GEODYNAMICS

Research within the Geodynamics Group covers a number of areas: (i) modelling of tectonic processes, including surface processes, (ii) precise geodetic monitoring and analysis of crustal deformation, and (iii) glacial rebound and sea-level change. Surface process studies address issues related to landscape change under fluctuations of climate and tectonic forces. Particular processes investigated include soil transport mechanisms and glacier erosion. Lithospheric tectonic studies have included the three-dimensional modelling of the accretionary prisms that form at some subduction zones. Geodetic monitoring studies include two long-term projects in contrasting environments: the measurement of crustal deformation in Papua New Guinea and in Antarctica. The former project aims to define the major regions and styles of deformation which serve as boundary conditions on models for crustal tectonics. The latter project aims to measure slow movements resulting from past and present changes in the Antarctic ice load as well as any internal tectonic deformations of the Antarctic Plate. The group also operates a superconducting gravimeter as part of an international network of instruments to monitor and analyse deep and global geodynamic problems. Glacial rebound and sea-level research is aimed at understanding interactions between ice sheets and sea level during glacial cycles. Projects in 2000 have included studies in Antarctica, Greenland, Northwestern Australia, Europe and Barbados. Some highlights from each of the three broad research areas include:

(i) Study of landscape evolution in the presence of mountain glaciation. work on glacial erosion has brought new insight into the balance between tectonics, erosion and climate in active orogens. It has been shown for example, that, in the Southern Alps of New Zealand, geomorphic steady state has never been reached in the last two million years because the rate of climate change is too rapid to allow the landscape to reach equilibrium with the dominant landforming mechanism. Also, from a combination of geochronological data with morphometric measurements at a site in the Bega Valley, it has been possible to constrain the contribution to local soil transport from a variety of commonly assumed processes, and provide strong constraints on the various time scales characterizing soil movement on hill slopes in southeastern Australia.

(ii) Monitoring of the pre-seismic deformation across the South Bismarck and Pacific Plates and of the immediate post seismic deformation after the magnitude 8.0 New Ireland earthquake (Papua New Guinea): a longer-term post-earthquake monitoring program has been initiated but the initial results indicate that movement occurred on the Weitin Fault as mainly strike slip-motion, with the entire eastern end of New Britain having been rotated in a south-easterly direction relative to central New Britain. Movements of more than 1 meter have occurred a few tens of kilometers from the fault. The current and planned observation program is aimed at establishing the stress-cycle across a broad zone of deformation on either side of the fault.

(iii) Definition of the changes in ocean volume during the last glacial cycle from about 40,000 years ago to the present: new field data from Papua New Guinea and northwestern Australia, combined with published data and with models of glacio-hydro-isostatic rebound have been used to establish the changes in global sea-level from the period leading into the Last Glacial Maximum and then up to the present. The results indicate that the initiation of the peak glaciation occurred rapidly and that, once attained, it persisted for nearly 10,000 years. During an earlier period, Oxygen Isotope Stage.3, ice sheets changed rapidly by volumes equivalent to that of the former Scandinavian ice sheet, and periods of rapid rise appear to be associated with the Heinrich events noted in Atlantic sediment cores. The final deglaciation phase was also non-uniform, with several episodes of rapidly rising sea level.

Four theses were submitted: Julie Quinn, David Burbidge, Kevin Fleming and Jonathon Tomkin. Dr Johnston has left the group to join the private sector.

MODELLING OF TECTONIC PROCESSES AND LANDSCAPE EVOLUTION

On the nature of soil transport mechanisms

J. Braun, A. Heimsath[1] and J. Chappell

Proper parameterization of the transport laws operating on soil-mantled landscapes has basic implications not only for predicting how landscapes change under fluctuations of climate and tectonic forces, but also for better understanding how human land management can affect the landscape. Landscape evolution models have commonly made use of a linear sediment transport law, which sets the transport flux equal to a linear function of topographic slope. Recently, we have used soil production rates determined from concentrations of ^{10}Be and ^{26}Al as well as high resolution measurements of soil depth and topographic form to calibrate a new process-based landscape evolution model that combines sediment transport by simple creep, overland flow, and depth-dependent creep.

The model predicts that the various transport processes are active on different parts of the landscape. Simple creep dominates in regions of high slope, overland flow dominates in region of topographic convergence and depth-dependent creep dominates in regions of high soil thickness at lower levels. Soil production is greatest in regions of high negative curvature, i.e. near the top of the hills.

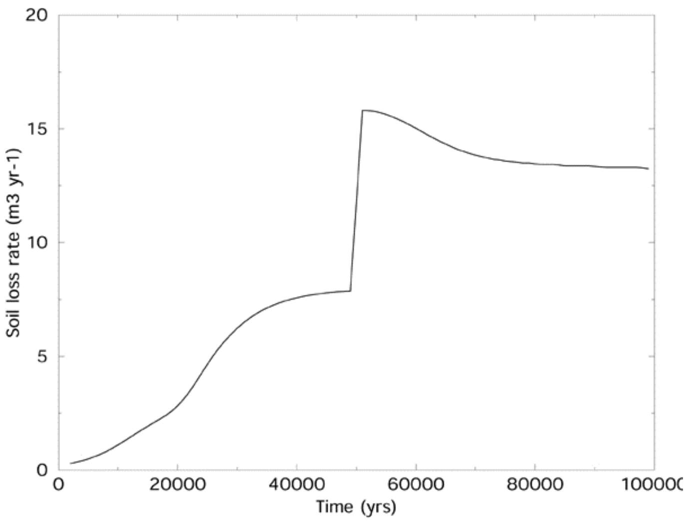

Figure 1: Predicted soil loss rate out of the modeled landscape for a set of model parameters constrained by the cosmogenic and geomorphometric data from the Bega Valley site. All transport parameters were artificially doubled at time t=50,000 yrs to simulate the effect of a rapid change in climate, such as a glaciation. The results show that it takes approximately 50,000 yrs for the system to adjust to changes in environmental conditions.

