Telling a Story in Google Earth - The 2006 eruption of Augustine Volcano

John E. Bailey, Arctic Region Supercomputing Center, Fairbanks, Alaska, USA
Lovro Valcic, Alaska Volcano Observatory, Fairbanks, Alaska, USA
Jonathan Dehn, Alaska Volcano Observatory, Fairbanks, Alaska, USA
Peter Webley, Arctic Region Supercomputing Center, Fairbanks, Alaska, USA

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Introduction

Since its introduction to the world in 2005, Google Earth has captured public interest in a way few computer programs have done before. Through Google Earth's synoptic view of our planet many have come to understand the benefits and possibilities of a portal that arranges information in a geographic context. The continuing addition of greater functionality, such as the ability to animate features using timelines (since September 2006), is increasing those possibilities. Most naturally Google Earth has captured the imagination of the scientific community seeking to visualize datasets with geographic components. Through development of Keyhole Markup Language, the code used to author features in Google Earth, it is developing into more than just a novelty tool that most people use to see what their neighbor's gardens look like. The next logical step in its evolution is to become a medium that not only stores information and displays it in a geographic context, but can also be used to relay a message and/or story. This is particularly true for Google Earth, whose enormous user base (200 million downloads as of March 2007; Carlson, 2007) represents a golden opportunity to present global issues as interactive format that magazines, television and movies, or even the World Wide Web cannot.

Since its initial release in 2005, Google Earth has become increasingly included informative content through development of the Google controlled "layers". Initially layers were primarily standard GIS content, such as location and names of towns, and maps of roads. There was also some basic geographic feature content, such as the (mis-spelt) names of volcanoes. However, the content rapidly improved to take fuller advantage of the opportunities the layers presented. One such early example, was the development of the Global Connection Project, a partnership between Carnegie Mellon University, NASA, National Geographic and NASA. Global Connection's original mission was to geo-locate National Geographic's stories, and overlay high-resolution images of Africa, captured by photographer Mike Fray in 2004 from overflights of a Cessna 182 light aircraft (Lubick, 2005).

This technique of overlaying images found an unexpected application when Hurricane Katrina flooded New Orleans and the surrounding areas on 29 August 2005. NOAA captured more than 8,000 images of flood-damaged areas over 10 days using a high-resolution camera mounted on a small high-speed aircraft. At the request of NOAA, the Global Connection team created new KML software tools to handle the images that were released on a daily basis, making them available in Google Earth, though which they were used as an invaluable tool for rescue efforts (Nourakhsh et al., 2006). These images, from a visual perspective, “told the story” of the aftermath of Hurricane Katrina in New Orleans.

The ability to link to dynamic data through overlays or the bubbles which are opened by clicking on placemarkers, led to the Discovery Channel and Google to team up to highlight US National Parks. The layer links to information and videos on the Discovery Channel’s website (Vascellaro, 2006). Other independent users also developed content that became so popular that it lead to other partnerships with Google. The previously unsatisfactory volcano layer was replaced by one generated and updated by the Smithsonian’s Global Volcanism Program (Gramling, 2007) whilst the Jane Goodall Institute’s Gombe Chimp Blog pushes Google Earth’s current HTML rending abilities to the limit (Geens, 2006), and is now located in the new “Global Awareness” layer.

However it is user applications of KML, particularly in scientific and environmental fields, that are doing most to highlightthe abilities and limitations that Google Earth has when it comes to telling coherent stories. Examples include maps of avian flu (Butler, 2006a), fights against logging, exploitation of the Alaska National Wildlife Refuge and other environmental issues (Dicum, 2006), tracking of changes in the polar regions (Butler, 2006b; Dworschak, 2006), and monitoring of storms (Smith and Lakshmanan, 2006), earthquakes (Taylor, 2006) and volcanoes (Gramling, 2007; Svoboda, 2007).

The Alaska Volcano Observatory remote sensing group (AVO) uses Google Earth as a visual context for satellite images and other geophysical data used to monitor over 100 volcanoes in the North Pacific region. During 2005 one of these volcanoes, Augustine Volcano, a small dome complex that forms an island near the mouth of Cook Inlet, Alaska (Figure 1), showed signs of unrest that eventually led to its eruption in January 2006. Observed by a multitude of instruments, on a scale previously unprecedented for an Alaskan eruption, the 2006 eruption of Augustine Volcano provided vast datasets that will be presented as a narrative using Google Earth. We will describe the monitoring undertaken and the four phases of the eruption, using figures that are unedited screenshots of the Augustine data displayed in Google Earth. The goal is to demonstrate the current capabilities of this program, whilst highlighting its limitations, and thus suggesting directions for its future development.

