GEOLOGICAL SURVEY OF CANADA
OPEN FILE 7054

Canadian Hazards Information Service Automated Public Earthquake Information via Social Network Messaging

W.N. Edwards, K. Hayek and C. Majewski

2012

Natural Resources Canada
Ressources naturelles Canada

Canada

GEOLOGICAL SURVEY OF CANADA
OPEN FILE 7054

Canadian Hazards Information Service Automated Public Earthquake Information via Social Network Messaging

W.N. Edwards, K. Hayek and C. Majewski

2012

doi:10.4095/291337

Recommended citation:
Edwards W.N., Hayek K., Majewski C., 2012, Canadian Hazards Information Service Automated Public Earthquake Information via Social Network Messaging; Geological Survey of Canada, Open File 7054, p.35. doi:10.4095/291337

Abstract

In the wake of the Val-des-Bois 5.0 Mw earthquake on June 23, 2010, the Canadian Hazards Information Service (CHIS) and *EarthquakesCanada* identified a need to rapidly disseminate earthquake information to the general population after a seismic event. In response, an automated process was developed, tested and implemented by which the continuous stream of seismic event solutions generated by the automated location algorithm AUTOLOC are screened. Automated seismic event solutions are reviewed to determine their robustness and filtered using a series of physically and statistically-based criteria and thresholds. Robust seismic events greater than magnitude 4.0 located within Canada trigger automatic alerts to on-duty seismologists and generate automatic notifications in both official languages to be sent directly to the public via the social networking service *Twitter* from @CANADAquakes and @CANADAseisme. Rates and accuracies of these automated notifications were tested with a series of simulations using six years of automated AUTOLOC solutions and the seismologist reviewed Canadian National Seismic Network (CNSN) earthquake catalogue. Early results of the implemented real-time system show a good correspondence between predicted and actual notification posting rates and the event magnitude accuracy.

Résumé

À la suite du séisme de magnitude 5,0 Mw près de Val-des-Bois (Qc) le 23 juin 2010, le Service d'information de risques Canadien (CHIS) et SéismesCanada ont identifié le désire pour les renseignements rapides après un séisme événement important. Alors un processus automatisé a été développé, vérifié et mis en application, qui surveille continuellement, en temps réel, les solutions produit par l'algorithme pour déterminer les épicentres automatisé AUTOLOC. Les solutions automatiques sont soumises à des tests d'assurance de la qualité, ensuite elles sont filtrées en utilisant une série de critères statistiques et physiques spécifiques. Les épicentres fiables des séismes d'une magnitude 4.0 ou plus au Canada déclenchent une alerte automatiques aux sismologues de garde et produisent des avis automatiques pour le public dans les deux langues officielles qui sont publiées sur le site *Twitter* par @CANADAquakes et @CANADAseisme. Les solutions automatiques produits par le système d'AUTOLOC pendant six ans ont été comparés à des solutions éxaminées par un sismologue dans la base nationale de données sismologiques pour vérifier le taux et la qualité des notifications automatiques. Les résultats préliminaires du système en temps réel en fonctionne indiquent une bonne correspondance entre les taux prévus et réels, et entre les magnitudes automatiques et les magnitudes déterminées par un sismologue.

Introduction

On June 23, 2010 at 17:41:41 UTC (1:41:41 EDT local time) a sizeable 5.0 Mw earthquake occurred in the Val-des-Bois region of southwestern Quebec, approximately 60 km north of Ottawa, Ontario. The earthquake was felt widely across eastern North America and most strongly in the Val-des-Bois and Ottawa-Gatineau regions, but also moderately strong in the heavily populated regions of Toronto, ON and Montreal, QC (Fig 1, Halchuck, 2010). Having occurred at mid-afternoon whilst a significant portion of people in these densely populated areas were at work and alert, the public demand for information regarding the source of the shaking was tremendous. With the proliferation of Internet-capable portable devices, beyond simply the desktop computer, the number of webpage requests at *EarthquakesCanada* quickly saturated the capabilities of the geographically closest web server (Ottawa) causing it to become incapable of serving the number of incoming requests and making the server appear to be down/offline as viewed by the user. At this time, the sister servers at the Western Canada office of *EarthquakesCanada* in Sidney, BC automatically assumed the overflow in traffic and then were themselves promptly saturated leading to a similar condition as that experienced in Ottawa. This massive demand, which was equivalent to a denial-of-service attack, caused a temporary "black-out" of information directly from *EarthquakesCanada* that lasted ~1 hour, with limited service afterward. A full return to normal operations was not reached until approximately 3-4 hours later. During this time webpage demand reached more than 80 times the normal baseline traffic and similar echoes of this demand (at lower levels) continued for several days afterward (Fig. 2). While details and information of the earthquake from *EarthquakesCanada* were promptly re-routed to the United States Geological Survey (USGS) for dissemination while *EarthquakesCanada* servers were incapacitated, as per standard emergency procedures, the web server "crash" vividly identified the increasing public and social need for prompt and timely information as soon as it is available.

In response to this increasing demand, a decision was made to use the automated earthquake solution algorithm currently in use across Canada, AUTOLOC (Edwards, 2012), as a prompting tool for an automated notification system for rapid information dissemination to the public. This would be an active "push" system, sending information out to the public using the social media messaging service *Twitter*, rather than a passive system like the *EarthquakesCanada* webpage. The purpose of the proposed system was to produce brief, 140 character messages that could notify the public regarding recent significant earthquake activity in Canada, which would be automatically sent out via *Twitter* to registered followers of the message service and could provide a link to an *EarthquakesCanada* webpage where more detailed and up-to-date information could be obtained regarding the event. In this way, critical information could be issued to alert the public quickly, while at the same time reduce some of the immediate load of requests to the *EarthquakeCanada* servers immediately after a significant earthquake event. Yet this proposed system would require a measure of robustness that current automated systems in use do not have.

This robustness of the proposed automated notification system is a necessity as the system would be used to alert and inform the general public (including emergency services) regarding potentially serious and damaging seismic events. While false alarms are always a possibility, if they were to occur too frequently or become commonplace, the integrity of the system would be called into question and the service would likely be ignored by the public. Conversely, should too many notifications be sent regarding legitimate seismic events of little interest to the public (e.g. frequent small magnitude events that are not felt), the service may similarly be ignored. Either case would result in a loss of effectiveness in public distribution of information after a significant earthquake. The goal is then to achieve a high measure of robustness for notifications and then establish what constitutes a significant seismic event to the general public, without saturating the service.

To achieve this goal, the automated earthquake solutions (origin time, geographical location and magnitude) produced by AUTOLOC in the past were investigated to determine their accuracy and false alarm rate so as to make the planned messaging system as robust, and reliable as possible.

CHIS Automated Earthquake Algorithm: AUTOLOC

The AUTOLOC algorithm for locating and assessing magnitudes of regional earthquakes is the primary tool employed by the Canadian Hazards Information Service (CHIS, the division of Natural Resources Canada to which *EarthquakesCanada* belongs) for automatic regional earthquake location across Canada. Like many automated location routines, AUTOLOC uses continuous lists of probable seismic phase detections generated from ground motion data recorded by the real-time seismograph stations located throughout Canada. As discussed by Edwards (2012), these individual station real-time detection lists or RDLs are generated for each station by continuously computing long term averages (LTA) and short term averages (STA) of the observed seismic ground motion, in multiple frequency bands. When the STA exceeds a given threshold above the LTA, for a preset length of time, a signal detection is declared and continuous calculation of the LTA is stopped. Upon the STA returning once more to the preset level, the detection is stopped and the calculation of the LTA is reinstated. If this occurs in the individual frequency bands in such a way that satisfies the system that the detection is that of an earthquake signal, the time and details of the detection are written to the RDL for that station. These individual station RDLs are then made available to AUTOLOC.

AUTOLOC uses the RDLs from a select subset of reliable real-time Canadian National Seismic Network and POLARIS (Atkinson et al., 2002, Eaton et al., 2005) stations across Canada to search for seismic events, locating them geographically, determining their origin time and measuring their magnitude. Each event location begins by selecting the most recent station phase detection and searching neighbouring stations for similar detections based upon individual detection times. Suspected seismic phase detections are then evaluated and given a probability of being associated with the same event based upon arrival time, 3D ground motion (in the case of three component stations) and likely phase (P-wave, S-wave or Surface Wave - Lg/Rg). These probabilities are then cross referenced with other station RDLs. Using this method AUTOLOC identifies probable seismic phases and computes trial locations and magnitudes, adding and subtracting stations or phases as necessary to fit a suspected event, until convergence or no likely station detections remain or are available. A quality factor (Q) is then computed for the solution using a combination of the number of phases and stations used and the overall fit to the data. This quality factor is a product of several quality assurance factors, or weights, and has the form:

$$Q = P_{DISTANCE} P_{PHASE} P_{TIME} P_{SPHASE} P_{NEAR} P_{LIKELIHOOD} \qquad (1)$$

where

$P_{DISTANCE}$: varies between 0.8 and 1.1, depending upon the estimate of distance which is based upon 3-component processing to determine the emergence angle of the seismic phase. Steeply oriented emergence values are given low values (signals from large distances, teleseisms), and shallow emergences are given higher values.

A default value of 1.0 is given if no distance estimate is available (e.g. single component station, missing channel etc.).

P_{PHASE} :	varies between 0 and 1.0 depending upon match of waveform characteristics to that of the named phase Pn / Pg / Sn / Sg / Lg / Rg (i.e. particle motion).
P_{TIME} :	1.0 for a location time residual of zero. 0 to 1.0 for larger time residuals, up to several seconds in magnitude.
P_{SPHASE} :	0.16 for S phases at a station without a corresponding detection of a P phase. 0.49 for an Lg phase at a station without a corresponding detection of a P phase. 1.0 otherwise.
P_{NEAR}	1.3 for stations with distances to epicentre of < 500 km 1.3 – 1.0 for stations with distances to epicentre between 500 and 1250 km 1.0 for stations with distances to epicentre > 1250 km
$P_{LIKELIHOOD}$:	1.0 typically 0.9 if there is a significantly closer* station that didn't detect event 0.75 if there are two significantly closer* stations that didn't detect event 0.69 or less if three or more significantly closer* that didn't detect event. Value based on the ratio of relative station distances from epicentre. *significantly closer is defined as the ratio of the two stations' distances from the event epicentre differing by a factor of 1.2 or more.

These trial events are then updated as new (or late) station RDLs become available until the event is completed, whereupon the final solution is sent to the CNSN system with the event location, estimated magnitude and origin time, as well as the stations, phases, arrival times and amplitudes used (Fig 3). The overall result of this process is that numerous AUTOLOC automated event solutions are produced continuously, of varying quality, for real and false events based on spurious associations, false detections and/or teleseismic phases. In general, a high *Q* has been used to disassociate false events from real. It is not, however, always the case that significant events must have high *Q*. The specific value of *Q* may vary due to an event's location, station coverage, available RDLs and station noise levels. Indeed significantly energetic events may have several solutions of various *Q* associated with them, each an iteration or update on the original trial solution. The typical distribution of AUTOLOC solution quality factors is shown in Fig. 4.

This duplication or re-iteration of event solutions is compounded by multiple copies of AUTOLOC currently running on the systems at *EarthquakesCanada*. For redundancy and continuity of service purposes there are two independent systems running the AUTOLOC algorithm at all times; one in the Eastern CHIS Office in Ottawa, Ontario and a second at the Western CHIS office at the Pacific Geoscience Centre (PGC) in Sidney, BC. Although the algorithms are identical, and most station data is received simultaneously, some stations' data are received by only one office and then forwarded to the other, incurring a short delay. This delay causes the times for some stations' detection updates to differ and provides different choices of station detections for the two algorithms, resulting in potentially drastically different solutions to the same event. A third copy of AUTOLOC also runs at PGC configured specifically to monitor the stations in the Vancouver Island and lower BC mainland region (VILM) only.

As timeliness as well as robustness is sought in the idealized automated public messaging system, it is necessary to determine the qualities that constitute a robust earthquake event, beyond simply the value of Q, as these automated event solutions arrive without any a priori knowledge of an event. To determine and evaluate these properties we investigate the past 6 years of AUTOLOC automated event solutions and compare these to the National Earthquake Database (NEDB) catalogue maintained and reviewed daily by CHIS seismologists.

Robust Assessment of Automated Solutions

To determine the best qualities to search for in any arbitrary, automated event solution, the automated solution catalogue of AUTOLOC (containing some 46,948 individual solutions between January 2005 and December 2010) was compared to the seismologist reviewed NEDB catalogue, which also includes significant Canadian mining/blasting activity. As an automated public messaging system would be designed to inform the public regarding significant "felt" earthquakes and a minimum amount of robustness would be required for such a system, a simple set of first pass filters were applied to the contents of the automated event solution catalogue for a period of 6 years from January 2005 to December 2010. From seismologists' experience, a relatively high initial filter of $Q = 14$ was suggested as typically reliable for the average AUTOLOC event solution (roughly corresponding to ~14 seismic phases used in the event). Although somewhat above the mean value (Fig. 4), this should represent more energetic events (i.e. likely to be felt and thus of more interest to the public) or events in populated areas where station density is high. A second magnitude-based filter was also applied for events >3.5 m_N or M_L corresponding to the typical level at which earthquakes begin to be felt.

During the application of Q and magnitude filters, each automated event solution was compared to events in the reviewed NEDB catalogue to identify whether the automated solution was in any way associated with earthquake or mining activity. An automated event solution was determined to be associated with a reviewed event if the solution's event location and origin time lay within 500 km and 60 seconds of a reviewed event. Duplicate solutions (multiple automated event solutions associated with the same event) were noted but not added to the total number of associated solutions. All automated event solutions not associated with reviewed events were classified as *False Alarms*, or equivalently *False Positives*. Events in the reviewed NEDB catalogue greater than magnitude 3.5, but not associated with an automated event solution, were classified as *Missed Events*. The overall results were then additionally classified into one of four separate regions; Eastern Canada, Western Canada, Northern Canada and the Yukon (Fig. 5). The results of this simple filtering process are shown in Fig. 6 for all of Canada. Statistics of all four individual regions were found to be similar to the national rates.

Overall, the results of this simple filtering process would be highly undesirable for a public messaging system. Although the number of missed events decreases as magnitude increases, across the entire range of seismic magnitudes, there are approximately four times as many false alarms than real seismic events (Fig. 6). This issue is compounded by the shear number of notification postings that would result. For example; at magnitude 4 alone, this method would result in ~150 false alarms each year compared to only 35 real events, or ~1 false alarm every 2-3 days compared to one real event every 10 days.

From these results, it became clear that such high false alarm rates, far in excess of the real seismic event rate, would not satisfy any reasonable measure of robustness. Further specific filtering of the data was required, but to determine the nature of these filters it was necessary to know the content of these numerous false positives. Thus all those automated event solutions found not to be associated with either reviewed blasts or earthquakes were investigated by CHIS seismologists to determine their nature and origin. In general these events tended to be one of several categories: mining activity not in the reviewed NEDB catalogue, global teleseisms mistaken for regional earthquakes and mis-located

U.S. or Greenland earthquakes (Fig. 7). Upon sorting these events by sub-region, it was found that each of the four regions suffered somewhat differently in terms of the contributions of each of these sources (Figs. 8-10), but throughout, the abundance of teleseisms mistaken for regional earthquakes by AUTOLOC was the dominant contributor to potential false alarms. Thus by identifying the common features in the AUTOLOC automated event solution that might uniquely identify or marginalize these misidentified teleseisms, the robustness of an automated public messaging process would be significantly improved.

