Emergency Situation Awareness: Twitter Case Studies

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Abstract. The Emergency Situation Awareness (ESA) system provides all-hazard situation awareness information for emergency managers using content gathered from the public Twitter API. It collects, filters and analyses Tweets from specific regions of interest in near-real-time, enabling effective alerting for unexpected incidents and monitoring of emergency events with results accessible via an interactive website.

ESA was developed in close collaboration with users to ensure fitness-for-purpose for the tasks performed by emergency services agencies. ESA processes large volumes of Twitter data and identifies discussion threads, trends and hot topics using language models. A burst detector generates alerts for unusually high frequency words that are filtered using text mining techniques and machine learning algorithms to identify Tweets of interest to emergency managers.

An overview of the ESA platform is presented along with example case studies of its use to detect earthquakes, identify bushfire events and provide all-hazard monitoring in a crisis coordination centre.

Keywords: Crisis Coordination, Disaster Management, Situation Awareness, Social Media, System Architectures, Twitter.

1 Introduction

Effective management of emergency events requires access to timely, authoritative and verifiable information. In Australia, authoritative content is being published on Twitter and other online communication channels by the emergency services to alert the community about incidents, inform them about events underway, reassure the public that a response is underway and provide advice to citizens to ensure their safety.

Emergency managers mostly operate under a command and control structure where only verifiable information from authoritative sources is used for operational decisions. While social media has been recognised as a new data channel to receive public crowdsourced information about emergency events [3,7,12] its adoption is not yet widespread in Australia. This is due to a number of limitations such as identifying relevant information from the large volume of content

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available, ensuring the veracity of what is being said and reliably determining the location of the event so that resources can be deployed appropriately. These issues are exacerbated by the work practices of crisis coordinators and emergency managers who need to make operational decisions under time constraints while ensuring that these decisions are based on the best available information.

These barriers will be overcome with the widespread and increasing acceptance of social media by the general community and emergency services personnel, so long as this information is appropriately identified. These issues are not solely technical. The policies and procedures used by emergency service organisations need to be revised to accommodate effective communication to the public on social media channels and obtain information from those who are reporting useful content.

To this end we have been exploring information published on Twitter in Australia and New Zealand to determine how best to identify useful content to help emergency managers. Various use cases have been targeted for our investigation, focusing on general 'all hazard' monitoring performed in a crisis command centre, the identification of unexpected events such as earthquakes and bushfires, and the ongoing monitoring of an unfolding event to improve situation awareness.

The use of crowdsourced Twitter content provides emergency management organisations with further information for decision making with the potential for improved community outcomes [2]. Tools currently exist that focus on crowdsourced information to improve the situational awareness of events as they unfold, see for example Twitcident [1] and Tweet4act [4]. Machine learning techniques have also been used to map crisis related Tweets into a disaster-related ontology to find information that contributes to situational awareness [6]. The ESA platform has evolved along similar lines.

The rest of the paper is organised as follows. First we provide background information describing the ESA platform noting how Tweets are collected and processed from Australia and New Zealand and the various interfaces available for users to explore *what's happening*. Then three case studies are presented outlining how ESA is currently used. Based on these case studies, a summary of the operational use of ESA is outlined and the paper concludes with a discussion of planned further work.

2 The Emergency Situation Awareness Platform

2.1 Overview

The ESA architecture is shown in Figure 1 where the red circles indicate the near-real-time processing steps. Tweets are gathered from Twitter and sent to JMS, indicated by the ① in Figure 1. The Tweets are saved in the repository ② for later reference and also processed by the *Burst Detector* ② which generates alerts ③. The alerts are also saved ④ and further processed by the *Event Detector* ④ to target specific keywords which may generate user notifications ⑤. These detector components are processing pipelines and are further explained below.

