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Macroscopic anomalies before the September 2010 $M = 7.1$ earthquake in Christchurch, New Zealand

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Abstract. Previous published work after the Kobe and İzmit earthquakes (1995 and 1999, respectively) demonstrated some reported meteorological and animal behaviour precursors were valid. Predictions were freshly tested for the Christchurch earthquake ($M = 7.1$, 4 September 2010). An internet survey with nearly 400 valid replies showed relative numbers of reports in precursor categories the day before the quake, were statistically significantly different from those in the preceding three days (excess meteorological events and animal behaviour). The day before the quake, there was also altered relative precursor class occurrence within 56 km compared with further away. Both these confirmed the earlier published work. Owners were woken up by unique pet behaviour 12 times as often in the hour before the quake compared with other hours immediately before (statistically highly significant). Lost and Found pet reports were double normal the week before, and 4.5 times normal both the day before the quake, and 9 days before. (Results were again statistically significant). Unique animal behaviour before the quake was often repeated before the numerous aftershocks. These pet owners claimed an approximate 80 % prediction reliability. However, a preliminary telephone survey suggested that animals showing any precursor response are a minority. Some precursors seem real, but usefulness seemed mostly restricted to 7 cases where owners were in, or near, a place of safety through disruptive pet behaviour, and one in which owners were diverted by a pet from being struck by falling fixtures. For a later 22 February 2011 $M = 6.3$ quake no reports of escape through warning by pets were recorded, which raises serious questions whether such prediction is practically useful, because lives claimed saved are extremely low compared with fatalities. It is shown the lost-pet statistics dates, correspond to ionospheric anomalies recorded using the GPS satellite system and geomagnetic disturbance data, and claimed as precursory. The latter more objective measurements may be the way of the future, but improved statistical treatment should include observations over longer periods of time without earthquakes.

1 Introduction

After a major earthquake there are always claims of possible precursors beforehand, particularly animal behaviour. Humans usually can find correlations where there are none, so it is reasonable for geophysicists and others to completely discount such reports. Published works (Rikitake, 2001; Tributsch, 1982; Ikeya, 2004) however strongly suggested not all these precursor observations should be dismissed. Also, Chinese scientists claim a 40 % success rate over the last 25 yr in prediction using combined tilt meters, infrasound and automated measurements of animal movement (Li et al., 2003).

Ikeya (2004) strongly opted for an explanation of these effects through ultra-low frequency (ULF) electromagnetic radiation, one of the few agents capable of travelling kilometers through rock from epicentres and underwater. Experiments with crushing of rock showed release of such radiation. A long and extensive programme of laboratory tests involving at least 35 types of animals (reviewed in Ikeya, 2004), showed many animals were very sensitive to these frequencies, showing unusually itchy and anxious behaviour.

Following the above work, a published paper (Whitehead et al., 2004) showed by statistical examination of ratios of class numbers of publicly reported precursors from Kobe, Japan (Wadatsumi, 1995) and İzmit, Turkey (Ulusoy and Ikeya, 2001, 2008) that some were probably real. The

principle was that if all alleged precursors were merely psychological human responses, there would be no difference in *relative* precursor class frequencies between a time very near the earthquake and slightly earlier. However statistically significant differences were found for both countries, suggesting some precursors were real although diluted with spurious reports. Earlier literature predictions by Rikitake (2001) for earthquakes of this size, of a dual peak in precursors the day before and about 10 days before, were confirmed, and also the supposed test distance of 100 km was essentially confirmed, though 80 km was a better dividing point. Meteorological precursors seemed important.

The Christchurch earthquakes offered another opportunity to test the predictions in the Whitehead et al. (2004) and earlier papers.

2 Setting

New Zealand is a seismically active country with a fairly high standard of living, and many regulations governing building so that earthquake damage will be survivable. Christchurch is a modern city of 377 000 people halfway down the east coast of the South Island at 43° S. Its setting and some relevant fault lines are shown in Fig. 1.

The 4 September 2010 $M = 7.1$ earthquake was at 4:35:46 LT (local time) on Saturday morning, and those awake must have been few. Centred near Darfield, 40 km north-west of Christchurch it was 10 km deep. No lives were lost, but there was extensive property damage in Christchurch, particularly from instability of old brick buildings. There was soil liquefaction, and sewage and water infrastructure damage (Stuart, 2010). Although there was a 5m horizontal land displacement under two electric high voltage (HV) pylons, it did not physically destroy the connections and electric power was restored to most areas within hours. The zero loss of life is the lowest recorded anywhere for an earthquake of $M = 7$ or above for a similar population, which suggests earthquake regulations and engineering have been partly successful. There were several thousand aftershocks extending through December, fairly typical for a similar sized earthquake.

