The role of the Kaharoa eruption in the early Polynesian perception of Aotearoa

A research article prepared by Isabella Bennett, Samuel Hampton and Daniel Hikuroa

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**Abstract**

In this study, we investigate the plausibility of Polynesian observation of the 1314 (+/-12) Kaharoa eruption of the Tarawera complex in Northland, New Zealand. The almost coincident nature of this eruption with the postulated date of 1280-1300 for Polynesian arrival to New Zealand raised the question; did this eruption produce an eruptive plume large enough to be seen from significant distance? If so, did this plume initially alert voyaging Polynesians to the presence of New Zealand? The likelihood of this occurrence was assessed using SketchUp and Google Earth to model the eruption plumes produced by a series of 11 plinian eruptions that occurred within the 4-5 year Kaharoa eruption. The model was based on data provided within previous studies regarding this eruption, and relies primarily on Pythagorean theorem to assess the visibility of these plumes from significant locations within greater Polynesia. The size and dimensions of these plume models ultimately demonstrates that this scenario is unlikely to have occurred. Based on the relative dates of Polynesian arrival to New Zealand and the Kaharoa eruption, it is more likely that the Polynesians witnessed this eruption as newly established inhabitants of New Zealand. In either case, the Polynesian observation of this eruption may have had a greater impact than has previously been explored, and the term Aotearoa (land of the long white cloud) may be a reference to the eruptive plumes produced by this eruption.

**Keywords**

Aotearoa, Kaharoa, eruption, plume, Maori, oral tradition, New Zealand, Tarawera, SketchUp, Google Earth

**Introduction**

When Polynesians set foot on the North Island of New Zealand they claimed the world’s last uninhabited landmass (Newnham et al., 1998; McGlone and Wilmshurst, 1999; Lowe et al., 2000; Hogg et al., 2002, 2008; Lowe, 2008). The most widely agreed upon date of Polynesian arrival to New Zealand is between 1280 and 1300 AD (Newnham et al., 1998; McGlone and Wilmshurst, 1999; Lowe et al., 2000; Hogg et al., 2002, 2008; Lowe, 2008). Central to Maori oral traditions is the notion that these Polynesians originated
from Hawaiki (Evans, 1997). Hawaiki is more of a conceptual location of Maori origin rather than a physical location; however there is evidence in support of Hawaii, Tahiti and Ra’iātea (an island in the Society Islands, north of Tahiti) as the origins of some of the first peoples to inhabit New Zealand (Best, 1915; Hiroa, 1949). In each of these instances, reaching New Zealand required the Polynesians to deviate from the previously employed navigational methods. The Polynesians are known to have sailed from west to east through Polynesia from Melanesia; which positioned waka into the prevailing winds and ensured that return journeys could be made more quickly (Evans, 1997; Goodenough, 1996). However, voyaging to New Zealand from Hawaii, Tahiti or Ra’iātea requires voyagers to sail south-westward.

Ra’iātea is about 4,000 km SW from the west coast of the North Island, where the Polynesians first settled, and Hawaii is about 7000 km. While voyaging waka could travel up to 250 km in a day under good conditions, extensive distances such as these could take more than 40 days, and would require stopping at multiple islands and a definitive destination (Taonui, 2012). How did Polynesians on Ra’iātea or Tahiti know that land awaited them some 4,000 km away? What convinced early Hawaiians to travel some 7,000 km south in search of land?

The purpose of this study is to examine whether volcanic plumes produced by the 1314 (+/- 12) Kaharoa eruption in the Taupo Volcanic Zone (TVZ) were visible to the Polynesians and therefore aided in the discovery of New Zealand. The estimated period of Polynesian arrival to New Zealand is based on carbon-dated artifacts, all of which have been found above the volcanic material extruded by the Kaharoa eruption (Nairn et al. 2000; Lowe, 2008). There is no evidence of human interaction with the land prior to the Kaharoa eruption (Lowe, 2008). The Kaharoa eruption series took place in the Tarawera complex over the course of 4-5 years, during which ~5 km$^3$ of tephra was extruded across the North Island (Bonadonna, et al., 2005). This eruption began as a pheatamagmatic eruption, followed by a more explosive plinian phase of 11 total eruptions, and concluded after a phase of dome extrusion (Bonadonna, et al., 2005). For the purpose of this study, we will focus on the plinian eruptions, as these eruptions
generated the most extensive volcanic plumes and would therefore have been the most visible of the three phases. Plinian eruptions are characterized by massive ash plumes and significant, explosive tephra dispersal (Bonadonna, et al., 2005). Previously conducted modeling has shown that Kaharoa plinian eruptions lasted between 2-6 hours and produced plumes between 16 and 26 km high, which extended to the northeast due to southwesterly prevailing winds (Bonadonna, et al., 2005). In order to understand if these plumes would have been visible to voyaging Polynesians, a model of the largest plume was created using empirical data sets where possible, and information regarding recent eruptions of comparable measure where historical data was not available.

