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SeisGuard: A Software Platform to Establish Automatically an Earthquake Forecasting Model

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Abstract

SeisGuard, a system for analyzing earthquake precursory data, is a software platform to search for earthquake precursory information by processing geophysical data from different sources to establish automatically an earthquake forecasting model. The main function of this system is to analyze and process the deformation, fluid, electromagnetic and other geophysical field observing data from ground-based observation, as well as space-based observation. Combined station and earthquake distributions, geological structure and other information, this system can provide a basic software platform for earthquake forecasting research based on spatiotemporal fusion. The hierarchical station tree for data sifting and the interaction mode have been innovatively developed in this SeisGuard system to improve users' working efficiency. The data storage framework designed according to the characteristics of different time series can unify the interfaces of different data sources, provide the support of data flow, simplify the management and usage of data, and provide foundation for analysis of big data. The final aim of this development is to establish an effective earthquake forecasting model combined all available information from ground-based observations to space-based observations.

Keywords

SeisGuard Platform, Geophysical Observing Data, Electromagnetic Emission, Time Series Database, Spatiotemporal Fusion, Earthquake Forecasting Model

1. Introduction

Earthquake (EQ) is one of the natural hazards that give the most serious threaten on people's lives and their properties in the world. There are statistically 20 large earthquakes occurred globally with a magnitude equal to or more than 7 every year, which cause a huge personal injury and property damage: 96,000 people lost their lives during the 2008 Wenchuan M_S 8.0 EQ, 22,000 during the 2011 Janpan M_S 9.0 EQ, and 50,000 during two Turkey M_S 7.8 EQs.

So far, earthquake forecasting is still the Saint Graal (a beautiful dream) of seismology, but the study of possible earthquake precursors should be better regarded in the framework of fundamental geophysics more than in trying to guess the future [1] [2]. China is one of the most seismically active countries in the world. Destructive earthquakes pose a major threat to lives and properties almost in all of the Chinese territory. There has been a long run since earthquake forecasting is put into practices in China. Earthquake forecasting with organized efforts started in 1966 immediately after a major M_S = 6.6 earthquake in Xingtai area Hebei Province, about 300 km southwest to Beijing. Since then, extensive research programs on earthquake forecasting and application have been carried out to prevention and mitigation of earthquake disasters in China [3]. In the terminology of China Earthquake Administration (CEA), earthquake forecasting in China has been classified into long-term (decades), medium-term (years), short-term (months to weeks) and imminent (weeks to days, even hours) ones. More details can be found in reference [4].

Several traditional subjects have been developed to search for probable potential earthquake precursory information in China: seismology, geodesy, electromagnetics, ground fluid or earthquake hydrology/hydro-seismology. So far, concerned these subjects, local and even national monitoring network has been established. More than 1000 ground-based observing stations have been put into service in this network, including about 4000 observing points, over 10,000 measuring items in total. Among these ground-based observing stations in China, there are 200 geomagnetic stations, 90 geomresistivity ones, 100 gravity field ones, 580 fluid ones, and 300 deformation stations, respectively.

These observation data have been accumulated for more than two decades, and new observation data (at the terabyte level) are being produced continuously. As a scientific problem that has not yet been completely solved, earthquake forecasting lacks a sound theoretical system and is still in the early stage of scientific exploration. Geophysicists have been carrying out arduous exploration and research from various angles and methods one. Most of these research results and new analysis algorithms can only be limited to algorithm test and verification stage.

To search for possible EQ precursory information, the processing of geophysical field data is the key step. At the same time, supplementary data, such as geology, meteorology, and geomagnetic index data are also considered during this time. How to collect these vast data and process them effectively to attain probable spatiotemporal information prior to an impending event is one of the most important issues under consideration.

The general platforms, such as MapInfo, CorelDraw, and so on are usually used to read outside seismic time series data and map but without connecting the professional database. The GIS-based Seismic Analysis and Forecasting System (MapSIS) [5] is a professional software broadly utilized in earthquake forecasting. It has been developed since 2002 and can easily connect all professional database developed for all ground-based observing data but without working all information in the same sheet.

As the development of the Earth observation from space, global positioning system (GPS) satellites, electromagnetic experimental satellites and global navigation satellite system (GNSS) related now have also been utilized into the field of earthquake monitoring and forecasting, especially the successful launch of China Seismo-Electromagnetic Satellite (CSES, also called ZH-1) in 2018, which indicates that the space-Earth integration monitoring system in China has been primarily established and also gain the necessity that all kinds of ground-based data and Earth observation from apace data will be integrate together to comparatively process to pursue EQ precursors.

Under these conditions, SeisGuard, a software system for analyzing earthquake precursory data will be introduced in this paper. This system provides a unified platform framework to analyze and process seismic observing data from either ground-based observation or space-based observation by connecting various professional databases and integrally displays all useful information from different sources in the same sheet. So the data processing methodology including the primary design motivation, the framework and the main modulus of this system will be described in Section 2. In Section 3, the forecasting routine of a strong earthquake acts as a primary output of this platform. The present state of the system and its main improving strategies are in Section 4.

2. Methodology

2.1. Design Motivation

To meet the stringent requirements of earthquake forecasting work, the design philosophies of this system are as follows:

Friendly interface: SeisGuard adopts a visual interface, reasonable interaction logic, a unified interaction mode. So researchers can quickly grasp the usage of software.

Modular design: Its function is divided into multiple modules reasonably. Each module is functionally independent. Meanwhile each module can cooperate to complete a more complex function. It can improve system robust, reduce redundant design and code lines.

Unified storage: For spatiotemporal analysis, we have designed a unified time series database to store raw data, processed data and result data. It supports the free flow of data by nodes and levels, and provides support for spatiotemporal fusion analysis of data.

Data pre-processing and analysis: SeisGuard can simultaneously analyze time series from different subjects and unify the data processing mode.

Embedded GIS: By embedding GIS, SeisGuard bridges the gap between earthquake catalogue, geology, stations, auxiliary items and analysis results, enabling spatial fusion of data analysis.

Open access: This system is primarily designed for China Earthquake Administration but can be publicly used worldwide. The operation manual is also available.

2.2. System Designs

According to the level and logical relationship of each function, the system framework is designed as Figure 1.

The system framework is divided into five levels. The bottom level is unified time series database, and the unified data source interface provides support for data flow. Based on this, we can implement data analysis functions, and extract anomaly analysis of earthquake forecast and forecasting. Station tree plays a necessary role during the analysis process.

Two innovations of SeisGuard: 1) Supporting data flow: According to the characteristics of time series of observation data and the growing demand of data, we design a time series database and implement a unified data source interface. It supports the free flow of data among nodes and levels, similar designs have not yet been seen in the field of earthquake forecasting. 2) Station tree: To locate station quickly, the station tree is displayed in three lists (can also refer to Figure 3). Station list, point list and item list can be sifted by setting parameters. Innovative design on the interactive logic makes software operation convenient and efficient.