Advanced Filtering & 6 Year Simulation of Automated Messaging

Inspection of the AUTOLOC automated event solutions identified by CHIS seismologists as originating from teleseisms misinterpreted by the system as regional earthquakes showed that several common features existed that might be exploited to assist in screening them out. These features included; (a) only one magnitude measurement or two magnitude measurements with significant inconsistency between them, (b) overly large distances between observing stations and epicentres, and (c) epicentres located in regions of generally low earthquake activity. Inspection of automated event solutions from mislocated US & Greenland earthquakes showed that these typically suffered from a known issue with regional earthquake networks wherein observing stations are located along a limited range of azimuths from an earthquake that poor constrain the event and result in a solution which is located closer to the observing stations than reality. Using this information, several types and methods of advanced event filtering were attempted.

All filtering methods were tested using the same 6 year period of AUTOLOC solutions and compared to the reviewed NEDB catalogue, noting the ability of each filter to remove undesirable false alarms (teleseisms and US/Greenland earthquakes) and pass legitimate seismic events (earthquakes and mining blasts). The result is a multi-filter methodology based upon the past experience of CHIS seismologists, physical and statistical constraints and exploiting the common features of undesired events noted previously to reach the desired level of robustness required for an automated public messaging system. The system uses a series of sequential filters, or “gates”, through which each automated event solution generated by all instances of the AUTOLOC algorithm must pass (Fig 11). Should any AUTOLOC solution fail to pass through a gate it is promptly discarded and ignored, while successful solutions are passed onward to be organized into a public event notification. These gates are described below with the detailed algorithm provided in Fig. 11.

GATE #1 : Quality Check

An initial AUTOLOC Quality factor, Q, cutoff. In essence a minimum number of seismic phases, Q_{min}, is required before any automated event solution is further considered. The majority of automated event solutions do not make it past this gate.

GATE #2 : Duplicate Solution Check

A precautionary check to ensure a notification for an event is not sent twice. The geographical location and origin time of the automated event solution is inspected and compared to the last posted automated public notification. If sufficiently similar, the solution is declared a duplicate and is ignored from any further consideration.

GATE #3 : Canadian Border Check

As EarthquakesCanada is the authoritative agency for earthquakes occurring within Canada only, the geographical location of the automated event solution is inspected to determine if it lies within the predefined monitoring borders of Canada (Fig. 5). Events occurring outside this region are ignored by the automated public notification algorithm.

GATE #4 : Number of Magnitude Measurements Check

An evaluation of the robustness of an event's magnitude. The automated event solution is inspected to determine the number of magnitude measurements made. If that number is less than a pre-determined value, n_{min}, the solution is removed from consideration for being insufficiently robust. This filter removes ~80% of undesirable teleseismic-sourced events.

NOTE: This minimum number of magnitude measurements must use the SAME magnitude scale, m_N, M_L or m_b, and NOT simply multiple combinations of these.

GATE #5 : Magnitude Uncertainty Check

A secondary robustness evaluation of an event's magnitude. The uncertainty or standard deviation of the overall event magnitude measurement is inspected and must be equal to or less than the specified tolerance, δM_{max}, to pass robustness inspection. All automated event solutions not meeting this criterion are dropped from consideration.

NOTE: Prior to undergoing this inspection, extreme outliers (10th and 90th percentiles) from the median magnitude are removed, lest these values unduly skew the uncertainty distribution.

GATE #6 : Magnitude Threshold Check

A preset threshold that is approximately equivalent to the magnitude at which seismic events typically begin to be widely felt. Only automated event solutions above this minimum event magnitude threshold, M_{min}, are considered. All other smaller magnitude events are ignored and removed from further consideration.

NOTE: The event magnitude inspected in this gate is that which has been recalculated after the removal of extreme measurement outliers in GATE #5.

GATE #7 : Nearest Observing Station Check

A physical constraint for regional earthquakes, wherein seismic phases observed by distant seismic stations and not by stations closer to the event's epicentre, is unphysical. The distance of the initial or first observing seismic station is inspected and must lie within the predetermined maximum distance, D_{max}, from the event epicentre, otherwise the automated event solution is determined to be unsuitable and is discarded. This gate is particularly effective at screening any remaining teleseisms making it through previous gates.

GATE #8 : CNSN Trusted Station Check

Finally the list of stations used in the automated event solution is checked against a list of trusted seismic stations, which currently consist of the core network of permanent CNSN seismograph stations. If there are a specified number of these trusted stations (which may vary from region to region) then the automated event solution is finally accepted for public automated notification, otherwise once more the automated solution is dropped.

SUCCESSFUL AUTOMATED EVENT

Upon any AUTOLOC automated event solution successfully passing through all gates, an automated process is triggered whereby all the information regarding the event's regional location (distance from nearest populated centre), magnitude and local time are extracted from the solution and formatted into a brief public notification message and immediately sent to the public via the social messaging service *Twitter* from the *CANADAquakes* (English) and

CANADAseismes (French) accounts and as an alert banner on the *EarthquakesCanada* and *SéismesCanada* websites.

This algorithm, using the nominal settings described in the following section, was applied once more to the same 6 year period of AUTOLOC automated event solutions and compared to the reviewed NEDB catalogue to evaluate the performance of the advanced filtering scheme and estimate the likely notification rate. Results of this simulation are shown in Figs. 12 – 16 for all of Canada and the various sub-regions in Fig. 5. In comparison to the simple threshold filtering of quality factor and magnitude (Figs. 7 – 10), the advanced filtering algorithm performs significantly better by removing the vast majority of misidentified teleseismic events in all regions (eliminating them completely in the North/Yukon) and by reducing the number of mislocated US/Greenland earthquakes by restricting events to fall within a certain regional monitoring boundary.

Over the six year simulation, the advanced filtering process identified 415 automated event solutions (out of nearly 47,000 candidates) related to seismic events greater than magnitude 3.5 and determined them to be robust enough to trigger an automated public notification (Fig. 17). The majority of these events are located in the various known active seismic zones across Canada. Of the known earthquakes and blasts in the reviewed NEDB catalogue with magnitudes of this size, 976 seismic events were "missed", i.e. either the automated event solutions for those events were not determined to be robust enough for a notification, or the event was unnoticed by AUTOLOC. The majority of missed events tended to be at smaller magnitudes ($M < 4.0$) and primarily along the offshore regions of the west coast, with a more diffuse collection located along the Alaska-Yukon border region and the Arctic coastline (Fig. 18). Part of the concentration offshore of British Columbia is explained by the numerous earthquake aftershock sequences resulting from larger earthquakes ($M > \sim 5.0$) along the Queen Charlotte fault. During these periods of increased activity immediately after a large earthquake (sometimes lasting several days), AUTOLOC has difficulty making valid associations with so many station detections so close together (C. Woodgold, Personal Communication). In Northern regions, the sparse station coverage and typically poor azimuthal distribution of these stations, coupled with non-continuous operation of some stations, make automated event location more difficult in general, particularly at smaller magnitudes. Yet overall very few continental events greater than magnitude 4.0 are missed by the advanced filtering process and indeed no continental events greater than 5.0 were missed at all over the 6 year simulation (Fig 18c).

Using the results of the 6 year simulation, we can investigate the typical accuracy that may be expected of these automated public notification messages. In general the automated event solutions determined to be reliable by the advanced filtering algorithm, are reasonably robust with a median epicentral distance offset of 31.5 km with 10 km and 105.5 km as 10th and 90th percentiles respectively and a magnitude error of -0.15 ± 0.48 in comparison to seismologists reviewed solutions (Fig. 19), showing a tendency to underestimate larger magnitudes $M > 4.5$ (Fig. 19d). Geographical location of epicentral uncertainty of automated public notification messages is generally moderate throughout the continental regions of Canada where CNSN seismic stations adequately surround and constrain the event (Fig 20). Where station azimuthal coverage is low and/or sparse, such as is the case along the northern regions of the Arctic coastline and the Yukon-Alaska border, larger uncertainties in event location are seen. This is to be expected and may suggest that more stations (perhaps international) need to be added to the real-time detection lists to compensate.

Underestimation of magnitude for larger events, however, may be a more significant issue and may suggest that the system should pause until all automated solutions from an event have been received prior to selecting the most robust and sending a notification. Yet inspection of these duplicate automated solutions shows that in general duplicate solutions do not significantly improve upon the initial automated event solution (Figs. 21a-c) and in many instances become poorer as unassociated phases from distant stations are added, while magnitude estimate uncertainties remain the same (Fig. 21d). Thus for speed of alerting to potentially damaging earthquakes or shaking that may be felt and thus be of concern to the public, the first automated event solution determined to be robust is chosen over all subsequent related solutions. Using the first qualifying robust solution upon which to base the public notification, an average response time of 5 minutes and 36.6 seconds (331.6 sec.) from the initial seismic event is predicted based upon simulation results, with the fastest 5% of alerts occurring within 3 minutes 19 seconds (199.0 sec.) and the slowest 5% being sent out after 8 minutes 10 seconds (490.0 sec.) (Fig. 22).

Current Settings and Thresholds

With the successful screening of potentially hazardous seismic events using the advanced filtering algorithm in the six year simulation, the assignment of the specific criteria and thresholds to be used in an online version of the algorithm were determined. Careful consideration was made to likely notification posting rates and the level of earthquake severity likely to generate significant public interest especially for those which might cause damage, injury or loss of life.

With these factors in mind, along with historical records of earthquakes reported as "felt" by the public, seismologists' experience and slightly modified national boundaries used by the seismic hazard maps of the National Building Code of Canada (Halchuck and Adams 2008), the following settings were established:

Automated solution Quality (Q) threshold:	14 (i.e. 14 or more seismic phases used)
Criteria for a Duplicate solution:	within 60 sec. & 500 km of prev. notification
Canadian Border:	As shown in Fig. 5
Minimum number of magnitude measurements:	3
Maximum magnitude uncertainty limit:	1.0 magnitude units
Minimum magnitude threshold:	4.0 $M_L/m_N/m_b$ Canada-wide
Maximum distance to nearest station:	9.0 degrees (~1000 km)
Number of CNSN Stations in solution:	10 (East/West), 4 (North/Yukon)

Using these criteria in the six year simulation, screening 46,938 individual AUTOLOC automated event solutions, resulted in the following rejection statistics:

Quality (Q) Rejections	73.3%
Duplicate Rejections	1.9%
Canadian Border Rejections	3.4%
Measurement Quantity Rejections	3.4%
Magnitude Uncertainty Rejections	0.3%
Magnitude Threshold Rejections	16.7%
Initial Station Distance Rejections	0.2%
CNSN Station Rejections	0.04%
Accepted Postings:	0.8%

Thus at these settings and with the assumption that the Canadian National Seismic Network remains in its current state, an estimated average of 25 automated earthquake notifications would be issued each year Canada-wide (Fig. 12). It is interesting to note that with these settings only 15 earthquakes reported as “Felt” by the public over the five year period were not automatically detected by AUTOLOC and therefore could not be reported automatically. Of these, 10 were events less than magnitude 4.0 and so would not have met the minimum magnitude threshold and 2 were outside the defined Canadian monitoring border (Fig. 5), leaving a 4.4 Mw earthquake in northern Washington, U.S.A., and two 5.6 Mw events (one offshore southwest of Haida Gwaii and one slightly southwest of the Yukon/Alaska border) undetected/reported automatically over this period.

Active Real-time Notifications: CANADAquakes and CANADAseisme

Using the screening algorithm and the thresholds and settings determined during the six year simulation as a template, a similar screening process was developed and incorporated into *EarthquakesCanada* and CNSN daily real-time processes. This algorithm is active at both Eastern and Western Canada seismology centres and constantly monitors the AUTOLOC program’s automated solution activity. Although still in development, these two systems will be linked such that one cannot issue a notification without the other knowing the notification was sent. For example, if the PGC office system determines that an AUTOLOC solution meets the threshold criteria and is sufficiently robust, thereby issuing an automated public notification, details of this notification are sent to the second server in the Ottawa office so that it will not issue a second similar alert should it find a solution determined to be a duplicate of the PGC notification. Should either office system be incapacitated, the remaining server will continue on independently. Currently, both systems run the algorithm and exchange automated event solutions, but only the system in Ottawa is configured to send automated public notifications.

Each time a successfully screened automated event solution is identified, a series of systems are automatically activated in order to issue an automated public notification. First, the successful solution is parsed for the information necessary to create a notification, specifically the event’s geographic latitude, longitude and depth, date and origin time, magnitude and regional location in Canada. From this information, a brief public notification message is constructed using predefined message templates in both English and French with no more than 140 characters each (Fig. 23). The notification is designed to convey to the public that a seismic event has been automatically detected and provides a preliminary magnitude, origin time and approximate regional location in Canada. Once constructed, the notification is then disseminated to the public using the social media service “Twitter”. Simultaneously, a preliminary public notification message for the event is created on the main homepage of the *EarthquakesCanada* / *SéismesCanada* website in bold, easily visible text. In addition, the notification is sent to both the Seismologist-On-Call (SOC) cellular telephones in the east and west. The SOC will then review the automated solution, confirm its validity and post an updated seismologist reviewed solution if the event is real, or cancel the notification if it is determined to be a false alarm. In either case, an updated Twitter message with a link to an official reviewed earthquake report is sent or, in the case of a false alarm, the original automated notification is sent preceded by “DELETED” (CHIS Standard Operating Procedures, 2011). Official reviewed earthquake reports consist of a set of web-pages providing: (1) the reviewed earthquake information (latitude, longitude, depth, origin time) with a regional map showing the location of the event plus information as to where the event was felt and whether damage or a tsunami could be expected, (2) a list and map to the nearest population centers, (3) a list and map of regional seismicity (both recent and historic), (4) maps of nearby seismic stations, (5) views of the local and regional seismic waveforms used in the event analysis. These pages, along with a link with which the public can submit “Felt” reports for the specific event, provide the public with the ability to obtain comprehensive information about a specific seismic event.

As of October 31, 2011 there are more than 3,200 active followers of the CANADAquakes Twitter service and 350 followers of the CANADAseisme service, receiving automatic (and reviewed) notifications of significant earthquakes that affect Canadians. These followers primarily include ordinary citizens, but also emergency management and search and rescue services, radio and news agencies, travel and shipping companies, as well as other Government of Canada departments. All these individuals and groups then have the ability to forward these notifications, distributing them to other account holders who may not necessarily be subscribed to the service themselves. In this way, the general public and specialty groups are informed rapidly, without the need to visit the *EarthquakesCanada* / *SéismesCanada* website.

Since its inception in January of 2011, the performance of the system has been on par with anticipated algorithm performance based on the predictions of the six year simulation. A total of 15 automated notifications have been sent to date (as of October 31, 2011), of which only one has been a false positive, associated with large teleseismic signals originating from the magnitude 9.0 earthquake off the east coast of Japan on March 11, 2011. The remaining 14 events have been significant earthquakes ranging between magnitudes 4.0 and 6.3, primarily offshore along the western Canada coastline but also in the Quebec seismic region, Northwest Territories and Yukon. Current mean magnitude errors in the automated system, as predicted, are reasonably small at -0.07 ± 0.33, with the largest overestimate at +0.6 for a 4.9Mw offshore event, and the largest underestimate being -0.6 for a 6.3Mw event offshore of the northern end of Vancouver Island, BC. These automated earthquake locations have a median distance of 18.6 km from the final seismologist reviewed locations, with 10th and 90th percentiles of 8.9 and 61.6 km respectively for the distribution. Although specific latitude and longitude coordinates of the location are not currently provided in the public notification, these distance measures are again comparable to that predicted in simulation.

