TEAM REPORT

Earthquake

EARTHQUAKE HAZARDS

CEOS DISASTER MANAGEMENT SUPPORT GROUP

SUMMARY

This Report is a summary of the current and projected utility of Earth Observation (EO) space technology applied to the management of earthquake risk. The study is compiled by the Earthquake Hazard Team of the Disaster Management Support Group of the Committee on Earth Observation Satellites compiled the study.

Currently, *operational* EO capabilities have some limited use in the mitigation and response phases of earthquake risk management, but not in the warning phase.

In terms of mitigation, EO is useful, particularly in developing countries, for base-mapping for emergency relief logistics, and estimation of settlement and structure vulnerability (e.g. building design) and exposure (e.g. proximity to active areas). In the response phase, EO's improving contribution is in damage-mapping – of prime concern to relief agencies that need to locate possible victims and structures at risk. EO is also valuable to the insurance industry, which needs to assess losses (the insurance industry is important because of the influence it has over the instigation of and adherence to earthquake-sensitive building codes). As for the warning phase (and in the case of earthquakes) this means prediction of an impending event, and any warning must meet stringent accuracy requirements. Currently, no EO approach comes near to the required level of reliability.

Improvements in damage mapping capability are marked by the new generation of Very High Resolution (VHR) missions, such as SpaceImaging's Ikonos-2, though bottlenecks in the data supply chain strain any claim to offer a Near-Real-Time (NRT) service (and additionally, the system's utility is reliant on cloud-free conditions). Although at the time of writing, IKONOS-2 is the only civilian VHR mission in operation, a number of similar missions are promised for the future (including cloud-penetrating radar) which should promote competition and be efficacious to faster delivery of less expensive data.

SAR interferometry (InSAR) holds increasing utility for the mapping of seismic ground deformation (as widely applied over Turkey for the Izmit earthquake of August 17 1999). By using InSAR to study pre- co- and post-seismic deformations, the technique contributes to the mitigation phase by adding to the spatial understanding of fault mechanism dynamics and strain. InSAR is also useful in the response phase as ground displacement can correlate with damage in built environments. Though a remarkable capability, system and process constraints preclude a routine or global application. There are, however, promising developments underway with the development of naturally occurring and man-made SAR signal reflector arrays in two hybrid techniques called Permanent Scatterer InSAR and Corner Reflector InSAR respectively. The three complementary InSAR techniques together, in combination with an appropriate SAR data acquisition strategy, promise an economic substitute or supplement for expensive ground-based GPS and laser-ranging networks in many circumstances.

Recently, commendable efforts have been made by a number of space agencies under the auspices of the *International Charter on Space and Major Disaster*' to acquire and disseminate 'response' data in terms of damage mapping for some earthquake events. We consider this a major step forward in co-operation and co-ordination, and foresee significant progress as other agencies enroll.

However, in general, such provisions are not co-ordinated or integrated with other services, and are not widely accessible to, or understood by the earthquake disaster management community. With the hopefully increasing availability of VHR data (and possible constellations of VHR satellites), co-ordination of effort and motivation to acquire imagery will become paramount.

In terms of capability, it is the conclusion of this report that base-mapping and damage-mapping will become the main operational contributions of EO to earthquake disaster management, with operational strain-mapping showing good potential for the future.

SUMMARY OF RECOMMENDATIONS

Adoption of the following specific recommendations would considerably enhance the utility of EO space technology for earthquake risk management:

Recommendations that are technically feasible now:

1. Compile base-maps of high risk areas: Expand existing global database of seismic risk zones, and integrate with population distribution, infrastructure and building stock databases, seismic history, relevant geology, known strain and EO/topographic map merges for base-maps.
2. SAR data providers to optimize the raw data supply chain for InSAR analysis.
3. SAR data providers to consider the acquisition of strategic datasets over high-risk areas to facilitate Permanent Scatterer InSAR strain mapping and co-seismic interferogram generation.
4. Undertake Permanent Scatterer InSAR over high risk areas to identify virtual positioning arrays and produce 9 year (period covered by ERS SAR data archive) record of strain.
5. Continue investigation into areas of earthquake forecasting research (e.g. thermal, electromagnetic).
6. Agency certification of EO products.

