Current developments of remote sensing for mapping and monitoring land degradation at regional scale

Prof Graciela Metternicht

Chair, ICA Commission on Mapping from Satellite Imagery

Curtin University of Technology

Perth, Western Australia

Email: g.metternicht@curtin.edu.au

UN-Zambia-ESA Regional Workshop on the Applications of GNSS in Sub-Saharan Africa

June 2006

What is land degradation?

- Land degradation is the reduction in the capability of the land to produce benefits from a particular land use under a specified form of land management (after Blaikie and Brookfield 1987).
- Soil degradation is one aspect of land degradation; others are degradation of vegetation or water resources.

Processes of land degradation

- Land degradation results in adverse effects of which we like to know the spatial and temporal variation.
- Knowledge of:
  - processes of land degradation, and hence
  - the process-controlling variables, and
  - the effects of degradation

  is a pre-requisite to determine which variables can be derived from remotely sensed images.

The Scale Factor

- Factors controlling spatial variation of land degradation depend on scale.
- Macro-scale: 1:1,000,000
  - **climate** is considered a very important factor
- Micro-scale: 1:50,000 and finer scales
  - Climate is fairly uniform
  - Variation of soil properties
  - Lithology
  - Topography
  - Vegetation properties, become important

The scale factor (cont)

- At micro-scale the short distance spatial variability of process-controlling factors becomes important.
- Using vegetation or soil maps with large mapping units doesn't make sense, as local variation has to be captured.
- Remote sensing can play an important role in capturing local variation

Methods for assessing land degradation

- *Expert opinion*: subjective assessment, using semi-quantitative definitions (e.g. GLASOD survey)
- ***Remote sensing***: satellite and airborne images, linked to ground observations. Ground-based radiometry
- *Field observations*: including stratified soil sampling and analysis, long term field observations of vegetation and biodiversity in specific sites.

Methods for land degradation assessment (cont.)

- *Productivity changes*: observing changes in crop yield
- *Land users opinions* and farm level field criteria: studies at farm level are seen as essential on a sample basis, to obtain a view of the severity of degradation and its causes, together with practicable remedial measures
- ***Modelling:*** based on data obtained by other methods, modelling is applied for:
  - Prediction of hazard to degradation (GIS-based models)
  - Extending the range of applicability of results on observed degradation.
- None of these consist in a single methodology, synergistic use (e.g. Combined approaches) are common.

Mapping and modelling land degradation

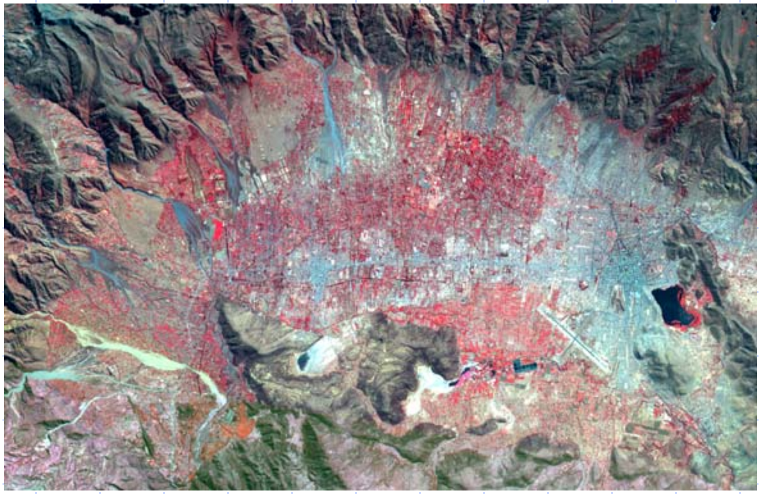
- Satellite imagery and aerial photographs are recommended tools for:
  1. Assessing the spatial and temporal distribution of land degradation features;
  2. Collecting input data for process simulation models in order to produce land cover maps, vegetation cover maps, bare soil fraction maps, etc

1. Assessing spatial and temporal distribution

- Surveying: to assess the current status of the land in terms of ongoing degradation processes. Aims:
  - Determining the spatial variability and status of:
    - Natural vegetation (coverage and structure)
    - Agricultural crops (performance, coverage)
    - Soil surface (e.g. sealing or crusting)
    - Presence of soil erosion surface features (gullies, rills)
  - Monitoring changes over time:
    - Development of crop canopy over a growing season (indicator of erosion)
    - Long term development of rill and gully formation in an area.

Detecting and measuring indicators: Techniques

- Indicators can be detected using a variety of techniques, including
  - Field observations (GPS),
  - Laboratory analysis,
  - Remotely sensed data or a combination thereof.

