Final Report to the Earthquake Commission on Project No. UNI/527: ‘Seismicity and seismic tremor in the Hikurangi subduction zone’

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1 Layman's abstract

Recent advances in geophysical monitoring have revealed a much broader spectrum of earth deformation processes than previously recognised, including several mechanisms operating on timescales between those of traditional seismology (in which earthquake rupture occurs in seconds) and geodesy (in which strain accumulates over years to decades).

Slow earthquakes are episodes of fault slip occurring over days or weeks, and were first identified using global positioning system (GPS) instruments. They have been detected in several subduction zones, where one tectonic plate is thrust beneath another, most notably in the western United States and Canada, Japan, and Mexico. Accompanying the slow earthquakes in western North America and Japan is a pronounced increase in coherent seismic noise, or "tremor", which is manifest as episodic bursts of low-frequency noise.

Slow earthquakes have also been detected in the Hikurangi subduction zone, beneath the eastern North Island, using GPS instruments deployed as part of the national GeoNet monitoring system. This project focuses on detecting and interpreting tremor in the Hikurangi subduction zone and will provide a clearer understanding of the roles played by slow slip and associated phenomena in accommodating slip on major faults.

The key accomplishments and findings of this project are the following:

1. We have conducted a detailed visual inspection of continuous seismic data for a 7 week period spanning the 2004 Gisborne slow slip event;

2. A tremor signal similar to that observed in Cascadia and Japan and hypothesised to be present in Raukumara does not appear to have been generated during the 2004 Gisborne slow slip event;

3. We have distinguished three suites of earthquakes: nearby events detected by routine GeoNet analysis ("routine"); distant events ("teleseismic"); newly identified local events that had not triggered the automated processing system ("newly detected");
4. The rate of earthquakes detected by routine GeoNet analysis does not appear to alter in the vicinity of the slow slip event during the period analysed;
5. In contrast, the slow slip event is accompanied by a pronounced increase in the number of newly detected small earthquakes;
6. These newly detected earthquakes appear to be preferentially concentrated near the Mahia Peninsula and to have occurred within the Pacific slab, beneath the principal plate boundary;
7. The newly detected earthquakes exhibit faulting characteristics compatible with reverse slip on a plane subparallel to the principal plate boundary interface;
8. The newly detected earthquakes, rather than seismic tremor, appear to be the seismological accompaniment to slow slip in this particular case;
9. Modelling results suggest that the newly detected events may constitute "coshocks" (Segall et al., 2006) occurring within the slab down-dip (deeper) than the area of the slow slip and triggered by the slow slip itself;
10. The reasons why slow slip near Gisborne triggers microearthquakes rather than tremor are not clear: however, this area differs from both Cascadia and southwest Japan in being generally cooler and in producing higher stress-drop slow slip. One or other of these two factors may have some influence on how the adjacent crust deforms in response to slow slip.

2 Technical abstract

Geodetically-detected episodes of slow slip appear in several subduction zones to be accompanied by bursts of low-frequency coherent noise known as seismic tremor, but whether a single physical process governs this association or even whether slow slip is invariably accompanied by tremor remains unresolved. Detailed analysis of broadband seismic data spanning a slow slip episode in the Hikurangi subduction zone, New Zealand, reveals that slow slip was accompanied by distinct reverse-faulting microearthquakes, rather than tremor. The timing, location, and faulting style of these earthquakes are consistent with stress triggering down-dip of the slow slip patch, either on the subduction interface or just below it. These results indicate that tremor is not ubiquitous during subduction zone slow slip, and that slow slip in subduction zone environments is capable of triggering high-frequency earthquakes near the base of the locked subduction thrust. The stress drop during slow slip appears to control the nature of the triggered seismicity, with higher stress drops triggering high-frequency microearthquakes and lower stress drops triggering seismic tremor.

3 Publications/outputs relating to this project

1. Delahaye, E., Townend, J., Reyners, M., and Rogers, G., 2008. "Microseismicity but no tremor accompanying slow slip in the Hikurangi subduction zone, New Zealand". *Earth and Planetary Science Letters*, submitted.

2. Delahaye, E., 2008. A seismological investigation of slow slip in the Hikurangi subduction zone, New Zealand. Aseismic Slip, Non-Volcanic Tremor, and Earthquakes Workshop, Sidney, British Columbia.

3. Townend, J., 2008. Seismology in the slow lane: microearthquakes triggered by slow slip in the Hikurangi subduction zone. Evison Symposium on Seismogenesis and Earthquake Forecasting, Wellington.

4. Delahaye, E., 2007. A seismological investigation of slow slip in the Hikurangi subduction zone, New Zealand. Unpublished MSc thesis, Victoria University of Wellington.

5. Delahaye, E., Townend, J., Reyners, M., and Rogers, G., 2007. Seismic phenomena associated with slow slip near Gisborne in 2004. In: Mortimer, N., and Wallace, L. (eds.), Programme and Abstracts, Geological Society of New Zealand/New Zealand Geophysical Society joint annual conference "Geosciences '07", Tauranga, New Zealand. Geological Society of New Zealand Misc. Publ. 123A.

6. Delahaye, E., Townend, J., Reyners, M., and Rogers, G., 2007. Triggered microearthquakes but no tremor accompanying slow slip in the Hikurangi subduction zone, New Zealand. American Geophysical Union Fall Meeting, San Francisco.

7. Townend, J., 2006. What's going into the Hikurangi subduction zone and how does it affect seismogenesis? Active Fluids, Faulting and Deformation Workshop, Lower Hutt.

8. Delahaye, E., Townend, J., and Reyners, M., 2006. Searching for non-volcanic tremor in the Hikurangi subduction zone, North Island, New Zealand. Symposium on Earthquake and Tsunami Disaster Preparedness, Bangkok.

A Seismological Investigation of Slow Slip in the Hikurangi Subduction Zone, New Zealand

by

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Abstract

This is the first study to systematically examine continuous broadband seismic data during slow slip events in New Zealand. A total of 20 weeks of continuous broadband seismic data was reviewed during the times of three slow slip events: two in the shallow region of the Hikurangi subduction zone near Gisborne (in 2004 and 2006) and one deeper, ∼18 month-long event beneath the Manawatu region (early 2004 to mid-2005). Seismic tremor similar to that seen elsewhere was not detected during any of these slow slip events. This observation does not appear to be the result of network limitations: as five additional seismographs were deployed in the latter stages of the 2006 Gisborne event to augment the permanent network, and still seismic tremor was not detected. However, local earthquakes that had not been detected during routine analysis were detected and located during this study. The analysis revealed a pronounced increase in microseismicity during the 2004 Gisborne event that is *spatially* restricted to a region of the subducting plate downdip from the slow slip patch inferred from GPS observations and *temporally* restricted to the period of slow slip. This increased rate of local seismicity is not evident in the routine analysis records and was only detected by a methodical review of continuous seismic data. The 2004 slow slip event triggered microseismicity with magnitudes of M_L ∼1–2, similar to the "co-shocks" reported by Segall et al. (2006) in an intraplate setting. A similar increase in microseismicity was not observed during the 2006 Gisborne event or the 2004–2005 Manawatu event. The analysis of the 2004–2005 Manawatu data is preliminary but these results indicate that seismic tremor or increased microseismicity did not occur during this slow slip event.

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Contents

Abstract i

Acknowledgements iii

Table of Contents v

List of Figures ix

List of Tables xiii

1 Introduction 1

1.1 Statement of objectives . . . 3

1.1.1 Thesis structure . . . 5

1.2 Episodic Tremor and Slip (ETS) . . . 5

1.2.1 Other seismic phenomena . . . 8

1.3 Regional tectonics . . . 8

1.3.1 Hikurangi subduction zone . . . 9

1.3.2 Seismicity and plate coupling . . . 11

1.4 Summary . . . 16

2 Slow slip and related phenomena **17**

2.1 Global observations of slow slip events . . . 17

2.1.1 Japan . . . 20

2.1.2 Cascadia . . . 21

2.1.3 Central and South America . . . 23

2.1.4 Alaska . . . 23

2.1.5 Hawaii . . . 24
2.2 Slow slip in New Zealand . . . 25
2.2.1 Shallow slow slip . . . 25
2.2.2 Deep slow slip . . . 26
2.3 Summary . . . 30

3 Data acquisition and analysis 33
3.1 National data acquisition . . . 33
3.1.1 Seismic network . . . 33
3.1.2 Continuous GPS network . . . 34
3.1.3 Seismic data acquisition and routine analysis . . . 34
3.1.4 2006 temporary deployment . . . 40
3.2 Review of continuous seismic data . . . 43
3.3 Summary . . . 44

4 Seismic tremor investigation 47
4.1 Slow slip events analysed in this study . . . 47
4.1.1 Slow slip near Gisborne, 2004–2006 . . . 47
4.1.2 Slow slip under the Manawatu region, 2004–2005 . . . 48
4.2 Tremor analysis . . . 53
4.2.1 Motivating results from Douglas (2005) . . . 53
4.2.2 Gisborne 2004 . . . 54
4.2.3 Gisborne 2006 . . . 57
4.2.4 Preliminary analysis, Manawatu 2004–2005 event . . . 57
4.3 Results . . . 57
4.4 Summary . . . 60

5 Other seismic phenomena 61
5.1 Methods and analysis . . . 61
5.1.1 Gisborne 2004 slip event . . . 65
5.1.2 Gisborne 2006 slip event . . . 65
5.1.3 Manawatu 2004–2005 slip event . . . 68
5.2 Results . . . 71
5.2.1 Gisborne 2004 . . . 71

5.2.2 Gisborne 2006 81
5.2.3 Manawatu 2004–2005 slow slip event 82
5.3 Discussion 87
5.4 Summary 89

6 Discussion and Conclusions 91
6.1 Lack of observed tremor 92
6.1.1 Seismic networks 92
6.1.2 Subduction zone characteristics 94
6.2 Gisborne 2004 95
6.2.1 Implications of this study 99
6.3 Future work 99

Appendices 108

A 2004 Gisborne earthquake hypocentres 109

B 2004 Gisborne relocated hypocentres 135

C 2006 Gisborne earthquake hypocentres 143

D 2006 Gisborne relocated hypocentres 155

E 2005 Manawatu earthquake hypocentres 159

List of Figures

1.1 New Zealand and CGPS and seismograph stations on the Raukumara Peninsula . . . 2
1.2 Raukumara Peninsula CGPS times series from 2002 to 2007 . 3
1.3 1–6 Hz bandpass-filtered continuous broadband seismic data . 4
1.4 Episodic tremor and slip in Cascadia . . . 6
1.5 Example of seismic tremor in Cascadia . . . 7
1.6 Tectonic setting of New Zealand . . . 10
1.7 Slip rate deficit on the subduction interface . . . 13
1.8 New Zealand seismicity . . . 14
1.9 Seismicity recorded during the 1994 Raukumara Peninsula survey . . . 15

2.1 Distribution of slow slip events observed globally . . . 18
2.2 Distribution of slow slip events and seismic tremor in Japan . 21
2.3 Spatiotemporal distribution of tremor episodes in Cascadia . . 22
2.4 Microseismicity associated with slip in Hawaii . . . 24
2.5 Distribution of slow slip events in New Zealand . . . 27
2.6 Douglas et al., 2005 slip model of the Gisborne 2002 slip event 28
2.7 CGPS time series for sites in the Manawatu region . . . 29
2.8 CGPS displacements for sites in the Manawatu region . . . 31

3.1 New Zealand National Seismograph Network . . . 35
3.2 New Zealand CGPS network . . . 36
3.3 Geophysical networks in New Zealand from 2000 to 2004 . . . 37
3.4 A flowchart of continuous seismic data collection at GeoNet . 38

3.5 A local earthquake displayed in the CUSP system 39
3.6 A photograph from the Mahia temporary station (MHGZ) . . 41
3.7 Map of temporary deployment in 2006 42
3.8 Hour-long seismic plot 45

4.1 Raukumara Peninsula CGPS and broadband seismograph locations. 49
4.2 CGPS and seismograph stations near Gisborne and CGPS time series 50
4.3 Map of CGPS stations and time series for 2002–2005 in the Manawatu region 51
4.4 Map of CGPS stations and seismographs used in the Manawatu region 52
4.5 A flowchart of the steps in the tremor analysis 55
4.6 Analysis summary for the Gisborne 2004 event 56
4.7 Analysis summary for the Gisborne 2006 event 58
4.8 Analysis summary for the Manawatu 2004–2005 event 59

5.1 A flowchart of steps in the seismic analysis 63
5.2 Newly detected local earthquake on 1 November 2004 64
5.3 Analysis summary of Gisborne 2004 event 66
5.4 CGPS and seismograph stations near Gisborne 67
5.5 Analysis summary of Gisborne 2006 event 68
5.6 Map of CGPS and seismograph stations used in Manawatu seismic analysis 70
5.7 Seismicity recorded during the 2004 Gisborne slow slip event . 72
5.8 Cumulative number of events and magnitude 73
5.9 Effects of relocation with the 3-D model for Gisborne 2004 . . 75
5.10 Relocated seismicity during the 2004 Gisborne slow slip event 76
5.11 Cross-section of relocated seismicity during the 2004 Gisborne slow slip event 77
5.12 Cumulative number of daily earthquakes in the Raukumara Peninsula during Gisborne 2004 event 79
5.13 Cumulative number of daily events near Mahia 80

5.14 Seismicity during the 2006 Gisborne slow slip event 83
5.15 Effects of relocation with the 3-D model for Gisborne 2006 . . 84
5.16 Relocated seismicity during the 2006 Gisborne slow slip event 85
5.17 Cumulative number of daily earthquakes in the Raukumara Peninsula during the Gisborne 2006 event 86
5.18 Seismicity during the Manawatu slip event from January 2004 to June 2005 88

6.1 Seismometer networks in New Zealand and Cascadia 93
6.2 Coulomb failure stress during the Gisborne 2004 slip event . . 96
6.3 Coulomb failure stress during the Gisborne 2004 slip event . . 97
6.4 Coulomb failure stress during the Gisborne 2004 slip event . . 98

List of Tables

2.1 Characteristics of globally observed slow slip events and associated phenomena . . . 19
2.2 Characteristics of slow slip events observed in New Zealand . . 25

3.1 Instruments in temporary deployment, July 2006 to February 2007 . . . 41

A.1 Earthquake hypocentres from 2004 Gisborne event 109

B.1 Relocated hypocentres from 2004 Gisborne event 135

C.1 Earthquake hypocentres from 2006 Gisborne event 143

D.1 Relocated hypocentres from 2006 Gisborne event 155

E.1 Earthquake hypocentres from 2004–2005 Manawatu event . . . 159

Chapter 1

Introduction

Since the installation of continuously recording Global Positioning System instruments (CGPS) in New Zealand, several slow slip events have been recorded in the Hikurangi subduction zone since 2003 (Figures 1.1 and 1.2; Douglas et al., 2005; Wallace and Beavan, 2006; Beavan et al., 2007). The slip events range in duration from days to months, and are similar to slow slip events recently discovered in the shallow parts of subduction zones in Japan and Cascadia (Hirose et al., 1999; Dragert et al., 2001). In those regions, slow slip has been associated with seismic signals, or non-volcanic tremor (Obara, 2002; Rogers and Dragert, 2003). It is important to determine whether tremor also accompanies slow slip events in New Zealand and by learning more about the processes associated with slow slip, such as tremor, we may be able to better define the locked zone of the Hikurangi subduction zone and therefore assess regional seismic hazards more accurately.

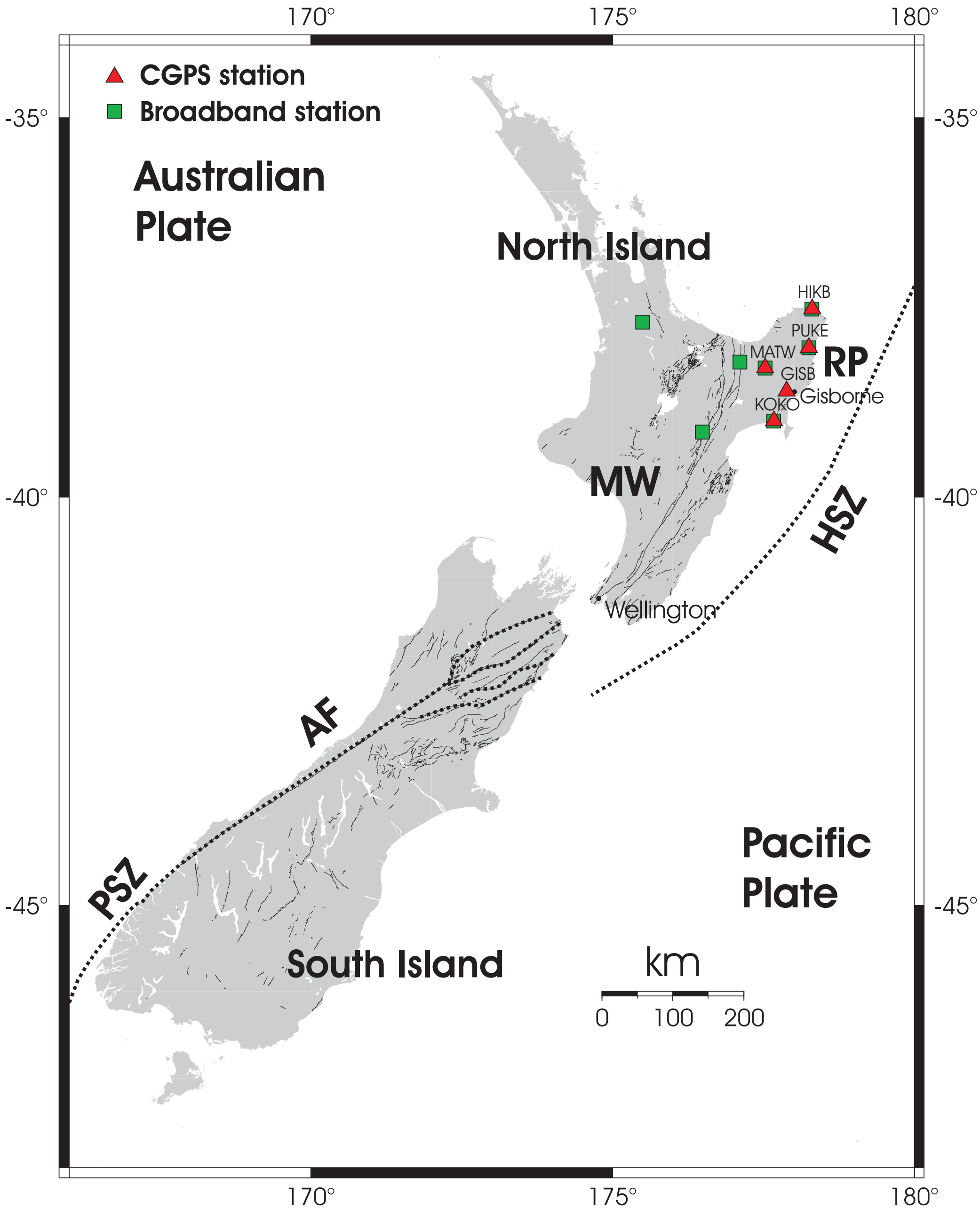

Figure 1.1: **New Zealand and CGPS and broadband seismograph stations on the Raukumara Peninsula.** The plate boundary between the Australian and Pacific plates is shown schematically as the black dashed lines. HSZ – Hikurangi subduction zone, RP – Raukumara Peninsula, MW – Manawatu region, AF – Alpine Fault, PSZ – Puysegur subduction zone. Refer to Figure 1.6 for more details on the tectonic setting.

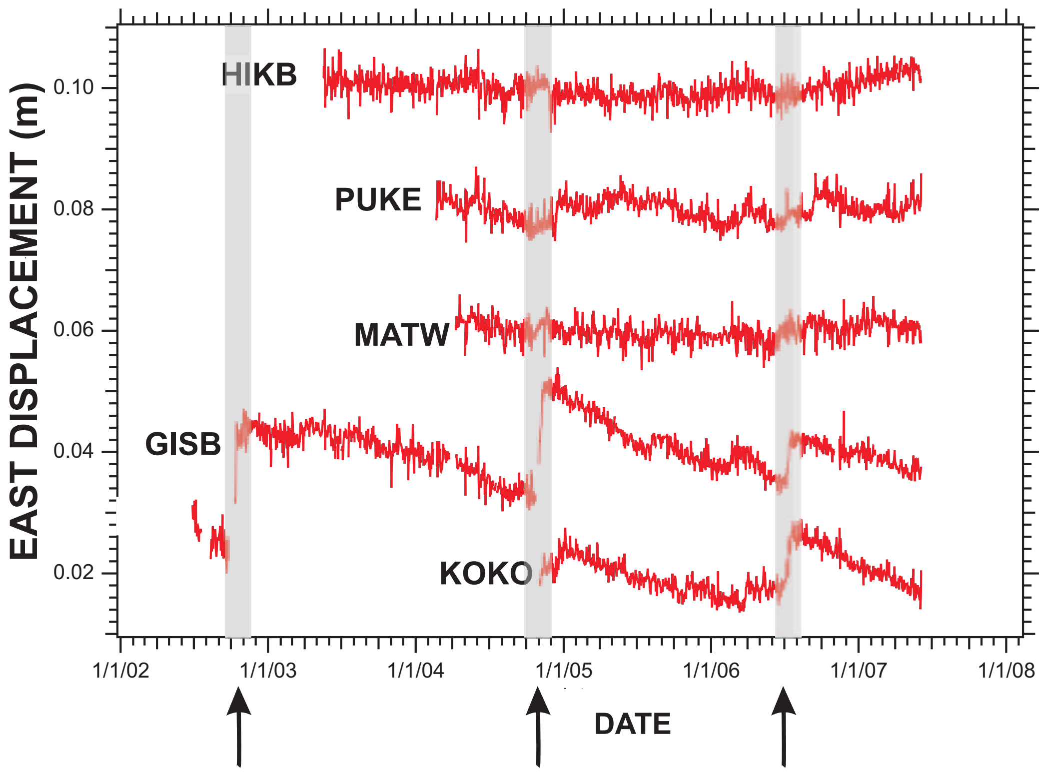

Figure 1.2: **CGPS time series from 2002 to 2007 for five sites on the Raukumara Peninsula.** Episodes of slow slip, observed at site GISB, near Gisborne are indicated by grey shading in 2002, 2004, and 2006. Station locations are shown on Figure 1.1.

1.1 Statement of objectives

The aim of this project is to determine whether slow slip events in the Hikurangi subduction zone are accompanied by non-volcanic seismic tremor. This is done by reviewing continuous broadband seismic data at the times of several slow slip events occurring in different portions of the subduction margin. Specifically, this study focuses on slow slip in the Gisborne and Manawatu regions to accomplish the following:

1. determine whether slow slip events are accompanied by seismic tremor in the shallow and deeper regions of the Hikurangi subduction zone;

2. deploy a temporary seismometer array during a slow slip event to determine if a denser network is necessary to observe tremor; and

3. determine if slow slip events are accompanied by seismic phenomena other than seismic tremor, such as increased levels of local seismicity.

The motivation for this project stems from the results of Douglas (2005), who suggested that a slow slip event in 2004 was accompanied by seismic tremor (Figure 1.3). Research on non-volcanic seismic tremor may help to better determine the locked and transition zones of subduction zones. The probability of a large mega-thrust earthquake occurring on a subduction zone may increase during periods of slow slip (Mazzotti and Adams, 2004), and the more we know about slow slip in New Zealand, as well as the underlying physical processes, the better we can estimate seismic hazards.

In this chapter, previous studies of non-volcanic seismic tremor are summarized, as well as studies on other seismic phenomena that have been as-

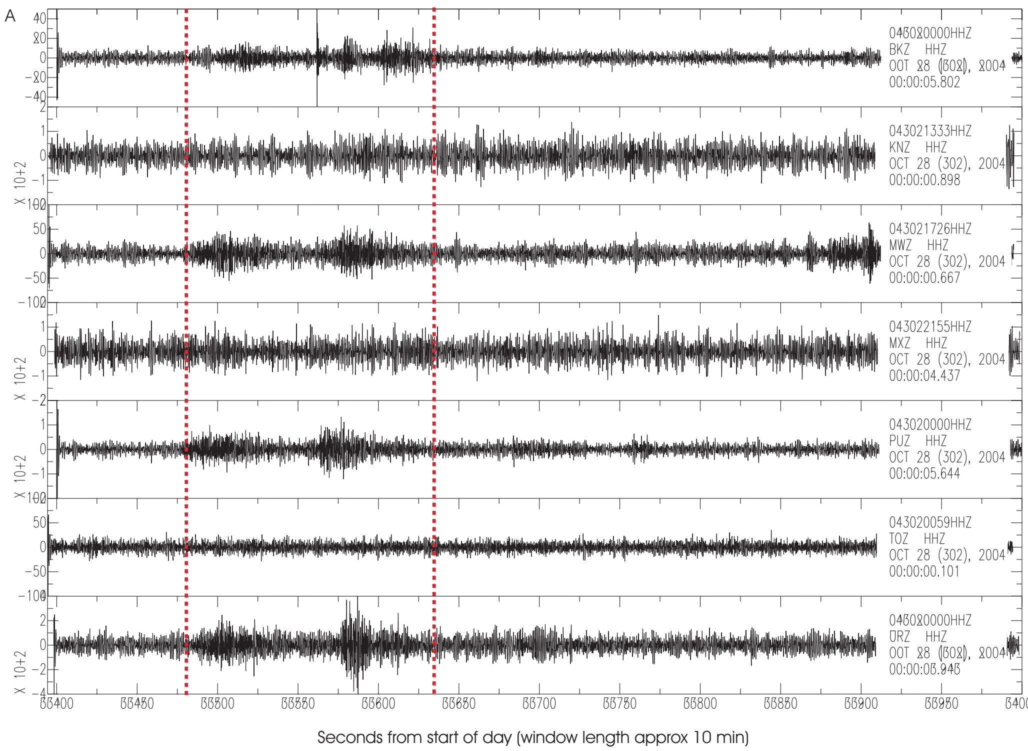

Figure 1.3: **1–6 Hz bandpass-filtered continuous broadband seismic data** for 10 minutes from October 28, 2004 for 7 seismic stations near the Hikurangi subduction zone. Station locations are shown on Figures 1.1 and 3.1. The period of suspected tremor lies between the red lines (from Douglas, 2005).

sociated with slow slip events around the world. The tectonic setting of the Hikurangi subduction zone is also presented.

1.1.1 Thesis structure

In this introduction, I present a summary of the tectonic and seismic settings of the Hikurangi subduction zone, discuss the motivation for this study and introduce non-volcanic seismic tremor, the main focus of this project. A summary of slow slip events that have been documented around the world, with a focus on slow slip events in New Zealand, is presented in Chapter 2. In Chapter 3 I discuss the geophysical networks, seismic data acquisition and analysis in New Zealand, as well as the methods used during field work and the first steps of data analysis. The methods used in the investigation of seismic tremor during three slow slip events and these results are presented in Chapter 4. I explain the methods used in the analysis of other seismic phenomena and present these results from three slip events in Chapter 5. This thesis concludes in Chapter 6 with a discussion of the results and suggestions for future work. The data analysed in this thesis is presented in the appendices following Chapter 6.

1.2 Episodic Tremor and Slip (ETS)

Slow slip events were observed at several subduction zones between 1999 and 2001 (Hirose et al., 1999; Freymueller and Beavan, 1999; Dragert et al., 2001; Lowry et al., 2001) and non-volcanic[1] seismic tremor was first documented in southwest Japan in 2002 (Obara, 2002), but it was not until 2003 that seismic tremor was shown to be associated with slow slip events. This phenomenon was first discovered in the northern Cascadia subduction zone and was termed "Episodic Tremor and Slip" or ETS (Rogers and Dragert, 2003, Figure 1.4). Slow slip events have been associated with seismic tremor in other parts of the world but it is generally referred to as ETS in Cascadia only.

[1] Seismic tremor was first observed near active volcanoes and often accompanies volcanic eruptions (Julian, 1994; Chouet, 1996).

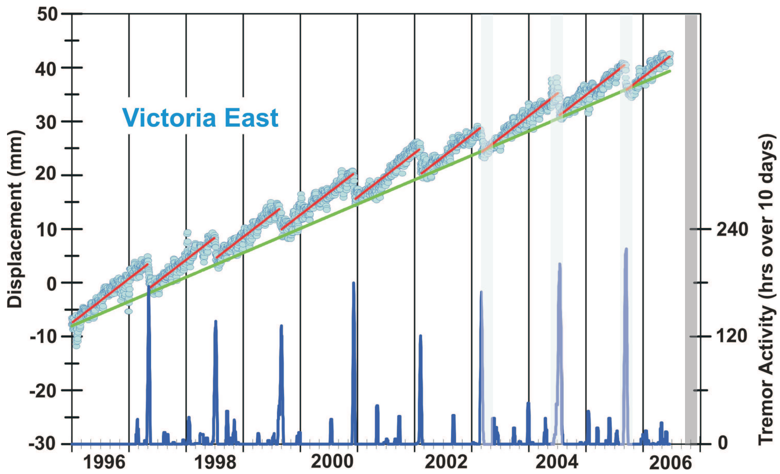

Figure 1.4: **Episodic tremor and slip in Cascadia.** Comparison of slip and tremor activity observed in Cascadia showing the long-term trend of plate motion (blue circles are CGPS daily time series) due to the convergence of the Juan de Fuca and North American plates, punctuated by reversals during times of slip. Non-volcanic seismic tremor (dark blue histogram) corresponds well to times of slow slip. Shaded bars indicate predicted time windows for ETS events. Figure modified from Rogers and Dragert (2003).

Seismic tremor associated with slow slip events is distinguishable from small earthquakes in several respects. The frequency content of tremor is mostly between 1–5 Hz, whereas the energy content of small earthquakes contains significant energy above 10 Hz (Obara, 2002; Rogers and Dragert, 2003). The onset of tremor (Figure 1.5) is emergent and the tremor can last for several minutes and up to hours or several days in duration. Tremor signals are strongest on horizontal seismographs and travel at shear wave velocities (McCausland et al., 2005). Because there are no impulsive P and S wave arrivals, seismic tremors generally cannot be located using traditional earthquake location methods, although envelope cross-correlation techniques have been developed to locate tremor sources in Japan (Obara, 2002) and the Source Scanning Algorithm was created to locate tremors in Cascadia

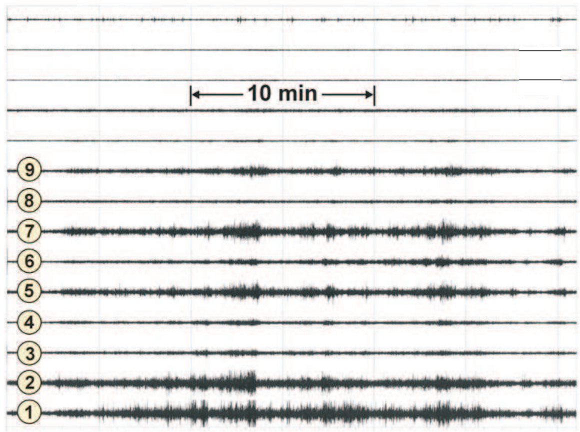

Figure 1.5: **Approximately 30 minutes of continuous non-volcanic seismic tremor in Cascadia.** Each horizontal line represents a seismic station. The approximate distance between stations is 50 km (From Rogers and Dragert, 2003).

(Kao and Shan, 2004).

Seismic tremor has not been documented at all subduction margins where slow slip events occur to date (e.g. Mexico, northwest Japan) and tremor has also been observed within a transform plate boundary beneath the San Andreas Fault (Nadeau and Dolenc, 2005). In most cases, seismic tremors have been found concentrated in a band approximately between the surface projections of the 30 and 50 km depth contours of subducted slabs (Kao et al., 2005; Obara, 2002), however the tremors can extend up to several hundred kilometres along strike (Kao et al., 2006). In Cascadia, tremors are located with a wide range in depths (from 10–40 km), but in southwest Japan the tremors are located near the plate interface (Kao et al., 2005; Obara, 2002; Obara et al., 2004).

The mechanism producing seismic tremor remains poorly understood, but in general it is thought to involve fluid migration, due to it's similarity with volcanic tremor, which results from the movement of magma (Julian, 1994). Another possibility is that seismic tremor results from shear failure during slow slip (Schwartz and Rokosky, 2007).

1.2.1 Other seismic phenomena

It is important to note that seismic tremor is just one of several seismic phenomena that have been discovered during slow slip events. Low frequency earthquakes (LFE) have been located in western Japan (Shelly et al., 2006). Shelly et al. (2006) used a combination of waveform cross-correlation and double-difference tomography to relocate LFEs (coherent S-wave and sometimes P-wave arrivals within non-volcanic seismic tremor) in western Japan. Their results suggest that the LFEs represent shear slip on the plate interface and that long duration tremor may be comprised of many simultaneous LFEs. Ide et al. (2007) studied the mechanisms of deep low frequency earthquakes and their results are consistent with thrust on the subduction interface.

Earthquakes with energy in the 0.02–0.05 Hz frequency range and seismic moment magnitudes (M_w) of 3.1 – 3.5 have been detected and located in southwest Japan and have been termed very low frequency (VLF) earthquakes (Ito et al., 2007). The VLF earthquakes have been located within a belt of non-volcanic seismic tremor that is associated with slow slip events. VLF earthquakes appear to always overlap with periods of tremor, but not all periods of tremor are associated with VLF earthquakes, which suggests that the non-volcanic seismic tremor and VLF earthquakes may be two separate phenomena (Ito et al., 2007).

Another recent observation is the association of increased rates of local seismicity (high-frequency earthquakes) with slow slip events (Segall et al., 2006; Reyners and Bannister, 2007). Segall et al. (2006) have shown that slow slip events in Hawaii triggered increases in local microseismicity. Similarly, Reyners and Bannister (2007) suggested that a swarm of earthquakes in New Zealand was triggered by a slow slip event. More details from these two studies are presented in Chapter 2.

1.3 Regional tectonics

New Zealand lies along the boundary between the Pacific and Australian plates (Figure 1.6). The Hikurangi subduction zone marks the present day boundary along which the Pacific plate subducts obliquely beneath the North Island. In the North Island, Australia-Pacific relative motion decreases in rate and becomes more oblique southward along the Hikurangi margin (DeMets et al., 1990, 1994). In the South Island, subduction yields to strike-slip dominated faulting, with the Alpine Fault accommodating the majority of the Australia-Pacific relative motion (Sutherland et al., 2007). Southwest of the South Island, the Puysegur Trench denotes the boundary where the Australian plate subducts beneath the Pacific plate.

1.3.1 Hikurangi subduction zone

Active tectonics in the North Island is dominated by subduction at the Hikurangi subduction zone, back-arc rifting in the Taupo Volcanic Zone (TVZ), and strike-slip faulting in the North Island dextral fault belt (NIDFB) (Reyners, 1980; Beanland and Haines, 1998). Subduction of the Pacific plate is inferred to have begun approximately 24 Ma and for the last 6 million years, the plate motion relative to the Australian plate has been 41–48 mm/yr trending at approximately 50° to the general strike of the modern-day margin (DeMets et al., 1994; Kamp, 1999). The Hikurangi Plateau is a large igneous province of a triangular shape, with an approximate area of 350 000 km^2 and is covered with volcanic edifices and seamounts (Mortimer and Parkinson, 1996, Figure 1.6). The thickness of the crust subducting beneath the North Island varies from about 10 km at the latitude of the Raukumara Peninsula to approximately 15 km in the northern South Island, whereas typical oceanic crust found at other subduction zones is around 7 km in thickness (Davey and Wood, 1994).

The variation in crustal thickness of the Hikurangi Plateau results in changes in fault style, changes in convergence rates and clockwise tectonic block rotations around vertical axes (Wallace et al., 2004). Seamounts entering the subduction zone in the Raukumara Peninsula region may act as asperities, resulting in a higher slip rate deficit, as observed by geodetic measurements (Wallace et al., 2004, Figure 1.7). Wallace et al. (2004) show that much of the North Island is rotating as several, distinct blocks (clockwise at

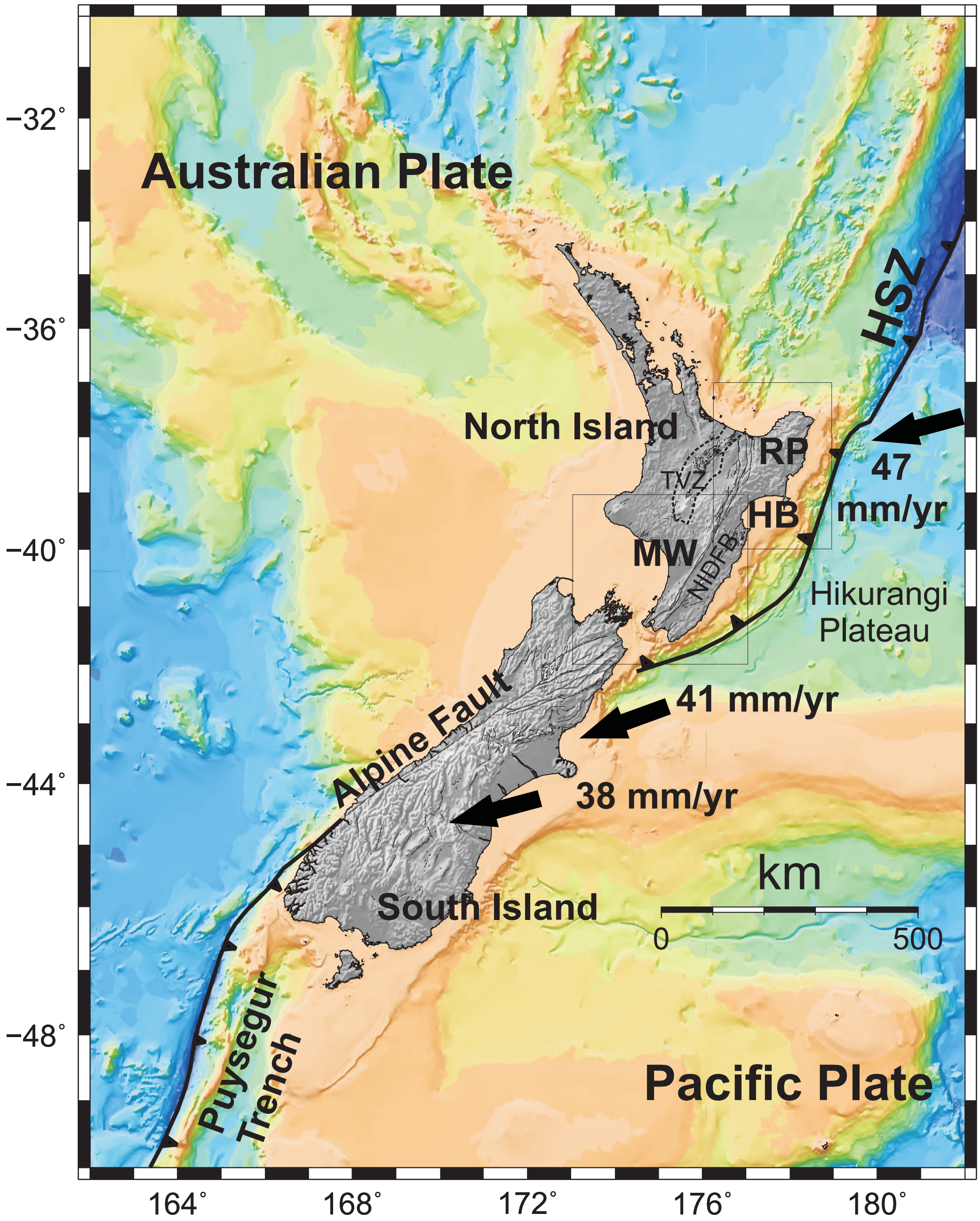

Figure 1.6: **Tectonic setting of New Zealand** showing the Australian-Pacific plate boundary zone. Vectors show the motion of the Pacific plate relative to the Australian plate (DeMets et al., 1990, 1994). The areas of study are outlined with boxes. HSZ – Hikurangi subduction zone, RP – Raukumara Peninsula, HB – Hawke Bay, MW – Manawatu region, TVZ – Taupo Volcanic Zone, NIDFB – North Island Dextral Fault Belt

0.5–3.8° per year about axes relative to the Australian plate. The convergence rate along the northern Hikurangi subduction zone is 45 mm/yr but the motion slows and becomes increasingly parallel to the transform plate boundary in the northern South Island (DeMets et al., 1990, 1994). Geodetic and geological data show that for the past ∼1.5 million years, oblique relative plate motion has been partitioned, with most (85%) of margin-normal motion accommodated on the plate interface, and most (> 60%) margin-parallel motion by strike-slip faulting and rotations in the upper plate (Nicol and Wallace, 2007).

1.3.2 Seismicity and plate coupling

Seismicity under the North Island forms a westward-dipping zone, which delineates the down-going Pacific plate (Ansell and Bannister, 1996; Reyners, 1998, Figure 1.8). The seismic zone associated with the subducted plate dips to the northeast at a strike of approximately 45° (Reyners, 1998). The subduction interface lies at about 15 km depth off the east coast of the Raukumara Peninsula, where slow slip near Gisborne has been observed. The subduction interface lies between 35–60 km depth beneath the Manawatu region where slip has also been observed (Ansell and Bannister, 1996).

Reyners et al. (1997); Reyners (1998) determined over 250 individual focal mechanisms from first motion polarity data and amplitudes of seismogram envelopes. Their models suggest a major change from weak coupling [2] in the northeast of the Raukumara Peninsula to strong or permanent coupling in the Wellington region and the northernmost South Island. The changes in coupling occur due to the rapid changes in crustal thickness of the subducted plate. The changes in crustal thickness also provide a mechanism for observed rotations in the upper plate (Reyners, 1998; Wallace and Beavan, 2006).

The slip rate deficit and plate coupling have been calculated by Wallace et al. (2004) and Wallace and Beavan (2006) from CGPS and campaign GPS measurements (Figure 1.7). They modeled GPS data from 24 regional deformation surveys conducted between 1991 and 2003. The data are supple-

[2] "Coupling" is the amount of locking at the subduction interface

mented by two regional and five national GPS campaigns carried out between 1994 and 1998. Their model showed a small patch with a significant slip rate deficit beneath the Raukumara Peninsula, near the area of several recent slow slip events (Figure 1.7). Both geodetic and seismological data indicate that the plate interface at the Hikurangi margin becomes increasingly coupled from north to south (Reyners, 1998; Wallace et al., 2004), and therefore the likelihood of a large subduction thrust earthquake increases to the south.

Seismicity of the Raukumara Peninsula

Reyners and McGinty (1999) carried out a survey on the Raukumara Peninsula during a five month period in 1994, in which they deployed 36 portable seismographs. With their observations, they calculated focal mechanisms for 117 earthquakes of M_L 2.4–4.9 and shallower than 80 km. Mechanisms were constrained using both first motion polarity data and amplitudes of seismogram envelopes (Reyners and McGinty, 1999).

The large amount of high-quality data enabled Reyners et al. (1999) to create a detailed three-dimensional (3-D) model of the crustal structure of the region. The data collected from the 1994 survey illustrates the background seismicity of the Raukumara Peninsula (Figure 1.9).

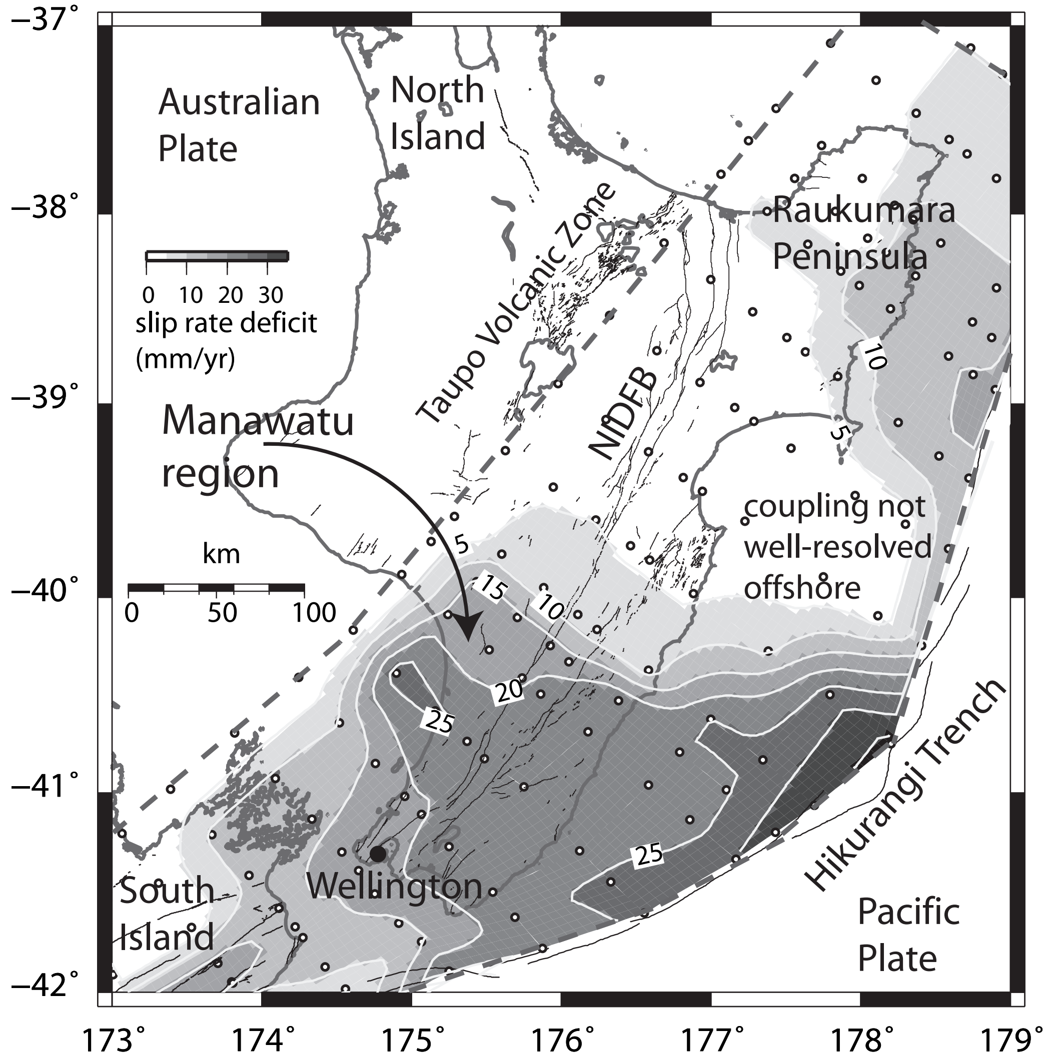

Figure 1.7: **Slip rate deficit on the subduction interface of the North Island.** The slip rate is shaded and contoured in 5 mm/yr intervals from Wallace and Beavan (2006) as determined from GPS campaign measurements. Coupling varies along-strike, in agreement with seismic and geologic observations (Reyners, 1998). Figure is from (Wallace and Beavan, 2006).

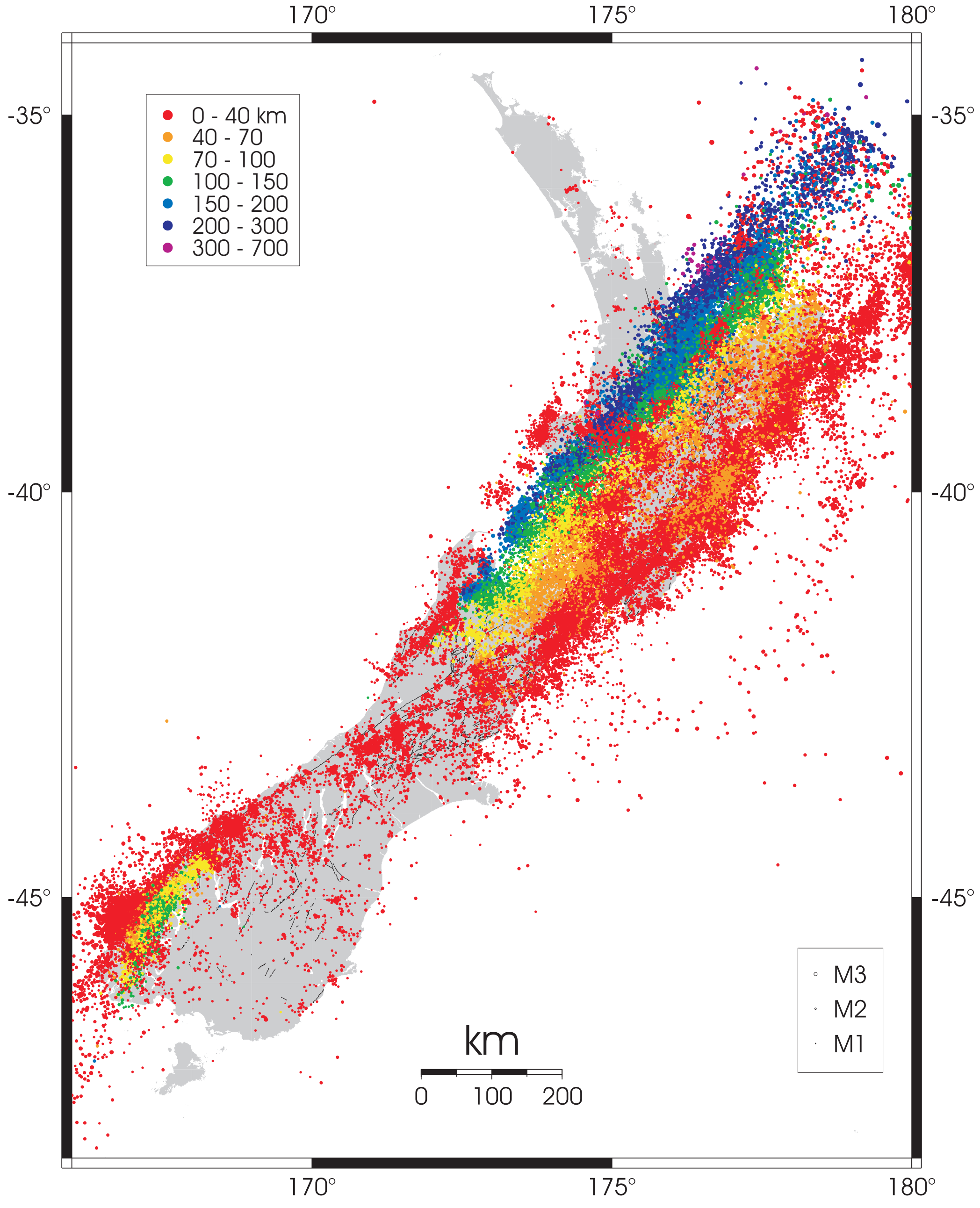

Figure 1.8: **New Zealand seismicity** from 2000 to 2006.

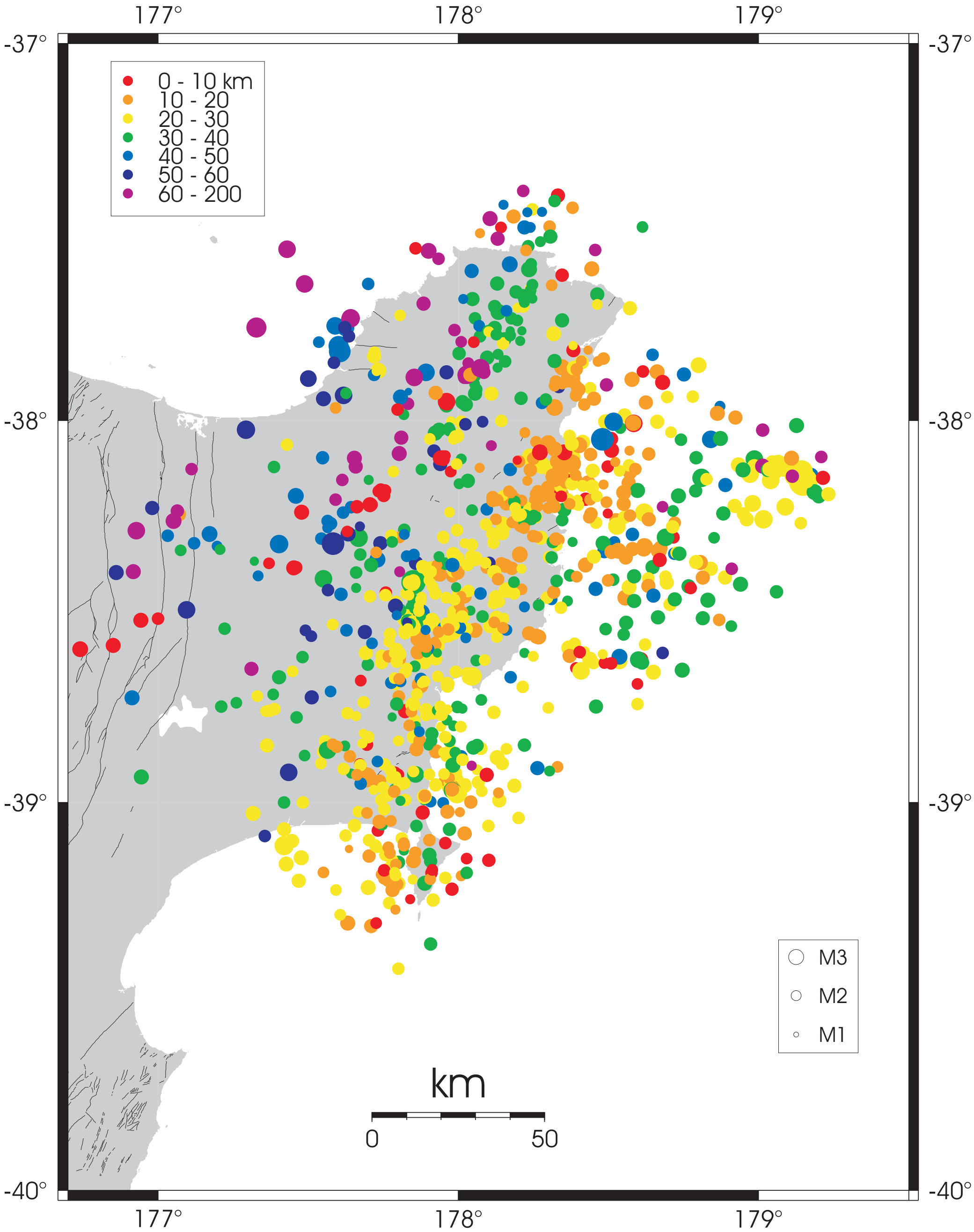

Figure 1.9: **Seismicity recorded during a five month survey in 1994 on the Raukumara Peninsula** by Reyners and McGinty (1999).

1.4 Summary

Slow slip events are a recent discovery observed at several subduction zones and other plate boundary settings around the world. Non-volcanic seismic tremor appears to be just one of a variety of seismic signals associated with slow slip and it is not clear whether seismic tremor or any of the other phenomena accompany all slow slip events. I will review continuous seismic data during the times of several slow slip events in New Zealand in an effort to determine whether slow slip events in New Zealand are accompanied by seismic tremor or any other seismic phenomena[3].

[3]This MSc research was conducted as part of a larger Marsden-funded project in close collaboration with John Townend, Martin Reyners and Garry Rogers. Where particular results depend strongly on other researchers efforts, this is indicated in the text.

Chapter 2

Observations of slow slip, seismic tremor and related phenomena

This chapter reviews slow slip events that have been documented around the world to date. Slow slip events that have been observed in New Zealand are also reviewed in detail.

2.1 Global observations of slow slip events

Slow slip events are a recently discovered phenomenon that have been detected by GPS instruments at plate boundaries around the world, predominantly at subduction zones (Hirose et al., 1999; Dragert et al., 2001; Lowry et al., 2001; Ohta et al., 2006). Slow slip events [1], similar to earthquakes but with longer durations, release tectonic strain as fault slips over days, weeks or months. Slow slip events may contribute significantly to moment release in subduction zones, and therefore, quantifying their size and periodicity is essential to calculating seismic hazard at subduction zones (Douglas et al., 2005; Wallace et al., 2004; Schwartz and Rokosky, 2007). The better

[1] Slow slip events are sometimes referred to as slow earthquakes or silent earthquakes. I will use "slow slip event" for describing these transient fault slips.

