Article

Not peer-reviewed version

Citizen Science and the University of Queensland Seis-Mo-Graph Stations (UQSS) – A Study of Seismic T Waves in S-W Pacific Ocean

Colin John Lynam * , Steve Hearn , Asanka Karunaratne

Posted Date: 25 May 2023

doi: 10.20944/preprints202305.1765.v1

Keywords: citizen science; seismology; earth observation; climate change; education for sustainable development; disaster preparedness; disaster alerts

doi:10.20944/preprints202305.1765.v1

Article

Citizen Science and The University of Queensland Seismo-Graph Stations (UQSS)-A Study of Seismic T Waves in S-W Pacific Ocean

Colin John Lynam [1], Steve Hearn [2] and Asanka Karunaratne [3]

[1] Royal Society of Queensland 1; col.lynam@gmail.com
[2] University of Queensland 2; steveh@velseis.com
[3] Brisbane State High School asanka@idestiny.com.au
* Correspondence: col.lynam@gmail.com; Tel.: (+61 438 339 221)

Abstract: This paper summarises an early and successful piece of citizen science, performed within The University of Queensland Seismograph Stations (UQSS) observatory, in cooperation with colleagues at CSIRO. It was designed to encourage young STEM students from Brisbane high schools to engage in "real" research, back in 1995. Having completed the project report, their (analog) results sat in a cupboard until the report was dusted off and the project was re-analysed in 2022 by an honors student, considering timely climate change applications for the study. This is a time when science is changing considerably from analog to digital medium and operational methods. The original project was called *Earthquake generated T phases on BRS Seismograph (Brisbane, Q'ld)- a predictor for Tasman Sea Tsunamis?* [1] Fortunately, seismology is a very collaborative field. The research question has since changed. There is a lot of data analysis involved in the science of recording earthquake signals, with auxiliary definitive catalogues, observers logbooks, housing of the recordings themselves (analog and digital) and the software mediums that change over time. In other words, a lot of headaches can be encountered in longitudinal data collection study such as this. The citizen science students used a pre-prepared decadal collection (1980-90) derived from the BRS observatory data catalogue. BRS is part of the global World-Wide Seismograph Station Network (WWSSN). Currently in Australia, university earth science observatories have diminished, and in their place, public seismic networks (PSN) have evolved, either in backyard sheds or school science labs. The level of expertise required fits the role of advancing citizen science for a real science advantage. This is a topical citizen disaster preparedness action area for today's climate emergency, which is threatening the globe and all lifeforms. Citizen engagement or mobilisation is an essential preparedness strategy.

Keywords: citizen science; seismology; earth observation; climate change; education for sustainable development; disaster preparedness; disaster alerts

1. Introduction

This story begins in 1995 and it concludes with a successful joint CSIRO Double Helix student research project with The University of Queensland Seismograph Stations (UQSS). The data and findings were tantalising and were archived. In 2021, the authors resurrected the data and began working with a larger digital earthquake database (ISC). This now raised the larger research question of: Would climate change effects in the oceans change the transmission velocity of earthquake T waves? If so, how could T waves, be used to measure climate change?

This paper exemplifies the application of education for sustainable development (ESD)? This is UNESCO's education sector's response to the urgent and dramatic challenges that the planet faces. The collective activities of human beings have so altered the earth's ecosystems that our very survival seems in danger because reparation strategies become more difficult to reverse every day. To contain global warming before it reaches catastrophic levels means addressing environmental, social, and economic issues in a holistic way. [2].

In Europe, implementation of the citizen science connection recognizes that "It is thus crucial to train the (local and national) population enabling them to increase their preparedness for disasters and, consequently, improve society's resilience." The European-Mediterranean Seismological Centre (EWSC) operates a global social media earthquake reporting system called @LastQuake. [3].

In the USA, we see the implementation of "ShakeAlert" that utilises the sensors in a mobile phone to both detect earthquakes (if enabled by the citizen owner) and also, give an early advance warning to threatened populations. [4].

In Australia, the first major government sponsored citizen science seismology research was the Australian Seismometers in Schools program [5], which was initially a four-year project (2011-2014) funded by the Geophysical Education Observatory component of AuScope Australian Geophysical Observing System (AGOS) funded by the Federal Government, under the Education Infrastructure Scheme. It is still operating today. The Auscope main page can be found at www.auscope.org.au. Another university based seismic monitoring exists at the Centre for Geomechanics (UWA) which was set up as a "public seismic network". [6].

More recently, the reverse is happening within universities. With post-Covid downsizing of universities and the casualisation of academic staff contributing to a knowledge malaise in the earth science and environmental teaching and research sector, there is now a paucity of extension projects to manage citizen science. This is indicative of systems not recovering from a major threat to their routines.

Australian Learned Societies would seem to be the only long-term operating platforms utilising naturalist volunteer activity. There are existing citizen organised "public seismic networks". Citizen scientists run the Seismological Association of Australia [7] which has an active instrument array in South Australia. Professional organisations such as Engineers Australia seem disinterested in engaging with volunteer citizen science, most probably because they have strict membership codes.

Raspberry Shake is globally growing commercial program appealing to amateur Australian citizens and teachers. Their stated mission is to "become the largest publicly available streaming seismic network in every country" [8]. The commercial venture proves the interest of citizens becoming amateur seismologists.

In 1995, two Brisbane Year 12 high school students investigated this UQSS study - believed to be the first of its kind in Australia using earthquake sound waves to predict tsunamigenic areas in the Tasman Sea affecting eastern Australia. Ms. Lahey and Mr. Karunaratne chose the seismology project from among topics listed with the CSIRO Student Research Scheme, a national program which allows selected senior secondary students to participate in small-scale research projects supervised by practicing scientists in research laboratories.

In 1995 Mr. Lynam (UQ Earth Sciences Senior Technical Officer) said the "University was happy to participate in the scheme to arouse the students' scientific research skills and foster the inquisitive excitement necessary for the potential scientists of tomorrow." He said the project also gave the students exposure to The University of Queensland's role as part of a world-wide earthquake monitoring network which has been operating since 1937. The UQSS recorded earthquakes on its two World Wide Standard Station Network (WWSSN) observatories located at Charters Towers (CTAO) and Mt Nebo (BRSA) in a globally co-operative venture with the U.S. Coastal and Geodetic Survey, the U.S. National Disaster Centre, and the Australian Seismological Centre (now Geosciences Australia). More recently the global supervisory role of CTBTO operates the global network whose chief focus is as a nuclear detection International Monitoring System and deterrent.

Observations of the Tasman Sea T (tertiary) wave occurrences were made routinely by observors at The UQSS (now defunct ~2005). They are one of nature's fractal measurement oddities, because their complexity changes with the measurement scale used. T waves are simply described as acoustic wave energy, travelling in the Sofar layer of oceans (~1Km depth). This oceanic phenomenon is an inversion layer interfaced by temperature, salinity, and pressure. T waves are observed in acoustic ocean bottom sensors (OBS) or on land-based seismograph recorders. Marine mammals also communicate in this ocean inversion layer medium. Its low attenuation properties transmit sound for 10,000 Km or more.

These T waves occur when a massive subduction fault movement generates earthquake energy which radiates out as seismic P waves through the earth's inner geological structures. Sometimes (depending on refraction), such impinging seismic P waves will strike the interface between the sloping continental shelf and ocean. The refracted energy will "leak" from many points along that wavefront into a specific ocean inversion layer – the Sofar inversion layer (~1Km depth). This energy will transmit as an acoustic sound, unattenuated, and arrive at another continental slope, refracting itself, at the correct angle, into an earthquake P wave again. Hence, the multi refractions and mediums give rise to complex transformation algorithms that must account for temperature, salinity, geophysics, oceanography, thermometry, and possibly climate change.

Should you live nearby an impinging T wave train, you may experience what you thought was a nearby earthquake [9]. Similar "sound" inversions happen in the air above oceans and are reported as "Barisal guns". Nature is indeed both fascinating and kind to seismologists.

The UQSS pilot study initially included analysis of previously recorded earthquake T wave data and correlation with aberrations registered on tide gauges. While checking tide records held in the Queensland Department of Transport Tidal Records section, Mr. Lynam and the students coincidentally discovered a link between an Indonesian earthquake and a tsunami affecting a tide gauge in Weipa (Cape York). The T wave data however could not be conclusively associated with tide gauge recordings of earthquake generated tsunami. This was a "null" outcome for an old theory.