Using the new model and input parameters constrained by field observations and exposure age data, we were able to determine an empirical expression for the response time of the landscape to external forcing that shows strong dependence on the relief, independent of the soil production rate. Global applicability of this new parameterization that accurately predicts hill slope evolution following the propagation of southeastern Australia's great escarpment is suggested. It may be used, for instance, to quantify upland carbon storage and removal, predict impacts of deforestation, and identify the frequency and magnitude of landslides.

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[1]Now at Dartmouth College, Hanover, USA

Landforming processes in glaciated orogens

J. Tomkin[2] *and J. Braun*

The interplay between tectonics and erosion in active compressional orogens has recently received much attention. While most studies have emphasized the role of fluvial and hill slope processes, it is well known that a large number of orogens have experienced significant glacial cover and thus were affected by glacial erosion during their development. In order to investigate the role of glacial erosion on the geomorphic and tectonic evolution of active orogens, we have developed a new surface processes model (ICE CASCADE) that incorporates ice flow calculations. Ice thickness and deformation are estimated over a two dimensional grid using a finite difference scheme. The model incorporates sub-glacial water flow, varying basal temperature and movement via both internal deformation and basal sliding. The rate of glacial erosion is proportional to the basal sliding velocity. The model also incorporates fluvial erosion proportional to stream power, orographic precipitation, lithospheric flexure and tectonic uplift.

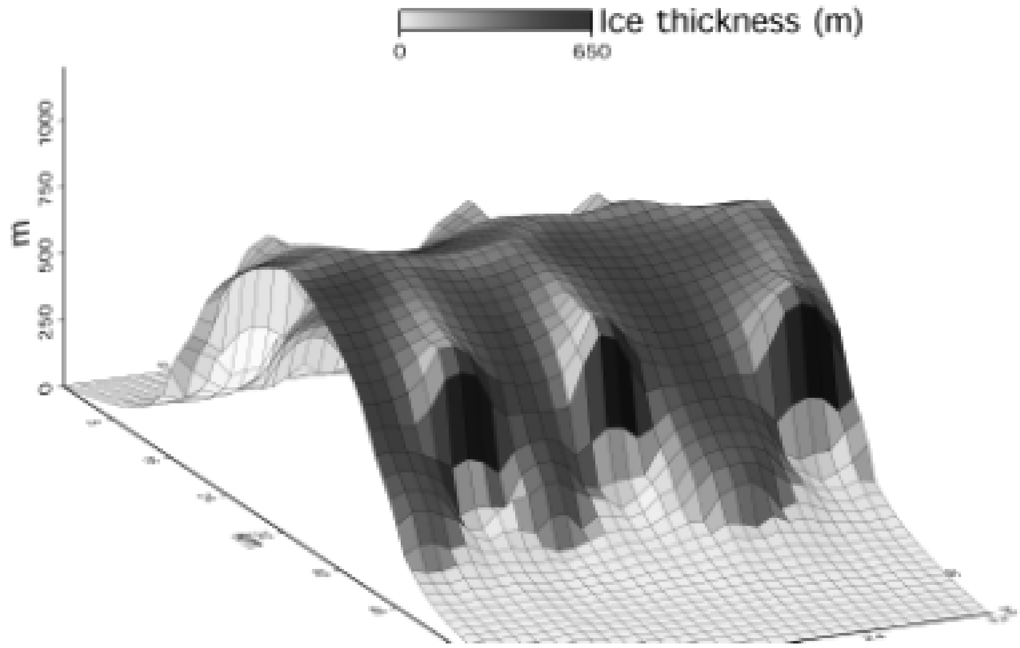

Figure 2: Results of the model at the peak of a glacial cycle showing the extent of the ice, coloured in shades of grey, over the bedrock surface. The left- and right-hand sides are characterized by cyclic boundary conditions. Note the Piedmont glaciers that have formed in each valley and are eroding the underlying bedrock to form glacial cirques and U-shaped glacial valleys.

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[2] Now at Department of Geology and Geophysics, Yale University, New Haven, CT, USA

Using this model we have demonstrated that, contrary to an earlier proposal that a cooler climate will lead to enhanced erosion, the creation of relief, and an isostatically-driven uplift of mountain peaks, relief is in fact reduced by glaciation. This is because glaciers (a) concentrate erosion near the peaks and (b) reduce fluvial erosion downstream. Under some circumstances, relief may be generated when the ice is frozen to bedrock near the peaks, and isostatic uplift at the mountain peaks may be generated by enhanced glacial valley erosion. However, unless the overall rate of erosion drops during glacial periods, our model predicts that relief is lowered by glaciation.

