INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS
INTERNATIONAL ASSOCIATION OF GEODESY

# Report of the Geodetic Works in South Africa for the Period from January 2007 to December 2010

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# Review of recent research and activities in geodesy in South Africa: 2007 - 2010

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## Introduction

This paper gives a brief review of activities and research results of South African institutes with activities relating to the International Association of Geodesy (IAG) during the quadrennium 2007-2010. The report forms part of the South African National Report to the International Union of Geodesy and Geophysics (IUGG) for presentation at the IUGG General Assembly to be held in Melbourne, Australia, during July 2011. South African institutions actively involved in IAG-related activities during the last four years included: Division of Geomatics, University of Cape Town (www.geomatics.uct.ac.za); Hartebeesthoek Radio Astronomy Observatory (HartRAO, http://www.hartrao.ac.za), National Research Foundation (NRF), Hartebeesthoek; Chief Directorate: National Geo-spatial Information, Department of Rural Development and Land Reform (www.ngi.gov.za) , Cape Town.

## The South African geodetic community

The South African geodetic community is relatively small and consists of about 10 geodesists, geophysicists and engineers who are involved in the activities of the IAG. Due to the size of the community, the IAG is not formally organized in South Africa. At a meeting of the South African National Committee for the IUGG in 30 March 2010 concern was expressed at the paucity and calibre of young researchers in the disciplines of geodesy and geophysics. Most of the researchers in these fields are of mature age and many will be retiring over the next five to ten years. The number of individuals beginning postgraduate studies is small, and a significant number of these, while being good MSc students, do not progress further to take up PhD studies. Although the committee has no formal figures to support this claim, we believe that the potential exists for a crisis in research in geodesy and geophysics within the next ten years.

Part of the problem is the small pool from which to draw potential researchers. I also believe that the limited career opportunities needs to be addressed. The number of undergraduate students taking geomatics and geology (from which most researchers in these disciplines are drawn) is small and diminishing. Most graduates from this small pool are attracted into industry and very few move forward into research. Members of the committee and their colleagues are doing their best, via schools and public outreach programmes, to enlarge the pool and to encourage graduates to study further.

# A. Commission 1: Reference Frames

## A.1. Establishment, maintenance, improvement of the geodetic reference frames.

**HRAO** has commenced with a project to derive a velocity field map over the African continent using data from Global Navigation Satellite Systems (GNSS) stations and coordinates as determined in the International Terrestrial Reference Frame (ITRF). Such a velocity field map will contribute towards a better understanding of the current intercontinental sub-plate movement and will therefore support the future establishment and maintenance of a unified geodetic reference frame for Africa. This work will be incorporated into the African Geodetic Reference Frame (AFREF) project as supported at HartRAO; it will entail densification of the GNSS network in Africa, data processing, archiving, GNSS station metadata log files maintenance and development of a software system for managing these activities. Data will be processed with the GAMIT GPS software package and estimated parameters will be utilised to describe crustal motion as a function of time to enable the development of datum transformation parameters for different countries on the African continent.

The active GNSS network, TrigNet, continued to expand from 43 stations in 2007 to 58 stations in 2011. Whereas only 29 stations were configured to provide both real time services and post processing product in 2007 all 58 station now provide the full set of real time and post processing services and products. Three clusters of stations with an inter-station spacing of between 70km and 90km have been established in Gauteng, Kwa-Zulu Natal and the Western Cape to provide networked RTK solutions. (see Figure 1) A networked DGPS service is available throughout the country. The co-ordinates of all stations are updated from time to time to cater for plate motions. TrigNet is currently based on ITRF 2005 (epoch 2010.03). South Africa has long been considered to be on a stable portion of the Nubian plate (Malservisi et al, 2009) and the positions between TrigNet stations remains relatively consistent.

Co-operation with the Hermanus Magnetic Observatory (now South African National Space Agency (SANSA) – Space Science) continues with space weather research being undertaken by that organization using TrigNet data as one of the fundamental data sets. Work has commenced in co-operation with the South African Weather Service (SAWS), NOAA Earth System Research Laboratory and the University of California San Diego to install a system for the estimation of precipitable water vapour using TrigNet data and surface meteorological data provided by SAWS. It is planned that this service will become fully operation in June 2011.

