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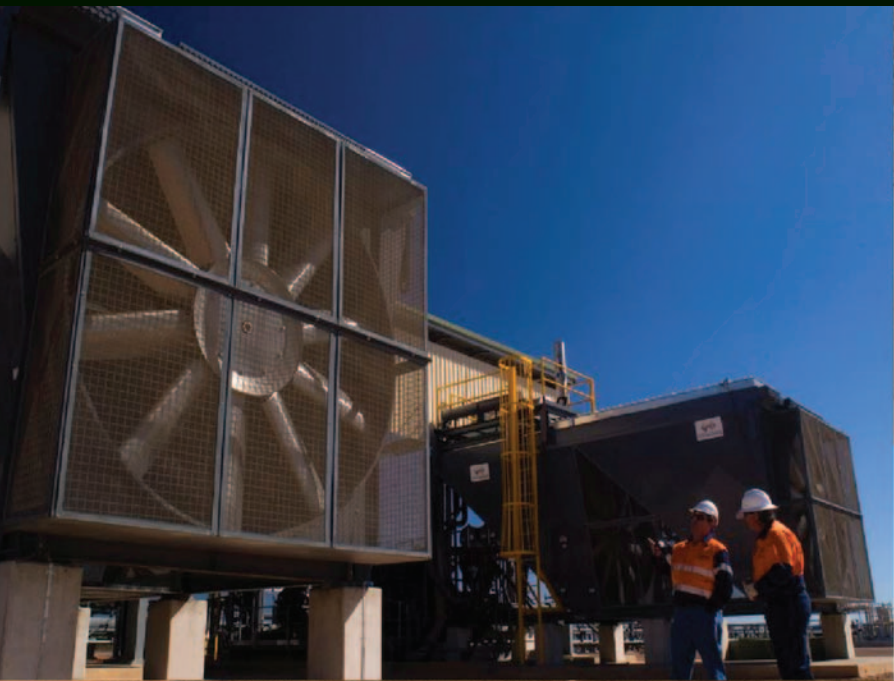
PREVIEW

AUSTRALIAN SOCIETY OF EXPLORATION GEOPHYSICISTS

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TerraWulf II: Many hands make light work of data analysis

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For more than 30 years geophysicists at the Research School of Earth Sciences (Australian National University) have been making use of large computers to analyse data recovered from seismic and other instruments deployed across the Australian continent. This began in the mid-1970s when then Director of the Research School of Earth Sciences (RSES), Prof. Anton Hales, was one of the first to recognise the potential of using computational power to perform the necessary calculations required to build the first depth varying seismic wave speed models of the Australian Lithosphere. In the days before the advent of national or even campus computing facilities, Prof. Hales established an in-house programme of building, running, repairing, patching, and ultimately coaxing the valve driven machines of the day into action. Since that time computational power and demand has grown exponentially, as has the diversity of applications (even within geophysics) that have made use of it.

In 2008, RSES launched the latest in a long line of dedicated computing facilities, TerraWulf II. As the name suggests, this is the second of its particular species. The first, built in 2003, capitalised on a worldwide trend of combining off the shelf PC computers to form a highly cost effective (BeoWulf) supercomputer. The second, TerraWulf II (or TII as it is known to users) has 10 times the compute power of TI (~1.5 Teraflops) and occupies one quarter of the room space. Its construction was a joint venture between ANU (through RSES) and AuScope Ltd (The Earth Science infrastructure initiative funded through the Federal Government's National Collaborative Research Infrastructure Strategy program). TII was designed primarily for use in earth imaging and geospatial applications however scientists are constantly finding new and innovative ways to exploit its power and convenience. For the technically minded the specifications of TII are summarised as follows: a cluster of 96 IBM x3455 compute nodes and one IBM x3655 head node. There are two AMD Opteron Dual-core 2.8 GHz processors per node, each with 160 GB SATA Hard Disk and 9 GB (or 17 GB for 24 nodes) DDR2 Memory. The communication network consists of Gigabit Ethernet with 48 nodes, also connected through higher speed Voltaire infiniband switches.

A key difference between modern computational clusters like TII and the earlier machines at RSES is the focus on parallelism. The increase in processing power of each generation of micro-processors has begun to slow down, however computational gains can still be made by combining multiple processors together to perform complex calculations. Hence the rise of parallel based clusters like TI and TII. The initial uses of parallel computers (more than 10 years ago) were largely in areas involving highly advanced simulations of physical phenomena, e.g. weather prediction, ocean modelling, mantle convection and seismic wavefield simulation through complex media. As a consequence, parallel computing facilities gained a reputation for being highly exotic and only for the specialised user. In recent times, this situation has begun to change, as the power of parallel computing has become accessible to a much wider range of scientists, even those without the interest in or need for advanced computational methods. A prime driver is the need to analyse data from large spatial arrays of instruments being used to build earth observing datasets, a task which is often particularly suited to parallelism. TII is increasingly being used for this type of 'loosely coupled' calculation.