Methods

1. Oral traditions
Information regarding Maori oral traditions was gleaned primarily from Nga waka o nehera: The first voyaging canoes (Evans, 1997). Specifically, this portion of the study was significant in determining a physical location for Hawaiki and the history behind the meanings behind the name Aotearoa. Information regarding historic Polynesian navigational tactics and voyaging oral traditions was primarily gathered by Daniel Hikuroa.

2. Plume modeling

   Visual
The likelihood that voyaging Polynesians observed the volcanic plumes generated by the Kaharoa plinian eruptions is entirely reliant on where the Polynesians were positioned in relation to New Zealand, and the visibility of the plume from that location (Table 3). In order to assess this, the size and visible extent of the largest plume was modeled using SketchUp Pro 2016 (hereafter referred to as SketchUp) (Figures 1, 2 & 3). SketchUp modeling software and Google Earth Pro were used to provide a visual, georeferenced model of the Kaharoa eruption plume (Figure 1). The model was created and edited within SketchUp and exported into Google Earth (Figures 1, 2 & 3).
**Dimensions**

Plume height information sourced from Bonadonna et al. (2005) provided a backbone from which vertical plume radii could be calculated based on the empirical relationship between height and expanse under normal atmospheric conditions (Sigurdsson, et al., 2000) (Table 1). Using the radii calculated, parallel circles were created at 5000m intervals with corresponding radii (Figure 3). Based on the nature of this study, the highest plume was modeled to understand maximum distal extent and therefore maximum visibility to traveling Polynesians.

*Table 1: Vertical plume radius (km) as a function of height (km).*

<table>
<thead>
<tr>
<th>Column Height</th>
<th>Vertical radius</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 km</td>
<td>Not given</td>
</tr>
<tr>
<td>20 km</td>
<td>10 km</td>
</tr>
<tr>
<td>15 km</td>
<td>4 km</td>
</tr>
<tr>
<td>10 km</td>
<td>2 km</td>
</tr>
<tr>
<td>5 km</td>
<td>1 km</td>
</tr>
<tr>
<td>0 km</td>
<td>&lt;1km</td>
</tr>
</tbody>
</table>

At each height, a two-dimensional circle parallel to the earth with the corresponding radius was created using SketchUp (Figure 2). These radii are based on the empirical vertical plume dispersal relationship described by Sigurdsson, et al., (2000).

After the formation of the two-dimensional circles, the “follow me” tool was used to connect these circles vertically, forming a funnel-like cone. This cone was then georeferenced to the central point of the Tarawera complex. Based on lack of data regarding plume shape and thickness, the horizontal portion of the plume was modeled using a rectangle shape extending horizontally from the top of the cone for 540 km to the northeast, following New Zealand’s prevailing southwesterly winds. In order to orient the plume in SketchUp, the directional lines were utilized. Within the program, the solid green line represents due north and the solid red line represents due east. The plume was created at a position of 45-degrees between the solid red and green lines in order to properly orient the plume to the northeast prior to export into Google Earth Pro. The
measurement of 540 km was based on plume data from recent, well-documented eruptions of comparable size (i.e. Eyjafjallajökull, 2010; and Klyuchevskaya, 1994) (Table 2). 540 km was chosen as a conservative yet viable length of visible plume to rule out overestimation and therefore minimize error, especially given the range of eruption sizes throughout the Kaharoa plinian series and 2-6 hour duration of each eruption.

**Table 2: Comparison of well-documented eruptions to the Kaharoa eruption**

<table>
<thead>
<tr>
<th>Eruption</th>
<th>VEI</th>
<th>Duration</th>
<th>Column height</th>
<th>Visible dispersal</th>
<th>Total estimated erupted mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kaharoa, New Zealand ~1314 AD</td>
<td>4</td>
<td>4-5 years</td>
<td>16-26 km</td>
<td>Unknown</td>
<td>~5 km$^3$</td>
</tr>
<tr>
<td>Kliuchevskoi, Russia September 15, 1994</td>
<td>4</td>
<td>~20 days</td>
<td>15-20 km</td>
<td>565 km</td>
<td>~1 km$^3$</td>
</tr>
<tr>
<td>Eyjafjallajökull, Iceland April 17, 2010</td>
<td>4</td>
<td>6 days</td>
<td>~9 km</td>
<td>Significant particle dispersal as far as 2400 km from source (sized at 20 micrometers in Germany)</td>
<td>~0.8 km$^3$</td>
</tr>
</tbody>
</table>

The comparative nature of these three eruptions is based primarily on shared VEI, which implies at least ~1km$^3$ of total erupted mass, and explosive plinian style eruptions, as well as extensive plume height. For the purpose of this study, Kliuchevskoi and Eyjafjallajökull provide hypothetical visible dispersal of plume data where it is unavailable and therefore “unknown” for the Kaharoa eruption. Note specifically the 565km visible dispersal of Kliuchevskoi, after which Figure 2 was modeled.

