Uses of Satellite Technology in Disaster Management

by Louis S. Walter

Satellite technology can make substantial contributions in each of the three phases of disaster management–preparedness, prevention and relief. Many of these contributions can be made with existing satellites and instruments; some will require modifications or the development of new technology.

The first sections of this report survey these existing and potential capabilities. Though much of this technological capacity has existed for a decade or longer, only a very small fraction of it is being used routinely. The reason is not lack of usefulness. Implementation has been delayed for other reasons, among which is a tendency of some technologists to emphasize technical development rather than recognize the needs and limitations of the disaster management community and the exigencies under which it operates. These problems will be considered in the final section. The focus will be on disaster-management needs in dealing with sudden natural disasters.

Earlier Studies

The needs for, and capabilities of, satellite technology in disaster management have been the subject of considerable study and discussion. Dr. Paul B. Richards of the U.S. Naval Research Laboratory has contributed several papers on the subject with particular reference to satellite remote-sensing systems.[1,2,3] These reports survey the current capabilities of such systems as well as the spatial and temporal resolution requirements for a wide variety of potential applications in disaster management.

The United Nations Office of the Disaster Relief Co-ordinator (UNDRO) reviewed requirements as well as existing and potential capabilities of satellite technology in disaster management for the International Conference on the Uses of Satellite Technology or "Unispace '82".[4]

In 1983, UNDRO also sponsored an Expert Meeting that brought together disaster-management specialists from a wide variety of international, national and independent agencies with space technologists in communications, meteorology and remote sensing. The forum was designed to let the technological community learn the requirements and operational methods of the disaster-management community, which could in turn discover the capabilities and potential of satellite technology.[5] The report of this meeting also lays out a program for the development and implementation of the technology, including requirements for research and development and training as well as legal, regulatory, operational and financial considerations.

More recently, the Committee on Safety and Rescue Studies of the International Academy of Astronautics produced a report that discusses the capability of space technology and the problems with its use in disaster management. [6] It calls for international and bilateral assessments of the role of space technology in disaster management and for continued dialogue between the communities, promoting proper and speedy development and implementation of the technology.

The material for this report has been drawn largely from these sources.

Satellite Technology

The Tools of the Trade

Since the birth of the space age more than 30 years ago, Earth-orbiting satellites have reached an advanced stage of complexity and diversity. They can, however, be rather conveniently separated into four categories: communications, meteorological, remote-sensing and geophysical.

Communications satellites have gained by far the widest use. Broadband satellite transmission of voice, video and digital business data has become a cornerstone of the communications industry, generally via satellites in equatorial geosynchronous orbit. Less well-known, though also of importance in disaster management, are the capabilities of unmanned ground stations and polar-orbiting and geosynchronous satellites in transmitting environmental data. The Sarsat/Cospas system, which transmits alert signals from foundering boats, downed aircraft and other vehicles in distress, is an important example of this capability.

Meteorological satellites are another relatively early development of the space age. Their synoptic observations of regional cloud distributions, nearly in real time from geosynchronous orbit, have become an important element in weather forecasting. Advanced techniques for determining cloud-top heights and wind fields are less well known but at least as important.

Remote-sensing satellites are used to observe, map and monitor features and phenomena on the Earth's surface. They are distinguished from meteorological satellites by their finer spatial resolution capability (they can generally resolve an object 100 meters wide or smaller). Such satellites orbit the Earth around its poles. For technical reasons (e.g., limitations on the rate at which data can be transmitted to Earth), these satellites' total field of view is limited to a swath a few hundred kilometers wide, thus limiting the amount of the globe they can observe in a day. Such satellites have an extremely wide range of potential applications but, because many factors including the suitability, timeliness and cost of the data and its collection and analysis, they have not yet attained that potential. Because of the diversity and the potential importance in disaster management, this type of satellite will be discussed in more detail below.

Geophysical satellites have received relatively little attention but may nonetheless play significant roles in disaster management. These satellites observe geophysical phenomena at or near the Earth's surface--monitoring the ocean surface, for example, or detecting minute changes in ground movements. Most of these capabilities are still in experimental stages but the future is bright for some significant breakthroughs.

Tradeoffs in Designing Remote-Sensing Systems

Any "system" consists of component parts: parts which are interrelated in such a way that a change in one often requires a change in another component--a "tradeoff." In considering the potential of remote-sensing systems for any application, in particular for disaster management, it is important to realize the tradeoff restrictions. Three parameters of such systems which are intimately related are the spatial, radiometric and spectral resolution.

A polar-orbiting satellite may circle the earth at an altitude of almost 1000 km, completing an orbit every 90 minutes. The point beneath the satellite moves with a velocity of about 400 km (240 miles) per minute. In one hundredth of a second, this point will move almost a hundred meters. If this is the resolution of the instrument on the satellite, then one hundredth of a second is the greatest amount of time which that instrument can afford to spend looking at any one spot on the Earth (the "dwell" time). In actuality, because of the way the instruments are designed, the time is much shorter. The result is that the visible light or other radiant energy by which the spacecraft sensor can "see" is limited. Thus, if we decrease (improve) the spatial resolution say, to 50 meters, we decrease the "dwell" time by 25 percent. Because of this, the detectors receive less energy and their ability to distinguish accurately small color differences is diminished. This capability is often important in characterizing the composition of surface materials. The result is a tradeoff between spatial and radiometric resolution.