3 Method

People with precursor stories were invited to take an internet survey, via an appeal on a national TV current affairs programme with almost complete New Zealand-wide coverage ("Close Up"). Wording of the appeal was that various people experiencing large earthquakes internationally had previously reported precursors in the five classes: phenomena in the sky/air, ground/water, animal or other biota behaviour, electronic, or sundry, and New Zealand reports were asked for, even if events appeared strange. The categories were derived from those reported for Kobe/İzmit (Wadatsumi, 1995; Ulusoy and Ikeya, 2001, 2008; Whitehead et al., 2004; Ikeya 2004). Contributions to the survey in these classes were therefore expected and probably some reports would not have been volunteered without such wording. Bias would be expected, and the frequencies reported will not be the same as those actually experienced in the whole population. The statistical tests mostly compared relative frequencies between precursor classes, so this did not matter. Distance or timeframe was not mentioned because these variables would be used for the statistical tests. It seemed likely that in the "sundry" category, there would be much reporting of subjective human feelings, as indeed found.

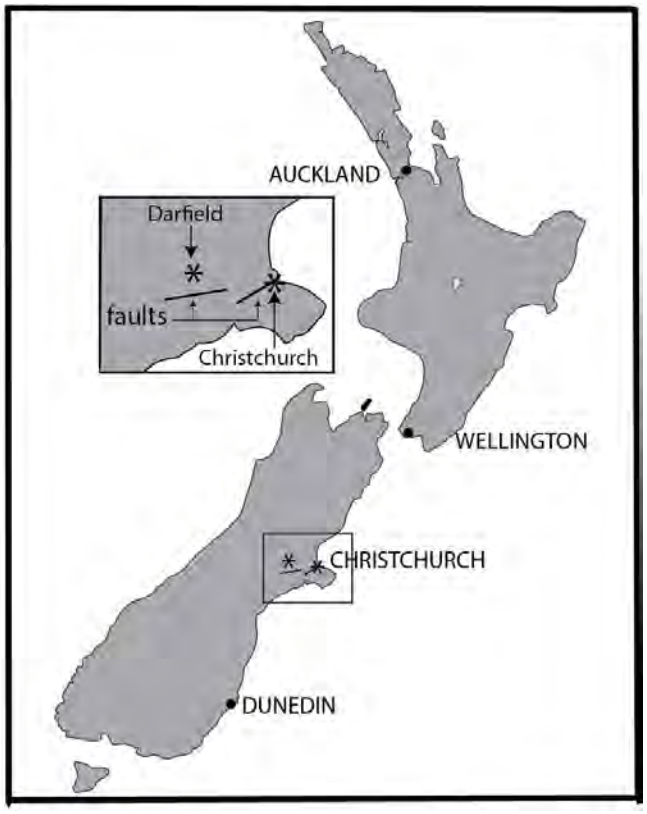

Fig. 1. Location map. Asterisks mark the Darfield (4 September 2010) and Christchurch (22 February 2011) earthquake epicentres.

A website was set up with an explanation of the survey and a link to the SurveyMonkey website (http://www.surveymonkey.com/) which collected answers to the survey questions and asked for location, time, duration and type of event. Up to three possible precursory events could be described on-line. An email address was set up for people to request a preliminary report, and about 100 reports were later distributed. To preserve anonymity no email addresses were requested from those who filled in the survey, though this was probably a mistake because some unexpected unique reports would have benefitted

from clarifying questions. The replies were divided into the 5 categories.

After the bulk of answers was received, a similar appeal was printed in a news article in the major local newspaper, *The Press (Christchurch)*. Separate chi-squared analysis of those survey contributions (another 10 %) showed that ratio of numbers in the precursor classes were not significantly different from those resulting from the TV appeal ($p = 0.18$) so all results were combined. A few contributions to the survey came from a similar radio appeal.

The data were evaluated using conventional chi-squared functions within the Excel spreadsheet program. A few other conventional statistics were used as appropriate.

A few days of random digit telephone dialing were used to try and judge pet precursory behaviour by asking owners whether they had noticed anything. Local vets were rung asking about excess pre-earthquake consultations, and the local wildlife parks contacted. Electronic alarm monitoring and computer repair services were also contacted, checking for possible electronic precursors, as reported from the Kobe earthquake and subsequently.

In the course of collecting information it became clear that there had been co-seismic bright blue/white flashes (earthquake light) observed and recorded on a few security cameras, so a special request for reports of this light was added to radio and newspaper appeals, although the light was not expected to be precursory. Results are being reported in a parallel paper (in preparation), and imply restrictions on possible physical theories for generation of such light.

Collection of data lasted six weeks. Following the severe $M = 6.3$ 22 February 2011 earthquake under Christchurch five months later, which had much worse ground acceleration, and killed 185 people, limited further data was collected, but is only mentioned in this paper when relevant and illustrative, and not used for the main statistical calculations.

Following previous reports in the literature it seemed possible that there could be an excess of pets lost in the days before the quake. Data to check this were taken from *The Press* newspaper, with a lesser number from the website of the Royal Society for the Prevention of Cruelty to Animals. Pets were lost at least one day previous to the advertisements.