The surprise outcome of the citizen science project was the collection, mapping and realisation of the travel path and velocity of T waves in the Tasman Sea. This was indeed a unique suite of geophysical data that linked subduction earthquakes and their crustal noise (land path), to a leakage transmission of energy through oceans (water path), then refracting back into a land path on continental shelves. The geographic location makes this pilot study unique in the S.W Pacific geophysics. New research is also added to fascinate the reader. No conclusions are arrived at – only more potential research questions.

2. Materials and Methods

2.1. Citizen science influences of the UQSS

Citizen science reporting has been an essential feature of the operation of the UQSS, since as far back as 1953 [9] when the then Director of UQSS, the late Dr Owen Jones and UQSS technician, Mr. A Crawfoot, built a home-made seismograph at Crawfoot's house in Woody Point. They encouraged other "amateur seismologists" to join them and collect seismograph data for the global seismology community. [10]

Even the daily UQSS observatory routine practice of collecting "felt report" data about the irregular local earthquake events, required descriptive responses from the general public who replied to mailed out Modified Mercalli questionnaire requests for felt experiences in an earthquake. Five to ten of these surveys might have been conducted each year. This macro data supplemented the lack of instrumental data.[11]. In recent times, seismology is able to interface directly with the public and their electronic media usage.

2.2. Seismograph observatory practice for data collection

The observational data used by these UQSS / CSIRO students was derived from the daily seismograms and observational bulletins, created by fulltime observors. The daily routine for seismological observors is to take the seismograms from the previous 24 hours and accurately:

- annotate the 6 charts (short period Z, N-S, E-W and long period Z, N-S, E-W) with their unique descriptors.
- provide station name, date/time ON-OFF; sensor direction; clocking error.
- methodically and chronologically pic timed events (blast. earthquake, local noise, microseism noise level) into the observors daily log of seismic phases, onset strength and direction and comments.
- telex the day logs of observed earthquake phase times and descriptors to the United States Geological Survey and Geosciences Australia (then BMR or AGSO), and then compile them into

 doi:10.20944/preprints202305.1765.v1

a weekly station bulletin publication. This was faxed to global agencies who compiled definitive catalogues of earthquake epicentres e.g., ISC, USGS and GA, as well as the UQSS archives [12].

When the UQSS earthquake monitoring began in 1937 (UQ, Gardens Point, Brisbane) [13] all of this observational interpretation was analog, handwritten, and teletype transmitted. In about 1973-74, the UQSS was able to digitally store observations onto the central computing facility at the UQ Prentice Centre. Thus, rapid digital searching of data became possible. The advent of programable computers made this process more flexible and data re-use friendly. Prior to that observer's earthquake phase data was typed into weekly "bulletins" and paper versions of these were bound into catalogued books.

The seismology observor makes observations about "squiggles" on the charts that may have been generated by local or teleseismic earthquakes, explosions, or nuclear blasts. These point sources (epicentres) send seismic/ sound energy in radial directions, and the waveforms are transmitted quickly (3Km/s to 8Km/s) through the geological formations or through the oceans (~1.5Km/s) or even into the ionosphere (infrasonically). The observer will note impulsive or emergent onsets at the date-time of the arriving P phase and then the later arriving (S phase) and maybe the more damaging surface waves (L, R phases). There are a multitude of refracted wave types recorded.

The rationale for running the first and longest Australian university continuous seismograph observatories at The University of Queensland is best described by the late Dr Jack Webb (Director UQSS) in **Cooperation and the UQ Seismograph Stations** [14].

2.3. Brief review of (BRS) T wave historical research literature

Prior to the inception of this CSIRO project, the UQSS observors had become aware of a strange new type of phase (T phase) with a characteristic signature and much later arrival. The observor learnt from colleagues that these T waves travelled (earth>ocean SOFAR layer> earth) and were usually detected by observatories near the ocean. The first scientific reference to the T wave is attributed to Linehan [15] (Figure 1) who documented their arrival on Caribbean seismograms, shown in Figure 1.

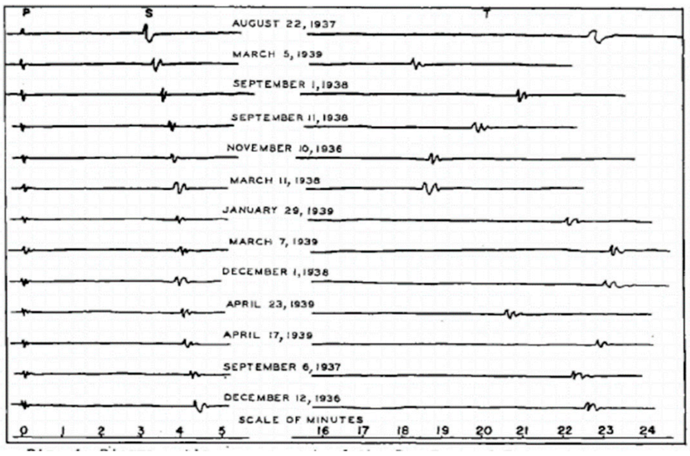

Figure 1. Figurematic arrangement of the P-, S-, and T-groups according to Increase in (S-P)-interval. [9].

A study of more than 200 records of T from the Atlantic 7 has shown that in all cases the period ranges upward rather than downward from 0.5 sec., being for the most part between 0.5 and 1.0. This is significant, because SOFAR propagation (SOFAR stands for sound fixing and ranging) along an axis of minimum velocity cannot explain transmission of waves of periods longer than 0.5 sec. carrying the greater part of the energy in T. T does not travel with the velocity of sound in water for the part of its path crossing deep water. Its oceanic velocity ranges from 1.70 km/sec to 2.65 km/sec, in different parts of the Atlantic (5,577 to 8,695 ft/sec.), in contrast to • velocities of sound in water

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 May 2023 doi:10.20944/preprints202305.1765.v1

from 1.46 to 1.53 km/sec. (4,790 to 5,020 ft/see.). Its speed over land paths is 2.13 km/see. (6,988 ft/sec.). [15]

Another observation at BRS (Gardens Point) occurred on 23-09-1949 (Table 1) when an event was recorded on the BRS Benioff Z (short period) sensor recorder. This event was reported to the Smithsonian Institute for Short Lived Phenomena and was later picked up by researchers as a T wave generated by the Queen Charlette Islands earthquake (Canada) and reported in a research paper [16] (Figure 2). This is an incredible distance for sound to travel in an ocean.

Table 1. T wave recorded in BRS, 23-08-1949 from Queen Charlotte Is. Earthquake.

DATE.	PHASE.	U. T. h. m. s.	UNIT.	REMARKS.
August 13th	ePN	18-30-46	M-S	Dilatation
	iPZ	30-47	B	
	i E	31-46	M-S	Δ ± 28°
	i Z	31-50	B	Washington H = 18h. 24m. 49s.
	i N	32-23	M-S	Epicentre 0° 146°E
	iSE	35-30	"	Admiralty Islands region.
	iSN	35-31	"	
	iSSE	37-01	"	
" 17th	iPZ	18-45-18	B	Dilatation Washington 18h. 34m. 07s. E coast Hokkaido Japan 43° N 146°E. (Fowkey)
" 22nd	iPZ	04-21-21	B	Compression Washington H. = 04h 01m. 12s 54°N 133°W. off coast of British Colombia
	eS ?Z	05-15-18	B	N-S Milne-Shaw not working;
	iSS ?Z	19-29	"	E-W Milne-Shaw record
	iL_1 ?Z	28-08	"	complicated by drift.
	o Z	52-12	"	
" 23rd	e N	20-49-19	M-S	Washington H. = 20h. 24m. 32s.
	i E	49-20	"	Epicentre 53°N 132°W.
	i E	50-30	"	(Queen Charlotte Islands)

