Co-location of High Precision Space Geodetic Techniques:- Products for Mapping, GIS, Satellite Positioning and Global Change Monitoring.

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ABSTRACT:

The products of high precision space geodetic techniques such as VLBI, SLR, GPS, DORIS, PRARE, satellite altimetry and satellite gradiometry are of significant importance to mapping, GIS, satellite positioning and global change monitoring in the context of “mapping for management” – management of the changing environment due to the natural processes within the Earth and from anthropogenic causes.

The current most significant product of space geodesy to mapping and GIS in Australia is the establishment and adoption of the GDA. The ITRF, within which the GDA is established, is a product of the co-location of VLBI, SLR, LLR and GPS and their subsequent estimated transformation parameters. Densification of the ITRF is achieved through GPS, DORIS and PRARE.

Products such as the Earth’s gravity field, ocean tide models, earth orientation parameters, precession and nutation parameters are all necessary for any satellite positioning applications. Other products of the co-location / combination of space geodetic techniques contribute to the monitoring of global change – secular changes occurring in the solid earth and the oceans.

These and other techniques and products are discussed – demonstrating the importance of the co-location and combination of space geodetic techniques to mapping, GIS, satellite positioning and global change monitoring.

INTRODUCTION:

The Geocentric Datum of Australia (GDA) is defined by the co-ordinates of the Australian Fiducial Network (AFN) within the International Earth Rotation Service Terrestrial Reference Frame 1992 (ITRF92) at epoch 1994.0. These co-ordinates were estimated (at epoch) using GPS observations. By the turn of the century, GDA will provide the horizontal datum for all Mapping and GIS products. The ITRF itself is established by the co-location (and combination) of high precision space geodetic techniques – Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), Lunar Laser Ranging (LLR) and the Global Positioning System (GPS). In addition, satellite positioning (GPS) for GIS, mapping and charting applications, require several products that are provided by the other space geodetic techniques. Satellite positioning requires Earth Orientation Parameters (Earth Rotation and Polar Motion), a model for the Earth’s gravity field (static geopotential model), changes in the Earth’s gravity field due to Ocean tides (dynamic geopotential) and the relationship of the terrestrial reference system to the celestial reference system. These are products of VLBI and SLR.

Co-location of space geodetic techniques (VLBI, SLR and GPS) are also used to determine and monitor global change, resulting from natural and anthropogenic causes such as plate tectonics, horizontal and vertical crustal motion, and absolute sea level changes respectively, with a view to developing a prediction capability of natural hazards such as earthquakes. The altimeter satellites such as TOPEX/Poseidon provide ocean topography and ocean circulation information. Global SLR, GPS and the Doppler Orbitography and Radio Positioning Integrated by Satellite (DORIS) measurements are used to determine the precise orbit of the TOPEX/Poseidon satellite. The altimeter measurements can also be used to derive gravity anomalies over the oceans for computation of both the geoid, global geopotential models and map the ocean bed. The co-location of GPS and tide gauges will eventually provide an accurate regional / global vertical datum. Absolute Gravity provides a modern high precision (terrestrial) technique for monitoring vertical crustal movement and a current practice is to co-locate absolute gravity with space geodetic measurements.

"MAPPING FOR MANAGEMENT" IN THE CONTEXT OF MODERN GEODESY:

Some of the traditional definitions of Geodesy are listed below.

- "science of measurement and mapping of the Earth surface" (Helmert, 1880)
- "The problem of Geodesy is to determine the figure and the external gravity field of the Earth and other heavenly bodies as functions of time; as well as to determine the mean Earth ellipsoid from parameters observed on and exterior to the Earth's surface (Draheim, 1971).
- "mathematical survey and measurement of the Earth's surface, involving allowance for curvature" (Collins English Dictionary, 1976).
- "the branch of science concerned with determining the exact position of points and the shape and size of the Earth" (Collins Concise English Dictionary, 1985).
- "the branch of mathematics dealing with the figures and areas of the Earth or large portions of it" (Concise Oxford Dictionary, 1991).