After the work on the Christchurch precursor reports was complete, a paper appeared (Yao et al., 2012), which used data from the Global Navigation Satellite System (GPS) to pinpoint ionospheric precursors for the September event. The paper also reported similar geomagnetic precursors. Similarities in the findings to the lost pet data are discussed below.

4 Results

The detailed reports from respondents are not presented here, but the statistical evaluation. An Excel spreadsheet and Word document with all the replies is available from the authors, and online at www.chchquake.co.nz.

Six veterinary clinics contacted had experienced no excess of consultations about animal health the week before the quake. However, a seventh which prefers anonymity, in a wealthy suburb, reported approximately 10 times the normal flood of stress-related consultations (it is not surprising such expensive consultations did not occur in poorer suburbs). It therefore seems some pets suffered precursory stress/anxiety symptoms.

No computer repair firm had experienced excess requests. No electronic alarm monitoring company had reported undue false alarms. Any electronic precursors did not significantly affect this type of consumer electronics, though there were a few personal reports of strange computer behaviour of uncertain significance, and radio/TV reception disturbance reports were fairly common, but varied.

One wildlife park (Orana) reported dogs wanting outside at 04:00 LT, just before the September earthquake and subsequently about 5 min before aftershocks. Similarly their birds tended to go silent for the same time period, and a waterbuck had unusual silent defensive reactions several minutes before aftershocks, sufficiently predictable it was termed by one staff member their "earthquake indicator". The Willowbank wildlife park has two rare Takahe (*Notornis:* Giant Rail). A visitor supplied a photo of them preening before aftershocks, reflecting reactions similar to those before ULF exposure (ultra-low frequency EM waves) reported in Ikeya (2004) though the visitor did not know the latter research. There were no observations of unusual eel behaviour, nor from a commercial eel harvesting company, though unusual activity might have been expected (Ikeya, 2004). An unusual sighting of a near-albino, extremely large eel in the Avon River which occurred 4 days before the 22 February quake is hard to evaluate.

Beekeepers did not report any unusual precursory behaviour, although in previous work (Tributsch, 1982; Ulusoy and Ikeya, 2008) bees were supposed to be unusually disturbed, and there is the same informal and independent tradition among New Zealand beekeepers of abnormal behaviour of bees before earthquakes. However, half an hour before the 22 February earthquake (i.e. at about 12:20 LT) a man in the centre of the city watched a swarm of bees the size of a large single-decker bus flying through the city on a main road several kilometers from open country. Although this was a very unusual place, an unusual swarm size, was almost the beginning of Southern Hemisphere autumn and rather an unusual time for spontaneous bee swarms, and was close to the time of the quake, the event might just be within the bounds of the normal, hence not precursory.

ECAN (Environment Canterbury) with automated 15 min-monitoring of water levels in water bores saw no precursory changes. The Synlait milk product plant by the Rakaia River about 60 km south west of Christchurch recorded a sudden 4 m increase in water level in a 100 m deep bore at 04:00 LT, i.e. half an hour before the quake, which is a precursor, but detailed statistical analysis of previous changes is

not available. These types of precursors have been reported world-wide, but this paper does not attempt to collect extra data outside the online survey for detailed statistical analysis, restricting analysis to cases in which comparisons may be made within the dataset.

Out of 586 survey responses (mostly from the TV program) 389 usable descriptions were obtained. The remainder did not give more than a precursory category and sometimes failed to give any response at all. Their data could not be used, because no distance or time or detail was supplied.

The usable responses probably came from a slightly more literate/computer-literate population than average, or at least with a longer attention span. Older people from their sixth decade on are likely to be less represented, because fewer are computer literate. Some replies, from their content and spelling, were obviously from the computer-literate but young, who will be over-represented. The collection is unlikely to be from a fully representative sample, but this should not matter.

The category distribution of the 389 usable replies was earth 9 %, meteorological 11 %, animal 56.5 %, electronic 6.4 %, other 17 %, as shown in Fig. 2. "Other" is almost entirely human reaction responses. The combination of "other" and "animal" is 74 % and the corresponding reply frequencies for Kobe and İzmit (Wadatsumi, 1995; Ulusoy and Ikeya, 2001, 2008; Whitehead et al., 2004) were 51 and 53 %, respectively, which is rather less. Meteorological responses at 11 % were significantly less than the 27–29 % for the Kobe/İzmit responses. Reasons are not clear, but could include cultural mind-sets or depend on the local season. Claimed plant precursors were not reported at Christchurch.

Following are limited summaries, with some representative/illustrative replies, edited as little as possible. Locations are in the Christchurch area unless otherwise specified. Editorial comment is in square brackets.