Finally, the overall system response time for the real-time algorithm is also performing as predicted. Current times, from the occurrence of a significant earthquake to the time the public notifications are sent via CANADAquakes and CANADAseisme, have an average delay of 5 minutes 13.1 seconds (313.1 sec.) with the fastest 5% of notifications occurring within 3 minutes 7.4 seconds (187.4 sec.) and 95% of all notifications are sent after 8 minutes 5.4 seconds (485.4 sec.). These response times fall well within the anticipated distribution predicted by simulation (Fig. 24). Thus overall, although the current rate of automated event notifications sent to date (~1.4/month or 16.8/year) is slightly below the average predicted rate of 25/year or ~2/month (Fig. 12), all indications are that the system is successfully performing as predicted in simulation.

Summary & Future work

Using the results of the current Canada-wide automated earthquake location algorithm, AUTOLOC, an automated public notification system has been devised and implemented by the Canadian Hazards Information Service at *EarthquakesCanada* / *SéismesCanada*. The notification system relies on a series of physical and statistically-based thresholds and filters to screen the steady stream of automated event solutions produced daily by AUTOLOC, searching for robustly determined seismic events with magnitudes large enough to be of concern to the public. Upon identification of a robust automated event solution with a magnitude greater than 4.0 within Canada, the system automatically generates a pre-formatted message in both official languages and posts it to two Twitter accounts: CANADAquakes and CANADAseisme, while simultaneously updating the main *EarthquakesCanada* / *SéismesCanada* web-pages with similar message headlines and alerting the on-call seismologists for immediate review of the event. Twitter notifications can then be further distributed amongst the public by the public, thereby potentially avoiding excess traffic and load on the website, whilst providing timely and authoritative information about Canadian seismic events significant to Canadians.

Simulations of the feasibility and potential performance of this system were performed by using a database of logged AUTOLOC automated event solutions as input and then comparing results to the seismologist reviewed events in the NEDB. Results from the real-time application of this event screening algorithm show that the actual performance is inline with these simulated predictions in terms of notification rates, frequency of false alarms, magnitude and location uncertainties, and system response times.

Future work that may be applied to future revisions of the automated notification system may include:

1. Modifications to current thresholds and settings to potentially optimize the system for the current or future CNSN network.

2. Refinement of duplicate solution checking to allow for the possibility of two or more significant seismic events occurring successively, but in geographically different regions of Canada.

3. Addition of new real-time international stations to, or removing current troublesome stations from, the detection lists AUTOLOC employs to populate its event lists, to better constrain teleseismic and Canada/US border events.

4. Inclusion of an automated event location's latitude and longitude as part of the public notification message and/or the seismic event banners posted on the website.

5. Generation and posting of automated webpage reports for automatically detected events which may include more detailed information, maps, seismograms and "felt report" links.

6. Optimization of individual station RDL settings to reduce the number of false and misidentified seismic phase detections being sent to AUTOLOC.

7. Incorporation of automated seismic event detections generated by the Antelope real-time seismic monitoring and analysis software currently in use at CHIS.

References

Atkinson G., Adams J., Asudeh I., Bostock M., Cassidy J., Eaton D., Ferguson I., Jones A.G., Snyder D., and White D. (2002) POLARIS Update: Fall 2002, Seismological Research Letters, 74(1), 41-43.

Eaton D., Adams J., Asudeh I., Atkinson G.M., Bostock M.G., Cassidy J.F., Ferguson I.J., Samson C., Snyder D.B., Tiampo K.F., and Unsworth M.J., 2005. Investigating Canada's lithosphere and earthquake hazards with portable arrays. EOS, Transactions, American Geophysical Union, 86(17), 169-176.

Edwards W.N., 2012., Performance comparison between current automated earthquake location methods, Autoloc and Antelope, Geological Survey of Canada, Open File 7000, p.24 doi:10.4095/OF7000.

Halchuck, S., 2010., Intensity reports for the Val-des-Bois, Quebec, earthquake of June 23, 2010; Canadian Hazard Information Service Internal Report 2010-3.1, 15 pages.

Halchuck S. and Adams J., 2008., Fourth generation seismic hazard maps of Canada: Maps and grid values to be used with the 2005 National Building Code of Canada; Geological Survey of Canada, Open File 5813, p.32 doi:10.4095/OF5813

National Building Code of Canada, 2005., National Research Council of Canada, NRCC 47666 Ottawa, Canada.

Canadian Hazards Information Service, 2011., Standard Operating Procedures: Earthquakes and Tsunamis, Canadian Hazard Information Service Internal Procedures, 68 pages.

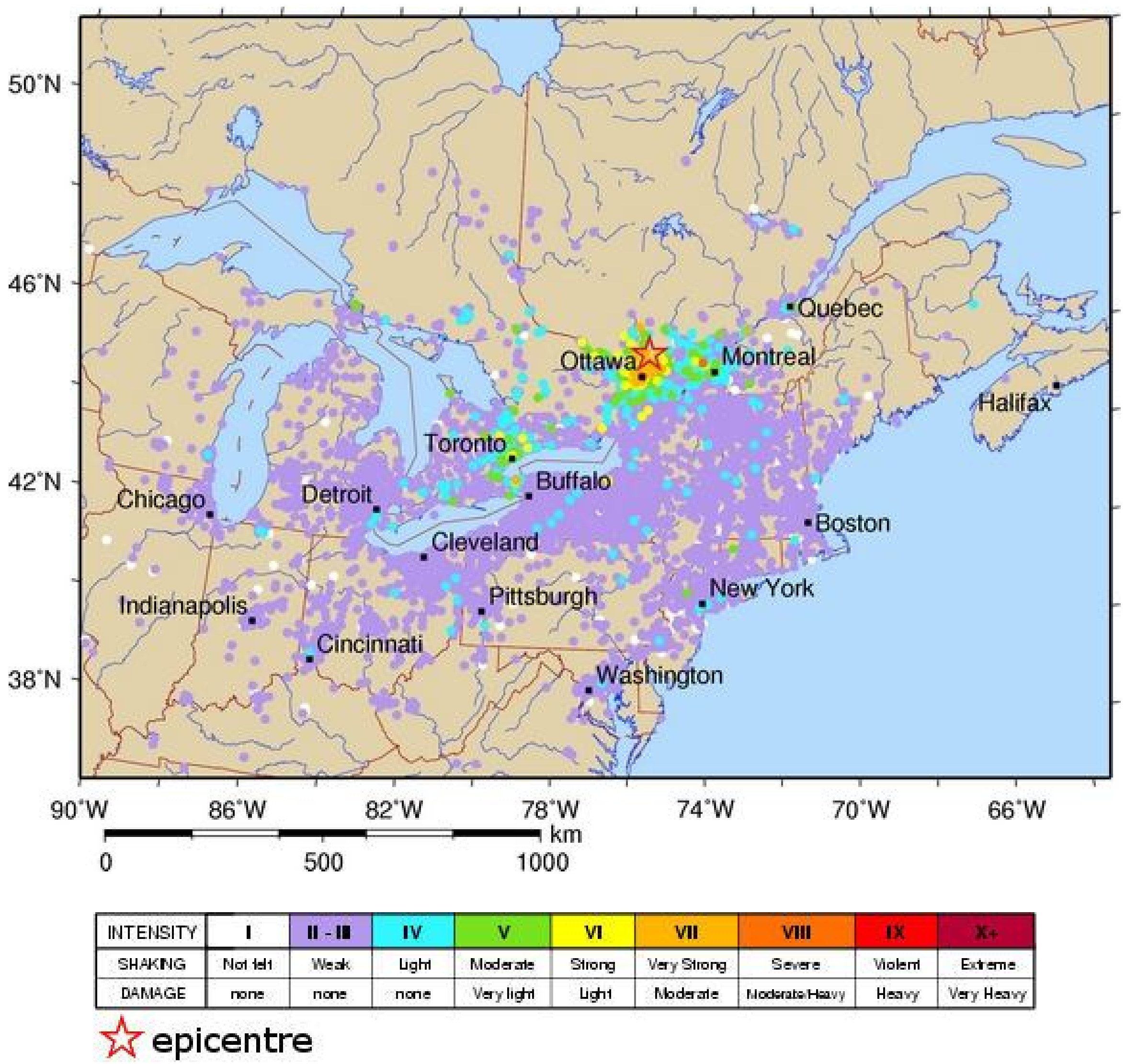


Fig. 1: Distribution and relative strength of the shaking as reported by citizens across Eastern North America and around the Val-des-Bois region after the 5.0 Mw earthquake on June 23rd, 2010 (Halchuck, 2010).

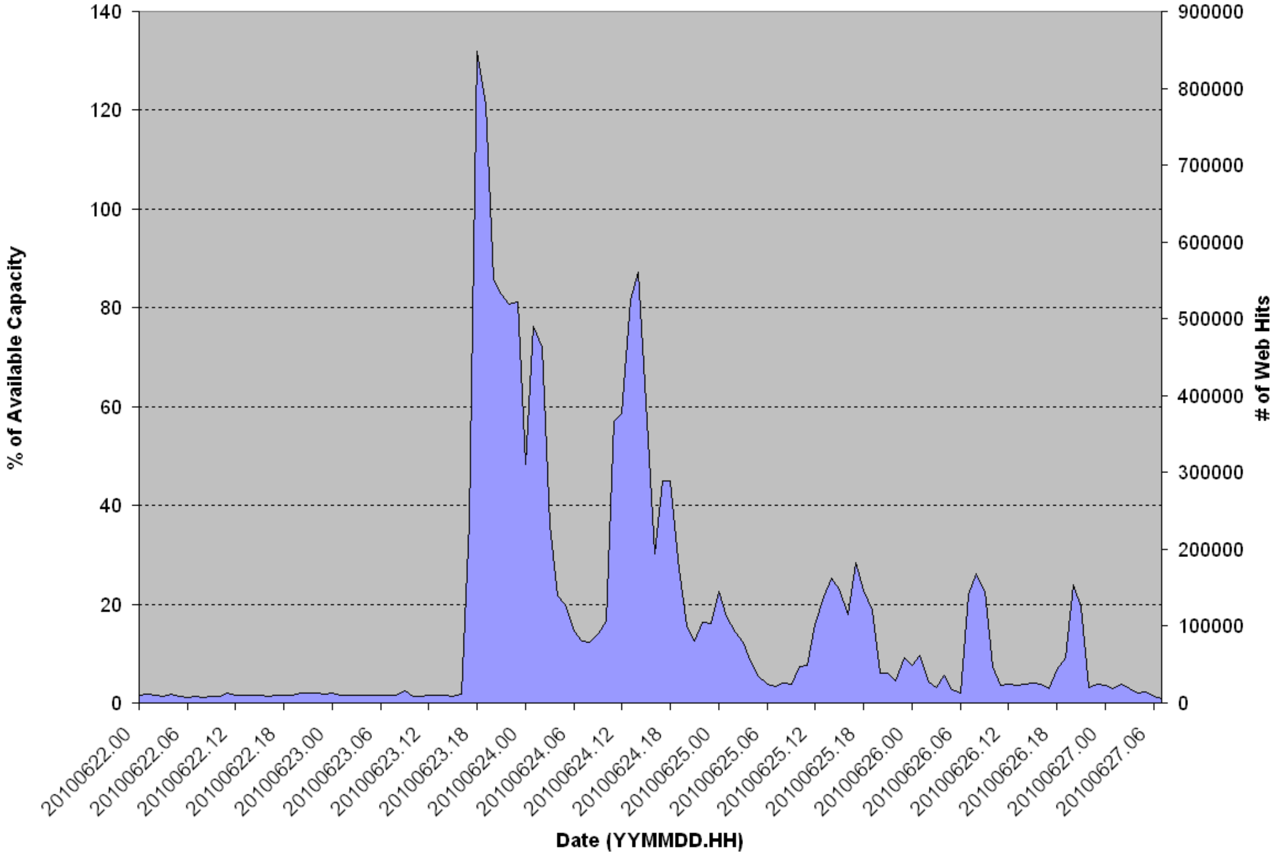
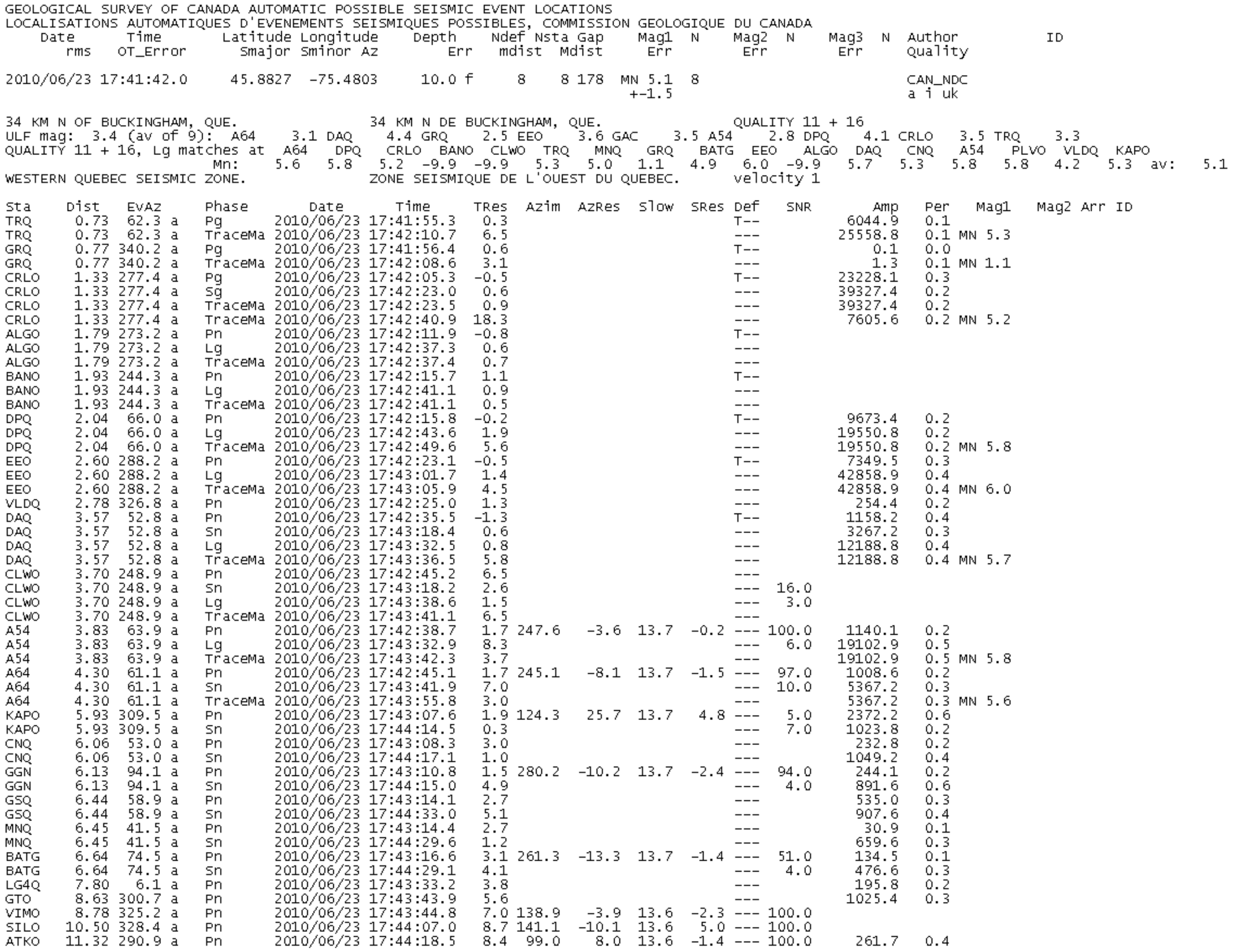