We also demonstrated that a feedback effect between topography and ice thickness exists by which ice masses in active orogens may oscillate in size without climate change. The surface processes model was used to show that the period of this oscillation is inversely proportional to the rate of tectonic uplift and is between 10,000 and 100,000 years in duration. The erosion-driven oscillation can act to reinforce the effect climate variation has on the size of ice masses.

Finally, experiments where model parameters are chosen to create an orogen similar to the Southern Alps of New Zealand and in which the orogen's asymmetry in topography, precipitation and metamorphic grade is reproduced, suggest that the recent glacial periods experienced by the Southern Alps are responsible for the lack of geomorphic steady state on both sides of the divide. Western draining rivers are incising at a greater rate then they are being uplifted as they are responding to the change in landform caused by the recent Otira glaciation.

Three-dimensional numerical models of accretionary prisms

D. R. Burbidge and J. Braun

The Earth's crust is broken up into tectonic plates. Occasionally these plates collide and one plate slides beneath another in a process known as subduction. The top part of the subducting plate (the upper crust) is scraped off and builds up against the over-riding plate to form an accretionary wedge or prism. Most numerical models treat this as a "head-on" collision, i.e. the angle between the direction of motion of the subducting plate and the over-riding plate is 90 degrees. This has the advantage of making the problem two-dimensional. However, most collisions are not head-on, but occur at an oblique angle which varies from one plate boundary to another. In order to understand this type of problem we need a numerical model which is fully three-dimensional.

We have extended our two-dimensional numerical model described in the 1999 Annual Report to examine three-dimensional crustal deformation problems. We have used this new model to study the effect known as strain partitioning at obliquely convergent plate boundaries. At some oblique boundaries, the strain generated by the subduction process is separated onto two separate fault systems (e.g. the San Andreas fault system) and in others all the strain is accommodated along a single fault system (e.g. the Southern Alps, New Zealand). Some models of this process indicate that the change from a partitioned state to a non-partitioned state occurs suddenly at a critical obliquity angle. Others argue that the change is a gradual one. We have conducted a range of three-dimensional numerical models of this process. Our results are consistent with a gradual change in the amount of partitioning as the obliquity angle changes from a head-on collision to a glancing collision.

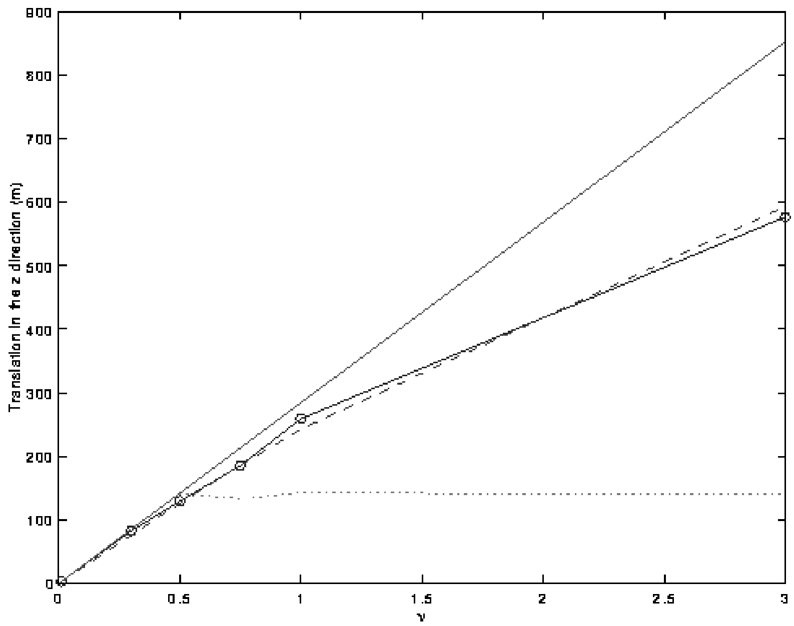

Figure 3: Amount of displacement of an accretionary prism in the z direction (parallel to the plate boundary) versus the obliquity ratio, ν. When the obliquity ratio is zero the collision is head on (i.e. there is no z translation). As the ratio increases the collision becomes more oblique and there is more displacement in the z direction (solid line). The line with the circles are the amount of this displacement which is conferred to the prism in our numerical model. The dashed line is the theoretical model when there is a gradual change in strain partitioning. The dotted line is the theoretical model which assumes that there is a sudden change in partitioning at a critical obliquity. Our numerical results are consistent with the former but not the latter.

GEODETIC MONITORING OF MOVEMENTS AND DEFORMATION OF THE CRUST

Monitoring present-day tectonic motion in Papua New Guinea

P. Tregoning, H. McQueen, R. Stanaway, S. Saunders[3], R. Curley[4], and K. Lambeck

In 2000 Richard Stanaway was employed to organise and conduct Global Positioning System (GPS) observations on a network of sites spanning most of Papua New Guinea. As in previous years, the considerable support received from the Papua New Guinea University of Technology at Lae and the Rabaul Volcano Observatory enabled a cost-effective and comprehensive fieldwork program to be completed. The fieldwork was carried out over a four month period from July and included observations at over twenty sites. A new network was installed spanning the Bismarck Sea Seismic Lineation near Wewak (including five sites on islands in the Schouten Islands group) and the 1998 network in the New Ireland/New Britain region was re-observed. An additional three sites were installed on New Ireland, providing greater densification of the network near the Weitin Fault.