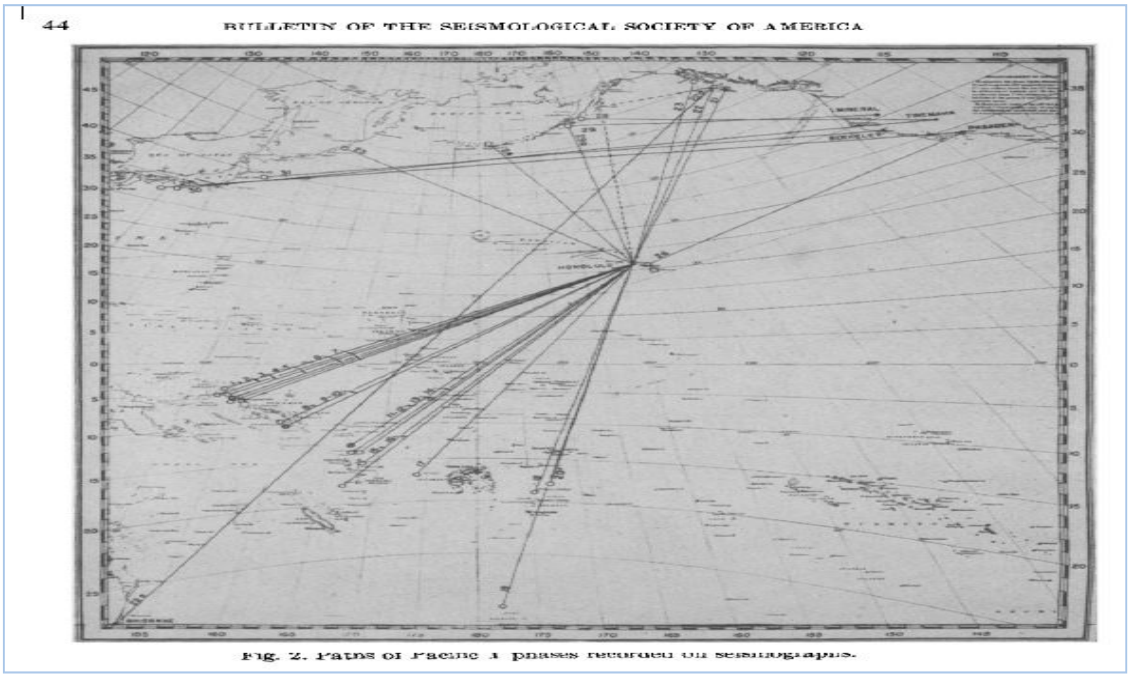

Figure 2. T wave recorded in BRS, 23-08-1949 from Queen Charlotte Is (Can). Earthquake.

2.4. Reviewing recent research literature about the research relevance of T waves.

- Why Research "T" waves?

"Nevertheless, recording T waves in the oceans has far-reaching utility for seismic studies and beyond, including tracking icebergs [17] monitoring submarine volcanic eruptions [18] and

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 May 2023 doi:10.20944/preprints202305.1765.v1

Comprehensive Nuclear Test-Ban Treaty verification [19]. Most recently, Wu et al. [20] demonstrated that decadal-scale ocean-warming trends are manifest in the differences in travel-time delays between T waves generated by repeating earthquakes" [21]

- New techniques linking seismology to oceanography;

"The deployment of around 4,000 autonomous devices called Argo floats that capture temperature information has helped enormously, but there are big gaps in our knowledge. This is especially true in relation to what's happening in the waters deeper than 2,000m. But now a team of researchers has developed a very different approach that exploits the fact that the speed of sound in seawater depends on temperature. The idea was first proposed and trialled in the late 1970s using sound waves generated by scientists. However, concerns over the impact of these sounds on marine mammals and rising costs saw the idea abandoned." [22]

- Are T waves a tsunami predictor;

"T" Phases and tsunami waves can be generated by earthquakes simultaneously, or NOT, and so "T" wave detection on ocean bottom sensors (OBS) or floating sonar buoys or land-based seismographs are not an early warning indicator.

- Mechanism and fault relationship;

"These "T" phase arrivals can be observed in seismograms from receivers on land. Although most often recognised at coastal stations (or hydrophones), T phases can have large continental paths on the receiver end and have been observed at land stations several hundred kilometres away from the coast."[23]).

"The mechanism of coupling from acoustic waves to seismic waves is not clear but has been proposed to be related to the slope of the seafloor near the shore, and the contrast."

"The T phase does not depend only on the earthquakes' magnitude, but also on the depth where earthquakes occur, the continental slope, the conversion location, and the conversion efficiency" [24])

- T waves are a disaster hazard;

T waves retransmit back into seismic P waves and can cause felt effects in structures [8], (or cause submarine landslides).

- Thermometry and bathymetry;

Predicting the travel-time changes from the temperature anomalies estimated by ECCO. The speed with which the sound travels is governed by the depth, the salinity, and the water temperature. Consequently, experiments have been proposed and executed to actively monitor the ocean temperature under global warming with hydro-acoustic observations [25].

- This so-called acoustic thermometry

is based on the efficient propagation through the SOFAR channel and uses the above-mentioned dependence of the sound speed on the temperature.

  - Diurnal variations in the SOFAR channel were found by analysing the travel time differences from the source to the receivers.
  - From this, propagation in the Atlantic appeared to vary strongly between the north and south Atlantic Oceans, which is further studied in Sec. IV. The celerity approach and findings are evaluated in Sec. V, where also opportunities for future research are identified. The conclusions from this study are drawn in Sec. V [25].

2.5. Student (citizen science) project

In 1995, the student project was believed to be the first of its kind in Australia, using earthquake sound waves derived from the tsunamigenic areas in the Tasman Sea affecting eastern Australia. University lecturer in exploration geophysics, Dr Steve Hearn was supervising the study by Ms. Bronwyn Lahey, of Brisbane Girls Grammar School, and Mr. Asanka Karunaratne, of Brisbane State High School.

They set out to study the link between tsunamis (commonly but incorrectly called tidal waves) and submarine earthquakes. Dr Hearn said when an earthquake occurred below continental slopes,

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 May 2023 doi:10.20944/preprints202305.1765.v1

it generated a number of different sound waves, including a packet of energy known as a T-wave, which travelled more slowly (1.5km/sec) and arrived later than other sound waves.

"An earthquake originating off Fiji might generate a fast-travelling P-sound wave, which would travel through the earth at 6 km/sec and be recorded in Australia 10 minutes later," he said.

"A T-wave generated by the same earthquake would travel more slowly through water (at l.5km/sec) and be recorded on seismographs in Australia about 30 minutes after the event. Scientists in Australia have devoted most of their attention to the faster-travelling sound waves to record earthquakes, but at The University of Queensland we are now looking at the slower T-wave as a predictive tool for tsunamis- While these kinds of studies have been undertaken elsewhere in the world, including at Hawaii and Japan, it is a relatively new research field for Australia. The exploratory work these students are undertaking will greatly assist more detailed studies which we hope can be achieved with competitive research funding."

More recently, we have become aware of the relationship that T waves have with ocean heat waves, as outlined in Section 2.4

Seismograph station senior technician in the university's Earth Sciences Department. Mr. Col Lynam said, “At sea, tsunamis were very small - only one third to half a metre high - but they had enormous wavelengths which could be up to 200km long. As the wave reached the shore the wave crest(s) build up rapidly and could rise 30m in 10 to 15 minutes, with devastating results.”

3. Results

The students began by analysing all BRS observatory daily earthquake “pics”, for the period of 1980 to 1990. These had been digitised for BRS seismogram bulletins in the mid-1980’s with the assistance of the Prentice Computer Centre at UQ. Observors conducted a search of the digital BRS seismology bulletins for all observed earthquake P phase arrival times that had associated T phase arrival times, dates and times and observations. This yielded 68 earthquake T wave events. These are tabulated in Table 2.

Having tabulated those events, the students then commenced searching for confirming epicentre origin times and descriptors, using definitive catalogues published by USGS. and ISC [26]. They produced Table 3, which defined the source locations and depth, magnitude and azimuth of the T wave generating earthquakes together with the velocities and the wave path(s) in the Tasman Sea area of the S-W Pacific Ocean. No consistent relationship with known tsunami events was discovered, so it was decided that result nullified the T wave <> Tsunami relationship.

3.1. Student T wave data collection and epicentre location analysis results

The student analysis data is tabulated and mapped below, showing the earthquake epicentres that caused a T wave to be generated and detected on the BRS seismograph. What becomes evident from their the analysis (Figure 4) is;

- *Not all earthquakes generate T waves*
- *T waves originate from only certain tectonic zones (some misnamed?)*
- *There is a wide variation in T wave travel velocity*
- *There does appear to be a seasonality in T wave reception by BRS*
- *There is a paucity of T waves passing across the submerged Zealandia continent*
- *T wave paths also plot clear paths for tsunami hazard along east coast of Australia [27]*

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 May 2023 doi:10.20944/preprints202305.1765.v1

Table 2. Student T wave data epicentre location analysis – arranged in location clusters.

