Co-funded by the
Erasmus+ Programme
of the European Union

SUNRAISE: Sustainable Natural Resource Use in Arctic and High Mountainous Areas

Report on:
Lecture Material
Remote Sensing, GIS for Emergency Management

Partner number: P12

Jawaharlal Nehru University, New Delhi
India

Disclaimer

Remote Sensing, GIS for Emergency Management

Semester -I: January – June

Coordinator	Prof P K Joshi
Credits	4 Credits
Lecturers	Prof P K Joshi
Level	M.A.
Host institution	Special Centre for Disaster Research (SCDR), Jawaharlal Nehru University, New Delhi
Course duration	One Semester [January – June] Started in July 2020

Summary

This one full semester core course provides the Master level students of Disaster Studies the basic understanding of remote sensing and GIS for emergency management.. This course focuses on basics of spatial data including remote sensing, GIS database and GPS technology. This course is about procedures to acquire and process satellite remote sensing data, create, collect, analyze and evaluate geospatial data for risk assessment from natural and man-made hazards. The course includes individual assignments.

Target Student Audiences

Semester - II Students of M.A.

Prerequisites

- Nil

Aims and Objectives

This course has been designed with a view to help students in developing a comprehensive understanding and knowledge on remote sensing and GIS for emergency management. This course introduces the principal concepts and techniques of Remote Sensing and GIS, primarily from the perspective of disasters and its aptness for disaster management. It addresses fundamentals and theoretical aspects of interpretation. Course consists of two interrelated parts: a theoretical one that focuses on the concepts to understand disasters footprint as one of Sendai priorities and a practical one that aims at developing hands-on skills in understanding and displaying risk prone areas using (mostly software) tools.

General Learning Outcomes:

By the end of the course, successful students will:

- Understand the fundamental concept and science of remote sensing and GIS
- Learn the processing of satellite remote sensing data
- Learn spatial data creation and spatial modelling tools
- To know and use sources of remote sensing and GIS datasets,
- Understand importance of geospatial approaches for disaster depiction and understanding

Overview of Sessions and Teaching Methods

The course will make most of interactive and self-reflective methods of teaching and learning including mainly lectures and presentations. It will start with an overview of spatial and temporal data concepts and related terms. Subsequently it will build the science and practice of remote sensing and geospatial data and their integration in geospatial approaches. The sessions will be take help of blended teaching and learning approaches for interaction lecturing and hands-on on different course components.

Course Workload

The table below summarizes course workload distribution:

Activities	Learning outcomes	Assessment	Estimated workload (hours)
In-class activities			
Lectures and Presentations	Introduction to the concepts of spatial and temporal data. Significance of space, location, place and map making	Mid Semester Examination	04
Lectures and Presentations	Understanding Disaster and associated risk: Introduction to disasters, impact and mitigation in Global and Indian context; causes and consequences of disaster, elements of risk mapping, assessment, and reduction strategies	Mid Semester Examination	04
Lectures and Presentations	Remote Sensing: The electromagnetic radiation principles, spectral reflectance curves, sensors and platforms, multispectral, thermal, microwave, LiDAR, hyperspectral, image interpretation, specific missions for earth observation, IRS/Landsat series, GEOSS, Geocast, NOAA, long term environmental observation sites and land information system.	Mid Semester Examination	04
Lectures and Presentations	Digital Image Processing: Rectification, enhancements, classification – unsupervised, supervised, hybrid, accuracy assessment	Mid Semester Examination	10
Lectures and Presentations	Geographic information system and spatial data types: vector and raster representation, topology and spatial relationships, scale and resolution, spatial data entry and preparation, integration of data and map. Global Position System: basic concepts, functions, data collection	End Semester Examination	10
Lectures and Presentations	RS & GIS Global and national initiatives for Disaster Risk Management: Disaster management framework of India and recent initiatives by Govt. of India with special emphasis on DRR, Global initiatives (UNISDR, Committee on the Peaceful Uses	End Semester Examination	04

	of Outer Space and etc),		
Lectures and Presentations	Disaster Management Support (DMS), Status in India for use of space inputs Mainstreaming DRR in Development, Planning Sustainable development in the context of Sendai framework and SDG's, Disaster Recovery-Strategy	End Semester Examination	04
Independent work			
Hands-on exercises	Ability to interpret data, and to use the concepts, tools, and methods for communicating information	Individual Presentations	16
Total			**56**

Grading

The students' performance will be based on the following:

- Quizzes/Surprise Test – 10%
- Mid Semester Examination – 30%
- End Semester Examination – 50%
- Individual Assignments – 10%

Course Schedule: **Semester -I: July – December (Proposed)**

Course Assignments

The Structure of Individual Assignments will be as follows:

- Hands-on exercises using Quantum GIS an SAGA GIS.
- Review of research articles and working paper with given objectives.

Literature

- Jensen, J.R. (2004). Introductory Digital Image Processing: A Remote Sensing Perspective. 3rd Edition, Prentice Hall. ISBN-13: 978-0131453616
- Jensen, J.R. (2006). Remote Sensing of the Environment: An Earth Resource Perspective. 2nd Edition, Pearson Series. ISBN-13: 978-0131889507
- Joseph, G. (2003), Fundamentals of Remote Sensing, Orient Longman Press, Bangalore.
- Kumar P, Geneletti D (2015) How are climate change concerns addressed by spatial plans? An evaluation framework, and an application to Indian cities. Land Use Policy 42: 210–226. doi: 10.1016/j.landusepol.2014.07.016
- Lillesand, T. R. W. Kiefer, J. Chipman (2007) Remote Sensing and Image Interpretation. 6th Edition, Wiley. ISBN-13: 978-0470052457
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Reading List Used

SET - I

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2. Kaes, MS, Gruber, K., Frigerio, S., Bell, R., Keiler, M., Glade, T. 2012. The MultiRISK platform: The technical concept and application of a regional scale multi hazard exposure analysis tool. *Geomorphology* 151-152, 139-155.

3. Shaw, R. 2020. Thirty years of science, technology, and academia in disaster risk reduction and emerging responsibilities. *International Journal of Disaster Risk Science* (April 2020)

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SET – II

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11. Zhou, G. 2012. Future Intelligent Earth Observation Satellite System (FIEOS) Advanced System of Systems. IntechOpen.

SET - III

12. Cova, T.J. GIS in emergency management (Chapter 60).

13. Leidig, M.,Teeuw, R. 2015. Free software: A review, in the context of disaster Management. International *Journal Applied Earth Observation and Geoinformation* 42, 49-56.

14. Schumann, G.J-P., Brakenridge, G.R., Kettner, A.J., Kashif, R., Niebuhr, E. 2018. Assisting flood disaster response with earth observation data and products – A critical assessment. Remote Sensing 10, 1230.

15. Li, Q., Kng, L., Tang, D., Zhu, Y. 2011. Applications of spatial information technology in natural disasters. *Procedia Environmental Science* 10, 1396-1400.

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SET – IV

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31. Singh, A., S.S. Nair, A.K. Gupta, P.K. Joshi and V.K. Sehgal (2013). Comprehensive drought hazard analysis using geospatial tools – a study of Bundelkhand Region, India. In: Disaster Management and risk reduction – role of environmental knowledge (Eds. Gupta et al.,), Narosa Publishing House, New Delhi, pp 33-58.

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Digital Image Processing

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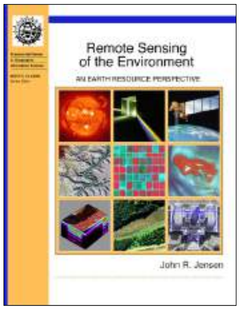
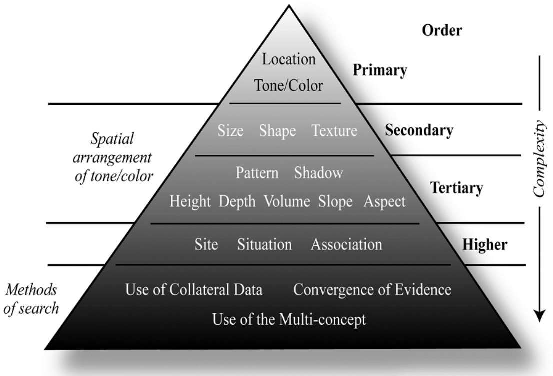


Satellite data – *Visual Interpretation keys*
Digital Image – *an Introduction*

Remote Sensing of the Environment – An Earth Resource Perspective – John R. Jensen Chapter 5
Introductory Digital Image Processing – A Remote Sensing Perspective – John R. Jensen Chapter 1

“ The act of examining photographic images for the purpose of identifying objects and judging their significance.”

Visual Interpretation keys



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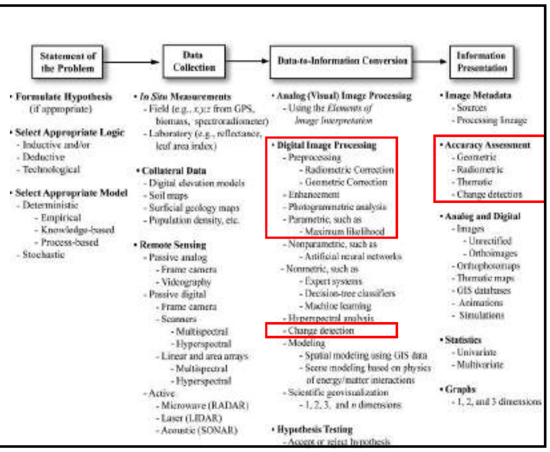
Element	Common Adjectives (quantitative and qualitative)
x,y location	• x,y image coordinates: column (x) and row (y) coordinates in an unrectified image • x,y image map coordinates: silver halide crystals or pixels in photograph or image are rectified to a map projection (e.g., UTM)
Tone/Color	• gray tone: light (bright), intermediate (gray), dark (black) • color: IHS = intensity, hue (color), saturation; RGB = red, green, and blue; Munsell
Size	• length, width, perimeter, area (m^2) • small, medium (intermediate), large
Shape	• an object's geometric characteristics: linear, curvilinear, circular, elliptical, radial, square, rectangular, triangular, hexagonal, pentagonal, star, amorphous, etc.
Texture	• characteristic placement and arrangement of repetitions of tone or color • smooth, intermediate (medium), rough (coarse), mottled, stippled
Pattern	• spatial arrangement of objects on the ground: systematic, unsystematic or random, linear, curvilinear, rectangular, circular, elliptical, parallel, centripetal, serrated, striated, braided
Shadow	• a silhouette caused by solar illumination from the side
Height/Depth/Volume/Slope/Aspect	• z-elevation (height), z-bathymetry (depth), volume (m^3), slope °, aspect °
Site Situation Association	• Site: elevation, slope, aspect, exposure, adjacency to water, transportation, utilities • Situation: objects are placed in a particular order or orientation relative to one another • Association: related phenomena are usually present

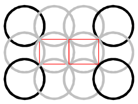
Convergence of Evidence

“measures of constructs that theoretically should be related to each other are, in fact, observed to be related to each other.”

A reasoning process to relate an object to its surroundings.



What’s there in a PIXEL



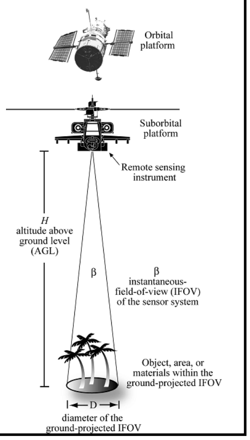
$$L = f\left(\lambda, s_{x,y,z}, t, \theta, P, \Omega\right)$$

λ = wavelength, $s_{x,y,z}$ = x, y, z location of the picture element and its size (x, y), t = temporal information, θ = set of angles that describe relationships among the radiation source (e.g., the Sun), the terrain target of interest (e.g., a corn field), and the remote sensing system, P = polarization of back-scattered energy recorded by the sensor, Ω = radiometric resolution (precision) at which the data are recorded by the remote sensing system.

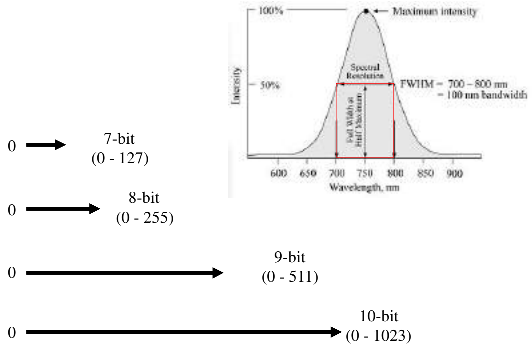
Spatial Resolution

$$Tan\ (\beta/2) = \frac{D/2}{H}$$

$$D = 2H[Tan\ (\beta/2)]$$



Spectral & Radiometric Resolution



Radiometric and atmospheric corrections

– sources of errors

Introductory Digital Image Processing – A Remote Sensing Perspective – John R. Jensen Chapter 6

Image capturing

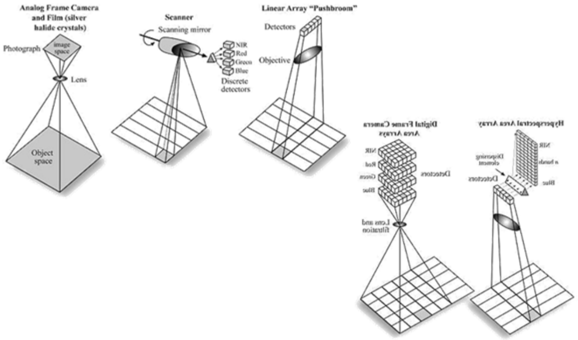
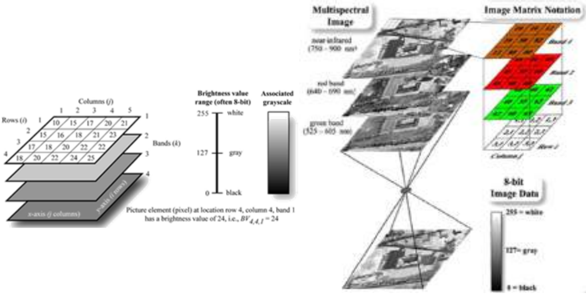
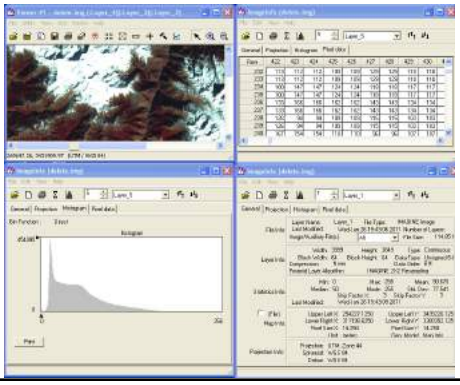


Image formation – *color composite*



Looking at Image



System detector errors

- ✓ Random bad pixels (shot noise),
- ✓ Line-start/stop problems,
- ✓ Line or column drop-outs,
- ✓ Partial line or column drop-outs, &
- ✓ Line or column striping.

	col_{j-1}	col_j	col_{j-1}
row_{i-1}	BV_1	BV_2	BV_3
row_i	BV_8	BV_{ijk}	BV_4
row_{i-1}	BV_7	BV_6	BV_5

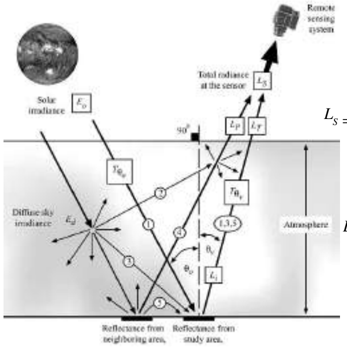
$$BV_{i,j,k} = \text{int}\left[\frac{\sum_{n=1}^{8} BV_n}{8}\right]$$

$$BV_{i,j,k} = \text{int}\left[\frac{BV_{i-1,j,k} + BV_{i+1,j,k}}{2}\right]$$

Atmospheric correction

- ✓ Absolute atmospheric correction
- ✓ Relative atmospheric correction

Path of radiance



$$L_S = \frac{1}{\pi}\rho_\lambda T_{\theta_v}\left(E_{o\Delta\lambda}T_{\theta_o}\text{Cos}\,\theta_{o\Delta\lambda} + E_d\right) + L_p$$

$$L_S = L_T + L_p$$

$$L_S = \left[\frac{(L_{max} - L_{min})}{C_{max}} \times BV_{ijk}\right] + L_{min}$$

Some models

ATREM
Atmospheric REMoval - seven atmospheric gases (H_2O, CO_2, O_3, N_2O, CO, CH_4, O_2) based on water vapor amount

FLAASH (http://www.creaso.com)
Fast Line-of-sight Atmospheric Analysis of Spectral Hypercube - corrects for water vapors, oxygen, carbon dioxide, methane, and ozone in the atmosphere, as well as molecular and aerosol scattering.

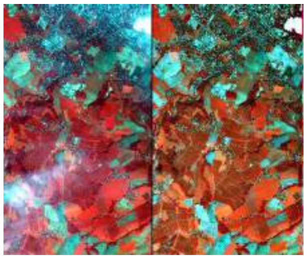
ACORN (http://www.imspec.com)
Atmospheric CORrection Now - atmospheric gas absorption as well as molecular and aerosol scattering effects

ATCOR (http://www.rese.ch)
aerosol type, the visibility or optical thickness, and the water vapor.

HATCH, TAAFKA

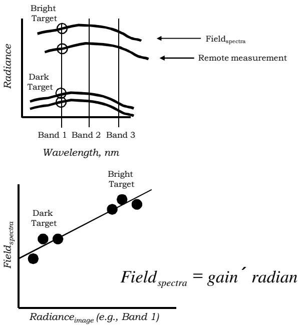
Some models – *data required*

- ✓ latitude and longitude of the remotely sensed image scene;
- ✓ date and exact time of remote sensing data collection;
- ✓ image acquisition altitude (e.g., 700 km AGL);
- ✓ mean elevation of the scene (e.g., 200 m ASL);
- ✓ an atmospheric model (e.g., mid-latitude summer, mid-latitude winter, tropical)
- ✓ radiometrically calibrated image radiance data (i.e., data must be in the form W m2 mm-1 sr-1)
- ✓ data about each specific band (i.e., its mean and full-width at half-maximum (FWHM)
- ✓ local atmospheric visibility at the time of remote sensing data collection (e.g., 10 km, obtained from a nearby airport if possible)



ACORN (http://www.imspec.com)

Empirical Line



$$Field_{spectra} = gain \times radiance_{image} + offset$$

Band 1

48	49
47	48
48	50

m = 48
F = 55

Band 2

55	54
54	57
55	56

m = 55
F = 59

Band 3

40	40
40	39
42	41

m = 38
F = 48

Band 1

9	10
10	11
12	10

m = 10
F= 13

Band 2

5	4
6	5
4	6

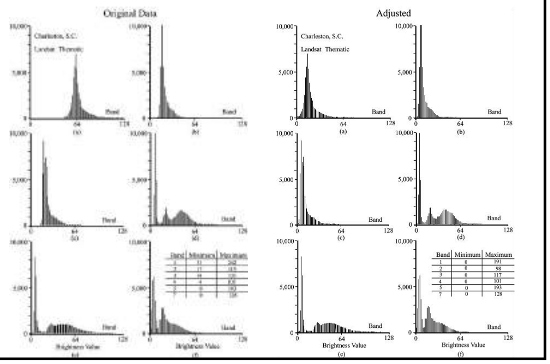
m = 5
F = 7

Band 3

0	0
0	4
2	1

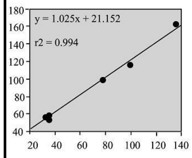
m = 1
F = 4

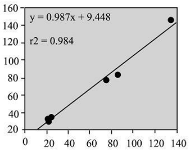
Single Image Normalization – *histogram adjustment*

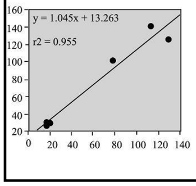


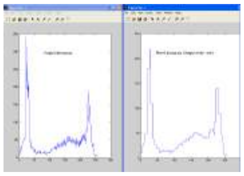
The atmosphere selectively scatters shorter wavelengths of light. Atmospheric scattering produces haze, which results in low image contrast and poor brightness. To reduce these effects, the value of an intercept offset is substracted from the digital numbers of each spectral band (histogram minimum method). The left image shows uncorrected Landsat Thematic Mapper (TM) data (bands 7, 4, and 1 in red, green, and blue) of the Chilean Coastal Cordillera with apparent haze and dull colors. The right image shows corrected Landsat TM data with resultant high contrast and color saturation. Correction of atmospheric scattering is essential for further image optimization and classification (http://geosphere.gsapubs.org/content/2/4/236.full).

Regression analysis/Histogram matching





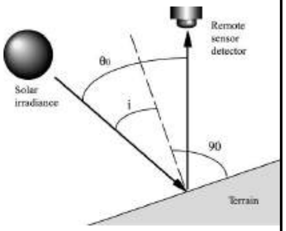




Cosine Correction

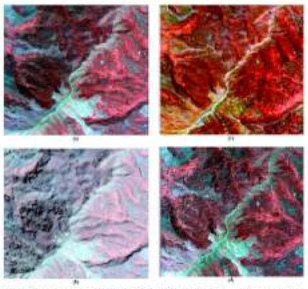
$$L_H = L_T \frac{\mathrm{Cos}\,\theta_o}{\mathrm{Cos}\theta_i}$$

L_H = radiance observed for a horizontal surface (i.e., slope-aspect corrected remote sensor data).
L_T = radiance observed over sloped terrain (i.e., the raw remote sensor data)
θ_o = sun's zenith angle
θ_i = sun's incidence angle in relation to the normal on a pixel



$$L_H = L_T\,\mathrm{Cos}^k i\,\mathrm{Cos}^k e$$

e = slope angle
i = incident angle
K = Minnaert constant



[illegible] http://www.isprs.org/proceedings/XXXV/congress/comm3/papers/347.pdf

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Geometric corrections
– projection, format, geo-referencing etc.

Introductory Digital Image Processing – A Remote Sensing Perspective – John R. Jensen Chapter 7

Recap

- ✓ Absolute atmospheric correction
- ✓ Relative atmospheric correction

ATREM
FLAASH (http://www.creaso.com)
ACORN (http://www.imspec.com)
ATCOR (http://www.rese.ch)
HATCH, TAAFKA
Empirical Line

Single Image Normalisation
Regression analysis/Histogram matching
Cosine correction

??

…procedure that corrects spatial distortions in an image

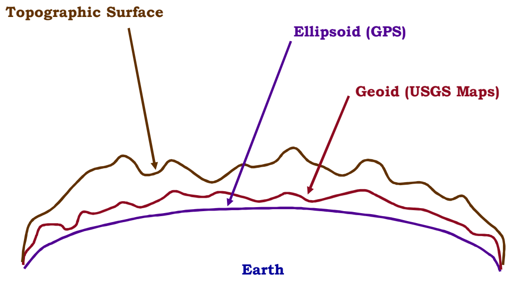
…process by which imagery is corrected for all source-dependent errors and geometrically transformed to the desired map projection, being resampled to a standard square pixel size.

Map projection

Map projections refer to the techniques cartographers and mathematicians have created to depict all or part of a 3D, roughly spherical surface on 2D, flat surfaces with minimal distortion.

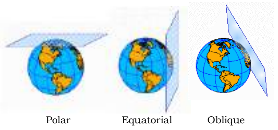
- ✓ Equal Area (*Equivalency*) - Area ;
- ✓ Conformal (*Conformality*) - Shape;
- ✓ Equidistant (*Equidistancy*) - Distances;
- ✓ Azimuthal (*Azimuthalcy*) - Direction;

Measuring Earth

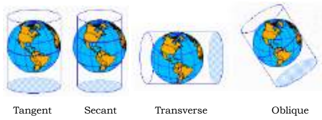


Projection types

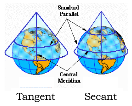
Azimuthal/Plannar



Cylindrical



Conic



Systematic errors - *predictable*

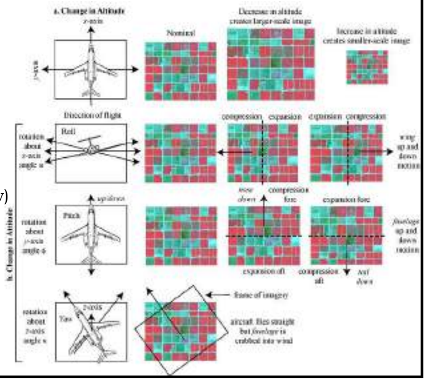
…introduced by the remote sensing system itself or in combination with the Earth rotation or curvature characteristics

- *skew* caused by Earth rotation effects,
- variation in ground resolution cell size,
- one-dimensional relief displacement, and
- tangential scale distortion.

