White Paper towards the establishment of the International Institute for Space Geodesy and Earth Observation (IISGEO)

IISGEO Working Group

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• Introduction and Executive Summary

The international Space Geodesy community faces major instrumental and network changes within the next decade. Societal relevant issues such as natural hazards, climate change and space engineering requirements demand an increase in performance from the global geodetic networks. The interdisciplinary nature of Space Geodesy plays a major role in improving our understanding of the causes and the effects of man's contribution to global climate change and the mitigation of natural hazards.

The different space geodesy techniques need to meet requirements of the Global Geodetic Observing System (GGOS) (http://www.ggos.org/) project of the International Association of Geodesy (IAG) and the science driven geodetic objectives as set out by the NASA Solid Earth Science Working Group Report. All the space geodetic techniques face major challenges; the global networks need to be re-equipped and its geometric distribution improved.

In order to meet current and new requirements in the Space Geodesy arena, South Africa should consider building a new Space Geodesy facility, which could be an outstation of HartRAO or even a new National Facility. Failing this, we will gradually fall behind and will eventually be unable to participate at the required level demanded for a "Fiducial Station". This white paper sketches the background and rationale for the new station and proposes a strategy to enable South Africa to remain and improve its contributions and participation in the field of Space Geodesy.

We are currently evaluating Matjiesfontein as a possible site for a new space geodesy observatory (dubbed International Space Geodesy and Earth Observation Institute, IISGEO), as Matjiesfontein meets requirements of clear skies, power, water, and accessibility. This site should eventually house a facility which will be a new Fundamental Station for South Africa, hosting all the main Space Geodesy techniques (VLBI, SLR/LLR, GPS DORIS) as well as complimentary scientific equipment. All these techniques are globally managed and steered by the IAG services (IVS, ILRS, IGS, IDS, IERS) and will operate within the framework of GGOS, which forms an important component of the Global Earth Observing System of Systems (GEOSS). The different space geodetic techniques have unique and overlapping properties. GPS is suitable for densification of the reference frames and dense scientific networks, SLR/LLR allows accurate determination of Earth scale, VLBI uniquely determines Earth orientation parameters in an inertial reference frame and DORIS provides continuous orbit determination. All of these techniques are accurate enough to provide station velocities and all of have unique scientific products. When combined, the benefits exceed the sum of the individual contributions; this leads to a strong interdependency between the techniques to support the large number of different uses and applications of the data and its consequent products.

The major support we have continually received from the international community over the last decades for space geodesy is directly related to the geographical advantage and institutional capacity provided by South Africa in terms of improving global network geometry and thus the scientific products from Space Geodesy. Continued participation of South Africa in these global networks is very valuable and internationally recognised as key to support capacity development in the SADC region. Our continued participation however, must be at an appropriate level; this level will soon be unreachable due to the continued development in this field and higher specifications set.

Higher specifications required by the scientific and user community include 1 mm accuracy on global baselines, continuous measurements for time series of station positions, Earth orientation parameters and less than 24 hr turnaround time for initial geodetic results.

These demands come at a time when most space geodesy facilities, including HartRAO, experience problems with ageing equipment such as radio antennas, satellite laser ranging (SLR) and GPS equipment. This is exacerbated by increased sky pollution, deteriorating radio frequency quiet environments, obsolete electronics and an increasing demand for very highly skilled technical and scientific staff.

During November 2006, a small workshop (sponsored by the NRF) was held at Matjiesfontein to discuss the future of Space Geodesy in South Africa. In general the local scientific community who uses or are potential users of Space Geodesy products or applications felt that such a new station would be beneficial and should be supported.

A follow-up workshop is being organised which will be held during 10-15 November 2007 at Matjiesfontein. This workshop will concentrate on activities during the intervening period, especially student projects and progress, scientific outcomes and presentations from these projects as well as short courses on specialised topics. It is envisaged that several foreign space geodesy institutes will be represented, including visitors from France and Saudi Arabia.

A short budget summary is provided on page 21, R22 M is required for the initial phase of the new station, which includes only the development of the S/LLR. Seed funding of R2 M has been allocated via the NRF STAF programme for the initial stages of S/LLR development and student training. The complete station (over a period of 10 years) will require a capital budget of R110 M.

• Background

– Vision/Mission

The vision and mission of IISGEO is closely tied to those of the IAG GGOS project. It also supports those of the Group on Earth Observations **(**GEO**).** GEO was established by a series of three ministerial-level summits and currently includes 66 member countries, the European Commission, and 46 participating organisations (including the IAG) working together to establish a Global Earth Observation System of Systems (GEOSS). The GEO vision is to realise a future wherein decisions and actions for the benefit of humankind are informed via coordinated, comprehensive and sustained Earth observations and information. During the next 10 years GEO will work with and build upon existing national, regional, and international systems to provide coordinated Earth observations from thousands of instruments worldwide, channelled into vital information for society.

Vision

IISGEO will operate different geodetic techniques and support complimentary instrumentation and projects, to ensure long-term monitoring of the geodetic observables and observables that support Earth observation across all disciplines. IISGEO will operate within the framework of GGOS to:

- aid the maintenance of a stable, accurate and global terrestrial reference frame
- support maintenance of the celestial reference frame
- monitor the Earth's kinematics and dynamics
- participate in high quality scientific research
- provide support to and participation in the services of the IAG
- contribute to the realisation of GEO/GEOSS
- provide capacity and a road to capacity building in space geodesy and related disciplines

IISGEO will contribute to Earth sciences and through a multi-disciplinary approach, be a bridge to other disciplines that can be supported through its techniques, data or unique infrastructures. Furthermore, IISGEO will provide a platform for scientists and students in the SADC region to participate at high level in international projects.

Mission

IISGEO will collect, archive and disseminate data to the global community via the IAG services and related data centres to support the fundamental fields of geodesy and related disciplines; will participate in scientific and technical research to further knowledge and discoveries in S&T and will participate in capacity building through tertiary education and other capacity building initiatives.

– IISGEO objectives

Objectives of IISGEO can be divided into four main categories:

- The establishment, maintenance and operation of instrumentation and infrastructure to support its vision and mission.
- Research and publication of research results.
- Capacity building in the SADC region through regional (SADC) and international collaboration.
- Capacity building through close links and interaction with tertiary educational institutions

– Capacity building and science awareness component

Closely linked to the development of the new station and its equipment will be the contribution of young scientists, engineers and students in other fields that will support the development of the new facility. It is envisaged that special bursaries be made available to support and facilitate post-graduate and post-doctoral training.

Matjiesfontein as a proposed site lends itself uniquely to a preferred destination for science awareness due to the fact that the town is situated at the corner of the triangle between SAAO (Sutherland) and Cape Town, on the main national road between Johannesburg and Cape Town. IISGEO will therefore be able to participate in the national drive to create awareness of science and technology in the minds and imaginations of young and old, stimulating the growth and interest in scientific endeavours. This science awareness component will thus support the need of the country that more young people should develop an interest in pursuing science and works towards S&T careers and study directions.

Special S&T EDU train

It has been proposed that as a major component of the IISGEO science awareness programme, the establishment of a special "Science and Technology Educational Train" be incorporated into the development of

IISGEO. This train will be based at Matjiesfontein where its educational content will be developed and alternated. Shunting of the train throughout South Africa as tag-on to existing cargo or passenger routes will allow this EDU train to visit remote schools throughout South Africa, bringing hands-on science experiments and demonstrations to thousands of young learners who otherwise will not be reached due to the remoteness of their schools. The basic concept is that five wagons will be utilised to create a travelling scientific activity, complete with activity centre, science demonstration laboratory, small astronomical observatory and on-board accommodation for the travelling train lecturers.

– The current state of global space geodesy: its products, customers, equipment and processes

All the space geodetic techniques produce products which are mutually supportive and linked in one way or another; the different techniques, the science and product rationale for each technique, are also not to be separated and combine to create unique products such as the International Terrestrial Reference Frame (ITRF) or the Celestial Reference Frame (CRF). Maintenance of the CRF, UT1-UTC and Earth orbital parameters is extremely important for optical and radio astronomy purposes. The science plans and rationale (as an explanation of the fundamental reasons for the funding an existence of the scientific field of astronomy) can therefore directly be used as the rationale for the existence of space geodesy networks. In addition, a multitude of additional applications are derived from the space geodetic data which have applications in satellite orbital management, Earth gravity field determination, ocean and land mass level monitoring, hazard mitigation and crustal dynamics.

The global networks consisting of VLBI, GNSS, SLR/LLR and DORIS equipment are operated and maintained by a large number of countries and institutions. Of these techniques, GNSS receivers are the easiest to proliferate as the equipment cost substantially less and is much less complicated to operate than e.g. SLR or VLBI equipment. The equipment form four networks in the space geodesy arena and each network (VLBI, GPS, SLR and DORIS) provides data, has analysis groups and specialised working groups within the services of the IAG (IVS, IGS, ILRS, IDS). This combination forms the organisational structures within which these networks operate. The distribution of stations within the networks is depicted in Figures 1 to 4. The distribution of DORIS stations is far more uniform than the other techniques at present.

IGS GNSS Network

Figure 1 depicts the IGS network of recently active hourly stations (http://igscb.jpl.nasa.gov/network/hourly.html). The IGS network, Data Centres, and Analysis Centres provide high-quality GPS data and data products (some of it in near real time) to meet the objectives of a wide range of scientific and engineering applications. HartRAO is an IGS Regional Data Centre, and provides GPS data to local and regional users.

