Implementation and future challenges of seismotectonic mapping system for earthquake emergency response

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Abstract. Earthquake emergency response maps represent a set of geographical maps related to the seismic activity, geological tectonic background, assessment of economy and population losses, secondary disaster probability, as well as other information for emergency response and rescue. It requires producing these kinds of maps as quickly as possible after an earthquake. The seismotectonic map is one of the most important maps for earthquake emergency response. In this study, we developed an earthquake emergency response system to produce the map automatically. This paper introduces a intelligent system framework using spatial analysis, version management and web communication technology for emergency response, data maintenance, remote map revision, version management and statistics, which is not discussed in previous studies. The system based on MySQL, ArcGIS platform, python, and curl. It can detect the earthquake fast report proactive. When capturing the official report, it activated the response function module. The system achieved the first version mapping, fault data pushing, and earthquake catalogue updating by data-driven method automatically and rapidly. The mapping process can be divided into map layout and expert knowledge. The expert knowledge part can be divided into a geography map and explanatory note. The system performed well on the map layout and geography map. The explanatory note in the map, which introduces regional tectonics and expert knowledge, can provide the nearest fault's name, active age, and feature in the first version. Experts need to produce the second version manually. The fault data of 5°×5° area centred on the main shock is clipped and sent to a specified mailbox. The system added the earthquake parameters to the database. The result shows that this system finished these work well automatically and reduce the respond time and data maintenance time. If the earthquake causes serious calamity, seismogeology experts need to collect, summarize and analyse literature, document, and other information for successor versions and even predicting aftershock and disaster. It is practically needed to build a more intelligent and efficient system to produce a successor version of the map and push more knowledge in the future. The challenge in the future is to develop a more intelligent system to self-explain the seismotectonic map and push expert knowledge. This goal can only be achieved by processing...
expert knowledge data like regional lithology, tectonic structure, paleo earthquake, and historical earthquake in the database layer, data access layer, and business logic layer of the system.

**Key words** seismotectonic map, auto mapping system, earthquake emergency response

1. **Introduction**

   Earthquake is one kind of nature disaster with powerful destructive power. Seismic activity and damage have certain pattern. Is the strong earthquake main shock or front shock? Will more and stronger earthquake happen after the shock? What kind of secondary disaster will happen? These questions are relative to the seismic activity pattern, geological structure, disaster background, social economy, population distribution, secondary disaster probability and other factors in the region. For disaster reduction and relief, government needs information as soon as possible after a strong earthquake. A set of thematic maps is a visual and important form to show these information and disaster-inducing factors. These maps include knowledge-based maps like seismotectonic map and crustal movement velocity map, and inversion maps like focal mechanism solution and aftershocks distribution map. The seismotectonic map visually show the regional seismotectonic background and the possible seismogenic fault. It is required to output seismotectonic map in 2 hours after strong earthquake (M≥5.0) under the demand of earthquake emergency response system. It takes about 1 hour for cartography, data slicing, data packing, validation, and data pushing. Considering that cartographer is not always sitting in front of the computer, the response time of 2 hours is just enough. However, the work is not efficient enough.

   Auto mapping triggered by earthquake rapid report is an efficient technique for emergency response. U.S. Geological Survey (USGS) and China Earthquake Networks Center (CENC) both have rapid emergency respond system to produce seismic epicenter distribution map automatically. The rapid mapping method and technique is also used in earthquake disaster loss assessment, shake map, building damage estimation, casualty estimation, and landslide prediction[1-8]. Previous researches focused on the parameter calculation algorithm, technology platform or implementation. The rapid mapping system in this paper is not only focusing on auto-mapping, but also on automatically data updating, remote map updating and pushing. This paper mainly studies on function, framework, advantages and prospects of auto seismotectonic mapping system for earthquake emergency response. This study proves that data updates, version management, web communication and spatial analysis are also important in response efficiency, system maintenance cost, map revision and production updates. It is rarely studied in previous studies.