4.1 Farm animals

Quite a few reports were of farm animal behaviour because a productive agricultural area surrounds Christchurch. A frequent report was of abnormal animal noise then complete silence 5–10 min before the quake and various aftershocks. A summary could be "panicked, then paralysed through fear". A few hundreds strong herd of cows due for milking, a few tens of kilometers inland, suddenly all sat on the ground several minutes before the quake. Possible physiological reasons are in Ikeya (2004) who reported the same lowering to the ground for an elephant in the Ahmedabad Zoo before the $M = 7.7$ Gujarat earthquake in 2001. Reasons centred on animals trying to minimize exposure paths to irritating ULF radiation, by altering body position.

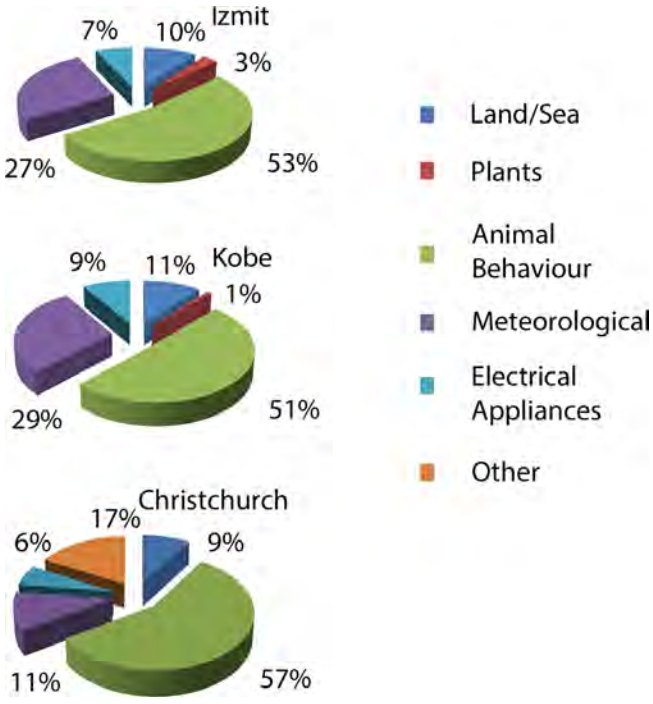

Fig. 2. Various unusual phenomena retrospectively reported through letter, fax, and e-mail by citizens **(a)** before the İzmit earthquake in 1999 and **(b)** before the Kobe earthquake in 1995. (Ulusoy and Ikeya, 2008), **(c)** before the Christchurch earthquake in 2010.

4.2 Birds

A universal observation was birds outside making a tremendous fuss for tens of minutes before the quake but completely silent for ten minutes immediately before. This has been reported from many places, with the added ominous point that the lone bird left calling (with an altered call) is the pheasant, when present. This precise sequence was reported from Lake Ellesmere near Christchurch (but for an aftershock). Pheasants are reported to do this from accounts as early as the 11th Century in Iran.

Another type of reaction was

> [Christchurch] "After the first large shake, me and my partner proceeded to go outside and stand in our back lawn as we felt safer there. I noticed a large grouping of birds in our Totara tree. I could not tell what type of birds. There are usually birds in this tree but at a guess I would say there were around 60–100 birds. The birds all of a sudden began to spiral upwards from the tree and began to fly around in a anti-clockwise direction. I was quite hypnotised by them and watched them for about 15 s, then a large aftershock hit. . . "

As in the case of dogs and cats, birds in cages inside houses went wild a few minutes before the quake.

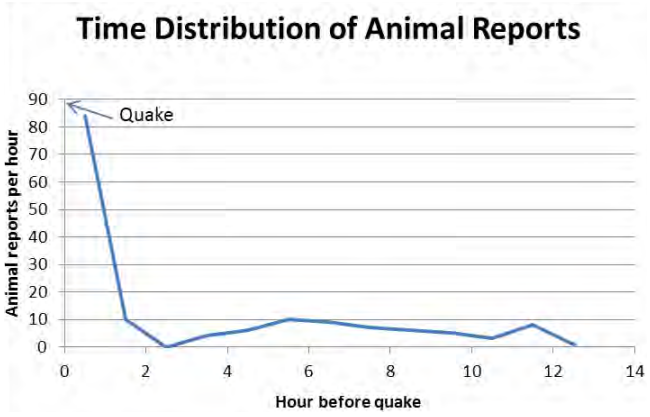

Fig. 3. Animal precursor reports each hour before the quake.

4.3 Worms

Three independent reports came in of remarkable excesses of earthworms the day before the September quake. Two were on street pavements in Rolleston and Belfast, at opposite ends of Christchurch and the third was in a Christchurch garden, (suburb not given). Although participants in the survey would not be aware of this, a similar occurrence was recorded in Taiwan before a major quake (a photo may be found in Ikeya, 2004). The emergence of the worms was not due to sub-surface flooding because the weather was dry. The intense reactions of worms to ULF from the experiments of Ikeya (2004) is also shown in the videoclip at www.eqsigns.net.

4.4 Pet precursors

There were numerous reports of dogs near observers creating a chorus of barking several minutes to tens of minutes before the quake and aftershocks, but choruses of barking were not always followed by an aftershock so any reaction was erratic.

