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AuScope Geospatial: Towards a high resolution four-dimensional reference frame

Upgrades usher in new era of precision geodesy

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AuScope is an initiative established under the National Collaboration Research Infrastructure Strategy (NCRIS) to characterise the structure and evolution of the Australian continent. AuScope includes a Geospatial component that will enhance the accuracy and resolution of the National Geospatial Reference System including its temporal variability. This will have a direct impact on the many fields of science and industry that require accurate positioning to improve effectiveness. Ultimately it will also significantly improve the way geospatial data sets can be integrated.

AuScope Geospatial will complement the other geoscience elements of AuScope by providing contemporary estimates of continental deformations including those resulting from plate tectonics stresses and anthropogenic (or human induced) causes. Knowledge of the deformation of the continent will lead to improved assessments of the state of stress of the continental crust and earthquake risk. This supports the development of improved risk mitigation procedures and updating of building codes. The improved understanding of the deformation of the continent will also assist studies of landscape evolution, research into soil types (agriculture) and salinity (land degradation). Geoscience Australia is working collaboratively with the Australian National University, University of Tasmania, Curtin University, and all of the state and territory governments to implement this program over four years to 2011.

AuScope Geospatial will upgrade the ground infrastructure in all four key geodetic areas through:

- Increasing the density of the network of Global Navigation Satellite System (GNSS) Continually Operating Reference Stations (CORS)
- Establishment of an array of radio telescopes for Very Long Baseline Interferometry (VLBI)
- Enhancement of the satellite laser ranging (SLR) capability at Mt Stromlo, in the Australian Capital Territory, to allow more efficient ranging to high-orbiting satellites
- Establishment of a National geodetic gravity monitoring program.

The refinement of the global geodetic frame of reference requires a multi-technique approach. Broadly speaking SLR provides the definition of the origin of the frame (that is, the geocentre). VLBI provides the orientation of the frame within the celestial reference system and the scale of the terrestrial frame. GNSS provides the density of stations within the frame to allow effective monitoring of the global tectonic processes as

Figure 1. Typical AuScope GNSS installation at Norfolk Island collocated with Australian Tsunami Warning Service (ATWS) seismograph station.

well as give users access to the frame. Gravity provides the linkage between the geometric frame and the gravimetric potential surfaces. Refinement of the International Terrestrial Reference Frame (ITRF) is a continual process, and updated versions of the frame are essentially the numerical realisation of the improved accuracy that is seen in each element of geodetic science.

GNSS Continually Operating Reference Stations

Global Navigation Satellite System (GNSS) is a generic term used to describe the US Global Positioning System (GPS) and other constellations such as the Russian Global Navigation Satellite System (GLONASS), that provide geospatial positioning across the Earth (see figure 1). Over the last two decades the GNSS has proved to be a very accurate and efficient method of measuring the tectonic motion of the continents.

By collecting geodetic data from GNSS Continually Operating Reference Stations (CORS), Geoscience Australia is able to measure the relative locations of points up to several thousand kilometres apart with an accuracy to several millimetres. As such, the Australian Regional GNSS Network (ARGN) operated by Geoscience Australia is the national foundation for all positioning applications in Australia. However this network is sparse and tells us little about intraplate deformation and the resultant neo-tectonic stresses. In addition, it does not provide good proximity for the many surveying applications that use the ARGN data.

Figure 2. AuScope Patriot 12 metre VLBI telescope dish to be installed at Katherine, Northern Territory and Mingenew, Western Australia.

The AuScope GNSS network which will be implemented by Geoscience Australia and the state and territory governments is designed to distribute GNSS stations along transects with a nominal spacing of 200 kilometres. Researchers will be able to monitor the deformation of the Australian continent in greater detail in near real-time, and the benefits of such a high-accuracy reference system will flow through to other areas of geoscientific research.

