Visual Analysis of Ionospheric Disturbance Hypotheses about Earthquake

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Abstract

In seismic research, a working hypothesis is that ionospheric disturbances is related to lithosphere activities such as earthquakes. Domain scientists are working to find patterns from certain ionospheric attributes related to seismic activities. However, to find patterns from large amount of data is challenging, since it is hard to extract, formulate and search patterns. To address on these challenges, we developed an interactive system which supports the workflow of seismic research on ionospheric data. Our system can assist domain scientists to propose and examine hypotheses on relationships between ionospheric disturbance and seismic activities.

1 Introduction

A working hypothesis in seismic domain is that ionospheric disturbances has association with earthquake activities. DEMETER satellite is the first satellite devoted to the study of the ionospheric disturbances related to seismic and human activity. Analysis on DEMETER data can help domain scientists understand spatiotemporal correlation between seismic events and ionospheric disturbances.

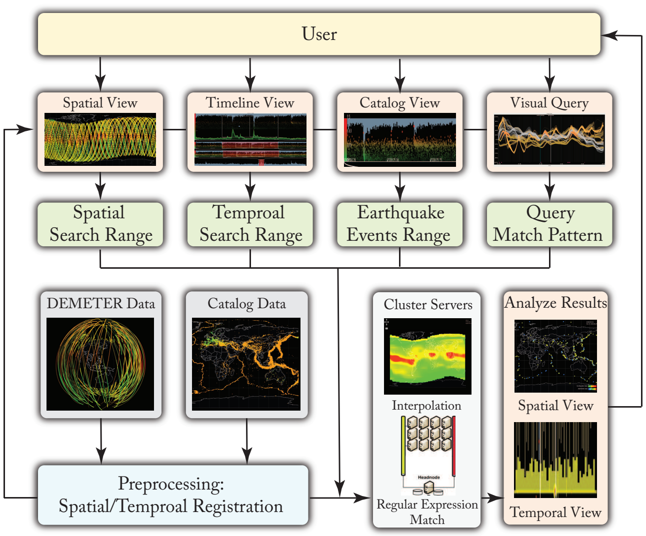

Figure 1: Our system supports workflow from seismic domain which enables scientists to investigate the relationships between earthquake occurrences and ionospheric disturbances.

In this work, we present a query-based visual analysis system that enables interactive visual query on earthquake catalog data together with the satellite-based DEMETER data. Users are able to extract patterns of ionospheric disturbances from a few earthquake events and then search patterns among all earthquake events. In existing search tools of time series, patterns are usually described as sequences of real values[4] or motifs[2], which is not feasible enough to describe fuzzy and complex patterns. Inspired by regular expression in text matching[3], our system provides domain scientists with the ability to extract and formulate the patterns of attributes. Domain scientists are able to summarize and examine hypotheses based on search results. By supporting such workflow, our system can assistant domain scientists greatly in seismic research (Fig 1).

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2 Data and Preprocessing

In our system, visual analysis is performed based on preprocessing and integration of earthquake catalog data and DEMETER satellite data.

Earthquake catalog data comes from the Advanced National Seismic System. It contains 645,619 records of seismic event, including attributes as time, latitude, longitude and magnitude. DEMETER data was collected by DEMETER project operated by France CNES. Data are sampled about every 3 seconds along the satellite orbit. Projected latitude and longitude information are included in dataset as well as electronic and magnetic attributes recorded by sensors. We consider 7 attributes on the density and temperature of electron and ion in our system. Since DEMETER data is highly anisotropic in spatial domain, we preprocessed the DEMETER data using Kriging interpolation into 3-d rectilinear grid meshes.

3 Visual Analysis Workflow

Goal of our system is to provide domain scientists the ability to investigate the relationships between earthquake occurrences and ionospheric disturbances. To be specific, domain scientists expect to find pattern that can describe abnormal changes of ionospheric attributes before or after occurrences of earthquake. Such anomalies may be bursting, continuous increase, sharp decrease, etc. To formulate possible patterns in our system, we use modified regular expression, which is described as follows.

- $[-1.8, 12.0]$: one value range for a single time step. It indicates the value should fit in such range.
- $[-0.3, 0.3]*$: one value range that values of zero or more consecutive time steps should fit in.
- $[0, 1.5][-0.3, 0.4][0, max]*$: a pattern composed by a sequence of value ranges. It indicates that values of consecutive time steps match the value range successively.