Amongst the reported animal data (Fig. 3) were 16 stories of owners being pawed awake (mostly by cats) and usually on the face, a few minutes prior to the quake. This was usually said to be unique behaviour for the animal within the ownership period, and is hence rather convincing. Many of a further 40 reports were of owners woken by extreme barking and dogs wanting out of the house. In 7 cases the owner let the dog out, but was standing in or very near the door when the earthquake occurred. They were inadvertently led to the (probably) safest part of the house, and thus the dog acted as an accidental safety source. One respondent reported that the incident led to escape from injury when wall ornaments above the bed were dislodged. In Kobe similarly, dogs particularly tried to make owners go outside with them. One could argue as one Christchurch respondent did that being woken could lead to more alertness and a more appropriate reaction when the quake struck.

Seven owners reported pets which persistently reacted before aftershocks as well as before the main shock. In two cases owners reported the reaction was characteristically seconds before the aftershock, but other owners reported reactions typically about 1 min before, and in a few cases 3, 5 or 10 min before.

There were three estimates of accuracy of the "prediction" by the pet: "most cases", 80 % and 90 %.

It became clear from replies not long before the major 22 February earthquake that many people were using their pets as earthquake indicators and even warning relatives that an aftershock/earthquake was on its way. Discussion later in this paper will evaluate how successful a strategy this was.

4.5 Meteorological precursors

> "Driving to ChCh [Christchurch] from Darfield at 09.30 p.m. on Friday 03/09/10 (the night of the Quake). Saw a strange halo/arc of light over the city of Chch. It was blue... I guess. Do not know how long it went on as I was concentrating on driving. Not too sure if connected to Quake but did seem odd at the time."

(There were a few other such precursory reports of light, but the predominant reporting was of the rather well known co-seismic earthquake lightning which is not a precursor.)

Unusual fine settled weather labelled "earthquake weather" in Turkey, New Zealand, the USA and many other places since the time of Aristotle, was cited by many retrospectively as a predictor. However, obviously such weather occurs overwhelmingly with no associated earthquake and is not a useful precursor.

There were several reports that stars looked unusually close. This rather unique non-scientific phrase was also independently reported cross-culturally from Kobe and İzmit. It probably means unusual atmospheric stillness and clarity. One report was of an abnormally elongated appearance of the moon (also reported and photographed from Kobe). See Ikeya (2004) for one hypothesis to explain this, involving ultralow-frequency electromagnetic waves causing water droplet condensation and an atmospheric lensing effect.

4.6 Earth precursors

These were sometimes described as creaking, or sometimes like explosions in the ground, once like a bubble bursting. Unusual silting of streams occurred in dry weather. These events were some days before the quake and typical of what is reported worldwide. It is difficult to use them as reliable precursors.

4.7 Electronic precursors

> "The TV lost its signal several times, maybe 6 or 7 times, from 11:00 LT . . . to 11:30 LT. . . when we went to bed [day before the earthquake] It kept displaying "no service" and could only be resolved by turning the TV off and on again. This was the first time this sort of thing had happened and we thought it was weird as the TV is only a couple of months old. Thought maybe it was faulty, but it has not happened again since the quake."
>
> [Friday 17:45 h the day before the quake] "Interference with the digital television signal. The picture pixellated (if that is right word) intermittently but more annoying was sound-picture mismatch to a huge degree whereby at one stage the sound was actors talking (*Friends* [TV programme]) and the last credits were rolling on the picture. I changed to analogue because it was so out of kilter and could not watch it."
>
> [Saturday morning, note earthquake was at 04:35 LT]. "Immediately after the earthquake I discovered that not only had my watch stopped at 03:17 LT but so had my clock radio i.e. well before the quake struck. Both were on the bedside table."
>
> "Electric shocks (static electricity) before main (week before and almost constant). Also similar before aftershock."

These could accompany the fine settled weather; perhaps the static electricity excess was a cause of some of the various electronic glitches reported. This was not reported from Kobe or İzmit.

One respondent reported the TV emitted unique groaning noises, probably due to interference effects on the audio circuits.

Checks with local engineers showed there was no interruption to the TV signal transmission and some type of local interference was therefore detected. This is similar to ionospheric turbulence pre-quake reported for earthquakes in other locations, and reported from the DEMETER satellite etc. (Parrot et al., 2006) (see later).

4.8 Human precursors ("Other")

> "[No duration given] I have been hearing deep pulsing/buzzing noise when it is quiet at night. (A bit like a helicopter or airplane a long, long way away.) It is so deep I can almost feel rather than hear it. I have turned everything electrical off in the house and could still hear it. The rest of my family cannot hear it. When I go outside I cannot hear it. It stops and starts and often wakes me up in the night suddenly. I thought it was tinnitus so had my hearing checked by an audiologist who said my hearing is very good and that maybe I could hear things other people cannot hear. A week or so ago I was talking to my neighbour and mentioned the noise and she said she has been hearing it too, and so has several of her women friends, and their families also think they are imagining it. Since the earthquake it has almost stopped although I do hear it still sometimes. I wonder if it is something to do with the earthquake although it was over several months rather than just before it."