Fig. 2: CHIS internet traffic after the Val-des-Bois earthquake. Traffic peaked at more than 130% of the available web capacity at the time, causing the *EarthquakesCanada* public webpage to become unavailable for ~1 hour. During this time the public were unable to access pertinent information regarding the earthquake directly from NRCan. While limited service was available afterwards, normal operations did not resume until ~3-4 hours later. In the ensuing days after the earthquake, daily web traffic mirrored this peak with slowly decreasing peaks as public interest waned.



```
GEOLOGICAL SURVEY OF CANADA AUTOMATIC POSSIBLE SEISMIC EVENT LOCATIONS
LOCALISATIONS AUTOMATIQUES D'EVENEMENTS SEISMIQUES POSSIBLES, COMMISSION GEOLOGIQUE DU CANADA
    Date      Time       Latitude Longitude    Depth    Ndef Nsta Gap    Mag1  N    Mag2  N    Mag3  N  Author          ID
       rms   OT_Error      Smajor Sminor Az         Err   mdist  Mdist     Err        Err        Err     Quality

2010/06/23 17:41:42.0     45.8827  -75.4803     10.0 f     8    8 178  MN 5.1  8                        CAN_NDC
                                                                        +-1.5                           a i uk

34 KM N OF BUCKINGHAM, QUE.               34 KM N DE BUCKINGHAM, QUE.               QUALITY 11 + 16
ULF mag:  3.4 (av of 9):  A64    3.1 DAQ    4.4 GRQ    2.5 EEO    3.6 GAC    3.5 A54    2.8 DPQ    4.1 CRLO   3.5 TRQ    3.3
QUALITY 11 + 16, Lg matches at  A64   DPQ   CRLO  BANO  CLWO  TRQ   MNQ   GRQ   BATG  EEO   ALGO  DAQ   CNQ   A54   PLVO  VLDQ  KAPO
                        Mn:    5.6   5.8   5.2  -9.9  -9.9   5.3   5.0   1.1   4.9   6.0  -9.9   5.7   5.3   5.8   5.8   4.2   5.3  av:   5.1
WESTERN QUEBEC SEISMIC ZONE.              ZONE SEISMIQUE DE L'OUEST DU QUEBEC.      velocity 1

Sta    Dist   EvAz     Phase       Date       Time       TRes  Azim  AzRes   Slow  SRes Def   SNR       Amp   Per   Mag1   Mag2 Arr ID
TRQ     0.73  62.3 a   Pg      2010/06/23 17:41:55.3   0.3                           T--          6044.9   0.1
TRQ     0.73  62.3 a   TraceMa 2010/06/23 17:42:10.7   6.5                           ---         25558.8   0.1 MN 5.3
GRQ     0.77 340.2 a   Pg      2010/06/23 17:41:56.4   0.6                           T--             0.1   0.0
GRQ     0.77 340.2 a   TraceMa 2010/06/23 17:42:08.6   3.1                           ---             1.3   0.1 MN 1.1
CRLO    1.33 277.4 a   Pg      2010/06/23 17:42:05.3  -0.5                           T--         23228.1   0.3
CRLO    1.33 277.4 a   Sg      2010/06/23 17:42:23.0   0.6                           ---         39327.4   0.2
CRLO    1.33 277.4 a   TraceMa 2010/06/23 17:42:23.5   0.9                           ---         39327.4   0.2
CRLO    1.33 277.4 a   TraceMa 2010/06/23 17:42:40.9  18.3                           ---          7605.6   0.2 MN 5.2
ALGO    1.79 273.2 a   Pn      2010/06/23 17:42:11.9  -0.8                           T--
ALGO    1.79 273.2 a   Lg      2010/06/23 17:42:37.3   0.6                           ---
ALGO    1.79 273.2 a   TraceMa 2010/06/23 17:42:37.4   0.7                           ---
BANO    1.93 244.3 a   Pn      2010/06/23 17:42:15.7   1.1                           T--
BANO    1.93 244.3 a   Lg      2010/06/23 17:42:41.1   0.9                           ---
BANO    1.93 244.3 a   TraceMa 2010/06/23 17:42:41.1   0.5                           ---
DPQ     2.04  66.0 a   Pn      2010/06/23 17:42:15.8  -0.2                           T--          9673.4   0.2
DPQ     2.04  66.0 a   Lg      2010/06/23 17:42:43.6   1.9                           ---         19550.8   0.2
DPQ     2.04  66.0 a   TraceMa 2010/06/23 17:42:49.6   5.6                           ---         19550.8   0.2 MN 5.8
EEO     2.60 288.2 a   Pn      2010/06/23 17:42:23.1  -0.5                           T--          7349.5   0.3
EEO     2.60 288.2 a   Lg      2010/06/23 17:43:01.7   1.4                           ---         42858.9   0.4
EEO     2.60 288.2 a   TraceMa 2010/06/23 17:43:05.9   4.5                           ---         42858.9   0.4 MN 6.0
VLDQ    2.78 326.8 a   Pn      2010/06/23 17:42:25.0   1.3                           ---           254.4   0.2
DAQ     3.57  52.8 a   Pn      2010/06/23 17:42:35.5  -1.3                           T--          1158.2   0.4
DAQ     3.57  52.8 a   Sn      2010/06/23 17:43:18.4   0.6                           ---          3267.2   0.3
DAQ     3.57  52.8 a   Lg      2010/06/23 17:43:32.5   0.8                           ---         12188.8   0.4
DAQ     3.57  52.8 a   TraceMa 2010/06/23 17:43:36.5   5.8                           ---         12188.8   0.4 MN 5.7
CLWO    3.70 248.9 a   Pn      2010/06/23 17:42:45.2   6.5                           ---
CLWO    3.70 248.9 a   Sn      2010/06/23 17:43:18.2   2.6                           ---  16.0
CLWO    3.70 248.9 a   Lg      2010/06/23 17:43:38.6   1.5                           ---   3.0
CLWO    3.70 248.9 a   TraceMa 2010/06/23 17:43:41.1   6.5                           ---
A54     3.83  63.9 a   Pn      2010/06/23 17:42:38.7   1.7 247.6    -3.6  13.7  -0.2 --- 100.0    1140.1   0.2
A54     3.83  63.9 a   Lg      2010/06/23 17:43:32.9   8.3                           ---   6.0   19102.9   0.5
A54     3.83  63.9 a   TraceMa 2010/06/23 17:43:42.3   3.7                           ---         19102.9   0.5 MN 5.8
A64     4.30  61.1 a   Pn      2010/06/23 17:42:45.1   1.7 245.1    -8.1  13.7  -1.5 ---  97.0    1008.6   0.2
A64     4.30  61.1 a   Sn      2010/06/23 17:43:41.9   7.0                           ---  10.0    5367.2   0.3
A64     4.30  61.1 a   TraceMa 2010/06/23 17:43:55.8   3.0                           ---          5367.2   0.3 MN 5.6
KAPO    5.93 309.5 a   Pn      2010/06/23 17:43:07.6   1.9 124.3    25.7  13.7   4.8 ---   5.0    2372.2   0.6
KAPO    5.93 309.5 a   Sn      2010/06/23 17:44:14.5   0.3                           ---   7.0    1023.8   0.2
CNQ     6.06  53.0 a   Pn      2010/06/23 17:43:08.3   3.0                           ---           232.8   0.2
CNQ     6.06  53.0 a   Sn      2010/06/23 17:44:17.1   1.0                           ---          1049.2   0.4
GGN     6.13  94.1 a   Pn      2010/06/23 17:43:10.8   1.5 280.2   -10.2  13.7  -2.4 ---  94.0     244.1   0.2
GGN     6.13  94.1 a   Sn      2010/06/23 17:44:15.0   4.9                           ---   4.0     891.6   0.6
GSQ     6.44  58.9 a   Pn      2010/06/23 17:43:14.1   2.7                           ---           535.0   0.3
GSQ     6.44  58.9 a   Sn      2010/06/23 17:44:33.0   5.1                           ---           907.6   0.4
MNQ     6.45  41.5 a   Pn      2010/06/23 17:43:14.4   2.7                           ---            30.9   0.1
MNQ     6.45  41.5 a   Sn      2010/06/23 17:44:29.6   1.2                           ---           659.6   0.3
BATG    6.64  74.5 a   Pn      2010/06/23 17:43:16.6   3.1 261.3   -13.3  13.7  -1.4 ---  51.0     134.5   0.1
BATG    6.64  74.5 a   Sn      2010/06/23 17:44:29.1   4.1                           ---   4.0     476.6   0.3
LG4Q    7.80   6.1 a   Pn      2010/06/23 17:43:33.2   3.8                           ---           195.8   0.2
GTO     8.63 300.7 a   Pn      2010/06/23 17:43:43.9   5.6                           ---          1025.4   0.3
VIMO    8.78 325.2 a   Pn      2010/06/23 17:43:44.8   7.0 138.9    -3.9  13.6  -2.3 --- 100.0
SILO   10.50 328.4 a   Pn      2010/06/23 17:44:07.0   8.7 141.1   -10.1  13.6   5.0 --- 100.0
ATKO   11.32 290.9 a   Pn      2010/06/23 17:44:18.5   8.4  99.0     8.0  13.6  -1.4 --- 100.0     261.7   0.4
```

Fig 3: Example of an AUTOLOC automated event solution for the Val-des-Bois earthquake on June 23, 2010. Solution provides geographic coordinates, origin time, depth and magnitude of the event, along with the various stations and associated seismic phases used for determining this location. Individual station magnitude measurements used in estimating the overall event magnitude are also provided.

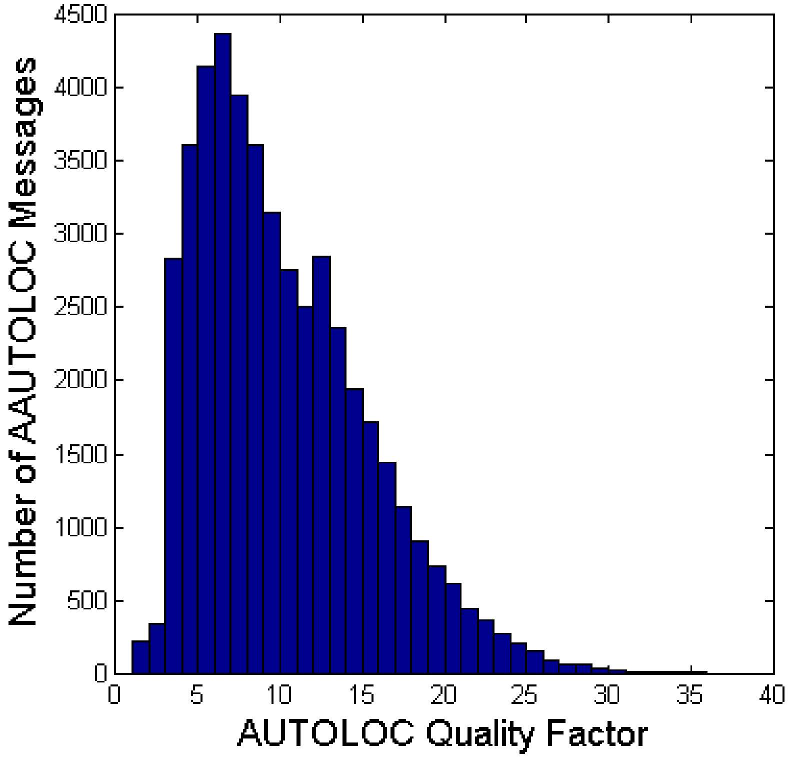


Fig. 4: Histogram of AUTOLOC Quality factor, *Q* for all solutions from January 2005 through to November 2010.

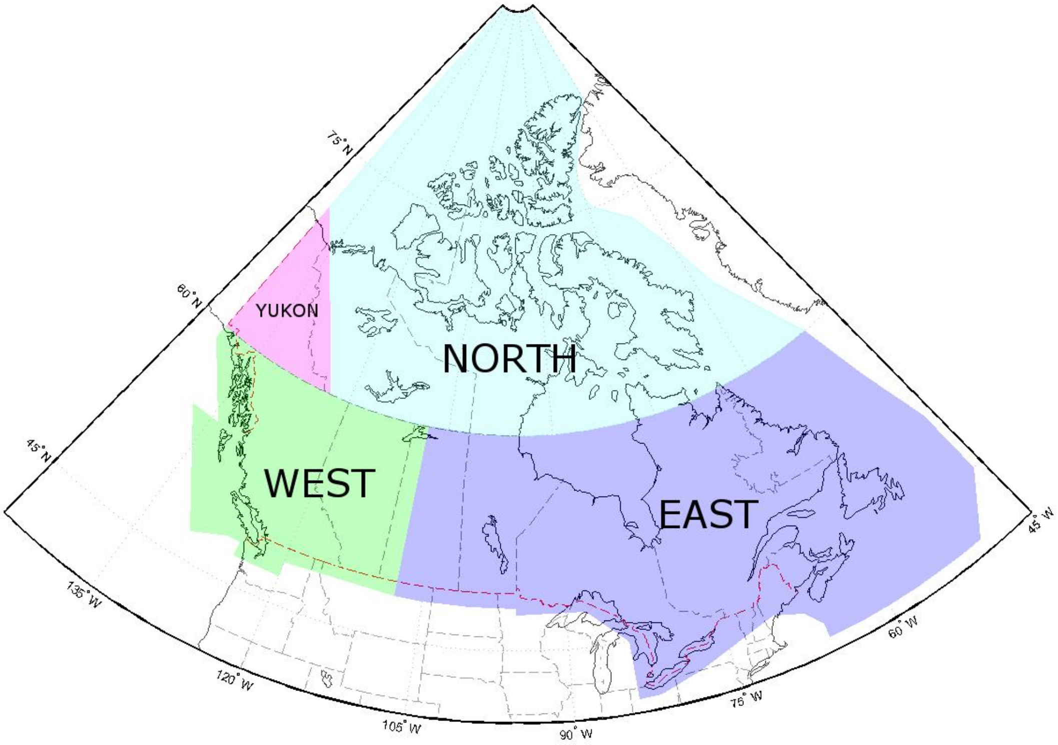


Fig. 5: Regional divisions and borders of Canada used in the assessment of AUTOLOC automated event solutions. This Canadian border region uses a similar boundary as employed by the Canadian National Earthquake Hazard Map (Halchuk & Adams, 2008) used by the National Building Code of Canada (National Building Code of Canada, 2005), but extends this ~100 km beyond the Canada/US border.

