ARCHAEOLOGY IN NEW ZEALAND

Early Maori Telecommunications: Visual Signalling (Use of signal fires as a warning system)

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Author's Note: This article is one section of a broader paper entitled *'Information Archaeology: an Archaeological Genre Whose Time Has Come?'* available in draft on the academia.edu web site. The topic was also presented at the 2015 NZAA conference in Paihia.

Introduction

The author's interest in this subject arose at a public field trip to view the archaeology of the Bowentown area in 2012. During a visit to pa sites on the eastern tip of the Bowentown promontory, the guide (Brigid Gallagher) mentioned that iwi along the Bay of Plenty coast used smoke from signal fires to warn of approaching hostile taua (war parties). Geographic locations used for signalling included Bowentown Heads and Mt Maunganui (Mauao), which are 25 km apart (and clearly inter-visible on a clear day), and other prominent high points and pa along the Bay of Plenty coast. Another likely site for a warning fire along the coast is Mayor Island (Tuhua), which is approximately 30 km east of the coastline around the Waihi Beach - Whangamata area.

Tuhua (Mayor Island) was an important source of obsidian, a key raw material for tool manufacture. As such, Tuhua was a key strategic location, and was permanently occupied. The only specific literature reference found relating to Maori use of smoke signals along the Bay of Plenty coast was from Prebble (1971): "By means of fire and smoke signals they [Tuhua residents] could communicate with the mainland from where, at times, chiefs would come to visit." There is, however, literature reference to Maori smoke signalling in other regions of NZ, as will be outlined later.

Two pa sites on the eastern end of Bowentown promontory are recorded archaeological sites (Te Kura a Maia U13/31 and Te Ho U13/39). Mauao pa is recorded as U14/149. There is no mention of any evidence of signal fire features at Bowentown; however, at Mauao, there is mention of "...a large hangi was discovered at the entrance to the pa...It was covered over by a light layer of topsoil." Other smaller hangi sites were recorded. It is possible that the 'large hangi' was a signal fire, but it is likely that the recorders (at both sites) may have been unaware of the possibility of the remains of large signal fires being present. Such remains would likely consist of large patches of charcoal (of the order of 2-3m in diameter) and/or patches of soil, of roughly the same dimensions, showing signs of burning or scorching.

The site record for Te Ho pa (U13/39) states: “According to an article in the Bay of Plenty Times (4th June 1971) this was occupied by British Forces during the closing stages of the Maori-Pakeha war, who maintained a heliograph communication with Tauranga.”