**Curvature of the earth and plume height**

The curvature of the earth was applied to the SketchUp model using the Pythagorean theorem in order to maintain a constant plume height above the surface of the earth (Figure 2). Essentially this meant curving the originally straight, rectangular plume to follow the Earth’s mean radius of curvature in a non-direction-specific orient at height. Constant plume height was modeled due to lack of empirical data regarding plume
thickness, and the relationship between vertical dispersal and distance from source (figures 2 & 3).

**Visualization**

In order to depict the visibility of the plume, the model was exported into Google Earth Pro. This software shows the geographical relevance of the plume in context to the surrounding landforms (Figure 3). In order to better interpret the visual data, Pythagorean theorem was employed to derive the specific range of visibility to the horizon as a function of altitude assuming proficient, unaided human vision (Table 3). Specifically the formula provides distance to the visible horizon (d) as a function of 3.57 multiplied by the square root of height above sea level (h):

\[ d = 3.57 \sqrt{h} \]

**Table 3: Distance visible to horizon as a function of altitude**

<table>
<thead>
<tr>
<th>Height above sea level (meters)</th>
<th>Context</th>
<th>Visible distance to horizon (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 m</td>
<td>Person standing on a beach</td>
<td>~5 km</td>
</tr>
<tr>
<td>3 m</td>
<td>Person aboard voyaging waka</td>
<td>~6 km</td>
</tr>
<tr>
<td>154 m</td>
<td>Highest point of east coast New Zealand (East cape lighthouse location)</td>
<td>~43 km</td>
</tr>
<tr>
<td>1,017 m</td>
<td>Highest elevation on Ra’iātea</td>
<td>~114 km</td>
</tr>
<tr>
<td>4,140 m</td>
<td>Top of Mona Loa, southern Hawaii</td>
<td>~229 km</td>
</tr>
<tr>
<td>16,000 m</td>
<td>Smallest Estimated Kaharoa plinian plume height</td>
<td>~451 km</td>
</tr>
<tr>
<td>21,000 m</td>
<td>Intermediate estimated Kaharoa plinian plume height</td>
<td>~517 km</td>
</tr>
<tr>
<td>26,000 m</td>
<td>Highest estimated Kaharoa plinian plume height</td>
<td>~575 km</td>
</tr>
</tbody>
</table>

The formula distance=\(3.57\sqrt{h}\) describes the relationship between the human eye and the distance to the horizon based on height above sea level (h). This distance provides a
measure of how far the plume could be seen from, assuming normal atmospheric conditions. Note that a plume 26,000m high would be visible from ~575km away.

3. Data extraction
The collation of data from both the SketchUp model and the mathematical formula representing distance to the visible horizon served to provide a clear boundary of visibility surrounding the plume, assuming normal atmospheric conditions (Table 3, Figure 1). Using Google Earth, it is possible to observe the model from sea level, which provides a rough idea of when the model is no longer visible, however in order to establish accurate data, the mathematical modeling provided more reliable data. The model instead served more as a visual representation of the data gleaned through mathematical reasoning, especially at the ~575 km boundary (Table 3). Within the green boundary circle, the plume is visible, and this is reflected in the Google Earth model at a view from sea level.

Considerations
The prevailing winds over the North Island of New Zealand are subject to change based on seasonality, however southwesterlies are dominant. For lack of data regarding exact dates of each eruption within the Kaharoa plinian series, the model was created assuming winds originating in the southwest, which would carry the plume out to the northeast as the model depicts (Figures 1 & 2).

