Imaging the future

Inaugural address

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Meneer de Rector, Members of the Board of Governors, Members of the scientific council, distinguished speakers of today's symposium, Professor Su, professors, staff and students of ITC, distinguished guests, dear friends.

Ladies and gentlemen,

Global earth observation strategies

Earth observation systems consist of tools that provide measurements of air, water, and land from a combination of ground-based, airborne and spaceborne sensors. Satellite observations are of particular importance as these ensure long time series of data that enables monitoring, modelling and understanding earth processes. While these measurements have been observed historically in isolation, the current Global Earth Observing System of Systems (GEOSS) is designed to consider and analyse these elements together and to study their interactions.

'Understanding the Earth system –its weather, climate, atmosphere, water, land, geodynamics, natural resources, ecosystems, and natural and human-induced hazards – is crucial to enhancing human health, safety and welfare, alleviating human suffering including poverty, protecting the global environment, reducing disaster losses, and achieving sustainable development.' This is the preamble to the 10 year implementation plan of the Global Earth Observation System of Systems (GEOSS) endorsed by over 60 countries and the European Commission on 16 February 2005 [1]. This plan is a breakthrough for earth observation as it represents a world-wide coordinated effort to study the earth from space and integrate geoinformation with policy making at the highest possible political level. It is of utmost importance for the future direction of earth sciences as it puts fields such as geodynamics, environment and geohazards high on the political agenda. During the world summit in Johannesburg in 2002 it became evident that the present system of earth observation including the scientific infrastructure is poorly prepared for this major role foreseen.

The European contribution to GEOSS is the Global Monitoring of Environment and Security (GMES) initiative of the EU and ESA [2]. GMES focuses on environmental control and security issues including land degradation, land cover changes, and geohazards, again earth sciences are in the heart of the definition of the GMES concept. GMES is an ambitious concept, which reconciles the political needs associated with environment and safety issues with the scientific and technological capacities offered by

information society technologies and Earth observation technologies. The advantage of looking at interacting components of a system is that this allows a better integration of scientific ideas. The use of components to describe a system intrinsically requires knowledge on the individual components and their interaction which in turn allows to engage on complexity rather than to rely on simplification.
Earth scientists at ITC strive at providing reliable earth science information that is used to understand earth dynamic processes in all their three dimensions and variation over time, to manage resources (energy, economic and industrial minerals) and cope with environmental effects of exploitation of resources, and to minimize loss of life and property from natural and man-induced disasters [3]. The work-field covers the earth surface and the (shallow) sub-surface and covers both geological as well as geotechnical aspects of the earth. The GEOSS 10 year implementation plan is of utmost importance to earth scientists at ITC as our research themes, a focus on environmental issues and natural hazards and disaster management, are in line with the international agenda in earth observation.

Earth scientists and earth observation

What can earth sciences through earth observation do for society at large and how are the earth sciences positioning themselves within the framework of these earlier described international developments? By looking at the role that the US Geological Survey, an example of a leading survey organisation, and the International Union of Geological Sciences the IUGS, a leading society in the field of earth sciences, see for them this question may be answered.

The IUGS in its vision and strategy implementation document gives "new directions for science", suggesting high-priority geoscience activities of demonstrable relevance to society, to be including, but not limited to: reducing the vulnerability of communities to natural hazards, mitigating the effects of waste and pollution, understanding global environmental change, understanding biodiversity, managing resources and sustaining the environment, understanding the relationship between geology and health [4]. The US Geological Survey wishes to serve the Nation by providing reliable scientific information to describe and understand the Earth, minimize loss of life and property from natural disasters, manage water, biological, energy, and mineral resources, and enhance and protect our quality of life [5]. Clearly showing a focus on exploration and exploitation issues of georesources on the one hand and natural disaster studies on the other hand. The USGS is not merely the sole keeper of geological data sets anymore, but it actively participates in the national and international debate by providing information and answers to problems that are of societal relevance. This is not merely an example but symbolizes a world-wide trend in which Geological Survey organizations are changing their focus and activities from the traditional map making toward a public service organization for information provision on earth science processes. This change of focus requires that geological survey organizations anticipate and respond in a timely manner to a broad array of national earth science issues. Hence these institutes serve as a forum for an integrated mixture of monitoring and research assessment activities using novel techniques in earth observation and geo-information.

I have sketched the developments in policy making and practice in earth observation and earth sciences. Earth observation is receiving an increasingly more important role in earth and natural sciences because it can provide, through long time series and systematic measurement campaigns, insights in the dynamics of our earth system. An integrated approach coupling various earth observation measurements be they spaceborne, airborne or in-situ is advocated and a further integration with policy making. Environmental issues and natural and man-induced hazards become increasingly important in the international agenda. ITC has for long had the term earth sciences in the institutes name. The last years we have lived without a thematic disciplinary context expressed in our name. I would advocate to include the word disaster management in the institutes name.