Figure 2 shows the main interface of this system. The interface is divided into four working areas presented within four blue rectangular respectively in Figure 2: system menu (top left area), data analysis menu (top right area), station list area (bottom left area) and data display area (bottom right area). These four areas use page controls for functional division uniformly. We can switch to the corresponding function by clicking page button.

In order to reduce the number of times users switch menus, the system functions and data analysis functions are divided into two menu items. This is a small innovation in the user interaction interface.

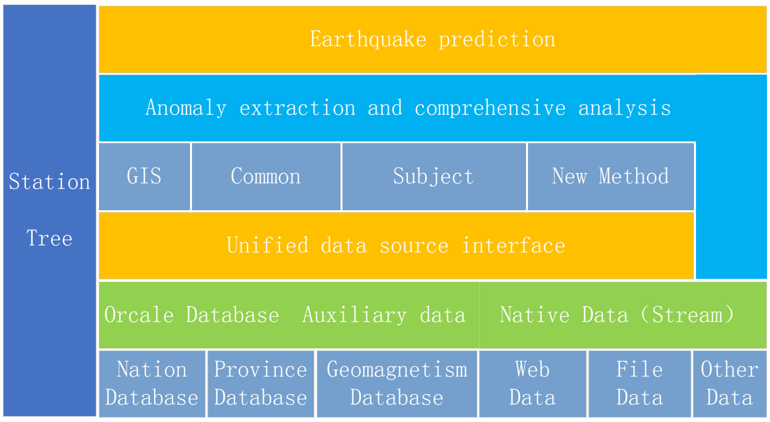


Figure 1. SeisGuard framework.

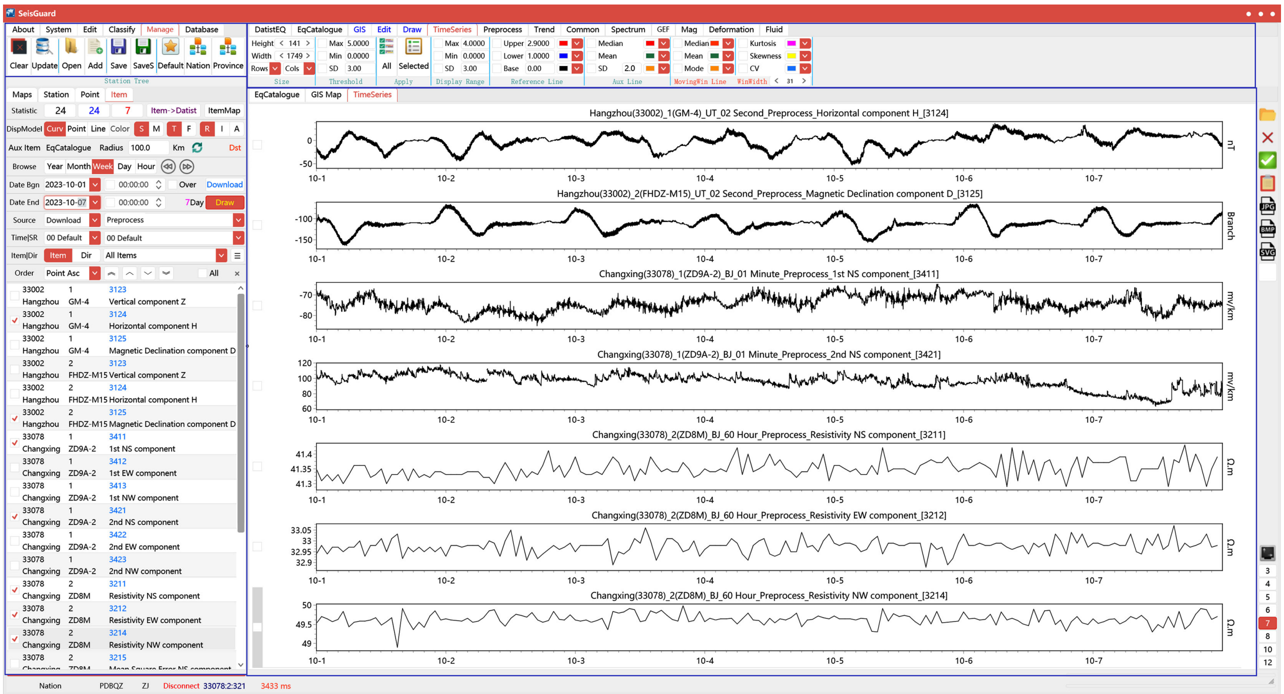


Figure 2. SeisGuard interface.

The system menu is located in the upper left area of the interface (**Figure 2**). It includes the management of database and station tree, as well as system configurations and other system functions.

The data analysis menu is located in upper right area of the interface (**Figure 2**). It includes menus for data pre-processing and analysis in various subjects, earthquake catalogues and GIS. The functions of spatiotemporal analysis are located in this area also.

The Navigation area is located in bottom left area of the interface (**Figure 2**), mainly including: The maps library view provides a shortcut to map data; the station list view includes station list view, point list view and item list view. Level by level selection can quickly sift the station list, point list and item list. Subsequent time series curve drawing and data analysis are based on the selected three lists.

The display area is located in lower right area of the interface (**Figure 2**). It provides display and interaction for earthquake catalogue, spatial distribution maps, time series curves.

2.3. System Module

Functional modules are roughly comprised of data storage, data analysis, graphics and interactive logic. The data storage module includes sub modules, such as data download, data format, and data flow. The data analysis module includes several sub-modules like data pre-processing, general processing, temporal and spatial analysis of various subjects. The graphics drawing module includes sub-modules like temporal and spatial graphics drawing, and map drawing. The interaction logic is divided into sub-modules such as station tree, temporal graph interaction and spatial graph interaction.

Due to a wide range of functions involved in the system, there are many modules. Even each sub-module also contains specific implementation functional modules with a large amount of data. The following details only some of the modules that help readers understand how the software is used.

China Earthquake Administration has constructed more than 1000 geophysics stations, including 4000 observing points (instruments), over 10,000 measuring items (components). How to locate the stations quickly becomes the first issue to be solved. After multiple attempts and failures, we ultimately adopt a hierarchical station tree scheme and divide them into three lists: station list, point list, and item list (Figure 3). Points and items will be located conveniently through step-by-step sifting.

In station list view, users can acquire their desired stations by two steps (refer to Figure 3(a)). Firstly, set the parameters of the provinces related and corresponding methods. Secondly, select the desired stations from the sifted list of stations. The points involved in the selected stations will be displayed in the points list.

In point list view, users can acquire their desired points by two steps, too (see Figure 3(b)). Firstly, set the parameters of instrument type and sampling rate. Secondly, select the desired points from the sifted list of points. The items included in the selected points will be displayed in the items list.

In item list view, users can acquire their desired items by two steps, too (see Figure 3(c)). Firstly, set the parameters such as begin and end time, data source, data type, time zone, data sampling rate and item (or directory). Secondly, select the desired items from the sifted list of items.