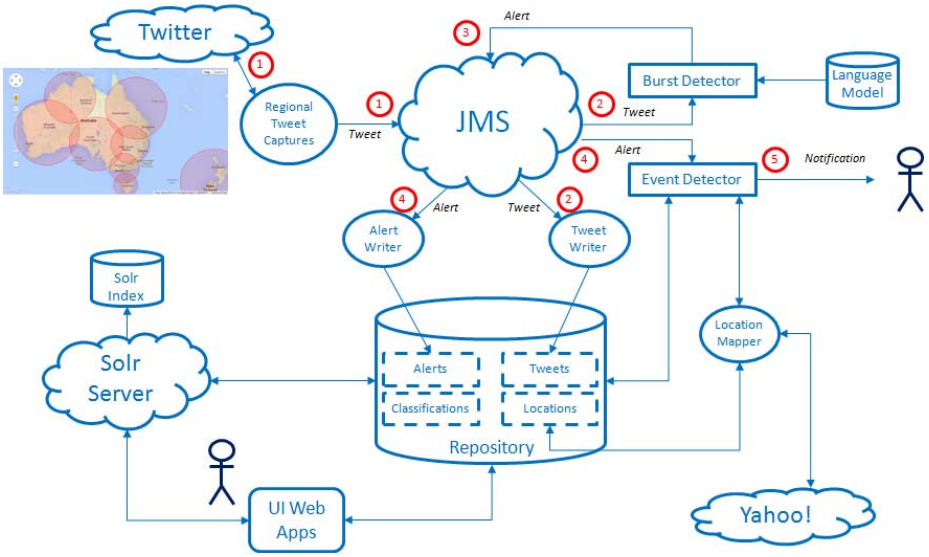


Fig. 1. ESA Conceptual Architecture

JMS provides flexible deployment of new Tweet ② and Alert ④ consumers to extend the system. For example, new language models and burst detection techniques can be easily deployed as can new alert monitors to target different alert words of interest for different users. There are various user interfaces in ESA indicated by the *UI Web Apps* component in Figure 1. They access the *Solr Server* which provides efficient searching over Tweet content and the *Repository* which contains an archive of Tweets, alerts and other derived content. The *Location Mapper* service estimates the user's Tweet location based on their profile using the Yahoo! GeoPlanet API with the derived locations archived.

The following sections briefly describe the core components of the ESA platform, including the backend tasks for gathering and processing Tweets, the various user interfaces available to explore the live Tweet stream and tools used to review previously processed Tweets.

2.2 Tweet Processing

As noted above, Tweets are collected using the Twitter REST Application Programming Interface (API)[1] by providing a latitude/longitude coordinate pair and search radius which returns a collection of matching Tweets. To cover Australia and New Zealand, we have set up nine capture regions. For each of the capture regions, a query is made every 20 seconds which to date has been sufficient to obtain all the published Tweets. Tweets have been collected from the

[1] `https://dev.twitter.com/docs/api/1.1`

whole of Australia and New Zealand since late September 2011 and we have processed over 1.6 billion Tweets at a rate of approximately 1500 per minute.

Originally there were eight capture regions. However in early April 2013, Twitter changed their method of determining a user's location for the Search API which resulted in no Tweets being retrieved when the user's profile location was defined as 'Australia'. The issue was due to the suburb called *Australia* in the Mexican town of Saltillo[2]. The resolution was to configure a specific regional capture to retrieve Tweets originating from this location in Mexico which includes a filter for just the English language Tweets.

2.3 Alerts as Bursting Words

ESA produces alerts every minute by examining word frequencies within a rolling 5-minute window of Tweets. A word is said to be a 'bursting word', representing an alert, when its frequency in the 5-minute window deviates from its typical frequency. A background language model contains typical frequencies for all words and other tokens historically encountered in the Tweet stream. The scale of the deviation gives rise to the colour of the alert, ranging from green to red.

The model is created by processing the Tweets in uniform time periods, currently set to a five minute buffer. All Tweets in the buffer are processed by: extracting the individual words in the text; stemming the words to their common 'root', for example *running*, *runs* and *run* all have the same stem of *run*; then counting the number of Tweets containing each distinct stem in the buffer. The result is the expected Tweet frequency for each stem which is averaged over all buffers giving the final value used in the language model [13].

As Tweets are collected in near-real-time by the regional captures they are buffered into a five minute window and the same processing is performed as described above to calculate the Tweet frequencies of the stems. When the frequencies in the dynamic buffer are significantly different to those in the historical language model, a burst is found. If the burst is significant enough, an alert is generated. The alert thresholds can be adjusted to target words of interest and place less significance on those not considered of value, such as stop words.