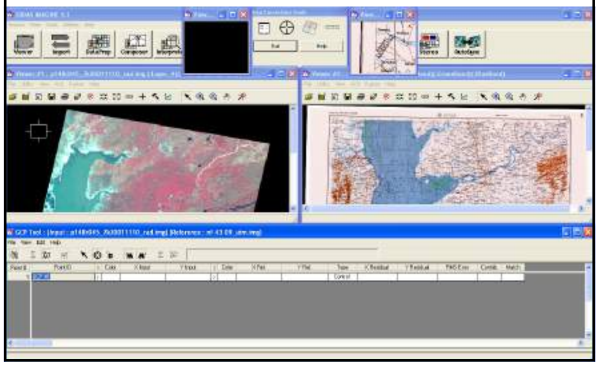
Non-systematic errors - *Unpredictable*

Altitude changes

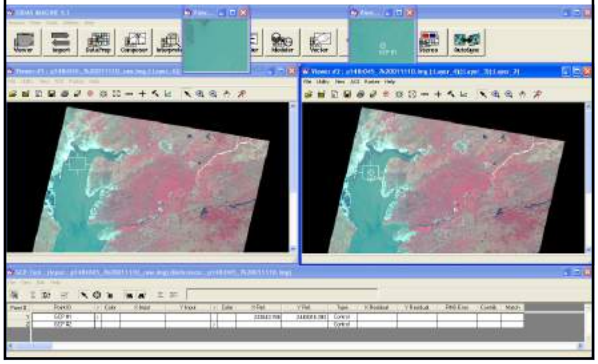
Attitude changes (roll, pitch, and yaw)



Geo-referencing – *image to map*



Geo-referencing – *image to image*

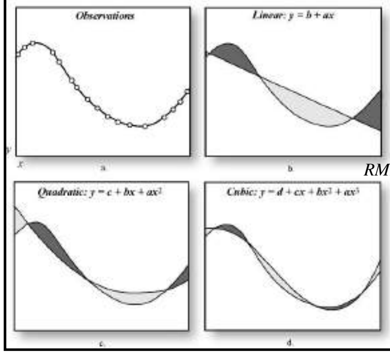


Interpolation

Two basic operations must be performed to geometrically rectify a remotely sensed image to a map coordinate system:

- Spatial interpolation, and
- Intensity interpolation.

Spatial **Interpolation**



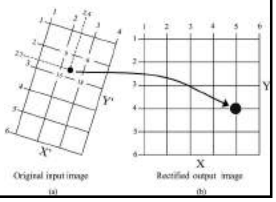
$$RMS_{err} = \sqrt{(x' - x_o)^2 + (y' - y_o)^2}$$

Spectral **Interpolation**

Generally referred as resampling

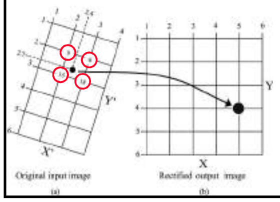
- Nearest neighbor
- Bilinear interpolation and
- Cubic convolution

NN - BV closest to the predicted x', y' coordinate is assigned to the output x, y coordinate.

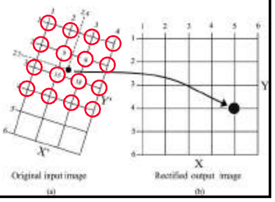


Spectral **Interpolation**

BII - BV in two orthogonal directions (4 values) computes a new BV values based on the weighted distance to these points to the predicted x', y' coordinate is assigned to the output x, y coordinate.



CC - Assigns values to output pixels in the same manner as BII, except that the weighted values of 16 pixels surrounding the location



Orthorectification

...is a process of making the geometry of an image planimetric, or map-accurate,

... by modeling the nature and magnitude of geometric distortions in the imagery.

...these distortions are caused by topography, camera geometry, and sensor-related errors.

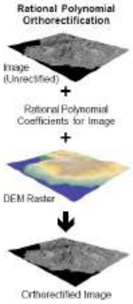
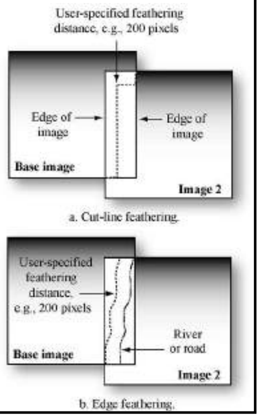


Image Mosaic

Individual images should be rectified to the same map projection and datum.

The base image and image 2 will normally overlap a certain amount (e.g., 20% to 30%).

It is common to blend the seams between mosaicked images using feathering.



a. Cut-line feathering.

b. Edge feathering.

Image Enhancement Techniques - I

Introductory Digital Image Processing – A Remote Sensing Perspective – John R. Jensen Chapter 8

...techniques used to emphasize the tonal and textural differences in images

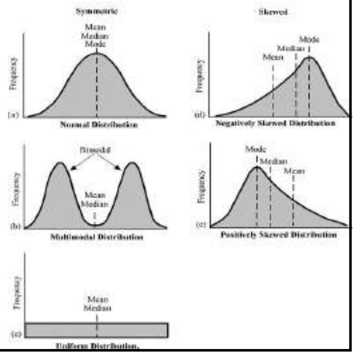
...data manipulation...

...any one of a group of operations that improve the detectability of the targets or categories

...include, but are not limited to contrast improvement, edge enhancement, spatial filtering, noise suppression, image smoothing, and image sharpening

...there is no thumb rule

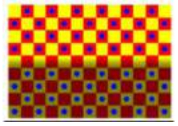
Image type



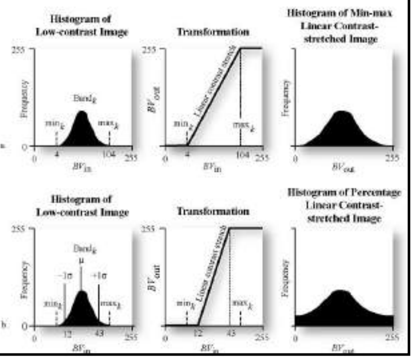
Contrast

...the ratio between the energy emitted or reflected by an object and its immediate surroundings.

...the brightness ratio of the lightest to the darkest part of an image.



Contrast enhancement



Contrast …

$$BV_{out} = \left(\frac{BV_{in} - \min_k}{\max_k - \min_k} \right) \times quant_k$$

where:

BV_{in} is the original input BV

$quant_k$ is the range of the BV

min_k is the minimum BV in the image

max_k is the maximum BV in the image

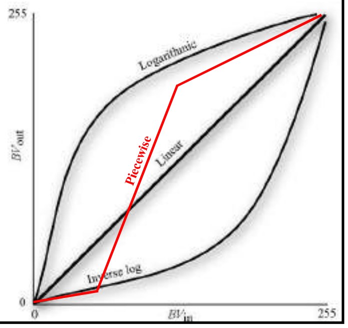
BV_{out} is the output BV

$$BV_{out} = \left(\frac{4 - 4}{105 - 4} \right) \times 255 = 0$$

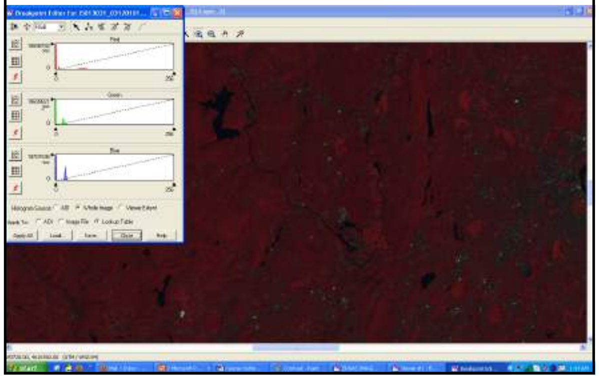
$$BV_{out} = \left(\frac{105 - 4}{105 - 4} \right) \times 255 = 255$$

Minimum-maximum
Percentage linear
Standard deviation
Piece-wiseGaussain
Near-Gaussain

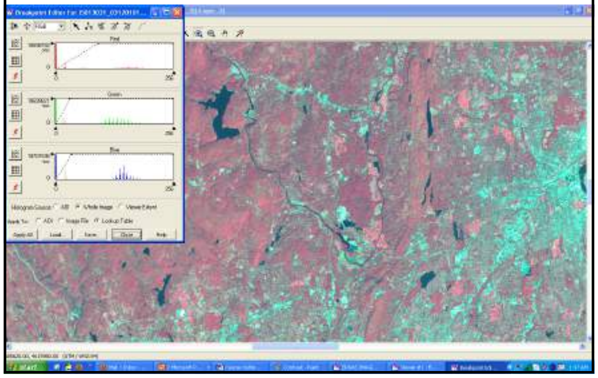
Linear & Nonlinear stretching



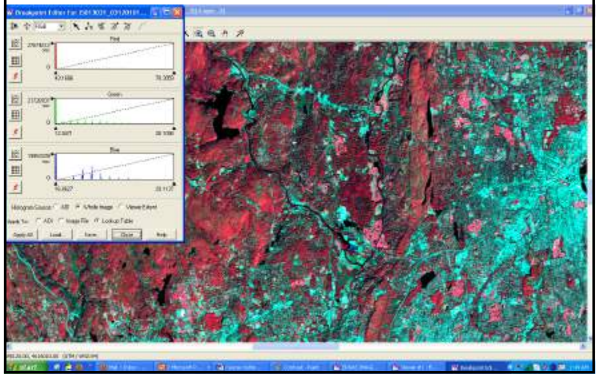
Raw Image



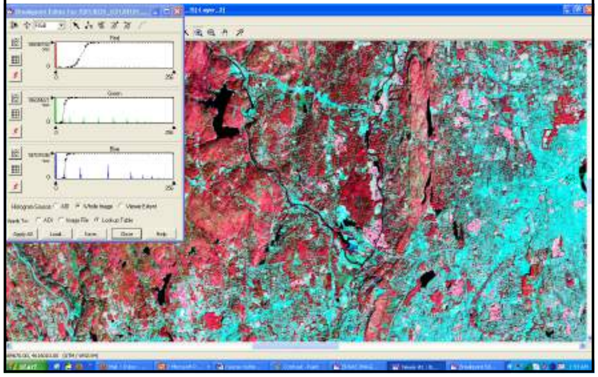
Default stretching



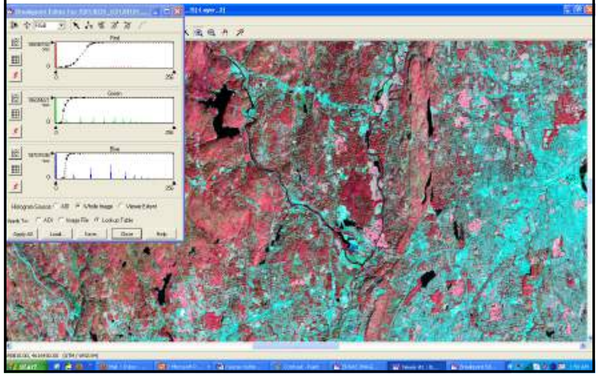
Linear stretch



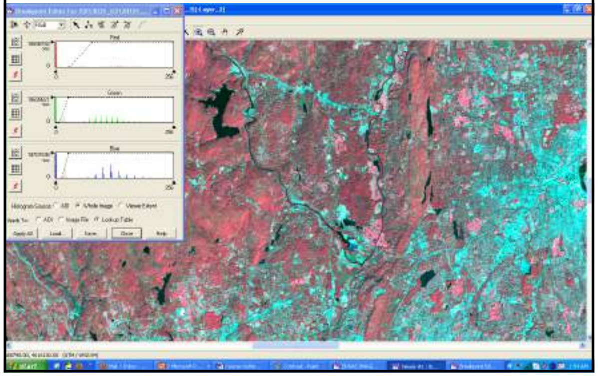
Histogram equalization



Gaussian stretch



Standard deviation



Spatial enhancement

Spatial frequency in remotely sensed imagery may be enhanced or subdued using two different approaches:

… *Spatial convolution* filtering based primarily on the use of convolution masks, and

… *Fourier analysis* which mathematically separates an image into its spatial frequency components.

Spatial convolution

The size of the neighborhood convolution mask or kernel (n) is usually 3 × 3, 5 × 5, 7 × 7, or 9 × 9

We will constrain our discussion to 3 × 3 convolution masks with nine coefficients, ci, defined at the following locations:

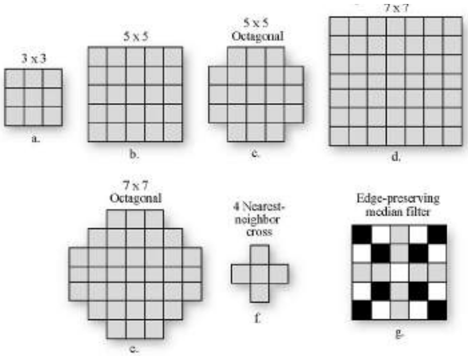
1	1	1
1	1	1
1	1	1

Mask template =
c1 c2 c3
c4 c5 c6
c7 c8 c9

Mask template =
c1 × BV1 c2 × BV2 c3 × BV3
c4 × BV4 c5 × BV5 c6 × BV6
c7 × BV7 c8 × BV8 c9 × BV9

input pixel under investigation at any time is BV5 = BVi,j

Convolution mask



Low-pass filter

Mean
Mode
Median
Maximum
Minimum
Olympic
Adaptive box

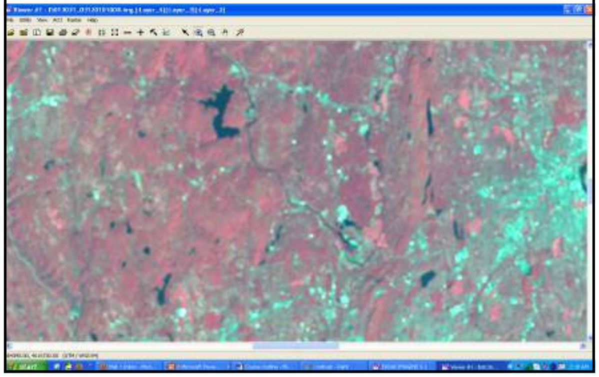
$$LFF_{5,out} = \text{int}\left(\frac{\sum_{i=1}^{9} c_i \, x \, BV_i}{n}\right)$$

$$= \text{int}\left(\frac{BV_1 + BV_2 + BV_3 + \dots BV_9}{9}\right)$$

1	1	1
1	1	1
1	1	1

1	1	1
1	2	1
1	1	1

Low-pass filter



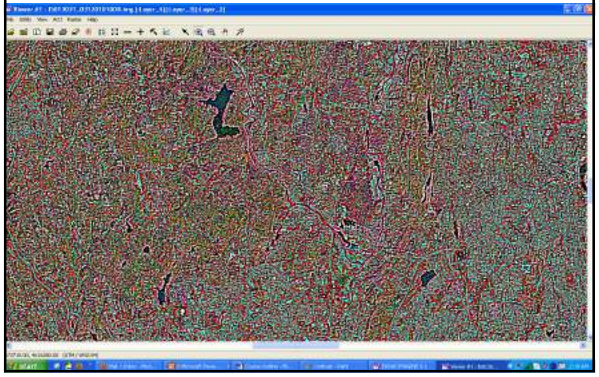
High-pass filter

-1	-1	-1
-1	9	-1
-1	-1	-1

$$HFF_{5,out} = (2 \, x \, BV_5) - LFF_{5,out}$$

1	-2	1
-2	5	-2
1	-2	1

High-pass filter



Edge enhancement

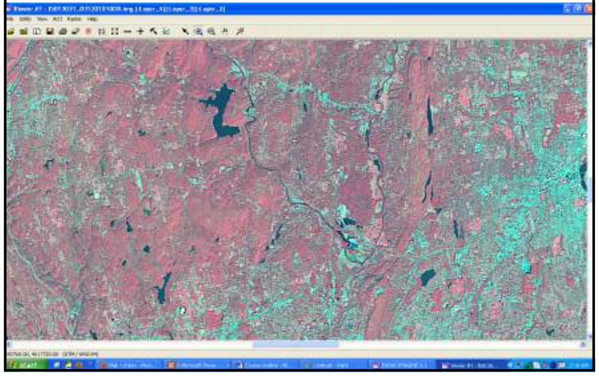
$$\text{Vertical} = BV_{i,j} - BV_{i,j+1} + K$$

$$\text{Horizontal} = BV_{i,j} - BV_{i-1,j} + K$$

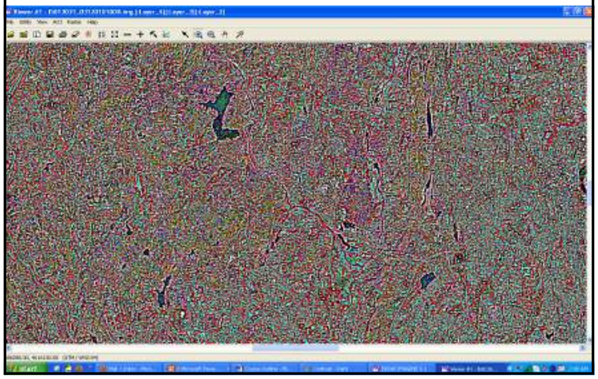
$$\text{NE Diagonal} = BV_{i,j} - BV_{i+1,j+1} + K$$

$$\text{SE Diagonal} = BV_{i,j} - BV_{i-1,j+1} + K$$

Edge enhancement

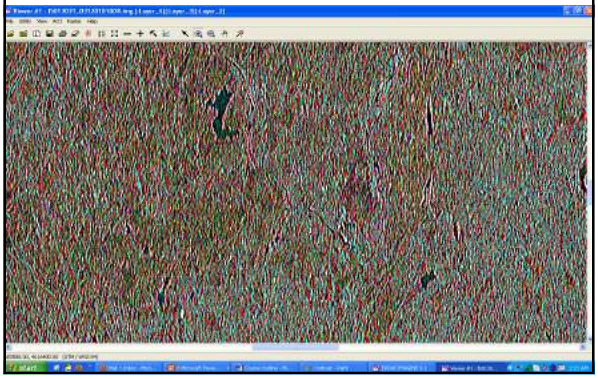


Edge detection

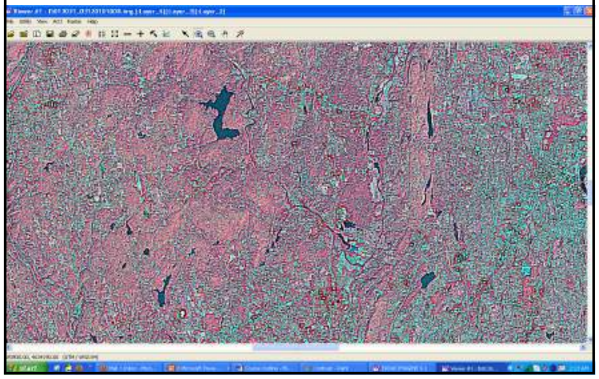


Horizontal filter

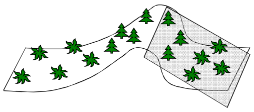
Vertical filter



Summary filter



Terrain Shadowing

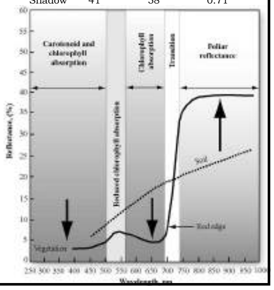


Adapted from Lillesand and Kiefer

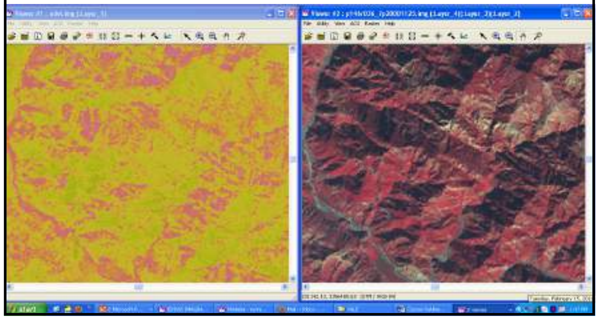
		Band#1	Band#2	Ratio 1/2
Deciduous	Sunlit	140	150	0.93
	Shadow	56	61	0.92
Conifer	Sunlit	102	145	0.70
	Shadow	41	58	0.71

$$SR = \frac{NIR}{red}$$

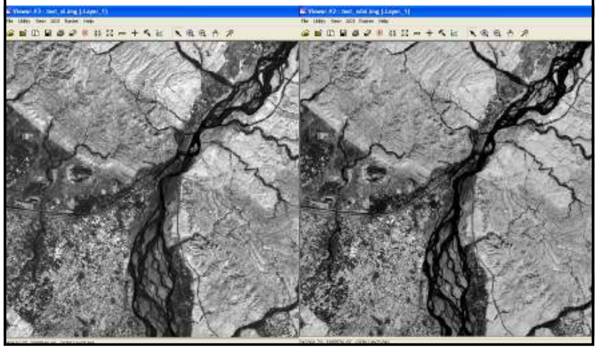
$$NDVI = \frac{NIR - red}{NIR + red}$$



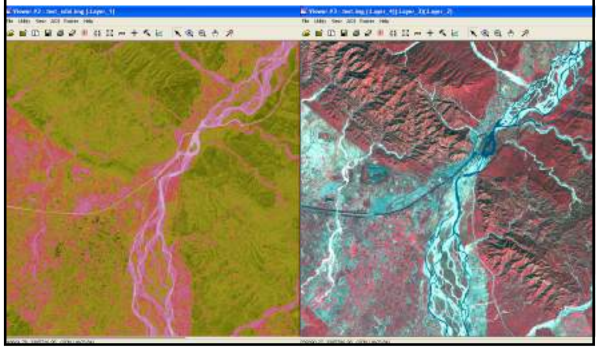
NDVI



NDVI



NDVI



Other Indices

Built - up

$$NDBI = \frac{MIR - MIR}{MIR + NIR}$$

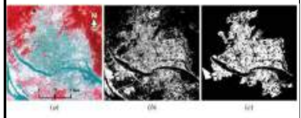
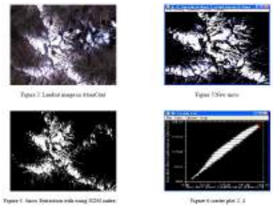


Figure 2. Landsat ETM+ image of Fuzhou City: (a) false colour image (RGB 432), (b) IBI image, enhanced built-up land features are in a light-grey to white tone and suppressed background noise is in a dark-grey to black shade and (c) built-up land extraction image.

International Journal of Remote Sensing
17 Feb 2011

Snow

$$NDSI = \frac{TM2 - TM5}{TM2 + TM5}$$



The Int Phot., RS & Spatial Information Sciences
2008

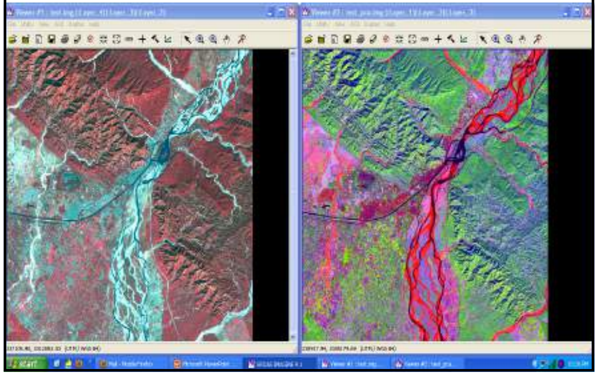
Principal Components

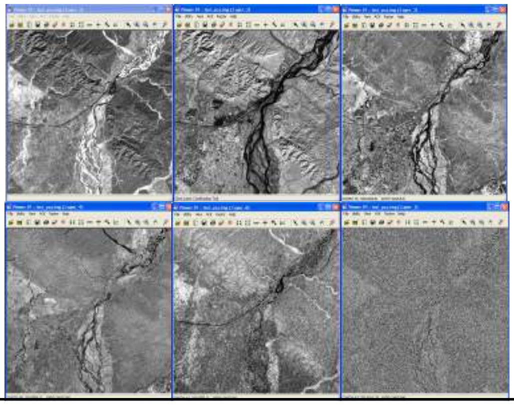
…transformation of the raw remote sensor data using PCA can result in new PC images that may be more interpretable than the original data.

…also be used to compress the information content of a number of bands of imagery into just two or three transformed PC images.

