by Nick Rengers, Robert Soeters, and Cees J. van Westen

Remote sensing and GIS applied to mountain hazard mapping

Airborne and satellite remote sensing techniques, such as photography, imaging radar, and multispectral scanning, provide imagery of the Earth's surface that is a valuable tool for the inventory and monitoring of mountain hazard phenomena. When this imagery is processed by the use of computer-based geographic information systems, spatially distributed geographic data can be combined with information derived from digital processing and visual interpretation of remote sensing imagery. This combination of data enables us to analyze the influence of terrain factors upon the occurrence of mountain hazard processes.

Special emphasis is given to the importance of the scale (regional, medium, and large) at which hazard maps are prepared for regional, local, and site-planning purposes. In addition, the number of ground resolution cells that are necessary to detect, recognize, or identify objects in photographic or other types of remote sensing imagery provide us with information about the dimensions of features needed in order to determine the existence of mass-movement processes.

Introduction

For the past two decades, nonphotographic remote sensing has undergone enormous development and has found widespread applications. However, in many cases, strong overselling of the potentials of remote sensing has created disappointment for its users. At the same time, we have seen the development of the applications of geographic information systems (GIS) in the earth sciences.

Although the integration of remote sensing and GIS offers very interesting opportunities (Ehlers and others, 1989), we will review critically herein the possibilities and limitations of this integration as it applies specifically to mountain hazard mapping.

The authors are involved in a research program that is sponsored by the United Nations Educational, Scientific, and Cultural Organization (UNESCO), the European Economic Community, and the Netherlands Government. This research program, within the framework of the International Decade for Natural Disaster Reduction, aims to develop mountain hazard mapping methods that use GIS based on personal computers (PC). Further, we intend to transfer these methods to hazard mapping specialists in the Andean countries of Bolivia, Colombia, Ecuador, Peru, and Venezuela. In the methods that we have developed, remote sensing imagery plays a large role.

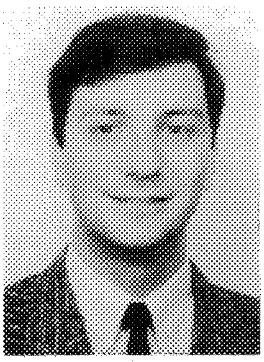
Remote sensing and GIS

Both digital remote sensing and GIS are based on assigning numerical values to well-defined areas (scene elements) of the Earth's surface in order to produce a numerical image of this surface. Through a process of image correction and resampling, the remote sensing data coded by geology can be matched with the raster cells of the GIS. This opens many possibilities for correlation studies between basic remote sensing data and the thematic information derived from the introduction of maps digitized in GIS.

In order to determine the limitations of these correlations, we must define both the type of data that are available from digital remote sensing and its resolution, as well as how these data fit with the thematic information introduced into GIS from other sources. Figure 1 shows the relationship between GIS and remote sensing in general terms, remote sensing being one of several possible types of data put into a GIS.

Figure 2 shows in more detail the possibilities that exist for the input of remote sensing data or information derived from remote sensing data into the GIS. These include (1) direct inputting of raw remote sensing data into the data base of a GIS; (2) digital image processing of the raw remote sensing data (this may include geometric correction, image enhancement and resampling procedures, and subsequent input of calibrated and (or) data coded by geology into the GIS); and (3) digital image processing of the raw remote sensing data, preparation of a picture, visual interpretation of the picture, and input of the thermatic interpretation into the GIS by digitization of the thematic interpretation map. The dashed line in figure 2 encloses a GIS in which the digital image processing capabilities are integrated. An example of such a GIS is the PC-based Integrated Land and Watershed Management Information System (ILWIS) that has been developed at the International Institute for Aerial Survey and Earth Sciences (Netherlands) (Valenzuela, 1988) and that was used in a hazard assessment analysis described by the authors (Soeters and others, 1991). A schematic representation of ILWIS is given in figure 3.

The introduction of the capability of digital image processing in GIS results in important advantages. For instance, the ILWIS software allows the display of geometrically corrected images (orthophotography, Landsat Thematic Mapper (TM), and SPOT imagery) and overlaying of thematic information from other sources; screen digitizing over displayed raster imagery; display of individual bands or color composites that use tools such as linear stretching, histogram equalization, and filtering; and supervised classification in the imagery.



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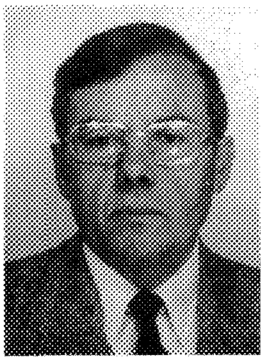