Recommendations for the future:

1. Support diversity of VHR missions to improve temporal resolution and coverage.
2. Bring VHR providers into the *International Charter* to facilitate damage assessment (though CNES already a signatory and SPOT 5 should make significant contribution).
3. Lobby for planned VHR SAR missions to be InSAR-friendly, e.g. orbit control, metadata, and strategic acquisition.

Recommendations internal to the CEOS working group:

1. Consider the instigation of a single co-ordinating, expert body that will serve the EO requirements of the earthquake disaster management community, whilst negating any need for them to become involved in EO technically.
2. Look for common recommendations between disaster types for a possible method of prioritisation.
3. Determine audience(s) for the Disaster Management Support Group website and establish links from/to other relevant sites.

I. SCOPE AND BACKGROUND

Due to the devastating socio-economic impact of earthquakes, considerable scientific and technological effort is expended towards understanding and assisting in the disaster phases of mitigation, warning and response. However, this effort can result in inflated aspirations or claims. For this reason, this document, if it is to be well grounded, must carefully weigh the claims and evidence for the effectiveness of results. Furthermore, especially inasmuch as disaster management practitioners are responsible for lives and property, there is every need to ensure that proposed science/technological solutions or contributions are reliable as well as effective. There is little room in this community for techniques or methods, which have not been proven. A comprehensive literature survey forms the basis for this report.

In this document, categories of EO capability are distinguished thus:
Operational: Where science is proven and technology, systems and processes exist to provide a continuing operational service (not necessarily everywhere).
Developmental: Methodology/technology has been validated and is in the process of being implemented operationally.
Research: Results are uncertain or form the basis for ongoing research and understanding. Not expected to be directly used by the practitioner. The mechanisms and occurrence of earthquakes are not understood as well as they are in the case of most other disasters. For this reason, in comparison with other disasters, more emphasis and effort are placed on earthquake-related research.

Three phases of operation are recognised – mitigation, warning and response. For earthquakes specifically, these terms mean the following:
Mitigation: Involves risk reduction and monitoring to lessen socio-economic impact of a possible earthquake event. Can be GIS-based and include mapping of population vulnerability (including building stock) and exposure as input to planning and building regulations. Mapping strain (particularly by ground-based networks) and geology, planning logistics for response scenarios, planning evacuation routes, public education programmes.
Warning: Forecasting and warning processes and systems. For earthquakes, this implies predicting an event to within 15km, a few days, and one order of magnitude – a current impossibility by accepted scientific methods.
Response: Mapping damage extent and nature; primarily for purposes of relief. The information required in the first hours after an event is not necessarily the same as that required days or weeks afterwards, e.g. mapping damage for insurance loss estimation.

The rest of the document discusses each of these three phases in turn, considering:

- The disaster manager's information requirement
- The current EO capability, stating whether the capability is operational, developmental or research
- Ideal EO capability
- Recommendations for next steps

II. MITIGATION

Earthquake disaster mitigation means trying to protect the public against the possible impact of future earthquake events. The obvious course for action is to remove populations from zones of known high seismic risk. In most cases this is not economically practical, and, particularly in developing countries, the reverse is in fact occurring.

Alternatively, it is possible but very costly to construct an environment, which will withstand almost any earthquake. But the high cost is often prohibitive and therefore dictates the need for an accurate assessment of the exposure and vulnerability of settlements in terms of the probability of occurrence and magnitude, and the accelerations likely to be experienced. EO can certainly help in mapping exposure (e.g. settlement proximity to areas at risk) and can go some way in identifying vulnerability (e.g. building characterisation). Assessing the probability of occurrence, magnitude and likely accelerations, however, is an extremely difficult task in regions where earthquakes occur frequently, and a practically impossible challenge where they are rare.

Where there are enough seismic data, the frequency of large-magnitude events can be gauged by extrapolation from the frequency of smaller events. This, however, is providing only a first approximation; to get a better assessment, geophysicists try to locate, map, and understand local faults and their frequency and mechanism of rupture. This understanding is placed in the context of the regional tectonic setting of crustal motion (neo-tectonics). In areas of low seismicity (where earthquakes can still pose a serious threat), assessments of frequency and magnitude are based on geological evidence (slickensides, sand blows, etc.) as well as tectonics. It is important to recognise that this fundamental geophysical research makes a direct and important link to the practical issues of effective earthquake mitigation.

There is consequently a requirement for a variety of spatial and temporal information from different sources: demographics, building stock characterisation, seismic history and neo-tectonic understanding, the location of faults and an understanding of their mechanism dynamics, including fault motion and strain.