[3] Rabaul Volcano Observatory, Papua New Guinea

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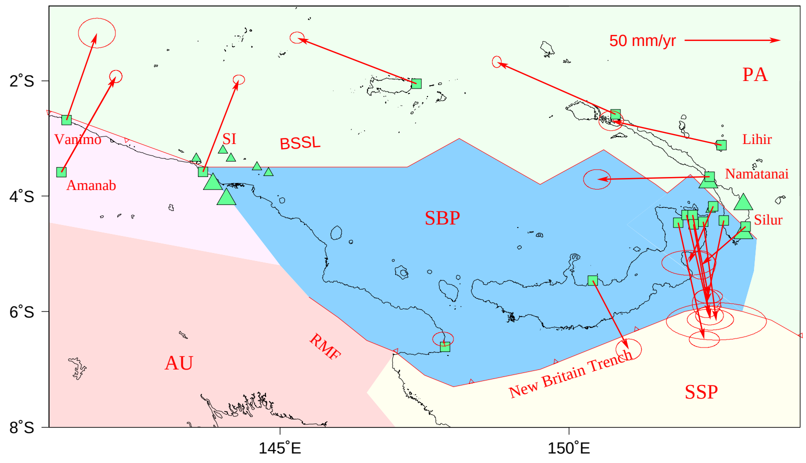

Figure 4: GPS sites observed in 2000. Observations were made at 16 existing sites (squares) and 11 new sites (triangles) were installed. New site velocities estimated in 2000 are shown. BSSL: Bismarck Sea Seismic Lineation; RMF: Ramu-Markham Fault; SI: Schouten Islands.

While the main focus of the field campaign in 2000 was to initiate a monitoring network near Wewak and to improve the distribution of sites near the Weitin Fault in New Ireland, repeat observations on some sites first observed in 1998 have led to new site velocity measurements. In particular, velocities at Amanab, Vanimo and Wewak show internal deformation within the northern margin of the Australian Plate, while velocities at Namatanai, Silur and Lihir are affected by the interseismic strain accumulation on the Weitin Fault.

The November 16, M_w=8.0 New Ireland earthquake, Papua New Guinea

P. Tregoning, H. McQueen, R. Stanaway, S. Saunders[3], R. Curley[4], and K. Lambeck

On 16 November a magnitude 8.0 earthquake occurred about 40 km northeast of Rabaul between New Britain and New Ireland. It was a shallow, sinistral event which released accumulated strain between the South Bismarck and the Pacific Plates and is the largest recorded event in this region. The US Geological Survey point source location for the event is at the prolongation of the Weitin Fault to the northwest, while the Harvard CMT solution has a similar focal mechanism but locates the centroid moment tensor at the southeastern end of the Weitin Fault in New Ireland, suggesting that the whole length of the Weitin Fault may have ruptured.

The GPS network spanning the boundary between the South Bismarck and Pacific Plates was observed only weeks before the earthquake. Post-seismic re-observations at the sites by staff at Rabaul Volcano Observatory and the University of Technology immediately after the event allowed co-seismic displacements to be estimated. As much as 1.2 meters of horizontal motion was detected at sites to the southwest of the fault, with the magnitude decreasing approximately linearly further from the fault. These geodetic displacements will be inverted to estimate fault characteristics of locking depth, length of rupture and the dip of the fault. The available geodetic information will provide more information about the earthquake, the release of strain and the tectonic regime of the area than is currently available from the global seismic data.

[3] Rabaul Volcano Observatory, Papua New Guinea
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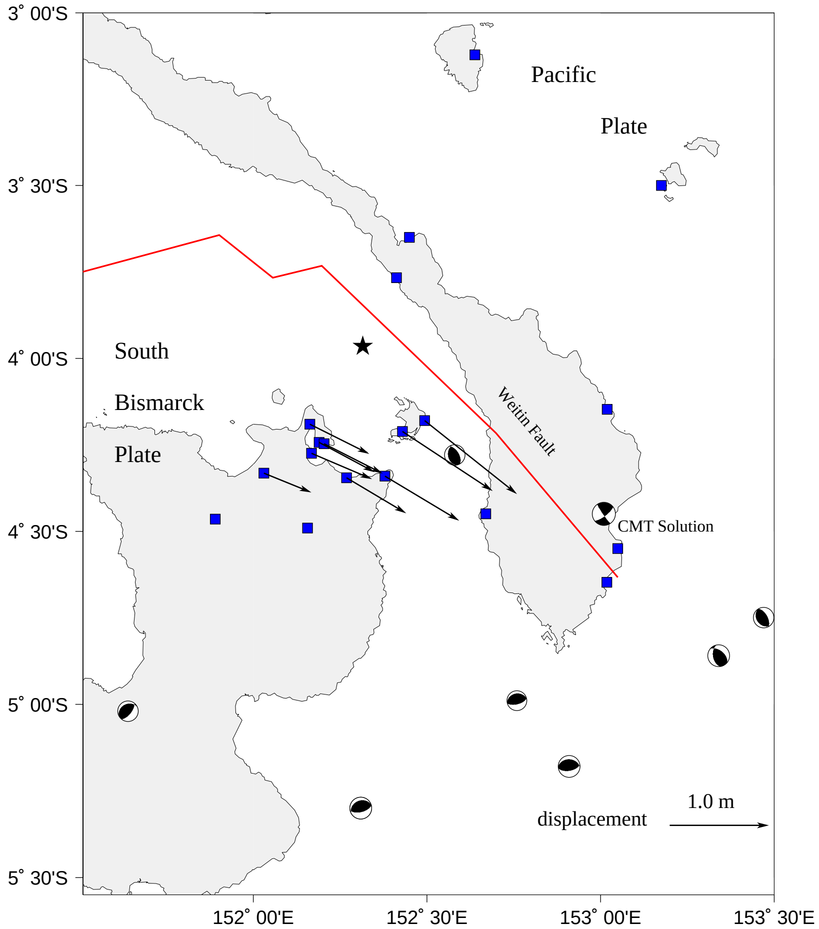