Much of the information a spacecraft instrument can gather about objects on the Earth's surface concerns their spectral "signatures." These instruments generally take pictures of the surface in several spectral bands simultaneously. It is often desirable to make these bands as narrow as possible in order to improve the capacity to identify surface objects. Here again we are limited by the energy available to the instrument: higher spatial resolution curtails this energy and thus reduces spectral discrimination capability.

If high spatial resolution is a strong requirement, several steps may be taken. It is important to maintain radiometric resolution in order to be able to differentiate objects on the surface but spectral discrimination may be sacrificed, as in the case of high-resolution imagery from a French SPOT satellite. In addition, the satellite can be made to orbit at a lower altitude, though that decreases the width of the field that can be seen and thus the frequency with which it can revisit and observe any particular place on Earth. (A remedy for this is to enable the satellite to change orbits, but that becomes enormously expensive.)

Frequency of observation, a critical factor in terms of sudden disasters, may be considered the satellite's "temporal resolution." There are several ways it may be improved.

Polar-orbiting meteorological satellites can observe the entire Earth once a day because the area covered under the satellite (the swath) extends for a thousand kilometers on either side of the orbital track. Spatial resolution, however, is sacrificed in order to achieve this coverage. (Such instruments typically have spatial resolutions on the order of 1 km. A better spatial resolution would tremendously increase the rate at which data would have to be telemetered to Earth or would result in a decrease in either the number of scenes that may be acquired or the radiometric resolution.) In order to maintain (relatively) high temporal resolution without sacrificing spatial resolution, the SPOT satellite uses a pointable imager in order to select specific scenes from this broad field of view.

Temporal resolution also may be improved somewhat by employing non-polar orbits such as low-inclination orbits--for example, an orbit between 50 $^{\circ}$ north and south of the equator. Temporal resolution is improved because the satellite has less surface area to cover. However, in this example--an orbit too low to cover the United Kingdom or much of the German Federal Republic or the USSR--the satellite still covers more than 75 percent of the Earth's surface. Thus, the improvement in temporal resolution is not very great.

By lowering the spacecraft's altitude, the orbiting frequency may also be increased, but also minimally. This is because the frequency increases as a function of the proximity of the satellite to the center of the Earth. A change of even several hundred kilometers in altitude is small with respect to the distance to the center of the Earth--more than 6000 km--making a small difference in orbital frequency. This discussion assumes that the total field of view remains constant. If we are willing to reduce that field to observe only 500 km on either side of the satellite nadir, the revisit frequency can be reduced to four days. In this case, however, spatial resolution for much of the swath will be degraded when areas far off-nadir are observed and, again, either the telemetry rates will become very high or the number of scenes acquired will have to be reduced.

Raising the orbit to the altitude of a geosynchronous satellite can provide continuous coverage, but the greatly increased distance to the Earth's surface either degrades spatial resolution or add the cost of an extremely large optical system to achieve the resolution. In addition, at least three such instruments would be needed to provide complete coverage of the Earth and, even then, observations at higher latitudes will be degraded due to the planet's curvature.

The rigidity of orbital mechanics and optical physics as well as realities of system costs thus considerably constrain the spacecraft characteristics that are most desired for response to sudden disasters: radiometric, spatial and temporal resolution. For the time being, the optimal instrument appears to be a pointable imager that sacrifices spectral capability for spatial (and/or temporal) resolution. Some improvements would be achieved by flying such an instrument in a low-inclination orbit.

An important factor not yet considered in this discussion is cloud cover. A good rule-of-thumb is that approximately half of the opportunities for observing the Earth are lost because of cloud cover. Of course, this proportion varies considerably from place to place. Another important consideration is that, if a particular place on Earth must be observed on one day and it turns out to be obscured by clouds, the probability that it will be obscured on the second day is greater than normal because cloud patterns are likely to persist.

Instruments sensitive to microwaves can avoid this problem because they can "see" through clouds. While their capacity for spectral discrimination is limited, they can have good radiometric resolution. High spatial resolution (e.g., as low as 10 meters from a 400-km orbit) may be achieved using the synthetic aperture technique, which involves correlating the signal from several points along the spacecraft's orbit. (This correlation, however, may require more time and effort in data processing than required by optical systems.) Temporal resolution using the technique is subject to approximately the same restrictions as in the case of optical systems.

Current Capabilities

Remote-Sensing Satellites

The prototypical remote-sensing satellite was the Earth Resources Technology Satellite (ERTS), first launched in 1972, which carried as its prime instrument the MultiSpectral Scanner with a spatial resolution of 80 meters and a temporal resolution of 16 days. More recently called Landsat, the satellite now carries the Thematic Mapper as its primary instrument. This achieves a spatial resolution of 30 meters over a swath 185 km wide. Beginning in 1989, it was expected to have a 15-meter panchromatic resolution. Its repeat frequency will remain 16 days.