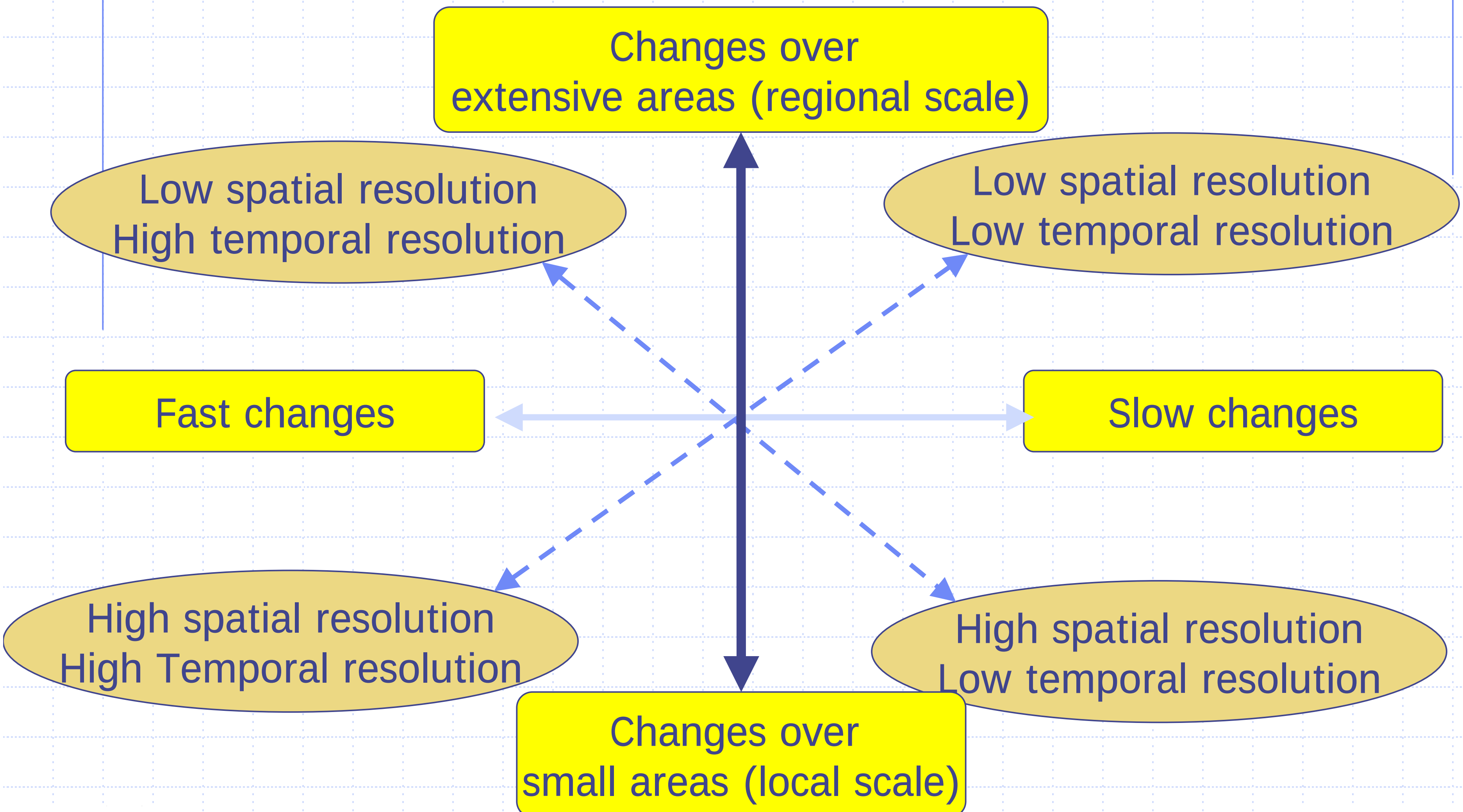



2. Input data for modelling

- Process controlling variables such as:
  - rainfall interception,
  - water canopy storage and
  - changing agricultural land use through the growing season

  are derived from air- or satellite-borne images to use the information in process simulation models.

Land degradation processes/ remote sensing requirements: temporal and spatial



Land degradation mapping and monitoring

Factors influencing the use of RS as a mapping tool

Sensors and platforms commonly used

Factors affecting feature discrimination and mapping

- The one-to-many relationship between surface features and land degradation processes, one feature characterising many degradation process (Figure 1);
- The spectral similarity among surface component associated with land degradation; and
- The differences in spatial resolution of various data sources used for mapping purposes, including remotely sensed data, field observations and laboratory determinations.

Constraints on the use of remote sensing: land salinization example

- Salts at the terrain surface can be detected from remotely sensed data:
  - Directly: salt efflorescences, salt crusts, bare soils
  - Indirectly: through vegetation type and growth; vegetation health's status

Remote Sensing Sources: soil salinity as a form of land degradation

Satellite

Airborne

Ground-based

Sources of remote sensing data

Satellite-borne sensors			
Sensor	No of bands	Spectral Range (µm)	Spatial resolution
Landsat TM4&5 Landsat TM7-ETM+	7 (1-7) 8 (1-8)	Visible, NIR, mid- and thermal infrared	
		B1: 0.45-0.52	Bands 1-5 and 7: 30 m Band 6: 120m Band 8: 15m
		B2: 0.52-0.60	
		B3:0.63-0.69	
		B4:0.76-0.90	
		B5: 1.55-1.75	
		B6: 10.40-12.50	
		B7: 2.08-2.35	
		B8: 0.52-0.90 (pan)	
SPOT 1-3	4 (Xs1-3 & Pan)	Visible, NIR	Xs or Xi: 20 m Pan and Mono: 10 m
		Xs1: 0.50-0.59	
		Xs2: 0.61-0.68	
		Xs3: 0.79-0.89	
SPOT 4	5 (Xi1-4 and Mono)	Xi4: 1.58-1.75	
		Pan:0.51-0.73	
		Mono:0.61-0.68	
LISS-III	4	Visible, NIR, mid-infrared	Bands 1-3: 23 m Band 4: 70 m
		B1: 0.52 - 0.59	
		B2: 0.62 - 0.68	
		B3: 0.77 - 0.86	
		B4: 1.55 - 1.70	
LISS-II	4	Visible, NIR	36.25m
		B1: 0.45-0.52	
		B2: 0.52-0.59	
		B3: 0.62-0.68	
		B4: 0.77-0.86	
IRS-1C	1	0.5-0.75 (pan)	5.8m
JERS-1	1	Microwave	18-12.5 m

Airborne sensors			
Aerial photographs		B/W; colour infrared	variable, depending on flight height
Narrow-band videography	3	Visible, NIR	3.4 m
		0.54-0.55	
		0.64-0.65	
		0.84-0.85	
DMSV (Digital Multispectral Video Systems)	4	Visible, NIR	variable: 0.25m-2m
		0.44-0.46	
		0.54-0.56	
		0.64-0.66	
		0.74-0.76	
AIRSAR-TOPSAR	3	Microwave (full polarimetric)	10m
		P-, L- and C-bands	
Hyperspectral Hymap	128	Visible, NIR, mid-infrared	2- 10 m
		0.45 - 2.5	
Hyperspectral DAIS-7915	79	0.4 - 12	3 - 20 m
		0.4-1 (32 bands)	
		1.5-1.8 (8 bands)	
		2 - 2.5 (32 bands)	
		3 - 5 (1 band)	
		8.5 - 12.3 (6 bands)	
Airborne geophysics		gravity	
		magnetic	
		electromagnetic	
		gramma-ray	