These products include improvement and densification of the International Terrestrial Reference Frame (ITRF), crustal dynamics (plate tectonics, earth crust movement due to earthquakes), the monitoring of Earth rotation and variations in the liquid Earth (sea level, ice-sheets, etc.), scientific satellite orbit determinations, ionosphere monitoring (Total Electron Content maps), and determination of precipitable water vapour. Special projects such as TIGA (Tide Gauge at GPS) allows calibration of ocean level studies, which is important for global warming and long-term climatological studies. HartRAO has installed 2 TIGA stations (Richards Bay and Simons Town) with another in process at Marion Island.

The fact that GNSS receivers are (relatively) more affordable than the other space geodetic techniques allows a denser network and this facilitates projects such as the African Reference Frame (AFREF), which strives towards the unification and standardisation of a geodetic reference frame throughout Africa. This requires the densification of the ITRF at regional level, to allow countries in Africa to move from old geodetic datums to ITRF. HartRAO is involved in this project and has established and facilitated the installation of several GPS stations in Africa; this is an ongoing project and is a prime example of how scientific applications can be used to eventually benefit the man in the street. HartRAO is currently (in collaboration with Chief Directorate: Surveys and Mapping, the AFREF steering committee and University of the Beira Interior, Portugal) establishing itself as a regional analysis centre for AFREF and as an AFREF Data Centre. Through support from the NRF and Inkaba yeAfrica project (a multi-disciplinary earth-science project with Germany), several more GNSS stations will be installed in the SADC region this year.

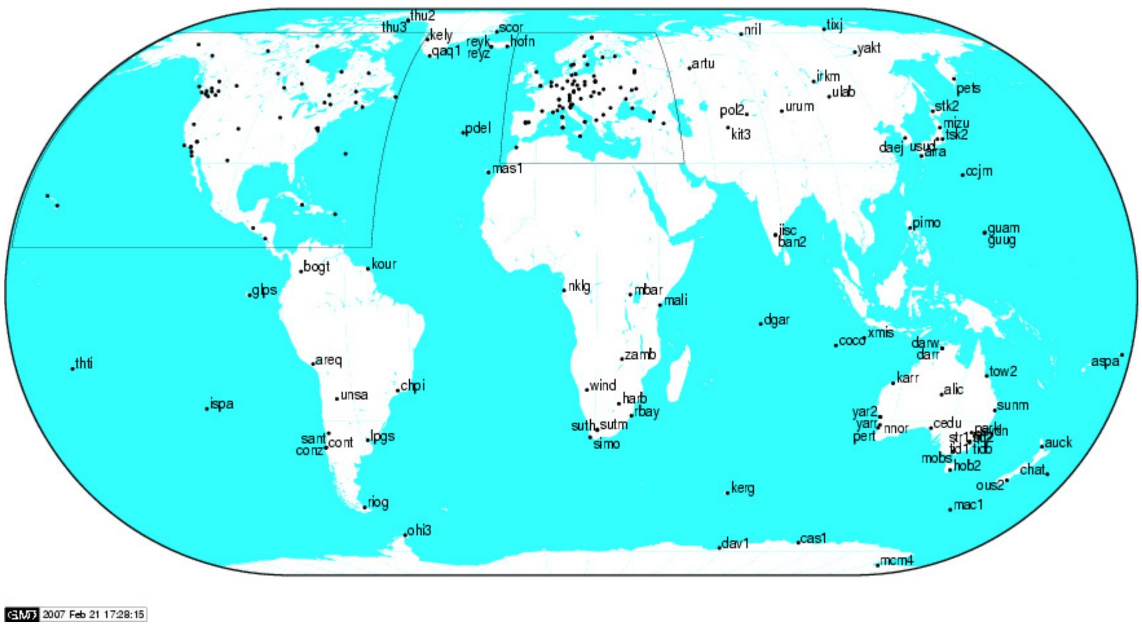

Figure 1. The IGS GNSS network of active (hourly) sites. During 2007 the HartRAO Space Geodesy Programme will install additional sites in the SADC region.

DORIS network

DORIS is a satellite tracking system developed for precise orbit determination and precise ground location (Tavernier et al. 2006). It is onboard several satellites (Jason-1, ENVISAT altimetric satellites and the remote sensing satellites SPOT-2, SPOT-4 and SPOT-5). The Doris system is based on the principle of the Doppler effect that causes the frequency of a wave to shift when a transmitter and receiver are in motion relative to one another. Figure 2 (http://ids.cls.fr/) shows the good geometry of the DORIS network. This system is an active, autonomous system and can practically be located anywhere where power is available. The receiver is on the satellite and the transmitters are ground beacons. The equipment on the ground does not have to be located where access to Internet is available (or there is no need for a satellite data link) as is required with the other techniques.

HartRAO has collocated a GPS system with the DORIS station at Marion Island and with the support of several international institutions plan to install a tide gauge (August 2007) there as part of the Indian Ocean Tsunami Early Warning System. This combination will make Marion Island an important node in the GEO system and will provide important information to this EWS and the oceanographic community. It is envisaged that a DORIS system will be installed at the IISGEO site, as it will add greatly to collocation and technique dependent inter-comparisons.

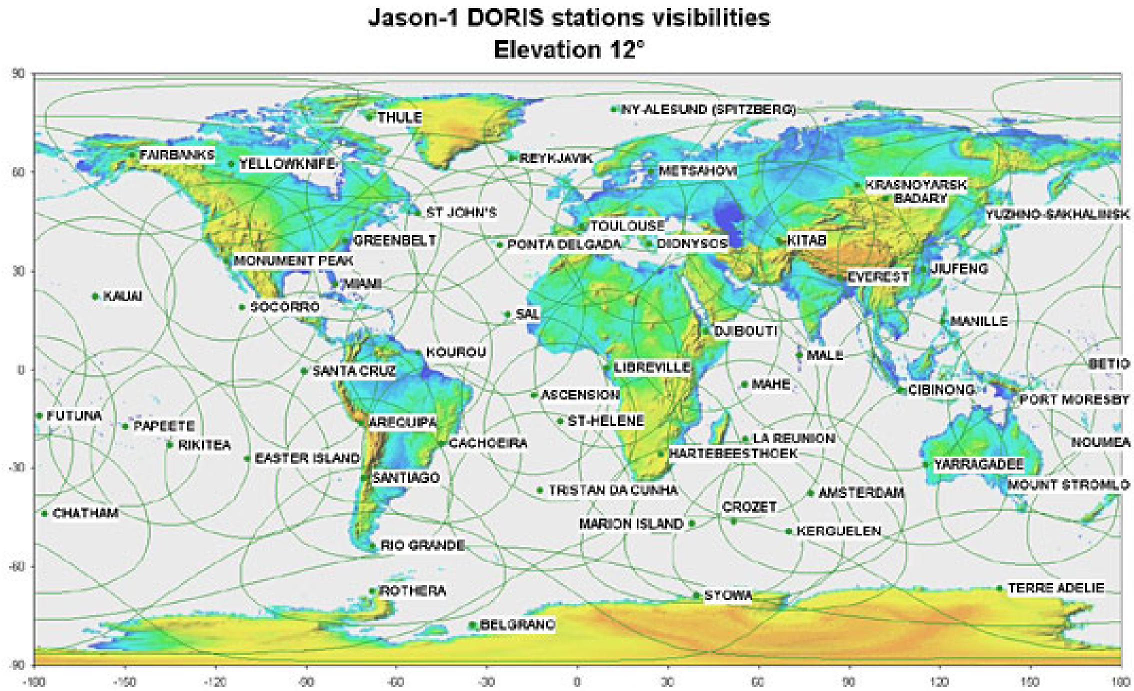

Figure 2. The DORIS network is well distributed globally in comparison to the other SG techniques.

IVS network

The International VLBI Service for Geodesy and Astrometry (IVS) (see http://ivscc.gsfc.nasa.gov) is a Service of the International Association of Geodesy (IAG), International Astronomical Union (IAU) and of the Federation of Astronomical and Geophysical Data Analysis Services (FAGS).

The objectives of the IVS are (Schlüter and Vandenberg, 2002; Schlüter et al. 2002):

- to provide a service to support geodetic, geophysical and astrometric research and operational activities,
- to promote research and development activities in all aspects of the geodetic and astrometric VLBI technique,
- to interact with the community of users of VLBI products and to integrate VLBI into a global Earth observing system.

The IVS is responsible for the delivery of Earth Orientation Parameters (EOPs), Terrestrial Reference Frame (TRF), Celestial Reference Frame (CRF) and data used for other applications.