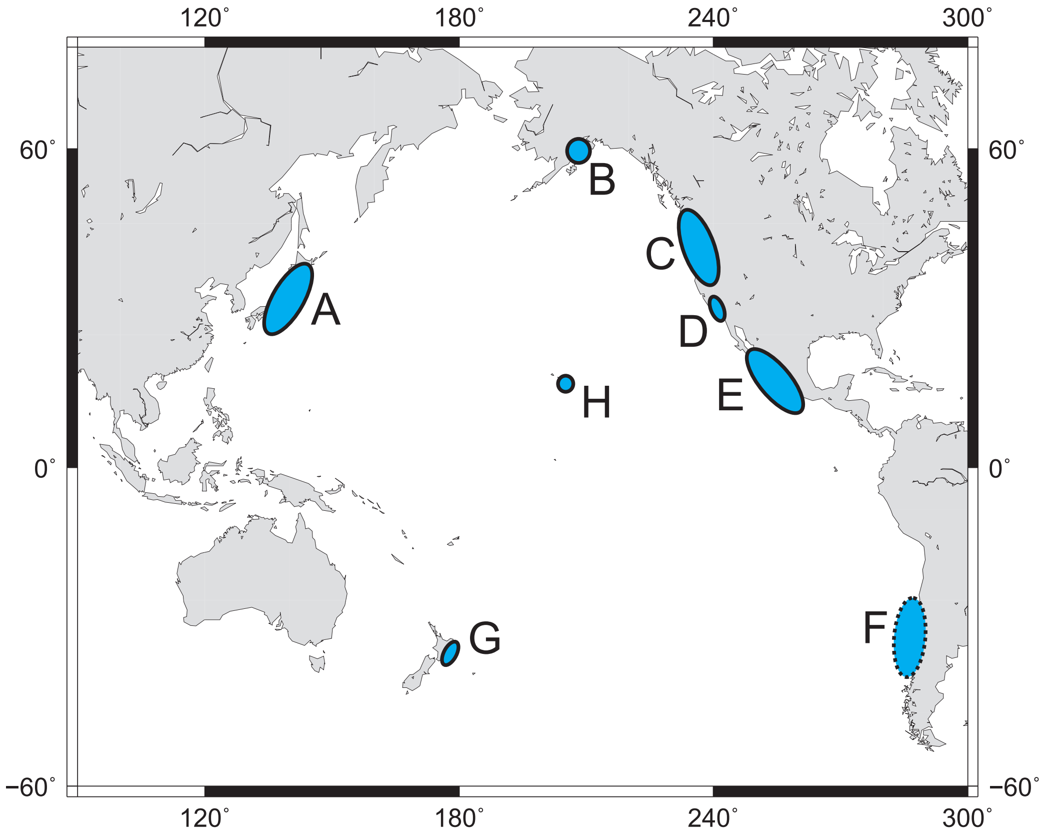

Figure 2.1: **Distribution of slow slip events observed globally.** Letters correspond to those in Table 2.1. The dashed line at F indicates that there are no GPS observations documented to date, but the presence of non-volcanic seismic tremor suggest the possibility that slow slip events occur in the region.

we understand where slip is occurring and the physical processes associated with slip the more accurately we can assess seismic hazard, and ultimately risk. Slow slip episodes have been observed by GPS measurements in Cascadia (southwest Canada and northwest United States), southwest and central Japan, Mexico, New Zealand, and Alaska (Figure 2.1, Table 2.1, Dragert et al., 2001; Miller et al., 2002; Hirose et al., 1999; Ozawa et al., 2002; Lowry et al., 2001; Douglas et al., 2005; Wallace and Beavan, 2006; Ohta et al., 2006), and the observations from these studies are reviewed individually in this chapter.

Region	A	B	C	D
	Japan	Alaska	Cascadia	SAF
Depth (km)	(BU) 30–40 (TO) 20–30 (BO) 10–20	30–40	25–40	20–40
Moment release (M_w)	(BU) 6.6–7.0 (TO) > 7.1 (BO) 6.0–6.6	7.2	6.5–6.8	<1.5
Duration	(BU) 4–10 months (TO) > 4 years (BO) 5–60 days	∼3 years	3–4 weeks	?
Recurrence time	(BU) 6.5 years (TO) >6 years (BO) 6–7 years	5–15 years?	11–14 months	?
Associated phenomena	(BU) Tremor, LFE, VLF (TO) Tremor, VLF	Tremor	Tremor	Tremor
Region	E	F	G	H
	Mexico	Chile	New Zealand	Hawaii
Depth (km)	< 40	?	(GB) 10–14 (MW) 25–60	∼5–10
Moment release (M_w)	6.5–7.5	?	(MW) up to 7.0	5.5–5.8
Duration	6–7 months	?	(GB) 10 days (MW) 1.5 years	2 days
Recurrence time	2–3 years	?	(GB) 2–3 years (MW) 10–15 years?	2.12 years
Associated phenomena	Tremor?	Tremor	(GB) Tremor? (MW) Increased seismicity	Increased seismicity

Table 2.1: **Characteristics of globally observed slow slip events and associated phenomena.** Letters correspond to those in Figure 2.1. Refer to Figure 2.2 for slip locations in Japan. Refer to Table 2.2 and Figure 2.5 for more details on the slip events in New Zealand. SAF – San Andreas Fault, BU – Bungo, TO – Tokai, TB – Tokyo Bay, BO – Boso, CH – Choshi, LFE – low frequency earthquake, VLF – very low frequency earthquake, GB – Gisborne, MW – Manawatu and Paekakariki. Sources: Column A (Mitsui and Hirahara, 2006; Shelly et al., 2006; Ito et al., 2007,and references within), B (Ohta et al., 2006; Peterson et al., 2006), C (Dragert et al., 2004; Miller et al., 2002; McCausland et al., 2005), D (Nadeau and Dolenc, 2005), E (Lowry et al., 2001; Kostoglodov et al., 2003; Franco et al., 2005; Cabral-Cano et al., 2006; Brudzinski et al., 2007), F (Gallego et al., 2006), G (Douglas et al., 2005; Wallace and Beavan, 2006; Beavan et al., 2007), H (Cervelli et al., 2002; Segall et al., 2006; Brooks et al., 2006). Refer to Schwartz and Rokosky (2007) for more detailed tables reviewing global occurrences of observed slow slip events and seismic tremor.

2.1.1 Japan

Slow slip events were first detected beneath the Bungo Channel, southwest Japan (Figure 2.2; Hirose et al., 1999). Since then, slow slip events have been observed in several regions in southwest Japan, at the Nankai Trough, where the Philippine plate subducts beneath the Amurian plate and also at the Japan Trough (central Japan), where the Pacific plate subducts beneath the Amurian plate. Slip events of varying durations, from 1–2 days to over 4 years have been observed by CGPS and tiltmeter or strainmeter observations (Hirose et al., 1999; Miyazaki et al., 2003; Yamamoto et al., 2005, Figure 2.2). Slow slip events have been associated with non-volcanic seismic tremor, low frequency earthquakes (LFE), and very low frequency (VLF) earthquakes (Obara et al., 2004; Obara and Hirose, 2006), as discussed in Chapter 1 in southwest Japan. However in central Japan, slow slip is observed without associated seismic signals.

Peacock and Wang (1999) showed how the age of subducting slabs in Japan influences the thermal structure and controls dehydration reactions in the subducting plate. The Philippine plate, subducting beneath southwest Japan is $\sim$15 Ma, while the Pacific plate, subducting beneath central Japan is $\sim$130 Ma. Seismic tremor has only been observed in southwest Japan, where fluids are released during dehydration reactions at shallow depths ($<$50 km). However, in central Japan, where seismic tremor has not been observed, the cooler subducting plate does not undergo dehydration reactions until $>$100 km depth (Peacock and Wang, 1999; Schwartz and Rokosky, 2007).

It is interesting to note that slow slip events were first detected in Japan (Hirose et al., 1999), non-volcanic tremor was first detected in Japan (Obara, 2002), and to date LFE and VLF events have only been documented in Japan (Shelly et al., 2006; Ito et al., 2007), which may be partly due to the high-quality and densely spaced geophysical networks in the country. As geophysical networks expand around the world, it is possible that more seismic phenomena, such as LFE and VLF earthquakes will be observed in more locations.

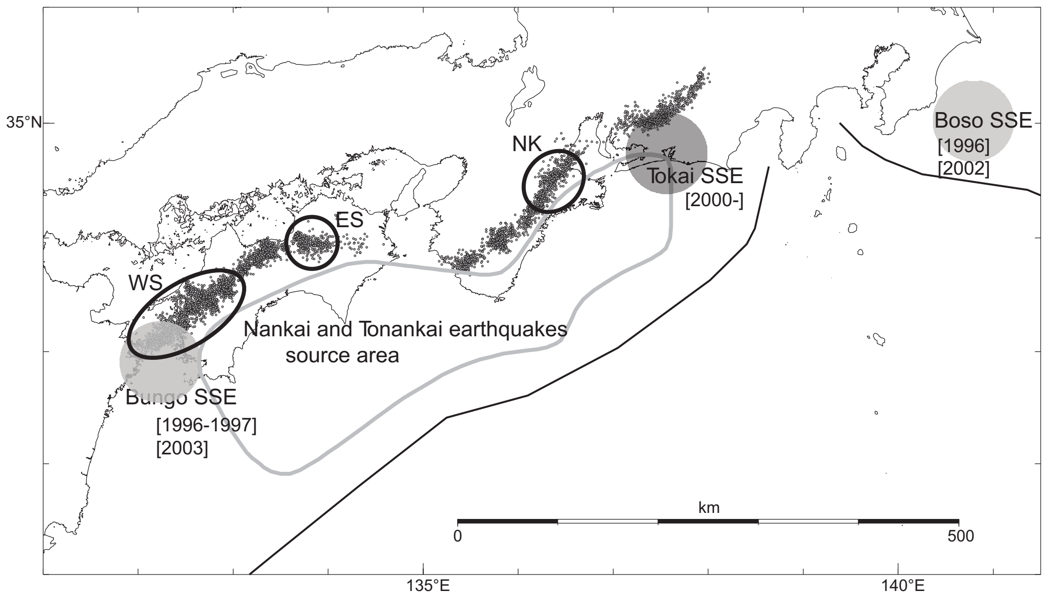

Figure 2.2: **Distribution of slow slip events and seismic tremor in Japan.** Regions of slow slip are indicated by the grey shading and bold circles. Located tremors are shown near WS (western Shikoku), ES (eastern Shikoku), and NK (northern Kii Peninsula. Figure is from Obara and Hirose (2006).

2.1.2 Cascadia

Cascadia slow slip events were first observed in Canada (Figure 1.4; Dragert et al., 2001), where the Juan de Fuca plate subducts beneath the North American plate, but have since been detected in Washington, Oregon and California states (Miller et al., 2002; Szeliga et al., 2004). Slow slip events occur with a remarkable periodicity; 14±2 months on the northern end of the subduction margin, and 11±1.2 months at the southern end of the margin (Melbourne et al., 2005; Dragert et al., 2004). This regularity has allowed researchers to successfully forecast imminent slip events and deploy additional instruments during periods of slip (Kao et al., 2007a; McCausland et al., 2005). The average displacement during a slip event is 5 mm, which accounts for 2/3 of the full convergence rate at the Cascadia subduction margin (Dragert et al., 2004). It is unclear whether the remaining 1/3 of slip deficit is released during minor slip events, which are inferred to occur on the basis of observations of non-volcanic tremor, but on a scale too small to detect with GPS. The slip events are equivalent to M_w 6.5–6.8 on aver-

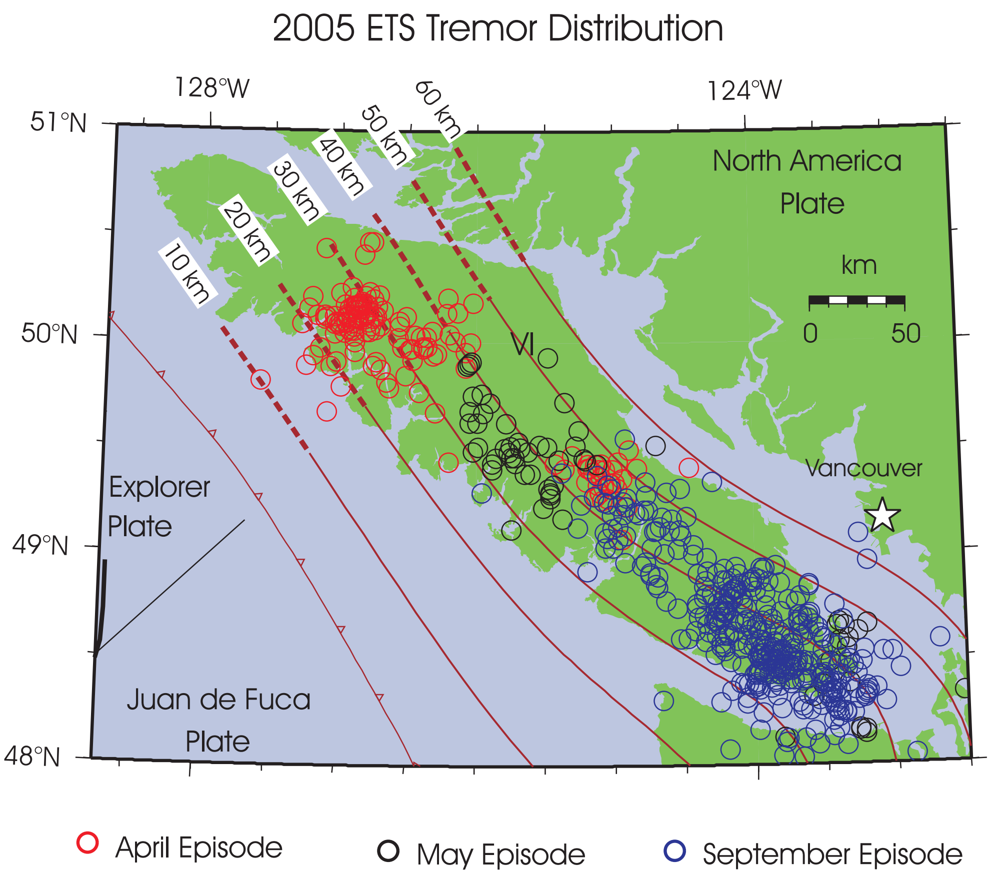

Figure 2.3: **Spatiotemporal distribution of tremor episodes in Cascadia margin in 2005.** The red lines are depth contours of the interface of the Juan de Fuca and Explorer plates at 10 km intervals from the trench. Most tremors are located within a narrow band between surface projections of the 30 to 50 km isodepths but occur over several hundred kilometres along strike and are widely distributed in depth. (From Kao et al., 2006)

age (Dragert et al., 2004). Slip events are well-correlated with non-volcanic tremor along the entire Cascadia margin (Rogers and Dragert, 2003; Szeliga et al., 2004; McCausland et al., 2004; Kao et al., 2006). Seismic tremor occurs in a band lying roughly between the surface projections of the 30 and 40 km depth contours of the subducted slab (Kao et al., 2006, 2007a), however the tremors can extend up to several hundred kilometres along strike (Kao et al., 2006, Figure 2.3) and they are located with a wide range in depths, from 10–40 km (Kao et al., 2005).

2.1.3 Central and South America

Nine slow slip events have been observed between 1993-2007 by continuous GPS and campaign GPS data in the Oaxaca subduction zone, Mexico, where the Cocos plate subducts beneath the North American plate (Lowry et al., 2001; Kostoglodov et al., 2003; Franco et al., 2005; Brudzinski et al., 2007). The events have been estimated to have equivalent magnitudes of M_w 6.5–7.5 (Lowry et al., 2001; Kostoglodov et al., 2003; Franco et al., 2005). The largest slip event observed in Mexico to date occurred in 2001. The slip is modeled as an average of 10 cm of slip over an area of 550 km $\times$ 250 km (Kostoglodov et al., 2003).

Preliminary results from Cabral-Cano et al. (2006) suggest that slow slip events in Mexico are accompanied by non-volcanic seismic tremor, similar to seismic tremor in Cascadia and Japan. Gallego et al. (2006) have located non-volcanic seismic tremor near the Chile Triple Junction region, which suggests that slow slip may occur along the subduction margin, but geodetic data have not revealed slow slip to date.

2.1.4 Alaska

A large slow slip event was observed between 1998 and 2001 in south central Alaska on the subduction interface between the Pacific and North American plates (Ohta et al., 2006). The average slip rate over the three year period was approximately 40 mm/yr over an area of 150 km $\times$ 150 km, which corresponds to $M_w \sim 7.2$ (Ohta et al., 2006). The slip occurred over a depth range of 25–45 km, and similarly to other subduction zones, the slip occurred in the inferred transition zone between where the plates are locked and freely slipping. To date, there has been one slow slip event recorded in Alaska, but an event of this magnitude is estimated to amount to 5–15 years of slip deficit, and therefore a correspondingly long recurrence interval may be expected (Ohta et al., 2006). Preliminary analysis suggests that the slip event was accompanied by non-volcanic seismic tremor (Peterson et al., 2006), but the relationship between the slip and tremor is still being investigated.

2.1.5 Hawaii

Slow slip events have been detected in an intraplate setting on the island of Hawaii, United States. Sudden aseismic fault slips have been observed by GPS on the flank of Kilauea volcano in Hawaii (Cervelli et al., 2002). Four slow slips have been detected since 1998 and they have occurred with a remarkable periodicity of 774±7 days (Brooks et al., 2006). The moment magnitude for the events have been estimated to be M_w 5.5-5.8 (Brooks et al., 2006).

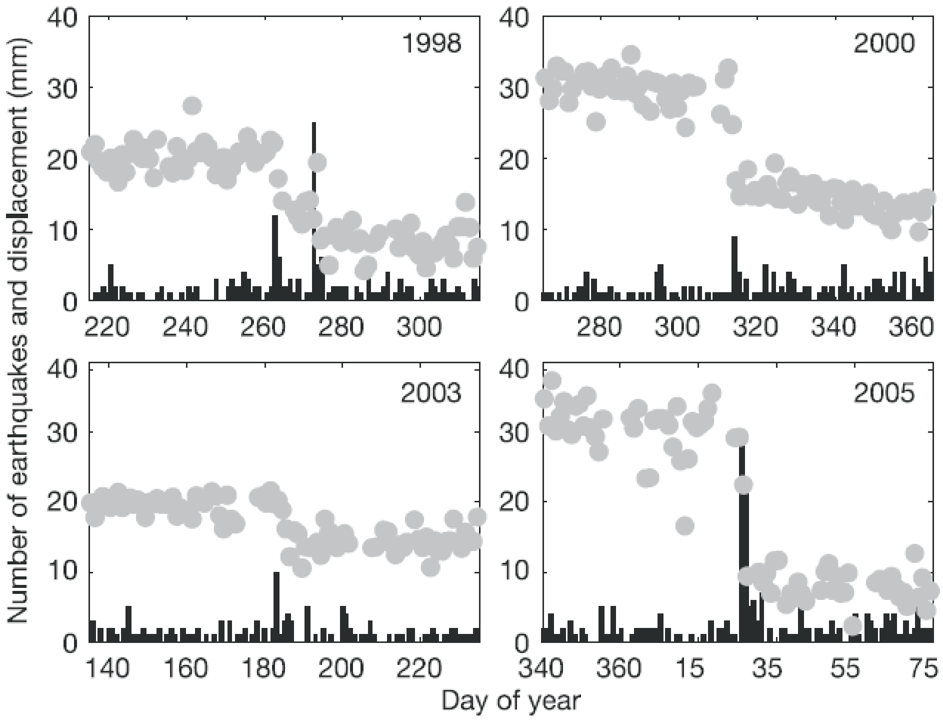

Figure 2.4: **Microseismicity associated with four slip events in Hawaii.** Grey circles are CGPS time series from the flank of Kilauea. Black histograms are the number of local earthquakes per day. The number of local earthquakes per day increases during slow earthquakes. Figure from Segall et al. (2006).

Slow slip events on Kiluaea have been followed by increases in microseismicity, but no earthquakes of $M_L > 3.5$. Segall et al. (2006) suggest that the association of high-frequency earthquakes with slow slip may be explained by either the earthquakes opening the fault and allowing the slip to occur or that the slow slip stresses nearby faults, which increases seismicity rates. The timing of the microseismicity suggests that the events are triggered and can be considered "co-shocks" (Figure 2.4; Segall et al., 2006) The spatial-temporal relationship between the "co-shocks" and slow slip events are discussed further in Chapters 5 and 6.

2.2 Slow slip in New Zealand

Several slow slip events on the Hikurangi subduction zone, beneath the North Island of New Zealand have been detected by CGPS observation since 2002 (Figure 2.5, Table 2.2). Slip events have been observed on the northern Hikurangi subduction zone at shallow depths (10–14 km) and on the central or southern Hikurangi subduction zone at greater depths (25–60 km). In both cases, slip is interpreted to have occurred near the down-dip end of the locked portion of the subduction interface (i.e. in the transition zone from where the plates are locked to where they are freely slipping) (Douglas et al., 2005; Beavan et al., 2007).

Region	GB	HB	MW
Depth (km)	10–14	10–14	25–60
Convergence rate (mm/yr)	47	45	41
Moment release (M_w)	?	?	7.0
Duration	∼10 days	∼10 days	∼1.5 years
Recurrence time	∼2 years	∼2 years	∼10–15 years?

Table 2.2: **Characteristics of slow slip events observed in New Zealand.** GB – Gisborne, HB – southern Hawke Bay, MW – Manawatu and Paekakariki. Refer to 2.5 for locations of slow slip.

2.2.1 Shallow slow slip

Slip events have been observed by CGPS observations near Gisborne in 2002, 2004 and 2006 (Figure 1.2). The 2002 and 2004 events have been interpreted as ∼20 cm of slip occurring along the subduction plate interface at a depth of 10–14 km (Figure 2.6; Douglas, 2005; Douglas et al., 2005; Beavan et al., 2007). Approximately 20–30 mm surface deformation was detected in both the 2002 and 2004 events, whereas only ∼10 mm of surface displacement was observed during the 2006 event. The slip model for the 2002 slow slip event near Gisborne indicates that a relatively high amount of slip occurred over a relatively small area. Douglas (2005) modeled the 2002 Gisborne slow slip as 18 cm of slip over an area of 1500 km^2 which is equivalent to a stress drop of 2.4×10^5 Pa. In comparison to some of the other slow slip events discussed earlier in this chapter the stress drop of slow slip in Gisborne is generally an order of magnitude larger than slip events in Japan, Cascadia and Mexico. Douglas (2005) estimated stress drops of 1.2×10^4 Pa for a slow slip event in Cascadia in 1999, 1.4×10^4 Pa or a slow slip event in Mexico in 2001, and 1.8×10^5 Pa for a slow slip event in southwest Japan in 1997.

Several small displacements have been recorded at the CGPS site HAST, in the southern Hawke Bay region, since its installation in 2002. Due to sparse CGPS station spacing in the region, the events have not been modeled. There is an indication that these events followed those of Gisborne by a couple of months, suggesting a possible along-strike migration with time, as observed in Cascadia, and in Japan (Beavan et al., 2007). As the CGPS network expands throughout the North Island, more slow slip events have been detected in the Hawke Bay region. Several slow slip events with 7 day durations were recorded in June and September of 2006 [2]. These events also occurred within 2 months of the Gisborne 2006 slip event.

2.2.2 Deep slow slip

There have been two slip events detected further south along the Hikurangi subduction zone. These events were of a much longer duration than the slow slip events on the northern segment (up to 18 months) and occurred deeper on the subduction interface (between 25–60 km depth).

[2]Refer to http://magma.geonet.org.nz/resources/gps/timeseries/ for CGPS time series data.

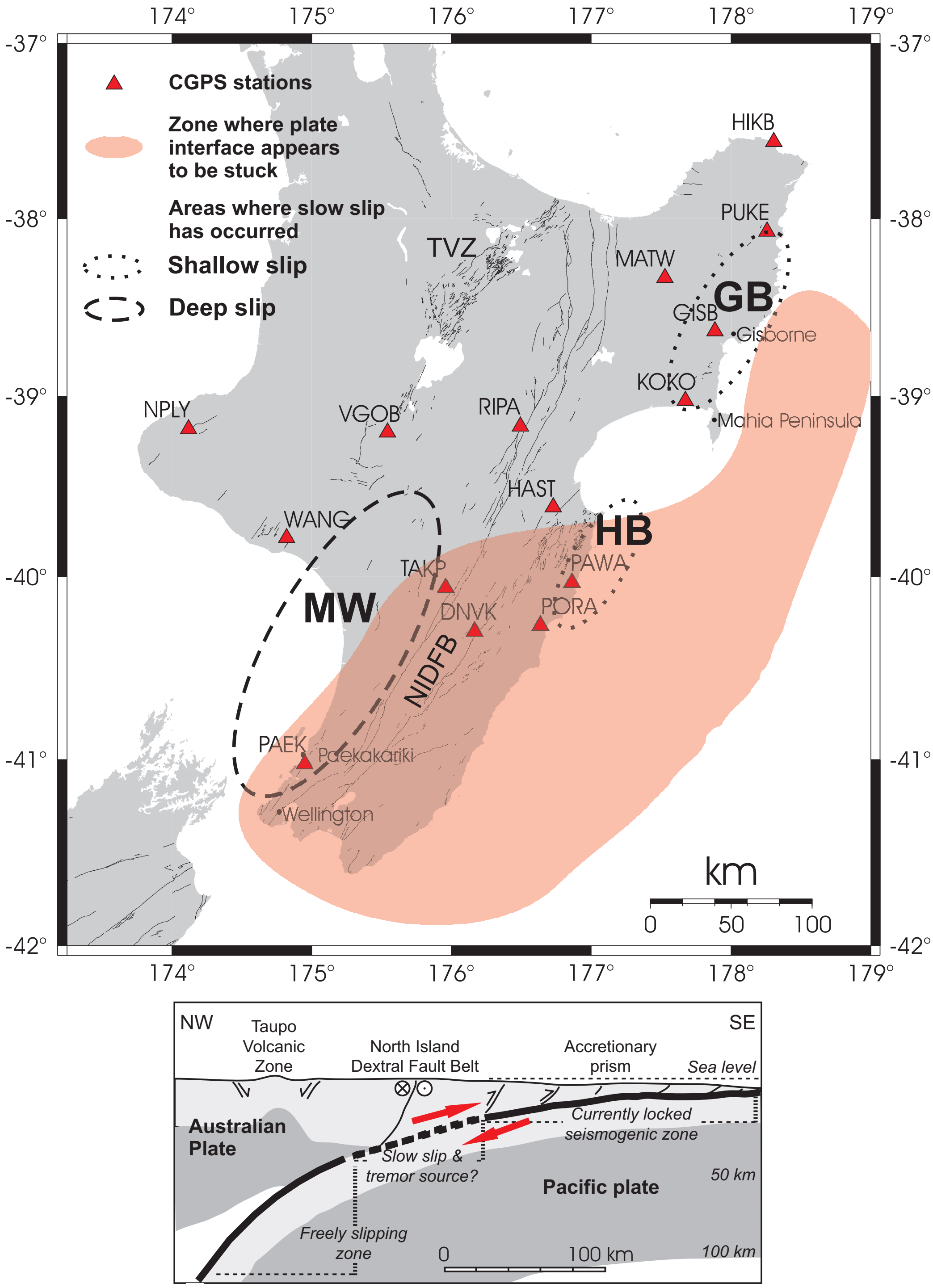

Figure 2.5: **Distribution of slow slip events in North Island, New Zealand.** Areas of observed slow slip events are indicated by the ellipses. CGPS stations mentioned in the following sections and figures are indicated on the map. GB – Gisborne, HB – southern Hawke Bay, MW – Manawatu and Paekakariki, TVZ – Taupo Volcanic Zone, NIDFB – North Island Dextral Fault Belt. The labels correspond to the regions in Table 2.2. Cross-section modified after J. Townend, pers. comm., 2007.

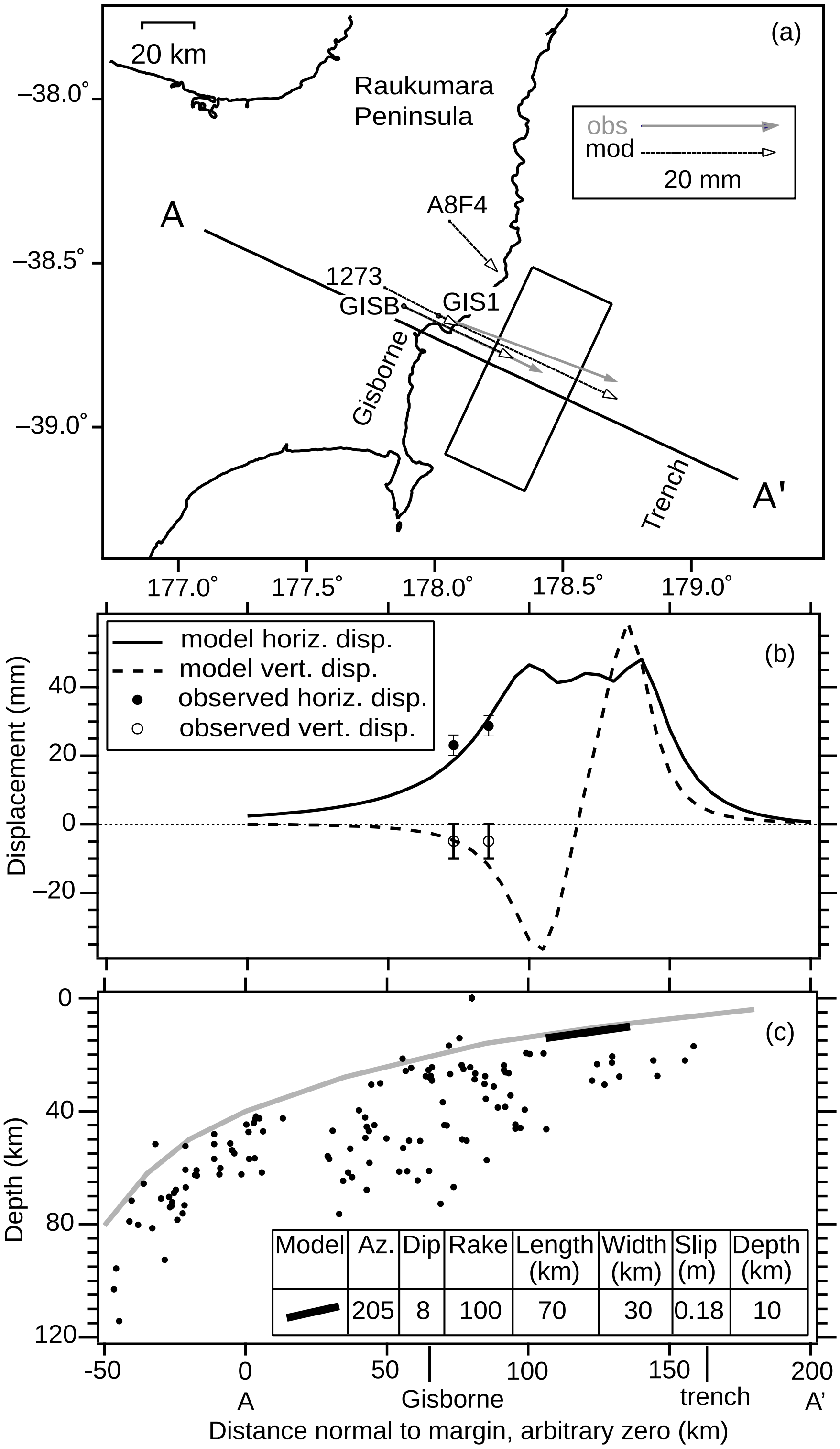

Figure 2.6: **Douglas et al., 2005 slip model of the Gisborne 2002 slip event**. a) Model slip plane and observed and predicted displacements for 2002 event. b) Observed and predicted displacements along A-A'. c) Profile along A-A' showing model slip plane, current seismicity and subduction interface. An alternative model was described by (Douglas, 2005), but this model is preferred. (From Douglas et al., 2005).

These slip events are interpreted to have occurred in the transition zone between the locked zone of the subduction zone and the deeper, hotter portion where the plates are freely slipping (i.e. similar to the shallow slow slip events in the northern Hikurangi subduction zone but the transition zone deepens to the south) (Wallace and Beavan, 2006; Beavan et al., 2007).

In the earlier southern North Island event, the CGPS site at Paekakariki (PAEK), north of Wellington, moved westward at 25 mm/yr (relative to the Australian Plate) from 2000 until May 2003, when it slowed to only 15 mm/yr in the same direction. Uplift was recorded simultaneously at this site at a rate of 10 mm/yr. The changes in motion were observed for approximately one year and then the site carried on with the same direction of motion that was observed from 2000 to early 2003. This event has been interpreted as ∼500 mm of slip originating from a deep part of the subduction interface (between 30–40 km depth) (Beavan et al., 2007). Several swarms of local earthquakes up to M_L ∼5 were recorded up-dip of the region of slip from mid 2003 to early 2005. These observations suggest that stress changes produced by the slow slip triggered incremental slip in the crust of the subducted plate (Reyners and Bannister, 2007).

From January 2004 to June 2005, a large slow slip event was observed on up to seven CGPS sites in the Manawatu region (Figure 2.7). The data were modeled as 300 mm on the subduction interface, over an area of the order of 100 km × 100 km. The slip event began further down-dip on the subduction

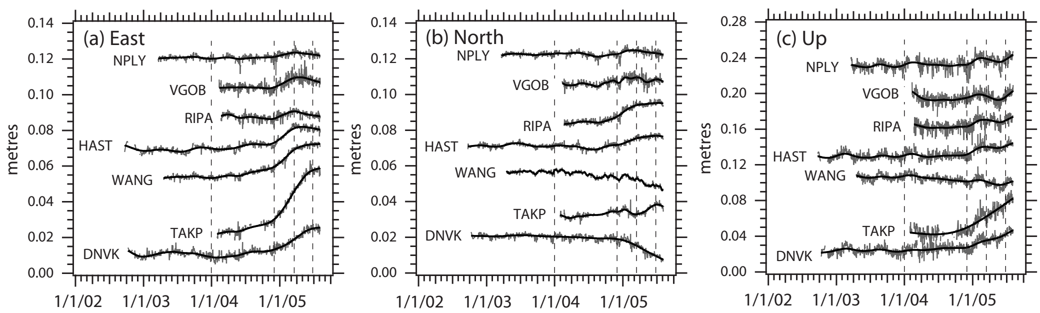

Figure 2.7: **(a) East, (b) north and (c) up time series for GPS sites affected by the Manawatu slow slip event.** Grey traces are daily solutions. Black traces are smoothing spline fits. Vertical dashed lines divide time periods of slow slip sub-events. (From Wallace and Beavan, 2006).

zone and propagated up-dip and then southwards along strike (Wallace and Beavan, 2006, Figure 2.8). Along-strike migration of slip has been observed in Cascadia (Kao et al., 2005), but not margin-normal migration.

2.3 Summary

Slow slip events were first detected in the late 1990s, and since then, they have been observed at many subduction zones, and at other plate boundary settings. CGPS has been a key instrument in the discovery of slow slip events, and as CGPS networks develop around the world, slow slip events may be observed in more locations. Slow slip events at subduction zones are varied in their individual characteristics, yet it appears that these events all occur at the transition from the shallow, locked portion to the deeper, freely sliding portion. Seismic phenomena, including seismic tremor and increased local seismicity, are associated with slow slip events in many different locations around the world.

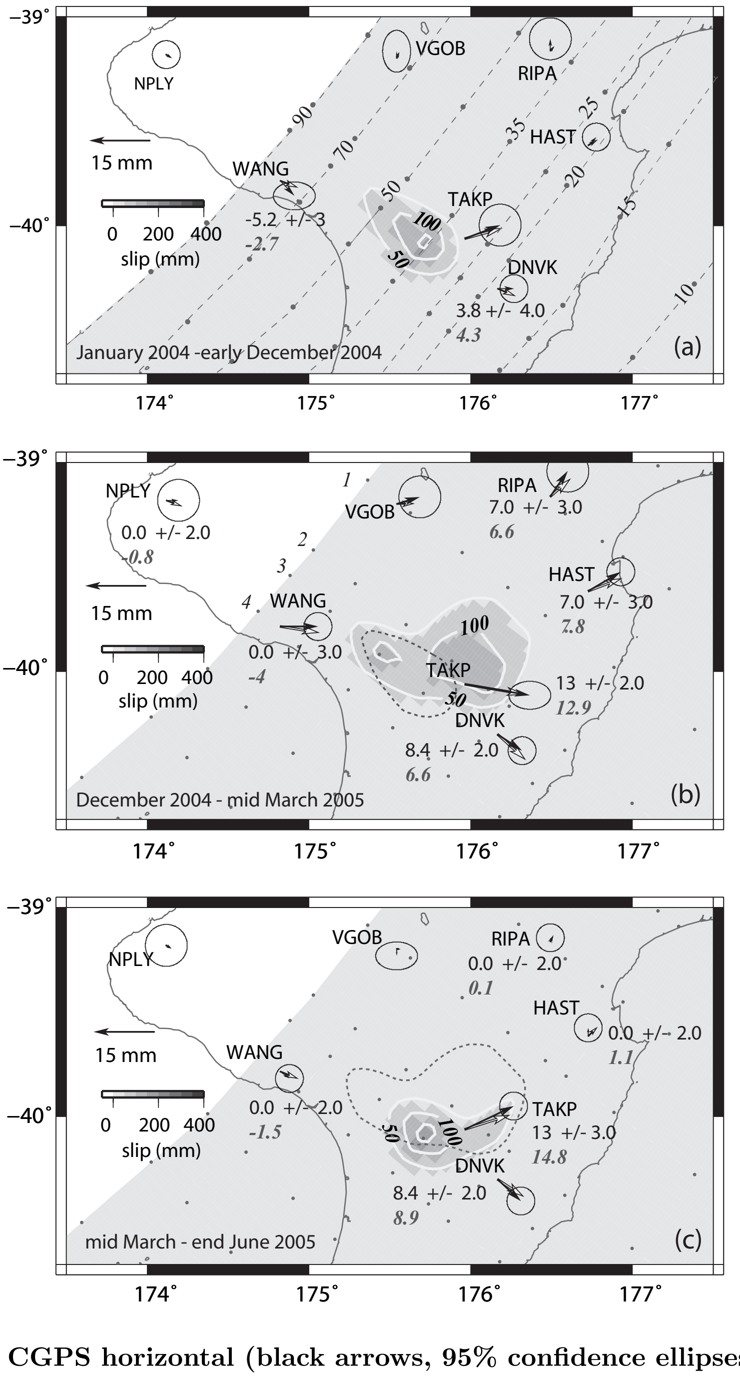

Figure 2.8: **CGPS horizontal (black arrows, 95% confidence ellipses) and vertical (numbers with uncertainties) displacements for the three stages of the Manawatu slow slip event.** (a) January-early December 2004 (b) December 2004-March 2005 (c) March-early June 2005. Dashed dark grey contours in (a) show depth (in km) of the subduction interface. The best-fitting slip distribution on the subduction interface from inversion (shaded and contoured in 50 mm intervals). Zero mm slip on the interface is light grey. Dashed lines in (b) and (c) outline the regions of slip for the previous stage. (From Wallace and Beavan, 2006).

Chapter 3

Data acquisition and analysis

This chapter presents the geophysical networks in New Zealand and the processes used for the collection and routine analysis of seismic data. The field methods and the first steps of data analysis from this study are also presented.

3.1 National data acquisition

The GeoNet Project, located at GNS Science in Lower Hutt, Wellington, is responsible for monitoring geohazards by overseeing real-time monitoring and data collection for rapid response and research. Data collected are available freely to the public via their website[1]. The project was established in 2001 and when fully complete, it will encompass a network of geophysical instruments, including seismometers, CGPS instruments, strong motion sensors and tsunami gauges.

3.1.1 Seismic network

The New Zealand National Seismograph Network, previously operated by the New Zealand Seismological Observatory, has almost reached completion (Figure 3.1). When complete, the network will consist of 46 foundation sites, spaced evenly throughout the country to provide a uniform location and data

[1] Refer to http://www.geonet.org.nz for more information on the project.

collection capability. Each site consists of a broadband seismometer, a strong motion accelerometer, a data logger and a high speed data connection to the data centres. The national network is supplemented by regional networks, in areas of increased seismic risk, including the Taupo Volcanic Zone and the east coast of the North Island.

3.1.2 Continuous GPS network

The New Zealand CGPS network (Figure 3.2) currently consists of approximately 30 stations throughout the country (in collaboration with Land Information New Zealand). The national network is also supplemented by a regional network along the Hikurangi subduction zone at ∼30 km spacings and campaigns conducted periodically throughout the country.

Because the development of a nation-wide network is a large task, the new sites are being upgraded and built in stages. Figure 3.3 summarizes the development of the CGPS and digital broadband sites in the eastern North Island during times of past slow slip events.

3.1.3 Seismic data acquisition and routine analysis

Continuous seismic data travels from the national network sites by satellite communications to the data office in Wellington, where the waveform data are archived in their raw format as Mini-SEED files [2]. Data from the regional network travels to the data centre via terrestrial means including radio telemetry or broadband internet (K. Fenaughty & M. Chadwick, GeoNet Project, pers. comm., 2007), where the data are stored in the main GeoNet archive (Figure 3.4).

GeoNet uses the CUSP (CalTech-USGS Seismic Processing) system for earthquake analysis. The software provides a database management system and the utilities required to edit and display earthquake parameters, including picks, amplitudes, hypocentres and station codes (Figure 3.5). Programs have been added to customize the system to New Zealand's requirements for

[2]Mini-SEED files are data-only waveform files, where SEED is an acronym for Standard for the Exchange of Earthquake Data

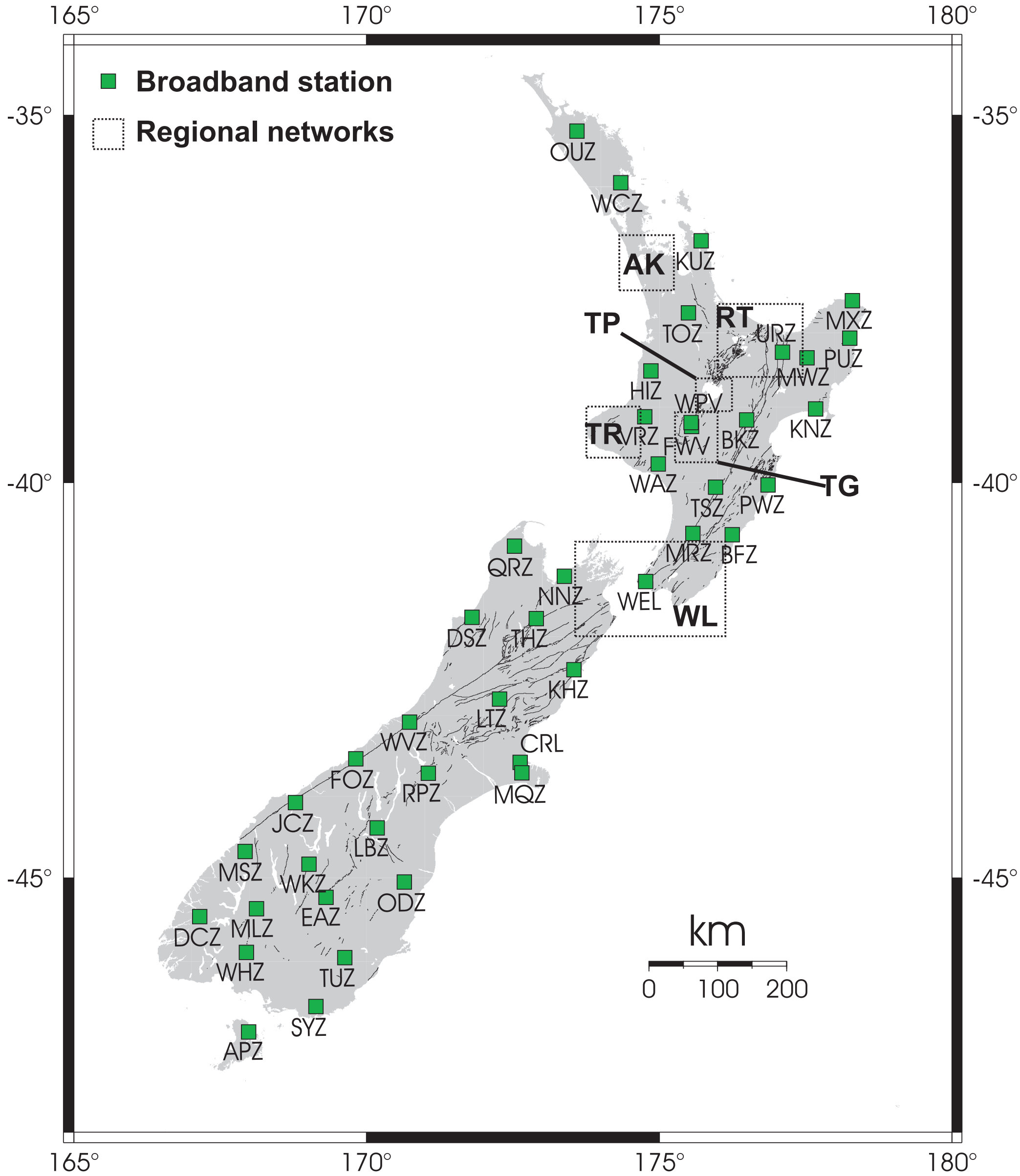

Figure 3.1: **New Zealand National Seismograph Network as of early 2006.** Regional seismograph networks are located within the dashed boxes. AK – Auckland, RT – Rotorua, TP – Taupo, TG – Tongariro, TR – Taranaki, WL – Wellington.

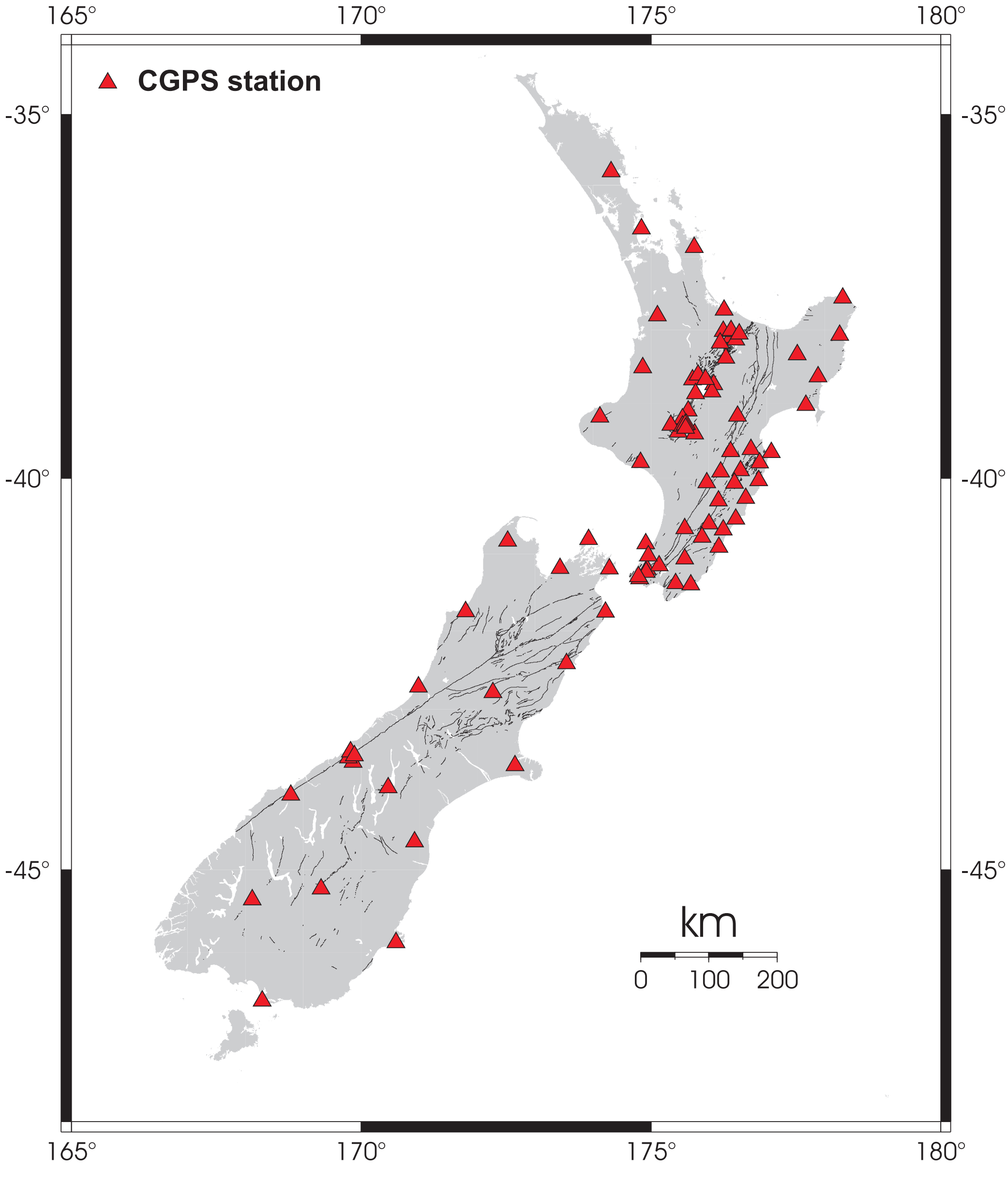

Figure 3.2: **New Zealand CGPS network as of early 2006.**

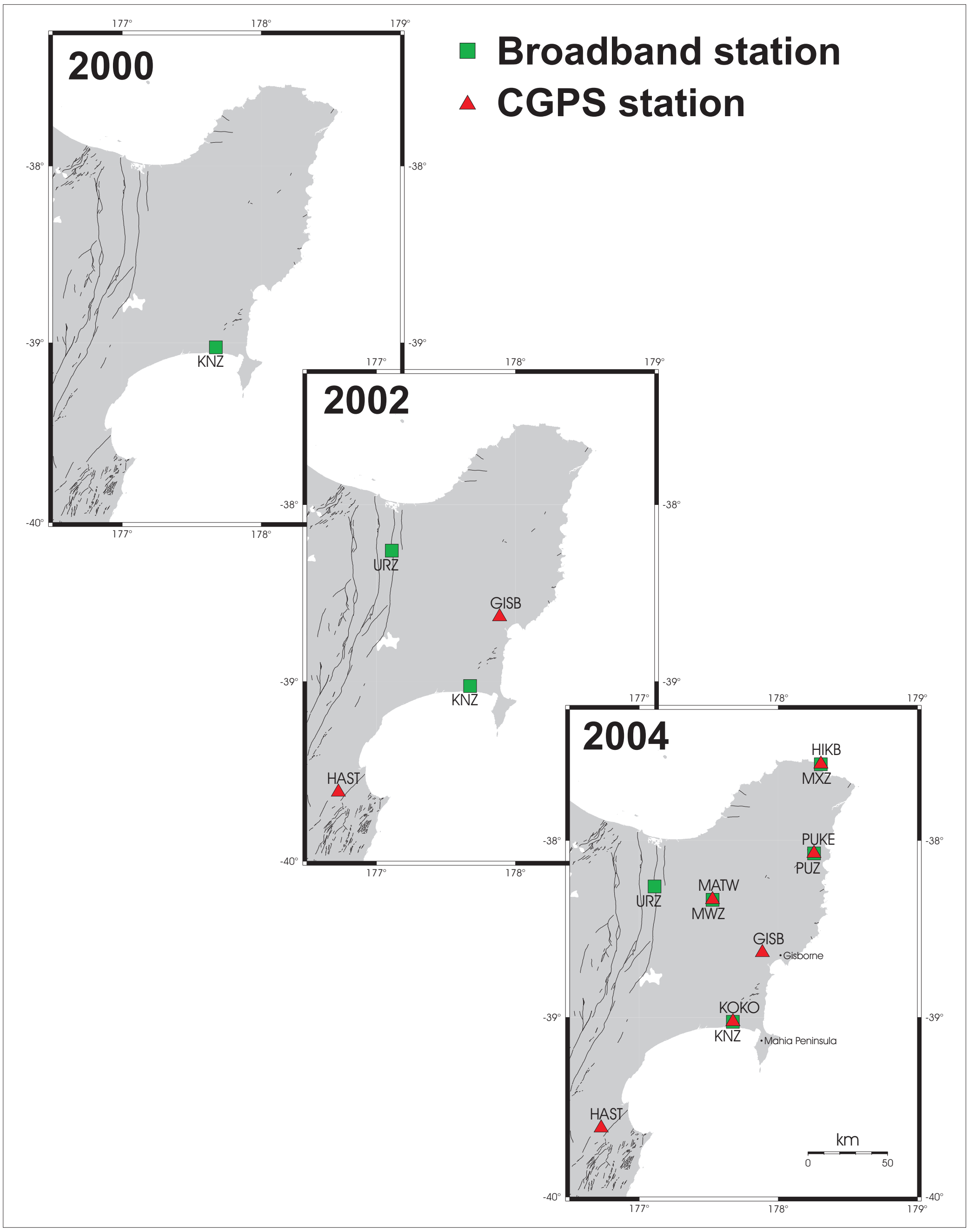

Figure 3.3: **The evolution of the seismograph and GPS networks in the Raukumara Peninsula.** Slow slip events were observed in late 2002 and 2004 (and 2006). Prior to 2002, there were no CGPS stations and only one seismometer on the Raukumara Peninsula, and our record of slow slip events is restricted to 2002 and subsequent years.

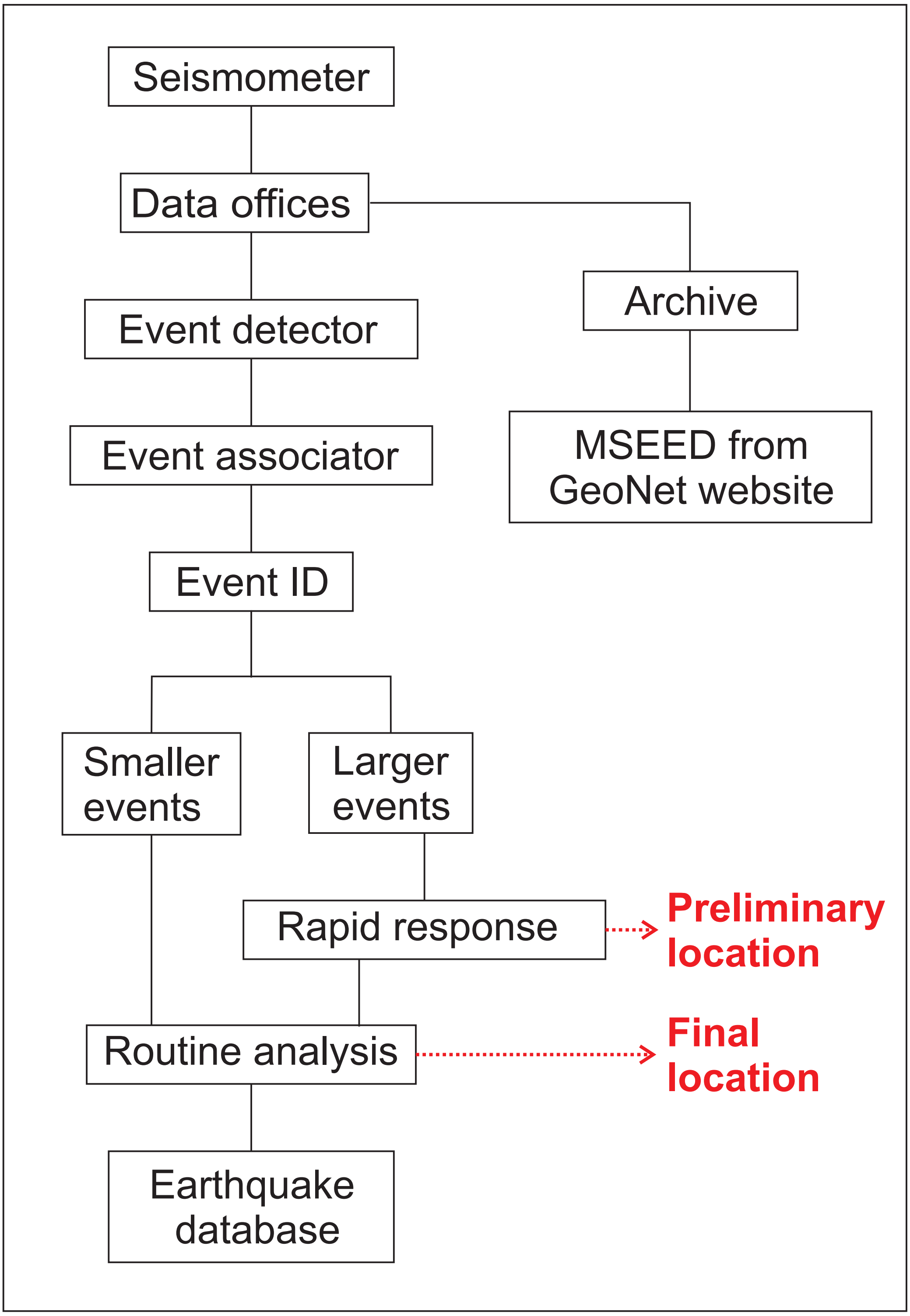

Figure 3.4: **A flowchart of continuous seismic data collection in New Zealand.** Data travels from seismometers to data office via satellite, radio telemetry or broadband internet. Data are concurrently sent to event detector and the data archive.

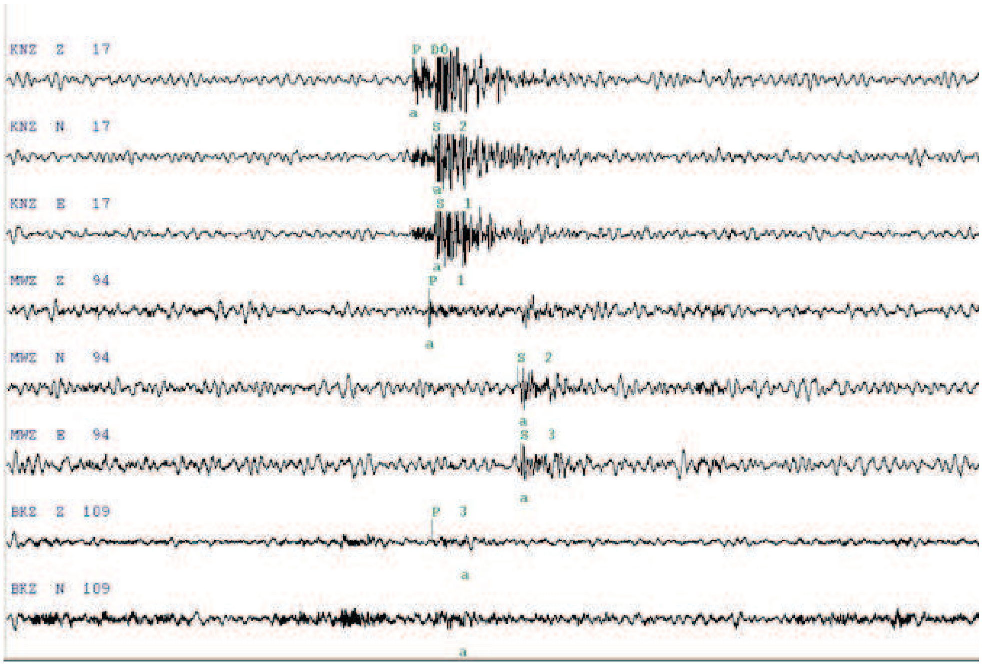

Figure 3.5: **A local earthquake displayed in the CUSP system** A screenshot of the quake editing window in CUSP, showing a small local earthquake. P and S arrivals are indicated in green. The letter **'a'** indicates amplitude measurements for magnitude calculation.

routine earthquake analysis and archiving (K. Fenaughty & M. Chadwick, GeoNet Project, pers. comm., 2007).