2. **Implementation**

2.1. **Platform**

   The emergency system in this paper based on ArcGIS and developed using ArcObjects, Python and curl. Mapping data is stored in ArcGIS format. System data like user information is managed in MySQL. ArcGIS is a GIS platform which has brilliant ability in mapping and GIS data management. ArcGIS can build data into a map with independently-developed technology of symbol library, label engine and map representation. The user-designed map layout, symbol, label etc, can be store in map template. The map template can be used to make a new map with same design if the mapping data schema is the same and only the data content is changed. A new map with same style and layout view can be finished only by changing data source. ArcGIS 10 and later version also provides data-driven mapping tool. Based on the configuration of map template, mapping data and a set of mapping area, the tool can move the output window and make a set of thematic maps in the same style. When strong earthquake occur, emergency personnel use prepared seismotectonic data and geography data to make a seismotectonic map by changing main sock location and mapping area. The map produced every
time must be in the same layout, symbol and style. ArcGIS map template and data-driven mapping tool is suitable for this application scenario.

2.2. Workflow

Once China National Seismic Network monitors a strong earthquake, it rapidly reports a message automatically. After a few minutes, CENC corrects the earthquake parameter error and publishes a formal report. The rapid report and formal report are published and pushed in many ways. For example, WeChat Official Account, Sina Weibo, E-mail, phone message and App. The response team members must make thematic maps once received the formal report. The seismotectonic map was made by prepared data and map template in an area of about \((3\text{~}5)\times(3\text{~}5)\) centred on the earthquake. The nearest fault’s name, feature and active age is also described in the map. This first version can help geological experts to make a preliminary estimate of seismogenic structure. In the circumstances of having new explanation of seismogenic structure, fault data relocated after shock, a newer version map must be made again. Emergency team members need to send it to experts and specific persons. In order to avoid errors caused by negligence, every version must be checked before formally reporting to superiors.

The current version of seismotectonic auto-mapping system achieved some work of the emergency response described in the previous paragraph. In addition, it can record the product version and output statistical products report. The system includes three work flows as follow: 1) auto-mapping of the first version, 2) remote modifying the description text on the map, 3) recording and calculating the productions. When receiving the earthquake report, remote request of modifying descriptor or statistic, the system deals the request with specific modules as shown in figure 1. These modules and functions in figure 1 will introduce in the next section.

![Figure 1. Workflow](image)

2.3. Module and function

2.3.1. Mapping. The system automatically detects earthquake reports regularly. Once the conditions for producing emergency maps are met \((M \geq 5.0)\), the system will automatically produce the first version of seismotectonic map based on pre-set map template. After receiving a request of modifying the description text of the map, the system will automatically produce the subsequent version of the
emergency map. This module achieves to output a map with name, legend, scale and description text automatically (figure 2). The description text includes earthquake’s location and magnitude, and nearest fault’s name, direction, active age and distance from the epicentre.

2.3.2. **Product distribution.** The system’s production includes JPG image version of the map, ArcGIS mxd file, shapefile format vector sections of faults in the 5°×5° region centred on the earthquake, earthquake parameter file, shapefile format vector file of earthquake catalogue updated by the system within one year, and statistical report of map products. All these productions can be distributed and pushed to certain person. This module has functions of data slicing, data packing and data pushing to certain mail.

2.3.3. **Authority management.** This module realizes the group and classification management of productions. The users can receive productions which they have right to get. For example, JPG image version of the map and shapefile format vector sections of faults are sent to emergency response members, while cartographer can receive all products.

2.3.4. **Data updates.** When the system produces the first version, the earthquake’s parameter is added to earthquake catalogue. This work is automatically also. So far, this module can add the earthquake (M≥5.0) automatically to the database.

2.3.5. **Version management.** The system can automatically tab the map product with version number and record the production time. Therefore, the system can provide the version information of the specified map.