The buffer is advanced every minute creating a sliding five minute 'window' where the oldest Tweets are removed, new ones added, the Tweet stem frequencies for the modified buffer contents recalculated to produce a new set of alerts.

2.4 Alert Monitor

A key component of the ESA platform is the near-real-time burst detector that identifies alerting words using the pre-calculated language model described above. The dynamically generated alerts are stored in a database and presented via the Alert Monitor web page, shown in Figure 2. The main components of ESA are not tailored to emergency events. Politics, sport and celebrity gossip frequently generate alerts within the system.

[2] See `http://earth-explorer.appspot.com/Mexico/Coahuila-de-Zaragoza/Saltillo/Saltillo/Australia`.

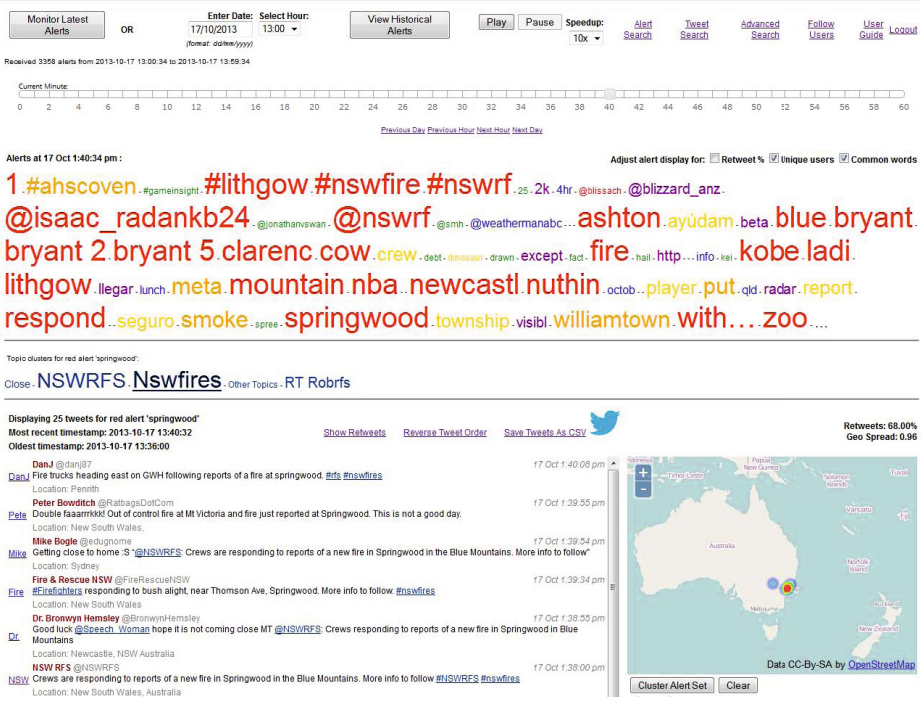


Fig. 2. ESA Alert Monitor User Interface

The Alert Monitor web page has six components: a header consisting of mode settings (to monitor the latest alerts or review historical ones); playback controls (to automatically advance the display of historical alerts at varying speeds); hyperlinks to other ESA interfaces; a time section consisting of a 60 minute slider control with hour and day navigation links; an alert tag cloud of stemmed words; Tweet cluster summaries; Tweet display and the alert heatmap.

The cluster summary, Tweet display and alert heatmap are activated by clicking a stemmed word in the alert tag cloud. The tag cloud can be adjusted to minimise the influence of users who repeatedly Tweet the same or similar content, to minimise alerts that are primarily due to significant retweets and hide common stop words.

The Tweet cluster summary provides a high-level summary of topics from all Tweets contributing to the selected alert word. Topics can be selected to display the Tweets belonging to that cluster. The Tweet display appears on the bottom left of the page and conforms to the Twitter Display Requirements[3]. It includes other features, such as links to the Twitter user's home page and has a means

[3] `https://dev.twitter.com/terms/display-requirements`

of identifying the original Tweet for a retweet. There are also display options to hide all retweets, reverse the chronological order or export the Tweet content to a CSV file.