An event associator is run as part of the CUSP system. It reads the auto-detection time at a seismic station and creates a unique event identification number. The associator uses a time window of six minutes and includes all physically compatible picks during the time window. Earthquakes that have a higher number of associations or have been recorded on strong motion instruments, and consequently may have been felt by the public, are sent to a rapid response duty officer, who calculates a preliminary location within approximately 30 minutes. These earthquakes are generally larger than M_L 3.5 unless they occurred at shallow depths or within a volcanic region. Smaller earthquakes are located later by routine analysts, who also calculate more complete locations for the events reviewed by duty officers (Figure 3.4, K.

Fenaughty & M. Chadwick, GeoNet Project, pers. comm., 2007). The earthquake magnitude threshold varies throughout the country; it is lower in areas spanned by regional networks (Figure 3.1) and higher where the seismometer spacing is greater. The magnitude threshold for the Raukumara Peninsula is approximately M_L 2. The magnitude threshold for the Manawatu region is approximately M_L 1.5.

3.1.4 Temporary seismic deployment during the Gisborne 2006 slip event

Douglas (2005) and Douglas et al. (2005) estimated a recurrence interval of 2–4 years for slow slip beneath the Raukumara Peninsula. Prior to this study, slow slip events had been observed in October 2002 and late October to mid November 2004, suggesting that the next event might occur in late 2006. In order to determine whether seismic tremor accompanies shallow slow slip in the Gisborne region, I wanted to augment the existing national and regional networks in the Raukumara Peninsula with 5–6 additional temporary seismometers during a CGPS-detected slow slip event. In conjunction with GeoNet's ongoing site testing as part of the expansion of regional seismographs in the Raukumara Peninsula, I collaborated with several GeoNet staff during the field work. We began looking for suitable sites (at approximately 30 km spacing, including the existing permanent stations) from April to June 2006, and we planned to deploy the sites from August 2006 to January 2007, in anticipation of a slow slip event in late 2006. However, in July 2006, the GISB CGPS site began to move rapidly. Unfortunately a glitch in the GeoNet CGPS program delayed our response to the slow slip event. Anomalous GPS points were disregarded for several days and therefore the slow slip event was well underway before we could deploy the instruments. Once we recognized the GPS signal we deployed 6 stations (Figures 3.6 and 3.7, Table 3.1). There was an unexplained problem with one site (HANG) and as a result no data was recorded from this site. We deployed both broadband (Guralp CMG-40T) and short period (Lennartz LE-3Dlite) sensors. All portable data loggers were Nanometrics Taurus. The broadband

Figure 3.6: **A photograph of the temporary seismic site at Mahia (MHGZ).** A temporary seismic site from the 2006 deployment. The short period sensor is placed in the ground and the seismograph and battery are on top of the ground and covered by a tarpaulin.

sensors record between 60 s (i.e. 0.016 Hz) and 50 Hz and the short period sensors record above 1 Hz. Both short period and broadband sensors sample at 100 Hz.

Station code	Longitude	Latitude	Elevation (m)	Sensor type	Dates of operation
MHGZ	177.90702	–39.15424	290	S.P.	2006–07–20 to 2007–02–01
PRGZ	177.88314	–38.92420	474	S.P.	2006–07–22 to 2006–08–17
CNGZ	178.20717	–38.48534	159	B.B.	2006–07–20 to 2006–08–17
DUNX	178.04083	–38.45748	542	B.B.	2006–07–23 to 2006–08–17
GISX	177.88600	–38.63530	87	B.B.	2006–07–21 to 2006–08–17
HANG	177.60710	–38.70204	541	B.B	none

Table 3.1: **Instruments in temporary deployment.** S.P. denotes Lennartz LE-3Dlite short period sensors. B.B. denotes Guralp CMG-40T broad band sensors.

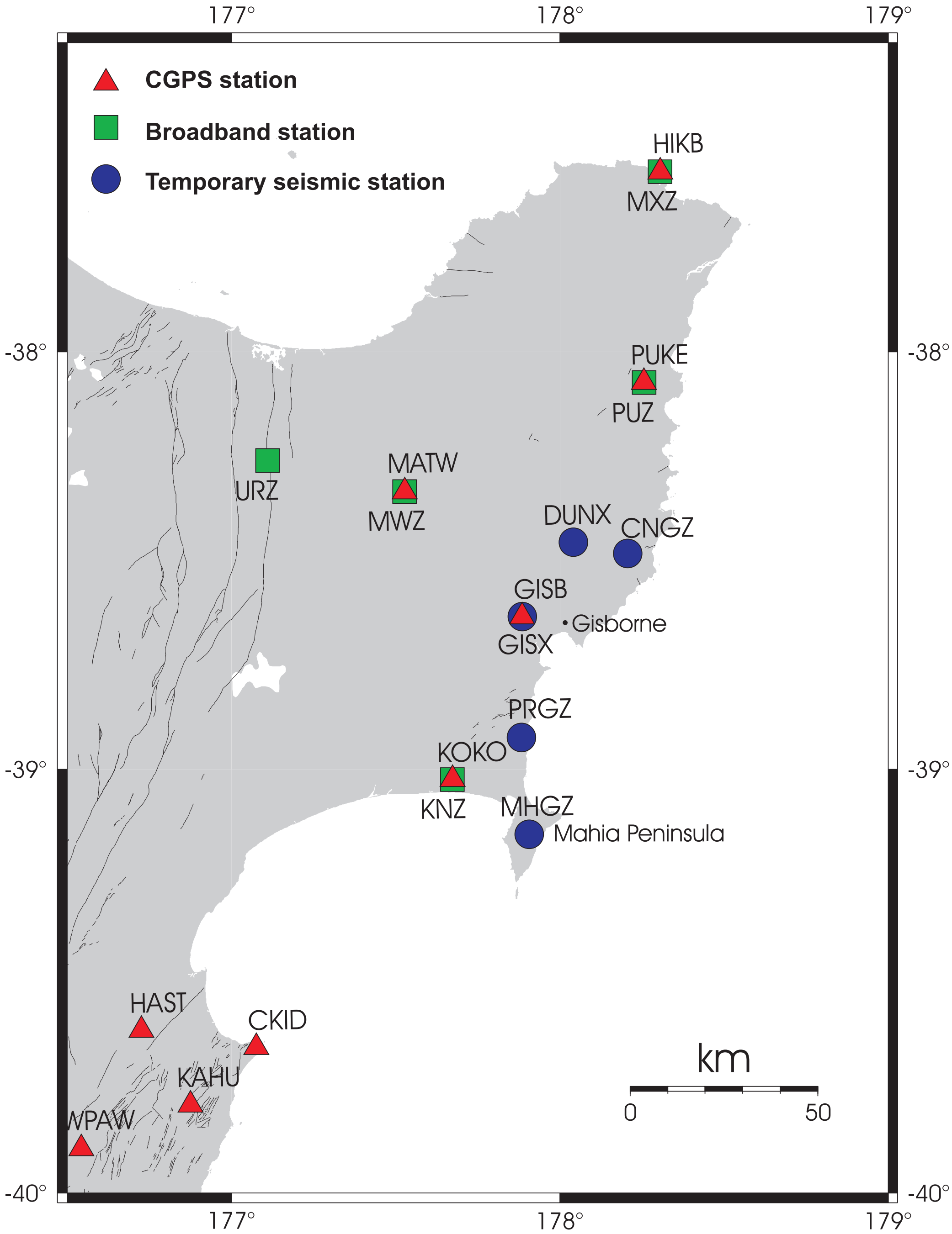

Figure 3.7: **Temporary seismic site deployment in 2006 in the Raukumara Peninsula.**

3.2 Review of continuous seismic data

One method used by overseas researchers to identify and quantify periods of non-volcanic tremor is a visual inspection of letter-size paper plots of continuous seismic data (G. Rogers, Geological Survey of Canada, pers. comm., 2006). Letter-size paper with hour-long records of seismic data is the easiest scale to visually detect seismic tremor (determined by trial and error). I worked with this method previously in Canada and was successful in identifying and quantifying periods of seismic tremor in northern Cascadia. I reviewed two months of data from Cascadia; one month during an ETS event, as well as the following month and I obtained consistent results with Garry Rogers. The same methods are applied to New Zealand data to perform a systematic investigation of seismic tremor.

Continuous broadband seismic data during three slow slip events was extracted and used to create plots for the visual examination. The plots (Figure 3.8) contain one hour of data horizontally and up to 25 stations vertically. With the help of Mark Chadwick, I created a script to retrieve raw data (vertical component only[3]) from the required stations, and then bandpass-filter the data between 1–6 Hz and plot the waveforms. The stations are plotted roughly according to geographic locations, in order to better discern the amplitude envelope of emergent tremor signals. A different set of stations was used for each slip event (cf. Figures 5.4 and 5.6).

Figure 3.8 is an example of a plot made for visual inspection for the slow slip event near Gisborne in 2004. The stations are from the east coast of the North Island and the most northern stations are at the top of the plot (Figure 3.1). Two stations (MLZ and WHZ) were added from near the Puysegur subduction margin in order to perform a preliminary investigation for seismic tremor (as an indication of as yet undetected slow slip) in the South Island. The seismic plot files are quite large (approximately 15 megabytes), and it

[3] As mentioned in Chapter 1, tremor signals are strongest on horizontal seismographs. In Japan and northern and southern Cascadia, researchers created paper plots using the vertical components (G. Rogers, Geological Survey of Canada, pers. comm., 2006; W. Szeliga, Central Washington University, pers. comm., 2006), therefore we did the same. Further on in our investigation I reviewed all three components of the seismic waveforms (Chapters 4 and 5).

was easiest to set the plots to print overnight. The subsequent stages of analysis are described in Chapters 4 and 5.

3.3 Summary

GeoNet is responsible for developing and maintaining geophysical monitoring networks in New Zealand, including national CGPS and broadband seismograph networks and the data are freely available to the public. In collaboration with GeoNet staff, I deployed temporary seismometers during a slow slip event in 2006 to decrease the station spacing in the Gisborne region. The first step of analysis of continuous broadband seismic data was the creation and visual inspection of hour-long paper plots, to be used for the investigation of seismic tremor during three slow slip events in New Zealand.

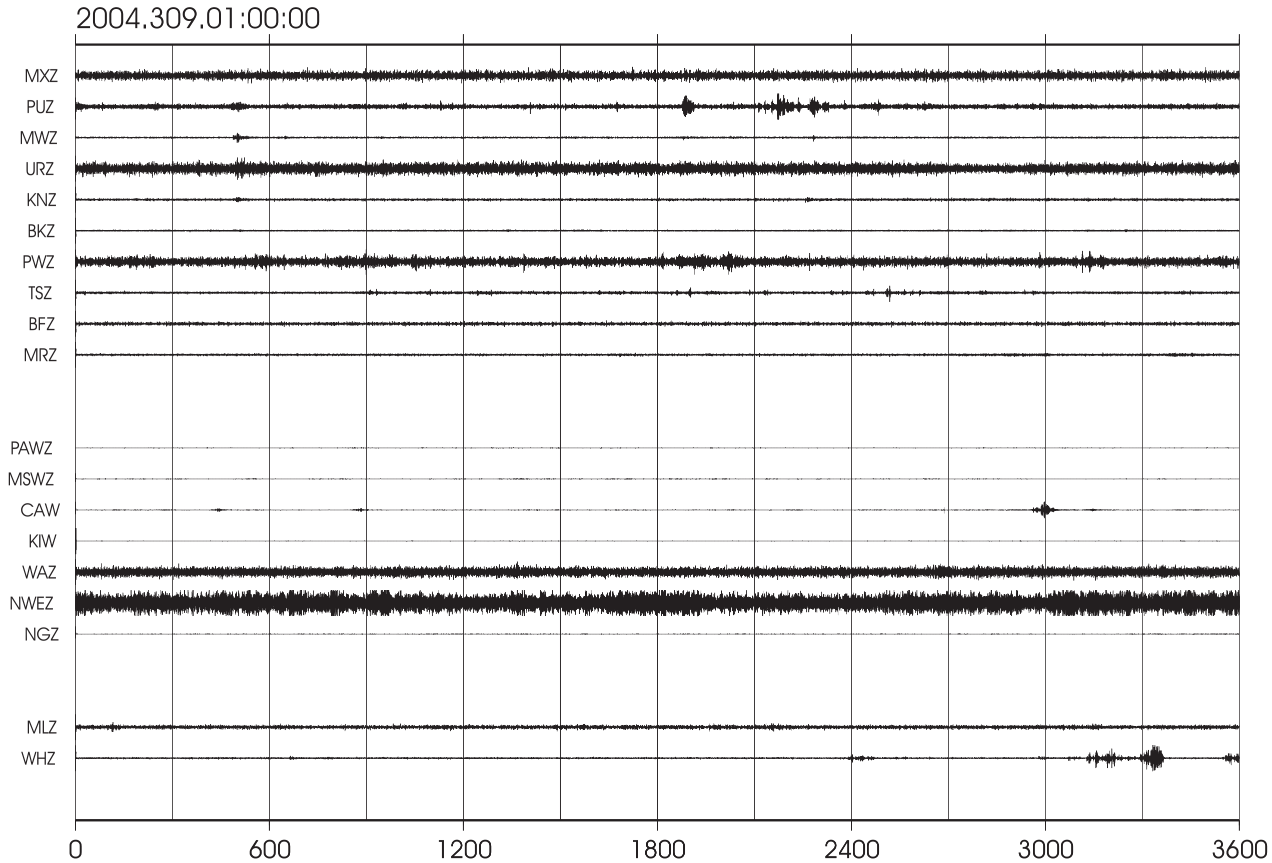

Figure 3.8: **Hour-long seismic plot** used for visual review of continuous broadband seismic data. Example is from hour 01:00 UTC on 4 November 2004. Refer to Figure 3.1 for broadband station locations (left-hand vertical axis). Stations PAWZ, MSWZ, CAW, KIW, NWEZ and NGZ are regional network stations in the Wellington (WL), Taranaki (TR) and Tongariro (TG) regional networks. Horizontal axis is time in seconds. There are two local earthquakes detected during this hour. The first event occurred at 01:07 (~420 s) and was M_L 2.6. The second event occurred at 01:37 (~2220 s) and was M_L 2.1. Both events are located near the Mahia Peninsula (Figure 3.7).

Chapter 4

Seismic tremor investigation

In this chapter the methods used to detect and characterize seismic tremor associated with three New Zealand slow slip events are presented.

4.1 Slow slip events analysed in this study

I performed a comprehensive review of seismic data during the times of three slow slip events in New Zealand. Two slip events occurred in the shallow part of the Hikurangi subduction zone, near Gisborne on the Raukumara Peninsula, and one slip event occurred on the deeper interface beneath the Manawatu region. These particular events were chosen for review because the slip events have very different characteristics in the two regions.

4.1.1 Slow slip near Gisborne, 2004–2006

As discussed in Chapter 2, slip events have been detected by CGPS observations near Gisborne in 2002, 2004 and 2006 (Figure 4.1). Douglas (2005); Douglas et al. (2005) interpreted geodetic data from the 2002 slow slip event (Figure 2.6). The 2004 and 2006 slip events have not been modeled from geodetic observations, but the 2004 event is thought to fit the 2002 model, and the 2006 slip event as well, but with a smaller amount of slip (L. Wallace, GNS Science, pers. comm., 2007). This study reviews the slip events in 2004 and 2006 because there were more broadband seismic stations operating than during the 2002 slip event (Figure 3.3). In response to the 2006 event, an array of temporary seismometers was deployed to determine if a denser seismic network is necessary to observe seismic tremor.

The seismometer and CGPS site spacings in the Raukumara Peninsula are both approximately 100 km (Figure 4.1). The majority of stations now operating on the Raukumara Peninsula were installed prior to the 2004 slow slip event, but after the 2002 slow slip event. The 2002 slow slip event was only observed on one site, GISB, near Gisborne city, but the 2004 and 2006 slip events were observed at several sites, GISB and KOKO, and possibly PUKE (Figure 4.1).

4.1.2 Slow slip under the Manawatu region, 2004–2005

As discussed in Chapter 2, a large slow slip event was observed in the Manawatu region from January 2004 to June 2005 (Figure 4.3). Wallace and Beavan (2006) modeled the geodetic data as $\sim$300 mm of slip on the subduction interface (Figures 2.7 and 2.8). The CGPS and broadband seismometer station spacings vary throughout the region but overall are more dense than the Raukumara Peninsula.

Wallace and Beavan (2006) split the event into three parts. The first sub-event, from early 2004 to December 2004, shows smaller displacements than the following sub-events, but the displacements are still significant. The second and third sub-events are based on the change in direction of motion at site TAKP (Figures 4.3 and 5.6), which moves southward from the end of December 2004 through mid-March, and northward from mid-March through June 2005.

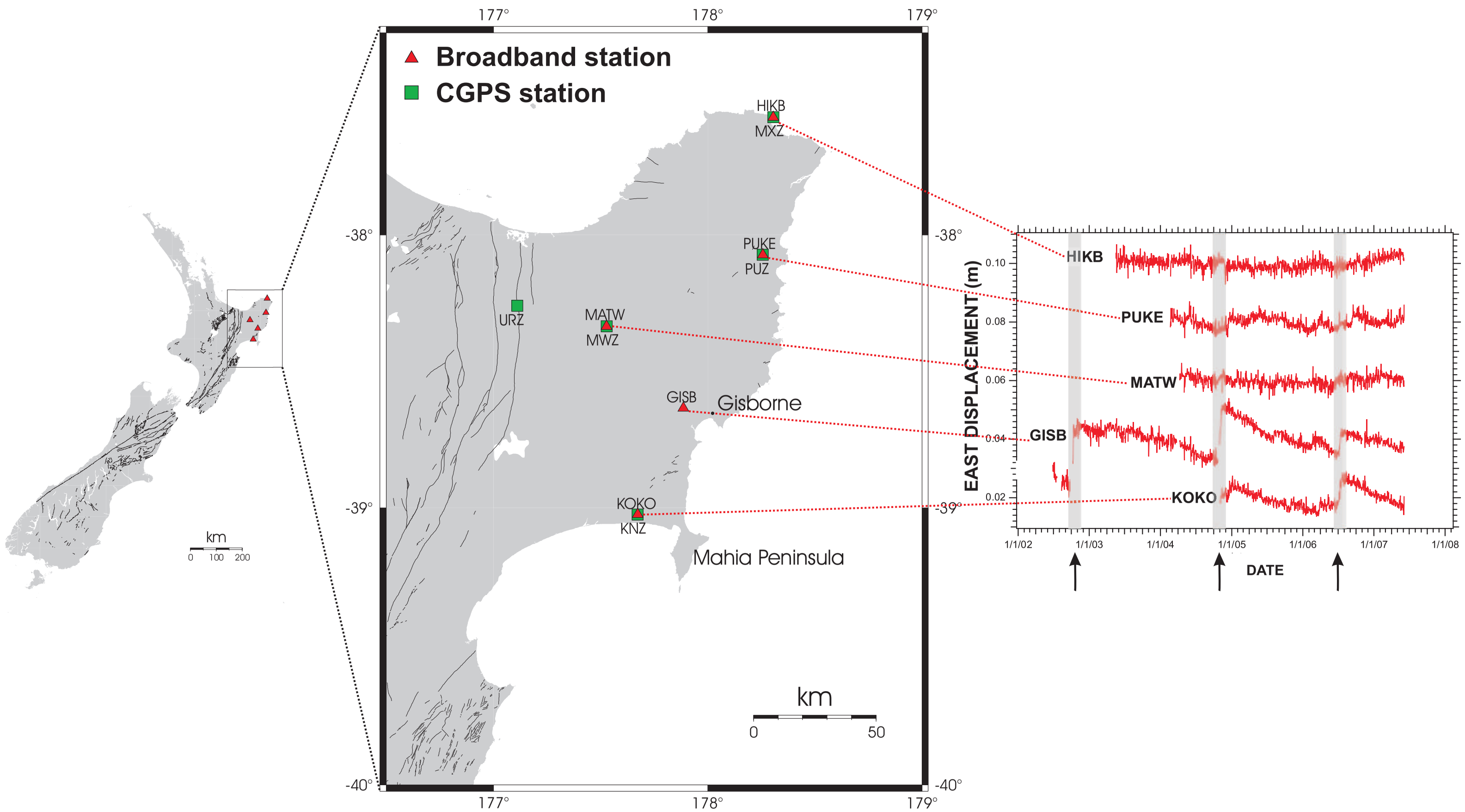

Figure 4.1: **Raukumara Peninsula CGPS and broadband seismograph locations.** Slow slip events were detected at CGPS site GISB in 2002, 2004, and 2006. Smaller amounts of slip were observed at sites PUKE and KOKO in 2004 and 2006. The grey shading and black arrows indicate periods of slow slip.

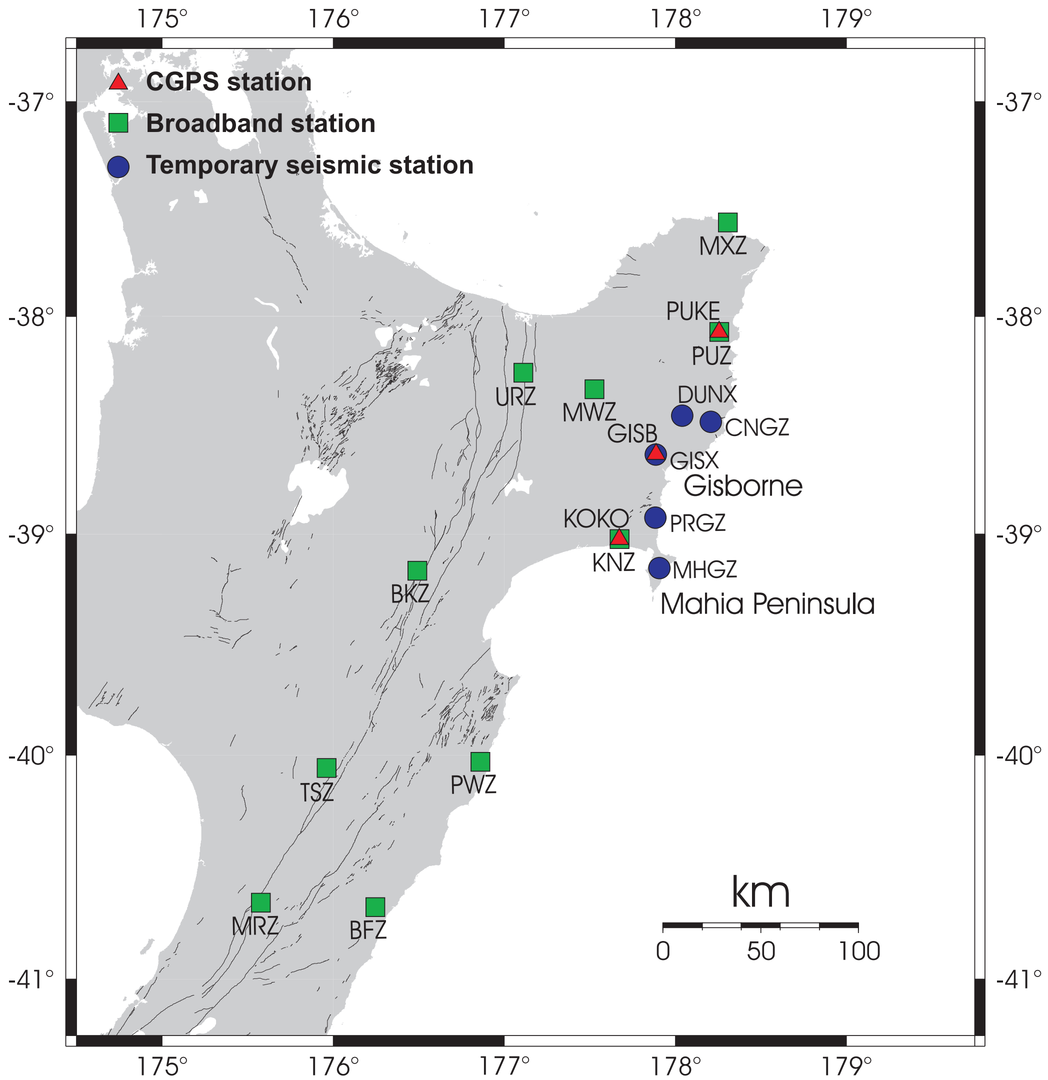

Figure 4.2: **Map of stations used in this study for the 2004 and 2006 slip events**. All of the permanent seismometers and CGPS sites illustrated had been installed before the 2004 slip event. Temporary seismographs were deployed during the 2006 slip event.

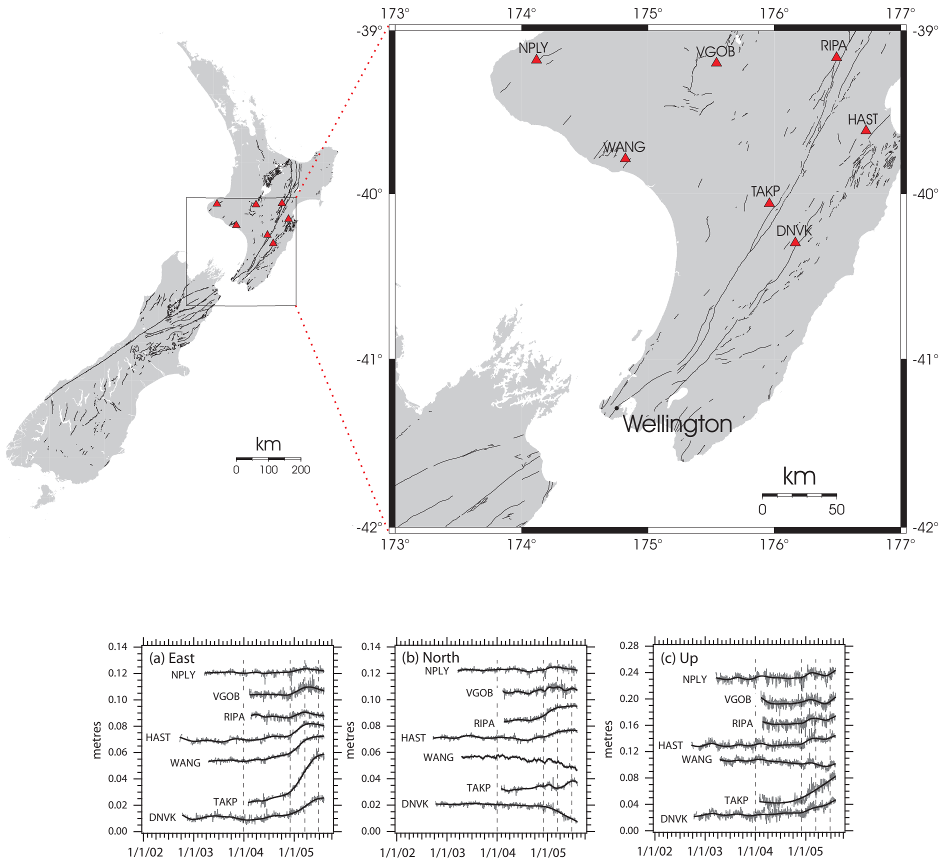

Figure 4.3: **Map of CGPS stations and time series for 2002–2005 in the Manawatu region.** Red triangles indicate CGPS stations where slow slip was observed. (a) East, (b) north and (c) up time series for GPS sites affected by the Manawatu slow slip event. Grey traces are daily solutions. Black traces are smoothing spline fits. Vertical dashed lines divide time periods of slow slip sub-events. (Time series is from Wallace and Beavan, 2006).

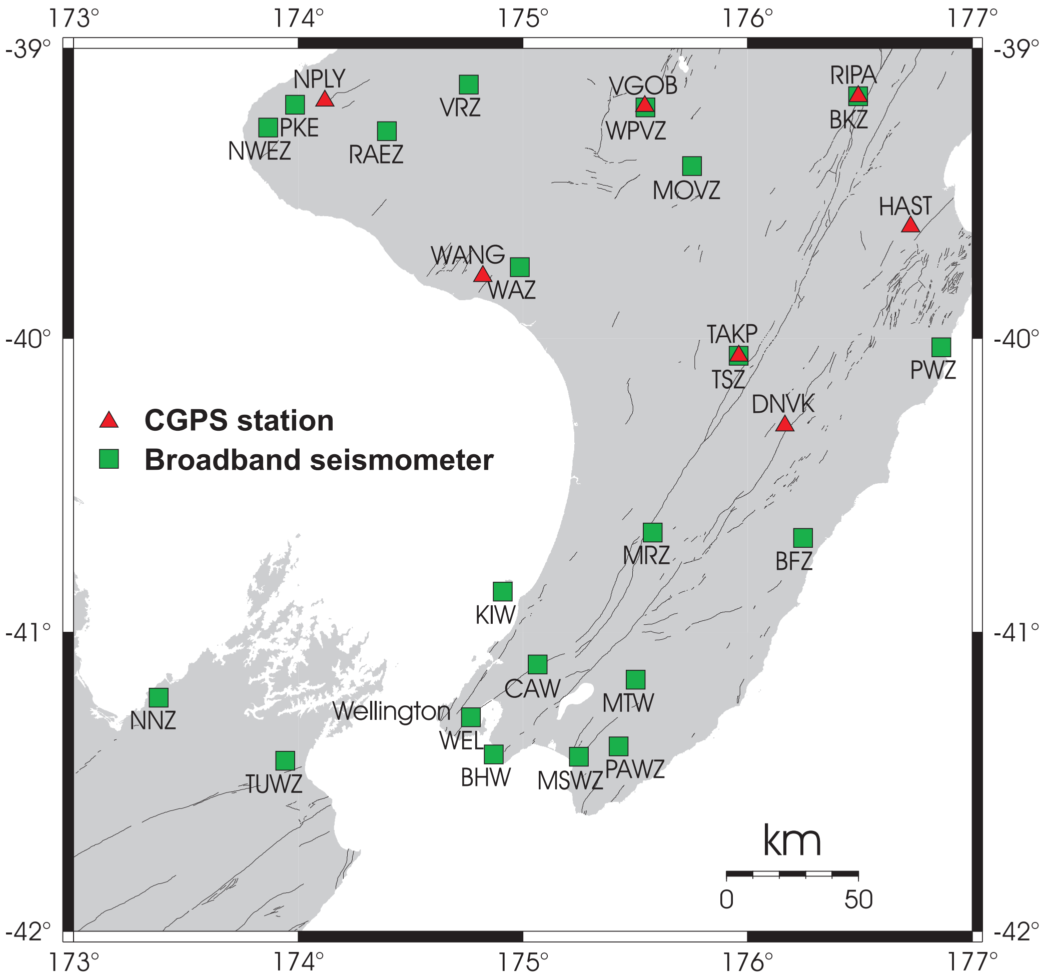

Figure 4.4: **Map of stations used in this study for the 2004–2005 slip event**. All of the seismometers and CGPS sites illustrated had been installed at the start of the 2004–2005 slip event.

4.2 Tremor analysis

As discussed in Chapter 3, the first stage of tremor analysis was the creation of hour-long plots of continuous seismic data. The systematic review covered three periods of slow slip in two different regions of the Hikurangi subduction zone. The steps used for the tremor analysis are outlined as a flow diagram in Figure 4.5. In order to thoroughly review the data, as tremor has not been formally documented in New Zealand, I interpreted all visible events in the plots. A list of all local and regional earthquakes that were located during routine analysis from the GeoNet CUSP database and a list of teleseisms from the National Earthquake Information Center (NEIC) were also extracted. Seismic signals were noted during the visual inspection of the hour-long plots and were classified as one of the following: confirmed teleseismic arrivals from either the NEIC catalogue or the GeoNet record of teleseisms; local or regional earthquakes (R) located during routine analysis; and all other seismic signals required closer examination. The arrival times of the unrecognized seismic signals were used to extract in 5-minute waveform files for systematic analysis in the CUSP quake editing system.

4.2.1 Motivating results from Douglas (2005)

Douglas (2005) showed three possible seismic tremor signals during the 2004 Gisborne slow slip event. The times of these seismic signals were examined closely in the CUSP system. The example shown in Figure 1.3 is most likely a teleseism, probably originating somewhere north of New Zealand, along where the Hikurangi subduction zone becomes the Tonga-Kermadec trench. It is not large enough to obtain a good hypocentre solution, but it has similar characteristics to other teleseisms that I could obtain locations for (i.e. emergent arrivals, more lower frequency energy than local earthquakes). The S-P time is $\sim$ 75 seconds, which corresponds to a distance of 600 km from the Raukumara Peninsula and the move out of arrival times indicates an origin to the northeast of the Raukumara Peninsula. This is consistent with an earthquake originating along the Kermadec Trench.

It is difficult to determine the origin of many teleseismic arrivals because although there is a great deal of seismic activity in the southwest Pacific, there is little land in the region and there are not many seismic networks. Consequently, many earthquakes are not documented in earthquake databases. The smallest earthquakes north of New Zealand (along where the Hikurangi subduction zone becomes the Tonga-Kermadec Trench) that are recorded in the NEIC (USGS National Earthquake Information Center) are between $M_L \sim 3.8$–4.0. Arrivals from many smaller magnitude teleseisms are recorded on New Zealand stations but are still too small to locate accurately.

Another example from Douglas (2005) has similar characteristics to a teleseism, with very emergent arrivals and a long S-P time. Again, this example is too small in magnitude to obtain a good-quality location, but the S-P time is consistent with an earthquake north of New Zealand, along the Tonga-Kermadec Trench. The third example of a possible tremor signal in Douglas (2005) has two clear arrivals (a P arrival and an S arrival) with an S-P time of two seconds, consistent with a local event on the Raukumara Peninsula, but the amplitudes of this event are too small to obtain a stable solution. None of these suggested seismic tremor are long-lasting (compared to tremors in Cascadia which can last for several minutes up to hours) and this type of signal was not seen repeatedly throughout my systematic review of continuous seismic data.

4.2.2 Gisborne 2004

Hour-long plots of continuous broadband seismic data were created and reviewed for a seven week period spanning the 2004 Gisborne slow slip event (before, during and after the slow slip event). During the seven week period, all other seismic signals (i.e. not a confirmed teleseism or a local or regional earthquake in the GeoNet CUSP catalogue) were extracted in 5-minute files to review more closely in CUSP. A total of 587 files was extracted to examine in detail. The seismic tremor analysis is summarized as a time series in Figure 4.6, where the start time of each file analysed is indicated as a black bar. The seismic data reviewed were from stations on the Raukumara Peninsula and along the east coast of the North Island (Figure 5.4).

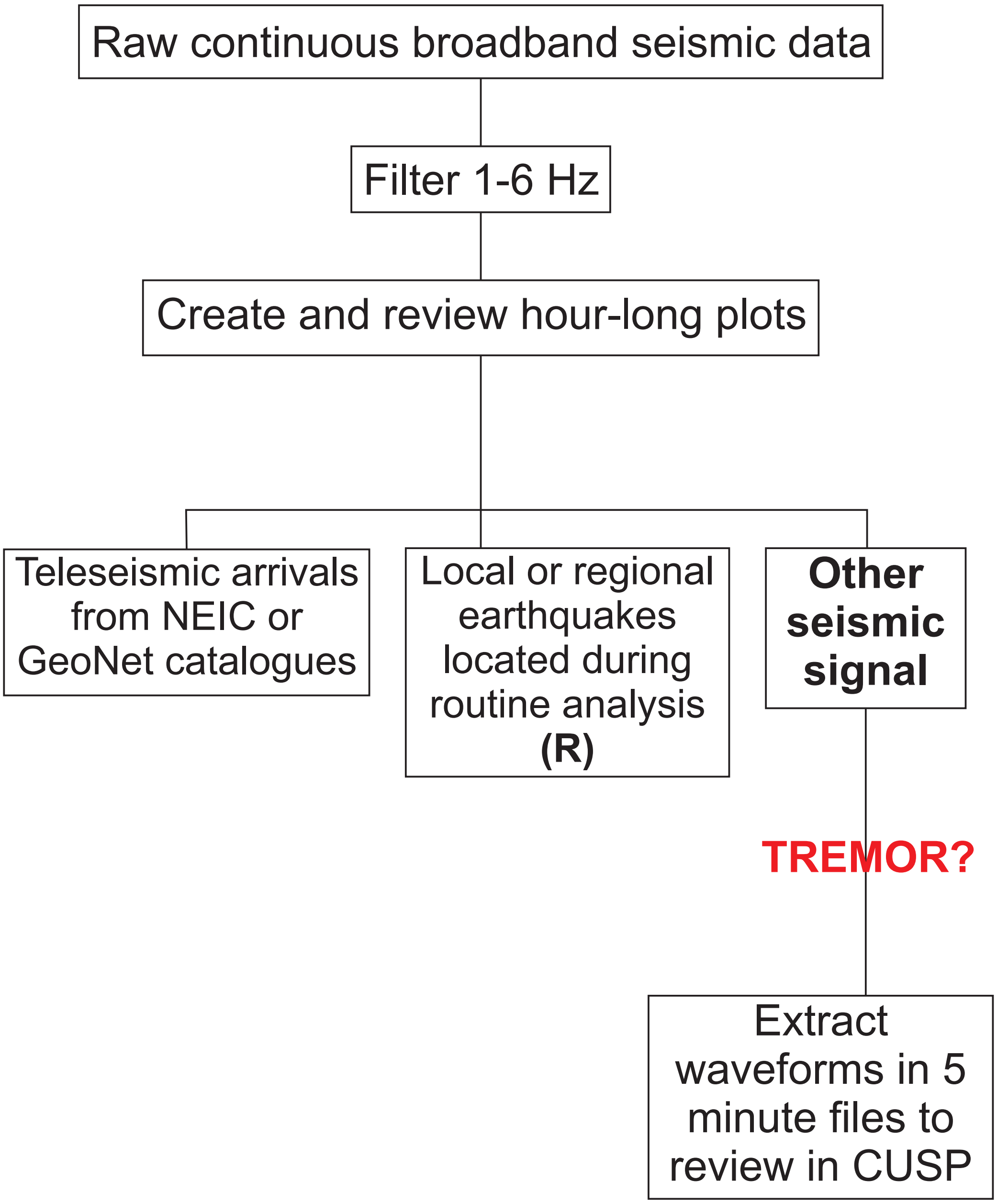

Figure 4.5: **A flowchart of the steps in the tremor analysis.** Method used for visual analysis of plots of continuous seismic data.

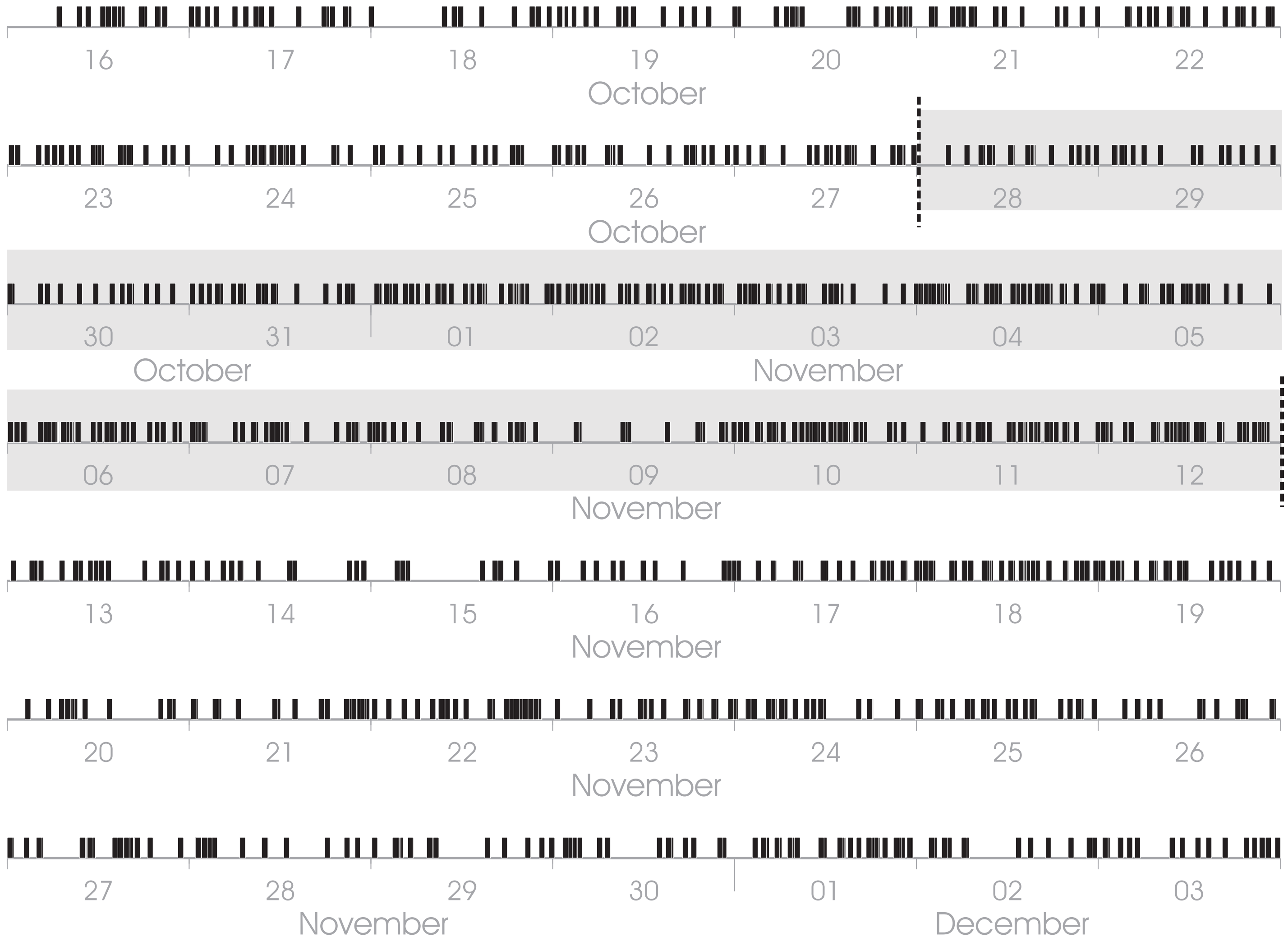

Figure 4.6: **Analysis summary for the Gisborne 2004 event** for a seven week period spanning the 2004 Gisborne slip event. The black bars indicate the start of five-minute waveform files reviewed in the CUSP system. The black dashed lines and grey shading indicate the timing of the geodetically inferred slow slip.

4.2.3 Gisborne 2006

Hour-long plots of continuous broadband seismic data were created and reviewed for a five week period during and after the 2006 Gisborne slow slip event, with the addition of five temporary stations (broadband and short period instruments). The seismic analysis is summarized as a time series in Figure 4.7. There were no temporary stations deployed before the slip event started, so I restricted the data review to a period during the slip event and following the slip event. As discussed in Chapter 3, there was a delay in our field deployment due to a problem with the GeoNet GPS programs and the instruments were only collecting data on the last day of the slow slip event and the period following the slow slip event. However, seismic tremor continues for several weeks after the GPS signal indicates the end of slow slip in Cascadia (Kao et al., 2006), therefore it is possible that a seismic tremor signal could continue after the end of the geodetically inferred timing of slip in New Zealand as well. In total, 236 files were reviewed in detail.

4.2.4 Preliminary analysis, Manawatu 2004–2005 event

The Manawatu slow slip event occurred over an 18 month period and due to the time constraints of this study, the review of continuous broadband seismic data was limited to an eight week period during the slow slip event. I reviewed the period beginning 1 January 2005 because the observed motions were the greatest during this period (Wallace and Beavan, 2006,Figure 2.7), using data from stations in the Manawatu and Wellington regions (Figure 4.4). The station spacing is denser here than the network in the Raukumara Peninsula, and as a result, small amplitude seismic tremor signals should be easier to identify. A total of 153 files were extracted and reviewed in the CUSP system in detail, during the eight week period.

4.3 Results

Followed methods used successfully overseas by other workers and myself, I reviewed a total of 20 weeks of continuous broadband seismic data during

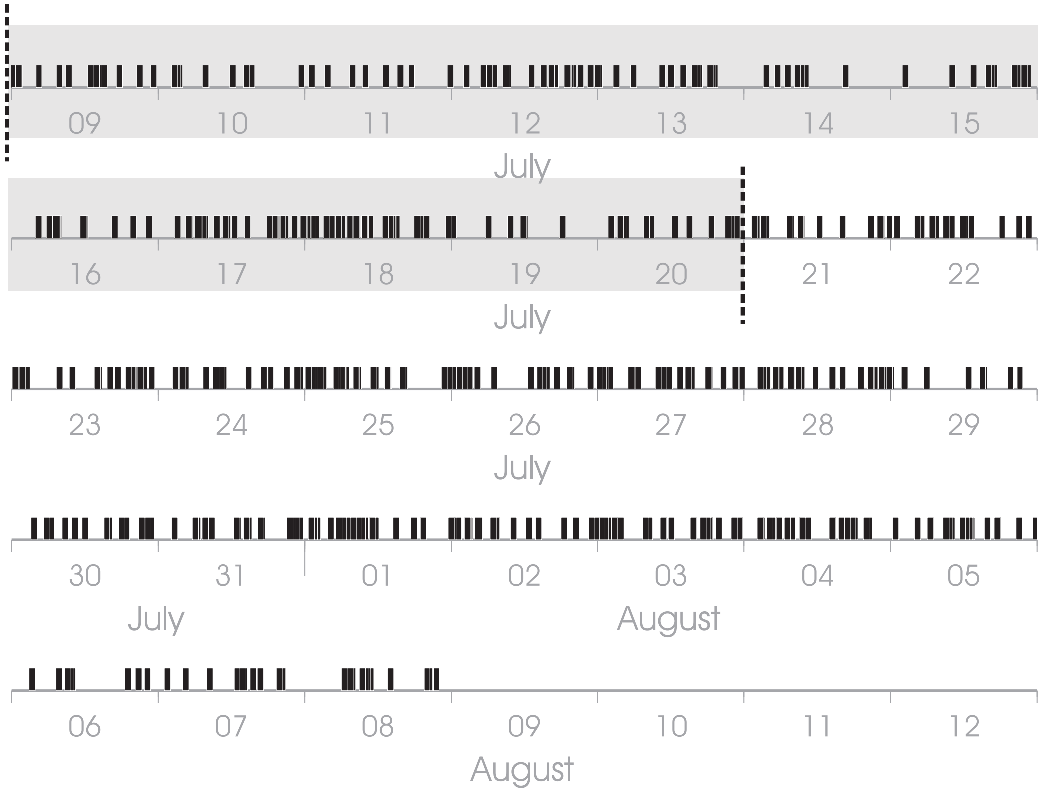

Figure 4.7: **Analysis summary for the Gisborne 2006 event** for a four and half week period during and after the 2006 Gisborne slip event. The black bars indicate the start of five-minute waveform files reviewed in the CUSP system. The black dashed lines and grey shading indicate the timing of the geodetically inferred slow slip.

three different slow slip events in New Zealand, two in the shallow region of the Hikurangi subduction zone and one on the deeper region.

I did not detect non-volcanic seismic tremor during the Gisborne 2004 slip event (or anytime in the seven week period analysed). With the addition of five more seismometers during the 2006 Gisborne slip event, the station spacing decreased from 50–100 km to ∼30 km in the region nearest the slip. Even with the extra seismic data, seismic tremor was not observed during the Gisborne 2006 slip event. As mentioned earlier, the extra seismic data was only collected at the very end of the geodetically inferred time of slow slip in 2006, in spite of this, the extra data still indicates that tremor did not occur during the 2006 slow slip event. Seismic station spacing is approximately 50 km on the northern Cascadia margin, where seismic tremor is detected

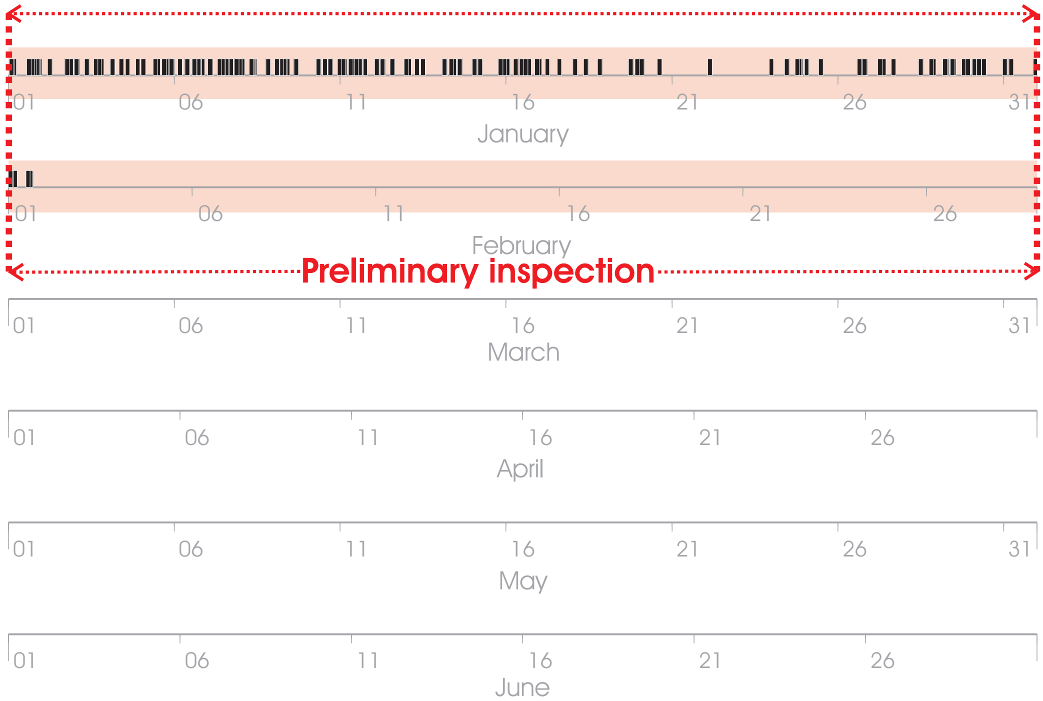

Figure 4.8: **Analysis summary for the Manawatu 2004–2005 event** for a 6 month period during the slow slip event. The black bars indicate the start of five-minute waveform files reviewed in the CUSP system. The red dotted lines and red shading indicate the period of the visual inspection of hour-long plots of seismic plots. Slow slip continued throughout the period shown here. Note that each row represents a whole month (cf. Figures 4.6 and 4.7.

without difficulty. Limitations in the seismic network are not likely the reason why seismic tremor has not been detected.

Both the Gisborne slip events occurred at shallow depths, so it is interesting to compare the results with the preliminary investigation for tremor on the deeper region of the Hikurangi subduction zone during the 2004–2005 slow slip event in the Manawatu region. Due to the long duration of the Manawatu slow slip event, I did not review continuous seismic data during the entire event. These results are preliminary, but seismic tremor was not detected during the eight week period analysed (during the period with the most rapid displacements and therefore when it is expected that seismic tremor is most likely to occur). The initial results from this study suggest that non-volcanic tremor is absent during slow slip on the deeper parts of the Hikurangi subduction zone.

As mentioned in Chapter 3, seismic data from two stations near the Puysegur subduction margin were included in the hour-long seismic plots for the Gisborne 2004 event. This is a preliminary investigation for seismic tremor or other seismic phenomena, which could give an indication of whether slow slip events are occurring on the subduction zone in the South Island of New Zealand. This very limited overview, shows no indication of non-volcanic seismic tremor along the Puysegur margin.

This is the first study to carry out a thorough and systematic review of continuous seismic data to determine if slow slip events on the Hikurangi subduction zone are accompanied by non-volcanic seismic tremor. The findings from 20 weeks of data consistently indicate that slow slip events in New Zealand are not accompanied by seismic tremor (with similar characteristics to documented tremor associated with slow slip events in Cascadia or southwest Japan).

4.4 Summary

The first part of analysis in this study was a thorough review of continuous seismic data to investigate the presence of seismic tremor during periods of slow slip. The first two objectives of the study are to determine if slow slip events in New Zealand are associated with non-volcanic seismic tremor and also to determine if a more dense seismic network is necessary to detect seismic tremor. I obtained a negative result for both of these objectives, therefore the focus of the study was directed to answering the third objective, which is to determine if slow slip events in New Zealand are accompanied by other seismic phenomena, such as low frequency and very low frequency earthquakes, and increases in microseismicity, as discussed in Chapters 1 and 2. In particular, during the tremor analysis, I noticed a substantial amount of local microseismicity that had not been located during the routine analysis at GeoNet.

Chapter 5

Other seismic phenomena associated with slow slip

The results from the review of continuous broadband seismic data in the investigation of other seismic phenomena, particularly spatiotemporal changes in local seismicity during three slow slip events on the Hikurangi subduction zone, New Zealand are presented in this chapter. Motivation for the work in this chapter comes from Segall et al.'s (2006) observation that a concerted effort should be made to search for very small earthquakes accompanying slow slip events elsewhere. I focus first on the 2004 and 2006 Gisborne slow slip events, which were only a few weeks in duration and then on a portion of the 2004–2005 Manawatu slow slip event.

5.1 Methods and analysis

The first part of analysis in this study was a thorough review of continuous seismic data to elucidate the occurrence of seismic tremor spanning three slow slip events, as described in detail in Chapter 4. The first two objectives of the study are to determine if slow slip events in New Zealand are associated with non-volcanic seismic tremor and also to determine if a more dense seismic network is necessary to detect seismic tremor. The analysis revealed that no tremor accompanied these events and this mostly likely is not a network issue, therefore I directed my efforts to answer the third objective, which is to determine if slow slip events in New Zealand are accompanied by other seismic phenomena, such as those discussed in Chapters 1 and 2. In particular, during the tremor analysis, I noticed a substantial amount of local seismicity that had not been located during the routine analysis at GeoNet.

Because there was not a definitive example of seismic tremor or other seismic phenomena accompanying slow slip events in New Zealand, all seismic events[1] were confirmed or investigated further. The analysis steps are outlined as a flowchart in Figure 5.1. As discussed in Chapter 4, a record was made of all previously unidentified seismic events after accounting for all local and regional earthquakes located during routine analysis: "R" earthquakes, and all teleseisms located during routine analysis at GeoNet or the NEIC (National Earthquake Information Center). All remaining seismic events were reviewed in detail in the CUSP system and assigned to one of three groups. "N" events are regional or local earthquakes that were previously undetected during routine analysis. The newly detected earthquakes are recorded on at least three stations, but were not triggered on the GeoNet auto detection system. The newly detected earthquakes are generally smaller magnitude than the earthquakes located during routine analysis ($M_L \sim$1–2, depending on the region). First motions were picked whenever possible for the newly detected earthquakes. Previously undetected teleseisms "T" were most commonly located north of New Zealand, along the Kermadec Ridge. As discussed in Chapter 4, the area to the north of New Zealand, where the Hikurangi subduction zone becomes the Kermadec Ridge (part of the Tonga-Kermadec Trench), is seismically active and many earthquakes in the area are not located by the NEIC. I could detect and recognize many of these teleseisms, but could only locate some of them. "X" events are seismic signals that were visible on the seismic paper plots but further examination did not produce event locations. The seismic signals could be either station noise or local, regional or teleseismic earthquakes that were too small to locate.