Information requirement summary

- Demographics
- Infrastructure (communications, utility and high risk installations, hospitals, relief centres)
- Building stock
- Seismic history
- Neo-tectonics
- Lithology
- Fault locations and fault mechanism dynamics
- Strain estimates and budgets

Information user

- National to local authorities (planners, building regulators).
- Government agencies with specific charge to mitigate against earthquake risk.
- National survey agencies.
- Possible disaster management co-ordinating body (see recommendations).
- Possibly some relief agencies (planning for disaster scenario).
- Insurance/re-insurance industry (assess liability).
- Risk management consultancies.
- Private enterprise (to mitigate financial impact and losses)

Current EO capability

Following are areas of contribution of space technology to earthquake disaster mitigation (ranging from operational to research):

Demographics and infrastructure: Basic maps simply showing the location of settlements are still considered secret intelligence in many parts of the world. After the Afghanistan earthquake of February 20 1998 which killed approximately 10,000 people relief efforts were hampered by the unavailability of such simple maps – aid workers simply did not know the location of affected villages. High resolution, e.g. SPOT panchromatic, and VHR data could play a significant role in this type of base-mapping of all regions in the developing world in zones of high seismic risk. Augmenting the locations of settlements, risk managers ideally want databases of building stock. With this information, rapid estimates of damage can be made for any given earthquake scenario, either pre-event for planning, or post-event for response. With the right political will, such databases could be instigated now within a GIS environment, coincided with other data layers including seismic history, geology, known strain, locations of relief centres, hospitals, etc. This would have the added benefit of highlighting vulnerability and exposure in a more systematic and consistent fashion than is currently performed. Such a database would be invaluable in providing rapid base information to those administering relief and managing disaster logistics. ***Status: operational*** (if resourced).

Tectonic setting: The regional tectonic setting of an area forms the basis for assessing its seismicity. In some cases, e.g. Japan and Southern California, the setting is well known, but in others, e.g. Central and Eastern US, the origin of seismicity is less clear. Several space-based techniques continue to contribute significantly to our understanding of regional tectonics including satellite geodesy (satellite laser ranging, very long baseline interferometry and use of GPS). Radar, and in the future laser altimetry, is useful, especially over the ocean to map the geoid and gravity field. Even satellite data on the magnetic field are used to study and interpret regional tectonics. Geophysical contributions from these satellites will increase as their capabilities in terms of sensitivity and resolution improves. ***Status: operational.***

Neo-tectonics: Recent tectonic activity is closely associated with contemporary seismicity and is studied in several ways using satellite observations. Both optical and radar data are used to image, for example, active fault scarps, actively growing folds at the surface that record buried tip-line thrusting and stream offsets or topographic breaks of slope that relate to active faulting. Multispectral or hyperspectral optical satellite data may, under some circumstances, be used for lithological discrimination that must be mapped to allow geo-chronological correlation. Most of these techniques require as good a resolution as is available, though Landsat TM at 30m (and now ETM) is often the standard tool. In addition, satellite data can be used to map lithology within a seismic zone to infer potential mechanical responses to an earthquake, such as liquefaction in flat lying coastal or lacustrine environments or slope failure for a continuum of rock competencies. ***Status: operational.***

Lineament mapping: These often-obscure features are observed in synoptic space images as, for example, alignments of vegetation and topography. They may be the surface manifestation of active faults and evidence of seismicity. Virtually constant (solar or radar) illumination angle can seriously bias results and the relationship between lineaments and seismicity is not very strong. Nevertheless, in areas susceptible to occasional earthquakes and/or where other data are sparse, lineament mapping is a useful operational tool. Visible and infrared imagery with moderate (>10m) resolution is generally used. Synthetic Aperture radar (SAR) may also be used but the self-illumination of radar can create false impressions of linearity. ***Status: operational.***

Fault-motion and strain: For two decades satellite laser ranging and very long baseline interferometry have been used to monitor strain and crustal motion respectively in the vicinity of active faults. These techniques have since been superseded by GPS as rapid development of receivers has made it possible to install them in dense networks to monitor large areas, e.g. the Los Angeles Basin and the whole of Japan. Using these arrays, it is possible to improve maps of known faults, detect possible unknown faults, and locate places on these faults which are locked and therefore susceptible to sudden rupture and earthquakes.