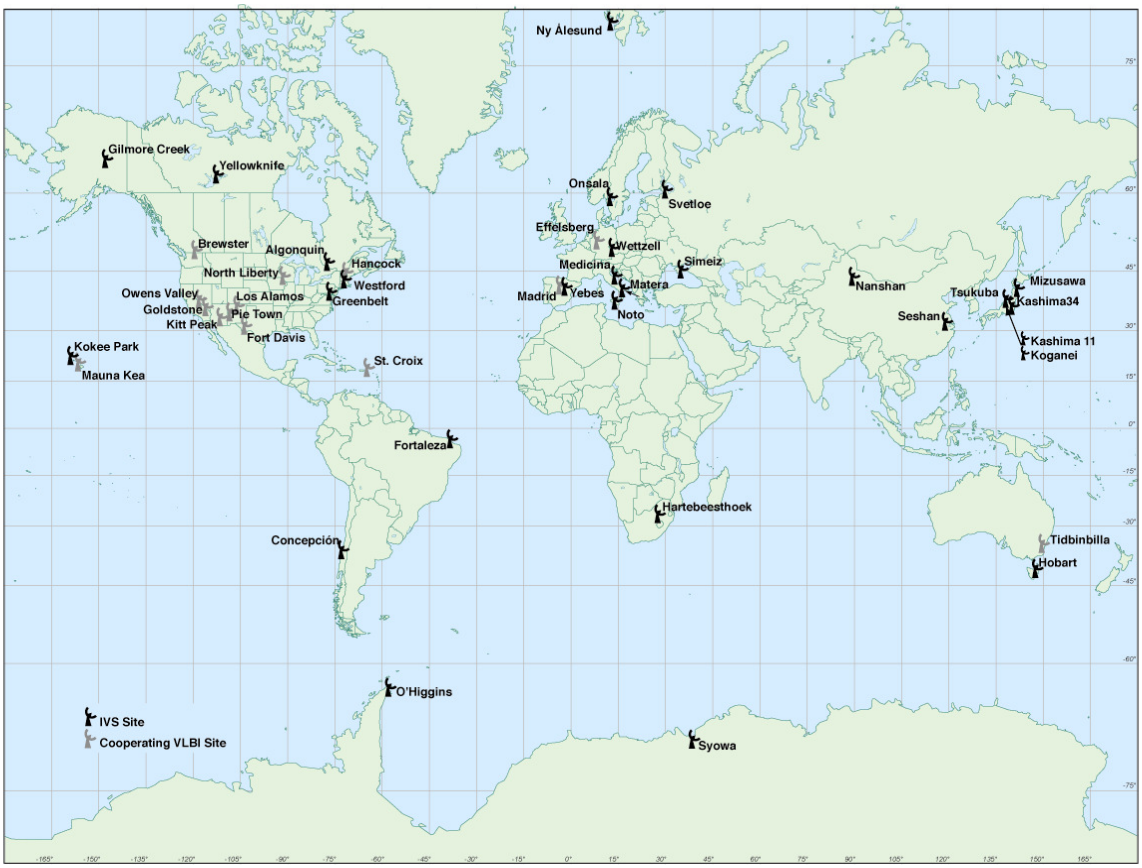

Figure 3. The IVS network indicating the sparse population of geodetic VLBI antennas.

The distribution of IVS stations (Figure 3) is not homogeneous as most stations are located in the northern hemisphere with clusters in Europe, North America and Japan. Furthermore, many stations are not dedicated Geodetic VLBI antennas, but share time with radio astronomy (at HartRAO about 15% of the telescope time is dedicated to space geodesy).

Following Schlüter and Vandenberg, 2002, the 2nd IVS General Meeting held in Tsukuba/Japan in February 2002 led to the following resolution:

1) that geodetic and astrometric VLBI is fundamental for the establishment and maintenance of the ICRF and contributes extensively to the generation of the ITRF, and
2) that geodetic VLBI plays an essential role in geodesy and astrometry due to its uniqueness in observing the complete set of Earth orientation parameters (EOPs) which describes the transformation between the ICRF and ITRF stable over a time span longer than a few days, and
3) that providing the reference frames and EOPs consistent over decades on the highest accuracy level will be a challenging role for IVS,

and in considering the final report of the IVS Working Group 2 for Product Specifications and Observing Programs, recommends that all IVS components should concentrate their effort and resources to accomplish the following objectives:

- significant improvements of the accuracy of VLBI products
- shorter time delay from observation to availability of results
- continuous temporal coverage by VLBI sessions.

This resolution is not unlike the sentiments of the other SG networks, where an improvement in accuracy, coverage and low data latency is required. VLBI2010, as an objective of the IVS community will strive to meet these objectives through modernizing equipment, construction and development of new stations and the utilisation of high-speed networking.

During 2001 IVS Working Group 2 reviewed the IVS products and the corresponding observing programs and in an interpretation by Schlüter et al. (poster) the required steps to improve the current IVS products would include:

- overcome unbalanced network configuration
- increase observing capabilities,
- reduce technical failures of old components (antennas),
- avoid radio frequency interference,
- obtain compatibility in technology, in particular in data recording,
- develop dynamical scheduling to make best use of observation resources,
- speed up data transmission,
- reduce latency between observations and product provision,
- reduce systematic errors of the instrumentation,
- reduce systematic errors caused by the analytical and numerical models,
- increase automation in the data handling process from the correlator to the final analysis,
- support combination with other techniques.

VLBI2010 hopes to address these steps. In a poster presentation by Niell et al. which reflects the efforts of IVS Working Group 3, consideration is given to certain performance enhancing strategies, which required a complete examination of all aspects of geodetic VLBI, including equipment, processes, and observational strategies. The results of this examination have led WG3 to make a set of recommendations, which are listed as:

Design a new observing system based on small antennas

- automated and unattended operation
- small antennas (10-12 m diameter) that are fast-moving and mechanically reliable
- economic replication of antennas
- broad, continuous observing frequency range (1-14 GHz)
    - includes current S-band and X-band frequencies for backwards compatibility
    - allows much more agility to avoid RFI
    - allows more bandwidth to significantly improve delay measurement precision

The new network will include some components of the existing network

- update the best of the existing large antennas with the new small-antenna system for compatibility
    - allows co-observations to preserve continuity with the historical record
    - allows improvement of the CRF measurements made primarily by the large antennas

VLBI2010 is slowly turning into reality as several role players are already involved in the conceptualisation, detail design and construction of the various components which will be required for the new system.

ILRS network

The primary mission of the ILRS (Pearlman et al., 2002) as stated in the organisation's Terms of Reference is "*to support, through satellite and lunar laser tracking data and related products, geodetic and geophysical research activities.*" The global network (Figure 4) is very well presented in Europe, but in Africa only two stations are listed; HartRAO (operational) and Helwan in Egypt (not operational at the moment). Furthermore only about twenty stations contribute high quality and sufficient quantity of data to form a sub-network of Operational Stations, the others are termed Associate Stations. HartRAO (Moblas6) is an operational station, and serves a very important geographical role by providing data in an otherwise very empty area.

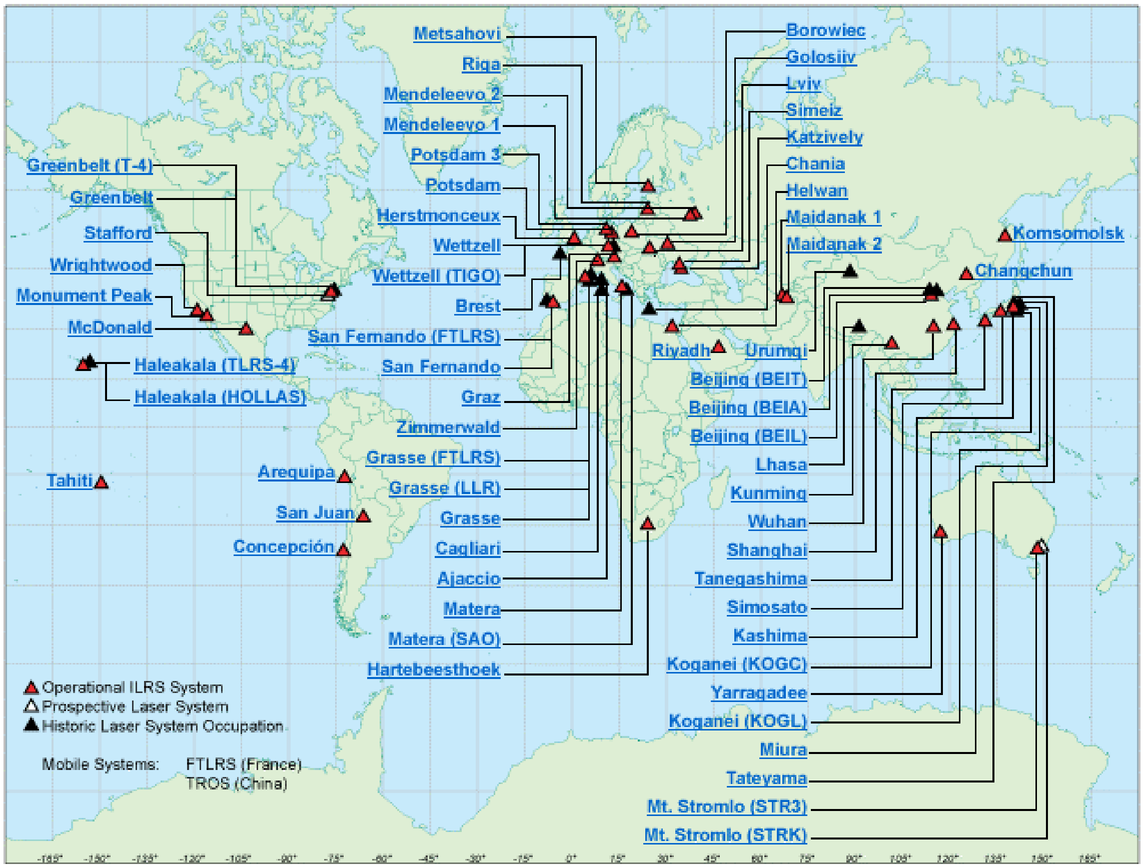

Figure 4. The ILRS network, only two stations are active in Africa, of which only HartRAO (MOBLAS6) is operational.