[1] In this chapter, I use the term 'event' to mean a discernible signal in the waveforms, recorded at three or more stations, that may or may not be an earthquake

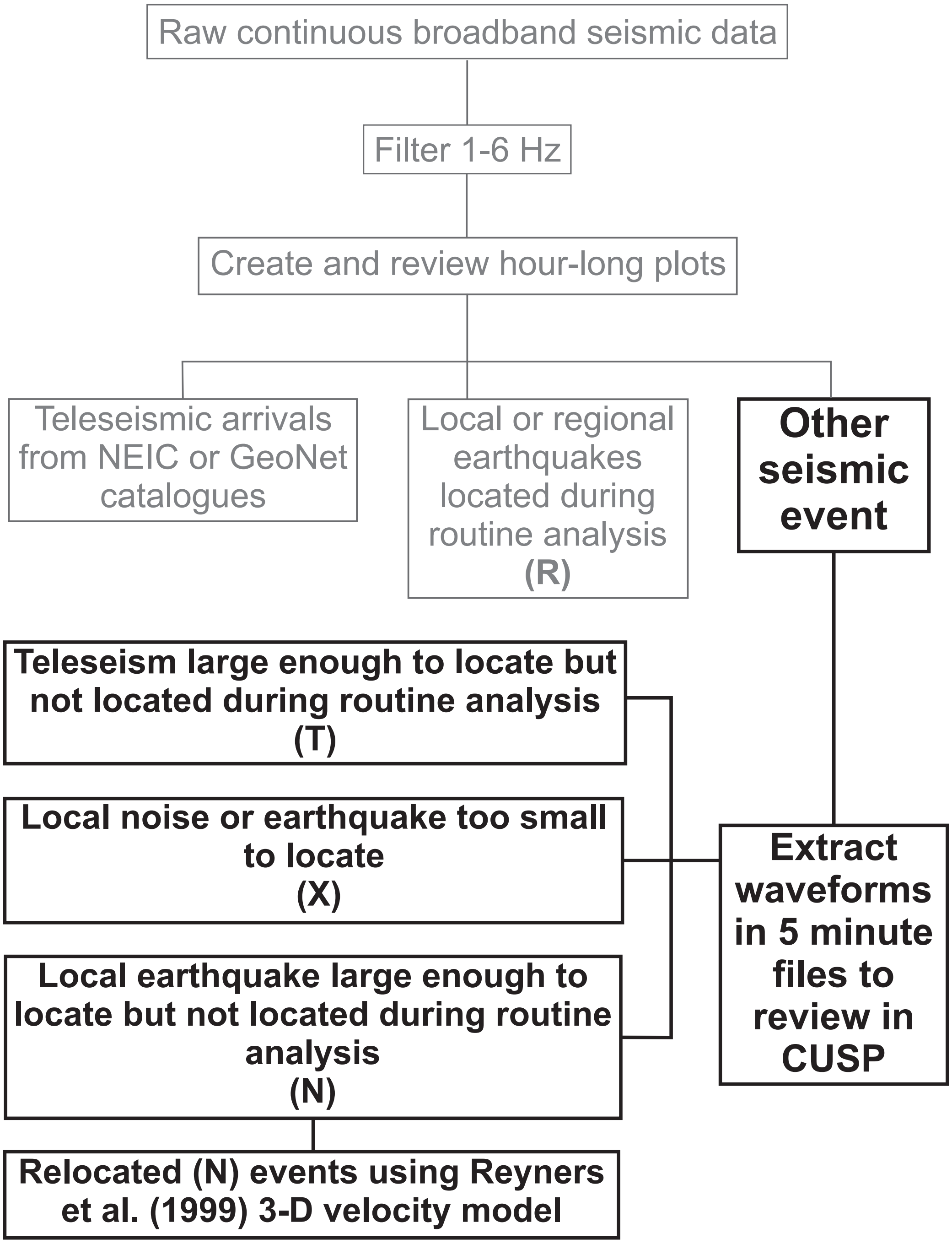

Figure 5.1: **A flowchart of steps in the seismic phenomena analysis** (cf. Figure 4.5). Method used for visual analysis of paper plots and the waveform analysis in the CUSP system.

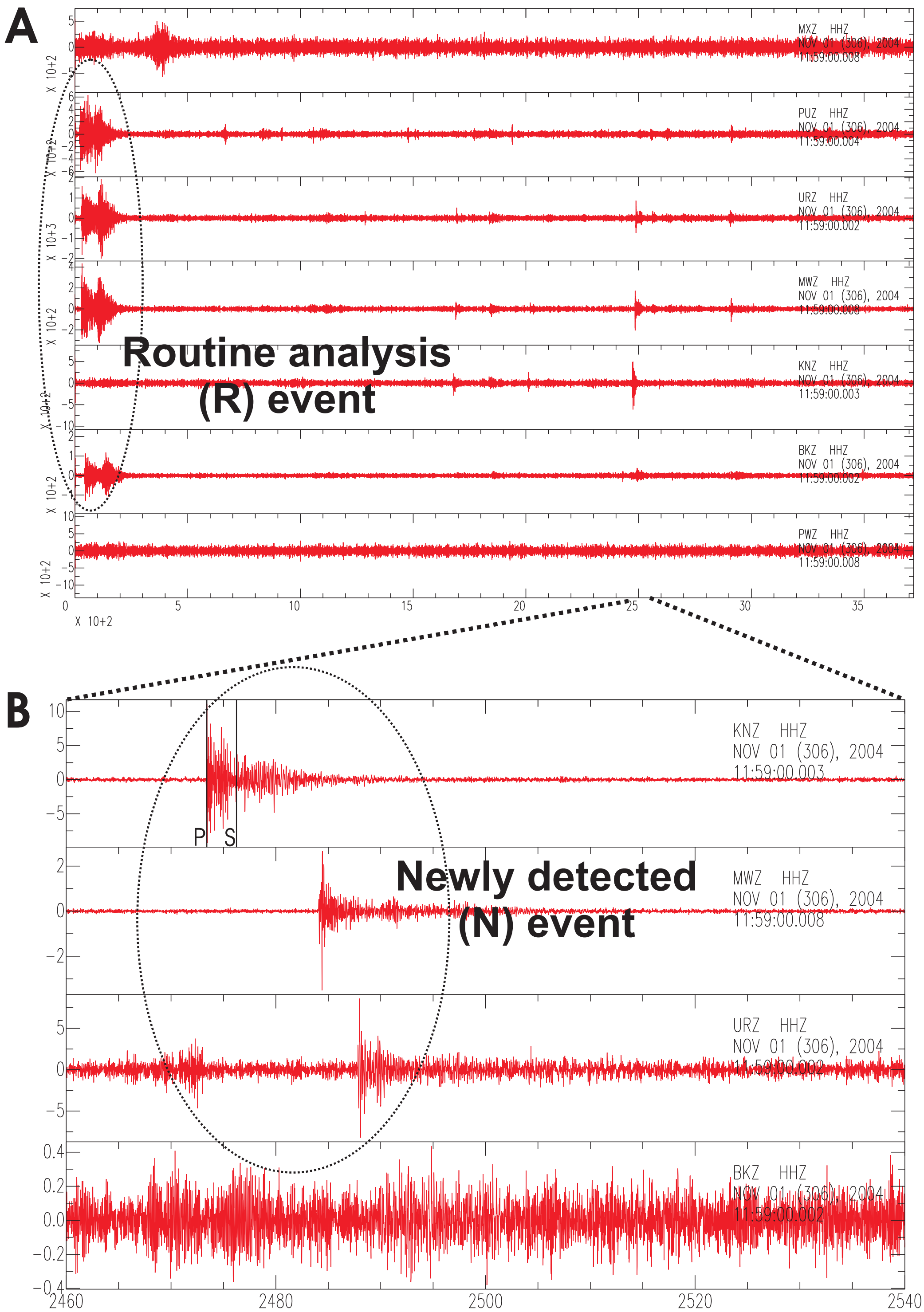

Figure 5.2: **Local earthquake of 1 November 2004. A) One hour of 1–6 Hz bandpass filtered continuous broadband seismic data** during the 2004 Gisborne slow slip event from the hour 12:00 UTC. **B) An expanded view of a newly detected local event near the Mahia Peninsula.** The window length is 80 s. Refer to text for details on the earthquakes in this figure.

Figure 5.2 illustrates examples of a “R” routine analysis earthquake and a “N” newly detected local earthquake, during one hour of continuous seismic data during the Gisborne 2004 slow slip event. The broadband stations are on the Raukumara Peninsula (Figure 5.4). There is a regional event located north of Gisborne, m_b 4.6, (origin time 11:57 UTC) which shows up on the first few minutes of the hour (location from the NEIC). There is a newly detected local earthquake later in the hour, which is located near the Mahia Peninsula at approximately 2476 seconds (12:40 UTC), and is M_L 2.2. The P and S arrivals are indicated at station KNZ and the S-P time is approximately 4 seconds. Note the impulsive character of the P arrivals at stations KNZ, MWZ and BKZ.

5.1.1 Gisborne 2004 slip event

The analysis of the Gisborne 2004 slow slip event is summarized as a time series in Figure 5.3. The data used in the Gisborne 2004 study were collected from the broadband seismic stations shown in Figure 5.4 over a seven week period spanning the slow slip event. The seismic waveforms of all events analysed are available from the GeoNet archives. Of the 587 events reviewed in detail in the CUSP system, 306 were newly detected earthquakes and 114 were teleseisms. The remaining 167 events were local noise or earthquakes too small to locate.

5.1.2 Gisborne 2006 slip event

The analysis of the Gisborne 2006 slow slip event is summarized as a time series in Figure 5.5. As described in Chapter 3, five temporary seismic stations were deployed in the Gisborne area once it was established that a slow slip event was underway. Because there were no temporary stations deployed before the slip event started, I reviewed data during and following the slow slip event. The data used in the Gisborne 2006 study were collected from broadband seismic stations and the additional five temporary broadband and short period stations (Figure 5.4). In total, 236 events were reviewed in detail, of which 190 local earthquakes and five teleseisms were located and the

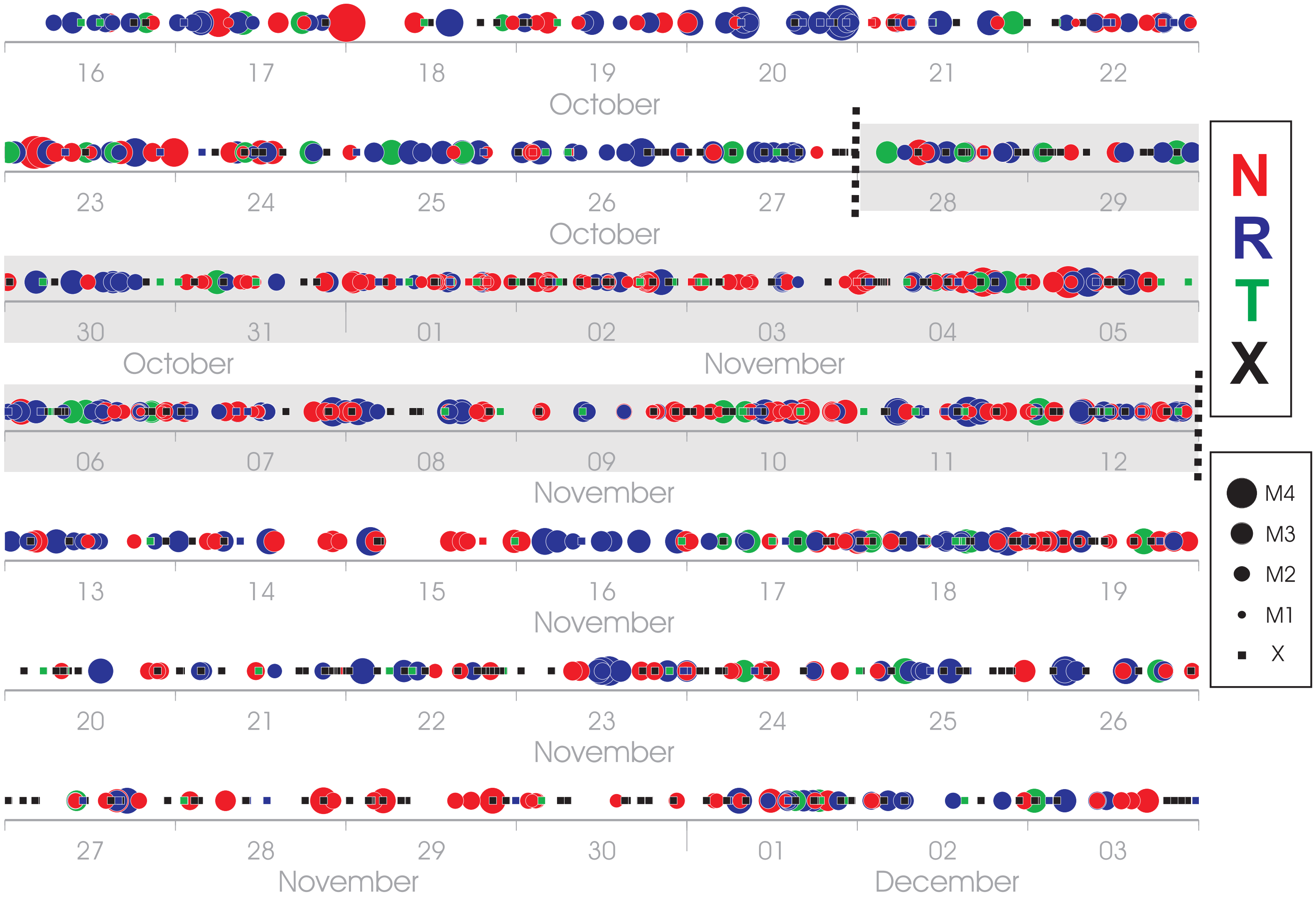

Figure 5.3: **Analysis summary for a seven week period spanning the 2004 Gisborne slip event.** N events are newly detected and located earthquakes from this study; R events are earthquakes detected and located by routine CUSP analysis; T events are newly detected teleseisms from this study; X events are local noise or earthquakes too small to be located. The black dashed lines and grey shading indicate the timing of the geodetically inferred slow slip. Refer to text for further details.

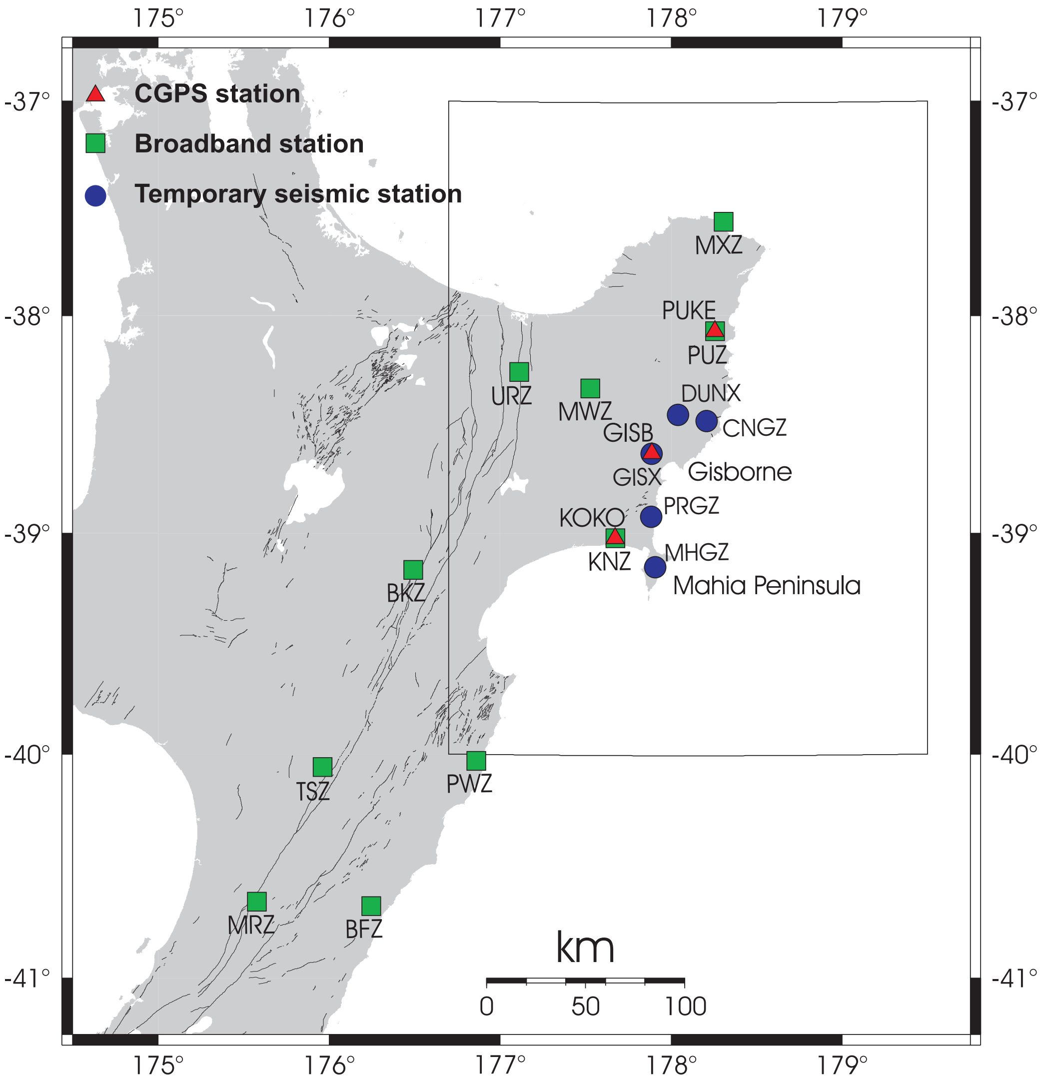

Figure 5.4: **Map of stations used in this study for the 2004 and 2006 slip events**. All of the permanent seismometers and CGPS sites illustrated were installed before the 2004 slip event. Temporary seismographs were deployed during the 2006 slip event. The box highlights the area of the maps in Sections 5.2.1 and 5.2.2 .

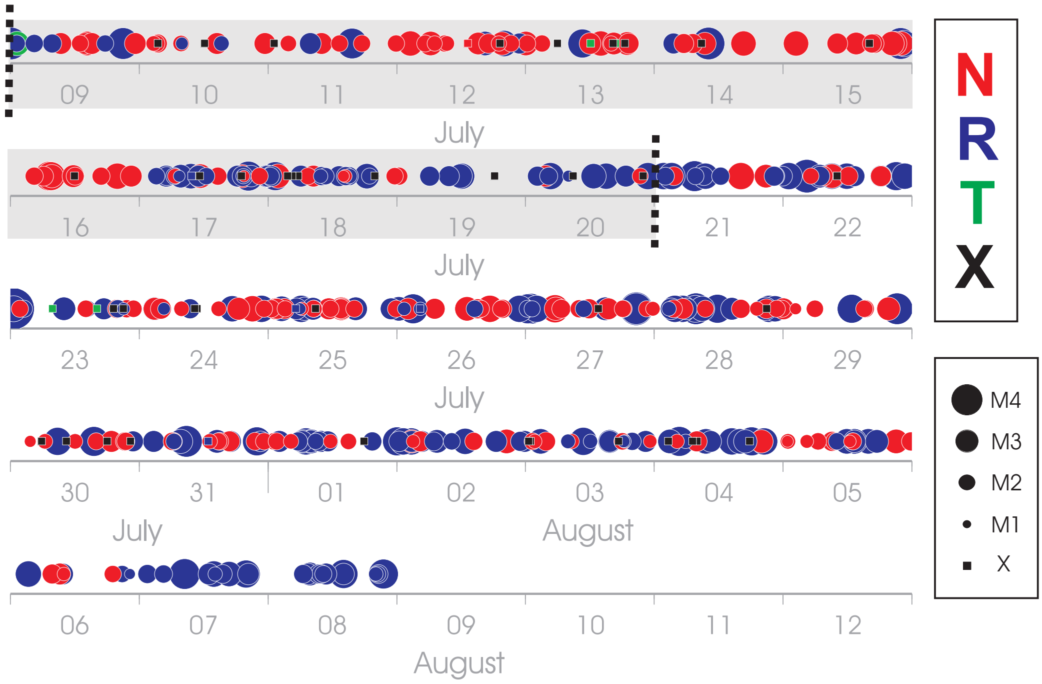

Figure 5.5: **Analysis summary for a four and half week period during and after the 2006 Gisborne slip event.** N events are newly detected and located earthquakes from this study; R events are earthquakes detected and located by routine CUSP analysis; T events are newly detected teleseisms from this study; X events are local noise or earthquakes that are too small to be located. The black dashed lines and grey shading indicate the timing of the geodetically inferred slow slip. Refer to text for further details.

remaining 41 events were local noise or earthquakes too small to locate.

5.1.3 Manawatu 2004–2005 slip event

The Manawatu slow slip event occurred over a 18 month period and due to time constraints of this study, the review of continuous broadband seismic data was limited to an eight week period during the slow slip event. I reviewed the period beginning January 2005 because the observed motions were the greatest during this period (Wallace and Beavan, 2006, Figure 2.7). The review of continuous broadband seismic data was made for an eight week period for the tremor analysis and then a five week period with a more detailed look at 5-minute files of waveforms. In total, 153 events were reviewed in CUSP and of these events 97 newly detected earthquakes were located, using seismic data from stations in Figure 5.6.

The broadband seismic station network is more dense in the Manawatu region than the Raukumara Peninsula, and the Manawatu region is also supplemented by the Taranaki and Wellington regional networks (Figure 3.1). Consequently, the magnitude threshold is lower in the Manawatu region and the routine analysis does a more complete job at detecting and locating microseismicity, consequently the additional newly detected earthquakes did not show any significant patterns of seismicity. There were five $M_L > 5.0$ earthquakes during the two months reviewed, with many aftershocks. Therefore, the majority of previously undetected events that I could detect during the review of the plots were small aftershocks, and most likely were not associated with slow slip. Reyners and Bannister (2007) show that at least one of these larger earthquakes (an M_L 5.5, located approximately 40 km north of Wellington on January 20, 2005) may have been triggered by changes in Coulomb failure stress resulting from the slow slip in 2003–2004 near Paekakariki (Chapter 2, Figure 2.5).

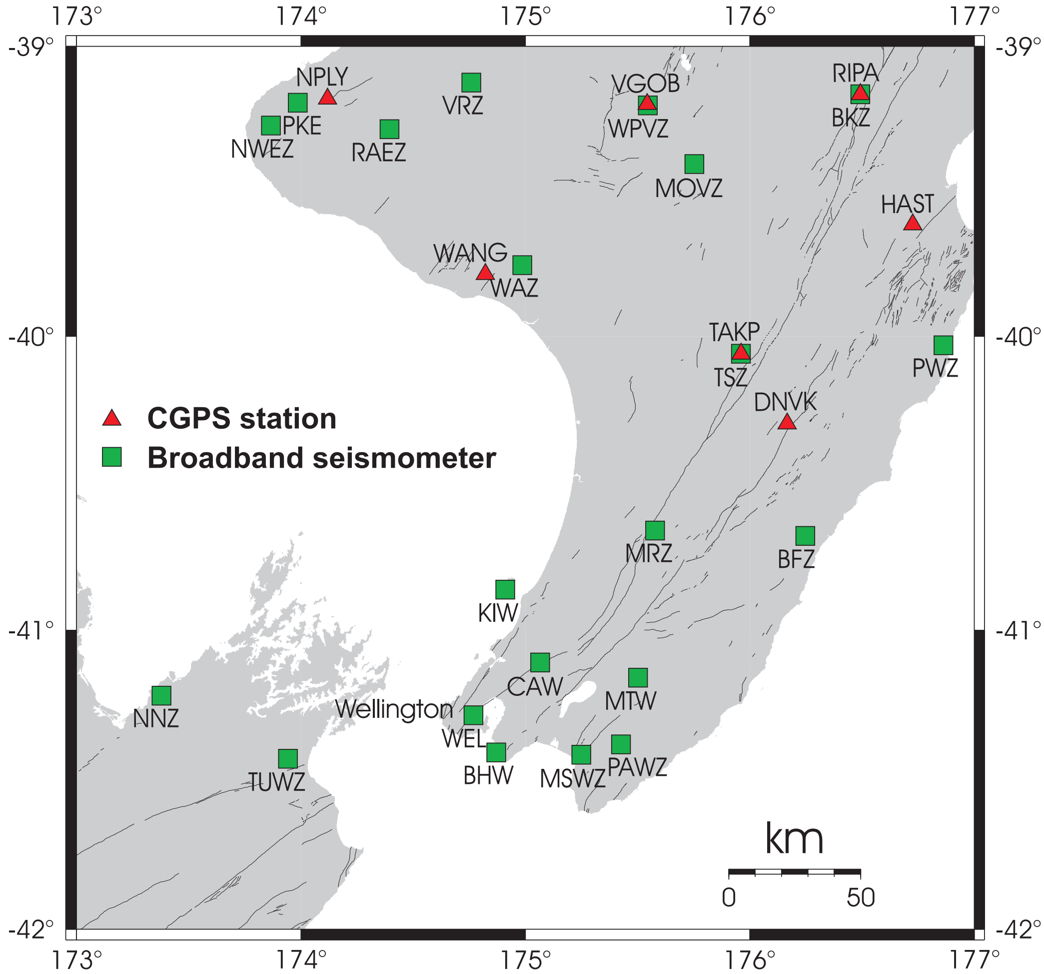

Figure 5.6: **Map of CGPS and seismograph stations used in this study for the 2004–2005 slip event**. All of the permanent seismometers and CGPS sites illustrated were installed before the slow slip event commenced in 2004.

5.2 Results

I located many newly detected earthquakes during the 2004 and 2006 slow slip events near Gisborne (496 local or regional events and 119 teleseisms). The spatial and temporal relationships of the newly detected seismicity during slow slip is compared with the seismicity from the routine analysis.

5.2.1 Gisborne 2004

The seismicity of the entire time period analysed is summarized in Figure 5.7. The events are colour coded, where blue denotes earthquakes that were detected and located during routine analysis (R), and red denotes earthquakes that were newly detected (N) and located during this study. The events are also differentiated by the timing of the events, where solid symbols occurred during the 2004 slip event (28 October to 12 November, 2004 or Julian dates 302–317). The open symbols occurred outside the period of slip (16-27 October or 12 November to 3 December, 2004 or Julian dates 290–301 or 318–338). Some earthquakes do not have calculated magnitudes (indicated as square symbols); I infer these events to be of magnitude M_L ~1.

The detection limits for the newly detected events from this study are approximately M_L ~0.75–1.0 lower than the detection limits for earthquakes detected and located during routine analysis (Figure 5.8). Results from the 1994 Raukumara Peninsula survey (Reyners and McGinty, 1999, Chapter 1) show a lower detection threshold, compared to routine analysis, because of the dense station spacing during the survey. It is important to note that the sampling periods for the data from Figure 5.8 vary between the groups. The red (newly detected) and blue (routine analysis) groups are from a seven week period in 2004 and the black (1994 Raukumara survey) group is from a five month period in 1994. Although most of the newly detected seismicity is between M_L 1.0–2.0, there are local earthquakes up to M_L 3.3 that were missed during routine analysis. There is a noticeable amount of seismicity near the Mahia Peninsula consisting of events that are newly detected and occurred during the slow slip event (solid red circles). I examine, in more detail, the timing of these events below (Figures 5.12 and 5.13).

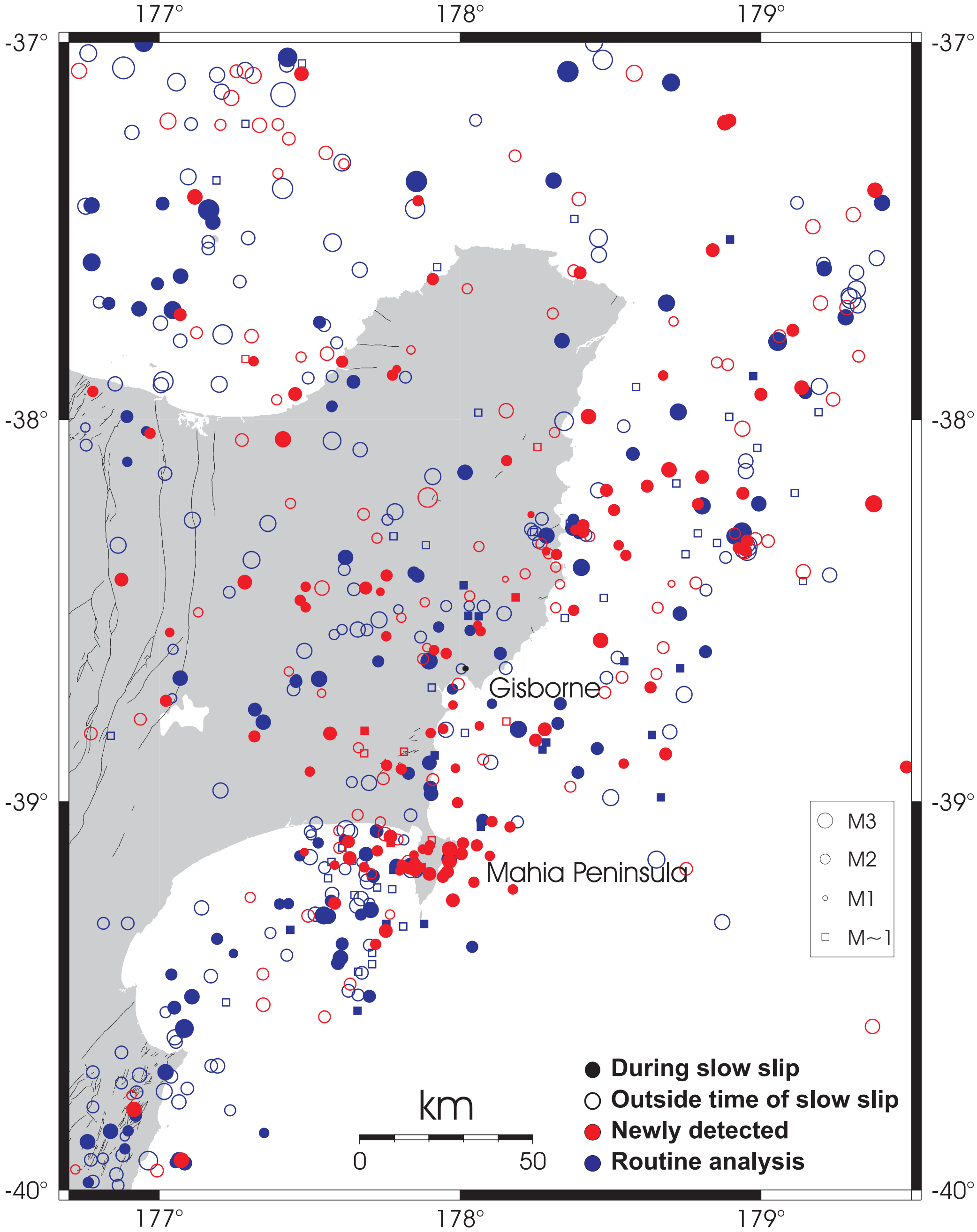

Figure 5.7: **Seismicity recorded during the 2004 Gisborne slow slip event**. Seismicity near the Raukumara Peninsula region during the period 16 October to 3 December, 2004 (Julian dates 290–338). The slip event dates are approximately between 28 October to 12 November, 2004 (Julian dates 302 to 317).

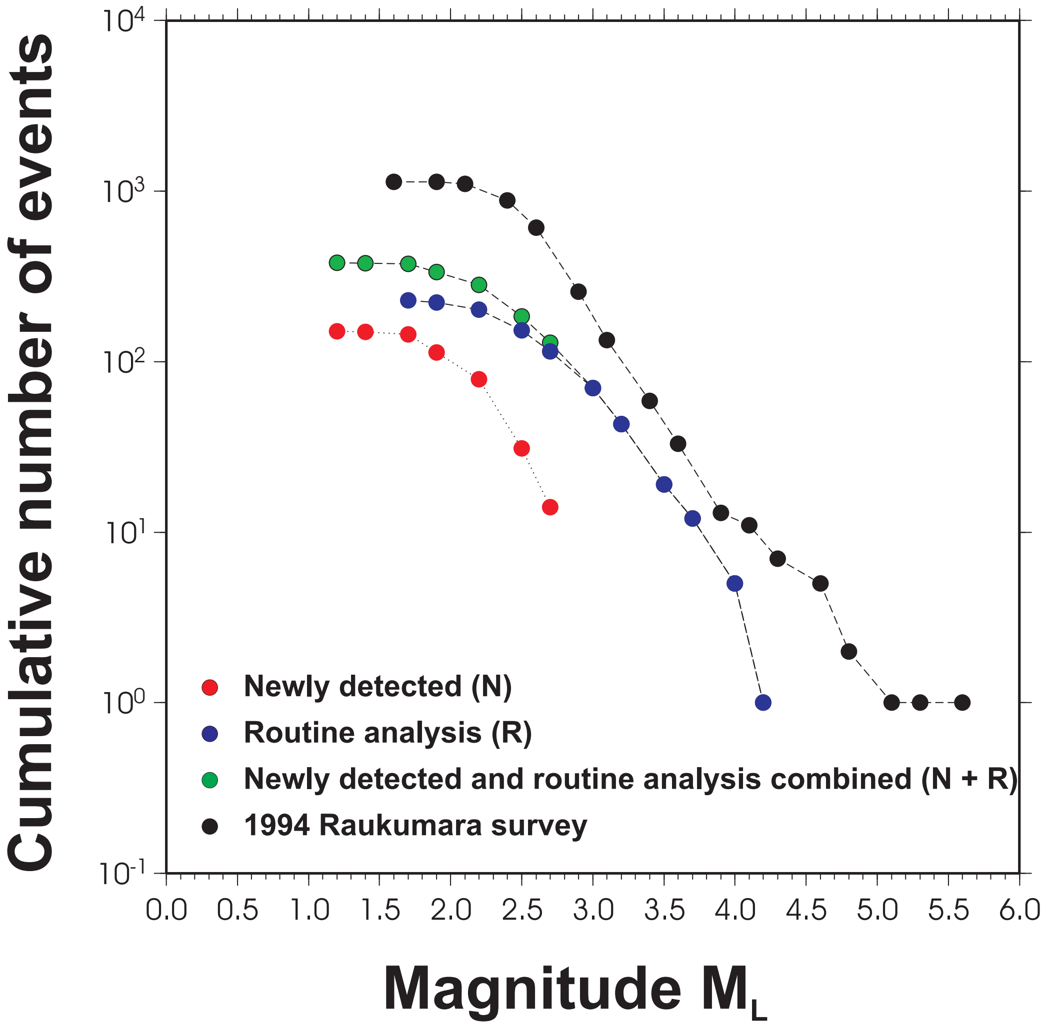

Figure 5.8: **Cumulative number of events and magnitude (M_L).** The black circles correspond to events from a survey of Raukumara Peninsula in 1994 (Reyners and McGinty, 1999). The newly detected and routine analysis dataset are from a 7 week period and the Raukumara survey dataset is from a 5 month period. Note that earthquakes for which no magnitude could be estimated are omitted from the data.

Relocations of 2004 seismicity

In order to understand precisely where the seismicity during the 2004 slow slip event occurred, the earthquakes were relocated using a 3-D velocity model to obtain more accurate locations and better depth control. I tried using HypoDD [2] to relocate all the earthquakes relative to each other, but the sparse network and station geometry are not favorable for using HypoDD. Therefore, with the help of Martin Reyners, all the newly detected (N) and routinely analysed (R) earthquakes are relocated using the 3-D velocity model of the Raukumara Peninsula that was created by Reyners et al. (1999), as discussed in Chapter 1. Figure 5.9 illustrates the effect the relocation has on the original locations and Figure 5.10 shows the final locations and the timing of earthquakes (cf. Figure 5.7). In general, the epicentres of offshore earthquakes (regardless of whether they were newly detected or routinely analysed) were shifted by larger amounts than the epicentres of onshore earthquakes. The original earthquake epicentres were calculated using a general 1–D velocity model, that is not appropriate for calculating accurate locations in the Raukumara Peninsula. During the relocation process, earthquakes with high residuals (RMS $>$ 0.3 seconds or standard error in longitude, latitude, or depth $>$ 5 km) were thrown out. Therefore, there are less earthquake epicentres shown on Figures 5.9 and 5.10 compared to Figure 5.7, but these relocated earthquakes have well-controlled solutions.

After relocating earthquakes with the 3-D velocity model and discarding the earthquakes with poorly constrained solutions, the concentration of seismicity near the Mahia Peninsula persists, especially during the period of slow slip (solid red circles in Figure 5.10). The group of earthquakes apparently lies southwest of the Gisborne 2002 preferred slip model (Figure 2.6 by Douglas (2005). The shaded pink rectangle on Figure 5.10 is Douglas (2005) preferred slip model for the Gisborne 2002 slow slip event. Slip models have not yet been created for the Gisborne 2004 or Gisborne 2006 slow slip events, but the 2002 model is assumed to be a reasonable fit for the later events (same area and location, but a smaller amount of slip during the 2006

[2]HypoDD is a computer program package for relocating earthquakes with the double-difference algorithm of Waldhauser and Ellsworth (2000).

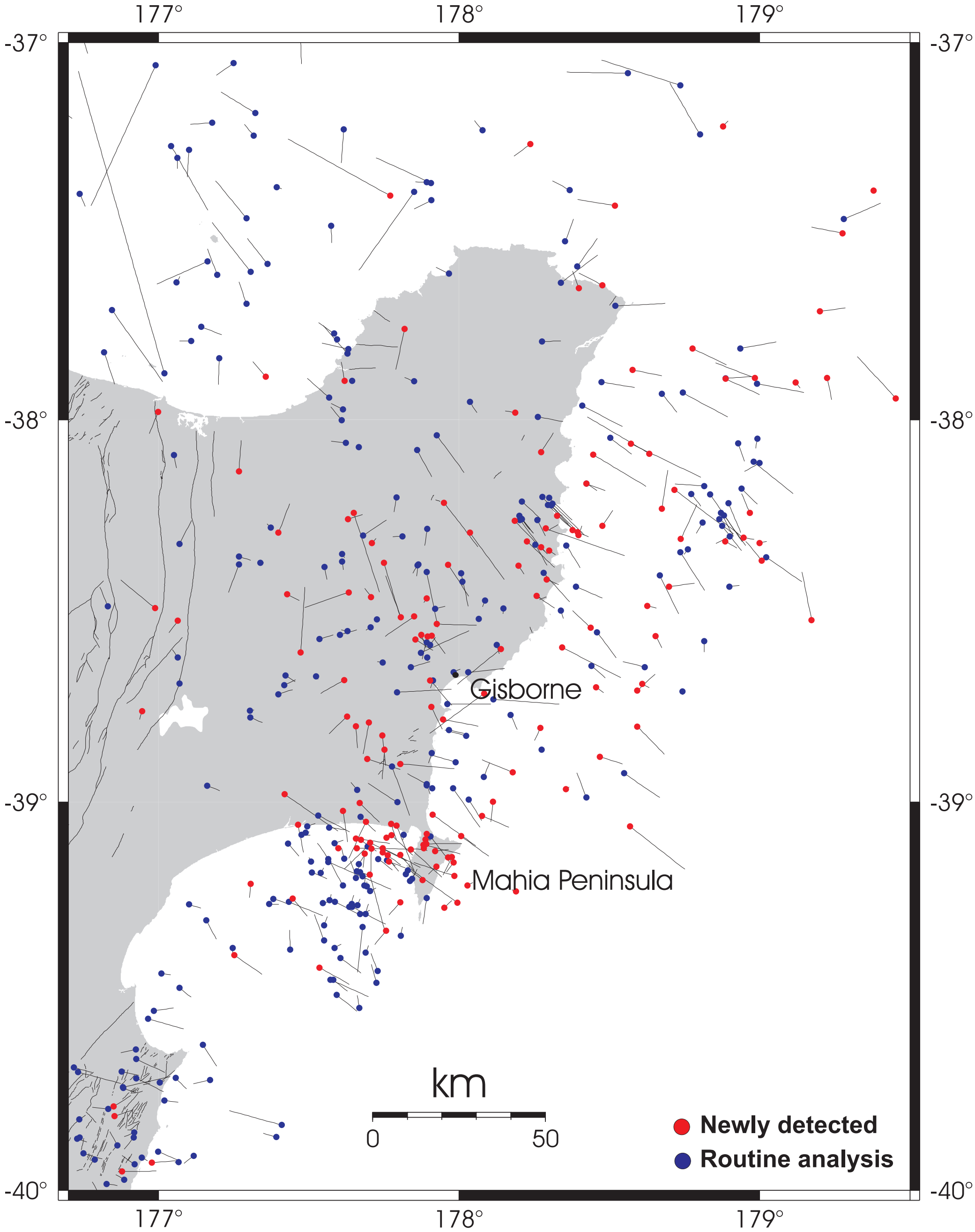

Figure 5.9: **Relocated seismicity of the 2004 Gisborne slow slip event**. Seismicity near the Raukumara Peninsula region during the period 16 October to 3 December, 2004 (Julian dates 290–338). Vectors indicate the direction and amount of change between the original locations and the locations relocated with the 3-D velocity model. The circles denote the final relocated epicentres and the circles are not scaled to magnitude.

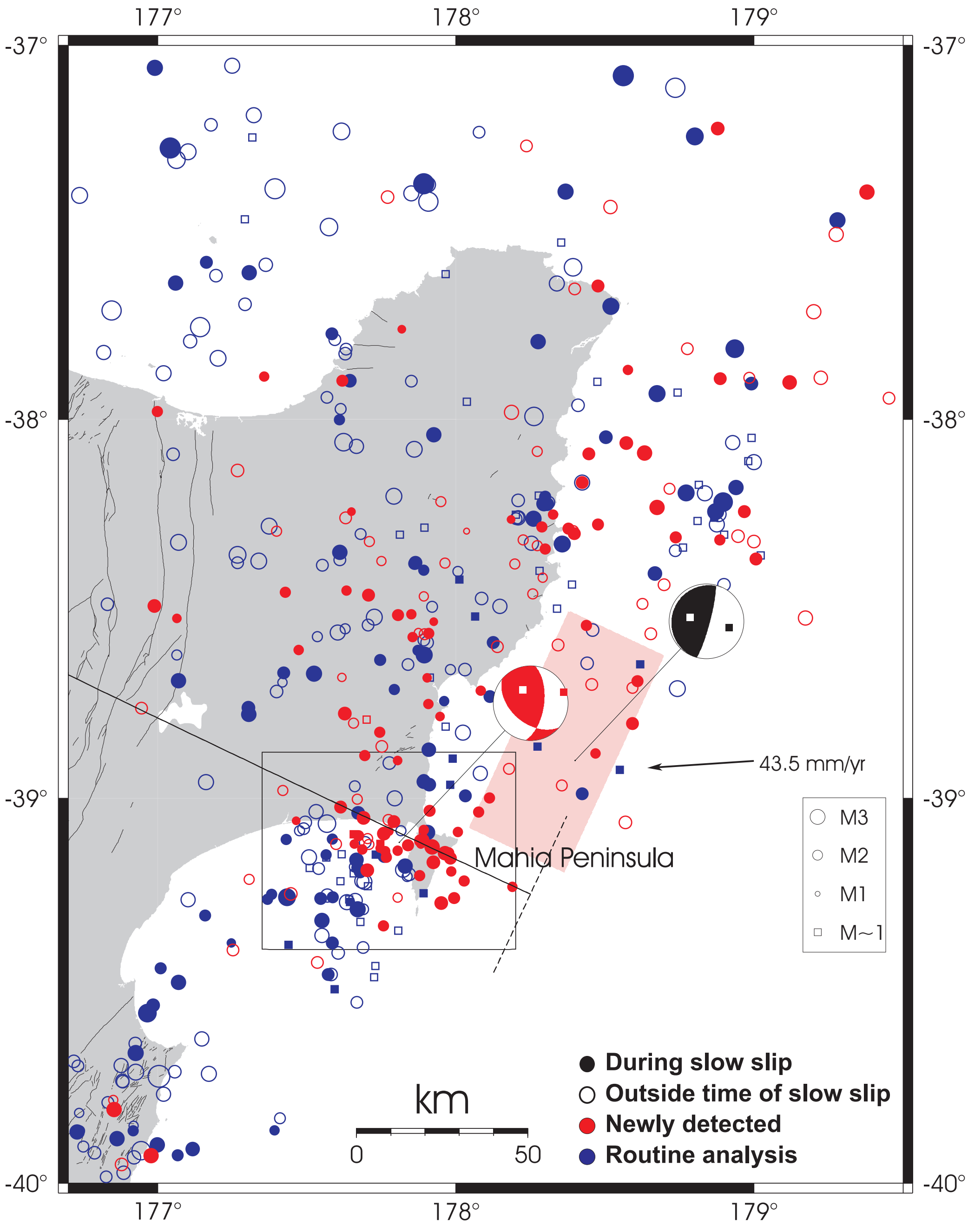

Figure 5.10: **Seismicity relocated with 3-D velocity model (From Reyners et al., 1999) during the 2004 Gisborne slow slip event**. Seismicity near the Raukumara Peninsula region during the period 16 October to 3 December, 2004 (Julian dates 290–338). The slip event dates are approximately between 28 October to 12 November, 2004 (Julian dates 302 to 317). The pink shaded rectangle is the preferred slip model by Douglas (2005) for the Gisborne 2002 slip event. The red beach ball is a composite focal mechanism calculated from 18 newly detected earthquakes (N) and the black beach ball is the mechanism from the slip model by Douglas (2005). The mechanisms are not scaled to magnitude. The arrow represents the velocity of the Pacific plate relative to the Australian plate. The black and black dashed lines define the cross-section and cross-axis width, respectively, of the projected data shown in Figures 5.11, 6.2, 6.3 and 6.4.

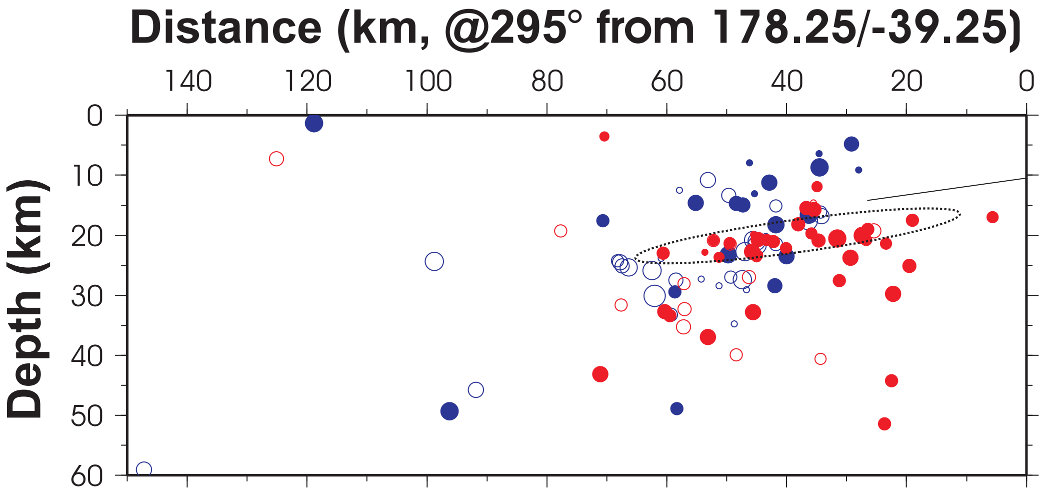

Figure 5.11: **Cross-section of relocated seismicity** using 3-D model (From Reyners et al., 1999) of the 2004 Gisborne slow slip event. Profile is from Figure 5.10. The dashed ellipse indicates the earthquakes that were used to calculate the composite focal mechanism. The dipping line represents the slip model from (Douglas et al., 2005).

event, L. Wallace, GNS Science, pers. comm., 2006).

There is no particular alignment of the newly detected earthquakes near the Mahia Peninsula, when viewed in map view, which suggests that the earthquakes are not concentrated along shallow faults. However, in cross-section (Figure 5.11) the seismicity shows an alignment along or parallel to the slab interface. This suggests that an increase in stress, caused by the movement during the slow slip event, weakened the area down-dip of the slip and triggered microseismicity.

A composite focal mechanism (Figure 5.10) was calculated using 45 first arrival motions from 18 newly detected earthquakes, indicated on Figure 5.11. The thrust mechanism is consistent with reverse slip on the slab interface and the P axis is close to the direction of plate convergence. The mechanism is not consistent with normal faulting, which would be expected for faulting within the subducted slab (Reyners and McGinty, 1999; Reyners and Bannister, 2007).

Timing of increased seismicity

There is a significant amount of local seismicity near the area of slip modeled by Douglas (2005), in particular near the Mahia Peninsula. I examine the timing of the local seismicity near the Mahia Peninsula in Figures 5.12 and 5.13. First, I consider how the spatial distribution affects the rates in daily seismicity, specifically in the area near the Mahia Peninsula and the area outside of the Mahia Peninsula (refer to box in Figure 5.10 for area coordinates).

The rate of daily seismicity increases slightly during the period of slow slip for the earthquakes in the entire study region (black curve), but the rate of daily seismicity is nearly constant for all the earthquakes outside of the Mahia area (dashed green curve). However, the rate of daily seismicity for the region near the Mahia Peninsula (green curve), increases significantly during the period of slow slip (Figure 5.12). Figure 5.12 illustrates that there is a spatial relationship of the rate of seismicity during the slow slip event.

If the earthquakes located near the Mahia region are separated by type (i.e. newly detected earthquakes or routinely analysed earthquakes; green curve in Figures 5.12 and 5.13), there is a dramatic difference in the daily rates of seismicity for the earthquakes located during routine analysis (blue curve) and the events newly detected in this study (red curve). Specifically, the daily rates of seismicity of the routine analysis earthquakes (R) is constant throughout the entire period analysed, but the daily rate of seismicity of the newly detected earthquakes (N) increases significantly during the period of slow slip. Figure 5.13 illustrates that the increased seismicity during the slow slip event is solely due to the increased rate of newly detected (N) earthquakes and if only the routine analysis earthquakes were examined, the increased seismicity is imperceptible. The seismic response to the Gisborne 2004 slow slip event is limited to small magnitude earthquakes.

Pratt (2006) suggests that patterns in local seismicity rates in Cascadia may follow a similar periodicity to that of ETS events (episodic tremor and slip). This observation of increased microseismicity during a slip event is very similar to the results of Segall et al. (2006).

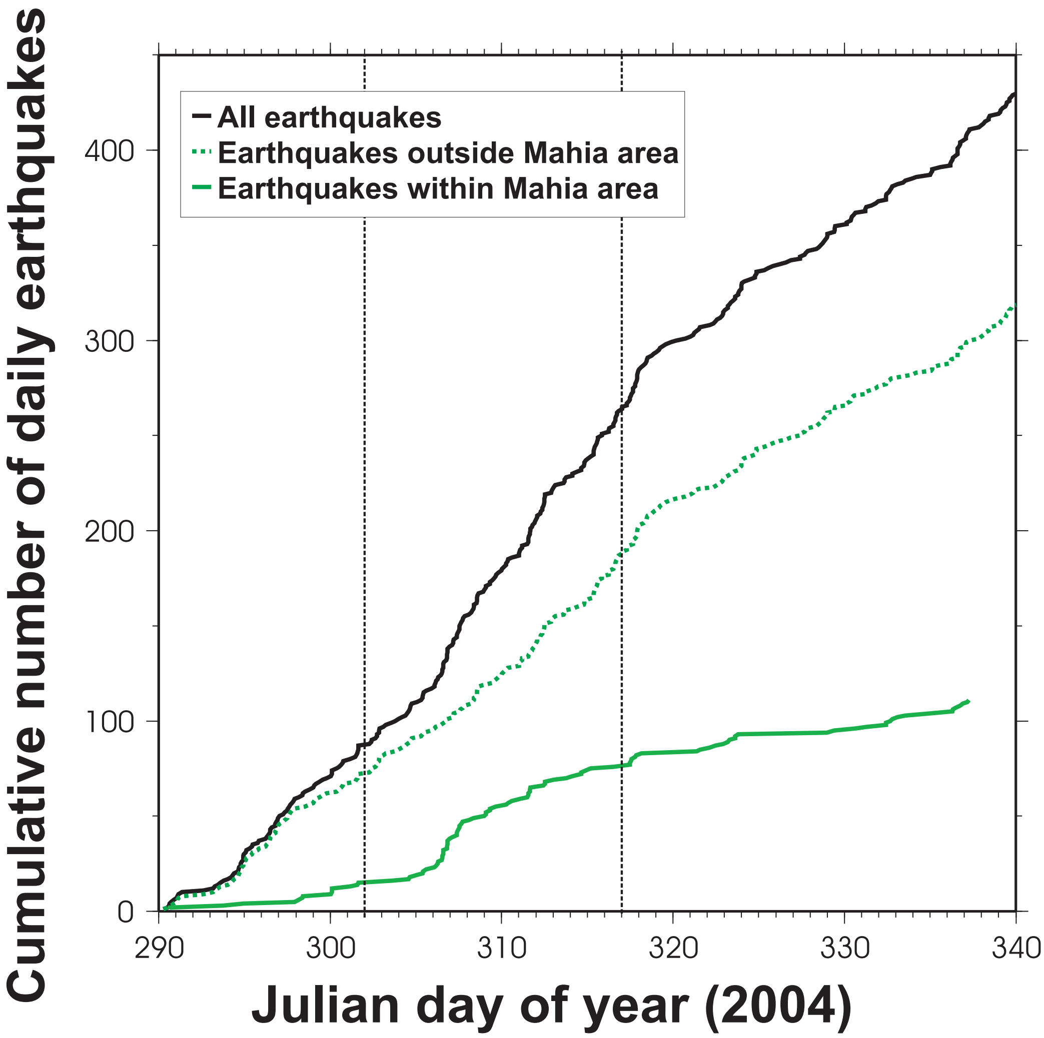

Figure 5.12: **Cumulative number of daily earthquakes near the Raukumara Peninsula** during the Gisborne 2004 slip event. The timing of the slow slip, inferred from GPS observations is indicated by the black dashed lines. Earthquakes referred to as within Mahia area are located within the box shown on Figure 5.10 and earthquakes outside the Mahia area are located outside of the box.

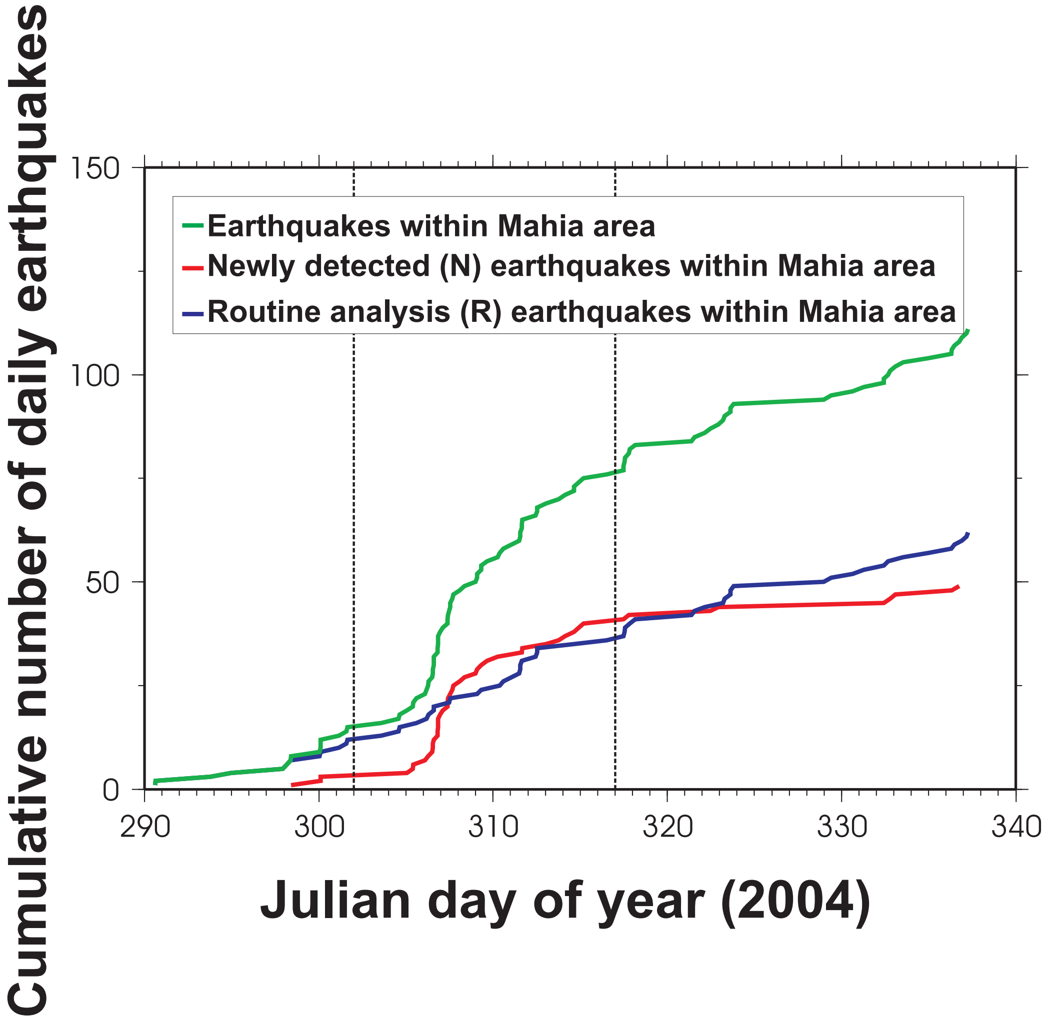

Figure 5.13: **Cumulative number of daily events near the Mahia Peninsula** during the Gisborne 2004 slip event. The timing of the slow slip, inferred from GPS observations is indicated by the black dashed lines. Events referred to as within Mahia area are located within the box shown on Figure 5.10 and events outside the Mahia area are located outside of the box.

The results from this study show that there is a delay between the observed geodetic signal and the onset of increased microseismicity of ∼3–4 days. Similarly, in Hawaii there is a delay of approximately one day from when the geodetic signal is observed to the onset of increased microseismicity for a 2 day slow slip event (Segall et al., 2006). Both Segall et al. (2006) and Reyners and Bannister (2007) demonstrate that slow slip events caused changes in the local stress regime and the increased stress triggered local seismicity.

5.2.2 Gisborne 2006

The seismic analysis for both the Gisborne slow slip events was performed in the same manner. However, it is difficult to show a comparison between the routine analysis (R) locations and the newly detected (N) earthquakes for the Gisborne 2006 event. The routine analysis for the GeoNet catalogue is not performed in real-time and therefore the catalogue is currently not up to date (as of August 2007, the routine analysis catalogue lags by approximately 16 months). The only events that have been located for this time period are larger magnitude events given preliminary locations by the duty officers (see Chapter 3 for further details).