ITC's clients in earth sciences and earth observation

Now let us look at our traditional earth science client group within the world of ITC and the changing environment in which they are acting.

Our clients in the LDC Countries are geological and soil survey organizations, universities and research/training institutes, application departments of space agencies, ministries concerned with resources and disaster mitigation, and to a lesser extent the private sector (notably the mining and petroleum industry). Many non-Western countries are dependent on primary resources more than on their secondary (industry), tertiary (services) or quaternary (knowledge) sectors, but these economic plates are shifting extremely fast. Survey organizations are changing their focus and activities from the traditional map-making toward a public service organization for information provision on earth science processes. This implies that emphasis should be on interdisciplinary research, acknowledging the importance of crossing traditional discipline boundaries in investigating complex Earth systems. Acknowledging this change toward understanding dynamic processes implies a change from resource inventory to a dynamic, process-based approach with the ultimate goal of not only gathering information on natural geologic resources, but aiming at modeling the dynamics of the environment and the processes driving the Earth dynamic system. Monitoring on the basis of remote sensing is part of the ITC tradition. However we need to make the step forward from monitoring, visualizing what we see in time, to process-based modelling, describing in a quantitative manor how the earth reacts to the forces that act upon it. This requires the use of novel data acquisition techniques in the area of earth observation and geophysics/geochemistry combined with the development of global accessible and flexible geologic databases for spatial geoinformation storage and retrieval, thus enhancing the impact of individual data products and making the aggregate product attractive to a larger and more diverse group of customers.

Earth observation has for many years been the exclusive territory of selected western countries or consortia of western countries. We have seen the shift from mono-sensor to multi-sensor missions, we are at present in a phase where earth observation is integrated with policy making and where space-based observations, airborne and in-situ measurements are being coupled to global models describing the earth as a system. But the earth observation sector is no longer the exclusive territory of selected western countries. In particular in the Asian and Pacific regions, earth observation is a booming business. India has had for many years an excellent space programme. Other examples of space initiatives in Asia include: Thailand who is developing the Thailand Earth Observation System (THEOS) due to be launched by mid-2007, the National space organisation of Taiwan which operates the FORMOSAT-2, Japan with its Whale Ecology Observation Satellite (WEOS) in addition to the ADEOS programme, Malaysia developing the MACSAT, no renamed RazakSAT mission and the Indonesian National Institute of Aeronautics and Space of Indonesia, LAPAN developing the LAPAN TUPSAT. This list merely shows some examples and is not intended to be all inclusive.

The plates indeed are shifting fast, but not in all parts of the world where ITC is active. The NigeriaSat-1 is Nigeria's contribution to a network called the Disaster Monitoring Constellation. With that, Nigeria becomes the third African country to have a presence in space, after South Africa and Algeria. As the space sector is booming in Southeast Asia, Africa is lacking behind in the space-race.

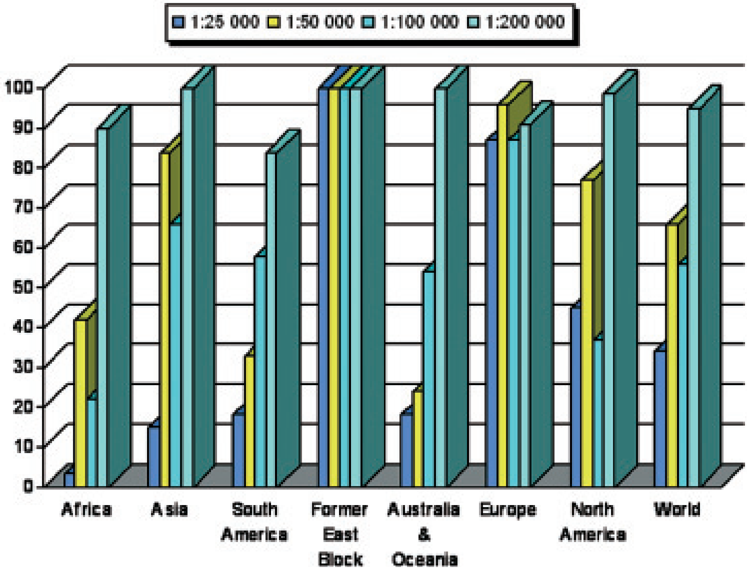


Figure 1: existing topographic map coverage (after: [9]). Courtesy T. Woldai.