The screenshot in Figure 2 shows the Alert Monitor web page for 13:40 on 17 October 2013 during the Blue Mountains fires near Sydney. The Springwood fire[4] started approximately 10 minutes before this time, caused by damage to powerlines, and resulted in evacuations and school lock-downs and eventually went on to destroy 193 houses.

The public were Tweeting about this event soon after it began as can be seen in Figure 2. This screen shot shows the Alert Monitor web page after the user has selected the *springwood* alert, which generates five cluster summaries including *Nswfires*. The 25 Tweets contributing to this alert are listed in the bottom left hand corner, accessible using the scroll bar. The alert heatmap provides a visual indication of where the Tweets originated from and includes measures of the retweet percentage and geographic spread. These measures are useful for further analysis of the Tweets and are described further in Section 3.2.

2.5 Alert Search

ESA maintains an archive of all alerts generated, enabling any alert to be revisited and further investigated. The Alert Search page, Figure 3, provides access to the alert archive which can be explored by providing a list of alert words, a date range and minimum alert level.

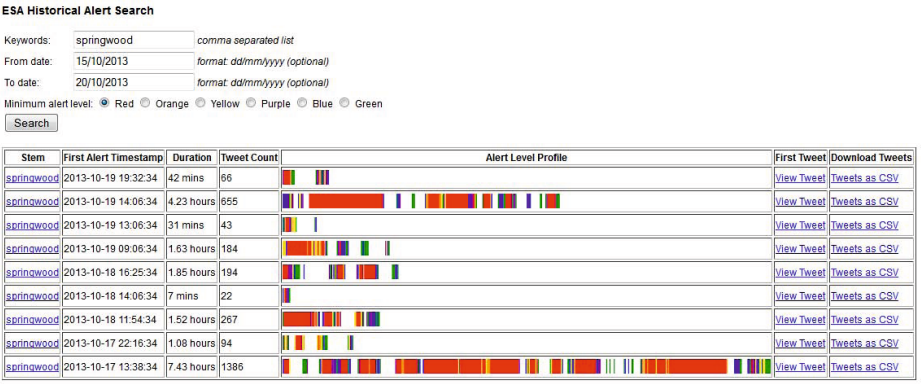


Fig. 3. ESA Alert Search

The example above shows search results returned for the alert word *springwood* with at least one red alert for the period 15–20 October 2013. The result table lists each alert word stem and a summary of the alert profile. The stem is

[4] `http://en.wikipedia.org/wiki/2013_New_South_Wales_bushfires`

hyperlinked back to the Alert Monitor page and will open the monitor page (in historical mode) at the date and time of the first alert. The alert level profile is colour coded and proportional to the alert level and duration. A gap of up to 30 minutes is indicated by the white sections.

2.6 Tweet Search

The Tweet Search page provides keyword search over Tweets from the previous four days using a Solr[5] index. A query consists of keywords optionally combined with conjunction and disjunction operators and using brackets to override default precedence. The screenshot in Figure 4 shows an example of searching for Tweets containing 'fire OR smoke'. The timeline chart on the right shows the volumes of matching Tweets in five minute intervals.

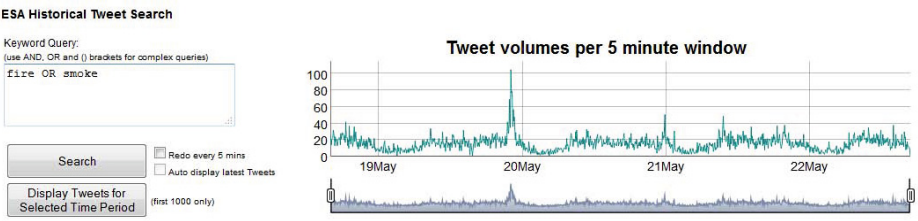


Fig. 4. ESA Tweet Search

A continuous search capability is provided with optional automatic display of latest Tweets and clusters. The time period can be adjusted by dragging the side bars on the lower portion of the chart to display the matching Tweets and their cluster labels.