… must be analyzed to produce usable results

Principal Components



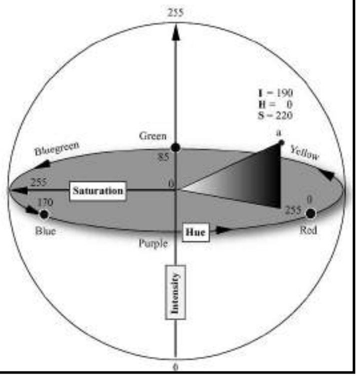


IHS

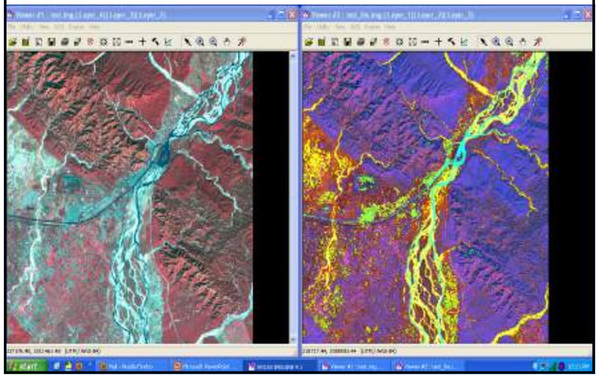
$$I = R + G + B$$

$$H = \frac{G - B}{I - 3B}$$

$$S = \frac{I - 3B}{I}$$



RGB to IHS



Tasseled Cap Transformation (Kauth-Thomas)

A another kind linear transformation and make the new components have meaning for interpreter

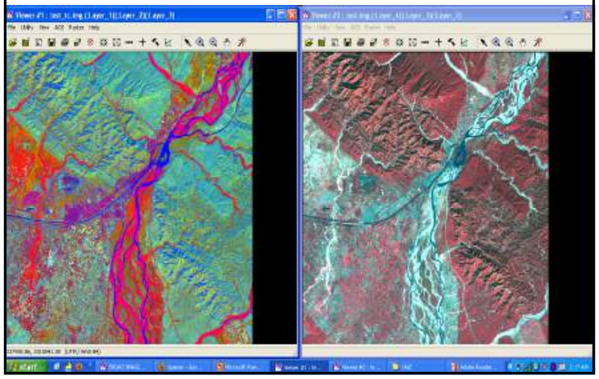
Brightness (B) a weighted sum of all bands, defined in the direction of the principal variation in soil reflectance.

Greenness (G) orthogonal to brightness, a contrast between the near-infrared and visible bands. Strongly related to the amount of green vegetation in the scene.

Yellowness (Y) relates to canopy and soil moisture

Non-such (N)

Tasseled Cap Transformation (Kauth-Thomas)



Tasseled Cap Transformation (Kauth-Thomas)

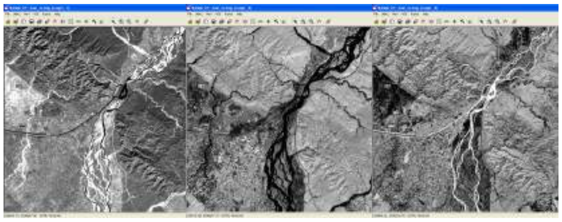
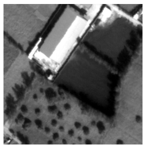


Image Fusion

$Red_{brovey} = \frac{R' P}{I}$	*RGB*	*RGB*
$Green_{brovey} = \frac{G' P}{I}$	*IHS*	*PC1,2,3*
$Blue_{brovey} = \frac{B' P}{I}$	*PHS*	*P, PC2, 3*
$I = \frac{R+G+B}{3}$	*RGB*	*RGB*

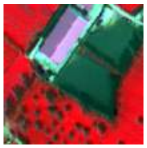
Image Fusion


Raw 2


Raw 0.5


Raw 0.5


Fused (B)


Fused (PCA)

Unsupervised classification

Introductory Digital Image Processing – A Remote Sensing Perspective – John R. Jensen Chapter 9

…. commonly referred to as clustering

…. is an effective method of partitioning remote sensor image data in multispectral feature space

…. normally requires only a minimal amount of initial input from the analyst

---

Chain Method
ISODATA (Iterative Self-Organizing Data Analysis Technique)

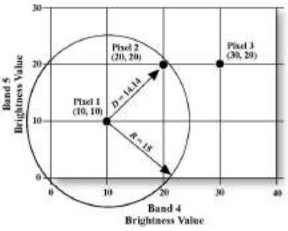
Chain method

Pass #1: The program reads through the dataset and sequentially builds clusters (groups of points in spectral space). A mean vector is then associated with each cluster.

- R, a radius distance in spectral space used to determine when a new cluster should be formed (e.g., when raw remote sensor data are used, it might be set at 15 brightness value units).
- C, a spectral space distance parameter used when merging clusters (e.g., 30 units) when N is reached.
- N, the number of pixels to be evaluated between each major merging of the clusters (e.g., 2000 pixels).
- Cmax, the maximum number of clusters to be identified by the clustering algorithm (e.g., 20 clusters).

Pass #2: A minimum distance to means classification algorithm is applied to the whole dataset on a pixel-by-pixel basis whereby each pixel is assigned to one of the mean vectors created in pass 1. The first pass, therefore, automatically creates the cluster signatures (class mean vectors) to be used by the minimum distance to means classifier.

Chain …

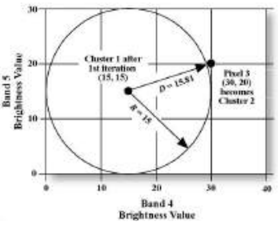


The distance (*D*) in 2-dimensional spectral space between pixel 1 (cluster 1) and pixel 2 (potential cluster 2)

in the first iteration is computed and tested against the value of *R*=15, the minimum acceptable radius.

In this case, *D* does not exceed *R*. Therefore, we merge clusters 1 and 2 as shown in the next illustration.

Chain …

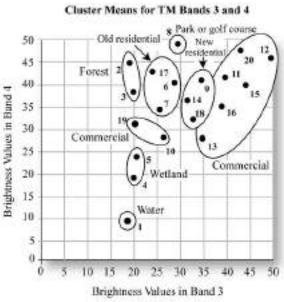


Pixels 1 and 2 now represent cluster #1. Note that the location of cluster 1 has migrated from 10,10 to 15,15 after the first iteration.

Now, pixel 3 distance (D=15.81) is computed to see if it is greater than the minimum threshold, R=15.

It is, so pixel location 3 becomes cluster #2. This process continues until all 20 clusters are identified. Then the 20 clusters are evaluated using a distance measure, C (not shown), to merge the clusters that are closest to one another.

Chain …



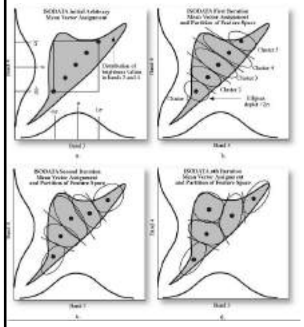
Grouping (labeling) of the original 20 spectral clusters into information classes. The labeling was performed by analyzing the mean vector locations in bands 3 and 4.

ISODATA

Phase 1: ISODATA Cluster Building using many passes through the dataset.

Phase 2: Assignment of pixels to one of the Cmax clusters using minimum distance to means classification logic.

ISODATA

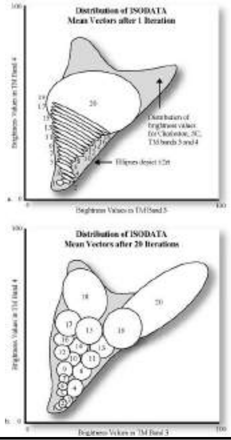


ISODATA initial distribution of five hypothetical mean vectors

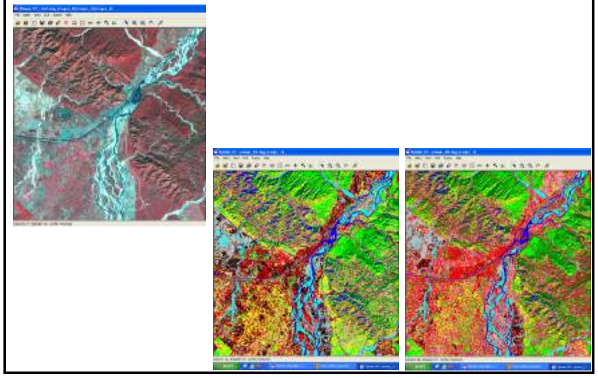
In the first iteration, each candidate pixel is compared to each cluster mean and assigned to the cluster whose mean is closest in Euclidean distance.

During the second iteration, a new mean is calculated for each cluster based on the actual spectral locations of the pixels assigned to each cluster. Now every pixel in the scene is assigned to one of the new clusters.

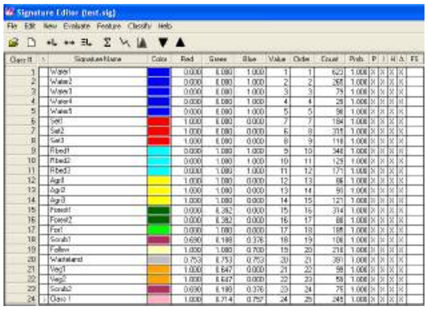
ISODATA



Unsupervised – Output

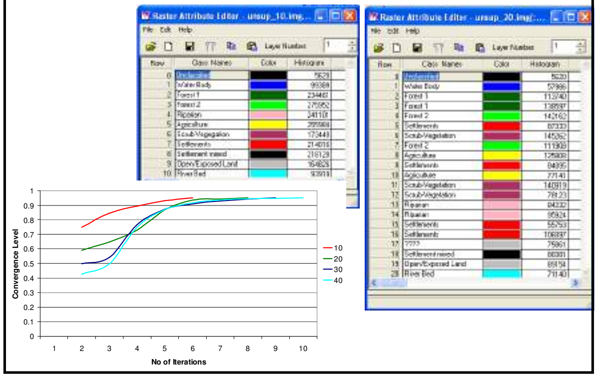


Supervised – Training sets



Class #	>	Signature Name	Color	Red	Green	Blue	Value	Order	Count	Prob.	P	I	H	A	FS
1		Water1	🟦	0.000	0.000	1.000	1	1	623	1.000	X	X	X	X	
2		Water2	🟦	0.000	0.000	1.000	2	2	268	1.000	X	X	X	X	
3		Water3	🟦	0.000	0.000	1.000	3	3	79	1.000	X	X	X	X	
4		Water4	🟦	0.000	0.000	1.000	4	4	28	1.000	X	X	X	X	
5		Water5	🟦	0.000	0.000	1.000	5	5	98	1.000	X	X	X	X	
6		Set1	🟥	1.000	0.000	0.000	7	7	184	1.000	X	X	X	X	
7		Set2	🟥	1.000	0.000	0.000	6	8	315	1.000	X	X	X	X	
8		Set3	🟥	1.000	0.000	0.000	8	9	118	1.000	X	X	X	X	
9		Rbed1	🟦	0.000	1.000	1.000	9	10	348	1.000	X	X	X	X	
10		Rbed2	🟦	0.000	1.000	1.000	10	11	129	1.000	X	X	X	X	
11		Rbed3	🟦	0.000	1.000	1.000	11	12	171	1.000	X	X	X	X	
12		Agri1	🟨	1.000	1.000	0.000	12	13	86	1.000	X	X	X	X	
13		Agri2	🟨	1.000	1.000	0.000	13	14	90	1.000	X	X	X	X	
14		Agri3	🟨	1.000	1.000	0.000	14	15	121	1.000	X	X	X	X	
15		Forest1	🟩	0.000	0.392	0.000	15	16	314	1.000	X	X	X	X	
16		Forest2	🟩	0.000	0.392	0.000	16	17	88	1.000	X	X	X	X	
17		For1	🟩	0.000	1.000	0.000	17	18	185	1.000	X	X	X	X	
18		Scrub1	🟫	0.690	0.188	0.376	18	19	106	1.000	X	X	X	X	
19		Fallow	⬜	1.000	1.000	0.700	19	20	218	1.000	X	X	X	X	
20		Wasteland	⬜	0.753	0.753	0.753	20	21	391	1.000	X	X	X	X	
21		Veg1	🟧	1.000	0.647	0.000	21	22	98	1.000	X	X	X	X	
22		Veg2	🟧	1.000	0.647	0.000	22	23	58	1.000	X	X	X	X	
23		Scrub2	🟫	0.690	0.188	0.376	23	24	75	1.000	X	X	X	X	
24	>	Class 1	🟪	1.000	0.714	0.757	24	25	245	1.000	X	X	X	X	

Unsupervised – Output



Row	Class Names	Color	Histogram
0	Unclassified	⬛	5629
1	Water Body	🟦	99389
2	Forest 1	🟩	234467
3	Forest 2	🟩	275952
4	Riparian	🟪	341101
5	Agriculture	🟨	295984
6	Scrub-Vegetation	🟫	173448
7	Settlements	🟥	214018
8	Settlement mixed	⬛	218129
9	Open/Exposed Land	⬜	164825
10	River Bed	🟦	93918

Row	Class Names	Color	Histogram
0	Unclassified	⬛	5620
1	Water Body	🟦	57986
2	Forest 1	🟩	113740
3	Forest 1	🟩	138897
4	Forest 2	🟩	142162
5	Settlements	🟥	87333
6	Scrub-Vegetation	🟫	145262
7	Forest 2	🟩	111909
8	Agriculture	🟨	125808
9	Settlements	🟥	84895
10	Agriculture	🟨	77141
11	Scrub-Vegetation	🟫	140919
12	Scrub-Vegetation	🟫	78123
13	Riparian	🟪	84232
14	Riparian	🟪	95924
15	Settlements	🟥	55753
16	Settlements	🟥	106897
17	????	⬜	75861
18	Settlement mixed	⬛	88301
19	Open/Exposed Land	⬜	89158
20	River Bed	🟦	71140

Supervised classification

Introductory Digital Image Processing – A Remote Sensing Perspective ~ John R. Jensen Chapter 9

….the identity and location of some of the land-cover types are known *a priori* through…

… attempts to locate specific sites in the remotely sensed data that represent homogeneous examples …

… are commonly referred to as *training sites* because the spectral characteristics of these known areas are used *to train* the classification algorithm …

… multivariate statistical parameters (means, standard deviations, covariance matrices, correlation matrices, etc.) are calculated for each training site.

Every pixel both within and outside the training sites is then evaluated and assigned to the class of which it has the highest likelihood of being a member.

Training sets

\# *of pixels* - want to statistically characterize the spectral properties of an informational class, should have >10n pixels

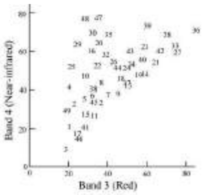
location - geographically dispersed, boundaries away from edge/mixed pixels

nature - Homogenous but heterogeneous

number of areas - depends on number of information categories, n+1 at a minimum

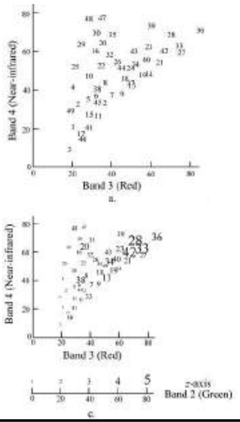
uniformity - unimodal distributions, not easy due to spectral variation present

Feature space

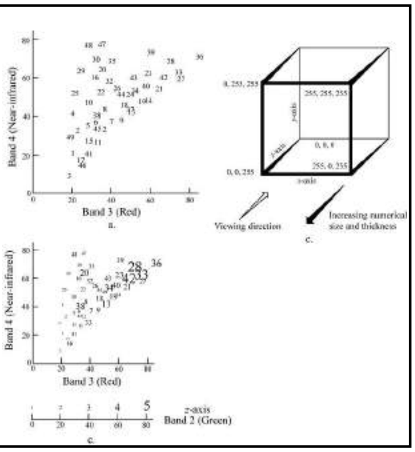


a.

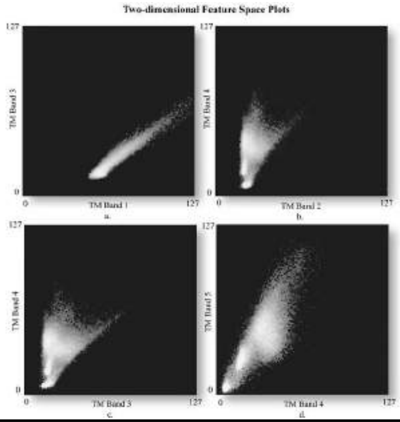
Feature space



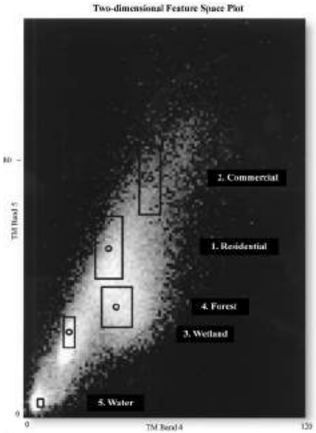
Feature space



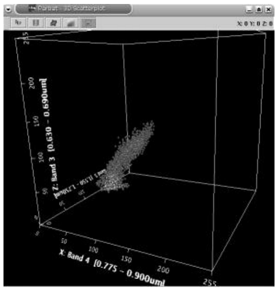
Feature space

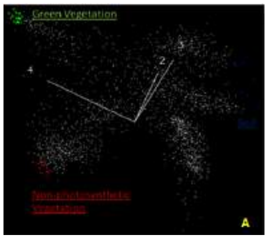


Feature space



Feature space



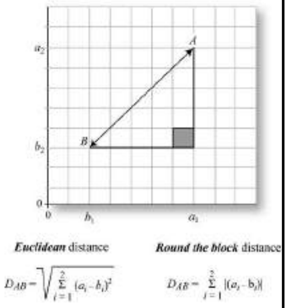


Minimum distance to means

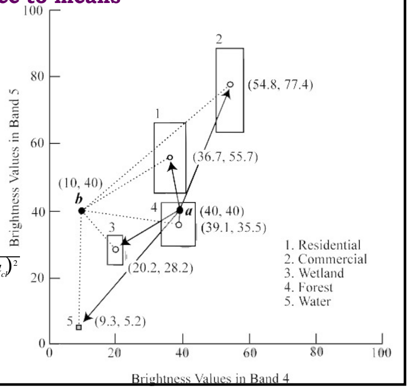
The minimum distance to means decision rule is computationally simple and commonly used.

It requires that the user provide the mean vectors for each class in each band μ_{ck} from the training data.

To perform a minimum distance classification, it calculates the distance to each mean vector μ_{ck} from each unknown pixel (BV_{ijk}).



Minimum distance to means



$$Dist = \sqrt{\left(BV_{ijk} - \mu_{ck}\right)^2 + \left(BV_{ijl} - \mu_{cl}\right)^2}$$

Parallelepiped/Box

This is a widely used digital image classification decision rule based on simple Boolean “and/or” logic.

Training data in n-spectral bands are used to perform the classification.

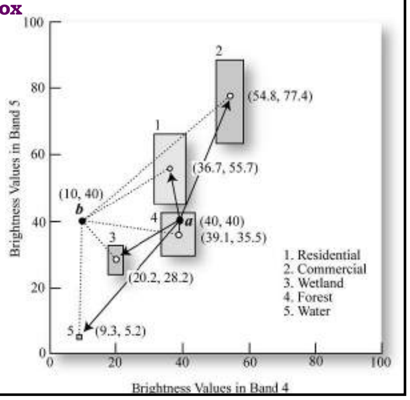
Brightness values from each pixel of the multi-spectral imagery are used to produce an n-dimensional mean vector, $M_c = (\mu_{ck}, \mu_{c2}, \mu_{c3},, \mu_{cn})$ with μ_{ck} being the mean value of the training data obtained for class *c* in band *k*

σ_{ck} is the standard deviation of the training data class *c* of band *k*.

Parallelepiped/Box

$$\mu_{ck} - \sigma_{ck} \le BV_{ijk} \le \mu_{ck} + \sigma_{ck}$$

$$L_{ck} \le BV_{ijk} \le H_{ck}$$



Maximum Likelihood

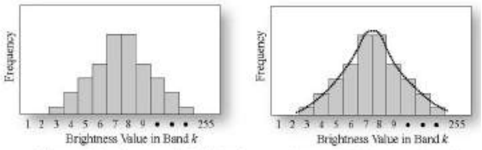
The maximum likelihood decision rule is based on probability.

The maximum likelihood procedure assumes that the training data statistics for each class in each band are normally distributed (Gaussian).

The probability of a pixel belonging to each of a predefined set of m classes is calculated, and the pixel is then assigned to the class for which the probability is the highest.

The maximum likelihood decision rule is still one of the most widely used supervised classification algorithms.

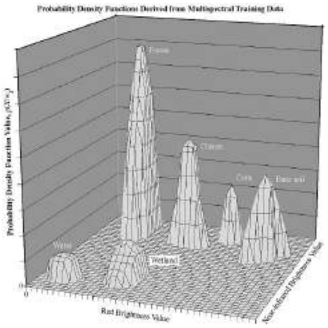
MLC/MXL



a. Histogram (data frequency distribution) of forest training data in a single band *k*.

b. Data distribution approximated by a normal probability density function.

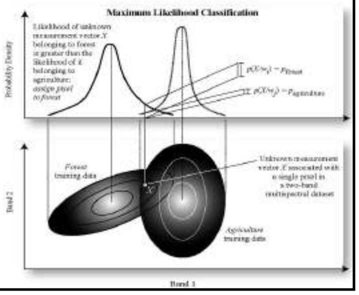
MLC/MXL



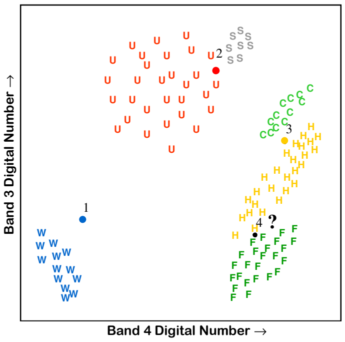
MLC/MXL

Say, two hypothetical normally distributed probability density functions associated with C1 and C2 training data measured in bands 1 and 2.

In this case, pixel X would be assigned to *forest* because the probability density of unknown measurement vector X is greater for forest than for agriculture.

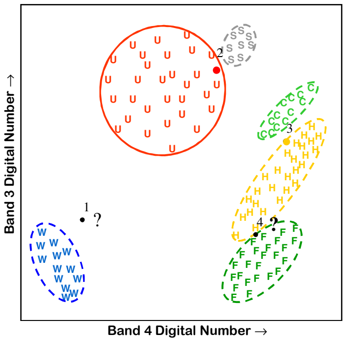


Minimum distance to means



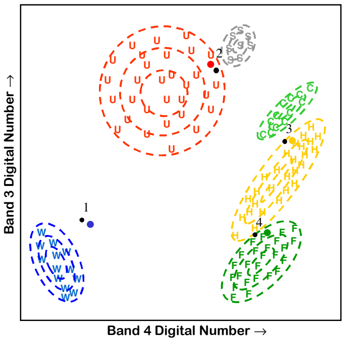
Adapted from Lillesand and Kiefer

Parallelepiped/Box



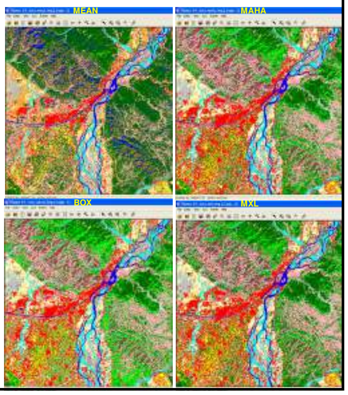
Adapted from Lillesand and Kiefer

MLC/MXL

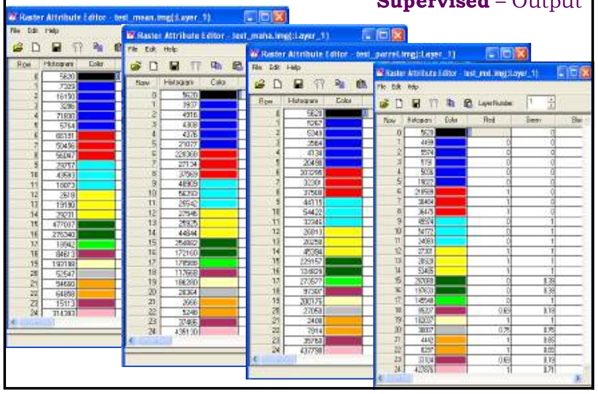


Adapted from Lillesand and Kiefer

Supervised – Output



Supervised – Output



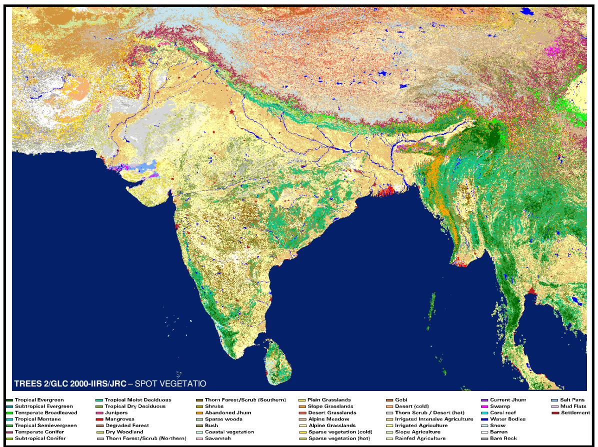
Accuracy Assessment

Introductory Digital Image Processing – A Remote Sensing Perspective – John R. Jensen Chapter 13

Quick Questions

1. What is Accuracy Assessment?
2. What are characteristics of samples used for accuracy assessment?
3. List two synonymous terms used for error matrix.
4. List the different kind of information extracted from the error matrix.
5. What is difference between producer's and user's accuracy?
6. What is difference between error of commission and error of omission?
7. What is importance of Kappa/K_{hat} statistics?
8. Calculate accuracy of the classified map using the given matrix.