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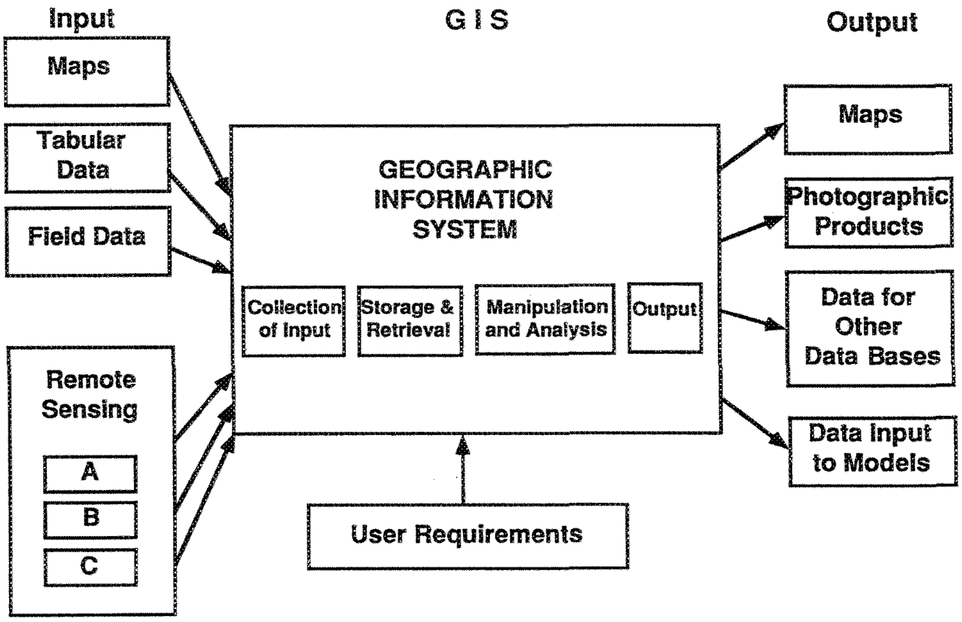

Figure 1.—Relationships between GIS and remote sensing.

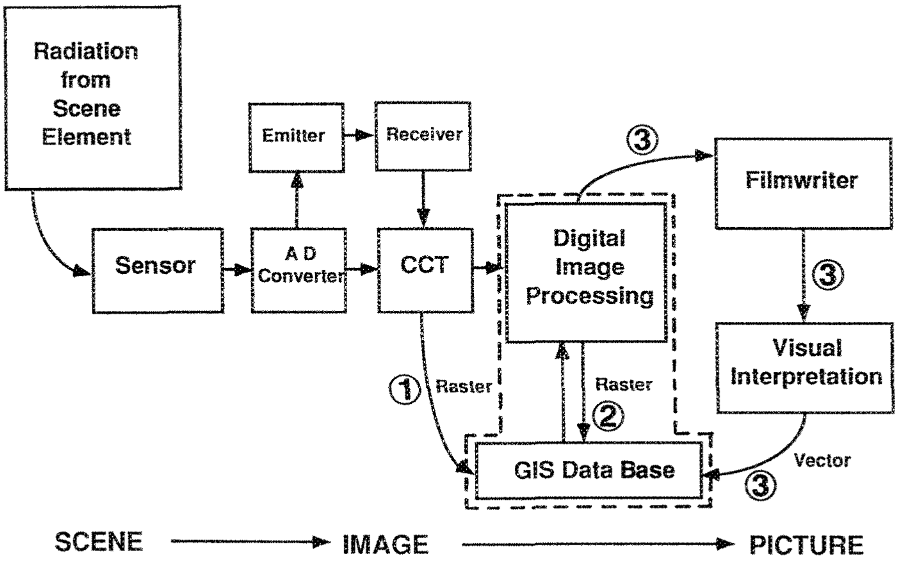

Figure 2.—Input of remote sensing data into a GIS. The interrupted line encloses a GIS in which digital image processing has been integrated. For explanation of numbers, see text. Abbreviations: AD, analog-digital; CCT, computer compatible tape.

Mountain hazard mapping at various scales

Natural hazard mapping is not restricted to the delineation of occurrences of phenomena such as mass movement, flooding, earthquakes, and volcanism in the past, but it is focused on making predictions about the occurrences of such phenomena in the future (Varnes, 1984). Hazard maps outline zones that are defined in terms of the probability of occurrence of potentially damaging phenomena within a certain span of time.

During the preparation of such maps, the influence of a number of factors must be assessed on the likelihood of occurrence. The more detailed the resulting map should be, the more factors will have to be studied. Therefore, the methodology that has to be followed depends upon the scale of the map to be prepared, the purpose for which it is to be made, and the amount of information that is available for the area concerned.

The following section gives an overview of the various scales of maps showing mass-movement hazards. These were prepared in the mountain hazard mapping research project described by Soeters and others (1991). We will describe the purpose for which the maps are