Most, predominantly sub-Saharan African economies, still lean heavily on earth resources. However in finding and exploring earth resources, base topographic and geologic data sets are essential. In Europe over 80% of the area has topographic maps at 1:50.000 scale and more than 90% has topographic maps at 1:100.000 and 1:200.000 scale [6]. On the contrary, in Africa a mere 40% of the area is covered at 1:50.000 scale and only 4 to 5% of the continent is covered at 1:25.000 scale (*Figure 1*). In terms of geologic maps, just over 10% of the African continent is mapped at 1:50.000 scale, a scale which is about the upper limit in terms of resolution for geological prospecting. Hence geologic foundation data is a luxury rather than a common standard in many African countries.

Most of these maps are produced through an analogue processing chain and few survey organisations in Africa have made the transition to digital data production, dissemination and use. This transition is essential if a organisation wishes to be able to produce on demand products to serve a wide variety of thematic applications. Our research and training in digital field data capture techniques, digital geological data infrastructures, data integration and GIS predictive modelling in combination with our attempts in recent projects in Mozambique, Tanzania, tailor made programmes for the Geological Survey of Bhutan to capitalize on this knowledge are essential in assisting survey organisations in Africa and elsewhere to make the transition from analogue to digital and from map maker to service provider. Fieldwork is an integral component of this work as it allows us to validate and calibrate our models, to understand the outcomes of the models, understand the complexity of the real-world and to bring together scientists with various backgrounds in multi-disciplinary teams. However the main conclusion of the discussion is that if we wish to be truly loyal to our ODA mission we should focus on Africa.

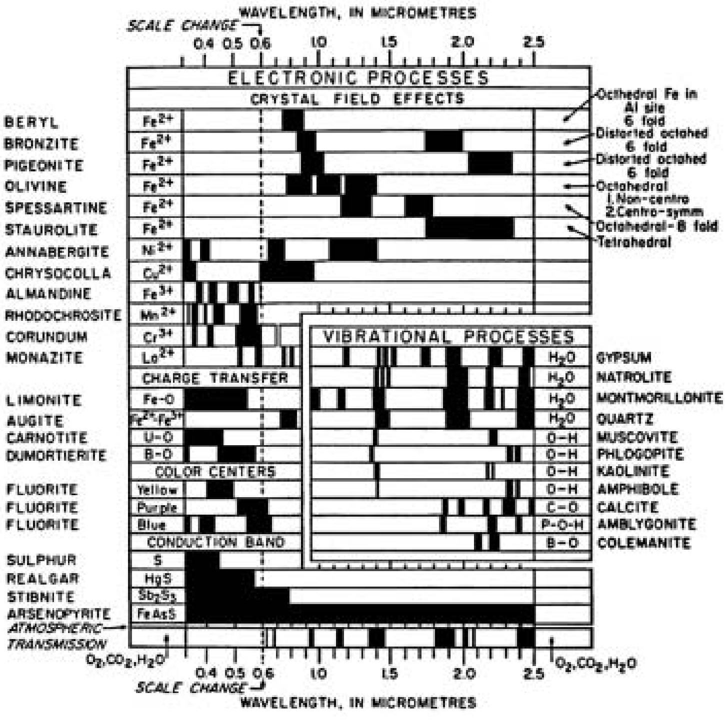


Figure 2: Mineral absorption features in the VNIR-SWIR (after [7]).

Also in education both in terms of content as well as mode of delivery we have seen the plates shifting fast. The ITC I came into in 1989 was one of small divisions with their own courses and little integration between programmes. The present ITC searches for partnerships in education in which ITC operates a gateway function within partnership networks, focuses more and more on capacity building within the framework of earlier described international developments. A further diversification and demand-orientation, a focus on one high quality degree programme in ITC with spin-offs world-wide primarily in short and targeted programs is envisaged. This asks a high degree of flexibility and sometimes improvisation from our staff, bur creates a highly multi-disciplinary and dynamic working environment. The world of ITC is the world says it all.

Geologic remote sensing

In 1859 Gaspard Tournachon took an oblique photograph near Paris from a balloon. Without knowing he became the founding father of earth observation science. Aerial photography was used during the first world-war for observation behind enemy lines and in the second-world war RADAR technology was developed for intercepting enemy aircraft. The meteorological sector already early recognized the great importance of satellite observations, whilst the first step toward earth observation of the land surface was done using the earth resources technology satellite launched in 1972.