DATE	TME_REC (utc)	LOCATION	LAT (S)	LONG (E)	DEPTH (Km)	AZMUTH	MS	MB
25/05/1981	11:09:40	AUCKLAND ISLANDS	49.41	164.28	12	334	5.1	
25/05/1981	11:30:10	AUCKLAND ISLANDS	49.35	164.58	19	333		4.6
25/05/1981	14:18:10	AUCKLAND ISLANDS	49.34	164.27	33	334		4.3
25/05/1981	20:07:10	AUCKLAND ISLANDS	49.35	164.28	33	334		4.4
25/05/1981	22:23:05	AUCKLAND ISLANDS	49.28	164.23	33	334		4.5
28/05/1981	0:48:00	AUCKLAND ISLANDS	49.5	163.88	33	335		4.3
28/05/1981	05:52:00	AUCKLAND ISLANDS	49.13	164.43	12	333		4.9
30/05/1981	09:12:28	AUCKLAND ISLANDS	49.14	164.63		333	5.3	5.8
31/05/1981	08:24:00	AUCKLAND ISLANDS	49.82	164.1	33	335		4.2
16/06/1981	16:29:45	AUCKLAND ISLANDS	49.07	164.79	33	332		5.3
6/08/1981	11:52:20	AUCKLAND ISLANDS	49.76	163.96	33	335		4.6
16/08/1981	05:41:45	AUCKLAND ISLANDS	49.54	164.32	33	334		4.5
22/04/1986	22:19:23	AUCKLAND ISLANDS	49.96	163.69	10	336		4.8
3/05/1987	12:52:33	AUCKLAND ISLANDS	49.17	164.6	13	333	5.3	4.6
20/12/1988	14:20:10	AUCKLAND ISLANDS	50.5	163.1	10		4.7	4.8
26/10/1989	03:09:00	AUCKLAND ISLANDS	50.7	162.8	10		4.7	4.4
21/11/1989	15:03:21	AUCKLAND ISLANDS	50.18	162.6	10		5.8	5.6
23/02/1991	15:26:00	AUCKLAND ISLANDS	49.1	164.9	10	332		4.9
17/09/1989	06:28:10	BAL.LENY ISLAND	61.4	154.1	10		5.6	5.4
16/01/1980	04:17:50	LOYALTY ISLANDS	21.85	170.58	56		5.6	5.4
6/07/1981	03:25:36	LOYAL TY ISLANDS	22.29	171.64	114	250		6.3
6/09/1981	11:19:30	LOYALTY ISLANDS	21.5	169.61	36	246		6.0
29/10/1981	12:23:47	LOYAL TY ISLANDS	23.65	169.11	18	252		5.1
15/11/1984	03:03:22	LOYALTY ISLANDS	22	170.91	119	248		6.3
15/01/1986	20:33:57	LOYAL TY ISLANDS	21.37	170.31	144	246		6.0
1/05/1986	19:49:00	LOYAL TY ISLANDS	21.85	170.13	71	247		5.7
31/07/1988	13:06:41	LOYALTY ISLANDS	22.26	171.02	85			5.7
21/09/1988	11:21:00	LOYALTY ISLANDS	22.27	170.97	88			5.1
17/02/1991	07:16:23	LOYAL TY ISLANDS	21.17	169.76	73	245		5.5
31/12/1984	22:21:27	MACCQUARIE ISLAND	60.21	153.8	10	359	5.5	5.3
3/09/1987	00:07:17	MACQUARIE ISLAND	58.86	158.48	15		7.2	5.9
15/11/1989	19:48:37	MACCQUARIE ISLAND	52.34	160.07	10		5.4	5.7
17/09/1990	14:15:00	MACCQUARIE ISLAND	53.17	159.64	10	346	6.0	5.9
23/05/1984	00:05:44	N OF MACQUARIE I	51.88	161.08	10	342	5.8	5.8
18/09/1981	09:24:05	NEW CALDONIA	22.81	167.6	33	248		4.4
17/12/1988	01:13:45	NEW CALEDONIA	26.93	167.53	25		5.3	5.5
24/02/1991	09:52:00	NEW CALEDONIA	22.72	166.64	33	247	5.0	4.9
28/01/1980	12:55:10	NEW ZEALAND	45.26	167.5	118		5.1	
26/07/1987	22:12:12	NW OF NZ	30.23	165.8	10		5.4	5.2
25/05/1988	13:41:39	NWOF NZ	30.7	167.7	10		4.4	4.8
27/09/1985	03:59:30	SOLOMON ISL.ANDS	9.81	165.85	33	200	6.8	6.2
30/08/1980	06:19:02	SOUTH ISLAND NZ	45.06	167.67	112	321		4.6
27/05/1981	19:23:00	SOUTH ISLAND NZ	48.48	164.48	12	332		4.6
22/11/1981	19:00:15	SOUTH ISLAND NZ	44.46	167.63	18	320		
4/07/1982	16:05:00	SOUTH ISLAND NZ			10	320		4.7
27/09/1984	22:04:21	SOUTH ISLAND NZ	44.14	168.66	1	317		4.7
12/09/1985	13:16:30	SOUTH ISL.AND NZ	45.4	167.36	80	322		5.1
11/07/1986	17:20:05	SOUTH ISLAND NZ	44.54	167.45	12	321		4.2
16/05/1988	10:19:00	SOUTH ISLAND NZ	44.17	168.13	12			4.2
3/06/1988	23:47:20	SOUTH ISLAND NZ	44.86	167.64	82			5.7
9/06/1988	12:33:30	SOUTH ISLAND NZ	44.99	167.48	65			4.2
14/06/1988	16:07:00	SOUTH ISLAND NZ	44.47	168.34	8			4.2
15/02/1991	11:12:16	SOUTH ISLAND NZ	42.08	171.59	8	308	5.0	5.8

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 May 2023 doi:10.20944/preprints202305.1765.v1

DATE	TME_REC (utc)	LOCATION	LAT (S)	LONG (E)	DEPTH (Km)	AZMUTH	MS	MB
28/05/1981	21:18:00	VANUATU	15.01	166.97	121	225		4.8
6/04/1984	23:25:10	VANUATU	18.95	168.89	185	237		5.8
16/07/1986	12:58:08	VANUATU	19.52	169.16	21	239		6.2
12/08/1990	21:41:50	VANUATU	19.48	169.12	164	239		6.3
15/06/1981	02:56:00	W COAST, SIS NZ	48.46	165.11	33	331	5.3	5.2
27/06/1981	22:04:00	W COAST, S IS NZ	48.8	164.2	33	333		4.4
23/12/1981	15:24:00	W COAST, SIS NZ	47.74	165.77	10	329		3.8
31/01/1985	04:56:00	W COAST, SIS NZ	46.01	165.16	10	328	6.0	5.8
21/09/1985	14:14:26	W COAST, S IS NZ	46.37	165.78	22	327		4.9
3/04/1986	14:33:22	W COAST, S IS NZ	45.81	165.24	33	327		4.8
11/07/1986	08:51:30	W COAST, SIS NZ	45.46	166.33	33	325	5.5	5.3
15/05/1988	18:45:53	W COAST, SIS NZ	43.85	168.68	10		4.9	5.5
15/05/1988	19:42:00	W COAST, SIS NZ	43.94	168.46	4			4.0
18/01/1980		No info found						
7/02/1980		No info found						
5/08/1981	03:30:24	No info found						
27/06/1982	16:48:17	No info found						
30/10/1986	00:24:31	No info found						
17/02/1987	09:52:30	No info found						

Figure 3 replicates the data in Table 3, showing the diversity of T wave earthquake epicentre sources, but now showing a unique sonar travel path of earthquake energy converted into SoFaR sound waves travelling the Tasman and Coral Sea and converted back to seismic waveform recorded at the UQSS seismograph station, Brisbane (BRS). The blur of purple dots shows the prolific earthquake activity in the SW Pacific subduction zone region.