An example is the geospatial scientist who has to perform the same processing tasks on many separate subsets of data independently (e.g. one analysis for

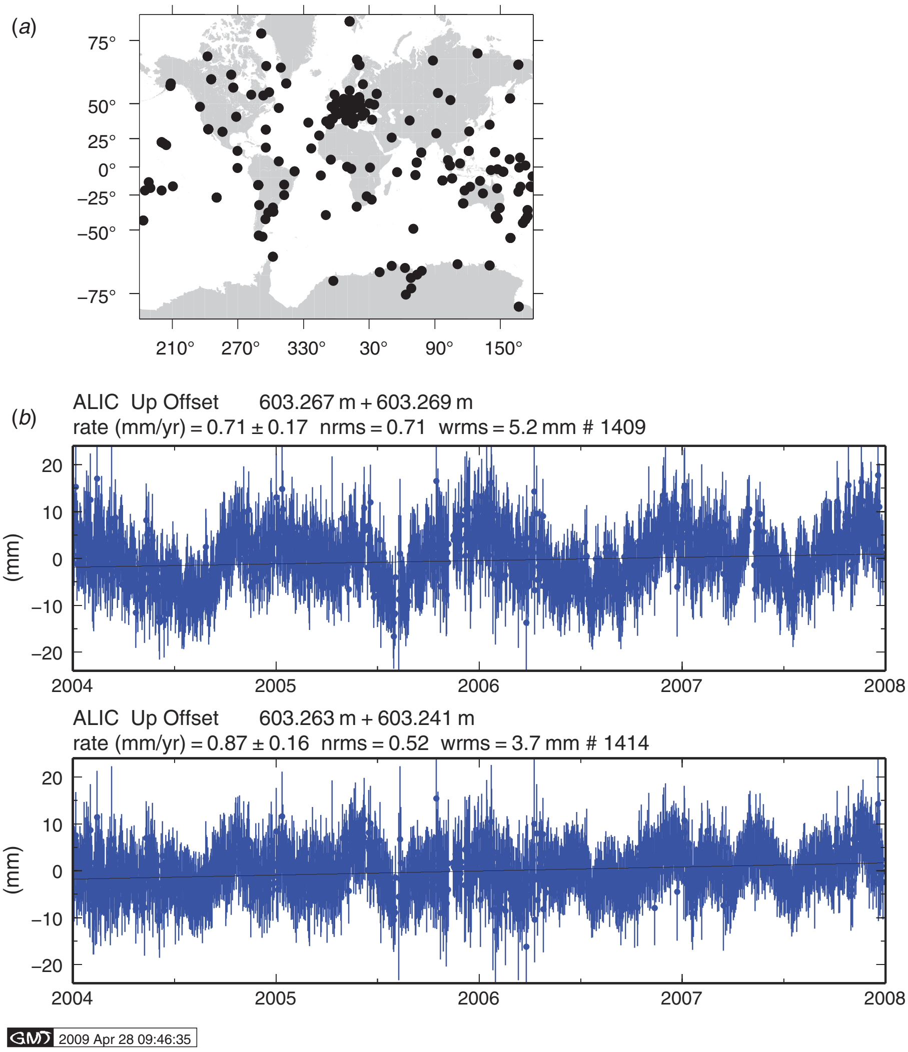

Fig. 1. *(a) Map of GPS site locations used in the analysis (left). The time series of the height estimate of the site at Alice Springs, NT, (b) from the original analysis (upper right) and (c) the refined analysis (lower right). The weighted root-mean-square of the daily height estimates has been reduced from 5.2 to 3.7 mm.*

each day of recorded observations). This is illustrated in the first example below. With a cluster of computers, each independent job is performed simultaneously in parallel meaning that the whole task can be achieved in a fraction of the time that it would normally take with single processor workstations. Another example is in the use of Monte Carlo based data inference (inversion) methods where many independent potential solutions to a problem need to be tested against the data, e.g. seismic models of the Earth interior fitting observed travel times or waveforms. This is illustrated in the second example below. TII has been used for both types of calculation, as well as the more traditional simulation of geophysical phenomena using advanced computational techniques. In its short life it has already racked up over seven hundred thousand cpu-core hours of use across applications ranging from earth imaging, geospatial analysis as well as simulation of geophysical processes from the Earth's surface to its core. In addition it has been used as a test bed to develop a new generation of data inference tools. We present two examples below of recent applications.