Unusual feelings of pressure, or headaches were also frequently reported before many aftershocks. Similar reactions are proverbial in Christchurch during local Fohn winds. However, there are no rigorous epidemiological studies published about the effects of Fohn winds worldwide, only a suspicion that pressure drop/positive ion excess is involved. A few people reported unusual itchiness.

4.9 Precursor distribution

The bulk of the answers (197) were from Christchurch at about 40 km from the more sparsely settled epicentre, and 63 were from within 40 km of the epicentre. Six were from 800 km or more, and the furthest single report within New Zealand was 960 km. Alleged precursors were recorded from as close as 10–15 s before the quake to as long as a vague "months".

Animal precursor timing

Animal precursor mean for hours 05:00 LT to midnight of 3 September (Fig. 3), is 6.75 ± 2.25 per hour and of course this is statistically remote from the 84 in the hour before as shown by a t-test ($P \ll 0.001$) or by the Tschebychev theorem ($p < 0.00085$). Most of the 84 results were minutes before the quake, and thus are not subsonic-related, because any major emission of subsonics would arrive with the first p-waves (and seismic records did not show precursory activity). The slight dip in reports 2–4 h before the quake may be because people were asleep.

The data base of results of the survey in Excel format will be maintained to be available from the authors for some years on request, or from the website www.chchquake.co.nz, and is being deposited with the National Library of New Zealand.

5 Discussion

The most popular time for alleged precursors was within the preceding day, but this may reflect psychological bias rather than precursor frequency.

For 8 people with pets, one reported a pet reaction before the quake, and another reported subsequent reaction before aftershocks. This suggests that the majority of pets will not show them. The result although its error is large, is consistent with the Kobe result of 25–33 % of pets showing unusual behaviour before the quake (Ikeya, 2004).

Table 1. Chi-squared test comparing data of day before, with days 2–4 before.

	Sky	Animal	Earth+Electronic	other	sum
4–24 h	27	76	16	20	139
2–4 days	4	13	5	15	37
Expected	7.18	20.2	4.26	5.3	37

Chi-squared $p = 0.0048$.

Table 2. Chi-squared test for events inside and outside 56 km.

	Earth	Sky	Animal	Electronic	Other	Sum
Inside 56 km	30	38	158	20	53	299
Outside	5	5	61	5	13	89
expected	8.92	11.31	47.03	5.95	15.77	89

Chi-squared $p = 0.0397$.

5.1 Dependence of classes of precursors on time

This is shown in Table 1.

Combining days 2–4 was necessary for minimum cell size, and kept to a minimum number of days to minimize psychological reasons for possible different precursor ratio reporting. Earth and electronic categories were combined to achieve reasonable cell size.

The day before is here defined as hours 4–24 before the quake, because there was a highly anomalous number of events in the last hour before. If those first four hours are included the probability value for the chi-squared test becomes extremely small, and extremely statistically significant but the calculation is arguably not a fair comparison.

The p-value of 0.0048 is highly significant and shows the two distributions are not the same. There are excess meteorological/animal events the day before. However, a test for all precursors in days 7–9 compared with 2–6 gave $p = 0.49$ (NS). This does not support the previous work which found an anomaly at 7–10 days before both the Kobe/İzmit earthquakes. On the other hand, the excess pets lost at day −9 as shown below, does support the earlier finding.

Although the difference is statistically significant it is worth pointing out that most animal excess events close to the earthquake time, were only about 50 % higher than those earlier. This is not a dramatic difference and is approximately similar to excesses reported earlier for Kobe and İzmit (Whitehead et al., 2004). It makes using pet data as precursory inherently difficult.

5.2 Dependence of classes of precursors on distance

A test distance prediction for the Christchurch event was calculated using the 80 km critical distance for the Kobe quake (Whitehead et al., 2004) and an assumption that energy scaled in an inverse square or quadratic fashion with distance. This gave for $M = 7.1$ a test distance of 63 km. The distances reported only allowed relevant tests at 56 and 66 km. A test for 56 km is given in Table 2.

This is significant statistically at $p = 0.05$. Tests at all other distances were not significant at $p = 0.05$, but the result for 66 km was very close to significance (a trend).

This confirmed the previous work, when allowances were made for event size. That is, the distribution of precursor classes varies significantly with the predicted distance, which is not expected from psychological factors alone, and includes a contribution from some real precursors. The distance represents not the maximum distance that precursors may be reported, but the distance they create a statistically significant difference. This probably has a statistical rather than a physical meaning.

Report numbers decreased with distance from the epicentre, but the interpretation could be psychological. It seems likely that the further away people are from the epicenter the less they believe they have experienced a precursor. When report numbers are transformed to logarithms and regressed against distance, as much as 68 % of the variance is explained which probably corresponds to an exponential decrease or an inverse square law, which cannot be statistically distinguished given the degree of scatter on the points. This might mean an exponential decrease in reports is a psychological characteristic. If the interpretation on the other hand is a genuine decrease in precursor intensity, the distance for decrease to 50 % is 150 km.