France's Systeme Pour l'Observation de la Terre (SPOT) carries a pointable imaging system capable of 20-meter resolution in four spectral bands or 10 meters panchromatically. Its swath is 60 km wide. Although its repeat cycle is 26 days, pointability allows it to observe anyplace on Earth every three or four days (though cloud cover may still obscure the view).

The European Space Agency (ESA) is planning to orbit a synthetic aperture radar (SAR) satellite in the future. This instrument is being designed for a 30-meter ground resolution and a swath width of 100 km. (The U.S. Seasat satellite once provided SAR imagery at 25-meter resolution but is no longer operating.) In 1992, Canada plans to launch a SAR, which is supposed to provide 15 to 30-meter resolution.

Space imagery at 5-meter resolution, obtained by the U.S.S.R. using photographic cameras, may be ordered from Sojuzkarta for any place on Earth outside the Soviet Union. However, procedures for film return probably would not provide sufficiently quick response to be of great value in disaster-relief operations.

The Japanese are planning to launch ERS-1 in 1991. This satellite will provide data similar to that collected by Landsat's Thematic Mapper.

The government of India has proposed to build and launch an instrument, LISS-II, which would provide a spatial resolution of 3.6 meters over a swath of 148 km. The frequency of coverage is not stated but, in order to provide global coverage at this swath width, the repeat frequency would be more than 20 days, assuming that the instrument is not pointable.

The U.S. Earth Observing System (EOS) is currently being designed for launch in the 1990s and will carry a wide assortment of instruments. Of particular interest in the management of sudden disasters may be the satellite's High Resolution Imaging Spectrometer (HIRIS) and the SAR, which are to provide imagery at 30-meter resolution in the visible/infrared and microwave portions of the spectrum, respectively.

While many of these systems are of potential interest and use to the disaster-mitigation community, only two may currently be considered operational: Landsat and SPOT. Data from other satellites is less certain to become available.

Geophysical Satellites

The U.S. and other nations have launched many satellites to explore aspects of the Earth's environment including the particle and energy fluxes from space and the Earth's magnetic and gravity fields. Precise mapping of the gravity field was a by-product of the tracking of satellites: Undulations in their orbits reflect the variations in the intensity of this field. With such precise gravity-field measurements, it has become possible to predict satellite orbits to within a few centimeters and this has led to several applications of potential interest in disaster mitigation.

It is now possible, using satellite-borne microwave altimeters, to measure the sea height to within five to ten centimeters. This information on sea state may be of use in routing ships as well as in tracking storm surges. Such information is being provided by the U.S. Navy's Geosat satellite and will also be acquired in the future by NASA's Topex mission.

In addition, laser tracking from the ground to satellites with special reflectors permits determination of baseline lengths to within about two centimeters. Repeated observations of baselines in earthquake-prone regions can detect the buildup of strain that may indicate of an impending earthquake.

A variation of this technique would place the laser aboard the satellite and the reflector on the ground thus enabling a greater density of measurements and more precise location of the accumulated strain. Furthermore, the expansion of volcanoes may be monitored using this method to provide information which may lead to the prediction of eruptions. Such an instrument is being designed for flight aboard the EOS spacecraft.

The U.S. Navy's Global Positioning System (GPS) is also being used for similar purposes. This approach uses Doppler tracking of several of the (projected) 21 satellites which have been emplaced to provide position location for the military. It appears that, while positional measurements would be slightly more difficult and expensive than with the spaceborne laser system, the GPS system would provide similar accuracies (within a number of centimeters).

Of these systems, only the Geosat and GPS may be considered operational.

Meteorological Satellites

Five satellites whose major function is the virtually continuous synoptic observation of global weather patterns surround the Earth's equator at geosynchronous altitude. Two of these were built by the U.S. and one each by Japan, India and the European Space Agency. There is an agreement that one of the satellites will be replaced if it fails. The primary instruments on the U.S. satellites (GOES) observe the Earth at 1 km resolution (8 km for temperature maps) and also make soundings of the atmosphere's temperature and water content.

Several types of polar-orbiting meteorological satellites have been launched by the U.S. including the National Oceanographic and Atmospheric Administration's TIROS, NASA's Nimbus and the Defense Department's DMSP satellites. These capture images of clouds and land surface with a resolution of 1 to 4 km resolution, covering the Earth daily. They also perform cloud-, land- and sea-surface temperature mapping as well as ozone mapping. The Soviet Union's Meteor-2 satellite provides daily global imagery of the Earth at 1 and 2 km and temperature maps at 2 km spatial resolution.

As in the case of the geosynchronous satellites, the polar-orbiting meteorological satellites are expected to be a continuous source of environmental data and should be considered operational.

NASA has proposed an experimental satellite, TRIM, that would measure rainfall, especially over oceans, using both a microwave radiometer and synthetic aperture radar. It is designed primarily to observe Earth's equatorial regions, where it should provide valuable information for tracking monsoons and predicting floods.

Communications Satellites

This paper focuses on remote-sensing satellite and other kinds with particular uses in disaster mitigation, but it should be noted that there are pertinent applications for the now commonplace communications satellites as well.