TrigNet data is being streamed for various projects and programmes outside of South Africa such as the IGS Real Time Working Group, NOAA's GPS Meteorological programme and the UCAR Constellation Observing System for Meteorology, Ionosphere & Climate (COSMIC) programme among others.

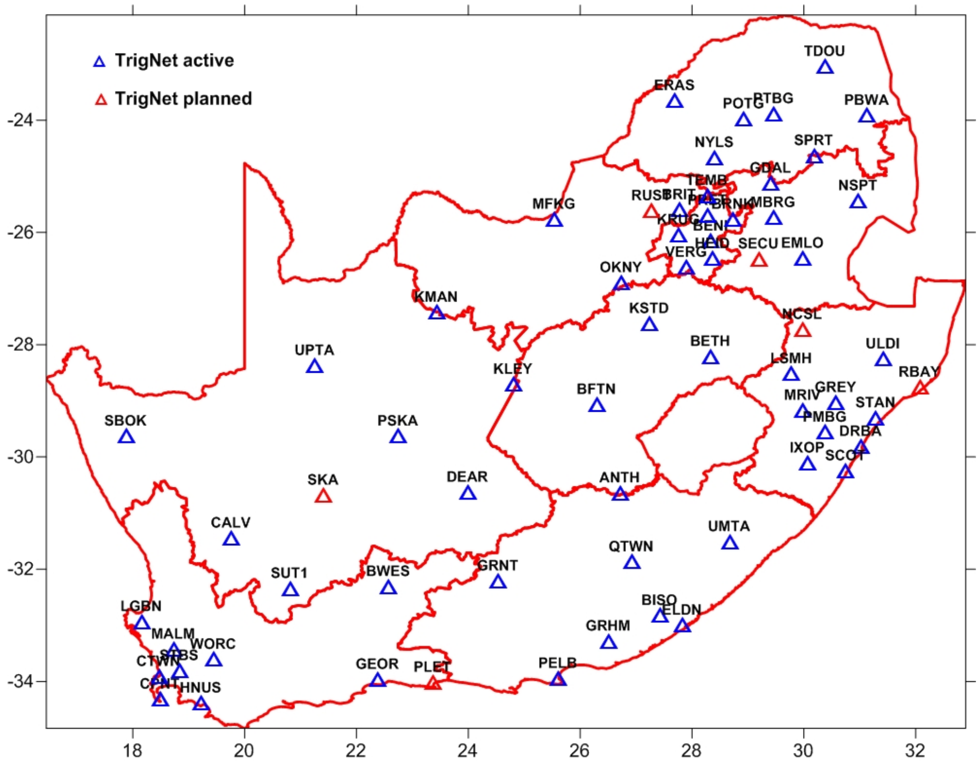


Figure 1 Distribution of TrigNet Stations as at February 2011

**Commission 1 Sub-Commission 1.3d Africa**

The NGI has been closely involved with the UNECA CODIST project to unify the geodetic reference frames in Africa for a number of years. This project, known as the Africa Reference Frame Project (AFREF), falls within the activities of the IAG Commission 1 Sub-Commission 1.3d Africa which is represented on the AFREF Steering Committee.

In 2010, the NGI established an AFREF Operational Data Centre to archive data from continuously operating GNSS base stations in Africa. To date, the ODC is able to access data from 60+ stations but, on average, data from less than 50% of these stations is being archived daily.

A Call for Participation is in preparation for the processing of data from the ODC publically available stations and includes a strong emphasis on capacity building and technology transfer with African National Mapping Agencies and Universities.

A concerted effort is being made to collaborate with other Earth Science programmes within Africa to co-locate equipment such as GNSS receivers, Meteorological sensors and seismometers. Such programmes are the Africa Array (Seismology), AMMA-GPS (Meteorology) and IHY/SCINDA (Space weather) programmes.