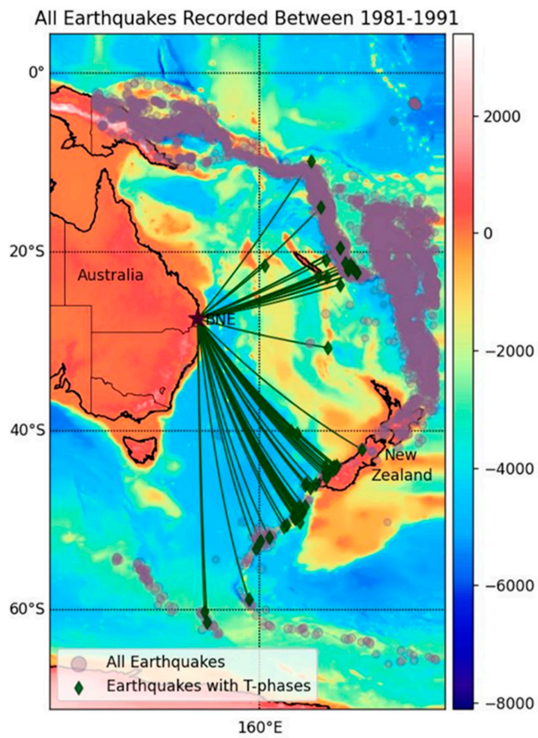

Figure 3. Map of locations included in Table 3 using modern computational techniques to plot the T Wave paths from epicenter to BRS Seismograph station. Index is Bathymetry depth in Metres (courtesy E. Sands).

There appears to be a causal geometry between the western side of subduction fault zones and T wave generation.

 doi:10.20944/preprints202305.1765.v1

The recently classified and submerged Zealandia continent (yellow/ orange bathymetry) seems to effect the SoFaR depth or is it temperature/ salinity effect. This is only a recent research discovery.

3.1. Student T wave travel times derived from epicentre location analysis - showing T wave velocities calculated.

The right-hand columns in Table 3 show the T wave velocities calculated by the students in 1995 with only basic cartographic formulae to use. There is sufficient variation in this velocity observation to conjecture that:

- **Accurate bathymetric path** plots should better discriminate SoFaR travel time and seismic travel time.
- **Is there a seasonality effect**? There appear to be more T waves recorded from all cluster areas between May to September over the decadal data collection. Refer to Figure 4.
- **Is it a salinity effect** of the **migrating Antarctic Converge boundary** that could affect the ocean temperatures around Macquarie Island, Auckland Island and Balleny Island sourced T waves? (See Figure 5).

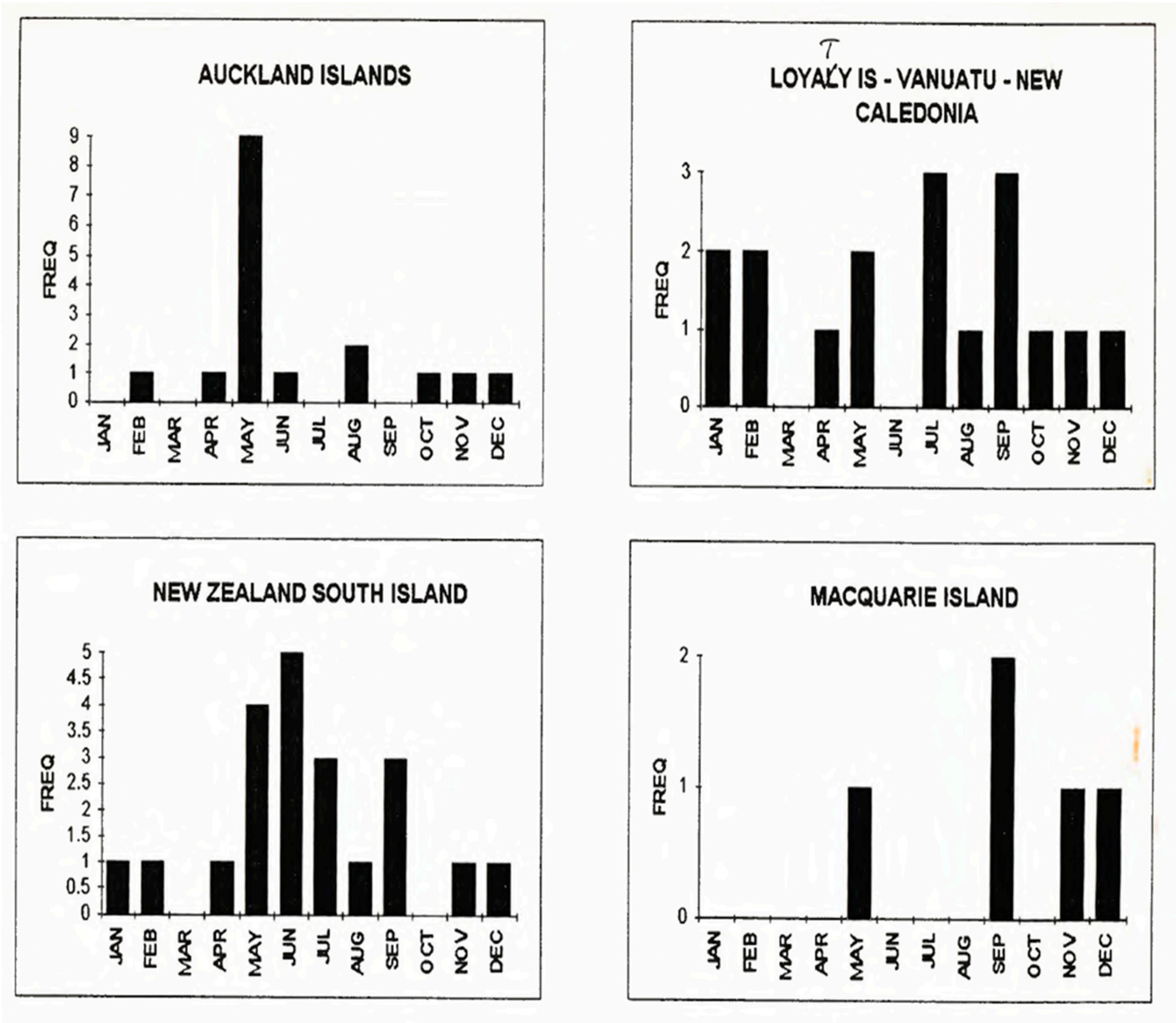

Figure 4. 10-year (1980-90) T wave occurrence at BRS seismographs, analysed by month of occurrence and regions of origin, to show any seasonality (Original plots by 1995 students).

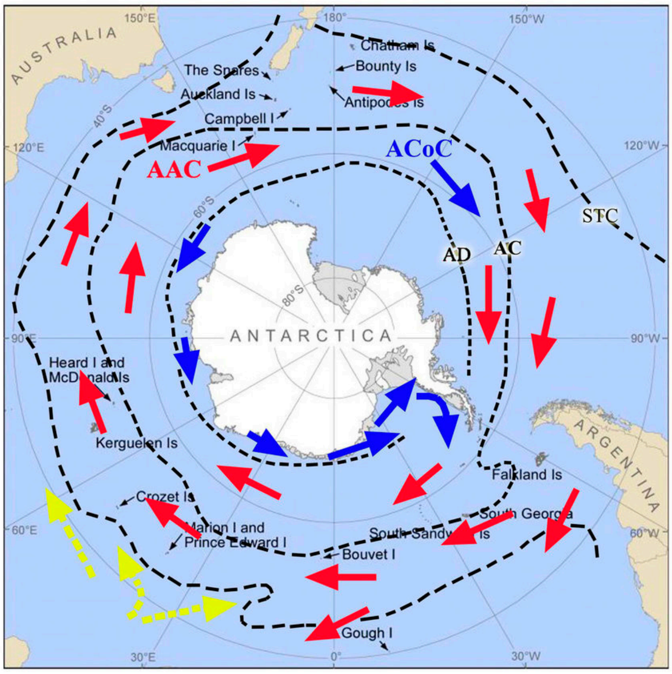

Figure 5. ***Major*** currents and fronts in the Southern Ocean and Subantarctic region: Antarctic Circumpolar Current (AAC), Antarctic Coastal Current (ACoC), Antarctic Divergence (AD), Antarctic Convergence (AC), Subtropical Convergence (STC) (4) (PDF) Obsidian floater washed up on a beach in the Chatham Islands: geochemical composition and comparison with other volcanic glasses [28].

Table 3. Student T wave travel times derived from epicentre location analysis.