Traditionally, one of the fundamental functions of geodesy has been to provide the horizontal and vertical datums (control) for mapping on a national or regional scale. The unsurpassed accuracies achievable, at global scale, from space geodetic measurement techniques has made it possible to measure and determine slow deformations of the Earth – Geophysical Geodesy. The evolving functions of Geodesy / Geodetic Science is, therefore, to facilitate accurate state-of-the-art four dimensional positioning in Earth space for:

- Development and maintenance of national and international infrastructure
- Monitoring, modelling and hence predicting physical changes in the Earth due to natural processes within the Earth
- Monitoring, modelling and hence predicting physical changes in the Earth due to anthropogenic causes
- Monitoring, modelling and hence predicting global, regional and local geodynamics for the maintenance of national, regional and global terrestrial reference frames at the appropriate accuracies, their mathematical relationships mutually and with the celestial reference frame.

A modern definition of operational Geodesy is then suggested as:

"The applied science which deals with the CHANGING shape, size, position and orientation of the Earth in space" with the aim of an informed management of our changing environment.

In this context, the products of space geodesy are therefore fundamental to the theme of "Mapping for Management" – a representation and monitoring of global change for better and more informed management of our changing environment – mapping the Earth (continents, oceans and ocean bed) and the Earth in space through the products of space geodesy as follows:

- Mapping the topography of the solid Earth and any secular changes.
- Mapping the Earth's gravity field, geoid and the ocean bed.
- Mapping sea surface topography (deviations from the geoid), Ocean levels and any detected secular changes in sea level.
- Mapping ocean circulation

SPACE GEODETIC TECHNIQUES:

Table 1, lists the current space geodetic techniques that are employed in Global Geodesy and the Geosciences.

Table 1: Space Geodetic Techniques:

Technique	Observed
Very Long Baseline Interferometry (VLBI)	Quasars
Satellite Laser Ranging (SLR)	Lageos-1 & 2, Ajisai, Starlette, Stella, TOPEX, GPS, Glonass, Etalon 1&2, ERS-1&2, Metero-2&3, GfZ-1, etc.
Global Positioning System (GPS)	GPS satellites, TOPEX/Poseidon, Ultra Violet Explorer, MicroLab-1
Doppler Orbitography and Radio Positioning Integrated by Satellite (DORIS)	TOPEX/Poseidon
Precise Range and Range Rate Experiment (PRARE)	Meteor-3, ERS-2
Glonass	Glonass Satellites
Satellite Altimetry	TOPEX/Poseidon, Geosat, Geosat, Seasat (no longer exists), GEOS-3 (mission ended) Geosat-FO (to be launched)
Satellite Gradiometry / Gravity	Aristoteles, Superconducting Gravity Gradiometer Mission (SCGGM), Gravsat. (still to be launched)

SPACE GEODETIC PRODUCTS:

Table 2: Space Geodesy -- Products.

Technique	Unique Product	Common Product	Geo-science Contribution	Supports
VLBI	Celestial Reference Frame (Source position) Earth Rotation (UT1-UTC) Precession and Nutation	Polar Motion Terrestrial Reference Frame	Plate Tectonics Crustal Deformation Sea Level Monitoring	GPS, SLR, DORIS, PRARE, All Remote Sensing Satellites, All Communications Satellites through the CRF, EOP, Precession, Nutation.
SLR	Static Geopotential Model Dynamic Geopotential Centre of Mass (Geocentric Positions) Orbit Determination (of all satellites equipped with retroreflectors	Polar Motion Terrestrial Reference Frame UT1-UTC	Plate Tectonics, Crustal Deformation Sea Level Monitoring Earth Models (coefficients)	GPS, SLR, DORIS, PRARE, All Remote Sensing Satellites, All Communications Satellites through the TRF, Geopotential Model and EOP, Orbit determination to support Altimeter satellites.
GPS	Orbit Determination of GPS satellites Orbit Determination of other satellites with spaceborne GPS receivers Densification of the TRF	Polar Motion Terrestrial Reference Frame UT1-UTC	Plate Tectonics, Crustal Deformation Sea Level Monitoring GPS Meteorology	Co-location of VLBI and SLR sites Orbit determination to support Altimeter satellites, TRF to support All Remote Sensing Satellites, All Communications Satellites
DORIS	Orbit Determination	Terrestrial reference Frame		Obit Support for Altimetry, Sea Level Monitoring, Ocean Circulation
Altimetry TOPEX/ Poseidon Geosat Geosat-FO (future)	Global Ocean Tide Models Sea Surface Topography Gravity Anomalies over the oceans Ocean Circulation		Sea Level Monitoring Ocean Tide Site Deformation	Global Geopotential Models Region and Global geoid determination.
Gradiometry	Earth's gravity field		Sea Level Monitoring	Geoids