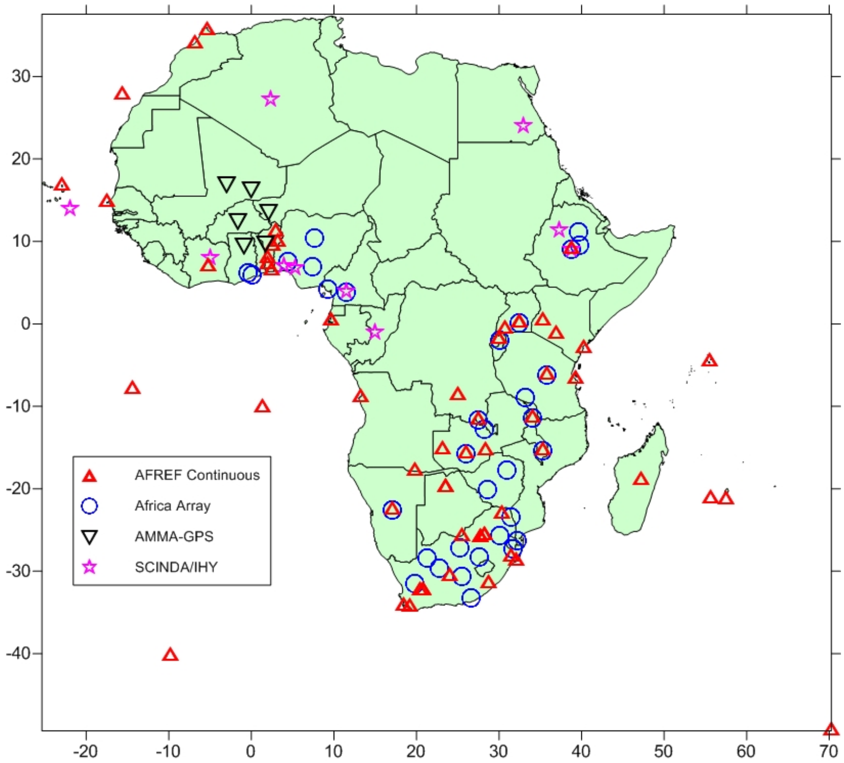

Figure 2 Potential co-location of sensors for Earth Observations

## A.2. International collaboration for the definition and deployment of networks of terrestrially-based space geodetic observatories.

HartRAO has commenced with the development of a Satellite and Lunar Laser Ranging system, based on an ex France (Observatoire de la Cote D'Azur) 1 m telescope. The system will be developed at HartRAO and will after completion be moved to an appropriate site where atmospheric conditions are more conducive for lunar laser ranging. Such a site has been identified at Matjiesfontein, in the semi-desert region of the Karoo. A 200 mJ laser will be developed in collaboration with NASA. The S/LLR will enhance and improve data capture from the southern hemisphere, supporting the International Laser Ranging Service (ILRS) and its users. It is envisaged that Matjiesfontein will be equipped with other geodetic and geophysical equipment. Towards this end a GNSS station was installed during December 2009.

## A.3. Collaboration with space geodesy/reference frame related international services, agencies and organizations.

**HartRAO** has continued support of the IAG services by participating in the IVS, ILRS, DORIS, IGS and IERS. Support has been given to the GGOS concept, and proposals have been developed to initiate the development of new fundamental stations at Klerefontein (Northern Cape) and Matjiesfontein (Western Cape). Proposals have been submitted towards obtaining one or more VLBI2010 GGOS compatible radio telescopes.

**NGI** is also involved with the United Nations Economic Commission for Africa's (UNECA) Committee for Development Information Science and Technology (CODIST) project to unify the geodetic reference frames of Africa AFREF.

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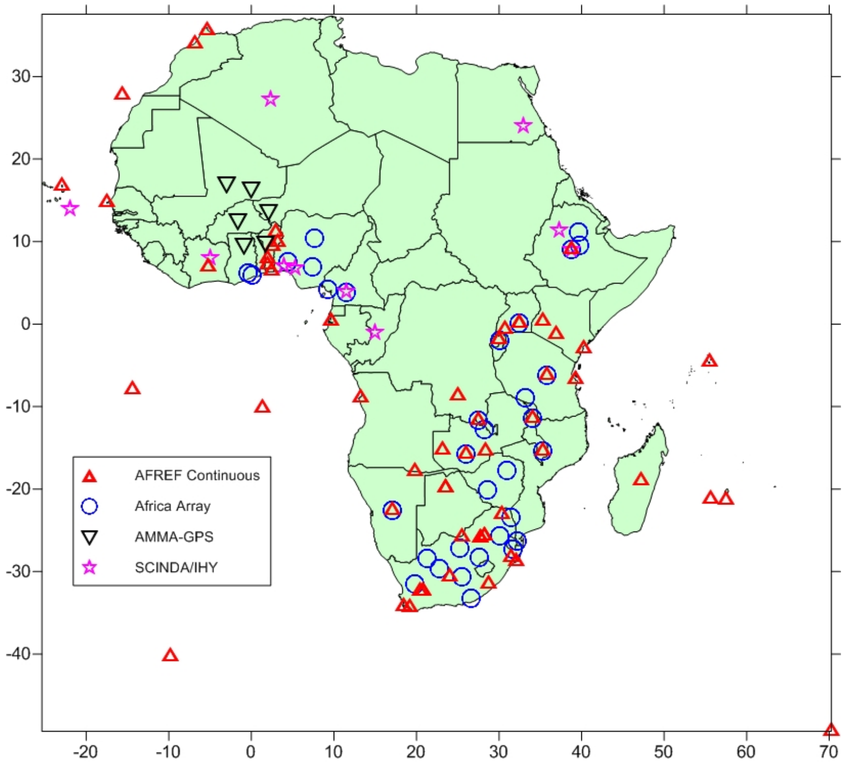