Measurement of ground strain and stress accumulation is a direct and valuable input to models of earthquake risk, and for prone countries that have the money, wide-area GPS arrays are now used to monitor horizontal ground motions. In recent years, InSAR has demonstrated the ability to map line-of-sight ground motions, and work is underway to develop hybrid InSAR technologies to supplement or even replace GPS networks.

Three complementary InSAR techniques are appropriate in earthquake risk management: conventional (imaging) InSAR, Permanent Scatterer InSAR (PSInSAR), and Corner Reflector InSAR (CRInSAR).

Conventional InSAR: This technique can deliver spectacular measurements of the large-scale ground deformations associated with main earthquake events, *provided* the temporal separation and horizontal baseline between the two SAR scenes used are kept within appropriate limits. Many examples exist. Such results on their own offer unique input to strain models and support the understanding of fault mechanisms, and have even been successfully used for the verification of insurance claims. Though usually applicable to the main co-seismic event, and so is perhaps a 'response' technique, the deformation information can provide valuable understanding of fault mechanisms and thus input to forecast models in the mitigation phase. However, conventional InSAR is not considered a tool for the measurement of the millimetre-scale motions associated with interseismic activity; the displacement resolution of the technique becomes degraded by temporal decorrelation and/or atmospheric heterogeneity resulting in phase ambiguites of similar orders of magnitude as the ground displacements anticipated.

Corner reflector InSAR: This technique involves the placement of man-made radar reflectors, against which precise, sub-centimetre measurements of displacement can be measured over time. CRInSAR is appropriate for the motion monitoring of specific structures (dams, bridges, power stations, etc) or more localised areas at risk The attraction of using corner reflectors is their positional stability, zero maintenance requirement and, in particular, their persisting high coherence over the time-spans needed to detect tectonic motion. However, the techinique is invasive and there can be issues of reflector security on the ground.

Permanent scatterer InSAR: This technique involves the processing of more than 30 interferograms over the same place to identify a network of temporally-stable, highly reflective ground features – permanent scatterers. The phase history of each scatterer is then extracted to provide interpolated maps of average annual ground motions, or more importantly, the motion history, up to 9 years (length of SAR data archive), of each individual scatterer, thus providing a 'virtual' GPS network with 'instant' history. Due to the relatively high density of scatterers that occur in built environments (a few hundred per square kilometre) and the large number of atmosphere samples (SAR scenes) used, the heterogeneity of the atmosphere can be accurately modelled so that measurements of sub-millimetre accuracy can be calculated. A limitation of PSInSAR is the lack of control over precise scatterer location, but with the densities obtained in built environments this is not considered an issue for the mapping of interseismic ground motions.

Status for InSAR techniques: Developmental & operational (dependent on land cover characteristics and SAR data coverage).

Ideal EO capability

InSAR synergy: None of the three InSAR techniques on their own offer a complete solution to the monitoring of co- and interseismic ground motions. Each technique has its own advantages and disadvantages. The degraded resolution of conventional InSAR renders the technique more appropriate to the mapping of larger scale displacements in terms of both magnitude and coverage, in other words it is more appropriate to the measurement of main earthquake events. Given sufficient repeat SAR data, the sub-millimetre accuracy of PSInSAR does represent an effective tool for the measurement of interseismic ground motions. However, the PSInSAR model makes assumptions about the atmosphere that might not be true from one urban conurbation to another (within the same SAR frame) that might be separated, for example, by 25km of non-scattering, rural farmland. Interpolating PS results between such large distances could be misleading. Depending on the density of scatterers, PSInSAR is more appropriate to the monitoring of contiguously developed areas. The advantage of CRInSAR is that the target against which measurements are made can be sited exactly where required - across a bridge, around a dam, along a pipeline, across a fault. Because of the invasive nature of CRInSAR and the costs associated with the manufacture and deployment of reflectors, CRInSAR is considered more appropriate to localised installation[1].

If we assume an existing 30-scene + archive of SAR data, and a promised continuity of repeat acquisitions, then the InSAR technique to apply is determined by a) area to be monitored, b) ground velocity, and c) distribution of existing scatterers. Consider the table below.