Imaging spectrometry and interferometric SAR are in my perception the two major steps forward in earth observation for earth sciences made in the late eighties. While Interferometric SAR allows to measure sub-millimetre surface deformations of the earth surface crust that can aid in understanding stress and strain changes and in turn can help in understanding crustal dynamics, imaging spectrometry allows detailed surface composition to be revealed from satellite observations. Also great promise lies in the area of gravity missions. New satellites such as GRACE but especially GOCE now give unprecedented resolution and where in the past gravity data could be mainly used for mass flux analysis now the increased resolution also allows analysis of satellite gravity data in a tectonic framework. As satellite gravity missions give a complete coverage of the Earth including the previously ‘white spots’ in air- or ground-based gravity surveys, the combined analysis and interpretation with seismological data will give renewed insight in tectonic processes for many previously un- or under-explored areas such as large part of the African continent.

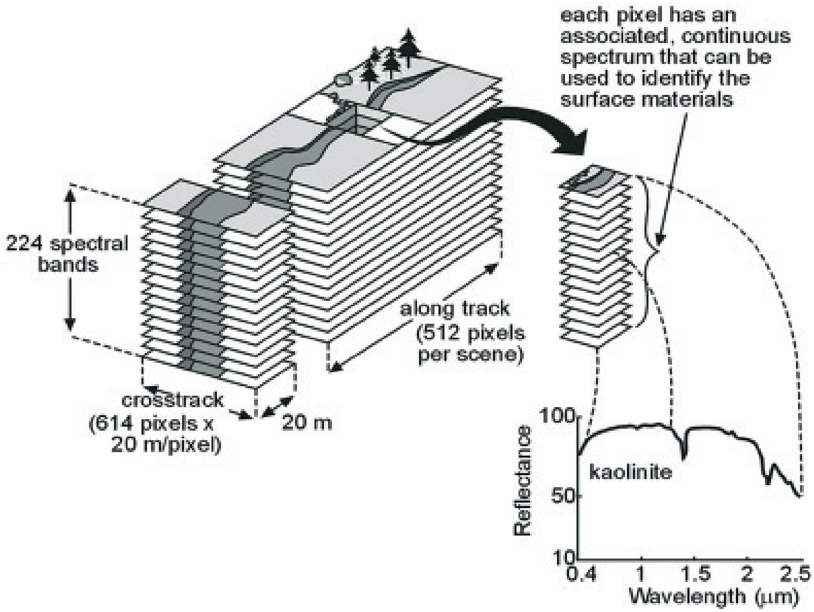


Figure 3: Principle of imaging spectrometry (after [8]).

In the 1980's, Graham Hunt and John Salisbury [7] and their team measured reflectance spectra of minerals and subsequently rocks and build the first catalogues of spectra (*Figure 2*). In the early nineteenth century James Maxwell developed his theory showing that light is a form of electromagnetic radiation that travels at a speed of 300.000 kilometer per second. In 1905, now precisely 100 years ago, Albert Einstein proved that light behaves as a particle wave with the smallest energy packages being the photons. These photons when bombarding materials such as minerals cause electronic transitions and static vibration of molecular bonds. Quantum mechanics describes these processes and with the advent of high resolution spectrometers Hunt and Salisbury showed the significance of this theory. Their work not only was the first systematic approach to reflectance spectroscopy, but these authors also showed that diagnostic absorption features of minerals are in the order of 10-20 nanometers in width. This implied that for instruments to be able to produce detailed compositional information on the earth surface, the image resolution needed to be in the order of 10 to 20 nanometers. The position, shape, depth, width, and asymmetry of absorption features are controlled by the particular crystal structure in which the absorbing species is contained and by the chemical structure of the mineral. Thus, variables characterizing absorption features can be directly related to mineralogy and chemistry. The work of Hunt and Salisbury led to the re-definition of the Landsat TM payload now including the for geologists very valuable band 7 in the shortwave infrared. The work of Hunt and Salisbury also led to the establishment of a new field of remote sensing in the late 1980: imaging spectrometry (*Figure 3*).

Imaging spectrometers acquire images in a large number of (>40), narrow (<0.01 to 0.02 mm. in width), contiguous (i.e., adjacent and not overlapping) spectral bands to enable the extraction of reflectance spectra at a pixel scale that can be directly compared with similar spectra measured either in the field or in a laboratory. The objective of imaging spectrometry is to measure quantitatively the components of the Earth System, radiance, upwelling radiance, emissivity, temperature and reflectance, from calibrated spectra acquired as images for scientific research and applications. Nowadays reflectance spectra are used in a wide variety of fields. In addition to the natural and life sciences, near infrared spectroscopy is used in the pharmaceutical industry, food industry and in forensics. Using the partial least squares regression concepts developed by Wold in 1981 we can link measured reflectance spectra as variables to explain, regulate, or predict the behaviour of other parameters of more direct interest such Ph, Eh, CeC etc.