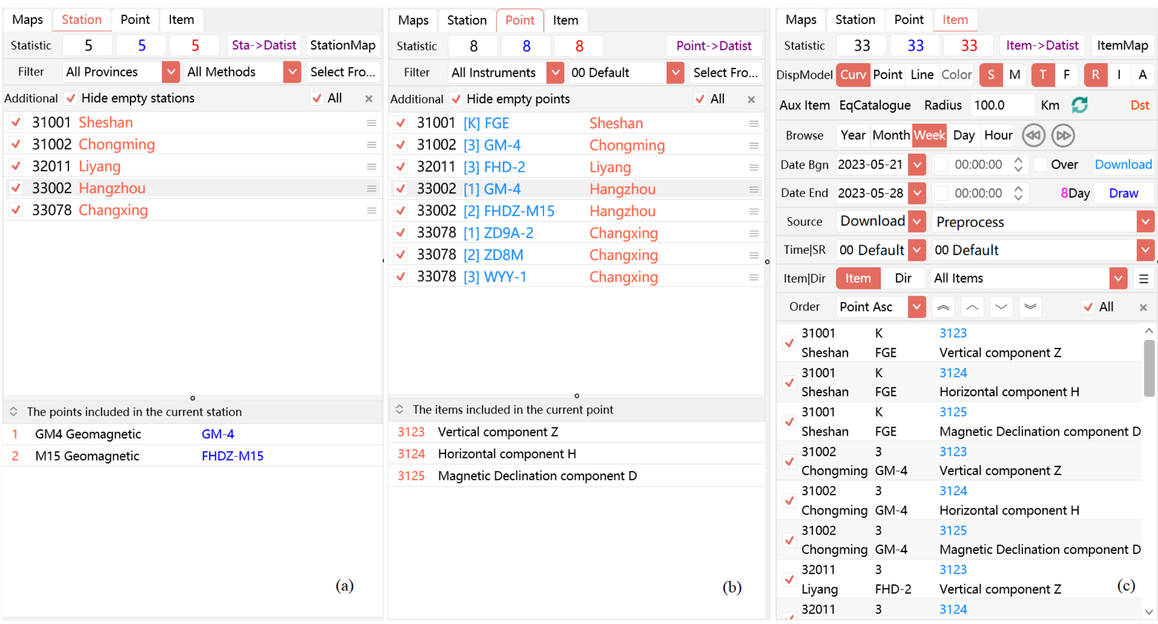


Figure 3. Hierarchical station tree scheme of the system. (a) Station list, (b) Point list, and (c) Item list.

For new stations that are not included in the station tree, users can manually add them. The Edit menu in the system menu area can be used to add stations. The add steps are as follows.

Step 1: Add a station. The indispensable information is station ID and station name. Other station information can be filled in as needed, such as longitude and latitude coordinates.

Step 2: Add a point. The indispensable information is point ID, point name, instrument type and sampling rate. Other station information can be filled in as needed also, such as longitude and latitude coordinates.

Step 3: Add items one by one. The indispensable information is item ID, item name, item unit and sampling rate. Other item information can be filled in as needed, such as item angle.

After selecting the required points and items, click Download or Draw button to download data or draw time series curves. Moreover, using relevant methods in data analysis menu, users can carry out data analysis. A unified interactive mode for stations, points and items simplifies the usage and improves the efficiency.

2.4. Data Source Fusion and Time Series Data Storage

At present, the main source of data is relation database. The China Earthquake Networks Center, each provincial agency and each subject usually have their own dedicated databases. These databases are almost identical in scheme and the differences only exist in the Blob field.

Generally, observation data is stored as a string in the Blob field. In the case of second sampling or higher sampling, table query efficiency will significantly decrease due to the Blob field. Some databases compress data before storing them, which brings significant efficiency improvements. However, compatibility issues arise for differences in compression format. In SeisGuard, data format has been mapped to the IP address of the database, so data can be automatically identified and responded to during data download.

The raw data observed by instruments have different formats. We have made corresponding matching, so different format data can be imported into SeisGuard too. In addition, the geomagnetic index on the website can also be imported into SeisGuard. If the file format used is proprietary and not supported in SeisGuard, users can contact author to add the format.

Through the methods above, we integrate various data such as databases, instrument observation data files, and geomagnetic indices into SeisGuard.

Unified data source only solves the problem of data acquisition. The storage of time series data not only involves the storage of observation data, but also involves the storage of intermediate data during processing and the storage of processed result data. The relationship between the observation data and its processing results is not a one-way path, but a multi-path dependent network structure. Therefore, it is necessary to design a unified architecture to store all types of data, satisfying the continuous growth of time series data and supporting the demand for data flow.

After practical testing and optimization, we have designed and implemented the data storage architecture over three years. The physical structure of storage architecture is based on file directories and HDF format. We have designed and implemented an innovative time series database (TSDB4EQ) to store the time series data observed by stations. The physical structure of the database consists of hierarchical directories and HDF files, and its search logic based on station information tree is built-in in SeisGuard. The advantage of this implementation is that there is no need to install a database, and performance of search will not decrease even if the data volume is big.

The depth of the directory structure is seven levels. It includes RootDir, Station, Point, DataKind, TimeZone, SampleRate and Item (**Table 1**).

RootDir is the first level directory, and it includes three types of data: Download, Processing and Result. The Download directory is mainly used to store raw data and pre-processed data downloaded from database. The Processing directory is used to store temporary data during processing. The Result directory is used to store final results. In addition, for the convenience of users, each subject has its own independent directory structure.

Station is the second level directory. Its naming method is "StationID_StationName". StationID and StationName are determined by the selected stations in station list view (**Figure 3(a)**).

Point is the third level directory. Its naming method is "PointID_InstrumentType". PointID and InstrumentType are determined by the selected points in point list view (**Figure 3(b)**).

DataKind is the fourth level directory. The name of this level directory not only includes "! RawData" and "Pre-processedData". Users can also use customized names, such as FFT spectrum, daily variation amplitude, and other names. Where "!" is added before "Rawdata". It is not only to make raw data directory appear first when displayed, but also to remind users not to modify the data in this directory.

Table 1. Local data store directory structure.

Level	Classification	Name
1	RootDir	Download or Processing or Result
2	Station	StationID_StationName
3	Point	PointID_InstrumentType
4	DataKind	RawData or Pre-processData or CustomDir
5	TimeZone	UT or BJ or LT or ZT
6	SamplingRate	Second or Minute or Hour or Day or other
7	Item	ItemID or CustomDir

TimeZone is the fifth level directory. It includes four types: UT (International Time), BJ (Beijing Time), LT (Local Time) and ZT (Zone Time). It is mainly used to store observation data or conversion data in different time zones.

SamplingRate is the sixth level directory. Its naming method is "SamplingRateCode_SamplingRateText" (such as: 01_minute value), users can not only understand the sampling rate, but also know its numerical code.