Mission	Launch Year	Instrument	Spatial Resolution (meters, at nadir)					Swath (km)	Repeat Cycle (day)
			PAN*	VNIR*	SWIR*	TIR*	SAR*/ band		
Landsat 5	1984	TM		30	30	120		185	16
SPOT-2	1990	HRV	10	20				60	1 to 26
ERS-1	1991	AMI-SAR					30/C	100	16-35
		ATSR-1		1000	1000	50000		500	16-35
IRS-1B	1991	LISS I		72				148	22
		LISS 2		36				74x2	22
IRS-P2	1994	LISS 2		36				132	24
Resurs-O1 N3	1994	MSU-SK		170		600		600	2 to 4
ERS-2	1995	AMI-SAR					30/C	100	16-35
		ATSR-2		1000	1000	50000		500	16-35
IRS-1C	1995	PAN	6					70	5 to 24
		LISS 3		23	70			142-148	24
	1995	WiFS		188	188			774	5 to 24
Radarsat	1995	SAR					10-100/C	45-500	4 to 6
IRS-P3	1996	MOS		500				200	5
		WiFS		188	188			770	5
IRS-1D	1997	PAN	6					70	5 to 24
		LISS 3		23	70			142-148	24
		WiFS		188	188			774	5 to 24
SPOT-4	1998	2xHRV-IR	10	10, 20	10, 20			60	3
		Vegetation		1000	1000			2200	1
Landsat 7	1999	ETM+	15	30	30	30		185	16
Ikonos	1999	Ikonos	1	4				11	3
CBERS	1999	CCD	20	20	20			120	3 to 26
		IR-MSS	80		80	80		120	26
		WFI		260	260			900	3 to 5
Terra (EOS AM-1)	1999	ASTER		15	20	90		60	16
		MISR		240, 480, 960, 1900				370-408	2 to 9
		MODIS		250, 500, 1000	500, 1000	1000		2300	2
Quickbird 2	2001	Quickbird	0.6	4				22	1 to 5
ADEOS-2	2002	GLI		250	250	1000		1600	4
Aqua (EOS PM-1)	2002	MODIS		250, 500, 1000	500, 1000	1000		2300	2
ENVISAT-1	2002	AATSR		1000	1000	1000		512	3
		ASAR					30/C	100	3
SPOT-5a	2002	HRG	5	10	20			60	3
		Vegetation		1000	1000			2200	1

Forthcoming High Resolution

Optical Satellite	Sensor	Spatial Resolution (meters) and (# Bands)					Swath (Km)	Repeat Cycle	Year Launch
		PAN	VNIR	SWIR	MWIR	TIR			
IRS-P5 (CartoSat-1)	PAN-F	2.5					30	5	2005
ALOS	PRISM,	2.5					35(70)	46(2)	2005
	AVNIR-2		10(4)				70		
CBERS 3 & 4	MUX		20 (4)				120	26	2008
	PAN	5					60	1 - 26	2011
	ISR		40	40 (2)		80	120	26	
	WFI		73 (4)				866	5	
TopSat[2]	RALCam1	2.5	5 (3)				25	4	2005
Plèiades[3]–1 & 2	HiRI	0.7	2.8 (4)				20	26 to 4	2008-2009
RapidEye A-E[4]	REIS	6.5	6.5 (5)				78	1	2007
EROS B - C	PIC	0.7	2.8				11		2005-2008
RazakSat[5]	MAC	2.5	5 (4)				20	13-15[7]	2005
China DMC+4 (Tsinghua-1)	MS DMC	4	32 (3)					600	2005
Resurs DK-1[6]	ESI	1	3 (3)				28.3	N/A	2005

[1]DMC (Disaster Monitoring Constellation of 4 satellites) of sun-synchronic circular orbit, daily revisit cycle.

[2] Circular, sun-synchronic orbit

[3] two-spacecraft constellation of CNES (Space Agency of France), with provision of stereo images.

[4] five-satellite constellation

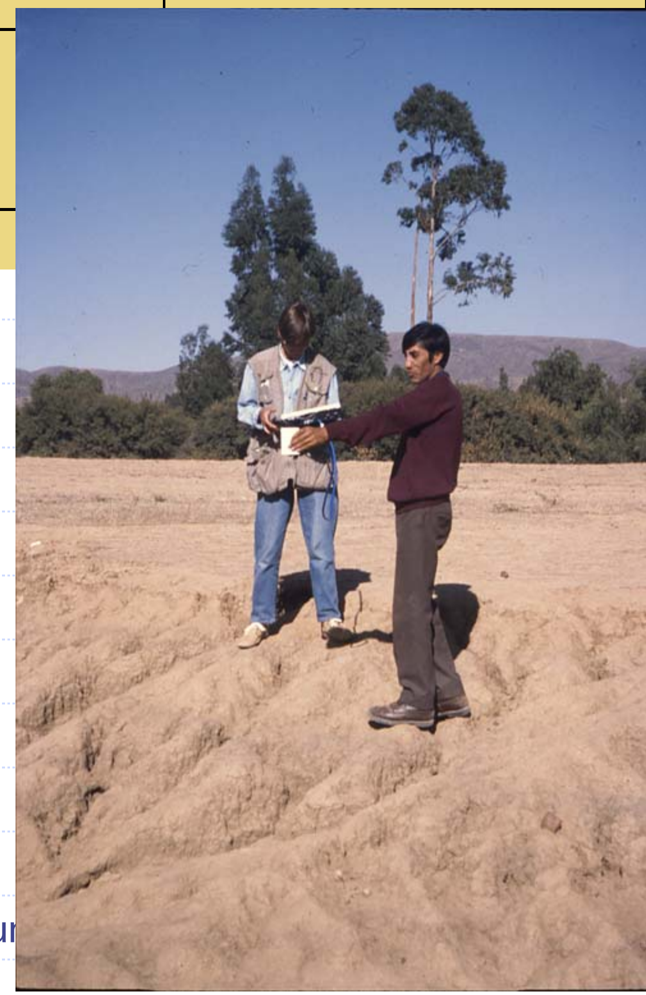
[5] near equatorial low Earth orbit (NEO)