ITC's geologic spectroscopy work

My contribution to earth observation is intimately linked to reflectance spectroscopy and started with the use of imaging spectrometry data for geological applications in the early 1990's. During that time we development a number of pixel-based approaches to link the observed image spectra to known field or library spectra. The ultimate goal was to produce validated surface compositional information. Indicator kriging-based classifiers were developed as well as algorithms based on the pixel spectral cross correlogram.

Next, we shifted toward coupling of field and image data using a wide variety of geostatistical techniques including co-kriging and simulation (*Figure 4*). The next step made some 5-6 years ago was to develop ways in which geological prior information could be included at the start of the processing chain. Using data inversion concepts borrowed from geophysics notably seismics this was made possible. With colleague De Jong we published a book on Imaging Spectrometry: basic principles and prospective applications in 2001 [8], which to my humble and biased opinion summarizes very well the state of the art in this field of sciences and our contributions to it at that time.

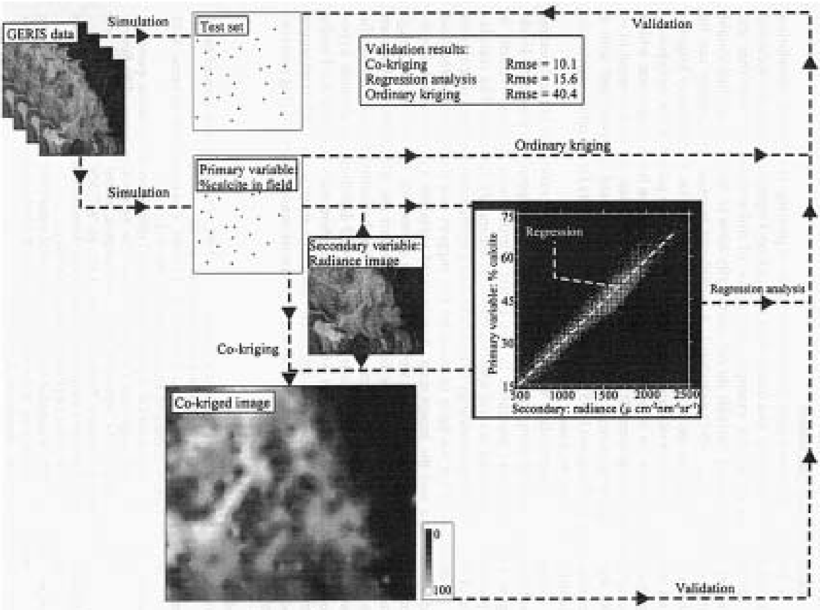
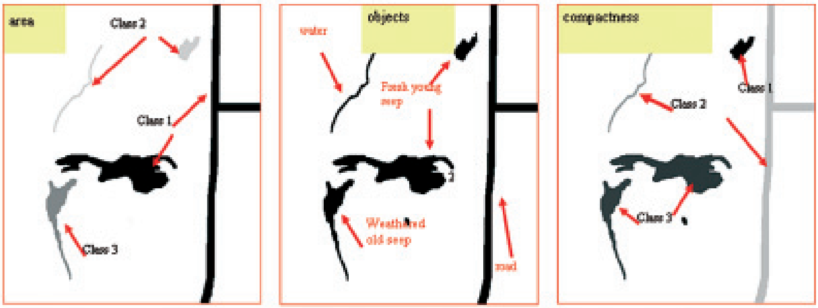


Figure 4: Coupling field and image data using co-kriging (after [9]).

But the strengths of remote sensing lies in its ability to capture spatial and temporal characteristics of the earth surface. The weakness of the remote sensing community lies in its incompatibility in using this notion. Most image processing techniques that are available to analyse hyperspectral data by-pass three important aspects of remote sensing and earth observation data sets:

- Neighbourhood information is not incorporated and hence the common knowledge formulated in geostatistics that nearby control points are more likely to contain information more similar than far apart control points is neglected,
- surface information is not coupled to shallow subsurface information although many problems are 3 dimensional in nature and require a 3 dimensional solution,
- and the change over time of the spectral signature of certain earth surface material containing information on the type (and use) of the material at hand that may allow a better understanding of processes is not used.

Why is it relevant to try to merry spectral information with spatial information on object shapes? To illustrate this I show you a small example of looking at a number of spectrally dark and featureless objects in a hyperspectral AVIRIS image. Spectral classification per pixels fails at separating these objects for the simple reason that they are spectrally similar and their spectral properties overlap so much that this results in too much confusion to properly map the objects. Object-based classification will be able to separate the different dark objects as their shapes are different (*Figure 5*). Aggregating information on object shape and combining that with the subtle spectral differences allows proper classification of the objects. Therefore during the past years we have focused on stepping away from pixel-based approaches and entering into the domain of the contextual image analysis.



		area			roundness			Compact	
	Cl.1	Cl.2	Cl.3	Cl.1	Cl.2	Cl.3	Cl.1	Cl.2	Cl.3
Water	X	X			X			X	
Road					X			X	
Old seep			X			X			X
Young seep1		X		X			X		
Young seep2	X			X					X

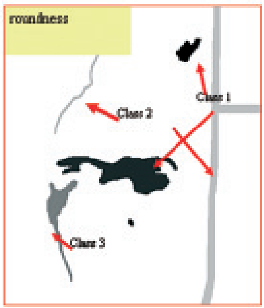


Figure 5: spectrally dark and similar objects that cannot be properly classified can be separated on the basis of the differences in object shape. This notation is the basis for spatial-contextual modelling (after [9]).