	LOCATION	DATE/	TIME OF ORIGIN	BRS TIME (UTC)	LAT (S)	LONG (E)	distance to BRS (degrees)	AZIMUTH	DEPTH	MB	MS	T travel time (secs)	Distance to origin(Km	Velocity (Km/s)
3	AUCKLAND ISLANDS	06/08/81	11:25:47	11:52:20	49.76	163.96	23.93	335	33	4.6		1593	2655	1.730769
4	AUCKLAND ISLANDS	03/05/87	12:26:53	12:52:33	49.17	164.6	23.57	333	13	4.6		1540	2620	1.473566
5	AUCKLAND ISLANDS	02/23/91	14:59:40	15:26:00	49.1	164.9	23.63	332	10	4.9		1580	2620	1.08804
6	AUCKLAND ISLANDS	02/25/81	11:03:02	11:30:10	49.35	164.58	23.02	333	19	4.6		1628	2620	1.609037
7	AUCKLAND ISLANDS	04/22/86	21:53:05	22:19:23	40.06	163.6	24.04	336	10	4.8		1578	2665	1.73051
8	AUCKLAND ISLANDS	05/25/81	10:44:25	11:09:40	49.27	164.41	23.71	334	12			1515	2635	1.730274
9	AUCKLAND ISLANDS	05/25/81	13:27:50	14:18:10	40.34	164.27	23.64	334	33	4.3		3020	2620	0.86755
10	AUCKLAND ISLANDS	05/25/81	19:39:13	20:07:10	49.35	164.28	23.66	334	33	4.4		1677	2635	1.571258
11	AUCKLAND ISLANDS	05/25/81	21:50:51	22:23:05	49.28	164.23	23.58	334	33	4.5		1934	2620	1.354705
12	AUCKLAND ISLANDS	05/28/81	0:21:15	0:48:00	49.5	163.88	23.67	335	33	4.3		1605	2635	1.641745
13	AUCKLAND ISLANDS	05/28/81	5:25:52	5:52:00	49.13	164.43	23.5	333	12	4.9		1568	2610	1.664541
14	AUCKLAND ISLANDS	05/30/81	9:47:12	10:12:28	49.14	164.63		333		5.8		1516	2665	1.757916
15	AUCKLAND ISLANDS	05/31/81	7:57:07	8:24:00	49.82	164.1		335	33	4.2		1613	2665	1.709429

doi:10.20944/preprints202305.1765.v1

16	AUCKLAND ISLANDS	06/16/81	16:03:46	16:29:45	49.07	164.79	23.56	332	33	5.3	1559	2620	1.64469
17	AUCKLAND ISLANDS	08/16/81	5:10:11	5:41:45	49.54	104.32	23.84	334	33	4.5	1894	2645	1.005017
18	AUCKLAND ISLANDS	10/26/89	2:14:14	3:09:00	50.67	162.76	24.47		10	4.4	3286	2755	1.786641
19	AUCKLAND ISLANDS	11/21/89	14:37:39	15:03:21	50.18	164.6	23.97		10	5.6	1542	2665	1.696372
20	AUCKLAND ISLANDS	12/20/88	13:53:32	14:20:10	50.5	163.1	21.57		10	4.8	1598	2400	0.730371
21	BALLENY ISLAND	07/09/89	5:48:02	6:28:10	61.4	154.1	34.01		10	5.4	2408	3780	3.624161
22	LOYALTY ISLANDS	06/07/81	3:08:34	3:25:36	22.29	171.04	17.86	250	114	6.3	1022	1980	1.962339
23	LOYALTY ISLANDS	06/09/81	11:02:41	11:19:30	21.5	160.61	16.41	246	30	6	1009	1820	1.786065
24	LOYALTY ISLANDS	01/05/86	19:31:42	19:49:00	21.85	170.13	16.72	247	71	5.7	1038	1855	1.873737
25	LOYALTY ISLANDS	01/15/86	20:17:31	20:33:57	21.37	170.31	17.06	246	144	6	986	1900	1.830443
26	LOYALTY ISLANDS	01/I6/80	4:00:27	4:17:50	21.85	170.58	17.1		56	5.4	1043	1900	1.8591
27	LOYALTY ISLANDS	02/17/91	6:59:14	7:16:23	21.17	169.76	16.67	245	73	5.5	1029	1865	0.79126
28	LOYALTY ISLANDS	07/31/88	12:50:11	13:06:41	22.26	171.02	16.61		85	5.7	990	1845	1.904025
29	LOYALTY ISLANDS	09/21/88	11:04:51	11:21:00	22.27	170.97	17.28		88	5.1	969	1920	1.865889
30	LOYALTY ISLANDS	10/29/81	12:06:48	12:23:47	23.65	169.11	15.21	252	18	5.1	1019	1690	1.85524
31	LOYALTY ISLANDS	11/15/84	2:46:21	3:03:22	22	170.01	17.33	248	110	6.3	1021	1920	1.047262

32	MACQUARIE ISLAND	03/09/87	6:40:11	7:17:00	58.86	158.8	31.7		15	5.9	2209	3520	2.046512
33	MACQUARIE ISLAND	05/23/84	5:16:34	5:44:00	51.88	161.08	25.25	342	10	5.8	1646	2800	2.777778
34	MACQUARIE ISLAND	09/17/90	13:47:26	14:15:00	53.17	159.64	26.25	346	10	5.9	1654	2910	1.767922
35	MACQUARIE ISLAND	11/15/80	19:10:57	19:48:37	52.34	160.07	22.61		10	5.7	2260	2500	1.511487
36	MACQUARIE ISLAND	12/31/84	21:42:10	22:21:27	60.21	153.8	32.81	359	10	5.3	2357	3645	1.650068
37	NEW CALEDONIA	02/24/91	9:36:57	9:52:00	22.72	166.64	13.4	247	33	4.9	903	1490	1.02759
38	NEW CALEDONIA	09/18/81	9:07:17	9:24:05	22.81	167.6	14.22	248	33	4.4	1008	1580	1.644121
39	NEW CALEDONIA	12/17/88	0:58:14	1:13:45	20.93	167.53	13.15		25	5.5	931	1465	1.011661
40	NEW ZEALAND	01/28/80	12:30:56	12:55:10	45.26	167.5	21.36		118	5.1	1454	2375	3.149867
41	NW OF NZ	05/25/88	13:25:23	13:41:39	30.7	167.7	13.43		10	4.8	976	1490	1.219313
42	NW OF NZ	07/26/87	21:59:38	22:12:12	30.23	105.8	11.77		10	5.2	754	1310	1.342213
43	SOLOMON ISLANDS	09/27/85	3:39:08	3:59:30	9.81	165.85	18.31	200	33	6.2	1222	2035	1.465083
44	SOUTH ISLAND NZ	08/30/80	5:55:53	6:19:02	45.06	167.67	21.27	321	112	4.6	1389	2365	1.53372
45	SOUTH ISLAND NZ	04/07/82	15:42:24	16:05:00			21.15	320	10	4.7	1356	2355	1.736726
46	SOUTH ISLAND NZ	12/09/85	12:53:02	13:16:30	45.4	107.36	21.4	322	80	5.1	1408	2380	1.690341
47	SOUTH ISLAND NZ	03/06/88	23:27:35	23:47:20	44.06	107.04	21.11		82	5.7	1185	2455	2.07173
48	SOUTH ISLAND NZ	02/15/91	10:48:09	11:12:16	42.08	171.59	21.23	308	8	5.8	1447	2355	1.627505