Figure 3  Potential co-location of sensors for Earth Observations

# B. Commission 2: Gravity Field

## B.1. Gravity field modeling.

Hartebeesthoek Radio Astronomy Observatory (HartRAO) has developed software to evaluate Global Gravity Models (GGMs) using satellite laser ranging data. Precise orbit determination of satellites tracked by the global network of the International Laser Ranging Service (ILRS) stations is an important research focus with applications in geodesy, geodynamics, hydrology, lunar studies as well as other recent satellite altimeter missions. The orbits of such low earth orbiters are often affected by many forces e.g., gravitational and non-gravitational forces, which must be taken into account during routine SLR data analysis.

The research (part of a PhD project) focuses on assessing the accuracy of a number of gravity field models that have been developed over the last two decades by use of SLR data for precise orbit determination and geophysical parameter recovery. For this purpose, the SLR analysis software developed at HartRAO is utilised with the analysis options following the ILRS recommendations. Current results show that the recently developed gravity field models have higher accuracy compared to older models. This is clearly indicated by a decrease (e.g., by a factor of two over a 15 year period) in the root mean square (RMS) of the observed minus computed residuals of the SLR range measurements between the SLR tracking stations and satellites LAGEOS 1 and 2).

The accuracy of most of the latest gravity field models in terms of precise orbit determination is currently at cm level. Improvement in Earth gravity field modelling is anticipated as quantitative and qualitative data (in particular from low earth orbit satellites) become available in the future. Such expectations require that the accuracy and precision of existing gravity field models be assessed. The validation of gravity field models in terms of satellite orbit determination is often based on the difference between the observed and computed range. The resulting range residuals are considered an important index when determining the accuracy of the gravity models and hence the satellite orbits.

## B.2. Satellite orbit modeling and determination.

Using HartRAO's advanced precise orbit determination software; Parameterised Post Newtonian (PPN) parameters $\gamma$ and $\beta$ (which should equal unity if general relativity is valid) were estimated through the analyses of four years of LAGEOS 1 and LAGEOS 2 data. To reduce the chance of possible imprinting of general relativistic effects which could be contained in the Earth gravity model used, several low order spherical harmonic coefficients were solved in the orbit estimation and propagation process. After convergence were reached, the solved PPN parameters $\gamma$ and $\beta$ were kept fixed at their solved values and scaling coefficients were introduced to explore the possibility of open parameter space in the accelerations due to the Schwarzschild field, frame dragging and de Sitter (geodesic) precession. It was found that some parameter space were available in the radial acceleration component, which could be taken up by including post Post-Newtonian components of general relativity, or it could be due to some other radial acceleration component that was not adequately modelled. The inclusion of scale coefficients in the least-squares process proved to be a valuable tool in evaluating the solutions for $\gamma$ and $\beta$.

## B.3. Geoid determination.

Research at the **Division of Geomatics at the University of Cape Town** has concentrated on developing software for geoid determination, and then applying this software to the computation of regional and continental geoids. Special attention has been paid to the refinement of 2D spherical convolution, the contribution of the Molodensky G1 term and the influence of changing the geopotential reference model.