??



Accuracy Assessment

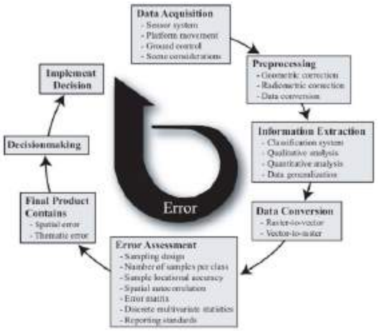
…unfortunately, the thematic information contains error.

…recognize the sources of the error, minimize it as much as possible, and

…inform the user how much confidence one should have in the thematic information.

Remote sensing–derived thematic maps should normally be subjected to a thorough accuracy assessment before being used in scientific investigations and policy decisions.

Why do we need this?



Accuracy Assessment

..process of comparing certain pixels (a sample) of the classified map to the reference (for which the class is known) pixels.

The source of reference pixels could be field work, previously test maps, high resolution datasets like aerial photograph, Goggle Earth images etc.

Sample

...locate ground reference test pixels (or polygons) in the study area.

...sites are not used to train the classification algorithm --- represent unbiased reference information.

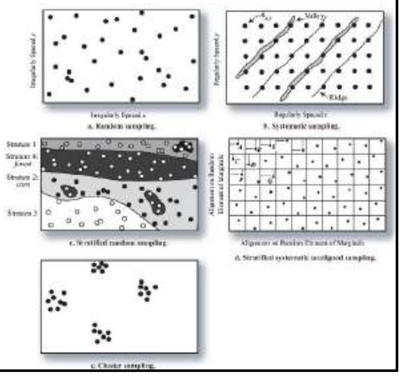
...possible to collect *a prior* ground reference test information to the classification, perhaps at the same time as the training data.

...are collected after the classification has been performed

...spatial scale of reference plots and remotely-sensed data

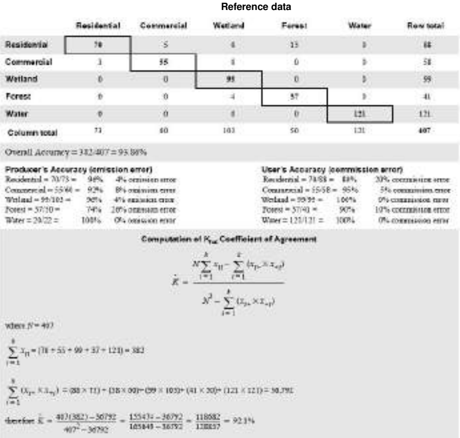
...position/location and number of samples

Sampling



Matrix

Error
Confusion
Contingency



Reference data

Classified data	Residential	Commercial	Wetland	Forest	Water	Row total
Residential	70	5	0	13	0	88
Commercial	3	55	0	0	0	58
Wetland	0	0	99	0	0	99
Forest	0	0	4	37	0	41
Water	0	0	0	0	121	121
Column total	73	60	103	50	121	407

Overall Accuracy = 382/407 = 93.86%

Producer's Accuracy (omission error)

Residential = 70/73 = 96% 4% omission error
Commercial = 55/60 = 92% 8% omission error
Wetland = 99/103 = 96% 4% omission error
Forest = 37/50 = 74% 26% omission error
Water = 121/121 = 100% 0% omission error

User's Accuracy (commission error)

Residential = 70/88 = 80% 20% commission error
Commercial = 55/58 = 95% 5% commission error
Wetland = 99/99 = 100% 0% commission error
Forest = 37/41 = 90% 10% commission error
Water = 121/121 = 100% 0% commission error

Computation of K_{hat} Coefficient of Agreement

$$\hat{K} = \frac{N\sum_{i=1}^{k} x_{ii} - \sum_{i=1}^{k}(x_{i+}\times x_{+i})}{N^2 - \sum_{i=1}^{k}(x_{i+}\times x_{+i})}$$

where $N = 407$

$$\sum_{i=1}^{k} x_{ii} = (70 + 55 + 99 + 37 + 121) = 382$$

$$\sum_{i=1}^{k}(x_{i+}\times x_{+i}) = (88\times 73) + (58\times 60) + (99\times 103) + (41\times 50) + (121\times 121) = 36{,}792$$

$$\text{therefore } \hat{K} = \frac{407(382) - 36792}{407^2 - 36792} = \frac{155474 - 36792}{165649 - 36792} = \frac{118682}{128857} = 92.1\%$$

Matrix

Coefficient of Agreement can be used to calculate agreement between the reference and remote sensing–derived data with chance agreement eliminated *for an individual class*

$$\hat{K} = \frac{N(x_{ii}) - (x_{i+} \times x_{+i})}{N(x_{i+}) - (x_{i+} \times x_{+i})} \qquad \hat{K}_{\text{Residential}} = \frac{407(70) - (88 \times 73)}{407(88) - (88 \times 73)} = 0.75$$

Quick Questions

1. What is Accuracy Assessment?
2. What are characteristics of samples used for accuracy assessment?
3. List two synonymous terms used for error matrix.
4. List the different kind of information extracted from the error matrix.
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ISPRS Int. J. Geo-Inf. **2012**, *1*, 166-185; doi:10.3390/ijgi1020166

OPEN ACCESS
ISPRS International
Journal of
Geo-Information
ISSN 2220-9964
www.mdpi.com/journal/ijgi/

Review

An Analysis of Geospatial Technologies for Risk and Natural Disaster Management

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*Received: 15 June 2012; in revised form: 18 July 2012 / Accepted: 26 July 2012 /
Published: 7 August 2012*

Abstract: This paper discusses the use of spatial data for risk and natural disaster management. The importance of remote-sensing (RS), Geographic Information System (GIS) and Global Navigation Satellite System (GNSS) data is stressed by comparing studies of the use of these technologies for natural disaster management. Spatial data sharing is discussed in the context of the establishment of Spatial Data Infrastructures (SDIs) for natural disasters. Some examples of SDI application in disaster management are analyzed, and the need for participation from organizations and governments to facilitate the exchange of information and to improve preventive and emergency plans is reinforced. Additionally, the potential involvement of citizens in the risk and disaster management process by providing voluntary data collected from volunteered geographic information (VGI) applications is explored. A model relating all of the spatial data-sharing aspects discussed in the article was suggested to elucidate the importance of the issues raised.

Keywords: volunteered geographic information (VGI); spatial data infrastructure (SDI); remote sensing (RS); disaster management

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1. Introduction

The frequency and intensity of natural disasters have increased in the last few decades. According to the World Disaster Report 2011, 4,022 natural disasters occurred between 2001 and 2010 worldwide, reportedly killing a total of 1,221,332 people [1]. As reported in [2], high population growth, intense urbanization and industrialization and disorderly occupation promote the presence of high-density populations in risk areas, which may be responsible for the increase in natural disasters.

The international community is recognizing that the magnitude and recurrence of these events, as well as the number of victims, are increasing [3]. Disorderly occupation and a lack of urban planning are primarily responsible for the loss of human lives.

Some natural disasters occur in an abrupt manner and affect large areas; therefore, it is difficult to develop preventive plans, for example, tsunamis, tornados, earthquakes. On the other hand, disasters such as floods and landslides tend to be mapped more easily, and the people who will potentially be affected can be predicted in advance because the vulnerable areas in which these events occur are generally known [4].

Due to their broad applicability, remote-sensing (RS), Geographic Information System (GIS) and Global Navigation Satellite System (GNSS) techniques are valuable tools for risk and disaster management [5].

However, to use RS and GIS techniques for risk and natural disaster management, data and information must be available. Moreover, the government needs to have technical staff prepared to handle and analyze the associated information. A Spatial Data Infrastructure (SDI) has been proposed by the scientific community and implemented as an alternative to address data sharing issues.

In developing countries, technological institutions and research groups should provide assistance through natural disaster preventive and emergency programs to minimize the negative consequences of disasters. Thus, the United Nations (UN) has established the Platform for Space-Based Information for Disaster Management and Response (SPIDER) to ensure that organizations and countries have access to and develop the capability to use space-based information to support the entire risk and disaster management cycle. The main purpose of this platform is to promote the use of satellite information to monitor geological, hydrological and climatic conditions to facilitate planning, mitigation and rapid response in the event of natural disasters [6].

The use of RS, GIS and GNSS techniques and data is very important in natural disaster management, and discussions regarding the actual condition of the applications and methodologies permit the identification of gaps in usability and opportunities to facilitate data use. In addition, the establishment of data and information sharing and the use of initiatives, such as the implementation of an SDI, are very important.

This paper presents the state of RS, GIS and GNSS technologies for disaster management. In addition, the importance of the accessibility of previously produced spatial data and the proposed technologies, such as SDIs, for receiving, integrating and sharing new spatial data, particularly with respect to interoperability issues, are discussed. Finally, the prominence and significance of volunteered data provided by citizens (VGI), particularly for disaster management when information is lacking, is discussed. A conceptual model relating all spatial data is proposed, and sharing aspects are discussed throughout the article. Important issues, such as metadata and institutional and political agreements, are also considered.

A review of applications, such as the use of RS, GIS and GNSS technologies in disaster management, is presented in Section 2, the SDI is presented in Section 3 and VGI is discussed in Section 4. The discussion and conclusions are presented in Sections 5 and 6, respectively.

2. Satellite Images, GIS and GNSS Data for Risk and Disaster Management

Global natural disasters cause billions of dollars in infrastructure damages, unexpected disruption to socioeconomic activities and the tragic loss of human lives each year [7]. Remote-sensing techniques and GIS and GNSS tools are frequently used in applications for disaster management in pre- and post-disaster activities. Pre-disaster applications are associated with mitigation and preparedness efforts. Mitigation refers to activities that reduce the vulnerability of societies to the impacts of a disaster, while preparedness refers to activities that facilitate preparation for responding to a disaster when it occurs [8]. Post-disaster applications are associated with response and recovery efforts. Response is related to the immediate and short-term effects of a disaster, while recovery refers to activities that restore communities to pre-disaster conditions, such as reconstruction [8].

Applications associated with mitigation and preparedness efforts are usually associated with landslide and flood disaster prevention, as part of land-use planning studies and/or the identification of vulnerable areas. GIS techniques are commonly used to analyze remote-sensing information, permitting process comprehension and the identification of standards and relationships between variables. In addition, geological, geomorphological and climatological information may be combined with risk assessments to provide important planning subsides.

To evaluate areas vulnerable to landslides, methodologies that involve the use of GIS and remote sensing and that have been proposed in recent decades usually analyze land cover maps developed through the classification of satellite images with other map information, such as topography, geology and geomorphology. Apart from the different geographical areas studied, the differences between landslide studies are usually derived from the model proposed to combine the information in the GIS, the method used to assign the weights for each information layer, the type of satellite image used and the method used to classify the satellite images. In [9], the weights-of-evidence model (a Bayesian probability model) was used to choose variables (maps) and respective weights. In [10], the use of rough set theory to accommodate the complex geographical characteristics of landslide susceptibility and to determine rules relating landslide conditioning factors and landslide events was explored. A multivariate logistic regression model was used in [11] to combine variables in the GIS and SPOT (Système Pour l'Observation de la Terre) 5 and Landsat TM satellite images to map landcover, while [12] used multivariate regression analysis. A methodology involving photogrammetry and 3D GIS analysis was developed in [13].

The use of satellite imagery has demonstrated that satellite observations are complementary to traditional *in situ* measures and are important tools to enable analysis and geospatial products to meet the operational demands of decision support systems for all types of natural disasters [14]. There is a diverse and growing constellation of remote-sensing satellites, and studies of natural disasters usually explore different types of images with different spatial, spectral and radiometric resolutions and different image processing methodologies. In [15], object-oriented image analysis associated with machine learning algorithms was used to propose a supervised workflow to reduce manual labor and objectify the choice of significant object features and classification thresholds, which was tested with different images, including Quickbird, IKONOS, Geoeye-1 and aerial photographs of sites affected by landslides. Object-based image analysis techniques were also used in [16] to classify soil exposure to identify erosion and landslide susceptibility according to slope models. A generic algorithm for the detection of elements at risk from high-resolution images was proposed in [17].

Regarding flood disaster preparedness and mitigation, some studies have considered the use of GIS to explore the development of hydrological models and have proposed methodologies for the elaboration of flood area scenarios and maps. Floods and flash-flood areas were mapped in [18,19] by combining morphological information extracted from digital elevation models and hydrological models using GIS tools. In [20], a web-based hydrological modeling system was developed that permits the integration of real-time rainfall data from a wireless monitoring network in a spatially distributed GIS-based model.

Many studies of flood disasters have used remote sensing in the response and recovery phases, mainly to detect changes in land cover. In [21], SPOT images were used with a multi-temporal change-vector algorithm to produce change maps displaying the impact of flood disasters. A methodology based on MODIS (Moderate Resolution Imaging Spectroradiometer) time series imagery to detect spatio-temporal changes in flood inundation was presented in [22]. In [23], the use of satellite images such as ETM+ (Enhanced Thematic Mapper Plus) and UK-DMC (a satellite that is one of a number of satellites in the Disaster Monitoring Constellation) to map change detection after a flood disaster was investigated, and it was suggested that this mapping could be used in areas affected by any type of natural disaster that could result in land cover changes. In fact, there are many studies, not only of flood disasters, but also earthquakes, fires, landslides and tsunamis, among others, that have explored the use of remote-sensing techniques in the response and recovery phases to detect changes in land cover.

A methodology to identify damaged buildings and land-use changes in a post-tsunami disaster using IKONOS and Quickbird images was proposed as a quick-response methodology for use immediately after a disaster in [24]. In [25], images from the FORMOSAT-2 satellite, which was designed to acquire timely and low-cost daily images, were assessed for their adequacy for use in evaluating damage in areas devastated by earthquakes and tsunamis. The use of MODIS images after a 2004 tsunami disaster was explored in [26], which concluded that, even though it is not possible to determine land cover type from these moderate-resolution satellite images, rapid assessments of severe damage to land resources can be provided. In [27], a methodology was proposed to explore multi-sensor and multi-temporal images with GIS data to evaluate infrastructure objects, such as roads, for usability immediately after a natural disaster using near-real-time analysis. In [28], landslide hazards caused by an earthquake were examined with Beijing-1 microsatellite data in combination with digital elevation and slope gradient maps before and after the disaster event to calculate changes in vegetated areas and to monitor mass movements caused by the earthquake. Beijing-1 data were also used in [29] to map land cover after the Wenchuan earthquake in 2008. In [30], methods were suggested to estimate areas impacted by the loss or reduction of city lights using Defense Meteorological Satellite Program Operational Linscan System (DMSO-OLPS) images. Advanced Land Observing Satellite (ALOS) and Phased Array Type L-band Synthetic Aperture Radar (PALSAR) data from areas affected by the 2008 Japan earthquake were analyzed in [31] to identify 11 of the 13 landslide areas. The use of Light Detection and Ranging

(LIDAR) was explored in [32] to detect transport network obstructions using data from before and after Hurricane Katrina to analyze routing schemes to reduce the response time to reach disaster sites.

For fire disasters, a method to detect and monitor the plumes produced by large amounts of smoke emitted by a fire was developed in [33] using AVHRR (Advanced Very High Resolution Radiometer) data. Data acquired from the International Charter "Space and Major Disasters" from NigeriaSat-1 was used in [34] to study the extent of the total burned area from a fire disaster to analyze its environmental implications. An index based on MODIS/ASTER data was proposed in [35] to assess fire severity to coordinate a timely post-fire rehabilitation response.

Beyond imagery, out-space technologies are also useful for precise positioning, such as the GNSS, the most popular of which is the Global Positioning System (GPS). GPS data are used in most preventive, management and emergency situations in natural disasters because they provide precise geographical location information.

GPS technology has been frequently applied in natural disasters and in the monitoring of geophysical phenomena, mainly landslides, which require the application of a different type of GPS technique [36]. The Sensing Node Network System (SNNS) is an example of the detection of slow mass movements and is used in Japan [37].

GPS data were also used for natural disaster monitoring of the Koyulhisar landslide, which was located to the north of Koyulhisar City (Turkey). The efficacy of the fast static method for slope monitoring was demonstrated in [36]. The authors highlighted the applicability of the method for other regions with similar physical characteristics, as well as for the monitoring of volcanic activity.

According to [38], landslides may occur due to natural phenomena, such as earthquakes, high precipitation and volcanic activities, affecting roads and buildings. In a study of the southern Italian Apennines, the authors monitored landslides with a combination of inclinometer data and GPS stations. The GPS stations were crucial for the detection of potential landslides.

Using monitoring data from GPS stations in Taiwan, [39] demonstrated the co-seismic displacement of the Chi-Chi earthquake (Japan). The measurements were taken at pre- and post-phases of the event, generating a complete dataset for displacement studies.

In addition, portable navigation receivers are widely used in natural disaster situations, as observed in the mapping efforts after the tsunami in 2004 at Escotra Island, Indian Ocean. With portable receivers, the water level was measured, and the flooded areas were mapped [39]. The use of GEO-PICTURES was proposed in [40], which is a system that integrates satellite images, *in-situ* sensors, geo-tagged pictures, text and other pertinent types of information. This system may aid in providing missing information in remote-sensing analyses, another important contribution of GNSS to natural disaster management.

The integration of GIS, remote-sensing and GNSS data may facilitate the comprehension of climate-related disasters, the identification of slope instabilities (regional scale), an understanding of the geological and geomorphological controlling factors of seismicity and the effects of earthquakes on ground structure and infrastructure. All of this information facilitates the compilation of databases on natural disasters and supports humanitarian relief and disaster management activities [41]. Although these are good examples of the applicability of GIS, remote-sensing and GNSS techniques, it is important to demonstrate that the methodologies and information can be shared to achieve results. In addition, the technical staff of risk and disaster management centers must be trained, and the methodologies must be adapted to each specific case.

In Brazil, natural disasters recently occurred in the highlands of the state of Santa Catarina in 2008; high precipitation levels led to flood and landslide events, causing heavy damage in southern and southeastern Brazil, in the city of São Luiz do Paraitinga (state of São Paulo) in 2010 and in the Petrópolis and Teresópolis highlands of the state of Rio de Janeiro in 2011. As presented in this section, examples of the use of remote-sensing and GIS techniques can be identified worldwide, although only a few studies have occurred in Brazil. In the highlands of Santa Catarina (southern Brazil), geotechnologies were applied to understand the distribution of precipitation and floods over the years and throughout the territory of the state ([42,43]). Remote-sensing techniques were used to understand the relationship between the presence of vegetation and the occurrence of floods in the same region [44]. In the state of São Paulo, where a rural city suffered a severe flood that destroyed almost the entire city, post-disaster analysis with remote-sensing data was used to understand the flooding process and establish preventive plans [45]. In the highlands of Rio de Janeiro (southeastern Brazil), studies have investigated the mapping of risk areas [46] and the development and application of a web-based GIS model to support emergency response activities [47].

Related to emergency response, in [48] the relation of time and information concept is presented, as well as the information that can realistically be derived from remote sensing data, three days after a disaster. The first information derived is the disaster type, its location and rough magnitude, which is followed by a refined magnitude and the damage extent. A preliminary aerial survey is commonly made by the police or media. An aerial photography survey on visible and thermal channels is collected, as well as the generation of a Digital Elevation Model (DEM) and its integration with pre-disaster data.

In addition, the suitability of the technical solution to the natural disaster is discussed, once there are sensors that capture essential information for some specific cases. Furthermore, several technical solutions can be used to achieve the adequate response. However it must be supported by the financial and technical means available. Some events have consequences that call for appropriate remote sensing tools, which can provide sophisticated products to the integration in a GIS environment, improving the response capability. In this sense, airborne remote sensing has a great potential to aid in an emergency situation, due to its facility of data acquisition [48].

However, according with [49], due to technical limitations, satellite data still have some difficulties in real-time data. Some of the critical technical aspects for this are: spatial, spectral and temporal resolution, spatial coverage as well as 2D and 3D capacity. Moreover, another challenge is the capability to interpret and extract information from satellite imagery for some specific disasters.

The lack of information of satellite data due to the limitation of spatial resolution within an urban context might be solved by land-based mobile mapping systems to rapidly acquire detailed geospatial data. The integration of platforms and sensors establishes a trend towards real-time spatial data acquisition. In this sense, individuals might become potential data collectors. Besides the applications in transportation problems, terrestrial mobile mapping systems might be used to support on-site investigation for emergency response and disaster management in urban areas [50].

In all of the technologies mentioned, RS, GIS and GNSS are increasingly being used and will be used even more in the near future as the constellation of remote-sensing and GNSS satellites grows and open-source or free-access GIS software alternatives emerge. Nevertheless, the importance of sharing spatial data to facilitate risk and disaster management will increase, as will be discussed in the next section.

3. The Importance of Web-Based Data-Sharing Systems to Facilitate Risk and Disaster Management

Spatial data and associated technologies have been important for effective collaborative decision-making in disaster management [8]. Nevertheless, challenges remain in spatial data-sharing in disaster management activities. Some studies have suggested the use of a Spatial Data Infrastructure (SDI) to overcome some of these challenges. One of the challenges of a data-sharing system is the establishment of technologies and standards for data management such that the technical staff of risk and disaster management institutions can access and use the data easily and rapidly. SDIs can be used to facilitate the development of risk assessment and relocation planning and can also support the establishment of disaster management plans to minimize damage from a potential natural disaster. The use of SDIs in disaster management aids in creating the technology for web-based access to spatial information and involves organizations in disaster management as the main stakeholders for producing, updating and maintaining the required spatial datasets for disaster response. If these data are shared and exchanged, datasets will be accessible to a wider disaster management community. This collaborative environment is based on the concept of partnerships in spatial data production and sharing [51].

A SDI can be used as an important framework to facilitate decision-making for disaster management. According to [52], an SDI is a set of mechanisms and standards for interoperability, exchange, access and data distribution. Designing an SDI model for a disaster management community, as well as the use of relevant information and communication technologies in disaster management, will improve decision-making and increase the efficiency and effectiveness of all levels of disaster management activities from mitigation to the preparedness, response and recovery phases. Governmental and non-governmental organizations are the producers and maintainers of different spatial databases. Once this set of data is shared, it can be accessed by the disaster management community to develop preparedness actions and to mitigate natural disasters.

In [53], the SDI components are defined, and their hierarchy is established. The establishment of an SDI is a dynamic process in which people are a key element, as they are needed to continue to provide data to maintain the SDI. The relationship between people and data exchange must be defined by policies, standards and networks. Because the data sharing policies must be defined, access to the data and data interoperability must be clearly established.

The hierarchy of the SDI is defined based on jurisdiction levels. Corporative SDIs, which demand fewer policies and arrangements, constitute the lowest level of this hierarchy. At the next level is the Local SDIs; at this point, the SDI is primarily formed by the integration of different datasets. From this level on, the SDI demands rigorous standards and policies. The subsequent levels are State/Province, National, Regional and Global. As the hierarchy level increases, so does the demand for standards and policies. An interesting intergovernmental initiative is the Global Earth Observation System of Systems (GEOSS), which comprises 88 nations, the European Commission and 64 international organizations and has the goal of promoting scientific networks for earth observation systems [54]. Another example of intergovernmental geo-information collection initiative was the Infrastructure for Spatial Information in Europe (INSPIRE), which emerged as an action of the European Commission and aims to promote the accessibility of geo-information in the formulation, implementation and evaluation of policies of the European Union [55].

Another aspect related to data sharing in the context of natural disasters is the Network-Centric Operations (NCO), originated in the US Department of Defense (DoD) and first mentioned by David Alberts, Art Cebrowski and John Gartska with a series of articles, started in 1996. According to [56,57], network-centric can be considered as a set of necessary capacities for better sharing and access to information for people involved in risk management. According to the concept of NCO, the information is not distributed in a hierarchical way, which facilitates collaboration between the groups involved and the speed of data transmission. Thus, the implementation of a spatial data infrastructure becomes important for the organization and sharing of information, because this should be available at all levels and simultaneously through information networks.

In addition, missing metadata should be emphasized in the creation of an SDI. The use of spatial data and the establishment of a spatial database must be accomplished with very reliable metadata standardization. This step must be accomplished before the data sharing process begins. It is a prerequisite to information sharing, and the maximum information about the data must be provided to enable the best use of it [58].

If the metadata structure is defined, the number of data users can be greatly expanded without wasting resources. Metadata are essential for data comprehension, utilization and management. There are many proposed metadata standards (e.g., ISO 19115, Dublin Core and Federal Geographic Data Committee), although a single standard must be chosen and followed strictly when optimizing the data-sharing procedure [59].

Semantics are another important aspect of metadata and data sharing. Complete interoperability requires not only a syntactic equivalence between the entities represented by the systems but also the equivalence of the concepts and meanings of these entities. Therefore, the definition of ontologies aids the identification of data, thus facilitating data sharing [60,61].