2.3.6. **Product statistics.** This module can output a statistic report of earthquake parameters, product version and time.
2.4. Data

The data layers of seismotectonic map include main shock, fault, quaternary, earthquake catalogues, river system, administrative boundary and resident point. Main shock data is auto-generated based on the parameters fetched from CENC’s formal earthquake report. Fault data is an updated version of fault in “Seismotectonic Map in China and its Adjacent Regions (in Chinese)” [9], which scale is 1:4 000 000. The older version was reconstructed using Python and PyShp [10]. Then it was updated based on an active fault-surveying project from 2009 to 2016. In this project, nearly ~100 active faults were surveyed and mapped in the scale of 1:50 000. These data from the project are more spatially accurate and more reliable than the 1:4 000 000 one. This data is published on the website now. (http://www.neotectonics.cn/arcgis/apps/webappviewer/index.html?id=3c0d8234c1dc43eaa0bec3ea03 bb00bc) The earthquake data is the official earthquake catalogue published by CENC. River system, administrative boundary and resident point data are official data of National Geomatics Center of China (NGCC) on the scale of millions. The sources of mapping data is reliable. It ensures the integrity and accuracy of the final product.

2.5. System performance

The seismotectonic auto-mapping system was launched in September 2019 to produce real-time emergency response map for strong earthquake (M≥5.0). After three version from the beginning, the system have achieved all the works in section 2.3, output 51 map products, finished 36 times of data slicing and packing, and distributed products 51 times. There are only JPG format map files in the first 16 times, which were send to a specific QQ group. In the last 36 times, the system pushed different products in groups to specific users’ mailbox. Figure 4 and figure 5 shows the ArcMap document files and JPG image files of seismotectonics map from September to December 2019 for strong earthquake(M≥5.0) occurred in China. Figure 6 shows that the system distributed products through QQ and e-mail.
Figure 5  

a. JPG image files were sent to QQ group (the second message in the JPG image files)  
b. Products were pushed to users’ email. The first black column is e-mail names. The second gray column is the content. The last black column is the received date of e-mails.

This system greatly shortens the response time of earthquake emergency mapping. Let us take the Yangbe M 6.4 earthquake in Yunnan Province and Maduo M 7.4 earthquake in Qinghai Province as examples. Yangbe M 6.4 earthquake happened at 21:48 on May 21, 2021. The system fetched the formal earthquake report at 21:56, and get ready to make a map. The emergency response map was finished at 21:58. Slice vector fault data has been prepared and packed at 21:59. User received products at 22:01 via email (take QQ mail as example). Maduo M 7.4 earthquake happened at 2:04 on May 22, 2021. The system fetched the formal earthquake report at 2:14, and get ready to make a map. The emergency response map was finished at 2:16. Slice vector fault data has been prepared and packed at 2:17. User received products at 2:19 via email. The system response to these two earthquake and finished mapping and distribution within 15 minutes. It works more efficient than operation and mapping by hand. The auto-mapping also avoid the manual errors when modifying the map name, legend, explanatory text and other contents in the map.

3. Discussion and conclusion

Since the three version of the system launched, it auto-complete earthquake response for 11 times (Table 1). The average response time is 10.63 minutes. The shortest time is 8 minutes, while the longest time is 15 minutes. This response time is calculated form main shock happened to the time when the system has completed data distribution. (The response time mentioned below is as the same.) The system has completed emergency map-making, fault data slicing, earthquake data appending (M≥5.0), data packing and distribution. Suppose cartographer is sitting in front of computer all the time. The time of receiving formal report within 10 minutes after earthquake happened. When received the formal earthquake report, cartographer can respond immediately. It will take 30~40 minutes to output map, slice data, pack data and distribute products. After emergency response, it will take about 15 minutes to add new earthquake data to database. All these will take more than 1hour. Statistical results shows that the system reduced the response time to an average of about 10 minutes with a fast and efficient response ability.