Apply this technique
Conventional InSAR
CRInSAR
PSInSAR

When

Area to be monitored	Ground velocity (slow= interseismic) (fast=coseismic)	Scatterer distribution
Regional	Fast	Poor
Structure specific	Slow or fast	Poor
Contiguous development	Slow or fast	Good

Assuming a supply of data, the ideal strategy might be as follows:

- Continuous acquisition of data over the area at every opportunity to enable PSInSAR as soon as possible.
- Installation of CRs around sensitive developments or faults. Measurements against these can be made after only two post installation acquisitions.
- The acquisition strategy allows for the generation of a conventional interferogram should an earthquake of large magnitude strike.

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[1] *A new and promising hybrid to CRInSAR is the development of a small and inexpensive 'active transponder' that will emit SAR frequency radiation when illuminated by the same. Providing such devices can prove phase-stable over time, the possible applications are widespread.*

If a mission existed that could acquire coverage say twice a day, coherence should be adequate for all but the most rainforested of areas. This, plus continuous additions to the interferogram time-series could allow the atmosphere to be modelled out. If such a mission existed, conventional InSAR on its own might enable the reliable measurement of interseismic motions (above some millimetre threshold).

It is important to note that in all InSAR techniques, phase change measurements are line-of-sight between the satellite and the target. The InSAR result on its own does not de-couple horizontal from vertical displacements. The technique also becomes progressively less sensitive if the vector of displacement nears that of the satellite track. For these reasons, until such times as mulit-view angle satellite constellations exist, InSAR techniques are likely to be largely supplemental to other ground-based monitoring systems.

Recommendations for earthquake disaster mitigation

1. Compile base-maps and building stock databases of high risk areas: Expand existing global database of seismic risk zones, and integrate with population distribution, vulnerability and exposure, seismic history, relevant geology, known strain, estimated InSAR coherence levels and optical VHR-derived base-maps.
2. SAR data providers to optimize the raw data supply chain for InSAR analysis.
3. SAR data providers to consider the acquisition of strategic datasets over high-risk areas to facilitate Permanent Scatterer InSAR strain mapping and co-seismic interferogram generation.
4. Undertake Permanent Scatterer InSAR over high risk areas to establish virtual positioning arrays and produce 9 year record of strain.
5. Agency certification of EO products.

III. WARNING

A prediction of earthquake can be extremely dangerous. It can ignite fear and anxiety, resulting in disorder and chaos and a level of damage and injury that might approach that of the predicted earthquake itself. It is for this reason that some authorities have established strict protocols for the evaluation and issuance of earthquake warnings. In addition to being validated and issued by an official authority, an effective prediction should be specific and accurate in three regards: time, place, and magnitude. The accuracies required vary with respect to the purpose of the prediction: public alerts should be accurate to within (about) 15km of the epicenter, a few days of occurrence and within 1 unit of magnitude. For other purposes (for example, advanced warning to officials and public works) they may be less accurate but, in this case, care must be given to avoid public release or disclosure.

There are no generally accepted operational methods for predicting earthquakes. Although some successes have been claimed, they are questionable and, in any case, not sufficiently reliable. Techniques being investigated range from the reaction of animals, to inert gas content of well waters. Variations in the electrical field have also been claimed to be precursors to earthquakes. Some of these “signals” have been observed from space and reported in Russian and Chinese literature. However, the validity of this technique is hotly disputed. Thermal anomalies, particularly over the ocean, are also claimed as earthquake precursors but here again the reliability (and physics) of the process is questioned. While research on these space-based (and other) techniques continues, it seems that we are still far from a method, which will provide predictions of sufficient accuracy to meet operational requirements.

Information requirement summary

- Timing of event accurate to within a few days.
- Location of predicted epicentre, accurate to within around 15km.
- Magnitude of event accurate to within 1 unit of measurement.

Current EO capability

None. Claims that thermal and electromagnetic signals may provide warnings are being investigated.

Ideal EO capability

Science and technical issues not understood sufficiently to recommend any ideal EO capability.

Recommendations for earthquake disaster preparedness/warning

Maintain awareness of, and support investigations into areas of earthquake forecasting research (e.g. thermal, electromagnetic).

