Earth Quake Prediction Using Satellites

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Abstract:

Earthquake prediction is concerned with the magnitude of future Earthquakes with the specifications of the time, location and the magnitude of the Earthquake. An Earthquake prediction can be beneficial only if it is precise, timely and reliable. During 1990s this accuracy has reached to 8-10. This paper presents the use of satellites for Earthquake prediction, and broadcasting the alert over the particular area of high probability. Also the modern technological developments in the field with the challenges. The paper reviews the method of InSAR (interferometric-synthetic aperture radar). This technique is sensitive enough to detect slow ground motions as tiny as 1 mm per year. With the help of these motions high strain points can be figured out. These can be further verified using ionospheric dimples through thermal or infrared detection.

Keywords:
GPS; Seismic monitoring; Richter scale; Tectonic plates; InSAR; GESS; interferogram

1. INTRODUCTION

1.1 Earthquakes as disaster

In a general sense an Earthquake is described as any seismic event that generates seismic waves. Earthquake is one of the major catastrophes that, over the time have been a source of devastation for many lives. At the Earth's surface an Earthquake originates by shaking or displacement of the ground though they can be caused due to a number of reasons. Strong earthquakes can result in collapse of enormous buildings, trigger landslides, tsunamis, floods, sandblasting and other events which may lead to disruption of life of common public as well as officials. The largest earthquakes in most recent times have been of the magnitude as high as 9, in Japan in 2011, although there is no limit to the possibility of the highest magnitude. Thus Earthquake prediction, if done with precision and timely enough, can help in avoiding damage to great extent.

1.2 Necessity of Earthquake Prediction

The Indian subcontinent has witnessed devastating earthquakes over the time. The globe has six tectonic plates—the Pacific plate, the Asia and Europe plate, the African plate, the inter-American plate, the Indian Ocean Plate and the Antarctic plate. The reason for such high frequency and intensity of earthquakes in India is believed to be the movement of Indian plate

into Asia at a rate of 47mm/year. A report presented by World Bank and UN shows the estimates of the exposure to Earthquakes of about 200 million Indian citizens by 2050. Major earthquake occurrences in India are:

a.) 2001 Gujarat Earthquake- the Earthquake occurred on 26 January 2001, measuring 7.7 on Richter scale, killing over 20,000 people.
b.) 1934 Bihar Earthquake-One of the worst Earthquakes in India that hit the state of Bihar on January 15, 1934 had a magnitude of 8.1, killing over 30000 people.
c.) 1950 Assam Earthquake- Also known as the Medog earthquake it occurred 15 august 1950 measuring as high as 8.6.

2. THE SATELLITE TECHNOLOGY

A satellite in general terms can be referred to as space based receiving and transmitting radio. In other words, it sends EM Waves, carrying information over distances without the use of wires. Today, satellite technology has become a flexible and economically viable solution for domestic and international networks. It has become a solution for some of the most complicated access problems. The benefits of satellite technology have steadily expanded its usage. Expected life of a satellite is 10-15 years.Satellites transmit the information within a specified range of frequency called the frequency band. The primary commercial bands in use are C-Band(operating range is 4-6 GHz) and Ku-Band(operating range is 11-14 GHz). There is a relationship between the amount of bandwidth and the amount of power available from the satellite. Each transponder has a maximum amount of power and bandwidth available to it.

2.1 History

The Merriam-Webster dictionary defines a satellite as a celestial body orbiting another of larger size or a manufactured object or vehicle intended to orbit the earth, the moon, or another celestial body.Today's satellite communications can trace their origins all the way back to the Moon. A project named Communication Moon Relay was a telecommunication project carried out by the United States Navy. Its objective was to develop a secure and reliable method of wireless communication by using the Moon as a natural communications satellite. The first American satellite to relay communications was Project SCORE in 1958, which used a tape recorder to store and forward voice messages. It was used to send a Christmas greeting to the world from U.S. President Dwight D. Eisenhower.NASA launched the Echo satellite in 1960; the 100-foot (30 m) aluminised PET film balloon served as a passive reflector for radio communications. Courier 1B, built by Philco, also launched in 1960, was the world's first active repeater satellite. It is commonly believed that the first "communications" satellite was Sputnik 1. Put into orbit by the Soviet Union on October 4, 1957, it was equipped with an onboard radio-transmitter that worked on two frequencies: 20.005 and 40.002 MHz. Sputnik 1 was launched as a step in the exploration of space and rocket development. While incredibly important it was not placed in orbit for the purpose of sending data from one point on earth to another. Hence, it was not the first "communications" satellite, but it was the first artificial satellite in the steps leading to today's satellite communications. Telstar was the first active, direct relay communications satellite. Belonging to AT&T as part of a multi-national agreement between AT&T, Bell Telephone Laboratories, NASA, the British General Post Office, and the French National PTT (Post Office) to develop satellite communications, it was launched by NASA from Cape Canaveral on July 10, 1962, the first privately sponsored space launch. Relay 1 was launched on December 13, 1962, and became the first satellite to broadcast across the Pacific on November 22, 1963.

