Studying the Earthquake Effects on Lineament Density Changes by Remote Sensing Technology

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ABSTRACT:

Recently remote sensing technology has widely been used to study and forecast possible earthquakes. Destructive earthquakes throughout the world have little or no advance warning and are naturally unpredictable. Since large earthquakes start as small ones, which in turn start the lineament changes, detection and analysis of these changes play a key role in predicting strong earthquakes.

In this study ASTER high resolution images together with feature-based processing methods are used to detect systematical changes in the number of lineaments which are straight or curved features. Lineament detection in some cases depends on ruptures presence in the earth crust surface. This enables one to extract changes in faults and fractures system due to strong earthquakes.

Seven major earthquakes occurred throughout the country of Iran with the magnitude higher than five Mw are analyzed. In order to facilitate the tracking process of seismic activity features, they are selected from regions with limited seasonal variations. It is seen that the number and orientation of structural lineaments in the pre-earthquake images comparing to ones that achieved when the system returns to its initial mode, has mainly changed prior to earthquake occurrence. This result can be used as an important factor to disaster management in regions with the same geological conditions.

INTRODUCTION

Since devastating Earthquakes frequently occur with little or no advance warning, studying the possibility of earthquake forecasting continues to be an ongoing research topic. A wide range of space borne technologies for this purpose has appeared during the last decades.

Brune (1979) proposed that earthquakes may be inherently unpredictable since large earthquakes start as smaller earthquakes, which in turn start as smaller ones, and so on. He assumed that most of the faults are in a state of stress which is less than what is required to initiate any slip, but they can be triggered and caused to slip by nearby earthquakes or propagating ruptures. It was also mentioned that any precursory phenomena will only occur when stresses are close to the yield stress, so one still faces the impossible task of deciding which of thousands of small events will lead to a runaway cascade of rupture composing of a large event.

Recently the application of remote sensing technology has become popular due to its ability to cover vast territories and areas with are difficult to access. The measurement of various ionosphere precursors of earthquake such as changes in electromagnetic ELF radiation (Serebryakova et al., 1992, Gokhbery et al. 1995), ionosphere electron temperature (Shorma et al.2006), and density (Trigunait et al., 2004) can be mentioned as application of remote sensing in earthquake prediction.

During the last decade, SAR Interferometry Technique has also been successfully applied to study of ground deformations associated with earthquakes related to the movement of tectonic plates. The IR thermal anomalies in the surface latent heat flux data have been detected a few days prior to coastal earthquakes to study pre-earthquake thermal anomalies (Cervone et al., 2005, Singh and Ouzounov, 2003; Day et al., 2004).

Recently Arellano et al. (2006) have found that presence of earthquake can strongly affect the system of lineaments extracted from the high-resolution ASTER satellite Images. The main characteristic of these Images is that a significant number of lineaments appear nearly one month prior to occurrence of a strong earthquake and then it returns to its initial stage after one month. These features have been detected during the analysis of 8 major earthquakes in south and North America and China.

Singh V.P. and Singh R.P. (2005) used the lineaments analysis to study changes in stress pattern around the epicenter of the Mw=7.6 Bhuj Earthquake occurred on January 26th, 2001 in India. Indian Remote sensing (IRS-1D) LISS data are used. The lineaments are extracted using high pass filter (Sobel filter in all direction). The results confirm that the lineaments obtained from the images 22 days before the earthquake differ from the lineaments retrieved 3 days after the earthquake. It is assumed that they are related to fractures and faults, their orientation and density give an idea about the feature pattern of rocks. A high level of correlation between the continued horizontal maximum compressive stress deduced from the lineament and the earthquake focal mechanism is the most important result.

Studies of lineament dynamics can also contribute to better understanding of the nature of earthquakes. The term lineaments originally proposed by Hobbs (2004) as significant lines of landscape that reveal the hidden architecture of the rock basement. However, O'Leary et al. (1976) defined lineaments as a simple or composite linear feature whose parts are aligned in a rectilinear or slightly curvilinear relationship and which differs from the pattern of adjacent features that reflects some subsurface phenomenon.

Image processing of extraction lineament system using different algorithms (Wang et al., 1990, Zlatopolsky, 1992, 1997) makes possible to retrieve the information about the dynamics of the earth crust even tens of kilometers underground that is distributed over a surface. As deeper events are disseminated over vast areas and require lower resolution images for their detection, 10-30 m resolution images are useful for earthquake studies. Although they are not able to see some single cracks, they are able to integrate the information about the presence of faults tens of kilometers below, and track the

changes related to accumulation or relaxation of strength due to the movement of tectonic plates.
In this study seven major earthquake ASTER high resolution images occurred through out the country of Iran are used to detect systematical changes in the number of lineaments which are straight or curved features and can be distinguished by feature based processing techniques.