Figure 5: Co-seismic displacements deduced from GPS observations before and after the M=8.0 earthquake. The US Geological Survey focal mechanism for the event is plotted at their estimate of the location.

Measuring postglacial rebound near the Lambert Glacier, Antarctica

P. Tregoning, H. McQueen and K. Lambeck

In February 2000 the Beaver Lake GPS installation was visited and found to have collected data until 22 February 1999 when the GPS receiver's memory filled. An additional 21 days of data were retrieved. The sophisticated power monitoring system developed at RSES during 1999 was installed along with a hydrogen fuel cell and satellite phone. Data were transferred automatically from Beaver Lake to Canberra for a few days before a software problem caused a failure of the data transmission procedure. The GPS equipment was left operating. New sites were installed at Dalton Corner at the southern end of the Mawson Escarpment and Landing Bluff at the northeastern edge of the Amery Ice Shelf. The equipment at Landing Bluff was removed at the end of the summer season while that at Dalton Corner was left to operate throughout the winter.

In addition, a test system was installed at Davis to monitor the operation of a fuel cell as well as the performance of our electronics systems. The fuel cell suffered a fatal internal fault and was returned to Canberra for repair at the end of the summer season; however, the electronics equipment remained at Davis and operated properly throughout the winter. In particular, it was found that the batteries had continued to supply power to the 0.6 W power controller throughout the winter and that, with some firmware modifications, it would be possible to "hibernate" the system at the end of summer and to have the equipment recommence observing the GPS satellites when sufficient solar power returned. Such modifications were made to the power controller during 2000 in preparation for deployment for the 2001 winter.

In October 2000 our field party returned to Landing Bluff and installed a solar-powered system including a GPS receiver, satellite phone and power controller. Data have been transferred back to Canberra on a daily basis since December 2000. Unfortunately problems with helicopters prevented the field party from accessing the Dalton Corner site and we will not be able to retrieve data from 2000 until the next season, nor have we been able to install new equipment for operation in 2001. The equipment at Beaver Lake was found to have recorded GPS data until 20 February 2000 and environmental data until May 2000 before the batteries failed.

Figure 6: Equipment installed at Beaver Lake in February 2000. The white radome of the satellite phone can be seen between the solar panels, while all the electronics equipment is stored inside the silver box.

Analysis of the data recorded to date shows that there is no significant relative uplift between Mawson and Beaver Lake. This result will be used to constrain ice models of the Antarctic region in order to model the postglacial rebound of the continent.

Super-Gravimetry

H. McQueen , K. Lambeck and T. Sato[5]

The Geodynamics group in RSES operates a Superconducting Gravimeter (SG) at Mt Stromlo in collaboration with the Japanese National Astronomical Observatory, Mizusawa. The SG is currently the most sensitive type of gravity meter, with a sensor consisting of a niobium sphere cooled to a superconducting state in a liquid helium bath and levitated by a magnetic field in an evacuated chamber. Gravity fluctuations down to one part in 10^{12} of earth's surface gravity can be determined by accurate monitoring of the sphere's position. The facility is part of the Global Geodynamics Project (GGP), an international network of gravimeters attempting to detect motions in the earth's deep interior, infer details of its internal structure, and provide information on a range of problems in global geodynamics. Data from the site is regularly archived at the GGP data centre in Brussels.

Mt Stromlo gravity station continues to operate successfully as one of the most sensitive of the worldwide SG sites. A new calibration with the Strasbourg FG5 absolute gravimeter was performed at the station in March during a visit by Dr Martine Amalvict from EOST at the Université Louis Pasteur in Strasbourg with support from AUSLIG. Such determinations provide the necessary calibration of the super-conducting instrument and permit the measurement of its drift characteristics and the secular change of gravity at the site, which is essential for the analysis of processes acting on timescales of years.