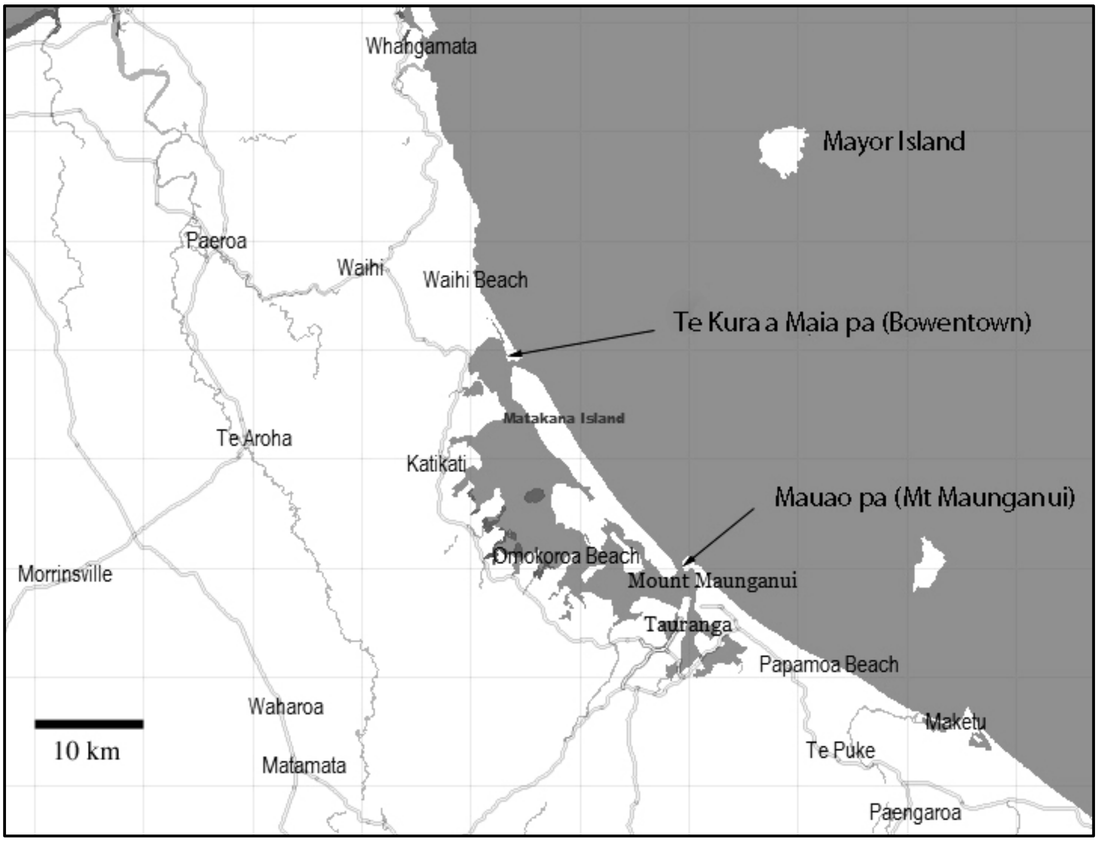

Figure 1. Map of the Bay of Plenty area, showing possible visual signalling sites. The distance from Bowentown to Mt Maunganui is 25 km, Mayor Island is 28 km offshore and the three sites are inter-visible on a clear day.

Ironically, on the Bowentown field trip mentioned above, Mt Maunganui was clearly visible from Bowentown (a distance of 25 km); however, Mayor Island, a roughly similar distance to the northeast, was completely obscured by low cloud and rain. A fairly obvious research question emerged:

RQ 1. How effective would smoke signalling be over distances of the order of 25 km in NZ climatic conditions? (That is, given two sites that are geographically inter-visible, what percentage of time would atmospheric conditions allow the sighting of smoke at the receiving end?)

This led to a study of the effectiveness of smoke signalling in NZ climatic conditions, which will be outlined below.

Historical and Archaeological Background

A brief literature review of visual communications technologies was conducted. This included recorded historical and pre-historical instances of the early use of signal fires for communication, the factors that influence successful communication, and recorded archaeological instances of the use of signal fires (initially, limited to NZ).

Early telecommunications technologies can be roughly divided into the following categories: visual (e.g. smoke, fire, flags, mirrors etc), aural (sound; e.g. drums, horns etc.) and physical delivery, (e.g. messenger) (Barber and Lord 1996). There is considerable information in general and Internet literature about the use of visual communication, and, particularly, signal fires. The latter utilised smoke plumes[1] to communicate by day and firelight to communicate by night. The considerations for the effectiveness of both modes are largely the same, except that smoke plumes can usually rise much higher than flames, and, therefore, smoke plumes by day should be able to be seen at greater distances than firelight by night.

A typical general description to be found in the on-line literature is as follows:

> "Classically, beacons were fires lit at well-known locations on hills or high places, used either as lighthouses for navigation at sea, or for signalling over land that enemy troops were approaching, in order to alert defenses. As signals, beacons are an ancient form of optical telegraphy, and were part of a relay league. Systems of this kind have existed for centuries over much of the world. ..." (http://en.wikipedia.org/wiki/Beacon)

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[1] In hydrodynamics, a *plume* is a column of one fluid moving through another. ... A *thermal plume* is one which is generated by gas rising above a heat source. The gas rises because thermal expansion makes warm gas less dense than the surrounding cooler gas. (https://en.wikipedia.org/wiki/Plume_(fluid_dynamics))

Smoke signalling was carried out by many early civilisations. For example:

> "... the Greek commander sent news of the fall of Troy (1184 BC) to his wife by means of a signal fire message. The relay spanned nine stations on the way to a 555 km distant Argos" [an average relay span of c. 50 km] (Meinell and Sack 2014).

North American Indians, in particular, appeared to utilise very sophisticated systems of visual communications involving smoke and also mirrors (heliography):

> "In making the smoke signals, different fuels were used to produce different kinds of smoke. Damp leaves and dung would be used to produce dark smoke, while wood and some dried grasses tend to produce a white smoke. To produce different puffs or streams of smoke, a wet blanket or hide would be placed over the fire and then removed.
>
> Among the Karankawa of South Texas, more than 20 different kinds of smoke signals were used. These included columns, spirals, zig-zags, and diverging lines..." (http://nativeamericannetroots.net/diary/1386).