The seismicity is summarized in Figure 5.14 but the distribution of blue (routinely detected earthquakes) will change once this time period is reviewed by the GeoNet analysts. The newly detected earthquakes (red circles) were also relocated using the 3-D velocity model of Reyners et al. (1999) (Figure 5.16). Figure 5.15 illustrates the effect the relocation had on the original earthquakes locations and similarly as is shown in Figure 5.9, the epicentres of the offshore earthquakes change more dramatically than the epicentres of the onshore earthquakes. The blue events (routine analysis) were not relocated with the 3-D model because these are only preliminary locations and the phase picks are not complete yet. The open symbols indicate earthquakes that occurred after the time of slip (between 16 July to the 16 August, 2006 or Julian dates 197–218) and the solid symbols denote earthquakes that occurred during the period of slow slip (between 9–15 July, 2006 or

Julian dates 190–196).

There is not a significant spatial clustering of earthquakes near the Mahia Peninsula during the 2006 slip event and the amount of daily microseismicity does not change appreciably during the 2006 slow slip event (Figure 5.17). This analysis will need repeating in due course once the routine analysis is complete, in order to make an equivalent comparison between the routine analysis (R) earthquakes and the newly detected (N) earthquakes.

5.2.3 Preliminary results from the Manawatu slow slip event

Because the seismicity catalogue from GeoNet's routine analysis is quite complete in the Manawatu region, where the magnitude threshold is relatively low (as opposed to the catalogue in the Raukumara Peninsula area, where our detailed analysis clearly shows there is a moderate amount of local microseismicity missed during routine analysis), I look at seismicity distribution of earthquakes from the catalogue. As mentioned in Chapter 2, Wallace and Beavan (2006) divided the 2004–2005 Manawatu slow slip event into three sub-events (Figure 2.7) and this same division was used to examine seismicity during the slow slip event.

Figure 5.18 indicates the shallow seismicity (< 40 km) from the routine analysis catalogues and the slip models from Wallace and Beavan (2006). The slip initiated at 60–35 km depth and propagated up-dip to 35–25 km depth. It is interesting to note that there are relatively low levels of seismicity in the areas of the slip, while the surrounding areas are much more seismically active during the slow slip.

Figure 5.18 A is the shallow seismicity (< 40 km depth) for the first sub-event during the period 1 January to 31 December, 2004 (Julian dates 1–366). The largest earthquake during the first sub-event was a M_L 5.0, and there were 14 earthquakes $M_L \geq 4.0$. Figure 5.18 B is the shallow seismicity for the second sub-event during the period 1 January to 15 March, 2005. This was the period with the most rapid observed motion Figure 2.7. The largest earthquake during the second sub-event was a M_L 5.6 earthquake. During

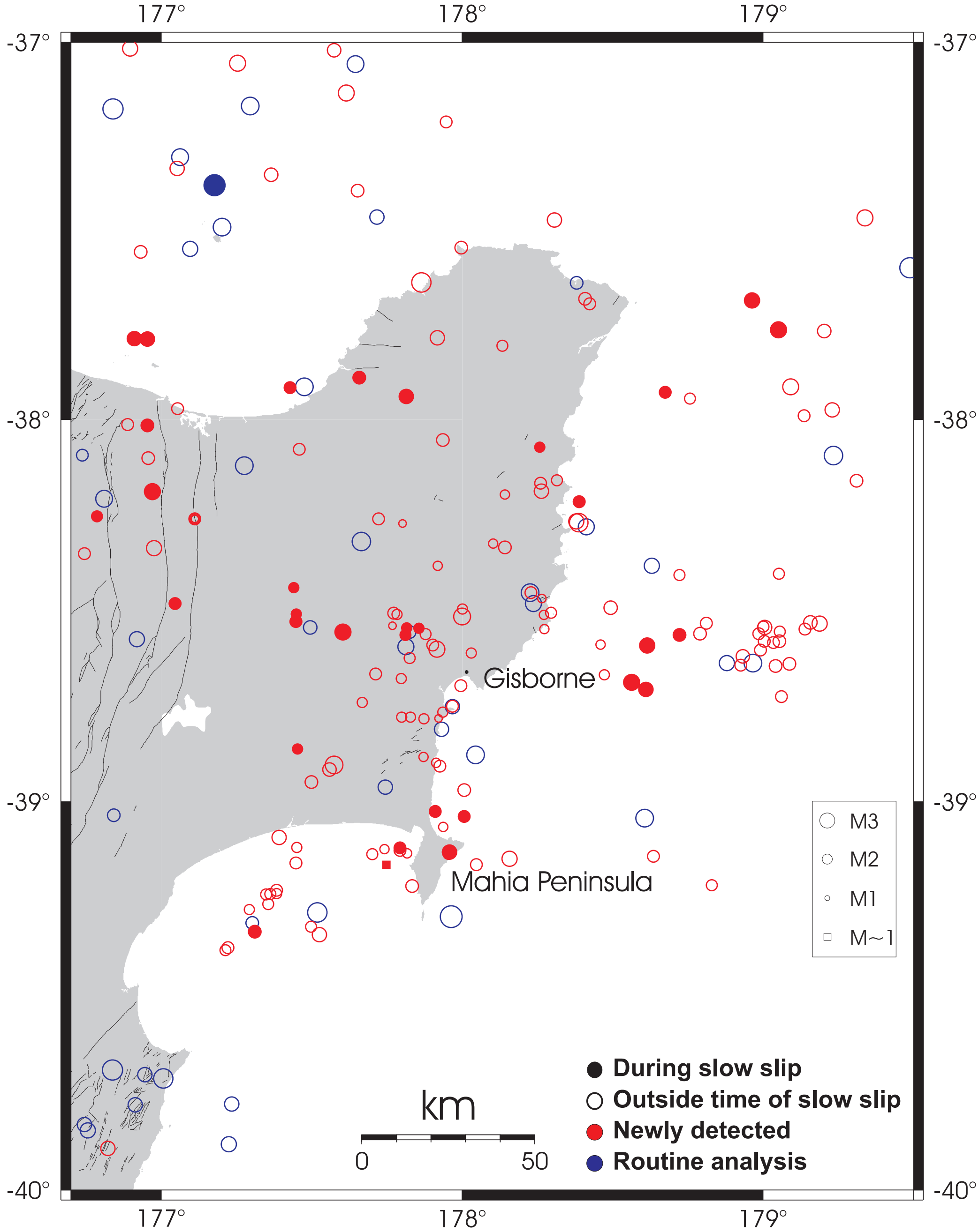

Figure 5.14: **Seismicity during the 2006 Gisborne slow slip event**. Seismicity near the Raukumara Peninsula region during the period 9 July to 16 August, 2006 (Julian dates 190–218). The slip event dates are approximately between 9–20 July, 2006 (Julian dates 190–201).

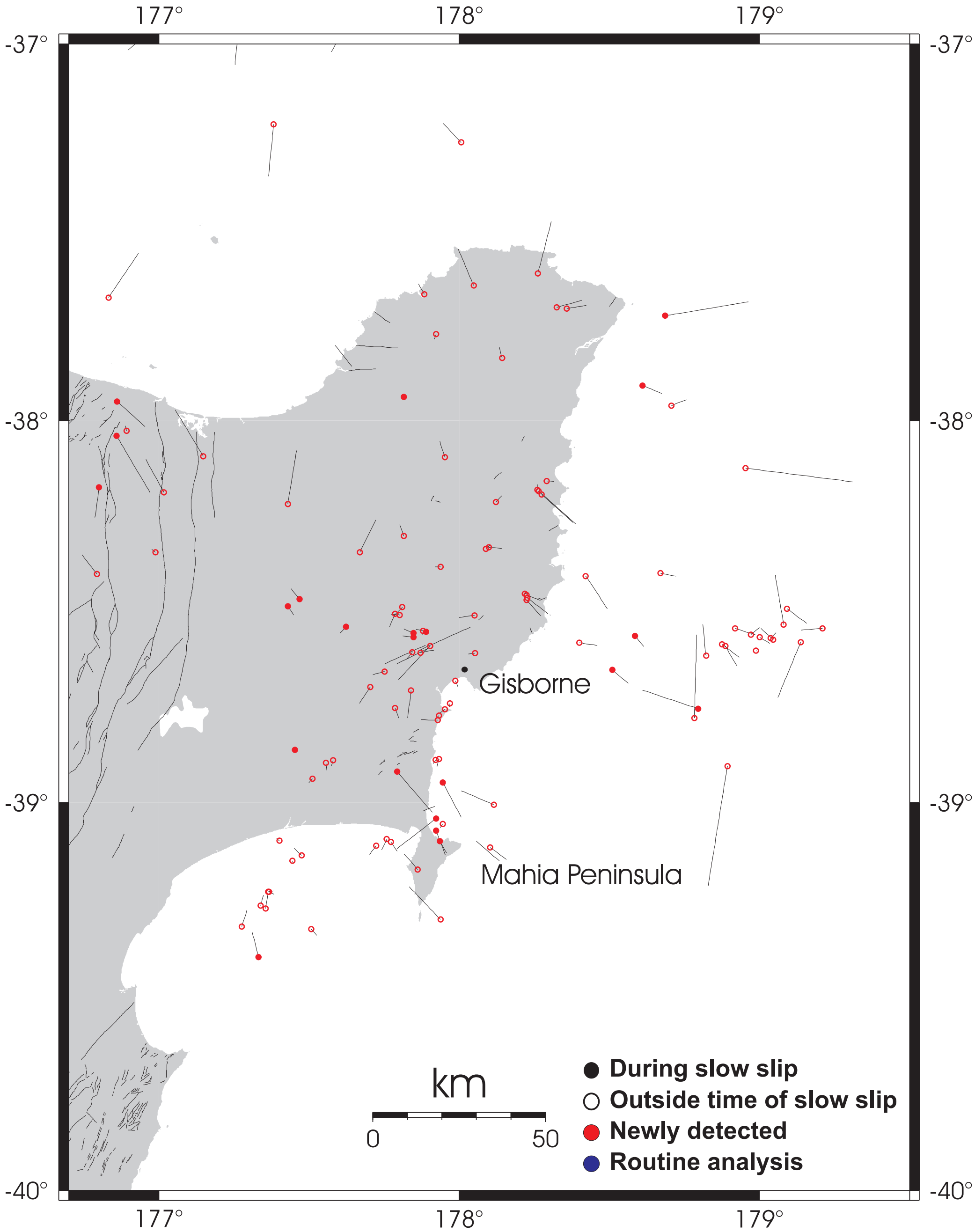

Figure 5.15: **Seismicity relocated with 3-D velocity model (From Reyners et al., 1999) of the 2006 Gisborne slow slip event**. Seismicity near the Raukumara Peninsula region during the period 9 July to 16 August, 2006 (Julian dates 190–218). Vectors indicate the direction and amount of change between the original locations and the locations relocated with the 3-D velocity model. The circles denote the final relocated epicentres.

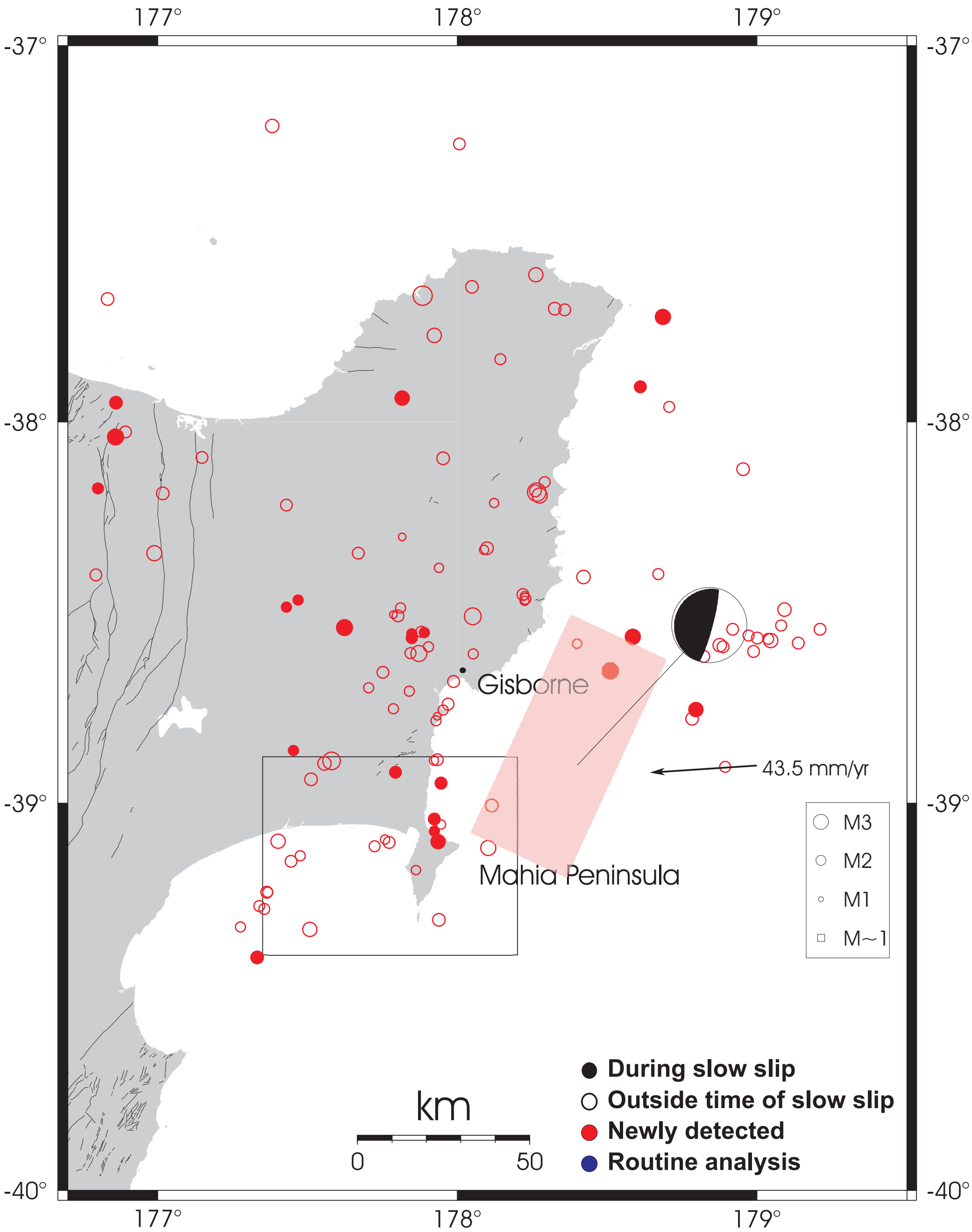

Figure 5.16: **Seismicity relocated with 3-D velocity model (From Reyners et al., 1999) during the 2006 Gisborne slow slip event**. Seismicity near the Raukumara Peninsula region during the period 9 July to 16 August, 2006 (Julian dates 190–218). The slip event dates are approximately between 9–20 July, 2006 (Julian dates 190–201). The pink shaded rectangle is the preferred slip model by Douglas (2005) for the Gisborne 2002 slip event. The black beach ball is the slip mechanism from Douglas (2005) and is not scaled to magnitude. The arrow represents the velocity of the Pacific plate relative to the Australian plate.

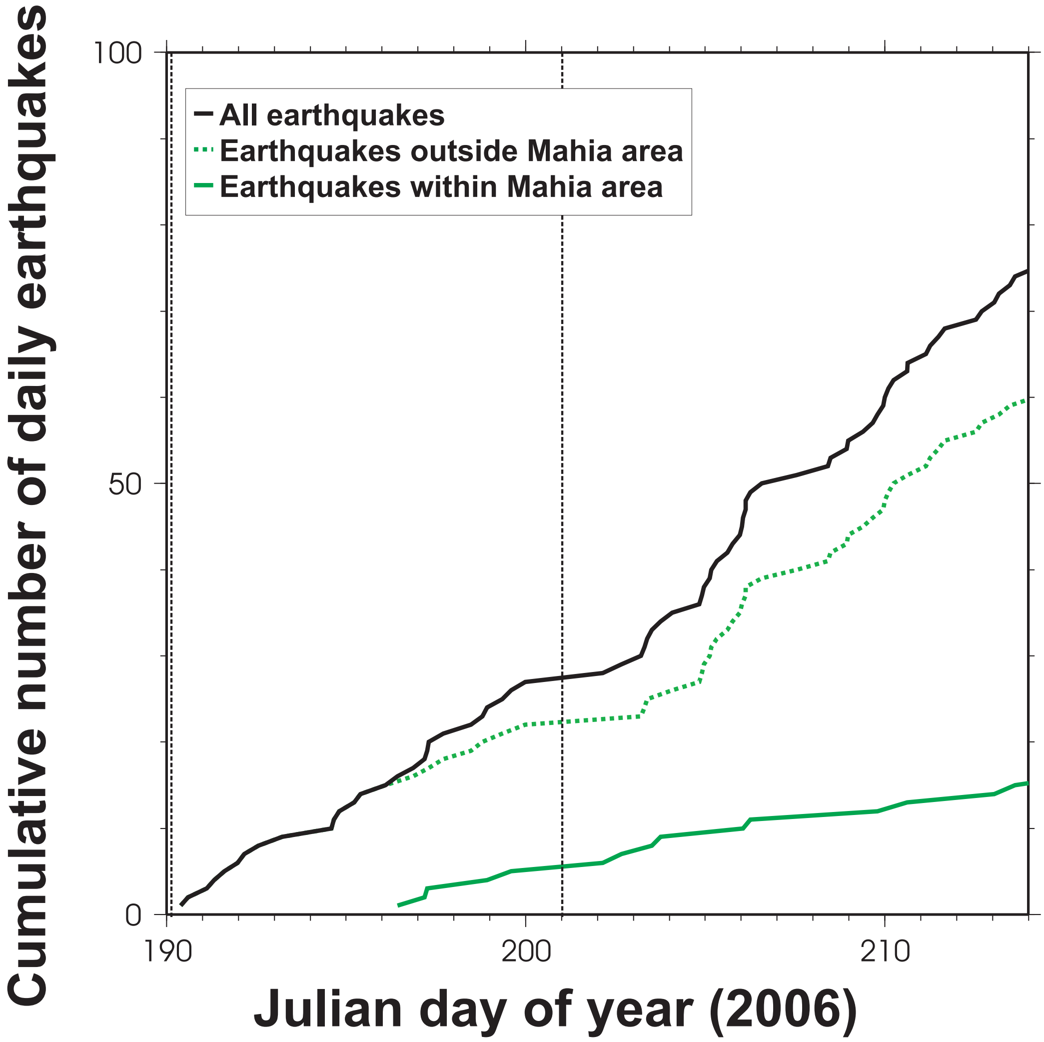

Figure 5.17: **Cumulative number of daily earthquakes near the Raukumara Peninsula** during the Gisborne 2006 slip event. The timing of the slow slip, inferred from GPS observations is indicated by the black dashed lines (between the y axis and the dashed line). Earthquakes referred to as within Mahia area are located within the box shown on Figure 5.16 and earthquakes outside the Mahia area are located outside of the box (cf. Figure 5.12).

the second sub-event, there were seven earthquakes $M_L > 4.0$, including five earthquakes $M_L > 5.0$. Figure 5.18 C is the shallow seismicity for the third sub-event during the period 16 March to 30 June, 2005. During the third sub-event, there were eight $M_L \geq 4.0$ earthquakes, including one M_L 5.0 earthquake.

Due to the great amount of seismic data available during the Manawatu slow slip event (seismic data from > 20 continuous stations over 1.5 years), this study has only briefly examined approximately 10% of the archived waveforms during the Manawatu slow slip event. Kao et al. (2007b) developed an algorithm that automatically detects and characterizes seismic waveforms associated with seismic tremor in Cascadia. This method is currently being investigated with the seismic data during the Manawatu slow slip event.

5.3 Discussion

I reviewed continuous seismic data during three slow slip events to investigate the association of seismic phenomena, other than seismic tremor, that have been linked to slow slip events in other parts of the world.

There is an increase in local seismicity during the Gisborne 2004 slow slip event near the Mahia Peninsula, southwest of the area of slip. This increase in microseismicity is not observed during the routine analysis. It is interesting to note that although the majority of newly detected (N) earthquakes are M_L 1–2, local earthquakes up to M_L 3.3 were newly detected and located in this study. Therefore the auto-detection and triggering system at GeoNet did not detect local earthquakes as large as M_L 3.3, which is a surprising observation. I did not investigate into why earthquakes of such large magnitudes have been missed by the auto-detection system, but further work is planned, such as investigating the spectral properties of the newly detected earthquakes.

The results from this work suggest that the slow slip event triggered microseismicity near the Mahia Peninsula, in agreement with results from Segall et al. (2006) and Pratt (2006). The spatial distribution of these earthquakes does not delineate obvious upper-plate faults. The composite focal mechanism calculated from first arrival motions from 18 triggered earthquakes is

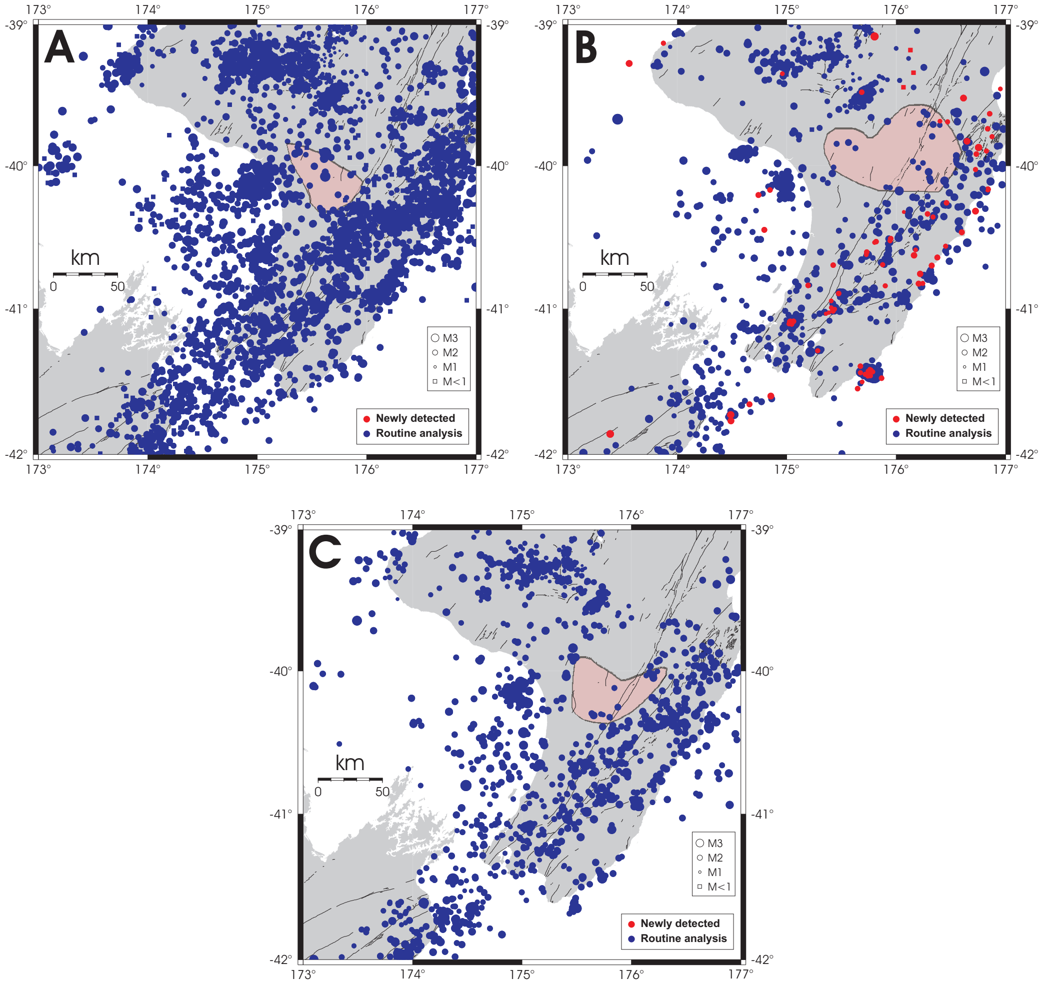

Figure 5.18: **Seismicity during the Manawatu slip event from January 2004 to June 2005**. Shallow seismicity (<40 km) from the routine analysis (R) CUSP catalogue and newly detected (N) earthquakes during the following time periods: A) 1 January to 31 December 2004; B) 1 January to 15 March 2005; and C) 16 March to 30 June 2005. The shaded pink areas indicates the approximate regions of slip as modeled by Wallace and Beavan (2006).

consistent with thrust faulting along the interface. It important to emphasize that the increased seismicity are small magnitude earthquakes (M_L ~1.0–2.0) and that these earthquakes are not detected during routine analysis.

A similar increase in microseismicity is not evident during the Gisborne 2006 slow slip event. I infer the slip to have occurred in the same location for both the 2004 and 2006 slip events, but there are some differences between the two events. The duration of the Gisborne 2006 slip event is several days shorter than the 2004 event and a smaller surface displacement was observed during the 2006 slip event (20–30 mm in 2004 and ~10 mm in 2006). It is not yet clear whether these differences are responsible for the apparent absence of triggered seismicity during the 2006 slip event.

I have conducted a preliminary investigation for associated seismic phenomena during the 2004–2005 Manawatu slow slip event. Due to the long duration of the Manawatu slow slip event, and the number of broadband stations in the region, there is a very large amount of continuous seismic data to be reviewed in detail. I reviewed eight weeks of data in a more broad investigation of seismic tremor, followed by a review of almost five weeks of seismic data files in greater detail. It would be ideal to look for long-term variations in seismic energy and frequency in the Manawatu region using an automated technique, such as the algorithm developed by Kao et al. (2007b).

5.4 Summary

A review of 20 weeks of continuous seismic data reveal that at least one slow slip event in New Zealand triggered local microseismicity. There is an increase in local seismicity during the Gisborne 2004 slow slip event and the increased seismicity is restricted to an area near the Mahia Peninsula to the southwest of the region of slip. The timing of these earthquakes suggest that they have been triggered by changes in the local stress regime. The triggered earthquakes were not detected during routine analysis and were only revealed during the methodical review of continuous seismic data during this study. The triggered earthquakes are in the magnitude range of M_L ~1.0–2.0. A similar spatiotemporal relationship between microseismicity and the Gisborne 2006 slow slip event is not shown. The preliminary work for the Manawatu slow slip event does not show an association of seismic phenomena during two months of the slow slip event, but further work is warranted.

Chapter 6

Discussion and Conclusions

I have addressed all of the objectives from Chapter 1 and made the following findings:

1. I do not detect seismic tremor in association with three separate slow slip events in both the shallow and deeper regions of the Hikurangi subduction zone;

2. I deployed temporary seismometers during a slow slip event near Gisborne in 2006 and do not detect seismic tremor with the extra seismic data, which suggests that the absence of tremor is not due to limitations of the seismic network; and

3. I determine that an increase in local microseismicity was likely associated with the slow slip event near Gisborne in 2004.

The preliminary results by Douglas (2005) suggest that seismic tremor may have accompanied a slow slip event near Gisborne in 2004, and these results were part of the motivation for this project. The systematic review of continuous seismic data during the times of three slow slip events in New Zealand, at two different regions of the subduction zone revealed that seismic tremor was not observed during periods of slow slip. Two main possibilities exist: (1) limitations in the seismic network prevent us from detecting a weak, emergent signal such as seismic tremor, or (2) seismic tremor does not accompany slow slip events in the Hikurangi subduction zone.

In this chapter, I consider these two possibilities in more detail and introduce a possible model of the relationship between slow slip and microseismicity during the Gisborne 2004 slow slip event.

6.1 Possible reasons for the lack of observed seismic tremor

A simple explanation for the lack of observed seismic tremor in New Zealand is that the seismic network is not capable of detecting small amplitude seismic signals such as tremor. I show that this is unlikely and instead I consider why slow slip events are not accompanied by seismic tremor. The characteristics of the Hikurangi subduction zone are compared with other subduction zones where seismic tremor is prevalent during periods of slow slip.

6.1.1 Seismic networks

Figure 6.1 illustrates the permanent seismograph station spacings in Cascadia, where seismic tremor is observed during times of slow slip, and the two areas of slow slip in New Zealand from this study (the maps are all scaled 1:5 000 000). The pink shaded areas are the slip models by Douglas (2005) in A, Wallace and Beavan (2006) in B and Dragert et al. (2004) in C. In Cascadia, seismic tremor is detected on all the stations on Vancouver Island, the stations on the islands near Vancouver Island and the stations on the coastal mainland. During times of peak tremor, seismic tremor is detected as far away as station LLLB, which is nearly 300 km away from the area of slip. The permanent network in New Zealand is not as densely spaced as the network in Cascadia, but it is adequately spaced in order to detect seismic tremor in both the Raukumara Peninsula and the Manawatu regions, as the majority of stations used in this study are well under 300 km distance from the slip areas.

The newly detected earthquakes were generally between M_L 1–2 and given that these small amplitude earthquakes were easy to detect during the tremor analysis, it is unlikely that a prevalent seismic tremor signal was overlooked.

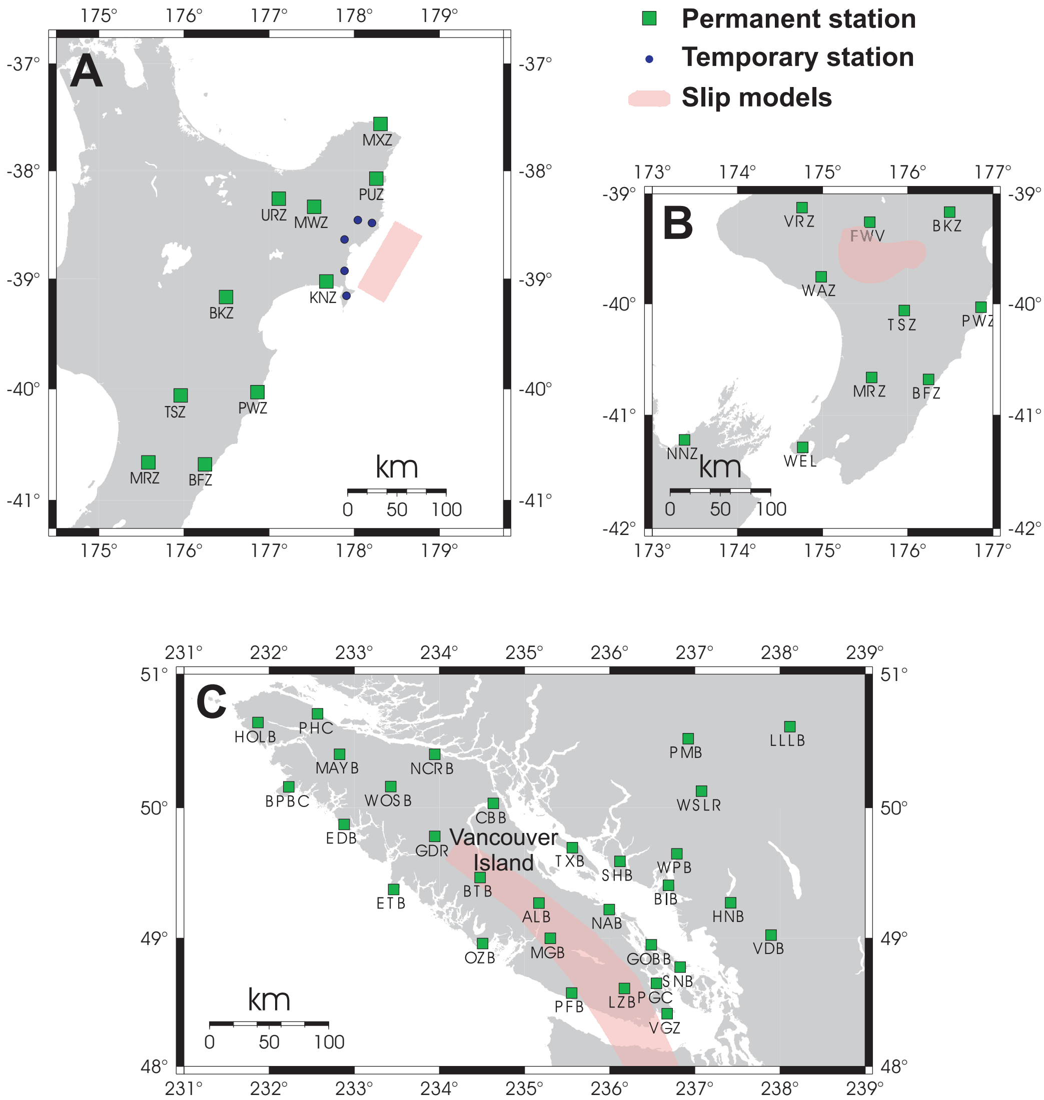

Figure 6.1: **Permanent seismometer networks in New Zealand and Cascadia.** The shaded pink areas are models of slow slip. The maps are all scaled 1:5 000 000.

6.1.2 Subduction zone characteristics

The exact mechanism of seismic tremor is not well understood, but it is generally accepted that fluids are involved due to the similarity between seismic and volcanic tremors (Schwartz and Rokosky, 2007). Volcanic tremor is generated during the migration of gases and magma (Julian, 1994). The amount of fluids at the Hikurangi subduction zone may be related to the absence of seismic tremor. As discussed earlier in Chapter 2, there have been slow slip events observed in several regions in Japan but not all of the slow slip events are associated with seismic tremor. Specifically, seismic tremor is observed in southwest Japan, where the young ($\sim$ 15 Ma) Philippine plate is subducting. There has been no seismic tremor observed in central Japan, where the much older ($\sim$ 130 Ma) Pacific plate is subducting.

A similar comparison can be made between the Cascadia subduction zone and the Hikurangi subduction zone. As discussed earlier in Chapters 1 and 2, slow slip events in Cascadia are well-correlated with seismic tremor. Both the subduction zones have comparable convergence rates: 37 mm/yr for Cascadia, and 47–41 mm/yr for Hikurangi (Riddihough, 1984; DeMets et al., 1990). The Juan de Fuca plate (Figure 2.3) varies in age from 6–7 Ma (Riddihough, 1984), whereas the Hikurangi Plateau is approximately 115–125 Ma (Mortimer and Parkinson, 1996). Another difference is the thickness of the subducting plates. The Hikurangi Plateau is much thicker than typical oceanic crust ($\sim$7 km for average ocean crust, such as the Juan de Fuca plate) with the thickness varying from 10–15 km at the latitudes of the Raukumara Peninsula to Wellington (thickening to the south) (Riddihough, 1984; Mortimer and Parkinson, 1996).

The thermal structure at subduction zones varies due to a number of factors, such as plate convergence rate, age of the subducting plate, sediment thickness and possibly rates of shear heating (Peacock and Wang, 1999). The thermal structure controls dehydration reactions during subduction, where blueschist-eclogite dehydration reactions release large amounts of water (Peacock and Wang, 1993). Because the subducting Juan de Fuca plate is young and warm, it readily releases water at relatively shallow depths, in contrast to the much older and colder Hikurangi Plateau that cannot undergo dehydration reactions until much greater depths. This may partly explain why seismic tremor was not observed during periods of slow slip in New Zealand.

6.2 Gisborne 2004

The analysis from Chapter 5 has shown that the Gisborne 2004 slow slip event was associated with microseismicity that is both spatially restricted to a region of the subducting plate down-dip from the area of slow slip inferred from GPS observations and temporally restricted to the period of slow slip. A possible mechanism for the increased seismicity is that the slow slip caused perturbations in the local stress regime which triggered the increased microseismicity.

Figures 6.2, 6.3, and 6.4 show the Coulomb failure stress during the slow slip event. The slip model parameters used are the preferred model from Douglas (2005). Parts A in these three figures show the Coulomb failure stress in map view for the Mahia Peninsula and part of the Raukumara Peninsula, while the parts B in the figures illustrate the Coulomb failure stress in cross-section. Relocated hypocentres are indicated by the black circles but they are not scaled to magnitude (magnitudes are approximately M_L 1–2). Figure 6.2 illustrates the relocated seismicity during the entire period of analysis (16 October to 3 December 2004). Figures 6.3 and 6.4 show the relocated seismicity during the period of slip and outside the period of slip, respectively. In all cases, the majority of seismicity is located in the region of positive Coulomb stress change, but the number of earthquakes increases significantly during the period of slip (compare Figures 6.3 and 6.4. There are more earthquakes during the time of slow slip (a 14 day period) than during all of the time outside of the slow slip (a 33 day period). This is a simple model, but it suggests that the increased microseismicity near the Mahia Peninsula and during the 2004 slow slip event was triggered by the local increase in Coulomb stress. Rate and state stress models for the triggered microseismicity near the Mahia Peninsula during the Gisborne 2004 slow slip event are currently under investigation.

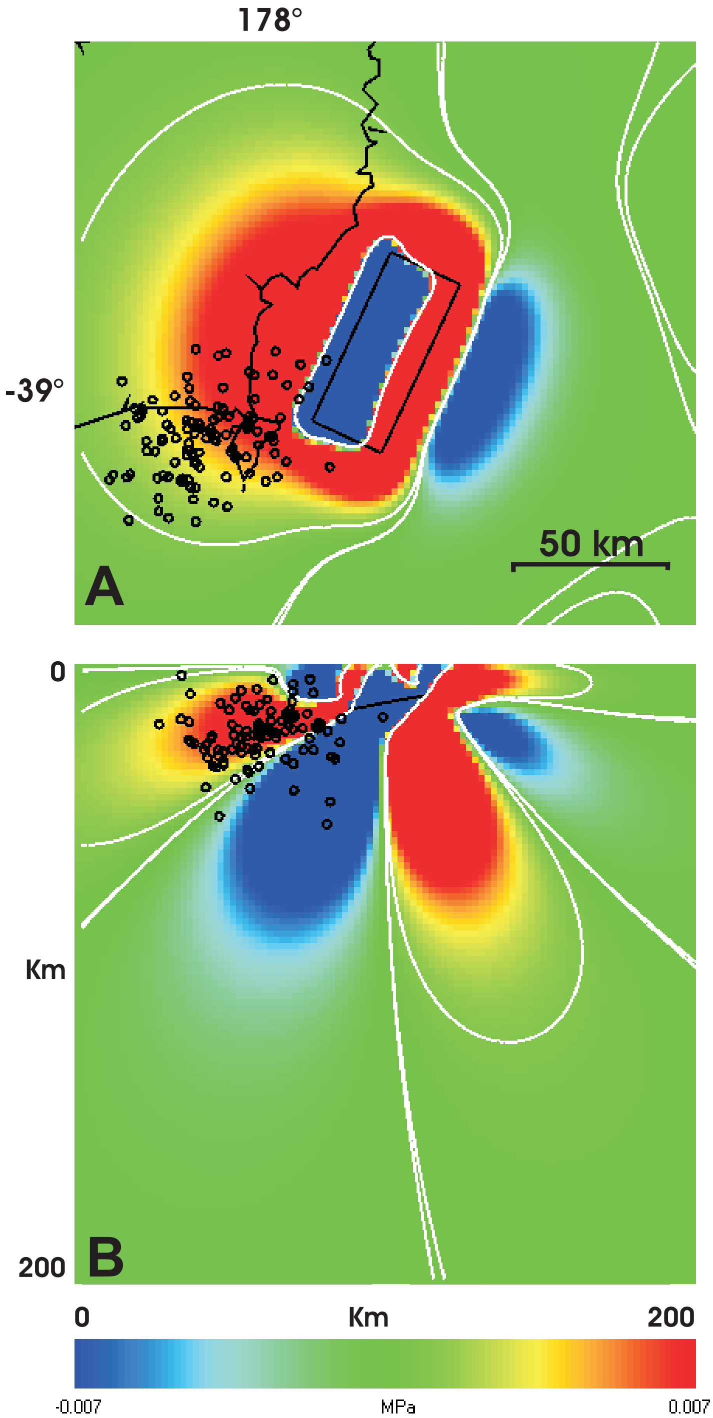

Figure 6.2: **Coulomb failure stress during the Gisborne 2004 slip event.** A) Map view of the Coulomb-stress failure. B)Cross-section is from Figure 5.10 and there is no vertical exaggeration. Earthquake hypocentres are from the entire period analysed (16 October to 3 December 2004) and are indicated by the black circles. Contours are shown at values of $\pm 1^{-5}$ and 1^{-3} MPa.

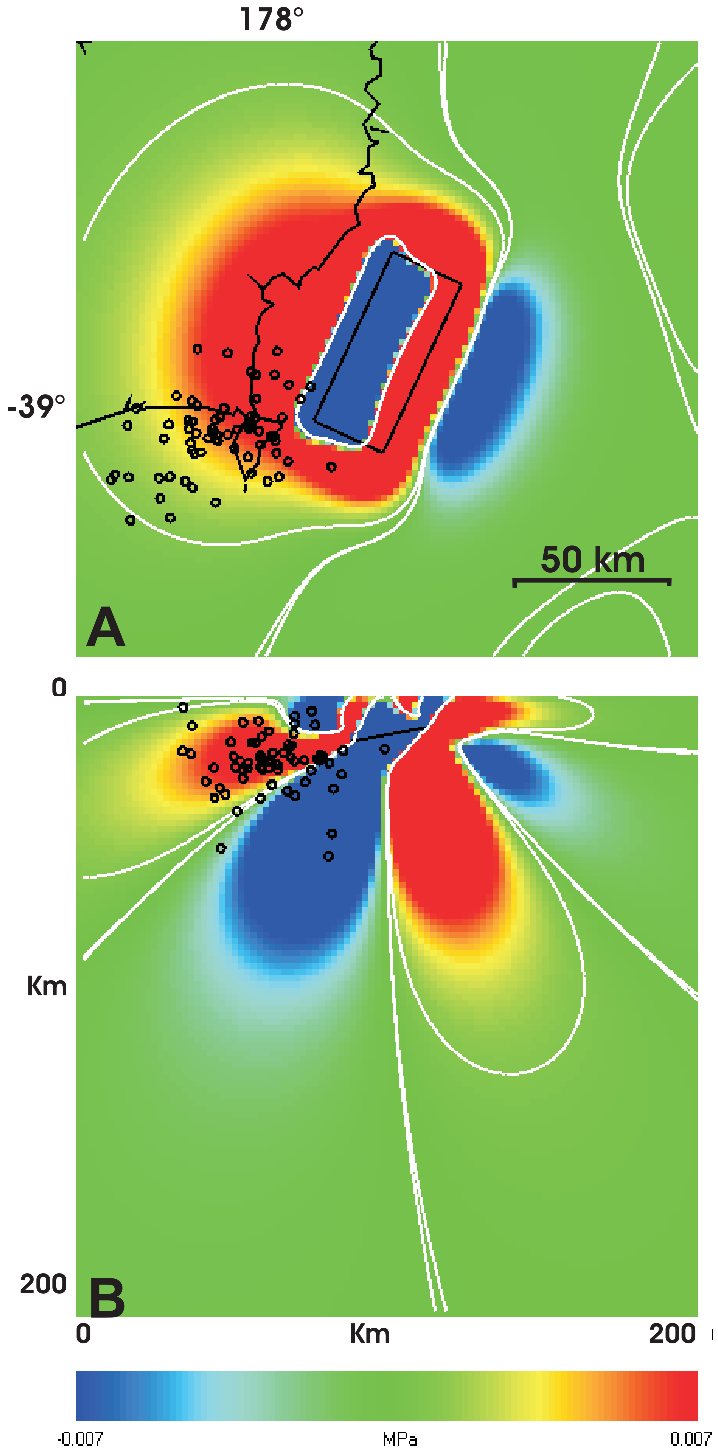

Figure 6.3: **Coulomb failure stress during the Gisborne 2004 slip event.** A) Map view of the Coulomb-stress failure. B) Cross-section is from Figure 5.10 and there is no vertical exaggeration. Earthquake hypocentres are from the period of slow slip (16 October to 12 November 2004) and are indicated by the black circles. Contours are shown at values of $\pm 1^{-5}$ and 1^{-3} MPa.

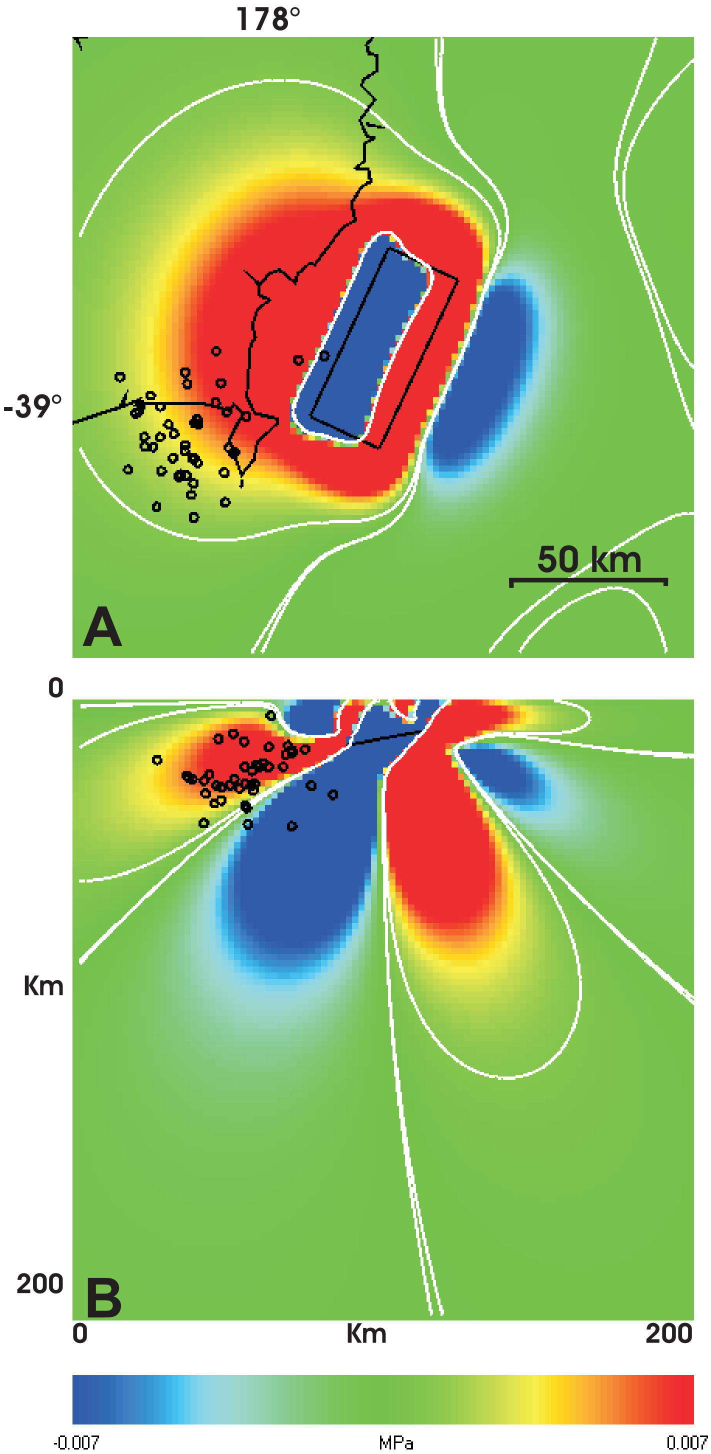

Figure 6.4: **Coulomb failure stress during the Gisborne 2004 slip event.** A) Map view of the Coulomb-stress failure. B) Cross-section is from Figure 5.10 and there is no vertical exaggeration. Earthquake hypocentres are from the periods outside the time of slip (16–27 October and 13 November to 3 December 2004) and are indicated by the black circles. Contours are shown at values of $\pm1^{-5}$ and 1^{-3} MPa.

6.2.1 Implications of this study

The results of this study show that local microseismicity was spatiotemporally associated with a slow slip event on the shallow part of the Hikurangi subduction zone in 2004. It may be possible that slow slip on the Hikurangi subduction zone could trigger larger earthquakes, or maybe triggered microseismicity could grow into larger, more destructive earthquakes. Segall et al. (2006) show that the locations of triggered microseismicity help to constrain the depth of slow slip events in Hawaii. Because slow slip events observed near the Gisborne and Hawke Bay regions are offshore, slip models are not well-constrained due to a lack of CGPS data, and triggered seismicity may help to constrain the depth and along-strike margins of slip. Dragert et al. (2004) show that slow slip events in Cascadia stress the locked portion of the plate, and each slow slip event may bring the locked zone closer to failure. It is feasible that slow slip events in all subduction zones, including the Hikurangi subduction zone could be a trigger mechanism for a subduction thrust earthquake.

6.3 Future work

This is the first study to systematically examine continuous seismic data during periods of slow slip on the Hikurangi subduction zone, in an effort to determine if slow slip events in New Zealand are accompanied by seismic tremor or other seismic phenomena observed elsewhere. Twenty weeks of continuous seismic data were reviewed during this study, but there is still a great deal of seismic data that has not been analysed yet. With the analysis methods established during this study, it will be easier to review more seismic data during more recent and future slow slip events in the Hikurangi subduction zone.

It would be ideal if the microseismicity levels during all slow slip events in the Hikurangi subduction zone were examined, but this may be challenging due to the large station spacings. It will be necessary to review the seismicity rates in the Raukumara Peninsula, during the period of slip near Gisborne in

2006, once the routine analysis is complete. Local microseismicity patterns during periods of slow slip may help to constrain offshore slip models in the northern Hikurangi subduction zone.

As discussed earlier, not only were small local earthquakes newly detected in this study, but also local earthquakes up to M_L 3.3. One possibility is that the spectral characteristics of the newly detected earthquakes differ from the routinely detected earthquakes and therefore the auto-detection system at GeoNet cannot detect certain earthquakes. Further work is required.

The research on the Manawatu slow slip data has been a preliminary effort. Due to the long duration of the event and the abundance of seismic data, it is necessary to establish a more automated method to review long periods of continuous seismic data. Presently, my colleagues and I are collaborating with researchers in Cascadia to explore using the automatic detection algorithm developed by Kao et al. (2007b), in an effort to review longer periods of data during the Manawatu 2004–2005 slow slip event.

The study of slow slip events and of all the different types of associated seismic phenomena, such as non-volcanic seismic tremor and triggered seismicity, is a work in progress around the world. The relationship between slow slip and microseismicity during the 2004 Gisborne event appears to be consistent with the "co-shocks" model of Segall et al. (2006). My colleagues and I have just begun exploring this model in more detail.