2.7 Advanced Search

The Advanced Search page shown in Figure 5 provides three additional features: search by location; continuous search with alarm; and integration with fire warnings published by authoritative emergency services agencies[6].

The search location is defined using the interactive map to navigate to the region of interest and Tweets that report to be within this region are returned. This feature uses either the Tweet's geotag, when present, or the user's profile location. To assist with identifying the region to focus on, RSS web feed data from a number of state fire authorities has been integrated and mapped. This has been made available from the Emergency Response Intelligence Capability (ERIC) platform[5].

[5] http://lucene.apache.org/solr/
[6] http://eric.csiro.au

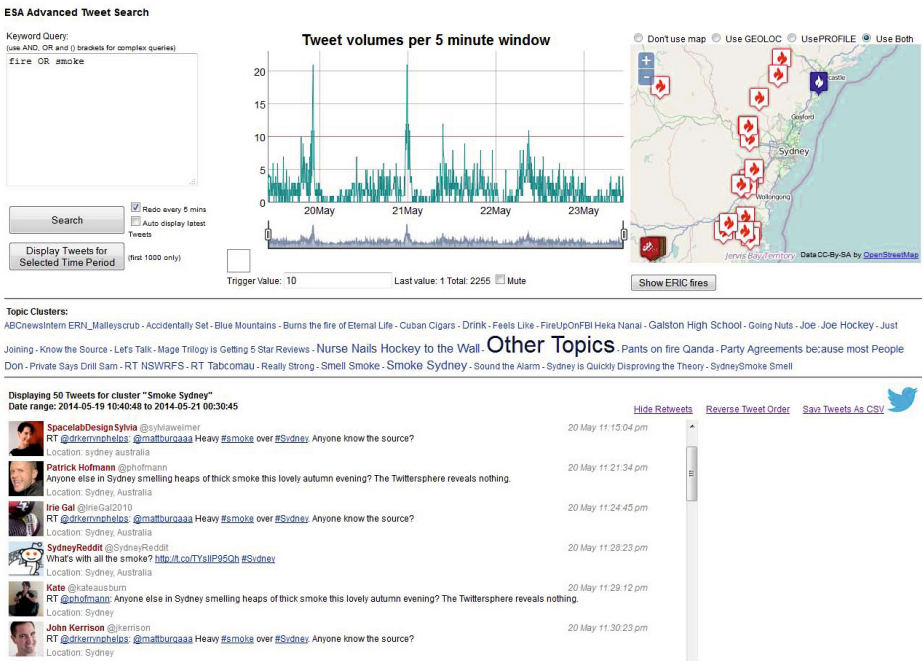


Fig. 5. ESA Advanced Search User Interface

Continuous search is particularly useful in combination with the alarm feature where an alarm sound is activated when the latest search data exceeds a trigger value. In the screenshot of Figure 5, the trigger value has been set at 10 and the red line shows when the Tweet volumes have gone over this threshold.

2.8 Follow Users

The Follow Users page has been configured to display Tweets from around 400 official Australian emergency related Twitter accounts. These accounts are grouped into categories and geographic regions, so that it is possible to focus on accounts that will likely be tweeting about an ongoing event of interest. Tweets from these accounts are specifically gathered via the Twitter Streaming API. Tweets are received almost instantly via the Streaming API whereas there is a delay of up to 20 seconds via our Search API regional captures. It is also useful to have a redundant source of these important Tweets in case one of the Twitter API's becomes unavailable during an emergency.

3 Case Studies

ESA provides the ability for emergency managers and crisis coordinators to use information from the public available on Twitter during emerging and ongoing

crisis situations. ESA has demonstrated that it is capable of providing additional, real-time situational awareness not available through other channels, which can enable more effective and timely decision making and responses. The following sections describe the use of ESA in three different scenarios.

3.1 Crisis Coordination Centres

ESA was designed for use by watch officers in national or state based crisis coordination centres that are responsible for monitoring and coordinating responses to large scale crisis events. A key feature of these centres is that they deal with all hazards, including natural and man-made disasters, terrorist attacks, pandemics and so on. For this reason, the core components of ESA are not tailored for specific event types. An important watch officer role is to monitor a variety of open-source media channels and web sites constantly in order to build and maintain situation awareness about all hazards.