PRODUCTS FOR MAPPING, GIS, SATELLITE POSITIONING AND GLOBAL CHANGE MONITORING.

The GDA is defined by the co-ordinates of the AFN within the ITRF92 at epoch 1994.0. These co-ordinates were estimated (at epoch) using GPS observations. By the turn of the century, GDA will provide the horizontal datum for all Mapping and GIS products. The ITRF itself is established by the co-location (and combination) of high precision space geodetic techniques -- VLBI, SLR, LLR and GPS. Figure 1 below, shows the procedure for establishing the ITRF by co-location of techniques. The densification of the ITRF is achieved using the GPS, DORIS and PRARE systems. Geologically or geodetically determined station velocities are applied to update station coordinates for tectonic plate motion.

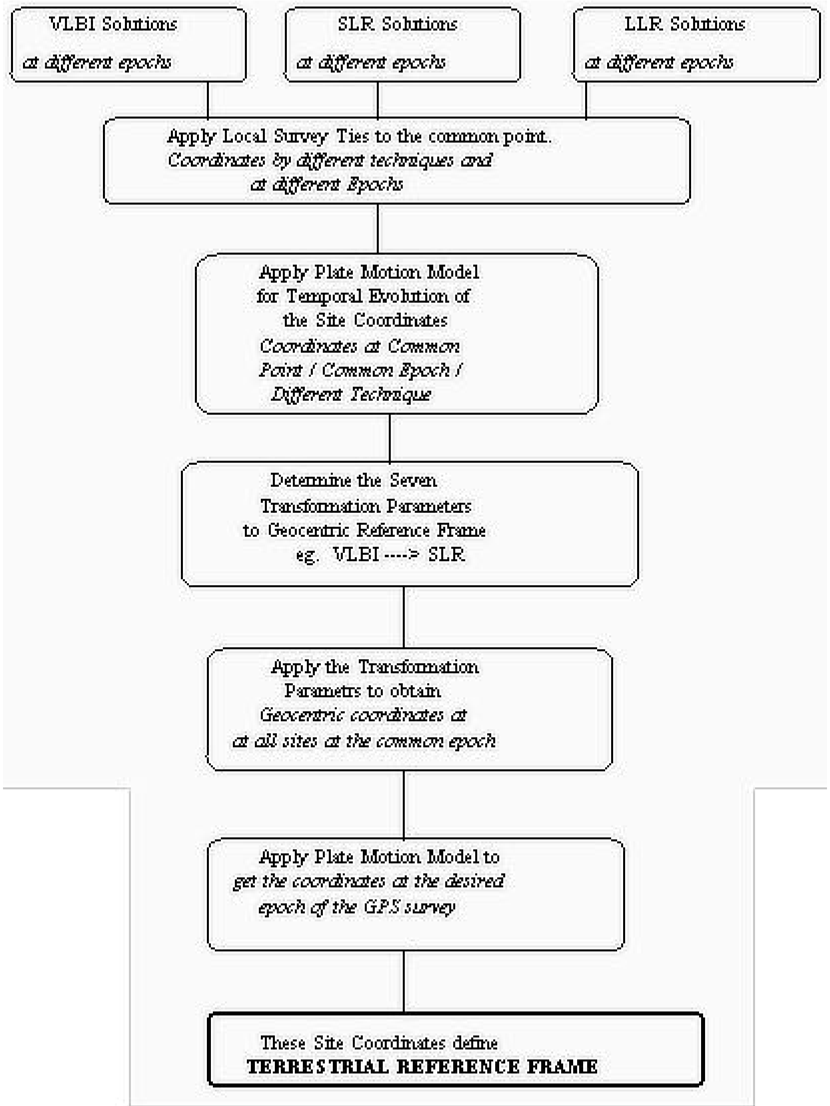

Figure 1 Determination of the Global Terrestrial Reference Frame.