Assessing processing strategies in GPS analyses

The ability to estimate position using the Global Positioning System (GPS) has decreased from ~0.2 m in the 1980s to around 1–2 mm today. Recent improvements have resulted not only from an enhanced global tracking network but also from improvements in modelling of the propagation of the GPS signals through the atmosphere, deformation of the surface from atmospheric pressure loading and ocean tide loading (the increase/decrease in ocean and atmosphere mass causes elastic deformation of the surface of the Earth that can be detected in high-accuracy GPS analyses).

In a recent study utilising the TII, Tregoning and Watson (2009) analysed GPS observations on a global network of over 80 sites (Figure 1*a*). The analysis was performed using several different mathematical functions to represent

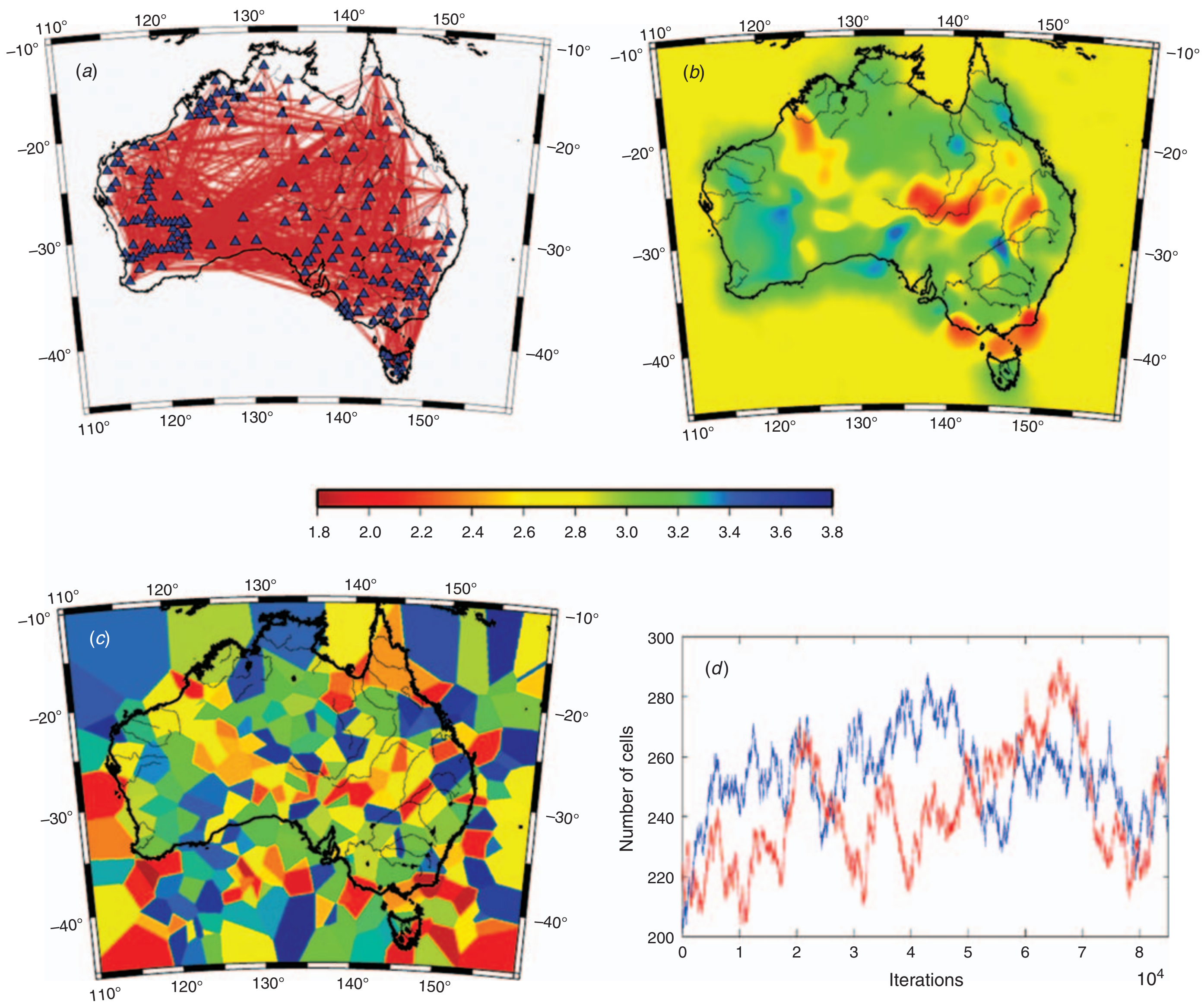

Fig. 2. *(a) Ray path density for 1158 rays in ambient noise dataset of Saygin and Kennett (2009). (b) Shear wave speed model produced by averaging 8000 models generated by the Bayesian Monte Carlo procedure, (c) best fit model obtained, (d) number of cells in the model as a function of iteration. Red and blue lines represent results from two of the 200 independent random walks through the model space.*

- the atmospheric delay at any angle,
- the *a priori* hydrostatic delays in the vertical direction, and
- different models for the atmospheric pressure deformation, including the once/day and twice/day atmospheric tides (which cause periodic deformation of up to 1.5 mm in height).

Eight years of data were analysed and the resulting time series of positions for each site were assessed in the time and frequency domains to ascertain which suite of models yielded the 'best' solutions. On a single CPU, the analysis undertaken in this study would have taken over 23 years to complete. Only the efficient power of the TII could enable such a study be contemplated seriously.

Figure 1*b* shows time series of height estimates at the GPS site near Alice Springs, NT, using processing strategies typical of the 1990s as well as those considered to be the most accurate today (Figure 1*c*). There is a clear decrease in coordinate variation, demonstrating that the new modelling techniques yield more accurate estimates.

Imaging the seismic structure of the Australian continent

Figure 2 shows results from a new Bayesian Monte Carlo seismic imaging procedure developed on TerraWulf II. Unlike standard approaches that gradually refine a single image of the Earth's interior, this new approach reported by Bodin *et al*. (2009) refines an ensemble of many potential solutions. Here ambient noise seismic data from Saygin and Kennett (2009) are used to generate an image of the Rayleigh wave group wave speed of the Australian upper crust. A unique feature of the process is that both the surface