A revised geoid model for the continent of Africa was completed in 2007, using as a basis the Eigen GL04C geopotential field, supplemented with regional gravity data, the KMS02 marine gravity data set, and the SRTM DEM. This model was tested using GPS/levelling data from South Africa and Algeria. For the 62 points in South Africa a RMS agreement of 17cm was achieved, while for the 14 points in Algeria the RMS agreement was 26cm. This represents a slight improvement over the AGP2003 model, but a significant improvement over EGM96.

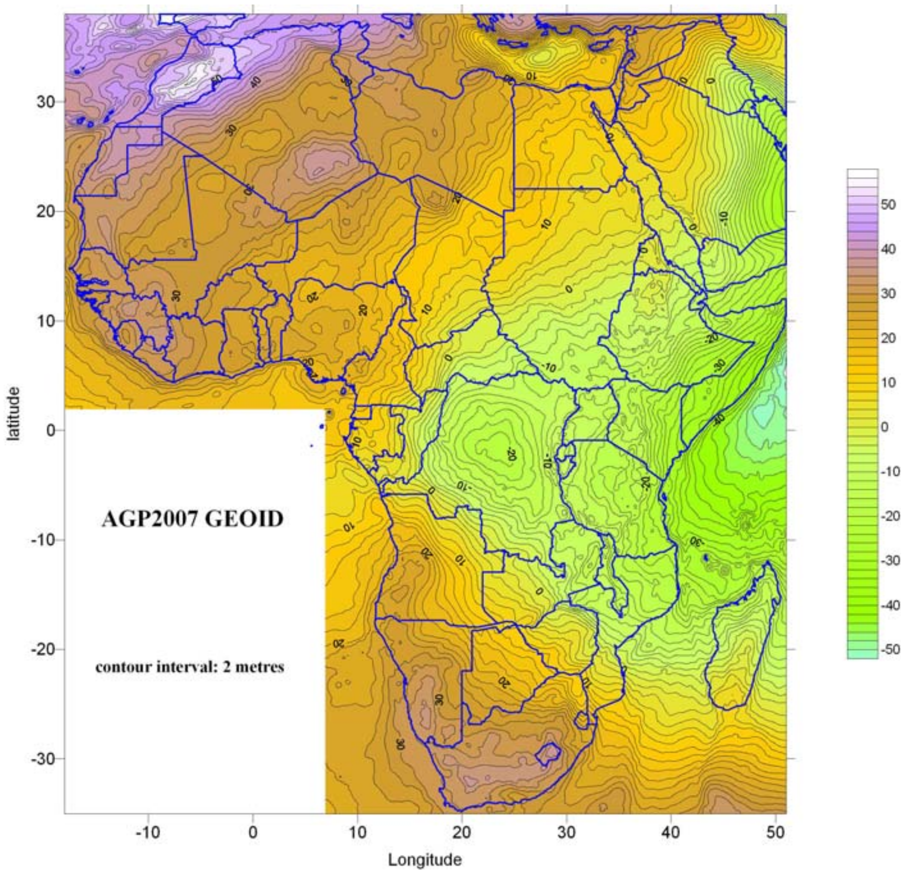


**Figure 2.1: AGP2007 Geoid model for Africa**

The Division of Geomatics also participated in an evaluation of the EGM2008 geopotential model, as part of an international working group. Significant differences (up to 5m) exist between the EGM2008 and AGP2007 geoid models. Most of these differences exist in areas where there are no terrestrial gravity data, and may be due to differences in the approaches used to fill in these gaps. A new set of GPS/levelling data for South Africa (described below) were used to assess the accuracy of EGM2008. The RMS discrepancy at the 79 data points used is 17cm for EGM2008, 24cm for AGP2007, and 35cm for EGM96.

The Division of Geomatics at the University of Cape Town and the Chief Directorate: National Geospatial Information of the Department of Rural Development and Land Reform jointly produced a new hybrid geoid model for South Africa - SAGEOID10. This has been adopted as the official geoid model for South Africa. The model uses a combination of a precise gravimetric geoid, and 118 point geoidal heights derived from GNSS measurements at benchmarks of the precise levelling network. The gravimetric geoid is based upon the EGM2008 geoid model (to degree 360), supplemented by regional gravity data and a G1 correction term. The point geoidal heights make use of a special campaign to produce accurate ellipsoidal heights (WGS84 ellipsoid) at the precise levelling benchmarks. The GNSS measurements make use of the TrigNet base stations, with reference co-ordinates fixed ITRF2005 (2010.06) values.