Item is the seventh level directory. The directory adopts "ItemID" or "CustomDir" naming method (**Figure 3(c)**), where the naming of customized directory is determined by the specific data analysis and processing module.

The SeisGuard stores data in HDF format can identify and read the data onboard some satellites, such as the CSES. The data of each item is stored in their respective directory (ItemID or CustomDir). HDF format not only satisfies the storage of downloaded data (time series), analysis results (time series, frequency domain, etc.) as well as auxiliary observation data, but also stores necessary additional information. The daily observation data is stored as an independent dataset in an HDF file. The naming convention for the dataset is YYYYMMDD, where YYYY is year, MM is month, and DD is date. Data download is usually stored in a one-dimensional array in a dataset. Processing data or result data can be stored in a dataset as a one-dimensional or two-dimensional array. Additional information includes relevant parameters of stations and data structures, such as Station_ID, Point_ID, Item_ID, begin and end time, sampling rate, data type, etc.

While designing time-data storage architecture, HDF files were used to store temporal data only, without using its hierarchical structure. The advantages of this design are as follows: 1) Convenient for SeisGuard software itself and users to locate stations, points, and items. 2) Avoid disorderly growth of HDF file size, as HDF format cannot completely delete the occupied data space. 3) The separation of item data files can improve parallel access efficiency and reduce access conflicts among multiple threads.

In summary, time series storage architecture enables unified storage and management of observation data. SeisGuard utilizes built-in locating logic, thus forecasting researchers only need to focus on data usage, eliminating many unnecessary intermediate operations.

2.5. Time Series Curve Drawing and Data Analysis

In order to meet the requirements of more complex time series curve drawing and support the related functions of data flow, the software provides many display customization functions. The software provides four sets of mode switch buttons for drawing of customized time series curves.

Time series curve type pattern group: diagram types include curves, scatters, volumes and colors. See **Figure 4** for details.

Diagram of curves is mainly used to draw time series of observing data (**Figure 4(a)**). The diagram of scatters is for drawing azimuth time series data, which is more conducive to analyzing the clustering phenomenon of angles (**Figure 4(b)**). And the diagram of volumes is for the drawing of M-T (magnitude-time) diagrams (**Figure 4(c)**), to compare and analyze earthquake sequences with observation data and their processing results.

Single or multi-graph pattern group: In single-graph pattern, multiple curves will be drawn in a single frame. In multi-graph pattern, only one curve will be drawn in each frame.

Time or frequency pattern group: In time pattern, abscissa of the data curve is time. In frequency pattern, abscissa of the data curve is frequency.

Real part, imaginary part, or amplitude pattern group: In real part pattern, the curve is the real part of observed data or spectral data. In imaginary part pattern, the curve represents the imaginary part of spectral data. In amplitude pattern, calculate the amplitude of spectrum first, and then draw the curve.

The above four drawing modes can be combined with each other. Users can draw their desired data curves based on the situation of data source.

Data analysis is the core function of SeisGuard, based on station tree and data flow, the data analysis process becomes very simple. The data analysis process usually consists of four steps: 1) Download the data, before data analysis, it is recommended to download data first. Although it is possible to connect directly to the database, there are issues with network connection stability and IO efficiency. 2) Pre-process the data, the main goal is to eliminate peaks and steps in data. 3) Prepare data, such as mean value, time zone conversion and so on. 4) Analyze data, select the analysis method and set parameters to analyze and process the data of selected points and items.