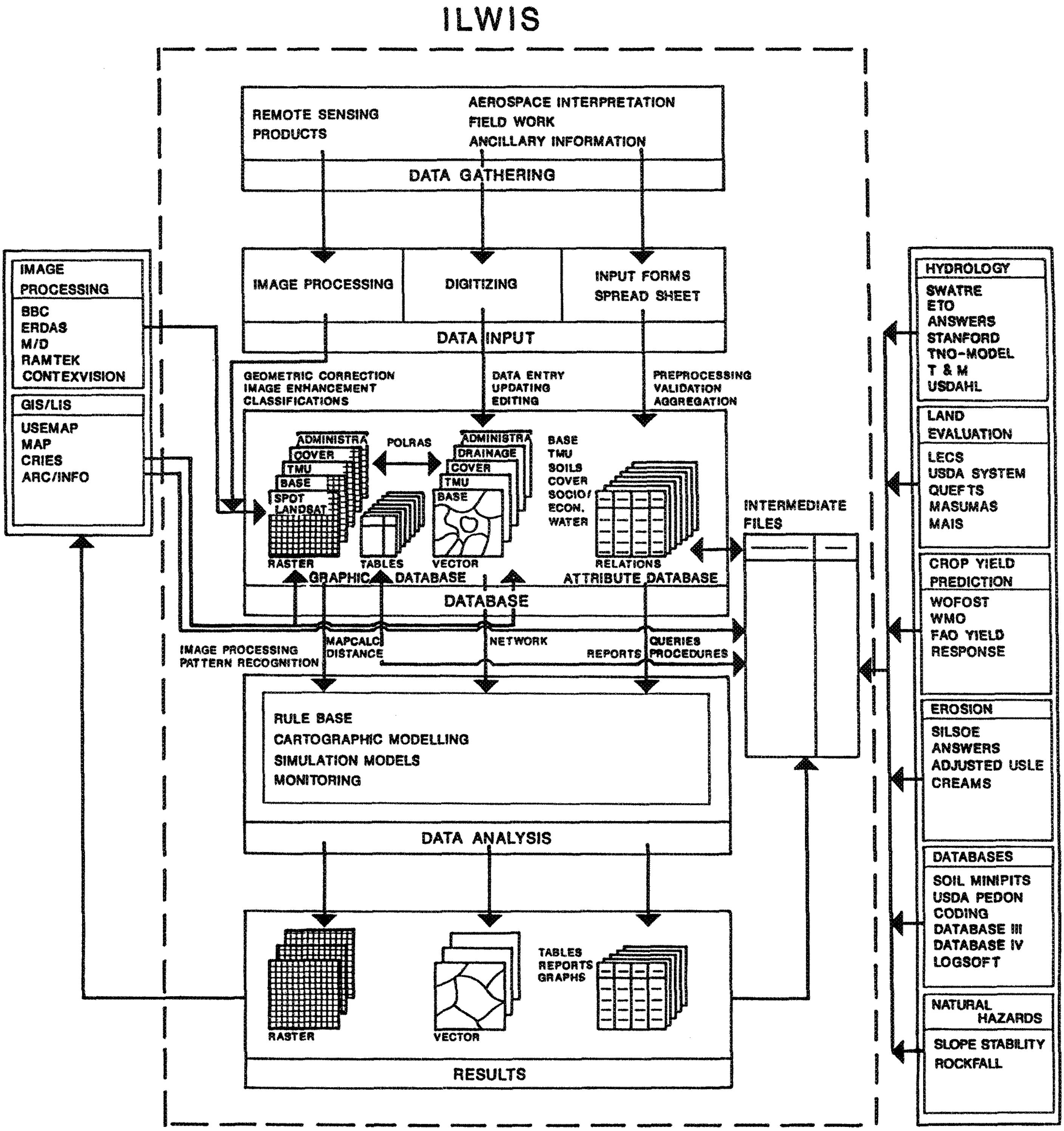

Figure 3.—Schematic representation of ILWIS (taken from Valenzuela, 1988).

used, the methodology that is applied, the input information that is necessary, and the type of remote sensing imagery that can be used.

Regional scale hazard mapping

Regional scale hazard mapping (1:100,000 to 1:250,000) is applied in the early planning stages of regional (infrastructural) development and uses a semiquantitative methodology that includes map overlays. This mapping requires information from thematic maps on the geology, geomorphology, land use, topography, and drainage network of the area at a regional (small) scale. Often, such information is not available, and the delineation of terrain mapping units (see Meijerink, 1988) can be followed instead. A terrain mapping unit is a zone that has a unique combination of morphology, soil, and bedrock and can be outlined in stereo imagery at a small scale. Mapping of individual mass-movement phenomena is not possible in this stage, except for some sample areas. Available records and data bases on landslide occurrences may help if they are available.

As terrain zoning at this scale is based primarily on the morphological characteristics of the terrain, use can be made of stereo imagery at a small scale (1:60,000 to 1:150,000). This imagery is either panchromatic black and white or multispectral and can be combined into a color composite picture. Radar imagery may be useful at this stage if the ground resolution is sufficient to delineate terrain mapping units.

Medium-scale hazard mapping

Medium-scale hazard mapping (1:25,000 to 1:50,000) is used to determine hazard zones that are better defined for the location of engineering structures of various kinds including, for instance, road location and urban planning. The methodology employs a variety of analytical methods, mostly statistical, in order to determine hazard zones by multivariate analysis and weighing of the different factors that contribute to the development of potentially damaging phenomena. This mapping calls for detailed topographic information in the form of digital elevation models and various types of thematical maps, such as maps showing lithology, geological structure, geomorphological processes, and occurrences of slope processes of different types.

Remote sensing stereo imagery of medium scale (1:15,000 to 1:25,000) is required, and it may be either panchromatic black and white or multispectral. The spatial resolution must allow for the identification of individual mass-movement phenomena that are larger than 10 m in dimension.

Large-scale hazard mapping

Large-scale hazard mapping (1:5,000 to 1:15,000) is needed in the early stages of site investigation in order to determine quantitatively the hazard for a particular civil engineering work. Quantitative analytical methods are used that include multivariate statistical and numerical slope stability analyses. This mapping requires very detailed topographic information from a good-quality 1:5,000- or 1:10,000-scale topographic base map. In addition, detailed information is needed on geology, geomorphology, land use, and slope instability processes, as well as on the hydrogeological and geotechnical characteristics of the geological units.