[6] Near-circular non-sun synchronous orbit

[7] passes/day

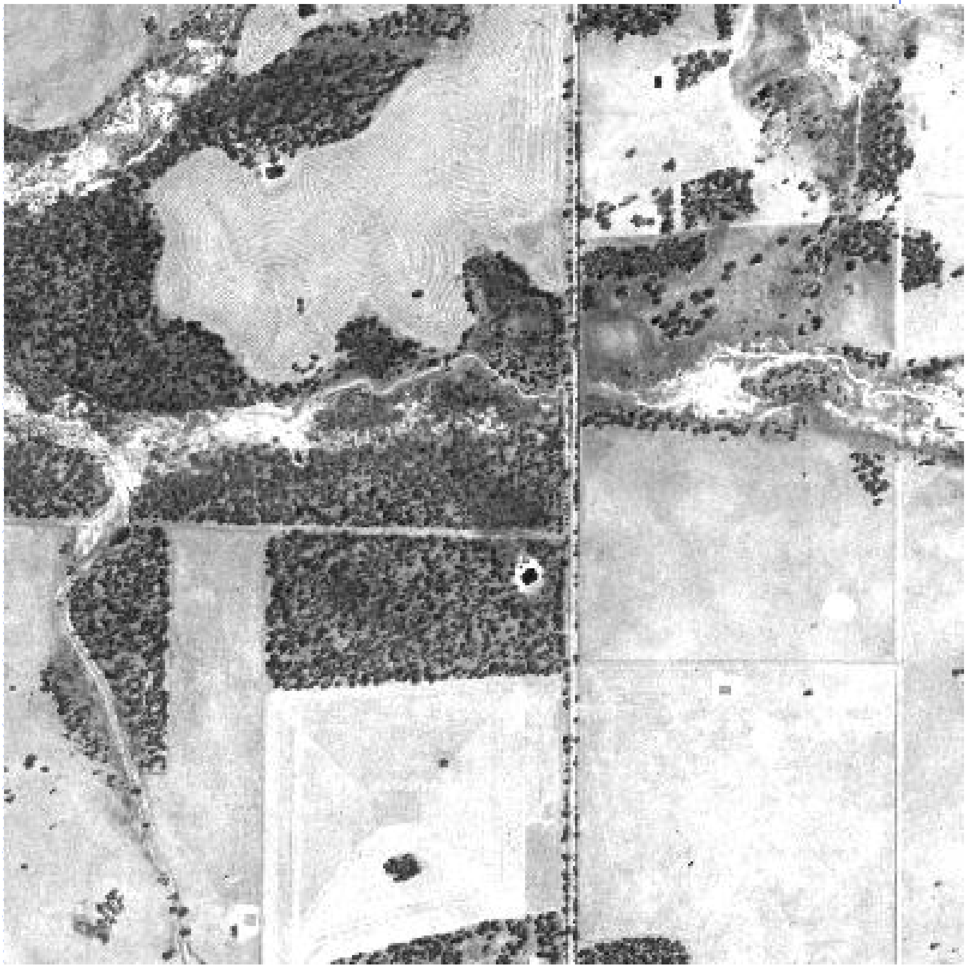
Sources of Remote Sensing data

Ground-based sensors			
Electromagnetic induction meter (EM38, EM31, EM34-3, EM39)		Electromagnetic conductivity meters, measures the bulk electrical conductivity of soils	
Crop Scan multi-band radiometer (Skye Instruments Ltd, UK)	8	Visible, NIR	

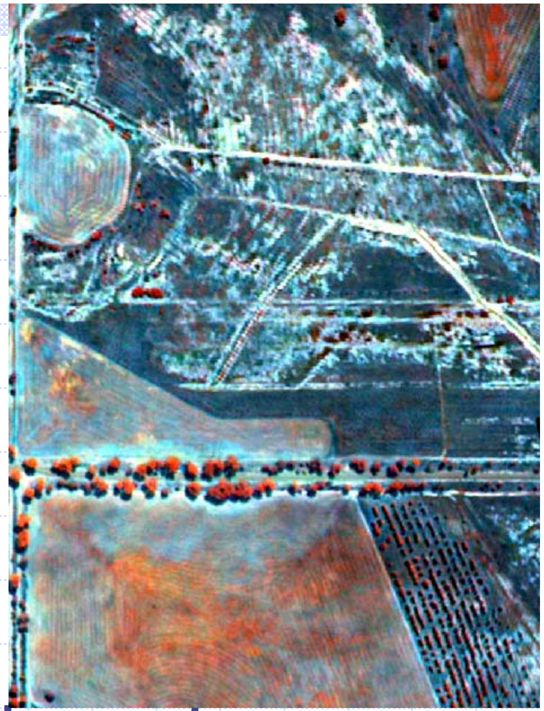


Aerial Photographs

- Delineation of salt affected features depends from a combination of geomorphic features and grey tones or colors;
- Field verification is essential to determine variations in salt contents
- Aerial photographs are still useful in historical studies;