IV. RESPONSE

Earthquakes can completely devastate a region in a very short space of time, so it is necessary to provide emergency help quickly. Emergency managers must therefore have some information, even if it is approximate, on what they are facing within hours after the event. The urgency for information following a severe earthquake is so immediate that some major relief organizations depend on damage assessment models. These models will contain data on building stock, infrastructure, utilities and other important aspects of the built environment (e.g. hazardous chemical stockpiles). In addition, the models will contain data relative to seismic acceleration (depth to bedrock, soil type etc). With specific data on location, depth, magnitude and first arrival of a seismic event, these models can provide very valuable timely approximations to the extent of damage. An example of such methodology, though still in its infancy, is the Russian ‘Extremum’ system. *Note that the database recommended for the mitigation phase is relevant to response.*

The information required is a function of both time and geographic distribution. For buried victims to have any chance of being brought out alive, information on the location of damage and access routes is needed from immediately after the event to within a few days. The information need not be cartographically accurate, as most emergency services able to respond within this time frame will have some knowledge of local geography. It is when more formal, non-local relief arrives that accurate, georeferenced maps become essential. Registered data are also needed to map the fires, which frequently accompany earthquakes.

In the days following an earthquake, more detailed information on structural damage is needed. As days become weeks, additional information becomes less and less important. The rate at which the life-saving value of new information decays depends, in large part, on the geographic extent and communication infrastructure of the affected area and the concentration of population. In sparsely populated mountainous areas for example, information on villages affected by large earthquakes may be valuable days and even weeks after the event as rescue teams try to locate people in need of assistance.

It is important to recognise the needs of the insurance industry and the risk management consultancies that serve them. This is because the insurance industry influences the instigation and adherence to earthquake-sensitive building codes, therefore mitigating against future loss of life and damage. Insurers need to map risk and damage to assess their liability and validate claims. To this user, there is no NRT requirement, damage maps still being useful weeks after an event.

Information requirement summary

- Location, nature and extent of damage
- Databases of infrastructure and building stock
- Location of fires
- Location of utilities (including both those of potential use and those of high-risk, e.g. chemical plants, nuclear reactors, dams, etc)
- Changes to access (e.g. roads or bridges destroyed)
- Extent of any flooding

Information user

- Emergency services
- Relief agencies
- National and local authorities
- Insurers and risk management consultancies
- National surveys and mapping agencies
- Construction industry
- Media

Current EO capability

Damage mapping using image-differencing: *A*s stated within the mitigation section, pre-prepared GIS databases and delivery systems would be of value in the response phase when relief services are planning logistics to reach victims and make safe damaged structures. Using post-event acquisitions, the EO imagery contained within such databases could also be used to generate difference images to assist in the mapping of damage. 1m VHR data, such as that acquired by IKONOS-2 can map damage directly to useful degrees of accuracy, though utility is much improved given pre-event imagery with which post-event imagery can be differenced (though differences in incidence angle and solar azimuth between the two acquisitions can cause mis-classifications).

Recent work performed for the *International Charter* on the Indian Gujurat earthquake illustrated some of the difficulties in classifying damage (*Chiles, NPA, 2001*). 10m resolution pre- and post-event SPOT panchromatic imagery was acquired and differenced to map change. Results were then compared against a single post-event IKONOS image where damage was directly and thus more easily identifiable. Only one classification of damage out of 30 made from the SPOT temporal difference image was verified as correct using the single post-event 1m IKONOS image. Differing incidence angle and solar azimuth between the pre- and post-event SPOT acquisitions caused many misclassifications of the SPOT data.

IKONOS interpretation of sites from SPOT change detection processing	Sites with no apparent damage	Large or brightly reflective building	24
		Flat ground or possible low buildings	3
		Trees and ground only	2
	Sites with damage	Collapsed building	1
		Partially damaged building	0

Comparison of damage classification between SPOT temporal difference image and single post-event IKONOS

Useful results have also been produced using pre- and post-event 5.8m resolution IRS data over Izmit with effective results, clearly revealing many of the changes to the built environment that occurred due to the quake. The use of IRS data is not currently an NRT application and so is only of relevance to those estimating losses and planning for reconstruction. Ideally, pre- and post-event VHR data should be used for the most accurate damage classification, as there was still some confusion with the single post-event IKONOS scene caused by the extreme density of building stock in this particular Indian town. ***Status: operational*** (if resourced and cloud free).

Non-NRT deformation field mapping: There can be correlation between ground deformation and damage when mapped using conventional InSAR, though damage in this case is dependent on building design and the ground accelerations experienced. This is not currently an NRT application, and so is largely of relevance to those estimating losses and planning for reconstruction. However, it can and has been of significance to those analysing vulnerability and exposure in efforts to re-site populations to safer locations. ***Status: operational*** (where land cover characteristics and SAR data coverage allow).