The ILRS collects, merges, archives and distributes Satellite Laser Ranging (SLR) and Lunar Laser Ranging (LLR) observation data sets. These data are of sufficient accuracy to be used in a wide range of scientific, engineering, and operational applications and experimentation. These data sets are used by the ILRS (http://ilrs.gsfc.nasa.gov) to generate a number of scientific and operational data products including:

- Earth orientation parameters (polar motion and length of day)
- Station coordinates and velocities of the ILRS tracking systems
- Time-varying geocentre coordinates
- Static and time-varying coefficients of the Earth's gravity field
- Centimetre accuracy satellite ephemerides
- Fundamental physical constants
- Lunar ephemerides and librations
- Lunar orientation parameters

The accuracy of SLR/LLR data products is sufficient to support a variety of scientific and operational applications including:

- Realisation of global accessibility to and the improvement of the International Terrestrial Reference Frame (ITRF)
- Monitoring three dimensional deformations of the solid Earth
- Monitoring Earth rotation and polar motion
- Support the monitoring of variations in the topography and volume of the liquid Earth (ocean circulation, mean sea level, ice sheet thickness, wave heights, etc.)
- Tidally generated variations in atmospheric mass distribution

- Calibration of microwave tracking techniques
- Picosecond global time transfer experiments
- Astrometric observations including determination of the dynamic equinox, obliquity of the ecliptic, and the precession constant
- Gravitational and general relativistic studies including Einstein's Equivalence Principle, the Robertson-Walker b parameter, and time rate of change of the gravitational constant;
- Lunar physics including the dissipation of rotational energy, shape of the core-mantle boundary (Love Number k2), and free librations and stimulating mechanisms
- Solar System ties to the International Celestial Reference Frame (ICRF)

GGOS

A project termed Global Geodetic Observing System (GGOS) has been launched (http://ww.ggos.org) by the IAG to improve the network geometry as well as modernise and improve equipment accuracy to reach new science and product requirements. This will lead to additional stations, improved network geometry and better products, which in turn will enhance the global usefulness and multi-disciplinary applications of the data and products. This project encompasses all the IAG services, therefore all the SG techniques.

Basically, the new space geodetic observatories will be equipped with smaller geodetic VLBI antennas (HartRAO currently has a 26 metre antenna), be automated, observe continuously (currently only 15 % telescope time is allocated to space geodesy at HartRAO), 10-12 metre in size, fast moving, and be able to observe over a continuous frequency range of 1-14 GHz. For geodetic VLBI use can be made of SKA or DSNA type technology if suitable, or in the case of HartRAO, perhaps utilising a special high frequency version of the KITTY/KAT prototype/demonstrator of the SKA.

SLR stations are moving to faster (1-2 KHz) sampling rates (HartRAO currently samples at 5 Hz) and higher (mm) accuracies, a factor of ten improvement on current equipment.

The white paper on GGOS fully describes the scientific case for GGOS, the arguments contained therein pertains to the South African case as well.

– South Africa's role in Space Geodesy

South Africa plays a unique role in Space Geodesy by providing a fundamental station (station where 4 space geodesy techniques are collocated) in Africa and the Southern Hemisphere. Not only is there the huge geographical advantage but also the skilled manpower and political will to support such a station has provided South Africa with a positive image in the science arena. HartRAO's contribution has extended beyond its borders into the SADC region and GPS stations have been installed in Namibia, Botswana, Mozambique and Zambia through collaboration with other agencies. This works supports the African Reference Frame project and densifies the ITRF in Africa. GPS stations have also been collocated with tide gauges in South Africa to assist global sea level monitoring projects. These projects are ongoing and provide a steady growth in the number of stations available to local and international users and provide the basis for capacity building in several spheres of science. Several students are undergoing their post-graduate training at HartRAO and it is planned that a selection of these students will become the core of the future of space geodesy in South Africa.

The value of our participation in the space geodesy networks is indisputable and is clearly illustrated by the willingness of the international community to support our activities by the provision of equipment, which we have not been able to fund ourselves. As an example, all the GPS equipment we have installed since 1996 until 2006, were provided by foreign collaborators, especially the Jet Propulsion Laboratory (JPL) of NASA. The SLR (MOBLAS-6) operated by HartRAO is also an ongoing NASA/HartRAO collaboration. However, the presence of equipment does not always go hand in hand with the presence of adequately supported local capacity, which in itself requires facilitation by the science funding organisations in South Africa. The equipment we have currently is functional, but maintained with difficulty due to the age of the technology around which these systems were developed. For South Africa to keep playing a growing, academically and technologically competent role, the ageing equipment and the too small scientific and technical component in terms of manpower must be radically enhanced to secure our continued (and improved) global participation. This new role will require the development of local human capacity and technical competence, the development and training of keen young scientists within a system that will provide careers and job satisfaction, as well as the development of a new space geodesy observatory equipped with state of the art equipment. It is envisaged that continued support by the international community will in any event lead to the placement of additional advanced instrumentation which support space geodesy, Earth observation or related scientific fields at the new site.

– Science requirements, trends and projections

The purpose of this white paper is not to make the case for space geodesy, that case has already been made elsewhere (see GGOS white paper); the purpose is rather to sketch the way forward in solving the looming problem in South Africa of the country not being able to continue (and to improve on) our high-level participation and academic contribution in Space Geodesy, which is required to participate in the current GGOS initiative towards higher accuracy and improved output.

Disturbingly enough though has been the trend to reorganise the field of Geodesy into other disciplines, facilitated by the multi-disciplinary nature of the science. This tendency globally has led to the closure of Geodesy departments or their absorption into other broader fields such as GIS or Geomatics. The result is a lack of specialist development and training in a specialised field. This scenario has also taken its toll in South Africa, with space geodesy being virtually absent at the local universities. Currently HartRAO has a combined project with the University of Pretoria to establish a strong section supporting and teaching space geodesy and its applications within the Department of Geography, which will hopefully lead to the establishment of a Special Chair for Space Geodesy at the university.

Space Geodesy has shown that it is an integral part of Earth and planetary exploration satellite missions due to its applications of time transfer, velocity and three-dimensional position applications achieved through satellite tracking and its representation in highly accurate, well maintained reference systems and frames. These systems, frames and techniques are universally regarded as indispensable prerequisites for Astronomy and Space Science missions, and are therefore often found to co-exist in a symbiotic way with these fields, as there is a fair amount of synergy and the option of sharing either equipment or data, which is mutually beneficial for the participants of the relationship. The interdisciplinary nature of Space Geodesy provide additional input and a means to understand the processes leading to global climate change, the mitigation of natural hazards such as tsunamis, sea level rise and tectonic events, which every year causes the destruction of property and leads to a loss of life and on an international level, vigorously supports the role that it can play in supporting these activities. The inclusion of Space Geodesy as a project within GEOSS, underlines the value which is placed by the international community and the world governments on the role that reference frames and space geodesy data play in supporting any form of spatially distributed data dependent on position.

The importance of Space Geodesy is furthermore recognised by cadastral surveyors and government departments dependent on accurate ITRF coordinates to enable modern maps and land management techniques to be utilised through the establishment of ITRF based mapping datum's for countries (e.g. ITRF94 Hartebeesthoek Datum for South Africa adopted by the Chief Directorate: Surveys and Mapping, Department of Lands).

Space missions such as CHAMP, GRACE and GOCE, will provide results that describe variations in the gravity field with extremely high time resolution (Schlüter and Vandenberg, 2003) and new altimeter missions will result in very precise information on profiles of the Earth. Therefore the consistency of the reference frames over decades of time is a serious requirement as well as the ability to describe geometric and geophysical phenomena in one common reference frame in order to generate comparable results. The accuracy of information will be on the level of 10^{-8} to 10^{-9}, which at least requires a uniform reference frame precise to 10^{-9} (Schlüter and Vandenberg, 2003).

A reference frame at the level of 10^{-9} cannot be achieved by only one technique. The limitation comes from observing errors, modelling errors and unknown systematic effects. A requirement of the scientific community and the IAG is the combination of results provided by various techniques (VLBI, GNSS, SLR, DORIS) so as to benefit from the different sensitivities and to minimize technique dependent errors and biases.

The change in the Earth's gravity field caused by the moving ocean mass, earth-tide, ocean-loading, atmospheric-loading and pole-tide, the change in the Earth's shape and changes in rotation and orientation in space can be measured by Space Geodetic systems. For instance, the rotation vector of the solid Earth exhibits small, complicated changes, which causes a variation of several milliseconds in the length of the day and the rotation vector's orientation relative to the solid Earth's axis of figure varies several hundred milliarcseconds in polar motion (Gross et al. 2003). These changes in the rotation vector of the solid Earth are due to torques acting on the solid Earth and changes in the mass distribution within the solid Earth, which alter its inertia tensor. These techniques can therefore study the response of the Earth to external forces as well as the forces themselves, leading to an improved understanding of the Earth's interior structure and the time-varying evolution of the force mechanisms.