2006 Eruption of Augustine Volcano

Prior to 2006, there had been five known major historical eruptions (1883, 1935, 1963-64, 1976, 1986) of Augustine volcano. Typically these events involved explosive eruptions followed by a period of lava emplacement. Located 280 kilometers southeast of Anchorage International Airport, Augustine lies along the path of several local and international air traffic corridors (Power et al., 2006). It also represents a threat to local communities around Cook Inlet, who are susceptible to the impacts of ashfall and the potential for tsunamis generated by large slope failures of the volcanic edifice. The latter last happened as result of the 1883 eruption (Beget and Kienle, 1992; Siebert et al., 1995; Waythomas and Waitt, 1998; Beget and Kowalik, 2006).

Previously, Augustine had been fairly well instrumented due to the potential hazards, proximity to communities and relatively easy accessibility (Power et al., 2006). However, the long period of precursory unrest allowed the Alaska Volcano Observatory (AVO) to deploy suites of additional instruments including five temporary continuous global positioning system (CGPS) receivers, six additional broadband seismometers, five ocean bottom seismometers (deployed by the United States Geological Survey and Woods Hole Oceanographic Institute), two web cameras, a time-lapse camera, an atmospheric pressure transducer, accelerometer and ash collection buckets. These instruments supplemented the CGPS receivers, short-period and broadband seismometers already installed on the volcano (Figure 1).

Figure 1. View in Google Earth of Augustine Island, with ground-based instrumentation used to monitor the volcano shown as placemarkers. (Top right) Map inserted as a screen overlay showing the location of Augustine Island.

Flights to obtain visual observations, measure gas flux and capture thermal imagery (using the forward-looking infrared [FLIR] camera) were undertaken regularly. Researchers from the University of Alaska Fairbanks (UAF) operated low-light cameras, whilst a joint group from UAF and the New Mexico Institute of Mining and Technology deployed a lightning detection system (Thomas et al., 2007). Visual and thermal wavelength satellite images, and derived products, were provided by the AVO's remote sensing group (AVORS). They receive Advanced Very High Resolution Radiometer (AVHRR) data, from the National Oceanic and Atmospheric Administration's (NOAA) Polar Orbiting Satellites (POES), and Moderate Resolution Imaging Spectroradiometer (MODIS) data, from the National Aeronautics and Space Administration's (NASA) terra and aqua satellites. The data are collected by receiving stations operated by the Geographic Information Network of Alaska (GINA) at the Geophysical Institute (GI), UAF. Additional AVHRR data are received from NOAA's Gilmore Creek satellite tracking station. Data from the Geostationary Operational Environmental Satellites (GOES) are provided by the Naval Research Laboratory (NRL), Monterey Bay.

The multitude of available datasets made the events at Augustine Volcano the most intensely monitored eruption in AVO history. The range of activity displayed by the volcano further enriched the diversity of these dataset, with both explosive (of phreatic and magmatic origins) and effusive events occurring. The evolution of the eruption was defined by four distinct phases, characterized by different styles of activity (Figure 2). The first phase, was the precursory stage, which indicated increasing unrest at the volcano. Phase two saw the onset of explosive eruptions, which culminated with a continuous eruption of material during phase three. The fourth and final phase saw the cessation of ash cloud producing explosions, with juvenile material instead being emplaced as lava at the summit of the volcano. The data collected by the combined monitoring efforts of AVO during all phases of activity represent a scientifically and visually compelling record of the life cycle of the eruption of a subduction zone volcano. Furthermore the inherently geographical nature and large component of imagery within these datasets make them an ideal subject for display using a virtual globe program such as Google Earth.