Fig1: Satellite in space

2.2 Applications of Satellites

2.2.1 Telephone: Remote islands such as Saint Helena, Diego Garcia and Easter Island are the places where no under-sea cables can be employed are in need of satellite telephones. There are also regions of some continents where laying down of wires is not possible for example mountains, valleys, deserts. The ships at sea also use satellite phones. Satellite phones can be accomplished in many different ways. On larger scale often there will be local telephone system in the isolated area with a link to a telephone system in a main land area. There are services that will patch a radio signal to a telephone system in this example most any type of satellite can be used. Satellite phones connect directly to a constellation of either geostationary or low-earth-orbit satellites. Calls are then forwarded to a satellite teleport connected to the Public Switched Telephone Network .

2.2.2 Television: The DTH (Direct to Home) television receives signal through satellites. Special antennas for mobile reception of DBS Television have also been introduced which employ GPS Technology so that they automatically re-aim to satellite in case of change of location.Some manufacturers have also introduced special antennas for mobile reception of DBS television. Using Global Positioning System (GPS) technology as a reference, these antennas automatically re-aim to the satellite no matter where or how the vehicle (on which the antenna is mounted) is situated. These mobile satellite antennas are popular with some recreational vehicle owners. Such mobile DBS antennas are also used by JetBlue Airways for DirecTV (supplied by LiveTV, a subsidiary of JetBlue), which passengers can view on-board on LCD screens mounted in the seats.

2.2.3 Digital cinema: realisation and demonstration of the first digital cinema transmission by satellite in Europe on 29 Oct 2001, the feature film by Bernard Pauchon and Philippe Binant.[France telecom, Commission Superieure Technique de l'Image et du Son, *communiqué de presse*, Paris, October 29th,2001]

2.2.4 Radio: A satellite radio is a digital radio signal that is broadcast by satellite covering much wider range than the terrestrial radio signals, this allows listeners to listen to same audio programming anywhere they go. Initially available for broadcast to stationary

TV receivers, by 2004 popular mobile direct broadcast applications made their appearance with the arrival of two satellite radio systems in the United States: Sirius and XM Satellite Radio Holdings. Later they merged to become the conglomerate SiriusXM. Radio services are usually provided by commercial ventures and are subscription-based. The various services are proprietary signals, requiring specialized hardware for decoding and playback. Providers usually carry a variety of news, weather, sports, and music channels, with the music channels generally being commercial-free.

2.2.5 Internet access: since the 90s, satellite technology has been used to provide internet services. This can prove to be beneficial to those areas where broadband connection is not viable.

2.2.6 Military: one of the areas where satellite technology has proved to be highly beneficial is the military and defence department. Urgent messages over large distances are communicated through satellites. In case of disasters where ground system may fail, satellite technology provides the only possible means of communication.Communications satellites are used for military communications applications, such as Global Command and Control Systems. Examples of military systems that use communication satellites are the MILSTAR, the DSCS, and the FLTSATCOM of the United States, NATO satellites, United Kingdom satellites (for instance Skynet), and satellites of the former Soviet Union. India has launched its first Military Communication satellite GSAT-7, its transponders operate in UHF, F, C and K_u band bands. Typically military satellites operate in the UHF, SHF (also known as X-band) or EHF (also known as K_a band) frequency bands.

3. Earthquake Prediction

There is, on average, about one Richter magnitude (M) of 8 or larger earthquake somewhere in the world each year, and there are 15 or so "major" M ≥ 7 quakes per year. The United States Geological Survey (USGS) reckons another 134 "large" quakes above M 6, and about 1300 quakes in the "moderate" range, from M 5 to M 5.9 ("felt by all, many frightened"). In the M 4 to M 4.9 range – "small" – it is estimated that there are 13,000 quakes annually. Quakes less than M 4 – noticeable to only a few persons, and possibly not recognized as an earthquake – number over a million each year. To be meaningful, an earthquake prediction must be properly qualified. This includes unambiguous specification of time, location, and magnitude. These should be stated either as ranges ("windows", error bounds), or with a weighting function, or with some definitive inclusion rule provided, so that there is no issue as to whether any particular event is, or is not, included in the prediction, so a prediction cannot be retrospectively expanded to include an earthquake it would have otherwise missed, or contracted to appear more significant than it really was. To show that a prediction is not post-selected ("cherry-picked") from a number of generally unsuccessful and unrevealed predictions, it must be published in a manner that reveals all attempts at prediction, failures as well as successes.