Three factors decides the response time: CENC’s response time to release formal earthquake report, the interval time of fetching the CENC’s report, and the run time of mapping, packing and distribution. The CENC release formal earthquake report after main shock in 5 to 10 minutes through Sina Weibo. The interval time to refresh Weibo is limited. So the emergency mapping system fetched the report every 3~5 minutes one time. The run time of mapping, packing and distribution is about 3 minutes, which is relatively fixed. Because of the first two factors, the whole response time varies with them. If the CENC’s response time is shorter and fetching time is near report releasing time, the response time is shorter.

Table 1. The response time of the third version system in 2021

| No. | Eq.Date     | Eq.Time | Magnitude | Location                        | Finished time | Run time S(minute) |
|-----|-------------|---------|-----------|----------------------------------|---------------|--------------------|
| 1   | 2021/3/24   | 5:14    | 5.4       | Baicheng County, Aksu Prefecture, Xinjiang Province | 5:29          | 15                 |
| 2   | 2021/3/30   | 1:27    | 5.8       | Shuanghu County, Nagqu City, Xizang Province       | 1:39          | 12                 |
| 3   | 2021/4/16   | 16:06   | 4.3       | Lanzhou City, Tangshan City, Hebei Province        | 16:15         | 9                  |
| 4   | 2021/4/18   | 22:11   | 5.6       | Hualien County, Taiwan                  | 22:22         | 11                 |
| 5   | 2021/4/18   | 22:14   | 6.1       | Hualien County, Taiwan                  | 22:26         | 12                 |
The seismotectonic emergency map is usually used for analysing regional seismogeological structure. The region area of the map is about 90000 ~ 200000 square kilometres to show the whole earthquake-triggering tectonic system on computer screen. The map scale of 1:5000000 or smaller is enough. The fault data is in the scale of 1:4000000. The geographical base map scale is 1:1000000. The latitude and longitude of earthquakes are reserved to two decimal places. These data meet the requirement of map accuracy.

Software auto-mapping significantly improves accuracy. In tradition, cartographer manually typed in longitude and latitude of earthquake to make main shock data, and modified map name, legend, scale and explanatory text. Every operation by hand may cause map errors if cartographer missed something. However, software auto-mapping can avoid this type of errors. The function of remote modification and products distribution can help geologists and cartographers to maintain the same database. The different version of products will not vary a lot because different operator and software version.

The current version of the system performs well in emergency response of producing and distributing the first version map and later version with changed explanatory text. The result is kind of like CENC’s rapid report having auto-generated map and explanatory text. For some cases, the system processing capacity is limited. For example, only strong earthquake (M ≥ 5) is appended to database. The earthquake catalogues are not synchronized with those published by CENC. The system cannot distinguish aftershock from main shock if the magnitude of aftershock is larger than 5.0. Because of these system limitation, products are only pushed to emergency team member. All maps must be check by cartographer before submitted. The system cannot produce maps with relocated aftershock. These requirements will be refined in subsequent version of the system.

The seismotectonic map is used to study seismogenic structure and short-term earthquake disaster prediction in earthquake emergency. Only a small amount of fault information can be literalized by the system. The seismogenic structure explanatory text is still write by experts. For short-term disaster prediction, experts and geologists needs to find relative literatures, summarize and analyze collected data based on experience and knowledge. If this work can be done or assisted by the system, the system’s abilities in disaster reduction will be promoted a lot. This “smart” system should be developed in all system layers. For example, expert knowledge database should be expanded to lithology, tectonics, stress setting, historical earthquake, palaeoseismic and other seismotectonic knowledge in database layer. Intelligent query strategy and information extraction algorithm based on GIS and keywords should be developed in data access layer. It requires network search, real-time feedback and data updates algorithm in application layer. Once the system can automatically interpret maps and push data “smartly”, its ability to serve experts and government will be greatly improved.

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