However our approach therein differs from that of the signal processing community. The signal processing community uses clustering techniques or segmentation approaches to classify objects that are spectrally similar in images. This can be considered a data-driven approach. Our approach is knowledge-driven in the sense that we try to include human reasoning and observation skills into the processing of image data. This sounds like a trivial task, but the human ratio is capable of seeing complex arrangement of objects in an image in a much more efficient and effective way than traditional image processing algorithms and packages can do.

We now have a number of techniques that allow combining spatial context of an image and spectral information for object-based image analysis and classification. These spectral-spatial contextual image analysis approaches make full use of the available information in the hyperspectral domain and the increasingly high spatial resolution and image context in the spatial domain. An example is the template matching algorithm that is central to the PhD research of Harald van der Werff. The template consists of a one or two dimensional array that is filled on both sides of a central pixel with spectra that characterize certain cover types of interest. The template is matched with an image by moving the kernel over the image and matching it to the spectral information in the image. At each node the template is also rotated and in doing so a number of matching parameters are calculated. The template matching approach has been applied to extract alteration facies and facies transitions from HyMAP data both in the Rodalquilar epithermal gold deposits (*Figure 6*) of south-eastern Spain as well as for the VMS deposits of the Pilbara in Australia.

Results obtained by Frank van Ruitenbeek show that successive phases of alteration characterising the fluid pathways in these vent systems can be modelled using the template approach. Another example of spatial-contextual image analysis uses the Hough transform developed in 1962. This transform is frequently used for detecting shapes in images. This technique fits a parameterized shape through a point dataset (for example pixels in an image) and combines the parameters needed to describe its shape, its position and its orientation with the number of pixels covered by this shape. We have progressed considerably over the last years in including neighbourhood information in the analysis of hyperspectral data sets. Our first ideas have been laid down in the book 'Remote Sensing Image Analysis: Including the Spatial Domain' published in 2004 [9] and we are determined to continue this line of research. In the near future we intend to extent the spatial-contextual image analysis methods to the temporal domain as well as to the third dimension (i.e., the shallow subsurface).

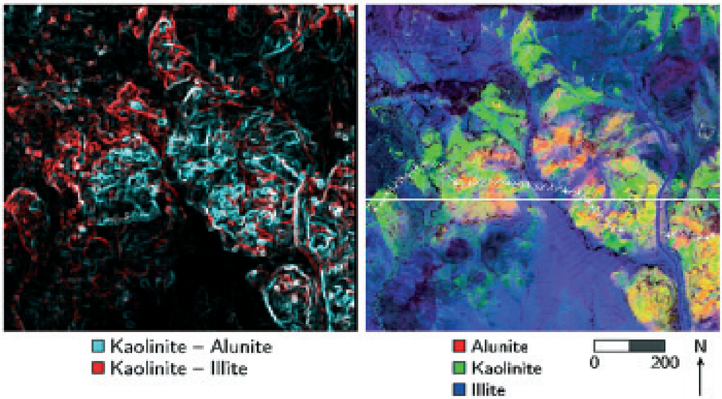


Figure 6: Application of template matching to a subset of a HyMAP image over the los Tollos area in the Rodalquilar mining region of SE Spain. The left image shows the rotation variance using two (a kaolinite-alunite and a kaolinite-illite) template enhancing spectral facies boundaries, the right image is a FCC of SAM rule images enhancing mineral occurrences. Images courtesy Harald van der Werff.

Why should one look at the third dimension? The obvious answer of a geologist would be that the surface information does not permit one to have full appreciation of the three dimensional shape of objects. Another reason arises when trying to model pathways of gases or fluids through the shallow subsurface and understanding their surface expression. To give you an example I show a hyperspectral data set acquired over an area in Utah known to show mineral alteration caused by chemical reaction of gas with iron–rich sandstones which results in a bleaching effect (*Figure 7*). The source of the gas is petroleum reservoirs in the subsurface that leak gas venting at the surface. The effects are very obvious in the field and can be easily mapped using hyperspectral images, however the spatial pattern of alteration nowhere near matches the know subsurface extend of the petroleum reservoirs. There are two reasons for this. Firstly the migration pathways of gases to the surface is not vertical, but follows a complex pattern influenced by zones of weakness in the surface such as faults and the presence of lithological boundaries between permeable and impermeable formations. Secondly to the north of the imaged area coal seams occur. The coal also emits methane which is causing similar reactions as the gases leaking from petroleum reservoirs. Hence surface anomalies can only be properly understood when taking into consideration the full three dimensional geometry of a system.