Changing sea levels and ice sheet mass variations will contribute to these changes. As geodetic observations (in particular SLR) are used to calibrate and determine the orbits of satellites equipped with sea surface height measuring equipment, space geodesy contributes to the measurement of ocean level change. It also defines and maintains the terrestrial reference frame within which these measurements are made. According to Douglas et al., 2001 the global rate of ocean level rise has been about 1 mm/yr during the last century. Being able to accurately determine this rate, its causes and consequences is of course very important for several reasons. To validate and maintain these measurements the reference frame stability and accuracy should be at least ten times better, i.e. to within 0.1 mm/yr. This leads to the rather stringent requirement that geodetic site positions must be determined with sub-millimetre accuracy. Currently sub-centimetre accuracy is attained.

We will not re-visit why the monitoring of ocean level is critical as the reader will be aware of the arguments and its implications. It is however important to at least point out at that the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report indicates that apart from the measured average rate of 1-2 mm/year during the past 100 years, that the rate of rise of sea level could increase significantly during the 21st century, perhaps tripling the rates observed during the past 100 years. Such a rise (of the order of 50 cm) would have major impacts on all coastlines in all countries, rich or poor (Woodworth and Aarup, 2003).

Improved geodetic measurements are a requisite to an improved understanding of the interacting Earth systems. An overall improvement in measurement accuracy, stability and the consistent combination of techniques (combination of reference systems) need to be improved by a factor of at least ten to meet these objectives.

– Site selection

HartRAO has investigated the suitability of some sites, which will meet the criteria of clear skies, low cloud cover, relatively low radio frequency interference and existing infrastructure. As the site will have to house a complete National Facility, which will be hosting several space geodetic and related instruments, several hectares of ground will be required. The site should eventually contain LLR, SLR, GPS, DORIS, VLBI, TEC instrumentation, Water Vapour Radiometer and supportive science instrumentation, adequate buildings to house these, technical workshops, on site accommodation for shift personnel and scientists as well as a suitable venue for an active science awareness and public outreach programme.

Initial Site Geology Investigation

After considering a site in Lesotho, SAAO Sutherland and the Sutherland environment, consideration was given to Matjiesfontein (Figure 5). A report (Combrinck *et al.* 2007) entitled "Geotechnical and tropospheric site investigation for a proposed space geodesy observatory near Matjiesfontein in the Great Karoo", is available which describes the investigation of the site in some detail.

Figure 5. The proposed site for IISGEO is enclosed in a natural valley, which would protect the site from RFI and would reduce visual impact from the road. An existing gravel road services the site. The village is about three km towards the north.

Matjiesfontein in our view has many benefits in terms of existing infrastructure, and meets the requirements in terms of cloud cover, seeing conditions and site stability which are the main criteria for a space geodetic site. We have had several discussions with the management and owner of Matjiesfontein, and a tract of land towards the south of the town has been identified which will suit our purposes very well.

A new source of water has been found quite close this site, and we will be able to tap into an already existing pipe that has been put in recently, this will have to be pumped over a distance of one km to the IISGEO site. An overhead high voltage line is about one km from the site, and one would have to construct a substation to feed IISGEO.

Matjiesfontein (http://www.matjiesfontein.com/) provides synergy to a large extent due to existing infrastructure; railway line, N1 national road, landing strip, water, electricity, stable geology, clear skies and remoteness of large towns and cities. Furthermore, the infrastructure at the village, provides unique opportunities to host workshops and conferences, regional and international, which are currently held in either Europe or the USA. Workshops such as these will provide additional opportunities and exposure to the global community of space and earth sciences which could benefit the country through the medium of international participation and awareness.

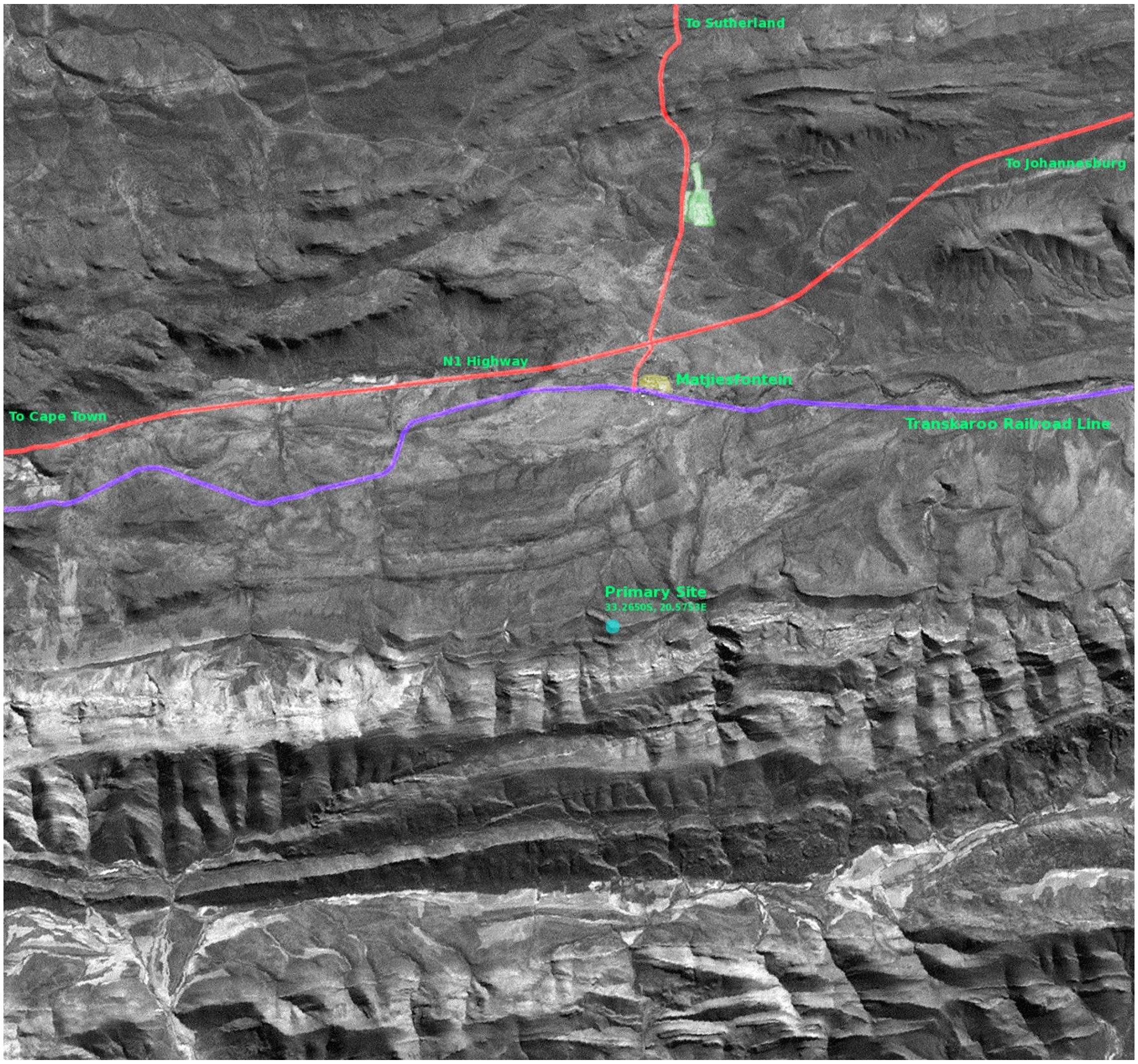

Figure 6. Matjiesfontein is about 3 km north of the IISGEO site, which itself is nestled close to the Witteberge. Laingsburg is 26 km towards the east from Matjiesfontein.

IISGEO will to a certain extent, provide local employment opportunities, but will be able to contribute to local education through involvement in teaching at the local village school and at Laingsburg.

Preliminary site investigations have been done with most of the efforts concentrated at Matjiesfontein in the Western Cape, 70 km south of Sutherland. The proposed location (due north and between Williston and Carnarvon) of the Square Kilometre Array (SKA) is unsuitable as IISGEO will require equipment which will void the SKA site of its radio quiet zone status due to the possible addition of a 9 GHz radar slaved with the SLR/LLR equipment and the likelihood that a French DORIS geodetic system (which transmits on 2 frequencies in the L band) will be hosted at the station. Preliminary discussions and 2 rounds of presentations to SAAO has confirmed that the Sutherland SAAO site will be unsuitable due to light pollution by the SLR/LLR system and the additional drain on existing infrastructure and resources e.g. water and power. The possibility also exists that an Australian high power space debris-detecting laser will be hosted by IISGEO and this system is very likely to cause an increase in the background sky brightness that will adversely affect optical astronomy and specifically the SALT system.

Matjiesfontein is attractive due to several reasons:

- The owner (Mr David Rawdon) has indicated that a suitable tract of land will be available for use by IISGEO
- The tract of land is nested in a small valley flanked by a ridge and a mountain providing adequate shelter for VLBI instrumentation
- Proximity of water, power, road and railway line.
- The site is located in a semi-arid area with about 200 mm rainfall per year, this provides cloudless days and clear skies with good astronomical seeing conditions required for SLR/LLR purposes.
- Capacity building and science awareness potential due to being located close to the main road between Johannesburg and Cape Town, and falling within an area which could possibly become a scientific tourist rate encompassing SAAO (Sutherland), SKA (Carnarvon/Williston) and Sutherland.
- Potential benefits to the local community

Figure 7. Matjiesfontein is a small Victorian town, a national monument, so is not allowed to expand which could threaten the isolation value of the site for IISGEO.