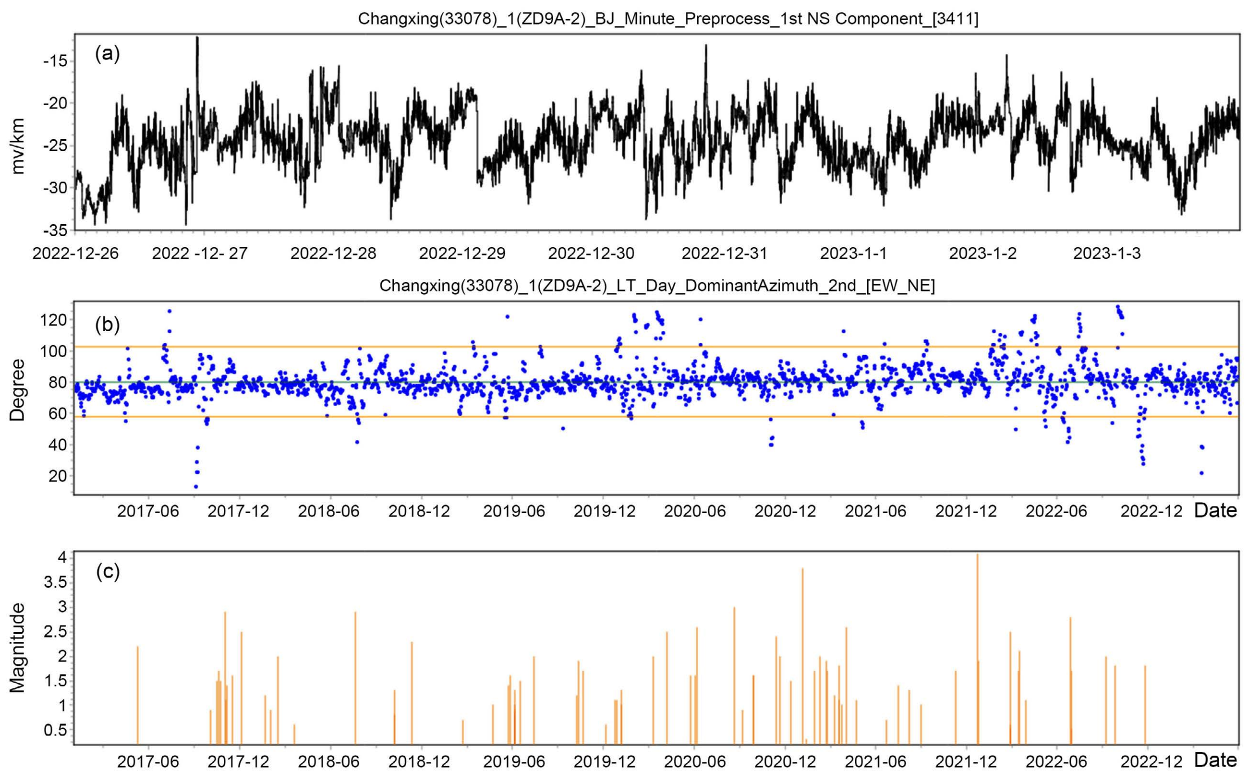


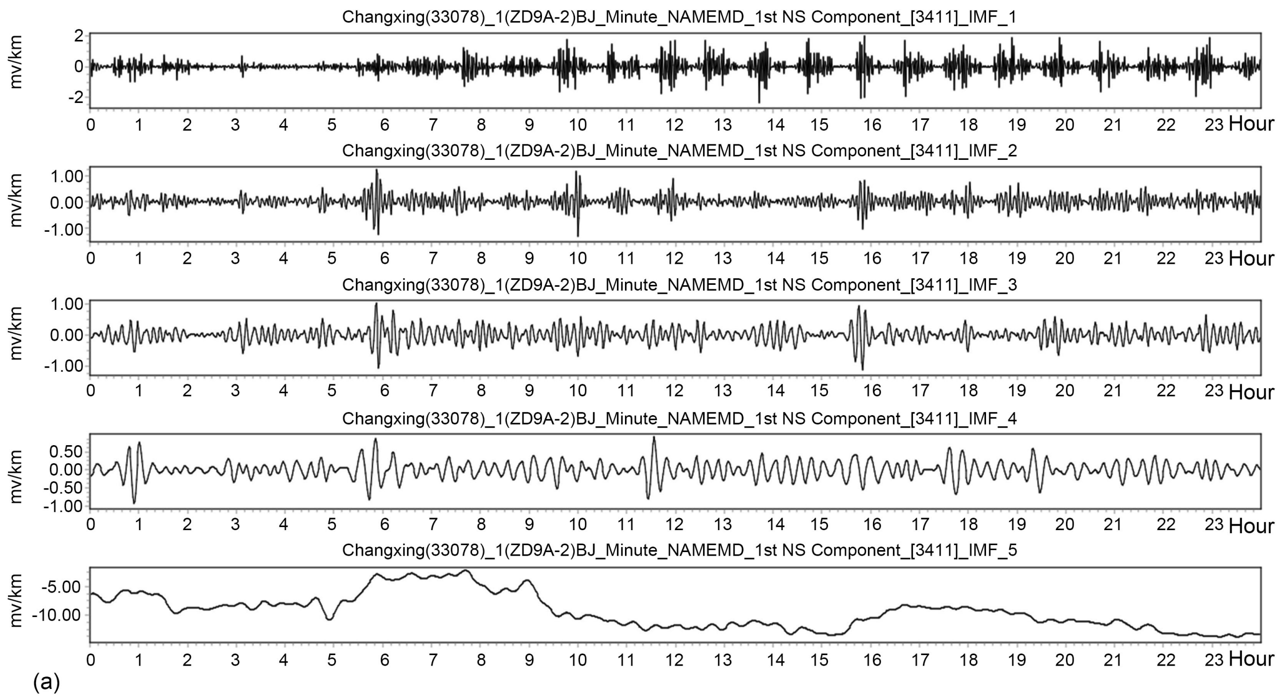
Figure 4. Diagram of curves. (a) Time series of electric field data at Changxing station, (b) Scatters of azimuth time series data at Changxing station, and (c) M-T series.

Data analysis methods cover pre-processing, general processing, and subject specific processing methods. Pre-processing methods are typically used to eliminate peaks and steps. General processing methods are usually used to calculate mean or difference, extract moment values, decompose signals, convert time zone, etc.

SeisGuard provides analytical methods for electromagnetics, geodesy, ground fluid or earthquake hydrology/hydro-seismology. The geomagnetic field processing methods include daily ratio, extreme value ratio and polarization analysis, etc. The geoelectric field processing methods include the dominant azimuth, mean and difference. The geodesy processing methods include barometric correction, apparent azimuth, speed analysis and signal decomposition, etc. The ground fluid processing methods include speed analysis, signal decomposition, mean and difference, etc.

Signal decomposition adopts a noise-assisted multivariate empirical mode decomposition (NA-MEMD) algorithm, which can synchronously decompose multiple observation components. As a universal signal processing algorithm, NA-MEMD algorithm has a wide range of applications and can be used for deformation, fluid, and electromagnetic fields.

The observation of earthquake precursors generally involves multiple components. EMD method is widely used for data analysis of earthquake precursors [6] [7] [8], but it only can decompose single component signals. When using EMD algorithm to decompose multi-component signals, the IMFs components from data components are different. NA-MEMD method avoids the above drawbacks and can perform synchronous decomposition on multi-component signals, see **Figure 5** for details.



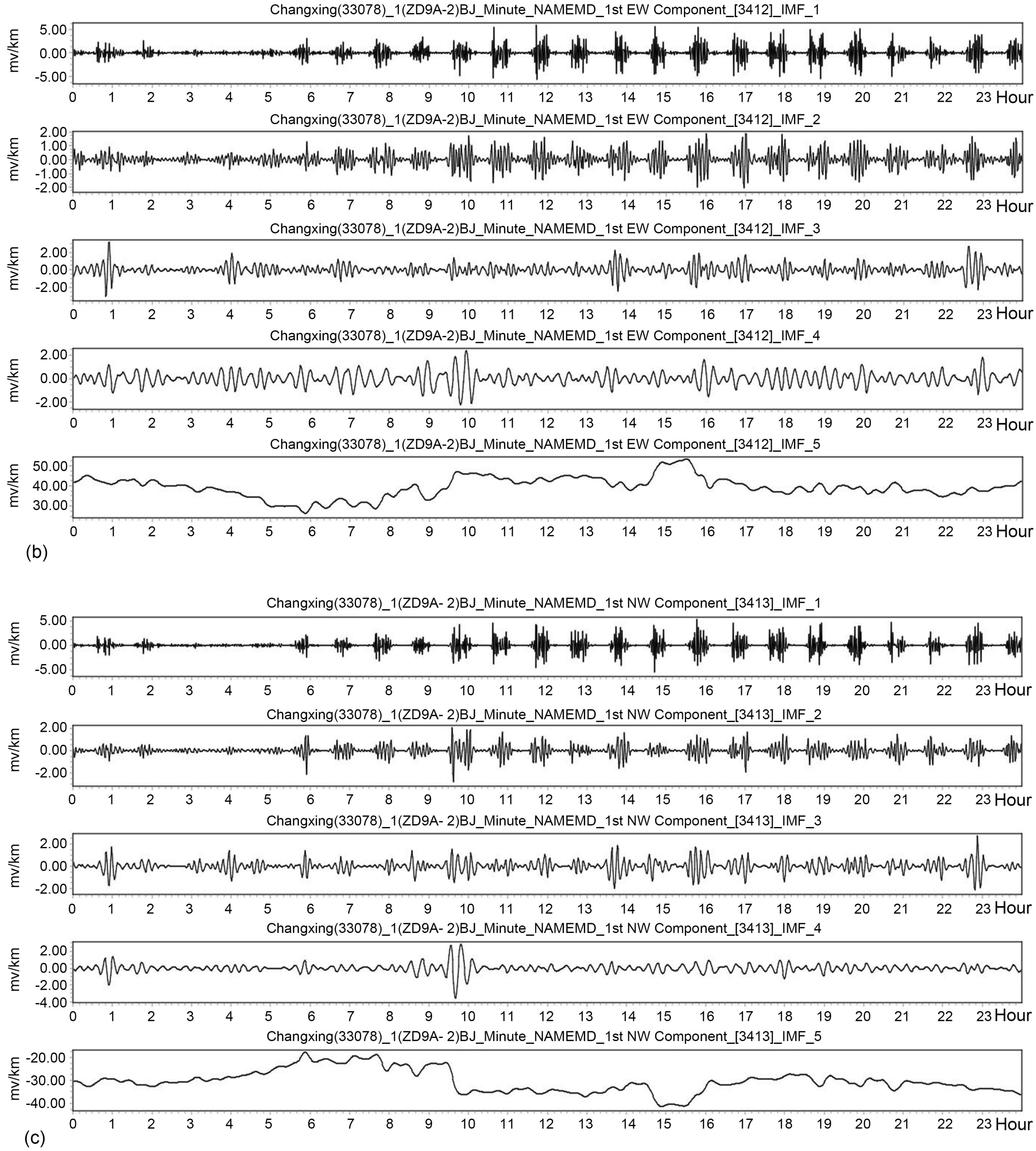


Figure 5. Decomposition results on three components of (a) NS (north-south), (b) EW (east-west), and (c) NW (north-west) of first observation system.

