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Precursor Tsunami Signals Detected by Elephants

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Abstract: Signals generated by the December 26, 2004 Asian earthquake that can be detected by elephants are examined. Arrival time differences serve to identify two acoustic and one olfactory as potential warning signals.

Keywords: Elephant response, elephant behavior, acoustic-olfactory signals, tsunami, sixth sense.

INTRODUCTION

There is a large body of anecdotal evidence that animals can anticipate as well as react to major tectonic events such as an earthquake as well as a tsunami which might be triggered by that event [1, 2]. In modern times, Chinese and Japanese scientists and authorities have attempted to quantify and incorporate animal behavior in their earthquake prediction services [3-5]. On February 4, 1975, Chinese authorities evacuated the City of Haicheng several hours before a 7.3 magnitude earthquake destroyed 90% of the city. The evacuation order was based on observations of unusual animal behavior. It was estimated that 90,000 lives were saved. Failure to predict other earthquakes as well as false alarms, have, however, undermined attempts to use animal behavior as a predictor [6].

Elephants have been shown to possess sensory capabilities which allow them to detect and interpret extremely low-frequencies [7-9]. Evidence has been presented which shows that frequencies below 20 Hz and possibly as low as 1 Hz propagating in the atmosphere as sound and at the earth's surface as seismic waves can be detected by elephants [10-15]. Earthquakes generate signals with frequencies between 1 and 100 Hz in the earth's surface and atmosphere, and, in the case of the December 26, 2004 tsunami, there is anecdotal evidence that elephants might have responded to this event at considerable distances from the epicenter [16-19].

In this note, precursor signals are examined that might have been detected and responded to by elephants as far away from Sumatra as Thailand and Sri Lanka.

THE DECEMBER 26, 2004 INDIAN OCEAN EARTHQUAKE

On December 26, 2004, a magnitude 9.0 earthquake occurred some 160 km (3.32EN 95.85EE) off the NW coast of Sumatra, Indonesia a minute before 0800 local time (00:58:53 UCT). The earthquake, at a depth of 30 km below mean sea level, extended an estimated 1200 km along the subduction line of the Indian and Burman Plates. These plates may have moved vertically some 15 m relative to each other. Seismographic data suggest that the slip took place in two phases over a period of several minutes.

In the first phase a rupture about 400 km long and 100 km wide formed running north-northwesterly for about 100 sec. A pause of about 100 sec then occurred, after which the rupture continued northwards at about 2 km/sec towards the Andaman and Nicobar islands. This two-phase displacement was transmitted to the sea bottom resulting in a longitudinal drop of the ocean surface of several meters. Unlike a point source generating concentric rings of ripples such as those caused by a pebble thrown into a pond, this sudden longitudinal displacement at the sea surface was more like two telephone poles crashing end-for-end and in rapid succession into the pond.

Radar measurements from satellites found the height of the tsunami wave to be 60 cm after 2 h of travel (1400 km). Water particles in response to the tsunami wave rotate about the longitudinal axis of the wave at right angles to the direction of travel. The water particles experience only an up and down motion with no horizontal displacement. The crest of the wave, however, propagates at about 700 km/hr.

As the ocean shoals, the water in contact with the bottom slows, destabilizing the elliptical path. The height of the tsunami grows rapidly and on December 26th reached heights in places of more than 15 m. The breaking wave of the tsunami on a coastline produces infrasound in frequencies which range below 1 Hz up to 10 Hz [20]. A withdrawal of water exposing as much as 2.5 km of some of the beaches preceded the tsunami wave by up to 20 mins.

SEISMIC AND ACOUSTIC SIGNALS

An earthquake generates vibrations in the earth's mantle and, as in the December 26, 2004 case, a wave on the ocean's surface. Four types of seismic waves are generated: primary or P-waves, secondary or S-waves, Love waves and Rayleigh waves. The P-wave is of small amplitude; the latter two waves generate the greatest amplitude at the earth's surface.

The Love waves are transverse shearing waves which vibrate the ground in a horizontal direction perpendicular to the direction of travel. Being transverse waves they cannot be transmitted in either the ocean or the atmosphere. They are formed by the interaction between the S-wave and the surface and are dispersive waves. Dispersive waves break down into different frequencies and hence wavelengths and wave speeds. Love waves range in frequencies from 1000 Hz

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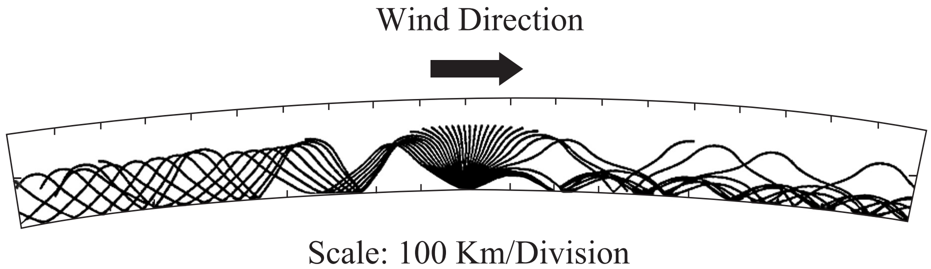

Fig. (1). Computer ray trace models show how infrasound at a frequency of 1 Hz is refracted and channeled over long distances by the temperature and wind structure of the atmosphere. A 60 m/s jet of wind blowing to the right at 60 km altitude is simulated to show the difference between upstream and downstream propagation. Rays that end abruptly are absorbed by atmospheric viscosity and thermal conduction. (After Bedard and Georges, 2000).

to less than 1 Hz and speeds can range between 2 and 6 km per sec or 7,000 to more than 20,000 km per hour (4,000 to more than 12,000 mph).