The annual variation of gravity at a site contains contributions from several processes including solid earth tides, polar wander (movements of the earth's rotation axis), ocean tides, and non-tidal environmental variations in ocean loading. Recent calculations have used the record at Canberra in a comparison with predictions based on the effects of satellite determined sea-surface height fluctuations. These comparisons indicate that gravity variations at the current levels of accuracy are affected by annual changes in the water mass and volume of ocean basins, and are even sensitive to the value of the steric coefficient which relates sea surface height to mean ocean temperature. While these phenomena are presently at the limits of sensitivity, continuing observations with these exceptionally stable instruments are steadily increasing the effective sensitivity.

ICE SHEETS, SEA LEVEL AND MANTLE VISCOSITY

Changes in ocean volumes during the past 40,000 years

K. Lambeck, Y. Yokoyama[6]*, A. Purcell, and P. Johnston*[7]

Sea-level change caused by the growth or decay of ice sheets is spatially variable because of the adjustment of the earth's surface to the time-dependent ice-water load and because of the changing gravitational potential of the earth-ocean-ice system. Observations of relative sea-level change therefore do not bear a simple relation to changes in ice volume (or ice-equivalent sea level), and at most localities corrections for glacio-hydro-isostasy are required. Changes in ocean volume inferred from sea-level data will therefore be dependent on models of glacio-hydro-isostasy and will be functions of the spatial and temporal distribution of the ice load and on the rheological response of the Earth to surface loading. However, through an iterative approach, useful estimates of grounded and land-based ice volumes can be inferred from sea-

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[5] Japanese National Astronomical Observatory, Mizusawa
[6] Now at Lawrence Livermore Laboratories, California
[7] Now at MITS Logica, Perth WA

level data, particularly when the data is from sites that lie far from the former ice sheets, so that the otherwise dominant glacio-isostatic term is relatively small. Earlier estimates of changes in ice volume have been made through some improvements in the theory for the isostatic effects and through additional observational sea-level evidence from different localities around the world, including Papua New Guinea and the Northwest Shelf of Australia. This has been combined with published data from other localities to produce a new estimate of changes in the

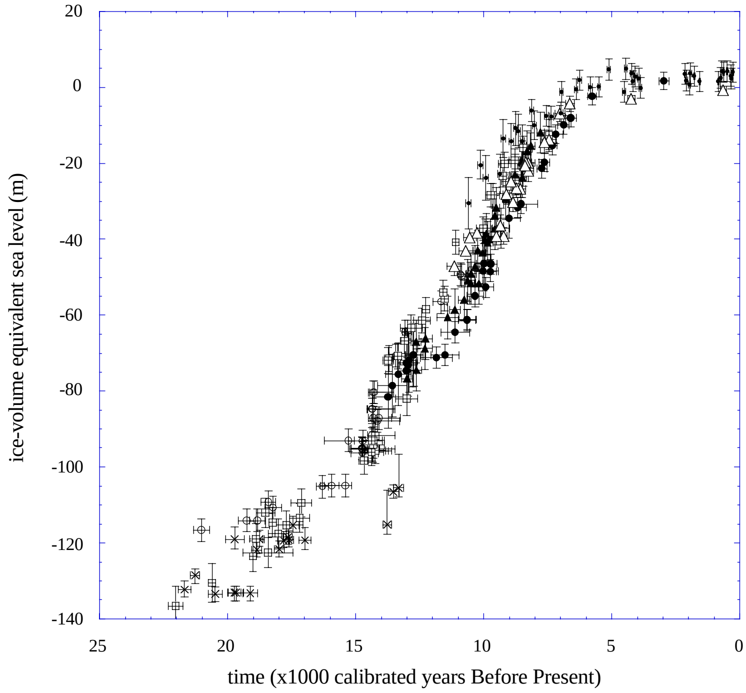

Figure 7: Ice volume equivalent sea-level change inferred from local relative sea-level observations corrected for tectonic and glacio-hydro-isostatic effects.

ocean volumes back to oxygen isotope stage 3 (about 40000 years ago). The results include evidence for rapid oscillations in sea level during oxygen isotope stage 3 of 10–15 meters amplitude indicating that rapid changes in ice volume can occur during glacial stages. Of significance is that the occurrence of the rapid sea-level rise events coincide with the occurrence of the Heinrich and ice-rafted debris events noted in the Atlantic and that the Heinrich events correspond to very substantial ice discharge events where ice volumes equivalent to the volume of the Scandinavian ice sheet at its maximum are discharged into the oceans in periods of only a few hundred years. The final lead in to the maximum glaciation was rapid and maximum ice volumes persisted for about 10,000 years until about 20,000 (calendar) years ago. The final melting was rapid and was largely complete by 7000 years ago although a small increase in ocean volume occurred until about 2000 years ago. This is consistent with evidence from the Scott coast of Antarctica for late melting in northern Victoria Land and McMurdo Sound that continued into Late Holocene time.

Sea-level change from Mid-Holocene to recent time along the Australian margin.