Of course, the flexible design of SeisGuard system framework allows to customize new analysis methods quickly. Based on station tree and data flow, the addition of any new method is extremely simple and convenient. The software development work only needs to consider the implementation of algorithms, other functions will be implemented by the software framework.

2.6. GIS Function

GIS module is embedded in SeisGuard. Its implementation is based on TatukGIS Developer Kernel (DK). DK is a professional grade GIS library used by customers in a wide range of industries to develop custom GIS applications [9]. DK supports dozens of vector and grid file formats, and users' existing ArcGIS and Mapinfo map data can be imported.

GIS module has implemented mapping of stations, earthquakes, geology, analysis results and other spatiotemporal data (**Figure 6**). Users can conveniently draw spatial distribution maps of stations, earthquakes, tectonics, rivers and lakes, roads and DEM in their respective layers.

In general, users can use earthquakes to select stations on the map and feed back into the station list. Then select the required points and/or items for data analysis, and the analysis results can be drawn on contour and pseudo color map layers. After integrating multiple element information on spatial distribution map, it provides convenience for users to conduct anomaly comprehensive analysis. The entire analysis process is completed in SeisGuard, avoiding tedious process of data format conversion, so that hours or even days of work can be completed within minutes.

3. Primary Forecasting Model of the 8 January 2022 Menyuan M_S 6.9 Earthquake

In this section, we attempt to present a retrospective study of the total process of

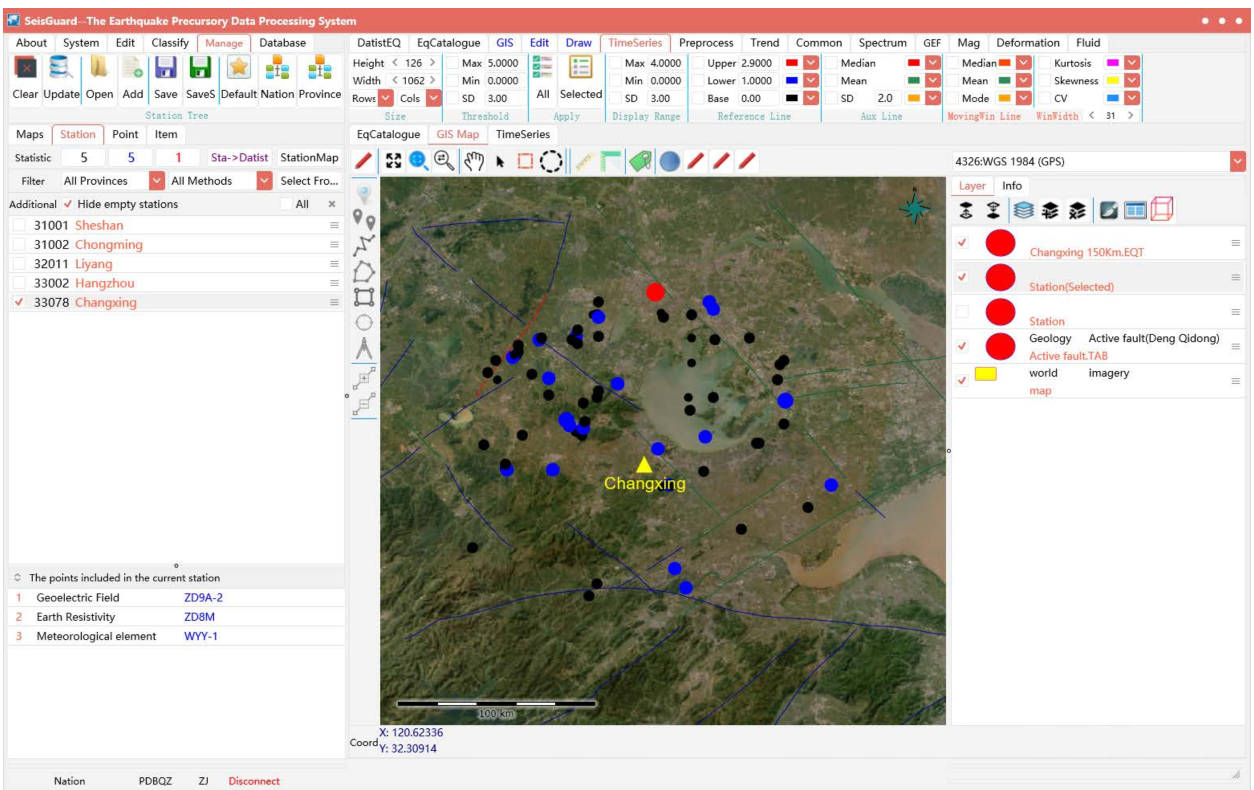


Figure 6. GIS module demonstration.

extinguishing the probable precursory information of the impending Menyuan event on January 8 2022 in order to validate the effectiveness of the output from this system.

In daily tracing of observing data on earthquake precursory subjects of geodesy, electromagnetics, ground fluid or earthquake hydrology/hydro-seismology, the system can timely scan time-serious of all items concerned. The item will be labeled in red once its variation reaches a specific number, for example, up to 1% for resistivity. An Area with a collective various subjects or stations in a specific time period will be considered seismic hazard zone. Sometimes, a seismic hazard zone is also specified by a special data processing method like polarization method on geomagnetic observation.

Variations of fluid observation have been firstly registered at the Menyuan station at the middle in September 2021 by the system and the number of anomalous stations increases to 8 till the beginning of December. Variations of time-serious of four stations among them have been presented in **Figure 7**. These stations are automatically recognized by the system and labeled in the map with black triangles in **Figure 8**. One can see that these stations locate collectively in north-west area of Qinghai province. Therefore, this area can be considered as one seismic hazard zone and will be traced in the following days.

As a routine geomagnetic data tracing method, polarization method had been primarily developed by Hayakawa *et al.* in 1996 [10] and then it has been gradually utilized to derive possible precursors associated with seismic activities [11] [12] [13].