Finding and evaluating a suitable site for IISGEO near Matjiesfontein in the Great Karoo involved the Geophysics Division at the Council for Geoscience and the Space Geodesy Programme at the Hartebeesthoek Radio Astronomy Observatory (HartRAO). The site is in a small depression to shield it from radio frequency interference emitted by cell phones and microwave ovens. It is also particularly suitable because of the many cloudless days and clear skies.

The site is 5km south of Matjiesfontein and is very close to the contact between the Karoo Supergroup geology and the Witteberg Group, which is part of the Cape Supergroup. It can be located on the 3320BA Matjiesfontein and 3320BC Fisantekraal sheets and lies on the 3320BC Fisantekraal 1:50 000 sheet (Figure 8).

The geological investigation was geophysical and geotechnical in nature and included a magnetic, electromagnetic and seismic refraction survey. The purpose was to detect possible dykes and faults that may occur in the area. Samples of the geology were also collected to measure physical properties such as the density and conductivity of the lithologies. A seismic refraction survey was done to obtain the seismic velocity of the subsurface. This velocity gives an indication of the rock hardness, which was found to quite adequate for the construction and monumentation we have in mind.

The geotechnical investigation consisted of eight backacter test pits. Refusal depths were determined and one soil sample was analysed and tested to determine the heave potential and collapsibility of the subsurface. The dip of the geology is almost vertical, which makes slipping of structures on the bedrock under pressure nearly impossible. The information gathered indicates that the site is very suitable for the proposed development.

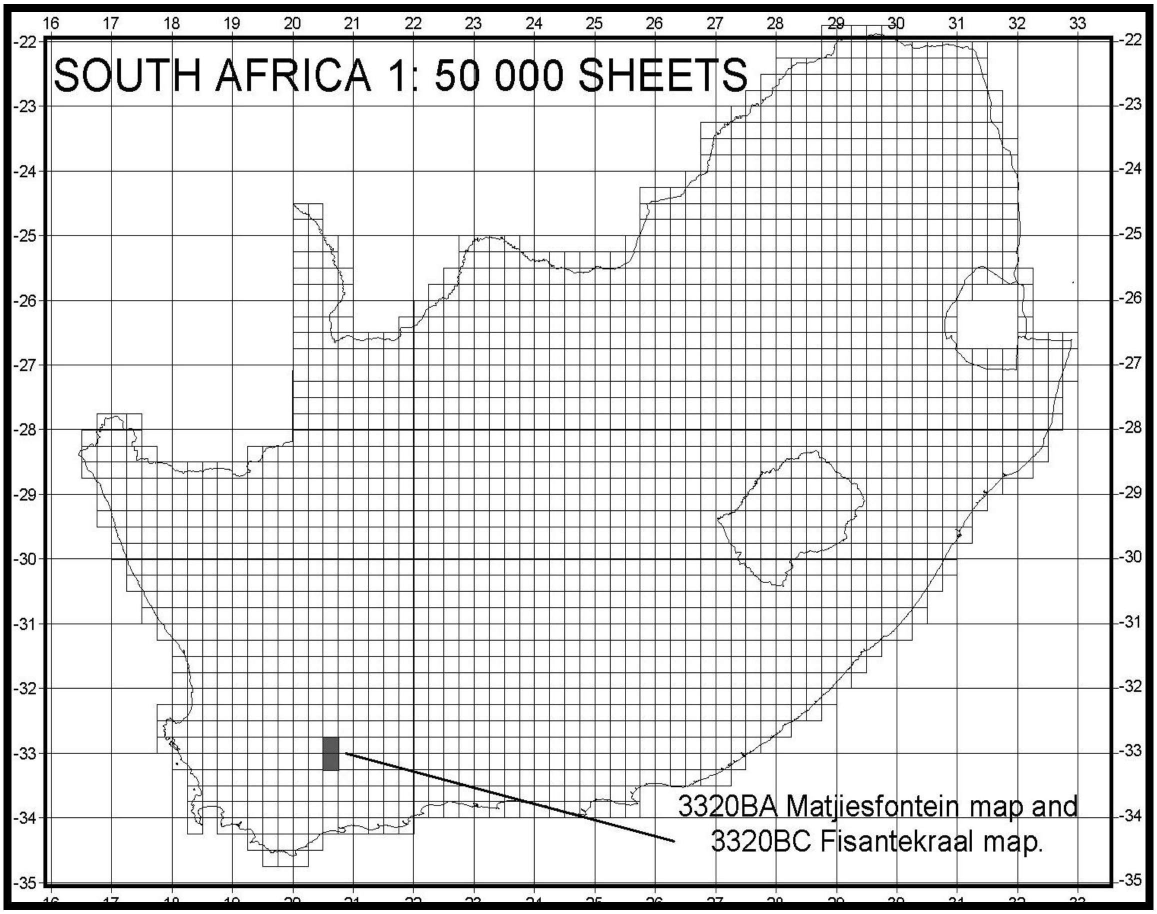

Figure 8. Position of the Matjiesfontein and Fisantekraal maps in South Africa.

– Evaluation and prioritisation of technologies

The sequence of instrumentation development and commissioning will follow a parallel strategy as all major SG techniques are currently undergoing revision. Weighting of the different technologies can however be done by dividing the project into phases, which would not necessarily be in sequence but would provide some idea of time scale and implementation expectations. All of the phases (and sub-components) will as far as possible incorporate post-graduate student projects so as to maximise capacity development and a local "grow your own timber" approach.

Preparation Phase

This phase will include the installation of a standalone GNSS station (including meteorological equipment and communications terminal), which will be autonomous in operation with independent (of the grid) power (solar and wind system). It is planned to install this system as soon as possible as the data will not only provide the start point of station position and plate velocity time series, but will also provide site evaluation parameters such as atmospheric water content.

Phase 1

As Phase 1 of the realisation of IISGEO, we have been negotiating with the Observatoire de la Côte d'Azur (OCA) during the last three years to take over their existing 1 metre SLR telescope and have proposed to convert it to a Satellite/Lunar Laser Ranger. This is a large and technically complex task, which will allow the development of rare skills within South Africa, and although not a very expensive project, is prestigious due to the utmost technical skill and competence that will be required to build the S/LLR. Currently there is no S/LLR in the Southern Hemisphere, and only two working systems in the world. This phase would encompass the refurbishment and development of the 1 metre telescope into a modern SLR system, which can range to satellites and the Moon.

Phase 2

This phase will include the development of necessary initial infrastructure on the IISGEO site and the move and installation of the S/LLR system to the site.

Phase 3

Phase 3 will include the development and construction of the geodetic VLBI component of the system

Some components of the different phases will be executed in parallel as their timeframes overlap and much of the system development (e.g.VLBI2010 and SL2000) is to a large extent dependent on the contributions and timeframes of other institutions.

– Recommended technologies

Basic Proposal for Phase 1

It is proposed that the 1 metre CNES SLR system currently operated by OCA be moved to South Africa for conversion to an SLR/Lunar Laser Ranging System. This new LLR will after successful conversion and refurbishment, be moved from HartRAO (located at Hartebeesthoek) to a suitable new location in South Africa, where eventually, it will be supplemented with collocated space geodesy systems (GPS, SLR2000, VLBI2010, DORIS) to form a node of the proposed IAG Global Geodetic Observing System, termed the International Institute for Space Geodesy and Earth Observation (IISGEO), a new National Facility of the NRF. Some instrumentation e.g. GPS may precede other equipment, to facilitate. The addition of this system to the very small international network of systems capable of LLR will enhance science and open avenues of collaboration with OCA.

We envisage that the global geodetic community will support this project, and support in terms of designs, software and training has in principle been given by several participants in the ILRS such as NASA (GSFC) and BKG (Wettzell). Once final approval is given by CNES, HartRAO will have to arrange collection of the telescope, and with NRF and DST, endeavour to source adequate funds for the transportation, refurbishment and conversion of the telescope into a LLR system.

A proposed preliminary time-table is presented here but will obviously be tied to funding in terms of adhering to dates. A five year period is suggested as framework, as this seems to be a realistic period after discussions with other groups (e.g. McDonald Observatory) who have done similar developments.

The project will have strong capacity development components, and will involve several local universities and a number of post-graduate students. The idea is to utilise young scientists and technologists through a participation process by shaping post-graduate and post-doc projects around the development of IISGEO and the LLR in particular.

Preliminary refurbishment and conversion time-table; IISGEO phase 1

Stage	***Month***	***Description***
1	**0**	Build appropriate temporary shelter for telescope. Fact finding visits to other international SLR/LLR sites.
2	**0.5**	Visit OCA and arrange packing/shipping of telescope. Set up collaboration MOUs.