Rayleigh waves are compressional waves, moving particles in an elliptical trajectory thus displacing particles upwards and downwards about a mean horizontal position. Rayleigh waves can propagate at speeds between 1 and 5 km per sec but are typically the slowest of the above four waves and might be assumed, for purposes of this discussion, to have a speed near 4,000 km per hour (2,400 mph).

The breaking of the tsunami wave on a coastline generates low-frequency sounds at and below 100 Hz with much of the energy residing in infrasonic frequencies between 1 and 10 Hz. These sounds travel in the atmosphere at the speed of sound. Over the tropical ocean surface (~ 30EC) this speed will be about 1,260 km/hr.

Very low-frequency sound in the atmosphere suffers little attenuation with distance because of its long wavelength (350 m at 1 Hz). In the low latitude location of the December 26th tsunami, winds increase with height from a few meters per second at the surface to over 25 m s^{-1} at 12 km. Temperatures decrease up to the tropical tropopause and then increase with height in the stratosphere reaching surface temperatures at the stratosphere/mesosphere boundary.

When temperatures and winds increase with increasing height above the ground or ocean surface, sound waves are refracted downward to the surface. Surface reflection results in the trapping of the sound wave as in a wave duct. Such ducting eliminates spherical spreading of the wave which can then travel over even greater distances as shown in Fig. (**1**) [21, 22].

For example, ocean waves breaking on the east and west coasts of North America produce low-frequency sounds (~ 0.2 Hz) which travel in the atmosphere and can be detected by sensitive instruments in Boulder, CO, some 3,000 to 4,500 km (1,800 to 2,800 mi) from the source (Bedard, personal communication).

The December 26th earthquake and tsunami thus created signals that traveled at different speeds in the earth's crust, at the ocean surface and in the atmosphere over great distances. The seismic signals were detected globally, while the tsunami wave itself was recorded as far away as South Africa (some 10,000 km from the epicenter).

The locations in Thailand and Sri Lanka where elephants were reported to have reacted to the approach of the tsunami are about 1,000 km away from the epicenter. Table **1** shows the representative travel times of five waves over an arbitrary distance of 1,000 km. Secondary radiation from intermediate terrain and local Rayleigh wave passage are signals not included in Table **1**. These signals would be weaker than but essentially coincident in timing with the essential seismic signals listed [23]. Seismic signals would have arrived only a few minutes after the occurrence of the earthquake and more than 70 min before the arrival of the tsunami. A sound wave produced by the first impacts of the tsunami on the coasts of NW Sumatra would have arrived 30 to 40 min prior to the arrival of the ocean wave.

REPORTED ELEPHANT BEHAVIOR ON DECEMBER 26, 2004 ON COASTS OF THAILAND AND SRI LANKA

There are numerous reports of elephants behaving abnormally on the coast of Sri Lanka (Yala National Park) and on the west coast of Thailand (Phuket/Klao Lak). Two elephants on the coast in Yala National Park in Sri Lanka carried GPS transmitters allowing their movements to be recorded with a time resolution of 4 h [24]. Results from these collared elephants suggest that they moved about 500 m dur-

Table 1. Representative Travel Times of Five Waves Over an Arbitrary Distance of 1,000 km

	Medium in Which the Wave Travels and Wave Type				
	Earth's Crust			**Atmosphere**	**Ocean Surface**
	S-wave	**Love**	**Rayleigh**	**Sound**	**Tsunami**
Speed (km/hr)	16,000	12,000	4,000	1,200	700
Travel time over distance of 1,000 km (mins)	3.75	5	15	47.6	85.7

ing the 4 h satellite interrogation interval. The (female) collared elephant closest to the coastline at 0200 h LST on December 26th was about 105 m from the inshore boundary of the beach and 280 m from the water's edge. No position is available for this elephant at 0600 h due to failure of the satellite uplink. The tsunami struck the beach at 0900 h. At 1000 h the female had moved inland. The other collared elephant was a juvenile male that ranged within 6 km of the coastline before the tsunami struck [24]. Both elephants were associated with a herd, each led by a matriarch 30-40 years of age. While the time resolution of the observations and location of these collared elephants relative to the tsunami is poor, these records show no unusual change in the two elephants movements either before, during or after the tsunami struck the coast of Sri Lanka.

In the absence of any evidence of a response of the collared elephants, the anecdotal evidence must be treated with added caution. A number of observers noted the relative time difference between the unusual behavior and the time that the tsunami struck. These time differences may serve to identify candidate signals that could have been detected by elephants.

Reports from observers in both Yala National Park, Sri Lanka, and on the beaches of Thailand, place response times of unusual behavior of elephants as occurring between 20 and 60 min prior to the arrival of the tsunami. This time interval would appear to eliminate the seismic signals as potential cues for any pronounced response. It is possible, however, that the seismic waves served to underscore the signals received later. The 20-60 min lead time is, however, compatible with the differences noted in Table **1** between the time of arrival of the sound and the tsunami (38 min).

Two other potential cues need to be noted. The withdrawal of water prior to the arrival of the tsunami on the shoreline would create an unusual sound as well as unusual smells. This withdrawal could have occurred as much as 20 min before the arrival of the tsunami and cannot, therefore, be eliminated as a possible auditory and olfactory cue.

There is little doubt that a tsunami of the magnitude of that occurring on December 26, 2004 can produce signals which elephants can detect. Whether and how memory operates and whether, as seems likely, more than one signal is utilized remain challenging questions. Not only is it likely that elephants would react to unusual stimuli but that they have the cognitive capability of drawing deductions from simultaneous multiple inputs [25]. There is, however, no need to call upon some unknown sixth sense to explain how elephants might detect and respond to such an event.

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