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Appendix A

2004 Gisborne earthquake hypocentres

Table A.1: **Earthquake hypocentres** from the 2004 Gisborne slow slip event. CUSP ID is the unique event identifier, TYPE: R are routine analysed earthquakes, N are newly detected earthquakes, T are newly detected teleseisms, and X are local noise or earthquakes too small to locate, JDay is the Julian day of year. Waveform data is available from http://www.geonet.org.nz

CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2308655	R	290.286	20041016	065158.63	-38.263	177.758	56.5	2.2	0.27
2308702	R	290.397	20041016	093111.55	-37.699	179.321	33.0	3.0	0.39
2596558	T	290.446	20041016	104243.39	-32.788	179.235	412.9		0.13
2308752	R	290.525	20041016	123549.86	-39.500	177.661	29.8	2.3	0.16
2596785	T	290.557	20041016	132132.01	-33.165	179.126	421.3		0.13
2308773	R	290.591	20041016	141045.59	-39.034	177.835	26.4	2.6	0.20
2596786	T	290.613	20041016	144225.50	-37.077	177.257	175.5	2.6	0.12
2308793	R	290.632	20041016	150938.93	-39.099	177.813	22.1	2.1	0.14
2308835	R	290.738	20041016	174241.00	-37.792	177.070	88.6	2.7	0.09
2596787	X	290.756	20041016	18090.00					
2596789	X	290.826	20041016	19490.00					
2596790	T	290.83	20041016	195442.39	-36.640	-179.440	98.8	2.9	0.12
2655243	N	290.866	20041016	204714.15	-38.312	177.723	28.5	2.0	0.20
2308956	R	291.013	20041017	001916.48	-39.397	177.424	29.4	2.4	0.08
2308971	R	291.049	20041017	011032.08	-37.982	178.060	67.5		0.02
2308989	R	291.102	20041017	022635.65	-37.798	177.590	56.6	2.4	0.26
2309009	R	291.149	20041017	033352.37	-38.109	178.949	30.7	2.9	0.14

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CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2309010	R	291.15	20041017	033606.92	-39.150	178.652	33.0	3.4	0.11
2596791	T	291.251	20041017	060200.12	-38.205	177.893	5.9	3.9	0.00
2596793	N	291.311	20041017	072817.37	-38.432	178.703	29.3	1.4	0.05
2309101	R	291.368	20041017	085011.68	-37.565	178.461	41.6	3.0	0.05
2596794	T	291.396	20041017	093030.88	-36.848	177.252	181.4	3.3	0.12
2309138	R	291.453	20041017	105258.24	-38.730	177.043	12.0	1.9	0.04
2596795	T	291.603	20041017	142739.63	-39.580	179.371	66.2	2.8	0.27
2596797	T	291.742	20041017	174837.85	-36.518	-179.368	30.0	3.1	0.23
2596798	T	291.756	20041017	180758.90	-40.672	176.799	33.0	1.9	0.03
2309252	R	291.789	20041017	185624.44	-39.544	177.021	33.0	2.2	0.09
2309277	R	291.86	20041017	203741.34	-37.887	177.575	69.3	2.3	0.15
2596799	X	291.879	20041017	21060.00					
2596801	N	292.002	20041018	000247.99	-31.144	171.133	295.6	5.2	0.81
2596802	N	292.404	20041018	094207.62	-37.459	179.306	17.6	2.8	0.09
2596803	T	292.459	20041018	110020.94	-32.662	-179.955	431.6		0.17
2596804	X	292.492	20041018	11490.00					
2309601	R	292.609	20041018	143639.07	-38.005	178.345	32.7	3.8	0.25
2596805	X	292.789	20041018	18560.00					
2655245	X	292.885	20041018	21150.00					
2596806	T	292.92	20041018	220516.56	-36.528	177.326	93.9	2.4	0.24
2596807	N	292.98	20041018	233118.93	-37.836	177.471	35.5	2.0	0.09
2596809	X	293.039	20041019	00560.00					
2655246	X	293.043	20041019	01020.00					
2309809	R	293.047	20041019	010816.61	-39.620	177.056	5.0	2.6	0.09
2655247	X	293.069	20041019	01400.00					
2596810	T	293.117	20041019	024810.23	-37.655	178.024	16.8	2.1	0.05
2596812	T	293.183	20041019	042401.79	-37.076	176.733	27.8	3.0	0.64
2309874	R	293.183	20041019	042403.36	-37.910	177.005	149.8	3.0	0.31
2596813	T	293.24	20041019	054531.70	-31.777	-176.579	33.0		0.15
2596815	T	293.363	20041019	084216.12	-39.321	176.155	64.8	1.9	0.08
2309969	R	293.401	20041019	093656.60	-37.691	176.800	5.0	2.4	0.30
2309988	R	293.443	20041019	103730.87	-39.747	177.016	50.3	3.3	0.28
2310067	R	293.608	20041019	143542.81	-38.602	177.046	61.8	2.0	0.13
2596816	N	293.709	20041019	170052.41	-37.948	177.390	33.0	2.1	0.12
2310137	R	293.777	20041019	183845.30	-38.897	178.102	28.0	2.9	0.16
2596818	T	293.857	20041019	203429.19	-38.442	177.541	200.0	2.9	0.00
2596821	N	294.001	20041020	000110.78	-39.083	177.750	26.1	2.7	1.05
2310257	R	294.021	20041020	002940.38	-37.533	177.576	108.4	3.6	0.15
2310359	R	294.228	20041020	052759.40	-38.812	177.952	45.1	3.0	0.14
2596822	N	294.285	20041020	065104.35	-37.742	178.709	33.0	1.8	0.15
2481994	R	294.316	20041020	073505.08	-38.821	178.015	27.5		0.26
2310400	R	294.333	20041020	075851.92	-37.068	176.881	312.2	4.4	0.12
2310402	R	294.337	20041020	080509.56	-37.746	177.004	129.2	2.8	0.18
2310417	R	294.37	20041020	085212.56	-37.891	177.495	60.4	2.4	0.23

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CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2485055	R	294.627	20041020	150315.76	-38.634	177.904	33.0	2.3	0.14
2596824	X	294.631	20041020	15090.00					
2310530	R	294.66	20041020	155015.58	-38.265	177.110	57.0	3.3	0.15
2310535	R	294.678	20041020	161624.21	-37.915	178.584	12.0		0.25
2485080	R	294.777	20041020	183915.47	-38.187	178.459	5.0	3.1	0.22
2485082	R	294.78	20041020	184340.16	-37.368	177.190	105.0		0.03
2310607	R	294.841	20041020	201100.18	-38.075	178.987	33.0		0.21
2596826	X	294.86	20041020	20390.00					
2310644	R	294.907	20041020	214549.04	-37.140	177.411	143.7	4.9	0.19
2310648	R	294.914	20041020	215643.53	-37.443	177.851	92.7	3.9	0.16
2486365	R	294.932	20041020	222238.39	-38.468	178.477	12.0		0.28
2310664	R	294.939	20041020	223249.97	-39.911	176.878	46.6	2.7	0.21
2310678	R	294.964	20041020	230741.48	-38.948	177.640	33.0	2.2	0.11
2596827	N	295.082	20041021	015732.56	-38.874	177.681	49.4		0.07
2655248	N	295.102	20041021	022646.02	-38.598	177.889	41.2	1.7	0.10
2596829	X	295.197	20041021	04440.00					
2596830	T	295.218	20041021	051314.55	-40.769	175.954	15.7	2.5	0.07
2310809	R	295.228	20041021	052742.68	-39.682	177.173	33.0	2.6	0.20
2480163	R	295.228	20041021	052816.08	-39.519	177.222	18.6		0.06
2596832	T	295.256	20041021	060846.77	-40.412	175.764	33.0	2.4	0.02
2310850	R	295.301	20041021	071304.80	-38.654	178.004	30.3	2.1	0.16
2596834	T	295.318	20041021	073756.84	-39.118	176.672	33.0		2.01
2310909	R	295.435	20041021	102655.85	-38.325	178.854	29.6		0.18
2596835	T	295.44	20041021	103307.71	-34.101	-179.702	126.5		0.08
2310930	R	295.483	20041021	113602.74	-37.908	177.199	71.7	3.3	0.09
2596836	X	295.58	20041021	13550.00					
2311040	R	295.773	20041021	183348.17	-38.369	177.307	46.1	3.4	0.20
2655249	N	295.822	20041021	194331.65	-38.520	177.805	28.0	1.9	0.17
2596837	T	295.911	20041021	215132.56	-36.845	179.045	102.5	3.2	0.24
2596839	X	295.995	20041021	23530.00					
2596840	X	296.158	20041022	03480.00					
2596842	T	296.169	20041022	040239.70	-38.745	-168.346	33.0		0.03
2311270	R	296.225	20041022	052423.40	-38.394	177.615	56.8	2.3	0.15
2596843	N	296.28	20041022	064311.27	-38.419	178.150	27.2	1.2	0.08
2655251	X	296.318	20041022	07380.00					
2311338	R	296.39	20041022	092136.48	-39.726	176.874	48.7	2.4	0.33
2596844	N	296.399	20041022	093435.07	-39.524	177.345	195.3	2.7	1.01
2311364	R	296.462	20041022	110537.70	-38.354	178.749	29.2		0.07
2483308	R	296.463	20041022	110626.56	-38.828	176.838	63.5		0.08
2311375	R	296.49	20041022	114550.39	-37.218	177.286	149.0		0.05
2596846	N	296.49	20041022	114550.64	-37.257	177.431	156.9	2.6	0.24
2311413	R	296.59	20041022	140910.65	-37.218	177.106	151.4	2.6	0.31
2596847	T	296.697	20041022	164408.21	-40.639	176.867	33.0	2.3	0.05
2596848	N	296.766	20041022	182245.18	-37.827	177.557	17.4	2.7	0.27

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CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2596849	N	296.785	20041022	185049.35	-38.870	177.813	50.3		0.03
2596850	X	296.79	20041022	18570.00					
2311497	R	296.795	20041022	190442.61	-39.774	177.065	42.7	2.9	0.17
2486368	R	296.795	20041022	190458.14	-39.740	177.093	33.0	2.6	0.23
2311527	R	296.856	20041022	203221.16	-37.598	177.923	84.8		0.11
2311562	R	296.935	20041022	222632.09	-37.752	177.548	54.4	2.5	0.09
2655252	N	296.954	20041022	225352.94	-38.717	177.539	54.0	1.7	0.16
2596851	T	297.023	20041023	003251.31	-35.241	179.011	173.7	3.0	0.27
2311615	R	297.056	20041023	012111.56	-37.132	177.207	138.0	3.1	0.08
2596852	T	297.056	20041023	012111.73	-37.149	177.240	139.1	3.1	0.10
2596853	N	297.172	20041023	040802.60	-34.568	172.350	499.2	4.5	0.89
2596855	N	297.22	20041023	051621.12	-32.071	163.970	447.3	4.3	0.83
2311695	R	297.26	20041023	061409.37	-38.721	178.744	19.9	3.3	0.15
2596856	T	297.298	20041023	070935.81	-38.822	176.773	50.0	2.6	0.00
2311737	R	297.354	20041023	082937.56	-38.521	178.347	5.0		0.17
2596858	T	297.39	20041023	092212.67	-40.670	176.509	33.0	2.6	0.03
2596859	X	297.473	20041023	11210.00					
2596860	T	297.479	20041023	113000.11	-36.914	176.302	33.0	2.9	3.50
2596862	N	297.502	20041023	120256.06	-39.757	176.908	49.5	1.8	0.14
2311797	R	297.518	20041023	122622.78	-38.453	177.233	43.8	2.3	0.05
2311834	R	297.622	20041023	145612.20	-38.551	177.659	29.5	3.0	0.24
2596863	T	297.643	20041023	152606.13	-36.518	177.373	238.8	2.9	0.20
2311853	R	297.671	20041023	160601.75	-38.551	177.608	33.0	2.1	0.25
2596865	T	297.679	20041023	161802.47	-38.872	-178.460	33.0	3.2	0.04
2311885	R	297.764	20041023	181942.42	-37.047	178.474	33.0	3.9	0.22
2596866	N	297.866	20041023	204738.19	-39.951	176.993	37.8	2.6	0.08
2311939	R	297.911	20041023	215203.33	-39.241	177.649	33.6		0.04
2596867	N	297.991	20041023	234656.31	-35.768	175.901	451.7	3.9	1.48
2312045	R	298.156	20041024	034513.48	-39.323	177.811	28.9		0.25
2596869	X	298.232	20041024	05340.00					
2596870	T	298.323	20041024	074535.14	-38.999	-177.535	33.0	2.9	0.38
2312155	R	298.361	20041024	083955.98	-39.269	177.658	30.1	3.1	0.17
2655253	N	298.397	20041024	093217.15	-39.292	177.767	31.0	1.8	0.09
2596872	X	298.406	20041024	09450.00					
2655254	T	298.41	20041024	095042.25	-36.551	177.948	35.1	2.8	0.56
2312199	R	298.456	20041024	105643.77	-38.498	177.795	36.1	1.8	0.19
2596873	X	298.466	20041024	11110.00					
2312222	R	298.503	20041024	120341.67	-37.003	178.444	33.0	3.4	0.24
2596874	T	298.503	20041024	120341.89	-37.083	178.579	25.1	3.3	0.23
2596876	X	298.512	20041024	12170.00					
2312238	R	298.536	20041024	125135.59	-39.960	176.858	47.4	2.7	0.22
2596877	T	298.569	20041024	133846.55	-40.110	178.637	396.8	3.2	1.57
2596879	X	298.63	20041024	15070.00					
2596880	T	298.796	20041024	190634.61	-36.198	177.136	33.0	3.2	0.48

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CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2312360	R	298.81	20041024	192703.22	-39.923	176.772	45.3	2.5	0.20
2596881	X	298.886	20041024	21160.00					
2655255	N	299.024	20041025	003506.44	-39.247	177.303	46.3	2.1	0.16
2483329	R	299.063	20041025	013108.27	-37.993	178.894	28.0		0.35
2312506	R	299.164	20041025	035546.47	-39.709	177.039	46.9	2.7	0.32
2596882	T	299.267	20041025	062402.41	-36.636	177.415	171.5	3.4	0.10
2312591	R	299.38	20041025	090644.42	-38.243	177.783	31.2	3.3	0.26
2312612	R	299.447	20041025	104333.43	-37.427	179.120	15.2	2.6	0.13
2312656	R	299.567	20041025	133605.95	-38.273	177.361	39.2	3.2	0.18
2655257	N	299.63	20041025	150645.10	-38.506	177.129	12.0	1.9	0.07
2312703	R	299.683	20041025	162331.93	-37.913	179.194	22.6	3.3	0.18
2655259	T	299.685	20041025	162641.86	-36.159	178.484	89.3	3.1	0.12
2312741	R	299.777	20041025	183914.76	-37.075	177.286	145.7	3.3	0.08
2312753	R	299.807	20041025	192245.55	-38.194	179.111	22.4		0.15
2596884	T	299.828	20041025	195213.52	-40.643	176.445	33.0	1.7	0.07
2596885	X	300.01	20041026	00140.00					
2596887	X	300.013	20041026	00190.00					
2312875	R	300.032	20041026	004551.53	-39.143	177.501	28.1	3.0	0.14
2655260	N	300.085	20041026	020141.01	-37.771	177.124	35.8	2.3	1.07
2312926	R	300.092	20041026	021232.49	-39.170	177.549	30.8	2.4	0.22
2655261	N	300.096	20041026	021841.68	-39.152	177.826	17.5	2.1	0.27
2657032	N	300.097	20041026	021905.68	-39.099	177.905	7.4		0.11
2312959	R	300.137	20041026	031739.68	-38.330	176.863	228.3	3.3	0.22
2596888	T	300.171	20041026	040536.97	-28.121	-179.269	33.0		0.11
2596890	T	300.301	20041026	071248.49	-34.946	179.823	33.0		0.21
2596892	T	300.312	20041026	072925.38	-40.297	178.886	200.0		0.00
2596893	T	300.315	20041026	073302.56	-45.319	165.323	33.0		0.37
2313034	R	300.33	20041026	075442.42	-38.446	177.647	56.6	2.5	0.08
2313047	R	300.371	20041026	085411.15	-38.490	178.031	27.2	2.1	0.16
2313095	R	300.531	20041026	124442.55	-39.920	176.813	40.1	2.2	0.21
2313137	R	300.639	20041026	151950.45	-38.624	178.523	12.0	2.5	0.17
2313164	R	300.734	20041026	173707.98	-37.900	177.014	128.5	3.9	0.23
2596896	X	300.767	20041026	18250.00					
2596896	T	300.767	20041026	182504.66	-31.651	-178.375	475.3		0.08
2313183	R	300.779	20041026	184143.40	-37.470	178.380	36.7		0.19
2596897	X	300.831	20041026	19560.00					
2596899	X	300.875	20041026	21000.00					
2596901	N	300.96	20041026	230247.70	-37.841	177.286	33.0		0.51
2313271	R	300.96	20041026	230247.88	-38.142	177.019	5.0	2.7	0.21
2596904	X	301.008	20041027	00110.00					
2596906	X	301.078	20041027	01520.00					
2313359	R	301.152	20041027	033816.99	-39.177	177.836	25.8	3.1	0.10
2655262	N	301.157	20041027	034620.85	-39.167	177.856	24.9	2.2	0.17
2655263	T	301.266	20041027	062302.39	-36.041	178.408	212.9	3.1	0.18

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CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2596907	X	301.267	20041027	06250.00					
2313471	R	301.41	20041027	095049.45	-38.607	177.482	60.8	3.0	0.15
2313487	R	301.452	20041027	105114.09	-37.521	177.295	96.6	2.7	0.12
2596910	X	301.453	20041027	10520.00					
2313509	R	301.506	20041027	120840.94	-39.706	176.934	49.7	2.8	0.18
2596911	T	301.525	20041027	123519.50	-25.023	-179.230	33.0		1.26
2610467	X	301.572	20041027	13440.00					
2313534	R	301.573	20041027	134442.79	-39.174	177.860	25.4	2.6	0.14
2487760	R	301.617	20041027	144812.17	-39.274	177.141	27.6	2.8	0.43
2313553	R	301.627	20041027	150315.17	-39.182	177.856	26.1	2.1	0.20
2313558	R	301.643	20041027	152520.28	-38.303	178.417	8.9	2.5	0.07
2610550	X	301.657	20041027	15460.00					
2610551	N	301.762	20041027	181721.56	-39.947	176.721	33.0	1.8	0.22
2610553	X	301.87	20041027	20530.00					
2610554	X	301.907	20041027	21460.00					
2610555	X	301.913	20041027	21550.00					
2610557	X	301.925	20041027	22120.00					
2610558	X	301.985	20041027	23390.00					
2655264	T	302.174	20041028	041007.63	-36.791	175.152	263.7	3.1	0.12
2313823	R	302.277	20041028	063837.99	-38.706	177.974	27.2	2.1	0.24
2610560	X	302.356	20041028	08320.00					
2610561	N	302.363	20041028	084230.40	-39.506	174.713	529.6	3.5	1.04
2610563	N	302.4	20041028	093630.04	-38.187	178.487	5.0	2.4	0.32
2313876	R	302.421	20041028	100533.38	-37.368	178.311	5.0	3.0	0.21
2610564	X	302.517	20041028	12250.00					
2313915	R	302.525	20041028	123536.93	-37.731	179.281	26.2	3.1	0.22
2655265	X	302.612	20041028	14410.00					
2610566	T	302.625	20041028	145943.91	-36.828	179.146	12.0	2.7	0.11
2651966	X	302.625	20041028	15000.00					
2313950	R	302.634	20041028	151242.13	-37.622	177.071	143.5	2.8	0.13
2610567	T	302.636	20041028	151605.29	-39.364	175.103	124.3	3.0	0.17
2655266	X	302.641	20041028	15230.00					
2313994	R	302.741	20041028	174716.69	-38.310	178.945	24.4		0.14
2655267	N	302.741	20041028	174716.77	-38.337	178.924	21.4	2.0	0.15
2655268	X	302.742	20041028	17490.00					
2314042	R	302.851	20041028	202547.11	-37.928	179.148	26.0	2.6	0.14
2610568	N	302.851	20041028	202547.43	-37.916	179.135	23.5	2.7	0.32
2314063	R	302.893	20041028	212550.90	-37.434	176.776	151.2	3.0	0.18
2610570	X	302.942	20041028	22360.00					
2610572	X	302.988	20041028	23420.00					
2314165	R	303.088	20041029	020606.98	-38.139	178.017	42.7	2.8	0.17
2610573	T	303.091	20041029	021033.19	-36.968	177.397	140.6	2.7	0.09
2651968	X	303.091	20041029	02110.00					
2610574	X	303.131	20041029	03080.00					

continued on following page

continued from previous page

CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2610576	X	303.143	20041029	03260.00					
2610577	X	303.191	20041029	04350.00					
2610578	N	303.25	20041029	060028.67	-38.702	178.633	12.0	2.2	0.13
2610580	X	303.342	20041029	08120.00					
2610581	N	303.523	20041029	123245.21	-37.215	178.879	5.0	2.8	0.10
2314432	R	303.563	20041029	133111.21	-39.135	177.688	28.0	2.7	0.11
2610584	X	303.677	20041029	16150.00					
2610585	X	303.717	20041029	17130.00					
2314537	R	303.79	20041029	185657.27	-39.504	177.108	26.0	2.9	0.25
2610587	T	303.872	20041029	205558.59	-36.690	177.031	245.8	3.3	0.21
2651969	X	303.872	20041029	20560.00					
2314620	R	303.961	20041029	230323.98	-38.793	177.345	53.7	2.9	0.28
2655269	N	304.016	20041030	002318.07	-37.933	177.451	12.0	2.5	0.25
2610589	X	304.026	20041030	00380.00					
2314745	R	304.184	20041030	042452.11	-38.227	178.805	27.0	3.2	0.07
2610591	T	304.222	20041030	051925.78	-34.776	179.677	258.7		0.05
2610593	X	304.292	20041030	07000.00					
2314839	R	304.397	20041030	093112.45	-38.389	178.403	5.0	3.3	0.29
2655270	N	304.487	20041030	114116.49	-38.357	178.550	12.0	2.1	0.25
2314912	R	304.576	20041030	134959.85	-39.165	177.835	25.7	2.8	0.13
2314932	R	304.633	20041030	151117.06	-37.430	177.011	153.8	2.6	0.20
2314933	R	304.634	20041030	151339.02	-39.280	177.703	30.6	3.1	0.18
2314948	R	304.672	20041030	160711.02	-38.091	178.574	26.4	2.5	0.16
2314952	R	304.684	20041030	162516.96	-38.222	178.992	25.9	2.9	0.15
2314985	R	304.765	20041030	182127.31	-38.687	177.455	52.3	2.3	0.08
2610595	X	304.827	20041030	19510.00					
2610596	T	304.909	20041030	214922.61	-34.961	179.336	33.0		0.23
2610597	T	305.017	20041031	002456.24	-35.494	-178.917	33.0		0.33
2651972	X	305.017	20041031	00250.00					
2655271	N	305.067	20041031	013632.87	-39.174	177.839	24.5	2.2	0.16
2651973	X	305.112	20041031	02410.00					
2610598	T	305.112	20041031	024155.00	-30.358	-179.461	307.5		0.05
2655272	N	305.154	20041031	034146.44	-38.555	178.068	25.7	1.9	0.18
2655273	T	305.172	20041031	040754.46	-38.108	178.154	12.0	2.0	0.14
2610600	T	305.245	20041031	055219.71	-36.659	177.071	22.1	3.3	0.20
2655275	X	305.283	20041031	06470.00					
2315219	R	305.298	20041031	070936.43	-38.745	178.333	21.3	2.4	0.25
2655276	N	305.381	20041031	090816.31	-39.173	177.831	24.7	2.0	0.09
2610601	N	305.397	20041031	093223.84	-38.037	176.969	61.8	2.1	0.11
2655277	N	305.421	20041031	100533.62	-39.156	177.849	22.0	1.9	0.23
2655278	N	305.463	20041031	110612.79	-38.439	177.487	52.1	1.9	0.25
2610602	T	305.473	20041031	112147.92	-34.943	-179.668	33.0		0.15
2651976	X	305.474	20041031	11220.00					
2315346	R	305.592	20041031	141232.16	-39.047	178.075	14.8	2.4	0.19

continued on following page

continued from previous page

CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2610604	X	305.752	20041031	18030.00					
2610606	X	305.827	20041031	19510.00					
2610607	N	305.87	20041031	205250.83	-40.609	176.381	28.3	2.6	0.14
2315476	R	305.897	20041031	213220.13	-39.850	176.838	47.3	2.8	0.16
2655279	T	306.034	20041101	004814.79	-38.427	177.284	76.7	2.7	0.86
2655281	T	306.044	20041101	010331.10	-38.052	177.411	200.0	3.1	5.62
2610609	N	306.085	20041101	020239.76	-38.915	177.805	20.3	2.1	0.40
2315569	R	306.102	20041101	022609.97	-37.901	177.646	40.1	2.5	0.06
2610610	N	306.135	20041101	031422.00	-37.848	177.608	20.6	2.2	0.15
2315613	R	306.19	20041101	043345.87	-38.879	177.915	32.2		0.25
2655282	X	306.224	20041101	05220.00					
2610612	N	306.258	20041101	061200.06	-39.134	178.004	5.0	2.3	0.24
2315663	R	306.312	20041101	072853.83	-39.065	178.069	12.0		0.04
2610614	T	306.369	20041101	085039.14	-34.167	-178.298	292.1		0.44
2651977	X	306.369	20041101	08510.00					
2315695	R	306.401	20041101	093658.74	-39.981	176.764	48.5	2.0	0.16
2655283	N	306.442	20041101	103556.65	-38.748	177.976	33.0	1.7	0.44
2655285	N	306.519	20041101	122651.95	-39.113	178.055	6.2	2.2	0.23
2655286	X	306.519	20041101	12280.00					
2655287	X	306.522	20041101	12320.00					
2610615	N	306.528	20041101	124007.52	-39.107	178.009	5.0	2.2	0.23
2655288	X	306.532	20041101	12460.00					
2610616	N	306.555	20041101	131922.03	-39.177	177.850	18.2	2.3	0.22
2315765	R	306.597	20041101	141939.98	-39.149	177.964	12.0	2.8	0.18
2315770	R	306.609	20041101	143723.64	-39.176	177.778	17.0		0.05
2655289	N	306.612	20041101	144122.33	-39.179	177.799	18.9	1.7	0.15
2610618	T	306.617	20041101	144818.37	-33.231	-178.087	260.2		0.10
2315779	R	306.623	20041101	145648.62	-37.642	176.994	135.3	2.4	0.16
2610619	T	306.719	20041101	171512.33	-40.455	-174.391	33.0		0.26
2651979	X	306.719	20041101	17160.00					
2610621	T	306.766	20041101	182325.84	-35.464	-175.502	100.0		0.29
2651980	X	306.767	20041101	18240.00					
2651981	X	306.776	20041101	18370.00					
2610622	T	306.776	20041101	183802.63	-32.203	-179.528	33.0		0.17
2655290	N	306.787	20041101	185255.22	-37.765	179.106	26.5	2.4	0.11
2315865	R	306.796	20041101	190609.00	-38.296	178.396	9.8	2.5	0.11
2315868	R	306.802	20041101	191447.67	-37.479	177.178	117.5	2.9	0.16
2655291	N	306.809	20041101	192429.45	-39.169	177.680	18.5	1.8	0.15
2655292	N	306.827	20041101	195056.76	-39.169	177.872	9.9		0.16
2655293	N	306.83	20041101	195553.91	-39.334	177.753	28.3	2.6	0.40
2655294	N	306.832	20041101	195813.09	-39.126	177.894	6.6	1.7	0.18
2610624	N	306.856	20041101	203317.06	-39.186	177.898	21.3	2.5	0.07
2655296	N	306.968	20041101	231334.77	-39.208	178.046	8.7	2.1	0.15
2655297	X	306.974	20041101	23230.00					

continued on following page

continued from previous page

CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2610625	T	306.994	20041101	235120.52	-30.488	176.829	33.0		0.10
2651982	X	306.994	20041101	23520.00					
2610626	X	307.032	20041102	00460.00					
2655298	X	307.083	20041102	02000.00					
2610627	T	307.091	20041102	021103.93	-34.842	-178.324	353.3		1.54
2651983	X	307.092	20041102	02120.00					
2610630	N	307.12	20041102	025319.01	-39.154	177.965	13.5	2.7	0.15
2655299	N	307.161	20041102	035114.50	-37.868	177.789	5.0	1.5	0.77
2655300	N	307.181	20041102	042020.48	-38.737	177.022	5.0	2.2	0.57
2655301	N	307.183	20041102	042334.95	-37.847	177.314	72.6	1.9	0.39
2651984	X	307.189	20041102	04320.00					
2610631	T	307.191	20041102	043433.01	-38.579	178.467	0.0	2.9	0.37
2316088	R	307.209	20041102	050111.24	-38.517	178.062	57.3		0.16
2610633	T	307.247	20041102	055611.35	-31.822	179.278	33.0		0.26
2655302	X	307.275	20041102	06360.00					
2610635	X	307.372	20041102	08560.00					
2655303	N	307.378	20041102	090408.92	-39.194	177.943	7.5	2.2	0.20
2655304	N	307.395	20041102	092929.31	-39.170	177.821	16.8	2.0	0.24
2655305	N	307.416	20041102	095918.42	-39.138	177.846	19.1	1.7	0.23
2655306	X	307.458	20041102	11000.00					
2610636	X	307.464	20041102	11080.00					
2487792	R	307.466	20041102	111140.96	-38.926	177.828	30.0	2.3	0.18
2655307	X	307.526	20041102	12370.00					
2316247	R	307.532	20041102	124610.23	-39.076	177.722	19.1	2.5	0.23
2655308	N	307.534	20041102	124918.42	-39.180	177.852	14.4	1.8	0.21
2657491	T	307.534	20041102	124918.42	-39.180	177.852	14.4	1.8	0.21
2610637	N	307.539	20041102	125638.24	-38.474	177.469	22.2	2.0	0.29
2610639	X	307.553	20041102	13160.00					
2316294	R	307.608	20041102	143450.12	-37.792	178.339	52.7	2.9	0.09
2655309	N	307.65	20041102	153619.65	-39.122	177.875	9.6	1.7	0.29
2655310	N	307.711	20041102	170404.06	-39.164	177.583	15.1	1.7	0.13
2655312	N	307.718	20041102	171333.65	-39.163	177.806	16.7	1.8	0.16
2610640	T	307.723	20041102	172145.48	-33.340	-179.232	380.7		0.07
2651986	X	307.724	20041102	17220.00					
2610642	N	307.754	20041102	180545.77	-40.180	176.807	44.3	2.6	0.12
2614272	N	307.755	20041102	180640.05	-40.180	176.818	48.9	2.3	0.11
2610643	N	307.77	20041102	182816.87	-39.002	177.992	27.5	2.1	0.13
2610644	T	307.774	20041102	18355.86	-38.114	176.121	175.1	3.0	0.11
2610645	X	307.798	20041102	19090.00					
2316423	R	307.85	20041102	202341.82	-37.795	179.055	33.0	3.6	0.17
2610647	X	307.892	20041102	21250.00					
2610648	T	307.919	20041102	220251.34	-33.227	-178.465	256.3		0.10
2651988	X	307.919	20041102	22030.00					
2610650	X	307.928	20041102	22160.00					

continued on following page

continued from previous page

CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2655313	N	308.027	20041103	003903.04	-39.171	177.836	11.2		0.21
2655314	X	308.036	20041103	00520.00					
2610651	T	308.056	20041103	012057.30	-31.963	-175.627	33.0		0.11
2651989	X	308.057	20041103	01220.00					
2655315	X	308.062	20041103	01300.00					
2655317	N	308.08	20041103	015442.39	-39.090	177.768	20.2	2.5	0.29
2610652	T	308.109	20041103	023656.50	-33.982	-177.928	33.0		0.11
2655318	X	308.126	20041103	03020.00					
2651991	X	308.188	20041103	04310.00					
2610654	T	308.189	20041103	043210.26	-32.588	-178.193	33.0		0.07
2610656	T	308.194	20041103	043930.89	-26.866	174.549	33.0		0.25
2651992	X	308.195	20041103	04410.00					
2655319	N	308.243	20041103	055012.03	-38.295	178.410	9.0	2.2	0.15
2655321	N	308.303	20041103	071555.40	-38.194	178.940	29.2	2.3	0.14
2610660	N	308.351	20041103	082516.81	-38.913	177.984	17.0	1.7	0.15
2655322	N	308.373	20041103	085714.61	-38.840	178.251	22.6	2.3	0.35
2655323	N	308.383	20041103	091107.80	-38.605	177.913	33.0	1.8	0.45
2655325	X	308.494	20041103	11510.00					
2316783	R	308.53	20041103	124308.64	-39.540	177.659	29.4		0.28
2316798	R	308.561	20041103	132731.14	-38.285	178.375	5.0	2.9	0.17
2316799	R	308.564	20041103	133144.01	-38.411	177.859	23.5	2.6	0.15
2490028	R	308.565	20041103	133419.11	-38.403	177.846	25.4	2.4	0.22
2655326	N	308.586	20041103	140319.59	-38.238	178.512	11.3	2.2	0.10
2316851	R	308.651	20041103	153807.66	-39.392	177.246	58.0	1.7	0.16
2610662	X	308.826	20041103	19500.00					
2655327	N	308.926	20041103	221336.06	-38.568	177.754	29.9	1.8	0.30
2655328	N	308.998	20041103	235635.51	-38.815	177.682	5.0		0.14
2610663	N	308.998	20041103	235635.85	-39.107	177.769	20.4		0.23
2610665	T	309.009	20041104	001236.58	-37.869	176.363	202.8	3.4	0.16
2655329	X	309.023	20041104	00330.00					
2610666	N	309.047	20041104	010748.26	-38.811	178.281	93.0	2.6	0.09
2655331	N	309.068	20041104	013729.29	-39.369	177.719	22.9	2.1	0.07
2317072	R	309.068	20041104	013729.34	-39.316	177.880	23.9		0.01
2610667	X	309.094	20041104	02160.00					
2610669	X	309.115	20041104	02450.00					
2610670	X	309.126	20041104	03020.00					
2655332	X	309.14	20041104	03210.00					
2655333	X	309.153	20041104	03400.00					
2610672	N	309.157	20041104	034557.66	-38.467	178.184	157.5		0.10
2610673	X	309.17	20041104	04050.00					
2610674	T	309.288	20041104	06545.01	-35.025	-179.951	33.0		0.17
2610676	N	309.308	20041104	072252.06	-39.227	178.176	19.8	1.8	0.15
2317193	R	309.321	20041104	074132.70	-39.165	177.788	15.4	2.6	0.12
2317195	R	309.325	20041104	074841.26	-37.708	176.933	129.1	2.9	0.12

continued on following page

continued from previous page

CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2655334	X	309.386	20041104	09160.00					
2655335	X	309.412	20041104	09530.00					
2317251	R	309.435	20041104	102544.54	-38.264	178.376	12.0	2.2	0.14
2616051	N	309.454	20041104	105359.39	-37.883	177.775	200.0	2.1	2.77
2610678	T	309.455	20041104	105441.49	-36.612	-179.446	75.4	2.6	0.12
2610679	T	309.529	20041104	124153.64	-38.643	175.847	155.0	2.5	0.14
2651997	X	309.529	20041104	12420.00					
2655336	X	309.533	20041104	12480.00					
2317309	R	309.544	20041104	130342.66	-38.861	178.455	33.0	2.4	0.19
2655337	N	309.557	20041104	132147.81	-38.355	178.321	8.0	2.0	0.18
2493639	R	309.589	20041104	140753.52	-38.516	178.027	49.5		0.11
2610682	X	309.594	20041104	14150.00					
2610684	T	309.62	20041104	145315.96	-37.762	-178.418	300.6	3.1	0.07
2655338	N	309.665	20041104	155657.49	-39.189	177.946	17.9	2.0	0.14
2317385	R	309.687	20041104	162948.10	-38.305	178.287	24.0	3.0	0.22
2610685	T	309.717	20041104	17135.88	-36.183	178.858	33.0	2.7	0.17
2655339	X	309.721	20041104	17180.00					
2610686	N	309.735	20041104	173758.76	-34.244	176.427	366.0	4.0	2.40
2655341	T	309.799	20041104	191047.50	-38.374	176.015	171.0	3.3	0.13
2655342	X	309.807	20041104	19220.00					
2317457	R	309.813	20041104	193058.06	-39.877	176.761	50.6	2.9	0.19
2610688	T	309.877	20041104	210301.85	-36.788	179.956	52.8	3.1	0.07
2610690	T	309.968	20041104	231412.70	-35.104	-179.677	127.3		0.17
2610693	N	309.975	20041104	232327.15	-38.875	178.683	14.1	2.4	0.20
2655343	X	309.995	20041104	23530.00					
2610696	N	310.025	20041105	003606.18	-38.442	177.686	53.9	2.3	0.07
2610698	N	310.147	20041105	033207.08	-39.794	176.916	50.4	2.9	0.11
2610699	N	310.237	20041105	054040.39	-35.185	174.012	419.8	4.4	1.65
2655344	N	310.255	20041105	060711.90	-39.113	177.899	16.8	1.8	0.09
2317710	R	310.264	20041105	062050.44	-38.680	177.531	57.5	3.0	0.22
2317761	R	310.352	20041105	082645.40	-37.446	177.164	160.1	4.0	0.14
2317773	R	310.389	20041105	092004.62	-39.106	177.529	48.8	2.1	0.14
2317778	R	310.4	20041105	093624.40	-37.525	178.897	29.3		0.27
2655346	N	310.4	20041105	093625.79	-37.553	178.839	21.1	2.5	0.58
2610700	X	310.467	20041105	11120.00					
2655347	N	310.477	20041105	112715.37	-38.921	177.500	29.1	1.8	0.37
2655348	X	310.505	20041105	12070.00					
2610702	X	310.547	20041105	13080.00					
2317859	R	310.579	20041105	135320.77	-39.265	177.400	31.1	2.1	0.21
2317869	R	310.599	20041105	142208.73	-37.001	176.948	227.4	3.6	0.20
2652001	X	310.703	20041105	16530.00					
2610704	T	310.704	20041105	165411.10	-37.014	179.953	33.0	2.8	0.14
2610705	T	310.779	20041105	184222.16	-35.050	-178.285	33.0		0.18
2652002	X	310.78	20041105	18430.00					

continued on following page

continued from previous page

CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2610707	T	310.941	20041105	223541.60	-32.262	-172.324	100.0		0.30
2652003	X	310.942	20041105	22360.00					
2318062	R	311.017	20041106	002435.68	-38.613	178.133	5.0	2.3	0.15
2318063	R	311.018	20041106	002547.97	-38.435	178.011	58.5		0.08
2318093	R	311.055	20041106	011905.34	-38.544	177.929	11.5	2.1	0.13
2318104	R	311.087	20041106	020536.40	-39.296	177.562	31.3	2.9	0.10
2610708	T	311.095	20041106	021624.35	-38.374	-178.718	200.0	3.61	0.51
2318147	R	311.184	20041106	042434.04	-37.693	178.686	28.1	3.2	0.35
2318160	R	311.209	20041106	050020.26	-38.634	178.545	66.3		0.11
2610710	X	311.231	20041106	05320.00					
2610712	T	311.253	20041106	060422.17	-31.309	177.508	33.0		0.20
2652004	X	311.253	20041106	06050.00					
2610713	T	311.261	20041106	061532.75	-31.707	-178.687	33.0		0.13
2652005	X	311.261	20041106	06160.00					
2610714	X	311.265	20041106	06220.00					
2610716	X	311.31	20041106	07260.00					
2655349	X	311.328	20041106	07520.00					
2318219	R	311.344	20041106	081459.46	-37.965	177.575	66.2	2.0	0.13
2652006	X	311.351	20041106	08260.00					
2610718	T	311.389	20041106	092032.84	-35.261	178.716	205.9	3.2	0.09
2610720	T	311.473	20041106	112102.03	-36.398	179.877	250.0	3.3	0.30
2318304	R	311.509	20041106	121302.32	-39.367	177.608	28.3	2.3	0.16
2318321	R	311.55	20041106	131118.98	-39.698	177.021	47.7	3.1	0.21
2318330	R	311.572	20041106	134334.28	-39.294	177.547	33.3	3.4	0.24
2493776	R	311.573	20041106	134518.39	-39.263	177.429	29.7	2.0	0.20
2655351	N	311.589	20041106	140842.50	-38.421	176.875	5.0	2.6	0.11
2610721	N	311.642	20041106	152434.58	-39.140	178.099	17.6	1.9	0.13
2318376	R	311.657	20041106	154528.99	-38.979	177.903	27.9	2.7	0.09
2610722	N	311.694	20041106	163958.54	-39.065	178.166	39.2	2.0	0.12
2610724	N	311.783	20041106	184752.75	-39.957	176.585	44.9	2.1	0.19
2318435	R	311.788	20041106	185511.49	-37.992	176.893	12.0	2.3	0.14
2495734	R	311.789	20041106	185531.79	-38.031	176.957	12.0	1.9	0.35
2318437	R	311.795	20041106	190417.51	-38.898	177.898	27.5	2.7	0.18
2610726	T	311.797	20041106	190744.85	-38.250	178.236	0.0	1.2	0.26
2652009	X	311.822	20041106	19430.00					
2610729	T	311.857	20041106	203435.52	-36.580	177.702	135.4	2.7	0.14
2610732	T	311.862	20041106	204043.14	-35.164	177.979	154.0	3.1	0.22
2652011	X	311.862	20041106	20410.00					
2610734	N	311.921	20041106	220652.44	-38.346	178.285	12.0	1.5	0.09
2610736	N	311.924	20041106	221103.86	-38.909	179.483	12.0	2.3	0.14
2655352	N	311.941	20041106	223419.52	-38.905	177.755	41.4	2.1	0.09
2610738	T	311.946	20041106	224133.42	-38.270	176.249	159.6	2.7	0.13
2652012	X	311.946	20041106	22420.00					
2490445	R	312.019	20041107	002705.40	-38.609	178.815	5.0	2.3	0.33

continued on following page

continued from previous page

CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2610740	X	312.035	20041107	00500.00					
2610741	T	312.053	20041107	011547.86	-37.099	179.932	86.7	2.9	0.11
2610743	N	312.076	20041107	014942.69	-37.934	179.000	29.1	2.4	0.09
2318574	R	312.076	20041107	014942.89	-37.886	178.973	29.2		0.08
2318580	R	312.087	20041107	020444.75	-38.796	178.324	26.4	2.3	0.32
2318663	R	312.254	20041107	060513.36	-38.553	178.033	28.2	2.1	0.31
2610744	N	312.294	20041107	070300.69	-39.960	176.678	45.7	2.6	0.14
2318701	R	312.355	20041107	083147.67	-38.652	178.731	33.0		0.10
2610745	N	312.365	20041107	084510.28	-37.394	179.379	15.8	2.8	0.09
2318704	R	312.365	20041107	084510.34	-37.428	179.402	12.0	3.0	0.31
2318724	R	312.424	20041107	101012.47	-39.316	177.755	20.1		0.17
2655353	N	312.457	20041107	105759.79	-38.539	178.058	28.8	1.6	0.16
2318748	R	312.486	20041107	114030.28	-38.745	178.106	29.9	1.9	0.15
2655354	N	312.486	20041107	114030.89	-38.821	177.902	50.7	1.8	0.37
2491352	R	312.503	20041107	120435.42	-38.760	177.318	67.5	2.6	0.13
2318765	R	312.537	20041107	125342.53	-39.192	177.711	24.2	2.4	0.20
2491358	R	312.537	20041107	125353.05	-39.375	178.040	33.0	2.2	0.20
2318767	R	312.541	20041107	125934.92	-39.193	177.711	23.5	2.3	0.20
2655355	X	312.647	20041107	15310.00					
2655356	T	312.812	20041107	192843.41	-37.412	177.119	130.9	2.8	0.14
2610747	N	312.878	20041107	210342.03	-38.822	177.567	51.9	2.5	0.09
2652014	X	312.897	20041107	21310.00					
2610749	N	312.916	20041107	215832.68	-39.262	177.583	5.0	2.3	0.28
2318938	R	312.922	20041107	220701.84	-37.079	178.358	32.5	4.0	0.29
2318971	R	312.994	20041107	235109.73	-38.811	178.194	33.0	3.2	0.27
2610750	T	313.008	20041108	001138.04	-38.211	176.165	147.3	2.7	0.07
2652016	X	313.035	20041108	00500.00					
2610754	N	313.039	20041108	005532.31	-39.255	177.976	25.5	2.6	0.09
2319008	R	313.071	20041108	014251.80	-37.041	177.427	142.3	3.7	0.10
2492779	R	313.124	20041108	025811.71	-38.678	177.070	12.0	2.8	0.21
2319052	R	313.185	20041108	042638.01	-39.849	176.897	62.0	2.1	0.24
2655358	X	313.261	20041108	06160.00					
2655359	X	313.393	20041108	09260.00					
2655360	X	313.428	20041108	10170.00					
2655361	X	313.437	20041108	10290.00					
2610757	T	313.58	20041108	135514.73	-33.338	-175.096	33.0		0.11
2652017	X	313.581	20041108	13560.00					
2655371	T	313.6	20041108	142436.46	-38.687	176.395	52.5	2.1	0.27
2319231	R	313.609	20041108	143643.02	-37.585	176.776	171.7	3.4	0.26
2319232	R	313.612	20041108	144042.13	-37.966	177.573	72.1	2.0	0.17
2319265	R	313.678	20041108	161555.70	-37.108	178.701	12.0	3.4	0.15
2493236	R	313.684	20041108	162419.19	-38.509	178.731	12.0	2.7	0.15
2655372	N	313.766	20041108	182326.41	-39.051	178.106	43.9	2.1	0.17
2610758	N	313.804	20041108	191723.90	-40.710	176.405	24.3	2.8	0.09

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continued from previous page

CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2610760	N	313.828	20041108	195216.23	-37.630	177.909	41.8	2.2	0.13
2610761	X	313.841	20041108	20110.00					
2610763	T	313.905	20041108	214334.78	-31.758	-179.880	391.5		0.14
2652018	X	313.906	20041108	21440.00					
2655373	N	314.128	20041109	030417.67	-38.802	178.064	27.6	1.7	0.23
2655374	X	314.131	20041109	03080.00					
2610764	N	314.145	20041109	032853.44	-39.145	177.633	34.6	2.5	0.16
2610765	T	314.386	20041109	091511.37	-32.633	179.280	33.0		0.10
2491391	R	314.393	20041109	092523.70	-37.602	179.210	33.0	2.8	0.15
2319606	R	314.416	20041109	095943.06	-39.447	177.040	30.4	2.2	0.14
2319703	R	314.63	20041109	150706.69	-39.140	177.467	28.5	2.0	0.07
2610767	N	314.63	20041109	150707.25	-39.103	177.629	32.0	2.3	0.15
2617344	N	314.798	20041109	190910.16	-38.810	177.944	64.2	1.9	0.12
2610768	N	314.799	20041109	191006.60	-37.422	177.860	54.6	2.0	0.09
2610771	X	314.806	20041109	19200.00					
2610772	N	314.823	20041109	194514.18	-38.613	177.953	40.0	2.1	0.11
2319788	R	314.829	20041109	195348.54	-37.744	177.532	49.8	2.3	0.10
2610773	N	314.927	20041109	221416.47	-39.122	177.965	10.1	2.8	0.22
2610775	X	314.933	20041109	22230.00					
2610777	T	314.949	20041109	224607.18	-37.709	176.582	71.6	2.4	0.32
2655375	X	314.997	20041109	23550.00					
2610778	X	315.033	20041110	00480.00					
2610780	N	315.067	20041110	013555.86	-38.501	178.378	5.0	2.0	0.16
2610781	X	315.126	20041110	03020.00					
2610783	T	315.14	20041110	032207.39	-37.724	177.069	93.2	2.3	0.24
2655376	N	315.19	20041110	043308.59	-39.130	177.482	5.0	1.6	0.23
2610786	T	315.212	20041110	050521.71	-36.322	178.763	136.9	3.2	0.13
2655377	X	315.226	20041110	05260.00					
2655378	X	315.267	20041110	06240.00					
2610787	T	315.328	20041110	075241.92	-35.709	-179.601	33.0		0.55
2652024	X	315.328	20041110	07530.00					
2652025	X	315.335	20041110	08030.00					
2610790	T	315.342	20041110	081248.16	-35.445	178.488	249.8	3.0	0.15
2652026	X	315.342	20041110	08130.00					
2320050	R	315.368	20041110	084959.94	-38.864	178.274	33.0		0.40
2655379	N	315.373	20041110	085742.45	-38.223	178.791	11.1	2.2	0.07
2320060	R	315.394	20041110	092727.62	-38.923	178.392	33.0	2.4	0.22
2320069	R	315.413	20041110	095509.32	-38.846	178.286	33.0		0.31
2320080	R	315.437	20041110	102925.03	-39.895	176.885	26.7	2.0	0.08
2610792	X	315.444	20041110	10390.00					
2320087	R	315.457	20041110	105742.08	-37.712	177.045	129.2	3.4	0.15
2610794	N	315.485	20041110	113903.31	-37.209	178.895	17.2	2.6	0.10
2610796	T	315.529	20041110	124128.16	-36.897	179.737	59.1	2.9	0.12
2655381	N	315.545	20041110	130451.87	-37.884	178.674	7.1	1.9	0.09

continued on following page

continued from previous page

CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2655382	N	315.579	20041110	135347.54	-38.290	178.383	7.4	1.8	0.15
2320152	R	315.61	20041110	143819.79	-37.980	178.725	47.1	3.3	0.13
2610797	N	315.621	20041110	145427.20	-38.319	178.954	21.4	2.4	0.12
2610799	T	315.666	20041110	155902.16	-27.510	-179.999	33.0		0.11
2652027	X	315.667	20041110	16000.00					
2320180	R	315.67	20041110	160518.50	-37.694	176.832	74.1	2.4	0.15
2610801	N	315.672	20041110	160739.16	-38.345	178.949	19.4	2.2	0.06
2610803	T	315.694	20041110	163841.43	-36.764	-179.341	33.0	3.5	0.26
2610804	T	315.713	20041110	170725.98	-38.320	179.543	250.0	3.1	0.00
2610806	N	315.852	20041110	202633.14	-38.132	178.694	31.6	2.9	0.22
2618784	N	315.852	20041110	202729.18	-37.926	176.780	156.4	2.1	0.10
2610807	N	315.857	20041110	203342.81	-38.151	178.804	30.6	2.6	0.15
2320274	R	315.877	20041110	210321.72	-39.809	176.922	48.4	2.4	0.18
2610808	N	315.929	20041110	221800.37	-38.222	179.374	200.0	3.3	0.00
2610810	T	316.035	20041111	005004.16	-37.231	-173.453	33.0		0.22
2652029	X	316.035	20041111	00510.00					
2655384	X	316.157	20041111	03460.00					
2655385	X	316.169	20041111	04040.00					
2320429	R	316.234	20041111	053652.49	-38.296	178.937	19.7	3.8	0.16
2320431	R	316.24	20041111	054459.15	-38.306	178.913	16.3	3.3	0.11
2655386	N	316.287	20041111	065341.41	-37.613	178.399	49.6	2.3	0.28
2610811	T	316.339	20041111	080809.74	-34.477	-175.042	592.2		0.19
2652030	X	316.34	20041111	08090.00					
2320492	R	316.364	20041111	084406.91	-38.112	176.894	5.0	1.9	0.15
2320510	R	316.4	20041111	093532.08	-38.826	178.638	33.0		0.18
2320559	R	316.509	20041111	121323.01	-39.331	177.436	40.1		0.03
2610813	N	316.531	20041111	124412.87	-38.279	178.408	10.2	2.4	0.20
2610815	T	316.573	20041111	134500.58	-40.474	176.093	50.3	2.3	0.14
2320588	R	316.58	20041111	135449.08	-39.355	177.192	33.0	2.2	0.22
2652031	X	316.584	20041111	14010.00					
2610818	T	316.595	20041111	141640.30	-34.741	-177.784	134.2		0.17
2610820	T	316.629	20041111	150608.83	-34.109	178.845	119.9		0.24
2610821	N	316.636	20041111	151538.73	-38.175	178.622	10.3	2.3	0.16
2320620	R	316.652	20041111	153836.65	-37.371	177.854	95.6	4.1	0.16
2655387	N	316.667	20041111	160101.88	-38.452	177.735	20.2	1.6	0.37
2320652	R	316.718	20041111	171332.26	-39.586	177.084	30.9	3.6	0.24
2320663	R	316.736	20041111	173919.67	-39.532	177.050	23.4	2.6	0.26
2610822	T	316.768	20041111	182601.79	-40.393	176.262	46.1	2.4	0.02
2652034	X	316.815	20041111	19330.00					
2610827	N	316.827	20041111	195018.54	-38.410	177.755	58.9	2.2	0.21
2610828	T	316.88	20041111	210642.82	-37.968	176.449	145.9	2.6	0.23
2610831	T	316.998	20041111	235641.16	-38.830	177.317	58.6	2.2	0.17
2655388	N	317.023	20041112	003333.88	-38.559	177.034	56.7	1.7	0.03
2610832	T	317.039	20041112	005554.04	-32.090	178.042	33.0		0.23

continued on following page

continued from previous page

CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2652036	X	317.039	20041112	00560.00					
2320821	R	317.045	20041112	010530.51	-38.634	177.728	51.9	2.2	0.27
2652037	X	317.047	20041112	01070.00					
2610836	T	317.065	20041112	013256.48	-35.613	179.522	168.1	3.8	0.23
2652038	X	317.065	20041112	01330.00					
2610838	X	317.147	20041112	03320.00					
2610839	T	317.152	20041112	033910.14	-37.084	177.472	155.2	2.7	0.10
2652040	X	317.183	20041112	04230.00					
2320939	R	317.303	20041112	071646.54	-38.362	177.619	55.3	2.9	0.22
2320942	R	317.313	20041112	073033.85	-38.633	177.897	33.0	3.3	0.14
2610843	T	317.323	20041112	074440.29	-39.767	-178.694	5.0	3.5	0.26
2610844	X	317.376	20041112	09020.00					
2610846	X	317.383	20041112	09110.00					
2610848	T	317.397	20041112	093220.22	-30.683	178.127	273.5		0.21
2652042	X	317.398	20041112	09330.00					
2320988	R	317.415	20041112	095800.91	-39.854	177.348	33.0	1.9	0.06
2610849	X	317.422	20041112	10080.00					
2321002	R	317.444	20041112	103939.13	-39.403	177.602	12.0	2.9	0.15
2610850	T	317.472	20041112	111911.39	-30.664	178.721	33.0		0.05
2321014	R	317.478	20041112	112811.62	-39.099	177.615	33.0	2.0	0.17
2652043	X	317.483	20041112	11360.00					
2655389	N	317.488	20041112	114251.14	-39.181	177.958	20.0	2.3	0.28
2321048	R	317.538	20041112	125523.13	-39.257	177.571	28.9	2.3	0.21
2655390	X	317.568	20041112	13380.00					
2321064	R	317.578	20041112	135220.08	-39.292	177.671	22.4	2.2	0.14
2321104	R	317.665	20041112	155754.76	-38.988	178.667	33.0		0.13
2610853	N	317.665	20041112	155755.05	-38.900	178.544	5.0	1.9	0.12
2321108	R	317.67	20041112	160428.89	-39.503	177.699	17.3	2.4	0.12
2495790	R	317.67	20041112	160507.79	-39.417	177.594	12.0	2.6	0.23
2655391	N	317.679	20041112	161806.63	-38.331	178.527	33.0	1.9	0.44
2610854	N	317.777	20041112	183858.40	-37.992	178.426	6.6	2.8	0.13
2610855	N	317.799	20041112	191051.34	-39.127	177.725	18.6	2.1	0.17
2652044	X	317.815	20041112	19330.00					
2321194	R	317.86	20041112	203832.35	-38.963	177.901	29.0	2.6	0.13
2321198	R	317.867	20041112	204756.55	-39.923	177.066	33.0	2.8	0.27
2610858	T	317.88	20041112	210700.43	-30.676	-179.745	33.0		0.08
2610860	N	317.898	20041112	213334.60	-39.924	177.074	36.0	2.8	0.04
2496232	R	317.908	20041112	214654.36	-39.929	177.054	33.0	2.2	0.08
2321217	R	317.908	20041112	214656.34	-39.931	177.085	33.0	2.7	0.28
2655392	N	317.926	20041112	221358.13	-38.493	177.487	53.7	1.8	0.20
2321267	R	318.034	20041113	004918.60	-38.509	178.146	29.7	2.9	0.23
2321314	R	318.137	20041113	031715.89	-39.173	177.618	15.6	2.4	0.02
2610861	X	318.151	20041113	03380.00					
2610862	T	318.157	20041113	034523.25	-37.780	177.306	106.6	2.7	0.10

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continued from previous page

CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2610863	T	318.185	20041113	042653.06	-37.382	176.582	213.7	3.1	0.20
2321380	R	318.301	20041113	071322.39	-38.526	177.731	50.4	3.3	0.21
2610864	X	318.376	20041113	09020.00					
2321425	R	318.403	20041113	094101.13	-39.647	176.875	47.6	2.5	0.11
2321449	R	318.457	20041113	105838.14	-38.571	177.869	28.8	2.3	0.39
2610866	N	318.488	20041113	114250.13	-38.433	178.332	21.5	1.9	0.21
2321477	R	318.517	20041113	122509.64	-38.448	178.817	12.0	2.3	0.12
2321493	R	318.556	20041113	132004.73	-39.052	178.191	33.0	2.3	0.21
2610868	N	318.756	20041113	180911.91	-38.463	178.032	27.7	2.0	0.18
2610870	T	318.85	20041113	202431.34	-27.891	-168.613	4.8		0.40
2652048	X	318.853	20041113	20280.00					
2321628	R	318.879	20041113	210502.59	-38.490	177.953	32.1	2.2	0.20
2652049	X	318.944	20041113	22390.00					
2496187	R	319.018	20041114	002616.90	-37.605	177.667	108.8	3.0	0.05
2655393	X	319.099	20041114	02230.00					
2610873	N	319.188	20041114	043049.37	-38.249	177.679	38.8	2.4	0.31
2655394	N	319.234	20041114	053712.19	-38.940	177.744	41.4	2.3	0.11
2321811	R	319.28	20041114	064322.75	-38.409	179.228	5.0	2.8	0.31
2610874	N	319.28	20041114	064322.97	-37.693	179.198	14.4	2.8	0.10
2652050	X	319.284	20041114	06490.00					
2610875	T	319.286	20041114	065116.73	-38.368	176.550	84.8		0.48
2321856	R	319.38	20041114	090642.98	-38.330	177.886	58.9		0.21
2321948	R	319.552	20041114	131440.62	-37.657	179.317	17.2	3.5	0.12
2655395	N	319.58	20041114	135433.08	-37.977	178.153	62.7	2.9	0.15
2610877	N	319.883	20041114	211049.08	-38.429	178.783	12.0	2.4	0.16
2610878	T	319.921	20041114	220619.58	-37.379	176.551	5.0	3.0	0.48
2655396	N	319.961	20041114	230333.59	-39.033	177.659	35.8	2.2	0.09
2322249	R	320.144	20041115	032745.53	-37.682	179.300	16.8	3.9	0.12
2610880	N	320.176	20041115	041251.94	-37.705	179.286	12.0	2.8	0.15
2655397	X	320.183	20041115	04230.00					
2655398	X	320.202	20041115	04510.00					
2610882	T	320.613	20041115	144310.62	-37.477	-179.956	33.0	2.8	0.16
2610883	N	320.683	20041115	162345.96	-38.348	178.947	11.6	2.7	0.15
2655399	N	320.713	20041115	170657.70	-38.960	178.367	21.8	2.2	0.04
2610885	T	320.801	20041115	191359.77	-38.073	178.257	33.0		0.00
2610886	T	320.987	20041115	234034.78	-36.765	178.430	5.0	3.2	0.13
2610888	T	320.989	20041115	234349.93	-28.154	-178.058	515.7		0.11
2652053	X	320.99	20041115	23450.00					
2610889	N	321.026	20041116	003722.90	-37.947	179.240	12.0	2.7	0.25
2322785	R	321.166	20041116	035904.42	-39.925	176.964	50.6	3.7	0.14
2322818	R	321.239	20041116	054343.29	-38.330	178.953	12.0	3.1	0.14
2322865	R	321.332	20041116	075817.47	-38.067	176.757	5.0	2.3	0.33
2322888	R	321.381	20041116	090831.37	-39.440	177.662	12.0		0.29
2322938	R	321.497	20041116	115551.65	-37.906	176.854	86.9	2.8	0.28

continued on following page

continued from previous page

CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2322966	R	321.562	20041116	132940.38	-39.291	177.519	38.6	2.9	0.13
2323043	R	321.717	20041116	171238.80	-38.989	178.501	33.0	3.2	0.24
2323151	R	321.943	20041116	223712.58	-37.674	179.292	17.6	3.3	0.17
2610891	T	321.969	20041116	231558.30	-34.432	175.824	200.0		0.07
2652054	X	321.969	20041116	23160.00					
2610893	T	321.994	20041116	235128.59	-37.221	177.333	144.4	2.9	0.06
2610895	T	322.021	20041117	003013.14	-37.721	178.308	0.0	2.2	3.00
2323246	R	322.13	20041117	030728.06	-39.371	177.699	30.2	2.4	0.12
2652056	X	322.212	20041117	05050.00					
2610896	T	322.213	20041117	050615.18	-36.594	177.869	33.0	2.4	0.64
2652057	X	322.216	20041117	05110.00					
2323347	R	322.335	20041117	080210.71	-37.531	177.163	123.6	2.5	0.06
2323352	R	322.348	20041117	082056.26	-39.787	176.779	50.7	2.3	0.11
2610898	T	322.363	20041117	084322.36	-35.863	178.107	158.0	3.2	0.12
2610900	N	322.486	20041117	113925.70	-39.098	177.792	25.6	2.2	0.17
2610901	T	322.5	20041117	115941.33	-24.880	-176.257	369.7		1.34
2652059	X	322.501	20041117	12020.00					
2323448	R	322.576	20041117	135008.94	-37.981	179.191	23.3		0.16
2652060	X	322.65	20041117	15360.00					
2610902	T	322.651	20041117	153737.13	-36.739	177.515	194.4	3.1	0.20
2323536	R	322.755	20041117	180747.36	-39.442	177.674	27.9	2.6	0.15
2610903	T	322.766	20041117	182227.92	-40.785	175.517	200.0	3.1	3.13
2652061	X	322.817	20041117	19360.00					
2610905	T	322.818	20041117	193721.28	-34.667	-179.519	226.8		0.12
2652062	X	322.843	20041117	20140.00					
2610909	N	322.864	20041117	204354.32	-38.715	178.481	5.0	2.4	0.13
2610910	N	322.928	20041117	221608.45	-39.052	177.735	28.5	2.1	0.02
2323635	R	322.934	20041117	222537.15	-38.707	177.446	53.8	2.5	0.09
2610912	T	323.002	20041118	000314.45	-40.756	175.590	200.0	3.4	3.65
2323681	R	323.014	20041118	002033.88	-37.088	177.192	158.5	3.0	0.08
2610913	T	323.014	20041118	002034.30	-37.089	177.312	162.1	3.2	0.17
2652063	X	323.015	20041118	00210.00					
2610914	T	323.049	20041118	010958.34	-38.791	178.153	138.6		0.77
2610915	T	323.08	20041118	015456.85	-36.184	178.511	115.7	3.1	0.33
2652065	X	323.087	20041118	02060.00					
2610917	T	323.088	20041118	020724.57	-36.732	179.113	33.0	2.3	0.20
2655400	N	323.195	20041118	044100.60	-38.598	178.675	13.5	2.3	0.28
2323784	R	323.208	20041118	045948.41	-39.206	177.693	28.0	3.0	0.13
2652066	X	323.265	20041118	06210.00					
2323830	R	323.297	20041118	070805.67	-39.188	177.688	27.5	2.9	0.05
2655401	X	323.373	20041118	08570.00					
2610919	T	323.386	20041118	091508.47	-35.420	179.856	186.6		0.13
2323868	R	323.389	20041118	091934.13	-39.863	176.886	39.8	1.9	0.10
2610921	T	323.397	20041118	093127.00	-40.937	176.175	33.0	2.0	0.90

continued on following page

continued from previous page

CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2610923	T	323.407	20041118	094625.17	-33.094	-176.989	100.7		0.09
2323901	R	323.468	20041118	111337.44	-38.021	176.755	5.0	1.8	0.24
2497493	R	323.518	20041118	122606.40	-37.612	179.317	12.0	2.8	0.13
2323929	R	323.526	20041118	123748.99	-38.018	178.544	22.2	2.5	0.08
2610924	T	323.575	20041118	134808.48	-34.910	168.090	462.2		0.97
2652069	X	323.577	20041118	13510.00					
2610926	T	323.587	20041118	140551.21	-30.775	178.608	33.0		0.11
2652070	X	323.588	20041118	14070.00					
2500091	R	323.611	20041118	143932.48	-39.263	177.698	29.3	2.2	0.05
2323965	R	323.611	20041118	143950.93	-39.251	177.670	29.3	2.9	0.14
2610927	T	323.611	20041118	144005.21	-31.012	-177.684	248.5		0.07
2652071	X	323.613	20041118	14420.00					
2610930	T	323.639	20041118	151952.64	-35.652	178.525	159.3	3.3	0.30
2652072	X	323.64	20041118	15210.00					
2610931	T	323.664	20041118	155533.25	-35.583	178.970	150.0	3.1	0.08
2652073	X	323.664	20041118	15560.00					
2324010	R	323.727	20041118	172734.55	-37.590	179.208	33.0	2.7	0.13
2324049	R	323.817	20041118	193655.33	-38.951	177.697	26.8	3.1	0.21
2610933	N	323.82	20041118	194052.50	-37.855	178.889	28.0	2.4	0.06
2324080	R	323.881	20041118	210806.63	-37.776	177.210	106.4	3.9	0.15
2652074	X	323.91	20041118	21500.00					
2655402	X	323.938	20041118	22300.00					
2610936	N	323.941	20041118	223441.88	-36.925	179.466	12.4	2.7	0.07
2324133	R	323.985	20041118	233858.06	-38.681	177.456	45.8	1.9	0.10
2610937	N	323.993	20041118	234927.15	-39.445	177.344	44.7	2.3	0.17
2324140	R	323.999	20041118	235811.99	-37.889	177.818	78.9	2.4	0.21
2610938	N	324.022	20041119	003154.47	-37.850	178.853	24.1	2.2	0.09
2610940	X	324.025	20041119	00360.00					
2610941	T	324.079	20041119	015350.72	-38.473	176.515	120.1	2.7	0.78
2652077	X	324.108	20041119	02360.00					
2610942	T	324.109	20041119	023737.70	-38.721	176.492	108.7	2.8	0.30
2324195	R	324.127	20041119	030249.86	-39.682	177.194	12.0	2.9	0.18
2610944	T	324.209	20041119	050031.95	-36.907	177.301	189.5	3.2	0.13
2652078	X	324.209	20041119	05010.00					
2652079	X	324.292	20041119	07010.00					
2610948	N	324.304	20041119	071706.14	-37.817	177.837	5.0	1.7	0.06
2324266	R	324.312	20041119	072846.33	-39.608	177.051	12.0	3.1	0.10
2610950	X	324.372	20041119	08560.00					
2610951	X	324.392	20041119	09240.00					
2610952	X	324.448	20041119	10450.00					
2610953	T	324.46	20041119	110149.83	-40.389	176.287	46.4	1.7	0.07
2610956	N	324.482	20041119	113327.28	-38.859	177.662	37.4	2.0	0.12
2652080	X	324.622	20041119	14550.00					
2610957	T	324.623	20041119	145633.49	-37.350	177.394	136.6	2.1	0.07