INSTRUMENTATION AND DATA ANALYSIS

For this study the images from Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) on board the TERRA satellite are used.
TERRA was launched to a circular solar synchronous orbit with altitude of 705 km.
The radiometer is composed by three instruments: Visible and Near Infrared Radiometer (VNIR) with 15m resolution (bands1-3), Short Wave Infrared Radiometer(SWIR) with 30m resolution (bands4-9) and Thermal Infrared Radiometer (TIR) with 90m resolution (bands 11-14) which measures the reflected and emitted radiation of the earths surface covering the range 0.56 to 11.3 µm (Abrams, 2000).
The images are processed using the LINE lineament extraction task (Geomatica V.9.1) which provides a schematic description of the position and orientation of short and linear structures through detection of small linear features. This task also makes it possible to extract the lineaments- straight lines crossing a significant part of the image. To make this extraction, a set of long and narrow windows crossing the entire image in different direction is used.
A lineament is usually defined as a straight or somewhat curved feature in an image. In a satellite image, lineaments can be the result of man made structures such as transportation networks (roads, canals, etc) or natural structures such as geological structures (faults/fractures, lithological boundaries, unconformities) or drainage networks (rivers). Since many mineralization zones occur near fracture zone, lineaments are useful for locating these.
A lineament is distinguishable by the change in image intensity as measured by gradient. By applying edge detection filters to the image, a numerical method for lineament detection can be constructed. This method, however, is not as good as the human visual system. The human visual system is very good at extrapolating linear features. Thus, to the eye, a lineament which varies in intensity along its length may be viewed as a single long lineament whereas to a numerical method, this may appear as several short lineaments. Thus, a numerical method for extracting lineaments must be robust and allow for gradual or sudden changes in gradient along the lineament, and also for minor changes in direction.
The algorithm of LINE consists of three stages: edge detection, thresholding, and curve extraction.
In the first stage, the canny edge detection algorithm is applied to produce an edge strength image. The Canny edge detection algorithm has three sub-steps. First, the input image is filtered with a Gaussian function whose radius is given by the RADI parameter. Then gradient is computed from the filtered image. Finally, those pixels whose gradient are not local maximum are suppressed (by setting the edge strength to 0).
In the second stage, the edge strength image is thresholded to obtain a binary image. Each ON pixel of the binary image represents an edge element. The threshold value is given by the GTHR parameter.
In the third stage, curves are extracted from the binary edge image. This step consists of several sub-steps. First, a thinning algorithm is applied to the binary edge image to produce pixel-wide skeleton curves. Then a sequence of pixels for each curve is extracted from the image. Any curve with the number of pixels less than the parameter value LTHR is discarded from further processing. An extracted pixel curve is converted to vector form by fitting piecewise line segments to it. The resulting polyline is an approximation to the original pixel curve where the maximum fitting error (distance between the two) is specified by the FTHR parameter.

Finally, the algorithm links pairs of polylines which satisfy the following criteria: (1) two end-segments of the two polylines face each other and have similar orientation (the angle between the two segments is less than the parameter ATHR); (2) the two end-segments are close to each other (the distance between the end points is less than the parameter DTHR). The final polylines are saved in a vector segment.

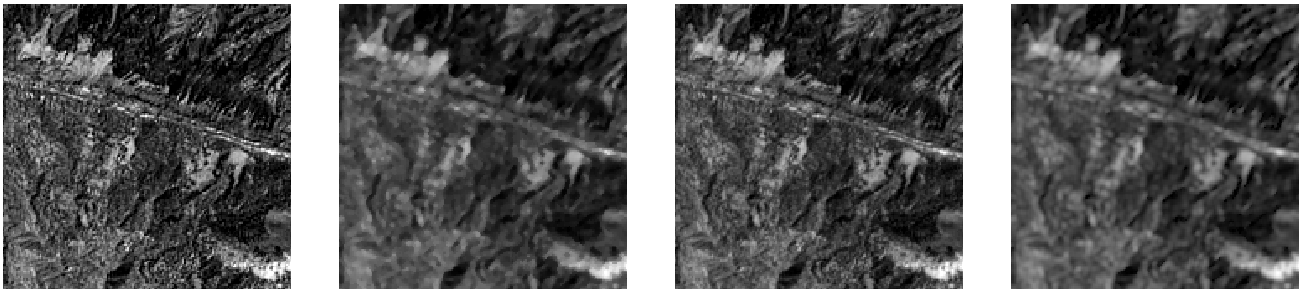
The lineament extraction algorithm implemented here takes these problems into account to extract linear features from an image. The algorithm consists of three steps. First, an edge detection operator is applied to the image which produces a gradient image (Note: all 16-bit or 32-bit input images are first scaled to 8-bit, using a nonlinear scaling routine). Second, the gradient image is thresholded to create a binary edge image. Finally, linear features are extracted from the binary edge image. This last step contains many sub-steps such as edge thinning, curve pruning, recursive curve segmentation, and proximity curve linking.

