NEW MAPPING TECHNOLOGIES-MAPPING AND IMAGING FROM SPACE

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Abstract

New and significantly enhanced space based observational capabilities are available which are of potential use to the hazards community. A great advantage of spaceborne systems is global access and uniform data products. In many parts of the world, basic data is unavailable and ground access may be limited. Even in more accessible areas, field work and data availability may be expensive, inconsistent, or limited. In combination with existing methodologies, these instruments and data can significantly enhance and extend current procedures for seismic zonation and hazards evaluation. This paper provides a very brief overview of several of the more useful data sets available.

Introduction and Overview

Space based data has reached a level of spatial and temporal resolution, areal coverage, and reliability, that such data can now be usefully incorporated into seismic zonation studies, particularly for international situations where data availability and access may be less than ideal. Potential implementations range from standard image interpretation activities similar to airphoto analysis with the highest resolution satellite image data, to geographically comprehensive remote surface deformation mapping using radar interferometry, and long term analysis of in-situ GPS data to continuously measure surface deformation. In addition, because these data are digital, and have well defined spatial properties, they can be incorporated into GIS (Geographic Information System) databases.

These capabilities include local scale 1meter pixel (picture element)[2] black and white image data from the Ikonos satellite, regional scale multispectral Landsat Thematic Mapper (TM) data with 15 meter pixels, multispectral thermal infrared data from ASTER (Advanced Spaceborne Thermal Emission Radiometer/spectrometer), and radar data from the European Radar Satellites (ERS) which, in addition to providing radar images, can be used to create interferograms mapping surface displacements related to tectonic and volcanic activity, or human induced subsidence at the cm level. In addition, extremely precise continuous monitoring of surface deformation via GPS (Global Positioning System) receiver networks can provide continuous, long term, and detailed records of point to point deformation in all stages of the earthquake cycle, and for movements related to volcanic activity, ground water or petroleum withdrawal, and even landsliding.

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[2] Often the surface area represented by a pixel is imprecisely referred to as the "resolution" of the image data.

Such networks are in operation in Southern California (SCIGN) and also in Japan. As global digital topographic data becomes available from the recently flown Shuttle Imaging Radar Mission (SRTM), studies benefiting from uniform high resolution topographic data will be possible in most parts of the world. Studies aided by good topographic data include mapping of landforms indicative of tectonic, volcanic, and landslide activity. It is also worth noting that a huge amount of map, topography, and image data, is readily searchable and available from the US Geological Survey at: http://edcwww.cr.usgs.gov/webglis

Space based instrumentation and technologies

Following is a brief overview of various instruments and technologies available for hazards applications. The list is by no means comprehensive. Additional details on some of the instruments and capabilities are provided by other papers in this session. It is worth noting that these systems are operational, not experimental.

Ikonos

Ikonos is a high resolution commercial satellite owned by Space Imaging. This satellite provides near airphoto resolution (1 meter pixel size) black and white digital images on demand for anywhere on Earth. Ikonos also has 4 m pixel size color capability, which can be merged with the 1m data for apparent 1 m color images. The web pages below provide information on the satellite and how to obtain data.
http://www.terrasys.com/Pages/ikonos.htm
http://www.spaceimaging.com/carterra/geo/prodinfo/geotech.htm

SPOT

Data from the French SPOT satellite series has been available since the mid 1980's. Both 10 meter panchromatic, and 20 meter multispectral mode images are available, and images represent about 60 X 60 km in area. Topographic maps can be made from the panchromatic data acquired in the stereo mode. These data are now of somewhat lesser importance with the advent of 15 m Landsat data (discussed below), and 1m Ikonos data described above, in addition to the impending availability of topographic data from both the SRTM mission and the ASTER instrument. However, the temporal continuity of moderately high spatial resolution data going back into the mid 1980's is valuable for change detection studies. Information on data availability and pricing is available at the following web address.
http://www.spot.com/

Landsat 7 Thematic Mapper

Landsat 7 is the latest of a series of land observation satellites launched by the United States. While the first Landsat was launched in 1972, it wasn't until the launch of Landsat 4 in 1982 that the capabilities reached a truly useful stage for the solid earth science community. Landsat 4, and the subsequent Landsat satellites, incorporate the "Thematic Mapper" or "TM" instrument. Each TM scene covers about 180 by 170 km (equal to about 9 SPOT images in areal coverage) with 30 meter pixels. Data is acquired in the visible and reflective infrared in a total of 6 channels, plus a lower resolution thermal infrared channel. The recently launched Landsat 7 has additionally incorporated a 15 m pixel size black and white channel which can be used by itself, or used as a "sharpening" band to increase the apparent resolution of the other bands.

The visible and near infrared coverage afforded by Landsat TM is very important as many rock and soil types, and other landscape features are more distinctive at these wavelengths. For example, Landsat images have been used to detect otherwise obscure faults (Ford, et. al., 1990), and map volcanic features (Siebe, et. al., 1996). Because Thematic Mapper data are available from 1982 on, these data are useful for change detection studies. Finally, TM data have proven particularly useful in terrain visualizations in combination with digital topographic data. Visualizations of tectonic landforms and faults in the San Francisco area are shown on the third web page listed below as an example.