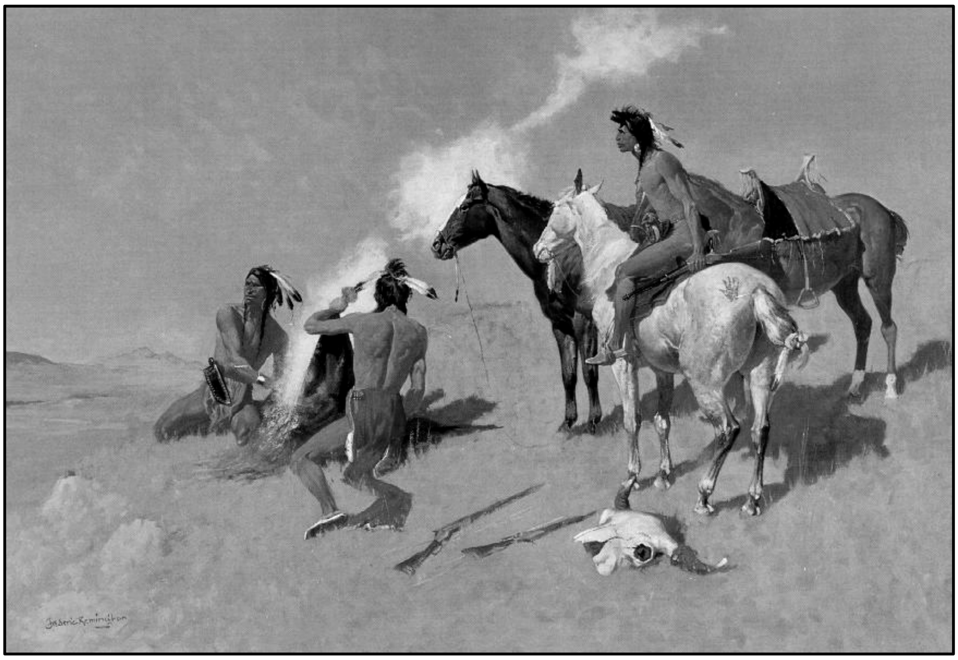

Figure 2. Painting of North American Indians using a signal fire (Remington, 1905).

A painting (Figure 2) by Frederic Remington (1905) gives an (apparently) authentic view of a small signal fire in operation. As well as providing historical context, this painting also introduces some of the physics considerations associated with signal fires and smoke-making: for example, the thermodynamic properties of smoke, the heat of the fire required to make a large, tall plume of smoke, and how close the signalling blanket (and blanket operators) can get to the fire without being incinerated!

For effective smoke signalling, a number of factors are involved. These are well summarised by US Army Field Manual 3-50, (1996):

- Wind less than 10 knots.
- Stable atmospheric conditions (temperature normally decreases uniformly with increasing altitude; non-typical layering can cause smoke to be ducted horizontally, rather than rising vertically).
- No precipitation and/or cloud cover.
- Open terrain (not heavily wooded or jungle).

It should be noted that this reference is concerned with producing smoke for screening targets or installations close to the ground, rather than producing tall plumes of smoke which can be seen a long distance away, and therefore the factors must be applied in a logical fashion. For example, heavy vegetation cover tends to trap smoke close to the ground, which is desirable in a screening situation, but highly undesirable for signalling.

Another critical factor for producing a tall plume of smoke which can be seen over long distances is a high intensity fire (i.e. hotter source):

> "… measurements indicate that larger summertime heights are the result of higher fire intensity, likely due to more severe fire weather during these months. This work demonstrates the significant effect of fire intensity and atmospheric structure on the ultimate rise of fire emissions, and underlines the importance of considering such physical processes in modelling smoke dispersion" (Martin et al. 2010).

The reason that a smoke plume rises to a certain high and then disperses is due to the fact that the smoke is initially hotter than the surrounding air, so it rises. When it cools to the temperature of the surrounding air, the vertical force disappears and the smoke then inter-mingles with the air molecules (often moving in the direction of any wind present).

Figure 3. Example of smoke plume dispersing when smoke particles cool to ambient air temperature (author's photo).

Based on the author's experience of making and observing experimental fires as part of this study, the fire of Figure 2 above is likely to be hot enough to produce a vertical plume of smoke no more than about 5 m tall (possibly much less, depending on air temperature, wind etc). Effective signalling would be limited to a range of about 5-10 km using a fire of this size. A larger fire would mean more heat at ground level, and therefore make it much more difficult for humans to get close enough to manipulate a blanket, to make patterns in the smoke.

A brief survey of historical and archaeological evidence of visual signalling in NZ was also conducted; mostly related to the pre-European era. Several references were found in historical sources, mainly originating from oral traditions within iwi, but also some historical accounts by early European observers and authors. There are few Maori smoke signalling sites recorded on ArchSite, and those are based on oral tradition rather than archaeological evidence (It is quite possible that this is due to lack of awareness of signalling sites on the part of archaeologists who are identifying and recording sites, rather than the absence of such sites).