Airborne Videography & Digital Multispectral cameras

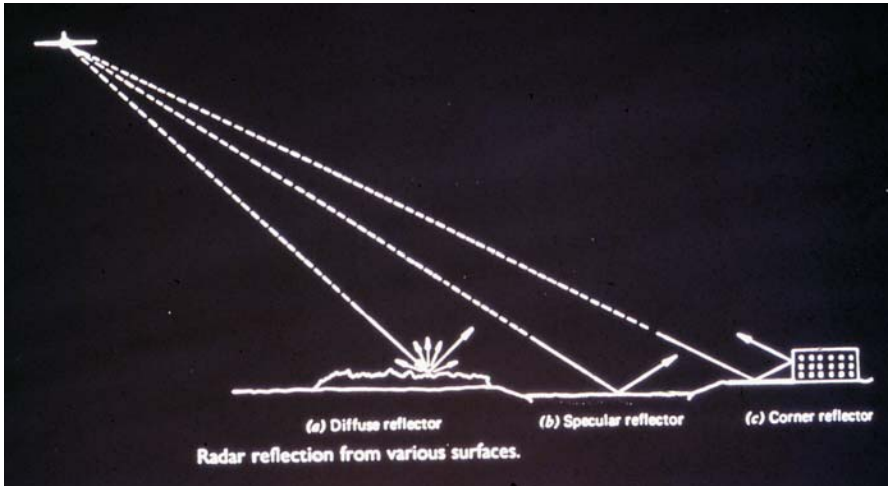


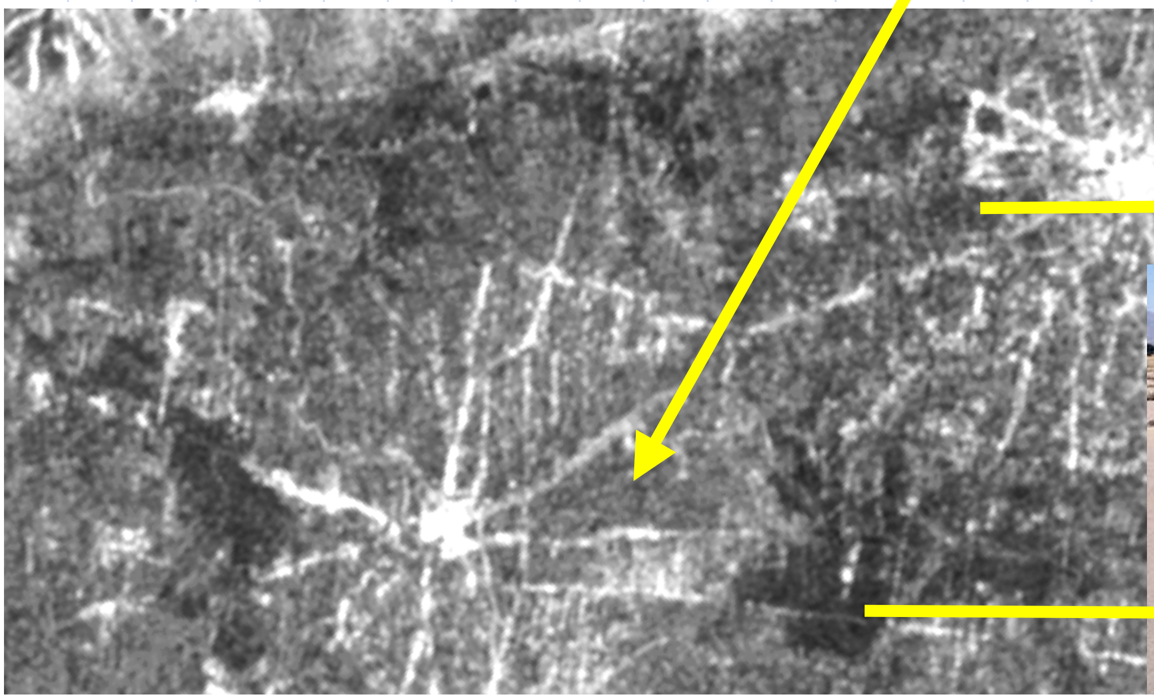
- It presents the advantages of:
  - High spatial resolution
  - Near real time data acquisition
  - Digital multispectral images
- Previous studies have demonstrated good correlations between spectral variations and the response of cotton to soil salinity, in the range of the blue to NIR
- For salt affected areas, colour infrared composites and red narrow band images have proven better than green and NIR bands.

Microwave Sensing

- Relatively few studies have investigated the possibility of using microwave for mapping areas degraded by salinization
- C-, P- and L- bands are considered adequate for detecting salinity
- Previous studies have focused on the following features:
  - Saline water detection by analysing the dependence of microwave responses on salinity and temperature
  - Soil salinity identification by relating salinity levels to the imaginary parts of the complex dielectric constant
  - Soil salinity mapping, including discrimination of salinity levels by mapping surface roughness and vegetation types related to salinity
  - The info above is then used as ancillary data to estimate the extent of salinity at regional level.

Microwave: backscattering





Forthcoming Satellite SARs

SATELLITE3	ERS-1	ERS2	RADARSAT-1	JERS-1	ENVISAT	RADARSAT-2	ALOS	TERRASAR-X	COSMO/SKYMED 1
Sensor	AMI	AMI	SAR	SAR	ASAR	SAR	PALSAR	TSX-1	SAR-2000
Space Agency	ESA	ESA	RadarSat Int	NASDA	ESA	RadarSat Int	NASDA	DLR/Infoterra GmbH	ASI
Operational since	1991	1995	1995	1992	2002	2005	2004	2006	2005
Out of Service Since	2000			1998					
Band	C	C	C	L	C	C	L	X	X
Wavelength (cm)	5.7	5.7	5.7	23.5	5.7	5.7	23.5	3	3
Polarization	VV	VV	HH	HH	HH/VV	QUAD-Pol*	All	All	HH/VV
Incidence angle (°)	23	23	20-50	35	15-45	10-60	8-60	15-60	Variable
Resolution range (m)	26	26	10-100	18	30-150	3-100	7-100	1-16	1-100
Resolution azimuth (m)	28	28	9-100	18	30-150	3-100	7-100	1-16	1-100
Scene width (km)	100	100	45-500	75	56-400	50-500	40-350	5-100 (up to 350)	10-200 (up to 1,300)
Repeat cycle (days)	35	35	24	44	35	24	2-46	2-11	5-16
Orbital elevation (km)	785	785	798	568	800	798	660	514	619

ACI

logy

Hyperspectral sensing

- Experiments carried out using Hymap (128 bands, 450-2500 nm). Mapped: salt scalds halophytic vegetation and soils with varying salinity degrees and types.
- Visible and NIR: enable detection of features related to hydrated evaporite minerals.

Ground sensing: electromagnetic induction

- The EM series (EM 31, EM34-3, EM38, EM39) estimate soil salinity by measuring the bulk electrical conductivity of the soil, which depends on the salinity of the soil solution, porosity and the type and amount of clay in the soil.
- The instrument measures the apparent soil salinity (ECa) in a volume of soil below the transmitter and receiver coils.
- EM surveys are a way for rapid diagnosis and mapping of soil salinity. Survey speed depends on terrain conditions, topography and land use.

EM: how it works?