Landsat 7 information:
http://landsat.gsfc.nasa.gov/
Landsat 4 and 5 data and information:
http://edcwww.cr.usgs.gov/Webglis/glisbin/guide.pl/glis/hyper/guide/landsat_tm
Landsat image data combined with earthquake fault information for San Francisco:
http://www.sfbayquakes.org/

ASTER

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) is currently operating onboard NASA's Earth Observing System, Terra, which was launched December,1999. ASTER has three spectral bands in the VNIR (visible and near infrared), six bands in the SWIR(short wavelength infrared), and five bands in the TIR (thermal infrared) regions with 15, 30, and 90 m ground resolution respectively, data are provided for 60 X 60 km area blocks. In addition to nadir viewing, the VNIR subsystem has one backward-viewing band to provide along-track stereo. These stereo images can be used to create high resolution digital topographic maps anywhere in the world. ASTER provides the highest spatial resolution multispectral thermal data of any Earth orbiting system.

The primary science objective of the ASTER mission is to improve understanding of the local- and regional-scale processes occurring on or near the Earth's surface. The wavelengths of many of the spectral bands were chosen specifically to aid in geologic and soil mapping. The thermal infrared spectral region contains a wealth of surface compositional information for a wide range of geologically important materials that are difficult or impossible to distinguish using visible and near infrared observations. One goal of ASTER is to provide a cloud-free, multispectral, map of all the land surface of the Earth, with stereo imaging. Upon request, data will also be acquired multiple times

over an area to monitor changes. Information about ASTER, and on obtaining data, can be found at the following web site.
http://asterweb.jpl.nasa.gov/

ERS-European Radar Satellites

The ERS satellites can provide radar images with a swath width of about 100km and pixel size of about 25 meters. In addition to radar images, always useful for geomorphic analysis, of principal interest here is the utility of radar data from the ERS 1 and 2 satellites in the production of radar interferograms to detect surface motion, especially of tectonic origin. Radar interferometry capitalizes on the fact that the radar signal is coherent, and therefore multiple data acquisitions can be used to form interferomgrams to measure topography, and surface displacements. The ERS satellites have been in orbit since the early 1990's, and image data suitable for making interferograms is available for many areas of the world. Unfortunately, these satellites were not designed for interferometry, and the 6 cm (C band) wavelength chosen is not optimum. While outstanding science has been done with data from the ERS satellites, interferometry is not possible using this wavelength radar data in environments which change significantly. For example, in areas with significant vegetation cover, or seasonal variations, it is typically not possible to create interferograms. At present there is a large effort to get a radar satellite in orbit with characteristics more optimum for interferometry.

The above concerns not-with-standing, amazing results have been achieved with radar interferometry. For example, regional scale deformation mapping at cm scale of the Landers, Eureka Valley, and Hector Mine earthquakes in California, and the Manyi, Tibet, and Izmit, Turkey, earthquakes have been accomplished with ERS data (e.g., Massonett, et. al., 1993, Peltzer, et. al., 1994, Zebker, et. al., 1994, Peltzer and Rosen, 1995, Ozawa, et. al., 1998, Peltzer and King, 1999). Interestingly, the phenomenon of decorrelation mentioned above prevented use of ERS data in making interferograms for the Northridge California, and the 1995 Sahkalin Russia, earthquakes. Interferograms for these earthquakes were made using data from the Japanese Earth Remote Sensing Satellite, which used a longer radar wavelength. Unfortunately this satellite is no longer operational.

Post seismic and even aseismic deformation has also been measured using radar interferometry (Bürgmann, et. al., 1998, Peltzer, et al., 1996), as has volcanic inflation at Etna (Lanari, et. al., 1998), subsidence due to ground water withdrawl (Amelung, et. al., 1999) and oil extraction (Fielding, et. al., 1998). Clearly this is an extraordinary technique for hazards evaluation.
ERS satellite information:
http://earthnet.esrin.esa.it/
Examples of InSAR mapping of earthquakes
http://www-radar.jpl.nasa.gov/sect323/InSar4crust/home.html

SRTM (Shuttle Radar Topographic Mapper)

In February of 2000, the SRTM (Shuttle Radar Topographic Mapper) mission acquired and unprecedented data set which will provide high resolution, uniform, digital topographic data for nearly all the land surface of the earth (57D South to 60D North). These data will have 30 m postings (X,Y) and better than 16 m absolute and 10m relative elevation accuracy (Z). This level of topographic detail is essentially equal to the best DEMs (digital elevation models) available from the USGS (United States Geological Survey) for the US. Visualizations of fault systems such as those at http://www.sfbayquakes.org/ will be possible globally. The mission and data are described in detail by Farr and Kobick in this volume. A complete overview of the mission, data, and sample products are available at: http://www.jpl.nasa.gov/srtm/

GPS and GPS networks

The GPS satellites (Global Positioning System) were originally designed for precise, all weather navigation, for the military. Today, these satellites are used for many civilian purposes as well, ranging from hiking to car and boat navigation. An extremely important application for scientific and hazards work is placing of receivers, either for a short period of time, or permanently, to precisely determine and monitor position.