Among the least well-known satellites in this fleet are the relatively small and very inexpensive polar orbiting OSCAR satellites, which are launched (free-of-charge, piggyback) for use by amateur radio ("ham") operators. These provide an excellent (though perhaps somewhat less reliable and secure), very inexpensive mechanism for global communications, using ground relays set up by the amateur operators themselves.

The U.S. meteorological satellites have a small, but possibly important, function in communications. They carry transponders for telemetering data from ground-based sensors to Earth receiving stations so that on-the-spot measurements can be almost instantly available to analytical facilities. The Search and Rescue (SAR) system may be considered an extremely important subset of this function. Monitoring the Doppler shift in reception from a transmitting distress beacon as the satellite passes over beacon allows rescue teams to take a directional "fix" on the beacon's location. Another satellite passing from another direction, generally within an hour or so, can provide another directional fix and the position of the beacon is determined (to within about a kilometer) at the intersection of the vectors. As stated earlier, such battery-powered beacons are now routinely carried aboard planes and ships. The system, which has been operational for less than 10 years, has already been credited with saving many lives.

All of these systems may be considered operational.

The Use of Satellites in Sudden Disasters

Despite several decades of development, operational use of satellites in disaster management must be considered limited, especially in contrast to the tremendous potential of this technology. Indeed, much of this potential has been demonstrated, often under actual or simulated operational conditions, but in only a few cases has the technology become a continued, integrated part of the operational function with, more significantly perhaps, a commitment (or implicit commitment) for non-interrupted service of the space segment. The operational and potential uses of space technology in disaster management will be discussed here: the reasons for the disparity will be the subject of the next section.

Current Applications

Only two applications of satellite technology can be considered operational in disaster and emergency functions: storm warnings and search-and-rescue location.

Storm Warnings

The issuance of storm warnings depends, in part, on the geosynchronous meteorological satellites' capability for observing large-scale weather systems. For instance, they can observe, monitor and track the large circular convective patterns that give rise to winds of hurricane force. Through a global communications network, precise positions of such storms are reported to disaster management agencies every few hours, which may be very useful in warning residents to take precautionary steps. However, the effectiveness of those warnings depends on the communications system that will disseminate the warning, on people's readiness to take action and on the accessibility of defenses against the storm. In this case as in all other cases of disaster warning, the effectiveness of the warning is only as good as the state of preparedness.

Another important factor that influences the effectiveness of storm warnings is their degree of reliability. With the current state of the art, a storm location cannot be predicted more accurately than within several hundred kilometers, 24 hours in advance. Research on the dynamics of such weather systems and improved data from satellites on wind velocities and temperature distributions will improve the reliability in the future but, at present, storm alerts are subject to errors that cause many people to discount the warnings.

Search and Rescue

Initially based on the transmission of environmental meteorological data from unmanned ground stations via satellite (the ARGOS system), an international program for transmission of distress signals has become operational using transponders aboard U.S. and U.S.S.R. weather satellites (Cospas/Sarsat). Doppler tracking using multiple satellite overpasses allows precise (within a few kilometers) location of a radio distress beacon. Thusfar the beacons have been installed primarily aboard boats and aircraft so they may be located in case of accident. The system may also be of use in disaster relief operations.

An experimental beacon for transmitting information during relief operations was developed in a joint program of the Office of the U.N. Disaster Relief Co-ordinator (UNDRO) and the Centre Nationale d'Etudes Spatiale (C.N.E.S.) of France. The inexpensive, battery-powered beacon, contained in a small suitcase, had a keypad with which up to 40 characters of digital information could be entered into a memory buffer. The data would be transmitted repeatedly with a short (20 cm) antenna to passing polar-orbiting satellites. This encoded information concerning the disaster situation (dead, injured, homeless and requirements for clothing, housing, food and medicines, etc.) was relayed from the satellite to a center in Wallops, Virginia; then via communications satellite to Toulouse, France, and finally by telex to UNDRO in Geneva. The information was available about two hours after transmission.

The usefulness of the system is somewhat limited by its lack of two-way communication, which, more than anything else, prohibits the sender from knowing whether the message was received. It also constrains the range of information that may be transmitted, but this has a subtle advantage in terms of objective reporting: The coded form used acted as a "checklist" for the disaster relief officers. Gaining entry for such a communications device into a stricken country--even under diplomatic privilege--might also pose a problem. Many countries have strict rules against transmissions which are out of the control of the country's telecommunications agency.

Potential Applications

A thorough study would be needed to adequately define all the potential uses of satellites in disaster management. The works cited in the introduction (references 1 through 6) represent some initial steps toward such a comprehensive effort. This paper will cover some of the most useful, imminent or interesting applications in the three main aspects of disaster management--prevention, preparedness and relief.

Disaster Prevention

Hazard Mapping: Hazard maps indicate the distribution of hazards by type, intensity and incidence. Data from satellites can be used in mapping various types of hazards though they must often be analyzed with data from other sources to be meaningful.

The infrequency of earthquakes prohibits accurate prediction of future occurrences on the basis of statistical probability. Thus, earthquake hazard maps are often based on a theoretical understanding of earthquake propensity combined with information about regional and local tectonics. Among the features that may characterize active tectonic zones are lineaments (subtle alignments of topography, river valleys, vegetation, etc.), which may be observed and mapped effectively and efficiently using space imagery. [7] In addition, small horizontal and vertical movements that may indicate neotectonic activity can be monitored using techniques previously described in this paper.