Multi-scale modelling

Integrating remote sensing and GIS for defining areas of priority of intervention

Modelling at multi-scale level

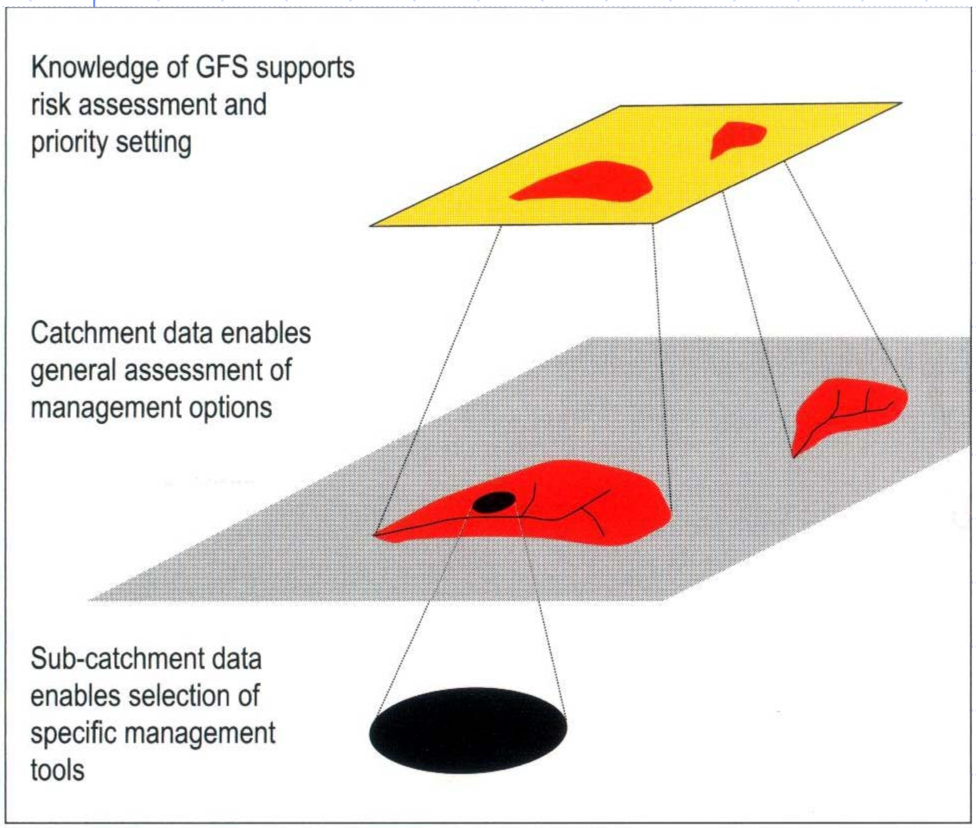
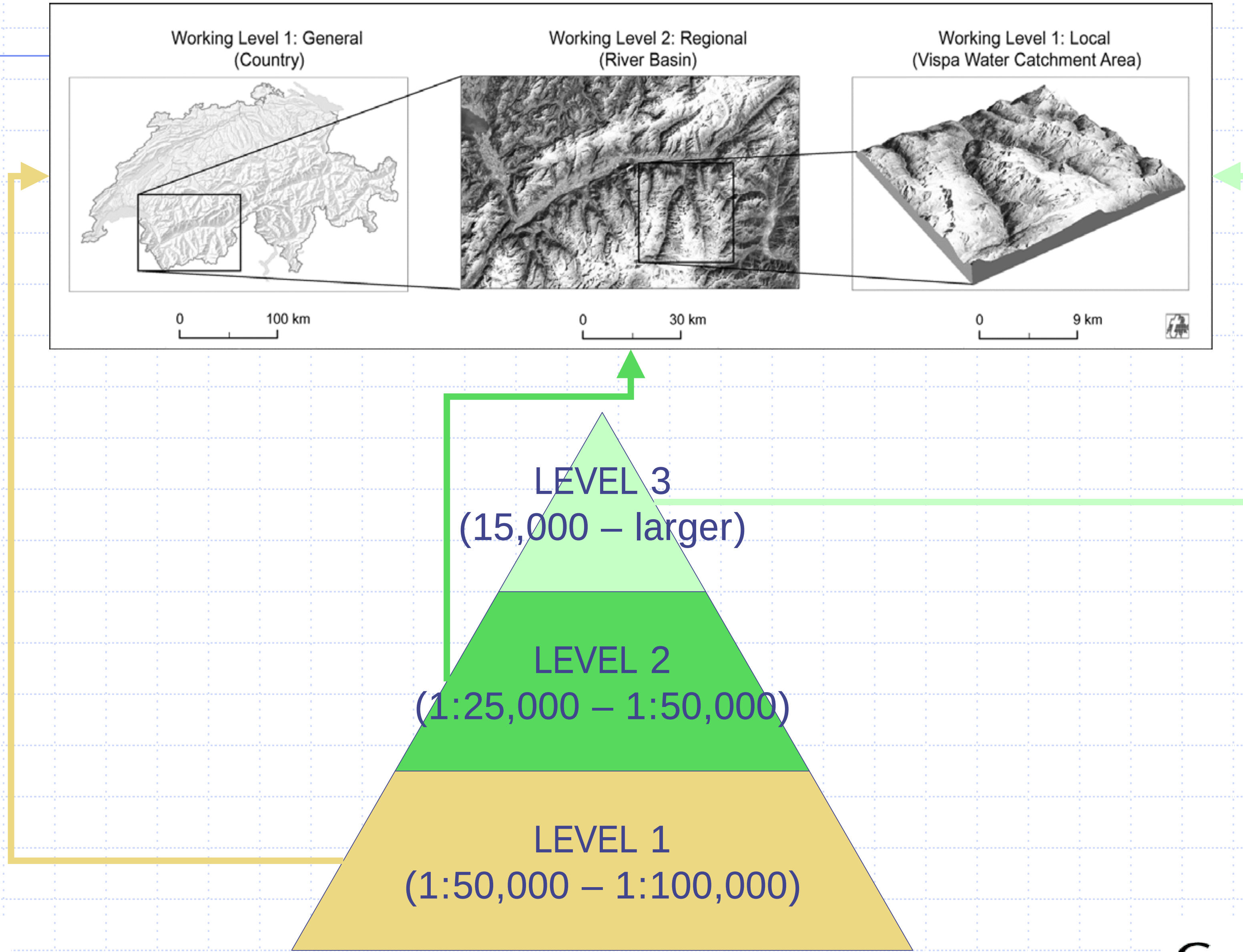