There is not currently a method to accurately model an undocumented eruptive plume. The thickness, or horizontal and vertical dispersion of a plume varies immensely between eruptions based on duration, eruptive mass and velocity, wind speed and direction, and atmospheric conditions. These conditions much be observed or measured in order to accurately model a plume. In the absence of this information, satellite images and data collected from recent eruptions of similar size and composition were used to infer a probable plume size and extent. In this case, the Kaharoa eruption relates most closely with the Eyjafjallajökull and Klyuchevskaya eruptions, off of which the plume extent is modeled (table 3).
Discussion and Results

A plume of these dimensions would have been visible on the horizon to a person at sea level from ~575 km away (Table 3, Figure 1). Being that the largest plume is estimated to have extended at least 540 km from the source, the endpoint of the visible plume would be visible a total of ~1115 km away from the source of the eruption at the Tarawera complex, or ~1070 km from the coast of the Bay of Plenty (green circle, Figure 1). In context to Hawaii, Ra’iātea and Tahiti, this is too significant a distance to stumble upon, and would instead require the Polynesians to have previous knowledge of land prior to embarking to New Zealand.

As depicted, there are no significant islands within this boundary of visibility, and the Polynesians would therefore have to have been coincidentally sailing straight for New Zealand during or directly following an eruption in order to have witnessed any portion of the Kaharoa plinian eruption phase (Figure 1). It is possible that the 540 km plume length is an overly conservative estimation based on the notion that the Eyjafjallajökull eruption spread tephra up to 20 micrometers as far as Germany (2,400 km) (Table 3). However, the Kliuchevskoi eruption, upon which this model is primarily based, had a visible dispersal to ~565 km. Because there is currently no data to provide a guideline as to the total extent of these eruptions, which varied widely in size, a conservative estimation of 540 km is better than an overestimation. This being said, unless these eruptions were significantly larger, an increase by the order of tens of kilometers would not have a serious impact on the viability of this hypothesis, as it is still a relatively insignificant distal plume in context to the distance to surrounding landforms. Unless the plume reached as far as Tonga or a similarly significant island, it is still unlikely that these plumes would have been visible to traveling Polynesians.

The likelihood that voyaging Polynesians witnessed the Kaharoa plinian eruptions is therefore small. This being said, there is not currently enough data available to rule out this theory. Given more time and access to Maori court records of oral traditions, more definitive evidence may have been attainable. There are however multiple avenues for
future study that may yield evidence in support of the hypothesis that the Polynesians relied on the Kaharoa plinian eruption series in the discovery of New Zealand. Namely, this study would benefit greatly from the provision of more information regarding specific plume dimensions and dispersal patterns in order to more accurately model the eruption and therefore provide more conclusive data.

A lesser known translation of Aotearoa, “land of the glowing cloud,” (McLintock, 1966) may also provide more conclusive evidence that the early Maori witnessed this eruption, as the particulate friction within VEI 4 eruptions such as these can cause volcanic lightning, which would in turn cause the plume to glow. Would a glowing plume be visible from farther away? Specifically, would the light generated by the lightning reflect off of the ocean’s surface and back into the cloud and so forth, enhance the visibility of the cloud during the night? Furthermore, due to the proximity of the Tarawera complex to the Bay of Plenty, large amounts of tephra would have been deposited into the ocean during each of these eruptions. Depending on the porosity and permeability of the pumice within these deposits, oceanic currents could conceivably transport floating pumice rafts to great distances, which could then have been witnessed by the Polynesians and understood as a sign of proximity to land.

Finally, it is important to consider the notion that the Polynesians may have found New Zealand prior to the Kaharoa eruption. In this case, the name Aotearoa may still be a reference to the Kaharoa eruptive plumes, as these eruptions would most certainly affect the Polynesian perception of New Zealand through the prolonged presence of expansive plumes, the deterrence of sunlight, dispersal of sizable tephra in areas proximal to the eruption, among other factors of VEI 4 eruptions, depending on the proximity of settlements to the Tarawera complex.

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Abroad community is also greatly appreciated for the continuous provision of support and guidance.

References


Figures

**Figure 1:** Google Earth representation of Plume visibility

The central rectangular feature is a simplified model of a 540 km long, 26 km wide volcanic plume originating from the Tarawera complex. Concentric circles denote the level of visibility of the farthest northeastern portion of the plume. The blue circles radiate at 100 km intervals and represent the area within which the plume would be visible. At a distance beyond the green circle, a plume of these dimensions would not be visible on the horizon (Table 3). Note the abundance of proximal South Pacific Islands, upon which the Polynesians are known to have sought shelter and supplies during voyages.
Figure 2: Sketchup plume model dimensions and curvature

The model plume is curved to follow the curvature of the Earth. The dimensions of the plume are based off of the size of the eruption column and data from recent, comparable eruptions (Table 2).
Figure 3: The model eruption column

This figure serves to show the model prior to export into Google Earth (Figure 1). Each segment of the eruption column is 5 km high. Radii was sourced from Sigurdsson, et al., (2000) (Table 1).