Damage mapping using night-time differencing: Some useful ‘emergency’ assessments of urban damage have been made by the Japanese Disaster Prevention Research Institute of Kyoto by differencing pre- and post-event night-time optical imagery from NOAA’s AVHRR instrument which makes up to six passes a day. By mapping changes in the distribution of artificial lighting, estimates can be made of potential damage. However, caution is required due to the low, 2.5km spatial resolution, the fact that damage to a single power station might cause large regions to be blacked-out, and of course issues of cloud cover. ***Status: operational*** (where cloud-free imagery exists)

Ideal EO capability

An ideal capability would allow us to map the extent and nature of damage within hours and the deformation field within a few days. Such an NRT service could only be facilitated by multi-platform VHR constellations, preferably SAR, which would have the all-weather capability needed. Besides the hardware in space, supply chains would have to be optimised to ensure the fastest data access and delivery mechanisms.

It is likely that such constellations will one day exist, but be commercially driven and operated by a number of disparate consortia. There are consequently issues of co-ordination to ensure the most efficient imaging regimes for a given event, and commercial/altruistic motivation (who is going to pay?). These issues are common to all disaster types that will benefit from VHR - being the first to image a spectacular volcano is of high promotional value, but the loss of crops after a storm?

Recommendations for earthquake disaster response

1. Compile base-maps of high risk areas: Expand existing global databases of seismic risk zones, and integrate with population centres, infrastructure and building stock databases, seismic history, relevant geology, known strain and optical VHR-derived base-maps.
2. SAR data providers to optimize the raw data supply chain for InSAR analysis.
3. Bring VHR providers into the *International Charter* to facilitate damage assessment (note CNES is already a signatory and SPOT 5 should make significant contribution).
4. Lobby VHR providers for assurance of co-ordinated satellite tasking, data acquisition and rapid data access.
5. Support diversity of VHR missions (in order to improve temporal resolution).
6. Agency certification of EO products.

Proposed Earthquake Emergency Scenario

Activation:

- Dependent upon issues of vulnerability and exposure *vs* magnitude of event.
- Dependent on level of threat to life and / or property (threshold?).

Obtain background information

Check if considered

1.	Location and depth of event (lat, long, km)	
2.	Magnitude: Richter (energy release) and Modified Mercalli Intensity (effects)	
3.	Date and time of event	
4.	Responsible relief agencies	
5.	Contact information for relief agencies (including on-scene commander/coordinator)	
6.	Exposure, i.e. proximity of population centers, structures at risk	
7.	Vulnerability, i.e. information on earthquake resistance (e.g. building design)	
8.	Availability of base maps for logistics and communication	

Map damage and extent (utility for base-mapping also)

- Relevant satellites: SPOT-1/2/4, SPOT 5, IRS, IKONOS-2, QuickBird.
- Pre- and post-event imagery imperative for SPOT-1/2/4 and IRS, but desirable for all listed to improve damage classification accuracy.

1.	Availability of pre-event imagery (all listed satellites)	
2.	Availability of post-event imagery (all listed satellites)	
3.	New acquisitions required (*International Charter* signatories?)	
4.	Order pre- and post-event imagery where already acquired	
5.	Submit programming request for new post-event imagery	
6.	Register data and difference, classify damage, package, courier/ftp results	

Map deformation field

- Relevant satellites: ERS-1/2, ENVISAT and Radarsat-1.
- Relevant techniques dependent on previous strategies: Conventional InSAR, PSInSAR, CRInSAR.

1.	Check ERS/ENVISAT archive for minimum threshold repeat coverage for PSInSAR	
2.	Check ERS/ENVISAT archive for post-event acquisitions for conventional InSAR compliant pre- and post-event pairings, and to update CRInSAR analysis if relevant	
3.	Check Radarsat archive for post-event acquisitions for conventional InSAR compliant pre- and post-event pairings, and to update CRInSAR analysis if relevant	
4.	Submit programming request for new post-event acquisitions	
5.	Process, interpret, package, courier/ftp results	

Priorities for image acquisition planning

1.	Post-event VHR acquisitions for damage and base mapping	
2.	Post-event ERS/Radarsat for InSAR deformation field mapping	

Notes:

- Data delivery channels to be determined, e.g. via space agency or distributor?
- Specifications of finished product to be determined.
- Delivery mechanism and protocols to be determined.

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