Flood hazard maps usually show areas as defined by their frequency of flooding. Thus, if the data on flooding and related parameters such as rainfall are sufficiently complete in a watershed, a flood-hazard map can be constructed on the basis of the historical record. The value of historical records is limited, however, because the interval of recurrence may change due to alterations in land cover and land-use patterns in the watershed.

Another approach to flood hazard mapping is through modelling, involving a complex, computer-based representation of the watershed embodying characteristics such as soil type, topography and surface cover. It has been demonstrated that satellite data can be used to provide the land cover data and the geographic reference base for such models.

Landslides, mudslides and avalanches present some of the most deadly hazards faced by man. Here, too, satellite imagery can play a part by providing information on different types of surface cover. Unstable, barren, unconsolidated slopes (e.g., the Aberfan tip disaster in Wales) may be detected and mapped using satellite imagery. Laser or radar altimetric data (or perhaps stereoscopic imagery) may be used to determine topography. In the case of volcanoes, the heat during eruptions can melt snow and ice around the summit and cause catastrophic mudflows, as in the 1985 eruption of the Nevado del Ruiz volcano in Colombia. Again, satellite imagery can also be used to map such hazards.

Vulnerability Mapping: Such maps, which show both hazard levels and land uses for an area, alert the user to populated and developed land that may be vulnerable to catastrophe. Spatially accurate synoptic mapping of the Earth's surface provided by space imagery at resolutions of 10 to 30 meters can be used to show land use at appropriate scales.

Planning: Imagery from satellites may also be used in planning disaster-control measures. In the development of flood-control systems, such information could be used in developing flood-plain models and in siting catchments and levees. It may also be useful in planning slope-stabilization measures to prevent landslides.

Disaster Preparedness

The use of satellite data in storm warning, already operational, has already been discussed. Other kinds of warnings using current or projected satellite capability could be developed.

Floods: Several types of floods may be distinguished based on their causes and, in each case and in different ways, satellite data may be useful for providing warnings. The few warning programs now operating are based primarily on ground-based sources of data such as rainfall and stream levels. Satellite telemetry is occasionally used to transmit these data from automatic data collection platforms.

Many floods result from the melting and rapid runoff of accumulated snow cover. The extent, depth and water content of the snow, now estimated by laborious and costly sampling, can also be determined by satellite instruments. Important information on potential melt rate may also be obtained by estimating ground surface temperature using satellites.

Current satellite technology can also make a modest contribution in predicting floods caused by excess rainfall. Where there are no other means of obtaining this information, geosynchronous satellites can provide data to map clouds that may be the source of rain. Over large areas, the resulting inferences about rainfall distribution help in assessing flooding probabilities.[8] More advanced techniques based on the microwave attenuation of rainfall are being developed for future, more accurate, satellite determination of precipitation.

Storm surges--the pile-up of water due to wind stress on the ocean surface--have caused tremendous loss of life in densely populated, low-lying areas such as a the coast of Bangladesh. The Seasat satellite has already shown that it can accurately determine the wind stress field, and satellites such as Topex and ESA-1 will continue to provide these data in the future, making it possible to provide advance warning of surges.

Landslides: Given a base map depicting landslide vulnerability, precipitation information from satellites (using either cloud mapping or microwave techniques) could help in providing alerts of landslides.

Volcanic Eruptions: Explosive volcanic eruptions are often preceded by dilation (topographic expansion) of the flanks of the volcano. Mount Saint Helens, for instance, bulged 100 meters before it erupted. This change in relief would be readily detectable by interferometric analysis of synthetic aperture radar data provided by future satellites. More precise (but spatially less dense) measurements will be possible using satellite-borne laser ranging systems now being designed.

The Total Ozone Mapping Spectrometer (TOMS) currently operating on the Nimbus-7 satellite can detect the sulfur dioxide emitted by explosive volcanoes. This information could be useful, for instance, to airlines and their pilots in providing warnings of the possible presence of volcanic dust, which can foul jet engines. In order to provide timely warnings, however, continuous observations from geosynchronous satellites would be required. It is also possible that satellite data on the rate of sulfur dioxide release before an eruption could help in forecasting the event.

Earthquakes: Geodetic ranging is based on one of several space technologies--satellite laser ranging (either from the ground to a satellite or vice versa) or microwave interferometry (using either quasars or Global Positioning System sources). These techniques can provide precise data for monitoring the accumulation of stresses. As previously discussed, earthquakes often occur due to the sudden release of such stresses built up through a long process of slow earth movements. Data from satellites may prove very valuable in the total ensemble of data required for earthquake prediction, but considerable research in the area is still required.

Disaster Relief

Communication: Relief provided for sudden disasters generally is on a small scale, involving only a few relief experts with minimal equipment. Communication systems entailing several technicians and bulky equipment (including power supplies) is not consonant with this level of operations and would thus be of limited utility. A useful system would be easily transportable, battery-powered, rugged and operable without technical support. It would provide two-way communication but not necessarily at a high data rate.