Australian Very Long Baseline Interferometry (VLBI) Array

The Very Long Baseline Interferometry (VLBI) technique was developed in the 1960s and has been used globally for geodetic purposes on a regular basis since 1979. It measures weak radio signals from remote radio sources (quasars) using radio telescopes, and records an interferometric signal from each telescope for processing and analysis. VLBI reveals information that helps to solve many scientific problems, and advances our knowledge of the dynamics of the Earth. It was the first technique that directly measured the motions of the tectonic plates, and since 1998 is the only technique used to fix the Earth's reference frame to celestial reference frames replacing the previous optical astronomy techniques.

The Australian VLBI network constructed and operated by the University of Tasmania will include three 12-metre radio telescopes (see figure 2) located in Hobart (Tasmania), Yarragadee (Western Australia), and Katherine (Northern Territory). Together with other international telescopes they will form a series of baselines that can be used for measuring the deformations of the Australian Plate at a continental scale with an accuracy to a few millimetres. They will also be used in conjunction with the 64-metre dish at Parkes (New South Wales) to effectively form a large astronomical instrument with an aperture the size of the Australian continent to identify the positions of remote quasars.

The geodetic strength of the VLBI technique is its ability to accurately measure the Earth Orientation and Rotation Parameters (EOPs). These are fundamental to the accuracy of orbit predictions for a wide range of satellites including the GNSS constellations. EOPs are also important for studying the natural processes in the Earth's atmosphere, crust, mantle and core and their interaction. The new Australian geodetic VLBI network will improve the accuracy of the daily EOPs and nutation angle estimates to the accuracy of 10 to 30 micro arc seconds.

Beyond the immediate geodetic applications, the VLBI array will also be used for more fundamental science. The array can detect small systematic effects in the quasar apparent proper motion, which can be a sign of cosmologic effects, that is, rotation and anisotropic expansion of the Universe, and primordial gravitational waves.

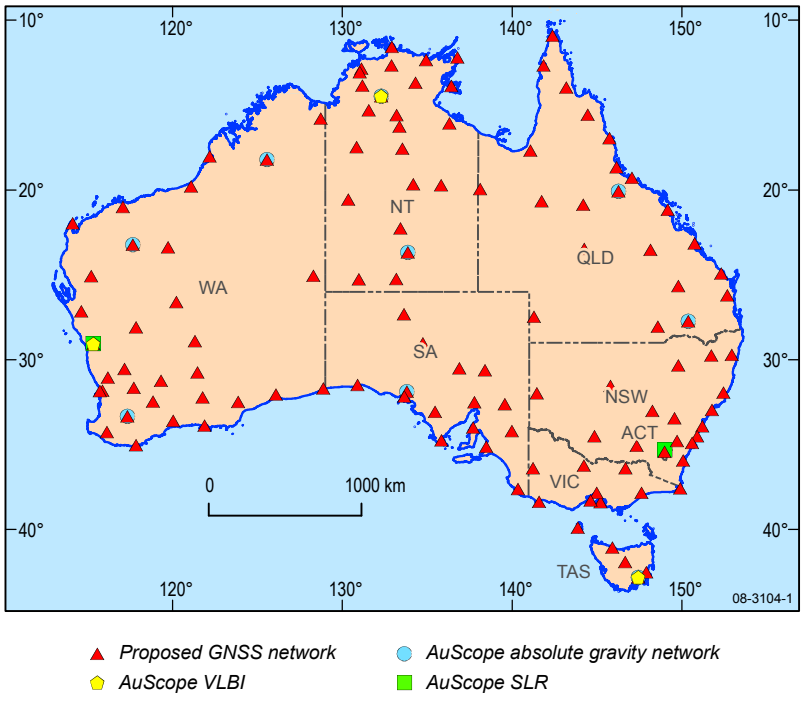

Figure 3. Spatial distribution of AuScope Geospatial infrastructure. The GNSS and absolute gravity stations are indicative only.