Figure 2. Chronology of events at Augustine volcano from 1 August 2005 to 15 May 2006, including (a) measured sulfur dioxide (SO2) emission, (b) number of hot pixels in a single advanced very high resolution radiometer (AVHRR) scene, (c) maximum 3.5-micron brightness temperature in each AVHRR scene, (d) elevation changes between EarthScope CGPS stations AV02 and AV59, (e) RSAM (real-time seismic amplitude measurement, an automated proxy for seismic energy) at station AU15, and (f) located earthquakes within 10 kilometers of the volcano's summit. Vertical lines correspond to times of phreatic (dotted) and magmatic (solid red) explosions. The bar at the base

indicates the level-of-concern color code used to communicate the level of volcanic unrest and the various phases of the eruption (Figure from Power, J.A., Nye, C.J., Coombs, M.L., Wessels, R.L., Cervelli, P.F., Dehn, J., Wallace, K.L., Freymueller, J.T., Doukas, M.P. (2006). The reawakening of Alaska's Augustine Volcano, *Eos - Transaction of American Geophysical Union* 87, No 37, pp. 373, 377)

Phase 1: Precursory Activity

The Precursory phase began as an increase of microearthquakes beneath the volcano (Power et al., 2006). Initially, occurring once or twice a day, the frequency steadily increased to 15 per day by mid-December (Figure 3). GPS measurements suggested pressurization of the volcano at sea level centered beneath the edifice (Cervelli et al., 2006). Starting in December small phreatic explosions were recorded by seismometers (McNutt, 2006), the largest of which occurred on 10, 12 and 15 December 2006. The 12 December event led to vigorous steaming and formed a 75 kilometer-long plume that was visible in MODIS and AVHRR images. This represented the first signs of activity visible in satellite data. The 15 December explosion disabled the telemetry for two seismic stations located highest up the edifice (Power et al., 2006; Figure 1). High-resolution satellite data, from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instrument on NASA’s Terra spacecraft, and visual overflights observed light dustings of ash on the snow-covered volcano. This ash was later identified as primarily remobilized material from the 1986 eruption (Wallace et al, 2006).

Figure 3. True color MODIS satellite composite image overlay in Google Earth showing a steam plume extending from Augustine Volcano for approximately 75 km (50 miles) towards the southeast. Image was acquired 12 December 2005 at 21:19 UTC and processed by GINA. (Top Right) Earthquakes counts recorded at Augustine Volcano from May 2005 to April 2006 (courtesy of Celso Reyes, AVO)

Phase 2: Explosive Activity

Steaming continued for the next month, then on 11 January 2006 activity increased. Beginning at 03:00 UTC a strong swarm of volcano-tectonic (VT) earthquakes were recorded (McNutt, 2006). MODIS and AVHRR images acquired at 07:26 and 07:43 UTC, respectively, showed the first observed thermal anomalies for the eruption. Thermal anomalies, elevated radiant temperatures at volcanic edifices relative to the surrounding background, are common precursors to explosive events at volcanoes in the North Pacific region (Dehn et al., 2000). The VT earthquake swarm culminated in explosive eruptions at 13:44 and 14:12 UTC. Ash clouds were produced by the explosions that were assessed to have reached altitudes of over 9 kilometers altitudes above sea level (asl) by the National Weather Service (NWS), using NEXRAD weather radar data (Schneider et al., 2006). These explosions marked the start of a new phase of activity that lasted 18 days (11 to 28 January), during which time 13 discrete explosive events were observed (Table 1).

Subsequent analysis showed that ash from the first two events primarily consisted of weathered or reworked material. However, fresh magma was finally erupted by six powerful explosions recorded by instruments on 13 and 14 January. Several of the instruments located close to the summit were destroyed by these explosions (Figure 1). NEXRAD located the ash clouds up to an altitude of 14 kilometers asl, placing them within the region's air traffic corridors. The ash clouds were also observed in visible and thermal band satellite images (Figure 4a). These explosions were also accompanied by large increases in the radiant temperatures at the volcano (Figure 4a).

Table 1. Explosive events that occurred at Augustine Volcano during the second phase of its 2006 eruption. Measurements are based on monitoring by seismic instruments.

After the last event on 14 January, six separately identifiable plumes were visible in images captures over the Gulf of Alaska. A brief period of quiescence followed before another strong explosion occurred at 16:58 UTC on 17 January and sent ash to altitude of 13 kilometers asl (Figure 4b). This was followed by 10 more days of relative quiet before 4 more discrete explosions occurred on 28 January (UTC).