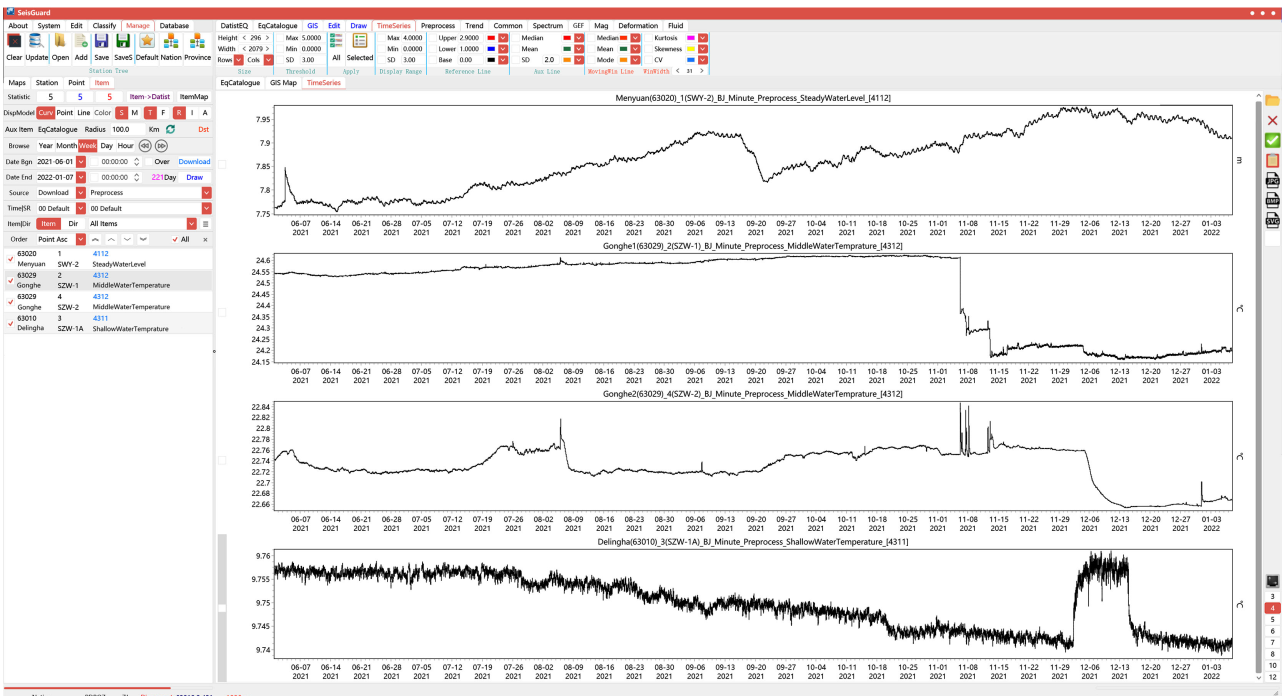


Figure 7. Variations of time-serious of four fluid observing stations of Menyuan, Gonghe1, Gonghe2 and Delingha from the top to the bottom.

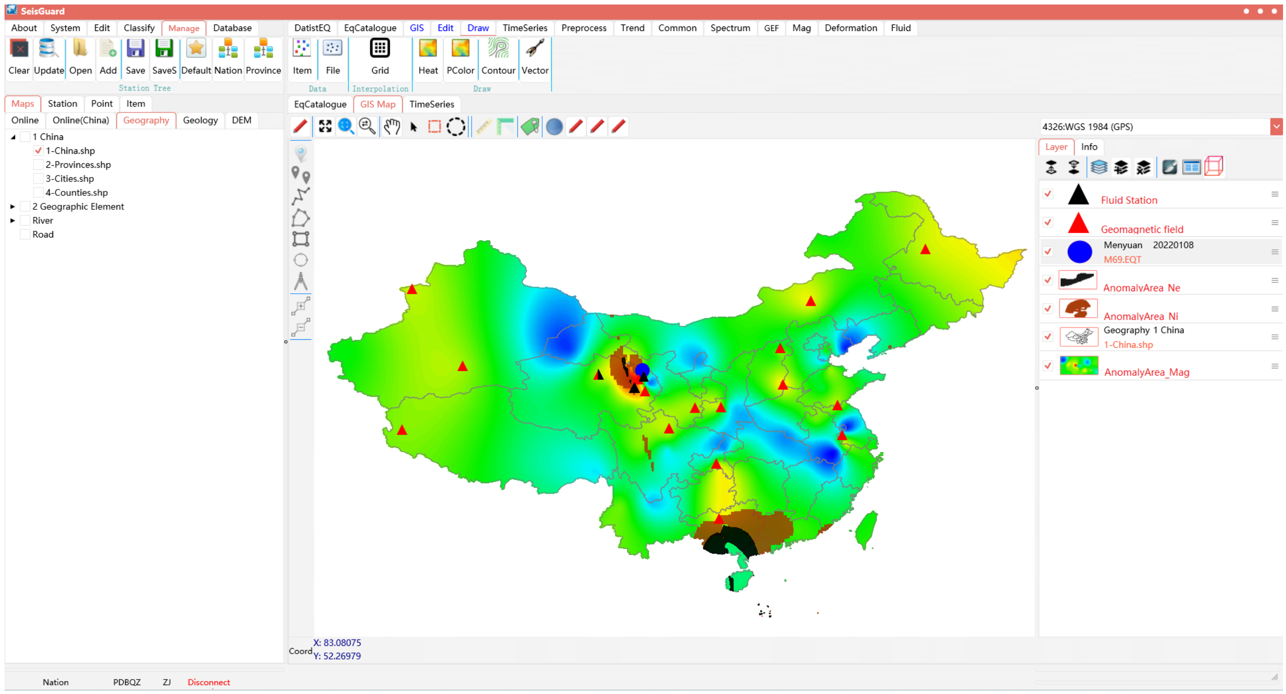


Figure 8. A primary earthquake forecasting model formed by precursory information and the impending earthquake. The mid part of the figure shows the distributions of integrated anomalous information and the earthquake event. The legend lies in the right part: ground-based anomalous fluid stations with black triangles, geomagnetic polarization anomaly in jet color and its related stations with red triangles, space-based CSES ionospheric variations of electron density in black and ion density in brown and the Menyuan M_S 6.9 earthquake is labeled by a blue dot.

The polarization on geomagnetic vertical component can strengthen anomaly signals from the hypocentral area by controlling signals from outside sources. Its mathematics formula is:

$$Y_{ZH} = \left|\frac{Z(\omega)}{H(\omega)}\right|, \quad H(\omega) = \sqrt{H_X^2(\omega) + H_Y^2(\omega)} \tag{1}$$

Here, $Z(\omega)$ is spectral amplitude value of geomagnetic vertical component, $H(\omega)$ is of geomagnetic horizontal component, $H_X(\omega)$ is of geomagnetic north-south component, and $H_Y(\omega)$ is of geomagnetic east-west component. Geomagnetic unit is nT and ω is circular frequency.