4. Earthquake Prediction through InSAR

4.1 For a long time now, satellite technologies are being developed at NASA and many other places, where they might be able to spot the signs of earthquake lurking beneath the ground, days or weeks before it hits, giving everyone time to plan and prepare beforehand.A company called QuakeFinder is hoping that these faint magnetic signals (typically less than 1 nanotesla) can be detected by a satellite in low-Earth orbit. Ground-based sensors can detect these fluctuations as well, but polar-orbiting satellites have the advantage of covering most of the Earth's surface each day.On June 30, 2003, Quakefinder launched QuakeSat. Measuring only 4 in. x 4 in. x 12 in., the satellite will operate for a year to see whether it can sift out magnetic signals generated by tectonic activity. The first six months of the mission will be spent calibrating the satellite and gathering baseline data. After that ground controllers will be looking in earnest for quakes.Both the infrared and magnetic methods of quake detection are controversial. For now InSAR seems to be a safer bet for earthquake forecasting. All three, however, offer a tantalizing possibility: Someday the local weather report will forecast not only of the storms above us, but also the ones brewing beneath our feet.There are several satellite based methods that show promise as forecasters to earthquake activity. One of the most promising method is InSAR i.e. Interferometric-Synthetic Aperture Radar. In general terms, InSAR uses two RADAR images of a given tectonic area, combine them through process called data fusion, and any changes in ground motion beneath the surface may be detected. Current methods are less certain. For example, the US Geological Survey released an updated assessment of Earthquake risk in the San Fransisco Bay Area based on seismic history of the area, its geology, and computer models. The study reported a 62% chance of a major quake hitting the area sometime within next 30 years. This technique is preferable over others because it is sensitive to detect even slow ground motions, as slight as 1mm per year. Such sensitivity alongwith the landscape view offered by satellites, helps in observing the tiniest motions and contortions of land around a fault line in more detail. These motions help in determining where the joints of high strains may be building up. A network of satellites called the Global Earthquake Satellite System (GESS) with the help of InSAR can monitor fault zones around the world. Observers can issue a monthly warning of the likelihood of a major earthquake due to a given fault by inferring the data of InSAR, when stresses in the Earth's crust have reached a dangerous level. Geostationery meteorological satellites are more suitable for this purpose than polar, it has advantage in time consistency and place comparability.