Einstein's theory of gravitation can also be tested by observing passages of close large planets such as Jupiter and Saturn in front of quasars to observe the gravitational lensing effect and to measure if the observed behaviour matches the predicted.

Satellite Laser Ranging

Satellite Laser Ranging (SLR) as its namesake suggests measures distances to earth orbiting satellites using a powerful laser to detect a satellite's variation from its predicted orbit. It is uniquely suited to accurately determine the variation of Earth's centre of mass, along with the orbit parameters of satellites orbiting Earth. Data from a global network of SLR stations are used to estimate the orbital parameters of satellites which revolve around the Earth's centre of mass. Therefore the position of Earth's Geocentre, which is the origin of the global reference frame, can be monitored through time.

The Satellite Laser Ranging component of AuScope Geospatial has two primary outputs. The first is the upgrade to the laser power at the Mt Stromlo SLR facility near Canberra, which will improve the efficiency with which the system can range to high Earth orbiting satellites, especially the GNSS satellites. The second is the completion of a mobile SLR campaign for altimeter calibration

at Burnie, Tasmania. This campaign was undertaken primarily by the University of Tasmania using the French Mobile Laser Ranging System. It will allow a calibration of the satellite based altimeter systems that are currently used for measuring the surface heights of the world's oceans which are an indicator of sea level rise.

Gravity Program

Geoscience Australia and the Australian National University are jointly operating the geodetic gravity component of the Program, aiming to improve the understanding of the temporal gravity changes across the Australian continent. The geodetic gravity program has two separate outcomes. The first one is to use absolute gravimetry as an independent measure for vertical movements of the crust and/or other long-term gravity signals of interest. This objective is based on the principle that gravity changes as deformation occurs between the surface and the centre of the Earth. The second objective is to improve our understanding of temporal deformation of the Earth's surface induced by tidal changes on gravity caused by the movements of the sun and moon. These movements also cause ocean tides which deform the surface when large tidal masses of water are moved around the Earth. This deformation can be in the order of centimetres and can affect the other fundamental precision geodetic measurement systems of GNSS, VLBI & SLR.