K. Lambeck and A. Purcell

Observed relative sea-level change reflects changes in ocean volume, glacio-hydro-isostasy, vertical tectonics and redistribution of water within ocean basins by climatological and oceanographic factors. Together these factors produce a complex spatial and temporal sea-level signal. For the tectonically stable Australian margin, where tectonic contributions will not exceed 0.1 mm/year, geological evidence indicates that sea-levels at 6000-5000 years ago were between 0 and 3 meters above present level, due primarily to glacio-hydro-isostatic effects of the last deglaciation. The spatial variability of this signal determines the mantle response to the surface loading and leads to an effective lithospheric thickness of 75-90 km and an effective upper mantle viscosity of $(1.5\text{-}2.5)\times10^{20}$ Pa s. This latter value is less than that found for northern Europe $(3.5\text{-}4.5)\times10^{20}$ Pa s from similar analyses and it points to there being a lateral variation in the upper mantle viscosity that is consistent with seismic evidence and thermal considerations.

Analyses of the Australian sea levels for the past 6000 years also indicate that ocean volumes continued to increase after 6000 years ago, ending before about 2000 years ago, by enough to raise global mean sea level by about 3 meters. Most of the melting of the last great ice sheets was complete by 6000 years ago but the evidence points to an ongoing reduction in the Antarctic ice sheet beyond this time. Geological models provide the necessary elements with which to predict the present-day isostatic contributions to sea-level change measured by tide gauges. The two longest records from the Australian margin (Sydney and Fremantle) give an isostatically corrected rate of regional sea-level rise of 1.40 ±0.25 mm/year although the two rates on opposite sides of the continent are substantially different. Comparisons of this average rate with rates from other regions indicate that spatial variability in present-day secular sea-level is significant, with estimates of regional rates ranging from about 1 mm/year to 2 mm/year. These present-day rates of secular change cannot have persisted further back in time than a few hundred years because high-resolution geological and archaeological indicators of sea-level change do not indicate changes in ocean volume of this magnitude having occurred in the past 1000 or so years.

Figure 8: Predicted relative sea level around the Australian margin at 6000 years before present. If the glacio-hydro-isostatic effect was the sole contributor, sea levels would be falling today in most locations except southern Tasmania.

Ice sheets and sea level change during a glacial cycle

E-K. Potter, K. Lambeck and T. Esat

A record of the magnitude, timing and rates of sea-level changes during the last glacial cycle can be deduced from raised fossil coral reefs. These coral records can lead to an understanding of the controlling factors in climate change by providing an estimate of equivalent sea level and ice sheet distribution. In other proxy records, such as changing $\delta^{18}O$ of forams within deep sea cores, the record can be obscured and complicated by components such as local temperature and isotopic variations. Oxygen isotope stage (OIS) 5e, (the last interglacial period) when climate conditions were similar to the present, was followed by a series of large scale oscillations between colder, low sea level stadials (substages 5d and 5b) and warmer, higher sea-level periods (substages 5c and 5a). The combination of inadequate sampling of coral terraces and sometimes poor sample quality has meant that the timing, duration and magnitude of these sea level oscillations are not yet reliably constrained. In addition, the effect of the Earth's isostatic response to changing ice and water loads is often neglected in the interpretation of relative sea-level estimates.

In this study, the raised terraces of Barbados and Huon Peninsula are being reinvestigated to constrain further the relative sea-level history during OIS 5 at these sites. Using high precision U-Th mass spectrometric analysis, we aim to analyse a large number of samples representative of each OIS 5 sea-level maximum. The distribution of these ages will be used to define the age and duration of that oscillation and, combined with knowledge of local uplift rates, the relative sea level at that time.

The new sea-level data from the intermediate-field site, Barbados, and the far-field site, Huon Peninsula, will be combined with existing sea-level information for the same period. In particular, analysis of sea levels throughout the Caribbean region, including Barbados, will allow us to investigate the effect of the Laurentide ice sheet distribution Preliminary isostatic models of OIS 5 sea levels predict that the differences in relative sea level between northern and southern Caribbean sites during the peaks of substages 5a and 5c could be up to 15 metres. This is comparable to the difference reported for different sites in this region but is often attributed to uplift rate uncertainties or other complicating factors.

Constraints on the Greenland Ice Sheet using glacial rebound models and observations of sea-level change

K. Fleming and K. Lambeck

As part of an ongoing program within the Geodynamics Group, where glacial rebound studies are used to resolve glacial histories and the Earth's rheology, the behaviour of the Greenland Ice Sheet since the Last Glacial Maximum (~ 21,0000 years before present) has been investigated. The importance of the Greenland Ice Sheet is twofold. First, it is the only major northern hemisphere ice mass (with the exception of local glaciers and ice caps) to have survived the transition between glacial and interglacial climatic conditions, which is especially interesting considering it is located in a region characterised by vigorous climatic change. Second, recent studies indicate that it is likely to be an important contributor to future changes in sea level. Therefore, understanding its past behaviour provides boundary conditions for studies that endeavour to reproduce its ongoing response to past climatic changes that in turn affect its current state.