Large-scale (1:5,000 to 1:10,000) black and white or color stereo imagery is necessary. It must have sufficient resolution to identify the elements of mass-movement phenomena that are smaller than 5 m in dimension.

All scales

In conclusion for all scales of hazard mapping, stereo imagery is of the utmost importance because the zones into which the terrain is divided are distinguished primarily on the basis of morphology, rocks, and soils. For hazard mapping at scales more detailed than the regional mapping, the resolution of the imagery is of greater importance. At these larger scales, the occurrence of individual mass movements becomes important input information in the analytical methods we use for hazard assessment. In the following section, we will discuss resolution and its relationship to the size of objects that can be detected, recognized, or identified.

Resolution of remote sensing imagery

The word "resolution" causes confusion as it has different meanings in photography and in nonphotographic remote sensing. In aerial photography, "ground resolution" is defined usually (see fig. 4) as the minimum number of meters required per line pair on the ground in order to be visible as two distinct lines of different color or grey tone in the picture. In nonphotographic remote sensing, the expression "ground resolution" is used mostly to indicate the size of the area on the ground ("scene element" or "instantaneous field of view") for which the radiation is integrated in order to give one radiation value in the image. When the image is presented as a picture without data reduction, then the ground resolution area will form the basic element (pixel) of the picture.

In order to prevent confusion, we prefer to use the expression "ground resolution cell," which is equal to the scene element in nonphotographic remote sensing. Furthermore, the resolution in terms of meters per ground resolution cell ($R_{m/grc}$) is related to photographic resolution in terms of meters per line pair ($R_{m/lp}$) in the following way (taken from Naithani, 1990):

$$R_{m/grc} = \frac{1}{2\sqrt{2}} \times R_{m/lp}$$

For simplicity reasons in the following text and tables, the size of a ground resolution cell in aerial photography will be rounded off to 1/2.5 times the value for the resolution in meters per line pair, as presented by Naithani (1990).

Figure 4B shows that only line pairs that are wider than one ground resolution cell per line are detectable on an image by their contrast in grey tone or color. Objects that are not lines but that are

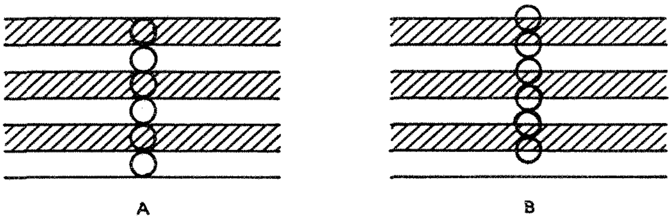

Figure 4.—Line pairs and ground resolution cells (circles) used to define resolution in aerial photography (taken from Naithani, 1990). **A**, *Six ground resolution cells resolve three line pairs;* **B**, *more than six ground resolution cells are needed in order to resolve three line pairs.* **B** *is the general case, and* **A** *is a very special case where lines of one ground resolution cell width would be just recognizable because they coincide in position.*

Table 1.—Number of ground resolution cells needed to detect, recognize, or identify an object of varying contrast in relation to its background

[In parentheses are given the minimum dimensions of a nonelongated object counted in numbers of ground resolution cells]

	Detection	Recog-nition	Identification
EXTREME CONTRAST white or black object in variable grey tone background	5 - 8 (2 x 3)	10-15 (3 x 4)	20 - 30 (5 x 6)
HIGH CONTRAST dark or light object in grey tone background	10 - 15 (3 x 4)	30-40 (5 x 7)	80 - 100 (8 x 10)
LOW CONTRAST grey tone feature in grey tone background	200 - 250 (10 x 20)	400-600 (20 x 30)	1000 - 1500 (30 x 40)

Table 2.—Minimum sizes needed for an object to be detected, recognized, or identified depending upon the conditions of contrast between the object and its background for various types of imagery

[Values should be used only as an indication of relative size. For a detailed explanation on the determination of size, see the text. Abbreviation: A.P., aerial photography]

		Landsat MSS	Landsat TM	Spot XS	Spot Pan	A.P.* 1:100.000	A.P.* 1:50.000	A.P.* 1:25.000	A.P.* 1:10.000
GROUND RESOLUTION CELL SIZE		80m	30m	20m	10m	1m	0.5m	0.25m	0.1m
HIGH CONTRAST feature-background	Detection	320m	120m	80m	40m	4m	2m	1 m	0.4m
	Recognition	560m	210m	140m	70m	7m	3.5m	1.8m	0.7m
	Identifica-tion	800m	300m	200m	100m	10m	5m	2.5m	1 m
LOW CONTRAST feature-background	Detection	1600m	600m	400m	200m	20m	10m	5m	2m
	Recognition	2400m	900m	600m	300m	30m	15m	7.5m	3m
	Identifica-tion	3200m	1200m	800m	400m	40m	20m	10 m	4m

*Without Forward Movement Correction

irregular in form need a minimum size of 2×3 ground resolution cells (see also table 1) in order to be detectable on the basis of their known spectral characteristics against a contrasting background.

We should define some more terms at this time. "Detection" means that it is possible to decide if an object of known spectral characteristics is present or absent at a defined geographic location. "Recognition" means that it is possible to decide if an object of known form and spectral characteristics is present anywhere in the picture. "Identification" means that it is possible to identify objects of variable forms and spectral characteristics on the basis of their characteristic forms and context within the background.