However, previous investigation using this method mainly on a single station and less regional anomalous information has been attained. This method has been performed on regional geomagnetic stations and a relationship between anomalous area and impending seismic events has been primarily established since 2019. Data processing steps are the following:

1) Second recording of three geomagnetic components Z, H_X and HY for each day are divided into 96 segments with as interval of 15 minutes and then Fourier spectral amplitude has been calculated for each vertical vector and horizontal vector, respectively.

2) Averaged polarization values of all points within 5 - 100 s (0.01 - 0.2 Hz) everyday are considered to be daily polarization value. Fourier fit has been con-

ducted on daily polarization values for at least each half year to get annual variation curve and the mean square deviation of residuals has also been calculated at the same time.

3) Polarization value for each frequency point is abstracted by the annual variation curve and all residuals beyond 2 mean square deviation are kept to form H_{ZH1}. Five-day averaged value for polarization values could be done if polarization anomaly for each station occurs in different time.

4) Variation range of H_{ZH1} for each station may be different due to different equipment or monitoring environment. Thus, normalization calculation on H_{ZH1} can be performed at this time to avoid the influence from different observing stations:

$$Y_{ZH2} = \frac{Y_{ZH1}}{2\sqrt{\sum_{j=1}^{n}\left(\left(Y_{ZH1}\right)_j - \overline{\left(Y_{ZH1}\right)_j \ldots \left(Y_{ZH1}\right)_n}\right)^2}} \quad (2)$$

Here, Y_{ZH2} is called normalized zero polarization value. Kriging mathematical interpolation is done for all non-zero polarization values in a specified area, such as the total Chinese area, and then we can attain 2D distribution of polarization values.

Regional polarization anomaly has been registered prior to the 2017 Jiuzhaigou M_S 7.0 earthquake and the 2017 Milin M_S 6.9 earthquake [14] [15]. Now this method has also been adopted in this platform to detect possible earthquake precursory information from geomagnetic monitoring.

The system processes a previous daily national wide geomagnetic observing data and gives a map of anomalous polarization values. It has been shown that there are 17 anomalous stations out of all 77 stations on October 27, 2021 and **Figure 8** present the 2D distribution of these anomalous values with jet color and anomalous stations are labeled with red triangles.

However, Feng *et al.* [16] have statistically investigate the relationship between polarization anomaly and occurrence time of earthquakes during 2015-2020 in west China and their results show that the occurrence probability of an earthquake with a magnitude more than 6 in the area near the threshold beyond 0.2 increases within a half year and the magnitude of the impending event positively relates with the anomalous area. We still do not know the right time of the approaching earthquake although the polarization anomalous area locates high coincidently with that of fluid anomaly.

Fortunately, Earth observation from satellites has rapidly developed due to its advantages of fast-speed, large-scale, and high-resolution results, especially for areas with harsh natural conditions. As a conductive part of the air, ionosphere is unexpectedly sensitive to seismic activities [17]. Abundant case and statistical investigations have shown that the seismo-ionospheric influence occurs within two weeks, especially 5 days, before the impending earthquakes in the epicentral areas as well as in their magnetically conjugated areas [18] [19] [20] [21] [22] but its seems no specified near relationship with the impending event: ionospheric influence induced by the 2008 Wenchuan M_S 8.0 EQ locates at 15˚ - 20˚ southeast its epicenter [23] [24] [25] [26] and shifts toward equatorward due to equatorial ionization anomaly (EIA) in low and equatorial latitudes [27] [28].

The successful launch of the China Seismo-Electromagnetic Satellite (CSES, also called ZH-1) on 2 February 2018 significantly improves the Earth-space monitoring of seismic hazards. Now data of ion density and electron density have been stored in this system and the system outputs a contour map weekly with Kp index less than 3 to avoid the solar effect. A threshold is also set but it can be changed with accordance to control the ionospheric background variations. The anomalies are more reliable if they appear on two parameters at the same time in near areas. The system can give an alarm is the relative variation is up to 20% and the effective period of an ionospheric anomaly is two weeks. Finally, a 3D map can be formed automatically by the system.

Ionospheric abnormities have occurred at the week during December 28 2012 to January 3 2022 on electron density (Ne) and ion density (Ni) and they have appeared simultaneously in the same day of December 28 2021 when the observing orbits are examined one by one. These anomalies have been integrated with ground-based fluid anomalous stations and geomagnetic polarization anomaly to form **Figure 8**.

As shown in **Figure 8**, all kinds of abnormities collectively appear in the similar location of the north-west area in Qinghai province. The geomagnetic polarization anomaly and fluid anomalous stations mainly indicate the possible location and the magnitude and the ionospheric abnormity indicates an urgent in time for the impending earthquake. The Menyuan M_S 6.9 earthquake occurred on January 8 2022, 11 days after the appearance of the ionospheric abnormity, and its geographic latitude and longitude are 37.77˚N and 101.26˚E, almost with the same location as the Menyuan fluid station (this event is labeled in a blue dot in **Figure 8**).

During this period, only data concerned with ground-based geomagnetic and fluid observations and space-based plasma density from the CSES satellite have been utilized but it can provide a simple framework of an earthquake forecasting model in the future in this platform. Combined with various observing data, as well as supplementary data, this forecasting model will become more and more effective as this system gradually improves in the future.

4. Conclusions

China is one of the countries facing huge seismic hazard. Ground-based multidisciplinary earthquake monitoring networks have been well constructed after a long-term development. As the Chinese CSES satellite has been launched successfully on February 2 2018, a promising way to improve our earthquake forecasting level is to combine ground data analysis with satellite Earth Observation (EO). Therefore, an effective multidisciplinary compatible platform will be a significant tool during this time. SeisGuard, a platform for analyzing earthquake precursory data, has been developed as the times require.

So far, SeisGuard has achieved most framework designs, providing a simple, efficient, and easy-to-use software platform for analysis and processing of earthquake precursor data. With further development, SeisGuard will implement more algorithms, and its stability and performance will also be gradually improved to establish an effective earthquake forecasting model.

It has been eight years since SeisGuard was originally developed in 2016 and a huge achievement has been attained already, especially on the basic framework designs. The code of its architecture has been basically stable, but there are still some bugs that need to be fixed; the functionality of GIS is still weak at present and needs to be expanded and improved; the CSES satellite data have been input into the system but lacking necessary processing and exhibiting methods; some new processing methods in geophysics, such as electromagnetic earthquake forecasting model and tidal earthquake forecasting model that we are developing, will be gradually added in the following development. The improvement of this system-SeisGuard is still being on the way.

Additionally, SeisGuard V1.0 has been authorized by the National Copyright Administration of the People's Republic of China under No. 2020SR1907598 and it can be used freely.

Author Contributions

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Institutional Review Board Statement

Institutional review board approval of our institute was obtained for this study.

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Data Availability Statement

The software and its operation manual can be access by the e-mail: 13336198523@126.com.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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