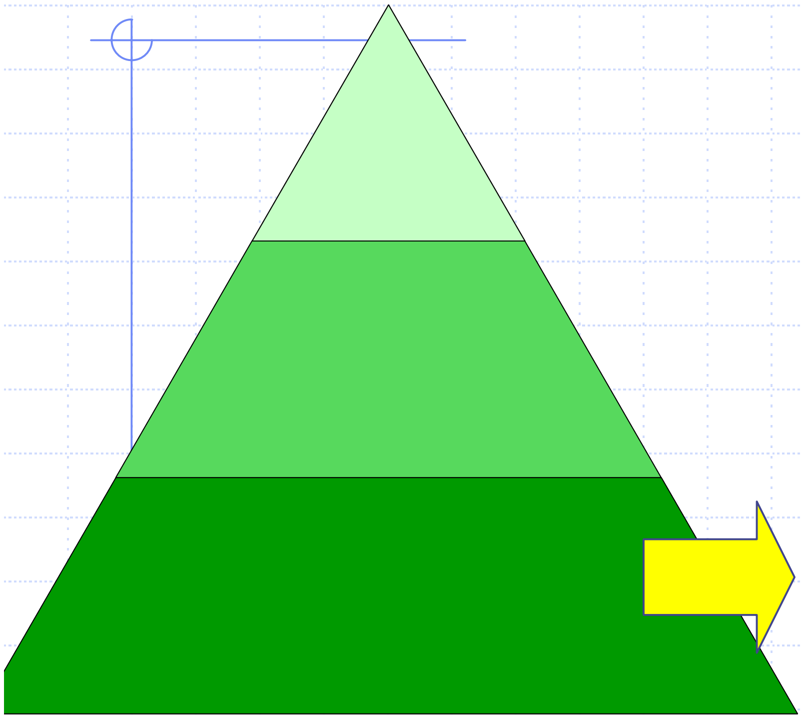
Figure 12: More detailed data is needed to meet the demands of local decision makers

- Multi-level approaches are cost-effective and enable decision maker focussing on areas of high priority of intervention

Conceptual Model proposed



The model



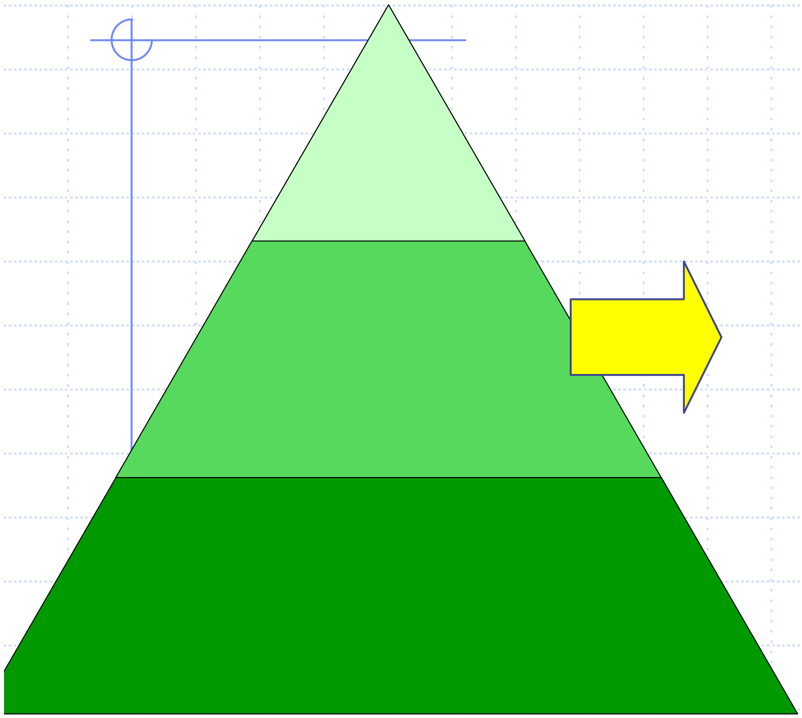
Level 1: Basic detection of *diagnostic features* over large areas.

Sensors: Terra ASTER, Landsat TM, IRS, SPOT, Radarsat, Envisat, ERS.

Multi-temporal &/or multi-sensor images can be used for mapping changes of environment-related factors over time.

More qualitative assessment: Detect *potentially dangerous areas of debris flows and associated hazards*.

The model

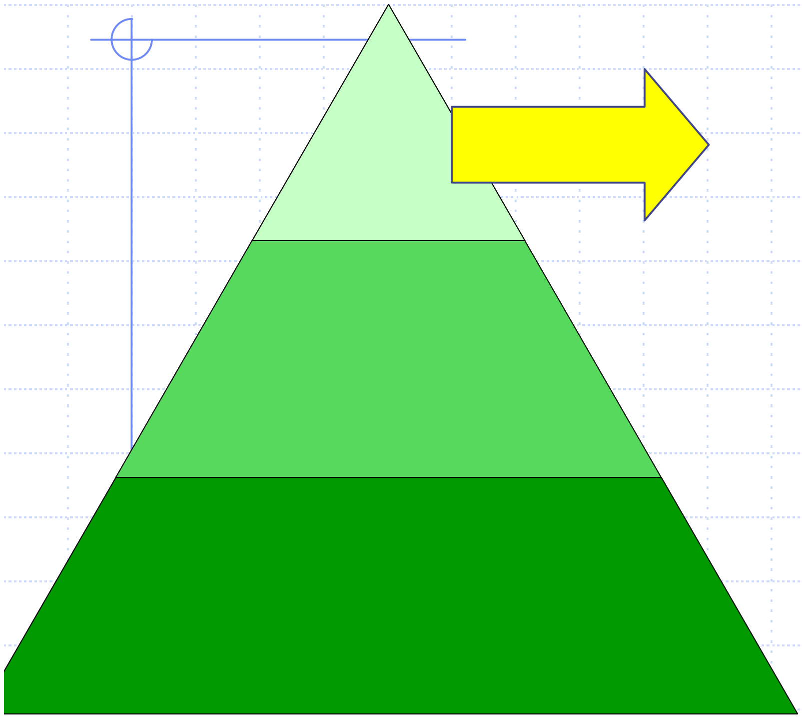


Level 2: assess hazard potential or diagnostic features at more detail, over areas identified as potentially dangerous in Level 1. Integrates GIS for analysis.