Stage	***Month***	***Description***
3	**2**	Import telescope, move it to HartRAO. Start development of IISGEO (Matjiesfontein); GPS, infrastructure 1st phase.
4	**3**	Installation and verification to testable configuration.
5	**4**	Determine parameters: pointing, encoders resolution, optical efficiency, etc.
6	**5**	Evaluation of parameters. Alternative solution for improvement.
7	**6**	Commence design of modification and detailed system drawings.
8	**8**	Implementation of modification, some of the next items will run in parallel with other sub-tasks. 1. Cablewrap. 2. Encoders. 3. Software. 4. Optics transmit/receive path. 5. etc.
9	**14**	Commence construction of permanent housing/dome for LLR/SLR at suitable location (site evaluation commenced in May 2004).
10	**36**	2 post-grad students at University of Stellenbosch Laser Institute. Commence development of laser. (Students registered January 2005) (One student Sandile Ngcobo, was taken over on a permanent basis by NLC, February 2007)
11	**14**	Software and interface development.
12	**18**	Initial testing of pointing/tracking using upgraded LLR/SLR station and new software.
13	**24**	Commence integration of laser and timing system with telescope.
14	**36**	Test phase of LLR/SLR station. Error evaluation, further improvements.
15	**48**	Place SLR system in operational mode.
16	**60**	Place LLR system in operational mode. **IISGEO Phase II; VLBI etc.**

Background

Ranging to the Moon is possible because of the retroreflector arrays left on the Moon by the American Apollo and Soviet Lunokhod missions to the Moon. Our main goal is to achieve precision of a few picoseconds, corresponding to about one millimetre in range to the Moon. Using this information, we will be able to gauge the relative acceleration of the earth and Moon toward the sun (like a modern-day Leaning Tower of Pisa experiment) in order to ascertain the free-fall properties of earth's gravitational self-energy.

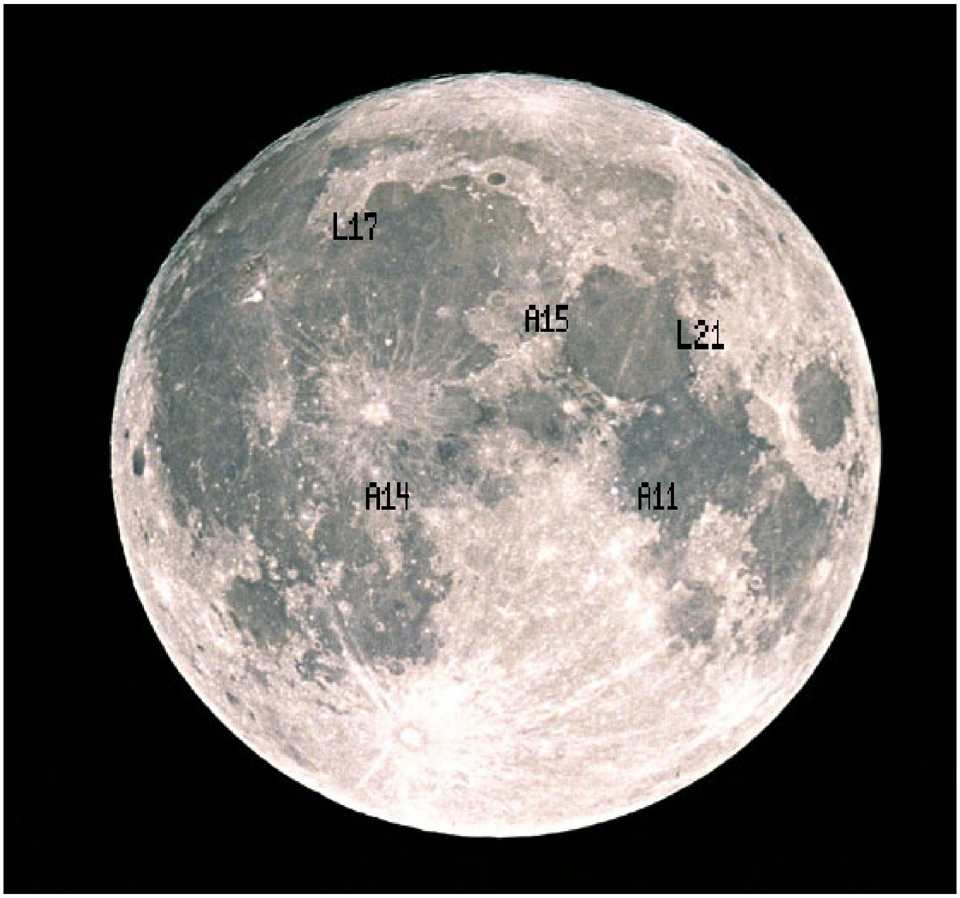

Figure 9. Placement of lunar retroreflector arrays. Future lunar missions might be expanding the network of arrays, which will lead to an improvement of LLR results.

LLR also provides the best test of the constancy of Newton's gravitational constant, G, currently limited to a variation of less than one part in 10^{12} per year. Relativistic geodetic precession is also best probed (currently) by LLR, now verified at the 0.35% level of precision. And the list goes on: LLR provides the best test of the motional influence on gravitational attraction (called gravitomagnetism) at the 0.1% level, and also sets the most stringent limits on deviations from the expected law of gravity. The points of reference for the Earth-Moon measurement will be the earth-based telescope—in this case, the 1 metre telescope at the new station site, and in particular, the intersection of the telescope mount axes—and the small, suitcase-sized retroreflector array placed on the lunar surface by Apollo astronauts. A total of four lunar retroreflectors (Figure 9) are functional: three Apollo reflectors from Apollo 11, 14, and 15 (three times bigger), and one French-built, Soviet landed (unmanned) unit from the Luna 21 mission. A significant part of the challenge of lunar range modelling is converting this point-to-point measurement into a distance between the centre-of-mass of the earth and the centre-of-mass of the Moon. It is only after this reduction that one can consider the interesting part of the problem: the dynamics of the Earth-Moon-Sun system.

The S/LLR system will be designed and built as a dual laser ranging system which will use the same devices for lunar ranging (the main goal), and for low orbiting (up to 1000 km) satellites using so called multi-wavelength laser ranging.

Finances and Support

The concept of an LLR for the southern Hemisphere was discussed at the 13th International ILRS Workshop (October 2002) in Washington at an LLR breakaway meeting and was received with enthusiasm by all LLR colleagues. The LLR was once more discussed during a meeting (requested by OCA) at the ILRS workshop during October 2005 in the UK where major role players in the ILRS community were present and the project was given full support. The concentration of LLR systems in the northern Hemisphere adversely affects data reduction and interpretation as all data is sampled in the north, creating biases. We have received several e-mails of support for this project from noted researchers utilising LLR data, as well as support from the Secretary and President of the ILRS.

Support in terms of factors such as scientific collaboration, design, software, training for students and participation in a working group for establishing an LLR in the South Africa have been offered by the NASA SLR network manager (USA), OCA (France), McDonald Observatory (USA), AUSLIG (Australia), GFZ Potsdam (Germany), BKG Wettzell (Germany) and the MLRO (Italy). We have had a close working relationship with many of these groups through our participation in SLR, GPS and VLBI since the early 1980's.

During the last 2 years, we have been canvassing the support of the National Research Foundation (NRF) for this project, and also simultaneously for the establishment of a new space geodesy observatory which would replace the HartRAO space geodesy programme eventually. This project has been approved in principle by the CEO of the NRF and has been proposed as a flagship programme by the "New Business Development" section of the NRF. We have been allocated (2007) R2M seed funding through the NRF STAF programme for the development of the S/LLR, but no funding for IISGEO as a fledgling new institute or National Facility. The acquisition of the telescope could provide leverage to obtain local and foreign funding through the establishment of an international working group for the development and conversion of the CNES 1 m telescope.

The Telescope

The telescope to be used is currently located at the Observatoire de la Côte d'Azur, close to Nice, in France. It has been removed from its previous shelter and is ready to be crated and shipped.

Figure 10. The one metre OCA telescope is an az-el mounted, Cassegrain telescope, which weighs about seven tons. It is too large to fit into a standard shipping container and the mount and tube will have to be specially crated and sealed against the harsh conditions to be encountered while at sea.

Although the telescope (Figure 10) has been operational until mid-2005, it needs substantial refurbishment and upgrades to meet the very stringent requirements of LLR. These upgrades, and the development of the LASER, timing and photon detection systems will have to be integrated into a complete LLR at HartRAO, before moving the system to the proposed site at Matjiesfontein. HartRAO has two post-graduate students (Sandile Ngcobo, MSc; Roelf Botha, PhD) registered at the Laser Institute at the University of Stellenbosch, who have during 2005 equipped themselves with the necessary theoretical and practical background work on the development of a suitable LASER system, which will provide the required power, beam quality and short pulse length of the system. It is envisaged that the bulk of the development work will be done through student and post-doc projects.

– Budget summary

The S/LLR project should take about five years if funding is adequate, and estimated cost is about R22 million Rand. In principle, the owners of the telescope (CNES, France) has given the green light on transferring the telescope, but we need ***to acquire full NRF and DST*** support to ensure we do not start with something we cannot finish. Apart from capital (development and equipment) funding, additional (ring fenced) yearly funding, perhaps in the form of increased running funds to the current SLR (MOBLAS6) project (currently R2 million) would be required to allow appointment of adequate manpower (including MSc and PhD projects) for the project; an increase to R7 million per year for running funds should be adequate. Alternatively, IISGEO could be given its own budget as a fledgling NRF facility. Site development at the proposed Matjiesfontein location, adequate to provide basic infrastructure for IISGEO would cost about R39 million, which would include road upgrade; water, electricity, backup generators, buildings, fencing, communications, staff accommodation etc.