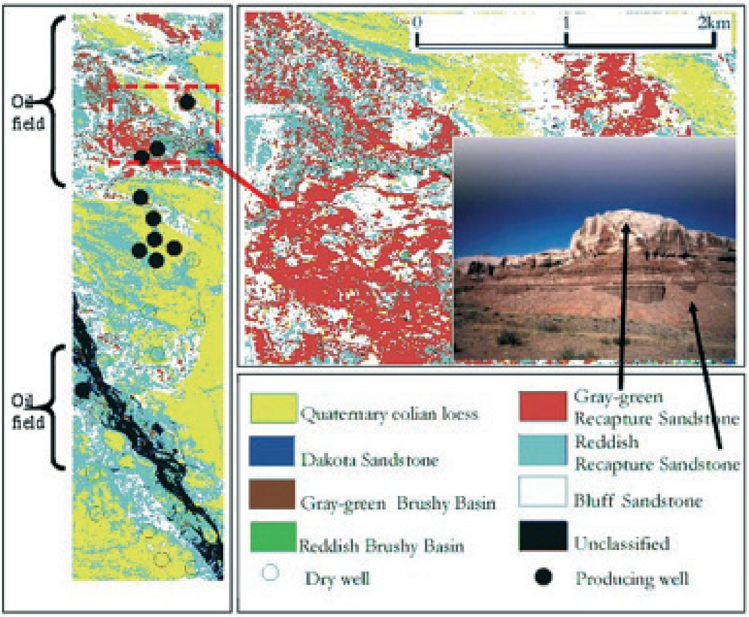


Figure 7: Classification of HyMAP data over an area of hydrocarbon seeps in Utah. Note the mismatch between surface extend of bleaching effect and the subsurface occurrences of oil and gas reservoirs due to non-vertical gas migration. Images courtesy Yang Hong.

ITC earth science research themes

Thematically we have started our work on the characterisation of hydrothermal alteration systems as these typically show a large suite of detectable minerals at the surface. It should be noted that imaging spectrometers are used for reconnaissance studies by the mining industry; a prime and unique example of operationalisation of remote sensing. In 1995 we started another very promising line of research, which from 1999 until 2004 I was able to expand while working part-time at Delft University; the monitoring of hydrocarbon seeps. Hydrocarbon reservoirs naturally leak small quantities of oil and gas to the surface. The visible products of such seepage, oil and tar deposits, are generally referred to as macroseeps, whereas the invisible gaseous products are referred to as microseeps.

Our worked focused on the use of spectral information to detect surface alterations in soil and rock as well as anomalous spectral behaviour of vegetation which would indicate the presence of hydrocarbons at depth. The latter part we developed in close collaboration with Andrew Skidmore, colleagues at Wageningen University and colleagues in Nottingham. Through various projects we were able to refine our techniques working closely with (and in project for) colleagues of Shell Rijswijk and Oman. We were able to interest the oil industry for our research, but linking our modelling work to the global climate change debate too date has failed. Our argumentation in that respect was that natural hydrocarbon seeps are one of several unknown contributions to the global methane budget which we intended to quantify using remote sensing in combination with field flux measurements. With a broad consortium we proposed this to the European Commission in the GEMINI proposal, unfortunately this did not get accepted. However, we did get response from a different direction namely the gas production industry. At present we are working on a project to see whether gas pipeline leakages can be detected using field and airborne spectroscopy. First results are positive, we now need to show that there is merit in our methodologies by exporting our findings to HyMAP hyperspectral data and combining our spectroscopy knowledge with spatial contextual modelling approaches.

Seeps and mineral potential have not been the only fields in which we are active. With former PhD graduate Patrick Kariuki, we started to work on the characterisation of the swelling potential of soils. This research line finds its applications in the engineering and construction industry. We have also looked at soil degradation and salinisation issues by combining hyperspectral data with shallow geophysical techniques.