It is interesting that for one Wellington (320 km) precursor report of a unique owner-rousing behaviour from a pet, the time noted was 4:35 LT (claimed very accurate) but this should have been 4:36:50 LT allowing for the travel rate of the p-waves from Darfield, (the p-waves were not noticed by the respondent). This appears again to be a precursor but before the fastest possible travel rate of the ground impulses and therefore likely to be caused by something electromagnetic, which is essentially instantaneous at 320 km. This supports a ULF interpretation.

5.3 Lost/found pets

Data taken from *The Press* newspaper, with a lesser number from the website of the Royal Society for the Prevention of Cruelty to Animals are shown in Fig. 4 with satellite-derived data superimposed (explained later). Tests for the city of Dunedin further south, were not possible because pet losses were pooled and published at irregular intervals by city council employees, with no indication of when the loss occurred.

The hypotheses to be further examined following work by Rikitake (2001), and support by Whitehead et al. (2004), are whether there are precursor excesses one day before and 7–10 days before for an earthquake of about this magnitude. The latter prediction is much vaguer. The two values of 13 correspond to the two predictions for which statistical tests must be done. The mean of all other results in Fig. 4

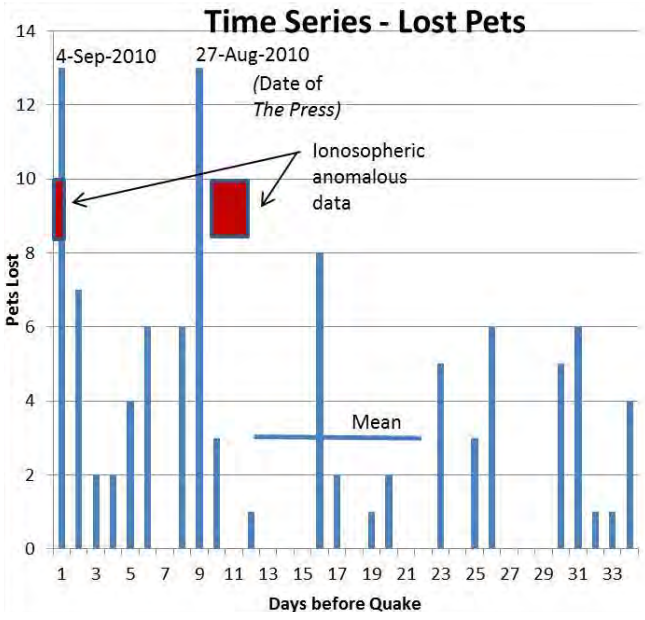

Fig. 4. Lost pet data for Christchurch, with ionospheric data superimposed (Yao et al., 2012). The data from *The Press* are from pets lost at least one day prior. Note there is a combined Saturday/Sunday edition, therefore, every 7th day lacks a data point and the Monday reports could be double average.

when the results with value 13 are tested is 3.0 per day (standard deviation 3.1 – this is calculated including one of the two values of 13), so either of the two results with value 13, are 4.5 times the mean and more than 3 standard deviations away from the mean. A statistical test hence shows the result on the day before the earthquake is significant at the $p = 0.01$ level but also for the 27 August. The summed result, 34 reports, for the week ending 4 September, was significantly greater at the $p = 0.01$ level compared with the mean of 16.7 for the other weeks. This means the week before the quake had double the normal reports of pets lost and found.

A similar calculation for Wellington (normalized to Auckland data to allow for any possible seasonal effects) suggested data were (30 ± 10) % higher in the week before the quake. This suggests that the distance from Christchurch for the pet losses to drop to about half is about 200 ± 100 km, because any effect at Wellington was small. This should be independent of psychological factors, but the error is large. Perhaps surprisingly it implies anomalies are detected hundreds of kilometers from the epicenter for a quake of $M = 7$. It is statistically not distinguishable from the 150 km calculated from precursor decrease with distance above.

An anecdotal report in the literature which asserted that in the month before the 17 October 1989 $M = 7.1$ California quake missing pets numbers were almost unprecedented, reported no statistical test, so their relevance is not clear (Orey, 2006). Statistical testing to see whether pets lost in San Francisco correlated with minor quakes in a year without a major close earthquake did not achieve statistical significance (Schaal, 1988), but data associated with a single large earthquake would have been more meaningful. However, the work in this paper using statistical tests does support a greater frequency of pet loss before the Christchurch earthquake. It finds a second peak 9 days before which is consistent with the supposed precursor peak from the previous paper (Whitehead et al., 2004).

The $M = 6.3$ earthquake of 22 February, occurred near midday of a work day and many of the precursors mentioned here are probably not applicable. Few people would be near their pets and daylight would mask many possible precursors.