wave velocity and the underlying cellular parametrization are solved for simultaneously. Figure 2*c* shows the best data fit model, which is relatively crude, but the average of 8000 final Earth models (Figure 2*b*) shows detailed features that correlate well with surface geology. In this example 17 million different Earth models were tested against the data, a feat that is only practical when the computation is spread across 200 cores of TerraWulf II.

These examples show how cluster-computing facilities like TerraWulf II are becoming an invaluable tool to the geophysicist. Clusters have been proliferating in research institutions, business and industry in recent years and as more applications evolve we can expect demand for such facilities to increase in the future.

Acknowledgments

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References

Bodin, T., Sambridge, M., and Gallagher, K., 2009, A self-parametrizing partition model approach to tomographic inverse problems: *Inverse Problems*, **25**, 055009, doi:10.1088/0266-5611/25/055009.

Saygin, E., and Kennett, B. L. N., 2009, Ambient seismic noise tomography of Australian continent: Tectonophysics, doi: 10.1016/j.tecto.2008.11.013.

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Research Foundation supports seven new projects in 2009

This year the Research Foundation received a total of thirteen applications to support new projects. Of these the Research Foundation committees have recommended seven. The following projects have been made offers:

In Petroleum:

- University of Queensland – BSc (Hons) – $4900
  'Optimization of sweep parameters and pre-correlation processing for Envirovibe seismic sources'
- University of Queensland – BSc (Hons) – $4900
  'Understanding very-shallow seismic reflection using acquisition modeling'
- University of Adelaide – David Tasson – PhD – $24 100 over three years
  'Uplift of the Otway Basin and implications for hydrocarbon exploration: integrating seismic with palaeoburial proxies'

In Minerals:

- Monash University – Brenton Crawford – PhD – $30 000 over three years
  'Defining the margins of Australia's ancient geological cratons from gravity and magnetic fields'
- University of Western Australia – Roger Clifton – PhD – $3000 over three years
  'Geophysical studies of the Kalkarindji flood basalts of the Northern Territory'
- RMIT University – Lachlan Hennessy – BSc (Hons) – $4900
  'Transform of coincident loop EM data to equivalent potential field responses'

In Engineering:

- Macquarie University – Jaime Lovell – BSc (Hons) – $4000
  'The usefulness of MASW in delineating soils'

Congratulations to the recipients and I wish them every success with their projects. We all look forward to hearing about the results at future ASEG conferences.

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Phil Harman
Chairman, ASEG RF Committee