Such a system was proposed in 1980 in a NASA study for UNDRO.

That study showed the technical feasibility of providing teletype communications with a suitcase-sized keyboard/printer/transmitter and a collapsible antenna. Although two-way voice communications using small portable satellite transceivers is already available for military applications, the teletype system would be available for civilian use and would be more than adequate. Frequency allocations should be facilitated under the International Telecommunications Union mandate to provide for disaster-relief communications.

Broad-scaled Surveys for Relief Operations: Broad-scaled surveys of large areas at moderate spatial resolution can sometimes provide valuable information for assessing the limits of damaged areas. In such cases, large areas must be surveyed in a short time, often under arduous conditions, and satellite observations can be of great use, for example, in mapping areas struck by floods or covered by volcanic debris, mudflows or landslides.

To apply remote sensing in this case, a pre-disaster land-cover map, preferably satellite derived, should be available. The tradeoff between spatial and temporal resolution may be especially important: For some uses, imagery at 1-km spatial resolution obtained daily from weather satellites, would be of use (e.g., in broad flooded areas). In other cases, more detailed (e.g., 10- to 30-m resolution) imagery would be needed. The temporal resolution may be provided by pointable imaging systems (e.g., SPOT) or by the use of (pointable) SAR sensors, which can "see" through cloud cover.

Detailed Surveys for Relief Operations: Current remote-sensing instruments are only marginally capable of showing the important details in a relief-operations area. At a resolution of 10 meters, one may be able to observe large houses which have been completely flattened (provided there is a base of data against which to compare the post-disaster images). One must remember that a resolution of 10 meters provides no information within a 100 square meter area so one must aggregate such "pixels" in order to provide a discernable picture.

Provision of higher spatial resolution from satellite altitudes is possible, but there are some technical limitations (i.e., the tradeoffs discussed earlier) and substantial cost barriers. There are also international political barriers limiting the availability of high-resolution imagery of foreign countries.

Beyond the limitation of spatial resolution is the problem of coverage frequency, which, as noted earlier, is worsened in the case of visible/infrared systems by cloud obscuration. For example, during the 1988 Armenian earthquake relief effort, inquiries were made to obtain SPOT imagery but, despite the strong effort of SPOTImage, this was not possible because the region was beclouded continuously for several weeks. Even aircraft coverage following the 1989 Loma Prieta earthquake was precluded for several days because of cloud cover and smog around San Francisco. Furthermore, (and this points out another limitation), it turned out that no imagery of this region had previously been acquired; if post-earthquake images had been obtainable, there would have been no "baseline" data against which to compare them.

In summary, it seems more likely that, given these restrictions on spatial resolution, space imagery will provide large-scale data that can be used to guide aircraft collecting more detailed images to be used in disaster relief activities.

Planning Relief Operations: During relief operations, there is often a need to determine evacuation routes, sites for temporary dwellings or sources of water or sewage systems. Satellite imagery of the region surrounding the disaster area may be of considerable use in aiding the disaster relief specialist in making the right decisions. In order to be useful, this imagery should generally be high resolution. Ideally, it should be available shortly after the disaster but may even have been shot beforehand and obtained from an archive.

Disaster Management and Space Technology

It would seem that the broad humanitarian (and economic) needs of disaster management would be ideally complemented by the far-reaching capabilities of space technology. This should have resulted in developments and acceptance that obviously have not taken place. Why is this? What can be done about it?

In order to answer the first of these questions, it is instructive to consider the most successful application of space technology. Satellite communication has succeeded because it provided a mechanism for fast, reliable and efficient transfer of information. But this speed, reliability and efficiency has only been demonstrated only since very large national and international organizations with resources, and technical competence and imagination began their ventures into space. These characteristics, which have fostered acceptance and development of space technology in the communications industry, are in marked contrast to the disaster-management community.

Factors Affecting Technological Acceptance by the Disaster-Management Community

Scale of Operations

Although a disaster may affect many people, few are generally available to combat disasters; the (fortunate) infrequency of major disasters militates against assigning large forces to stand ready for disaster relief operations, though police and military forces can be, and often are, of great service in this capacity. In most relief operations, the number of persons charged with acquiring information on the nature, scope and impact of a disaster is even more restricted. The scale of operations is considerably below that of the telecommunications industry, for example.

Level of Technical Expertise

Major concerns during a disaster relate to the medical and socio-economic needs of the affected population and region. At the same time, the relief-supplying organization must be aware of, and must respect, the sovereignty of the nation receiving assistance and this consideration also extends to assessment of disaster impact and relief requirements. Thus, the disaster relief specialists are often thoroughly engaged in, and experienced with, important and complicated humanitarian, socio-economic and political questions that abound during disasters. Their interest in technology is often limited.

Level of Finances

Though the societal cost of disasters is often enormous, the cost of relief efforts is small compared with--using the same example--the level of operational costs in the telecommunications industry. The disaster-relief community does not have many financial resources to "invest" in technological developments and (perhaps more importantly) the operation of sophisticated equipment. Before making commitments to new costs, relief organizations should perform a cost/benefit analysis to make certain that the development and operating costs will not far exceed current operating costs.