Figure 4. Visualizations of the explosive eruptions in Google Earth (a) Ash plumes from events on 13 January are shown as an overlay. Image is generated by the rightness temperature difference between two thermal bands of AVHRR data. The ash plumes caused Alaska and horizon airlines to cancel all flights over the region for the day. (b) The location of the ash plume erupted on 17 January is predicted for 24h after the eruption. (Top Right) A plot of the hottest pixels at the summit of the volcano shows peaks on 13/14 and 17 January 2006 that correlate to the observed explosions.

AVORS activities during the eruption included the implementation of Puff, an ash dispersal modeling program, to predict the likely paths of the ash clouds. Puff uses operator defined eruption parameters and gridded wind field data to calculate the distributions over time of a number of imaginary particles released at a volcano. For the events at Augustine the predictions made by Puff was able to track multiple clouds simultaneously (Webley et al., 2007) and results compared favorably with satellite observations (Dean et al., 2006). Recent developments in Puff have allowed results to be exported in the KML format, and displayed in Google Earth (Figure 4b).

Phase 3: Continuous Activity

Starting at on 28 January the volcano entered a state of continuous eruption. Substantial ash clouds, pyroclastic flows and block-and-ash flows were generated (Power et al., 2006), and led to the further destruction of instrumentation on the north and west flanks of the volcano (Figure 1). The use of the Puff model during the continuous eruption predicted that high altitude wind field patterns would carry a low concentrations of ash as far as Fairbanks, 685 kilometers northeast of Augustine Island. These small particles were indeed detected by light detection and ranging (LiDAR) and aerosol detector systems at UAF (Cahill et al., 2006; Sassen et al., 2007).

Figure 5. Visualizations in Google Earth showing Augustine volcano during the phase of continuous eruption (a) Overlay of AVHRR image acquired 30 January shows hot pixels (white) on the north slope of the volcano. The ash cloud is shown by darker pixels to the south and southwest. Each pixel represents 1.1 km (Top Left) View of ash clouds and pyroclastic flows captured on 29 January from on island webcam before ash

obscured the lens (b) High resolution Aster image acquired 1 February shows the hot deposits on the north slope and the ash plume to the east.

Phase 4: Effusive Activity

During the 36h following the first explosions on 11 Jan, several sequences of small, similar, regularly spaced VT earthquakes occurred (with rates as high as 3 to 4 per minute). Comparable events have been seen at other volcanoes, most notably Mount St. Helens (Dzurisin et al., 2005), in association with the emplacement of lava domes. During an overflight on 16 January a small new dome was observed at the summit of Augustine Volcano. It was partly destroyed by the 17 January explosion, which blasted a 20 to 30 m crater in the dome. However, the lava dome continued to grow during the phase of continuous activity and then as ash production ceased at the start of February it remained as the primary activity, defining phase four of the eruption. The new lava dome led to persistently high radiant temperatures, that saturated sensors, being observed at the summit (Figure 6a). It was also highly unstable and from late-January until mid-March, block-and-ash flows were created by regular collapses of volumes of fresh lava.

Figure 6. Augustine undergoing dome-building. (a) AVHRR overlay in Google Earth showing a saturated pixel at the volcano's summit on 2 February. Saturated pixels in satellite images and persistently high summit temperatures (shown top left) are typical for periods of dome growth (b) Hot summit area is also shown by semi-transparent infrared image shown against Google Earth's view of Augustine (c) Similar view to (b) shown by photograph taken during an observational overflight (image courtesy of Game McGimsey, AVO / US Geological Survey)

On 7 March seismic activity once again became persistent, repetitive, identical earthquakes that increased in rate and size, forming a continuous signal by 8 March (Power and Lalla, 2006). Lava extrusion at the summit increases markedly in association with these signals (Power et al., 2006). As the volume of lava grew, two blocky lava flows moved down the volcano's north and northeastern flanks (Figure 6b). From 14 March the repetitive earthquakes began a slow decline in frequency and disappeared by 16 March. Effusion of the lava had ceased by the end of March, although rockfalls and other collapses continued due to the friable nature of the new material. The final volume of effusively erupted material was estimated at 30 million cubic meters (Power et al., 2006).