On the basis of our experience in visually interpreting remote sensing imagery, we have concluded that, for various contrasts in grey tones between an object and a background, the numbers of ground resolution cells needed to detect, recognize, or identify objects in a picture are as listed in the table 1. In addition, we give in parentheses an indication of the size (expressed in number of ground resolution cells) needed for objects of nonelongated shape, as is usually the case for mass-movement phenomena. The larger dimension of an object is used in table 2 in order to indicate the minimum size needed for a mass-movement feature to be detectable, recognizable, or identifiable in photographic or other types of remote sensing imagery.

In terms of contrast, "extreme contrast" exists when a completely white or black object is present against a variable grey tone background. "High contrast" indicates a dark or light object against a grey tone background. "Low contrast" indicates that the spectral characteristics of an object do not differ significantly from the background and that objects can be identified or recognized only on the basis of their characteristic forms. These contrasts are illustrated by figures 5 and 6, which were derived from a large-scale aerial photograph that was digitized having a raster size as if the original ground

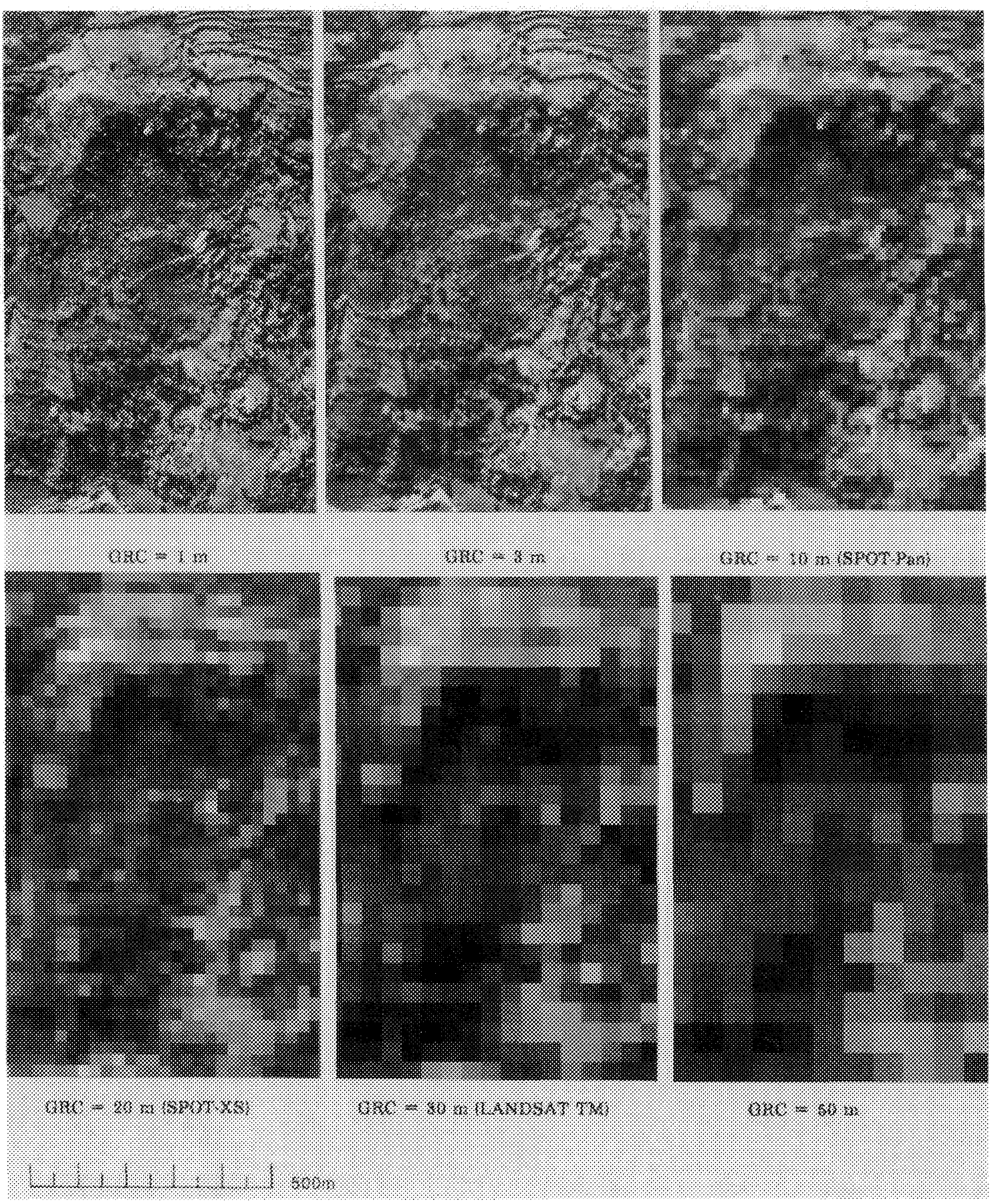

Figure 5.—An area in the Spanish central Pyrenees showing a landslide scar that is in shadow (high contrast) in the central upper part of the picture and a depositional area of landslide debris (low contrast) in the central to lower part of the picture. The pictures were derived from a digitized large-scale aerial photograph and have artificially aggregated pixel sizes determined as if the ground resolution cell (GRC) size of the pictures were 1, 3, 10, 20, 30, and 50 m.