The combination of the two data sets involved warping the gravimetric geoid to fit the GNSS-derived geoidal heights at the 118 benchmarks. The correction surface was fitted to the data with a precision of 6mm. Internal and external validation of the hybrid model shows that an accuracy of 7cm can be expected in using this model to convert GNSS-derived ellipsoidal heights to height above the South African Land Levelling Datum.

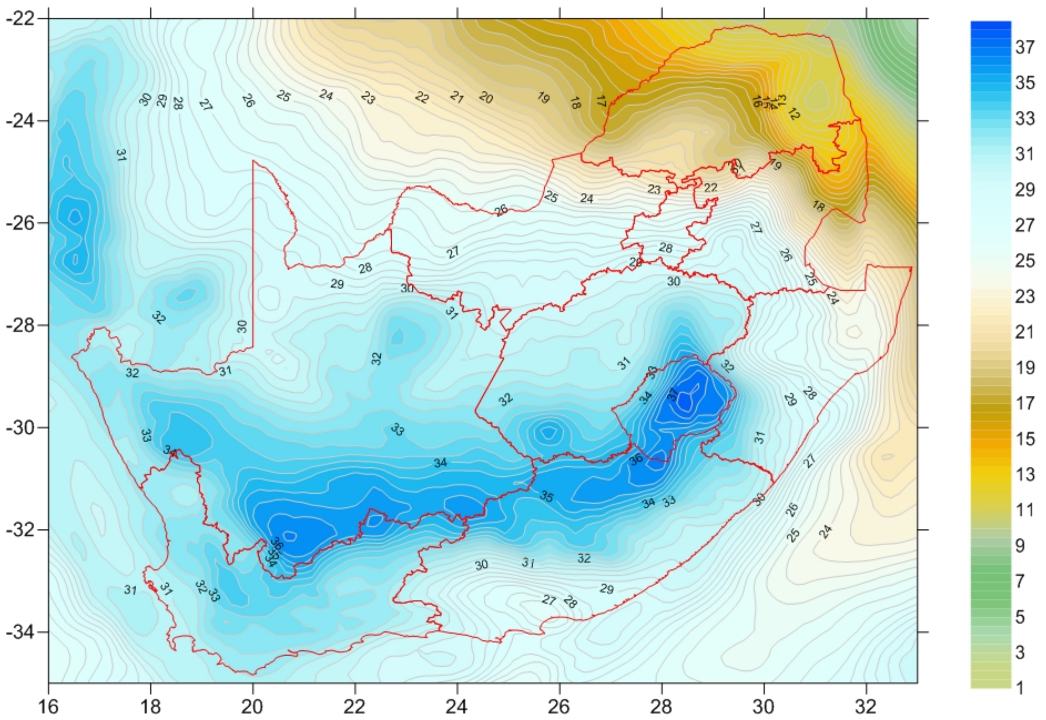

**Figure 2.2: South African Geoid 2010**

## B.4. Time-variable gravity field.

Apart from life loss and damages which earthquakes cause, their signature in the collected data either seismic and/or gravity enables us to define their location and dislocation (i.e., geometric parameters), time of occurrence, and magnitude. In addition, the Earth's interior physical parameters, such as density profile and anelasticity can be defined. Gravity data contribute additional knowledge about the Earth's interior through careful analyses of superconducting gravimeter (SG) records particularly after strong earthquakes. In this paper, SG data recorded after the Sumatra–Andaman earthquake in December 26, 2004 at eight SG stations, are used to investigate the properties of the long-period seismic modes: their frequencies, amplitudes, and quality factors. These parameters are estimated very precisely in this study.

# C. Commission 3: Earth Rotation and Geodynamics

## C.1. Tectonics and Crustal Deformation.

A new geodetic-quality Global Navigation Satellite Systems (GNSS) receiver (Topcon GB1000) has been installed by HartRAO at a carefully-selected location near Willowmore, to begin measuring potential crustal motion over the Cape Isostatic Anomaly (CIA). This anomaly is thought to portray the remainder of a deep root to the once topographically-higher Cape Fold Belt mountains. The low-density root is expected to experience considerable upward buoyancy relative to the surrounding more-dense lithosphere, generating stresses in the upper crust. Where pre-existing deep-seated lines of weakness in the crust already occur, for example the Kango-Baviaanskloof-Coega fault system along the southern margin of the anomaly, the mainly vertical stress is likely to be released episodically, generating both small and large earthquakes.