Diversity of the Disaster Management Community

A wide variety of organizations are involved in supplying disaster relief; many of these may be involved in any given disaster. National and international nongovernmental humanitarian organizations, most notably the League of the Red Cross/Red Crescent Societies, have accepted roles in providing disaster relief. Other relief organizations have religious affiliations (e.g., The World Council of Churches) or represent much-needed professions (e.g., Medecins Sans Frontieres). There are literally dozens of such organizations, large and small, which play important roles during disaster relief exercises.

The first level of relief aid often comes from military units with the stand-by capacity to provide prompt assistance. Some nations (e.g., Sweden) have specific military elements keyed to disaster relief. Most developed nations have some organization (e.g., the A.I.D. Office of Foreign Disaster Assistance in the U.S.), which is charged with the primary role in delivering or coordinating disaster relief. Some developing nations (e.g., the Philippines) also have organizations responsible for developing, receiving and transmitting disaster alerts.

At the inter-governmental level, there are also many agencies involved in delivery of disaster assistance. For example, the United Nations Office of the High Commissioner for Refugees (UNHCR) maintains an interest in the plight of disaster-stricken peoples. The Food and Agricultural Organization (FAO) is concerned with fulfilling alimentary requirements and the World Health Organization (WHO) is concerned with medical needs. Scientifically oriented organizations such as the World Meteorological Organization (WMO) and UNESCO may have interests in the technical aspects of a disaster (e.g., the analysis and forecasting of volcanic activity after an eruption). The United Nations Development Program (UNDP) also often responds to disasters.

Providing an overview function for all of these activities and organizations is the U.N. Office of the Disaster Relief Co-ordinator (UNDRO). This relatively small organization is charged with coordinating the assessments of damage and needs resulting from a disaster and integrating the response of voluntary, national and international organizations. This is an enormous enterprise considering the many disasters which occur each year.

The picture, therefore, is one in which there are dozens of relatively small and a few large volunteer organizations devoted to disaster relief; there are a few national organizations with mandates in this area and several international organizations that have some interests. Superimposed on all of these is the coordinating role of UNDRO, a relatively small organization. Again, this is unlike the situation in the communications industry which is dominated by several large corporations and the telecommunications authorities of the many governments. In contrast, the disaster-relief community is disparate and fragmented.

An Approach to Implementation

It is evident from much of the earlier discussion that space technology can now provide useful information for disaster management, and that further development of this technology could make it yet more useful. There are impediments to this progress, but several initiatives could help overcome them.

Determination of Requirements

Humanitarian motives sometimes lead space technologists to offer systems and products that turn out to be incompatible with the needs of the disaster managers. On the other hand, these managers seldom have the technical background to foresee the possibilities--or the restrictions--of satellite technologies that might meet their needs. An iterative dialogue between these two communities is sorely needed--a dialogue that can build up the necessary in-depth understanding of the possibilities and limitations on both sides. Such a dialogue was initiated at the 1983 Expert Meeting sponsored by UNDRO (see Note 5). This first step should be followed by a continuing exchange, preferably through a small standing committee.

Testing and Training

Technological developments of the scale conceived here generally proceed through prototype and testing stages, during which performance is evaluated and it is possible to modify system design. Both the disaster management and technological communities should recognize the need for such an effort and prepare for a continued dialogue during this stage.

It is likely that a single group of people will carry out both the definition of needs and the testing: the committee charged with bridging the gap between disaster-management and satellite technology. In order to implement this technology once it is developed, however, it will be necessary to train the operational disaster-management specialists. This same committee should guide that critical task.

Finances

It is unlikely that satellite developments usable in disaster management will ever have the financial impetus or the level of resources experienced in the telecommunications industry. However, as pointed out in previous sections, most of these developments are being funded for other applications; only small amounts of resources would be needed to configure these developments for disaster-management applications. It remains necessary only to point out the most efficient method for carrying them out.

Financial details should be worked out in accordance with the organizational structure proposed below. In general, however, the most appropriate funding arrangement might have the space community fund technical developments; the cost of testing would be split, and the costs of training would be funded by the disaster-management community. Operational costs would eventually be borne by the disaster-management community with the help of subsidies on space-segment transmission charges.

International Agreements

In order to protect their sovereignty, nations will restrict the use of technologies that tend to ignore national boundaries such as remote sensing and satellite communications. Mobile communication through handheld receivers, relayed by geosynchronous satellites, should be possible in the near future, but international radio-frequency regulations may preclude their use. An important step to prevent this problem might be taken at the forthcoming World Administrative Radio Conference (WARC) in 1992. At that time, member states of the International Telecommunications Union should be encouraged to enlarge upon resolutions of the 1979 WARC and make provisions for mobile disaster communications.

Other restrictions often apply to satellite remote sensing, due to some nations' aversion to high-resolution imaging of their territory. To avoid such impediments, it might be possible to devise international or bilateral protocols whereby a nation, in accepting disaster relief, would implicitly agree to limited acquisition of imagery necessary to facilitate relief operations.