The challenges for watch officers are many: to stay abreast of relevant information; analyse and gather relevant metrics from information; and use the analysis results to make consistent decisions about the next action.

The Queensland Department of Community Safety (DCS) has used ESA extensively in the State Disaster Coordination Centre throughout cyclone monitoring operations. Adam Moss provided feedback that:

> ... during TC Oswald (2013), the community tweeted various forms of information from road and bridge closures, river heights, damaged infrastructure, observed weather patterns from the ground, evacuations, and finally detailed community and resilience information. This information provided significant situational awareness thus providing elements of emergency planning when required. ESA also provided images of unfolding incidents informing situational awareness for the high level visits to impacted areas. This provided real time briefing information.

3.2 Earthquake Detection

The Joint Australian Tsunami Warning Centre (JATWC) is operated by Geoscience Australia (GA) and the Bureau of Meteorology. The Centre monitors, detects, verifies and warns the community of potential tsunami impacts on Australia's coastline and external territories. The principle is to provide at least 90 minutes warning of a potential impact on Australia's coastline from tsunami that are generated from earthquakes occurring on plate boundaries in the Indian, Pacific and Southern Oceans.

Recent studies [5,9,10,11] have shown that when an earthquake event occurs in populated regions, reports on Twitter can provide a faster method of detection compared to traditional approaches. The role of seismologists to verify and scientifically characterise earthquakes can be augmented by crowdsourced information that provides both an early warning and evidence of the impact experienced by the community affected.

Geoscience Australia, which provides the earthquake detection capabilities for the JATWC, have been actively using the ESA system extended to provide Twitter earthquake detection capabilities. The ESA earthquake detection process involves: monitoring the output of the burst detector for alerts matching earthquake-related keywords; testing the currency of the alert; determining if the original Tweets producing the alert are geographically close using a geographic spread measure and processing the individual Tweets contributing to the earthquake alert using a machine learning text classifier to determine if the Tweets are first-hand 'felt' reports [9]. The earthquake classifier is able to achieve an accuracy of 91%.

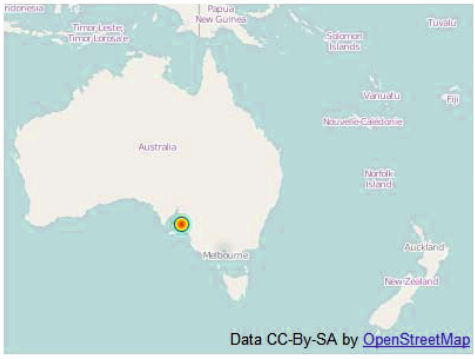
If ESA determines that the alert is related to an earthquake event, a notification email is sent to the JATWC duty officer summarising why the ESA system considers it to be evidence of firsthand earthquake 'felt' reports and includes a summary of the information from Twitter. A example is shown in Figure 6.

yellow 'earthquak' alert detected
Timestamp: Mon, 6 Jan 2014 08:58:32 +1100
View in the ESA Alert Monitor: https://esa.csiro.au/aus/index.html?date=2014-01-06&time=08:58&alert=earthquak

Statistics
Number of tweets (including retweets): 16
Retweets: 0%
Geographic spread: 1.56

Classification Results
Classifier used: Firsthand earthquake 'felt' reports
Percentage of tweets classified as positive: 93.75%
Geographic spread of positively classified tweets: 1.62

Location Summary (excluding retweets)
Adelaide (-34.926102,138.599884) - 12 tweets
Australia (-24.91213,133.397537) - 2 tweets
Melbourne (-37.817532,144.967148) - 1 tweets
*unknown location - 1 tweets



Cluster Topics
Earthquake in Adelaide - 9 tweets
Earthquake Just - 8 tweets
Adelaide Just - 4 tweets
Bed - 2 tweets
Sure - 2 tweets
Other Topics - 3 tweets