For satellite positioning, for example GPS, the position of the satellite at the observation epoch must be known in the terrestrial reference frame. Hence, the orbits of the satellites are determined in the terrestrial reference frame by tracking them at points with accurate coordinates in, for example, ITRF. However, the orbits of the satellites are integrated in a celestial reference system. Transformation between the celestial and terrestrial systems are obtained through precession and nutation [in addition to the Earth Orientation Parameters (EOP) polar motion and earth rotation]. The unique products of VLBI are the precession and nutation parameters – hence it is the sole technique that provides the relationship between the terrestrial and celestial reference systems. The polar motion and earth rotation parameters for the transformation are obtained as products of VLBI, SLR and GPS. These transformations, and hence the parameters, are required for determining the orbits of all satellites irrespective of their application.

SLR observations are used to determine the precise orbits of satellites that are equipped with retro-reflectors. A list of some of these satellites which have applications ranging from geodynamics, remote sensing to altimetry are given in Table 1. A unique product of SLR is the determination of the Earth's gravity field (geopotential model). Although, the geopotential model comprises of a set of spherical harmonic coefficients, it can be interpreted as a map of the Earth's gravity field and hence, its mass distribution – the shape and size of the Earth.

DORIS and PRARE are used to determine precise orbits of satellites in support of other major functions such as satellite altimetry (TOPEX/Poseidon) or remote sensing (ERS-2). This also applies to spaceborne GPS receivers on satellites such as TOPEX/Poseidon, and MicroLab-1.

The products of satellite altimetry comprise sea surface topography, gravity anomalies over the oceans, ocean circulation and global ocean tide models. Through satellite altimetry, secular changes in ocean levels resulting from say, the greenhouse effect are being detected. Gravity anomalies over the oceans are required for geoid computations and mapping the ocean bed. Ocean circulation maps are correlated with weather patterns – this has become significant in the management and prediction of droughts and floods.

It is now becoming routine to determine the important mean sea level or orthometric height component in mapping using GPS. However, the ellipsoidal height obtained from GPS computations must be transformed into orthometric heights by applying the geoid-spheroid separation. The geoid-spheroid separation is calculated using a global geopotential model and terrestrial gravity data. Future satellite gravity or gradiometry missions will provide significantly improved gravity data and hence more accurate geoids. The accuracies of GPS derived orthometric heights may then approach that of GPS determined ellipsoidal heights.

CONCLUSIONS:

Co-location of high precision space geodetic techniques is fundamental to modern geodesy and mapping; particularly in the context of global change monitoring. The establishment of the global terrestrial reference frame – ITRF --(within which the GDA has been established) is a product of the co-location of VLBI, SLR, LLR and GPS. VLBI being the most precise geodetic measurements and SLR providing the geocentric reference system. Further densification is achieved using GPS, DORIS and PRARE. Further, co-location of techniques provides a measure of the accuracy of the solutions in terms of the common products such as Earth Orientation Parameters, crustal deformation and plate tectonics. VLBI is the sole technique which provides access to the celestial reference system – so important for celestial/terrestrial system transformations necessary for satellite positioning.

The products of the combination of satellite altimetry measurements to the ocean surface with SLR, GPS and DORIS observations for orbit determination are sea surface topography, global ocean tide models, gravity anomalies over the oceans (for geoid computations) and ocean circulation. Secular changes in ocean levels are now being detected as a result of the combination of high precision space geodetic techniques.

These are all products for mapping, GIS, satellite positioning and global change monitoring.