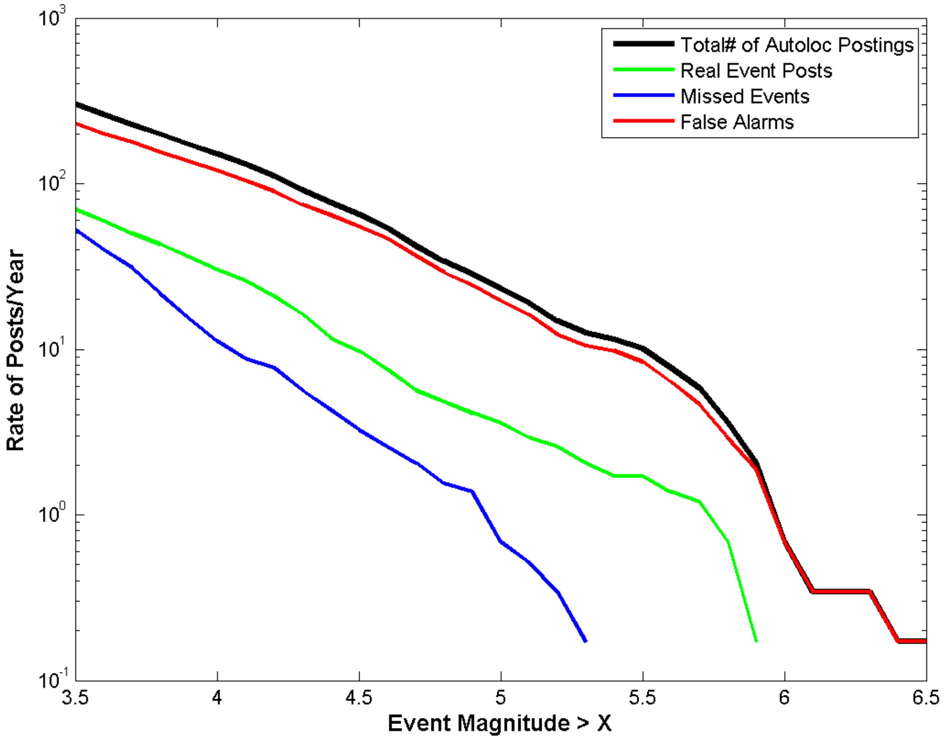


Fig. 6: Estimated yearly notification posting rates for a Canada-wide system with simple Quality factor, Q = 14, and magnitude 3.5 thresholds. While the number of missed events decreases with increasing magnitude, false alarms significantly outweigh the real seismic event posting rate.

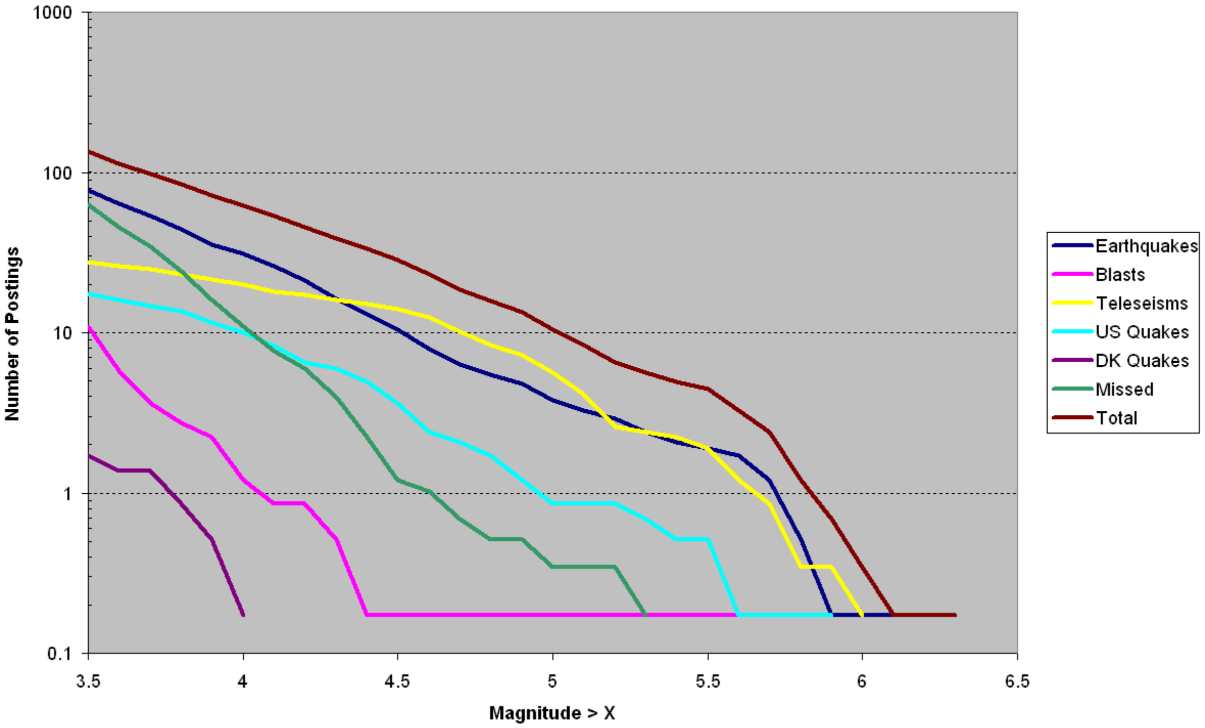


Fig. 7: Estimated number of notification postings for all of Canada as a function of magnitude and source for the simple filtering process with Q = 14 and magnitude 3.5 thresholds. US Quakes and DK Quakes represent mislocated earthquakes in the United States and Greenland respectively.

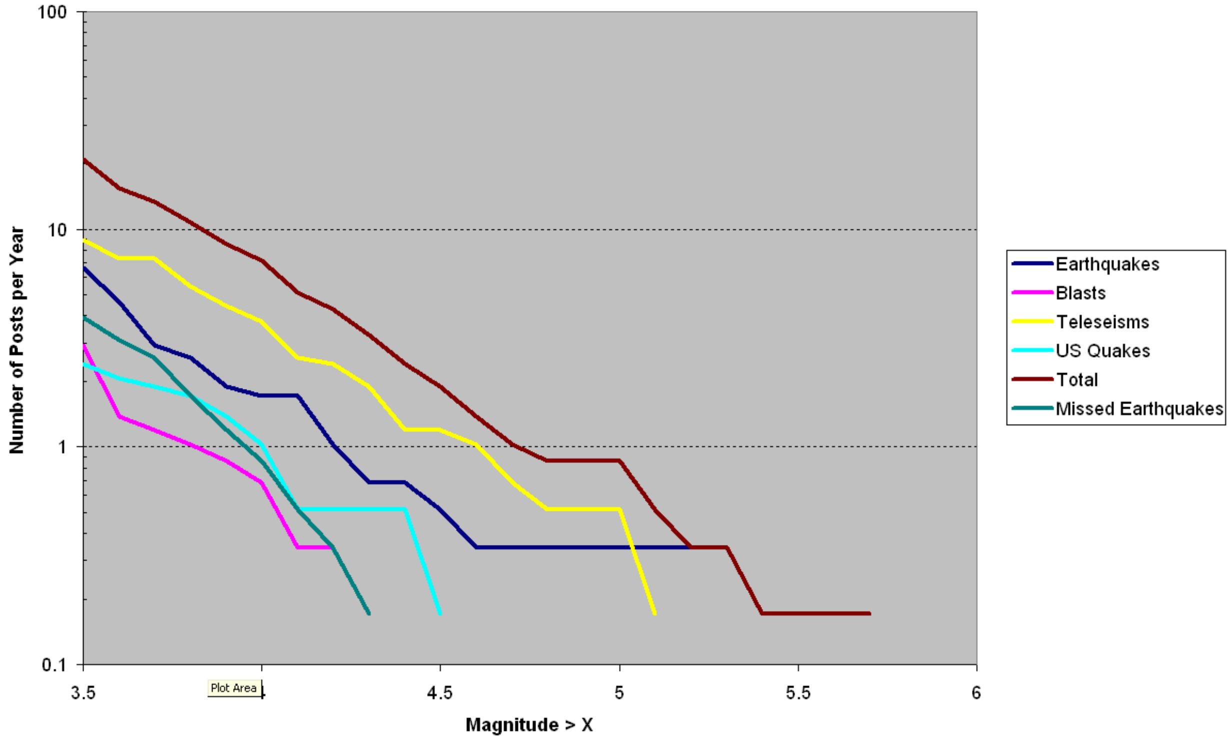


Fig. 8: Estimated number of notification postings for Eastern Canada as a function of magnitude and source for the simple filtering process with Q = 14 and magnitude 3.5 thresholds. US Quakes represent mislocated earthquakes in the United States.

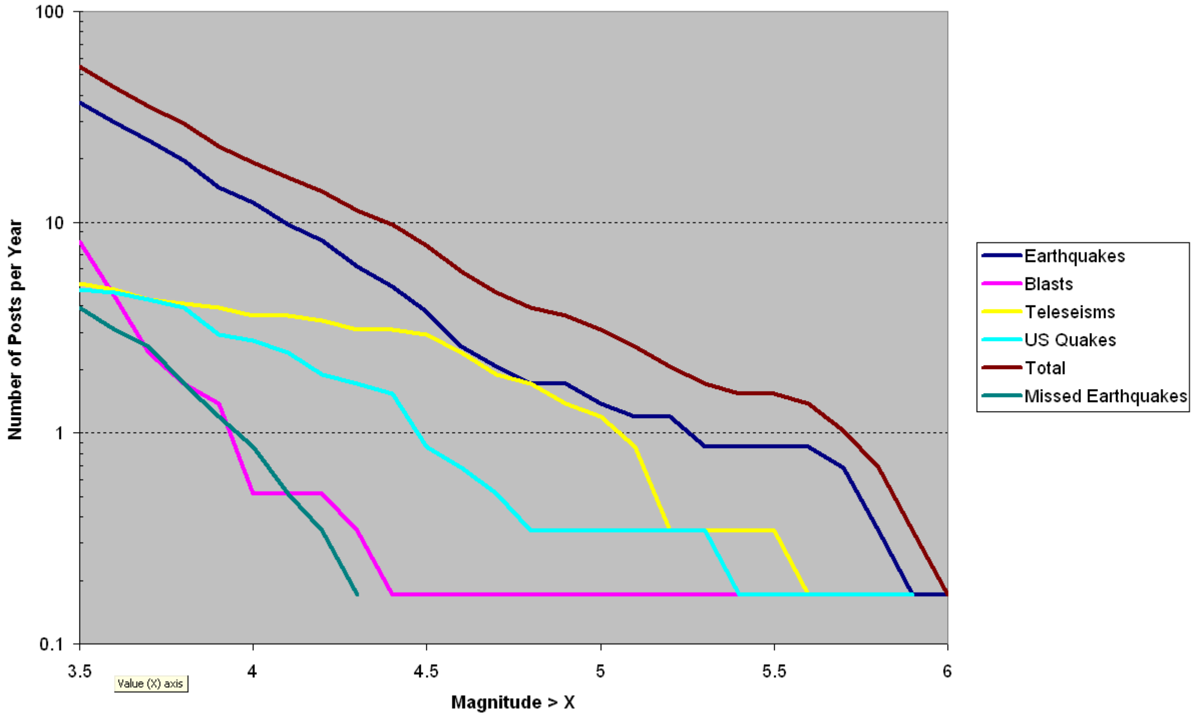


Fig. 9: Estimated number of notification postings for Western Canada as a function of magnitude and source for the simple filtering process with Q = 14 and magnitude 3.5 thresholds. US Quakes represent mislocated earthquakes in the United States.

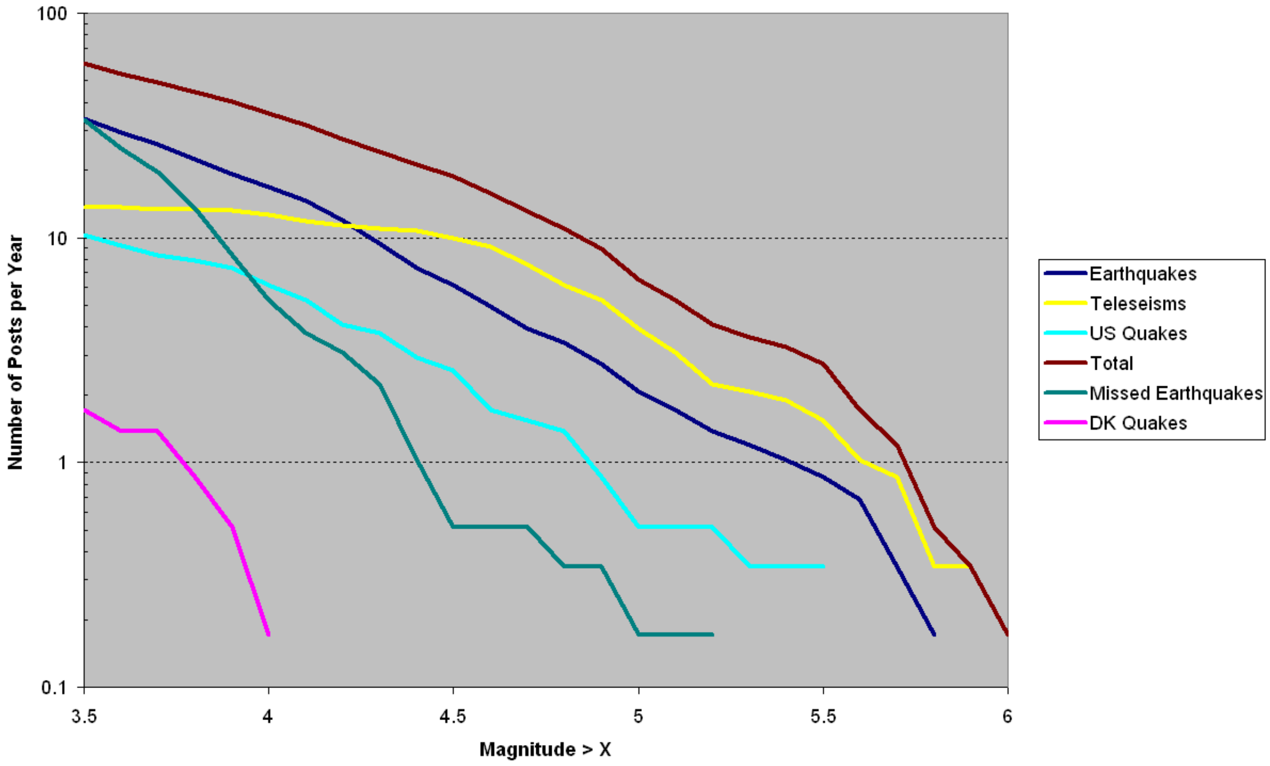


Fig. 10: Estimated number of notification postings for Northern Canada (encompassing the Northwest Territories and Nunavut) & the Yukon as a function of magnitude and source for the simple filtering process with Q = 14 and magnitude 3.5 thresholds. US Quakes and DK Quakes represent mislocated earthquakes in the United States and Greenland respectively.