Some studies have discussed SDI issues in disaster management applications. In [8], a research project was conducted for an earthquake disaster response in Iran. An SDI conceptual model and a web-based system were developed for disaster management with the collaboration of different organizations from disaster management communities. Enhancing this SDI for disaster management in Iran is associated with social, technical, technological, political, institutional and economic challenges. This SDI conceptual model is a framework that defines a clear regime for the partnership of organizations in spatial data production and sharing. Four important requirements were identified for standards, policies, interoperability, metadata standards, data quality standards, guides and specifications.

The concepts of spatial data infrastructures and the needs and requirements of an ongoing research and development project in the Netherlands are presented in [62]. A spatial data infrastructure is expected to facilitate and coordinate the exchange and sharing of static and dynamic spatial data between all emergency forces. In the Netherlands, there are currently two innovation projects that aim to improve spatial data exchange for emergency management: Geographical Data Infrastructure for Emergency management (GDi4DM) and Geo-information for Risk Management.

In [63], a pioneer system for sharing spatial information, called SIAPAD (Andean Information System for Disaster Prevention and Relief), was developed for the Andean Community that integrates spatial information from 37 technical organizations in the Andean countries (Bolivia, Colombia, Ecuador, and Peru). SIAPAD was based on the concept of a thematic Spatial Data Infrastructure (SDI) and includes a web application called GEORiesgo.

The use of SDI and mash-up applications for crisis management in natural disasters was analyzed in [64]. The authors concluded that the most complete solution should involve mash-ups for visualization and simple analysis, GIS for cartography and advanced analysis and an underlying SDI to serve data and web services.

In [65], a web system implemented by Information Technology for Humanitarian Assistance, Cooperation and Action (ITHACA), a non-profit association that built a web application for data sharing to allow both field and headquarter users to obtain data as soon as they were produced or updated after the Port-au-Prince earthquake in 2010, is described. The developed framework successfully accelerated ITHACA web mapping capabilities, which was useful during the emergency in Haiti. In fact, the ITHACA organization supports the United Nations (UN) and the World Food Programme (WFP) in the development and implementation of an SDI based on UN Geographic Information Working Group (UNGIWG) recommendations [66]. A geoportal for the SDI centered in transportation infrastructure (SDI-T) can be accessed online at http://geoportal.logcluster.org/useradmin/auth. In addition, many other examples of national, regional and local SDIs can be found on the Global Spatial Data Infrastructure Association webpage (http://www.gsdi.org/SDILinks).

The technology required to integrate spatial data exists, permitting initiatives such as the Brazilian Geowebsite Spatial Data Infrastructure [67], although there is a lack of public policies in disaster management to support data sharing in this area. The National Spatial Data Infrastructure was created by the Brazilian government in 2008 to establish an integrated set of technologies, policies, mechanisms and procedures to coordinate and monitor data sharing to facilitate the dissemination and use of public-produced geospatial data. Data, metadata and geospatial information are available through internet services (GeoWeb Services) according to international protocols, which permits access to the information with little technical knowledge required.

In this sense, at the last 2011 United Nations assembly, the Brazilian representative presented the use of digital nets to increase the availability of interoperable data on the internet and the development of an open data national infrastructure. The use of digital nets is essential for governmental transparency and accessibility to citizens and also aids in improving the educational, environmental, health and security sectors of society.

Recent studies have discussed the use of spatial information in disaster management. In addition to traditional data from remote sensing, GNSS and cartographic maps used in GIS, non-technical internet users have recently been increasingly producing data, known as Volunteered Geographic Information (VGI), which performed well in recovery efforts; for example, after the Hurricane Katrina disaster, VGI generated mobile information using GPS technology and cameras with mobile sensors [68]. More details regarding this initiative and its perspectives will be discussed in the next section.

4. Volunteered Geographic Information (VGI) in Natural Disasters

The use of spatial data in natural disaster management, as cited in the previous sections, demonstrates the importance of maps in emergency situations. According to [69], spatial data can be used to recognize affected areas, locate and identify necessary objects, plan actions to mitigate the problem, and route rescues, relocations and the distribution of food/medicines to the affected areas.

However, conventional maps can be ineffective in these situations depending on the degree of destruction because the area affected by a disaster can be greatly modified, invalidating maps made days before the occurrence of the event [69].

Thus, this technology is of great value, as it permits faster communication and eliminates wasted time. However, additional preventive measures should be promoted, such as the investment of resources, training and coordination by both civil society and government leaders [69].

Since the earthquake in Haiti, many efforts have been made in collaboration with civil society to produce maps of areas affected by natural disasters, and this collaboration has only become possible because of the development of information and communication technologies, such as GPS, Web 2.0 and mobile phones.

In [70], attention is drawn to current human behavior in the face of new technology, characterized by the contribution of large numbers of ordinary citizens, with few or no formal qualifications, to the creation of geographic information, a function that for centuries has been reserved for official institutions. These citizens are acting voluntarily, and their information may or may not be accurate. However, collectively, this represents a great innovation that will have a strong impact on GIS and is defined by [70] as VGI, or geographic information obtained by ordinary citizens, collectively and voluntarily, without the need for qualifications.

According to [71], humans can behave as sensors because, throughout their lives, they acquire knowledge about the places where they live, work or visit, such as place names, topographic features and transport networks. A human can be considered an intelligent mobile sensor that is equipped with the abilities of interpretation and integration that vary according to the person's experiences. These abilities could be enhanced through the use of mobile phones with embedded GPS, digital cameras, and tracking devices.

In [72], the characteristics of volunteered information are defined as being distinct from those of information obtained conventionally. According to [72], the information content; technologies used to acquire this information; questions about the quality, methods and related techniques; and social processes involved in the creation and impact of VGI create a different platform for the acquisition, sharing, dissemination and use of geographic information. Although many questions about VGIs remain, such as the reasons that lead people to contribute information, the quality of the data and the appropriate methods for the synthesis and analysis of VGI, the vast amount of data made available through the VGI system constitutes a rich and immediate source of geographic information for various purposes.

Recently, the number of webpages that allow users to contribute to a diversified range of geographic or attribute information has increased rapidly, e.g., WikiMapia, OpenStreetMap, Mapufacture, GeoCommons, TerraWiki, FixMyStreet, and WhoIsSick, among others. This so-called *wikification* has also reached GIS because the four main functions of GIS (data acquisition, storage, modeling and mapping/visualization) have been constantly realized in the wiki system. The most meaningful development in GIS wikification has occurred in the area of data production because *wikification* changes the behavior of individuals toward the vast geospatial information available online. People are now active users in the production and sharing of data, while, until recently, they were considered passive users [73].

To illustrate the ideas formulated in [73], consider the series of fires in Santa Barbara (CA/USA) during 2008/2009 that burned for days, destroying hundreds of homes. One of the fire episodes, namely the Jesusita Fire, occurred in May 2009, burned for two days and destroyed 75 homes. Several individuals mobilized and produced volunteer information, constantly providing updates on the perimeter of the fire. At the end of the event, 27 volunteer maps were available online, the most popular of which had 600,000 hits, providing essential information about the location of the points of fire, evacuation orders, and emergency shelters [74].

A similar phenomenon occurred in Australia (February 2009). Several volunteer maps appeared online during the fires in the states of Victoria, New South Wales and the Australian Capital Territory. The fires were marked with dots in the Google Maps API, which were linked to characteristics such as date and time, status, type, size, and vehicles available to help, among others [75].

With the same purpose, a platform called Ushahidi was developed in 2008 to generate dynamic maps dedicated to crisis management (e.g., political crises, natural disasters, and local conflicts).This application allows anyone to share information via SMS, e-mail or other available forms on the site. It is a free platform that is open-source and operates according to the logic of mash-ups, which combine several Web services, such as mapping, databases, data manipulation tools, and visual functionality, among others. Ushadidi was used during the Haiti earthquake in 2010 and, more recently, during the Christchurch earthquake in February 2011. Ushahidi has also been used in other disaster situations, such as to provide support to victims, non-governmental organizations (NGOs) and authorities in the response to events [75].

In Brazil, experiences with VGI are also emerging. There are several volunteer mapping websites, such as Wikimapa, WikiCrimes, and OpenStreetMap Brazil, among many others. This technology was used after the occurrence of the recent tragic landslides in the southern region of the country, the heavy rains and floods in southeastern Brazil and the great landslides in the mountainous region of the state of Rio de Janeiro in early 2011.

Volunteer data on natural disasters in Brazil are currently distributed over the internet. The website O ECO, published in January 2011, consists of a map with information about rain damage in 2011. Users can post photographs, videos and reports of floods, landslides and interment through a Google Maps database [76].

Another example is the Disaster Map created in 2009, which allows the inclusion of catastrophic events on a map of disasters worldwide, also based on Google Maps. Information can be posted in the form of text, photographs, videos or links after the occurrence of an event [77].

These experiences in Brazil and around the world demonstrate that there is a strong tendency for civil society to collect, share and disseminate data. People are increasingly engaged in the process, and the facilitation of information access permits the creation and publication of such data. VGI has become an important resource in natural disaster situations. In many cases, data and information are required within a few hours to save lives.

The availability of high-resolution satellite images, combined with services such as Google Earth, make it possible to provide spatial data through simple interfaces that ordinary people can use effectively in the absence of any professional qualifications other than the desire to collaborate [78].

Concerns have been raised regarding the suitability, for specific applications, of the essential features of a global data service in which data acquired from the Web and other sources are evaluated in terms of their qualities and users [79]. What protocols and procedures can be developed for VGI data, crowd-sourced social media and data obtained from officers to fill gaps in the infrastructure of spatial data? As challenges, the authors also propose that methods need to be developed to create applications of the generated data, track the source of the data, develop an approach to semantic interoperability and determine how to work with large quantities of data from different sources in real time. How can data with different accuracies and different levels of detail and generalization be combined?

With respect to data quality, [79] argue that the quality of VGI data can be evaluated by comparison methods; that is, information can be compared with other information on the same subject. Another indication may be the number of people contributing data; facts about more-populated places tend to be more accurate than facts about less-populated places. Furthermore, in many cases, data revision is conducted by a group of volunteers, which can also reduce errors [72].

In [80], an approach is made about the quality of VGI data through a conceptual workflow to automatically assess the quality of volunteered data in situations of crisis management. The authors emphasize the potential of VGI in such situations, but with some difficulties toward the quality control of data, since the content is generated by the user. One challenge would be acquisition: an automatized model for retrieval and filtering data, as well as integration with SDIs to support decision making in contexts of crisis. The conceptual model consists of the following steps: (1) retrieval of data from different sources of social media, (2) syntactic validation and formatting according to the needs of later phases of processing, (3) enriching the data with additional information (4) integration with SDIs available, and (5) dissemination of data. The assessment of the quality of data is realized during the processing phase when the credibility of the source and relevance of information are used as metrics. More specific are: observed rating from other users, the occurrence of keywords pre-defined, spatial information about the event and cross-checking between different sources (platforms) and also with administrative or commercial databases. Methods for studying VGI are already being developed, as observed in [81]. In [81], a quantitative method was developed to measure distances between the location of the author and the location of the subject, with a discussion of the role of distance in the production of VGI; in other words, how contributions are affected by distance, and, consequently, how socio-behavioral issues are generated from the new online forms of collective authorship, which the authors call "online collective authorship." In addition, according to [81], new approaches to the geolocation of geographic information contributors would have a significant impact on VGI research.

5. Discussion

The sharing of remote-sensing, GNSS, GIS and volunteer data, technology and procedures with risk and natural disaster management should be encouraged to support communication and transportation systems, avoid damage due to disasters and establish emergency plans. The exchange of information will aid in the development of intelligent systems, enable the communication of the precise location and magnitude of damage and the determination of escape routes, and facilitate the development of mitigation and aid procedures after disasters.

The United Nations is conducting an initiative in Latin American and Caribbean countries, through the United Nations Space-based Information for Disaster Management in Emergency Response (UN-SPIDER), to develop methodologies for the prevention and mitigation of natural disasters using satellite technologies, particularly orbital remote-sensing images. This enterprise is being supported by Latin American and Caribbean governments and universities.

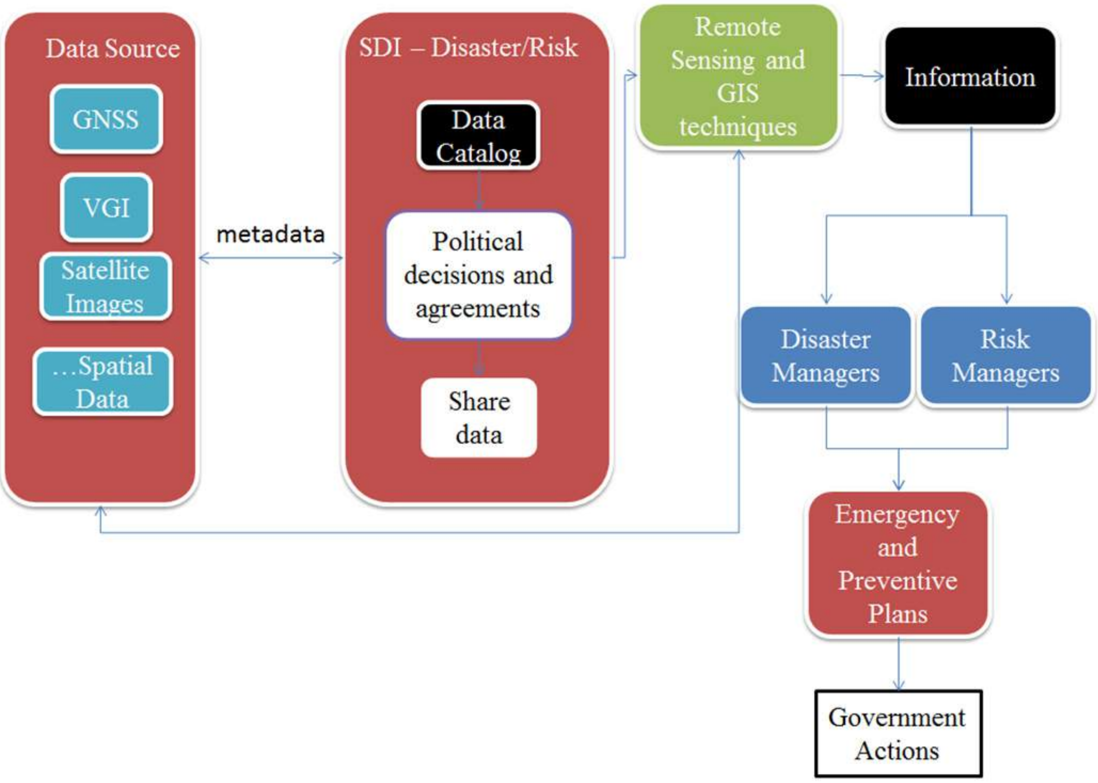
International arrangements guarantee the free provision of satellite images of affected regions during natural disasters. To specifically address the pre- and post-disaster phases, there is an international agreement for collaboration among space agencies, namely the International Charter for Space and Major Disasters. The charter members are the European Space Agency, Centre National d'Études Spatiales (CNES), Spotimage, NSPO, the Canadian Space Agency (CSA), the Indian Space Research Organisation (ISRO), the National Oceanic and Atmospheric Administration (NOAA), Argentina's Comisión Nacional de Actividades Espaciales (CONAE), the Japan Aerospace Exploration Agency (JAXA), the United States Geological Survey (USGS), Digital Globe, GeoEye, DMC International Imaging (DMC), Centre National des Techniques Spatiales (in Algeria), and National Space Research and Development (in Nigeria) [82].

Figure 1 presents a proposal for the organized use of VGI, RS and GNSS data for risk and natural disaster management. To facilitate data availability, an SDI should be established through political decisions and agreements to permit data sharing. Remote-sensing and GIS techniques permit the transformation of the data into information that will support decision-making by risk and disaster managers. Both the developed methodologies and the created information should be shared through political mechanisms. Sharing methodologies and techniques is an important mechanism for increasing the potential of the data and improving the risk and disaster assessment process. The information generated should be available for direct use by managers and may also be useful in further analyses (emergency and preventive). Therefore, with the relevant information, managers can develop plans and create processes that may decrease the potential damage of severe events.

New arrangements of data integration can be developed to increase the potential for data sharing. In addition, financial support for research in this area should be increased, particularly in developing countries, to contribute to the development of methodologies and techniques and ensure the adequacy of procedures for specific areas and events. To encourage these initiatives, the cost of damage recovery should be determined to demonstrate the amount of money that could be saved by investing in these studies.

The implementation of volunteered geographic information is another important initiative for improving alert systems and aiding emergency plans. The information provided by citizens is important for improving the disaster management system, although citizens should undergo training and the communities in risk areas should have a minimum number of volunteers to provide information and facilitate aid action during severe events.

Figure 1. Scheme for space-based data use for risk and natural disaster management.



Methods to assess the reliability of VGI data must also be established by the scientific community. The proposed inclusion of metadata in SDIs and increased flexibility of VGI data, as well as the necessity of standards, should be better investigated. The determination of VGI metadata could be associated with the potential development of statistical inferences of the reliability of the data, for example, by considering the characteristics of a user or by verifying the volume of data reaffirming the same event.

The implementation of VGI systems for emergency response will enhance the SDI data and improve the response time during crisis. The VGI information should be used not only to help managers to identify the best actions plans, but also to provide citizens' precious information. The Google Crisis Response [83] is an example of use of VGI information to transmit to the population the status of the crisis through maps and other tools. This kind of initiative enhances the disaster response and improves the results in post-disaster recovery.

Therefore, the political deals are the first step to achieve high quality results for the application of geospatial technologies in risk and disaster management. It will permit the establishment of an international SDI cooperative, which will facilitate information sharing. However it is important to emphasize that besides providing information with quality it is necessary to ensure the correct interpretation and usage of information. To do so, standardized procedures and well prepared technical staff should be available in order to facilitate the analysis and further actions.

6. Conclusion

In this paper, remote-sensing-, GIS- and GNSS-based methodologies and data sharing for risk and natural disaster management were discussed. A brief panorama of the data, information and techniques was presented to support planning and prevention initiatives for the management and mitigation of disaster situations.

In addition to social factors, geological and weather phenomena have contributed to the increased occurrence of natural disasters. Thus, the use of orbital platforms is very efficient for natural disaster emergency management. Satellite images can aid in preventing, monitoring and mitigating extreme events.

The use of remote-sensing data with GIS offers high potential for vulnerability analysis of the interest region, although these techniques should be adapted according to the analyzed area.

The easy accessibility of the available geotechnology should be highlighted; namely, the advent of the internet has resulted in the development of tools and rapid methods to obtain GIS software and satellite images. In addition, the popularization of GPS facilitates citizen participation, and GPS may become a new tool for natural disaster management through the use of VGI.

Ideally, more Spatial Database Infrastructures for natural disasters should be created and maintained by institutions that produce spatial data to generate information that may be useful for the management of risk and natural disasters. In addition, the exchange of data analysis knowledge in decision-support systems must be frequent and dynamic. However, this exchange will only be possible with the establishment of political deals and agreements.

Acknowledgments

We appreciate the support of the Department of Transport Engineering of the Polytechnic School of the University of São Paulo and financial support from FAPESP and CNPq.

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15

Remote sensing and the disaster management cycle

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1. Introduction

Disaster management planning is structured around the disaster management cycle model. The cycle consists of four stages – reduction, readiness, response and recovery. Remotely sensed data can provide a valuable source of information at each of these stages, helping to understand spatial phenomena, and providing scientists and authorities with objective data sources for decision making. The challenge with disaster management is that the inherent unpredictability and range of hazards does not allow for a single all-encompassing solution to be developed and explored. Instead, there are a multitude of different remote sensing platforms and sensors that can and should be employed for image acquisition. An extensive coverage of each, including optimal processing regimes for their data would be prohibitively long; instead this chapter aims to give some general examples of the use of remote sensing in disaster management, while directing the reader to more specific studies in the literature. The types of data required and information provision needs for each stage will be discussed including optical, thermal, and synthetic aperture radar as data sources over a variety of spatial and temporal scales.

Remote sensing can be used to assist risk reduction initiatives through identification of hazard zones associated with flood plains, coastal inundation and erosion, and active faults. It can also be used to verify hazard models by measuring the location and magnitude of actual events. Imagery is widely used by meteorologists for providing weather forecasting and warnings of potentially severe weather events, providing the public and emergency responders with information that can assist decision making around short term readiness. These images are commonly presented in print, television and on the internet, and they are well accepted by viewers around the world. Imagery of fires, volcanic eruptions and flooding are often used during the response phase for the visual impact that they provide. If people in potentially at-risk locations personalise the risk, they are more likely to take readiness actions such as making emergency plans for contact and evacuation or assembling emergency kits. Remote sensing images of similar communities experiencing hazards, or the progress of a hazard such as a fire front, can assist with this personalisation process. For agencies that respond to emergencies, remote sensing imagery provides a rapid method of assessing the magnitude of hazard impacts, areas most affected, and where key transport and other infrastructure links have been disrupted or destroyed. Remote sensing can also be used to provide an indication of the rate of recovery in an area post disaster based on indicators such as vegetation regrowth, debris removal, and reconstruction.

There are few examples where remote sensing is incorporated seamlessly into all stages of the disaster management cycle for planning purposes. This requires a collaborative effort from emergency managers, policy planners and remote sensing technical staff that may not always be co-located, or even working for the same organisation. However, data is becoming more readily available, and some satellites and constellations are even targeting at least partially the disaster management / emergency response community in recognition of the value remotely sensed imagery can provide. If this current trend continues, integrating remote sensing and emergency management will become increasingly more commonplace.

2. The disaster management cycle

The traditional approach to hazard risk and disaster management has been one primarily focussed on response to events as they occur (Gregg & Houghton 2006), managing residual risk through warning systems and emergency management plans, and more recently attempting to reduce risk through changing the hazard process or impacts (Board on Natural Disasters 1999). Examples of attempts at hazard modification include: the use of stopbanks and levees to provide opportunities to build in areas vulnerable to flood hazard; building codes for strengthened buildings to allow development in earthquake prone locations; and building seawalls along coasts to reduce susceptibility to erosion and coastal inundation. These measures have allowed greater development in hazardous areas, and are typically designed for protection up to a certain magnitude of event, but there always exists the potential for design limits to be exceeded (Burby 1998). Because of reliance on technological solutions, risk is increasing in the developed world as infill and migration increases in “protected” areas (Mileti 1999). In less-developed nations, risk is also increasing, although the drivers differ. Reliance on decreasing natural resources, population increase, poverty, and political drivers push communities into hazardous areas traditionally left un-settled (Donner & Rodriguez 2008). The body of research into the evolution of hazards and disaster management now recognises that it is primarily social drivers that create vulnerability to hazards, and consequently increase the potential for disasters (Board on Natural Disasters 1999, Cutter & Finch 2008, Donner & Rodriguez 2008, Pertrow et al. 2006, Wisner et al. 2004). The overall focus of emergency management has shifted to consider disaster management planning as part of a broader system of planning for sustainable, resilient communities. Whether a hazardous event will become a disaster - an event that is beyond the capacity of responding agencies, resources, and community coping capacity (Quarantelli 1985), can be influenced by effective disaster management planning.

This recognition of the importance of social drivers has brought about a change in how disaster planning is considered and undertaken. Many nations now plan using a variation of the Disaster Management Cycle, an integrated, four–phase planning system. Although the cycle can be considered as a continuum, traditionally the first phase of the cycle is considered to be reduction, followed by readiness, response, and recovery (Figure 1).