Tweets (excluding retweets, +/- labels indicate classification result)
+ 06/01/2014 08:55:44 (Adelaide, Australia) Was that an earthquake?
+ 06/01/2014 08:55:56 (Adelaide, Australia) Pretty sure I just felt an earthquake
+ 06/01/2014 08:56:19 (Lemonadelaide) Wooaahh did we just have an earthquake??
+ 06/01/2014 08:56:20 (Adelaide) Did we just have an Earthquake? #adelaide
+ 06/01/2014 08:56:30 (Adelaide, Australia) Was that just an earthquake in Adelaide or did I drink too much coffee this morning?!
+ 06/01/2014 08:56:33 (Adelaide, South Australia) Was that an earthquake just rolled through the #adelhills #feltlikeit #shookthehouse
+ 06/01/2014 08:56:56 (Adelaide, Australia) Earthquake in Adelaide??
+ 06/01/2014 08:56:57 (Australia) Alright I'm out of. Bed now, I think an earthquake just come though @.@

Fig. 6. Example Earthquake notification email

When the notification email is received, the duty officer can then assess if the alert is genuine and gain a quick overview of the intensity of the earthquake with reference to the number of Tweets reported and by reviewing their content. This provides an additional means of early warning to JATWC complementing the information arriving from their existing system based on seismic stations.

During its initial five months of operation the system generated 49 notifications of which 29 related to real earthquake events. The average time delay between the earthquake origin and when ESA sent a notification email was 3:03 (minutes:seconds) [9]. These notifications may also be the first electronic indication of the earthquake, arriving ahead of the seismic information.

Figure 6 shows the contents of the email that was sent for an earthquake that occurred near Adelaide on the 6th January 2014. The stemmed yellow alert 'earthquak' can be seen at the top of the email followed by the timestamp of when it was detected. The remainder of the email is structured to help the reader decide if the alert describes an actual earthquake event. This information includes: summary statistics; a link to the web interface to explore the Tweets; a summary of the probable locations of the Twitter users including the heat map; the cluster topics; and a list of the source Tweets highlighted after processing them through a classifier trained to determine the likelihood that the Tweets are evidence of first hand 'felt' reports. Note that not all Tweets are shown to save space.

According to Geoscience Australian's earthquake database[7] the earthquake corresponding to this event had a magnitude of 2.7 (ML) with an origin time of 08:55:15 (AEDT). The ESA burst detector generated a yellow 'earthquak' alert based on 16 Tweets at 08:59:13 and a notification email was sent at 08:59:29; a delay of 4 minutes and 14 secs. Daniel Jaksa from Geoscience Australia noted that for this event:

> ... the CSIRO Twitter alert was our first digital notification that an earthquake had happened.

3.3 Finding Fires

In Australia, State and Territory governments have responsibility for bushfire management. Each jurisdiction has its own agency that coordinates community preparedness and fire fighting activities such as the Rural Fire Service (RFS) in New South Wales (NSW) and the Country Fire Authority in Victoria. They conduct activities such as fire fighting, training to prepare communities to protect themselves, land management hazard reduction burns and search and rescue.

During the Australian disaster season, early October through to the end of March, these fire agencies continuously monitor weather conditions in preparation for responding to events when they occur. They also inform the community about known incidents[8].

The NSW RFS comprises over 2,100 rural fire brigades with a total volunteer membership of approximately 72,000. In addition, over 900 staff are employed to manage the day to day operations of the service. To assist with their ability to detect and monitor fires, they have been actively using ESA and we have received the following feedback of their use of the tool from Anthony Clarke:

[7] `http://www.ga.gov.au/earthquakes/getQuakeDetails.do?quakeId=3461047`

[8] See for example the NSW RFS Current Fires and Incidents page: `http://www.rfs.nsw.gov.au/dsp_content.cfm?cat_id=683`.

> ... ESA enabled users to see minute by minute the latest topics relating to the fires, evacuation centres, communities and shows individual Tweets as they come in on these topics.

To enhance ESA's fire detection and monitoring capabilities, the earthquake event detection software was reconfigured to look for fire related alerts from the burst detector and a new fire Tweet classifier was developed to help determine if a Tweet containing a fire related keyword refers to an actual fire event. As discussed in [8], automatically determining if a Tweet is referring to an actual fire is far more difficult than for earthquakes as the word 'fire' and its derivatives are commonly used with other meanings. The ESA fire classifier has an 80% accuracy, which has proved to be helpful in filtering out the non-fire related Tweets.