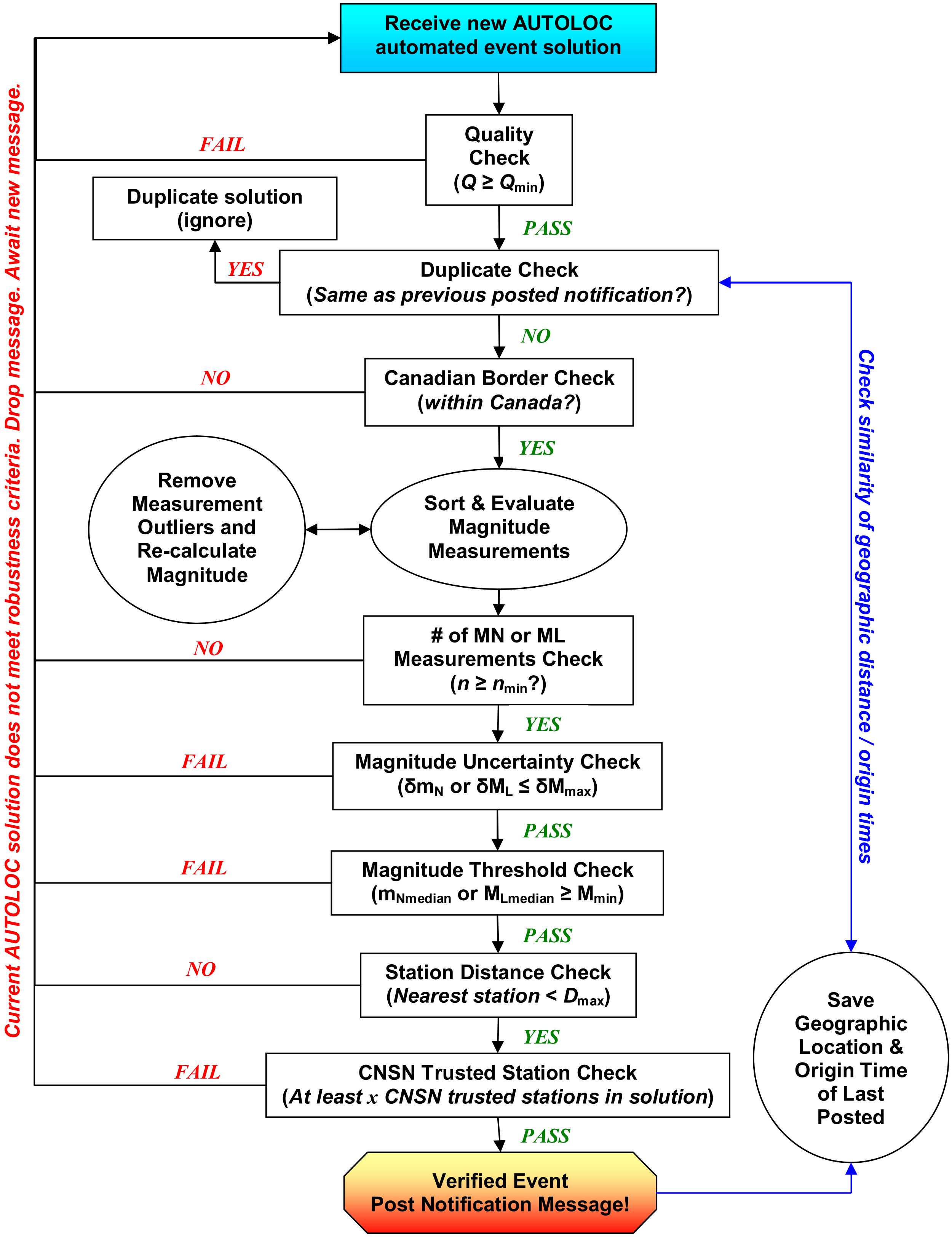


Fig. 11: Automated seismic event solution evaluation process. Each solution produced by AUTOLOC is similarly evaluated to determine its suitability and robustness prior to posting a public notification message.

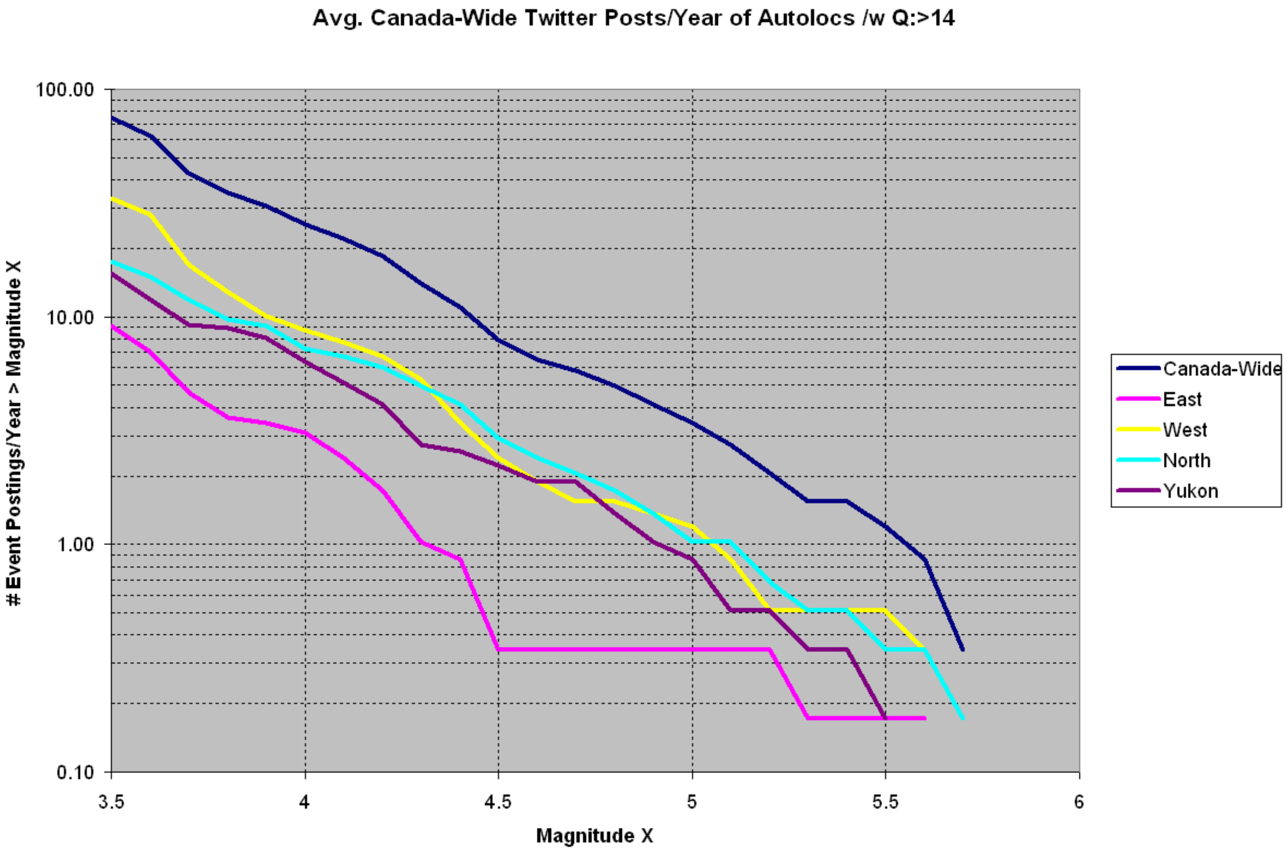


Fig. 12: Simulated Canada-wide average automated notification posting rate over a 5 year period as a function of increasing magnitude and sub-region after applying the advanced filtering algorithm to AUTOLOC automated event solutions.

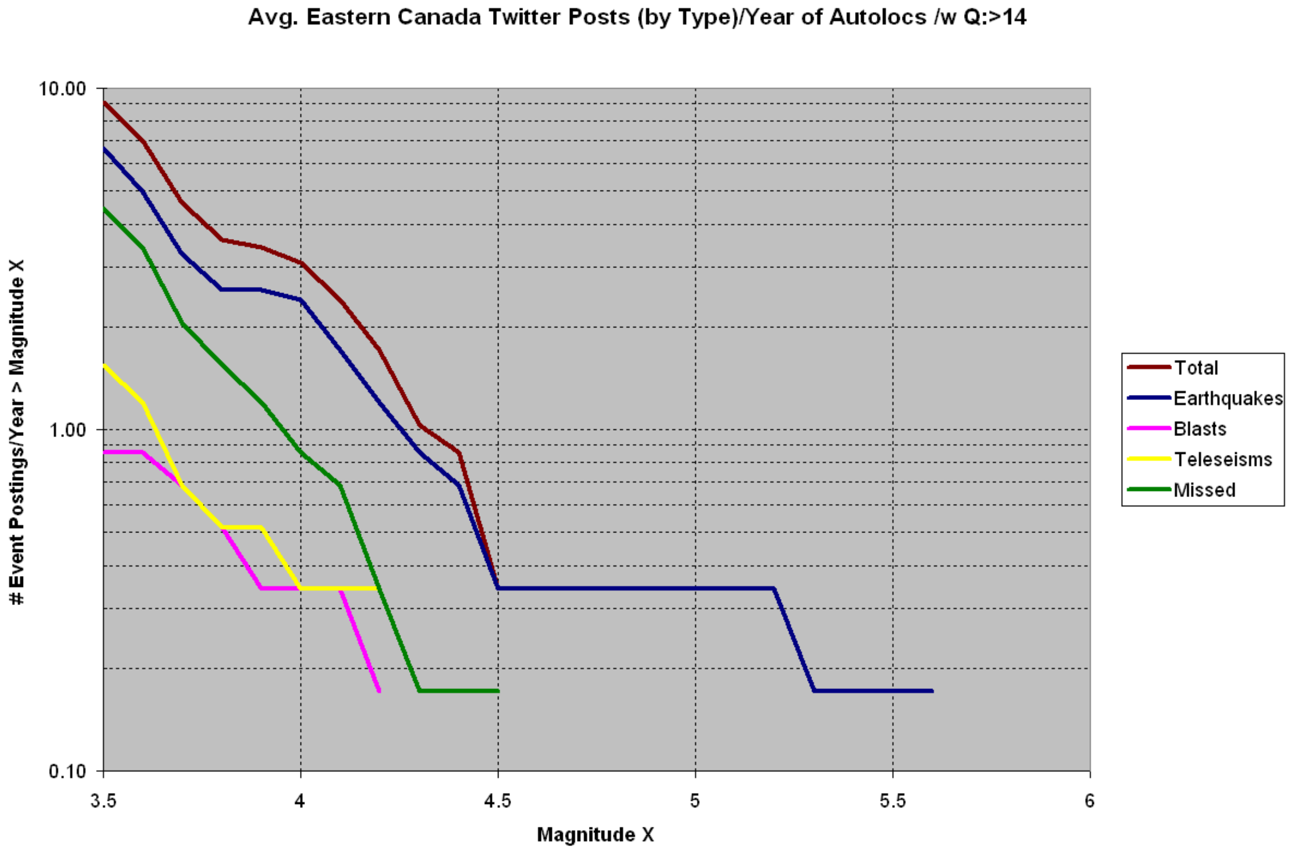


Fig. 13: Eastern Canada results of the 5 year simulation of automated notification postings as a function of increasing magnitude and region using the advanced filtering algorithm. Compared to simple Quality/magnitude thresholds (Fig. 8), the rate of falsely posted events has been significantly reduced below and eliminated above magnitude 4.5.

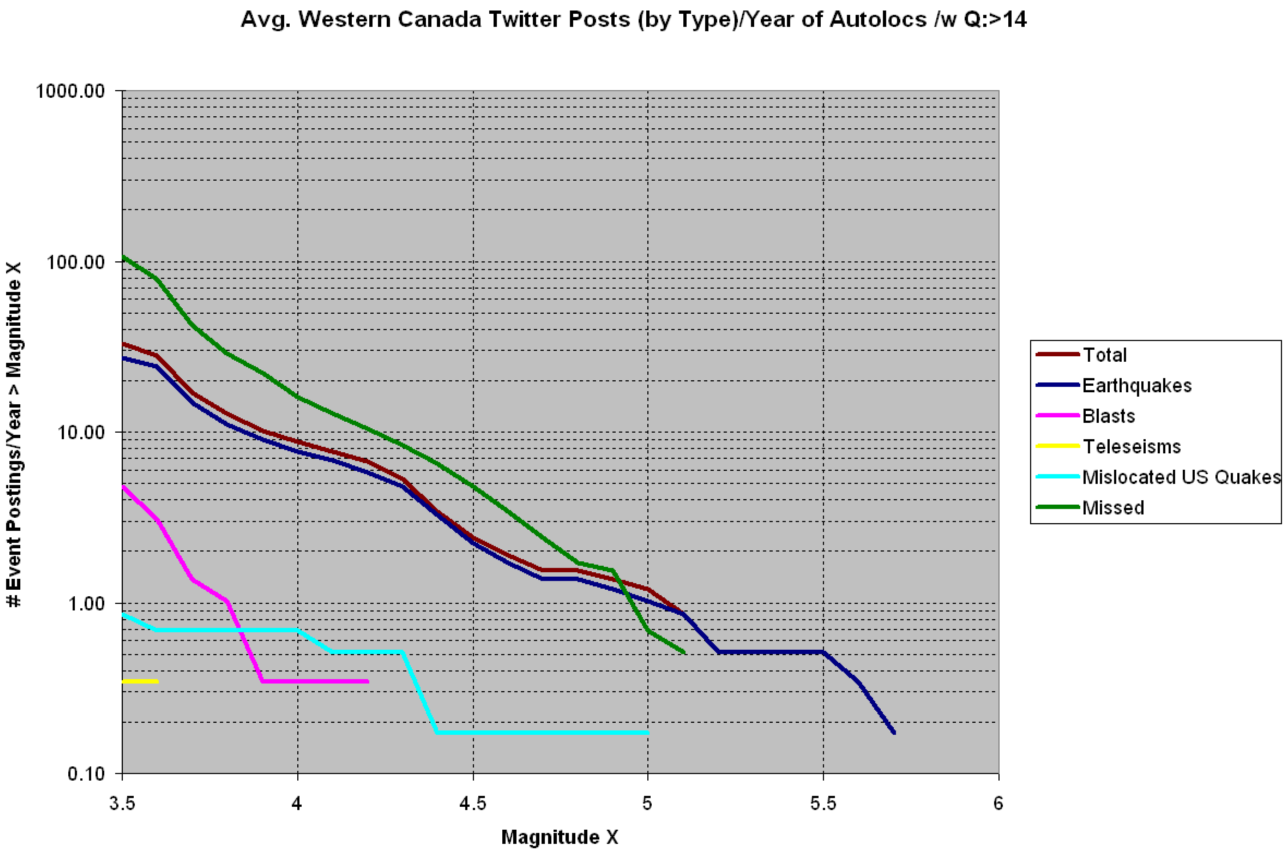


Fig. 14: Western Canada results of the 5 year simulation of automated notification postings as a function of increasing magnitude and region using the advanced filtering algorithm. Compared to simple Quality/magnitude thresholds (Fig. 9), the rate of falsely posted events related to teleseisms has been all but eliminated above magnitude 3.5, with mis-located US Quakes are also reduced.

