower.

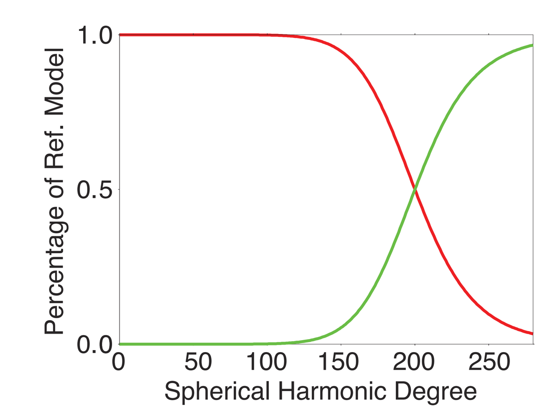

Figure 6: Blending of the new GOCO (red) and EGM2008 (green) gravity models using a Butterworth filter.

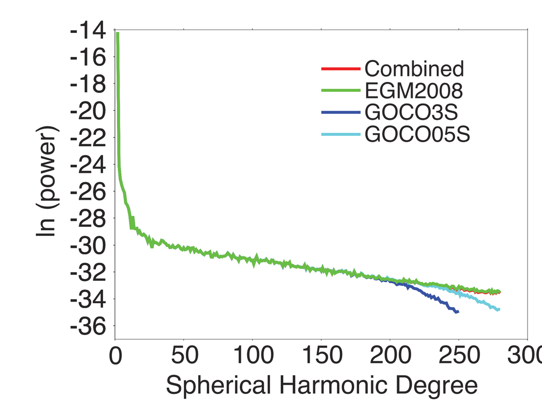

Figure 7: Power spectra of spherical harmonic series for different global gravity field models.

Table 2: Comparison of ellipsoidal, orthometric and Geoid heights for KEPA and KRSA from the EGM2008 and the Combined gravity models. Orthometric heights were computed using the Combined Geoid model.All values are in m.

	KEPA	KRSA
Height (ellip.)	346.2091	24.8900
EGM2008	20.4679	20.2304
Combined	20.2272	19.9927
Height (ortho.)	325.9819	4.8973

Benchmark Networks and Levelling Results

Two benchmark networks were installed: one at KEPA on Brown Mountain and a second one at KEP Research Station. The KEPA network provides a precise reference of the current GNSS antenna ARP in case the monument should get damaged or destroyed (not discussed further). The network at KEP Research Station provides the height connection of the KRSA antenna ARP to the tide gauge as well as allows stability monitoring of the KRSA monument. Figure 8 shows this benchmark network which incorporates two benchmarks used by the United Kingdom Hydrographic Office (UKHO). Table 3 shows the newly derived benchmark heights using KRSA as the new height datum. When compared to the heights of the UKHO benchmarks these results indicate a shift from the old to the new datum of approximately -73 cm. Furthermore, a comparison of the levelling results from 2013 and 2014 indicates subsidence of 7-9 mm near the tide gauge (Figure 9) [Teferle et al., 2014b]. It is therefore necessary to carry out further investigations. Nevertheless, the tide board height can now be used, although with caution, to calibrate the KEP tide gauge to make its records acceptable for the Permanent Service for Mean Sea Level. Figure 10 shows a first comparison of the daily mean sea level from the tide gauge and a 10-day altimetry data set (Beckley, 2014).

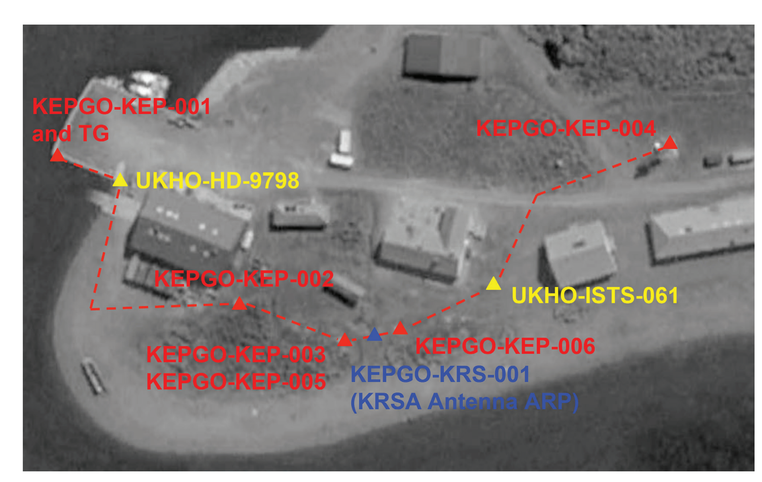

Figure 8: Benchmark network at KEP Research Station: tide gauge (TG) and KEP Geodetic Observatory (red), KRSA antenna and monument (blue) and UKHO (yellow). There are five benchmarks at the KRSA antenna and monument, only the one for the antenna ARP is shown. Imagery from Google Earth.