Organizational Structure

International Organization: The organization required to carry out these tasks must be able to represent and draw upon the resources of both the technological and disaster-management communities at the international level. The United Nations has recently approved the International Decade for Natural Disaster Reduction (IDNDR). This initiative, which will begin in 1990, focuses on the development and application of new technology in the field of disaster management: an objective which closely parallels the major requirements for the implementation of space technology. An organization, possibly UNDRO or one related to UNDRO, which will carry out this program will have to be identified. It is recommended that, at the international level, this organization be given the mandate for the development and implementation of space technological capability for disaster management applications along the lines suggested here. This organization will draw upon the support of other organizations as depicted in Figure 1.

International Decade for Natural Disaster Reduction

UNDRO

International Science
Committee on Space Research
International Astronautical Federation

International Technical
International Telecommunications Union
World Meterological Organization
UNESCO

International Satellite Communications
Inmarsat
Intelsat
Intercosmos

Space
European Space Agency
National Space Agencies
Space Organizations (*e.g.*, SPOT)

International Agencies
FAO
UNDP
WHO
UNHCR, etc.

International Voluntary
Red Cross/Red Crescent

Volunteer
World Council of Churches
Oxfam
Medecins Sans Frontieres, etc.

National Agencies

Representatives from Disaster-Prone Developing Nations

Figure 1: Proposed organizational structure for the International Decade for Natural Disaster Reduction--to be defined by the United Nations. Source: UNDRO.

Bilateral Arrangements: Several nations (e.g., the U.S. and France) have both a space capability and a national organization charged with disaster response. (The European Economic Community and the European Space Agency combined also have these responsibilities.) At this national level, development and utilization of the space capability may be more straightforward than at the international level. For this reason, procedures are recommended whereby such nations, when called upon to provide disaster relief, should, through bilateral arrangements with nations requesting disaster assistance, demonstrate the leadership of more highly developed nations and pioneer the use of satellite technology for disaster management.

Notes

1. Paul B. Richards, "Space Technology Contributions to Emergency and Disaster Management" in Advances in Earth Oriented Applications of Space Technology, Pergamon Press, 1982.
2. Paul B. Richards, "The Utility of Landsat-D and Other Satellite Imaging Systems in Disaster Management," Naval Research Laboratory Final Report, NASA DPR S-79677, June 1982.
3. Paul B. Richards, C.J. Robinove, D.R. Wiesnet, V.V. Salomonson and M.S. Maxwell, "Recommended Satellite Imagery Capabilities for Disaster Management," Technical Memorandum, Goddard Space Flight Center, Greenbelt, Maryland, 1981.
4. Office of the United Nations Disaster Relief Co-ordinator, "Contribution of the Office of the United Nations Disaster Relief Co-ordinator to Unispace '82," UNDRO, United Nations Offices at Geneva, Geneva, Switzerland, 1982.
5. Office of the United Nations Disaster Relief Co-ordinator, "Space Applications for the Acquisition and Dissemination of Disaster-Related Data," Report of the Expert Meeting, 14-17 June, 1983, UNDRO, United Nations Offices at Geneva, Geneva, Switzerland, 1983.
6. D. Carter, G.W. Heath, G. Hovmork and H. Sax, "Space Applications for Disaster Mitigation and Management," Acta Astronautica, 19, 229-249, Pergamon Press, 1989.
7. P. Cardemone, G.M. Lechi, A. Cavallin, C.M. Marino, and A. Zanferrari, "Application of Conventional and Advanced Techniques for Interpretation of Landsat 2 Images for the Study of Linears in the Fruili Earthquake Area, Boll. di Geof. Teof. ed Applic., 1337-1353, 1977.
8. E.C. Barrett, "An Interactive Technique for Satellite-Improved Rainfall Monitoring," Integrated Approaches in Remote Sensing, Proc., ESA SP-214, 191-199, 1984.

Definitions

A disaster may be defined as "an event, concentrated in time and space, in which a society (or a community) undergoes severe danger and incurs such losses to its members and physical appurtenances that the social structure is disrupted and fulfillment of all or some of the major functions of the society is prevented." The present study focuses on "sudden" disasters--those that give little time for warning, are relatively short in duration and require rapid reaction on the part of responding organizations. These papers will not consider long-term disasters, most notably drought and famine.

"Disaster management" is a comprehensive term which embodies all the mitigating activities carried out before, during and after a disaster. It is a useful concept because it emphasizes the fact that the actions and reactions in response to impending or actual disasters are all interrelated. There are three main elements to disaster management: preparedness, prevention and relief. Disaster preparedness seeks to minimize losses when disaster strikes through measures such as disaster warning. In disaster prevention, we try to avoid or control these hazards and their effects; we identify areas of potential hazard and attempt to prevent the threatening events from becoming disasters. Finally, in disaster relief, we provide aid (as rapidly, effectively and efficiently as possible) once a disaster has occurred.

The Author

Louis Walter is Senior Staff Scientist in NASA's Laboratory for Terrestrial Physics at the Goddard Space Flight Center. He has worked at NASA since 1962, with the exception of a stint (1981-83) as Senior Technical Relief Specialist in the U.N. Office of the Disaster Relief Co-ordinator. He has written extensively in geochemistry, mineralogy and remote sensing. Education: Ph.D., Pennsylvania State University (1960).