49	SOUTH ISLAND NZ	05/16/88	9:55:34	10:19:00	44.17	168.13			12	4.2	1406	2345	1.667852
50	SOUTH ISLAND NZ	05/27/81	18:57:18	19:23:00	48.48	164.48		332	12	4.6	1542	2345	1.520752
51	SOUTH ISLAND NZ	07/11/BG	16:56:38	17:20:05	44.54	167.45	20.78	321	12	4.2	1407	2310	1.641791
52	SOUTH ISLAND NZ	09/27/84	21:41:05	22:04:21	44 14	168.66	21.04	317	1	4.7	1396	2345	1.679799
53	SOUTH ISLAND NZ	11/22/81	18:37:00	19:00:15	44.46	167.63	20.8	320	18		1395	2310	1.655914
54	SOUTH ISLAND NZ	O6/09/88	12:10:04	12:33:30	44	167.48			65	4.2	1406	2345	1.205036
55	SOUTH ISLAND NZ	O6/14/88	15:43:21	16:07:00	44.4?	168.34			8	4.2	1419	2345	1.652572
56	VANUATU	10/07/86	12:41:29	12:58:08	19.52	169.16	16.94	239	21	6.2	999	1880	1.881882
57	VANUATU	12/08/90	21:25:24	21:41:50	19.48	169.12	16.93	239	164	6.3	986	1880	1.906694
58	VANUATU	04/00/84	23:08:22	23:25:10	18.95	108.89	17.02	237	185	5.8	1008	1890	1.875
59	VANUATU	05/28/81	21:04:22	21:18:00	15.01	166.97	18.06	225	121	4.8	818	2010	2.409287
60	W COAST, SOUTH ISLAND NZ	03/04/86	14:09:04	14:33:22	45.81	165.24	20.89	327	33	4.8	1458	2320	1.591221
61	W COAST, SOUTH ISLAND NZ	11/07/86	8:27:46	8:51:30	45.96	166.33	21.43	325	33	5.3	1424	2380	1.671348
62	W COAST, SOUTH ISLAND NZ	01/31/85	4:32:58	4:56:00	46.01	165.16	21.02	328	10	5.8	1382	2335	1.68958
63	W COAST, SOUTH ISLAND NZ	05/15/88	18:26:16	18:45:53	43.85	168.68	20.84		10	5.5	1177	2310	1.962617
64	W COAST, SOUTH ISLAND NZ	05/15/88	19:18:25	19:42:00	43.94	168.46	20.8		4	4	1415	2310	1.632509

doi:10.20944/preprints202305.1765.v1

65	W COAST, SOUTH ISLAND NZ	06/15/81	2:31:18	2:56:00	48.46	165.11	23.12	331	33	5.2	1482	2565	1.730769
66	W COAST, SOUTH ISLAND NZ	06/27/81	21:39:00	22:04:00	48.8	164.2	23.14	333	33	4.4	1500	266	1.71
67	W COAST, SOUTH ISLAND NZ	09/21/85	13:50:15	14:14:26	46.37	165.78	21.86	327	22	4.9	1451	2435	1.678153
68	W COAST, SOUTH ISLAND NZ	12/23/81	14:58:19	15:24:00	47.74	105.77		329	10	3.8	1541	2665	1.752137

doi:10.20944/preprints202305.1765.v1

4. Discussion

4.1. Value of citizen science in the laboratory

The pilot study was an instructional organisational exercise for supervisory staff. It was successfully completed, giving the students a CSIRO curriculum certificate to take with their graduation. Mr Karunaratne later became a temporary seismogram record changer while he studied his PhD in biochemistry.

As a pilot scientific project, it brought together discussion and data collation techniques that were very new at a time of very few in-house computers. We were lucky to have begun data collection on a main frame computer within the university.

In all of this thematic discussion, we suspect there is a natural curiosity amongst people and listening to the earth's noise, generated by earthquakes or related phenomena. The technology comes pre-packaged and is simple to deploy…just like a computer game.

4.2. Other discovered citizen science T wave recordings and research

Contemporary recent discussion with a prospective higher degree student reveals that a lot more Australian seismograph stations record these T phases on the East coast of Australia according to the ISC database. [26] There is an interesting citizen science seismograph run by Mr A. Michael-Phillips (Coonabarabran, NSW) code name EPSO, which has documented T waves recorded on his seismographs from 2013 to 2019. [30]. This paper has also referred to the South Australian citizen science group that maintains, operates, and analyses T wave data. Impressively they repair their own instruments and raise money for them by selling hotdogs for a day [6].

4.3. Climate change related acoustic thermometry

As discussed in the review of recent T wave research literature, the T wave could give researchers an identifiable way of measuring the changes in temperature and salinity at depth in our oceans. Because their travel path (Figure 3) is a very selective inversion layer in the ocean between -1-5 Km and- 0.9 Km depth (approx.) which could easily be disconnected if ocean temperature rises and salinity changes (see Figure 5). Of course, all types of animal life will be affected by such a catastrophe, especially krill which whales feed upon.

5. Conclusions

The authors have all been dedicated workers in the university sciences arena, and we enjoy communicating our work. We have grasped the urgency and dilemma of our epoch, the Anthropocene.

However, we believe that our paper demonstrates how the application of education for sustainable development (ESD), through the encouragement of citizen engagement in earth observation and other ongoing earth monitoring functions. It re-affirms the approach of UNESCO's education sector response to the urgent and dramatic challenges the planet faces.

We also recognise the urgency of our situation. We are not talking about the implementation of an academic segue into science; we are talking about the mobilisation of a groundswell to gain both citizen comprehension and understanding of the climate change emergency and also about developing a stoic mindset of persistence, to bear some of the impacts about to befall the planet.

The strategy behind this paper's approach was later signaled by Australia's CSIRO, a premier scientific body. The prescient CSIRO report, **Australia's Biosecurity Future** [31] looks at what this nation's biosecurity aims should be over the next 10 years to 2030 and the steps needed to get there.

The challenges facing Australia's biosecurity system are too big for any organisation or sector to tackle by themselves. The solution is a united, multifaceted approach. We need to harness the collective knowledge and eyes-on-the ground capability of our citizens, our communities, our industries, and our governments to ensure that all Australians are aware of their role in managing biosecurity risks and are working together to build the resilience of the biosecurity system. Shared responsibility involves improved community engagement; more systemic collaborations between Indigenous and non-Indigenous organisations and individuals; and working with industry to develop their role in surveillance. For it to work, every stakeholder has to understand its value and feel invested in Australia's biosecurity. Together, system connectivity and shared responsibility will allow us to quickly share critical information, resources, and expertise. We'll be able to coordinate prevention strategies, improve our rapid response, and efficiently identify research needs across the human health, agricultural, and environmental sectors. 'Science' is the application of scientific method to observations about the biophysical world.

We have already observed that the academic institutions in Australia are in a demoralised and cauterising economic mindset [32]. There will be no empathetic voluntary citizen science mobilisation coming from that quarter. The Australian public service is suffering a similar knowledge deficit after 10 years of neo-liberalising contracting out of their raison d'etre.

However, these big corporate focused university institutions do have sustainability programs endorsed by management. There may be an opportunity to implement a UNESCO defined ESD program addressed to university institutions' senior management, pitching it as a benevolent service to the community and mankind rather than an academic studies initiative. However, it is imperative that the climate's measurement is implemented.

We have observed that significant platforms exist already to mount a global UNESCO earth monitoring initiative, not for science's sake, but for the education and preparedness of citizens who are unable to grasp what climate emergency impacts will befall them. Misinformation abounds. Anecdotally, we recently checked the Raspberry Shake website for a Shake seismograph located in Brisbane (Queensland) following the Magnitude 7 earthquake(s) in the Loyalty Islands and were able to verify that T waves are easily visible, with some visual tweaking.

We believe a parallel can be drawn in Australia, which leads the world in citizen initiated solar panel installation on their rooftops. A large percentage of the population have ignored the nay-saying energy corporations and have installed domestic solar rooftop power. Those same energy companies are now currently selling citizens interest free loans to install 9.5 Kw batteries that can feed power back into the grid at night, after being charged by the citizen's solar panels during the day. Citizens are practical and capable problem-solvers.

