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Products of Space Geodesy and links to Earth Science and Astronomy

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ABSTRACT

Products of Space Geodesy such as Earth Orientation Parameters, polar motion and precise positioning, as well as various applications of these products are of importance to both Earth Sciences and Astronomy. Global geodetic site positions and velocities find application in geodynamics, on a local and global scale, including plate mobility and tectonics, on time scales varying from sub-seconds to millions of years. Precise orbit determination provides information on Earth's gravity field and changing shape, it also allows calibration of satellite platforms which measure ocean and ice levels. Nuisance parameters such as observable delays due to the ionosphere and atmosphere provide additional information about total electron content and integrated water vapour. Global reference frames on Earth, and celestial reference frames in the universe are maintained and linked to one another, providing unique positioning capability on Earth and in space. Accuracies and precision of techniques and instrumentation are such now that even relativistic parameters can be tested to new levels. Future developments are very promising as the scientific community moves towards implementation of the Global Geodetic Observing System (GGOS), where sub-cm accuracy on global scales is the objective, requiring a factor ten improvement in measurement accuracies and improved models in terms of factors which affect measuring accuracies. The different Space Geodesy techniques will be discussed briefly with examples of their applications, their links to astronomy and the earth sciences, as well as current and future developments, and South Africa's role currently and in the near future.

Keywords: Space Geodesy, Astronomy, Reference Frames.

INTRODUCTION

Geodesy is the scientific discipline that deals with the measurement and representation of the earth, its gravitational field, and other geodynamic phenomena. These include effects such as crustal motion, oceanic tides, and polar motion. For this geodesists design global and national control networks, using space and terrestrial techniques while relying on datums and coordinate systems.

In Geodesy, the four main techniques are:

- Global Navigation Satellite Systems (GNSS)
- Very Long Baseline Interferometry (VLBI) using Radio Telescopes
- Laser Ranging to Satellites and the Moon (SLR and LLR), used for accurate orbit determination
- Doppler Orbitography by Radiopositioning Integrated on Satellite (DORIS)

These techniques are used both separately *and in conjunction* with each other in Geodesy (figure 1). The collocation of two pieces (or more) of position determination equipment demonstrates a very important concept in the geodetic field. For geodetic measurements to be useful it must be known accurately what was measured as well as in which reference frame.

A short overview of each technique follows. These techniques will be discussed with examples of their applications, their links to astronomy and the earth sciences. South Africa's current role as well as in the near future will also be discussed.

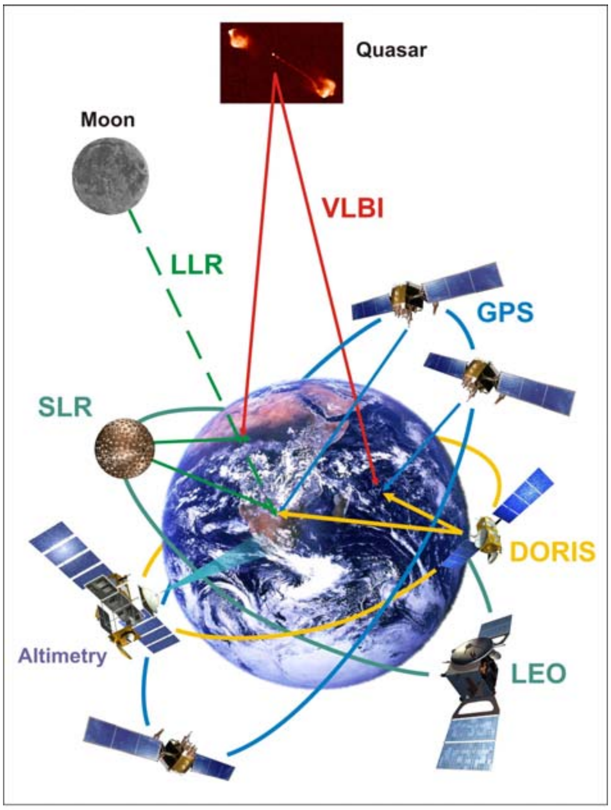

Figure 1: The combination of space geodetic techniques.

GLOBAL NAVIGATION SATELLITE SYSTEMS (GNSS)

The Global Navigation Satellite System (GNSS) is a network of satellite-based systems for positioning and navigation on the ground, in the air or in orbit. Apart from the space segment, each system also has a control segment, responsible for the system's maintenance and quality control, and a ground segment consisting of ground-based tracking stations. Currently GNSS comprises four systems:

- Global Positioning System (GPS), United States of America
- Global Orbiting Navigation Satellite System (GLONASS), Russian Federation
- Galileo, European Commission
- Beidou (translated as "Compass"), People's Republic of China

The International GNSS Service (IGS), formerly the International GPS Service, is a voluntary federation of more than 200 worldwide agencies that pool resources and permanent GPS and GLONASS station data to generate precise GPS and GLONASS products. The IGS is committed to providing the highest quality data and products as the standard for Global Navigation Satellite Systems (GNSS) in support of Earth science research, multidisciplinary applications, and education.