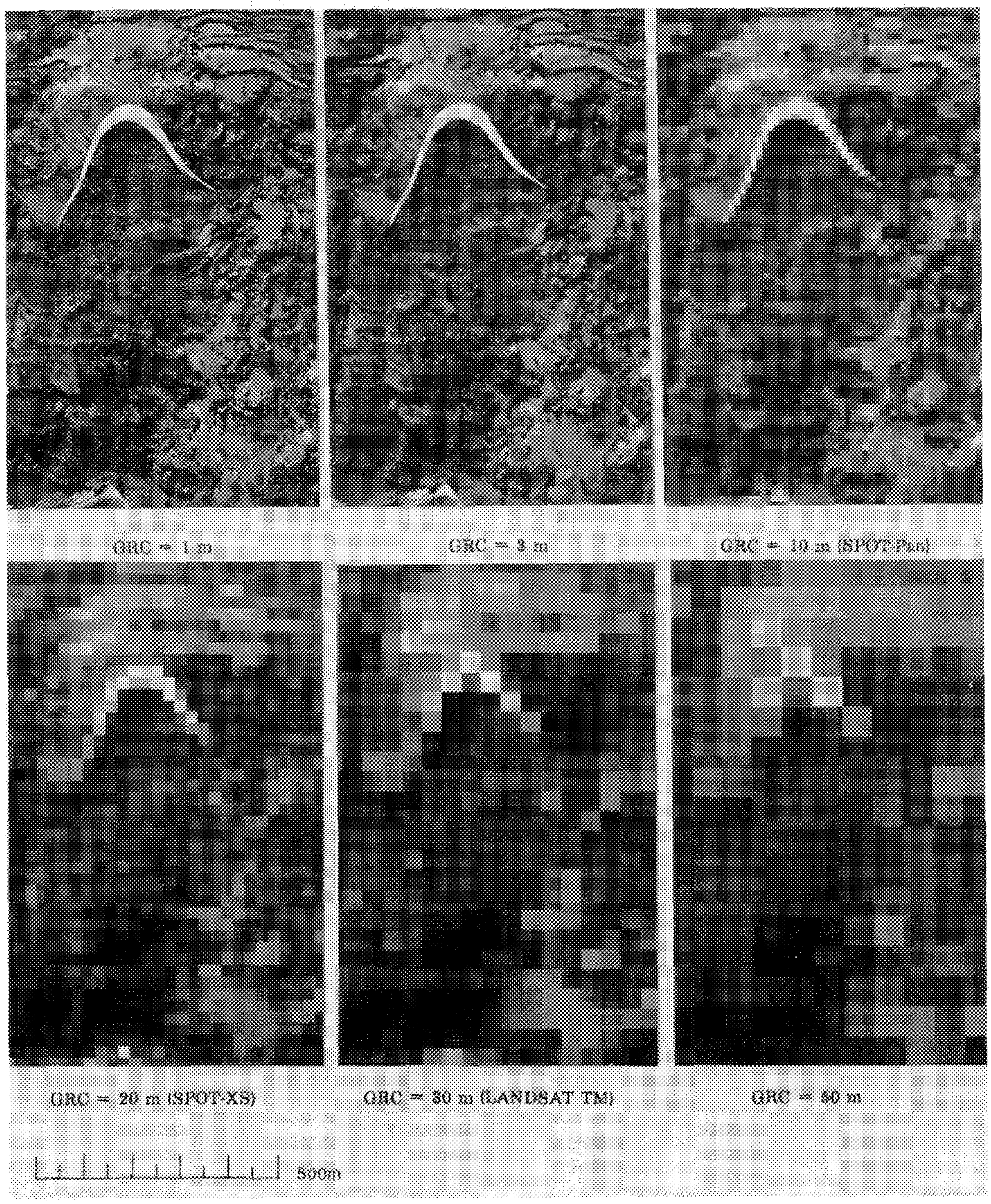

Figure 6.—The same area and the same ground resolution cell sizes as in figure 5, but here an artificially enhanced landslide scar is depicted completely in white in order to show the influence of extreme contrast on the resolution characteristics of pictures having various ground resolution cell (GRC) sizes. Such extreme contrasts rarely are encountered in imagery of parts of the continental Earth that are not covered by snow.

Table 3.—Current high-resolution satellite remote sensing missions suitable for GIS applications (taken from Ehlers and others, 1989)

Platform	Year	Spectral Bands	Spectral Range	Stereo	Ground Resolution Cell Size	Country
Shuttle	1983	1	Radar	No	17-58 m	U.S.A.
		2	VIS/NIR	No	20 m	W. GERMANY
Landsat-4/-5	1982/84	4	VIS/NIR	No *	80 m	U.S.A.
		7	VIS/NIR	No *	30 m	
			MIR/TIR	No	(TIR:120 m)	
SPOT	1986	1	Pan(VIS)	Yes	10 m	FRANCE
		3	VIS/NIR	Yes	20 m	
MOS	1987	4	VIS/NIR	No	50 m	JAPAN
IRS-1A	1988	4	VIS/NIR	No	36.5 m	INDIA

VIS = visible ; NIR = Near Infrared ; MIR = Middle Infrared ; TIR = Thermal Infrared
***Stereo can be produced using a good quality Digital Elevation Model**

resolution cell had been 0.3 m. The individual pictures then were printed with artificially aggregated pixels as if the ground resolution cell size had been 1, 3, 10, 20, 30, and 50 m.