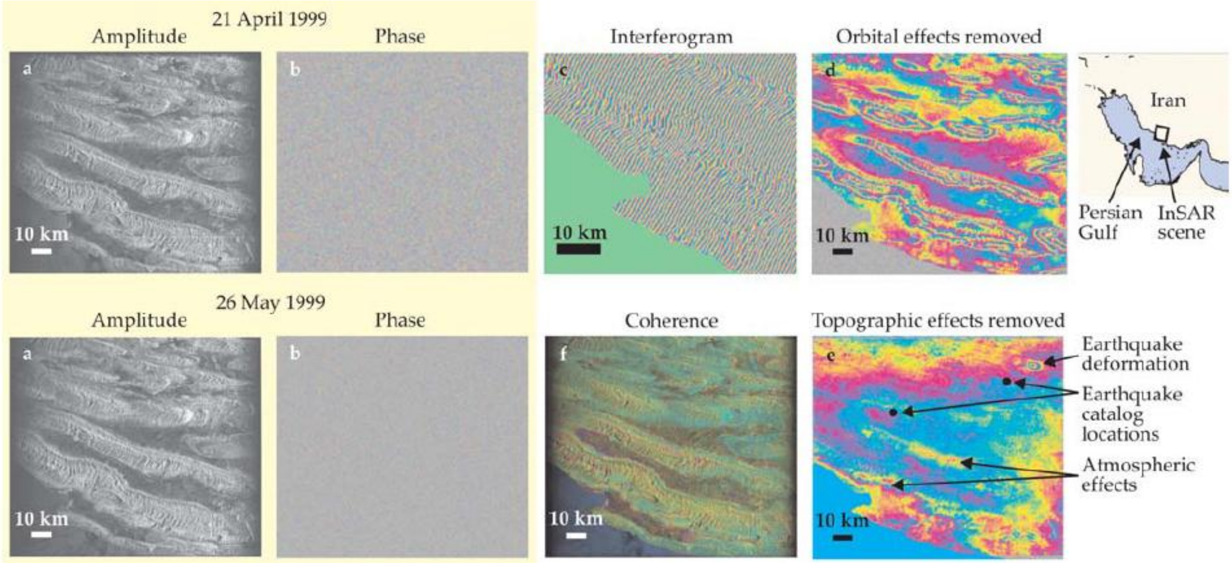

Fig2: Insar images

Radars that image Earth's surface have wavelengths greater than a few centimetres so they can see through clouds and precipitation; they thus can function day and night, no matter what the weather. To create a radar image, one must determine where the received radar energy interacted with the ground. The two coordinates most often used to describe that interaction point are the range, or distance perpendicular to the radar antenna and the azimuth or distance along the flight path. To discriminate ground features in the range direction, one precisely times the returns of radar energy. Features in azimuth are resolved by tracking changes in frequency caused by the Doppler effect, because many pulses from the radar are combined to create the image of a ground scatterer, the signal processing technique is called synthetic aperture radar, where the "aperture" includes the motion of the antenna over the many pulses. For a typical civilian satellite, SAR's range resolution is about 20m and its azimuth resolution is about 5m. Each pixel in a SAR image encodes a complex number whose amplitude corresponds to the intensity of the returned radar energy and whose phase represents a fraction of a complete wavelength. The fig2 shows how a pair of SAR images obtained at different times can be combined to form an interferogram and, with further refinements, yield surface deformation. The amplitude images appear similar to an optical image of the ground, although there are several important differences because the source of illumination is a satellite antenna. The phase in SAR image is random from one pixel to another because the phase at each pixel is a complicated function of scattering features located on the surface. However, when the phases from two images are subtracted to form an interferogram, the resulting phase differences fringed allow one to infer changes in the distance between the ground and the satellite antenna. Each fringe corresponds to a distance change of half of wavelength of radar. After the removal of effects ude to the slightly different locations of the antenna during the two observations, the remaining interferogram should represent surface deformation.

4.2 Possible improvements in InSAR

It has been observed that there are some thermal analogies associated with earthquakes, an example supporting this theory is that of the 1998 Zhanbei earthquake near the Great Wall of China. This Earthquake occurred when ground temperatures in the region were around -20^o C. Just before the quake, thermal sensors detected temperature variations as large as 6^o to 9^o[Chinese documents]. Thus satellites equipped with IR cameras can be used to detect these thermal radiations, referred to as hot spots or ionospheric dimples. NASA's Terra satellite discovered a warming of the ground in western India just before Gujarat quake in January 26, 2001. The theoretical explanation for these infrared radiations is that much of the Earth's rock has soaked up water, which has later been exposed to extreme heat and pressure inside the earth. This resulted in the breaking apart of water molecules creating electrically conductive crystals of oxygen that exist inside most rocks. Before an earthquake occurs, a pressure builds up, the oxygen molecules inside the rocks, creates a positive electrical charge that radiates out towards the surface of the earth. The charge creates subtle fluorescent, infrared glow and a magnetic field one to two months before a major earthquake. This light shines into space which can be detected through infrared sensors on the GESS. The positively charged magnet creates a dimple, upto 20 kilometres deep, in the earth's atmosphere by attracting negatively charged ions from as far away as 600 km above Earth's surface. Research is going on with the magnetometers, just before major earth quakes tiny slow fluctuations in Earth's Magnetic field has been recorded. An example supporting this observation is of Loma-Prieta earthquake that devastated San Fransisco in 1989. Almost 2 weeks before the quake, readings of low-frequency magnetic signals rose up to 20 times above normal levels and were recorded even higher on the day of Earthquake. While both magnetic and infrared methods are controversial, but using them alongwith InSAR can prove to be highly beneficial for Earthquake forecasting.

5. Conclusion

Insar only sees deformation in the line-of-sight direction of the radar beam, which impliesthat only one component of the deformation can be measured in an individual interferogram. By using multiple satellite passes with different observing geometries, one recovers more than a single component of deformation; that additional information is important for constraining physical deformation models. Though InSAR systems have provided many new insights, satellites to date have not been optimized for InSAR. A dedicated satellite able to make frequent and consistent observations could address some large scale problems in geophysics. Eventually constellations of InSAR satellites in a variety of orbits, including possibly geosynchronous orbits, could allow near-real-time imaging that would greatly assist the response to natural hazards, and even help anticipate some of them.

6. References

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