Products from GNSS include

- satellite ephemerides (2 – 5 cm accuracy),
- time (75 ps RMS accuracy)
- geocentric coordinates of IGS tracking stations (3 mm position, 2 mm / yr velocity accuracy)
- Earth rotation parameters such as polar motion (figure 2) and length-of-day
- atmospheric parameters such as tropospheric delay, Total Electron Content and Integrated Water Vapour

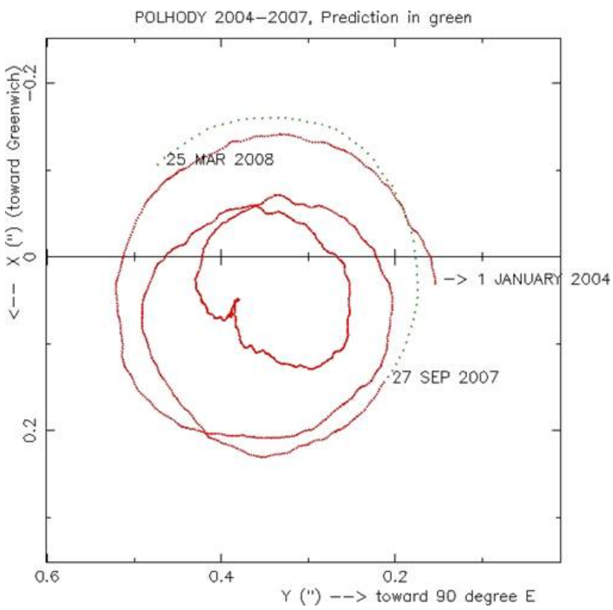

Figure 2: The polar motion of the Earth.

VERY LONG BASELINE INTERFEROMETRY (VLBI)

Radio Telescopes are utilised in Geodesy for VLBI (Very Long Baseline Interferometry), which is the most accurate geodetic technique for determining both the terrestrial and celestial reference frames (TRF & CRF). This in turn helps one to determine Earth's orientation in space. For the past four decades geoscientists have used the data products delivered by this technique in scientific applications such as investigating the changing Earth. Demand for an increase in both performance and accuracy required that a new set of criteria be laid down for a future geodetic VLBI system. This is envisioned as VLBI2010.

Geodetic VLBI is a space-based technique which allows for accurate measurement of the Earth and its orientation in inertial space. An inertial frame is defined by compact radio sources, billions of light years from Earth, called quasars. The Earth's orientation in this inertial reference frame is measured. The quasars are observed with a global network of radio telescopes. Telescopes in the network simultaneously record signals from quasars together with signals from local atomic clocks onto hard disks. At the correlator, data are processed to determine differential time delays. From these differences in arrival times of signals at the various telescopes, the baselines between the telescopes can be determined with an accuracy of a few millimetres. In addition, VLBI data allows us determine the CRF and TRF and to measure Earth orientation parameters (EOP) as well as tropospheric parameters.

Only geodetic VLBI provides the link between the CRF and TRF necessary for determining the Earth’s orientation in inertial space. Geodetic VLBI allows for accurate measurement of:

- positions and velocities of sites occupied by VLBI antennas
- Earth Orientation Parameters (EOP) – UT1, polar motion, nutation, precession
- Tropospheric parameters – total and wet zenith path delays, meteorological data for stations

Knowing the Earth’s orientation in inertial space and positions of VLBI antennas on Earth allow geoscientists to model phenomena that change Earth orientation (such as atmospheric angular momentum, ocean tides and currents, elastic responses of solid Earth) and station positions (such as tectonic plate motions, deformation of crust near faults, post-glacial rebound and volcanic activity).

SATELLITE AND LUNAR LASER RANGING (S/LLR)

Satellite Laser Ranging (SLR) is a technique used to determine the position of the earth and of the satellites relative to each other. Satellite laser ranging uses a global network of stations to measure the instantaneous roundtrip time of flight of ultra short pulses of laser light to satellites and back. These satellites are equipped with special reflectors. This provides instantaneous range measurements of centimetre level precision which can be accumulated to provide accurate orbits and a host of important science products.

The main objective with Lunar Laser Ranging (LLR) is to achieve mm-level precision for the range to the Moon. This corresponds to timing precision of a few picoseconds. Using this information, one is able to gauge the relative acceleration of the earth and Moon toward the sun in order to ascertain the free-fall properties of earth and its gravitational self-energy, amongst many others.

FUTURE OF SPACE GEODESY IN SOUTH AFRICA

The existing instrumentation in South Africa, as well as the current site is not optimal to fully participate at an appropriate level in the space geodesy networks. The global networks are upgrading to a new level of instrumentation, to achieve the objectives of the Global Geodetic Observing system (GGOS), a project of the International Association of Geodesy (IAG). This envisions a factor of ten improvement in accuracy levels, indicating millimetre accuracy and precision. To place South Africa favourably as a continued role player, it has been suggested to develop a new space geodesy observatory at Matjiesfontein, which should be occupied with collocated VLBI2010, SLR/LLR, GNSS and DORIS systems. This site has far better atmospheric characteristics and will be more radio frequency interference free, especially with regard to long-term considerations. Such a development at Matjiesfontein will ensure a long-term research platform in space geodesy, adequately resourced and optimally sited for future research and participation in the global space geodesy networks.