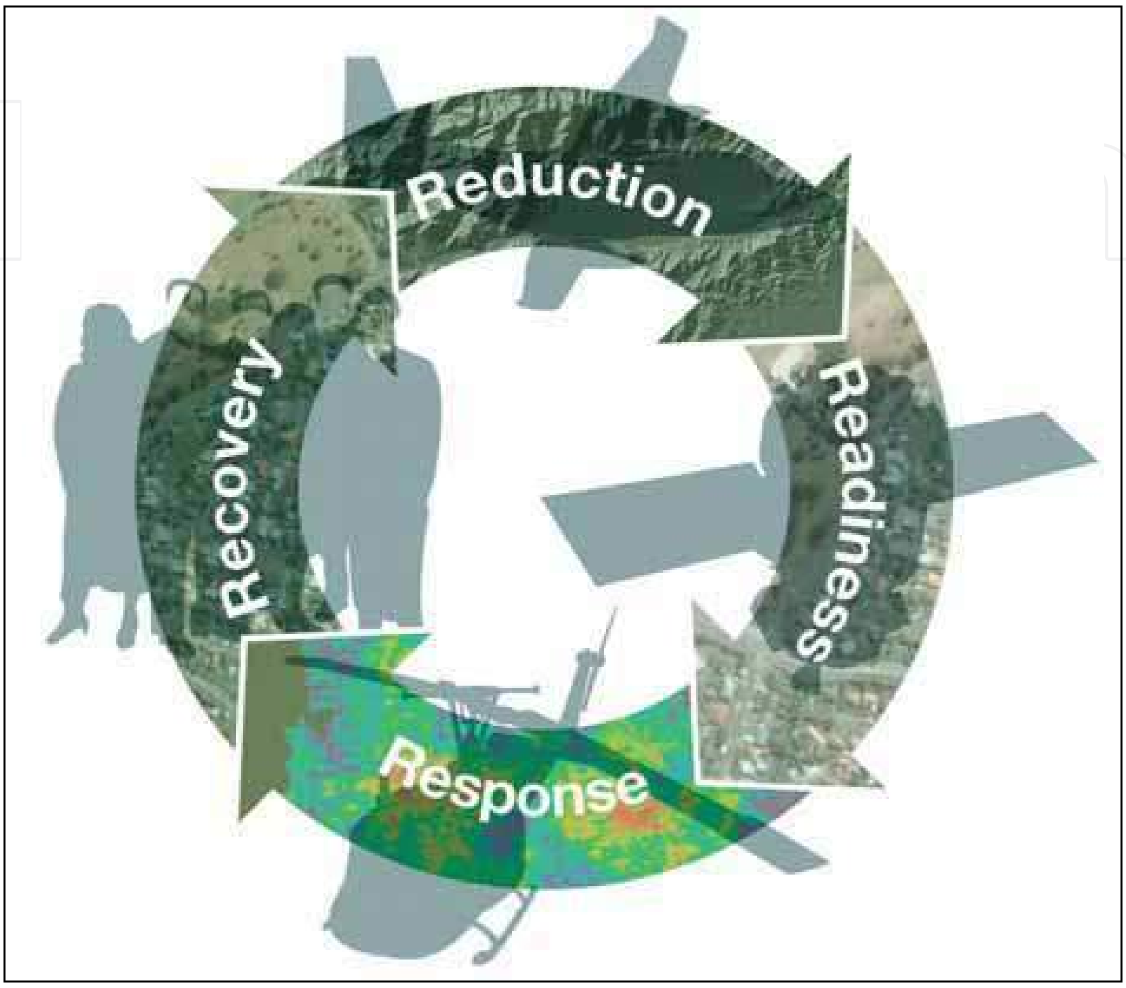

Fig. 1. The disaster management cycle

Reduction incorporates all measures and planning that reduce the likelihood of a disaster occurring. This is done through the process of risk identification and reduction; either by modifying the hazard process using traditional structural methods such as stopbanks or seawalls, or by modifying behaviours and the assets at risk (Gregg & Houghton 2006). Behaviour modification includes land use planning to: prevent development in hazardous areas; incorporate good access for response and evacuation; and foster interconnected and resilient communities (Burby 1998). In theory, land use planning can reduce all risk from disasters, but centuries of settlement in hazardous locations make this option unrealistic and impractical. Modifying assets at risk includes such methods as strengthening buildings and infrastructure and raising floor heights to reduce hazard impacts.

Readiness planning accepts that some residual risk is present for communities and that measures must be in place to ensure any response to hazards is efficient and reduces hazard impacts. Readiness planning includes: public education on hazards and their consequences, and how these consequences can be reduced; training of emergency planners and responders; installing monitoring and warning systems for hazards;

exercising response plans; and fostering community resilience through increased uptake in home preparedness such as learning first aid, having an emergency kit and an evacuation plan (Ronan & Johnston 2005).

The phase of disaster management that has traditionally received the most recognition, funding and planning effort is Response (Gregg & Houghton 2006). This fact is also reflected in the remote sensing community, with an overwhelming number of research papers dedicated to the use of imagery for disaster response, despite the fact that data often cannot be provided in the timeframe required to be of use for decision makers. The reality is that most nations do not have the capability to prevent disasters occurring; the best option for reducing the chance of a disaster is through reducing risk. However, response capability is important in any disaster as it involves the processes of coordinated effort to manage resources, including life essentials and personnel, for activities such as evacuation, relief, search and rescue and needs assessment (Quarantelli 1997).

Recovery, the fourth phase of the cycle has traditionally been focussed on restoration of lifeline utilities, and building reconstruction. There is now considerable research into holistic recovery processes, which recognise that for community recovery to be sustainable, the social, economic, built and natural environments must be considered (Norman 2004). The four environments are interlinked as communities rely on:

- Natural environment for amenity (recreation, psychological wellbeing), and resources (to provide opportunities for construction and employment);
- Built environment for lifeline utilities and structures to enable people to live, work and recreate;
- Economic environment to provide goods, services and livelihoods; and
- Social environment, to provide opportunities for political participation, community building, networking and psychological wellbeing.

The recovery phase of a disaster can be considered to have several steps, the initial restoration of lifeline essentials, and the longer term rebuilding of communities. The recovery phase is often considered to be an optimal time to include measures that will reduce the risk of future disasters (Becker et al. 2008).

The four phases of the disaster management cycle are not discreet; they are interrelated and ideally integrated throughout the planning process. Decisions about risk reduction methods will affect the degree of readiness planning and response that will be required. Readiness levels of affected communities and responders can determine whether an event becomes a disaster, as can be seen in the failure to provide evacuation options for the 20% of the New Orleans population with no vehicle or resources to leave the city prior to hurricane Katrina's landfall (Laska & Morrow 2006/7). The effectiveness of the response phase will play a significant role in how affected communities recover, both physically and psychologically. Lessons from the response phase can be incorporated into risk reduction and readiness planning. Finally, the recovery phase can include risk reduction measures to increase resilience and reduce future vulnerability.

3. Remotely sensed data types

In order to successfully use remote sensing for disaster management, physical indicators of features or attributes within the disaster management cycle that are measureable in imagery need to be identified. At that point, selection of the most appropriate remotely sensed data set is possible by identifying the spatial, spectral, temporal, and radiometric requirements. The use of a framework for selecting appropriate remotely sensed data has been demonstrated for mapping and monitoring coastal and tropical wetlands, tropical rainforests, coastal ecosystems and coral reefs (Phinn 1998, Phinn et al. 2006). This is an approach that can be modified and applied under many different circumstances and for various environments. Here we look to apply aspects of the framework to disaster management. During the reduction, readiness and recovery phases, there may be sufficient time to develop and apply the framework as the cycle is progressing. However, as timeliness is a critical factor in the response phase, it is of most use to already have systems in place to aid with appropriate data selection so that crucial decisions need not be made under the severe time constraints that are necessitated by rapid response. Preparation may therefore involve developing a range of scenarios representing potential situations that require rapid response at a set location, and applying the principles of data selection and processing in advance. In this way, the decisions regarding remote sensing in the response phase can actually be made during the readiness phase instead. This should be done as a collaborative exercise between both remote sensing experts and emergency management agencies.

The types of satellite and airborne sensors that can be used to support phases of the disaster management cycle are many and varied. It is most important to consider the spatial scale of the hazard, in addition to determining the most appropriate data type to address the problem. For example, geostationary satellites provide data over a large area, but with minimal spatial detail, and are appropriate for monitoring weather patterns (readiness) and volcanic ash and gas distribution (response). Conversely, very high spatial resolution data (e.g. aerial photography, Quickbird, Ikonos, Worldview) are appropriate for targeting relatively small areas where they can provide a great deal of detail. Examples of their use include baseline infrastructure mapping for scenario development and model validation (reduction and readiness), building damage (response), and observations of debris removal and reconstruction (recovery).

In the disaster reduction phase, the focus for remote sensing is often on mapping landscape features such as land cover / land use, and the location of potentially hazardous features or processes to avoid when developing infrastructure (e.g. active faults, flood plains). During the readiness phase, the emphasis is on monitoring these features or processes, developing models for forecasting purposes, and using maps and model for training and education. In the response phase, the timely acquisition of data and provision of information to emergency services is critical. Much of the attention will be placed on identifying infrastructure that has been damaged or is likely to be at risk in the near future (e.g. housing in the path of a bush fire). Finally during the recovery phase, the focus will shift to long term monitoring of debris removal, vegetation regeneration, and reconstruction.

3.1 Optical

There are a large number of applications for which optical remotely sensed imagery can be used to aid the disaster management cycle. Optical data can be of particular use to the disaster management community as it is generally simple to understand and interpret raw data, particularly when collected using standard true colour spectral bands (blue, green, and red). The characteristics of the sensor are important in selecting the most appropriate data type for use in individual situations. Consideration should be primarily given to the spatial and temporal resolution of the sensor. These factors will differ depending on the disaster management activity. For example, during the response phase, rapid acquisition of data following the event is crucial. During the recovery phase, the speed of acquisition is less important than repetition on a consistent basis. In the early stages of recovery, imagery may be useful on a monthly basis, though as time passes, an annual acquisition may suffice.

Optical data can be used for activities in all stages of the disaster management cycle, however the greatest potential contributions are for monitoring recovery, and helping to plan for reduction and readiness. The use of satellite optical data for immediate response at a local scale is currently hindered by the speed of data acquisition and delivery with polar orbiting satellites. For large events, a more regional synoptic view is possible using geostationary satellites; however the amount of detail able to be extracted from these images is reduced.

The greatest limitation of optical sensors under many hazard or disaster scenarios is the inability to obtain imagery through clouds, smoke or haze. Events such as wildfires, volcanic eruptions, and tropical cyclones or other severe storms are characterised by cloud and smoke, which can effectively obscure damage on the ground both during and immediately subsequent to an event.

3.2 Thermal

As energy decreases with increasing wavelength, thermal wavelengths have comparatively low energy levels and consequently thermal image data have a lower spatial resolution than that capable of being achieved with optical imagery. As yet there are no very high spatial resolution thermal satellite sensors commercially available. Nonetheless, thermal imagery provides a valuable source of information about volcanic eruptions and the location of wildfires. Robust techniques for automatic extraction of anomalous high temperatures or 'hotspots' have been thoroughly tested and considered operational on a global scale using MODIS, AVHRR or GOES imagery (Wright et al. 2002, Wright et al. 2004). The University of Hawai'i and Geoscience Australia both apply automated hotspot detection algorithms for the detection of volcanic activity and bushfires respectively and serve the information in near real time via the internet. These algorithms have primarily been developed to detect features above the background or average temperature values, and to avoid large numbers of false alarms, they are not sensitive to merely warm features. They are also unable to differentiate between the types of heat source, so addition spatial information or manual interpretation may be required.

Higher spatial resolution thermal imagery for analysis at local scales can be obtained using ASTER or Landsat TM/ETM+, though neither of these sensors have the ability to provide imagery of rapidly changing thermal features, as their orbits only allow them an overpass frequency of approximately 16 days. Nevertheless, both sensors are useful for tracking longer term temperature fluctuations, such as the warming and cooling cycles of volcanic lakes (Joyce et al. 2008b, Oppenheimer 1993, Oppenheimer 1997, Trunk & Bernard 2008). The higher resolution imagery can also be of use in calibrating and validating data obtained from the likes of MODIS.

As the temperature of an object increases, the wavelength of peak radiation decreases. Very hot features can therefore be seen in visible or shortwave infra red (SWIR) imagery and often become saturated in thermal infra red data if they are sufficiently large with respect to the pixel size. This relationship has been demonstrated using forest fire size and the temperature difference between a smouldering and flaming fire that could be of use in understanding different stages of fire development (Giglio et al. 2008). Unfortunately the SWIR bands on ASTER were declared non-functional in January 2009 after experiencing technical difficulties since May 2007. These five SWIR bands fall within a similar spectral range as Landsat TM/ETM+ band 7 that could be used as an alternative.

3.3 Synthetic Aperture Radar

Synthetic Aperture Radar (SAR) is an active microwave sensor that is capable of acquiring data in harsh weather and lighting conditions not suitable for optical sensors, such as dense cloud or smoke coverage (Elachi 1987, Franceschetti & Lanari 1999, Hanssen 2001). Most modern SAR sensors are designed to acquire data of various ground resolution elements ranging from 100s of metres to 1-3 metres, but higher spatial resolution images usually have significantly smaller spatial coverage and are limited by satellite storage and processing capacities. The incidence angle of SAR sensors can be manipulated in order to image different areas without changing the satellite orbit, thus decreasing necessary revisit time.

Both backscatter intensity and the phase of SAR images can be utilised. In most studies only the relative variability of backscatter intensity within the image is used but absolute values can be required for some multi-temporal studies. The precise interpretation of backscatter intensity can be complicated because of its dependence on the dielectric properties of the reflecting material, surface roughness, and sensor wavelength but at the same time the variety of useful information still can be easily observed (landslides, tsunami, flooding, and damage to infrastructure). Phase information of a single SAR image has no value but comparison of phases from two SAR images acquired at distinct times are utilised in SAR interferometry or InSAR. InSAR is capable of producing high resolution ground deformation maps with sub-centimetre accuracy (Rosen et al. 2000). These maps can then be used for studying the causes of deformation such as earthquakes or volcanic activity (Massonnet & Feigl 1998). Modern satellite SAR systems are capable of acquiring simultaneous data with more than one polarisation (e.g. Radarsat-2, ALOS PALSAR and TerraSAR-X). This information can be used in various studies utilising SAR polarimetry and POLInSAR techniques, such as land classification, detection of areas affected by fire or flooding (Cloude & Papathanassiou 1988, Pottier & Ferro-Famil 2008, van Zyl et al. 1990).

At present, commonly used satellite SAR data is acquired in three wavebands: X (3.1 cm); C (5.6 cm); and L (23.6 cm). Waveband selection depends on the type of application, land-cover, time span, and availability. The analysis of backscatter intensity by determining thresholds associated with certain features can be performed in standard GIS or image processing software, such as ArcGIS or ERDAS Imagine, but InSAR, SAR polarimetry and POLInSAR processing require specialised software (or add-on modules to basic packages) and extensive processing experience. The price of the data greatly varies from a few dollars per image for purely scientific applications to a few thousand of dollars for commercial applications. Several recently launched commercial satellites are available to acquire data of any hazardous event with a very short delay and deliver the data rapidly to the user, though the cost of priority commissioned data is significantly greater than that of archived imagery (RADARSAT-2, TerraSAR-X and Cosmo-Skymed).

4. Remote sensing applications

4.1 Reduction

Disasters are social constructs in that social drivers such as migration (forced and voluntary), conflict, modification of natural buffer systems, reliance on shrinking resources, private property rights, urban intensification, artificial protection structures, and economic and political vulnerability are all contributors to people living in hazardous locations or at levels of vulnerability that make a disaster more likely. Remote sensing technology can assist with addressing some of these "disaster drivers", through providing the data required to assist land use planners, emergency managers, and others tasked with disaster management. Reduction of risk, and therefore reduction in the probability of a disaster occurring, is an important part of the disaster management cycle. Remote sensing can be applied in disaster reduction initiatives through identification and understanding of hazards (Table 1). This knowledge is then applied to mitigation activities such as land use planning, engineering structures, building codes and hazard consequences modelling to determine methods for reducing vulnerability (Gregg & Houghton 2006). Note that the sensor examples given in Table 1 and subsequent tables are indicative of current or potential instrument use. Many alternative sensors with similar characteristics could also be used.

Understanding of hazards, their magnitude, frequency, duration, location, range and manifestation (e.g. heavy rainfall, tephra, strong winds) has long been accepted as essential to disaster management. Although it is primarily social factors that amplify a hazard event into a disaster (Quarantelli 1985, Wisner 2004), improved knowledge of hazards and their potential consequences is essential for decision making about modifying hazard characteristics, or modifying vulnerability of people and assets. Remote sensing can be used directly for hazard identification (e.g. flood plain modelling, slope stability and landslide susceptibility), but can also be used to derive hazard-independent information that can be used for disaster reduction (e.g. baseline building, infrastructure, and topographic mapping). An excellent example of the use of remote sensing for hazard identification is provided with LiDAR mapping of active fault location (Begg & Mouslpoulou 2009 in press). Traditionally fault location is conducted using stereo aerial photography interpretation followed by intensive field survey. However the horizontal and vertical resolution provided by airborne LiDAR imagery provides the capability for identifying fault traces and extracting elevation offsets with digital data in an objective manner. The identification of many previously unknown faults in northern New Zealand is shown in Figure 2.

Type of information	Data required	Sensor example	Application example
Location of fault traces and rupture zones	High resolution DEM	Airborne LiDAR, SAR	Use for land use planning around active faults to reduce risk from future development in fault hazard locations
Fault displacement	Interferometric SAR	ERS1/2, ENVISAT ASAR, ALOS PALSAR	Knowledge of fault displacement rates are used in numerical models in order to forecast the magnitude of possible earthquakes
Flood plain mapping	DEM	Airborne LiDAR, ERS1/2, ENVISAT ASAR, ALOS PALSAR	Identification of flood plains can help inform changes in land use, and identify areas developing protective measures (e.g. stopbanks)
Land cover / land use	Optical and polarimetric SAR	SPOT, ASTER RADARSAT-2	Used for catchment management planning to reduce flood and landslide risk
Vegetation change	Consistent time series of data	SPOT, ASTER RADARSAT-2	Determine drought zones, inform fire hazard mapping
Determining lahar and lava flow paths	DEM, high resolution optical imagery	SAR, Airborne LiDAR, SPOT, AVNIR-2, ASTER	Hazard zonation, public awareness, determining location of safety shelters
Locating potential and actual unstable slopes	DEM, Interferometric SAR, high resolution stereo optical imagery	Airborne LiDAR, ERS1/2, ENVISAT ASAR, ALOS PALSAR, aerial photography	Hazard mapping for infrastructure planning
Baseline infrastructure maps	Very high resolution optical imagery	Aerial photography, Quickbird, Ikonos, Worldview	Assist with hazard mapping to identify key infrastructure at risk – the risk can then be addressed through mitigation or built in redundancy. Can also be used for later damage assessment post-disaster
Baseline topographic data	Moderate to high resolution optical imagery	SPOT, AVNIR-2, Aerial photography, Quickbird, Ikonos, Worldview	Hazard modelling

Table 1. Examples of information and data requirements during the reduction phase

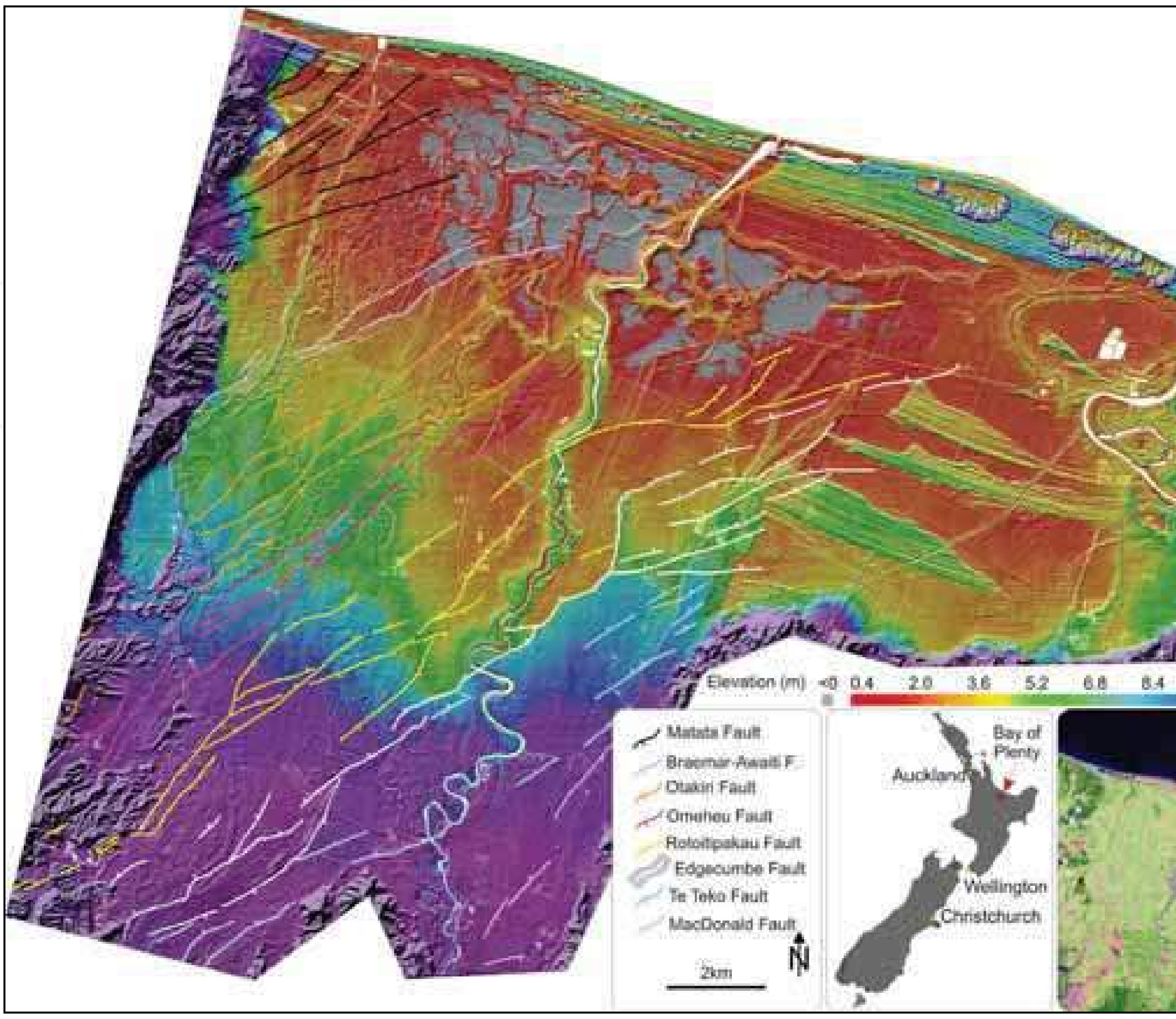

Fig. 2. Identification of known and new active faults using high resolution airborne LiDAR data acc
Mouslpoulou 2009 in press). Landsat ETM+ false colour composite (5,4,2) acquired in 2001 is inset fo
the site. Of the active fault traces shown here, approximately 85% were unknown before undertaki
also is the discovery of a large inland area that is below sea level (elevation <0m) and is a potent
tsunami related inundation

Remotely sensed data acquisitions can be used to inform land use planning, a key tool that authorities and communities employ to avoid or mitigate hazard risk (Burby 1998). By identifying the location and characteristics of hazards, land use planning methods can be applied to address the risk these hazards pose. Planning methods include mapping hazard zones (location and range of hazard impact) and identifying the probability of occurrence. Hazard maps are applied to developed and green field (undeveloped) land and options for risk treatment determined. Treatment options can include measures such as setback zones (no development within the hazard zone, e.g. proximal to active faults or within coastal erosion or inundation zones), or special building codes (e.g. minimum floor heights above base flood level) can be introduced to reduce the risk to assets and people (Godschalk et al. 1998). Understanding of hazard information is one of a number of critical factors influencing individual and group decision making for risk management (Paton & Johnston 2001). Where hazard information is readily available to the public in a variety of forms, including maps, there is a greater likelihood of public support for risk reduction initiatives introduced through land use planning (Burby 2001).

Other methods for land use planning based on remote sensing data include identifying changes in land use on flood plains to assist with flood hazard modelling. In the city of London, Canada, Landsat images taken over a 25 year period have been used to determine the spread of urban development (Nirupama & Simonovic 2007). The consequent increase in impermeable surface cover facilitated more rapid runoff and less natural absorption of rainfall. When compared with flood hydrographs, the rate of land use change correlates with smaller rainfall events producing flooding. The benefits to future land use planning are that it can be determined how land use changes affect the flood hazard risk, and this will guide future development in a way that mitigates the effects of continued urban sprawl.

Collecting asset data via high resolution remote sensing allows for identification of infrastructure and buildings in hazardous locations, which can then be targeted for strengthening or re-location. Asset data is also essential for hazard consequence modelling, whereby hazard data is combined with asset data and fragility (vulnerability) information to determine potential losses. Building fragility to hazards is based on such factors as construction materials (earthquake, volcanic ash fall, tsunami), engineering design (tsunami, landslide, earthquake), building height (wind), floor areas (earthquake), proximity of other structures and vegetation (fire) and roof pitch angle (ash fall, snow), and floor height (flood, tsunami). Remote sensing methods for collecting building and infrastructure data require high to very high resolution satellite or airborne imagery and is often completed using manual digitizing or more recently, segmentation and object oriented classification. Optical imagery is often complemented by LiDAR data, which can not only aid in detecting building edges, but is also used for calculating building heights. Incorporation of remotely sensed data into a GIS is vital during this phase for recording spatial attributes and combining with other data sets.