Barber and Lord (1996: 10) provide an informative description of Maori signalling:

> "Fixed communication was ... practised in a number of ways. The Maori developed long distance communication by using the resources available to them. They had the pahu, and one such large wooden gong was located in the One Tree Hill area of Auckland which was reputed to be audible over most of the Auckland isthmus. [See also Best (1925 pp. 297-8)] Also they had the pu kaea, which was a form of alpine horn. Fire and smoke were also used ... Another means of communicating was by shouting between fortifications or from cliff top to cliff top. This means of communicating was known as pari karangaranga.
>
> The native trumpet shell was the pu tara or war trumpet. This prized shell was used by iwi (tribes) to issue out a challenge to a potential enemy. If the challenge was answered then war would ensue. Abel Tasman unwittingly accepted the call to battle when he first heard the challenge by ordering his sailors to trumpet a reply. This misunderstanding of communications highlights the need...to understand the medium and exploit it to its fullest potential…"

Best makes numerous general references to the use of visual and aural signalling by Maori; for example: "*Whakapua* means to signal by means of smoke—a common practice in war and peace" (Best 1902). Skinner (1893) records the use of smoke signals as a warning in the Taranaki area:

> " …and last but most important of them all, Te Kawau, an island - at high water - about two miles south of the Mohakatino river. This was the key of the whole coast ... In times of danger, signal fires were lighted on this impregnable outpost, giving warning along the coast of the vicinity of the enemy, and on the approach of day-light reinforcements were poured in from all the *pas* mentioned above."

Similarly, Percy Smith (1910) records use of smoke signals as a warning in Northland:

> "… the taua arrived at Waikara, just to the north of Maunga-nui Bluff …Taoho, of Te Roroa hapu, was sitting at the door of his house in the pa of Tokatoka [P08/122], from which there is a very extensive view in all directions. He saw a column of smoke go up from Maunga-nui

> Bluff, the well-known signal used by these tribes for generations past to denote the presence of an enemy."

A search of ArchSite was conducted and a list of NZ sites identified as probable early visual signalling sites was compiled (details are at Appendix A to the main paper). This is very limited in extent, and includes the following sites:

- O07/6 Maunganui Bluff, Northland (now updated to include the information of Percy Smith (1910)).
- T24/35 Arawaru, Tararua Ranges. Oral evidence of Rangitane indicates that elements of the iwi were located on both sides of the range and communicated with each other using smoke, from the top of the ranges.
- Surrey (S12/38), Esk (S12/30), and Miranda (S12/46) Redoubts, Mangatangi Stream Corridor, northern Waikato. Waikato campaign redoubts built by the British forces to provide flank protection and an optical telegraph (probably semaphore) chain between the main force base at Pokeno, and ships operating in the Firth of Thames.

There are other potential signalling sites and anecdotal evidence which will be followed up as time permits. One example is a statement on the Ngati Huarere (Coromandel area) web site that "Huarere ... arranged his Pa so two Pa were always in view of each other. They were able to communicate over the distance between them through the use of smoke" (http://www.ngatihuarere.com/ngati-huarere). At the time of writing, possible signal fire features have been identified by Brigid Gallagher on the outside flanks of a recorded coastal headland pa in the Bay of Plenty. The report is currently in preparation (Pers. comm. B. Gallagher, December 2015).

Research Method

To recap, the research question posed in an earlier section was:

RQ 1. How effective would smoke signalling be over distances of the order of 25 km and longer in NZ climatic conditions?

A review of the literature revealed previous attempts to confirm prospective smoke signalling systems and the locations of signal fires in a non-NZ context. These include a study of potential use of smoke signals in the kingdom of Judah (Borowski et al. 1998). This study used GIS technology to ascertain whether or not potential sites of signal fires were geographically inter-visible from adjacent sites. Another study in the US (Beers 2014) used historical and ethnographic reports, coupled with archaeological evidence of signal fires, to demonstrate a high probability that North American Indians used such systems to communicate. Historical and archaeological evidence, in conjunction with line-of-site determinations using GIS technology, indicates a possibility of signal fires being used over distances of between 40 and 75 km (Beers 2014).

Both of these studies stop short of examining (and potentially quantifying) the success factors and effectiveness of early visual signalling systems. As noted earlier, visual systems using smoke as the communications channel are likely to be dependent on weather conditions, such as wind, precipitation and atmospheric visibility (cloud etc). They are obviously also dependent on pure geographic inter-visibility, but this is relatively easy to determine, using modern GIS or even web-based tools such as Google Earth.