Table 3: Benchmark heights from levelling in 2014 and using KRSA as new height datum. dh and Height denote the levelled height differences and orthometric heights, and SD and H.SD the associated standard deviations (1-σ, no error in height of KRSA assumed).

Benchmark	dh [m]	SD [m]	Height [m]	H. SD [m]
KEPGO-KEP-004			2.9947	0.0004
UKHO-ISTS-061	-0.6851	0.0001	2.3096	0.0004
KEPGO-KEP-005	0.3251	0.0001	2.6347	0.0003
KEPGO-KRS-001	2.2626	0.0003	4.8973	
KEPGO-KEP-006	-0.6307	0.0003	2.0041	0.0004
KEPGO-KEP-002	0.0431	0.0002	2.0472	0.0005
UKHO-HD-9798	-1.4728	0.0001	0.5744	0.0005
KEPGO-KEP-001	-0.0242	0.0002	0.5502	0.0005
Tide Board	-1.1623	0.0006	-0.6121	0.0008

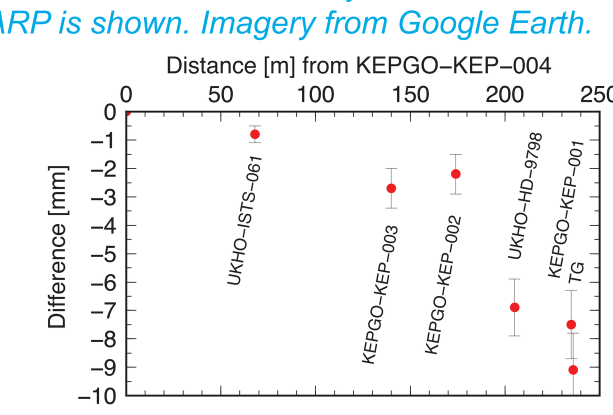

Figure 9: Height differences for benchmarks observed during the 2013 and 2014 levelling campaigns. Analysis assumes KEPGO-KEP-004 has been stable over this period. Uncertainties are 1-σ.

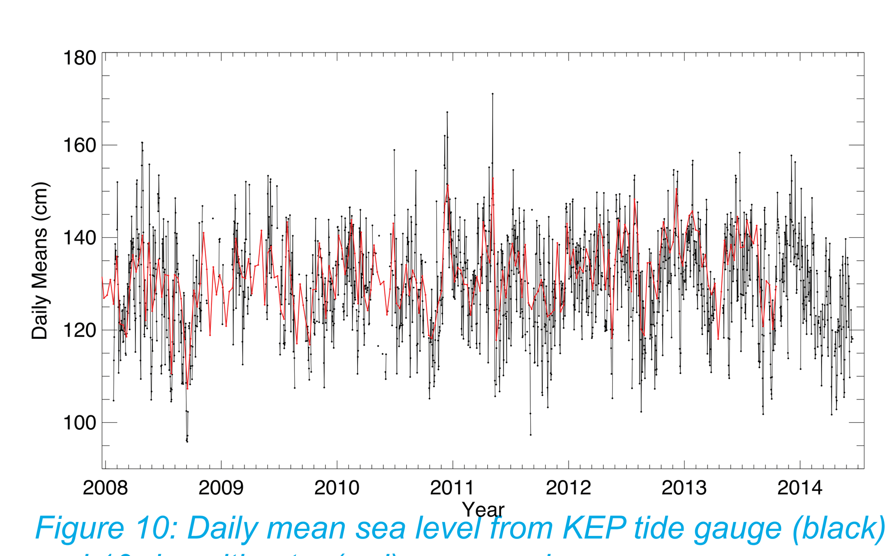

Figure 10: Daily mean sea level from KEP tide gauge (black) and 10-day altimetry (red) compared.

Conclusions

The new King Edward Point Geodetic Observatory, its continuous GNSS stations and their benchmark networks have been introduced. Together these link the tide gauge via the GNSS stations to the International Terrestrial Reference Frame and allow precise stability monitoring of monumentation and the area at KEP Research Station. A new approach to fuse the GOCO05S and EGM2008 gravity models to provide a Combined model was implemented. This model is believed to provide better coverage for this undersampled region in the South Atlantic Ocean but gives values 24 cm lower than EGM2008. Using this model a new height datum was defined which introduced a datum shift of -73 cm with respect to the UKHO one. The leveling campaigns in 2013 and 2014 indicate that 7-9 mm of subsidence may have occurred near the tide gauge over that period. Although a preliminary calibration of the tide gauge is possible, these findings indicate that more investigations are necessary.

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