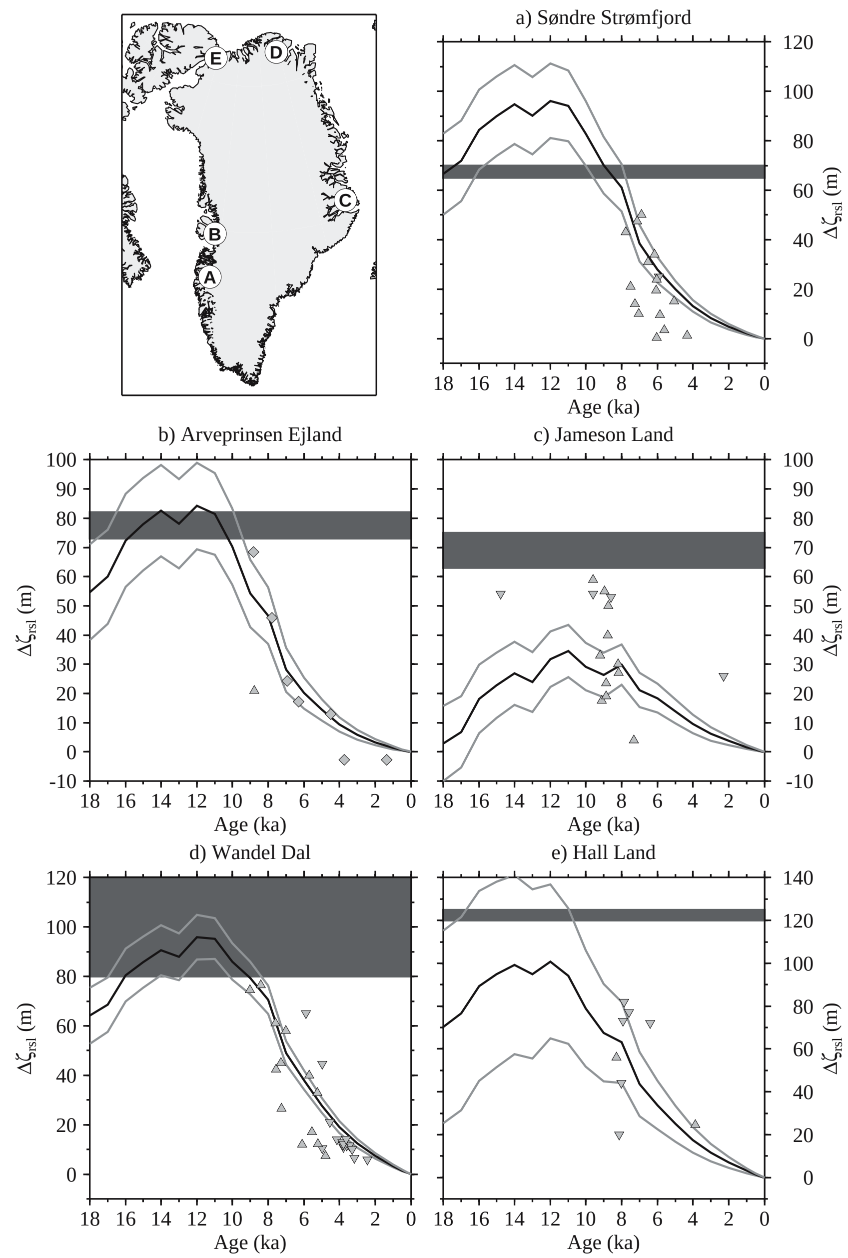

Figure 9: Predictions of sea-level change (solid black lines) for various sites about Greenland compared with observations. These predictions use a Greenland ice model that does not include a neoglacial component. Neoglaciation is required to reproduce the recession of the local sea level to below the present-day level observed in many areas (e.g. b. Arveprinsen Ejland). The range in the predictions (grey lines) are derived from uncertainties in the response from ice sheets outside of Greenland due to unknowns in the Earth's rheology and in the ice sheets themselves. The observations are divided between upper limits (inverted triangles), lower limits (upright triangles) and mean sea level (diamonds). The darker grey segments are the local marine limits, indicators of the highest past sea-level in a given locality. The irregularities in the general shape of the curves is partly a result of fluctuations in the rate of equivalent sea-level rise (global ice melting).

The approach followed required the use of a series of preliminary ice models that called upon differing assumptions about the climatic regime of the Last Glacial Maximum in this region. Predictions from the use of these models were compared with observations of sea-level change (mainly fossil marine material) from which a first-order ice-model was derived. It was found that during the late glacial stage the Greenland Ice Sheet contained significantly more ice than today. The melting of this ice contributed ~2.5 meters to present global sea level and leaves ~7 meters equivalent sea level locked in the ice sheet. It was also found that little could be inferred about the Greenland Ice Sheet, especially the timing of deglaciation, prior to about 12,000 years ago because it was only after that time that the coastline became ice free, thereby affecting the availability of data for the earlier period.

This second point is illustrated in figure 9, which shows examples of predicted sea-level curves from various sites around Greenland along with the available observations. Changes in ice loading outside of the ice sheet (for example the collapse of the former North American ice sheets) have a significant effect, contributing to the present sea-level change at a rate of between 2 to 3 mm per year. Any neoglaciation, a period where the Greenland Ice Sheet readvanced from its minimum post-glacial position, and that in some locations was several tens of kilometres behind the present margin, has a significant effect on Greenland's late Holocene sea-level history (past 4,000 years). This is in fact the only mechanism that reproduces the observed fall in sea level to below the present-day level. Transgressive periods that interrupted the general fall in sea level during the Holocene are more likely to be a result of fluctuations in the rate of equivalent sea-level rise (rate of melting of the global ice regime) as opposed to mechanisms often invoked, such as glacial readvances or forebulge collapse.