For the purposes of this study, the following research model was adopted:

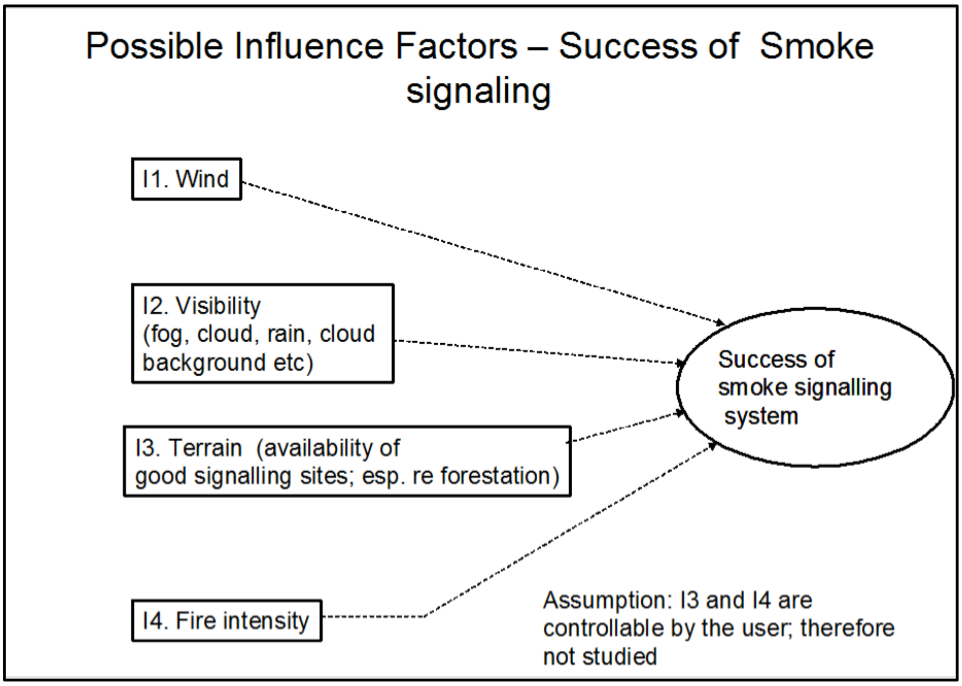

Figure 1. Research model for study of effectiveness of smoke signalling in NZ weather conditions (from Turban and Aronson 1998).

The model is in the form of an influence diagram (Turban and Aronson 1998), based on the success factors for smoke signalling cited in the literature (e.g. US Army FM 3-50). To simplify data collection, factors I3 and I4 were treated as constants, as it was felt that they were controllable by the user (i.e. the signalling system operators).

Various methods of gathering data were considered, and some actually attempted, including the building of experimental signal fires and determining the distance at which they could be observed. However, it soon became apparent that this method was impracticable, owing to legal and safety problems in using flares, smoke generators or open fires in public spaces (particularly on hilltops) and in obtaining enough results to be statistically significant.

Wind data was found to be available from a web site - www.windfinder.com. This is essentially a series of 'home' weather stations, operated by members of the public, which contribute data to a central repository, which, in turn, presents a variety of individual site, and summarised, data for public use. One very useful statistic provided for many sites allowed calculation of the probability of wind speeds <= 10 knots, which is the upper wind limit for successful smoke operations, as defined by US Army FM 3-50:

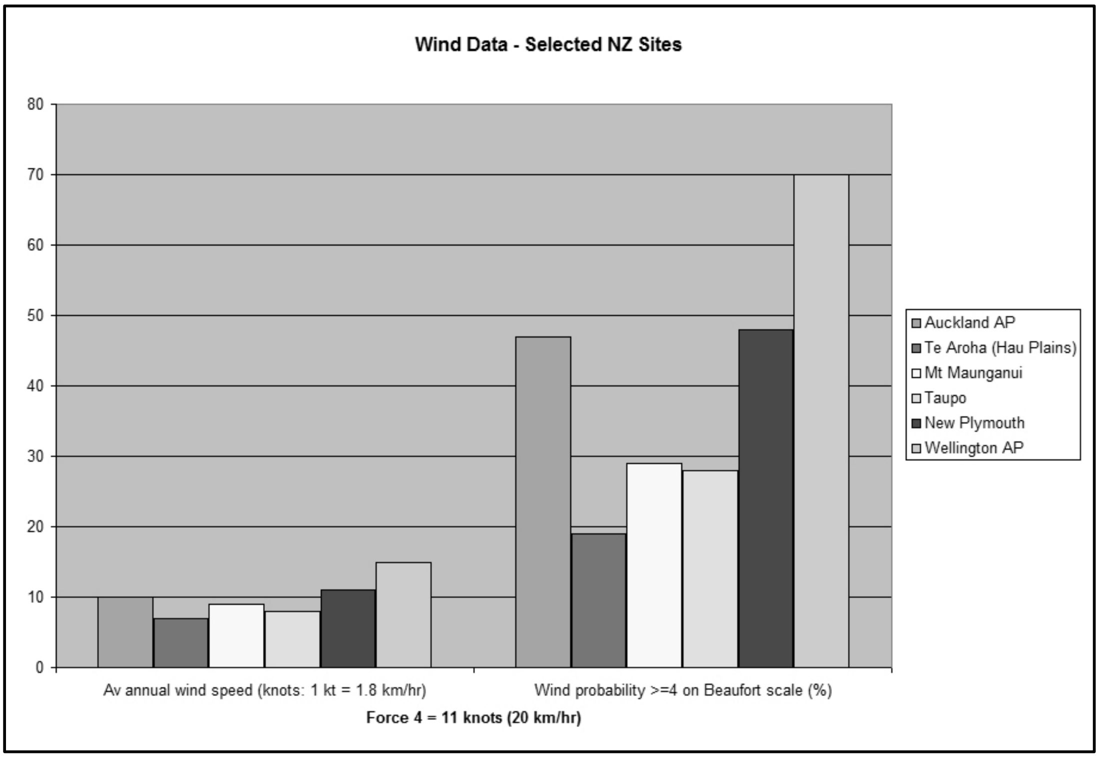

Figure 2. A selection of data available from windfinder.com. The wind probability of >= 4 on the Beaufort scale allows calculation of the probability of wind speed <= 10 knots, the indicative cutoff for successful smoke operations (US Army FM 3-50).

It was decided to test Influence Factor I2 (probability of visibility not obscured by cloud, fog, precipitation etc) by use of public web cameras. Four cameras were randomly selected, to provide data on atmospheric visibility over well defined optical paths (e.g. to prominent islands, hills etc) at ranges from about 3 km, up to about 65 km. The camera sites chosen were: Howick, Taupo, Kelburn (Wellington) and Hamilton. Also, data was gathered manually for one optical path from the home of a volunteer colleague (Roger Strong) near the summit of the Hapuakohe Ranges, to Thames, 25 km to the east. (This was chosen to replicate the 25 km path from Bowentown to Mt Maunganui, discussed previously.) Views from the web cams and of the manual path were recorded and are in Appendix B to the main academia.edu paper.

One interesting (serendipitous) result from the Taupo web cam was that, when the atmospheric visibility allowed, it provided views of a plume of natural steam, issuing from a volcanic vent on the northern slopes of Mt Tongariro, some 60 km away. This allowed a separate check on the validity of the method; i.e. the observer's ability to see a plume (in this case, of steam) in varying weather conditions. (Photos of this phenomenon are also at Appendix B to the main paper.)

One area of difficulty was in the treatment of sun-strike, as some of the early morning views faced east. It was decided to basically work around the problem, by taking observations at a slightly different time, when the sun was in a higher position. It was found (from the Kelburn camera) that the problem existed for only a couple of hours, so this work-around is not considered to significantly bias the results. The Hapuakohe - Thames optical path also suffered from early morning sun-strike, but this became apparent too late to remedy; therefore the data of successful observations for this path are lower than could have been expected.

Observations from the web cams and the Hapuakohe-Thames optical path were made twice-daily - early morning and mid-afternoon. Over a period of about four months, nearly 500 observations were made and the results compiled.

Results

For each web cam and the manual observations (Hapuakohe - Thames), the observer had to decide whether a smoke plume would have been visible in the atmospheric conditions prevailing at the time. That is potentially subjective and, initially, was considered a possible source of error. However, there were many opportunities to see actual smoke plumes, and the steam plume from Mt Tongariro, and the observers rapidly gained confidence in their ability to decide whether a smoke plume would have been visible or not, in the context of other objects in the view. Digital images of all web cam observations were kept and are available for inspection.

Results were collected from each path, summarised, collated as a probability function and plotted as a chart. The results, taking into account influence factor I2 (weather-related visibility) only, were as follows.