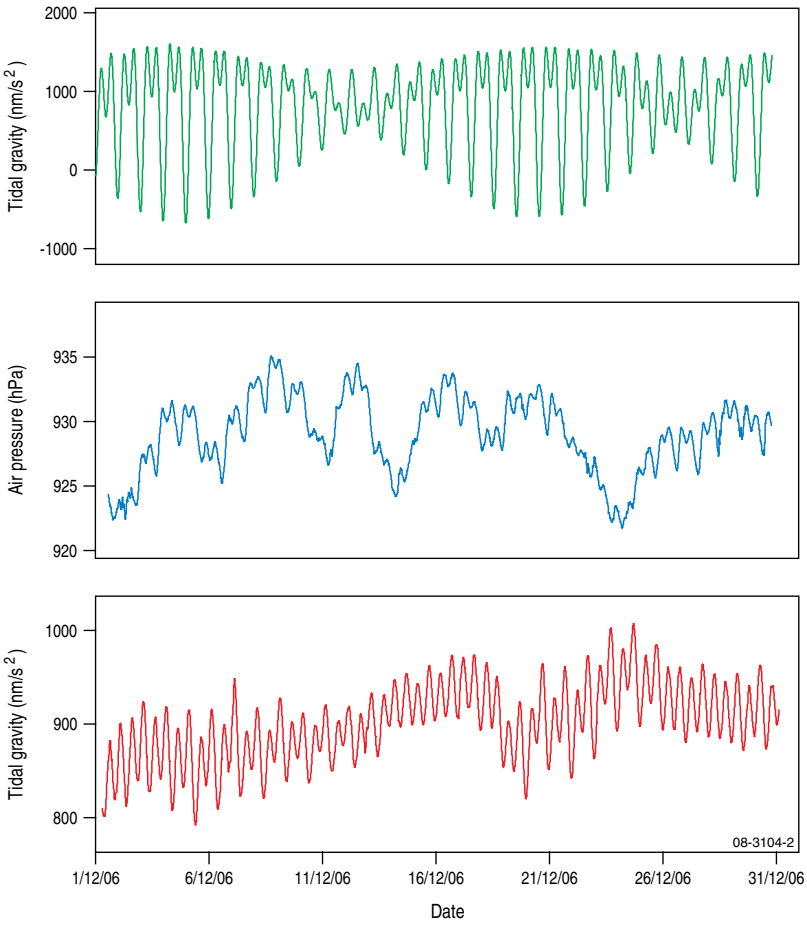

Figure 4. Figure shows tidal gravity recordings recorded over two weeks at Mount Stromlo, Canberra. Signal 1 is the tidal variation of gravitational acceleration in ($nm.s^2 = 10^{-9}$ $m.s^2$). Signal 2 is the atmospheric pressure variation (in hPa) which includes an atmospheric tide. The pressure reflects density changes which register small gravitational changes on the instrument and must be corrected. Signal 3 is the gravitational acceleration, which has been removed from the solid earth tide, leaving a residual with the Ocean Loading and attraction caused by deformation and attraction of large moving masses of tidal water.

The instrumentation and the observation programme is separated into two streams: absolute and relative. The absolute gravity program involves recording 24 to 48 hours of observations using an FG5 absolute gravimeter at around 10 geodetic sites across Australia which are co-located with continuous GNSS CORS (figure 3). The FG5 gravimeter can measure gravitational acceleration (g) to one part in 10^9 (8^{th} decimal place in m s^{-2}), or the equivalent of ~3 millimetres of height change. Therefore, monitoring small gravity changes over long time periods will allow changes in surface height to be accurately measured independently of other survey techniques.

The relative gravity program consists of a series of relative gravimeters suited to tidal gravimetry that will be used to improve the understanding of temporal gravity variations caused by tidal forces. Currently researchers rely on predictive models that have yet to be tested over most of the Australian continent. Currently there is some doubt about the accuracy of the models, particularly in the northern part of the continent. The greatest improvement to the understanding of the tidal models will come from observing the dominant tidal frequencies (which are in the diurnal and semi-diurnal tidal bands, around one and two periods/cycles per day respectively).

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Up to six months of data are required from each site to obtain sufficient precision in the local tidal parameters. Data from many years of observations from sites around the continent are necessary for an improved understanding of the Ocean Loading models that are applied across Australia (figure 4). Although uncertainties in these models provide the most pressing need for Earth tide measurements across the country, building a tidal catalogue across the country will also provide other benefits, potentially including additional knowledge of the Earth's sub-surface structure used for geodynamics research.

Conclusion

The AuScope Geospatial initiative offers an exciting period of research infrastructure development for Australia. The resulting research will herald a new era of precision geodesy previously unseen in Australia. The improved accuracies achieved across these geodetic techniques will be integrated to improve the accuracy and precision of the coordinate reference frame.

A coordinate reference frame with the proposed degree of accuracy will be used by many fields of scientific research including the measurement of the deformation of the Australian continent. For the first time achievable accuracies will allow the detection and subsequent interpretation of geophysical signals that were not previously measurable.

Ultimately, the GNSS network will provide the backbone of a new National Datum and the potential for a series of national and regional real-time positioning services. These will have a direct benefit to road transport safety systems, large scale precision mining, driverless vehicles, precision fertilizer distribution in agriculture, engineering projects and many unforeseen applications that will evolve as the degree of accuracy increases.

Importantly Australia has taken up the challenge of being one of the global leaders in the refinement of the global reference frame, in order to keep Australia competitive in the spatial industry, and all of the related fields of science and industry that rely on accurate positioning.

For more information

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Related websites

The Very Long Baseline Interferometry (VLBI) technique
www.ga.gov.au/geodesy/sgc/vlbi/vlbitech.jsp

Satellite Laser Ranging
www.ga.gov.au/geodesy/slr/