During this study we analyzed 7 earthquakes, occurred in various parts of Iran. Table1 resumes main characteristics of these earthquakes, indicating the date, location, geographic coordinates, magnitude and depth of the earthquake. The ASTER images available for each earthquake are also indicated, e.g. -126 mean that the image 126 days before the earthquake was used. The last column indicates that in all earthquakes, number and orientation of lineaments suffered changes before the earthquake. In case of Golestan earthquake we can't give a definite answer, because unfortunately the key images ten days before the earthquake were covered by clouds in approximately 50 % that made the lineament analysis difficult.

To illustrate the results obtained we give as an example a detailed analysis of 6.1 Mw earthquake which happened in south west of borujerd in Lorestan Province (See figure 1). The hypocenter was located in 14.10 Km deep in the crust. The coordinates were 33.65 Lat 48.91 Long. It is possible to see that the presence of clouds was low. The second line contains the images showing the system of lineaments obtained from the images above using the lineament extraction program. It is possible to see clear time estimation of lineaments, experimenting strong increase in the number of lineaments 5 days before the earthquake. Reorientation of lineaments can be taken as indirect evidence in favor to the theory of deformation. However, it is necessary to provide more detailed studies to make definitive conclusions.

Province	Location	Date	Magn.Mw.	Depth	Lat.	Long.	Images available	Changes in lineaments
Kerman	Bam	2003/12/26	6.5	13 km	29.08	58.38	-126,-5,139	Yes
Kerman	Hatkan	2005/02/22	6.4	14 km	30.80	56.76	-50,-3,+4,+73	Yes
Mazandaran	Pul	2004/05/28	6.3	28 km	36.37	51.64	-128,-43,+73	Yes
Sistan	Zabol	2005/03/13	6.2	55 km	27.32	61.54	-132,-118, 20	Yes
Lorestan	Khoramabd	2006/03/31	6.1	14 km	33.65	48.91	-120-60-6,132	Yes
Golestan	Gonbad	2004/10/07	6	17 km	37.35	54.56	-138,-10,4,86	?
Golestan	Gonbad	2005/01/10	5.6	15 km	37.38	54.58	-126,-40,-5,20	Yes

Table 1: Main characteristics of earthquakes analyzed



December 1,2005 (-120 days) | January 30, 2006 (-60 days) | March 26, 2006 (-6 days) | August 10, 2006 (+132days)

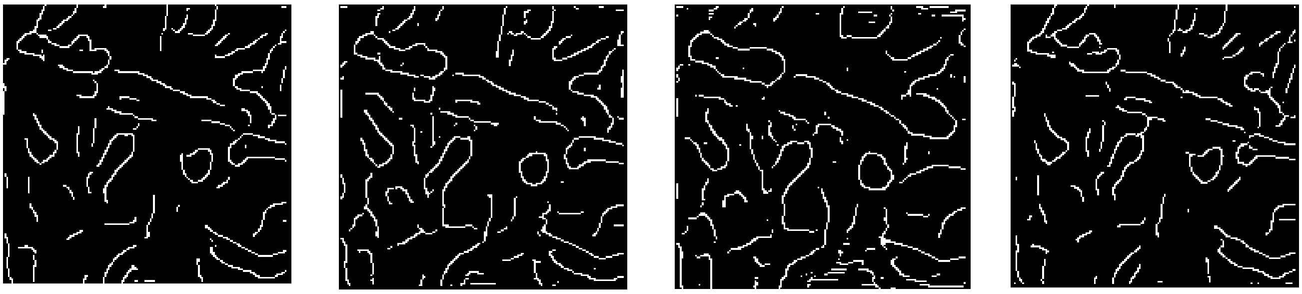


Figure1: ASTER band 3(VNIR) images around March 31, 2006 earthquake (Iran, Lorestan, Khoramabad).Below: Lineament system extracted from these images, using LINE program.

DISCUSSION AND CONCLUSION

In this paper, we used the ASTER/TERRA satellite images for detection and analysis of lineaments in the regions around strong earthquakes with magnitude more than 5 Mw. A lineament is a straight or nearly curved feature in an image, which can be enhanced by a special processing of images, based on directional filtering or Hough transform. It was established that the system of lineaments are very dynamical. By experimenting seven events of strong earthquakes, it was found that a significant number of lineaments appeared approximately one month before an earthquake and on month after it the lineaments returned to their initial state configuration.

The nature of lineaments is related to the presence of faults and discontinuities in the crust, situated at different depth. If a discontinuity is situated close to the surface, the fault appears as a singular lineament. In the case of a deep located fault, we observe the presence of extended jointing zones easily detectable in satellite images even up to zoom resolution.

Generally, detection of lineaments strongly depends on a number of factors, such as current level of stress in the crust. The accumulation of stress deep in the crust improves all processes and changes the density and orientation of lineaments, prior to a strong earthquake.

Therefore the density of lineaments indicates that the crust is more permeable and the elevation of fluids and gases is allowed to the surface.

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