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continued from previous page

CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2610958	T	324.679	20041119	161746.72	-35.296	177.525	33.0	3.5	0.36
2610959	X	324.722	20041119	17200.00					
2324467	R	324.772	20041119	183146.86	-38.425	179.140	20.8		0.12
2610961	N	324.772	20041119	183147.03	-38.400	179.141	19.5	2.9	0.18
2324509	R	324.854	20041119	203026.14	-38.491	178.078	27.7	2.5	0.25
2610962	N	324.857	20041119	203436.06	-37.491	179.172	12.0	2.8	0.21
2610963	T	324.938	20041119	223111.39	-37.295	177.554	117.4	2.7	0.23
2652083	X	325.113	20041120	02420.00					
2610966	T	325.226	20041120	052509.00	-32.173	179.025	330.7		0.07
2652084	X	325.226	20041120	05260.00					
2652085	X	325.299	20041120	07110.00					
2610970	N	325.332	20041120	075814.60	-38.628	177.877	57.4	2.2	0.20
2610971	X	325.341	20041120	08110.00					
2610973	X	325.345	20041120	08170.00					
2610975	T	325.353	20041120	082809.94	-28.208	-177.866	474.3		0.06
2652087	X	325.354	20041120	08300.00					
2652088	X	325.371	20041120	08540.00					
2652089	X	325.428	20041120	10160.00					
2324936	R	325.561	20041120	132738.63	-37.029	176.764	217.4	3.4	0.13
2610978	N	325.844	20041120	201455.59	-38.693	177.994	28.9	2.4	0.52
2652090	X	325.894	20041120	21280.00					
2610980	T	325.895	20041120	212922.55	-37.965	176.103	169.4	2.3	0.08
2655404	T	325.913	20041120	215441.96	-37.219	177.394	129.8	2.4	0.09
2652091	X	326.024	20041121	00350.00					
2652092	X	326.035	20041121	00500.00					
2325302	R	326.143	20041121	032616.38	-39.314	176.895	12.0	2.5	0.17
2610985	X	326.15	20041121	03360.00					
2325316	R	326.163	20041121	035509.84	-39.979	176.780	43.5	2.5	0.33
2652093	X	326.271	20041121	06300.00					
2610987	T	326.472	20041121	111908.93	-40.771	176.006	27.3	2.5	0.04
2610988	T	326.488	20041121	114252.83	-35.200	179.945	151.2		0.28
2325518	R	326.582	20041121	135745.13	-38.564	177.581	46.0	2.0	0.08
2652095	X	326.726	20041121	17250.00					
2652096	X	326.76	20041121	18150.00					
2325636	R	326.866	20041121	204640.62	-39.988	176.863	35.9	2.4	0.20
2652097	X	326.877	20041121	21030.00					
2610994	X	326.905	20041121	21430.00					
2652098	X	326.913	20041121	21540.00					
2610997	X	326.926	20041121	22130.00					
2610998	X	326.947	20041121	22440.00					
2610999	T	326.961	20041121	230310.31	-38.150	-177.226	37.1		16.08
2611001	X	326.977	20041121	23270.00					
2611002	X	327.019	20041122	00280.00					
2325734	R	327.098	20041122	022038.54	-37.107	177.057	219.1	3.6	0.32

continued on following page

continued from previous page

CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2652099	X	327.183	20041122	04230.00					
2611005	T	327.256	20041122	060819.17	-31.443	177.039	336.8		0.41
2652100	X	327.256	20041122	06090.00					
2325830	R	327.34	20041122	080859.96	-37.574	179.384	12.0	3.1	0.13
2611006	X	327.342	20041122	08130.00					
2611008	T	327.386	20041122	091621.47	-33.860	-177.582	33.0		0.40
2511565	R	327.392	20041122	092431.95	-38.703	177.905	33.0		0.29
2325868	R	327.419	20041122	100348.52	-39.750	176.924	45.1	2.6	0.32
2652102	X	327.465	20041122	11090.00					
2652103	X	327.467	20041122	11130.00					
2611014	T	327.522	20041122	123116.67	-37.324	177.614	1.4	2.0	0.39
2655405	X	327.654	20041122	15420.00					
2611016	N	327.668	20041122	160232.36	-37.833	179.325	20.6	2.3	0.25
2326010	R	327.744	20041122	175108.58	-38.677	178.487	20.4	2.5	0.17
2611017	X	327.772	20041122	18310.00					
2611019	X	327.8	20041122	19120.00					
2652104	X	327.82	20041122	19410.00					
2611022	N	327.847	20041122	201915.65	-38.054	177.275	43.0	2.5	0.13
2652105	X	327.849	20041122	20220.00					
2611025	X	327.878	20041122	21050.00					
2611026	X	327.907	20041122	21460.00					
2611028	T	327.924	20041122	220953.01	-30.868	178.994	307.3		0.11
2652107	X	327.924	20041122	22110.00					
2652108	X	328.025	20041123	00360.00					
2611032	X	328.203	20041123	04530.00					
2611033	T	328.329	20041123	075338.72	-38.275	176.323	102.8	2.6	0.41
2611034	N	328.369	20041123	085154.89	-37.418	178.394	64.3	2.7	0.09
2326326	R	328.481	20041123	113259.78	-37.358	177.096	153.0	3.2	0.17
2326335	R	328.502	20041123	120326.52	-38.346	178.953	12.0	3.8	0.18
2508745	R	328.504	20041123	120509.37	-38.362	178.882	12.0	2.3	0.28
2326361	R	328.542	20041123	130032.20	-38.333	178.954	12.0	4.0	0.09
2326404	R	328.611	20041123	143911.85	-38.344	178.939	12.0	3.0	0.17
2611036	N	328.732	20041123	173407.82	-38.314	178.981	21.6	2.6	0.15
2611038	X	328.741	20041123	17470.00					
2611039	N	328.807	20041123	192228.62	-38.319	179.023	21.1	2.5	0.22
2652109	X	328.813	20041123	19310.00					
2326560	R	328.885	20041123	211453.23	-38.321	178.943	12.0	3.0	0.17
2611042	T	328.897	20041123	213151.55	-30.336	178.676	286.0		0.13
2652110	X	328.897	20041123	21320.00					
2326607	R	328.979	20041123	232929.91	-39.156	177.572	30.4		0.07
2326616	R	328.998	20041123	235715.28	-39.311	178.871	33.0	3.0	0.13
2611045	N	328.998	20041123	235715.68	-39.174	178.751	5.0	2.6	0.27
2326619	R	329.005	20041124	000633.62	-37.057	177.475	194.8		0.11
2611047	X	329.075	20041124	01480.00					

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CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2611048	X	329.078	20041124	01530.00					
2611050	X	329.108	20041124	02360.00					
2655406	X	329.185	20041124	04260.00					
2655407	X	329.207	20041124	04580.00					
2655408	X	329.217	20041124	05120.00					
2655409	N	329.258	20041124	061134.07	-38.942	177.909	24.7	2.3	0.13
2611051	N	329.276	20041124	063735.84	-39.556	177.549	0.0	2.3	0.80
2611052	T	329.335	20041124	080221.55	-35.693	179.493	29.8	3.1	0.33
2326809	R	329.396	20041124	093011.74	-39.226	177.774	24.7		0.21
2326824	R	329.435	20041124	102626.29	-37.208	178.051	22.9	2.4	0.04
2611054	N	329.435	20041124	102626.59	-37.303	178.182	42.1	2.3	0.13
2611056	T	329.472	20041124	112019.47	-36.793	177.390	156.8	2.8	0.13
2326840	R	329.472	20041124	112020.56	-37.061	177.424	182.6	2.8	0.17
2652111	X	329.473	20041124	11210.00					
2655410	T	329.487	20041124	114152.70	-38.135	176.101	132.8	2.7	0.05
2655412	X	329.683	20041124	16230.00					
2326948	R	329.742	20041124	174900.25	-39.315	176.814	29.9	2.4	0.22
2611057	T	329.747	20041124	175547.11	-38.552	176.359	91.7	2.7	0.08
2611059	N	329.895	20041124	212856.82	-37.780	179.061	26.8	2.5	0.17
2611062	T	330.01	20041125	001400.84	-31.027	-174.853	471.0		0.07
2652112	X	330.01	20041125	00150.00					
2655413	X	330.021	20041125	00300.00					
2611063	N	330.118	20041125	024915.85	-38.494	178.317	23.5	2.1	0.11
2327139	R	330.139	20041125	032020.02	-38.080	177.668	72.6	2.8	0.05
2611064	X	330.198	20041125	04450.00					
2611065	T	330.28	20041125	064326.65	-36.555	177.074	247.6	3.5	0.18
2511540	R	330.307	20041125	072206.39	-38.818	178.697	5.0	2.8	0.24
2327269	R	330.367	20041125	084846.56	-39.698	176.779	49.3	2.5	0.29
2327280	R	330.389	20041125	092038.75	-39.796	177.236	39.6	2.2	0.14
2327301	R	330.428	20041125	101629.56	-39.391	177.707	32.3		0.22
2611066	X	330.504	20041125	12060.00					
2327374	R	330.544	20041125	130243.52	-37.321	177.608	58.1	3.4	0.13
2655414	X	330.598	20041125	14210.00					
2655415	X	330.636	20041125	15160.00					
2327437	R	330.648	20041125	153244.99	-39.222	177.724	27.3		0.08
2652114	X	330.793	20041125	19020.00					
2652115	X	330.844	20041125	20160.00					
2611071	X	330.891	20041125	21230.00					
2652116	X	330.903	20041125	21410.00					
2611074	N	330.978	20041125	232808.21	-38.024	178.938	20.5	3.1	0.21
2652117	X	331.146	20041126	03300.00					
2511961	R	331.215	20041126	050942.43	-38.150	177.909	70.2	3.2	0.13
2327726	R	331.22	20041126	051626.54	-37.390	177.410	129.7	4.0	0.18
2327768	R	331.282	20041126	064521.61	-39.239	177.575	29.7	2.7	0.21

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CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2611078	X	331.34	20041126	08090.00					
2611080	T	331.557	20041126	132229.56	-39.092	176.332	55.0	2.3	0.10
2327952	R	331.574	20041126	134641.54	-38.057	177.574	54.6	3.6	0.22
2611082	X	331.65	20041126	15360.00					
2655416	T	331.766	20041126	182338.13	-36.893	176.056	270.5	3.2	0.11
2328061	R	331.794	20041126	190331.15	-39.451	177.172	17.0	2.7	0.13
2611084	N	331.809	20041126	192431.76	-38.221	177.436	52.5	2.0	0.18
2611085	X	331.955	20041126	22550.00					
2611086	N	331.963	20041126	230712.48	-38.494	178.657	25.8	2.2	0.06
2611087	X	332.016	20041127	00230.00					
2611089	X	332.022	20041127	00310.00					
2655417	X	332.106	20041127	02330.00					
2611090	X	332.175	20041127	04120.00					
2611092	X	332.183	20041127	04230.00					
2328442	R	332.413	20041127	095446.18	-38.552	177.690	45.4	2.3	0.28
2611093	N	332.415	20041127	095654.27	-39.186	177.706	32.9	2.1	0.15
2328443	R	332.415	20041127	095654.60	-39.156	177.674	32.0	2.1	0.14
2611094	T	332.419	20041127	100335.75	-36.153	179.155	3.3	2.9	0.20
2328467	R	332.457	20041127	105813.44	-38.299	178.789	31.2		0.06
2655419	X	332.469	20041127	11160.00					
2655420	N	332.592	20041127	141234.76	-38.300	178.913	25.9	2.2	0.27
2652118	X	332.623	20041127	14570.00					
2328568	R	332.656	20041127	154434.22	-37.240	176.909	231.9	2.9	0.19
2611096	T	332.656	20041127	154435.00	-37.210	177.029	231.7	3.2	0.14
2328574	R	332.666	20041127	155826.22	-39.198	177.561	30.2		0.13
2655421	X	332.678	20041127	16160.00					
2328604	R	332.716	20041127	171020.90	-37.521	178.460	47.2	3.6	0.14
2611098	N	332.786	20041127	185209.33	-38.890	178.077	23.6	2.2	0.13
2611099	X	332.954	20041127	22540.00					
2611100	T	333.05	20041128	011238.93	-29.593	-179.564	33.0		0.52
2652120	X	333.051	20041128	01140.00					
2611102	N	333.085	20041128	020204.02	-39.295	177.495	40.3	2.6	0.14
2652121	X	333.11	20041128	02390.00					
2652122	X	333.139	20041128	03200.00					
2611106	T	333.293	20041128	070214.57	-40.073	176.771	49.1	2.9	0.11
2655422	X	333.414	20041128	09560.00					
2328966	R	333.42	20041128	100454.88	-38.274	178.364	10.0		0.05
2329019	R	333.536	20041128	125151.16	-39.119	177.609	29.4		0.22
2655423	X	333.761	20041128	18160.00					
2611107	T	333.869	20041128	205136.08	-36.783	177.361	21.0	3.7	0.14
2652123	X	333.869	20041128	20520.00					
2611108	N	333.926	20041128	221340.37	-38.785	176.937	5.0	2.3	0.25
2611109	X	334.021	20041129	00300.00					
2655424	X	334.133	20041129	03110.00					

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CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2611110	X	334.142	20041129	03250.00					
2652125	X	334.15	20041129	03360.00					
2611114	N	334.163	20041129	035513.86	-38.676	178.538	21.0	2.4	0.24
2652126	X	334.217	20041129	05130.00					
2611115	T	334.218	20041129	051404.83	-36.788	177.535	162.9	3.4	0.12
2655426	X	334.322	20041129	07440.00					
2655427	X	334.328	20041129	07520.00					
2611117	X	334.357	20041129	08340.00					
2611119	T	334.641	20041129	152325.17	-37.220	177.203	12.0	2.2	0.34
2611120	T	334.735	20041129	173744.94	-40.009	176.298	29.8	2.5	0.28
2611121	T	334.861	20041129	204030.16	-36.960	177.315	182.8	3.6	0.15
2652128	X	334.862	20041129	20410.00					
2611123	X	334.939	20041129	22320.00					
2655428	X	334.942	20041129	22360.00					
2329800	R	334.995	20041129	235217.82	-39.152	177.639	38.6		0.06
2655429	N	335.07	20041130	014034.15	-38.667	178.652	17.4	2.2	0.25
2611124	N	335.092	20041130	021226.48	-38.660	177.431	4.4	1.8	0.11
2611125	N	335.112	20041130	024124.77	-38.334	178.063	30.0	2.1	0.12
2611126	N	335.121	20041130	025426.79	-38.307	178.430	7.2	2.1	0.11
2611128	T	335.147	20041130	033148.99	-33.115	-178.895	33.0		0.11
2652129	X	335.147	20041130	03320.00					
2611129	X	335.257	20041130	06100.00					
2611131	X	335.3	20041130	07120.00					
2652130	X	335.3	20041130	07120.00					
2611132	N	335.587	20041130	140545.39	-38.480	177.882	60.3	1.9	0.07
2611133	X	335.635	20041130	15150.00					
2652132	X	335.65	20041130	15360.00					
2652133	X	335.729	20041130	17300.00					
2652134	X	335.775	20041130	18360.00					
2652135	X	335.92	20041130	22050.00					
2655431	N	335.94	20041130	223345.17	-38.327	178.270	5.0	2.2	0.28
2652136	X	336.113	20041201	02420.00					
2611141	N	336.159	20041201	034839.85	-38.034	178.314	43.2	2.1	0.50
2611142	N	336.175	20041201	041145.06	-38.405	178.216	8.5	2.0	0.14
2655432	X	336.233	20041201	05350.00					
2330500	R	336.244	20041201	055052.64	-38.169	178.718	30.2		0.33
2330539	R	336.305	20041201	071855.06	-39.071	177.621	35.2	3.5	0.20
2655433	N	336.313	20041201	073042.53	-39.075	177.597	32.7	2.1	0.16
2655434	X	336.345	20041201	08170.00					
2330642	R	336.476	20041201	112541.06	-39.086	177.504	30.7	2.1	0.01
2611144	T	336.491	20041201	114626.27	-37.206	176.629	253.7	3.3	0.07
2611146	T	336.579	20041201	135403.58	-39.991	176.430	33.0	1.9	0.08
2514519	R	336.591	20041201	141029.71	-38.299	178.248	12.0	2.9	0.12
2514523	R	336.592	20041201	141150.28	-38.296	178.245	12.0		0.20

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CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2330701	R	336.593	20041201	141430.35	-38.323	178.260	12.0	2.3	0.28
2330704	R	336.599	20041201	142150.47	-38.289	178.235	12.0	2.6	0.20
2611147	T	336.637	20041201	151655.38	-36.095	179.618	216.3	2.8	0.54
2652138	X	336.637	20041201	15170.00					
2330747	R	336.683	20041201	162412.41	-38.970	177.204	33.0	3.0	0.33
2330773	R	336.738	20041201	174219.89	-38.136	178.950	31.1	3.0	0.14
2652139	X	336.745	20041201	17530.00					
2611150	N	336.752	20041201	180327.67	-39.119	177.598	32.3	2.2	0.24
2652140	X	336.753	20041201	18040.00					
2611153	T	336.775	20041201	183638.53	-36.546	177.685	5.0	3.1	0.85
2611154	T	336.784	20041201	184827.20	-36.543	177.276	5.0		0.34
2611156	T	336.826	20041201	194845.70	-38.401	175.998	185.0	2.9	0.19
2330845	R	336.888	20041201	211807.68	-39.055	177.521	30.1	2.6	0.06
2655435	X	336.901	20041201	21380.00					
2611157	T	336.923	20041201	220836.43	-30.308	177.414	33.0		0.33
2652145	X	336.923	20041201	22090.00					
2655436	X	336.962	20041201	23050.00					
2655437	X	336.966	20041201	23110.00					
2330967	R	337.081	20041202	015609.05	-38.261	178.272	20.9	2.5	0.14
2611158	N	337.082	20041202	015826.94	-38.388	178.317	3.4	2.1	0.12
2611160	N	337.098	20041202	022111.80	-38.353	178.294	6.6	2.1	0.10
2652146	X	337.153	20041202	03410.00					
2331024	R	337.18	20041202	041858.87	-39.077	177.636	36.0	2.9	0.17
2331063	R	337.261	20041202	061546.43	-39.077	177.502	30.0	2.4	0.09
2652147	X	337.275	20041202	06360.00					
2331073	R	337.278	20041202	064023.81	-38.652	178.151	28.2	2.5	0.12
2331390	R	337.56	20041202	132629.23	-39.339	177.370	40.2	2.2	0.14
2611166	T	337.628	20041202	150358.64	-34.646	179.719	282.1		0.08
2652148	X	337.628	20041202	15040.00					
2652149	X	337.724	20041202	17230.00					
2331538	R	337.85	20041202	202435.16	-37.636	177.268	116.5	2.5	0.11
2652150	X	337.949	20041202	22470.00					
2611171	N	337.977	20041202	232724.18	-37.607	178.378	47.6	2.4	0.12
2611172	T	338.038	20041203	005450.09	-35.376	178.798	239.3	3.3	0.37
2652151	X	338.038	20041203	00550.00					
2655438	X	338.049	20041203	01100.00					
2331706	R	338.122	20041203	025556.07	-38.307	177.779	51.7		0.20
2611174	X	338.171	20041203	04060.00					
2331765	R	338.214	20041203	050832.62	-37.436	176.756	184.3	3.2	0.11
2331863	R	338.406	20041203	094359.13	-39.489	177.629	28.0	2.5	0.27
2611175	N	338.406	20041203	094359.37	-39.471	177.635	28.2	2.3	0.17
2515836	R	338.461	20041203	110406.23	-37.549	177.163	130.6	2.6	0.06
2611177	T	338.549	20041203	130958.40	-40.108	176.507	43.7	2.4	0.14
2611179	T	338.608	20041203	143453.55	-38.284	176.493	87.7	2.4	0.10

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CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2611180	T	338.698	20041203	164430.13	-38.224	175.287	258.0	3.3	0.25
2652153	X	338.814	20041203	19320.00					
2611182	X	338.858	20041203	20360.00					
2611183	X	338.9	20041203	21360.00					
2652154	X	338.935	20041203	22260.00					
2332177	R	338.985	20041203	233836.11	-39.420	177.708	33.0		0.11

Appendix B

2004 Gisborne relocated hypocentres

Table B.1: **Relocated earthquake hypocentres** from the 2004 Gisborne slow slip event. CUSP ID is the unique event identifier and JDay is the Julian day of year.

CUSP ID	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)
2308655	290.28610	20041016	065159.35	-38.304	177.681	54.88	2.2
2308752	290.52488	20041016	123549.41	-39.532	177.668	19.20	2.3
2308773	290.59082	20041016	141046.64	-38.907	177.777	10.83	2.6
2308793	290.63170	20041016	150939.26	-39.084	177.815	15.09	2.1
2308835	290.73797	20041016	174240.63	-37.792	177.109	99.39	2.7
2308971	291.04899	20041017	011032.45	-37.953	178.036	63.15	1.0
2308989	291.10181	20041017	022636.09	-37.788	177.594	52.25	2.4
2309009	291.14853	20041017	033352.83	-38.062	178.929	20.75	2.9
2309101	291.36820	20041017	085012.68	-37.638	178.339	34.22	3.0
2309601	292.60879	20041018	143639.31	-37.992	178.262	30.39	3.8
2596812	293.18336	20041019	042402.30	-37.878	177.019	169.23	3.0
2596813	293.25260	20041019	060344.76	-39.941	176.694	41.57	2.8
2309988	293.44272	20041019	103731.43	-39.713	176.926	52.31	3.3
2310067	293.60814	20041019	143542.90	-38.623	177.064	60.12	2.0
2310137	293.77692	20041019	183845.69	-38.934	178.082	27.59	2.9
2310257	294.02061	20041020	002940.40	-37.488	177.574	113.75	3.6
2310359	294.22777	20041020	052759.38	-38.827	178.023	41.14	3.0
2481994	294.31604	20041020	073505.44	-38.812	177.966	17.69	1.0
2310417	294.36959	20041020	085212.89	-37.942	177.568	59.38	2.4
2485055	294.62727	20041020	150316.40	-38.648	177.840	29.52	2.3

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CUSP ID	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)
2310530	294.65991	20041020	155015.89	-38.326	177.069	52.77	3.3
2310535	294.67807	20041020	161624.83	-37.901	178.474	7.41	1.0
2485080	294.77726	20041020	183915.44	-38.168	178.424	9.16	3.1
2485082	294.78032	20041020	184339.50	-37.467	177.292	133.71	1.0
2310607	294.84098	20041020	201100.36	-38.050	178.992	31.95	1.0
2310648	294.91439	20041020	215643.40	-37.420	177.908	97.68	3.9
2486365	294.93239	20041020	222238.52	-38.438	178.389	13.60	1.0
2310664	294.93946	20041020	223249.58	-39.934	176.921	50.74	2.7
2310678	294.96367	20041020	230741.45	-38.968	177.661	33.23	2.2
2310850	295.30075	20041021	071305.13	-38.661	177.981	26.06	2.1
2310909	295.43537	20041021	102655.55	-38.306	178.900	17.75	1.0
2310930	295.48336	20041021	113601.97	-37.838	177.202	77.32	3.3
2311040	295.77347	20041021	183347.92	-38.359	177.267	45.90	3.4
2311270	296.22527	20041022	052423.54	-38.372	177.611	55.10	2.3
2311338	296.39002	20041022	092137.30	-39.697	176.732	34.26	2.4
2311364	296.46224	20041022	110537.89	-38.340	178.761	22.58	1.0
2311375	296.49016	20041022	114549.69	-37.248	177.317	170.63	1.0
2311413	296.58970	20041022	140909.80	-37.214	177.178	177.86	2.6
2311497	296.79494	20041022	190443.04	-39.770	177.020	37.95	2.9
2486368	296.79512	20041022	190458.22	-39.712	177.057	28.08	2.6
2311527	296.85580	20041022	203221.27	-37.614	177.966	86.64	1.0
2311562	296.93509	20041022	222632.01	-37.826	177.629	62.14	2.5
2311615	297.05637	20041023	012110.59	-37.188	177.322	169.76	3.1
2311695	297.25982	20041023	061408.79	-38.712	178.743	8.19	3.3
2311737	297.35390	20041023	082937.05	-38.501	178.339	9.68	1.0
2311797	297.51832	20041023	122623.08	-38.380	177.267	43.67	2.3
2311834	297.62236	20041023	145611.88	-38.564	177.604	32.06	3.0
2311853	297.67085	20041023	160601.79	-38.554	177.629	30.89	2.1
2311885	297.76367	20041023	181941.35	-37.114	178.736	38.31	3.9
2311939	297.91115	20041023	215203.35	-39.264	177.642	29.06	1.0
2312045	298.15640	20041024	034513.01	-39.346	177.806	15.87	1.0
2312155	298.36107	20041024	083956.19	-39.271	177.634	22.74	3.1
2312238	298.53583	20041024	125135.34	-39.973	176.886	50.27	2.7
2312360	298.81045	20041024	192703.19	-39.922	176.788	46.28	2.5
2483329	299.06331	20041025	013109.61	-37.929	178.744	20.68	1.0
2312506	299.16373	20041025	035546.47	-39.736	176.881	55.40	2.7
2312591	299.37967	20041025	090643.66	-38.204	177.792	34.00	3.3
2312656	299.56673	20041025	133605.44	-38.283	177.373	41.79	3.2
2312753	299.80748	20041025	192245.89	-38.111	178.980	5.28	1.0
2312875	300.03185	20041026	004551.72	-39.154	177.507	25.88	3.0
2312926	300.09204	20041026	021232.59	-39.183	177.540	27.53	2.4
2313047	300.37097	20041026	085411.87	-38.403	178.006	26.93	2.1
2313095	300.53105	20041026	124442.99	-39.906	176.750	33.12	2.2
2313137	300.63879	20041026	151951.04	-38.557	178.459	11.50	2.5

continued on following page

continued from previous page

CUSP ID	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)
2313164	300.73410	20041026	173706.18	-37.711	176.845	139.41	3.9
2313183	300.77897	20041026	184143.30	-37.529	178.353	39.96	1.0
2313359	301.15159	20041027	033817.13	-39.187	177.822	17.57	3.1
2313487	301.45224	20041027	105113.88	-37.589	177.363	112.68	2.7
2313509	301.50604	20041027	120841.55	-39.696	176.877	42.78	2.8
2313534	301.57272	20041027	134442.74	-39.199	177.843	16.86	2.6
2487760	301.61681	20041027	144812.00	-39.265	177.101	19.68	2.8
2313553	301.62726	20041027	150315.20	-39.204	177.837	16.15	2.1
2313558	301.64261	20041027	152521.18	-38.221	178.310	18.70	2.5
2610550	301.65372	20041027	154121.82	-39.865	176.738	51.16	2.0
2313823	302.27684	20041028	063838.85	-38.714	177.793	11.24	2.1
2313876	302.42052	20041028	100533.33	-37.393	178.368	3.39	3.0
2313950	302.63382	20041028	151241.90	-37.637	177.060	156.77	2.8
2313994	302.74117	20041028	174716.94	-38.261	178.866	8.21	1.0
2314042	302.85125	20041028	202548.03	-37.905	178.991	12.08	2.6
2314063	302.89293	20041028	212549.51	-37.061	176.990	152.09	3.0
2314165	303.08758	20041029	020607.20	-38.041	177.926	31.41	2.8
2314432	303.56333	20041029	133111.32	-39.160	177.666	23.25	2.7
2314537	303.78954	20041029	185656.37	-39.480	177.069	9.39	2.9
2314620	303.96070	20041029	230324.59	-38.779	177.305	49.35	2.9
2314745	304.18394	20041030	042452.71	-38.195	178.772	19.21	3.2
2314839	304.39667	20041030	093112.52	-38.330	178.357	10.07	3.3
2314912	304.57639	20041030	134959.95	-39.177	177.829	16.59	2.8
2314933	304.63448	20041030	151339.16	-39.290	177.671	23.21	3.1
2314948	304.67166	20041030	160711.65	-38.048	178.503	24.66	2.5
2314952	304.68423	20041030	162517.33	-38.181	178.939	13.08	2.9
2314985	304.76490	20041030	182127.57	-38.670	177.423	53.36	2.3
2315219	305.29835	20041031	070937.10	-38.732	178.114	5.28	2.4
2315346	305.59204	20041031	141231.85	-38.993	178.032	4.81	2.4
2315476	305.89745	20041031	213219.44	-39.885	176.863	55.61	2.8
2315569	306.10150	20041101	022610.02	-37.898	177.644	40.84	2.5
2315613	306.19011	20041101	043345.42	-38.896	177.989	30.43	1.0
2315663	306.31174	20041101	072854.27	-38.964	177.980	6.38	1.0
2315765	306.59700	20041101	141940.45	-39.089	177.905	8.69	2.8
2315770	306.60931	20041101	143724.01	-39.147	177.731	13.09	1.0
2315779	306.62277	20041101	145647.58	-37.582	177.163	151.73	2.4
2315865	306.79594	20041101	190609.60	-38.225	178.307	18.49	2.5
2315868	306.80193	20041101	191446.65	-37.610	177.306	147.42	2.9
2316088	307.20916	20041102	050111.54	-38.522	178.065	59.10	1.0
2487792	307.46644	20041102	111140.76	-38.953	177.892	28.42	2.3
2316247	307.53207	20041102	124610.75	-39.038	177.672	14.61	2.5
2316294	307.60753	20041102	143450.59	-37.794	178.276	45.67	2.9
2316423	307.84980	20041102	202342.48	-37.812	178.935	19.02	3.6
2316783	308.52996	20041103	124308.40	-39.498	177.593	10.06	1.0

continued on following page

continued from previous page

CUSP ID	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)
2316798	308.56079	20041103	132731.87	-38.224	178.296	8.74	2.9
2316799	308.56370	20041103	133143.84	-38.380	177.864	22.05	2.6
2490028	308.56550	20041103	133419.02	-38.382	177.862	22.15	2.4
2316851	308.65147	20041103	153807.15	-39.377	177.246	67.13	1.7
2317072	309.06770	20041104	013729.64	-39.248	177.892	9.15	1.0
2317193	309.32052	20041104	074132.65	-39.151	177.760	11.22	2.6
2317251	309.43455	20041104	102544.80	-38.205	178.299	19.54	2.2
2317385	309.68736	20041104	162948.33	-38.264	178.260	22.83	3.0
2317457	309.81318	20041104	193058.53	-39.868	176.729	47.09	2.9
2317710	310.26448	20041105	062050.90	-38.672	177.524	53.47	3.0
2317761	310.35190	20041105	082643.94	-37.276	177.042	172.73	4.0
2317773	310.38894	20041105	092004.60	-39.147	177.565	48.87	2.1
2317859	310.57871	20041105	135320.53	-39.264	177.368	18.51	2.1
2318062	311.01708	20041106	002435.30	-38.590	178.125	11.95	2.3
2318063	311.01792	20041106	002548.35	-38.425	178.011	58.08	1.0
2318093	311.05493	20041106	011906.25	-38.400	177.892	22.02	2.1
2318104	311.08723	20041106	020536.32	-39.319	177.550	26.42	2.9
2318147	311.18374	20041106	042435.03	-37.700	178.520	30.04	3.2
2318160	311.20857	20041106	050020.24	-38.648	178.618	66.85	1.0
2318304	311.50905	20041106	121302.25	-39.377	177.586	19.13	2.3
2318321	311.54953	20041106	131119.16	-39.664	176.926	56.99	3.1
2318330	311.57193	20041106	134334.70	-39.258	177.433	27.35	3.4
2493776	311.57312	20041106	134517.60	-39.250	177.382	9.45	2.0
2318376	311.65659	20041106	154529.51	-38.956	177.893	18.24	2.7
2318437	311.79465	20041106	190417.44	-38.872	177.909	15.37	2.7
2490445	312.01882	20041107	002705.87	-38.580	178.816	9.00	2.3
2318574	312.07620	20041107	014943.41	-37.891	178.886	17.30	1.0
2318663	312.25364	20041107	060514.43	-38.611	177.873	17.09	2.1
2318704	312.36470	20041107	084510.10	-37.470	179.280	4.68	3.0
2318724	312.42376	20041107	101012.78	-39.271	177.644	7.96	1.0
2318748	312.48647	20041107	114031.41	-38.745	177.960	17.81	1.9
2491352	312.50319	20041107	120435.23	-38.762	177.304	71.93	2.6
2318765	312.53730	20041107	125342.74	-39.192	177.679	14.92	2.4
2318767	312.54138	20041107	125935.28	-39.181	177.671	14.74	2.3
2318938	312.92154	20041107	220700.86	-37.082	178.562	44.98	4.0
2318971	312.99386	20041107	235109.71	-38.773	178.171	16.46	3.2
2492779	313.12373	20041108	025809.99	-38.691	177.070	1.35	2.8
2319232	313.61160	20041108	144042.46	-38.001	177.609	70.82	2.0
2319265	313.67773	20041108	161556.05	-37.245	178.801	11.92	3.4
2493236	313.68357	20041108	162420.03	-38.408	178.667	10.51	2.7
2319606	314.41647	20041109	095943.32	-39.443	177.009	27.03	2.2
2319703	314.62994	20041109	150707.04	-39.107	177.431	17.58	2.0
2319788	314.82903	20041109	195348.36	-37.773	177.584	57.13	2.3
2320050	315.36805	20041110	084959.94	-38.864	178.274	33.00	1.0

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continued from previous page

CUSP ID	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)
2320060	315.39406	20041110	092726.89	-38.988	178.423	52.10	2.4
2320080	315.43709	20041110	102924.78	-39.865	176.918	22.35	2.0
2320152	315.60996	20041110	143820.32	-37.932	178.675	48.55	3.3
2320429	316.23393	20041111	053651.95	-38.220	178.896	5.52	3.8
2320431	316.23957	20041111	054458.90	-38.245	178.871	6.26	3.3
2320559	316.50929	20041111	121322.84	-39.382	177.438	31.43	1.0
2320588	316.57973	20041111	135448.76	-39.306	177.159	13.13	2.2
2320620	316.65181	20041111	153836.16	-37.372	177.892	106.97	4.1
2320652	316.71773	20041111	171332.25	-39.560	176.965	24.11	3.6
2320663	316.73563	20041111	173918.17	-39.539	176.985	4.88	2.6
2320821	317.04550	20041112	010531.07	-38.636	177.746	44.61	2.2
2320939	317.30332	20041112	071646.75	-38.352	177.611	52.56	2.8
2320942	317.31289	20041112	073033.98	-38.623	177.894	36.23	3.3
2320988	317.41528	20041112	095800.62	-39.864	177.391	32.26	1.9
2321014	317.47791	20041112	112811.83	-39.106	177.585	29.46	2.0
2321048	317.53846	20041112	125523.16	-39.261	177.547	19.33	2.3
2321064	317.57801	20041112	135220.12	-39.258	177.587	8.40	2.2
2321104	317.66522	20041112	155754.91	-38.925	178.549	10.01	1.0
2321108	317.66978	20041112	160429.30	-39.459	177.572	6.44	2.4
2321194	317.86010	20041112	203832.57	-38.964	177.910	23.55	2.6
2321198	317.86663	20041112	204756.85	-39.901	176.998	31.10	2.8
2496232	317.90757	20041112	214654.28	-39.928	177.067	32.61	2.2
2321217	317.90759	20041112	214655.88	-39.912	177.117	32.43	2.7
2321267	318.03424	20041113	004918.45	-38.495	178.148	19.16	2.9
2321314	318.13700	20041113	031716.44	-39.115	177.695	13.33	2.4
2321380	318.30096	20041113	071322.79	-38.524	177.726	47.09	3.3
2321425	318.40348	20041113	094101.01	-39.639	176.925	48.95	2.5
2321449	318.45738	20041113	105837.62	-38.584	177.893	19.27	2.3
2321477	318.51748	20041113	122510.03	-38.348	178.736	5.91	2.3
2321628	318.87851	20041113	210503.05	-38.496	177.920	31.43	2.2
2496187	319.01824	20041114	002616.36	-37.397	177.851	91.72	3.0
2321856	319.37965	20041114	090641.96	-38.287	177.894	72.47	1.0
2322785	321.16603	20041116	035905.26	-39.916	176.944	44.76	3.7
2322818	321.23869	20041116	054342.93	-38.251	178.881	3.24	3.1
2322888	321.38093	20041116	090832.36	-39.323	177.679	5.04	1.0
2322938	321.49711	20041116	115550.52	-37.822	176.819	98.08	2.8
2322966	321.56227	20041116	132940.05	-39.358	177.550	34.06	2.9
2323246	322.13018	20041117	030727.88	-39.389	177.689	21.45	2.4
2323352	322.34787	20041117	082055.82	-39.792	176.833	56.56	2.3
2323448	322.57443	20041117	134710.65	-39.819	176.736	57.71	1.8
2323536	322.75541	20041117	180747.34	-39.403	177.605	10.85	2.6
2323635	322.93447	20041117	222537.83	-38.719	177.398	45.79	2.5
2323681	323.01426	20041118	002032.05	-37.055	177.250	193.36	3.0
2323784	323.20820	20041118	045948.49	-39.218	177.693	21.66	3.0

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continued from previous page

CUSP ID	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)
2323830	323.29729	20041118	070805.60	-39.216	177.685	20.84	2.9
2323868	323.38859	20041118	091934.12	-39.852	176.919	37.77	1.9
2323929	323.52627	20041118	123749.88	-37.963	178.409	24.08	2.5
2500091	323.61079	20041118	143932.33	-39.290	177.689	21.44	2.2
2323965	323.61101	20041118	143950.86	-39.267	177.662	21.05	2.9
2324049	323.81730	20041118	193654.81	-39.000	177.794	27.43	3.1
2324080	323.88064	20041118	210807.13	-37.755	177.142	104.77	3.9
2324133	323.98540	20041118	233858.78	-38.695	177.418	32.89	1.9
2324140	323.99875	20041118	235812.01	-37.899	177.851	80.65	2.4
2324195	324.12696	20041119	030249.33	-39.627	177.147	8.33	2.9
2324467	324.77207	20041119	183147.00	-38.361	179.022	2.93	1.0
2324509	324.85447	20041119	203025.94	-38.474	178.086	22.37	2.5
2324936	325.56084	20041120	132736.50	-36.928	176.726	253.00	3.4
2325316	326.16331	20041121	035509.62	-40.005	176.799	44.87	2.5
2325518	326.58178	20041121	135745.63	-38.575	177.536	41.44	2.0
2325636	326.86575	20041121	204640.82	-39.984	176.827	30.74	2.4
2511565	327.39204	20041122	092431.92	-38.683	177.913	22.68	1.0
2325868	327.41932	20041122	100348.82	-39.738	176.883	41.50	2.6
2326010	327.74385	20041122	175108.30	-38.645	178.441	9.71	2.5
2326326	328.48125	20041123	113300.00	-37.286	177.101	156.13	3.2
2326404	328.61056	20041123	143912.19	-38.279	178.875	8.28	3.0
2326560	328.88535	20041123	211454.21	-38.196	178.835	8.31	3.0
2326607	328.97881	20041123	232929.52	-39.216	177.613	28.42	1.0
2326619	329.00454	20041124	000632.30	-36.691	177.463	189.78	1.0
2326809	329.39598	20041124	093013.01	-39.155	177.565	12.53	1.0
2326824	329.43503	20041124	102626.45	-37.234	178.078	25.25	2.4
2611056	329.47243	20041124	112017.64	-36.598	177.504	185.52	2.8
2327139	330.13912	20041125	032019.85	-38.072	177.666	76.43	2.8
2327269	330.36721	20041125	084847.25	-39.685	176.718	44.12	2.5
2327280	330.38932	20041125	092037.45	-39.833	177.410	42.72	2.2
2327301	330.42811	20041125	101628.91	-39.437	177.729	21.81	1.0
2327374	330.54355	20041125	130242.44	-37.232	177.616	70.30	3.4
2327437	330.64774	20041125	153245.15	-39.230	177.704	20.22	1.0
2511961	331.21508	20041126	050942.88	-38.080	177.860	66.73	3.2
2327726	331.21975	20041126	051626.35	-37.385	177.393	140.59	4.0
2327768	331.28150	20041126	064521.61	-39.254	177.569	25.55	2.7
2327952	331.57409	20041126	134641.38	-38.061	177.623	50.34	3.6
2328442	332.41303	20041127	095445.93	-38.544	177.705	51.06	2.3
2328443	332.41452	20041127	095654.69	-39.179	177.660	26.99	2.1
2328467	332.45710	20041127	105813.72	-38.270	178.810	28.77	1.0
2328574	332.66559	20041127	155826.60	-39.182	177.510	23.87	1.0
2328604	332.71553	20041127	171021.63	-37.595	178.393	42.12	3.6
2328966	333.42009	20041128	100455.36	-38.203	178.277	18.29	1.0
2329019	333.53601	20041128	125151.15	-39.146	177.617	27.33	1.0

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CUSP ID	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)
2329800	334.99465	20041129	235217.83	-39.196	177.657	34.77	1.0
2330500	336.24366	20041201	055052.00	-38.174	178.815	26.34	1.0
2330539	336.30481	20041201	071855.39	-39.066	177.567	30.12	3.5
2330642	336.47617	20041201	112541.34	-39.084	177.476	24.29	2.1
2514519	336.59062	20041201	141029.36	-38.261	178.209	17.35	2.9
2514523	336.59155	20041201	141150.10	-38.253	178.201	17.31	1.0
2330701	336.59341	20041201	141430.50	-38.263	178.202	15.81	2.3
2330704	336.59850	20041201	142150.10	-38.260	178.208	16.39	2.6
2330747	336.68347	20041201	162412.10	-38.957	177.162	24.34	3.0
2330773	336.73773	20041201	174219.81	-38.114	178.999	26.96	3.0
2330845	336.88759	20041201	211807.88	-39.063	177.495	24.55	2.6
2330967	337.08066	20041202	015609.32	-38.215	178.209	19.34	2.5
2331024	337.17986	20041202	041859.73	-39.034	177.531	25.39	2.9
2331063	337.26096	20041202	061546.69	-39.079	177.489	25.10	2.4
2331073	337.27806	20041202	064024.76	-38.662	178.031	18.57	2.5
2331538	337.85040	20041202	202434.86	-37.694	177.292	130.41	2.5
2331706	338.12218	20041203	025555.94	-38.306	177.812	54.63	1.0
2331765	338.21428	20041203	050833.50	-37.403	176.738	189.16	3.2
2331863	338.40554	20041203	094358.71	-39.460	177.582	10.80	2.5
2515836	338.46117	20041203	110405.26	-37.617	177.195	154.31	2.6
2332177	338.98513	20041203	233835.64	-39.467	177.725	25.30	1.0
2332229	339.08974	20041204	020913.51	-38.438	178.899	14.39	2.5
2332244	339.11391	20041204	024402.20	-38.590	177.903	18.55	2.6
2332307	339.23593	20041204	053943.98	-37.374	177.906	131.07	3.0
2332368	339.38216	20041204	091018.21	-37.307	177.063	168.48	3.5
2332399	339.44885	20041204	104620.88	-37.814	177.631	55.69	2.3
2332409	339.47098	20041204	111812.98	-38.402	178.281	18.06	1.0
2332484	339.61260	20041204	144208.94	-38.093	177.051	70.29	2.5
2332488	339.61880	20041204	145104.46	-38.386	177.552	58.75	2.3
2332549	339.73032	20041204	173139.91	-38.376	177.339	47.69	3.3
2332598	339.81246	20041204	192956.44	-38.490	176.831	59.07	2.5
2332756	340.05390	20041205	011736.95	-38.328	178.254	24.33	2.9
2515344	340.25631	20041205	060905.43	-37.024	176.416	229.63	1.0
2332900	340.32546	20041205	074839.36	-39.724	177.004	37.73	4.4
2332902	340.33017	20041205	075526.48	-39.717	177.171	49.54	3.0
2333114	340.67542	20041205	161236.58	-37.973	177.613	73.67	2.2

Appendix C

2006 Gisborne earthquake hypocentres

Table C.1: **Earthquake hypocentres** from the 2006 Gisborne slow slip event. CUSP ID is the unique event identifier, TYPE: R are routine analysed earthquakes, N are newly detected earthquakes, T are newly detected teleseisms, and X are local noise or earthquakes too small to locate, JDay is the Julian day of year. Waveform data is available from http://www.geonet.org.nz

CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2593438	R	190.002	20060709	000317.87	-37.472	176.596	210.9	4.3	0.12
2593462	R	190.05	20060709	011152.78	-39.541	175.627	20.2	2.2	0.24
2726810	N	190.053	20060709	011639.41	-35.714	178.927	234.4	3.2	0.20
2593533	R	190.186	20060709	042829.17	-39.166	174.824	26.9	2.4	0.25
2593592	R	190.326	20060709	074911.82	-39.670	176.346	30.1	2.5	0.27
2726812	N	190.392	20060709	092414.73	-37.940	177.814	70.7	2.9	0.18
2726813	N	190.54	20060709	125655.45	-38.216	178.389	2.9	2.3	0.35
2726814	N	190.579	20060709	135427.63	-37.788	176.954	65.6	2.9	0.06
2726815	N	190.595	20060709	141646.84	-38.558	177.604	41.2	3.2	0.23
2726816	N	190.632	20060709	151018.72	-37.787	176.910	68.6	2.8	0.22
2593777	R	190.735	20060709	173749.60	-38.956	175.699	8.2	2.2	0.10
2593838	R	190.876	20060709	210135.56	-41.668	174.147	9.0	4.1	0.23
2726817	N	190.968	20060709	231353.36	-37.924	176.401	157.4	2.8	0.24
2726818	N	191.113	20060710	024220.07	-38.548	177.856	27.4	2.0	0.41
2726819	N	191.133	20060710	031115.22	-37.928	178.674	13.4	2.3	0.10
2726820	N	191.144	20060710	032639.31	-37.890	177.658	73.0	2.5	0.50
2726821	X	191.146	20060710	03300.00					

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CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2726822	N	191.323	20060710	074534.57	-38.862	177.453	52.7	2.1	0.25
2594057	R	191.33	20060710	075540.02	-39.334	175.427	7.8	1.7	0.14
2726824	X	191.508	20060710	12120.00					
2726825	N	191.605	20060710	143055.50	-37.902	176.289	164.9	2.9	0.12
2594193	R	191.639	20060710	152002.29	-39.100	175.652	4.5	2.0	0.06
2726826	N	191.978	20060710	232831.98	-38.343	175.873	126.9	2.9	0.16
2726827	X	192.049	20060711	01100.00					
2726828	N	192.158	20060711	034801.57	-38.547	177.815	23.4	2.1	0.44
2594490	R	192.327	20060711	075119.27	-39.233	173.855	10.8	2.8	0.15
2726829	N	192.417	20060711	100019.85	-38.707	178.611	23.1	2.8	0.22
2726830	N	192.555	20060711	131954.18	-38.565	177.811	27.9	2.2	0.42
2594656	R	192.654	20060711	154125.76	-38.633	175.282	238.8	4.0	0.19
2726831	N	192.731	20060711	173308.00	-39.038	178.007	17.1	2.3	0.29
2726832	N	192.995	20060711	235215.02	-38.483	177.046	0.0	2.3	1.88
2726833	N	193.107	20060712	023324.64	-38.689	178.563	23.8	3.3	0.11
2726834	N	193.22	20060712	051640.01	-38.255	176.787	22.5	2.2	0.13
2726835	N	193.264	20060712	061930.68	-36.362	177.625	228.5	3.2	0.06
2726836	N	193.294	20060712	070306.73	-38.073	178.257	33.0	2.0	0.00
2726837	N	193.373	20060712	085743.82	-39.119	177.793	15.7	2.3	0.42
2726838	N	193.389	20060712	092043.11	-39.136	177.954	7.4	2.0	0.12
2726839	N	193.551	20060712	131259.34	-39.163	177.748	13.9	0.06	7
2726840	N	193.634	20060712	151240.02	-37.686	178.963	9.1	3.0	0.26
2595188	R	193.684	20060712	162515.53	-41.101	173.554	97.0	3.2	0.20
2726842	N	193.713	20060712	170652.55	-38.016	176.954	0.0	2.6	0.95
2726843	N	193.792	20060712	190023.78	-38.510	177.449	0.0	2.0	0.69
2726844	X	193.802	20060712	19150.00					
2726845	N	193.819	20060712	193904.10	-38.277	175.509	140.1	3.1	0.41
2595255	R	193.836	20060712	200401.25	-39.190	175.368	126.0	3.4	0.22
2726846	N	193.886	20060712	211511.85	-38.530	177.448	0.0	2.3	0.73
2595310	R	193.954	20060712	225406.15	-41.020	175.195	24.1	2.7	0.17
2726847	N	194.003	20060713	000459.81	-37.764	179.051	24.3	3.2	0.24
2726848	N	194.013	20060713	001917.22	-37.916	177.428	72.9	2.3	0.11
2726849	N	194.127	20060713	030329.93	-39.025	177.910	18.8	2.3	0.35
2726850	X	194.247	20060713	05560.00					
2595538	R	194.441	20060713	103512.97	-38.876	176.220	85.7	3.8	0.19
2726851	N	194.501	20060713	120137.35	-39.130	177.958	13.4	2.8	0.28
2726852	N	194.506	20060713	120801.73	-31.344	179.919	353.7	0.76	7
2726853	N	194.585	20060713	140203.26	-38.190	176.971	62.6	3.3	0.32
2726854	N	194.665	20060713	155725.76	-38.441	177.440	20.4	2.0	0.42
2726855	X	194.678	20060713	16170.00					
2726856	N	194.685	20060713	162553.31	-38.629	175.867	24.5	3.0	0.56
2726857	N	194.696	20060713	164222.29	-35.052	179.212	165.0	0.09	6
2726858	X	194.769	20060713	18280.00					
2726860	N	194.789	20060713	185542.79	-38.593	178.614	24.3	3.1	0.15

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CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2726861	N	194.8	20060713	191139.90	-39.608	175.947	26.3	2.7	0.14
2595839	R	195.151	20060714	033705.93	-39.135	175.035	6.6	2.7	0.19
2726862	N	195.229	20060714	052944.03	-39.336	177.311	45.3	2.6	0.04
2726863	N	195.298	20060714	070853.78	-38.565	178.722	23.3	2.6	0.76
2726864	X	195.365	20060714	08460.00					
2726865	N	195.394	20060714	092803.10	-38.291	175.944	145.9	3.0	0.06
2595954	R	195.423	20060714	100828.69	-37.381	177.177	165.8	4.3	0.15
2726866	N	195.694	20060714	163959.15	-40.115	-179.421	0.0	3.3	7.00
2726867	N	196.102	20060715	022713.85	-37.801	177.587	54.0	3.3	0.02
2726868	N	196.423	20060715	100917.78	-39.021	177.880	19.0	2.7	0.11
2726870	N	196.569	20060715	133845.65	-37.178	177.441	16.4	3.0	0.25
2726871	X	196.669	20060715	16030.00					
2726872	N	196.689	20060715	163146.37	-38.542	178.037	28.0	2.5	0.24
2726873	N	196.709	20060715	170103.04	-38.589	177.888	14.7	2.6	0.39
2726874	N	196.845	20060715	201720.99	-39.151	178.134	17.6	3.2	0.21
2726875	N	196.867	20060715	204825.99	-38.512	178.081	26.9	3.2	0.47
2596532	R	196.914	20060715	215539.72	-41.015	177.085	30.4	4.1	0.19
2726876	N	196.918	20060715	220147.37	-38.596	177.901	24.2	3.2	0.12
2596543	R	196.94	20060715	223304.40	-41.038	177.138	35.1	3.4	0.13
2726877	N	197.185	20060716	042556.73	-38.907	177.926	32.3	2.4	0.12
2726878	N	197.258	20060716	061108.59	-38.969	178.007	39.0	2.6	0.13
2726879	N	197.304	20060716	071709.56	-37.639	177.864	85.1	3.9	0.19
2726881	N	197.315	20060716	073417.94	-38.271	178.387	21.6	3.8	0.28
2726882	N	197.321	20060716	074251.02	-38.268	178.379	23.4	3.1	0.11
2726883	N	197.489	20060716	114447.51	-39.147	178.157	20.5	3.0	0.18
2726884	X	197.497	20060716	11550.00					
2726885	N	197.502	20060716	120210.78	-38.261	177.111	33.0	2.4	0.00
2726886	N	197.703	20060716	165252.62	-38.353	176.744	63.3	2.4	0.12
2726887	N	197.83	20060716	195452.93	-38.517	177.999	25.8	3.4	0.39
2726888	N	197.937	20060716	222914.94	-39.894	176.823	56.9	2.9	0.11
2597173	R	198.132	20060717	031047.07	-40.366	174.056	17.5	2.3	0.22
2597206	R	198.21	20060717	050241.09	-39.177	174.916	33.9	2.8	0.15
2597207	R	198.213	20060717	050617.74	-39.268	174.925	32.6	2.5	0.15
2597240	R	198.272	20060717	063135.66	-40.517	175.808	23.3	2.3	0.67
2726889	N	198.279	20060717	064122.70	-38.497	178.001	11.7	2.0	0.25
2597262	R	198.31	20060717	072643.93	-39.501	175.715	13.5	1.6	0.04
2597268	R	198.32	20060717	074103.78	-38.465	175.642	186.9	3.1	0.22
2597307	R	198.402	20060717	093856.98	-37.953	176.311	180.3	3.3	0.24
2597308	R	198.405	20060717	094229.48	-40.713	173.742	87.0		0.16
2597330	R	198.462	20060717	110557.91	-39.284	174.841	17.6	2.9	0.24
2726890	X	198.47	20060717	11170.00					
2726891	N	198.476	20060717	112510.76	-38.602	177.916	37.3	3.2	0.19
2597354	R	198.522	20060717	123107.43	-40.212	175.005	20.7	2.2	0.21
2726893	N	198.61	20060717	143752.77	-39.163	178.047	17.3	2.4	0.14