Remote sensing technology can also be applied to measure the success of risk reduction initiatives. A common method for addressing flood risk is the construction of stopbanks to contain flood waters for an event of a given magnitude. Aerial reconnaissance during major flooding events can identify whether stopbanks are performing to design standard and identify areas of weakness, overtopping or failure. Monitoring of non-structural risk reduction initiates is also possible. To address coastal hazard erosion and inundation risk, many communities choose non-structural options such as beach renourishment and dune restoration. In Florida, airborne LiDAR captured over time has been applied to measure coastal erosion from hazards, alongside the success of non-structural beach restoration methods through determining changes to beach morphology (Shrestha et al. 2005). Another example of measuring the effects of risk reduction initiatives is analysing post-disaster images of rainfall induced landslides on land under different vegetation covers for large events. From analysis of aerial photographs (oblique and vertical) of an event in 2004 which impacted the lower North Island of New Zealand, it was determined that vegetation cover played an important role in reducing loss of productive soil, and reducing landslide hazard to assets (Hancox & Wright 2005).

4.2 Readiness

Readiness planning and activities are undertaken in the realisation that residual risk from hazards has the potential to create emergencies, and in some cases, disasters for affected populations. Readiness is the identification and development of necessary systems, skills and resources before hazard events occur. The desired outcome of readiness planning and activities is that response to hazards is more coordinated and efficient, communities experience less trauma, and recovery times are reduced (Quarantelli 1997). Examples of readiness activities include public education, preparedness activities, trainng and exercising, evacuation planning, developing hazard monitoring and public alerting systems, and putting in place state, national and international plans and agreements for assistance and aid. Readiness activities and planning are undertaken at a number of levels to increase resilience and response capability for individuals, households, organisations, and states or nations. The provision of good hazard and asset information to assist these activities is essential and examples where remote sensing can assist this phase are given in Table 2. It is important in this phase to prepare an archive of and gain familiarity with the most up to date spatial information including (but not limited to) imagery, DEMs, and vector data. This information is required to assist with damage assessment during the response and recovery phases.

At the individual and household level there are identified factors that contribute to whether people will take actions to prepare for disasters. Personalisation of risk is essential (Barnes 2002, Slovic et al. 2000), e.g. “Will it affect me?”, “Do I need to do something about it”, and “What can I do about it?”. Other factors include belief in the benefits of hazard mitigation (outcome expectancy) and their belief that what they personally can do will make a difference (reduce negative outcome expectancy) (Paton 2006). At a community level, participation in community affairs and projects, and individual’s ability to influence what happens in their community (empowerment) and the level of trust they have in different organisations (trust) have also be shown to be key predicators of resilience. Therefore, communication of risk in a meaningful way is an essential part of preparedness planning. Remotely sensed data such as LiDAR are used to produce high resolution hazard and risk maps, which are used by authorities to communicate information about location and range of hazards to their communities. If individuals believe that a hazard is likely to affect them detrimentally within an understandable and pertinent timeframe, they are more likely to take actions to prepare. These actions might include having emergency supplies in the home, an action plan for evacuation and emergency contact with other household members, first aid training or training as a civil defence volunteer. The principle of risk perception aiding preparedness applies to both static and dynamic hazards, e.g. fault trace or flood plain mapping vs. cyclone or bushfire progression. Remotely sensed images showing the progression of a bushfire front or the track of a cyclone are commonly used by the media to inform the public of where hazards are occurring and where they are likely to impact as they evolve. As community resilience research has shown, awareness of hazards is not the only factor in triggering actual preparedness actions; however it is one significant driver (Paton 2006, Paton & Johnston 2001, Ronan & Johnston 2005).

Type of information	Data required	Sensor example	Application example
Severe weather warnings	RADAR, broadscale visible and infra red imagery	GOES, NOAA, Meteosat	Provide valuable advanced warning of severe events to the public and emergency planners via meteorologists
Movement and ground deformation	InSAR and PS-InSAR	ERS-1/2, ENVISAT ASAR, ALOS PALSAR	Rate of movement for slow moving landslides. Often acceleration of deformation rates means that a large event is about to follow. Early detection of deformation in volcanic regions is used for forecasting of possible eruptions
Soil moisture	Long wavelength SAR	SMAP	Water shortage leading to drought and agricultural productivity decline, ability of soils to retain water to indicate flood and landslide potential
Ground temperature variability	Thermal imagery, or SWIR in the case of very hot features	ASTER, MODIS, AVHRR	Monitoring heating and cooling cycles of volcanoes to understand pre-eruptive characteristics for forecasting purposes
Coastal and bathymetric mapping	SONAR, Laser depth ranging	LADS, Topex Poseidon / Jason	Tsunami hazard modelling
Display and advertisement of potential hazards	Moderate to high resolution optical imagery, often overlaying a DEM	Aerial photography, Quickbird, Ikonos - usually using black and white or true colour composites for ease of understanding	For use in public education about hazards and risks to foster greater readiness of individuals, households and organisations Use in civil defence emergency management exercises to provide realistic scenarios that will assist with staff professional development and planning
Detecting sea temperature or atmospheric pressure change in cyclone/hurricane/ typhoon generating latitudes	Broad scale thermal imagery, geostationary	MODIS, GOES, AVHRR	Advance warning of severe weather approaching to commence

Table 2. Examples of information and data requirements during the readiness phase

At the institutional level, a strong focus is placed on the development of plans and relationships. A primary way to test the effectiveness of these preparedness plans and relationship functions is through civil defence emergency management exercises. In order for exercises to provide an effective learning experience for participants, realistic hazard scenarios must be developed. Remotely sensed data can assist this process through the creation of hazard maps, providing realism to exercise injects (new information about hazards or consequences as the exercise plays out).

At local to national scales, obtaining an overall picture of the hazardscape; identifying at risk areas, and priority hazards for resources and planning is essential. Granger (2000) discusses the development of information infrastructure for disaster management in Pacific island nations, based on remotely sensed data, and GIS interpretation. For countries with limited budgets, collaboration to purchase remotely sensed data for disaster planning is beneficial because of cost savings, the opportunities for skill and process sharing, and the consistency of data for modelling (Granger 2000).

As discussed previously, hazard modelling is important for risk reduction (section 4.1); it is also important for readiness, as for many hazards residual risk dictates that an effective emergency response will be the most practical solution for disaster management. For example, New Zealand has several active volcanoes; Mt Ruapehu is the largest of these. Ruapehu is a national park and has two commercial ski fields in operation on its slopes. Depending on the time of year, visitors to the mountain are engaged in a variety of recreational, educational and scientific activities. The greatest hazards associated with the volcano are eruptive events and lahar flow (Carrivick et al. 2009). The volcano has a crater lake at the summit which produces periodic large lahars during eruptions and tephra dam bursts. These lahars follow channels which are bridged by the main trunk railway line and State Highway 1, as well as passing through ski field and hiking areas. A lahar event in 1953, before bridges were raised and strengthened, destroyed the Tangiwai rail bridge, and a passenger train unable to stop was derailed resulting in the death of 151 people. While bridges have been modified to reduce risk, considerable readiness planning has also been undertaken to ensure that the events such as the 1953 disaster cannot happen again (Galley et al. 2004).

Following eruptions in 1995 and 1996 a large tephra dam formed on the crater rim allowing the lake to fill to higher than normal levels. The volcanic rocks of Crater Lake rim now had a weakness, a section of the rim comprised of weaker tephra, which would fail when lake levels reached a certain height. Extensive modelling of potential lahar flow paths and velocities was undertaken based on high resolution remotely sensed data (Carrivick et al. 2009). The path was verified using aerial photography, LiDAR, ASTER and PALSAR imagery after the event (Joyce et al. 2009b). The modelling provided the necessary hazard information for authorities to manage the risk through a suite of preparedness activities. A bund (levee) has been constructed to prevent lahar flow onto the main highway; and a comprehensive monitoring and alarm system was constructed to detect lahar break outs. An integrated response plan involving emergency managers, police, the fire service, road managers, railways operators, ski field staff, scientists and national park managers, was developed to stop all trains outside the hazard zone, close the highway, trigger warnings and response plans at the ski fields (move to ridges away from flow paths) (Leonard et al. 2005), and locate and evacuate any hikers or workers in hazard zones within the national park. The tephra dam burst early in 2007, and the response based on high quality modelling went as planned. The lahar was of considerable size but remained within expected channels and the only significant damage was to an unoccupied public toilet building at the Tangiwai memorial site.

Lahar flows and eruptions remain an ongoing hazard at Ruapehu. To assist with preparedness for these hazards, remote sensing is part of the suite of monitoring systems employed to detect changes in volcanic activity. A combination of synthetic aperture radar, ASTER thermal imagery (Figure 3), and OMI UV/visible imagery is acquired on a routine basis for monitoring deformation, Crater Lake temperatures and gaseous emissions respectively.

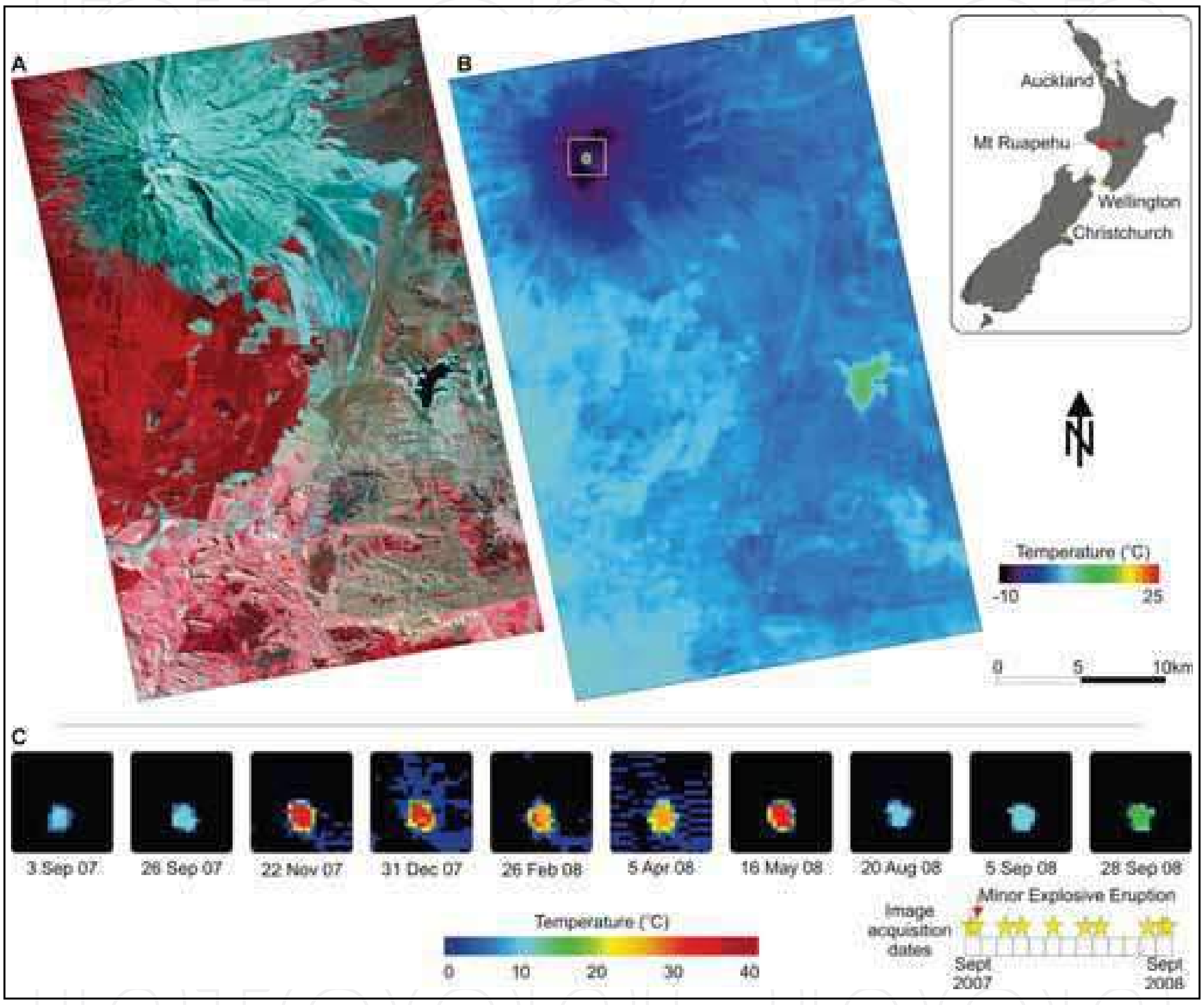

Fig. 3. Thermal monitoring of Mt Ruapehu. (a) SPOT-5 image obtained 15 March 2008 demonstrates land cover for contextual purposes; (b) Average temperature image calculated from night-time ASTER thermal data between 3 September 2007 and 28 September 2008; and (c) Mt Ruapehu Crater lake subsets using ASTER night-time thermal data. Note the temperature scale change for illustrative purposes.

The use of remotely sensed data of a previous event can be used in this phase to constrain geophysical models and help provide realistic scenarios for future events. For example, InSAR can be used to examine the deformation effects of a single event (such as an earthquake) by acquiring only two images as close in time as possible, one before and one after the event. Using this technique, the PALSAR L-band sensor on board the ALOS satellite was successfully used to map co-seismic deformation of a magnitude 6.7 earthquake in the vicinity of George Sounds, off the coast of the lower South Island on 16th October 2007 (Petersen et al. 2009 in review). After processing two PALSAR images (22 July and 22 October 2007) displacements were apparent in the coastal region closest to the epicentre (Figure 4). Landslides were also experienced in the area (though not evidenced in this figure). The long wavelength L-band is of particular use in this region due to its ability to penetrate dense vegetation to retrieve the ground signal. The amount and location of deformation is used in modelling studies to estimate earthquake parameters in order to learn more about the tectonics of this remote region. As this is an uninhabited area of New Zealand, there was no observed infrastructure damage that may have otherwise necessitated acquisition of high resolution optical imagery for response or recovery purposes.

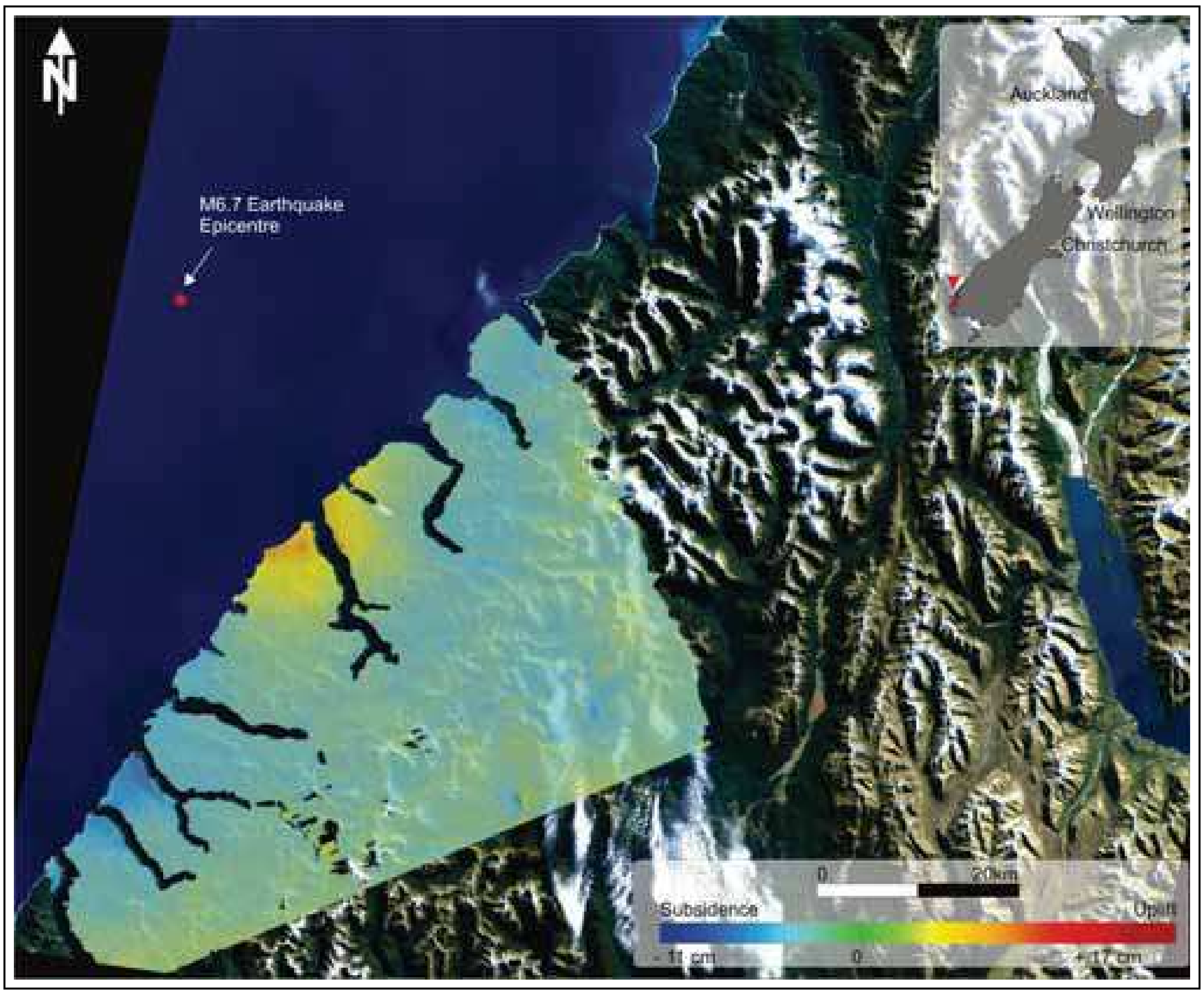

Fig. 4. Ground deformation following George Sounds earthquake in October 2007. Background image is a Landsat 7 ETM+ true colour composite scene

Monitoring longer term ground deformation effects such as that produced by ground water extraction, volcanic activity or slow moving landslides is conducted using multiple SAR images over a period of time. Using this technique it is possible to detect sub centimetre scale ground movement over large areas that could otherwise only be monitored or detected using networks of in-situ GPS. With this method, the C-band sensor on board the ENVISAT satellite was able to detect sub-centimetre deformation in the Auckland region (Figure 5). This figure was created using a stack of 117 images, spanning the period 17 July 2003 and 9 November 2007. InSAR is used in this manner for long term monitoring and produces a rate of change over time. It is believed that most of the observed InSAR signal shown here is caused by extraction of groundwater; however the link to volcanic activity has also been investigated (Samsonov et al. 2009 in review).

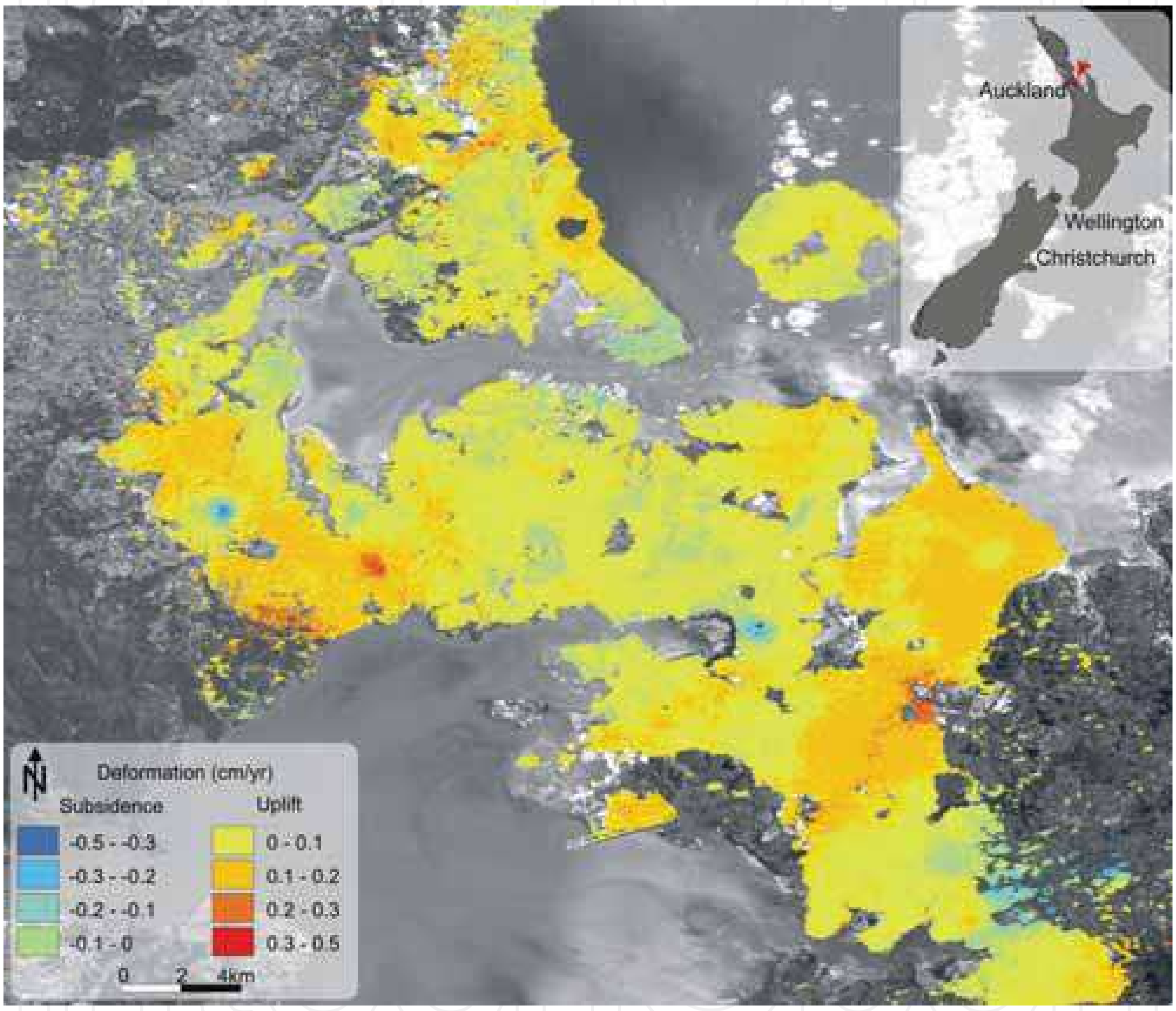

Fig. 5. Monitoring uplift and subsidence in Auckland. Background image is a green band grey scale mosaic of SPOT-5 and Landsat 7 ETM+ imagery.

4.3 Response

Response activities are primarily focussed on protecting life and property during disasters. Activities such as evacuations, search and rescue, sandbagging along riverbanks, evaluating building safety, establishing immediate emergency shelter, setting up command posts and other short-term tasks fall into the response phase. Remote sensing can be used here to provide immediate damage assessment if the data can be provided in a timely manner, and also to assist evacuation plans through the combination of observing weather patterns and hazard behaviour (e.g. fire front approaches, water level rises). Other examples of the use of remote sensing during the response phase are given in Table. 3. Ideally, recovery activities commence when the response phase begins, to ensure an integrated process for holistic recovery. This means that damage assessments undertaken via remote sensing during the response phase will also be integral to the recovery phase.

Type of information	Data required	Sensor example	Application example
Inundation	SAR, optical	Radarsat, SPOT, ASTER Quickbird, Ikonos	Determine magnitude, location and duration of impacts. Use SAR when cloud cover is still problematic
Widespread storm or earthquake induced landslides	SAR, moderate – high resolution optical	Radarsat, SPOT, ASTER Quickbird, Ikonos	Determine magnitude, location and duration of impacts.
Volcanic ash and gases	Shortwave infra red, thermal infrared	GOES, TOMS/OMI, MODIS	Highly temporally variable, so minimum of daily imagery required. Used for volcanic ash advisories and to warn airlines of hazardous flight paths
Public information during events	High resolution optical imagery	Quickbird, Ikonos	Assist those at risk to personalise hazard threat
Ship location	SAR	Terra SAR-X, Cosmo Sky-Med	Locating ships in the ocean during storm
Co-seismic and post-seismic deformation	InSAR	ERS-1/2, ENVISAT ASAR, ALOS PALSAR	Confirming magnitude of earthquake and forecasting possible aftershocks

Table 3. Examples of information and data requirements during the response phase

During the response phase, the temporal relevancy of remote sensing information is crucial to allow disaster managers to plan effective mitigation strategies on dynamic situations. In the case of wildfire events, it is critical to have current and timely intelligence on the fire location, fire-front, and fuel conditions. Near-real-time information allows the fire management team to plan fire attack appropriately, consequently saving resources, time and possibly lives. Concurrently, the information must be of sufficient spatial resolution to allow detailed tactical assessments and decisions to be made on the wildfire condition, and be spectrally-relevant to the phenomenon being observed or measured.