Sensors: VHR satellites, & SPOT-5, IRS CartoSat-1) and satellites with InSAR capabilities.

More quantitative assessment: Produce motion maps, etc.

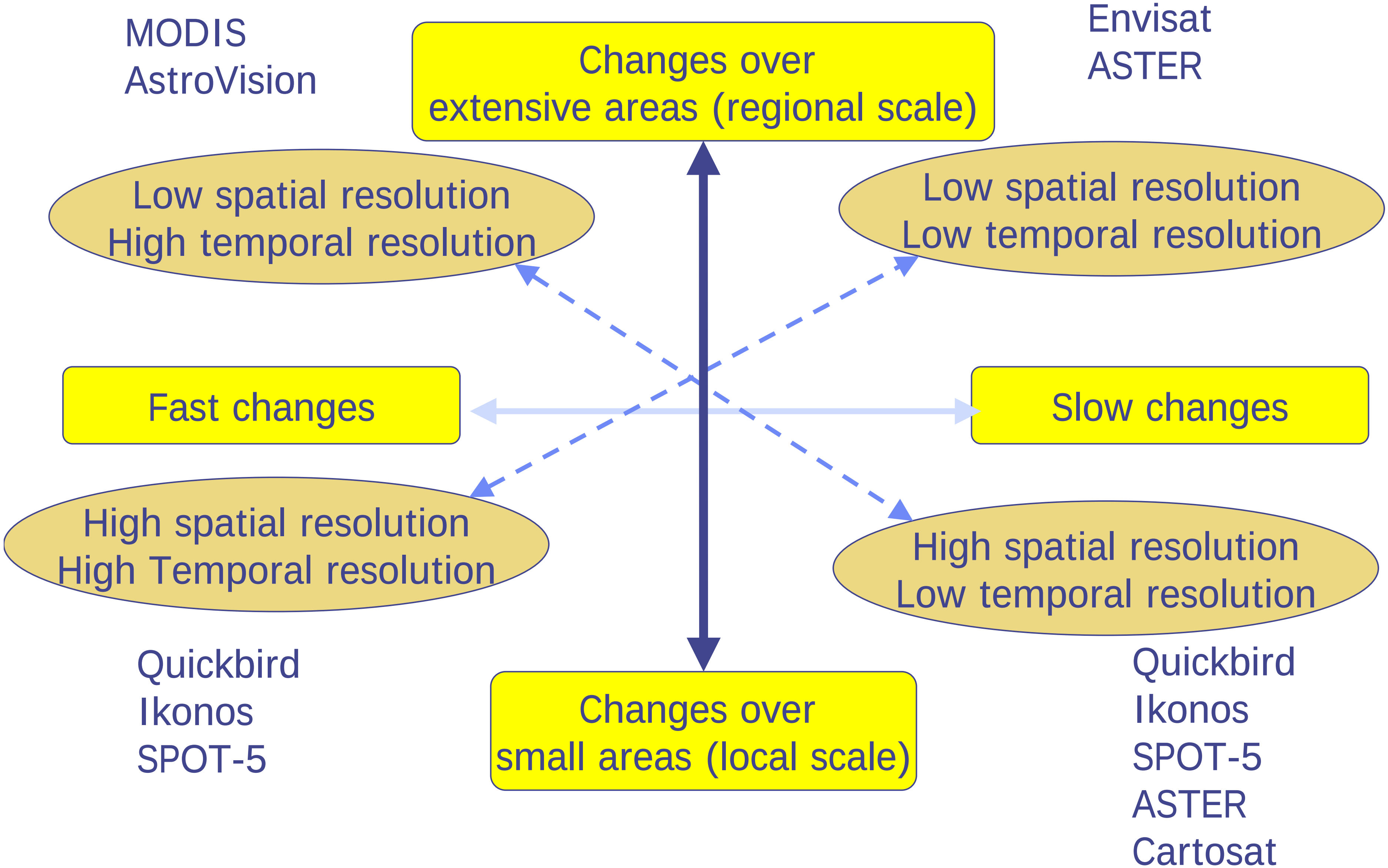
The model



Level 3: detailed investigations of areas identified in L1 & L2.
Sensors: mostly limited to sensors with DInSAR or InSAR capabilities, very high res. Images, LiDAR szstems, Ground based DInSAR.
Quantitative assessment: deposits thickness, motion, debris distribution along and across the debris flow deposits.

General conclusions

Perspectives: tools



Assessing Temporal and Spatial Changes

- Monitoring land degradation changes from past to present faces the difficulty that, in general, there is no ground-truth information available for past situations.
- Consequently, validation of historical remote sensing data involves uncertainties
- Fusion of multi-source remote sensing data and their integration with field and laboratory data can overcome part of this problem.

Issues in remote monitoring of land degradation

- As salt related surface features change with seasons, time series of remote sensing data must be captured in similar periods of the year, preferably at the end of the dry season if passive remote sensors are used.
- Geo-referencing and co-registration of multi-temporal data are essential
- Radiometric calibration between images so that digital numbers from different dates can be compared, particularly if direct application of a unique ‘training set’ is applied to the images.

Final comments

- Regardless the land degradation type mapped and/or monitored, the identification of correct indicators or diagnostic features is essential before any Remote Sensing or GIS modelling are applied.
- Salinity: monitoring of soil salinity and early warning of salinisation cannot be achieved from remote sensing data alone. It requires synergy between remote sensing, field observations, laboratory analysis, and GIS facilities for processing, displaying, modelling.