Figure 5 shows pictures of various ground resolution cell sizes for an area in the Spanish central Pyrenees (Sissakian and others, 1983). We see a landslide scar that is in shadow, which gives a high contrast in the upper middle part of the picture, and a depositional area of landslide debris, which has a low contrast in the central to lower part of the picture. The depositional area is recognizable by a characteristic surface texture (low contrast) and by a surrounding line of higher vegetation that has small-sized ground resolution cells. Figure 6 shows the same photograph, but here an artificially enhanced landslide scar is depicted completely in white in order to show the effect of extreme contrast on detectability.

Table 2 shows the minimum sizes of objects that can be detected, recognized, or identified in aerial photography of various scales and in various types of nonphotographic remote sensing imagery. The sizes were determined by multiplying the ground resolution cell size for the type of imagery by the larger of the two dimensions of the object given in table 1. The ground resolution cell size for aerial photography was determined by dividing the values for resolution in meters per line pair by a factor of 2.5, as given by Naithani (1990). The values in table 2 give only an indication of the order of magnitude of the relative size of the objects, as differences in form and contrast relationships will influence the resolution.

Possibilities for today

Satellite remote sensing can be a useful source of data when GIS is used for landslide hazard assessment if the GIS incorporates digital image processing. However, the application of both currently available satellite remote sensing and remote sensing planned in the near future is limited because of its spatial resolution (see tables 3 and 4). This resolution does not allow the identification of landslide features that are smaller than 100 m in conditions of high contrast between the feature to be mapped and the surrounding background. If contrast conditions are less favorable, identification is limited to features that are larger than an order of magnitude of 400 m.

Because of the spatial resolution limitations of most remote sensing, we need stereoscopic vision in order to recognize landforms. This requires stereo imagery, which enhances the applicability of currently available SPOT imagery. Therefore, SPOT imagery can be used for regional scale landslide hazard mapping that outlines terrain mapping units. Landsat TM images can be used as well if stereomates for stereoscopic vision are prepared with help of a detailed digital elevation model of the terrain. For larger scale hazard mapping at the medium and large scales, inventories of existing landslide phenomena are necessary, and to make these inventories, we need aerial photography that has good spatial resolution characteristics.

The potential use of radar imagery for landslide hazard mapping needs further investigation. Results of work on the classification of terrain roughness (Singhroy, Radar geology, this issue) seem encouraging, but problems are associated still with the production of calibrated and geometrically corrected radar imagery. Such corrected imagery is absolutely indispensable before the data can be introduced in the GIS for correlation with other thematic information on terrain characteristics.

European Remote Sensing satellite number 1 (ERS-1) radar imagery data will be used by the authors in the near future in a research project on mountain hazard mapping (Soeters and others, 1991), and we will evaluate the potential of its application to the classification of terrain roughness. We find it especially interesting that the application of radar imagery in tropical, mountainous areas is not dependent upon weather conditions for the collection of data.

Hopes for the future

Hopes for the future have emerged from our work on hazard mapping, including our use of remote sensing data in a GIS environment. Although space will not allow a full treatment of the history behind these hopes, we will express them here as suggestions to those who are involved in the development of GIS and in the planning for future remote sensing missions.

(1) The long-term availability of remote sensing imagery of the types now used widely (such as TM and SPOT) is essential for long-term monitoring of changes in the Earth's surface.
(2) For radar imagery, we need high-quality geometrical correction procedures that can produce radar imagery usable for input into GIS. Improvements in resolution may lead to wider applications of radar imagery in landslide hazard mapping, if the imagery yields suitable information on terrain roughness characteristics.

Table 4.—Planned satellite remote sensing missions suitable for GIS applications (taken from Ehlers and others, 1989)

[Abbreviation: ESA, European Space Agency]

Platform	Year	Spectral Bands	Spectral Range	Ground Resolution Cell Size	Country
Landsat 6	1991	8	Pan	15 m	U.S.A.
			VIS/NIR	30 m	U.S.A.
			MIR/TIR	120 m	U.S.A.
MOS 2	1991	4	VIS/NIR	50 m	JAPAN
ERS 1	1991	1	Radar	30 m	ESA
Shuttle	1992	2	Radar (SIR-C)	25 m	U.S.A.
		1	Radar (X-SAR)	25 m	GERMANY
JERS 1	1992	1	Radar (SAR)	20 m	JAPAN
SROSS-1	1992	1	Pan	52x80m	INDIA, GERMANY
SPOT-3	1993	1	Pan	10 m	FRANCE
		3	VIS/NIR	20 m	FRANCE
Radarsat	1994	1	Radar (SAR)	30 m	CANADA
EOS	1997	196	VIS/NIR	30 m	U.S.A.
		64	VIS/NIR	800 m	ESA, JAPAN
		1	Radar (SAR)	30 m	ESA, JAPAN

(3) For optical remote sensing, improvements would be welcomed in ground resolution. Ground resolution cell sizes on the order of 0.5 to 1 m would be necessary in order to be able to use satellite remote sensing for the inventory of landslide phenomena. Zooming into areas of particular interest would be an interesting approach.

(4) For the optimal integration of remote sensing and GIS, we should try to achieve a standardization in remote sensing of ground resolution cell sizes and systems for coding by geology. This would improve our possibilities of comparing and integrating data sets of different sources and scales, and it could reduce the volume of data sets with a quadtree approach, in which the ground resolution cell sizes are quartered in size in those areas where more detailed ground data are available.