VLBI2010 instrumentation is difficult to cost at the moment as the technology and systems are under discussion/investigation. A conservative estimate however would be about R12 million per radio telescope. For a network of four telescopes including a hydrogen MASER atomic standard, R50 million should suffice.

The total development and capital outlay would therefore be in the region of R110 million for the complete Space Geodesy observatory (over a period of about 10 years), and running funds per year would be R7 million in current monetary terms.

– Plan to implement recommendations, including identification of appropriate roles for collaborators and SADC country participants

Partners

With the development of the proposed new IISGEO, we envisage a collaborative partnership with several countries and institutions that are already engaged in space geodesy. Once the project is off the ground, which will basically start with the transfer of the CNES 1 m telescope to South Africa, we will engage in a process to solicit partners officially. Some partners have already committed resources in one way or another for IISGEO, e.g., NASA has indicated that they will provide an SLR2000 system for this new station.

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During the last 2 years, we have been canvassing the support of the National Research Foundation (NRF) for this project. This project was approved in principle by the then CEO of the NRF (Dr Mokhele) and has been proposed as a flagship programme by the "New Business Development" section of the NRF. We have not received special funding for the development of either IISGEO or the LLR as yet, and we are now at the stage where we need funding to continue. The acquisition of the telescope could provide leverage to obtain local and foreign funding through the establishment of an international working group for the development and conversion of the CNES 1 m telescope.

During the October 2005 SLR international workshop (Eastbourne, UK), a meeting was convened to discuss the issue of transferring the OCA telescope to South Africa, a subsequent resolution was passed that the ILRS supports this project (present were John Degnan (NASA), Peter Shelus, Jerry Wiant, Randy Ricklefs (McDonald/NASA LLR), Mike Pearlman (ILRS Secretary, Harvard-Smithsonian Centre for Astrophysics), Francis Pierron (OCA), Werner Gurtner (ILRS President, University of Berne), Ludwig Combrinck (HartRAO). This project will not be done in isolation, but in collaboration with the international community, and is supported for its scientific merit by several major role players in space science, and many smaller institutes.

The S/LLR will be a main component of the instrumentation sited at the new location of IISGEO and will be developed in collaboration and partnership with OCA and the rest of the SLR/LLR community where appropriate. We also intend to include several other African countries to facilitate the transfer of capacity and knowledge to African universities in support of local and international government initiatives for the development and support of Africa.

Although the S/LLR system will be but a component of this initiative for Africa, the S/LLR will be synergistically linked to projects such as the development of the African Reference Frame (AFREF) and the African Geoid. IISGEO will also be a major training centre for African geodesists and related sciences.

The Observatoire de la Côte d'Azur has shown support for this project and has recognised the benefits to the SLR/LLR community and related disciplines that a southern Hemisphere LLR system would bring to research and science. Specific advantages through collaboration with OCA, which a LLR station in South Africa would be able to exploit could include:

- Time transfer by laser link (T2L2) between France and South Africa
- Supporting interplanetary navigation through tracking laser transponder equipped spacecraft
- Simultaneous ranging to the moon (France and South Africa are on closely corresponding longitudes) using synchronized clocks
- Development and implementation of state of the art LLR sub-systems could facilitate future upgrades of the current OCA LLR system
- Sharing of developed software, electronic circuit and hardware development
- Contribution of southern Hemisphere LLR data to ILRS, providing improved LLR products such as produced by the Paris Observatory Lunar Analysis Centre
- Exploring high rate data transfers using LASER signals between South Africa and France
- Improved collaboration between South Africa and France in support of the France-South Africa bilateral agreement on Science and Technology
- Opportunities for student exchanges
- Future opportunities for additional CNES involvement with space geodesy and space sciences from South African soil
- Relativistic studies, determination of gravity constant G, geodetic precession, possible variation in speed of light, lunar science

The Director of the Norwegian Mapping Authority Geodetic Institute, Dr Bjorn Engen, has shown interest and we have had preliminary discussions concerning possible contribution via the South Africa/Norway bilateral agreement. Several other institutions including NASA (USA), Fundamental Station Wettzell (Germany) and

McDonald Observatory (USA) have shown interest.

Preliminary enquiries have been made by Australia to collocate a space debris tracking station (laser system with 2 metre telescope) at the IISGEO site.

CSIR participation

The National Laser Centre (NLC) of the CSIR has actively been involved in training students and doing research on the development of suitable laser technology for the S/LLR. Currently the Space Geodesy Programme of HartRAO has one full-time PhD student at the NLC who is working on the development of short-pulse high power lasers, with the intention to improve, by utilising alternative approaches, the NDYAG flash lamp pumped laser commonly used in SLR systems. Dr Christoph Bollig of the NLC is the collaborator who is driving the S/LLR development from the CSIR side.

There is the possibility to utilise a large room (at the Laser Centre) with suitable dimensions and a garage type door of adequate size leading to a cement platform for the refurbishment of the telescope. This will improve accessibility for on-site testing and work required in the characterisation and refurbishment of the telescope.

It is our viewpoint that the NLC is ideally positioned to play a major role in the development of the S/LLR and enhances the possibility of a successful conversion and refurbishment of the telescope to an operational S/LLR.

It is possible that other units of the CSIR may become involved, as there are several subsystems, which may benefit from local expertise.

• Conclusion

– Recommendations

The transition of the Space Geodesy Programme at HartRAO into a fully fledged facility at a new site, equipped with state of the art instruments and systems will be at least a five year project (Phase 1), and possibly more before the basic essential instrumentation and infrastructure is installed and commissioned. At the conclusion of the first phase, which should commence during 2007, at least one main SLR dedicated system (SLR2000, NASA), and the S/LLR system should be operational. As part of this phase, GPS, meteorological systems and basic infrastructure should be installed. IISGEO has the regional and international potential to make South Africa a leader in the field of space geodesy and its applications, and will be a training and research Centre for scientists globally but in particular of the African continent. After Phase 1, VLBI2010 as developed by the international community will have to be introduced as phase 3. Site development and infrastructure (phase 2) will have to be scaled to requirements as necessary and implemented as required.

It must be noted that the SLR/LLR system will only be a component of the new station, and that the other space geodetic techniques (VLBI, DORIS, GPS) will have to be added as well as additional phases; e.g. GPS could be had right at the outset as it is a relatively low cost item but essential for developing initial and continued inter-technique ties and long-term time series. The new VLBI instrumentation and radio telescopes will be developed in collaboration with the international community; there are existing international working groups who are already developing specifications and alternative designs and HartRAO will have to participate at a level which will provide value and add impetus to VLBI2010.

Continued operation of existing systems at HartRAO is essential until IISGEO is complete, as the collocation of GPS, DORIS, VLBI and SLR at HartRAO is extremely important for reference frame determinations; once the new facility is operational as a fiducial station, some components of space geodesy at HartRAO can be phased out totally. It is possible that MOBLAS6 can then be moved to a new location, perhaps Kenya to improve SLR coverage. GPS will remain, as it is part of the existing geodesy network, which extends into the SADC region.
IISGEO will be a new station in the GGOS fold and will not only enable South Africa to continue its participation

in the international SG arena, but will enable participation at a higher level.

• References

Combrinck, L., Fourie, C.S.J., Croukamp, L. and I. Saunders. Geotechnical and tropospheric site investigation for a proposed space geodesy observatory near Matjiesfontein in the Great Karoo Report, submitted for publication to SA Journal of Geology, 2007.

Douglas, B. C., M. S. Kearney, and S. P. Leatherman (Eds.), Sea level rise: History and Consequences, 242 pp., Academic Press, San Diego, California, 2001.

Gross, R. S., I. Fukumori, and D. Menemenlis, Atmospheric and oceanic excitation of the Earth's wobbles during 1980–2000, *J. Geophys. Res.*, *108*(B8), 2370, doi: 10.1029/2002JB002143, 2003.

Pearlman, M.R., Degnan, J.J., and Bosworth, J.M., "The International Laser Ranging Service", Advances in Space Research, Vol. 30, No. 2, pp. 135-143, July 2002.

W. Schlueter, E. Himwich, A. Nothnagel, N. Vandenberg, A. Whitney, "IVS and Its Important Role in the Maintenance of the Global Reference Systems", Advances in Space Research, Vol. 30, No. 2, pp. 145-150, July 2002.

W. Schlüter and N. Vandenberg, Prospective Development of the International VLBI Service for Geodesy and Astrometry over the next few years (Status: July, 2002). Report for the IVS Directing Board.

Wolfgang Schlüter, Dirk Behrend, Ed Himwich, Axel Nothnagel, Arthur Niell, Alan Whitney, IVS High Accuracy Products for the Maintenance of the Global Reference Frames as a contribution to GGOS, poster available on IVS webpage (http://ivscc.gsfc.nasa.gov).

Tavernier, G.; Fagard, H.; Feissel-Vernier, M.; Le Bail, K.; Lemoine, F.; Noll, C.; Noomen, R.; Ries, J.C.; Soudarin, L.; Valette, J.J.; Willis, P. 2006. The International DORIS Service: genesis and early achievements, in DORIS Special Issue, P. Willis (Ed.), JOURNAL OF GEODESY 80(8-11):403-417, DOI: 10.1007/s00190-006-0082-4

Woodworth, P. L. and T. A. Aarup, A report on the status of the GLOSS programme and a proposal for taking the programme forward, IOC/INF-1190, Paris, 2003.