In the greater Los Angeles area, a permanent array of GPS receivers is being installed to precisely measure tectonic deformation, at the mm level, over an extended period of time. This network is called "SCIGN" (Southern California Integrated Geodetic Network), and incorporates additional geodetic data as well. Variations in the distribution and rate of deformation are providing unprecedented insight into the tectonic processes. A recent overview of results from SCIGN, documenting the distribution of slip across the Los Angeles basin, is provided by Argus, et. al., 1999. An excellent explanation of the SCIGN network, and GPS applications is presented by Webb in this volume. Additional GPS networks have been established to monitor deformation at Mammoth, California, and in Japan. The website below contains comprehensive information on SCIGN.
http://scign/

Summary

The data sets reviewed above can provide significant information on regional and local tectonics, and fault locations, movements, and rates of movements of the crust. These data sets come from operational satellites and systems which therefore can provide data on a routine basis to incorporate into seismic hazard mapping. All of the analysis techniques mentioned are well documented in the literature and can be performed on generally available computer platforms. The costs of these data sets are not at all prohibitive, generally in the low $100's to a few $K per data set. Accordingly, it would seem good practice to include appropriate space based data into seismic hazard zonation activities.

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References

Amelung, F., D. L. Galloway, J. W. Bell, H. A. Zebker, and R. J., Laczniak, 1999, Sensing the ups and downs of Las Vegas, InSAR reveals structural control of land subsidence and aquifer system deformation: Geology, v. 27, p. 483-486.

Argus, D.F., M. B. Heflin, A. Donnellan, F. H. Webb, D. Dong, K. J. Hurst, D. C. Jefferson, G. A. Lyzenga, M. M. Watkins, J. F. Zumberge, 1999, Shortening and thickening of metropolitan Los Angeles measured and inferred by using geodesy: Geology, v. 27, 703-706.

Bürgmann R, Fielding E, Sukhatme J, 1998, Slip along the Hayward fault, California, estimated from space-based synthetic aperture radar interferometry: J: Geology 26: (6) 559-562.

Fielding, E. J., R. G. Blom, and R. M. Goldstein, 1998, Rapid Subsidence Over Oil Fields Measured By SAR Interferometry: Geophysical Research Letters, v. 25, p. 3215-3218.

Ford, J.P., R.K. Dokka, R.E. Crippen, and R.G. Blom, 1990, Faults in the Mojave Desert, California, as revealed on enhanced Landsat images. *Science,* 248 (4958), 1000-1003 and cover image.

Lanari, R., P. Lundgren, and E. Sansosti., 1998, Dynamic deformation of Etna volcano observed by satellite radar interferometry: Geophysical Research Letters. v. 25, p. 1541-1544.

Massonnet D, M. Rossi, C. Carmona, F. Adragna, G. Peltzer, K. Feigl, T. Rabaute, 1993, The Displacement Field Of The Landers Earthquake Mapped By Radar Interferometry Nature, v. 364, p. 138-142.

Ozawa, S., M. Tobita, S. Fujiwara, M. Murakami, H. Nakagawa, K. Nitta, P. A. Rosen, C.. L.. Werner, 1998, Fault Model of the 1995 Sakhalin Earthquake and its Afterslip: EOS Trasactions 1998 Fall AGU Meeting.

Peltzer G., Hudnut K. W., Feigl K. L., 1994, Analysis of Coseismic Surface Displacement Gradients Using Radar Interferometry - New Insights Into the Landers Earthquake: Journal Geophys. Research 99, 21971-21981.

Peltzer G., Rosen P., 1995, Surface Displacements of the 17 May 1993 Eureka Valley, California, Earthquake Observed By SAR Interferometry: Science 268: (5215) 1333-1336.

Peltzer G, Rosen P, Rogez F, et al., 1996, Postseismic rebound in fault step-overs caused by pore fluid flow: Science 273: (5279) 1202-1204 .

Peltzer G., Crampe F., King G., 1999, Evidence of nonlinear elasticity of the crust from the Mw7.6 Manyi (Tibet) earthquake: Science 286: (5438) 272-276.

Siebe, C., Abrams, M., Macias, J., Obenholzner, J., 1996, "Repeated disasters in Prehispanic time produced by Plinian eruptions at Popocatepetl volcano, Central Mexico: Past key to the future?", *Geology*, 24, 399-402.

Zebker, H. A., P. A. Rosen, R. M. Goldstein, A. Gabriel, and C. Werner, 1994, On The Derivation Of Coseismic Displacement Fields Using Differential Radar Interferometry: The Landers Earthquake: Jour of Geophysical Research, vol.99, no. B10, pp. 19,617 - 19,634.