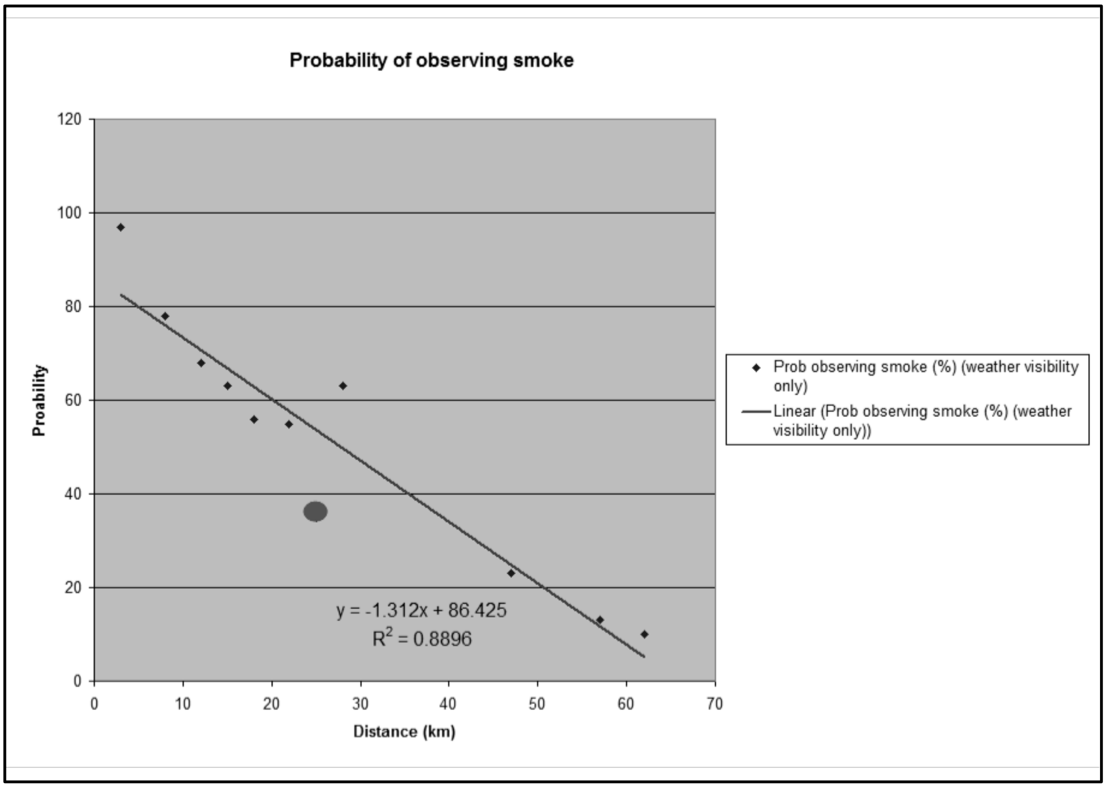

Figure 3. Probability of observing smoke (%) plotted against distance between the source and the observer. There is correlation between the two variables, with the R^2 factor of 0.89, indicating strong linearity. The data point for the Hapuakohe-Thames optical path is indicated as a large dot - sun-strike lowered the count of successful observations, but the data is still considered to be valid, and has been included.

The results demonstrate, for example, that the probability of successful smoke signalling between Mt Maunganui and Bowentown (25 km) would be about 55%, based on atmospheric conditions only (i.e. cloud, fog, precipitation etc). This is surprisingly low, based on the good geographical inter-visibility of the two peaks in clear weather conditions.

Another interesting result is that the chart predicts that the probability of successful communications (limited by atmospheric conditions only) tends to zero at around 70 km. This is consistent with the results of Beers (2014). Actual observations of the Ketetahi Springs steam plume on the northern slopes of Mt Tongariro from Taupo (62 km) demonstrates that visual signalling is clearly effective at that range - under clear atmospheric conditions. However, the steam plume was visible in only about 10% of the observations, due to obscuration by cloud etc.