Our pattern searching workflow acts in a search-by-example way. Users first select a few main shocks as examples by interaction in the map view and timeline view. Spatiotemporal domain around each main shock will be divided into grids with certain spatiotemporal resolution. Using Kriging interpolation, we sample

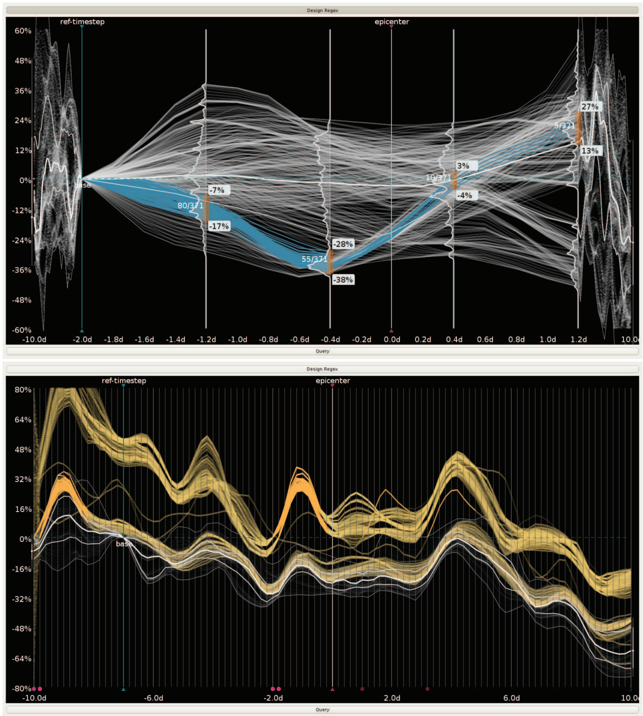

Figure 2: (a) Pattern extraction and formulation using regular expression through visual interaction (b) Search results are overlaid over existing samples using orange color. Filtering by value ranges or time span are supported for further pattern refinement.

time series representing the evolution of attributes at these grids. These time series are visualized in both pixel-wise view and curve view[5]. In curve view, we provide interaction to help formulate the pattern using regular expression in a visual way as shown in Fig 2(a).

After the pattern has been formulated, domain scientists would conduct pattern searching over all major earthquake events within a wide time span, say 1 year. Main shocks are automatically recognized, while aftershocks are left out. Our system would sample time series around main shocks with specific spatiotemporal resolution. Then search algorithm based on automaton is conducted to search given pattern in time series. All matches are transferred back to map view, timeline view and curve view, which enables summarization and further analysis for domain scientists. Further analysis such as brushing or filtering can be conducted in curve view to support pattern refinement.

4 Case Study

The following case study shows how to manage workflow described above in our system.

We interacted with the map view and timeline view to select main shocks. After division over the spatiotemporal domain around main shocks, we sampled time series from grid meshes which are visualized in curve view. We found that for H+ density attribute, these is a burst around 1.5 days before epicenter for a lot of positions. By interacting with curve view, we formulate pattern as [0.34, 0.37][0.14, 0.19] with 0.2 day time resolution for H+ density variation. We then search this pattern in all major earthquakes from Jan. 1st, 2008 to Dec. 31st, 2009 and filter out earthquakes whose magnitude is not in the range of $5 \sim 6$.

Results are visualized in both map view and timeline view (Fig 3). Yellow color indicates that system has found some occurrences of pattern around the main shocks, while blue color indicates not found. In the curve view, we can further adjust value ranges and limit time span to filter matches which leads to pattern refinement (Fig 2(b)).

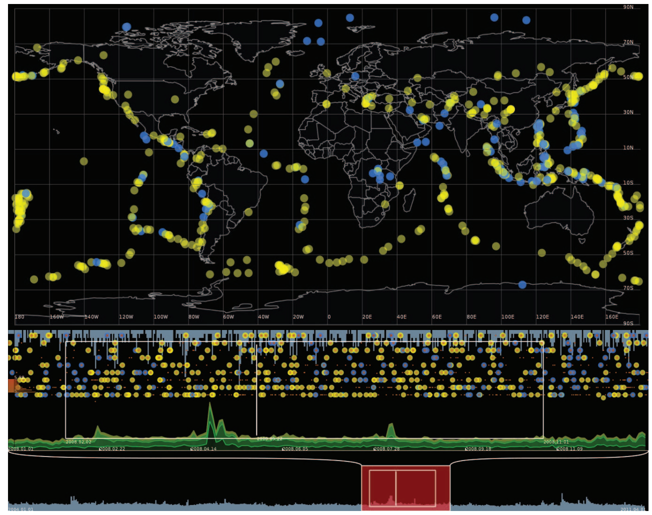

Figure 3: Map view and timeline view to show match status of every main shocks. Yellow color indicates pattern found around the main shocks, while blue color indicates not found.

5 Discussion

In our system, pattern extraction, formulation and searching using regular expression are the center of workflow. Domain scientists are involved a lot in setting parameters in the process in order to obtain patterns that have significant meaning. These parameters are spatiotemporal resolution when generating time series value ranges when extracting patterns, and so on. Even an expert may not know how these parameters affect pattern searching exactly. Some existing work has already analyzed on effects of spatiotemporal resolution visual analysis [1]. For our system, we also need further tools to help analyze parameter space in order to facilitate pattern refinement for the next iteration.

Acknowledgments

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