Despite the spectacular nature of imagery often captured during a disaster event, the use of remote sensing during the response phase has experienced mixed levels of success, particularly in the case of satellite platforms. Regional scale imagery of effects associated with the development of fire fronts (hot spot detection), volcanic eruptions (gas and ash emissions), or tropical cyclones (inundation) is generally successful where the area of impact is sufficiently large. For example, the wildfire management agencies in the United States currently utilize thermal-infrared (TIR) satellite data provided by MODIS to provide synoptic, 2-4 times-daily hot-spot detection of fire at continental scales (U.S. Forest Service 2009). The spatial resolution of MODIS is low / moderate (1000 meters), and is used to derive a regional estimate of fire distribution. Although the temporal frequency of the MODIS data is sufficient for regional fire assessment, its spatial resolution is insufficient for more localised events, or for assessing the specific on-ground impact. Conversely, polar orbiting satellites with appropriately high spatial resolution generally do not have the overpass frequency or data relay capability to provide imagery quickly enough to be of use for immediate response. The space science community is attempting to address this issue with the launch of satellite constellations such as Rapid Eye and the Disaster Monitoring Constellation (International collaboration between Algeria, China, Nigeria, Turkey and the UK). There are also avenues for collaboration between international organisations for data acquisition and provision in the event of disasters, such as the International Charter for Space Based Disasters (Ito 2005), and Sentinel Asia (Kaku et al. 2006). While potentially providing a considerable amount of data, neither of these tools can yet be used for immediate or first response due to the current time delay between requesting and receiving data. As such, research into airborne platforms has proven to be of greater utility for rapid data and information provision.

In 2006, 2007 and 2008, the National Aeronautics and Space Administration (NASA) and the U.S. Forest Service collaborated to evaluate and demonstrate the use of long-duration, large Unmanned Airborne Systems (UAS), innovative sensing systems, real-time onboard processing, and data delivery and visualisation technologies to improve the delivery and usefulness of remote sensing data on wildfire events. The objectives were to demonstrate the capabilities of providing sensor-derived, GIS-compatible, geo-rectified, processed data on wildfire conditions to incident management teams within 15-minutes of acquisition from the sensors on the UAS. The characteristics of this system render it ideal for emergency response that is not just isolated to wildfire events.

During the 2006, 2007 and 2008 U.S. wildfire season, a series of missions were flown over wildfires in the western U.S. to demonstrate the integration of the above-mentioned technologies to provide near-real-time information to disaster managers. The missions were flown on the NASA *Ikhana*, a modified General Atomics – Aeronautical Systems, Inc. Predator-B (MQ-9) Unmanned Aerial Vehicle (UAV), designed specifically for supporting NASA science missions. The *Ikhana* is capable of medium / high altitude and long-duration (24-hours) operations, making it an ideal platform for disaster event monitoring. The *Ikhana* UAS flew missions with the NASA AMS-Wildfire sensor onboard, which can be remotely operated and provides autonomous data processing capabilities (Ambrosia & Wegener 2009).

The use of the *Ikhana* and accompanying systems has proven successful over a number of events. In October 2007, four missions were flown over the Santa Ana wildfires in a five-day period (Figure 6a) and the resultant information was used to deploy fire fighting resources. In late June 2008, lightning storms in northern California ignited thousands of fires, that grew together to become over 25 major incidents covering millions of acres of forestlands. The national airborne remote sensing assets were overwhelmed and with a state emergency declared, the *Ikhana* and AMS-Wildfire were requested to support wildfire data collection operations. During the remainder of the summer, the *Ikhana* flew four missions in California, providing near-real-time data on numerous wildfires. The AMS-Wildfire real-time data were used effectively to locate a major fire surge encroaching on Paradise, California (Figure 6b). The data was used to support the emergency evacuation decision of the entire population of the community, an effective demonstration of the criticality of near-real-time remote sensing information supporting disaster management operations.

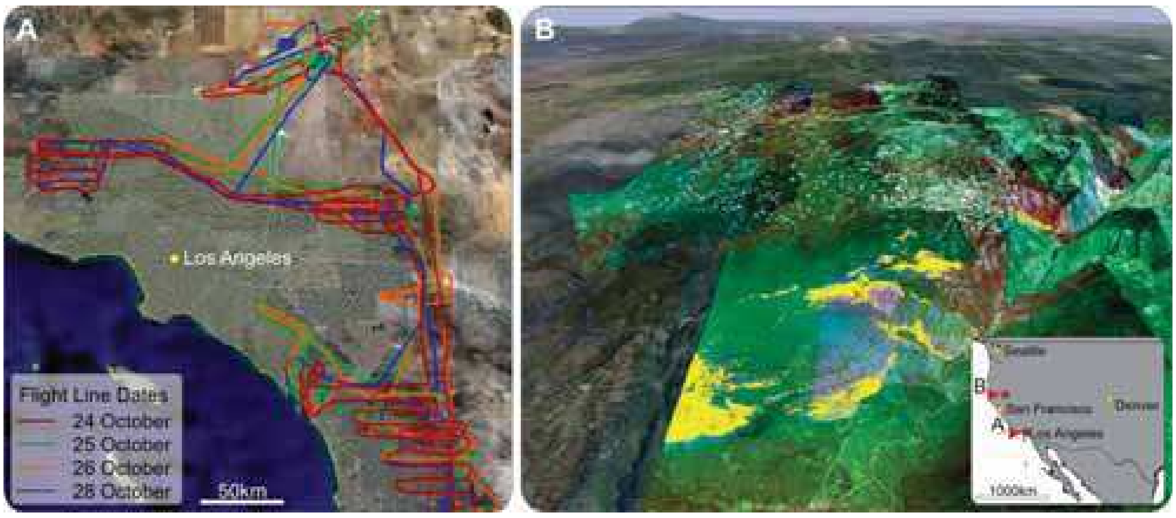

Fig. 6. (a) Flight routes required to cover 11 major wildfires California over four days in October 2007; and (b) AMS-Wildfire 3-band graphic image overlay and fire hot-spot detects (yellow areas) of the Canyon Complex fire approaching Paradise, California. The data was acquired on 8 July 2008. The hot-spot detect data, showing the fire moving rapidly towards Paradise, assisted in the evacuation determination for residents in the vicinity. This north-viewing 3-D data is displayed on Google Earth background information.

One of the key factors to the success of this system is the provision of not only data, but information that can be ingested and utilised immediately by emergency managers to aid their decision making. Part of this speed of information delivery is attributed to the autonomous processing onboard the UAS to create geo-rectified image raster products (GeoTIFF) and hot-spot detection vector files (*.shp* files). An emergency situation is not the time to be experimenting with new algorithms or processing techniques, thus it is necessary to ensure robust techniques have been thoroughly trialled and considered operational pre-event (Joyce et al. 2009a). The vector and raster products generated with this system are transmitted via the *Ikhana* telemetry system, through a communications satellite to servers on the ground, where they are automatically processed into Keyhole Markup Language (KML) files, compatible with Google Earth and made available in near-real-time at NASA servers. The combination of the near-real-time imagery and the simple Google Earth visualisation capabilities are a powerful tool that requires minimal (or no) training in its employment. Embedding a remote sensing specialist within the emergency management team can further assist with data integration, information understanding, and fielding specialized requests.

Although the Western States UAS Fire Imaging Missions were focused on demonstrating remote sensing capabilities to wildfire management entities, they resulted in direct emergency support to national incidents in all three years. Those missions allowed a comprehensive assessment of the technologies and resulted in the adaptation and integration of various components into operational use. The key components to the "usefulness" of the data were the timeliness of the data (from acquisition to product delivery) and the simple format which the data was available for visualisation and decision-making. While these factors are important at all stages of the disaster management cycle, they become particularly critical during the response phase, where rapid decision making is most important. The provision of simple hotspot information also means that the emergency management team is not overwhelmed with too much data or too many visualisation options. The choice of using Google Earth as a "front-end" display of the data was a careful decision to provide information in a format and software system that was easily operated and readily available to the fire management community. Fire Incident Command team members do not have the time to "learn" new software capabilities or new tools while they are in the midst of a major wildfire management activity. Google Earth provided a user-friendly capability to allow quick data integration, zoom capabilities, 3-D visualisation and ease of use.

The use of UAVs presents opportunities as well as risks. UAVs provide increased range and flight time and the ability to penetrate environments that might be too hazardous for piloted aircraft (Henson 2008). Mission and platform costs currently precludes immediate adaptation of UAS systems by disaster management agencies, but the disaster support missions we showcased are major steps forward in demonstrating UAS utility and sensor and processing capabilities available right now! These technologies need not be considered for use only with unmanned vehicles, but can be adopted for piloted aircraft, and hopefully for satellite platforms in the future. Autonomous onboard processing has been trialled with Hyperion for identifying hotspots associated with volcanic eruptions (Davies et al. 2006), though the challenge remains to progress these techniques to operational status.

4.4 Recovery

The use of remote sensing to aid or monitor disaster recovery is perhaps the least developed application of this technology. However, this is an area where the remote sensing community could contribute a great deal through the provision of objective time series analysis over large areas with both high and medium levels of spatial detail. In other specialisations, time series analysis of remotely sensed data is an established technique. Environmental applications such as deforestation and urban sprawl are common targets. In each case, the monitoring objective is clear. In disaster recovery, there are often some very clear indicators that can easily be measured and monitored with remote sensing imagery. Some of these indicators include construction and subsequent removal of medium and long-term emergency shelters; debris removal; commencement and completion of new construction or reconstruction (buildings, bridges, roads); vegetation regrowth; and reduction of siltation from waterways after flooding events (Table 4).

Type of information	Data required	Sensor example	Application example
Rate of recovery e.g. debris removal, vegetation regrowth, reconstruction	Moderate to very high resolution imagery in a continuous time series	Aerial photography, Quickbird, Worldview, Ikonos	Compare the effectiveness of different recovery strategies; Determine if aid funding is being used appropriately; Wildlife habitat recovery (eg after fire); Identify 'residual risk' – areas not recovered are more vulnerable to future events
Infrastructure and facilities locations	Very high resolution imagery	Aerial photography, Quickbird, Worldview, Ikonos	Create new baseline maps
Revised DEM	InSAR, LiDAR	ERS-1/2, ENVISAT ASAR, ALOS PALSAR	Necessary after large earthquake or volcanic eruption if the local and regional elevation changes
Status Quo	Very high resolution imagery	Aerial photography, Quickbird, Worldview, Ikonos	Plan areas for funding allocation

Table 4. Examples of information and data requirements during the recovery phase

Using high spatial resolution the amount of housing reconstruction can at least be visually identified by the presence and absence of blue tarpaulins covering roofs following Hurricane Katrina (Hill et al. 2006). Conceivably an automated detection method could be developed to identify these quickly and repeatedly in a time series dataset. The authors also provide a list of other recovery related features observable over time with Quickbird data. In Figure 7, the progression of recovery in a small area of New Orleans can be seen with high resolution data. Notable features in the image acquired a week before the hurricane are a large car park, sporting fields, and residential housing (Figure 7a). The progression clearly shows inundation in this area (Figure 7b), and remaining sediment shortly after the water subsidence. By March 2006, temporary housing is evident in the location of the car park, and is still visible three years after the event, though the number of roofs covered in blue tarpaulins has decreased. An analysis of the relative rate of change is given in Figure 7k, demonstrating that impervious surfaces and lines of communication such as roads moved towards recovery quite quickly after the event, while mature vegetation takes somewhat longer. Some roofing damage and a swimming pool appear to remain in an unrepaired state three years after the event. The key here is that a time series of data is vital to determine if any change is occurring, and to further extract rates of change.

Recovery rates following a widespread landsliding event in northern New Zealand can also be seen from a series of SPOT-5 and ALOS AVNIR-2 imagery (Figure 8). Here the landsliding is apparent as bright scars in the colour infra red imagery acquired four months after the event (Figure 8b). One year later, recovery of many of the grassy slopes on the eastern portion of the image can be seen, while the landslides in the western region are also becoming overgrown (Figure 8c). This recovery becomes even more apparent in the series of NDVI images, which highlight the contrast between landslides (black) and surrounding vegetation (various shades of grey) (Figure 8d-f). In an area that was covered with many thousand landslides (Joyce et al. 2008a), satellite remote sensing is the only time and cost effective manner of data collection for understanding recovery in the area. Similar techniques could be used to look at native habitat regeneration following bushfires.

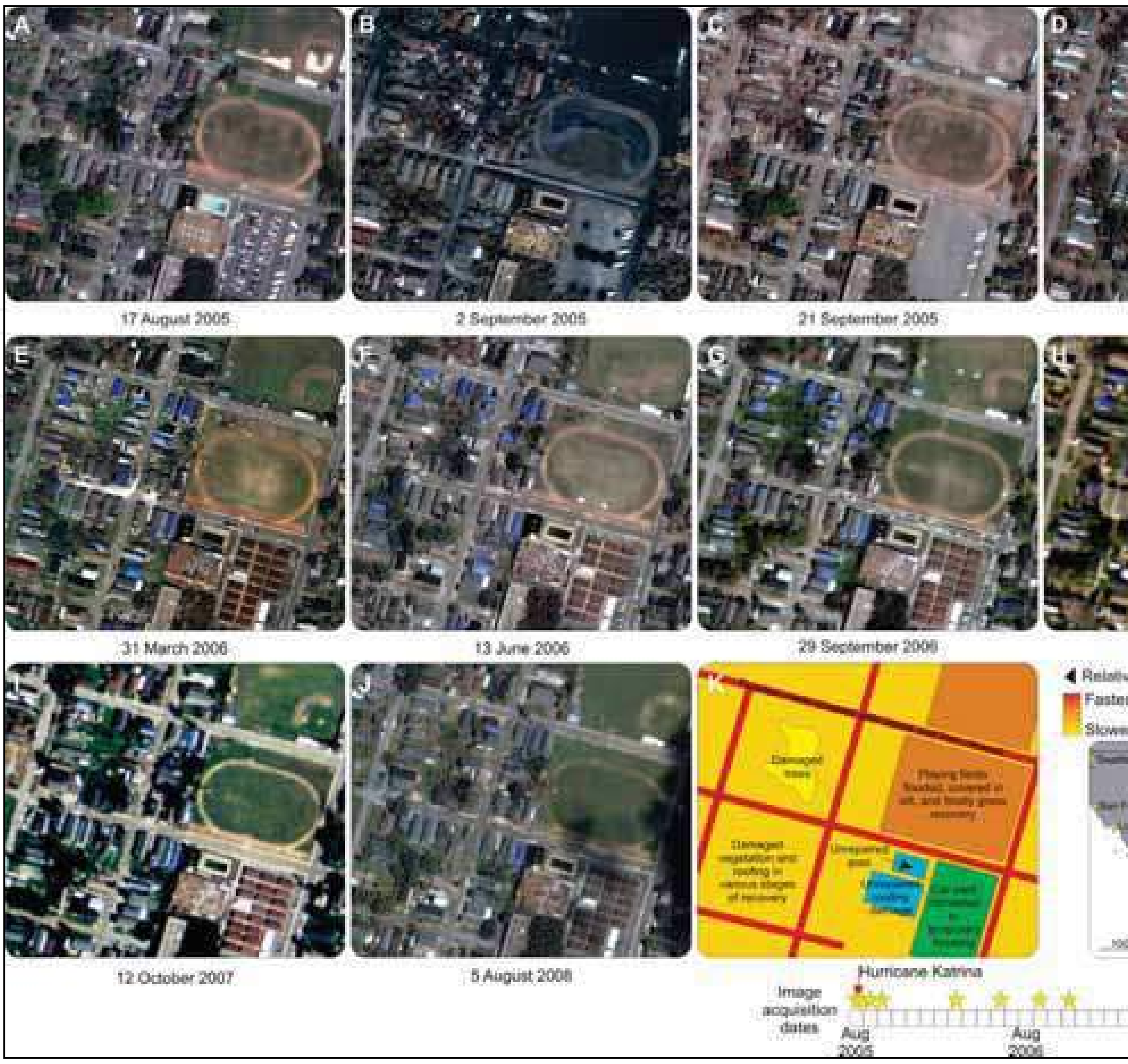

Fig. 7. Time series of high resolution imagery in New Orleans (a) Before Hurricane Katrina; (b) Soo
(c-j) Various time intervals following the recovery process; and (k) Interpreted rate of recovery. In
Google Earth 2009.

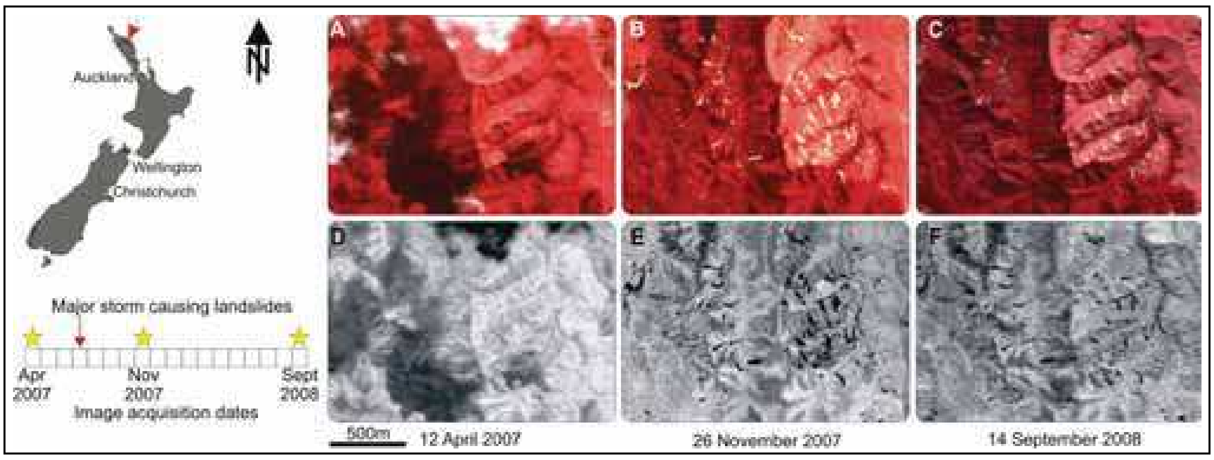

Fig. 8. Recovery of vegetation after a widespread landsliding event in northern New Zealand, July 2007. (a) SPOT-5 CIR obtained before the event; (b) SPOT-5 CIR obtained shortly after the event; (c) ALOS AVNIR-2 CIR imagery obtained one year later; and (d-e) NDVI images of the aforementioned data.

Analysis of time series imagery could also help to monitor the effectiveness of different recovery strategies. By extracting recovery rates from data acquired at appropriate time intervals, this assessment could help guide recovery plans for future events of a similar nature. This would also help identify areas of residual risk that require ongoing monitoring until the physical recovery process completed.

5. Conclusions

Remote sensing can be used to inform many aspects of the disaster management cycle. An exhaustive coverage of all potential applications would be impossible in a single book chapter, however we have shown several good examples from which inspiration can be sought for future use. It is important to consider all aspects of disaster management, rather than focussing on emergency response. By incorporating remote sensing into reduction and readiness activities, this can also educate both emergency management staff and the community about this type of information so that they are familiar with its use under a response and inherently pressured situation.

The key elements to facilitate the usefulness of remote sensing data in support of the disaster management community are being able to provide the appropriate information in a spectrally, temporally, and spatially relevant context. Additionally, one must be aware of the information requirements of that disaster management community, and tailor the remote sensing information to meet those needs. That can only come through close collaborations between the disaster management community and the remote sensing / geospatial community.

6. Acknowledgements

All SPOT 5 imagery used in this chapter is © CNES. This manuscript incorporates data which is © Japan Aerospace Exploration Agency ("JAXA") (2008). The data has been used in this manuscript with the permission of JAXA and the Commonwealth of Australia

(Geoscience Australia) ("the Commonwealth"). JAXA and the Commonwealth have not evaluated the data as altered and incorporated within the manuscript, and therefore give no warranty regarding its accuracy, completeness, currency or suitability for any particular purpose. Environment Bay of Plenty provided the licence to use the LiDAR data. Thank you to Andy Gray for assistance with graphics and to Phil Glassey and David Johnston for chapter review.

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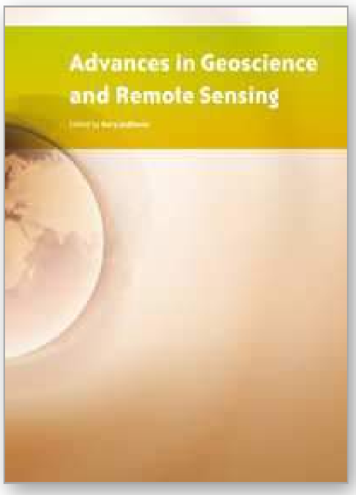
8. Glossary

Note that the satellite sensors listed here and within the text are simply examples of the types of instruments that can be used, rather than being a complete listing of all possibilities.

ALOS AVNIR-2	Japanese Space Agency (JAXA) Advanced Land Observing Satellite Advanced Visible and Near Infrared sensor. Useful for local to regional scale mapping and monitoring
ALOS PALSAR	Japanese Space Agency (JAXA) Advanced Land Observing Satellite L Band SAR satellite. Useful for deformation monitoring in regions of dense vegetation
ASAR	C Band Advanced Synthetic Aperture RADAR
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer on board NASA's Terra satellite. Useful for monitoring volcanic activity
AVHRR	Advanced Very High Resolution Radiometer (NOAA – National Oceanic and Atmospheric Administration). Useful for regional to national scale applications
CIR	Colour Infrared – three band standard display of green, red and near infrared light displayed as blue, green and red respectively

DEM	Digital elevation model
DMC	Disaster Monitoring Constellation. International collaboration between space agencies in Algeria, China, Nigeria, Turkey and the UK for regional scale mapping (optical)
ERS	European Space Agency Satellite with a suite of SAR and optical sensors
ENVISAT	European Space Agency Satellite with a suite of SAR and optical sensors
GOES	Geostationary Operational Environmental Satellites – used for metrological applications
Ikonos	Very high spatial resolution commercial satellite (GeoEye). Useful for local scale mapping and monitoring (e.g. buildings and assets)
InSAR	Interferometric Synthetic Aperture RADAR – technique used for measuring surface deformation
KML	Keyhole Markup Language – native language for Google Earth files
LADS	Laser Airborne Depth Sounder
Landsat ETM+	Enhanced Thematic Mapper plus. Useful for long term regional scale mapping and monitoring, though technical malfunctioning limits data coverage
Landsat TM	Thematic Mapper. Useful for long term regional scale mapping and monitoring
LiDAR	Light Detection and Ranging. Used for creating very high spatial resolution DEMs
Meteosat	European geostationary meteorological satellite
MODIS	Moderate Resolution Imaging Spectrometer. Used for hotspot monitoring of fires and volcanic activity on a regional to continental scale
NASA	National Aeronautics and Space Administration
OMI	Ozone Monitoring Instrument – used for monitoring volcanic gas emissions
POLInSAR	Polarimetric Interferometric Synthetic Aperture RADAR
PS-InSAR	Permanent Scatterers Interferometric Synthetic Aperture RADAR
Quickbird	Very high spatial resolution commercial satellite (Digital Globe). Useful for local scale mapping and monitoring (e.g. buildings and assets)
RADARSAT	Canadian Space Agency C Band SAR satellite
RapidEye	Constellation of five high resolution optical satellites, the combination of which provides a daily revisit capability
SAR	Synthetic Aperture RADAR. Active sensor capable of capturing data through clouds, smoke and haze
SMAP	Soil Moisture Active Passive – scheduled for launch in 2012
SPOT	Satellite Pour l'Observation de la Terre – French Space Agency (CNES – Centre National d'Etudes Spatiales) colour infrared and panchromatic earth observation satellite

SWIR	Short Wave Infrared. Used for volcanic ash and gas monitoring and also vegetation applications
Terra SAR-X	X-band SAR satellite
TIR	Thermal Infrared, used for fire and volcanic activity monitoring
Topex Poseidon	Joint CNES / NASA satellite altimetry mission, used for studying sea level, ocean bathymetry, tides and ocean currents (now succeeded by Jason)
UAS	Unmanned Airborne System
UAV	Unmanned Aerial Vehicle
UV	Ultra Violet – non-visible short wavelength radiation, useful for volcanic gas estimation
Worldview	Very high spatial resolution commercial satellite (Digital Globe). Useful for local scale mapping and monitoring (e.g. buildings and assets). Currently only panchromatic.



Advances in Geoscience and Remote Sensing

Edited by Gary Jedlovec

ISBN 978-953-307-005-6
Hard cover, 742 pages
Publisher InTech

How to reference

Karen E. Joyce, Kim C. Wright, Sergey V. Samsonov and Vincent G. Ambrosia (2009). Remote sensing and the disaster management cycle, Advances in Geoscience and Remote Sensing, Gary Jedlovec (Ed.), ISBN: 978-953-307-005-6, InTech, Available from: http://www.intechopen.com/books/advances-in-geoscience-and-remote-sensing/remote-sensing-and-the-disaster-management-cycle

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The appended material is based on course developed under the SUNRAISE Project.

The course is being offered at the Jawaharlal Nehru University. The teaching is carried out using the published research material. As the course is multi-disciplinary, finding a text book is challenging. The appended notes are using the material available as Open Access, which is distributed under the terms and conditions of the Creative Commons Attribution license.

Co-funded by the
Erasmus+ Programme
of the European Union