A review of the historical alerts associated with fire related keywords found that the fire detection email service is expected to perform better during the non-fire season. This is due to the large number of fire events simultaneously occurring around the country during periods of high fire danger. The detector has difficulty identifying new fire events since fire related discussions are popular topics in Twitter and ESA's burst detector produces fire alerts almost continuously. Refining the fire detection process is an area of ongoing research

This review also found that when fire related alerts are present, the names of the affected towns or regions are also alerting. An example of this is the Springwood fire shown in the alert monitor of Figure 2. As noted previously, this fire started just before 13:30[4] and ESA received its first Tweet mentioning 'smoke' and 'Springwood'[9] at 13:34 and generated its first *springwood* alert at 13:39. NSW RFS issued its first Twitter Emergency Warning at 14:10[10]. If ESA had been able to combine the alerts 'springwood' and 'fire' or 'smoke' and was able to determine that 'springwood' was the name of a town, this further location context could be used to improve the fire alerting process. This is also an area of current investigation.

4 Operational Experience

The ESA tool is deployed on a cloud infrastructure using the JMS messaging service platform to connect components. Tweets are gathered from Twitter and published to the messaging middleware and consumers process the Tweets for different purposes (identifying burst words, event detection, Tweet classification, database caching, archiving) where identified events are published back onto the messaging service platform and reprocessed. This allows a messaging chain to be easily integrated into the tool for incremental processing and filtering to identify high value Tweets.

ESA currently has over 140 registered users from more than 50 organisations Australia wide. The system has been in continuous 24/7 operation for over 18

[9] See `https://twitter.com/RJMajik/statuses/390666952571510784`.
[10] `https://twitter.com/NSWRFS/status/390676200387276800`

months with only minor outages occurring. These have primarily been due to Twitter downtime and electrical maintenance of the data centre supporting the CSIRO cloud infrastructure.

In addition to earthquake detection at JATWC, ESA has proved to be invaluable in bushfires, floods, and cyclones, and has been in use in this context by the Queensland Department of Community Safety and NSW Rural Fire Service (RFS). ESA has provided the ability for emergency managers and crisis coordinators to use information from the public available on Twitter during emerging and ongoing crisis situations to enhance their response.

ESA was developed in close collaboration with potential users to ensure its fitness-for-purpose for the real tasks people in various government emergency services agencies are performing and the challenges they are facing. The tools are user-focused and integrate into their existing work practices providing an alert monitor interface to easily determine what is 'unusual' combined with text mining techniques, machine learning algorithms and advanced visualisations.

ESA processes large amounts of Twitter data and, using pre-calculated language models, it identifies the topics of discussion, trends and hot topics. The burst detector will alert on any unusually high frequency words, so the technique is readily applied to other non-emergency related domains.

Tweets are grouped by discussion to enable the user to have the whole context of conversations. This is especially useful for social media monitors enabling them to obtain overviews of what is being discussed on Twitter and to drill down to specific discussions and individual Tweets. All Tweets are cached allowing historical review of content and forensic analysis.

5 Conclusions

The ESA system provides all-hazard situation awareness by using content gathered from the Twitter social network. It collects, filters and analyses Tweets from specific regions of interest in near-real-time, enabling effective alerting for unexpected incidents with results accessible via an interactive website.

ESA is used in a number of ways to support different emergency management tasks. We have presented its use as an all-hazards monitoring tool, a notification system to identify earthquakes and fires and for ongoing monitoring of bushfires. In all cases, ESA has demonstrated that it is capable of providing additional, real-time situational awareness not available through other channels, which can enable more effective and timely decision making and responses.

Planned future work includes improvements to the process of maintaining the currency of the background language model, better alert filtering, incremental machine learning training based on user feedback, deployment to other regions, and investigation of an ontology of alerts and cluster topics to help categorise and summarise the information content. We are also investigating the use of photos referenced on Twitter as further evidence to support the decision making process. For example, in the first four hours after the *spingwood* alert, 23 unique photos of smoke from the Springwood fire were tweeted (and retweeted), providing further information about the ongoing fire.

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