Acknowledgments: Thanks to former UQSS Hon. Director, Dr Steve Hearn for his ongoing interest in teaching things seismological and geophysical. We most likely came under earthquake "enrapturement "through the inspired leadership and mentorship of the late "Happy Jack" Webb (Hon. Director UQSS). Thanks to fellow observors Mr Russ Cuthbertson, Mr Jack Millican, Mr Paul Gaffy and Mr Ted Laundon, who created the UQSS seismic data in the database and the pioneer UQSS Directors.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Lynam C., Hearn S., Karunaratne A.M., and Lahey B. (Apr 2021), Earthquake generated T phases on BRS Seismograph (Brisbane, Q'ld)- a predictor for Tasman Sea Tsunamis? https://www.researchgate.net/publication/363533716_Earthquake_generated_T_phases_on_BRS_Seismograph_Brisbane_Q'ld-_a_predictor_for_Tasman_Sea_Tsunamis
2. UNESCO (Mar, 2023), What you need to know about education for sustainable development (cited 7-04-2023) https://www.unesco.org/en/education-sustainable-development/need-know
3. Ough T. (April 2023), The phones that detect earthquakes.,(cited 15-4-2023) BBC Future, (https://www.bbc.com/future/article/20230405-the-phones-that-detect-earthquakes
4. Sambridge M, Millar M.S., Salmon M. (2014) The Australian Seismometers in Schools Network (AuSIS), https://earthsciences.anu.edu.au/australian-seismometers-schools-network-ausis
5. Lade B. (Oct 2017) Newsletter of the Seismological Association of Australia Inc., (Vol 1 No.2) https://earthquake.net.au/wp-content/uploads/2022/07/SAA_Newsletter_2.pdf
6. Wesseloo J, Hudyma M.R., and Harris P., (2011) A community based seismic system for obtaining regional and local seismic data of strategic importance., Strategic versus Tactical Approaches in Mining 2011 — Y. Potvin (ed) © 2011 Australian Centre for Geomechanics, Perth, ISBN 978-0-9806154-6-3 https://doi.org/10.36487/ACG_rep/1108_12_Wesseloo

7. FDSN AM: Raspberry Shake ,FDSN Network Information - Citizen scientist earthquake monitoring network, (cited 14/02/2023) DOI: https://doi.org/10.7914/SN/AM.
8. Leonard M., (2004) T-phase Perception: The August 2003, Mw 7.1, New Zealand Earthquake Felt in Sydney 1,800 km Away, Seismological Research Letters, 2004 - pubs.geoscienceworld.org https://doi.org/10.1785/gssrl.75.4.475
9. Trundle P., (Feb 1953) Earthquake watching can be a new cheap sport. Courier-Mail, Wednesday 18 February 1953, (page 2) (cited 25/02/2021,
10. Lynam Colin J. (Jan2017), In the 1950's, a priest from Warwick (Qld) was inspired to discover cyclone related microseismic research on his home-built instruments. https://www.researchgate.net/publication/313391376_In_the_1950's_a_priest_from_Warwick_Qld_was_inspired_to_discover_cyclone_related_microseismic_research_on_his_home_built_instruments_Published_on_January_24_2017
11. **Lynam, Col (2022**). Seismology, earthquakes, tsunamis and seismographic data. **The University of Queensland. Data Collection. https://espace.library.uq.edu.au/view/UQ:2ede8a0**
12. University of Queensland. Seismological Station (1945). *Bulletin / University of Queensland, Seismological Station.* Brisbane: [University of Queensland University of Queensland Seismology Station Bulletin / University of Queensland, Seismological Station
13. Jones O.A., (July 1953), THE NEW UNIVERSITY OF QUEENSLAND SEISMOLOGICAL STATION, BULLETIN OF THE SEISMOLOGICAL SOCIETY OF AMERICA VOLUME 43 • NUMBER 3 • JULY,1953
14. Lynam C.J and Webb J.P, (2019) Cooperation and The Seismograph Stations of The University of Queensland - Departmental Seminar given by the late Dr Jack Webb (Senior Lecturer Geophysics), Honorary Director of University of Queensland Seismograph Stations, Dept of Geology and Mineralogy, on 27/08/1982. (Tape and transcript made by C.J. Lynam) https://www.researchgate.net/publication/347472073_Cooperation_and_The_UQ_Seismograph_Stations
15. Linehan Danial, (1940), Earthquake in the west Indian Region, Reports and papers, Eos, Transactions American Geophysical Union (pp229-232) https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/TR021i002p00229?casa_token=oS9uvuecFzcAAAAA%3A9yjf7TA8tMwk-lVN8jK1yzVKhvab6uV6Q3NazxEvt0oMUURnelghVwX8VSty0vBCCzxp3yq72ZDV3cCPCA)
16. Leet D. 1951, DISCUSSION OF "PROPOSED USE OF THE T PHASE IN TSUNAMI WARNING SYSTEMS"* Bulletin of the Seismological Society of America 1951 - pubs.geoscienceworld.org https://pubs.geoscienceworld.org/ssa/bssa/article-pdf/41/2/165/2691621/BSSA0410020165.pdf?casa_token=M69fCoeE7zgAAAAA:CAmdFIoj9fgH0MTL0PXBGxY0Bco1GuxFxGvbDHzwxg2v4xvciCc548Su6ePNulRdmCfJ3cKq8w)
17. Chapp, E., D. R. Bohnenstiehl, and M. Tolstoy (2005), Sound-channel observations of ice-generated tremor in the Indian Ocean, Geochem. Geophys. Geosyst.,6, Q06003, https://doi:10.1029/2004GC000889 .
18. Metz, D., Watts, A. B., Grevemeyer, I., and Rodgers, M. (2018). Tracking submarine volcanic activity at Monowai: Constraints from long-range hydro acoustic measurements. Journal of Geophysical Research: Solid Earth,123,7877–7895. https://doi.org/10.1029/2018JB015888
19. TALANDIER j. AND EMILE A. OKAL E.A., (Oct 1979) HUMAN PERCEPTION OF Z WAVES: THE JUNE 22, 1977 TONGA EARTHQUAKE FELT ON TAHITI, Bulletin of the Seismological Society of America, Vol. 69, No. 5, pp. 1475-1486, October 1979
20. Wenbo Wu, Zhongwen Zhan , Shirui Peng, Sidao Ni , Jörn Callies (2020) Seismic Ocean thermometry Science 369, 1510–1515 (2020) 18 September 2020
21. Simon, J. D., F. J. Simons, and J. C. E. Irving (2021). A MERMAID Miscellany: Seismoacoustic Signals beyond the P Wave, Seismol. Res. Lett. XX, 1–11, https://doi.org/10.1785/0220210052
22. McGrath M (2020) Climate change: Earthquake 'hack' reveals scale of ocean warming, Yahoo News, https://au.news.yahoo.com/climate-change-earthquake-hack-reveals-181429327.html
23. Buehler, J. S., and P. M. Shearer (2015), T phase observations in global seismogram stacks, Geophys. Res. Lett., 42, 6607–6613, https://doi:10.1002/2015GL064721 .
24. Zhou, Y., Chen, X., Ni, S., Qian, Y., Zhang, Y., Yu, C., et al. (2021). Determining crustal attenuation with seismic T waves in southern Africa. Geophysical Research Letters, 48, e2021GL094410. https://doi.org/10.1029/2021GL094410
25. Evers L. G., and Snellen (M., (2015): Probing the sound fixing and ranging channel Jnl.. Acoust. Soc. Am., Vol. 137, No. 4, April 2015 https://asa.scitation.org/doi/10.1121/1.4916267
26. Di Giacomo D., Olaru D., Armstrong A., Harris J., and Storchak D. A. (2021). The ISC Electronic Archive of Printed Station and Network Bulletins, Seismol. Res. Lett. XX, 1–4, https://doi:10.1785/0220210262
27. Lynam Colin (28-02-2020), On a Fine Day in Shorncliffe the Sea Came Boiling Upwards Across the Bathers … Proceedings of The Royal Society of Queensland Vol. 128, (pp29-48) ISSN 0080-469X http://www.royalsocietyqld.org/proceedings-128/)

 doi:10.20944/preprints202305.1765.v1

28. **Leach F., Campbell H., Eby N., Holt K., Regelous M., Richards R. and Weaver S., (2016**) Obsidian floater washed up on a beach in the Chatham Islands: geochemical composition and comparison with other volcanic glasses, Tuhinga 27 (pp 21–49) Copyright © Museum of New Zealand Te Papa Tongarewa https://www.researchgate.net/publication/304581597_Obsidian_floater_washed_up_on_a_beach_in_the_Chatham_Islands_geochemical_composition_and_comparison_with_other_volcanic_glasses
29. Green R., (14 Aug, 1961) Tasmanian Records of Earthquake T-Phases from New Zealand, New Zealand Journal of Geology and Geophysics Vol 5:2, pp322-330, https://www.tandfonline.com/action/showCitFormats?doi=10.1080/00288306.1962.10423122
30. **Philips M. (2022)'T-Phase' seismic events recorded at EPSO, Coonabarabran, NSW. http://www.map.id.au/seismic/epso_events_t-phase.html**
31. **CSIRO (2014)** 'Australia's Biosecurity Future: Preparing for future biological challenges, https://www.csiro.au/en/Research/BF/Areas/Our-impact-strategy/Biosecurity-Future-Report
32. Cassidy C., (April 2023), 'Appallingly unethical': why Australian universities are at breaking point. The Guardian, https://www.theguardian.com/australia-news/2023/apr/10/appallingly-unethical-why-australian-universities-are-at-breaking-point