To support research efforts in spectroscopy, in 1995 ITC bought its first field spectrometer, the PIMA. At present ITC operates besides the PIMA also a ASD fieldspec and a GER 3700. It should be noted that both in terms of spectrometer equipment as well as in terms of scientific expertise we should be exploiting the thermal region more. ITC has for long been engaged in research on detection and monitoring of active coal fires using thermal data sets, but thermal spectroscopy in relation to surface mineralogy particularly focusing on difficult to map silicate-group minerals has been a neglected field of application. I would argue that a thermal infrared field spectrometer is essential to fill this gap and also prepare us for future missions such as the ENMAP Mission and the airborne ARES instrument. I am pleased that Chris Hecker will focus his research efforts on this blank spot in ITC's earth observation capabilities.

Another point of concern is the resolution gap between field spectra and imaged spectra and derivatives from these sets of measurements. The fact that field spectrometers operate on a single point of observation and airborne systems are imaging devices in combination with the difference in both spatial as well as spectral resolution makes upscaling of parameters from the field to the image domain a complex matter. An intermediate solution could be provided by a field-based imaging spectrometer system. Together with colleague Jan de Leeuw we are proposing a hyperspectral photographic camera that could be used in the field but should also be light enough to be used on model aircraft and UAV's. We are convinced that with such facility we would be able to fill the existing resolution gap. A proposal will be drafted to NWO for which we wish to invite the entire spectroscopy community in the Netherlands to participate.

Imaging the future

Geologic remote sensing has concentrated on 'predicting what we already know', justification has been that we 'want to test our algorithms'. A good example of this has been the mapping of buddingtonite at Cuprite Nevada using AVIRIS data which can be found in at least a few dozen research articles. The key question though is 'can we use time series of earth observation (satellite and in-situ) data to better understand and model processes' so we can build scenarios for the future i.e. predict or at least image the future. Our research will progress along the path from inventory type to process-based modelling. We will enforce hyper-temporal analysis to address the relation between dynamic forcing mechanisms and the earth and environmental response to this to better understand geological processes. The next years we have a number of hurdles to take and gaps to be bridged amongst others the gap between the spatial and spectral domain, the gap between the surface and subsurface, the gap between the field and the image-domain and the gap between dynamic processes and monitoring capabilities.

I hope I made it sufficiently clear that the driving forces on the one-hand are international developments in our field of science and on the other hand the combined expertise that we can bring about to tackle these issues. Fluids and gases play a crucial role as we move from mineral exploration, fluid vent systems, to exploitation issues dominated by fluid mine drainage, from petroleum exploration to exploitation issues related to oil and gas releases to the environment.

With the sketched research programme I am confident we can maintain and expand our education and research position and help in bridging the existing gap between the earth observation community and the earth sciences community. I look forward to tackle these issues in the near future with my to be appointed colleague professor in earth surface systems analysis, with the ITC earth sciences community, with Steven de Jong and his group at Utrecht University, and with our many other collaborators in ITC, the Netherlands, Europe and over the world.

Word of thanks

Allow me to devote the last few minutes of my address to some words of thanks.

Thanks are due to my colleagues in the ITC in particular to the earth scientists. Together we have build up a strong scientific position in the field of geologic remote sensing in broadest sense and a presence world-wide. I am fortunate to have the opportunity to work in such a prosperous environment and with very pleasant and dedicated colleagues. In our work we need to act as a team and tackle issues of joint interest, but each one of us also needs to have his or her own scientific specialisation so we have a clear face and can address problems from various sides.

I would like to thank four individuals specifically. Bas Koopmans who put me on the track of hyperspectral remote sensing in 1990 by giving me some of the early NASA JPL proceedings and advised me 'to look into that promising new field of remote sensing'. Salle Kroonenberg who guided me trough my Ph.D., helped me with two unfortunately un-successful NWO PIONEER applications and ultimately brought me to Delft just before I had nearly escaped to Munich. Steven de Jong in whom I found a friend and fellow earth scientist that shares the passion for hyperspectral remote sensing and contextual methods. Martien Molenaar who guided me through the earth observation community in the Netherlands particularly when we both served in the KvAG board and who is one of those few managers that have kept up their in-depth knowledge of their scientific field and that is still actively contributing to its development. I have learned much from you as manager and as a scientist and you have given me the room to develop my own field in ITC.

I thank the rector of ITC, ITC's Board of Governors and Scientific Council for supporting my appointment. I thank Utrecht University in particular the Dean of the Faculty of Geosciences, Professor Hooijmeijer, for supporting my appointment at UU.

I thank the PhD researchers with whom I work or have worked for their inspiration and dedication to our research goals: Hong, Patrick, Michal, Klaas, Harald, Pravesh, Marleen, Frank, Bobba, Prasun, Jamshid, and Chris.

Lastly I thank Marianne, Bob, Hidde, Ids and Fenne for their patience and support.

Ladies and gentlemen, I thank you very much for your attention.

Meneer de Rector, ik heb gesproken.

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