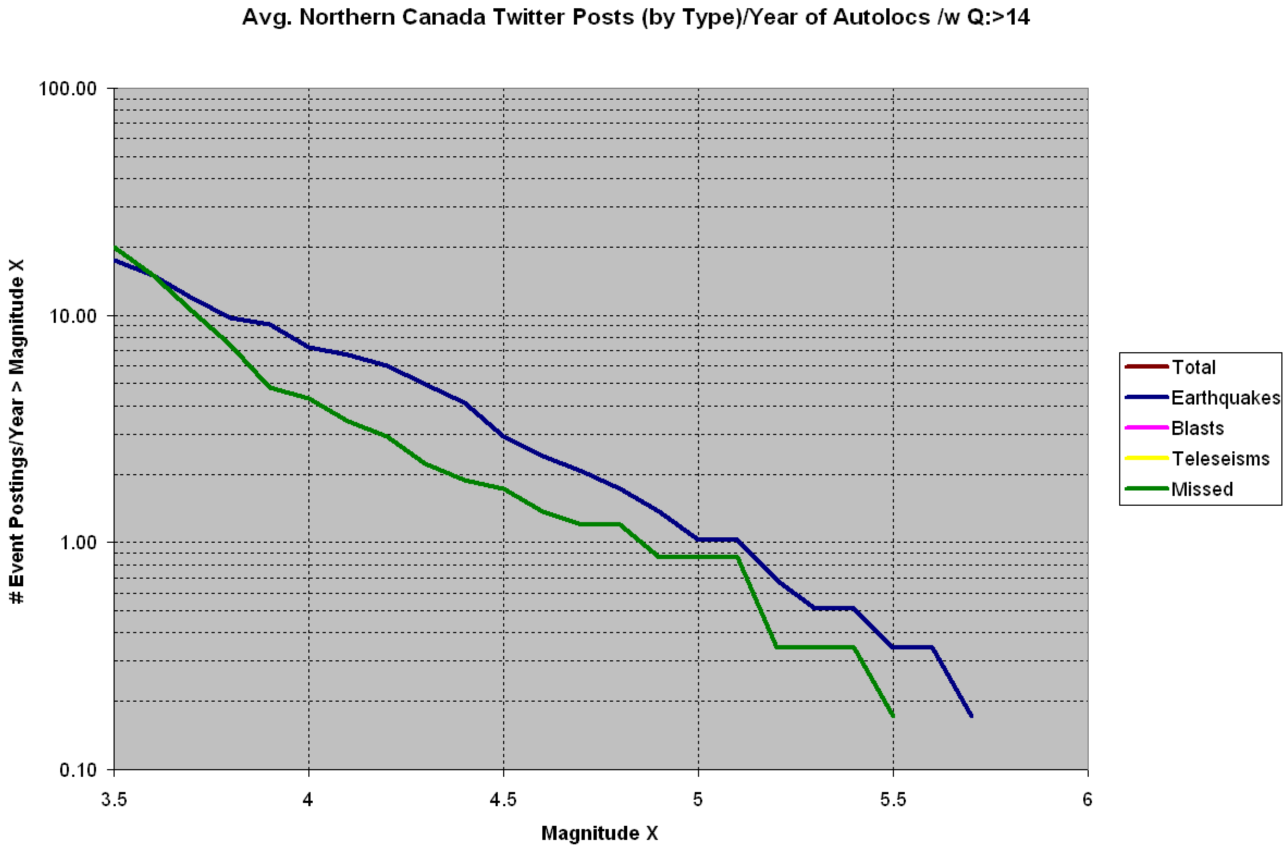


Fig. 15: Northern Canada results of the 5 year simulation of automated notification postings as a function of increasing magnitude and region using the advanced filtering algorithm. Compared to simple Quality and magnitude thresholds (Fig. 10), the rate of falsely posted events has been completely eliminated above magnitude 3.5.

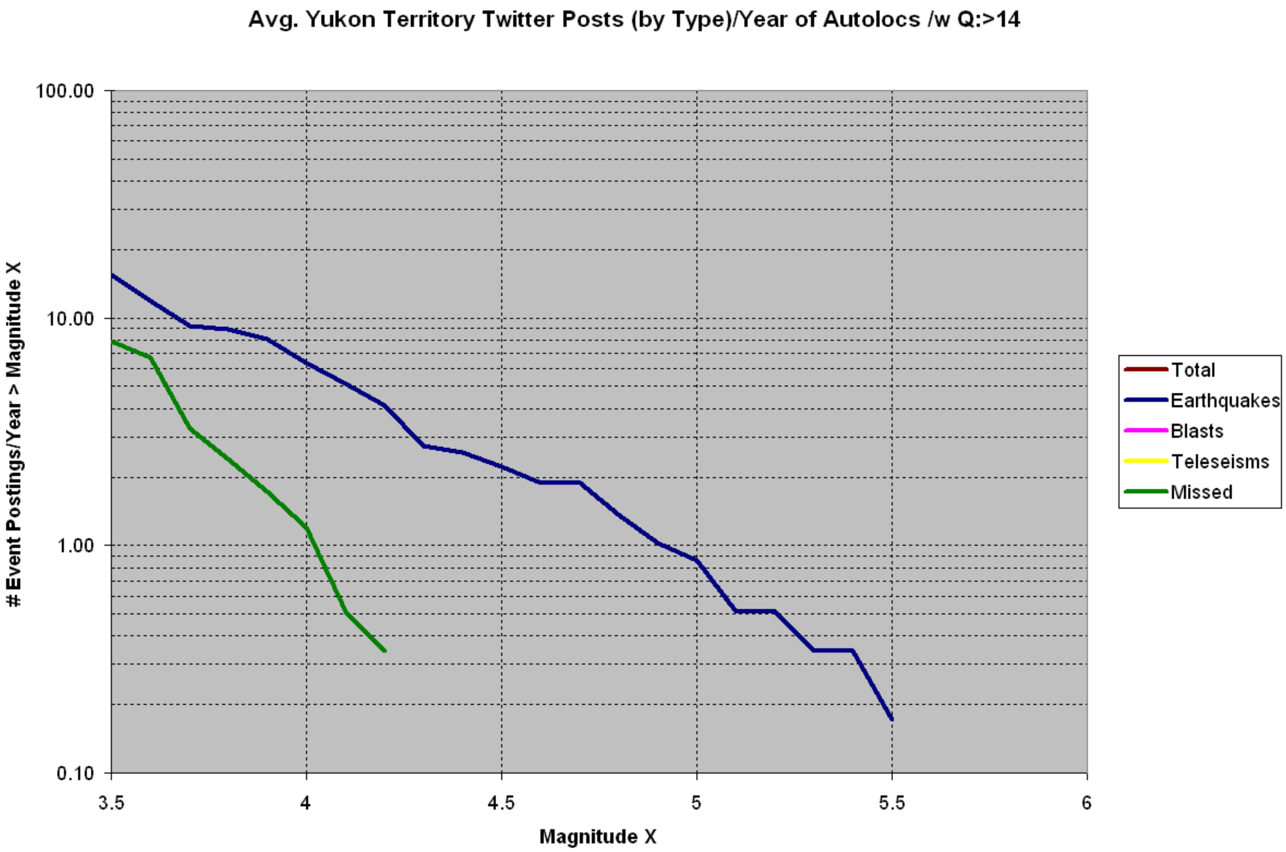
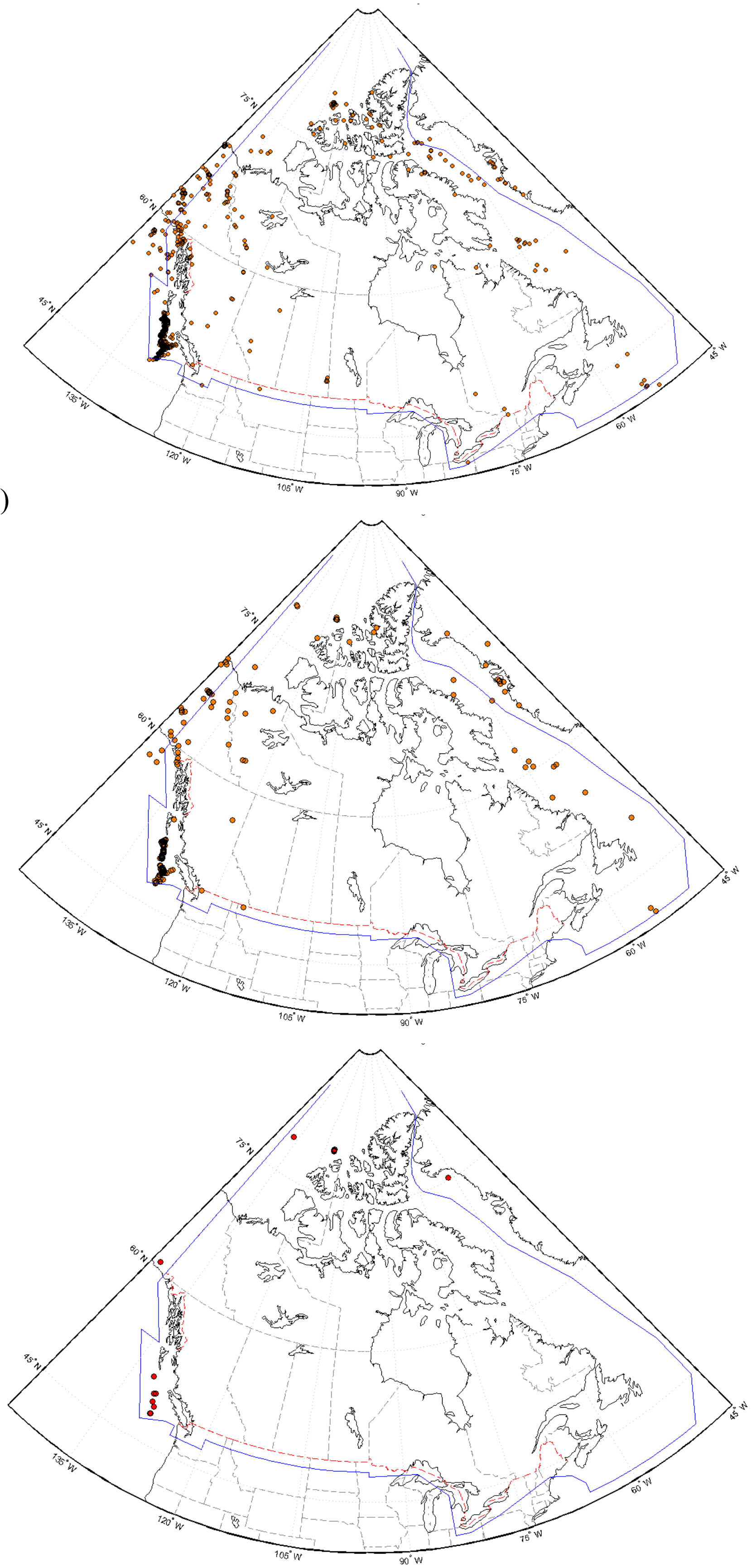


Fig. 16: Yukon Canada results of the 5 year simulation of automated notification postings as a function of increasing magnitude and region using the advanced filtering algorithm. Similar to that seen for Northern Canada (Fig. 15), the rate of falsely posted events has been completely eliminated above magnitude 3.5.



(a)

(b)

(c)

Fig. 17: Map of the locations of "missed" Earthquakes in the CNSN Earthquake Catalog by the automated system. (a) magnitudes 3.5 – 3.9 (b) magnitudes 4.0 – 4.9 (c) magnitudes >5.0.

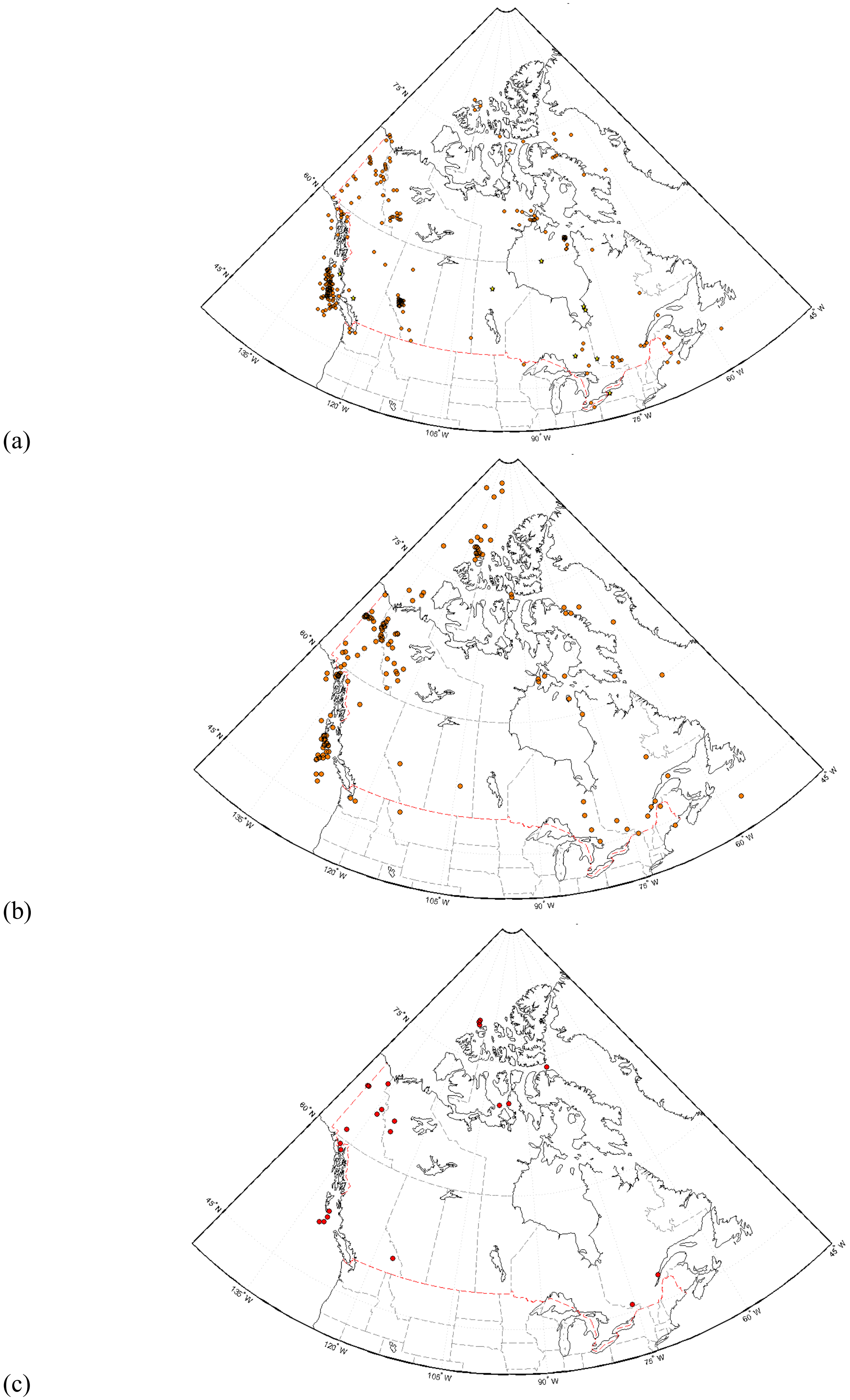


Fig. 18: Maps of 5 years of simulated Canada-wide automated notification messages as a function of magnitude. (a) Magnitudes 3.5 – 3.9 (b) magnitudes 4.0 – 4.9 (c) magnitudes 5.0 – 5.9.