In contrast to the 4 September earthquake, a fresh similar test using data on lost animals for the 22 February earthquake did not find an excess number missing. Either the first finding is spurious (though it was also found for the Kobe quake) or habituation had occurred in the animals, which was specifically claimed by some respondents, although others used their pets as earthquake indicators because the response apparently continued.

Although the animal data are consistent with the work of Ikeya et al. (2004), which preferred ULF as an explanation, some other explanations are not eliminated. Animals in air could be partly reacting to air ionisation, though this cannot be an explanation for reactions noted in aquaria, for example.

5.4 Geomagnetic/ionosopheric work

The French DEMETER satellite, designed to search for ionospheric changes possibly correlated with earthquakes and ionosopheric data derived from other satellites, has yielded much data since about 2005, typically free electron density, ELF or ULF electromagnetic density, GPS disturbances, or ground temperature, all of which seem to typically attain anomalous levels some days before a significant earthquake There has been statistical validation for prediction of earthquakes, for ionospheric electron and ion densities (Akhoondzadeh, et al., 2010) GPS or VLF network measurements (Hayakawa et al., 2010) although the proposed mechanism of charge transfer from lithosphere to ionosphere varies between different authors, and no mechanism has been clearly demonstrated. The statistical relationship between various precursors and earthquakes is significant. Another possible precursor is ground temperatures which are reported to be higher before a quake (Tronin et al., 2004). But the statistical treatment generally would benefit from further development and clarification. For some claimed precursors there is a worrying discrepancy between the area pinpointed by satellite and the actual epicenter (Yao et al., 2012).

The above unusual ionospheric events in many cases also occur without earthquakes. Given that proviso, there was an independent published analysis of ionospheric perturbation for the 4 September Christchurch event. Anomalous GPS data (Yao et al., 2012), were reported for the day before the

quake and also (transferred to local time equivalent) on 24–26 August from the ionosopheric electron data, and the geomagnetic disturbance data (Kp parameter). These correspond to the two highest pet losses shown in Fig. 4. However, many more such comparisons would be needed to establish a firm correspondence.

5.5 Has earthquake prediction got a future?

The Chinese scientists claim a long-term 40 % success rate, in other words worse than tossing a coin even when precursors apparently exist. Could this be improved? The present work is only slightly encouraging. Precursors seem to exist, but the unique ones are previously unobserved animal behaviour, and only a small percentage of animals show it. The present paper suggests that infrasound (subsonic) is not involved, and this conflicts with Chinese information. This needs further work to understand.

Even if it were possible to give some days warning of an earthquake, no house strengthening would be possible. The only benefit from such a warning would be to avoid for a few days known earthquake risks such as very old brick buildings, or streets near glass-fronted high-rise buildings. It is difficult to improve on the general civil defence advice "Be prepared with emergency supplies", and to enforce good building codes, which for the first earthquake in September prevented deaths. The 185 lives lost in the February quake shows further work on earthquake-proofing is essential. However, giving in to insistent pet whims in some cases could also save lives. It is also salutary that though many people had in some sense learned to use their pets as predictors, there were no reports of lives saved. One could argue that there is unlikely to be a better test of animal precursors, in such a forewarned and prepared population, but it was not practically useful. Ikeya (2004) reports a number of lives saved in various countries through animal precursors, though few compared with the death tolls in the same earthquakes. That finding is mirrored at Christchurch.

One person from the survey claimed for the 22 February earthquake experiencing a strong feeling they should not shop in the centre of Christchurch that day, but spend the day 30 km away. Even this claimed human precursor seems to have only moderate life-saving content.

The present authors conclude that although some precursors are probably real, a more objective prediction would rely on physical measurement. This may be eventually available, particularly through ionospheric measurements which have the advantage of being available for a very large area simultaneously, something probably logistically impossible by local observation of other claimed precursors.

6 Conclusions

This work confirms previous work – some real precursors are observed by the general populace, particularly in the few days before the quake, but many apparent precursors are doubtful. Unique animal behaviour was particularly reported, and accidentally led some owners to a safe place. Some unique behaviour was repeated before aftershocks. Pets also were lost at double the normal rate in the week before and 4.5 times normal in the day before the quake. Precursors seem to have been noticed as far as Wellington (320 km). For the later 22 February earthquake no life-savingly useful precursors from pets were recorded even given the "practice" on aftershocks following the 4 September quake. Even if precursors are valid their main use is immediate, i.e. warning of imminent quakes, and there is no substitute for stocks of emergency supplies, or good and enforced building standards. The observations fit a model where low frequency EM waves cause precursors, rather than infrasound. The correspondence with ionospheric/geomagnetic data is intriguing and mutually supportive, but needs orders of magnitude more work before a good correspondence is established, including long periods of observation without earthquakes to improve statistical precision.

7 Afterword

> [from survey replies]: "I tried to sleep but I was too scared. how dare the earthquake damage my hometown... Thank-you Sarrah"

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