Conclusions: Telling the Story

The 2006 eruption of Augustine Volcano is an example of geospatial event that can be easily visualized through the use of Google Earth, at least in terms of series of static snapshots (Figures 3 to 6). However, in order to fully tell the story of the eruption the program needs to further develop the tools that allow dynamic visualization. At the time of writing (April 2007) current capabilities allow users to snapshots (of overlays, placemarkers and other user defined content) for presentations. More dynamic views are available within Google Earth itself using the tour operation, along defined paths or to groups of placemarkers. The tour operation now allows placemarker bubbles to open automatically as they are reached. Placemarkers, overlays and even imported 3D models have also become more dynamic through the implementation of the time-tagging function. Navigation around these features can also by recorded by a movie-making module, but with is limited due to minimal ability to automate different styles and functions, e.g., it is not possible to open bubbles for varying periods of time at different placemarkers during a tour.

Future development of Google Earth needs to contain the ability to impose finer control and more functionality with the current or a different control function. Visualizations would be greatly enhanced by the ability to "script" tours so that multiple features can be demonstrated through the click of one button. This scripting ability would be further enhanced by improved camera views for tours and navigation in general, e.g. the option to pan around from one stationary spot or to follow along with an animated model from its viewpoint. Also useful would be the inclusion of powerpoint-style ability to include streaming media within Google Earth, and to allow linked navigation through other objects, e.g., a placemarker contains a link to fly to another placemarker, where the bubble opens and automatically plays a video. The ability to place videos within bubbles recently became available in Google maps (Lee, 2007), so it seems likely that integration into Google Earth is over the near horizon.

Currently the world of virtual globes is undergoing significant growth as recent upgrades to NASA World Wind, and with the release of Microsoft's Virtual Earth 3D and ESRI's ArcGIS Explorer, have created alternatives to Google Earth that potentially offer improved mediums for visualization on a 3D earth. However, the hope of the authors is that these globes will come together through the mutual support of KML as a cross-program standard, as now seems possible with the nomination of KML to become an Open Geospatial Consortium standard.

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Summary

Google Earth is currently the most popular "virtual globe" program available. It combines satellite images and terrain into a 3D model of the earth that the user can navigate around. It also offers an increasingly rich selection of geographic content placed in its planetary context. In addition Google Earth allows users to author their own content through the use of Keyhole Markup Language, enabling them to import their own images, 3D models, and many other types of geo-located information. These abilities have attracted the scientific community to use Google Earth as a method of visualizing their datasets.

As users' abilities with Google Earth become amplified, both by improvements to KML and their own imagination, it is has become apparent that the program offers on opportunity to provide more than just static snapshots of the earth. It can be used to illustrate a story using datasets placed in a geographic context. An example, of the current possibilities for this story telling has been shown for the 2006 eruption of Augustine Volcano, Alaska. This eruption was observed by a multitude of instruments, on a scale previously unprecedented for an Alaskan eruption. Many of these datasets are inherently geographically orientated, making them ideal subject matter for visualization using Google Earth. The four phases of the eruption at Augustine Volcano have been illustrated using only features currently available within Google Earth. Future improvements are suggested that would help make Google Earth an even better tool for scientists and others to tell their story to the world.

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Table 1. Explosive events that occurred at Augustine Volcano during the second phase of its 2006 eruption. Measurements are based on monitoring by seismic instruments.

Event	Date (UTC)	Time (UTC)	Local (AKST)	Duration (min:sec)
1	11-Jan-06	13:44	11-Jan-06 04:44	1:18
2	11-Jan-06	14:12	11-Jan-06 05:12	3:18
3	13-Jan-06	13:24	13-Jan-06 04:24	11:00
4	13-Jan-06	17:47	13-Jan-06 08:47	4:17
5	13-Jan-06	20:22	13-Jan-06 11:22	3:24
6	14-Jan-06	1:40	13-Jan-06 16:40	4:00
7	14-Jan-06	3:58	13-Jan-06 18:58	3:00
8	14-Jan-06	9:14	14-Jan-06 00:14	3:00
9	17-Jan-06	16:58	17-Jan-06 07:58	4:11
10	28-Jan-06	5:24	27-Jan-06 20:24	9:00
11	28-Jan-06	8:37	27-Jan-06 23:37	1:02
12	28-Jan-06	11:04	28-Jan-06 02:04	2:06
13	28-Jan-06	16:42	28-Jan-06 07:42	3:00