The results for atmospheric obscuration can be adjusted to take account of influence factor I1 (wind speed) by multiplying the probability of atmospheric visibility and the probability of wind speed <= 10 knots together. This can also be displayed as a chart, but is not strictly valid, as the probability of wind <= 10 knots depends only on the location (of the source fire) and not on the distance to the observer. However, it gives a graphic indication on the degrading effect of wind on the probability of successful smoke signalling:

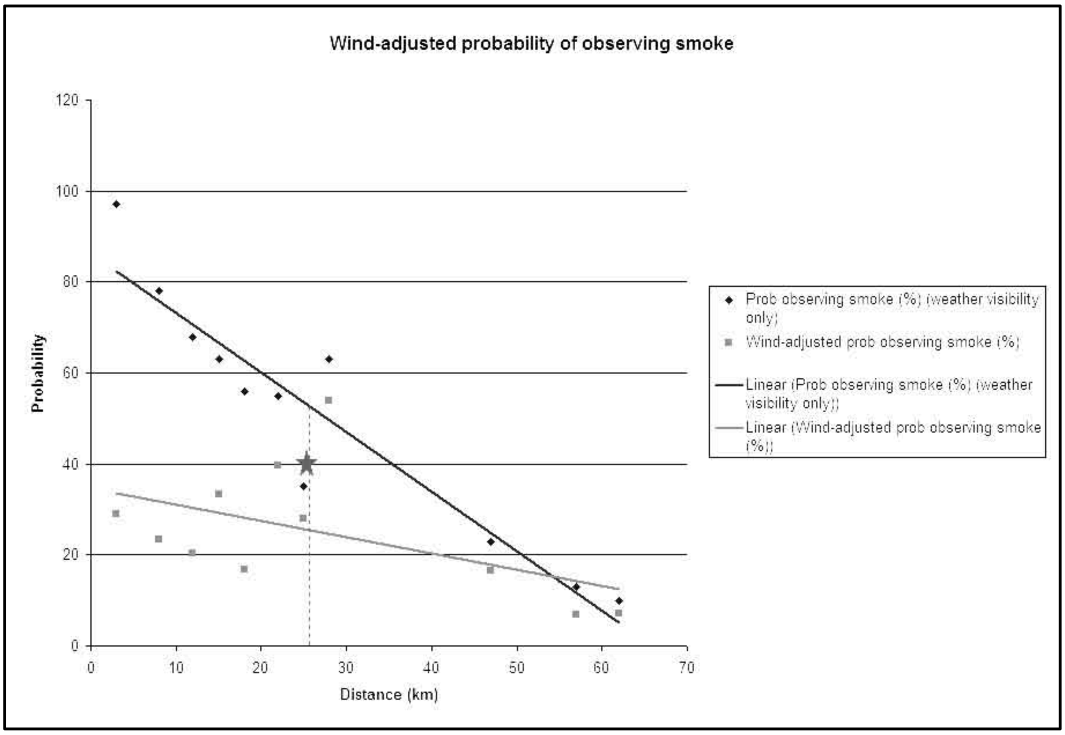

Figure 4. Wind-adjusted probability of observing smoke versus distance between fire and observer.

The wind-adjusted probability of observing smoke is roughly indicated by the lower line, and is significantly reduced from the wind-free scenario. In order to calculate the probability of smoke being observed over a particular path, it would be necessary to use the wind probability (<= 10 knots) for the actual location of the fire. In the chart above this has been plotted for Mt Maunganui (red star symbol), indicating that an observer at Bowentown would have a probability of about 40% of observing smoke from that source, taking into account the effects of atmospheric obscuration and wind.

Conclusions and Discussion

The design and execution of the above study has limitations, based on the simplified nature of the research model, data collection method and statistical analysis. However, the results are of interest, and are considered to add to the body of knowledge in the subject area: the effectiveness of communication by means of signal fires in a New Zealand context (particularly, in local weather conditions). The results demonstrate that the probability of observing smoke plumes from signal fires decreases linearly with distance, up to a maximum range of about 70 km; but the probability can be reduced significantly by winds in excess of 10 knots.

In terms of the overall Information Archaeology theme, it can be concluded that the use of smoke signalling, with a variable probability of success, represents what is known in modern networking terminology, as a 'best efforts' service. That is, if conditions are favourable, messages can be passed successfully, but if not, they won't get through. This is identical to some modern networking protocols, such as IP, which is used on the Internet (RFC 791, 1981). If messages are unable to be passed at the IP layer (for example, due to network congestion or link outages) then application-level services, such as Skype or video streaming, are unable to work.

Another observation is that there is ample historical and ethnographic evidence of Maori use of smoke as a warning. The possibility of archaeological evidence of this should be borne in mind when field work is undertaken. Any prominent hilltop with good inter-visibility to other high ground could be a possible signalling site. Many such sites may have been re-used in recent times, utilising more modern technology, such as radar, microwave radio and cellular telephony, as these all use electromagnetic radiation as the communications channel, which requires line-of-sight propagation, as does visual signalling. Indications of signal fires may be pits and/or charcoal deposits (or heated earth) larger than normal cooking fires, on high ground, but possibly on a sheltered slope or in an indentation or pit, to provide wind protection.

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