Local palaeoseismic investigations have indicated that the eastern part of the Kango fault segment, between De Rust and the Baviaanskloof, was ruptured by normal faulting at the start of the Holocene. Stress loading along strike, on the adjacent Baviaanskloof-Coega fault segments, and also on the nearby southern Kouga fault, is considered likely. Seismicity in the Eastern Cape is rare, but some recent small events plot directly on the segment boundary between the ruptured Kango fault and Baviaanskloof and Kouga faults. Since the CIA is the arguably the most local crustal-scale tectonic driver acting on these faults, it was decided to test if the anomaly is stable, or slowly warping the crust inland of the coast. Data collected by the new GPS station will be processed using a double-differencing technique within a network of local stations. These are located at Sutherland, Matjiesfontein, Hamburg, Simonstown, Richards Bay and HartRAO. Several stations located in Africa, and on other continents, will be included. It is estimated that millimetre accuracy of the north, east and vertical vector components will be available after about five years. Monitoring of the new geodetic station is expected to continue for several decades, since the rate of uplift over the gravity anomaly is likely very low. It is hoped that the geodetic results will contribute towards a better understanding of neotectonic processes in the south-eastern Cape, and ultimately be included in hazard analysis of existing and planned critical structures in the region.

## C.2. Sea surface topography and sea level changes.

HartRAO installed a GNSS receiver at Hamburg in the Eastern Cape during April 2010. The GNSS station is completely stand-alone; power is provided through a solar panel, charge regulator and battery bank, whereas communications for data download are done via a cell-phone data link. Briefly, the purpose of the station is to help quantify long-term variability in the Agulhas Current via improved Coastal Altimetry in combination with data from a state-of-the-art full-depth current moorings array deployed by the University of Miami, off the Eastern Cape coast. Captured GNSS data will help to model the troposphere, which will provide corrections for the area and will be included in the processing of altimetry data obtained by satellites. These satellites (Topex and Jason) pass over Hamburg, as well as over the array of current moorings. Topes and Jason were also tracked by the Satellite Laser Ranger at HartRAO.

Additional uses of the GNSS data include densification of the southern African GNSS network (useful for surveying work), ionospheric modelling and crustal stability studies. Understanding how climate change affects the oceans is very important, as the oceans play a major part in the energy and mass distribution on Earth. The Agulhas current affects the southern African climate, is a regulator of global climate change, so its variability will directly impact on farming and other economic activities. It is only through understanding the causes and processes which change our environment, that we can adopt alternatives and remedial strategies which will ensure continued productivity and minimal adverse impact on economic activities. This installation was done by HartRAO in collaboration with Dr. Paolo Cipollini (National Oceanographic Centre, Southampton), Dr. Luisa Bastos (University of Porto) and Dr. Lisa Beal (University of Miami). Recent modelling studies which are supported by satellite and other observations, suggest Agulhas Leakage (the transport of warm and salty Indian Ocean waters into the Atlantic Ocean ) is increasing as a result of changes in atmospheric pressure and shifts in winds resulting from global warming, resulting in more upper-layer salt export into the North Atlantic. The Agulhas Leakage is the main source of heat and salt for the surface branch of the Atlantic Meridional Overturning Circulation (AMOC) and therefore affects its stability.

# D. Commission 4: Positioning and Applications

## D.1. Interferometric laser and radar applications (e.g., Synthetic Aperture Radar).

HartRAO installed corner cube reflectors in Antarctica during December to January 2008/2009 to support the utilisation of TerraSAR-X radar images. The reflectors were installed in the Vesleskarvet region, mostly on mountains and were tied to the ITRF with GNSS receivers. Consequently the radar images could be geo-referenced as the reflectors appear as bright pixels in the radar images. Therefore translation, rotation and scaling could be done.

## D.2. Atmospheric investigations using space geodetic techniques.

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## D.3. Applications of geodetic positioning using three dimensional geodetic networks (passive and active networks), including monitoring of deformations.

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## D.4. Applications of geodesy to engineering.

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