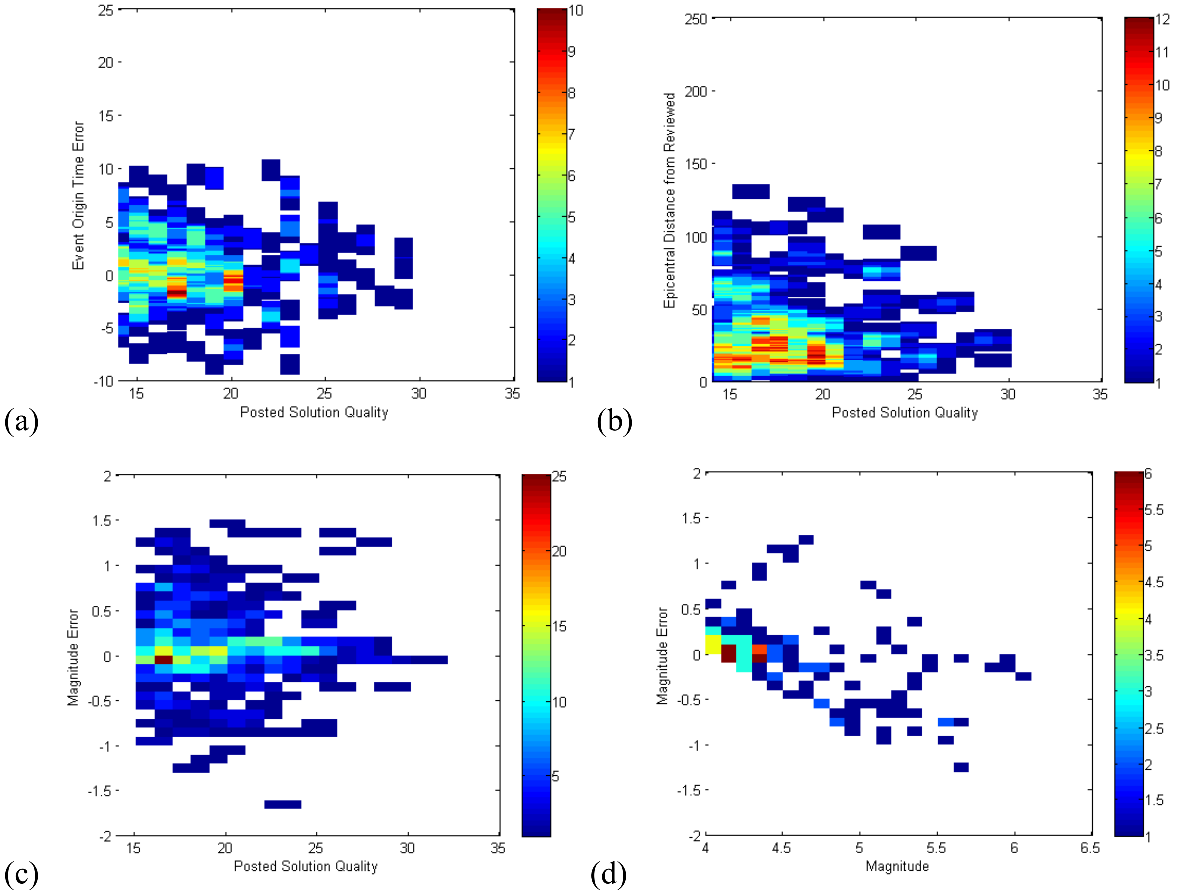


Fig. 19: Magnitude and location error distributions as a function of automated solution Quality for the simulated automated alert notifications as compared to the seismologist reviewed locations in the CNSN earthquake catalogue for a 5 year period. (a) Origin time error vs. Quality (b) Distance from reviewed epicentre vs. Quality (c) Magnitude error vs. Quality (d) Magnitude error vs. Magnitude. Colourbars indicate the number of individual automated solutions represented in each grid point.

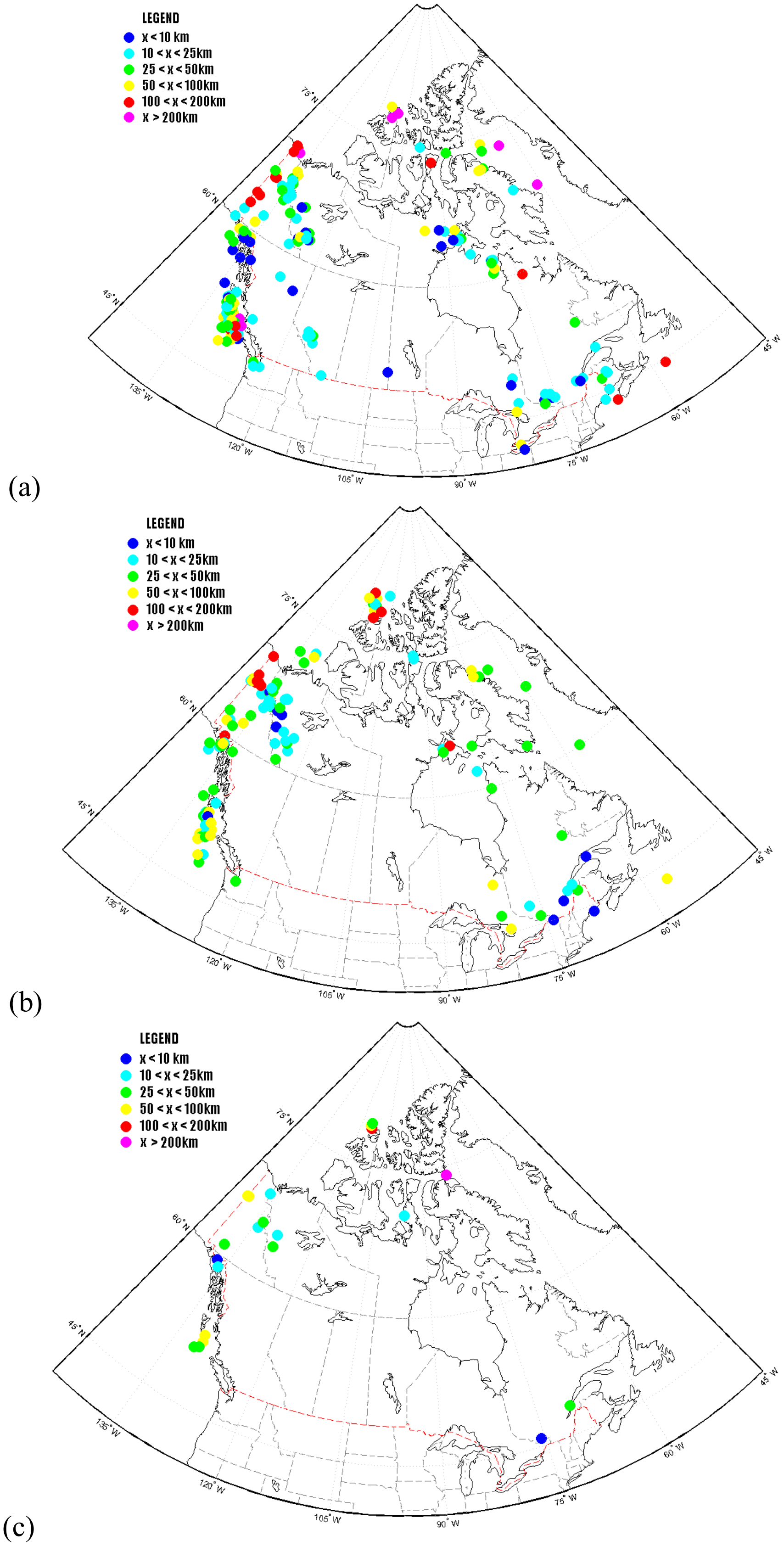


Fig. 20: Distribution of 5 years of automated notification, colour-coded according to distance from the seismologist reviewed epicentre. Larger epicentral errors are found along coastlines where poor station azimuthal coverage does not easily constrain events geographically, resulting in greater epicentre uncertainty. Magnitudes (a) 3.5 – 3.9 (b) 4.0 – 4.9 (c) >5.0.

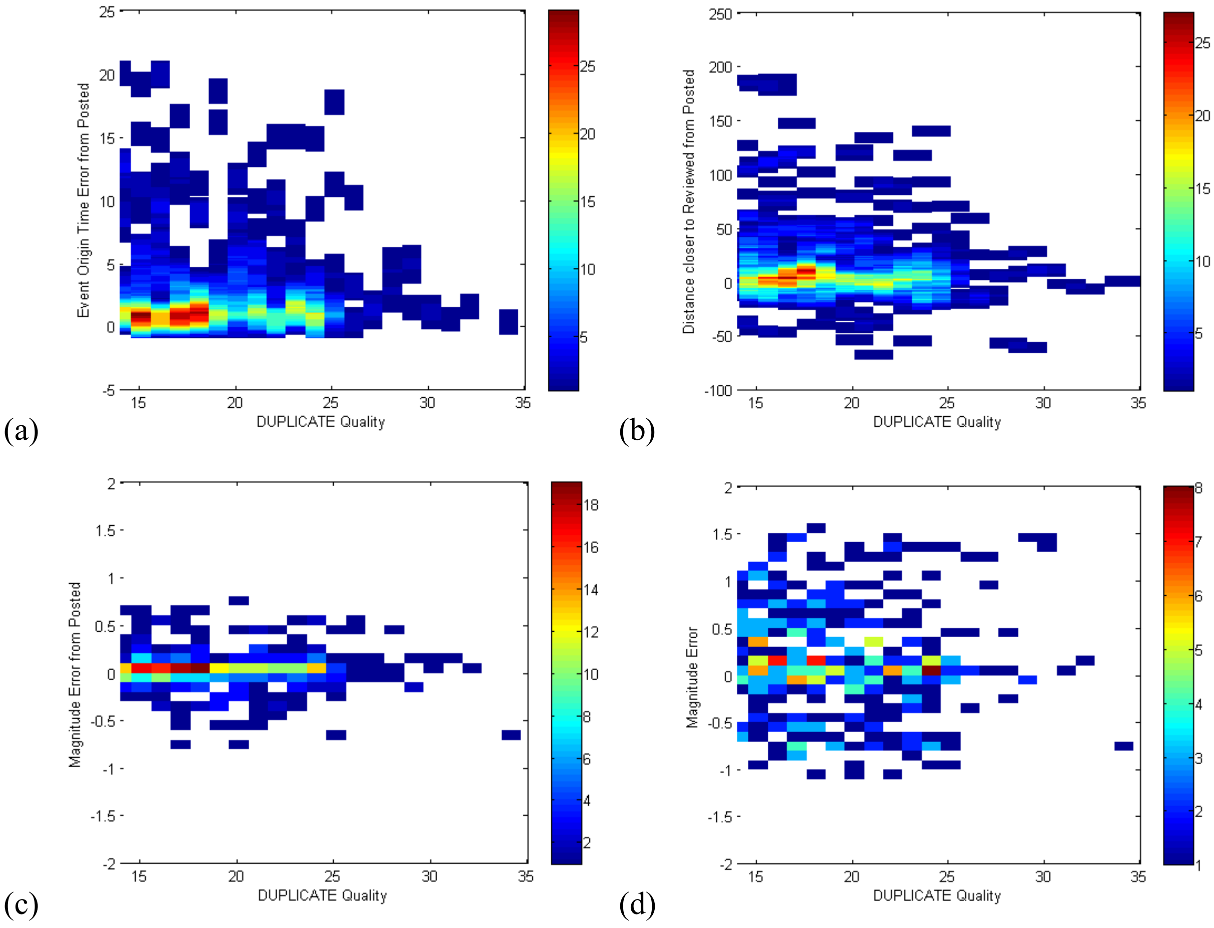


Fig. 21: Magnitude and location error distributions for duplicate solutions that were ignored after initial alert notifications were posted, as a function of Quality for the simulated automated notification messages as compared to the initial posted notification message. (a) Origin time error vs. Quality (b) Distance from reviewed epicentre vs. Quality (c) Magnitude error vs. Quality (d) Magnitude error vs. Magnitude. Colourbars indicate the number of individual duplicate solutions represented in each grid point.

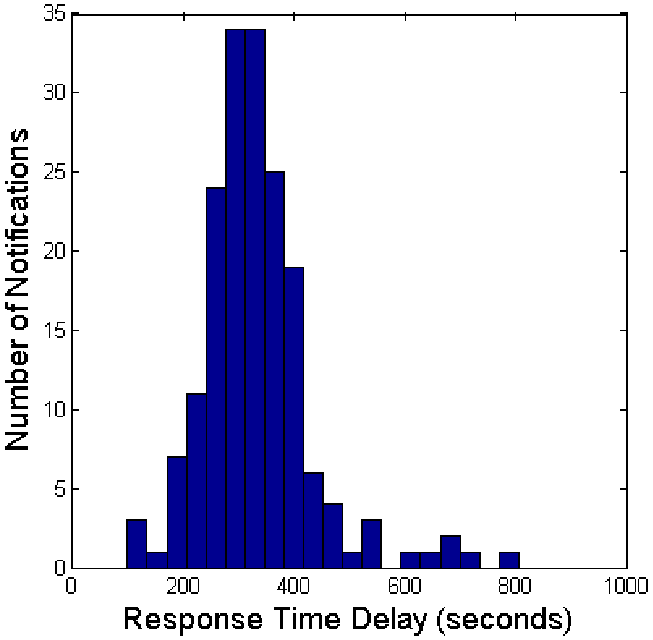


Fig. 22: Distribution of Twitter public notification posting delay times relative to the time of corresponding seismic events, as predicted by the 6 year AUTOLOC automated event solution simulation. Simulation predicts a mean delay time of 331.6 seconds, assuming that the time taken to apply the advanced solution filtering algorithm and submit the Twitter message does not significantly add to the delay.

(a)

CANADAquakes Earthquakes Canada
Automatic detection of a seismic event: magnitude 4.3 at 23:08 PDT on Aug 2 near BEAVER CREEK, Y.T.
3 Aug

English:

Automatic detection of a seismic event: magnitude X.X at XX:XX LTC on MONTH DAY near Regional township/location

(b)

CANADAseisme Seismes Canada
Détection automatique d'un évènement sismique: magnitude 4,3 le 2 aou à 23h08 HAP près de BEAVER CREEK, T.Y.
3 Aug

Français:

Détection automatique d’un évènement sismique: magnitude X,X le JOUR MOIS à XXhXX LTC prés de banlieue noire régionale/endroit

Fig. 23: Examples of an automatic public notification message posted via the social network messaging service “Twitter” in (a) English for CANADAquakes and (b) French for CANADAseisme accounts, with generic templates below. Note that LTC stands for: local clock time and is replaced by the specific time zone in which the event occurs.

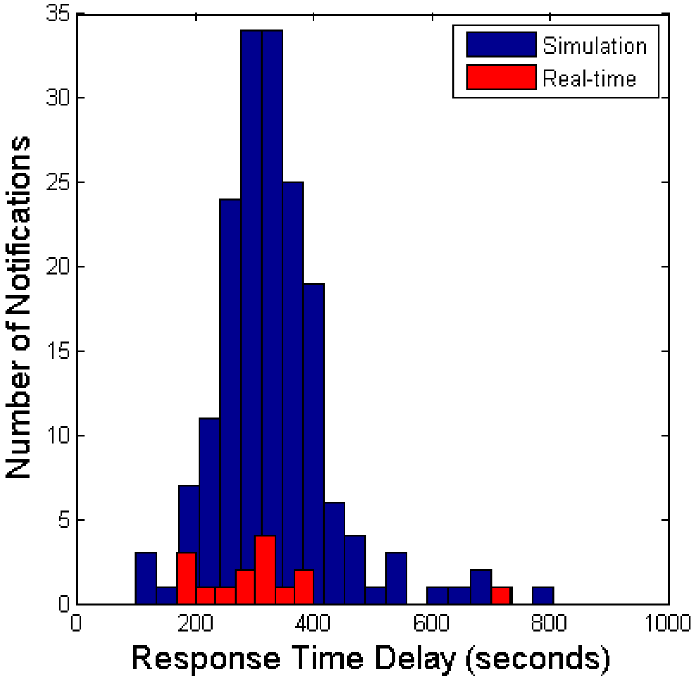


Fig. 24: Comparison of response times for the real-time application of the Twitter public notification message system to that predicted by simulation. Delay times correspond to the time between the occurrence of a seismic event and the posting of a public notification message to CANADAquakes and CANADAseisme. Simulation predicts a mean delay time of 331.6 seconds, while the current real-time system has a mean response time of 313.1 seconds.