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CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2597470	R	198.763	20060717	181804.03	-39.780	177.234	44.0	2.8	0.09
2726894	X	198.794	20060717	19030.00					
2726895	N	198.8	20060717	191124.34	-37.017	176.897	250.7	3.1	0.16
2597486	R	198.803	20060717	191640.01	-41.080	174.224	48.3	2.7	0.18
2597488	R	198.808	20060717	192342.16	-41.572	174.095	12.8	2.0	0.22
2726896	N	198.813	20060717	193024.63	-38.261	177.111	33.0	1.6	0.00
2597505	R	198.848	20060717	202107.08	-38.293	176.143	162.4	3.9	0.22
2597517	R	198.87	20060717	205232.81	-39.704	176.946	42.6	2.8	0.48
2726897	N	198.933	20060717	222407.49	-39.126	177.793	18.9	2.3	0.28
2597578	R	198.989	20060717	234450.89	-40.125	174.982	21.7	3.0	0.17
2597582	R	198.996	20060717	235445.50	-39.324	174.679	27.3	2.8	0.14
2597593	R	199.018	20060718	002518.17	-40.140	174.542	55.4	2.4	0.23
2597598	R	199.028	20060718	004052.64	-40.445	173.602	129.2	2.7	0.15
2597609	R	199.056	20060718	012028.07	-38.570	175.957	145.0	3.8	0.24
2726898	N	199.078	20060718	015254.76	-37.914	179.092	0.0	3.2	0.36
2726899	X	199.151	20060718	03370.00					
2726900	X	199.187	20060718	04290.00					
2726901	X	199.232	20060718	05340.00					
2597702	R	199.257	20060718	060929.28	-39.283	175.091	30.1	2.9	0.09
2726902	N	199.31	20060718	072556.77	-38.591	177.902	33.7	2.3	0.58
2726903	N	199.352	20060718	082717.02	-38.002	176.568	126.2	2.9	0.10
2597792	R	199.41	20060718	095027.67	-39.249	175.140	16.8	1.9	0.07
2597796	R	199.417	20060718	100040.30	-40.320	174.077	95.1	2.5	0.29
2597809	R	199.447	20060718	104420.62	-39.250	175.190	25.8	2.2	0.14
2597854	R	199.551	20060718	131349.32	-40.755	175.815	24.6	2.7	0.42
2726904	N	199.586	20060718	140358.31	-38.261	177.111	33.0	1.5	0.00
2726905	N	199.6	20060718	142406.10	-39.133	177.817	21.6	1.8	0.08
2597882	R	199.603	20060718	142806.26	-40.956	174.564	62.2	2.5	0.09
2597897	R	199.628	20060718	150433.31	-41.425	174.123	39.6	2.5	0.17
2597898	R	199.63	20060718	150754.60	-39.494	175.671	19.9	2.0	0.13
2597975	R	199.769	20060718	182650.81	-39.638	176.538	77.7	3.3	0.22
2597985	R	199.788	20060718	185441.43	-38.130	176.266	2.0	2.1	0.12
2726906	X	199.83	20060718	19550.00					
2726908	N	199.985	20060718	233801.70	-38.261	177.722	33.9	2.3	0.18
2726909	N	200.017	20060719	002451.09	-37.990	179.136	0.0	2.4	0.33
2598236	R	200.257	20060719	061015.02	-39.827	175.159	69.2	2.6	0.23
2598297	R	200.406	20060719	094448.24	-41.090	175.073	27.6	2.7	0.16
2598338	R	200.494	20060719	115114.08	-41.007	175.172	25.9	3.2	0.29
2598342	R	200.505	20060719	120650.92	-39.210	175.064	183.1	3.4	0.19
2726910	X	200.761	20060719	18160.00					
2598597	R	201.092	20060720	021246.43	-39.034	176.842	29.9	2.6	0.17
2726911	N	201.156	20060720	034423.62	-38.189	178.263	0.0	2.8	1.39
2598633	R	201.179	20060720	041717.74	-40.513	175.838	33.6	2.4	0.05
2598639	R	201.193	20060720	043721.95	-38.616	176.124	173.9	3.6	0.28

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CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2598698	R	201.335	20060720	080216.77	-38.172	176.237	4.5	1.6	0.0
2726912	X	201.37	20060720	08530.00					
2598787	R	201.529	20060720	124133.33	-39.725	174.822	132.1	3.3	0.13
2598945	R	201.626	20060720	150101.73	-38.607	175.433	141.9	3.4	0.24
2598890	R	201.778	20060720	184035.15	-40.124	176.324	15.5	2.8	0.43
2726913	N	201.892	20060720	212434.12	-38.261	177.111	33.0	2.1	0.00
2726915	X	201.912	20060720	21530.00					
2598963	R	201.95	20060720	224826.31	-37.914	177.476	61.2	3.5	0.19
2599011	R	202.071	20060721	014225.33	-38.758	175.680	190.8	3.6	0.13
2599016	R	202.086	20060721	020338.49	-39.332	174.855	25.0	2.4	0.30
2599038	R	202.136	20060721	031556.43	-38.121	177.276	58.5	3.5	0.26
2726916	N	202.154	20060721	034105.25	-38.948	177.499	23.9	2.5	0.21
2599113	R	202.312	20060721	072937.64	-39.693	176.838	32.5	4.0	0.38
2599117	R	202.32	20060721	074116.58	-40.188	174.012	109.1	2.3	0.13
2599143	R	202.385	20060721	091417.47	-40.897	175.678	24.7	2.5	0.08
2599148	R	202.395	20060721	092856.53	-38.208	176.810	80.1	3.4	0.47
2599191	R	202.515	20060721	122054.42	-41.571	174.462	18.5	2.4	0.22
2726917	N	202.672	20060721	160736.61	-38.904	177.574	27.9	3.5	0.34
2726918	N	202.869	20060721	205041.98	-37.232	179.590	0.0	3.1	0.17
2599352	R	202.929	20060721	221800.62	-41.152	175.471	18.9	2.6	0.16
2599357	R	202.937	20060721	222925.51	-40.714	174.979	37.3	2.6	0.27
2599389	R	202.995	20060721	235241.51	-40.064	175.519	35.4	2.6	0.28
2599411	R	203.045	20060722	010526.45	-39.042	178.606	22.3	3.6	0.17
2599476	R	203.186	20060722	042734.06	-39.297	177.963	50.4	4.4	0.17
2726919	N	203.215	20060722	050853.95	-38.779	177.828	28.9	2.1	0.33
2599527	R	203.286	20060722	065211.10	-40.451	176.314	43.9	3.1	0.28
2599863	R	203.287	20060722	065328.60	-40.356	176.246	24.0	2.6	0.42
2726920	N	203.31	20060722	072626.76	-38.102	176.956	65.0	2.6	0.23
2599573	R	203.38	20060722	090754.50	-38.391	176.233	169.1	3.4	0.35
2726921	N	203.381	20060722	090755.43	-38.175	175.923	141.5	3.2	0.13
2726922	X	203.419	20060722	10040.00					
2599613	R	203.496	20060722	115420.57	-37.124	176.555	221.3	3.4	0.14
2726923	N	203.509	20060722	121241.32	-39.218	177.834	52.2	2.5	0.15
2599635	R	203.553	20060722	131546.74	-41.156	175.315	27.4	2.7	0.28
2599872	R	203.761	20060722	181627.06	-38.962	177.745	38.6	2.8	0.11
2726924	N	203.761	20060722	181628.40	-38.916	177.559	27.6	2.7	0.31
2599768	R	203.878	20060722	210430.24	-38.473	175.763	152.5	3.8	0.17
2599796	R	203.946	20060722	224143.35	-38.572	175.527	159.8	3.4	0.38
2599829	R	204.023	20060723	003326.39	-41.347	173.210	113.0	3.4	0.27
2599831	R	204.026	20060723	003738.63	-40.600	173.285	172.4	5.5	0.20
2726925	N	204.073	20060723	014519.57	-38.563	177.879	24.3	2.2	0.22
2599871	R	204.106	20060723	023200.55	-39.546	175.740	22.7	2.2	0.67
2726927	N	204.327	20060723	075058.14	-33.240	169.896	59.6	13.79	6
2600011	R	204.415	20060723	095750.34	-40.521	173.605	122.8	3.1	0.20

continued on following page

continued from previous page

CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2726928	N	204.585	20060723	140207.77	-39.216	178.829	33.0	2.2	0.58
2600081	R	204.596	20060723	141806.85	-39.863	175.197	23.9	2.2	0.18
2726929	N	204.672	20060723	160802.69	-35.603	179.841	189.5	0.48	7
2600139	R	204.725	20060723	172403.36	-40.164	174.759	12.0	2.9	0.37
2727059	X	204.799	20060723	19110.00					
2726930	N	204.827	20060723	195021.06	-37.682	178.408	48.0	2.5	0.14
2600189	R	204.834	20060723	200135.20	-40.434	174.950	36.4	2.4	0.21
2726931	X	204.878	20060723	21040.00					
2600210	R	204.878	20060723	210408.79	-39.142	175.409	7.3	1.7	0.07
2726932	N	204.903	20060723	214051.36	-38.667	177.712	20.1	2.4	0.18
2726933	N	204.957	20060723	225752.01	-37.695	178.423	44.8	2.3	0.10
2600340	R	205.119	20060724	025158.43	-38.164	176.020	158.5	3.1	0.10
2726934	N	205.119	20060724	025159.02	-38.115	175.881	143.2	3.0	0.16
2726935	N	205.169	20060724	040238.79	-37.935	176.024	119.7	2.7	0.19
2600380	R	205.191	20060724	043451.43	-39.239	175.463	12.2	1.7	0.12
2726936	N	205.33	20060724	075444.07	-38.766	177.935	36.2	2.0	0.23
2600476	R	205.395	20060724	092826.38	-40.802	173.178	125.5	2.6	0.15
2726937	X	205.431	20060724	10210.00					
2726938	X	205.448	20060724	10450.00					
2726939	N	205.617	20060724	144852.24	-38.741	177.668	29.8	2.0	0.15
2600635	R	205.723	20060724	172033.31	-37.306	177.062	156.6	3.4	0.16
2726941	N	205.769	20060724	182758.95	-38.338	176.976	52.5	3.0	0.33
2726942	N	205.878	20060724	210356.18	-36.769	176.265	271.8	3.4	0.18
2600744	R	205.95	20060724	224806.34	-37.170	177.295	176.9	3.5	0.18
2726943	N	205.971	20060724	231831.26	-38.508	177.773	21.9	2.3	0.22
2726944	N	206.025	20060725	003554.07	-37.212	177.946	61.8	2.4	0.26
2726945	N	206.059	20060725	012440.47	-39.092	177.391	13.6	2.8	0.19
2726946	N	206.072	20060725	014321.29	-38.532	179.157	24.7	2.7	0.22
2600817	R	206.106	20060725	023256.50	-40.776	175.370	27.2	3.3	0.23
2726947	N	206.127	20060725	030218.88	-37.022	177.574	134.4	2.7	0.15
2726948	N	206.132	20060725	030956.84	-38.512	177.784	32.5	2.1	0.22
2600881	R	206.215	20060725	050959.13	-39.190	175.172	12.0		0.33
2600884	R	206.22	20060725	051729.11	-40.303	176.241	20.8	2.8	0.34
2600936	R	206.248	20060725	055625.49	-39.244	175.295	21.0	1.6	0.22
2600906	R	206.261	20060725	061511.00	-38.922	175.348	213.0	3.6	0.23
2726949	N	206.262	20060725	061754.03	-39.065	177.937	11.5	1.8	0.39
2600923	R	206.283	20060725	064808.88	-38.576	176.919	227.2	3.1	0.45
2600966	R	206.351	20060725	082554.21	-38.638	178.880	72.9	3.0	0.34
2726950	N	206.353	20060725	082809.19	-38.543	179.001	41.2	2.2	0.20
2726951	N	206.357	20060725	083418.05	-38.726	179.061	15.5	2.3	0.12
2726952	X	206.368	20060725	08500.00					
2726953	N	206.47	20060725	111711.96	-38.545	179.005	29.6	2.9	0.22
2726954	N	206.485	20060725	113855.91	-38.405	179.052	26.5	2.2	0.11
2726955	N	206.567	20060725	133629.41	-38.641	179.087	20.7	2.6	0.13

continued on following page

continued from previous page

CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2726957	N	206.571	20060725	134154.91	-38.536	179.188	48.4	3.1	0.24
2726958	N	206.574	20060725	134606.96	-39.159	174.453	190.7	2.9	0.12
2726959	N	206.672	20060725	160724.31	-39.323	177.497	22.8	2.2	0.31
2601127	R	206.68	20060725	161950.80	-39.699	173.912	220.4	3.1	0.33
2601269	R	206.956	20060725	225706.28	-41.018	173.286	97.9	2.9	0.15
2726960	N	206.993	20060725	234959.86	-38.160	178.315	25.0	2.2	0.25
2601301	R	207.016	20060726	002249.08	-39.195	175.249	157.1	3.2	0.13
2601323	R	207.059	20060726	012505.48	-39.242	175.474	16.5	1.8	0.05
2726961	N	207.088	20060726	020655.34	-39.344	177.526	24.9	2.9	0.27
2601359	R	207.126	20060726	030156.52	-39.286	177.519	40.5	3.9	0.29
2601386	R	207.18	20060726	041938.24	-39.453	174.927	34.6		0.17
2601387	R	207.181	20060726	042103.99	-39.210	175.090	30.4	1.8	0.12
2726962	N	207.296	20060726	070601.85	-37.767	179.203	19.0	2.7	0.26
2726963	N	207.546	20060726	130607.60	-37.056	177.253	145.4	3.2	0.18
2601610	R	207.606	20060726	143259.13	-39.139	175.439	10.9	2.2	0.30
2726964	N	207.631	20060726	150831.60	-37.508	176.641	64.0	2.6	0.54
2726965	N	207.654	20060726	154107.64	-38.605	178.991	23.6	2.3	0.18
2726966	N	207.723	20060726	172116.08	-36.774	176.610	253.2	3.6	0.24
2727061	N	207.81	20060726	192622.74	-38.550	179.139	22.3	2.3	0.17
2726967	N	207.82	20060726	194120.56	-38.582	179.054	12.1	2.5	0.26
2601790	R	207.953	20060726	225222.15	-38.194	176.065	190.8	3.5	0.46
2601821	R	208.015	20060727	002143.52	-37.431	179.835	12.0	3.9	0.19
2601879	R	208.016	20060727	002243.39	-40.860	174.766	16.6	2.3	0.40
2601831	R	208.041	20060727	005924.06	-38.326	176.217	238.8	4.0	0.04
2601830	R	208.041	20060727	005924.83	-37.874	176.379	165.0	4.0	0.19
2601837	R	208.052	20060727	011431.06	-41.374	175.125	24.3	2.1	0.10
2601857	R	208.087	20060727	020513.33	-40.046	173.688	211.8	3.5	0.27
2726968	N	208.229	20060727	052919.83	-36.687	179.637	12.0	3.7	0.20
2726969	N	208.237	20060727	054121.50	-36.575	177.147	219.4	3.1	0.08
2726971	N	208.278	20060727	063939.99	-38.161	179.310	22.1	2.5	0.39
2726972	N	208.417	20060727	100043.61	-38.698	177.996	31.6	2.4	0.22
2602045	R	208.451	20060727	105000.08	-40.263	176.770	51.3	2.2	0.04
2726973	N	208.492	20060727	114836.39	-37.558	176.931	125.9	2.6	0.46
2726974	X	208.565	20060727	13330.00					
2602136	R	208.619	20060727	145102.02	-39.515	174.331	151.4	3.1	0.28
2726975	N	208.645	20060727	152903.82	-37.975	179.230	0.0	2.9	0.24
2726976	N	208.755	20060727	180701.85	-39.240	177.348	21.7	2.2	0.25
2726977	N	208.763	20060727	181901.50	-39.239	177.363	21.9	2.2	0.20
2602249	R	208.861	20060727	204004.04	-37.478	175.957	287.2	4.4	0.19
2602247	R	208.861	20060727	204014.54	-37.712	176.266	212.7	4.2	0.36
2726978	N	208.94	20060727	223411.89	-38.679	177.798	41.3	2.1	0.21
2726979	N	208.987	20060727	234150.22	-38.326	178.103	31.2	1.9	0.19
2602383	R	209.115	20060728	024608.61	-41.388	175.656	24.6	1.9	0.09
2602388	R	209.131	20060728	030918.11	-38.811	177.931	24.7	2.9	0.46

continued on following page

continued from previous page

CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2726980	N	209.151	20060728	033652.67	-38.582	179.004	23.4	2.4	0.43
2602399	R	209.159	20060728	034830.05	-38.639	178.966	12.0	3.6	0.31
2602426	R	209.217	20060728	051311.21	-36.961	177.365	172.9	3.6	0.15
2726981	N	209.221	20060728	051808.49	-38.621	178.932	24.1	2.7	0.39
2602441	R	209.252	20060728	060217.41	-39.782	176.913	49.1	2.9	0.08
2602486	R	209.319	20060728	073947.34	-41.204	174.615	58.3	3.6	0.15
2602488	R	209.323	20060728	074535.79	-38.274	176.079	168.2	4.1	0.18
2602520	R	209.372	20060728	085501.89	-39.558	174.092	208.1	3.3	0.28
2726982	N	209.395	20060728	092906.97	-37.945	178.757	40.7	2.2	0.29
2602582	R	209.489	20060728	114447.18	-40.293	174.540	102.2	3.8	0.18
2602634	R	209.603	20060728	142822.24	-38.447	176.288	86.7	3.0	0.20
2726983	N	209.672	20060728	160701.45	-37.546	177.997	60.5	2.5	0.23
2726984	N	209.797	20060728	190730.48	-38.898	177.913	35.3	1.9	0.22
2602757	R	209.863	20060728	204309.56	-39.883	177.224	37.0	3.1	0.44
2726985	N	209.87	20060728	205211.88	-38.125	176.423	33.0	2.6	0.11
2726986	X	209.872	20060728	20560.00					
2602772	R	209.892	20060728	212430.48	-37.492	177.202	156.0	3.5	0.25
2602788	R	209.939	20060728	223130.30	-39.656	174.139	200.7	3.4	0.36
2726988	N	209.953	20060728	225136.40	-38.625	177.826	20.3	2.2	0.27
2726989	N	209.992	20060728	234832.74	-38.556	179.056	23.7	2.2	0.08
2726990	N	210.003	20060729	000402.76	-37.473	178.307	47.8	2.9	0.13
2726991	N	210.097	20060729	021933.41	-38.783	177.922	29.0	1.5	0.27
2726992	N	210.249	20060729	055811.41	-37.806	178.133	30.7	2.2	0.22
2603038	R	210.532	20060729	124639.84	-38.326	175.952	182.2	3.8	0.17
2726993	N	210.629	20060729	150622.66	-39.135	177.701	20.5	2.2	0.27
2726994	N	210.639	20060729	152046.48	-38.535	178.811	30.5	2.4	0.30
2726995	N	210.821	20060729	194145.53	-36.922	177.293	151.9	3.1	0.15
2603195	R	210.884	20060729	211236.92	-39.101	174.786	218.6	4.2	0.22
2726996	N	211.154	20060730	034117.40	-38.541	177.768	36.6	1.6	0.15
2726997	X	211.241	20060730	05470.00					
2726998	N	211.269	20060730	062756.02	-39.279	177.293	29.7	2.0	0.26
2603403	R	211.367	20060730	084813.24	-38.321	177.665	53.7	3.7	0.16
2726999	X	211.433	20060730	10230.00					
2727000	N	211.502	20060730	120251.57	-38.784	177.873	26.9	2.0	0.33
2603539	R	211.65	20060730	153557.64	-40.401	173.262	213.4	3.9	0.19
2727001	N	211.667	20060730	155953.17	-38.168	178.260	19.2	2.3	0.22
2727002	X	211.752	20060730	18030.00					
2727003	N	211.785	20060730	185103.12	-37.336	177.053	10.8	2.8	0.46
2727005	N	211.888	20060730	211905.90	-38.646	179.042	8.4	2.5	0.31
2727006	N	211.897	20060730	213126.93	-38.644	178.925	22.9	2.4	0.25
2727007	X	211.931	20060730	22200.00					
2603682	R	211.953	20060730	225219.74	-38.546	177.495	60.0	2.7	0.05
2603755	R	212.111	20060731	023943.87	-40.034	175.171	30.4	2.8	0.36
2727008	N	212.255	20060731	060745.75	-38.585	179.035	21.7	2.4	0.18

continued on following page

continued from previous page

CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2727009	N	212.266	20060731	062342.99	-38.562	178.986	24.0	2.4	0.17
2603846	R	212.269	20060731	062727.60	-40.013	174.977	36.5	2.1	0.43
2603867	R	212.32	20060731	074128.91	-37.666	176.322	191.1	3.2	0.85
2603881	R	212.368	20060731	084930.47	-37.600	179.487	12.5	4.1	0.57
2603953	R	212.537	20060731	125304.42	-40.422	174.055	58.8		0.45
2727010	N	212.546	20060731	130644.68	-38.780	177.799	47.1	2.0	0.42
2603978	R	212.605	20060731	143032.93	-40.211	173.440	163.8	3.1	0.41
2727011	N	212.615	20060731	144553.57	-39.384	177.213	27.3	2.2	0.26
2727012	N	212.623	20060731	145711.48	-39.377	177.222	28.7	2.4	0.28
2727013	N	212.7	20060731	164809.01	-37.353	177.365	114.6	2.7	0.11
2604021	R	212.708	20060731	165938.16	-41.424	174.433	30.5	2.8	0.21
2727014	N	212.901	20060731	213740.26	-38.013	176.888	0.4	2.4	0.86
2604109	R	212.914	20060731	215607.26	-39.560	175.647	23.1	3.8	0.05
2604121	R	212.941	20060731	223430.13	-39.452	174.950	31.0	2.7	0.26
2727015	N	212.97	20060731	231710.00	-38.751	177.968	35.7	2.3	0.23
2727016	N	213.047	20060801	010725.79	-39.229	177.383	27.8	2.3	0.26
2727017	N	213.067	20060801	013622.35	-39.265	177.356	23.1	2.2	0.31
2604192	R	213.088	20060801	020709.81	-39.410	176.203	5.6	2.9	0.11
2727018	N	213.18	20060801	041936.89	-38.612	178.031	26.8	2.0	0.23
2604274	R	213.236	20060801	053951.65	-41.016	174.552	49.2	2.5	0.21
2604285	R	213.266	20060801	062225.34	-39.688	174.261	143.0	2.9	0.10
2604286	R	213.268	20060801	062559.84	-41.029	173.581	90.3	3.1	0.22
2604297	R	213.294	20060801	070313.89	-40.182	174.886	22.1	3.6	0.18
2604311	R	213.332	20060801	075736.68	-41.152	174.015	56.4	3.0	0.23
2604313	R	213.336	20060801	080313.67	-39.265	175.449	16.7	3.2	0.12
2604327	R	213.371	20060801	085358.07	-41.463	173.547	57.4	2.1	0.22
2604337	R	213.396	20060801	093030.69	-40.546	174.741	19.2	2.6	0.27
2604342	R	213.411	20060801	095219.26	-36.946	178.155	28.0	2.9	0.46
2604362	R	213.464	20060801	110747.92	-40.914	174.681	62.8	2.7	0.22
2727019	N	213.486	20060801	114031.71	-38.384	177.919	31.0	1.9	0.27
2727020	N	213.624	20060801	145823.27	-39.118	177.450	20.5	2.1	0.11
2727066	X	213.747	20060801	17550.00					
2604503	R	213.811	20060801	192832.20	-41.134	174.655	31.2	2.5	0.08
2604588	R	214.002	20060802	000239.45	-39.672	174.065	204.6	3.8	0.28
2604597	R	214.019	20060802	002759.86	-40.555	174.841	10.8	2.7	0.29
2604610	R	214.052	20060802	011450.24	-38.455	178.225	28.7	3.5	0.59
2604637	R	214.113	20060802	024309.45	-38.878	178.045	37.7	3.5	0.17
2604638	R	214.117	20060802	024902.57	-38.022	176.507	3.9	2.9	0.13
2727021	N	214.117	20060802	024905.17	-38.110	176.578	2.0	3.1	1.14
2727067	N	214.127	20060802	030258.81	-38.513	178.271	31.7	1.8	0.05
2727022	N	214.182	20060802	042148.44	-38.494	178.494	28.8	2.7	0.27
2604672	R	214.193	20060802	043804.11	-37.465	177.717	155.7	2.9	0.43
2604719	R	214.287	20060802	065319.38	-37.640	178.380	53.8	2.5	0.08
2604732	R	214.31	20060802	072651.23	-37.550	177.096	147.2	3.1	0.29

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CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2604782	R	214.426	20060802	101332.17	-41.210	173.328	105.7	2.3	0.23
2604828	R	214.533	20060802	124704.46	-40.116	174.262	127.9	3.4	0.25
2727023	N	214.599	20060802	142243.27	-38.079	177.458	41.7	2.4	0.09
2604939	R	214.771	20060802	183046.23	-40.195	174.775	22.4	2.9	0.41
2727024	N	214.853	20060802	202736.11	-37.467	179.338	33.0	3.2	0.15
2605034	R	214.96	20060802	230300.79	-41.071	175.075	26.4	2.6	0.16
2605053	R	214.993	20060802	235037.43	-41.125	174.031	59.8	2.8	0.27
2727025	X	215.023	20060803	00330.00					
2727027	X	215.037	20060803	00540.00					
2727028	N	215.055	20060803	011841.36	-39.158	177.448	27.4	2.3	0.29
2727029	N	215.074	20060803	014607.83	-38.883	177.871	18.6	1.9	0.82
2605111	R	215.116	20060803	024646.24	-40.902	173.605	116.4	3.3	0.26
2727030	N	215.16	20060803	035034.09	-38.562	178.791	100.8	2.5	0.30
2605211	R	215.331	20060803	075651.55	-37.628	175.650	5.0	1.9	0.02
2727031	N	215.356	20060803	083307.52	-38.669	178.472	23.2	2.0	0.40
2605262	R	215.448	20060803	104456.88	-37.997	176.100	163.6	3.7	0.21
2605287	R	215.505	20060803	120651.67	-39.250	173.865	22.4	1.9	0.22
2605353	R	215.654	20060803	154148.49	-39.832	176.745	51.2	2.9	0.23
2605501	R	215.655	20060803	154247.65	-39.847	176.756	56.4	3.1	0.10
2727032	X	215.72	20060803	17170.00					
2727033	N	215.753	20060803	180441.60	-37.971	177.054	72.0	2.3	0.44
2605407	R	215.763	20060803	181912.90	-39.298	173.769	15.6	1.7	0.14
2605410	R	215.77	20060803	182830.74	-39.295	173.769	15.6	1.8	0.14
2605438	R	215.829	20060803	195334.31	-41.145	174.646	33.0	2.4	0.19
2605481	R	215.933	20060803	222329.64	-38.752	177.967	31.3	2.8	0.18
2727034	N	215.968	20060803	231423.04	-38.590	178.460	20.6	1.8	0.20
2727035	X	216.11	20060804	02380.00					
2605587	R	216.121	20060804	025435.10	-40.121	174.288	94.6	3.2	0.16
2727036	N	216.177	20060804	041419.04	-39.123	177.742	23.9	1.9	0.19
2605622	R	216.195	20060804	044025.89	-39.714	177.007	48.6	3.9	0.24
2605639	R	216.242	20060804	054814.89	-39.055	174.044	9.4	1.9	0.0
2727037	X	216.295	20060804	07050.00					
2727038	N	216.329	20060804	075339.67	-38.740	175.515	118.0	2.7	0.10
2727039	X	216.331	20060804	07570.00					
2605716	R	216.399	20060804	093441.40	-38.282	178.412	20.6	3.3	0.27
2605735	R	216.437	20060804	102934.49	-41.098	174.262	67.2	2.8	0.15
2605816	R	216.601	20060804	142558.43	-39.178	174.885	193.0	3.6	0.22
2605848	R	216.665	20060804	155734.01	-38.333	176.055	179.3	3.3	0.16
2605866	R	216.709	20060804	170035.45	-38.384	178.630	17.3	3.1	0.07
2727040	X	216.74	20060804	17460.00					
2605892	R	216.757	20060804	181003.51	-38.221	175.865	184.4	3.8	0.15
2727041	N	216.834	20060804	200053.65	-38.413	175.460	139.0	3.1	0.14
2605937	R	216.852	20060804	202730.08	-38.268	176.174	161.0	3.5	0.21
2727042	N	217.034	20060805	004815.61	-38.273	177.801	22.8	1.6	0.16

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CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2727043	N	217.039	20060805	005620.56	-39.238	177.384	26.7	2.0	0.19
2727044	N	217.183	20060805	042408.21	-38.197	178.142	22.6	1.8	0.24
2727046	N	217.273	20060805	063252.36	-38.454	178.228	25.9	2.3	0.23
2727047	N	217.38	20060805	090739.95	-37.395	177.652	112.1	2.6	1.07
2727048	N	217.402	20060805	093812.98	-39.141	178.635	5.0	2.4	0.22
2606188	R	217.418	20060805	100215.84	-41.143	174.374	36.8	2.3	0.18
2606215	R	217.493	20060805	115028.54	-38.483	178.237	27.8	3.3	0.24
2727049	N	217.519	20060805	122708.69	-38.470	178.264	30.4	1.7	0.32
2606238	R	217.54	20060805	125754.55	-39.307	175.043	29.5	2.3	0.12
2727050	N	217.545	20060805	130430.20	-38.507	178.295	31.1	2.2	0.07
2606246	R	217.554	20060805	131712.55	-40.992	174.059	80.8	3.0	0.18
2606248	R	217.556	20060805	131956.71	-39.628	173.999	201.2	3.3	0.27
2606298	R	217.663	20060805	155502.44	-38.596	177.813	31.2	3.3	0.27
2606333	R	217.728	20060805	172831.91	-40.024	175.064	24.5	3.1	0.25
2727051	N	217.879	20060805	210559.75	-37.135	177.615	6.3	3.2	0.89
2727052	N	217.993	20060805	234925.55	-38.054	177.935	32.8	2.5	0.33
2606539	R	218.139	20060806	032033.95	-39.214	175.475	92.6	3.4	0.12
2727053	N	218.324	20060806	074634.47	-38.336	178.142	42.7	2.6	0.21
2727054	N	218.384	20060806	091337.93	-37.785	177.917	69.5	2.8	0.14
2606668	R	218.404	20060806	094218.06	-40.640	174.918	33.7	2.8	0.19
2727055	N	218.415	20060806	095744.55	-38.550	178.273	31.7	1.8	0.08
2727057	N	218.795	20060806	190519.94	-38.409	178.722	30.1	2.2	0.28
2606867	R	218.867	20060806	204904.05	-39.185	176.065	12.0	2.2	0.23
2606895	R	218.928	20060806	221651.45	-39.514	175.720	14.6	1.4	0.05
2606960	R	219.064	20060807	013138.63	-40.109	174.933	19.3	2.5	0.30
2607029	R	219.19	20060807	043324.44	-41.367	174.949	28.7	2.4	0.10
2607092	R	219.352	20060807	082616.78	-37.178	176.839	250.6	4.0	0.08
2607166	R	219.539	20060807	125651.08	-40.370	175.354	43.0	2.9	0.27
2607187	R	219.58	20060807	135452.06	-37.059	177.646	183.3	3.4	0.46
2607192	R	219.591	20060807	141125.78	-39.277	173.942	21.5	1.9	0.13
2607218	R	219.649	20060807	153411.08	-39.406	175.884	55.8	2.5	0.17
2607233	R	219.699	20060807	164554.60	-40.636	174.264	88.9	3.3	0.26
2607283	R	219.832	20060807	195738.14	-38.095	179.234	11.0	3.7	0.34
2607289	R	219.848	20060807	202133.87	-40.172	174.998	13.1	2.9	0.36
2607485	R	220.271	20060808	063048.14	-39.313	177.303	42.8	2.5	0.08
2607500	R	220.31	20060808	072636.46	-40.308	176.170	46.6	2.8	0.31
2607509	R	220.326	20060808	074908.77	-39.367	176.396	69.9	3.1	0.12
2607544	R	220.396	20060808	092955.93	-41.525	173.254	92.1	2.6	0.20
2607549	R	220.413	20060808	095525.41	-38.558	177.826	20.6	2.5	0.32
2607556	R	220.429	20060808	101812.68	-38.094	176.737	4.6	2.3	0.22
2607565	R	220.45	20060808	104729.22	-41.651	173.926	9.9	2.8	0.23
2607637	R	220.586	20060808	140308.07	-37.973	176.395	149.5	3.8	0.14
2607638	R	220.587	20060808	140516.56	-40.124	174.974	24.4	2.8	0.19
2607761	R	220.836	20060808	200406.83	-39.493	175.746	17.1	1.9	0.02

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CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2607769	R	220.851	20060808	202456.94	-39.461	175.726	15.3	2.1	0.10
2607773	R	220.858	20060808	203606.84	-40.113	174.965	22.9	2.5	0.32
2607792	R	220.897	20060808	213209.39	-39.092	174.962	220.1	3.9	0.28

Appendix D

2006 Gisborne relocated hypocentres

Table D.1: **Relocated earthquake hypocentres** from the 2006 Gisborne slow slip event. CUSP ID is the unique event identifier and JDay is the Julian day of year.

CUSP ID	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)
2726812	190.39184	20060709	092415.33	-37.937	177.815	60.57	2.9
2726815	190.59499	20060709	141646.87	-38.541	177.623	39.61	3.2
2726818	191.11272	20060710	024219.34	-38.554	177.890	17.41	2.0
2726819	191.13282	20060710	031115.48	-37.907	178.611	17.33	2.3
2726822	191.32332	20060710	074534.57	-38.862	177.453	52.74	2.1
2726825	191.60479	20060710	143054.11	-37.883	176.377	193.93	2.9
2726826	191.97813	20060710	232830.34	-38.364	175.679	142.02	2.9
2726828	192.15834	20060711	034800.56	-38.558	177.848	16.04	2.1
2726829	192.41688	20060711	100018.66	-38.755	178.796	25.17	2.8
2726830	192.55548	20060711	131953.53	-38.568	177.847	18.54	2.2
2726831	192.73134	20060711	173308.05	-38.947	177.945	6.52	2.3
2726833	193.10652	20060712	023323.67	-38.654	178.510	4.58	3.3
2726834	193.21990	20060712	051639.62	-38.175	176.801	23.85	2.2
2726837	193.37341	20060712	085742.55	-39.041	177.923	4.67	2.3
2726838	193.38939	20060712	092043.28	-39.072	177.923	5.69	2.0
2726840	193.63384	20060712	151243.53	-37.723	178.686	14.57	3.0
2726842	193.71309	20060712	170650.76	-37.949	176.860	3.63	2.6
2726843	193.79194	20060712	190023.52	-38.487	177.430	0.40	2.0
2726849	194.12744	20060713	030330.80	-38.919	177.793	8.66	2.3
2726851	194.50112	20060713	120137.07	-39.100	177.935	7.41	2.8

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CUSP ID	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)
2726853	194.58473	20060713	140200.66	-38.040	176.859	79.31	3.3
2726854	194.66487	20060713	155725.04	-38.469	177.469	19.76	2.0
2726860	194.78869	20060713	185542.84	-38.565	178.586	11.45	3.1
2726861	194.79978	20060713	191140.60	-39.529	175.844	32.39	2.7
2726862	195.22898	20060714	052943.84	-39.400	177.332	41.10	2.6
2726865	195.39446	20060714	092801.49	-38.327	175.893	172.43	3.0
2726867	196.10225	20060715	022714.03	-37.857	177.643	55.34	3.3
2726868	196.42312	20060715	100917.14	-39.009	177.919	9.91	2.7
2726872	196.68874	20060715	163147.44	-38.602	177.868	16.99	2.5
2726873	196.70906	20060715	170102.59	-38.638	177.752	1.73	2.6
2726874	196.84538	20060715	201721.11	-39.100	178.057	5.80	3.2
2726875	196.86697	20060715	204826.04	-38.524	178.064	23.42	3.2
2726876	196.91791	20060715	220147.30	-38.638	177.792	8.89	3.2
2726877	197.18469	20060716	042556.97	-38.886	177.933	24.97	2.4
2726878	197.25773	20060716	061107.97	-39.005	178.116	33.51	2.6
2726879	197.30359	20060716	071710.38	-37.666	177.884	79.43	3.9
2726881	197.31550	20060716	073418.83	-38.185	178.264	22.71	3.8
2726882	197.32143	20060716	074251.52	-38.194	178.274	17.82	3.1
2726883	197.48943	20060716	114447.12	-39.116	178.103	5.74	3.0
2726886	197.70339	20060716	165252.53	-38.403	176.794	67.05	2.4
2726887	197.82977	20060716	195451.79	-38.511	178.051	15.45	3.4
2726891	198.47583	20060717	112511.29	-38.609	177.871	26.98	3.2
2726895	198.79955	20060717	191121.19	-36.862	177.118	295.80	3.1
2726897	198.93342	20060717	222407.80	-39.102	177.772	13.75	2.3
2726903	199.35227	20060718	082716.02	-37.926	176.359	133.08	2.9
2726905	199.60006	20060718	142405.21	-39.174	177.862	11.03	1.8
2726908	199.98475	20060718	233802.36	-38.346	177.669	31.74	2.3
2726916	202.15353	20060721	034105.04	-38.938	177.512	19.14	2.5
2726917	202.67195	20060721	160736.52	-38.890	177.580	19.44	3.5
2726919	203.21452	20060722	050854.54	-38.707	177.840	21.27	2.1
2726920	203.31004	20060722	072627.39	-38.189	177.017	63.31	2.6
2599573	203.38048	20060722	090753.60	-38.117	175.622	149.93	3.2
2726923	203.50880	20060722	121240.51	-39.303	177.938	56.39	2.5
2726924	203.76144	20060722	181628.29	-38.896	177.556	19.40	2.7
2726925	204.07314	20060723	014519.11	-38.552	177.880	22.15	2.2
2726928	204.58484	20060723	140209.75	-38.905	178.893	22.08	2.2
2726930	204.82664	20060723	195021.32	-37.701	178.324	44.09	2.5
2726932	204.90336	20060723	214050.63	-38.658	177.751	17.96	2.4
2726933	204.95685	20060723	225752.08	-37.704	178.358	42.80	2.3
2726934	205.11941	20060724	025157.45	-38.085	175.684	157.08	3.0
2726935	205.16850	20060724	040238.51	-38.051	175.991	141.20	2.7
2726936	205.32968	20060724	075444.05	-38.757	177.952	34.63	2.0
2726939	205.61727	20060724	144852.55	-38.699	177.704	23.64	2.0
2726941	205.76943	20060724	182758.82	-38.346	176.988	52.83	3.0

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CUSP ID	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)
2726943	205.97119	20060724	231830.41	-38.510	177.801	24.10	2.3
2726944	206.02492	20060725	003553.50	-37.263	178.006	93.73	2.4
2726945	206.05879	20060725	012439.54	-39.099	177.401	14.25	2.8
2726946	206.07177	20060725	014320.70	-38.494	179.092	5.20	2.7
2726947	206.12659	20060725	030217.01	-36.724	177.765	129.07	2.7
2726948	206.13191	20060725	030956.75	-38.490	177.810	28.73	2.1
2726949	206.26242	20060725	061753.33	-39.055	177.945	10.91	1.8
2726950	206.35289	20060725	082809.40	-38.562	178.971	24.61	2.2
2726951	206.35715	20060725	083417.61	-38.582	179.137	19.59	2.3
2726953	206.47027	20060725	111711.56	-38.575	179.046	20.86	2.9
2726954	206.48537	20060725	113856.01	-38.536	179.081	24.84	2.2
2726958	206.57367	20060725	134605.19	-39.282	174.166	205.16	2.9
2726960	206.99305	20060725	234959.37	-38.159	178.291	16.29	2.2
2726961	207.08813	20060726	020654.52	-39.328	177.508	8.73	2.9
2726963	207.54591	20060726	130606.64	-36.985	177.262	166.08	3.2
2726965	207.65356	20060726	154107.24	-38.604	178.988	10.67	2.3
2726971	208.27759	20060727	063943.72	-38.125	178.954	15.61	2.5
2726972	208.41717	20060727	100043.75	-38.682	177.987	25.87	2.4
2726973	208.49210	20060727	114837.31	-37.675	176.832	132.77	2.6
2726976	208.75486	20060727	180659.99	-39.267	177.338	5.80	2.2
2726977	208.76319	20060727	181859.65	-39.274	177.355	6.24	2.2
2726978	208.94042	20060727	223412.12	-38.591	177.903	37.16	2.1
2726979	208.98739	20060727	234150.23	-38.337	178.089	25.74	1.9
2726981	209.22094	20060728	051809.56	-38.587	178.876	25.41	2.7
2726982	209.39522	20060728	092907.41	-37.960	178.707	31.41	2.2
2726983	209.67155	20060728	160702.33	-37.643	178.048	53.15	2.5
2726984	209.79688	20060728	190730.61	-38.889	177.922	33.73	1.9
2726985	209.86958	20060728	205211.92	-37.999	176.518	23.71	2.6
2726988	209.95250	20060728	225135.79	-38.608	177.844	18.76	2.2
2726989	209.99205	20060728	234832.90	-38.571	179.037	14.01	2.2
2726990	210.00282	20060729	000404.05	-37.611	178.262	37.50	2.9
2726991	210.09691	20060729	021933.39	-38.773	177.933	23.22	1.5
2726992	210.24874	20060729	055810.96	-37.835	178.143	32.01	2.2
2726993	210.62943	20060729	150622.69	-39.112	177.724	14.30	2.2
2726994	210.63942	20060729	152046.22	-38.617	178.822	28.96	2.4
2726996	211.15368	20060730	034117.56	-38.507	177.787	28.87	1.6
2726998	211.26940	20060730	062755.88	-39.321	177.276	28.29	2.0
2727000	211.50198	20060730	120251.42	-38.785	177.928	21.59	2.0
2727001	211.66658	20060730	155952.38	-38.182	178.261	19.28	2.3
2727006	211.89685	20060730	213127.65	-38.592	178.886	20.48	2.4
2727008	212.25540	20060731	060746.40	-38.569	179.001	16.49	2.4
2727009	212.26647	20060731	062343.29	-38.545	178.918	10.10	2.4
2727010	212.54636	20060731	130645.42	-38.753	177.786	40.01	2.0
2727013	212.70008	20060731	164807.15	-37.215	177.382	133.74	2.7

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CUSP ID	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)
2727014	212.90116	20060731	213740.13	-38.027	176.892	1.75	2.4
2727015	212.97025	20060731	231710.02	-38.741	177.969	33.74	2.3
2727016	213.04682	20060801	010725.48	-39.231	177.364	16.00	2.3
2727018	213.18028	20060801	041936.31	-38.610	178.053	27.11	2.0
2727019	213.48648	20060801	114031.54	-38.384	177.938	26.78	1.9
2727020	213.62388	20060801	145822.86	-39.137	177.475	17.98	2.1
2727022	214.18182	20060802	042149.10	-38.408	178.421	18.72	2.7
2727023	214.59912	20060802	142243.74	-38.220	177.429	43.76	2.4
2727028	215.05465	20060803	011841.33	-39.151	177.444	20.07	2.3
2727030	215.16012	20060803	035034.73	-38.779	178.783	92.83	2.5
2727033	215.75327	20060803	180442.47	-38.094	177.148	72.41	2.3
2727034	215.96832	20060803	231422.99	-38.583	178.400	23.78	1.8
2727036	216.17661	20060804	041419.33	-39.094	177.759	16.33	1.9
2727038	216.32892	20060804	075338.92	-38.795	175.271	110.12	2.7
2727041	216.83394	20060804	200052.06	-38.535	175.317	163.13	3.1
2727042	217.03351	20060805	004815.12	-38.303	177.816	23.13	1.6
2727043	217.03912	20060805	005619.96	-39.231	177.367	12.36	2.0
2727044	217.18343	20060805	042408.05	-38.214	178.123	16.19	1.8
2727046	217.27283	20060805	063252.14	-38.454	178.219	22.27	2.3
2727049	217.51885	20060805	122709.06	-38.458	178.224	22.90	1.7
2727050	217.54480	20060805	130430.97	-38.465	178.227	23.57	2.2
2727052	217.99265	20060805	234925.31	-38.096	177.952	32.22	2.5
2727053	218.32402	20060806	074635.02	-38.333	178.099	31.13	2.6
2727054	218.38447	20060806	091338.09	-37.771	177.923	60.07	2.8
2727057	218.79538	20060806	190520.54	-38.401	178.670	18.74	2.2
2727061	207.80998	20060726	192622.28	-38.545	179.210	15.40	2.3
2727067	214.12708	20060802	030259.60	-38.471	178.224	23.27	1.8

Appendix E

2005 Manawatu earthquake hypocentres

Table E.1: **Earthquake hypocentres** from part of the 2004–2005 Manawatu slow slip event. CUSP ID is the unique event identifier, TYPE: N are newly detected earthquakes, T are newly detected teleseisms, and X are local noise or earthquakes too small to locate, JDay is the Julian day of year. Waveform data is available from http://www.geonet.org.nz

CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2709554	N	1.09332	20050101	021423.22	-40.027	176.726	41.4	1.7	0.19
2709559	X	1.10556	20050101	02320.00					
2709561	N	1.17773	20050101	041556.09	-41.860	173.387	42.6	2.7	0.23
2709562	X	1.61181	20050101	14410.00					
2709564	N	1.72407	20050101	172239.33	-40.170	174.846	22.7	1.9	0.27
2709566	X	1.76319	20050101	18190.00					
2709567	N	1.85244	20050101	202730.63	-38.654	178.701	97.2	3.3	0.17
2709569	N	1.89757	20050101	213229.98	-40.627	176.163	23.7	2.2	0.17
2709570	N	1.94248	20050101	223710.03	-39.633	176.854	12.0	1.9	0.20
2709572	X	2.24375	20050102	05510.00					
2709573	X	2.77292	20050102	18330.00					
2709575	X	2.88264	20050102	21110.00					
2709577	N	3.04984	20050103	011146.08	-39.350	174.961	31.7	1.6	0.23
2709579	N	3.08125	20050103	015659.78	-40.018	177.039	17.3	2.7	0.46
2709581	X	3.36458	20050103	08450.00					
2709583	N	3.6309	20050103	150829.80	-39.523	176.616	64.1	2.3	0.24
2709585	X	3.73264	20050103	17350.00					

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CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2709587	N	3.8051	20050103	191920.52	-38.621	177.072	12.0	2.8	0.28
2709590	N	4.13719	20050104	031733.07	-41.001	175.439	24.4	1.6	0.01
2709591	X	4.14167	20050104	03240.00					
2709593	N	4.15008	20050104	033607.22	-39.918	176.734	26.1	1.9	0.27
2709595	N	4.40453	20050104	094231.41	-41.601	174.855	29.3	2.4	0.19
2709598	X	4.58889	20050104	14080.00					
2709600	X	4.89792	20050104	21330.00					
2709602	N	5.05918	20050105	012513.24	-40.692	175.876	32.9	1.7	0.17
2709604	N	5.42839	20050105	101652.74	-38.502	176.002	168.7	3.6	0.29
2709606	X	5.5125	20050105	12180.00					
2709607	N	5.69139	20050105	163535.67	-39.084	175.803	107.0	2.8	0.23
2709610	N	5.76282	20050105	181827.33	-40.359	176.336	21.5	1.7	0.29
2709611	X	5.76597	20050105	18230.00					
2709614	N	5.91532	20050105	215803.39	-40.319	176.726	32.0	2.4	0.18
2709616	N	5.93934	20050105	223239.27	-40.538	175.803	33.2	1.5	0.13
2709618	N	6.17226	20050106	040803.49	-40.822	176.244	27.2	1.7	0.48
2709621	N	6.38331	20050106	091158.20	-41.088	175.032	27.8	2.2	0.06
2709623	N	6.41198	20050106	095314.96	-40.590	176.178	27.0	1.6	0.12
2709625	X	6.60139	20050106	14260.00					
2709626	X	6.62014	20050106	14530.00					
2709628	X	6.72847	20050106	17290.00					
2709631	X	6.74375	20050106	17510.00					
2709632	N	6.75207	20050106	180258.51	-39.827	176.647	22.6	2.4	0.32
2709633	N	6.84151	20050106	201146.30	-38.546	175.059	5.0	2.2	0.62
2709635	X	7.06806	20050107	01380.00					
2709638	X	7.11042	20050107	02390.00					
2709639	X	7.36181	20050107	08410.00					
2709641	X	7.45903	20050107	11010.00					
2709644	N	7.46715	20050107	111242.08	-38.839	175.719	120.1	2.7	0.18
2709647	X	7.47014	20050107	11170.00					
2709649	N	7.57385	20050107	134620.77	-38.780	175.720	143.5	2.8	0.22
2709652	X	7.71528	20050107	17100.00					
2709654	N	7.87937	20050107	210617.31	-41.771	174.491	30.3	2.4	0.21
2709656	N	7.97142	20050107	231850.75	-39.481	175.685	12.9	1.9	0.01
2709658	N	8.05117	20050108	011341.51	-39.446	176.066	40.1		0.43
2709660	N	8.32475	20050108	074738.74	-39.871	176.754	30.1	2.5	0.21
2709661	N	8.34234	20050108	081258.44	-38.942	175.900	104.9	3.0	0.14
2709663	X	8.36736	20050108	08490.00					
2709664	N	8.4143	20050108	095635.83	-41.658	174.659	48.5	2.1	0.09
2709667	N	8.8269	20050108	195044.20	-41.729	174.489	30.3	2.5	0.33
2709669	X	9.09097	20050109	02110.00					
2709671	N	9.11299	20050109	024242.66	-40.990	175.406	29.0	1.5	0.06
2709672	N	9.22405	20050109	052237.74	-39.182	176.131	70.4		0.20
2709674	X	9.32361	20050109	07460.00					

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CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2709675	N	9.3271	20050109	075101.11	-40.166	176.839	20.9	2.0	0.38
2709677	X	9.41042	20050109	09510.00					
2709678	X	9.67431	20050109	16110.00					
2709680	N	10.3499	20050110	082354.45	-41.503	175.689	17.7	1.6	0.16
2712262	N	10.3502	20050110	082421.43	-41.025	175.384	18.6	1.3	0.29
2709681	X	10.5431	20050110	13020.00					
2709683	N	10.6986	20050110	164555.48	-40.699	176.324	29.7	2.1	0.09
2709685	N	10.9805	20050110	233155.00	-39.691	176.470	12.0	1.7	0.33
2709687	N	11.1002	20050111	022417.83	-41.550	175.647	18.5	1.9	0.18
2709688	N	11.138	20050111	031844.18	-40.466	176.600	20.4	2.0	0.13
2709689	X	11.3139	20050111	07320.00					
2709692	X	11.3611	20050111	08400.00					
2709694	N	11.4725	20050111	112021.94	-38.738	176.180	109.2	2.7	0.13
2709696	N	11.5919	20050111	141217.73	-39.686	176.400	29.0	1.6	0.16
2709697	X	11.6188	20050111	14510.00					
2709698	N	11.7547	20050111	180650.05	-40.623	175.728	28.8	1.6	0.07
2709700	N	12.1025	20050112	022735.81	-40.248	177.007	61.5	2.1	0.35
2709701	X	12.2771	20050112	06390.00					
2709703	X	12.2951	20050112	07050.00					
2709707	X	12.5694	20050112	13400.00					
2709708	N	12.9923	20050112	234853.85	-40.450	174.794	26.4	2.0	0.31
2709709	N	13.0701	20050113	014056.66	-38.692	175.564	162.0	3.4	0.17
2709711	X	13.3153	20050113	07340.00					
2709713	N	13.494	20050113	115123.07	-41.288	175.284	25.5	1.7	0.07
2709715	N	14.144	20050114	032720.21	-40.836	175.195	33.8	1.8	0.08
2709717	N	14.1524	20050114	033930.68	-40.824	176.206	27.0	2.1	0.19
2709719	N	14.1585	20050114	034814.76	-40.840	175.900	28.4	1.7	0.19
2709721	N	14.1719	20050114	040731.79	-39.896	176.824	25.5	1.7	0.22
2709722	N	14.3535	20050114	082900.03	-41.013	175.422	24.1	1.8	0.06
2709723	X	14.4319	20050114	10220.00					
2709725	N	14.4387	20050114	103147.48	-40.605	175.731	27.0	1.8	0.19
2709727	X	14.6049	20050114	14310.00					
2709729	X	15.0437	20050115	01030.00					
2709731	X	15.2153	20050115	05100.00					
2709732	X	15.8313	20050115	19570.00					
2709735	N	15.9392	20050115	223226.82	-40.563	176.452	21.9	1.7	0.08
2709738	N	16.0263	20050116	003754.17	-40.531	175.817	30.2	1.8	0.13
2709739	N	16.0633	20050116	013106.29	-41.033	175.358	13.2	1.4	0.09
2709741	N	16.2913	20050116	065929.23	-36.230	178.490	150.3	3.6	0.31
2709742	N	16.4694	20050116	111600.30	-40.892	175.474	26.3	1.8	0.14
2709744	N	16.5906	20050116	141025.11	-40.642	176.376	30.2	2.1	0.04
2709745	N	16.6897	20050116	163310.45	-40.261	176.461	30.0	1.9	0.30
2709748	N	16.9274	20050116	221525.88	-38.627	175.685	177.6	3.7	0.29
2709751	N	17.0036	20050117	000511.54	-40.338	176.287	37.0	1.9	0.12

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CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2709752	X	17.2451	20050117	05530.00					
2709754	N	17.6103	20050117	143846.40	-40.511	175.950	30.4	1.8	0.03
2709756	X	18.0813	20050118	01570.00					
2709758	X	18.4	20050118	09360.00					
2709760	N	18.4049	20050118	094302.90	-41.478	175.867	11.7	1.9	0.09
2709761	N	18.8257	20050118	194902.02	-41.434	175.785	12.1	1.7	0.10
2709762	N	19.7599	20050119	181419.64	-39.277	173.560	5.0	2.3	0.17
2709764	N	19.9589	20050119	230048.56	-41.441	175.673	5.0	1.7	0.13
2709767	X	20.0917	20050120	02120.00					
2709770	N	20.6265	20050120	150208.26	-41.451	175.717	10.7	1.7	0.15
2709771	N	22.1488	20050122	033413.40	-40.696	175.425	12.5	1.8	0.16
2709773	N	24.0009	20050124	000114.48	-39.740	176.836	17.8	1.8	0.19
2709774	X	24.4653	20050124	11100.00					
2709776	N	24.7858	20050124	185130.90	-39.343	176.159	59.9		0.15
2709778	N	24.837	20050124	200516.94	-41.105	175.045	26.8	1.7	0.31
2709779	N	24.8708	20050124	205354.75	-40.325	176.069	32.9	1.2	0.09
2712742	N	24.8726	20050124	205631.43	-40.526	175.945	23.3	1.7	0.14
2709781	X	25.0611	20050125	01280.00					
2709783	N	25.4916	20050125	114751.64	-38.983	175.535	119.9	2.4	0.41
2709786	N	26.6498	20050126	153541.92	-41.104	175.020	29.4	1.6	0.11
2709787	N	26.8133	20050126	193112.36	-40.756	176.219	27.5	2.2	0.11
2709789	N	26.8319	20050126	195756.78	-41.396	175.673	11.7	1.9	0.25
2713048	N	26.8322	20050126	195825.50	-41.085	175.062	26.0	1.9	0.16
2709791	N	27.2703	20050127	062916.34	-41.087	175.035	29.3	1.7	0.18
2709792	N	27.3801	20050127	090718.68	-41.089	175.053	26.4	1.7	0.14
2709793	N	27.6788	20050127	161725.29	-41.417	175.759	11.1	1.5	0.11
2709795	X	28.5035	20050128	12050.00					
2709797	X	28.8201	20050128	19410.00					
2709799	N	28.8864	20050128	211628.81	-38.697	175.797	164.7	3.0	0.19
2709800	X	29.2354	20050129	05390.00					
2709802	X	29.2806	20050129	06440.00					
2709803	X	29.4583	20050129	11000.00					
2709806	N	29.4923	20050129	114857.04	-40.943	175.406	23.6	1.6	0.10
2709809	X	29.7979	20050129	19090.00					
2709811	X	29.9278	20050129	22160.00					
2709812	N	30.1164	20050130	024741.06	-41.435	175.788	14.5	1.5	0.17
2709814	N	30.2602	20050130	061440.38	-40.205	174.741	17.7	2.1	0.13
2709816	N	30.4114	20050130	095224.15	-39.133	173.872	13.0	1.7	0.15
2709817	N	31.0318	20050131	004547.46	-39.795	176.877	23.1	1.7	0.31
2709819	X	31.2306	20050131	05320.00					
2709820	N	31.9535	20050131	225306.15	-41.422	175.767	11.9	1.8	0.14
2709822	N	31.9663	20050131	231129.25	-41.429	175.767	13.0	1.8	0.10
2709823	X	32.0556	20050201	01200.00					
2709824	N	32.0634	20050201	013120.28	-41.465	175.741	11.6	1.6	0.19

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CUSP ID	TYPE	JDay	yyyymmdd	hhmmss.ss	Latitude	Longitude	Depth (km)	Mag. (M_L)	RMS (s)
2709826	N	32.0776	20050201	015143.46	-41.448	175.757	5.0	1.4	0.08
2709827	N	32.1762	20050201	041347.26	-41.462	175.766	10.7	1.7	0.16
2709829	N	32.5308	20050201	124421.12	-39.458	176.952	18.2	1.6	0.17
2709830	X	32.6028	20050201	14280.00					
2709831	N	32.6101	20050201	143831.62	-41.429	175.742	12.7	1.4	0.15