(5) In order to improve the applications of geology information systems to the applied earth sciences, the following improvements to such systems will be indispensable. We need to develop better models and rules of general applicability in order to describe geological and hazard-causing processes. We need to develop three- and four-dimensional (including the time factor) GIS systems for more detailed analysis of landslide hazards at a large scale. And we need to improve the user friendliness of GIS systems in order to benefit the general public.

(6) A strong need exists for the education of earth scientists in the applications of remote sensing and geology information systems. Not only should training in these fields be included in all university curriculums, but provisions also should be made for experienced earth scientists to take courses that teach applications of remote sensing and GIS in their work. We see a gap at this time not just between earth scientists in the developed world and Third World but also in the developed world between scientists who have and have not had the opportunity to work with remote sensing and GIS.

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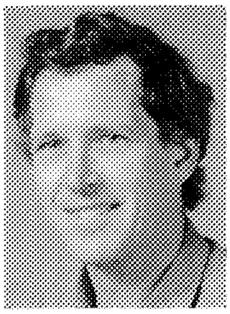

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by Peter J. Mouginis-Mark and Peter W. Francis

Satellite observations of active volcanoes: Prospects for the 1990s

Observations of volcanoes and volcanic eruptions worldwide are being made increasingly often by the use of sensors that are flown upon Earth-orbiting spacecraft. Particularly exciting are the new capabilities that enable remote measurements of the temperatures of lava flows and volcanic domes, the regional dispersal of eruption plumes, and the topography and structure of cloud-covered volcanoes in areas such as Indonesia, Central America, and the Aleutian Islands. These measurements will become an integral component of observations made by the National Aeronautics and Space Administration's Earth Observing System, due for launch in 1998, and will present new challenges in terms of data handling and the political aspects of volcano-hazard monitoring.

Introduction

The 1990s will see the use of many new remote sensing instruments in studies of volcanoes and volcanic eruptions. By providing access to a completely new range of observations, the instruments flown on satellites and aircraft will contribute significantly to our knowledge of both eruption processes and the impact of eruptions on the environment. By providing views of so many volcanoes so often, remote sensing techniques also provide entirely new means for monitoring volcanoes worldwide and thus of contributing to the mitigation of volcanic hazards. Space-based instruments provide a unique synoptic perspective on the massive perturbations to the atmosphere that are caused by large volcanic eruptions. Thus, in the decade ahead, the interaction between volcanism and the atmosphere will be one of several interdisciplinary studies that will draw geologists and other earth scientists into closer collaborations. Specifically, the monitoring of the dispersion of stratospheric aerosols from large eruptions will provide an important means of testing and refining the global circulation models that are critical to the current debates about atmospheric evolution and global climatic change.

This article reviews some of the satellite systems that are being used to study volcanoes, provides a summary of planned missions that will have a strong volcanology component, and discusses the implications of using remote sensing in order to identify and monitor volcanic hazards. A list of acronyms is provided in table 1.

Current capabilities

Mouginis-Mark and others (1989) reviewed the applications of many remote sensing techniques as they are applied to the analysis of volcanoes and volcanic terranes. Briefly, satellite and airborne sensors have been used already in the following types of volcanology investigations:

(1) Mapping the distribution of volcanic lithologies in remote areas (for example, Landsat TM studies of the central Andes: Francis and de Silva, 1989; de Silva and Francis, 1990);
(2) Identifying potentially active volcanoes and characterizing their styles of activity (de Silva and Francis, 1990);

Table 1.—Acronyms

Acronym	Full name
ADEOS	Advanced Earth Observing Satellite
ARGOS	Data storage and forward channel on European satellites
ASTER	Advanced Spaceborne Thermal Emission and Reflection radiometer
AVHRR	Advanced Very High Resolution Radiometer
AVO	Alaskan Volcano Observatory
CVO	Cascades Volcano Observatory
EOS	Earth Observing System
EOSP	Earth Observing Scanning Polarimeter
ERS-1	European Remote Sensing satellite #1
GOES	Geostationary Operational Environmental Satellite
GSFC	Goddard Space Flight Center
GVN	Global Volcanism Network
HVO	Hawaiian Volcano Observatory
IAVCEI	International Association of Volcanology and Chemistry of the Earth's Interior
IDNDR	International Decade for Natural Disaster Reduction
IGBP	International Geosphere-Biosphere Programme
JERS-1	Japanese Earth Resources Satellite #1
MISR	Multiangle Imaging SpectroRadiometer
MLS	Microwave Limb Sounder
MODIS	Moderate Resolution Imaging Spectrometer
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
RIDGE	Ridge InterDisciplinary Global Experiment
SAGE III	Stratospheric Aerosol and Gas Experiment #3
SAR	Synthetic Aperture Radar
SeaWIFS	Sea-viewing Wide Field Sensor
SIR-A	Shuttle Imaging Radar experiment A
SIR-B	Shuttle Imaging Radar experiment B
SIR-C	Shuttle Imaging Radar experiment C
SPOT	Systeme Probatoire d'Observation de la Terre
TES	Tropospheric Emission Spectrometer
TIMS	Thermal Infrared Multispectral Scanner
TM	Thematic Mapper (Landsat)
TOMS	Total Ozone Mapping Spectrometers